PAUL SCHERRER INSTITUT


WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

K. Kirch :: Paul Scherrer Institut & ETH Zurich

Recent highlights from experiments with muons and neutrons at PSI

Bormio, 60th International Winter Meeting on Nuclear Physics, Jan 22-26, 2024

This is what I promised for Wednesday …

The high intensity proton accelerator facility at the Paul Scherrer Institute (PSI) in Switzerland provides high intensities of pions, muons and ultracold neutrons for fundamental atomic, nuclear and particle physics measurements. Aspects of the facility will be shown and some of the latest experimental results will be presented.

… let’s see what I can do today …

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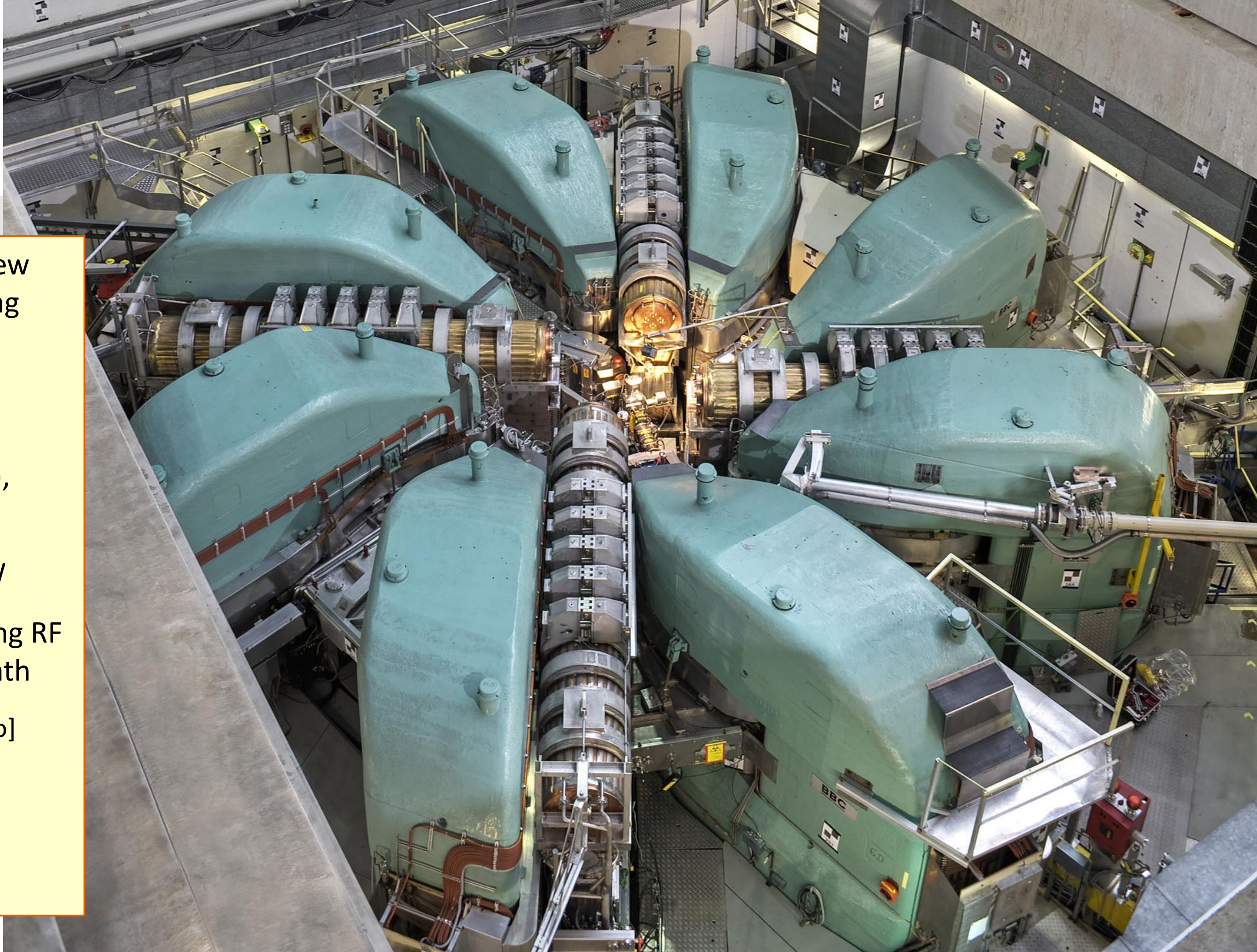
PSI

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

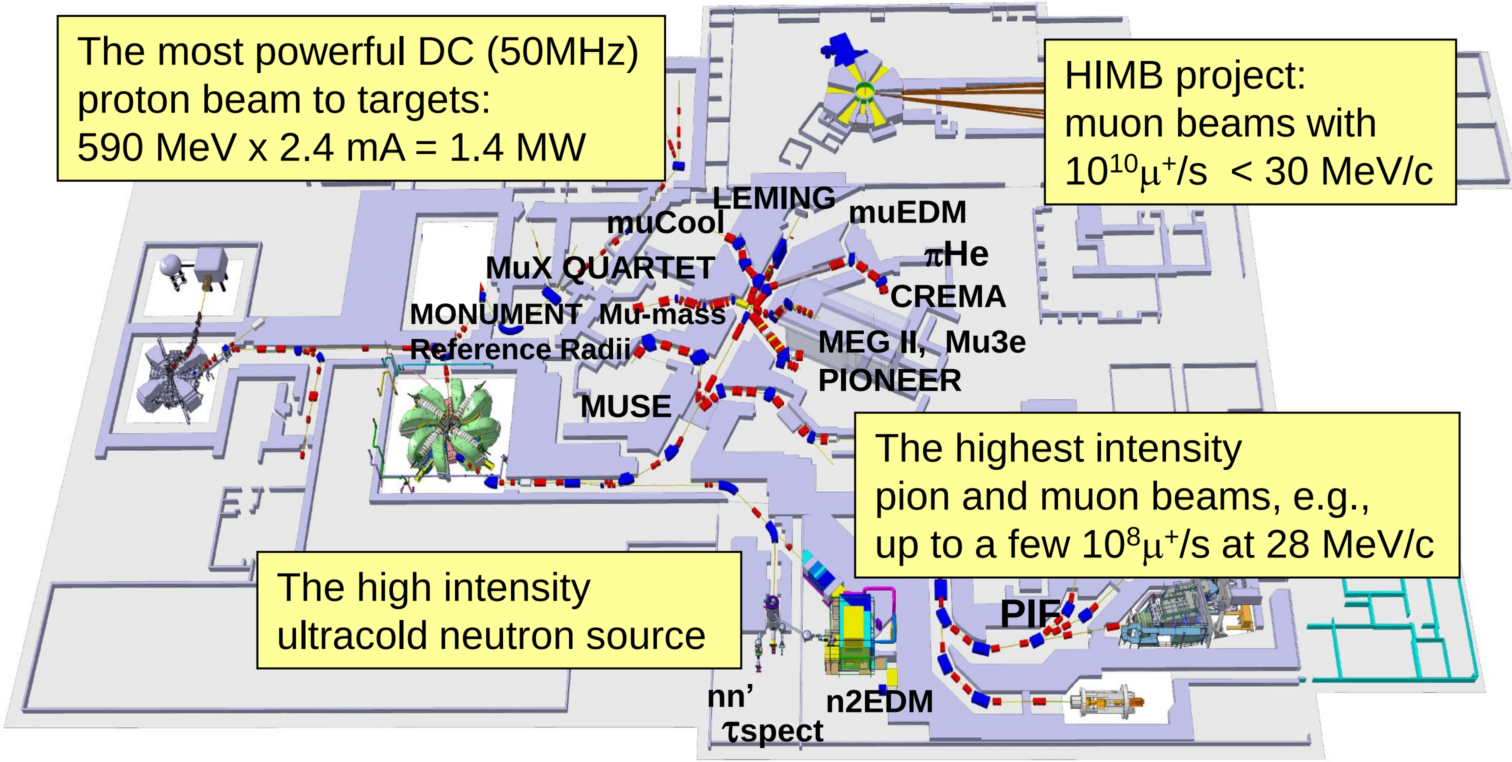
[losses ∝ (turn number)^3, W.Joho]

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



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

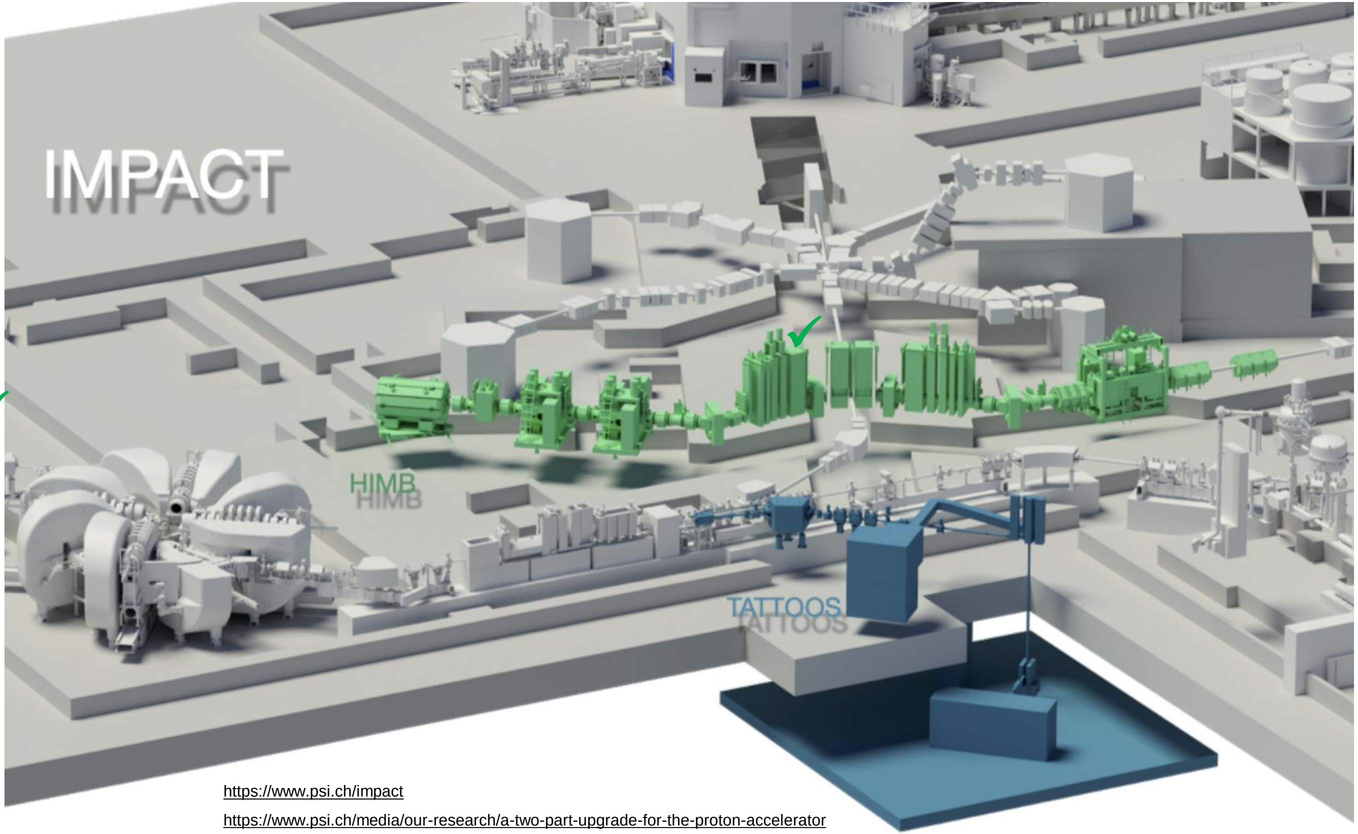
Swiss national laboratory with strong international collaborations

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

Review of Particle Physics at PSI

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
- 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

PAUL SCHERRER INSTITUT PSI

Nuclear Physics experiments at PSI - I

Evie Downie, Tuesday, “The Proton Radius: Are We Still Puzzled?”

MUSE	measuring form factors at low momentum transfer for scattering μ^+, e^+, μ^-, e^-, (π^+, π^-) off protons (in liquid H_2)

Randolf Pohl, Friday, “Nuclear structure from muonic atom spectroscopy”

CREMA	measuring 2S-2P Lambshift in μp, μd, μ^3He^+, μ^4He^+ and GHS in μp
muX	measuring muonic Xrays from microgram target materials to determine nuclear charge radii of heavy nuclei such as ^{226}Ra
QUARTET	measuring muonic Xrays from light muonic atoms of Li, …, Ne to provide benchmark nuclear charge radii and allow for QED tests

Nuclear Physics experiments at PSI - II

OMC4DBD, MONUMENT	measuring ordinary muon capture on various target nuclei and subsequent nuclear transitions to benchmark nuclear theory matrix element calculations for neutrinoless double beta decay (^{136}Ba, ^{76}Se, …)

https://indico.psi.ch/event/12027/contributions/34044/attachments/20759/34144/OMC4DBD_ProgressReport_BVR53.pdf

Reference Radii	measuring muonic Xrays from doublets or triplets of isotopes (muX method) to obtain absolute charge radii and benchmark laser spectroscopy on isotope chains (Al, K, Ag)

https://indico.psi.ch/event/13846/contributions/41667/attachments/24171/43445/Reference%20absolute%20charge%20radii.pdf

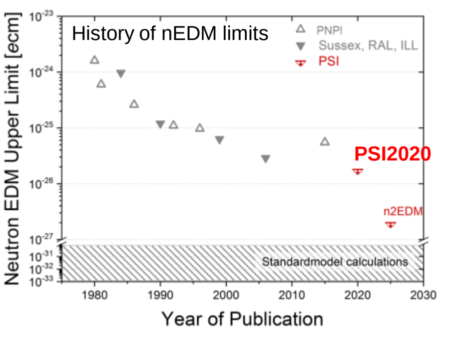
Nuclear Physics – low energy particle physics

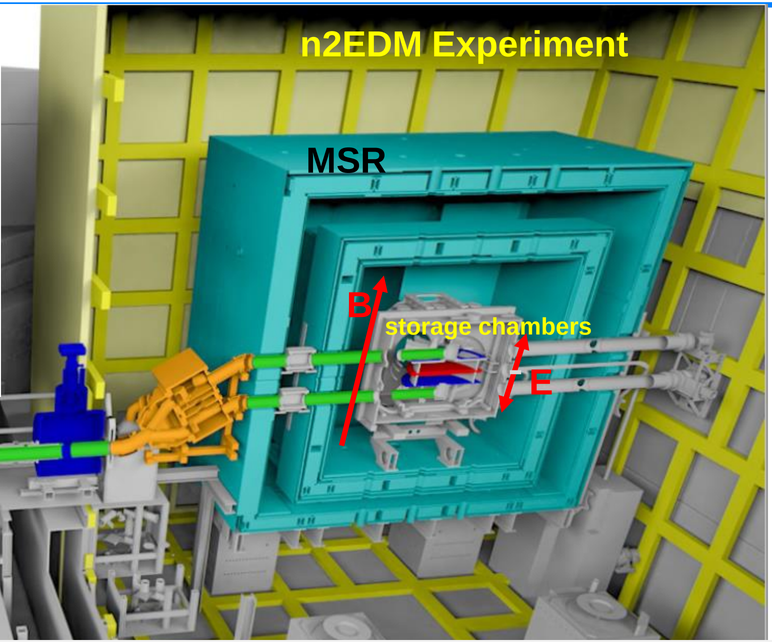
n2EDM, MEGII, Mu3e, PIONEER, tauSpect, Mu-MASS, LEMING, …

n2EDM - Search for a permanent neutron EDM

ultracold neutron (UCN) source

solid deuterium based high intensity UCN source





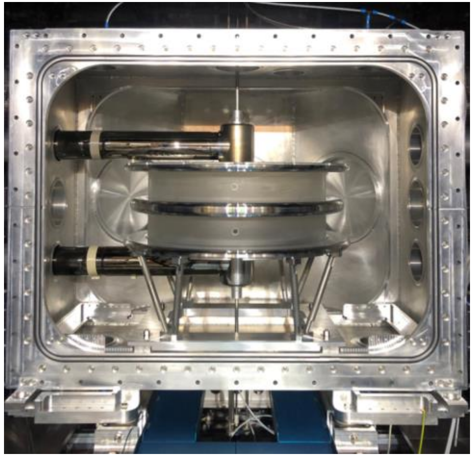
B.Lauss/2023

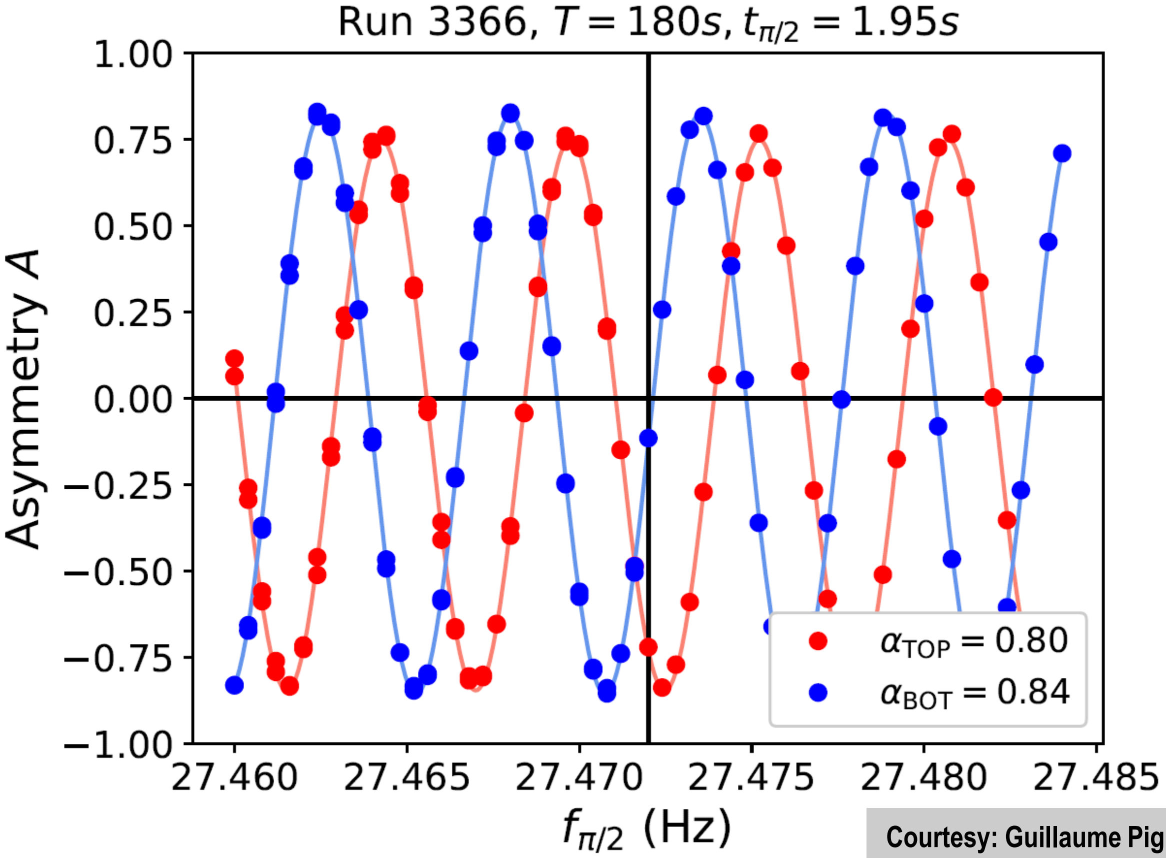
Status:

- record magnetically shielded room - shielding factor 100`000 at 0.01Hz - operating
- 57 km coils for active magnetic shield - operating
- magnetic field system at 1 µT and 60 ppm homogeneity - operating
- UCN chambers and beamline - commissioning
- start nEDM measurements 2024 - 500 days for 10^{-27} e·cm sensitivity goal in baseline
- planned 'MAGIC field' phase with further significant improvement

Courtesy: Bernhard Lauss

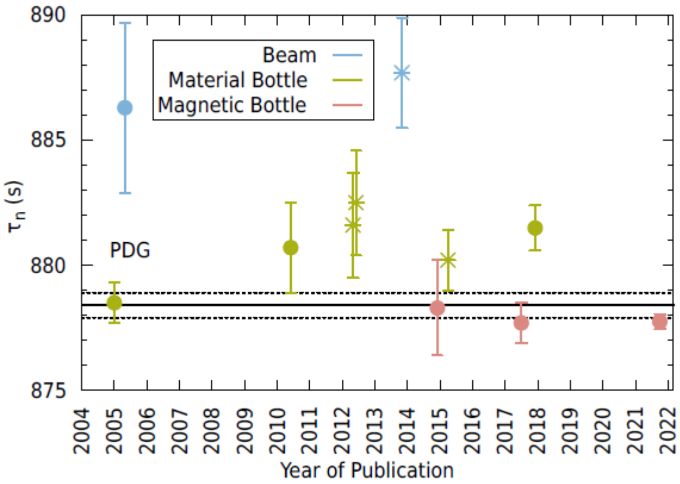
First Ramsey curve with n2EDM in 2023

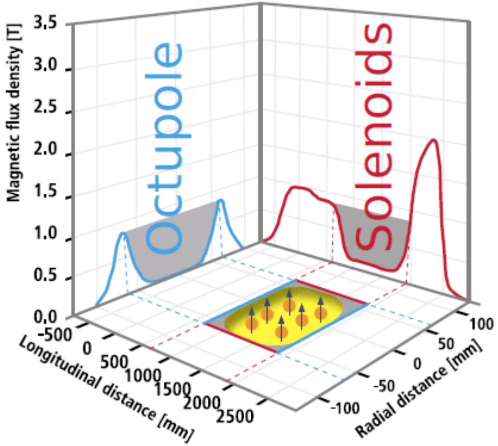


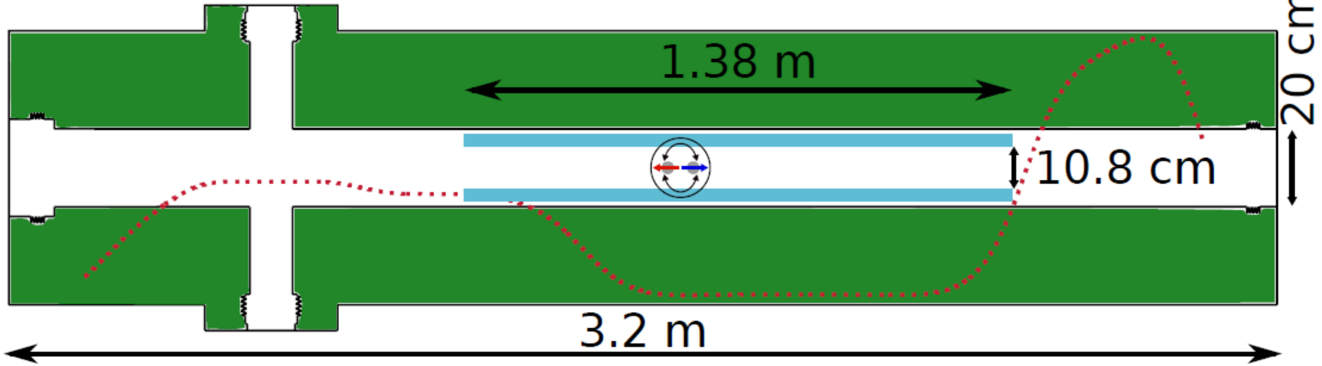


Courtesy: Guillaume Pignol

τSPECT: A fully Magnetic Neutron Trap







More info: Martin Fert (mfertl@uni-mainz.de) Dieter Ries (dieter.ries@psi.ch)

Courtesy: Dieter Ries

τSPECT

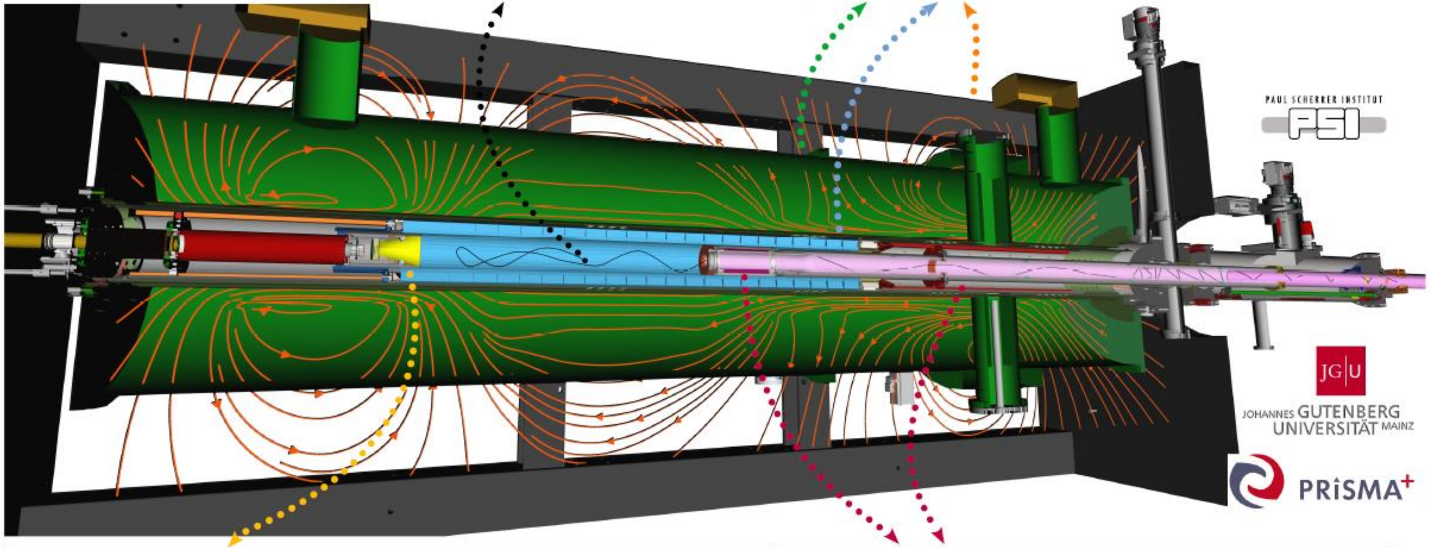
A magnetic storage bottle for measuring the free neutron lifetime

Depending on their spin orientation with the magnetic field (**polarisation**), UCNs are reflected by magnetic field gradients.

Aligned polarised UCNs, so called **Low Field Seekers**, can be stored in low magnetic field regions.

A longitudinal field is generated by **super-conducting coils** inside a **cryostat** (6 K).

A radial field is produced by a permanent **octupole magnet.**



A neutron **detector** moves through the storage volume to

- remove marginally trapped neutrons,
- count the remaining neutrons that have not decayed after a given storage time.

Removable **spin-flippers** reverse neutrons polarisation, when filled inside the bottle, making them storable in weak magnetic fields.

Courtesy: Dieter Ries

τSpect at PSI

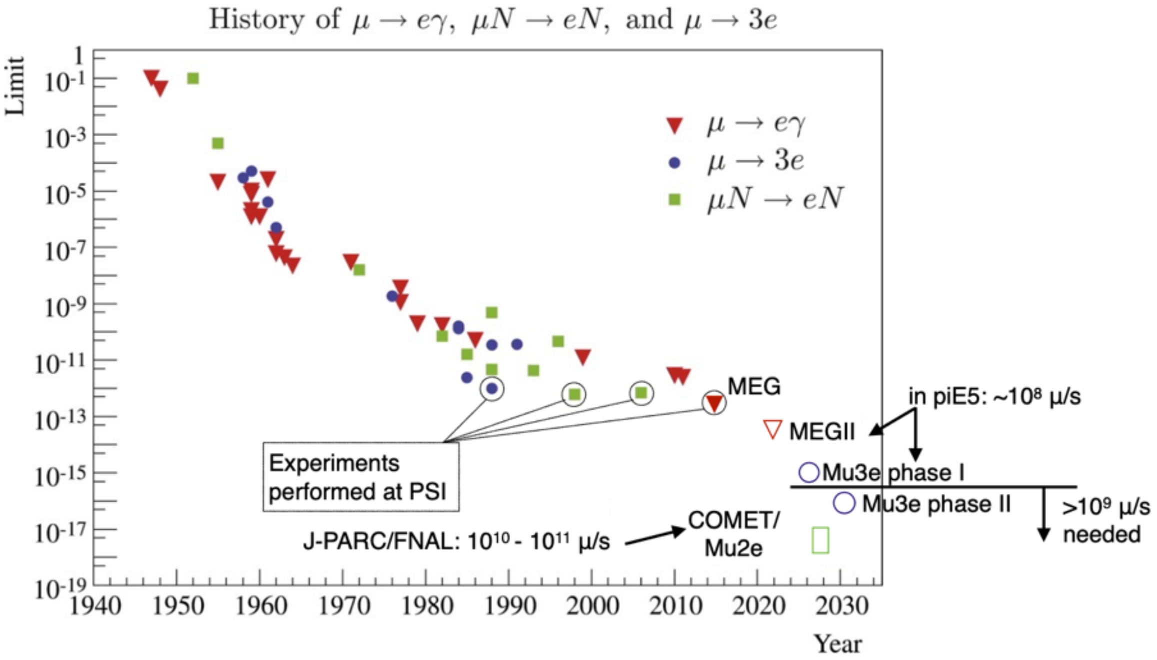
- τSPECT has been fully commissioned at TRIGA Mainz
- Move to PSI, set-up at UCN West-1 finished in 2023
- Aim for $\sigma(\tau_n) = 0.3\,\text{s}$ until long HIPA shutdown 2027

Courtesy: Dieter Ries

Muon cLFV experiments at PSI

- Neutrinoless muon decays are one of the most sensitive probes for new physics
- μ→eγ and μ→3e only possible at DC, high-intensity machines, such as HIPA

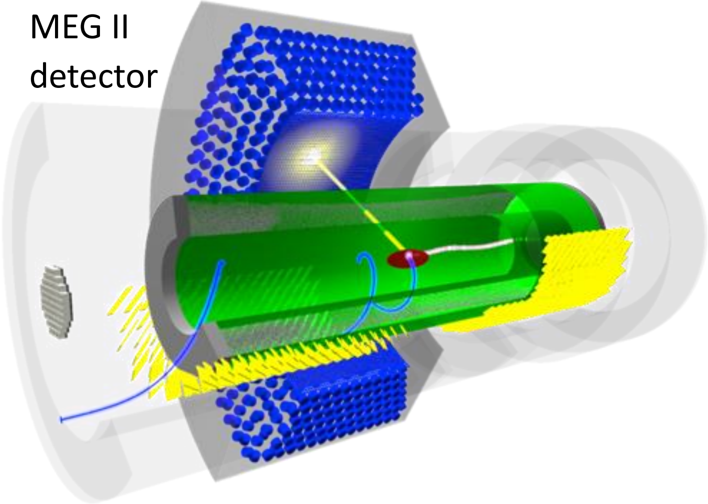
→ New project (HIMB) for muon experiments with unique sensitivities



The MEG II Experiment

- MEG II experiment searching for $\mu \to e\,\gamma$ aiming at $B(\mu \to e\,\gamma) < 6 \times 10^{-14}$ @90%CL
- MEG result 2016: $B(\mu \to e\,\gamma) < 4.2 \times 10^{-13}$ more than 28x improvement
  Eur. Phys. J. C (2016) 76:434
- MEG II data taking 2021-26
- 2021 data analysis has recently been released,
  arxiv.org/abs/2310.12614
  alone: $B(\mu \to e\,\gamma) < 7.5 \times 10^{-13}$
  combined with MEG: $B(\mu \to e\,\gamma) < 3.1 \times 10^{-13}$
- 2022&2023 → already ~5 times MEG data set

MEG II detector

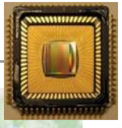



MEG II cylindrical drift chamber

Courtesy: Angela Papa

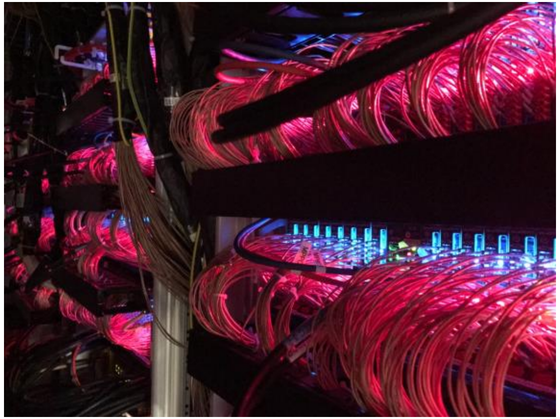
The WaveDAQ System

DRS4 chip

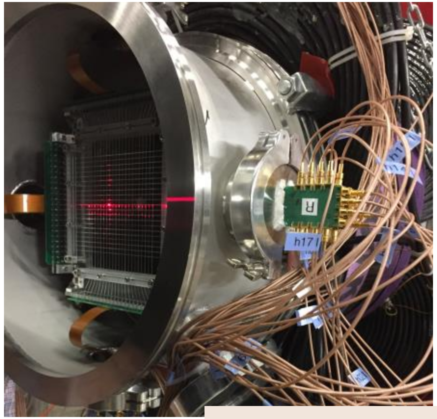


- Data acquisition system based on patented DRS4 chip with
  5 GSPS/12 bit developed at PSI
- Novel custom crate design allows compact triggering and DAQ
- WaveDAQintegrates signal amplification, triggering, DAQ andbias voltage generation in a single system
- Boards used in MEG, FOOT (INFN Pisa), Beam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

WaveDREAM Board



MEGII TDAQ

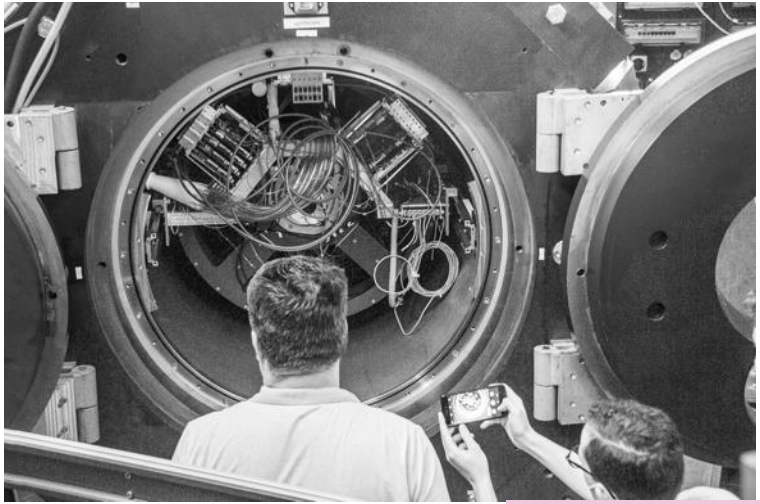


Beam monitoring

Courtesy: Stefan Ritt

The Mu3e experiment

- Search for LFV decay $\mu^+ \rightarrow e^+e^-e^+$
- First phase improves BR sensitivity to $2x10^{-15}$ (500x improvement)
- Discriminate signal from accidental background and conversion → use tracking and timing detectors
- Pixel detector with 0.1% X_0 per layer (50μm DMAPS sensors, ultralight mechanics, novel Helium gas cooling)
- Detector concept validated (2021), beam line commissioned (2022-23), engineering run (2024), physics runs (2025-26)
- 2028+ High Intensity Muon Beam



Courtesy: Stefan Ritt

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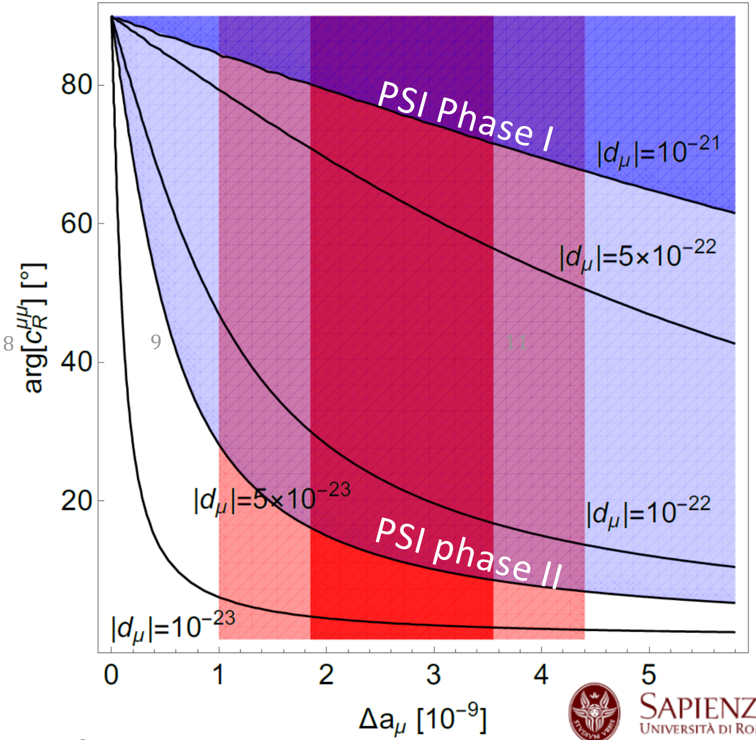
PSI muEDM

LOI 2021
Approved at PSI 2023

Phase I: 2023-2029
Phase II: 2029-203?



*A.Crivellin, M. Hoferichter, PSW PRD 98, 113002 (2018)

Key features:

- Magnetic only storage in 3T solenoid field
- Spiral injection using superconducting magnetic shield
- Frozen-spin technique by applying radial electric field
- Low momentum 28MeV/c (125MeV/c) in Phase I (Phase II) storage orbit radius 31mm (140mm)
- Positron tracker to deduce spin orientation as a function of positron momentum

Phase 1: $d_\mu < 3\times10^{-21}\mathrm{ecm}$
Phase 1I: $d_\mu < 6\times10^{-23}\mathrm{ecm}$

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UCL
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李政道研究所 Tsung-Dao Lee Institute
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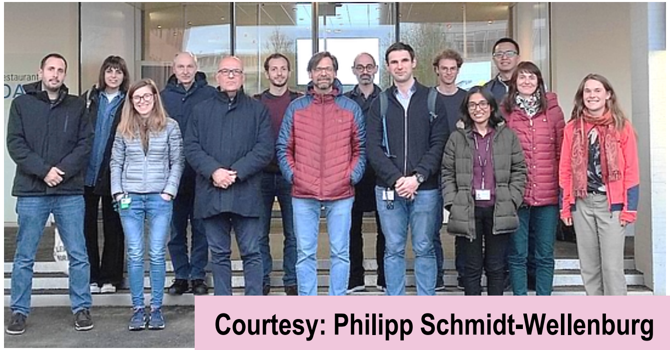
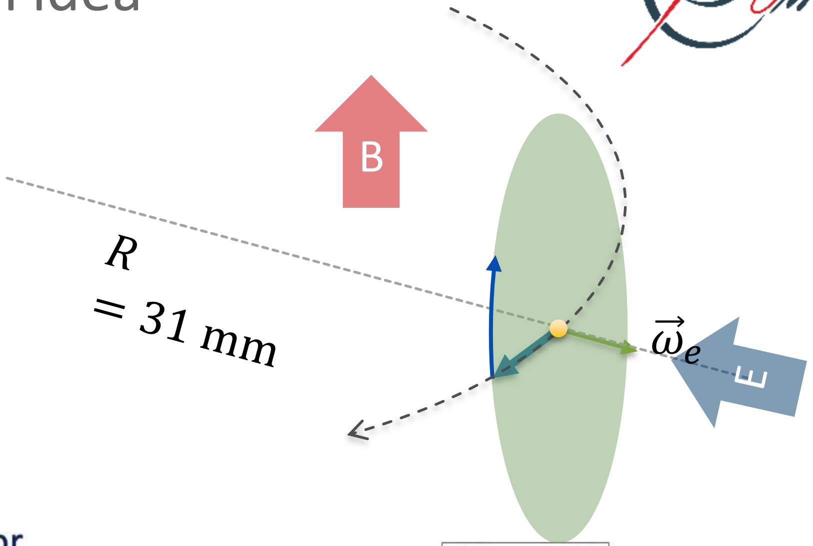
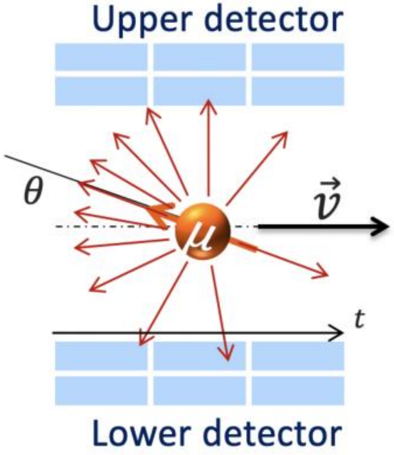


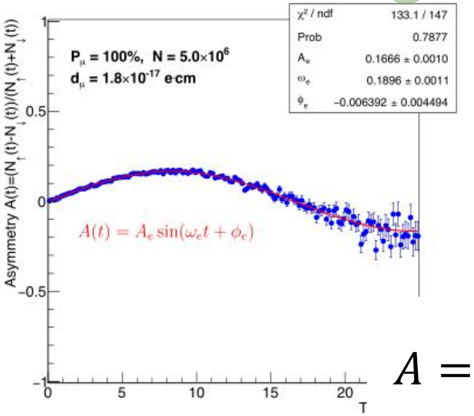
Courtesy: Philipp Schmidt-Wellenburg

The general experimental idea

- Muons are injected along a spiral into a solenoid
- A short magnetic pulse stores muons on a stable orbit in the center of the solenoid
- If the EDM ≠ 0, then there will be a vertical precession out of the plane of the orbit
  - An asymmetry increasing with time will be observed recording decay positrons
- If the EDM = 0, then the spin should always be parallel to the momentum asymmetry should be zero



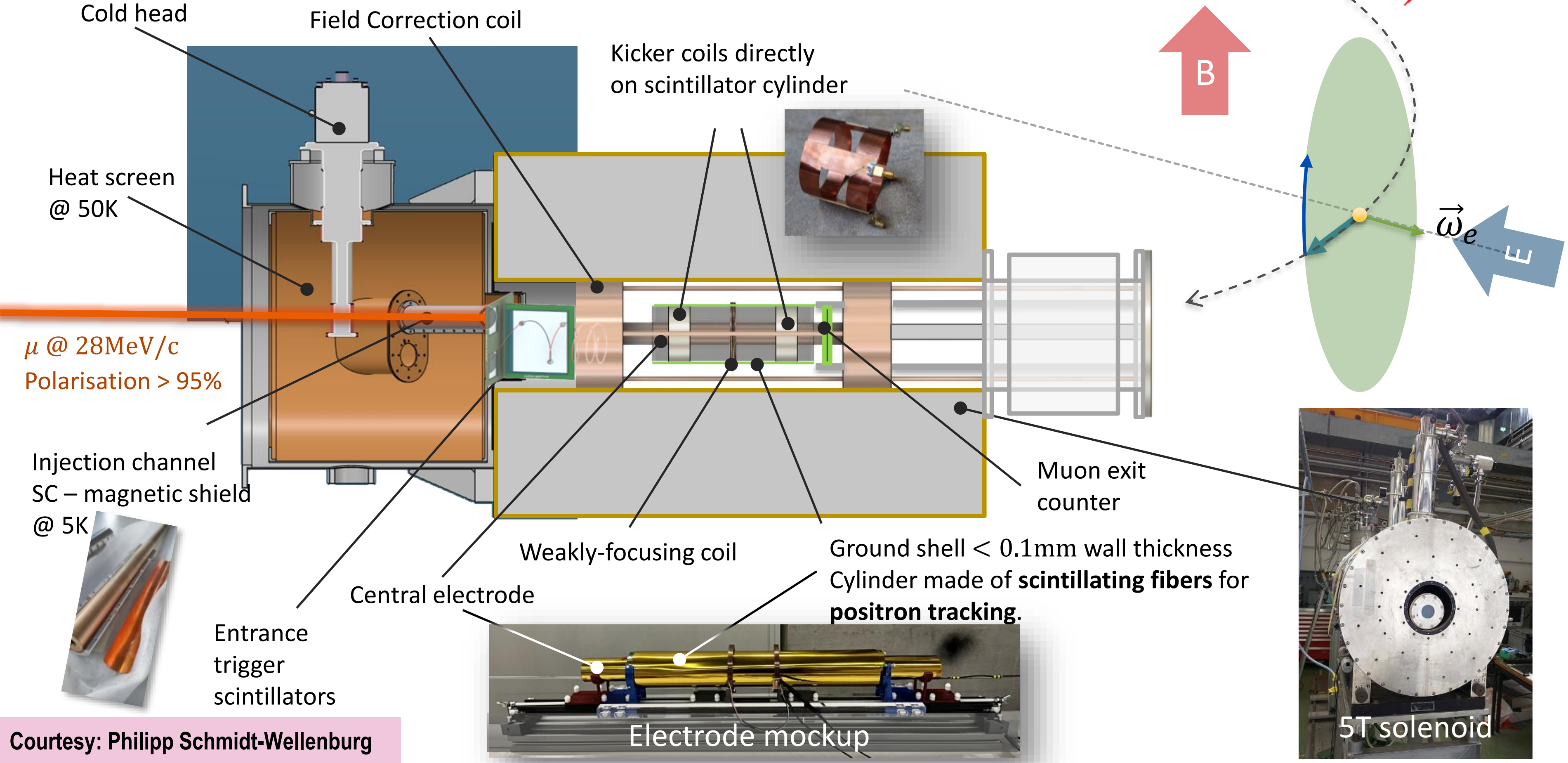




$$A = \frac{N_u - N_d}{N_u + N_d}$$

Contact: philipp.schmidt-wellenburg@psi.ch

Overview experiment Phase I



Cold head

Field Correction coil

Kicker coils directly on scintillator cylinder

Heat screen @ 50K

μ @ 28MeV/c
Polarisation > 95%

Injection channel
SC – magnetic shield
@ 5K

Entrance
trigger
scintillators

Central electrode

Weakly-focusing coil

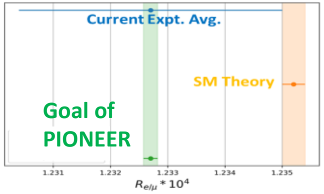
Muon exit
counter

Ground shell $< 0.1\mathrm{mm}$ wall thickness
Cylinder made of **scintillating fibers** for **positron tracking**.

Courtesy: Philipp Schmidt-Wellenburg

PIONEER at PSI
Next Generation Rare Pion Decay Experiment

PIONEER Goal: Improve precise SM tests by an order of magnitude.



- Phase I: Provide the best test of Lepton Flavor Universality; $\frac{g_e}{g_\mu} \sim \pm 0.005\%$

  * Measure $R_{e/\mu} = \frac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$: $O(\pm 0.01\%)$

  * Improve exotic decay search sensitivities by an order of magnitude

  e.g. $\pi \to e\nu_H ; \pi \to \mu\nu_H ; \pi \to e/\mu\nu\nu\bar{\nu} ; \pi \to (e/\mu)\nu X$

- Phase II → III: Provide the cleanest measure of V_{ud} and new input for $\frac{V_{us}}{V_{ud}}$

  * Measure $R_{\pi\beta} = \frac{\Gamma(\pi^+ \to \pi^0 e^+ \nu)}{\Gamma(\pi^+ \to all)}$: $O(\pm 0.2\% \to \pm 0.05\%)$

Courtesy: Doug Bryman

PIONEER Proposal: $\pi^+ \to e^+\nu$

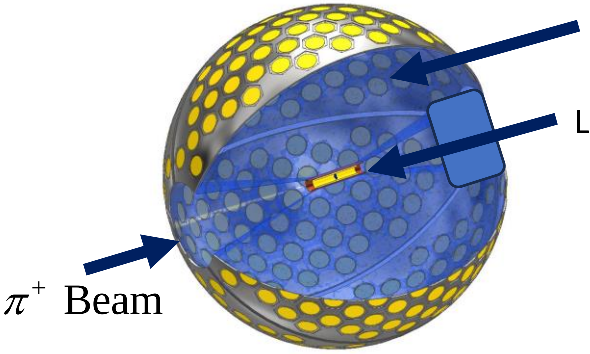
Approved at PSI 2022
Beam tests 2022,23

- PSI cyclotron, πE5 beamline
- LXe scintillation calorimeter (LYSO also under consideration)

  Fast, bright scintillation response
- Active Tracking Target "ATAR" (LGAD) Control of systematic uncertainties

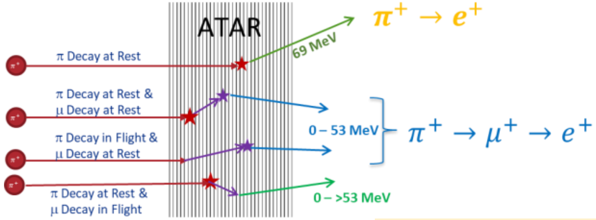
  Fast timing and pulse shape;allow $\pi \to \mu \to$ e decay chain observations
- Fast electronics and pipeline DAQ → Improve efficiency

Learn more about PIONEER:
Doug Bryman: doug@triumf.ca
David Hertzog: hertzog@uw.edu
Anna Soter: anna.soter@psi.ch



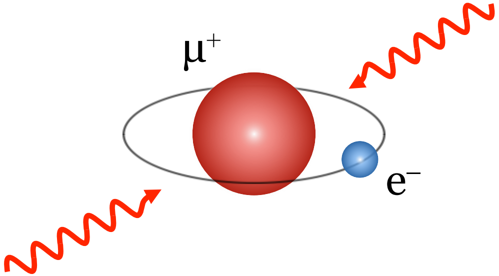
Calorimeter

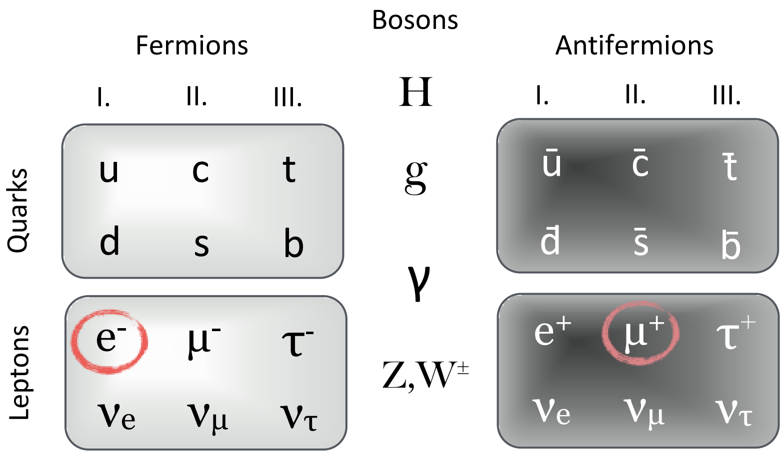
LGAD Si strip tracking target (ATAR)



Courtesy: Doug Bryman

Muonium - probing the SM and beyond





	Fermions			Bosons	Antifermions		
	I.	II.	III.		I.	II.	III.
Quarks	u	c	t	H	ū	c̄	t̄
	d	s	b	g	d̄	s̄	b̄
Leptons	e^-	μ^-	τ^-	γ	e^+	μ^+	τ^+
	ν_e	ν_μ	ν_τ	Z,W±	ν_e	ν_μ	ν_τ

Laser Spectroscopy

Purely leptonic exotic atom, dominated by QED effects:

- Fundamental constants (m_μ , μ_μ , R_∞)
- Test of bound-state QED & symmetries (q_μ / q_e)
- Effects on other precision experiments, e.g. muon g-2

$$E(1s-2s) \simeq \frac{3}{4} q_e q_\mu R_\infty \left(1-\frac{m_e}{m_\mu}\right) + \text{QED} + \ldots$$

Impact to muon g-2

Muonium HFS (22 ppb)

Storage ring [~200 ppb]

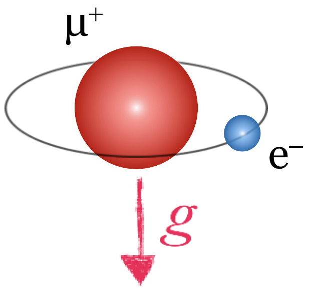
$$\frac{g-2}{2} = \frac{m_\mu}{e}\frac{\omega_a}{B} = \frac{\mu_p}{\mu_e}\frac{m_\mu}{m_e}\frac{g_e}{2}\frac{\omega_a}{\omega_p}$$

Hydrogen maser [3 ppb]

Electron g-2 + QED [0.26 ppt]

Courtesy: Anna Soter

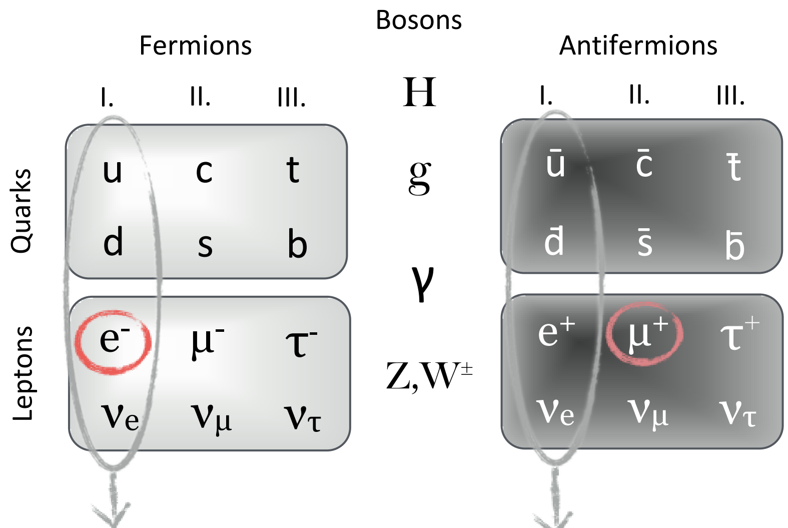
The LEMING experiment



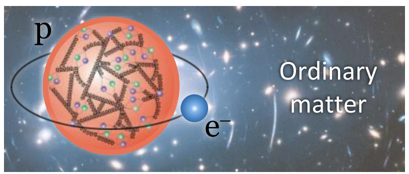
Measuring the free fall of Mu

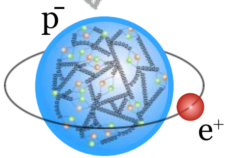
Test of the Weak Equivalence Principle by measuring the coupling of gravity to:

- fundamental parameters of SM (lepton masses), in the absence of the strong interaction
- second generation (anti)fermions of the SM - only possible probe of this sector



	Fermions I.	II.	III.	Bosons	Antifermions I.	II.	III.
Quarks	u	c	t	H	ū	c̄	t̄
	d	s	b	g	d̄	s̄	b̄
Leptons	e^-	μ^-	τ^-	γ	e^+	μ^+	τ^+
	ν_e	ν_μ	ν_τ	Z,W±	ν_e	ν_μ	ν_τ





Anti-hydrogen

Hadron mass

1% valence quark

99% strong interaction

↔

Muonium mass

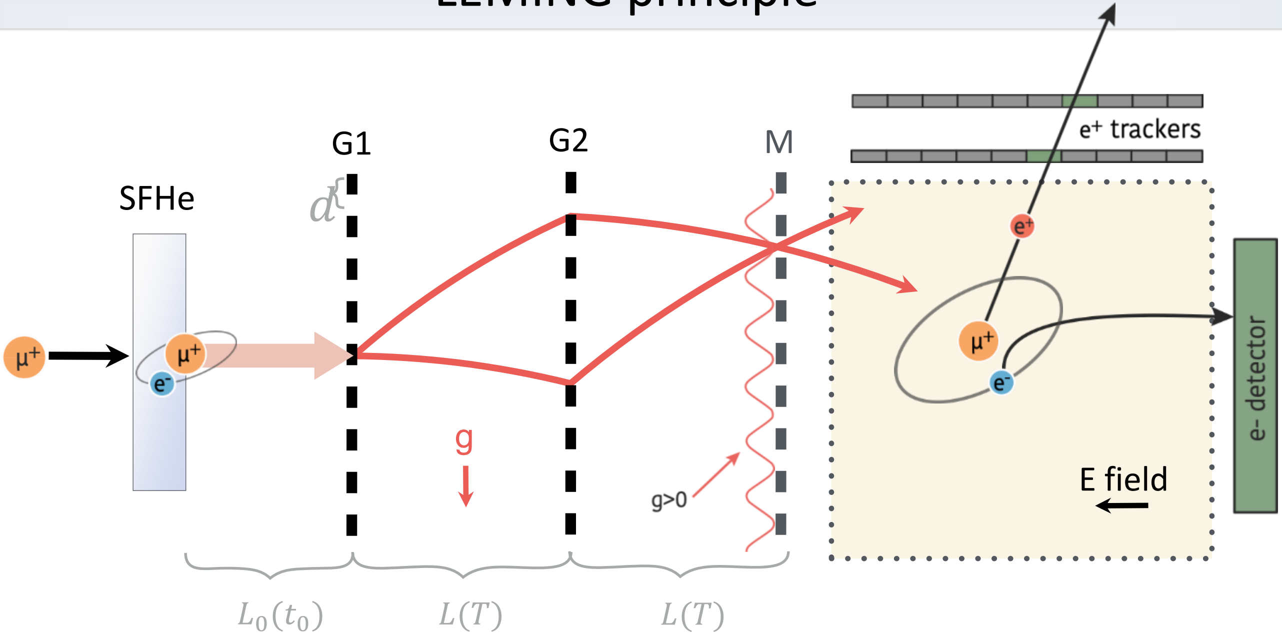
Binding 13.7 eV

μ^+ mass: 105.6583745(24) MeV/c

e^- mass: 0.5109989461(31) MeV/c

Courtesy: Anna Soter

LEMING principle



Sensitivity

$$\Delta g \approx \frac{1}{2\pi T^2}\frac{d}{C\sqrt{N_0\epsilon\eta^3 e^{-(t_0+2T)/\tau}}}$$

Grating period
d~100 nm

Interaction time
~4-5 μs, L~10 mm

Contrast C~0.3

Atom yield $N_0 > 10^5$/s

Losses

Sign of g in ~1 day

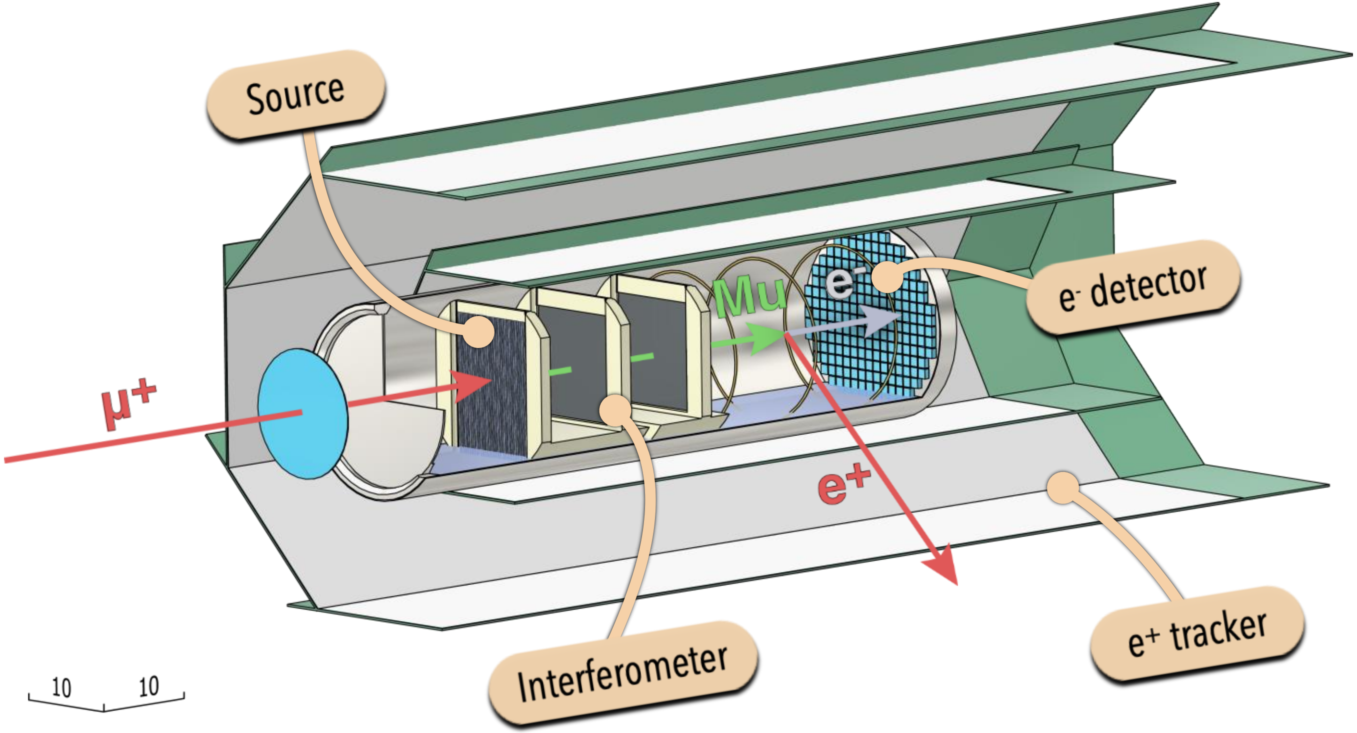
overall 1% sensitivity

@ PSI

world's highest intensity
cw muons

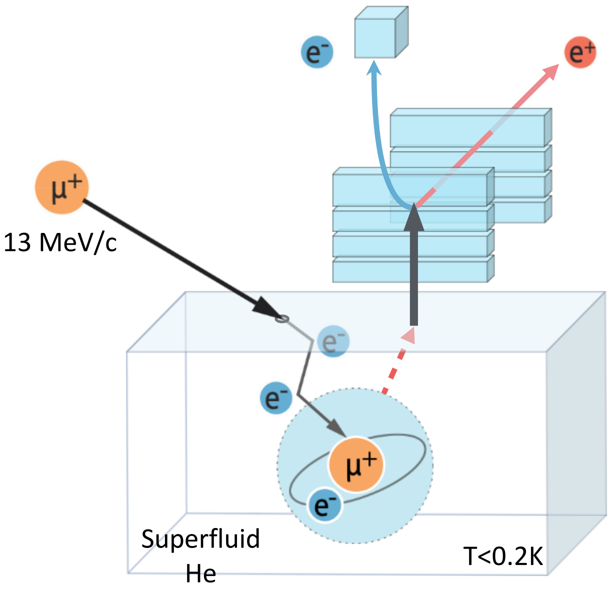
Courtesy: Anna Soter

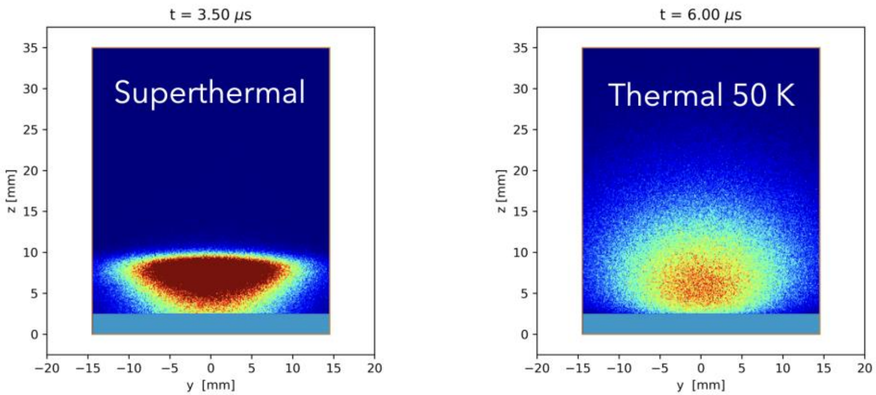
LEMING setup concept

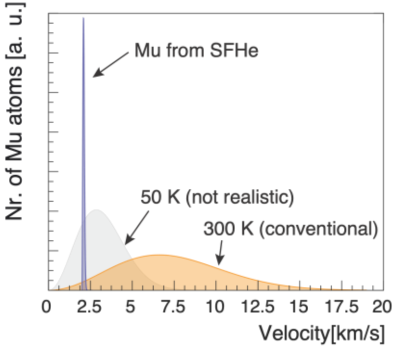


Courtesy: Anna Soter

First synthesis of superthermal muonium from SFHe



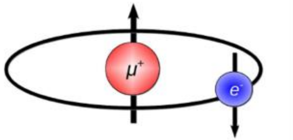




- Low mean velocity: $v_x \approx 2175\mathrm{m/s}$
- Narrow distribution: $\sigma_{v_x} \approx 100\mathrm{m/s}$
- High yield similar to best 300 K sources: $R(\mu^+ \rightarrow \mathrm{Mu_{vac}}) = 10\%$

Courtesy: Anna Soter

The Mu-MASS experiment at PSI – Status of CW laser spectroscopy

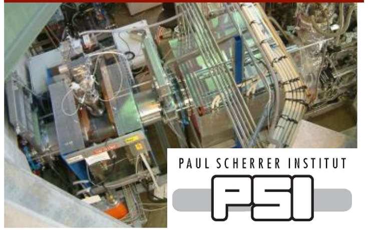


Mu-MASS focus on precision spectroscopy of muonium.
Aim is to reach an accuracy of the **1S-2S transition at the 10 kHz level** (currently 10 MHz)

- → **Muon mass @ 1 ppb**
- → Ratio of q_e/q_μ @ 1 ppt
- → Search for New Physics
- → **Test of bound state QED (1×10^{-9})**
- → Input to muon g-2 theory
- → **Rydberg constant @ ppt level**
- → New determination of α @ 1 ppb

P. Crivelli, Hyp. Int 239, 49 (2018).
arXiv:1811.00310

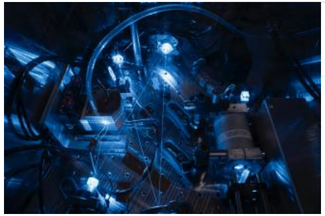
Low energy muon beam line (LEM)



Optics Express Vol. 31, Issue 17, pp. 28470-28479 (2023) • https://doi.org/10.1364/OE.496508

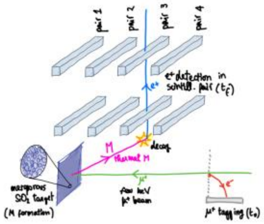
Pulsed CW laser for long-term spectroscopic measurements at high power in deep-UV

Nikita Zhadnov, Artem Golovizin, Irene Cortinovis, Ben Ohayon, Lucas de Sousa Borges, Gianluca Janka, and Paolo Crivelli



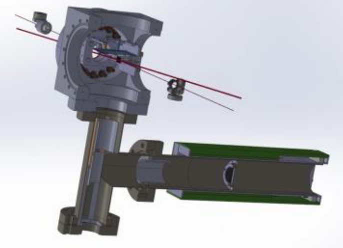
Development of high (1.8 W) power CW laser @ 244 nm & a new technique for long-term spectroscopy in DUV

Novel efficient muon → muonium converters



A. Antognini et al,
Phys. Rev. A 106, 052809 (2022)

Detection scheme:
BKG <1 event/day



I. Cortinovis et al., Eur. Phys. J. D 77, 66 (2023)

Beamline	Target	Timeline	1S-2S Uncertainty (kHz)
PiE4/LEM	SiO2 @ 300K	2024-2025	100
PiE1/muCool	SiO2 @ 100K	2026	10
HiMB/muCool	SFHe	2029-	1

First CW laser spectroscopy Muonium expected for 2024-2025

Mu-Mass

Courtesy: Paolo Crivelli

erc European Research Council Established by the European Commission

THIS WORK IS SUPPORTED BY an ERC consolidator grant (818053 -Mu-MASS) and by the Swiss National Foundation under the grant 197346.

Swiss National Science Foundation

ETH zürich

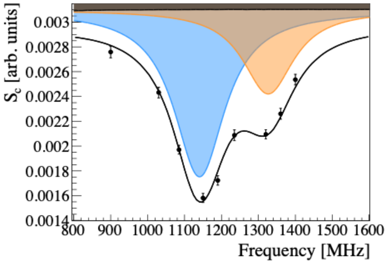
IPA

The Mu-MASS experiment at PSI – Status of MW spectroscopy

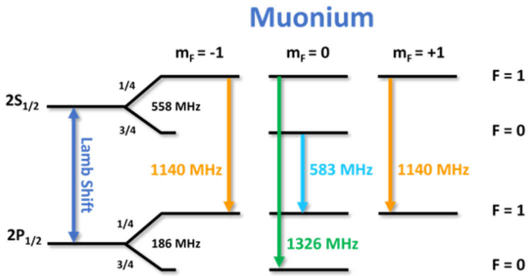

Precision Measurement of the Lamb Shift in Muonium

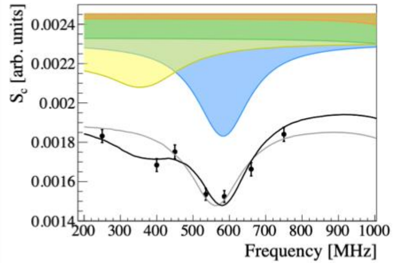
B. Ohayon, G. Janka, I. Cortinovis, Z. Burkley, L. de Sousa Borges, E. Depero, A. Golovizin, X. Ni, Z. Salman, A. Suter, C. Vigo, T. Prokscha, and P. Crivelli (Mu-MASS Collaboration)

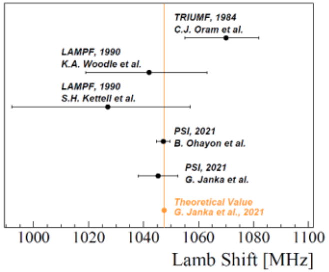
Phys. Rev. Lett. **128**, 011802 – Published 6 January 2022



Precision improved by an order of magnitude and new transitions measured for the first time -> 2S HFS.





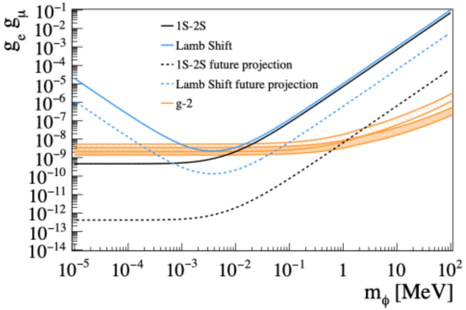



Article | Open Access | Published: 25 November 2022

Measurement of the transition frequency from $2S_{1/2}$, $F = 0$ to $2P_{1/2}$, $F = 1$ states in Muonium

Gianluca Janka, Ben Ohayon, Irene Cortinovis, Zak Burkley, Lucas de Sousa Borges, Emilio Depero, Artem Golovizin, Xiaojie Ni, Zaher Salman, Andreas Suter, Thomas Prokscha & Paolo Crivelli

Nature Communications **13**, Article number: 7273 (2022) | Cite this article



PAUL SCHERRER INSTITUT

PSI

Those measurements pave the way to much higher precision in the near future with the great prospects of **MuCool and HiMB at PSI**

Mu-Mass

Results in agreement with theoretical calculations. **Constraints on new physics in the muonic sector**

European Research Council
Established by the European Commission

THIS WORK IS
and by the Swis

Courtesy: Paolo Crivelli

-MASS)

Swiss National Science Foundation

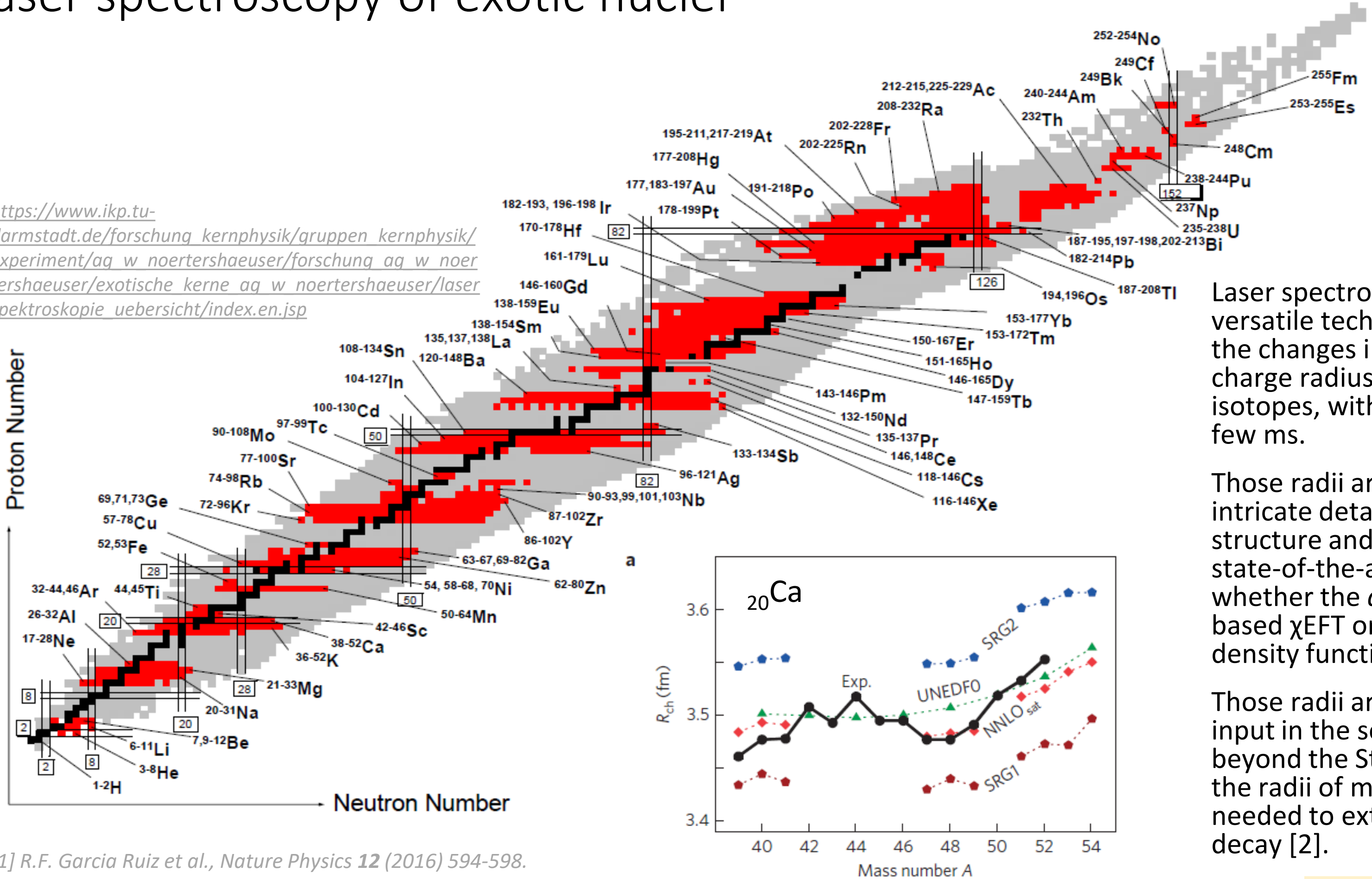
Reference Radii

Absolute radii to benchmark laser spectroscopy investigations of exotic nuclei

Courtesy: Thomas Cocolios

Laser spectroscopy of exotic nuclei

https://www.ikp.tu-darmstadt.de/forschung_kernphysik/gruppen_kernphysik/experiment/ag_w_noertershaeuser/forschung_ag_w_noertershaeuser/exotische_kerne_ag_w_noertershaeuser/laserspektroskopie_uebersicht/index.en.jsp



Laser spectroscopy is a very versatile technique that can study the changes in the mean-square charge radius across long chain of isotopes, with half-lives down to a few ms.

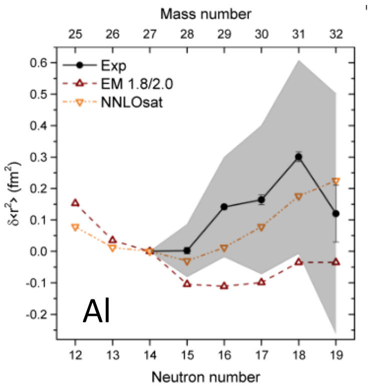
Those radii are used to investigate intricate details of nuclear structure and to challenge the state-of-the-art nuclear models, whether the *ab initio* models based χEFT or the global energy density functionals [1].

Those radii are also important input in the search for physics beyond the Standard Model, e.g., the radii of mirror nuclei are needed to extract V_{ud} from beta decay [2].

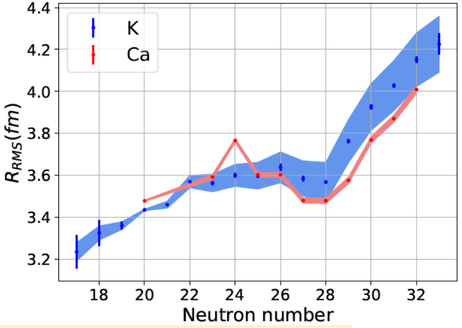
[1] R.F. Garcia Ruiz et al., Nature Physics ***12*** *(2016) 594-598.*
[2] P. Plattner et al., Physical Review Letters ***131*** *(2023) 222502.*

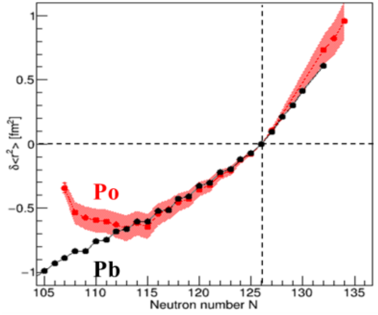
Courtesy: Thomas Cocolios

Radii extraction from laser spectroscopy



$$\delta\nu^{AA'} = \frac{A'-A}{AA'}\left(m_e\nu + \boxed{M_{SMS}}\right) + \boxed{F}\,\delta\langle r^2\rangle^{AA'}$$

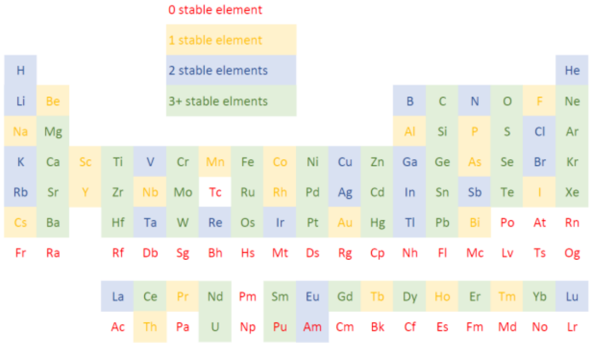




In laser spectroscopy, high precision measurements of the atomic transitions are used to measure the perturbations induced by the nuclear charge distribution on the atomic levels.

However, this response function has to be benchmarked to extract the changes in the mean square charge radius. This requires the measurements of 3 absolute radii (1 reference + 2 measurements).

However, no odd-Z element not any beyond lead have 3 stable isotopes with which conventional investigations can be performed.

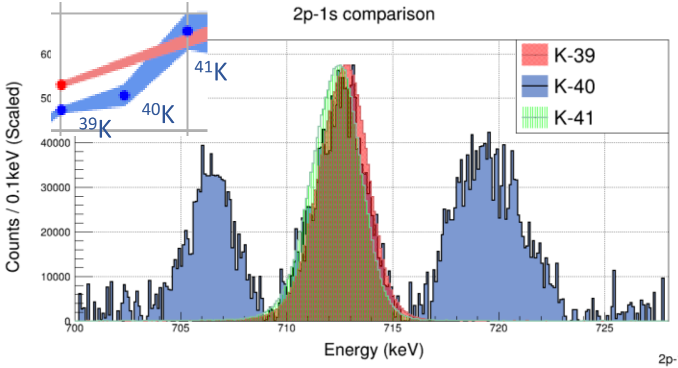


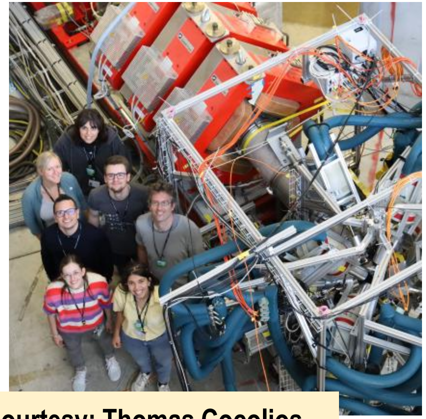
0 stable element
1 stable element
2 stable elements
3+ stable elments

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp	Nh	Fl	Mc	Lv	Ts	Og
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

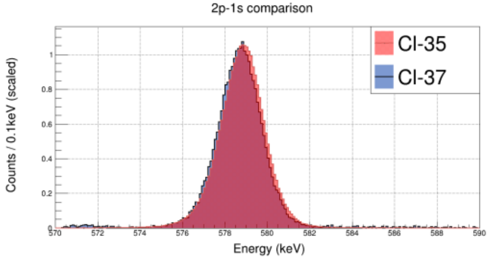
Courtesy: Thomas Cocolios

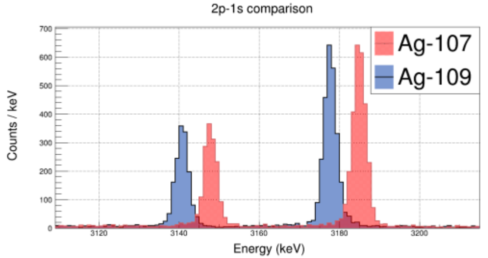
Reference radii 2022/23





Courtesy: Thomas Cocolios





Using the highly sensitive approach developed by muX, we can now perform muonic x-ray spectroscopy on samples as small as 5 µg, with ~10^{16}-10^{17} particles.

We have demonstrated the ability to use samples implanted at shallow depth in carbon, using electromagnetic mass separators such as a commercial high-current implanter for stable isotopes, or ISOLDE at CERN for radioisotopes.

The first case completed in 2023 is ^{39}K-^{40}K-^{41}K, using a ^{40}K sample produced with the new mass separator at iThemba LABS (South Africa).

Thanks to loans from ILL and ORNL, we could also perform the first muonic x-ray spectroscopy with enriched ^{35}Cl and ^{37}Cl.

First tests were performed with 107Ag and 109Ag in preparation for a future measurement of ^{108m}Ag ($T_{1/2}$=438 years) in the near future.

MONUMENT project (Measurement of ordinary muon capture (OMC) for verification of nuclear matrix elements of 2β-decays)

APPEC-2019, Recommendation 6: *The computation of nuclear matrix elements is challenging and currently is affected by an uncertainty which is typically quantified in a factor of 2-3... An enhanced effort is required and a stronger interactions between the particle physics and nuclear community would be highly beneficial. Dedicated experiments may be required.*

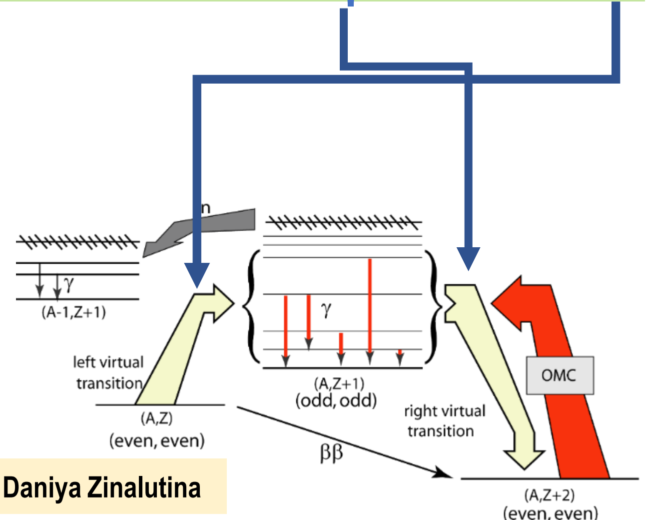
$$\frac{1}{T^{0\nu}_{1/2}} \propto \underbrace{\left|\sum_i U_{ei}^2 m_i\right|^2}_{\langle m_{\beta\beta}\rangle} G^{0\nu} \underbrace{\left|\langle A,Z+2|S|A,Z\rangle\right|^2}_{M^{0\nu}}$$

Effective Majorana Mass

Probability of the 0νββ process

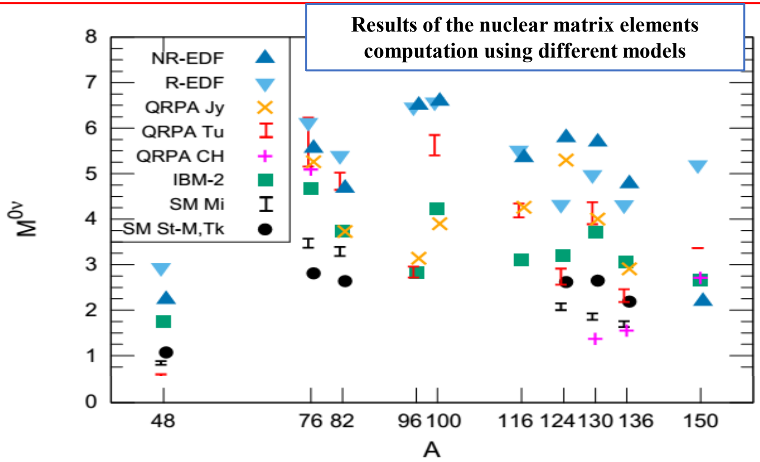
Nuclear Matrix Element (NME)

$$\langle A,Z+2|S|A,Z\rangle \propto \sum_n \underbrace{\langle Z+2|\hat{H}|Z+1,n\rangle}\underbrace{\langle Z+1,n|\hat{H}|Z\rangle}$$



Courtesy: Daniya Zinalutina

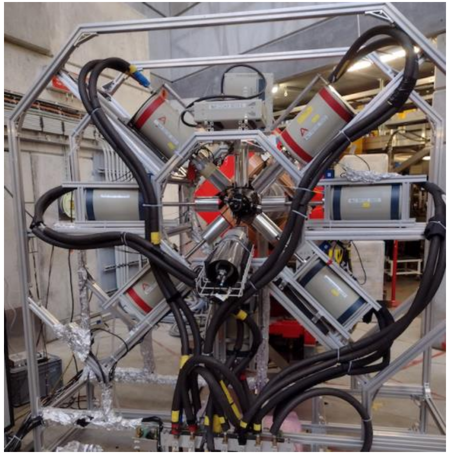
Results of the nuclear matrix elements computation using different models

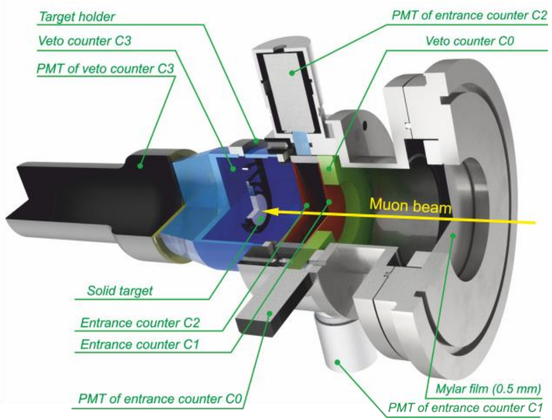


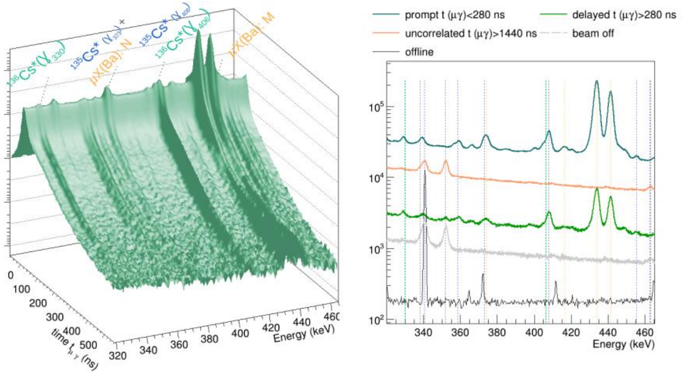
- ➢In case of observed 0νββ decay the experimental results could help to improve NME calculations to define the effective Majorana neutrino mass

- ➢ **Right virtual transitions in DBD will be tested by Ordinary Muon Capture -> OMC and 0νββ operate in the q ≈ 100 MeV momentum-exchange region** – high-lying states will be populated

Status and plans of the MONUMENT project







Purpose	OMC targets (enrichment)	Year/Status
experimental input for DBD NME calculations	^{76}Se (99.97%)	**2021** / analysis and publication
experimental input for DBD NME calculations	^{136}Ba (95.27%)	**2021** / analysis and publication
experimental input for astrophysics investigations with SN	^{100}Mo (97.3%)	**2022** / started data analysis
Nuclear spectroscopy, total cap. rates, yields	^{nat}Mo	**2022** / started data analysis
testing nuclear shell model (SM) calculations	^{48}Ti (99.9%)	**2023** / started data analysis
experimental input for DBD NME calculations, ab-initio calculations	^{96}Mo, ^{12}C, ^{13}C, ^{56}Fe	**2025-2028** / in preparation

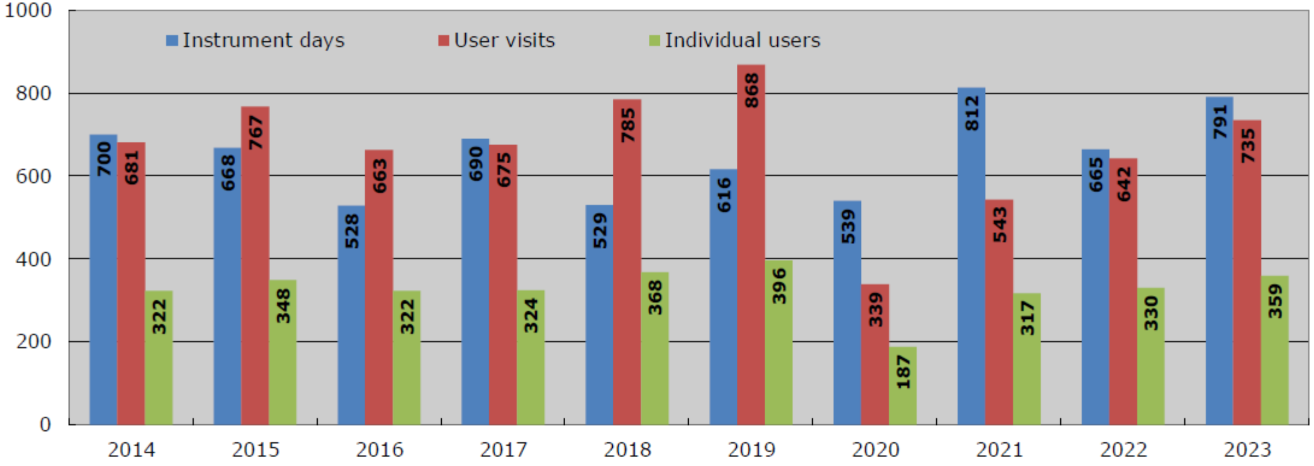
➢ **OMC is the sensitive tool to probe properties of DBD process**. It is based on mature experimental technique successfully developed during many years, which demonstrates satisfactory agreement between experimental and theoretical data;

➢ **The unique information obtained at OMC provide a significant experimental contribution to the nuclear spectroscopy**, which is very actual in the nowadays;

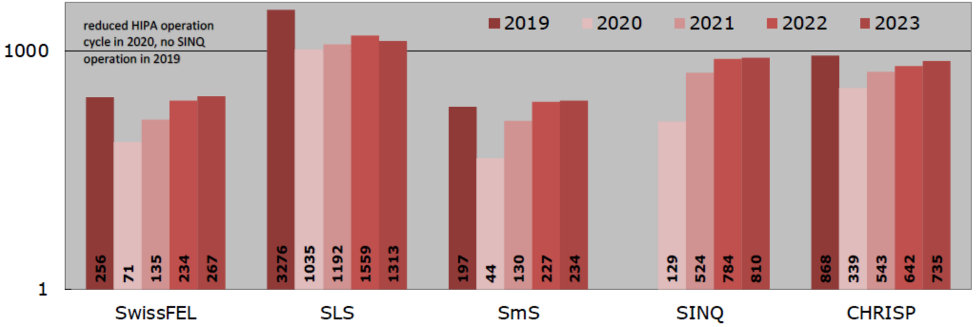
Courtesy: Daniya Zinalutina

Users at CHRISP (CH Research InfraStructure for Particle physics)

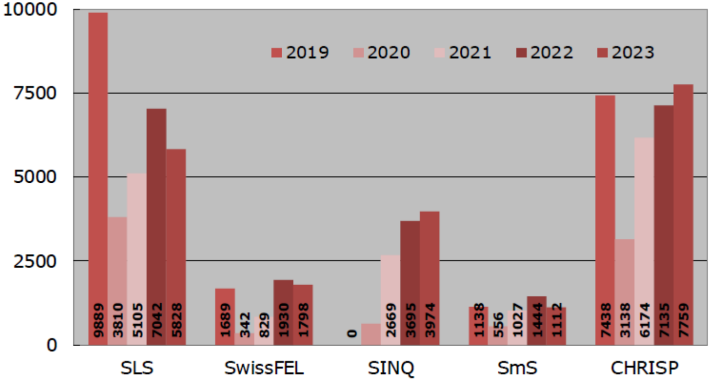
key numbers CHRISP - 10y history



user visits all facilities: 5y history (log scale)



duration of user stays [days] - 5y history



Thank you!