Systematic effects in the search of the muon electric dipole moment using the frozen spin technique

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Introduction & Motivation

At PSI we are developing a high-precision instrument to measure the muon electric dipole moment (EDM) using the frozen spin technique[1] in a compact solenoid.[2]

EDMs of fundamental particles are widely recognized as unique probes for New Physics.[3]

Presence of an EDM in an elementary particle implies time invariance and charge-parity symmetry violation.

CP-violating interactions provided by SM extensions:

- Could give rise to a measurable EDM.
- Simultaneously might explain the baryon asymmetry of the Universe.[4,5,6]

The only EDM probed directly on the bare particle.

The experiment

Muons enter in a 3 tesla solenoid field one by one and are stopped midway by a pulsed magnetic kick.

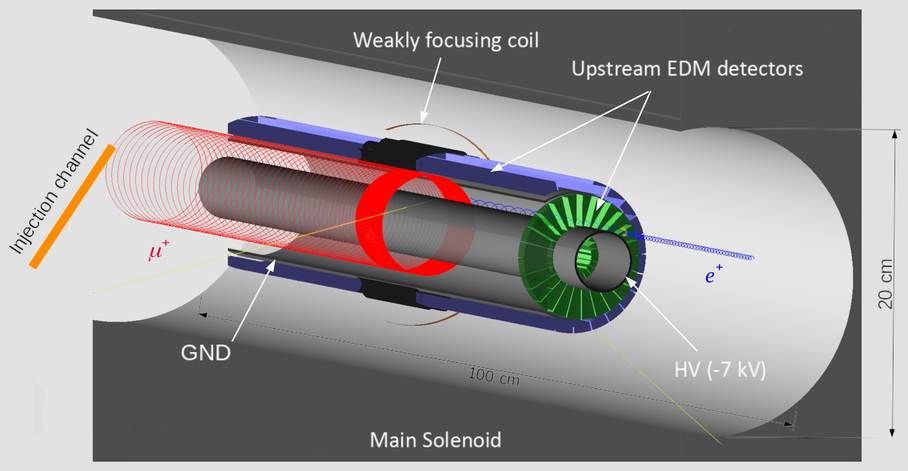
The muons are kept in a stable orbit by a weakly focusing field created by a coil.

The frozen spin technique: A radial E-field is applied by concentrical electrodes in order to cancel the *g-2* precession.

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

In the presence of a muon EDM there will be an accumulation of asymmetry between up-stream and down-stream detectors as a function of time.

Two staged experiment with precursor target sensitivity of $3\cdot10^{-21}$ e·cm and final sensitivity $6\cdot10^{-23}$ e·cm.



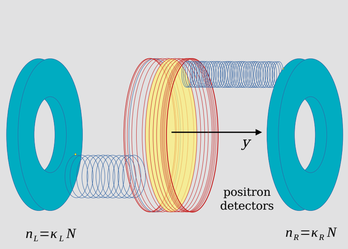
Systematic effects

All effects that lead to a real or apparent precession of the spin around the radial axis that are not related to the EDM.

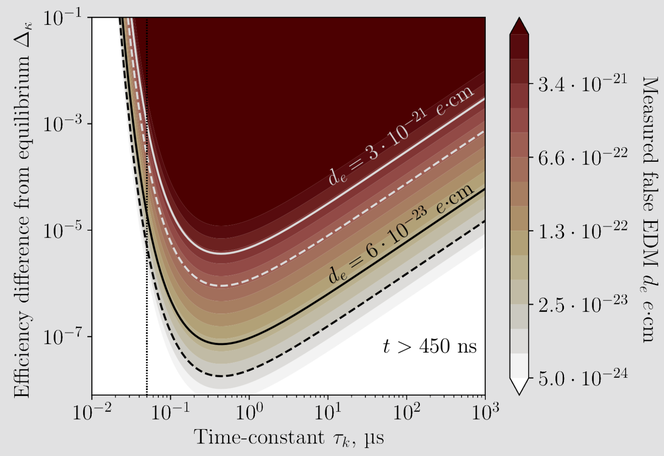
Some examples of major systematic effects are Early-to-Late variation of the detector response or coupling of the magnetic moment to the EM fields of the experimental setup.

Early-to-Late detector response

If there is a change of the efficiency of upstream relative to downstream detectors this will mimic an EDM signal (possible cause: pulsed magnetic kick).

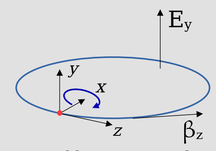


$$\dot{A}_m = \frac{2}{\tau_k}\Delta_\kappa e^{-t/\tau_k}$$



This systematic effect is significant only in the case of detectors placed in between the electrode structure as they would be sensitive to low-energy positrons.

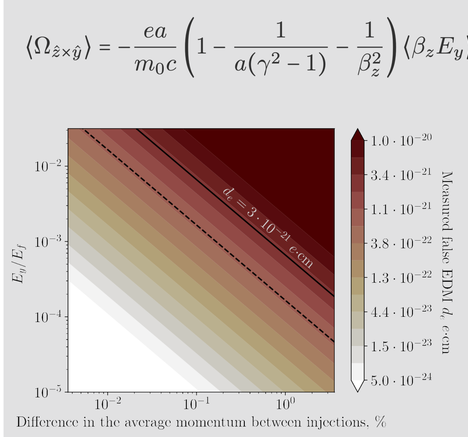
Longitudinal E-field component

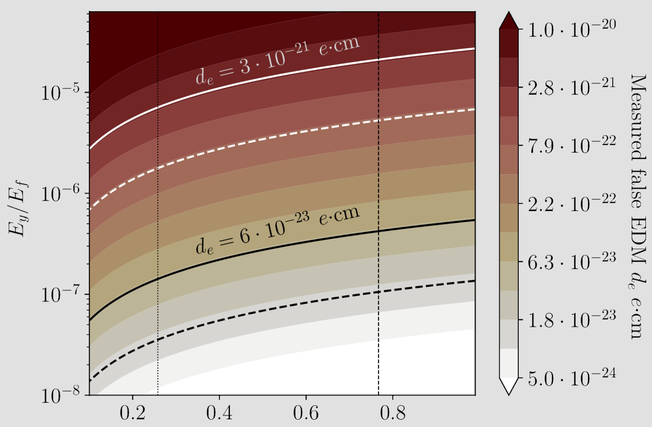


If a longitudinal E-field component is present it will couple to the anomalous magnetic moment and result in a precession in the vertical plane mimicking an EDM.

This effect can be largely cancelled if particles are injected alternatively in CW and CCW directions and subtracting the counts in the detectors.

$$\langle\Omega_{\hat{z}\times\hat{y}}\rangle = -\frac{ea}{m_0 c}\left(1 - \frac{1}{a(\gamma^2-1)} - \frac{1}{\beta_z^2}\right)\langle\beta_z E_y\rangle$$





Conclusions

Stringent limits in the order of 0.1 ppm on the horizontal component of the electric *spin-freeze* field were identified.

- The systematics due to the electric field would be largely cancelled by alternating CW and CCW muon injection.
- Limits on the CW and CCW average muon momentum are derived.

Limits on the early-to-late detection efficiency of the EDM detectors were calculated.

References

[1] Farley et. al., Phys. Rev. Lett. 93, 052001
[2] A Adelmann et al 2010 J. Phys. G: Nucl. Part. Phys. 37 085001
[3] arXiv:1910.11775
[4] A. Sakharov, Soviet Physics Uspekhi (1991),34(5): 392
[5] C. L. Bennett et al 2013 ApJS 208 20
[6] D. Morrissey and M. Ramsey-Musolf 2012 New J. Phys. 14 125003