THE G_2^p EXPERIMENT

A Measurement of Proton g_2 Structure Function and the Longitudinal-Transverse Spin Polarizability

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On behalf of the g_2^p collaboration

Hadron 2013, Huangshan, China

g_2^P Collaboration

Spokepeople

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- Don Crabb (UVA)
- Karl Slifer (UNH)

PhD Student

- Toby Badman (UNH)
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- Chao Gu (UVa)
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- Jie Liu (UVa)
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Post Docs

- Kalyan Allada (Jlab)
- Elena Long (UNH)
- James Maxwell (UNH)
- Vince Sulkosky (MIT)
- Jixie Zhang (Jlab)

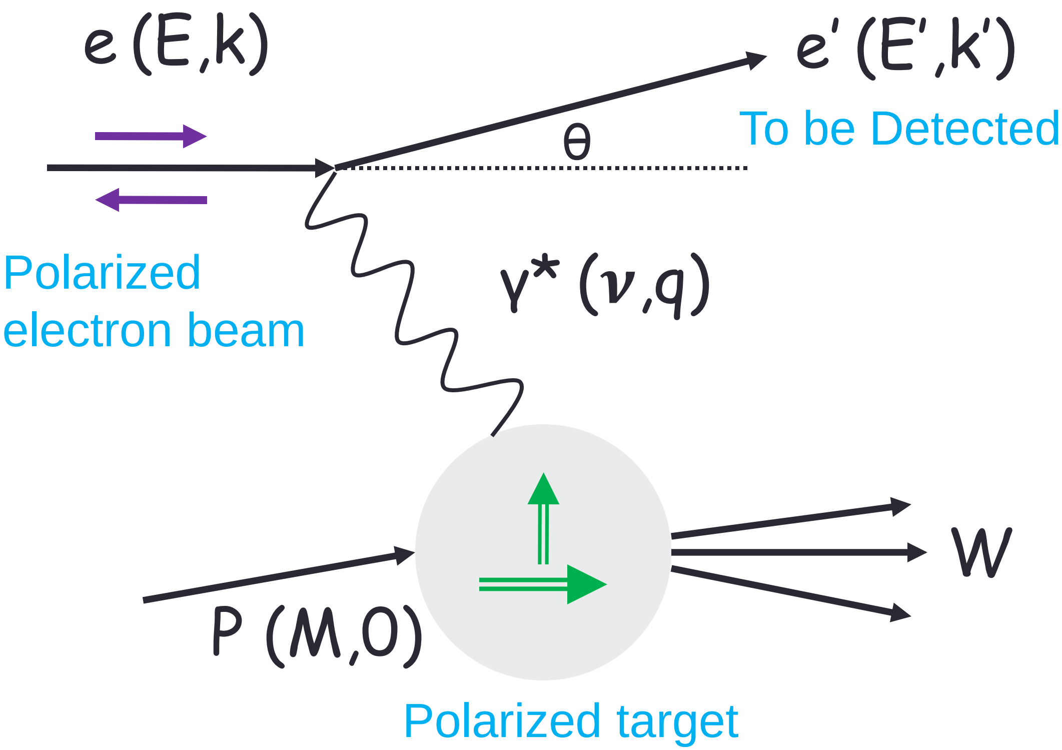
Institutions

- 20 Institutions/Collaborators

Outline

- Introduction
- Physics Motivation
- Experiment Setup
- Kinematics and Projection
- Summary

Inclusive Electron Scattering



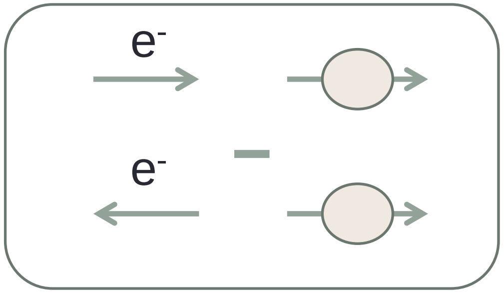
- Invariant Mass
  $W^2 = M^2 + 2M\nu - Q^2$
- Four momentum transfer squared
  $Q^2 = -q^2$
- Bjorken variable
  $x = Q^2/2M\nu$ fixed target

For point-like target

g1, g2: polarized nucleon spin structure functions

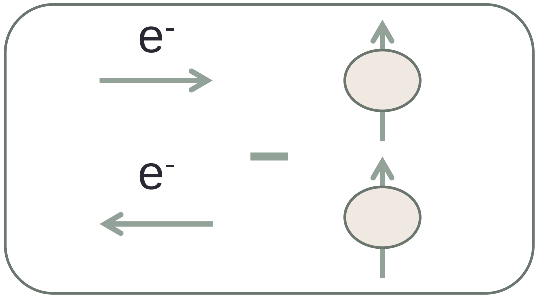
$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{\rm Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\frac{\theta}{2} + \gamma g_1(x,Q^2) + \delta g_2(x,Q^2)\right]$$

To get g_2^p

$\Delta\sigma_{\parallel} =$ 

Hall B EG4 measure g_1^p, g_2^p experiment has one measurement to cross check

$$= \frac{4\alpha^2 E'}{M\nu Q^2 E}[(E + E'cos\theta)g_1 - 2Mx g_2]$$

$\Delta\sigma_{\perp} =$ 

g_2^p experiment measure, g_2^p essential contribution to $\Delta\sigma_{\perp}$ in this kinematic region

$$= \frac{4\alpha^2 E'}{M\nu Q^2 E}[sin\theta(g_1 + \frac{2E}{\nu} g_2)]$$

Motivation

- Measure the proton spin structure function g_2 in the low Q^2 region ($0.02<Q^2<0.2$ GeV^2) for the first time
- Extract δ_{LT} to provide a benchmark test of χPT calculations
- Opportunity to test the Burkhardt-Cottingham sum rule
- Crucial inputs for hydrogen hyperfine splitting and proton charge radius measurements

g_2 Structure Function

❑ At high to intermediate Q^2

- g_2 can be separated into leading and higher-twist components

$$g_2(x,Q^2) = g_2{}^{ww}(x,Q^2) + \overline{g_2}(x,Q^2)$$

- g_2 leading twist related to g_1 by Wandzura-Wilczek relation

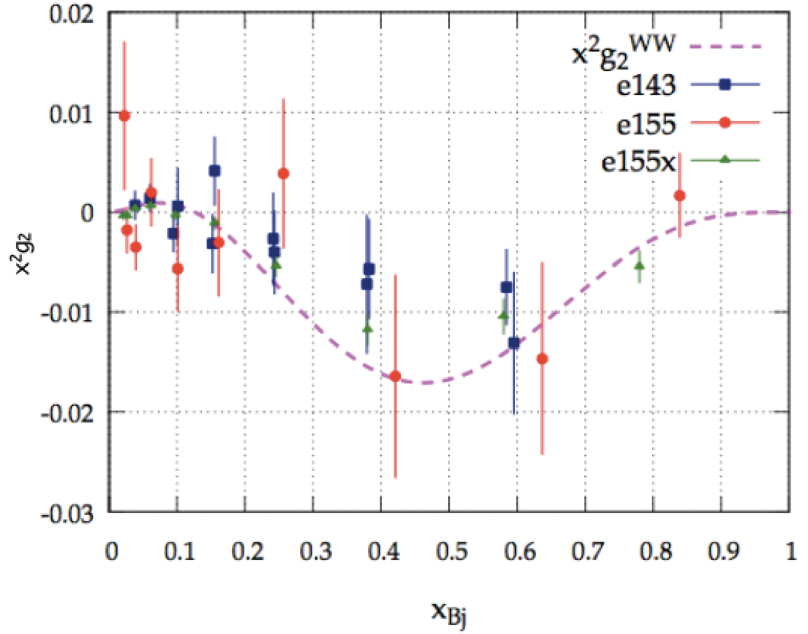
$$g_2{}^{ww}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{dy}{y} g_1(y,Q^2)$$

Good approximation as, $Q^2 \to \infty$

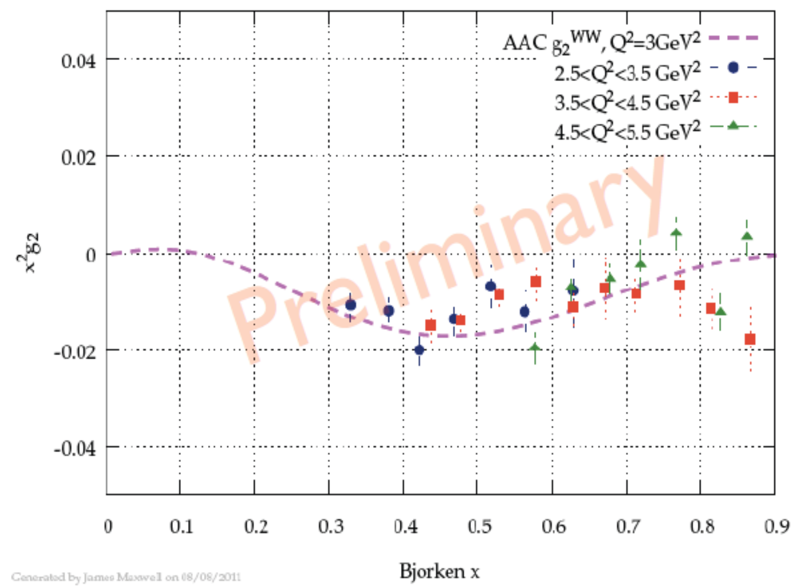
- g_2 exhibits strong deviations from this leading twist behavior at typical JLab kinematics

- $g_2 - g_2{}^{ww}$: a clean way to access higher-twist contribution, quantify q-g correlations.

g_2^p Existing Data

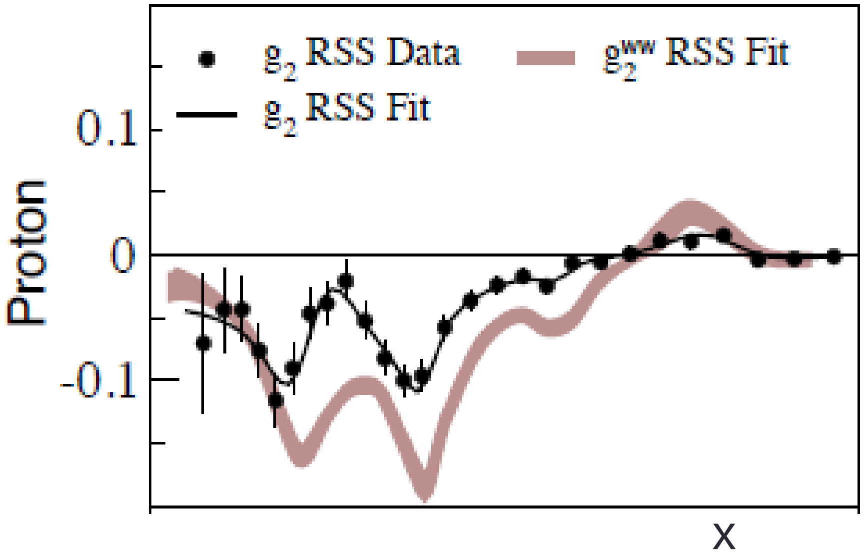


Proton g_2 Data from SLAC
Averaged $Q^2 \approx 5\ GeV^2$



Proton g_2 Data from Jlab SANE
$Q^2 \approx 2.5 - 5.5\ GeV^2$

g_2^p Existing Data



Proton g_2 Data from Jlab RSS
$Q^2 = 1.3\ GeV^2$

K. Slifer O. Rondon et al.
PRL, 105(2010)101601

Precision Measurement of ${g_2}^p(x, Q^2)$:
Can search for higher twist effects

BC Sum Rule

- BC Sum Rule:

$$\int_0^1 g_2(x, Q^2)\mathrm{d}x = 0$$

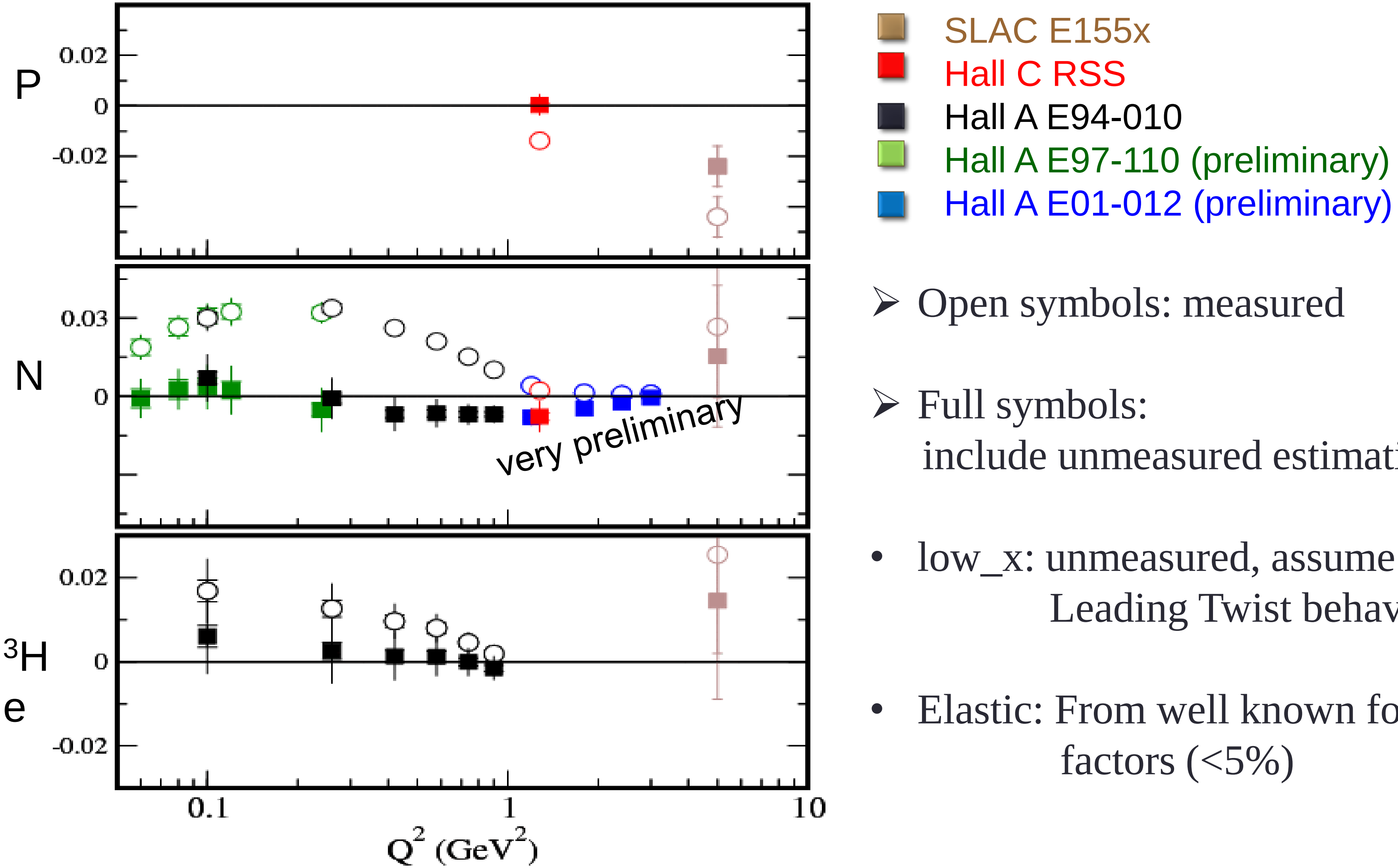
H. Burkhardt and W. N. Cottingham, Annals. Phys., 56(1970)453

- BC Sum Rule will fail if g2:
  - exhibits non-Regge behavior at low x
  - exhibits a delta function at x=0

R. L. Jaffe and X.-D. Ji, Phys. Rev. D, 43(1991)724

- Experiment test:
  - BC = Measured +low_*x*+Elastic

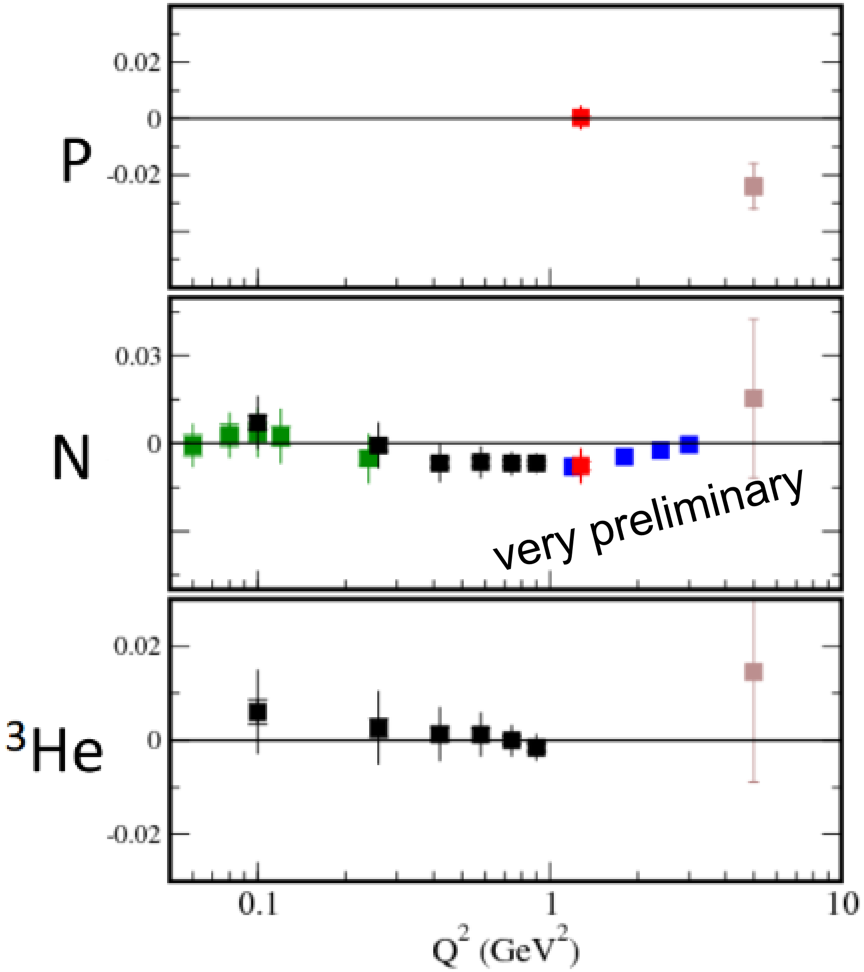
BC Sum Rule



- Open symbols: measured
- Full symbols: include unmeasured estimation

- low_x: unmeasured, assume Leading Twist behavior
- Elastic: From well known form factors (<5%)

BC Sum Rule



$$\int_0^1 g_2(x, Q^2)\mathrm{d}x = 0$$

- Violation suggested for proton at large Q^2
- Found within error for ^3He
- Within error for neutron, but barely in vicinity of $Q^2 \approx 1\ GeV^2$
- Mostly unmeasured for proton

Generalized Spin Polarizabilities

- Generalized Spin Polarizabilities:
  how nucleons respond to virtual photons

- Relate to doubly-virtual Compton scattering, with assumption: appropriate convergence and unsubtracted dispersion relation

- Generalized forward spin polarizability $\gamma_0(Q^2)$

$$\gamma_0(Q^2) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} dx x^2 [g_1(x,Q^2) - \frac{4M^2x^2}{Q^2} g_2(x,Q^2)]$$

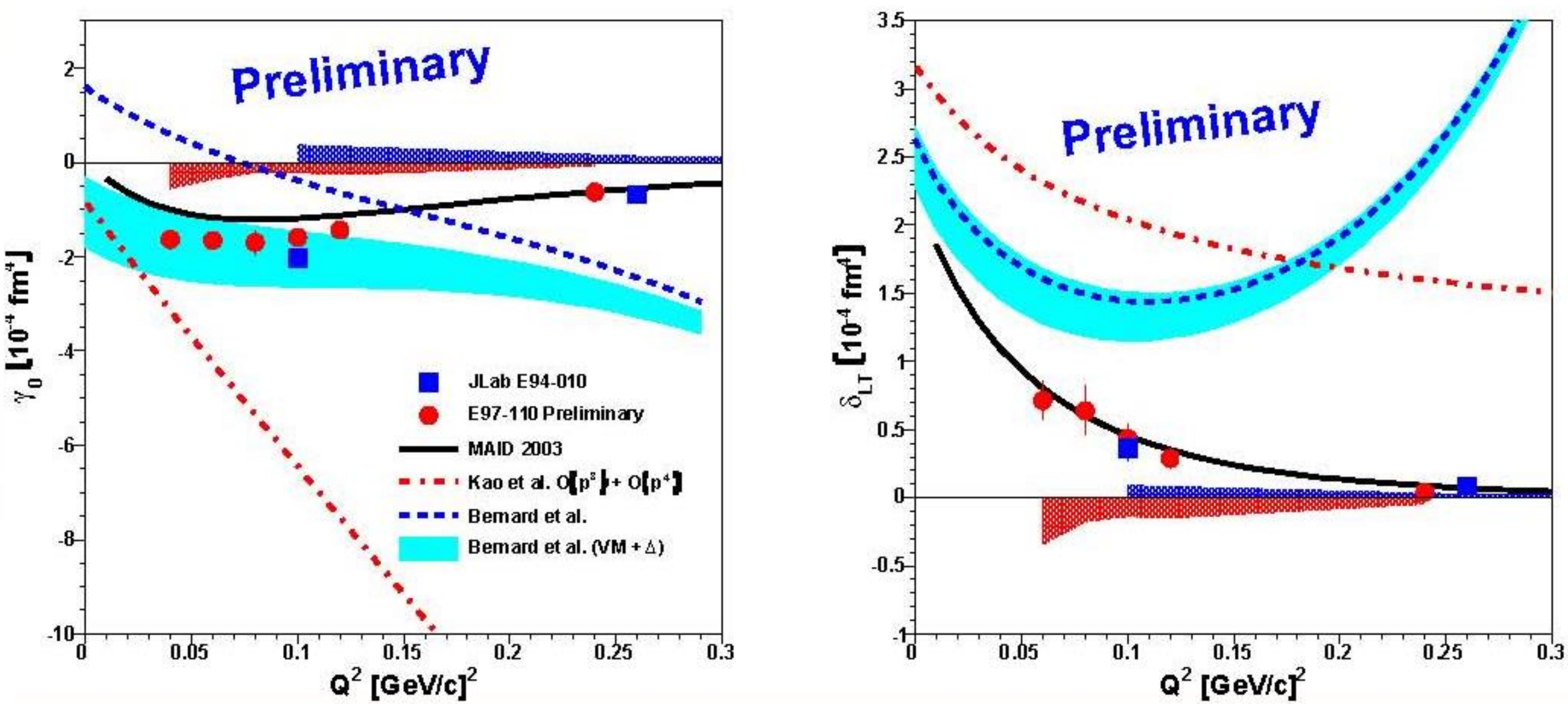
- Generalized longitudinal-transverse spin polarizability $\delta_{LT}(Q^2)$

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

- Can be calculated via Chiral Perturbation Theory

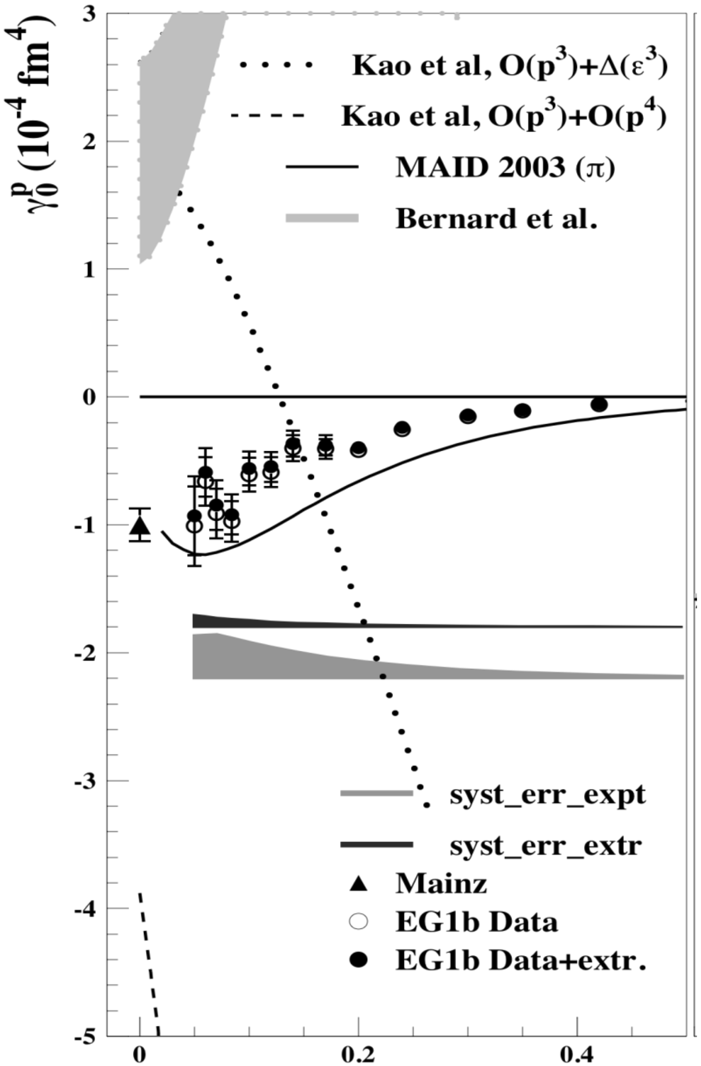
δ_{LT} Puzzle for Neutron

- δ_{LT} is insensitive to Δ resonance, more suitable than γ_0 to test χPT
- Significant disagreement between data and both χPT calculations for δ_{LT}
- Good agreement with MAID model predictions



Plots courtesy of V. Sulkosky : Preliminary E97-110 and Published E94-010

Proton Spin Polarizabilities



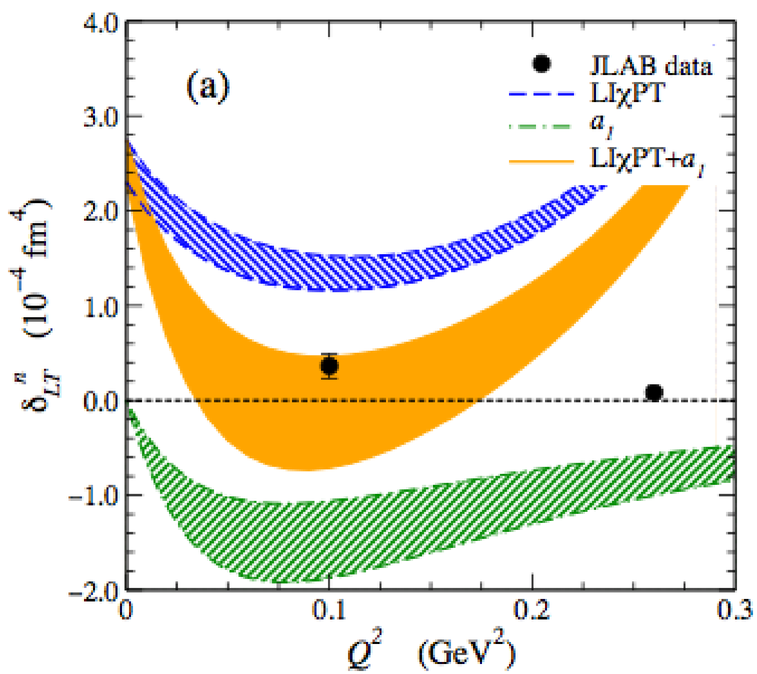
- χPT calculations still fails for proton γ_0
- γ_0 sensitive to resonance
- No data yet on proton δ_{LT} polarizability
- This experiment will provide proton δ_{LT} data

PLB672, 12 (2009)

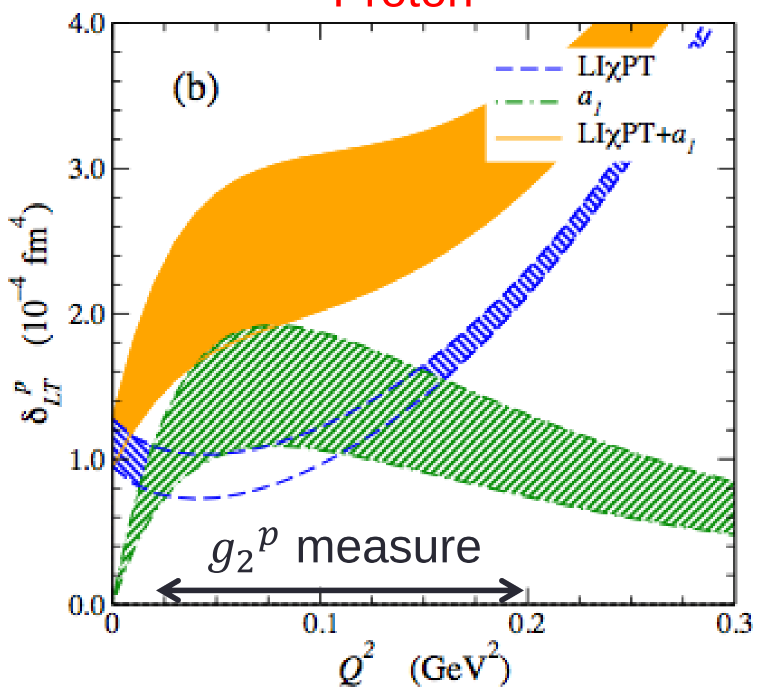
δ_{LT} Puzzle

- **New calculation result:** Kochelev & Oh. arXiv:1103.4892
  - Include the axial-anomaly a1(1260) meson contribution
  - Improves agreement with neutron
  - Need data on proton δ_{LT} polarizability

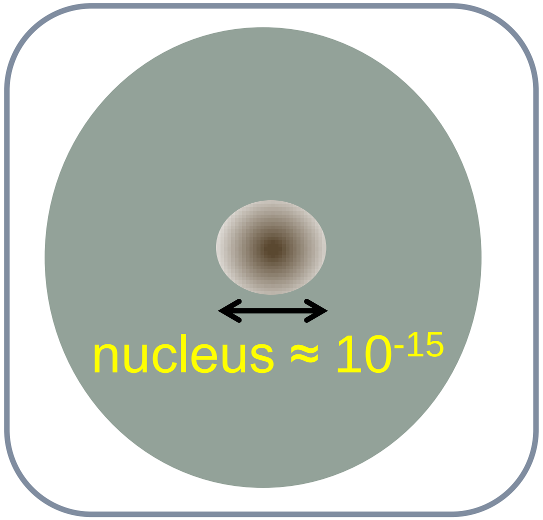
Neutron

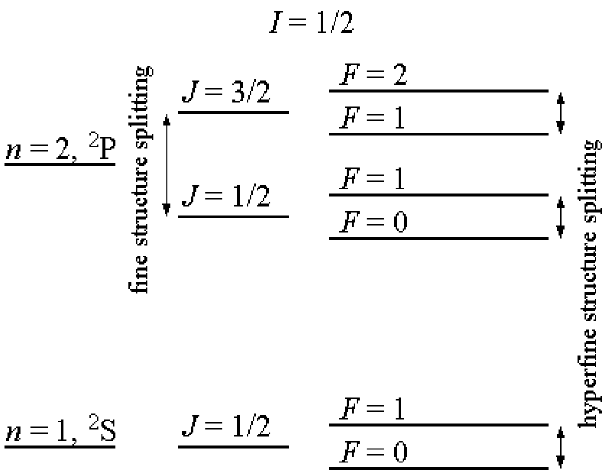


Proton



Hydrogen Hyperfine Structure





- Hydrogen hyperfine splitting in the ground state has been measured to a relative high accuracy of 10^{-13}

$$\Delta E = 1420.405\,751\,766\,7(9)\ MHz$$
$$= (1+\delta)E_F$$

$$\delta = \left(\delta_{QED} + \delta_R + \delta_{small}\right) + \Delta_s$$

- Δ_s : proton structure function correction
  - depends on ground state and excited properties of the proton
  - largest uncertainty

Hydrogen Hyperfine Structure

$$\Delta_s = \Delta_z + \Delta_{pol}$$

Elastic Scattering

D_Z=-41.0±0.5ppm

involves contributions $\Delta_{pol} \approx 1.3 \pm 0.3$ ppm where the proton is excited

$$\Delta_{pol} = \frac{\alpha m_e}{\pi g_p m_p}[\Delta_1 + \Delta_2]$$

Δ_1: involves Pauli form factor and the g_1 structure function

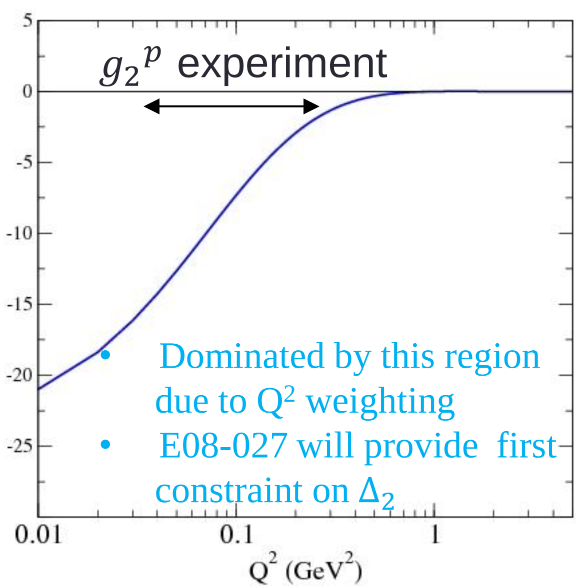
Δ_2: depends on g_2 structure function

$$\Delta_2 = -24 m_p{}^2 \int_0^\infty \frac{dQ^2}{Q^4}[B_2(Q^2)]$$

$$B_2(Q^2) = \int_0^{x_{th}} dx \beta_2(\tau)\, g_2(x, Q^2)$$

$$\beta_2(\tau) = 1 + 2\tau - 2\sqrt{\tau(\tau+1)}$$

Integrand of Δ_2



Proton Radius Puzzle

- Two ways to measure:

- Atomic physics:
  - energy splitting of the $2S_{1/2} - 2P_{1/2}$ level (Lamb shift)
  - The result from Lamb shift in muonic hydrogen is much more precise
    R. Pohl *et.al.,Nature, July 20102*

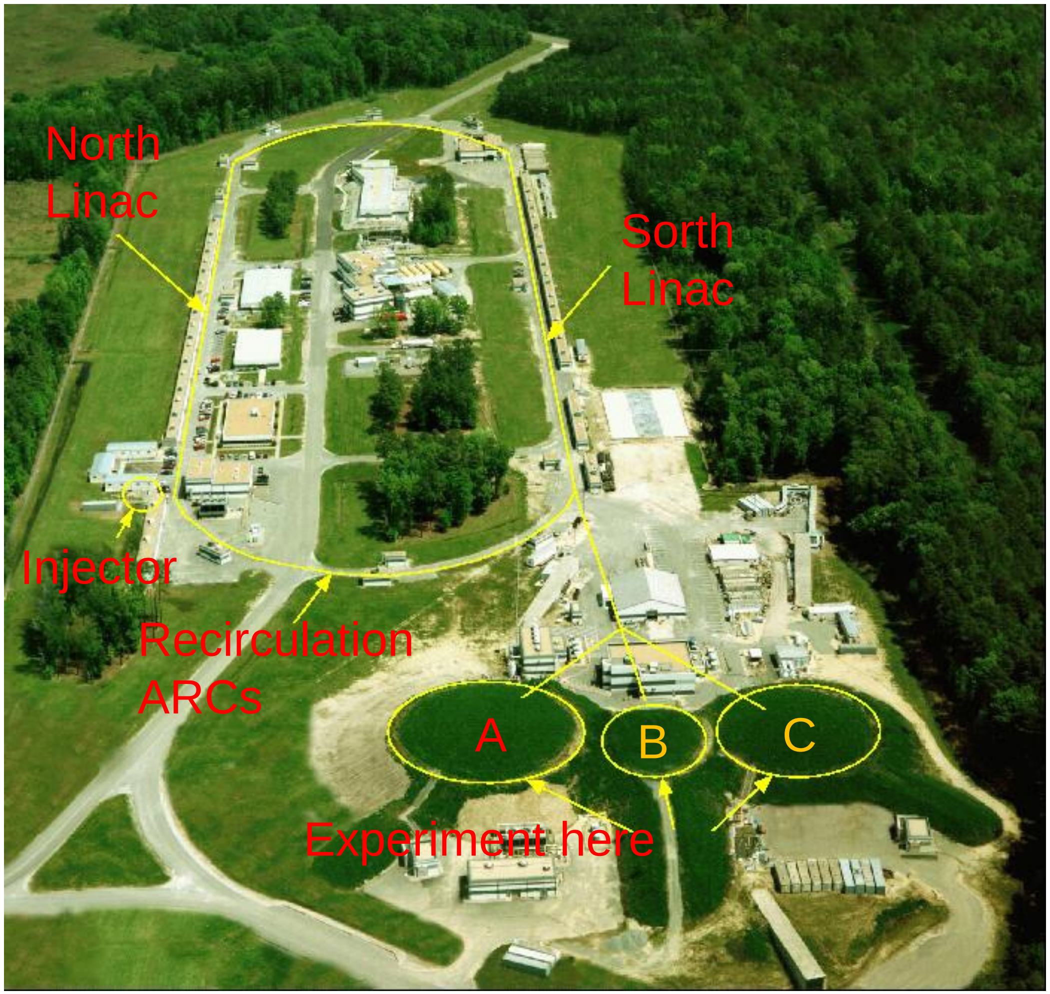
- Nuclear Physics:
  - $\frac{dG_{E(M)}(Q^2)}{Q^2}$ defines radius at $Q^2 = 0$

- Not agree with each other, around ~ 6%

- Main uncertainties originates from the proton polarizability and different values of the Zemach radius

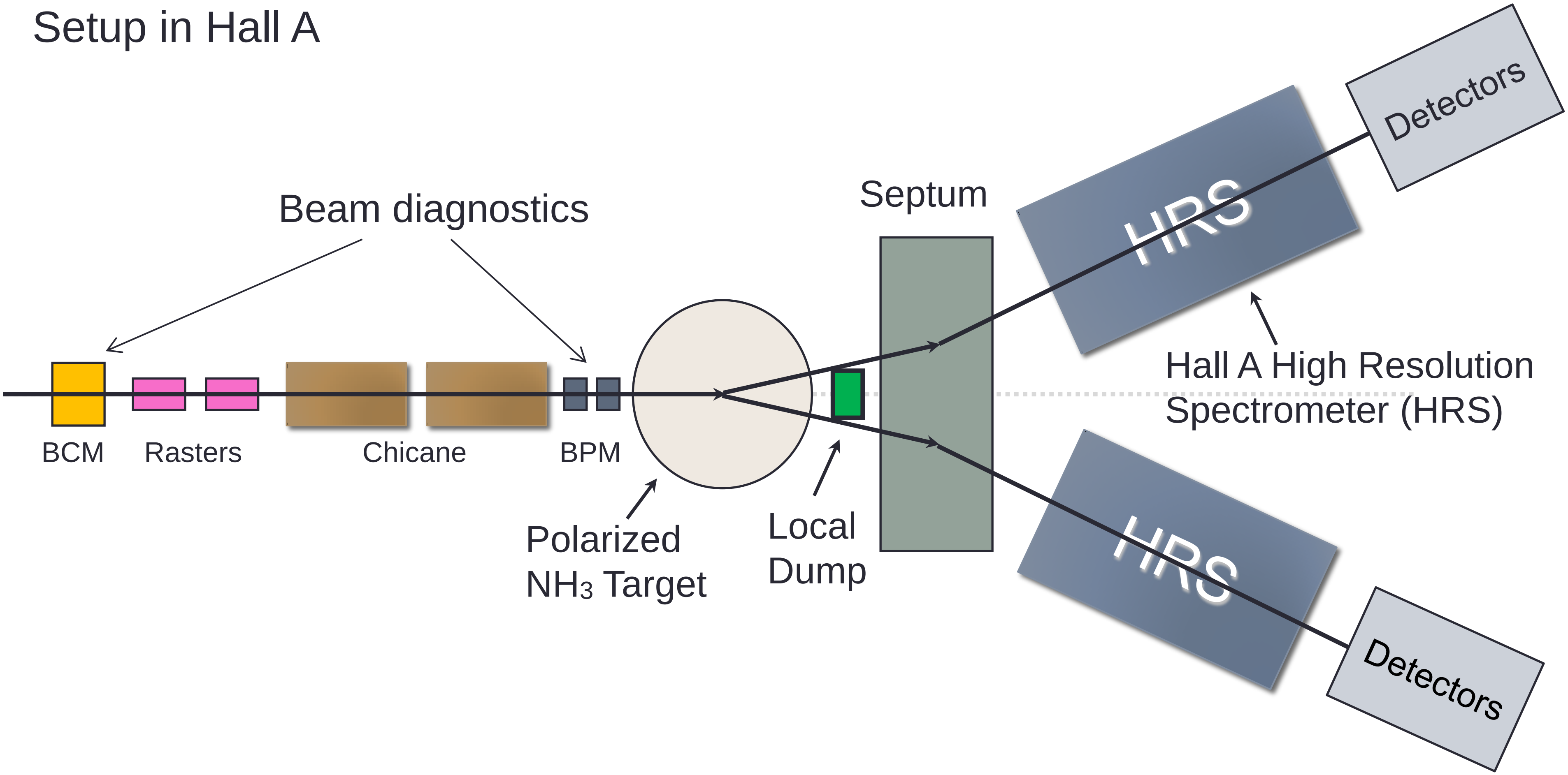
Experiment Setup

- ${g_2}^p$ experiment took data in Jefferson Lab Hall A from Feb 29th to May 18th 2012



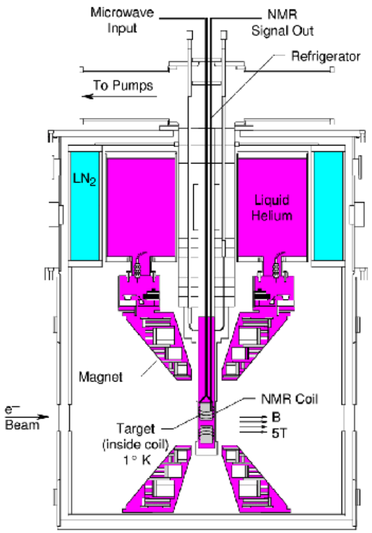
Experiment Setup

Setup in Hall A

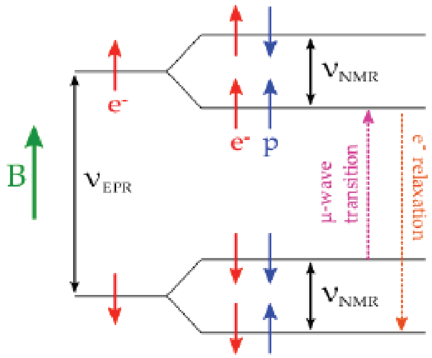


Experiment Setup

- Polarized NH_3 target (2.5T/5T)
  - Upstream chicane: to provide a incident angle beam,
  - Downstream local dump: some energy/target settings, beam cannot go into hall dump, to be deposited in local dump directly
- Low current polarized beam
  - Upgrades existing beam diagnostics to work at 50 nA
- Lowest possible Q^2 in the resonance region
  - Use septum magnets to bend the small scattering angle electrons, to access a lower Q^2
  - Detector package has a minimum angle limit at 12.5°



target

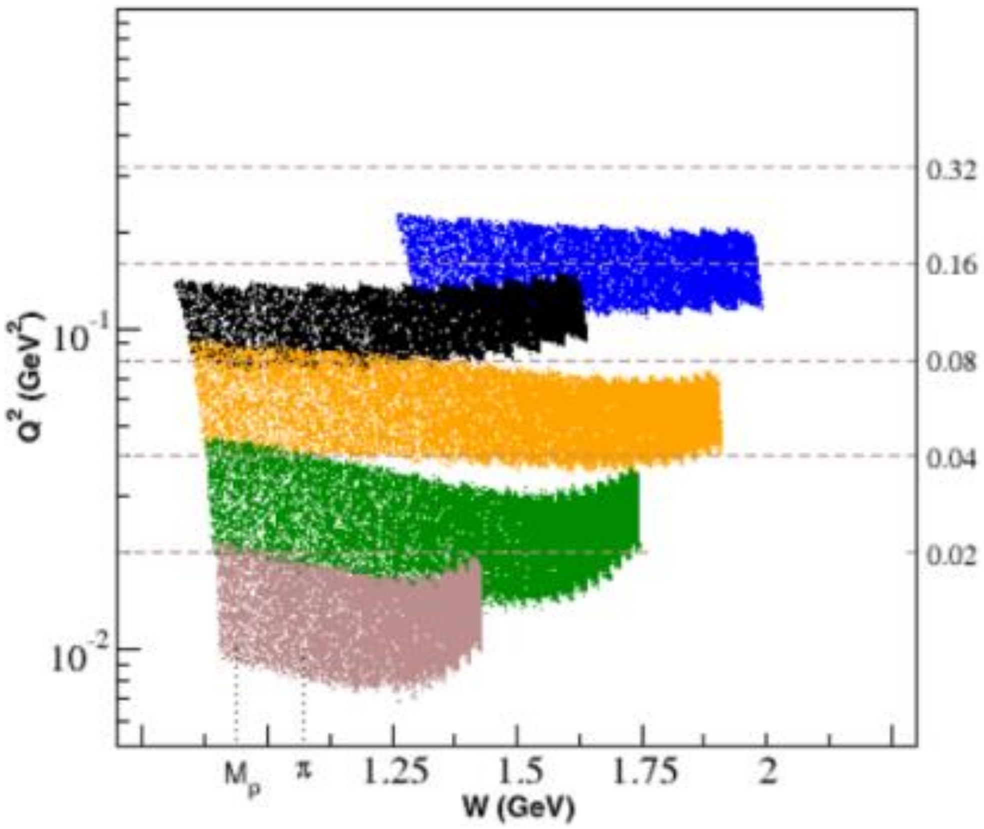


Dynamic nuclear polarization

Kinematics Coverage

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

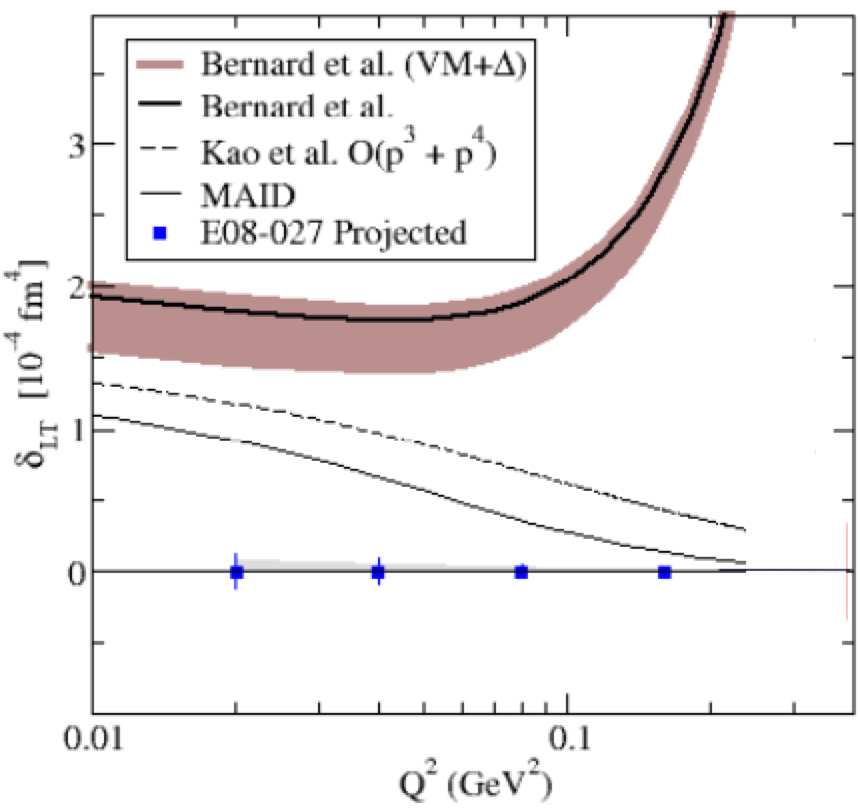
$M_p < W < 2\ GeV$



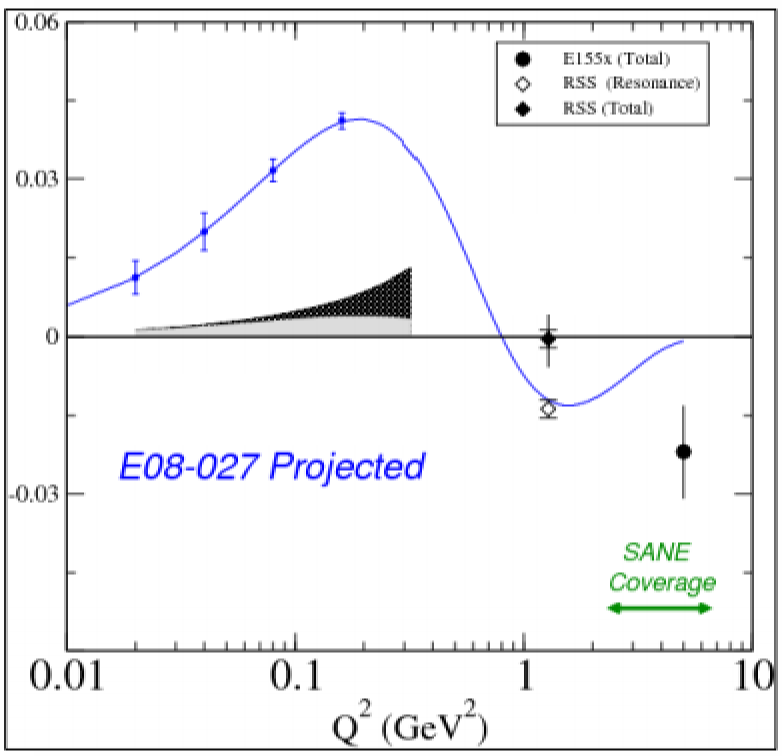
Beam Energy /GeV	Target Field /T
2.254	2.5
1.706	2.5
1.158	2.5
2.254	5.0
3.352	5.0

Kinematics and Projection

LT Spin Polarizability



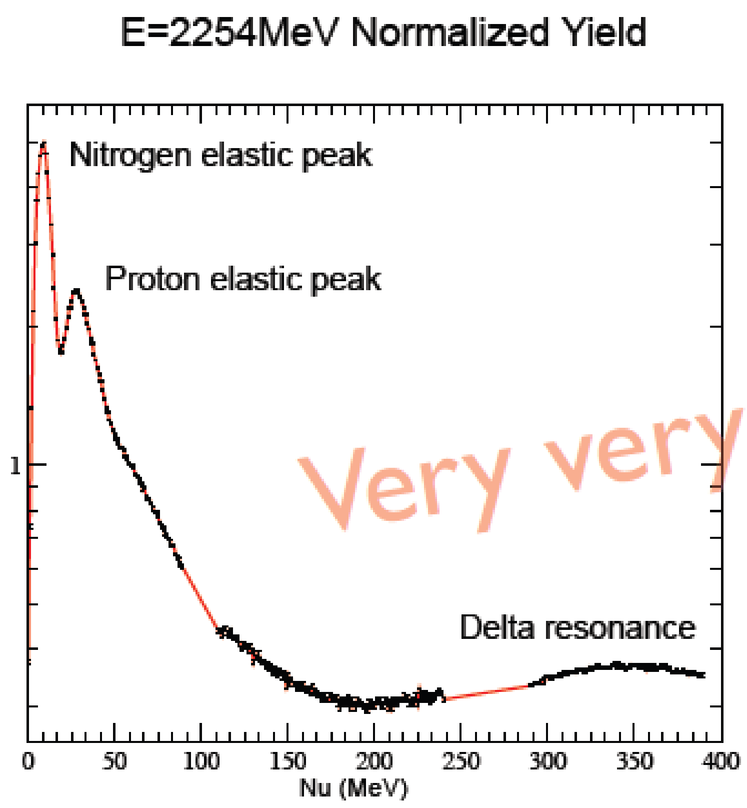
BC Sum Integral Γ_2

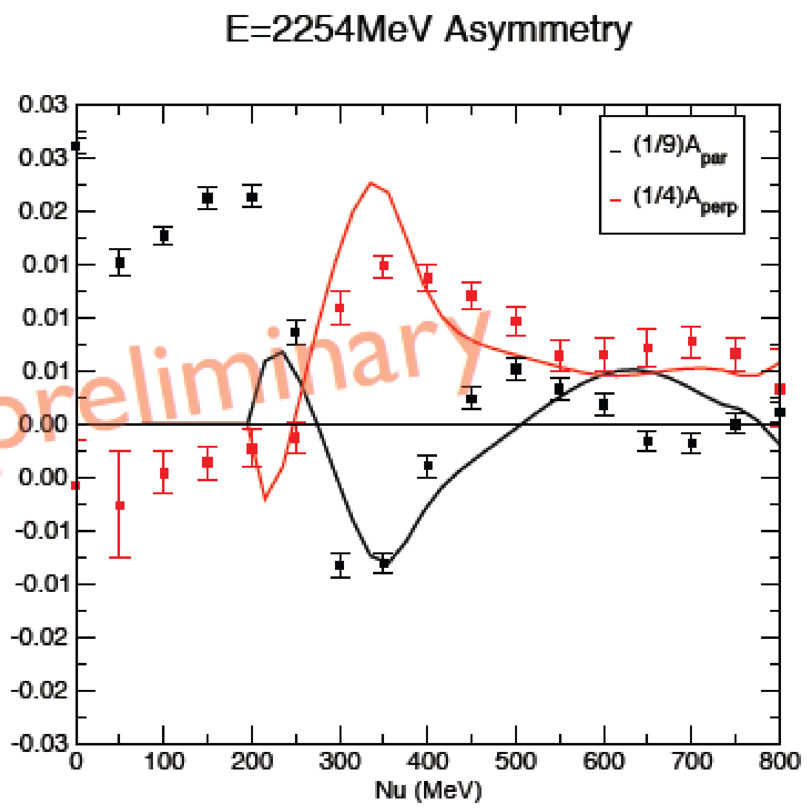


$$\delta_{LT}\left(Q^2\right) = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} dx x^2 [g_1(x,Q^2) + g_2(x,Q^2)]$$

$$\int_0^1 g_2(x,Q^2)\mathrm{d}x = 0$$

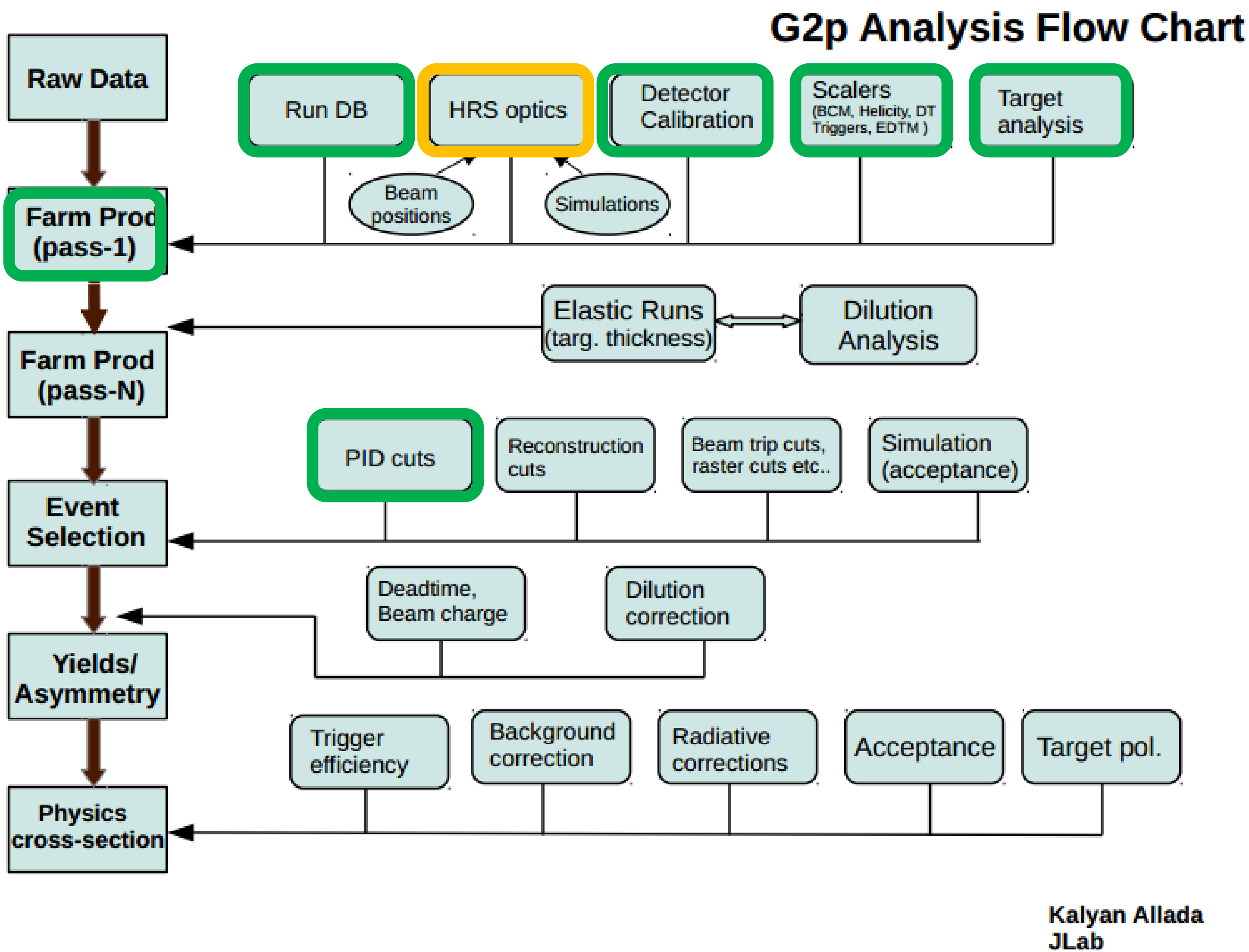
Online Results



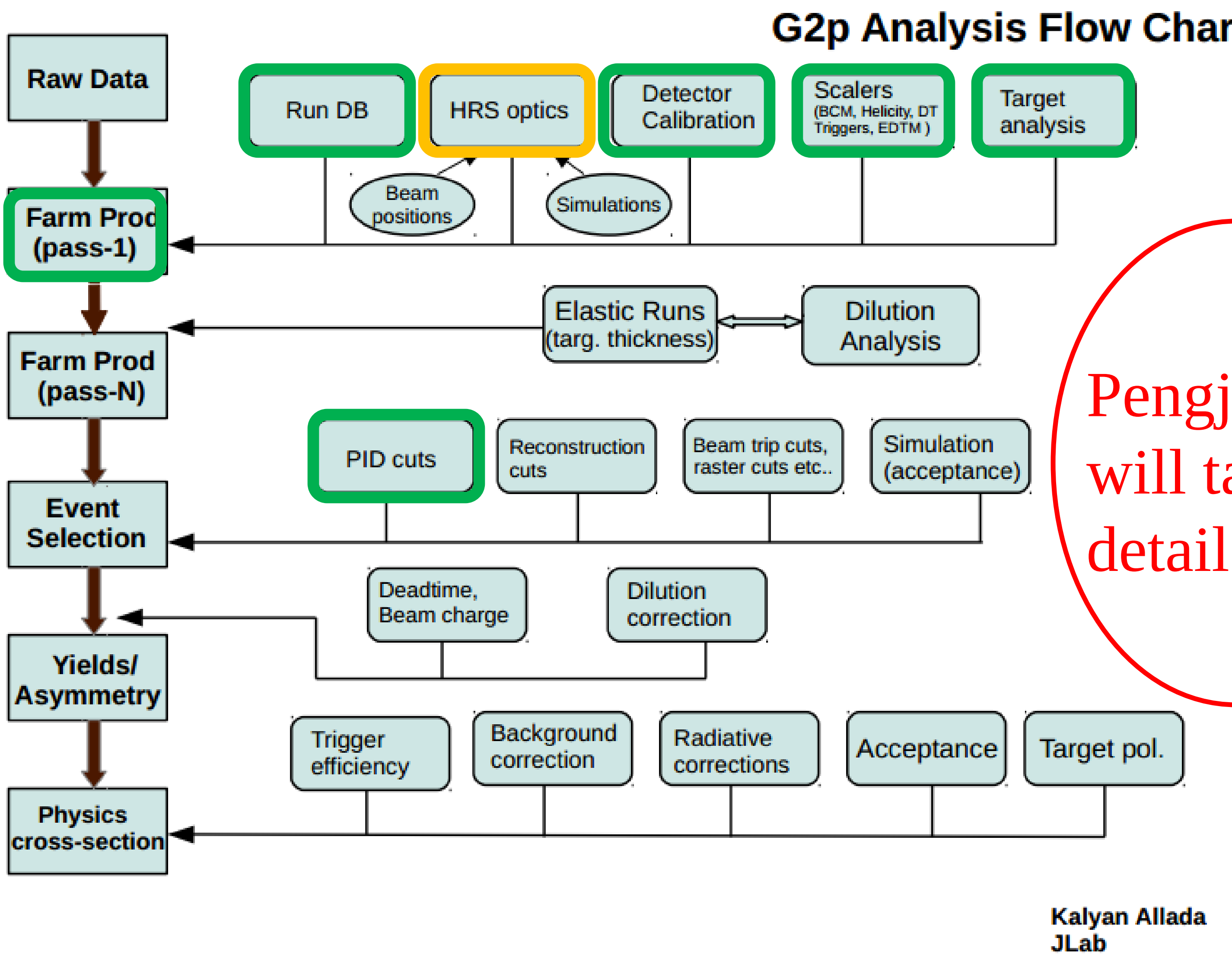


$$\sigma_{\perp} = \sigma_{total} * A_{\perp}$$

Analysis


G2p Analysis Flow Chart
Raw Data
Run DB
HRS optics
Detector Calibration
Scalers (BCM, Helicity, DT Triggers, EDTM)
Target analysis
Beam positions
Simulations
Farm Prod (pass-1)
Elastic Runs (targ. thickness)
Dilution Analysis
Farm Prod (pass-N)
PID cuts
Reconstruction cuts
Beam trip cuts, raster cuts etc..
Simulation (acceptance)
Event Selection
Deadtime, Beam charge
Dilution correction
Yields/ Asymmetry
Trigger efficiency
Background correction
Radiative corrections
Acceptance
Target pol.
Physics cross-section
Kalyan Allada
JLab

Analysis



Pengjia Zhu will talk in details

Summary

- The g_2^p experiment took data successfully covering $M_p < W < 2$ GeV, $0.02 < Q^2 < 0.2$ GeV^2
- Will provide a precision measurement of g_2^p in the low Q^2 region for the first time
- Will extract δ_{LT} to provide a benchmark test of χPT calculations
- Results will shed light on several physics puzzles

Thanks!