Electron EDM All-Electric Magic P Experiment

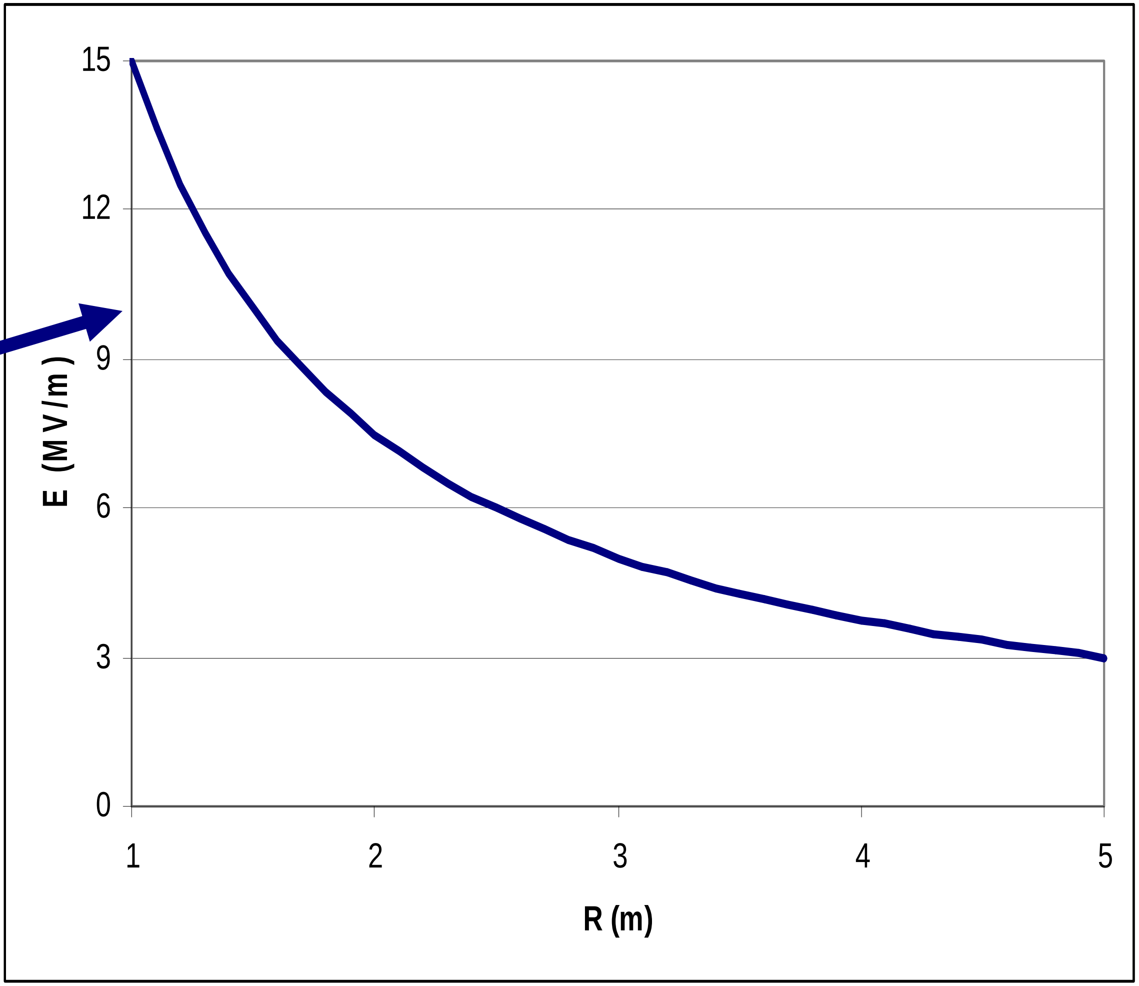
W. Morse - BNL

Storage Ring Pre-cursor Exp?

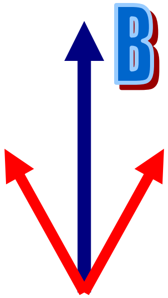
- Before the “big” 10^{-29} ecm pEDM exp:
- Yannis: “small” pEDM pre-cursor exp?
- I. Koop et al., Electric magic eEDM exp with Spin Wheel SQUID polarimeter.
- R. Talman et al., Magnetic eEDM exp.
- JEDI Collaboration: dEDM “spin flipper” at COSY.

Electron Magic Momentum

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



Sokolov-Ternov Effect



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

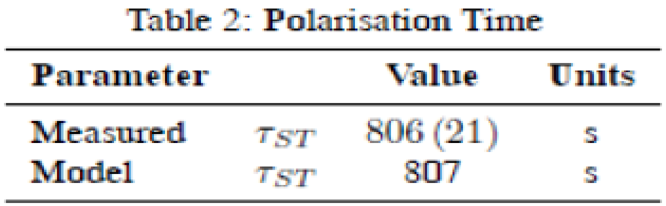
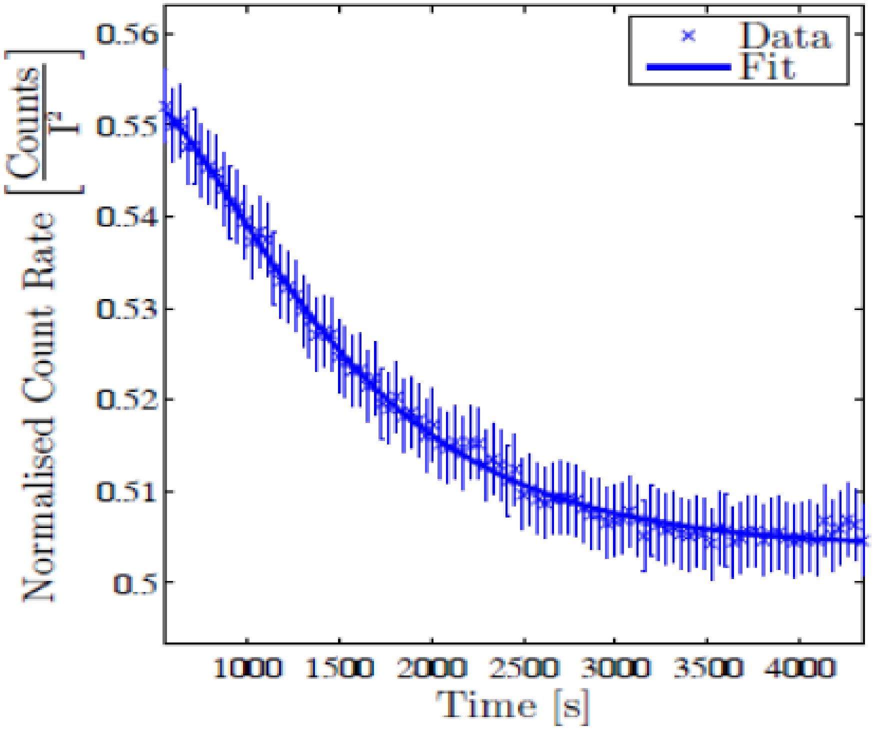
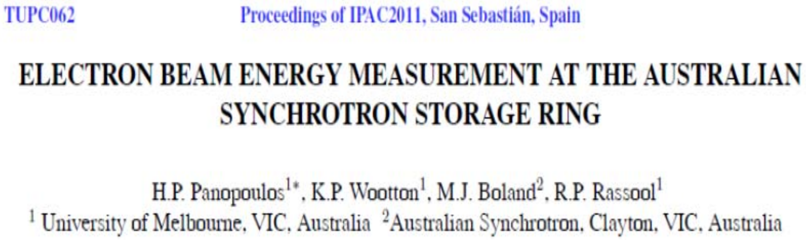


Table 2: Polarisation Time

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





ELECTRON BEAM ENERGY MEASUREMENT AT THE AUSTRALIAN SYNCHROTRON STORAGE RING

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Sokolov-Ternov Time Constant

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

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

Electron Proton Comparison

- Electron *ea/m* = 2.3 c^2/GV
- Proton *ea/m* = 1.9 c^2/GV

$$\vec{\omega}_a \approx \frac{e}{m}\left(a\vec{B} + \left(a - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right) \approx 0$$

Space Charge Tune Shift

- About the same for pEDM and eEDM!

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

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}

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

Intra-beam Scattering (IBS)

- About the same for pEDM and eEDM.

$$\propto \frac{e^4}{m^2 \beta^3 \gamma^4}$$

Touschek Scattering

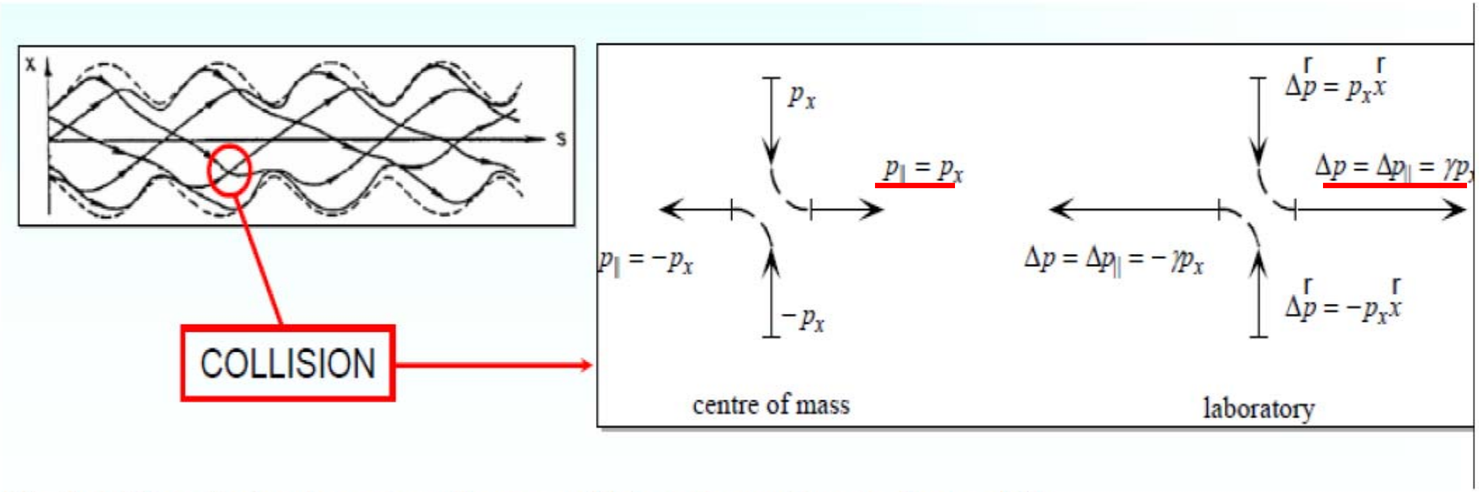
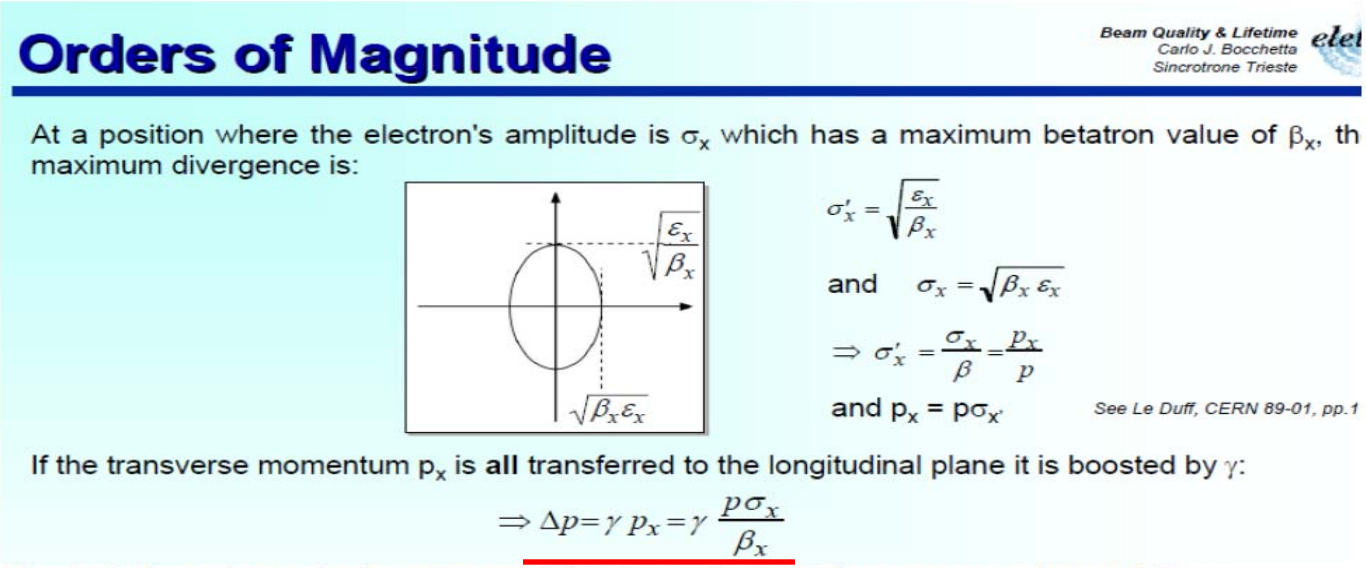


Fig. 3. IBS scattering in center of mass and laboratory reference frames [2].



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:

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

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

Beam-Beam Polarimeter?

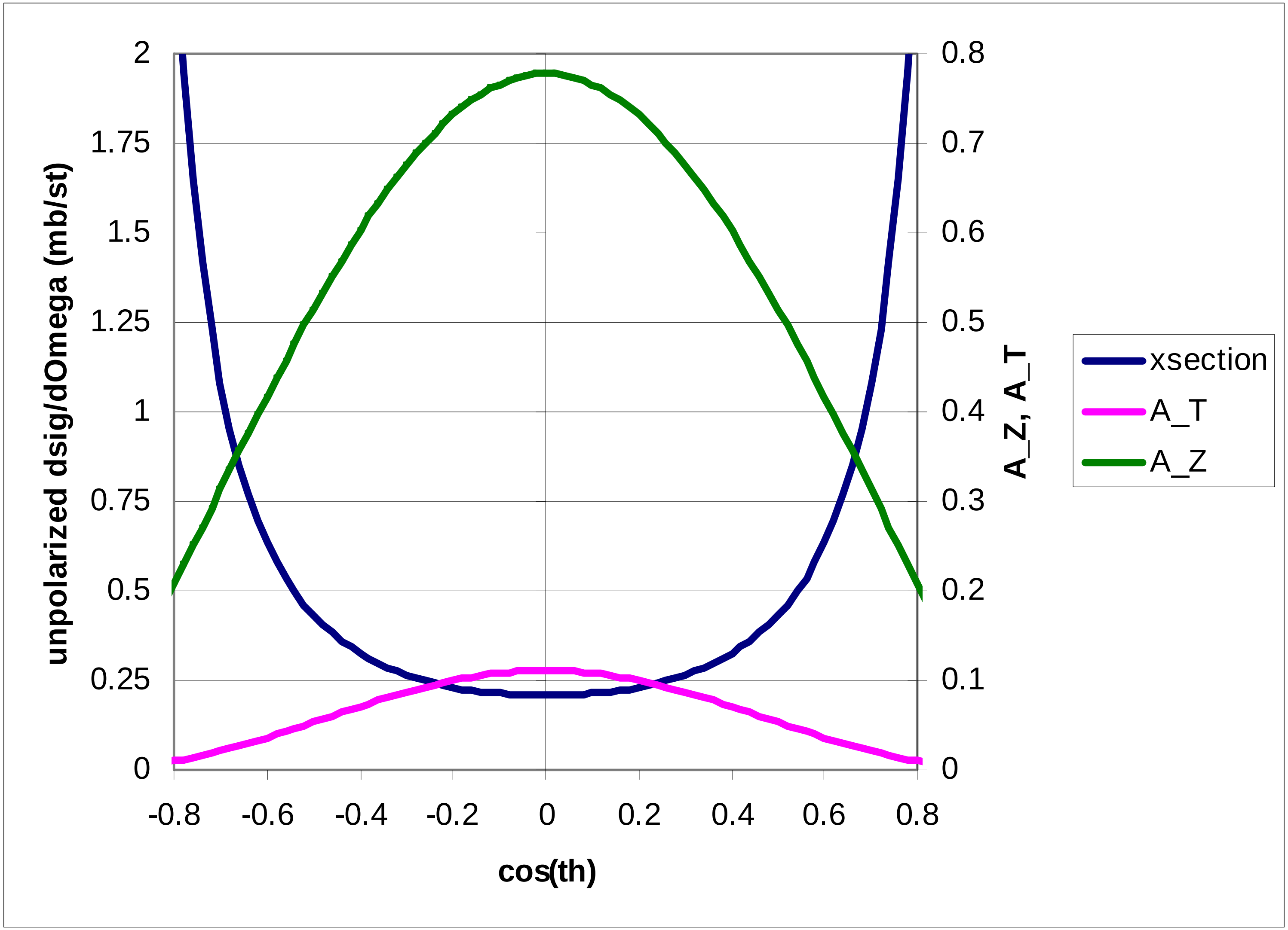
$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2}{s}\frac{\left(3+\cos^2\theta\right)^2}{\sin^4\theta}\left(1+A\right) \qquad (2)$$

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

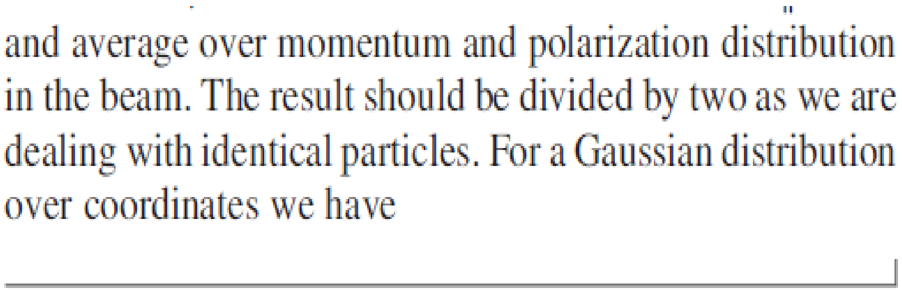
$$P_z=P\cos\theta_{spin} \qquad P_y=P\sin\theta_{spin}\sin\phi_{spin} \qquad P_x=P\sin\theta_{spin}\cos\phi_{spin}$$

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

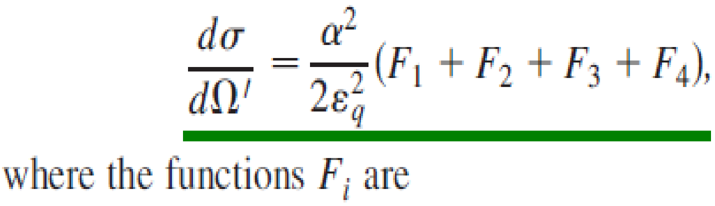
Beam-Beam Polarimeter?



$ee \to ee$ V. Strakhovenko, PRST 14, 012803 (2011)

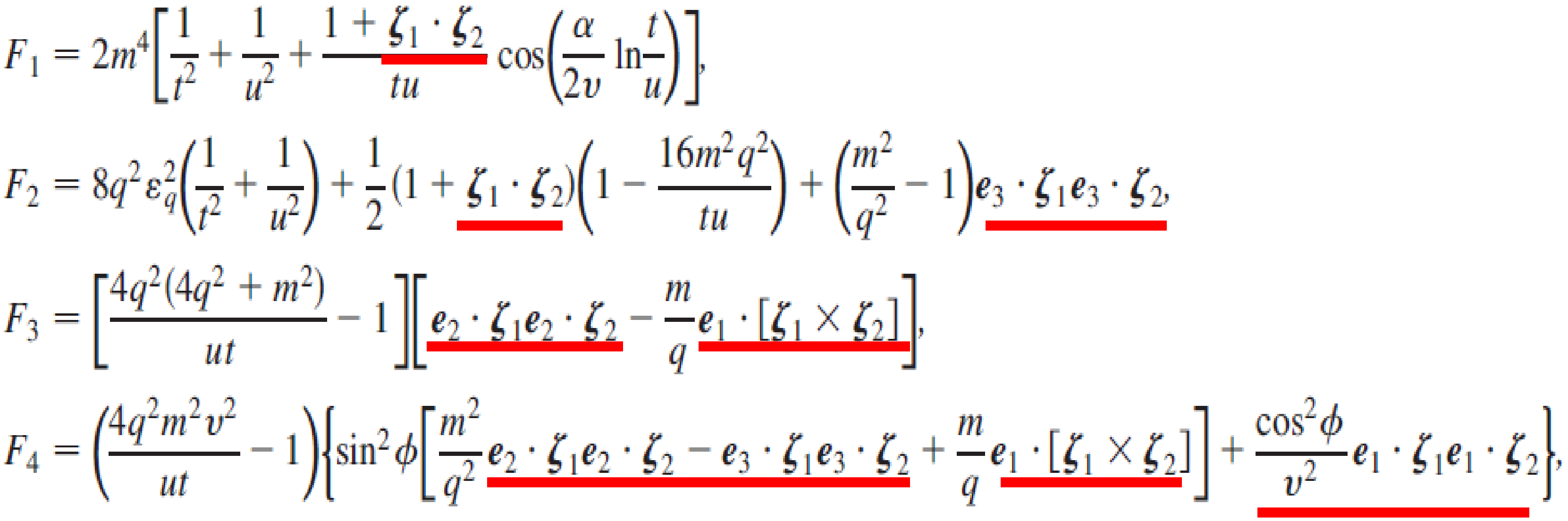


and average over momentum and polarization distribution in the beam. The result should be divided by two as we are dealing with identical particles. For a Gaussian distribution over coordinates we have



$$\underline{\frac{d\sigma}{d\Omega'} = \frac{\alpha^2}{2\varepsilon_q^2}(F_1 + F_2 + F_3 + F_4),}$$

where the functions F_i are



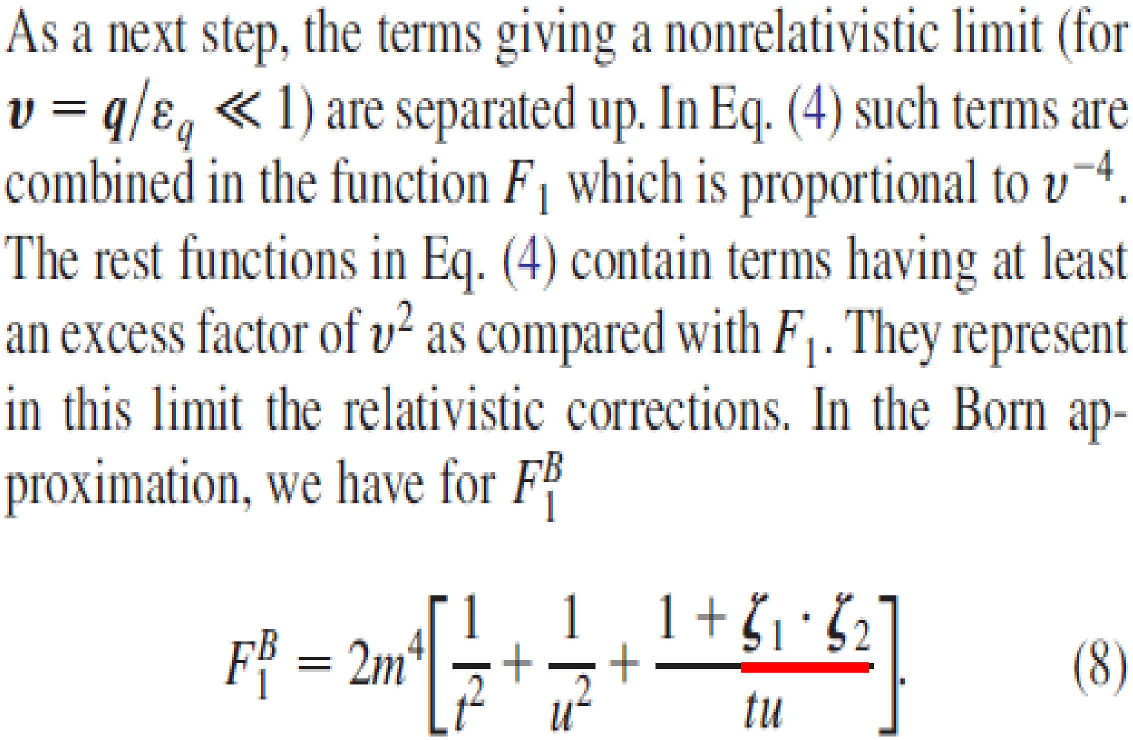
$$F_1 = 2m^4\left[\frac{1}{t^2} + \frac{1}{u^2} + \frac{1 + \underline{\zeta_1 \cdot \zeta_2}}{tu}\cos\left(\frac{\alpha}{2v}\ln\frac{t}{u}\right)\right],$$

$$F_2 = 8q^2\varepsilon_q^2\left(\frac{1}{t^2} + \frac{1}{u^2}\right) + \frac{1}{2}(1 + \underline{\zeta_1 \cdot \zeta_2)}\left(1 - \frac{16m^2q^2}{tu}\right) + \left(\frac{m^2}{q^2} - 1\right)\underline{e_3 \cdot \zeta_1 e_3 \cdot \zeta_2,}$$

$$F_3 = \left[\frac{4q^2(4q^2 + m^2)}{ut} - 1\right]\left[\underline{e_2 \cdot \zeta_1 e_2 \cdot \zeta_2} - \frac{m}{q}\underline{e_1 \cdot [\zeta_1 \times \zeta_2]}\right],$$

$$F_4 = \left(\frac{4q^2m^2v^2}{ut} - 1\right)\left\{\sin^2\phi\left[\frac{m^2}{q^2}\underline{e_2 \cdot \zeta_1 e_2 \cdot \zeta_2 - e_3 \cdot \zeta_1 e_3 \cdot \zeta_2} + \frac{m}{q}\underline{e_1 \cdot [\zeta_1 \times \zeta_2]}\right] + \frac{\cos^2\phi}{\underline{v^2}}\underline{e_1 \cdot \zeta_1 e_1 \cdot \zeta_2}\right\},$$

Non-Relativistic Limit
Touschek Scattering



As a next step, the terms giving a nonrelativistic limit (for $\boldsymbol{v} = \boldsymbol{q}/\varepsilon_q \ll 1$) are separated up. In Eq. (4) such terms are combined in the function F_1 which is proportional to v^{-4}. The rest functions in Eq. (4) contain terms having at least an excess factor of v^2 as compared with F_1. They represent in this limit the relativistic corrections. In the Born approximation, we have for F_1^B

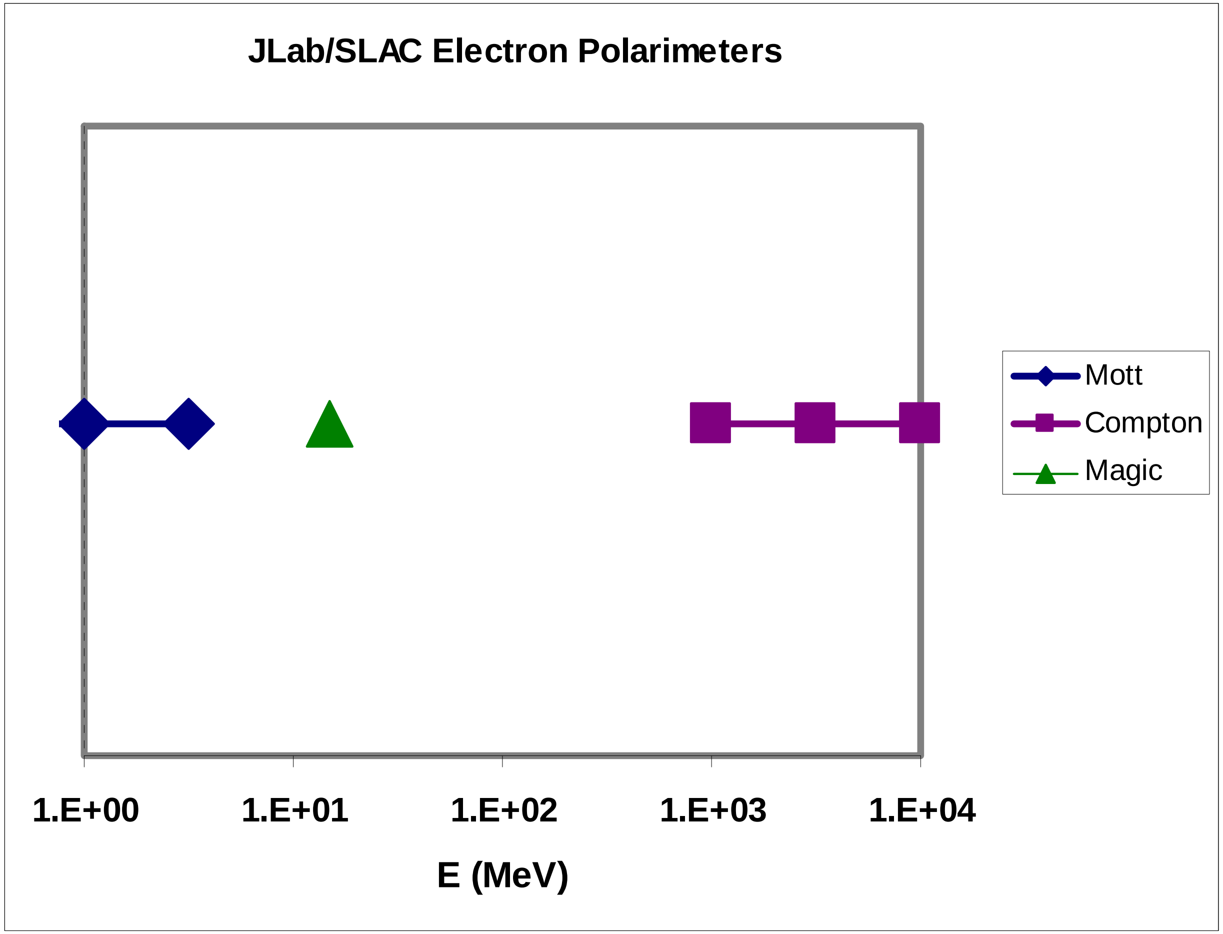
$$F_1^B = 2m^4\left[\frac{1}{t^2} + \frac{1}{u^2} + \frac{1 + \underline{\zeta_1 \cdot \zeta_2}}{tu}\right]. \qquad (8)$$

All Electric eEDM Conclusions

- Beam-beam polarimeter not good.
- Touschek polarimeter not good.
- Mott polarimeter not good (15MeV is too high).
- Compton polarimeter not good (15MeV too low).
- I. Koop: Spin Wheel/SQUID polarimetry.
- R. Talman: High Q resonator polarimetry.
- The three main issues are polarimetry, polarimetry, and polarimetry!
- The eEDM polarimetry needs R&D, etc.

Extra

Electron Magic Energy Polarimetry Stinks!



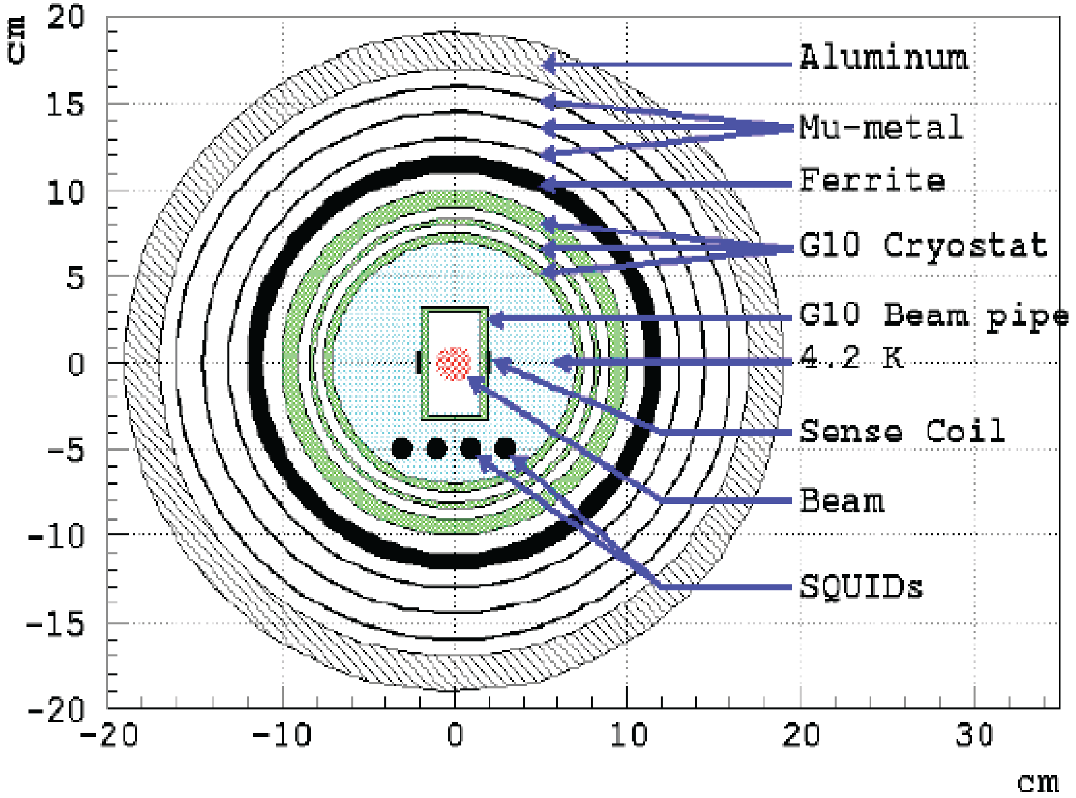
$\langle B_R \rangle$ Systematic

- 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.

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

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)

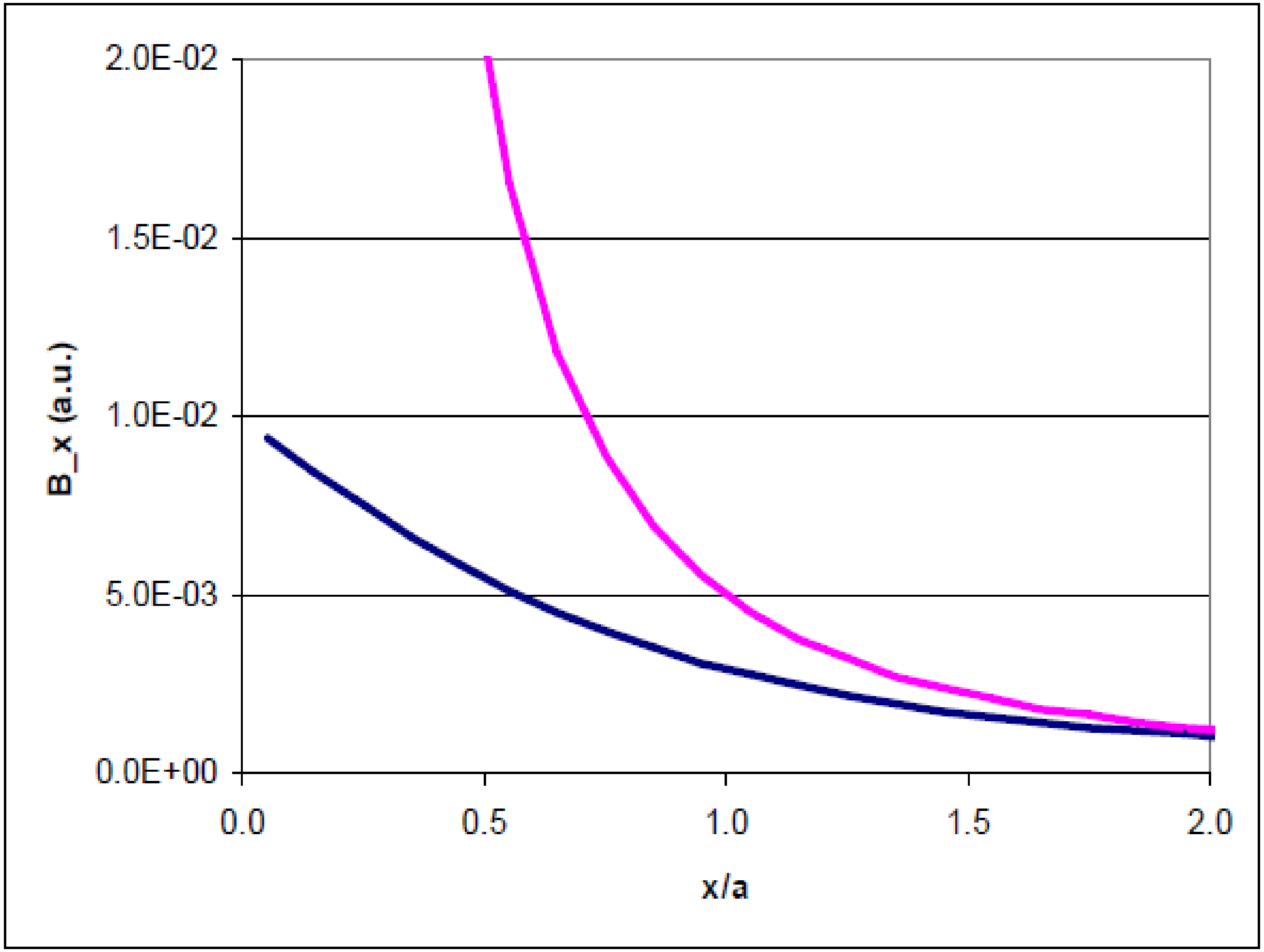


Fig. 3. $B_x(x, y = 0)$ vs. x/a for the beam distribution given in Fig. 1 (dark blue), and CW/CCW line currents with the vertical closed orbit difference (rose curve).

Touschek Scattering

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

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