Towards axion searches with polarized hadron beams and targets at the GSI/FAIR storage rings

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Motivation

- polarized hadron beams can be used to explore interactions that are not observable with unpolarized beams.
- axions are leading particle candidates for dark matter.
- axion like particles (ALP): similar properties as axions, but ALPs don't solve the strong QCD problem.

- in storage rings with polarized beams:

Axion/ALP field → Oscillating electric dipole moment (oEDM)

- first proof-of-principle experiment was performed with a polarized deuteron beam at COSY, Forschungszentrum Jülich.

Spin Motion in Storage Ring

$$\frac{d\vec{s}}{dt} = (\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM} + \vec{\Omega}_{wind}) \times \vec{s}$$

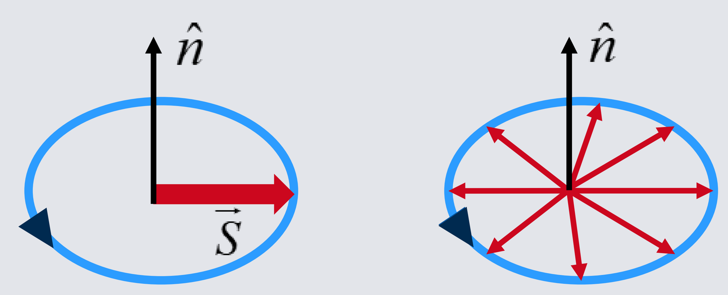
$$\vec{\Omega}_{MDM} = -\frac{q}{m}, \qquad \vec{\Omega}_{EDM} = -\frac{1}{S\hbar} d c \vec{\beta} \times \vec{B}.$$

$$d = d_{DC} + d_{AC}\cos(\omega_a t + \varphi_o)$$

oEDM induced by axion field

- spin tune: $\nu_s = G\gamma$.
- spin tune spread:

$$\Delta\nu_s = G\Delta\gamma = G\gamma\beta^2 \frac{\Delta p}{p} + \ \ldots$$

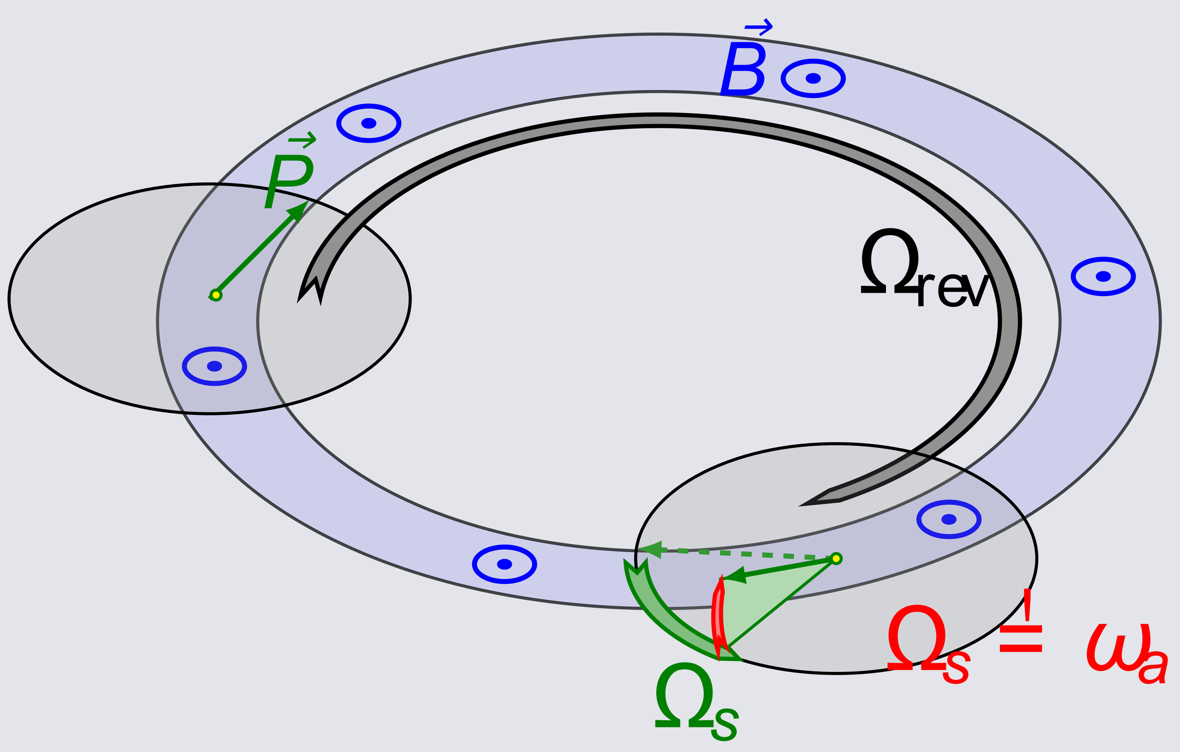


- spin coherence time (SCT):

SCT = time after total polarization drops to 1/e.

G: the gyromagnetic anomaly.

Experimental Method

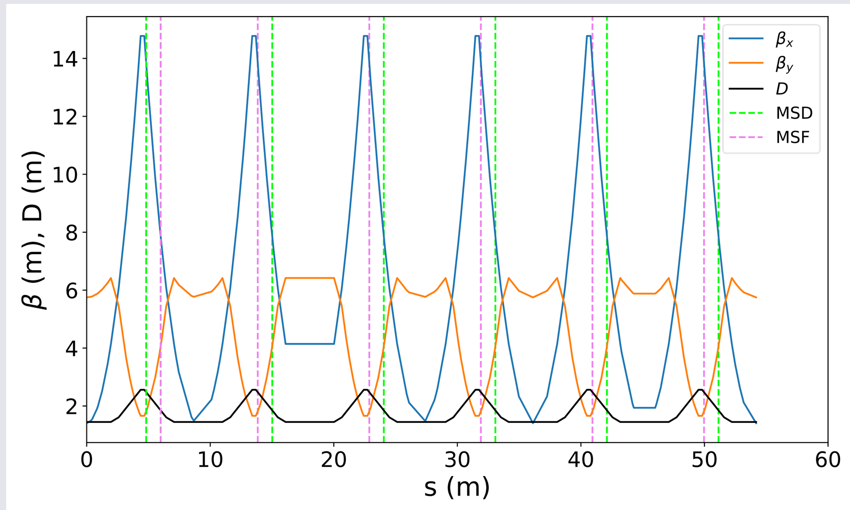


- store polarized hadrons.
- maintain precession in horizontal plane (long SCT).
- if $m_a c^2 \equiv \hbar\omega_a = \Omega_{MDM}\hbar$, polarization will turn out of the horizontal plane, resulting in a vertical polarization component.
- vertical polarization can be measured using a carbon target and a polarimeter.
- axion wind effect enhanced in storage rings when $v \approx c$.
- $\Omega_{MDM} = \gamma G \Omega_{rev}$, a wide mass range can be covered by:
  1) varying the three parameters γ, G and Ω_{rev},
  2) use additional electric field.

$$\vec{\Omega}_{MDM} = -\frac{q}{m}\left[G\vec{B} - \left(G - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

Simulation

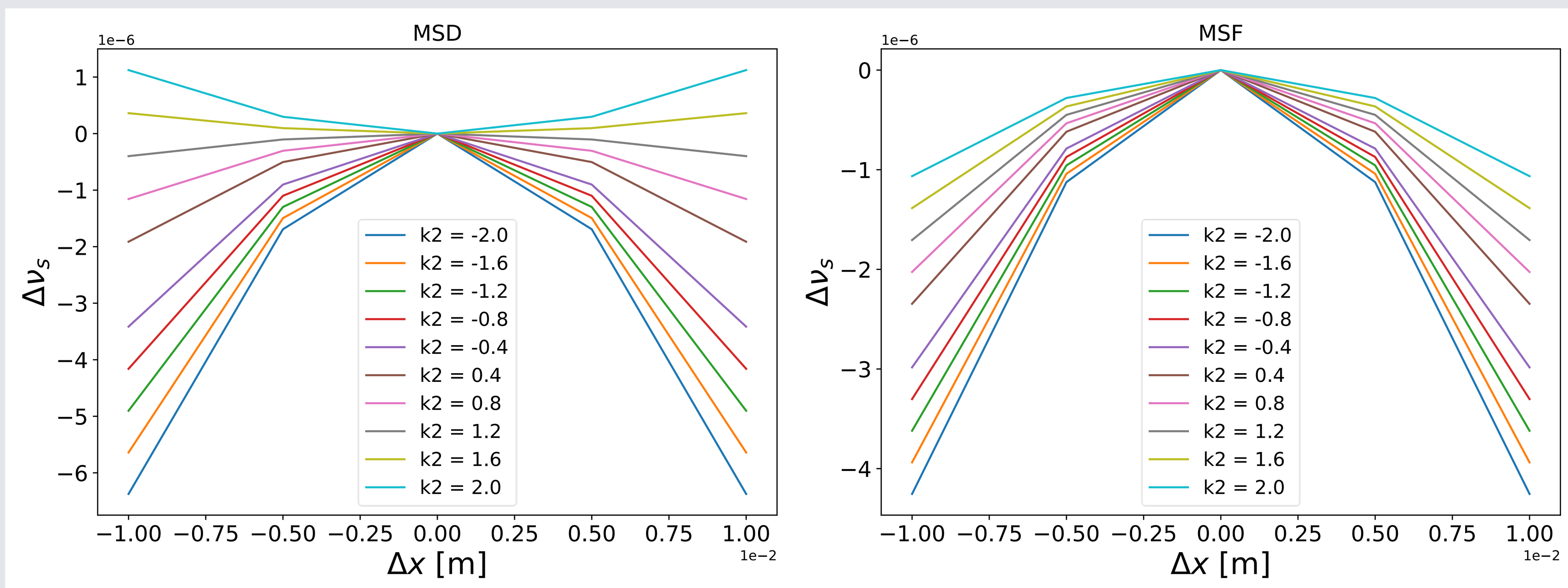
- CRYRING@ESR.
- spin tracking using the BMAD software library.
- betatron tune: $Q_x = Q_y = 2.42$



Two ways to optimize the SCT.

1. sextupole corrections:

$$\frac{1}{SCT} \propto \Delta\nu_s = |A + a_i I_i| \cdot (\Delta x^2) + |B + b_i I_i| \cdot (\Delta y^2) + |C + c_i I_i| \cdot \left(\frac{\Delta p}{p}\right)^2$$

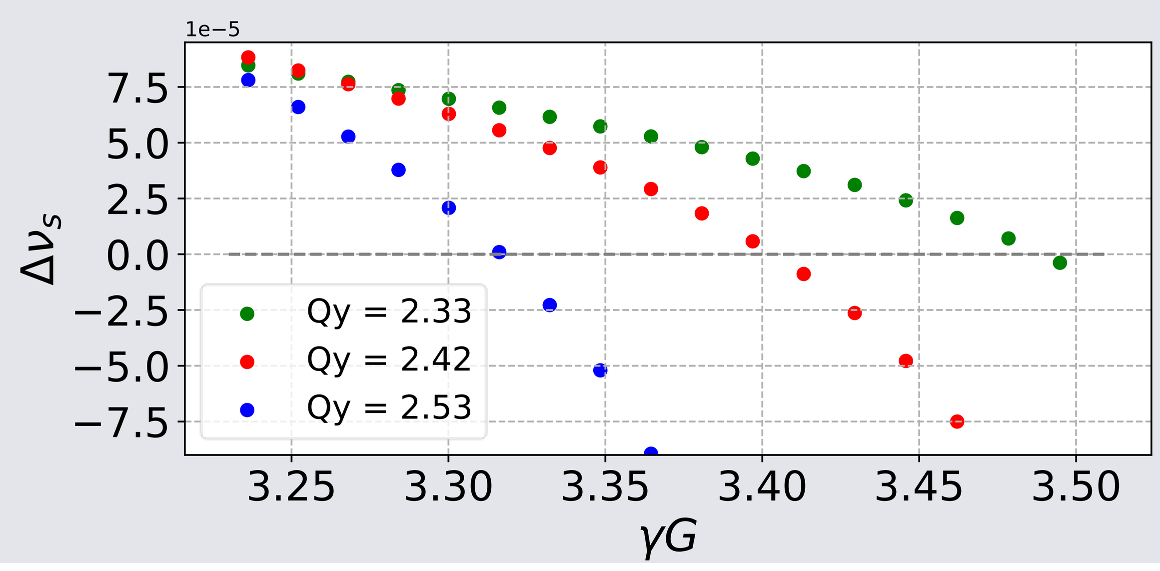


Minimum $\Delta\nu_s$ can be obtained by flattening the parabolas.

→at least 3 groups of sextupole are needed, and corrections are dependent on energy.

2. zero crossing shift induced by betatron tunes.
   Intrinsic spin resonances: $\gamma G = kP \pm Q_y$.

→unknown betatron tunes.



References

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2. Chang, Seung Pyo, et al. "Axionlike dark matter search using the storage ring EDM method." Physical Review D 99.8 (2019): 083002.
3. Karanth, Swathi, et al. "First Search for Axion-Like Particles in a Storage Ring Using a Polarized Deuteron Beam." Physical Review X 13 (2023): 031004.

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