Single Spin Asymmetries (SSA) in $^3He(e,e')$ from a vertically polarized ^3He target.

Nucleon structure studies using two photon exchange

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

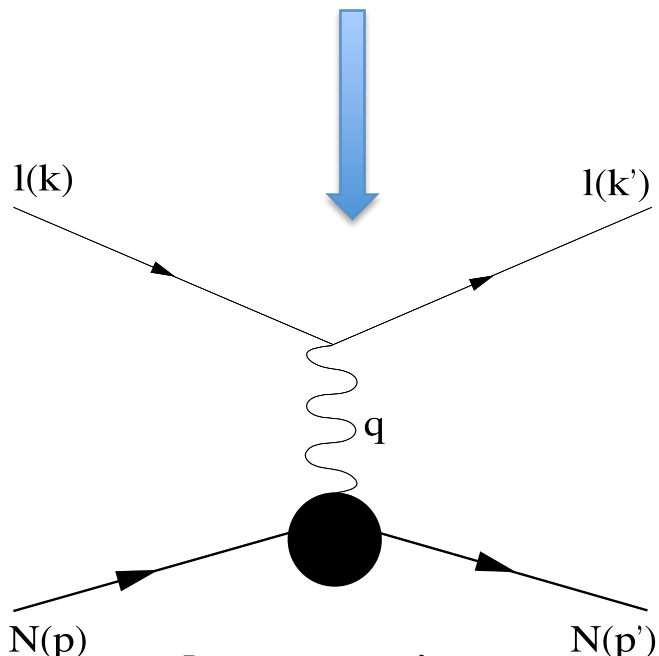
Program Goal: Measure the "vertical" target single spin asymmetry A_y in:

- quasi-elastic $^3He(e,e')$
- deep-inelastic $^3He(e,e')$

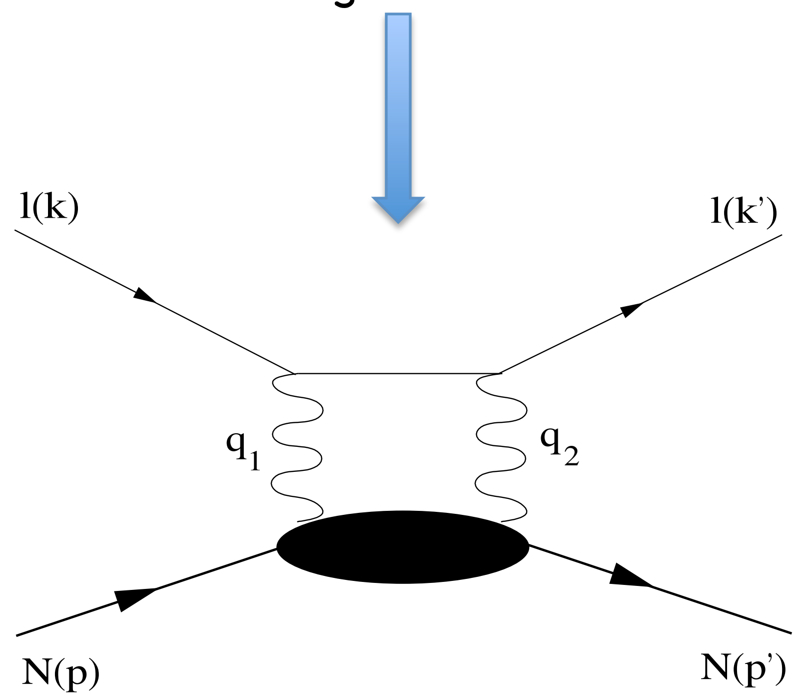
Born scattering and beyond

- Dominant contribution to EM electron scattering.
- Favorite diagram.

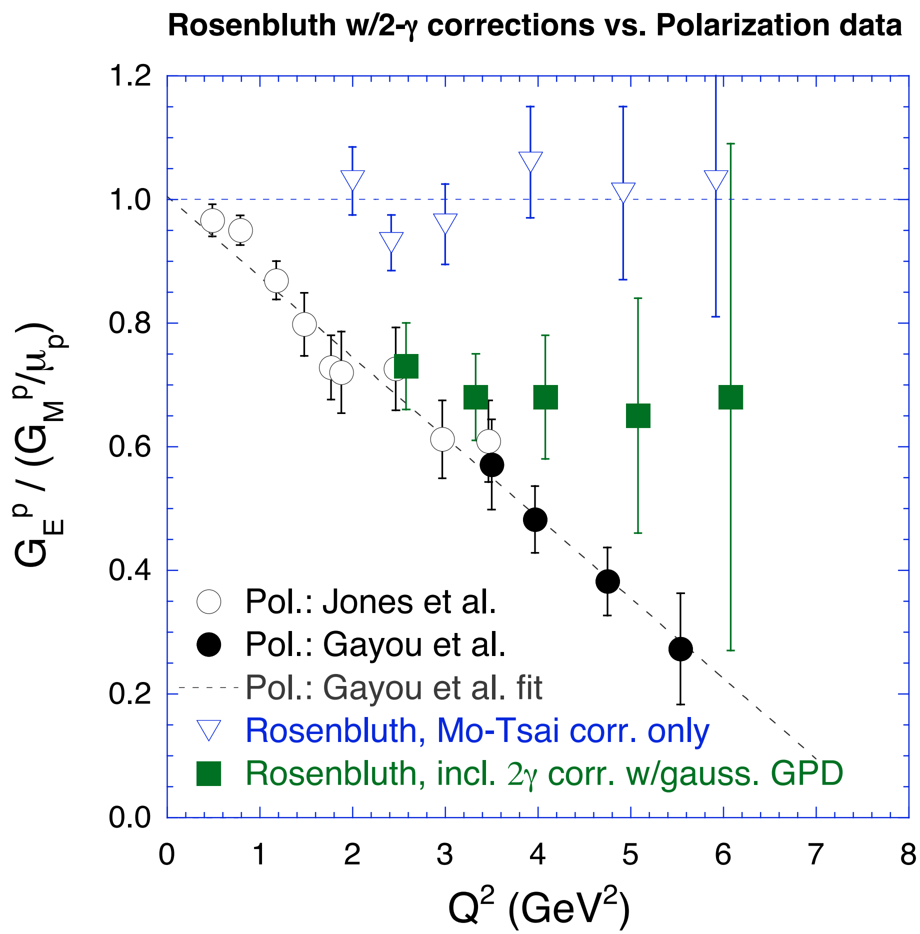
- Irritating correction to favorite diagram.
- Suppressed by α relative to Born diagram



Born scattering



Jefferson Lab G_E^p/G_M^p -- Perdrisat

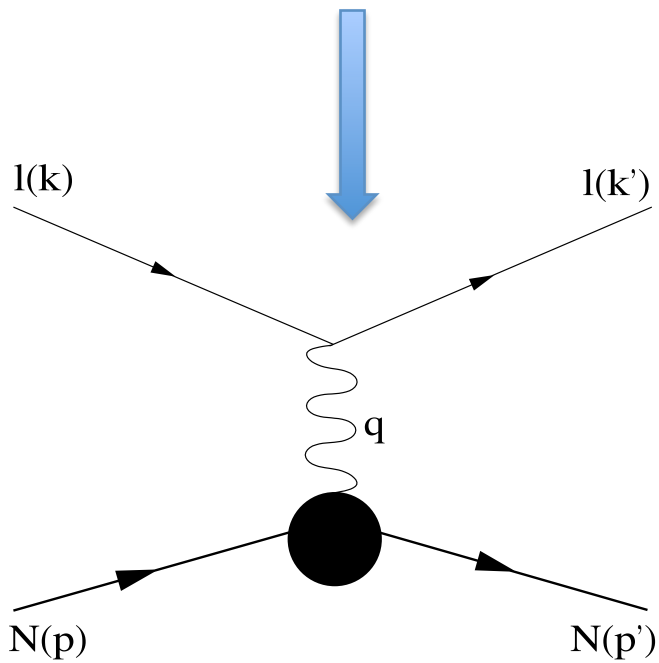


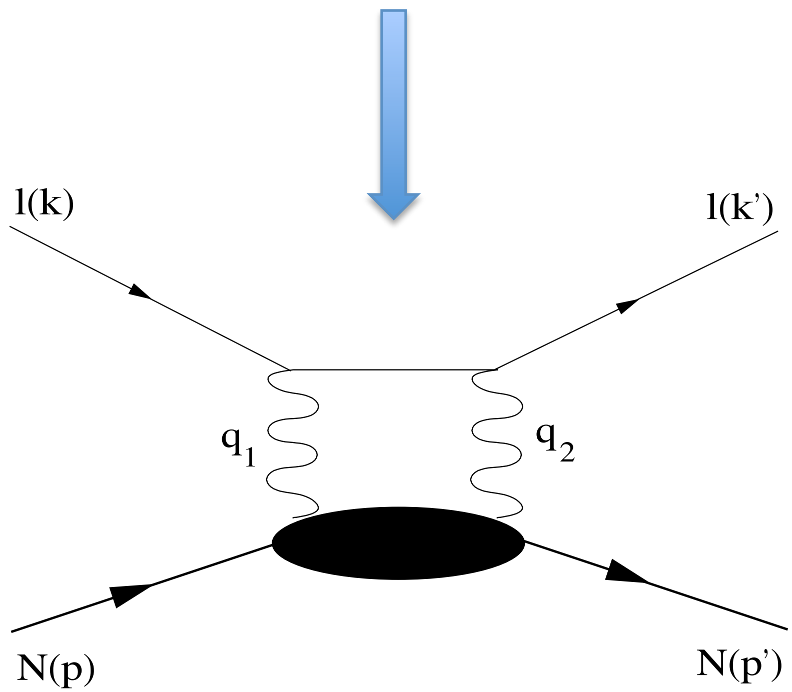
A. Afanasev *et al.,* Phys.Rev.D72:013008, 2005

Born scattering and beyond

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

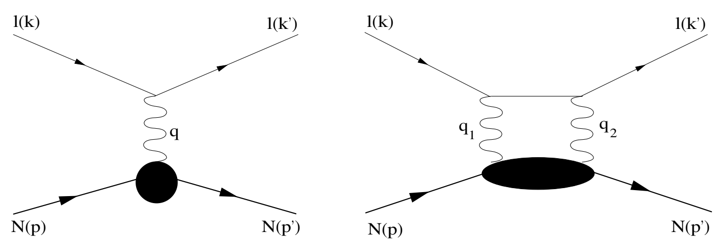
- How is it useful?
- Loop integral contains *entire nucleon response*.
- How do we observe this?

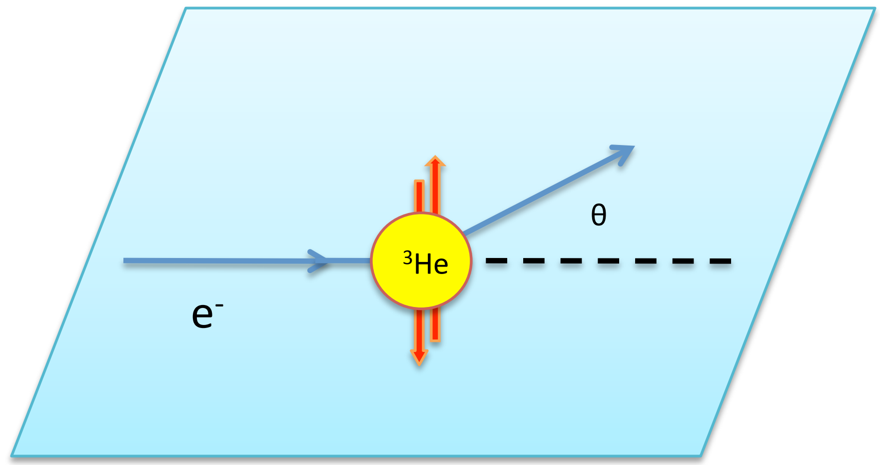




Target Single Spin Asymmetry (SSA)

$$A_y(Q^2) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$





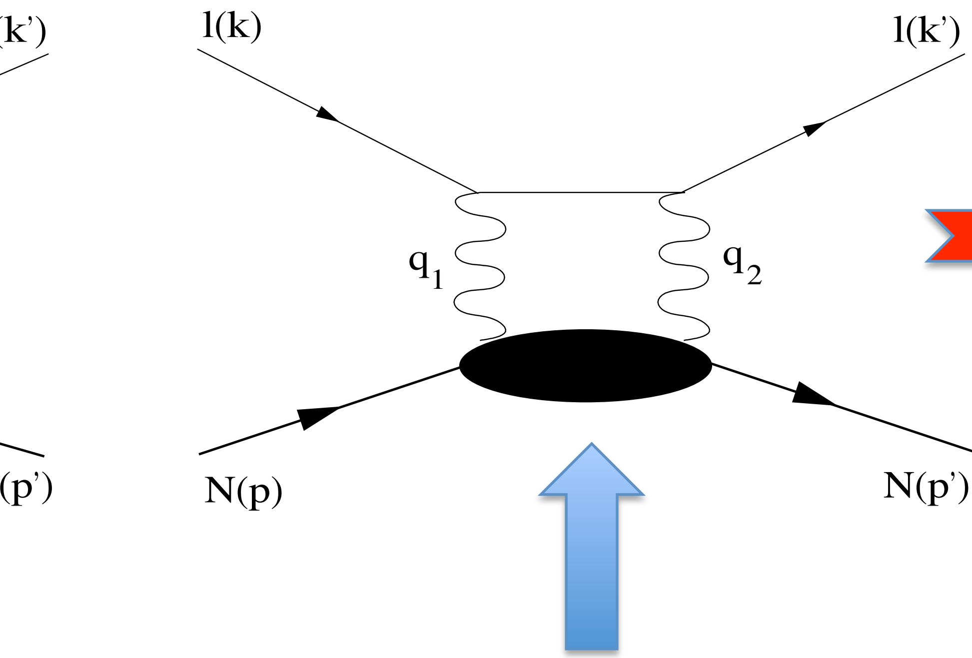
- Unpolarized e^- beam incident on ^{3}He target polarized normal to the electron scattering plane.

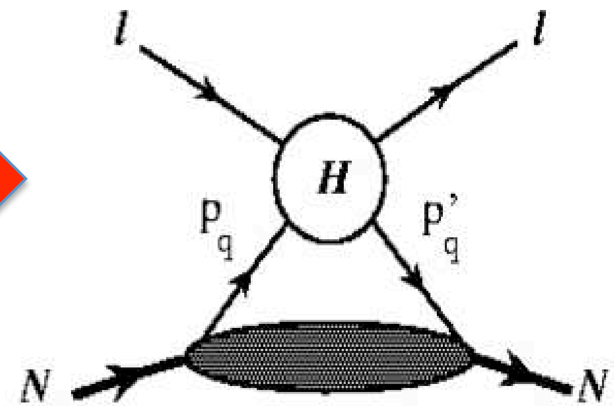
- However, A_y=0 at Born level,
  → sensitive to physics at order α^2; two-photon exchange.

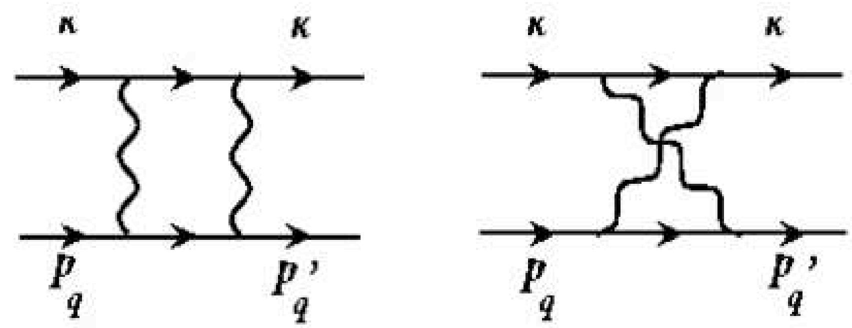
- Kinematic variable: $Q^2 = -q^2$ (Four-momentum)^2 of virtual photon)
  - low Q^2 = long wavelength photon; low resolution, nucleon physics
  - high Q^2 = short wavelength photon; high resolution, quark physics

At low Q^2, entire nucleon is involved

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







Loop integral contains entire elastic and inelastic response of nucleon

Topic 1: 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 $1\gamma \otimes 2\gamma$-interference (up to $\mathcal{O}(e^4)$)

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'), $A_y^{Born} = 0$

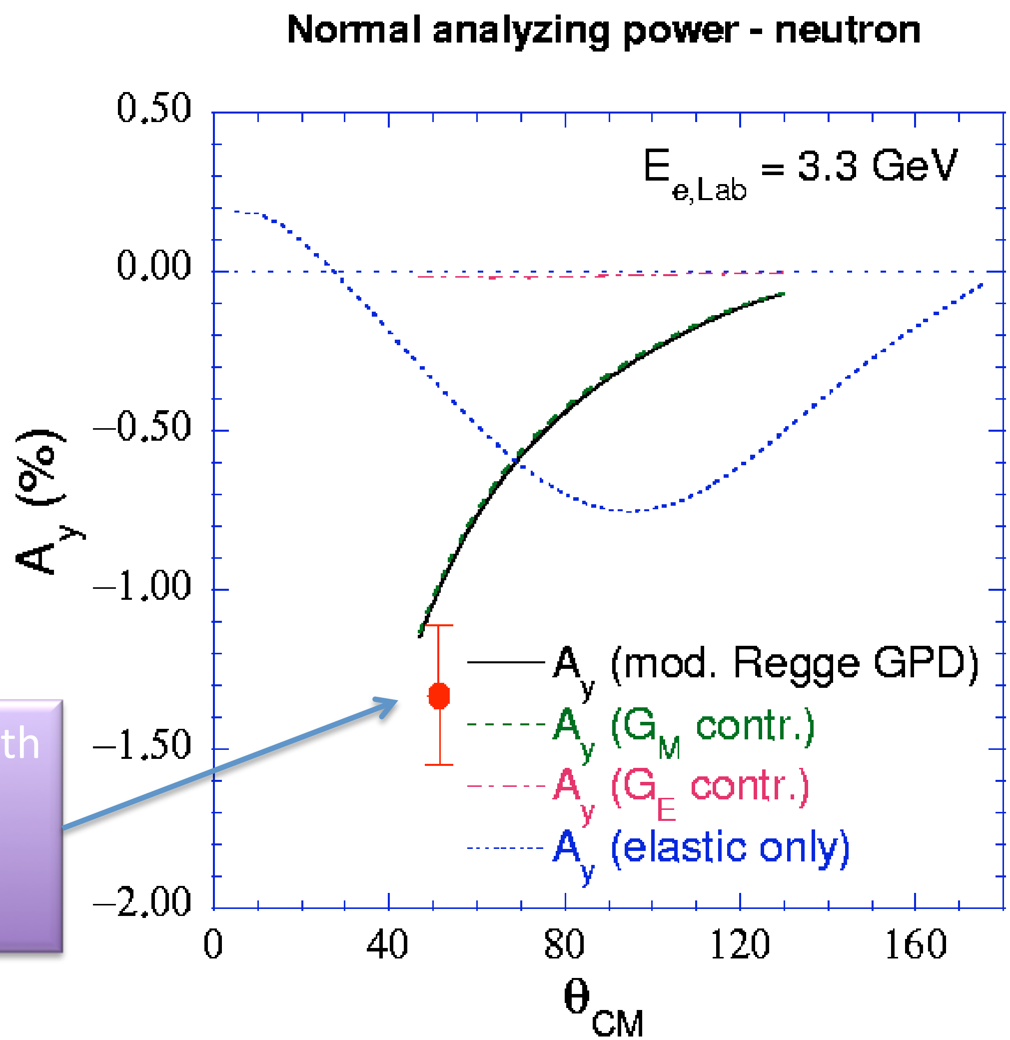
N. Christ-T.D.-Lee, Phys. Rev. 143 (1966) 1310

Time reversal invariance, parity conservation, and the hermiticity of the electromagnetic current operator

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

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

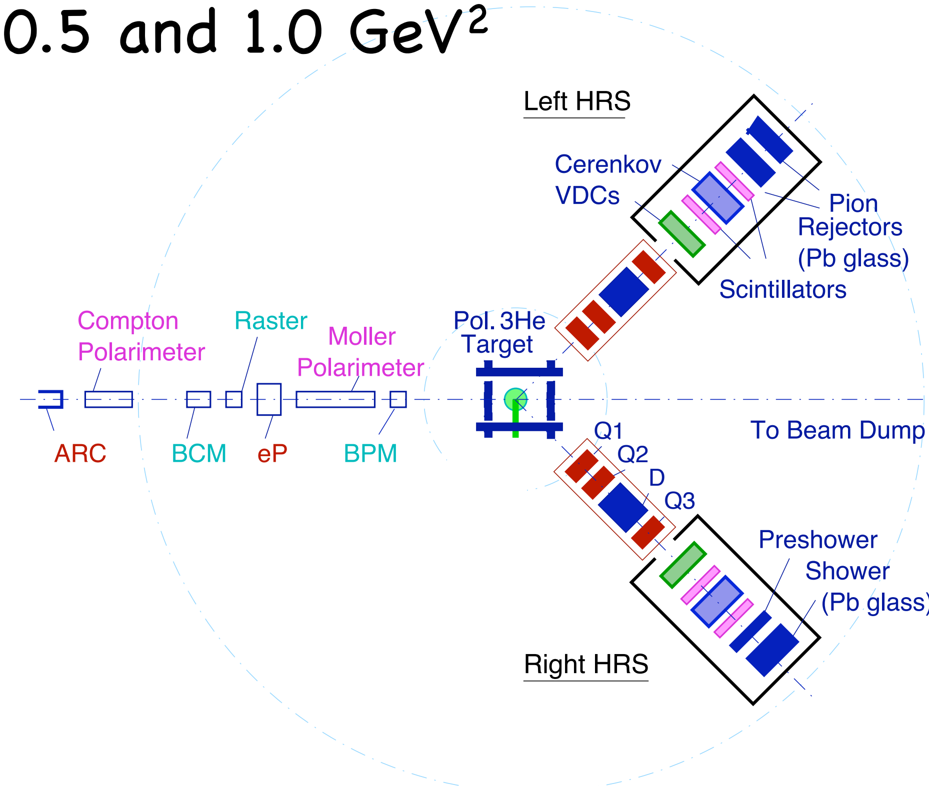
Prediction by Carlson et al. at Q^2=1.0 GeV^2



GPD prediction with our expected statistical uncertainty.

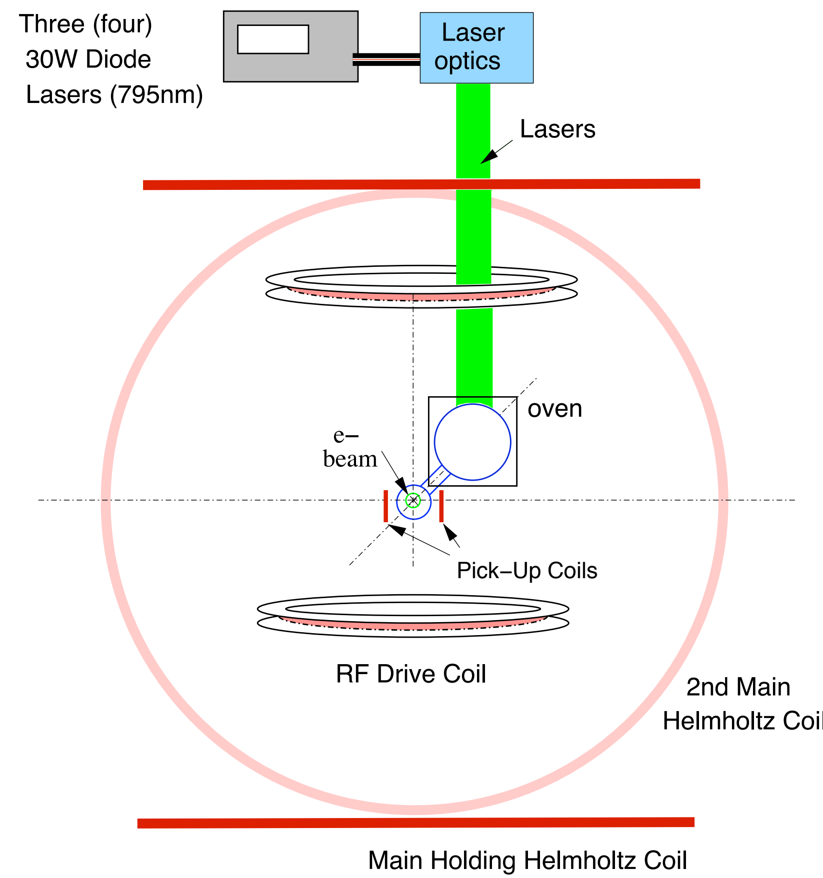
Experimental Design

- 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

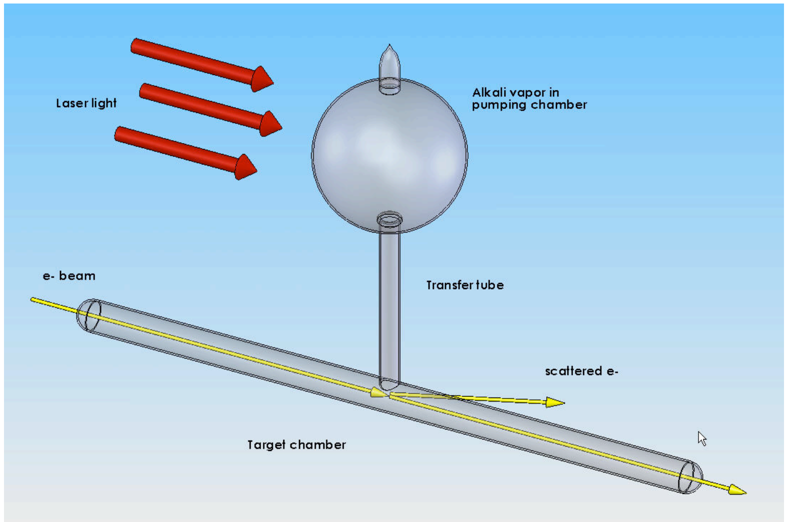


Hall A polarized ^{3}He target

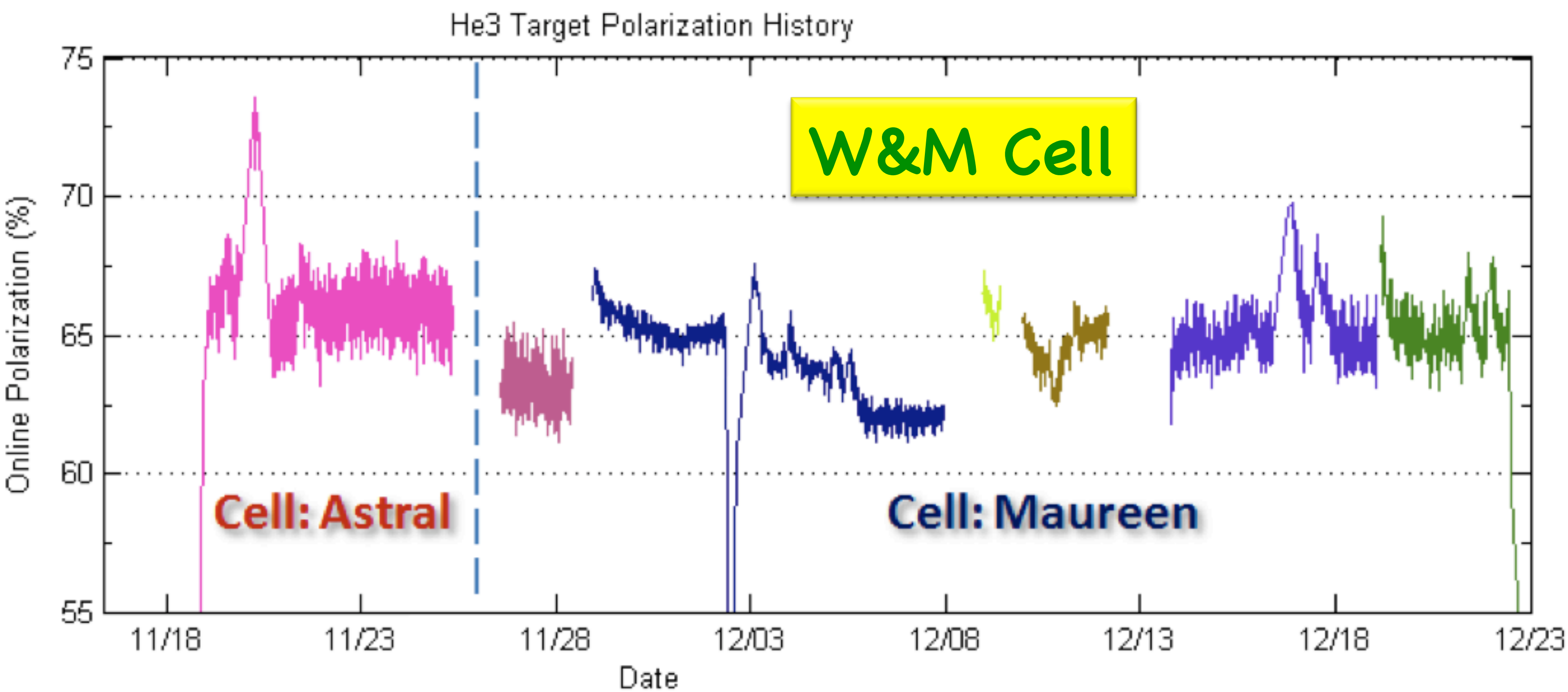
W&M, UVa, JLab



- Effective polarized neutron target
- Spin Exchange Optical Pumping (SEOP) technology
- New Innovations:
- 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 $L \sim 10^{36}$ /cm^2/s



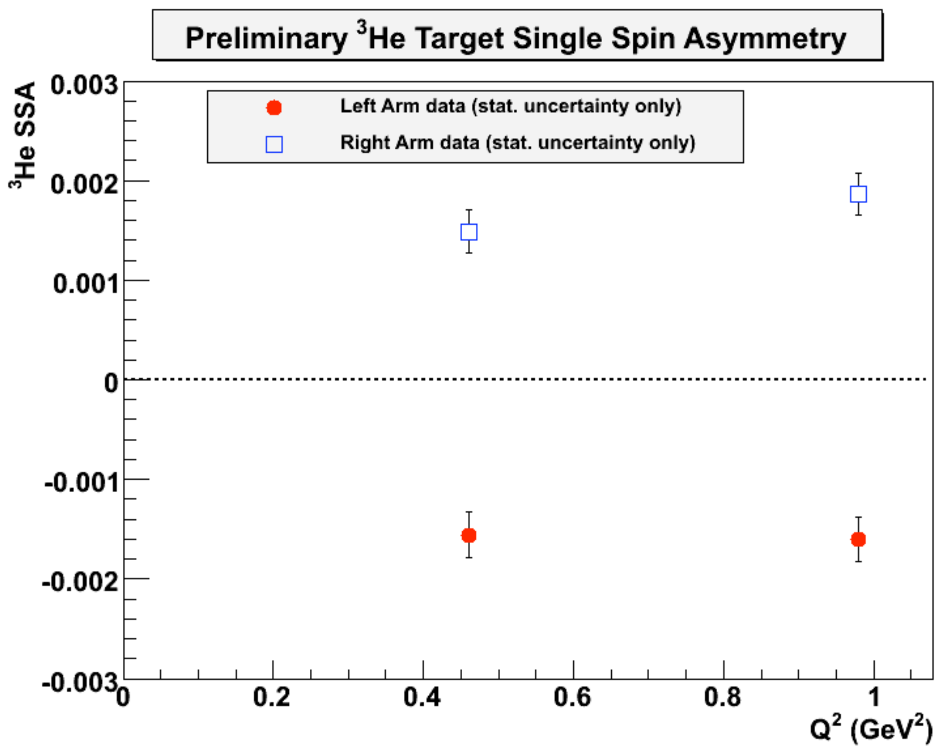
Recent Target Performance



World record performance

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

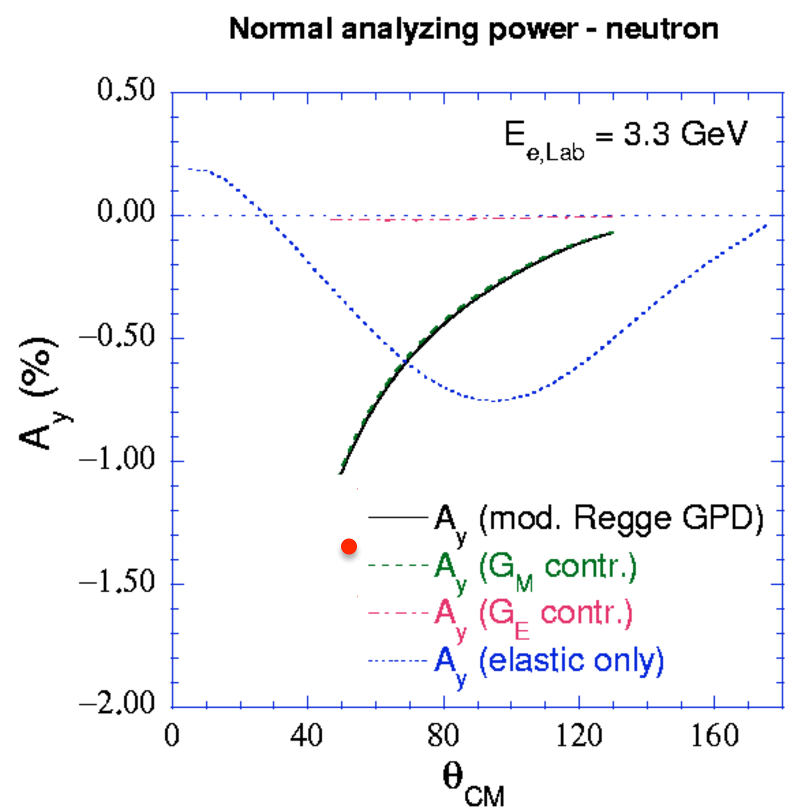
$^{3}He(e,e')$ A_y^{3He}



Data above is for helium-3, no correction to extract neutron results.

Analysis by Bo Zhao—College of W&M

Prediction below is for Q^2= 1 GeV^2
Carlson et al.--Neutron



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

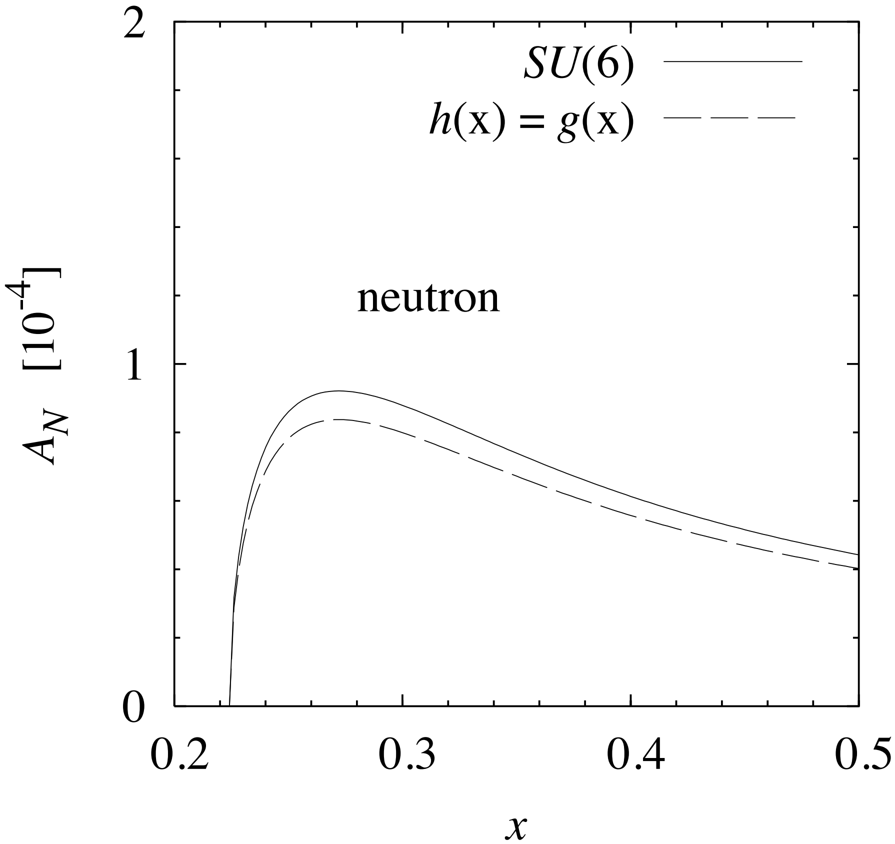
- The formalism remains the same:
  A_y=0 for 1-photon exchange

- 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.

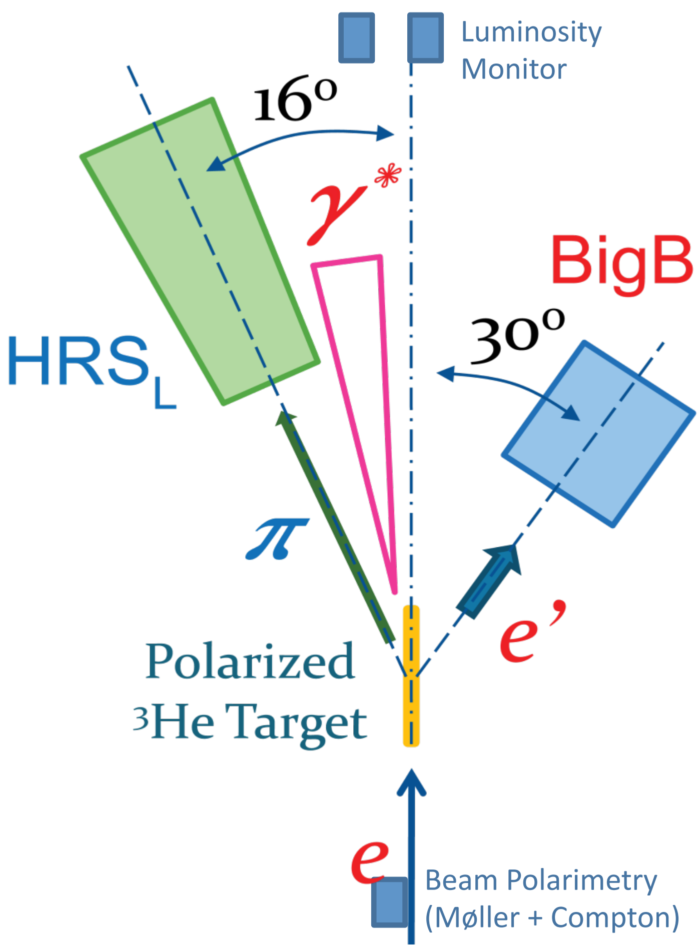
- Joe Katich-W&M Ph.D. thesis

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 $A_y \sim 10^{-4}$ 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.

Transversity kinematics

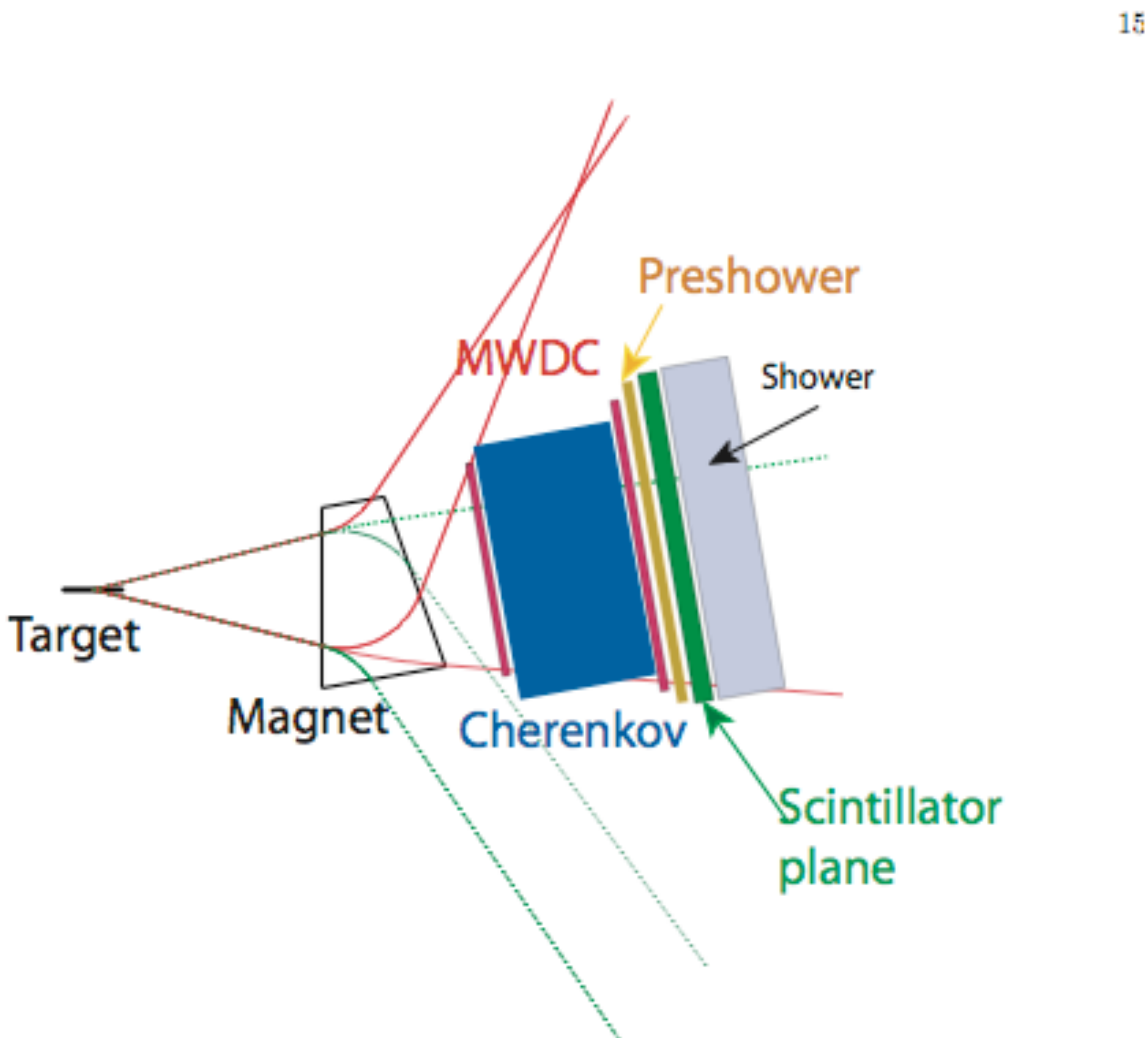


Measure ^{3}He(e,e') SSA using BB and LHRS in singles mode.

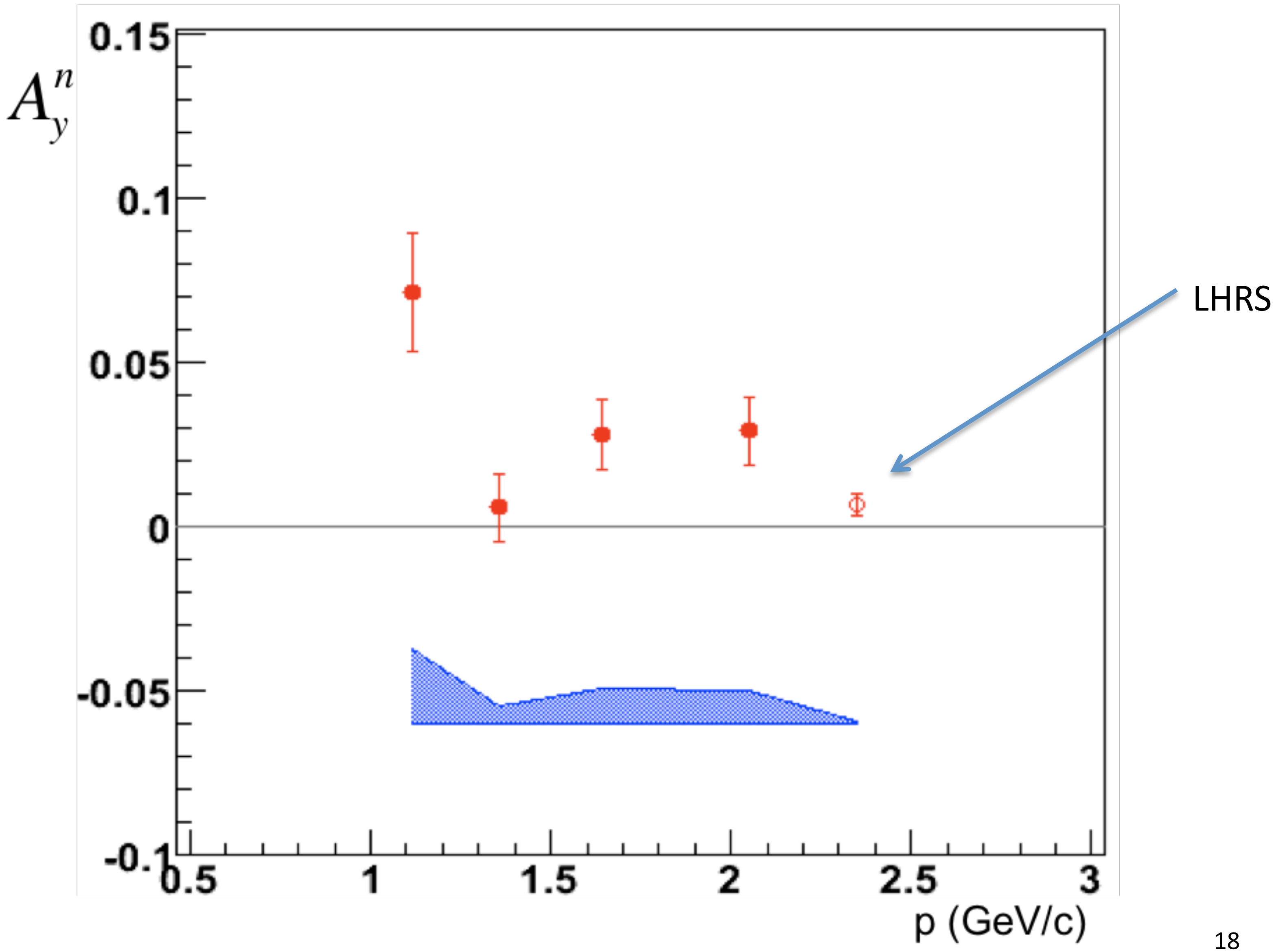
E=5.89 GeV

	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

Big Bite Detector

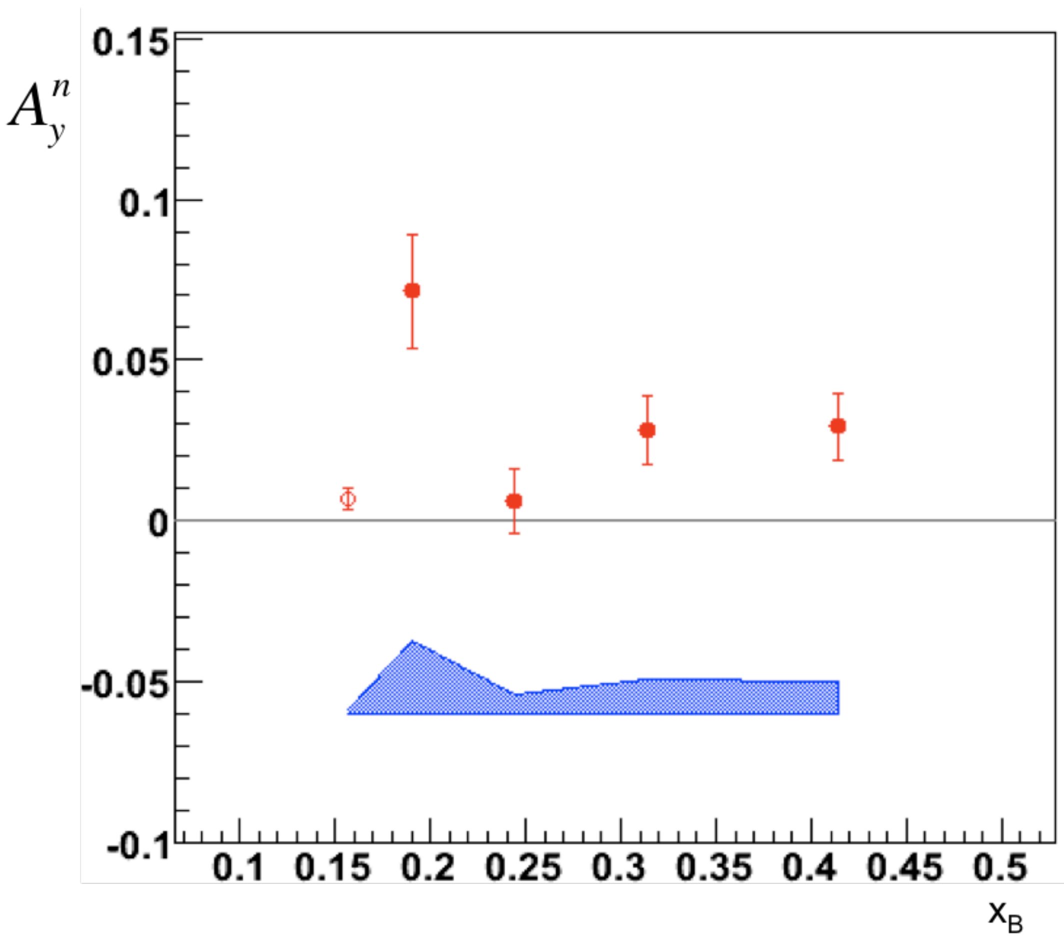


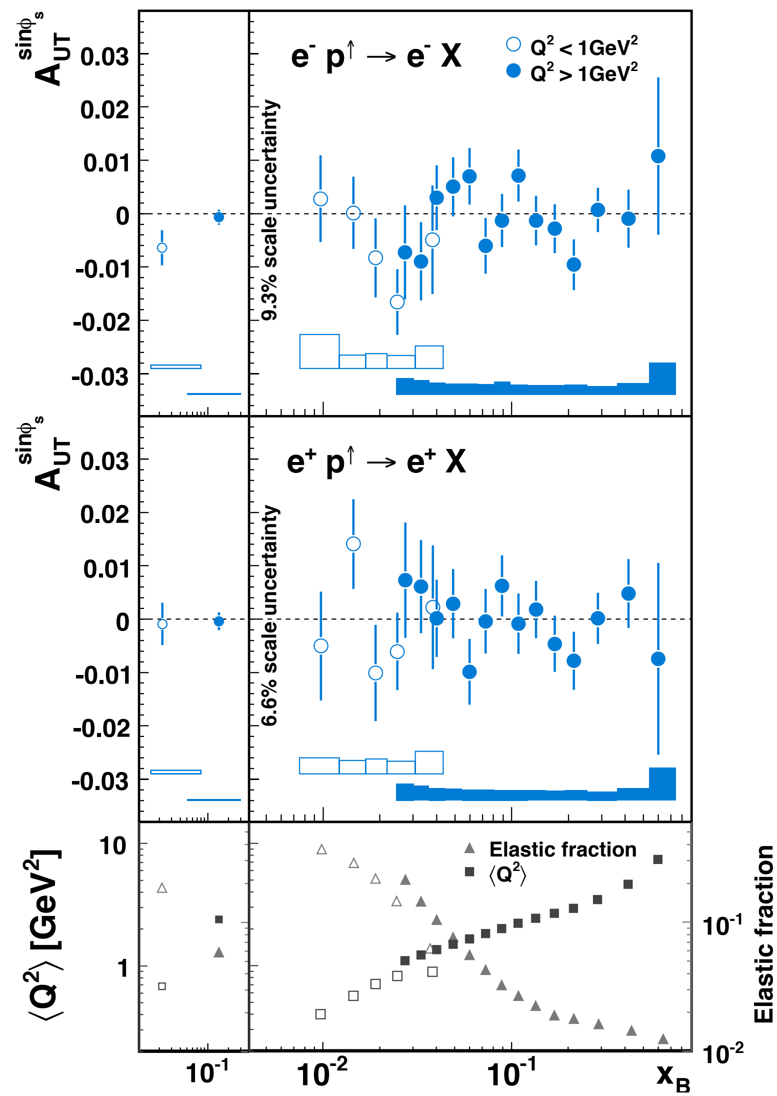
Preliminary Results



Preliminary Results
Neutron

HERMES Proton





A. Airapetian et al,
Phys. Lett. B682, 351 (2010)

Summary

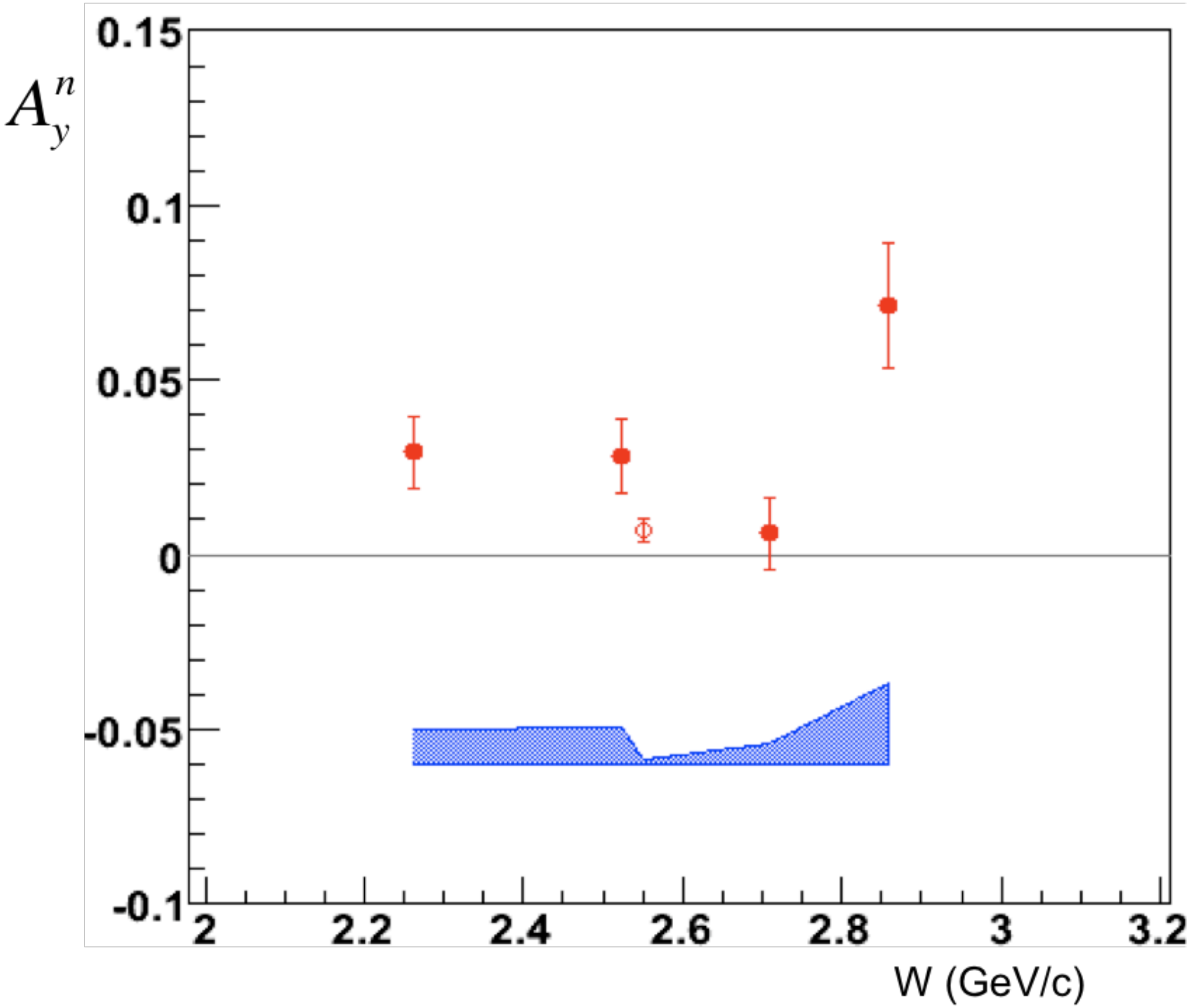
- Vertical target single spin asymmetry is a new tool that provides access to nucleon models over a wide range of kinematics.
- Preliminary data presented for A_y in the quasi-elastic and deep-inelastic regions.
- QE data show a clear and significant non-zero asymmetry as predicted by GPD model. No change at Q^2=0.5 GeV^2. Expect 0.1 GeV^2 result soon.
- DIS data show an asymmetry that is non-zero and two orders of magnitude larger (and opposite sign) than predicted by Afanasev et al. Large backgrounds at low momentum. Analysis will continue.
- Goal: publish both this year.

Backup Slides

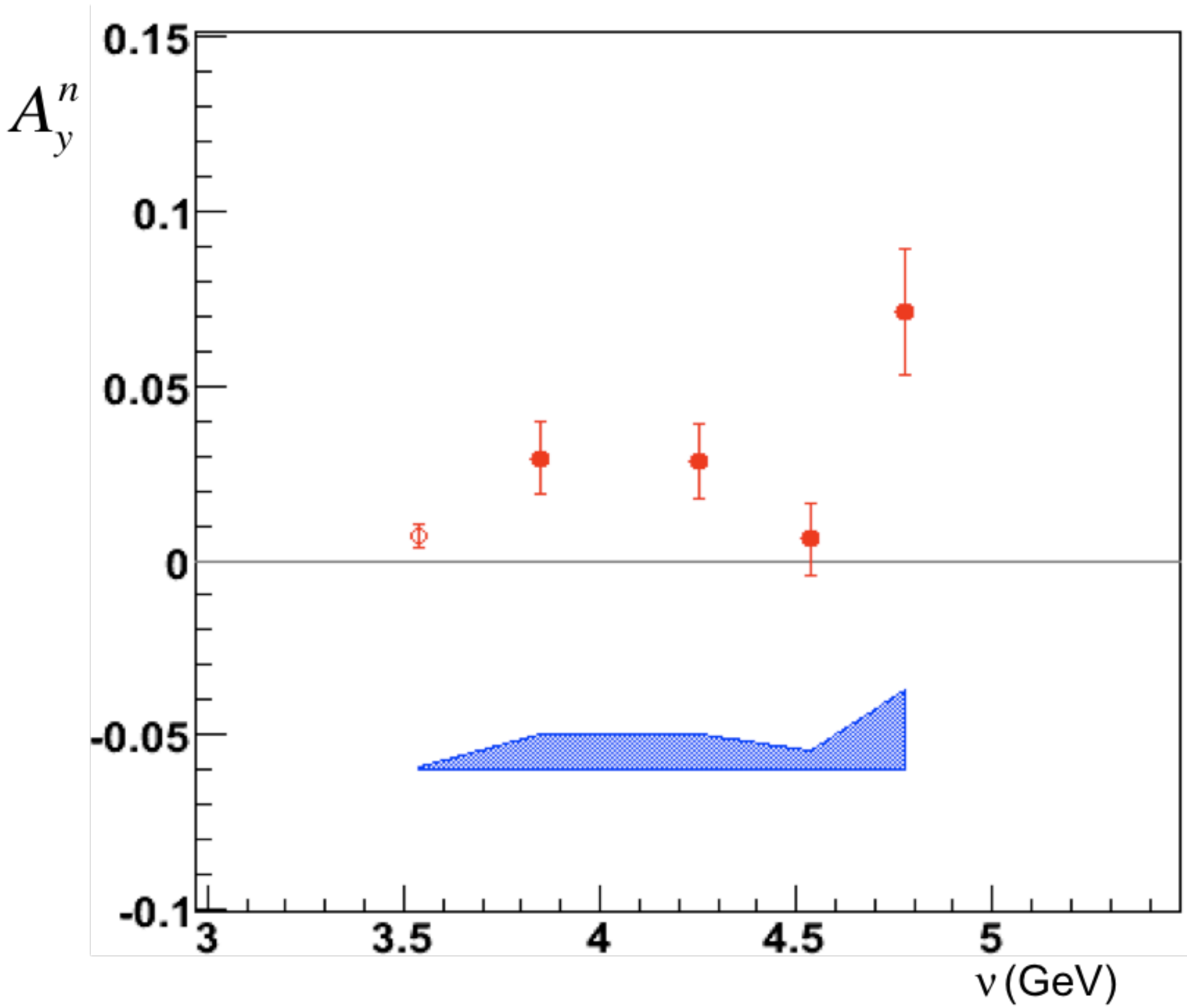
Summary of Systematic Error

BigBite Momentum Bin 1			
Source	Uncertainty	Relative / Absolute	δA_{sys}^{source}
A_{π^-}	0.0015	absolute	5.85×10^{-5}
A_{e^+}	0.0019	absolute	3.9×10^{-3}
C_{π^-}	100%	relative to C_{π^-}	1.97×10^{-3}
C_{e^+}	20%	relative to C_{e^+}	2.08×10^{-2}
P_T	5%	relative to P_T	3.56×10^{-3}
η_{N_2}	0.03	absolute	3.1×10^{-3}
^{3}He$\rightarrow n$	0.03	absolute	7.6×10^{-3}
$\rho_{^3He}$	2.1%	relative to δA_y^{stat}	3.8×10^{-4}
A_{lumi}	1.0×10^{-4}	absolute	1.0×10^{-4}
A_{LT}	1.5×10^{-4}	absolute	1.5×10^{-4}
Tracking	1.5%	relative to δA_y^{stat}	2.70×10^{-4}
Rad. Corr.	0.93%	relative to δA_y^{stat}	1.67×10^{-4}
		Added in Quadrature:	$\delta A_{sys} = 2.3 \times 10^{-2}$

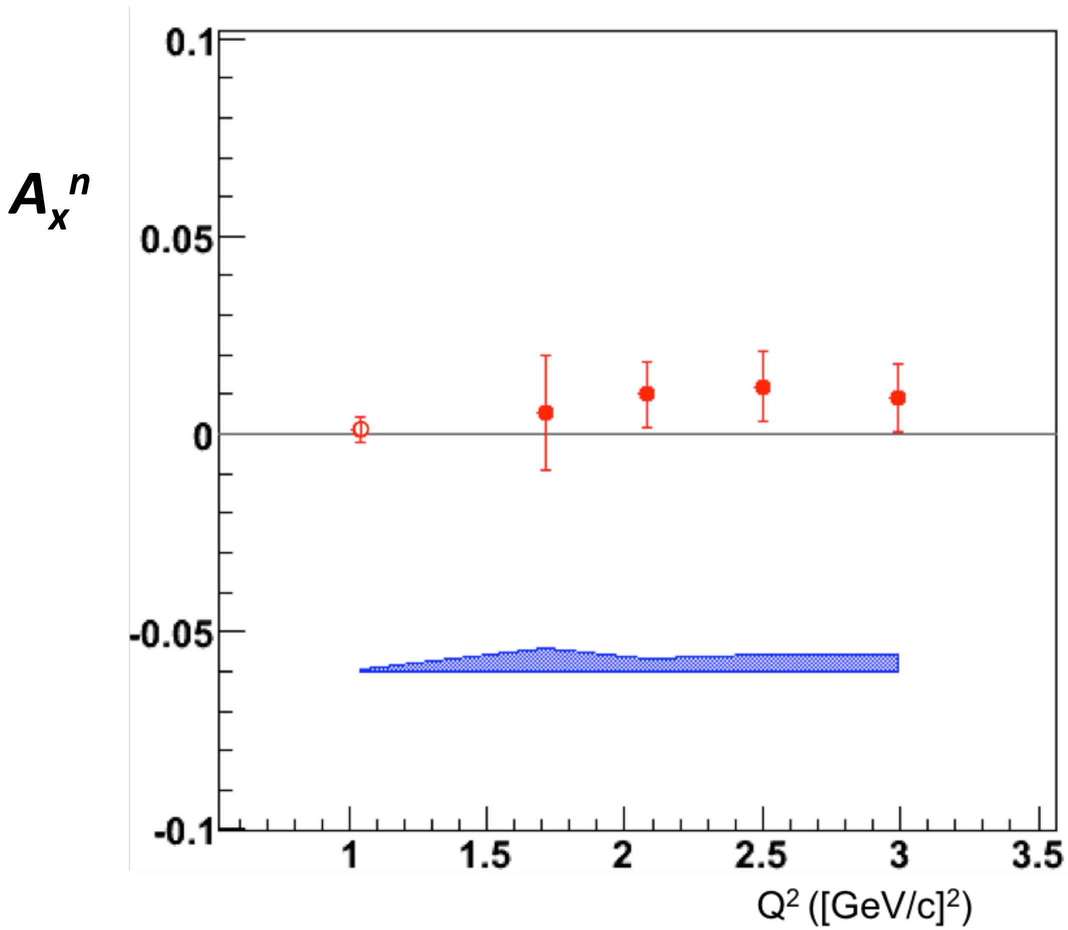
Preliminary Results



Preliminary Results

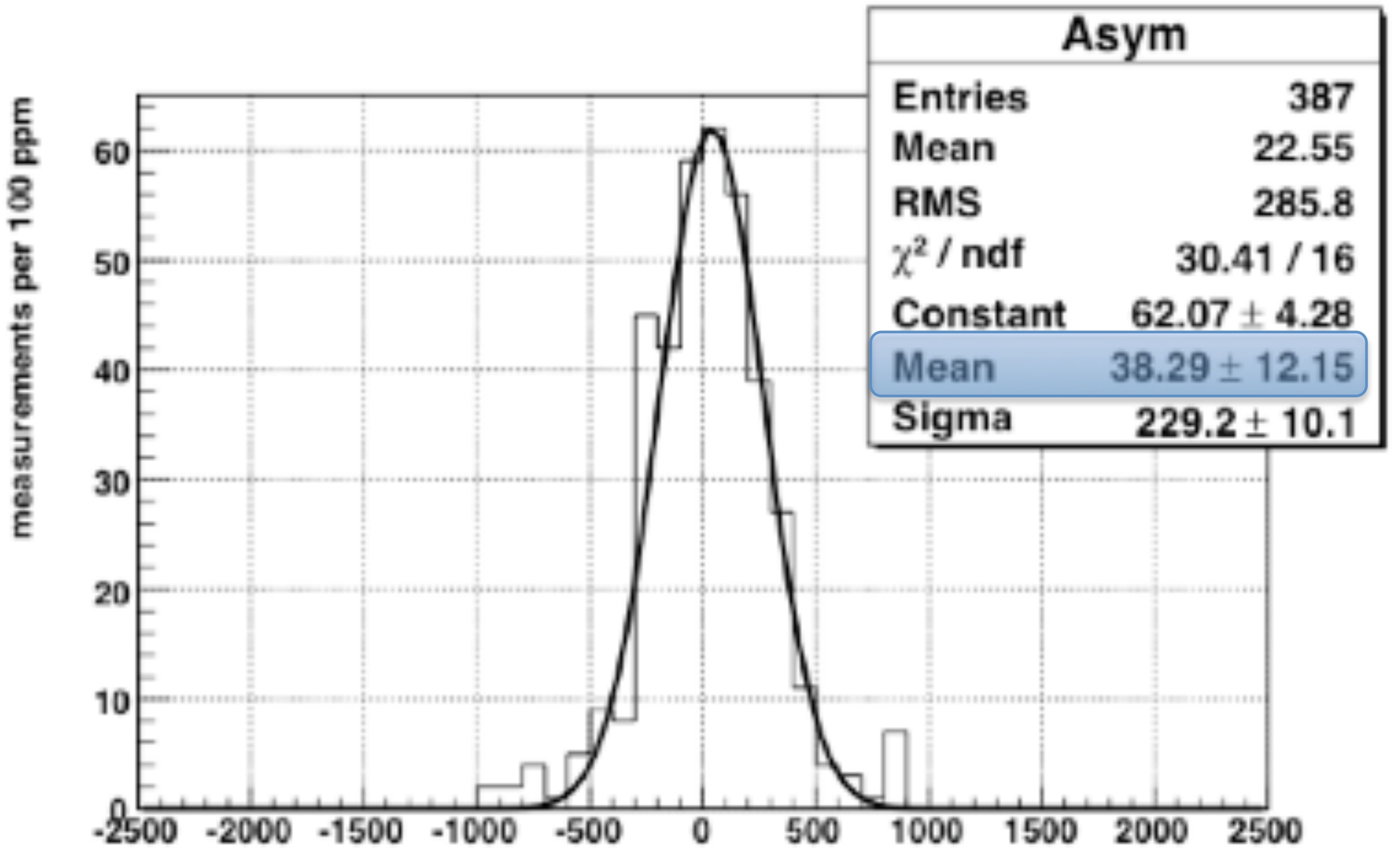


Transverse SSA



Should be exactly zero

Luminosity Asymmetry



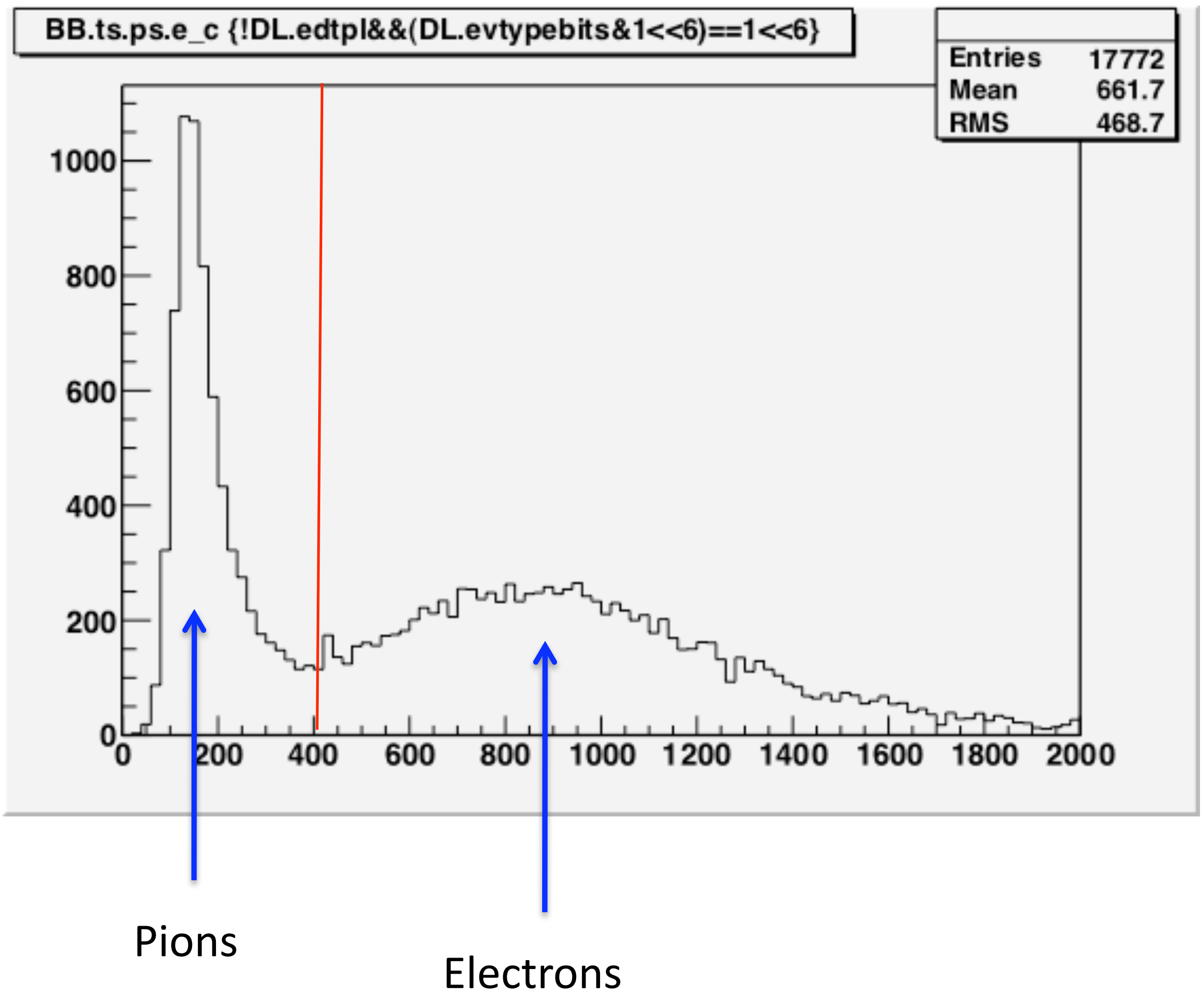
ppm

Backgrounds

- $\pi^{-/+}$ in BB $e^{-/+}$ spectrum. Cherenkov in BB not yet working for PID at 30 deg.
- Pair produced e^+/e^- pairs from π^0 decay.
  - Measure using positive polarity
  - 50% contamination in lowest momentum bin
    - Correct this for π^+ contamination….
  - Largest systematic uncertainty
  - LHRS data has no pions

Particle Identification

Energy Deposited in the Preshower Calorimeter



Contamination Studies

Two main sources of contamination

$$\pi^-$$

Despite high threshold on PS+SH, plenty of pions will still be recorded

Fit the shape of each peak and integrate each above some threshold

$$\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-$$

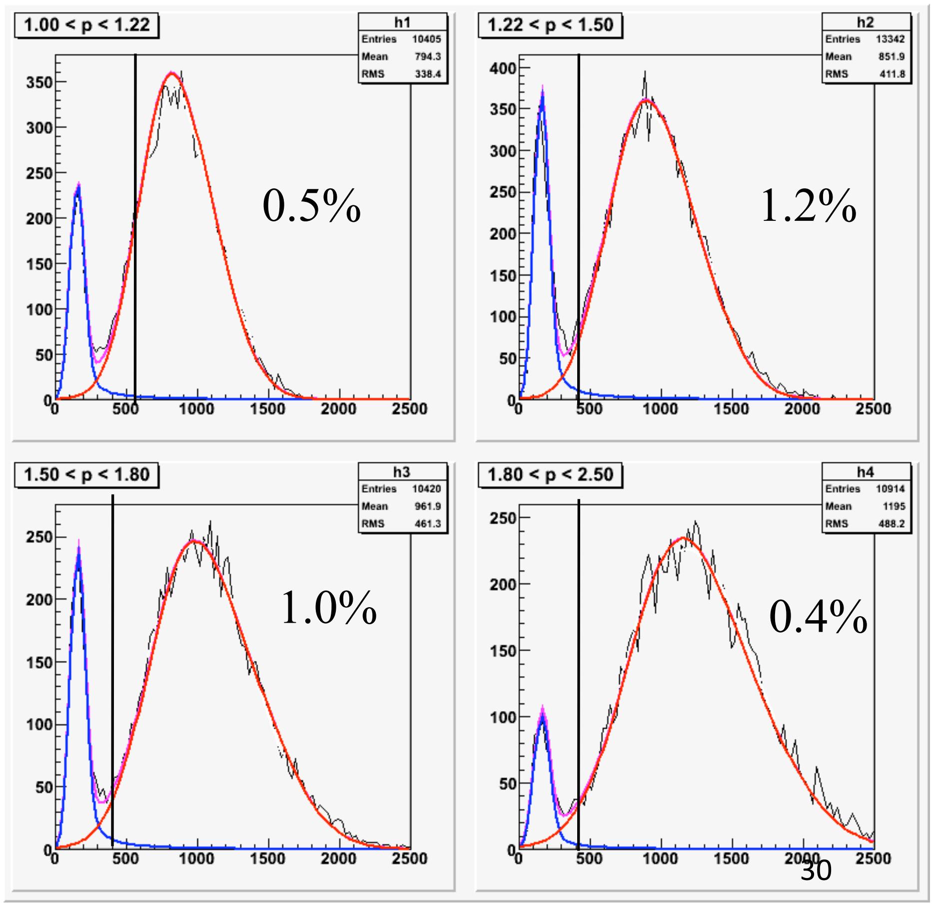
A bit more subtle…'bad' electrons will look just like 'good' electrons:

- good track
- same energy / momentum

Need 'positron' runs to estimate the contamination level

Contamination Studies

π^-

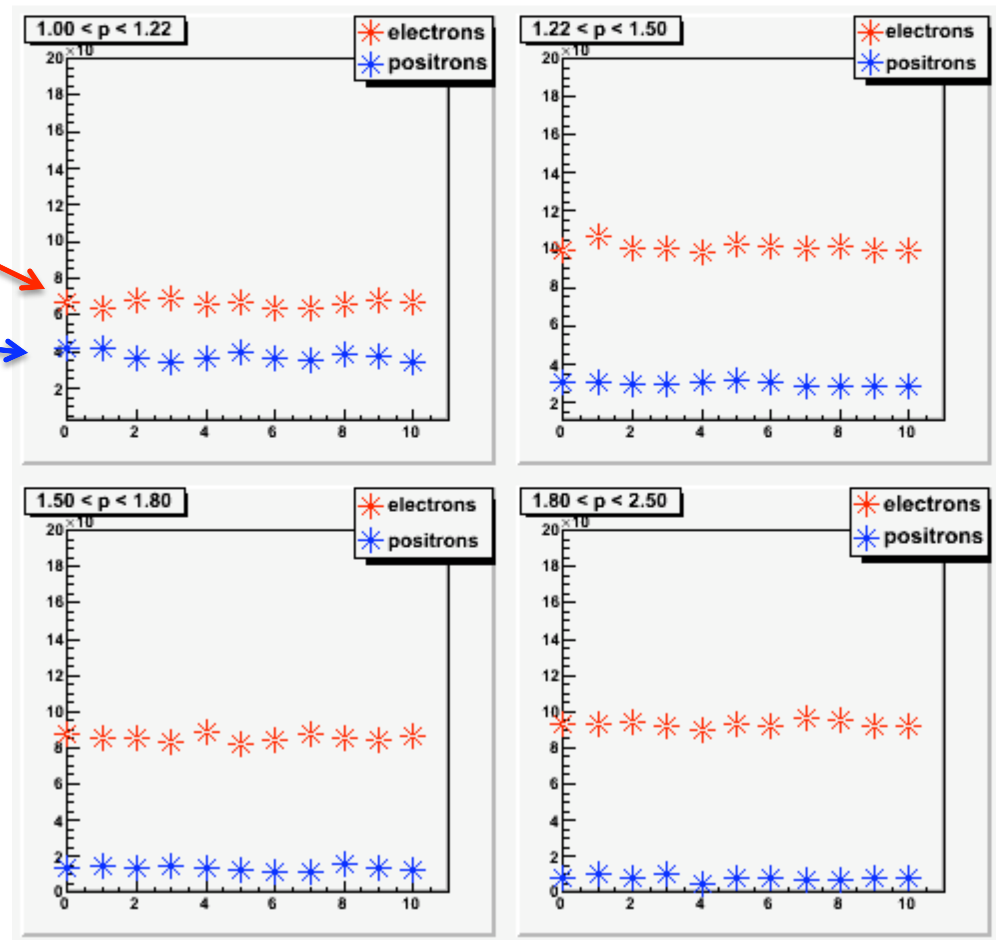


Contamination Studies

$$\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-$$

Electron Yield

Positron Yield



$$\%C^{e+} \propto \frac{Y^{e+}}{Y^{e-}}$$

Contamination Studies

$$\pi^0 \to \gamma\gamma \to e^+ e^-$$

momentum bin (GeV/c)	% contamination
1.00-1.22	56%
1.22-1.50	26%
1.50-1.80	13%
1.80-2.50	5%

***Both π^- and e^+ contamination are less than 1% in the HRS**

Radiative Corrections