PAUL SCHERRER INSTITUT

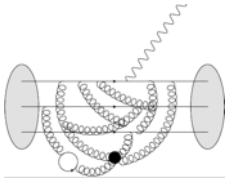
PSI

Lea Caminada (PSI – University of Zurich), Angela Papa (PSI – University of Pisa),
Klaus Kirch (PSI – ETH Zurich) :: Laboratory for Particle Physics :: NUM Division PSI

PSI Particle Physics

Visit of the President of CERN Council at PSI, December 21, 2023

PSI Laboratory for Particle Physics



Particle Physics (LTP)
Prof. Dr. K. Kirch (ETHZ)
3200

Particle Physics Theory
Dr. M. Spira
3201

High Energy Particle Physics
Prof. Dr. L. Caminada
3202

Muon Physics
Dr. S. Ritt
3203

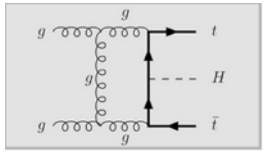
UCN Physics
Dr. B. Lauss
3204

Electronics for Measuring Systems
U. Greuter
3205

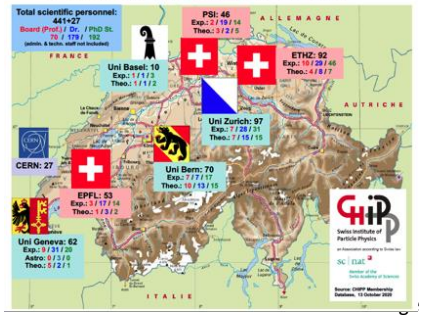
Detectors, Irradiation, Applied Particle Physics
Dr. M. Hildebrandt
3206

Electronics Vocational Training and Service Pool
C. Kämpf
3208

- Pursue leading research in experimental and theoretical, accelerator-based particle physics at PSI and at CERN.
- Develop, apply and make available cutting-edge technologies.
- Organize and support user activities at CHRISP.
- Work together closely with CHIPP, universities and international collaborations.
- Train next generation of physicists and electronicians at PSI and at universities.
- Inform and educate the broader public.

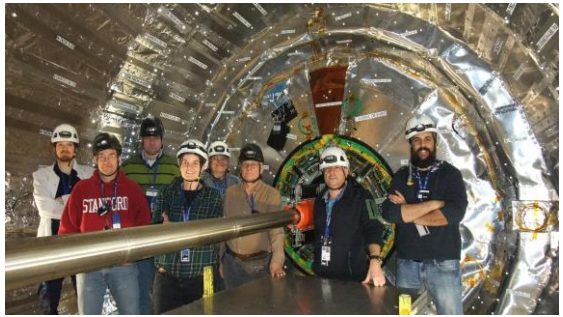


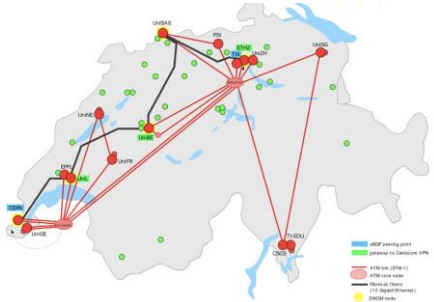
Swiss Particle Physics Landscape 2023

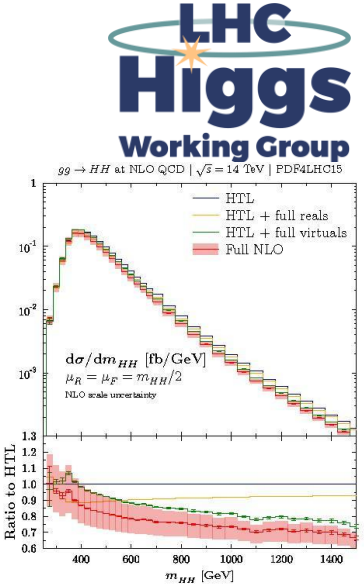


PSI groups at LHC

- High-energy physics group in CMS
  - 16 CMS members (including senior scientists, postdocs, PhD students, technicians and emeriti)
  - Leading contributions to detector development, physics analysis and ORD
  - Holding key positions within collaboration: Trigger Coordinator (M. Missiroli), Common Analysis Tools Coordination (C. Lange), TEPX Upgrade Coordinator (W. Erdmann), Secretary of CMS Management Board (Q. Ingram)
- High-performance computing and emerging technologies
  - Tier3 computing centre at PSI and Tier2 computing centre at CSCS
- LTP theory group
  - Phenomenology of physics at the LHC (Higgs, SM, SUSY, Exotica)
  - Coordination within LHC Higgs cross section working group (M. Spira)

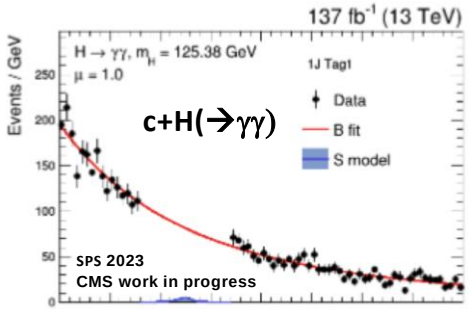




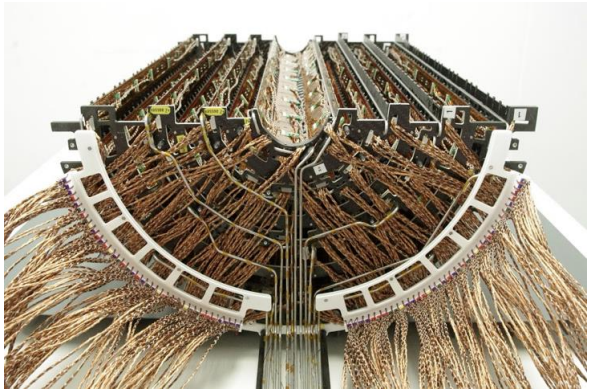


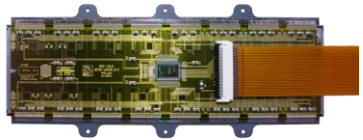
PSI activities in CMS

- CH consortium (PSI, ETH,UZH) led design, construction, integration, commissioning of original and Phase-1 CMS pixel detector
  - Major parts built at Swiss institutes with components from local industry
- Key contributions to pixel detector operation, calibration, performance monitoring, local reconstruction, tracking and vertexing
- Active in physics analysis, in particular Standard Model, B and Higgs physics




Installation of orginal CMS pixel detector (2008)

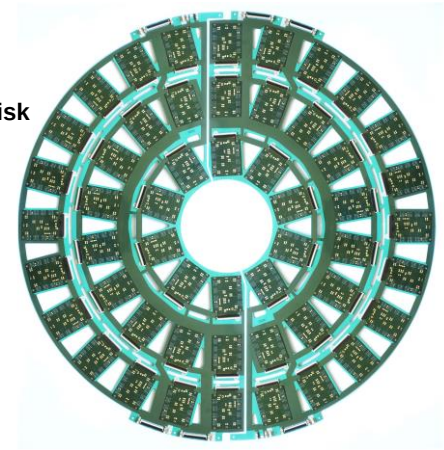




CMS Phase-1 pixel detector (2017)

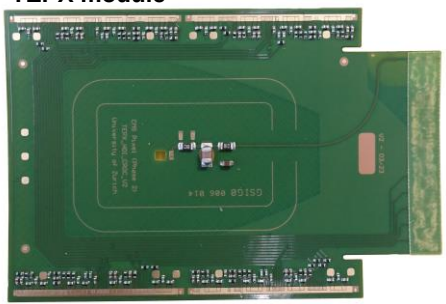
CMS at HL-LHC

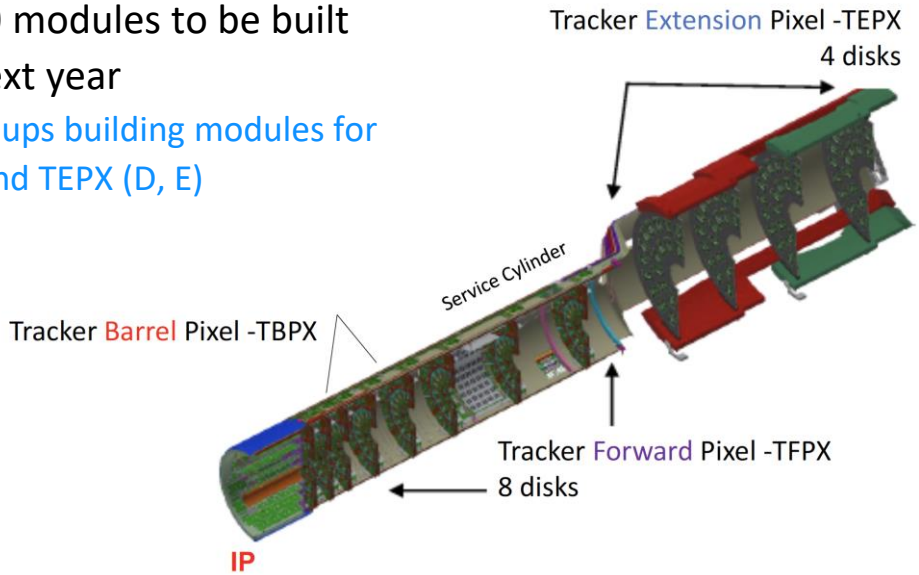
TEPX prototype disk



- PSI is responsible (together with UZH) for design and construction of extended pixel detector (TEPX) for CMS Phase-2
  - Module production and testing, mechanics, readout system, integration and installation
- Module production (about 1200 modules to be built at PSI, 60% of TEPX) will start next year
  - Close collaboration with other groups building modules for TBPX (INFN, ETH, E), TFPX (USA) and TEPX (D, E)
- Detector installation in 2028

TEPX module

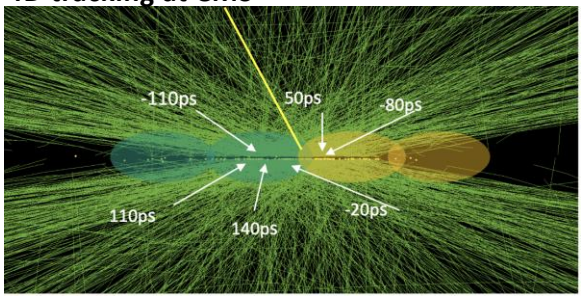




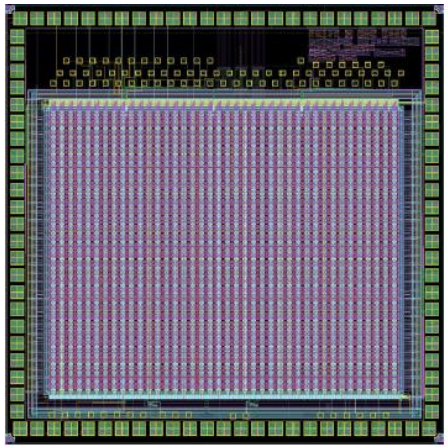
Detector R&D activities

- Development of readout electronics for fast silicon timing detectors (with time resolution < 30ps)
  - For “CMS Phase-3” (future upgrade in LS4) → timing information in TEPX → 4D tracking at CMS
  - Forming collaboration PSI/UZH/CERN for chip development in 28nm CMOS process
- Development of Depleted Monolithic Active Pixel Sensors (DMAPS) for applications in particle physics and beyond
  - Development of test structures and prototype chips in different processes
  - Partner organization in AIDAinnova WP5
  - Cooperation with ARCADIA
- Active part in forming CH collaboration towards research at FCC (CHEF)
- Participation in ECFA Detector R&D roadmap
  - DRD3 - Solid-state detectors
  - DRD7 - Electronics

4D tracking at CMS



MOTIC (Monolithic timing chip 2021)

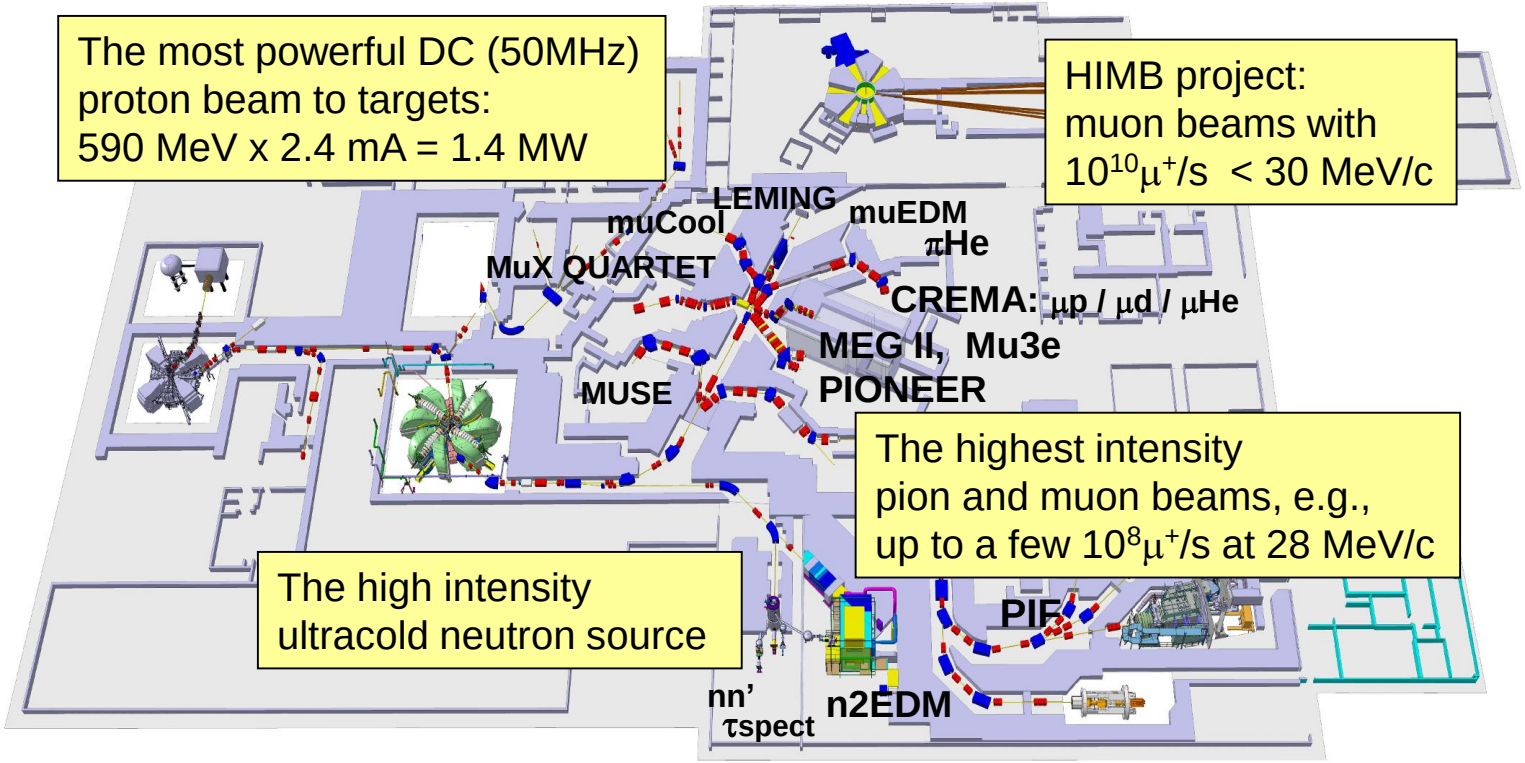


The intensity frontier at PSI: π, μ, UCN

Precision experiments with **the lightest unstable particles** of their kind

The most powerful DC (50MHz) proton beam to targets:
590 MeV x 2.4 mA = 1.4 MW

HIMB project:
muon beams with
$10^{10}\mu^+$/s < 30 MeV/c



The highest intensity
pion and muon beams, e.g.,
up to a few $10^8\mu^+$/s at 28 MeV/c

The high intensity
ultracold neutron source

Swiss national laboratory with strong international collaborations

See recent Particle Physics at PSI, https://scipost.org/SciPostPhysProc.5.001

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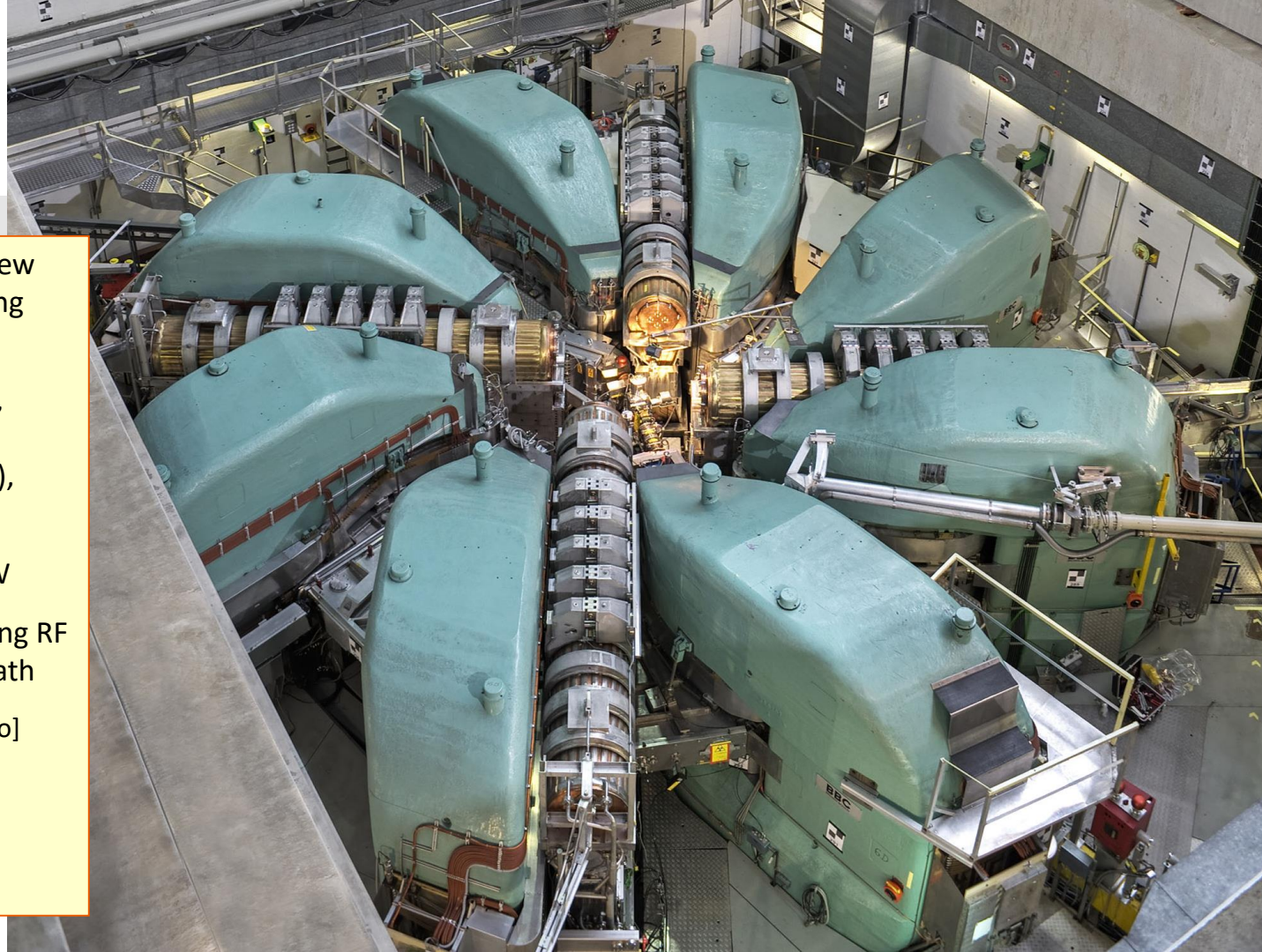
Ring cyclotron

- at time of construction a new concept: separated sector ring cyclotron [H.Willax et al.]
- 8 magnets (280t, 1.6-2.1T), 4 accelerating resonators (50MHz), 1 Flattop (150MHz), ∅ 15m
- losses at extraction ≤ 200W
- reducing losses by increasing RF voltage was main upgrade path

[losses ∝ (turn number)^3, W.Joho]

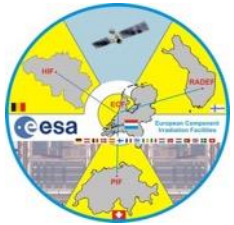
- 590MeV protons at 80%c
- 2.4mA x 590MeV=1.4MW



Proton Irradiation Facility PIF

Main functions:

- user-lab for studies of radiation effects
- realistic simulator of space radiation environment
- source of mono-energetic particles
- radiation qualification of space technologies
- calibration of detectors
- application oriented and user-friendly facility
- part of ESA “European Component Irradiation Facilities ECIF”



Main parameters:

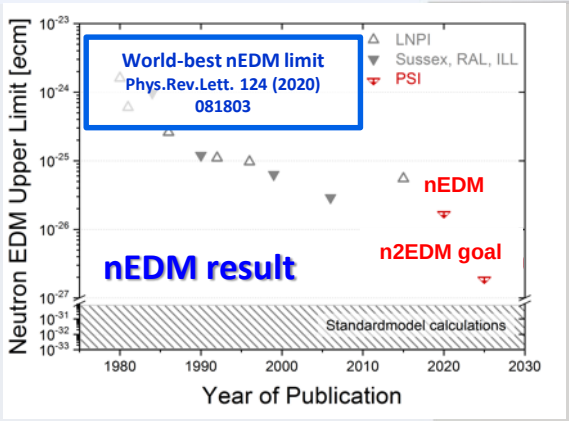
- proton energy range: 6 – 230 MeV
- proton flux range: 10^2 – 10^9 p/s/cm^2
- Gaussian-like profiles (FWHM 9 cm)
- options: focused (6mm) or flat beam profiles

Operation and User:

- ~120 test days/y with ~60 experiments/y
- ~150 visitors/y from about 40 institutions: research institutes, universities, aerospace and electronic industry from CH, EU, CHN and US
- main users: ESA and CERN

Search for a neutron Electric Dipole Moment

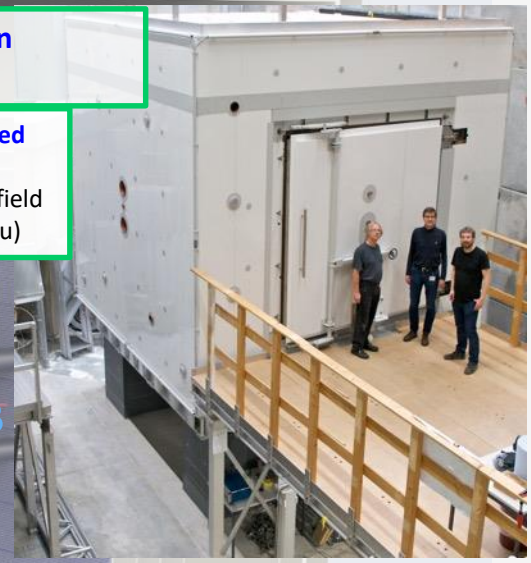
nEDM Collaboration @ PSI

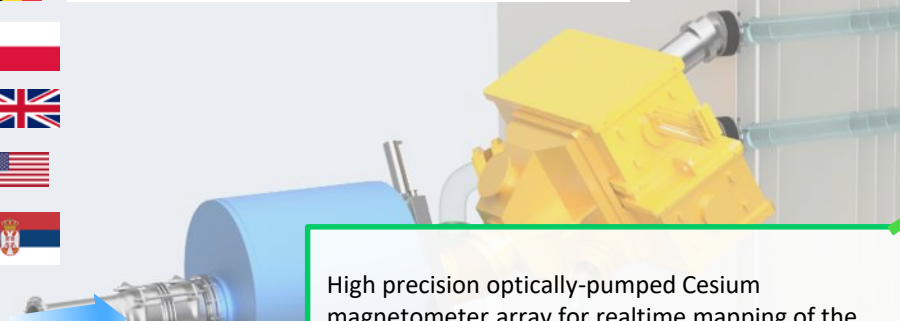


n2EDM project

- factor 10 higher sensitivity in baseline design
- apparatus with unique developments at PSI

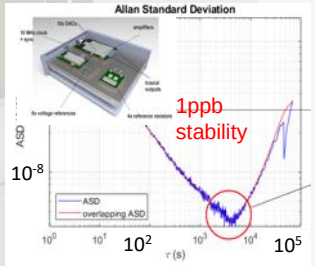
New magnetically-shielded room with worldrecord <150pT central field and field gradient (with VAC, Hanau)





High precision optically-pumped Cesium magnetometer array for realtime mapping of the magnetic field → **precision magnetometry Lab**

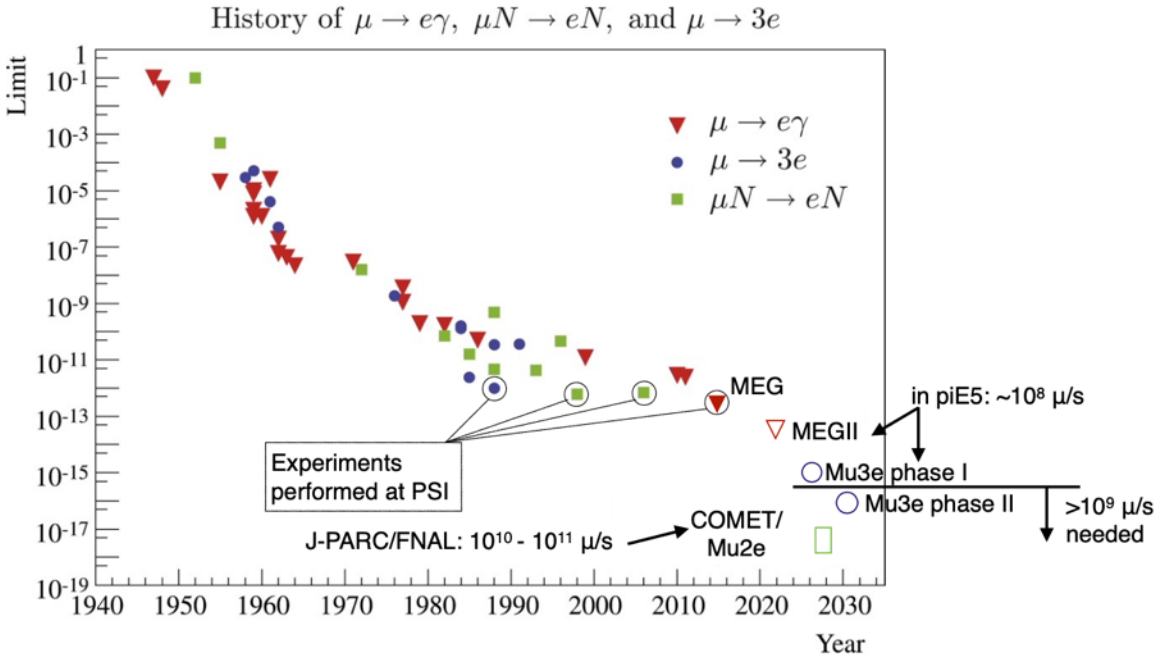
Development of ultralow-noise current source providing ultrastable magnetic field conditions



Future muon cLFV experiments at PSI

- Neutrinoless muon decays are one of the most sensitive probes for new physics
- $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ only possible at DC, high-intensity machines, such as HIPA

→ New project (HIMB) for muon experiments with unique sensitivities



A. Baldini et al. (MEG Collaboration), Eur. Phys. J. C73 (2013) 2365

A. Baldini et al. (MEG Collaboration), Eur. Phys. J. C76 (2016) no. 8, 434

The MEGII experiment at PSI

- The MEGII experiment aims at searching for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of ~ **$6\ 10^{-14}$**
- Best upper limit on the BR ($\mu^+ \rightarrow e^+ \gamma$) set by the MEG experiment (**$4.2\ 10^{-13}$** @90% C.L.)
- Five observables **(E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg})** to identify $\mu^+ \rightarrow e^+ \gamma$ events

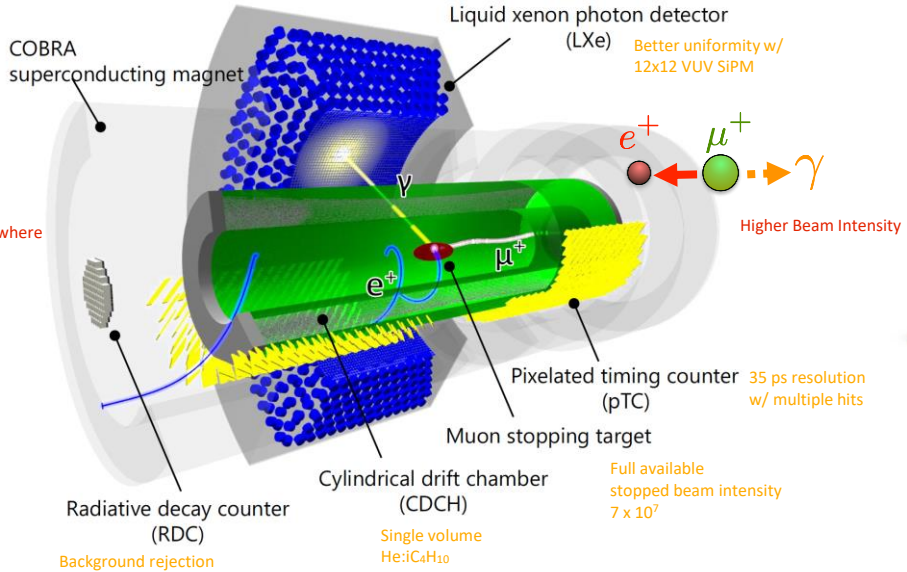
New electronics:
WaveDAQ

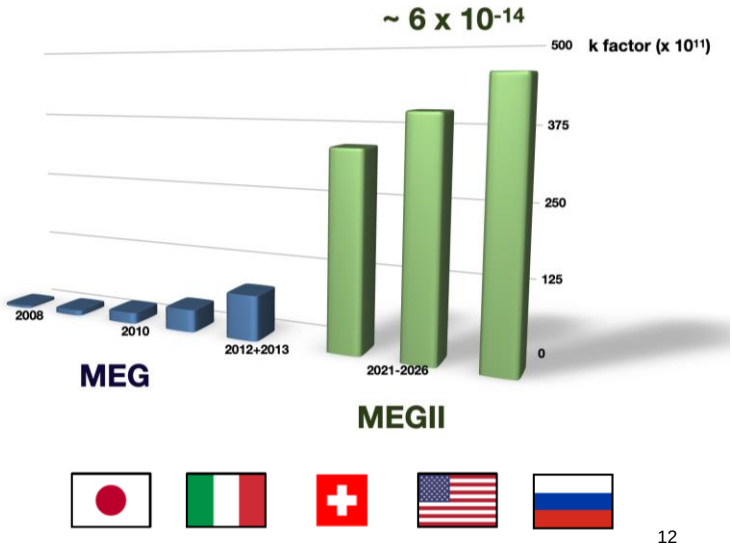
~9000 channels
at 5GSPS

2x Resolution everywhere

Updated and
new Calibration
methods

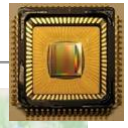
Quasi mono-chromatic
positron beam



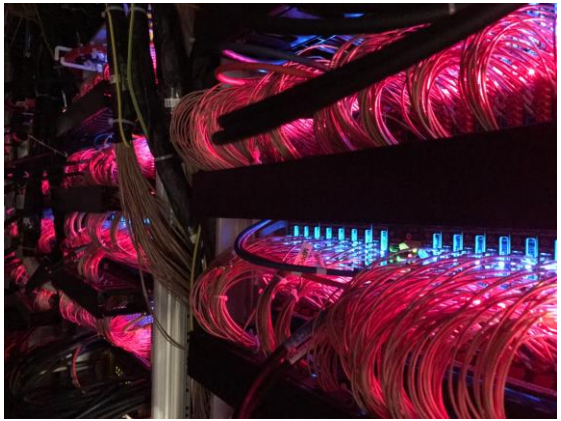


The WaveDAQ System

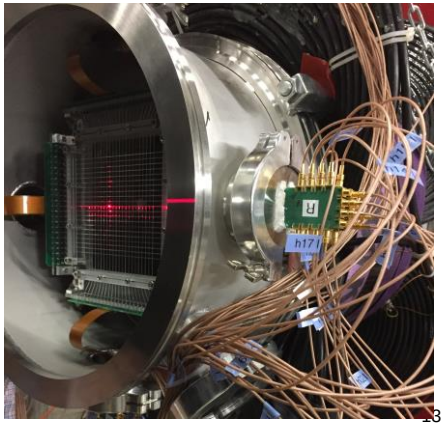
DRS4 chip



- Data acquisition system based on patented DRS4 chip with 5 GSPS/12 bit developed at PSI
- Novel custom crate design allows compact triggering and DAQ
- WaveDAQintegrates signal amplification, triggering, DAQ andbias voltage generation in a single system
- Boards used in MEG, FOOT (INFN Pisa), Beam profile monitorsand SwissFEL



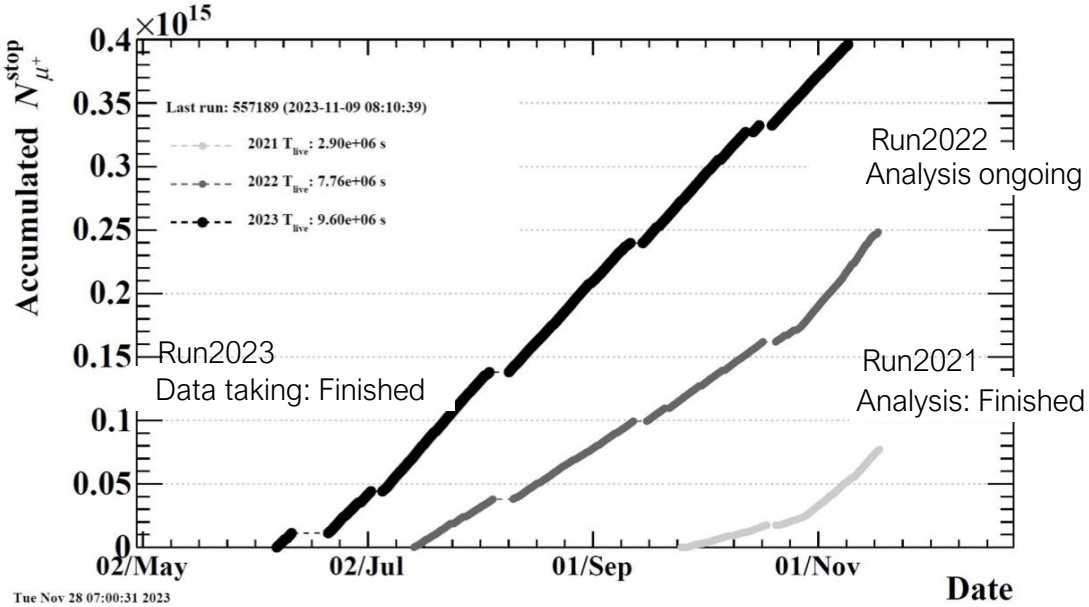
MEGII TDAQ



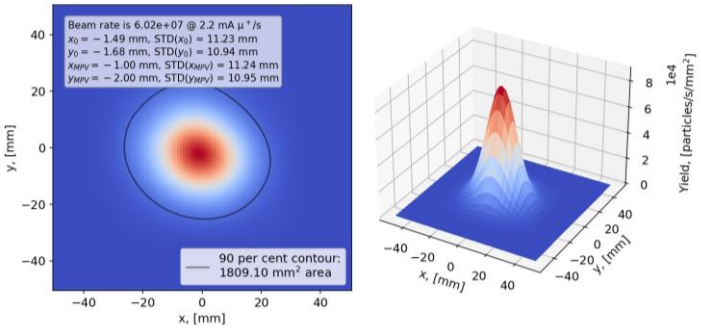
Beam monitoring

How is ongoing…Physics run 2023: completed

- **Very successful data taking period!**

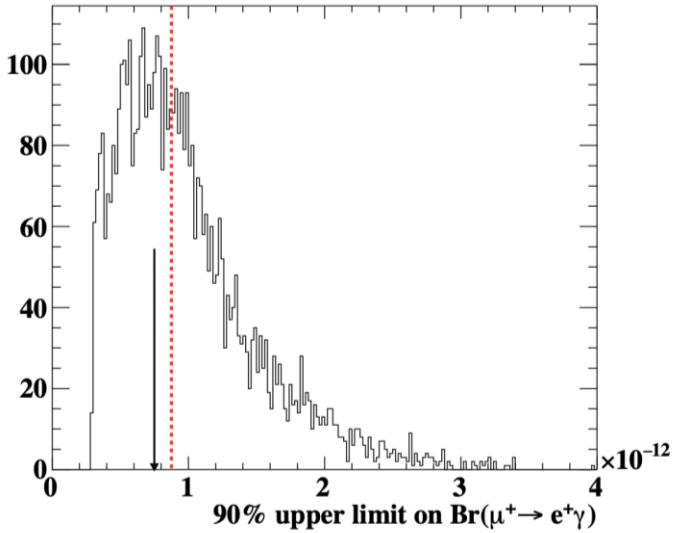


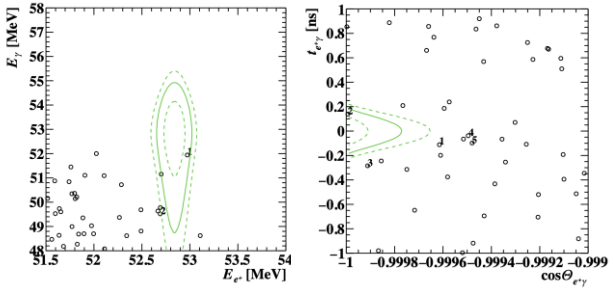
With a beam intensity =
4.27e7 mu/s@1.76 mA



https://arxiv.org/pdf/2310.12614.pdf
https://arxiv.org/pdf/2310.11902.pdf

First MEGII results - data sample “Run2021” and MEG combination





- Distribution of the 90% C.L. upper limits computed for an ensemble of pseudo-experiments with a null-signal hypothesis
- The sensitivity is indicated by a red dashed line while the upper limit observed (Run 2021) in the analysis region with a solid black arrow

- Upper limit on the BR ($\mu^+ \rightarrow e^+ \gamma$) set by the MEGII experiment **Run2021** (**$7.5\ 10^{-13}$** @90% C.L.)

- When **combined** with the final result of MEG, we obtain the most stringent limit up to date, BR ($\mu^+ \rightarrow e^+ \gamma$) < **$3.1\ 10^{-13}$** @90% C.L.

- The final goal (by 2026) is to reach a sensitivity to the $\mu^+ \rightarrow e^+ \gamma$ decay of $S_{90} \sim 6\ 10^{-14}$

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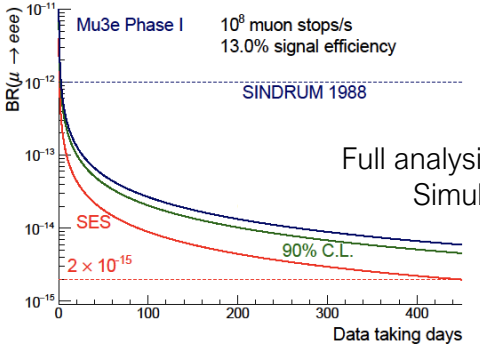
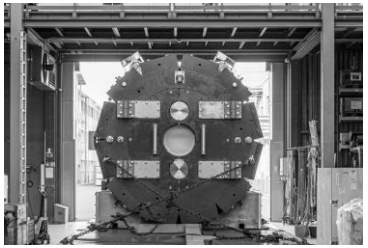
Mu3e: Latest news and currents status

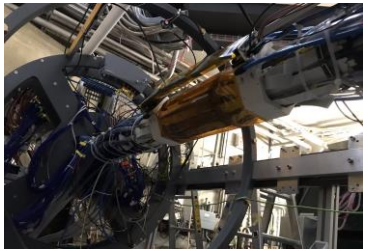
- The Mu3e experiment aims to search for $\mu^+ \rightarrow e^+ e^+ e^-$ with a sensitivity of ~10^{-15} (Phase I) up to down ~10^{-16} (Phase II)
  - Previous upper limit BR($\mu^+ \rightarrow e^+ e^+ e^-$) ≤ 1 x 10^{-12} @90 C.L. by SINDRUM experiment)

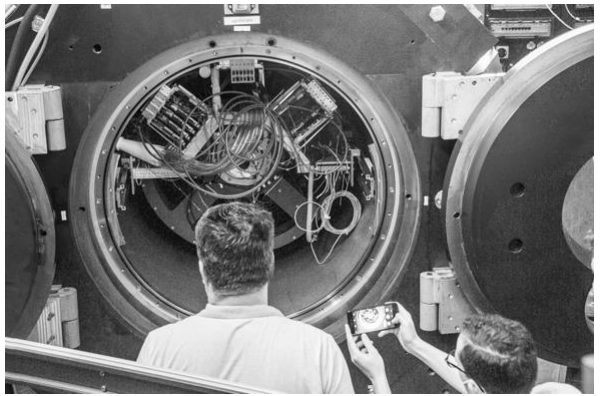
- **Detector concept validated during the Integration run 2021**
- **Full beam line commissioned during the beam time 2022 - fine tuning and further studies ongoing during the beam time 2023 [new record of transported muons at the collimator]**
- Very successful: TDR promised values **matched!**
  - **1.02e10^8 mu/s @2.4 mA** (Mu3e magnet) [run2022]

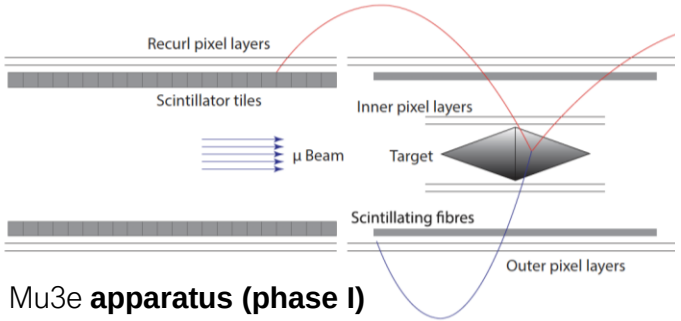


Full analysis performed on Simulated data

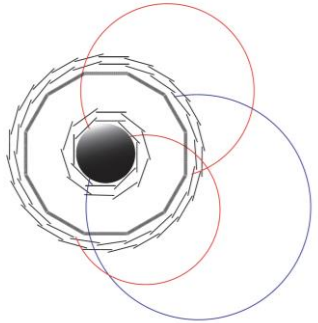








Mu3e **apparatus (phase I)**



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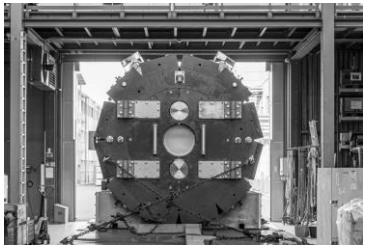

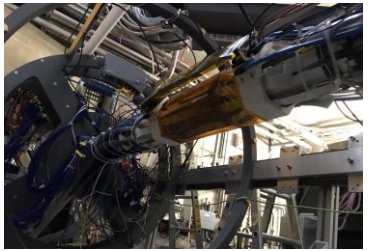

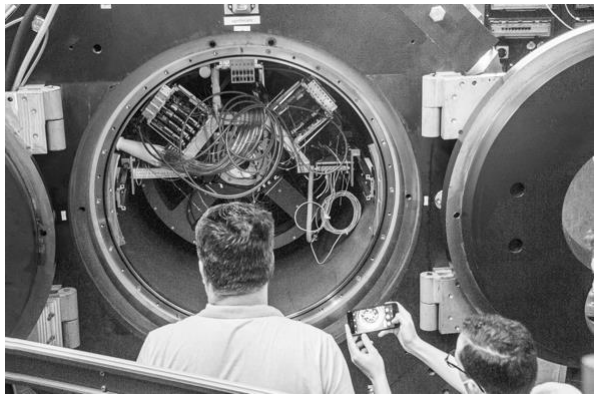

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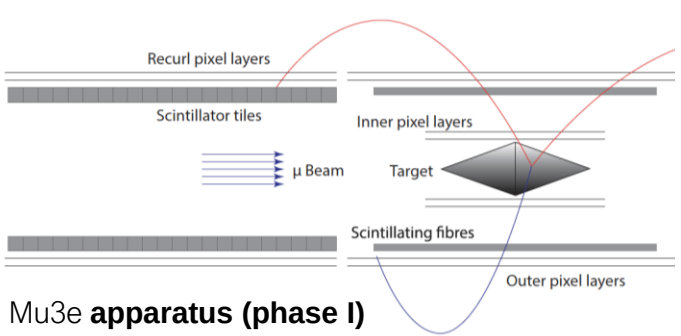
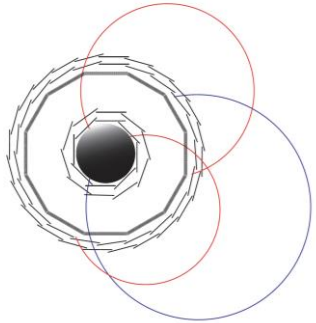
Time line phase I (exploiting current beamline intensity)

- Engineering run: 2024
- First physics run: 2025 - 2026

Phase II: It requires 10^9 mu/s —> **HiMB**

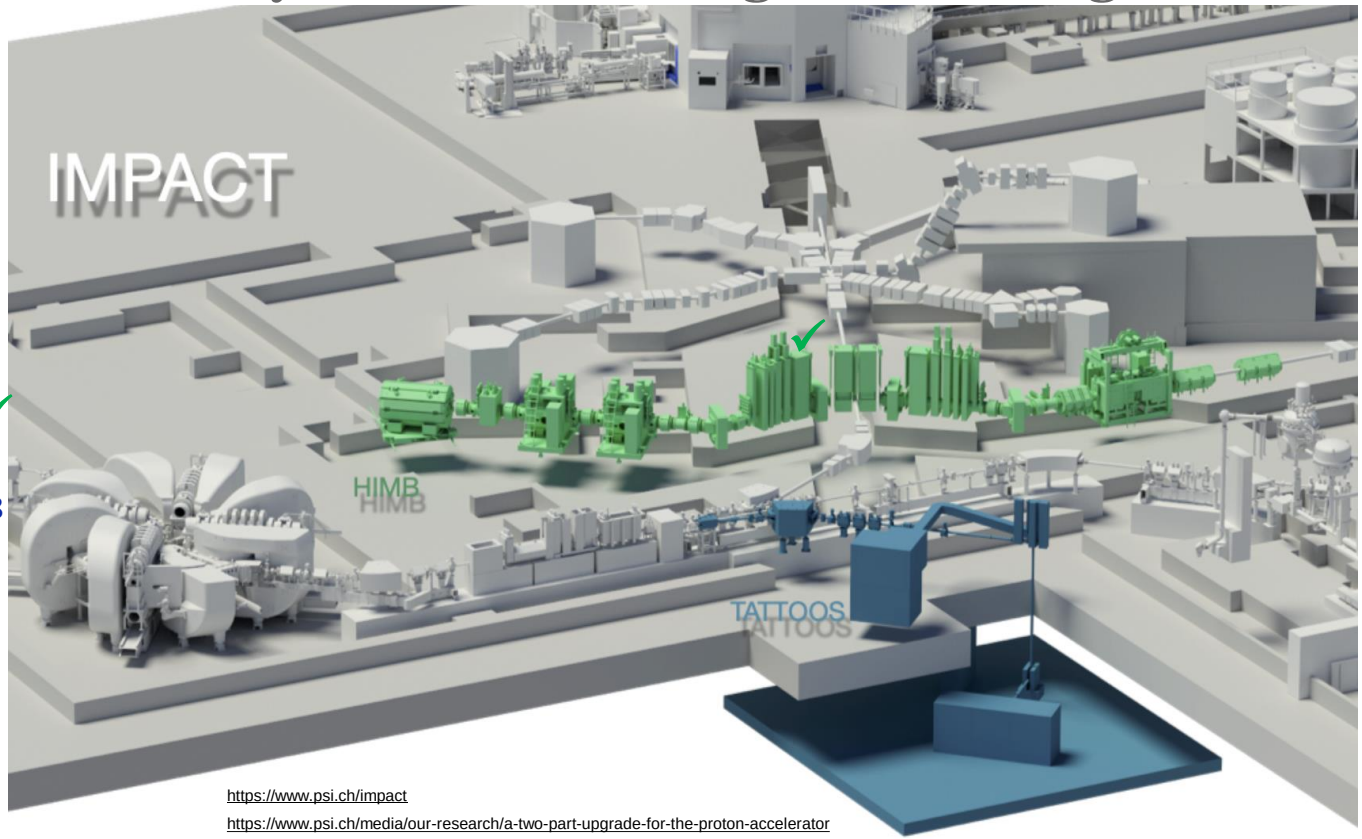


Mu3e **apparatus (phase I)**



IMPACT – Isotopes and Muon Production using Advanced Cyclotron and Target technologies

- 01/22 CDR published ✓
- 07/22 Scientific Review ✓
- 12/22 ETH Board: IMPACT for Swiss Roadmap of RIs 2023 ✓
- 2022-24 PSI funds pre-project ✓
- 12/24 Swiss parliament decision about funding 2025-28
- Full implementation
- 08/28 start HIMB
- 08/30 start TATTOOS



https://www.psi.ch/impact

https://www.psi.ch/media/our-research/a-two-part-upgrade-for-the-proton-accelerator

LTP – Strategy and Vision for 2026+

Harvest physics results 2022-2028+	Future activities 2026+	Future infrastructure 2026+
CMS MEG II Mu3e Phase I n2EDM CREMA, HyperMu Mu-MASS (@LEM) MUSE muX, QUARTET … ….	CMS at HL-LHC Mu3e Phase II n2EDM++ muEDM I & II PIONEER I & II Mu – spec&gravity …	HIMB (2029+) muCool (2024+) EZE UCN (2026+) HL-LHC (2028+) Pixel detectors & other technology

Aim at leading efforts in high- and low-energy particle physics with discovery potential

Synergies of experiment + theory + technology development & transfer + education

Foster collaborations within LTP, NUM, PSI, ETH&UZH&more, CHIPP, &internationally