Axion Searches at Storage Rings

J. Pretz
RWTH Aachen & FZ Jülich

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Axions/Axion Like Particles (ALPs)

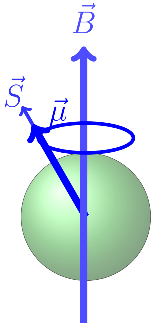
- hypothetical elementary particle postulated by the Peccei–Quinn to resolve the strong CP problem
- axion are also dark matter candidates
- axion like particles (ALP): similar properties as axions, (but ALPs don't solve the strong QCD problem)
- huge experimental effort to search for axion/ALPs (haloscopes, helioscopes, light shining through the wall, mainly coupling to photons)
- in storage rings with polarized beams axion-gluon/nucleon coupling and direct effect on spin can be studied

Spin Motion in storage ring

with respect to momentum vector in magnetic field

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

$$\vec{\Omega}_{\text{MDM}} = -\frac{q}{m}\, G\vec{B} \quad , \qquad \vec{\mu} = g\frac{q\hbar}{2m}\vec{S} = (1+G)\frac{q\hbar}{m}\vec{S}$$



B	magnetic field
G	magnetic anomaly
g	g-factor
μ	magnetic moment
S	spin
q, m	mass, charge

Spin Motion in storage ring

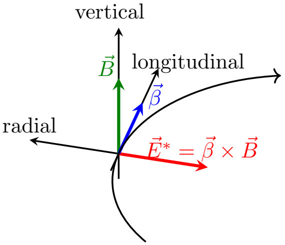
with respect to momentum vector in magnetic field

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

$$\vec{\Omega}_{\mathrm{MDM}} = -\frac{q}{m}\, G\vec{B}$$

$$\vec{\Omega}_{\mathrm{EDM}} = -\frac{1}{S\hbar}\, d\, c\, \vec{\beta} \times \vec{B}$$

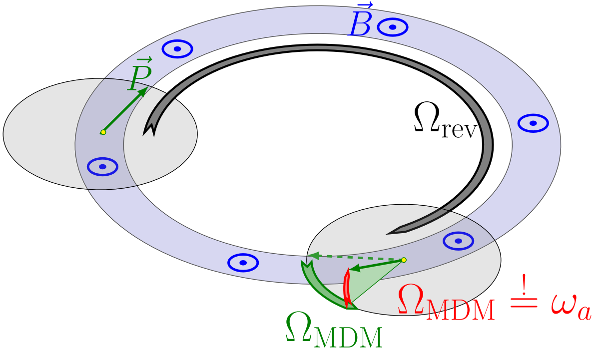
$$\vec{\Omega}_{\mathrm{wind}} = -\frac{1}{S\hbar}\,\frac{C_N}{2f_a}\left(\hbar\partial_0 a(t)\right)\vec{\beta}$$



axion field: $a(t) = a_0 cos(\omega_a t + \phi_0)$ $\quad d = d_{\mathrm{DC}} + d_{\mathrm{AC}} \cos(\omega_a t + \phi_0)$

$\hbar\omega_a = m_a c^2$ $\quad d_{AC} = a_0 g_{ad\gamma}$

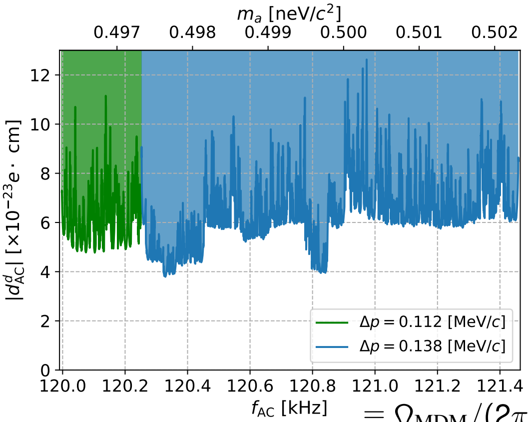
Axion Experiment at storage rings



Principle of experiment

- store polarized hadrons
- maintain precession in horizontal plane
- if $m_a c^2 = \Omega_{\mathrm{MDM}} \hbar$, polarization will turn out of the horizontal plane, resulting in a vertical polarization component
- Vertical polarization can be measured using a polarimeter (in case of deuteron: deuteron carbon scattering)
- AC measurement (i.e. systematics are under control)
- axion wind effect enhanced in storage rings ($v_{\mathrm{particle}} \approx c$)
- one can either scan a certain mass range by scanning Ω_{MDM} or measure at a fixed frequency to look for ALP at a specific mass.

Axion Analysis: d_{AC}, results from COSY

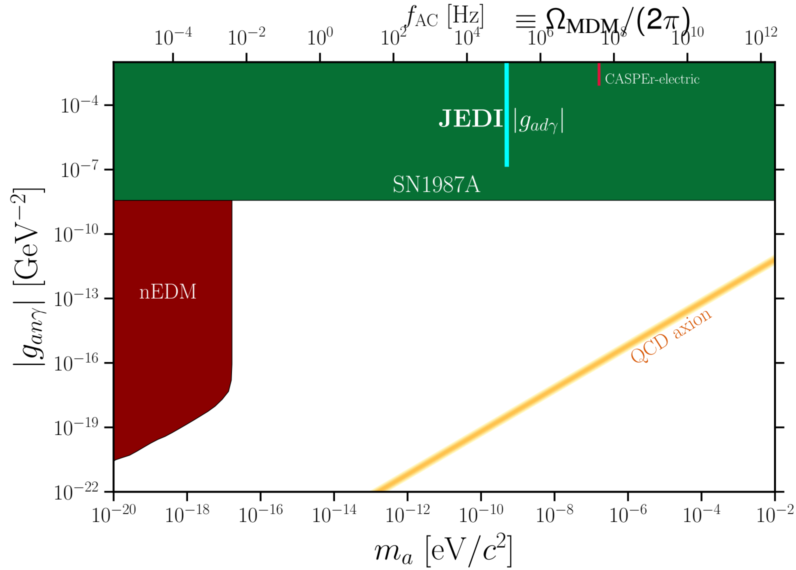


$\equiv \Omega_{\mathrm{MDM}}/(2\pi)$

- a few days of beam time
- $f_{AC} = \frac{1}{2\pi}\frac{m_a c^2}{\hbar} = \gamma G f_{\mathrm{rev}}$

https://arxiv.org/abs/2208.07293

Axion Analysis: axion anomalous coupling to gluons $g_{aN\gamma}$



How to explore a wider mass range m_a

$\Omega_{\mathrm{MDM}} = \gamma G \Omega_{rev}$

1. modify beam energy (changes γ, Ω_{rev})
2. use different nuclei (changes G)
3. Use additional electric field
   $$\vec{\Omega}_{\mathrm{MDM}} = -\frac{q}{m}\left[G\vec{B} - \left(G - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

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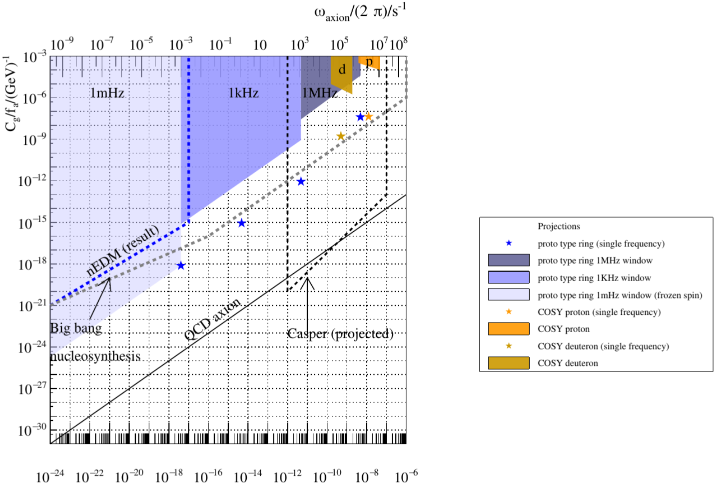

https://doi.org/10.1140/epjc/s10052-020-7664-9