Axion / ALPs searches in storage rings

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On behalf of the JEDI collaboration

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First Search for Axion-Like Particles in a Storage Ring Using a Polarized Deuteron Beam

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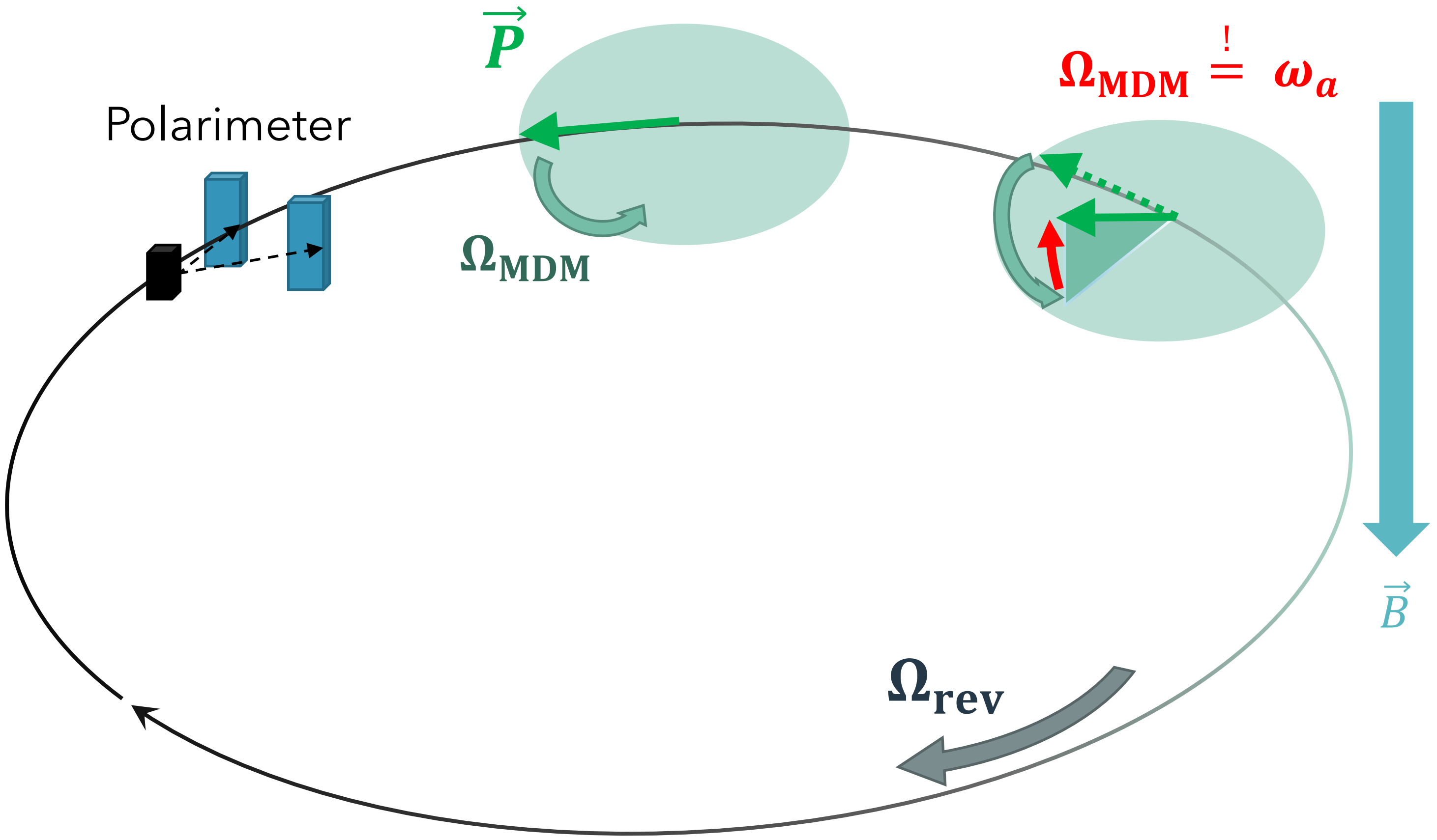
(JEDI Collaboration)

arXiv:2208.07293v1 [hep-ex]

Principle of storage ring Axion/ALP search



- Horizontally polarised deuteron beam.
- Frequency scan – search for $\Omega_{\mathrm{MDM}} = \omega_a$ resonance.
- Change in vertical polarization.

$\omega_a = m_a c^2/\hbar$ axion induced frequency to spin of nuclei.

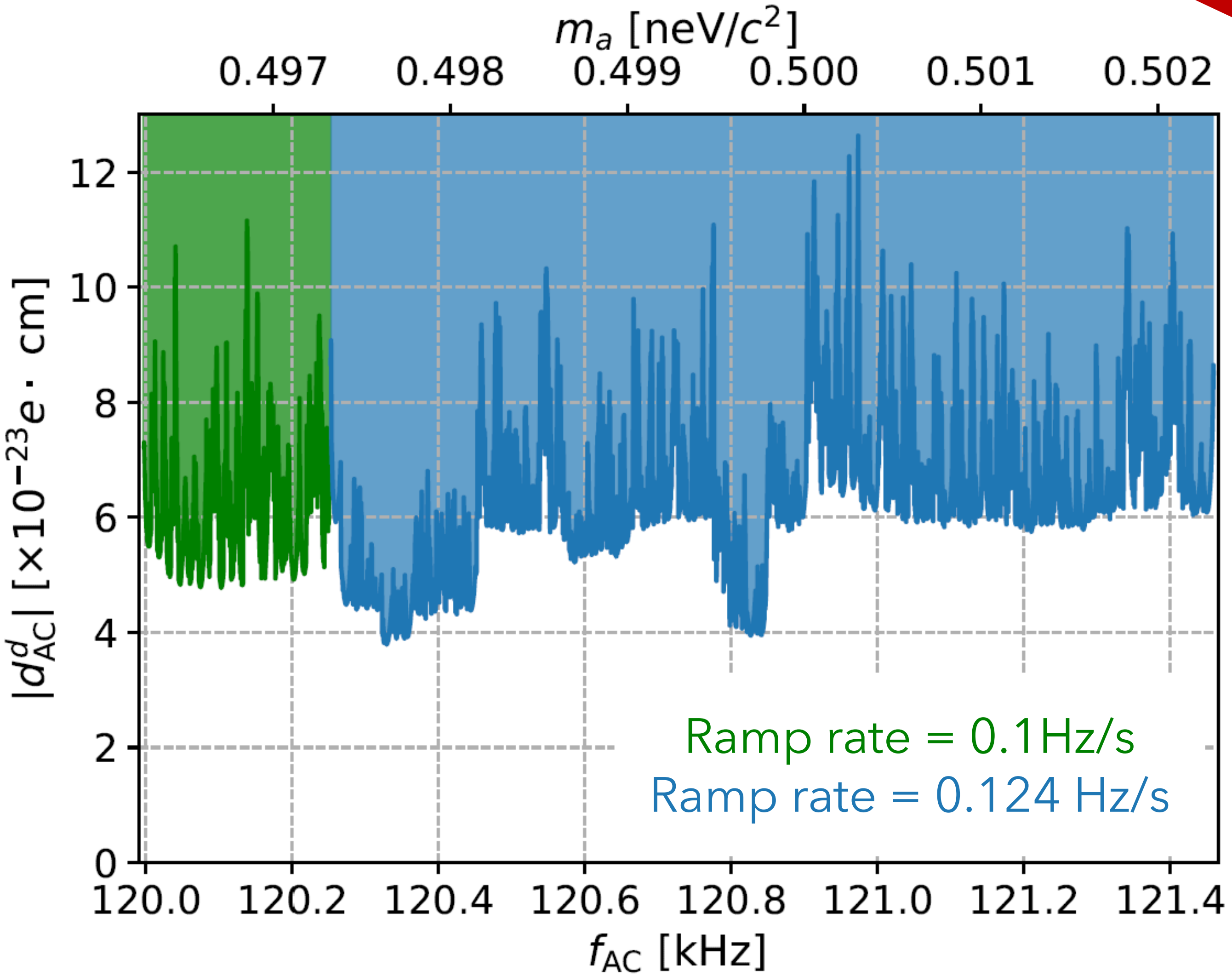
Bound on oscillating EDM of deuteron

First result

90 % CL upper limit on the ALPs induced oscillating EDM

Average of individual points
$|d_{\mathrm{AC}}| < 6.4 \times 10^{-23} e \cdot \mathrm{cm}$

Karanth et al, arXiv:2208.07293[hep ex]



Bound on ALP-EDM coupling

Coupling of ALP to deuteron EDM

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

Only few days of data taking.

Karanth et al, arXiv:2208.07293[hep ex]

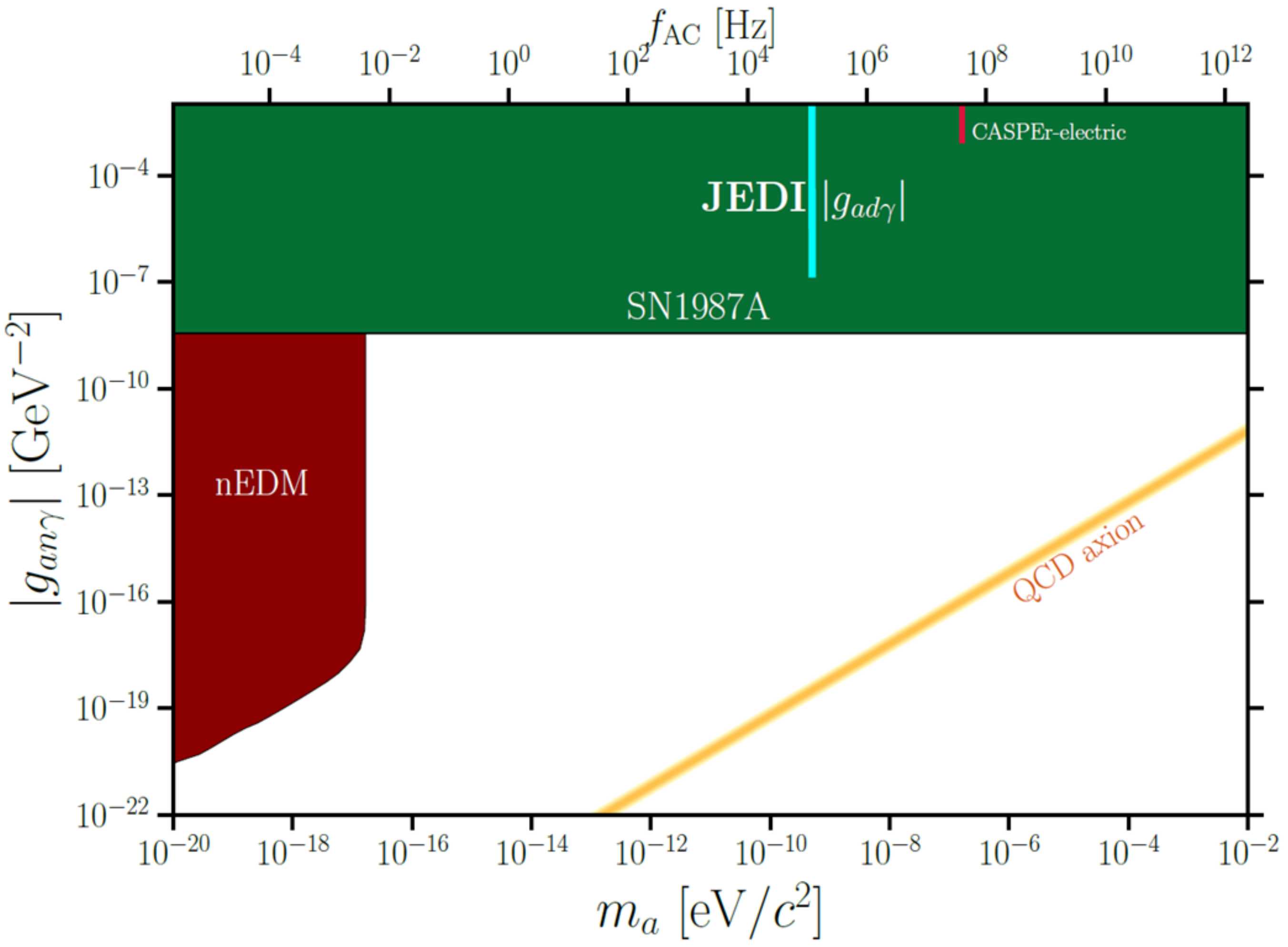


Figure courtesy of C. O'Hare, "cajohare/axionlimits: Axionlimits," (2020), URL https://doi.org/10.5281/zenodo.3932430

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Thank You

Erasmus+

erc European Research Council

Extra Slides

Axion / axion-like particle (ALPs)

Act as classical axion field $a(t) = a_0 \cos(\boldsymbol{\omega}_a t + \boldsymbol{\phi}_a)$

- ω_a ALP oscillation frequency – connected to axion mass $\hbar\omega_a = m_a c^2$
- ϕ_a Local phase of ALP field – unknown and changes with every new measurement

Oscillating coupling to spin of nucleons or nuclei:

- - Oscillating electric dipole moment
- - Axion wind effect

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

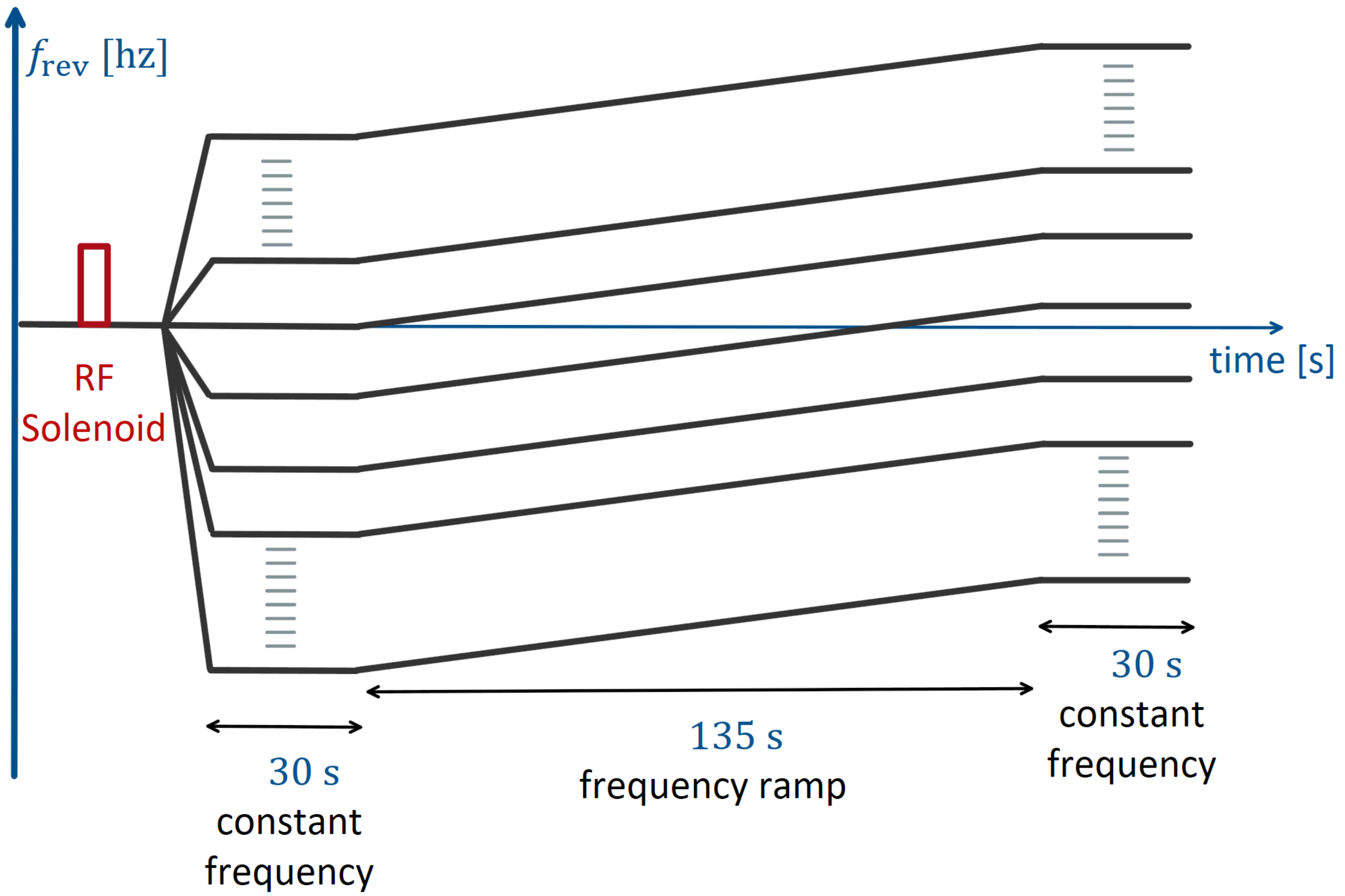
P. W. Graham et al., PRD 88, 035023 (2013)

Time development of the spin direction of a beam of polarized charged particles in a storage ring. Precisely measured

Scan management

- Vary the spintune frequency in search of resonance.
- Measure polarization as a function of time.
- About 100 scans
  - Frequency Range
    119997 Hz – 121457 Hz
    Total width $\approx$ 1500 Hz
  - ALP mass range
    0.496 neV – 0.502 neV

ramp rate $= \begin{cases} 0.1 \\ 0.124 \end{cases} \mathrm{Hz/s}$

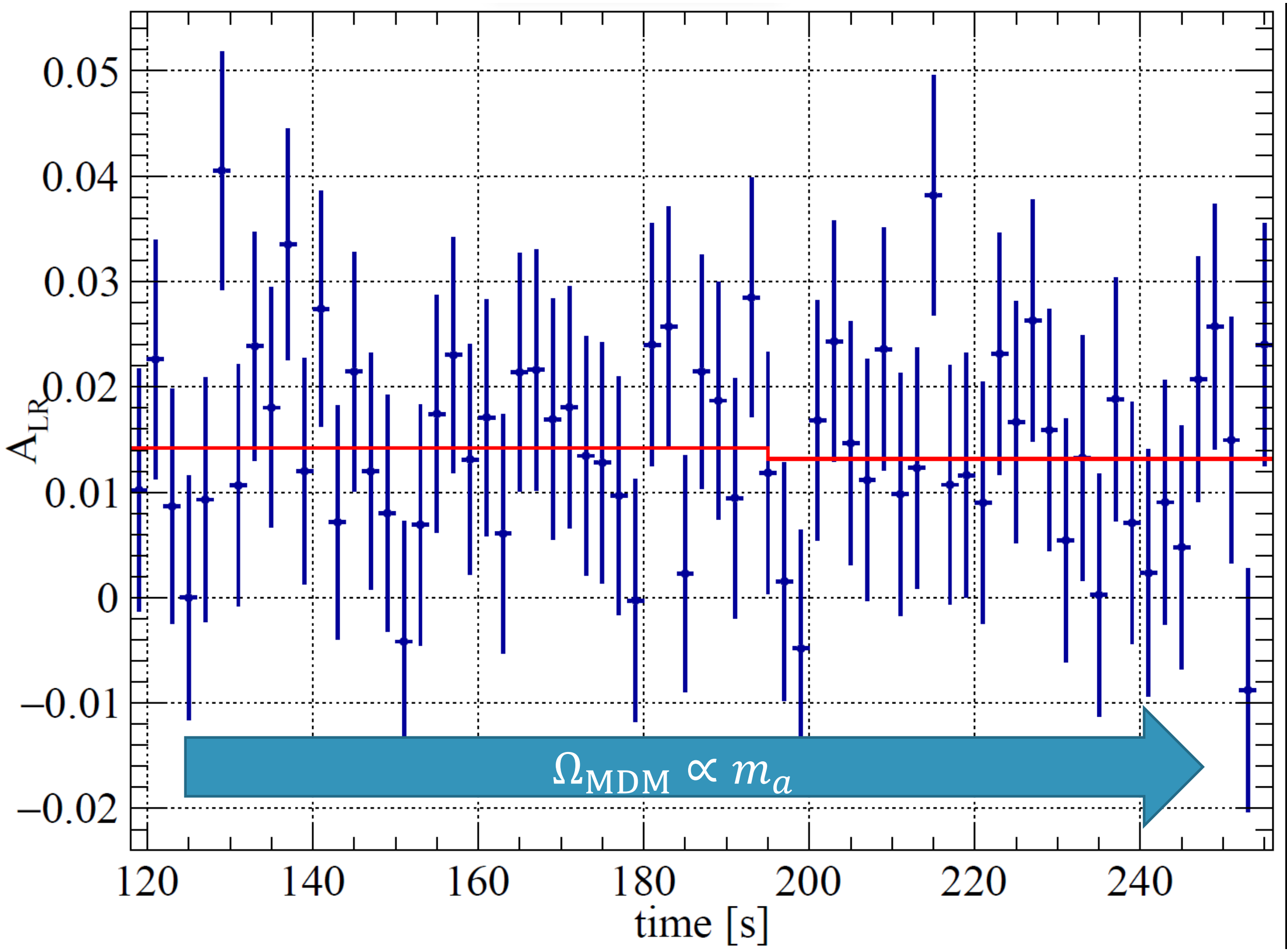


Axion scan - example

Data from a single bunch with a step function fit.

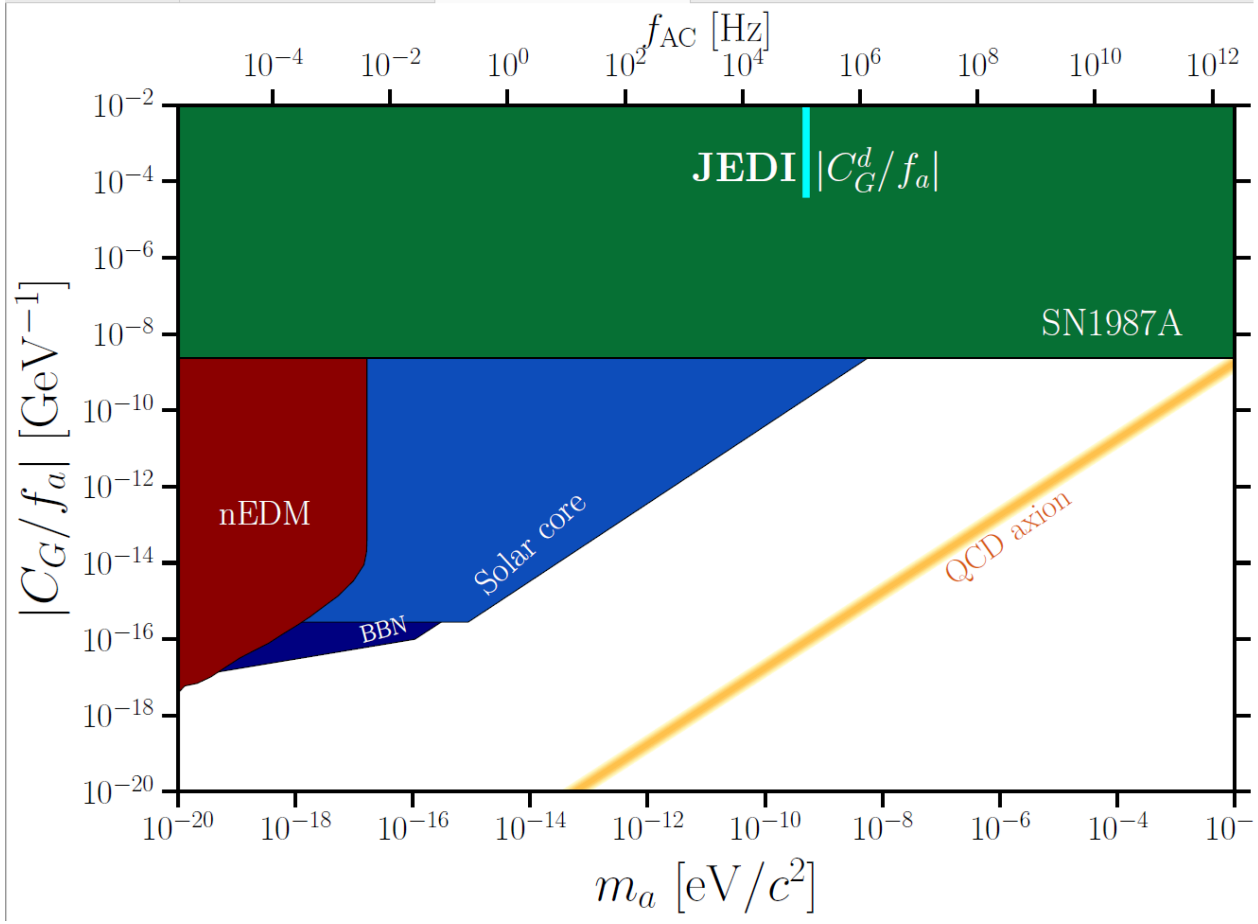
$$\Delta A_{LR} = -0.00105(233)$$

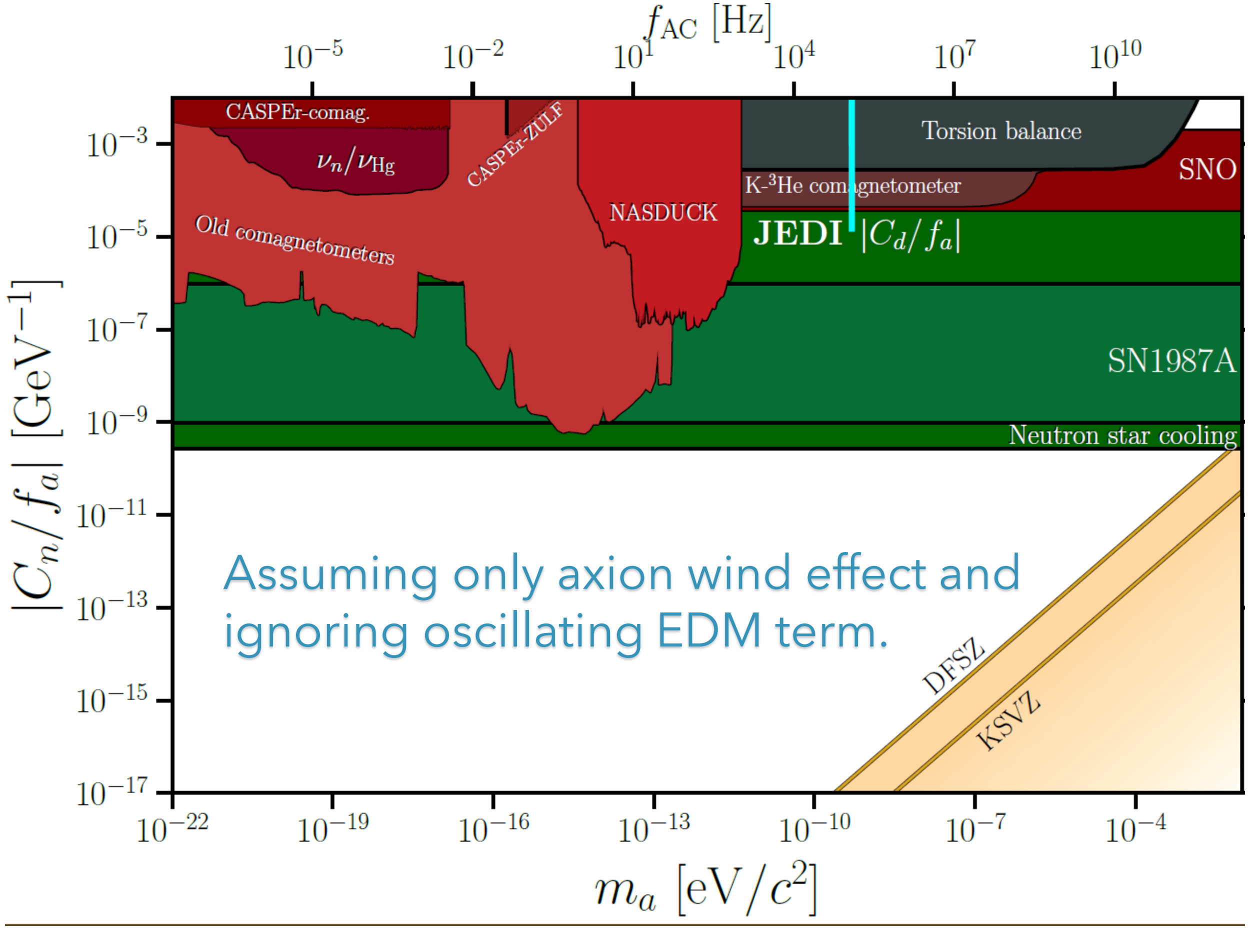
Jump must be present in all four bunches to be considered as a signal



Experimental data from WF

ALP-gluon and ALP-nucleon coupling



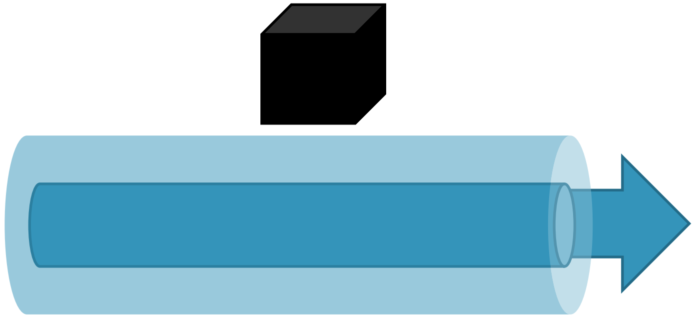


Assuming only axion wind effect and ignoring oscillating EDM term.

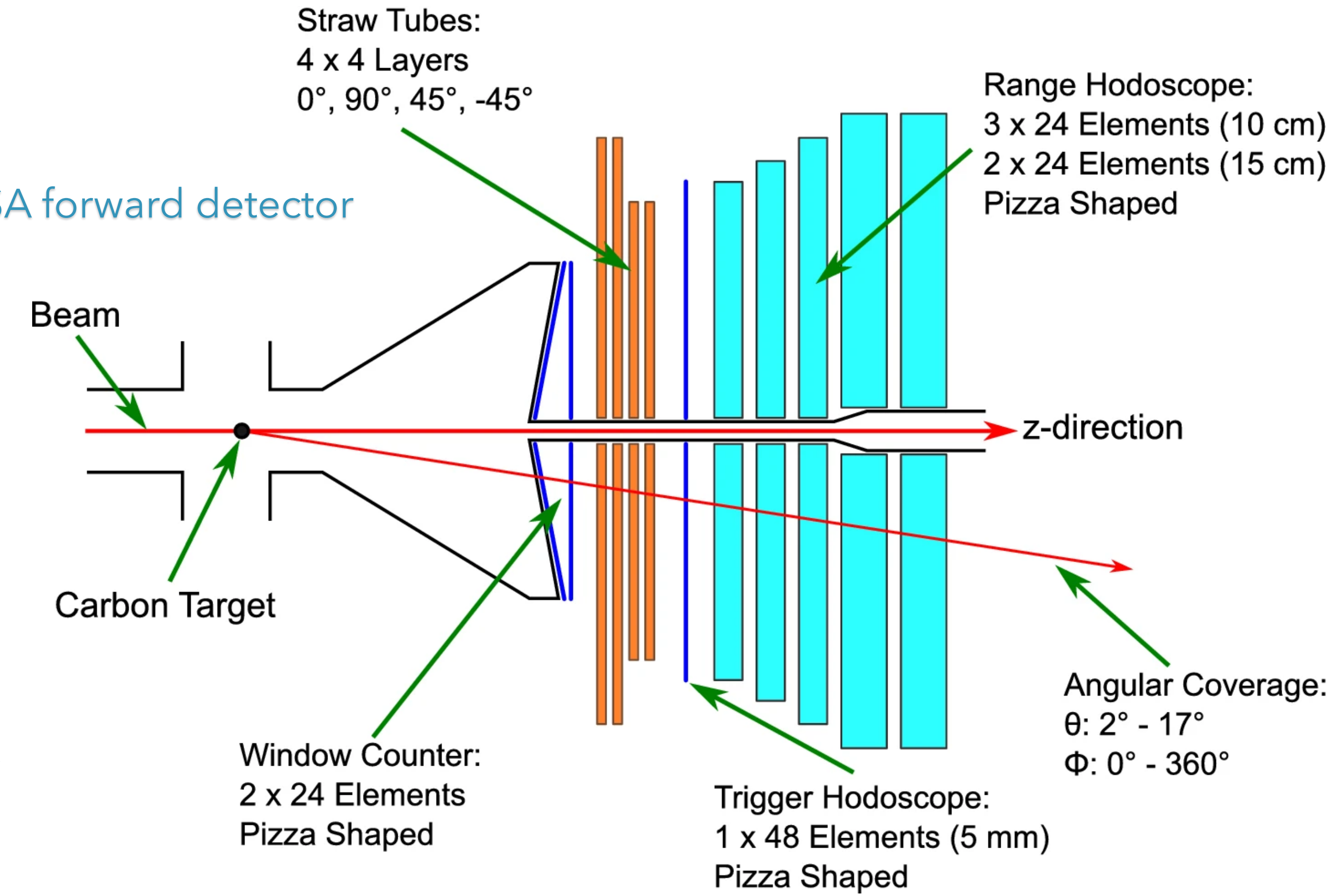
Figures courtesy of C. O'Hare, "cajohare/axionlimits: Axionlimits," (2020), URL https://doi.org/10.5281/zenodo.3932430

Polarimeter

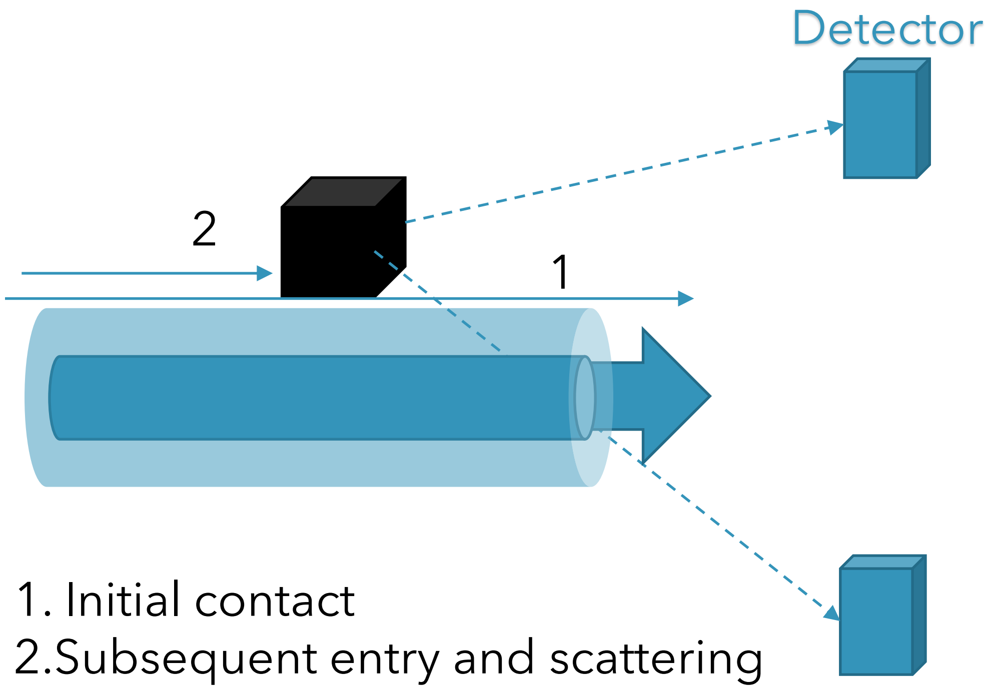
- Use forward angle elastic scattering on carbon target.
- White noise beam extraction.



WASA forward detector

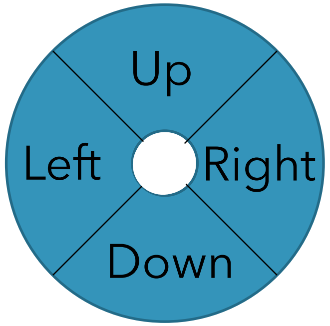


Polarimeter



1. Initial contact
2. Subsequent entry and scattering

Detector-beam view



Spin - orbit interaction gives the asymmetry in events.

Left-right asymmetry

$$\mathrm{A_{LR}} = \frac{N_L - N_R}{N_L + N_R} = P_y A_y$$

ALP signal

Up - down asymmetry

$$\mathrm{A_{UD}} = \frac{N_U - N_D}{N_U + N_D} = P_x A_y$$

Check horizontal pol.

Requires unfolding to find the in-plane polarisation.

Spin dynamics in a storage ring

Spin precession in a storage ring with $\vec{E}$ and $\vec{B}$ is given by Thomas-BMT equation.

Fukuyama et al, Int. J. Mod. Phys A28 (2003)

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

$$\vec{\Omega}_{\mathrm{MDM}} = -\frac{q}{m}\left(G + \frac{1}{\gamma}\right)\vec{B}$$

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

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

G: magnetic anomaly

$d(t)$: Electric Dipole Moment

$$d(t) = d_{\mathrm{DC}} + d_{\mathrm{AC}} a_0 \cos(\omega_a t + \phi_a)$$

C_N: Coupling constant

$$\partial_0 a(t) = \omega_a a_0 \sin(\omega_a t + \phi_a)$$