SEARCH FOR ELECTRIC DIPOLE MOMENTS AT COSY IN JÜLICH

Spin tracking simulations using Bmad

19.03.2019 I VERA PONCZA on behalf of the JEDI collaboration

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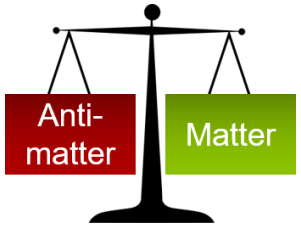
CONTENT

- Electric dipole moments (EDM)
- Measurement method
- Simulation results and comparison to measurement
- Summary & Outlook

MATTER ANTIMATTER ASYMMETRY

Big Bang



Equal amount of matter & antimatter

Early Universe

Preference of matter

Sakharov criteria:

- Baryon number violation
- No thermic equilibrium
- $\mathcal{C}, \mathcal{CP}$ **violation**

Today

Matter

Only matter

$$\frac{\text{matter} - \text{antimatter}}{\text{radiation}}$$

Observed:

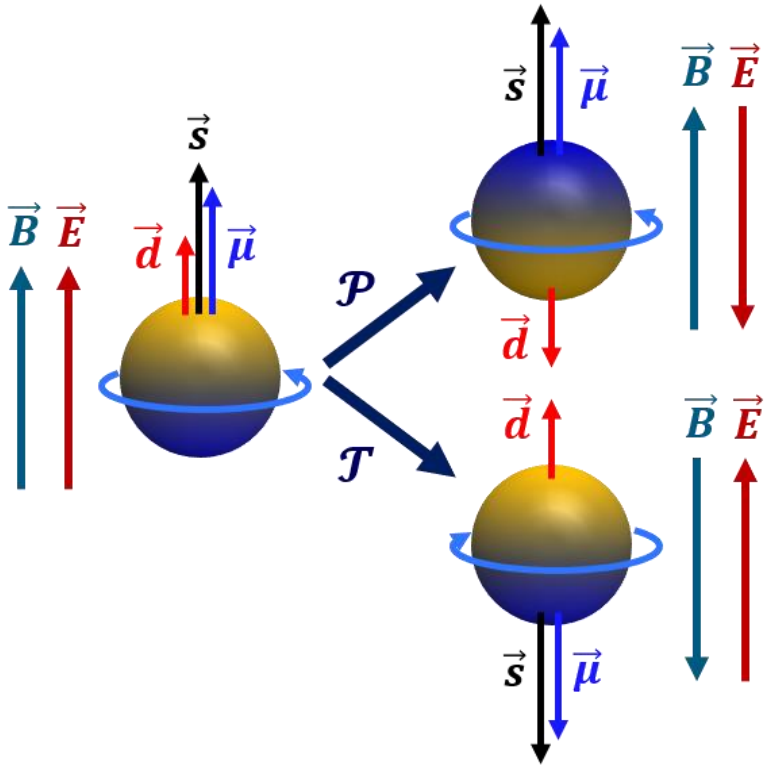
$$(6.14 \pm 0.25) \cdot 10^{-10}$$

Standard Model:

$$10^{-18}$$

Search for $\mathcal{CP}$ violation beyond the Standard Model

ELECTRIC DIPOLE MOMENTS (EDMS)



$\vec{s}$ spin

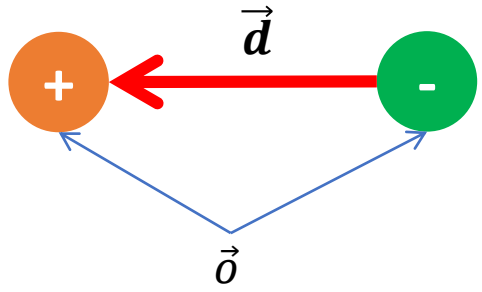
$\vec{d}$ electric dipole moment

$\vec{\mu}$ magnetic dipole moment

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

$$\mathcal{P}: \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$

$$\mathcal{T}: \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$



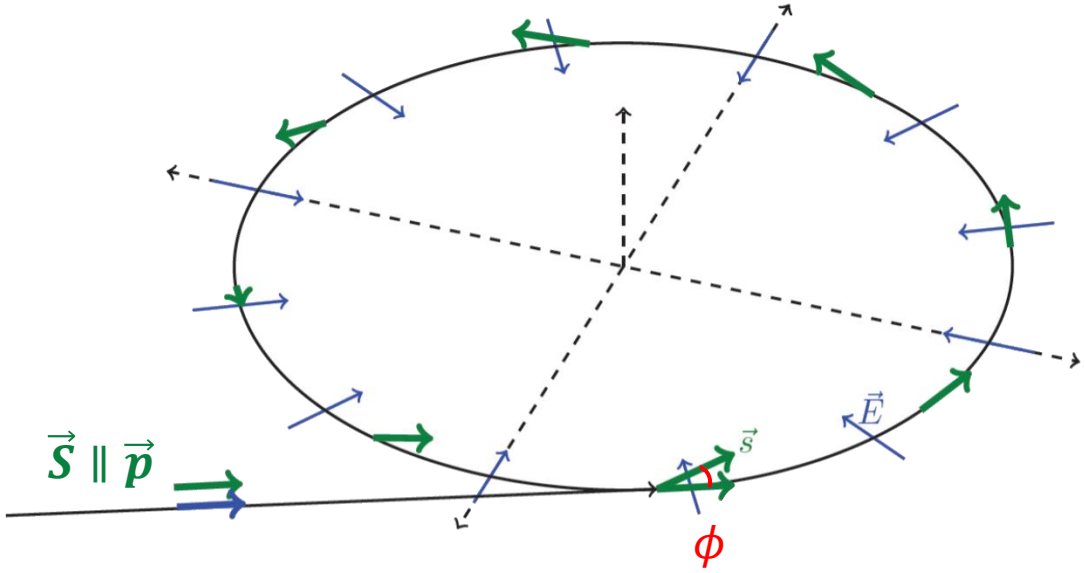
- **EDM**: a permanent separation of positive and negative charge (vector along spin direction)
- Fundamental property of particles (like mass, charge, magnetic moment)
- Existence of EDM only possible if violation of time reversal and parity symmetry

What are we talking about?

Neutron: $d < 3 \cdot 10^{-26}\ e \cdot \mathrm{cm}$

EDM MEASUREMENTS IN STORAGE RINGS

Example: pure electric ring



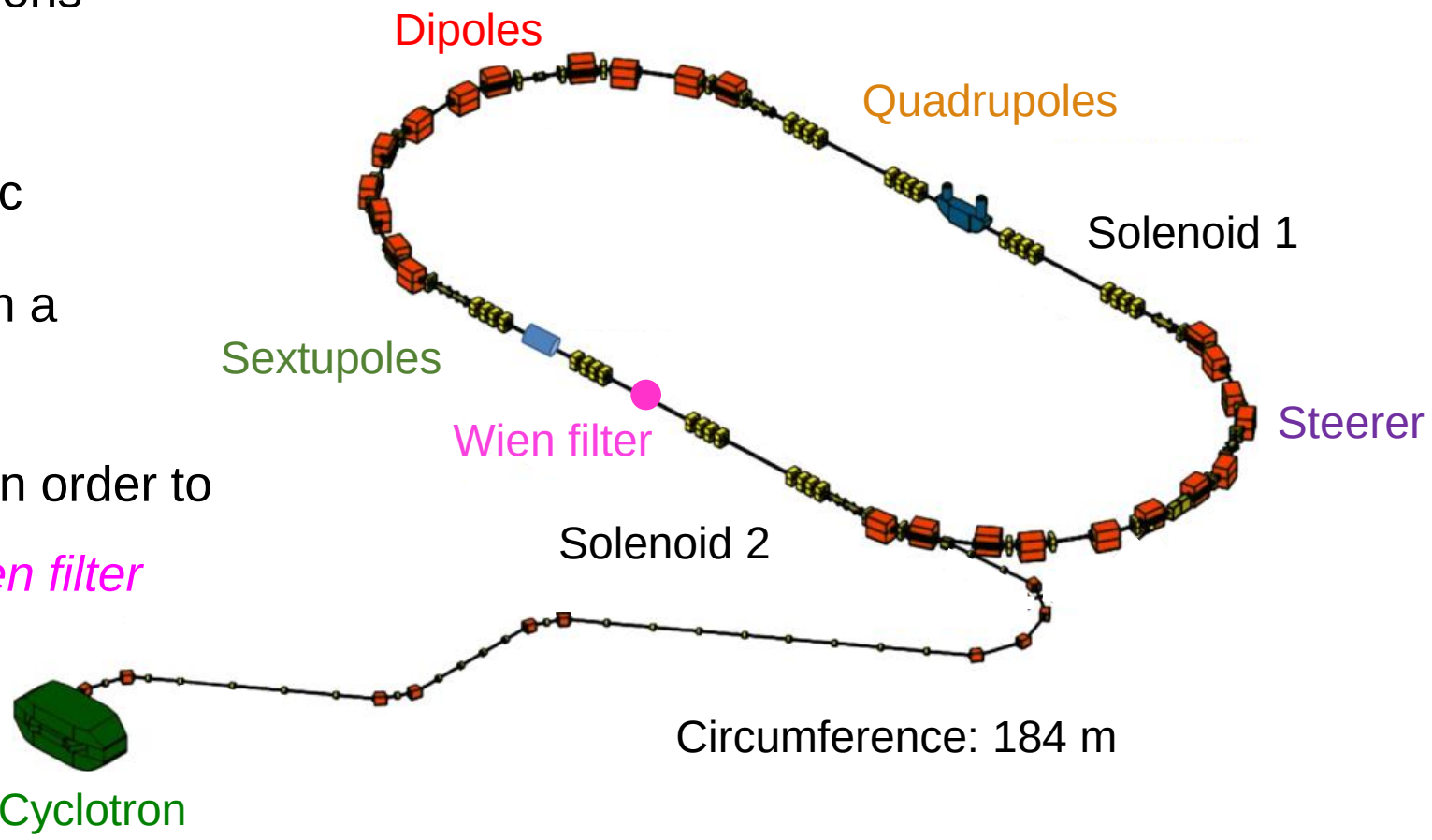
$$\frac{d\vec{S}}{dt} \propto \boldsymbol{d} \cdot \left(\vec{E} + c\vec{\beta} \times \vec{B} - A\,\vec{\beta}\left(\vec{\beta} \cdot \vec{E}\right)\right) \times \vec{S}$$

Basic idea:

- Inject particles with $\vec{S} \parallel \vec{p}$
- Use storage ring as particle trap
- Interaction of EDM with electromagnetic fields
- For $\vec{d} \neq 0$: spin rotates out of horizontal plane
- Measure: build-up of **vertical polarization ($\phi \propto |\vec{d}|$)**
- Different methods possible: pure E-field, pure B-field, combined versions

COOLER SYNCHROTRON COSY IN JÜLICH

- Polarized protons & deuterons
- Current experiments with deuterons at p = 970 MeV/c
- Measuring polarization with a polarimeter
- Special device necessary in order to measure the EDM: *RF Wien filter*

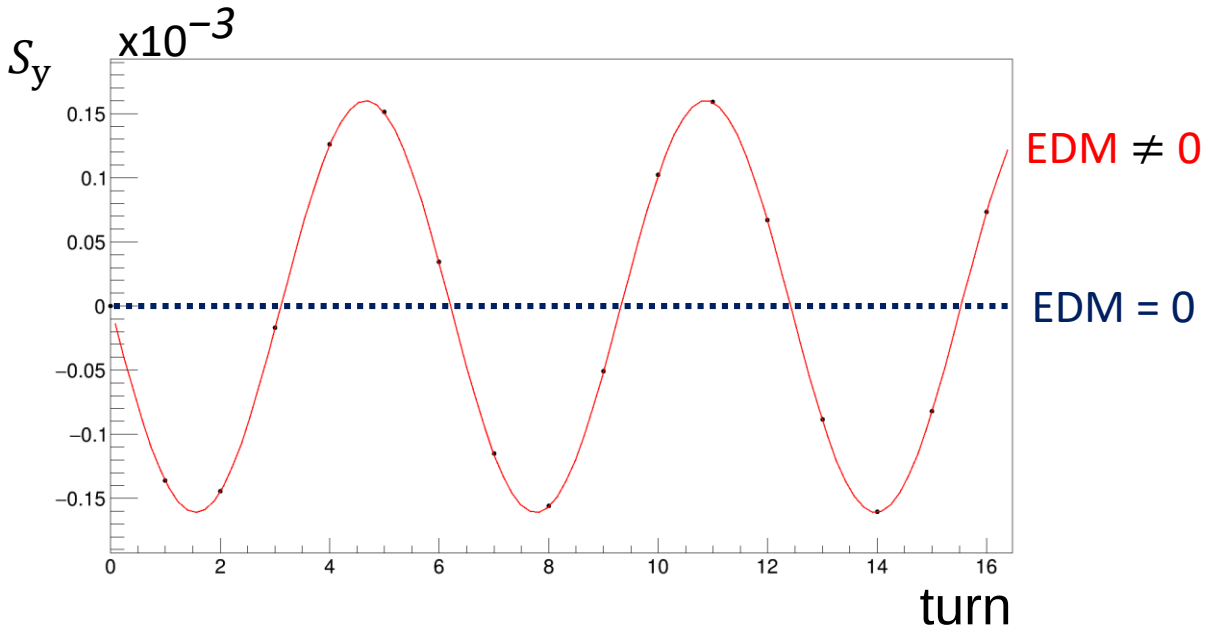


RESONANT WIEN FILTER METHOD

COSY: pure magnetic ring without RF Wien filter

$$\frac{d\vec{S}}{dt} = \left(\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}\right) \times \vec{S} = \left(\frac{q}{m} G\vec{B} + \frac{q\eta}{2m}\vec{\beta} \times \vec{B}\right) \times \vec{S} \quad \text{with} \quad \vec{d} = \eta \cdot \frac{q}{2mc}\vec{S}$$

- Vertical fields
- $\vec{S} \parallel \vec{p}$
- Spin rotates in horizontal plane
- $\vec{d} \neq 0$: oscillating vertical spin build-up

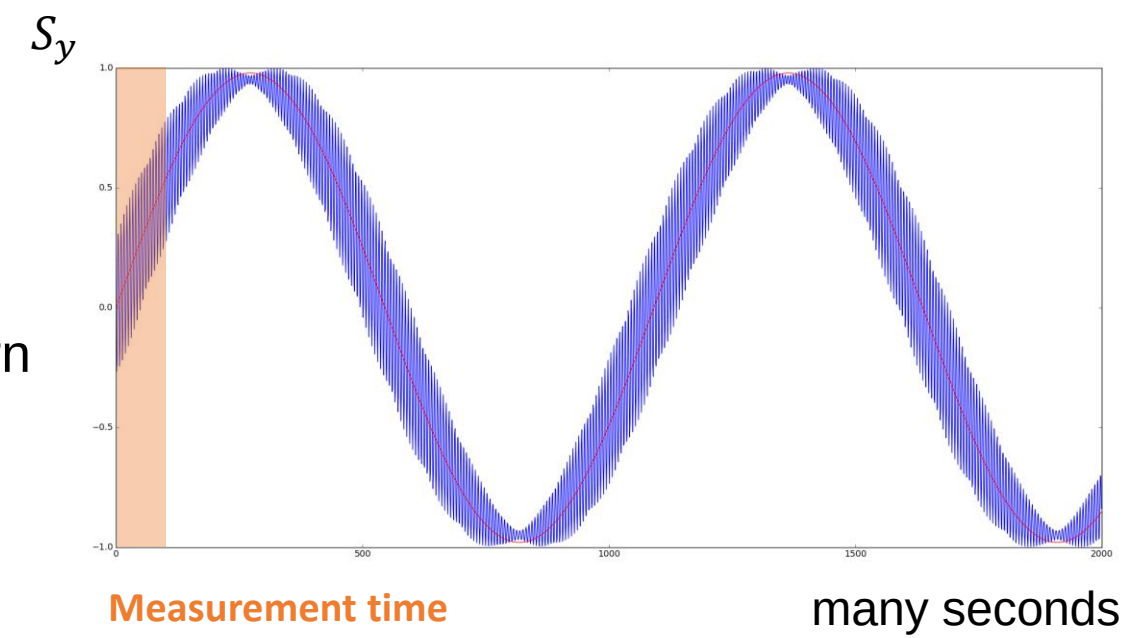


➡ No net EDM effect

RESONANT WIEN FILTER METHOD

- **Aim: prevent averaging out of EDM signal**
- RF device used to accumulate the EDM signal:
  - ✓ Radial electric field: $\boldsymbol{E_x \sim \cos(\omega t + \varphi)}$
  - ✓ Vertical magnetic field: $\boldsymbol{B_y \sim \cos(\omega t + \varphi)}$
- Additional time dependent phase advance each turn
- **Wien filter mode:** Lorentz force vanishes

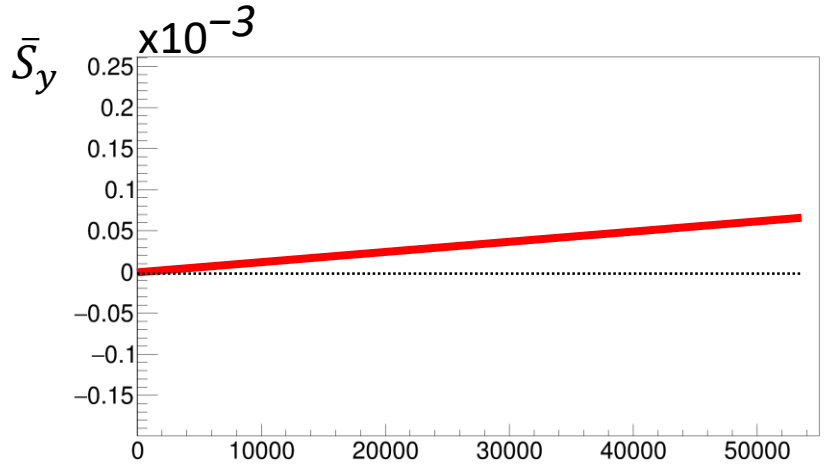
  → no beam perturbation
- RF frequency tuned to horizontal spin precession frequency ($\nu_s \approx -0.161/\mathrm{turn}$)



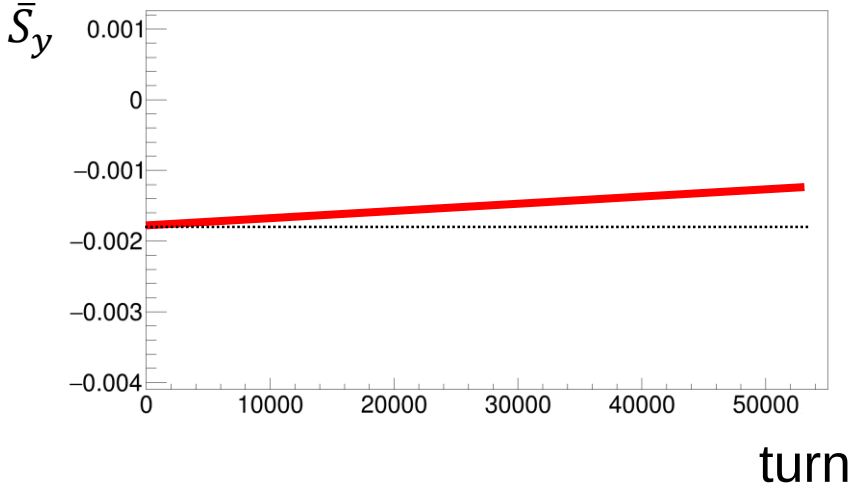
➡ Net EDM effect

SYSTEMATIC EFFECTS

- **Systematic effects** in the ring lead to EDM-like signals
- **Invariant spin axis tilts** due to radial and longitudinal magnetic fields
- Especially **radial B-fields** lead to vertical spin build-up
- **Simulations needed** to separate systematic effects from real EDM signal



$\eta = 0.0001$
$(d \approx 5 \cdot 10^{-19} e \cdot \mathrm{cm})$



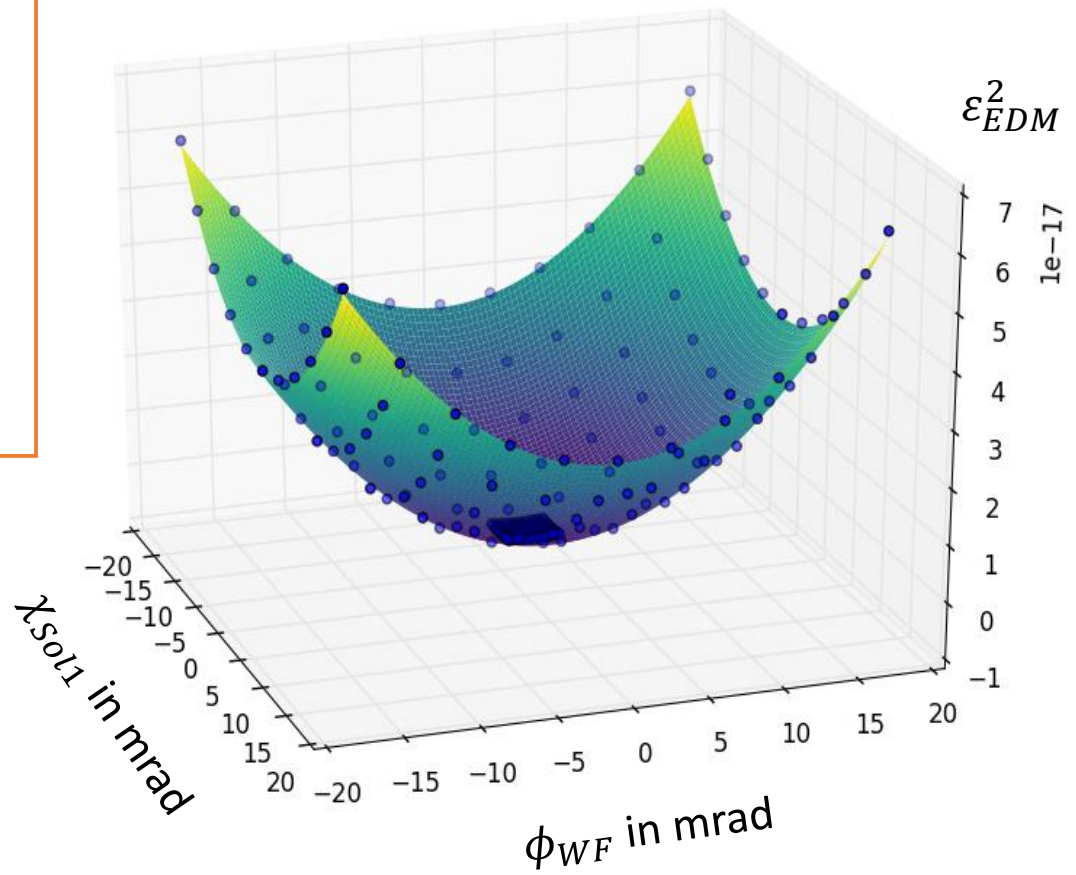
$\eta = 0$
+ random QP misalignments
($\mu = 0$ mm and $\sigma = 1$ mm
($\sigma = 1$ mrad))

MEASUREMENT METHOD

EDM resonance strength

$$\varepsilon_{EDM} = \frac{\Omega_{P_y}}{\Omega_{rev}} \quad \text{and} \quad \varepsilon_{EDM}^2 \propto A(\phi_{WF} - \boldsymbol{\phi_0})^2 + B(\chi_{Sol1} + \boldsymbol{\chi_0})^2$$

Ω_{P_y}	Angular frequency of vertical polarization oscillation
Ω_{rev}	Orbital angular frequency
ϕ_{WF}	Wien Filter rotation angle
χ_{Sol1}	Spin rotation angle of Solenoid 1



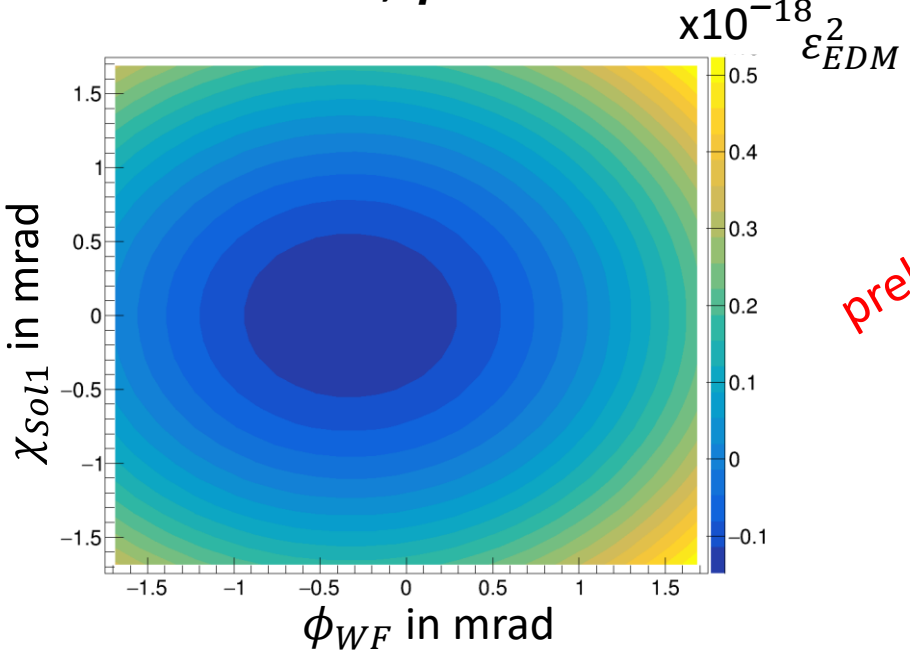
Basic idea:

- Manipulating the spin by
  1. rotating the Wien filter (ϕ_{WF})
  2. longitudinal B-field of a Solenoid (χ_{Sol1})
- Fitting point of minimal resonance strength ($\boldsymbol{\phi_0}$, $\boldsymbol{\chi_0}$)
- Fit parameter $\boldsymbol{\phi_0}$ is a measure of the EDM magnitude + **systematic effects**

SIMULATION INCLUDING MAGNET MISALIGNMENTS

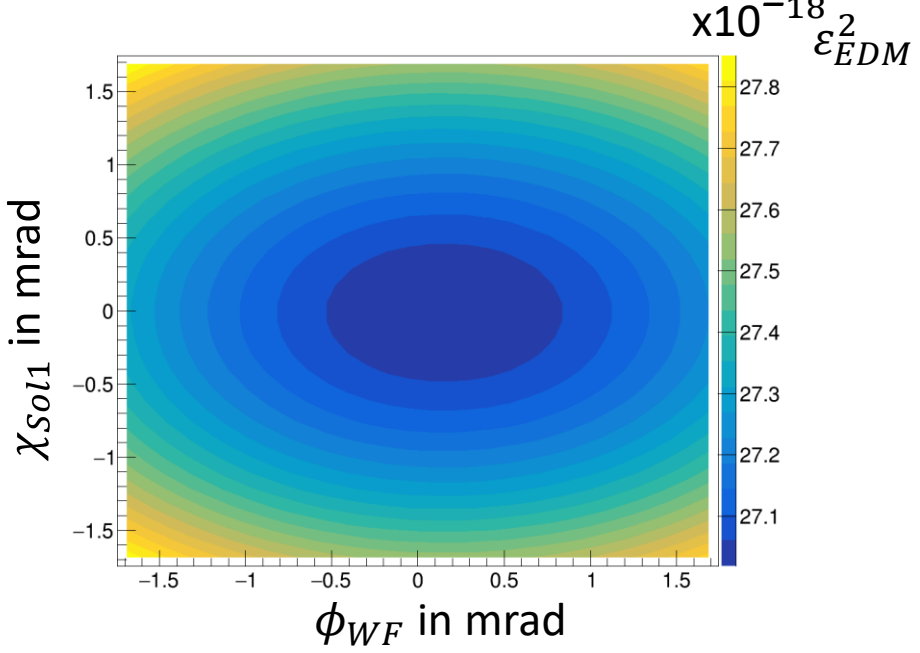
Spin tracking simulations using Bmad Software Library

Ideal lattice, $\eta = 0.0002$



preliminary

magnet misalignments, $\eta = 0.0$



$$\phi_0^{fit} = -0.32531 \pm 0.01764 \text{ mrad}$$

$$\phi_0^{theo} = -0.32127 \text{ mrad}$$

$$\phi_0^{fit} = 0.15328 \pm 0.01764 \text{ mrad}$$

$$\phi_0^{measured} = -3.42 \pm 0.28 \text{ mrad}$$

Code works

SUMMARY

- EDMs as candidate for physics beyond the Standard Model
- RF device was developed and is already installed and under test
- Systematic effects have to be investigated by simulations (Bmad software library + extensions)
- Simulations so far include magnet misalignments
- The results can not fully explain the measurement

OUTLOOK

- Additional systematic effects have to be considered and implemented
- Take measurement and position uncertainties of magnet positions into account
- **Build a realistic simulation model in order to support the data analysis**

THANK YOU