Beyond the Born Approximation

Measuring the Two Photon Exchange Correction in Hall D

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Hall D PWG
Newport News, VA

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Start with some conclusions

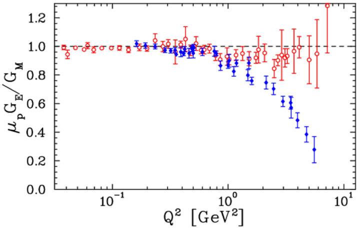
- Large discrepancy in G_E^p measurements that grows with Q^2
  $\rightarrow$ Resolvable by considering $\sigma(e^+p)/\sigma(e^-p)$
- CLAS eg5 experiment
  $\rightarrow$ Produced simultaneous e^+/e^- ($\sim$ 100 pA each)
  $\rightarrow$ Continuous beam energy distribution (Brem. beam)
  $\rightarrow$ Wide Q^2 and angle (ε) coverage
- Control over systematics
  $\rightarrow$ Extensive beam profiling
  $\rightarrow$ Simultaneous e^+/e^- measurements
  $\rightarrow$ Reversed magnets to remove acceptance and beam asymmetries
- Initial Hall B results consistent with e^+/e^- ratio needed to resolve G_E^p discrepancy.
- This experiment can be done much better in Hall D!
  $\rightarrow$ Discrepancy grows with Q^2
  $\rightarrow$ Can select high energy photons in Hall D
  $\rightarrow$ Tagger is in separate building
  $\rightarrow$ Install chicane magnet in Hall D alcove (install hermetic shielding wall)

Purpose of presenting today

- Show you some preliminary results from the Hall B experiment
- Let you know that we are interested in doing Hall B-like TPE experiment in Hall D
- Why we think Hall D can do it better.
- Who else is interested?
- Are there any show stoppers?

1. Physics Motivation
2. TPE
3. Experiment
4. Analysis overview
5. Results
6. Hall D

The Proton Formfactor Puzzle



- Rosenbluth Separation: (SLAC, MIT BATES, JLab et al.)

$$\sigma_r = \left(\frac{d\sigma}{d\Omega}\right)\left[\frac{\varepsilon(1+\tau)}{\sigma_{mott}}\right] = \tau G_M^2 + \epsilon G_E^2$$

$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\theta_e/2\right]^{-1} \quad \tau = \frac{Q^2}{4M^2}$$

- Separate G_E and G_M contributions at a particular Q^2 using different beam energies and scattered electron angles
- G_M measurement dominates at high Q^2, G_E is suppressed

- Polarization Transfer: (Hall A & C)

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E_e + E_{e'})}{2M}\tan\frac{\theta_e}{2}$$

- Longitudinal polarized electrons incident on proton target
- Measure transverse and longitudinal polarization of recoiled proton

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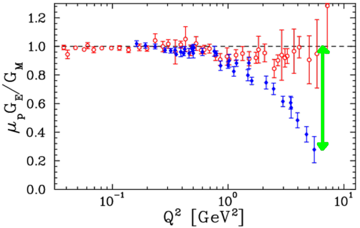

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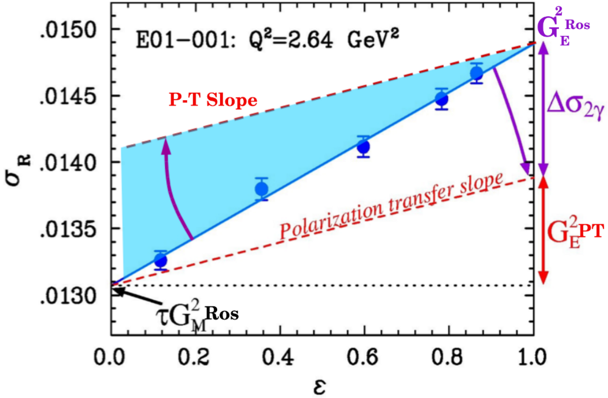
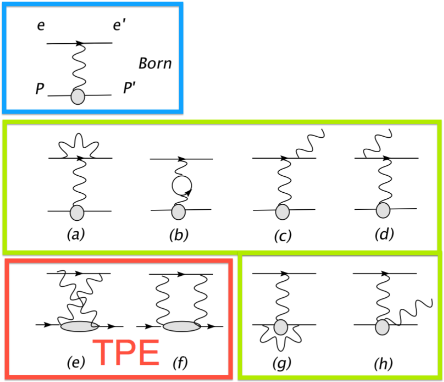


- Use G_M from Rosenbluth Separation and G_E from Polarization Transfer
- To account for the difference we need a ε dependent correction to the cross section on the order of a few percent

TPE Contribution



- Modified G_E and G_M
- New ε dependent term

The general $1-\gamma$ and $2-\gamma$ exchange amplitudes

$$A = \frac{e^2}{Q^2}\bar{u}(k')\gamma^\mu u(k)$$

$$1: \times \bar{u}(p')\left[G_M\gamma^\mu - F_2\frac{P^\mu}{M}\right]u(p)$$

$$2: \times \bar{u}(p')\left[\tilde{G}_M\gamma^\mu - \tilde{F}_2\frac{P^\mu}{M} + \tilde{F}_3\frac{\gamma K P^\mu}{M^2}\right]u(p)$$

The general $1-\gamma$ and $2-\gamma$ exchange cross section

$$1: \frac{d\sigma}{d\Omega} \propto \left[\varepsilon G_E^2 + \tau G_M^2\right]$$

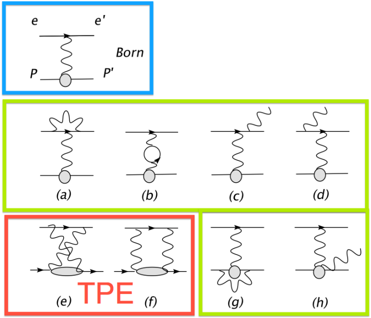
$$2: \frac{d\sigma}{d\Omega} \propto \left[\varepsilon \tilde{G}_E^2 + \tau \tilde{G}_M^2\right] + \left[2\varepsilon\left(\tau|\tilde{G}_M| + |\tilde{G}_E\tilde{G}_M|\right)Y_{2\gamma}\right]$$

$$Y_{2\gamma} \propto Re\left(\frac{\tilde{F}_3}{|\tilde{G}_M|}\right)$$

Guichon and Vanderhaeghen, PRL 91 (03) 142303

Positrons to the rescue!

- The Born amplitude changes sign as the the charge of the incident beam.
- The leading TPE terms of the elastic scattering cross section are sensitive to the lepton charge



The elastic $e^{\pm}p \rightarrow e^{\pm}p$ scattering contribution:

$$\sigma(e^{\pm}) \propto |A_{born} + \cdots \pm A_{2\gamma}|^2$$
$$\sigma(e^{\pm}) \propto |A_{born}(\alpha)|^2 \pm 2A_{born}(\alpha)\mathrm{Re}(A_{2\gamma})$$

The ratio of the cross sections isolates the TPE correction term

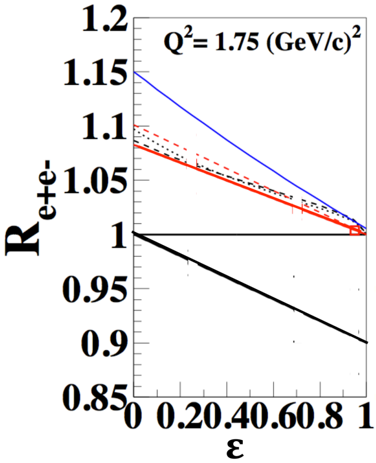
$$R = \frac{\sigma(e^+)}{\sigma(e^-)} = 1 - 2\delta_{2\gamma}$$
$$\delta_{2\gamma} = \frac{2\mathrm{Re}(A_{2\gamma})}{A_{born}}$$

- We can calculate this very well (QED)
- Theoretical calculation of the diagram is hard : Need to integrate over all baryon states
- The e^-p/e^+p ratio measures the real part of the TPE contribution

Phenomenology

Phenomenological TPE Extractions

(to make Rosenbluth and Polarization Transfer G_E^p agree)

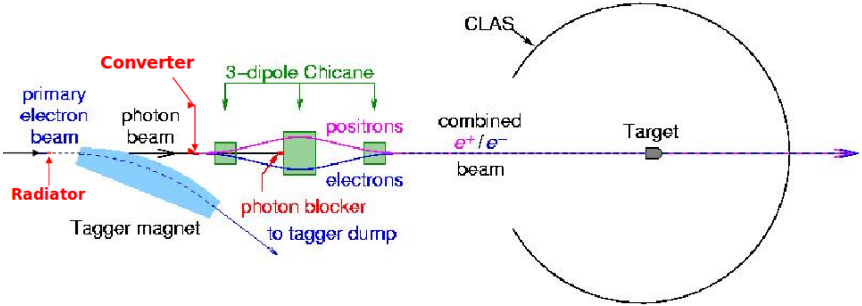


Parametrize the TPE amplitude and then fit the e+/e- ratio to the rosenbluth and polarization transfer data

Different e+/e- ratios can explain the G_E^p discrepancy

Qattan, Alsaad and Arrington, ArXiv arXiv:1109.1441

Making Positrons at CLAS



- Primary electron beam: 5.5 GeV and 100-120 nA
- Radiator: 0.9% of primary electrons radiate high energy photons
- Tagger magnet: Transport electrons tagger dump
- Converter: 9% of photons are converted to electron/positron pairs
- Chicane: separate the lepton beams
  – Remaining photons are stopped at the photon blocker
  – e^+ and e^- beams are then recombined and continue to the target
- Target: liquid hydrogen: length = 18cm (30 cm) & diameter = 6cm (6 cm)
- Detector: CLAS (DC, TOF)

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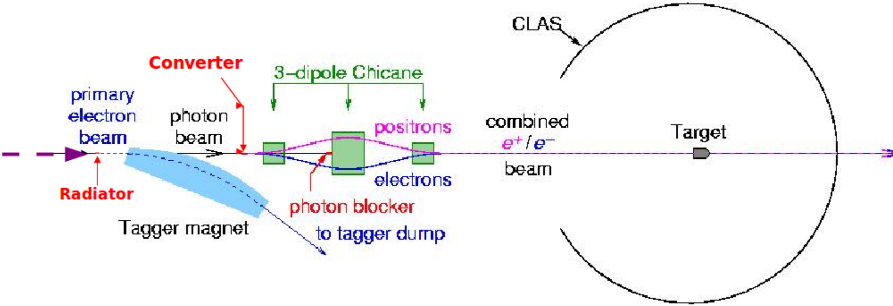

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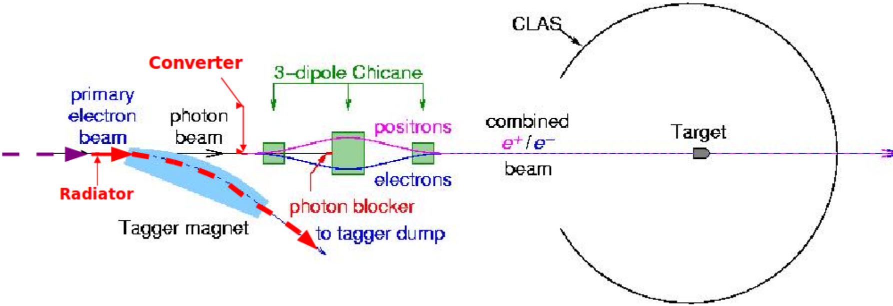

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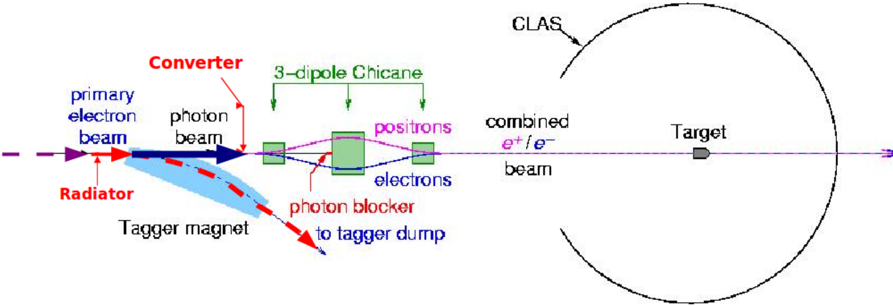

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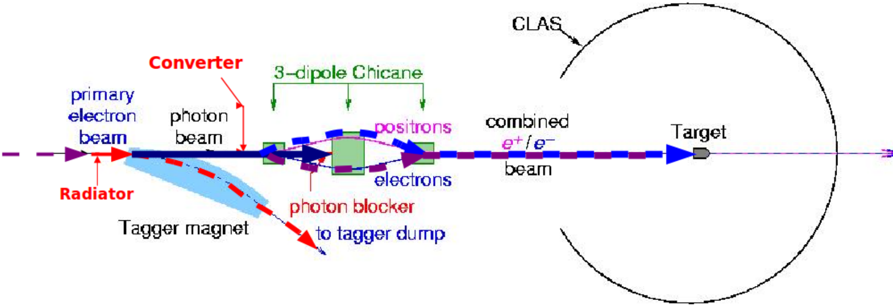

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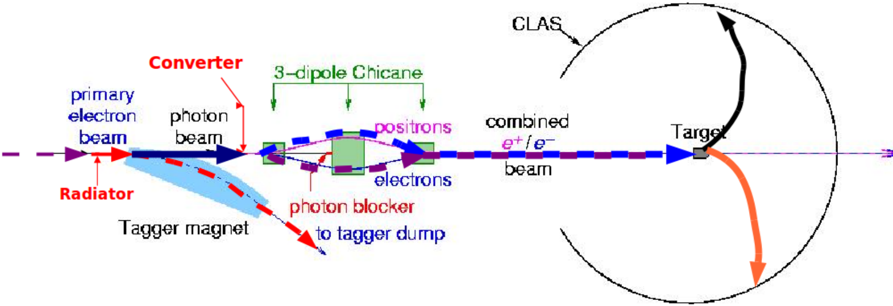

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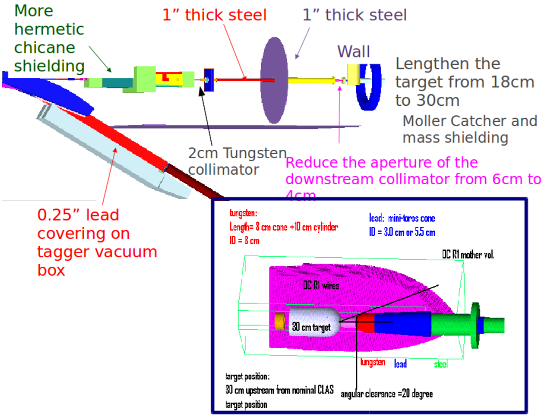
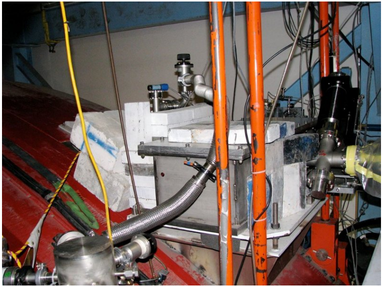
Beam Line Modification for TPE



- Extensive GEANT simulations of detector backgrounds.
- Confirmed simulation with test run data
- A lot of shielding added on tagger, tagger dump and chicane.
- Improved luminosity by a $\approx$ factor 100

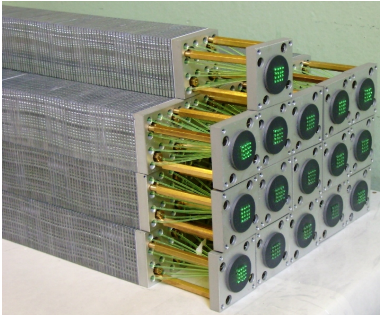
Beam Line Modification for TPE

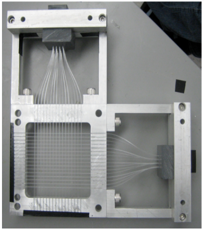


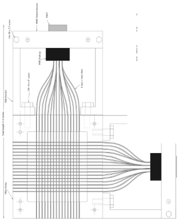
Beam Profiling

TPE Calorimeter

- Measure beam energy vs position during low luminosity run
- 30 module Shashlik (Pb/Scint) calorimeter
- Located directly downstream of CLAS on the forward carriage



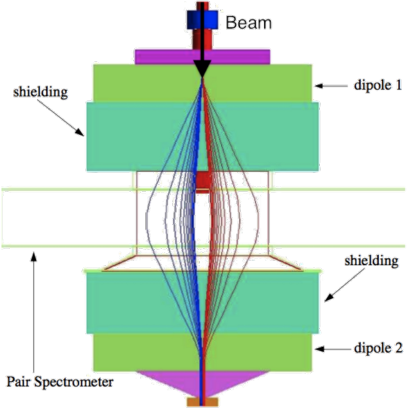


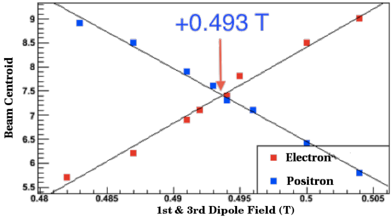


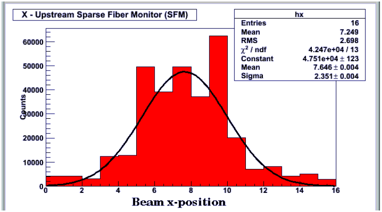
Fiber Monitors

- 16x16 Sparse fiber monitor continually monitoring beam profile before the target
- 64x64 Dense fiber monitor mounted on TPE Calorimeter face for beam profiling during low luminosity runs
- Bicron fibers spaced 5 mm (1mm) apart glued to a Hamamatsu PMT
- Beam size $\sim$ 15 mm radius

Systematic Beam Checks

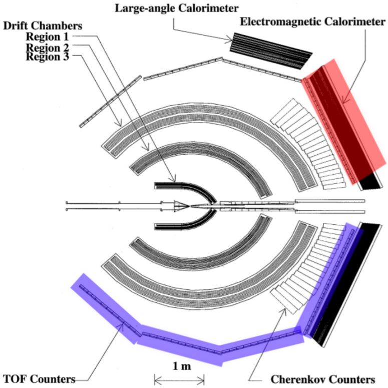






- Flipped chicane polarity about once a week
- Check for geometric alignment of e^-/e^+ on target – Varied steering magnet currents and measured individual beam positions at sparse fiber monitor
- Reproducible crossing for all chicane flips

Triggering, Cuts and Corrections



EC and TOF ($\theta < 45°$) and opposite sector TOF

1. Trigger on particle in forward 45^0 and anything in opposite sector
2. Target vertex cut (-45 cm $\leq V_z \leq -15$ cm)
3. Momentum Corrections
4. Proton energy loss corrections
5. Fiducial Cuts
6. Swimming – Acceptance matching $++$ and $+-$ events

Non-Standard PID & Elastic Event Selection

1. Select ++ and +− track pairs
2. Coplanarity cut ($\phi_{proton} - \phi_{lepton} \approx 180^0$)
3. Reconstructed Beam Energy:

$$\begin{aligned} E_1 &= M_P \left[\frac{1}{\tan(\theta_e/2)\tan(\theta_P)} - 1.0 \right] \\ E_2 &= P_e \cos(\theta_e) + P_p \cos(\theta_P) \\ \Delta E_{Beam} &= E_1 - E_2 \end{aligned}$$

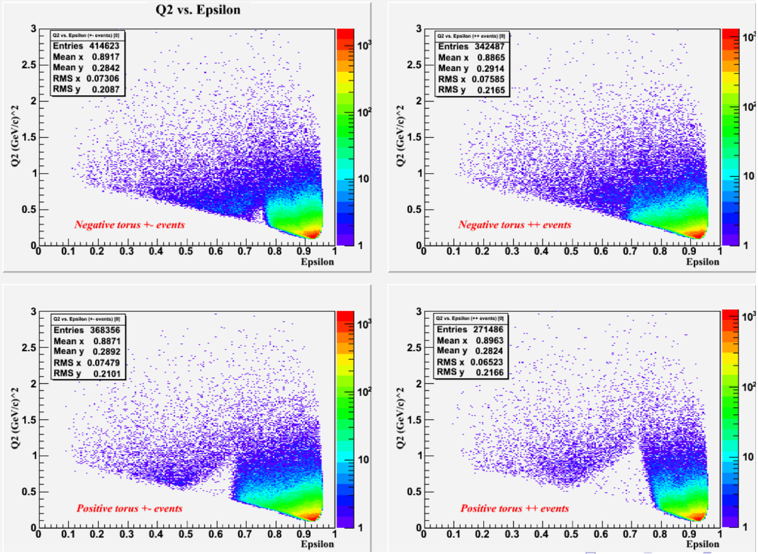
4. Scattered lepton Energy:

$$\Delta E'_e = E^e_{measured} - E^e(\theta_e, \theta_p)$$

5. Proton Momentum:

$$\Delta P(p) = P_p - \frac{P_e \sin(\theta_e)}{\sin(\theta_p)} \quad (1)$$

Q^2 vs ε (TPE II 2010-2011)



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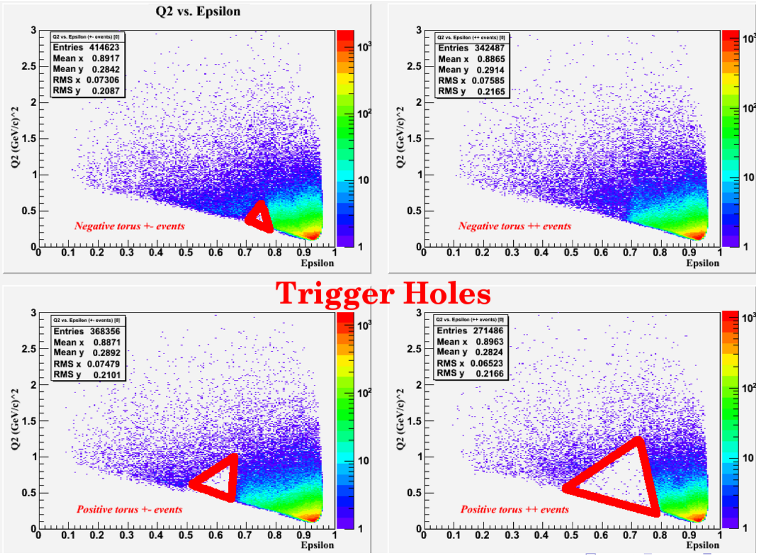
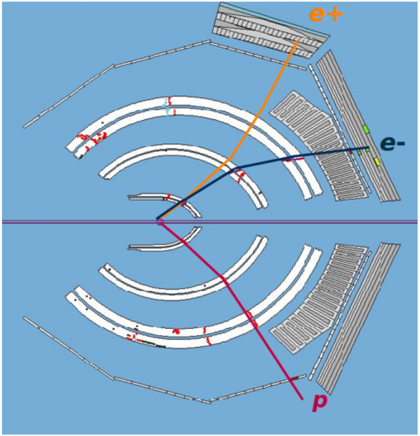


Ratios



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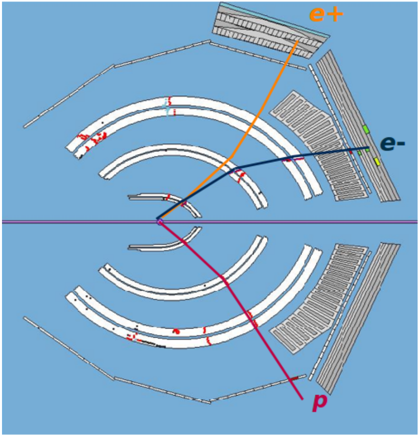

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   Proton acceptance cancels in the ratio

$$R = \frac{Y(e^+P)}{Y(e^-P)}$$

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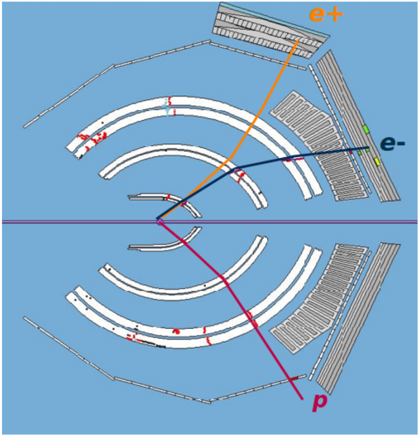

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$$R_2 = \sqrt{\left[\frac{Y_{e^+P}}{Y_{e^-P}}\right]^+ \times \left[\frac{Y_{e^+P}}{Y_{e^-P}}\right]^-}$$

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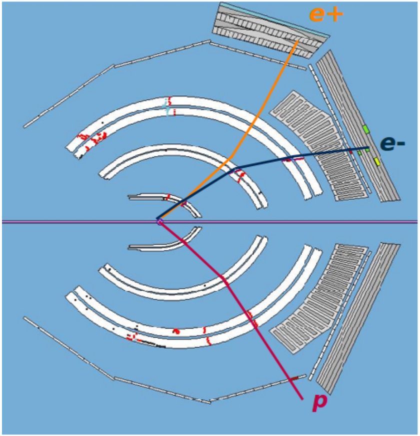

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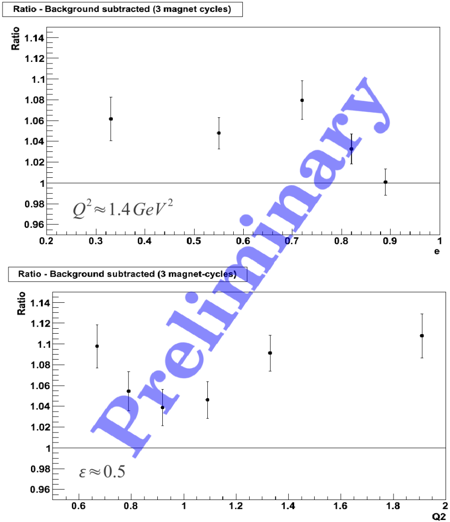
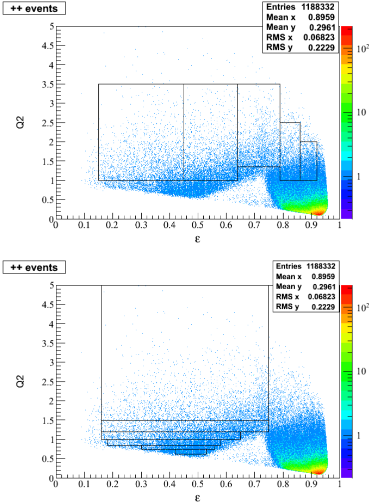
4. Flip chicane polarity: Beam asymmetries cancel in quadruple ratio

$$R_4 = \sqrt{R_2^+ \times R_2^-}$$

Preliminary Results



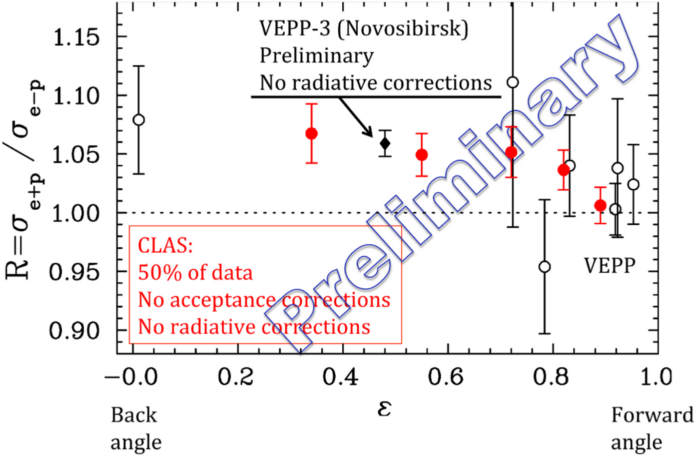
Binning



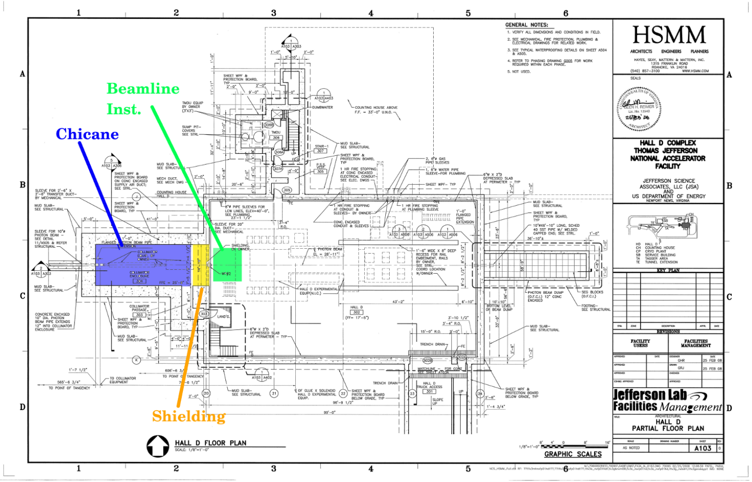
$\approx 75\%$ of total data set

Comparison to World Data

$Q^2 > 1$



Hall D Floorplan



Advantages of Hall D TPE

1. 12(9) GeV upgrade will provide much larger phase space – The G_E^P discrepancy grows with Q^2 ($\approx$ factor of 3 at $Q^2 = 6GeV$)
2. Hall D can select high energy photon beam
3. Photon beam is created in a separate building
   → Tracking efficiency suffered from high background rates

   → Limited our ability to push beam luminosity
4. There looks to be room to install the chicane in the alcove
   → Lots of shielding – wall off the alcove
5. Symmetric tracking of positively and negatively charged particles
6. Other programs interested in e^+ beam can piggy-back (e.g. DVCS)

Outstanding Hall D TPE Questions

1. Is the aperture at the target is wide enough. The tertiary beam we produced in Hall B was 5cm wide.
   – The start counter might be in the way
   – Can the start counter be removed and reinstalled without causing too much pain to Hall D?
2. Can the Hall-D solenoid magnetic field be reversed easily and in a repeatable way?
   – Unexpected detector asymmetries can cancel
3. Radiator thickness?
   – We used a 0.9% radiator in Hall B – Can we go thicker in Hall D?
4. What kind of dose can the tagger detectors handle?
   – We calculated that we would deposit several mega-Rad on the Hall B taggers, so we removed the plastic scintilators.
5. What p, θ and ϕ resolution can we acheive for e^+/e^-?
   – We will have to rely on over constrained kinematics to reconstruct the beam energy, since we would using brem beam
6. Any show stoppers I missed?

Thank you

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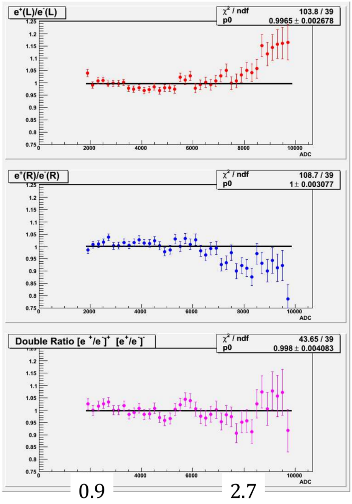
Beam Asymmetry



Incident lepton energy (GeV approx)

Beam asymmetries cancel in the super ratio

Normalized to incident beam charge

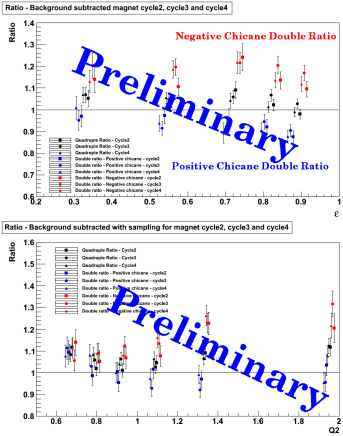
Left side of chicane:
Ratio of e+ to e-

Right side of chicane:
Ratio of e+ to e-

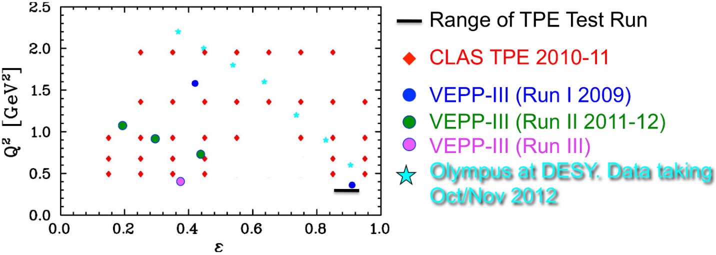
Combined e+/e- ratio
$\chi^2/ndf = 44/39$
$p0 = 0.998 \pm 0.004$

The chicane has a left/right asymmetry, not an e+/e- asymmetry

Magnet Cycle Dependence

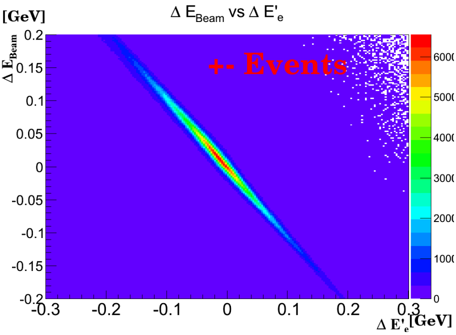


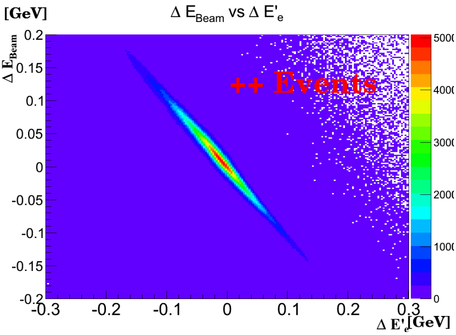
Comarison of Kinematic Coverage



ΔE_{Beam} vs $\Delta E'_e$

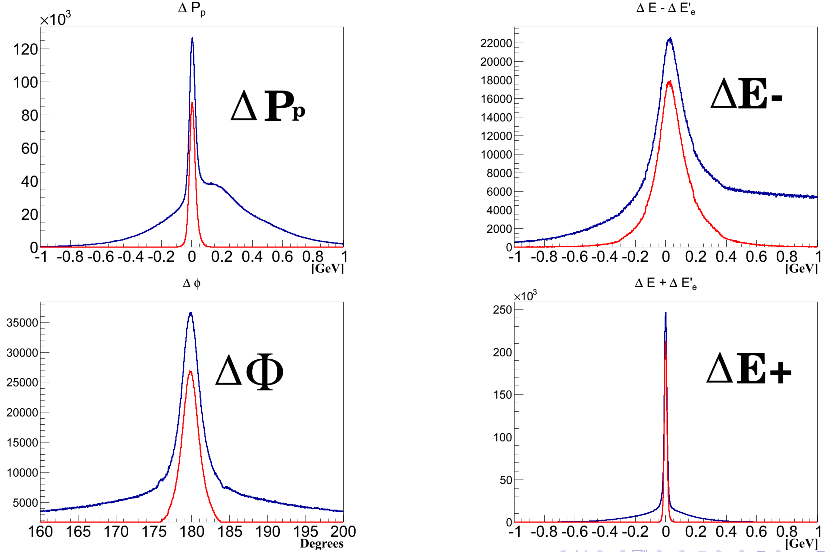
Δ E and Δ E'$_e$ are correlated, so we cut on the sum (Δ E+) and difference (Δ E−)



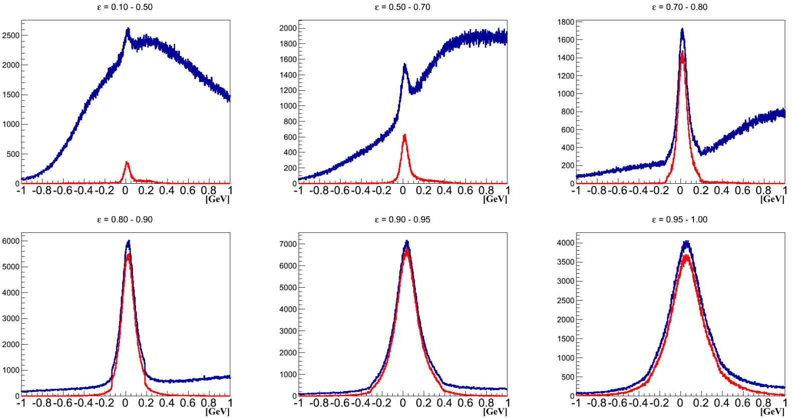


Kinematic Cuts

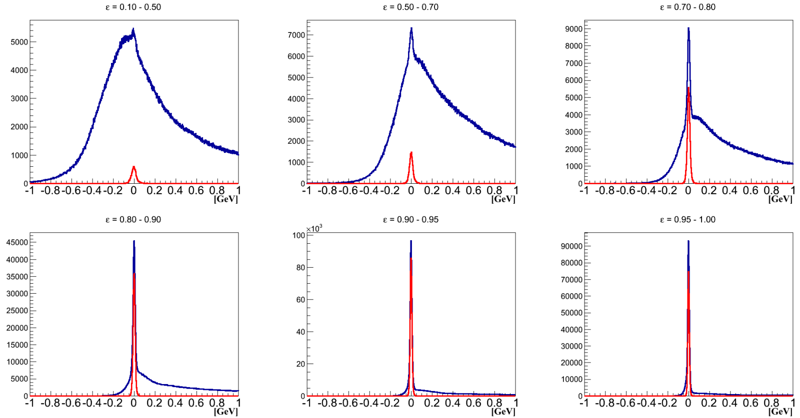
No cuts   Apply other 3 kinematic cuts



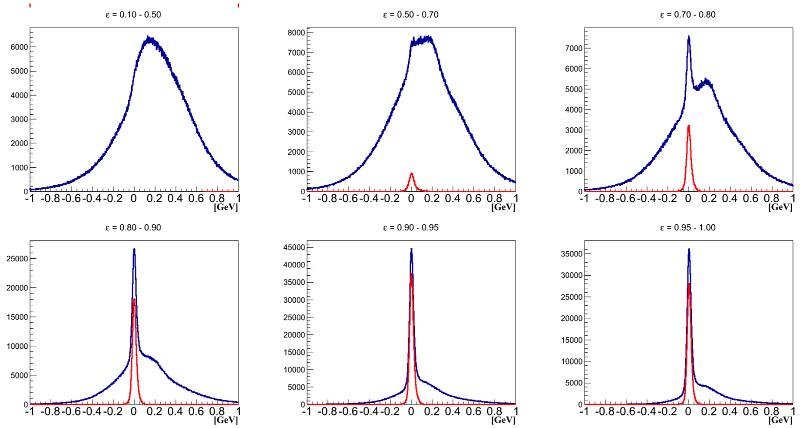
Δ E —: ε Dependence



Δ E +: ε Dependence



Δ P_p : ε Dependence



Personnel

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