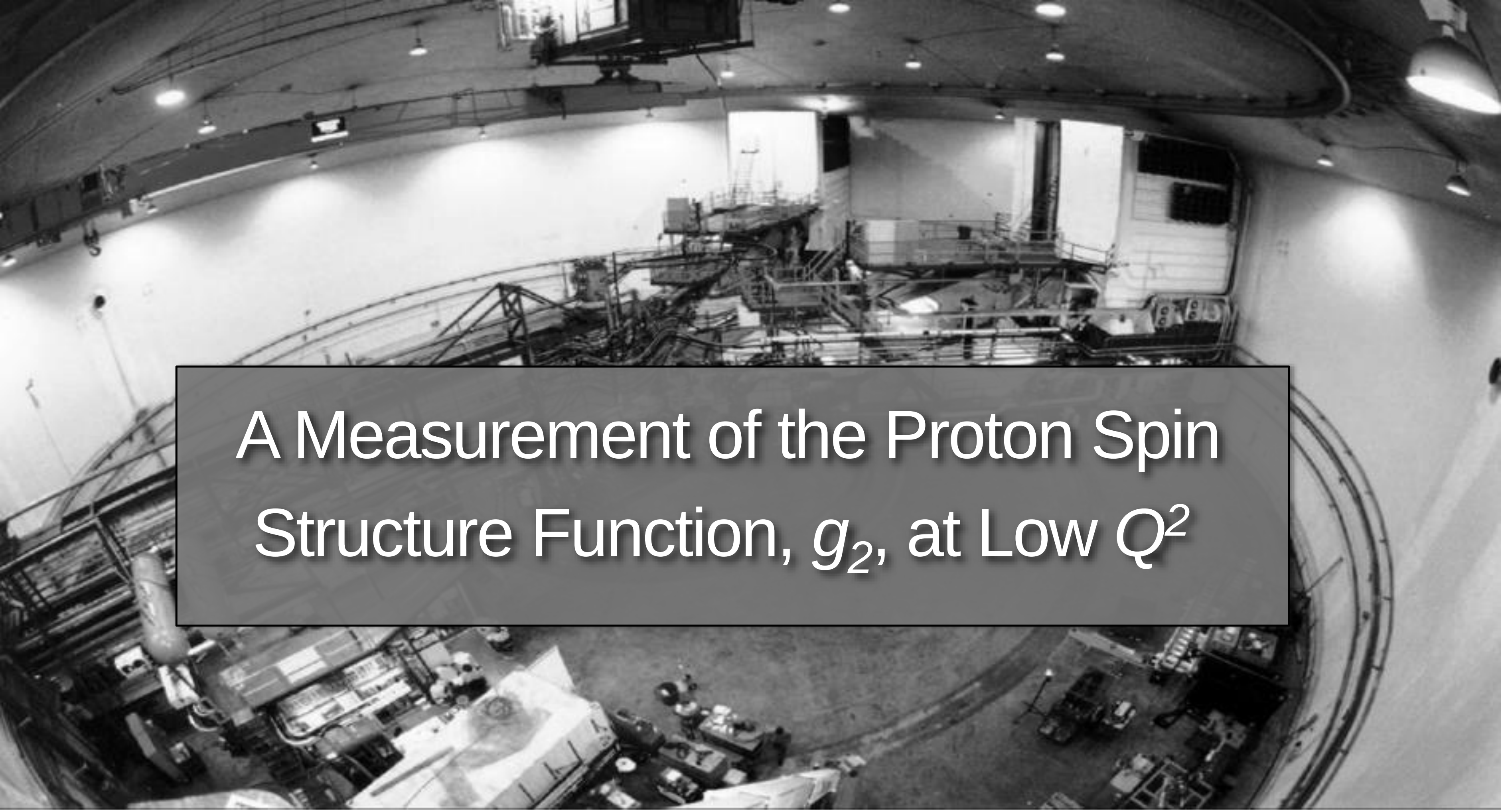


# A Measurement of the Proton Spin Structure Function, $g_2$, at Low $Q^2$

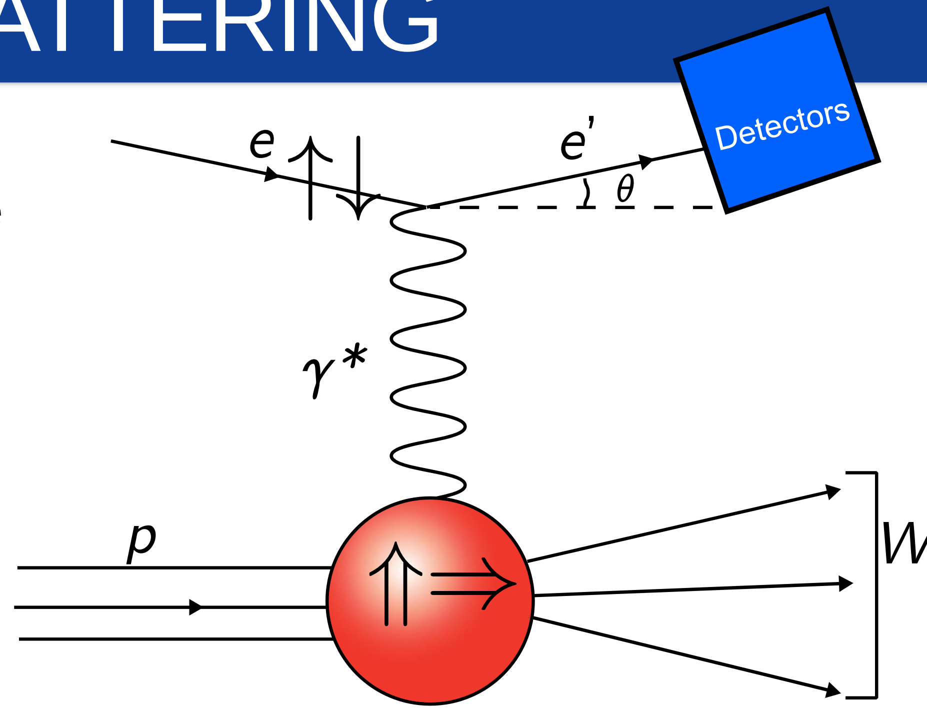

Ryan Zielinski

For the Jefferson Lab Hall A E08-027 (g2p) Collaboration


July 2, 2015


University of New Hampshire

# INCLUSIVE *ep* SCATTERING




Four structure functions characterize the scattering from a proton:

Inclusive *unpolarized* cross sections

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{\text{Mott}}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\frac{\theta}{2}\right]$$

Adding a *polarized* beam and target adds two more structure functions

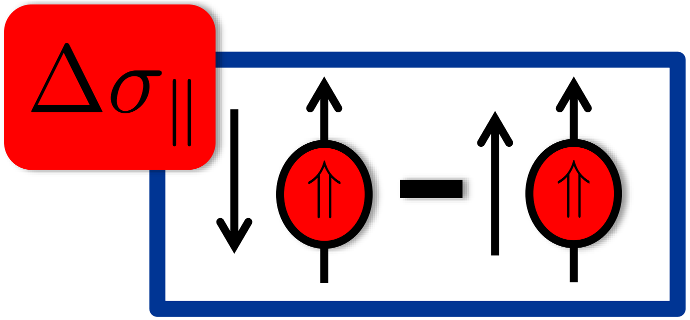
$$\frac{d^2\sigma^{\pm}}{d\Omega dE'} = \sigma_{\text{Mott}}\left[\alpha F_1(x,Q^2) + \beta F_2(x,Q^2) \pm \gamma g_1(x,Q^2) \pm \delta g_2(x,Q^2)\right]$$

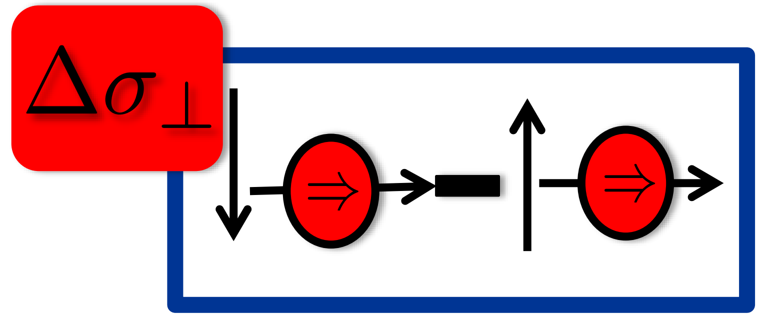
$g_1$ and $g_2$ related to spin distribution

$$Q^2 = -q^2 = 4EE'\sin^2\frac{\theta}{2}$$
$$x = \frac{Q^2}{2M\nu}$$
$$\nu = E - E'$$

# EXTRACTING SPIN STRUCTURE

Inclusive *polarized* cross sections




*Two equations, two unknowns…*

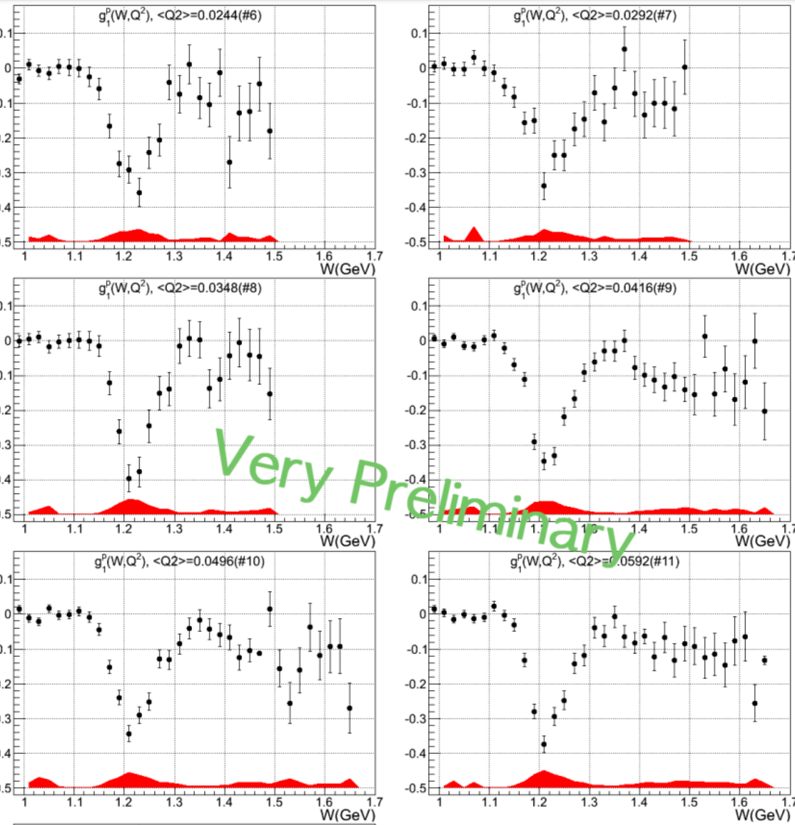
$\Delta\sigma_{\parallel}$ measured during EG4 experiment in Hall B: will extract $g_1$ at low $Q^2$

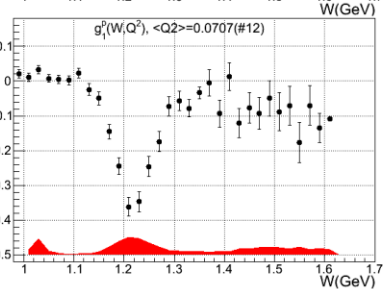
$$\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2}{M\nu Q^2}\frac{E'}{E}\left[(E+E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)\right]$$

$\Delta\sigma_{\perp}$ measured from g2p experiment

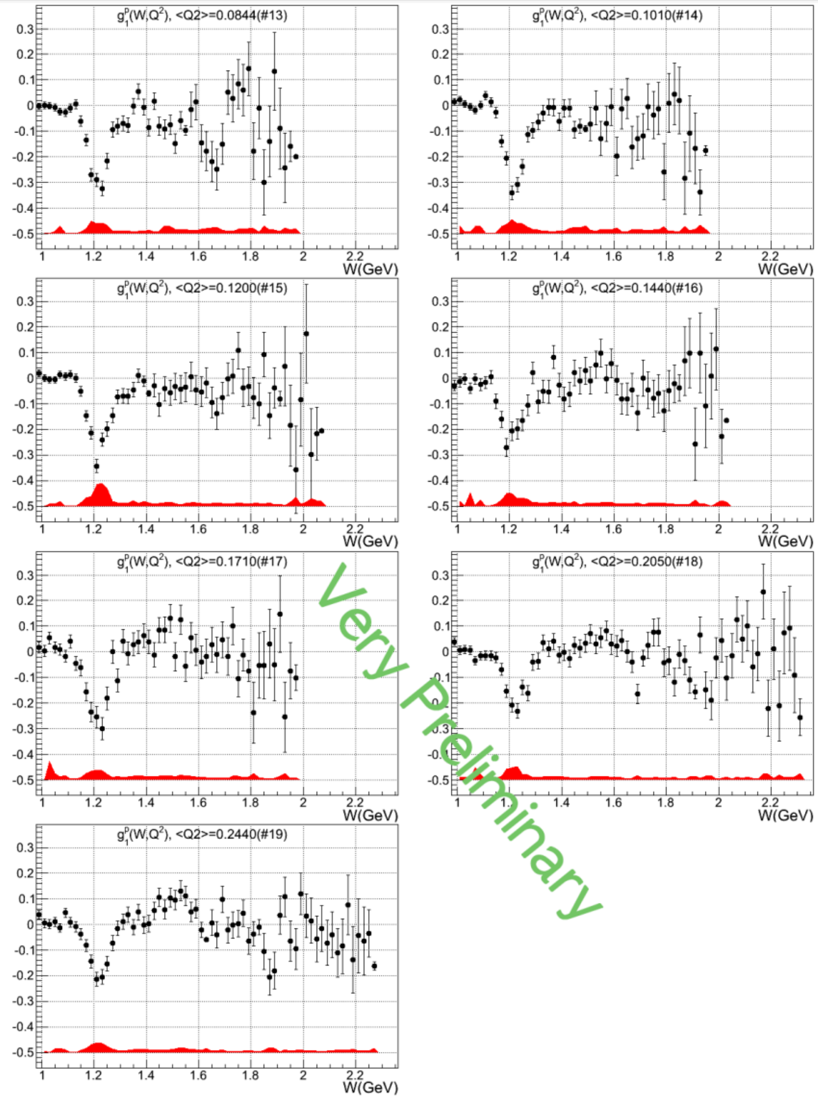
$$\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{M\nu^2 Q^2}\frac{E'^2}{E}\left[\nu g_1(x,Q^2) - 2E g_2(x,Q^2)\right]$$

# PRELIMINARY EG4 $g_1$ DATA




**Plots courtesy of Hyekoo Kang**

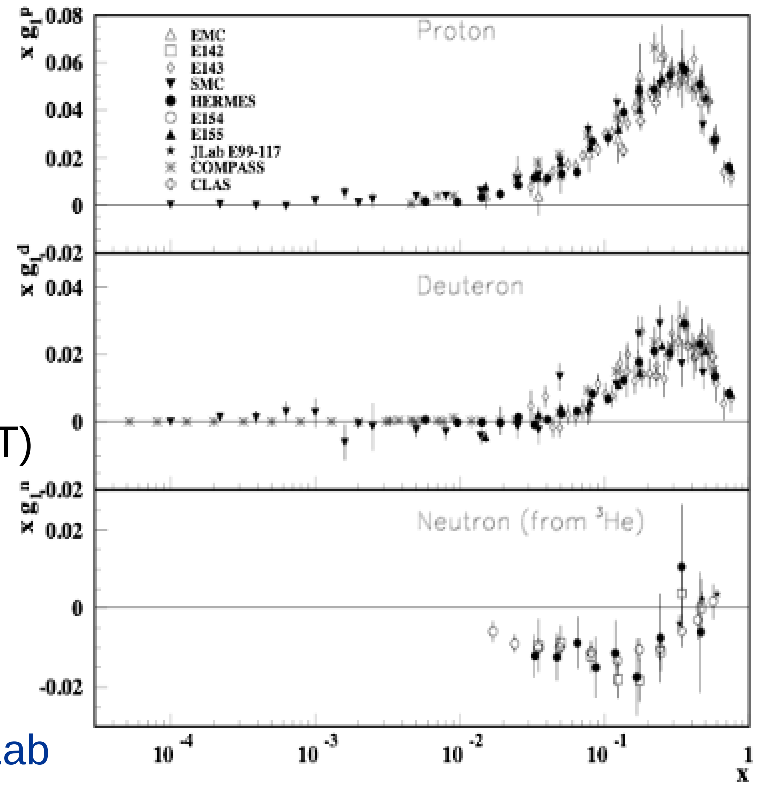


# MOTIVATION

Measure a fundamental spin observable ($g_2$) in the region $0.02 < Q^2 < 0.20$ GeV$^2$ for the first time

- First measurements of proton $g_2$ at SLAC E155x
- Measurements at Jefferson Lab:
  - RSS – medium $Q^2$ ( 1-2 GeV$^2$) (published)
  - SANE – high $Q^2$ (2-6 GeV$^2$) (analysis)
  - g2p – low $Q^2$ (0.02-.20 GeV$^2$) (analysis)
- Low $Q^2$ is useful:
  - Test predictions of Chiral Perturbation Theory (χPT)
  - Test sum rules and measure moments of $g_2$
  - Study finite size effects of the proton
- g2p experiment ran spring 2012 in Hall A at Jefferson Lab

*Lots of $g_1$ data…*




**Particle Data Group (2010)**

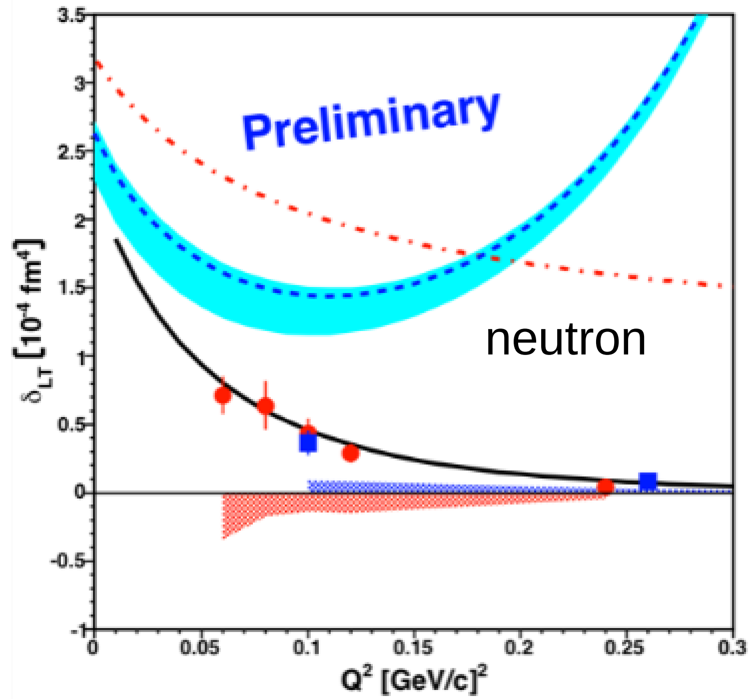


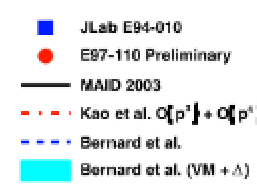
University of New Hampshire

# SPIN LT POLARIZABILITY

- Can be calculated via χPT
  - Difficulty is how to include nucleon resonance contributions
  - $\delta_{LT}$ insensitive to delta resonance
- Present neutron data shows some deviations for calculated polarizabilities
- No proton data yet!

**Plot courtesy of V. Sulkosky**



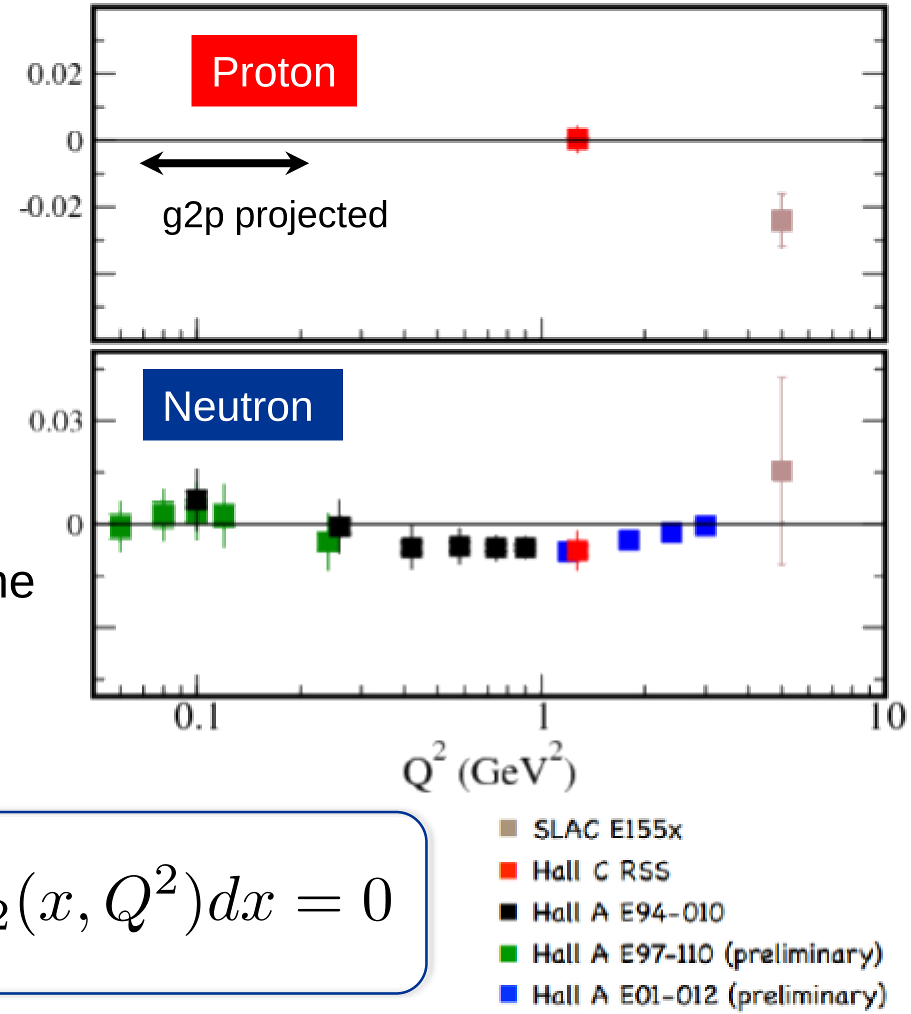

$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1(x,Q^2)+g_2(x,Q^2)]dx$$



University of New Hampshire

# THE B.C. SUM RULE

- Satisfied within error bars for neutron
- Inconsistency seen in the proton data
- Mostly unmeasured for proton




*BC Sum = Measured + Low x + Elastic*

- Low x: Hard to access low x portion of the integral – assume leading twist behavior
- Elastic: Use well known form factors

$$\Gamma_2(Q^2) = \int_0^1 g_2(x, Q^2)dx = 0$$



University of New Hampshire

# FINITE SIZE EFFECTS

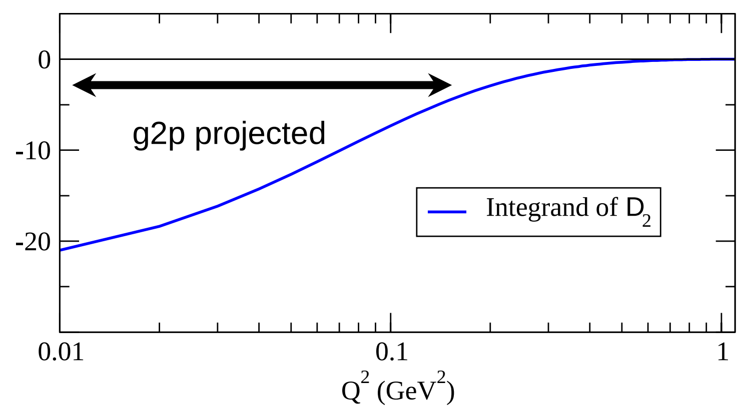
- Hydrogen hyperfine splitting can be calculated as

$$\Delta E = 1420.4057517667(9)\text{MHz}$$
$$= (1+\delta)E_F$$
$$\delta = (\delta_{\text{QED}} + \delta_R + \delta_{\text{small}}) + \Delta_S$$

$$\Delta_S = \Delta_Z + \Delta_{\text{pol}}$$
$$\Delta_{\text{pol}} = \frac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$$

- Structure correction is largest contributor to theoretical uncertainty

- $\Delta_2$ term is related to integral of $g_2$ and is dominated by low $Q^2$ region



# JEFFERSON LAB



**Continuous Electron Beam Accelerator Facility (CEBAF)**

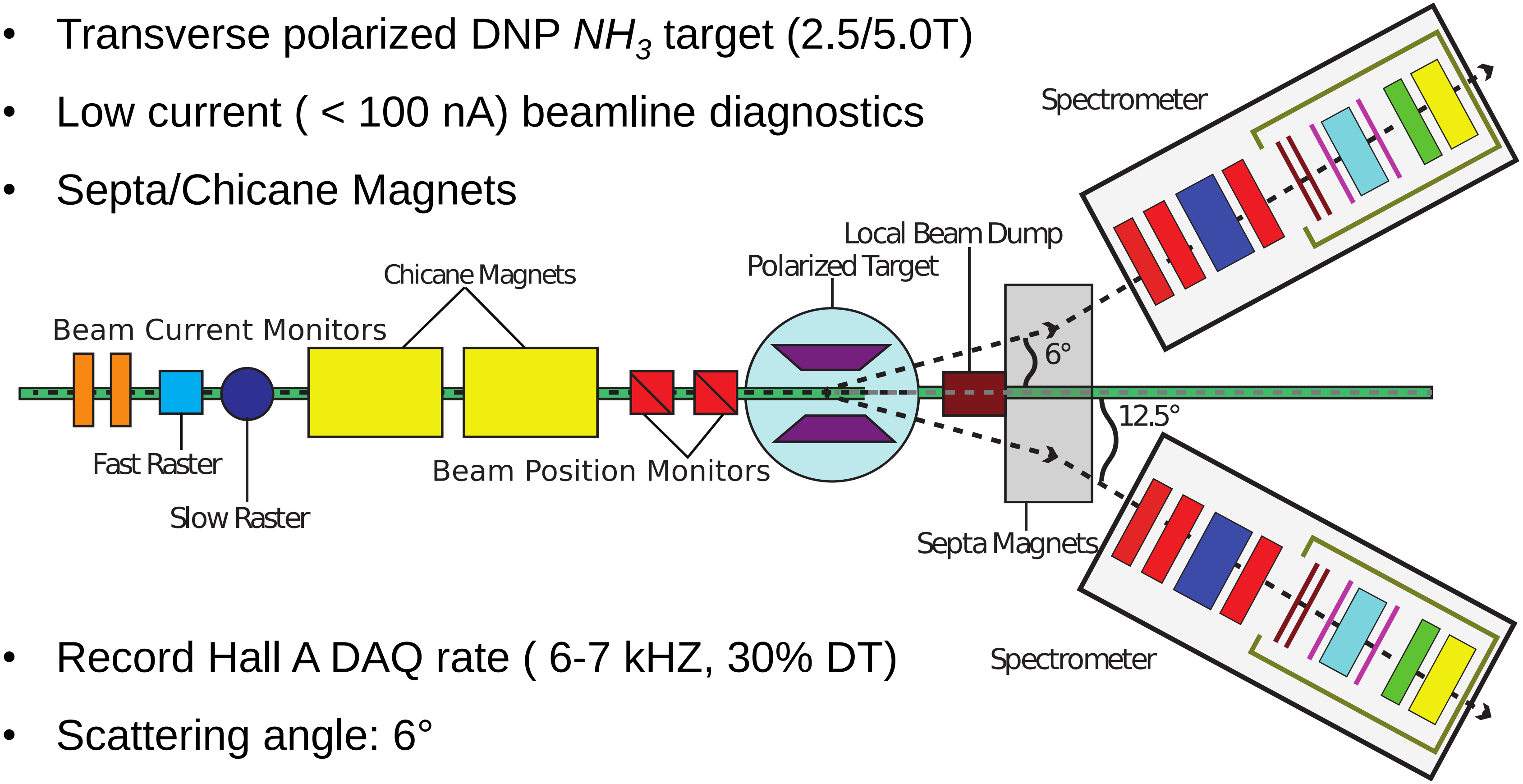
- 12 GeV maximum beam energy
- 200 μA maximum current
- 85% electron polarization



University of New Hampshire

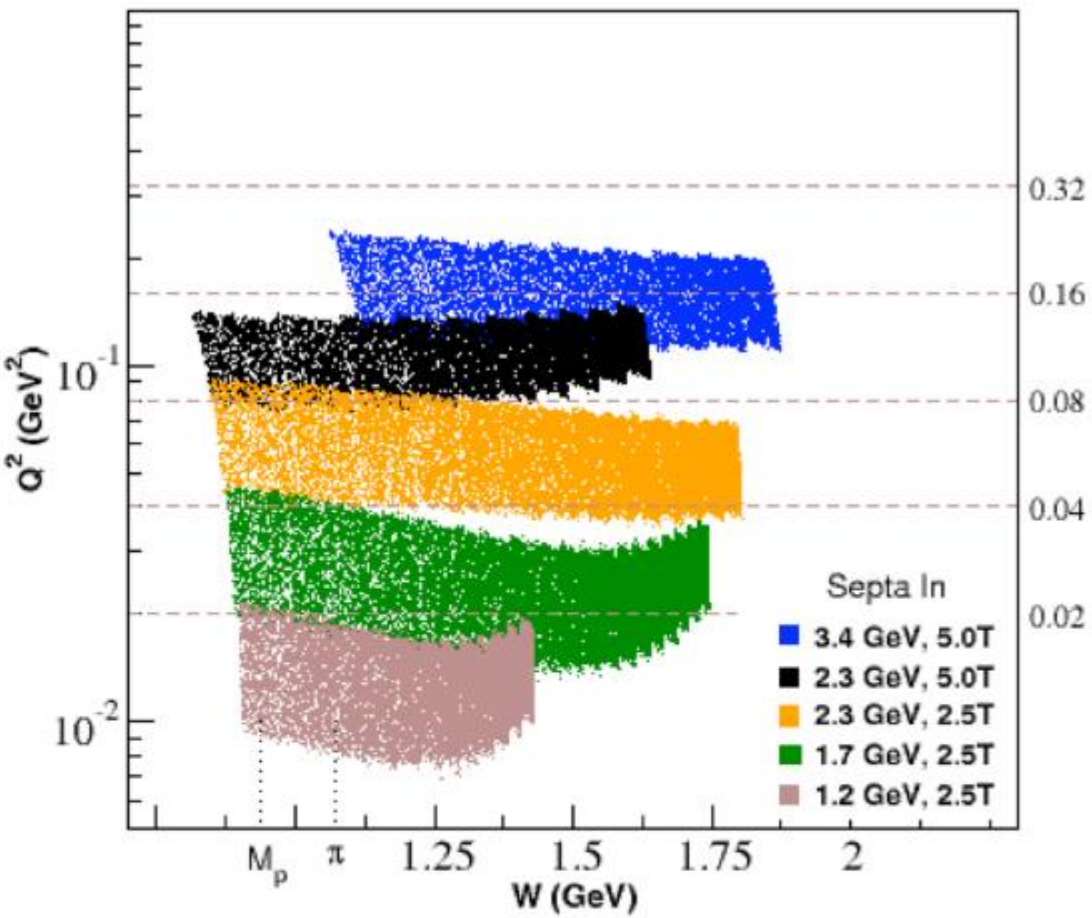
# G2P EXPERIMENTAL SETUP

- Large scale installation in Hall A
- Transverse polarized DNP $NH_3$ target (2.5/5.0T)
- Low current ( < 100 nA) beamline diagnostics
- Septa/Chicane Magnets




- Record Hall A DAQ rate ( 6-7 kHZ, 30% DT)
- Scattering angle: 6°

# KINEMATIC COVERAGE




$$M_p < W < 2 \text{ GeV}$$
$$0.02 < Q^2 < 0.2 \text{ GeV}^2$$

| $E_0$ (GeV) | Target Field (T) |
|---|---|
| 2.254 | 2.5 |
| 1.706 | 2.5 |
| 1.158 | 2.5 |
| 2.254 | 5.0 |
| 3.352 | 5.0 |

# STATUS OF ANALYSIS

**Completed**

- Run DB
- HRS Optics
  - Field measurement analysis
  - VDC $t_0$ calibration
  - Simulation package
  - Optics reconstruction
- Detector calibrations/efficiencies
- Scalers
  - Helicity decoding
  - BCM calibrations
  - Deadtime calculations
- Target polarizations (results published: *Nucl. Instrum. Meth. A738 54 (2014)*)
- BPM calibrations/Raster size calibration (paper submitted to *Nucl. Instrum. Meth.*)

**In progress**

- Dilution analysis
- Asymmetry analysis
- Radiative (unpolarized/polarized) corrections
- Acceptance study
- Packing fraction

**To do**

- Unpolarized/polarized cross sections
- Determination of $g_2$/moments

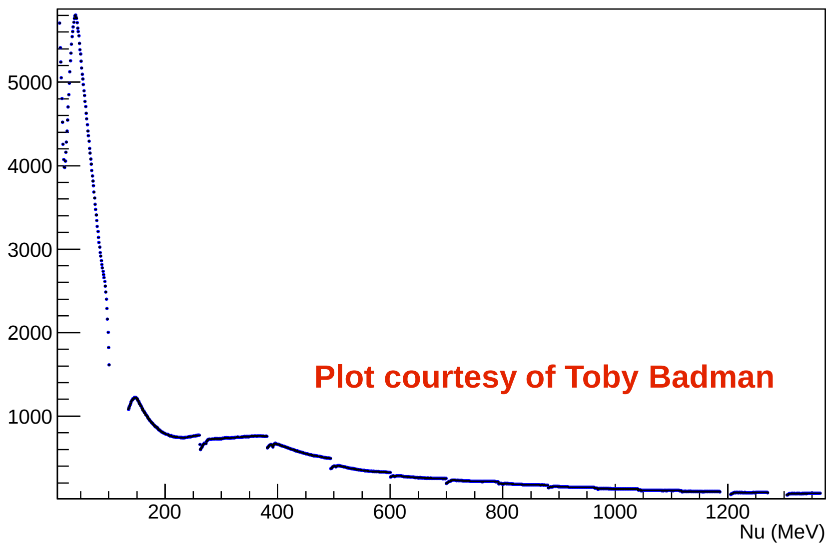


University of New Hampshire

# PRELIMINARY RESULTS

## 2254 MeV Ammonia Yield

2.254GeV 5T Transverse Left Arm Normalized Yield



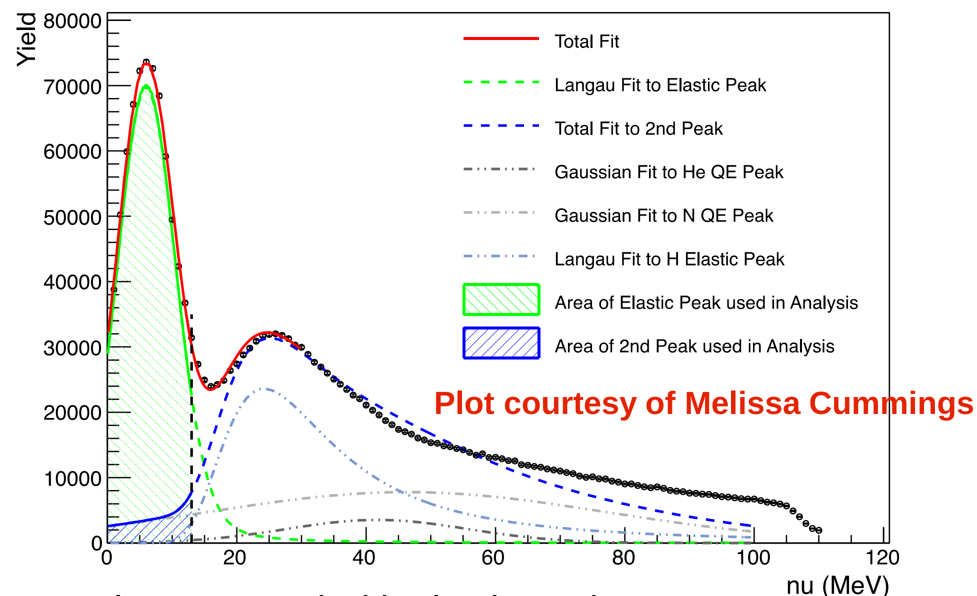

$$\Delta\sigma_{\|(\perp)}^{\text{exp}} = 2 \cdot A_{\|(\perp)}^{\text{exp}} \cdot \sigma_0^{\text{exp}}$$

$$Y_{\pm} = \frac{psN_{\pm}}{Q_{\pm} L T_{\pm} \epsilon_{\text{det}}}$$

Will measure both asymmetry and cross section

## 2254 MeV Packing Fraction

Fit to Elastic and QE Peaks



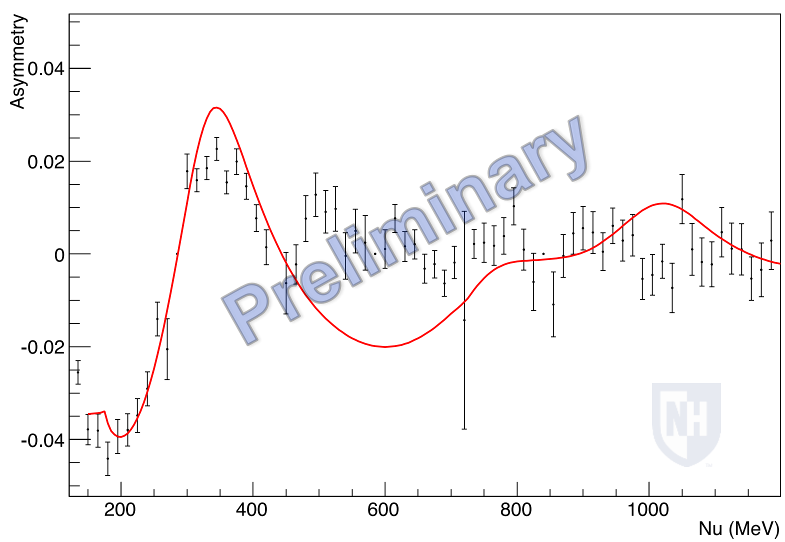

- Only concerned with elastic peak
- 2nd peak has contributions from multiple materials
  - Used QFS model to understand relative contributions

Preliminary Result: $p_f = 0.619 \pm 0.030$

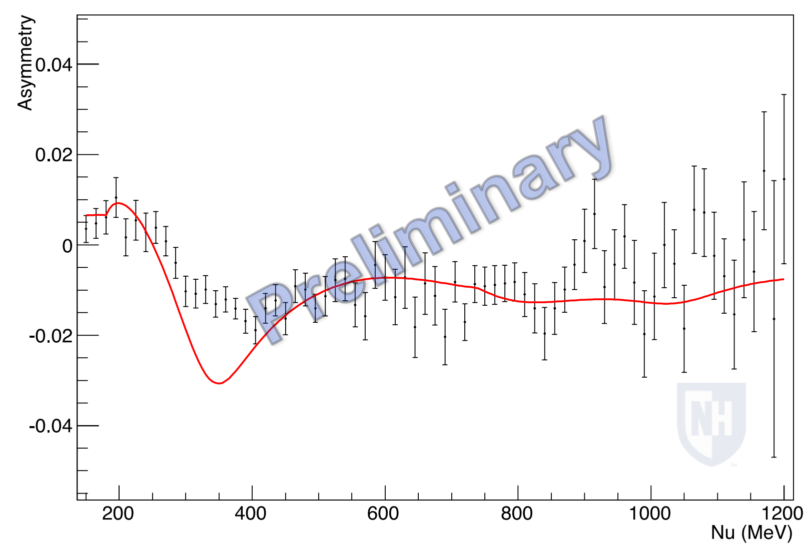
# PRELIMINARY RESULTS

## 2254 MeV Proton Asymmetries (data not radiatively corrected!)

2.254GeV 5T Longitudinal Asymmetry




2.254GeV 5T Transverse Asymmetry




**Plots courtesy of Toby Badman**

$$A_{\|} = \frac{\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Uparrow - \uparrow\Uparrow)}{\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Uparrow + \uparrow\Uparrow)},$$

$$A_{\perp} = \frac{\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Rightarrow - \uparrow\Rightarrow)}{\frac{d^2\sigma}{d\Omega dE'}(\downarrow\Rightarrow + \uparrow\Rightarrow)}$$

Fully radiated MAID 2007 (solid curve) asymmetries

- Unpolarized/polarized elastic tail and inelastic
  - Mo/Tsai for unpolarized
  - Akushevich/Ilyichev/Shumeiko for polarized

# SUMMARY

- The g2p experiment ran in spring 2012 and took data covering and $M < W < 2$ GeV and $0.02 < Q^2 < 0.20$ GeV$^2$
- A precision measurement of proton $g_2$ in low $Q^2$ region for the first time
- Results will shed light on several physics puzzles
  - Requires low $Q^2$ data
- Data analysis is currently underway

# THANK YOU

## E08-027 Analysis Team

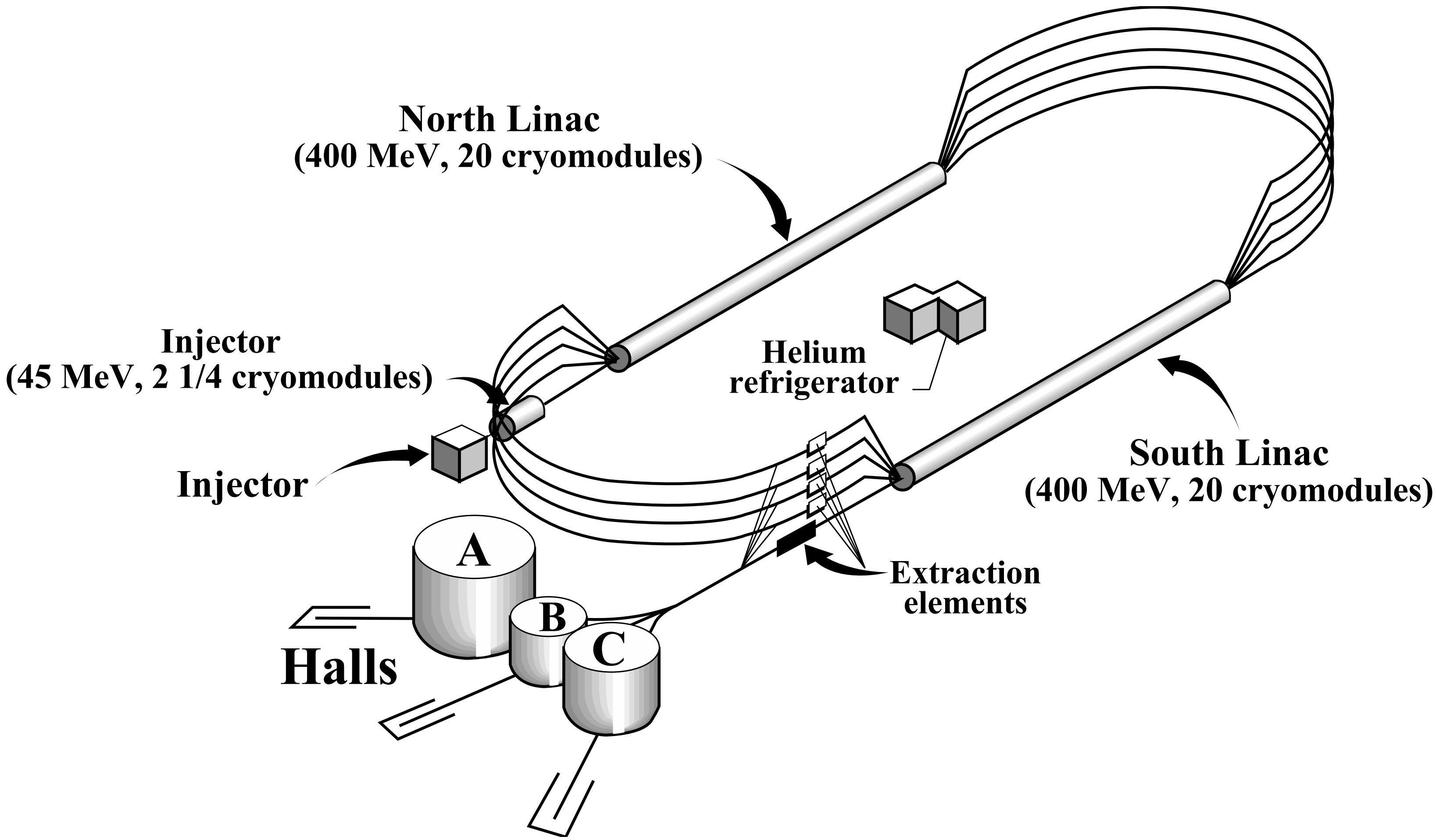
Spokespeople:
Alexandre Camsonne
JP Chen
Don Crabb
Karl Slifer

Post-Docs:
Kalyan Allada
Elena Long
James Maxwell
Vince Sulkosky
Jixie Zhang

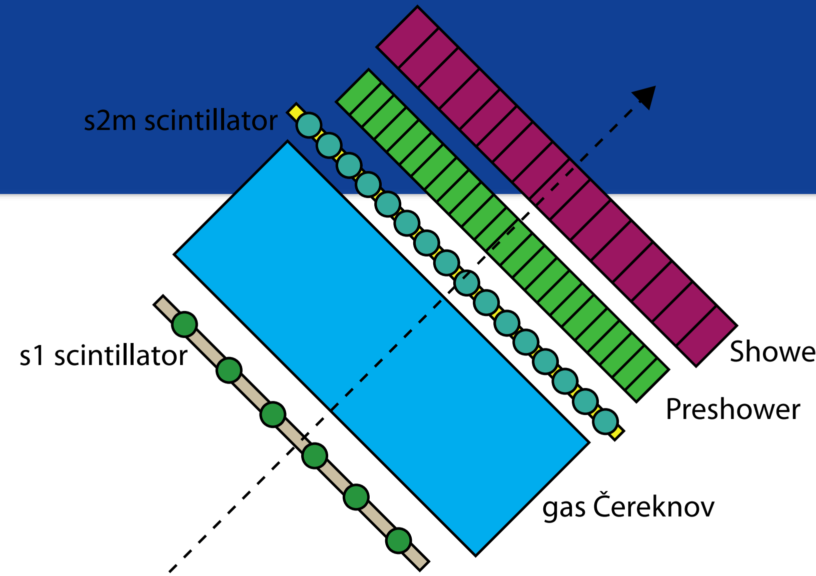
Graduate Students
Tobias E. Badman
Melissa Cummings
Chao Gu
Min Huang
Jie Liu
Pengjia Zhu
Ryan Zielinski

# BACKUP SLIDES

# JEFFERSON LABORATORY

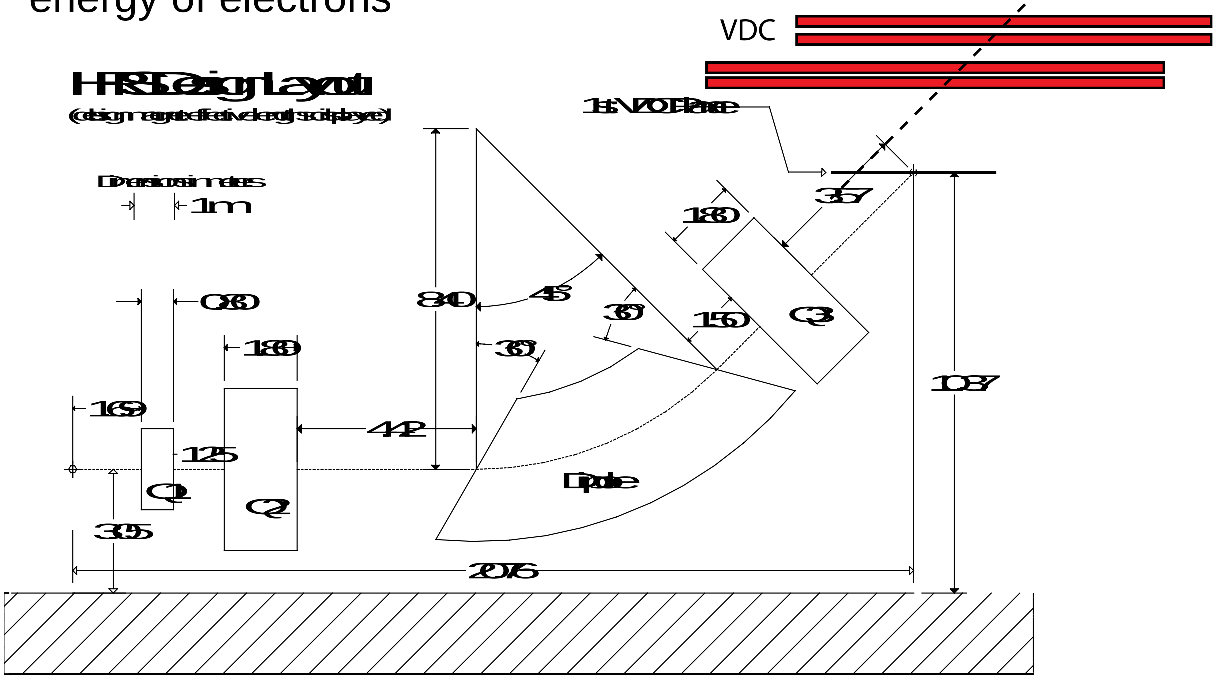


# HALL A SET UP




## High Resolution Spectrometers

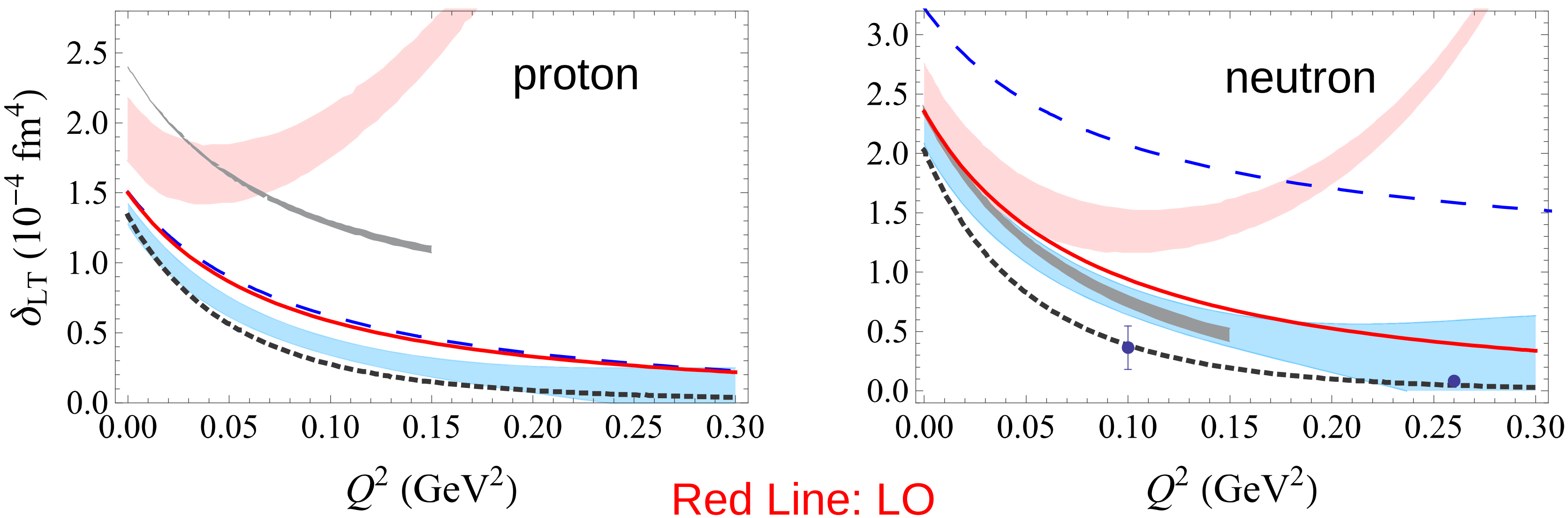
- Spectrometer detectors provide trigger, tracking and particle id
- Spectrometer magnets focus and select energy of electrons



# SPIN LT POLARIZABILITY

**Lensky, Alarcon & Pascalutsa. Phys Rev C 90 055202(2014)**

Neutron data from Jlab E94-010




Red Line: LO

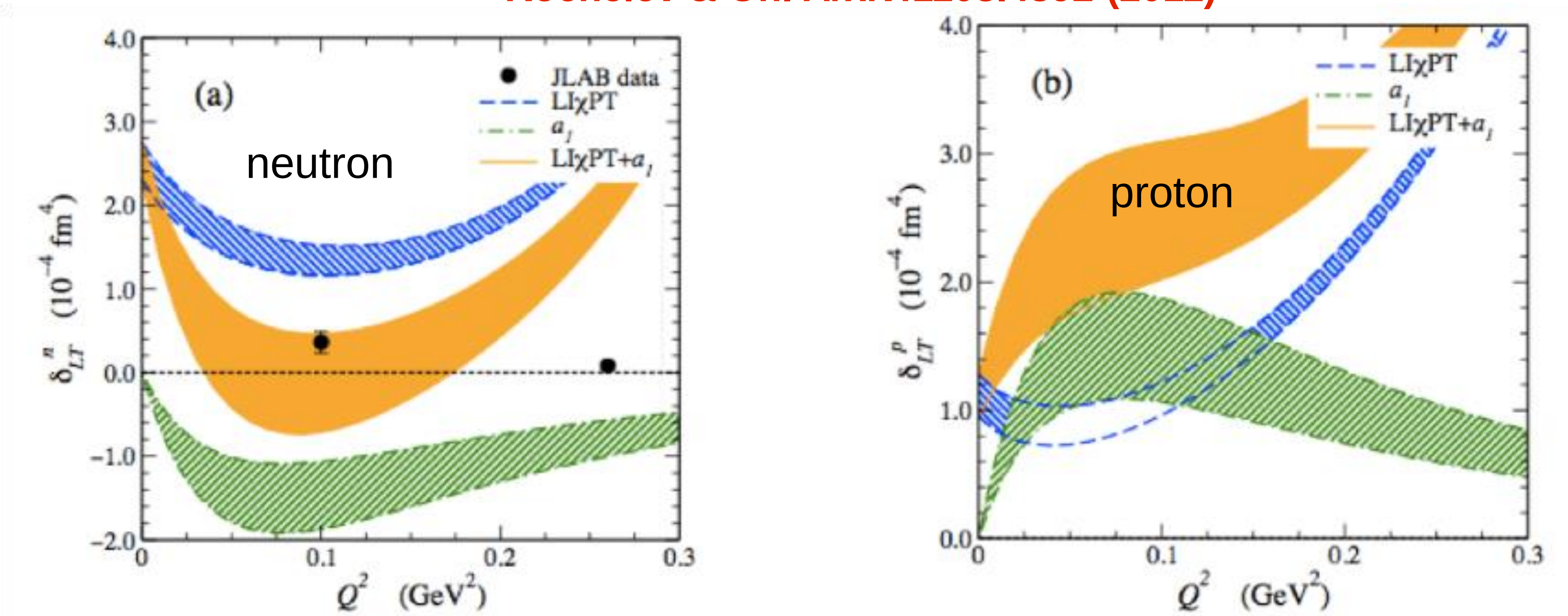
Blue Band: NLO

Black Line: MAID 2007

$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 [g_1(x, Q^2) + g_2(x, Q^2)] dx$$

# SPIN LT POLARIZABILITY

**Kochelev & Oh. Arxiv:1103.4892 (2011)**




$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1(x,Q^2)+g_2(x,Q^2)]dx$$

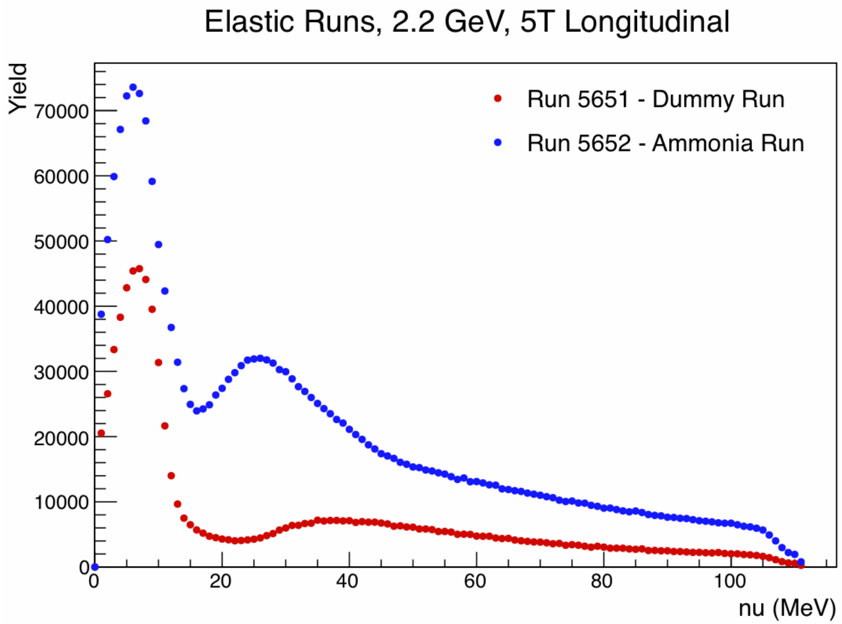
# PACKING FRACTION

• Purpose: packing fraction ($p_f$) describes the proportion of ammonia target material to the liquid helium in which it is immersed.

• To extract $p_f$, elastic events are analyzed

  • Additional runs were taken on "dummy" cells, which help understand the contribution from the helium elastic peak.

• Yields from data combined with input from cross section models to extract $p_f$



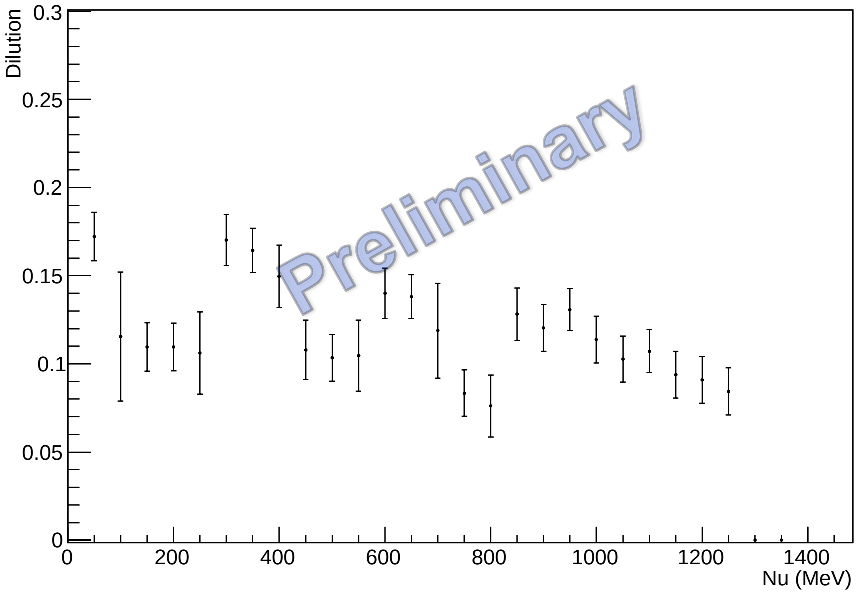



University of New Hampshire

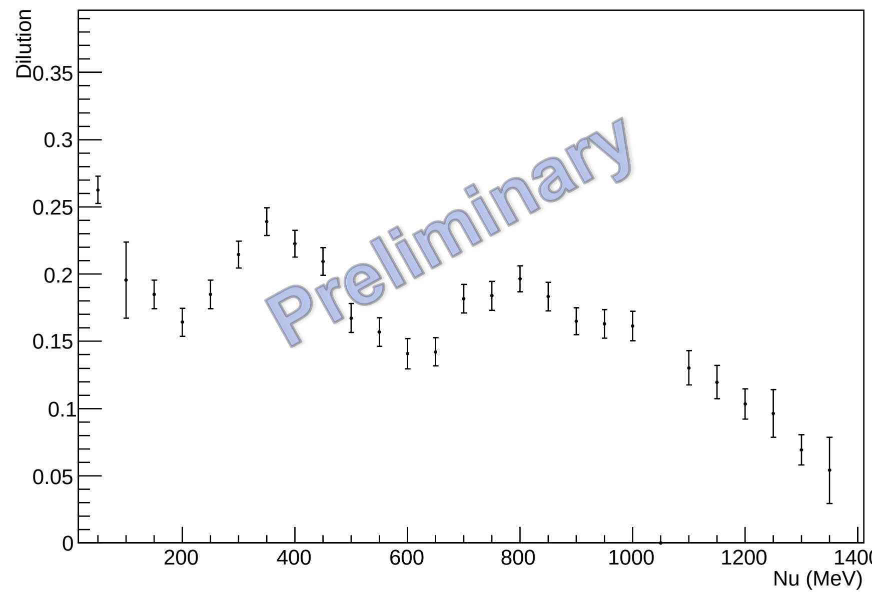
# DILUTION ANALYSIS

## 2254 MeV Dilution Factors

5T Longitudinal




5T Transverse




$$f = \frac{\sigma_+ + \sigma_-}{\sigma_+ + \sigma_- + \sigma_{\mathrm{unpol}}} \qquad A = \frac{1}{f \cdot P_t \cdot P_b}\left(\frac{N_+ - N_-}{N_+ + N_-}\right)$$