THE FIFTH STRUCTURE FUNCTION

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Overview

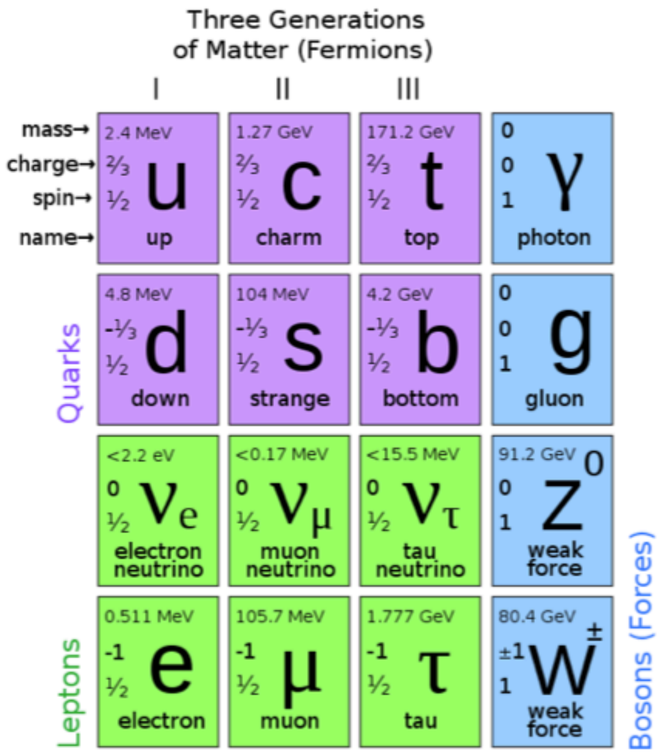
Scientific Background

History

- Democritus (400 BC)
  - "atomos"
- End of the 19th Century → 1930s
  - Electrons, nuclei, ions, photons
- Modern Era
  - 1964 – "Quark" or "Ace"

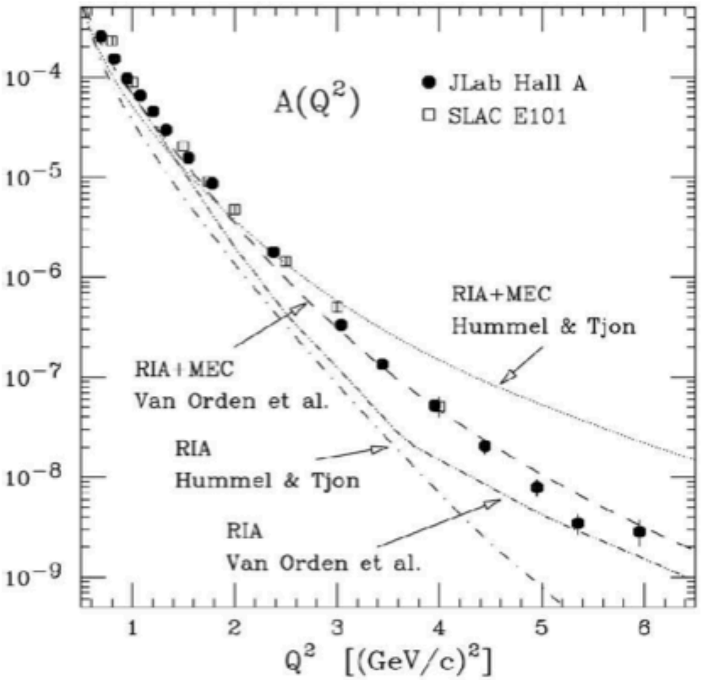
The Standard Model

- Sheldon Glashow
- 12 Elementary Particles: Spin 1/2
- 4 Force Mediating Partices: Spin 1
- Quark: Non-whole number electron charge
- Lepton: Whole number electron charge



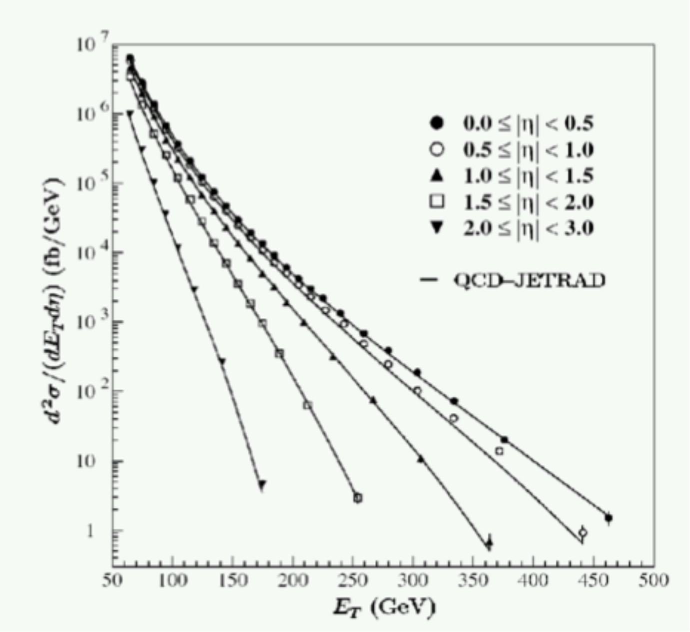
The Hadronic Model

- Interactions between hadrons
- Nuclei approximated as collections of protons and neutrons
- Low Energy Success



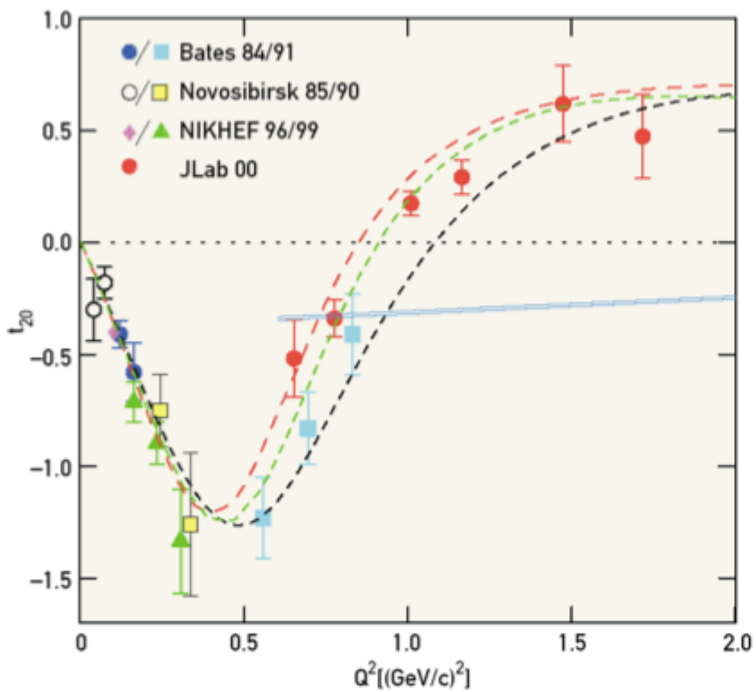
Quantum Chromodynamics (QCD)

- Color force
  - Interactions of quarks and gluons making up hadrons
- Asymptotic Freedom
- Confinement
  - ≈ 3 tons of force between
- High Energy Success
- Difficulty Testing



The Hadronic Model Vs. QCD

- Goal: Better understand the behavior of quarks at intermediate energies



Significance of the Fifth Structure Function

- Explore the quark-gluon structure of atomic nuclei
  - First, we need to understand atomic nuclei as collections of protons and neutrons.
- The Structure of the Deuteron
  - Important place to start our understanding of atomic nuclei
- Helicity Asummetry $A'_{LT} \rightarrow$ Fifth Structure Function
  - Seldom-measured part of Deuteron W.F. where Proton-Neutron force is expected to dominate

Objective

- Measure the largely unknown component of the deuteron wave function (the fifth structure)
  - $^{2}H(e,e'p)n$ Reaction
  - Never completed in this energy range
- Test the accuracy of our analysis
  - Monte Carlo Simulation

Experimental Background

CEBAF

- Continuous Electron Beam Accelerator Facility
  - Newport News, Virginia
  - ≈ 1 mile long
  - Max: 5.7 GeV Beam Energy

CEBAF

- Injector
- North/South Linear Accelerators
  - SRF technology
- Recirculating Arcs
- Experimental Halls

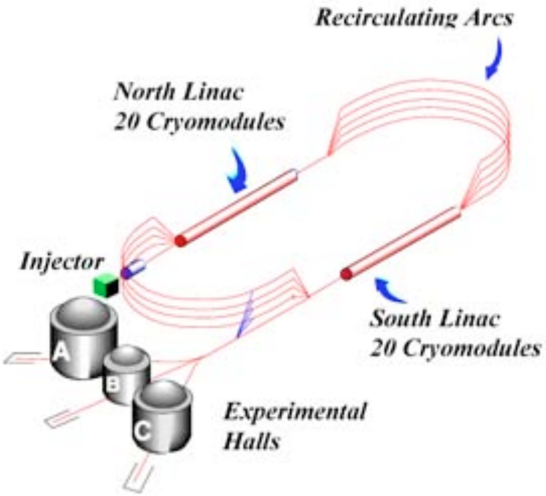
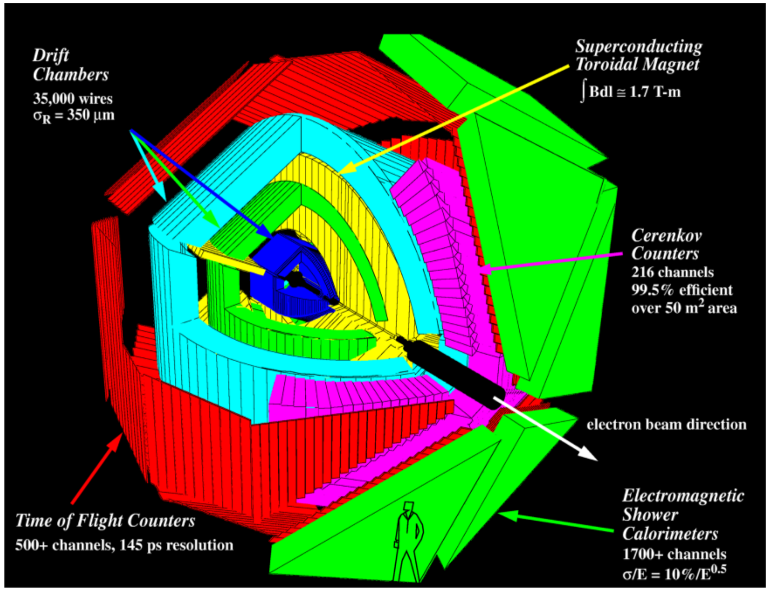


Figure 1: Layout of CEBAF.

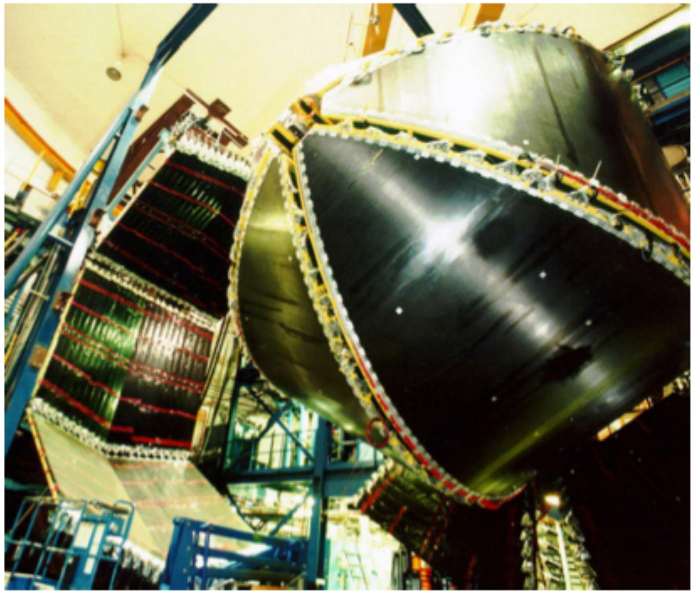
Hall B: CLAS

- CEBAF Large Acceptance Spectrometer
  - 1995-2012
- 45-ton, three-story, spectrometer
- Six identical Sectors
- Nearly 4π Solid Angle



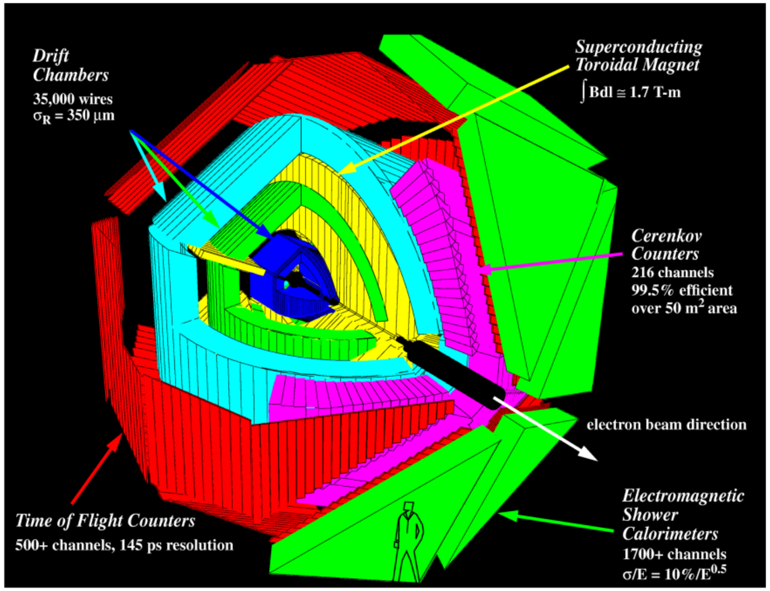
Hall B: CLAS

- Superconducting Toroidal Magnet
- Drift Chambers
- Cherenkov Counters
- Time-of-Flight Scintillators
- Electromagnetic Calorimeters



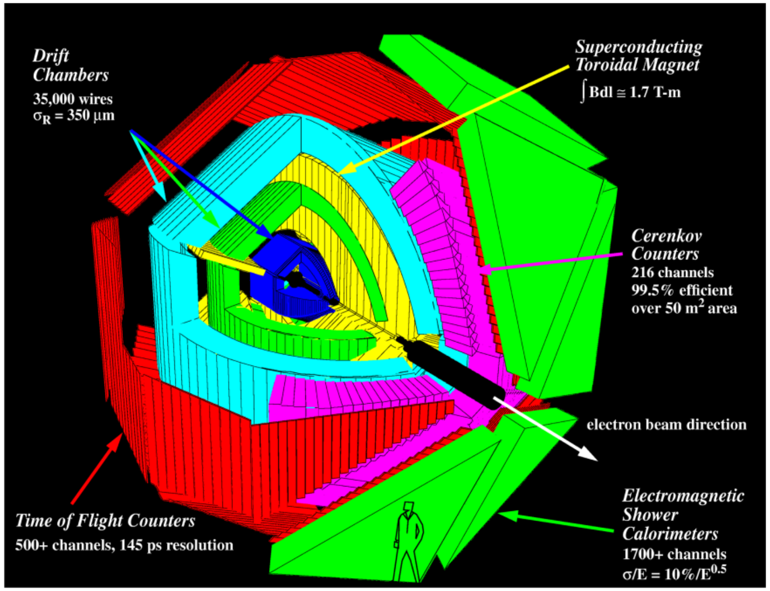
Hall B: CLAS

- Toroidal Magnet
  - Provides a magnetic field
  - Two magnetic polarity settings (Normal/Reversed)



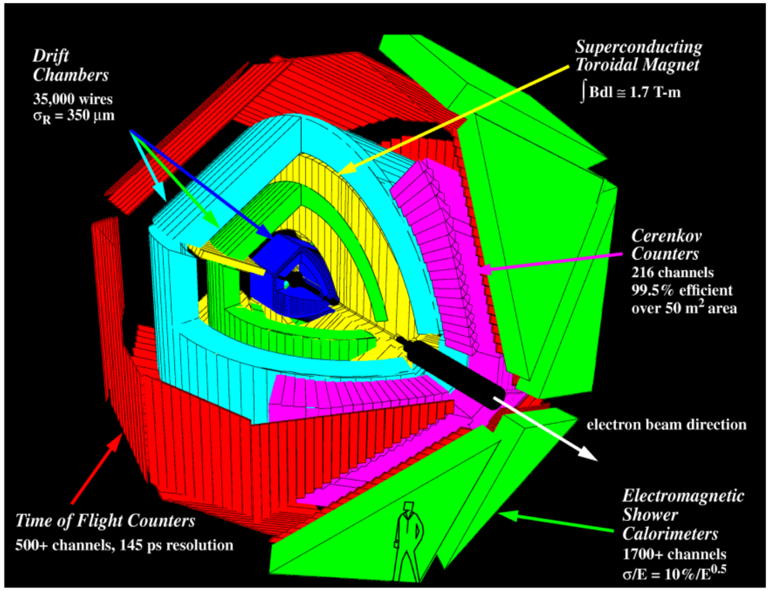
Hall B: CLAS

- Drift Chambers
  - Detector for particles with ionizing radiation
  - Detects both presence and location of radiation
  - Quasi-Geiger counter (I. Lab)
  - Three Regions



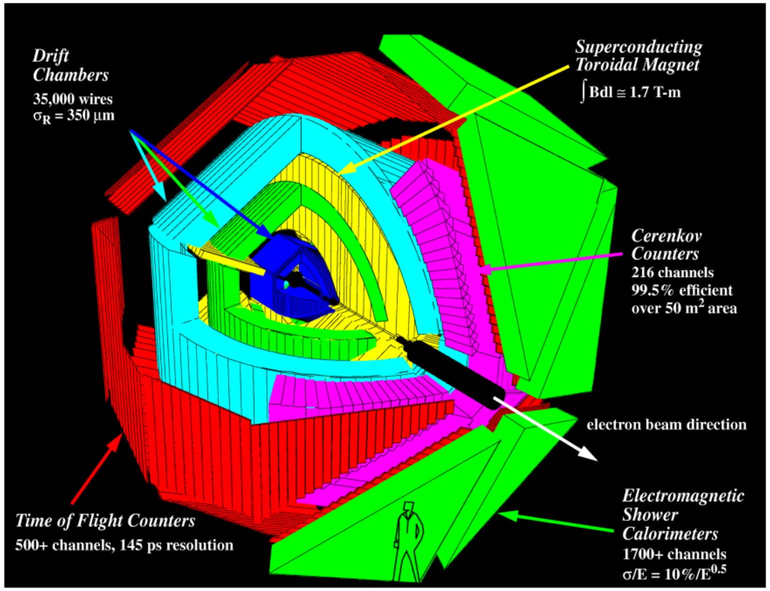
Hall B: CLAS

- Cherenkov Detectors
  - Allow us to differentiate between pions and electrons
  - Detects electromagnetic radiation emissions



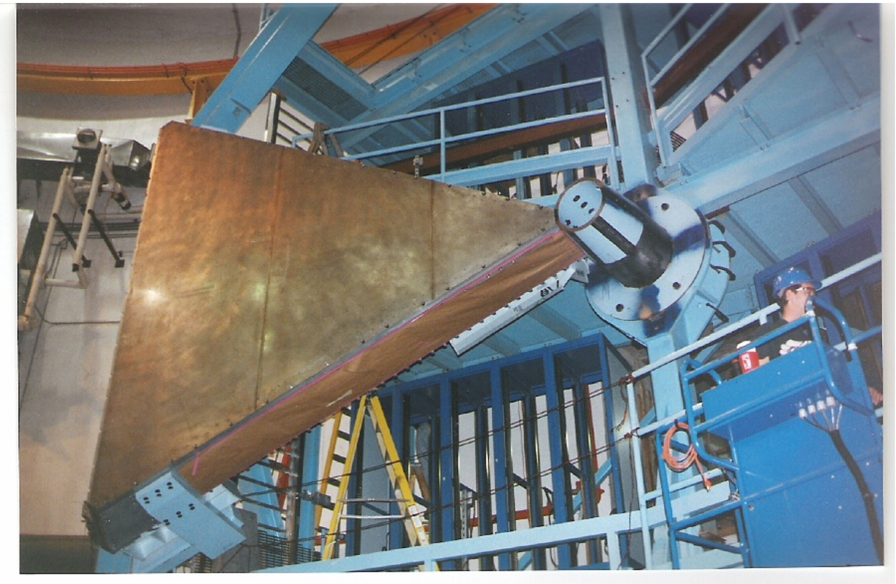
Hall B: CLAS

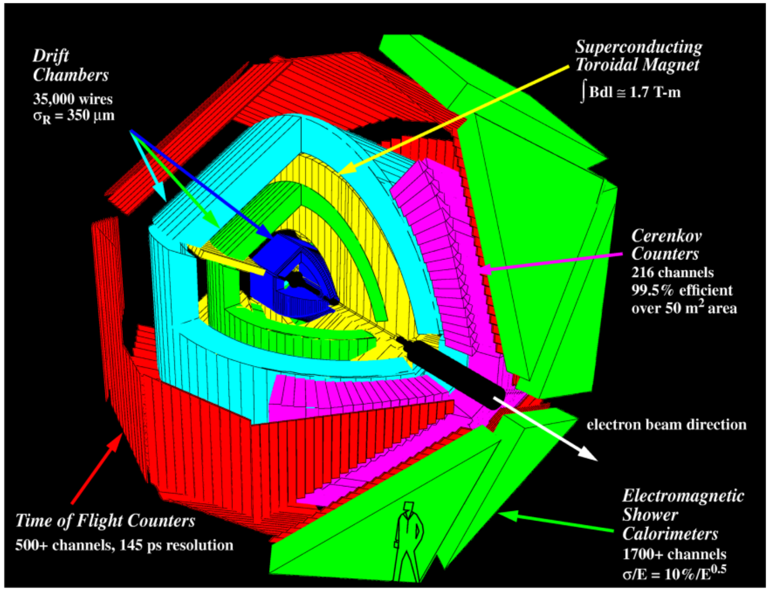
- Time-of-Flight Scintillators
  - Lighter and heavier particle differentiation
  - Scintillators: Variety of materials
  - Detection possible by photo multiplier tubes



Hall B: CLAS

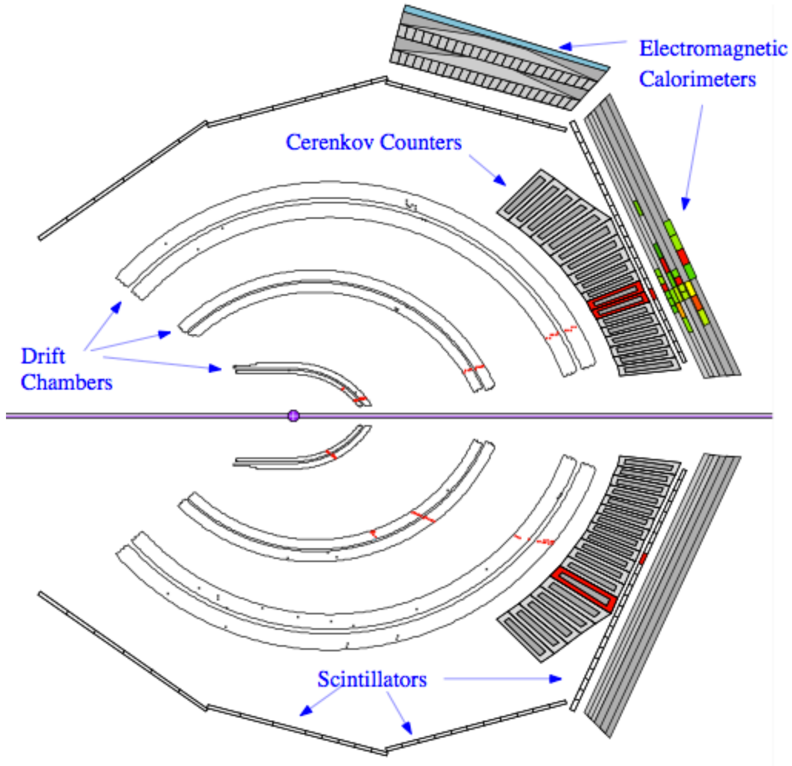
- Electromagnetic Calorimeters
  - Differentiate electrons and neutral particles
  - Comprised of alternating layers of lead/scintillator
  - Particles interact in the lead creating a shower of photons in the scintillator





Hall B: CLAS

- Trajectory
- Charge
- Momentum
- Energy
- Scattering Angle
- Velocity



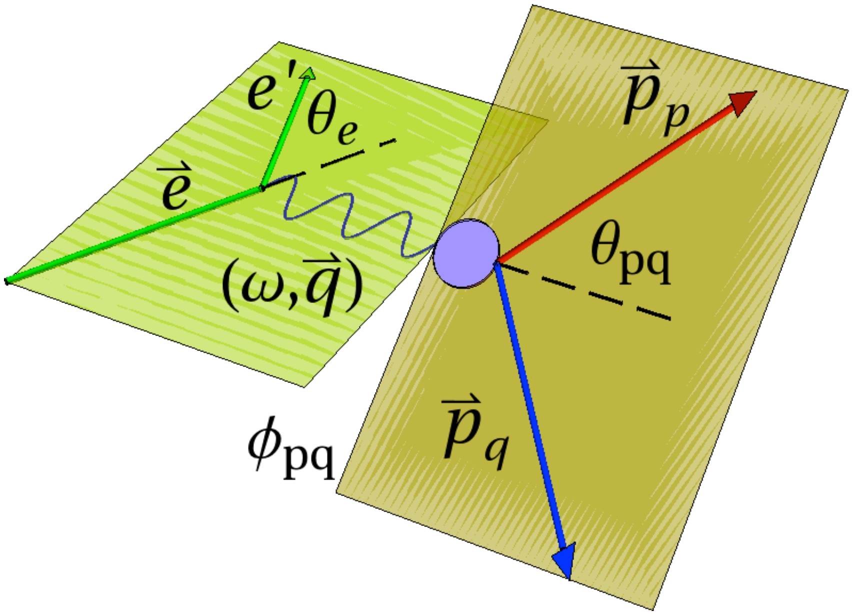
Experimental Setup

- 2.56 GeV beam
- Both normal and reversed magnetic torus polarities
- Dual, co-linear liquid hydrogen-deuterium cell target

Extracting the Asymmetry (Summer 2012)

Extracting the Asymmetry

- Kinematics of the $^2H(e,e'p)n$ reaction
  - Quasi-elastic collisions



Extracting the Asymmetry

- Mathematical Approach
  - Differential Cross Section

$$\frac{d^5\sigma}{dQ^2 dp_m d\phi_{pq} d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} + h\sigma_{LT'}\sin\phi_{pq}$$

  - Helicity Asymmetry

$$A_h(Q^2, p_m, \phi_{pq}) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Extracting the Asymmetry

- Mathematical Approach
  - Differential Cross Section

$$\frac{d^5\sigma}{dQ^2 dp_m d\phi_{pq} d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} + h\sigma_{LT'}\sin\phi_{pq}$$

$\approx |\Psi|^2$

  - Helicity Asymmetry

$$A_h(Q^2, p_m, \phi_{pq}) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Extracting the Asymmetry

- Mathematical Approach
  - Differential Cross Section

$$\frac{d^5\sigma}{dQ^2 dp_m d\phi_{pq} d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} + h\sigma_{LT'}\sin\phi_{pq}$$

$\vec{p}_m = \vec{p}_p - \vec{q}$

NOT ZERO FOR OUT-OF-PLANE MEASUREMENTS!

  - Helicity Asymmetry

$$A_h(Q^2, p_m, \phi_{pq}) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Extracting the Asymmetry

$$A_h(Q^2, p_m, \phi_{pq}) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

$$A_h(Q^2, p_m, \phi_{pq}) = \frac{(\sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} + \sigma_{LT'}\sin\phi_{pq}) - (\sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} - \sigma_{LT'}\sin\phi_{pq})}{(\sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} + \sigma_{LT'}\sin\phi_{pq}) + (\sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ} - \sigma_{LT'}\sin\phi_{pq})}$$

$$A_h(Q^2, p_m, \Phi_{pq}) \approx \frac{2(\sigma_{LT'}\sin\phi_{pq})}{2(\sigma_L + \sigma_T + \sigma_{LT}\cos\phi_{pq} + \sigma_{TT}\cos 2\phi_{PQ})}$$

$$A_h(Q^2, p_m, \Phi_{pq}) \approx \frac{\sigma_{LT'}\sin\phi_{pq}}{\sigma_L + \sigma_T} = A'_{LT}\sin\phi_{pq}$$

Extracting the Asymmetry

$$A_h(Q^2,p_m,\phi_{pq}) = \frac{(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}+\sigma_{LT'}\sin\phi_{pq}) - (\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}-\sigma_{LT'}\sin\phi_{pq})}{(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}+\sigma_{LT'}\sin\phi_{pq}) + (\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}-\sigma_{LT'}\sin\phi_{pq})}$$

$$A_h(Q^2,p_m,\Phi_{pq}) \approx \frac{2(\sigma_{LT'}\sin\phi_{pq})}{2(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ})}$$

$$A_h(Q^2,p_m,\Phi_{pq}) \approx \frac{\sigma_{LT'}\sin\phi_{pq}}{\sigma_L+\sigma_T} = A'_{LT}\sin\phi_{pq}$$

Extracting the Asymmetry

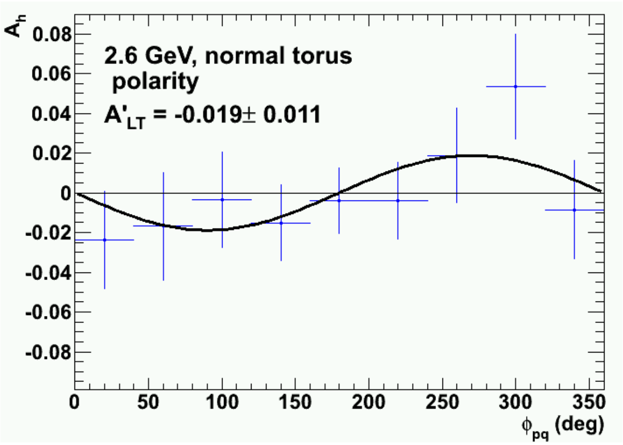
$$A_h(Q^2,p_m,\phi_{pq}) = \frac{(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}+\sigma_{LT'}\sin\phi_{pq}) - (\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}-\sigma_{LT'}\sin\phi_{pq})}{(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}+\sigma_{LT'}\sin\phi_{pq}) + (\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ}-\sigma_{LT'}\sin\phi_{pq})}$$

$$A_h(Q^2,p_m,\Phi_{pq}) \approx \frac{2(\sigma_{LT'}\sin\phi_{pq})}{2(\sigma_L+\sigma_T+\sigma_{LT}\cos\phi_{pq}+\sigma_{TT}\cos 2\phi_{PQ})}$$

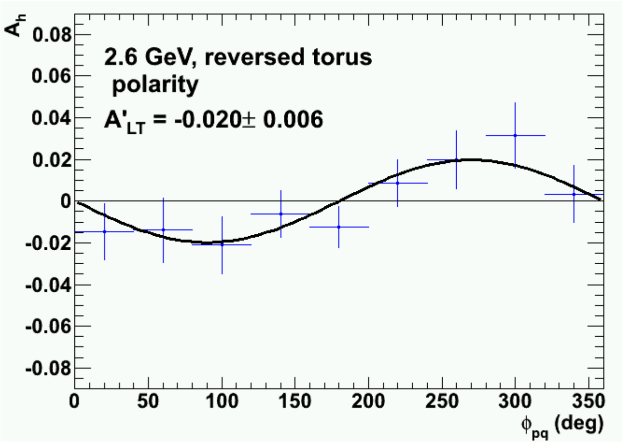
$$A_h(Q^2,p_m,\Phi_{pq}) \approx \frac{\sigma_{LT'}\sin\phi_{pq}}{\sigma_L+\sigma_T} = A'_{LT}\sin\phi_{pq}$$

Extracting the Asymmetry

- Computational Approach
  - C++ code
  - CERN ROOT package



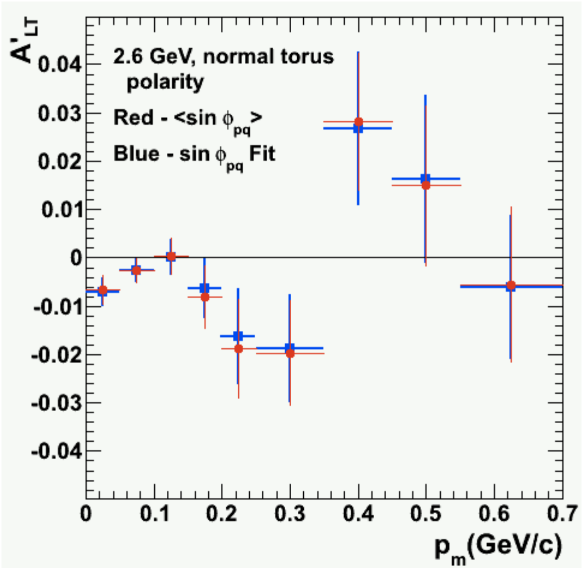
A_h, Normal Polarity, p_m=0.30 GeV/c

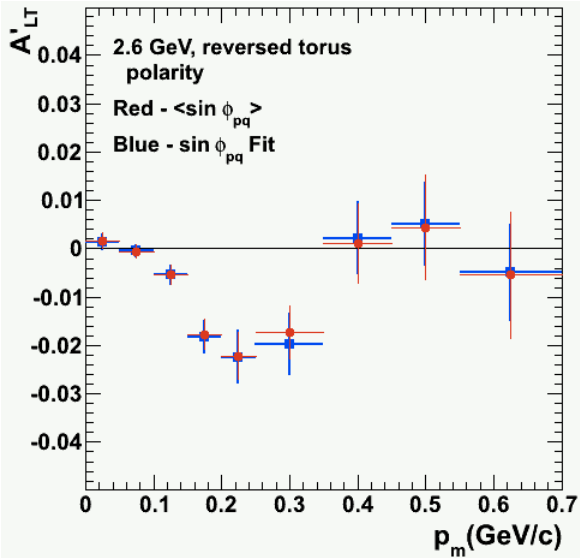


A_h, Reversed Polarity, p_m=0.30 GeV/c

Results (Summer 2012)

- The asymmetry A'_{LT}
  - Red: sin Φ_{pq}-weighted average
  - Blue: fits to A_h from above

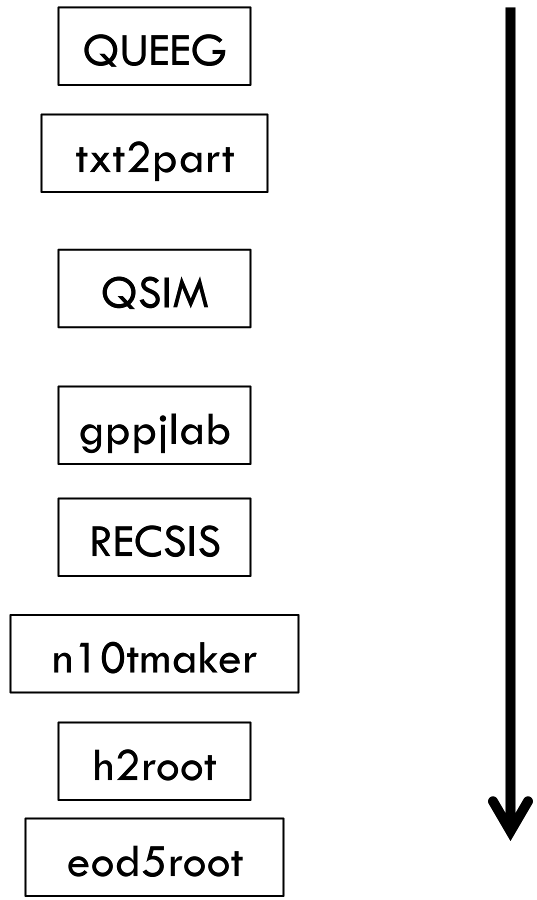




Simulation of CLAS (Summer 2013)

Simulation of CLAS

- Simulating a reaction in CLAS



Simulation of CLAS

- QUEEG
  - Generates quasi-elastic electron events

Simulation of CLAS

- txt2part
  - Converts the output files into BOS data files
  - BOS: CLAS data format

Simulation of CLAS

- GSIM
  - Simulates CLAS
  - Based on GEANT3

Simulation of CLAS

- Fitting the Asymmetry (C.A. Copos)
  - Incorporated into Monte Carlo simulation to model the Fifth Structure Function

$$A'_{LT}(p_m) = \frac{\delta_1 p_m^2 + \delta_2 p_m^4}{1 + \delta_3 p_m + \delta_4 p_m^2 + \delta_5 p_m^4 + \delta_6 p_m^6}$$

Simulation of CLAS

- gppjlab
  - Makes the GSIM output look real
    - Knocks out dead scintillators and wires

Simulation of CLAS

- RECSIS
  - Standard program for reconstruction of CLAS data

Simulation of CLAS

- n10tmaker
  - Converts the output into hbook ntuples

Simulation of CLAS

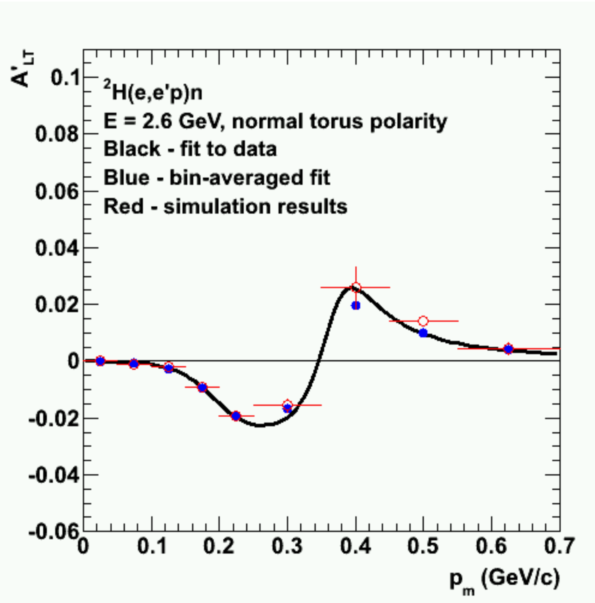
- h2root
  - Convers the ntuples into ROOT ntuples

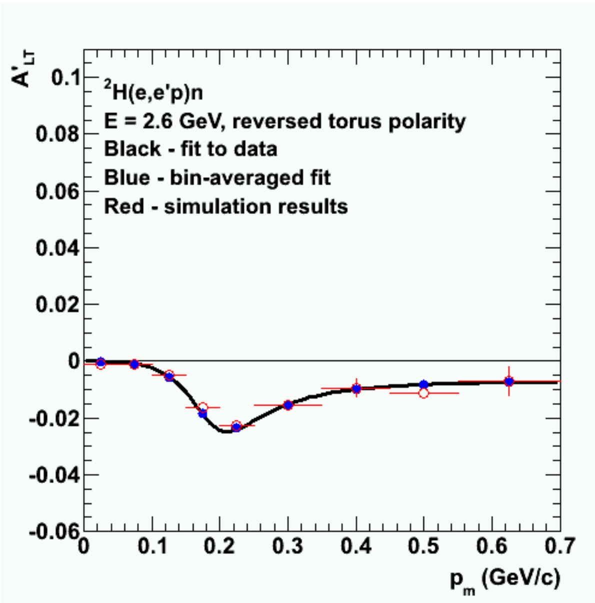
Simulation of CLAS

- eod5root
  - The analysis code in ROOT to extact A'_{LT}
  - Code used in Summer 2012

Results (Summer 2013)

- Testing the analysis
  - Red: simulated data
  - Blue: bin-averaged fit
  - Black: Fit to data





Conclusion

- Extracted the asymmetry A'_{LT} from fits to the helicity asymmetry
  - Normal and reversed polarities
  - Comparison to sin Φ_{pq}-weighted method
- Validated our analysis
  - Generated Monte Carlo events modeled after data
  - Events passed through simulation and then our analysis code

Acknowledgements

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- University of Richmond Physics Department
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- Kristen Greenholt (UR ‘07)

References

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