Introduction, Deuteron EDM issues

YKS
11/12/03

Size of Ring is Determined by

a) Spin Coherence Time Y. Orlov

b) Polarimeter Statistical Sensitivity E. Stephenson
Beam Intensity

c) Background effects Y.O., B.M., S.R., J.M., YKS,
A.S., E.S., ...

d) Cost A. Pendzick

Alexander Silenko's
Twist effect:
Due to Longitudinal B-fields

$$\eta_{\text{-twist}} = \frac{2\, \omega_{\text{"g-2"}}\, \vartheta\, \sin\phi}{\beta\, \gamma\, \omega_c}$$

$$d_{\text{-twist}} = 1 \times 10^{-14}\, e \cdot cm\, \frac{\omega_{\text{"g-2"}}\, \vartheta\, \sin\phi}{\omega_c}$$

We would need $\vartheta \simeq 10^{-6}$ rad

$$\frac{\omega_{g-2}}{\omega_c} \simeq 10^{-7}$$

$\rightarrow 10^{-27}\, e \cdot cm$

NP & HE Initiatives

Timescale / Probability	**Near term** Next 3 years	**Mid term** 2007 to 2012	**Long term** After 2012
Likely	**ATLAS Analysis Ctr.** Lattice Gauge Effort **LSST** QCDOC (20Tflop) **RSVP** **RHIC Enhancements** incl. EBIS **VLB Neutrino R&D**	**eRHIC R&D** **incl. 10 GeV ERL** LHC Upgrade R&D μEDM at J-PARC **RHIC II**	LHC Upgrade
Possible	**ATLAS Upgrade R&D** Medical synchrotron	LHC Theory Center Linear Collider R&D μ cooling R&D RHIC Fwd. Phys. Facility	**eRHIC** Linear Collider **VLB Neutrino**
Dream			Next Astro. project FFAG eRHIC light source 0.6TeV pol. p-p coll.

Red = Major Initiatives

Deuteron EDM Studies, 9/2003

1. Theoretical motivation:

- a) Current picture of EDM and physics beyond the SM
- b) Why is the deuteron EDM interesting?
- c) Under what assumptions is the deuteron EDM the best EDM experiment?

I. Khriplovich

2. Effect of fringe fields to spin dynamics:

- a) Design and shape the electric fringe field. What is the limit on E_v of the fringe field so that there is no appreciable vertical focusing due to E-field? N/A
- b) The magnetic fringe field produces vertical focusing (ala ZGS); any effect due to this? Spin tracking.
- c) Level of "Berry's" phase effects. Spin tracking.
- d) Longtudinal B-field effects: Can we use radially polarized beams or is their effect too large? Spin tracking.

Y.O., A.S., S.R., J.M.

3. Polarimeter design: E.S., G.O.

- a) Solid target as a colimator.
- b) Polarimeter rates. "Symmetric" rates CW and CCW.
- c) Gas or thin solid target as Coulomb Multiple Scattering Medium (CMSM).
- d) Effect of fields on polarizing the CMSM.
- e) Spin flip interactions influencing the polarization state early to late.
- f) How well do we fill up the phase space with the gas or thin solid target due to Coulomb Multiple Scattering?
- g) Particles with large betatron oscillations make it out to the solid target first. What is the early to late effect on the EDM signal due to this effect?

4. Deuteron source:

- a) RF or optical.
- b) Limit on tensor component. Measure it. For OPIS we need an RFQ (~$250K).
- c) Intensity; polarization; +, - polarization equality.

5. Spin tracking studies: J.M., S.R.

- a) Horizontal/vertical spin coupling.
- b) Effect of focusing
- c) Effect of RF field
- d) Effect of transient B and E-fields.
- e) Effect of corrugated B-field level.
- f) Effect of B and E-field multipoles.
- g) Effect of different injection angles and positions.
- h) CBO effect

6. Floating Charges: YKS

- a) Charges on the surface of metals due to oils, etc.
- b) Delta rays
- c) Currents and charges produced by ionizing the residual gas with the beam.

- 7. Inclinometer sensitivity:

- a) Estimate the motion of the front surface of the plates by measuring the inclination on the back of them.
- b) Systematic errors with B-field Up/Down
- c) Systematic errors with E-field in/out
- d) 1 nrad is currently possible, what's the limit? Is 1 prad possible with averaging?

8. Lattice of deuteron EDM ring for an:

- a) AGS size EDM ring (R~127m)
- b) Booster size EDM ring (R~32m)
- c) J-PARC muon EDM LOI size EDM ring (R~10m)

Y. Orlov, S. R.

9. Cost of deuteron EDM ring at BNL, IUCF, KVI, GSI for an:

- a) AGS size EDM ring (R~127m)
- b) Booster size EDM ring (R~32m)
- c) J-PARC muon EDM LOI size EDM ring (R~10m)

A. Pendzick

10. Beam polarization lifetime for:

- a) AGS size EDM ring (R~127m)
- b) Booster size EDM ring (R~32m)
- c) J-PARC muon EDM LOI size EDM ring (R~10m)

Y. Orlov, ~~B. Morse~~

11. Statistical Sensitivity with an:

- a) AGS size EDM ring (R~127m)
- b) Booster size EDM ring (R~32m)
- c) J-PARC muon EDM LOI size EDM ring (R~10m)
- d) Possible improvements for an even better sensitivity EDM experiment

E.S., YKS, Y.O., B.M.

12. Effects of Kicker Eddy current:

- a) Time dependent radial B-field
- b) Time dependent E-field
- c) EM pickup to magnet and electrostatic plates power supplies.

YKS

13. Proton runs:

- a) Proton run sensitivity to "vertical" E-field and its own EDM YKS
- b) Consequences of the fact that the radial E-field sign that cancels the g-2 precession is opposite going from protons to deuterons.
- c) The B-field required is lower for the protons. What are the conclusions one can have from protons run related to "vertical" E-field?
- d) RF compatibility between running protons and deuterons? Polarimeter compatibility. Y. O.

14. Effects of RF field to:

- a) Deuteron/protn spin S. R.
- b) Second order effects on g-2 cancellation
- c) EM pickup to magnet, electrostatic plates power supplies and polarimeters.

15. Effects of B-field reversal on: YKS

- a) Motion of structures (magnet, E-field plates, ...) yes
- b) Effects due to eddy currents in magnet, vacuume chamber, electro-static plates (ESP).
- c) Effect of magnetic force on the ESP due to possible leakage currents from them. This force changes with B-field reversal.

16. Spin gymnastics: E. S.

- a) The source: how well are the different polarization components controllable? They can be made opposite to what degree?
- b) Spin rotators: Spin rotations from vertical to horizontal. How well of a symmetry can we preserve rotating the spin left/right?

17. Magnetic field design: Y. O., S. R., J. M.

- a) Design of dipole magnetic field. Dipole B-field uniformity, strength of mulipoles allowed.
- b) Quadrupole B-field uniformity, strength of multipoles allowed.
- c) Magnet power supplies. Stability.
- e) Special magnets to cancel the high order multipoles of the B-field.

18. Magnetic Field Measurement: E. S. F. F. } Y.O.

- a) Precision needed.
- b) NMR, Hall probes.

19. Electric field design: T. Russo

- a) Design of radial electric field. Uniformity, strength of muliples allowed.
- b) Size and shape of plates, vacuum chambers, high voltage insulators.
- c) Power supplies. Stability. Feedback.

20. Electric field measurement by:

- a) Spectroscopic techniques.
- b) Measuring beam position.

21. Cancelling g-2 precession: B. M., G. O.

- a) Measurement of g-2 precession rate with polarimeter.
- b) Measurement of g-2 precession rate by combining NMR, and beam position information.
- c) Special E-field plates for feedback.

22. Beam Position Monitors: P. DeB.

- a) Beam position resolution needed.
- b) Pickup electrodes: resolution, signal/noise ratio.
- c) Beam position monitors for injenction tunig purposes.

23. List of potential systematic errors and resolution: J. M.

- a) Out of plane ("vertical") electric field. Floating charges. Delta-rays.
- b) Polarimeter rate effects.
- c) Horizontal to vertical spin coupling: Berry's phase due to local non-cancellation, etc.
- d) Deuteron quadrupole moment. (EDM note 48).

- e) Transient E and B-fields.
- f) Tensor effects.

24. Vacuum system:

- a) Requirements
- b) Interference/interaction with other systems (e.g. polarimeter).

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The Electric Plate Alignment as a Function of the E, B Field Values and Directions and the Fabry-Perot Sensitivity

Yannis Semertzidis - BNL

November, 2003

1. Introduction

The main systematic error, the out of plane electric field (Ev) problem in an EDM ring of R=30m is discussed in reference [1]. Typical parameters to cancel g-2 for a ring with radius ≈30m are shown in Table 1, reproduced from reference [1].

Table 1. Parameters for deuteron and proton storage.

	D	p
E (MV/m)	2.4	2.4
B (T)	0.1	0.01
p (GeV/c)	0.9	0.3
β	0.4	0.3

We are planning to use a polarized proton beam to probe the Ev field. However, since the magnetic field value while storing protons is very different, the E-field direction is opposite, etc. In this note we are addressing the concerns that arise due to the differences between the proton and deuteron runs as well as systematic influences of the B-field reversal on the electrostatic plates.

2. Effects of Magnetic Field Change in Value and/or Direction

The magnetic field reversal can in principle influence the electrostatic plates (ESP) alignment by

1. Inducing eddy currents in the ESP.
2. Magnet motion.
3. Magnetic forces on the ESP due to possible leakage currents that flow through them.

Some of the disturbances depend on the B-field direction, some on the field value and some depend on both of them.

1. The best way to avoid eddy currents on the ESP is to make them out of glass or ceramic material and just electro-plate the appropriate surface with a thin layer of metallic material [2]. This all but will kill the eddy currents due to the changing magnetic field. The vacuum chamber also needs to be made of a ceramic material or a metal with a very

high resistivity. Ceramic vacuum chambers have been used before and we are looking into costing them.

2. The magnetic forces act on the magnet poles try to bring the magnet poles together, they are trying to close the gap. This force will depend on the magnetic field value and not on its direction. We are planning to mechanically isolate the vacuum chamber from the magnet. The vacuum chamber will be supported on separate stands outside the magnet.
3. If there are leakage currents on the plates then there is going to be a force acting on each of them:

$$\vec{F} = I\left(\vec{L} \times \vec{B}\right) \quad 1)$$

where L is the length of the plates along which the current I flows and B is the magnetic field. Even if we assume 1μA leakage current (instruments can measure down to 0.1pA of leakage current) over 1m then for 0.15T the force equals to 1.5×10^{-7}N. Taking into account that 500gr weight caused a maximum tilt of 5μrad on a glass beam of 0.5m long by 10cm wide and 1" thick [3], then the above force will cause a deflection which is at least one order of magnitude below 1prad. The 500gr weight was located at the center of the beam while the beam itself was only supported at the ends (the long dimension). In our case the force is distributed along the whole length and therefore the deflection is going to be less even if we assume a similar ESP support.

3. Fabry-Perot Sensitivity

Even though the estimated effect from the magnetic field on the ESP orientation is expected to be below the sensitivity of the deuteron experimental goal it is non-the-less important to have a measurement of it. A group at Legnaro/Italy has developed a very sensitive, high finesse, Fabry-Perot resonator [4] for the needs of the PVLAS experiment. Their Fabry-Perot cavity is 1.7m long, "free running", and the laser wavelength they use is 1064nm (f=2.8×10^{14}Hz). The finesse of the cavity they achieved was 100,000 using high reflectivity mirrors. To lock the laser wavelength to the cavity they used feedback on the laser itself changing its wavelength to match the cavity frequency. The difference between the laser and cavity frequencies was kept at about 1mHz/√Hz at about 2Hz.

The correction signal has information on the mirror motion with a sensitivity of 1.8×10^{-12}m/√Hz at 1 Hz [5] and 1.8×10^{-11}m/√Hz at 0.1 Hz. As a reminder in case we use 5cm plate separation, 1prad corresponds to 5×10^{-14}m, i.e. we would need to average some 130,000 measurements to achieve the required sensitivity at 0.1 Hz and 1000 measurements at 1 Hz. However, if a reference cavity is used to lock the frequency to, the sensitivity is expected to improve by several orders of magnitude [5]. We therefore need to develop such a system with the help of the PVLAS group. This group has indicated that they are willing to help either as collaborators or indirectly, depending on their funding agency (INFN).

The idea is to install one mirror of the Fabry-Perot resonator on each plate of the ESP and test whether the plates move when the magnetic field value and/or its direction changes. One can even think of using the same laser light in two Fabry-Perot resonators, one on the top of the ESP and one on the bottom. This way the system can differentiate between real

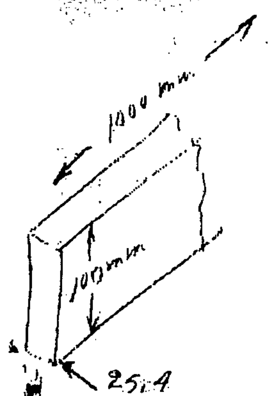
$$\delta = \frac{5 W L^3}{384 E I}$$

$W = wL$

$w = 100\ N/m$

$L = 1\ m$

$W = 100\ N$



$E = 9 \times 10^4\ N/mm^2$

$I = \frac{1}{12} b h^3$

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easy way

$I = \frac{1}{12}(100)(25.4)^3$

$= 1.3656\,e5$

hard way

$= \frac{1}{12}(1000)(25.4)^3$

$= 1.3656\,e6$

Easy Way

$$\delta = \frac{5\,(100\,N)\,(1000)^3\,mm^3}{384\,(9\,e\,4\,N/mm^2)\,(1.3656\,e5\ mm^4)}$$

$$= \frac{5 \times 10^{11}}{3.84\,(9)\,(1.3656) \times 10^{11}}$$

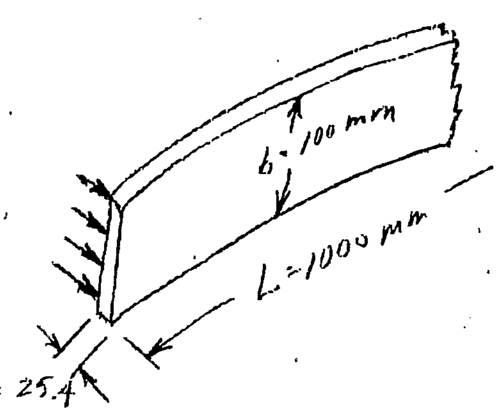
$$= 1.059 \times 10^{-1}\ mm$$

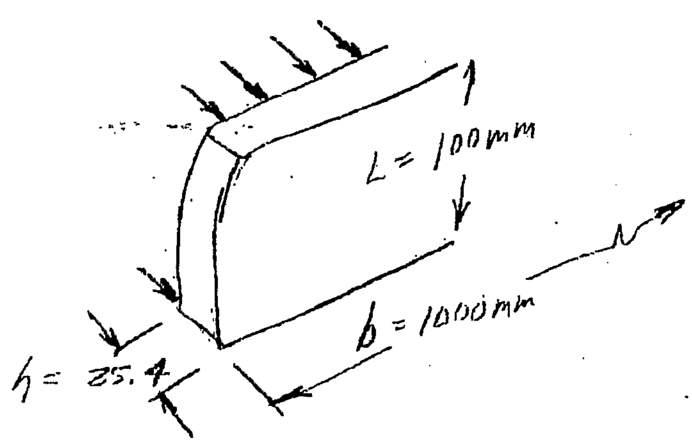
Hard Way

$$\delta = \frac{5\,(100)\,(100)^3}{384\,(9\,e\,4)\,(1.3656\,e6)}$$

$$= \frac{5 \times 10^8}{(3.84)(9)(1.3656) \times 10^{12}}$$

$$= 1.059 \times 10^{-5}\ mm$$





orientation changes and parallel displacement of the ESP or laser wavelength drifts due to temperature changes, etc.

4. Effects of Electric Field Change in Value and/or Direction

The ESP when energized will bend under the influence of the attractive electric field force between the two parallel plates. Assuming a geometry of two parallel plates, made out of zerodur glass, 5 cm apart with dimensions: length l=4m, height h=10 cm, and width d=2.5cm. The capacitance is about C=300pF, and assuming an E-field of 2.5MV/m then the total force on each of the plate is ~100N. The maximum bend, assuming that the plates are supported only at the ends of the long dimension while the top/bottom sides are free, at the center of the plates is 6.8mm [6]. That means a maximum inclination of the plates of up to 3.5mrad in the horizontal plane. For the case where the top/bottom sides are fastened by two horizontal plates, the vertical plates don't move horizontally but only bend vertically by 2.5μm or 50μrad maximum inclination in the vertical plane. The maximum inclination occurs at the top/bottom of the cross section of the plates and it is symmetric along the mid-plane. The average Ev is zero to first order but effects like vertical beam offsets will probably be there at the 10^{-2} level resulting to a net Ev of order 0.5μrad.

This attractive force between the plates will be the same clockwise and counter-clockwise as well as running with deuterons and protons. If the electric field is stable to 10^{-6} then the net effect will be less than 0.5prad better than the 1prad needed for 10^{-27}e·cm level for the deuteron EDM. The Fabry-Perot resonator will have the sensitivity to tell whether the plates return to the same place when running with deuterons and protons. As a matter of fact the Fabry-Perot resonator will have a very good measurement of the plate bend at the center and this information can be used to stabilize the electric field strength between the plates. The sensitivity is 1.8×10^{-12}m/√Hz or 1.8×10^{-12}m with 1s integration meaning that the electric field can, in principle, be stabilized to 1 part in 10^6 using this method with a free running cavity and many orders of magnitude better with a reference cavity.

4. Conclusion

A Fabry-Perot resonator with a reference cavity has the potential to have the sensitivity required to validate the proton run as a probe of the vertical component of the E-field. Its sensitivity will be such that it will tell whether the electric field plates move when going from clockwise to counter-clockwise and from the deuteron run to the proton run. Finally it could also, in principle, be used to stabilize the electric field strength between the plates to a very high degree.

References

1. Out of Plane Electric Field Systematic Error, Bill Morse and Yannis Semertzidis, edm note 46, October, 2003

2. At very high electric field values the electro-plating may be a problem since the field forces cause protrusions on the surface of the plate. At the E-field values we are considering here this is not a serious problem.

3. Precision Tiltmeter for the EDM Experiment, Sergio Rescia, Presentation at the EDM collaboration meeting, September, 2003; Estimation of tilt of Zerodur beam supported at ends, centrally loaded, from the tiltmeter home page.

4... A.M. De Riva, *et al.*, Rev Sci. Instrum. **67**, 2680 (1996) "Very high Q frequency-locked Fabry-Perot cavity"; G. Cantatore, *et al.*, "PVLAS developments on Fabry-Perot resonators locked to CW lasers suitable for laser assisted Lorentz stripping of H^- beams" Proceedings of a talk presented at Fermilab May 2003.

5. G. Cantatore, private communication.
6. L. Snydstrup, private communication; the estimation to be published as an EDM note.