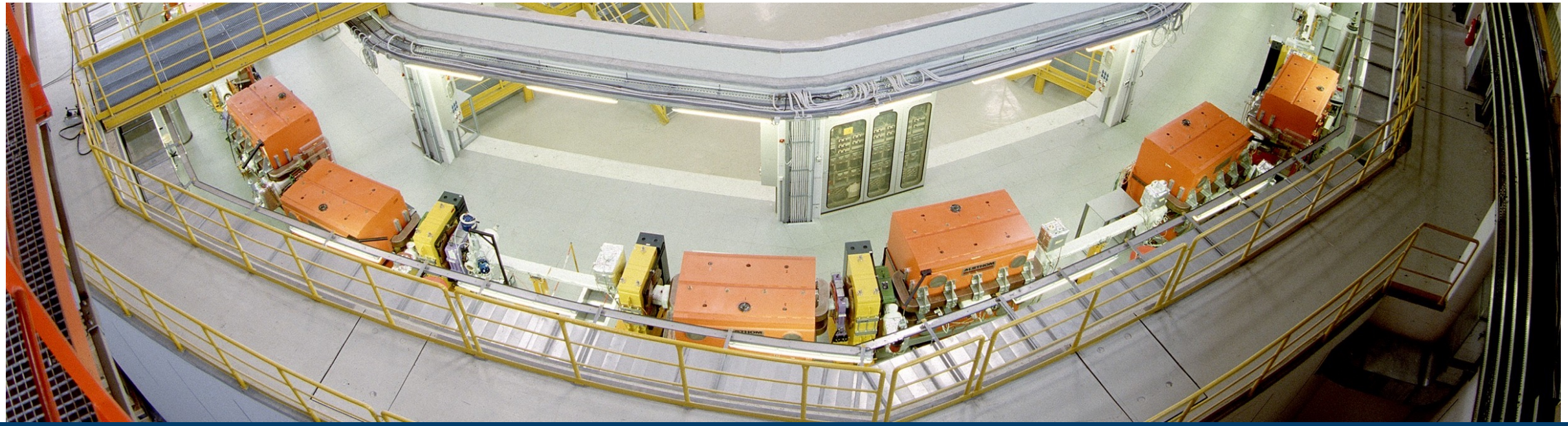

THE SEARCH FOR ELECTRIC DIPOLE MOMENTS OF CHARGED PARTICLES IN STORAGE RINGS

DPG Spring Meeting Karlsruhe

08.03.2024 I ACHIM ANDRES (ON BEHALF OF THE JEDI COLLABORATION)

JEDI

Physics Institute III B | RWTH AACHEN UNIVERSITY

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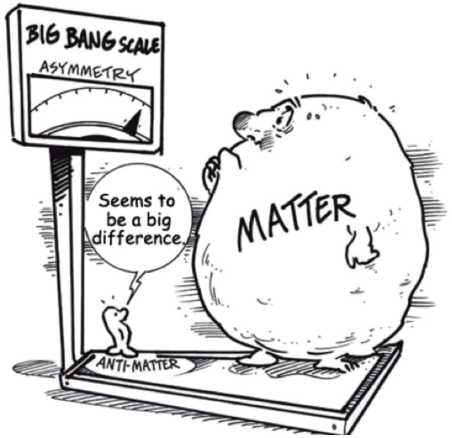
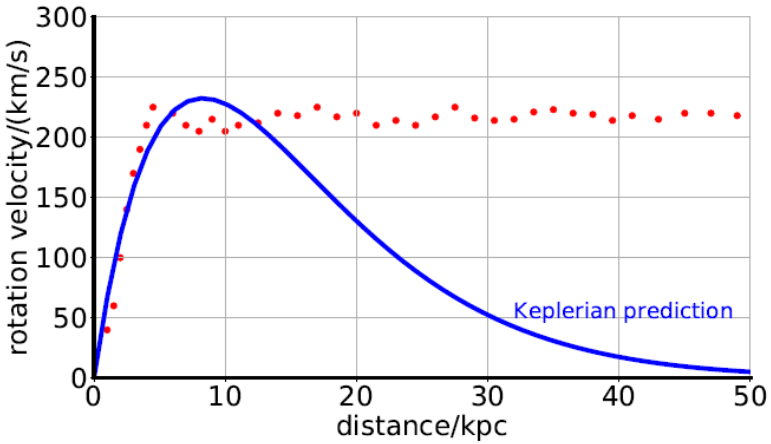
SCIENTIFIC MOTIVATION

JEDI Collaboration (2011) – Juelich Electric Dipole moment Investigations



$$\mathcal{L}_{\bar{\theta}_{\mathrm{QCD}}} = -\bar{\theta}_{\mathrm{QCD}} \frac{g_s^2}{64\pi^2} \epsilon^{\mu\nu\alpha\beta} G^a_{\mu\nu} G^a_{\alpha\beta}$$



- EDM is a ***vectorial*** property aligned with **the particles' spin**
- EDMs of fundamental particles are CP violating
- Matter Antimatter Asymmetry remains a mystery
- According to A. Sakharov: **CP Violation** is needed

$$d^{\mathrm{d}} = d_{\mathrm{DC}} + d_{\mathrm{AC}} \cos(\omega_a + \phi_a)$$

$$\omega_a = \frac{m_a c^2}{\hbar}$$

- Existence of an axion leads to an additional oscillating EDM component
- Axion could explain the strong CP - problem
- Axion are potential candidate for Dark Matter

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AXION SEARCH

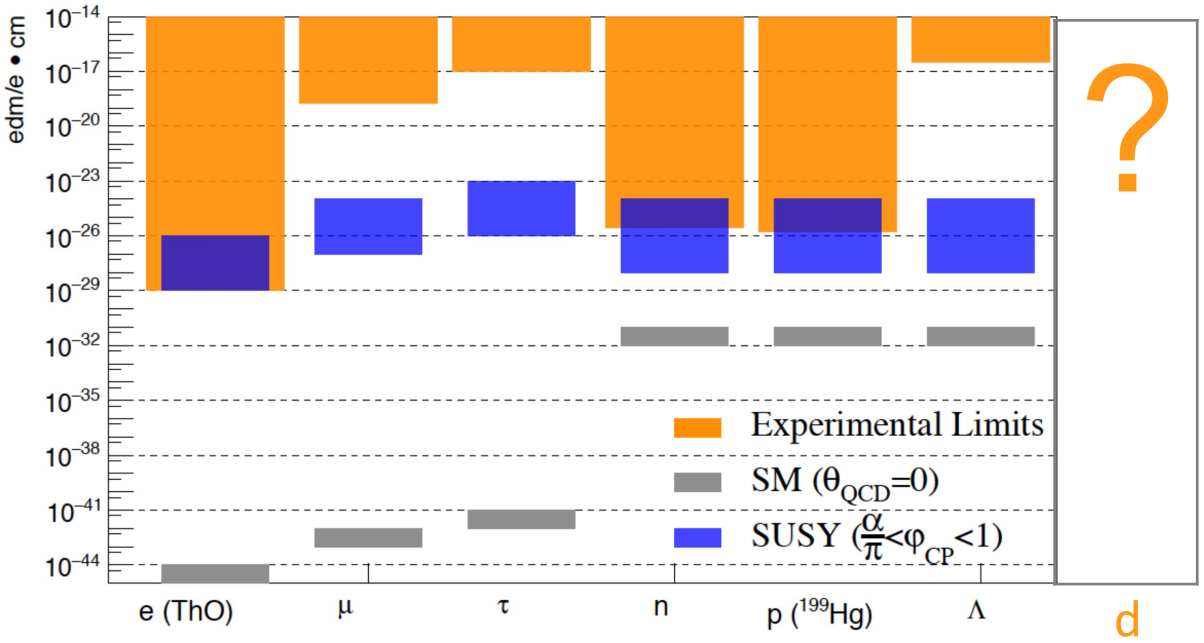
$$d^{\mathrm{d}} = d_{\mathrm{DC}} + d_{\mathrm{AC}}\cos(\omega_a + \phi_a)$$

$$\omega_a = \frac{m_a c^2}{\hbar}$$

- Constraints for the axion gluon coupling:

$$\left|g_{ad\gamma}\right| < 1.7 \times 10^{-7}\,\mathrm{GeV}^{-2}$$

- **Permant EDM component d_{DC}:**

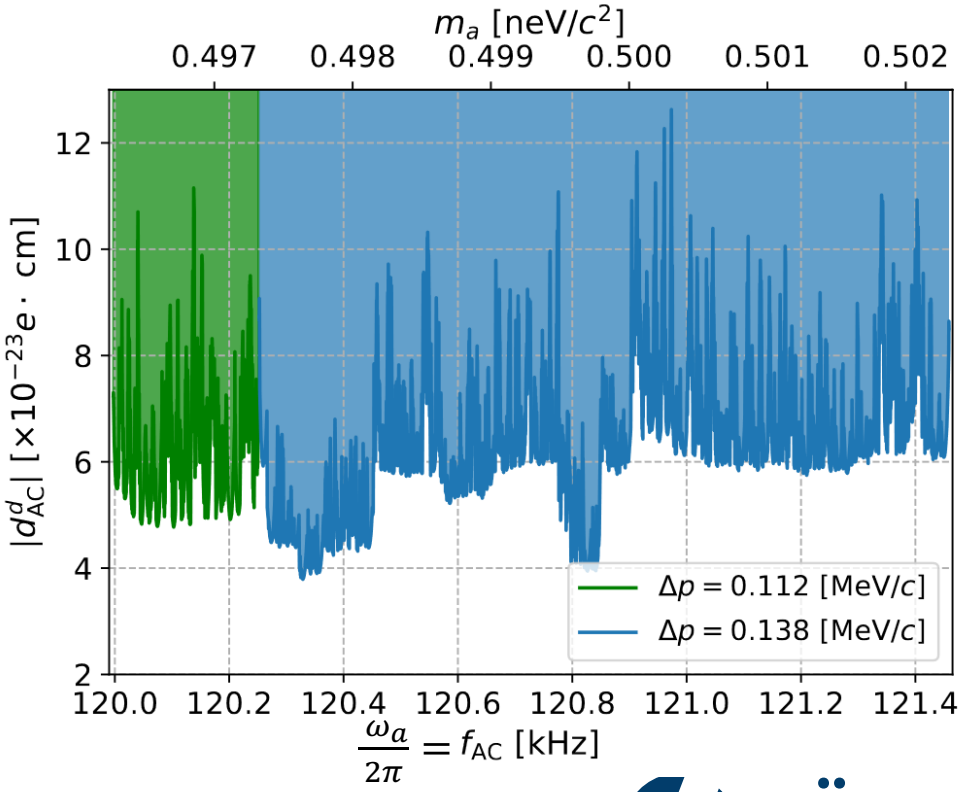


PHYSICAL REVIEW X 13, 031004 (2023)

First Search for Axionlike Particles in a Storage Ring Using a Polarized Deuteron Beam

S. Karanth,[1,*] E. J. Stephenson,[2,†] S. P. Chang,[3,4] V. Hejny,[5] S. Park,[4] J. Pretz,[5,6,7] Y. K. Semertzidis,[3,4] A. Wirzba,[5,8] A. Wrońska,[1] F. Abusaif,[6,5,¶] A. Aggarwal,[1] A. Aksentev,[9] B. Alberdi,[6,5,**,††] A. Andres,[6,5] L. Barion,[10] I. Bekman,[5,‡] M. Beyß,[6,5] C. Böhme,[5] B. Breitkreutz,[5,§] C. von Byern,[6,5] N. Canale,[10] G. Ciullo,[10] S. Dymov,[10] N.-O. Fröhlich,[5,‖] R. Gebel,[5,11] K. Grigoryev,[5,§] D. Grzonka,[5] J. Hetzel,[5] O. Javakhishvili,[12] H. Jeong,[13] A. Kacharava,[5] V. Kamerdzhiev,[5,§] I. Keshelashvili,[5,§] A. Kononov,[10] K. Laihem,[6,§] A. Lehrach,[5,7] P. Lenisa,[10] N. Lomidze,[14] B. Lorentz,[11] A. Magiera,[1] D. Mchedlishvili,[14,19] F. Müller,[6,5] A. Nass,[5] N. N. Nikolaev,[15,16] A. Pesce,[5] V. Poncza,[6,5] D. Prasuhn,[5,§] F. Rathmann,[5] A. Saleev,[10] D. Shergelashvili,[14] V. Shmakova,[10,§] N. Shurkhno,[5,§] S. Siddique,[6,5,§] J. Slim,[6,11,‖] H. Soltner,[17] R. Stassen,[5] H. Ströher,[5,7] M. Tabidze,[14] G. Tagliente,[18] Y. Valdau,[5,§] M. Vitz,[5,6] T. Wagner,[5,6,§] and P. Wüstner[17]

(JEDI Collaboration)



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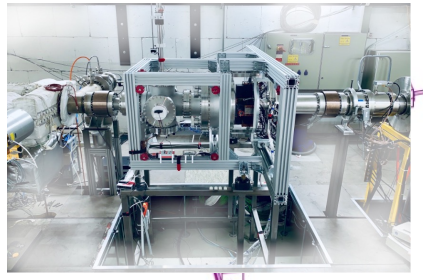
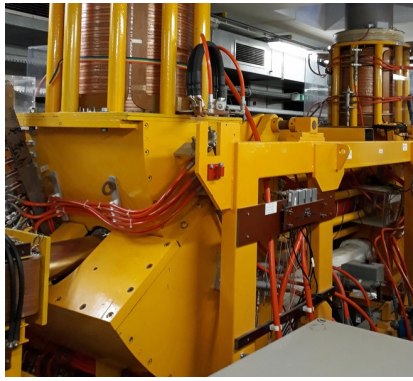
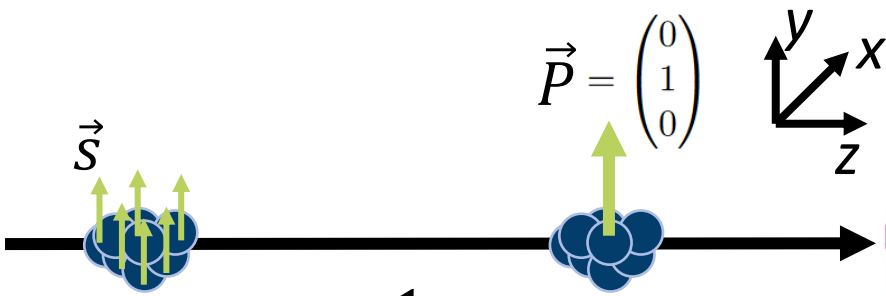
COSY - COOLER SYNCHROTRON (1993 – 2023)

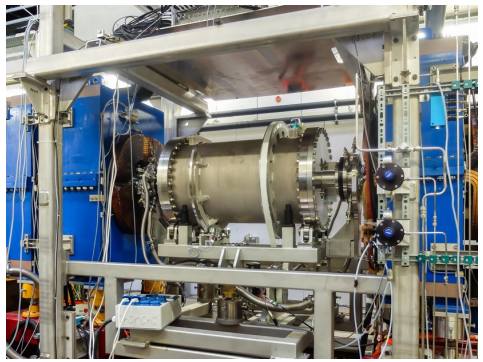
Overview

- Circumference 184 m
- Accelerate and Store **Polarized** / Unpolarized **Deuterons** and Protons
- $p = 0.3 \; - 3.7$ GeV/c
- Excellent Beam Quality
- Hadron Physics / **Precision** Experiments









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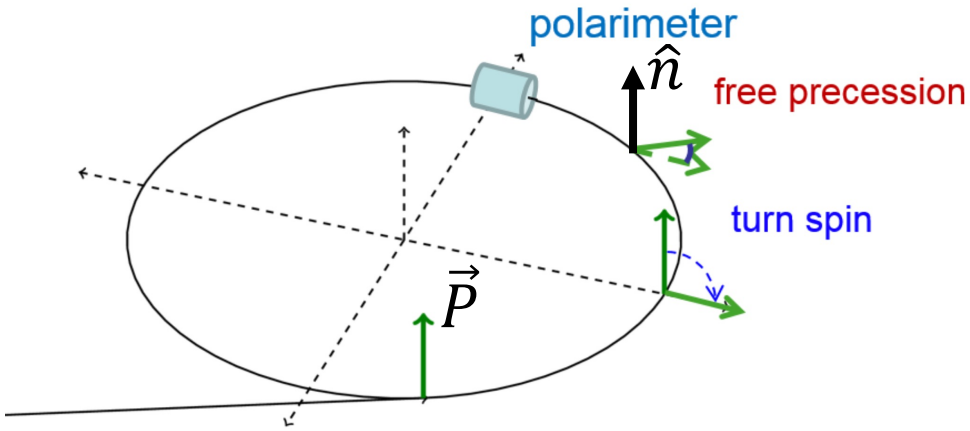
MEASUREMENT PRINCIPLE

- Measure **influence** of **EDM** on beam **polarization**
- **Injection** of vertically **polarized** deuteron beam
- **Rotate** polarization into **accelerator plane**
- COSY: **Magnetic** Ring → Polarization Vector **precesses** around invariant spin axis $\hat{n}$



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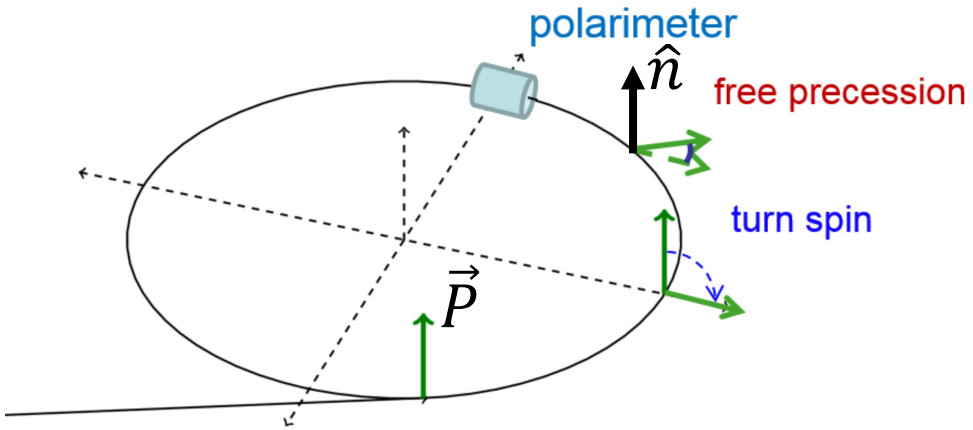
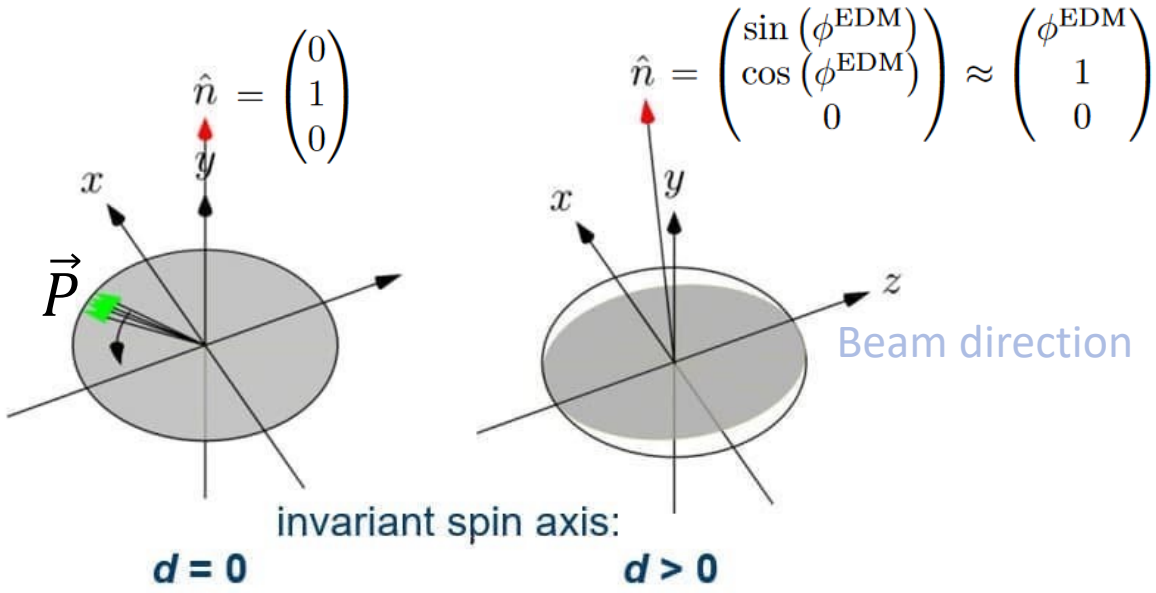
- Non-zero EDM: Tilts $\hat{n}$ in **radial** x direction by ϕ^{EDM} (no longitudinal effect expected)
- **Goal**: Determination of the **orientation** of $\hat{n}$





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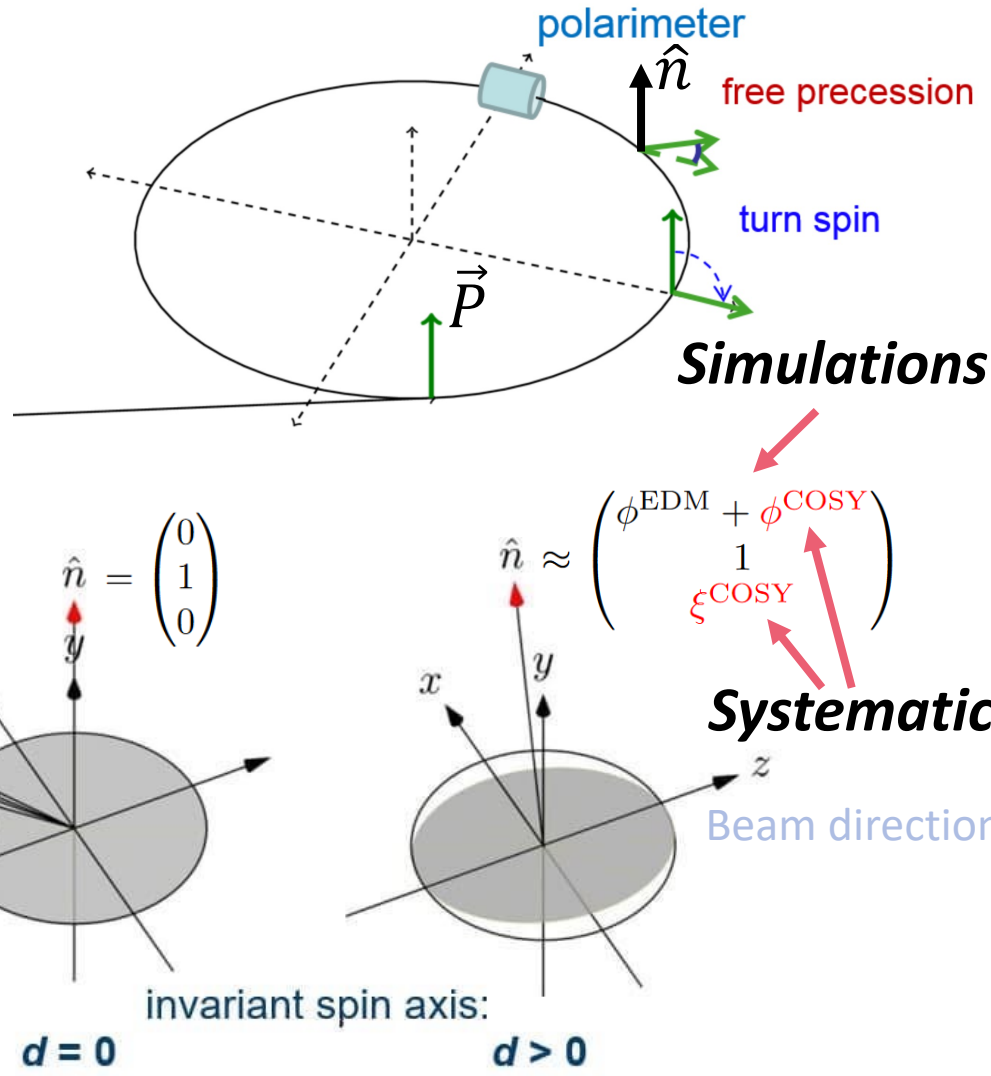
- **Goal**: Determination of the **orientation** of $\hat{n}$
- **Problem**: Ring **imperfections** (magnet misalignments,..) lead to rotations of $\hat{n}$ in **radial** (x) and **longitudinal** (z) direction



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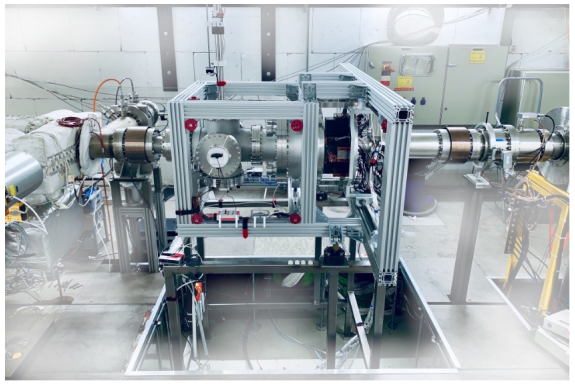
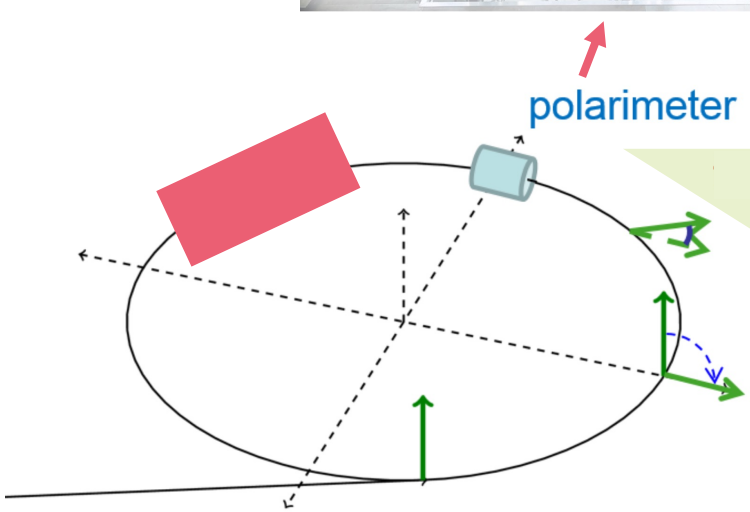
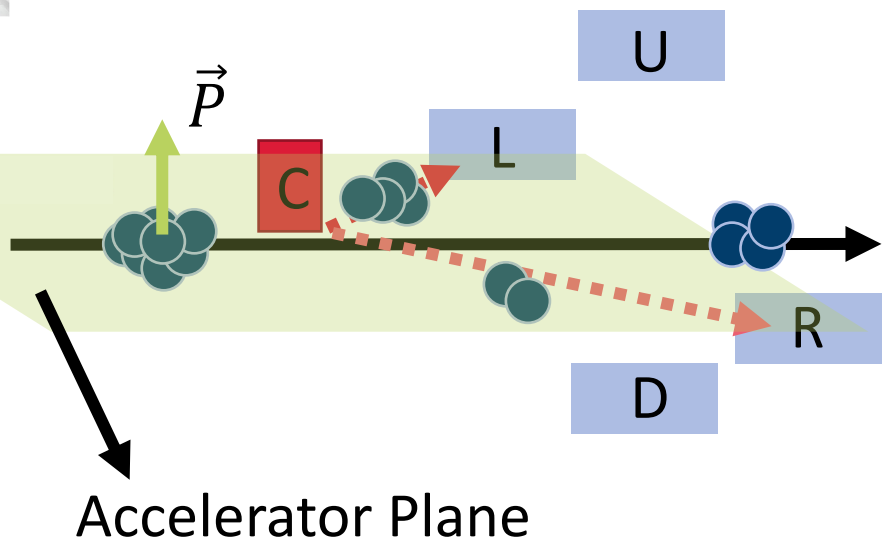
MEASUREMENT PRINCIPLE



$$p_y \propto \frac{N_L - N_R}{N_L + N_R}$$





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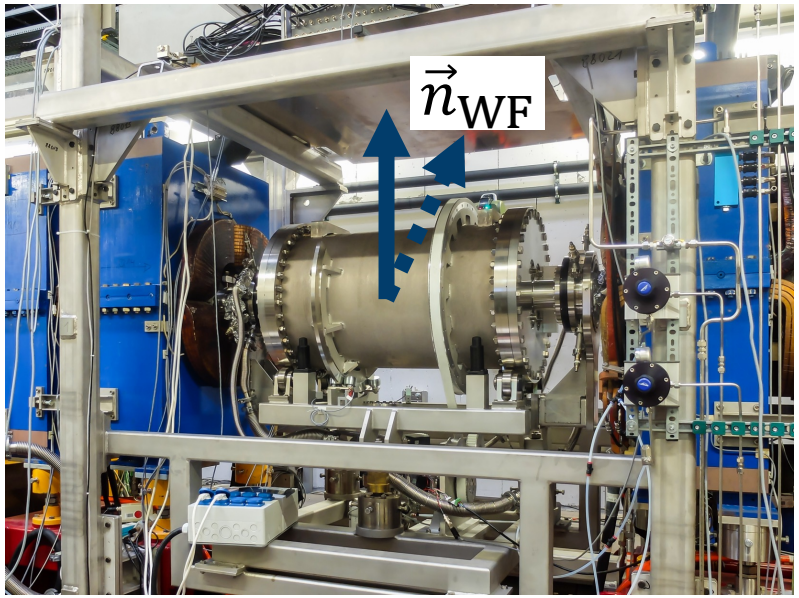
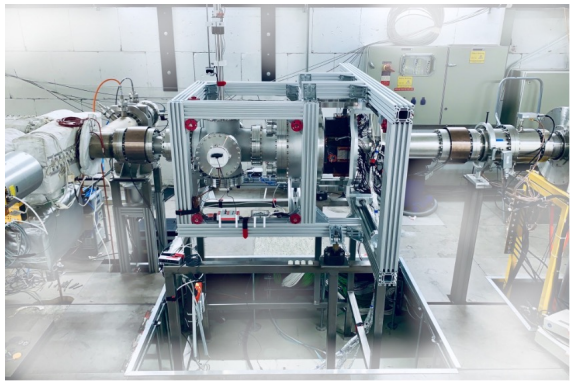
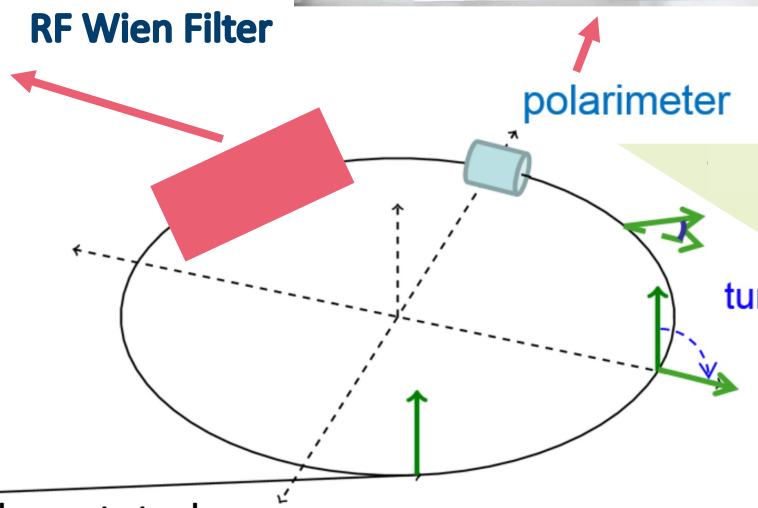
MEASUREMENT PRINCIPLE







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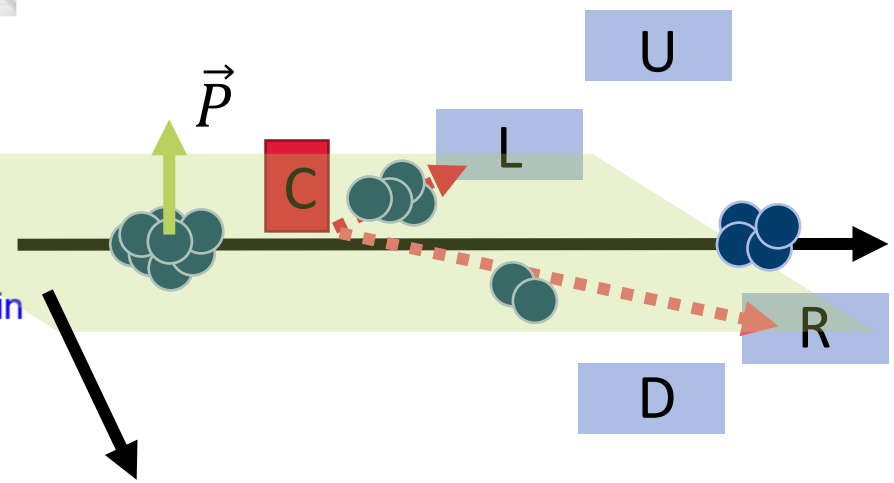
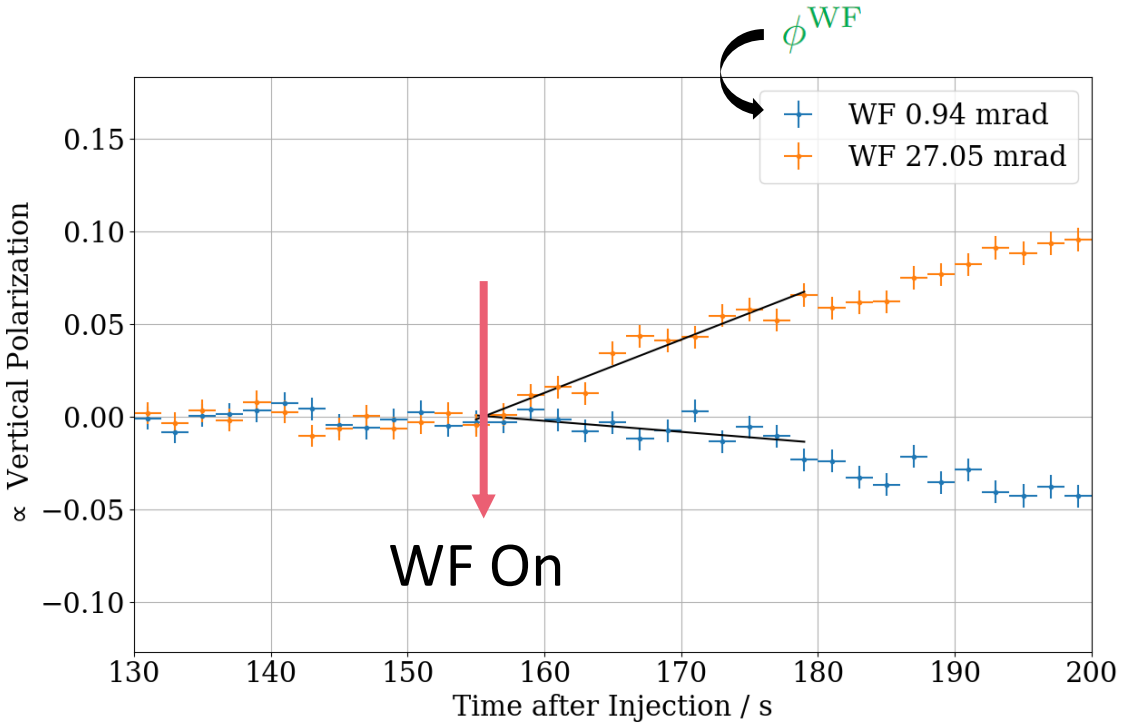
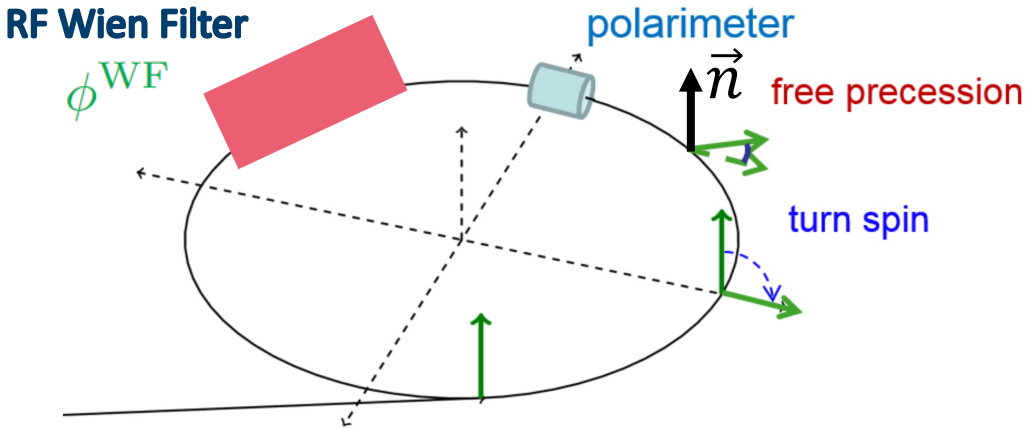


- $\vec{E} \perp \vec{B} \perp \text{Beam} \rightarrow \vec{F}_L = 0$
- **Rotational** Device: $\vec{n}_{\mathrm{WF}}$- Field can be rotated around the beam pipe by $\boldsymbol{\phi}^{\mathbf{WF}}$

$$\vec{n}_{\mathrm{WF}} = \begin{pmatrix} \sin\left(\phi^{\mathrm{WF}}\right) \\ \cos\left(\phi^{\mathrm{WF}}\right) \\ 0 \end{pmatrix} \approx \begin{pmatrix} \phi^{\mathrm{WF}} \\ 1 \\ 0 \end{pmatrix}$$

MEASUREMENT PRINCIPLE





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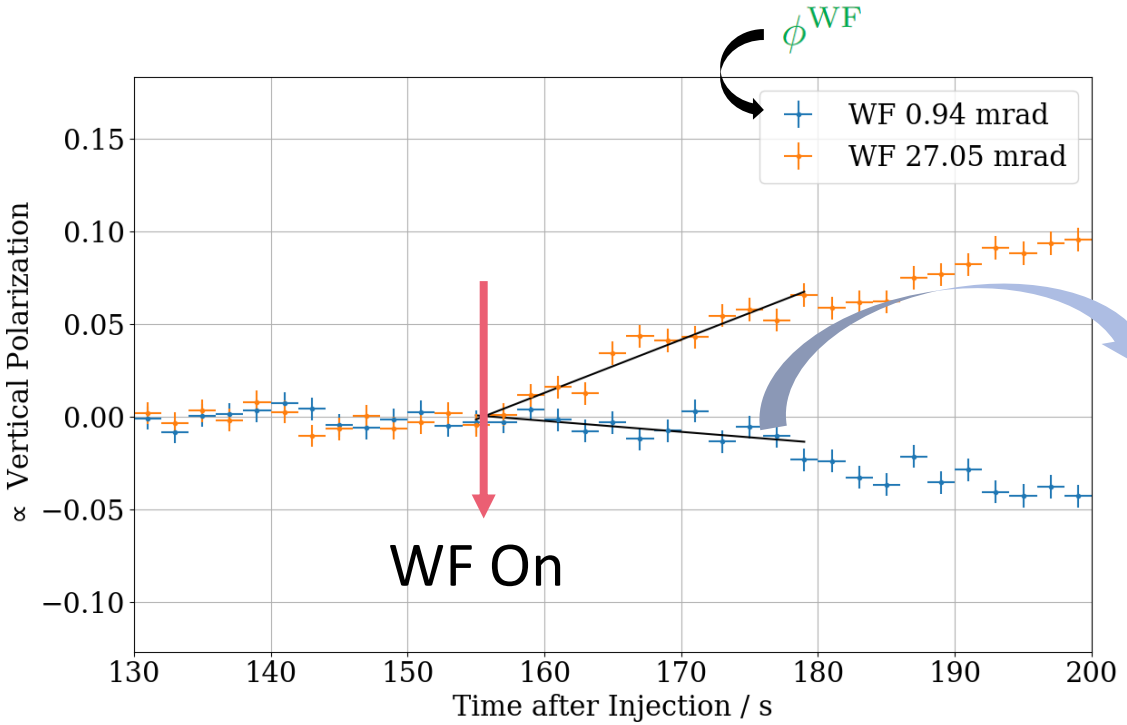
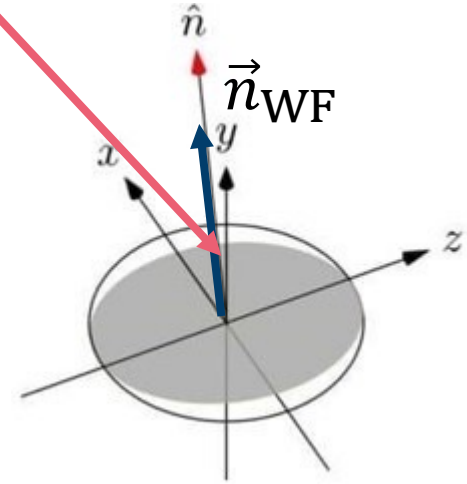
MEASUREMENT PRINCIPLE

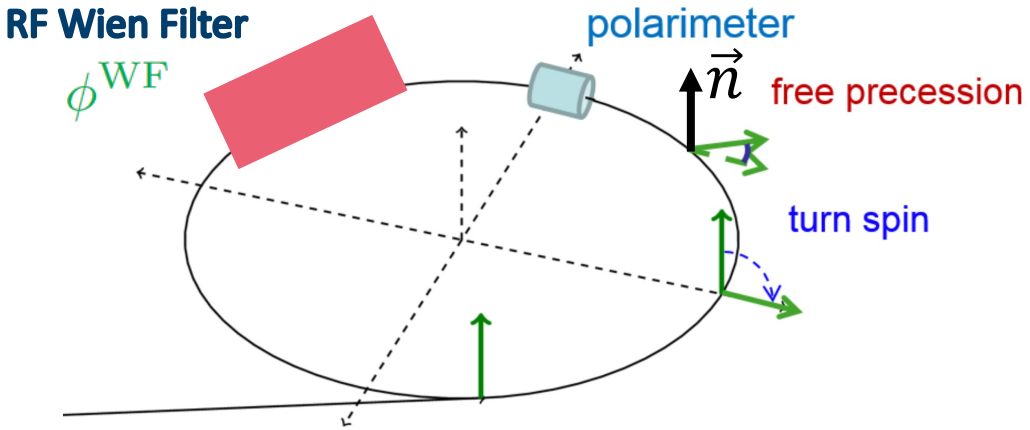


$$\epsilon^2\left(\phi^{\mathrm{WF}}\right) \propto \left|\vec{n}_{\mathrm{WF}} \times \vec{n}\right|^2 \quad \vec{n}_{\mathrm{WF}} : B \text{ field axis of rf Wien filter} \quad \vec{n} : \mathrm{ISA}$$
$$\propto A_1 \cdot \left(\left(\phi_0^{\mathrm{EDM}} + \phi_0^{\mathrm{COSY}}\right) - \phi^{\mathrm{WF}}\right)^2$$

Build up rate

$$\epsilon \propto \frac{\mathrm{d}}{\mathrm{d}t} p_y(t)$$





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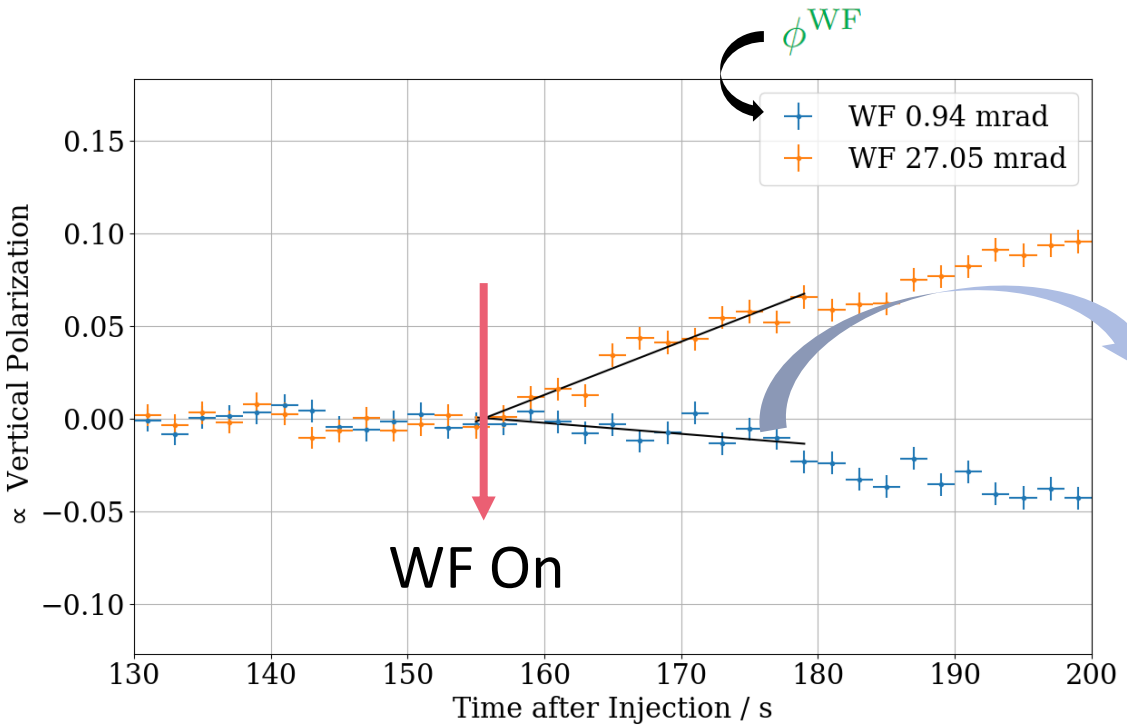
MEASUREMENT PRINCIPLE



$$\epsilon^2\left(\phi^{WF}\right) \propto |\vec{n}_{WF} \times \vec{n}|^2 \quad \vec{n}_{WF} : B \text{ field axis of rf Wien filter} \quad \vec{n} : \text{ISA}$$
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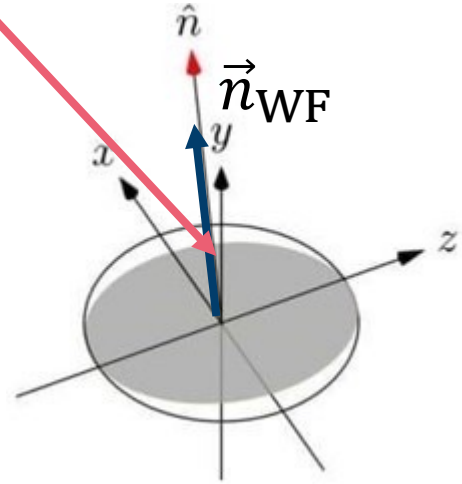

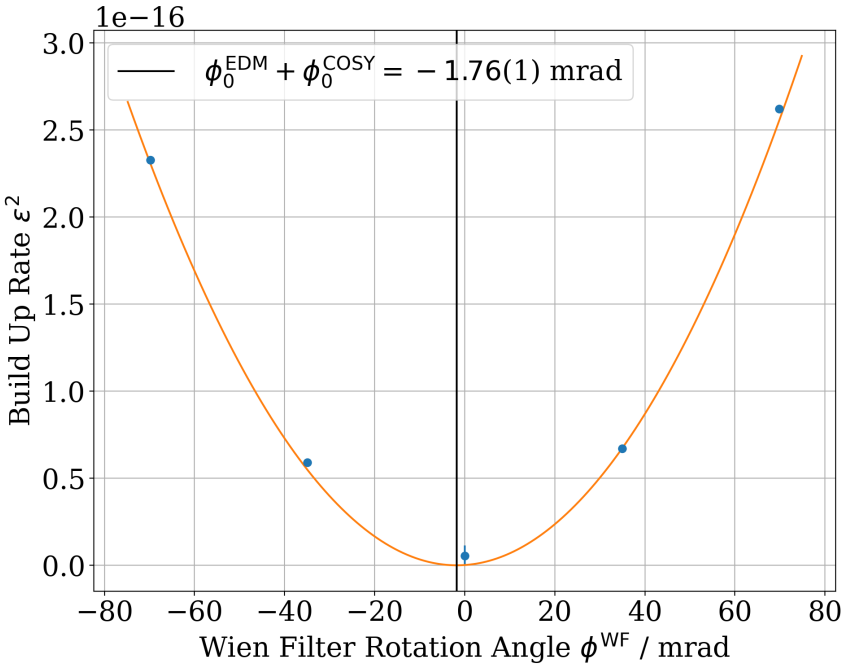

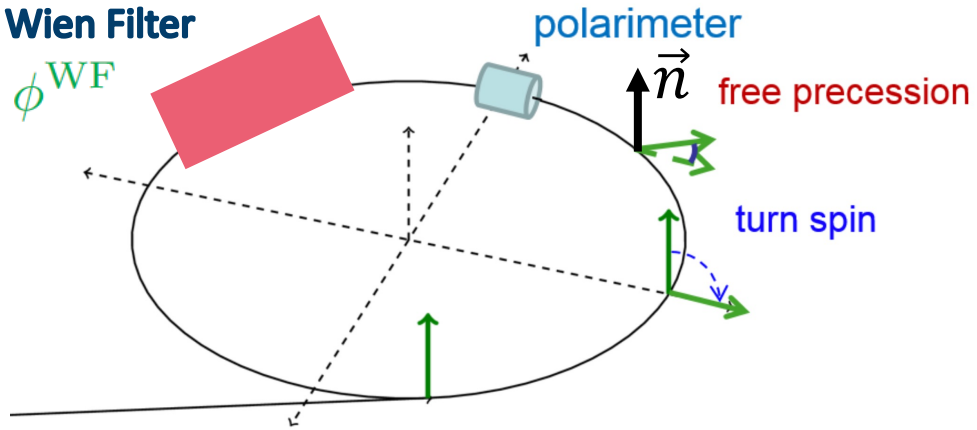

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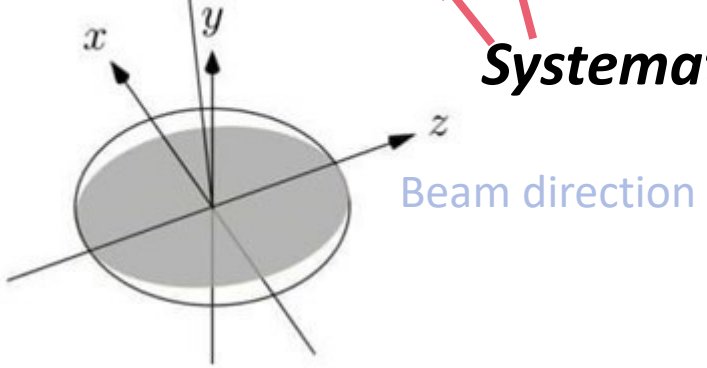
PRELIMINARY RESULTS

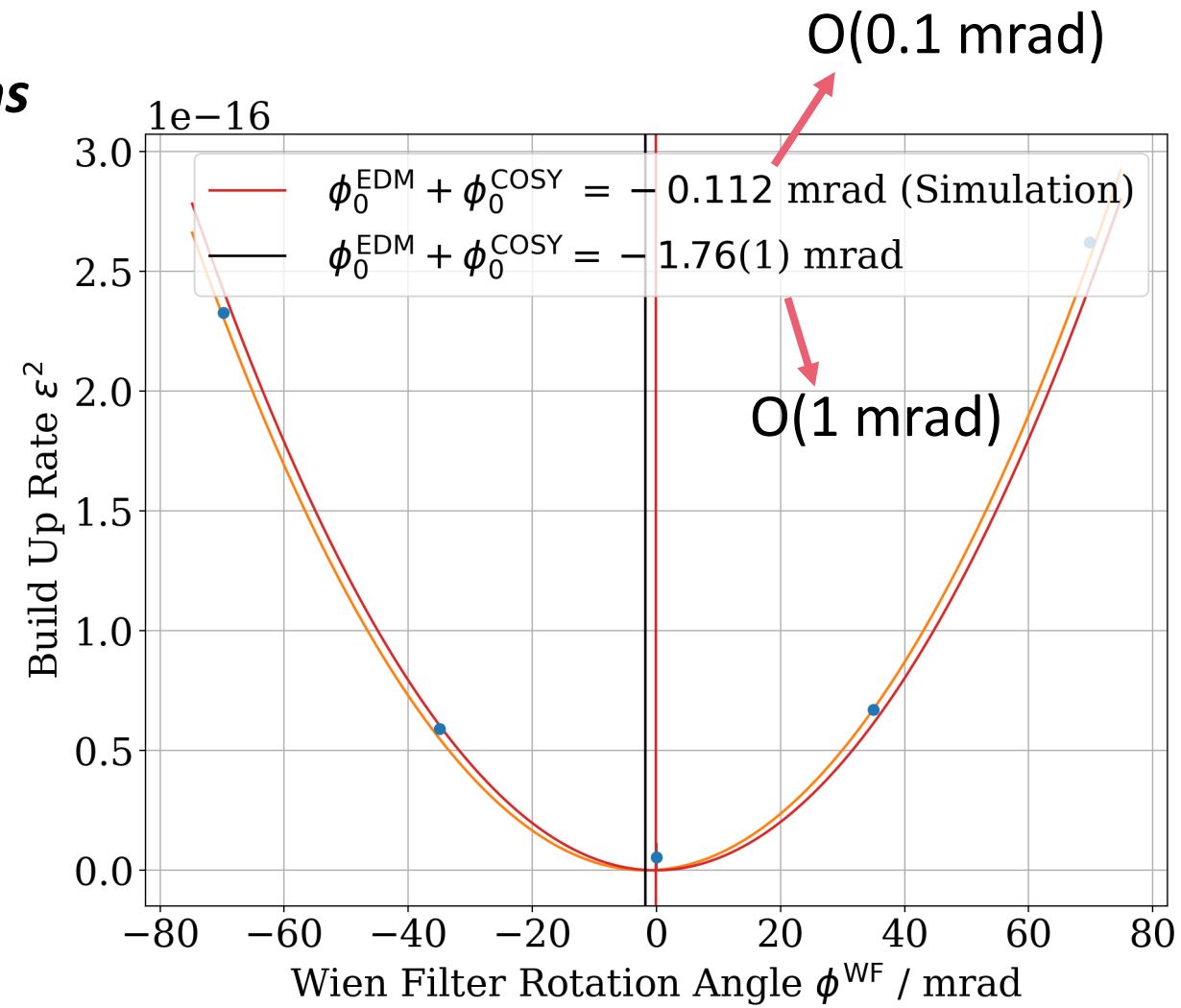
We are missing something!

$$\hat{n} \approx \begin{pmatrix} \phi^{\mathrm{EDM}} + \phi^{\mathrm{COSY}} \\ 1 \\ \xi^{\mathrm{COSY}} \end{pmatrix}$$

Simulations

Systematics





$1\ \mathrm{mrad} \approxeq 10^{-17} e \cdot \mathrm{cm}$

- Bmad **simulation** of the experiment (M. Vitz)
- Includes **current understanding** of (misaligned) magnets in COSY
- **Simulations predict** tilts of the invariant spin axis not larger than **O(0.1mrad)**
- Measured angles are an **order of magnitude too large**!

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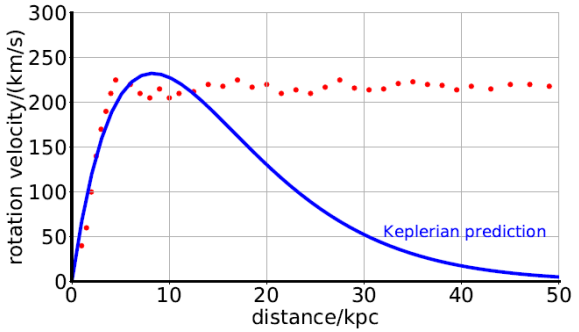
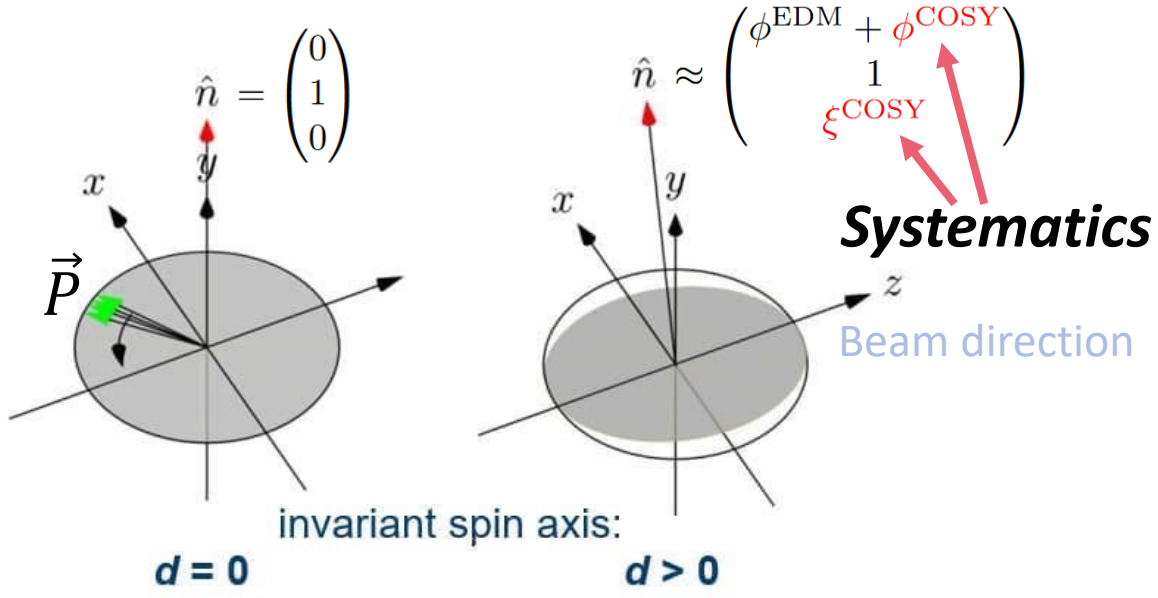
SUMMARY $d^{\mathrm{d}} = d_{\mathrm{DC}} + d_{\mathrm{AC}}\cos(\omega_a + \phi_a)$

- EDM as a source of **CP violation**
- Measure influence of EDM on **beam polarization**
- Orientation of **Invariant Spin axis** directly relates to **EDM strength**
- Order of magnitude is **too large**

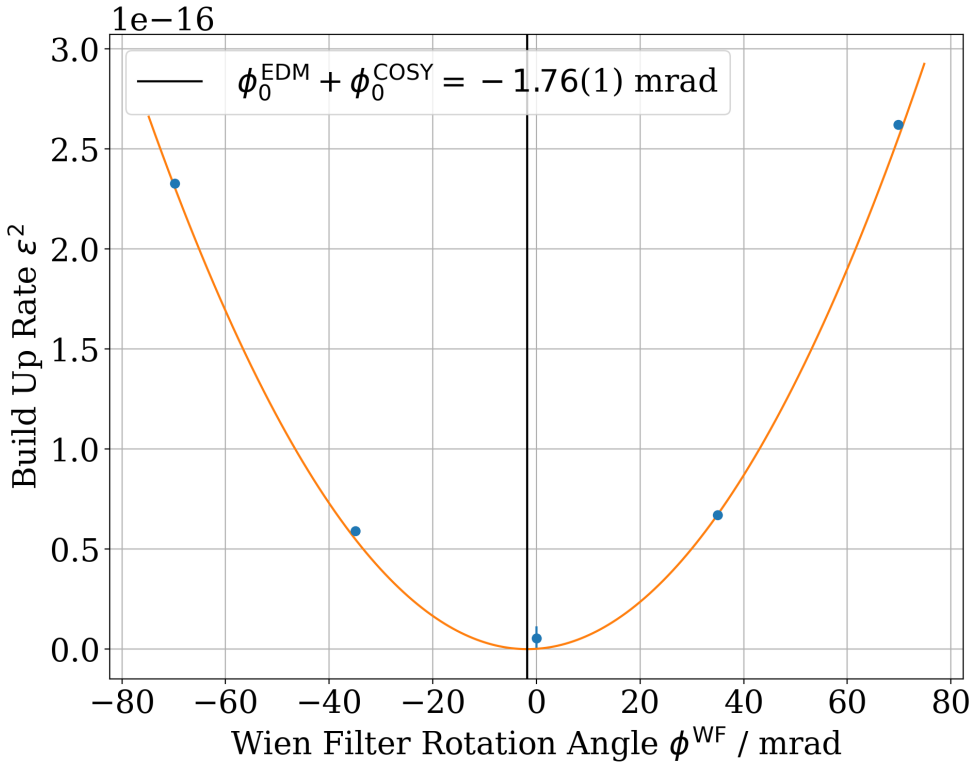


Simulations



Systematics

Beam direction



	$\phi_0^{\mathrm{EDM}} + \phi_0^{\mathrm{COSY}}$
Experiment	$-1.76(1)$ mrad
Simulation	-0.112 mrad

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