The Proton Spin-Dependent Structure Function, g_2, at Low Q^2

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Abstract

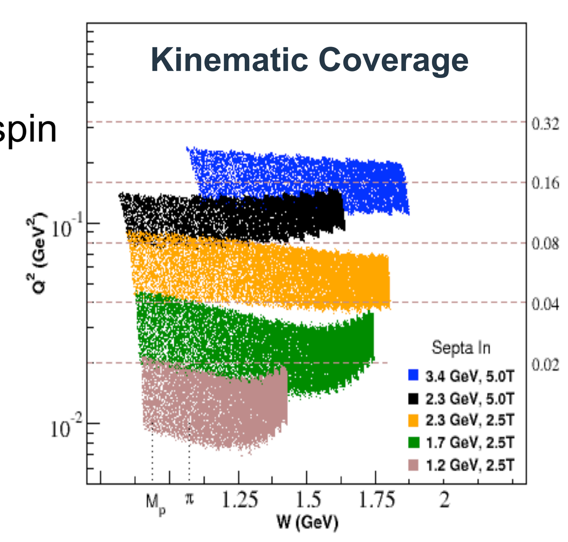
The Jefferson Laboratory accelerator has been used to great effect in the study of the polarized structure of nucleons. Measurements of the spin-dependent structure functions have been proven to be powerful tools in testing the validity of effective theories of Quantum Chromodynamics. While the neutron spin structure functions, g_1^n and g_2^n, and the longitudinal proton spin structure function, g_1^p, have been measured over a wide kinematic range, the second proton spin structure function, g_2^p, has not. This poster will present the E08-027 (g2p) experiment, which was an inclusive measurement of g_2^p in the resonance region at Jefferson Lab's Hall A. This is the first measurement of g_2^p covering 0.02 $GeV^2 < Q^2 <$ 0.2 GeV^2. The experiment will allow us to test the Burkhardt-Cottingham Sum Rule at low Q^2 as well as extract the longitudinal-transverse generalized spin polarizability and compare it to predictions made by Chiral Perturbation Theory. In addition, the data will reduce the systematic uncertainty of calculations of the hyperfine splitting of hydrogen and extractions of the proton charge radius.

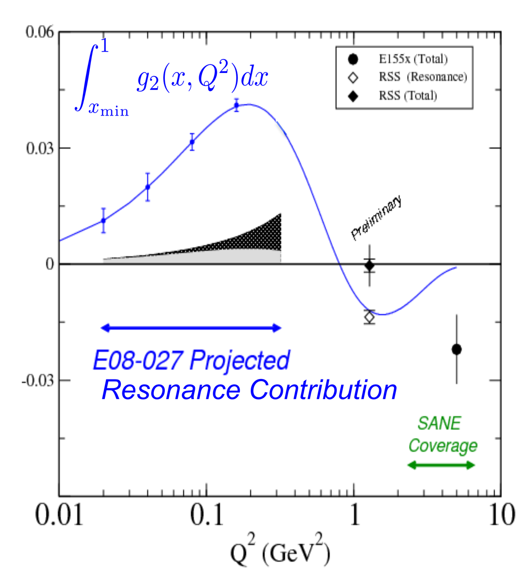
Motivation

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

Measurement of g_2^p is useful for …

- Extract longitudinal-transverse generalized spin polarizability (δ_{LT}) to test Chiral Perturbation Theory (χPT) calculations
- Test Burkhardt-Cottingham (BC) Sum Rule
- Crucial input for hydrogen hyperfine splitting and proton charge radius measurements

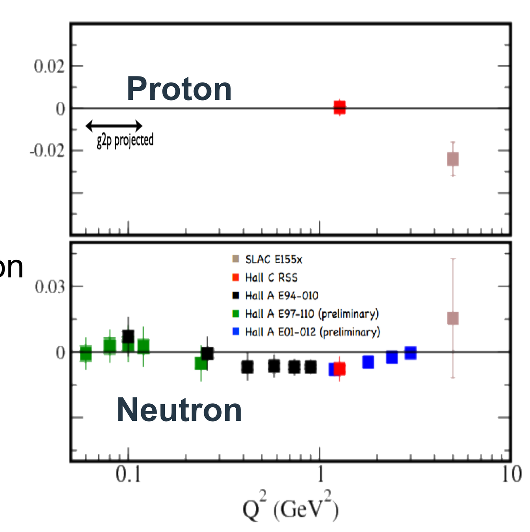




Burkhardt-Cottingham Sum Rule

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

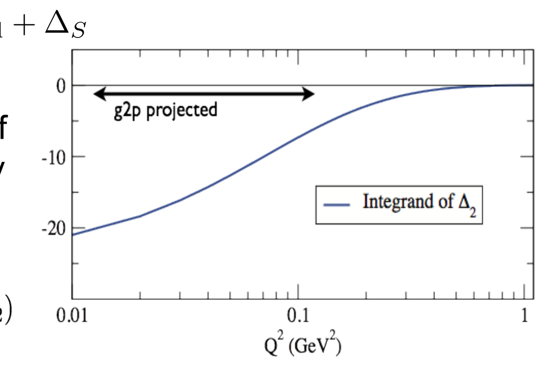
- BC Sum rule will fail if:
  - g_2^p behaves as a δ-function at x = 0
  - Exhibits non-Regge behavior



Hydrogen Hyperfine Splitting

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

- Δ_S is largest portion of theoretical uncertainty
- $\Delta_S = \Delta_Z + \Delta_{pol}$
  - $\Delta_{pol} = \frac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$

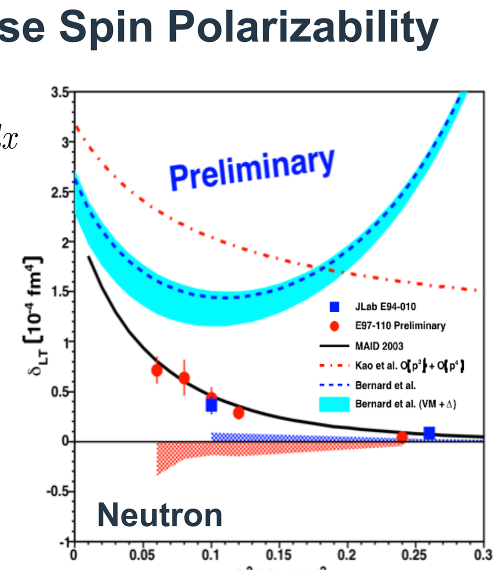


Δ_2 is dominated by low Q^2 g_2^p

Longitudinal-Transverse Spin Polarizability

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

- δ_{LT} is insensitive to Δ-resonance, so it is a good place to test χPT calculations
- Deviations from calculations could indicate significant short-range contributions



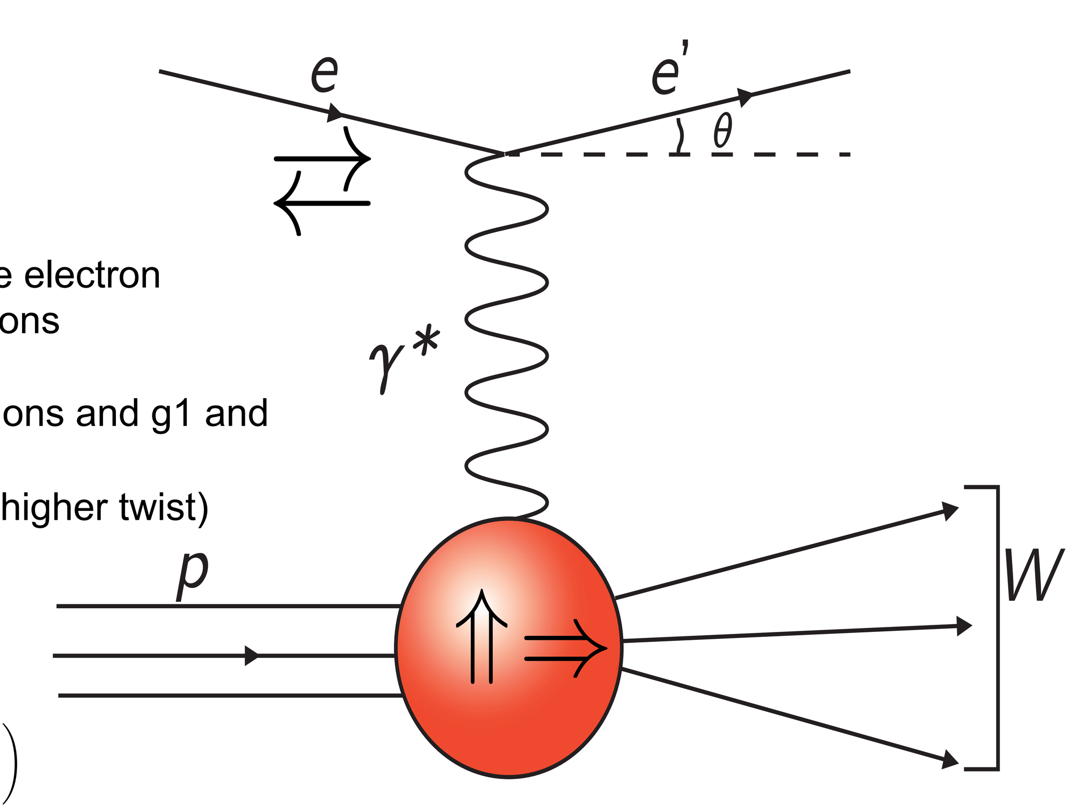
Proton Charge Radius

- Two ways to measure the charge radius
  - Energy splitting of 2S1/2 – 2P1/2 levels
  - e-P Scattering experiments

r_p (fm)	Unc. (fm)	σ	Method
0.84184	0.00067	0.0	μH Lamb Shift
0.897	0.018	3.1	e-P scattering
0.8768	0.0069	5.0	eH Lamb Shift

- Main uncertainties (μH) are related to integrals of the spin structure functions

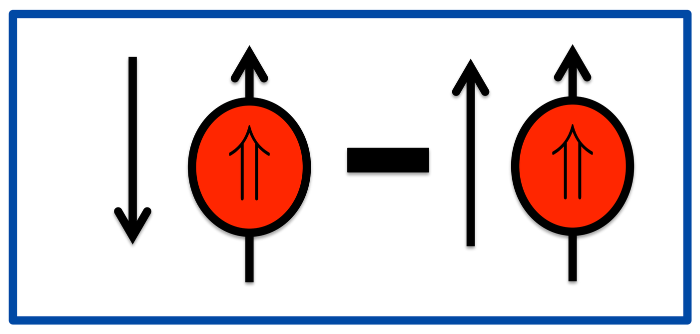
What is g_2^p ?

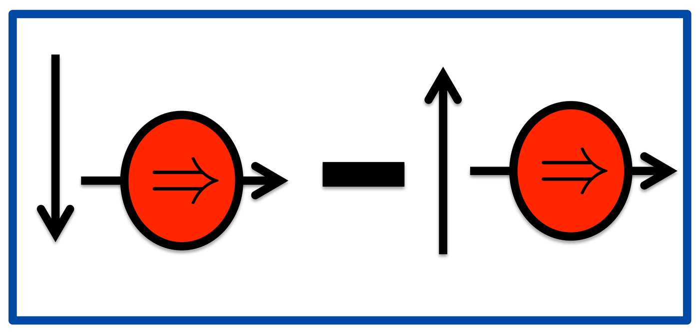


- Deviation from point-like scattering in inclusive electron scattering is described by four structure functions
- F1 and F2 are the unpolarized structure functions and g1 and g2 are the spin-polarized structure functions
  - g_2 is sensitive to quark-gluon interactions (higher twist)

Unpolarized

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





Longitudinal

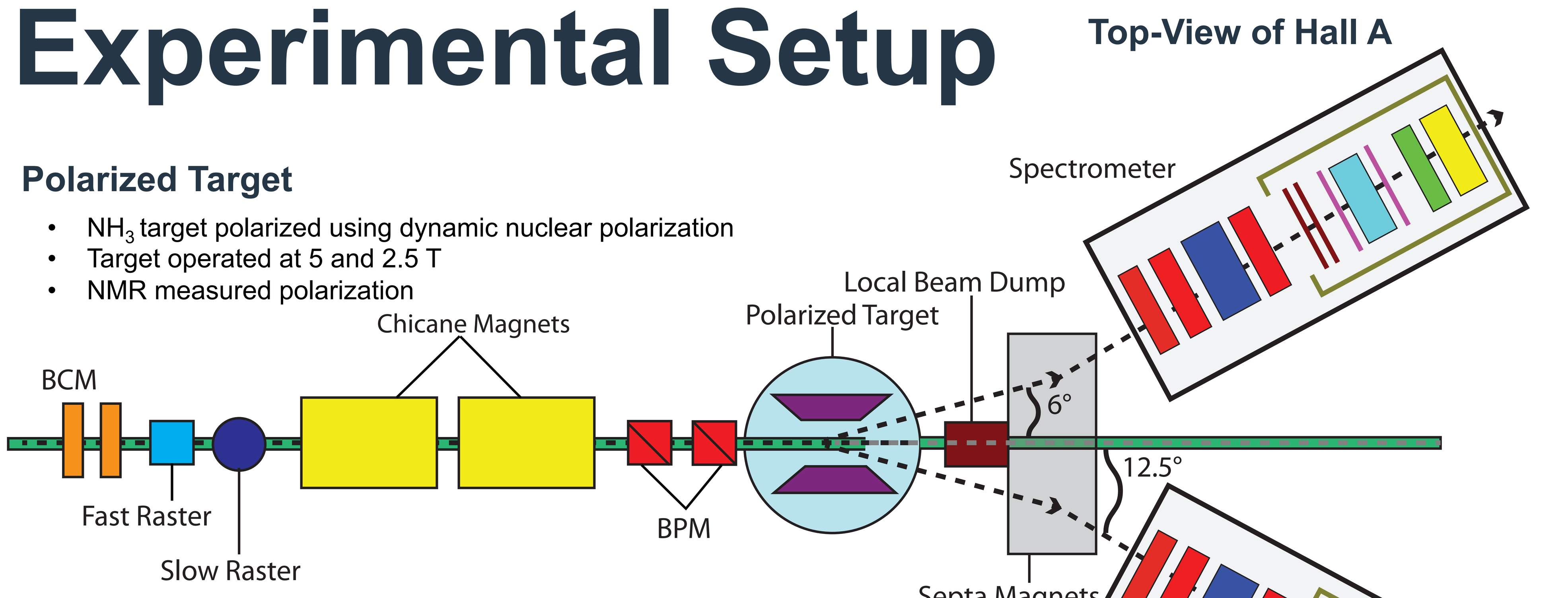
$$\frac{d^2\sigma}{d\Omega dE'}(\Downarrow\Uparrow - \Uparrow\Uparrow) = \frac{4\alpha^2}{M\nu Q^2}\frac{E'}{E}[(E + E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)]$$

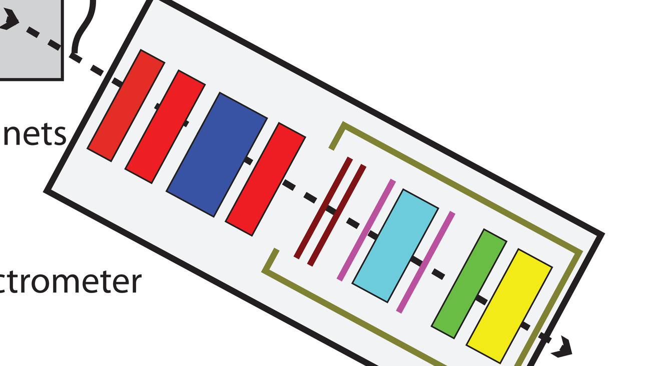
Transverse

$$\frac{d^2\sigma}{d\Omega dE'}(\Downarrow\Rightarrow - \Uparrow\Rightarrow) = \frac{4\alpha^2 \sin\theta}{M\nu^2 Q^2}\frac{E'^2}{E}[\nu g_1(x,Q^2) - 2Eg_2(x,Q^2)]$$

Experimental Setup

Top-View of Hall A





Polarized Target

- NH_3 target polarized using dynamic nuclear polarization
- Target operated at 5 and 2.5 T
- NMR measured polarization

High-Resolution Spectrometers

- Spectrometer detectors provide trigger, tracking and particle identification
- Achieved record Hall A DAQ rate of 6-7 kHz during the run period

Beamline Diagnostics

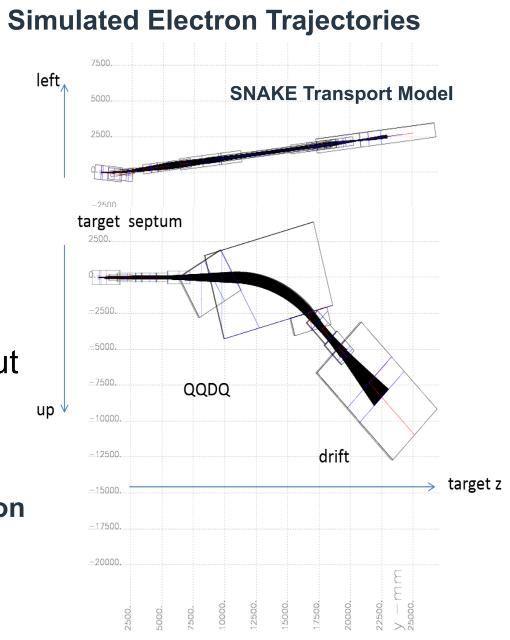
- Low beam current (50 – 100 nA) and fast/slow rasters used to minimize target depolarization
- Two dipole 'chicane' magnets correct for beam bending due to field from polarized target
- Septa magnets bend electrons scattered at 6° to spectrometers set at 12.5°
- Local beam dump for kinematic settings where beam won't reach Hall A dump

Analysis

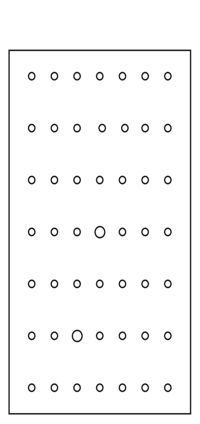
Optics and Simulation

- Optics calibration for the LHRS mostly complete (with and without target field)

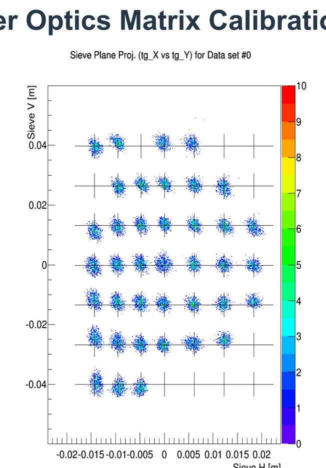
Simulated Electron Trajectories



Sieve Slit

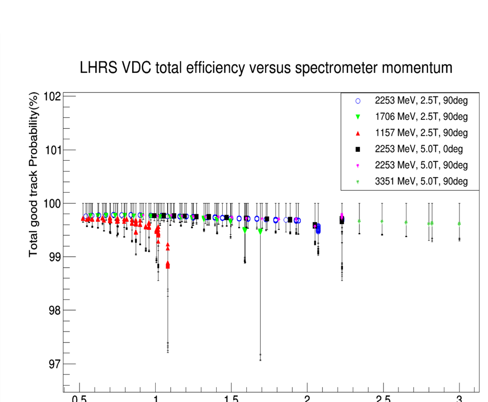


After Optics Matrix Calibration

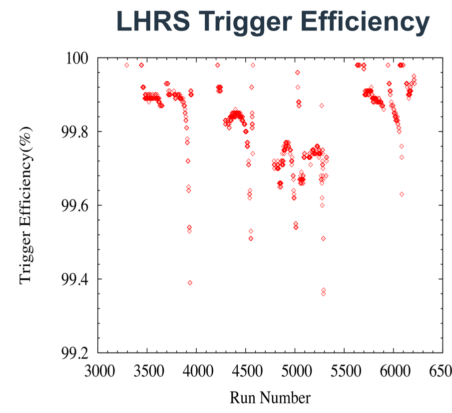


- Monte-Carlo simulates the effect of the target and septum fields in combination with HRS
- Used for optics calibration with target field and also acceptance study

Detector Calibration



LHRS Trigger Efficiency

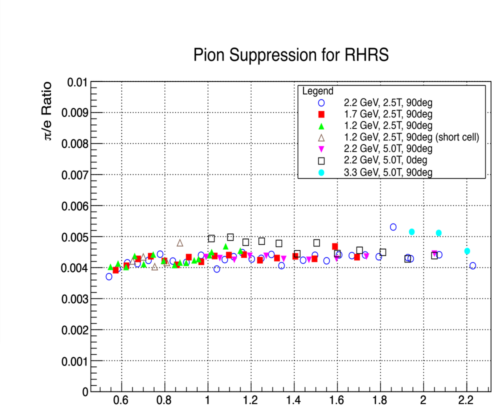


Trigger Efficiency

- Efficiency is above 99% on each HRS

VDC Track Efficiency

- Multi-track events are carefully examined and resolved bringing the systematic uncertainty below 1% for all settings

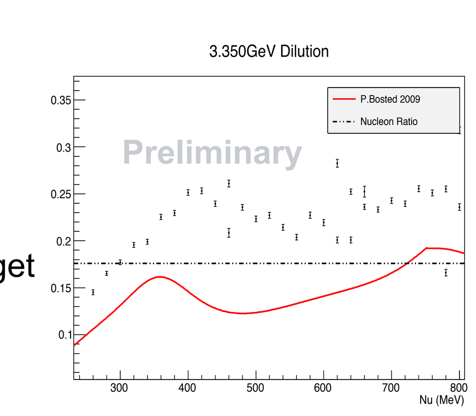


Particle ID

- Cuts to suppress pion contamination are chosen to keep electron detection efficiency above 99%

Dilution Study

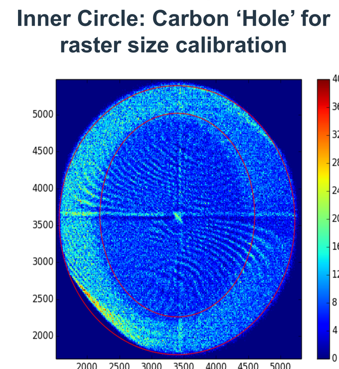
- Dilution factor accounts for scattering from unpolarized material in the ammonia target



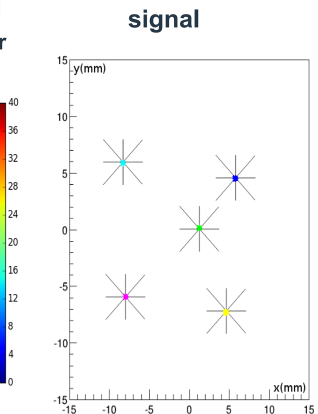
BPM Calibration

- BPM calibration is completed
- Position and angle uncertainty at target center are approx. 1mm and 1mrad, respectively

Slow raster shape at BPM
Inner Circle: Carbon 'Hole' for raster size calibration

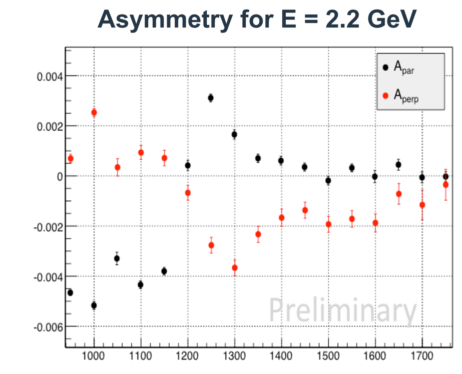


Asterisk: Harp Signal
Points: Calibrated BPM signal

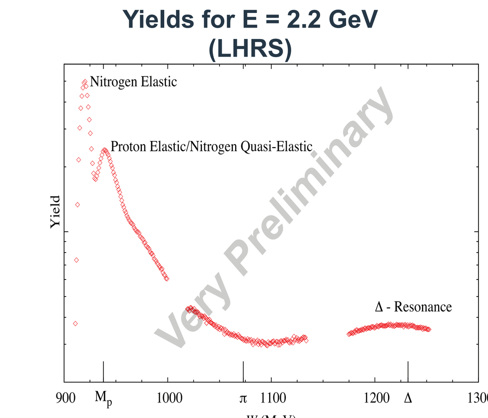


Online Results

Asymmetry for E = 2.2 GeV



Yields for E = 2.2 GeV (LHRS)



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