PAUL SCHERRER INSTITUT

PSI

Chavdar Dutsov :: Paul Scherrer Institute :: on behalf of the muonEDM collaboration

Measurement of the Muon Electric Dipole Moment

CHRISP Users Meeting BVR55

Feb 2024 – PSI

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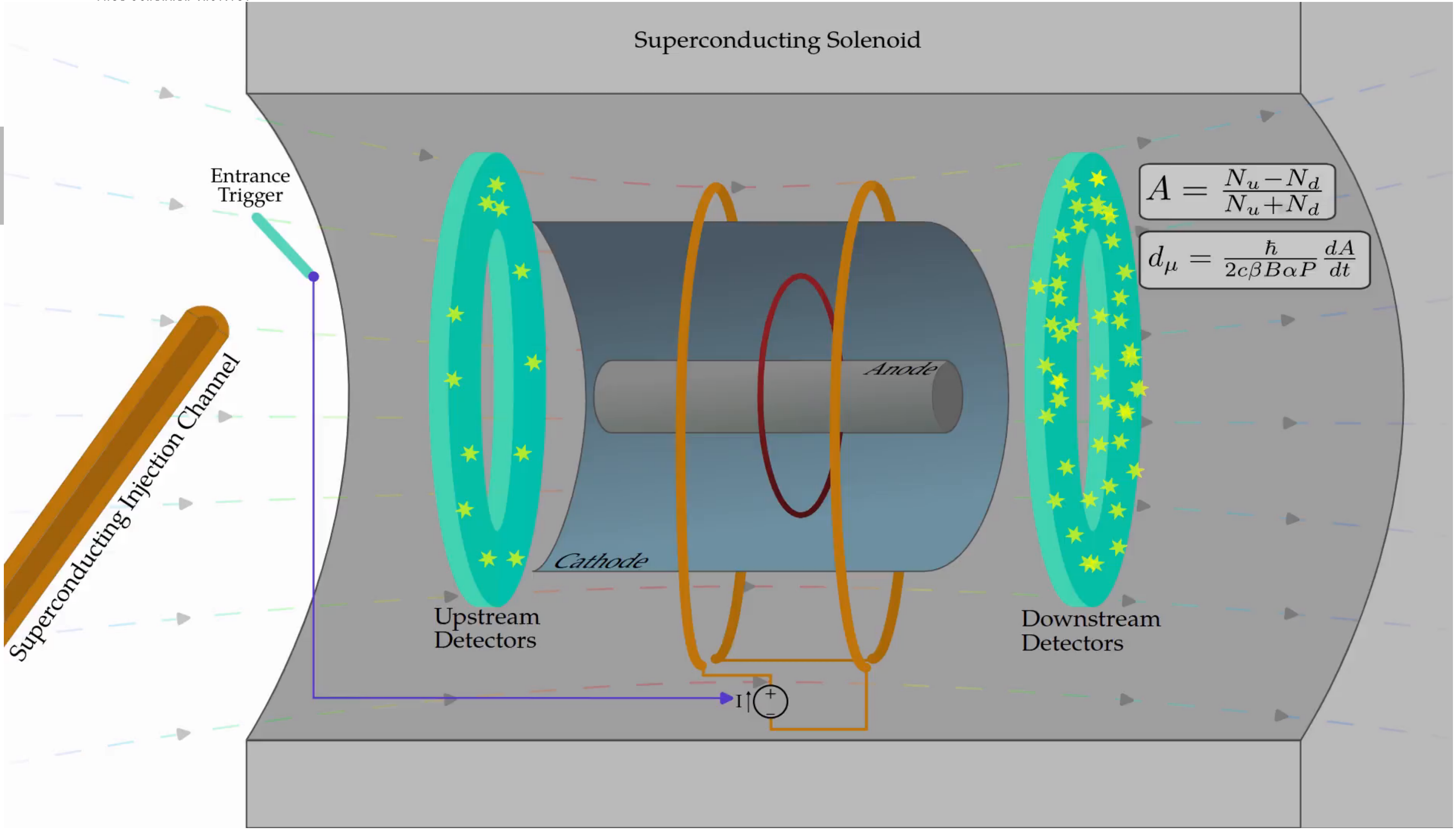
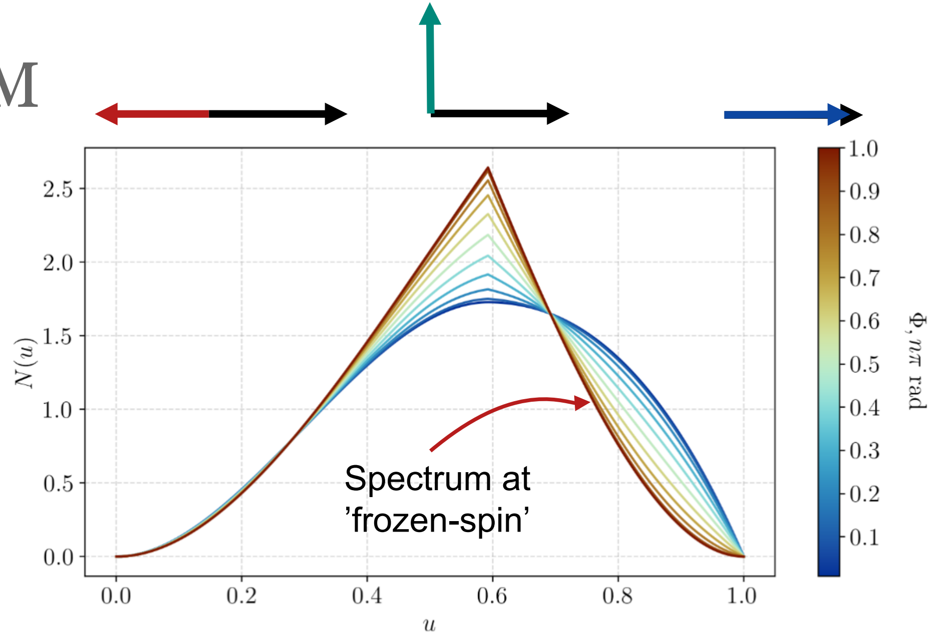
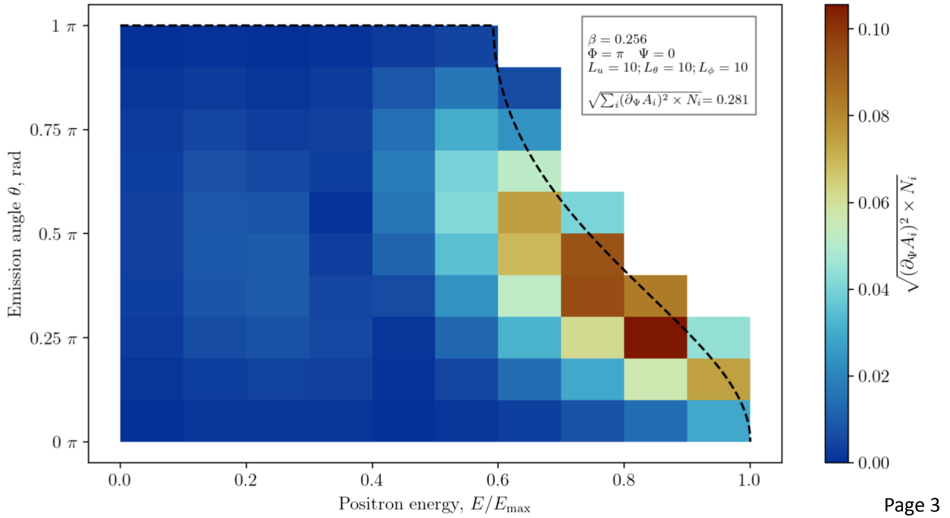


Superconducting Solenoid
Entrance Trigger
Superconducting Injection Channel
Upstream Detectors
Cathode
Anode
Downstream Detectors
$A = \frac{N_u - N_d}{N_u + N_d}$
$d_\mu = \frac{\hbar}{2c\beta B\alpha P}\frac{dA}{dt}$
I

Sensitivity to *g-2* and EDM

- We will tune the electric field until we do not see *g-2* precession → *frozen-spin*.
- The *g-2* precession frequency will be deduced from the change in the positron energy spectrum.
- The EDM will be deduced by build-up of asymmetry between positrons emitted along or opposite the main magnetic field.
- Derived analytical equations to calculate:
  - Lorentz boosted positron energy spectrum,
  - Asymmetry as a function of energy and emission angle.



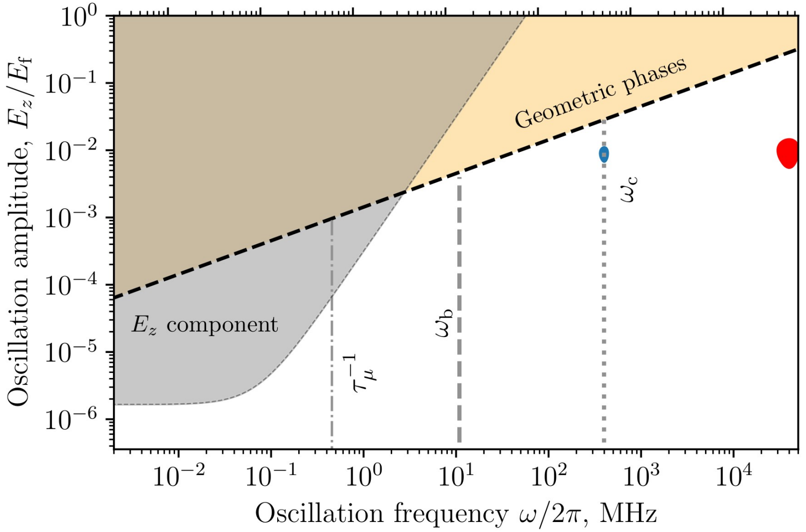


Update on systematic effects

- Finished a comprehensive study on the possible systematic effects due to the anomalous magnetic moment mimicking the EDM signal.
- Possible effect due to electric field component perpendicular to muon momentum:

$$\Omega \propto \vec{\beta} \times \vec{E}$$

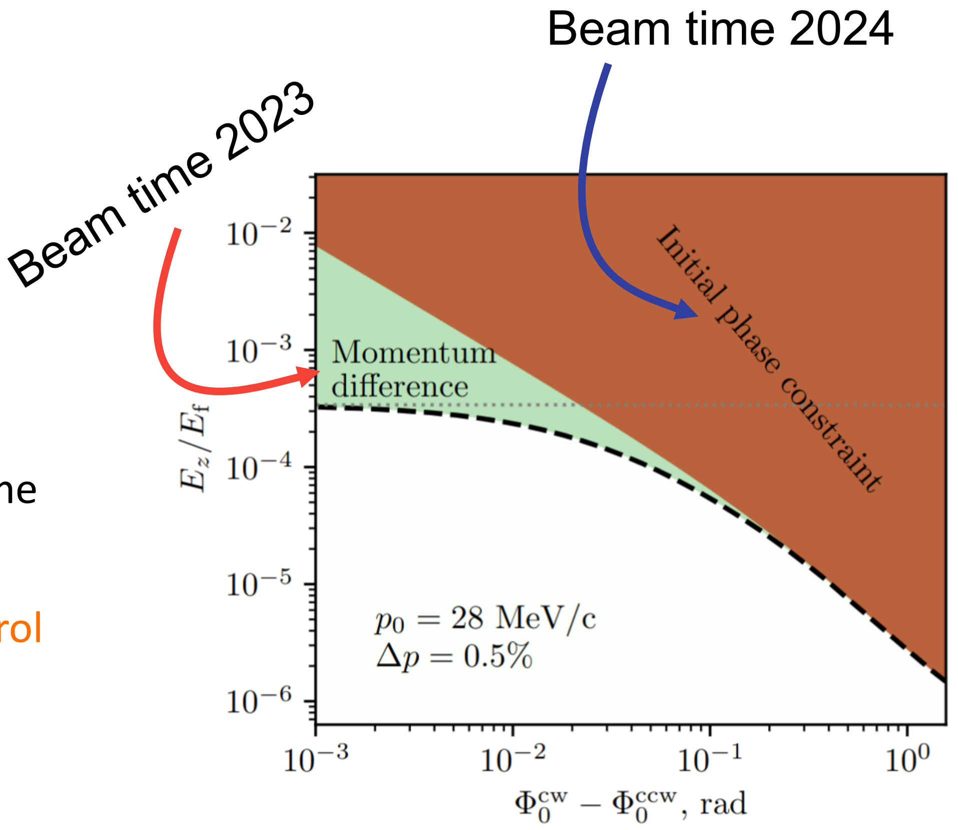
- Significantly mitigated by taking advantage of the CP-violating nature of the EDM and employing counter-rotating beams:
  Systematic stays the same; EDM flips sign.



	μ	d	$\mathbf{s}$	$\mathbf{E}$	$\mathbf{B}$	$-d\ \mathbf{s}\cdot\mathbf{E}$	$-\mu\ \mathbf{s}\cdot\mathbf{B}$
parity	+	+	+	-	+	$(++-)=-$	$(+++)=+$
time	+	+	-	+	-	$(+-+)=-$	$(+--)=+$
charge	-	-	+	-	-	$(-+-)=+$	$(-+-)=+$
charge & parity	-	-	+	+	-	$(-++)=-$	$(-+-)=+$

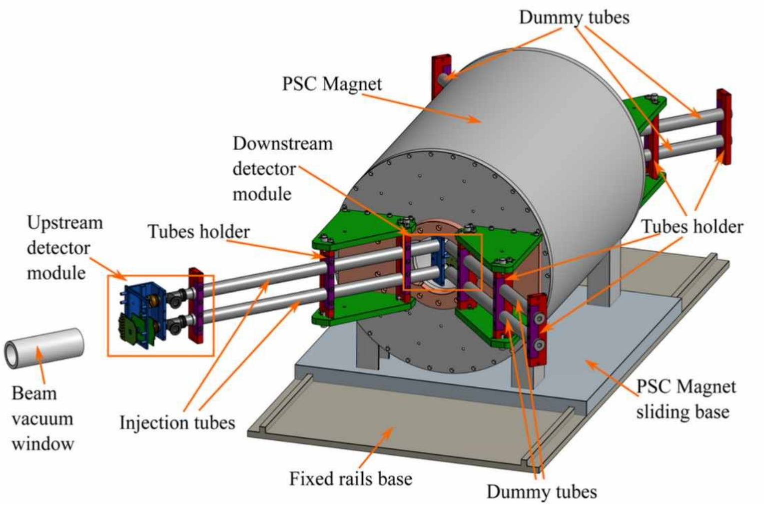
Update on systematic effects

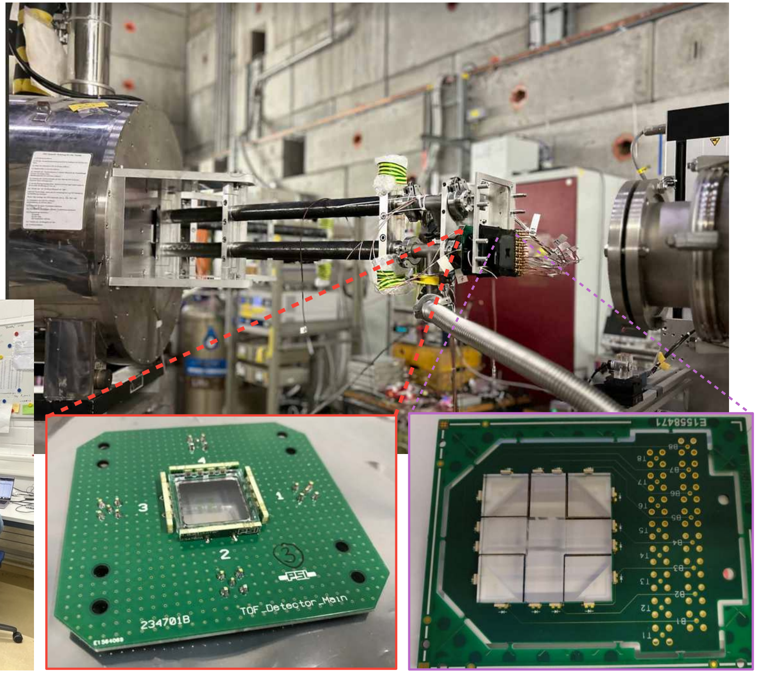
- Cancellation of the systematic effect works only if initial conditions in the positive/negative B-field setup are similar.
- One needs to keep the difference in mean muon momentum within 0.5%.
  - Tested in previous beam time.
- The difference in mean *g-2* phase at the time of injection must be below 25 mrad.
  - Experiment planned to show the control of this parameter.

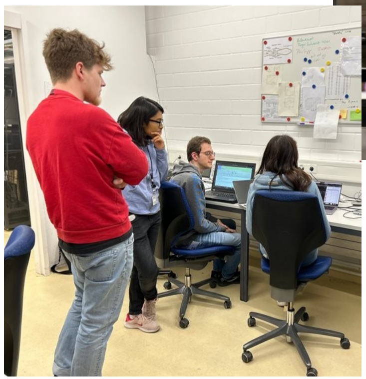


Test beam – December 2023

- Show control of the momentum of injected muons by measuremens of the ToF through injection tubes.
- Reproducibility of muon momentum distribution for positive and negative magnetic field.
- Fringe field shielding and hysteresis studies.
- Tests of a beam monitor to center the beam on the injection channel.

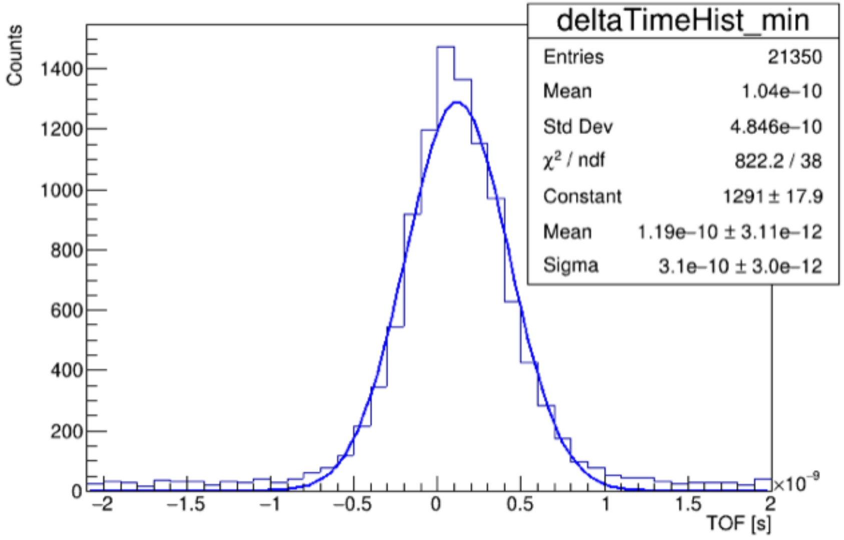


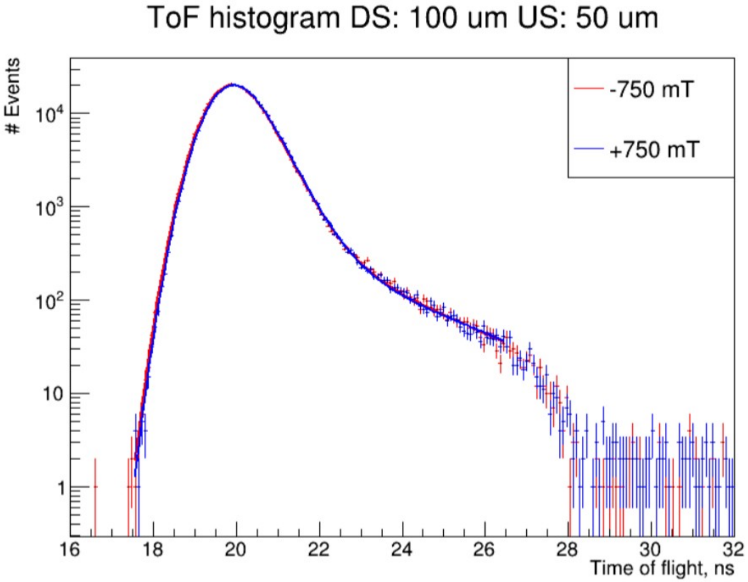




Test beam – December 2023

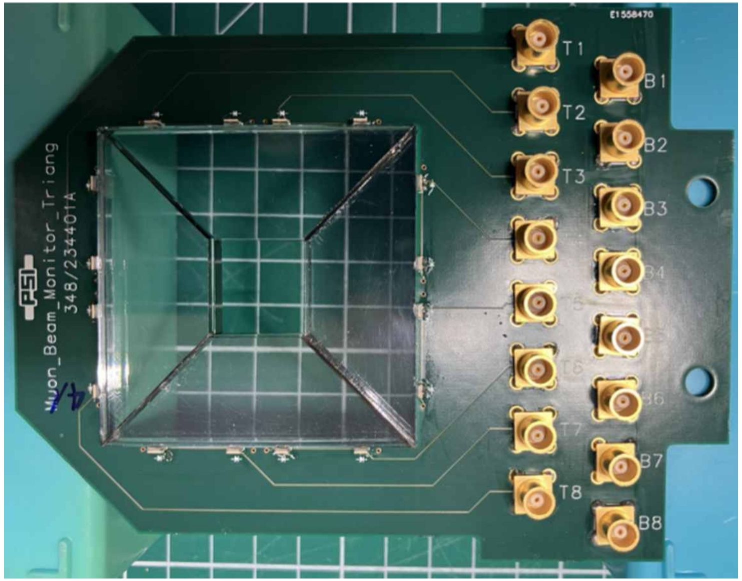
- First results show very good timing resolution on individual muons (~300 ps).
- ToF spectra for positive and negative magnetic field configuration with mean values within less than 0.2% difference.
- Strong indications that momentum control below 0.5% is achievable.

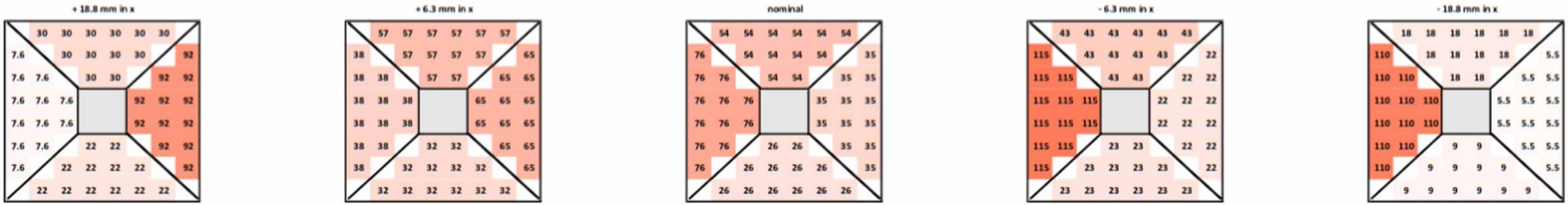




Test beam – December 2023

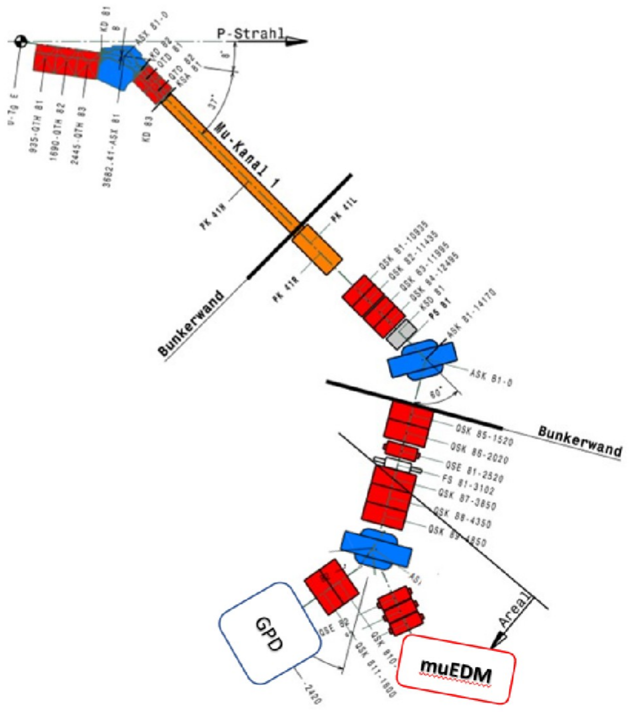
- Designed, built and tested beam monitors with different geometries and electron/muon discrimination capability.
- The detector allows to:
  - align the beam and injection channel for increased efficiency,
  - monitoring the stability of the beam profile between the positive/negative B-field modes.

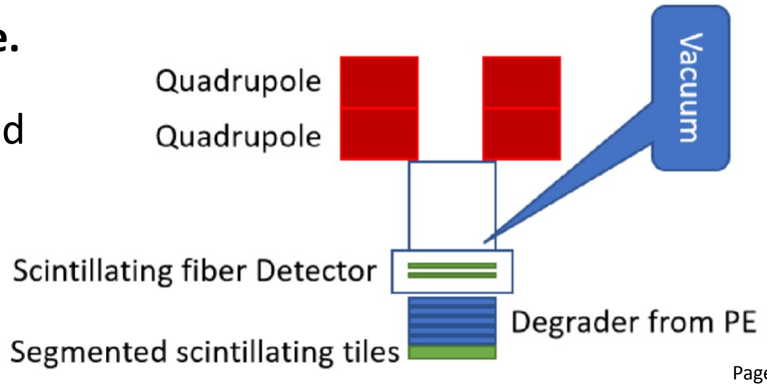




Beam time requests – muE1

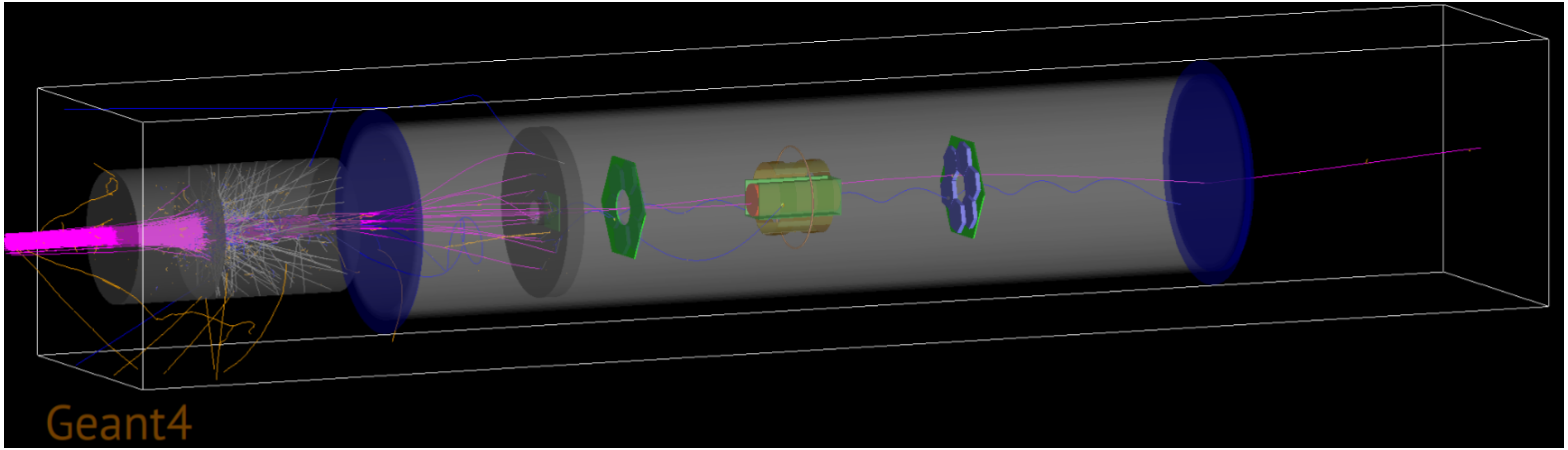
- **Goal:** Characterize the 4D lateral phase space of the muE1 beam in Z-configuration.
- Joint effort with the laboratory for muon spin rotation.
- Z-configuration permits operation of the
    - GPD muSR instrument,
    - GIANT instrument for muon-induced X-ray spectroscopy,
    - and the future muEDM **on the same beam line.**
- Phase space measurement using a SciFi detector and the quadrupole scan technique.





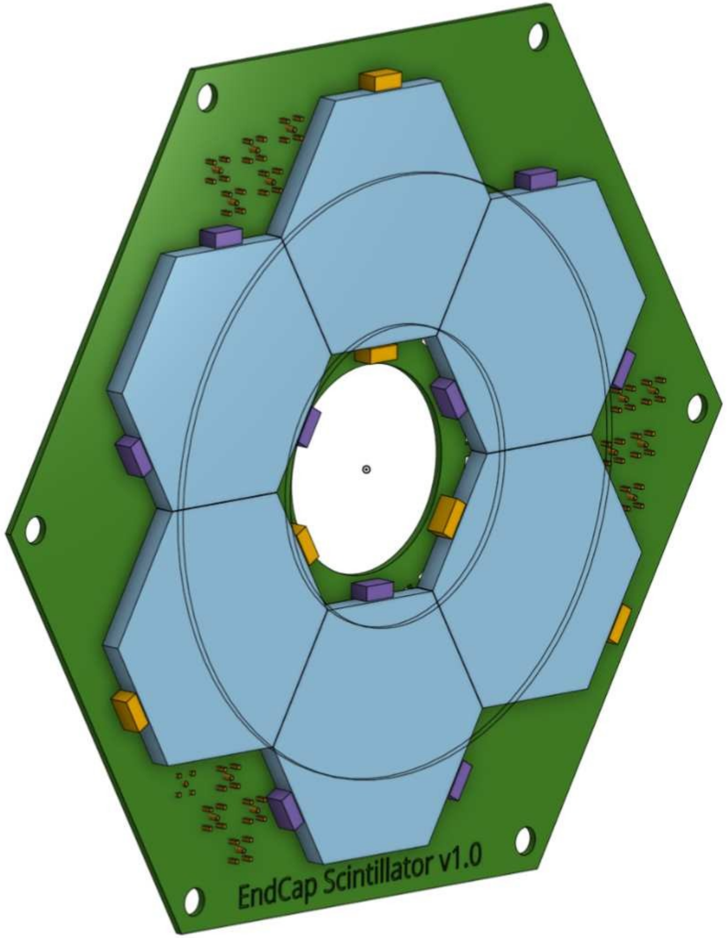
Beam time requests – piM1

- *Possible systematic effect:* time-dependent change in the detection efficiency of the positron detection system that is correlated to the magnetic kick.
- **Goal:** Measure the positron decay asymmetry as a function of time post-magnetic kick using two detectors placed on the sides of a stopping target for 200 MeV/c pions inside the 3 T solenoid field.
- Source of uniformly distributed positrons → any asymmetry change correlated to the kick will be a sign of a systematic effect.



Beam time requests – piM1

- Dedicated positron detectors with posibility to monitor detection efficiency.
- The tiles read by 3 SiPMs will be used to determine the detection efficiency:
  - Proportional to the ratio of coincidences between a *pair* of SiPMs and between *all three.*
- **Test online monitoring of the detection stability during the lifetime of the experiment.**
- Study possible detector degradation due to radiation damage.

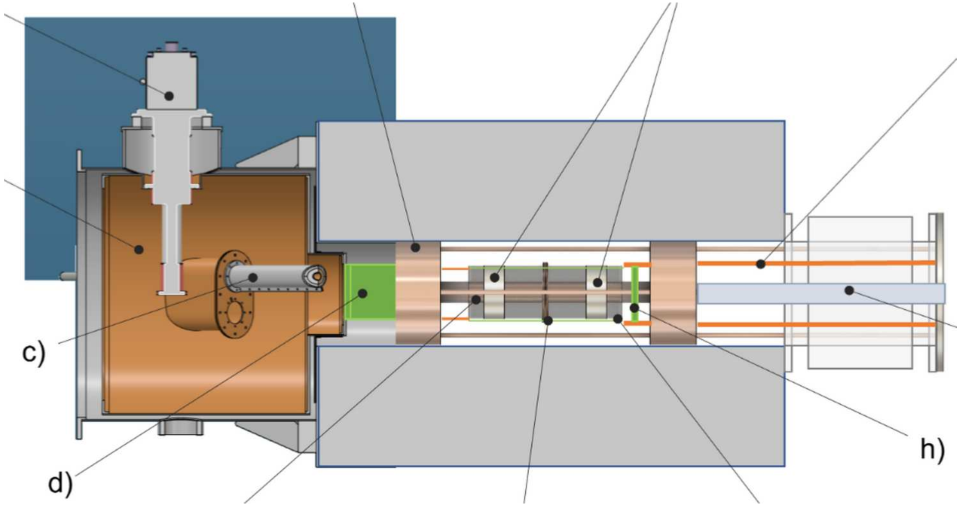


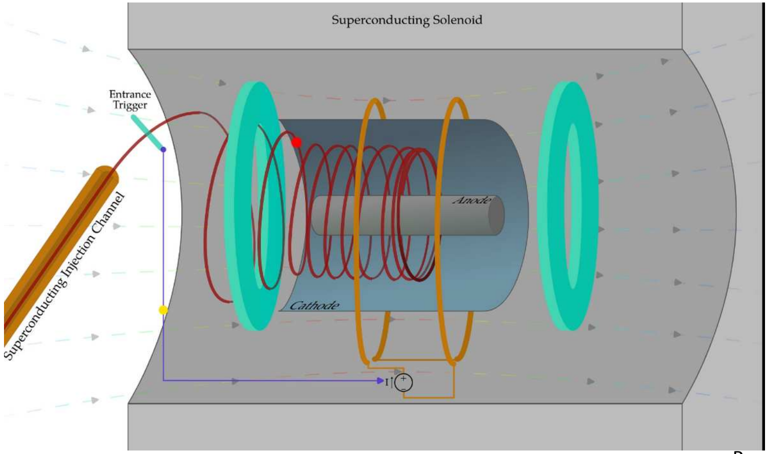
Beam time requests – piE1

I. Demonstrate the spiral injection into the solenoid through the cryocooled superconducting channel.

II. Stop all injected muons in a thin target and measure the muSR frequency and the initial phase to constrain the potential systematic effect related to it.

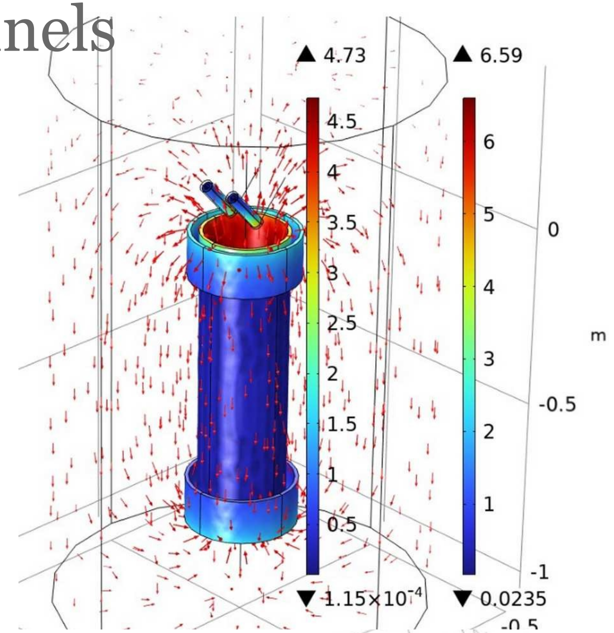
III. Demonstrate the storage of muons inside the solenoid using the magnetic kick.

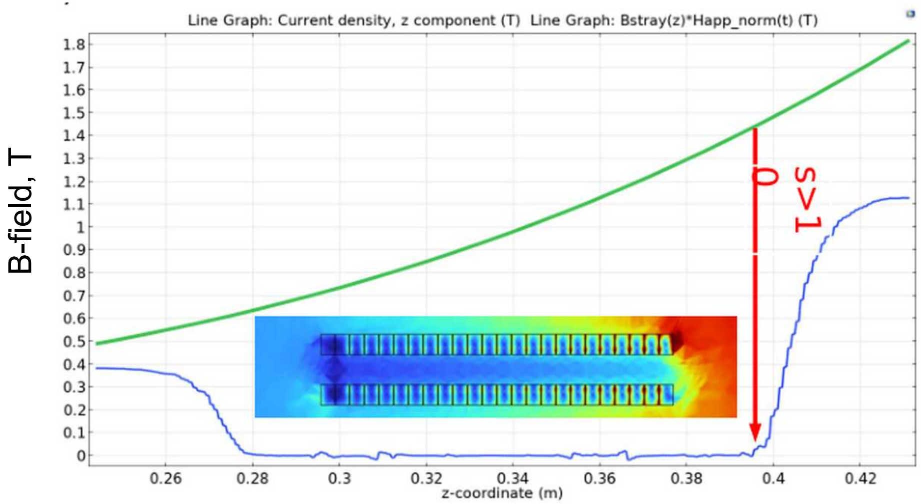


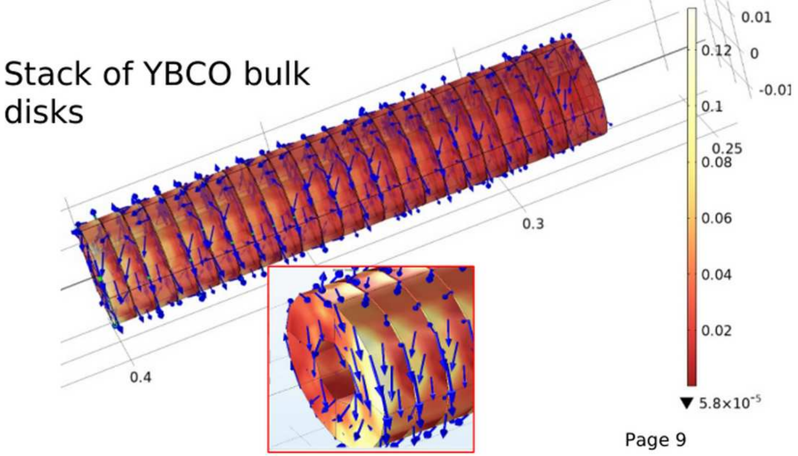


Beam time requests – piE1 – SC channels

- **Challenge:** Bring muons inside the bore of the solenoid without being deflected from the fringe field.
- Working on designs, simulations and tests of superconducting channels.
- Promising concepts with a stack of YBCO disks or Nb-Ti sheets formed into a pipe.







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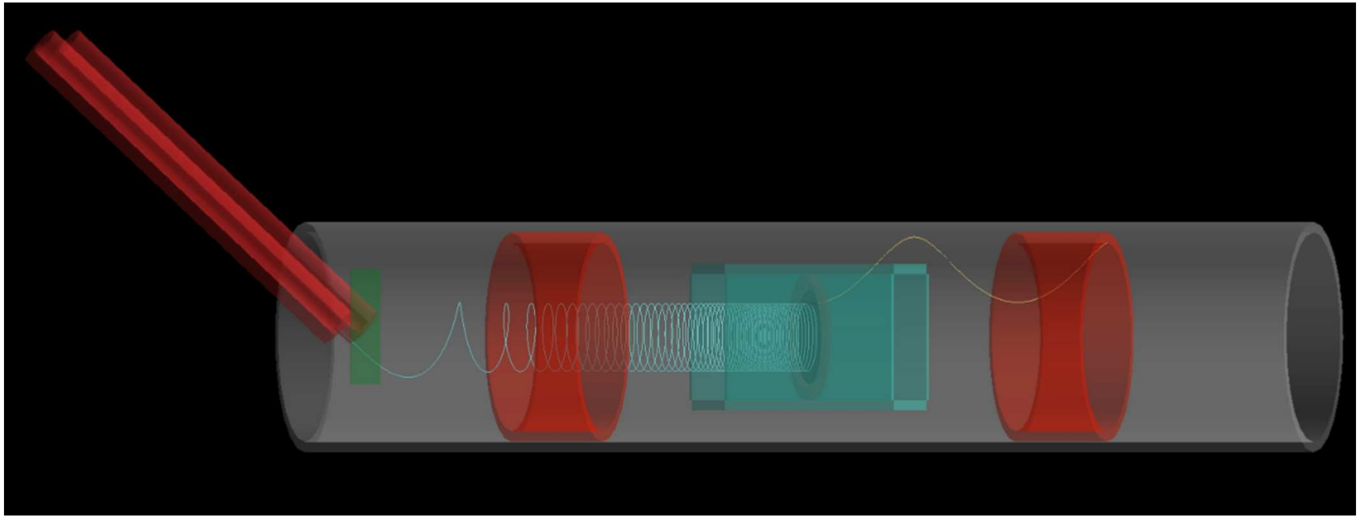

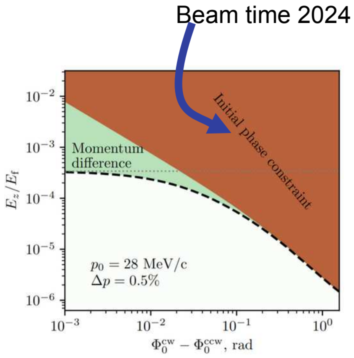

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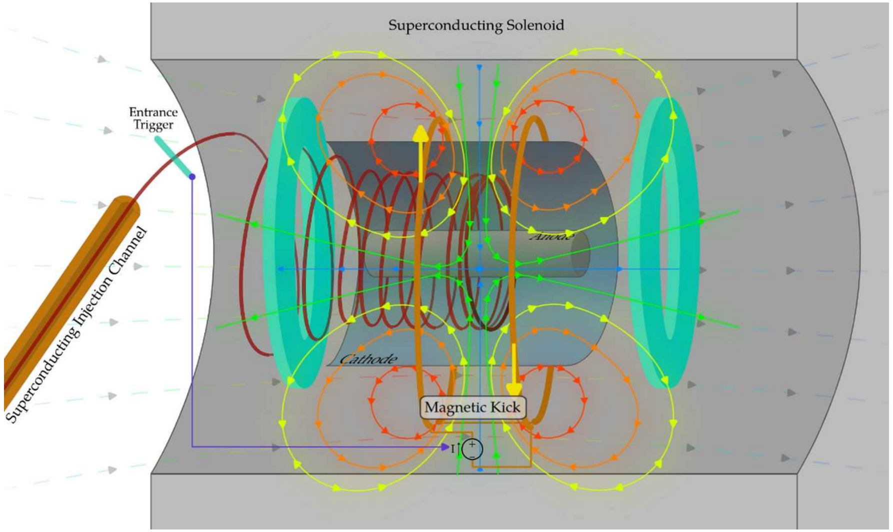
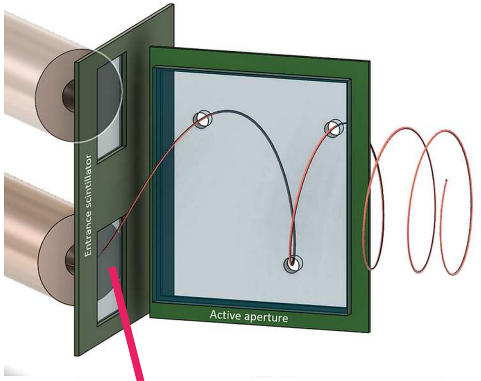
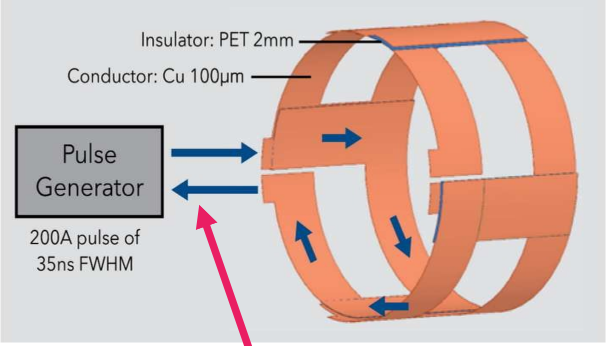
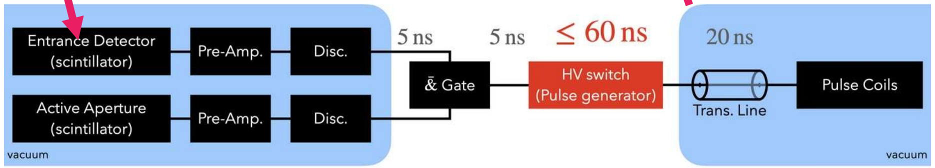


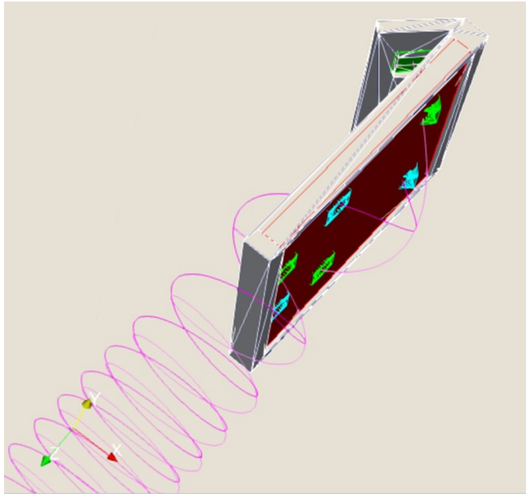


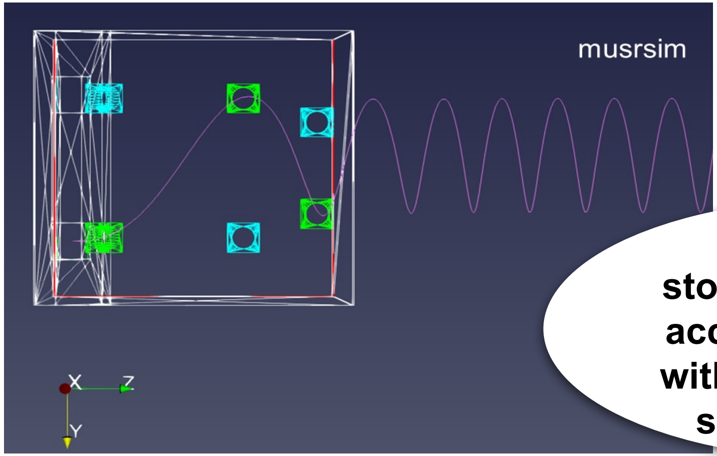




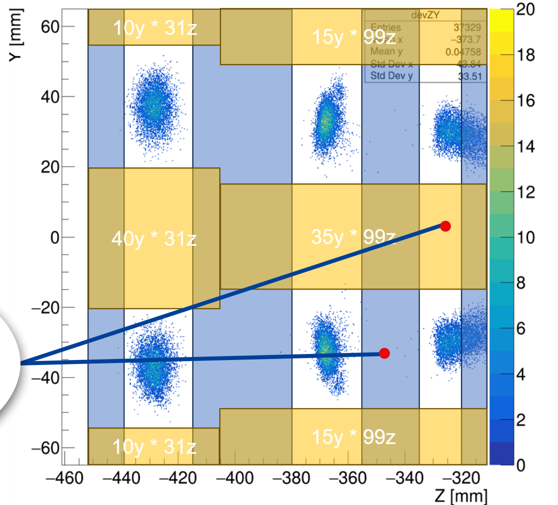
Beam time requests – piE1 – Entrance trigger

- Thin scintillation trigger followed by veto detector with pass-through holes around the nominal trajectory.
- A trigger to the magnetic kick is issued only if no detector is hit.
- Optimisation of entrance detector dimensions with simulations is underway.



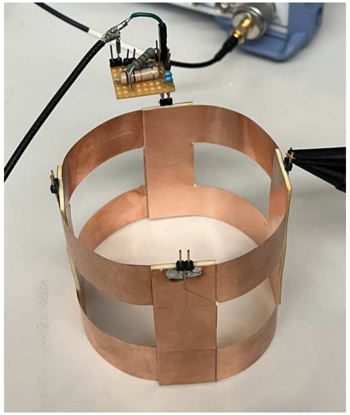


Hit positions on active aperture

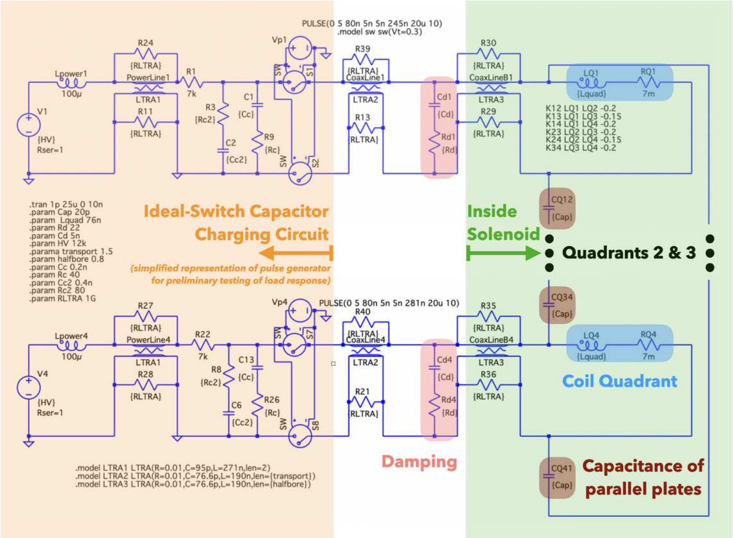


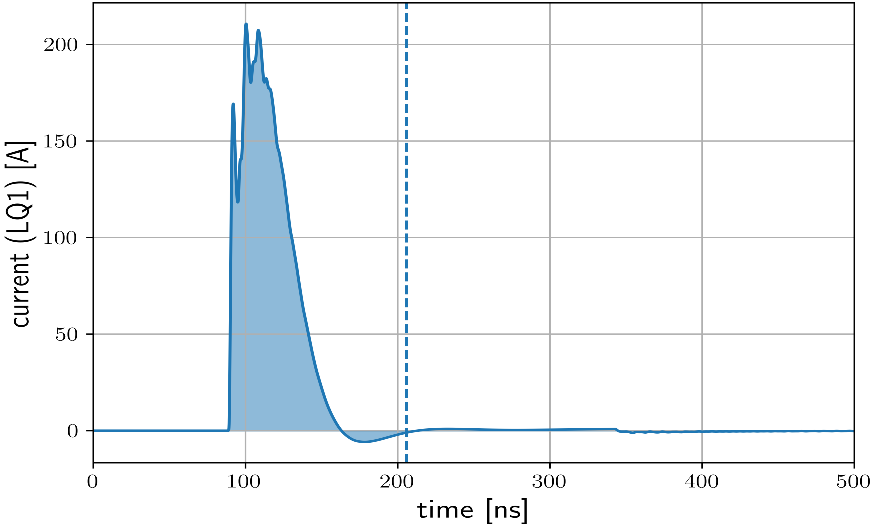
Muons within storage phase space acceptance selected with meshed array of scintillator strips

Beam time requests – piE1 – Magnetic kick



- **Challenge:** High amplitude, short duration pulsed magnetic field that must be rapidly triggered.
- Splitting coils into quadrants reduces the load inductance of each circuit while maintaining sufficient field uniformity.
- Simulations show that 200 A & 35 ns FWHM pulse is possible. Collaborating with KIT for a dedicated pulse generator.

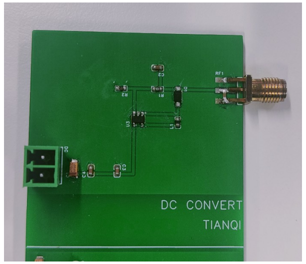




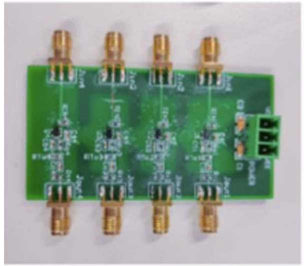
Beam time requests – piE1 – Fast electronics

- Prototype fast electronics were designed and tested.
- Propagation delay was evaluated at no more than 5 ns:
  3 ns for the discriminator,
  2 ns for the pre-amplifier and splitter.
- Individual components have been developed successfully and integration into a single board is underway.

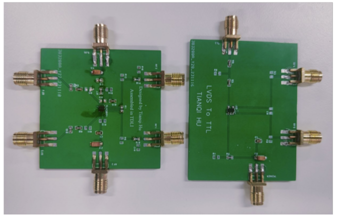
DC/DC Boost Converter

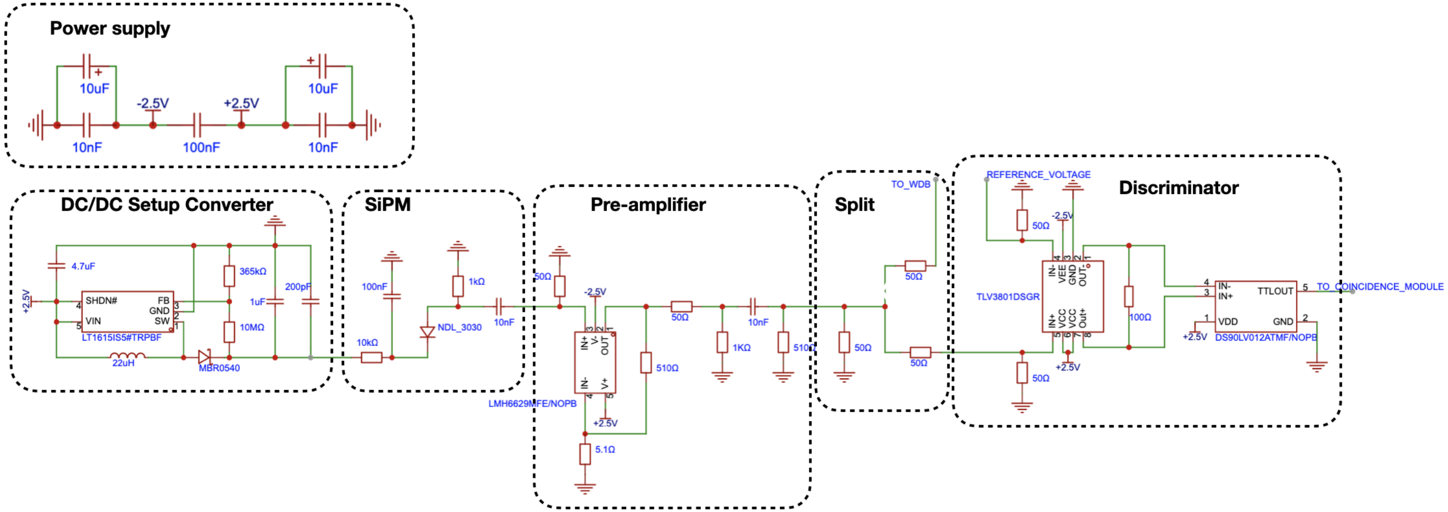


Pre-amplifier



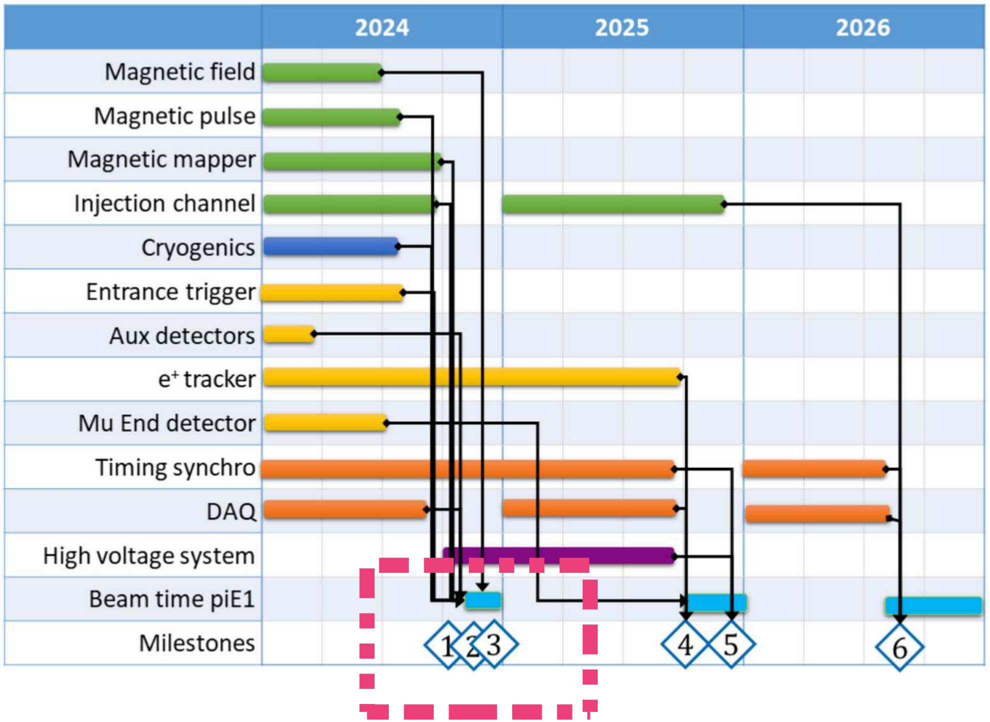
Discriminator
< 3 ns delay



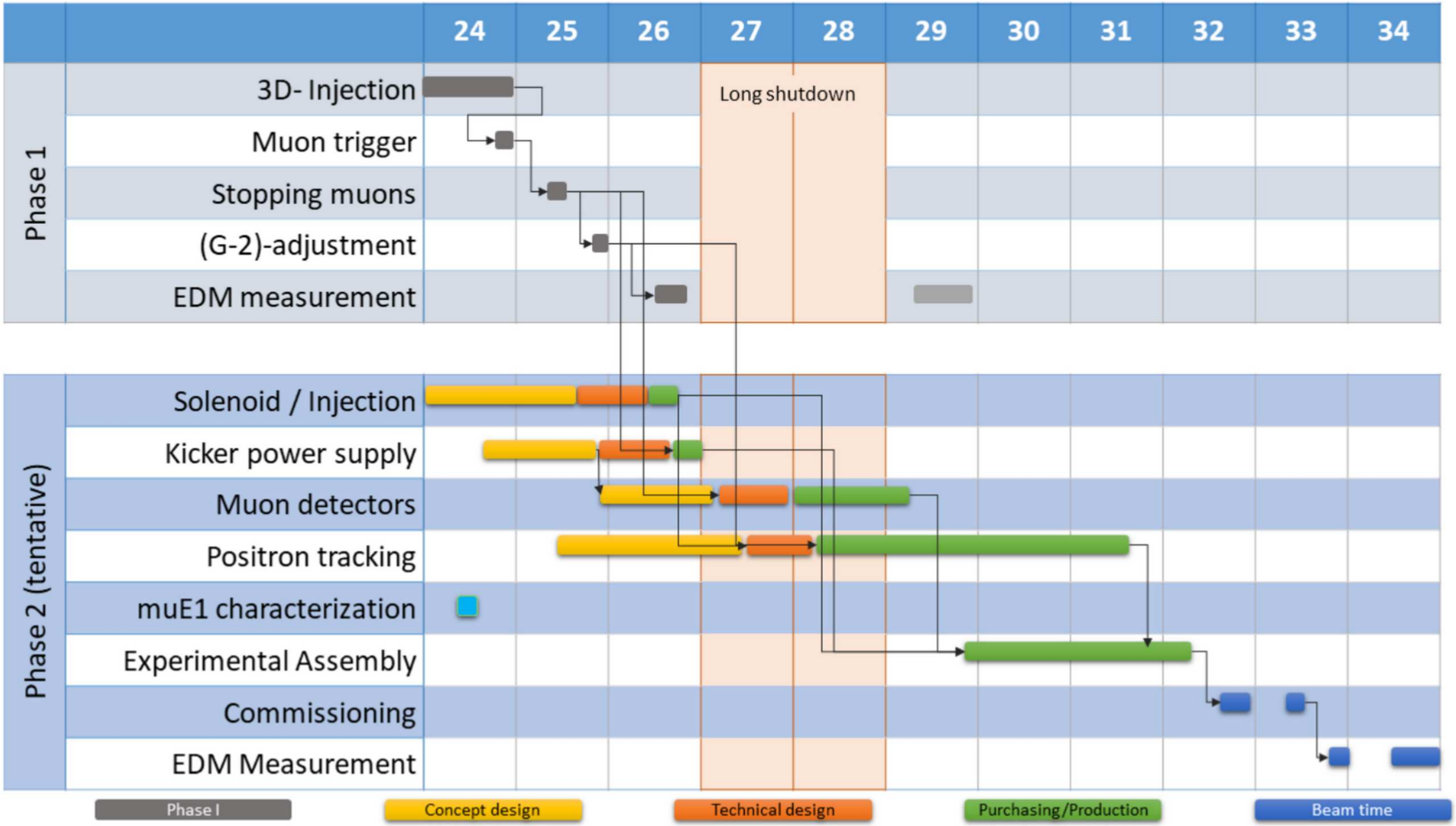


Beam time requests – piE1

- The spiral injection into the solenoid at 3 tesla is an essential milestone for the collaboration.
- Test bed for most of the major components of the final experiment:
  - Cryostat & superconducting shielding injection channels
  - Magnetic pulse
  - Entrance trigger & muon end detector
  - Field forming (correction) coils
  - DAQ



Long term timeline



Publications and conference proceedings

- *Anomalous spin precession systematic effects in the search for a muon EDM using the frozen-spin technique*, arXiv:2311.10508v1
  (accepted with minor revisions by The European Physical Journal C)

- *Operating the GridPix detector with helium-isobutane gas mixtures for a high-precision, low-mass Time Projection Chamber*, 2023 JINST 18 P10035

- **PhD Thesis:** M. Sakurai: Towards a Search for the Muon Electric Dipole Moment using the Frozen-spin Technique, 10.3929/ethz-b-000601572

- 10 conference proceedngs from 6 international conferences

Thank you for the attention

PSI proposal R-21-02.1

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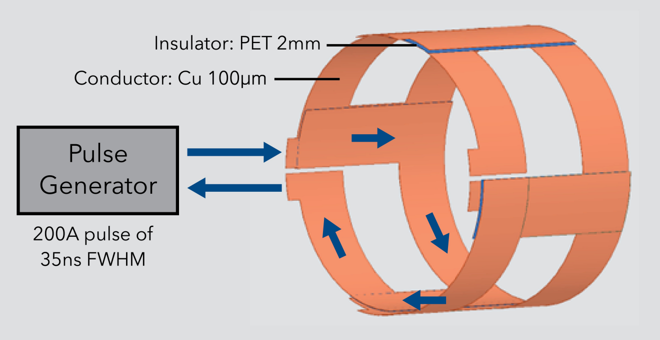
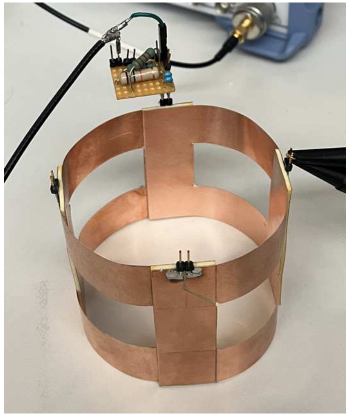
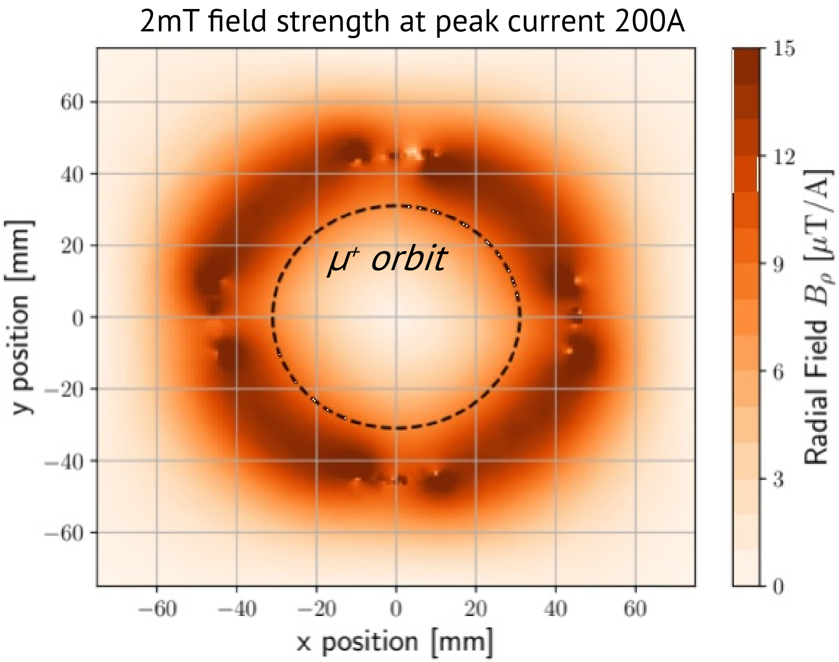
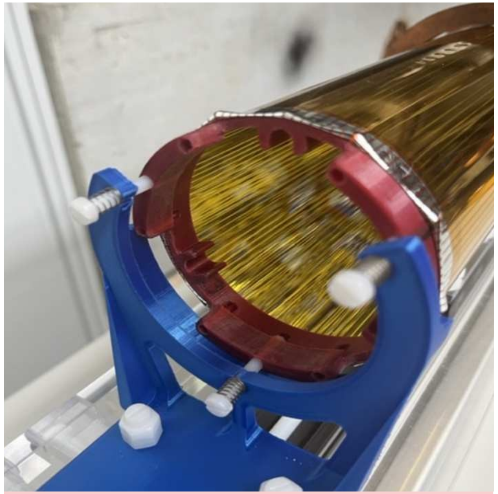
Pulse Generator & Coil System



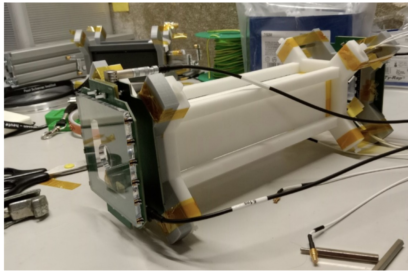


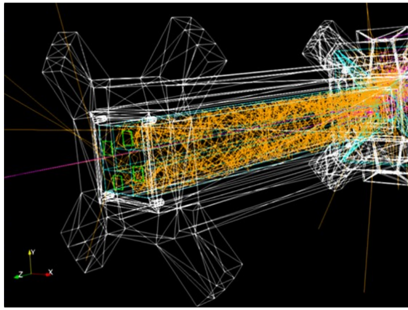




Frozen-spin electrodes:
Segmentation of AluKapton film into 2mm stripes prevents eddy-current shielding of the radial magnetic field, without compromising electric field uniformity.

Update on entrance trigger (test beam 2022)





- Data analysis and simulation were performed to evaluate the performance of the prototype at the test beam 2022
- Measured E1 beam profiles were implemented into the simulation for detector performance studies
- High fidelity Geant4 simulation including optical photons was performed to understand the detector response
- Good agreements reached for both optical responses and relative event rates for different event topologies