# 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

Member of the Helmholtz Association

III. Physikalisches Institut B | RWTH AACHEN UNIVERSITY

JEDI

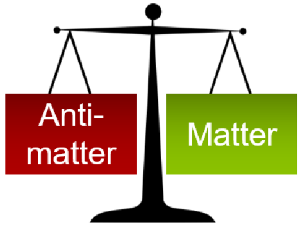
JÜLICH Forschungszentrum

# 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:**

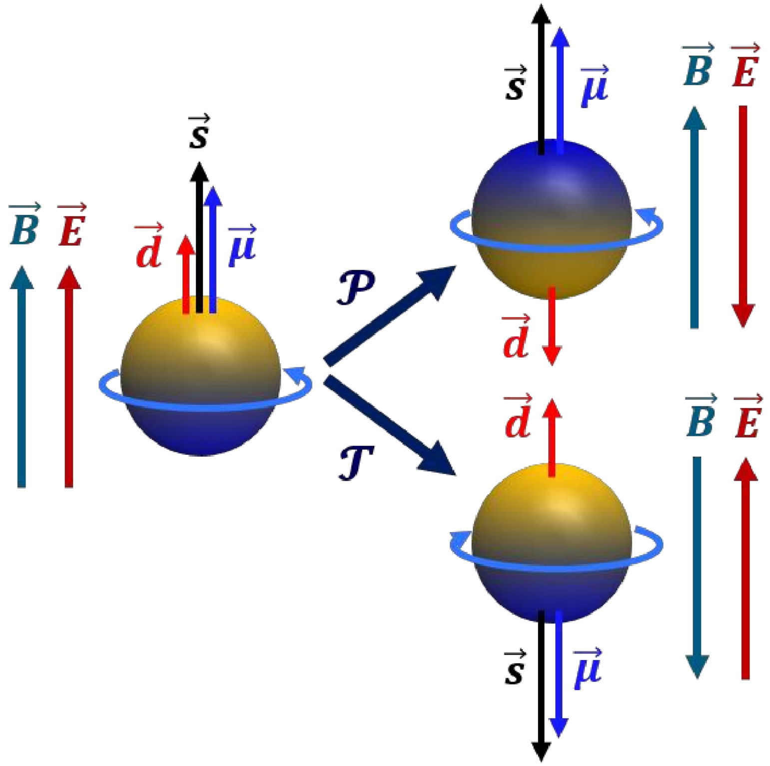
$(6.14 \pm 0.25) \cdot 10^{-10}$

**Standard Model:**

$10^{-18}$

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

# ELECTRIC DIPOLE MOMENTS (EDMS)

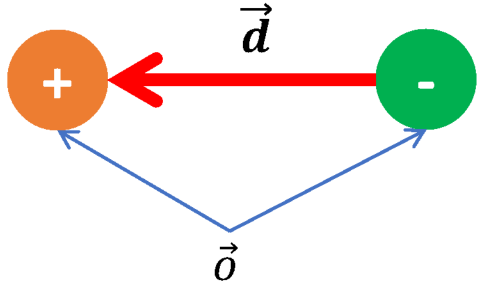



$\vec{s}$ spin

$\vec{d}$ electric dipole moment

$\vec{\mu}$ magnetic dipole moment

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



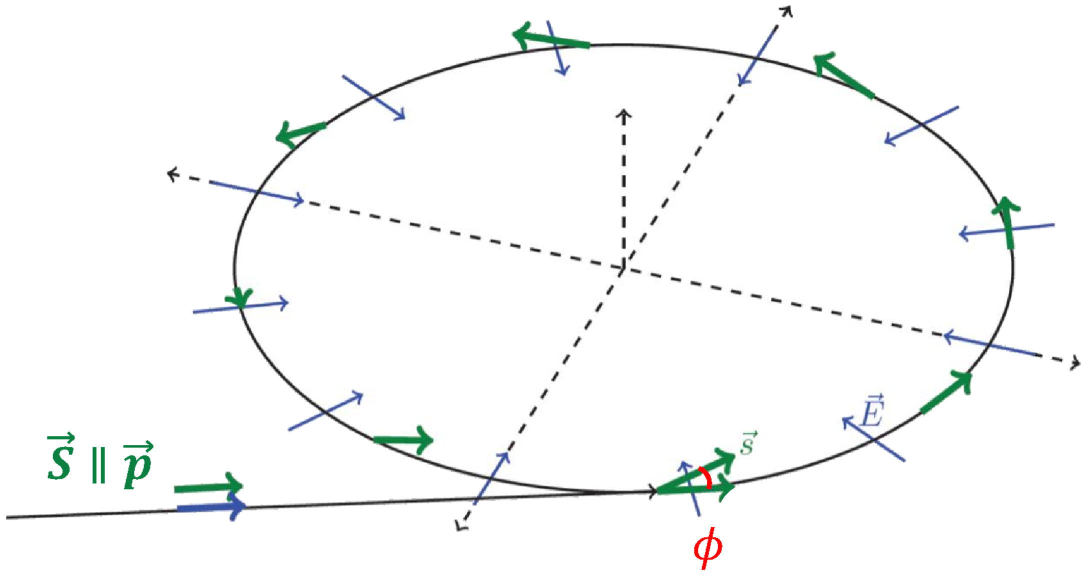

- **EDM**: a permanent separation of positive and negative charge (vector along spin direction)
- Fundamental property of particles (like mass, charge, magnetic moment)
- Existence of EDM only possible if violation of time reversal and parity symmetry

What are we talking about?

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

# EDM MEASUREMENTS IN STORAGE RINGS

Example: pure electric ring



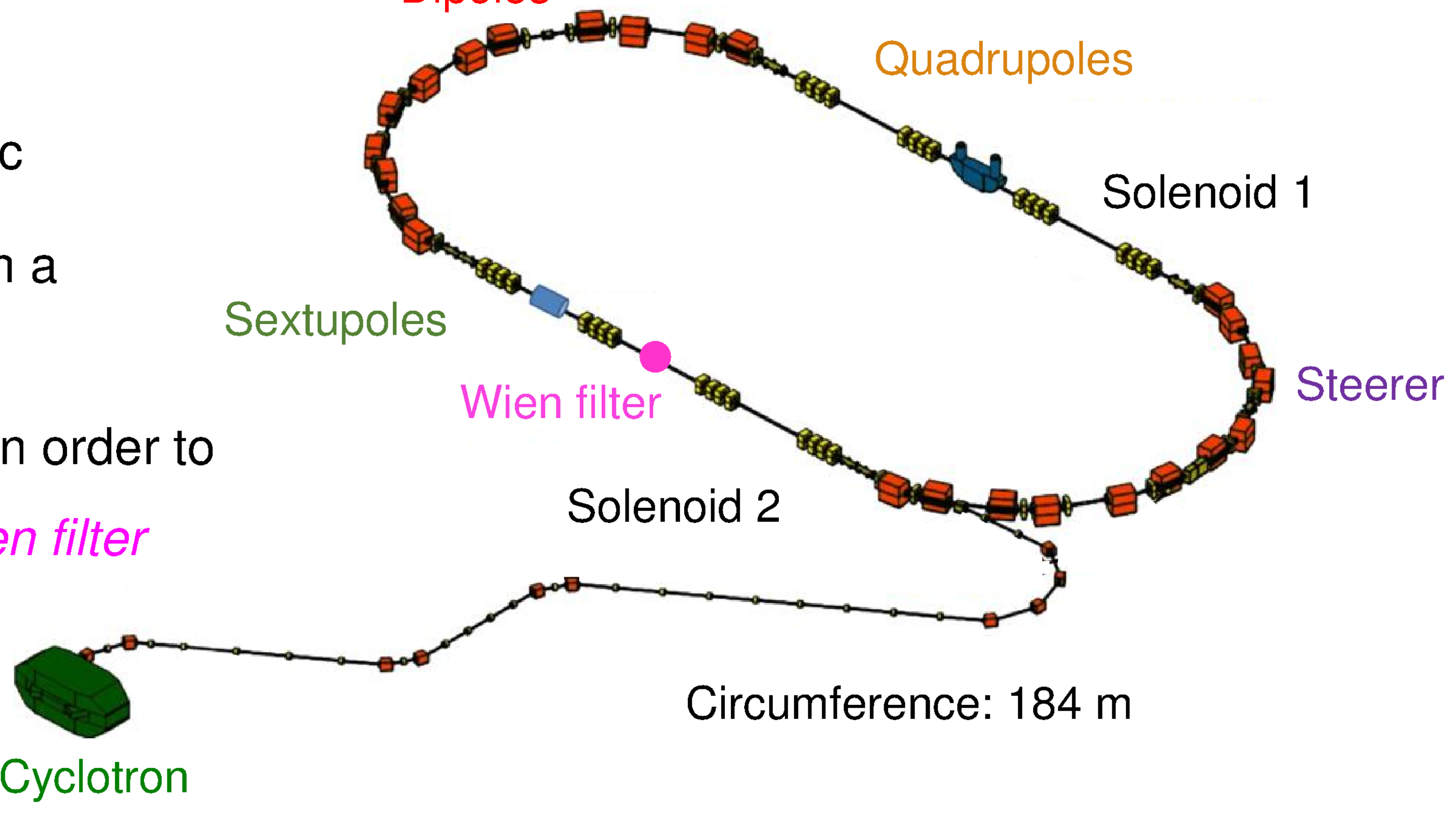

$$\frac{d\vec{S}}{dt} \propto \boldsymbol{d} \cdot \left(\vec{E} + c\vec{\beta} \times \vec{B} - A\,\vec{\beta}\left(\vec{\beta} \cdot \vec{E}\right)\right) \times \vec{S}$$

**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*

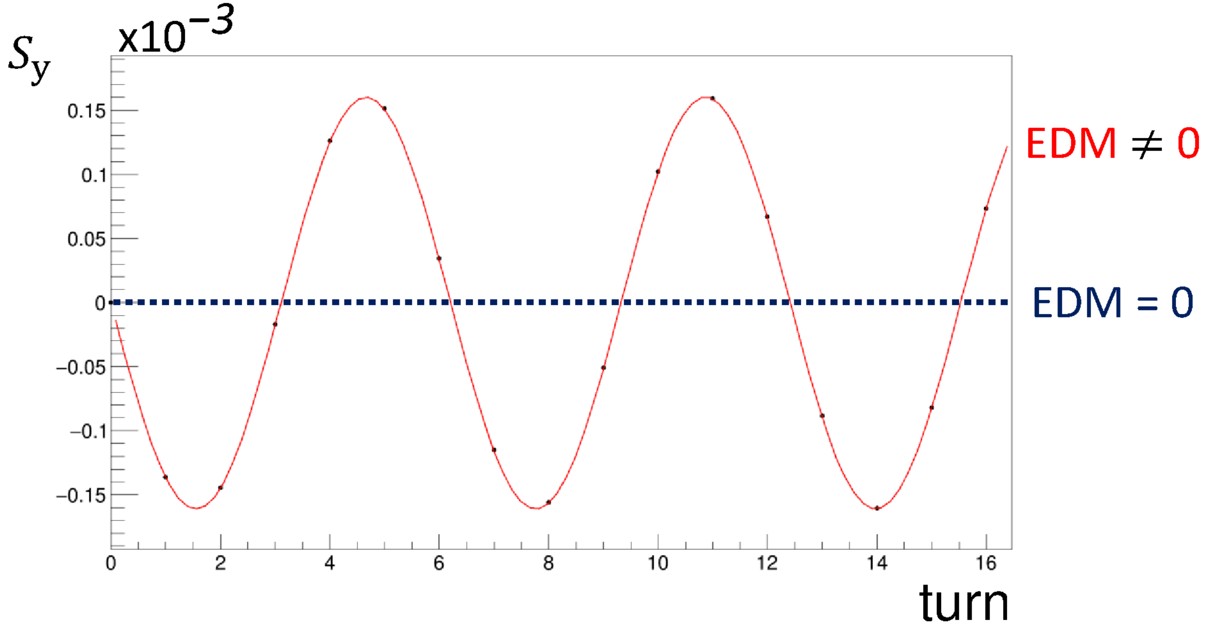


# RESONANT WIEN FILTER METHOD

## 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

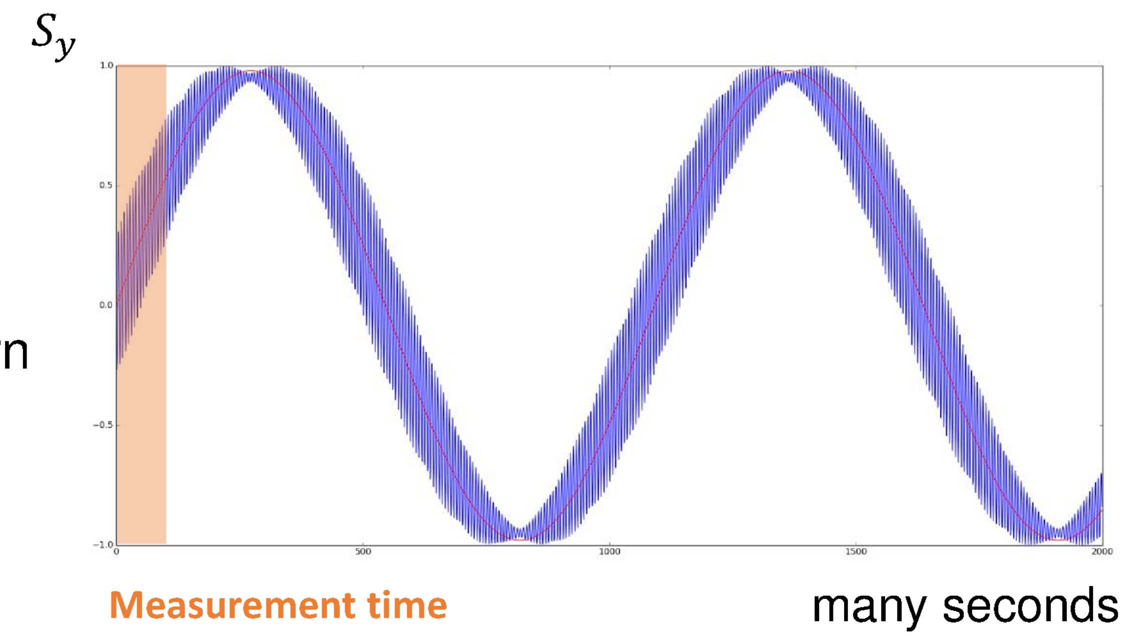
# RESONANT WIEN FILTER METHOD

- **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

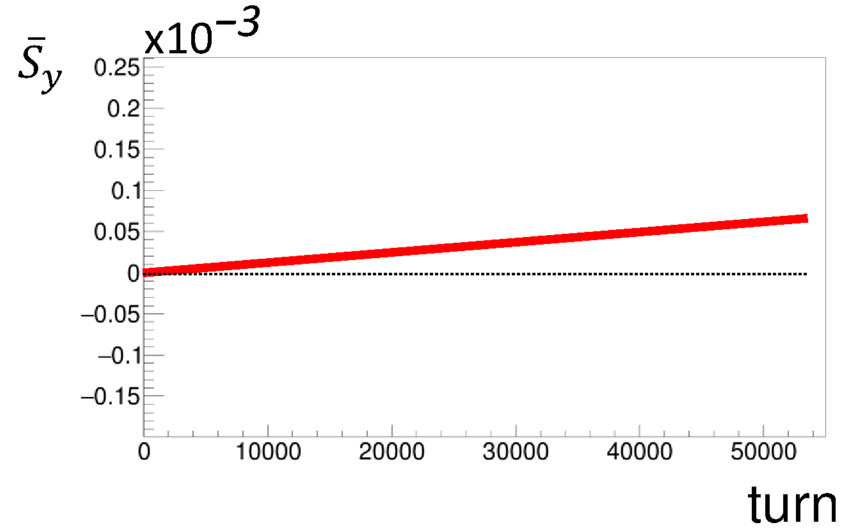
- RF frequency tuned to horizontal spin precession frequency ($\nu_s \approx -0.161/\mathrm{turn}$)

➡ Net EDM effect

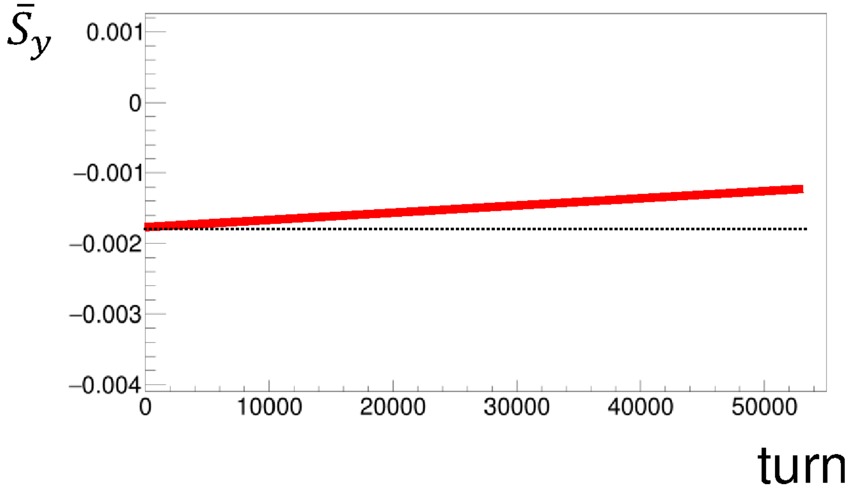


# SYSTEMATIC EFFECTS

- **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




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



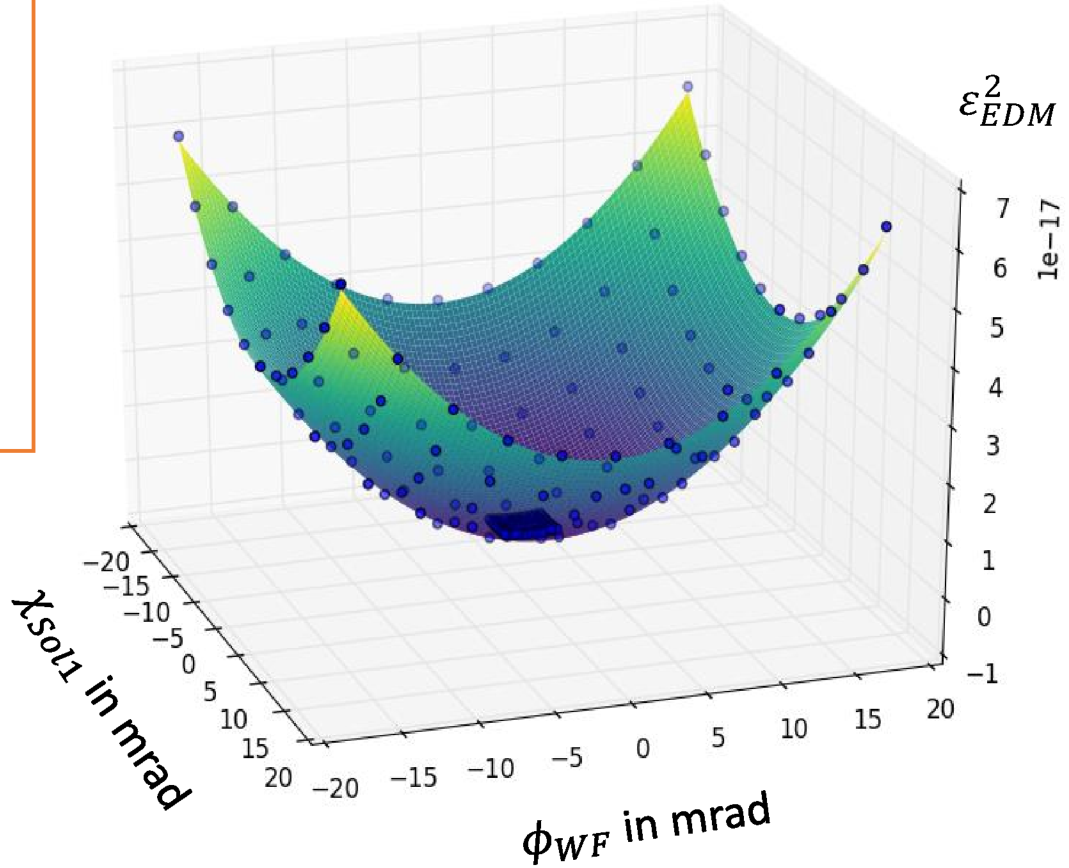

$\eta = 0$
+ random QP misalignments
($\mu = 0$ mm and $\sigma = 1$ mm
($\sigma = 1$ mrad))

# MEASUREMENT METHOD

**EDM resonance strength**

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

| | |
|---|---|
| $\Omega_{P_y}$ | Angular frequency of vertical polarization oscillation |
| $\Omega_{rev}$ | Orbital angular frequency |
| $\phi_{WF}$ | Wien Filter rotation angle |
| $\chi_{Sol1}$ | Spin rotation angle of Solenoid 1 |



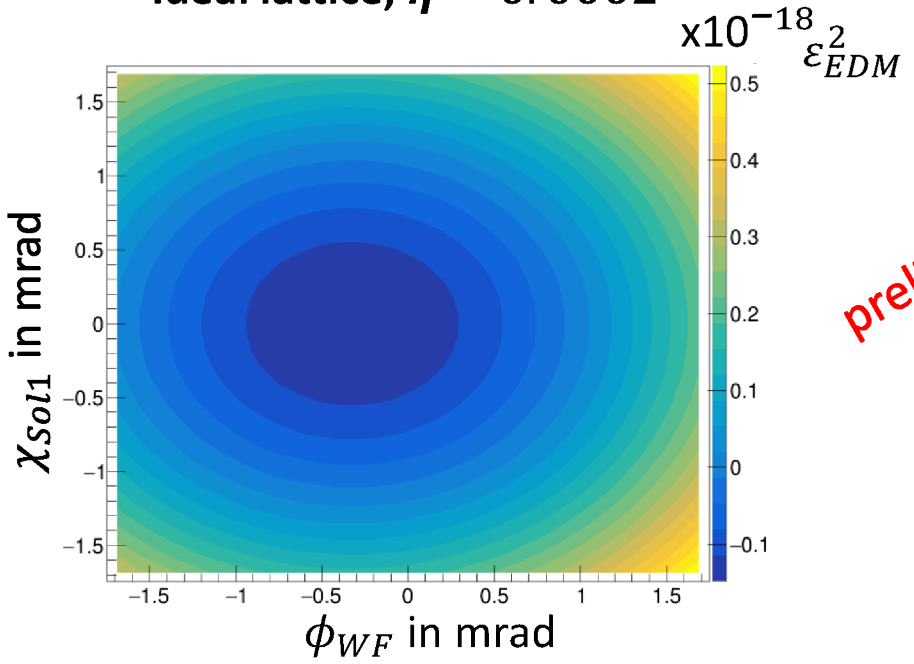

**Basic idea:**

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

# SIMULATION INCLUDING MAGNET MISALIGNMENTS

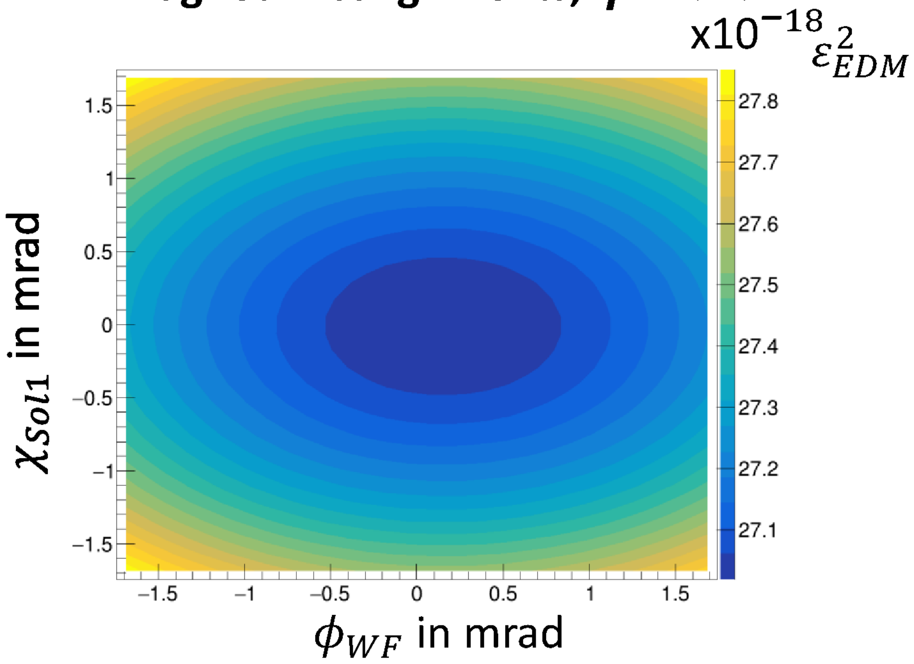
## Spin tracking simulations using Bmad Software Library

**Ideal lattice, $\eta = 0.0002$**




preliminary

**magnet misalignments, $\eta = 0.0$**




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

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

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

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

➡ Code works



RWTH AACHEN UNIVERSITY JEDI JÜLICH Forschungszentrum

# 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