The g_2^p Experiment: A Measurement of the Proton's Transverse Spin Structure Function

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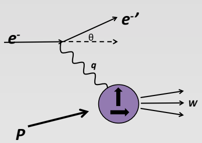
Introduction

A precision measurement of the nucleon spin structure functions is one of the key goals of hadronic physics. Moments of these quantities are powerful tools to test QCD sum rules and provide benchmark tests of Lattice QCD and Chiral Perturbation Theory. JLab Hall A g_2^p experiment explores proton structure function g_2 in the low Q^2 region: $0.02 < Q^2 < 0.2$ GeV^2.

What is g_2^p?

- Deviation from point-like scattering in inclusive scattering is described by *Structure Functions*
- F_1 and F_2 describe the unpolarized case, g_1 and g_2 arise with polarized beam and target
- g_2 is sensitive to higher-twist contributions (quark-gluon interactions)



Unpolarized

$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow + \uparrow\Uparrow) = \frac{8\alpha^2\cos^2(\theta/2)}{Q^4}\left[\frac{F_2(x,Q^2)}{\nu} + \frac{2F_1(x,Q^2)}{M}\tan^2(\theta/2)\right]$$

Longitudinal

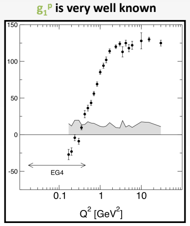
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2}{MQ^2}\frac{E'}{\nu E}\left[(E + E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)\right]$$

Transverse

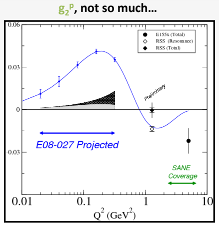
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right]$$

Existing Data

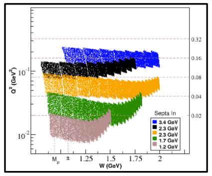
g_1^p is very well known



g_2^p, not so much…

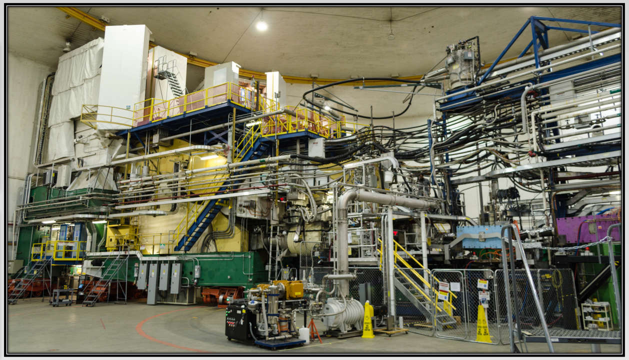


Kinematic Coverage



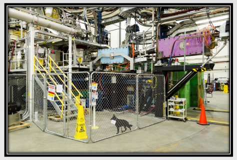
- Low Q^2 region: $0.02 < Q^2 < 0.2$ GeV^2
- This region has not been explored before!

Experimental Setup



Beamline Electronics

- Low beam current (~50 nA) used to minimize target depolarization
  - Required new beamline diagnostics:
    - New Readout electronics for Beam Profile Monitor (BPM) and Beam Current Monitor (BCM)
    - New Harp
    - Refurbished Tungsten Calorimeter, used to calibrate the BCM
    - Slow Raster



Moller Polarimetry

- Uses the principals of Moller scattering
- Measures the polarization of the electron beam

Chicane Magnets

- Electron beam bending due to target field
  - Chicane magnets used to correct for this
  - 1 fixed, 1 moveable for different energy settings
  - Local beam dump needed for 5T target magnet running

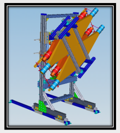
Polarized Ammonia ($^{14}NH_3$) Target

- Dynamic Nuclear Polarization
- Two in-plane directions of target polarization for g_2^p: 0° and 90°
- NMR to measure the target polarization
- 5T magnetic field: max polarization > 90%
- 2.5T magnetic field: max polarization ~40%
- Used at SLAC and Jlab for nearly 20 years

See poster by T. Badman for more details on polarized target

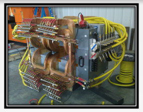
Third Arm Detector

- Online Measuring of beam and target polarization by measuring the elastic asymmetries
  - Measuring elastic asymmetries
  - Detects protons at 70 degrees
- Also very useful as a beam tuning diagnostic!



Septum Magnets

Needed to bend scattered electrons horizontally from 6° to 12.5° into the HRS



Detectors

Left and Right High Resolution Spectrometers (HRS)

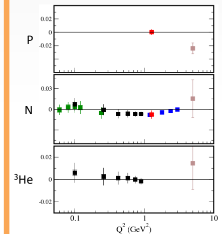
- Vertical Drift Chambers (VDCs)
  - Used to determine "track" of scattered electrons
- 2 planes of Scintillators
  - Form the "trigger" for the Data Acquisition System
- Gas Cherenkov
  - Particle ID: particles heavier than the electron won't produce Cherenkov light
- Lead Glass Calorimeters
  - Pion Rejection provides additional particle ID information

Data Acquisition

- Standard Fastbus Hall A Modules (ADC & TDC)
- Able to reach 6-7 kHz with 20% deadtime

Why g_2^p?

Burkhardt – Cottingham Sum Rule



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

- Fails if the virtual Compton Scattering amplitude (S_2) falls to zero faster than $1/x$
- To approximate the $x \rightarrow 0$ contribution, the Wandzura – Wilczek relation is used:

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

- Relies on the assumption that higher-twist terms vanish as $x \rightarrow 0$!

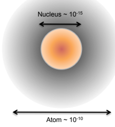
$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}h_T(y,Q^2) + \zeta(y,Q^2)\right]\frac{dy}{y}$$

"If it holds for one Q^2 it holds for all"

R.L. Jaffe Comm. Nucl. Part. Phys. 19, 239 (1990)

Proton Charge Radius

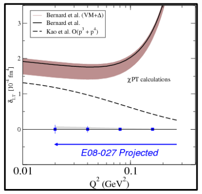
- Bound State QED systems
- Calculations of the hydrogen hyperfine structure
- Hyperfine splitting in ground state of hydrogen has been measured to a relative accuracy of 10^{-13} - Calculations of this quantity are only accurate to a few ppm



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

- Δ_S is the proton structure correction to the uncertainty, and Δ_{pol} contains contributions from g_1 and g_2

Spin Polarizability δ_{LT}



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

- Benchmark test of Chiral Pertubation Theory (χPT)
- χPT calculations are being used to extrapolate to the physical region in Lattice QCD
- Measurement of δ_{LT} would test χPT 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
- Main contribution to integral is from the resonance region