

Physics of fundamental Symmetries and Interactions - PSI2019

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PSI



Book of Abstracts

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Session / 157

Welcome

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Session / 112

Overview of worldwide efforts in the search for charged lepton flavour violation

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Charged-lepton flavour-violating (cLFV) processes provide a unique discovery potential for physics Beyond Standard Model (BSM). These cLFV processes explore new physics parameter space in a manner complementary to the collider, dark matter, dark energy, and neutrino physics programmes. Furthermore the observation of neutrino oscillations has clearly demonstrated that neutral lepton flavour is not conserved. This implies that cLFV can also occur in the SM enriched by massive neutrinos, although strongly suppressed ($B < 10E-50$). On the other hand, the simplest and most reliable BSM extensions predict measurable cLFV processes, some being even further enhanced by the recently measured large mixing angle Θ_{13} and in the reach of incoming experiments. The global program includes searches for $\mu \Rightarrow e$, $\tau \Rightarrow e$, and $t \Rightarrow \mu$ transitions at experiments hosted in Europe, the US, and Asia. The relative rates among the various transitions are model dependent and comparisons among these transitions offer powerful model discrimination. A full exploration of cLFV parameter space requires the pursuit of all available $\mu \Rightarrow e$ and $\tau \Rightarrow e$ transitions.

An overview of worldwide efforts in the search for charged lepton flavour violation is given.

Session / 5

BASE: High-Precision Comparisons of the Fundamental Properties of Antiprotons and Protons

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The striking imbalance of matter and antimatter in our universe is one of the hottest topics of modern physics, which inspires experiments to compare the fundamental properties of matter-antimatter conjugates at lowest energy and with great precision. The BASE collaboration at the antiproton decelerator of CERN is performing such high-precision comparisons with protons and antiprotons. Using advanced, ultra-stable, cryogenic particle traps and superconducting detectors with single particle sensitivity, we have performed the most precise measurement of the proton-to-antiproton charge-to-mass ratio with a fractional precision of 11 significant digits [1]. In another measurement, we have invented a novel spectroscopy method, which allowed for the first ultra-high precision measurement of the antiproton magnetic moment with a fractional precision of 1.5 parts in a billion [2]. Together with our recent measurement of the proton magnetic moment [3] this improves the precision of previous experiments [4] by more than a factor of 3000.

In my talk I will review the recent achievements of BASE and will outline strategies to further improve our high-precision studies of matter-antimatter symmetry. This outlook will involve the implementation of sympathetic cooling of antiprotons using quantum logic methods, as well as a motivation and first design studies for transportable antiproton traps.

[1] S. Ulmer et al., Nature 524, 196 (2015).

[2] C. Smorra et al., Eur. Phys. Journ. Spec. Top. 224, 16 (2015).

[3] G. Schneider et al., Science 358, 1081 (2017).

[4] J. DiSciaccia et al., Phys. Rev. Lett. 110, 130801 (2013).

Session / 19

Ultracold but cool – Pioneering experiments with ultracold neutrons

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Due to their outstanding property to be storable and hence observable for long periods of time (several hundreds of seconds) in suitable material or magnetic traps, ultracold neutrons (UCNs) with energies around hundred nanoelectron-volts are a unique tool to study fundamental properties of the free neutron, like its beta-decay lifetime, its electric dipole moment and its wave properties. The early days of UCN physics are briefly reported, and selected pioneering experiments with UCNs in the last two decades – subject to the author's taste - are described.

Session / 16

Searching for New Particles and Forces with Polyatomic Molecules

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The fact that the universe is made entirely out of matter, and contains no free anti-matter, has no physical explanation. While we cannot currently say what process created the matter in the universe, we know that it must violate a number of fundamental symmetries, including those that forbid the existence of certain electromagnetic moments of fundamental particles. We can search for signatures of these electromagnetic moments via precision measurements in polar molecules, whose extremely large internal electromagnetic fields can significantly amplify these moments. These effects would arise from physics beyond the Standard Model, which enables tabletop searches for new, symmetry-violating particles and forces. With modern, quantum science techniques to control polar molecules, these searches can currently reach into the TeV scale, and offer many routes to even higher scales. In this talk, I will discuss our lab's approach to performing these tabletop measurements with polyatomic molecules, whose complex structure offers a unique opportunity to combine robust precision measurement techniques with laser cooling and trapping. This allows us to build experiments with sensitivity to a variety of new physics sectors, and a route to exploring the PeV scale.

Session / 67

Measurement of the Permanent Electric Dipole Moment of the ^{129}Xe Atom

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We present our recently published [1] measurement of the CP-violating permanent Electric Dipole Moment (EDM) of the neutral ^{129}Xe atom. Our experimental approach is based on the detection of the free precession of co-located nuclear spin-polarized ^3He and ^{129}Xe samples. The EDM measurement sensitivity benefits strongly from long spin coherence times of several hours achieved in diluted gases and homogeneous weak magnetic fields of about 400 nT. A finite EDM is indicated by a change in the precession frequency, as an electric field is periodically reversed with respect to the magnetic guiding field. Our result, $(-4.7 \pm 6.4) \cdot 10^{-28}$ ecm, is consistent with zero and is used to place a new upper limit on the ^{129}Xe EDM: $|d_{\text{Xe}}| < 1.5 \cdot 10^{-27}$ ecm (95% C.L.).

[1] Measurement of the permanent electric dipole moment of the ^{129}Xe atom, F. Allmendinger, I. Engin, W. Heil, S. Karpuk, H.-J. Krause, B. Niederländer, A. Offenhäusser, M. Repetto, U. Schmidt, and S. Zimmer, Phys. Rev. A 100 (2019). DOI: 10.1103/PhysRevA.100.022505

Session / 110

A new measurement of the permanent electric dipole moment of ^{129}Xe using ^3He comagnetometry and SQUID detection

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We describe a new technique used to measure the EDM of ^{129}Xe with ^3He comagnetometry. Both species are polarized using spin-exchange optical pumping, transferred to a measurement cell with doped silicon electrodes, and transported into the BMSR2 magnetically shielded room at PTB-Berlin, where SQUID magnetometers detect free precession in applied electric and magnetic fields. Two campaigns in 2017 and 2018 have provided a combined statistical error approximately five-times smaller than the most precise prior result published in 2001. Detailed study of systematic effects including recent investigations of the sources of species-dependent drifts not compensated by the comagnetometer and the final combined result of the two campaigns will be reported.

Session / 95**PHYSICS BEYOND SM WITH KAONS FROM NA62****Author:** Cristina Lazzeroni¹¹ *University of Birmingham, UK***Corresponding Author:** cristina.lazzeroni@cern.ch

The decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, with a very precisely predicted branching ratio of less than $10 \exp(-10)$, is one of the best candidates to reveal indirect effects of new physics at the highest mass scales. The NA62 experiment at the CERN SPS is designed to measure the branching ratio of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ with a decay-in-flight technique. NA62 took data so far in 2016-2018. Statistics collected in 2016 allowed NA62 to reach the Standard Model sensitivity for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, entering the domain of $10 \exp(-10)$ single event sensitivity and showing the proof of principle of the experiment. Thanks to the statistics collected in 2017, NA62 surpasses the present best sensitivity. The analysis strategy is reviewed and the preliminary result from the 2017 data set is presented.

A large sample of charged kaon decays into final states with multiple charged particles was collected in 2016-2018. The sensitivity to a range of lepton flavour and lepton number violating kaon decays provided by this data set improves over the previously reported measurements. Results from the searches for these processes are also presented.

Session / 41

Gravity tests at short distances using ultracold neutrons: A review of the qBounce experiment

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Neutrons are excellent probes to test gravity at short distances – electrically neutral and only hardly polarizable. Furthermore, very slow, so-called ultracold neutrons form bound quantum states in the gravity potential of the Earth. This allows combining gravity experiments at short distances with powerful resonance spectroscopy techniques, as well as tests of the interplay between gravity and quantum mechanics. In the last decade, the qBounce collaboration has been performing several measurement campaigns at the ultracold and very cold neutron facility PF2 at the Institut Laue-Langevin in Grenoble/France. A new spectroscopy technique, Gravity Resonance Spectroscopy, was developed and snapshots of falling wavepackets of these gravitationally bound quantum states were recorded. The results were applied to test gravity at micron distances as well as various Dark Energy and Dark Matter scenarios in the lab, like Axions, Chameleons and Symmetrons.

In my talk, I will review the experiments, explain key technologies and summarize the results obtained.

Session / 147

Status of lattice results on contributions of CP violating operators to nEDM

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Steadily improving bounds on the neutron EDM provide stringent bounds on new interactions and theories at the TeV scale. To leverage this connection requires precise results on matrix elements of the Theta and novel CP violating interactions at the TeV scale. In this talk, I will update our results for the contributions of the quark EDM operator that are already being used in phenomenology, and present new results for the Theta term. In particular I will discuss the issues of the Q^2 and chiral behavior of the P and T violating form factor F_3 obtained from the matrix element of Theta term in presence of CP violation and the systematics of extracting its contribution to nEDM at $Q^2 = 0$ and at the physical pion mass. Finally I will present a status report on calculation of the chromo EDM and Weinberg operators.

Session / 146

Searching for the electric dipole moment of the neutron - a landscape overview

Author: Beatrice Franke¹¹ TRIUMF, Vancouver, Canada**Corresponding Author:** bfranke@triumf.ca

We live in a matter dominated Universe. Naively assuming a preference of nature for symmetries, it's somewhat unexpected that we observe much larger amounts of matter over antimatter. Asking our very successful Standard Model of Particle Physics for insight on this Baryon Asymmetry in the Universe (BAU), we learn that the observed asymmetry is actually even much larger than expected - by several orders of magnitude. The failure of the Standard Model to reproduce the magnitude of the observed asymmetry is one of the most intriguing problems of contemporary physics.

One way to investigate this asymmetry is to look for CP-symmetry violating processes – CP symmetry relates matter to antimatter and according to the Sakharov criteria is a condition for our observed BAU. A permanent non-zero electric dipole moment (EDM) of the free neutron violates T and P symmetry. If one assumes CPT to be a good symmetry of nature, T-violation is equivalent to CP-violation. Finding or improving the sensitivity for the so far elusive neutron EDM will thus shed light on the structure of our Universe and its underlying fundamental interactions.

In this presentation I will give an overview of the worldwide landscape of neutron EDM searches and briefly introduce the differing techniques which are applied in those highly sensitive and precise experiments.

Session / 58

The search for a neutron edm at ORNL using dilute solution of He3 as a co-magnetometer

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We outline the principles of the method for searching for a neutron edm using super-thermal production of UCN in He4, a dilute solution of He3 as a co-magnetometer and critical spin dressing and report on recent progress in designing and constructing the various sub-systems of the experiment.

Session / 3

Stringent tests of bound-state QED using highly charged ions

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The ultra-precise determination of the g -factor of highly charged ions is a unique possibility to test the validity of the Standard Model, particularly Quantum Electrodynamics (QED) in extreme electric fields up to 10^{16} V/cm. While the weak-field regime has been exquisitely tested, in the presence of strong fields higher-order contributions beyond the Standard Model might become significant. It is possible to sensitively search for such effects by measuring the Larmor- and cyclotron frequencies of single, highly charged ions in a cryogenic Penning trap with high precision. This way, by measuring the g -factor of medium heavy hydrogenlike ions with previously unprecedented precision, we have been able to perform the most stringent test of QED in strong fields. Particularly the effect of the nucleus on the g -factor of the electron is a novel and unique access to nuclear size and structure information.

To push these tests far into the strong-field, heavy ion regime, we have developed and commissioned the ALPHATRAP experiment at the MPIK in Heidelberg. ALPHATRAP has recently performed the first high-precision measurement of the g -factor of a boronlike highly charged ion, $^{40}\text{Ar}^{13+}$. This not only enables a sensitive test of multi-electron QED, but also paves the way towards a determination of the finestructure constant α . Furthermore, using a novel detection scheme, also the finestructure splitting in $^{40}\text{Ar}^{13+}$ has been detected by means of laser spectroscopy. The recent results of ALPHATRAP and the future prospects will be presented.

Session / 4

Nuclear structure corrections in muonic atoms

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The measurement of the Lamb shift in muonic hydrogen and the subsequent emergence of the proton radius puzzle have motivated an experimental campaign devoted other light muonic atoms, such as muonic deuterium and helium. For these systems nuclear structure corrections are the largest source of uncertainty and consequently the bottle-neck for exploiting the experimental precision to extract the nuclear radii. Utilizing techniques and methods developed in few-body nuclear physics, we have been able to provide the so far most precise determination of nuclear structure corrections due to a two-photon exchange diagram. I will review our recent calculations for light muonic atoms, and present an outlook for the future.

Session / 28

Status of the muX project at PSI

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Negative muons at rest quickly get captured by nearby atoms and subsequently de-excite via radiative and Auger transitions until the muon ends up in the 1s orbital. At the lower orbits, there is substantial overlap between the muon wave function and the nucleus, making this system an excellent laboratory to study the interaction between the muon and atomic nucleus. With a physics program focusing on Atomic Parity Violation (APV), the muX collaboration is exploiting the coverage and high multiplicity of germanium detector array in a series of muonic X-ray measurements at PSI.

A measurement of the charge radius of ²²⁶Ra, derived from the 2p-1s transition energy, will serve as crucial input for an upcoming APV experiment on electronic radium. To overcome the restrictions on the amount of radioactive target material, we have developed a novel D₂/H₂ gaseous target, where a sequence of transfer reaction enables us to stop a standard muon beam in a few micrograms of target material. During the 2017 and 2018 runs, we have achieved a stopping efficiency of a few percent in a 3 nm thick gold layer. The measurement with ²²⁶Ra is planned for the fall of 2019.

A second measurement program explores the possibility of observing APV directly in muonic atoms. APV arises from the mixing of the opposite parity 2p and 2s atomic states, leading to parity violation in the 2s-1s transition. We focus on Z=30 nuclei, where a measurable branching ratio of the single photon 2s-1s transition is expected. The high granularity of a large solid angle germanium detector array is exploited to suppress background from more intense transitions in the cascade. First measurements of the transition were made in 2017 and 2018. In 2019, we aim to improve the signal to background significantly.

In addition, we have measured the muonic X-ray spectrum of rhenium, deriving its quadrupole moment, and the muonic cascade of different noble gases after transfer. In this talk, we will give an overview of the muX program, and the status of the 2019 experimental campaign, where we will bring over and deploy the high-resolution Miniball germanium detector array from the ISOLDE/CERN facility.

Session / 137

Measurement of the nucleon axial coupling in neutron beta decay

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Precision experiments on neutron beta decay are used to determine the CKM matrix element V_{ud} and to search for novel scalar and tensor couplings beyond the axial-vector and vector couplings of the standard model. In this presentation, I will discuss the result of PERKEO III on the parity-violating beta asymmetry obtained using a pulsed cold neutron beam at the ILL. The result confirms recent measurements of the nucleon axial coupling with improved precision. In consequence, it largely rules out dark decay channels as an explanation of the persisting discrepancy between the beam and bottle methods to measure the neutron lifetime. I will discuss implications on V_{ud} from neutron decay and limits on scalar and tensor interactions. The status of the successor instrument PERC at the MLZ will be presented.

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Improved determination of the β - ν angular correlation coefficient a in free neutron decay with the aSPECT spectrometer

Author: Werner Heil¹**Co-authors:** Alexander Wunderle ; Christian Schmidt ; Ferenc Glück ; Fidel Ayala Guadia ; Gertrud Konrad²; Jan Kahlenberg ; Marcus Beck³; Martin Simson ; Michael Borg ; Michael Klopff ; Oliver Zimmer ; Raquel Munos Horta ; Romain Maisonrobe ; Romain Virot ; Stefan Baeßler ; Torsten Soldner ; Ulrich Schmidt¹ *Institute of Physics , JGU Mainz, Germany*² *Technische Universität Wien, Atominstitut , 1020 Wien, Austria*³ *Industry***Corresponding Author:** wheil@uni-mainz.de

We report on a precise measurement of the electron-antineutrino angular correlation (a coefficient) in free neutron beta-decay from the aSPECT experiment. The a coefficient is inferred from the recoil energy spectrum of the protons which are detected in 4π by the aSPECT spectrometer using magnetic adiabatic collimation with an electrostatic filter. Data are presented from a 100 days run at the Institut Laue Langevin in 2013. The sources of systematic errors are considered and included in the final result. We obtain $a = -0.10430(84)$ [1] which is the most precise measurement of the neutron a coefficient to date (PDG value $a = 0.1059(28)$). From this, the ratio of axial-vector to vector coupling constants is derived giving $\lambda = -1.2677(28)$. This talk gives an overview of the aSPECT experiment, discusses the treatment of systematic errors and shows the status of measurements (including our result).

[1] M. Beck et al. (aSPECT collaboration), arXiv:submit/2803505 [nucl-ex] 13 Aug 2019, submitted to Phys. Rev. C

Session / 68

Pendellosung Interferometry as a Probe for New Interactions

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When neutrons are Bragg diffracted from a crystal slab, Bloch waves form in the crystal. Interference between the Bloch waves cause oscillations in the diffracted beam whose phase is a function of neutron energy and the thickness of the crystal slab. This phenomenon is known as pendellosung interference and has a spatial period, called the pendellosung length, that is on the order of 50 micrometers. By measuring the phase of pendellosung oscillations in crystals that are thick (~1 cm) compared to the pendellosung length, the crystalline structure factor may be measured at a relative uncertainty on the order of 5×10^{-5} . The measured scattering amplitude is evaluated at a very well-defined momentum transfer given by the spacing of the relevant Bragg planes. The scattering amplitudes for a number of Bragg conditions as a function of momentum transfer may be fit to a functional form which takes into account lattice dynamics and the neutron charge radius. Additionally, such measurements are sensitive to perturbations from a beyond the standard model force mediator with a length scale that is on the order of the Bragg plane spacing. Presented are results from pendellosung interferometry in silicon, where in addition to measuring the (111), (220), and (400) structure factors, the crystal thickness and scattering length density was measured with equally high precision by placing the diffracting crystal in a neutron interferometer. This technique removes the need to optically polish the crystals, alleviating systematic uncertainties that occur in the presence of strain gradients caused by subsurface machining damage. The result is an order of magnitude improvement to current limits on the strength of a beyond the standard model force mediator at the 2 keV mass scale. The near future addition of other crystalline materials, such as germanium, as well as the inclusion of higher order Bragg planes, provides a promising outlook for pendellosung interferometry as a precision probe of lattice dynamics, the neutron charge radius, and non standard model forces.

Session / 12

The n³He experiment—a new era in Hadronic Parity Violation

Author: Christopher Crawford¹¹ *University of Kentucky***Corresponding Author:** crawford@pa.uky.edu

We report the parity violating proton asymmetry A_p in the reaction $\bar{n} + {}^3\text{He} \rightarrow p + {}^3\text{H}$ (the n-³He experiment), the most precise hadronic asymmetry ever measured. Hadronic parity violation offers a unique probe of nucleon structure and the underlying non-perturbative behavior of low-energy QCD. The hadronic weak interaction is characterized by five spin and isospin dependent S-P transition amplitudes. While it was first observed over 50 years ago in compound nuclei, which offer large nuclear enhancements, a systematic characterization of the weak interaction among strongly bound systems is still forthcoming, and requires multiple measurements in few-body systems with exactly calculable nuclear wave functions. New theoretical frameworks, experimental facilities, and advanced technology have rejuvenated efforts to map out this “complexity frontier” of the Standard Model. The n-³He experiment is a critical measurement in this campaign, being sensitive to the $\Delta I = 0, 1$ transition amplitudes. It was performed at the Fundamental Neutron Physics Beamline at Oak Ridge National Laboratory.

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The proton radius puzzle

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By means of laser spectroscopy we have measured several 2S-2P transitions in muonic hydrogen. From these measurements we have extracted a proton charge radius 20 times more precise than obtained from electron-proton scattering and hydrogen high-precision laser spectroscopy but at a variance of 7 sigma from these values. This discrepancy referred to as the “proton radius puzzle” has prompted various investigations in the context of bound-state QED, proton structure, atomic spectroscopy, BSM physics and scattering experiments. The status of the “proton radius puzzle” will be presented.

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Hydrogen Lambshift

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We have measured the Lamb shift in atomic hydrogen using a new FOSOF (Frequency Offset Separated Oscillatory Fields) method. We measure the $2S_{1/2}(F=0)$ -to- $2P_{1/2}(F=1)$ interval to be 909.8717(32) MHz, from which an rms proton charge radius of 0.833(10) fm can be determined.

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Status of MUSE at PSI

Co-author: MUSE collaboration

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It is rare to have a discrepancy in such a basic property as proton size, and yet during the past decade measurements of proton charge radius using muons and electrons have disagreed by almost six standard deviations. The MUon proton Scattering Experiment (MUSE) at PSI aims to shed more light on this puzzle, by measuring the elastic scattering of muons, electrons, and positrons on protons in one apparatus. The progress and status of the experiment will be presented in this talk.

Session / 108

Fundamental symmetries and exotics physics in atoms

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The extraordinary advances in quantum control of matter and light have been transformative for precision measurements with atoms. For example, the development of atomic clocks enabled searches for the variation of fundamental constants, dark matter, violations of Einstein equivalence principle, and other applications. I will give an overview of precision fundamental studies with atoms focusing on clock applications and discuss prospects for significantly improved sensitivity with highly charged ions and a nuclear clock. Recent advances in testing Lorentz invariance in the electron-photon sector are presented.

Session / 107

Optical lattice clocks and their applications

Author: Hidetoshi Katori¹¹ *The University of Tokyo***Corresponding Author:** katori@amo.t.u-tokyo.ac.jp

Clocks are devices that allow us to share time by taking advantage of ubiquitous oscillatory phenomena in nature. We once relied on astronomical observations, and today we use far regular oscillations of cesium atoms to define the international system of unit (SI) for time, i.e., the SI second. Recent optical atomic clocks have achieved 100-fold improvement over cesium clocks [1]. This extreme precision, in turn, allows clocks to investigate the constancy of fundamental constants that they rely on and to measure clocks' altitudes using their gravitational-potential-dependent tick rates, i.e., chronometric leveling [2]. Roles of the clocks are rapidly changing from those supposed previously. An "optical lattice clock" proposed in 2001 [3] benefits from a low quantum-projection noise by simultaneously interrogating a large number of atoms trapped in optical lattices tuned to the "magic frequency" [4] that largely cancels the light shift perturbation of the lattice trap. About a thousand atoms enable such clocks to achieve 10⁻¹⁸ instability in a few hours of operation, which allows intensive investigation of systematic uncertainties and finding new applications.

We overview the progress of optical lattice clocks and address recent topics including 1) an "operational magic condition" [5, 6] to reduce the clock uncertainty to 10⁻¹⁹ by cancelling out the higher-order light shifts than that given by the electric-dipole interaction, 2) transportable Sr-based clocks with an uncertainty of 10⁻¹⁸ that are being operated outside a laboratory, and 3) testing of the gravitational redshift using 450-m-high tower.

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***g*-factor of Boronlike Argon 40 Ar¹³⁺ at ALPHATRAP**

Author: Ioanna Arapoglou¹**Co-authors:** Alexander Egl¹; Martin H^ocker¹; Tim Sailer¹; Robert Wolf¹; Andreas Weigel¹; Bingsheng Tu¹; Sven Sturm¹; Klaus Blaum¹¹ *Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany*

The ALPHATRAP *g*-factor experiment is a high-precision Penning-trap experiment located at the Max Planck Institute for Nuclear Physics in Heidelberg. It has been designed for performing high-precision *g*-factor measurements on heavy highly charged ions (HCI), such as hydrogenlike ²⁰⁸Pb⁸¹⁺ and boronlike ²⁰⁸Pb⁷⁷⁺, which will be externally produced and injected into our setup. By determining the bound electron's *g*-factor, stringent test of bound-state quantum electrodynamics (BS-QED) can be carried out. Furthermore, such measurements can provide access to fundamental constants, such as the fine structure constant α which can be determined via the difference between the *g*-factor of a hydrogenlike and a boronlike ion. ALPHATRAP has been fully assembled and commissioned, after which the first measurement of the ground-state *g*-factor of boronlike argon ⁴⁰Ar¹³⁺ took place. This measurement was performed with a fractional uncertainty of 1.4×10^{-9} which is almost 3 orders of magnitude more precise than the currently most precise theoretical prediction. Due to the optimised design, prominent systematic effects in predecessor experiments are highly suppressed in our setup. This experimental result constitutes the first high-precision *g*-factor determination of a boronlike ion as well as the first result of ALPHATRAP. Our experimentally determined *g*-factor of ⁴⁰Ar¹³⁺ distinguishes between existing theoretical predictions that are in disagreement. Furthermore, this result lays the groundwork for BS-QED tests in even stronger fields and for the independent determination of the fine structure constant α .

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High-Precision Mass Measurements on Light Nuclei with the LI-ONTRAP experiment

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Please find the abstract attached.

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Probing neutrino nature and time reversal symmetry violation in elastic scattering of low energy neutrinos on polarized electrons in presence of nonstandard couplings

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Possibility of using elastic scattering of low energy electron neutrinos (ν_e s) on polarized electron target (PET) for testing time reversal symmetry violation (TRSV) and neutrino nature (NN) in leptonic interactions is considered. We analyze the two theoretically possible scenarios of physics beyond the Standard Model (SM) in which flavor-conserving (FC) standard and non-standard interactions of left chiral (LC) and FC exotic couplings of right chiral (RC) ν_e s are admitted.

The first option assumes that the incoming ν_e beam consists only of LC ν_e s detected by $V - A$ and S, P, T interactions. It turns out that T-odd correlation built of the polarization of the electron target, the incoming ν_e momentum and the outgoing electron momentum, and proportional to the interference between the S and T interactions in the cross section for the Dirac ν_e s appears and results in a departure from the standard prediction for the azimuthal asymmetry of recoil electrons. The spectrum and polar distribution of recoil electrons are not sensitive to the T-odd correlation, but allow us to differentiate between Dirac and Majorana ν_e s.

The second scenario is based on the assumption that the incoming ν_e beam is a superposition of LC states with RC ones. Consequently the transversal components of ν_e spin polarization (TCNSP) may appear and do not vanish in the limit of infinitesimally small ν_e mass.

LC ν_e s interact mainly by the standard $V - A$ interaction, while RC ones are only detected by the exotic $V + A$ and S_R, P_R, T_R interactions.

The differential cross section for Dirac ν_e s contains the interference terms between standard $V - A$ and exotic S_R, P_R, T_R couplings, while the differential cross section for the Majorana case does not include the interferences from V, T couplings. All the interferences are proportional to the various angular correlations (both T-even and T-odd) among the transversal

ν_e spin polarization, the polarization of the electron target, the incoming ν_e momentum and the outgoing electron momentum, and survive in the relativistic ν_e limit. In this way the azimuthal asymmetry, the electron spectrum and the polar angle distribution of the scattered electrons are sensitive to the TRSV and enable us to distinguish between Dirac and Majorana ν_e s. The considerations are model-independent and carried out for the flavour (current) ν_e s. To make such tests feasible, the intense (un)polarized artificial ν sources, PETs and the appropriate detector measuring both the polar and azimuthal angles of the outgoing electrons, and/or the recoil electrons energy with a high resolution have to be identified. This study is based on the published paper in the European Physical Journal C: W. Sobkow, A. Blaut, Eur. Phys. J. C {78}, 197 (2018), and the preprint arXiv:1812.09828.

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Study of Future 3D Calorimetry Based on LYSO or LaBrCe Crystals for High Energy Precision Physics

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In the field of charged lepton flavour violation (cLFV), one is investigating various decays, some of which contain photons in the final state. To discriminate between signal and background, detectors providing excellent resolutions in all particle variables are crucial.

The photons in muonic charged lepton flavour violating decays are expected to be on an energy scale in the range of 10 to 100 MeV. The state of the art technique to detect these is a calorimeter based on a scintillating material coupled to photosensors of various kind.

Two very promising materials for a future calorimeter are on the one hand LYSO and on the other hand Lanthanum Bromide. Recent progress in the crystal growing process makes it feasible to build a prototype in near future and to test its response to photons of the expected energy scale of future high precision experiments.

Coupling such a crystals to $\mathcal{O}(100)$ silicon photomultipliers results in a granular detection of the optical photons. This provides geometrical information about the distribution of the light amongst the photon sensors and hence allows for a three dimensional reconstruction of the position of the first interaction between the incident γ -photons and the scintillator.

The response of both, $\text{LaBr}_3(\text{Ce})$ and LYSO prototypes fired by gammas of an energy of 55 MeV have been studied and very promising results were obtained. The MC simulations are based on GEANT 4 and include customised codes for the whole electronics chain from the photosensors up to the data acquisition validated with measured data. The results presented here are based on the final reconstruction algorithm based on the full waveform analysis. The waveforms are digitised at a frequency of 2 GSamples/s.

For Lanthanum Bromide and LYSO crystals with a size of 10 Molière radii and 15 radiation lengths, these ultimate resolutions have been obtained for gammas of 55 MeV energy: an energy resolution significantly below 1 percent with clearly better values for Lanthanum Bromide, a time resolution of $\mathcal{O}(30)$ ps and a position resolution of $\mathcal{O}(5)$ mm. Such performances pose these future calorimeters at the technology forefront and makes them eligible candidates for upcoming cLFV experiments.

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The Mu3e Data Acquisition System

Author: Niklaus Berger¹¹ *Mainz University, Insititute for Nuclear Physics***Corresponding Author:** niberger@uni-mainz.de

The Mu3e Experiment at PSI is designed to search for the lepton-flavour violating decay of a positive muon to two positrons and an electron with an ultimate sensitivity of one in 10^{16} muon decays. The detector is based on ultra-thin high-voltage monolithic active pixel sensors combined with scintillating fibres and tiles for precise timing measurement. Already in the first phase of data taking with up to 10^8 muon stops/s, the detector will produce about 60 Gbit/s of raw data. The poster discusses the Mu3e data acquisition system, which transports these data out of the detector, time-sorts them and searches for interesting signatures by performing a full track and vertex reconstruction using graphics processing units (GPUs).

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Dispersive treatment of the EM radiative corrections to the pion vector form factor

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At the present level of uncertainty, the EM radiative corrections to the pion vector form factor become relevant in the HVP contribution to the anomalous magnetic moment of the muon. So far, their treatment is based essentially on scalar QED. In order to have a better understanding of these radiative corrections, we use unitarity and dispersion relations to express them in terms of integrals of well-defined purely hadronic quantities. We limit ourselves to contributions from two-pion intermediate states, which are dominant compared to higher hadronic states.

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Sensitive and stable vector magnetometer for operation in zero and finite fields

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We report on a Hanle-type magnetometer that uses the same physics package as the free spin precession magnetometer published in [1]. The magnetometer is most sensitive at zero magnetic field and uses four laser beams to gain measurements of the magnetic field vector components along two orthogonal directions. The influence of the common mode power fluctuations in the laser beams is greatly suppressed due to a differential detection scheme. This leads to high magnetometric sensitivity even at low detection frequencies.

Sensitivities of better than $60 \text{ fT}/\sqrt{\text{Hz}}$ could be demonstrated simultaneously for both measurement channels in a well shielded environment. A minimum Allan deviation, limited by residual field fluctuations, of better than 40 fT was observed for integration times of 2 s . The magnetometer is ideal for sensitive low-frequency field measurements in offset fields and close to zero field. Among the possible applications for this system is the determination of quasi-static shielding factors of passive magnetic shields and the search for undesired magnetic field correlations in fundamental physics experiments such as EDM searches.

[1] S. Afach et al., *Opt. Express* 23, 22108 (2015)

[2] G.Bison et al., *Opt. Express* 26, 17350 (2018)

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Study on Aging of Photomultiplier Tubes for MEG II Liquid Xenon Calorimeter

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A study on the aging of the photomultiplier tubes used in the liquid xenon calorimeter for the MEG and the MEG II experiment

BBQ - Drinks & Posters / 124**Status of the neutron lifetime experiment τ SPECT****Authors:** Jan Kahlenberg^{None}; Kim Ulrike Ross¹**Co-authors:** Peter Bluemler¹; Martin Fertl²; Werner Heil³; Dieter Ries²; Christian Schmidt⁴¹ *Johannes-Gutenberg-University Mainz*² *Johannes Gutenberg Universitaet Mainz*³ *Institute of Physics*⁴ *Johannes Gutenberg-Universität Mainz***Corresponding Authors:** jan.kahlenberg@uni-mainz.de, kim.ross@uni-mainz.de

The τ SPECT experiment aims to measure the neutron lifetime τ_n using a 3D magnetic storage technique. Due to the neutron's magnetic moment, very low-energetic neutrons (ultracold neutrons, UCN) with a maximum energy of ≈ 50 neV can be stored in the magnetic trap with a volume of ≈ 8 litres. τ SPECT is designed to determine τ_n using two independent measurement methods. In phase I, surviving UCN in the storage volume after varying storage times are counted. Phase II involves the in-situ detection of decay protons.

A proof-of-principle measurement using the magnetic field of the former α SPECT spectrometer (double hump structure) for longitudinal confinement and a fused silica tube for radial storage has been performed in July 2015 [1]. Since then, besides the successful upgrade of the UCN D source at the pulsed research reactor Mainz [2], the 3D magnetic trap using a magnetic octupole for the radial confinement has been installed and commissioned. Other relevant components are a movable neutron guide system with an adiabatic fast passage (AFP) spin flipper as well as a custom-designed UCN detector (boron-coated ZnS:Ag scintillator).

We will present the current status of the experiment and the progress of the initial commissioning runs.

References

[1] J. Karch, PhD thesis, Johannes Gutenberg University Mainz, 2017

[2] J. Kahlenberg et al., Eur. Phys. J. A **53**, 226 (2017)**Funding acknowledgement**

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Project 8: First application of CRES to tritium decay

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Neutrino flavor oscillation experiments prove that neutrinos have non-zero masses. Extensions to the Standard Model of Particle Physics have been developed to explain the non-zero masses and can be directly tested by a measurement of the absolute neutrino mass scale. The mass of the electron antineutrino $m_{\bar{\nu}_e}$ can be determined from the highest precision measurement of the β^- -decay spectrum of tritium around its endpoint region ($Q = 18.6$ keV). The current state-of-the-art experiment, KATRIN, stretches all technological limits to probe the range of $m_{\bar{\nu}_e}$ down to 200 meV/ c^2 . The Project 8 collaboration envisions a completely new path to measure $m_{\bar{\nu}_e}$. The recently demonstrated technique of Cyclotron Radiation Emission Spectroscopy (CRES) allows for a frequency-based measurement of the decay electron energy. I will present technical aspects of the apparatus used for the very first application of CRES to the measurement of the continuous decay spectrum of tritium.

This work is supported by the Cluster of Excellence "Precision Physics, Fundamental Interactions, and Structure of Matter" (PRISMA+ EXC 2118/1) funded by the German Research Foundation (DFG) within the German Excellence Strategy (Project ID 39083149), the US DOE Office of Nuclear Physics, the US NSF, and internal investments at all institutions.

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Axion-Dark-Matter Search using Cold Neutrons

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The current best estimate for the universe's matter content consists of 84% dark matter, and the search for its composition remains of great interest. One possible candidate is a so far undetected ultra-low-mass axion. Various astronomical observations, and only one laboratory experiment, using ultra-cold neutrons, currently constrain the axion mass and its interaction strength in the allowed phase space of the axion-gluon coupling. Here we present the idea of a new complementary laboratory search for an axion-induced oscillating neutron electric dipole moment using a cold neutron beam Ramsey setup.

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Study on Time Offset Effect for Scintillation Detectors with Series-Connected SiPM Readout

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Scintillation detectors read out by silicon photomultipliers (SiPMs) are used in a variety of experiments as a means to detect charged particles. In particular, series connection of SiPMs have recently been attracting more and more attention for precise timing measurement. Series-connected SiPMs yield smaller capacitance than a single SiPM, which leads to narrower signal waveform and better timing resolution.

We have discovered that the signal line of series-connected SiPMs can potentially produce a non-negligible time offset depending on the hit position of the particle. In addition, we have studied the effect of radiation damage to SiPMs, which can have an additional effect on the time offset. In the end, we present a possible method to correct this effect in the case of MEG II pixelated timing counter.

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The power distribution system for the Mu3e experiment.

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The first phase of the Mu3e experiment will search for the charged flavour violating decay of a positive muon into 2 positrons and one electron with a single events sensitivity of 2×10^{-15} . For this purpose, a DC muon beam will be stopped inside a Si pixel tracker constructed from High-Voltage Monolithic Active Pixel Sensors (HV-MAPS), complemented with timing detectors. The entire experiment resides within a superconducting solenoid providing a homogeneous magnetic field of 1 T.

A total of 3136 detectors ASICs need about 5 kW of power at ca. 2 VDC. In addition, frontend boards equipped with an ARRIAV FPGA will configure and read out these sensors and send off the data via optical links, adding another 2.7 kW. The power distribution system has to step down the 20 VDC supply voltage to the different DC voltages needed. Custom buck converters equipped with air coils will do this inside the magnet, as close as possible to the detector to avoid further power losses. Special care has to be taken to minimize interference between these high power devices and the sensitive tracker nearby.

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Efficient in-trap laser-induced loading of rare species into an EBIT for high-precision mass spectrometry at Pentatrap

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The electron capture (EC) decay of ^{163}Ho to ^{163}Dy is a promising candidate for the determination of the electron neutrino mass in the sub-eV range. For this purpose the ECHO collaboration [1] aims to perform a calorimetric measurement of the $^{163}\text{Dy}^*$ de-excitation spectrum. With its Penning-trap setup the `\textsc{Pentatrap}` [2] experiment performs a precision mass measurement of the mother and daughter nuclide with a relative mass-ratio uncertainty of 10^{-11} , thus contributing an independent value of the energy available for the EC decay (Q -value). To achieve such a precision, highly charged ions are necessary which can be produced in electron beam ion traps (EBIT).

To cope with the strongly limited amount of ^{163}Ho available, an efficient in-trap laser-induced loading technique into a Heidelberg compact EBIT [3] was developed for very rare atoms. Ions of various mass domains $A=40$ to $A=209$ have been successfully produced, in particular charge states of up to 45+ have been achieved for ^{165}Ho using a sample size of only about 10^{12} atoms (about 0.27 ng). These small samples lasted for the production of more than 30000 HCI bunches, each containing thousands of Ho ions.

The EBIT was recently connected to the *Pentatrap* beam line and is currently being commissioned for the measurement of the mass ratio of ^{163}Ho and ^{163}Dy .

[1] Gastaldo, L. et al., Eur. Phys. J. Special Topics 226, 1623 (2017)

[2] Repp, J. et al., Appl. Phys. B 107, 983 (2012)

[3] Micke, P. et al., Rev. Sci. Instrum. 89, 063109 (2018)

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GADGET: a novel ultra-cold neutron gaseous detector for the n2EDM project

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A new ultra-cold neutron (UCN) detector is required for the n2EDM experiment since the previous ⁶Li-doped glass scintillator (NANOSC) model, used in the nEDM experiment, is constrained by its small size and high price. Hence, the authors propose a novel detector (GADGET) composed of a chamber filled with ³He and CF₄ gases, and three perpendicular photo-multiplier tubes coupled to it. In order to access the optimal gas pressures, two experiments, one at the Paul Scherrer Institute with a pulsed UCN beam, and the other at the Mainz's TRIGA reactor with constant UCN flux, were carried out. As a result, under conditions of 400 mbar for CF₄ and 25 mbar for ³He, a relatively higher detection efficiency (twice the one of a Cascade detector) and a great background suppression (estimated in a 2% of the total counts at PSI) were achieved. In addition, to further improve the light emission properties of GADGET, tests with new customized photo-multiplier tubes, thinner entrance foils and higher transmittance chamber windows are also discussed.

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muEDM: Search for a Muon Electric Dipole Moment at PSI

Author: Mikio Sakurai¹**Co-author:** On behalf of the PSI muon EDM preparatory project¹ *ETH Zürich***Corresponding Author:** msakurai@phys.ethz.ch

We are studying in detail the feasibility of a dedicated search for a permanent electric dipole moment (EDM) of the muon at PSI. This would be the first dedicated search with a potential sensitivity of $5 \times 10^{-23} e \cdot \text{cm}$ employing the frozen-spin method in a compact magnetic storage ring. Such an experiment is an excellent probe for physics beyond the Standard Model (SM) and would provide an explanation of the matter-dominated Universe. In the past, the muon EDM has always been measured parasitically in storage rings designed for the highest precision measurements of the anomalous magnetic moment “(g-2)” of the muon. This leaves the muon EDM as one of the least tested areas of the SM. In the light of recent observed tensions with the SM in B decays as well as (g-2) of the electron and the muon, a dedicated muon EDM search is very attractive to further push EDM searches beyond the first generation of fundamental particles.

Towards the precision muon EDM measurement, several R&D studies are underway. Recently, we performed the characterisation of the $\mu E1$ beam line at PSI, a potential beam line to host the experiment. The phase space and the polarisation were studied for different beam tunes up to 125 MeV/c. This will provide essential input parameters for ongoing GEANT4 simulations of the experiment as well as injection studies. To establish a novel muon decay positron tracking scheme, detectors are being prepared using the MALTA CMOS pixel detector. This poster will present and discuss the current status and prospects of the muEDM experiment.

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Measurements for Control of Magnetic Field Related Systematic Effects for the PSI Neutron Electric Dipole Moment Experiment

Author: Nicholas Ayres¹¹ *ETH Zurich***Corresponding Author:** ayresn@ethz.ch

Measurements for Control of Magnetic Field Related Systematic Effects for the PSI Neutron Electric Dipole Moment Experiment

N. J. Ayres on behalf of the PSI nEDM Collaboration

The neutron's electric dipole moment (nEDM) is an observable with extraordinary sensitivity to CP violating new physics phenomena. While the Standard Model predicts a negligibly small value, a wide variety of theories predict values within reach of current and next-generation searches. The PSI nEDM experiment took data in 2015 and 2016, and collected enough statistics to produce a new world-leading result, which is set to be published soon.

In the nearly seven-decade long history of the measurement, the sensitivity to this parameter has improved by six orders of magnitude. Though the results have typically been limited by counting statistics, a crucial part of every experiment has been the control of magnetic field related systematic effects. To this end, an extremely well controlled magnetic environment must be established and monitored using online magnetometry measurements. However, recent studies have shown that higher order magnetic field gradients can produce extremely large systematic effects, which cannot be adequately controlled using the online magnetometry systems.

To control these effects, an automated field mapper device was used in several measurement campaigns before and after datataking to measure the magnetic field at over 3000 points within the vacuum chamber using a fluxgate magnetometer. The field is decomposed in terms of 63 components in a specially chosen basis with convenient properties. These measurements are combined to reconstruct the field within the apparatus during datataking with sufficient accuracy to control systematic effects down to the few $\times 10^{-27}$ e cm level.

The mapping apparatus and technique used, the data analysis strategy and methods used to correct for these systematic effects will be presented and discussed.

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Search for muon catalyzed d^3He fusion.

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The measurement of cross-section for the nuclear fusion reaction $d + {}^3He \rightarrow {}^4He + p$ at ultra-low energies is of interest in pure and applied physics. This fusion process is involved in the primordial nucleosynthesis of the light elements in the early Universe. This reaction is a mirror reaction of the $d + t \rightarrow {}^4He + n$ fusion process and can be considered as a perspective source of thermonuclear energy.

We present a detailed study of the search for muon catalyzed d^3He -fusion, which was performed using the MuSun experimental setup. Based on the collected statistics, an upper limit for the rate λ_f of muon catalyzed d^3He fusion was set in this experiment performed with the $D_2 + {}^3He(5\%)$ gas mixture at $31K$ temperature with the gas density $\phi = 6.2\%$ of the LHD $\lambda_f \leq 6.3 \cdot 10^4 s^{-1}$ at 90% C.L.

BBQ - Drinks & Posters / 75**NA64 - Search for dark matter at CERN SPS****Authors:** Emilio Depero¹; Paolo Crivelli²; Laura Molina Bueno¹; collaborations NA64³¹ *ETH*² *Institute for Particle Physics, ETH Zurich*³ *CERN***Corresponding Author:** deperoe@phys.ethz.ch

NA64 is a fixed target experiment at the CERN SPS aiming at a sensitive search for hidden sectors. In this talk, we will present our latest results on the search for a new sub-GeV vector gauge boson (A') mediated dark matter (χ) production. The A' , called dark photon, could be generated in the reaction $e-Z \rightarrow e-ZA'$ of 100 GeV electrons dumped against an active target which is followed by the prompt invisible decay $A' \rightarrow \chi\chi$. The experimental signature of this process would be a clean event with an isolated electron and large missing energy in the detector. This allows us to set new limits on the γ - A' mixing strength and constrain the new parameter space for the most interesting light dark matter models. Results on the search for the visible $A' \rightarrow e+e-$ decays, as well as $X \rightarrow e+e-$ decay of a new 17 MeV X boson, which could explain a recently observed anomaly in the ^8Be transitions will be also discussed.

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Probing neutrinos and nuclei with COHERENT

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The COHERENT collaboration operates multiple detectors at Oak Ridge National Laboratory to measure coherent elastic neutrino-nucleus scattering (CEvNS) in a variety of target nuclei. CEvNS cross sections scale as the square of the number of constituent neutrons in a given nucleus, thus giving large event rates compared to other neutrino detection modes. At the same time, the low recoil energies involved demands highly-sensitive low-threshold detectors. The COHERENT effort leverages the intense, pulsed source of neutrinos from pion decay-at-rest at the Spallation Neutron Source (SNS), combined with low-threshold detector technology, to facilitate precision measurements of CEvNS nuclear recoil distributions. These CEvNS measurements will be sensitive to a variety of new physics, such as beyond-standard model non-standard interactions and accelerator-produced dark matter. Further, there are opportunities for the measurement of charged- and neutral-current inelastic scattering cross sections at 10-50 MeV energies, needed to refine the predicted signal for supernova neutrinos in future large-scale detectors. Here we outline the ongoing and future COHERENT experimental program, and survey the potential physics studies with these efforts.

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Searching for Physics beyond the Standard Model using Antiprotons at BASE

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The Baryon Antibaryon Symmetry Experiment (BASE) at the antiproton decelerator of CERN is dedicated to high-precision measurements of the fundamental properties of the proton and the antiproton. Using single-particle multi-Penning-trap techniques, we compare the proton/antiproton charge-to-mass ratios [1] and magnetic moments [2,3] with ultra-high precision. Such experiments provide stringent tests of CPT invariance and direct tests of matter/antimatter symmetry in the baryon sector.

Our measurement campaigns typically span several months up to more than one year. Besides comparing static fundamental properties, we can apply time-based analysis methods to our data and gain sensitivity to additional effects beyond the Standard Model.

Signatures of different types of Lorentz violation (with and without CPT violation) appear as signals at harmonics of the sidereal frequency [4]. A difference in gravitational coupling to protons and antiprotons would induce an annual variation of their charge-to-mass ratios, providing a test of the weak equivalence principle. Moreover, a time-based analysis of the antiproton magnetic moment constitutes the first direct search for axion-like dark matter using antimatter, and allows to derive first limits on previously unconstrained coefficients of the Standard Model Extension [4].

In this contribution, I will discuss the latest technical improvements, including a newly invented superconducting multi-layer magnetic shielding system that made, compared to [1], a considerably improved charge-to-mass ratio measurement campaign possible. In addition, I will present the results of the time-based analysis of the most recent BASE measurements.

[1] S. Ulmer et al., Nature 524, 196 (2015).

[2] C. Smorra et al., Nature 550, 371 (2017).

[3] G. Schneider et al., Science 358, 1081 (2017).

[4] Y. Ding and V. A. Kostelecký, Phys. Rev. D 94, 056008 (2016).

BBQ - Drinks & Posters / 91**muCool: Development of ultra-cold high-brightness muon beam line****Author:** Ryoto Iwai¹¹ *ETH Zürich***Corresponding Author:** riwai@ethz.ch

At the Paul Scherer Institute, we are developing a novel positive muon beam at low energy with high brightness by compressing the 6-dimensional phase space of a standard surface muon beam. Muons are stopped in a helium gas target with a density gradient at cryogenic temperature and compressed by making use of complex-shaped B- and E-fields. Compression stages that act along two different (transverse and longitudinal) directions have been developed and tested individually. As a next step we combine both compression stages into a single stage with mixed longitudinal-transverse compression. The feasibility of this mixed scheme has been successfully demonstrated.

Latest results of the high-precision mass spectrometer Pentatrap

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High-precision mass-ratio measurements with relative uncertainties below 10^{-11} have applications, among others, in tests of the theory of special relativity (SRT) [1], bound-state quantum electrodynamics (QED) [2] and neutrino physics research [3, 4]. This precision is achievable in Penning-trap mass spectrometry, where the mass of a charged particle is determined by measuring its free cyclotron frequency in a strong magnetic field.

With the first proof-of-principle mass-ratio measurements of xenon isotopes the novel high-precision Penning-trap mass spectrometer PENTATRAP [5], located at the Max-Planck-Institut für Kernphysik in Heidelberg, has recently demonstrated a relative mass-ratio precision of 10^{-11} using highly charged xenon ions. Unique features of the setup are the use of electron beam ion traps [6, 7] as external ion sources for highly-charged ions and a stack of five cylindrical Penning traps [8]. This allows for simultaneous storage and measurement of several ion species, reducing systematic errors. Long storage times due to a cryogenic environment and dedicated image current detection systems [9] with single ion sensitivity allow for high-precision determination of the cyclotron frequencies in all traps.

Recent and ongoing measurements concentrate on nuclides relevant for neutrino physics research, namely ^{187}Re and ^{163}Ho [3, 4]. Preliminary results of the current measurements of rhenium and holmium as well as the present status of the experimental setup of PENTATRAP and future projects will be presented.

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- [1] S. Rainville et al., *Nature* 483, 1096 (2005).
 - [2] F. Köhler-Langes et al., *Nature Comm.* 7, 10246 (2016).
 - [3] S. Eliseev et al., *Ann. Phys.* 525, 707 (2013).
 - [4] L. Gastaldo et al., *Eur. Phys. J. ST* 226, 1623 (2017).
 - [5] J. Repp et al., *Appl. Phys.* B107, 983 (2012).
 - [6] G. Zschornack et al., *Rev. Sci. Instr.* 79, 02A703 (2008).
 - [7] P. Micke et al., *Rev. Sci. Instr.* 89, 063109 (2018).
 - [8] C. Roux et al., *Appl. Phys.* B108, 997 (2012).
 - [9] H. Nagahama et al., *Rev. Sci. Instr.* 87, 113305 (2016).

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The a SPECT experiment - Overview of systematic uncertainties

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The a SPECT experiment is a retardation spectrometer built to measure the proton energy spectrum in free neutron β -decay. From the shape of the spectrum, the β - $\bar{\nu}_e$ angular correlation coefficient a can be derived and thus $\lambda(a)$, the ratio of the weak axial-vector (A) to vector (V) coupling constant $\lambda = g_A/g_V$.

In 2013, a SPECT had a successful beam time at the Institut Laue-Langevin, Grenoble (France). Different parameter settings of the spectrometer helped to trace instrumental systematics. Supportive follow-up measurements were conducted, e.g. to determine the spatial and temporal work function fluctuations of the electrodes, which is a source of one of the main systematic uncertainties. These measurements were used as input for electromagnetic field computations and particle tracking simulations for a correction of systematics. The data of the runs in the individual configurations were combined and analysed using a multi-dimensional fit with a as free fit parameter.

From this beam time we obtain $a = -0.10430(84)$ [1] which is the most precise measurement of the neutron a coefficient to date (PDG2018 value $a = 0.1059(28)$). The ratio of axial-vector to vector coupling constant is derived giving $|\lambda(a)| = 1.2677(28)$. The sources of systematic uncertainties are considered and included in the results.

This poster gives an overview of the systematic uncertainties. Special focus is given on the systematics that could only be quantified by sophisticated electromagnetic field and particle tracking simulations as part of my Ph.D. thesis [2].

[1] M. Beck et al., arXiv:1908.04785 [nucl-ex], 13 Aug 2019, submitted to Phys. Rev. C

[2] C. Schmidt, Ph.D. thesis, Johannes Gutenberg-Universität Mainz, 2019.

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Data Acquisition for the n2EDM Experiment

Authors: Dieter Ries¹; Georg Bison²; Jacek Zejma³; Jochen Krempel⁴; Romain Viot⁵¹ *Johannes Gutenberg University Mainz*² *Paul Scherrer Institut*³ *JUC*⁴ *ETH Zürich*⁵ *LPSC-IN2P3, CNRS, Grenoble INP, Univ. Grenoble Alpes***Corresponding Author:** jochen.krempel@phys.ethz.ch

Currently a new experiment is being built for the measurement of the neutron electric dipole moment at PSI called n2EDM.

Compared to its predecessor, many improvements will be made not only to the apparatus itself, but also to the supervisory control and data acquisition system.

For nEDM it is essential to not only record, but also to influence the experiment automatically which incorporates decisions that are based on previous measurements.

The concept is completely modular, thus development can be done in parallel, and new devices can be added easily - even while the experiment is running.

The modules are connected via network using Standard Commands for Programmable Instruments (SCPI) over TCP for messaging.

Data sampling and recording is done simultaneous. Synchronization is achieved via Precision Time Protocol (PTP).

Multiple control stations are possible and any graphical user interface is separated operation and recording.

A simple command language for arbitrary sequences, loops and conditional execution is available.

While the framework is clearly optimised for an nEDM measurement, it may be used for other experiments with similar scale and measurement procedure.

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Searching for New Physics with the Mu3e Detector

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The Mu3e Experiment at PSI is designed to search for the lepton-flavour violating decay of a positive muon to two positrons and an electron with an ultimate sensitivity of one in 10^{16} muon decays. The detector is based on ultra-thin high-voltage monolithic active pixel sensors combined with scintillating fibres and tiles for precise timing measurement. The poster will discuss sensitivity studies performed for the Mu3e detector, both for the main signal decay in different models of new physics, as well as for electron-positron resonances, motivated by dark photon models, and two-body decays of the muon, motivated by Faimon models.

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UCN energy spectrum measurements using the OTUS spectrometer

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The energy spectrum of ultra-cold neutrons (UCN) is an important factor in determining the systematic effects in precision measurements utilizing UCN. The oscillating ultra-cold neutron spectrometer (OTUS) is a new tool designed for monitoring the energy distribution and its time evolution in different places of the transport system connecting a UCN source with experiments. We will present the current status of the project including measurements using the oscillating spectrometer installed at the PSI UCN source.

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Analysis of the hyperfine splitting of the $5 \rightarrow 4$ transitions in muonic Re-185 and Re-187

Authors: Stergiani Marina Vogiatzi¹; For the muX collaboration^{None}¹ *PSI - Paul Scherrer Institut, ETH Zurich***Corresponding Author:** stella.vogiatzi@psi.ch

An ongoing experiment at PSI aims to determine the nuclear charge radius of ^{226}Ra - needed by an experiment aiming at measuring atomic parity violation in a radium ion - by means of muonic atom spectroscopy. An intermediate test was performed with a $^{185,187}\text{Re}$ target which is the last stable element whose nuclear charge radius has not been measured and shows similar nuclear structure effects as radium. In $^{185,187}\text{Re}$ there exists an intermediate domain of energy states in which the quadrupole splitting is proportional to the spectroscopic quadrupole moment. In this contribution, the analysis of the $5g \rightarrow 4f$ hyperfine transitions in muonic $^{185,187}\text{Re}$ for the extraction of its spectroscopic quadrupole moment is presented.

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Search for a permanent electric dipole moment on the electron (eEDM) using BaF molecules

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As the NL-eEDM collaboration, we are searching for a permanent electric dipole moment on the electron (eEDM) in a BaF molecular beam. In preparation of such an experiment we have performed spectroscopic measurements in a supersonic BaF beam. The lifetimes of the $A^2_{1/2}$ and $A^2_{3/2}$ states were obtained using short light pulses generated from a CW laser beam with a pulsed acousto-optic modulator. An eEDM search in BaF puts stringent requirements on the fields in an interaction zone. Those include an electric field of O(10 kV/cm) and a magnetic field of O(10 nT), both with small field gradients i.e. less than 1% inhomogeneity. We are currently building the interaction zone to work with the intense supersonic BaF beam. Ultimately the sensitivity can be improved with a substantially decelerated and laser-cooled BaF molecular beam. In our experiment we aim at an eEDM sensitivity down to $5 \times 10^{-30} e \text{ cm}$.

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Positron Reconstruction Algorithms for MEG II Pixelated Timing Counter

Author: Masashi Usami¹**Co-authors:** Gianluigi Boca²; paolo walter cattaneo³; Matteo De Gerone⁴; Flavio Gatti⁵; Mitsutaka Nakao⁶; Miki Nishimura⁶; Wataru Ootani⁷; massimo rossella⁸; Yusuke Uchiyama⁶; Kosuke Yanai⁹; Fedor Ignatov¹⁰¹ *The Univ. of Tokyo, ICEPP*² *INFN Pavia, The University of Pavia*³ *INFN Pavia*⁴ *INFN Genova*⁵ *University and INFN of Genoa*⁶ *The University of Tokyo*⁷ *Univ. of Tokyo*⁸ *INFN - Sezione di Pavia*⁹ *University of Tokyo*¹⁰ *Budker Institute of Nuclear Physics***Corresponding Author:** usami@icepp.s.u-tokyo.ac.jp

The MEG II experiment is designed to achieve the world's most sensitive $\mu^+ \rightarrow e^+\gamma$ decay search with the most intense muon beam ($7 \times 10^7 \mu^+/s$) in Paul Scherrer Institut. This decay is prohibited in the standard model theory but predicted to occur in the many beyond standard model theories. Thus, to find this decay means to find the new physics.

To discover this undiscovered rare decay, the precise reconstruction of positron under the intense muon beam environment is necessary. We constructed the pixelated timing counter (pTC) to determine the positron crossing timing under 40 ps resolution.

We have been developed the positron reconstruction algorithms using pTC information effectively. For example, a tracking algorithm inside pTC has recently developed and this will give us even more information for the precise reconstruction. Here we will present a novel positron reconstruction algorithms to bring out the potential of pTC and achieve the best performance for the experiment.

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Recent Measurements of Vacuum Muonium

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Recently, we have performed measurements on vacuum muonium formation at room and cryogenic temperatures at the the Paul Scherrer Institute. These measurements were conducted in the context of our efforts on the investigation of the gravitational interaction of antimatter and second-generation particles. In our room temperature setup, the muon beam impinged on several targets such as zeolite powder, ablated aerogel and semiconductor carbon-nanotubes. The relative yield and velocity of the observed vacuum muonium are presented. At cryogenic temperature, the targets were dry and superfluid-helium coated aerogel. While vacuum muonium was not observed directly in this case, we did observe the formation of muonium by means of the spin rotation technique. This contribution will present and compare.

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Towards a beta spectrum shape measurement at WISArD (CERN)**Author:** Simon Vanlangendonck¹**Co-authors:** Bertram Blank²; Dalibor Zakoucky³; Dinko Atanasov⁴; Etienne Liénard⁵; Gilles Quemener⁶; Jerome Giovinazzo²; Laurent Daudin²; Leendert Hayen⁷; Lennert De Keukeleere; Mathias Gerbaux²; Mathieu Roche²; Maud Versteegen²; Nathal Severijns⁸; Pauline Ascher²; Philippe Alfaurt²; Stéphane Grévy²; Teresa Kurtukian-Nieto²; Victoria Araujo-Escalona⁹; Xavier Flechard¹⁰¹ KULeuven² CENBG³ Acad. Sci. Czech Rep., CZ-25068 Rez, Czech Republic⁴ CERN⁵ LPC Caen⁶ LPC CAEN⁷ IKS, KU Leuven⁸ Katholieke Univ. Leuven⁹ Instituut voor Kern- en Stralingsfysica, KU Leuven¹⁰ LPC Caen IN2P3/CNRS**Corresponding Author:** simon.vanlangendonck@kuleuven.be

There are indications that the measured number of antineutrinos emerging from reactor fission fragments inside a reactor is lower than theoretically predicted. Moreover, there is an additional anomaly in the energy spectrum of the antineutrinos. These observations are the reactor neutrino anomaly. One of the uncertainties in the theoretical description is the QCD influence on the β -decay of which the weak-magnetism term is the major contribution. Its value is unknown experimentally in the mass range of the reactor fission fragments. [1] A direct measurement is possible with the beta energy spectrum and would be the first of its kind in this mass range. In addition, the performed fit can include the Fierz interference term to probe beyond standard model (BSM) physics, i.e. weak tensor or scalar currents. BSM experiments aim for a precision close to 10^{-3} and, thus, complementarity to high energy experiments, e.g. LHC, within an effective field theory. [2]

Spectrum shapes were measured extensively in the past but only recently attracted renewed interest. The main sources of systematic uncertainties are energy losses in the source (foils), the detector dead layer and the rather high backscattering probability for electrons. Using the progress in Monte Carlo simulation (e.g. Geant4) over the last couple of years it is possible to improve on previous results. [2]

During the long shutdown at CERN we will adapt the existing WISArD set-up at CERN with the objective to measure the beta-spectrum shape of In114, a pure Gamow-Teller decay. With two energy detectors along a high magnetic field the set-up has a full solid angle. Moreover, backscattered particles are not lost but spiral towards the other detector. Using Geant4 a feasibility study is completed and first data taking is planned in short notice thus preliminary results might be shown.

A complementary approach using a multi-wire drift chamber is also under development in our research group and will also be presented at PSI2019. [3]

[1] A. C. Hayes and P. Vogel. Reactor neutrino spectra. *Annual Review of Nuclear and Particle Science*, 66(1):219–244, 2016.

[2] M. González-Alonso, O. Naviliat-Cuncic, N. Severijns. New physics searches in nuclear and neutron β decay. *Progress in Particle and Nuclear Physics*, 104:165-223, 2019.

[3] L. De Keukeleere. Unpublished.

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Ultracold neutron production and extraction from the solid deuterium converter of the PSI UCN source

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Ultracold neutrons (UCN) with energies below 300 neV can be trapped for hundreds of seconds in containments made of materials with high optical potential. They are used in experiments that benefit greatly from long storage times, like the n2EDM experiment currently assembled at PSI, searching for a permanent electric dipole moment of the neutron. The PSI UCN source makes use of solid deuterium as superthermal converter to produce UCN. A reduction over time of the initial UCN output after preparation of the solid deuterium and a conditioning procedure to counter this effect and maximize the UCN output has been developed. Enhancing the UCN extraction from the converter is an ongoing effort. We study the impact of structural features in the deuterium and other parameters of the converter on UCN extraction by dedicated measurements and detailed simulations. This will provide important insights helping to further increase the UCN output of the PSI UCN source.

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Overview of the Beam EDM Project and Latest Results

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The search for a neutron electric dipole moment (EDM) is of significant interest in understanding the observed baryon asymmetry in the universe. Historically, two methods have been employed to measure an EDM, storage of ultracold neutrons (UCN) and cold neutron beams, with the latter being abandoned in the 1980s due to a limiting relativistic systematic effect. The Beam EDM experiment developed at the University of Bern represents a novel concept to overcome this limitation with a cold neutron beam using the time-of-flight method. The ultimate goal of this project aims to reach a sensitivity competitive with future UCN experiments. This poster will present an overview of the Beam EDM project and latest results.

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Evaluation of Radiation Effects on VUV-MPPC

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Results of PDE measurements for VUV-MPPCs irradiated by γ , neutron or VUV light

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n2EDM Ramsey Chamber

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We present details of the simulations, design, and half scale initial tests of the Ramsey Chamber apparatus for the n2EDM experiment. The Chamber is a double chamber cylindrical geometry with a 80 cm internal diameter. The two UCN volumes are stacked vertically and separated by a central high voltage electrode. The volumes are sealed on top and bottom by an insulating spacer and ground electrodes. The distance between the high voltage and ground electrodes is 12 cm and designed to hold voltages up to 250 kV. Simulations were performed to optimise the geometry of the Chamber to maximise the applied voltage.

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Towards quantum logic inspired techniques for tests of discrete symmetries with (anti-)protons

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We present an experimental approach based on quantum logic inspired cooling and readout techniques to contribute to CPT tests in the baryonic sector. Within the BASE collaboration [1], these techniques would allow to cool single (anti-)protons to sub-Doppler temperatures by means of coupling to a laser-cooled beryllium ion [2, 3]. For this purpose, both ions will be co-trapped in an advanced cryogenic Penning trap system using an engineered double-well potential [4]. In addition, these techniques will lead to faster g -factor measurements of the (anti-)proton, resulting in better statistics and enabling proton-antiproton comparisons within daily sidereal timescales. In this contribution, we will show the current status of the project emphasizing the latest results on Doppler cooling of $^9\text{Be}^+$ ions as well as the latest modifications of the cryogenic Penning trap system.

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Searching for Neutron - Mirror Neutron Oscillations

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Neutron to mirror-neutron oscillations [1] could be an observable baryon number violating process. Baryon number violation is required for baryogenesis in order to explain the observed asymmetry between matter and antimatter in the universe. Two separate groups [2],[3] performed experiments in search of mirror-neutron oscillations and reported having found no evidence. The limit set on the oscillation time was $\tau_{nn'} > 414$ s (90% C.L.) at mirror magnetic field $B' = 0$. Furthermore, when the results of these two experiments were further analyzed by Berezhiani et al., statistically significant signals for mirror-neutron oscillation in presence of a mirror magnetic field were reported [4]. The current leading constraints upon $\tau_{nn'}$ in Refs. [2],[3],[4],[5],[6],[7] do not exclude these signals [7]. The PSI nEDM collaboration performed a series of experiments to test these signals and the latest results of this effort will be presented.

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Electromagnetic design of NoMoS, a neutron decay products momentum spectrometer

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The beta decay of the free neutron provides several probes to test the Standard Model of particle physics as well as to search for extensions thereof. NoMoS, the neutron decay products momentum spectrometer, presents a novel method of momentum spectroscopy: it utilizes the $R \times B$ drift effect to disperse charged particles dependent on their momentum in an uniformly curved magnetic field. The NoMoS spectrometer is designed to precisely measure momentum spectra and angular correlation coefficients in free neutron beta decay. We present recent developments in the electromagnetic design of the spectrometer.

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BRAND: Search for BSM physics at TeV scale by exploring the transverse polarization of electrons emitted in neutron decay

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Neutron and nuclear beta decay correlation coefficients are sensitive to the exotic scalar and tensor interactions that are not included in the Standard Model (SM). The BRAND experiment will measure simultaneously 11 neutron correlation coefficients (a, A, B, D, H, L, N, R, S, U, V) where 7 of them (H, L, N, R, S, U, V) depend on the transverse electron polarization – a quantity which vanishes in the SM. The neutron decay correlation coefficients H, L, S, U, V were never attempted experimentally before. The expected impact of the proposed experiment that currently takes off on the cold neutron beamline PF1B at the Institut Laue-Langevin, Grenoble, France, is comparable to that of the beta spectrum shape measurements [1] but offers completely different systematics and additional sensitivity to imaginary parts of the scalar and tensor couplings. In the poster, challenges of the proposed techniques will be presented together with a setup designed for testing them in the real environment at ILL.

*) Poster presenter

[1] L. De Keukeleere et al. – poster in this conference.

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Monte Carlo studies of μp diffusion for the hyperfine-splitting experiment at PSI

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Spectroscopy of muonic hydrogen (μp) atoms allows for precise investigations of the proton's electromagnetic structure. At PSI we want to measure the groundstate hyperfine-splitting of muonic hydrogen, from which the Zemach radius of the proton can be deduced. The experiment will use a new detection scheme which is based on the diffusion of laser-excited μp atoms inside a gas cell filled with H_2 . Monte Carlo simulations of the μp diffusion process help to develop constraints on various parameters of the experimental setup and to estimate the sensitivity of the measurement. This poster presents the detection scheme of the hyperfine-splitting experiment and outlines the deployed Monte Carlo diffusion studies.

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The ASACUSA hydrogen hyperfine structure measurement

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The ASACUSA (Atomic Spectroscopy And Collisions Using Slow Antiprotons) Collaboration of the AD-facility at CERN aims to measure the ground-state hyperfine structure of antihydrogen to test the CPT-Theorem [1]. For this purpose, a spectroscopy apparatus has been built and tested with hydrogen [2]. An upgrade of the interaction region enabled to induce two transitions between the hyperfine transition sublevels by using the same experimental setup. It was shown, that the apparatus works as expected with a relative precision of ppb [3]. Further, analysis of data acquired at lower magnetic fields (~ 46 mG to ~ 0.231 G), i.e. small Zeeman splitting of the energy levels, shows a systematic shift due to interactions between the sublevels [4].

The poster will show the hydrogen beam experimental setup, the investigation of the systematic shift, the correction of the results and conclusions for the antihydrogen experiment.

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Design of the detection system for the measurement of the hyperfine splitting in muonic hydrogen

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Muonic hydrogen, ground-state hyperfine splitting, detection system, MeV-energy X-rays, scintillation detectors.

Muonic hydrogen (μp) is a bound-state of a negative muon and a proton. Since a muon is 207 times heavier than an electron, the energy levels of μp are very sensitive to the nuclear structure. By means of laser spectroscopy, we are aiming at the measurement of the ground-state hyperfine splitting to extract the two-photon exchange contribution and the Zemach radius of the proton. This experiment is being conducted at Paul Scherrer Institute and it requires designing a detector system capable of measuring the MeV-energy X-rays produced by the muonic atoms. The variation of thin and thick scintillation detectors can be used to define energy cuts to distinguish between an electron and a high-Z material (μZ) X-ray.

Work is supported by SNF project 200021_165854 and ERC CoG. #725039.

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Measurement of the Lamb Shift of Antihydrogen

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Antihydrogen studies aim to shed light on the observed baryon/antibaryon asymmetry in the Universe by comparing the properties of matter and antimatter with very high precision. In the context of the GBAR experiment [1] located at CERN, our aim is to perform a measurement of the antihydrogen Lamb shift with an uncertainty of 100 ppm, which allows extracting the antiproton charge radius at a level of 10% [2]. Due to the two years shutdown of the accelerator complex at CERN, no experiments with antihydrogen can be performed until 2021. In the meantime, the setup is being tested and optimized by using the same detection method with a hydrogen beam at ETH Zurich. The experimental setup and the current status will be presented.

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Towards parity violation and tunneling in chiral molecules: An experiment in the mid-infrared range using a pulsed slit jet expansion.**Author:** Gunther Wichmann¹**Co-authors:** Eduard Miloglyadov¹; Georg Seyfang¹; Martin Quack¹¹ *ETH Zürich***Corresponding Author:** gunther.wichmann@phys.chem.ethz.ch

Our scheme aims to measure the parity violating energy difference between the enantiomers of chiral molecules which has been predicted to be very small, e.g. about 100 aeV for CHFClBr [2] and 1 feV for 1,2 Dithiine [3], but so far has never been measured. The effect might be important for the origin of biomolecular homochirality and for precision tests of the standard model of particle physics at low energy [4]. The scheme starts with the preparation of a pure parity state of the molecule in a two photon process by exciting to a rovibrational state with an excitation energy close to or above the barrier for the interconversion of the two enantiomers [5]. Essential for the preparation step is a complete understanding of the IR-spectrum in this energy region where tunneling splittings are large. To measure such infrared spectra with high accuracy a new setup has been built to investigate polyatomic molecules of moderate size in the required spectral range from 2800 to 3500 cm⁻¹ (3.6 μm to 2.9 μm) using an OPO referenced to a frequency comb reaching an accuracy better than 1 kHz for the mid-IR laser frequency. The spectra are measured in a slit jet molecular beam expansion using cavity ring-down spectroscopy [6, 7]. Due to the Doppler shift the effective frequency uncertainty is about 1 MHz. We will present test results for ammonia (NH₃), which is also of general interest as prototype tunneling molecule [8] as well as for nuclear spin symmetry (see [9, 10] and Refs. cited). The results of the experiments are consistent with nuclear spin symmetry conservation in seeded supersonic jet expansions providing cooling to temperatures below 7 K. In the achiral molecule NH₃ one has also effective intramolecular parity conservation [5]. Results on potential chiral candidates for measuring parity violation will be presented as available at the time of the meeting.

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Experiment on measuring the ratio of the axial and vector constants of weak interaction

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The possibility of experimentally determining the ratio λ of the axial weak-interaction constant G_A to the vector weak-interaction constant G_V by simultaneously measuring the electron and neutrino asymmetries at the same setup is discussed. The proposed measurement and data-processing procedures are described. The determination of λ by the method in question permits disregarding the possible contribution of the Fierz interference term and dispensing with an accurate measurement of the neutron polarization.

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A Tracking Detector for the P2 Experiment

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The P2 experiment at the new electron accelerator MESA in Mainz aims for a determination of the weak mixing angle at low momentum transfer with unprecedented precision. To this end, the parity violating asymmetry in electron proton scattering is studied with integrating Cherenkov detectors at very high rates of scattered electrons. In order to determine the average momentum transfer Q^2 and precisely study systematic effects which could lead to false asymmetries, a tracking detector is required. The poster presents the design of such a detector based on high-voltage monolithic active pixel sensors (HV-MAPS), which are well suited to deal with the enormous rates of scattered electrons and photons and put a minimum amount of material into the particle path.

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NNLO corrections in massive QED

Authors: Adrian Signer¹; Pulak Banerjee²; Tim Engel¹; Yannick Ulrich¹¹ *Paul Scherrer Institut/Universität Zürich*² *PSI - Paul Scherrer Institut***Corresponding Author:** tim.engel@psi.ch

Low-energy experiments with leptons such as MEG, Mu3e, MUonE and MUSE complement the research at the high-energy frontier. However, to fully exploit the experimental data, the corresponding Standard Model background has to be known to a high accuracy. For this reason we calculate the fully differential NNLO QED corrections to the processes $\mu \rightarrow e\nu\nu$, $\mu e \rightarrow \mu e$, $\mu p \rightarrow \mu p$ and $ep \rightarrow ep$. Since small-mass effects become non-negligible at this level of precision, the leading logarithmic corrections are taken into account. The corrections due to real photon emissions are computed using FKS², an extension of the FKS subtraction scheme to NNLO in massive QED.

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Manipulating the translational and internal degrees of freedom of hydrogen atoms

Author: Simon Scheidegger¹**Co-authors:** Paul Jansen ¹; Josef A. Agner ¹; Hansjürg Schmutz ¹; Frédéric Merkt ²¹ *ETH Zurich*² *ETH Zurich, Laboratory of Physical Chemistry***Corresponding Author:** simon.scheidegger@phys.chem.ethz.ch

The first experiments designed to control the translational motion and the internal state of the hydrogen atom were performed almost 100 years ago by Rabi [1] using the beam methods developed by Gerlach and Stern [2]. We present a method with which paramagnetic atoms and molecules can be generated in a specific magnetic sublevel of a selected internal state and with which the atom or molecule velocity can be manipulated at will. The selected magnetic state and velocity is achieved by multistage Zeeman deceleration [3, 4].

Of particular interest are slow beams ($v \leq 300 \text{ m s}^{-1}$) of cold hydrogen atoms in view of precision frequency measurements of fine- and hyperfine structure intervals as well as intervals to high-Rydberg states, which are relevant in the context of the proton charge-radius puzzle [5, 6]. In our experiment we generate the hydrogen atoms by photodissociation of NH_3 in a capillary mounted at the orifice of a pulsed valve. The hydrogen atoms are entrained in the supersonic expansion of a rare gas and enter a multistage Zeeman decelerator, with which they are slowed down from initially 500 m s^{-1} to $50 - 100 \text{ m s}^{-1}$ [7]. After leaving the decelerator they are photoexcited to $n\text{p}$ -Rydberg states in a $2+1'$ resonant three-photon excitation sequence via the $2s \ ^2S_{1/2}$ ($F = 0, 1$) intermediate state and detected by pulse-field ionization. We will report on our experimental progress on the precision measurements of $n\text{p}$ - $2s$ transition frequencies.

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Muonic Atom Spectroscopy: Preparations Regarding a Measurement of the Charge Radius of Radium

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Presentation of the preparations regarding the nuclear charge radius measurement of radium.

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Two-Higgs-Doublet Models with Soft CP-violation Facing Current and Future EDM Tests

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- I. Brief Introduction to 2HDM with Soft CP-violation (Type I,II,III,IV)
- II. Current Constraints through Collider, Flavor, S-T parameter, and especially the ACME II electron EDM measurement;
- III. The importance of neutron EDM: current constraint on CP-even and -odd mixing angle, and why is it irreplaceable in constraining Type II and III models: possible cancellation in electron EDM;
- IV. Conclusions and Discussions.

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Calibration of VUV-sensitive MPPCs of MEG II Liquid Xenon Gamma-ray Detector

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- Development of calibration measurements for VUV-sensitive MPPCs in MEG II Liquid Xenon Gamma-ray detector
- Performance evaluation of VUV-sensitive MPPCs under high-intensity muon beam

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Detection System for NoMoS

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NoMoS, the neutron decay products momentum spectrometer, aims to measure the momentum spectra of the charged decay products (electron and proton) in neutron beta decay with high precision. It uses the so-called R x B effect in a uniformly curved magnetic field to separate and a spatially resolving detector to measure the charged decay particles according to their momentum. In this poster, the proposed spatial detection system as well as the veto detectors of NoMoS alongside their systematics investigations will be described.

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Beta spectrum shape measurements using backscatter recognition**Author:** Lennert De Keukeleere^{None}**Co-authors:** Dagmara Rozpedzik¹; Kazimierz Bodek²; Konrad Lojek¹; Leendert Hayen³; Maciej Perkowski¹; Nathal Severijns⁴; Simon Vanlangendonck⁵¹ *Marian Smoluchowski Institute of Physics, Jagiellonian University*² *Jagiellonian University, Institute of Physics*³ *IKS, KU Leuven*⁴ *Katholieke Univ. Leuven*⁵ *KULeuven***Corresponding Author:** lennert.dekeukeleere@kuleuven.be

Beyond Standard Model (BSM) theories can be probed in two types of experiments. In collider experiments, such as those carried out at LHC, exotic bosons are directly produced in high-energy proton-proton collisions. Another way to test BSM's, is by studying low-energy observables. This is facilitated by the small effects/currents of the same exotic bosons on these observables[1]. The shape of the beta spectrum, which is the topic of this research, is sensitive to two exotic currents, scalar and tensor, both prohibited in the SM weak interaction. For allowed transitions, these currents introduce a correction term, called the Fierz term b_{Fierz} , which is inversely proportional to the energy.

In addition to BSM's, the beta spectrum shape is a useful tool to probe SM effects, caused by the strong interaction and which could mimic effects of new physics. The largest of these is called Weak Magnetism (WM). For some transitions, a measurement of WM can provide a good test for the Conserved Vector Current hypothesis (CVC). Furthermore, the knowledge of WM for high-mass neutron-rich nuclei is crucial in the analysis of reactor anti-neutrino experiments[2].

With this in mind, an attempt will be made to measure the spectrum shape of the pure Gamow-Teller decay $^{114}\text{In} \rightarrow ^{114}\text{Sn}$, at the precision level of 10-3. As backscattering is the main source of systematic uncertainty, a scintillation detector in combination with a multi-wire drift chamber was designed to measure the beta spectrum shape. The purpose of the drift chamber is to identify electrons that are backscattered from the scintillator and as a result do not deposit their full energy in the detector. In addition to backscatter recognition, the setup allows for several filtering and calibration methods. For example, by requiring coincidence between detector and drift chamber, noise and gamma particles can be filtered out. Furthermore, in order to correct for non-uniform light collection, tracking conversion electrons can be used to make a 2D gain map of the detector surface.

The poster will display the current results and progress with respect to calibrations and the first efforts to tackle systematics in the measured ^{114}In -spectrum. In addition, the results will be compared with Monte-Carlo simulations, i.e. Geant4 and Garfield++, as the analysis will be strongly depending on it.

Complementary to this project, an alternative approach, investigated by our research group, is also presented at the conference. Here, two detectors are placed on both sides of the source and a magnetic field is applied to obtain a 4π solid angle, thereby resolving the issue of backscattering[3].

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Asacusa's Ramsey spectrometer for high precision hyperfine spectroscopy

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The ASACUSA (Atomic Spectroscopy And Collisions Using Slow Antiprotons) collaboration, based at the Antiproton Decelerator facility of CERN aims to measure the ground state hyperfine structure of antihydrogen at a ppm level relative precision with a Rabi-type beam experiment [1,2]. ASACUSA produces antihydrogen atoms by the mixing of antiprotons with positrons in a double cusp trap with strong magnetic field gradients for the formation of a polarised beam [3].

For the Rabi-type experiment, a spectrometer line with a strip-line microwave cavity has been fully commissioned with studies on hydrogen. With the use of this spectroscopy apparatus a relative precision of 10^{-9} has been achieved, which is so far the most precise measurement of the hyperfine splitting of hydrogen in a beam method [4]. A Ramsey type beam spectroscopy method [5] has the potential to improve this precision by a factor of 10. However, the existing strip line cavity, is not well suited for the Ramsey scheme as the decisive Ramsey fringes near the transition frequency can't be observed. This demanded the design of new microwave devices.

I shall discuss the finite element simulations and design aspects of various options for cavity and transmission lines, which will be used as the source of the perturbing field for driving transitions in the hyperfine levels. The flexibility of the device which can allow us to better study the systematics shall also be addressed.

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Precision tests of discrete symmetries in the decays of positronium atoms using the J-PET detector**Author:** Sushil Sharma¹¹ Jagiellonian University**Corresponding Author:** sushil.sharma@uj.edu.pl

Positronium is a purely leptonic object self annihilating into photons. It is an atom bound by a central potential and thus the states of positronium are parity eigenstates. Furthermore, as an atom composed of a particle (e^-) and its antiparticle (e^+), it is an eigenstate of the charge conjugation operator. Therefore, the positronium is a unique laboratory to study discrete symmetries whose precision is limited, in principle, only by the effects due to the weak interactions expected at the level of 10^{-14} [1] and photon-photon interactions expected at the level of 10^{-9} [2]. Violation of T or CP invariance in purely leptonic systems has not been observed yet [3]. The experimental limits on CP and CPT symmetry violation in the decays of positronium atom are set at the level of 10^{-3} [4,5] and limits on charge conjugation violation are set at the level of 10^{-7} [6-8]. Thus, there is still a margin of six orders of magnitude as regards T and CP, and two orders of magnitude as regards the C symmetry, where the phenomena beyond the Standard Model can be sought for by improving the experimental precision in investigations of decays of positronium atoms.

The Jagiellonian Positron Emission Tomograph (J-PET) is constructed of 192 polymer scintillators placed in three consecutive cylindrical layers of diameter 85, 93.5 and 115 cm respectively [9-15]. J-PET is optimized for the registration of photons from the electron-positron annihilation and provides a superior time resolution, higher granularity and lower pile-ups in comparison to crystal based detectors. With higher angular resolution of plastic scintillators, the geometrical acceptance of J-PET allows us to estimate the angle between the planes of gamma photons before and after the scattering. Thus, the J-PET is one of the unique facilities, which allows studying the polarization direction of photons [16-17]. The capability of registering multi-photons originating from the decays of positronium atoms enables to perform tests on discrete symmetries via the determination of the expectation values of the discrete-symmetries-odd operators, which might be constructed from the spin of ortho-positronium atom and the momenta and polarization vectors of photons originating from its annihilation [16-20].

In the proposed talk, the proof of capabilities of the J-PET in performing the precision tests on the discrete symmetries will be presented and the first experimental results (with precision higher than in the previous experiments) obtained in the recent data taking campaigns with the J-PET detector will be discussed.

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Data analysis of the search for an electric dipole moment of the neutron

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An electric dipole moment of the neutron (nEDM) is intrinsically violating the combined symmetry of charge and parity (CP). One necessary condition to create a matter/antimatter asymmetric universe from symmetric starting conditions is a sufficiently strong source of charge/parity violation (CPV) in the fundamental physics describing the early Universe. A discovery of a nEDM value larger than the SM prediction ($\leq 1\text{E-}31$ ecm) would be an indication for a yet unknown source of CPV and might help to explain the matter/antimatter asymmetry of the Universe, or shed light on to the strong CP problem.

At the Paul Scherrer Institute (PSI) in Switzerland, a collaboration of 16 institutions is searching for the nEDM using ultracold neutrons (UCN). In 2015 and 2016, we took more than 55000 single measurements each with an average of approximately 11500 UCN. The dataset with a pre-analysis sensitivity of 0.95×10^{-26} ecm is sufficient to improve the current upper limit, $d_n < 3 \times 10^{-26}$ ecm @90% C.L. [J.M. Pendlebury et al. PRD 92, 092003 (2015)]. This poster will present the summary of the ongoing analysis by combining results from two analysis groups, both working on independently blinded data.

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The TRIUMF UltraCold Advanced Neutron source and EDM experiment

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The goal of the TUCAN collaboration is to measure the electric dipole moment (EDM) of the neutron with a sensitivity of 10^{-27} ecm. To achieve this within a reasonable time, we are building the world's strongest ultracold-neutron source, based on superthermal conversion of cold neutrons in superfluid helium. At TRIUMF, we recently commissioned a new proton beamline with a beam power of up to 20 kW, a new neutron spallation target, and a prototype ultracold-neutron source developed in Japan, which we use to test components and benchmark our simulations.

Thanks to extensive optimizations with these simulations, we expect the TUCAN source to produce $1.6 \cdot 10^7$ ultracold neutrons per second, while keeping the superfluid helium at a temperature of 1.1 K. This would allow us to reach the EDM sensitivity goal within about 400 beam days. The new source is expected to go into operation in 2021.

This presentation will show results of tests with the prototype source, compare them to simulations, and show the design and expected performance of the new TUCAN source and EDM experiment. This work is supported by NSERC, CFI, and JSPS.

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Neutron spin rotation at Laue diffraction in a weakly deformed transparent noncentrosymmetric crystal

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The effect of neutron spin rotation at Laue diffraction in a weakly deformed neutron-transparent noncentrosymmetric crystal has been described theoretically and studied experimentally. The effect is due to the bending of a Kato trajectory of the neutron in the deformed crystal. At a certain type of the deformation, one of two neutron waves excited at Laue diffraction, which propagate in opposite crystal fields in the crystal with no center of symmetry, leaves the crystal. As a result, the spin of the remaining neutron wave will rotate by a certain angle with respect to initial direction due to the interaction of the magnetic moment of a moving neutron with the intracrystalline electric field. This effect is absent in an undeformed perfect crystal, where only the depolarization of a beam occurs because both waves in opposite electric fields have the same amplitude. The method of controlled deforming of a perfect single crystal by creating a temperature gradient in it is developed. Thus, a new way for measuring electric fields acting on neutrons in non-centrosymmetric crystals is implemented, as well as a method for controlling these fields in experiments to study the fundamental properties of the neutron.

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Testing the Pauli Exclusion Principle for electrons with the VIP-2 experiment

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The VIP2 experiment is a major upgrade of the VIP (Violation of the Pauli exclusion principle) experiment and is testing the Pauli Exclusion Principle (PEP) for electrons, looking for a possible forbidden transition energy which could point out a violation of PEP.

The transition energy monitored in VIP and VIP2 is that of the $K\alpha_1$ line of the copper atom, which is 8047.8 eV. The transition energy forbidden by PEP is 7747 eV, as calculated using the Multi Configuration Dirac-Fock and General Matrix Element (MCDFGME) program.

The VIP experiment, which took place at National Laboratory of Gran Sasso (LNGS) of the National Institute of Nuclear Physics (INFN) from 2006 to 2010, set a new upper limit to the violation of PEP for electrons which is 4.7×10^{-29} .

In this talk I shall review the latest activities within the VIP2 collaboration and I shall explain theoretical reasons of this important test for the PEP.

I shall speak about the installation of the upgraded setup at LNGS, highlighting the significant improvements performed on the apparatus and based on which we have set the goal that VIP2 should be able to achieve. I shall show the preliminary results obtained with the new setup of VIP2 using the data collected until 2018 and present the random walk model which describes the electron path inside the copper target, and gives the possibility of setting a further smaller upper limit.

Future perspectives will be illustrated, including a possible experiment using germanium detectors. Finally I shall comment on the data analysis procedure and as well on the theoretical activities for the interpretation of the results in the framework of theories beyond the Standard Model.

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The τ SPECT neutron lifetime experiment

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Ultracold Neutrons (UCN) provide a unique tool for fundamental neutron research with long observation times.

The τ SPECT experiment, which is currently being commissioned at the pulsed UCN source of the TRIGA Mainz research reactor, aims to utilize this fact in order to precisely measure the free neutron lifetime. In order to reduce systematic errors with respect to storage experiments using material bottles, τ SPECT implements 3D magnetic storage of spin polarized UCN and will be able to measure both the decaying and the surviving UCN.

The current state of the τ SPECT experiment and results from the first tests with neutrons will be presented.

This work has been supported by the Cluster of Excellence “Precision Physics, Fundamental Interactions, and Structure of Matter” (PRISMA+ EXC 2118/1) funded by the German Research Foundation (DFG) within the German Excellence Strategy (Project ID 39083149)

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Correlating Tauonic B Decays to the Neutron EDM via a Scalar Leptoquark

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We investigate the correlations between tauonic B meson decays (e.g. $B \rightarrow \tau\nu$, $B \rightarrow D^{(*)}\tau\nu$, $B \rightarrow \pi\tau\nu$) and electric dipole moments (EDMs), in particular the one of the neutron, in the context of the S1 scalar leptoquark (LQ). This LQ naturally arises in the R-parity violating MSSM as the right-handed down-squark. We perform the matching of this model on the effective field theory taking into account the leading renormalization group effect for the relevant observables. We find that one can explain the hints for new physics in $b \rightarrow c\tau\nu$ transitions without violating bounds from other observables. Even more interesting, it can also give sizable effects in $B \rightarrow \tau\nu$, to be tested at BELLE II, which are correlated to (chromo) electric dipole operators receiving $m\tau/m_u$ enhanced contributions. Therefore, given a deviation from the Standard Model (SM) expectations in $B \rightarrow \tau\nu$, this model predicts a sizable neutron EDM. In fact, even if new physics has CP conserving real couplings, the CKM matrix induces a complex phase and already a 10% change of the $B \rightarrow \tau\nu$ branching ratio (with respect to the SM) will lead to an effect observable with the n2EDM experiment at PSI.

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Search for new internucleon short-range interaction in neutron scattering

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There are 4 known types of interaction in nature, but nowadays the existence of a new force mediated by new unknown bosons is widely discussed in the literature [1], [2]. This work deals with the application of neutron scattering technique for the search for a new short-range interaction and for setting constraints on the coupling constant of such interaction.

The main idea is to perform an experiment of neutron scattering on the powder of silicon (powder diffraction) and to get the information on scattering amplitude dependence on scattering angle. Within this work the calculations showing the possibility of the idea were made. The coupling constant constraints were obtained using the data of silicon powder diffraction from the FRM II reactor, Munich, Germany. It is shown that the new constraints are competitive with the existing ones.

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Improvements in analyzing Lorentz symmetry violation in double-beta decay

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Possible deviations from Lorentz invariance in the framework of the Standard Model Extension are more and more studied at present, including the neutrino sector. Observable effects due to the so-called countershaded operator cannot be investigated by measurements of neutrino oscillations and time of flight, but can be in double-beta decay (DBD) experiments, for example by a detailed analysis of the summed electron spectra emitted in the two-neutrino double-beta decay. A precise measurement of these spectra corroborated with accurate theoretical predictions allows constraint of the coefficient \tilde{a}_3 of which control the Lorentz violation (LV) effects due to the time-like component of this operator.

In this work we present a more rigorous method to predict theoretical summed electron spectra in two-neutrino double beta decay within the LV formalism. This is based on a precise calculation of phase space factors (G) and their deviations due to LV effects (dG). In our method the Fermi functions are built from “exact” electron wave functions obtained as solutions of a Dirac equation in a Coulomb-type potential given by a realistic distribution of the protons in the daughter nucleus and with inclusion of finite nuclear size and screening effects. In addition, in the expressions of the phase space factors kinetic factors related to the electrons and neutrinos energies are taken into account, while in previous analyzes they were omitted.

Our study is done for four experimentally interesting nuclei, namely ^{48}Ca , ^{82}Se , ^{100}Mo and ^{136}Xe . We found that the differences between the G and dG values calculated with our method and with previous methods raise with the atomic number Z and amount up to 30% for the ^{136}Xe . Our results can be of interest for the current investigations of LV effects in DBD experiments and can lead to relevant improvements of the actual constraints on the \tilde{a}_3 of coefficient.

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BBQ - Drinks & Posters / 109**WISArD : Weak Interaction Studies with ^{32}Ar** **Author:** Maud Versteegen¹**Co-authors:** Dinko Atanasov²; Victoria Araujo-Escalona³; Philippe Alfaut¹; Pauline Ascher¹; Bertram Blank¹; Xavier Flechard⁴; Laurent Daudin¹; Mathias Gerbaux¹; Jerome Giovino¹; Stéphane Grévy¹; Teresa Kurtukian-Nieto¹; Etienne Liénard⁵; Gilles Quemener⁶; Mathieu Roche¹; Nathal Severijns⁷; Simon Vanlangendonck⁸; Dalibor Zakoucky⁹¹ CENBG² CERN³ Instituut voor Kern- en Stralingsfysica, KU Leuven⁴ LPC Caen IN2P3/CNRS⁵ LPC Caen⁶ LPC CAEN⁷ Katholieke Univ. Leuven⁸ KULeuven⁹ Acad. Sci. Czech Rep., CZ-25068 Rez, Czech Republic**Corresponding Author:** versteeg@cenbg.in2p3.fr

Nuclear beta decay offers a very powerful tool to test the Standard Model (SM) in the electroweak sector. The wide variety of nuclei and beta transitions allows us to choose the perfect candidate for specific tests of the SM which are complementary to high energy physics studies [1]. In particular, the possible existence of scalar (resp. tensor) currents in the well-established vector – axial-vector ($V - A$) description of the electroweak interaction can directly be probed using the beta-neutrino angular correlation coefficient $\alpha\beta\nu$ for pure Fermi (resp. Gamow-Teller) beta decays. As the neutrino is not easily accessible, the $\alpha\beta\nu$ coefficient is determined from the recoil of the daughter nucleus. This recoil can either be measured in dedicated trap measurements or from the kinematic shift it induces on the energy distribution of emitted particles in the case of unstable daughter nuclei.

One of the best precision to date on $\alpha\beta\nu$ for a pure Fermi transition was obtained using ^{32}Ar , from the broadening of the beta-delayed proton group emitted by the isobaric analogue state of the daughter nucleus ^{32}Cl [2]. In the new WISArD experiment, we propose to reach the 10-3 uncertainty on $\alpha\beta\nu$ with ^{32}Ar , both for the pure Fermi and pure Gamow-Teller transitions. Instead of focusing on the proton spectrum broadening, energy shifts between beta-delayed protons emitted in the same or the opposite direction to the beta will be measured [3].

A proof-of-principle experiment performed at the ISOLDE-CERN facility in Nov. 2018 yields a value of $\alpha\beta\nu$ in agreement with the SM. The uncertainty is at the 5×10^{-2} level for the Fermi transition and is dominated by statistics. These preliminary results as well as systematics studies that will play a crucial role for the final experiment will be presented.

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qBOUNCE: first results of the Ramsey-type GRS experiment

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This talk focuses on the control and understanding of a gravitationally interacting elementary quantum system using gravity resonance spectroscopy (GRS) with ultracold neutrons (UCN). This technique offers a new way of looking at gravitation at short distances based on quantum interference. In the past years, the qBOUNCE collaboration has designed and built a new Ramsey-type GRS experiment at the Institute Laue-Langevin (Grenoble), which increases the achievable sensitivity by more than an order of magnitude with respect to previous implementations. In 2018 we were able to demonstrate gravitational state transitions. The new Ramsey-type implementation is not only sensitive to a range of hypothetical variations of Newton's potential at the microscale, but it can also be used to test the electric charge neutrality of the neutron. We present the results of first charge measurements performed in 2018 and give an outlook on further developments.

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Update on Commissioning and Development of Cryogenic SOS@PULSTAR apparatus

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Measuring particle EDMs is one of the most challenging experiments in the field of high precision physics. Present neutron EDM experiments are approaching limits of the traditional measurement technique due to both, statistic and systematic limitations. nEDM@SNS collaboration is working on realization of new approach, which employs production of trapped neutrons and measurement of neutron polarization in LHe environment below 0.5K with use of polarized He-3 as both, neutron polarization detector and co-magnetometer. This technique potentially is restricted only by neutron beam intensity. Realization of the technique relies on simultaneous precision spin manipulations of both, neutron and He-3 atoms. To start practical realization of the spin manipulation system, we have designed a smaller cryogenic NMR system, which is now undergoing commissioning at NC State University. We describe the goals and methods of the project and report on recent progress.

BBQ - Drinks & Posters / 96**SEARCH FOR EXOTIC DECAYS WITH NA62****Author:** Patrizia Cenci¹¹ *INFN Perugia (IT)***Corresponding Author:** patrizia.cenci@pg.infn.it

The features of the NA62 experiment at the CERN SPS - high-intensity setup, trigger-system flexibility, high-frequency tracking of beam particles, redundant particle identification, and ultra-high-efficiency photon vetoes - make it particularly suitable to search for long-lived, weakly-coupled particles within Beyond the Standard Model physics.

We report the results of a search for π^0 decays to one photon and an invisible massive dark photon. From a total of about 400\$ million π^0 decays, no signal is observed beyond the expected fluctuation of the background and limits are set in the plane of the dark photon coupling to ordinary photon versus dark photon mass. Searches for Heavy Neutral Lepton (HNL) production in charged kaon decays using the data collected by the NA62 experiment are reported. Upper limits are established on the elements of the extended neutrino mixing matrix for HNL masses in the range 130-450 MeV, improving on the results from previous HNL production searches. Sensitivity results for production and decay searches of Axion-Like Particles are also presented.

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Considerations for a caesium magnetometer array for the n2EDM experiment

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The search for the neutron electric dipole moment d_n , carried on by the n2EDM experiment at PSI could provide a better insight on the baryon asymmetry of the universe and/or new physics. The experimental goal to reach an order of magnitude higher sensitivity than previous efforts, means its systematic effects need to be better controlled. The appearance of a false d_n ($d_{Hg \rightarrow n}^{false}$) due to the different motional magnetic fields seen by the neutrons and Hg atoms of the comagnetometer is one of such obstacles. A Cs-Magnetometer (CsM) array is then to be built such that $\Delta d_{Hg \rightarrow n}^{false} < 4 \times 10^{-28} e.cm$. Furthermore, the presence of magnetic impurities in the apparatus perturbs the performance of the CsM array. Calculations of this effect are shown, together with the impurity criteria that would preserve the normal functioning of the array.

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Nondecoupling Signatures of Supersymmetry and an $L_\mu - L_\tau$ Gauge Boson at Belle-II

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We propose that the $\gamma + \cancel{E}$ signal at the Belle-II detector will be a smoking gun for supersymmetry (SUSY) in the presence of a gauged $U(1)_{L_\mu - L_\tau}$ symmetry. A striking consequence of breaking the enhanced symmetry appearing in the limit of degenerate (s)leptons is the nondecoupling of the radiative contribution of heavy charged sleptons to the $\gamma - Z'$ kinetic mixing. The signal process, $e^+e^- \rightarrow \gamma Z' \rightarrow \gamma + \cancel{E}$, is an outcome of this ubiquitous feature. We take into account the severe constraints on gauged $U(1)_{L_\mu - L_\tau}$ models by several low-energy observables and show that any significant excess in all but the highest photon energy bin would be an undeniable signature of such heavy scalar fields in SUSY coupling to Z' . The number of signal events depends crucially on the logarithm of the ratio of stau to smuon mass in the presence of SUSY. In addition, the number is also inversely proportional to the $e^+ - e^-$ collision energy, making a low-energy, high-luminosity collider like Belle-II an ideal testing ground for this channel. This process can probe large swathes of the slepton mass ratio vs the additional gauge coupling (g_X) parameter space. More importantly, it can explore the narrow slice of $M_{Z'} - g_X$ parameter space still allowed in gauged $U(1)_{L_\mu - L_\tau}$ models for superheavy sparticles.

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Simulation model of the UCN optics system of the n2EDM apparatus at PSI

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on behalf of the nEDM collaboration at PSI

The quest of a permanent electric dipole moment of the neutron, a CP-violating property, is one of the highest priorities in low-energy particle physics. The design of the n2EDM apparatus, now under construction at the PSI ultracold neutron (UCN) source, was strongly supported by neutron optics simulations using the MCUCN code. In order to obtain as realistic results as possible, the calculations treat the UCN source, beamline, and n2EDM apparatus as one system. One scope was to maximize the number of stored UCN in the double-chamber setup as a function of the geometry and coating quality of the guide system and the two storage volumes. The asymmetry in UCN counts, energy spectra, and centre of mass offsets in the two chambers had to be kept minimal. Future use of the n2EDM simulation model will be the support of a series of measurements which will be conducted in order to test and characterize the UCN optics parts of the apparatus including the spin analysis. This will provide effective parameters of the wall coatings (loss and spin flip), and help to identify possible ways for further improvements. A fine-tuned simulation model of n2EDM will finally provide detailed energy spectra for the upper and lower chambers as a function of storage time. The energy distribution of UCN is an important input for the study of systematic effects. In this poster we will give a status on the n2EDM simulation model, e.g. the recently implemented complete sequence of UCN filling, storing and spin analysis in one run.

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Next generation active magnetic shielding for n2EDM

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on behalf of the nEDM collaboration at PSI

The n2EDM experiment hosted at the Paul Scherrer Institute is seeking an improvement in the measurement of the neutron electric dipole moment (nEDM) by one order of magnitude.

In order to achieve this goal, it is crucial to stabilize the magnetic fields inside the precession chamber, where neutrons are stored and Ramsey measurements are performed, down to 30 fT. This is especially challenging considering that the surrounding magnetic fields undergo substantial changes due to the activity of neighboring experiments. Therefore, an active magnetic shielding, which compensates the surrounding field and the occurring field changes via a feedback loop, is indispensable. We present how our compensation system design can meet the high performance goal despite various challenges, such as spatial constraints.

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PADME experiment status

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A possible solution to the dark matter problem is to speculate that it lives in a separate sector with respect to the SM and that it interacts with it only by means of new particles called portals. The simplest one foresees an additional U(1) symmetry, whose mediator, the dark photon A' , could mix with the standard photon and faintly interact with SM particles.

The PADME experiment, hosted at Laboratori Nazionali di Frascati, is designed to search for a dark photon produced in the reaction $e^+ e^- \rightarrow A' \gamma$. The experiment took its first data from October 2018 to February 2019. Here we present the status of the detector and of the ongoing analysis.

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The bound beta decay of the free neutron (BOB) - a unique tool to study the weak interaction at low energies

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In order to improve the non- Standard Model weak interaction scalar and tensor coupling upper limits by an order of magnitude and to determine the helicity of an antineutrino combined with a low velocity charged lepton, the free neutron bound beta decay ($n \rightarrow H + \bar{\nu}_e$) (BOB) shall be measured. Thereby, monoenergetic metastable BOB H atoms ($T \sim 326$ eV) with a single hyperfine state, selected by a spin filter, generated at the center of a high flux beam reactor throughgoing beam tube (for example at the PIK reactor, Gatchina), are transformed with high efficiency ($> 10\%$) into H^- ions within an Ar cell. After extraction from the beam tube by means of a pulsed electric deflector, the H^- are measured by a velocity filter based on the Bradbury Nielsen Gate technology and an MCP detector. Although the bound beta decay branching ratio is small ($4 \cdot 10^{-6}$), the experiment seems feasible. Necessary experimental components, as a Bradbury Nielsen (BN) gate velocity filter, a pulsed electric deflector and an electrical quadrupole doublet have been developed, built and tested using low energy proton and oxygen beams. As an application for the BN gate chopper, the secondary electron yield from protons passing thin carbon foils has been measured.

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Search for Axion-like Particles with the nEDM Spectrometer at PSI

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on behalf of the nEDM Collaboration at PSI

There is so far no experimental evidence of CP violation found in the strong interaction. The non-observation of a neutron electric dipole moment (nEDM) constrains the CP violating term (θ -term) in the QCD Lagrangian to be nine orders of magnitude smaller than naturally expected [1]. A solution proposed in 1977 postulated that an additional symmetry, which was later called “Peccei-Quinn symmetry”, could be introduced [2], replacing the static CP violating angle (θ) with a dynamic CP conserving field, which spontaneously breaks at some high energy levels. A new pseudo-scalar boson, axion, emerges as the Goldstone boson of this broken symmetry [3,4]. A short-range spin-dependent interaction which could be mediated by axions or other hypothetical bosons, which has similar properties as an axion and are normally called axion-like particles (ALPs), was brought forward in 1984 [5], which involves the $g_s g_p$ coupling.

Using the nEDM spectrometer at the Paul Scherrer Institute (PSI), we have searched for an interaction between polarized ultracold neutrons (UCN) and unpolarized nucleons in the bulk materials of the chamber wall, which could be mediated by ALPs [6]. This spin-dependent interaction can be regarded as a pseudo-magnetic field, which influences the spin-precession frequencies of stored UCN and ¹⁹⁹Hg atoms. With careful investigation on the frequency ratio between the two species, the coupling constant $g_s g_p$ can be derived. To achieve an improvement in sensitivity from the previous measurement in 2015 [6], two approaches were taken. First, an electrode of the precession chamber was replaced with a material of higher nucleon density. Second, the magnetic-field gradients will be analyzed by incorporating the field data recorded by online Cs-magnetometer arrays and offline field maps, to have a better control of the gradients. With this apparatus upgrade followed by dedicated analysis method, a sensitivity gain by an order of magnitude is expected. This study targets to achieve a new limit on the $g_s g_p$ coupling with an improved sensitivity, constraining the allowed parameter space of beyond Standard Model theories.

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qBounce: Ramsey gravity resonance spectroscopy explained

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The qBOUNCE experiment investigates gravity at small distances. This is done using high precision frequency based spectroscopic methods. Ultracold neutrons (UCNs) form macroscopic bound states above a flat surface in the gravity potential of the Earth, connecting the quantum mechanical neutron wavefunction and gravity. Using this system we developed techniques for Gravity Resonance Spectroscopy (GRS). We realized measurements of a Ramsey flip between two states using Ramsey's method of separated oscillating fields with gravitationally bound UCNs. This method can be used to probe all interactions which shift the eigenenergies of the neutron. Previous iterations of the qBounce experiment implemented GRS in a Rabi configuration to set limits on chameleon dark energy, axion-like dark matter and symmetron dark energy scenarios. The current GRS setup aims to improve the energy resolution and, thus, the sensitivity to frequency shifts. The qBounce experiment is located at the UCN source PF2 at the Institut Laue-Langevin (ILL) in Grenoble. After achieving the proof of principle for Ramsey-GRS in 2018 and optimization of experimental parameters during the first half of 2019 we are prepared to take data at a projected sensitivity of $5e-16$ eV/day.

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Mu3e fibre telescope

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Mu3e is a dedicated experiment searching for the charged lepton-flavour violating decay $\mu^+ \rightarrow e^+ e^+ e^-$. The experiment consists of three subdetectors: A central barrel tracking device realised as two double layers of HV-CMOS pixel detectors, a scintillating fibre detector for timing measurements in the central region and a scintillating tile detector for timing in the end regions.

The scintillating detectors are read out by a mixed-mode ASIC named MuTRiG. This year, we operated a telescope made up of four scintillating fibre ribbon prototypes read out by 16 MuTRiGs. First results of the performance of this fibre telescope will be presented.

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Method to search for axion-like particles (ALPs) in storage rings

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A particle called the axion has been proposed to explain the small size of the CP violating term in quantum chromodynamics. It would be light in weight and weakly coupled to nucleons. If sufficiently abundant, it might be a candidate for dark-matter in the universe. Axions or axion-like particles (ALPs), when coupled with gluons, introduce an oscillating Electric Dipole Moment (EDM) along the nucleon's spin direction. This can be used in an experiment to search for axions or ALPs in a storage ring.

In spring of 2019, at the Cooler Synchrotron (COSY) in Juelich, we performed a first test experiment to search for ALPs using an in-plane polarized deuteron beam with a momentum of 0.97 GeV/c. If the EDM oscillation due to ALPs is in resonance with the spin precession frequency of the beam, then there is an accumulation of vertical polarization. The experiment involved the development of a long polarization lifetime beam with four bunches, each with different polarization direction. Two of these bunches had orthogonal directions which allowed us to cover all values of the axion phase. We scanned the frequency space around the spin precession frequency of 121 kHz. I will present the working principle of this method and preliminary results.

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Ordinary Muon Capture studies for the matrix elements in double-beta decay.

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In the poster we observe our previous experience at the PSI muon facility, namely high precision gamma-spectroscopy with negative slow muons on the $\mu E-4$ and $\mu E-1$ beams with HPGe – detectors and with isotopically enriched targets (solid and gas). Such experiments could be divided in to three parts: 1) Doppler profile of gamma-lines following OMC (angular correlation with neutrino) ; 2) Partial capture rates (for double beta decay, as an example) ; 3) Muonic X-rays (electronic catalogue www.muxrays.jinr.ru) .

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Charged particle spectra from nuclear muon capture on Al

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Nuclear muon capture (NMC) begins with a weak interaction process occurring within the nuclear volume. Information about NMC comes from the final-state particles, of which protons and deuterons are important components. However, published information is rather limited despite being important for the design of some current searches for lepton flavor violation. μ^- Al data taken using the TWIST spectrometer, which was developed for a precise measurement of the Michel spectrum, were analyzed to obtain momentum spectra of protons and deuterons following NMC on aluminum.

Using a novel unfolding technique, a precision of better than 10% over the momentum range of 100–190 MeV/c for protons is obtained; for deuterons of 145–250 MeV/c the precision is better than 20%. Values for the measured partial and extrapolated total yields will be reported. A comparison is made with other measurements and model predictions.

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High-Resolution Spectroscopy of He₂ and He₂⁺ for testing ab initio calculations and metrology

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Measurements of the level energies of few-electron atoms and molecules provide reference data to test the results of quantum chemical calculations. In recent years, molecular spectroscopy has reached the level of precision at which such measurements can play a role in the context of fundamental tests of the standard model of particle physics and extensions thereof [1] and provide an alternative route to determine the values of fundamental constants. For example, the new SI definition of the Kelvin is based on the Boltzmann constant, directly linking temperature to energy [2]. The numerical value of the Boltzmann constant is determined, among other methods, by dielectric-constant gas thermometry. Such measurements [3] rely on accurate ab initio calculations of the dynamic polarizability of atomic helium [4]. The high accuracy demanded by the metrological application requires the determination of nonadiabatic, relativistic and QED corrections with reliable error control in the theory.

We have performed systematic studies [5,6] of the rovibrational structure of He₂⁺ using MQDT-assisted Rydberg-series extrapolation in cold molecular beams of He₂ in its metastable a 3Σ^u+ electronic state (He₂^{*}). Our measurements provide benchmark data that enable to test the polarizability calculations of atomic helium via the two-body interaction potential. In addition, our measurements revealed a discrepancy with the most recent ab initio calculations of He₂⁺ that are available in literature [7]. This discrepancy can partially be attributed to the neglect of nonadiabatic contributions in these calculations [8].

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A multi-pass optical cavity for the HyperMu experiment

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The measurement of the hyperfine splitting (HFS) in muonic hydrogen at the ppm level by means of pulsed laser spectroscopy allows for extraction of the Zemach radius of the proton at the per mille level. This measurement, ongoing at the Paul Scherrer Institute, features a novel laser system to excite the HFS transition at 6.8 μm . To increase the transition probability, we will use a multi-pass optical cavity, which enhances the average light fluence on the muonic atoms. The poster presents the principle of the experiment, the cavity requirements and the current state of the optical design.

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The photon dipole in generic extensions of the Standard Model

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Matching conditions for photon penguin diagrams in the generically extended Standard Model.

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Experimental Limiting Factors for the search of $\mu \rightarrow e\gamma$ at Future Facilities

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The search for the Lepton Flavor Violating decay $\mu \rightarrow e\gamma$ exploits the most intense continuous muon beams, which can currently deliver $\sim 10^8$ muons per second. In the next decade, accelerator upgrades are expected in various facilities, making it feasible to have continuous beams with an intensity of 10^9 or even 10^{10} muons per second. We investigate the experimental limiting factors that will define the ultimate performances, and hence the sensitivity, in the search for $\mu \rightarrow e\gamma$ with a continuous beam at these extremely high rates. We then consider some conceptual detector designs and evaluate the corresponding sensitivity as a function of the beam intensity.

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BL3: A next generation "beam" experiment to measure the neutron lifetime

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Neutron beta decay is an archetype for all semi-leptonic charged-current weak processes. A precise value for the neutron lifetime is required for consistency tests of the Standard Model and is needed to predict the primordial ^4He abundance from the theory of Big Bang Nucleosynthesis. An effort is under way for an in-beam measurement of the neutron lifetime that is able to evaluate the systematic uncertainties at the 0.3 s level. This effort is part of a phased campaign of neutron lifetime measurements based at the NIST Center for Neutron Research, using the Sussex-ILL-NIST technique. Recent advances in neutron fluence measurement techniques as well as new large area silicon detector technology address the two largest sources of uncertainty of in-beam measurements, paving the way for a new measurement. The experimental design, schedule, and projected uncertainties for the main subsystems will be discussed.

Session / 130

Rare pion decay studies in the PEN experiment

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Relatively simple dynamics, and extremely well controlled radiative and loop corrections, ensure that pion and muon decays are described with unprecedented precision within the Standard Model, typically with relative uncertainties of $\sim 10^{-4}$ or lower. This theoretical precision makes the π and μ decays suitable as a sensitive means of testing the underlying symmetries, especially the universality of weak fermion and quark couplings. Of particular interest is the ratio $R_{e/\mu}^\pi = \Gamma(\pi \rightarrow e\bar{\nu}_e(\gamma))/\Gamma(\pi \rightarrow \mu\bar{\nu}_\mu(\gamma))$ which provides the current best limit on the universality of W coupling to the first two lepton generations, i.e., (e, ν_e) and (μ, ν_μ) , respectively, with broad implications, including in the neutrino sector. The PEN collaboration is at the threshold of obtaining new results for $R_{e/\mu}^\pi$ at sub- 10^{-3} relative precision from measurements completed at PSI several years ago. We discuss the status of the PEN data analysis for several rare decay channels, the expected uncertainty limits, as well as complementarity with results of high-energy studies.

Session / 20

Testing lepton flavor universality with pion decays

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Since the discovery of the muon, the lack of understanding of flavor is one of the most intriguing and persistent problems in particle physics. Many hypotheses which extend the Standard Model suggest that observations of non-universal charged current interactions could be due to effects at high mass scales, possibly approaching 1000 TeV, or to the existence of sterile neutrinos. Measurement of the pion decay branching ratio $R_{\pi \rightarrow e} = \frac{\Gamma(\pi^+ \rightarrow e^+ \nu + \pi^+ \rightarrow e^+ \nu \gamma)}{\Gamma(\pi^+ \rightarrow \mu^+ \nu + \pi^+ \rightarrow \mu^+ \nu \gamma)}$ in comparison with the extraordinarily precise Standard Model prediction provides one of the best tests of universality, currently indicating consistency with $e - \mu$ universality at the 0.1 % level. This presentation will discuss the PIENU experiment at TRIUMF which aims to improve the precision of the measurement of $R_{\pi \rightarrow e}$ and to search for evidence of sterile neutrinos involved in pion decay.

Session / 1**The Mu2e experiment****Author:** Stefano Di Falco¹¹ *INFN Pisa***Corresponding Author:** stefano.difalco@pi.infn.it

The Mu2e experiment at Fermilab will search for the neutrinoless conversion of a muon into an electron in the field of an aluminum nucleus. A clear signature of this charged lepton flavor violating coherent two-body process is the monoenergetic conversion electron of 104.97 MeV produced in the final state. The experiment will have a single-event sensitivity of $\sim 2 \times 10^{-17}$, and either set a 90% CL at $\sim 8 \times 10^{-17}$ or make a 5σ discovery at 2×10^{-16} .

The experimental apparatus consists of an intense pulsed proton beam interacting on a tungsten target, a set of superconducting magnets selecting negative muons, a segmented aluminum target stopping the muons and a set of detectors used to identify conversion electrons and to reject backgrounds from the beam, from decays of muons through the normal weak interactions, and from cosmic rays.

The experiment will begin operations in 2023 and will need about 3 years of data taking to achieve a factor of 10^4 improvement on the current best limit on the conversion rate. After an introduction to Mu2e physics, the status of the different components of the experimental apparatus will be discussed.

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AlCap: Measurements of the particle emission spectra following nuclear muon capture for muon-to-electron conversion experiments

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presented on behalf of the AlCap collaboration

Observation of neutrinoless muon-to-electron conversion in the presence of a nucleus would be unambiguous evidence of physics Beyond the Standard Model. Two experiments, COMET at J-PARC and Mu2e at Fermilab, are under construction and will search for this process with a detection sensitivity of 10^{-16} , 10,000 times better than previously reported. The AlCap Experiment was jointly developed by COMET and Mu2e to measure Standard Model processes that could ultimately limit their sensitivity. Knowledge of the particle emission spectra after nuclear muon capture in candidate target materials is important for optimizing the new experiments to suppress potential background and noise rates, as well as for developing normalization techniques.

AlCap performed three data-taking campaigns between 2013 and 2015 at the Paul Scherrer Institut. Robust results require careful modeling of the muon beam stopping profile in ultra-thin target foils, which is needed to generate the response matrix for the silicon detector system employed for the reaction products inside a vacuum vessel.

Systematic effects arising from those quantities are strongly mitigated by a symmetric detector setup around the AlCap target. The analysis demonstrates that the extracted heavy charged particle spectra produced in muon capture are stable against changes in the unfolding parameters and particle identification cuts.

In this talk the results for the AlCap proton spectra from Al and Si targets with a full systematic analysis will be presented for the first time.

Session / 24

Measurement of the fine-structure constant as test of the standard model

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The fine-structure constant α is ubiquitous in physics, and a comparison among different experiments provides a powerful test of the Standard Model of particle physics. The most precise measurement of α (to date) is our recently published result, $\alpha = 1/137.035\,999\,046(27)$, with an uncertainty of 200 parts per trillion (ppt). A $2.5 - \sigma$ tension with the value obtained from the electron gyromagnetic anomaly $g_e - 2$ is a potential sign of new physics that mirrors the well-known $3.7 - \sigma$ tension observed in the muon $g_\mu - 2$. It motivates a deeper investigation at the frontier of precision measurement. $g_\mu - 2$ is currently being re-measured by E989 at Fermilab, which expects to reduce the error more than threefold. Gerald Gabrielse (Northwestern University) is currently re-measuring $g_e - 2$ and expects an improvement by an order of magnitude to 20 ppt. We will present our result and our project to improve the accuracy in the fine-structure constant to 40 ppt and, eventually, 10 ppt.

Session / 87 **$\tau \rightarrow \mu\mu\mu$ at a rate of one out of 10^{14} tau decays?****Author:** Matteo Fael¹**Co-authors:** Emilie Passemar²; Patrick Blackstone³¹ *KIT Karlsruhe*² *Indiana University/JLab*³ *Indiana University***Corresponding Author:** matteo.fael@gmail.com

Recent improvements of the Large Hadron Collider luminosity and the beginning of Belle II experiment will increase the sensitivity to tau lepton-flavour violating modes. In particular, it has been claimed by Pham in hep-ph/9810484 that $BR(\tau \rightarrow 3\mu)$ could be as large as 10^{-14} in the Standard Model with massive neutrinos, contradicting earlier predictions for $BR(\mu \rightarrow 3e)$. If this were to be true, this limit could be reached experimentally in the near future (with further upgrades).

In this talk, we present a new calculation of these branching ratios in full generality within the Standard Model including massive neutrinos. By making use of the method of regions, we determine the rates as a double expansion in m_ν/m_τ and m_τ/M_W . We also report some discrepancies with previous predictions.

Session / 169

High-precision QED prediction for low-energy lepton experiments

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Past years have seen an impressive progress in perturbative calculations. We apply these techniques to compute high-precision QED contributions to low-energy processes involving muons and other leptons.

In this talk, I will review the current situation.

Session / 64

Dyssymmetry: Unleashing Extra Yukawa Couplings

Author: George W.S. Hou¹¹ *National Taiwan University***Corresponding Author:** wshou@phys.ntu.edu.tw

The $h(125)$ boson was discovered at the LHC in 2012, but as Run 2 has ended, nothing beyond the Standard Model (SM) has emerged, be it supersymmetry, extra gauge bosons, or any new particle. We call this situation, Dyssymmetry, as spoken by Nature. As such, we take the simplicity path to reexamine any presumed symmetries. In particular, we scrutinize the usual Z_2 symmetry associated with having an extra Higgs doublet. Releasing this Z_2 symmetry assumption, extra Yukawa couplings are rightfully restored to the general two Higgs doublet model ($g_2\text{HDM}$). Compared to the Natural Flavor Conservation condition proposed by Glashow and Weinberg over 4 decades ago, Nature has spoken since: there be charged fermion mass and mixing hierarchies; let the $h(125)$ boson be rather close to the SM Higgs boson — alignment. Together with the exotic Higgs being somewhat heavier, these emergent phenomena can help contain the problems with flavor changing neutral Higgs (FCNH) couplings.

In this talk we elucidate: 1) how an extra top Yukawa coupling (or two) could give enough CP violation to drive electroweak baryogenesis (EWBG); 2) how $O(1)$ Higgs quartics, needed for first order electroweak phase transitions for sake of EWBG, could still allow the alignment phenomenon to emerge, i.e. to allow large parameter space for exotic CP-even Higgs H not to mix much with $h(125)$; 3) associated phenomenology, from electron EDM, $\tau \rightarrow \mu\gamma$, $B \rightarrow \mu\nu(\text{bar})$, and LHC collider signatures involving extra $t\bar{t}A/H$, $t\bar{c}A/H$ and $\tau\mu A/H$ Yukawa couplings, where A and H are exotic CP odd and even scalars of $g_2\text{HDM}$. The A , H and charged Higgs H^\pm could well be sub-TeV in mass and awaiting LHC discovery.

Simplicity could be quite complex, as Nature decides.

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MuSun: Analysis of the First Production Dataset

Authors: Rachel Ryan¹; The MuSun Collaboration^{None}¹ *University of Washington***Corresponding Author:** rachryan@uw.edu

The MuSun experiment utilizes a unique cryogenic time projection chamber to extract the μd capture rate to better than 1.5% precision via determination of the 10^{-3} deviation of the muon lifetime in deuterium gas from the free muon lifetime. This measurement will lead to a benchmark result in calibrating weak interactions in the two nucleon system, relevant for calculating fundamental reactions in neutrino-astrophysics within modern effective field theories. The full statistics required were collected over two beam periods in the $\pi E1$ area of the Paul Scherrer Institute in 2014 and 2015. However, the ambitious precision goal would not be met until a series of subtle systematic uncertainties were under control, leading to a challenging analysis over the subsequent years. In order to understand and correct for these systematic issues, including muon-catalyzed fusion interference, determination of the gas purity to unprecedented levels, and unexpected beam electron backgrounds, several advanced studies and techniques have been developed. The analysis of the first dataset is nearly finished, with all systematic uncertainty contributions close to the design goal. This analysis will be presented in detail together with an outlook for the full MuSun dataset.

Session / 102

The Muon $g-2$ experiment at Fermilab: Overview and status update

Author: Peter Winter¹

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The Muon $g-2$ experiment E989 at Fermilab will measure the anomalous magnetic moment of muon, a_μ , with a precision goal of 140 part-per-billion (ppb). The experiment is aiming to resolve the discrepancy of more than 3 standard deviations between the previous measurements dominated by the Brookhaven E821 result and the Standard Model calculation of a_μ .

The experimental concept uses a polarized muon beam at the magic momentum which is stored in the extremely homogeneous magnetic field of the storage ring. Parity violation in the weak decay is used as a spin analyzer; the detected rate of the decay electrons oscillates with the frequency, ω_a , in the magnetic field expressed in terms of the free proton Larmor frequency, ω_p . Since a_μ is derived from the ratio of ω_a and ω_p , both are equally important and systematic uncertainties must be kept below 70 ppb for each observable.

The experiment has just finished its second data collection period and has acquired more than two times the BNL statistics. In this presentation, the experimental concept and new improvements will be discussed along with an update on the ongoing data analysis and an outlook for the upcoming Run-3 starting in October 2019.

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Explaining $(g - 2)_e$ and $(g - 2)_\mu$ together naturally

Authors: Clara Hormigos-Feliu^{None}; Daniel F. Litim^{None}; Gudrun Hiller^{None}; Tom Steudtner^{None}

The anomalous magnetic moments of the electron and the muon hint at lepton-nonuniversality from physics beyond the Standard Model (SM). We propose a natural explanation in the framework of an asymptotically safe SM, with an extended scalar sector and Yukawa couplings between vector-like fermions and ordinary leptons, which links flavor to new physics. Both leptons' magnetic moments are induced at 1-loop, with the difference in size and sign of their respective deviations from the SM driven by a flavorful vacuum. Two concrete models are presented, one in which the BSM fermions are charged under $SU(3)_C \times SU(2)_L \times U(1)_Y$ as the SM singlet leptons, and one as the SM doublet leptons. The models are stable and predictive up to the Planck scale and beyond and can be searched for at hadron and lepton colliders.

Session / 10

Pseudoscalar contribution to the muon $g-2$

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In their 2004 paper, Melnikov and Vainshtein derive a short-distance constraint for the pseudoscalar-pole light-by-light four-point function. To satisfy this constraint, Melnikov and Vainshtein dropped the pseudoscalar transition form factor at the vertex where the external photon is hooked. We present a way to satisfy the short-distance constraint of Melnikov and Vainshtein with an infinite sum over radially-excited pseudoscalar-pole diagrams (without dropping the singly-virtual transition form factor). For this, we develop a suitable model for the pseudoscalar transition form factor. We compare our result for the pseudoscalar-pole contribution to the muon $g-2$ with the literature values. In addition, a prediction of the Schwinger sum rule for the pseudoscalar contribution is presented.

Session / 89

Flavour Anomalies: status and prospects

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Some recent measurements of b-hadron decays at the LHCb experiment and B-factories show a discrepancy with respect to Standard Model expectations. They consist of tests of lepton flavour universality in rare and semileptonic decays and measurements of rare semi-muonic decays. While each of these measurements has a limited statistical significance, intriguingly, they seem to form a coherent pattern.

I will review the status of the Flavour Anomalies and I will discuss future prospects and scenarios.

Session / 13

Combined explanations of $(g-2)_\mu$, $(g-2)_e$ and implications for a large muon EDM

Author: Andreas Crivellin¹¹ *PSI&UZH***Corresponding Author:** andreas.crivellin@cern.ch

We consider possible beyond-the-Standard-Model (BSM) effects that can accommodate both the long-standing tension in the anomalous magnetic moment of the muon, $a_\mu=(g-2)_\mu/2$, as well as the emerging 2.5σ deviation in its electron counterpart, $a_e=(g-2)_e/2$. After performing an EFT analysis, we consider BSM physics realized above the electroweak scale and find that a simultaneous explanation becomes possible in models with chiral enhancement. However, this requires a decoupling of the muon and electron BSM sectors to avoid the strong constraints from $\mu\rightarrow e\gamma$. In particular, this decoupling implies that there is no reason to expect the muon electric dipole moment (EDM) d_μ to be correlated with the electron EDM d_e , avoiding the very stringent limits for the latter. While some of the parameter space for d_μ favored by a_μ could be tested at the $(g-2)_\mu$ experiments at Fermilab and J-PARC, a dedicated muon EDM experiment at PSI would be able to probe most of this region.

Session / 125

Overview of recent efforts and results of the neutron lifetime measurements

Author: Alexander Saunders¹¹ *Los Alamos National Lab***Corresponding Author:** asaunders@lanl.gov

Measurement of free neutron decay to a proton, electron, and antineutrino provides information about the fundamental parameters of the charged weak current of the nucleon and constrains many extensions to the Standard Model at and above the TeV scale. Knowledge of the lifetime to an accuracy of better than 1 s is necessary to improve BBN predictions of elemental abundances and to search for physics beyond the Standard Model of nuclear and particle physics. The neutron lifetime has recently been measured by two different techniques: the “disappearance” method, counting the surviving ultracold neutrons after storage in magnetic or material-walled traps, with an average result of 879.3 ± 0.8 s; and the “appearance” method, counting the number of decay products emerging from a passing beam of cold neutrons, with a result of 888.0 ± 2.1 s. The results of these techniques disagree by 8.7 s, or 3.9 standard deviations. In this talk, we will review recent and upcoming efforts to measure the neutron lifetime using both the appearance and disappearance techniques and with independent systematic uncertainties, as well as look at future efforts to push the total uncertainty on the lifetime to the 10^{-4} level.

Session / 42

Neutron lifetime measuring experiments with UCN magnetic storage

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Precision measurements of the neutron lifetime provide stringent tests of the standard electroweak model [1] as well as crucial inputs for Big-Bang nucleosynthesis calculations [2]. When combined with measurements of other neutron beta decay correlation coefficients [1], the neutron lifetime enables the determination of the V_{ud} element of the Cabibbo-Kobayashi-Maskawa quark mixing matrix, providing a complementary unitarity test to that obtained from superallowed nuclear beta decay [3]. The neutron lifetime is also one of the key parameters for the determination of yields of light elements in BBN since the ratio between the free neutron and proton abundances drives the extent of fusion reactions during the first few minutes of the Universe [2].

Magnetic trapping of ultracold neutrons (UCN) permits to control neutron losses during neutron lifetime measuring. To realize this advantage of UCN magnetic storage is possible only using of magnetic shutter. Without this unique opportunity, experiments with magnetic storage are indistinguishable from experiments with storage in material traps. Systematics in neutron lifetime measuring experiments using UCN magnetic storage is discussed.

Measurement of the neutron lifetime using ultracold neutrons stored in a magneto-gravitational trap made of permanent magnets is discussed. Neutrons surviving in the trap after fixed storage times have been counted and the trap losses have continuously been monitored during storage by detecting neutrons leaking from the trap. The value of the neutron lifetime resulting from this measurement is $\tau_n = (878.3 \pm 1.6_{\text{stat}} \pm 1.0_{\text{syst}}) \text{ s}$ [4]. A unique feature of this experiment is the monitoring of leaking neutrons providing a robust control of the main systematic loss.

Main features of a new magnetic trap with enlarged volume are discussed.

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Session / 114

Testing the weak equivalence principle using Gravitationally bound quantum states of ultracold neutrons

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Gravitationally bound quantum states of ultracold neutrons, which have been measured using pixelated silicon imaging sensor for cold neutrons[1], would be an unique and interesting system to see gravity-like phenomena beyond Newtonian expressions or the general relativity. We are now designing and developing the experimental details to manipulate this quantum system to fit our planning experiment of testing the weak equivalence principle, as the first physics target. In this presentation, current situation of developments are shown.

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Session / 59

Frequency shift at interaction of waves with accelerating object

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The report is devoted to the evolvement of views at the Accelerating Medium Effect, which consists in changing the frequency of a wave passing through a refracting sample moving with acceleration. At different times, theoretical predictions of such a change in frequency were made for electromagnetic waves passing through a dielectric plate moving with acceleration [1], neutron waves passing through an accelerated sample [2,3], and later for electron neutrinos passing through an accelerating layer of matter [4].

Experimental confirmation of these predictions was found only for neutron waves [5,6]. Since the phenomenon of refraction in a medium exists for waves of any nature, a conclusion was made in [5] about the very general nature of this optical effect.

However, from a simple consideration based on the principle of equivalence, it follows that the idea of the relation of the effect only with the refraction phenomenon is unreasonably narrow, and a change in the wave frequency should inevitably occur during scattering by any object moving with acceleration [7].

Such an object may be an elementary scatterer, a quantum object, or any device transmitting a signal. The effect is almost as general in nature as the well-known Doppler effect, but the frequency shift is determined not by the speed of the object, but by its acceleration. This relation with the Doppler effect is not accidental, since, with some reservation, the effect can be interpreted as the differential Doppler effect, in which the capture and emission of a wave are separated by the time interval during which the object's speed changes.

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Session / 104

Fundamental Physics with Cold Antihydrogen: 20 years of AD and a new era with ELENA

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It has been 20 years since the start of the Antiproton Decelerator (AD) facility at CERN. During this time, tremendous progress has been made in synthesizing, trapping, and interrogating cold antihydrogen atoms. The field of antihydrogen physics has now arguably advanced from the proof-of-principle stage to the precision physics stage. This talk will review recent progress, with some focus on the results from the ALPHA experiment. We will also discuss new prospects with ELENA, an upgrade to the AD facility currently under construction at CERN.

Session / 31

Neutron-antineutron oscillations with ultracold and cold neutrons

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The search for neutron-antineutron oscillations is currently of great interest as a process with baryon number violation. The results of the Monte Carlo simulations of the experiment based on the storage of ultracold neutrons in a material trap and of the experiment at cold neutron beam are presented. The possibilities of increasing the sensitivity of the experiment due to the accumulation of the antineutron phase in the collisions of neutrons with the walls are considered.

Session / 26

Test of the crystal-diffraction ultra-precise neutron spectrometry.

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Recently proposed ultra-precise neutron spectrometry technique based on the effects of dynamic neutron Laue-diffraction in perfect crystals was experimentally tested.

This technique is based on the effect of enhancement of angular deviation of neutron trajectory inside the crystal when the angle of neutron incidence on the crystal is slightly varied. Moreover, there is an additional gain factor $\tan^2(\theta_B)$ that becomes significant in the case of large diffraction angles. This factor is due to the fact that the neutron propagation time inside the crystal is increased with increasing the diffraction angle. We propose to use these two effects of the angular amplification for studies of the impact of external forces that might influence diffracting neutrons.

Such a technique could be used for a broad range of experiments:

The accuracy of the neutron electric charge experiment can be improved by one order of magnitude compared with the current experimental limit;

A test of the equivalence of inertial and gravitational neutron masses can be done with an accuracy of 10^{-5} ;

Neutron scattering amplitudes can be measured with high accuracy both for solid materials and gases;

Neutron diffraction in perfect crystals and crystal properties on the inter-planar distance homogeneity about $\Delta d/d \sim (10^{-6} - 10^{-8})$ can be studied.

A double-crystal setup made of highly-perfect silicon crystals to test this technique was constructed and mounted on the PF1b beam at ILL reactor.

The factor of diffraction amplification of the beam splitting in a magnetic field gradient (analogy of Stern-Gerlach effect) was measured. This factor reaches $6 \cdot 10^6$ for the (220) silicon plane at Bragg angle equal 82° in comparison with a free neutron.

Session / 18

In search for BSM Physics in the beta decay of ^{45}Ca

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The Standard Model (SM) has become one of the most complete theories encapsulating fundamental particle interactions. Despite its far ranging success, neutrino flavor oscillations, the observed baryon asymmetry, the dark matter puzzle, and complete absence of gravity from the theory makes it clear that there must exist interactions and particles beyond the standard model (BSM). A nonzero Fierz interference term in beta decay is one such candidate to test BSM physics. The Fierz term results from scalar and tensor interactions not included in the SM. The strength of the coupling manifests in the form of a distortion of the beta decay electron energy spectrum. A set of beta spectrum measurements for ^{45}Ca was completed at the Los Alamos Neutron Science Center in 2017 and I will present details of analysis along with preliminary results.

Session / 39

Cyclotron Radiation Emission Spectroscopy for measuring neutrino mass and searching for chirality-flipping interactions

Author: Elise Novitski¹¹ *University of Washington***Corresponding Author:** en37@uw.edu

Measurements of the β^- spectrum of tritium give the most precise directly measured limits on neutrino mass. Cyclotron Radiation Emission Spectroscopy (CRES) is a new experimental technique that has the potential to surmount the systematic and statistical limitations of current-generation direct measurement methods and reach an effective electron antineutrino mass sensitivity of ~ 40 meV/ c^2 . I will introduce CRES, report recent results from the Phase II of Project 8—including systematic studies using ^{83m}Kr and the first continuous spectrum measurement using CRES, in molecular tritium—and present Project 8's path to a full-scale neutrino mass measurement using atomic tritium. I will also describe recent progress on a precision β^- spectrum measurement in ^6He that is searching for chirality-flipping interactions using CRES.

Session / 57

Test of lepton universality and search for light neutral bosons with TREK/E36 at J-PARC

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Experiment E36 has recorded stopped-kaon decay data at the J-PARC K1.1BR beamline for a precision measurement of the ratio of decay widths $\text{BR}(K^+ \rightarrow e^+ \nu_e)$ and $\text{BR}(K^+ \rightarrow \mu^+ \nu_\mu)$, respectively, to test lepton universality, and to search for rare decay modes producing light neutral bosons. An overview of the experiment and analysis status will be presented.

This work has been supported by DOE awards DE-SC0003884 and DE-SC0013941 in the US, NSERC in Canada, and Kaken-hi in Japan.

Session / 103

The BL2 Experiment: An In-Beam Measurement of the Neutron Lifetime

Author: Jimmy Caylor¹¹ *The University of Tennessee - Knoxville***Corresponding Author:** jcaylor2@vols.utk.edu

Neutron beta decay is the simplest example of semi-leptonic decay. A precise measurement of the neutron lifetime and λ , the ratio of axial vector and vector coupling constants of the weak interaction, allow for a determination of the CKM matrix element V_{ud} that is free from nuclear structure effects. The neutron lifetime provides an important test of unitarity and consistency of the Standard Model. The neutron lifetime is also the largest uncertainty in Big Bang Nucleosynthesis calculations of light element abundance. A new measurement of the neutron lifetime using the in-beam method is ongoing at the NIST Center for Neutron Research. This method requires the absolute counting of the decay protons in a neutron beam of precisely known flux. Improvements in the neutron and proton detection systems as well as the use of a new analysis technique should allow for a thorough investigation of major systemic effects. The experimental status, systematic tests, analysis techniques and early data will be presented.

Session / 23

UCNTau status and plans

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C. L. Morris for the UCNTau collaboration

A new method for counting surviving neutrons in neutron lifetime measurements, using bottled ultracold neutrons, which provides better characterization of systematic uncertainties and enables higher precision than previous measurement techniques will be described. An active detector that can be lowered into the trap has been used to measure the neutron distribution as a function of height and measure the influence of marginally trapped UCN on the neutron lifetime measurement. In addition, measurements have demonstrated phase-space evolution and its effect on the lifetime measurement. The current state of the experiment aimed at obtaining a precision of 0.25 s for the neutron lifetime and plans for an upgrade that will allow a precision of less than 0.1 s will be described.

Session / 15

The CKM unitarity problem: A trace of new physics at the TeV scale?

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After the recent high precision determinations of V_{us} and V_{ud} , the first row of the CKM matrix shows more than 4σ deviation from unitarity. Two possible scenarios beyond the Standard Model can be investigated in order to fill the gap. If a 4th quark b' participates in the mixing, with $|V_{ub'}| \simeq 0.04$, then its mass should be no more than 6 TeV or so. A different solution can come from the introduction of the gauge horizontal family symmetry acting between the lepton families and spontaneously broken at the scale of about 6 TeV. Since the gauge bosons of this symmetry contribute to muon decay in interference with Standard Model, the Fermi constant is slightly smaller than the muon decay constant so that unitarity is recovered. Also the neutron lifetime problem, that is about 4σ discrepancy between the neutron lifetimes measured in beam and trap experiments, is discussed in the light of the the novel determinations of the CKM matrix elements.

Session / 11

Some recent approaches to ultralight bosonic dark matter searches

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I will survey some of the recent experiments, including the Cosmic Axion Spin-Precession experiments (CASPER), the use of sensor networks to detect topological dark matter, possibly trapped in the gravitational potential of the Earth, as well as experiments looking for scalar dark-matter fields oscillating at frequencies of up to hundreds of megahertz.

Some references can be found at: <http://budker.berkeley.edu/PubList.html>

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Winner of Poster prizes

Session / 36

Exploring the Dark Matter ALPs

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Very light and very weakly coupled particles, including in particular axion-like particles, provide interesting opportunities for dark matter. We consider a variety of different types of such light dark matter candidates and explore possible experimental and observational tests.

Session / 148**Searches for the neutrinoless double beta decay - status and prospects****Author:** Laura Baudis¹¹ *University of Zurich*

Neutrinos are the only known elementary particles that are Majorana fermion candidates, implying that they would be their own antiparticles. The most sensitive and perhaps only practical probe the Majorana nature of neutrinos is an extremely rare nuclear decay process, the neutrinoless double beta decay. I will present the experimental techniques to search for this decay, show current results from leading experiments and discuss future projects and the prospects to probe the co-called inverted neutrino mass ordering scenario.

Session / 33

Present status and future prospect of Neutrino-4 experiment search for sterile neutrino

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Present status of experiment Neutrino-4 search for sterile neutrino is discussed. The effect of oscillations into sterile neutrino with parameters $\Delta m_{14}^2 \approx 7.3 \text{ eV}^2$, $\sin^2 2\theta_{14} \approx 0.39$ is observed at the 2.8σ level. The detailed analysis of possible systematic errors is presented. Plans to improve the existing installation and create a new installation with a sensitivity increased by 3 times are discussed.

Session / 127

muCool: A novel low-energy muon beam for future precision experiments

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Experiments with muons (μ^+) and muonium atoms (μ^+e^-) offer several promising possibilities for testing fundamental symmetries of particle physics with high precision. Examples of such tests include the search for the muon electric dipole moment, measurement of the muon $g-2$ and muonium laser spectroscopy. These experiments could benefit from a high-quality muon beam at low energy with small transverse size and high intensity.

At the Paul Scherrer Institute, we are developing a novel device (muCool) that produces such a high-quality muon beam, reducing the phase space of a standard μ^+ beam by 10 orders of magnitude with 10^{-3} efficiency. The phase space compression is achieved by stopping a standard μ^+ beam in a cryogenic helium gas and subsequently manipulating the stopped μ^+ into a small spot using complex electric and magnetic fields in combination with gas density gradients. Finally, muons are extracted through a small orifice into the vacuum and into a field-free region. The whole process takes less than $10\ \mu\text{s}$, which is essential due to a short muon lifetime of $2.2\ \mu\text{s}$. Various aspects of this compression scheme have been demonstrated in the last few years. Comparison of the measurements with GEANT4 simulations confirms that the proposed efficiency can be achieved.

In this talk, I will explain the working principle of the muCool device and present the most recent measurements and current developments.

This work is supported by SNF grant 200020\172639.

Session / 22

Precision measurements in molecular hydrogen

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Few-electron molecules are attractive systems for precision spectroscopy because their properties can be calculated with high accuracy by quantum-chemical methods.^{1,2,3} The measurements serve to test theoretical predictions, ideally at the level where their accuracy is limited by the uncertainties of the fundamental constants or by unrecognized physical effects. I will report on precision measurements of energy intervals in cold samples of H₂. In particular, we determine the ionization energy with a precision ($\Delta\nu/\nu$) of 10^{-10} from high-resolution Rydberg spectra^{4,5,6} and derive the dissociation energy with an accuracy of 350 kHz, approaching the level where the size of the proton and the uncertainty in the proton-to-electron mass ratio would limit the accuracy of otherwise exact calculations. Comparison will be made to recent theoretical results in the context of a more-than-100-year-long series of experimental and theoretical determinations of the dissociation energy of H₂. I will also discuss the determination of an upper bound for a hypothetical global shift of the energy level structure of ortho-H₂ with respect to that of para-H₂.

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Session / 77**25 years of ultimate-resolution exotic atom X-ray spectroscopy****Author:** Detlev Gotta¹¹ *Forschungszentrum Jülich***Corresponding Author:** d.gotta@fz-juelich.de

Exotic atoms allow studies in the fields of particle and nuclear physics as well as atomic and molecular phenomena. Inherent to exotic-atom research is a low count rate in the presence of demanding background conditions. Therefore, facilities providing high muon, pion and antiproton fluxes are mandatory in particular for ultimate resolution spectroscopy when using crystal spectrometers. Such high fluxes for pions and muons are available at the PSI pion factory with continuously increasing intensity and for antiprotons up to the year 1996 at the LEAR facility at CERN. Of special interest in the case of hadrons are the elementary systems formed with hydrogen where the strong-interaction effects give access to important threshold parameters, the scattering lengths and volumes. The performance crystal spectrometers allows the determination of the mass of the charged pion at the ppm level. In addition, Doppler broadening caused by collisional and molecular effects becomes directly detectable giving insight in exotic-atom formation and de-excitation.

Session / 53

Precise spectroscopy of muonium hyperfine structure using Kr-He mixture gas

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MuSEUM (Muonium Spectroscopy Experiment Using Microwave) collaboration aims to perform a precise spectroscopy of the ground state muonium hyperfine structure (MuHFS) with high-intensity pulsed muon beam at J-PARC. Our goal is a ten-fold of improvement in a precision of MuHFS compared to the preceding experiment at LAMPF [1]. Muonium is the bound state of a positive muon and an electron. Its hyperfine structure is precisely calculable because muonium is free from the finite size effect of nuclei unlike hydrogen. Therefore, a precision spectroscopy of MuHFS provides the most rigorous test of bound-state QED theory. The muonium hyperfine spectroscopy also gives the muon-to-proton magnetic moment ratio. It is one of two parameters to determine the muon anomalous magnetic moment, which has taken researchers attention since there is more than 3σ discrepancy between theoretical and experimental values of it [2].

In 2019, we used Kr-He mixture gas instead of Kr gas as a target of muon beam to suppress the systematic uncertainty related to the gas pressure. The transition frequency of muonium measured in a gas varies with its pressure due to the collision between a gas atom and a muonium one, thus we have to extrapolate MuHFS in a vacuum using data at various pressures and this causes the systematic uncertainty. The collision in Kr gas decreases MuHFS, whereas that in He gas was expected to increase it because it shows such a behavior in the measurement of hydrogen HFS [3]. Therefore, we expected reduction of the collisional shift of MuHFS in the Kr-He mixture gas by cancelling out the effects. In the last beamtime in 2019, we successfully observed MuHFS resonance in Kr-He mixture gas, which was the first observation of MuHFS using a mixture gas, although the analysis in detail is ongoing. In this presentation, we will report the preliminary result of the measurement.

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Positronium and Muonium precision spectroscopy: Measurement of the 1S-2S and excited state hyperfine transitions

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Positronium and Muonium are excellent systems to test bound-state QED theory to high precision. This has motivated numerous precise experiments aimed at measuring the hyperfine splitting and 1S-2S transition of these atoms.

Currently, there is some disagreement with the most recent bound-state QED calculations for the hyperfine splitting in positronium. Our approach to resolve this, PHySES, eliminates several possible sources of systematics present in earlier experiments by a novel experimental design.

Furthermore, measurements of the 1S-2S transition can test bound state QED in the ppb range and determine fundamental constants, e.g., the muon mass. Here we present current efforts to reach this sensitivity.

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Satellite Workshop - EQLIPS / 164

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hall

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Fundamental Physics possibilities @ ESS

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The European Spallation Source (ESS) is being constructed in Lund, Sweden, to be the brightest cold (< 0.025 eV) spallation neutron source in the world. The facility uses a 2 GeV proton beam hitting a tungsten target to produce neutrons via spallation. The neutrons are then moderated in cold and thermal moderators consisting of liquid hydrogen and water, respectively. Surrounding the moderators are 42 beamports, which view the moderator's outside surfaces.

The scope of ESS, is to build and operate 22 world-leading instruments in an open user program. Of these, the first 15 will be brought on-line by the end of 2025. For the remaining 7 instruments, a recent document from ESS has analysed the capability gaps remaining after construction of the first 15 instruments, and the result of this analysis has shown that one of the communities that is most obviously not catered is the particle physics community. Therefore, it is in the ESS view that the science program should include at least a particle physics instrument.

Four different instruments for particle and nuclear physics have been identified at ESS:

- the cold beam line: ANNI,
- an Ultra Cold Neutron source,
- the neutron-antineutron experiment: NNBAR
- the HIBEAM beamline "High Intensity Baryon extraction and measurement"

I will give an overview of the present status of the ESS and of the possibilities for the fundamental physics community