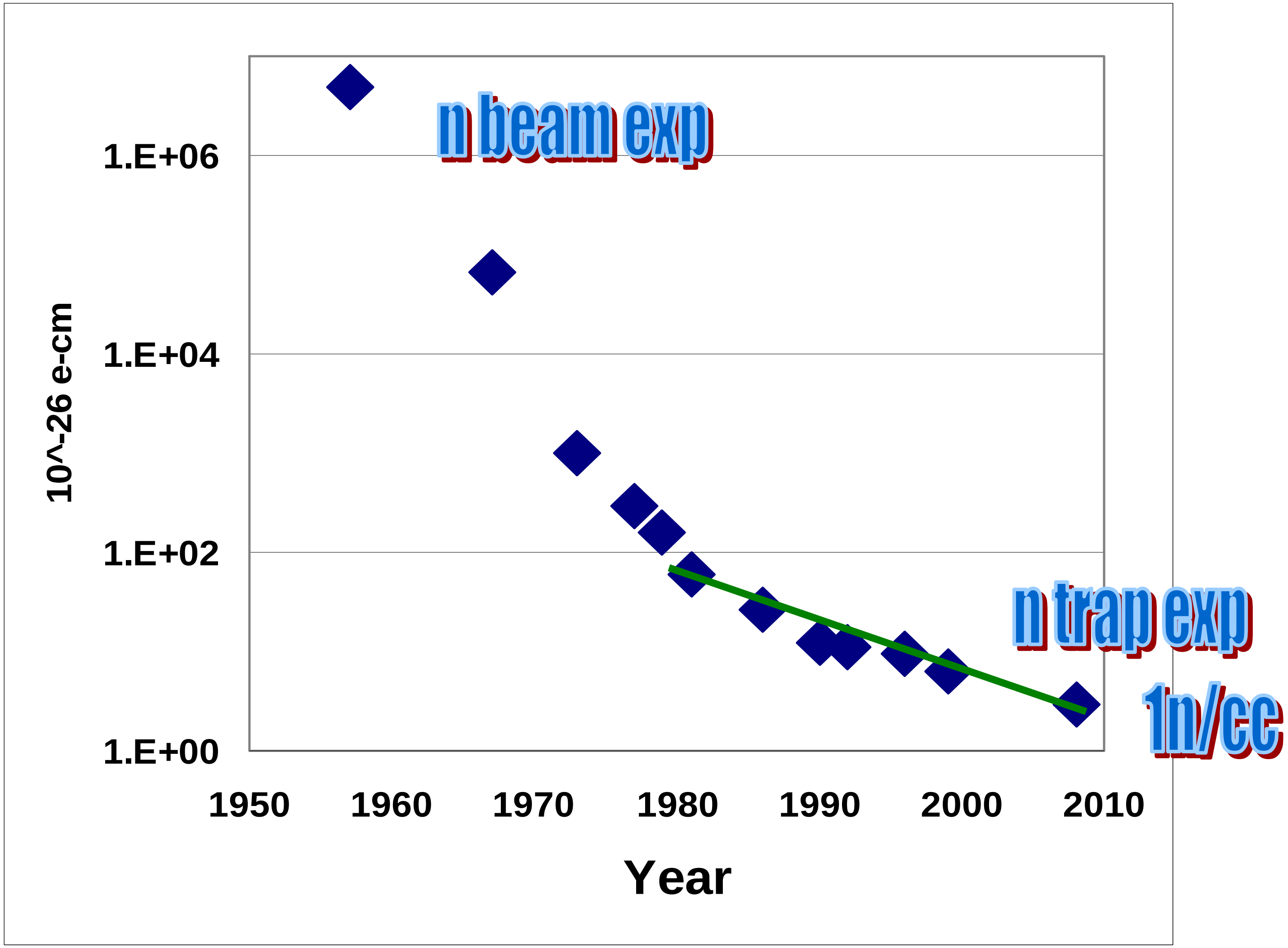
Electron EDM All-Electric Magic P Experiment

W. Morse - BNL

Neutron EDM Limit vs. Year



Storage Ring = Beam in a Trap!

MDM

$$\frac{d\left(\hat{\beta}\bullet\vec{S}\right)}{dt}=\frac{e}{mc}\vec{S}_T\bullet\left[a\hat{\beta}\times\vec{B}+\left(\frac{g\beta}{2}-\frac{1}{\beta}\right)\vec{E}\right]\approx 0$$

0

EDM

$$\frac{d\vec{S}}{dt}=\vec{d}\times\left(\vec{E}+\vec{\beta}\times\vec{B}\right)$$

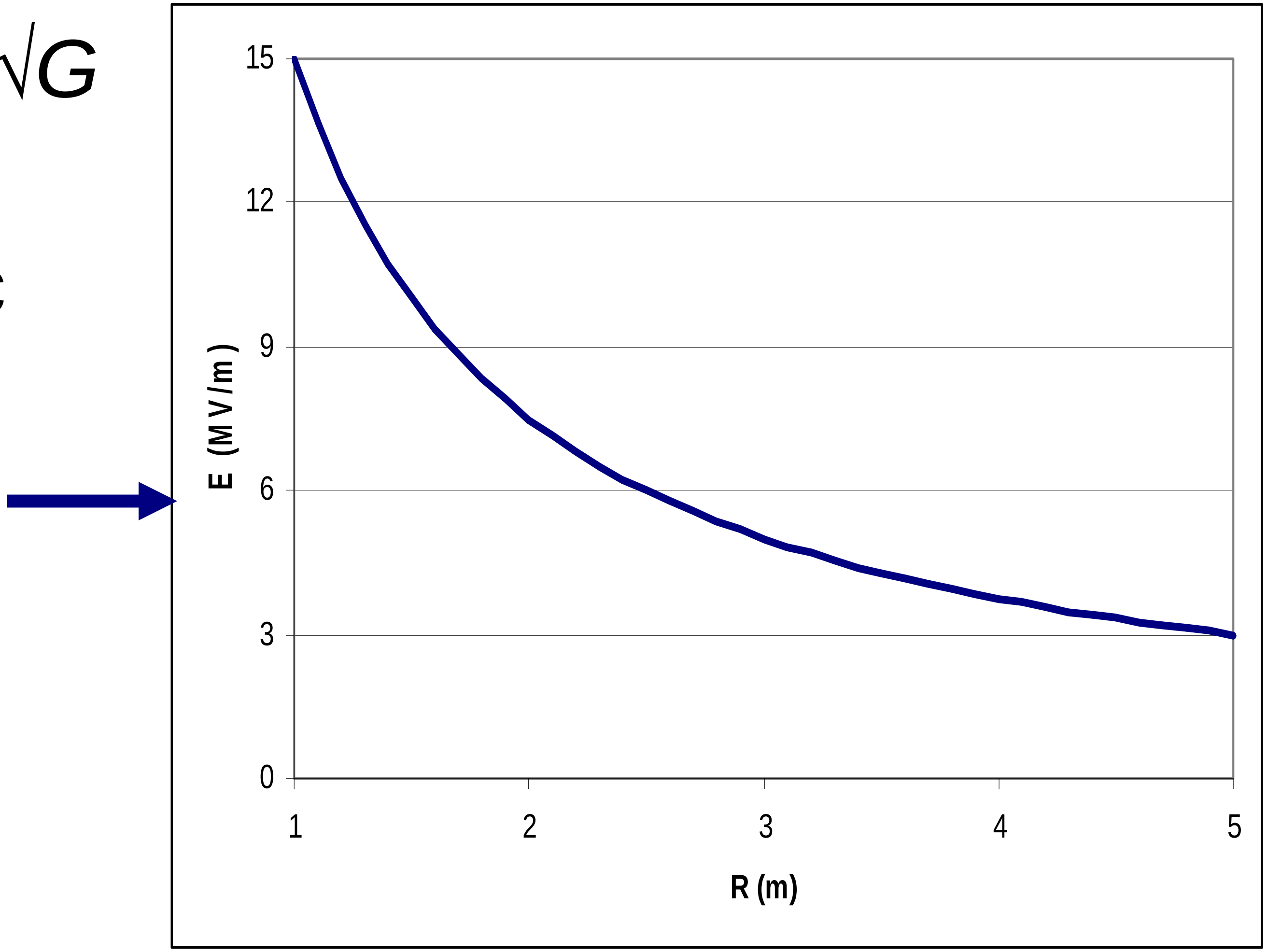
0

Magic All Electric Pre-cursor Experiment?

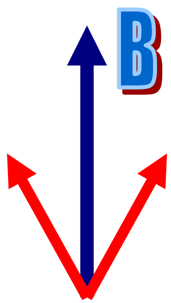
- Before the “big” 10^{-29} ecm pEDM experiment:
- Yannis: “small” pEDM pre-cursor experiment?
- I. Koop, Novosbirsk: eEDM experiment with spin wheel and SQUID polarimeter.
- This talk: eEDM experiment with IBS Touschek Polarimeter.
- JEDI Collaboration: dEDM “spin flipper” at COSY.

Electron Magic Momentum = 15MeV/c

- $P_m = Mc/\sqrt{G}$
- Proton 0.7GeV/c
- Electron 15MeV/c



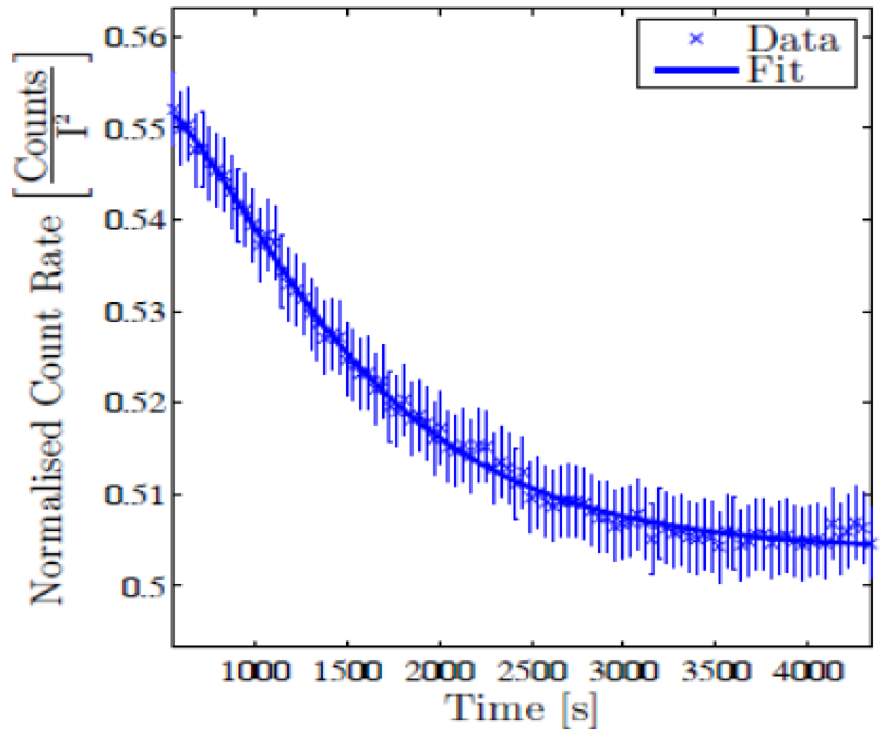
Sokolov-Ternov Effect



$$P = \frac{8}{5\sqrt{3}} = 0.92$$

Table 2: Polarisation Time

Parameter		Value	Units
Measured	τ_{ST}	806 (21)	s
Model	τ_{ST}	807	s



TUPC062 Proceedings of IPAC2011, San Sebastián, Spain

ELECTRON BEAM ENERGY MEASUREMENT AT THE AUSTRALIAN SYNCHROTRON STORAGE RING

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Sokolov-Ternov Time Constant

- Need $\tau_{ST} > 10^9 s$

$$\tau_{ST} \approx \frac{8}{5\sqrt{3}} \frac{m_e \rho^2 R}{\hbar \gamma^5 r_e} \approx 2 \times 10^{12} s$$

Space Charge Tune Shift

- About the same for pEDM and eEDM!

$$\Delta Q_{sp} \approx -\frac{\lambda r_0 R}{2\varepsilon_n \beta\gamma^2}$$

$$r_0 = \frac{e^2}{m_0}$$

Beam-Gas Scattering

- About the same for pEDM and eEDM!

$$\frac{\theta_{sc}}{\theta_{st}} \propto \frac{R}{\beta p}$$

$$pc\beta = eER$$

Main Systematic

- About the same pEDM and eEDM experiment!

	proton	electron
g	5.6	2.0
m	938 MeV	511 KeV
γ	1.25	29.4
$g/m\gamma^2$	3.8 GeV^{-1}	4.5 GeV^{-1}

$$\frac{eg < B_R >}{2m\gamma^2}$$

<B_R> Systematic

- With an all-electric ring the CW/CCW beams have exactly the same vertical closed orbits.
- Measure the spitting with BPMs around the ring to determine B_{RN}, and correct.

$$\Delta y_{CW-CCW} = \pm \frac{c\beta B_{RN} R_0}{E_0\left(N^2 - Q_y^2\right)} \cos\left(N\left(\theta + \phi_N\right)\right)$$

Main Systematic

- βR_0 is smaller for eEDM by an order of magnitude.
- 10^{-29}ecm $\rightarrow$ 10^{-28}ecm

$$\Delta y_{CW-CCW} = \frac{c\beta < B_R > R_0}{E_0 Q_y^2}$$

Intra-beam Scattering (IBS)

- About the same for pEDM and eEDM.

$$\propto \frac{r_0^{\,2}}{\beta^3 \gamma^4}$$

$$r_0 = \frac{e^2}{m_0}$$

Touschek Scattering

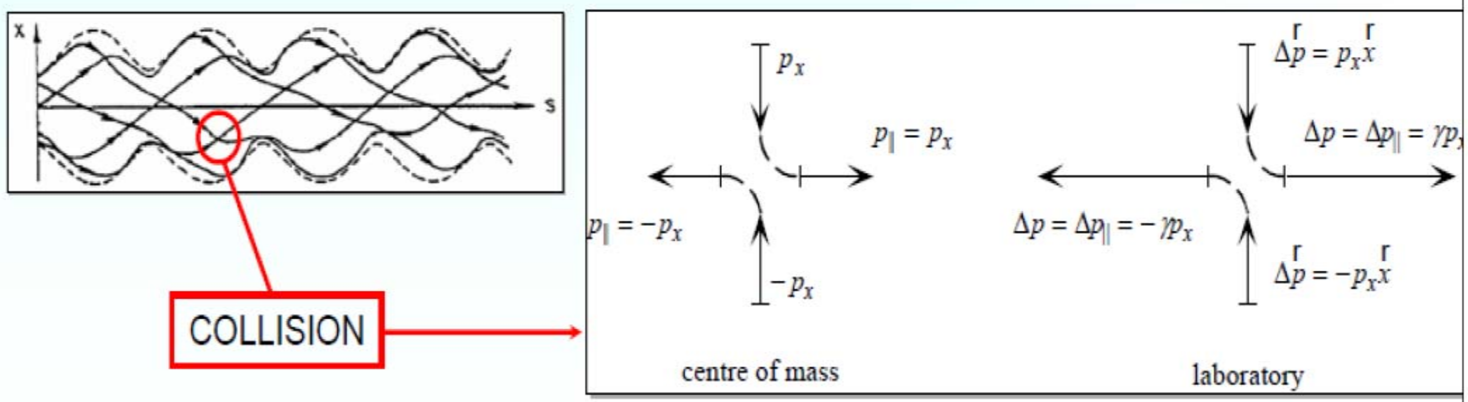
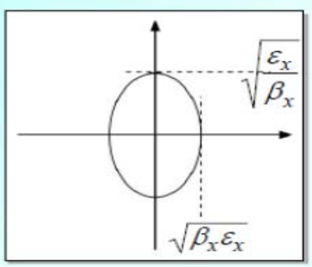


Fig. 3. IBS scattering in center of mass and laboratory reference frames [2].

Orders of Magnitude

Beam Quality & Lifetime
Carlo J. Bocchetta
Sincrotrone Trieste

At a position where the electron's amplitude is σ_x which has a maximum betatron value of β_x, th maximum divergence is:



$$\sigma'_x = \sqrt{\frac{\varepsilon_x}{\beta_x}}$$

and $\sigma_x = \sqrt{\beta_x \varepsilon_x}$

$$\Rightarrow \sigma'_x = \frac{\sigma_x}{\beta} = \frac{p_x}{p}$$

and $p_x = p\sigma_{x'}$

See Le Duff, CERN 89-01, pp.1

If the transverse momentum p_x is **all** transferred to the longitudinal plane it is boosted by γ:

$$\Rightarrow \Delta p = \gamma\, p_x = \gamma\, \frac{p\sigma_x}{\beta_x}$$

Fig. 4. Orders of magnitude estimate of the change in the Lab momentum from ref. 2.

Touschek Scattering

$$\Delta p_{\parallel} \approx \frac{30 \times 5mm \times 15MeV/c}{2m} \approx \pm 1MeV/c$$

$$\Delta T_{admit} \approx \pm 0.1MeV$$

Moller Scattering ($e^-e^-\rightarrow e^-e^-$)

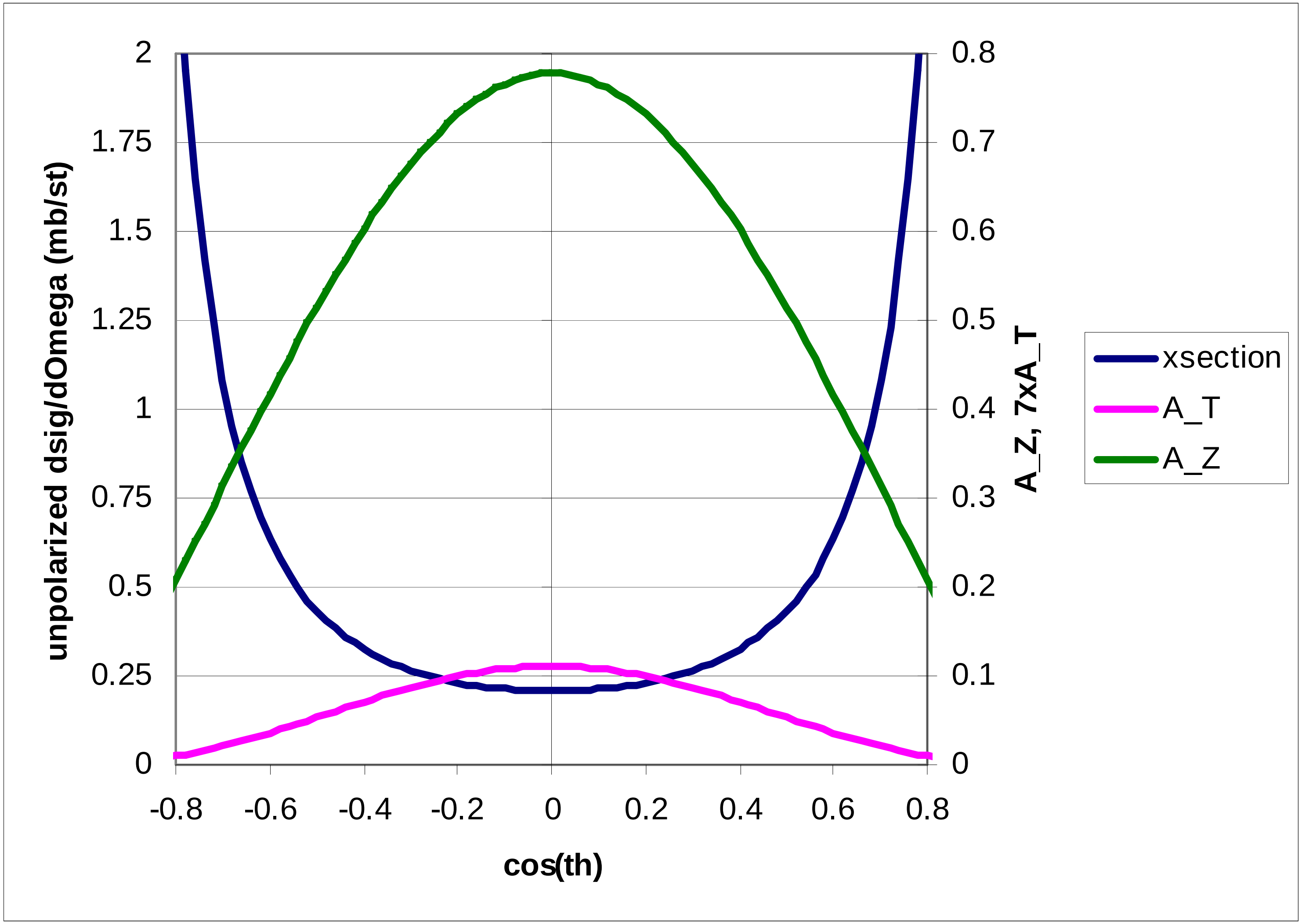
$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2}{s}\frac{\left(3+\cos^2\theta\right)^2}{\sin^4\theta}\left(1+A\right) \qquad (2)$$

$$A(\theta,\phi)=-P_z^2A_Z(\theta)-P_T^2A_T(\theta)\cos\left(2\phi-2\phi_{spin}\right) \qquad (3)$$

$$P_z=P\cos\theta_{spin} \qquad P_y=P\sin\theta_{spin}\sin\phi_{spin} \qquad P_x=P\sin\theta_{spin}\cos\phi_{spin}$$

$$P_T^2=P_x^2+P_y^2$$

Moller Scattering



Sokolov-Ternov Polarimeter

- $A_z \approx 0.05$

Table 2: Polarisation Time

Parameter		Value	Units
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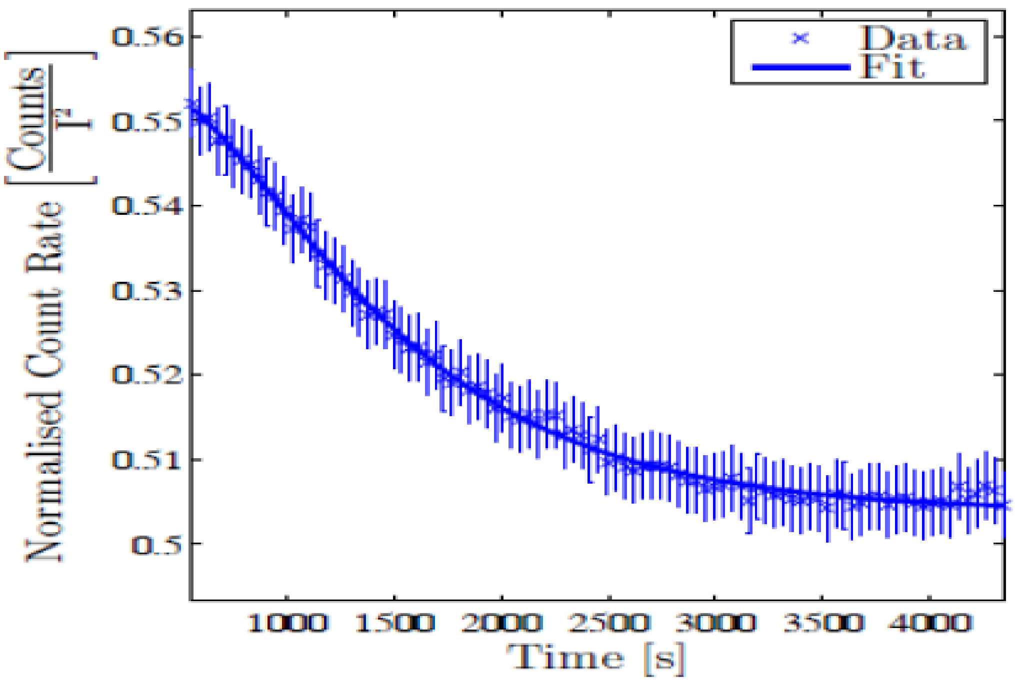
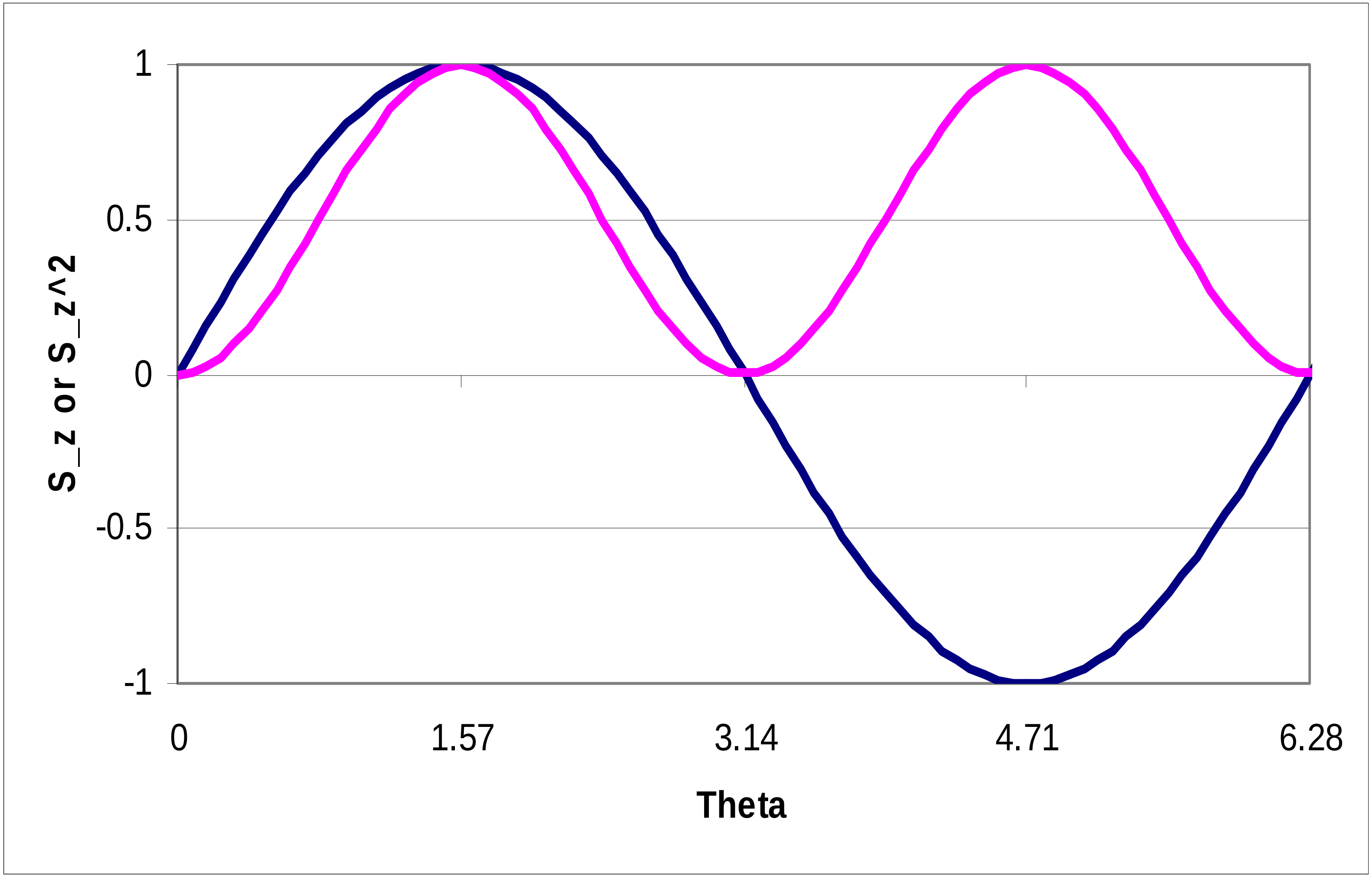


pEDM $\theta_{spin} \approx 0$
eEDM $\theta_{spin} \approx \pi/4$



eEDM vs. pEDM

Table 1. 2011 BNL PEDM Proposal. f is the fraction of the stored beam that eventually ends up being counted in the polarimeter. A is the averaged polarimeter asymmetry. $f^{0.5}AP$ is the edm polarimeter sensitivity figure of merit.

Momentum	700.7 MeV/c
E	10.5MV/m
gap	± 15mm
V	± 150KV
Q_y	0.1 – 0.2
Q_x	1.3
f	10^{-2}
A	0.6
$f^{0.5}A$	0.06
sensitivity per 10^7s	2×10^{-29} ecm

***P* = 15 MeV/c**

***f* ≈ 0.01 ?**

***A* ≈ 0.05 guestimate**

eEDM Statistical Sensitivity

- Guestimate $\approx 10^{-27}$ecm for one month of data taking.
- Comparable to present eEDM limits from atom and molecule experiments.
- They plan to increase sensitivity by an order of magnitude in a few years.

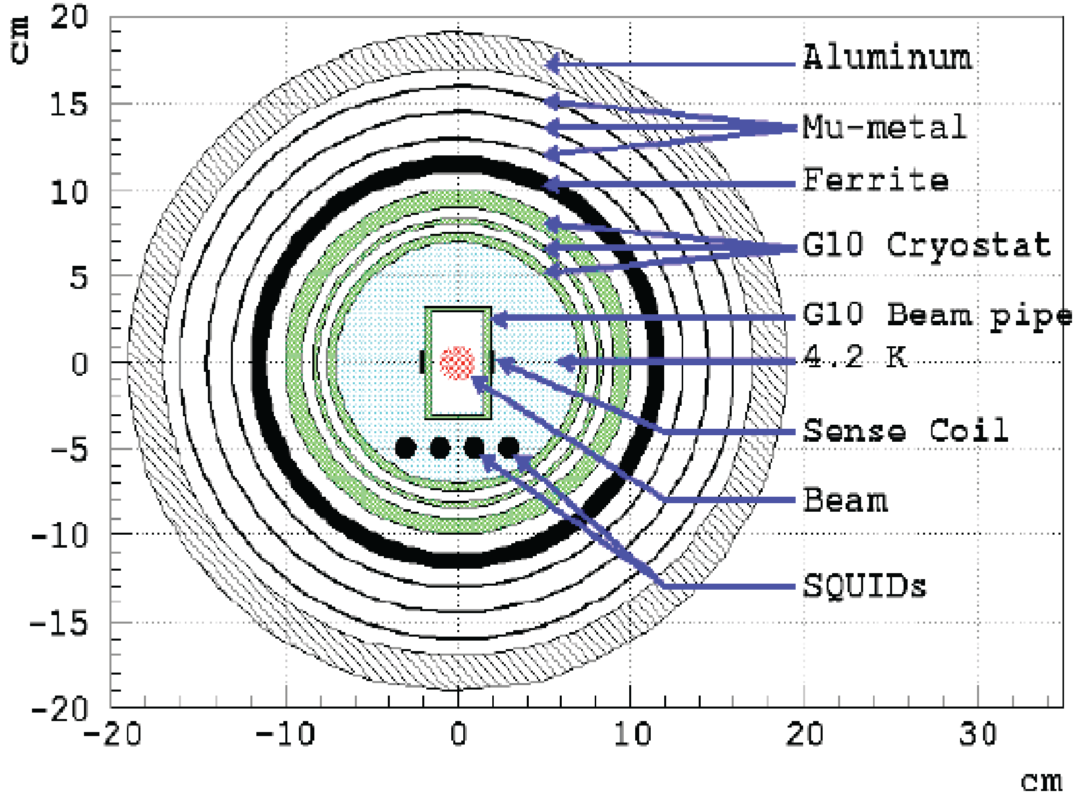
eEDM Conclusions

- Needs lattice, simulations besides order of magnitude estimates.
- Needs Touschek Polarimeter design.
- Polarimeter systematics.
- EDM is difference between CW and CCW polarimeter signals.
- Could be a fun project.

Extra

What is critical

The beam vertical position tells the average radial B-field; the main systematic error source



D. Kawall

First funding from US-Japan for testing at RHIC

1. Beam Position Monitors

- Technology of choice: Low T_c SQUIDS, signal at ~10^4Hz (10% vertical tune modulation)

- R&D sequence: (First funding from US-Japan)

1. Operate SQUIDS in a magnetically shielded area-reproduce current state of art
2. Operate in RHIC at an IP (evaluate noise in an accelerator environment)

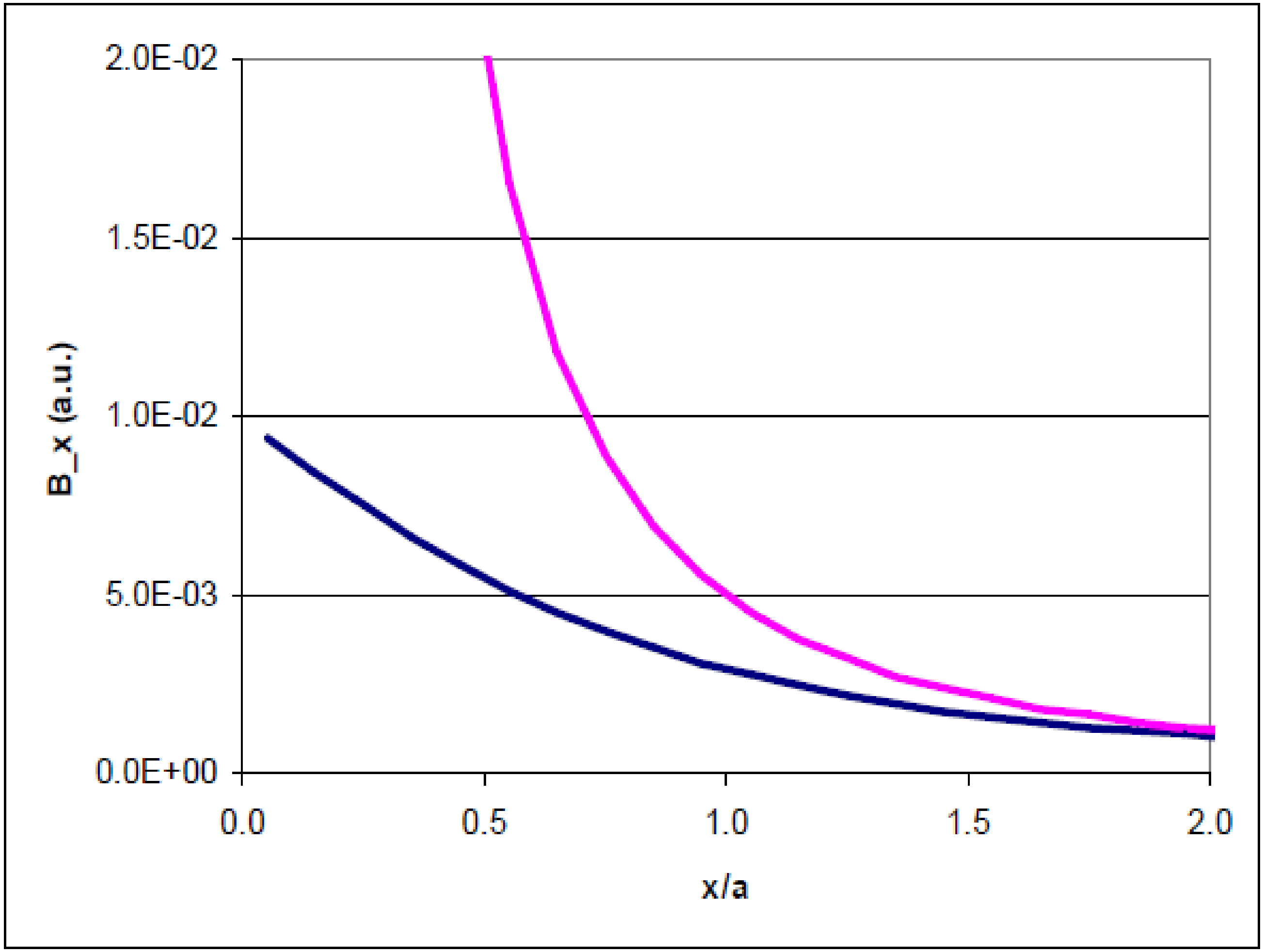


Fig. 3. $B_x(x, y = 0)$ vs. x/a for the beam distribution given in Fig. 1 (dark blue), and CW/CCW line currents with the vertical closed orbit difference (rose curve).