Measurement of the Target Single-Spin Asymmetry in Quasi-Elastic $^3\text{He}^{\uparrow}(e, e')$

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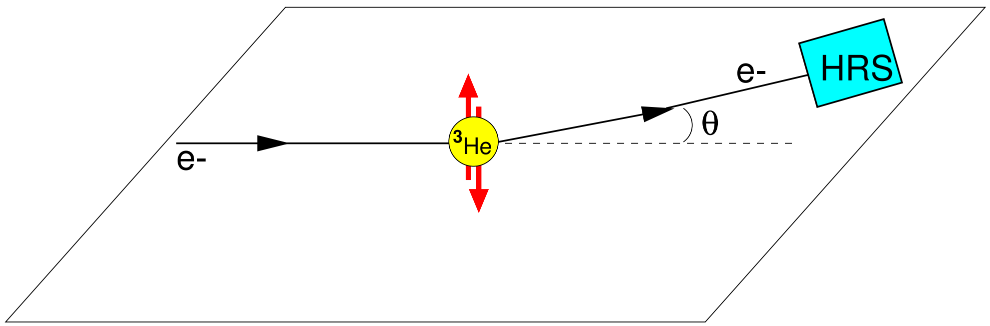
A Hall A collaboration experiment

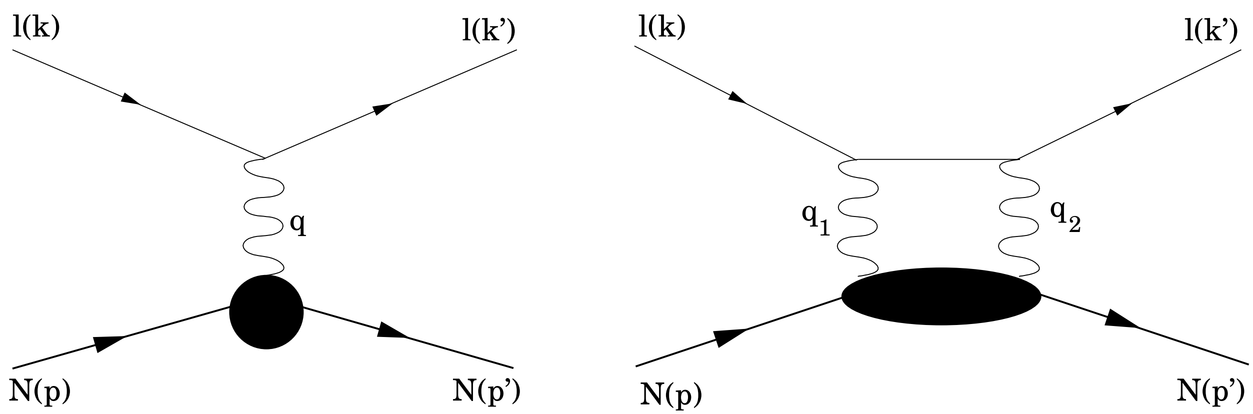
Overview and Goals



- Inclusive quasi-elastic scattering, unpolarized beam.
- Spin-1/2 target polarized perpendicular to electron scattering plane.
- Measure single-spin asymmetry (SSA) A_y from target spin flip.
- Non-zero A_y arises when 2γ-exchange is included.
- 2γ exchange sensitive to nucleon dynamics; related to GPD moments.

$$A_y = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Key Points of this Experiment



$\Longrightarrow A_y \equiv 0$ for 1γ exchange

$\Longrightarrow A_y \neq 0$ due to imaginary part of $1\gamma \otimes 2\gamma$ interference

- A clearly non-zero A_y has never been measured.
- Evaluation of box diagram involves *full* nucleon response to doubly virtual Compton scattering. Model dependent.

P.A.M. Guichon and M. Vanderhaeghen, arXiv:hep-ph/0306007 v3

Key Points (con't)

- Below pion threshold, elastic intermediate state only; well-understood
- Above pion threshold, inelastic response needed.
- Can insert specific resonant or DIS response.

  A. Afanasev, I. Akushevich and N.P. Merenkov, arXiv:hep-ph/0403058
- Or, nucleon response can be related to moments of GPDs.
- Neutron has unique sensitivity to GPDs due to small G_E^n.
- Neutron technically much easier than proton measurement; No new equipment needed.

Elastic eN Scattering

Y.-C. Chen, A. Afanasev, S. J. Brodsky, C. E. Carlson and M. Vanderhaeghen, PRL **93** (2004) 122301

- For the elastic reaction $e(k) + N(p) \;\rightarrow\; e(k') + N(p')$,

$$T_{\lambda_h, \lambda'_N \lambda_N} = \frac{e^2}{Q^2}\,\bar{u}(k', \lambda_h)\gamma_\mu u(k, \lambda_h)$$

$$\times\,\bar{u}(p', \lambda'_N)\left(\tilde{G}_M\,\gamma^\mu - \tilde{F}_2\frac{P^\mu}{M} + \tilde{F}_3\frac{\gamma\cdot K P^\mu}{M^2}\right)u(p, \lambda_N)$$

The λ_i are the lepton and hadron helicities, P, K are kinematic factors.

- Complex functions containing nucleon structure information:

$$\begin{aligned}
\tilde{G}_M(\nu, Q^2) &= G_M^{(\mathrm{Born})}(Q^2) + \delta\tilde{G}_M(\nu, Q^2) \\
\tilde{F}_2(\nu, Q^2) &= F_2^{(\mathrm{Born})}(Q^2) + \delta\tilde{F}_2(\nu, Q^2) \\
\tilde{F}_3(\nu, Q^2) &= 0 \text{ for Born scattering}
\end{aligned}$$

- $\delta\tilde{G}_M$, $\delta\tilde{F}_2$, $\tilde{F}_3$ come from 2γ-exchange (up to $\mathcal{O}(e^4)$)

2γ-Contribution to eN Scattering

- Unpolarized cross section related to *Real* part of amplitude,

$$\sigma_R = G_M^2 + \frac{\varepsilon}{\tau} G_E^2 \quad \text{(Born)}$$
$$+ \; 2G_M \mathcal{R}\text{e}\left(\delta\tilde{G}_M + \varepsilon\frac{\nu}{M^2}\tilde{F}_3\right) + 2\frac{\varepsilon}{\tau} G_E \mathcal{R}\text{e}\left(\delta\tilde{G}_E + \frac{\nu}{M^2}\tilde{F}_3\right)$$

- For 1γ-exchange,
  - $\delta\tilde{G}_M = \delta\tilde{F}_2\,(\delta\tilde{G}_E) = \tilde{F}_3 = 0$
  - Time-Reversal Invariance requires $G_M,\; F_2\,(G_E)$ are real
- For 2γ-contribution,
  - Two terms, proportional to G_E and G_M
  - 2γ-contributes $\approx 2\%$ to cross section; Important for G_E^p/G_M^p

2γ-Contribution to A_y

- Assuming Time-Reversal Invariance, A_y is related to the *Imaginary* (absorptive) part of transition amplitude, (T_A),

  A. DeRujula *et al.*, Nuc. Phys. B35 (1971) 365.

$$A_y \propto \frac{\mathcal{I}\mathrm{m}(T^* T_A)}{|T|^2}$$

- For 1γ-exchange,
  - T_A is zero, $\Longrightarrow$ $A_y \equiv 0$ for all Born processes.
- For $1\gamma \otimes 2\gamma$-interference, amplitude is complex.
  - 2γ box diagram gives non-zero absorptive part; $T_A \neq 0$
  - $\Longrightarrow$ $A_y \neq 0$

2γ-contribution to A_y (con't)

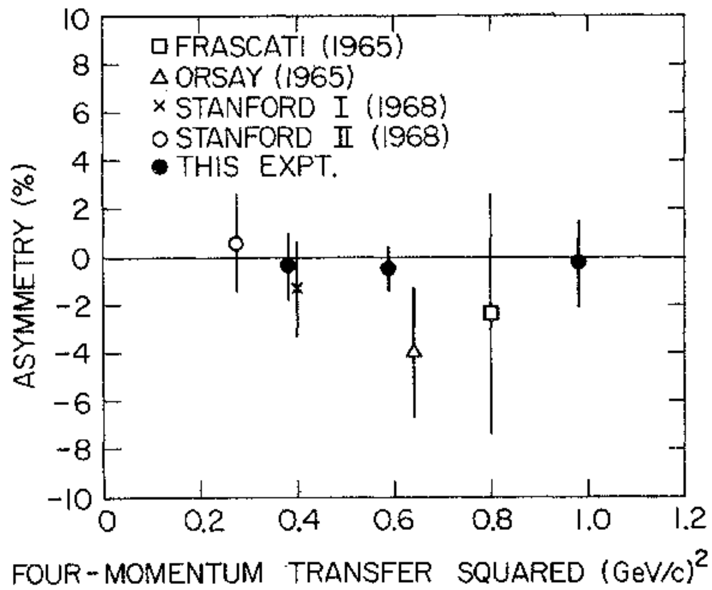
$$A_y = \sqrt{\frac{2\,\varepsilon\,(1+\varepsilon)}{\tau}}\;\frac{1}{\sigma_R}$$

$$\times\left\{-G_M\,\mathcal{I}\mathrm{m}\left(\delta\tilde{G}_E + \frac{\nu}{M^2}\tilde{F}_3\right) + G_E\,\mathcal{I}\mathrm{m}\left(\delta\tilde{G}_M + \left(\frac{2\varepsilon}{1+\varepsilon}\right)\frac{\nu}{M^2}\tilde{F}_3\right)\right\}$$

- For the neutron, G_E^n is small $\Longrightarrow$ A_y^n dominated by G_M^n term.

Existing A_y Data

- SLAC Proton Data, expected $A_y^p < 1\%$, T. Powell *et al.*, PRL **24** (1970) 753.

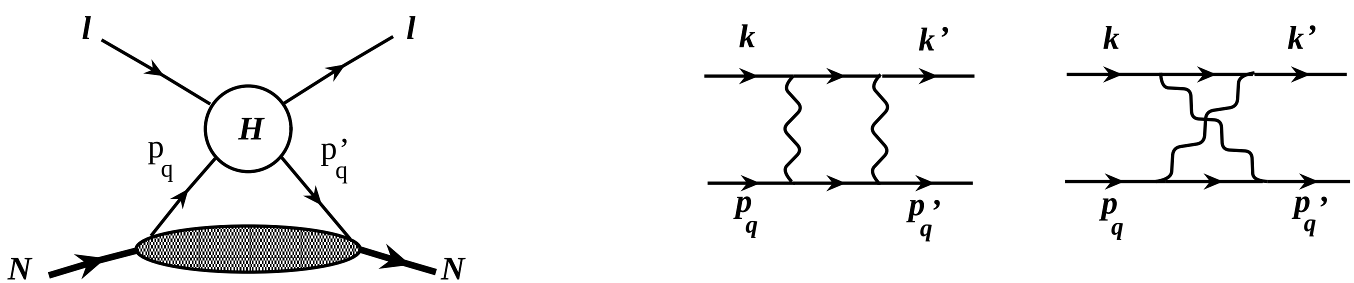


- NIKHEF QE ^{3}He$^\uparrow(e,e')$ at $Q^2 = 0.1$ GeV^2 gave $A_y = -9.5 \pm 5.4\%$.

  M. C. Harvey, Ph.D. thesis, Hampton University, 2001

- Precision measurements of A_y do not exist!

Connection with Generalized Parton Distributions (GPDs)



- For large enough Q^2, assume scattering described by hangbag diagram with box and crossed diagrams for 2γ exchange at hard vertex H.
- Only 2γ box diagram contributes to A_y.
- Elastic intermediate believed well-understood, $A^n_{y,elas} \approx -1\%$

  A. Afanasev *et al.*, arXiv:hep-ph/0403058
- Inelastic intermediate state calculated using GPD model.

Connection with (GPDs) (con't)

Y.-C. Chen, A. Afanasev, S. J. Brodsky, C. E. Carlson and M. Vanderhaeghen, PRL **93** (2004) 122301

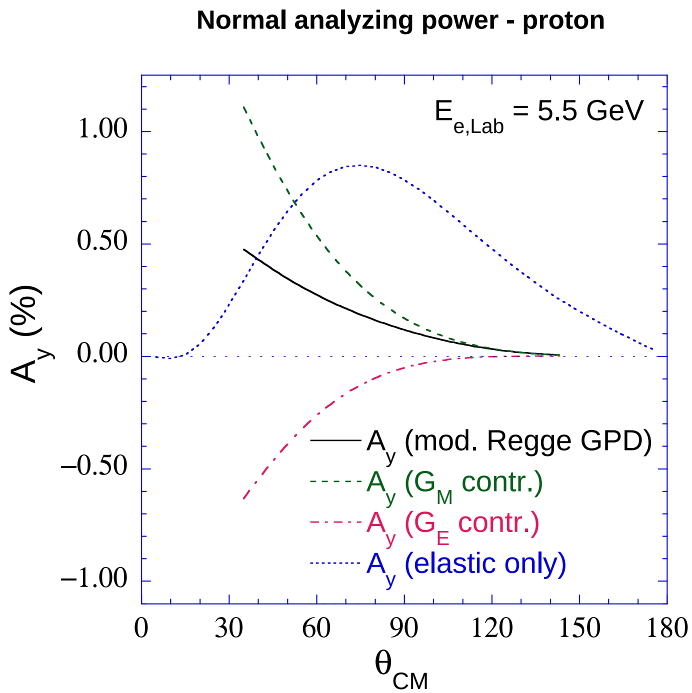
$$A_y = \sqrt{\frac{2\,\varepsilon\,(1+\varepsilon)}{\tau}}\;\frac{1}{\sigma_R}\,\{-G_M\,\mathcal{I}\mathrm{m}\,(B) + G_E\,\mathcal{I}\mathrm{m}\,(A)\}$$

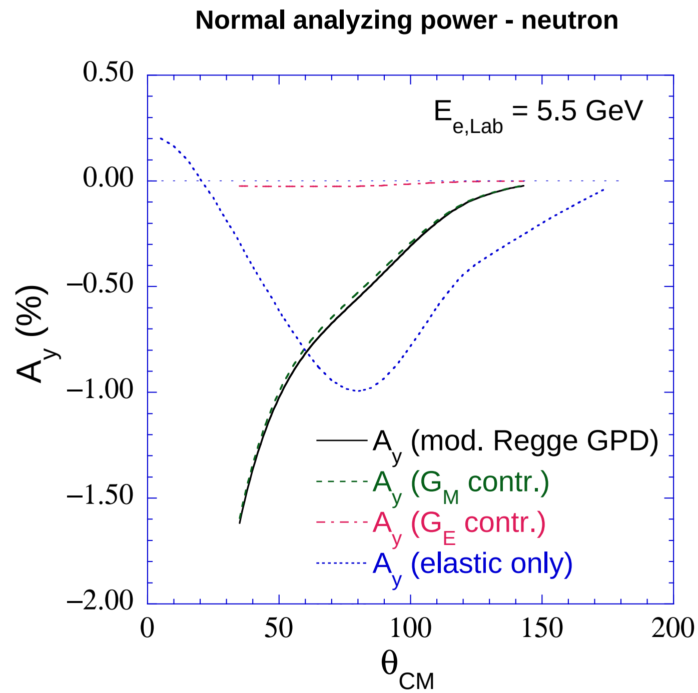
$$A = \int_{-1}^{1} \frac{dx}{x} K \sum_q e_q^2 \left[H^q(x,0,t) + E^q(x,0,t)\right]$$

$$B = \int_{-1}^{1} \frac{dx}{x} K \sum_q e_q^2 \left[H^q(x,0,t) - \tau E^q(x,0,t)\right]$$

- $t = -Q^2$, K and K' contain the contributions from the hard scattering amplitudes.
- H^q and E^q are GPD's for quarks of flavor q.

GPD model calculations





- Neutron dominated by G_M^n term.
- Proton has approx. equal and opposite contributions from G_E^p and G_M^p.
- Neutron asymmetry $A_y^n \approx -1.7\%$ at $\theta_{cm} \approx 60^\circ$

The Experiment

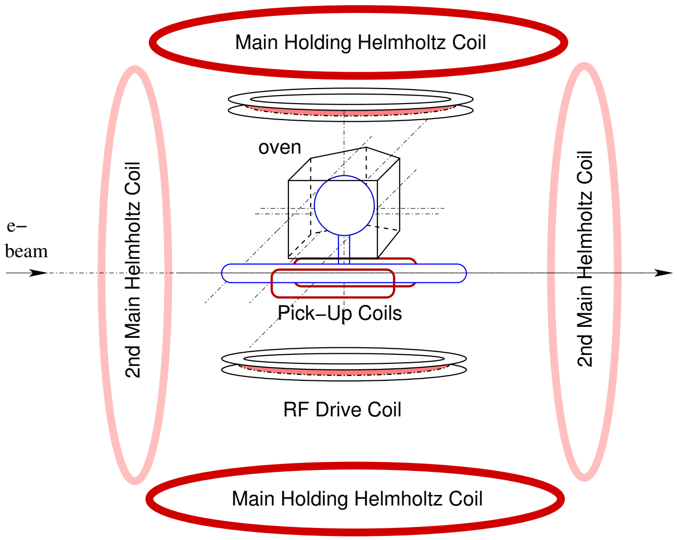
- Measure A_y using vertically polarized ^{3}He at $Q^2 = 1.0$ and 2.3 GeV^2.
- Expected statistical error $\delta A_y^n \approx 0.0023$ (15% relative to GPD model prediction).
- Use HRS spectrometers in singles mode for electron detection, (note $A_y(\theta) = -A_y(-\theta)$).
- Vertically polarized target available from E03-004 (Transversity expt).
- Beam request: 28 days
- Easy installation; No new equipment required

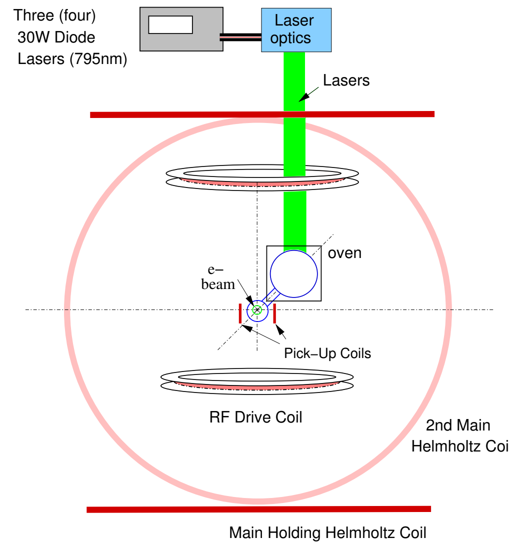
Kinematics

E_0 (GeV)	Q^2 (GeV^2)	E' (GeV)	θ_e (deg)	θ_e^{cm} (deg)	e^- rate (10^6/day)	Time (days)	δA_y^n ($\times 10^{-3}$)
3.30	0.50	3.03	12.85	35.4	405.0	1	1.2
3.30	1.01	2.76	19.15	51.1	28.6	6	2.1
5.50	2.26	4.30	17.80	58.4	2.3	17	2.5

- Production beam time = 24 days
- Target and detector overhead = 4 days
- **Total beam time request = 28 days**

Vertically Polarized ^{3}He Target





- New hybrid target technology expected to improve in-beam ^{3}He polarization.
- Assume $P_t \approx 0.42$, $I_{beam} \approx 15\mu$A.
- Fast spin reversals needed to minimize systematic uncertainties.

Backgrounds

- Inclusive reaction; Hadronic final states are integrated over

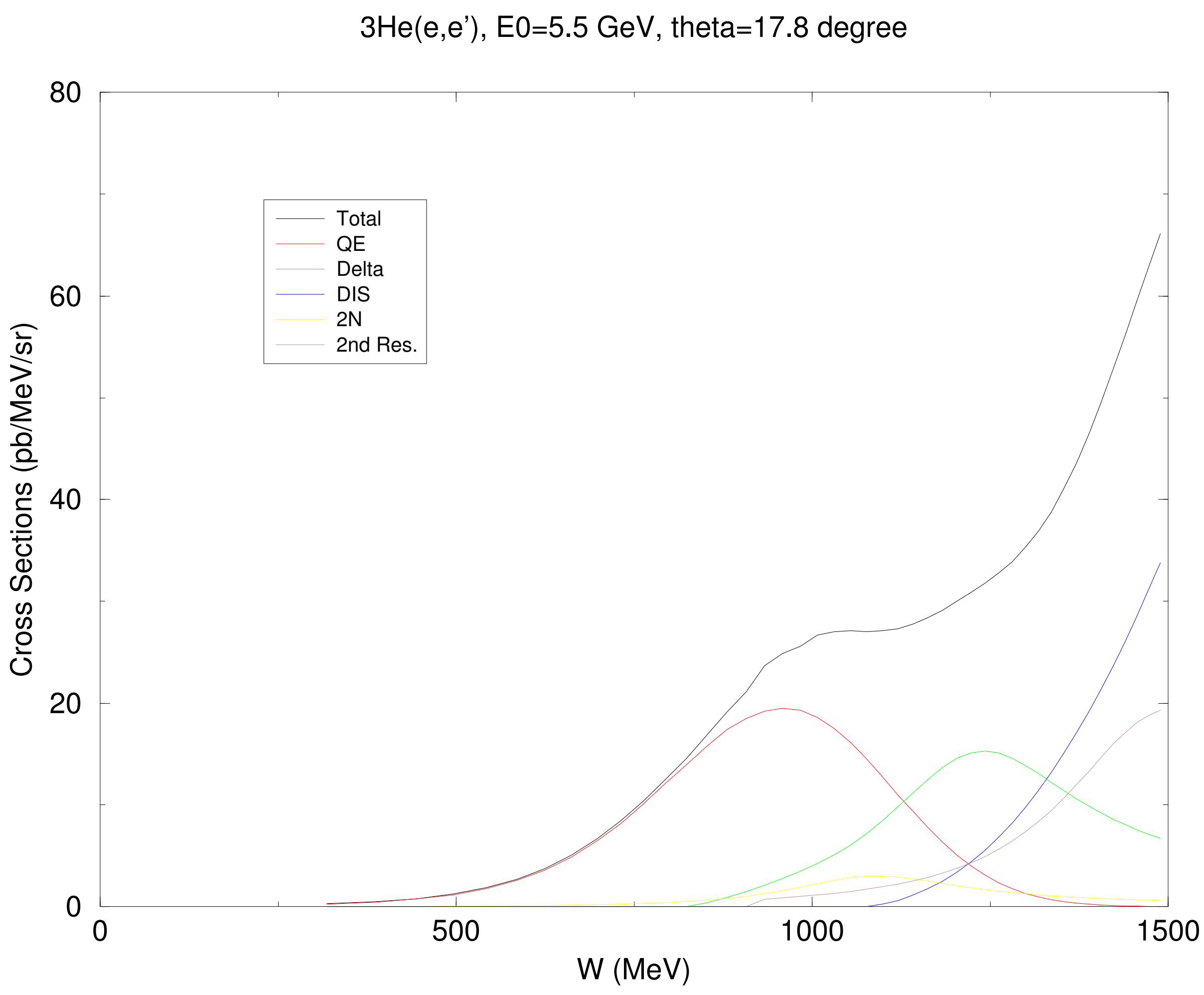
  $\Longrightarrow$ no FSI contribution to A_y.

  N. Christ, T.D. Lee, Phys. Rev. **143** (1966) 1310

- There are no channels which contribute at Born-level.

- 2γ backgrounds:
  - Elastic tail negligible at these kinematics.
  - Inelastic tail contributions from resonances and DIS.
  - Estimate $A^n_{inelas} < 2\%$ for Δ and DIS, A. Afanasev calculation
  - Systematic error from tails $\delta A^n_{inelas} \simeq 0.0003 - 0.001$

Inelastic Tails



Nuclear Correction

F. Bissey *et al.*, Pys. Rev. C**65** (2002) 064317

- Correct for proton polarization in ^{3}He

$$A_y^{^3\mathrm{He}} = \frac{\sigma^n}{\sigma^0} P_n A_y^n + \frac{\sigma^p}{\sigma^0} P_p A_y^p$$

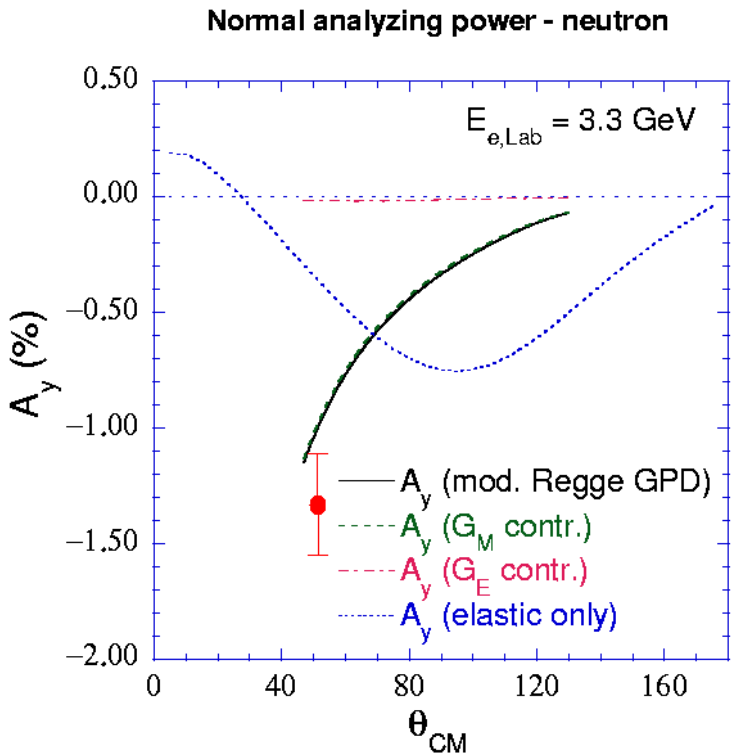
- σ^n, σ^p and σ^0 are the unpol. QE cross sections for n, p, and $total$.
- $P_n \simeq 0.86$ and $P_p \simeq -0.028$
- Largest experimental uncertainty comes from unmeasured A_y^p and gives $4-8\%$ systematic uncertainty on A_y^n.

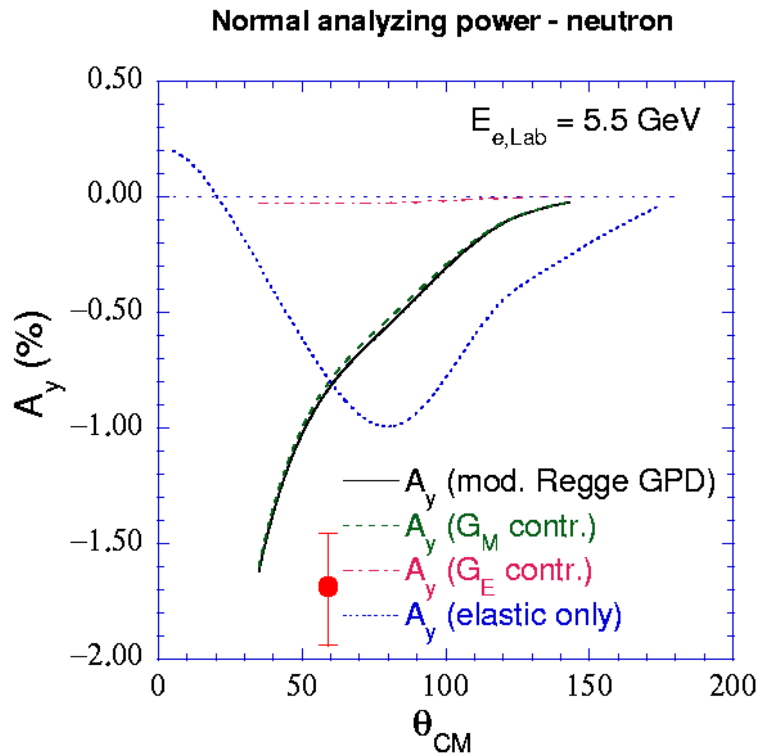
Systematic Uncertainties

Source	Uncertainty in A_y (%, relative to GPD model prediction)
Target polarization	4
Nuclear correction	4-8
Radiative corrections	3
Luminosity correction	1
Inelastic background	2-6
All others	3
Total	**7-12%**

- Expected statistical uncertainty $\delta A^n_{stat} \simeq 15\%$ (relative to GPD model predicton).

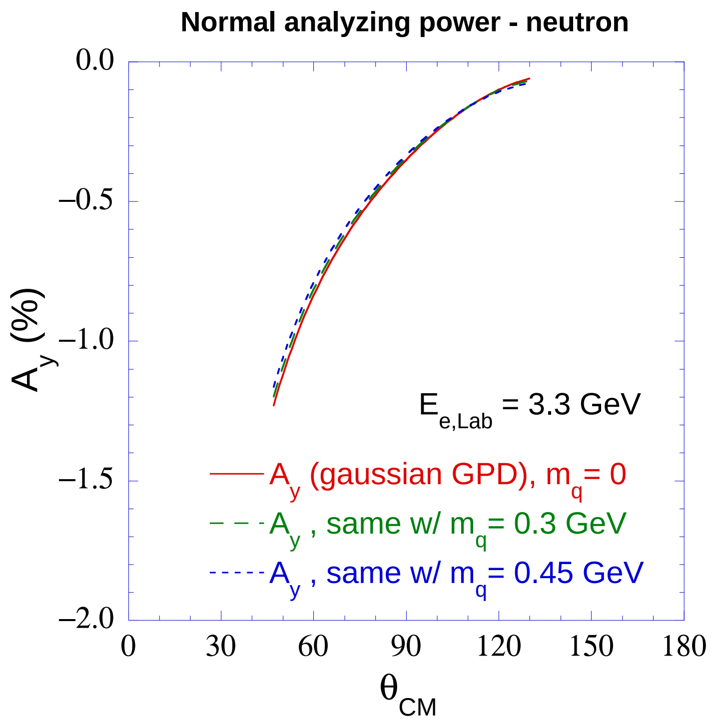
Expected Results





GPD interpretation

- Validity of GPD interpretation requires hard scattering vertex; No higher twist effects, $m_q = 0$.
- Study effect of nucleon dynamics by increasing m_q, C. Carlson, M. Vanderhaeghen, A. Afanasev, private comm.



Higher Twist Effects at $Q^2 \simeq 1$ GeV^2 ???

- Recent analysis of DIS moments for g_1 at $Q^2 = 1$ GeV^2 find no evidence for higher-twist effects.

  M. Osipenko *et. al.*, arXiv: hep-ph/0404195 (2004), A. Deur, et. al., Phys. Rev. Lett. 93, 212001 (2004),

  Z.E. Meziani, et. al., arXiv:hep/ph/0404066 (2004)

- Recent JLab g_2 data at $Q^2 = 1$ GeV^2 show non-zero higher-twist contribution, but not large.

  E97-103 preliminary results

- Global analyses of unpolarized Parton Distribution Functions (PDFs) from MRST and CTEQ show no indication of higher twist effects except at large x.

  A. D. Martin, R.G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C**35**, 325 (2004); J. Pumplin et. al.,

  JHEP **0207**, 012 (2002), arXiv: hep-ph/0201195.

- Our two Q^2 values will also provide information

Summary

- Non-zero A_y is a clear signature of 2γ-exchange
- Non-zero A_y has never been clearly established
- 2γ-exchange provides a new tool to probe nucleon dynamics
- Direct access/constraint to GPD model input
- Technically straight-forward measurement; no special equipment needed
- Inelastic backgrounds under control; No FSI
- 28 days of beam requested
- Test GPD prediction for A_y at 15% (stat.) level