

Mu3e and MuEDM

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HEP Meeting

19 May 2022

Interesting physics, ranked

1. Muons
2. [everything else]

Muon physics

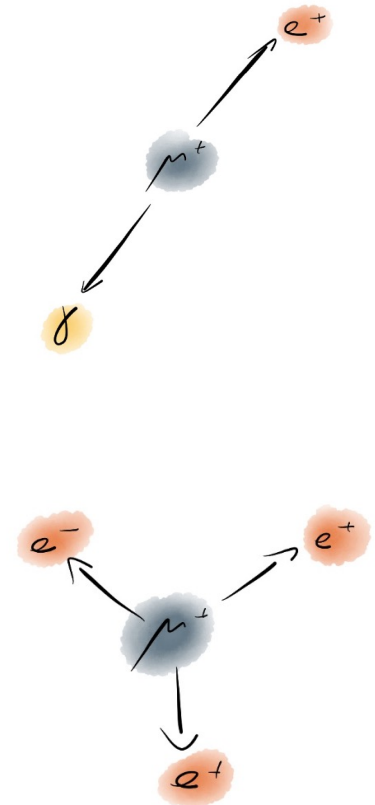
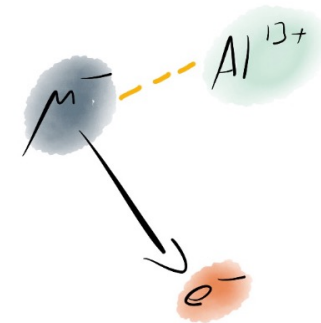
Search for new physics in muon sector since muon discovery, recently boosted by results from $g - 2$ and lepton universality results.

If there is new physics in the muon sector:

- cLFV experiments will explore possibility of non-zero flavor mixing
- Muon EDM measurements provide sensitivity to CP violation

Charged Lepton Flavor Violation?

- No reason to expect lepton flavor conservation
 - See flavor violation in quarks and neutrinos
- $\mu \rightarrow e\gamma$
 - MEG-II (PSI)
- $\mu N \rightarrow eN$
 - COMET (J-PARC)
 - Mu2e (Fermilab)
 - Just 1 electron
- $\mu \rightarrow eee$
 - Mu3e (PSI)
 - Properly 3 electrons



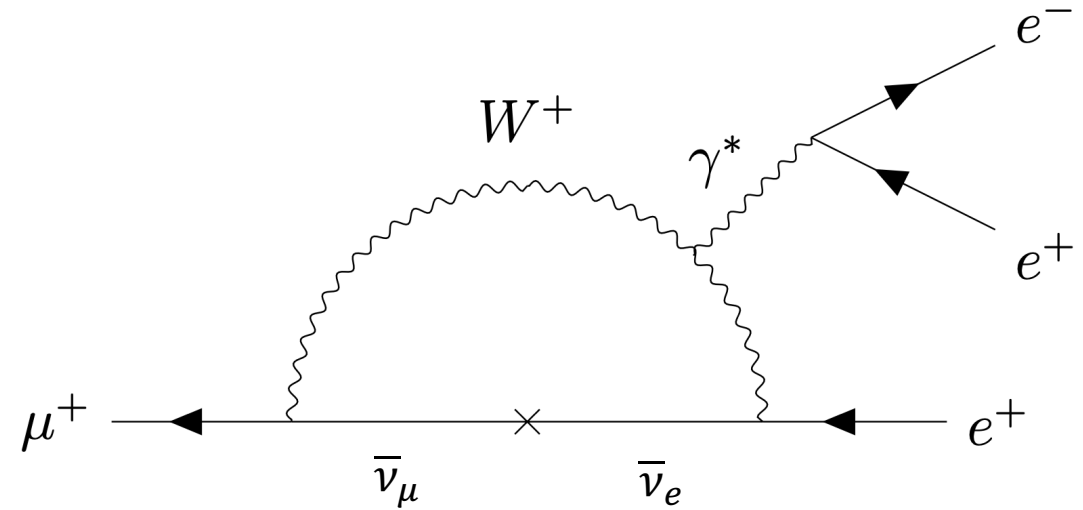
$\mu \rightarrow eee$

- Mu3e

- SM : $\text{BR}(\mu \rightarrow eee) < 10^{-50}$
 - Neutrino mass mixing

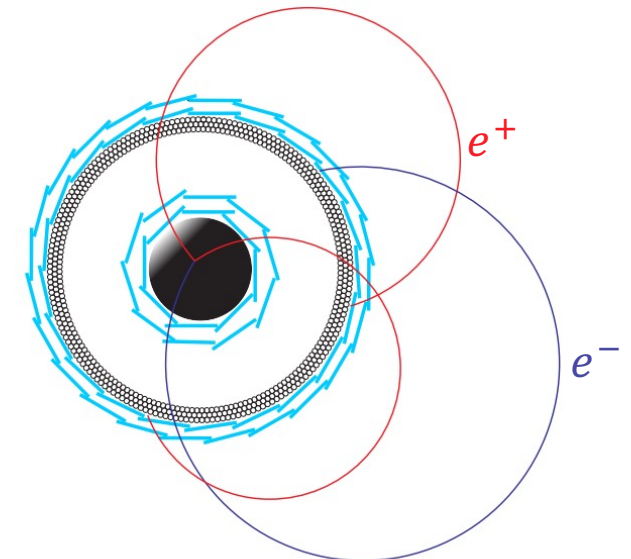
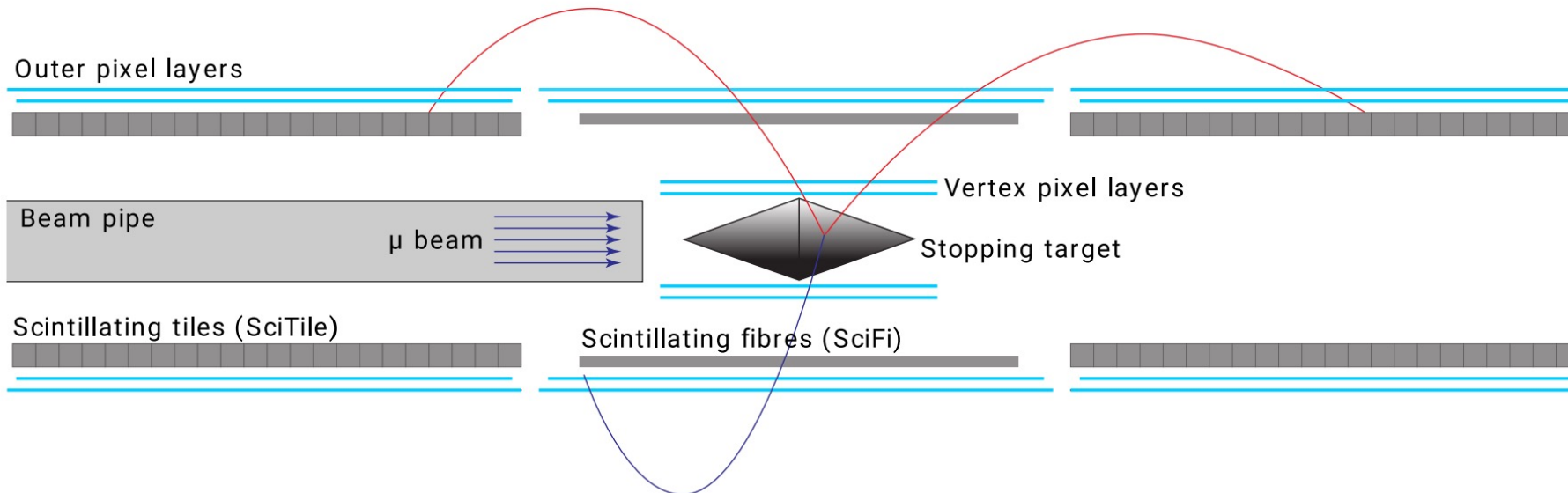
- Current limit, SINDRUM (1988) : 10^{-12}

- Phase-I goal : $2 \cdot 10^{-15}$



Mu3e at Paul Scherrer Institut (PSI)

- 10^8 muons / s stopped on mylar double-cone target
- Pixel layers for tracking
- Scintillating fibers/tiles for timing



Liverpool roles

- Module assembly tooling development
- Construction of thermo-mechanical mock-up modules
- Construction of full central outer tracker thermal test stand for Helium cooling verification
- Assembly of all outer pixel modules
 - Ladders are assembled in Oxford
- Tooling for module mounting

Mu3e construction status

Experiment overall

- Muon beam line and experiment solenoid in place at PSI
- Detector cage with prototype vertex detector operated in 2021
- Full readout chain and much of the external services operational
 - Subset of final gaseous Helium cooling system operational. New approach based on compact turbo compressors.

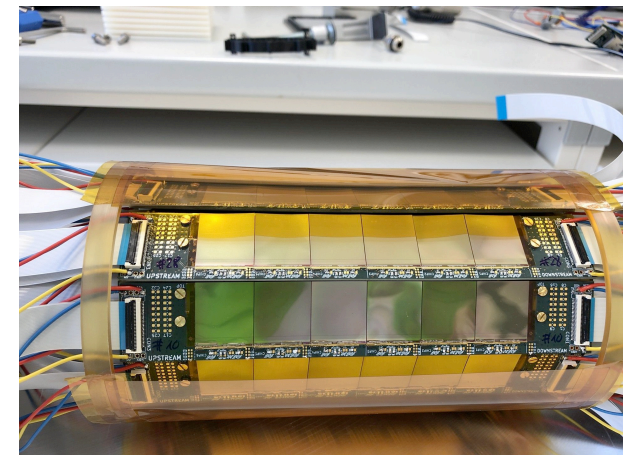
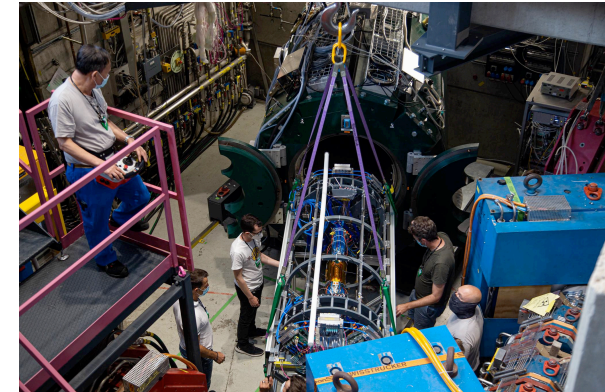
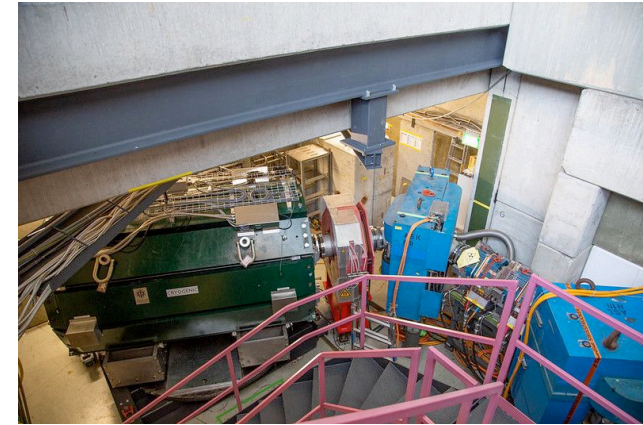
For the pixel project

UK groups responsible for the outer pixel layers, based on the MuPix HV-CMOS chips

- Full set of inner pixels with MuPix10 prototype chips successfully operated in integration test 2021
- MuPix11, final production chip expected from foundry in June/July
- Very challenging loss of manufacturer of the low mass Al-kapton flex circuits (the company is based in Kharkiv, Ukraine).. alternatives now under development
- The UK outer pixel ladder and modules project is still going through tooling development/optimisation.

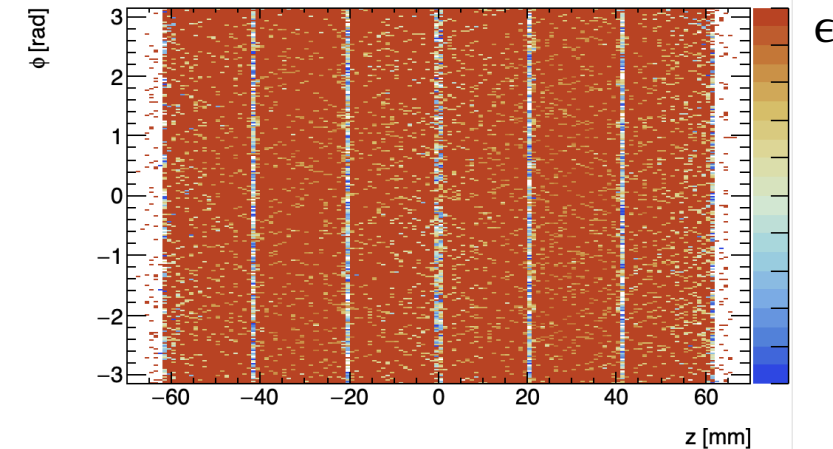
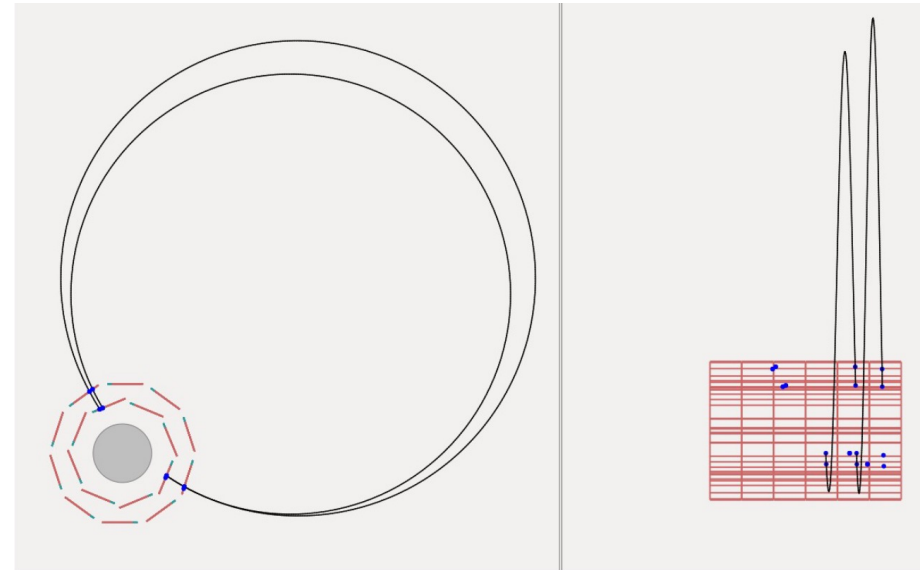
Current schedule

- Installation by start of 2024
- Commissioning 2024
- Physics (Phase-I) operation 2025/2026 before HIMB shutdown in 2027



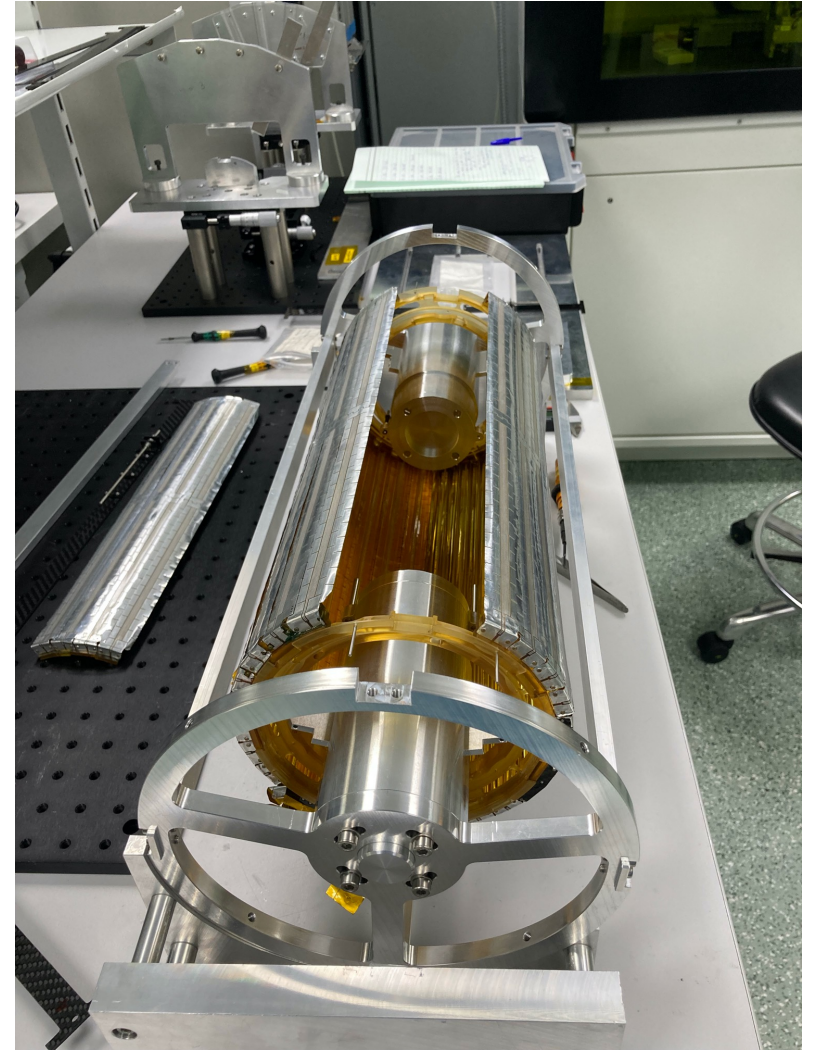
Reconstruction and analysis work

- 2-layer tracking (Sean)
 - Setup of Integration Run 2021 and Cosmic Run 2022
- Production of large-scale MC samples (Carlos)
 - Benchmarking different versions of Mu3e code
- Tracking with inefficient and noisy pixels (Afaf)
- Measuring efficiency of chips with data



Thermal test stand

- Current Helium cooling infrastructure provides 2 g/s
 - For the vertex detector (inner 2 layers)
- Need ~ 16 g/s to cool the outer layers
- Mock-up of layers 3 and 4 using resistive heater modules
- Build setup locally
 - Take to PSI for helium tests



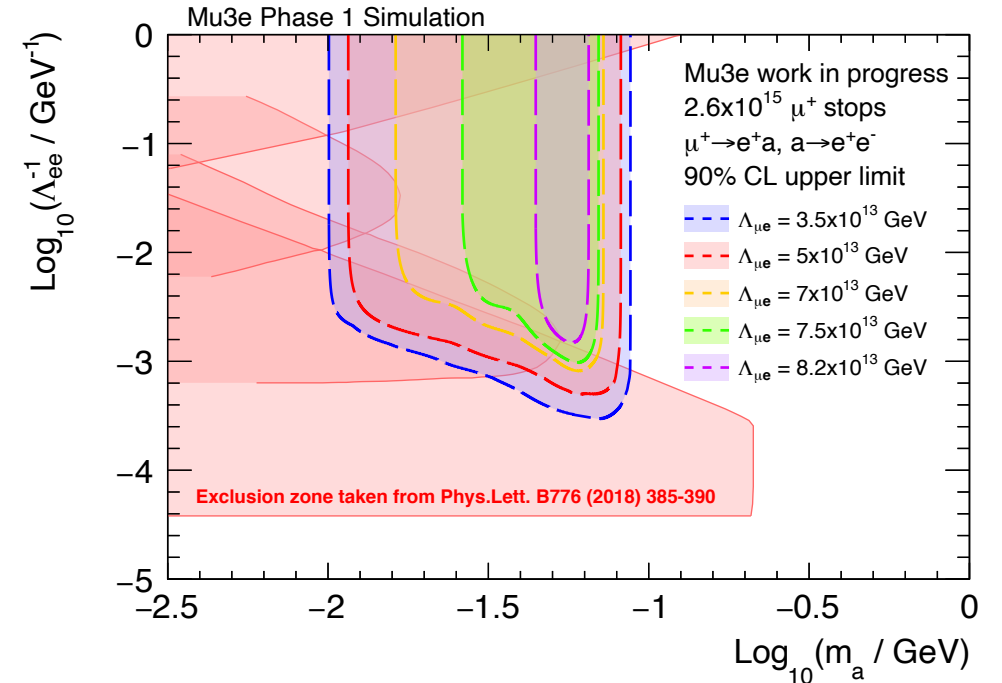
Contribution to Snowmass 2021

- [arXiv:2204.00001](https://arxiv.org/abs/2204.00001)
- Highlighting the possibility of searches for dark photons and axion-like particles using the Mu3e detector and analysis framework

The Mu3e Experiment

Gavin Hesketh, Sean Hughes, Ann-Kathrin Perrevoort, Nikolaos Rompotis (on behalf of the Mu3e Collaboration)

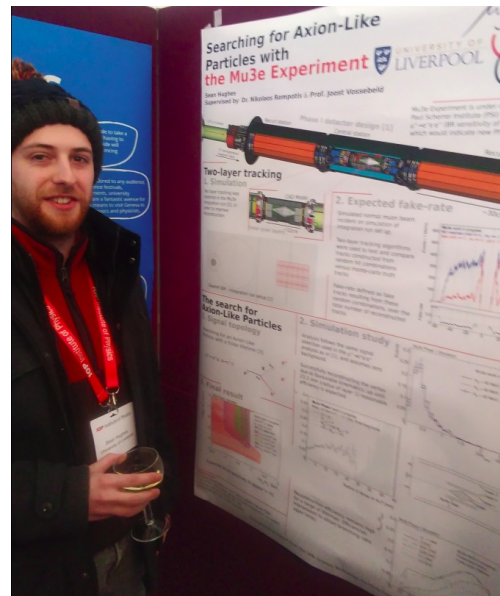
The Mu3e experiment at the Paul Scherrer Institut will search for the lepton-number-violating decay $\mu \rightarrow e e e$, extending the sensitivity by four orders of magnitude compared to existing limits. This probe of new physics is complementary to the existing collider, dark matter and neutrino particle physics programmes, and part of a global programme investigating the charged lepton flavour sector. As well as the main $\mu \rightarrow e e e$ search, Mu3e will also extend the sensitivity to low-mass dark photons, and additional flavour-violating decays involving long-lived or stable particles.



Congratulations!

- **Dr. Andrew Groves**
 - First Liverpool PhD on Mu3e

- **Sean Hughes**
 - IOP poster runner-up



Mu3e Collaboration Meeting at PSI



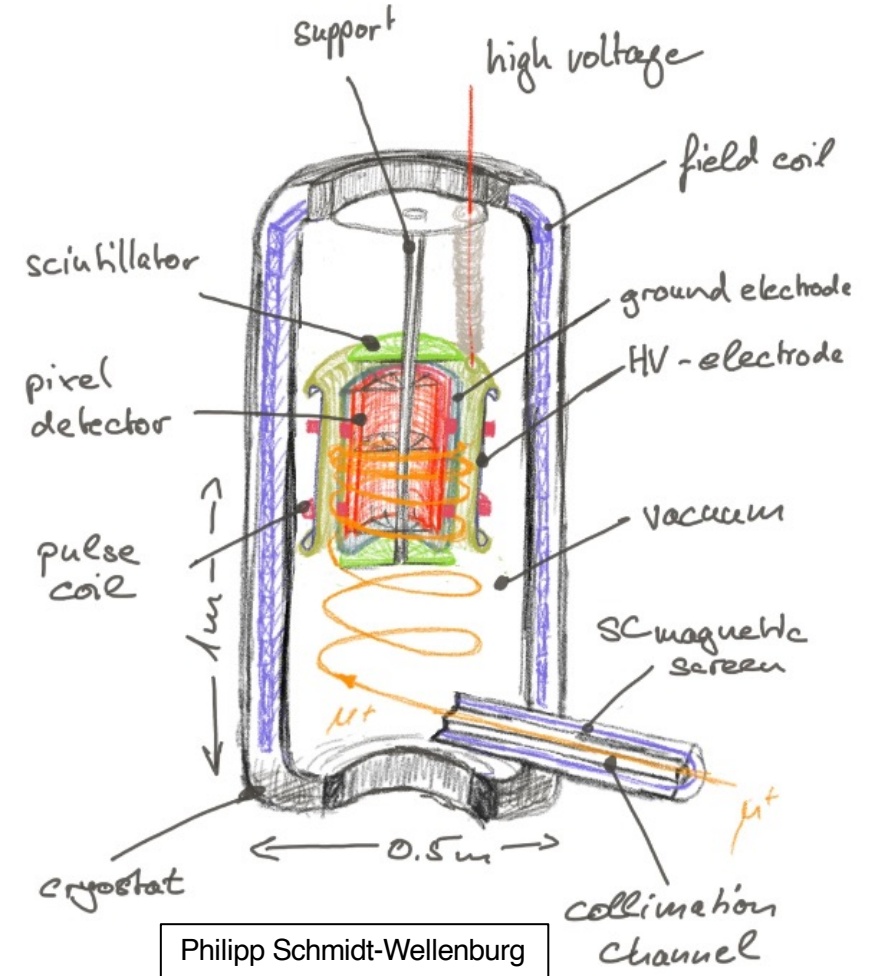
MuEDM

MuEDM measurement concept

- I. Muons are injected into a solenoid on a vertical spiralling path ..
- II. Trigger station identifies muons on a suitable trajectory and triggers a magnetic pulse to remove the muon's longitudinal movement
- III. Weak focussing field traps the muon in a circular orbit
- IV. Modified "frozen spin" technique: E-field tuned to remove the g-2 precession leaving only the out of plane component due to the EDM

$$\vec{\omega} = \frac{q}{m} \left[\underbrace{a\vec{B} + \left(\frac{1}{1-\gamma^2} - a \right) \frac{\vec{\beta} \times \vec{E}}{c}}_{\text{g-2 term}} + \underbrace{\frac{\eta_d}{2} \left(\frac{\vec{E}}{c} + \vec{\beta} \times \vec{B} \right)}_{\text{EDM term}} \right]$$

- V. Radial detector layers in and outside muon orbit measure residual g-2 precession
- VI. Up-down detector layers measure the out of plane precession



Proposed programme at PSI

Proposal for muEDM experiment in two phases:

I. Precursor

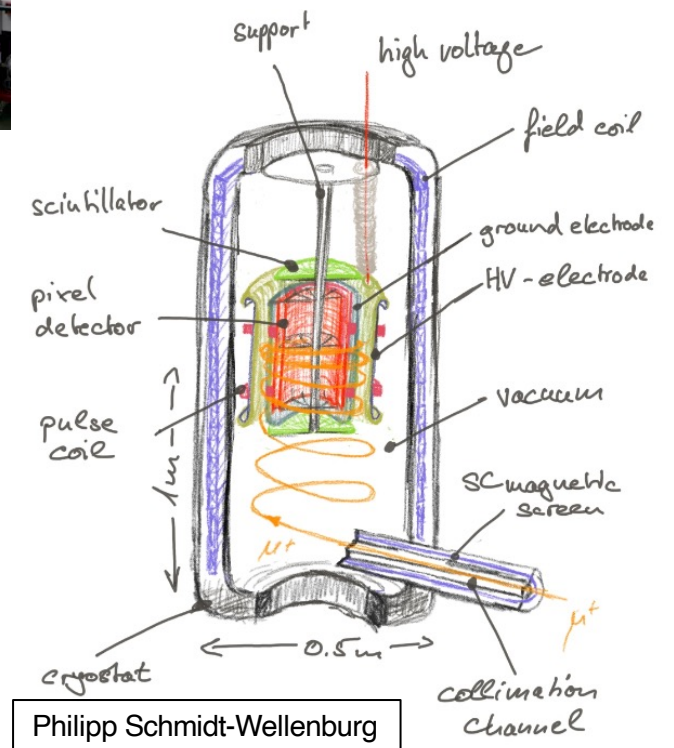
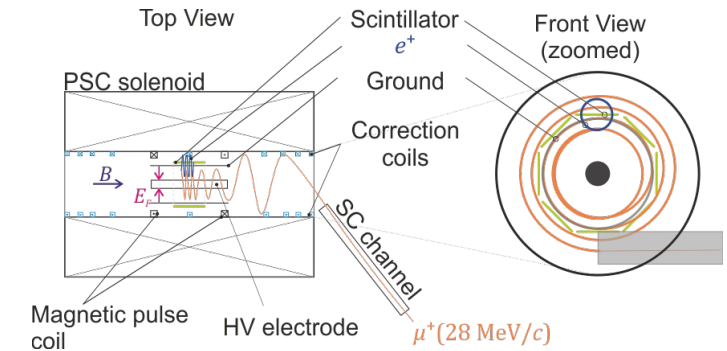
- 28 MeV muons in 200mm 3T solenoid
- Start of assembly 2025, first data 2026
- Demonstration of frozen spin technique for muon EDM
- muEDM precision expected $3 \times 10^{-21} \text{ ecm}$
- g-2 like thin straw tubes likely contender for radial layers

Formal approval precursor project at PSI foreseen for Feb 2023

Statement-of-Intent to STFC by UK groups this year.

I. Final muEDM search

- 125 MeV muons in larger bore magnet
- Start of assembly after HIMB upgrade, around 2028
- muEDM precision expected $6 \times 10^{-23} \text{ ecm}$
- Radial layer proposed to use MuPix chips



Thanks!

More muons to come...