An Update on the g_2^p Experiment

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The College of William and Mary
On Behalf of the E08-027 Collaboration

Hall A Collaboration Meeting
December 10th, 2012

E08-027 Collaboration

Spokespeople

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Jixie Zhang

Graduate Students

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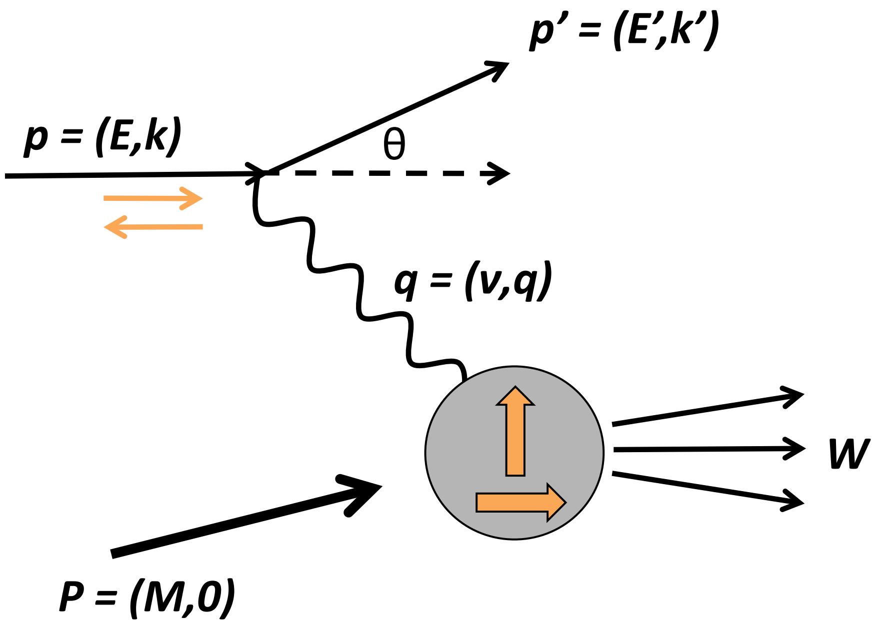
Chao Gu
Min Huang
Jie Liu
Pengjia Zhu
Ryan Zielinski

Inclusive Electron Scattering

F_1, F_2: unpolarized structure functions

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

g_1, g_2: polarized structure functions

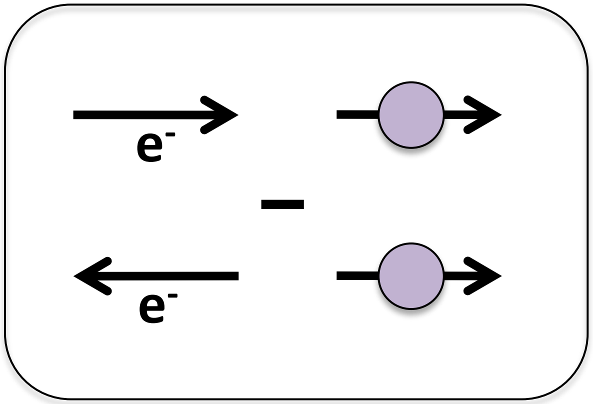


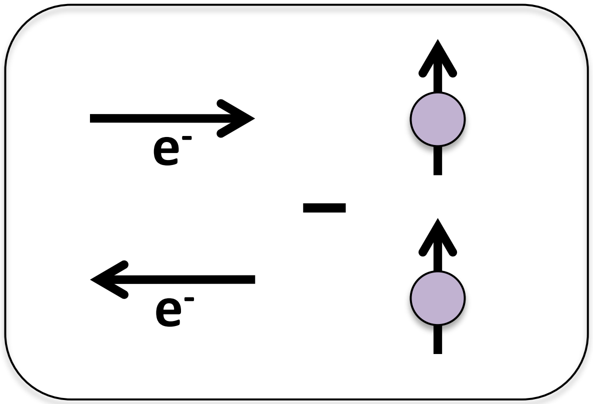
Motivation

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

- Provide insight on several outstanding physics puzzles:
  - Benchmark test of χPT with extraction of δ_{LT}
  - Examine the Burkhardt-Cottingham Sum Rule at low Q^2
  - Hyperfine splitting of hydrogen – lack of knowledge of g_2 contributes to uncertainty
  - Proton charge radius from μP lamb shift disagrees with eP scattering result

Experimental Technique





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

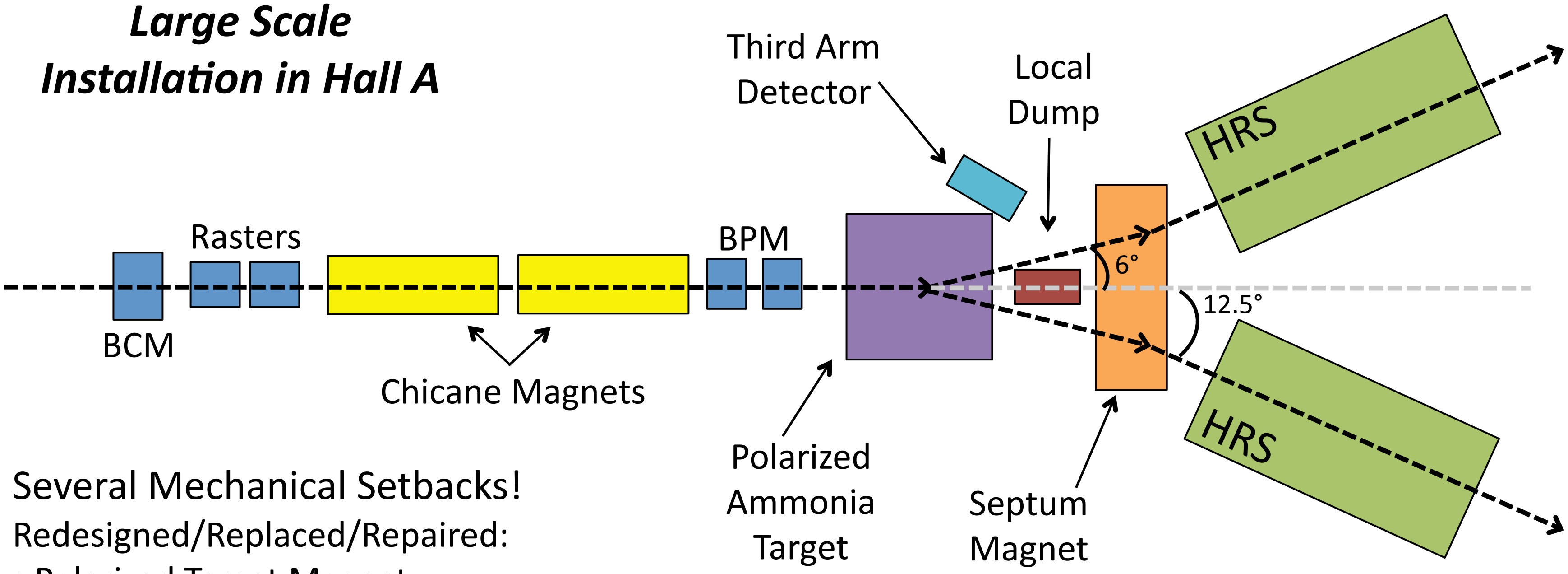
$\Delta\sigma_{||}$ measured during EG4 experiment in Hall B: will extract g_1^p at low Q^2

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

$\Delta\sigma_{\perp}$ obtained from g_2^p experiment and combined with EG4 data to obtain g_2^p

Experimental Setup

Large Scale Installation in Hall A



Several Mechanical Setbacks!

Redesigned/Replaced/Repaired:

- Polarized Target Magnet
- Chicane Bellows
- Right Septa Magnet
- Both Septa Max Field
- Local Dump Cooling
- Harp Wires

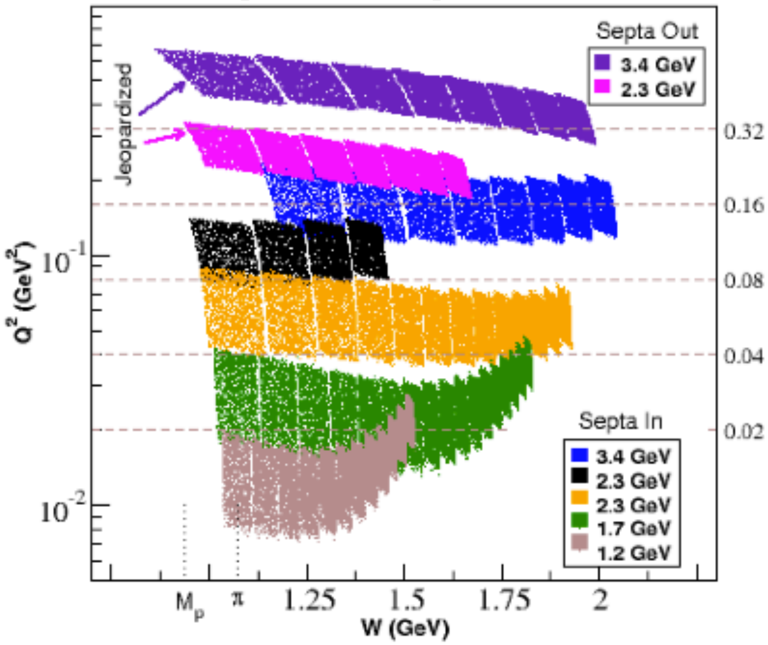
Summary of Run

- Ran from 3/2/12 – 5/18/12
- Concurrent with E08-007 (GEp)

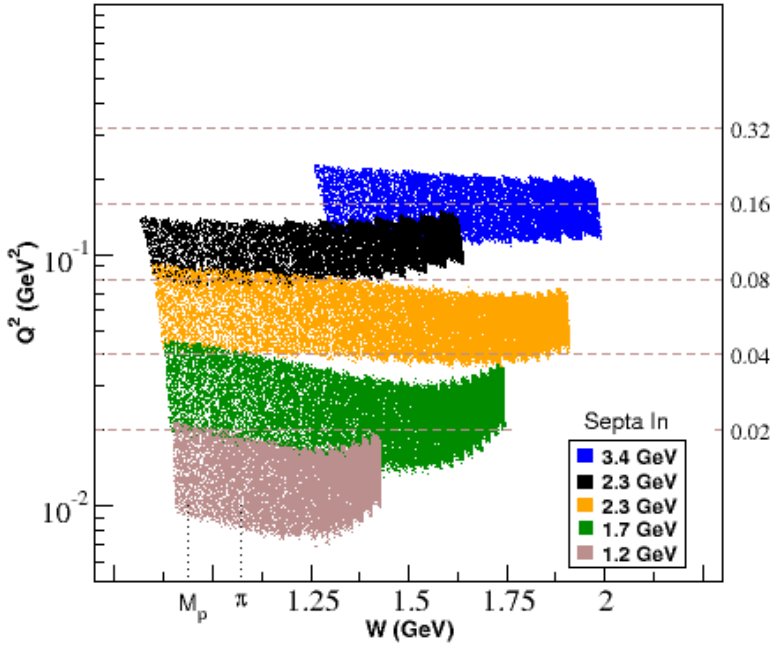
W < 2 GeV

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

Proposed Experiment

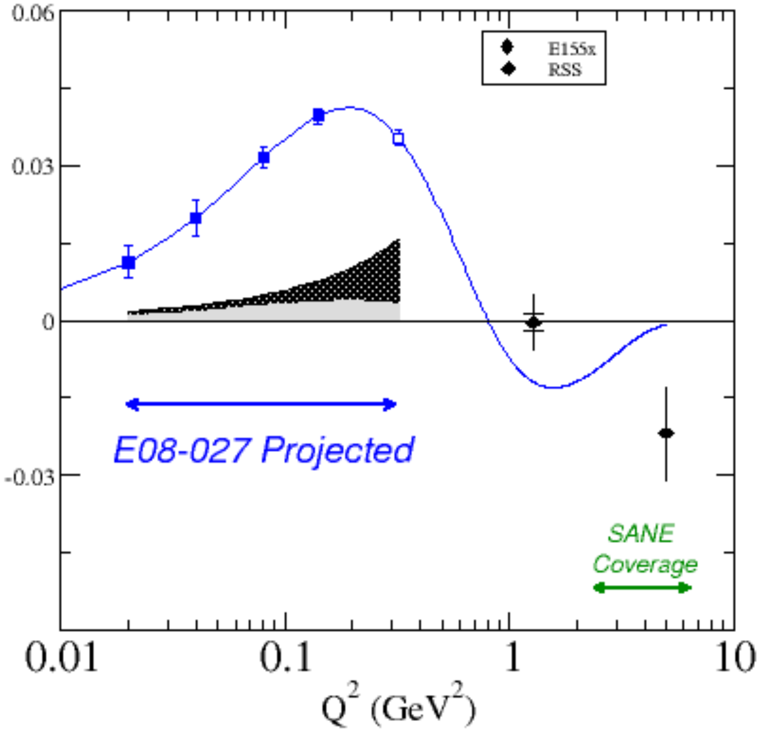


Reduced Kinematics

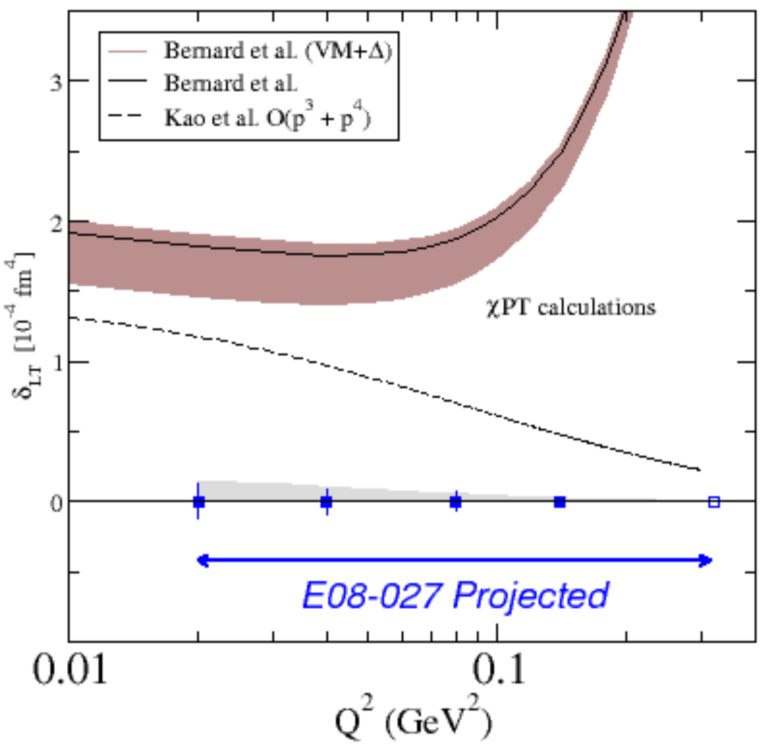


Projected Results

BC Sum Integral Γ_2



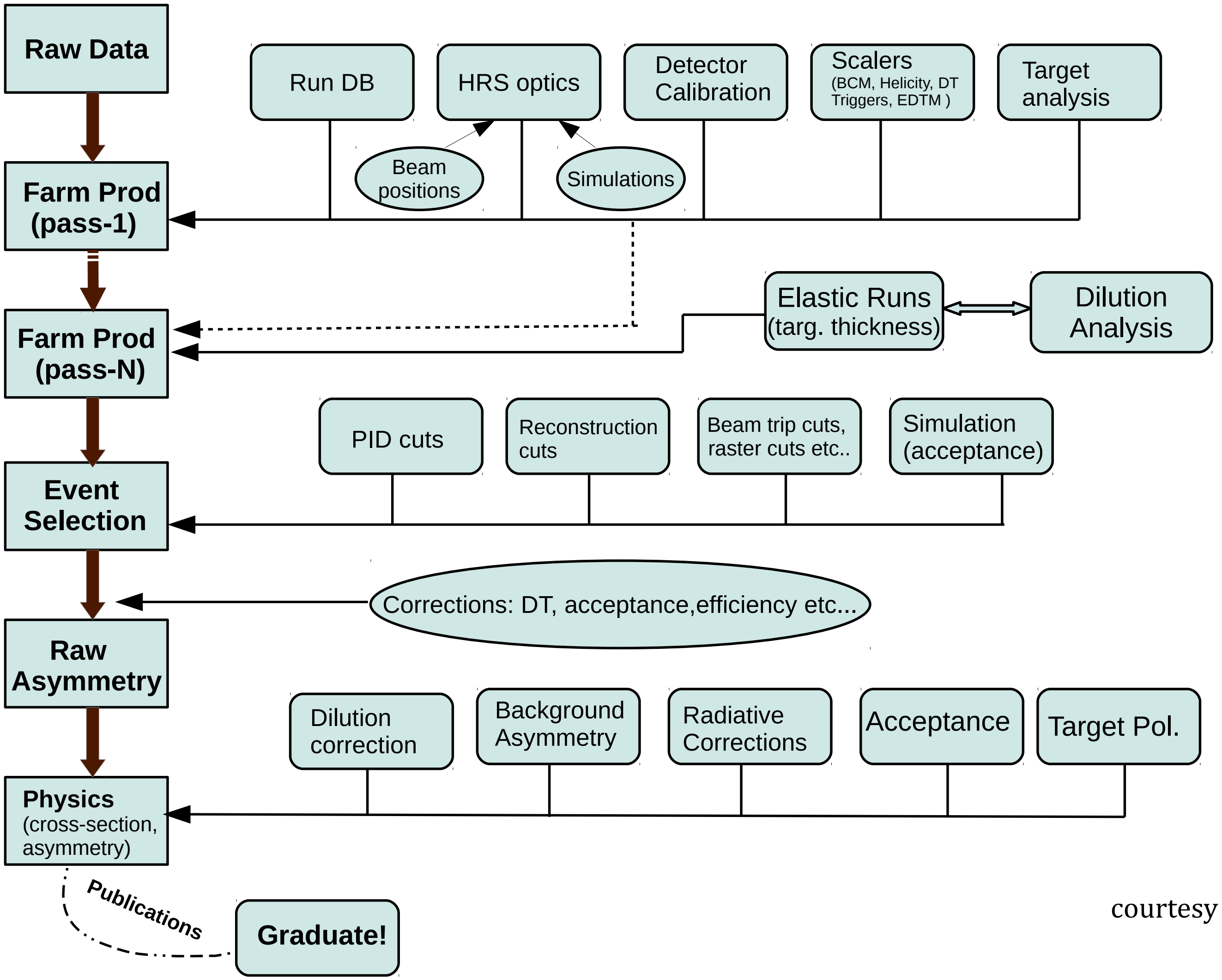
LT Spin Polarizability



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

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

Status of Analysis



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

Corrections: DT, acceptance,efficiency etc...

Raw Asymmetry

Dilution correction

Background Asymmetry

Radiative Corrections

Acceptance

Target Pol.

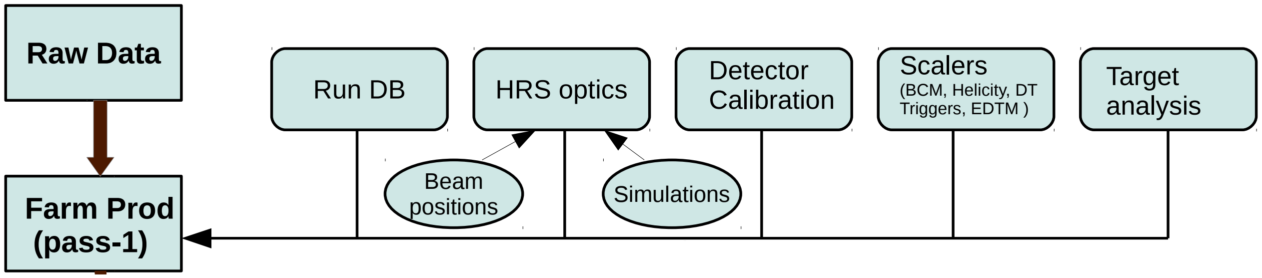
Physics (cross-section, asymmetry)

Publications

Graduate!

courtesy K. Allada

Status of Analysis



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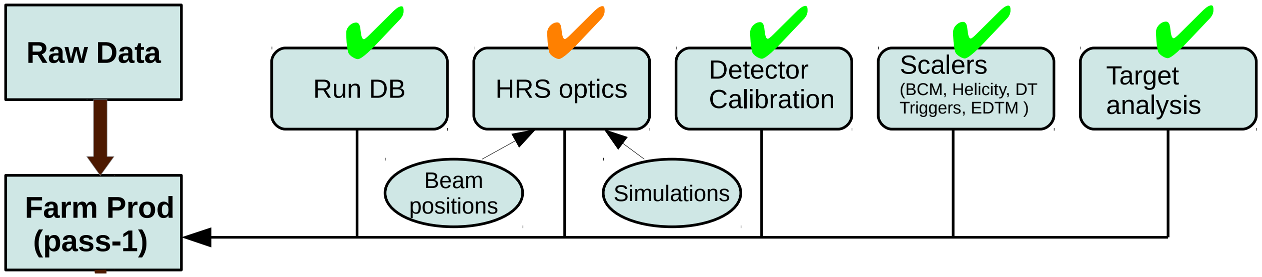
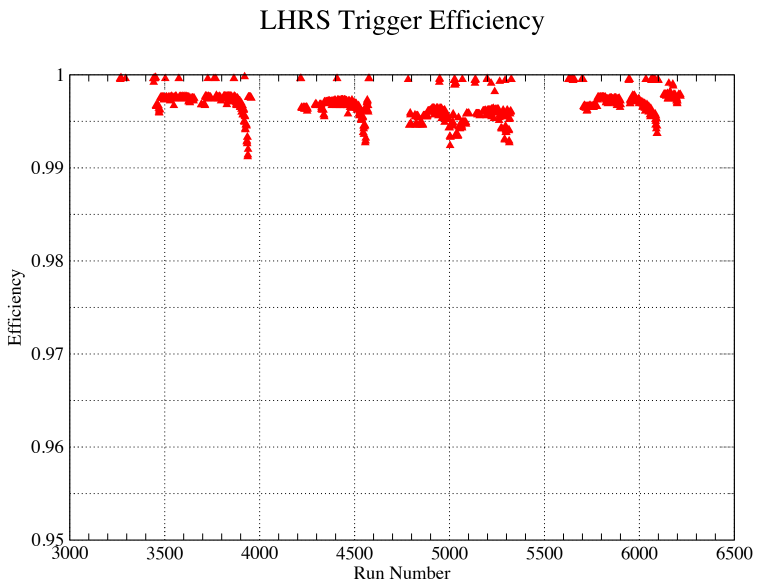


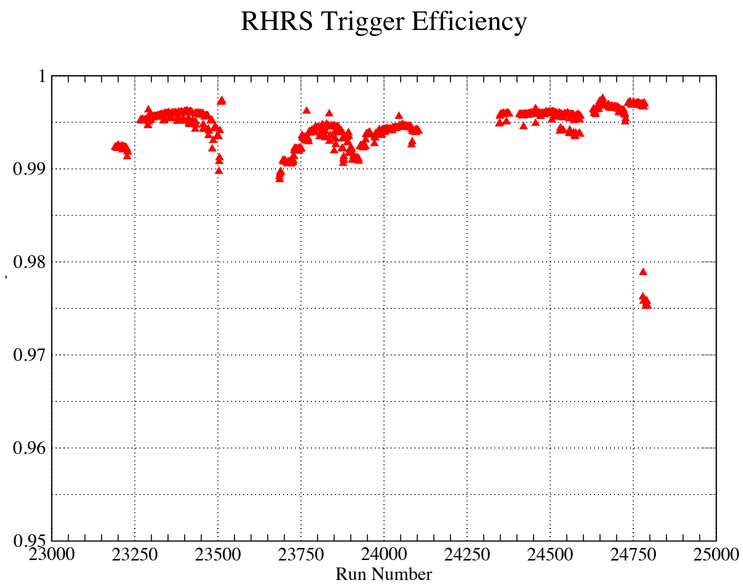
- Run DB – complete!
- Straight-thru optics (with good septum) – complete!
- Detector calibrations – complete!
- Scalers
  - BCM calibration – complete!
  - Helicity decoder – complete!
  - Trigger efficiencies – complete!
- Offline target calibration constants – complete!

Trigger Efficiencies

- Efficiency for the LHRS [RHRS]defined as: $\frac{T3[T1]}{T3[T1]+T4[T2]}$
  - T1,T3: singles triggers (s1 && s2m)
  - T2,T4: efficiency triggers (s1&&GC)||(s2m&&GC)

- Efficiencies are corrected for deadtime and prescales: $\frac{T_3 * PS_3}{1-DT_3}$

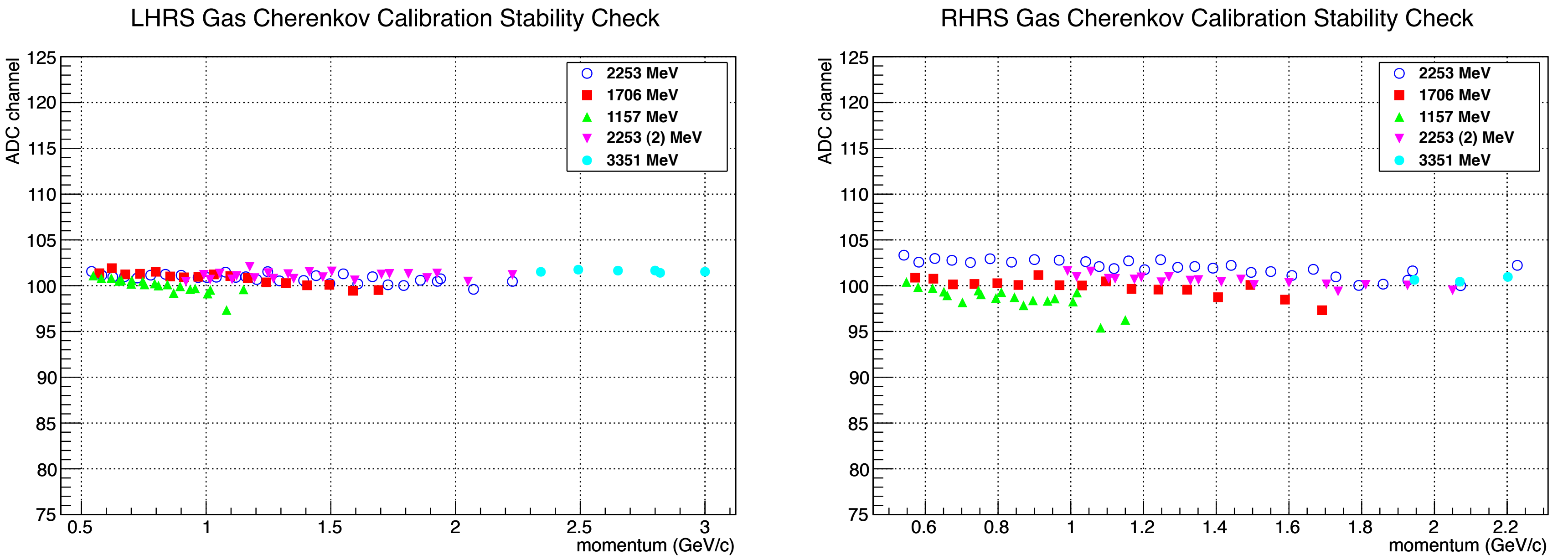




courtesy R. Zielinski

Detector Calibrations

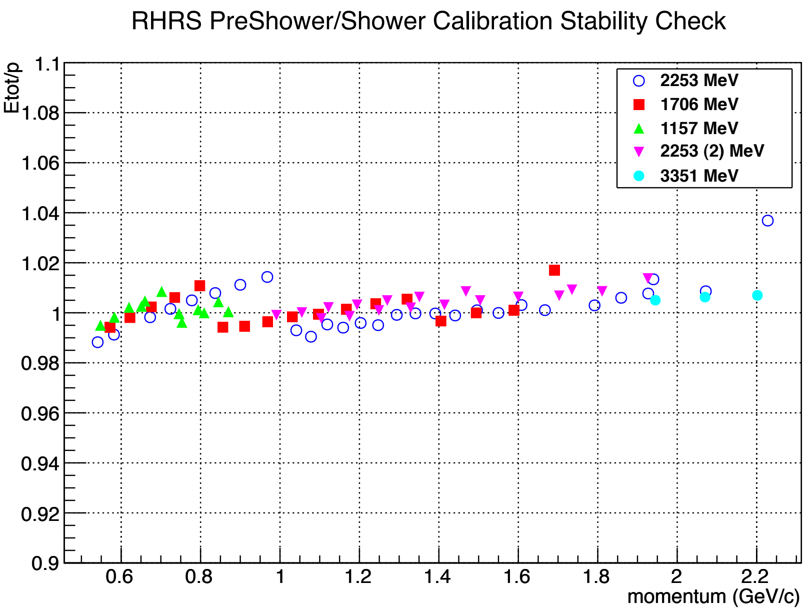
- Gas Cherenkov
  - Isolate single photoelectron peak
  - Align to channel 100

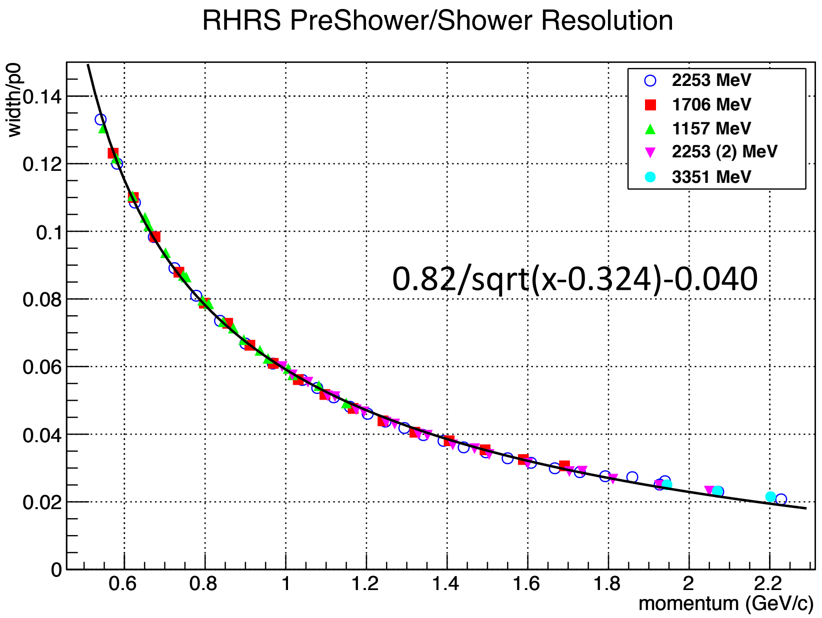


single photoelectron peak location – average of 10 channels

Detector Calibrations

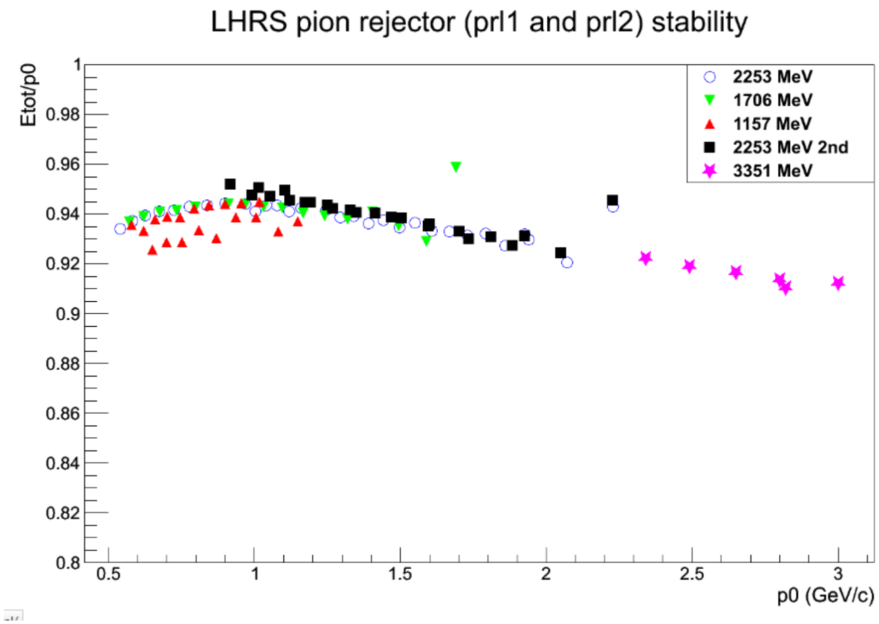
- Lead Glass
  - RHRS: Fumili minimization technique used to determine calibration constants for each channel of preshower/shower
  - Resulting distribution of E_{tot}/p centered around 1



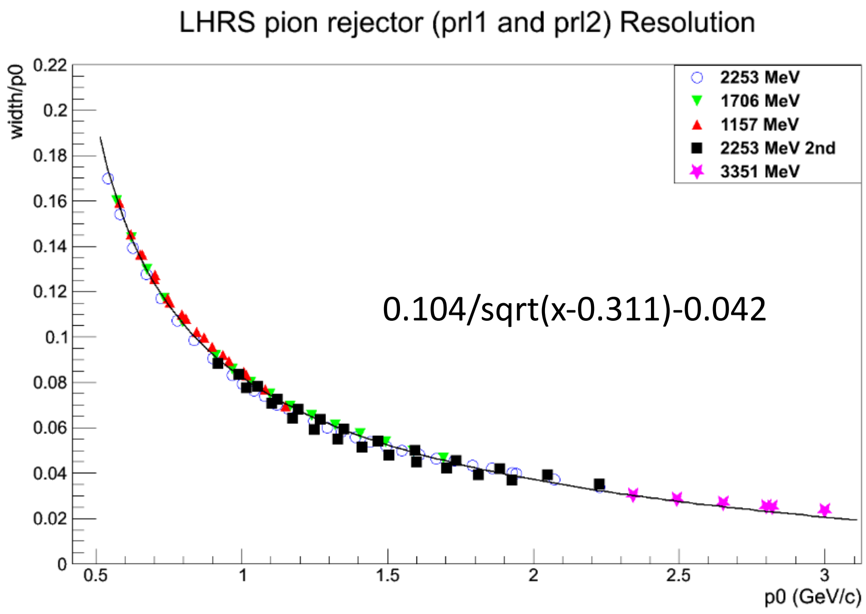


Detector Calibrations

- Lead Glass
  - LHRS: Determine energy deposited for each momentum setting
  - Use minimization technique to determine calibration coefficients
  - Resulting distribution of E_{tot}/p centered around 0.95



LHRS pion rejector (prl1 and prl2) stability



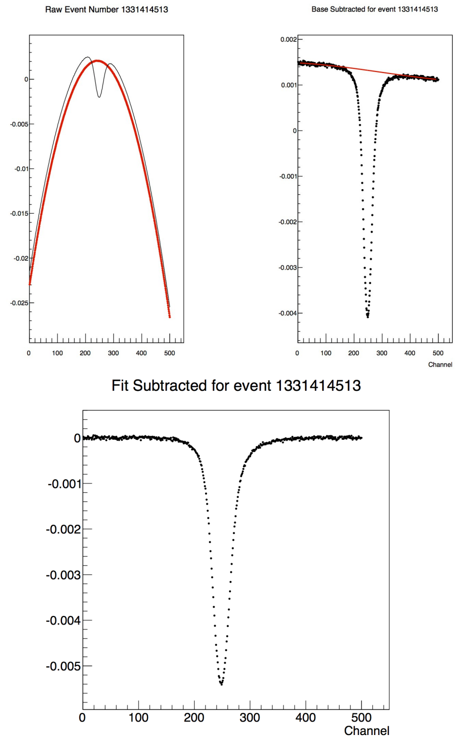
LHRS pion rejector (prl1 and prl2) Resolution

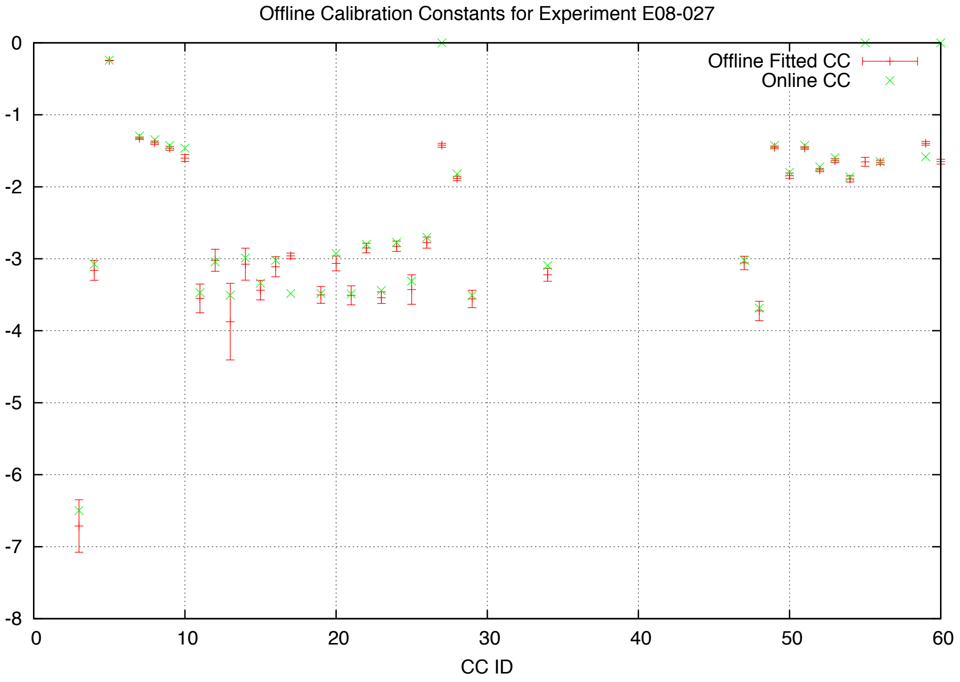
0.104/sqrt(x-0.311)-0.042

courtesy J. Liu

Target Polarization

- Offline Calibration Constants
  - Baseline subtracted from raw signal, 3rd order polynomial fit to wings

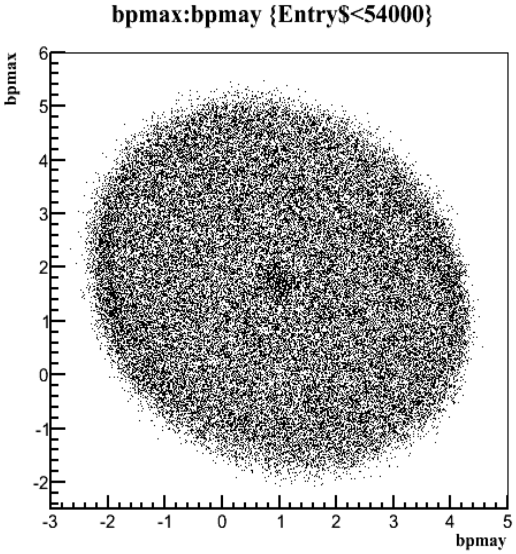




courtesy T. Badman

BPM Calibration

- Straight-thru calibration done!
    - error analysis in progress
- New method to calculate beam position from 4 antennas
- Additional transfer function from BPM to target for strong transverse target field (still in progress)
- New independent package for BPM information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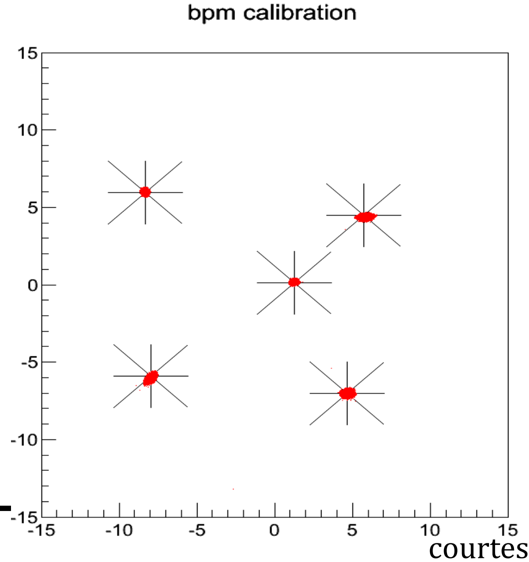
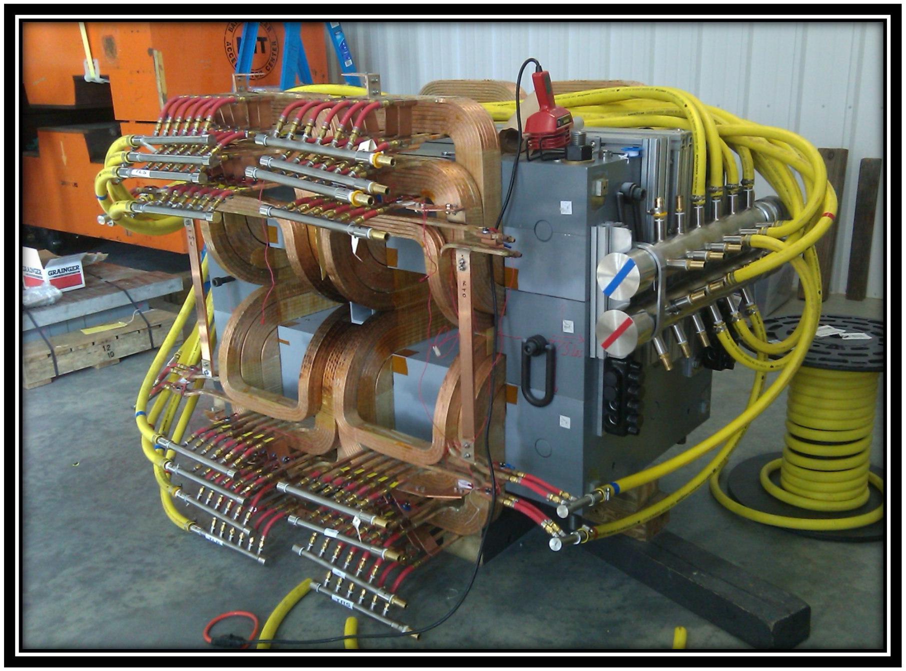

bpm calibration

courtesy P. Zhu

Optics

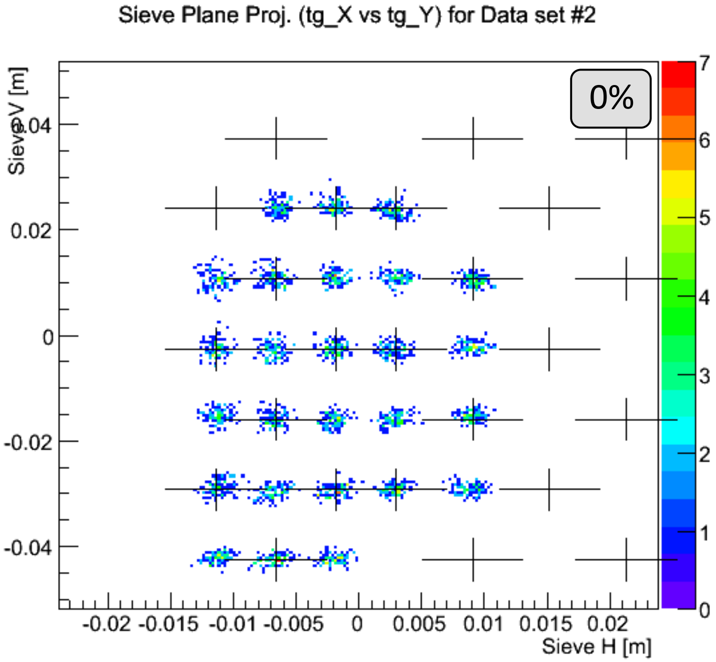
- Due to septum problems during the run period, there are 3 different configurations of the RHRS septum:

1) Good	2) Bad	3) Very Bad
48-48-16	40-32-16	40-0-16



Optics

- First task in optics analysis:
  - E_{beam} = 2.253 GeV, 0T Target Field at 6°
  - Will serve as a base for optics with non-ideal septum
  - Matrix angle calibrations shown below (for LHRS)



courtesy M. Huang

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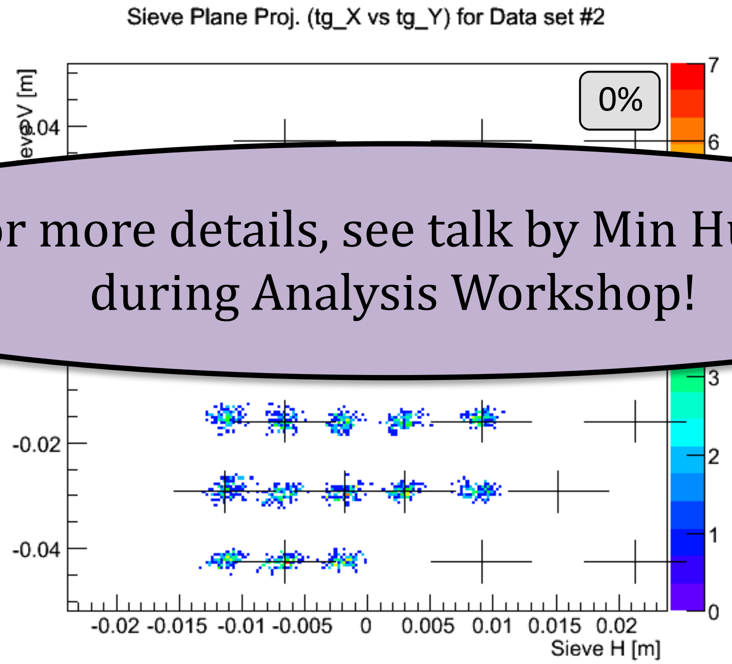
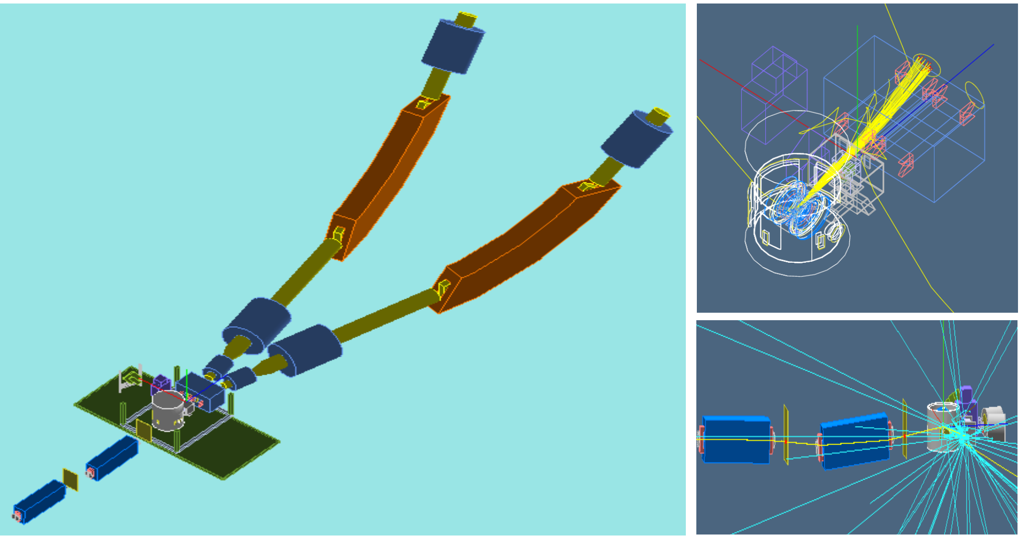


For more details, see talk by Min Huang during Analysis Workshop!

courtesy M. Huang

Geant4 Simulation Package (HRSMC)

- Propagates scattered electron from target to sieve slit
- Uses SNAKE forward model with no target field to transport electron to the focal plane
  - Reconstruction is done with no target field SNAKE backward model or the no target field REAL optics matrix
- When target field if on, reconstruction will stop at sieve plane
  - Then drift electron in magnetic fields back to the target



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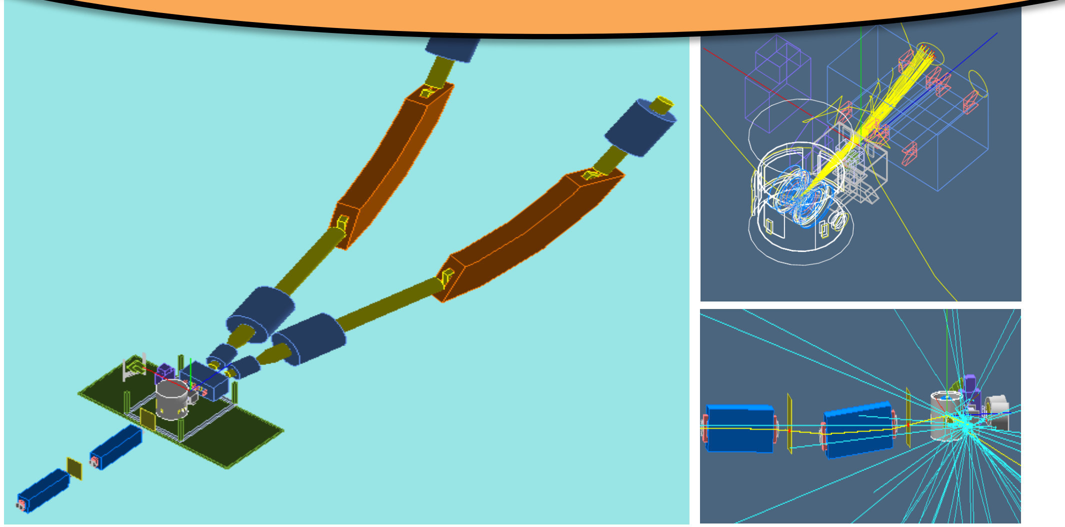
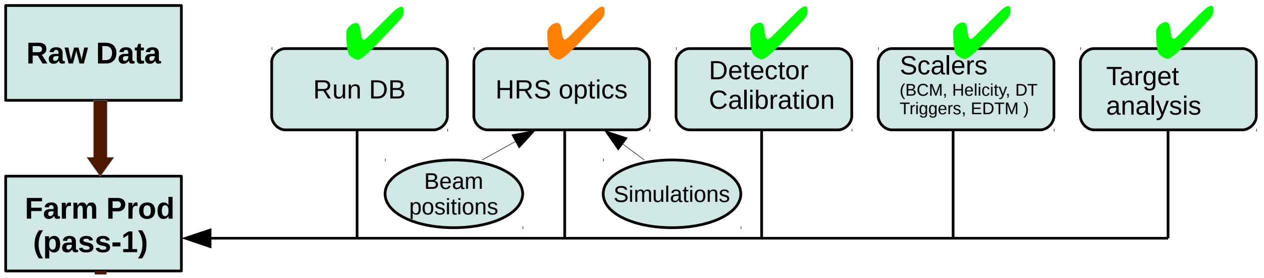


courtesy J. Zhang

Up Next



Raw Data

Farm Prod (pass-1)

✓ Run DB

✓ HRS optics

✓ Detector Calibration

✓ Scalers (BCM, Helicity, DT Triggers, EDTM)

✓ Target analysis

Beam positions

Simulations

- Optics for straight-thru with bad septum – in progress
- BPM calibrations for non straight-thru – in progress
- Preparing for first pass of farm production

Summary

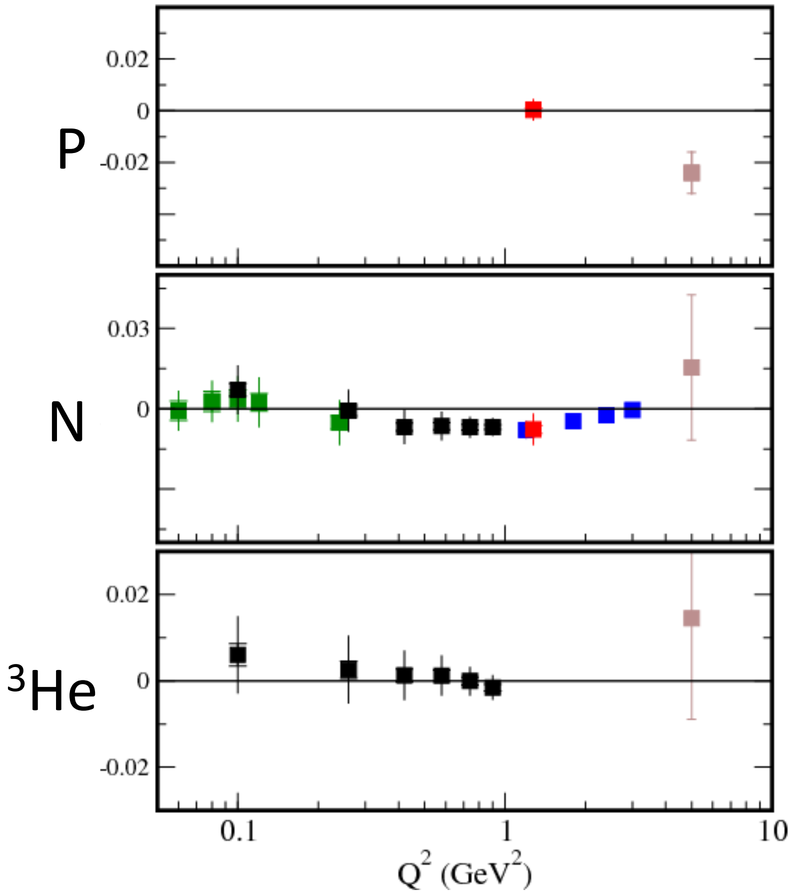
- New instrumentation in Hall A brought many challenges to g_2^p
- Will still accomplish most of our physics goals, despite reduced kinematics
- Will provide the first measurement of g_2^p in the low Q^2 region
- Data will also provide insight on several outstanding physics puzzles

Backup

BC Sum Rule

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

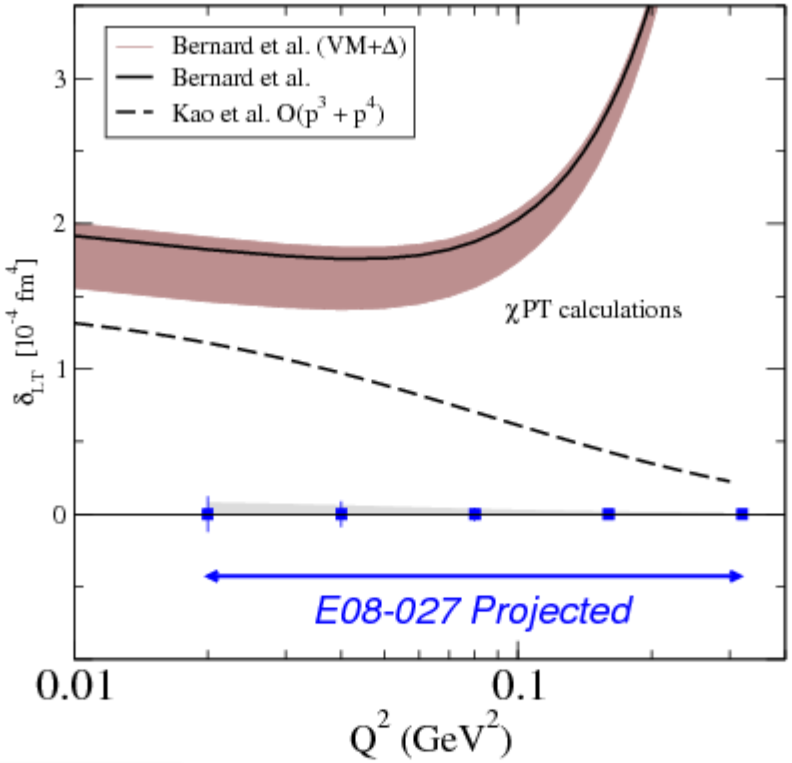
- Fails if the virtual Compton Scattering amplitude (S_2) falls to zero faster than 1/x
- Fails if g_2 behaves as a delta function at x=0
- Violation is suggested for the proton at large Q^2



Spin Polarizability - δ_{LT}

- Benchmark test of Chiral Pertubation Theory
- Measurement of δ_{LT} would test χ^{PT} by measuring a nucleon observable that is insensitive to contributions from virtual π-Δ intermediate states
- Significant disagreement of data with predictions would indicate substantial short distance contributions

Longitudinal-Transverse Spin Polarizability



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

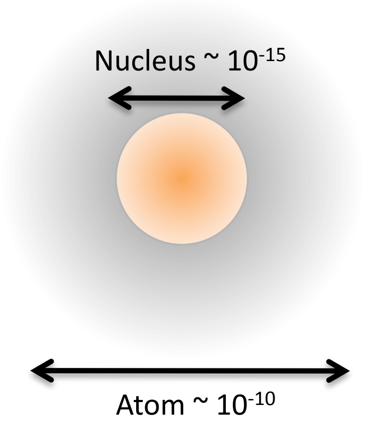
Hyperfine Splitting of Hydrogen

Splitting expressed in terms of Fermi Energy E_F:

$$\Delta E = (1 + \delta) E_F$$

Where:

$$\delta = 1 + (\boxed{\delta_{QED}} + \boxed{\delta_R} + \boxed{\delta_{small}}) + \boxed{\Delta_S}$$



- QED radiative correction

- Accounts for recoil effects

- Hadronic and muonic vacuum polarizations & the weak interaction correction

- Proton structure correction (largest uncertainty)

Hyperfine Splitting of Hydrogen

Δ_S depends on ground state and excited properties:

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

Determined from elastic scattering:

$$\Delta_Z = -2\alpha m_e r_Z (1 + \delta_Z^{rad})$$

Involves contributions where the proton is excited:

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

Involves the Pauli form factor and g_1 structure function

Depends only on the g_2 structure function

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

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

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

$\tau = \nu^2/Q^2$ $\quad$ $x^{th} =$ pion production threshold

Proton Charge Radius

- Proton charge radius from μP disagrees with eP scattering result by ~6%

$\langle R_p \rangle = 0.84184 \pm 0.00067$ fm	Lamb shift in muonic hydrogen
$\langle R_p \rangle = 0.897 \pm 0.018$ fm	World analysis of eP scattering
$\langle R_p \rangle = 0.8768 \pm 0.0069$ fm	CODATA world average

- Main uncertainties arise from the proton polarizability and different value of the Zemach radius