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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>( \tau_{ST} )</td>
<td>806 (21) s</td>
</tr>
<tr>
<td>Model</td>
<td>( \tau_{ST} )</td>
<td>807 s</td>
</tr>
</tbody>
</table>

Electron Beam Energy Measurement at the Australian Synchrotron Storage Ring

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Sokolov-Ternov Time Constant

• Need $\tau_{ST} > 10^9$ s

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

- Electron $ea/m = 2.3 \text{ c}^2/\text{GV}$
- Proton $ea/m = 1.9 \text{ c}^2/\text{GV}$
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!

<table>
<thead>
<tr>
<th></th>
<th>proton</th>
<th>electron</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$</td>
<td>5.6</td>
<td>2.0</td>
</tr>
<tr>
<td>$m$</td>
<td>938 MeV</td>
<td>511 KeV</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.25</td>
<td>29.4</td>
</tr>
<tr>
<td>$g/m\gamma^2$</td>
<td>3.8 GeV$^{-1}$</td>
<td>4.5 GeV$^{-1}$</td>
</tr>
</tbody>
</table>
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

At a position where the electron’s amplitude is $\sigma_x$ which has a maximum betatron value of $\beta_x$, the maximum divergence is:

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

and

$$\sigma_x = \sqrt{\beta_x \sigma_x^2}$$

If the transverse momentum $p_x$ is all transferred to the longitudinal plane it is boosted by $\gamma$:

$$\Rightarrow \Delta p = \gamma p_x = \gamma \frac{p x}{\beta}$$

Fig. 4. Orders of magnitude estimate of the change in the Lab momentum from ref. 2.
Beam-Beam Polarimeter?

\[
\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{s} \frac{(3 + \cos^2 \theta)^2}{\sin^4 \theta} (1 + A) \quad (2)
\]

\[
A(\theta, \phi) = -P_z^2 A_z(\theta) - P_T^2 A_T(\theta) \cos(2\phi - 2\phi_{\text{spin}}) \quad (3)
\]

\[
P_z = P \cos \theta_{\text{spin}} \quad P_y = P \sin \theta_{\text{spin}} \sin \phi_{\text{spin}} \quad P_x = P \sin \theta_{\text{spin}} \cos \phi_{\text{spin}}
\]

\[
P_T^2 = P_x^2 + P_y^2
\]
Beam-Beam Polarimeter?

![Graph showing unpolarized differential cross-section and polarizations $A_Z$ and $A_T$.]
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

\[
\frac{d\sigma}{d\Omega'} = \frac{\alpha^2}{2\epsilon_q^2} (F_1 + F_2 + F_3 + F_4),
\]

where the functions \( F_i \) are

\[
F_1 = 2m^4 \left[ \frac{1}{l^2} + \frac{1}{w^2} + \frac{1 + \xi_1 \cdot \xi_2}{tu} \cos \left( \frac{\alpha}{2\nu} \frac{t}{u} \right) \right],
\]

\[
F_2 = 8q^2 \varepsilon_q^2 \left[ \frac{1}{l^2} + \frac{1}{w^2} \right] + \frac{1}{2} \left( 1 + \xi_1 \cdot \xi_2 \right) \left( 1 - \frac{16m^2q^2}{tu} \right) + \left( \frac{m^2}{q^2} - 1 \right) e_3 \cdot \xi_1 e_3 \cdot \xi_2,
\]

\[
F_3 = \left[ \frac{4q^2(4q^2 + m^2)}{ut} \right] - 1 \left[ e_2 \cdot \xi_1 e_2 \cdot \xi_2 - \frac{m}{q} e_1 \cdot [\xi_1 \times \xi_2] \right],
\]

\[
F_4 = \left( \frac{4q^2m^2v^2}{ut} - 1 \right) \sin^2 \phi \left[ \frac{m^2}{q^2} e_2 \cdot \xi_1 e_2 \cdot \xi_2 - e_3 \cdot \xi_1 e_3 \cdot \xi_2 + \frac{m}{q} e_1 \cdot [\xi_1 \times \xi_2] \right] + \frac{\cos^2 \phi}{v^2} e_1 \cdot \xi_1 e_1 \cdot \xi_2.
\]
As a next step, the terms giving a nonrelativistic limit (for $v = q/\epsilon_q \ll 1$) 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 $F_1^B$

$$F_1^B = 2m^4 \left[ \frac{1}{t^2} + \frac{1}{u^2} + \frac{1 + \zeta_1 \cdot \zeta_2}{tu} \right].$$  \hspace{1cm} (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.
- The three main issues are polarimetry, polarimetry, and polarimetry!
- The eEDM polarimetry needs R&D, etc.
Extra
Electron Magic Energy Polarimetry Stinks!

JLab/SLAC Electron Polarimeters
\(<B_R>\) 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.

\[ \Delta y_{CW-CCW} = \pm \frac{c_\beta B_{RN} R_0}{E_0 \left( N^2 - Q_y^2 \right)} \cos(N(\theta + \phi_N)) \]
What is critical

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

First funding from US-Japan for testing at RHIC
1. Beam Position Monitors

- Technology of choice: Low $T_c$ SQUIDS, signal at $\sim 10^4$Hz (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

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

\[ \Delta T_{\text{admit}} \approx \pm 0.1 \text{MeV} \]