-lockwise (CW) & Counter-Clockwise (CCW) Issues

YKS.

7 Feb, 2003

— Paths: How well do they need to overlap?

— How often CW ⟷ CCW?

CW and CCW Paths-How Well Do They Need to Overlap?

Yannis K. Semertzidis
Brookhaven National Laboratory

December 11, 2002

EDM note # 28

Abstract

A study of the out of plane electric field uniformity as well as the overlap needed of the clockwise and counter-clockwise paths of the muon and deuteron beams is presented here.

1 Introduction

The out of plane (vertical) electric field in the single ring configuration is a severe systematic error. One way to remedy this problem, suggested by Francis Farley [1], is to inject clockwise (CW) and counter-clockwise (CCW) the same kind of particles (muons or deuterons) into the same ring. For example positive muons could be injected CW and CCW requiring the flipping of the magnetic field direction but not the E-field [1]. The conclusion was that the background due to the out of plane electric field has the same sign whereas the EDM signal flips sign.

Since the EDM signal is very small is it important to find out how uniform the out of plane electric field versus radius does it have to be in order for the background to be the same to the required accuracy.

EDM signal

$$\frac{d\bar{s}}{dt} = \bar{d} \times (\bar{E} + \bar{v} \times \bar{B}) \simeq \bar{d} \times (c\bar{\beta} \times \bar{B})$$

Background due to $E_v \equiv \vartheta_{NP} \cdot E$

$$\frac{ds}{dt} = \mu \, \vartheta_{NP} \, E / (c \beta \gamma^2)$$

$\mu = 0.857 \, e\hbar/(2m_p)$ for deuterons

$\mu = 1.001 \, e\hbar/(2m_\mu)$ for muons

$$\Rightarrow \boxed{\vartheta_{NP} E = \frac{d \, c^2 \beta^2 \gamma^2 B}{\mu}}$$

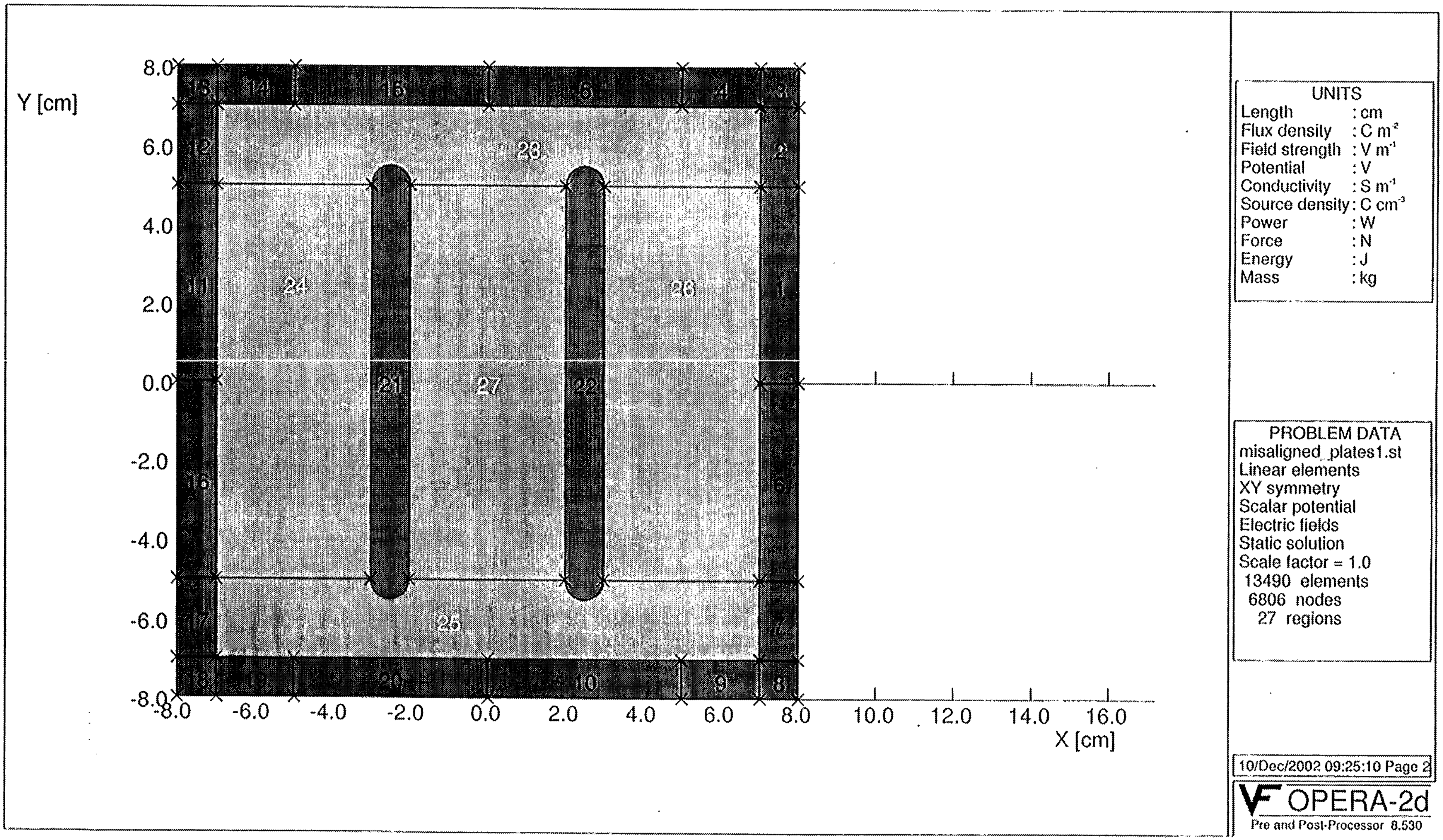
$\Rightarrow$ For 10^{-24} e·cm EDM sensitivity

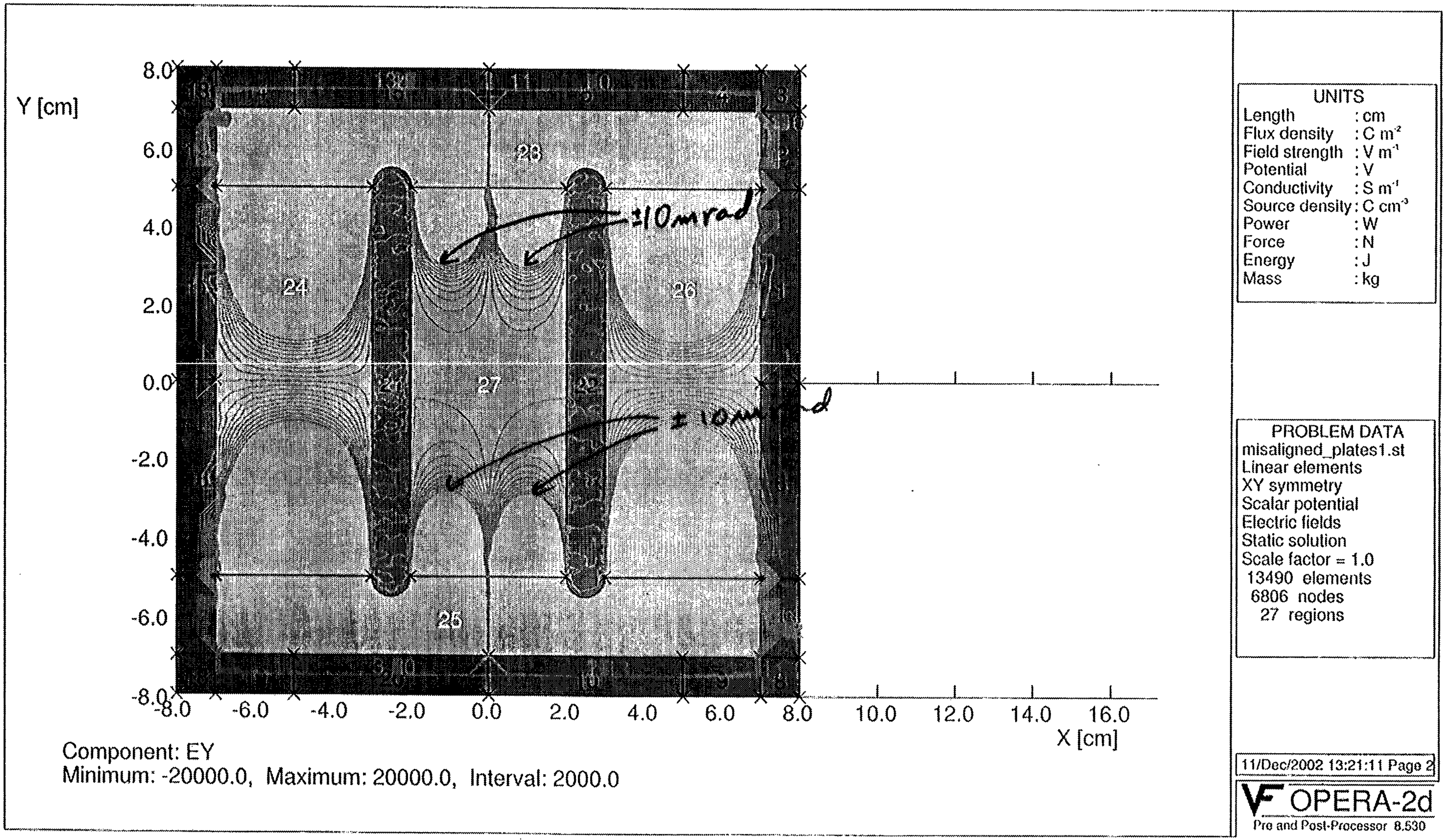
μ: $\langle E_v \rangle < 10$ nrad · E

d: $\langle E_v \rangle < 0.33$ nrad · E

Example:

$E_R = 2\,MV/m$





Y [cm]
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
X [cm]
23
24
26
27
25
±10mrad
± 10mrad
Component: EY
Minimum: -20000.0, Maximum: 20000.0, Interval: 2000.0
UNITS
Length : cm
Flux density : C m-2
Field strength : V m-1
Potential : V
Conductivity : S m-1
Source density : C cm-3
Power : W
Force : N
Energy : J
Mass : kg
PROBLEM DATA
misaligned_plates1.st
Linear elements
XY symmetry
Scalar potential
Electric fields
Static solution
Scale factor = 1.0
13490 elements
6806 nodes
27 regions
11/Dec/2002 13:21:11 Page 2
OPERA-2d
Pre and Post-Processor 8.530

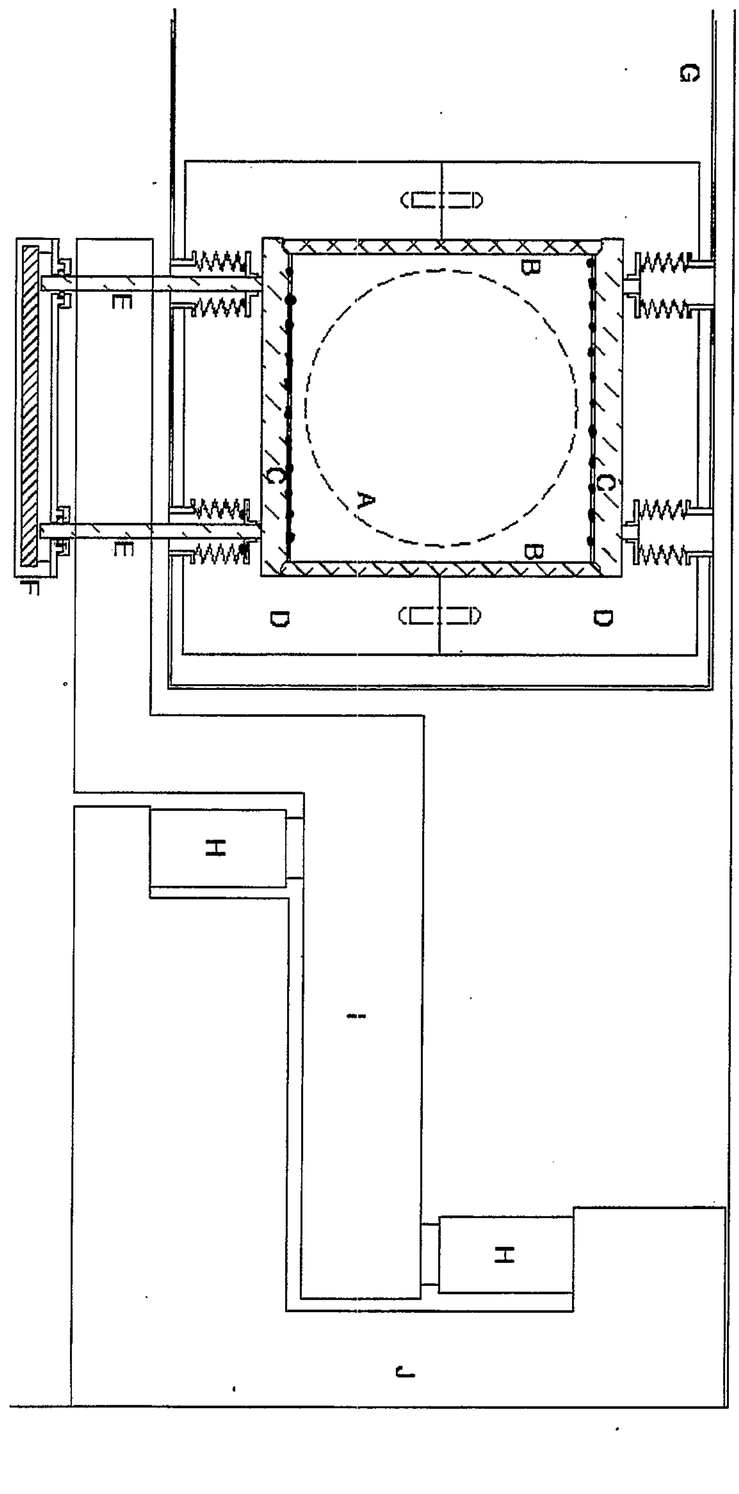
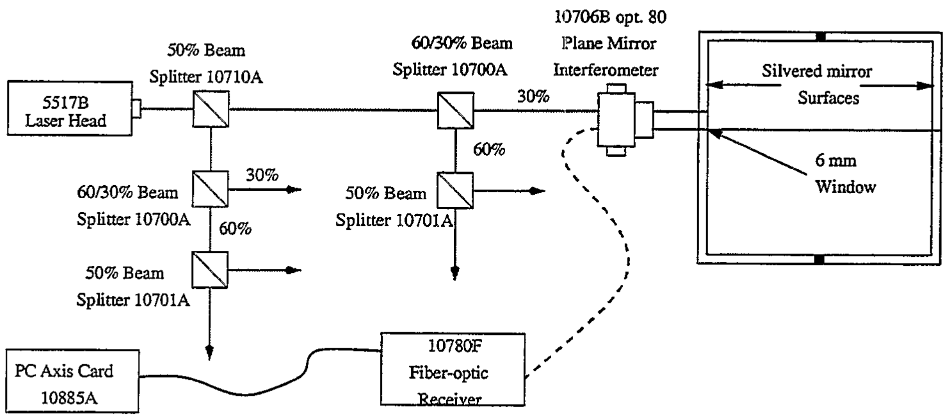


Figure 6: Scheme of electrode alignment showing: (A) muon storage region; (B) electrodes; (C) conductive glass plates with insulating support webbing; (D) ceramic alignment yokes; (E) glass reference rods; (F) hydrostatic reference surface; (G) vacuum chamber; (H) piezoelectric driver; (I) lever; and (J) support beam.



6 Axis per Laser Head

The plane mirror interferometers 10706B will measure the change in spacing of the 2 silvered surfaces. The detailed optical layout for all 40 measurement axis is done by the integrater. Other optical components such as Beam Benders 10707A and Adjustable Mounts, 10710A & 10711A, are available to aid in layout and alignment.

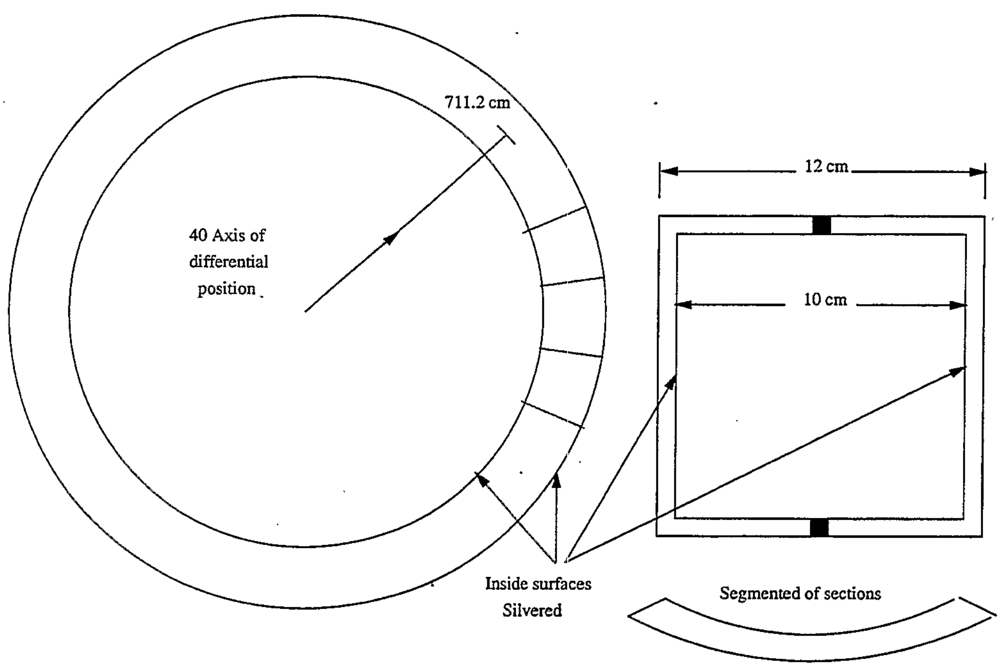
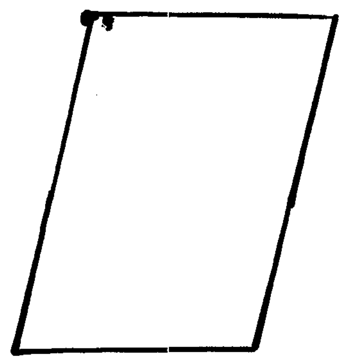


Figure 11: The cross section of the plates (10 cm by 10 cm) is shown on the right. The top and bottom plates consist of conductive glass plates. On the top of the figure the laser interferometer is shown which has 5 nm relative position resolution with 33 KHz response speed.

E_v as a function of radius

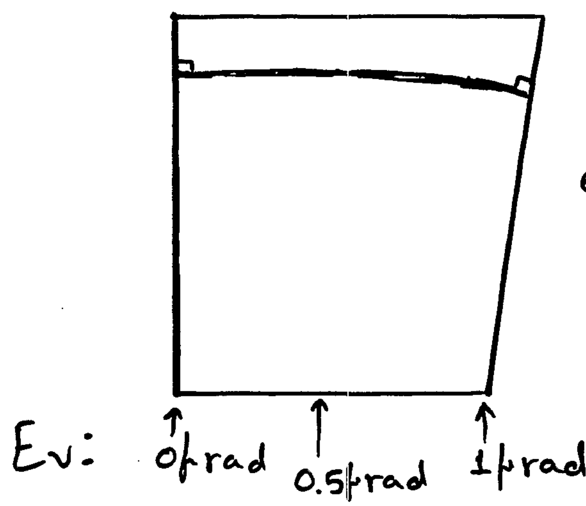
1)



If the plates are parallel

E_v ✓

2)



E_v depends on radius

e.g. left plate vert.
right " off vert
by 1μrad
(≈100 nm)

i.e. $10\mu m/m = \dfrac{dE_v}{dR}$

Table 1: Required overlap of CW and CCW paths for the case of an inhomogeneity in the vertical electric field component.

Particle	EDM Value	Average Vertical E-field Inhomogeneity	Beam Size	Overlap Needed
Muon	$10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$	$10\,\mu$rad/m	100 mm	1 mm
Deuteron	$10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$	$10\,\mu$rad/m	20 mm	$33.3\,\mu$m

there is $10\,\mu$rad/m change of the vertical E-field component as a function of radius.

In order to cancel the 10 nrad vertical electric field, the CW and CCW paths need to overlap within 1 mm for the muon EDM of $10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$ and $33.3\,\mu$m for the deuteron EDM of the same level, see Table 1. The overlap needed for the same particle is linear with the aimed EDM level. In both cases the required overlap is a small fraction, 1% and 0.15%, of the expected muon and deuteron beam sizes correspondingly. Bill Morse has proposed to scan the electric field region with the deuteron beam to map the vertical component as a function of radius. This procedure should be adequate to correct the electric field region as long as it is sufficiently stable as a function of time.

4 Conclusion

The vertical electric field homogeneity is an important parameter and seems to be possible to control will a special attention to it. I have enjoyed useful conversations on the subject with Bill Morse and Francis Farley.

References

[1] Francis J.M. Farley, Ring Distortions and the EDM for mu plus and mu minus, muon EDM note 22, 30 August 2002.

[2] AGS Letter of Intent-Search for a Permanent Muon Electric Dipole Moment, 11 February 2000. The document can be downloaded from our EDM web site:
http : //www.bnl.gov/edm/papers/loiedm0002_v3.pdf

AGS Letter of Intent-Search for a Permanent Muon Electric Dipole Moment

R.M. Carey, J.P. Miller*, O. Rind, B.L. Roberts, L.R. Sulak

Boston University

R. Larsen, D.M. Lazarus, W. Meng,

W.M. Morse, C. Ozben, R. Prigl, Y.K. Semertzidis*

Brookhaven National Lab

V. Balakin, A. Bazhan, A. Dudnikov, B. Khazin, G. Sylvestrov

BINP, Novosibirsk

Y. Orlov

Cornell University

K. Jungmann

University of Heidelberg

P.T. Debevec, D.W. Hertzog

University of Illinois

E. Stephenson

Indiana University

F.J.M. Farley

Yale University

February 11, 2000

* Spokesperson

Table 1: Required overlap of CW and CCW paths for the case of an inhomogeneity in the vertical electric field component.

Particle	EDM Value	Average Vertical E-field Inhomogeneity	Beam Size	Overlap Needed
Muon	$10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$	$10\,\mu\mathrm{rad/m}$	100 mm	1 mm
Deuteron	$10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$	$10\,\mu\mathrm{rad/m}$	20 mm	$33.3\,\mu\mathrm{m}$

there is $10\,\mu\mathrm{rad/m}$ change of the vertical E-field component as a function of radius.

In order to cancel the 10 nrad vertical electric field, the CW and CCW paths need to overlap within 1 mm for the muon EDM of $10^{-24}\,\mathrm{e}\cdot\mathrm{cm}$ and $33.3\,\mu\mathrm{m}$ for the deuteron EDM of the same level, see Table 1. The overlap needed for the same particle is linear with the aimed EDM level. In both cases the required overlap is a small fraction, 1% and 0.15%, of the expected muon and deuteron beam sizes correspondingly. Bill Morse has proposed to scan the electric field region with the deuteron beam to map the vertical component as a function of radius. This procedure should be adequate to correct the electric field region as long as it is sufficiently stable as a function of time.

4 Conclusion

The vertical electric field homogeneity is an important parameter and seems to be possible to control will a special attention to it. I have enjoyed useful conversations on the subject with Bill Morse and Francis Farley.

References

[1] Francis J.M. Farley, Ring Distortions and the EDM for mu plus and mu minus, muon EDM note 22, 30 August 2002.

[2] AGS Letter of Intent-Search for a Permanent Muon Electric Dipole Moment, 11 February 2000. The document can be downloaded from our EDM web site:
http : //www.bnl.gov/edm/papers/loiedm0002_v3.pdf

6.4 Pickup Electrode Measurement of Vertical Component of Electric Field

The AGS can deliver about 5×10^9 polarized deuterons with $dp/p = 10^{-3}$ and emittance about $30\pi\,\mathrm{mm} - \mathrm{mrad}$ at 0.4 GeV/c momentum. The average vertical position of the beam will be where:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) = 0 \tag{25}$$

Of course, there will be betatron oscillations about the average. For a weak focusing machine

$$n = \frac{R_0}{B_0}\frac{dB_r}{dy} \tag{26}$$

The change in height due to the vertical electric field will be:

$$dy = \frac{R_0}{B_0}\frac{E_v}{vn}$$

We haven't yet decided on an n value for the edm experiment, however, for discussion purposes, let's take n = 0.137 (this is what the muon g-2 experiment used). For weak focusing, the accepted emittances and dp/p are given above in the Weak Focusing Ring subsection.

The deuteron betatron oscillations would occupy ±24 mm vertically, and ±15 mm radially (for dp/p=0). dp/p = 10-3 would occupy ±8 mm (equilibrium orbits). Then $dy = 0.1\,\mu\mathrm{m}$, for B = 0.2T, R = 7.11m, and $E_v = 10^{-8} \times 2\mathrm{MV/m}$. This is very small; however, we would be measuring differences. This could be measured with pickup electrodes (described below) or by kicking the beam onto a detector. By kicking the beam onto a segmented detector, we would have a sensitivity of $24\mathrm{mm}/\sqrt{N}$ or $0.1\,\mu\mathrm{m}$ per AGS pulse. Also, we will run with positive and negative E, i.e. pointing inward and outward.

The beam position monitor (BPM) for the deuteron beam vertical shift, due to a vertical component of the electric field consists of four 1 meter long pickup electrodes, installed symmetrically around the beam. The electrodes are connected to ground potential through variable capacitors needed for electrically zero tuning of the monitor. The induced voltage is q/C_i, where $C_i = C(\text{variable}) + C_0$ where C_0 is the capacitance of the electrode. $q \approx Ql/L$ with l the monitor length and L the orbit length.

When the BPM measures the relative shift of the beam, connected with the voltage difference between the opposite electrodes $U_1 - U_2$, one can see that by changing the capacitance of the electrodes to ground we will be able to tune to zero the differential signal for the equilibrium beam position in horizontal and vertical directions, independently from the initial alignment of the pickup electrodes. This approach allows us to use the so-called "zero-method" for measurements.

All electrodes are connected with charge-sensitive amplifiers. The sum of these signals is used for a measurement of the total beam charge, whereas the difference gives a rough estimation of the beam position. The relative voltage between opposite plates is measured for precise position estimation by two completely insulated from ground, low-noise charge-sensitive amplifiers with integration time sufficiently greater than the betatron oscillation period. These amplifiers measure the beam shift from "zero" position. Using this system the procedure of the beam shift caused by the applied electric field looks like this: One injects the deuteron beam with fixed energy in the ring without electric field. By varying the magnetic-field and the variable capacity one can reach zero signal from precise amplifiers. Then we switch on the radial electric field and inject the deuteron beam with the same fixed energy. You can reach the same "zero" position in radial direction by changing magnetic field. A parasitic vertical component of the electric field will push the equilibrium orbit in the vertical direction and will be measured by the precise charge sensitive amplifiers connected to the vertical plates.

The estimated sensitivity is $dU/dx \approx Ql/(L\,c\,a)$ with a the half of aperture, and c the integral capacity of the electrodes.

Using modest low-noise amplifiers developed at B.I.N.P./Russia with $5\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ noise and integrated time 1ms we will have 100nV noise. The final sensitivity for single measurement for $a = 5$ cm, $l = 1$ m, $L = 50$ m, $c = 400$ pF, and assuming a modest number of deuterons of 10^9 is about 1 micron. The noise limitation of sensitivity is decreasing as sqrt(number of measurements), and for 0.1 μm we would need 100 pulses or 20s at 5 Hz. The final accuracy will be limited by systematic errors.

How often CCW ⟺ CW ?

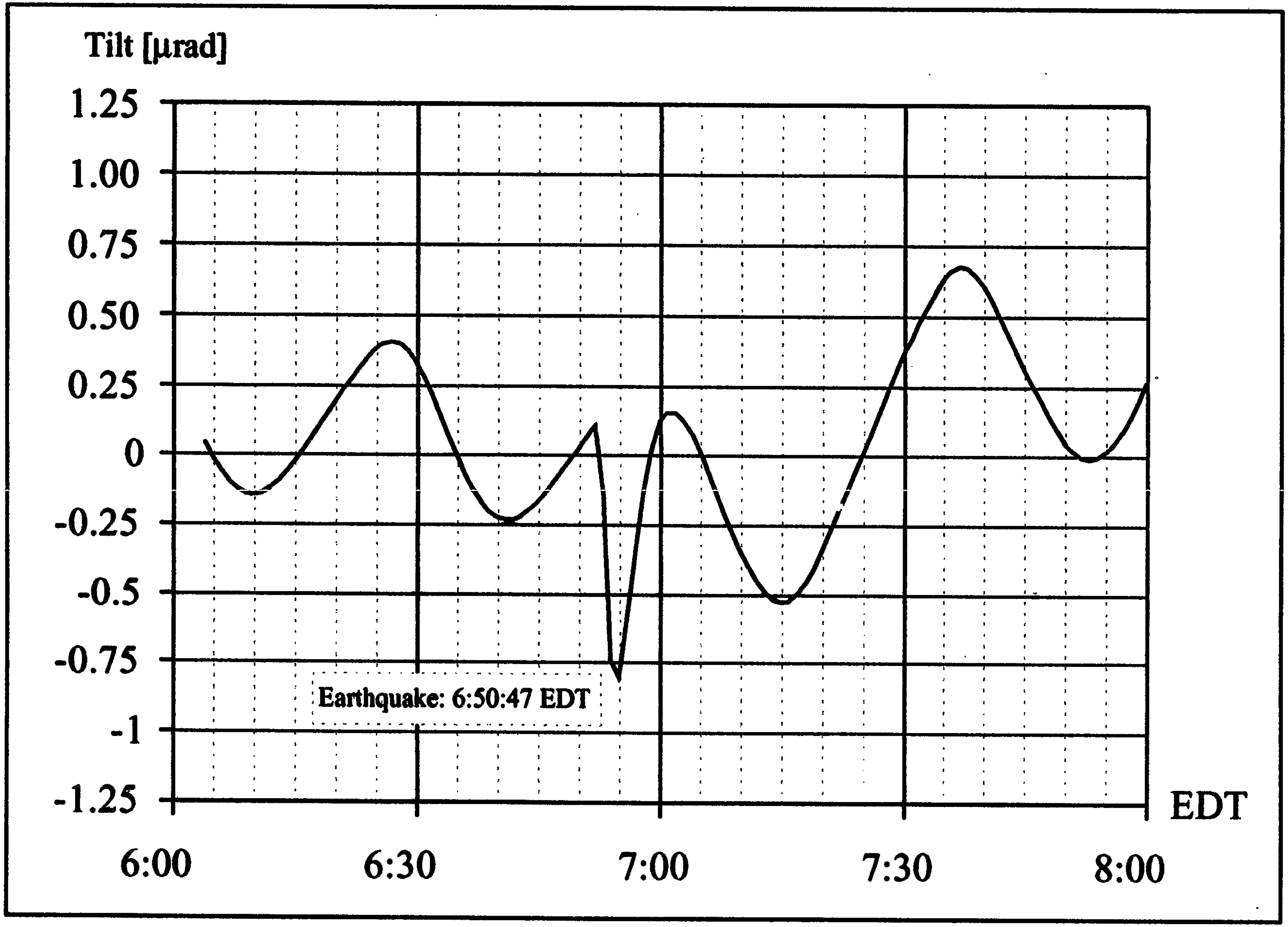
e.g. If stability w/ time
is such that $0.5\,\mu\text{rad}/1800\,\text{s}$

then with 1 Hz : $\frac{0.5\,\mu\text{rad}}{1800\,\text{s}} = 2.8 \times 10^{-10}$ rad/s

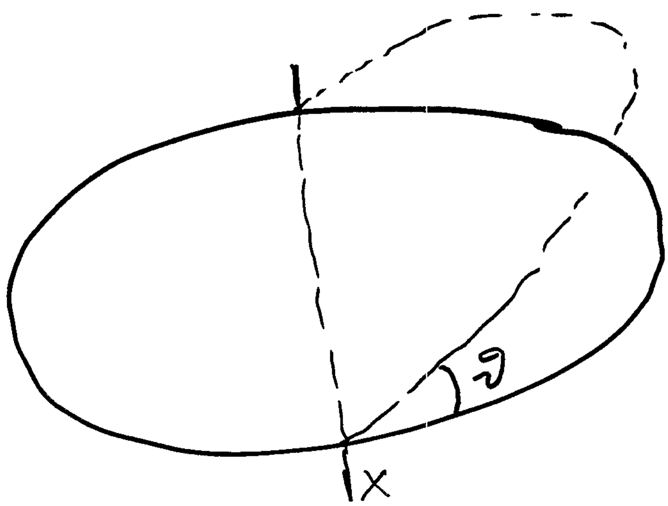
We need $< 3 \times 10^{-11}$ rad for $d_d < 10^{-25}$ e·cm

i.e. ~ 100 injections ✓

4/20/2002 tiltmeter data

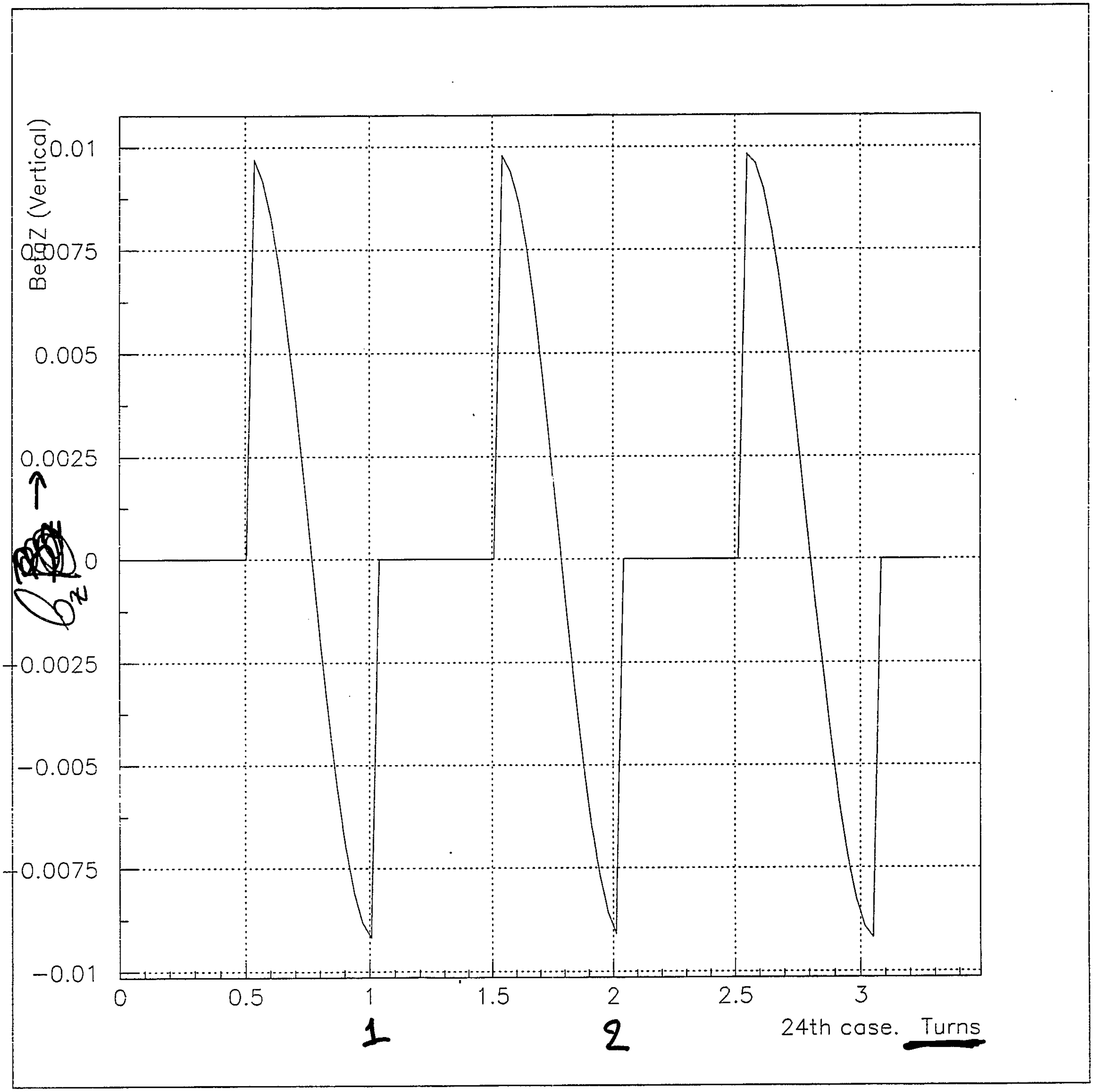


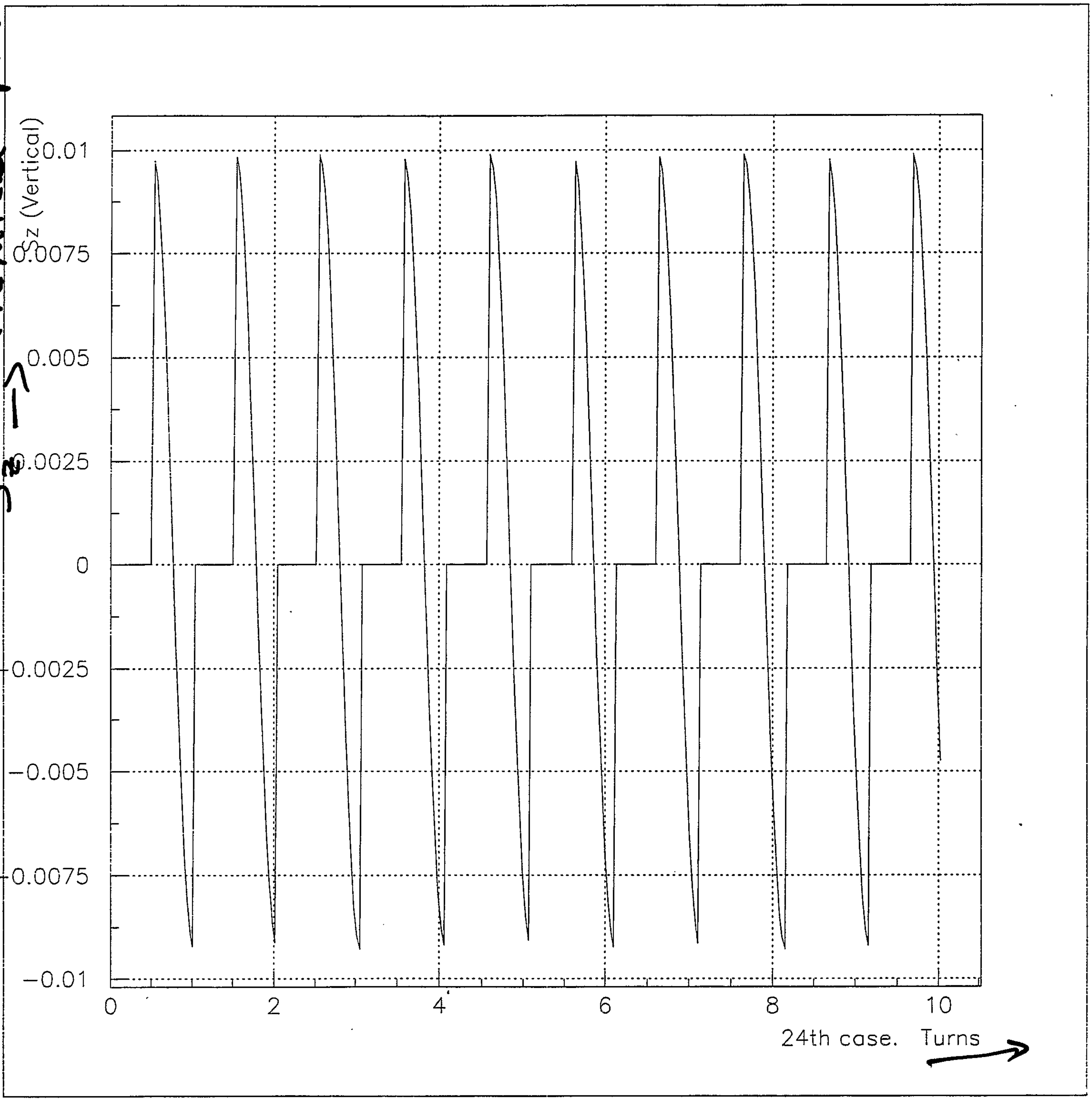
Saucer Effect:



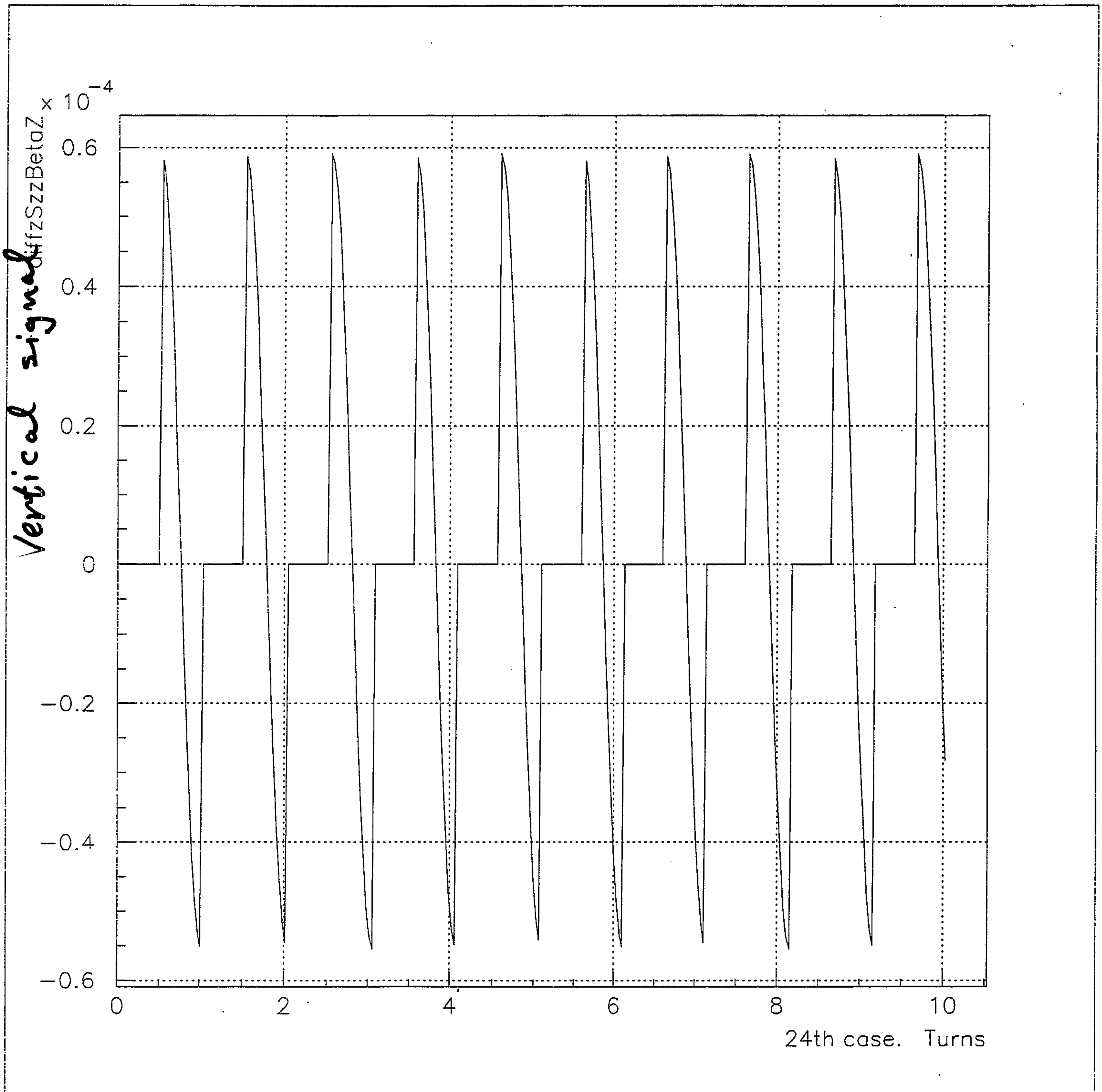
- Spin & momentum tracking
- Equations taken from J.D. Jackson
- No focusing used only equilibrium orbits. B_d, E_{radial}
- B_d -> in half ring rotated by ϑ

$\vartheta = 10\mu rad$

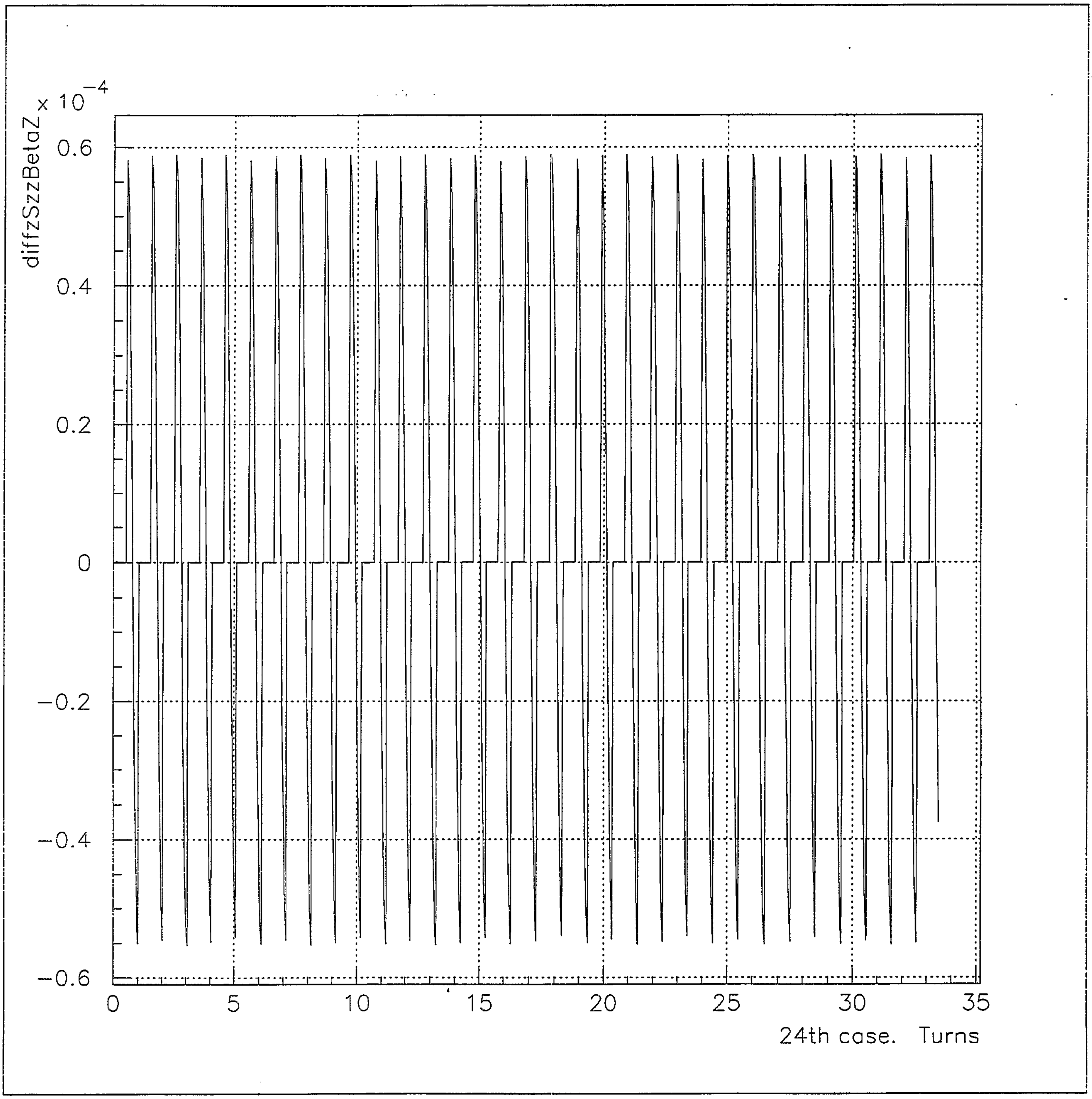




$S_z \rightarrow$ (vertical spin compound



→ when $E_v = 0$, the average vertical signal is zero <u>exactly</u>.


diffzSzzBetaZ × 10⁻⁴
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
5
10
15
20
25
30
35
24th case. Turns