The Search for Charged Particle Electric Dipole Moments in Storage Rings

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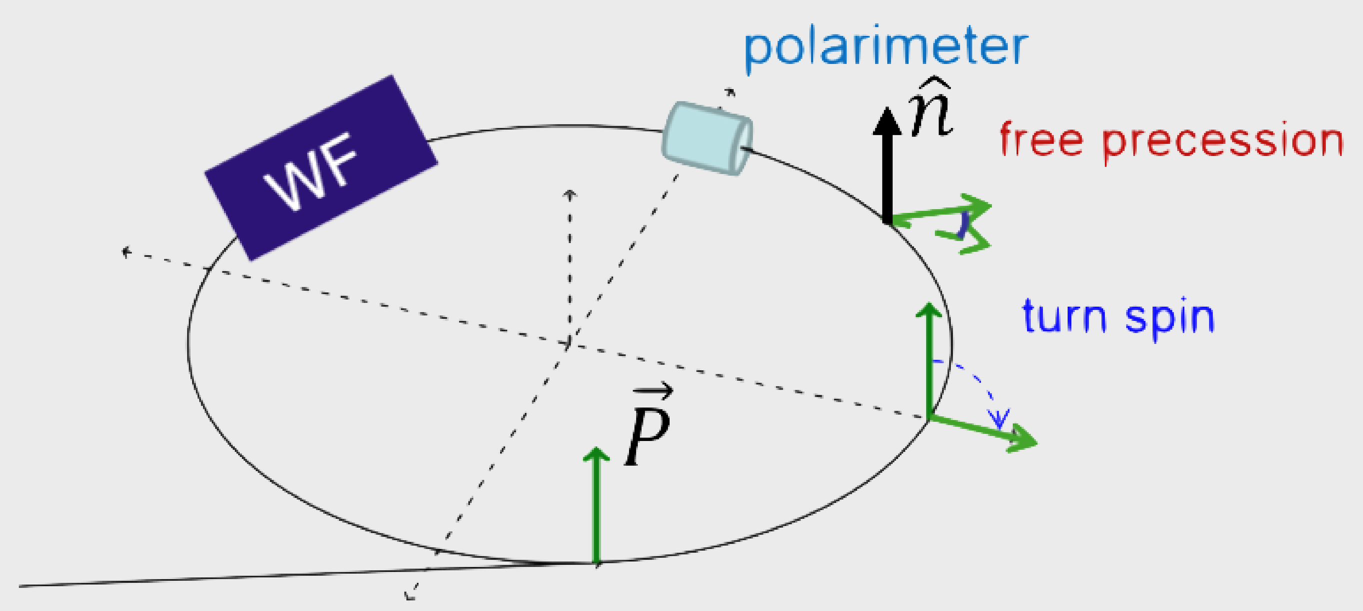
Electric Dipole Moments (EDMs)

- Fundamental (vector) property of a particle aligned with the particles spin axis
- Requires $\mathcal{P}$ and $\mathcal{T}$ violation $\overset{\mathcal{CPT}}{=}$ $\mathcal{CP}$ violation
- Close connection to **matter antimatter asymmetry**
- **Goal:** First direct measurement of the **deuteron** EDM
- Current neutron EDM limit $\sim 10^{-26}\,\mathrm{e\cdot cm}$ [1] $\rightarrow$ Measurement requires **precise** experiments

Technique Part I

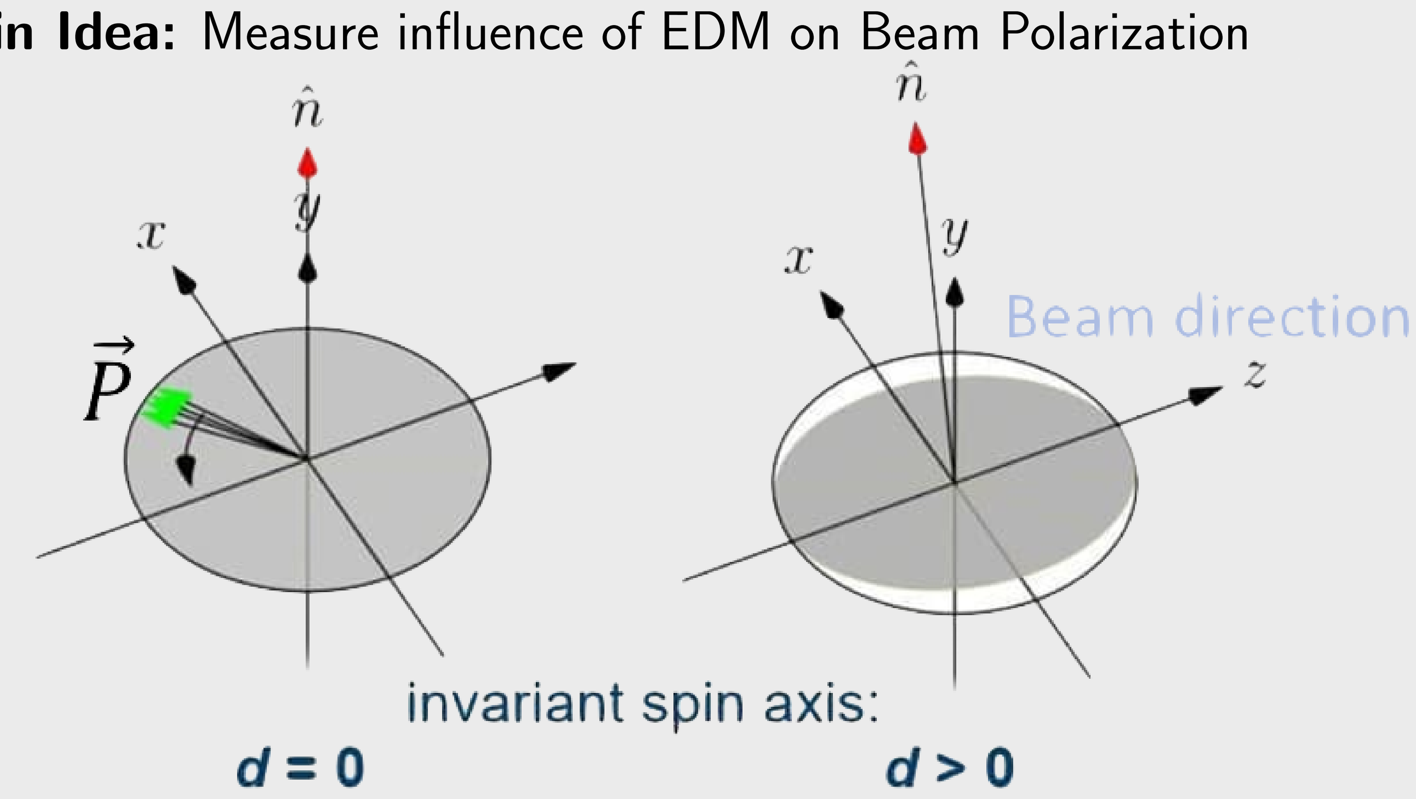
- COSY @ Forschungszentrum Jülich: Magnetic Ring (184 m)



- Inject a **vertically polarized** deuteron beam
- Rotate the polarization into the **accelerator plane**
- Polarization starts to **precess** around the so-called Invariant spin axis $\hat{n}$ (ISA)
- Beam polarization is constantly measured by a polarimeter

Spin Dynamics

- **Main Idea:** Measure influence of EDM on Beam Polarization



- In absence of an EDM & ideal accelerator: ISA $\perp$ accelerator plane
- Non zero EDM rotates the ISA $\hat{n}$ in radial (x) direction

$$\hat{n} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \overset{\mathrm{EDM}}{\Rightarrow} \begin{pmatrix} \sin\phi_0^{\mathrm{EDM}} \\ \cos\phi_0^{\mathrm{EDM}} \\ 0 \end{pmatrix} \approx \begin{pmatrix} \phi_0^{\mathrm{EDM}} \\ 1 \\ 0 \end{pmatrix}$$

- Magnet misalignment add additional systematics to the orientation of the ISA $\hat{n}$ in radial (x) and longitudinal direction (z)

$$\hat{n}_{\mathrm{meas.}} = \begin{pmatrix} \phi_0^{\mathrm{EDM}} + \phi_0^{\mathrm{COSY}} \\ 1 \\ \xi_0^{\mathrm{COSY}} \end{pmatrix}$$

- Simulations are needed to disentangle ϕ_0^{EDM} and ϕ_0^{COSY} (M. Vitz)
- **Goal:** Measurement of the orientation of the Invariant spin axis $\hat{n}$

References

[1] C. Abel *et al.*, *Measurement of the Permanent Electric Dipole Moment of the Neutron*, feb 2020.

[2] F. Rathmann, N. Nikolaev, and J. Slim, *Spin dynamics investigations for the electric dipole moment experiment*, Feb 2020.

Technique Part II

- The radio frequency (rf) Wien filter provides a vertical $\vec{B}$ and horizontal $\vec{E}$ field

$$\vec{E} \perp \vec{B} \perp \mathrm{Beam} \rightarrow \vec{F}_L = \vec{0}$$

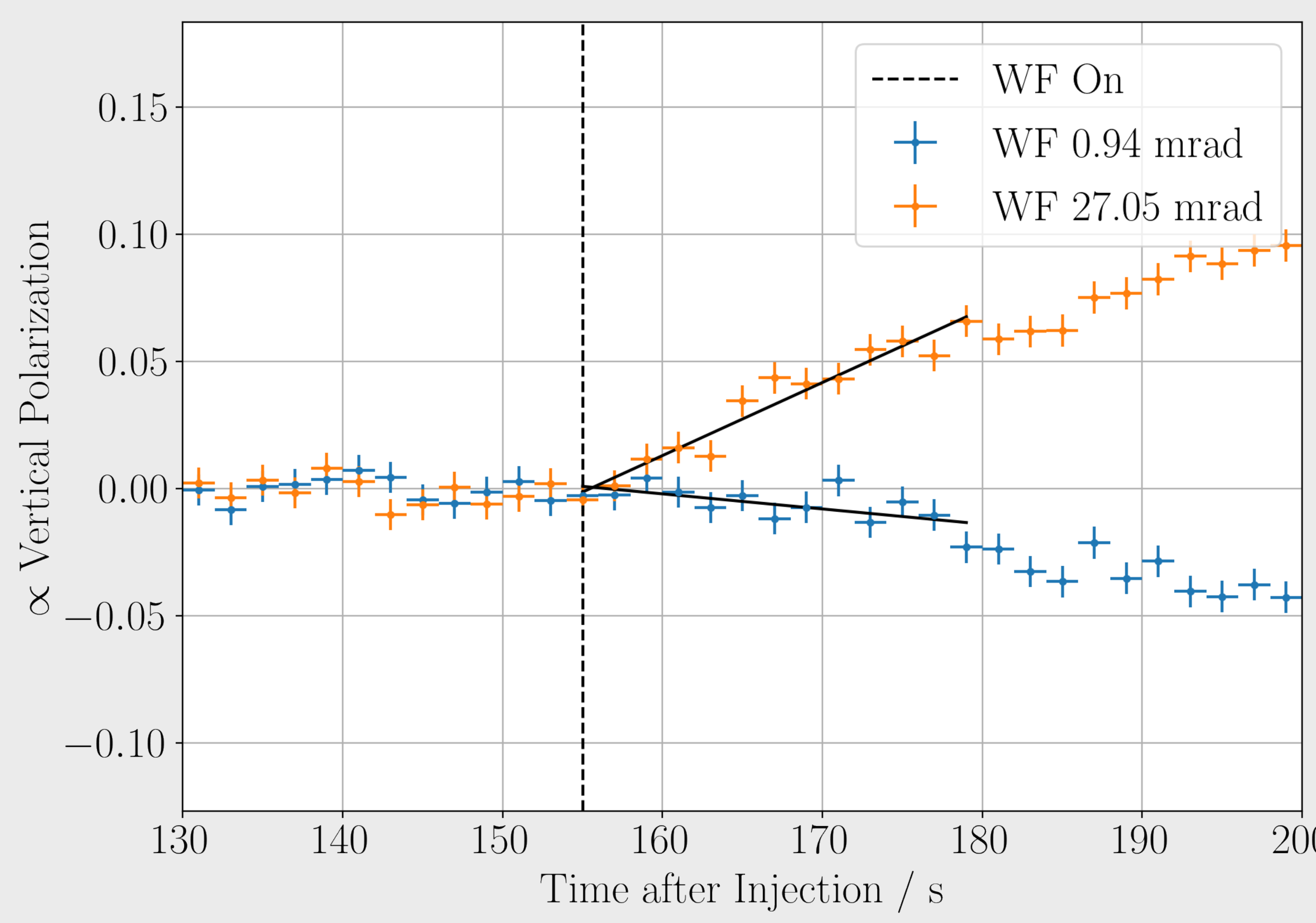
- No influence on beam $\rightarrow$ Ideal Spin manipulator
- The Wien filter can be radially rotated around the beam pipe. The **magnetic field direction** of the Wien filter is given by

$$\hat{n}_{\mathrm{WF}} = \begin{pmatrix} \sin\phi^{\mathrm{WF}} \\ \cos\phi^{\mathrm{WF}} \\ 0 \end{pmatrix} \approx \begin{pmatrix} \phi^{\mathrm{WF}} \\ 1 \\ 0 \end{pmatrix}$$

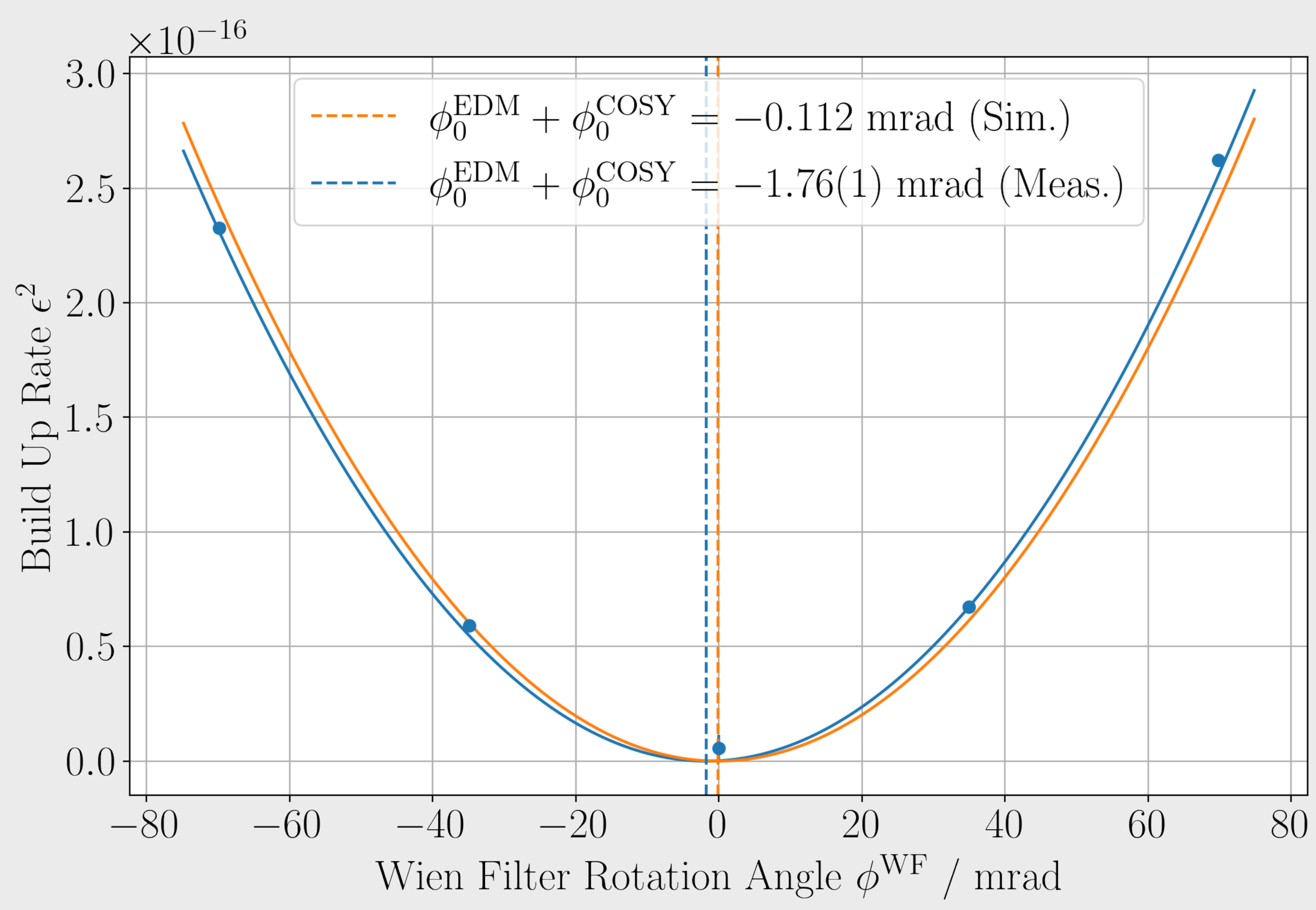
- The rf Wien filter induces a **linear build up** of the vertical polarization
- The **build up** depends on the direction of the **magnetic field axis of the rf Wien filter** $\hat{n}_{\mathrm{WF}}$ and the orientation of **ISA** $\hat{n}_{\mathrm{meas.}}$ [2]

$$\epsilon^2\left(\phi^{\mathrm{WF}}\right) \propto |\hat{n}_{\mathrm{WF}} \times \hat{n}_{\mathrm{meas.}}|^2$$
$$\propto \left(\left(\phi_0^{\mathrm{EDM}} + \phi_0^{\mathrm{COSY}}\right) - \phi^{\mathrm{WF}}\right)^2 + \epsilon_0\left(\xi_0^{\mathrm{COSY}}\right)$$

- No build up if $\hat{n}_{\mathrm{WF}} \parallel \hat{n}_{\mathrm{meas.}}$



Preliminary Results



- Orientation of ISA in radial direction including ring systematics

$$\phi_0^{\mathrm{EDM}} + \phi_0^{\mathrm{COSY}} = -1.76(1)\,\mathrm{mrad}$$
$$\approx 10^{-17}\,\mathrm{e\cdot cm}\ \text{Upper Limit}$$

- **Simulations** of the experiment (including magnet misalignments, steerer & magnet settings,..) **predict** radial angles **not larger than $\mathcal{O}$(0.1) mrad**.
- We are **missing systematics** of an order of magnitude
- Systematic Studies are ongoing

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