Single Spin Asymmetries (SSA) in n(e,e′) from a vertically polarized ^{3}He target.

Nucleon structure studies using two photon exchange

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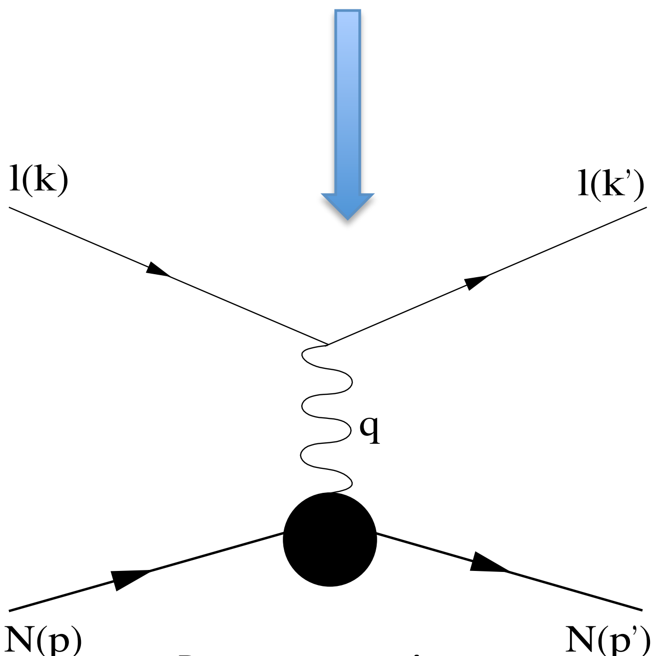
On behalf of the Jefferson Lab Hall A and polarized ^{3}He collaborations

Program Goal: Measure the "vertical" target single spin asymmetry A_y in:

- quasi-elastic ^{3}He(e,e′)
- deep-inelastic ^{3}He(e,e′)
- quasi-elastic ^{3}He(e,e′n)

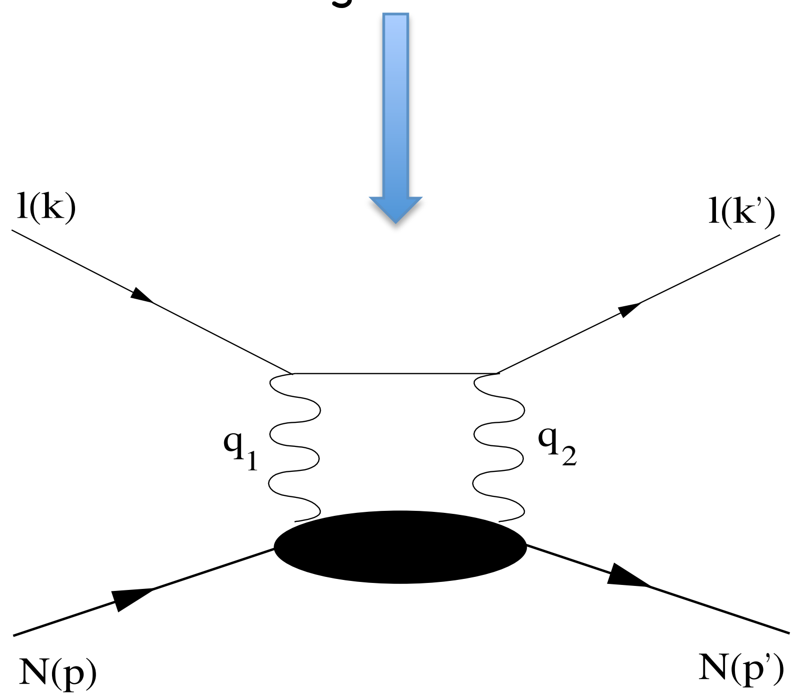
Born scattering and beyond

- Jefferson Lab physicists' favorite diagram (required for every talk):



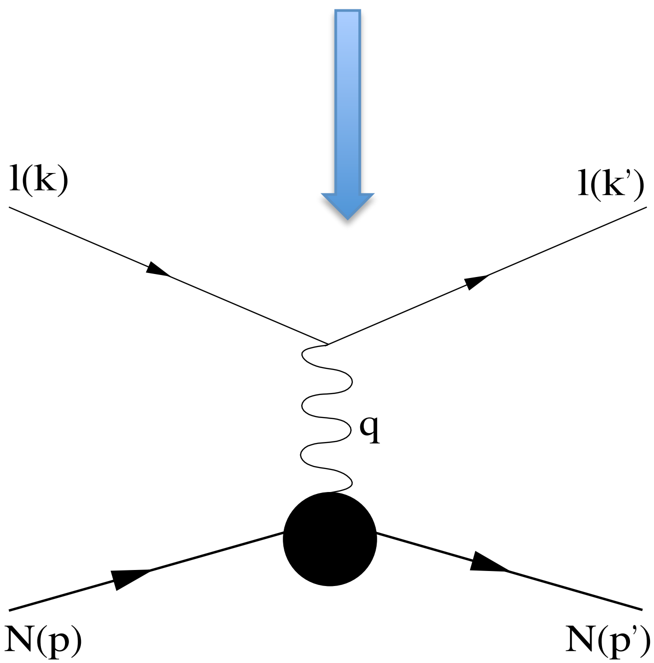
Born scattering

- Irritating correction to favorite diagram.
- Suppressed by α relative to Born diagram

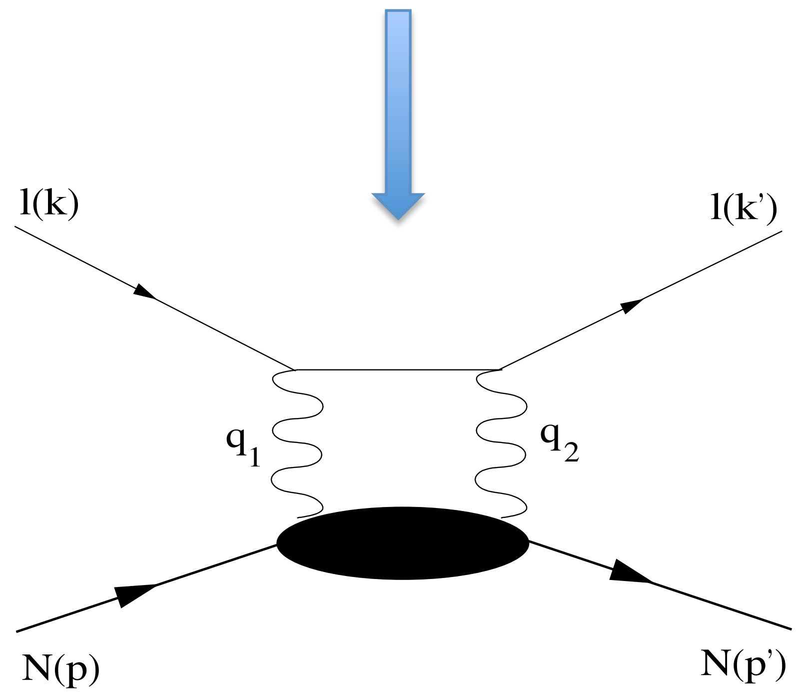


Born scattering and beyond

- Dominates unpolarized and most polarized N(e,e') scattering.



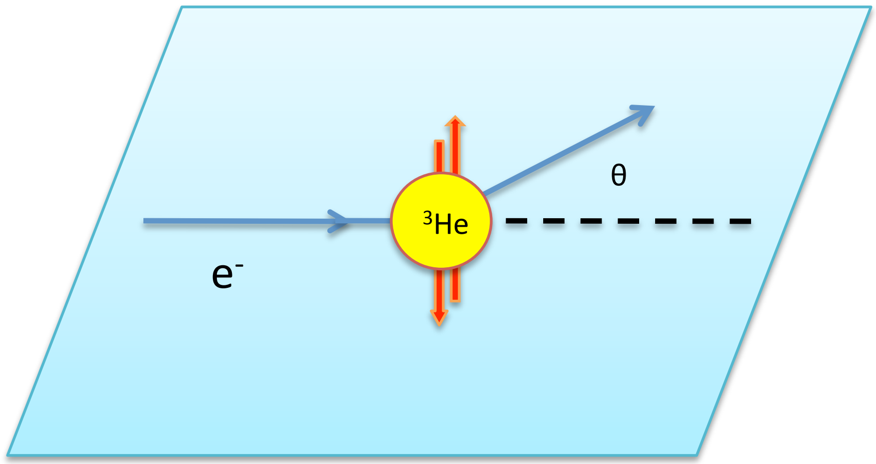
- How is it useful?
- Loop integral contains *entire nucleon response*.
- How do we observe this?



Target Single Spin Asymmetry (SSA)

- Unpolarized e^- beam incident on ^3He target polarized normal to the electron scattering plane

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



- Note that unpolarized eN scattering and double spin asymmetries (DSA) with beam and target polarization in-plane are dominated by 1-photon exchange. e.g. measurements of G_e^n, G_M^n, F_1, F_2, g_1, g_2 <----(Born approximation)

- However, A_y=0 at Born level,
  → sensitive to physics at order α^2; two-photon exchange.

Two Photon Physics

- Topic 1: Elastic N(e,e') scattering with two photon exchange:

$$l(k,h) + N(p,\lambda_N) \rightarrow l(k',h') + N(p',\lambda'_N)$$

$$T = T_{1\gamma} + T_{2\gamma} = \frac{e^2}{Q^2}\bar{u}(k',h)\gamma_\mu u(k,h) \times \bar{u}(p',\lambda'_N)\left(\tilde{G}_M\gamma^\mu - \tilde{F}_2 P^\mu + \tilde{F}_3\frac{\gamma\cdot KP^\mu}{M^2}\right)u(p,\lambda_N)$$

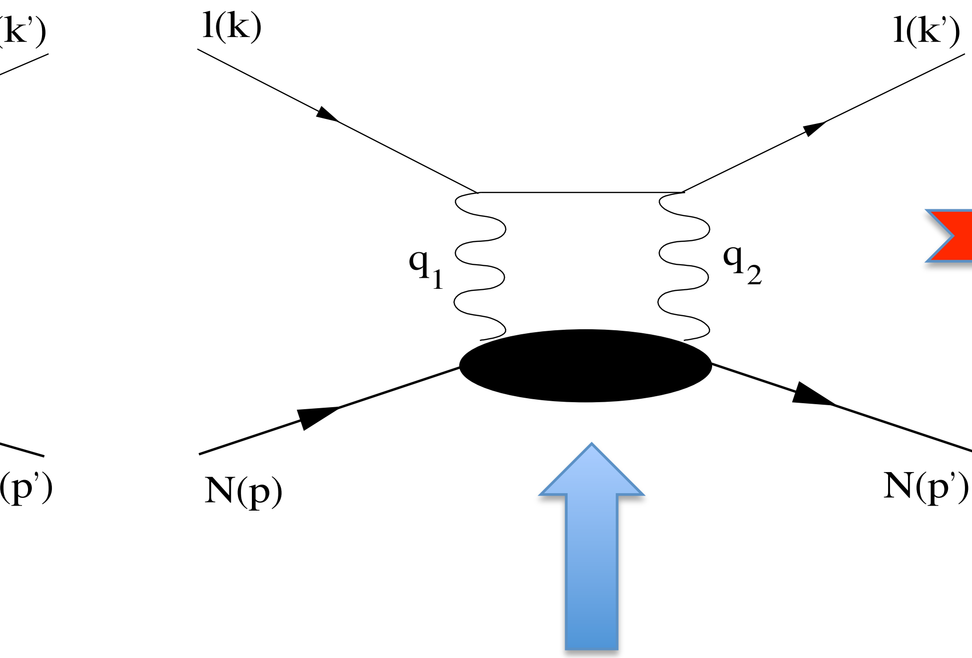
- h=electron helicity, $\lambda_N(\lambda'_N)$=nucleon helicity, K=(k+k')/2, P=(p+p')/2

- The functions $\tilde{G}_M^{Born}$, $\tilde{F}_2^{Born}$, $\tilde{F}_3^{Born}$ are complex and reduce to the usual (real) structure fucntions and form factors in 1γ exchange:

$$\tilde{G}_M^{Born}(\nu,Q^2) = G_M(Q^2)$$
$$\tilde{F}_2^{Born}(\nu,Q^2) = F_2(Q^2)$$
$$\tilde{F}_3^{Born}(\nu,Q^2) = 0$$

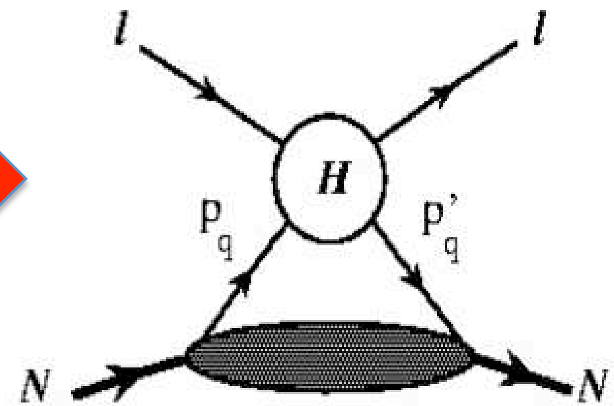
A. Afanasev *et al.*, Phys.Rev.D72:013008, 2005

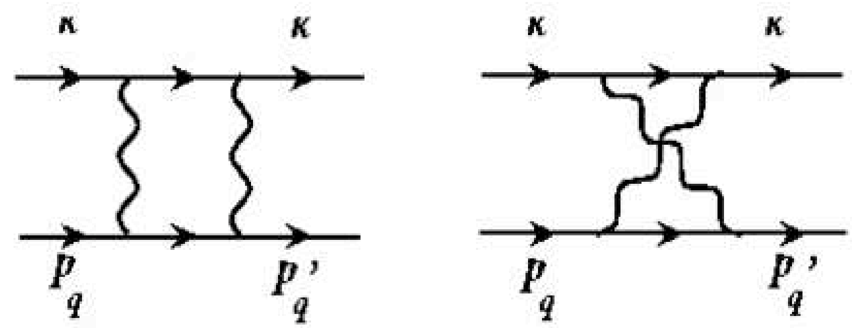
At low Q^2, entire nucleon is involved



Loop integral contains entire elastic and inelastic response of nucleon

At large Q^2, assume interaction with a single quark





Elastic form factor data: 2-photon exchange correction at large Q^2

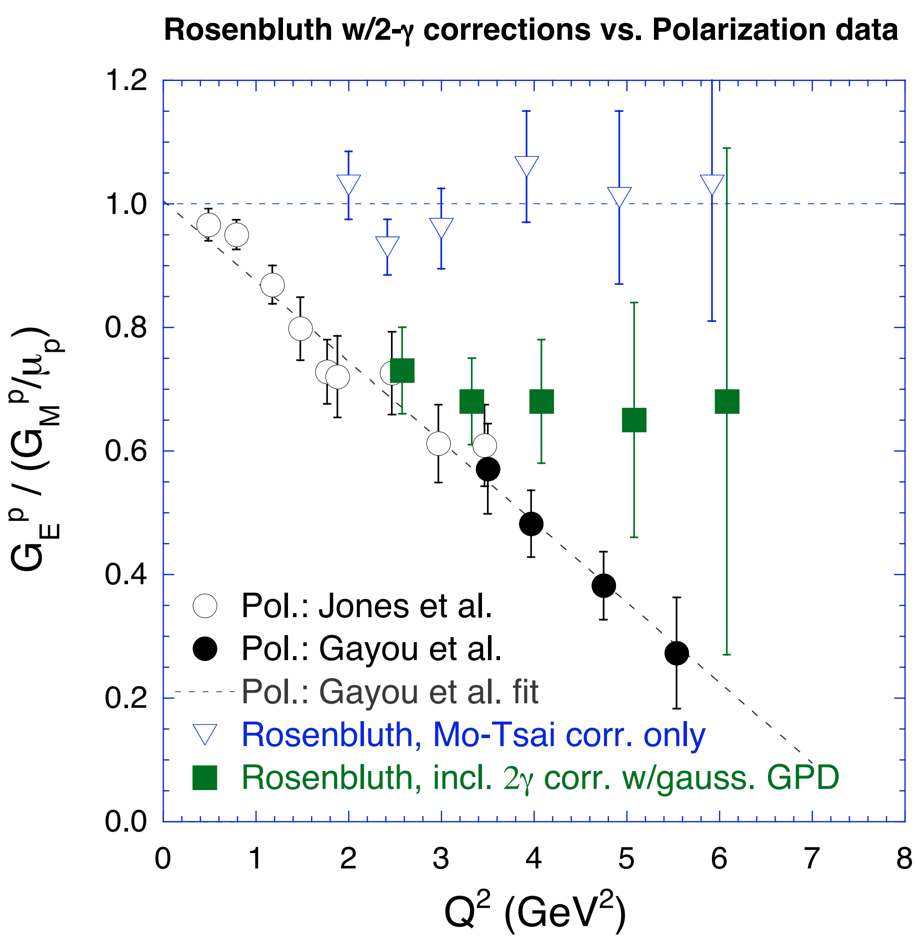
- Note that both recoil polarization and Rosenbluth separation measurements of nucleon form factors must be corrected for 2-photon exchange

- Depends on the *real* part of the interference:

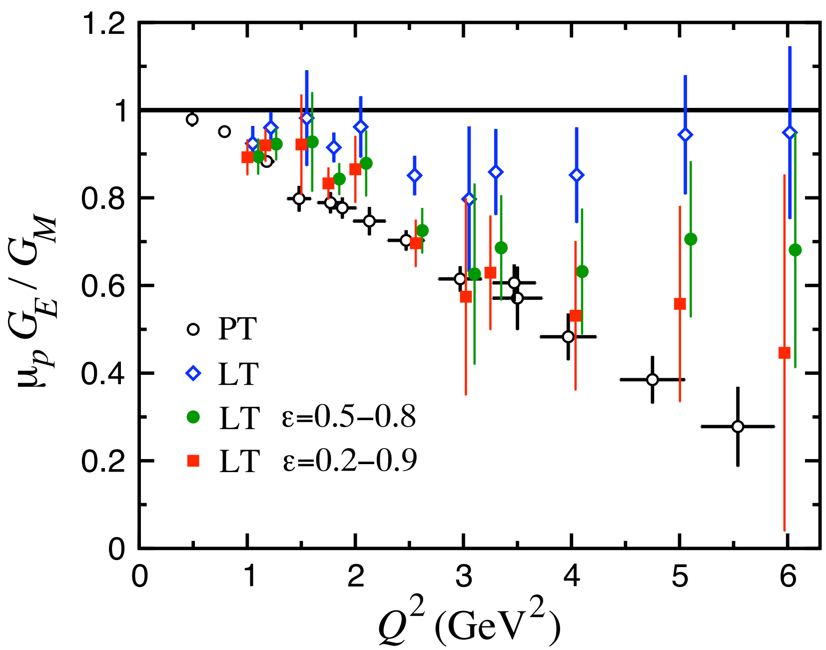
$$\sigma \propto Re(T_{1\gamma}^{*} T_{2\gamma})$$

- Elastic contribution well known. Inelastic contribution estimated at large Q^2 using e.g. form factors, resonances, moments of GPD's, ….

Jefferson Lab G_E^p/G_M^p



A. Afanasev *et al.,* Phys.Rev.D72:013008, 2005



Blunden *et al.*
Phys. Rev. C72 (2005) 034612

2-photon SSA physics

$$A_y \propto \frac{Im(T_{1\gamma} T^*_{2\gamma})}{|T|^2}$$

Absorptive part=Imaginary contribution

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

For *inclusive* scattering N(e,e'), $A_y^{Born} = 0$

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

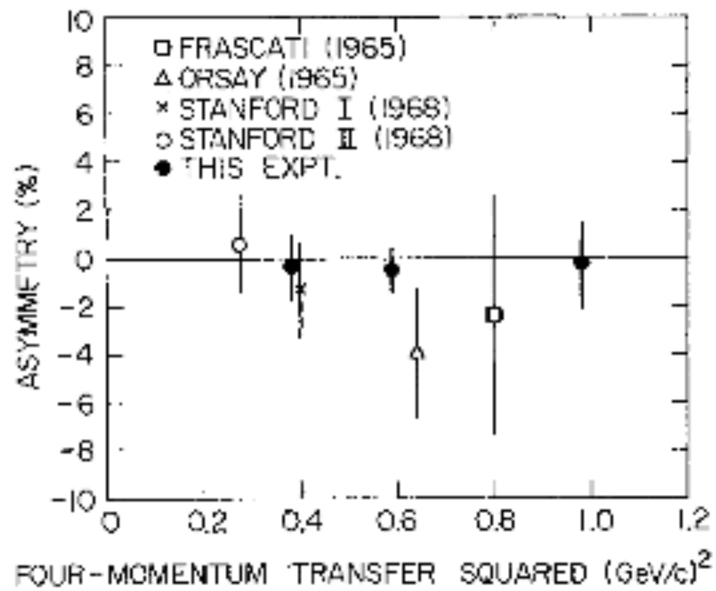
When we allow 2-photon exchange, the leading contribution is from 1γ + 2γ interference

- Calculable at large Q^2 using moments of GPD's.
- Measurement of A_y at large Q^2 provides new constraint on GPD's

Existing A_y Data

- SLAC Proton Data for A_y (solid) and P_n (open); expected $A_y^p < 1\%$

T. Powell *et al.*, PRL **24** (1970) 753.



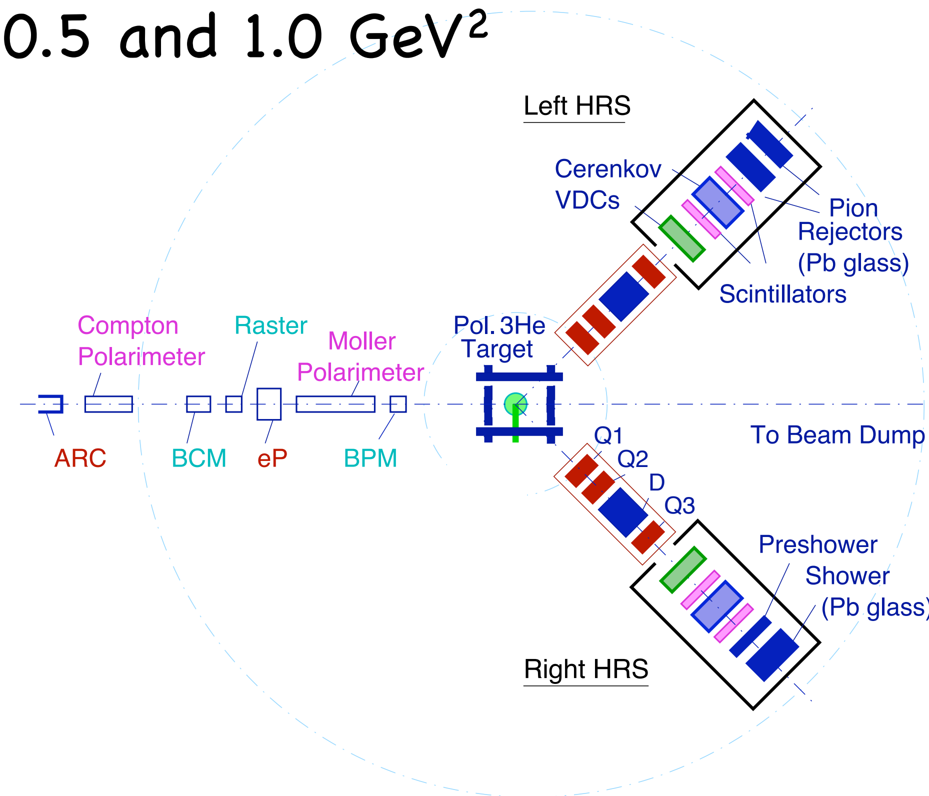
- NIKHEF QE ^{3}He$^\uparrow(e,e')$ at $Q^2 = 0.1$ GeV^2 gave $A_y = -1.0 \pm 5.4\%$.

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

- Precision measurements of A_y do not exist! A non-zero A_y never measured!

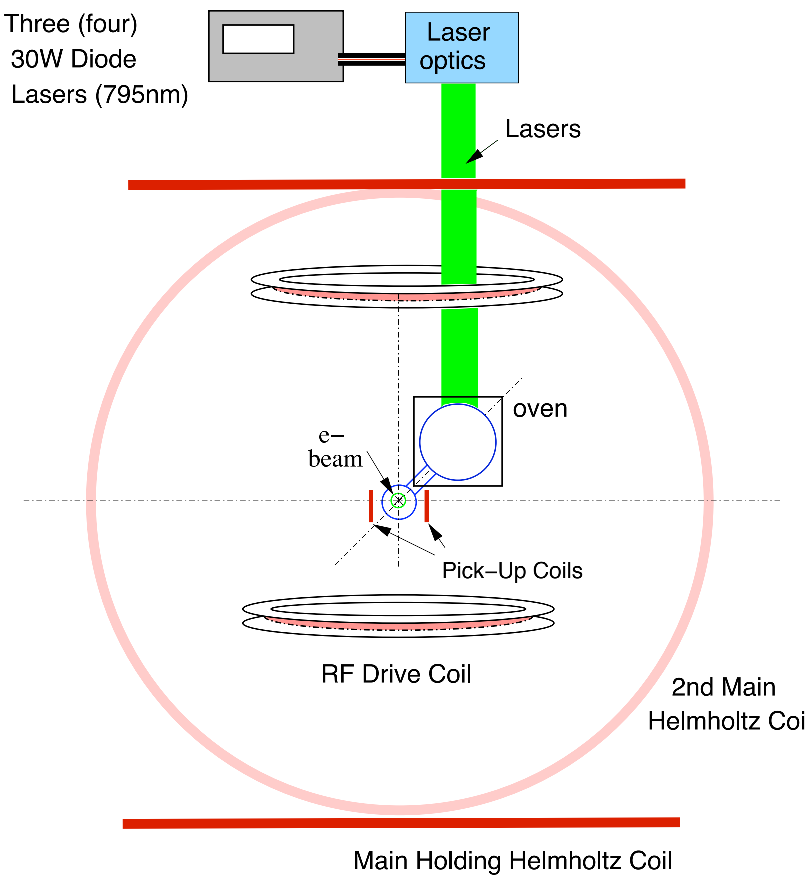
Experimental Design

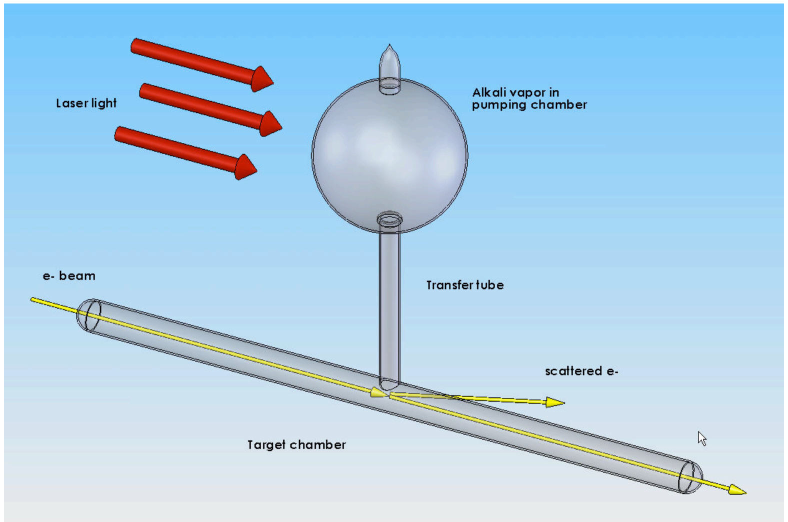
- Use two symmetric spectrometers for singles electron detection. Jefferson Lab Hall A HRS spectrometers.
- Vertically polarized ^3He target.
- Measurements at Q^2=0.1, 0.5 and 1.0 GeV^2
  - Test GPD calculation
  - Study Q^2 dependence
  - Parton to hadron transition

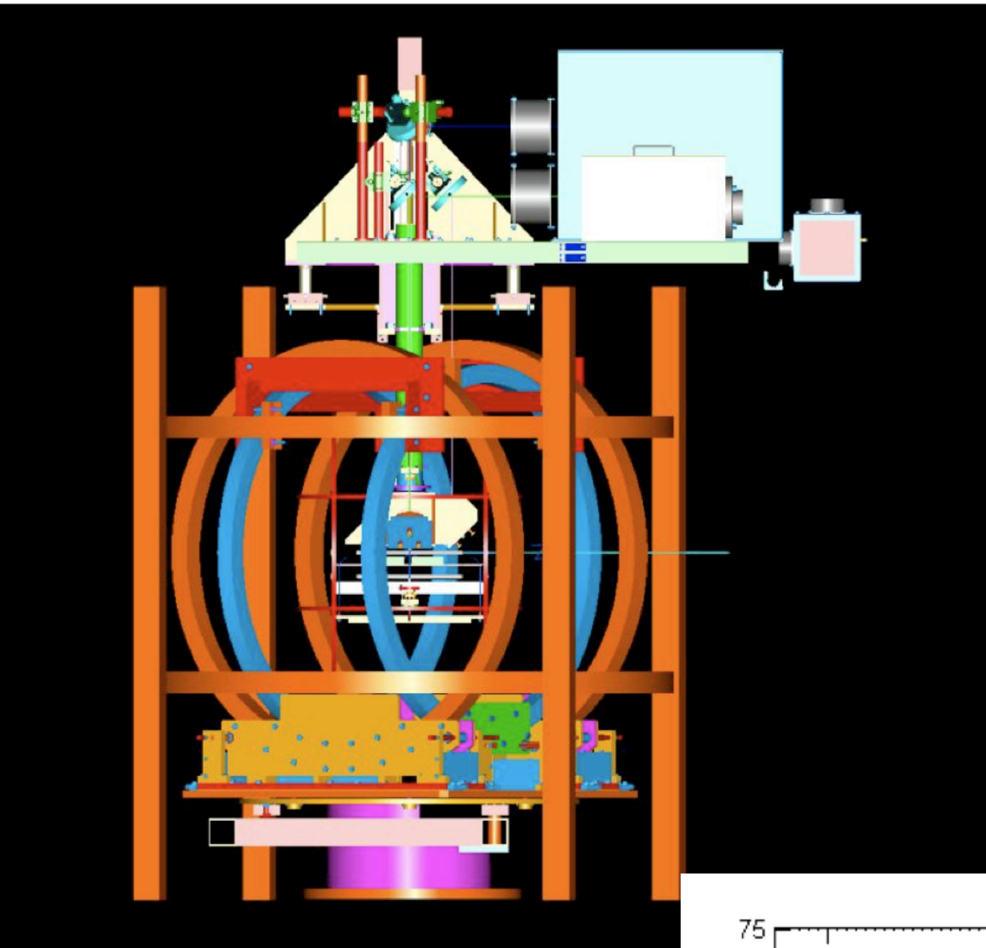


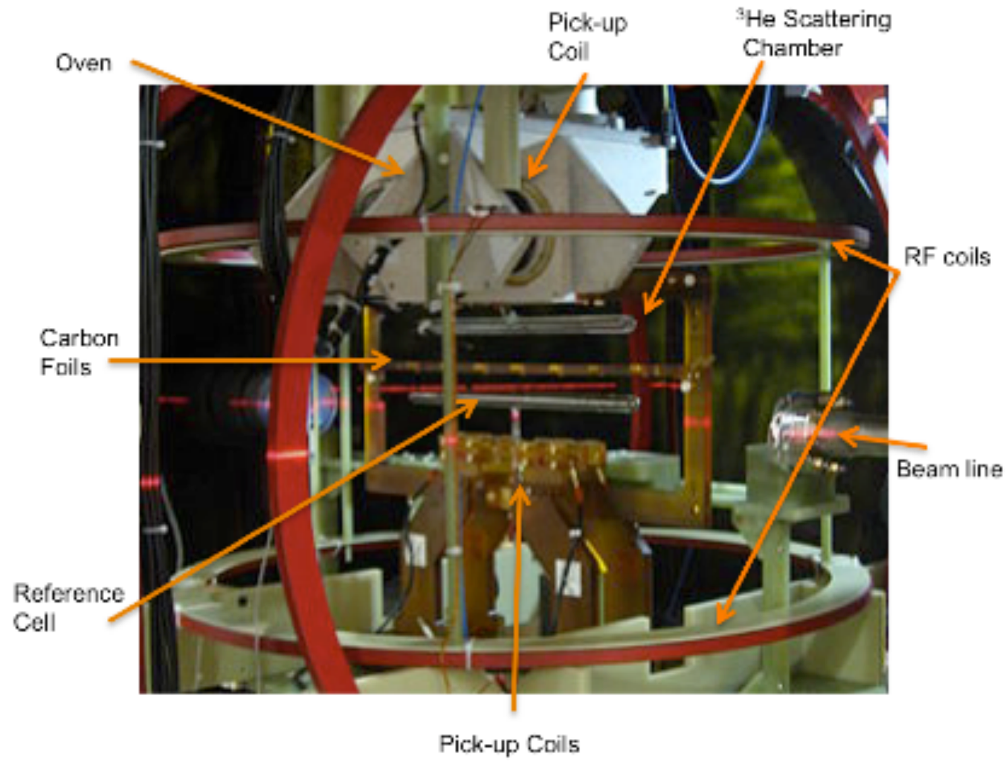
Hall A polarized ^{3}He target

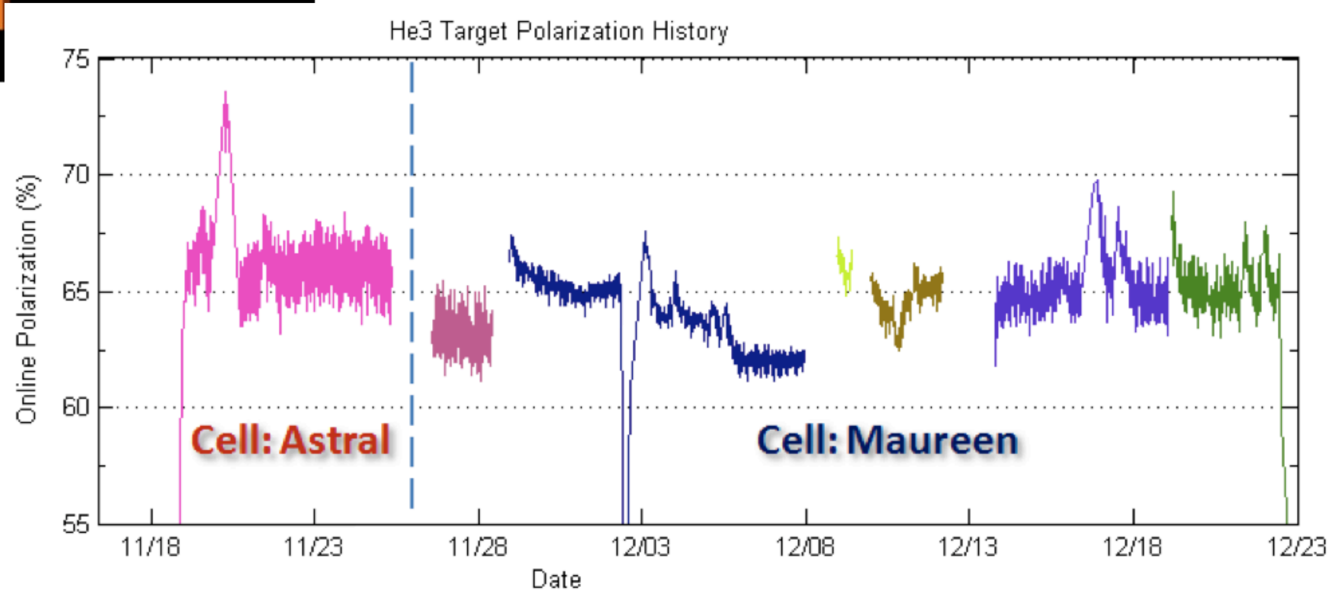
- Effective polarized neutron target
- Spin Exchange Optical Pumping (SEOP) technology
- 5:1 ratio of K:Rb for high efficiency optical pumping and spin exchange.
- Spectrally narrowed diode lasers
- With 15uA beam, $\langle P_{targ} \rangle \sim 65\%$
- Luminosity L ~ 10^{36} /cm^2/s











New record for polarization at this luminosity

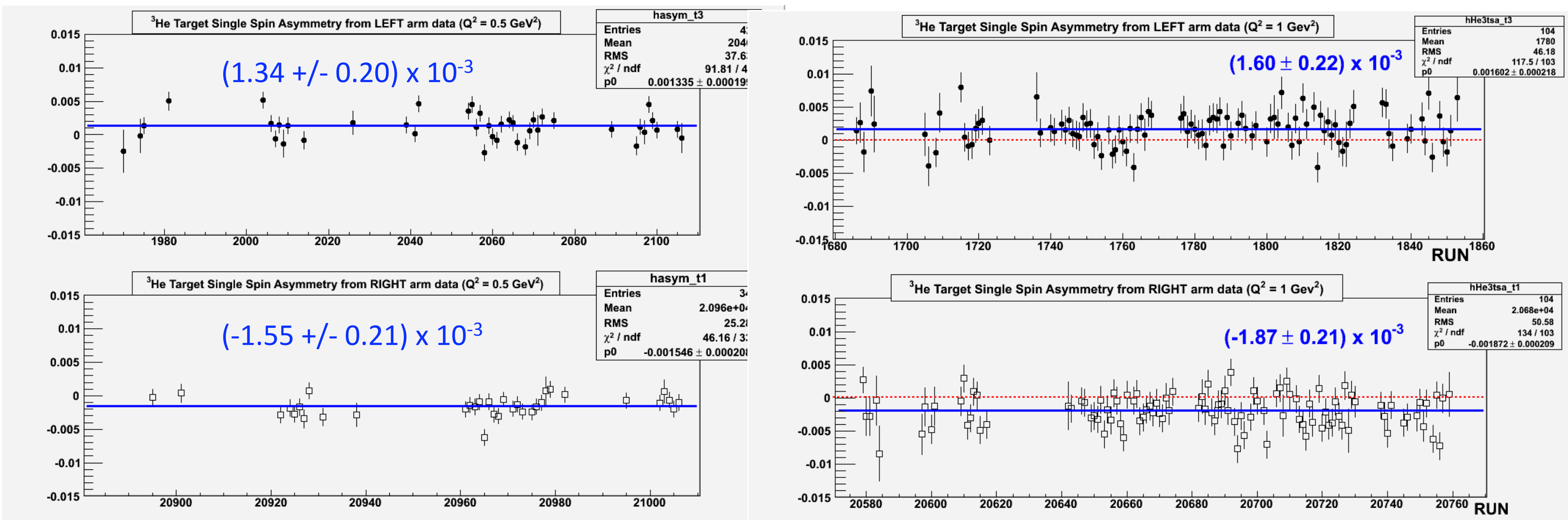
6/22/10

Preliminary results

- Next two slides will show A_y for ^3He
- Preliminary results with target polarization and nitrogen dilution corrections applied.
- No radiative corrections applied
- ^3He to neutron correction needed
- Systematic uncertainties not finished

Preliminary ^{3}He results at Q^2=0.5 and 1.0 GeV^2

Q^2 = 0.5 GeV^2 Q^2 = 1.0 GeV^2



- A_y^{3He} ~ - 0.17% at Q^2=1 GeV^2, A_y^{3He} ~ - 0.14% at Q^2=0.5 GeV^2,
- Data at Q^2=0.1 GeV^2 being analyzed. *Seems to show little Q^2 dependence.*

Topic 2: What about A_y for n(e,e') in DIS?

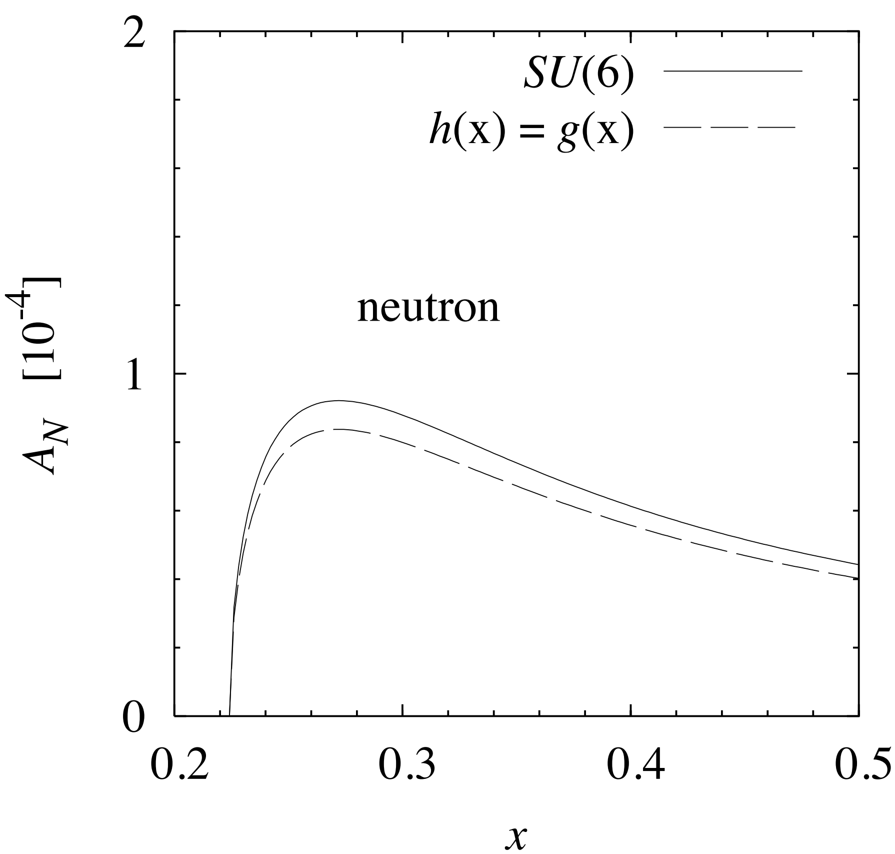
- The formalism remains the same:
  A_y=0 for 1-photon exchange

- For DIS, one assumes that the scattering is dominated by two photon exchange with a single quark.

- This was measured in Hall A during the transversity experiment, using the BigBite Spectrometer in singles mode.

- Joe Katich-W&M graduate thesis student

n(e,e') prediction for DIS



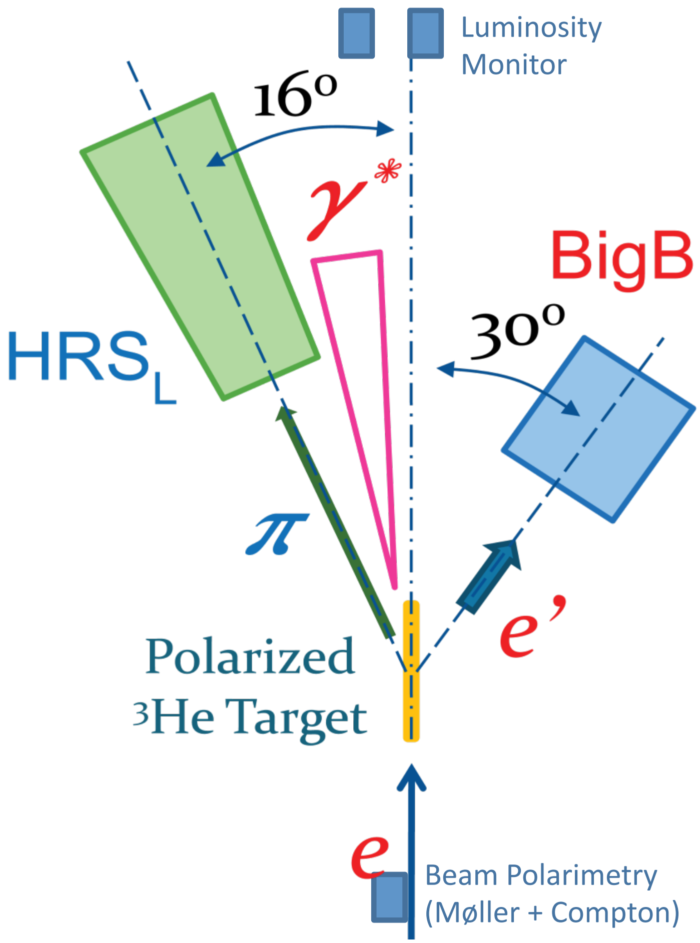
- In a simple quark model, A_y=0 for two-photon exchange due to helicity conservation at the quark level.

- Afanasev, Strikman, Weiss (Phys.Rev.D77:014028,2008) predict A_y~10^{-4} using a model based on the quark transversity distribution and non-zero quark masses.

- *The SSA should change by two orders of magnitude from DIS to QE kinematics.*

- Allows one to study the "transition" from hadron-like to parton-like behavior.

Kinematics

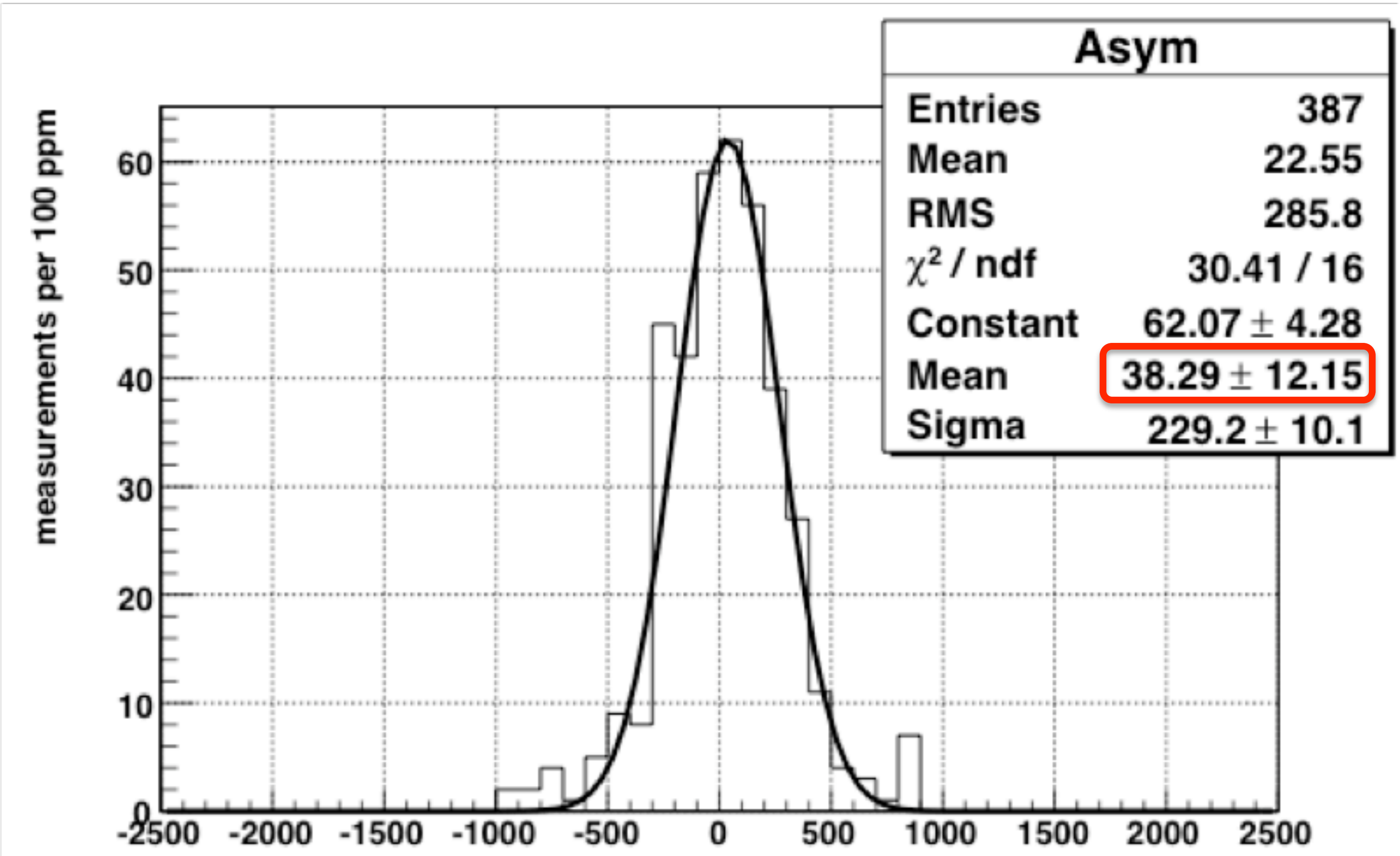


Measure ^{3}He(e,e') SSA using BB and LHRS in singles mode.

E=5.89 GeV

	LHRS	BB			
		1	2	3	4
θ (deg)	16.00	29.60	29.60	29.50	28.80
θ (rad)	0.28	0.52	0.52	0.51	0.50
E (GeV)	5.89	5.89	5.89	5.89	5.89
E' (GeV)	2.35	1.12	1.36	1.65	2.05
ν (GeV)	3.54	4.78	4.53	4.25	3.84
Q^2 (GeV^2)	1.07	1.71	2.09	2.51	2.99
W^2 (GeV^2)	6.45	8.13	7.30	6.33	5.09
X	0.16	0.19	0.25	0.32	0.42

Check for False Asymmetries: Luminosity Asymmetry



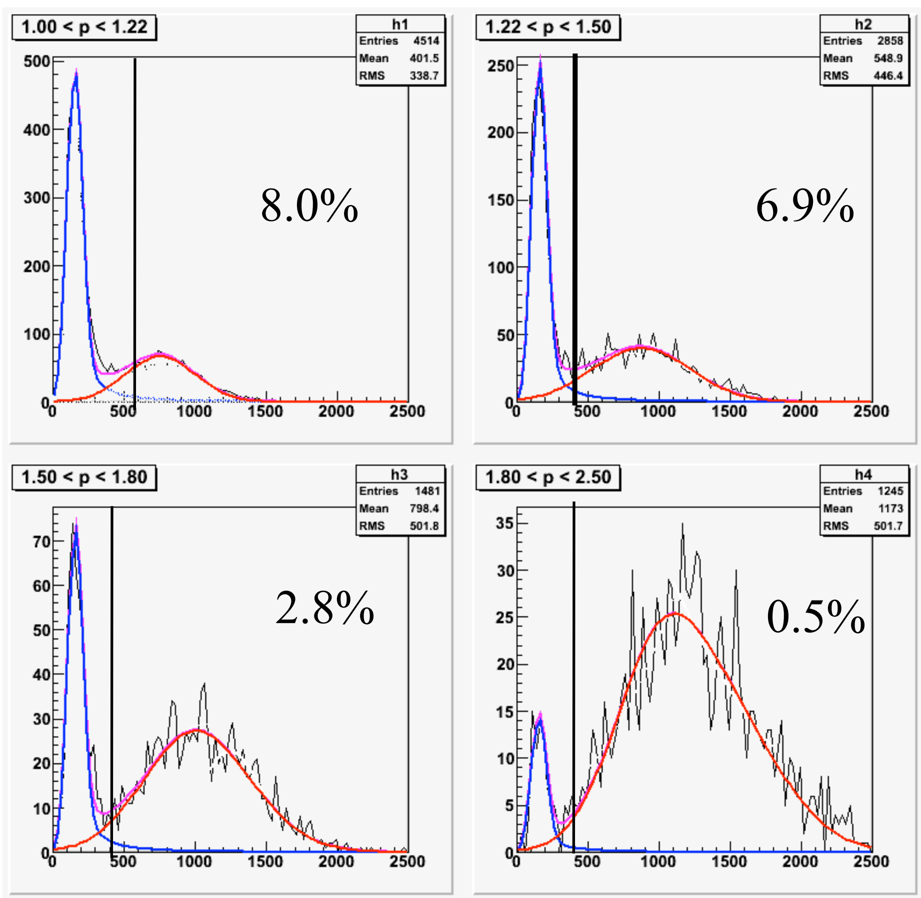
ppm

Backgrounds

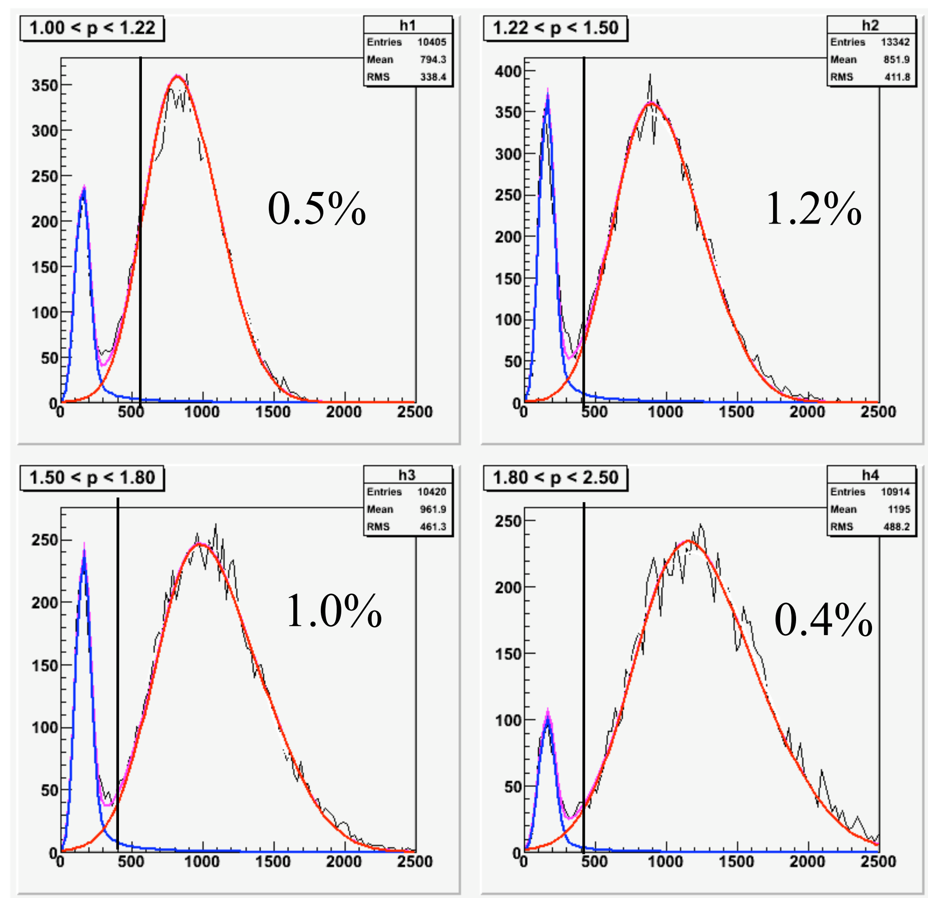
- BigBite: Pair produced e^+/e^- pairs from π^o decay.
  - Measure using positive polarity
  - 50% contamination in lowest momentum bin
  - 1% in largest momentum bin
  - Largest systematic uncertainty
- BigBite: π^- in $e^{-/+}$ spectrum. No Cherenkov detector. EM pre-shower and shower calorimeter
- LHRS spectrometer, virtually background free.
  - Good PID
  - Highest momentum = negligible pair-electron contamination

Final pi- Contamination

T1

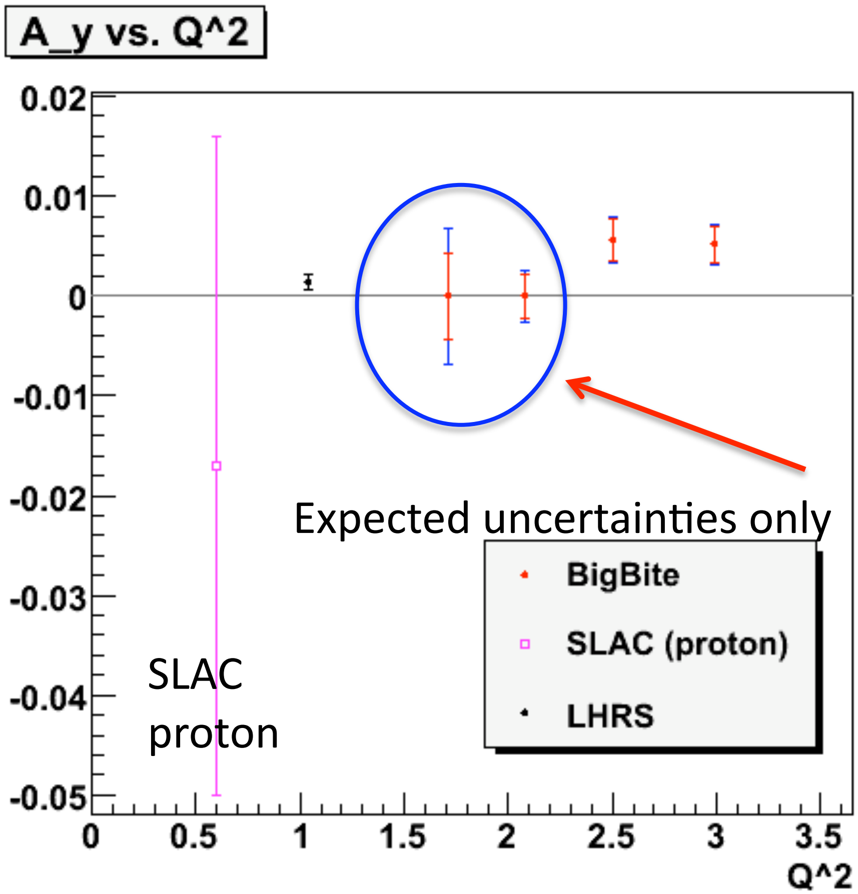


T6



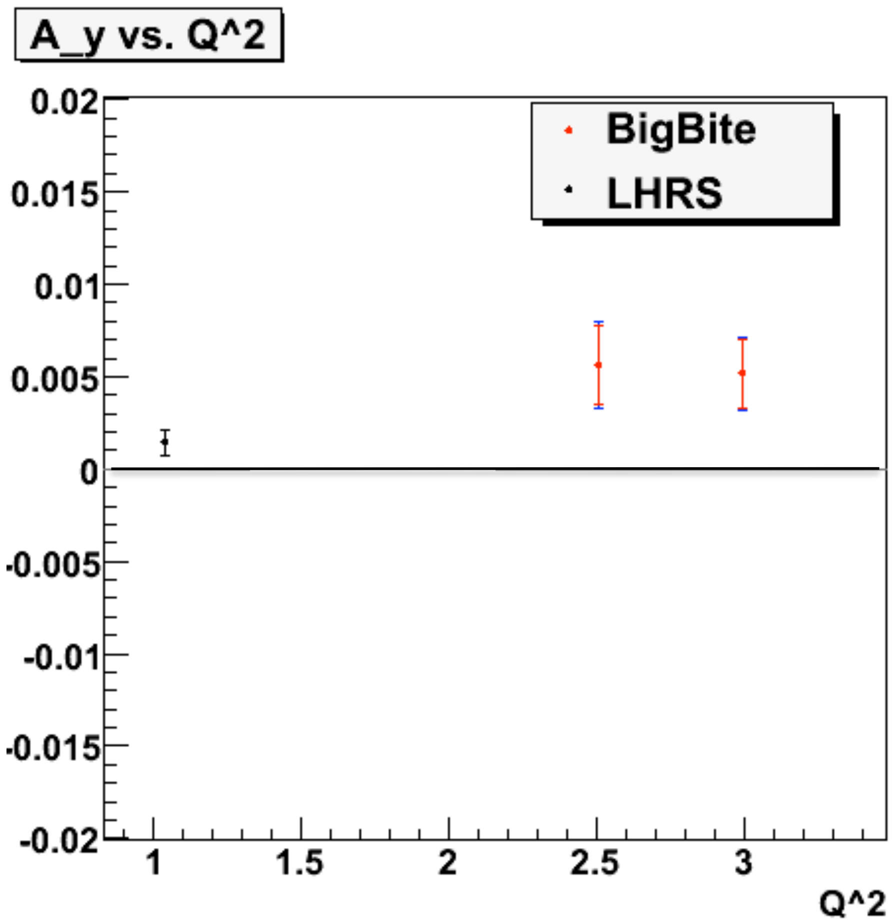
A_y for ^{3}He versus Q^2

Preliminary results

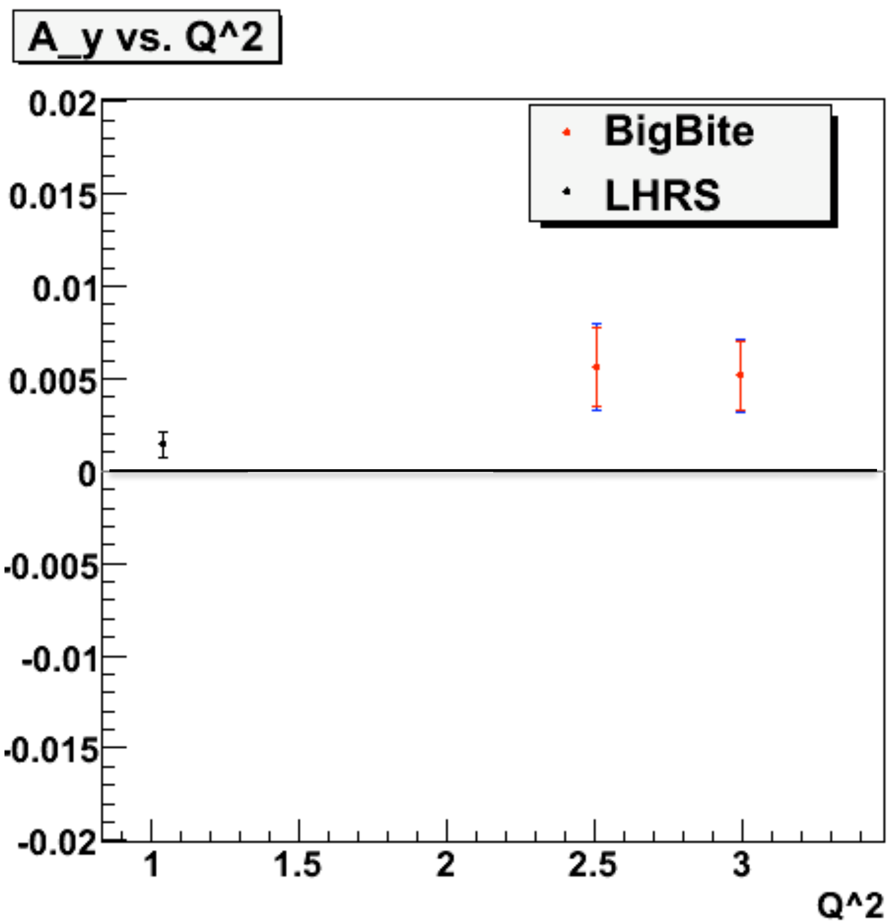


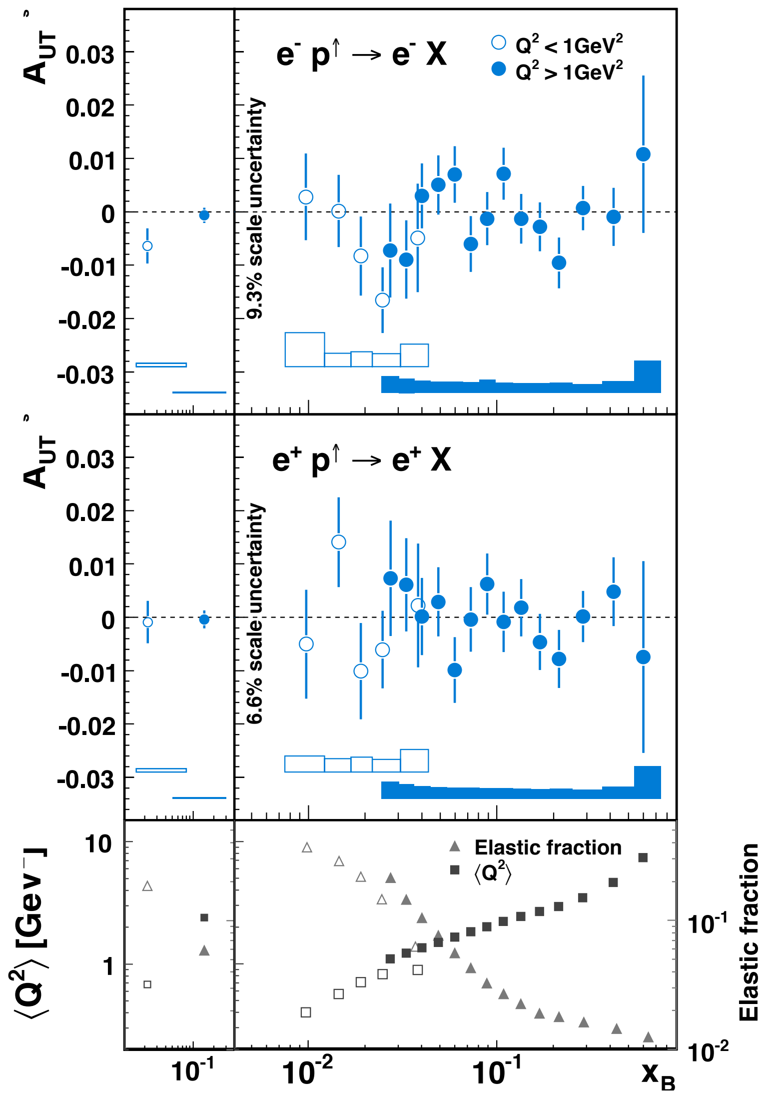
Statistical and systematic uncertainties included

A_y^{3He} ~ 1-5 x $10^{-3,}$ not zero??



HERMES proton DIS data





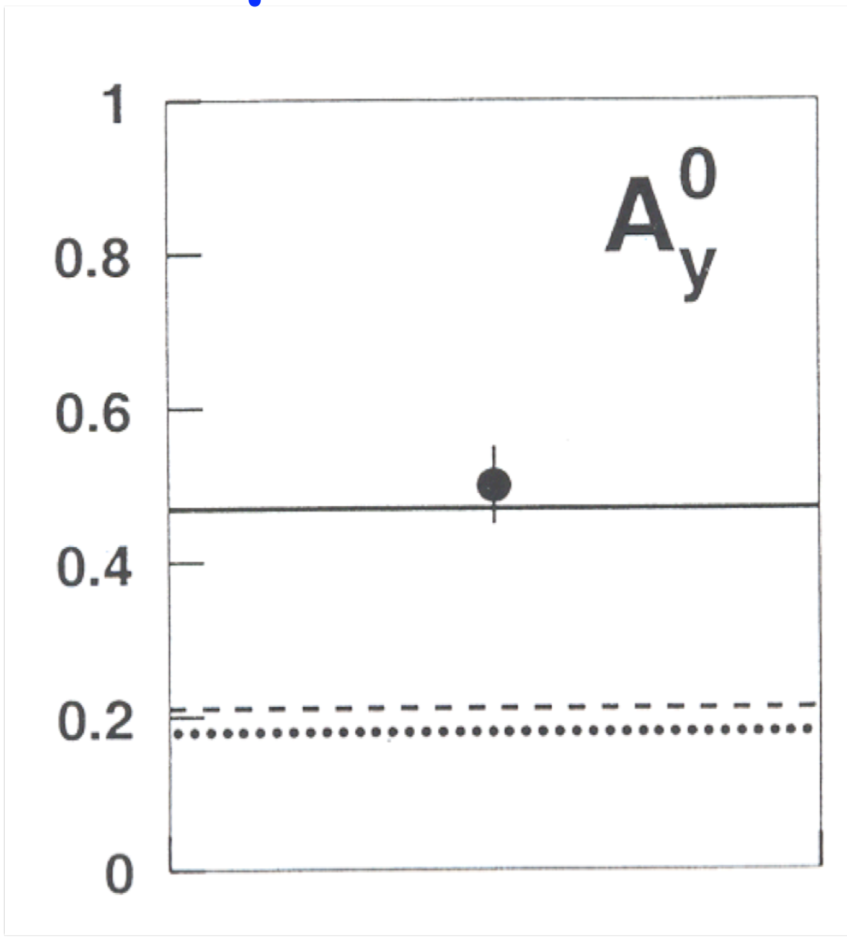
A. Airapetian et al,

Phys. Lett. B682, 351 (2010)

Topic 3: SSA in quasi-elastic $^3He(e,e'n)$

- Detect recoil neutron during QE scattering.
- Christ-Lee theorem doesn't apply for semi-inclusive scattering. A_y not necessarily zero.
- Sensitive to final state interactions
- PWIA predicts A_y=0
- Unpublished NIKHEF result shows A_y=50%
- Precise laboratory for studying ^{3}He wavefunction

Unpublished NIKHEF Measurement



- Measured A_y ~ 50% !!!
- Q^2=0.2 GeV^2

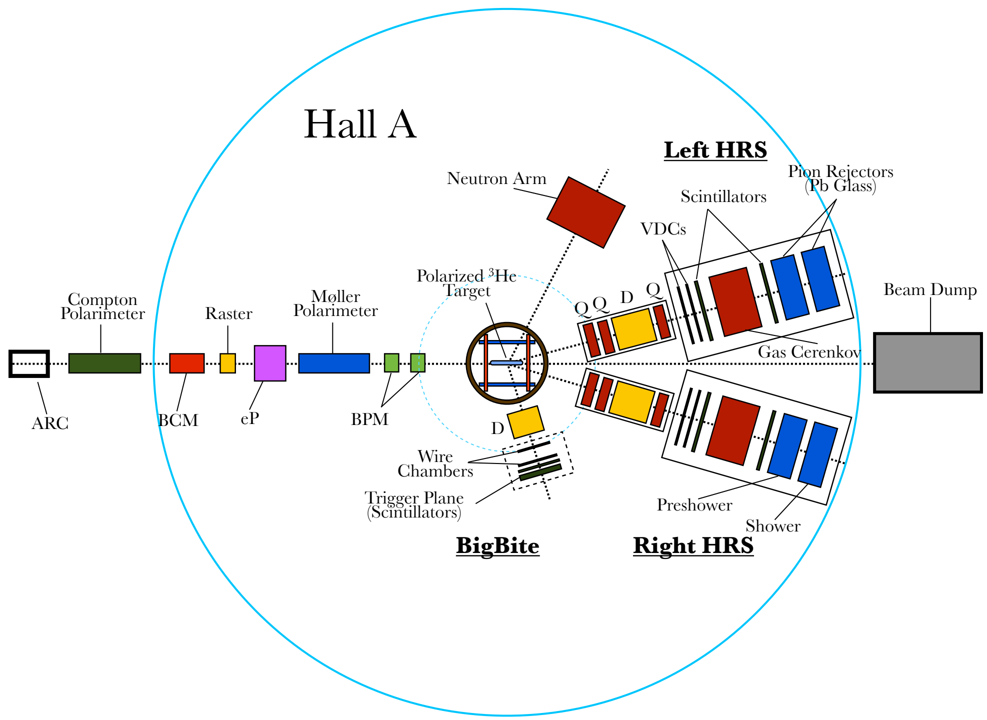
Golak et al., non-relativistic Fadeev

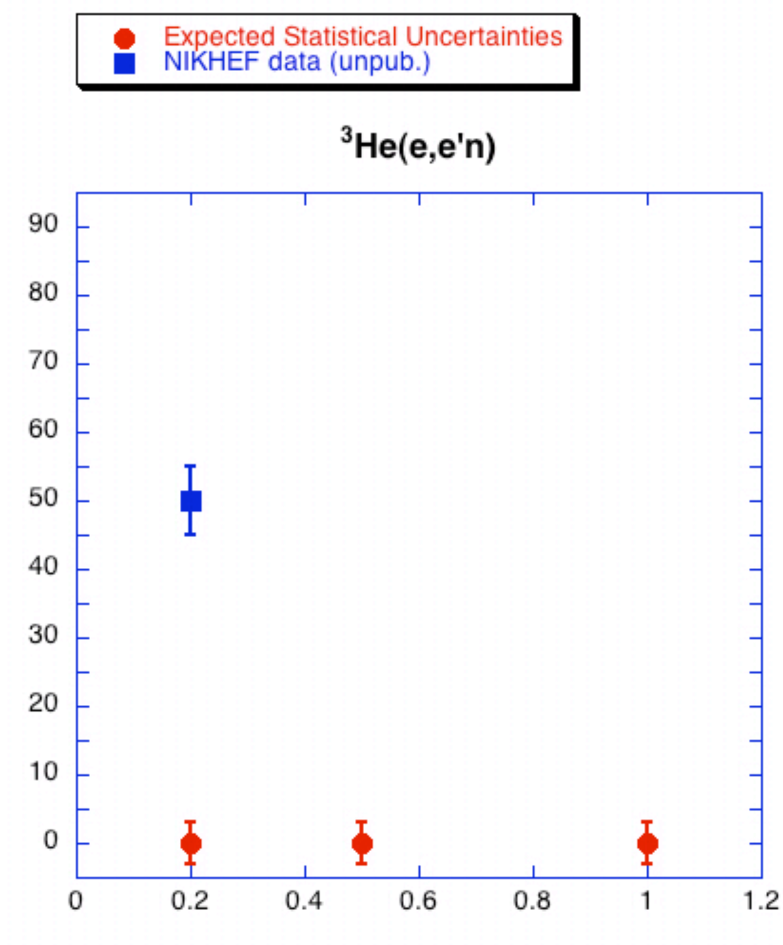
Laget, Nagorney, 3-body partial wave analysis

PWIA

Note: Golak calculation was used to extract G_e^n from deuteron and ^{3}He data.

Hall A Neutron Detector (HAND)





- Detect coincidence between RHRS and HAND

Summary

- First measurements of the inclusive target SSA using vertically polarized ^3He in QE, DIS scattering.

- Measured QE A_y^{3He} ~-0.14, 0.17% for Q^2=0.5, 1.0 GeV^2

- Measured DIS A_y^{3He} ~-0.14, 0.17% for Q^2=0.5, 1.0 GeV^2

- First DIS results for A_y ~ 1-5 x 10^{-3} for ^3He at Q^2=1.0-3.0 GeV^2.
  - Statistical precision comparable to HERMES proton results.

- Precision results for SSA in $^3He(e,e'n)$.

- Theoretical calculations needed.

- Measurements at high Q^2 possible with Jefferson Lab 12 GeV upgrade.

Connection with (GPDs) (con't)

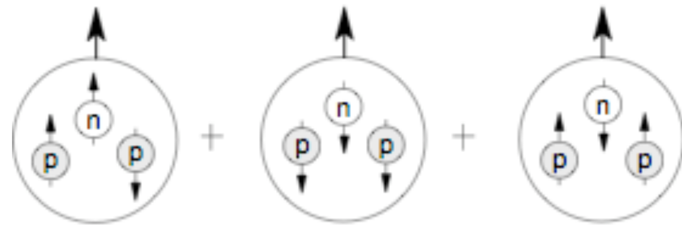
Y.-C. Chen, A. Afanasev, S. J. Brodsky, C. E. Carlson and M. Vanderhaeghen, PRL **93** (2004) 122301

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

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

$$B = \int_{-1}^{1}\frac{dx}{x}\tilde{K}'\sum_q e_q^2\,[H^q(x,0,t) - \tau E^q(x,0,t)]$$

- H^q and E^q are GPD's for quarks of flavor q.
- $\tilde{K}$ and $\tilde{K}'$ contain the contributions from the hard scattering amplitudes.
- $\mathcal{I}m(A)$ and $\mathcal{I}m(B)$ are non-zero through 2γ contribution in $\tilde{K}$ and $\tilde{K}'$.
- Measuring *neutron* A_y provides new constraint on specific GPD moment.



S state (89.93%) *D* state (8.75%) *S'* state (1.26%)

S, S', D, Δ-isobar contributions to ^{3}He wavefunction

$$A_y^n = \frac{F_2^{3He}}{P_n F_2^n (1 + \frac{0.056}{P_n})}\left[A_y^{3He} - 2\frac{F_2^p}{F_2^{3He}} P_p A_y^p \left(1 - \frac{0.014}{2P_p}\right)\right]$$

$$P_n = 0.86^{+0.036}_{-0.020}, \quad P_p = -0.028^{+0.009}_{-0.004}$$

Phys. Rev. C65, 064317 (2002)