Site Info for a Possible Deuteron EDM Experiment

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May, 2003

The muon edm collaboration has submitted an LOI [1] to JPARC to measure the edm of the muon to 10^{-24} *e-cm*. Recently, it occurred to us that it might be fun and interesting to try to measure the edm of the deuteron. Presently, there is no limit on the edm of the deuteron. The deuteron is a proton and neutron bound state with spin one. The latest PDG value for the proton and neutron edms are $d_p = (4 \pm 6)\times 10^{-23}$ *e-cm* and $d_n < 0.63\times 10^{-25}$ *e-cm.* An experiment with a level of sensitivity for the deuteron of 10^{-25} *e-cm* would be quite interesting [2]. This note is the beginning of a dialogue with the machine physicists on the technical aspects of the beam issues of such an experiment.

In this experiment, a radial electric field is applied to stop the g-2 precession. The value needed is:

$$E \approx aBc\beta\gamma^2$$

where $a = (g\text{-}2)/2 = -0.14$ for the deuteron. The precession of the spin due to the electric dipole moment d is:

$$\frac{dS}{dt} \approx d \times (E + c\beta \times B) \approx \frac{dE}{a}$$

Thus for $\gamma \approx 1$, the edm effect is directly proportional to the electric field value. We show in Table 1 electrode information from three experiments which required high electric field strength in vacuum. The smaller the distance between the electrodes, D, the higher the maximum electric field strength $E=V/D$.

Table 1. KEK beam separator[3], ILL neutron beam edm experiment[4], and Berkeley atomic thallium experiment[5] electrode parameters.

Exp.	V	D	E = V/D	W	L
KEK	250KV	10cm	25KV/cm	40cm	9m
n beam	100KV	1cm	100KV/cm	9cm	1.8m
Thallium	24.6KV	2mm	123KV/cm	5cm	1m

We need to know the normalized emittance of your beam: smaller is better, as the smaller the beam the higher the electric field that we can apply and the more sensitive the experiment.

The nominal momentum is $0.4 GeV/c$ (total deuteron momentum, not per nucleon). Yuri Orlov's edm ring lattice[1] parameters are given in Table 2.

Table 2. Ring parameters for 0.5 *GeV/c* muons (0.4 *GeV/c* deuterons).

E	B	R	<R>	ν_x	ν_y	Periods
20KV/cm	0.24T	6.5m	≈11m	4.42	4.2	16

JPARC LOI

R is the bending radius given by:

$$p = 0.3\left[B - \frac{E}{\beta c}\right]R$$

$$p(GeV/c) \approx 0.26BR(Tm)$$

$\langle R \rangle$ is the edm ring circumference divided by 2π. The low value of *E* was chosen because the electrode aperture was $D \approx 10cm$ for the muon beam, which has a very large emittance. We decided[6] to optimize the deuteron experiment for the deuteron beam emittance, not the muon beam emittance. I give in Table 3 an example of possible ring parameters for $E = 60KV/cm$.

Table 3. EDM ring parameters for $E = 60KV/cm$.

E	*B*	*p*	*R*	<*R*>
60*KV/cm*	≈0.4*T*	≈0.7*GeV/c*	≈6.5*m*	≈11*m*

β ≈ .35
γ ≈ 1.07

The emittance is $\varepsilon = \varepsilon_N/\beta\gamma$. The background from a non-planar electric field goes as $1/\beta\gamma^2$, so higher deuteron momentum would be somewhat beneficial, but would require a larger radius EDM ring:

$$R \approx \frac{ac}{0.26EM}p^2$$

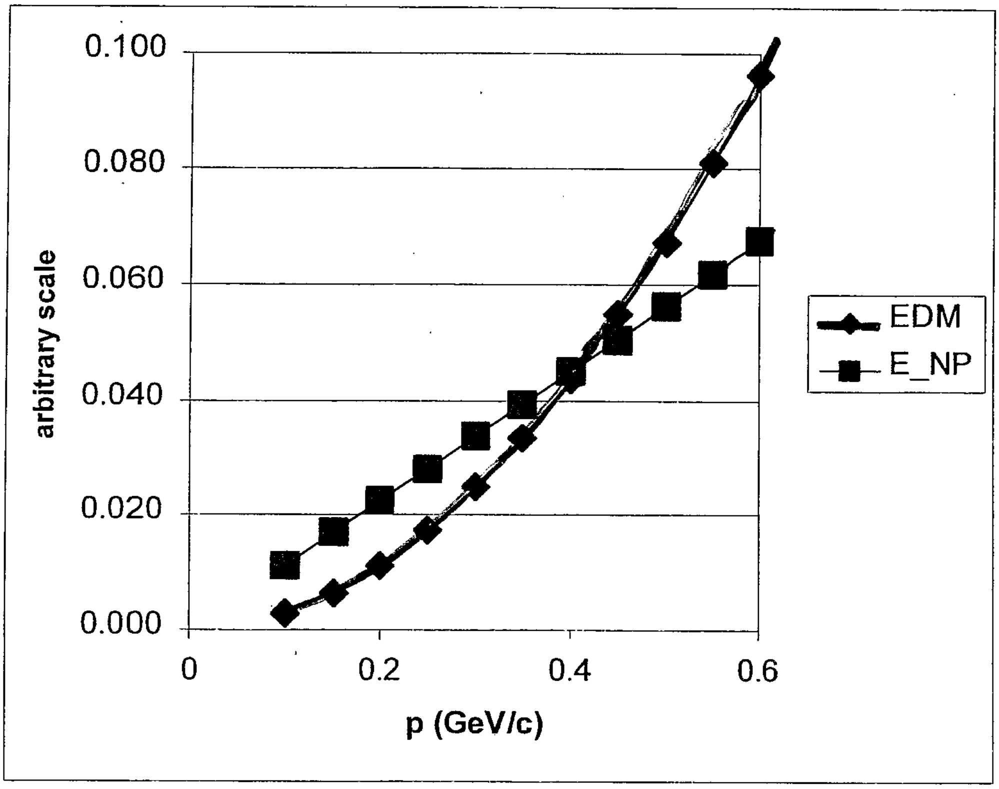
where *E* is the electric field and *M* is the deuteron mass. Thus it depends on what size edm ring you could accommodate at your site.

The average *dp/p* over the measurement time of $\approx 1s$ should be $<10^{-6}$. This can be achieved with a modest amount of RF. A complication is that energy is also gained and lost in the betatron oscillations in the radial electric field. A simplified simulation showed that initial $dp/p = \pm 10^{-3}$ and beam width $\pm 20ns$ was acceptable. What is your *dp/p* and beam width?

Finally, we need to know the deuteron intensity (higher is better), vector polarization (higher is better), and tensor polarization (lower is better), as well as the momentum and polarization stability.

Also, we need to run at lower deuteron momentum. For any given ring design, this is done by lowering E and B. The EDM effect is approximately quadratic in momentum under these conditions, while the non-planar electric field effect is approximately linear, as shown schematically in Fig. 1. If we claim an EDM effect, we must verify that it follows this momentum dependence.

Fig. 1. The effect of varying the momentum for any given ring design, ie. radius. We must conform that the edm effect is quadratic in momentum.



$\frac{ds}{dt} \cdot \frac{dE}{a}$

$\frac{ds}{dt} = \frac{\mu E \theta}{\beta \gamma^2}$

References

1. http://www.bnl.gov/edm/

2. I.B. Khripolovich and R. Korkin, Nucl. Phys. A665 (2000) 365.

3. A. Yamamoto et al., Nucl. Inst. and Methods 148 (1978) 203.

4. W. Dress et al., Phys. Rev. D15 (1977) 9.

5. B. Regan et al., Phys. Rev. Lett. 88 (2002) 071805; E. Commins et al., Phys. Rev. A50 (1994) 2960.

6. EDM Collaboration Meeting, February, 2003.

What E field can we achieve?

Condition for canceling g-2:

$$aB + (1/(\gamma^2 - 1) - a)\beta\times E/c = 0$$

Radial electric field:

$$E_R \approx aBc\beta\gamma^2 \approx aBc\beta$$

Spin precession due to edm:

$$\frac{dS}{dt} = d\times(E + c\beta\times B) = dc\beta B(1+a) = \frac{d(1+a)}{a\gamma^2}E_R \approx \frac{d}{a}E_R$$

Spin precession due to background:

$$\frac{dS}{dt} = \frac{\mu E\,\theta_{NP}}{c\beta\gamma^2}$$

Non-planar E field

NP

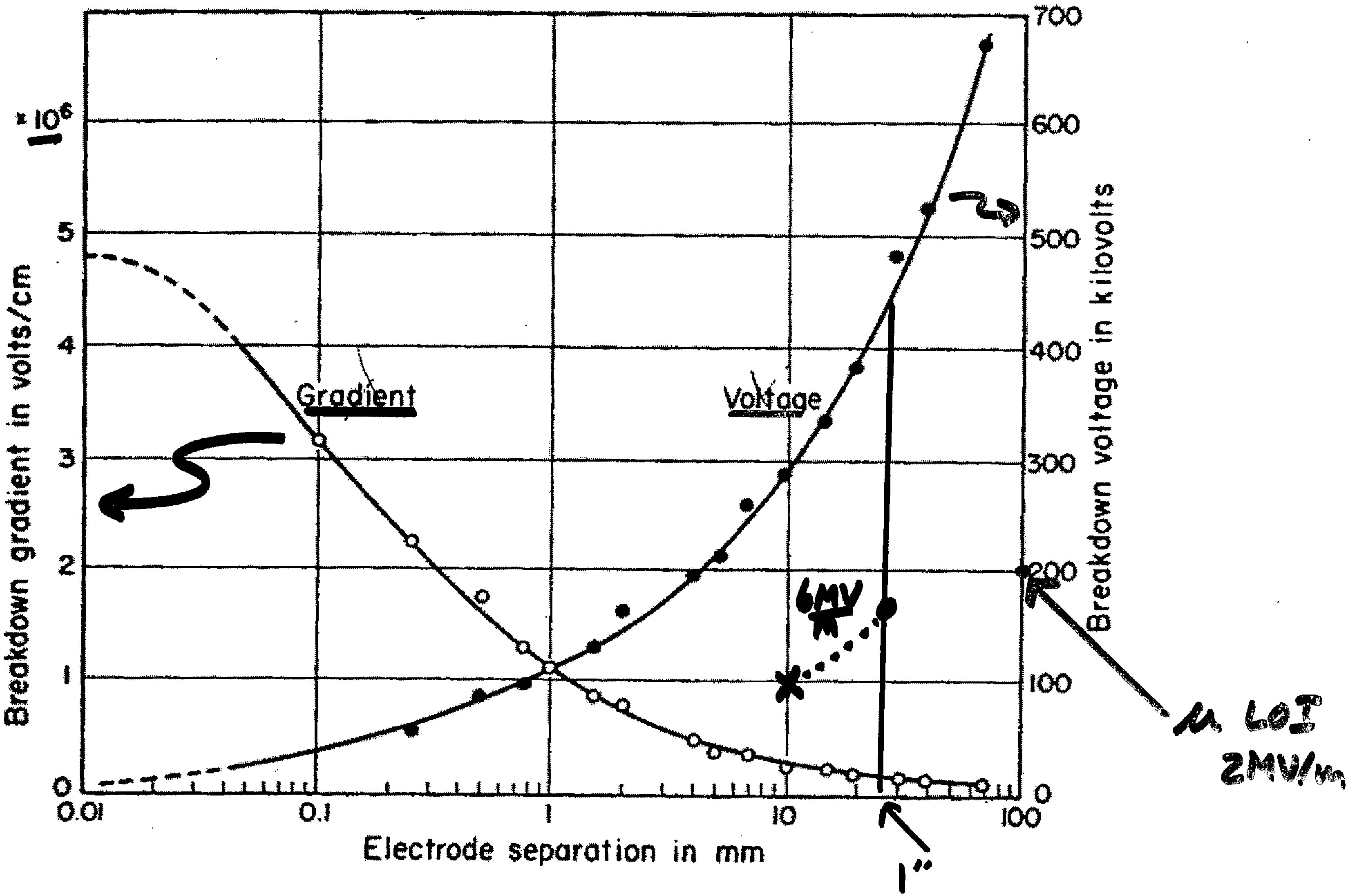
Ratio of background to signal:

$$R = \frac{\mu a}{dc}\,\frac{\theta_{NP}}{\beta}$$

CW/CC

http://p25ext.lanl.gov/~mischke/edm

Breakdown data for vacuum



$V \propto \sqrt{d}$ $E \propto \frac{1}{\sqrt{d}}$

$\frac{400KV}{.0254m} = 15.7 MV/m$

A. Yamamoto et al. NIM 148 (1978) 203.

63% Ne 37% He

10cm gap 9m long.

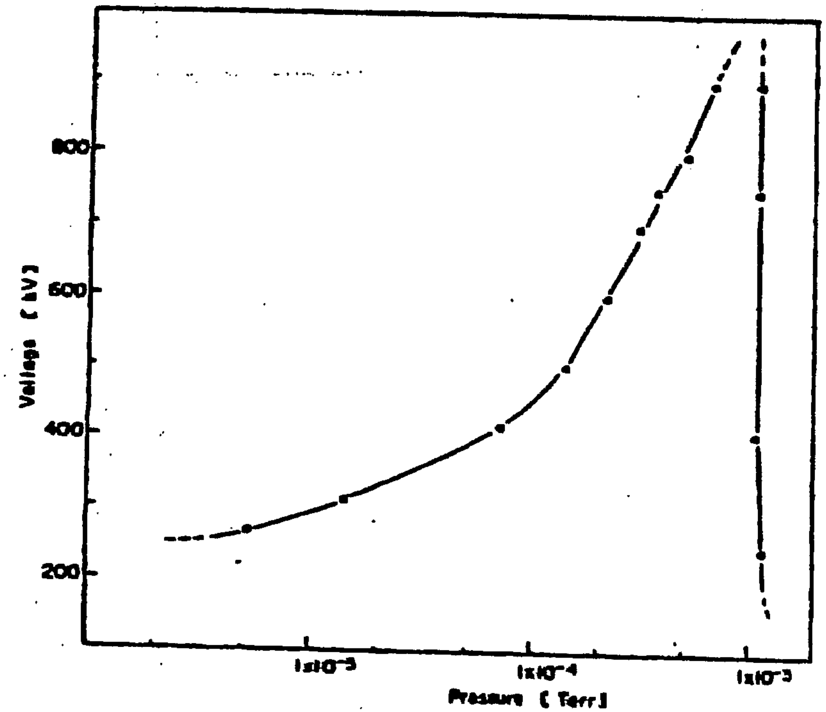


Fig. 5. Performance of the 3 m separator. High-voltage is supplied between stainless-steel anode and anodised aluminium cathode. The gap spacing is 10 cm. A gas mixture of neon and helium (36.5%) is used to adjust the working pressure. Pressures are "equivalent nitrogen".

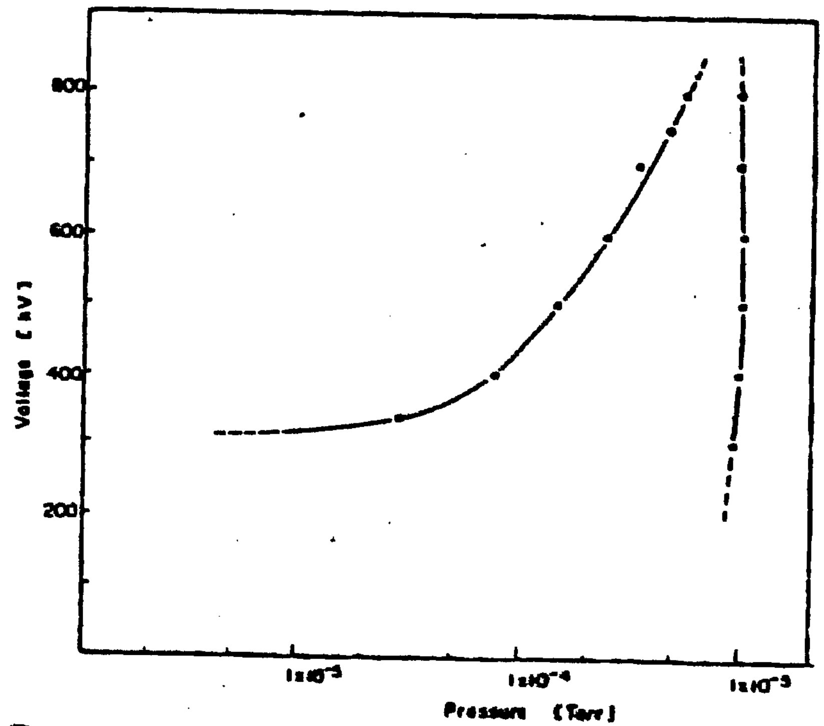


Fig. 6. Performance of the 9 m separator. The conditions of electrodes, gas mixture and gap spacing are the same as those of the 3 m separator. Pressures are "equivalent nitro-