The Proton Spin-Dependent Structure Function, g_2, and Longitudinal Transverse Spin Polarizability at Low Q^2

Ryan Zielinski - University of New Hampshire
For the Jefferson Lab Hall A E08-027 (g2p) Collaboration

DNP Meeting, October 26, 2013

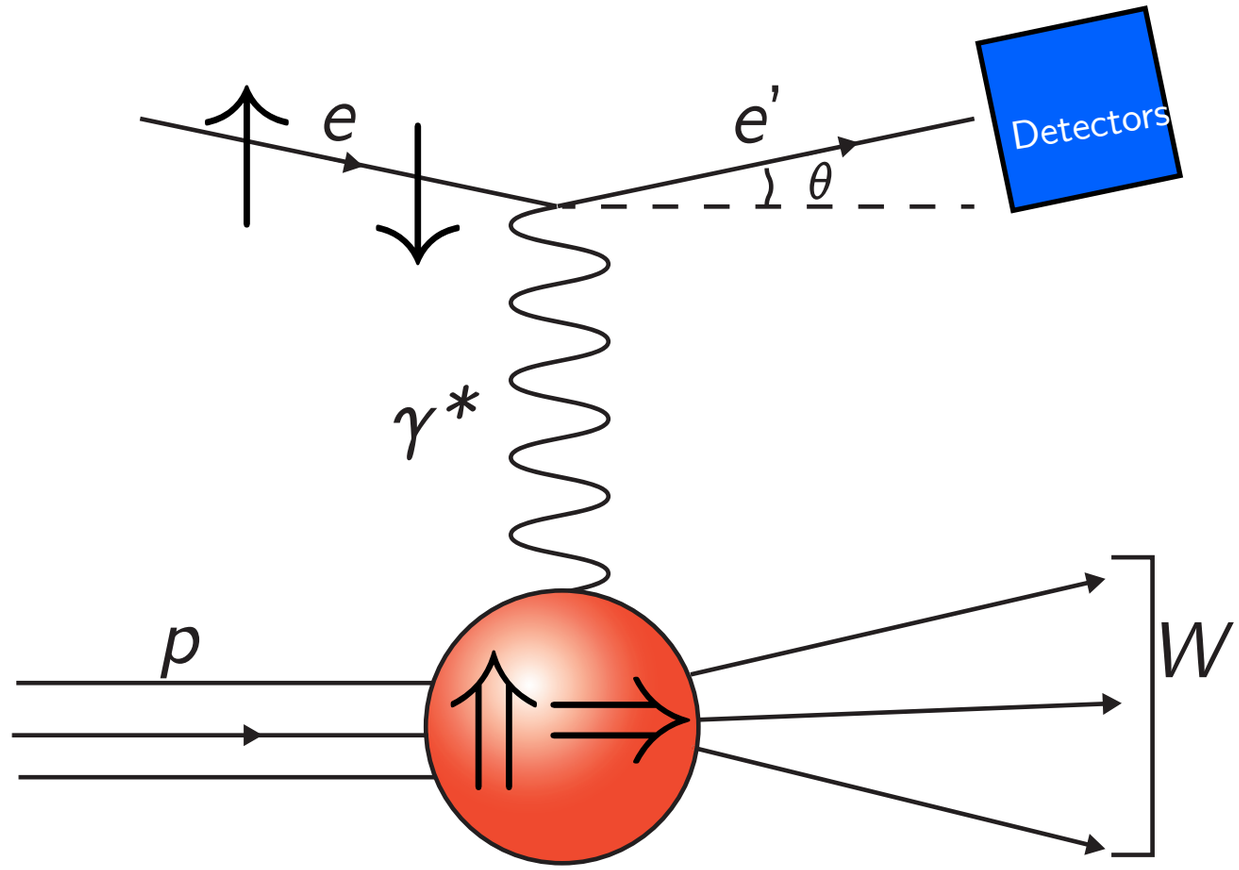
University of New Hampshire

Jefferson Lab

Polarized

Inclusive *ep* Scattering

- Q^2 : 4-momentum transfer
- W : invariant mass of target
- x : momentum fraction
- υ : E - E', energy transfer
- Scattering angle: θ ~ 6°

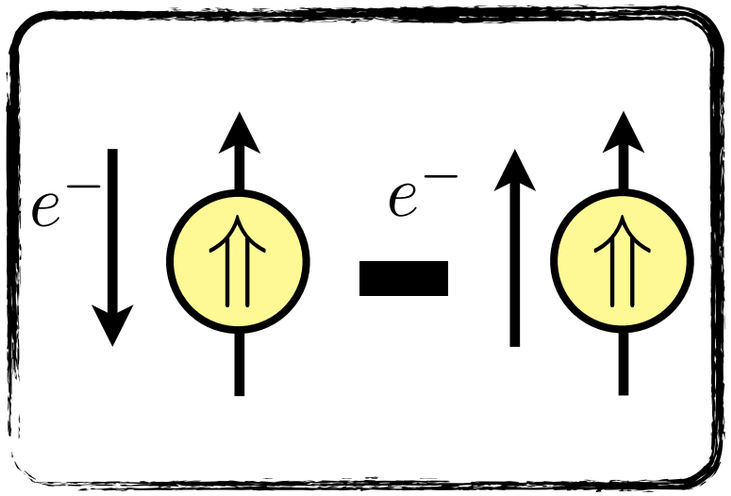


Spin distribution

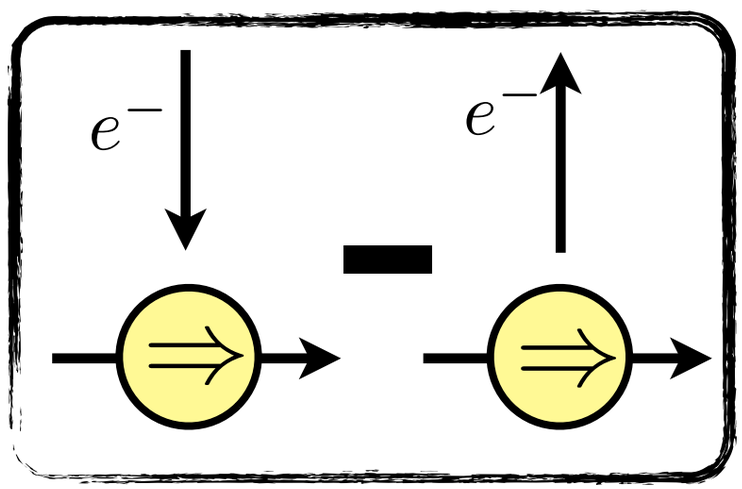
$$\frac{d^2\sigma^{\pm}}{d\Omega dE'} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} (\alpha F_1(x,Q^2) + \beta F_2(x,Q^2) \pm \gamma g_1(x,Q^2) \pm \delta g_2(x,Q^2))$$

Extracting Spin Structure

$\Delta\sigma_{||}$



$\Delta\sigma_{\perp}$



- Experiment measured $\Delta\sigma_{\perp}$ **essential contribution to g_2 in this kinematic region**

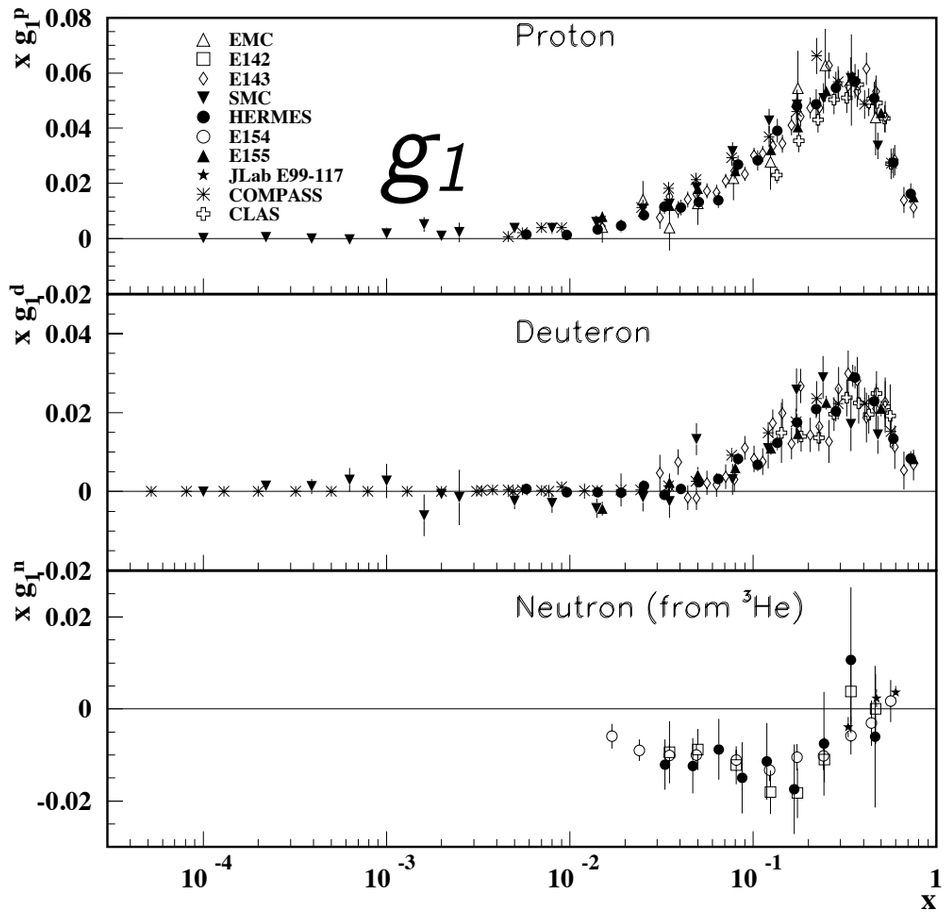
$$g_2^p = \frac{MQ^2}{4\alpha^2}\frac{y^2}{2(1-y)(2-y)}\left(-\Delta\sigma_{||} + \frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}\Delta\sigma_{\perp}\right)$$

- Will use JLab Hall B EG4 data for $\Delta\sigma_{||}$.
  - Measured $\Delta\sigma_{||}$ at one kinematic setting as cross-check

Motivation

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

- Extract $\delta_{\rm LT}$ as a test of χPT calculations
- Test Burkhardt-Cottingham (BC) sum rule
- Crucial inputs for hydrogen hyperfine splitting and proton charge radius measurements

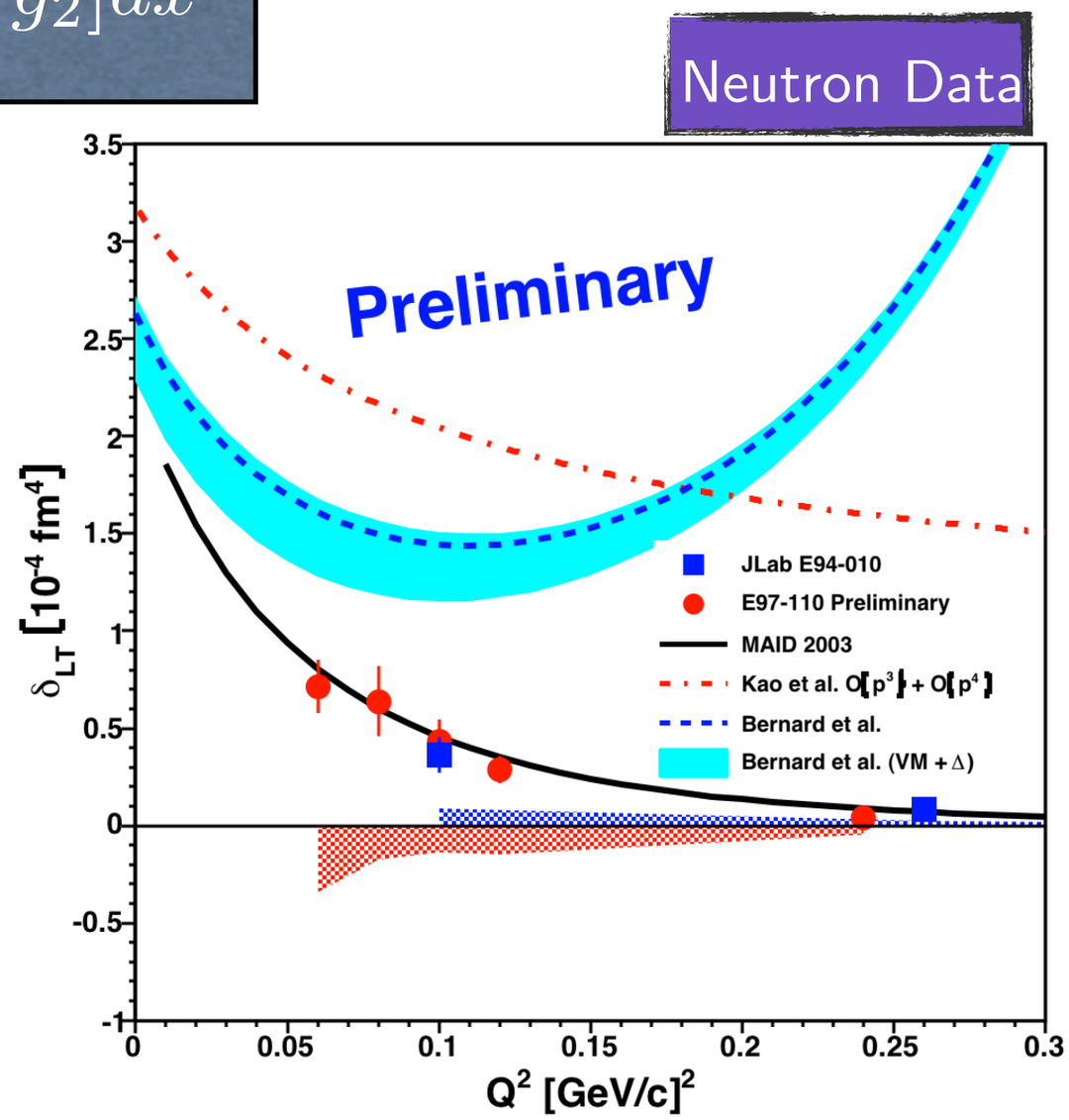


Particle Data Group (2010)

Spin LT Polarizability

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

- Can be calculated via χPT
- Neutron data shows some deviations for calculated polarizabilities
- No proton data yet!



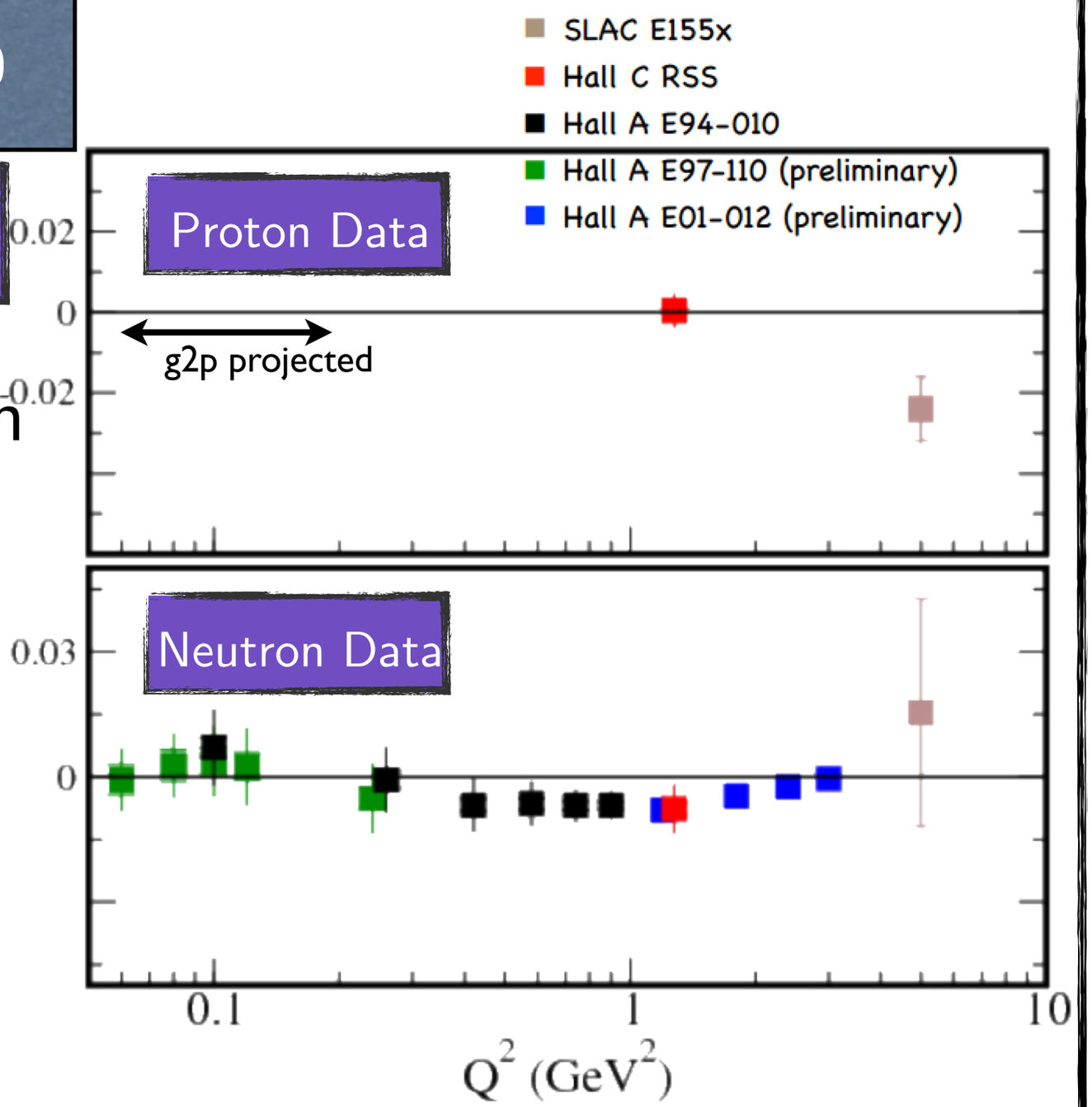
plot courtesy of V. Sulkosky

The B.C. Sum Rule

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

H. Burkhardt and W.N. Cottingham
Annals. Phys., 56 453 (1970)

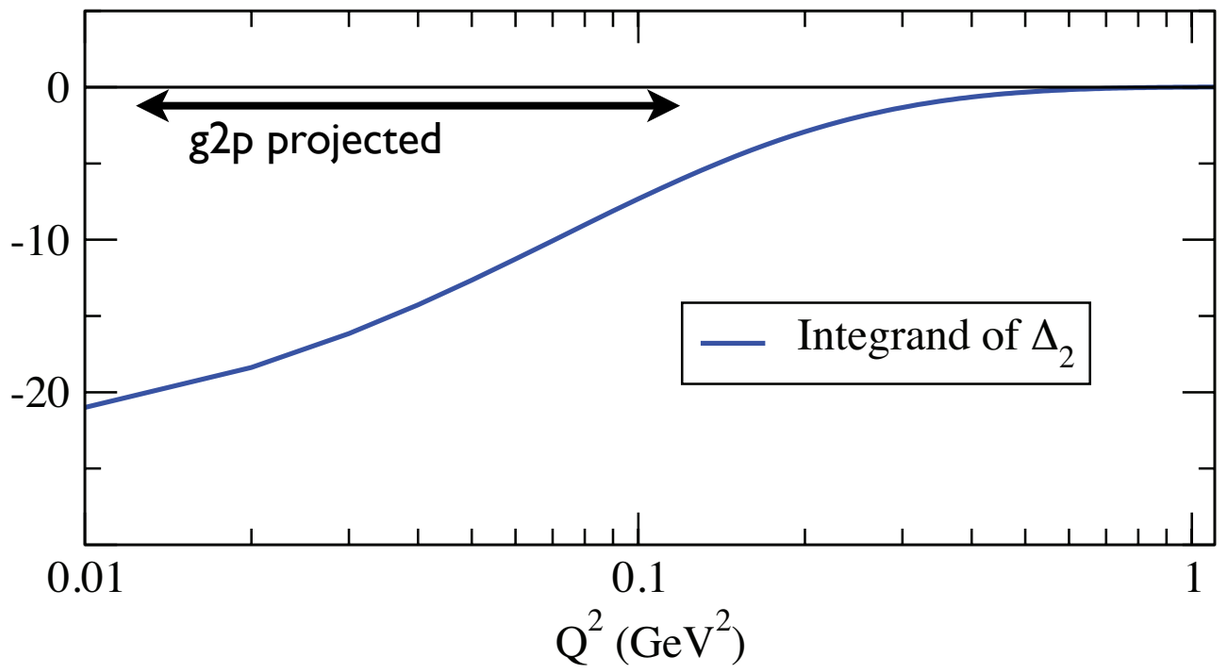
- Sum rule satisfied within errors for neutron
- Inconsistency seen in proton data
- Mostly unmeasured for proton



Finite Size Effects

Hydrogen Hyperfine Splitting

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



- Structure correction has largest uncertainty to theoretical calculation
- $\Delta_S = \Delta_Z + \Delta_{pol}$
  - $\Delta_{\text{pol}} = \dfrac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$

Dominated by low Q^2 g_2

Finite Size Effects

Proton Charge Radius

- 2 ways to measure:
  - Energy splitting of $2S_{1/2}$ - $2P_{1/2}$ level (Lamb shift)
    - $\Delta E = 209.9779(49) - 5.2262 r_p^2 + 0.0347 r_p^3$ meV
  - Scattering experiment
- Two results do not match
  - Main uncertainties are from proton polarizability terms
    - Related to integral of spin structure functions

Lamb Shift

$\langle R_p \rangle = 0.84182 \pm 0.00067$fm

$\langle R_p \rangle = 0.87680 \pm 0.0069$fm

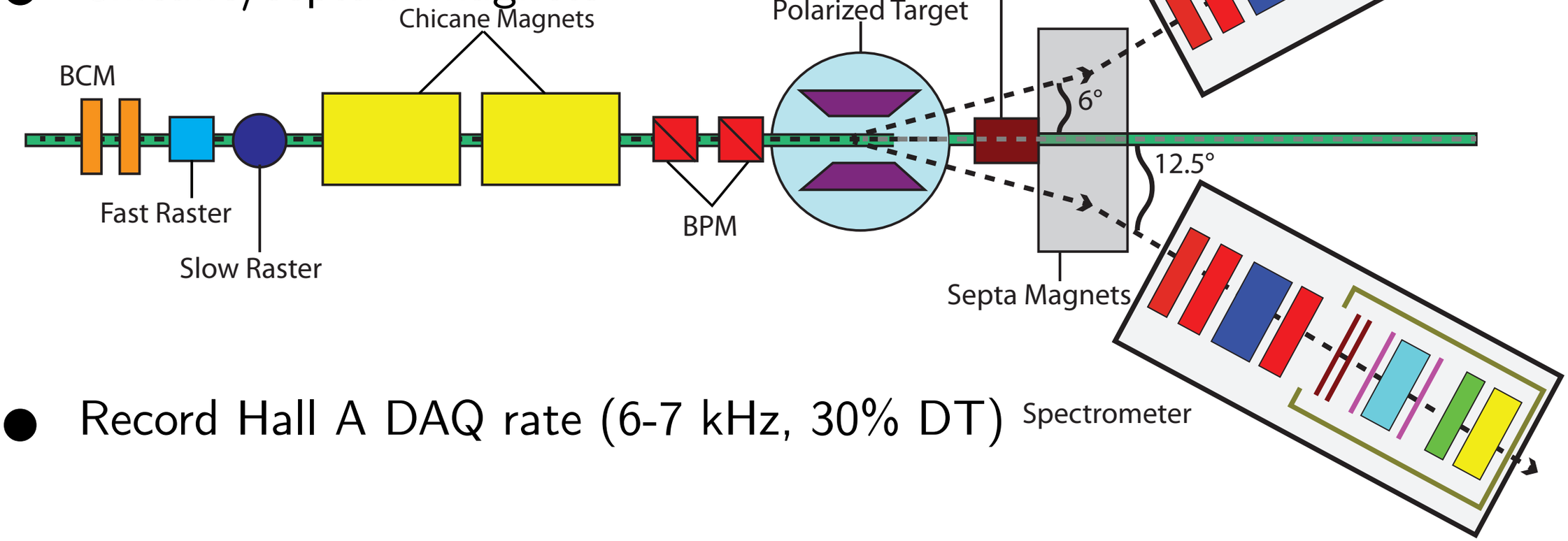
Scattering

R. Pohl et al, Nature, 466(2010)213

Experimental Set Up

JLab Hall A

- Large scale installation in Hall A
  - Transverse polarized NH3 target (2.5/5.0T field)
  - Low current (< 100 nA) beamline diagnostics
  - Chicane/septum magnets

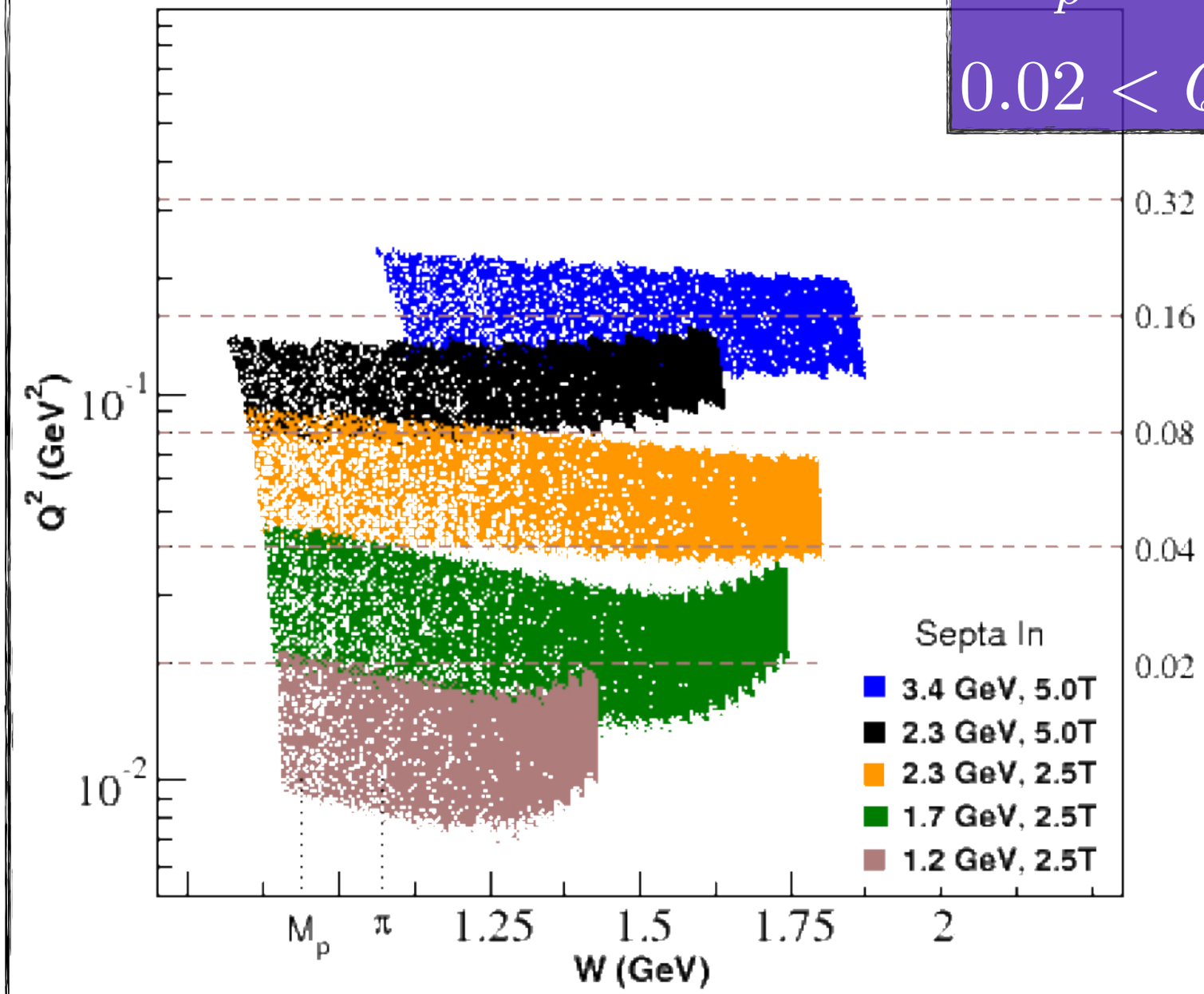


  - Record Hall A DAQ rate (6-7 kHz, 30% DT)

Kinematic Coverage

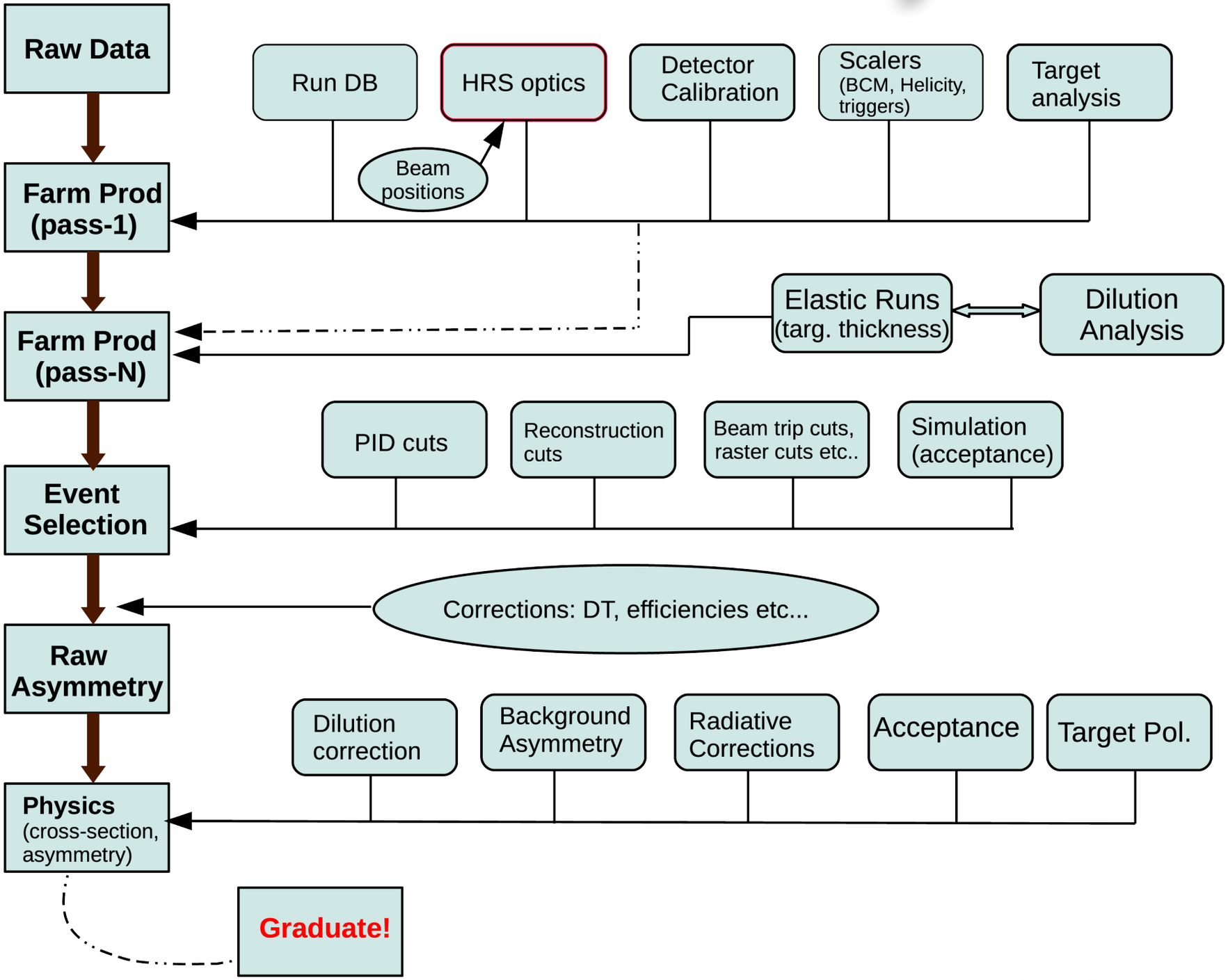
$$M_p < W < 2GeV$$

$$0.02 < Q^2 < 0.2GeV^2$$

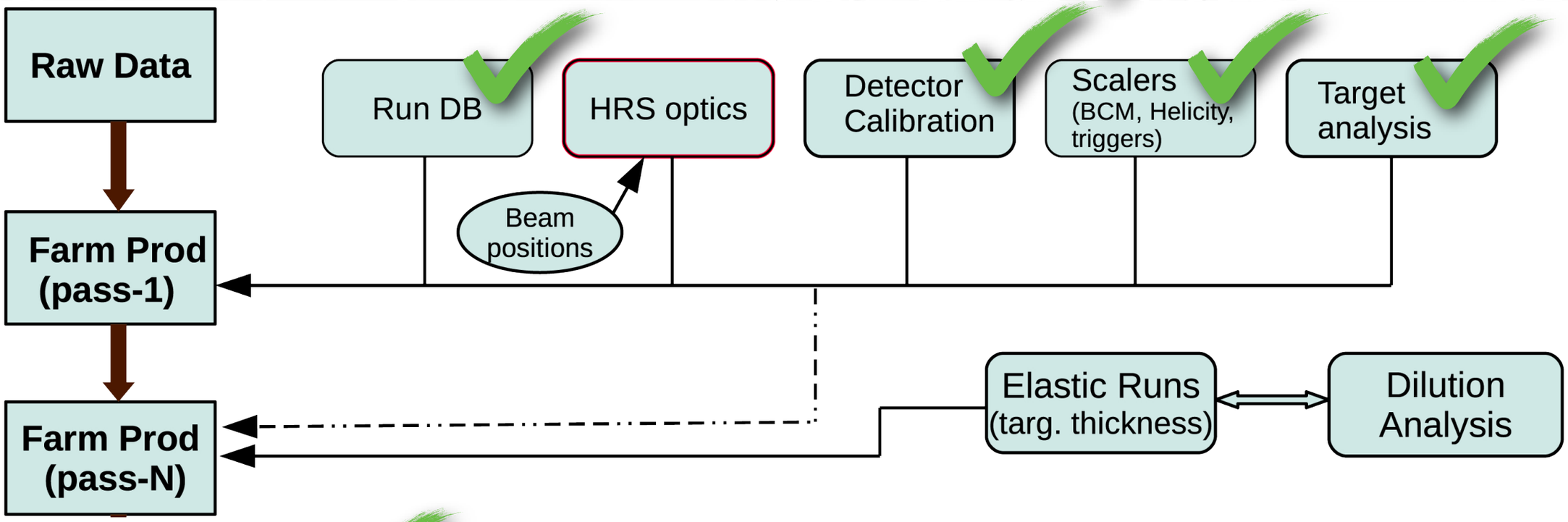


Beam Energy (GeV)	Target Field (T)
2.254	2.5
1.706	2.5
1.158	2.5
2.254	5.0
3.352	5.0

Status of Analysis



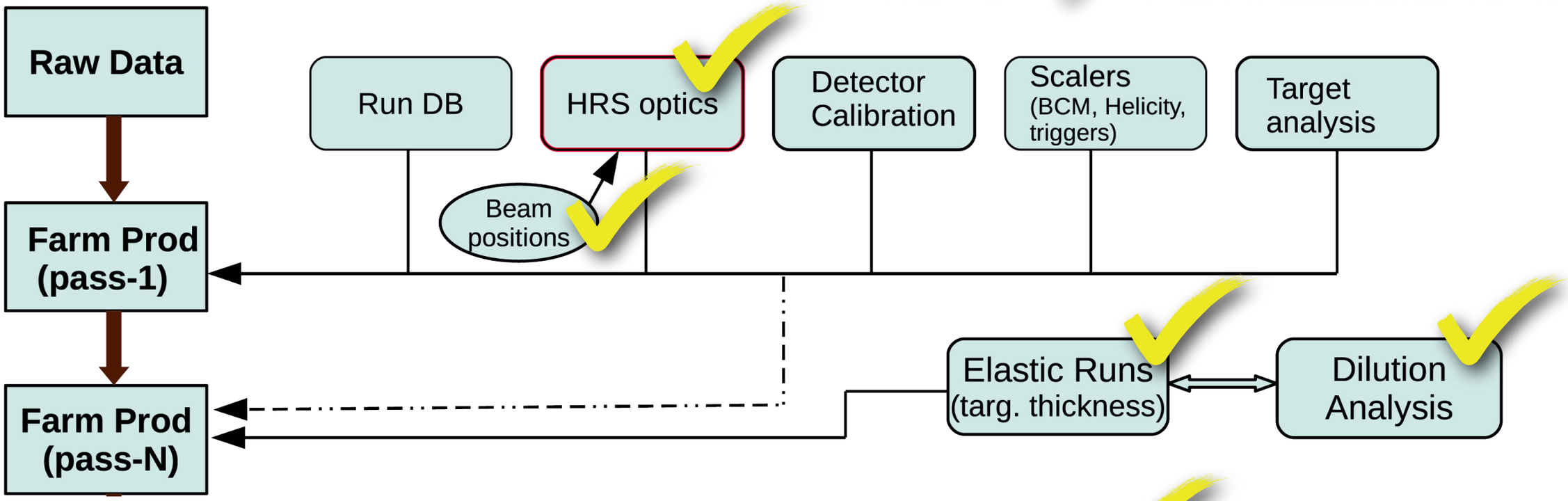
Status of Analysis



Completed

- Run database
- HRS Optics w/o target field
- Detector Calibrations
- Scalers
- Target Polarization Analysis

Status of Analysis



Completed

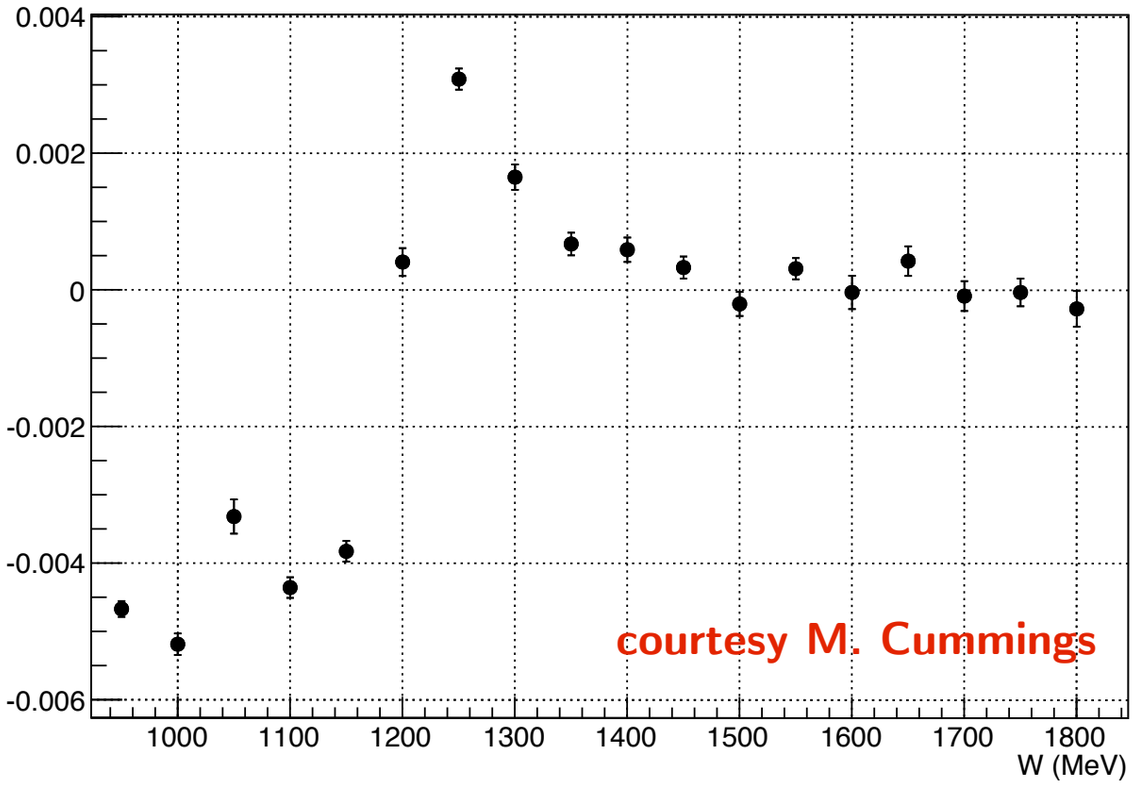
- Run database
- HRS Optics w/o target field
- Detector Calibrations
- Scalers
- Target Polarization Analysis

In Progress

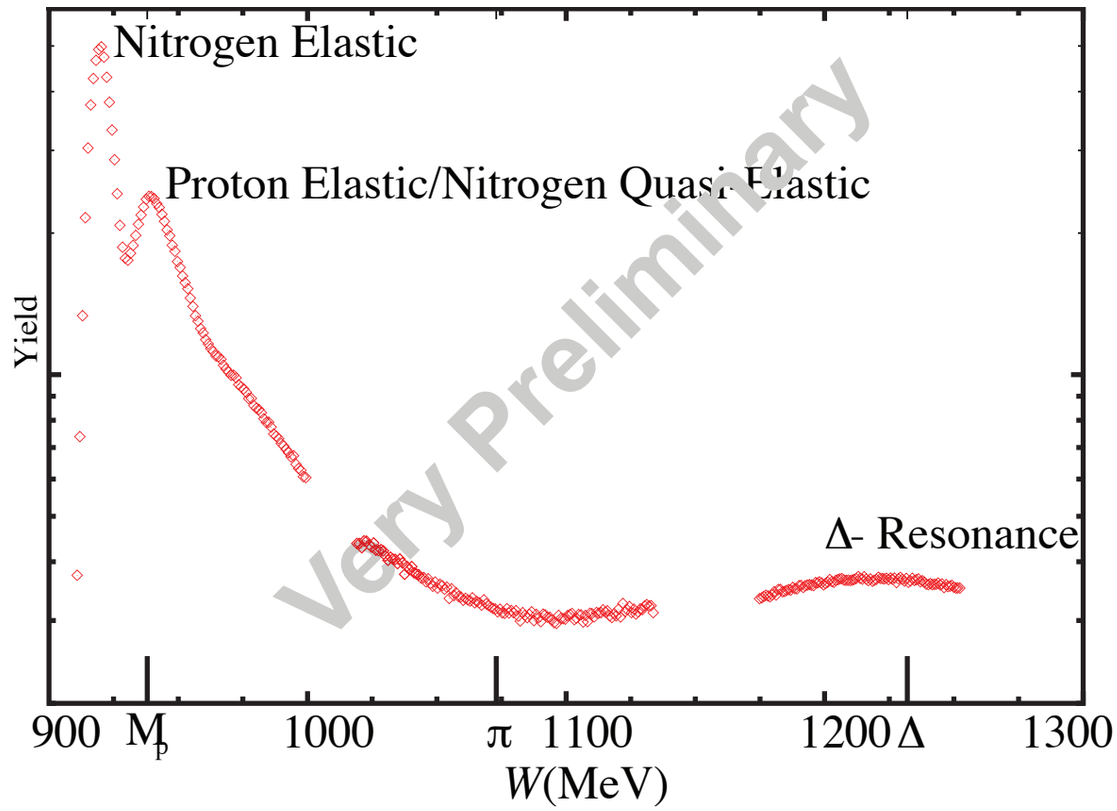
- Optics with target field
- BPM/raster calibrations
- Dilution Analysis
- Elastic Analysis
- Yield/Radiative Correction study

Preliminary Offline Results

Asymmetry



Yield



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

Will measure asymmetry/cross section

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

Summary

- The g2p experiment ran in spring 2012 and took data covering $M_p < W < 2GeV$ and $0.02 < Q^2 < 0.20GeV^2$
- Will provide a precision measurement of g_2^p 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

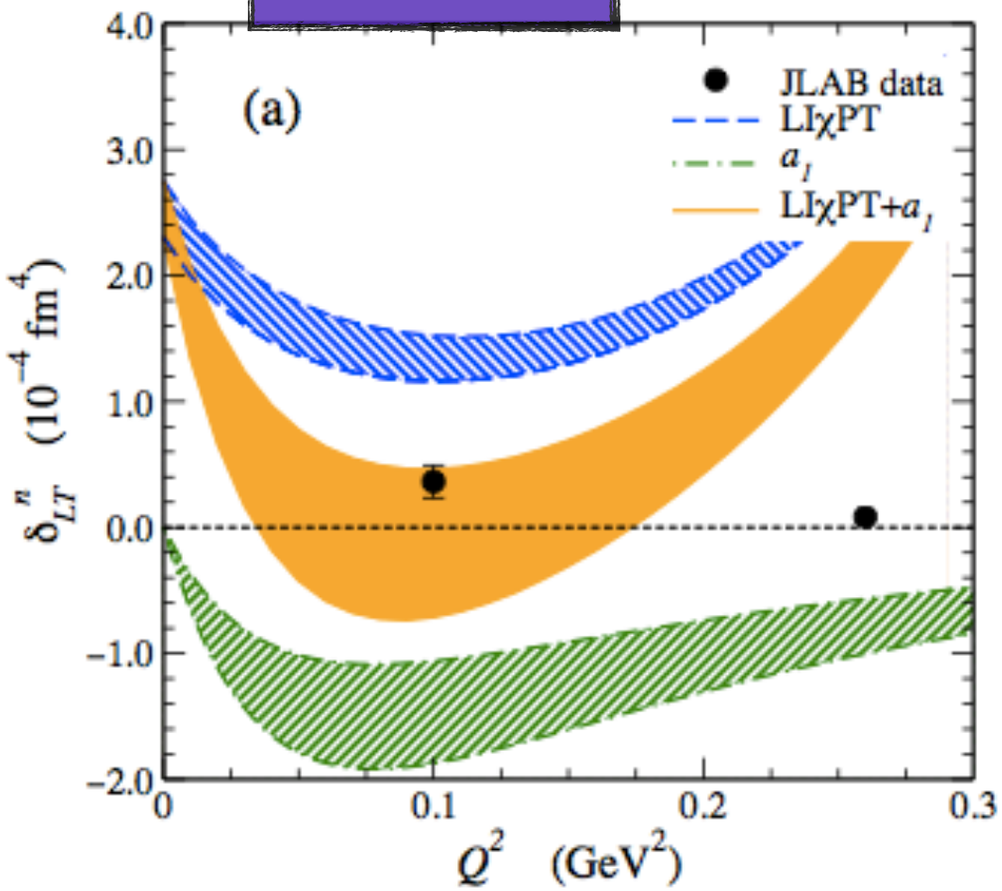
Graduate Students:

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

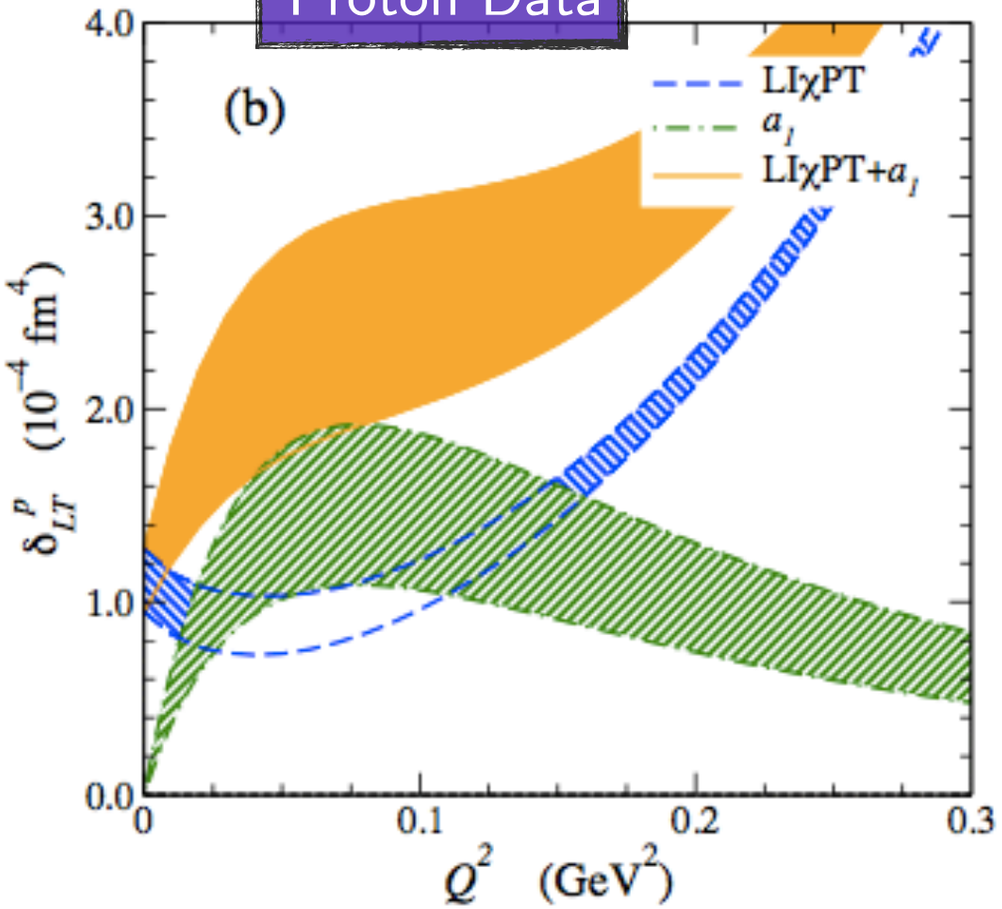
Spin LT Polarizability

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

Neutron Data



Proton Data



Kochelev & Oh. arxiv:1103.4892 (2011)