CLAS TWO PHOTON EXCHANGE EXPERIMENT

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Abstract

The electromagnetic form factors are essential pieces of our knowledge of nucleon structure. However, there is a large discrepancy between the proton electric form factor (G_E^p) measured using the Rosenbluth separation and polarization transfer methods. The most likely explanation is two-photon exchange (TPE). The real part of the TPE amplitude is proportional to the ratio of the cross sections of electron-proton and positron-proton elastic scattering. The TPE experiment recently measured this ratio in Jefferson Lab Hall B using a mixed identical electron/positron beam hitting a liquid hydrogen target. We measured the resulting e^+p and e^-p elastic scattering events simultaneously in CLAS for Q^2 up to 2.5 GeV^2 and nearly the entire epsilon range.

1. Motivation

- In non-relativistic limits, proton form factors $G_E(Q^2)$ and $G_M(Q^2)$ give the spatial distribution of charge and magnetism carried by proton.

Rosenbluth separation method – $p(e, e')$

- Elastic electron-proton scattering (one photon exchange)

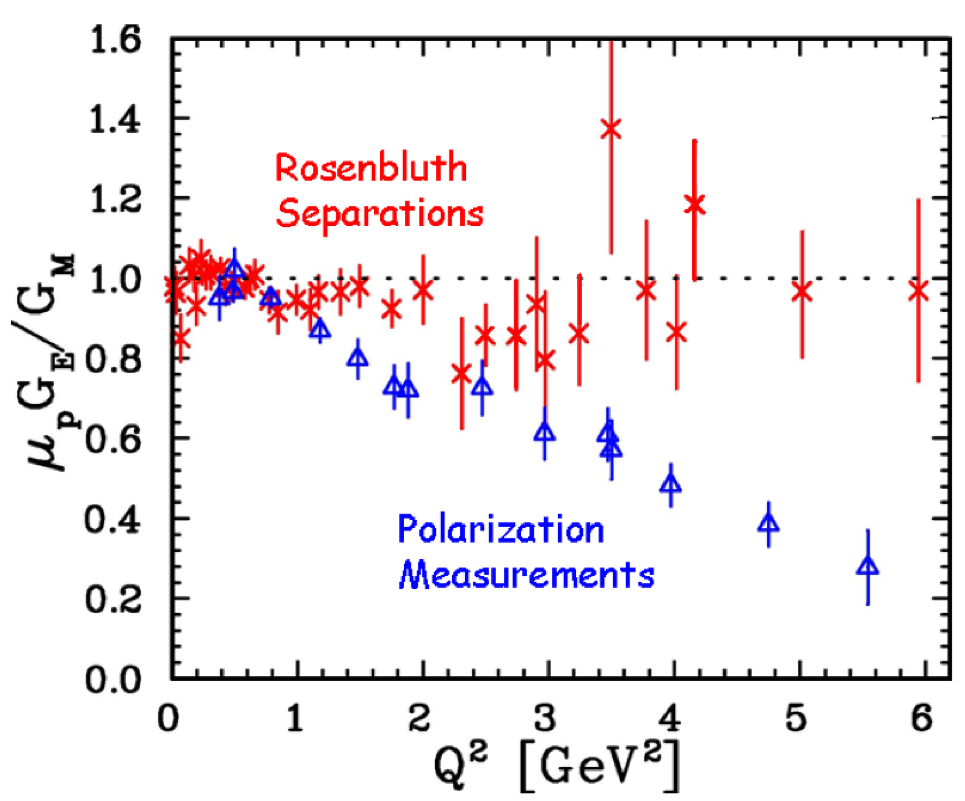
$$\frac{d\sigma}{d\Omega} = \sigma_{mott}\frac{E'_e}{E_e}\left\{\frac{G_E^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2\tan^2(\theta_e/2)\right\} \quad \text{where } \tau = \frac{Q^2}{4M_p^2}$$

- Separate G_E and G_M by varying incident electron energy (E_e) and scattering angle (θ_e) at fix Q^2

Polarization transfer method - $p(\vec{e}, e'\vec{p})$

- A longitudinally polarized electron transfers its polarization to recoil proton.
- Transverse (P_t) and longitudinal (P_l) polarization of the recoiled proton are measured.

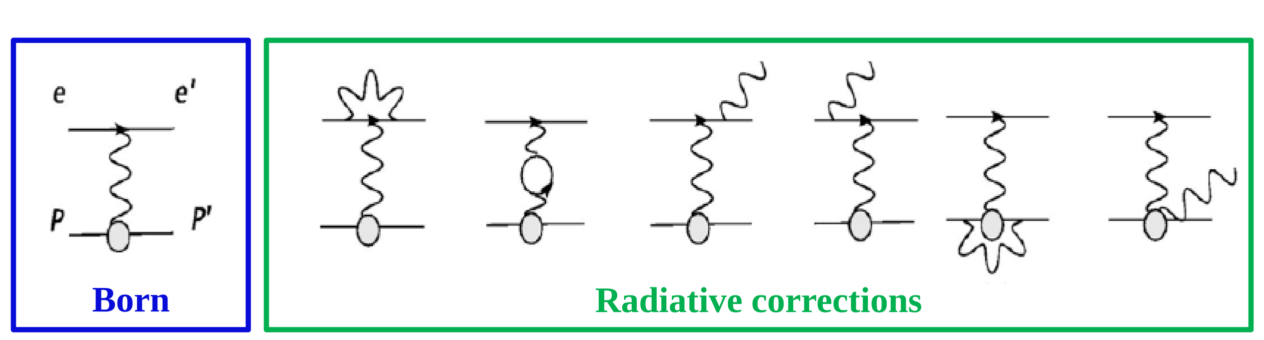
$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{E_e+E'_e}{2M_p}\tan(\theta_e/2)$$

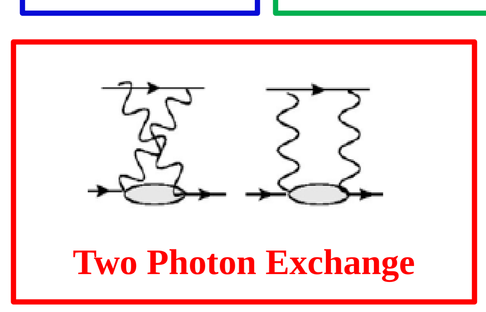


- Possible explanation is the two photon exchange correction to the Rosenbluth separation measurements.

2. Two Photon Exchange (TPE)

- We measure the positron-proton to electron-proton elastic scattering cross-section ratio to determine the TPE correction.





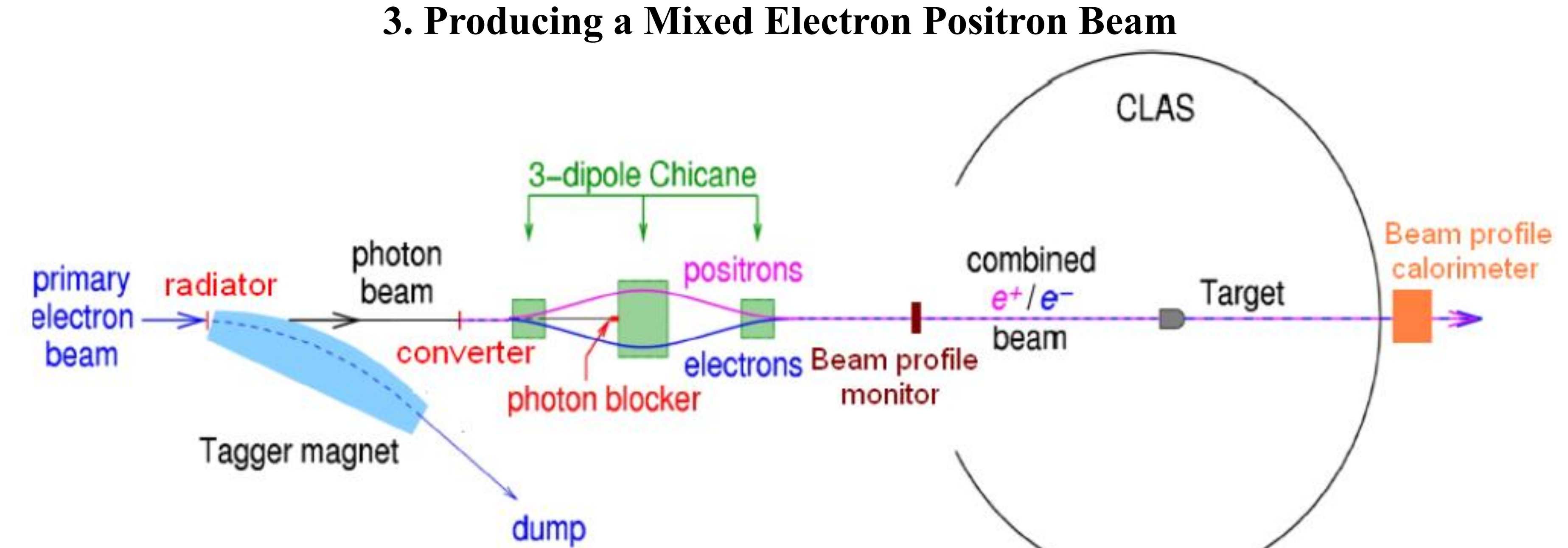
$$\sigma(e^{\pm}p) \propto |A_{ep\to ep}|^2 = |A_{Born} + \ldots + A_{2\gamma}|^2$$

$$\sigma(e^{\pm}p) \propto |A_{Born}|^2 \pm 2A_{Born}\mathrm{Re}(A_{2\gamma})$$

$$R = \frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 - \frac{4\mathrm{Re}(A_{2\gamma})}{A_{Born}}$$

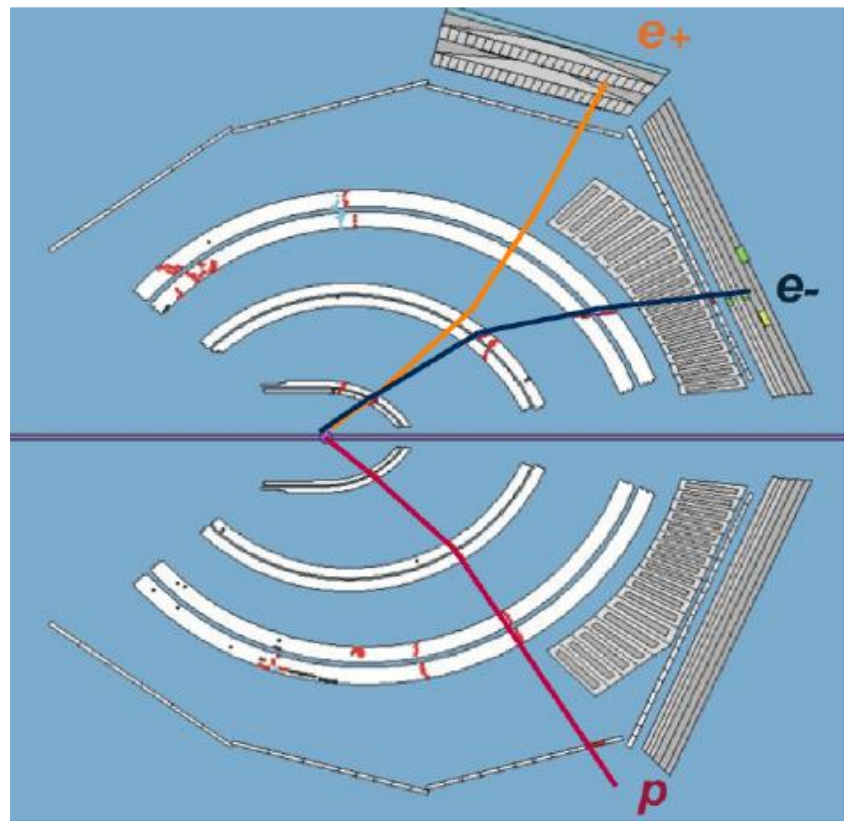
- TPE contribution is expected to be ~ 5-8% in Rosenbluth cross-section.

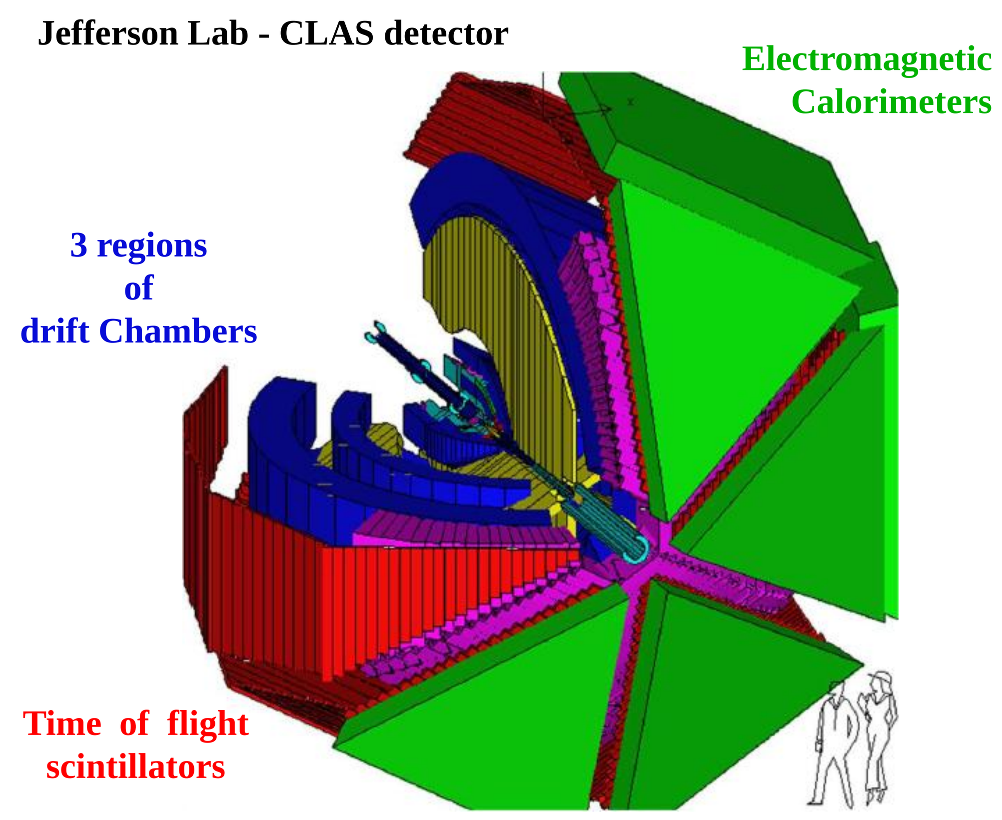
3. Producing a Mixed Electron Positron Beam



- Primary electron beam: 5.5 GeV and 100-120 nA
- Radiator: 0.9% of primary electrons radiate high energy photons
- Tagger magnet: sweep the primary electrons to the tagger dump
- Converter: 9% of photons convert to electron/positron pairs
- Chicane: separate the lepton beams, stop photons and recombine the e+ and e- beams
- Target: 30 cm liquid hydrogen
- Detector: CEBAF Large Acceptance Spectrometer (CLAS)
- Lots of shielding (not shown)

4. TPE Data Collection (Nov 30, 2010 - Feb 25, 2011)





- Trigger on particle in forward TOF and EC hit on the same sector in coincidence with TOF hit on the opposite sector → EVENT
- For positive torus, electrons bend in, positrons bend out
- Torus magnet polarity reversed weekly → reverses particle bending
- Chicane magnet polarity reversed weekly → reverses electron positron beam distributions
- Collected 12 billion trigger events

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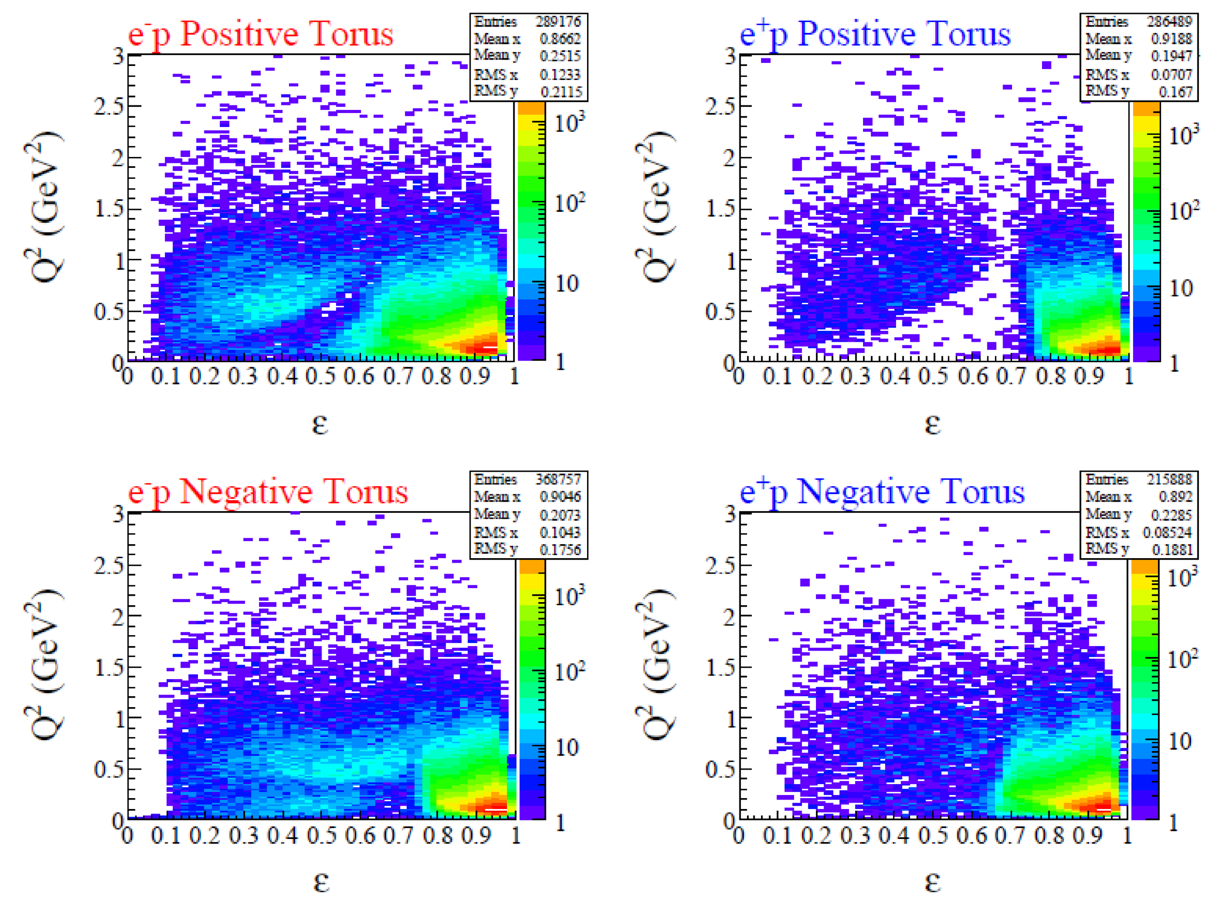
&

CLAS Collaboration

5. Elastic Event Identification

- Look for two particle events with ++ or −+ charge combination
- For ++ events, use timing information to identify positron
- Target-vertex cut: ensure events come directly from target
- Co-planarity cut: $\Delta\varphi = \varphi_e - \varphi_p \approx 180^\circ$
- Transverse momentum cut: conserve total momentum transverse to beam direction
- Beam energy difference cut: $\Delta E = E_1 - E_2 \approx 0$
  where $E_1 = P_{pz} - P_{ez}$ and E_2 depends only on the electron and proton angles.

Presented here is only 2% of total statistics
Preliminary without calibration and acceptance corrections



6. Acceptance Effect Elimination

- Determine regions of the CLAS with full acceptance for both positive and negative particles
- Remaining proton acceptance effects cancel in the ratio R of e^+p/e^-p events for one torus polarity
- Remaining e^+ and e^- acceptance effects cancel in the product $R_2 = (R_+ R_-)^{1/2}$ of the ratios for the two torus polarities
- e^+ and e^- beam asymmetries cancel in the product $R_4 = (R_{2+} R_{2-})^{1/2}$ of the double ratios for the two chicane polarities

7. Conclusion

- First measurement using simultaneous identical electron/positron beams
- Measure the ratio of cross sections for e^+p to e^-p elastic scattering to extract TPE effect
- Determine if TPE explains the proton form factor discrepancy
- Calibration and analysis are under way
- Exciting physics result expected soon!!!