Transverse Asymmetries from HAPPEX and E158

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Some slides stolen from Krishna Kumar
Outline

• Why we bother with the ep transverse asymmetry
• What is known about ep transverse asymmetry
• Results from HAPPEX (and hints from E158)
• Moller Transverse Asymmetry
Transverse Asymmetries

Beam-Normal Asymmetry in elastic electron scattering

Electron beam polarized transverse to beam direction

\[ A_T \equiv \frac{2\pi}{\sigma^\uparrow + \sigma^\downarrow} \frac{d(\sigma^\uparrow - \sigma^\downarrow)}{d\phi} \propto S_e \cdot (k_e \times k'_e) \]

Interference between one- and two-photon exchange

\[ A_T \propto \frac{\alpha m_e}{\sqrt{S}} \]

Effect suppressed by
- \( \alpha \)
- Lorentz boost

\( A_T > 0 \) means "elastic"

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Transverse Asymmetry
Parity-Violation experiments

All PV experiments can, and do, measure these to control possible systematic errors.

PV experiments are optimized for small asymmetries:
• High luminosity, low noise
• Careful control of false asymmetries
• Rapid helicity flip to cancel drifts, reduce noise
• Symmetric configurations to cancel beam asymmetries

Measurements are (or will be soon) available sampling a wide range of kinematics:
• SAMPLE (200 MeV, back angle)
• A4 (570 MeV, 855 MeV, large angle)
• HAPPEX (3 GeV, forward angle)
• G0 (3 GeV, forward angles)
• E158 (45 GeV, very forward angle)
• future back-angle A4, G0
(Surprising?) Radiative Correction

Rosenbluth vs polarization transfer measurements of $G_E/G_M$ of proton

Two methods, two different results!

SLAC
Rosenbluth data

Jlab/Hall A
Polarization data
Jones et al. (2000)
Gayou et al. (2002)
Interest in 2-γ Diagrams

Speculation: missing radiative corrections

Speculation: there are radiative corrections to Rosenbluth experiments that are important and are not included.

Missing correction: linear in $\varepsilon$, not strongly $Q^2$ dependent.

$G_E$ term is proportionally smaller at large $Q^2$,
effect more visible at large $Q^2$.

\[ Q^2 = 6 \text{ GeV}^2 \]

\[ \frac{G_E^2}{\tau G_M^2} = \frac{4 M^2}{Q^2 \mu_p^2} = 7.5\% \]

if both FF scale in same way.
Interest in $A_T$

$G_E/G_M$ is influenced by the real part of 2-$\gamma$ amplitude. $A_T$ is generated from the imaginary part of the 2-$\gamma$ amplitude.

$A_T$ is T-odd, P-even

- As a radiative correction, it is similar to other T-odd QED FSI that obscure measurements of nuclear $\gamma$-decay, neutron $\beta$-decay, or other searches for T-odd, P-even interactions.

Probe of nucleon structure

- Doubly virtual Compton scattering (VVCS) constrains interpretation from DVCS

Dominated by spectrum of hadronic intermediate states

- Provides a clear and accessible window on the treatment of hadronic intermediate states in box diagrams.

Pasquini & Vanderhaeghen

Diaconescu & M.J. Ramsey-Musolf

hep-ph/0405303

nucl-th/0405044

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**A_\perp Data from 0.2 GeV**

Adding magnetic piece to Mott asymmetry seems to explain the data.

Requires no inelastic intermediate state to match A_n at this energies.

Approach limited to very low E_e.

Pasquini & Vanderhaeghen

Resonance region treated in a model incorporating pion electroproduction amplitudes.
Resonance region treated in a model incorporating pion electroproduction amplitudes

Sum over intermediate states shows quasi-real compton peak near $W_{\text{max}}$

A4 and G0 at backward angle are ideal places to study the large expected strength from the resonance region

New data at forward angle from G0 and HAPPEX at 3 GeV:

$A_T$ begins to get strength from $W > 2$ GeV
Integrand: beam normal spin asymmetry

$E_e = 0.855 \text{ GeV}$

$\theta_{\text{c.m.}} = 30^\circ$

$\theta_{\text{c.m.}} = 60^\circ$

$\theta_{\text{c.m.}} = 120^\circ$

$W (\text{GeV})$

$\sqrt{s}$

$\pi^0 p$

$\pi^+ n$

Total

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Transverse Asymmetry
Integrand: beam normal spin asymmetry

\( E_e = 3 \text{ GeV} \)

\( W_{\text{max}} = 2.55 \text{ GeV} \)

\( \theta_{\text{c.m.}} = 30^\circ \)

\( \theta_{\text{c.m.}} = 60^\circ \)

\( \theta_{\text{c.m.}} = 120^\circ \)

\( W (\text{GeV}) \)

\( \pi^0 p \)

\( \pi^+ n \)

MAID

Total

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$A_T^{ep}$ at low $Q^2$, Forward Angle

- **Optical theorem**: relate to $\sigma_{tot}(\gamma^{(*)}p)$

- **Low $Q^2$ and very forward angle**
  - Reproduces Pasquini and Vanderhagen when single-pion cross-sections are used with $W_{cut} = 2 \text{ GeV}$
  - $\frac{3}{4}$ of asymmetry comes from $W > 2 \text{ GeV}$

For a fixed $Q^2$, flat with beam energy

Afanasev and Merenkov, hep-ph/0406127

![Graph showing normal beam asymmetry for elastic ep-scattering](image)

- Normal asymmetry for elastic ep-scattering
- Unitarity-based model predictions
- $E_c = 3 \text{ GeV}$
Two high resolution spectrometers
- acceptance approximately in horizontal plane
- left-right symmetric spectrometers

Vertical Polarization:
- Created in injector using solenoid to rotate polarization
- Measured in injector with Mott, not expected to change
- Measured (roughly) in Hall A using tilted Moller foil
HAPPEX 2004 Result

\[ E_e = 3 \text{ GeV}, \theta_{CM} \sim 16^\circ \]

\[ A_T = -6.6 \text{ ppm } \pm 1.5 \text{ ppm (stat)} \pm 0.2 \text{ ppm (syst)} \]

Total corrections \(\sim 200 \text{ ppb}\)

Dominant systematic errors:
- Polarimetry (190 ppb)
- Beam asymmetry (100 ppb)
- Al background dilution (70 ppb, assumed \(A_T^{\text{Al}} = 0\))

Compare to A4:
(same \(Q^2, E_e = .85 \text{ GeV}\))
\[ A_T = -8.59 \pm 0.89_{\text{stat}} \pm 0.75_{\text{sys}} \text{ ppm} \]

Coming Soon: much from G0

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E158 Spectrometer

- Magnetic spectrometer focuses signal, removes background
- Analog integration of calorimeter signal
  - Very forward angle, azimuthal acceptance
  - Line-of-sight shielding requires a “dogleg” or “chicane”
Spectrometer
Quadrupole Quadruplet

- primary & scattered electrons enclosed in quadrupoles
- Mollers (e-e) focused, Motts (e-p) defocused
- full range of azimuth

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Transverse Asymmetry
Transverse Asymmetry

46 GeV
$ep \rightarrow ep$

$Q^2 \sim 0.06 \text{ GeV}^2$

$\sim 24 \text{ hrs of data}$

Sign: $A_T < 0$
Magnitude: $\sim 2.5 \text{ ppm}$

Without enhancement by inelastic states, $A_T \sim 10^{-10}$

Final Precision will approach 3% (stat) and 7% (syst)

Corrections to be made:
- Polarization
- Background corrections
  - $\sim 25\%$ inelastic $ep$ ($A_T = 0$)
  - Pions $\sim 0.5\%$ and $A_T < 10 \text{ ppm}$

Dominant Systematic Errors:
- Polarization
- Background
- Spectrometer Acceptance (kinematics)

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Transverse Asymmetry
A\_T in Møller Scattering

\[ \sqrt{s} \approx 200 \text{MeV} \]

**E158 acceptance is mostly in the backward direction**

Theory References:
1. A. O. Barut and C. Fronsdal, (1960)
2. L. L. DeRaad, Jr. and Y. J. Ng (1975)
3. Lance Dixon and Marc Schreiber: hep/ph-0402221
   *(Included bremsstrahlung corrections: few percent)*

Prediction for 46 GeV: ~ -3.5 ppm

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Transverse Asymmetry
$A_{T^{ee}}$ at E158

46 GeV
$ee \rightarrow ee$
backward angle

Sign: opposite $A_{T^{ep}}$?
Magnitude: ~3.5 ppm

If confirmed, sign would disagree with published predictions, BUT
• experimental cross-checks are not complete
• some authors now wonder about the sign...

Final Precision will approach 3% (stat) and 10% (syst)

Corrections to be made:
• Polarization
• Background corrections
  • ~9% ep

Dominant Systematic Errors:
• Polarization
• Background
• Spectrometer Acceptance (kinematics)
Conclusions

$A_T$ provides a window on imaginary part of $\gamma$-exchange amplitude.

Large angle points <1 GeV show sensitivity to resonance region.

Forward angle 3 GeV results appear well modeled, with clear influence of $W>2$ GeV.
New $G_0$ Data will test calculations with increasing angle at 3 GeV.

E158 will provide precise 46 GeV points for very forward ep, backangle Möller.