Jefferson lab Hall A DIS program at 12 GeV
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Outline

• Physics:
  • Neutron spin structure at high \( x \); \( A_n^1 \)
  • Parity violating DIS (PVDIS)
  • Semi Inclusive DIS (SIDIS)

• Instrumentation:
  • Hall A provides very high luminosities both unpolarized (1.4 \( \times \) \( 10^{37} \) cm\(^{-2}\)s\(^{-1}\)) and polarized neutron (5 \( \times \) \( 10^{38} \) cm\(^{-2}\)s\(^{-1}\))
  • Hall A has been set aside as the “special installation” hall for 12 GeV: opportunity for creative instrumentation solutions to meet very demanding experimental requirements

  • Super-Bigbite spectrometer
  • Hall A solinoid spectrometer
Neutron spin structure at high $x$: $A^1_n$

- test fundamental predictions of nucleon structure.
- flavor decomposition of polarized PDFs
  - One of the highlighted experiments in the 12 GeV plan
Virtual Photon Asymmetry

\[ A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{g_1}{F_1} \]
$A_1^n$ vs. $x$ for various experiments:

- **This work**
- E142 [51]
- E154 [52]
- HERMES [50]

Graphs showing:

1. $(\Delta u + \Delta d) / (u + d)$
2. $(\Delta d + \Delta \bar{d}) / (d + \bar{d})$

Each graph has a range of curves and data points, indicating different theoretical and experimental results across the x-axis range of 0 to 1.
Already possible with existing equipment

- 6.6 GeV, 8.8 GeV polarized electron beams: 10 µA, Pe = 0.8
- Hall A polarized \(^3\)He target: 30 cm of useful length.
- Bigbite Spectrometer @ 30°
- HRS-L @ 30°
Bigbite Spectrometer in Gen

- successfully used for hall A high $Q^2$ Gen exp.: powerful combination of BigBite + Polarized $^3$He target; up to $L \sim 4.5 \times 10^{36} \text{ cm}^{-2}\text{s}^{-1}$.

- 76 msr over 40 cm of target.
- ~1% momentum resolution
- ~5 mm $y_{tg}$ resolution
With Bigbite alone

Using Bigbite with 6.6 GeV and 8.8 GeV beam ~ 500 h
• GEM trackers - much higher luminosity compared to Bigbite; up to $L \approx 5 \times 10^{38}$ cm$^{-2}$s$^{-1}$.

• 40 msr over 40 cm of target.
• ~0.5% momentum resolution for 4 GeV electrons.
• ~5 mm $y_{tg}$ resolution
Projected data: DIS

- 11 GeV DIS Projected for MPS: 300 hours
- 8.8 GeV DIS: MPS: 75 hours
- 6.6 GeV DIS: MPS: 25 hours
- E99-117 Results

MPS 600 hours @ 40°
Parity Violating Deep Inelastic Scattering (PVDIS)

\[ A_{PV} = \frac{G_F Q^2}{\sqrt{2\pi\alpha}} \left[ a(x) + Y(y) \ b(x) \right] \]

\[ x \equiv x_{\text{Bjorken}} \]
\[ y \equiv 1 - \frac{E'}{E} \]
\[ f_i^{\pm} \equiv f_i \pm f_i \]

For an isoscalar target like $^2\text{H}$, structure functions largely cancel in the ratio at high $x$

At high $x$, $A_{PV}$ becomes independent of $x$, $W$, with well-defined SM prediction for $Q^2$ and $y$

New combination of:
- Vector quark couplings $C_{1q}$
- Also axial quark couplings $C_{2q}$

$C_{2q}$ inaccessible in elastic scattering

Sensitive to new physics at the TeV scale
• Physics potential
  – Excellent sensitivity to $C_{2u}$ and $C_{2d}$.
  – Standard Model Test
  – Charge Symmetry Violation (CSV)
  – Higher Twist
  – d/u for the Proton
E08-011: PVDIS off $^2\text{H}$ at 6 GeV

Proposal approved for 11 GeV:
Factor of ~ 2 to 3 improvement

- 08-011 provides first look, at $x\sim0.25-0.3$
- Insensitive to CSV, HT, but possibly sensitive to the quark sea?
- 11 GeV, allows greater precision at higher $x$, but doesn’t provide lever arm to fully separate QCD effects
A Design for Precision PV DIS Physics

- **High Luminosity on LH$_2$ & LD$_2$**
- **Better than 1% errors for small bins**
- **x-range 0.25-0.75**
- **$W^2 > 4$ GeV$^2$**
- **$Q^2$ range a factor of 2 for each $x$**
  - (Except $x$~0.75)
- **Moderate running times**

- **Solenoid (from BaBar, CDF or CLEOII )**
  - contains low energy backgrounds (Moller, pions, etc)
  - trajectories measured after baffles
- **Fast tracking, particle ID, calorimetry, and pipeline electronics**
- **Precision polarimetry (0.4%)**
SoLID Spectrometer

- Gas Cerenkov
- Baffles
- GEM’s
Statistical Errors (%) vs Kinematics

Strategy: sub-1% precision over broad kinematic range for sensitive Standard Model test and detailed study of hadronic structure contributions

Error bar $\sigma_{A/A} (%)$ shown at center of bins in $Q^2$, $x$

4 months at 11 GeV

2 months at 6.6 GeV
Sensitivity: $C_1$ and $C_2$ Plots

World’s data

Precision Data

1/27/2009
Impressive precision on $\sin^2 \theta_w$ (comparable to $Q_{\text{weak}}$) but real value is not sensitive to different combination of couplings.

Constraint on contact interactions

$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2 + g_{RL}^2 - g_{LR}^2|}} \approx 2.5 \text{ TeV}$$
CSV with PVDIS

Parton-level charge symmetry assumed in deriving $^2\text{H}$

$A_{PV}$

Charge Symmetry Violation

$$\delta u(x) = u^p(x) - d^n(x)$$

• $u,d$ quark mass difference

$$\delta d(x) = d^p(x) - u^n(x)$$

• electromagnetic effects

$$R_{CSV} = \frac{\delta A_{PV}(x)}{A_{PV}(x)} = 0.28 \frac{\delta u(x) - \delta d(x)}{u(x) + d(x)}$$

• Direct observation of parton-level CSV would be very exciting!

• Important implications for high energy collider pdfs

• Could explain significant portion of the NuTeV anomaly
Higher Twist

Does higher twist fully cancel from the asymmetry?

At higher x, a more interesting higher twist effect may be evident:

\[ F_2(x,Q^2) = F_2(x)(1+D(x)/Q^2) \]

- \( A_{PV} \) sensitive to diquarks: ratio of weak to electromagnetic charge depends on amount coherence
- Do diquarks have twice the x of single quarks?

\[ A_{PV} = A_{PV}(1+C_{HT}(x)/Q^2) \]
PVDIS on the Proton: d/u at High x

\[ a^P(x) \approx \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)} \]

Deuterons analysis has large nuclear corrections (Yellow)

A_{PV} for the proton has no such corrections (complementary to BONUS)

The challenge is to get statistical and systematic errors ~ 2%

3-month run
Neutron Transversity

- Transversity and *TMDs*
  - From exploration to precision study
  - Transversity: fundamental PDFs, tensor charge
  - TMDs provide 3-d structure information of the nucleon
  - Laboratory to study QCD
  - Learn about quark orbital angular momentum
  - Multi-dimensional mapping of TMDs
  - 3-d \((x, z, P^\perp)\)
  - Q2 dependence
  - multi facilities, global effort

- Demanding measurement
  - Multi-dimension, small asymmetries, precision \(\rightarrow\) very high statistics
  - High luminosity AND large acceptance needed
  - With the proposed spectrometers Hall A can do Transversity and *TMDs*: unprecedented precision
Solenoid detector for SIDIS

GEMs

Gas Cerenkov

Calorimeter

3\textsuperscript{He} target

3\textsuperscript{He} target
SIDIS Kinematical with the Solenoid ($10^\circ - 170^\circ$)

- $Q^2$ vs $x$
- $P_T$ vs $x$
- $W$ vs $x$
- $z$ vs $x$
Projection vs $P_T$ and $x$ for $\pi^+$ (60 days)

- For one $z$ bin (0.5-0.6)
- Will obtain 4 $z$ bins (0.3-0.7)
- Also $\pi^-$ at same time
- With upgraded PID for $K^+$ and $K^-$
Measurement of the Semi-Inclusive $\pi$ and $K$ electro-production in DIS regime from transversely polarized $^3$He target with the SBS & BB spectrometers in Hall A

G. Cates, E. Cisbani, G.B. Franklin, B. Wojtsekhowski
and the SBS Collaboration

http://hallaweb.jlab.org/12GeV/SuperBigBite

- Extract Sivers and Collins (and Pretzelosity) asymmetries on $\pi$ and $K$ with high statistics
- Provide 2D binning (at least) on the relevant variables: $x$, $P_\perp$ and $z$, for both hadrons
- Provide $Q^2$ dependence
- Explore for the first time the high $x$ valence region (with overlap to HERMES, COMPASS, JLab6 data)
Experimental Setup and parameters
\[ e^{+} + ^3\text{He} \rightarrow e^{'+} + \pi(K)^{\pm} + X \]

**Beam:** 50 μA, E=8.8 and 11 GeV (80% long. Pol.)

**Target:** 65% polarized 3He ⇐ GEn(2)/PR-09-016

\[ \text{Luminosity: } 1.4 \times 10^{37} \text{ cm}^{-2}\text{s}^{-1} \text{, } 0.05 \text{ sr} \]

**BB:** e-arm at 30°
- Ω = 45 msr
- GEM Tracker
- Gas Cherenkov Shower

\[ \text{⇠ GMn/PR-09-019} \]

**SBS:** h-arm at 14°
- Ω = 50 msr
- GEM tracker
- excellent PID / RICH
- Hadron CALO

**Event rate:** \( \sim 10^4 \times \text{HERMES} \)

60 days of production
expected stat. accuracy:
1/10 of proton HERMES
We will investigate the $Q^2$ dependence of the Sivers and Collins functions, with overlap in the region of HERMES; reveal higher twist effects. Analysis of the $Q^2$ effect will use also the results of presently running 6 GeV E06-010 Transversity experiment.
Conclusion

• Proposed Super-Bigbite and SoLID spectrometers in Hall A enable a very exciting DIS program
• Neutron spin structure at high $x$: $A_1^n$
  • test fundamental predictions of nucleon structure.
  • flavor decomposition of polarized pdfs
• Parity violating DIS (PVDIS)
  • Excellent sensitivity to $C2u$ and $C2d$.
  • Test CSV at quark level.
  • Unique window on higher twists.
• Semi Inclusive DIS (SIDIS)
  • ~3 orders of magnitude improvement
  • Transversity and TMDs
  • Entering a new era of precision study:
  • 3-dimentional “mapping” ($x$, PT and $z$)