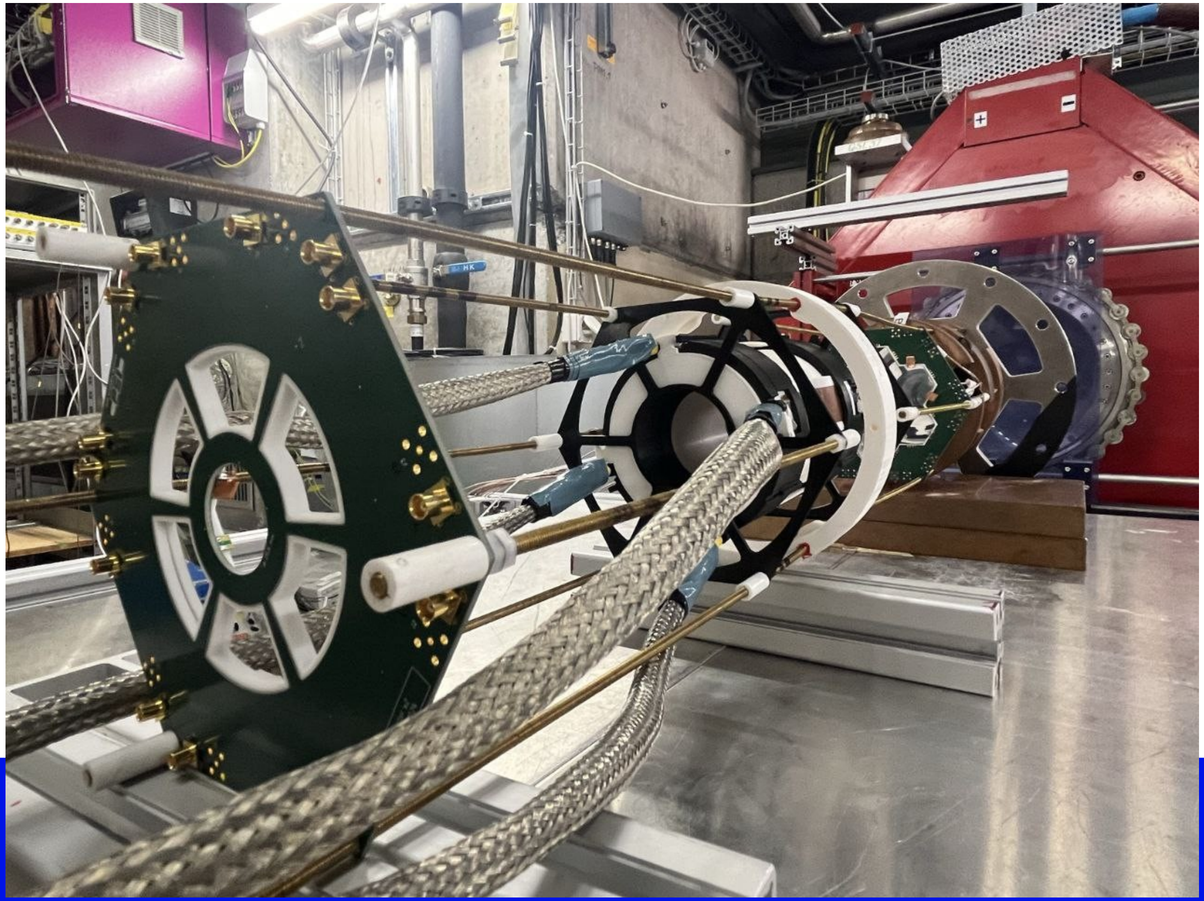
Systematic effects

Study and mitigation strategies



Chavdar Dutsov
PSI, DD Month YYYY

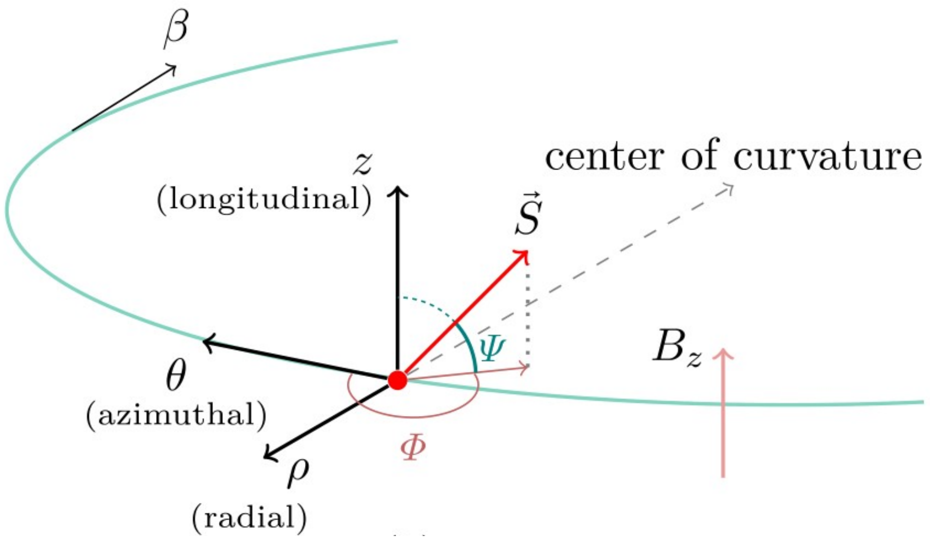
Systematic effects

Effects that lead to a *real* or *apparent* precession of the spin around the radial (E-field) axis that are not related to the EDM.

Types of systematic effects:

- Coupling of the anomalous magnetic moment with the EM fields of the experimental setup ***(real)***
- Early to late variation of detection efficiency of the EDM detectors ***(apparent)***

To limit systematic effects we require that precession due to the **anomalous magnetic moment** is smaller than the target EDM signal:



$$\vec{\Omega} = -\frac{e}{m_0}\left[a\vec{B} + \left(\frac{1}{\gamma^2 - 1} - a\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)\right]$$

AMM EDM

Systematic effects

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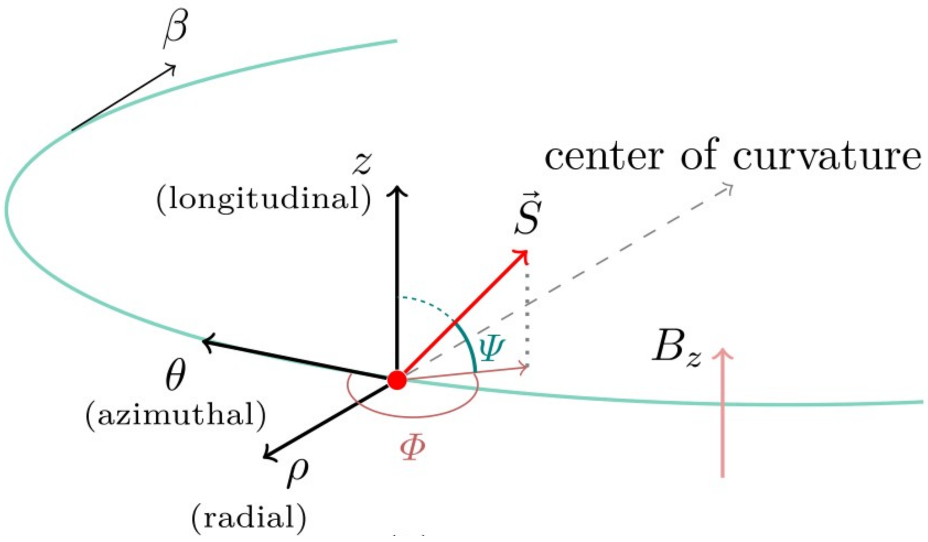
- Comprehensive analysis of systematic effects published in the beginning of 2024 (Cavoto et. al., Eur. Phys. J. C (2024) 84 :262)

- Analyzing the Thomas-BMT equation we identify tw important sources of a false EDM signal related to electromagnetic field:

$$\left\langle \left(\vec{\Omega}_{\mathrm{MDM}}\right)_\rho \right\rangle = -\frac{ea}{mc}\left\langle\left(1-\frac{1}{a(\gamma^2-1)}-\frac{1}{\beta_\theta^2}\right)\beta_\theta\right\rangle\langle E_z\rangle + \frac{ea}{m}\langle B_\rho(t)\rangle$$



- Net radial B-field component ***Bρ***
  (can be non-zero due to residual fields from the magnetic kick)

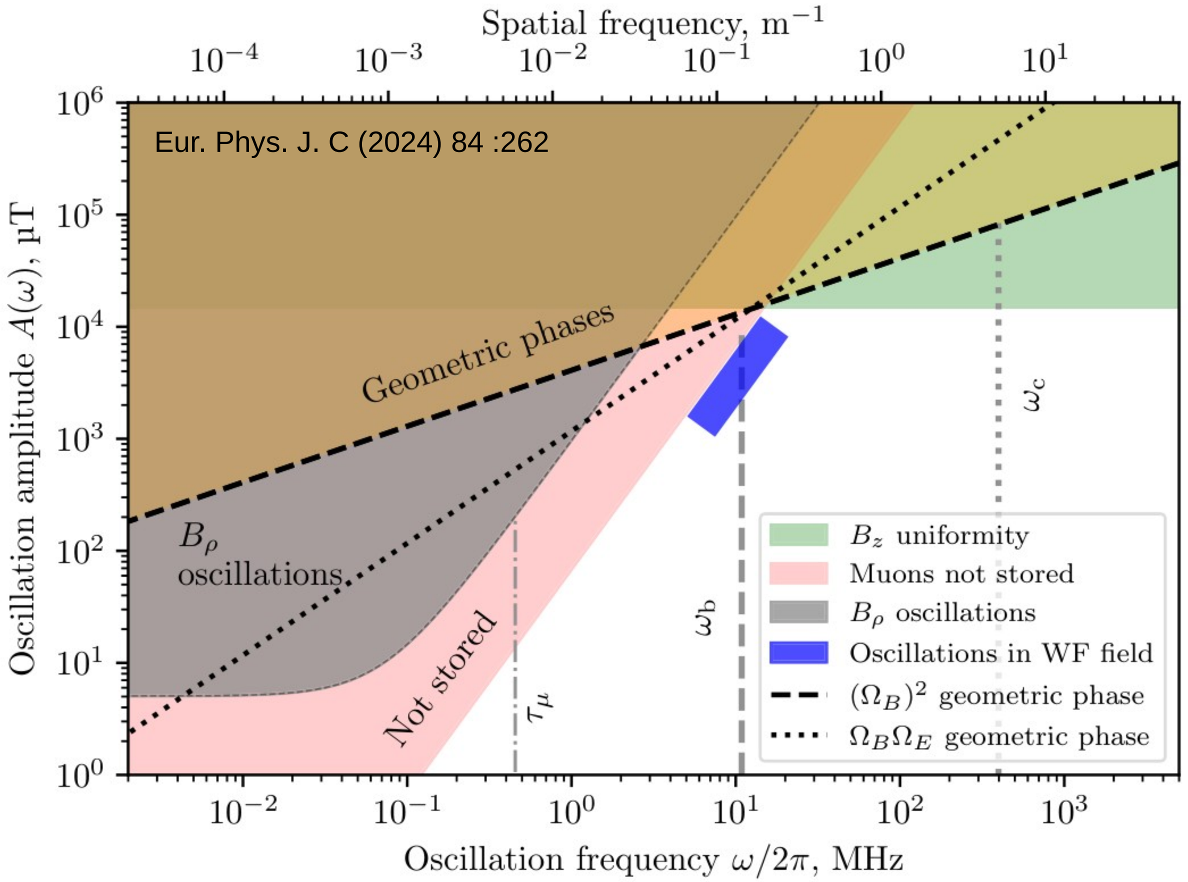
- Radial magnetic field in the reference frame of the muon due to a ***β*** ***E*** term
  (non-zero if there is E-field prependicular to the muon orbit)

Magnetic field stability and uniformity

Static or variable radial B-field

Acts in three ways:

- Inducing EDM-like spin-precession
  - Excluded as strong enough fields do not correspond to stored muons as radial B-field also rotates momentum vector
- Combination of oscillations around different axes could lead to accumulation of a geometric phase
  - Not an issue for the intrinsic muon motion frequencies in the experiment



Magnetic field stability and uniformity

Static or variable radial B-field

Acts in three ways:

- Rotating the muon momentum vector, thus changing the preferred direction of decay positrons
  - Places limits on the design of the magnetic kicker
  - Necessary to limit ringing and afterpulses to 140 uT @ 100 kHz *(corresponding to 10 A current through the coils)*

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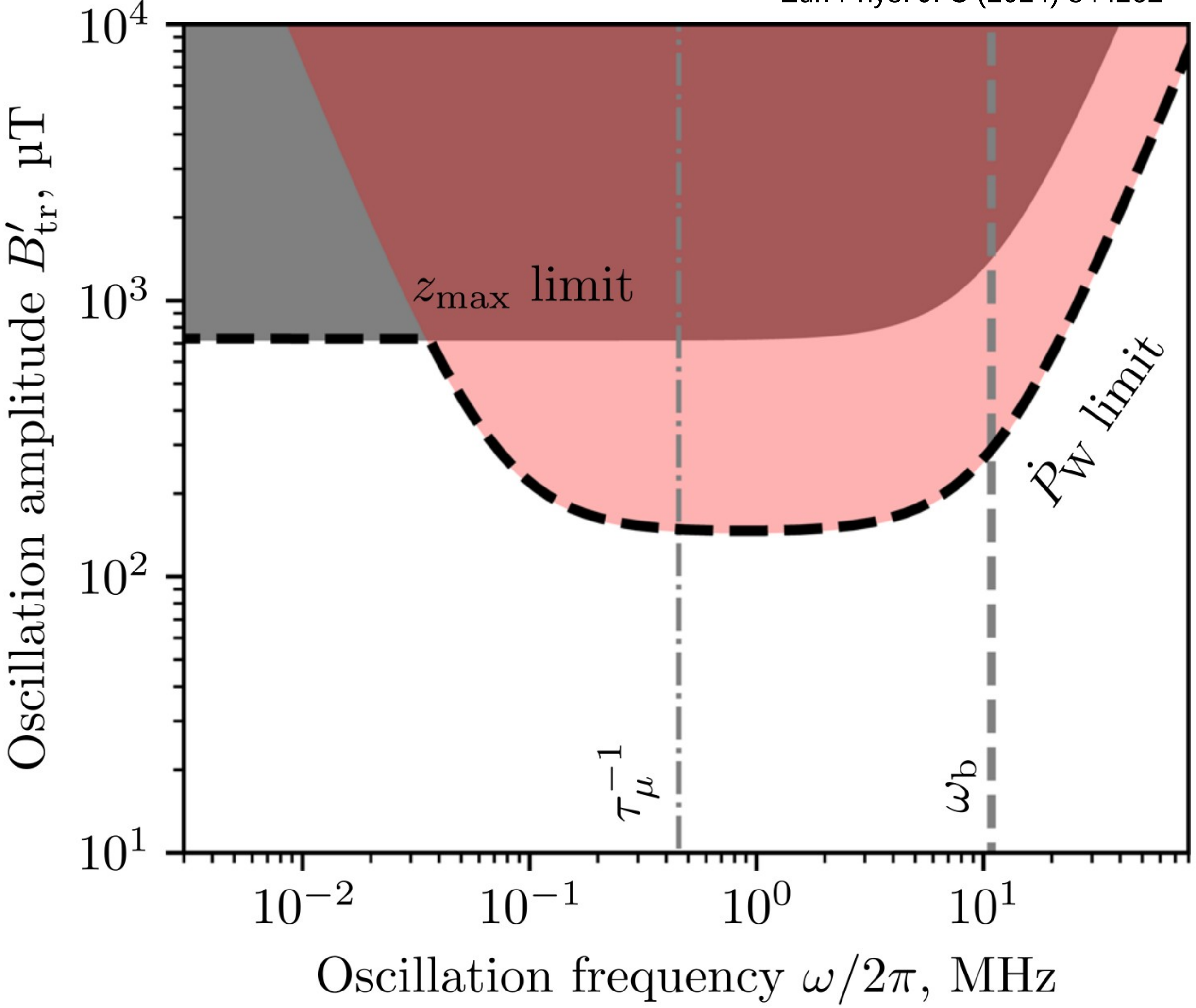


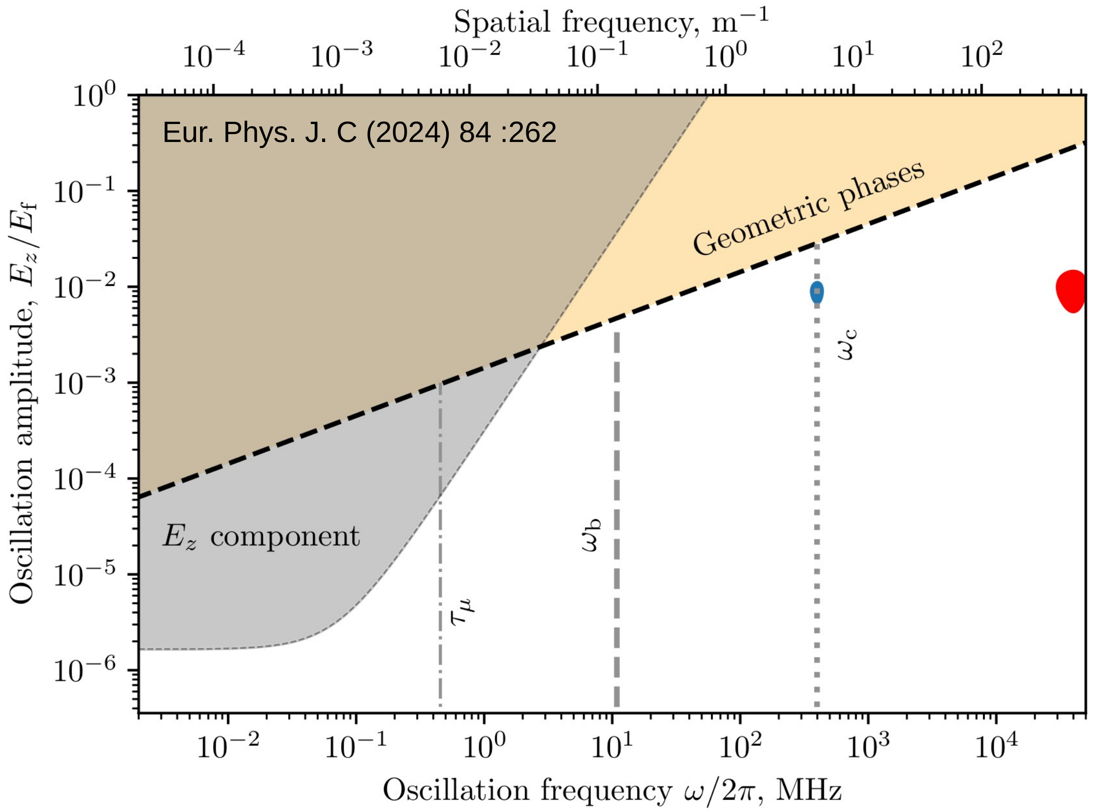
Magnetic field stability and uniformity

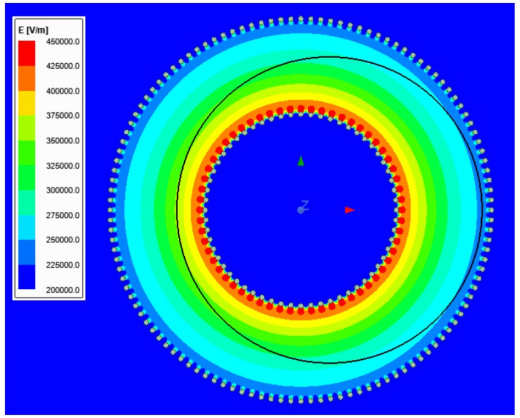
E-field non-uniformities are not excluded from storage considerations.

Blue dot: Maximum expected oscillation amplitude and frequency for a uniform cylinder electrode system.

Red dot: oscillation amplitude and frequency for a segmented electrode system (120 x 0.5 mm wires for cathode and 60 x 0.5 mm for anode).

Stringent limit on the low-frequency (and constant) longitudinal E-field.





Magnetic field stability and uniformity

E-field component parallel to the B-field will move orbit out of central plane until:

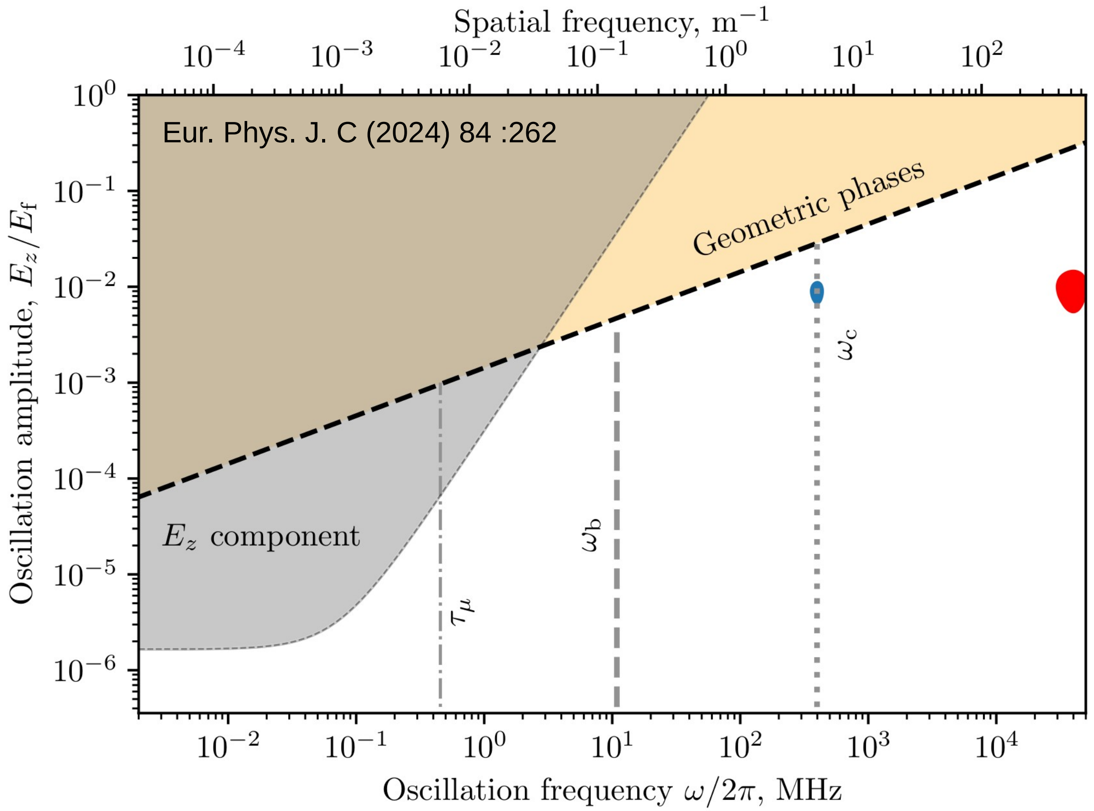
$B^*_r = E_z / \beta\gamma$

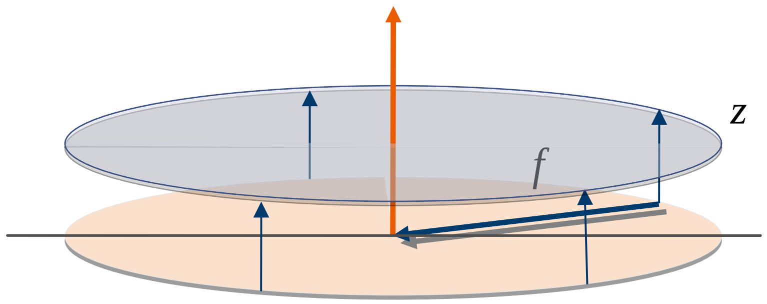
- This induces a radial B-field in the muon rest frame

Effect cancels if particles are injected alternatively CW and CCW and subtracting counts in the detectors.

CW and CCW orbit directions are done by switching the main B field direction

$$\vec{\Omega} = -\frac{e}{m_0}\left[a\vec{B} + \left(\frac{1}{\gamma^2 - 1} - a\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$





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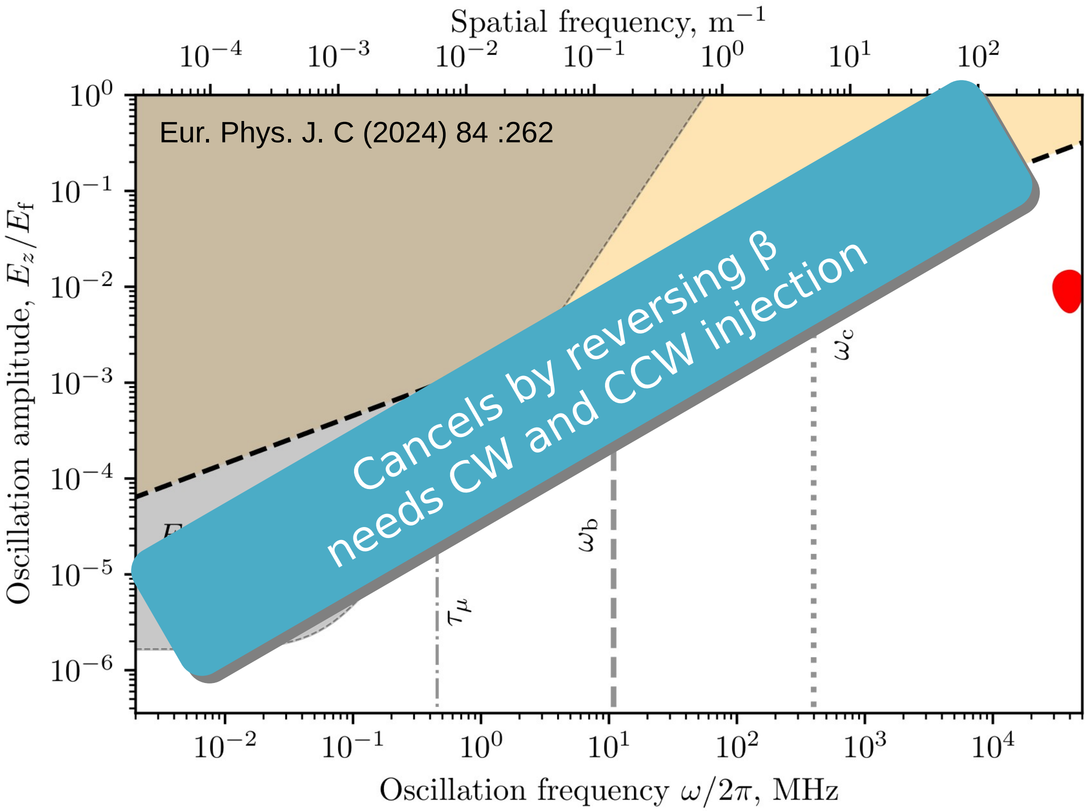
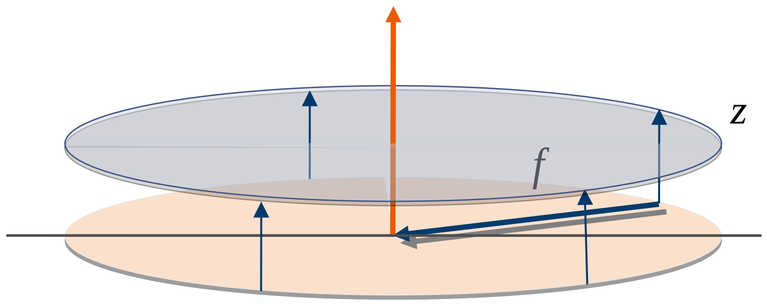




Magnetic field stability and uniformity

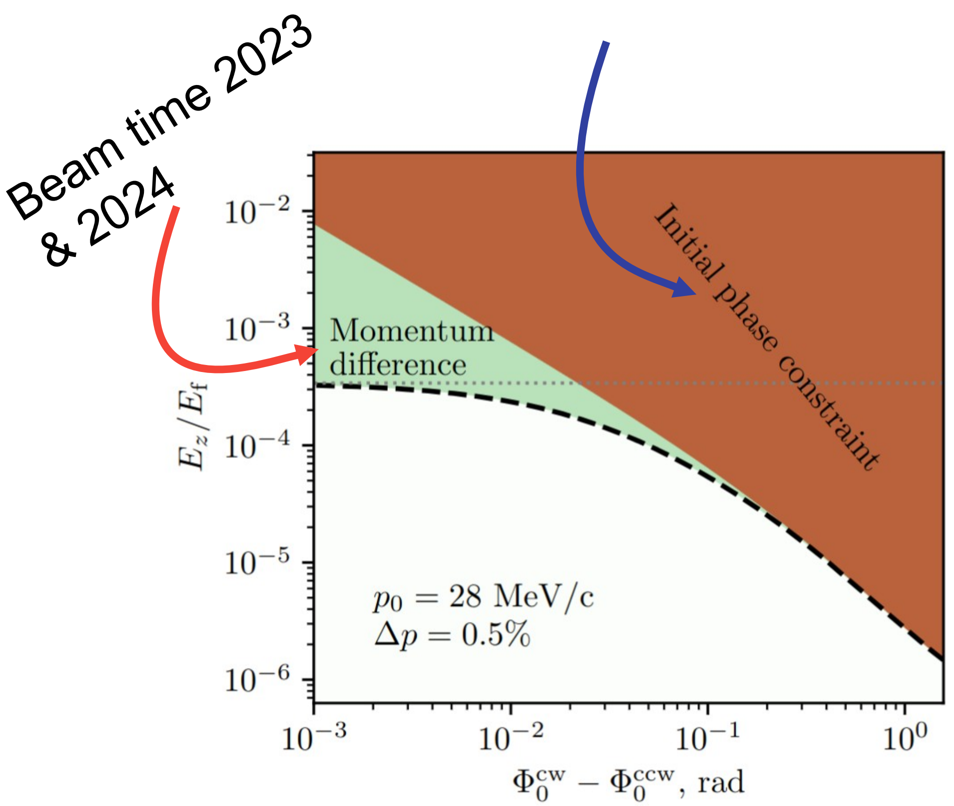
Cancellation of the systematic effect works only if initial conditions in the positive/negative B-field setup are similar.

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.



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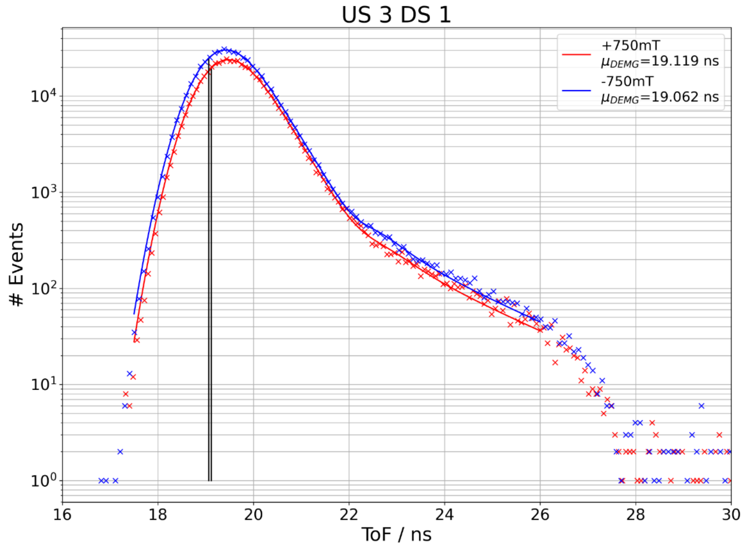
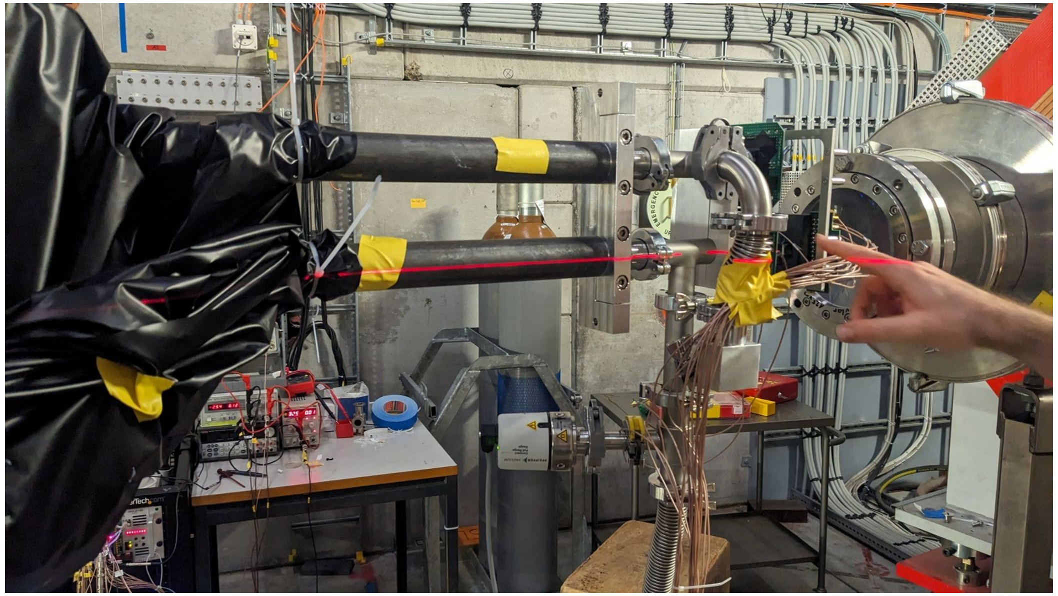
Stability of CW/CCW mean momentum

- To monitor the incoming muon momentum we measure the Time-of-Flight (ToF) through the injection channel.
- In December 2023 we tested various thickness entrance and exit scintillation detectors for optimal timing resolution and repeatibility.
  - We observed below 0.3% momentum difference for positive and negative B-field.
- In Nov. 2024 we performed measurements for CW/CCW mean momentum with the magnet lifting mechanism (analysis pending).





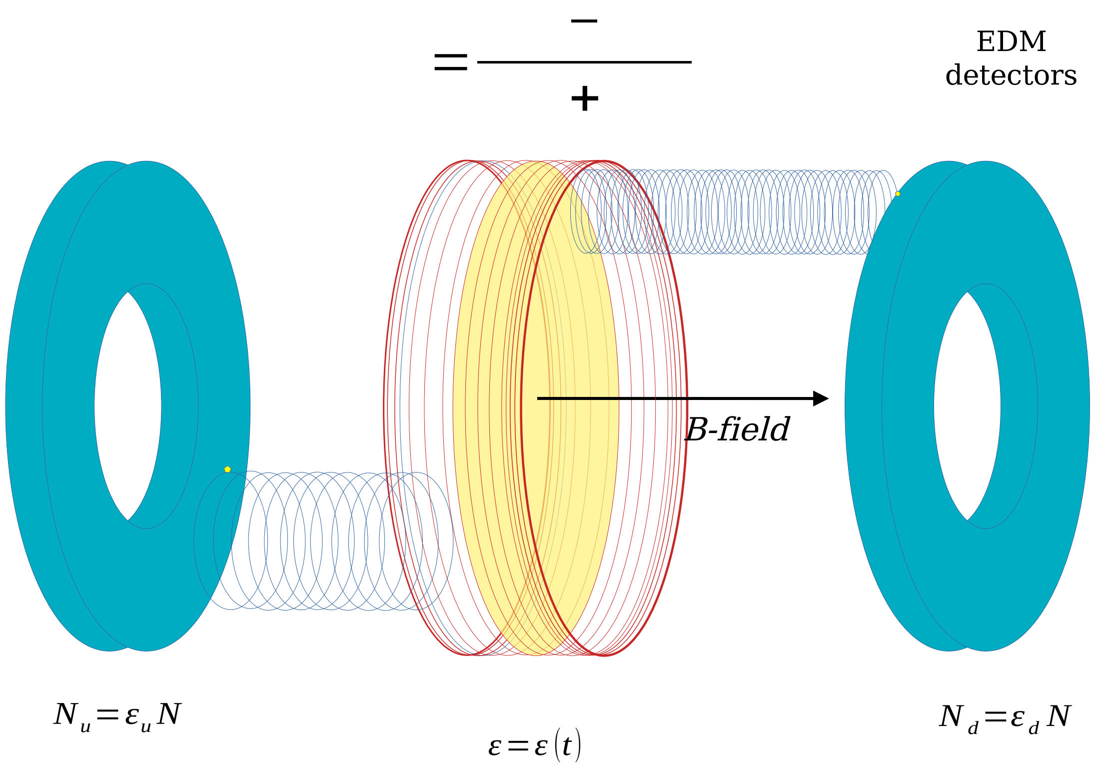
Early-to-late detection efficiency changes

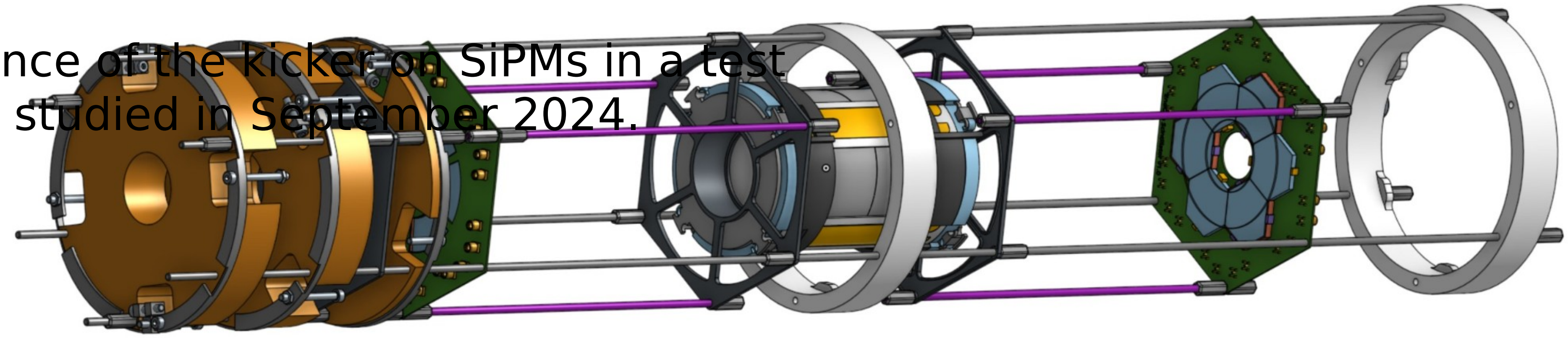
Static differences in up and down detectors would not lead to a systematic effect.

Time-dependent changes in the overall detection efficiency of a set of detectors can be seen as a false EDM signal.

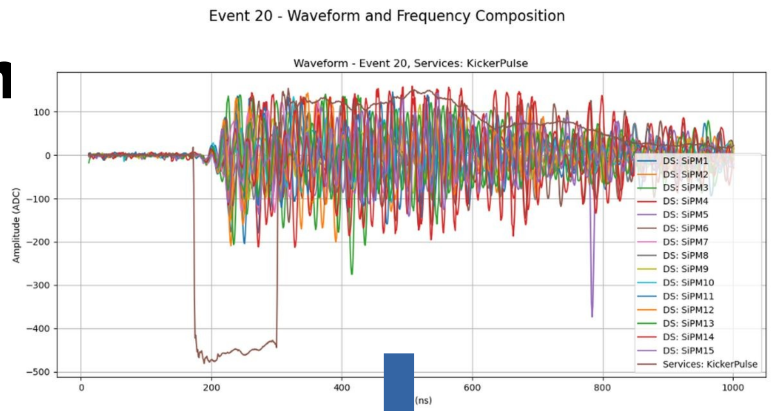
Strong pulsed magnetic field →
eddy currents, noise, heat in detectors and associated electronics.

Influence of the kicker on SiPMs in a test setup studied in September 2024.

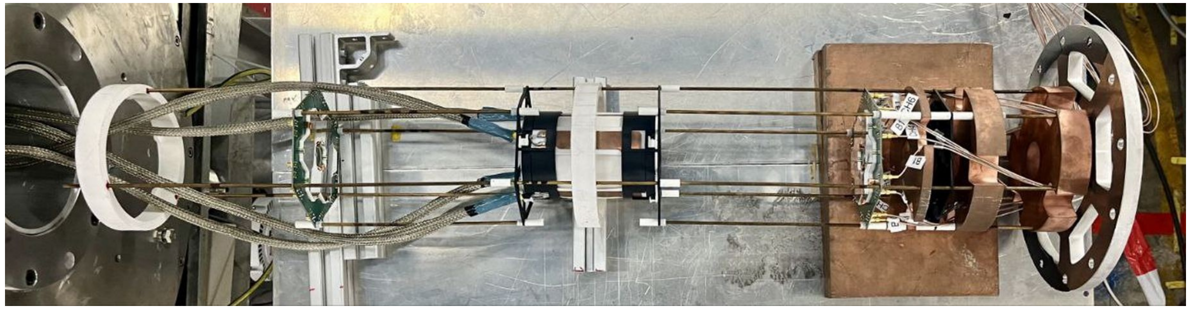


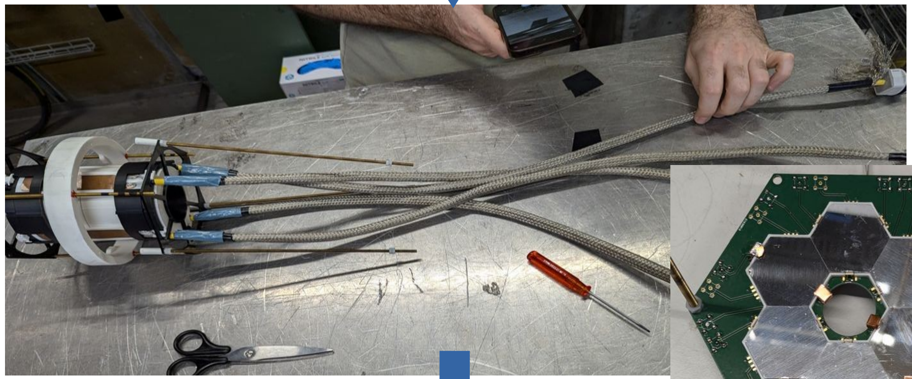


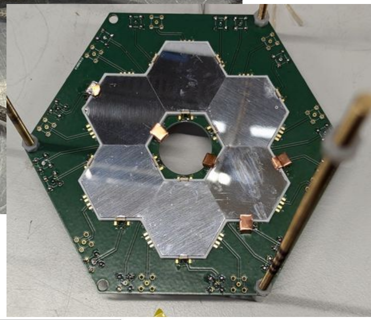
Early-to-late detection efficiency chan



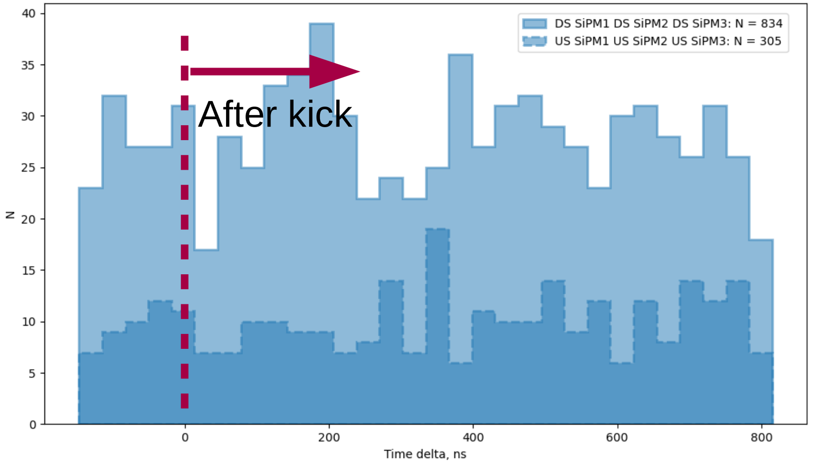
Two sets of detectors positioned around a target to measure positrons from muons at rest.

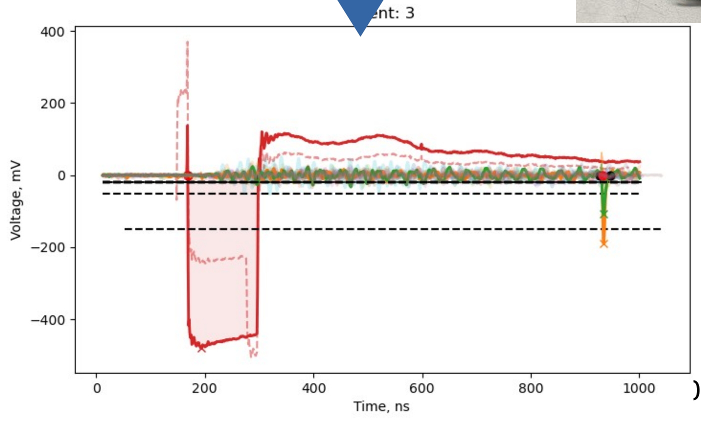






Measure the rates as a function of the time to the last kicker pulse → study kicker effects and establish mitigatio





Conclusions

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- A major possible systematic effects is a non-zero net longitudinal E-field component (i.e. parallel to B-field)
- Effect cancels if we alternate between CW and CCW injections, determined by the polarity of the main solenoid.
- Requrires control of the mean CW/CCW muon momentum and inital spin polarization direction.
- Muon momentum measured for CW/CCW with the magnet lifter setup and data analysis is pending.
- Early-to-late variations of detectors changing efficiency, baseline, noise level, etc. due to the kicker were tested in September 2024.
- The gathered data will be used to evaluate the extent of the effects.