# Storage Ring Probes of New Physics

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**Yannis Semertzidis, On Kim, Selcuk Haciomerogulo, Zhanibek  Omarov**

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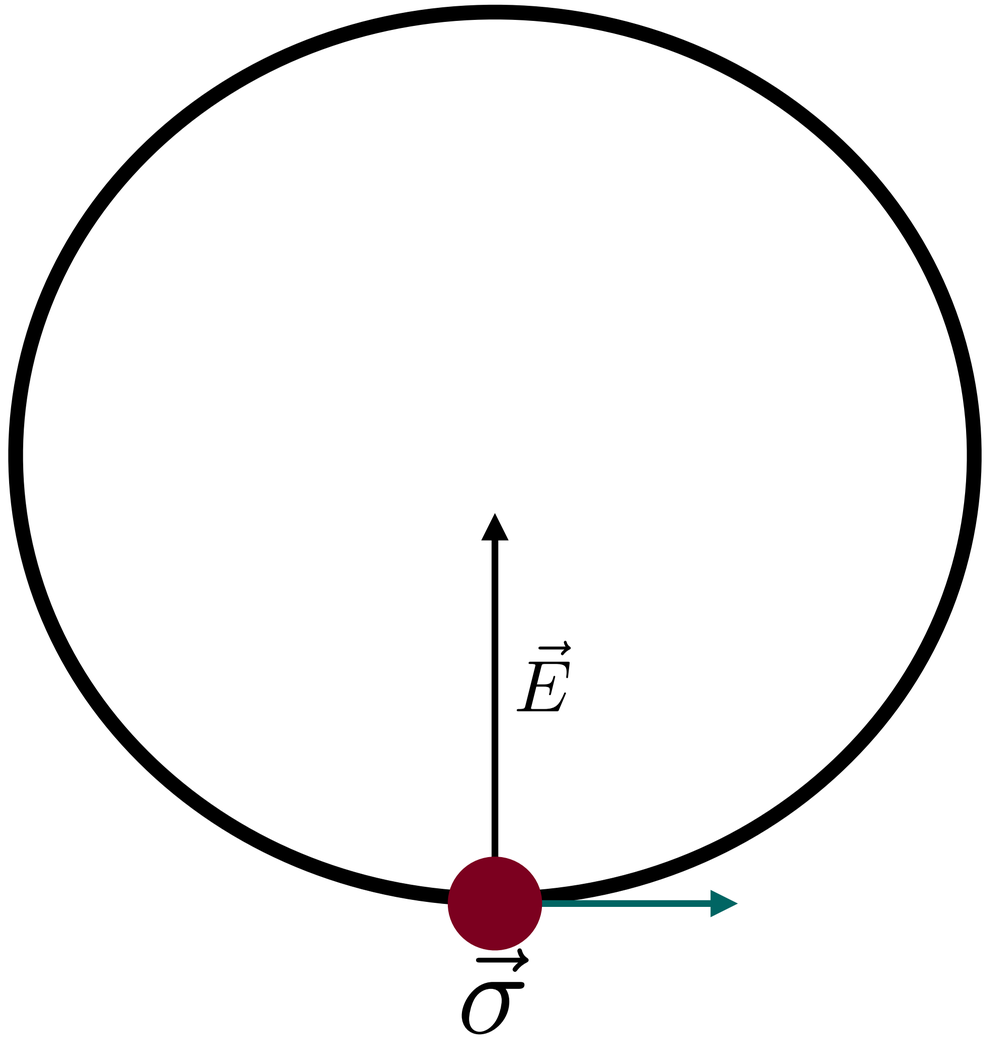


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Suitably orient spins

Look for precession of spin from new physics

Technology developed to look for electric dipole moments

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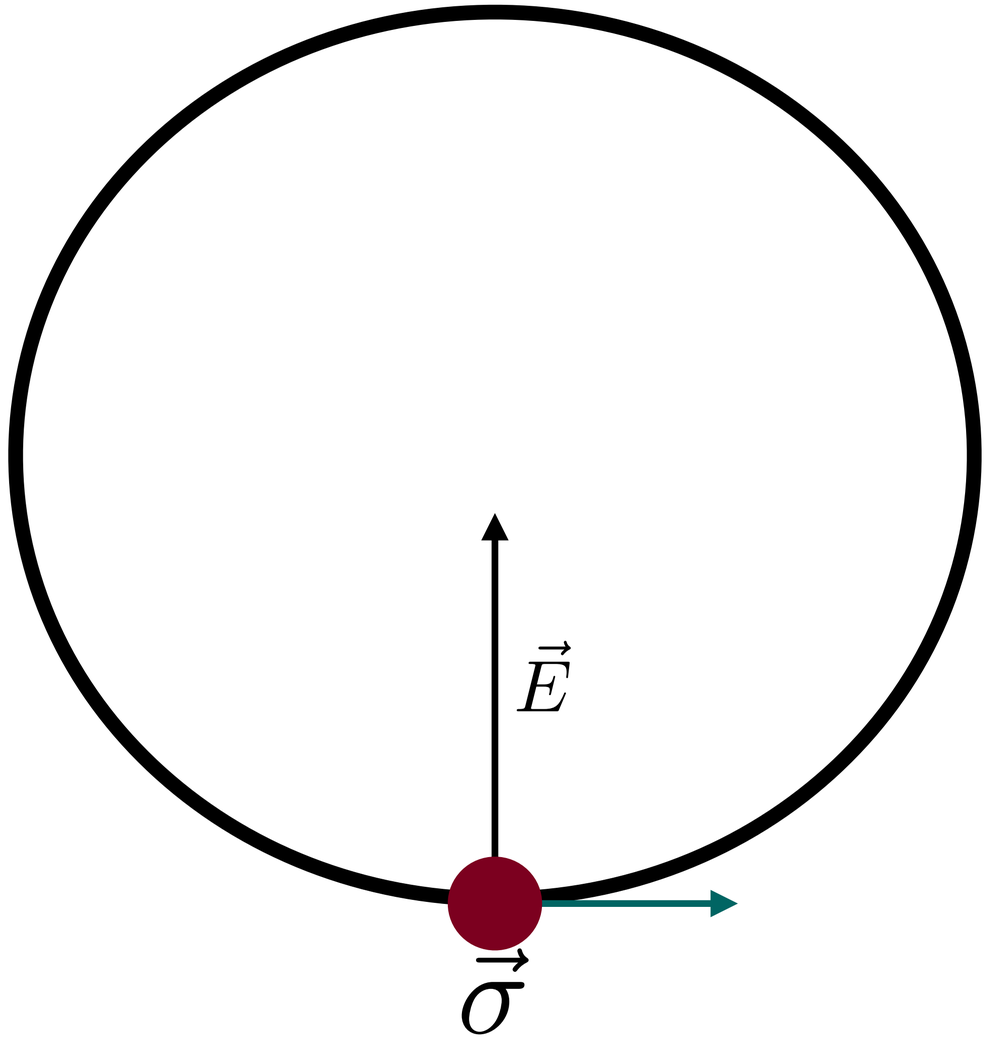


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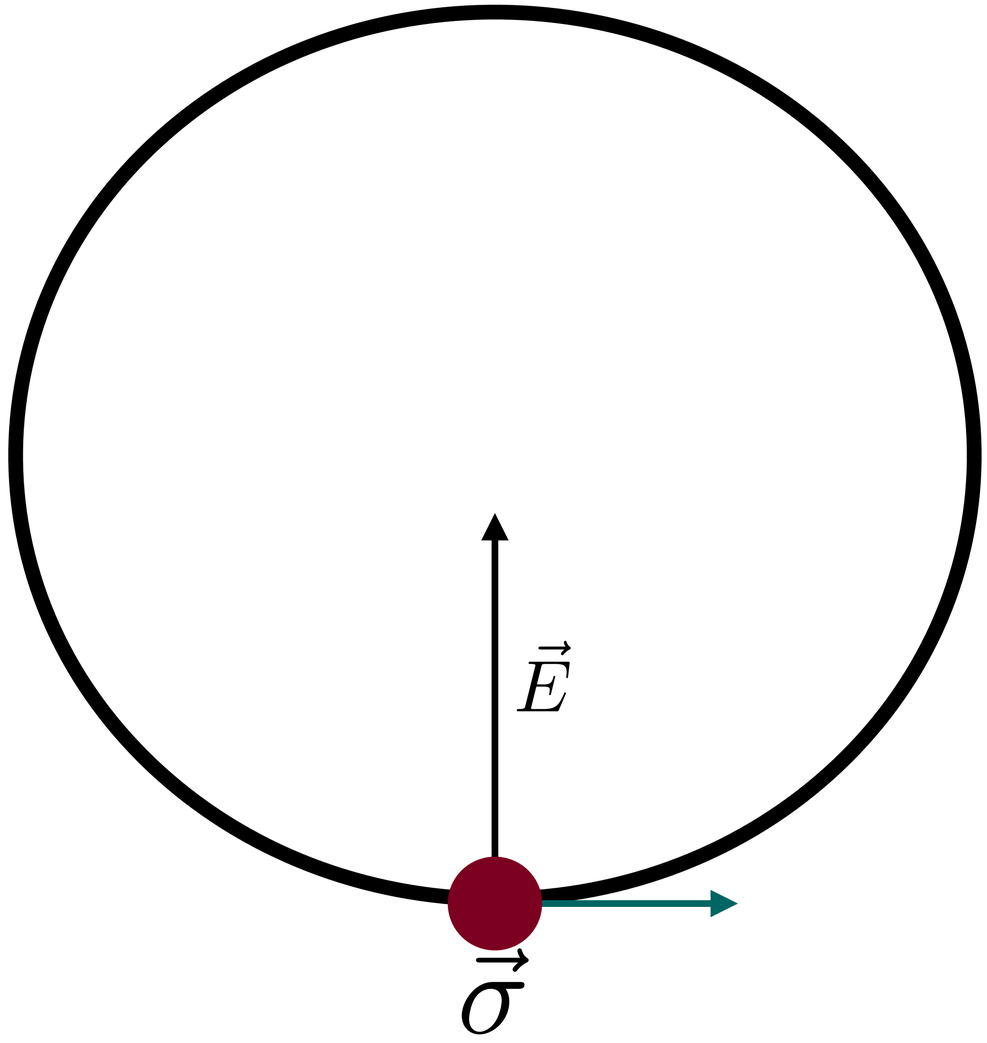


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Spin Couplings - “new” magnetic fields

# Spin Couplings

## Pseudoscalars

$$\frac{\partial_\mu \phi}{f_a} \bar{\Psi} \gamma^\mu \gamma_5 \Psi$$

## Axions

$$H_N \supset \frac{\nabla \phi}{f_a} . \sigma_N$$

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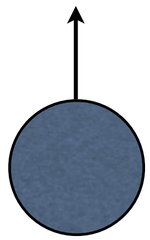

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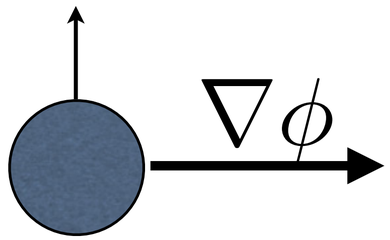

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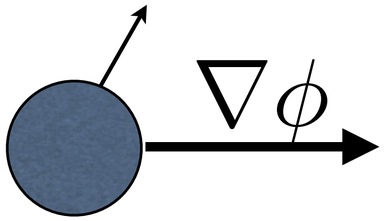

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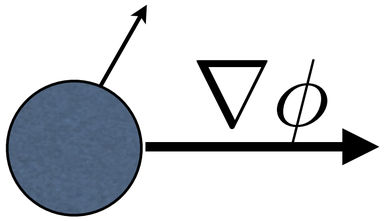


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**Dark Electric and Magnetic Moments**

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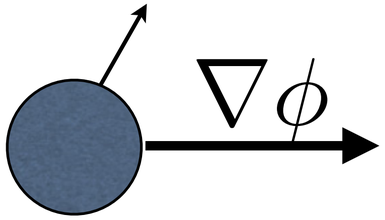


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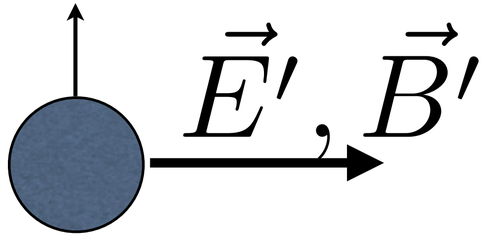

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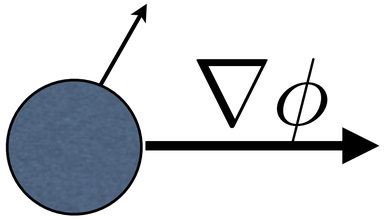


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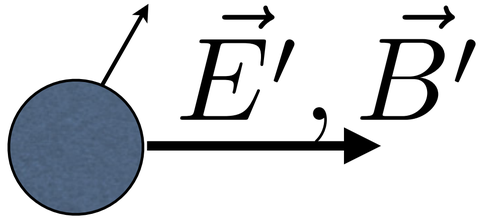

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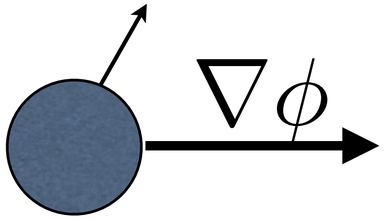


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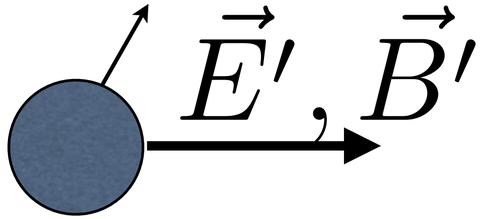


**Common phenomenology, focus on axions**

# Outline

1. Dark Matter

2. Dark Energy

3. Laboratory Sources

4. Conclusions

# Dark Matter

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Relativistic Boost

$v_r = 1$

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$$\rho_{dm} \sim m^2\phi_0^2$$

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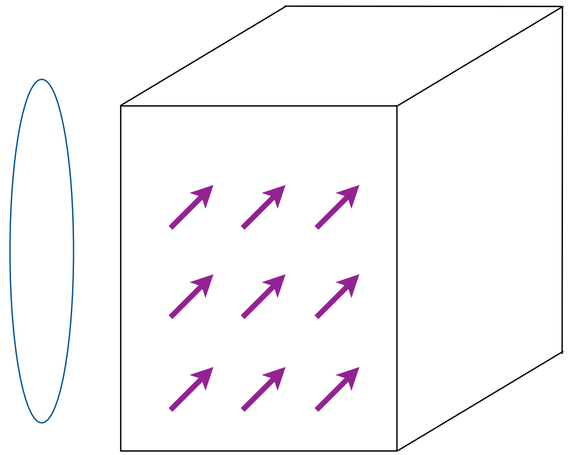


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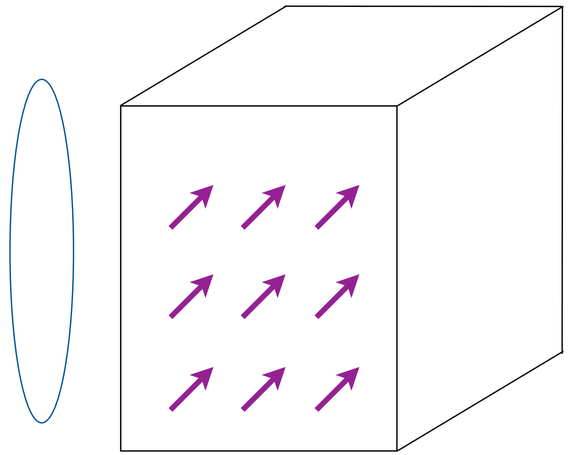


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Comparison with NMR Searches

Relativistic boost, long coherence time (~ 1000 s), but lower phase resolution

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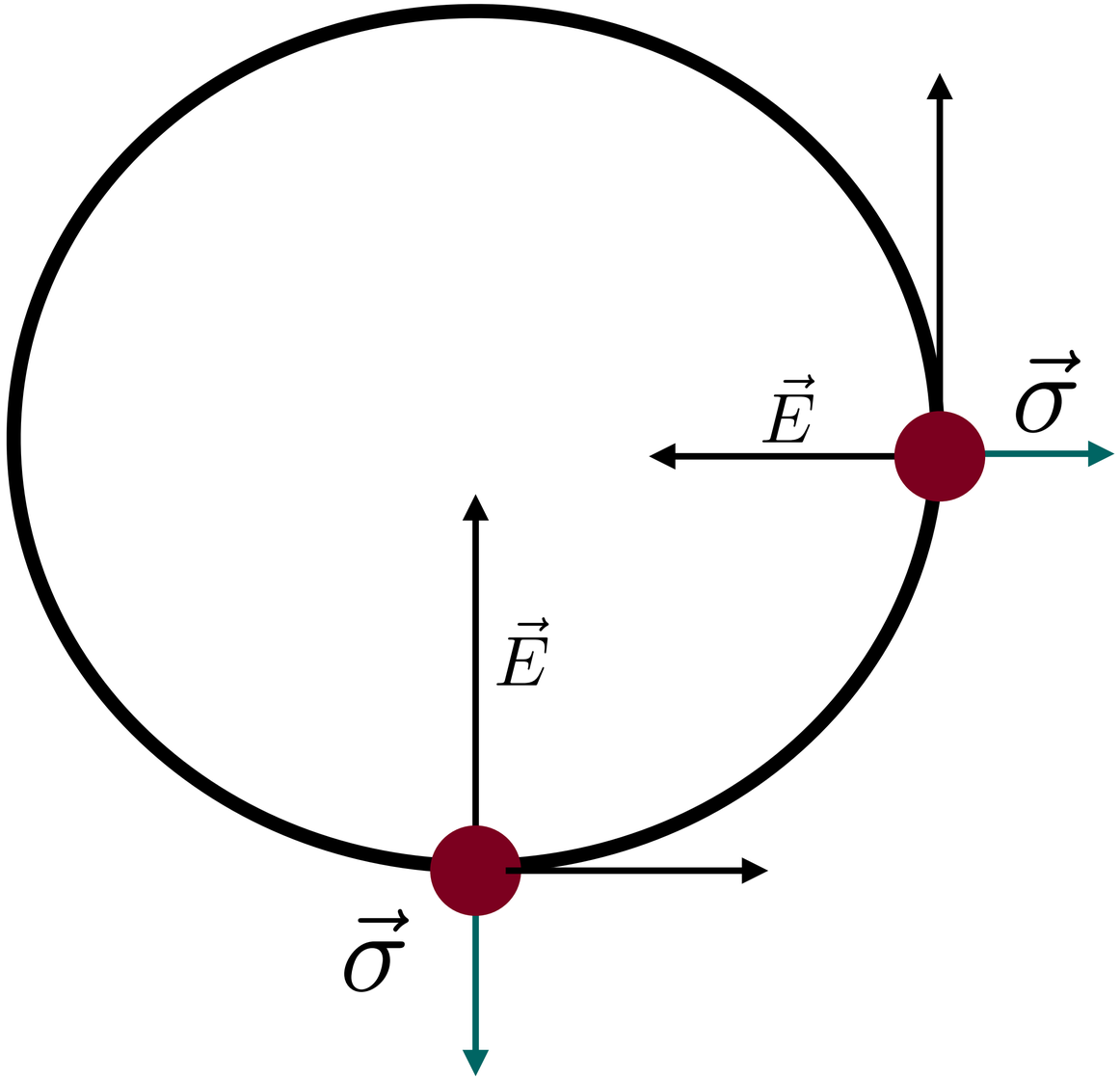


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Spin precession axis - tangential, along velocity

Spin precesses out of the plane

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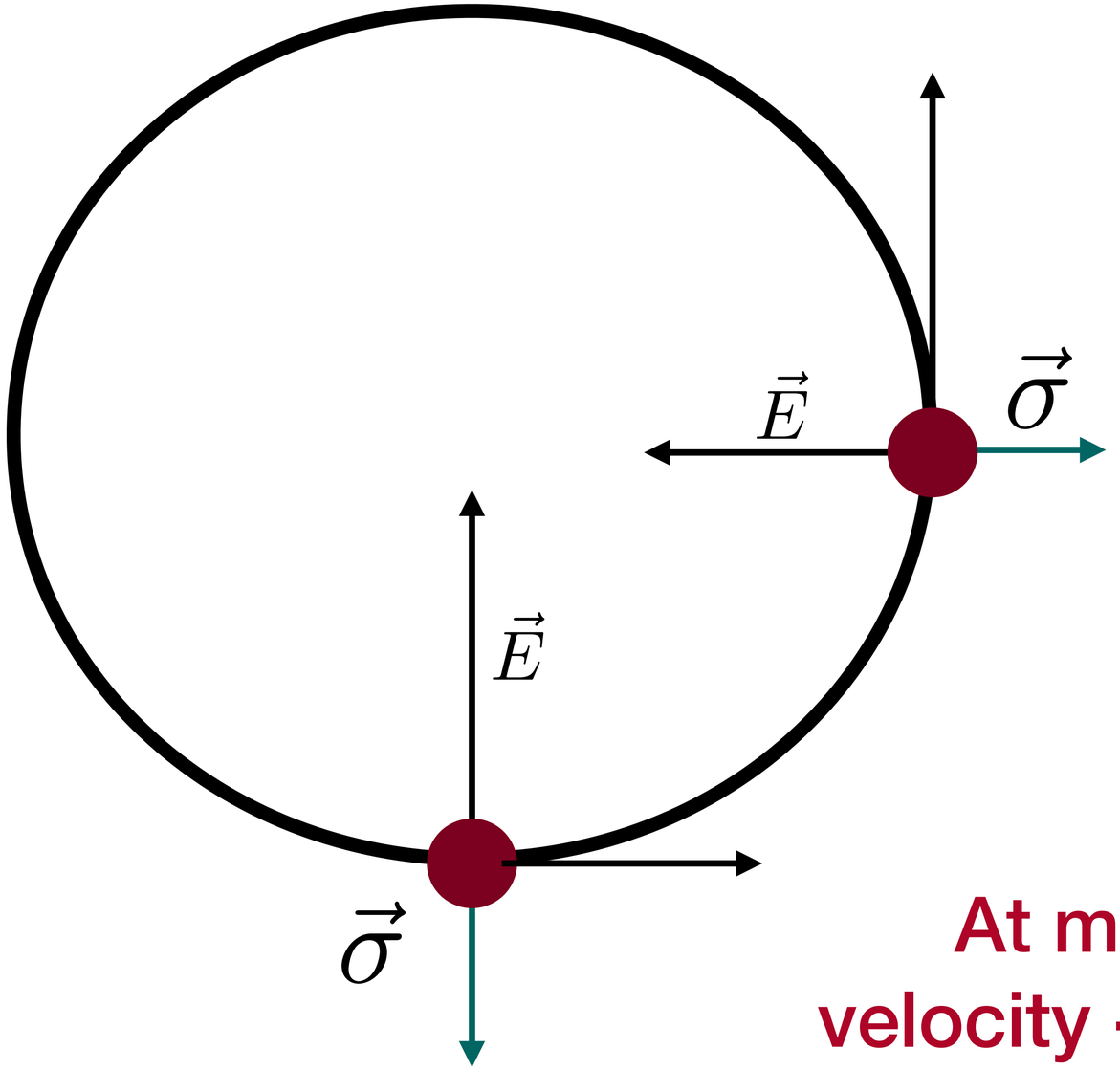


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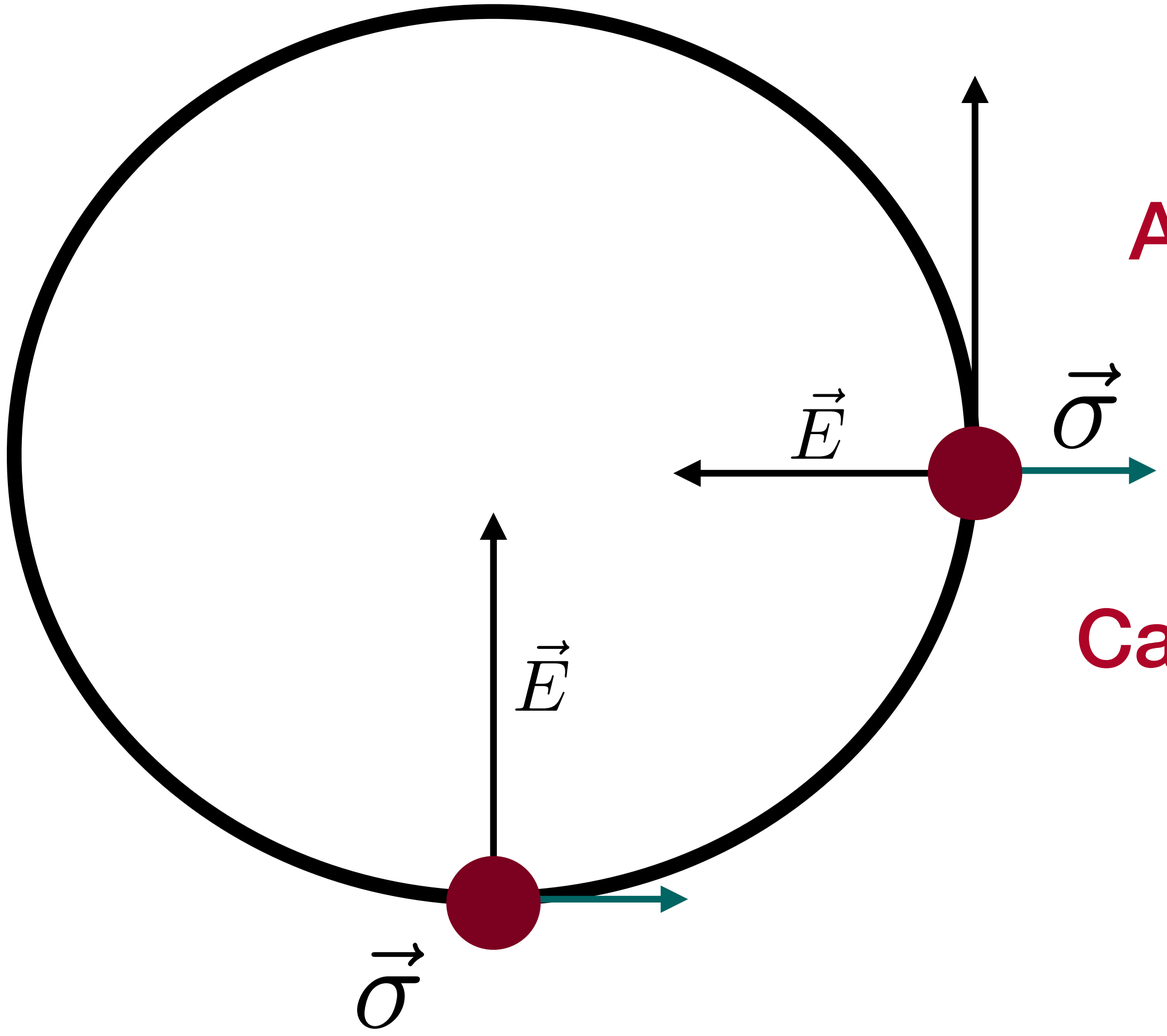


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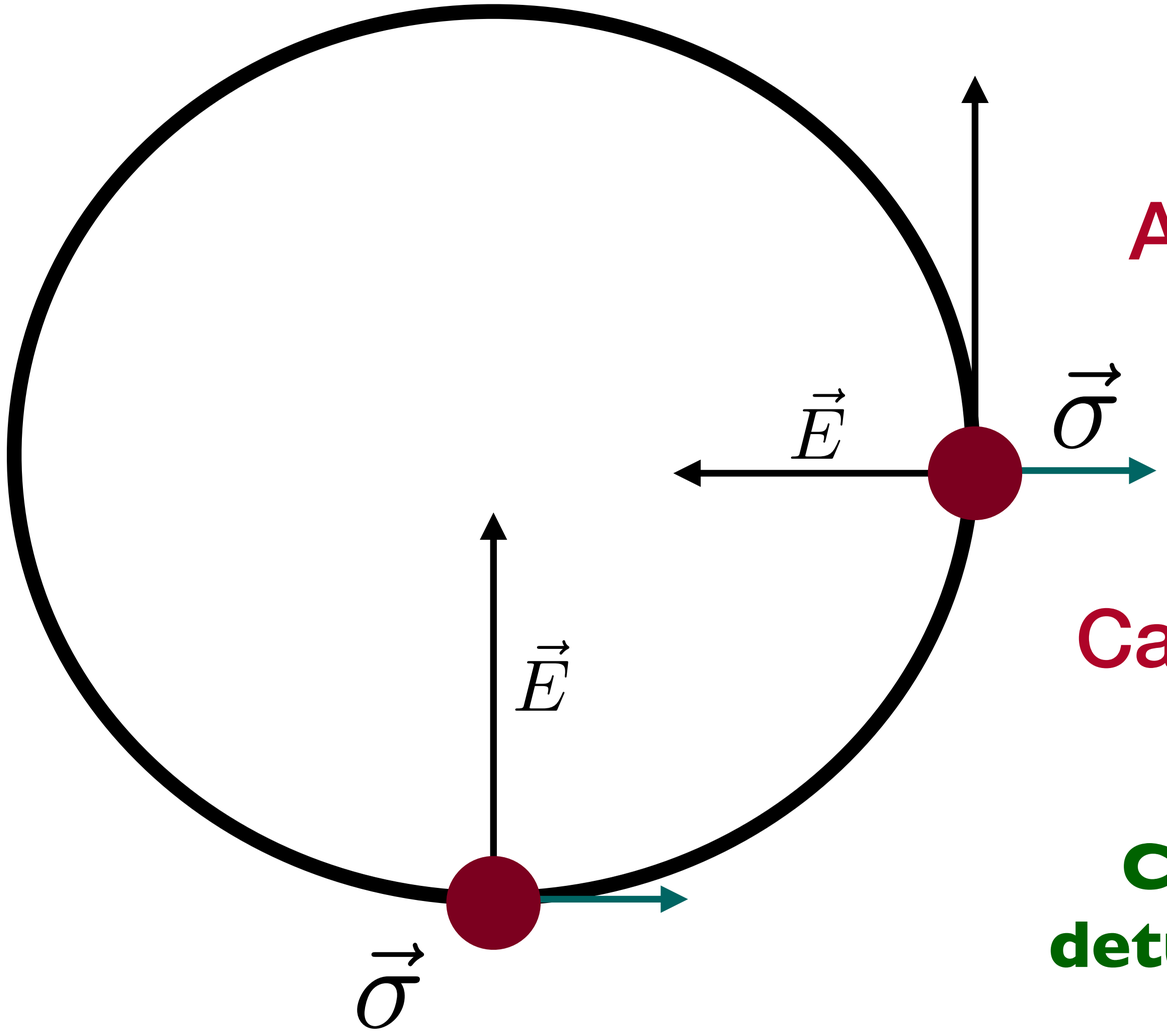


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**Could Resonate - choose momentum detune velocity precession rate from spin precession rate**

# Backgrounds

| Effect | Remediation |
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| Radial B-field. | Small effect. |
| Unwanted vertical forces when other than magnetic focusing is present. | Small effect. |
| Dipole vertical E-fields. | Small effect. |
| Quadrupole E-field in the electric bending sections. | Small effect. |
| Corrugated (non-planar) orbit. | Minimize effect with symmetric lattice design. Finally, keep the stored beams at zero average vertical angle when integrating over the electric field bending sections. |
| Longitudinal B-field. | The CW and CCW stored proton spins rotate in *same* direction, while the (pseudo-)scalar fields rotate them in opposite directions. |
| Geometrical phase effect due to lattice elements imperfections. | Equivalent to a spin resonance due to lattice elements imperfections. Magnetic quadrupoles: beam-based alignment to 1$\mu$m rms. E-field sections: Absolute beam position monitors to <0.01mm per injection. |
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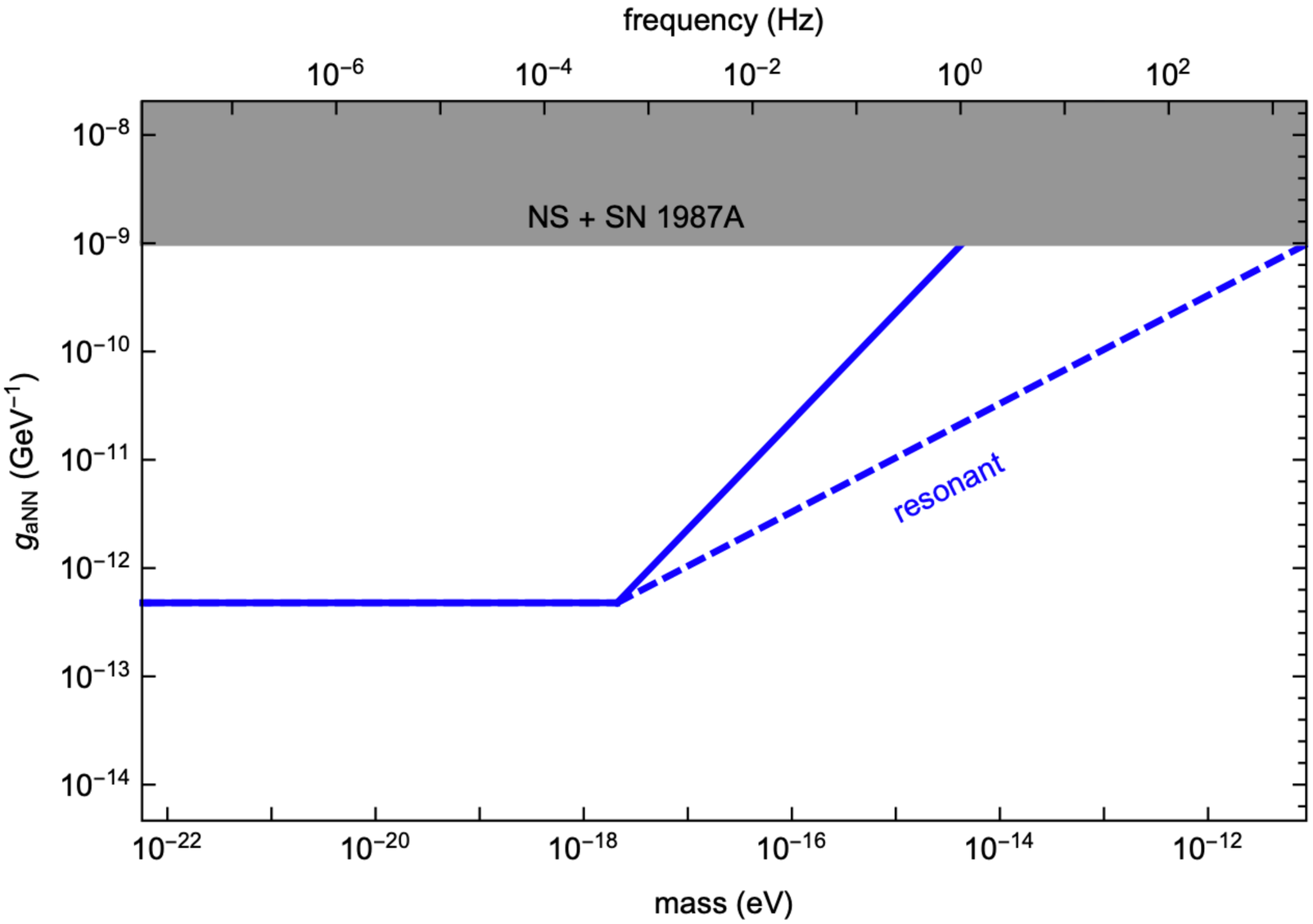


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What are the signatures of dark energy?

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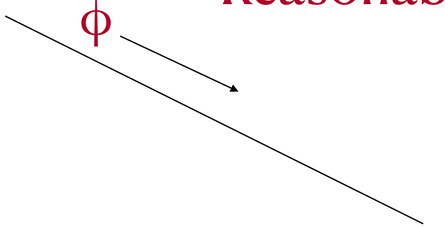


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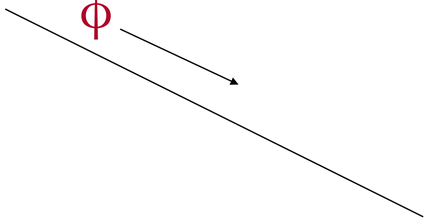


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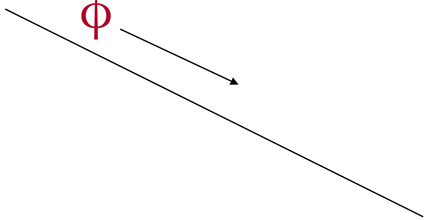


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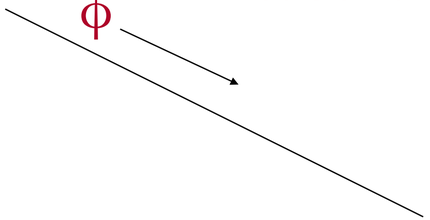


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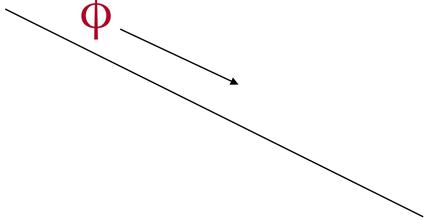


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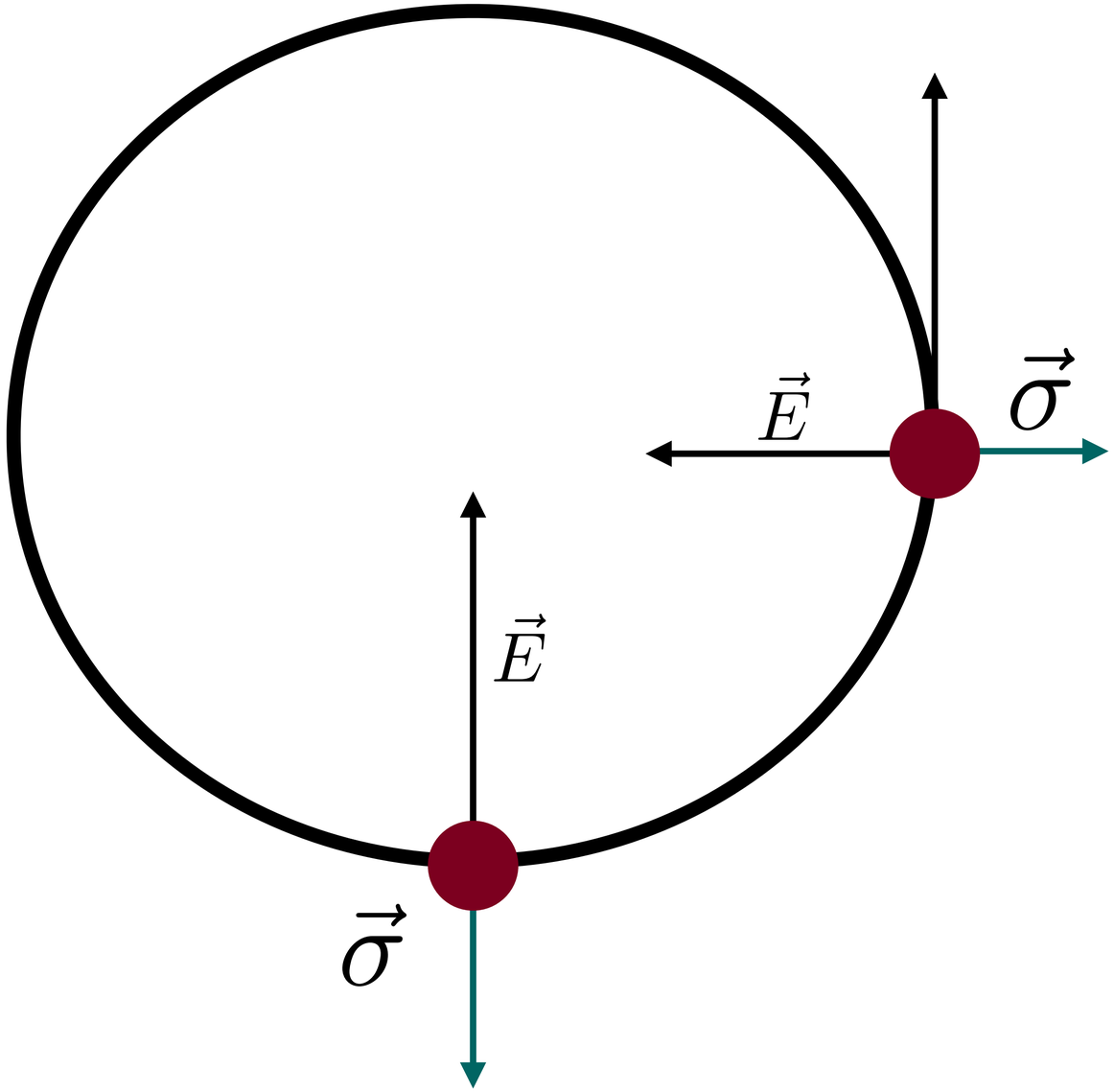
**Spin Precession**

**Signal is completely DC (Dark energy changes over Hubble time)**

# Dark Energy at Storage Rings

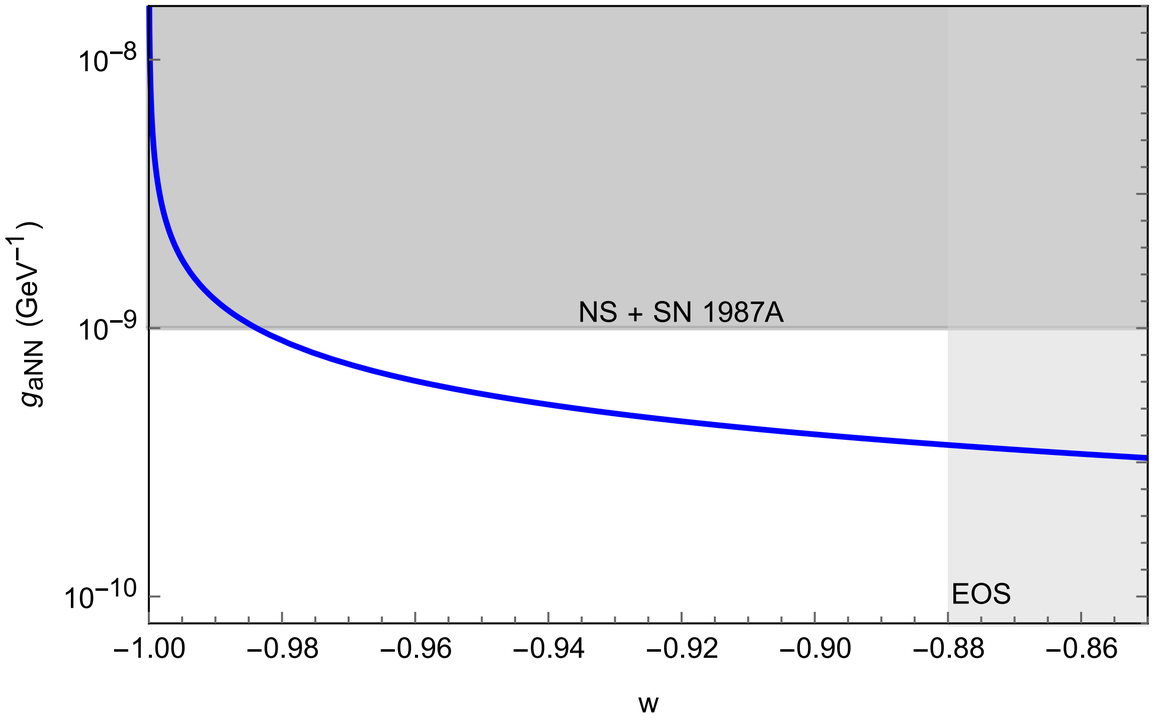



Proton @ magic momentum, spin “frozen”

At magic momentum, spin locked to velocity - signal adds coherently

No cancellation since signal frequency is at least as low as Hubble

# Projected Sensitivity




1000 s storage time (protons), $10^{-6}$ phase resolution

Lorentz Violation experiments also have comparable sensitivity

# Spin Dependent Forces

# Monopole Dipole Forces

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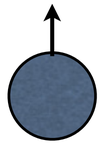
Local Source


$$g \phi \bar{\Psi} \Psi$$

Monopole Source



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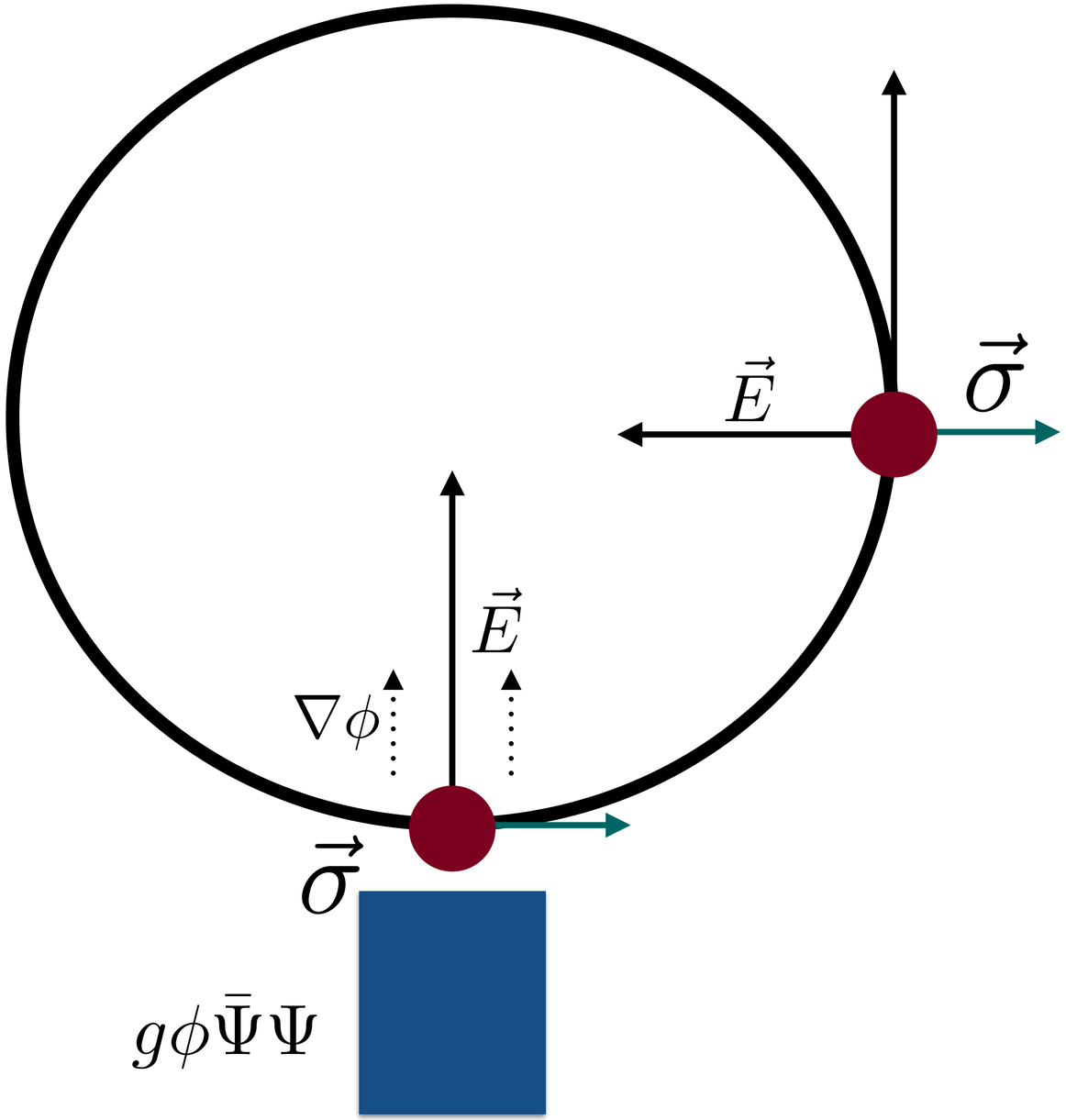
Spin Sensor

# Monopole Dipole Forces From Test Bodies

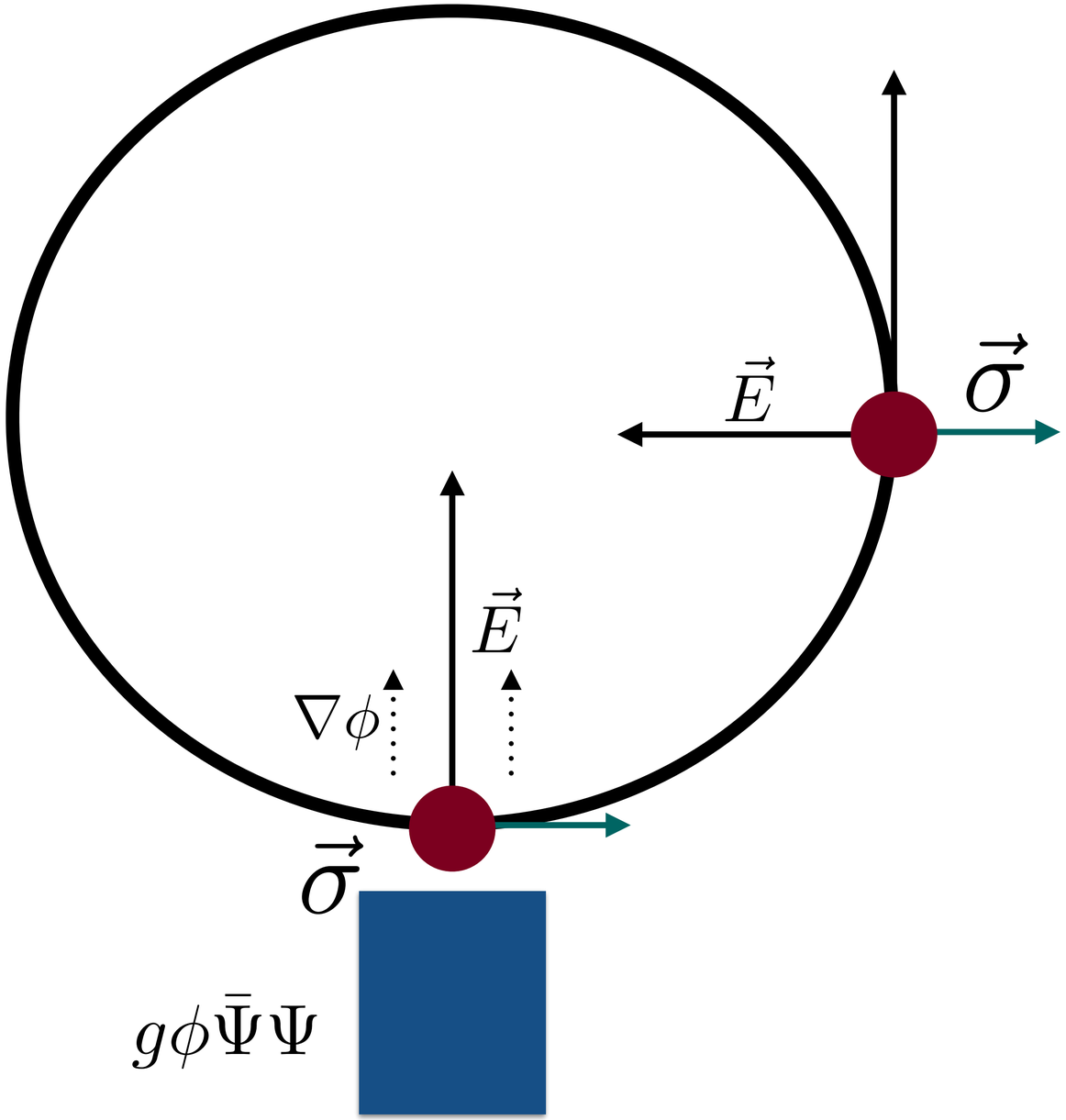



Precession Occurs near local test mass

Choice of gradient direction

Spin precess out of plane, in vertical direction

# Monopole Dipole Forces From Test Bodies




Precession Occurs near local test mass

Choice of gradient direction

Spin precess out of plane, in vertical direction

Interesting Handle: Fixed axion gradient, particle and anti-particle precess in same direction, unlike electromagnetic background

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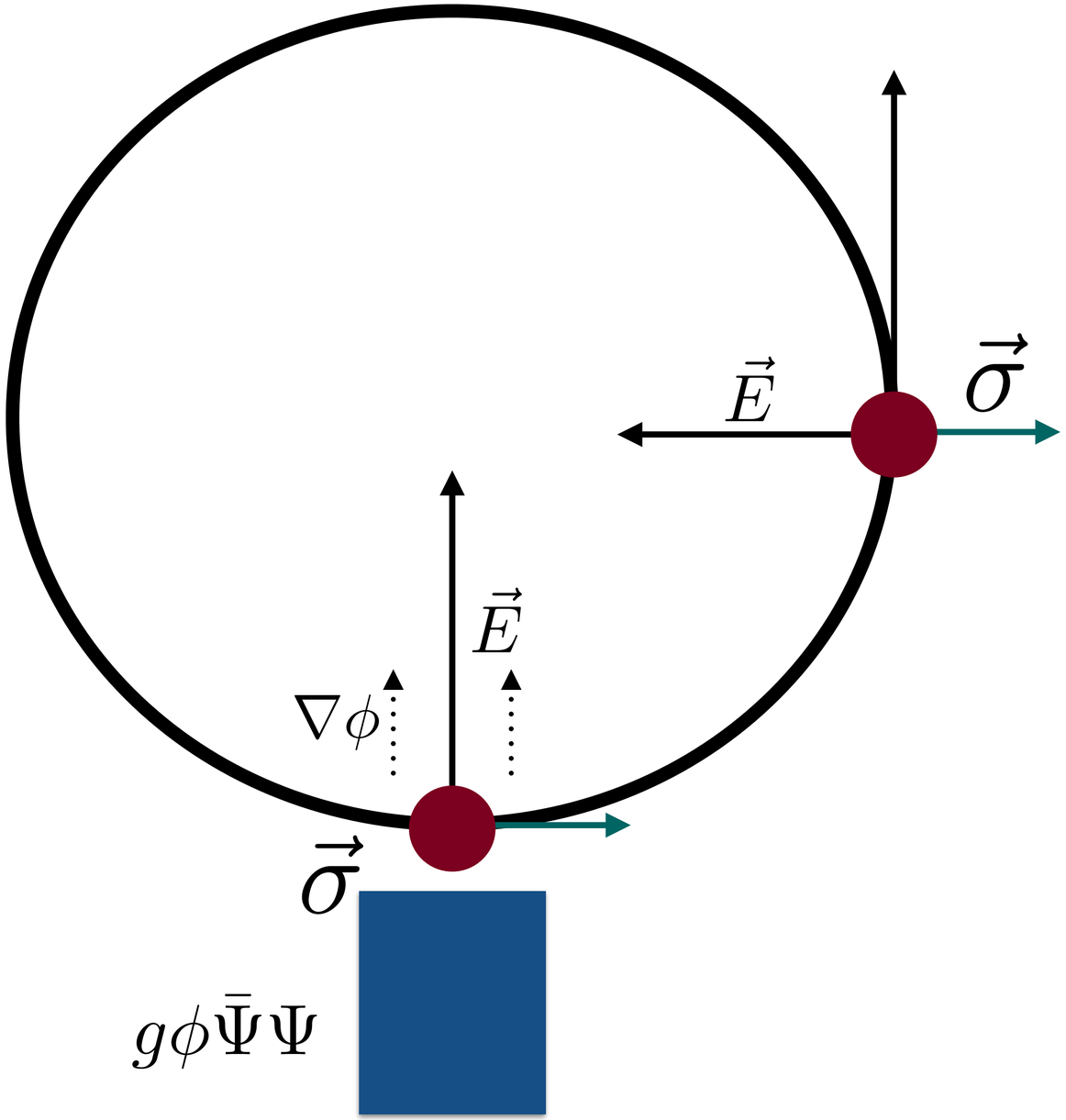



Precession Occurs near local test mass

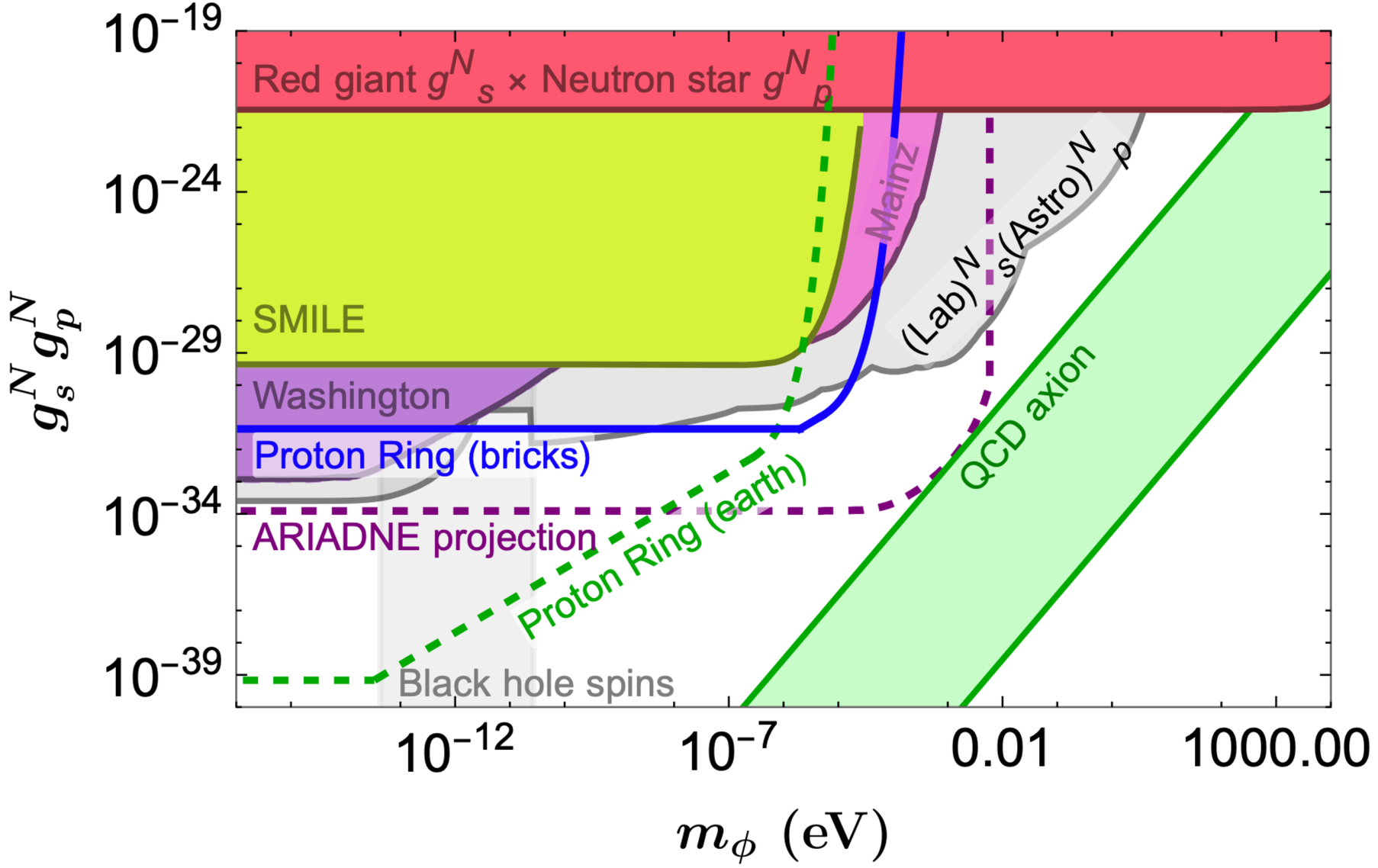
Choice of gradient direction

Spin precess out of plane, in vertical direction

Interesting Handle: Fixed axion gradient, particle and anti-particle precess in same direction, unlike electromagnetic background

Could also look for vertical gradient from Earth

# Sensitivity




Assuming ~ 10 tons of lead bricks spread over ~ 10% of ring

# Conclusions

# Conclusions

1. Storage Rings can be precision spin sensors

2. Technology well developed for electric dipole moment searches

3. Synergistic searches possible for dark matter, dark energy and monopole-dipole forces

# Axion Dark Matter

Photons

$$\vec{E} = E_0 \cos(\omega t - \omega x)$$

Detect Photon by measuring time varying field

# Axion Dark Matter

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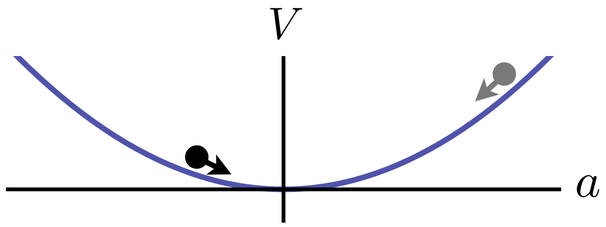
Detect Photon by measuring time varying field

## Dark Bosons

Early Universe:
Misalignment Mechanism




$$a(t) \sim a_0 \cos(m_a t)$$

Spatially uniform, oscillating field

$$m_a^2 a_0^2 \sim \rho_{DM}$$

# Axion Dark Matter

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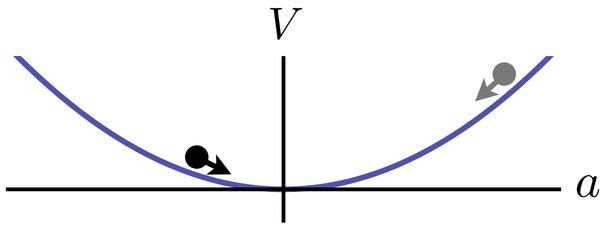
## Dark Bosons

### Early Universe: Misalignment Mechanism

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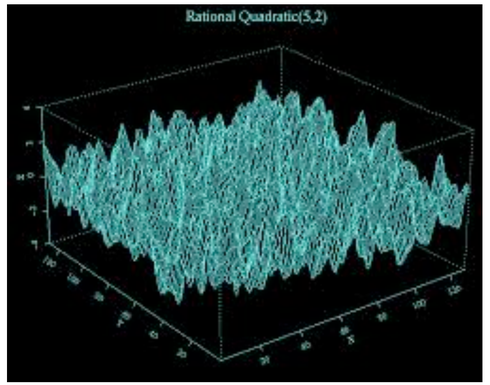


Correlation length
~ $1/(m_a\ v)$

Coherence Time
~ $1/(m_a\ v^2)$
~ 1 s $(\mathrm{MHz}/m_a)$

# Axion Dark Matter

## Photons

$$\vec{E} = E_0 \cos(\omega t - \omega x)$$

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## Dark Bosons

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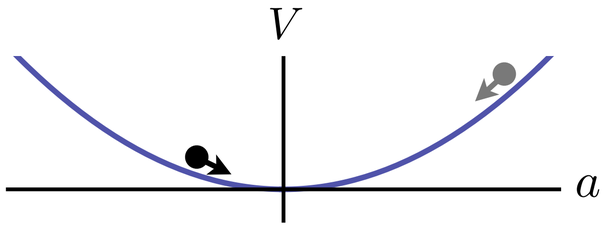


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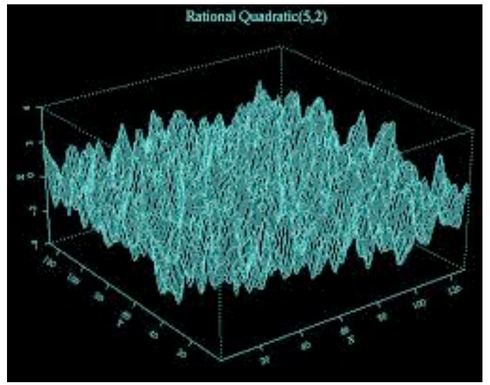



Correlation length
~ $1/(m_a v)$

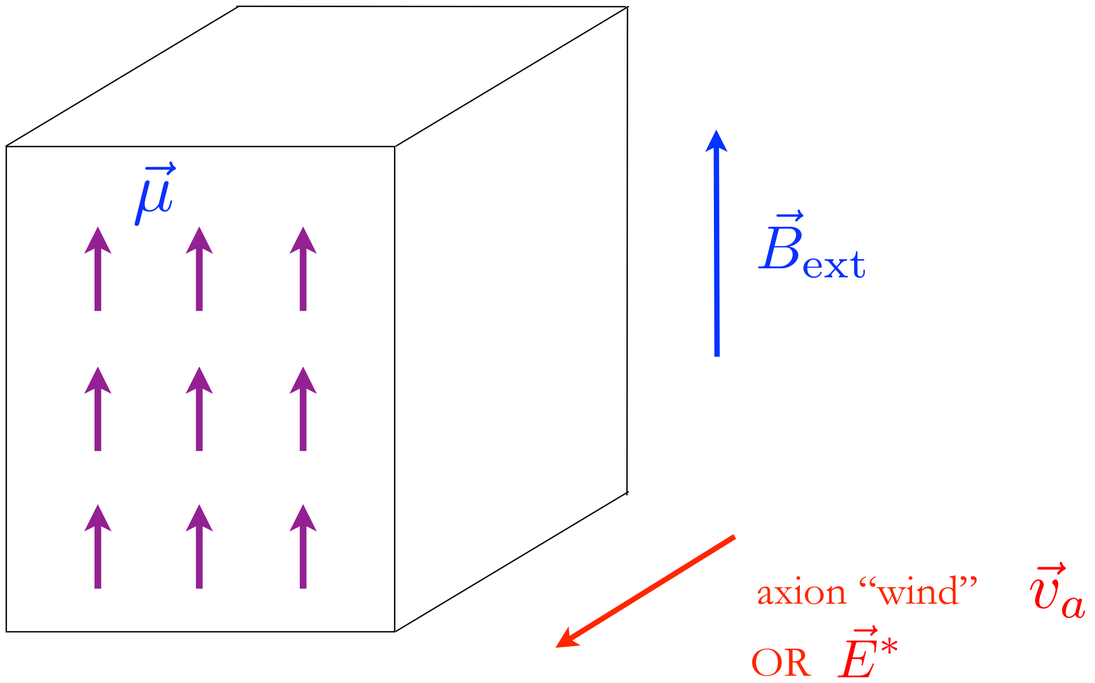
Coherence Time
~ $1/(m_a v^2)$
~ 1 s $(MHz/m_a)$

Detect effects of oscillating dark matter field

Resonance possible. Q ~ $10^6$ (set by v ~ $10^{-3}$)

# CASPEr

Axion affects physics of nucleus, NMR is sensitive probe




Larmor frequency = axion mass ➔ resonant enhancement

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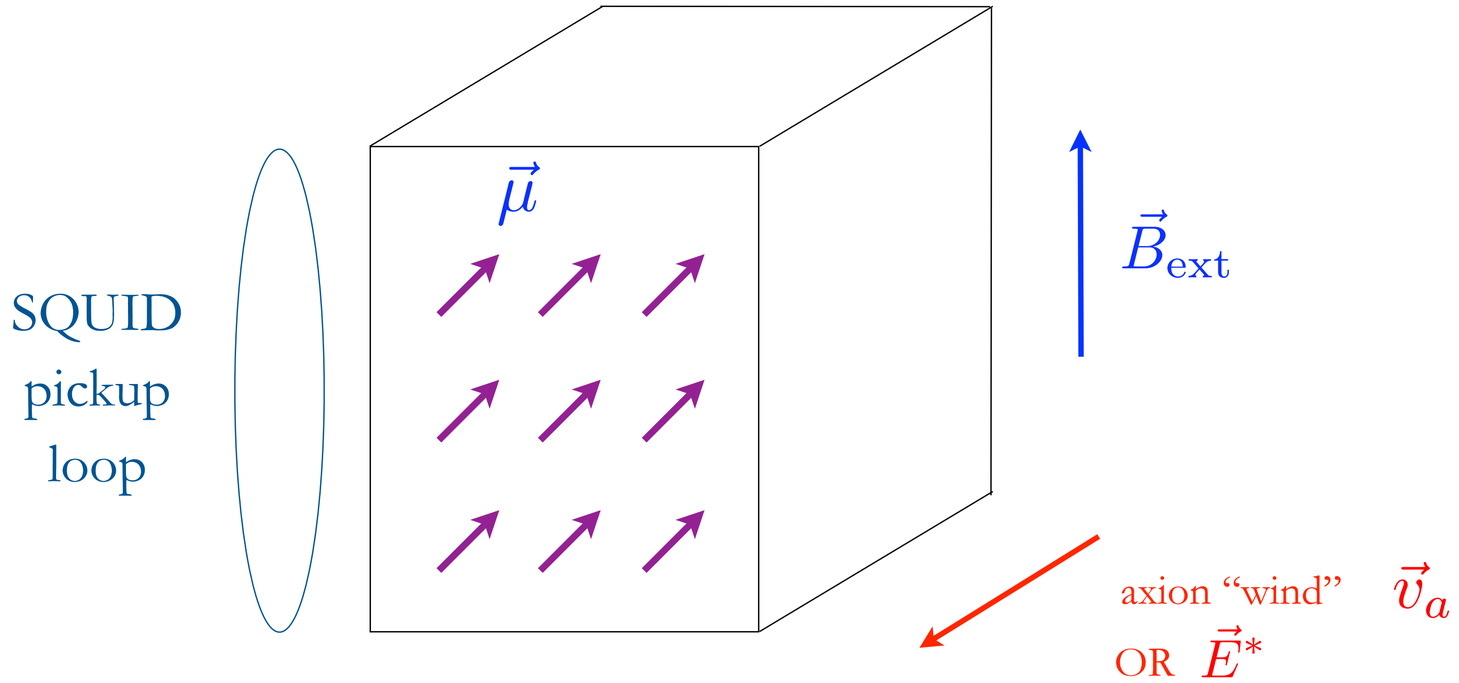


Larmor frequency = axion mass ➔ resonant enhancement

SQUID measures resulting transverse magnetization

NMR well established technology, noise understood, similar setup to previous experiments

Example materials: LXe, ferroelectric $PbTiO_3$, many others