Polarimetry for Deuteron EDM Search

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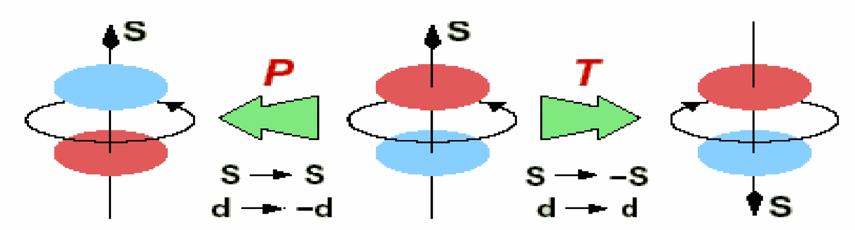
Trapped Radioactive Isotopes: μicro-Laboratories for Fundamental Physics

T/CP VIOLATION AND EDMs

Symmetry Breaking

Electric dipole moments (*EDMs*) *break* both *Parity* and *Time reversal* symmetries



$$H = -2\left(\vec{\mu}\cdot\vec{B} + \vec{d}\cdot\vec{E}\right) = -2\left(\mu\vec{B} + d\vec{E}\right)\cdot\vec{S}$$

Standard Model prediction : EDM ~ 0

PERMANENT EDM ≠ 0 → NEW PHYSICS

Few-body EDMs

- Contributions

$$d_{nuclear} = d_n \oplus d_p \oplus d_{interaction}$$

Measurements of n, p, ^{2}H, ^{3}He,… necessary

- Sensitivities

Standard Model: strong CP violation

$$d_p(\bar{\theta}) : d_{^2H}(\bar{\theta}) : d_{^3He}(\bar{\theta}) \approx (3:1:-3)\times 10^{-16}\,\bar{\theta}\,[e\cdot cm]$$

New Physics: Chromo EDMs (e.g.)

$$d_n = -0.01\tilde{d}_d + 0.49\tilde{d}_u \qquad d_{^2H} = -4.67\tilde{d}_d + 5.22\tilde{d}_u$$

DEUTERON → AN EXCELLENT CANDIDATE

Generic EDM experiment

- Beam and Spin preparation

Polarize : state selection using known technology

Accelerate : LINAC or cyclotron

- Interaction with E-field

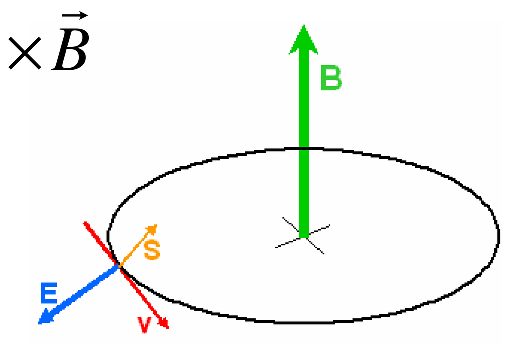
EDM interacting with E-field → spin precession

Large motional E-field → $\vec{v}\times\vec{B}$

- Polarimetry

Monitor spin continuously

Possible via scattering



INTERACTION WITH E-FIELD

Spin precession for a relativistic particle

$$\vec{\Omega} = \frac{e}{m}\left[a\vec{B} + \left(a - \frac{1}{\gamma^2 - 1}\right)\vec{v}\times\vec{E} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \vec{E}\right)\right]$$

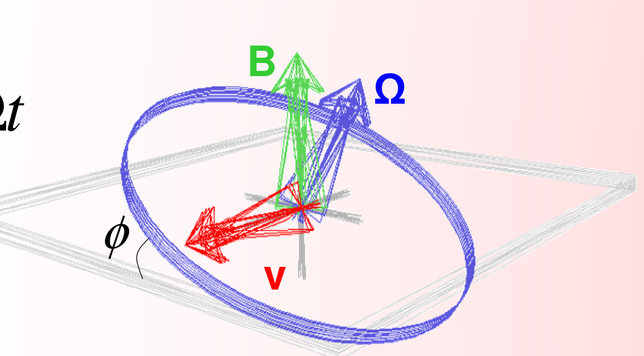
η: electric dipole moment
a : *anomalous* magnetic moment

The parasitic method

EDM causes a tilt ϕ in the spin precession plane and a change in frequency Ω

The only completed EDM experiment using the g-2 muon storage ring

$$P_{\parallel} \approx P_0 \frac{\eta\beta}{2a}\sin\Omega t$$

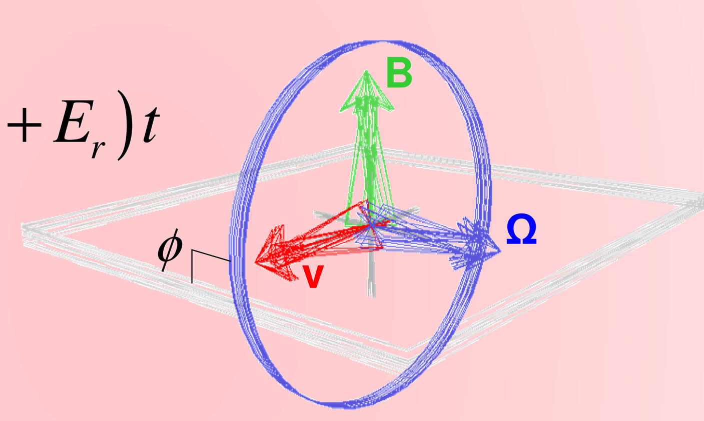


The frozen spin method

Spin precession *not* depending on EDM is removed using a radial E-field $\approx aBc\beta\gamma^2$

Cyclotron and spin frequencies match

$$P_{\parallel} \approx P_0 \frac{\eta e}{4mc}(\beta B + E_r)t$$



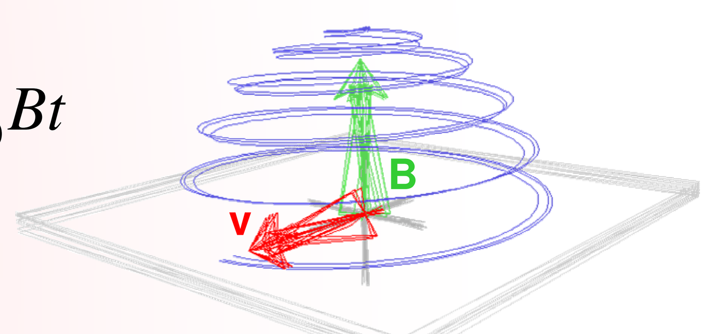
The resonance method

Modulate $E(t) = v(t)\times B$ at spin frequency

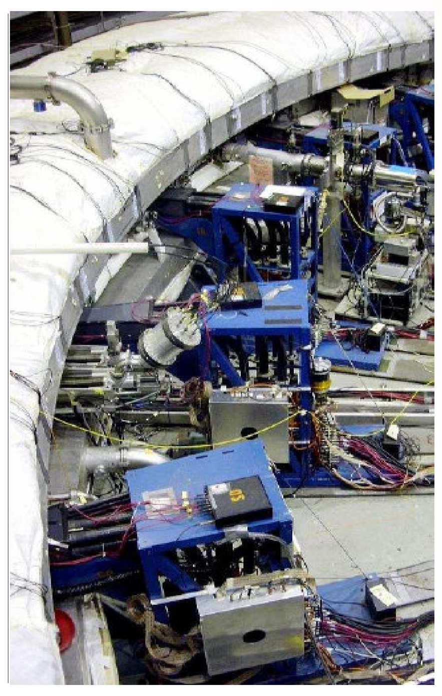
Synchrotron and spin frequencies match

Similar to *Rabi's Oscillatory Fields Method*

$$\hat{P}_{\parallel} \approx \frac{e}{8mc}\eta\Delta\beta P_0 Bt$$



THE EDM SIGNAL IS IN THE VERTICAL POLARIZATION COMPONENT



$$d_\mu < 2.8\times 10^{-19}\ [e.cm]$$

Systematics limited method
Use β dependence to improve

J. Bailey et al., J. Phys. G : Nucl. Phys. **4**, 345,1978
R. McNabb, http://www.arxiv.org/abs/hep-ex/0407008.

$$d_\mu^* < 10^{-24}[e.cm] \quad d_D^* < 10^{-27}\ [e.cm]$$

Suitable for particles with a small *anomalous* magnetic moment, such as the muon or ^{2}H

F.J.M. Farley *et al.*, *A new method of measuring electric dipole moments in storage rings*, Phys.Rev.Lett. **93** (2004) 052001
Y.K. Semertzidis *et al.*, *A New Method For A Sensitive Deuteron EDM Experiment*, http://www.arxiv.org/abs/hep-ex/0308063

$$d_D^* < 10^{-29}\ [e.cm]$$

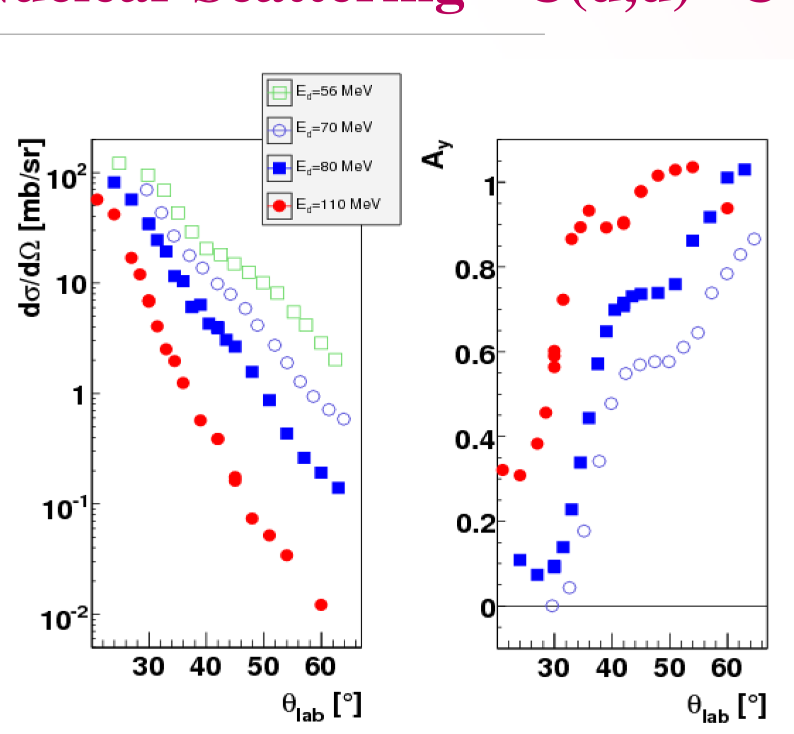
*projected

Suitable for particles whose synchrotron and spin tunes can be brought to resonance (aγ ~ 0,1,2,…) such as ^{1}H,^{2}H,^{3}H,^{3}He,…

Yu.F. Orlov, W.M. Morse and Y.K. Semertzidis, *Resonance Method of EDM Measurements in Storage Rings*, Phys.Rev.Lett **96** (2006) 214802

POLARIMETRY

Nuclear Scattering ^{12}C(d,d)^{12}C



$$N(\theta,\varphi) = N(\theta)\left(1 + \frac{3}{2}P_z A(\theta)\cos\varphi + \ldots\right)$$

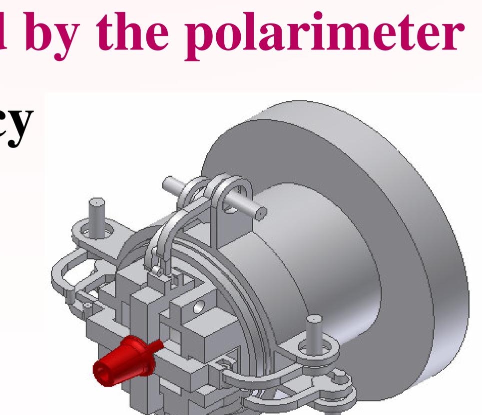
Statistical precision

$$\sigma_d \approx \frac{4\hbar}{\sqrt{\tau\tau_p}E^* P_0 A\sqrt{\varepsilon N}}$$

τ_p: spin coherence time
E*: effective electric field
P_0: initial polarization
N: number of particles

- Parameters affected by the polarimeter

ε : detector efficiency
A: analyzing power
τ: beam lifetime



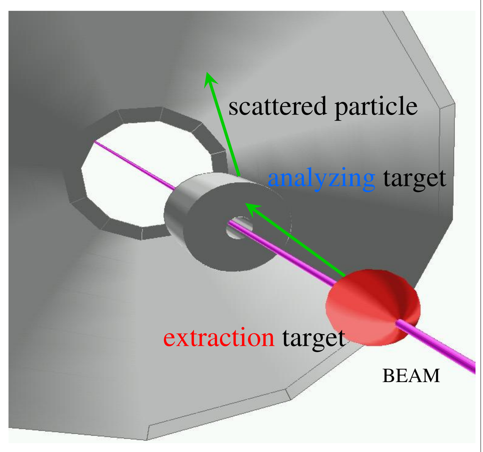
G. Mul
Graduation thesis
Hogeschool van Amsterdam
June 21, 2005

Maximize in design

Concept

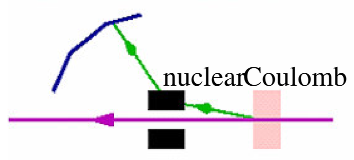
Slow extraction through Coulomb scattering in thin extraction target

High efficiency nuclear scattering in thick analyzing target with high sensitivity



- Work in preparation

Detailed analytic and tracking simulations



Ed Stephenson (IUCF)

Component Analysis
Design Report

October 2006