Beyond the Born Approximation

Measuring the Two-Photon Exchange Effect at CLAS

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Old Dominion University
for The CLAS Collaboration

E07-005
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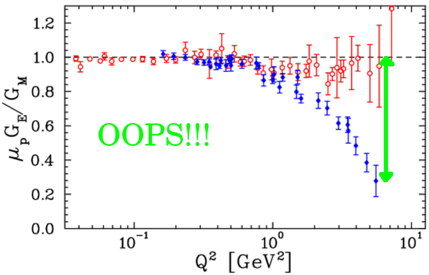
June 24-29, 2011

Plan of Attack



1. Provide a model independent measurement of the two photon exchange correction to the proton form factor

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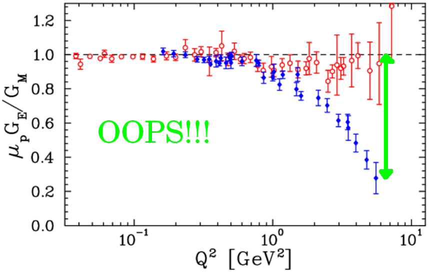

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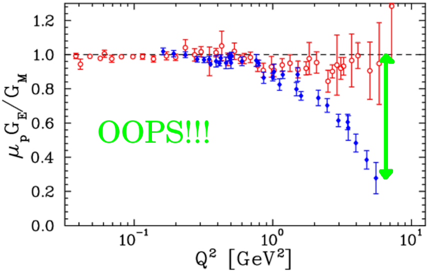

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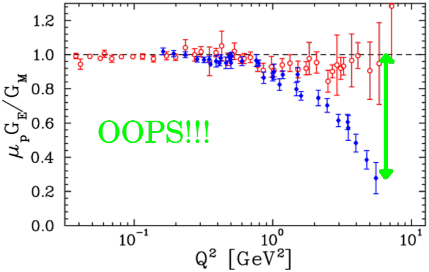

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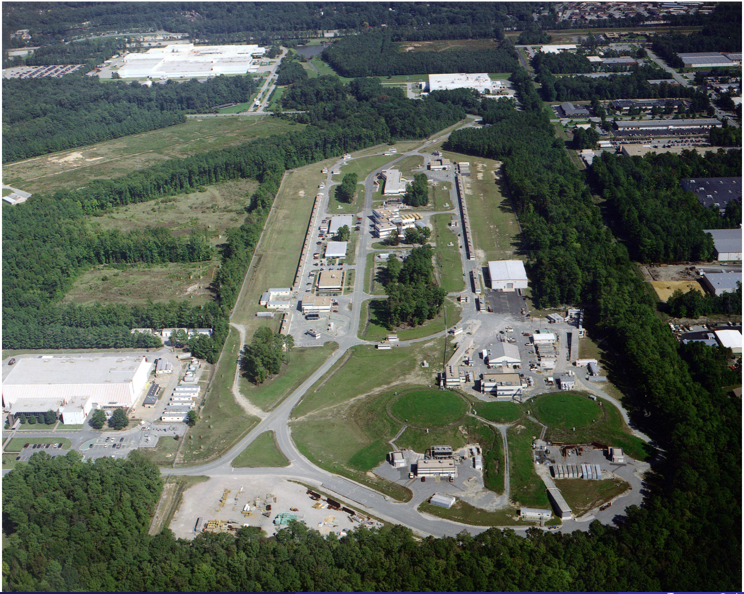
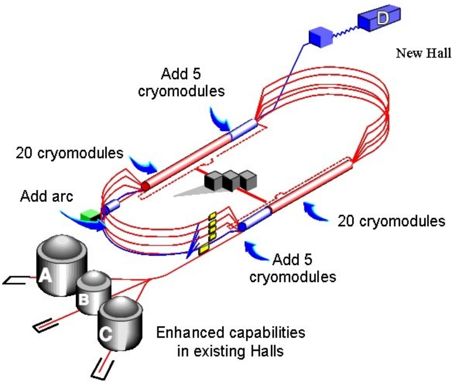
2. Measure $\sigma(e^+P)/\sigma(e^-P)$
3. Use JLab high intensity e^- beam to produce simultaneous, identical beams of electrons and positrons
4. Use CLAS detector to measure $\sigma(e^+P)$ and $\sigma(e^-P)$ over a large range in Q^2 and ε

Jefferson Laboratory

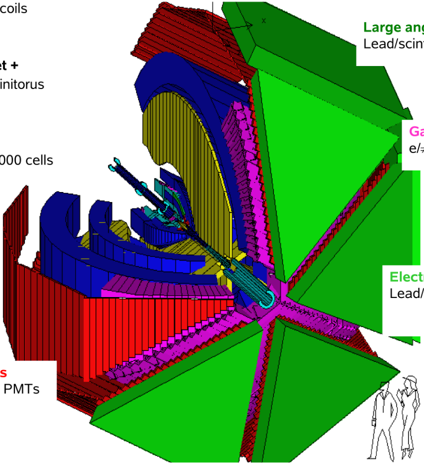


Continuous Electron Beam Accelerator Facility (CEBAF)

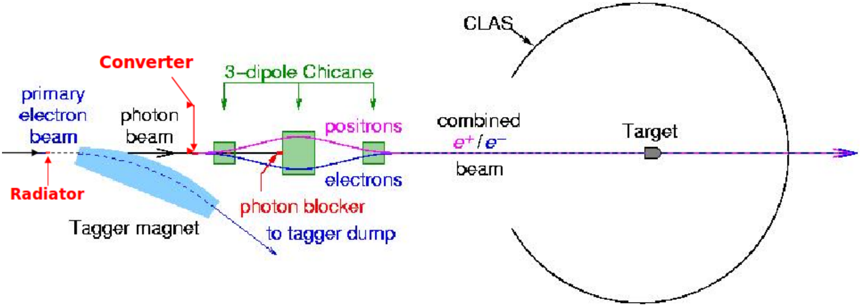


- 5 pass super-conducting accelerator
- Polarized electrons up to 6 GeV
- Maximum Current $\sim 100\ \mu$ A
- Upgrading to 12 GeV
- 3 experimental halls running (A, B, & C) (D is coming soon)

CEBAF Large Acceptance Spectrometer



Simultaneous, Idential e^+/e^- Beams



- Primary electron beam: 5.5 GeV and 100 nA
- Radiator: 1% of primary electrons radiate high energy photons
- Tagger magnet: Transport electrons tagger dump
- Converter: 10% of photons are converted to electron/positron pairs
- Chicane: separate the lepton beams
- Remaining photons are stopped at the photon blocker
- e^+ ande^- 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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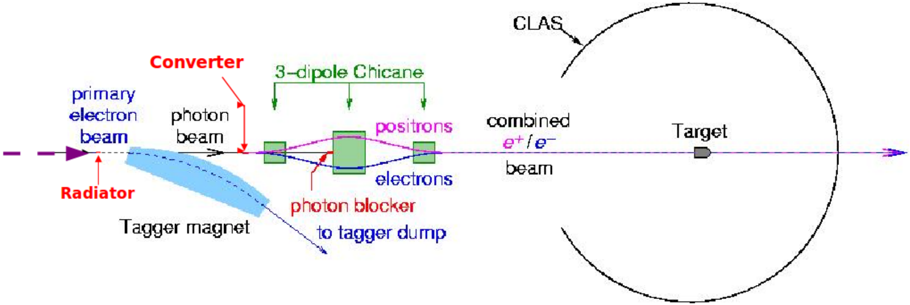

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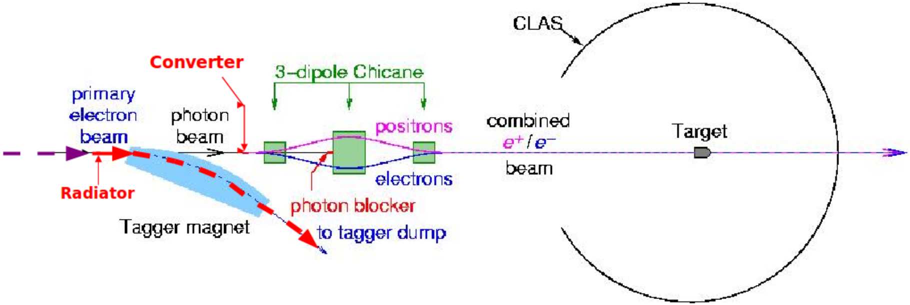

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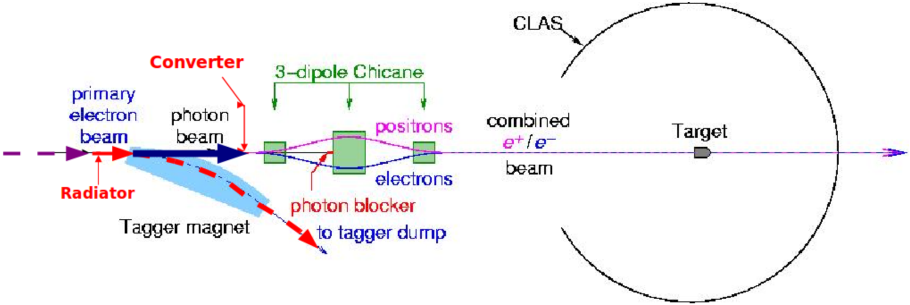

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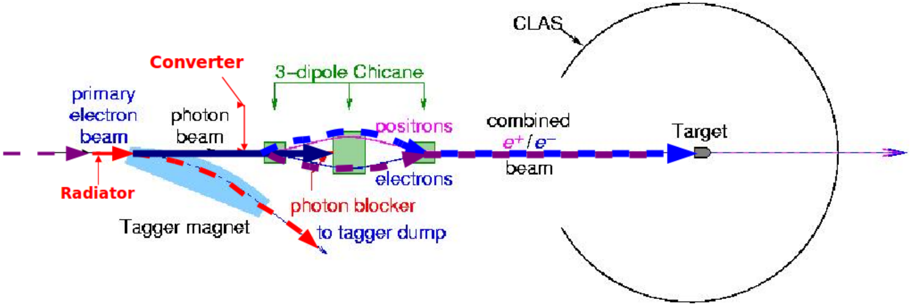

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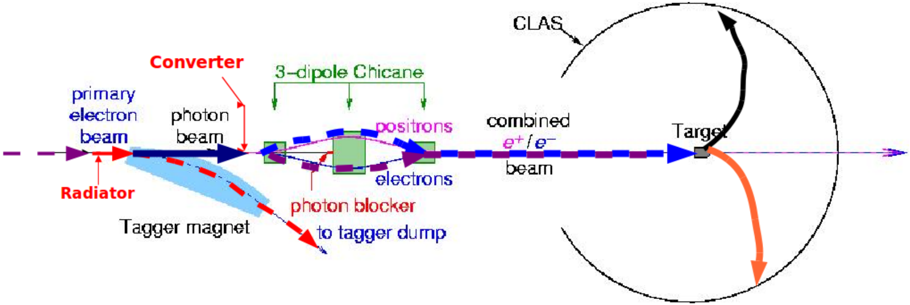

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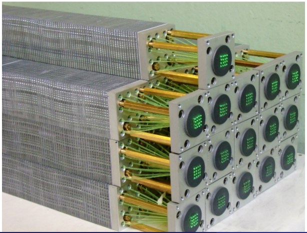
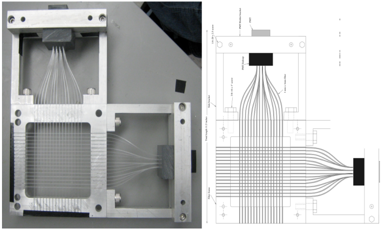
Beam Profiling

TPE Calorimeter

- 5x6 tower, 3.8mm × 3.8mm × 450mm Shashlik type calorimeter
- Located directly downstream of CLAS on the forward carriage
- Dense fiber monitor mounted on the face of TPEcal.

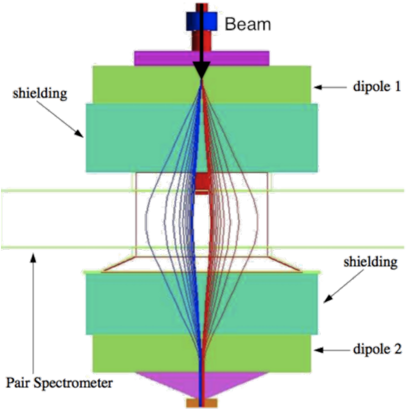


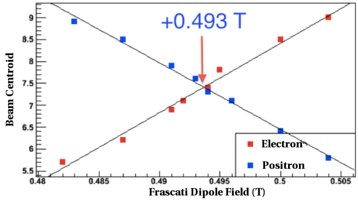


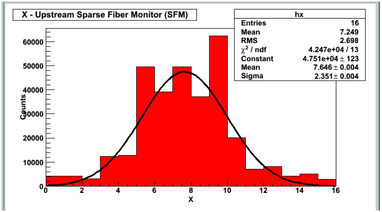
Fiber Monitors

- 16x16 (64x64) channel Upstream Sparse Fiber Monitor
- Bicron fibers spaced 5 mm (1mm) apart glued to a Hamamatsu PMT
- Beam size ∼ 15 mm radius

Systematic Checks

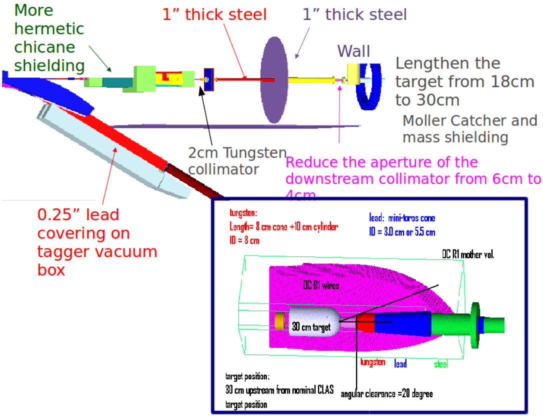






- Flipped chicane polarity about once a week
- Check for geometric alignment of e^-/e^+ on target
- Varied steering magnet currents
- Measured individual beam positions at Sparse Fiber Monitor
- Reproducible crossing for all chicane flips

Beam Line Modification for TPE

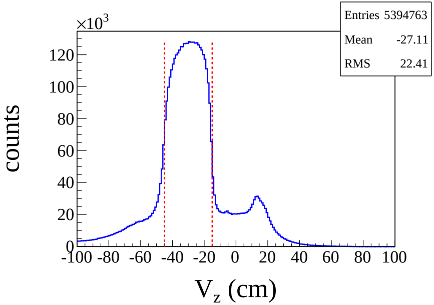


- The biggest hindrance to increasing beam luminosity is the drift chamber occupancy.
- Extensive GEANT simulations to optimize shielding
- Factor of 10 in luminosity + 30 PAC days of beam

Shielding

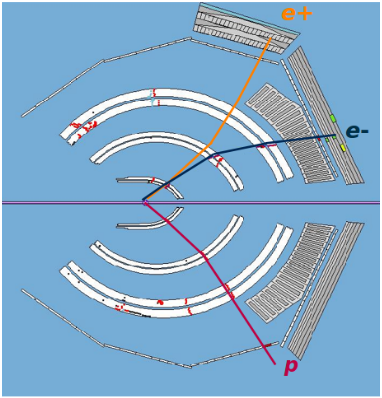
Shielding

Target



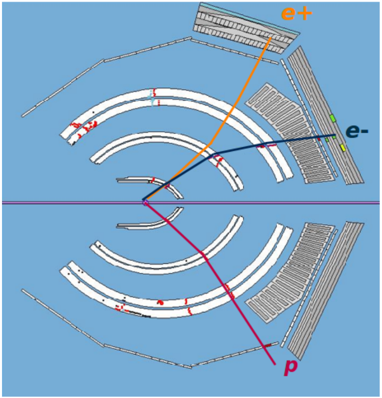
- 30 cm long x 6 cm ID (Liquid H_2)
- Kapton cell wall
- Installed -30 cm from CLAS center
- Tungsten Moller shielding and mini-torus

The Basics



1. Measure Elastic Scattering Ratio

The Basics



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$$R = \sqrt{\frac{Y^{+}_{e^{+}P}}{Y^{+}_{e^{-}P}} \times \frac{Y^{-}_{e^{+}P}}{Y^{-}_{e^{-}P}}}$$

2. **Systematics**
   - Extensive beam profiling
   - Flip torus polarity
   - Flip chicane polarity

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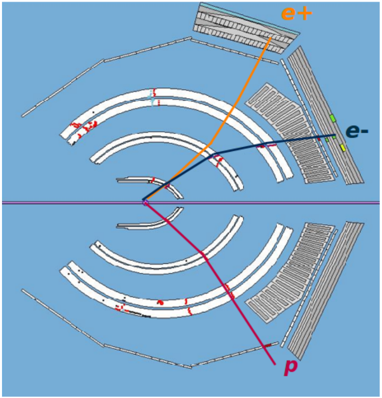

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   - Beam energy for a given event is unknown
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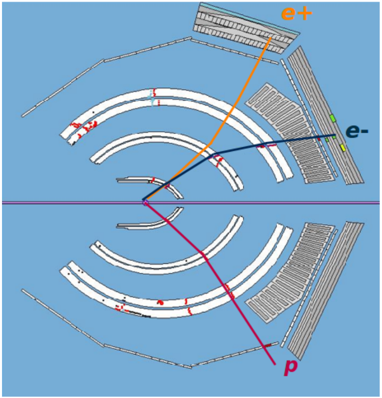

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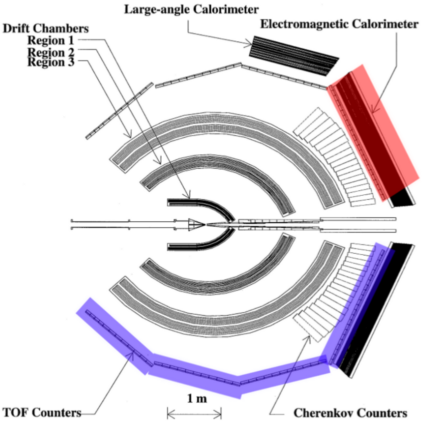
4. **Analysis Solutions**
   - Look for coplanar pairs (opposite sectors)
   - Identify ++ and +− pairs
   - Exploit over constrained kinematics
   - Straight through running of primary beam

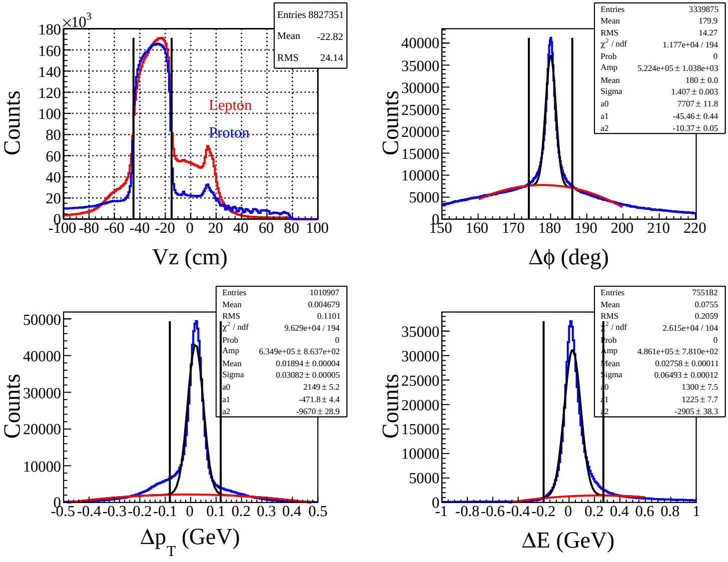
Summary of Data Analysis



1. Trigger on particle in forward 45^0 and anything in opposite sector
2. Vertex cut ($-45cm \leq V_z \leq -15cm$)
3. Azimuthal angle cut ($\phi_{proton} - \phi_{lepton} \approx 180^0$)
4. Transverse Momentum cut ($P_T \approx 0$)
5. Beam Energy cut ($E_{beam}(angles) \approx E_{beam}(PConsv.)$)
6. Fiducial Cuts
7. DOCA cut between tracks
8. Swimming – Acceptance matching ++ and +− events

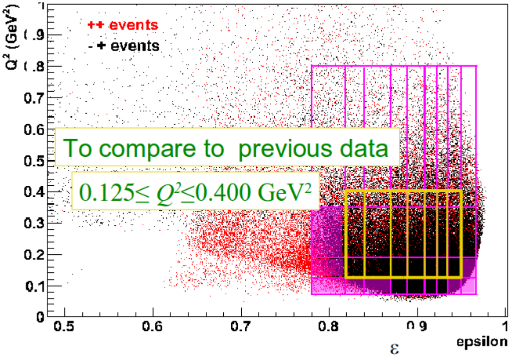
EC and TOF ($\theta < 45°$) and opposite sector TOF

Analysis Cuts



2006 Test Run

1.5 days of low luminosity beam



$\langle Q^2 \rangle = 0.472$ GeV^2

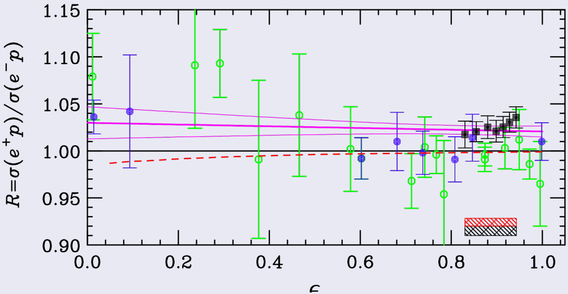
$\langle Q^2 \rangle = 0.246$ GeV^2

$\langle Q^2 \rangle = 0.152$ GeV^2

$\langle Q^2 \rangle = 0.103$ GeV^2

2006 Test Run Results

Cross Section Ratio



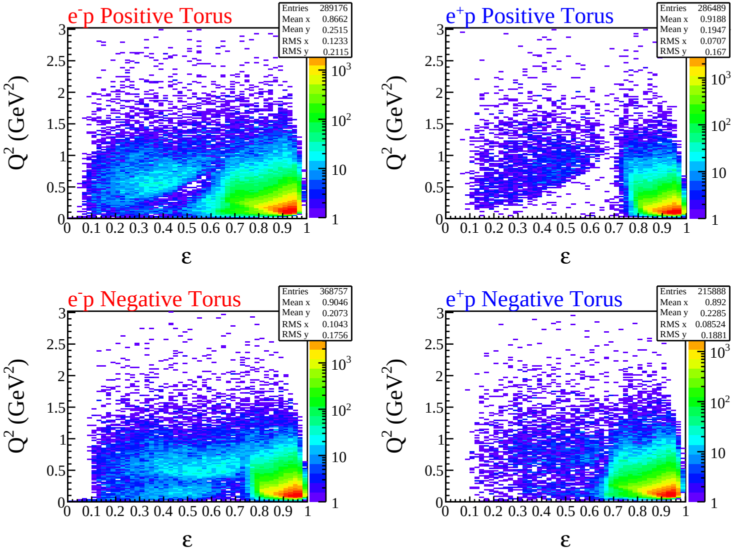
- Maryam Moteabbed Thesis (FIU) $< Q^2 >= 0.206\ GeV^2$
- Megh Niroula Thesis (ODU)
- World data

- Scale-type systematic uncert. ~ 0.010 (e+/e- relative luminosity)
- Point-to-point systematic uncert. ~ 0.0080 (acceptance & effects of cuts, coupled to statistical precision)
- Magenta: Fit to blue and black points
- Dashed Red: BMT Calculation
- Constat fit: $R = 1.024 \pm 0.005 \pm 0.01$

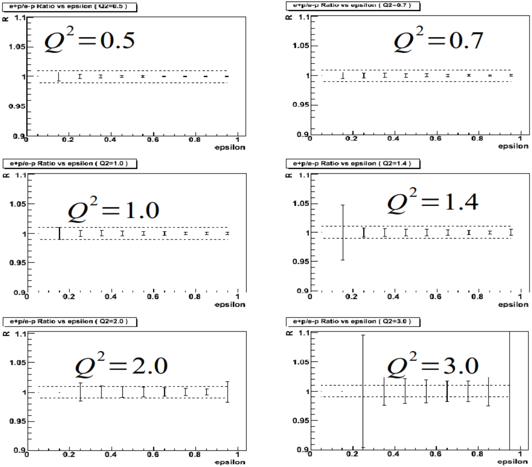
The CLAS TPE Experiment

- Nov 30, 2010 - Feb 25, 2011 (30 PAC days)
- 5.6 GeV @ $\sim 100 - 120$ nA unpolarized electron beam
  - $\rightarrow$ Photon beam
  - $\Rightarrow$ Electron-positron beam ~ 50 pA
  - $\Rightarrow$ 30 cm Liquid Hydrogen target (-30 cm from CLAS center)
- Luminosity limitations:
  - DC occupancies
  - Trigger rate
- Systematic error control:
  - Flipped torus polarity weekly
  - Flipped lepton beam line magnet (chicane) polarity weekly
  - Zero field mini-torus runs
  - Half-field torus runs
  - Compare six different sector results
  - 2.2 GeV run
    - Electron beam run at 0.3 nA directly on target (~ 1 day)
    - Two different torus polarities
    - In-bending and out-bending particle reconstruction
- ~ 12 billion triggers $\Rightarrow$ 12 million elastic events over all kinematics
- No accurate measure of luminosity, estimates: $\sim 2.5 \times 10^{32}$ cm^{-2}s^{-1} for electron and positron separately (Simulation)

Q^2 vs ε (TPE II 2010-2011)



Projections



- In 30 PAC days (Nov 2010 - Feb 2011),CLAS collected more events in 1 hour than the entire test run in 2006 (over 12 Billion triggers several terabytes of data)
- CLAS will map out the TPE effect over large areas of $Q^2 - \epsilon$
- CLAS will be able to obtain $< 1\%$ statistical and systematic uncertainties out to $Q^2 = 2GeV^2$
- Not the only game in town: Olympus at DESY and VEP-III at Novosibirsk

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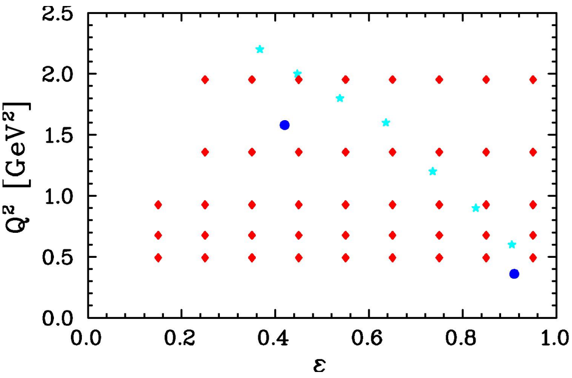

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Complementary Measurements

OLYMPUS

- High statistics over thin slice of $Q^2 - \varepsilon$
- Known beam energy, unknown target thickness
- Radiative corrections to beam energy
- Can tune beam to most interesting kinematics

CLAS

- Large $Q^2 - \varepsilon$ coverage with varying precision
- Unknown beam energy, liquid H_2 target
- Bremsstrahlung beam just means a different beam energy
- Get what the bremsstrahlung beam gives us

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Orthogonal Systematics!

Summary

- Rosenbluth and Polarization transfer experiments measure G_{E_P} that differ by a factor of 3 at $Q^2 = 6$
- Understanding the origin of this discrepancy is essential to many other measurement in nuclear physics
- Two Photon Exchange may be able to explain the discrepancy
- The e^+p/e^-p ratio is the only way to measure the real part of the TPE amplitude
- CLAS was able to produce simultaneous, nearly identical beams of electrons and positrons
- Test run results showed promise but were severely statistics limited
- This year we significantly increase our luminosity, through shielding and engineering
- We should expect small ($< 1\%$ stat. and $< 1\%$ sys.) uncertainties for in R over a large area in $Q^2 - \varepsilon$ space
- CLAS and Olympus experiments will provide good cross checks for eachother

Thank you

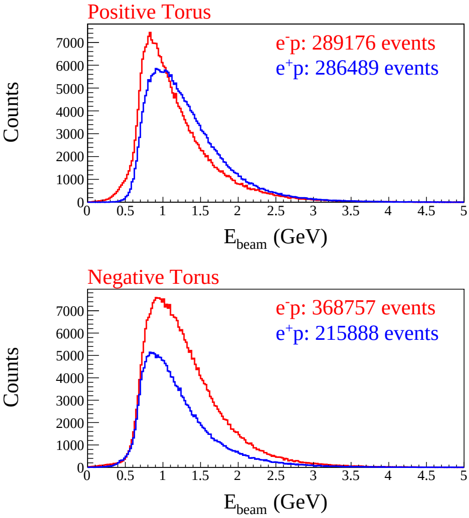
Thank you

$$E_{Beam} = M_P(\frac{1.0}{(tan(\theta_e/2.0) * tan(\theta_P))} - 1.0) \quad (1)$$

$$E_{Beam} = (P_{z1} + P_{z2}) \quad (2)$$

$$E_{Beam} = E_e E_p - P_e P_p cos(\theta_e + \theta_p)/M_p \quad (3)$$

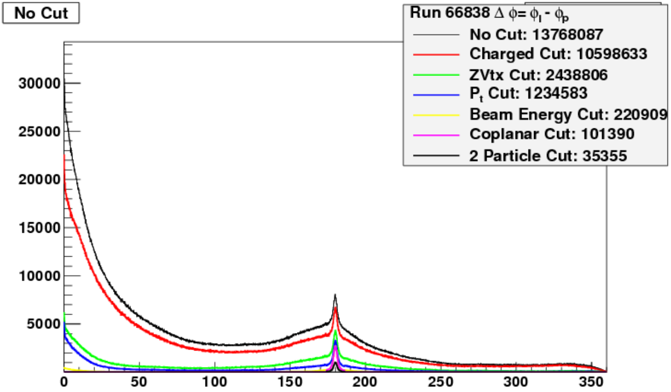
Beam Energy



Very Preliminary

Analysis Cuts Summary

- Summary of analysis cuts



Triggers

Trigger Setup

Description	Trigger Bit	Rates (Hz) @ 100nA
Low Threshold EC and TOF ($\theta < 45°$) and opposite sector TOF ($\theta > 45°$)	1 2 3 4 5 6	500 500 400 650 800 800
High Threshold EC and TOF ($\theta < 45°$) and opposite sector TOF ($\theta < 45°$)	7	1700
TOF ($45° < \theta < 60°$) and opposite sector TOF ($45° < \theta < 60°$)	8	40,000 (disabled)
3 Hz Pulser	10	3
Low Threshold EC any sector	12	100 (Prescaled)

- Bit 8: Needed to fill kinematic hole - Rates too high!
- Could not implement Level 2 trigger due to hardware restrictions

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Personnel

1. **Spokespersons**
   - Larry Weinstein, Brian Raue, Will Brooks, John Arrington, Andrei Afanasev & Kyungseon Joo
2. **Post Docs**
   - Puneet Khetarpal
   - Mauri Ungaro
   - Robert Bennett
3. **Graduate Students**
   - Dasuni Adikaram
   - Dipak Rimal
   - Cristian Peña
   - Hashir Rashad