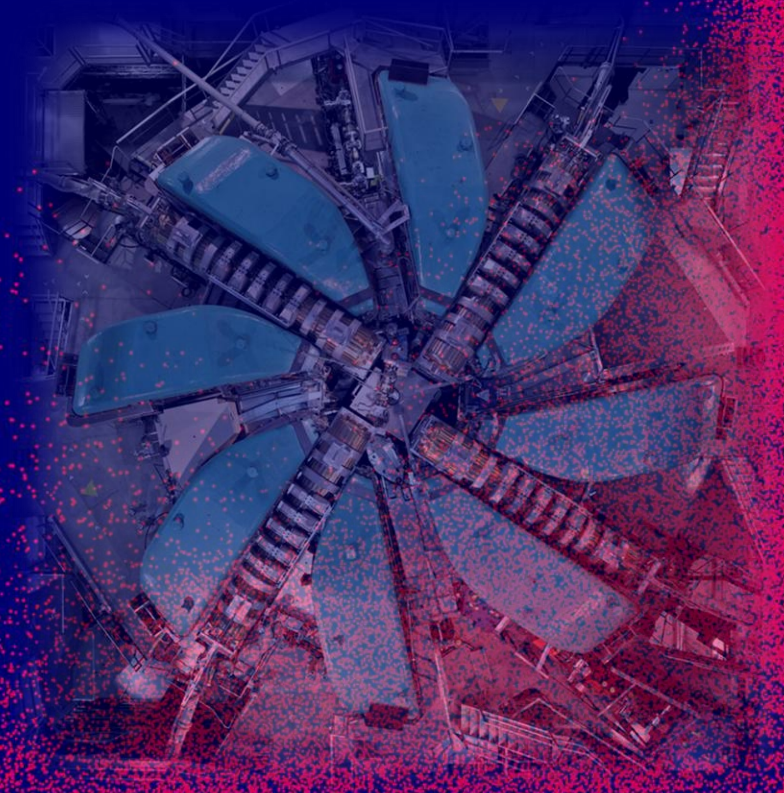
PSI Center for Neutron and Muon Sciences



The muEDM experiment at PSI

muEDM collaboration :: **Pranas Juknevicius**

DISCRETE 2026

Bratislava Nov 2026

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

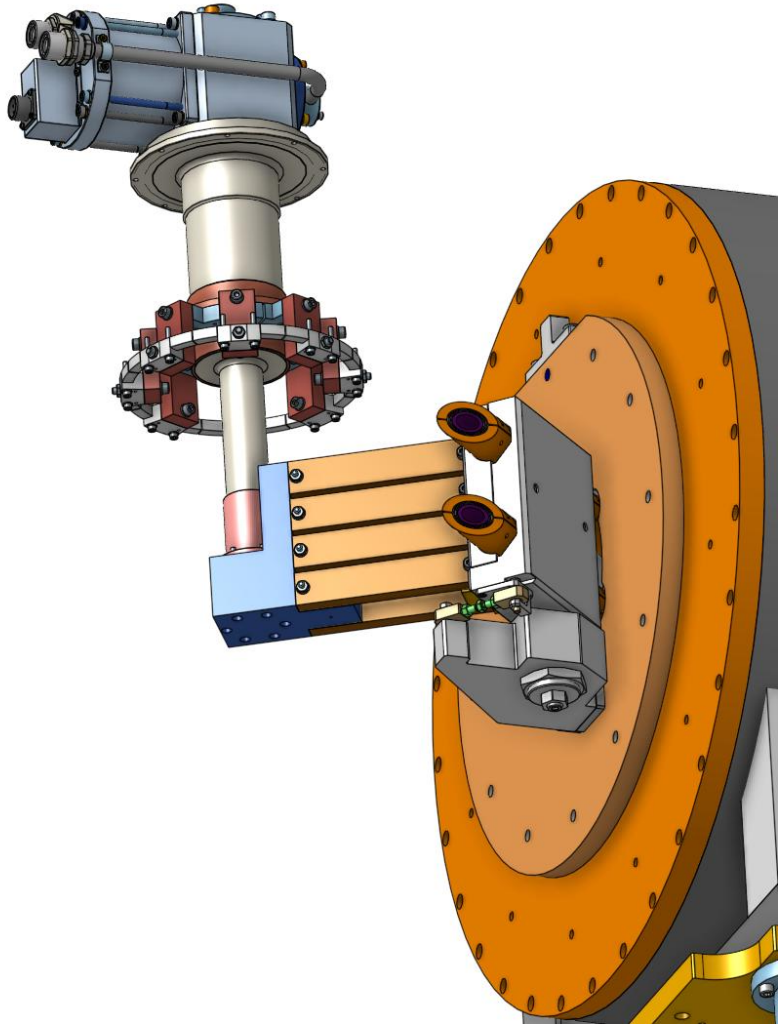
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION
This work is financed by the SNSF under grant № 204118.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 884104 (PSI-FELLOW-III-3i)

Content

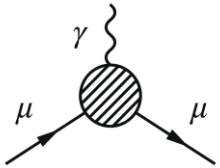
- ❖ **Muon electric dipole moment**
- ❖ **The muEDM experiment**
  - Muon injection
  - Muon entrance trigger
  - Fast magnetic pulser
  - The frozen-spin technique
  - Cylindrical positron tracker
- ❖ **Conclusion**



EDM & CP violation

$$H = -\vec{\mu} \cdot \vec{\mathrm{B}} - \vec{d} \cdot \vec{\mathrm{E}}$$

$$\vec{\mu} = g \frac{q}{2m_\mu} \vec{s} \qquad \vec{d} = \eta \frac{q}{2m_\mu c} \vec{s}$$



DISCRETE 2026 Symmetries

	C	P	T
$\vec{\mu} \cdot \vec{\mathrm{B}}$	+	+	+
$\vec{d} \cdot \vec{\mathrm{E}}$	+	-	-

muEDM is a pure leptonic systemic that violates CP.

Known sources of CP violation are insufficient to explain baryon asymmetry.

Standard Model

- Leptonic EDMs heavily suppressed (4th-loop)
- Largest prediction of the muon EDM:
  $d_\mu^{SM} = 1.4 \times 10^{-38} e \cdot cm$
  (Yamaguchi & Yamanaka, 2020)
- Current best limit by ***muon g-2 collaboration***:
  $d_\mu^{\mathrm{exp}} \leq 1.10 \times 10^{-19} e \cdot cm$
  (Aguillard, 2026)

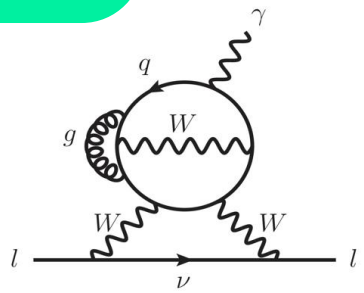
muEDM collaboration goal

Phase I

$$\sigma(d_\mu) \leq 4 \times 10^{-21} e \cdot cm$$

Phase II

$$\sigma(d_\mu) \leq 6 \times 10^{-23} e \cdot cm$$

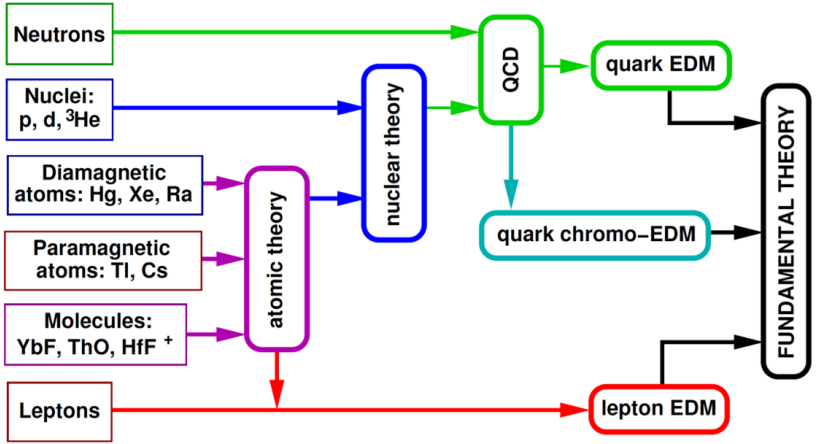


Beyond the Standard Model

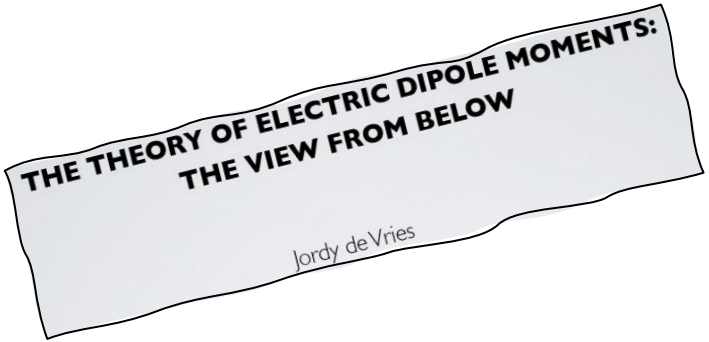
At current sensitivity, EDM offers “background-free” search for new physics incorporating CP violation.

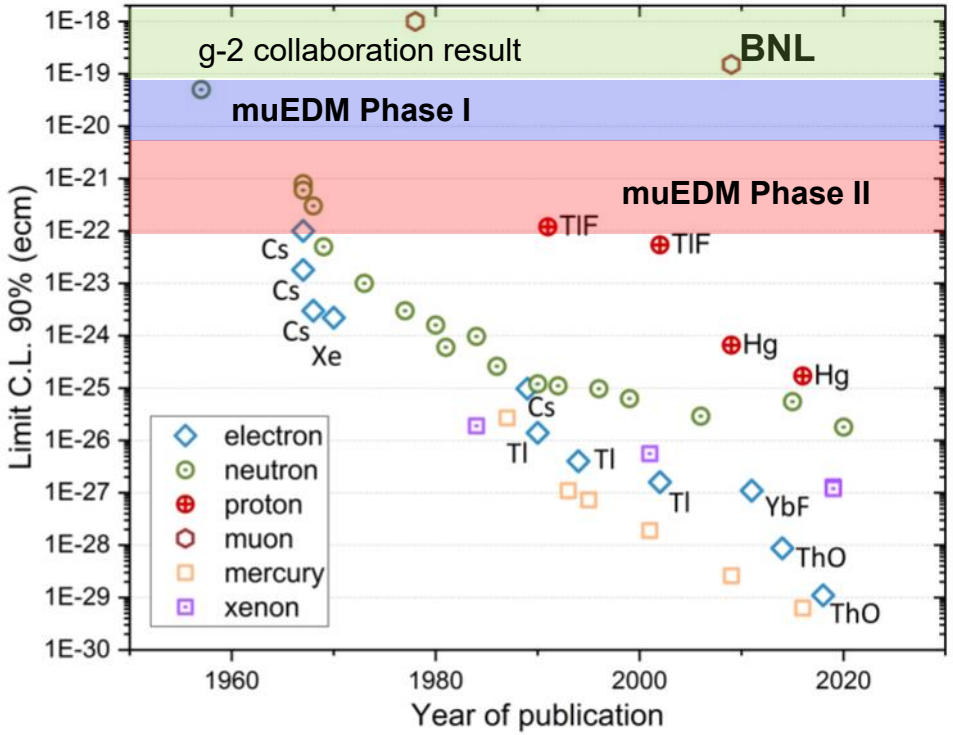
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EDM landscape



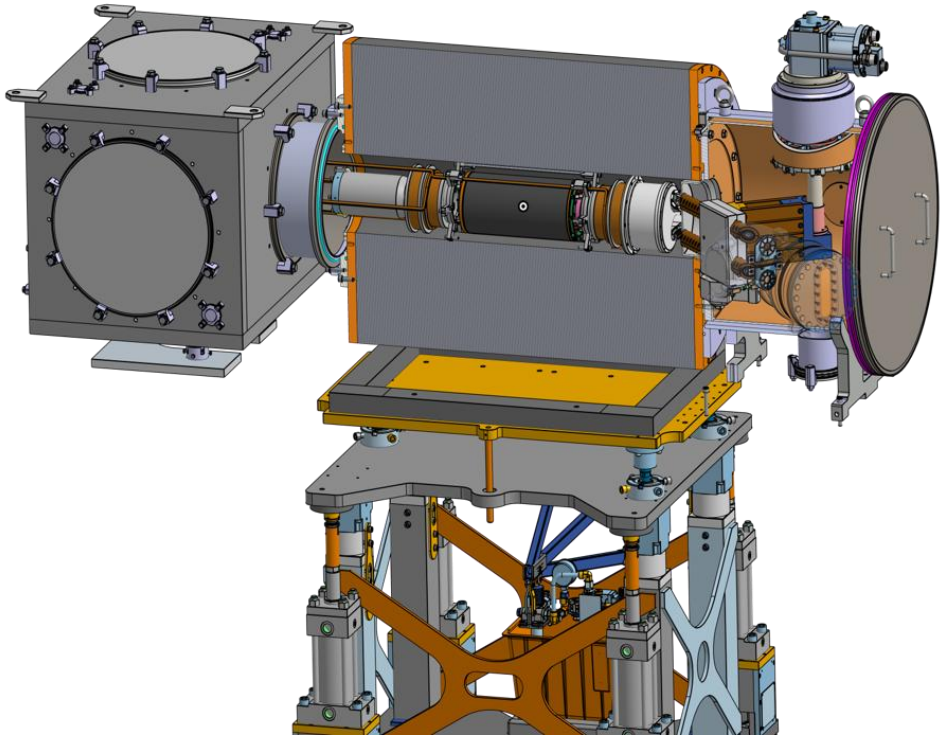
Scheme: adapted from Rob G.E. Timmermans

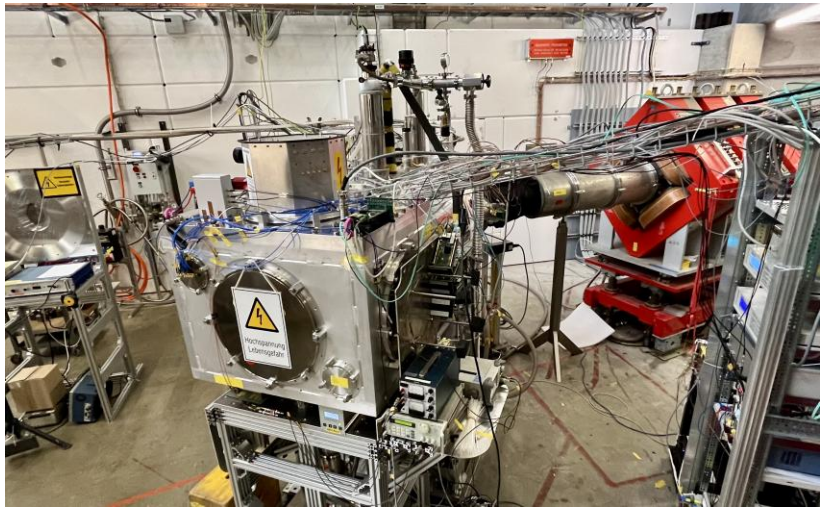


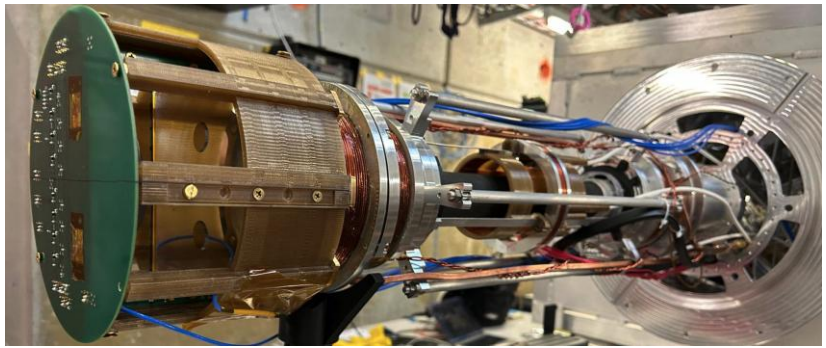


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The muEDM experiment

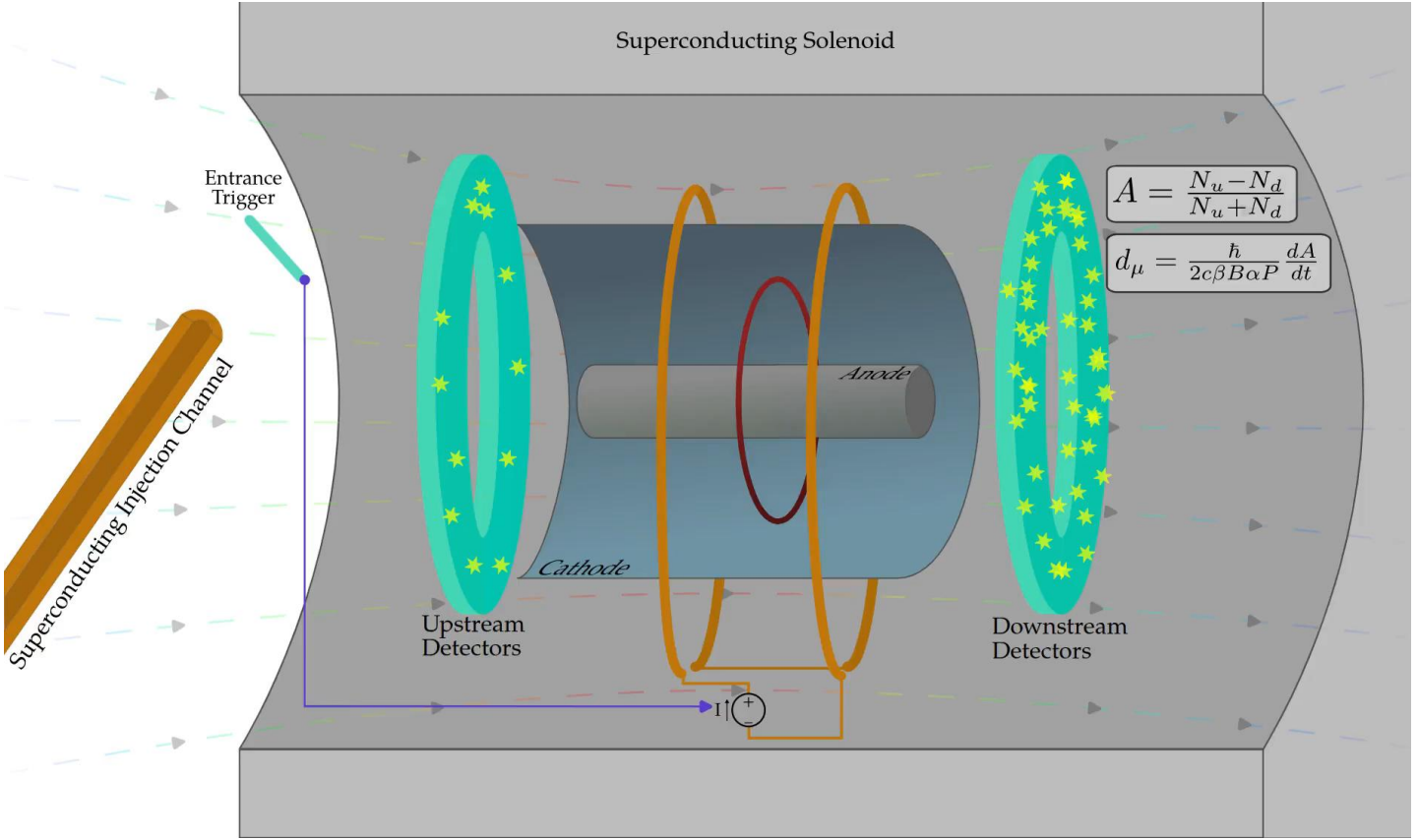






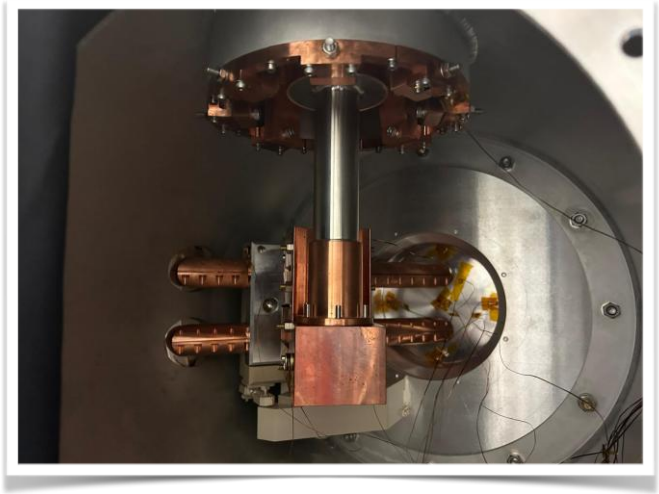
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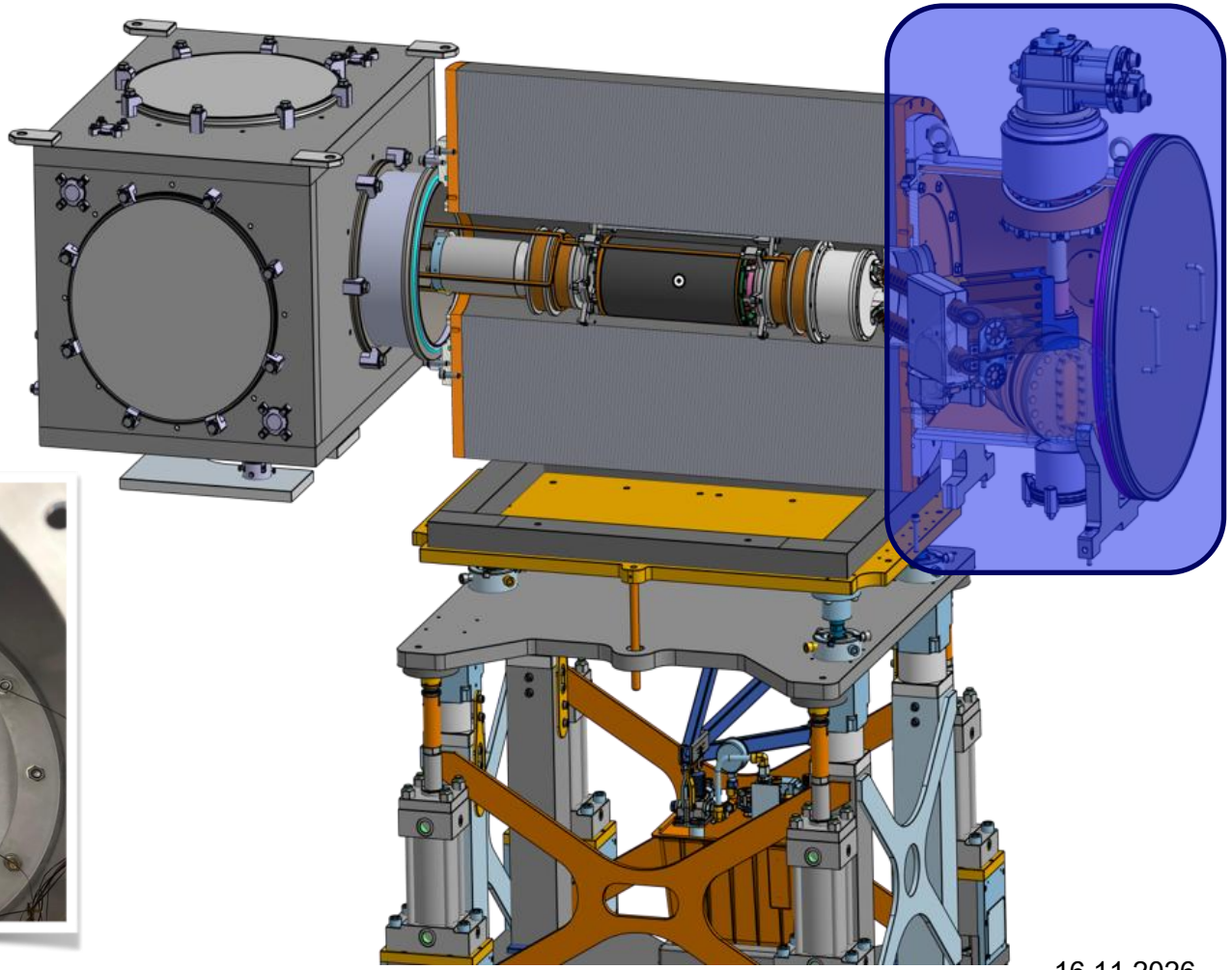
The muEDM experiment



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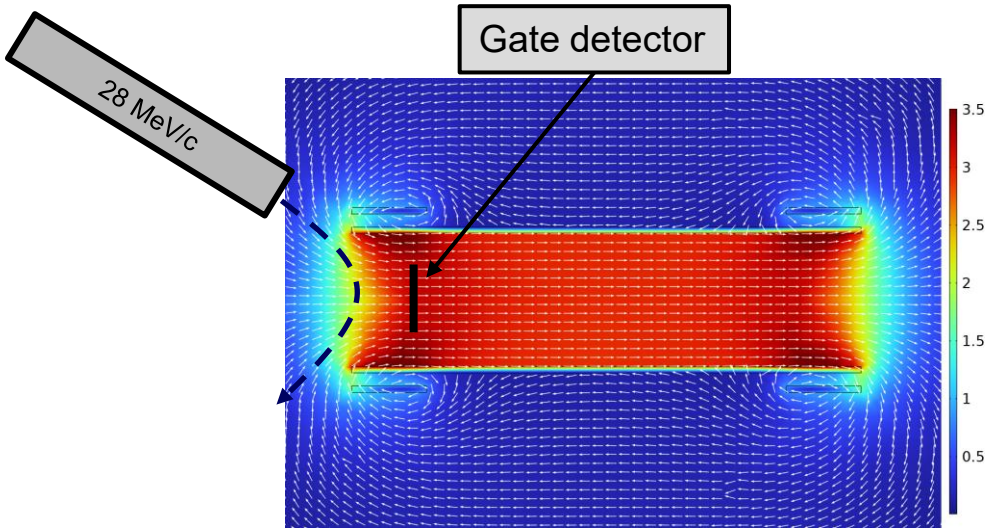
Muon injection





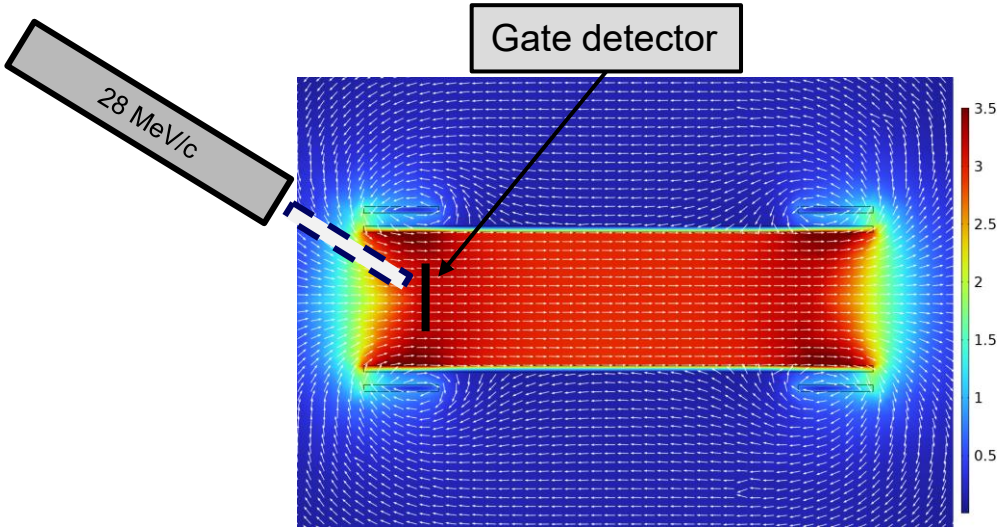
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Muon injection



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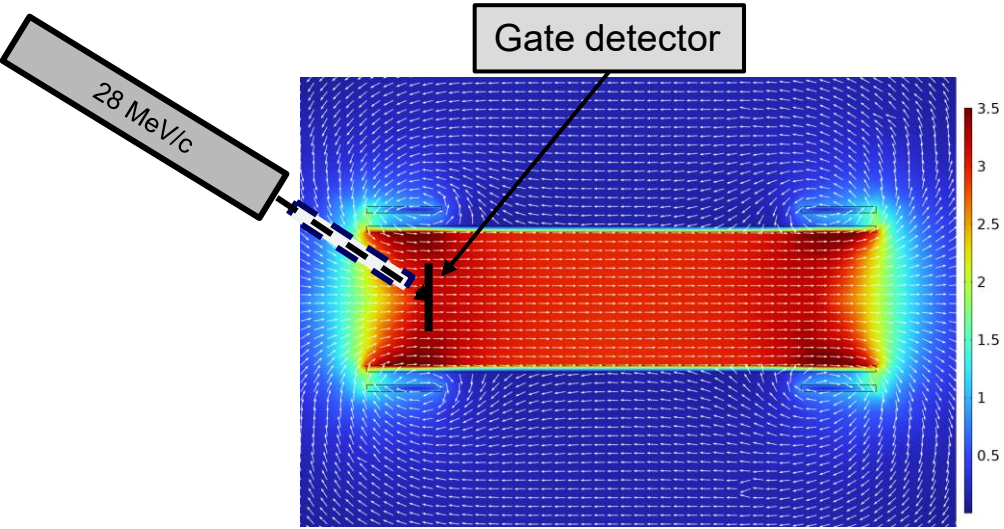
Muon injection



Challenges:
- Non-uniform fringe field
- Strong gradient ~2T magnetic field

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Muon injection



In collaboration with V. Karpati, D. Barna
Design is based on DOI:10.1109/TASC.2022.3149726 D. Barna et al.

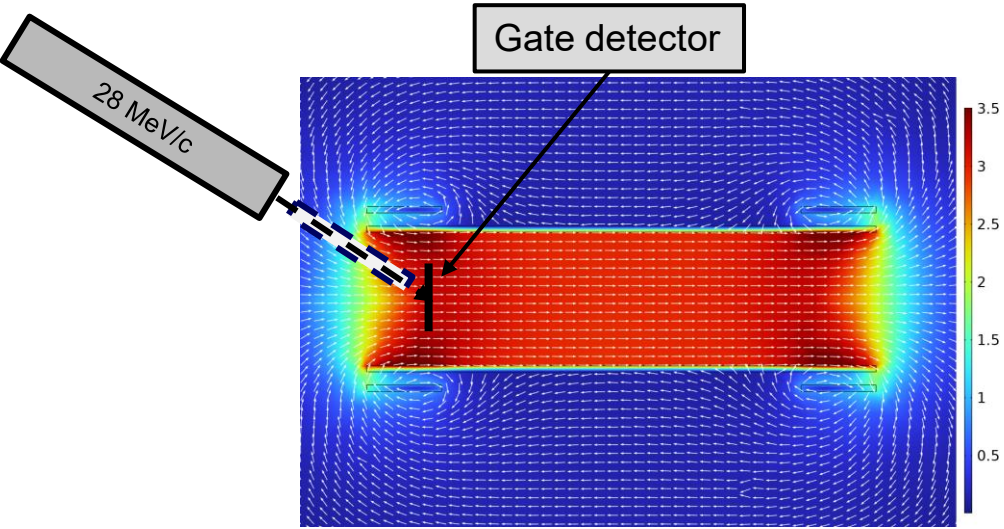


Challenges:
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- Strong gradient ~2T magnetic field

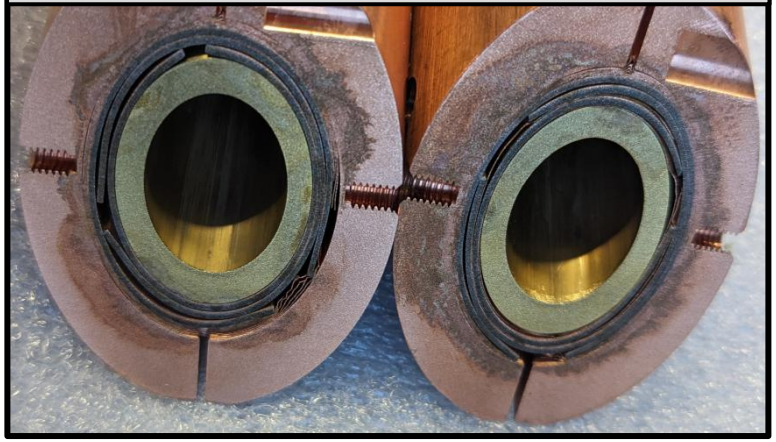
Solution:
- **Superconducting** injection channel

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Muon injection



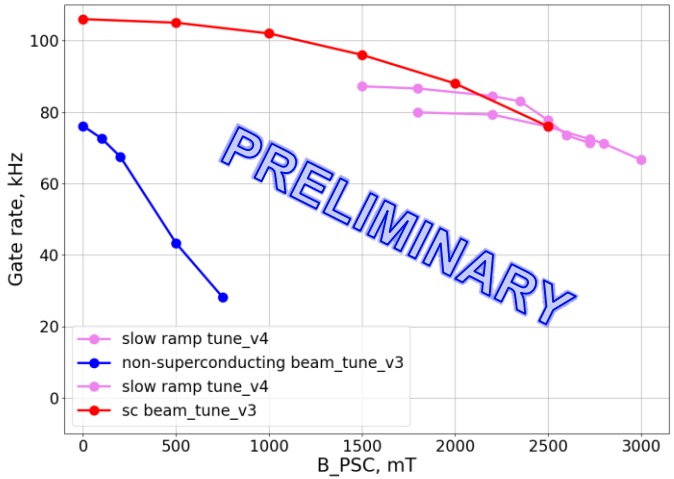
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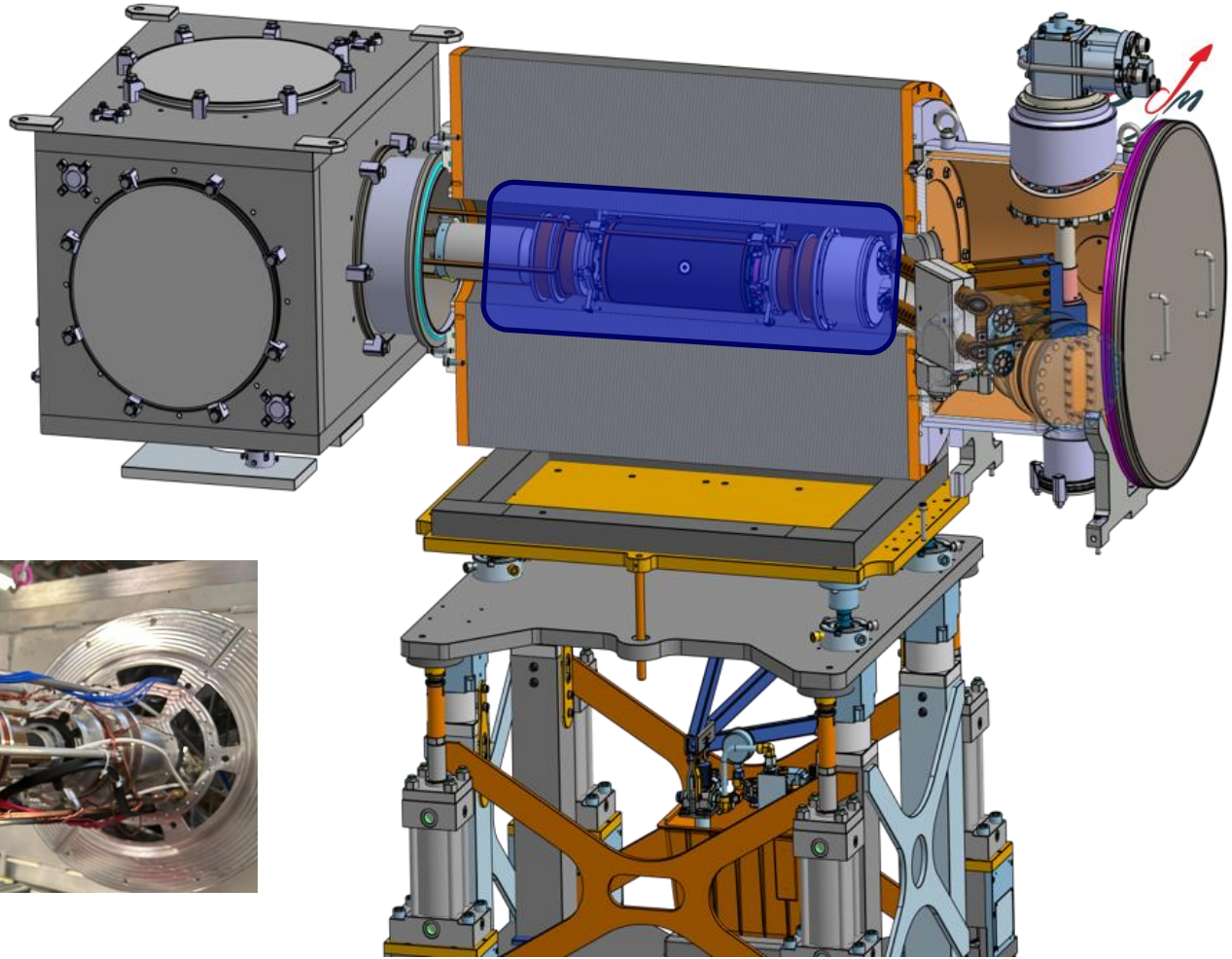
Solution:
- **Superconducting** injection channel

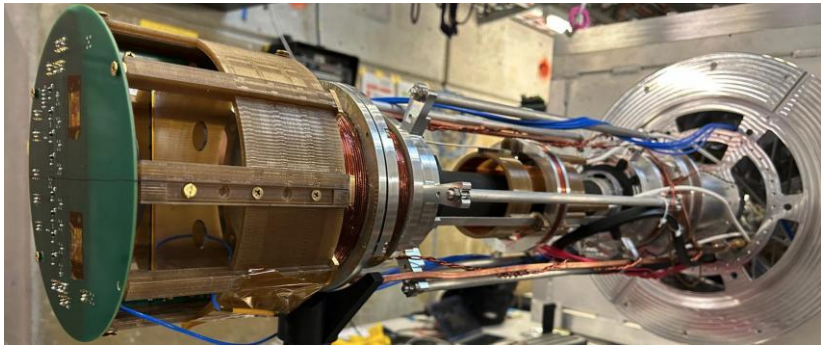
✓ Demonstrated in beamtime 2025



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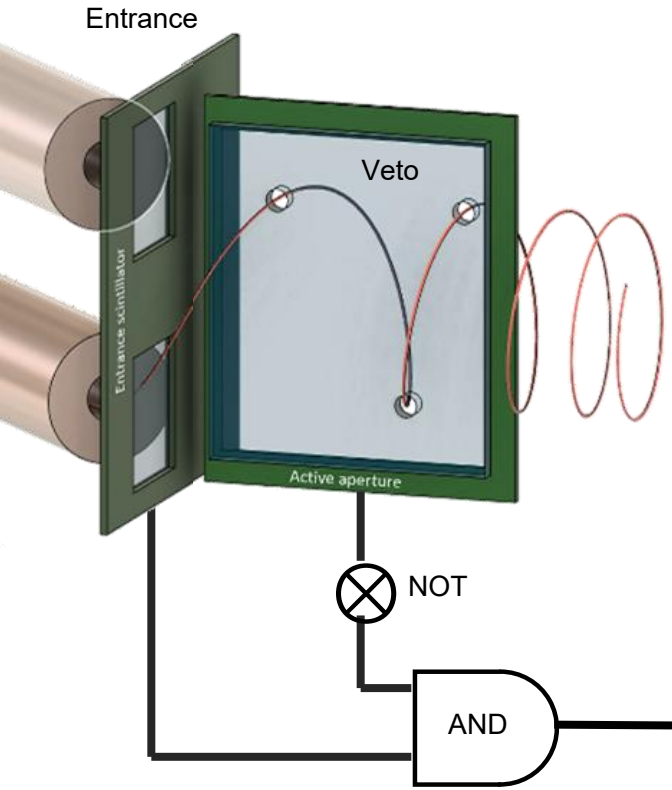
Internal structure





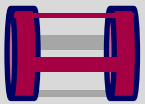
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Muon Entrance Trigger



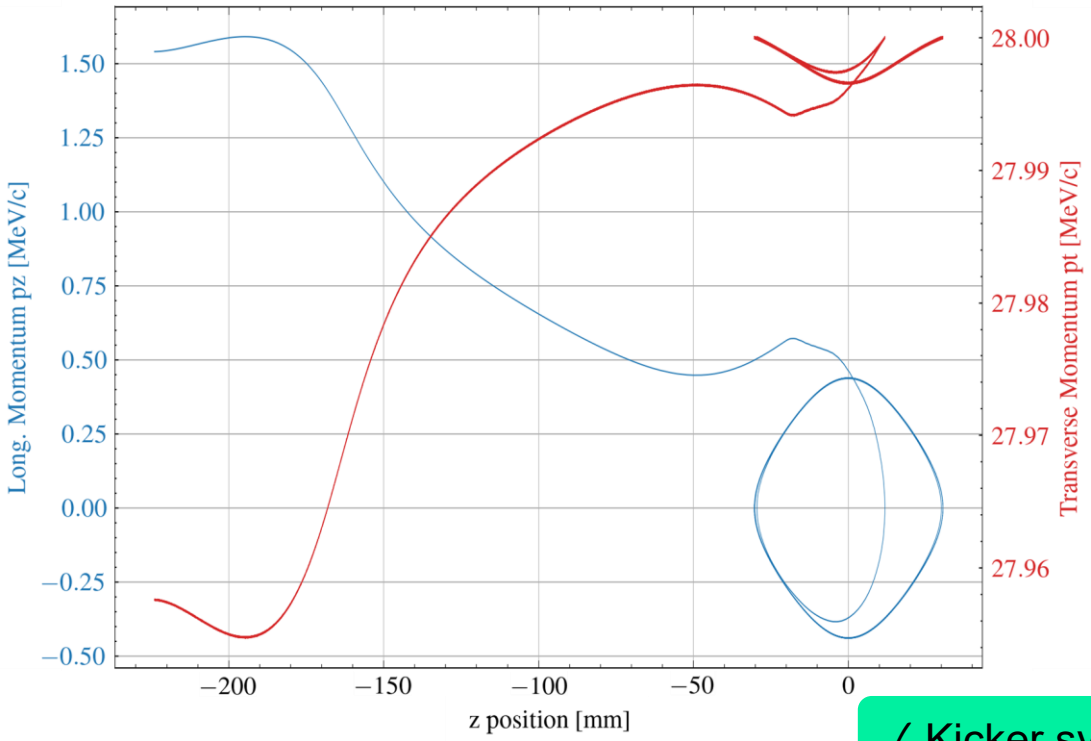
- Magnetic pulse is triggered **only** on muons with the correct trajectory
- Only **0.4%** of muons are in the **acceptable** phase space (*Geant4 simulation*)
- Entrance Detector: Thin (≤100µm) scintillator
- Veto Detector: Thick scintillating slab with holes

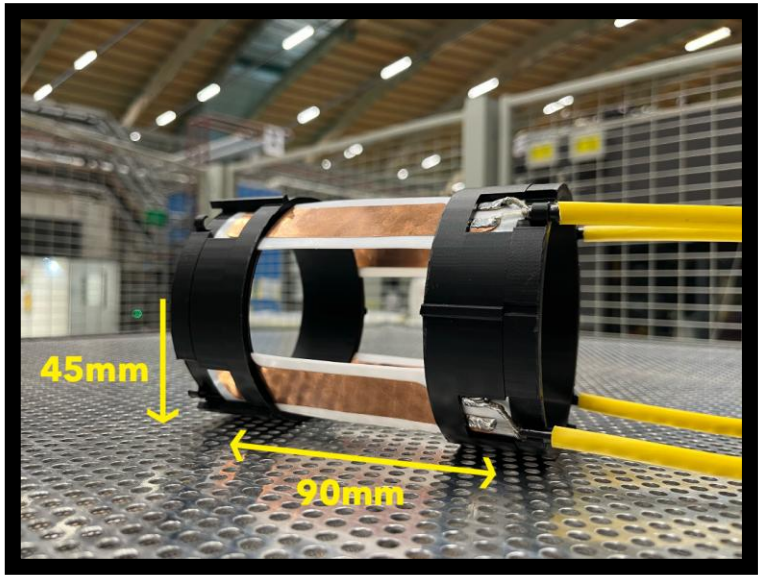
✓ Tested in beamtime 2024



Magnetic kicker system

Magnetic kicker coil





Magnetic pulse characteristics:
- Peak amplitude ~1mT
- Pulse fullwidth ~50ns
- Triggered <100ns

✓ Kicker system tested in beamtime 2024

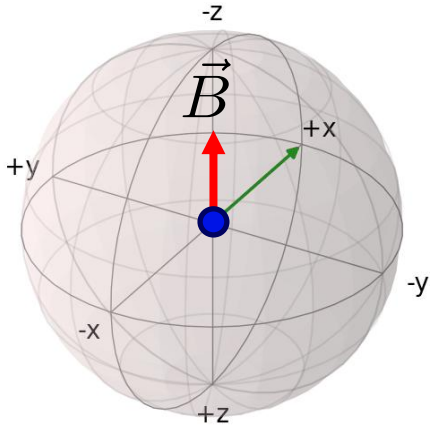
🎯 Goal to demonstrate storage beamtime 2026

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Frozen-spin technique

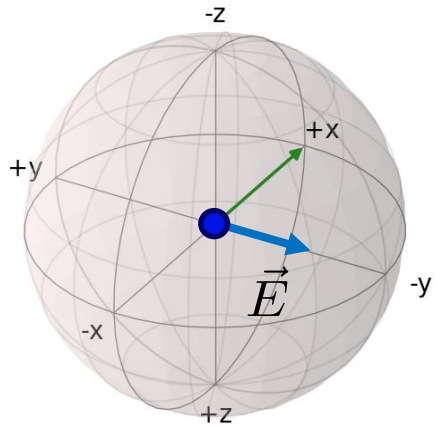
$$H = -\vec{\mu} \cdot \vec{\mathrm{B}} - \vec{d} \cdot \vec{\mathrm{E}}$$

$$\vec{\mu} = g \frac{q}{2m_\mu} \vec{s}$$



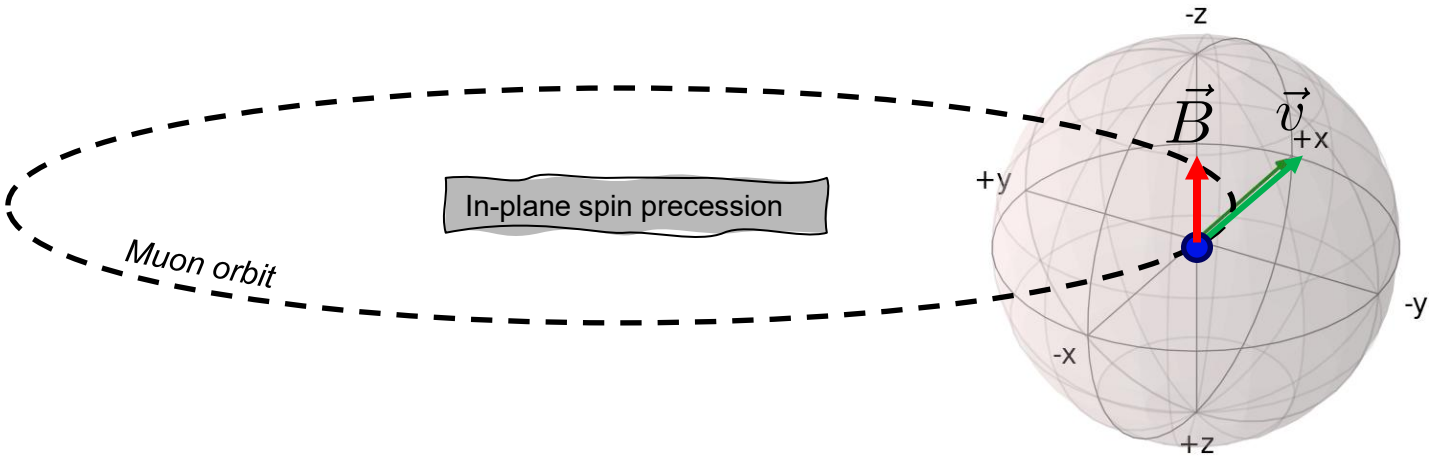
Larmor precession

$$\vec{d} = \eta \frac{q}{2m_\mu c} \vec{s}$$



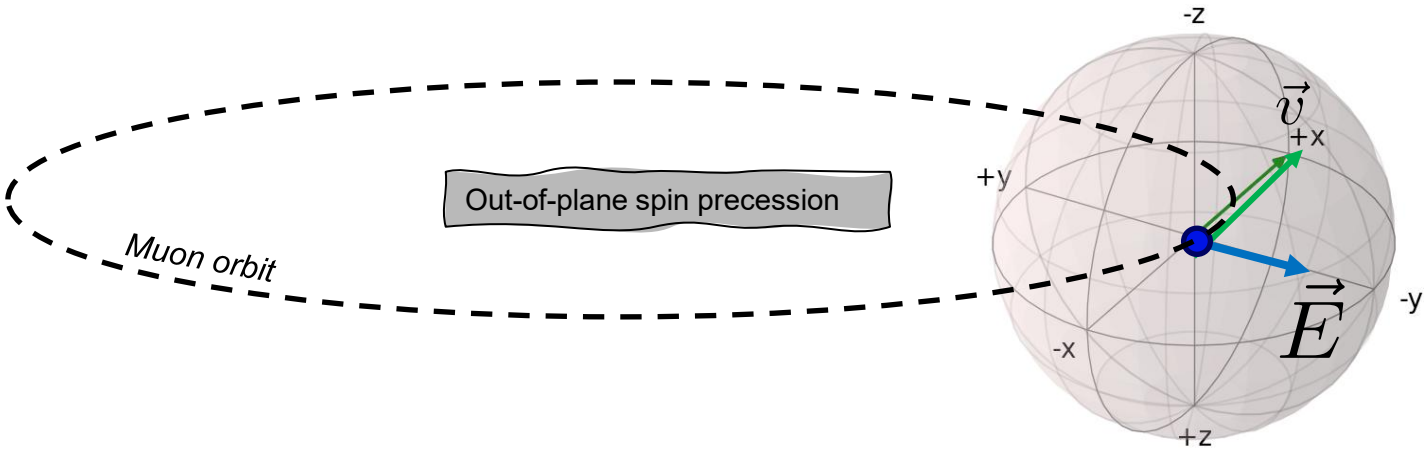
Spin precession due to muon EDM

Frozen-spin technique



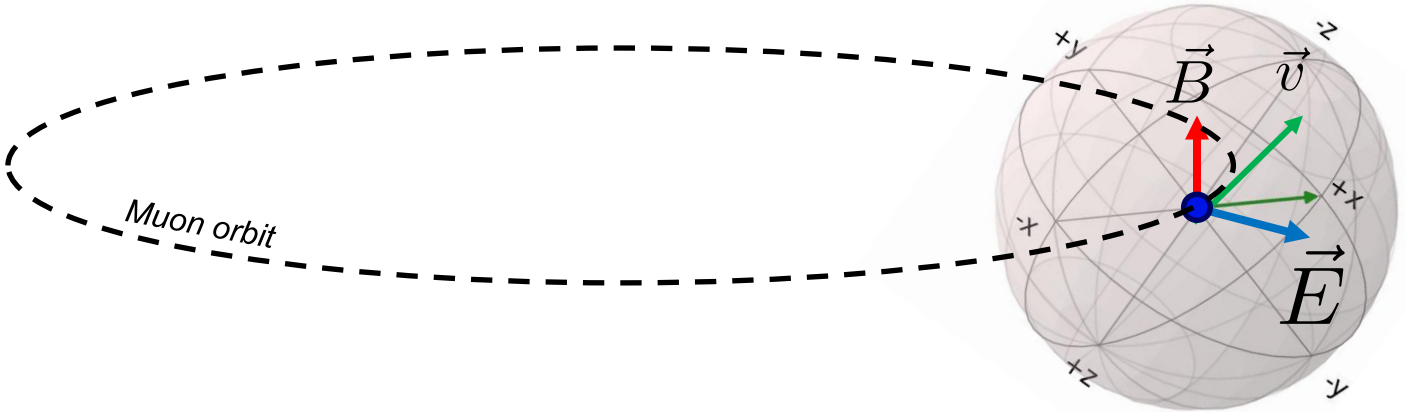
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Frozen-spin technique



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Frozen-spin technique



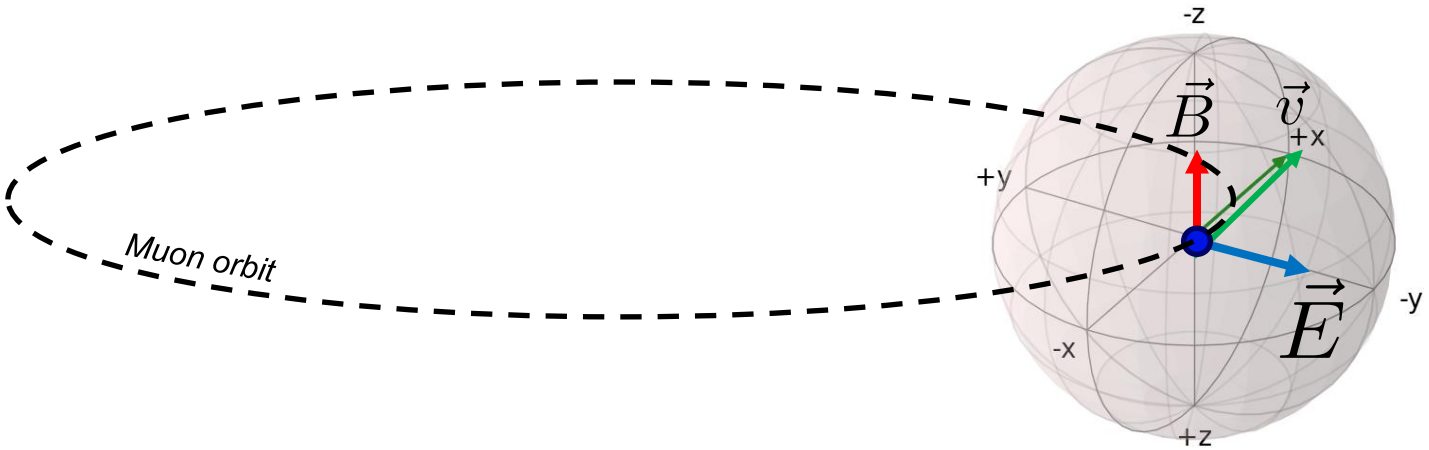
Thomas BMT Equation

EDM contribution

$$\vec{\Omega} = \frac{q}{m}\left(a\vec{\mathrm{B}} - \frac{a\gamma}{\gamma+1}(\vec{\beta}\cdot\vec{\mathrm{B}})\vec{\beta} - (a+\frac{1}{1+\gamma^2})\frac{\vec{\beta}\times\vec{E}}{c}\right) + \frac{\eta q}{2mc}\left(c\vec{\beta}\times\vec{B} + \frac{\gamma c^2}{\gamma+1}(\vec{\beta}\cdot\vec{\mathrm{E}})\vec{\beta} + \vec{E}\right)$$

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Frozen-spin technique



Thomas BMT Equation

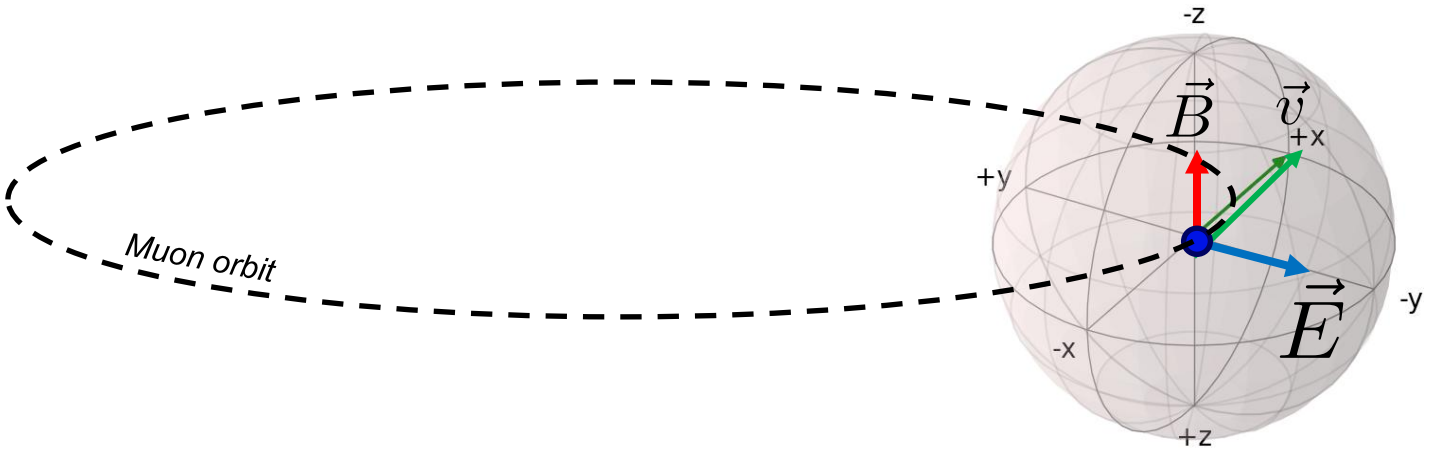
EDM contribution

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$\vec{\mathrm{B}} \perp \vec{\beta} \perp \vec{\mathrm{E}}$

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Frozen-spin technique



Thomas BMT Equation

EDM contribution

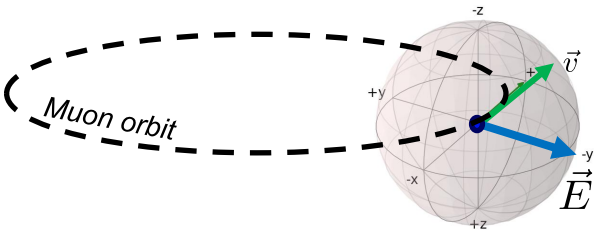
$$\vec{\Omega} = \frac{q}{m}\left(a\vec{B} - \frac{a\gamma}{\gamma+1}(\vec{\beta}\cdot\vec{B})\vec{\beta} - (a+\frac{1}{1+\gamma^2})\frac{\vec{\beta}\times\vec{E}}{c}\right) + \frac{\eta q}{2mc}\left(c\vec{\beta}\times\vec{B} + \frac{\gamma c^2}{\gamma+1}(\vec{\beta}\cdot\vec{E})\vec{\beta} + \vec{E}\right)$$

$\vec{B} \perp \vec{\beta} \perp \vec{E}$

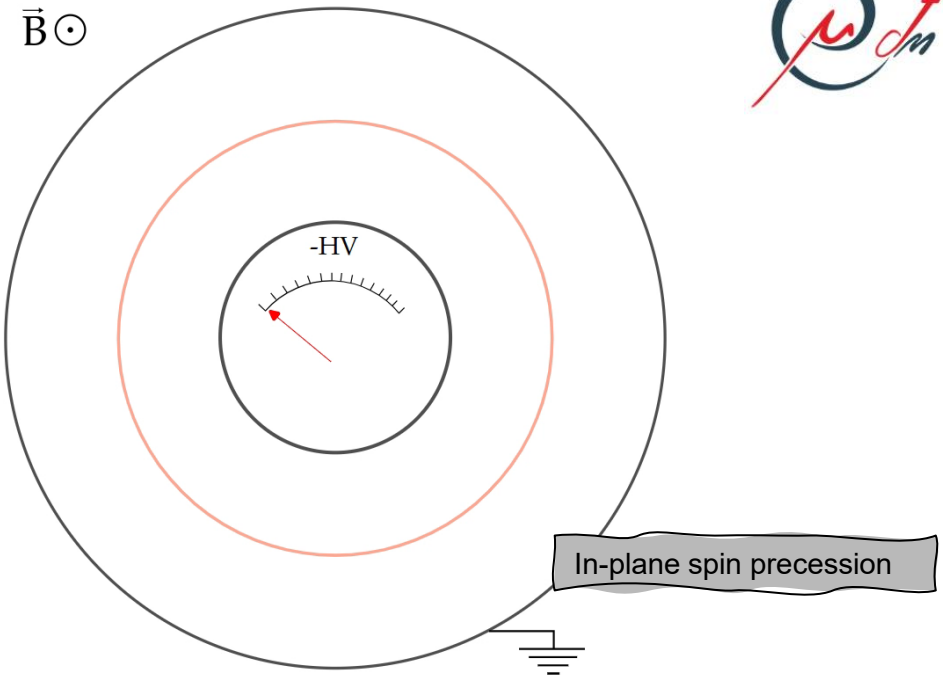
$$E \approx aBc\gamma\beta^2$$

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Frozen-spin technique



Out-of-plane spin precession



In-plane spin precession

EDM contribution

$$\vec{\Omega} = \frac{\eta q}{2mc}\left(c\vec{\beta} \times \vec{B} + \vec{E}\right)$$

$\vec{B} \perp \vec{\beta} \perp \vec{E}$

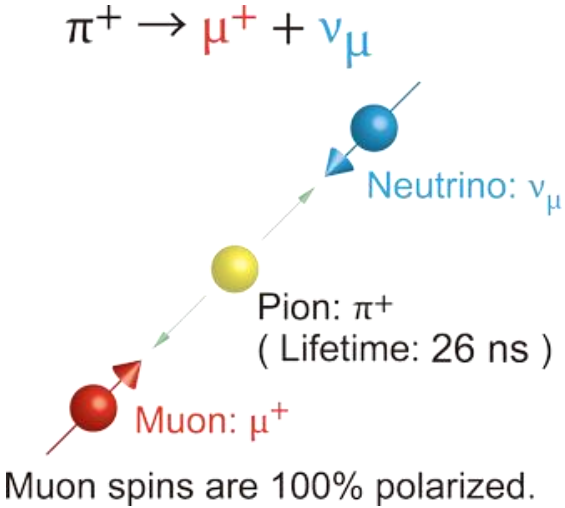
$$E \approx aBc\gamma\beta^2$$

In the **frozen-spin condition** the source **for out-of-orbit-plane** spin precession proportional to **only** the muon EDM.

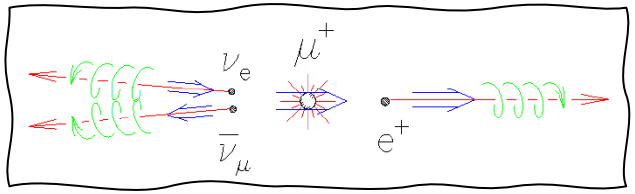
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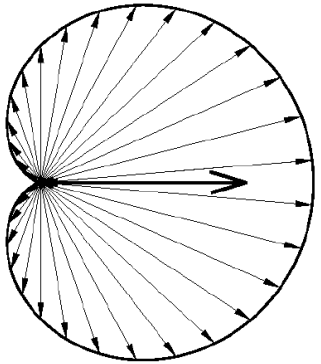
Measuring muon spin direction

Parity violating pion decay → muons are polarized



Muon spins are 100% polarized.





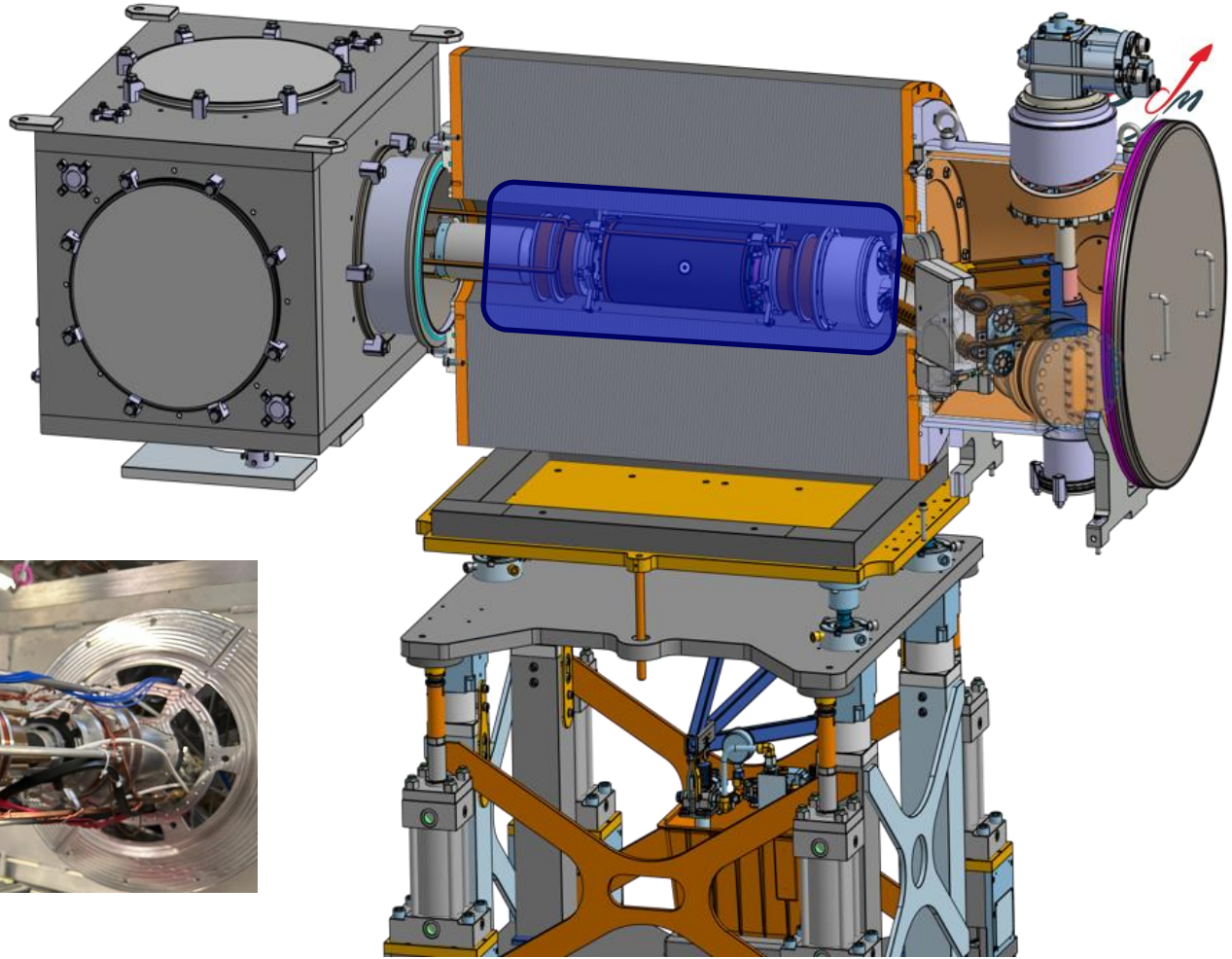
Detecting emitted positron direction from a polarized muon beam → muon **spin direction**.

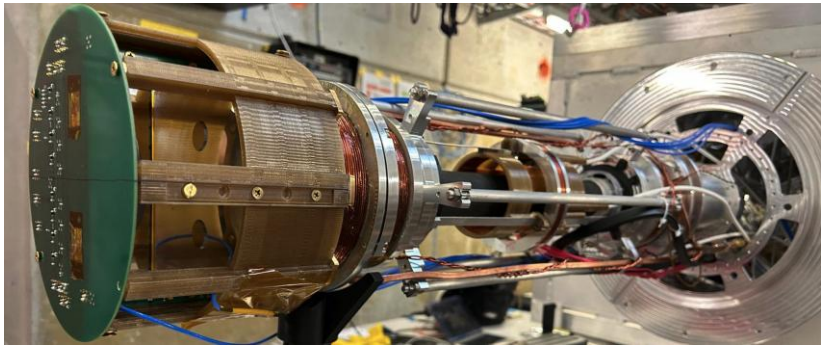
Experiment sensitivity to the muon EDM:

$$\sigma(d_\mu) = \frac{\hbar}{2P_0\beta c B\sqrt{N}\gamma\tau_\mu\tilde{\alpha}}$$

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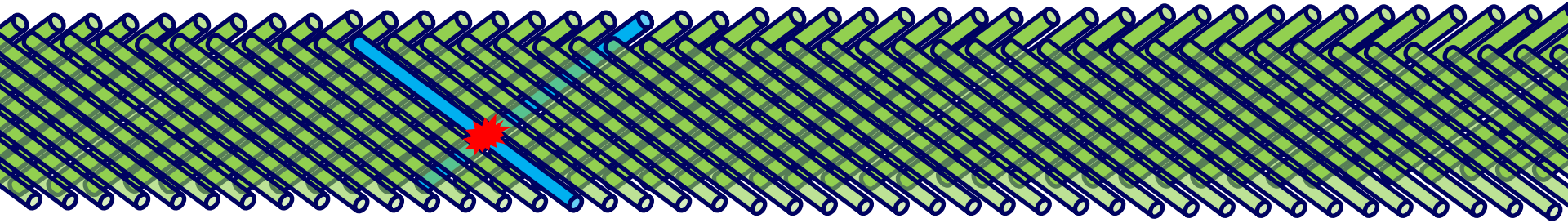
Internal structure





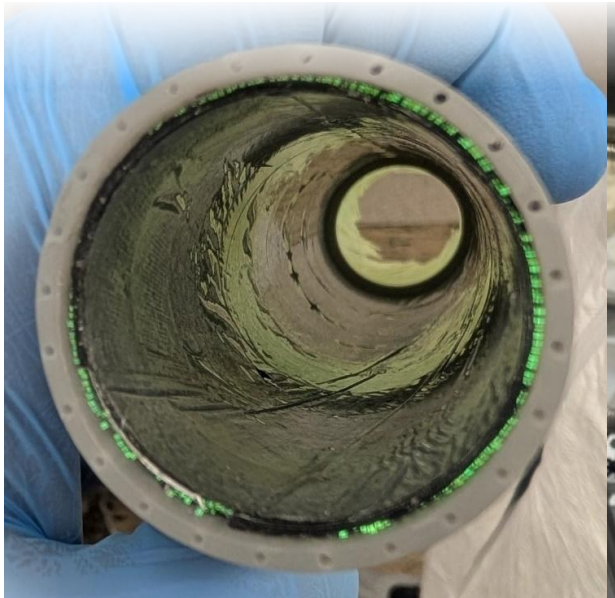
pranas.juknevicius@psi.ch

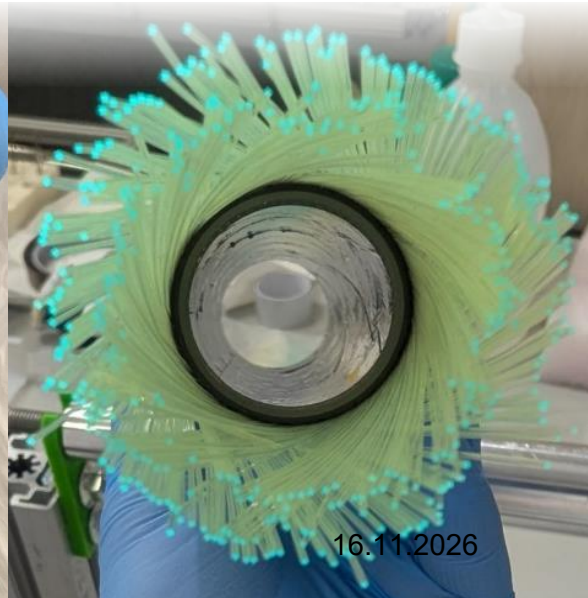
The Positron Tracker



Scintillating fiber detector:

- ~O(1000) scintillating fibers in hexagonal configuration
- Fiber coincidence → positron detection
- Able to reconstruct emitted positron trajectory
- Coaxial cylinders with 17 mm and 21 mm radius





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Conclusion

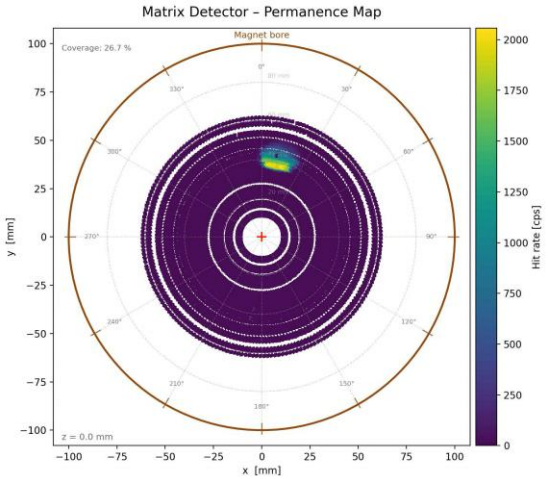
muEDM is a dedicated search for the muon electric dipole moment with a novel frozen-spin method approach.

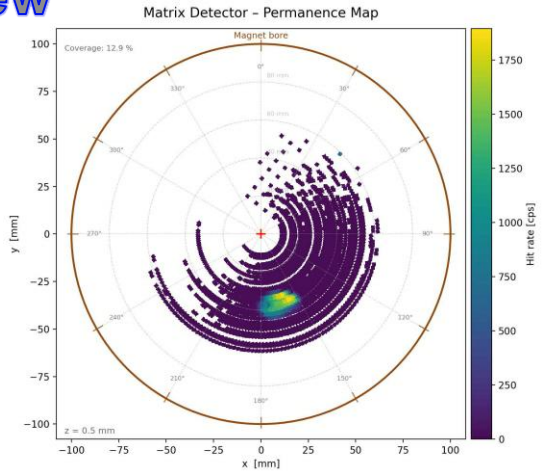
2025 integrated and tested:
- Injection with SC channel
- Kicker system for pulsed field
- Cylindrical positron detectors
- DAQ system

2026 focus:
- Integration of frozen-spin electrodes
- **Demonstrate muon storage**
- **Demonstrate the frozen-spin method**

2027 focus:
- **Establish per muon sensitivity to EDM**

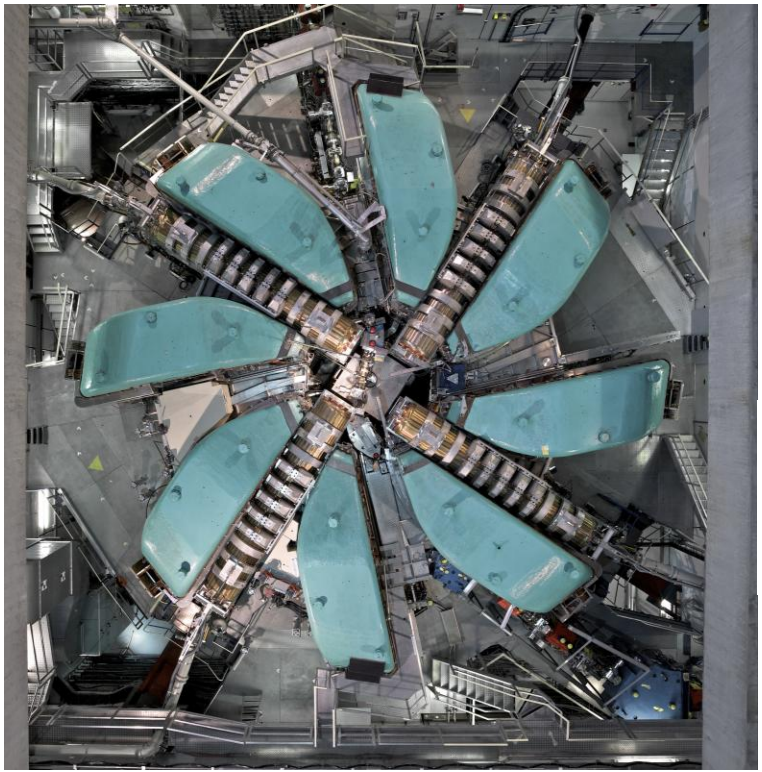
Beamtime 2026 preview





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The muEDM collaboration





Questions?

INFN
Istituto Nazionale di Fisica Nucleare

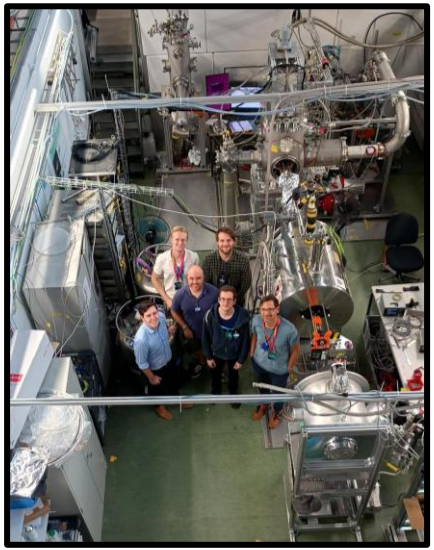
PSI

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

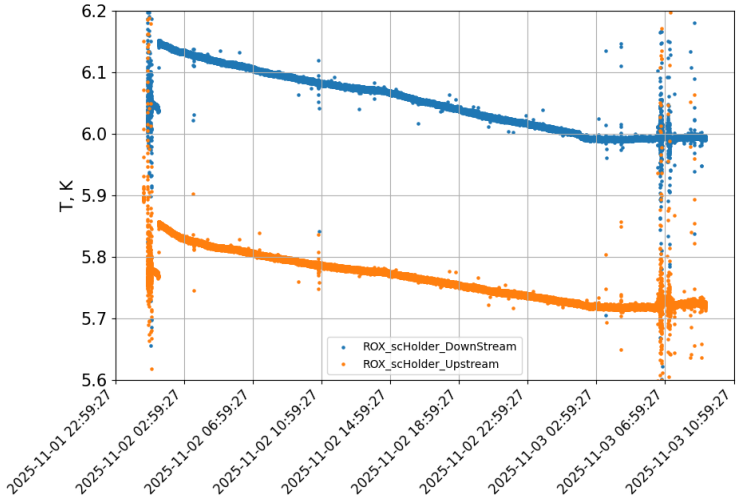
Swiss Confederation

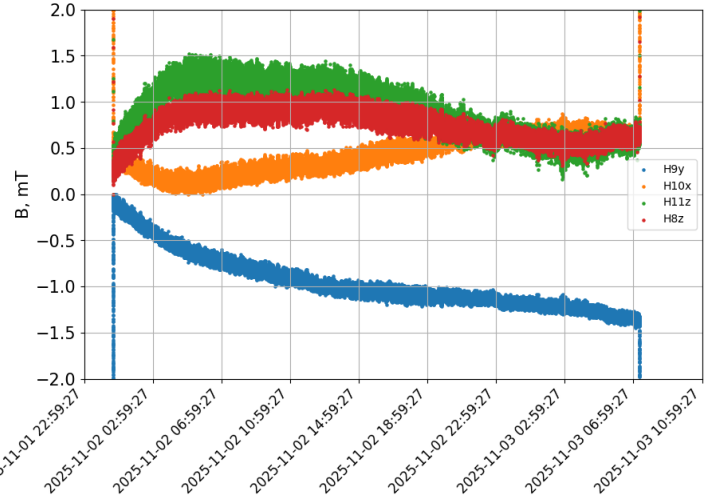
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI



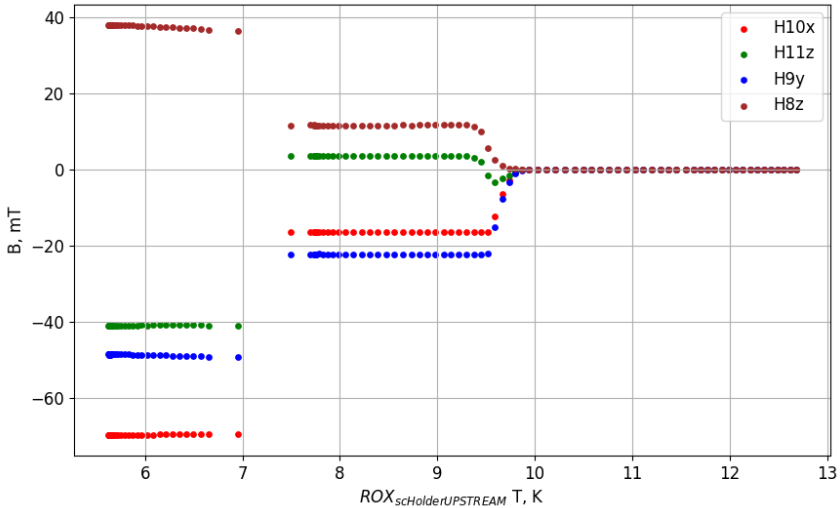
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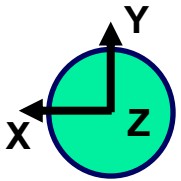
Shielding current decay at 1T





Tc measurement at 0T

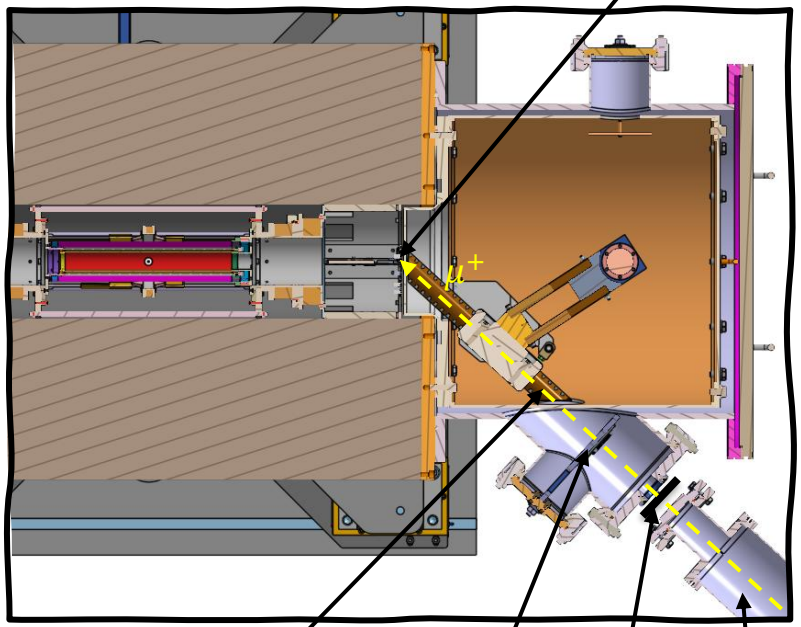


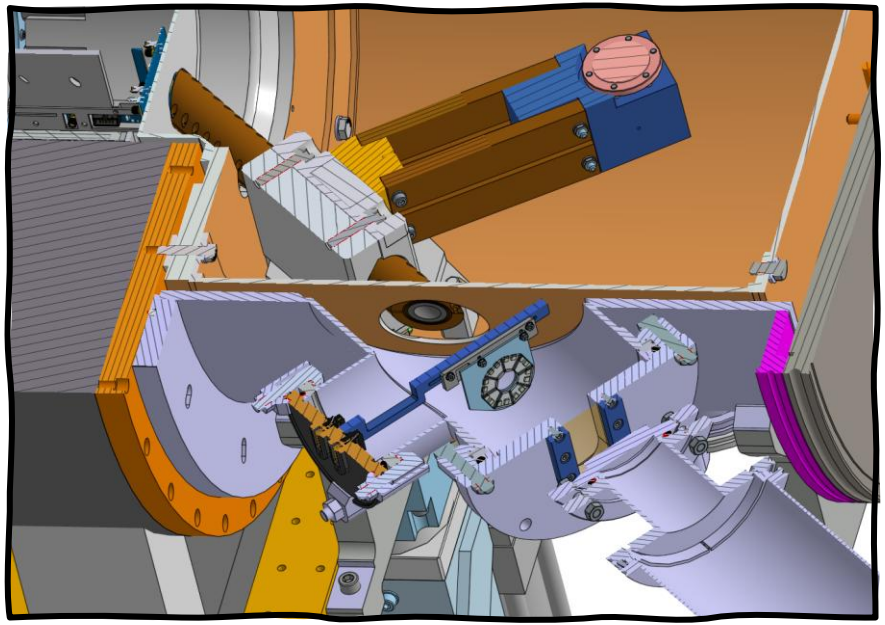


Literature value of Nb-Ti $T_c(\mu H_{\text{ext}} = 0) = 9.6$ K
J. Guo et al., *Record-High Superconductivity in Niobium–Titanium Alloy*, *Advanced Materials* **31**, 1807240 (2019)

16.11.2026

Beamtime results





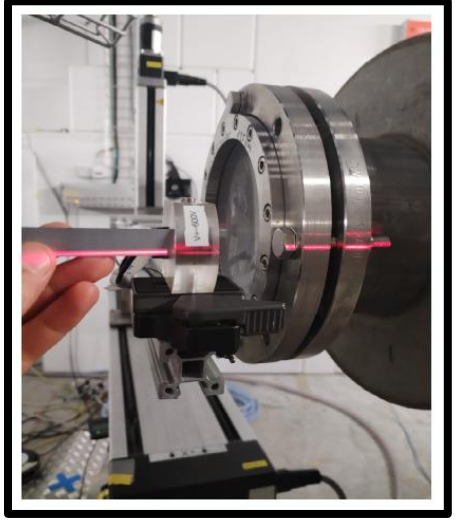
Vacuum $p \approx 2 \cdot 10^{-6}$ mBar.
Cooldown time 300K to 4K $t \approx 31$ hours .
Heat up time 3K to 300K t $\approx$ 30 hours.

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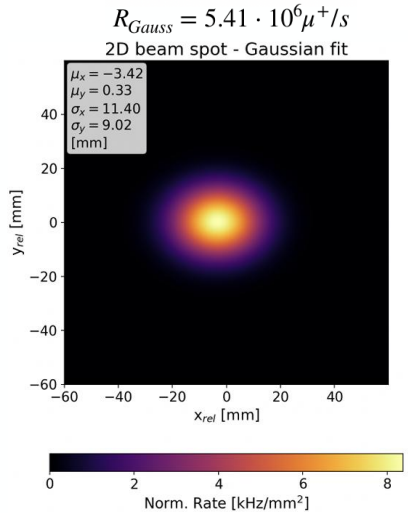
Beam phase space measurements

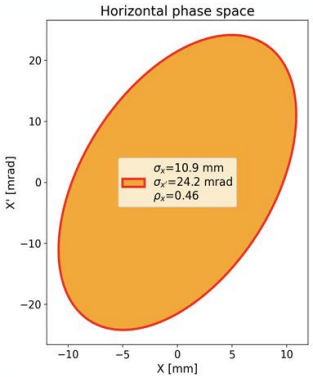
Setup:

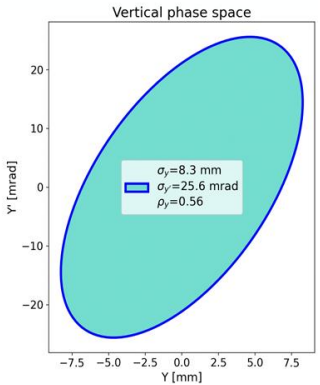
- Plastic scintillator (r = 1 mm) with PhotoMultiplier Tube (PILL) readout.
- X-Y positioning table for automated scans.

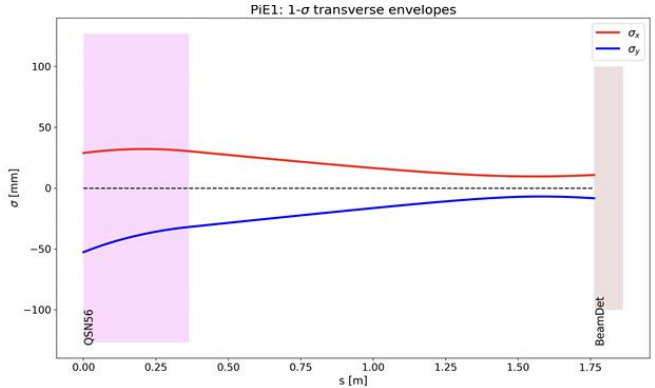


Results from beam phase space measurements using *muEDM_2025_27.5_Gate_v3.sp*







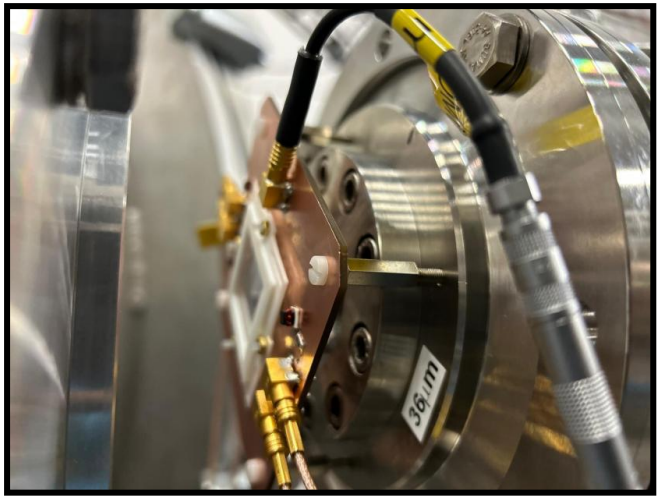


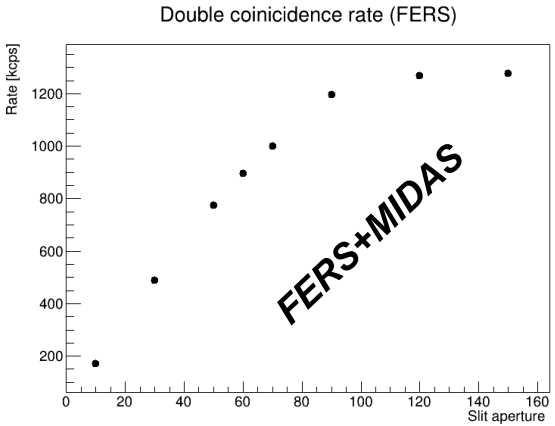
Credits to Francesco Leonetti.

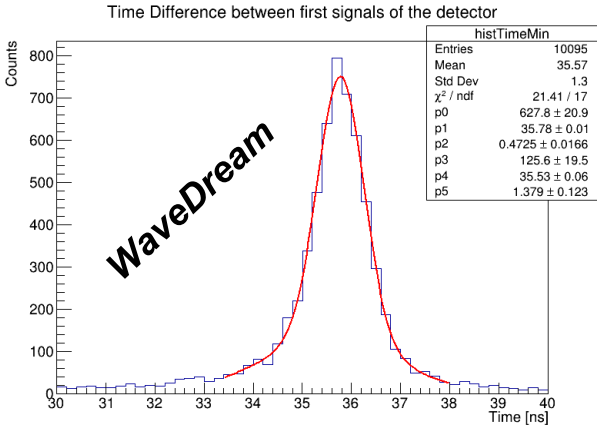
ToF detector

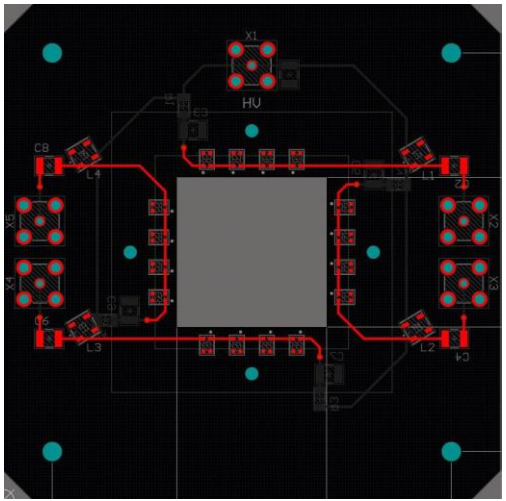
Time of flight (ToF) detector used to measure muon momentum with the requirements:

- $\sigma_p < 1\%$ essential to control systematic uncertainties.
- Time resolution $\sigma_t < 1\ ns$ (measured $\sigma_t \approx 473$ ps using WaveDream).
- Readout using Caen FERS boards using MIDAS DAQ system.



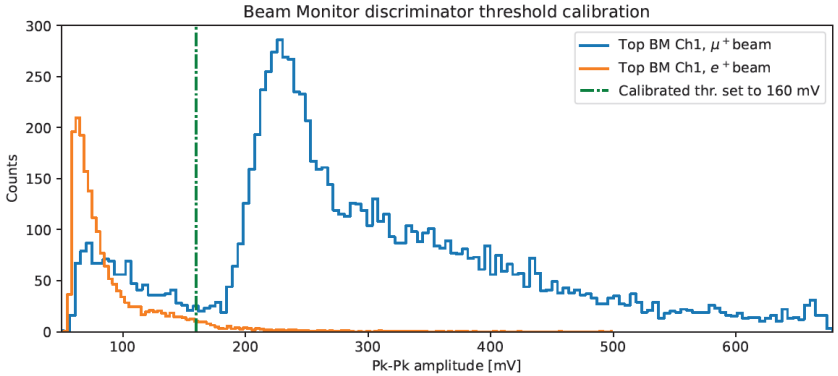


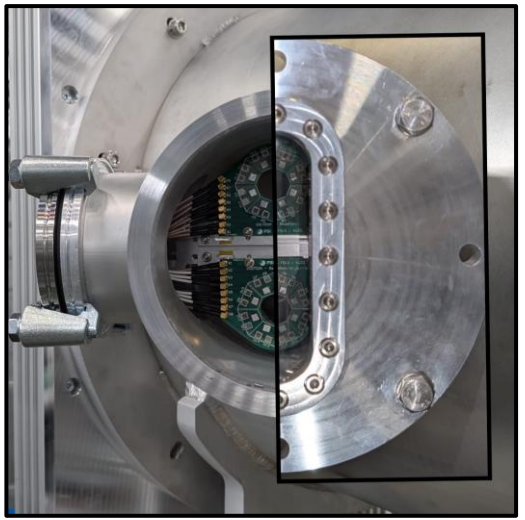


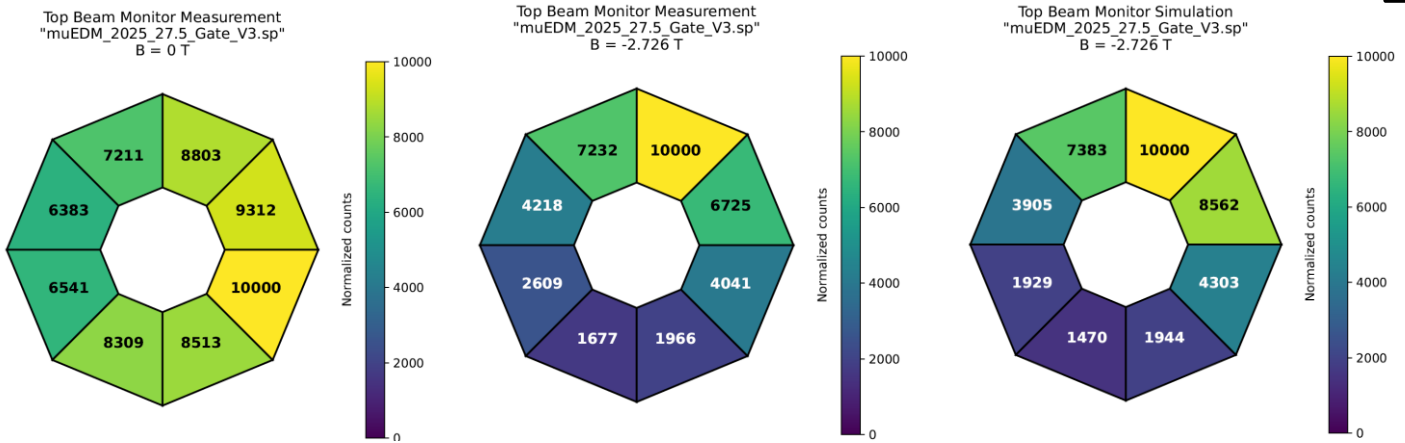


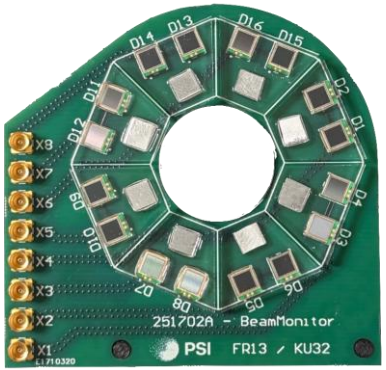
Credits to Angela Papa and Elisa Checchi.

Beam monitor



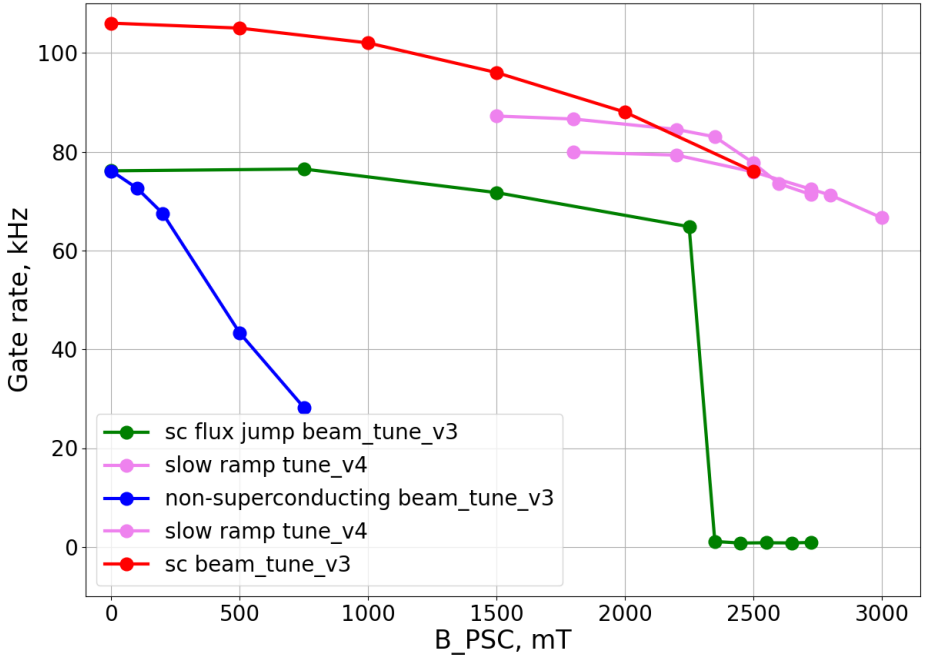




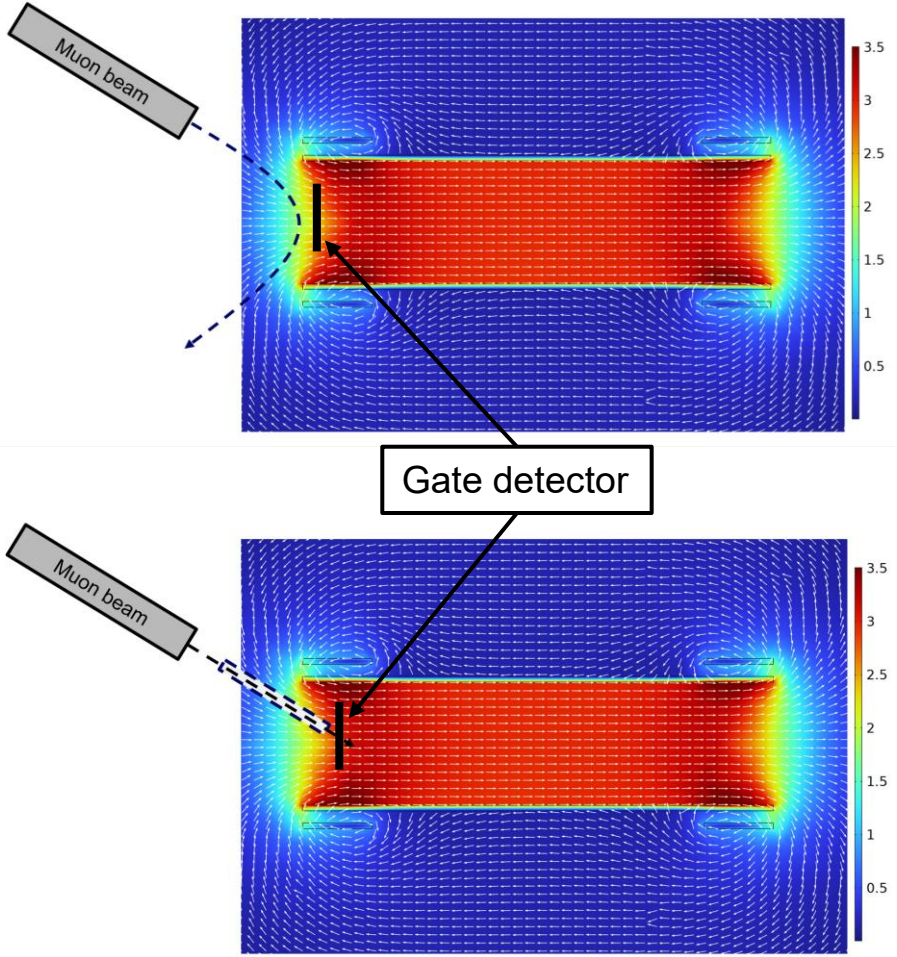


Credits to Simone Mariottini and Liljana Morvaj.

Beamtime results

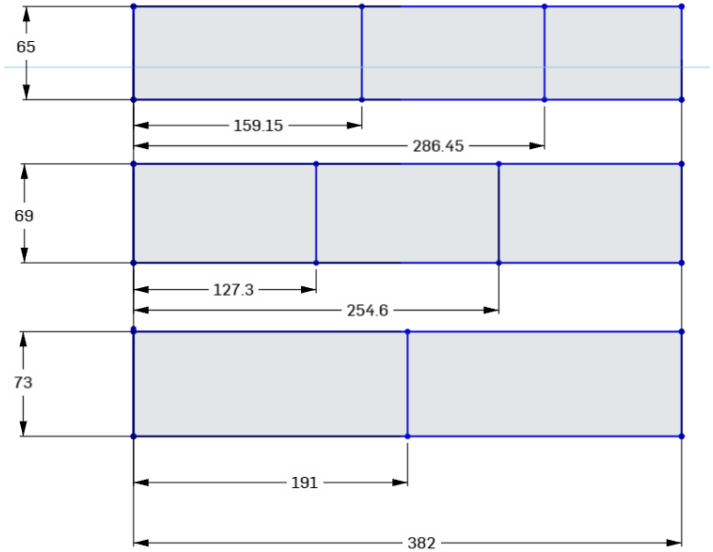


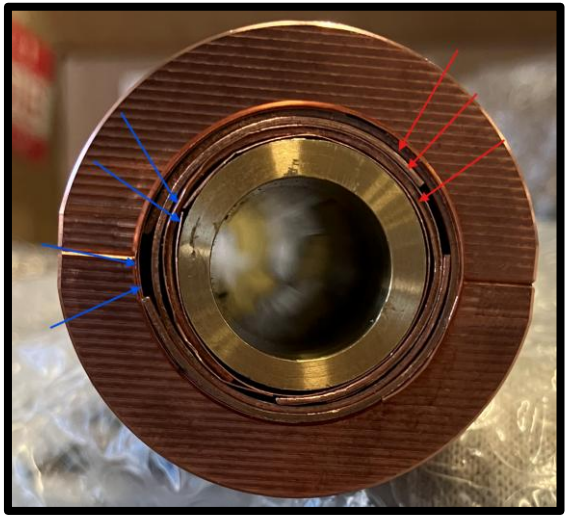
Unexpected flux jumps at $B_{\mathrm{PSC}} > 2$ T.
$T_{\mathrm{sc_holder}} \approx 3.1$K, while in prebeamtime studies $T_{\mathrm{sc_holder}} \approx 5.6$K.
Similar unstable behaviour for Nb-Ti/Cu/Ti sheets was reported in *DOI:10.1109/TASC.2022.3149726 D. Barna et al.*



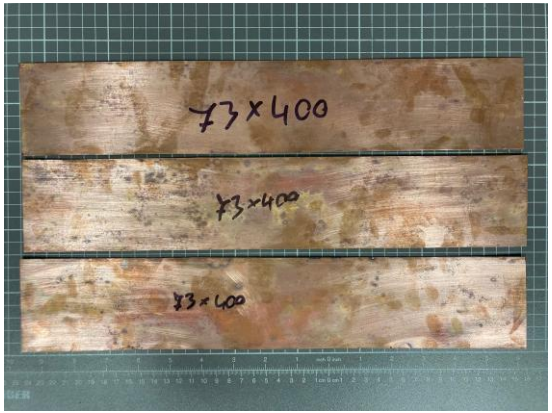
16.11.2026

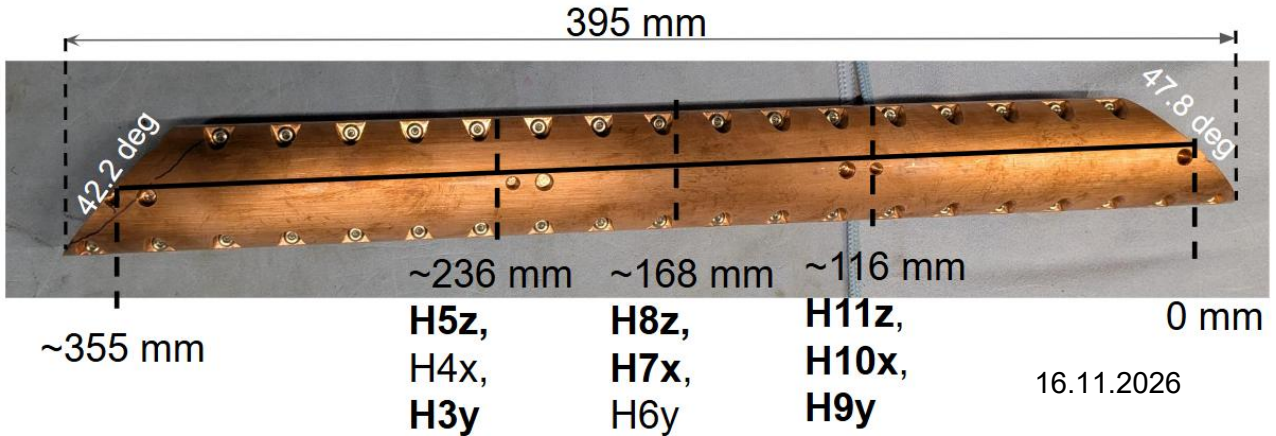
Injection channel design



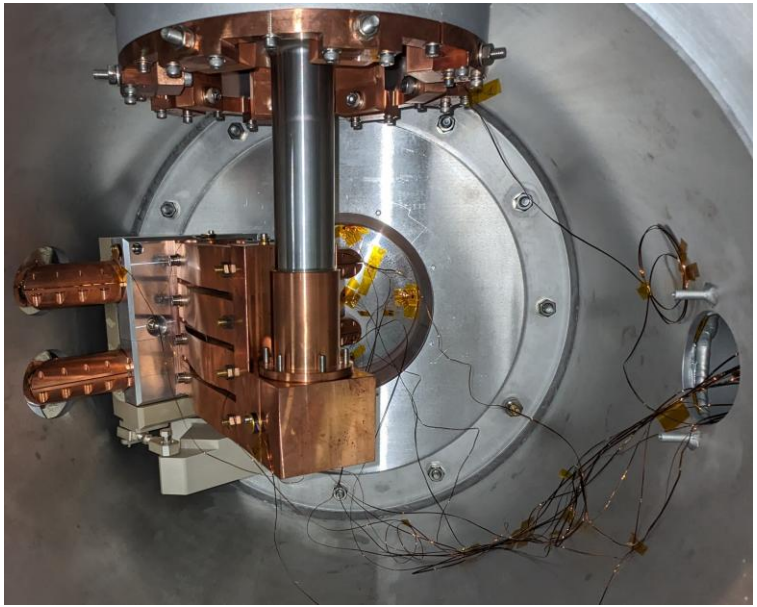


Cross section of the sc injection channel. Red arrows – NbTi sheets w = 0.7mm, blue arrows – 0.1mm Cu fillers. ID = 15mm and OD = 40mm.





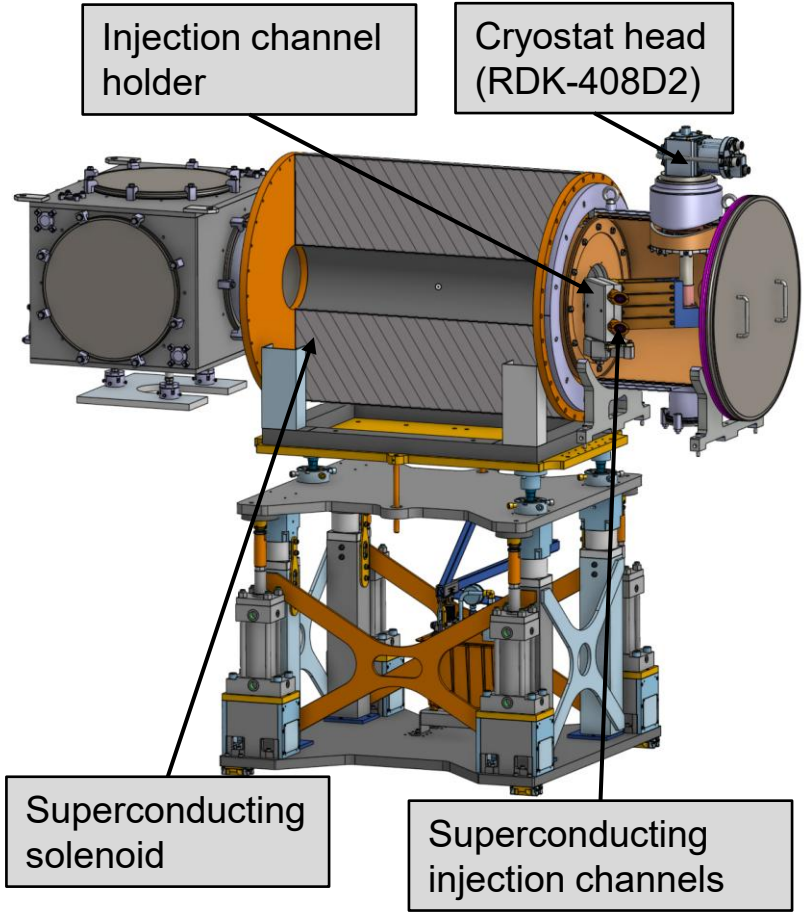
Backup

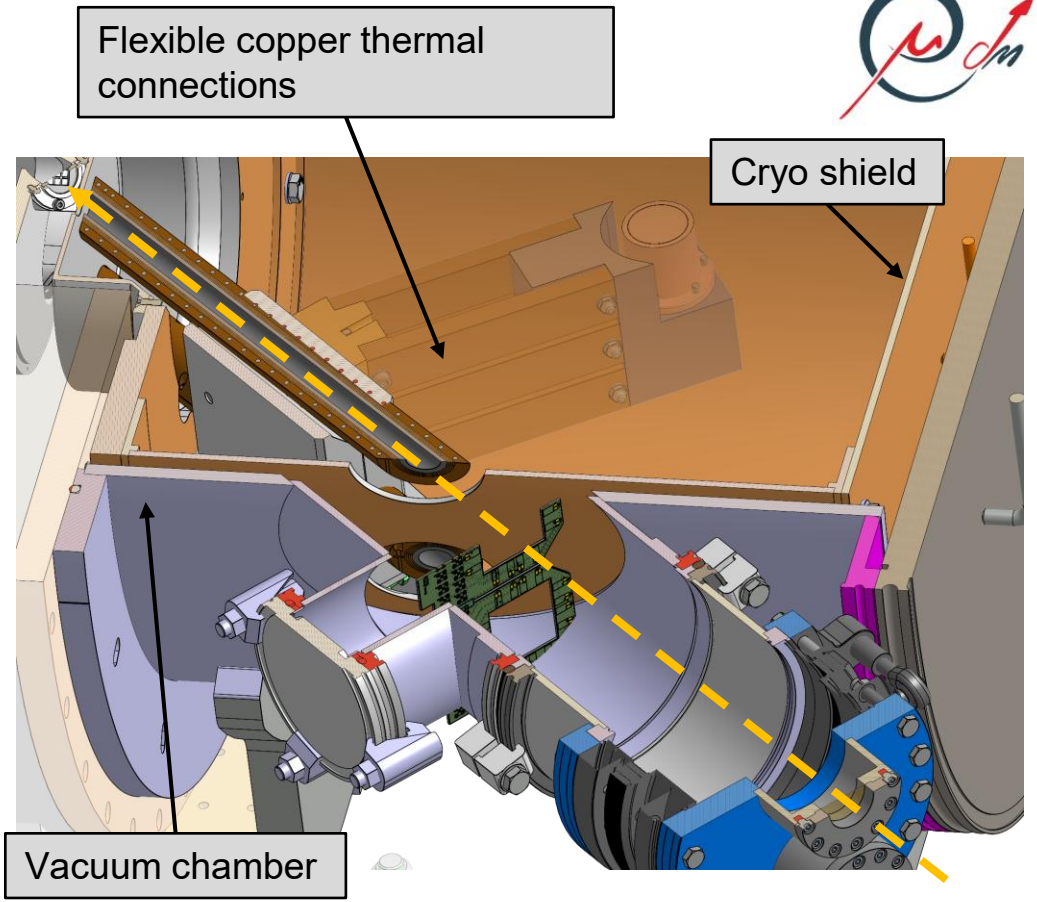




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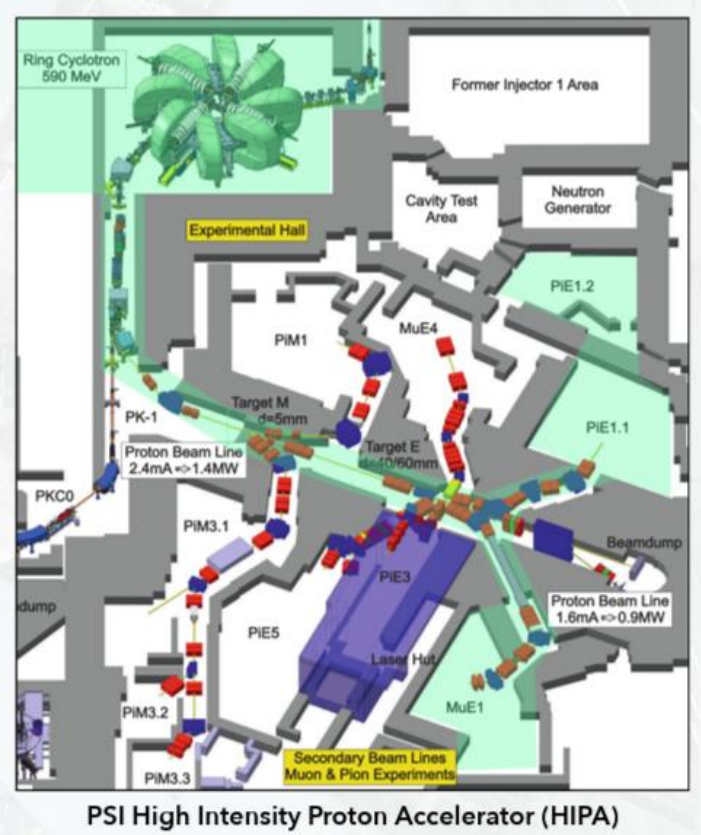
Beamtime results





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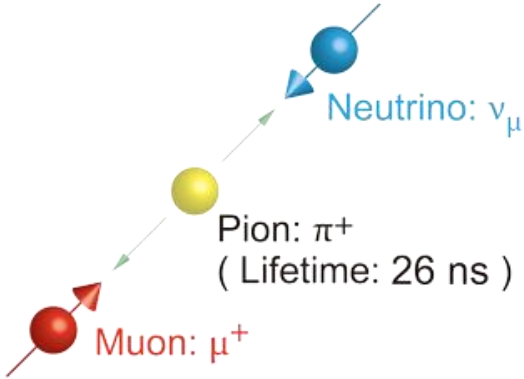
Muon production at PSI



PSI High Intensity Proton Accelerator (HIPA)

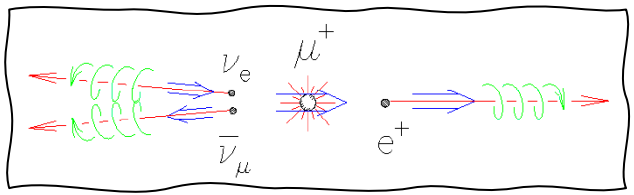
Pion decay at rest

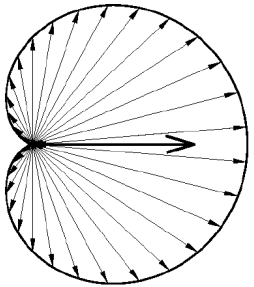
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$



Muon spins are 100% polarized.

Muon decay



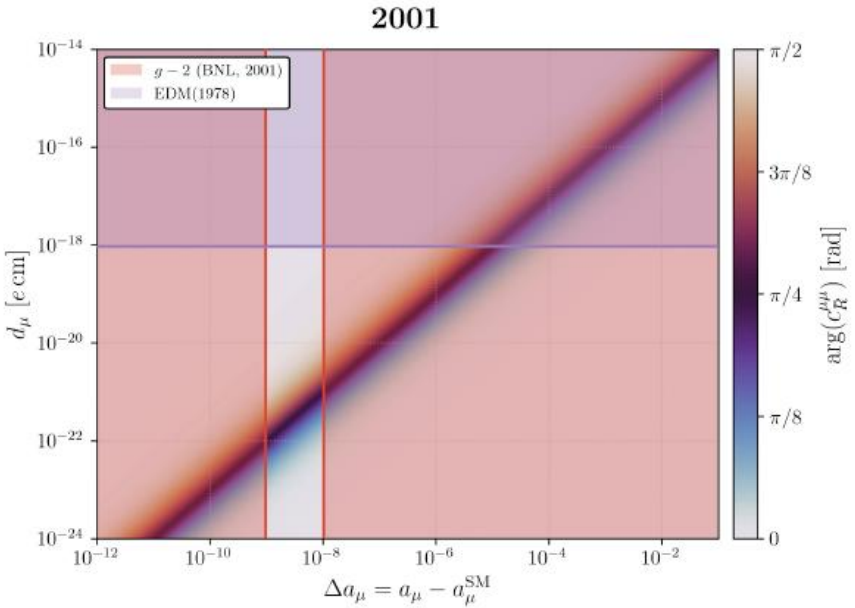


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$$H_{\text{eff}}^{NP} = c_R^{\mu\mu}\,\bar{\mu}\,\sigma_{\alpha\beta}P_R\,\mu\,F^{\alpha\beta} + \text{h.c.}$$

The phase $\arg(c_R^{\mu\mu})$ of its Wilson coefficient relates the two moments.

$$\Delta a_\mu = \frac{4m_\mu}{e}\text{Re}(c_R^{\mu\mu}) \qquad d_\mu \approx \Delta d_\mu = -2\text{Im}(c_R^{\mu\mu})$$



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