Measurements of the Neutron Magnetic Form Factor with CLAS

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For The CLAS Collaboration

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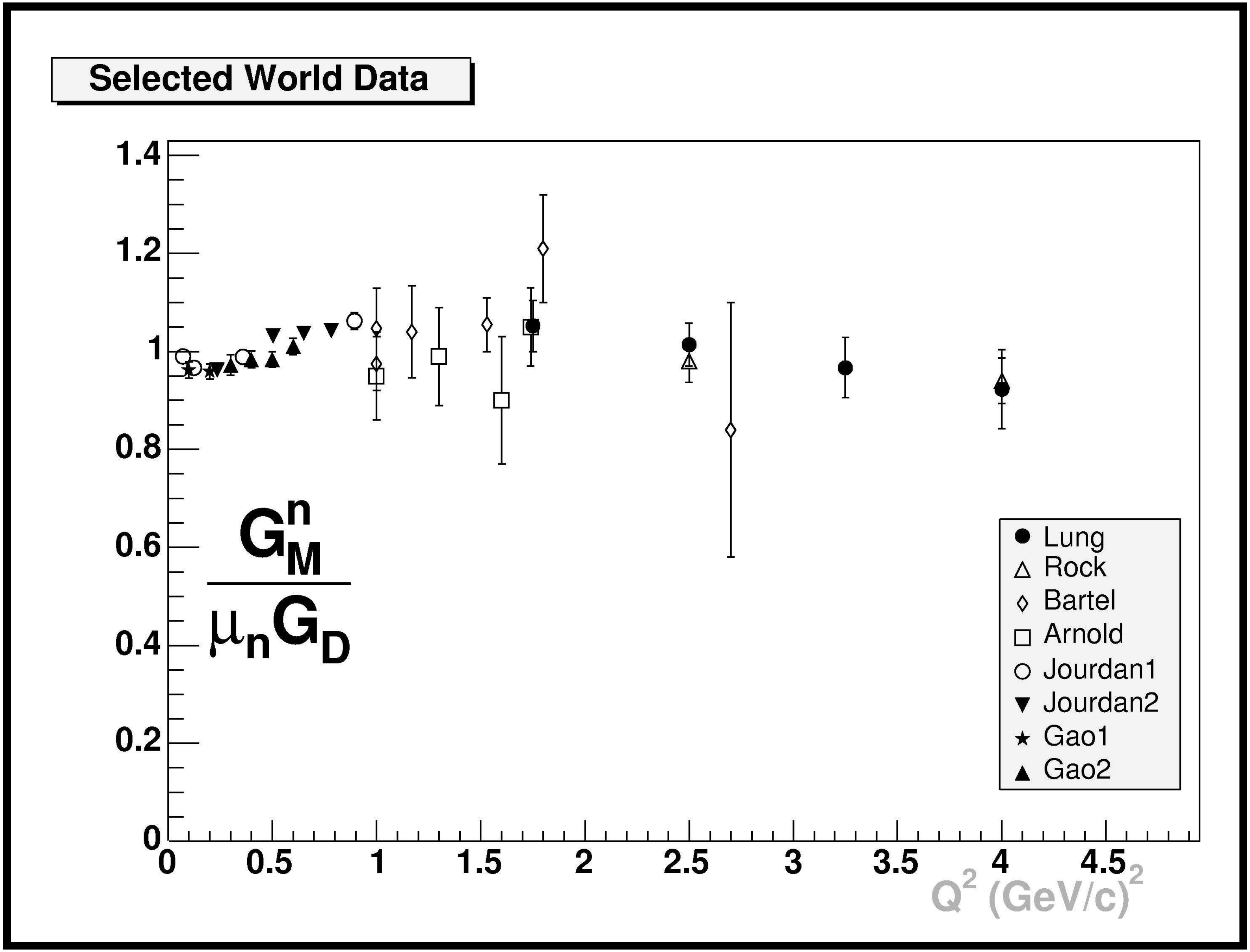
Overview

- Motivation
- Jefferson Lab Experiment 94-017
- CEBAF Large Acceptance Spectrometer
- Data Analysis
- Preliminary Results
- Summary


Selected World Data
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
$\frac{G_M^n}{\mu_n G_D}$
Q^2 (GeV/c)^2
Lung
Rock
Bartel
Arnold
Jourdan1
Jourdan2
Gao1
Gao2

Motivation

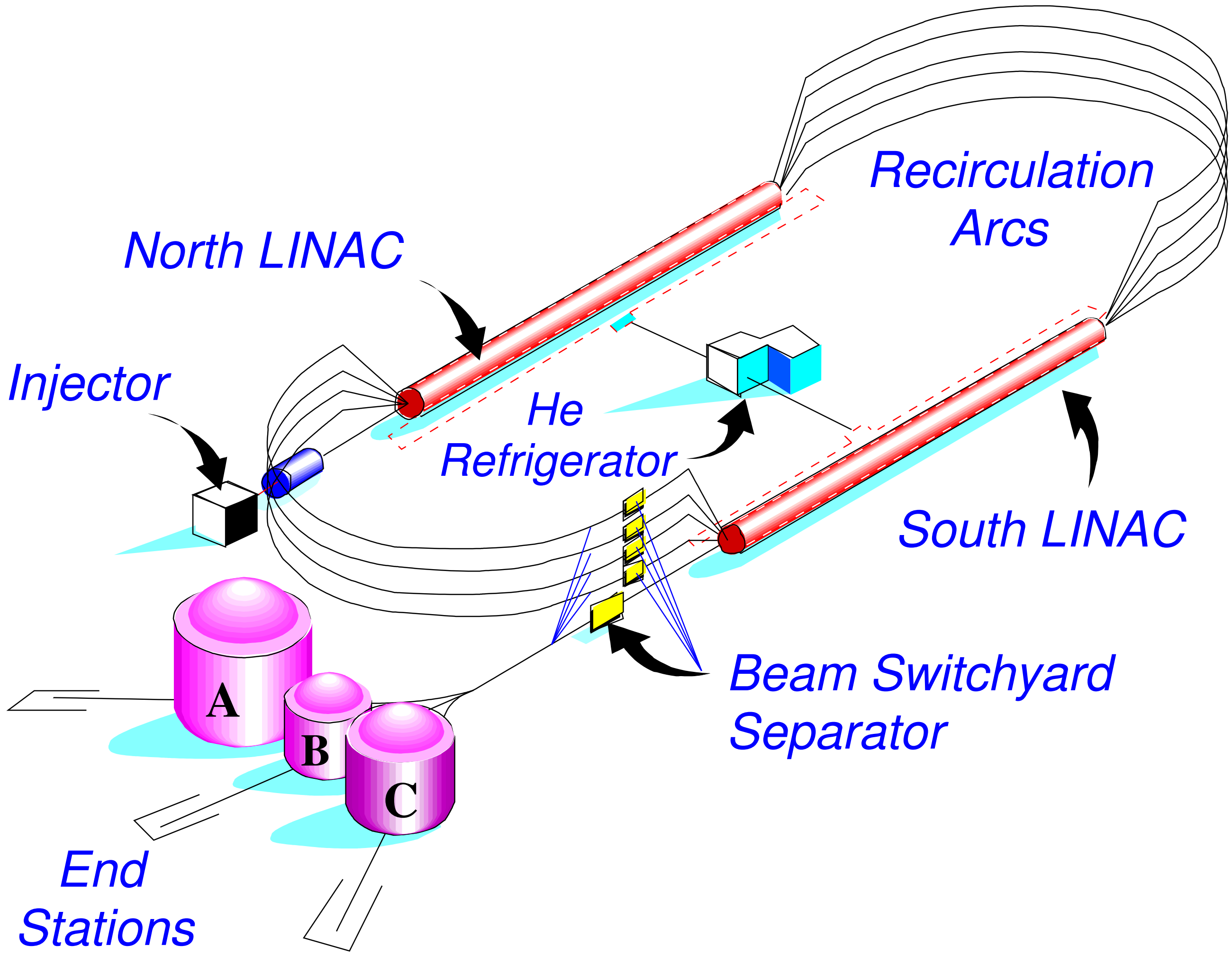
- Nucleon elastic form factors have been calculated using a wide variety of models (e.g., VMD, CQM, RQM, pChQM, Skyrme/soliton, CBM, ...)
- Predictions have been made at high Q^2using pQCD
- Progress is being made on lattice QCD calculations
- Form factors are related to the generalized parton distributions
- A definitive test of these theoretical efforts is to predict all four nucleon form factors simultaneously
- Limited range and quality of the existing data for G_M^n reduces the discriminating power of such a test
- High quality data for G_M^n over a large Q^2 range are clearly needed

Experimental Technique of E94-017

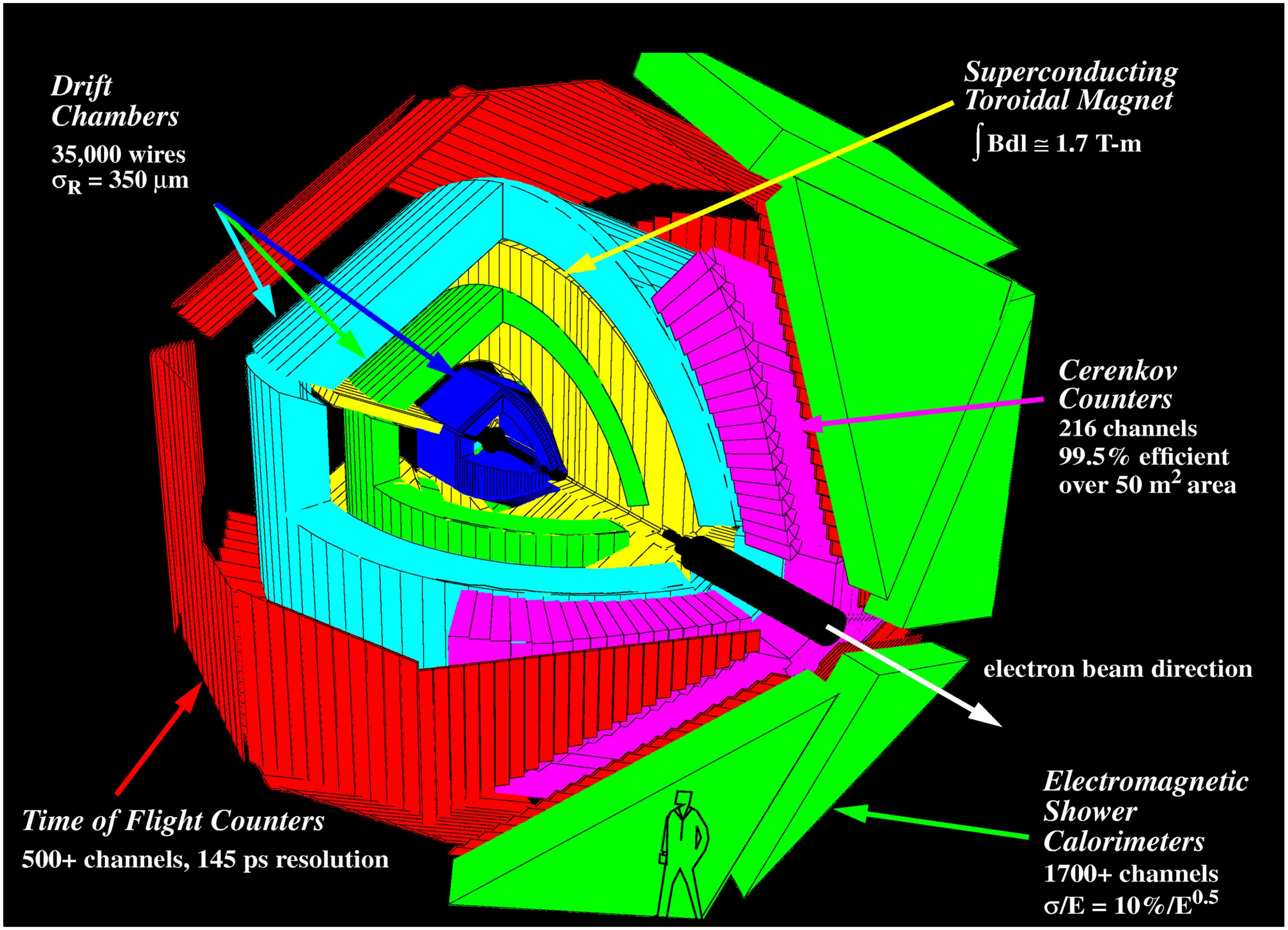
- Measure the ratio of quasi-elastic e-n to e-p scattering in deuterium with CLAS in Hall B at Jefferson Lab
- Extract G_M^n from ratio using G_E^p, G_M^p, and G_E^n
- Many of the systematic errors inherent in absolute cross section measurements cancel
- Neutron detection efficiency must be calibrated accurately
- Dual-cell deuterium-hydrogen target used in the experiment so that the ep $\rightarrow$ e$'$ π^+(n) reaction on the hydrogen target is used to measure the neutron detection efficiency

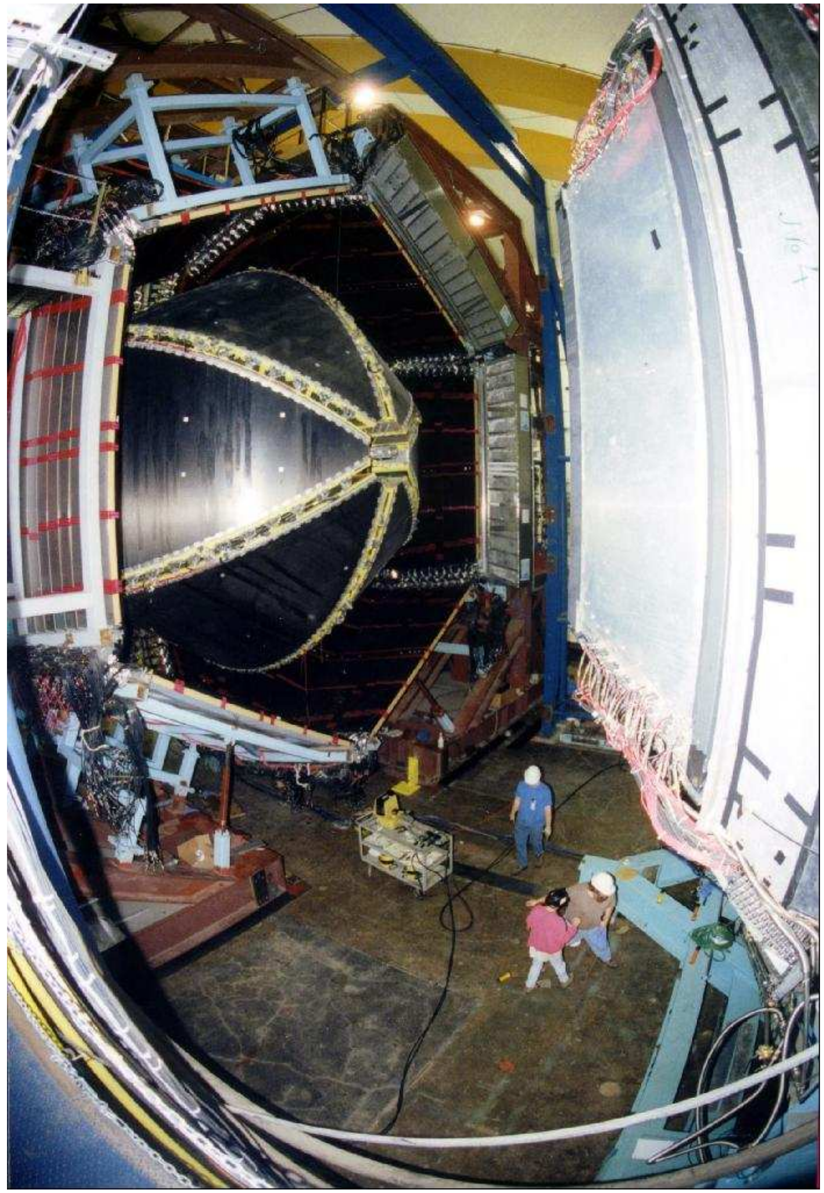
$$R_D = \frac{\frac{d\sigma}{d\Omega}\left[D\left(e,e'n\right)\right]}{\frac{d\sigma}{d\Omega}\left[D\left(e,e'p\right)\right]} \approx R_F = \frac{\left[\frac{G_{En}^2+\tau G_{Mn}^2}{1+\tau} + 2\tau G_{Mn}^2 \tan^2\left(\frac{\theta}{2}\right)\right]}{\left[\frac{G_{Ep}^2+\tau G_{Mp}^2}{1+\tau} + 2\tau G_{Mp}^2 \tan^2\left(\frac{\theta}{2}\right)\right]}$$

CEBAF at Jefferson Lab

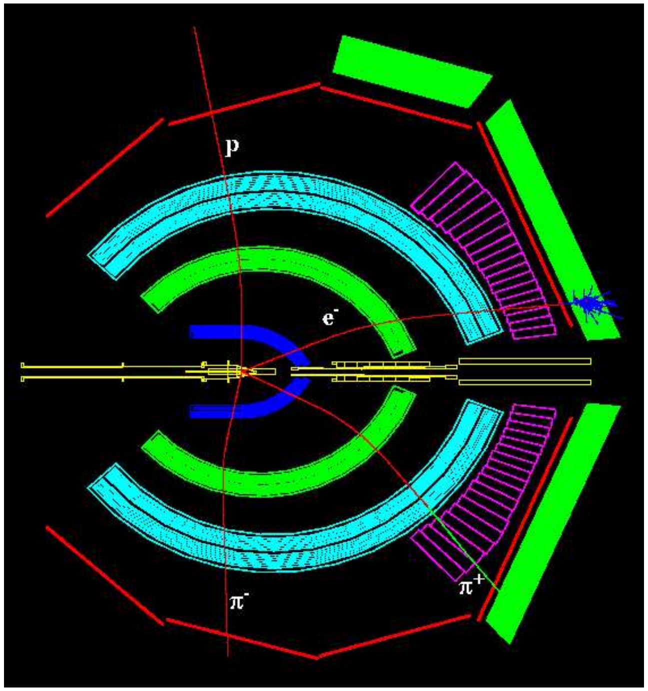


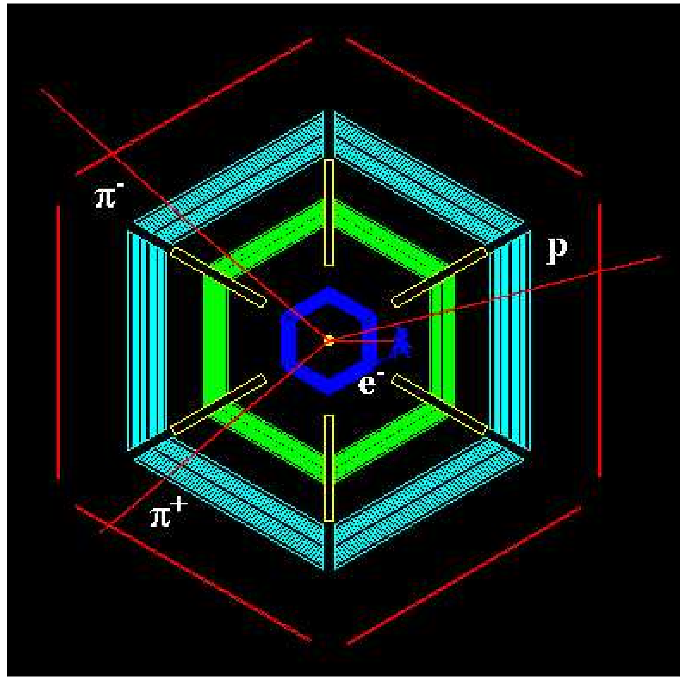
The CEBAF Large Acceptance Spectrometer (CLAS)





Particle Detection and ID





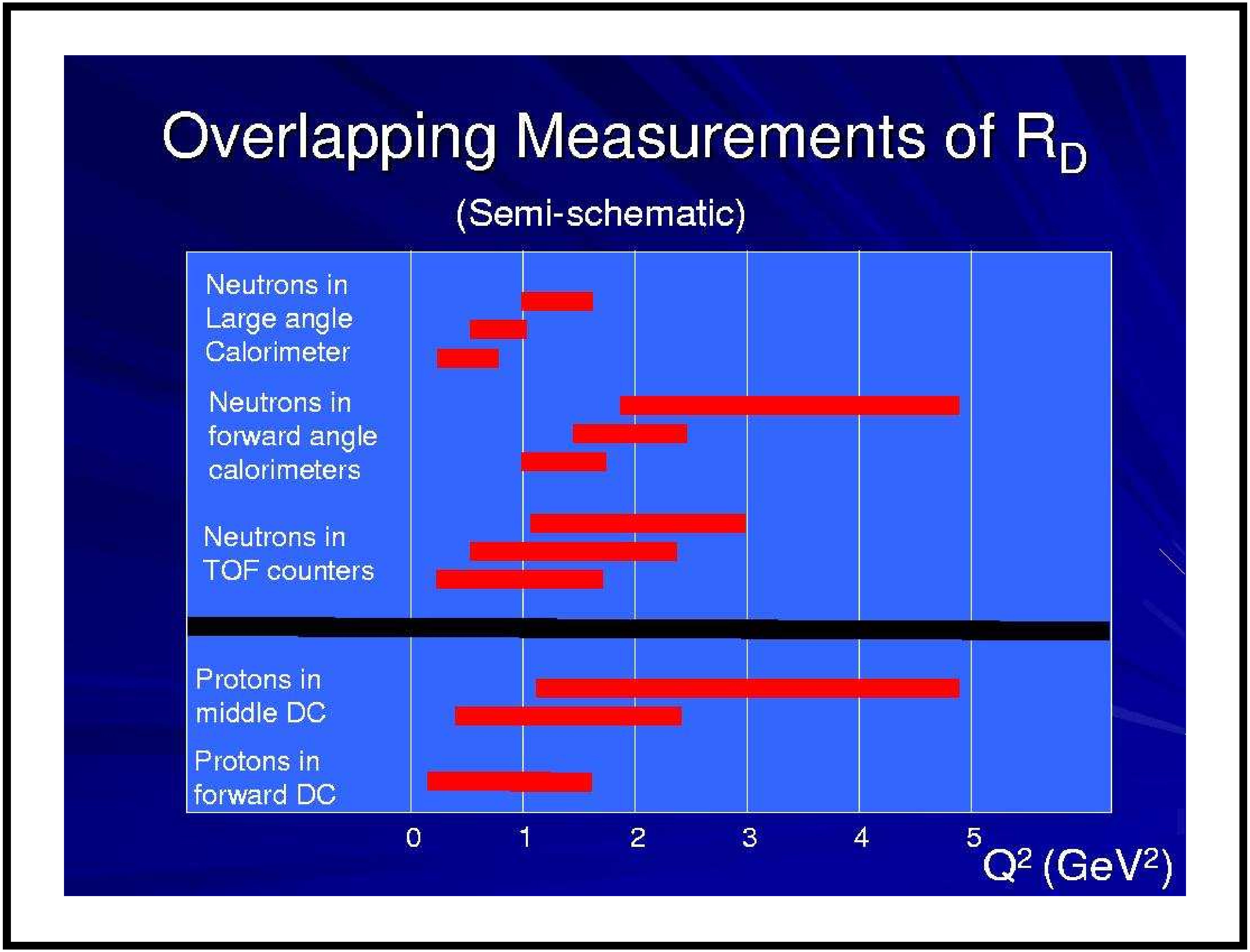
- Charged particle $\theta = 8°$-$144°$
- Neutral particle $\theta = 8°$-$75°$ $(144°)$
- Charged particle momentum resolution $\sim$0.5%
- Charged particle angular resolution $\sim$0.5 mrad
- Particle ID (e^-, p, π^+, π^-, K^+, γ, n,...)

The CLAS E5 Run

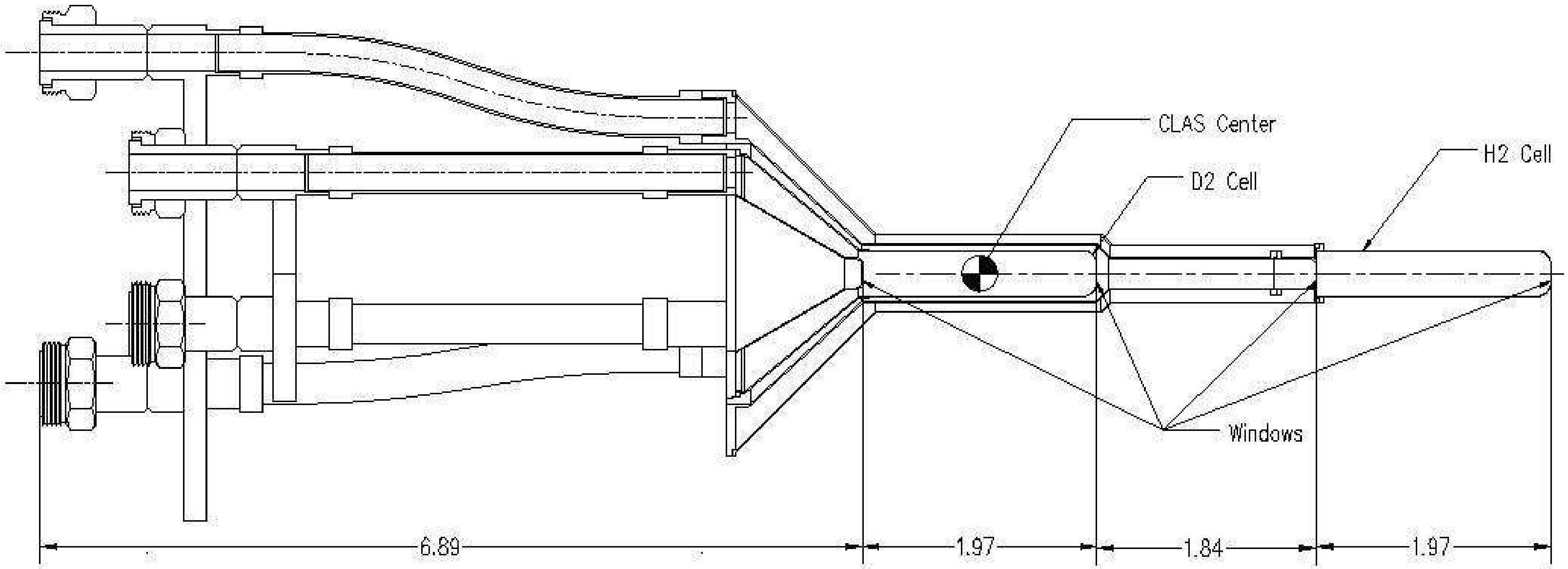
- Approximately 2.3 billion triggers were acquired in 30 days of operation
- Q^2 range 0.3 - 4.5 (GeV/c)^2
- Three different running conditions provided overlapping Q^2 coverage
  - 4.2-GeV beam with magnetic field at 90% of maximum reaches high Q^2
  - 2.5-GeV beam with field at 60% covers intermediate Q^2 range
  - 2.5-GeV beam with field at 60% but with reversed polarity to reach lowest Q^2

Benefits of CLAS

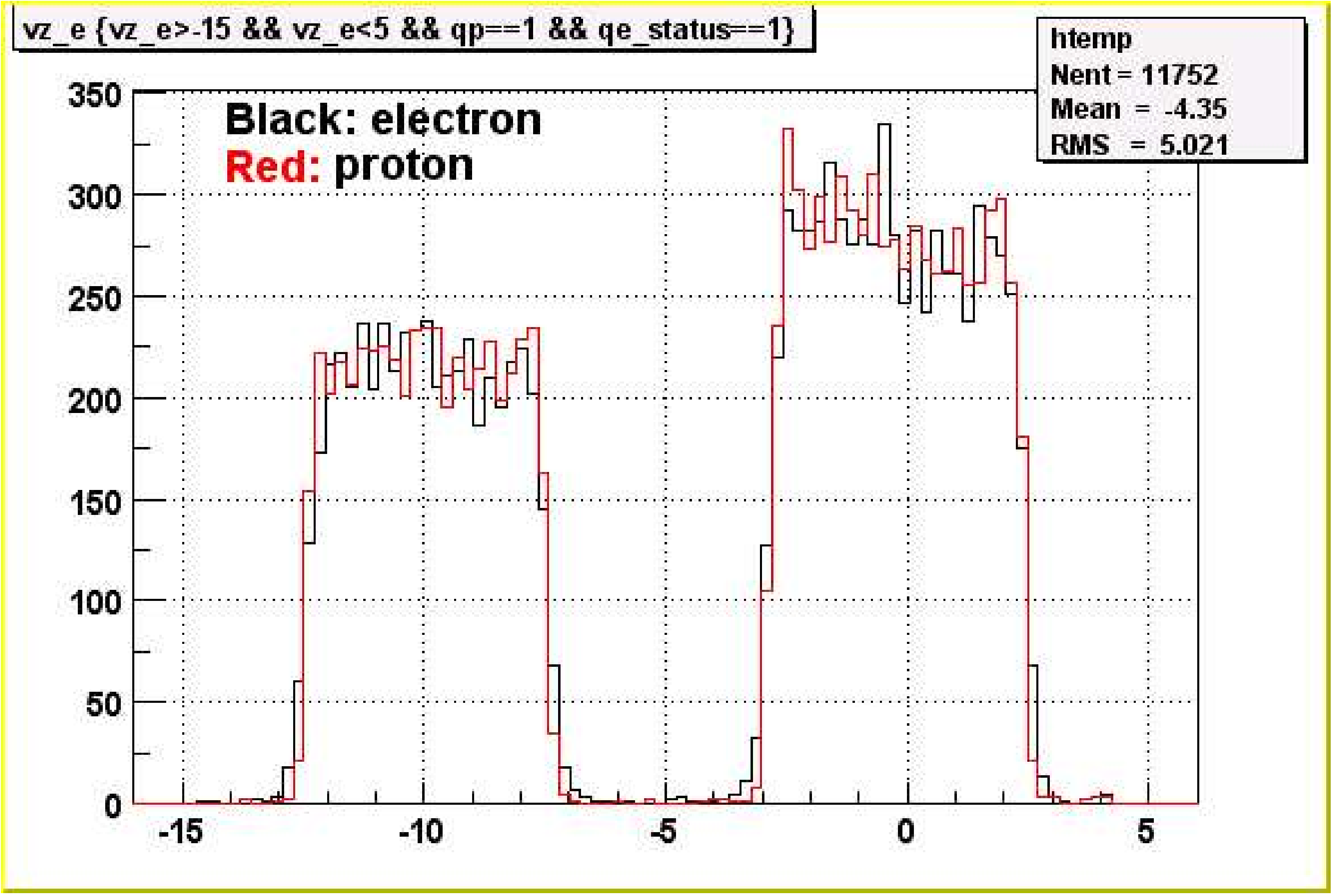
- Numerous cross-checks
  - Three independent, overlapping measurements of e-n
  - Three different beam energy and magnetic field combinations allow independent, overlapping measurements of e-p
  - Multiple, overlapping measurements of G_M^n
- Accommodates dual-cell target
  - In-situ neutron tagging
  - In-situ proton elastic scattering (proton detection efficiency, momentum corrections, and alignment)
- Inelastic background suppression using information from detected nucleons


Overlapping Measurements of R_D
(Semi-schematic)
Neutrons in Large angle Calorimeter
Neutrons in forward angle calorimeters
Neutrons in TOF counters
Protons in middle DC
Protons in forward DC
0
1
2
3
4
5
Q^2 (GeV^2)

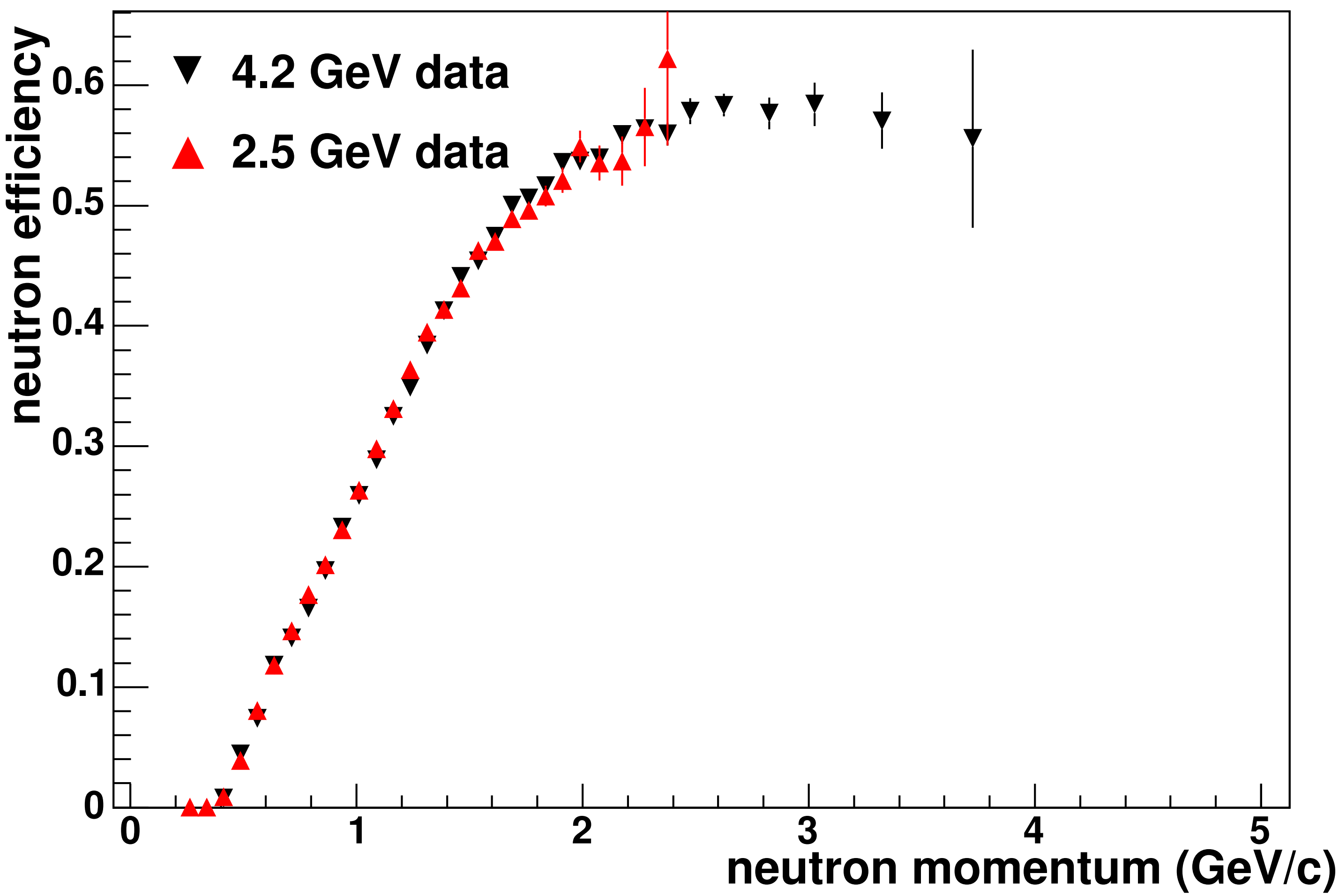
Dual-Cell Liquid Cryotarget



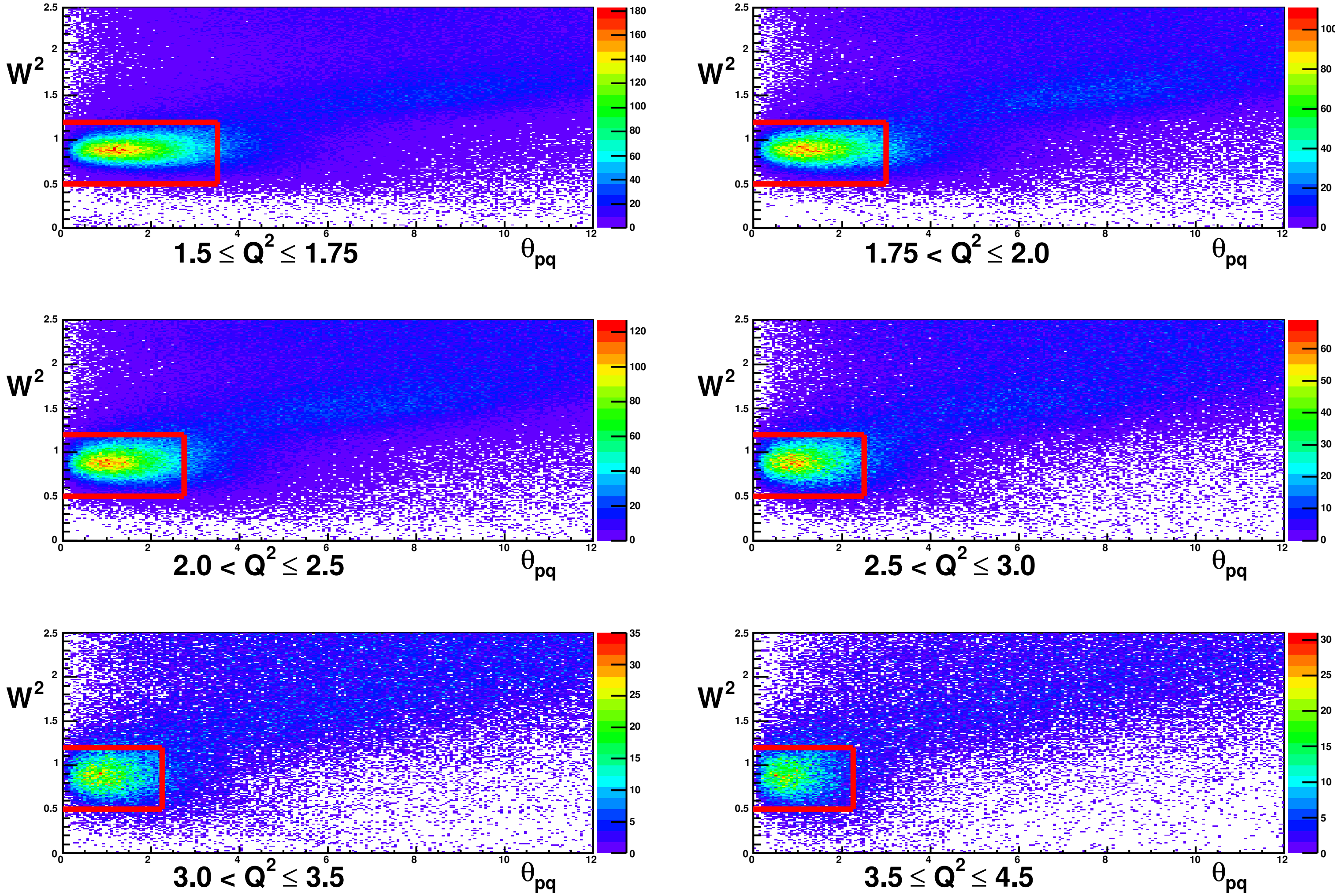
Z-Vertex Distribution for e-p Events



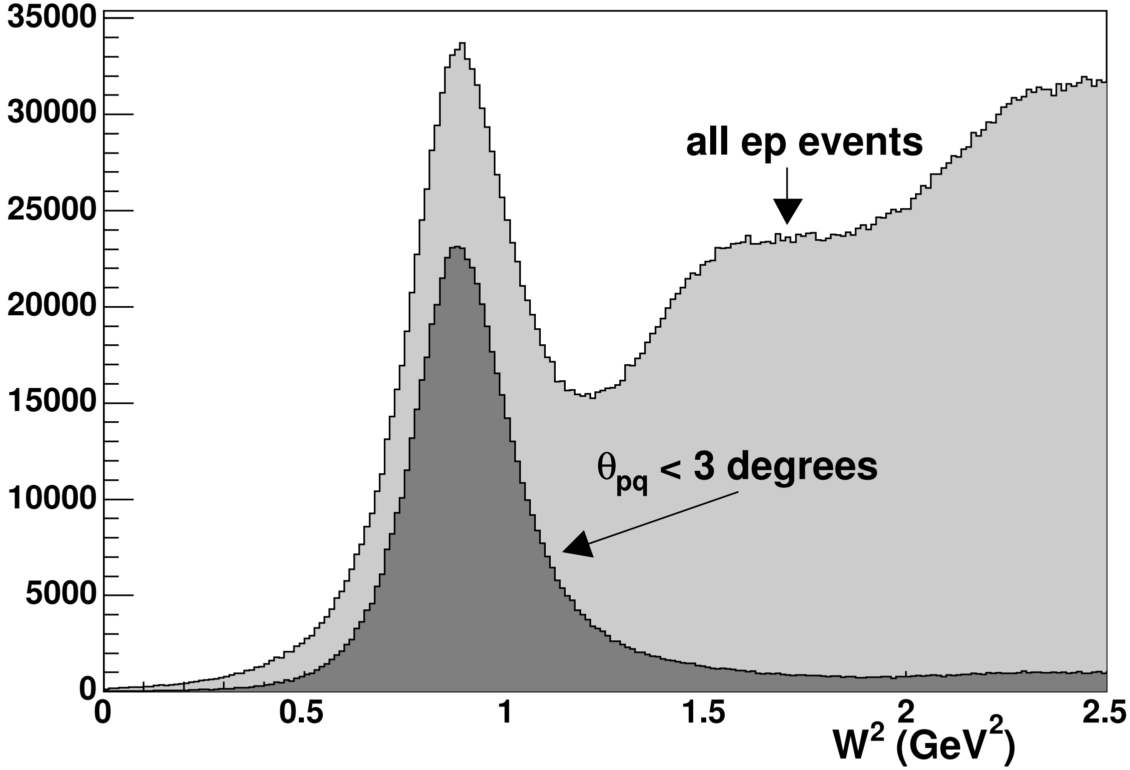
EC Neutron Detection Efficiency



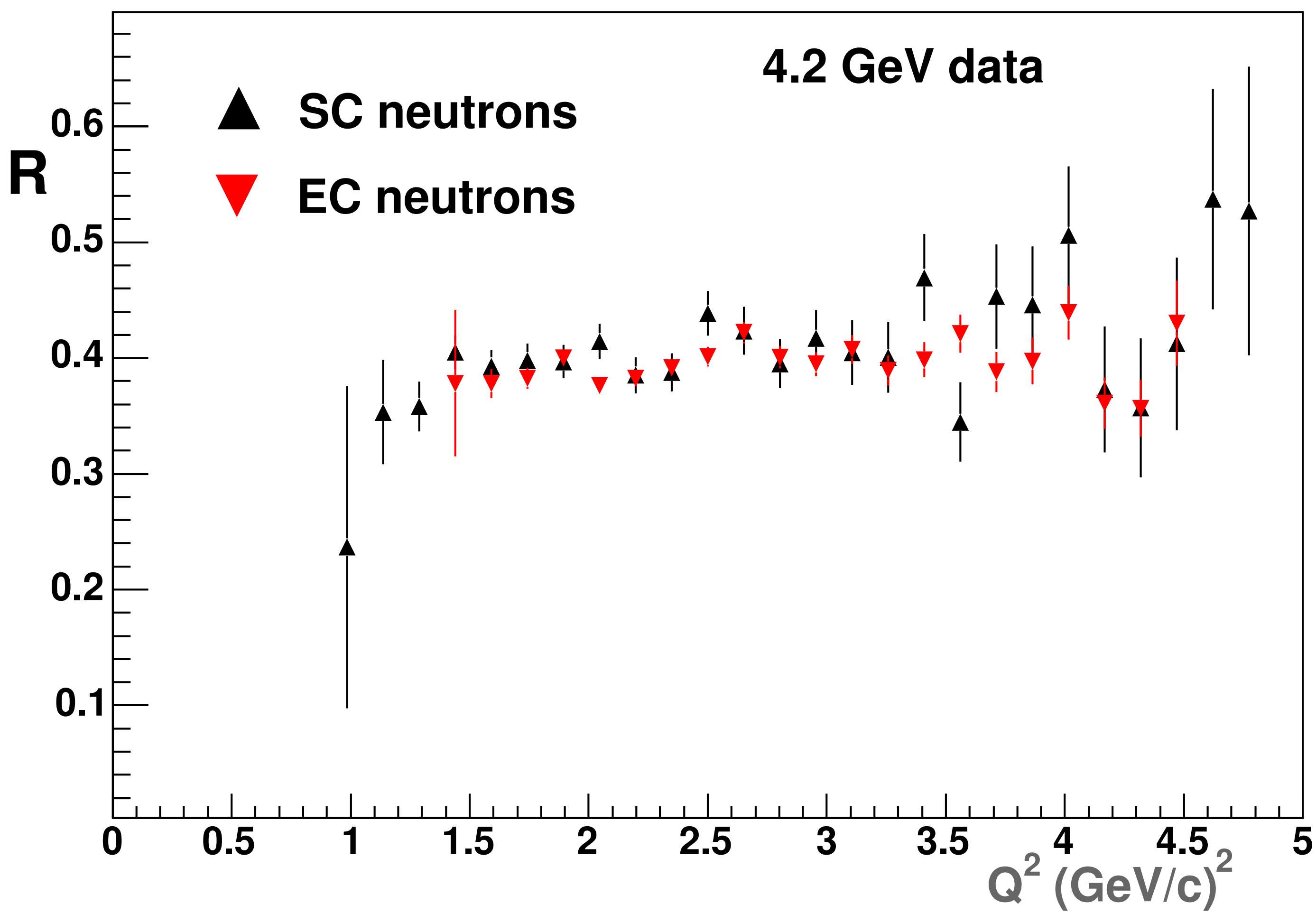
Quasi-Elastic Cuts



Effect of θ_{pq} Cut



Ratio of Quasi-Elastic e-n to e-p Scattering in Deuterium



Corrections to the Ratio

$$R_C\left(Q^2\right) = c_{nuc}\left(Q^2\right) c_{rad}\left(Q^2\right) c_{fermi}\left(Q^2\right) R_D\left(Q^2\right)$$

- $c_{fermi}\left(Q^2\right)$ - corrections for losses near the edge of the acceptance due to fermi motion in the target - estimated with Monte-Carlo simulation
- $c_{rad}\left(Q^2\right)$ - radiative corrections performed with a modified version of EXCLURAD (Afanasev *et al.*)
- $c_{nuc}\left(Q^2\right)$ - nuclear corrections performed using calculations by Arenhovel for $Q^2 \leq 1$ (GeV/c)^2 and Jeschonnek for $Q^2 \geq 1$ (GeV/c)^2

Extraction of G_M^n from the Ratio

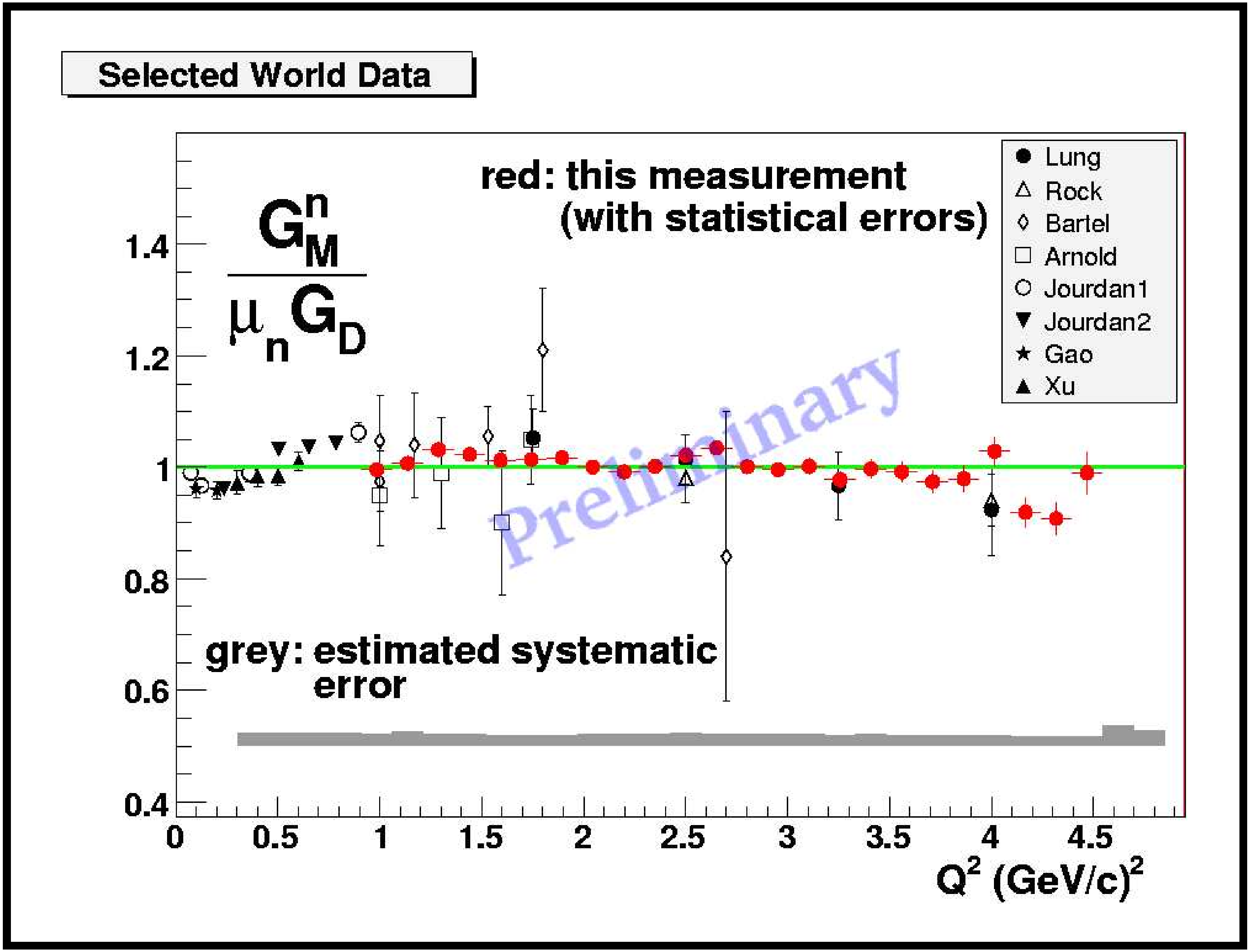
$$R_C = \frac{\sigma^n_{Mott}\left(G^2_{En} + \frac{\tau_n}{\epsilon_n}G^2_{Mn}\right)\left(\frac{1}{1+\tau_n}\right)}{\sigma^p_{Mott}\left(G^2_{Ep} + \frac{\tau_p}{\epsilon_p}G^2_{Mp}\right)\left(\frac{1}{1+\tau_p}\right)}$$

$$G_M^n = \sqrt{\left[R_C\left(\frac{\sigma^p_{Mott}}{\sigma^n_{Mott}}\right)\left(\frac{1+\tau_n}{1+\tau_p}\right)\left(G^2_{Ep} + \frac{\tau_p}{\epsilon_p}G^2_{Mp}\right) - G^2_{En}\right]\frac{\epsilon_n}{\tau_n}}$$

- Arrington parametrization used for G_E^p and G_M^p
- Galster parametrization used for G_E^n

Sources of Systematic Errors

- Uncertainties in the other form factors
- Detection efficiencies
- Inelastic background
- Acceptance
- Fermi loss corrections
- Radiative corrections
- Nuclear corrections



Selected World Data
$\frac{G_M^n}{\mu_n G_D}$
red: this measurement
(with statistical errors)
grey: estimated systematic
error
Preliminary
Lung
Rock
Bartel
Arnold
Jourdan1
Jourdan2
Gao
Xu
1.4
1.2
1
0.8
0.6
0.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Q^2 (GeV/c)^2

Acknowledgements

- The E5 Run Group
  - W. Brooks (Jefferson Lab)
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  - L. Kramer (Florida International University)
- The CLAS Collaboration

*Present Address: Old Dominion University

Summary

- G_M^n has been extracted from the ratio of quasi-elastic e-n to e-p scattering from deuterium over a broad range of Q^2
- A dual-cell H-D target was used allowing in-situ measurements of the neutron detection efficiency using the $ep \rightarrow e' \, \pi^+(n)$ reaction
- The use of multiple beam energies, magnetic field settings, and neutron detectors provided independent measurements over overlapping ranges in Q^2
- Consistency of overlapping measurements indicates that systematic errors are under control
- The dipole parametrization provides a good description of the data at $Q^2 > 1$ $(\mathrm{GeV/c})^2$
- Technique can be extended to higher Q^2