The g_2 Spin Structure Function

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Electron Scattering

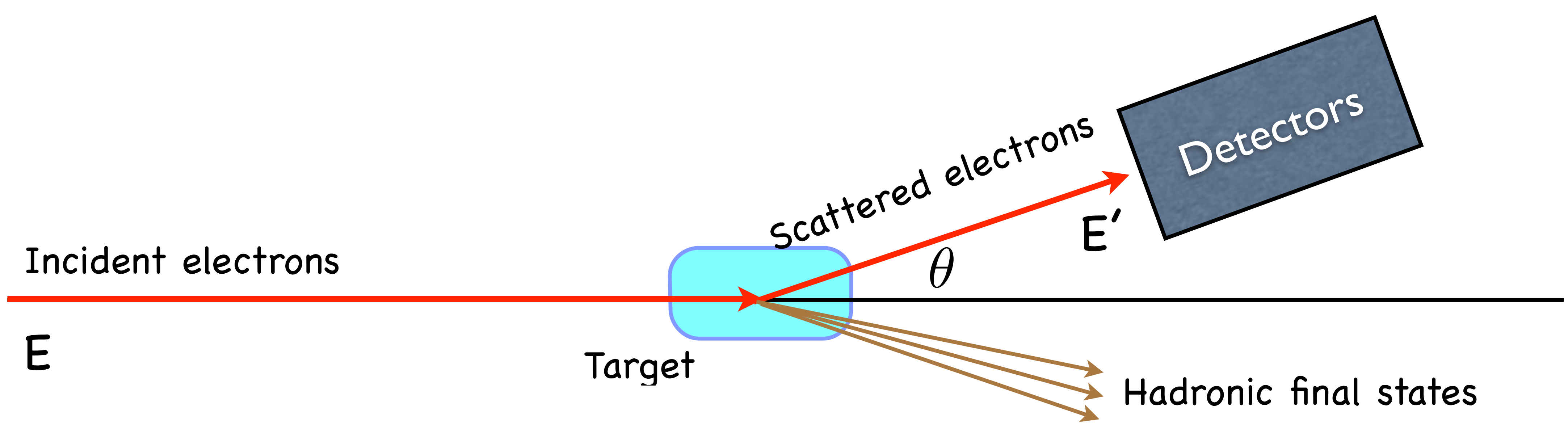
- Inclusive unpolarized cross section:

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

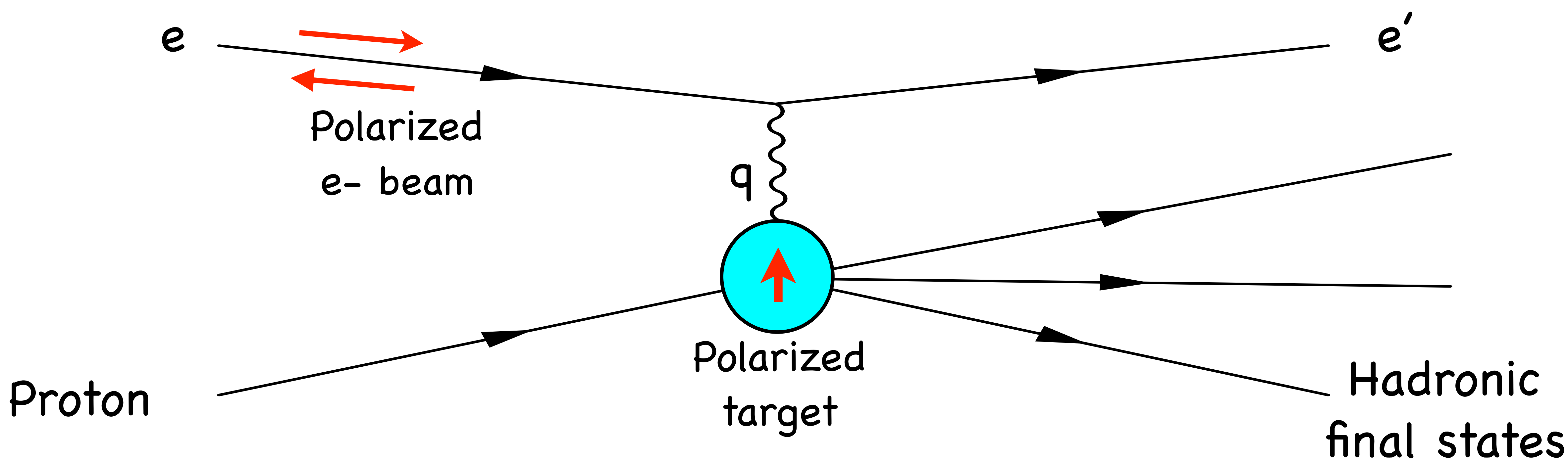
Structure Function which indicates the parton distribution

- At Bjorken Limit $Q^2 \to \infty$:

$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \qquad\qquad F_2 = 2xF_1$$



Electron Scattering



- If the beam and target are polarized, the asymmetric part of the lepton and hadron tensor will not vanish, which leads to 2 additional structure functions g_1 and g_2

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

2 addition structure functions which are related to the polarized parton distributions

Structure Function

- At Bjorken limit, g_1 related to the polarized parton distribution functions

$$g_1 = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x) \qquad \Delta q_i(x) = q_i^{\uparrow}(x) - q_i^{\downarrow}(x)$$

- However g_2 does no show a simple relation with parton distribution functions at Bjorken limit

- g_2^{WW} is the leading twist part of the g_2:

$$g_2(x,Q^2) = g_2^{\mathrm{WW}}(x,Q^2) + \bar{g}_2(x,Q^2)$$

which can be calculated from g_1 with the Wandzura-Wilczek relation

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

Structure Function

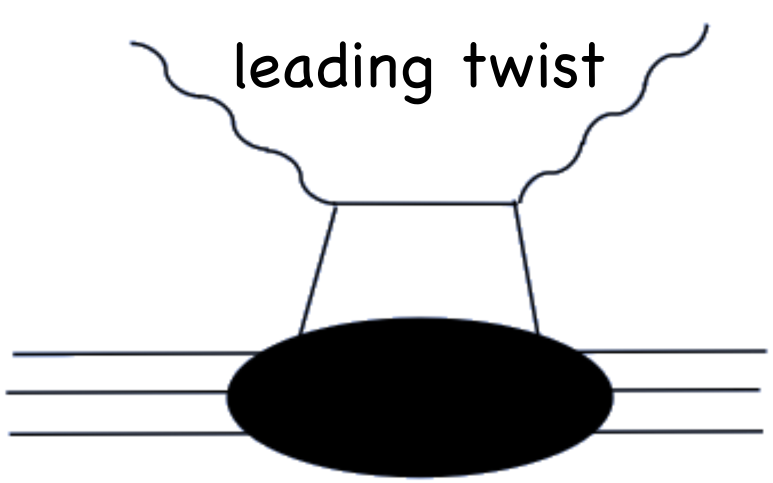
- Higher twist components can be expressed as:

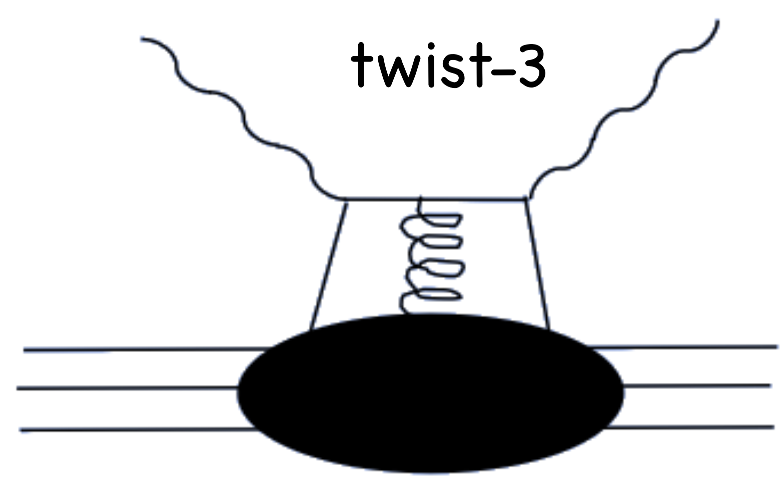
$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M} h_T(y,Q^2) + \zeta(y,Q^2)\right]\frac{\mathrm{d}y}{y}$$

quark transverse momentum contribution (h_T)

twist-3 part which arises from quark-gluon interactions (ζ)

- Will get information about higher twist effect when measuring g_2





Measurements of g_2 and its Moments

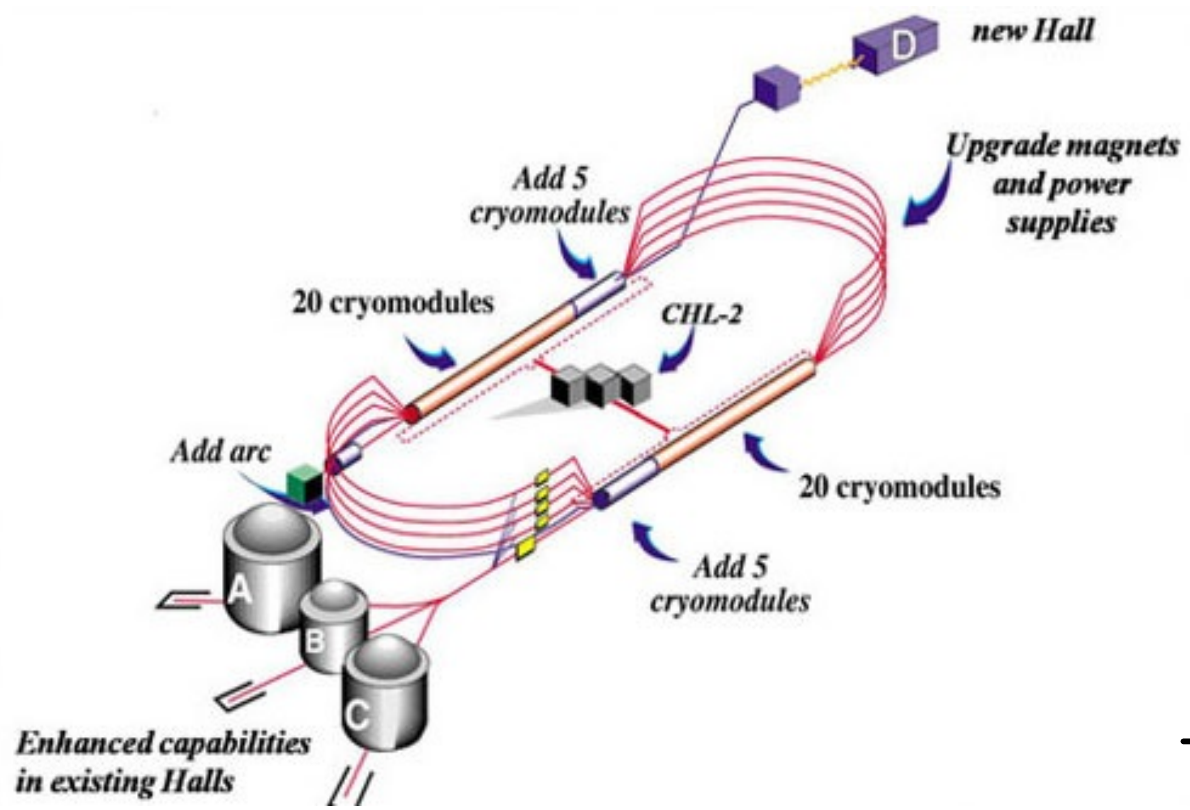
- Measurements of g_2 need transversely polarized targets, more difficult experimentally
- 0th moment (no x-weighting): Burkhardt-Cottingham (BC) Sum Rule

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

  - Valid at all Q^2
- 2nd moment (x^2 weighting):
  - High Q^2 – d_2, twist-3 color polarizability, test of lattice QCD
  - Low Q^2 – spin polarizabilities, test of Chiral Perturbation Theory (χPT)

Measurements of g_2 and its Moments

- High-intensity electron accelerator
- E_{max} = 6 GeV
- I_{max} = 200 uA
- Pol_{max} = 90%
- Upgrading to 12 GeV

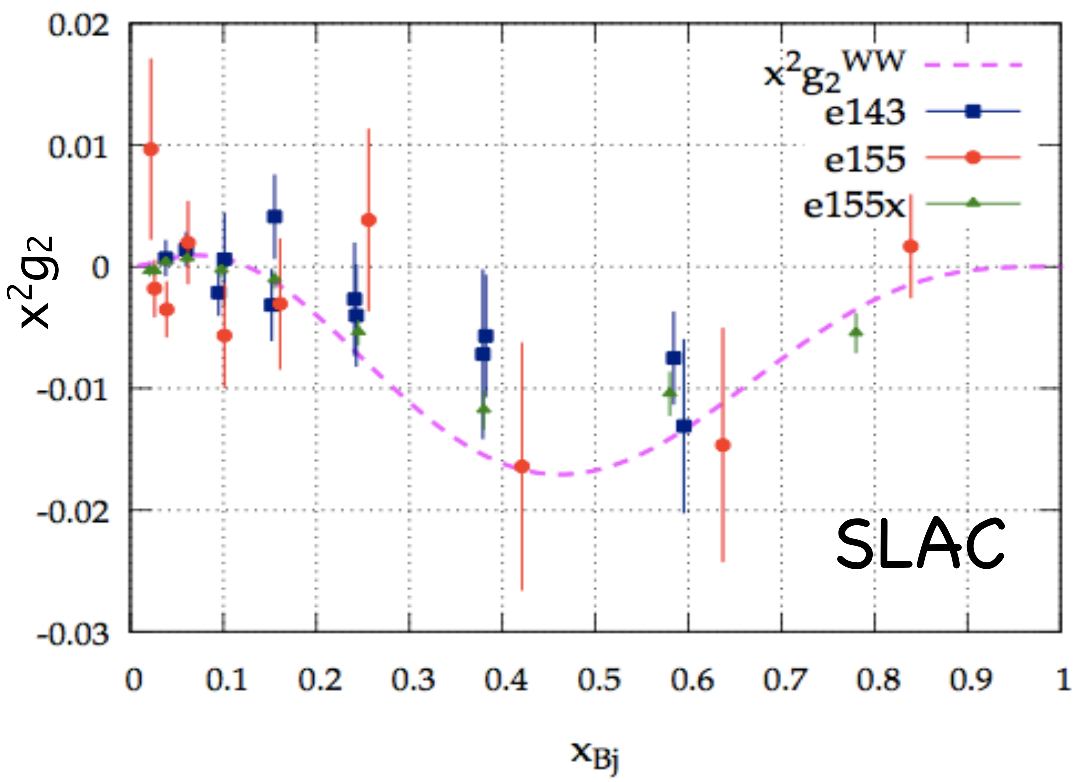


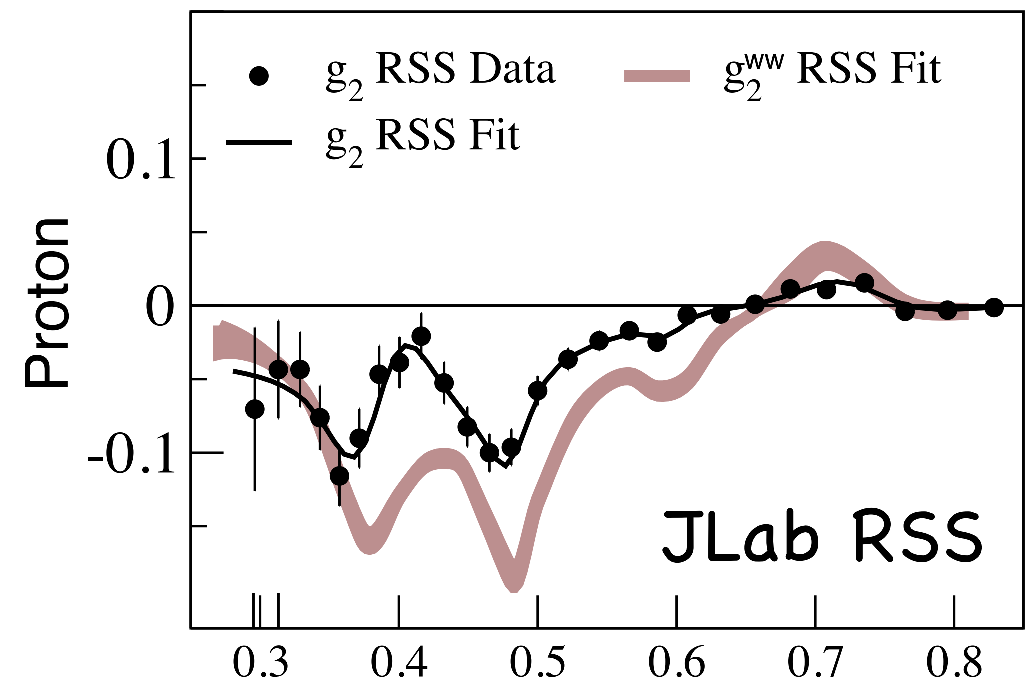
Thomas Jefferson National Accelerator Facility

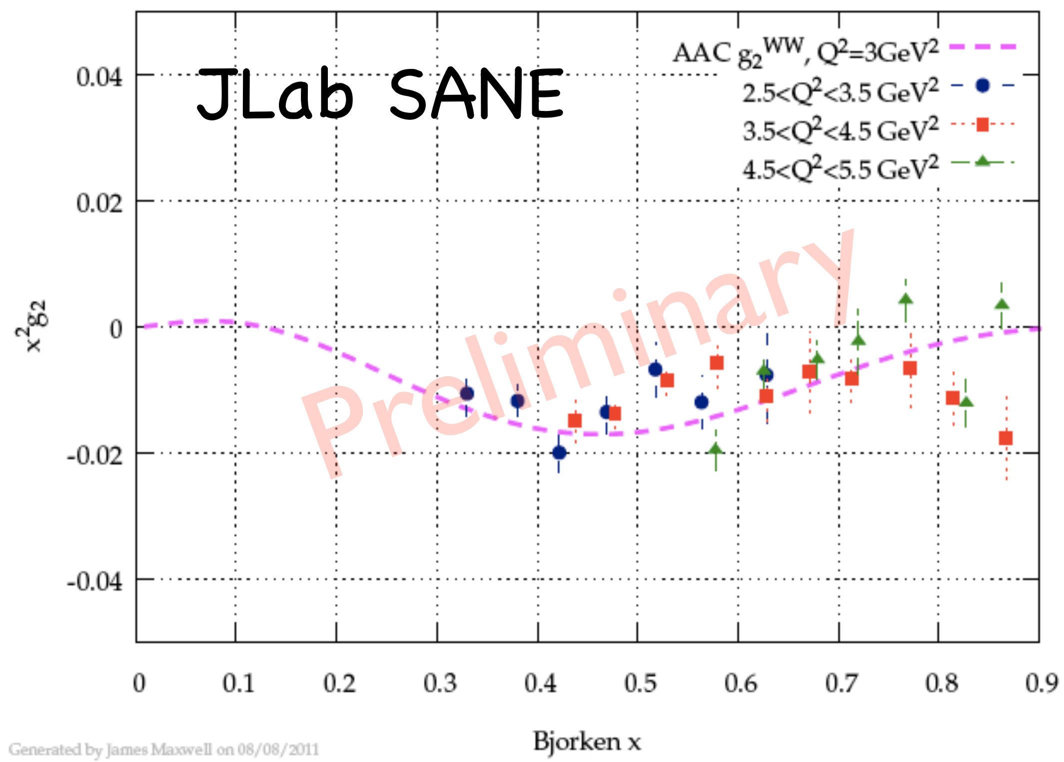
Measurements of g_2 and its Moments

- SLAC E155x: Only dedicated measurement before JLab, not high precision, wider range of Q^2 for moment
- g_2 Measurements on the neutron at JLab:
  - E97-103: W>2 GeV, $Q^2 \approx 1 GeV^2$, $x \approx 0.2$, study higher twist (published)
  - E99-117: W>2 GeV, high Q^2 (3-5 GeV^2) (published)
  - E94-010: moments at low Q^2 (0.1-1 GeV^2) (published)
  - E97-110: moments at very low Q^2 (0.02-0.3 GeV^2) (analysis)
  - E01-012: moments at intermediate Q^2 (1-4 GeV^2) (submitted)
  - E06-014: moments at high Q^2 (2-6 GeV^2) (published)
- g_2 Measurements on the proton at JLab:
  - RSS: moments at intermediate Q^2 (1-2 GeV^2) (published)
  - SANE: moments at high Q^2 (2-6 GeV^2) (analysis)
  - E08-027 (g2p): moments at very low Q^2 (0.02-0.2 GeV^2) (analysis)

Measurements of g_2 and its Moments



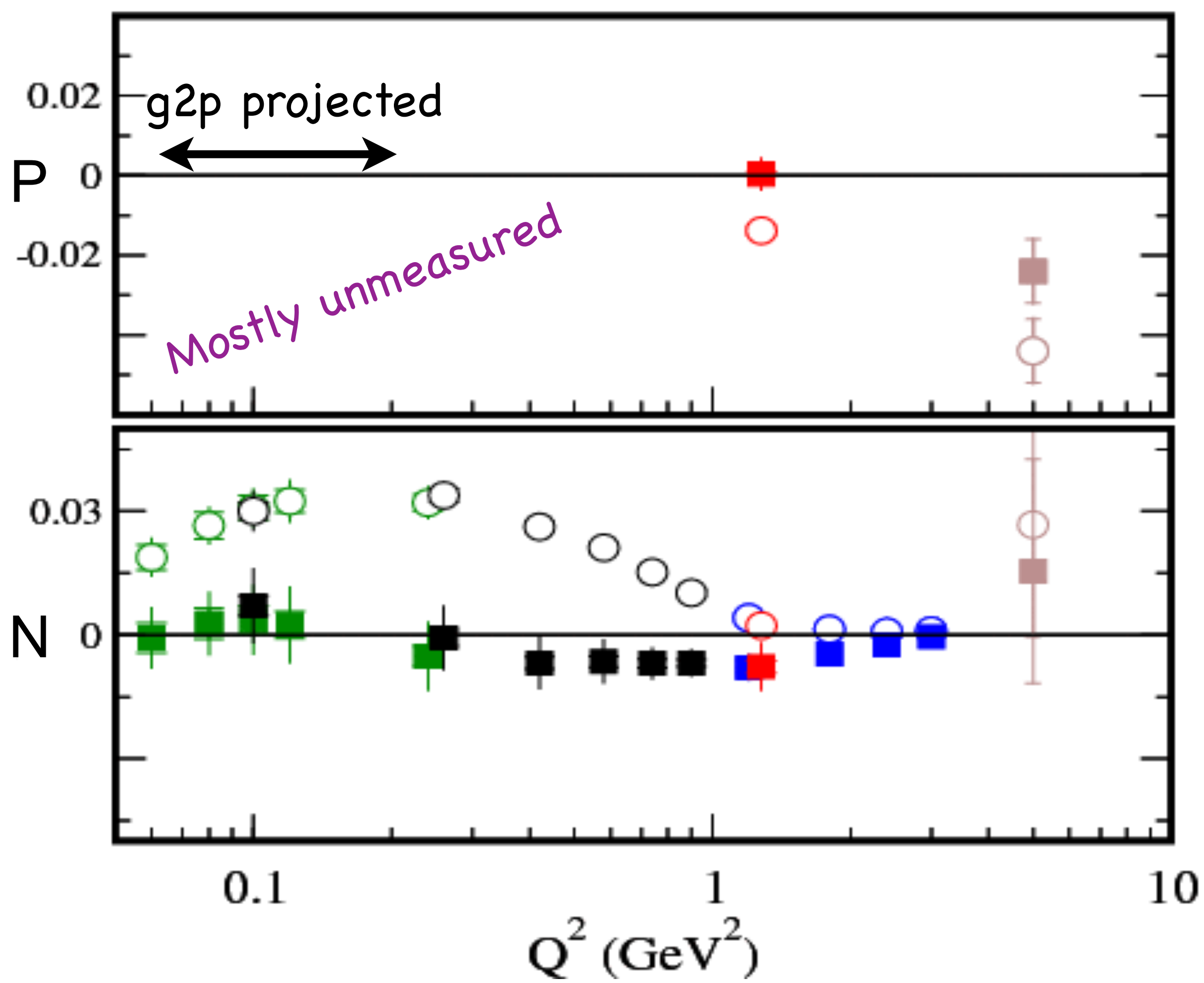




- g_2 Measurements on the proton:
  - SLAC: 1 ~ 10 GeV^2
  - SANE: 2 ~ 6 GeV^2
  - RSS: 1 ~ 2 GeV^2

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

BC Sum Rule: 0th Moment



- SLAC E155x
- Hall C RSS
- Hall A E94-010
- Hall A E97-110 (preliminary)
- Hall A E01-012 (preliminary)

- BC Sum Rule:

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

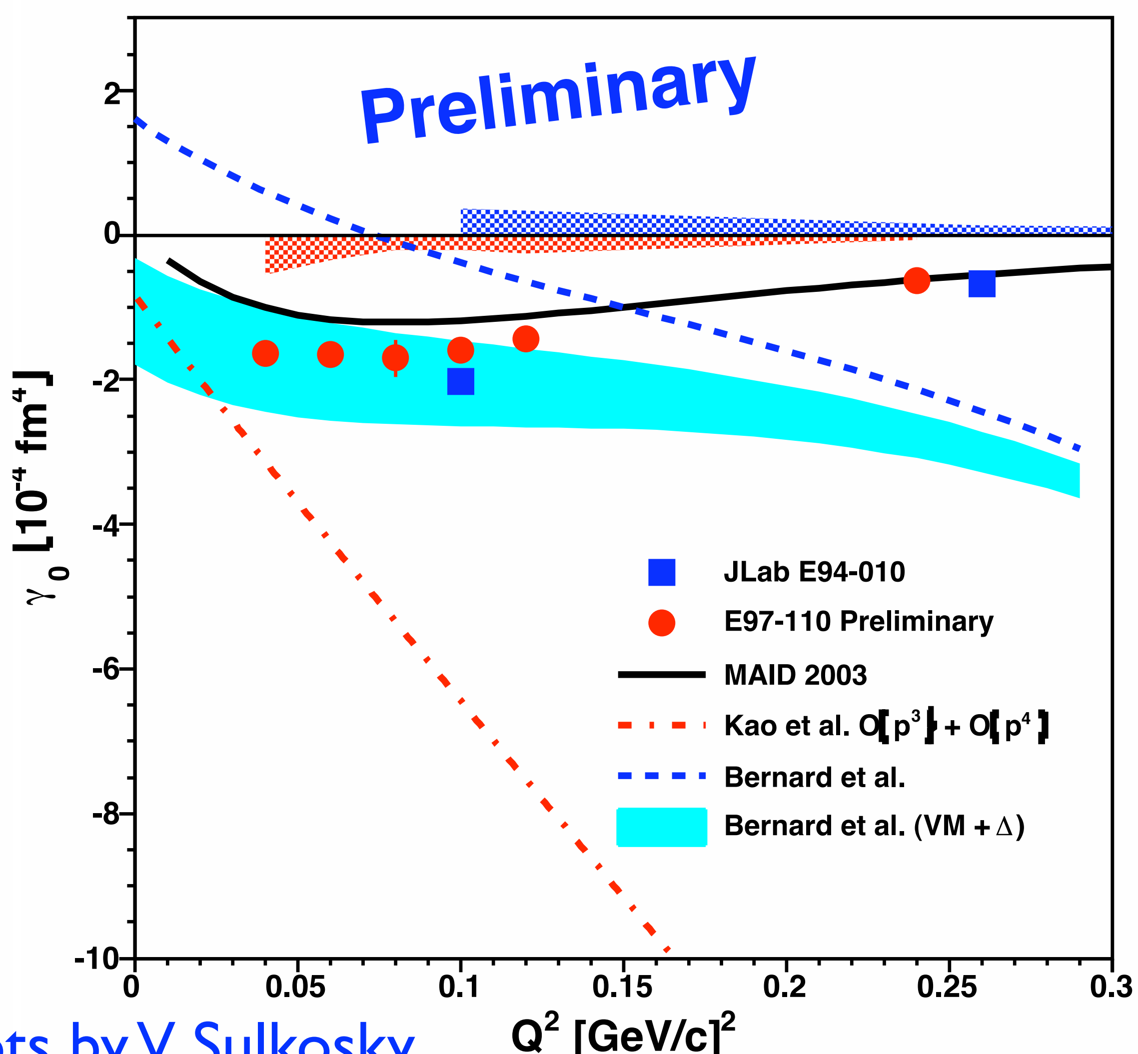
- Violation suggested for proton at large Q^2
- BC Sum = Meas + Low x + Elastic
  - "Meas": measured x range (open circle)
  - "Low x": unmeasured low-x part of the integral - assume leading twist behavior
  - "Elastic": from well known Form Factors (<5%)

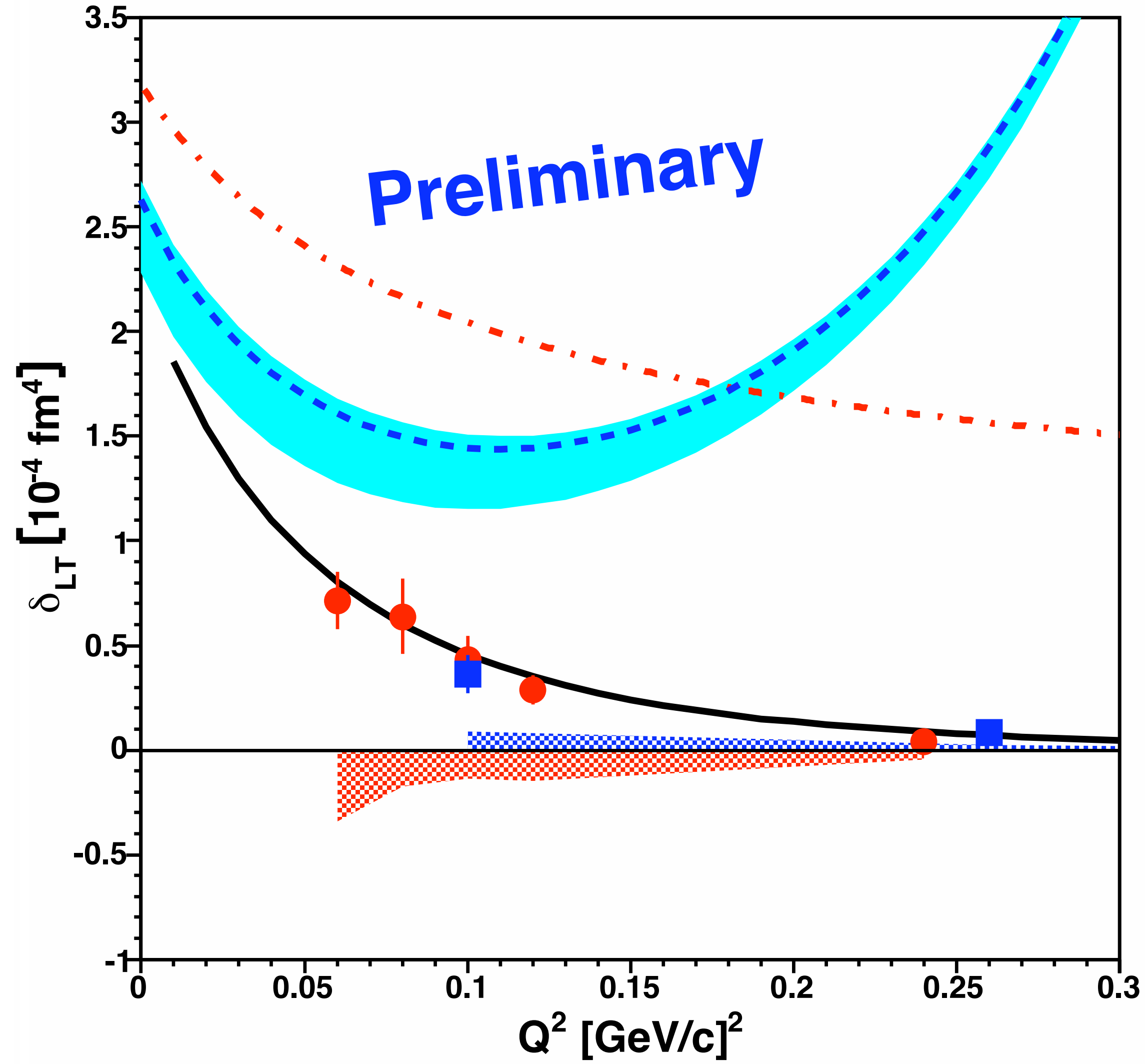
Spin Polarizability: 2nd Moment

- Generalized spin polarizabilities γ_0 and δ_{LT} are a benchmark test of χPT
- One difficulty is how to include the nucleon resonance contributions
  - γ_0 is sensitive to resonances, δ_{LT} is not

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

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

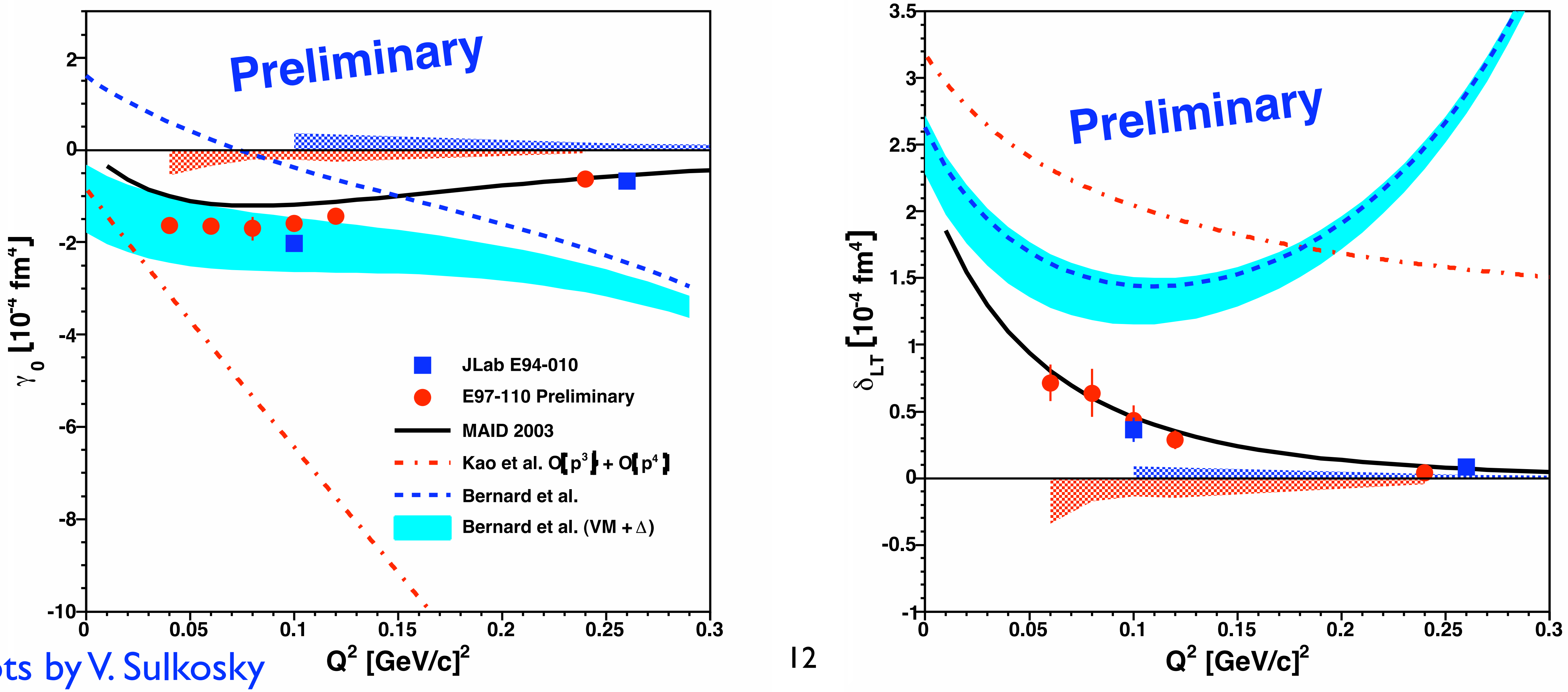




Plots by V. Sulkosky

Spin Polarizability: 2nd Moment

- δ_{LT} is seen as a more suitable testing ground of χPT – insensitive to Δ resonance
- Significant disagreement between data and both χPT calculations
- No proton data yet

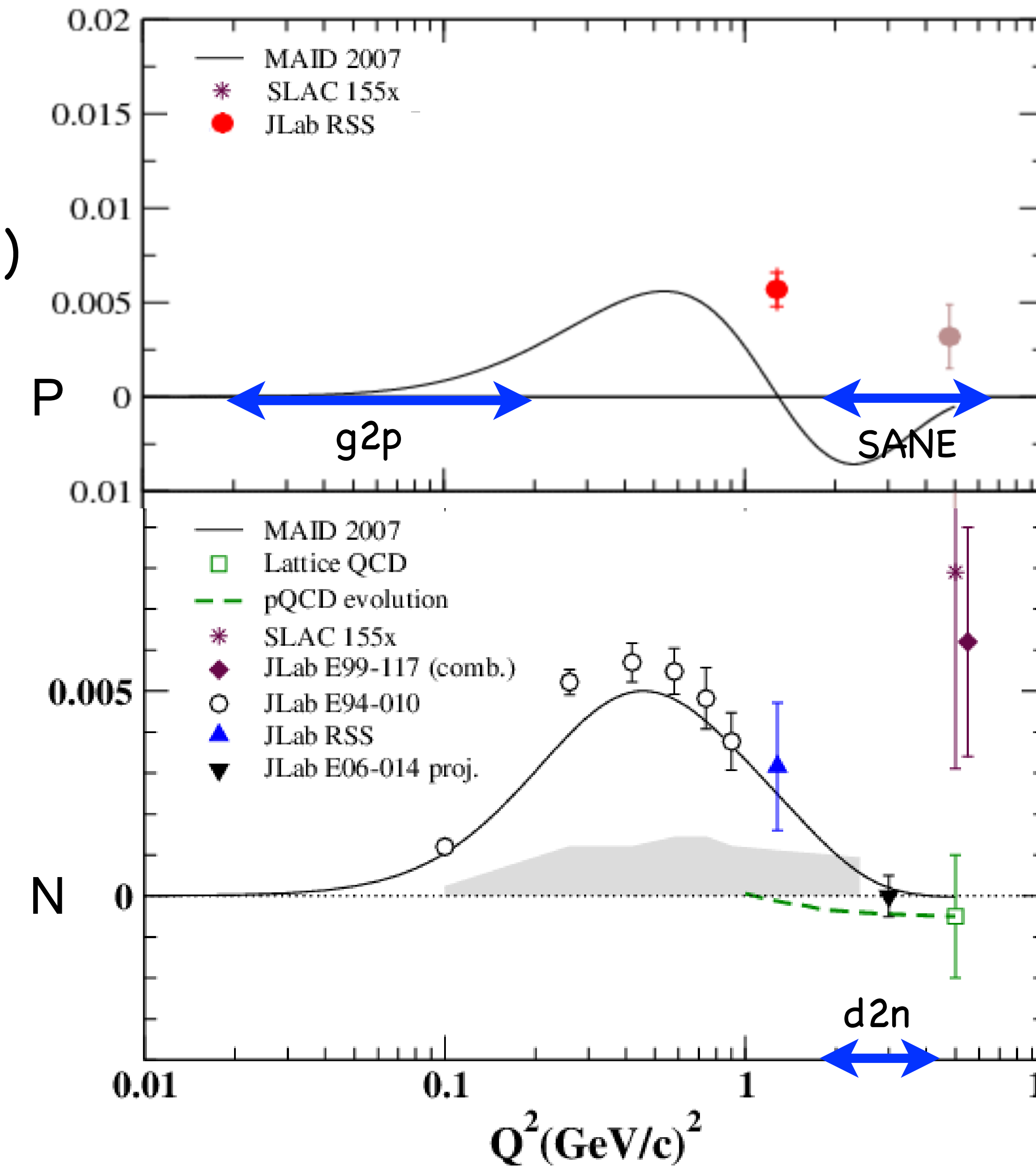


Plots by V. Sulkosky

d_2 and Higher Twist

$$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]\mathrm{d}x$$
$$= 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]\mathrm{d}x$$

- Clean access of higher twist (twist-3) effect
- Only contributions from measured region
  - Elastic not included, only important for $Q^2 < 2\text{GeV}^2$
  - Contributions from unmeasured low x region usually not significant due to x^2 weighting.
- A benchmark test of Lattice QCD predictions at high Q^2



Plots by K. Slifer

g2p Experiment at JLab

- First Measurement of the proton structure function g_2 in the low Q^2 region (0.02-0.2 GeV^2)
  - Extract spin polarizability δ_{LT} as a test of χPT calculations
  - Test BC Sum Rule
  - Finite size effects:
    - Hydrogen hyperfine splitting: proton structure contributes to uncertainty
    - Proton charge radius: proton polarizability contributes to uncertainty
- Data were taken in Jefferson Lab Hall A in 2012
- Analysis is currently underway

g2p Collaboration

Spokespeople

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Elena Long

James Maxwell

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Melissa Cummings

Chao Gu

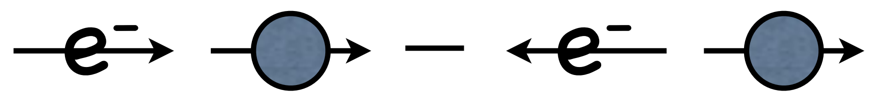
Min Huang

Jie Liu

Pengjia Zhu

Ryan Zielinski

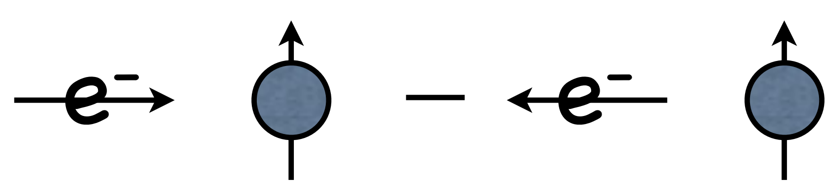
How to get g_2

$$\Delta\sigma_{\parallel} =$$ 

$$= \frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'}$$

$$= \frac{4\alpha^2 E'}{M\nu Q^2 E}[(E + E'\cos\theta)g_1 - 2Mxg_2]$$

JLab Hall B experiment EG4 measured this quantity

$$\Delta\sigma_{\perp} =$$ 

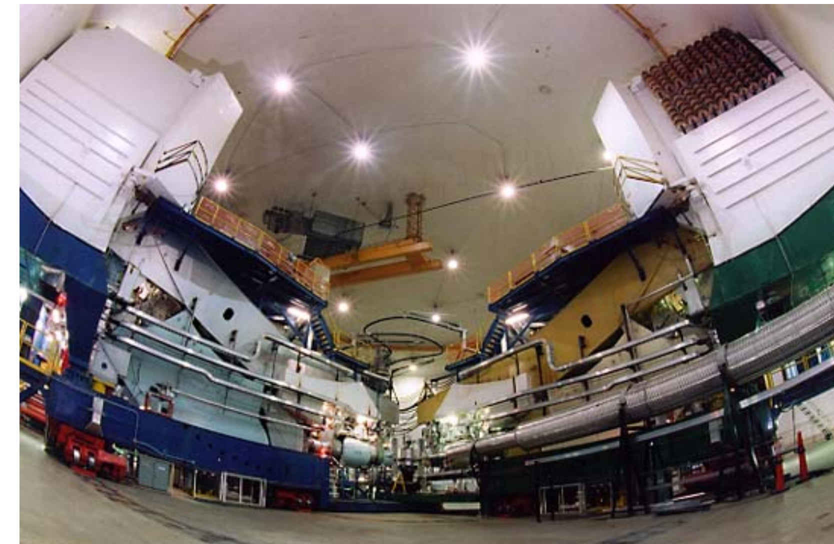
$$= \frac{d^2\sigma^{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Rightarrow}}{d\Omega dE'}$$

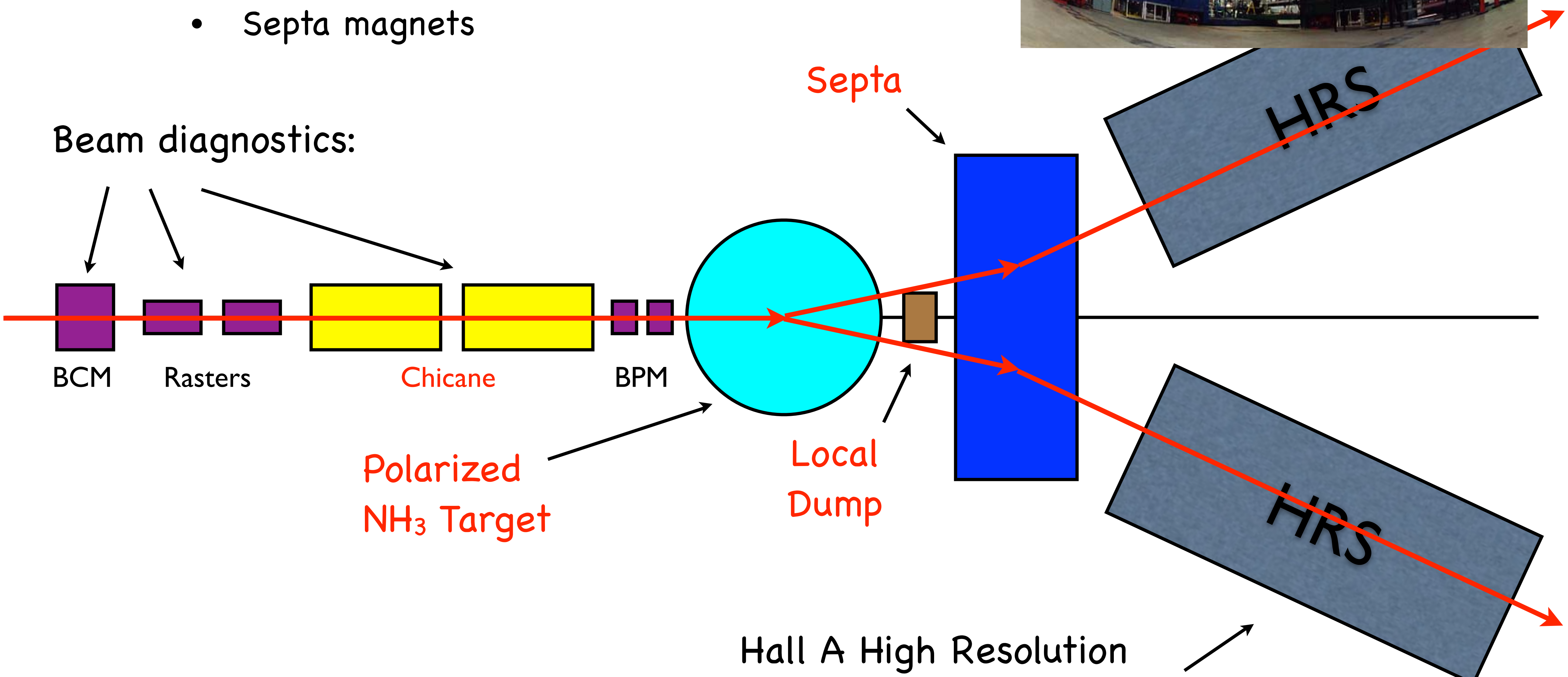
$$= \frac{4\alpha^2 E'^2}{M\nu Q^2 E}\sin\theta[g_1 + \frac{2E}{\nu}g_2]$$

g_2^p experiment will measure this, combining the EG4 data to get g_2^p at low Q^2

Experiment Setup

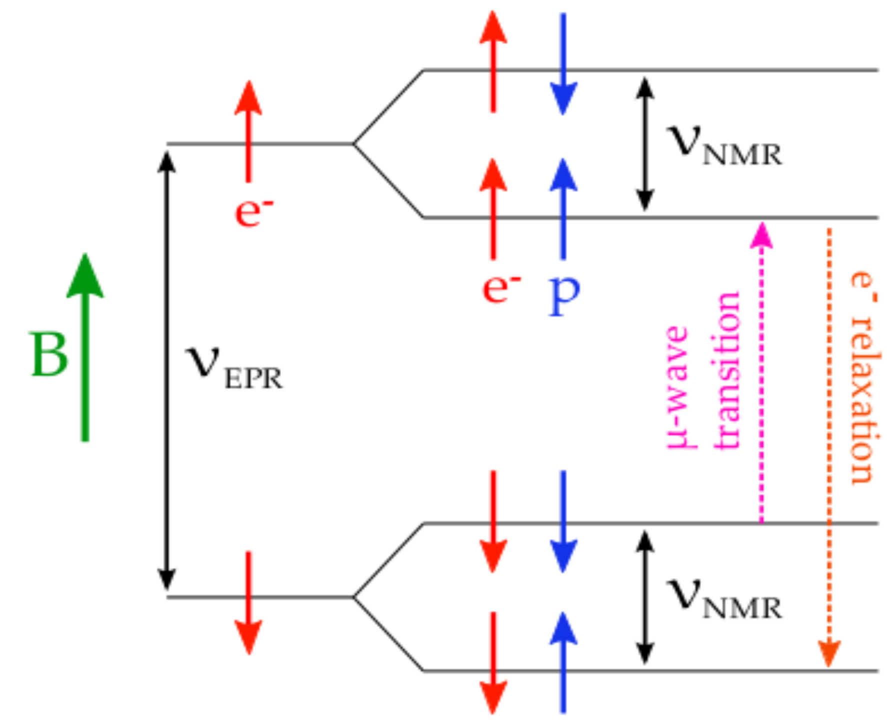
- Major New Installation in Hall A
  - Polarized NH_3 Target with 2.5/5T magnetic field
  - Low current (<100nA) beam line diagnostics
  - Septa magnets



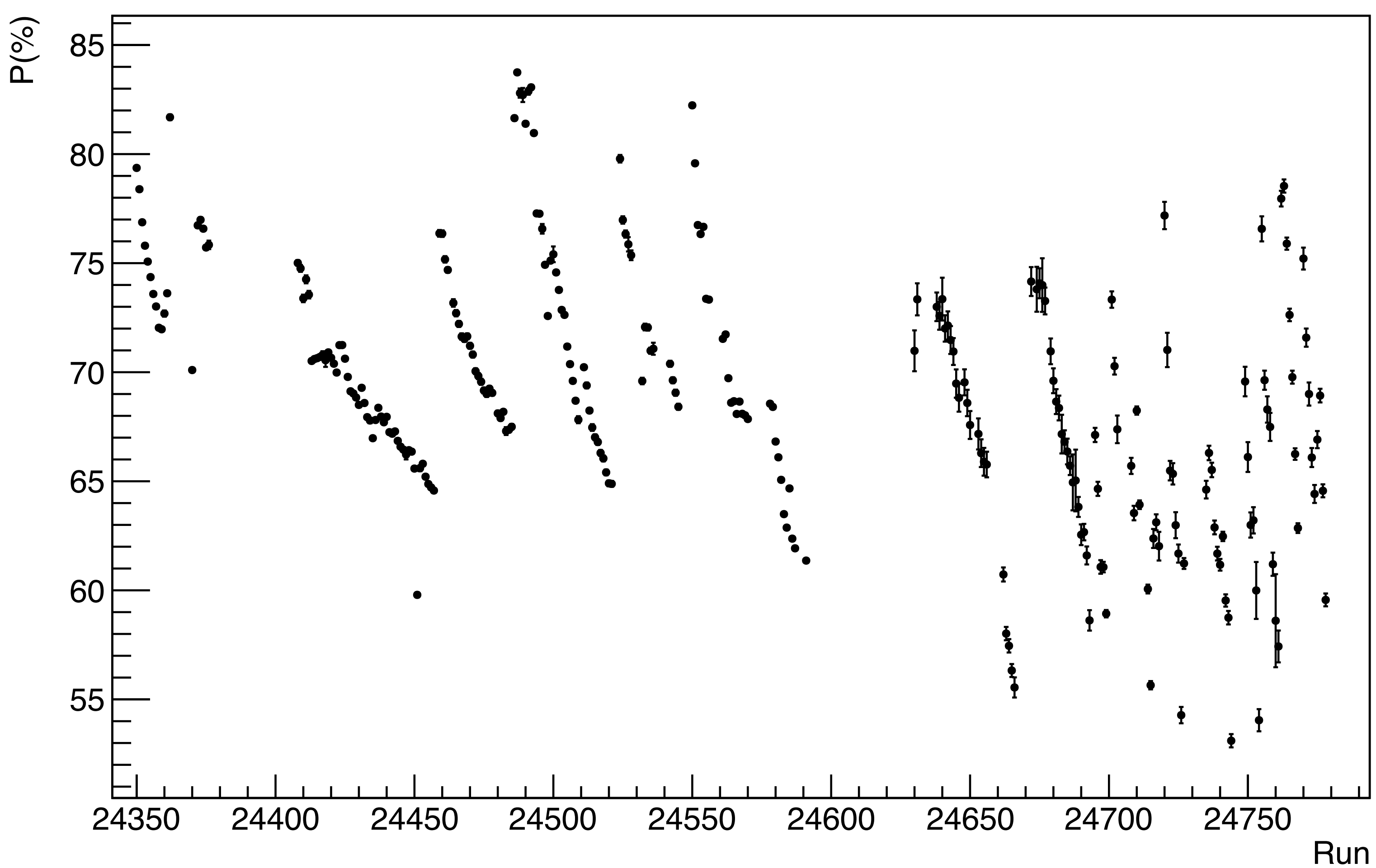


Experiment Setup

- Polarized NH_3 Target
  - Dynamic nuclear polarization
  - Target polarization measured via NMR



Target Polarization Results for 5T Field Setting

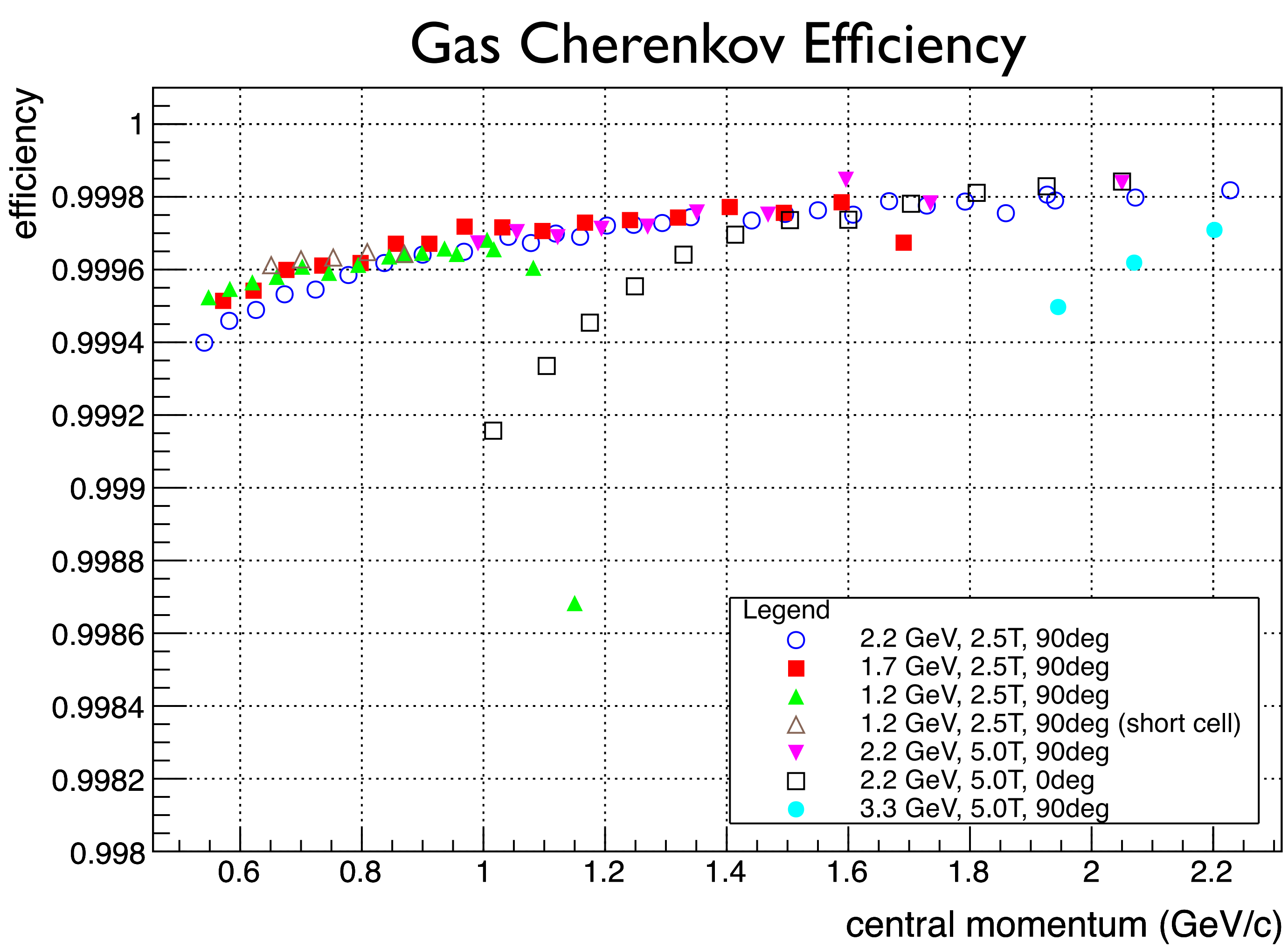


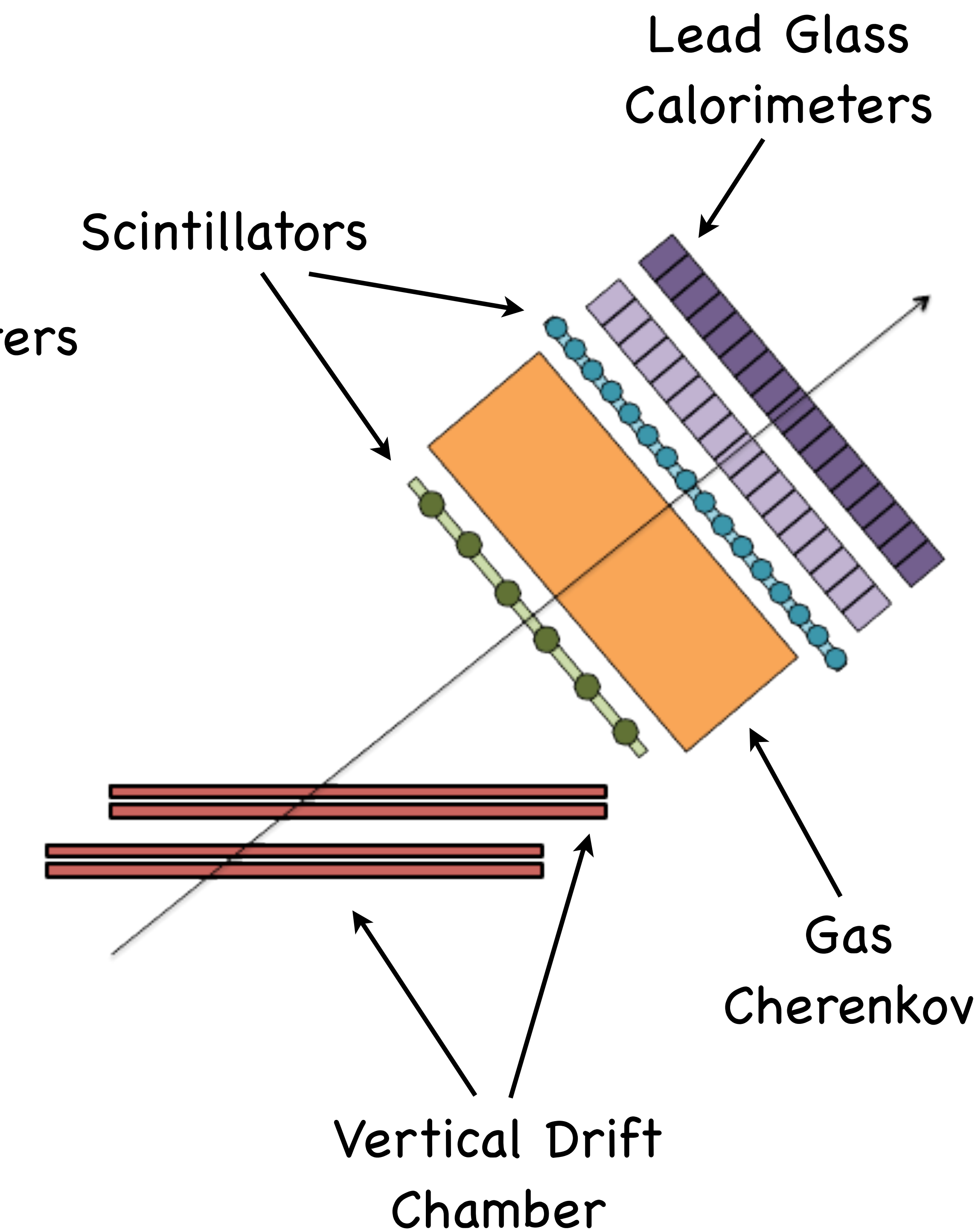
- Average Polarization:
  - 2.5 T: ~ 15%
  - 5.0 T: ~ 70%

Plots by T. Badman

Experiment Setup

- HRS Detector package
    - Vertical Drift Chamber (VDC)
    - Particle identification (PID) Detectors
        - High Efficiency (>99%) for gas Cherenkov and lead glass calorimeters

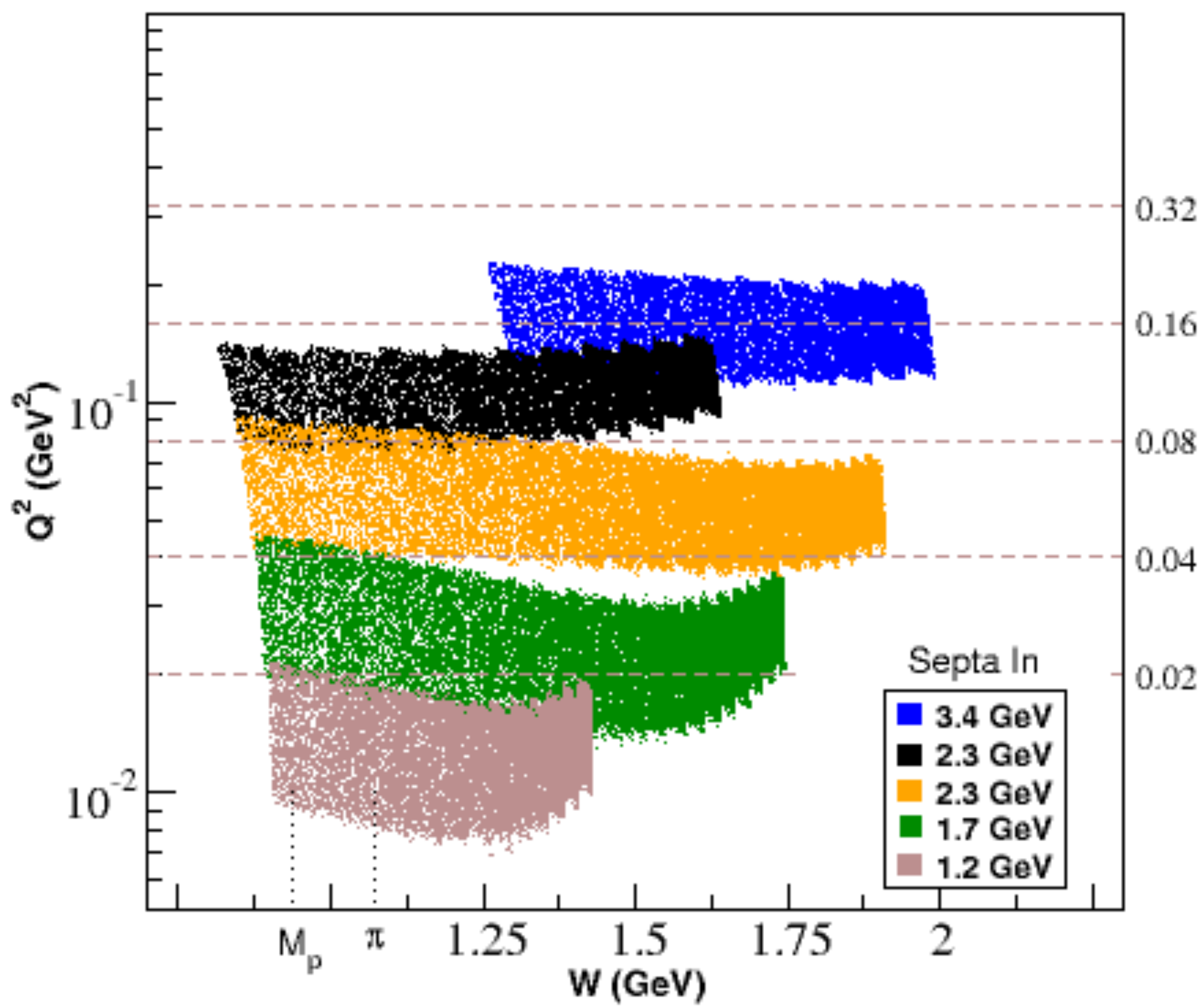




Kinematics Coverage

$M_p < W < 2$ GeV

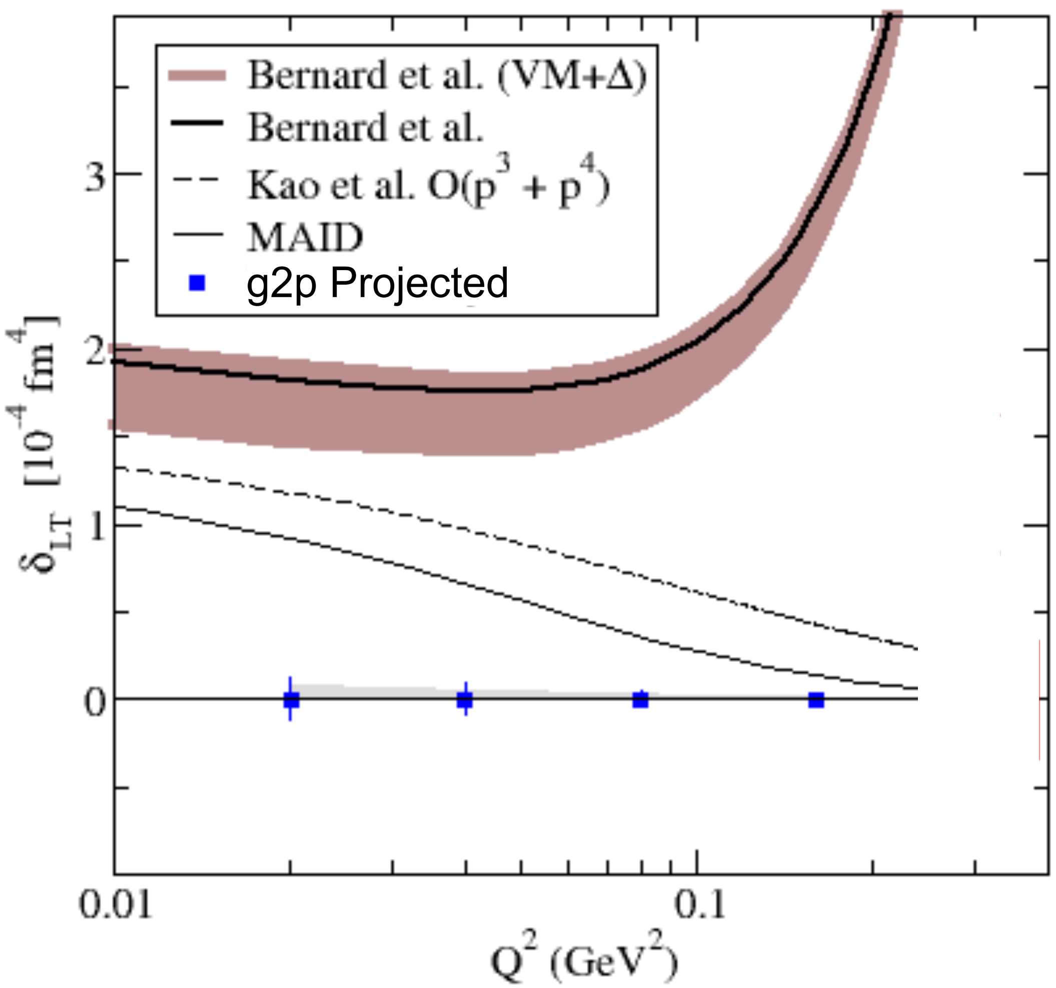
$0.02 < Q^2 < 0.2$ GeV^2



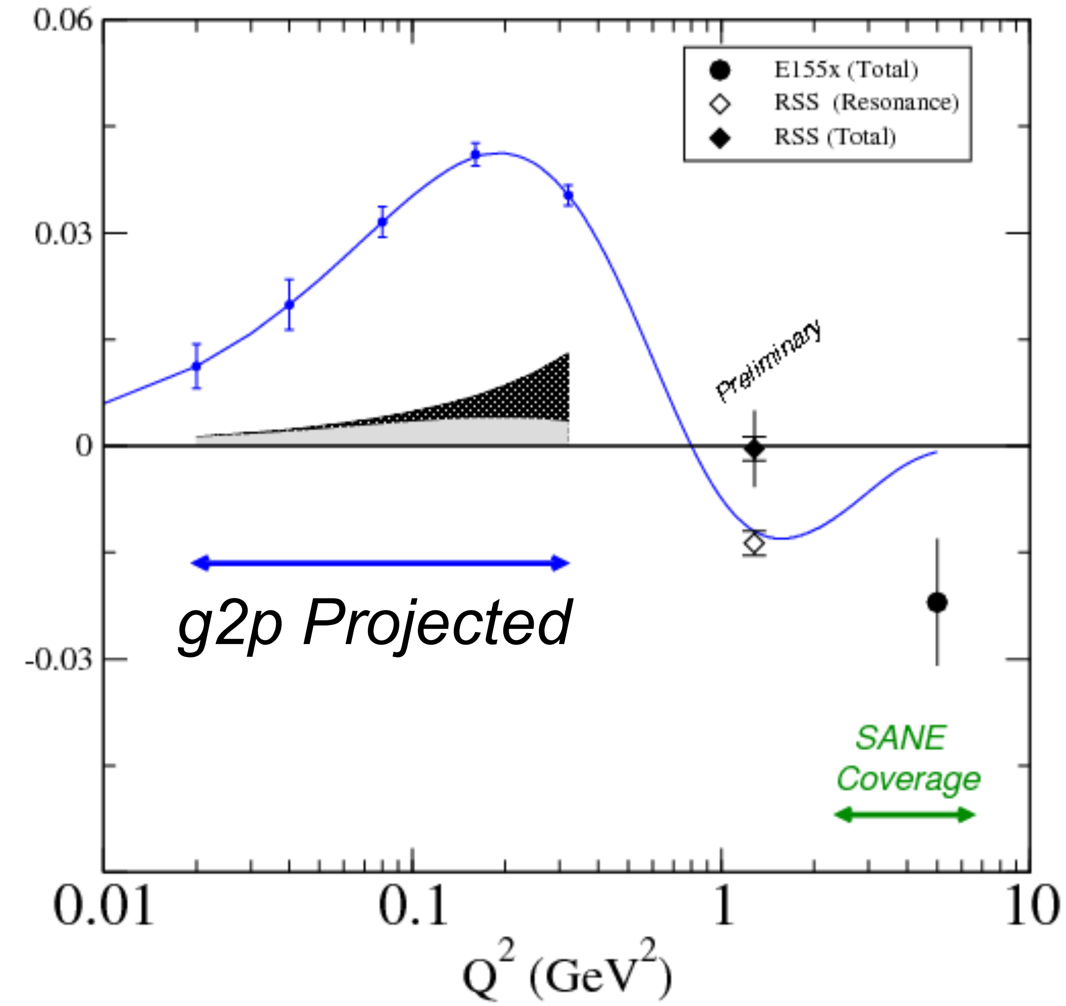
Beam Energy (GeV)	Target Field (T)
2.254	2.5
1.706	2.5
1.158	2.5
2.254	5
3.352	5

Projections

LT Spin Polarizability



BC Sum Integral



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

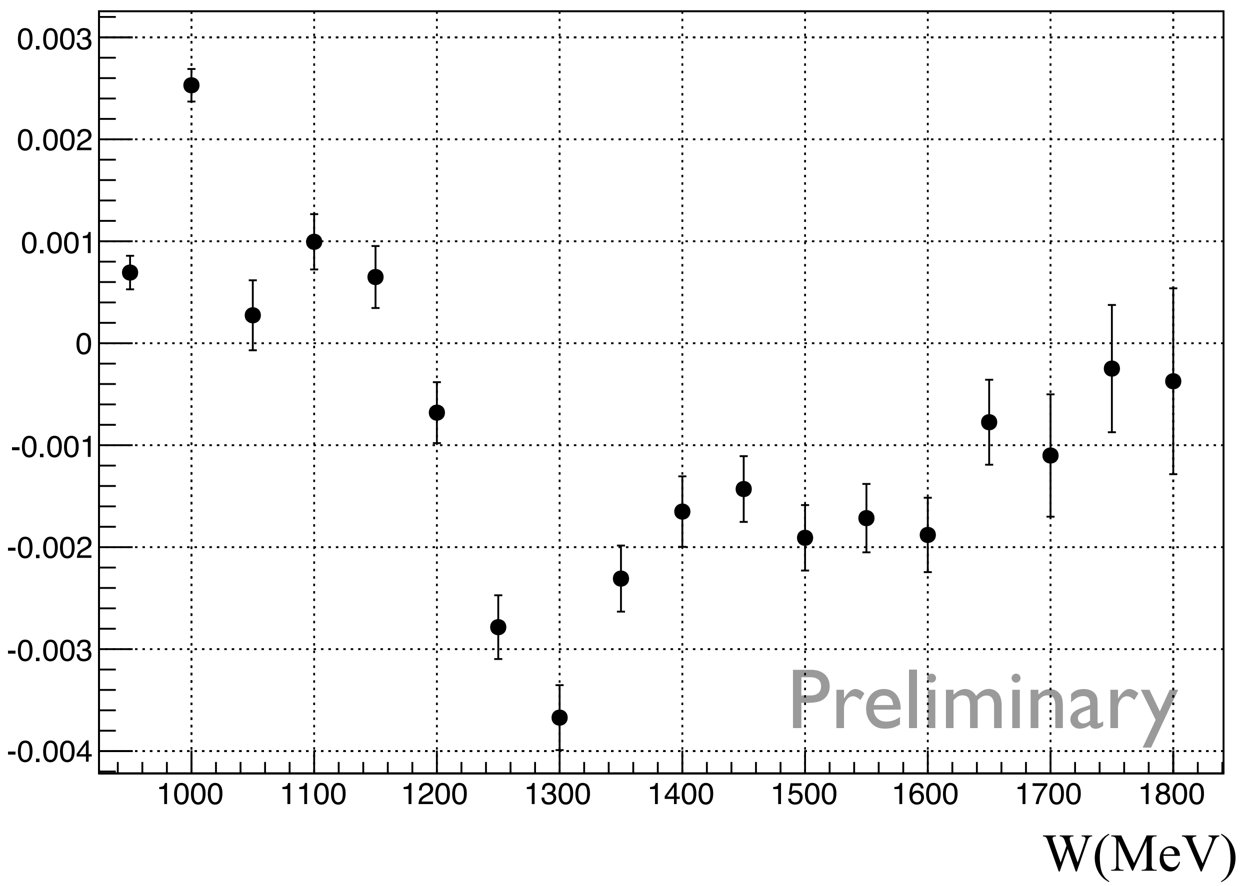
$$\int_0^1 g_2(x,Q^2)\mathrm{d}x = 0$$

Analysis Status

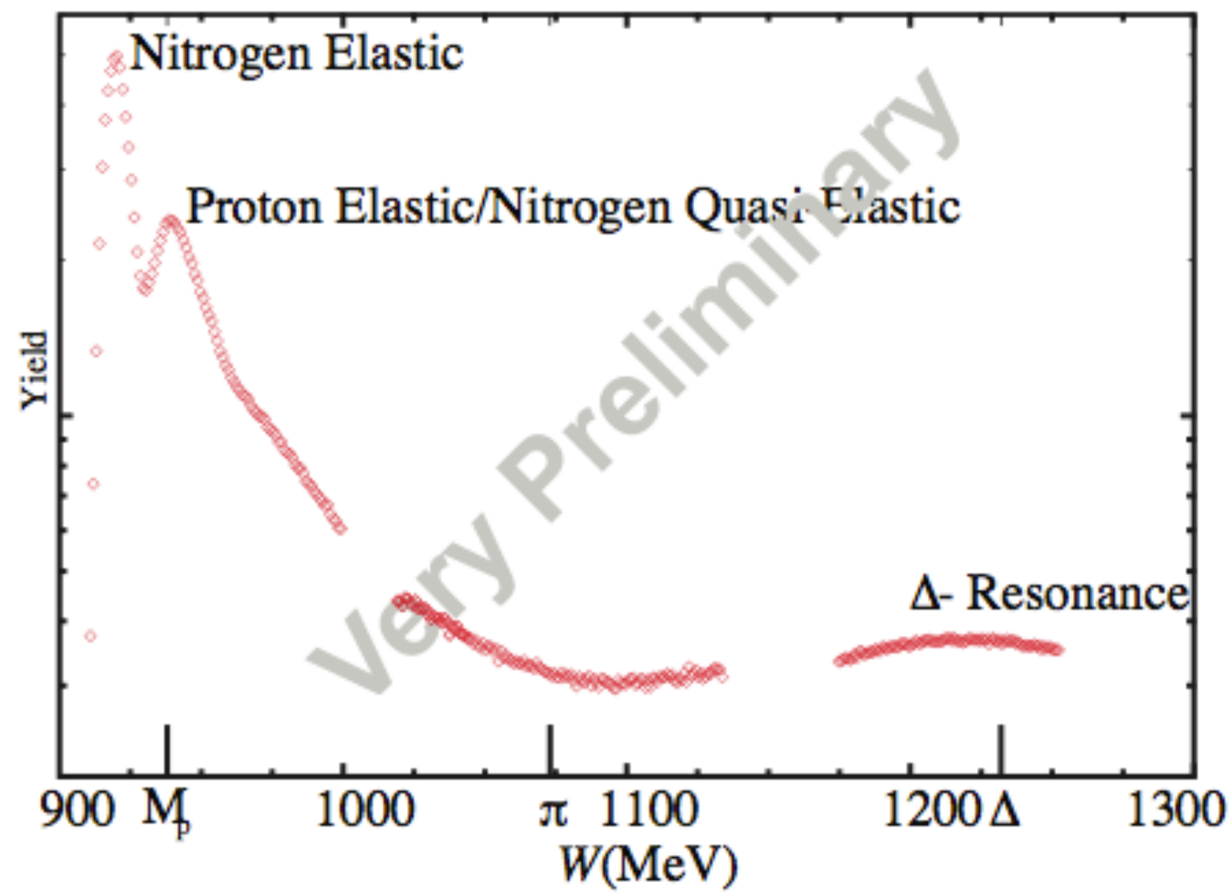
- Completed
  - Run Database
  - HRS Optics
    - Field measurement analysis
    - VDC t_0 calibration
    - Simulation package
    - Optics with target field (LHRS)
  - Detector Calibrations/ Efficiency Studies
    - Gas Cherenkov
    - Lead Glass Calorimeters
    - Scintillator trigger efficiencies
  - Scalers
    - BCM calibration
    - Helicity decoding
    - Dead time calculations
  - Target Polarization Analysis
  - BPM Calibrations
- In Progress
  - Raster Size Calibrations
  - Packing Fraction/Dilution Analysis
  - Elastic Analysis
  - Yields/Radiative Corrections

Preliminary Results

Asymmetry



Yield



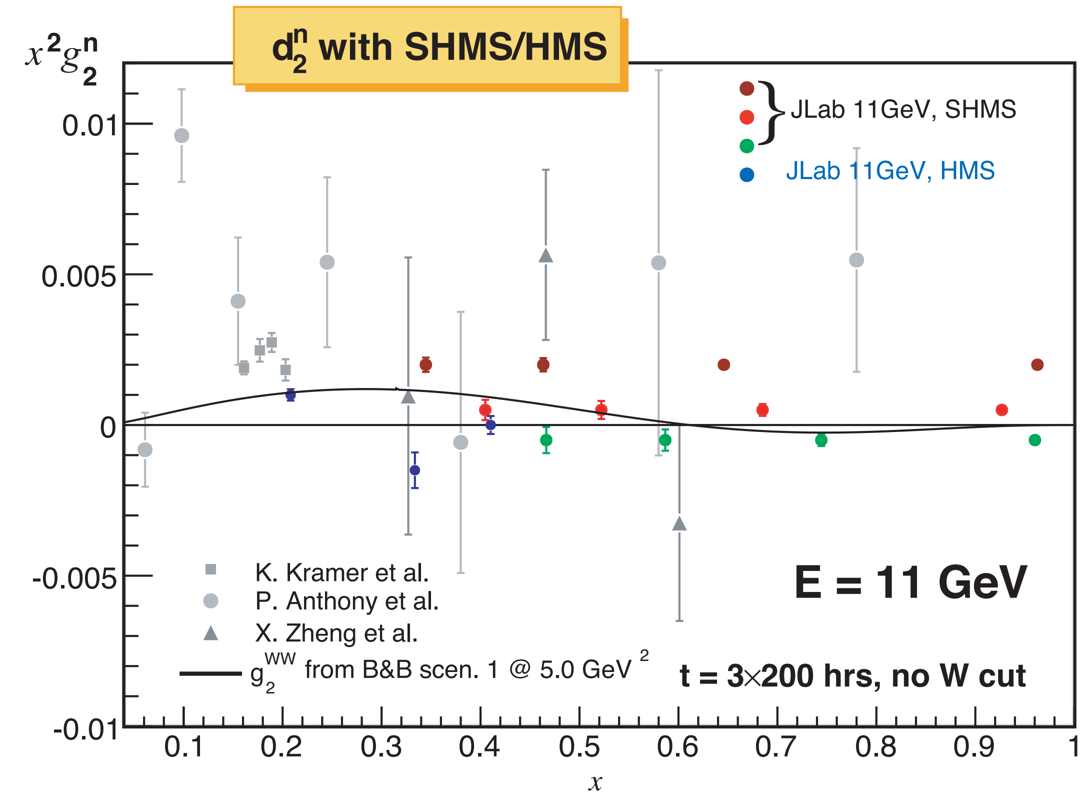
$$\Delta\sigma_{\perp} = \sigma_{\text{total}} \cdot A_{\perp}$$

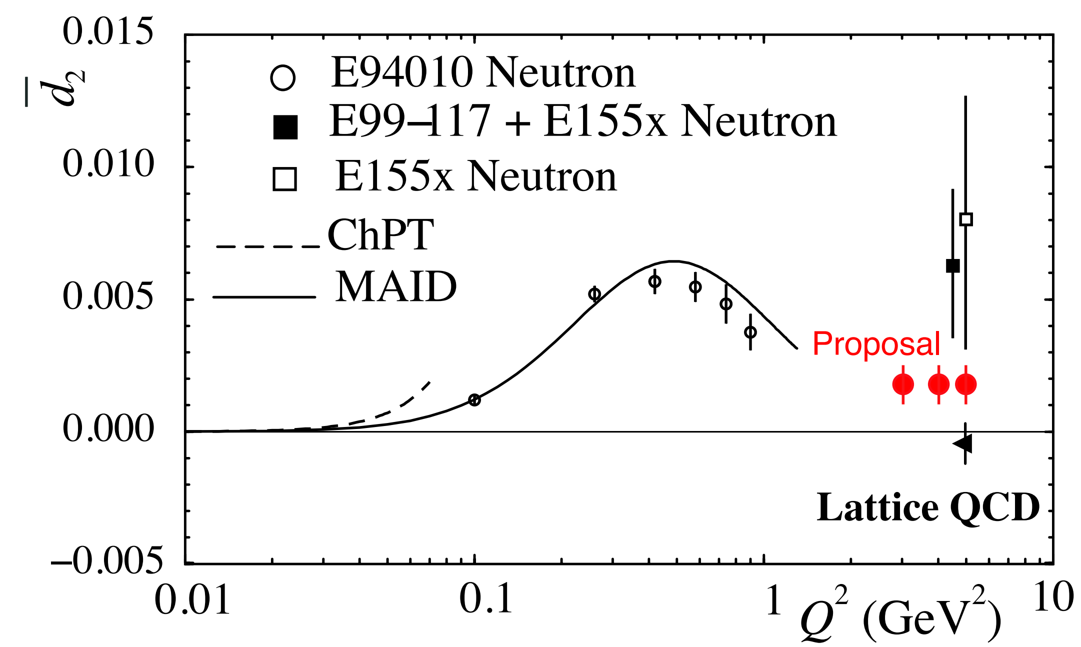
Conclusion of g2p

- g2p experiment will provide first measurement of the proton structure function g_2 in the low Q^2 region (0.02-0.2 GeV^2)
- The result will provide insight on several outstanding physics puzzles:
  - Spin polarizability δ_{LT} discrepancy seen for neutron data
  - BC Sum Rule violation suggested for proton at large Q^2
  - Contribute to the uncertainty of some finite size effects like hydrogen hyperfine splitting and proton charge radius puzzle

Future Experiments

- JLab at 12 GeV
- Hall A
  - E12-06-122: A1n in valence quark region (8.8 and 6.6 GeV)
- Hall B
  - E12-06-109: longitudinal spin structure of the nucleon
- Hall C
  - E12-06-110: A1n in valence quark region (11 GeV)
  - E12-06-121: g2n and d2n at high Q^2

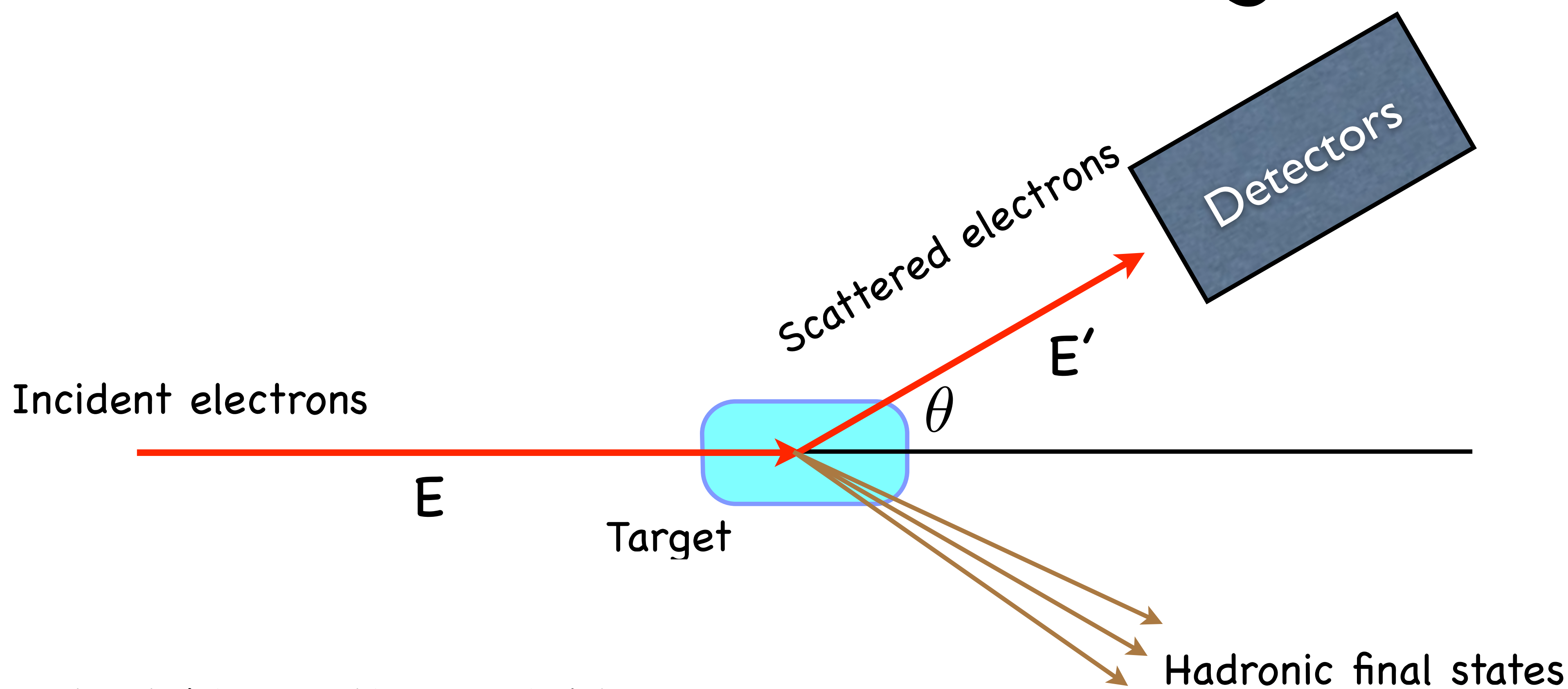




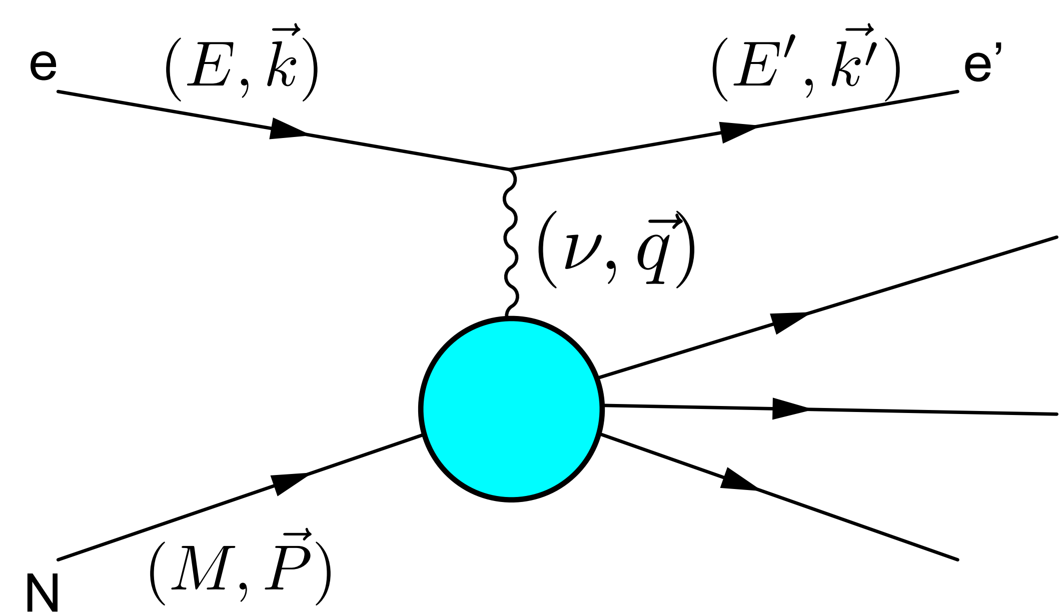
Thanks

Backups

Electron Scattering



- Important kinematics variables:
    - $\nu = E - E'$
    - Q^2 : Momentum transfer squared
    - W : Invariant mass of residual hadronic system
    - $x = \frac{Q^2}{2M\nu}$ Bjorken variable: fraction momentum of struck quark



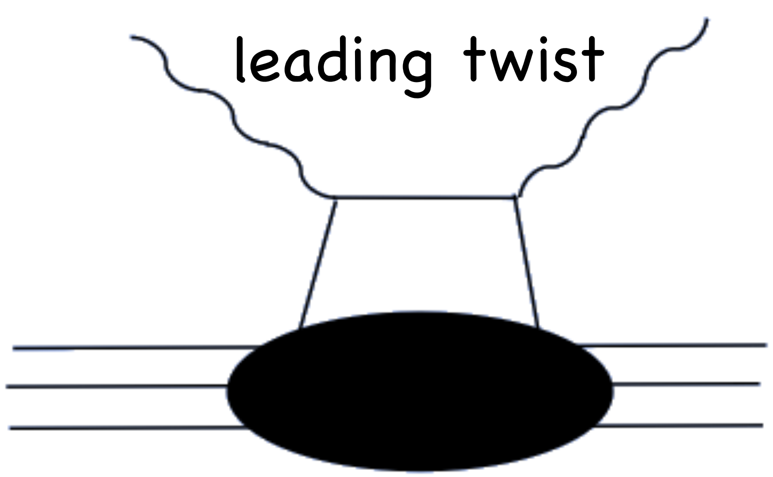
Structure Function

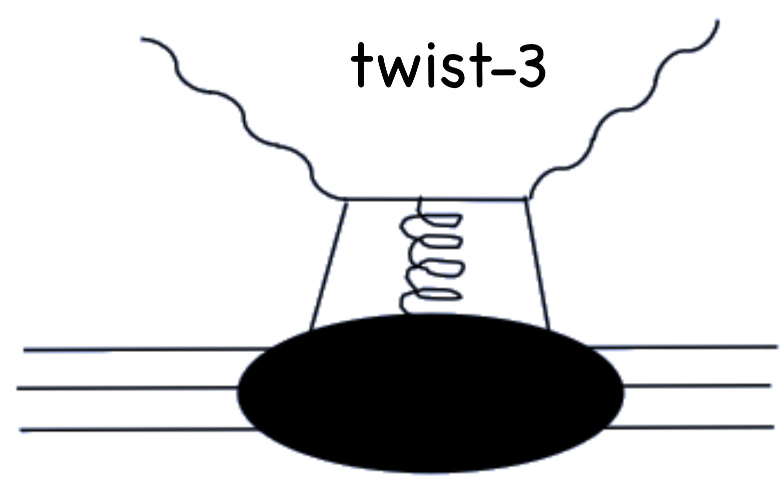
- "twist" in Operator Production Expantion

$$
\begin{aligned}
T_{\mu\nu}(P,q) &= i\int d^4z \exp(iq\cdot z)\,\langle N(P)|\mathcal{T}\left(j_\mu(z)j_\nu(0)\right)|N(P)\rangle \\
&= \sum_{n=\text{even}} \langle N(P)|O_n^{\mu_1\cdots\mu_n}|N(P)\rangle \frac{2^n}{(Q^2)^n}\Bigg(P_{\mu\nu}^{(L)}C_n^{(L)}(Q^2)q_{\mu_1}\ldots q_{\mu_n} \\
&\quad + \left[-q^2 g_{\mu\mu_1}g_{\mu_2\nu} + [g_{\mu\mu_1}q_{\mu_2}q_\nu + g_{\mu_2\nu}q_\mu q_{\mu_1}] - g_{\mu\nu}q_{\mu_1}q_{\mu_2}\right] \\
&\quad \times C_n^{(2)}(Q^2)q_{\mu_3}\ldots q_{\mu_n}\Bigg),
\end{aligned}
\tag{5.125}
$$

Structure of Nucleon, eq 5.125

- quark-quark and quark-gluon correlation





Proton Polarizability

- Proton electric and magnetic polarizabilities: response to low-frequency, long-wavelength electromagnetic fields

- From the dispersion relation of the real Compton scattering (RCS) amplitude, one could derive electric and magnetic polarizability and forward spin polarizability

$$\alpha + \beta = \frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_T}{\nu'^2} \mathrm{d}\nu'$$

electric and magnetic polarizability

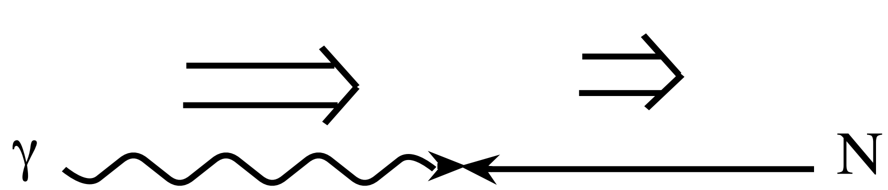
$$\gamma_0 = -\frac{1}{4\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_{TT}}{\nu'^3} \mathrm{d}\nu'$$

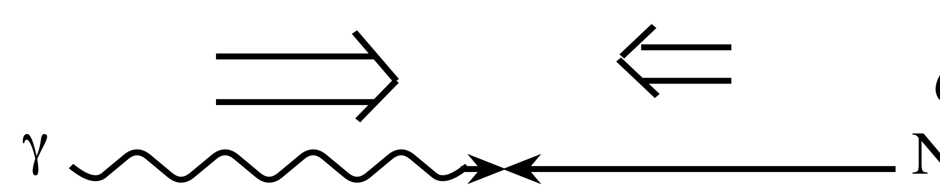
forward spin polarizability

$$\sigma_T = \frac{1}{2}(\sigma_{1/2} + \sigma_{3/2})$$

$$\sigma_{TT} = \frac{1}{2}(\sigma_{1/2} - \sigma_{3/2})$$

$\sigma_{1/2}$





$\sigma_{3/2}$

Generalized Longitudinal-Transverse Polarizability

- Start from forward spin-flip doubly-virtual Compton scattering (VVCS) amplitude g_{TT} and g_{LT}

$$\mathrm{Re}[g_{TT}^{\text{non-pole}}(\nu, Q^2)] = \frac{\nu}{2\pi^2}\mathcal{P}\int_{\nu_\pi}^{\infty}\frac{\mathrm{d}\nu' K}{\nu'^2 - \nu^2}\sigma_{TT}(\nu', Q^2)$$

$$\mathrm{Re}[g_{LT}^{\text{non-pole}}(\nu, Q^2)] = \frac{1}{2\pi^2}\mathcal{P}\int_{\nu_\pi}^{\infty}\frac{\mathrm{d}\nu' \nu' K}{\nu'^2 - \nu^2}\sigma_{LT}(\nu', Q^2)$$

- g_{TT} and g_{LT} can be expanded in power series of ν

O(ν³) term of g_{TT} leads to the generalized forward spin polarizability γ_0

$$\gamma_0(Q^2) = \frac{1}{2\pi^2}\int_{\nu_\pi}^{\infty}\frac{K(\nu, Q^2)}{\nu}\frac{\sigma_{TT}(\nu, Q^2)}{\nu^3}\mathrm{d}\nu = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1 - \frac{4M^2}{Q^2}x^2 g_2]\mathrm{d}x$$

O(ν²) term of g_{LT} leads to the generalized longitudinal-transverse polarizability δ_{LT}

$$\delta_{LT}(Q^2) = \frac{1}{2\pi^2}\int_{\nu_\pi}^{\infty}\frac{K(\nu, Q^2)}{\nu}\frac{\sigma_{LT}(\nu, Q^2)}{Q\nu^2}\mathrm{d}\nu = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1 + g_2]\mathrm{d}x$$

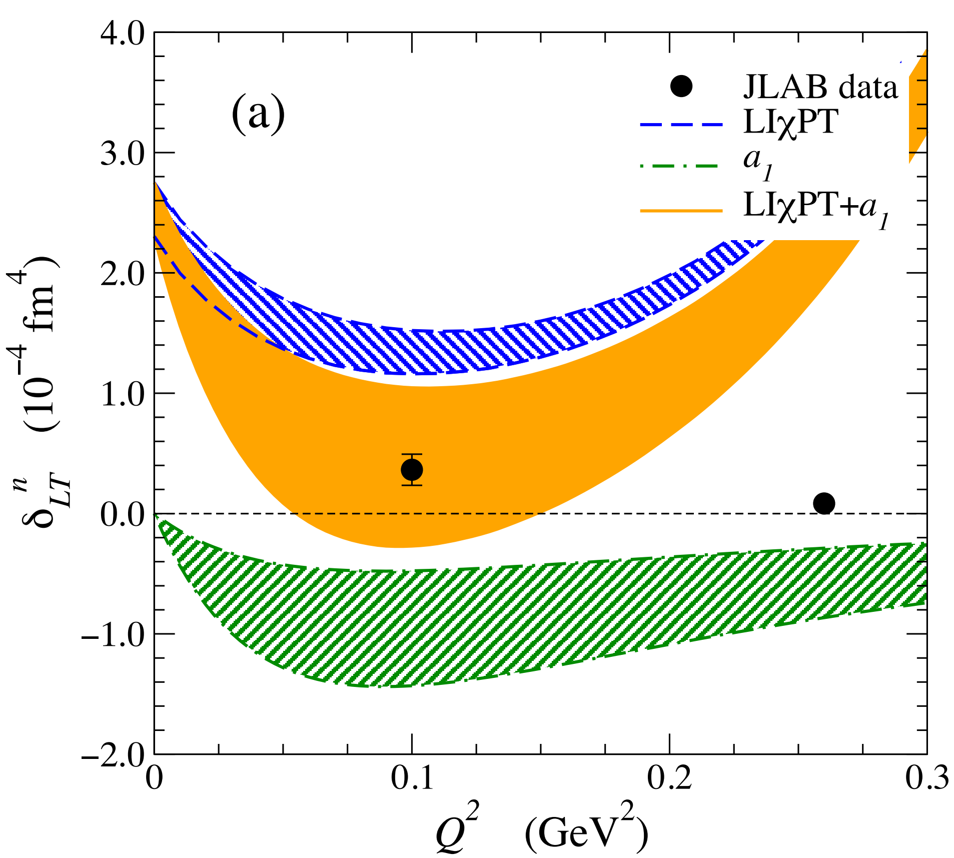
δ_{LT} puzzle

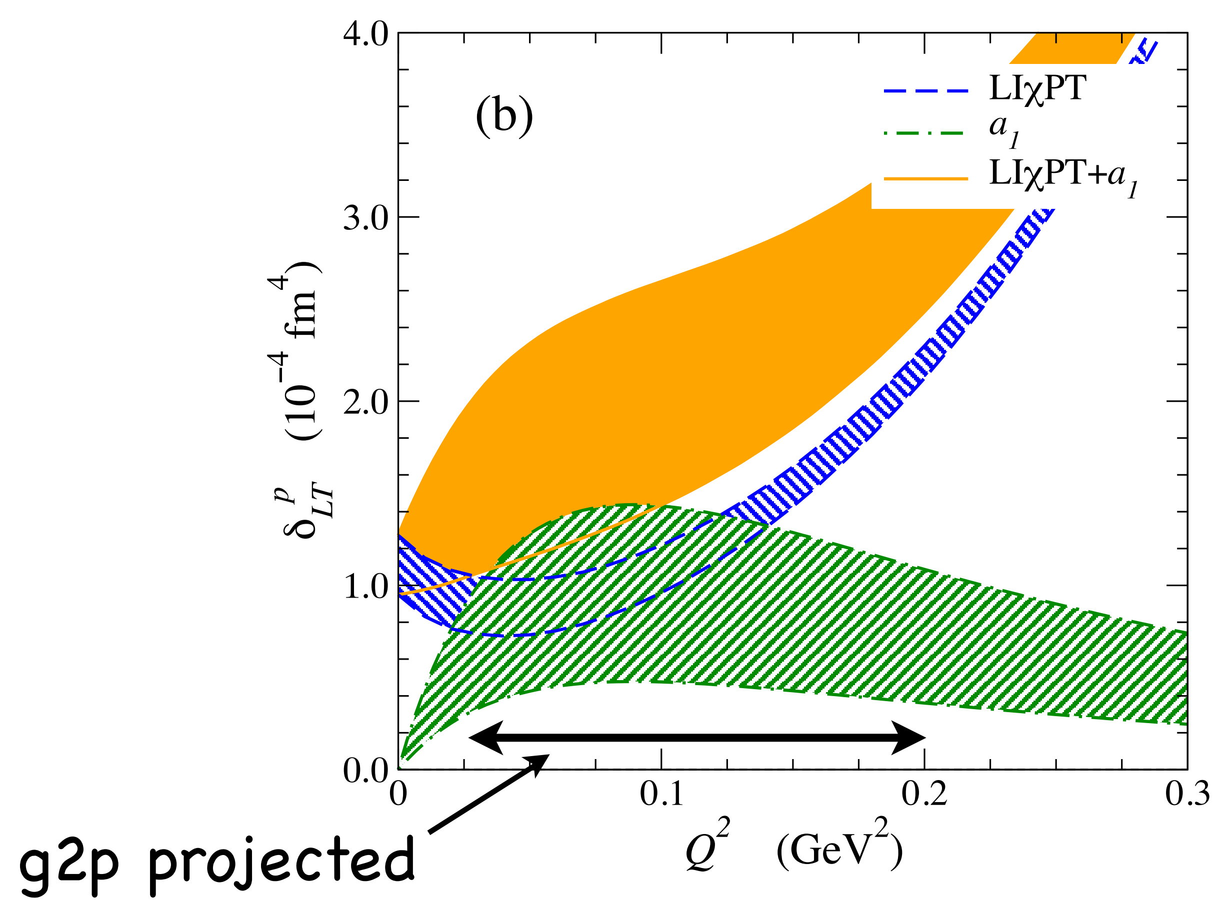
- At low Q^2, the generalized polarizabilities have been evaluated with NLO χPT calculations:
  - Relativistic Baryon χPT (V. Bernard, T. Hemmert and Ulf-G. Meissner, Phys. Rev. D, 67(2003)076008)
  - Heavy Baryon χPT (C.W. Kao, T. Spitzenberg and M. Vanderhaeghen, Phys. Rev. D, 67(2003)016001)
- One issue in the calculation is how to properly include the nucleon resonance contributions, especially the Δ resonance
  - γ_0 is sensitive to resonances
  - δ_{LT} is insensitive to the Δ resonance
- δ_{LT} should be more suitable than γ_0 to serve as a testing ground for the chiral dynamics of QCD

δ_{LT} puzzle

Kochelev's new calculation result:

- Include the axial-anomaly $a_1(1260)$ meson contribution
- Improves agreement with neutron



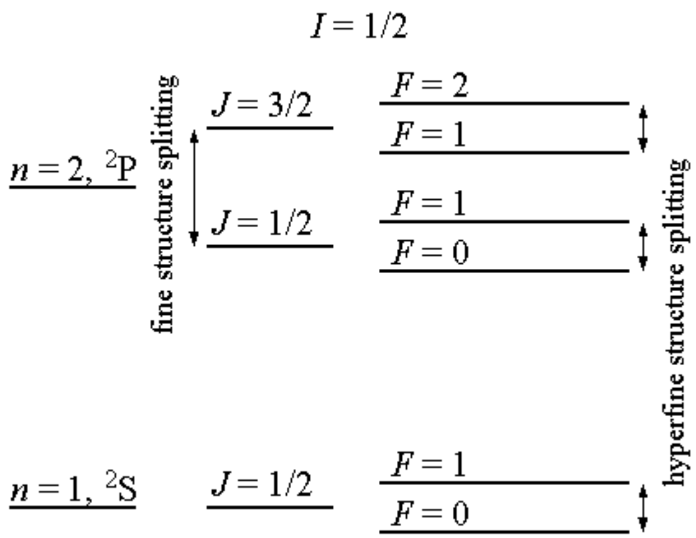


Still need Proton δ_{LT} Data

Kochelev & Oh. arXiv:1103.4892

Hydrogen Hyperfine Structure

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



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

- Δ_S is the proton structure correction and has the largest uncertainty

$$\Delta_S = \Delta_Z + \Delta_{\mathrm{pol}}$$

- Δ_Z can be determined from elastic scattering, which is $-41.0 \pm 0.5 \times 10^{-6}$
- Δ_{pol} involves contributions of the inelastic part (excited state), and can be extracted to 2 terms corresponding to 2 different spin-dependent structure function of proton

Hydrogen Hyperfine Structure

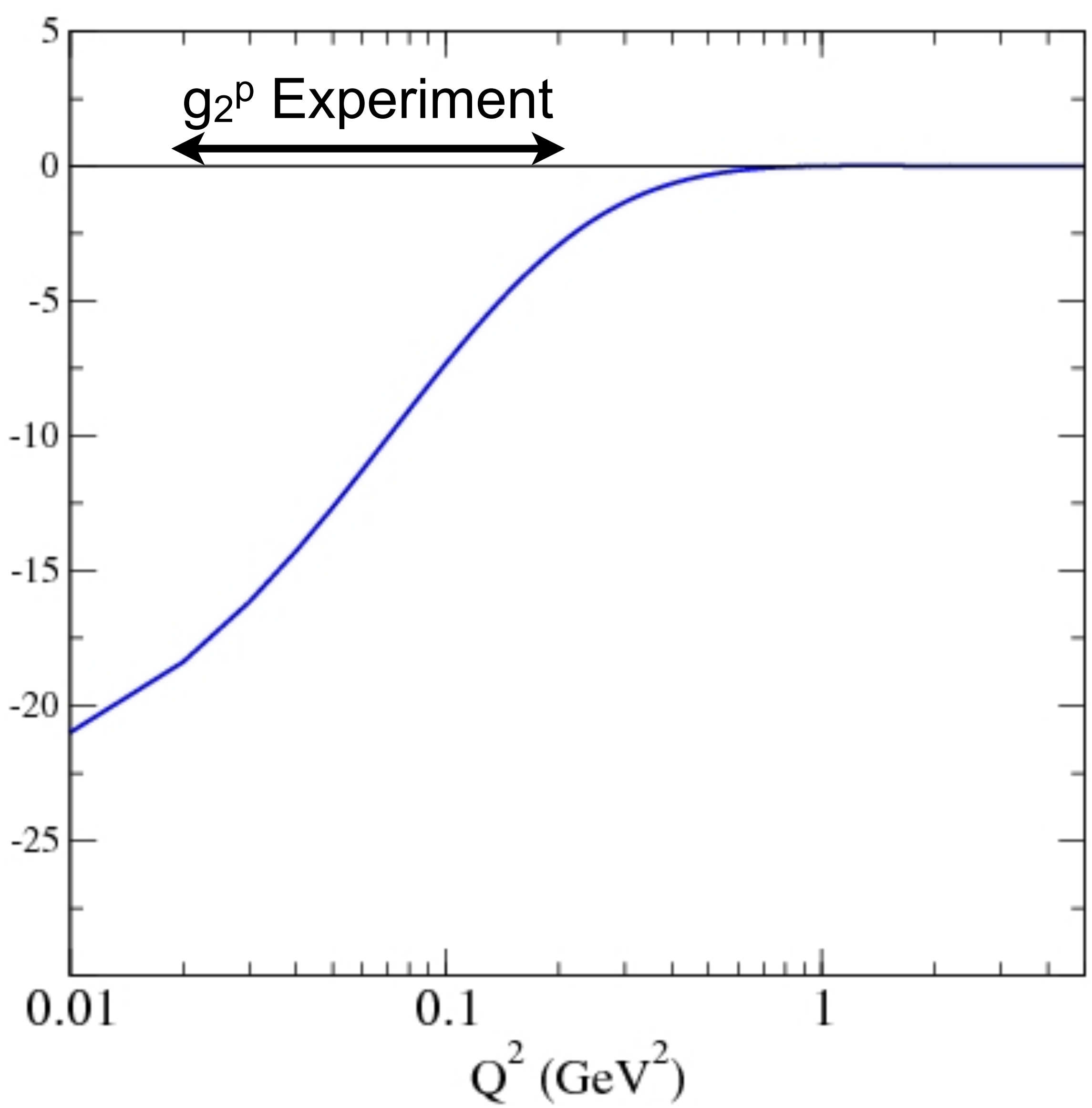
$$\Delta_{\text{pol}} = \frac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$$

$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{\mathrm{d}Q^2}{Q^4} B_2(Q^2)$$

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

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

Integrand of Δ_2

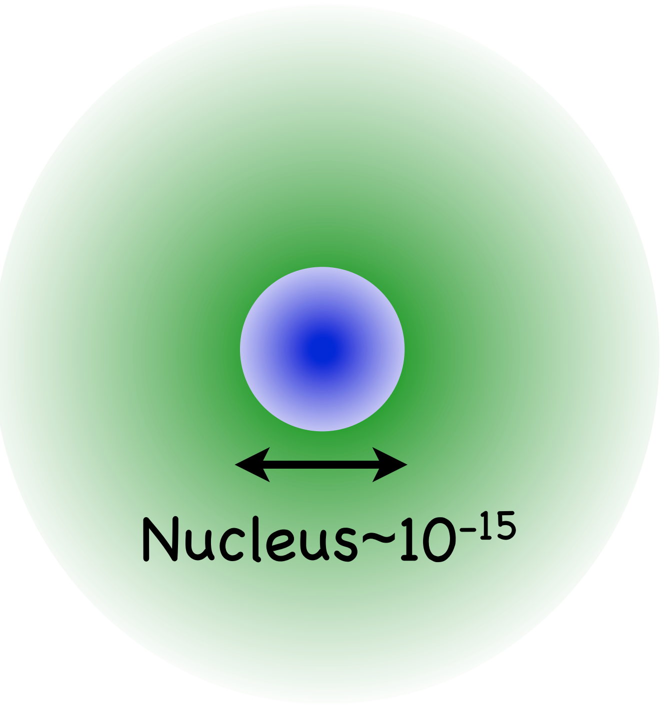


- B_2 is dominated by low Q2 part
- g_2^p is unknown in this region, so there may be huge error when calculating Δ_2
- This experiment will provide a constraint

Nazaryan, Carlson, Griffieon, PRL, 96(2006)163001

Proton Size Radius

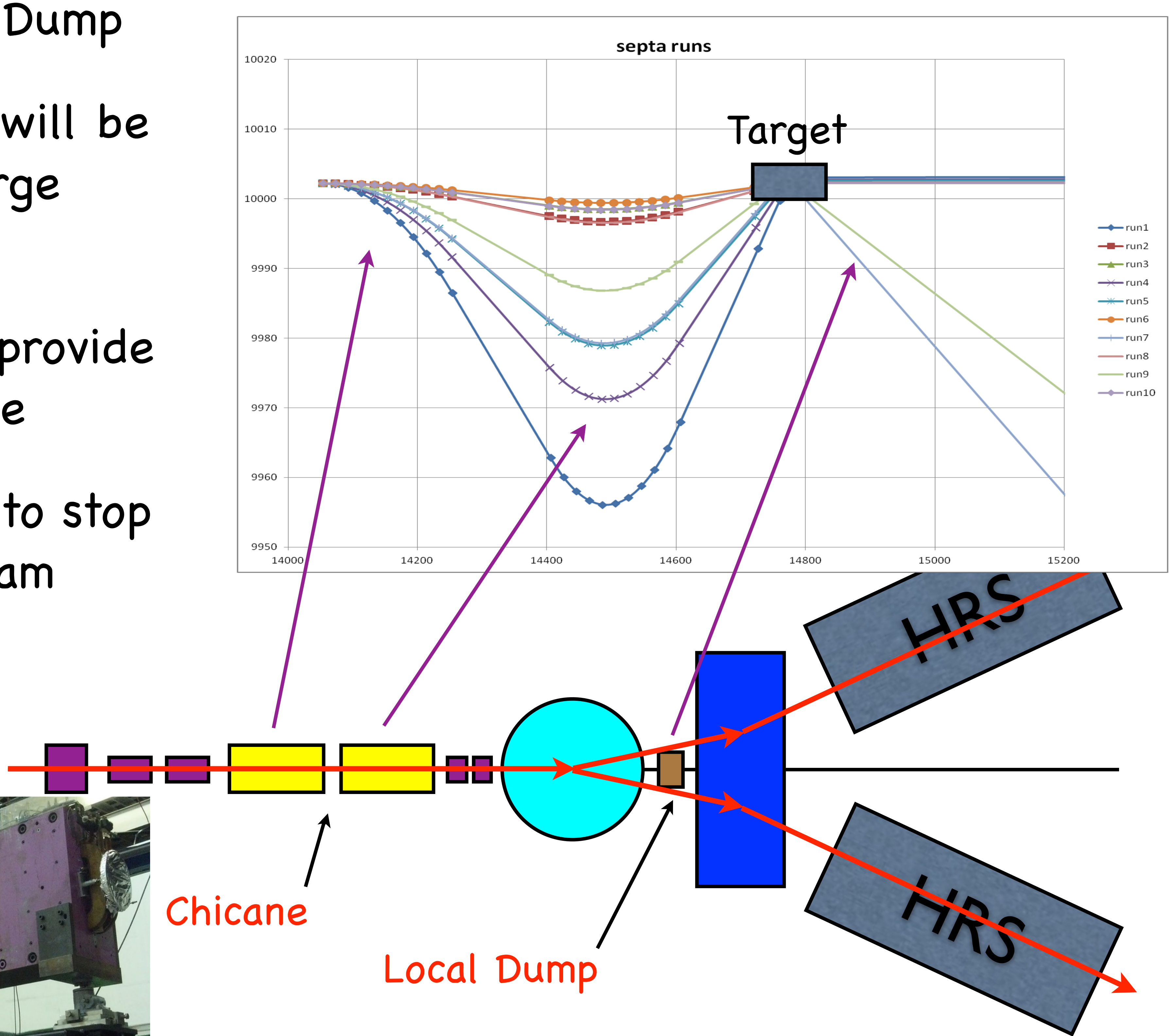
- The finite size of the nucleus plays a small but significant role in atomic energy levels
- Simplest: proton
- 2 ways to measure:
  - energy splitting of the $2S_{1/2}$-$2P_{1/2}$ level (Lamb shift)
  - scattering experiment
- The result do not match when using muonic hydrogen
  - $\langle R_p \rangle$ = 0.84184±0.00067fm by Lamb shift in muonic hydrogen
  - $\langle R_p \rangle$ = 0.87680±0.0069fm CODATA world average

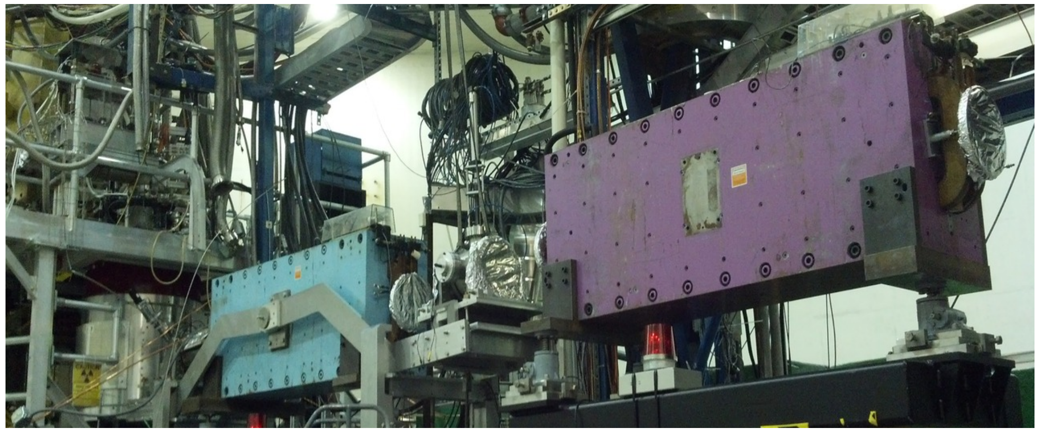


R. Pohl et al, Nature, 466(2010)213

Experiment Setup

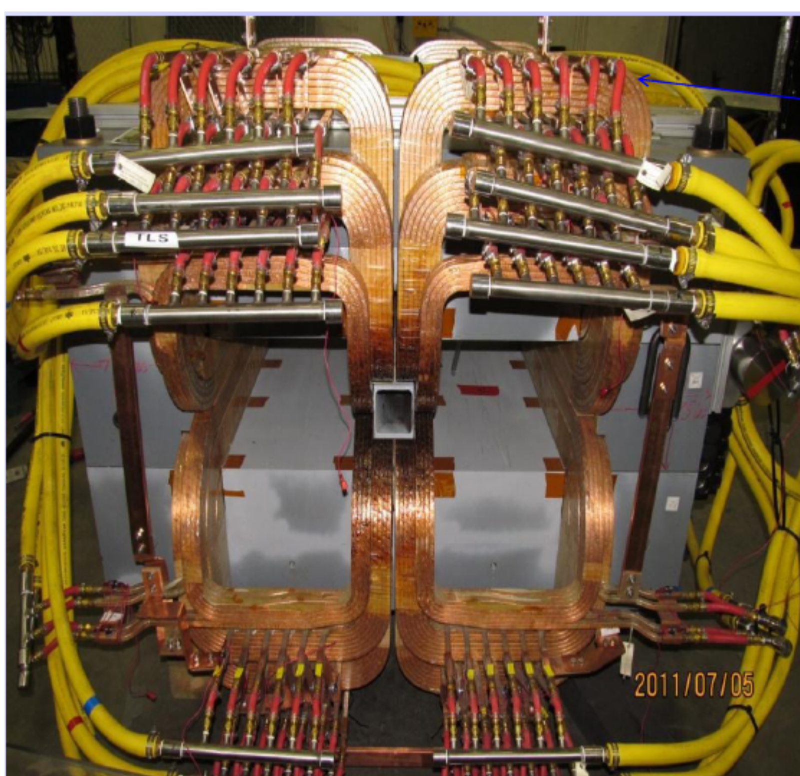
- Chicane and Local Dump
  - Outgoing beam will be tilted by the large target field
  - Use Chicane to provide an incident angle
  - Use local dump to stop non-straight beam

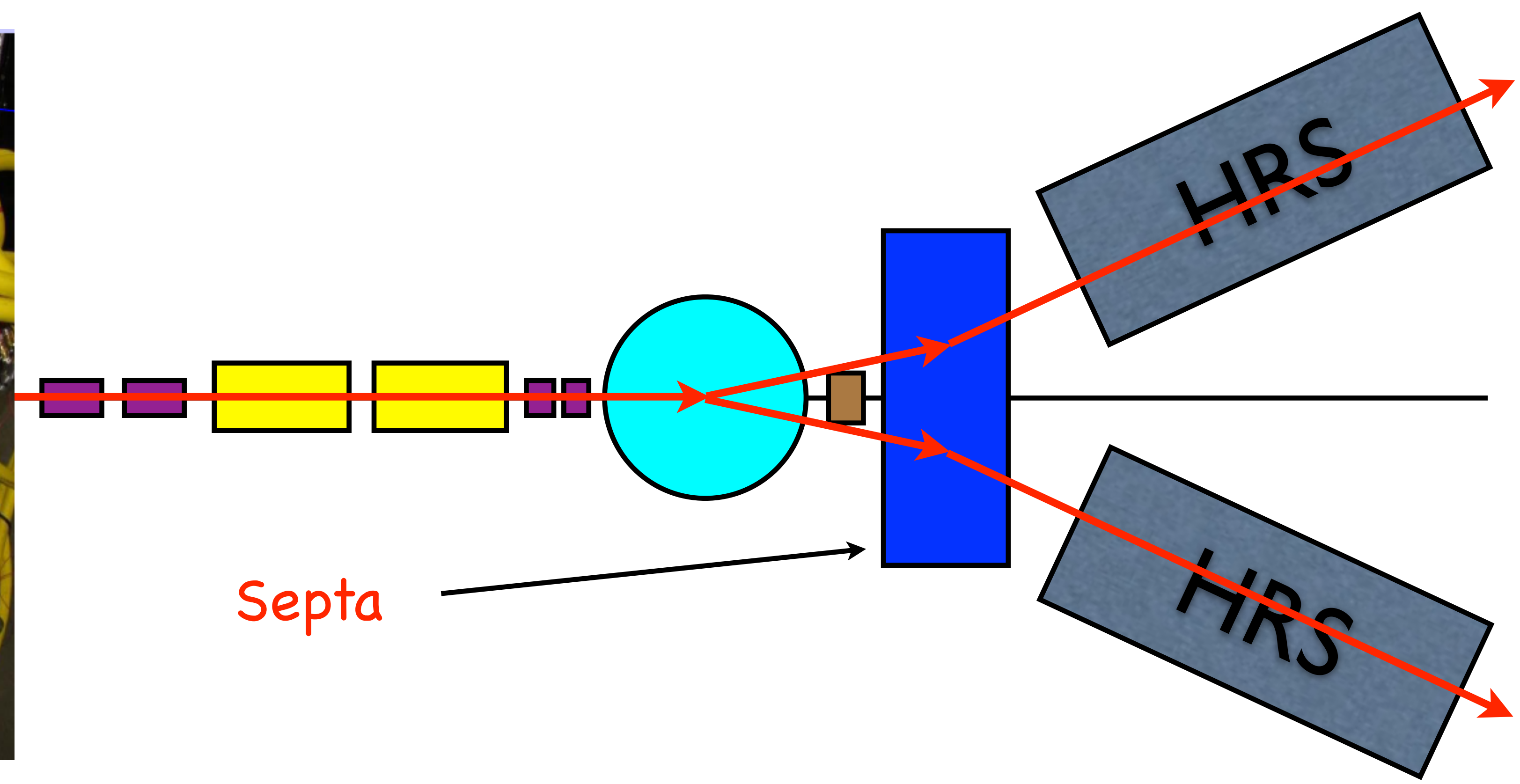




Experiment Setup

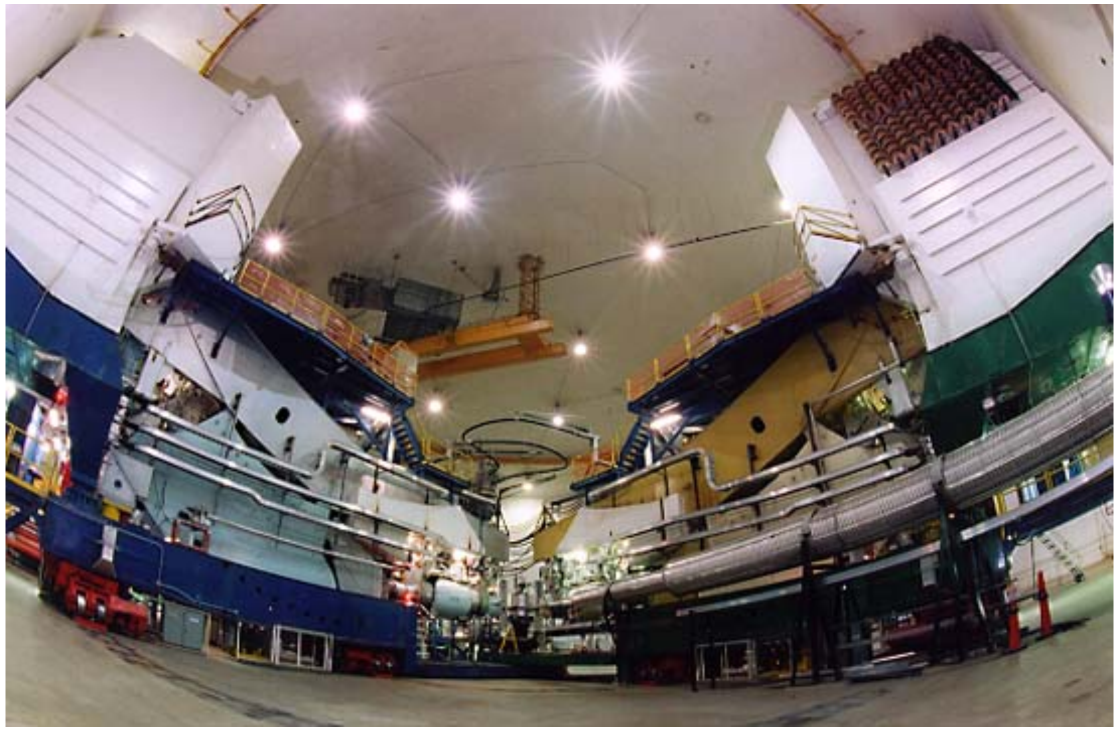
- Septa magnets
  - Detector package has a minimum angle limit at 12.5°
  - Use septa magnets to bend 5.6° scattered electrons to 12.5° to allow access to the lowest possible Q^2

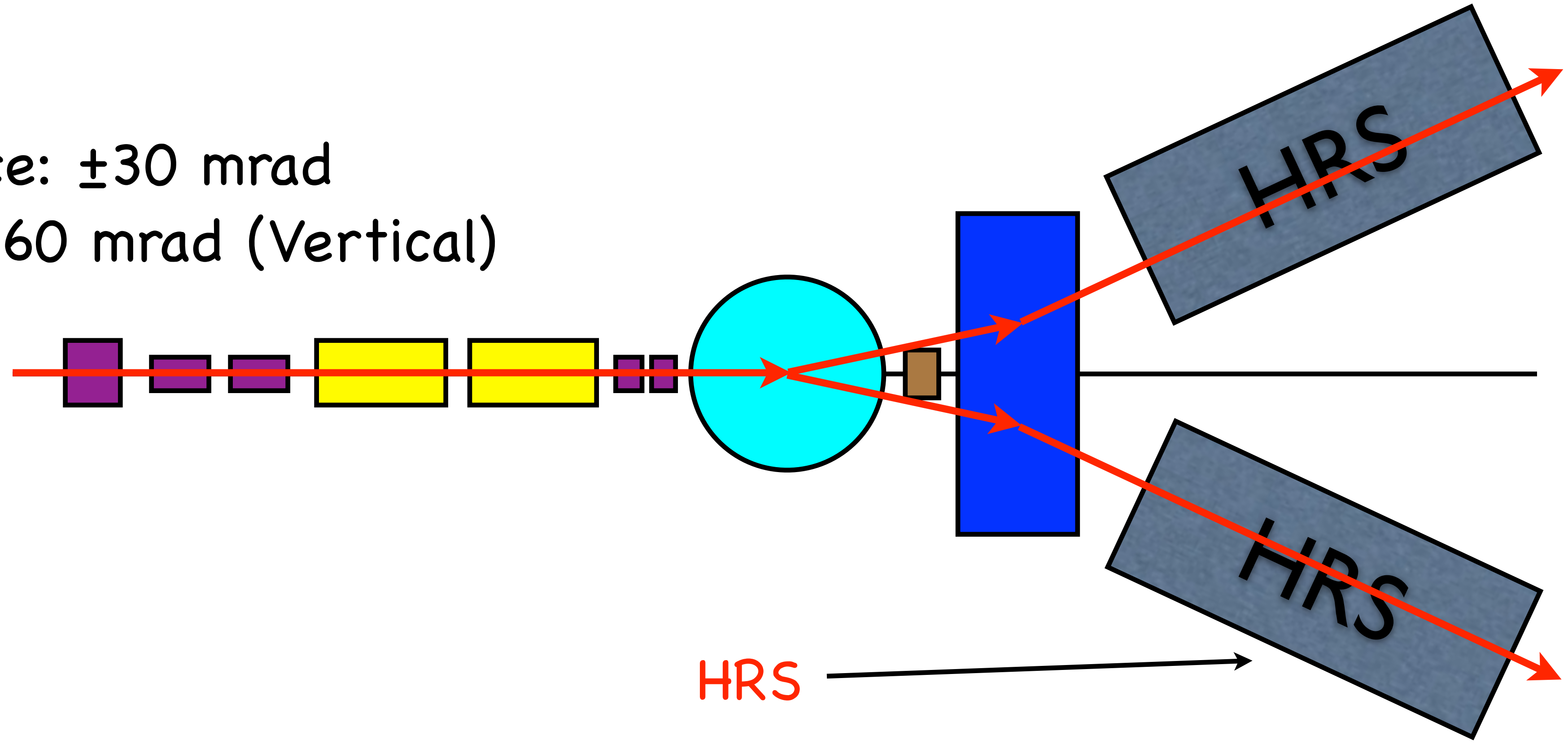




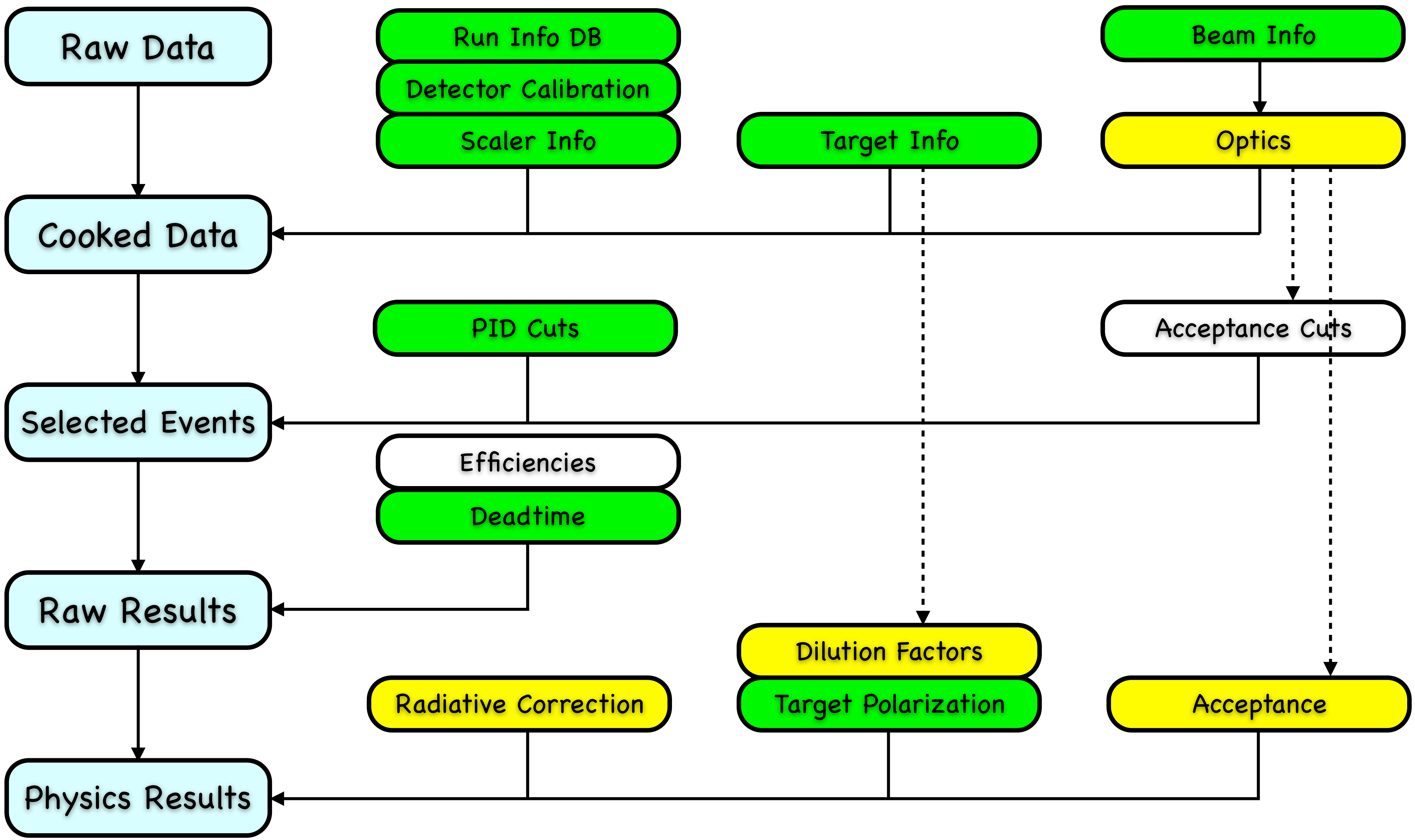
Experiment Setup

- Hall A High Resolution Spectrometer
  - High momentum resolution: 10^{-4} level over a range of 0.8-4.0 GeV/c
  - High momentum acceptance: $|\delta p/p| < 4.5\%$
  - Wide range of angular settings: 12.5°~150° for left arm, 12.5°~130° for right arm
  - Angular acceptance: ±30 mrad (Horizontal) and ±60 mrad (Vertical)





Analysis Status

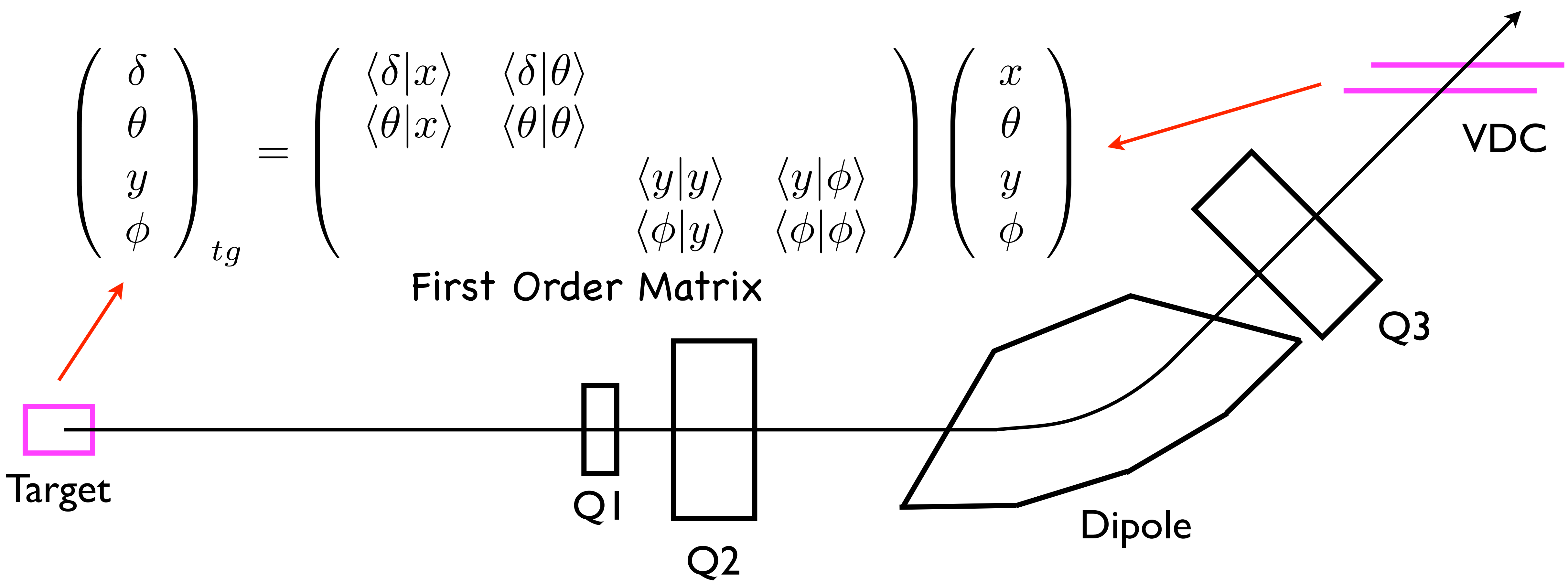


HRS Optics: Overview

- HRS has a series of magnets
  - 3 quadrupoles to focus and 1 dipole to disperse on momentums
- Optics study will provide a matrix to transform VDC readouts to kinematics variables which represents the effects of these magnets

$$\begin{pmatrix} \delta \\ \theta \\ y \\ \phi \end{pmatrix}_{tg} = \begin{pmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & & \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & & \\ & & \langle y|y\rangle & \langle y|\phi\rangle \\ & & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{pmatrix} \begin{pmatrix} x \\ \theta \\ y \\ \phi \end{pmatrix}$$

First Order Matrix

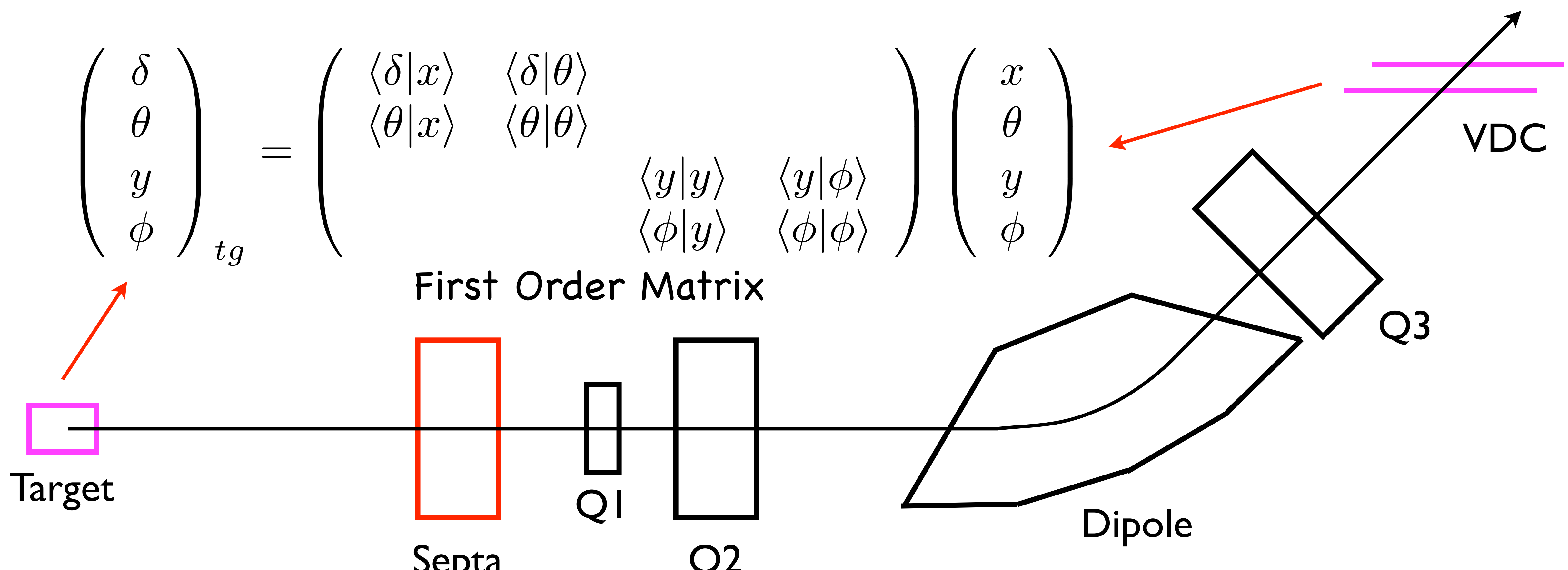


Optics for g2p

- Septa magnet
- Target magnetic field
- Optics matrix will cover septa magnet
- Target magnetic field will break the focusing nature of the spectrometer so more difficult

$$\begin{pmatrix} \delta \\ \theta \\ y \\ \phi \end{pmatrix}_{tg} = \begin{pmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & & \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & & \\ & & \langle y|y\rangle & \langle y|\phi\rangle \\ & & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{pmatrix} \begin{pmatrix} x \\ \theta \\ y \\ \phi \end{pmatrix}$$

First Order Matrix



Optics Goal

- The g2p experiment will measure the proton structure function g_2 in the low Q^2 region (0.02-0.2 GeV^2) for the first time
- Goal: 5% systematic uncertainty when measuring cross section
- Optics Goal:
    - <1.0% systematic uncertainty of scattering angle, which will contribute <4.0% to the uncertainty of cross section

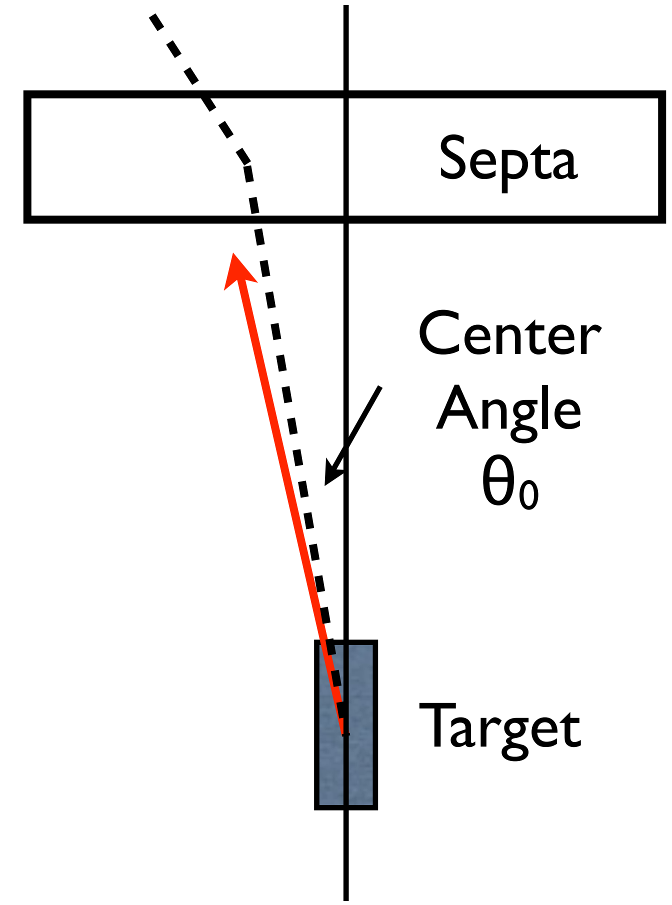
$$\sigma \sim 1/\sin^4(\theta/2)$$

    - Momentum uncertainty is not as sensitive, but it is not hard to reach 10^{-4} level

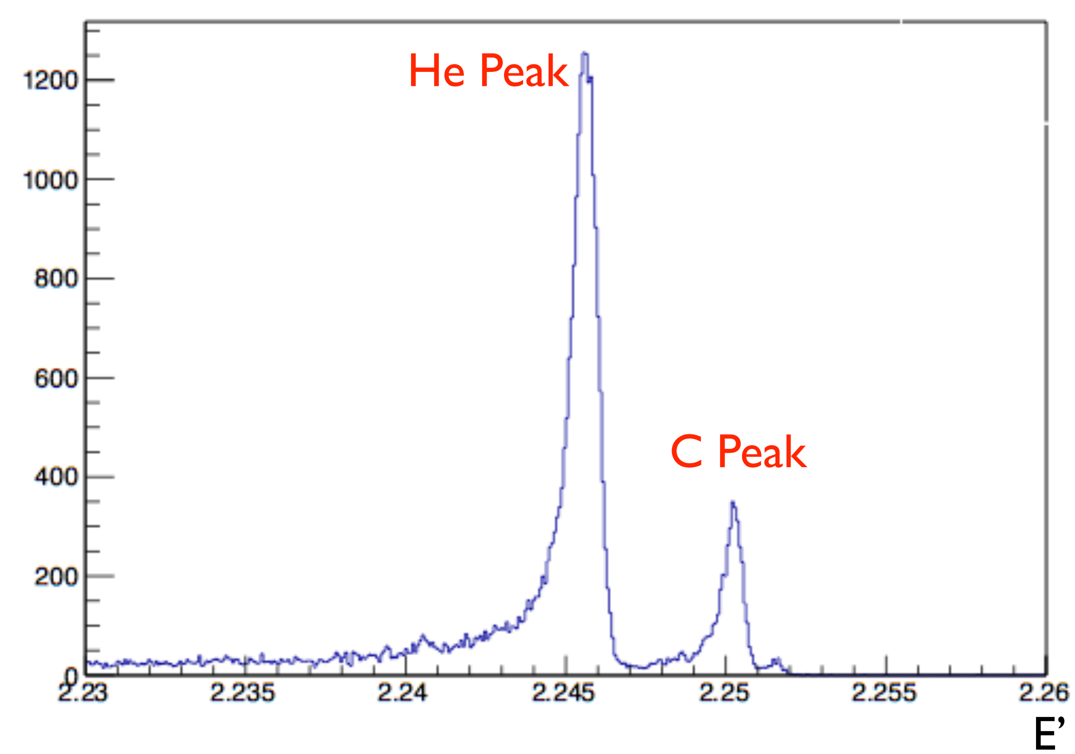
Angle Calibration

- Determine the center scattering angle
  - Survey: ~1mrad
  - Idea: Use elastic scattering on different target materials

$$\Delta E' = \frac{E}{1+\frac{E}{M_1}(1-\cos\theta)} - \frac{E}{1+\frac{E}{M_2}(1-\cos\theta)}$$

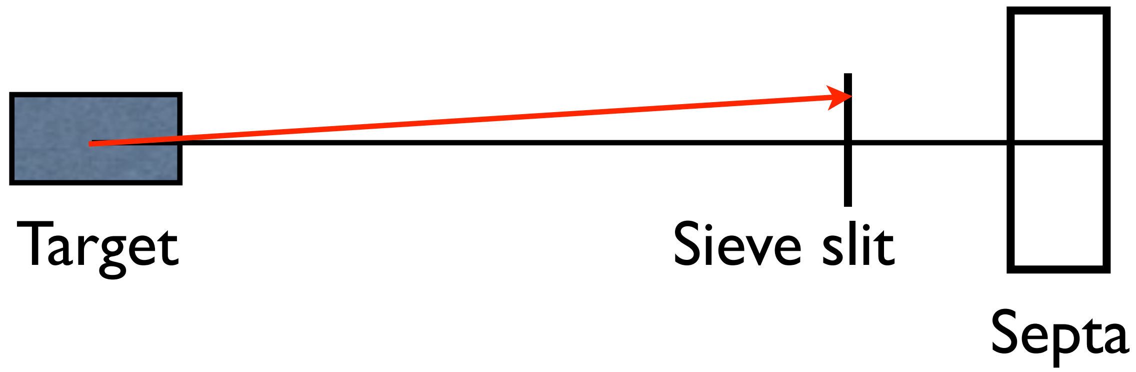


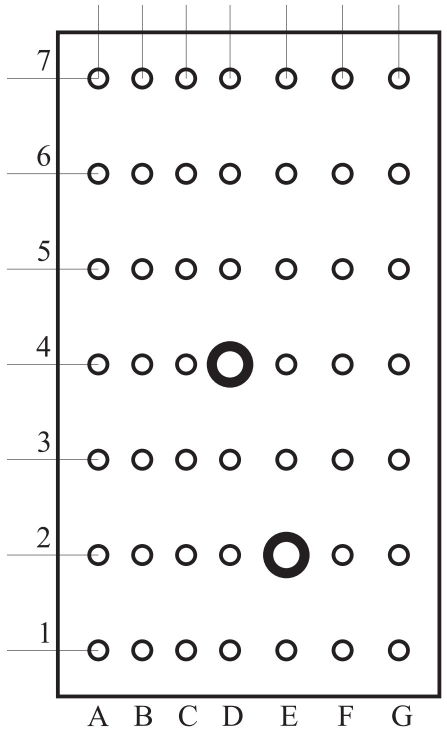
  - Data taking: Carbon foil in LHe, or CH_2 foil
  - Two elastic peak took at the same time
  - The accuracy to determine this difference is <50KeV -> <0.5mrad



Matrix Calibration

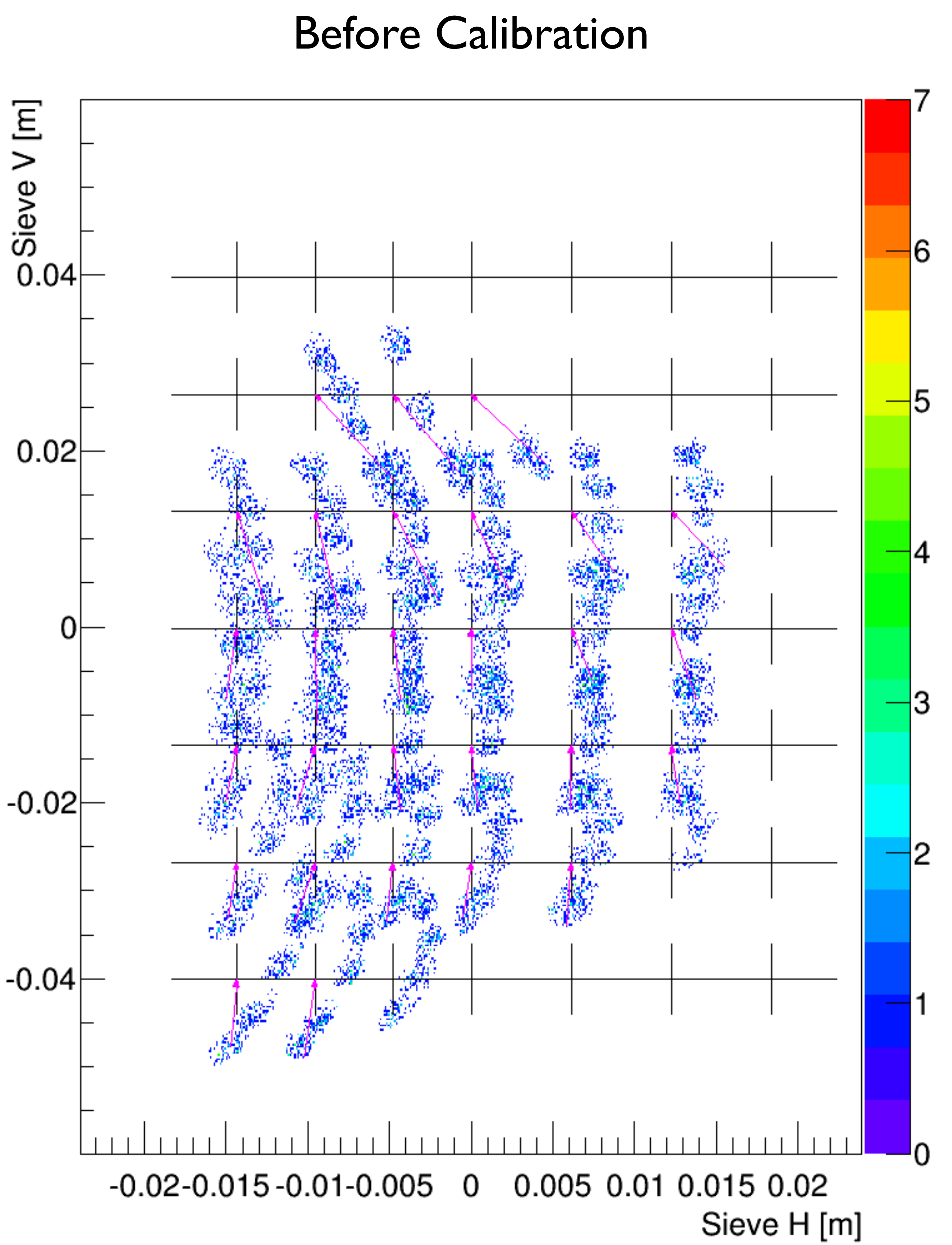
- Calibrate the angle and momentum matrix elements:
  - Use carbon foil target and point beam
  - Use sieve slit to get the real scattering angle from geometry
  - Angle: Fit with data which we already know the real scattering angle
  - Momentum: Use the real scattering angle to calculate elastic scattering momentum of carbon target

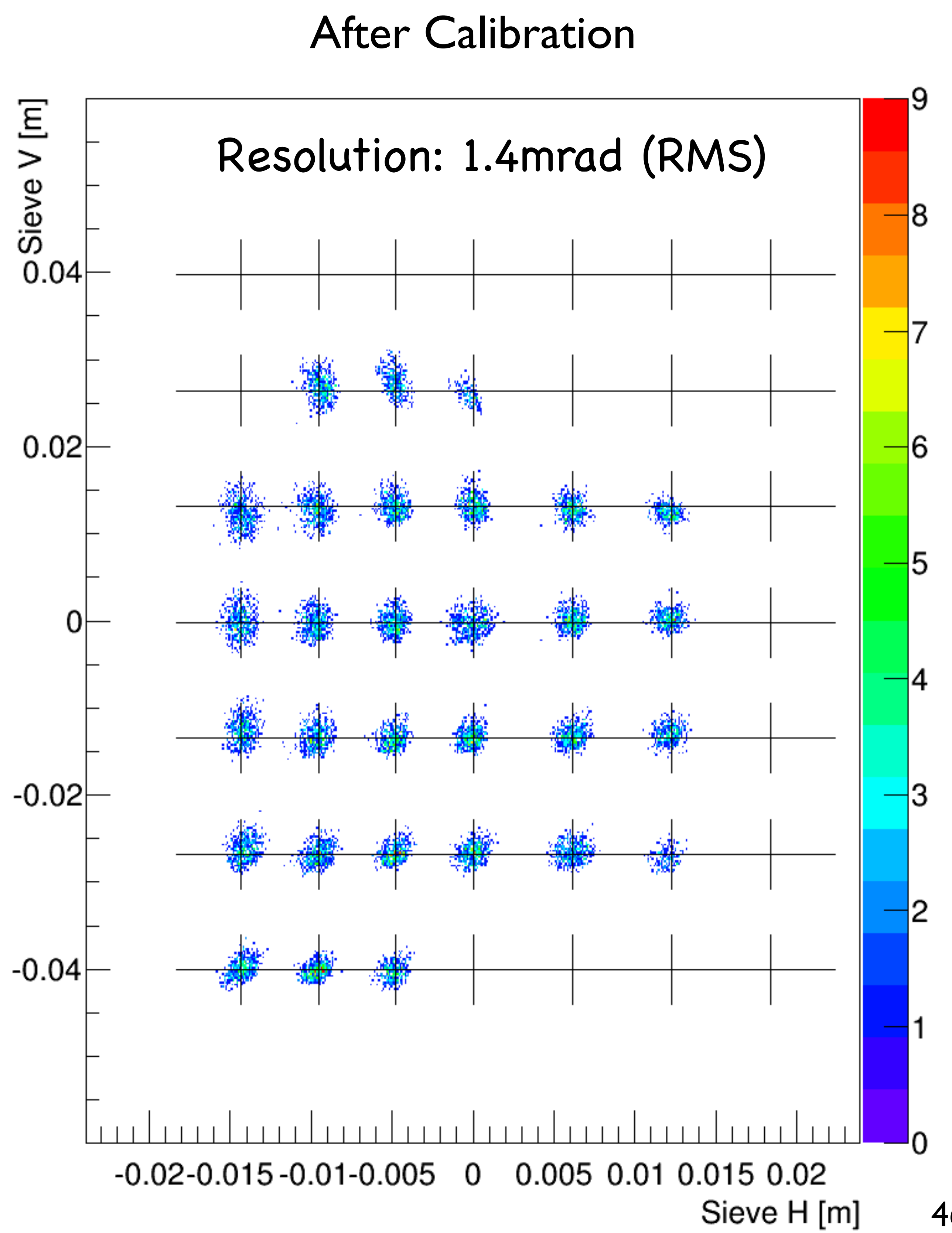




Matrix Calibration: Angle

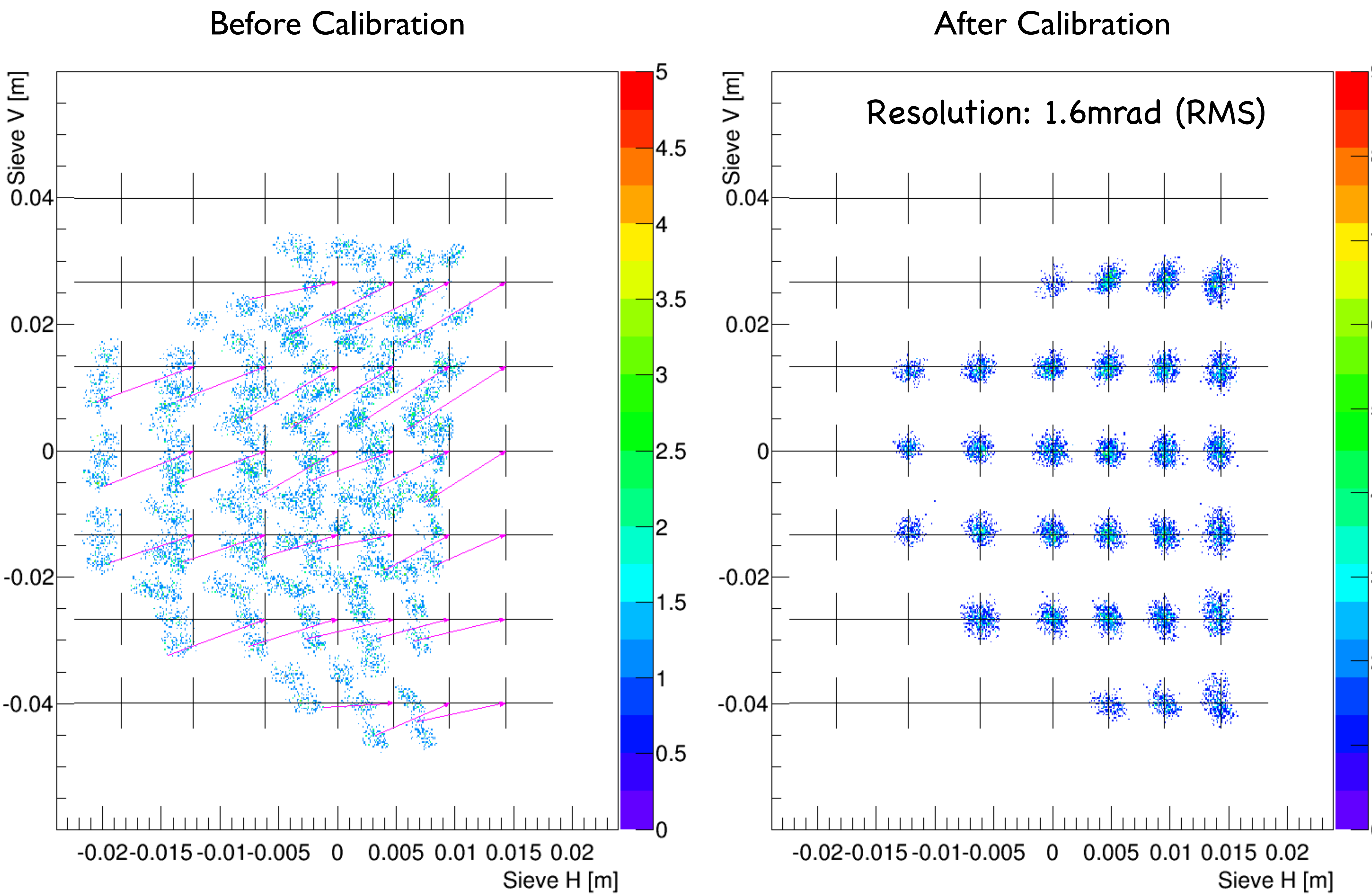
LHRS





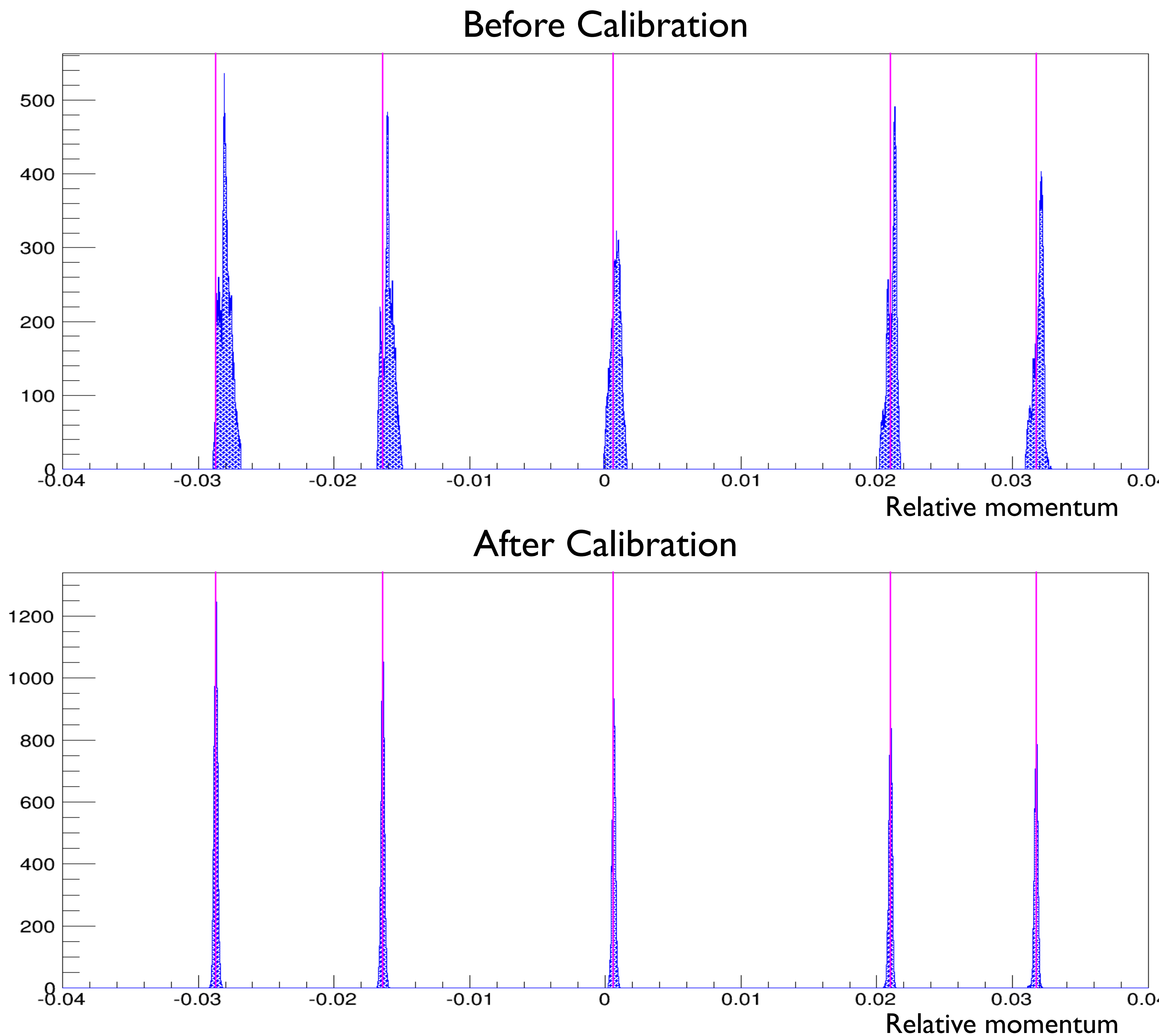
Matrix Calibration: Angle

RHRS



Matrix Calibration: Momentum

LHRS

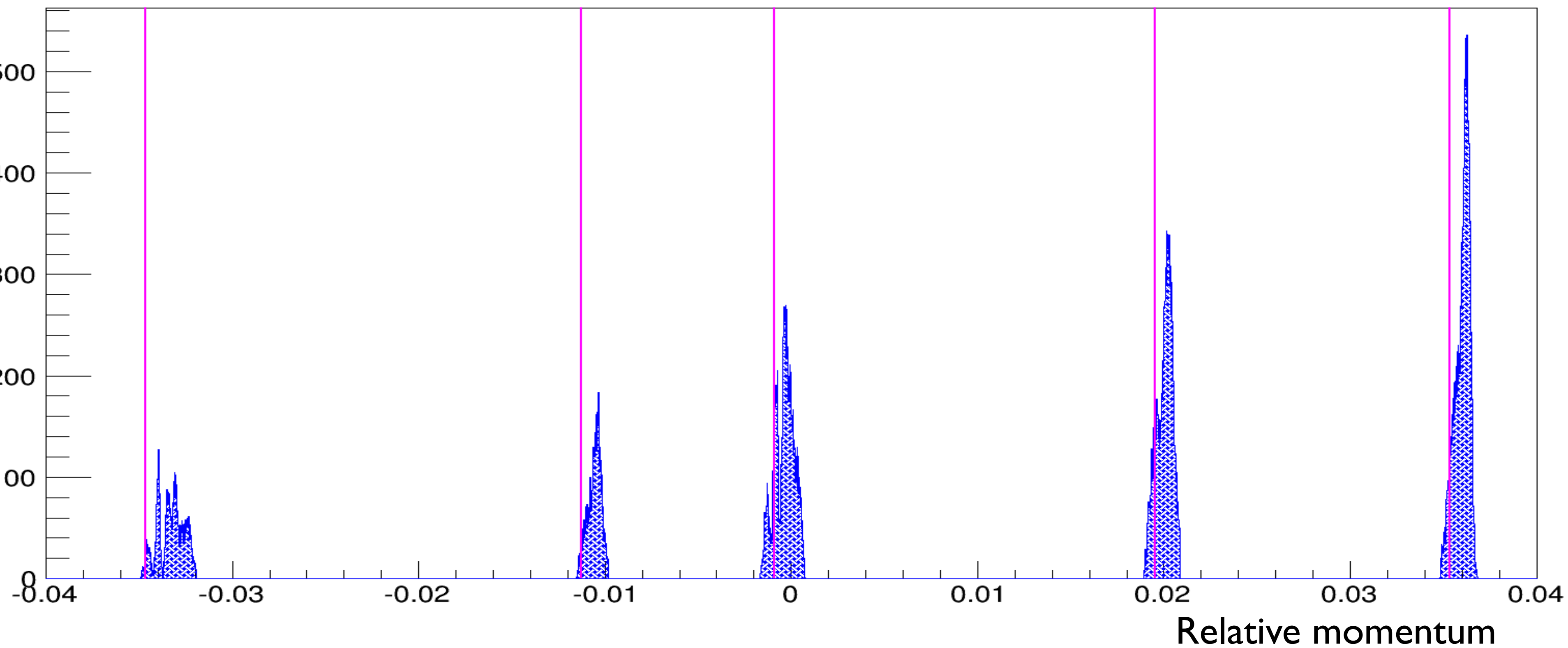


RMS: 1.4×10^{-4}

Matrix Calibration: Momentum

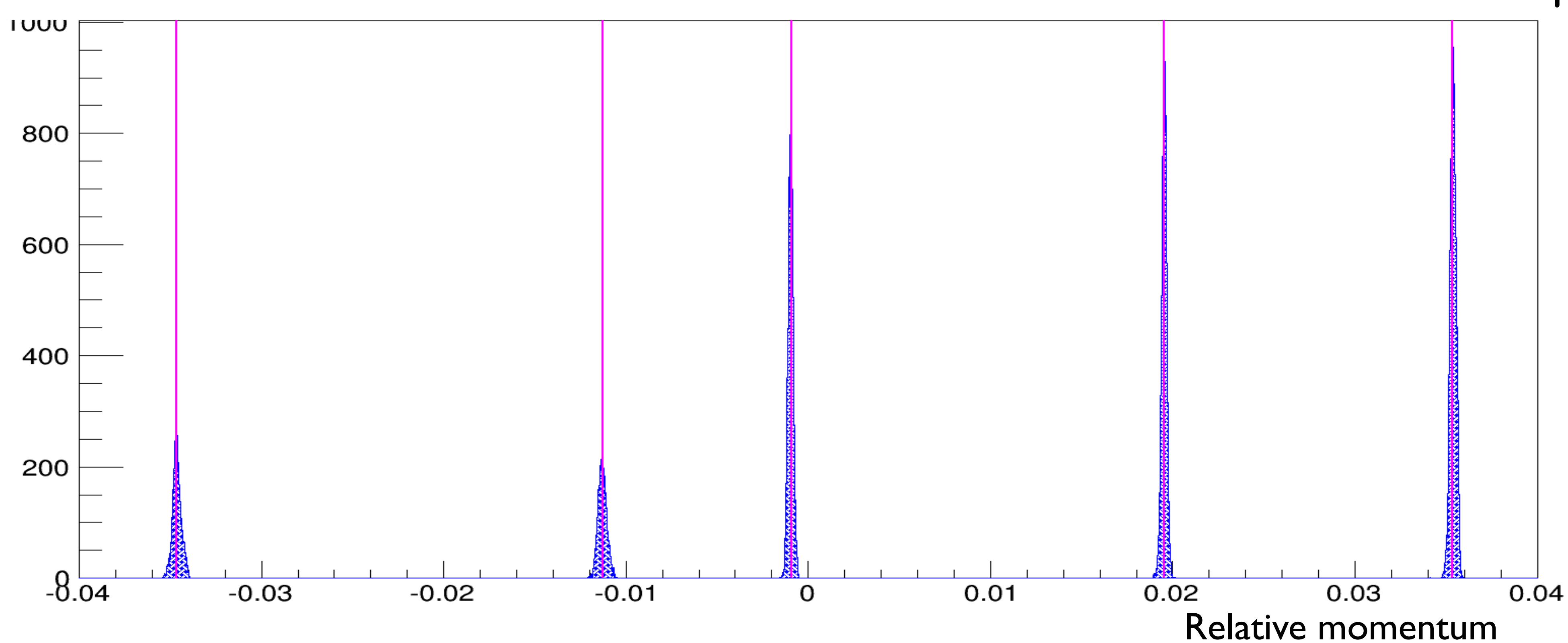
RHRS

Before Calibration



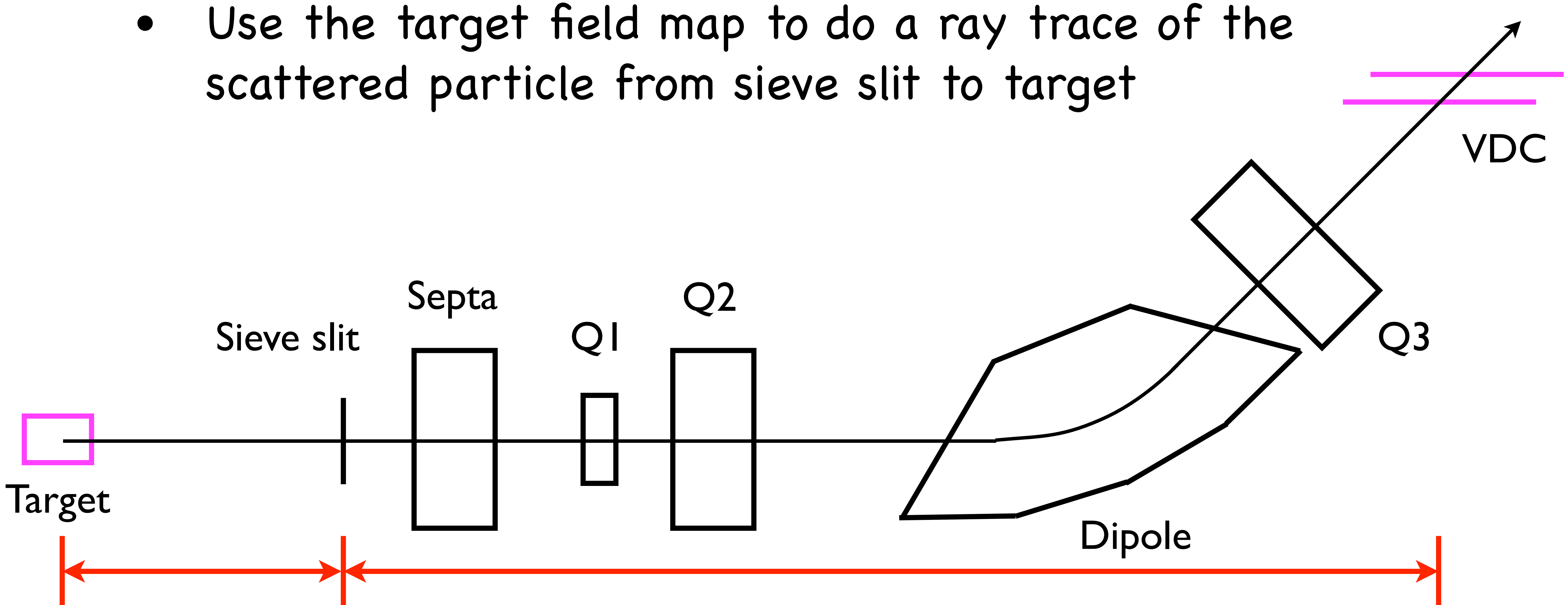
After Calibration

RMS: 1.7×10^{-4}



Optics Study with Target Field

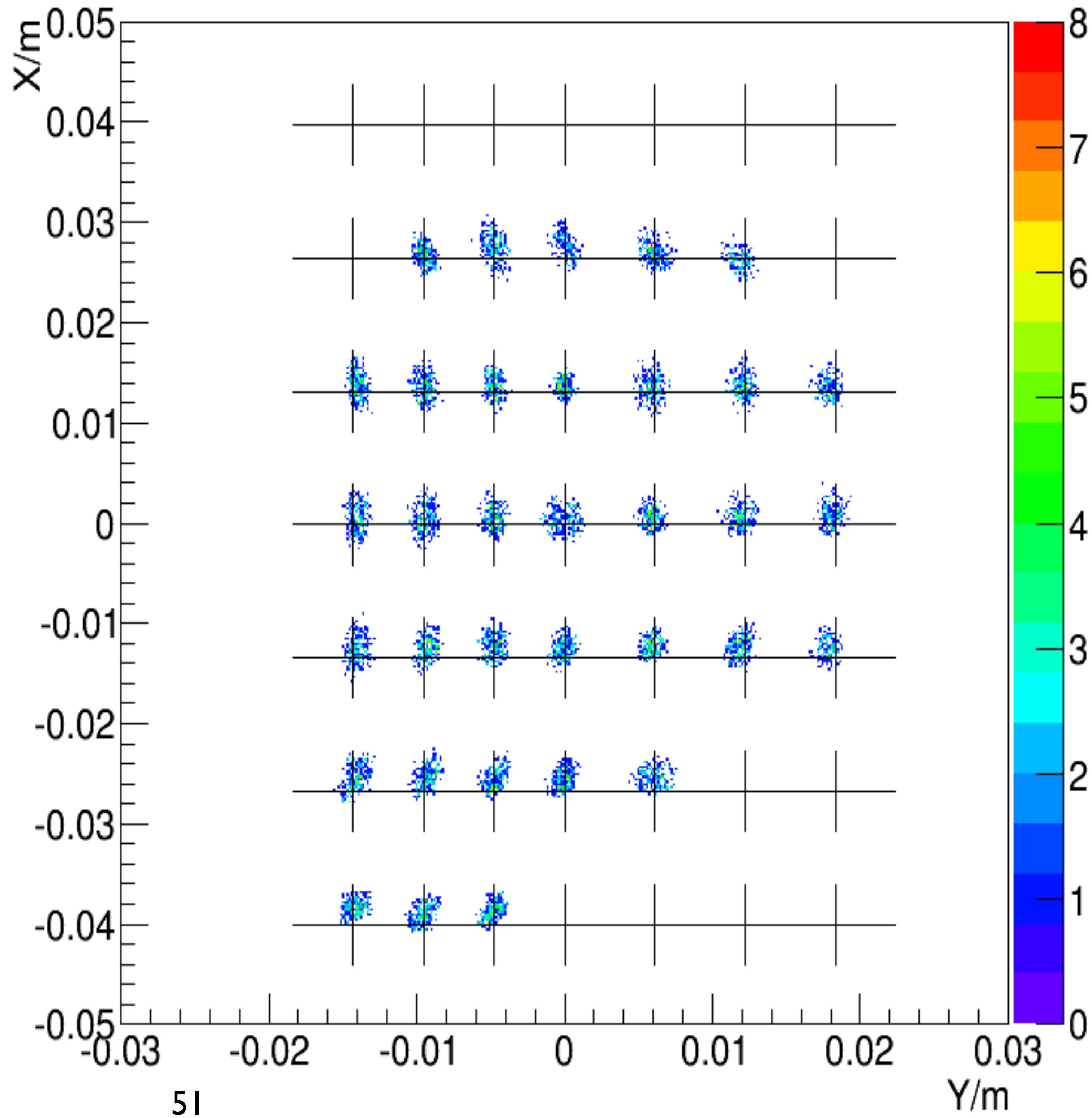
- To include target field
    - Normal sieve slit method is not useful
- Idea: separate reconstruction process to 2 parts:
    - Use HRS optics matrix to do the reconstruction from VDC to sieve slit
    - Use the target field map to do a ray trace of the scattered particle from sieve slit to target



Optics Study with Target Field

- Use carbon foil target and point beam
- Sieve pattern is decided by both the beam position and the reconstructed angle
- Directly use BPM readout to provide beam position here

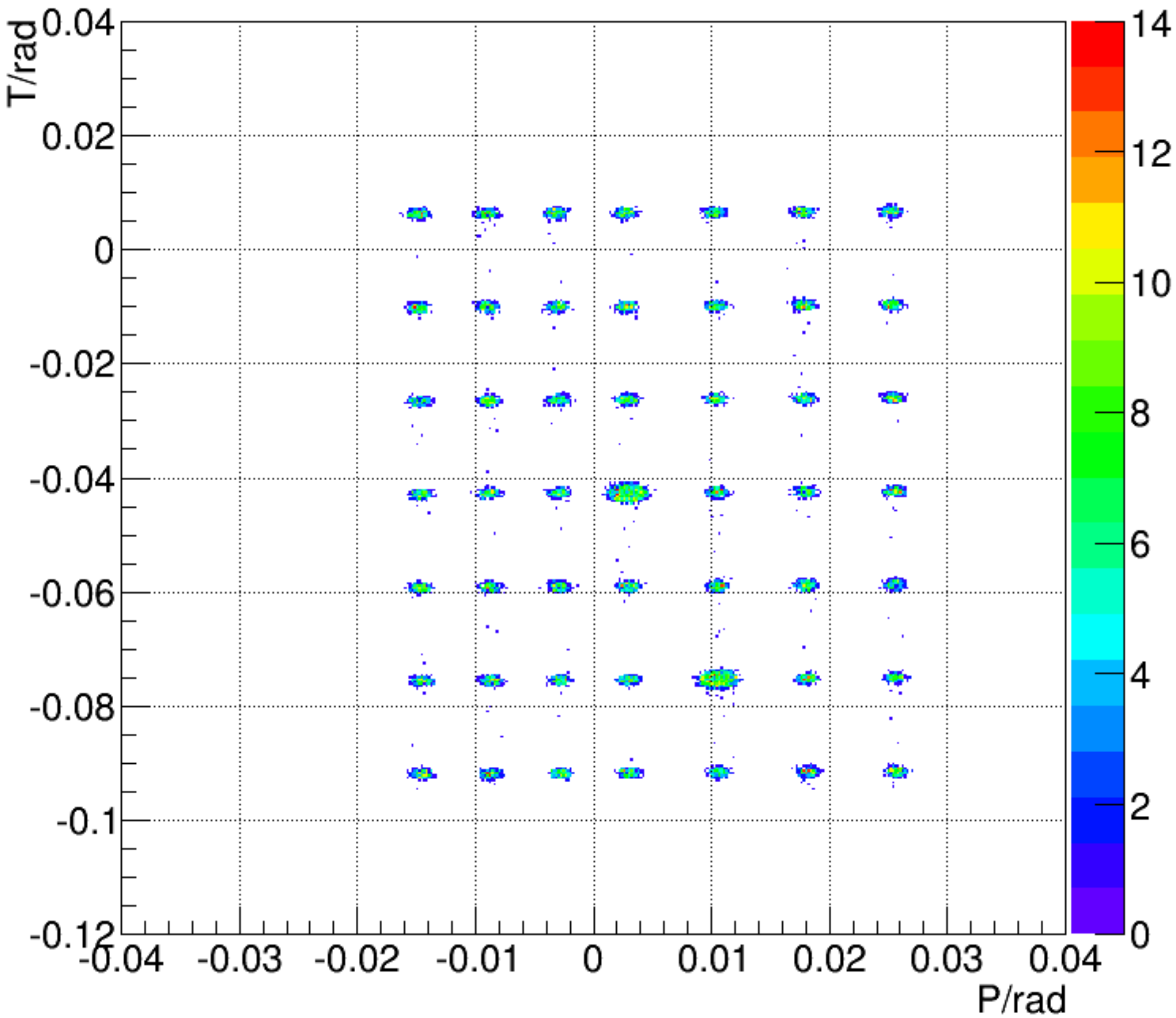
Sieve pattern after calibration



Optics Study with Target Field

- Compare reconstructed target theta and phi angle with the calculated result

Calculated theta and phi



Reconstructed theta and phi