New method to search for axion-like particles with a polarized beam at the COSY storage ring

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TOWARDS STORAGE RING ELECTRIC DIPOLE MOMENT MEASUREMENTS - 744. WE-HERAEUS-SEMINAR

Axion – axion-like particle (ALPs)

- Proposed to explain the lack of CP violation in the strong interaction.
- Candidates for dark-matter in the universe.
- Axion/ALPs – gluon coupling induces an oscillating Electric Dipole Moment (EDM).

$$d = d_{static} + \boldsymbol{d_{osc}\,cos(\omega t + \phi)}$$

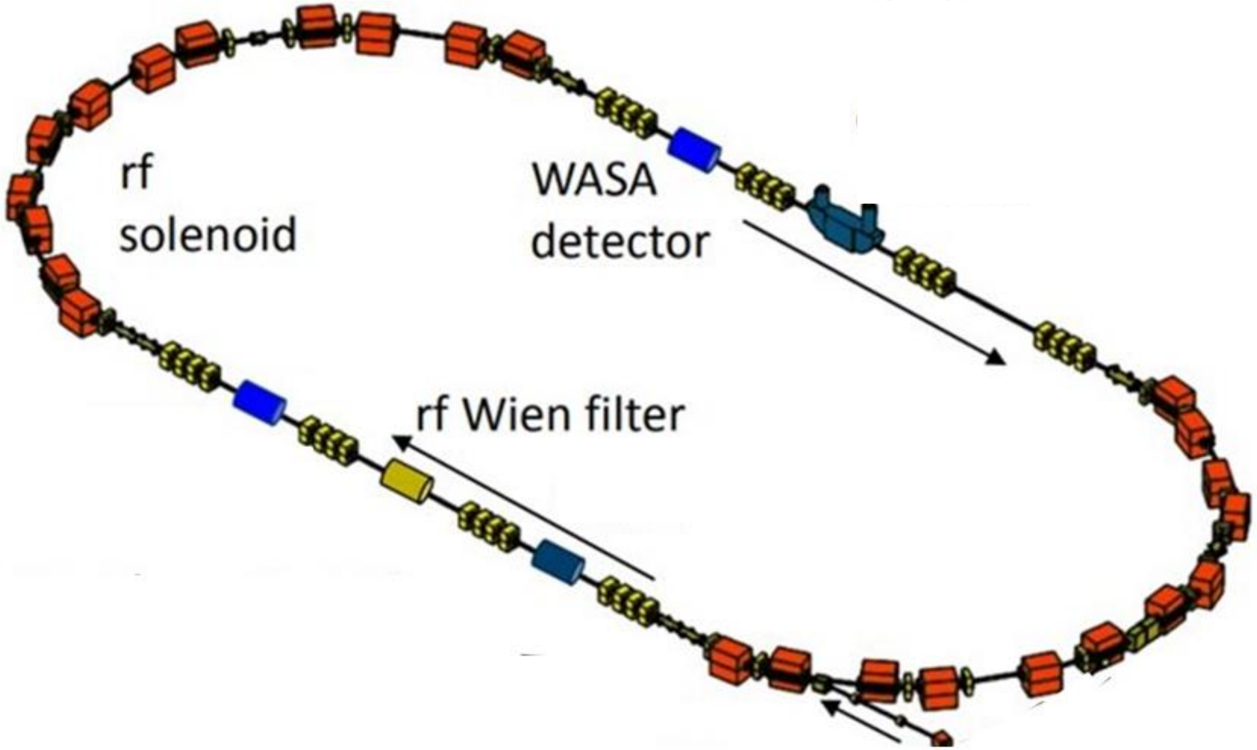
Oscillation frequency connected to axion mass $\omega = \frac{m_a c^2}{\hbar}$

Phase of the oscillating EDM is unknown.

See: P. W. Graham et al., PRD 84, 055013 (2011)

Cooler Synchrotron (COSY)

- A proof-of-principle experiment to search for ALPs
- Polarized and cooled deuterons
- WASA detector as the polarimeter



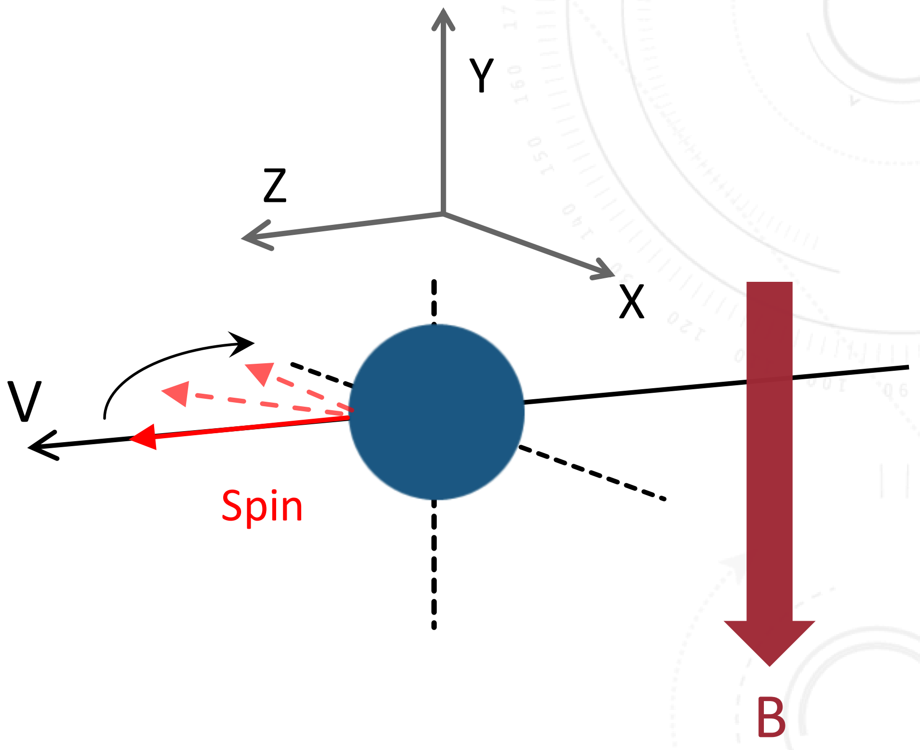
How to search for ALPs in a storage ring?

- Horizontally polarized beam
- Spintune$(\nu_s) = \dfrac{\text{\#spin rotation}}{\text{\#particle revolution}}$

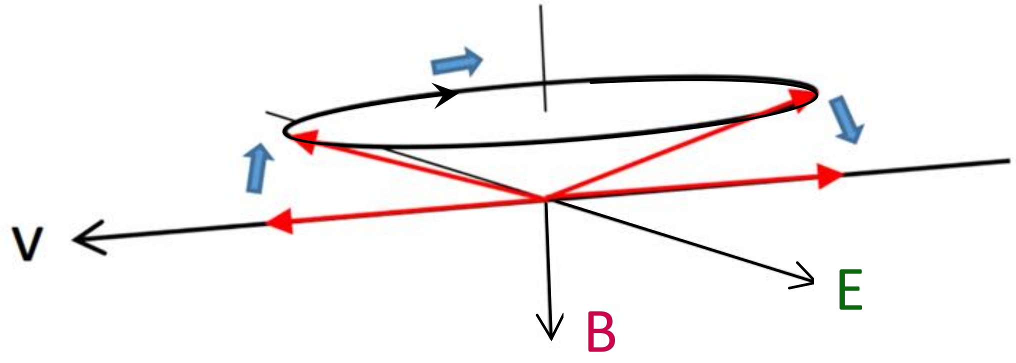
$$\nu_s = G\gamma$$

G: anomalous magnetic moment

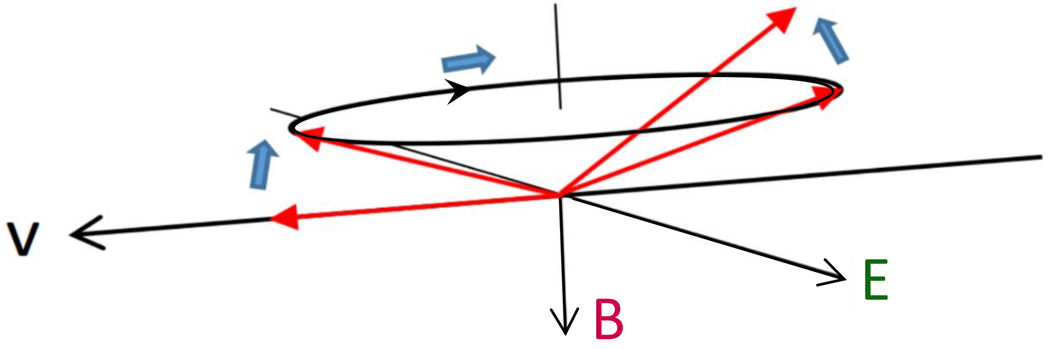
γ: Lorentz factor



How to search ALPs in a storage ring?



Static EDM

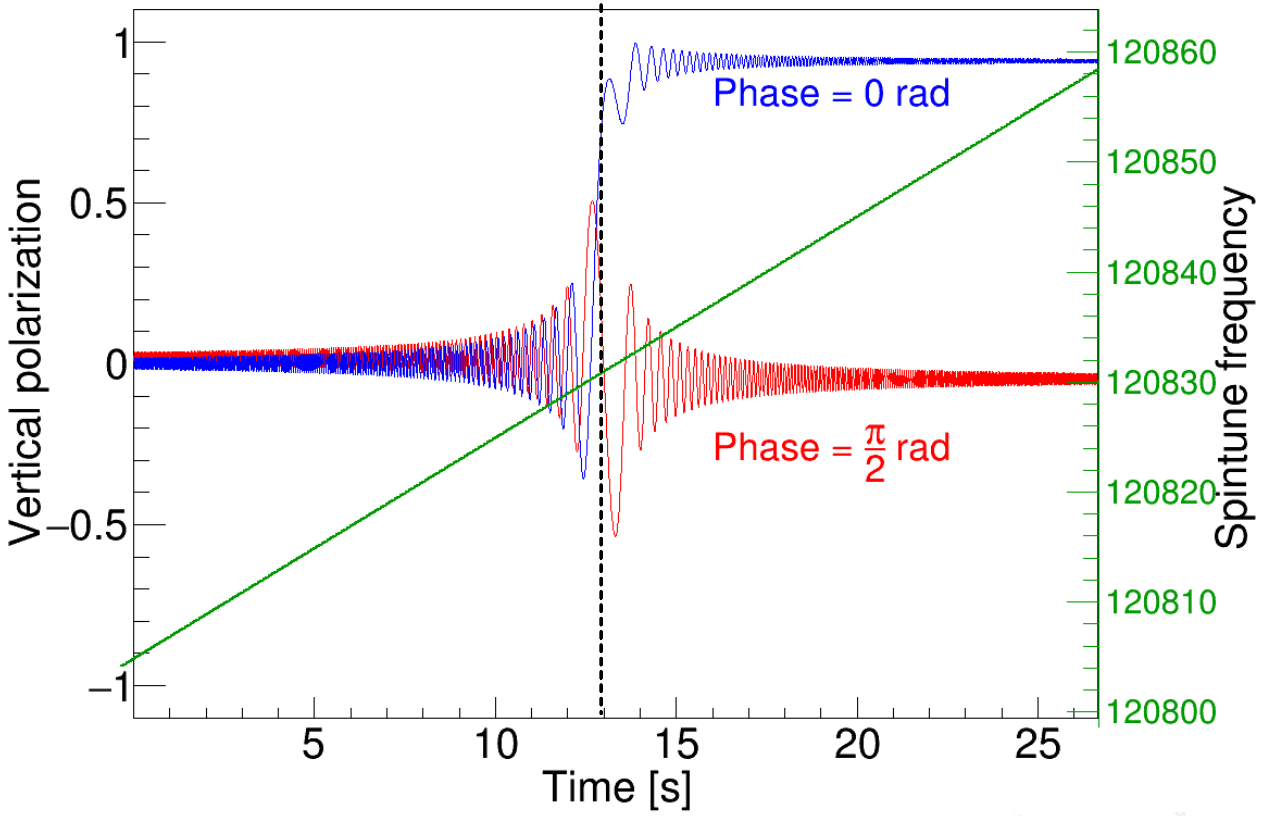


Oscillating EDM

Axion oscillation frequency = Spin tune frequency ⇒ Accumulation of vertical polarization

Model calculations

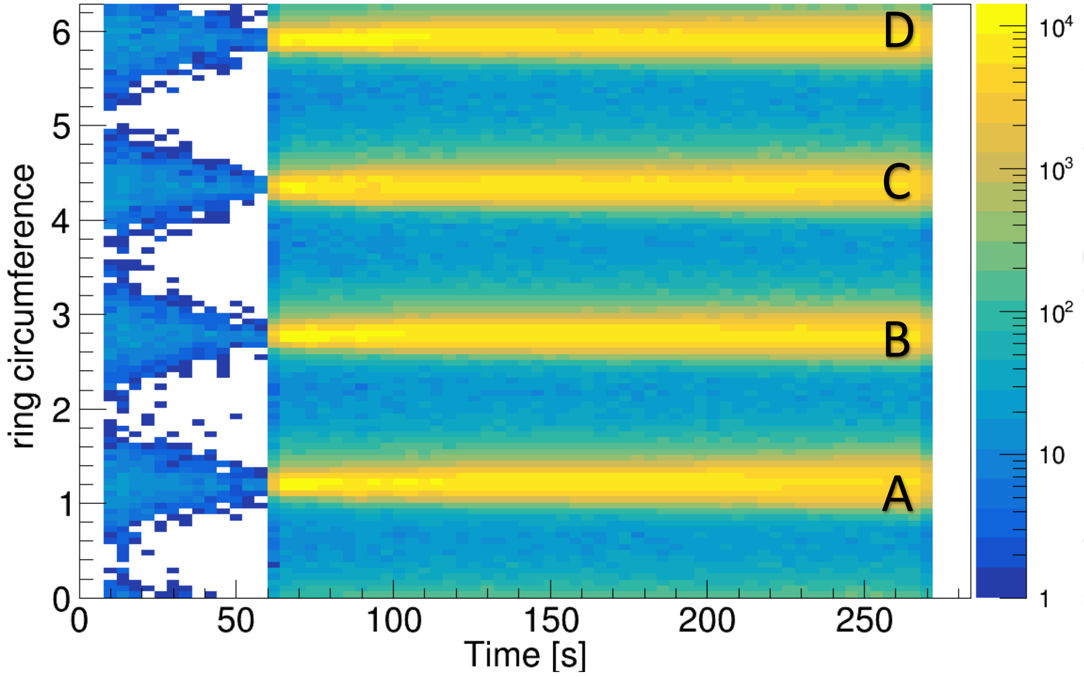
- Ramp frequency in search of resonance
- Describe the polarization jump at resonance crossing.
- Phase plays an important role in determining the jump.



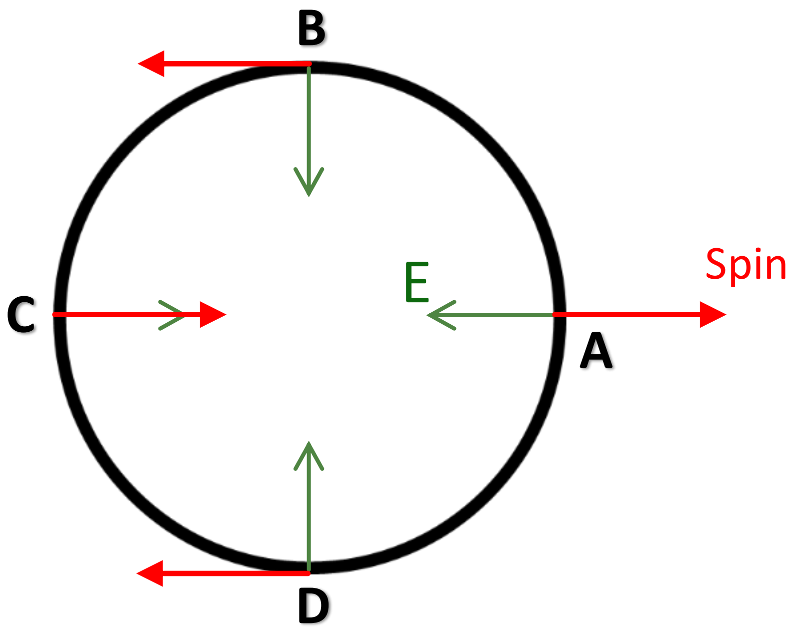
Unknowns of the experiment: frequency and phase

Phase problem and 4 bunches

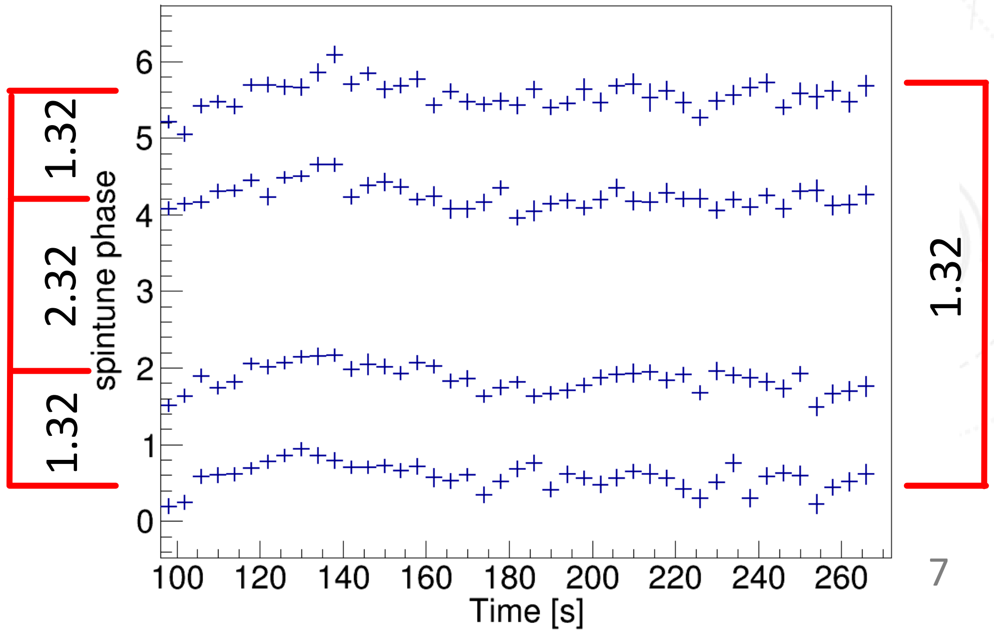
- Simultaneous searches with perpendicular beam polarization using 4 bunches.
- RF solenoid run at $f_{rev}(1 + G\gamma)$



A top down view of the ring.

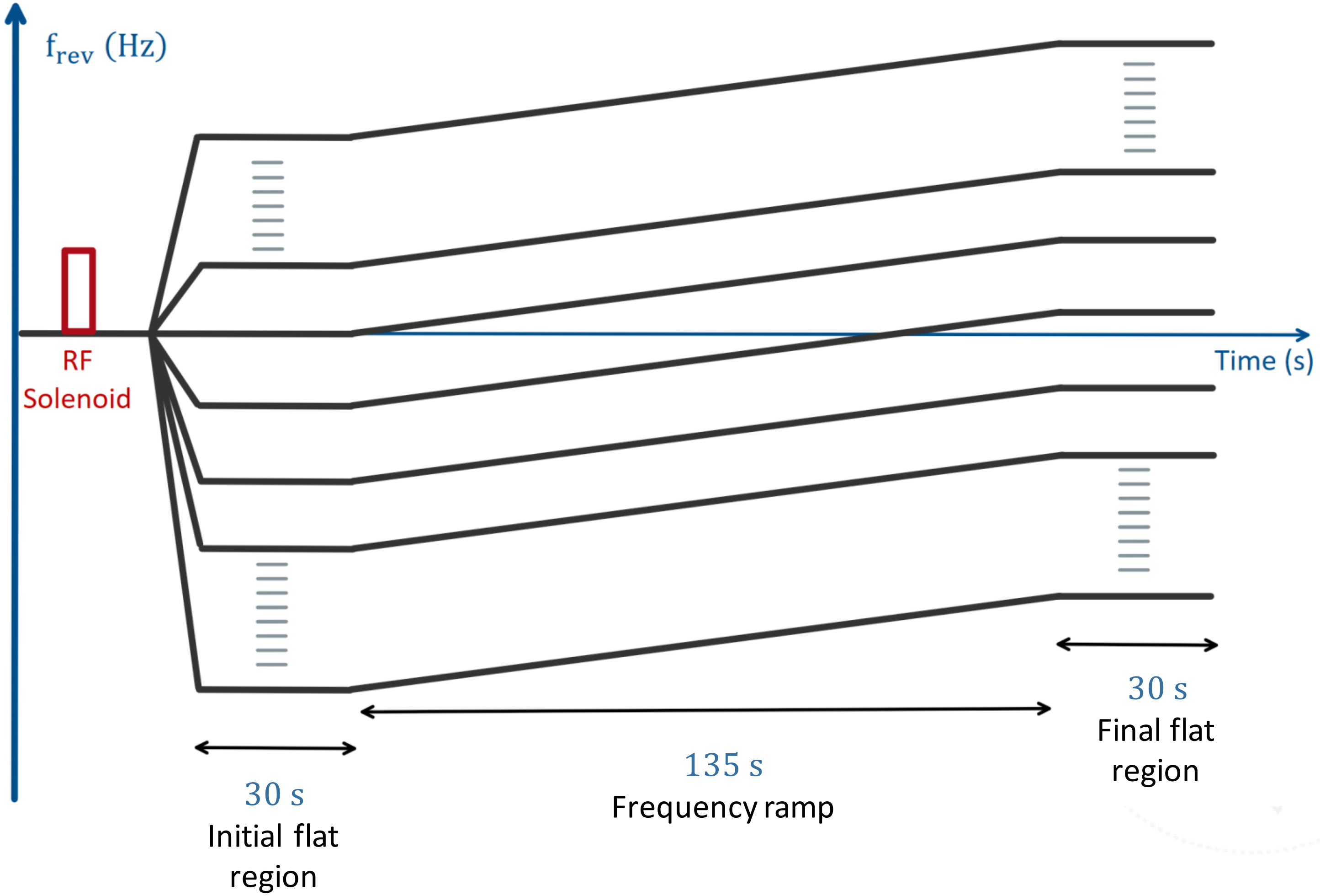


At the detector



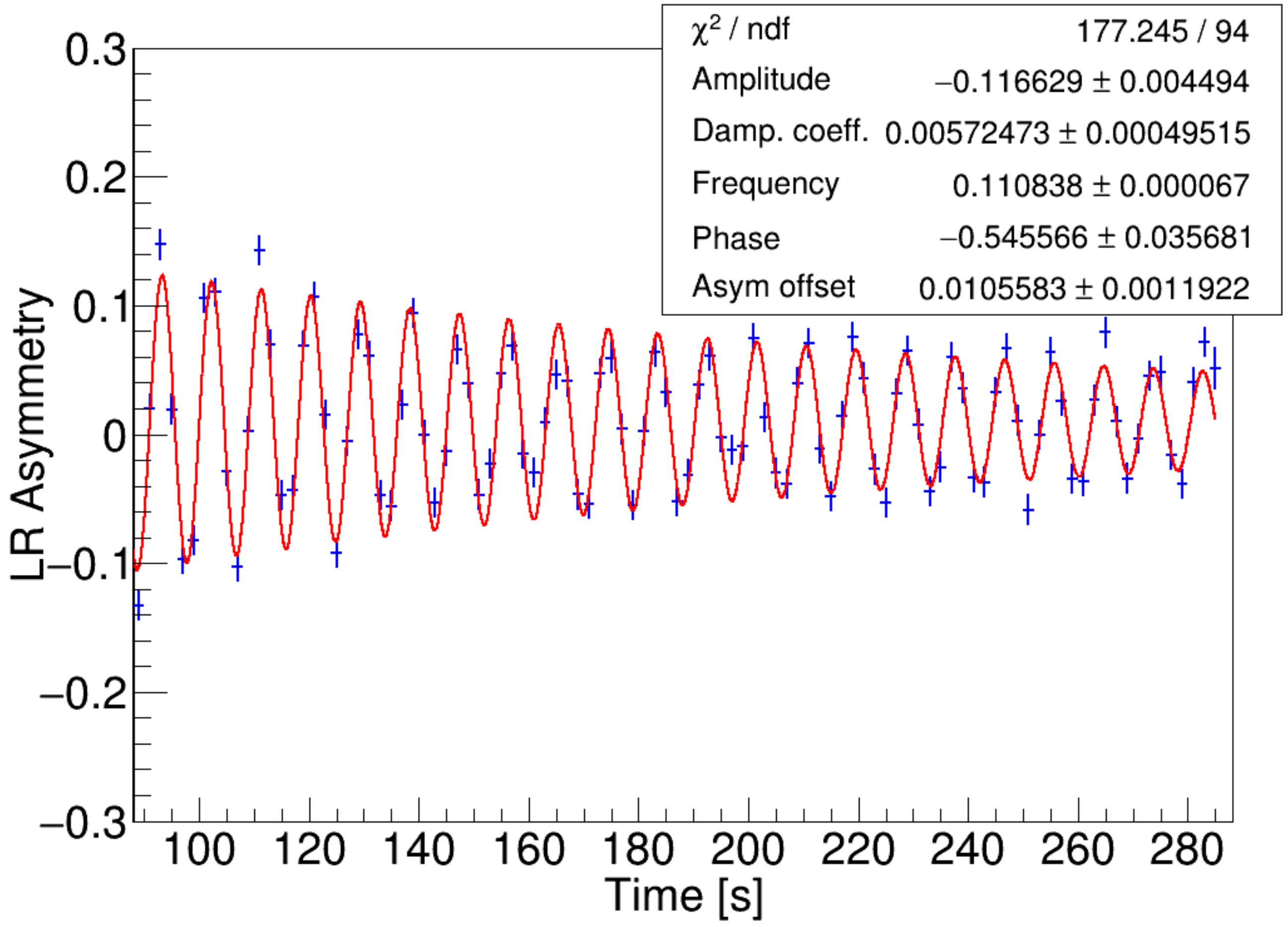
Measurement procedure

- Vary the spintune frequency (ramp rate $\approx 0.1\text{Hz/s}$) in search of resonance.
- Measure polarization.
- About 100 scans
  - Frequency Range $119997\ \text{Hz} - 121457\ \text{Hz}$
  - Total width $\approx 1.5\ \text{kHz}$
  - ALP mass range $4.96 \times 10^{-9}\text{eV} - 5.02 \times 10^{-9}\text{eV}$



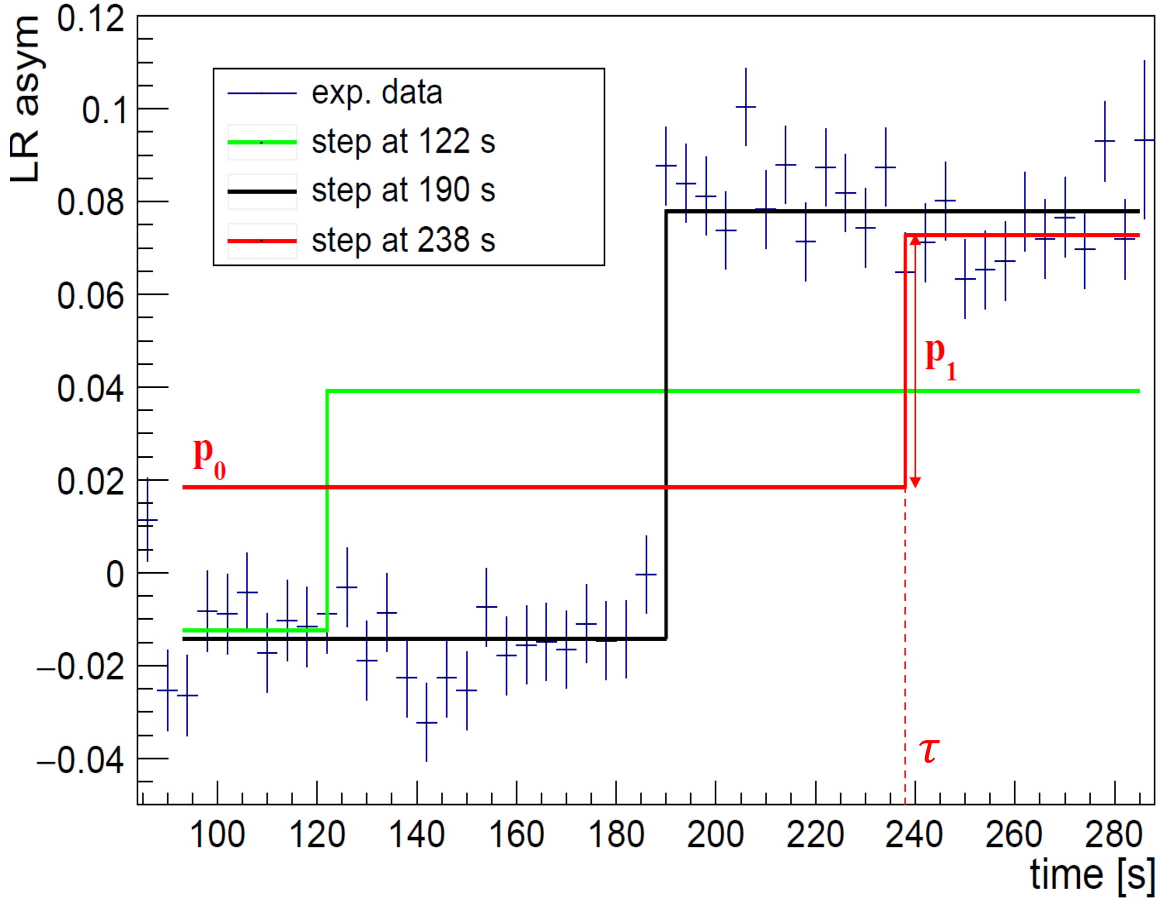
RF Wien filter test

- Set WF with radial magnetic field.
- Produces driven oscillations.
- Revolution/turn: $\epsilon = \frac{f_{osc}}{f_{rev}}$.



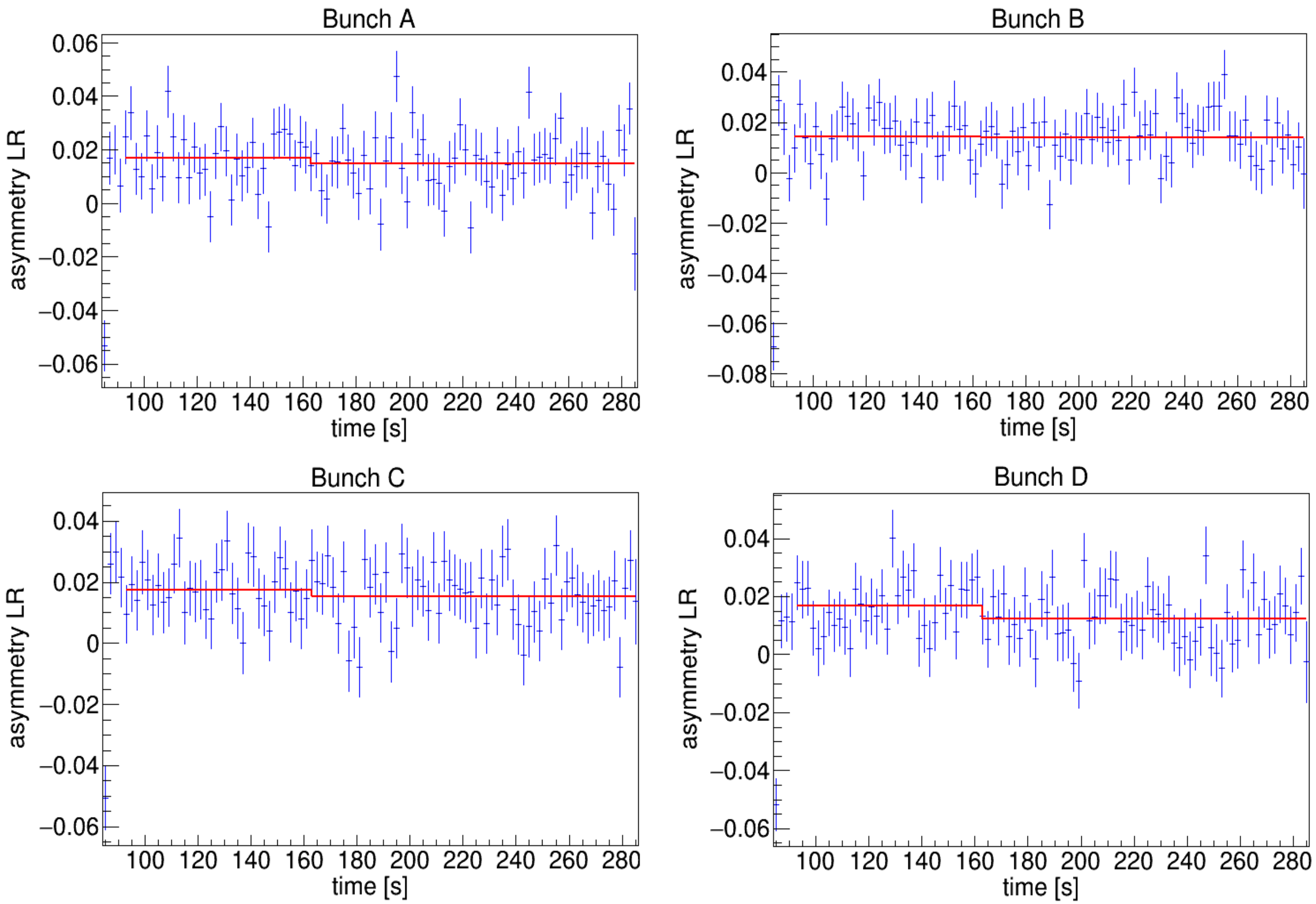
Wien filter scan and analysis of data

- Test of methodology.
- The size of the jump is as expected based ϵ.
- A check for the calibration used to calculate the d_{osc} from data.



Axion scan

- Analysis is ongoing.
- No signal seen.

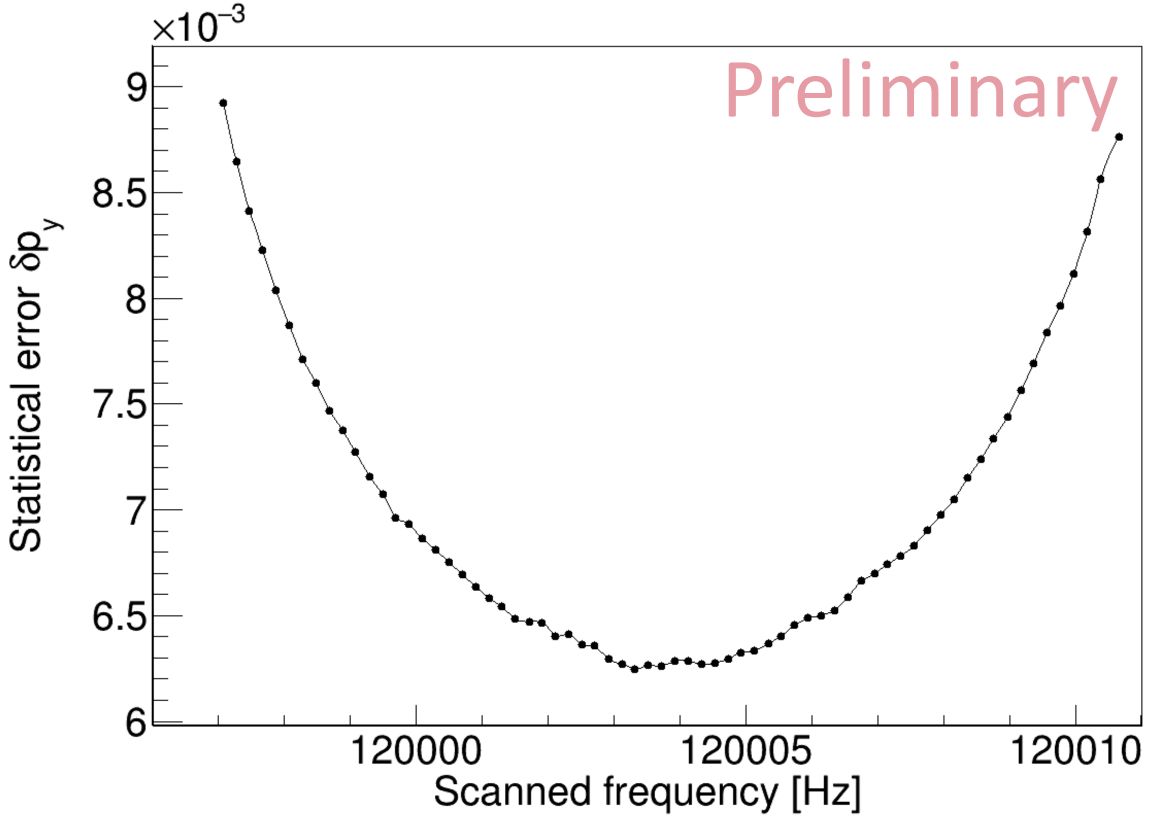


Example for one scan

- Rotation of spin: $\omega_{\mathrm{EDM}} \propto \delta P_y$
- From T-BMT equation,

$$d_{osc} = \frac{\hbar\, \omega_{\mathrm{EDM}}}{c\, \beta\, B}$$

- $d_{osc} = 10^{-16} a_0 \frac{C_G}{f_a}$
  - a_0 - dependent on local axion density
  - $\frac{C_G}{f_a}$ - axion-gluon coupling strength



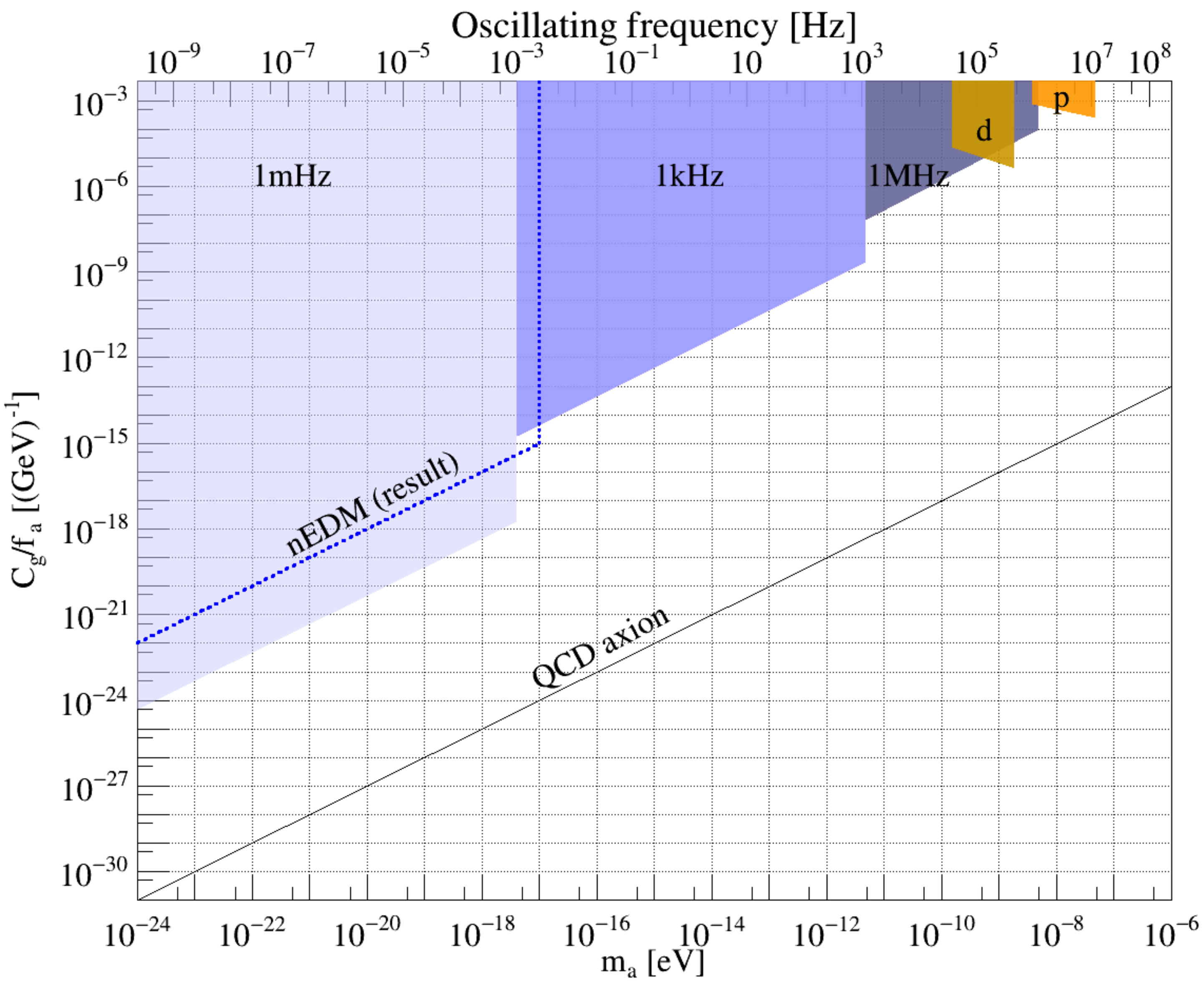
Future experiments – at COSY and other rings

- High beam intensity.
- Large polarization and long spin coherence times.
- Larger frequency overlap with adjacent scans.
- Slower ramp rate.
    - Make sure to cross a frequency faster than axion coherence time;
    - Resonance width should be lie completely within one scan range.

Prototype ring / COSY

	prototype ring	
	proton	
$p/\mathrm{GeV}/c$	0.25	0.30
$\Omega_{\mathrm{MDM}}/\ 10^6\,\mathrm{s}^{-1}$	7.35	0.0
m_a/eV	$5 \cdot 10^{-9}$	0
B/T	0.0	0.033
$E/\mathrm{MV/m}$	7.4	7.4
N	10^{10}	
f	0.005	
A	0.5	
P	0.8	
τ /s	1000	

- COSY - protons
- COSY - deuterons
- Prototype ring - protons



See: J. Pretz, et al., Eur. Phys. J. C 80, 107 (2020)

Summary

- ALP induces an oscillating EDM (d_{osc}), allows searching for ALPs in a storage ring.
- Polarized deuteron beam to search for resonance between the oscillating EDM frequency and the spintune frequency.
    - Frequency Range $119997\ \mathrm{Hz} - 121457\ \mathrm{Hz}$. Total width $\approx 1.5\ \mathrm{kHz}$.
    - ALP mass range $4.96 \times 10^{-9}\mathrm{eV} - 5.02 \times 10^{-9}\mathrm{eV}$.
- RF Wien filter used as a test to observe a signal at resonance crossing.
- No signal was found.

Thank You