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PSI

Klaus Kirch :: Laboratory for Particle Physics :: Paul Scherrer Institut

Particle Physics at PSI

Summer student lecture, July 6, 2016

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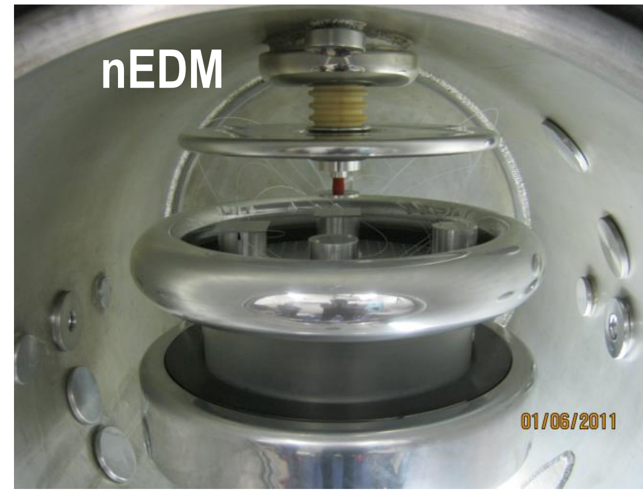
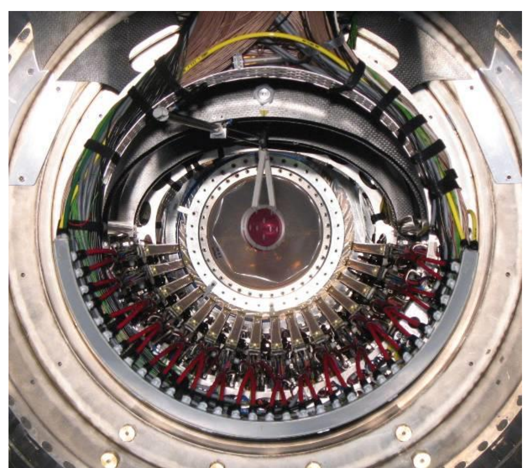
Overview

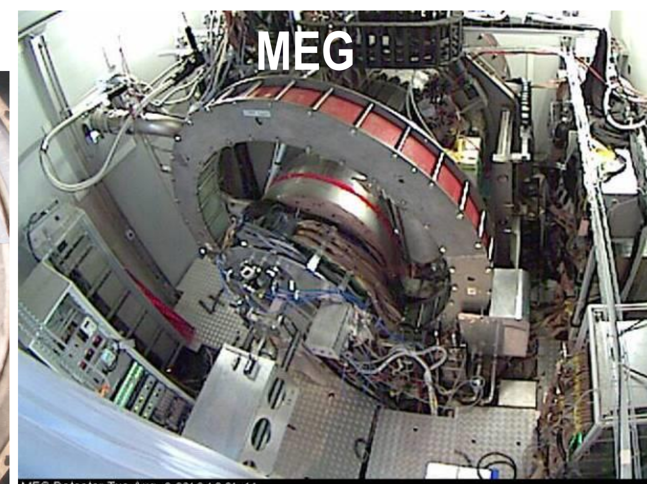
← Basel Germany ↑ Aarau/Bern ↓ Zürich →

Matter research – fundamental particle physics

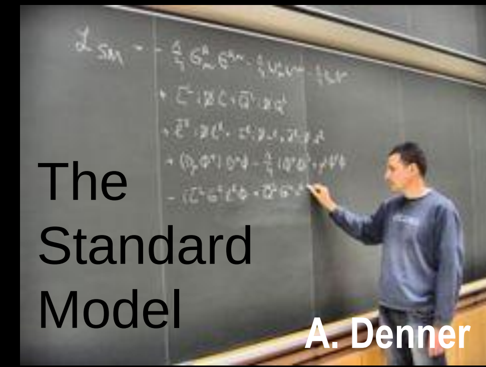


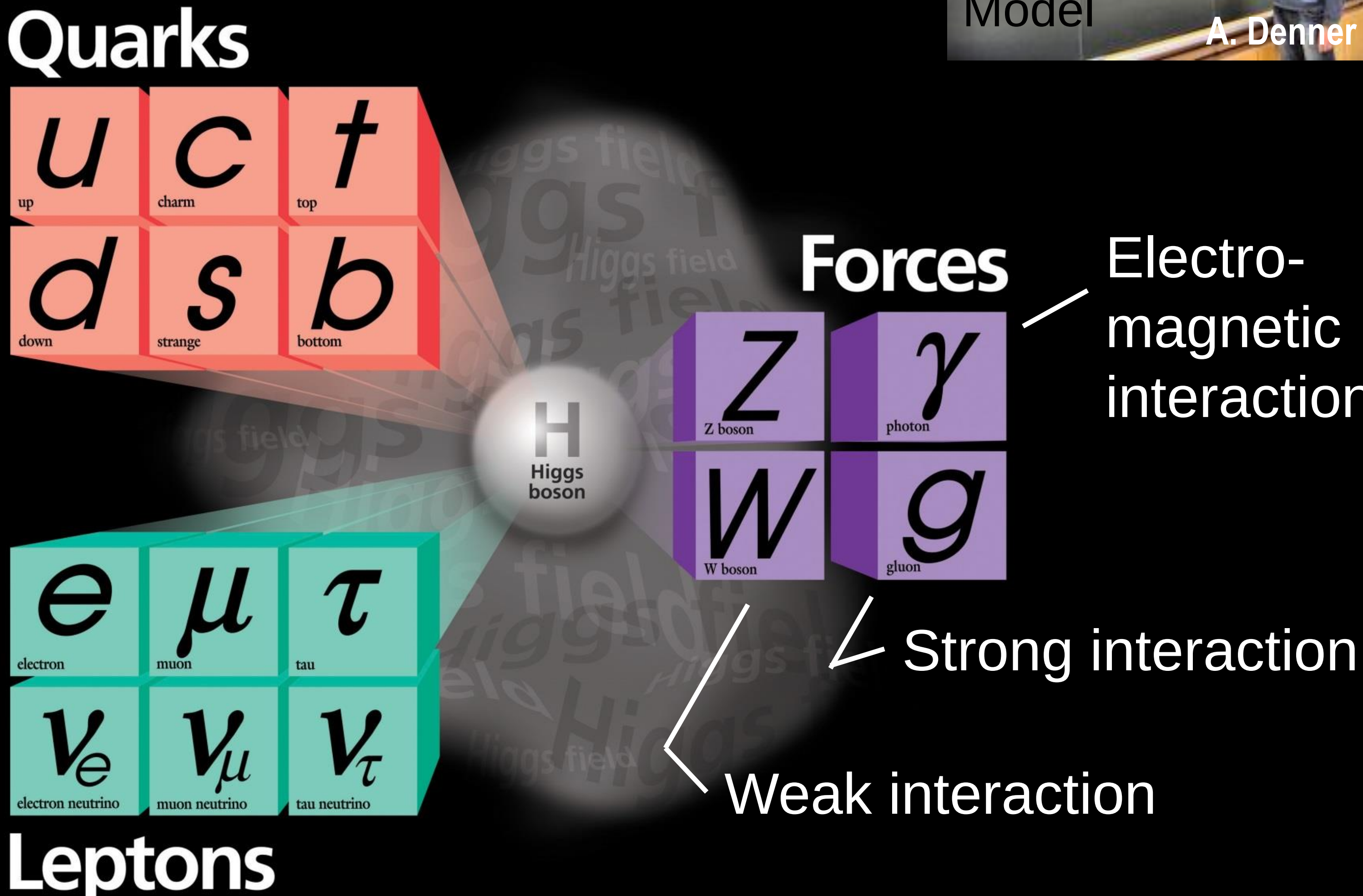
Discovery physics at high and low energies





The building blocks



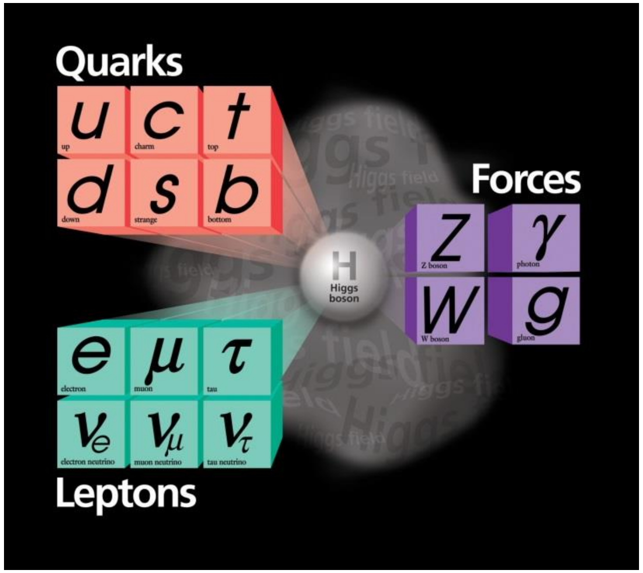


Source: FNAL

The Standard Model of Particle Physics

- is extremely successful …

- … but it does not explain
  - Gravity, Dark matter
  - Dark energy
  - 3 families
  - QCD theta term
  - Values of particle masses and couplings
  - Baryon Asymmetry of the Universe
  - Conservation of baryon and charged lepton number
  - …



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Fundamental Particle Physics

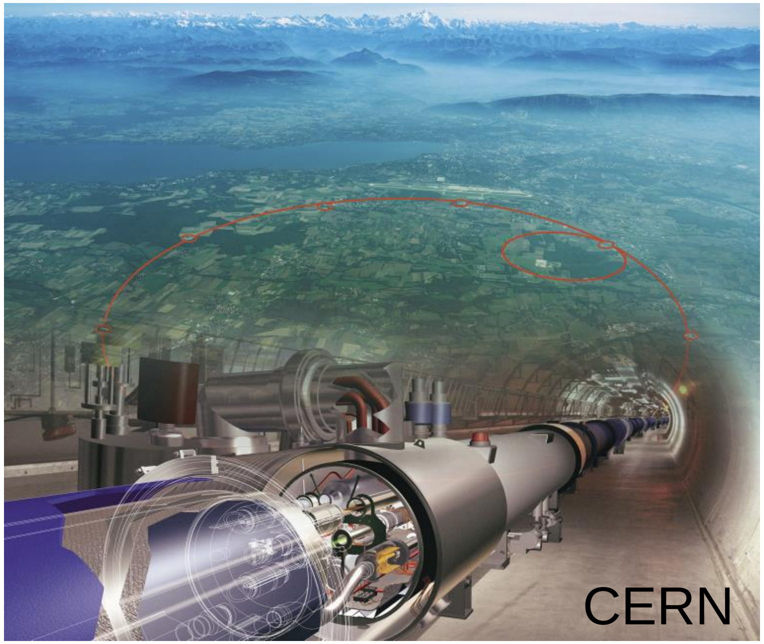
- I like to distinguish
  - Precision measurements of parameters of the Standard Model
  - Searches for physics beyond the Standard Model (ideally where its prediction is zero)

- Both are absolutely necessary to build a complete picture

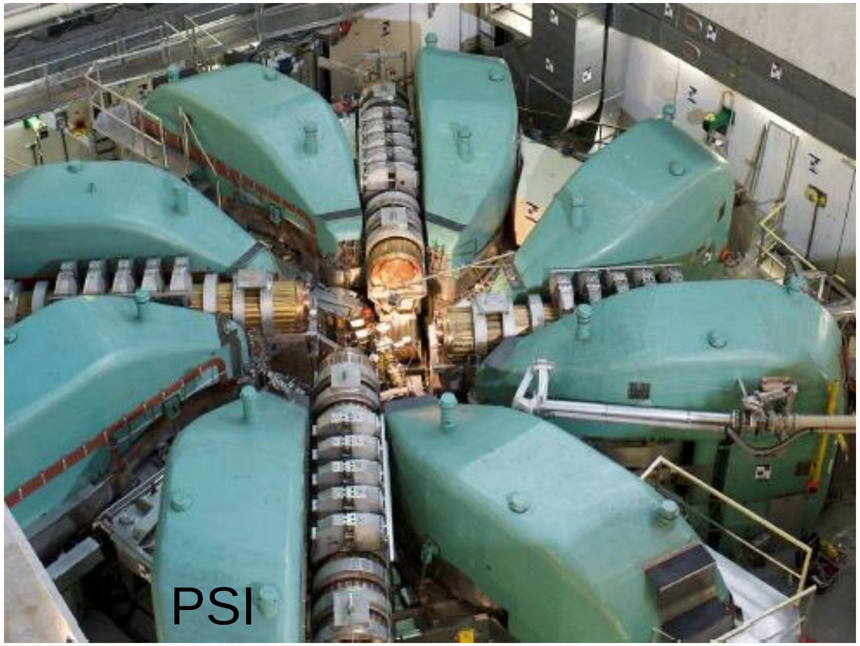
- The more successful a theory – the more we need to test it to its extremes!
- For example, QED tests, electroweak tests, and especially null tests

Complementary approaches

High Energy



High Intensity



PSI laboratory for particle physics is involved in both. High intensity: at PSI.
Both test our current understanding of fundamental particles and interactions.

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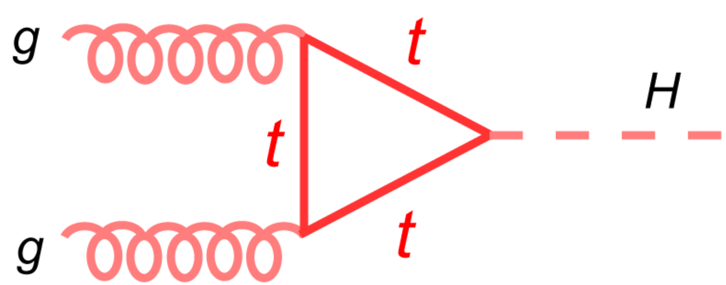
Search for new physics

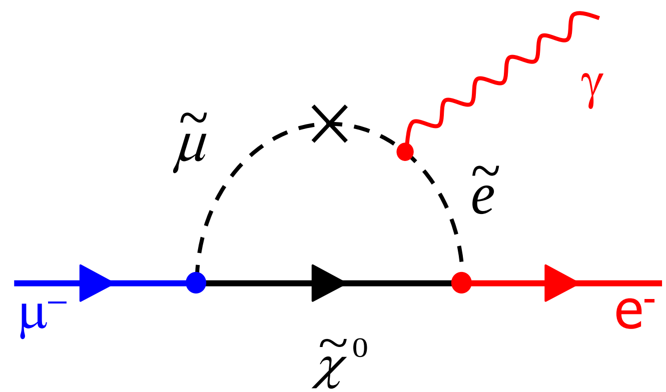
High Energy

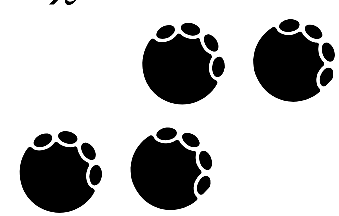
direct production of new particle



High Intensity

For example:
Search for $\mu \rightarrow e\gamma$





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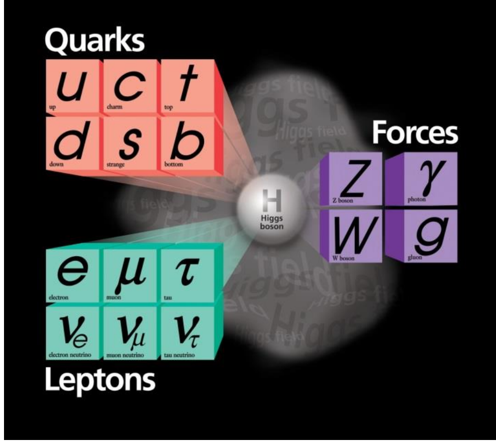
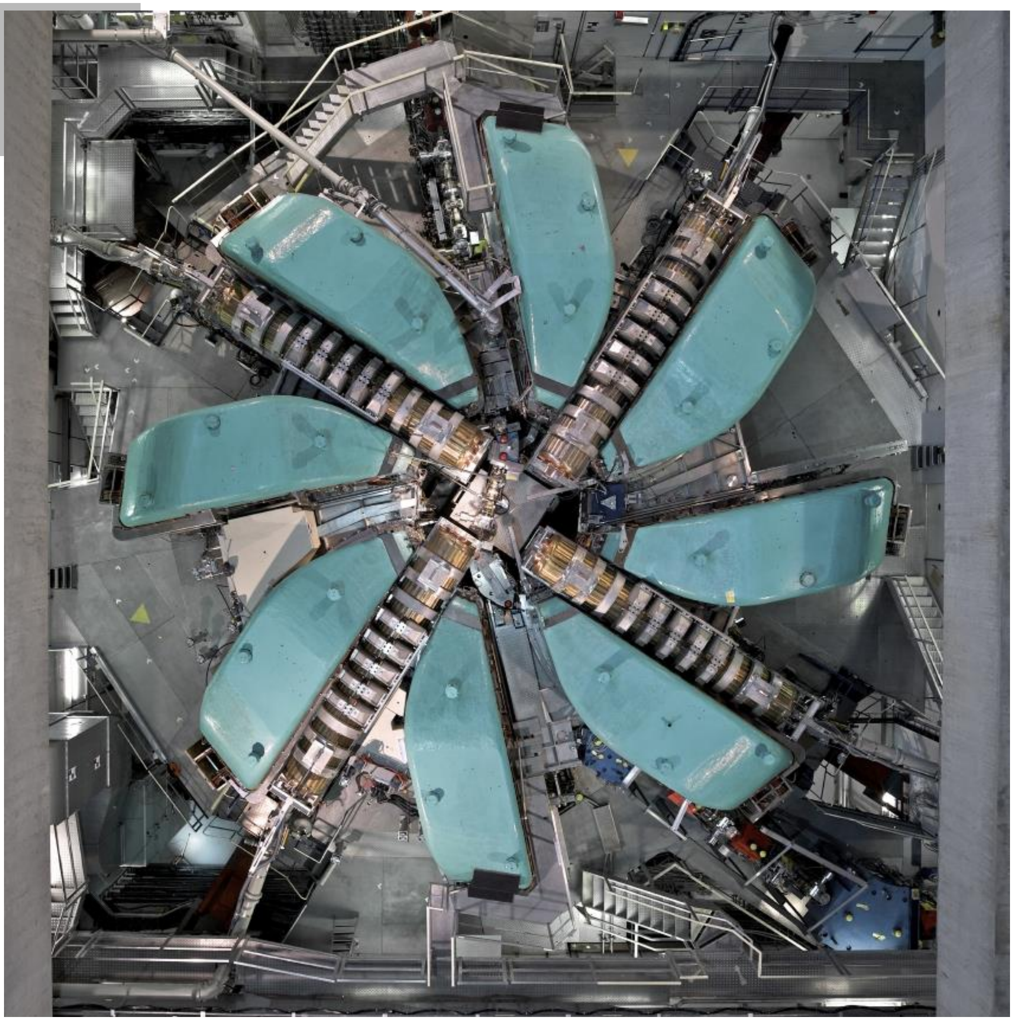
Unique opportunity





This machine

Together with suitable targets and beamlines

produces

the world-wide highest intensities of the lightest unstable particles of their kind:

Mesons: **Pions, π^+, π^-, π^0**

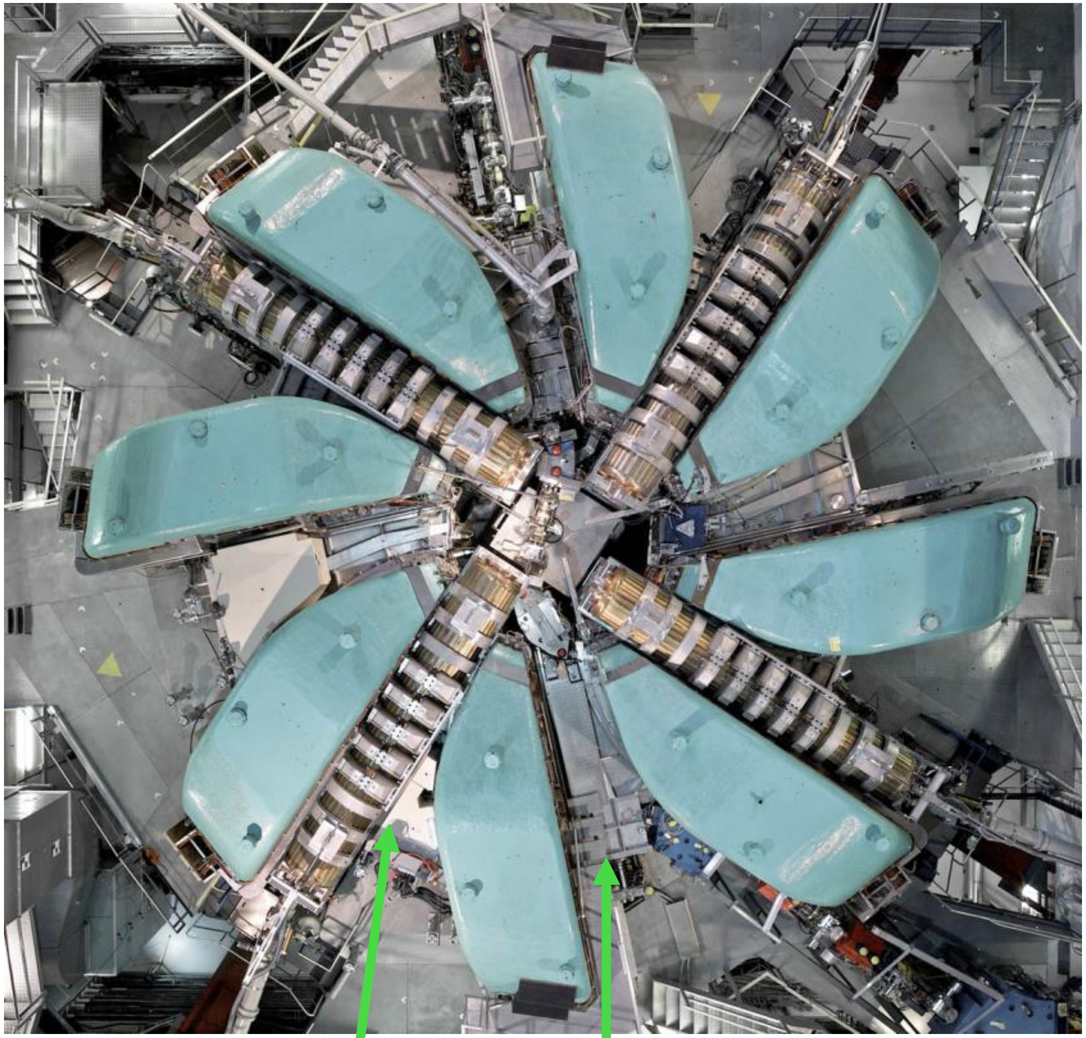
Leptons: **Muons, μ^+, μ^-**

Baryons: **UCN, n**

The Heart of HIPA: The Ring Cyclotron

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

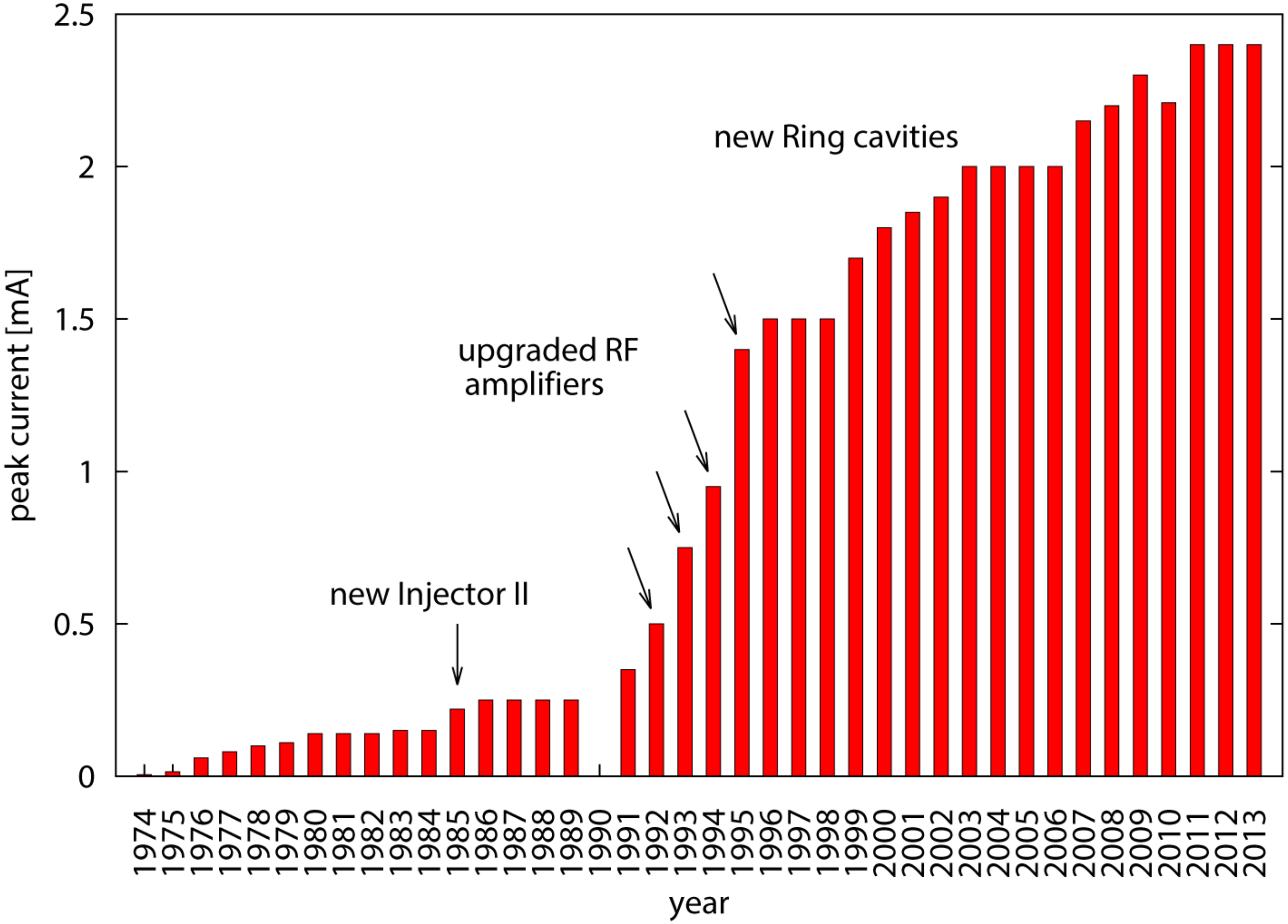
[losses ∝ (turn number)^3, W.Joho]



50MHz resonator

150MHz resonator

History of maximum beampower



milestones:

- new injector cyclotron ('84)
- upgrading Ring RF power
- replacing Ring cavities
- new ECR source

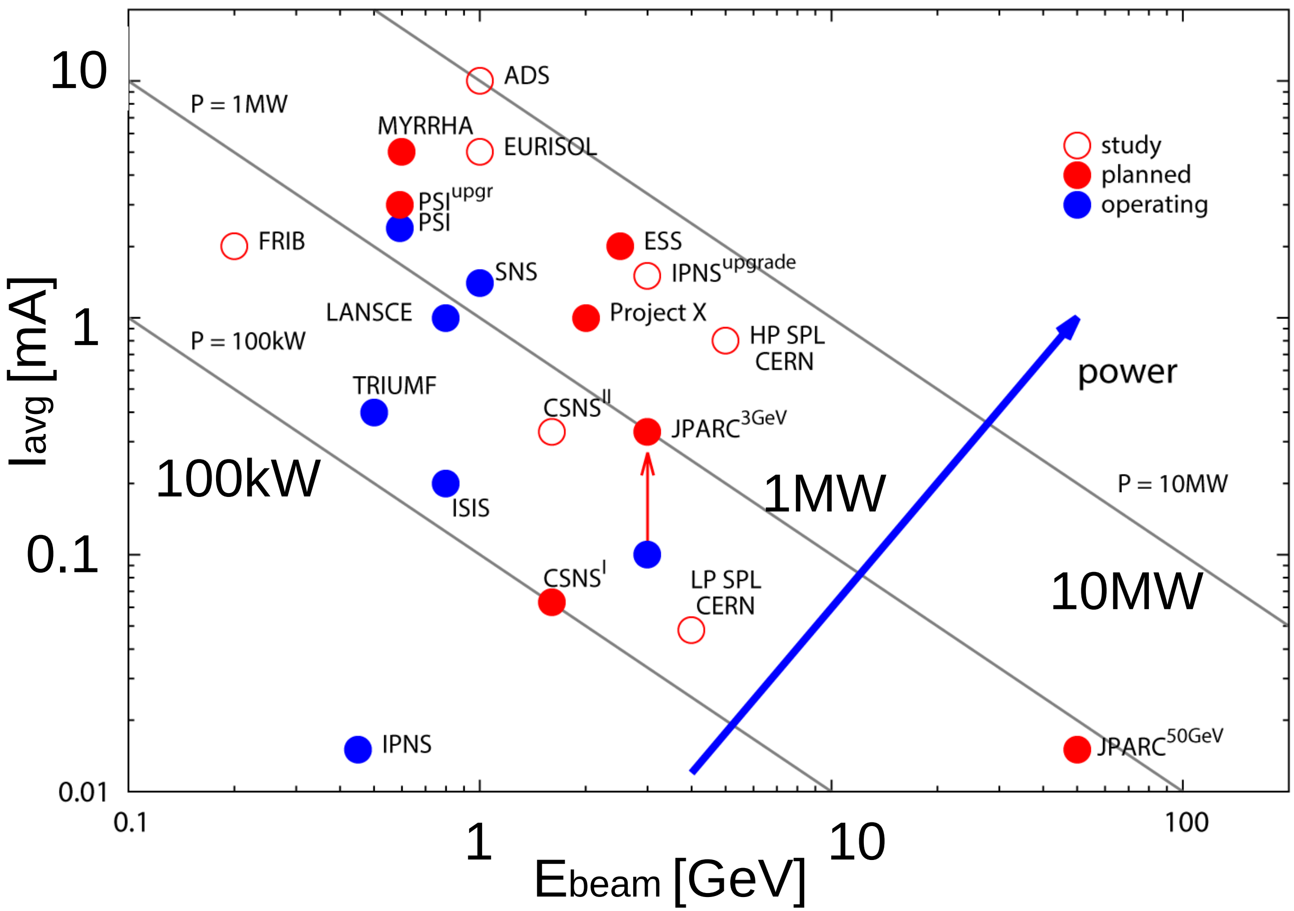
Originally planned: ≈100μA

today: 2.400μA

[routine: 2.200μA]

Courtesy: M. Seidel

PSI HIPA in the international context



Neutron Sources:

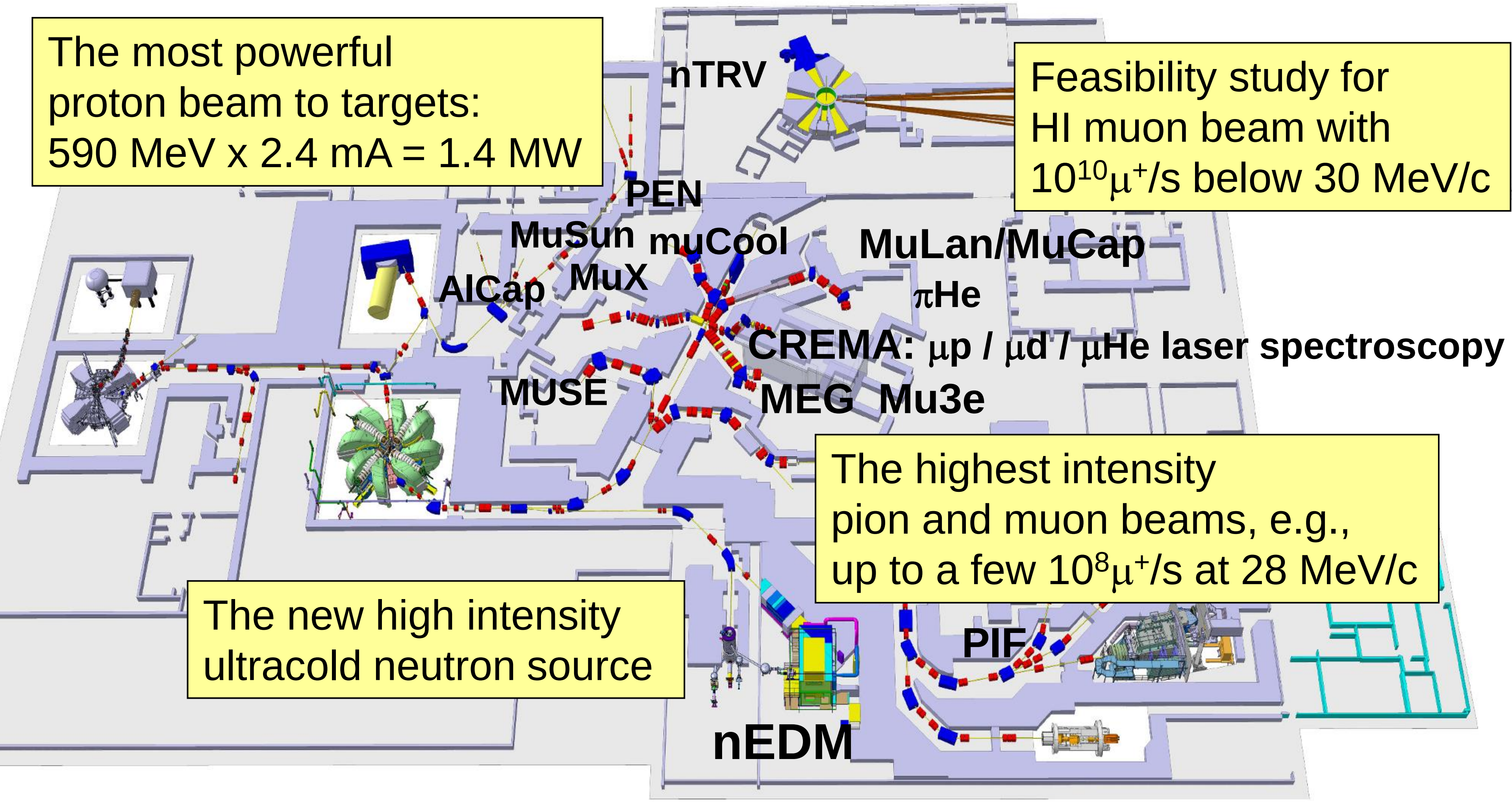
	Energy [GeV]	Power [MW]
ISIS	0.8	0.18
J-Parc	3.0	0.3 (1.0)
SNS	1.0	1.4
PSI	0.59	1.4
ESS	2.5	5.0
CSNS	1.6	0.1...0.5

Courtesy: M. Seidel

HIPA serves three communities

The intensity frontier at PSI: π, μ, UCN

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



The most powerful proton beam to targets: 590 MeV x 2.4 mA = 1.4 MW

Feasibility study for HI muon beam with $10^{10}\mu^+$/s below 30 MeV/c

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

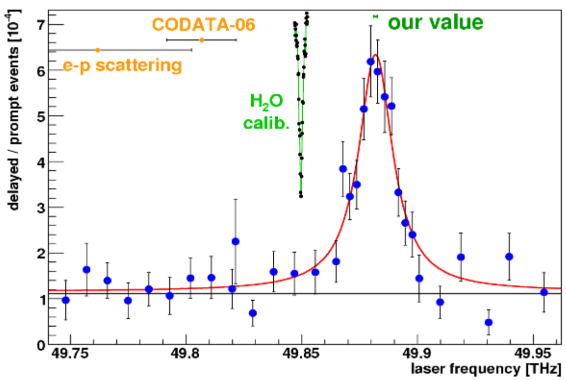
The new high intensity ultracold neutron source

Swiss national laboratory with strong international collaborations

Fundamental physics with muons

Bound state QED

The most precise value of the **proton charge radius** via a measurement of the Lambshift in muonic hydrogen



r_p=0.84087(39) fm

muhy.web.psi.ch

R. Pohl et al., Nature 466 (2010) 213
A. Antognini et al., Science 339 (2013) 417

Weak interaction

The most precise measurement of any lifetime: **MuLan**´s μ^+ and a 0.6 ppm determination of the **Fermi coupling constant**

τ = 2 196 980.3 ± 2.2 ps (1.0 ppm)

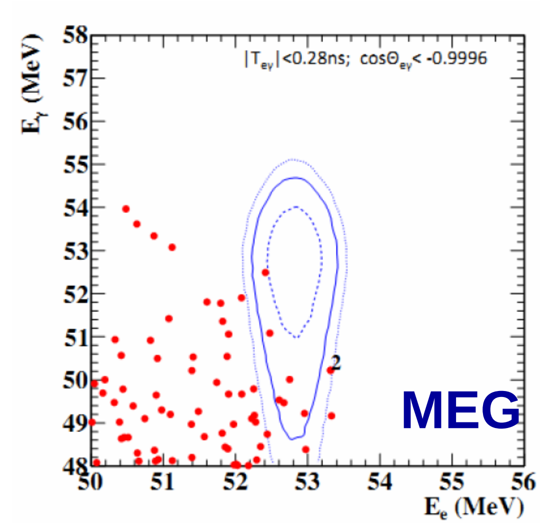
The most precise measurement (10ppm) of the μ^- lifetime in pure hydrogen yields **MuCap**´s 1% determination of the μ^-p capture rate resolving the longstanding issue with the **Pseudoscalar coupling g_p**

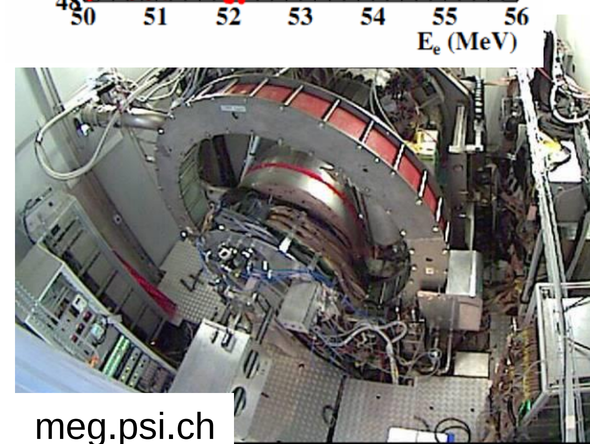
www.npl.washington.edu/muon/

D.M. Webber et al., PRL 106(2011)041803
V.A.Andreev et al., PRL 110(2013)012504

New physics search

The best rare decay limit:
A new **search for $\mu \rightarrow e\gamma$** yields a branching **less than 4.2x10^{-13}**



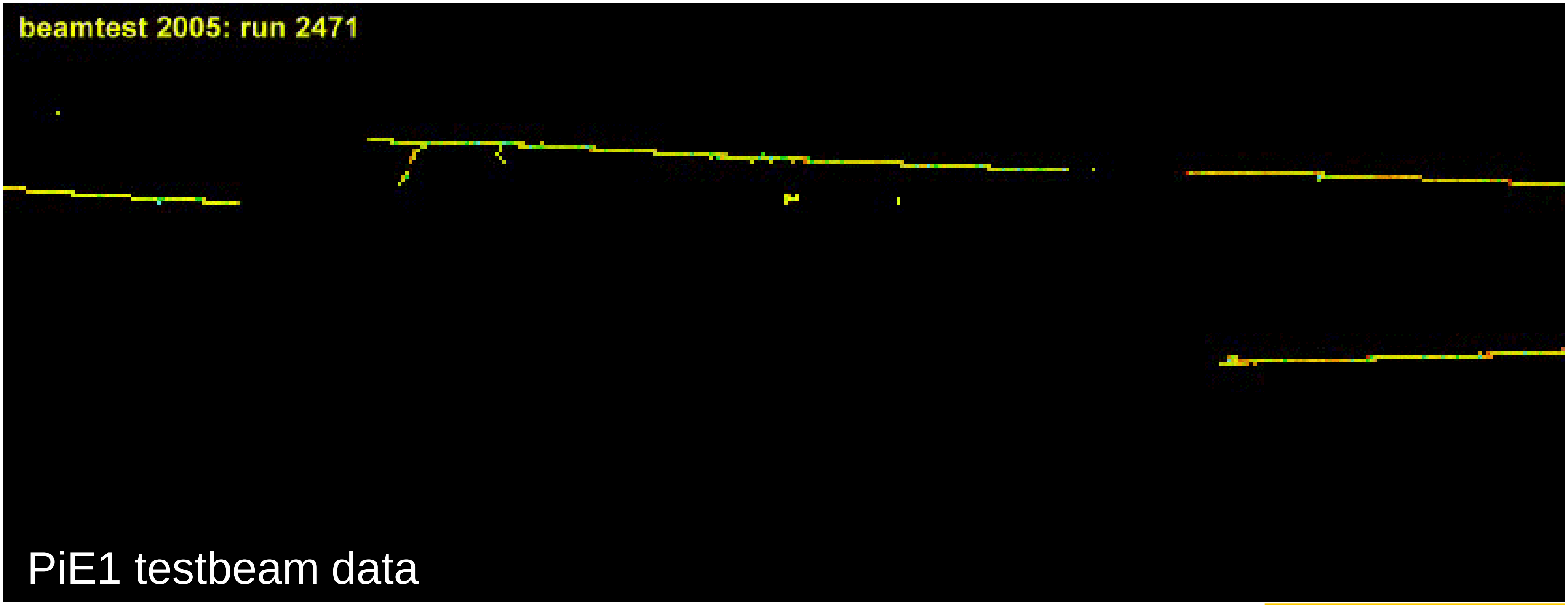


meg.psi.ch

arXiv:1605.05081

Synergies of high and low energy technologies

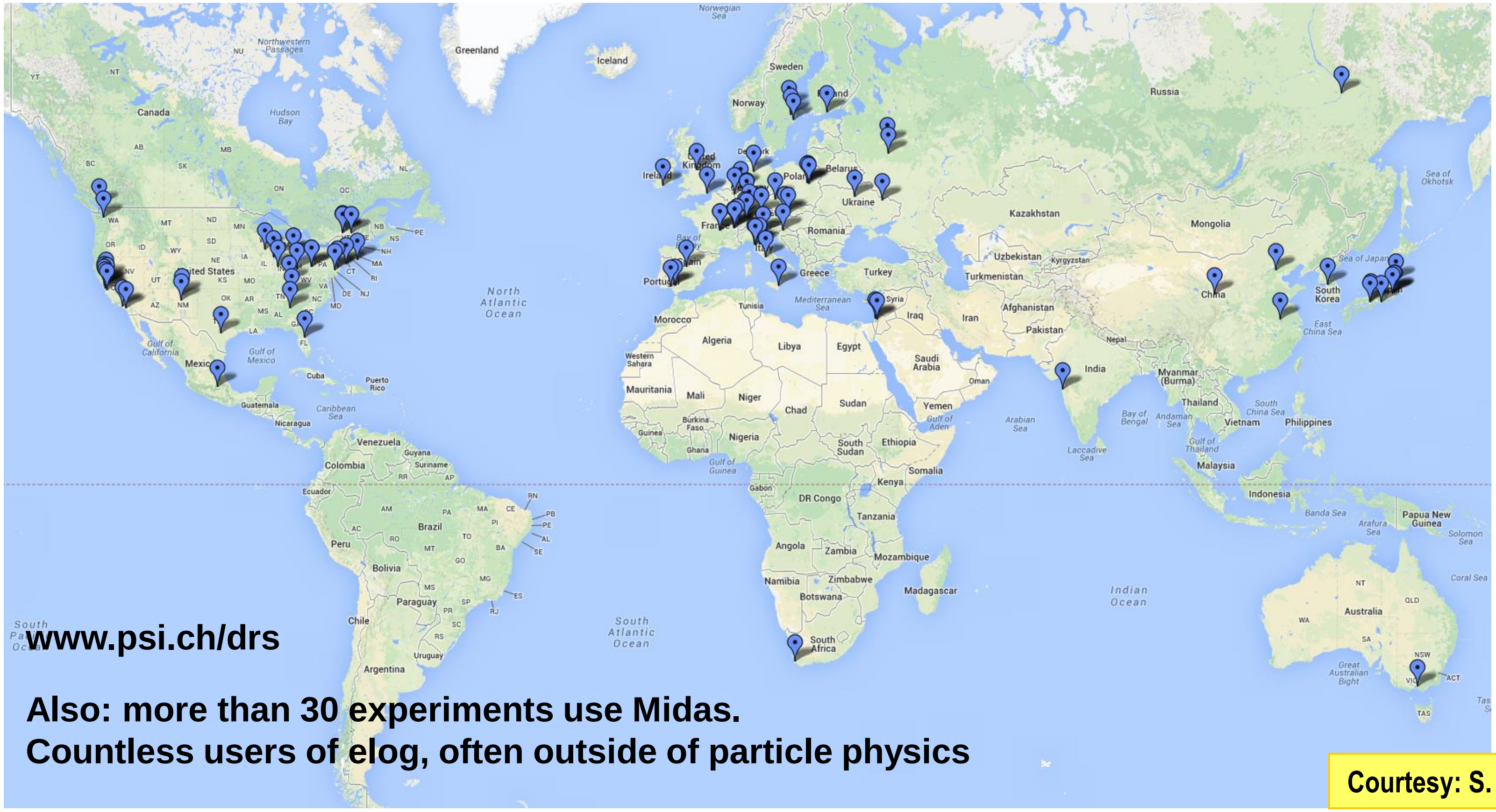
CMS pixel detector development combines: chip and electronics design, advanced software, bonding technology and test beams:



Courtesy: R. Horisberger

Synergies of high and low energy technologies

PSI´s DRS-4 Chip in use around the world:
more than 2500 chips in about 30 experiments



www.psi.ch/drs

Also: more than 30 experiments use Midas.
Countless users of elog, often outside of particle physics

Courtesy: S. Ritt

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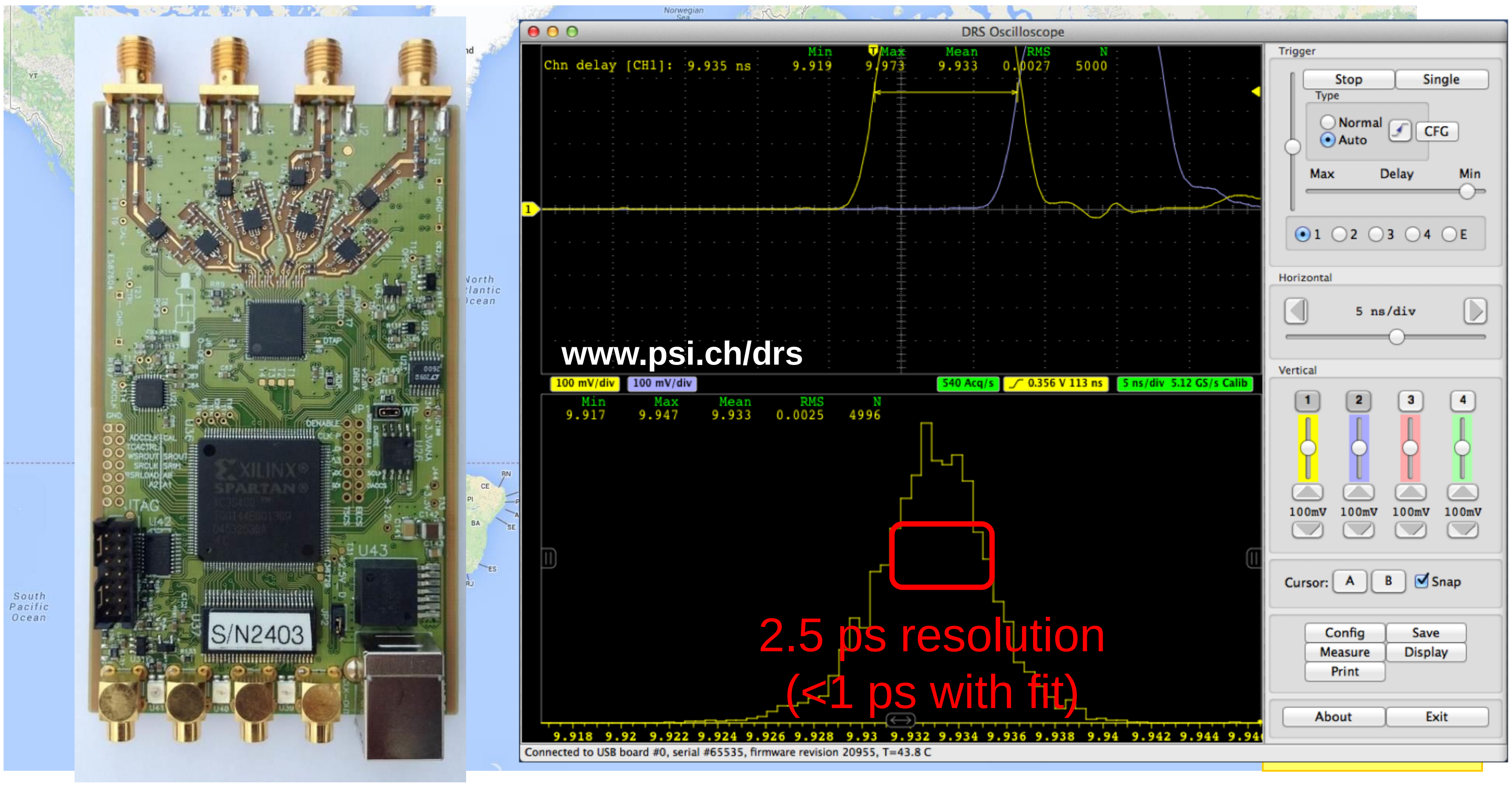
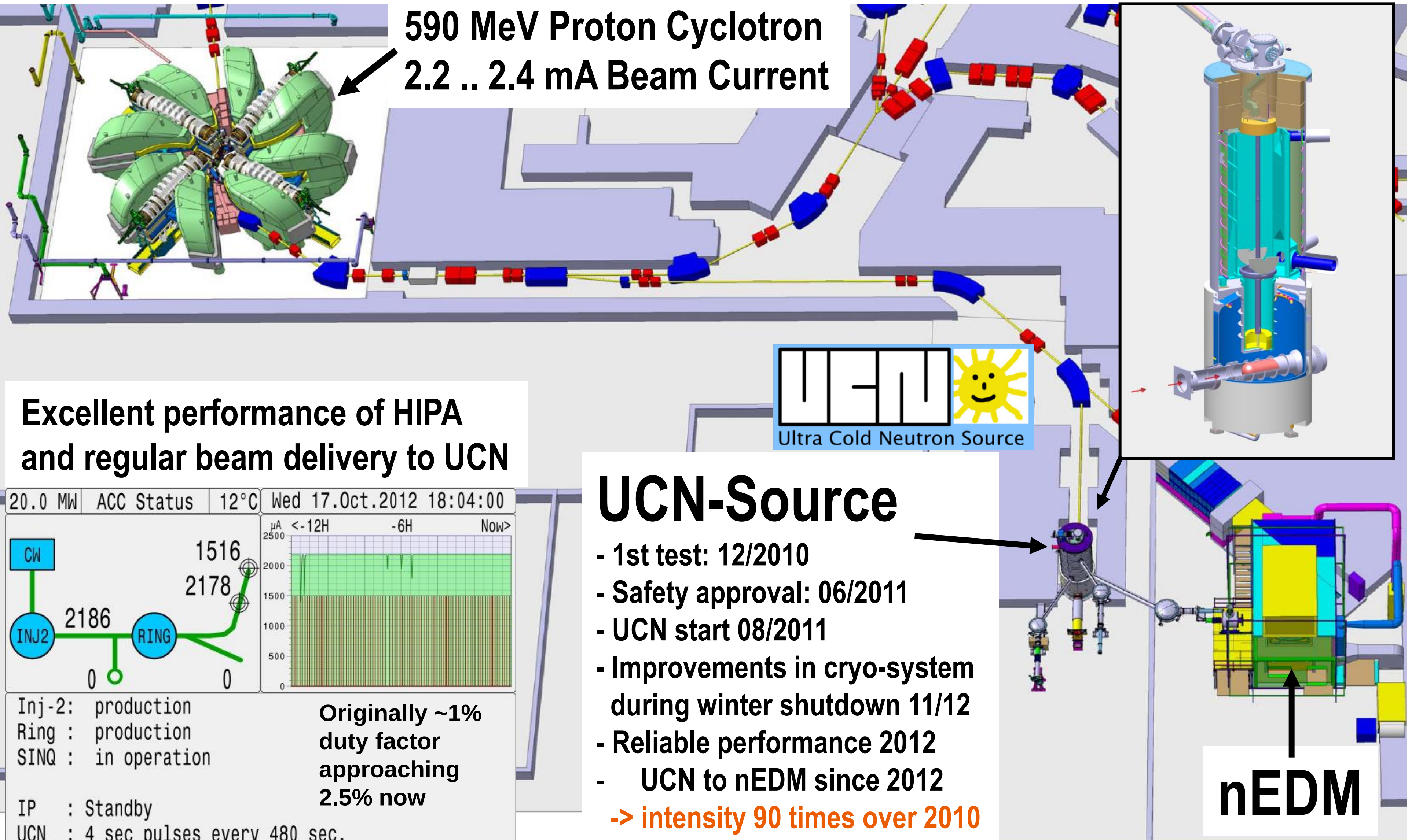
Synergies of high and low energy technologies

PSI´s DRS-4 Chip in use around the world:
more than 2500 chips in about 30 experiments



UCN Source at the Paul Scherrer Institut



590 MeV Proton Cyclotron
2.2 .. 2.4 mA Beam Current

Excellent performance of HIPA and regular beam delivery to UCN

Originally ~1% duty factor approaching 2.5% now

Ultra Cold Neutron Source

UCN-Source

- 1st test: 12/2010
- Safety approval: 06/2011
- UCN start 08/2011
- Improvements in cryo-system during winter shutdown 11/12
- Reliable performance 2012
- UCN to nEDM since 2012

-> intensity 90 times over 2010
-> ctd. improvements

Observed*:

$$(n_B - n_{\bar{B}}) / n_\gamma = 6 \times 10^{-10}$$

SM expectation:

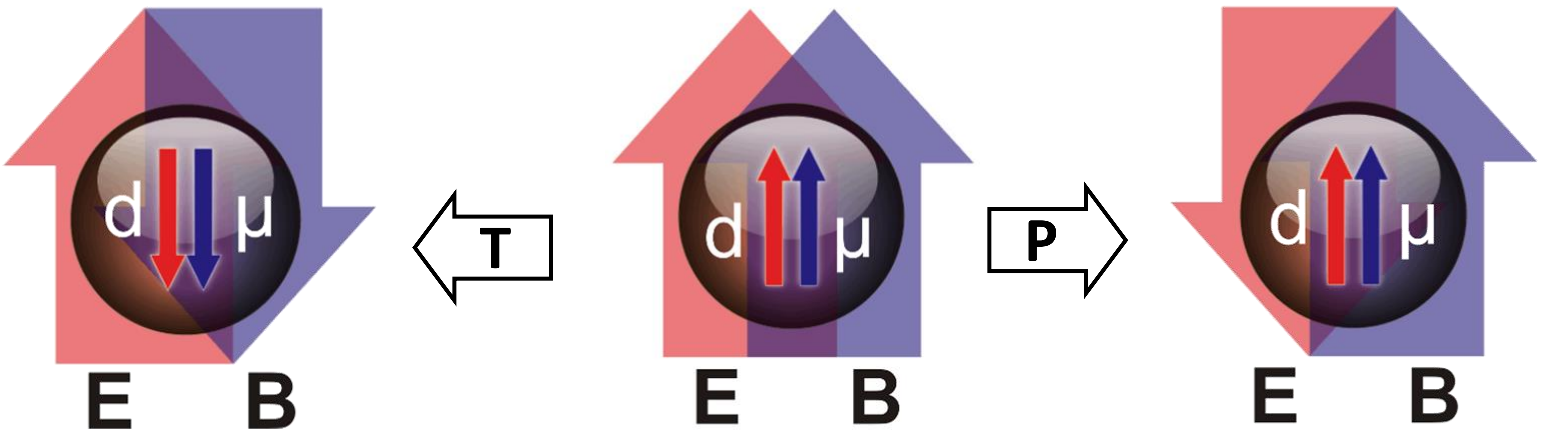
$$(n_B - n_{\bar{B}}) / n_\gamma \sim 10^{-18}$$

Sakharov 1967:
B-violation
C & CP-violation
non-equilibrium
[JETP Lett. 5 (1967) 24]

* WMAP + COBE, 2003
$n_B / n_\gamma = (6.1 \pm^{0.3}_{0.2}) \times 10^{-10}$

EDM and symmetries

$$H = -\left(d \frac{\vec{\sigma}}{|\vec{\sigma}|} \cdot \vec{E} + \mu \frac{\vec{\sigma}}{|\vec{\sigma}|} \cdot \vec{B} \right)$$



A nonzero particle EDM violates P, T and, assuming CPT conservation, also CP

Purcell and Ramsey, PR78(1950)807; Lee and Yang; Landau

Courtesy: H.W. Wilschut

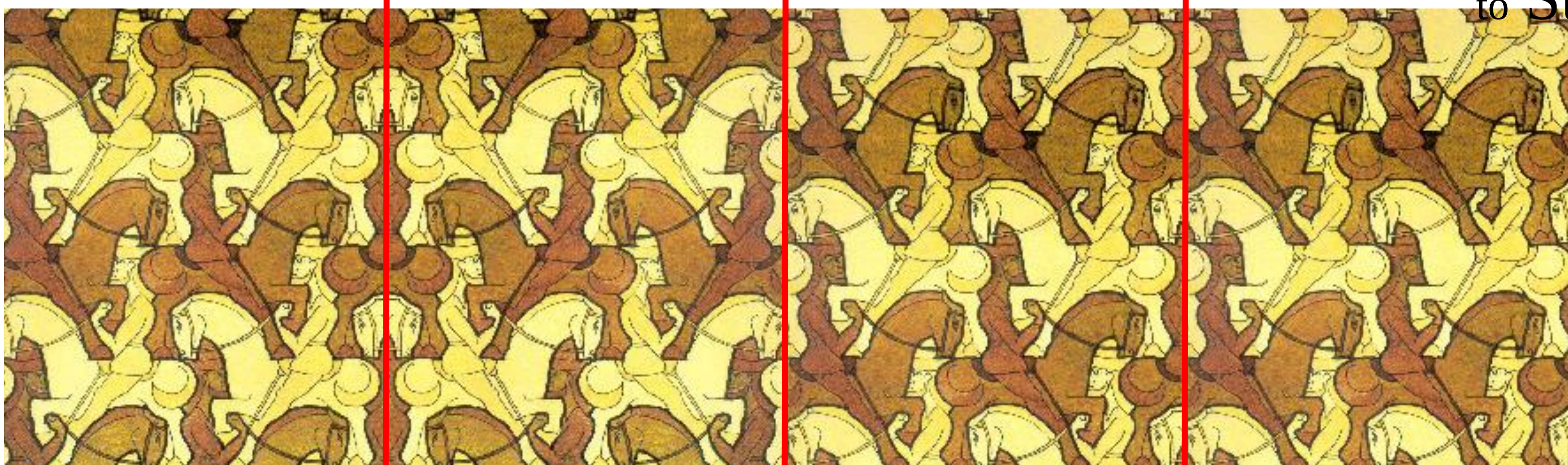
PCT-Theorem a la Escher

P **C** **T**

Matter | Antimatter

identical to Start

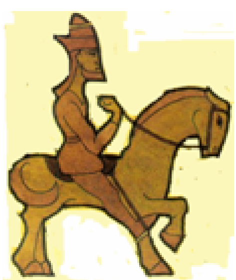
Start



Mirror image

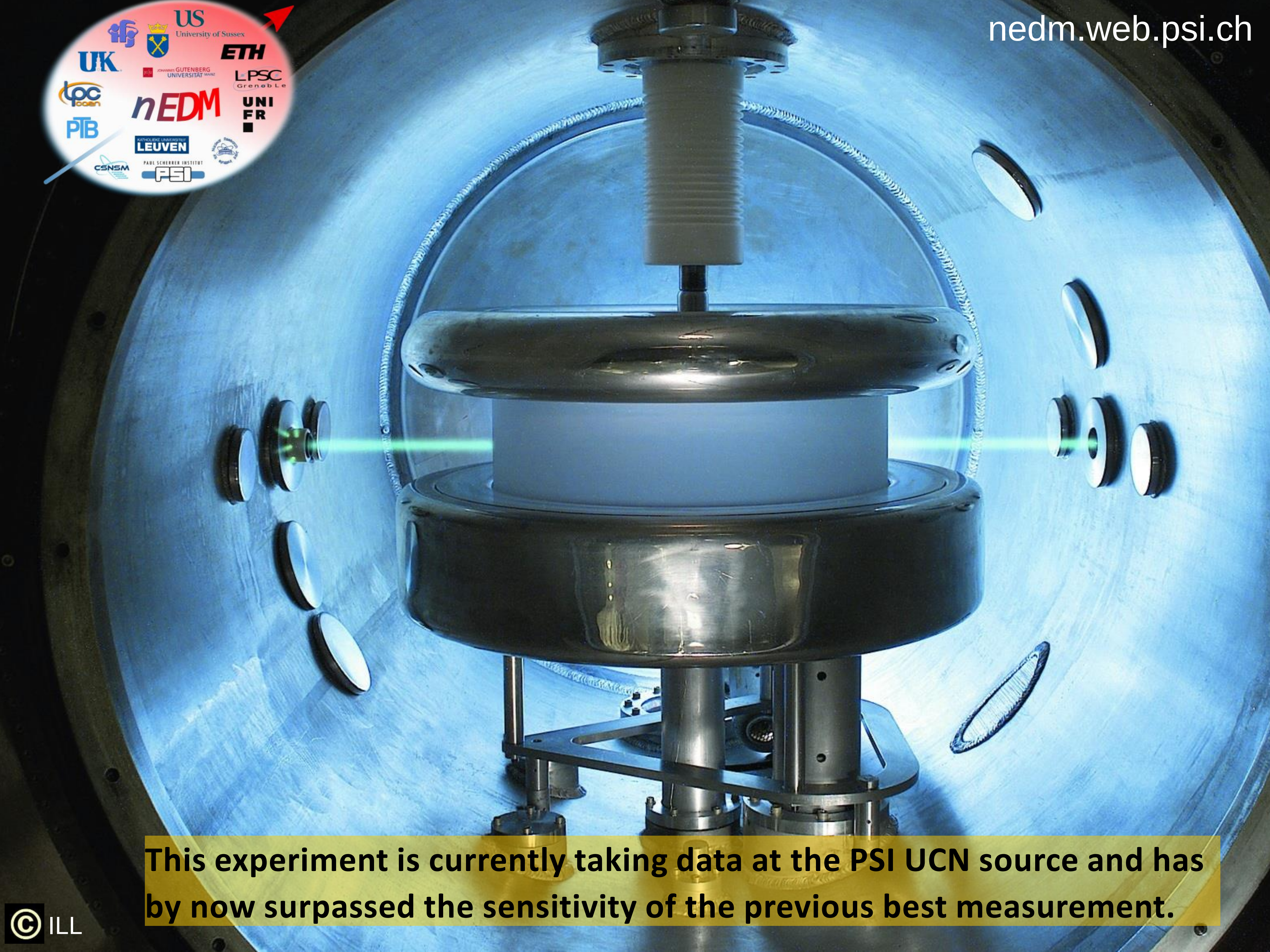
Time →

← Time



Antiparticle

Particle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This experiment is currently taking data at the PSI UCN source and has by now surpassed the sensitivity of the previous best measurement.
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Thank you!

Picture: K. Schuhmann