Two photon exchange in deep-inelastic scattering

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

This analysis was done by Joe Katich, College of William and Mary

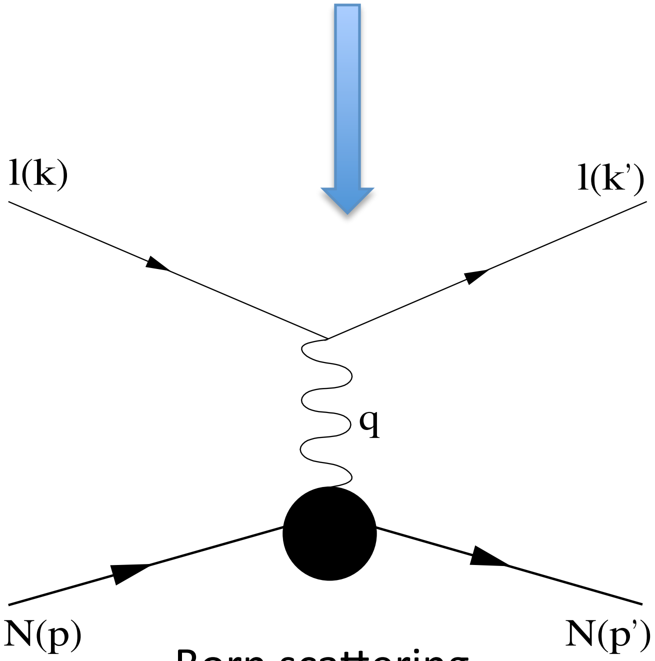
Program Goal: Measure the "vertical" target single spin asymmetry A_y in:

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

•http://www.jlab.org/~jkatich/Dissertation.pdf

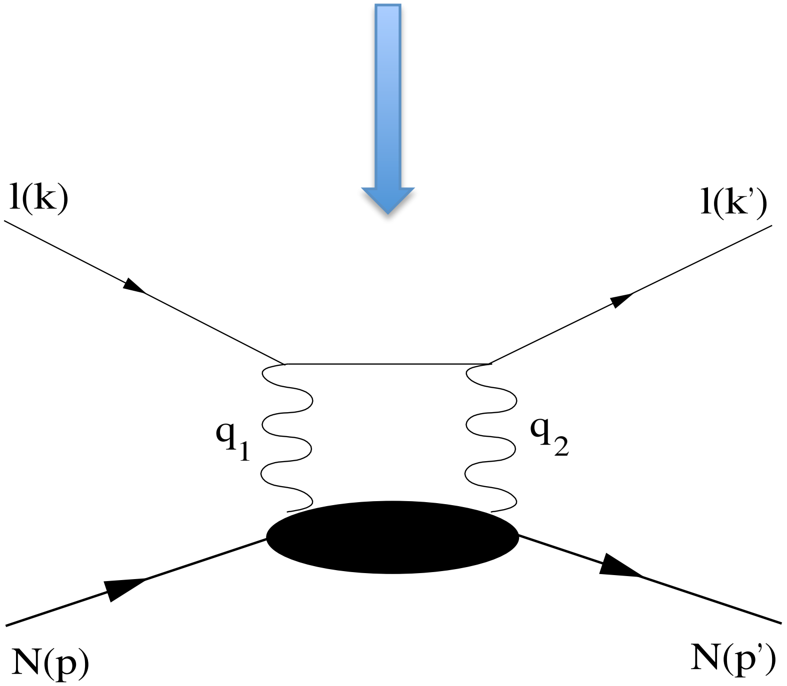
Born scattering and beyond

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



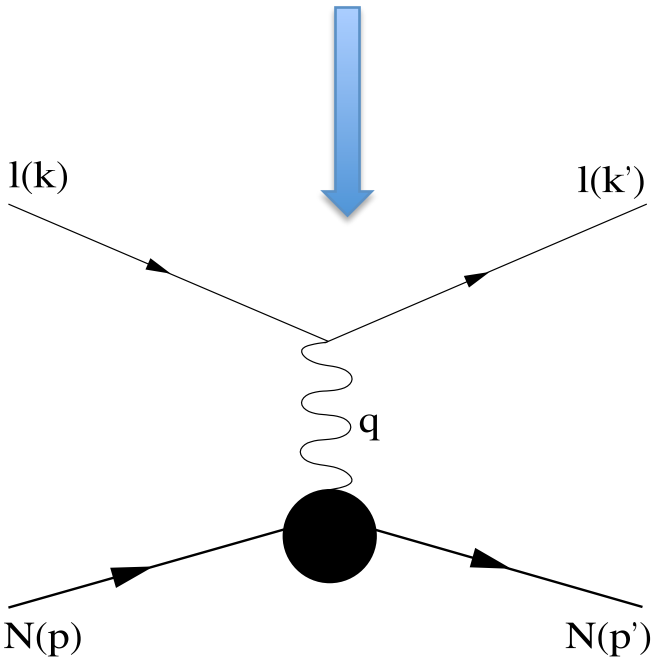
Born scattering

- Irritating correction to favorite diagram.
- Good news—suppressed by α relative to Born diagram

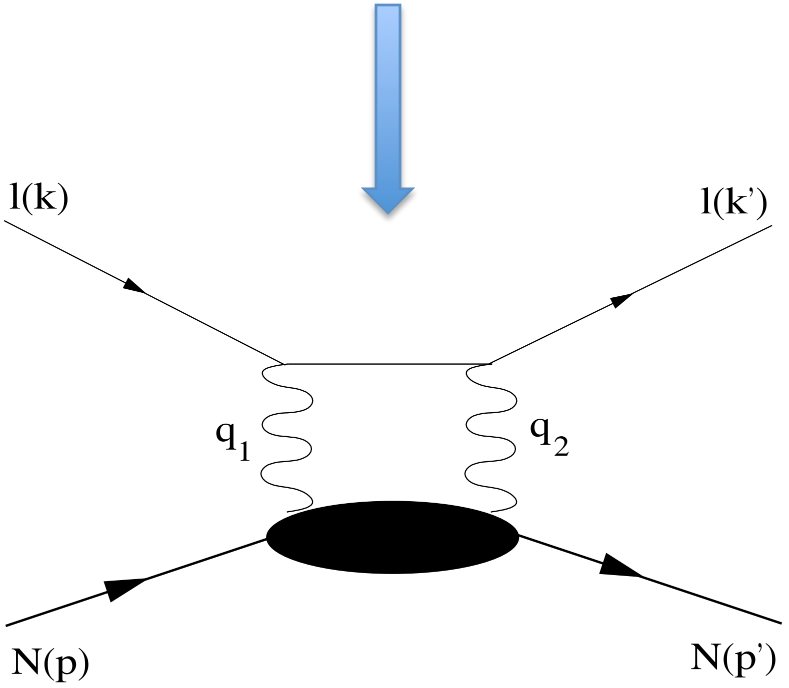


Born scattering and beyond

- Dominates unpolarized and most polarized N(e,e’) scattering.
- True for N=nucleons, nuclei, quarks.



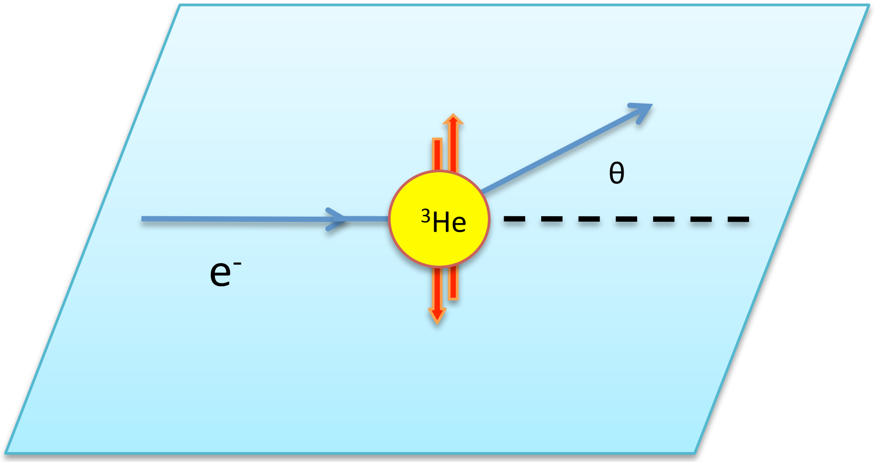
- How is it useful?
- Loop integral contains entire nucleon response.
- How do we observe this?



Target Single Spin Asymmetry (SSA)

- Unpolarized e^- beam incident on ^{3}He 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.

2-photon physics

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

e.g. unpolarized two-photon (interference) amplitude depends on 3 complex structure functions:

$$T = T_{1\gamma} + T_{2\gamma} \propto \tilde{F}_1(\nu, Q^2), \tilde{F}_2(\nu, Q^2), \tilde{F}_3(\nu, Q^2)$$

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

Absorptive part=Imaginary contribution

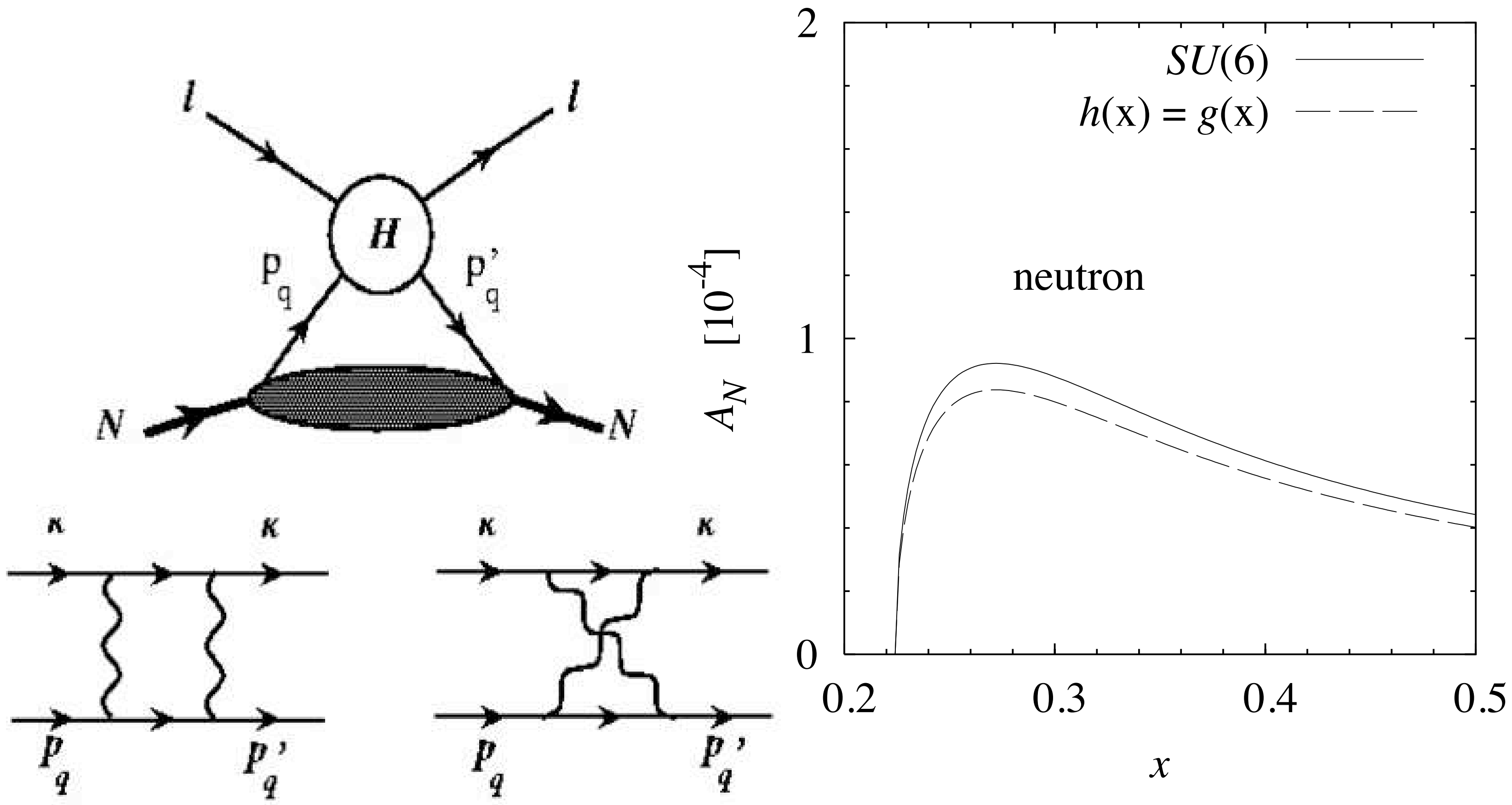
A. DeRujula *et al., Nuc. Phys. B35* (1971) 365

G_E^p data: 2-photon correction to elastic scattering

- 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 same interference:
- Estimated at large Q^2 using moments of GPD's

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

DIS→Interaction with a single quark

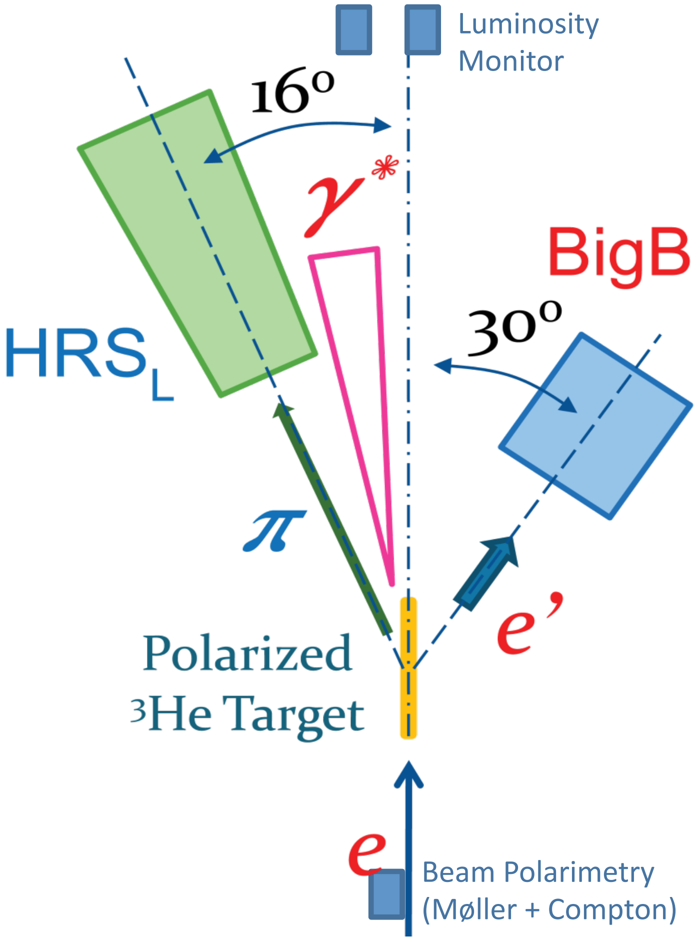


Afanasev, Strikman, Weiss (**Phys.Rev.D77:014028,2008)**

Physics Motivation

- Ran concurrent with Transversity experiment. Good kinematics, target.
- Made a first measurement of A_y^n in the DIS region.
- Prediction: $A_y = 0$ in simple quark models by 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.
- This means *the SSA should change by two orders of magnitude from DIS to QE kinematics.* This is a direct study of the "transition" from hadron-like to parton-like behavior.
- A factor of 10^2 smaller asymmetry expected compared to quasi-elastic $A_{y.}$

Transversity kinematics

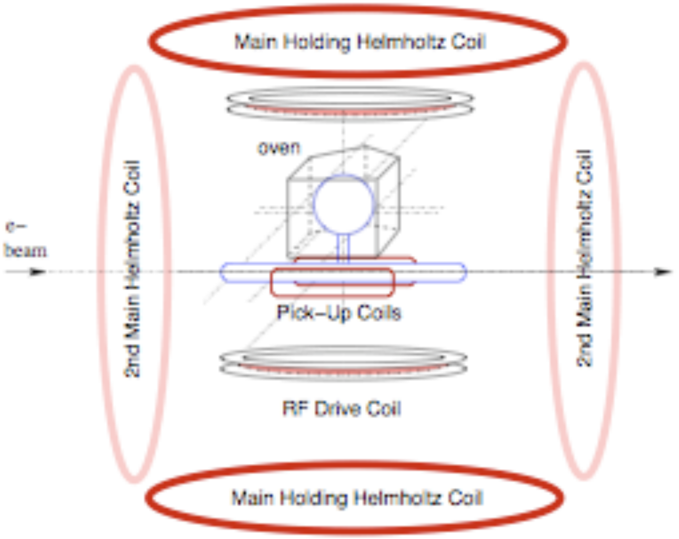


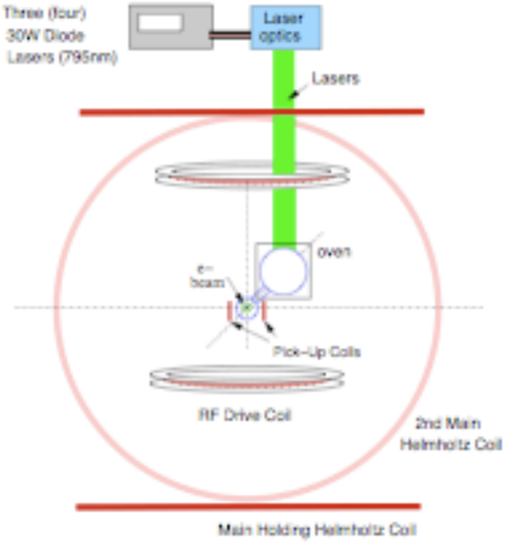
Measure ^{3}He(e,e') SSA using BB and LHRS in singles mode.

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

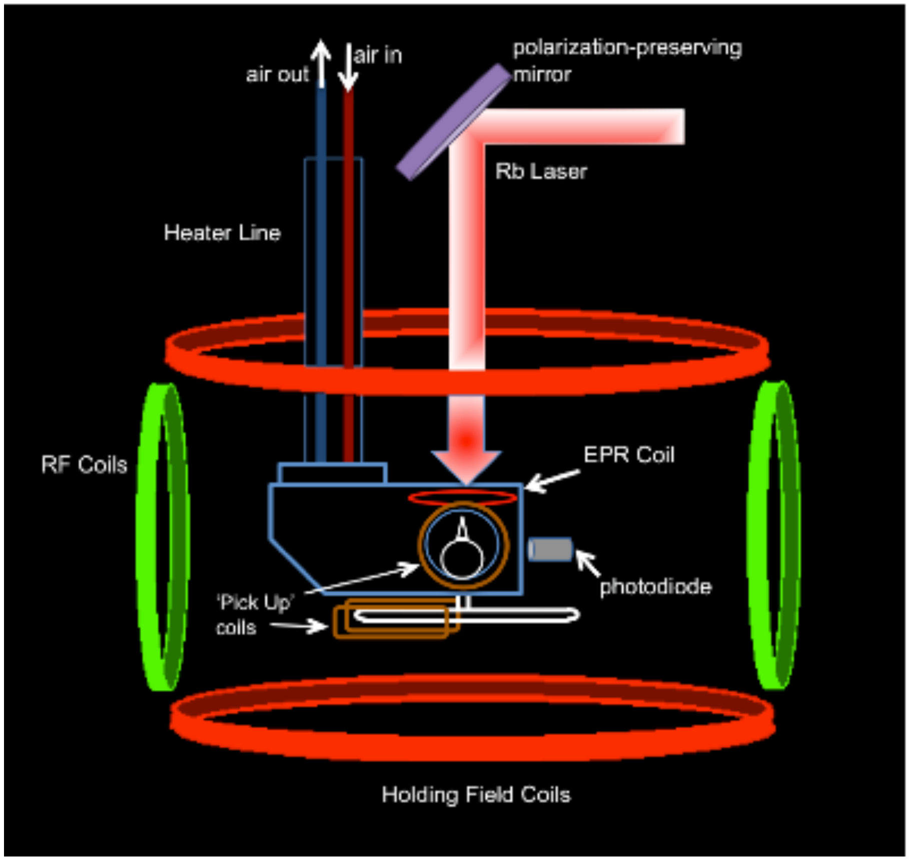
Vertically Polarized ^{3}He Target

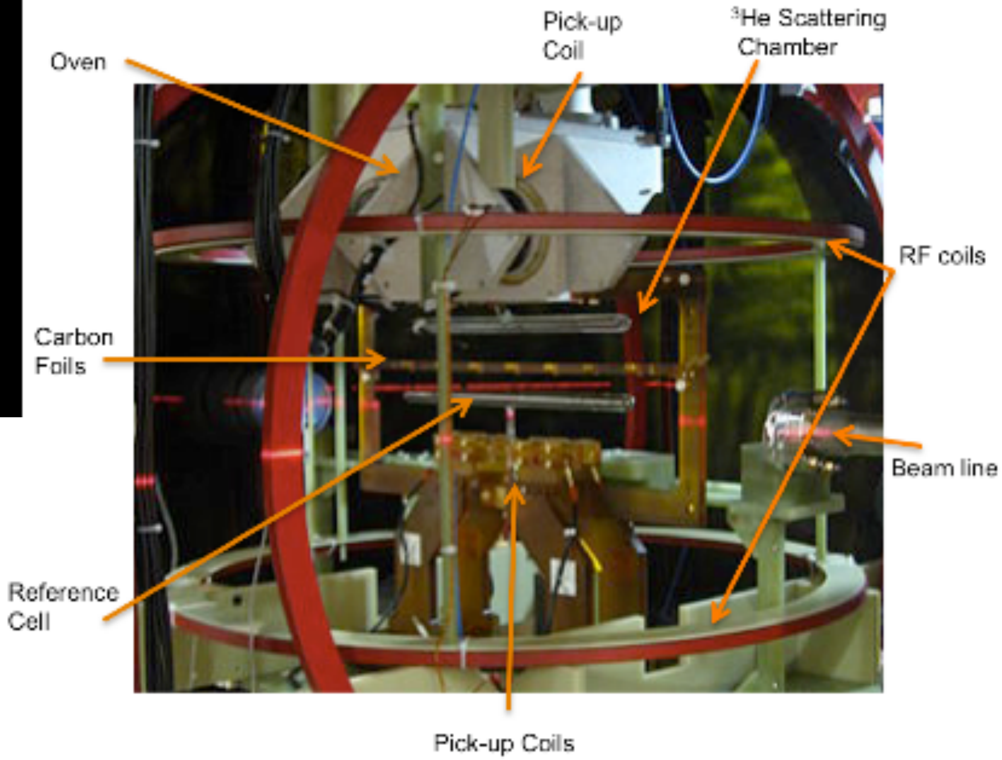




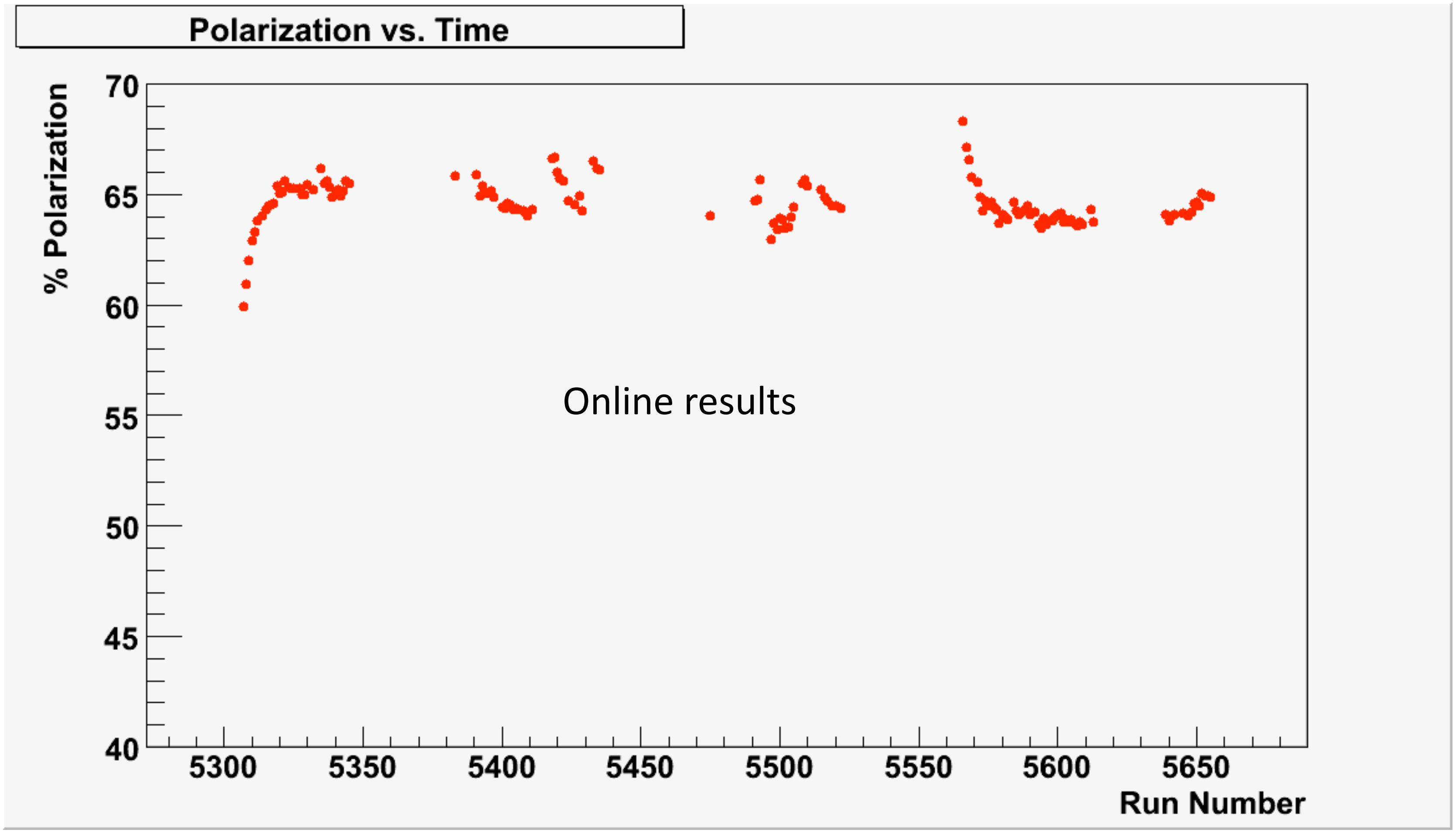
- Spin-exchange optically-pumped gas target. Now standard technology.
- New polarized target now achieving 65% in-beam polarization due to hybrid alkali and narrowed lasers.
- Reverse target spin direction every 20 minutes or less.

Vertically polarized ^{3}He target



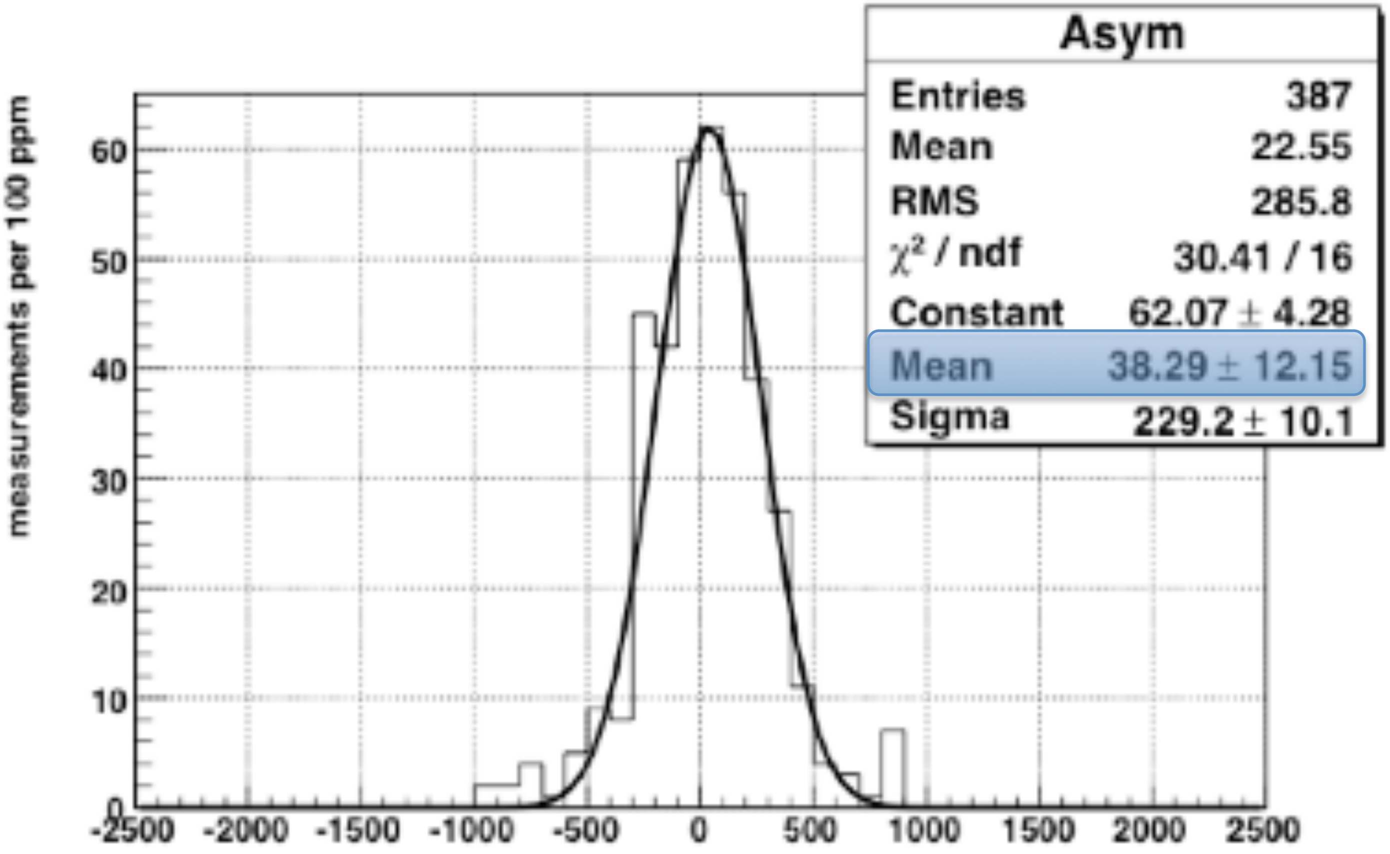


Target polarization for typical SEOP ^{3}He Hall A target



Online results

Luminosity Asymmetry

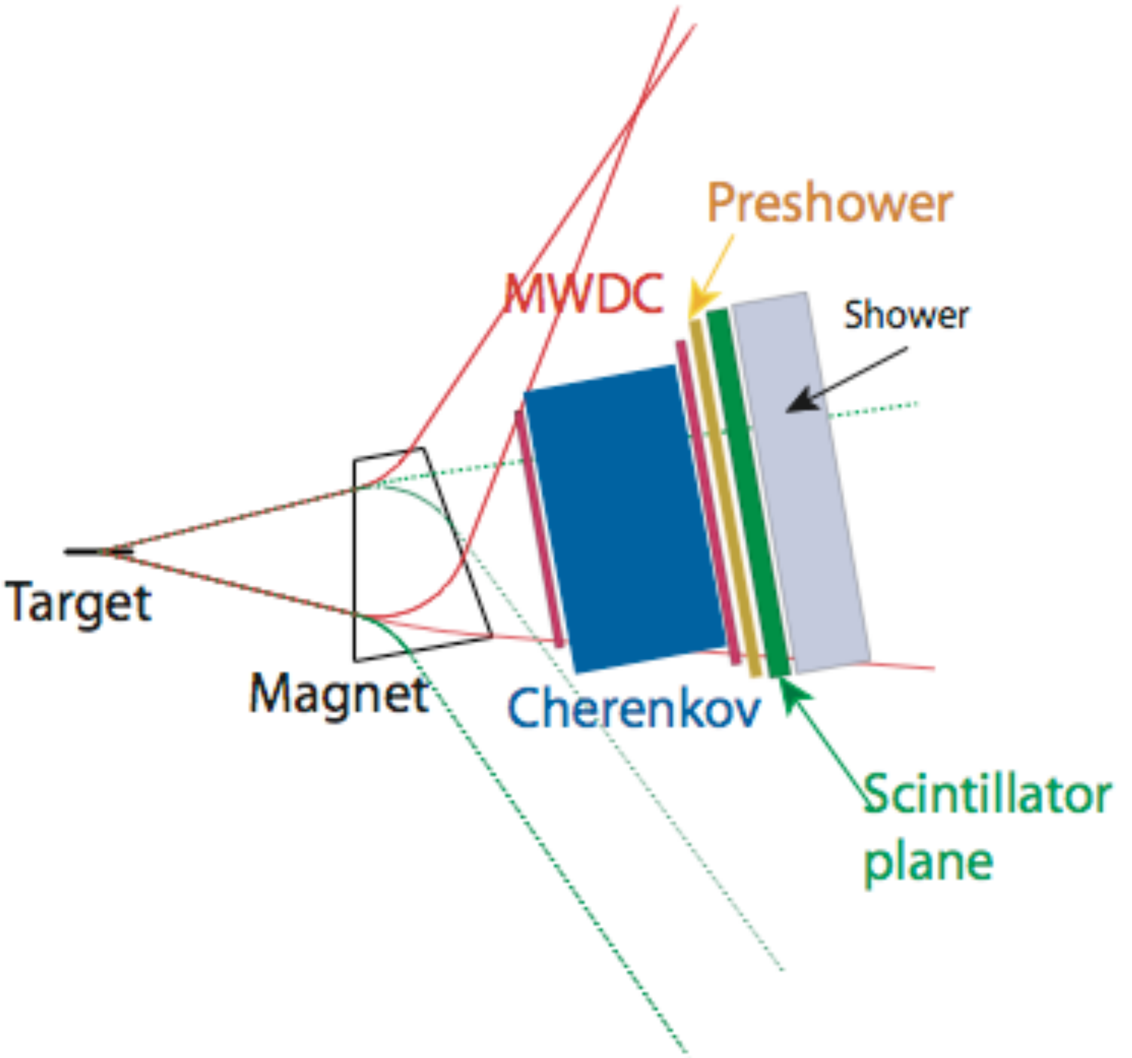


ppm

Backgrounds

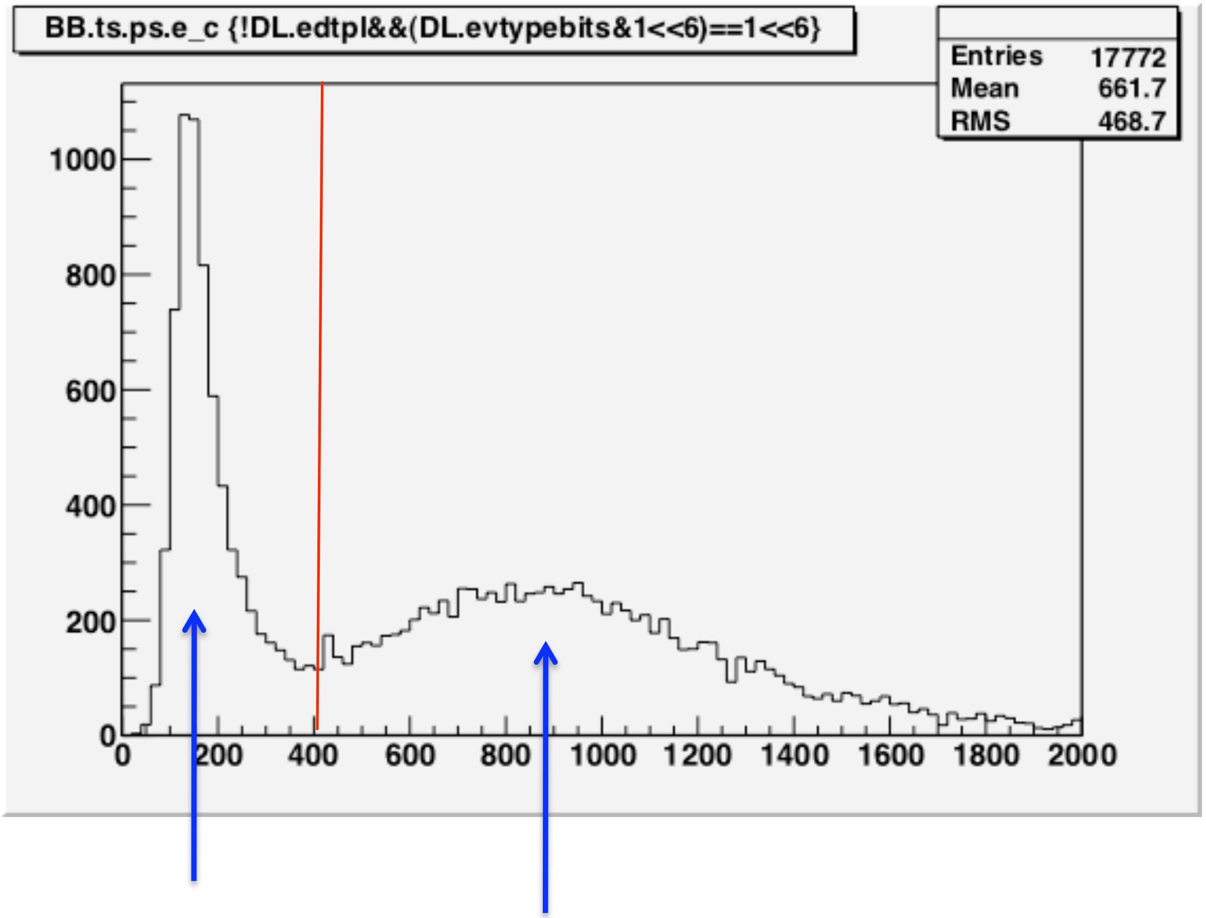
- $\pi^{-/+}$ in BB $e^{-/+}$ spectrum. Cherenkov in BB not yet working for PID at 30 deg.
- Pair produced e^+/e^- pairs from π^0 decay.
  - Measure using positive polarity
  - 50% contamination in lowest momentum bin
    - Correct this for π^+ contamination….
  - Largest systematic uncertainty
  - LHRS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

Big Bite Detector



Particle Identification

Energy Deposited in the Preshower Calorimeter



Pions

Electrons

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

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

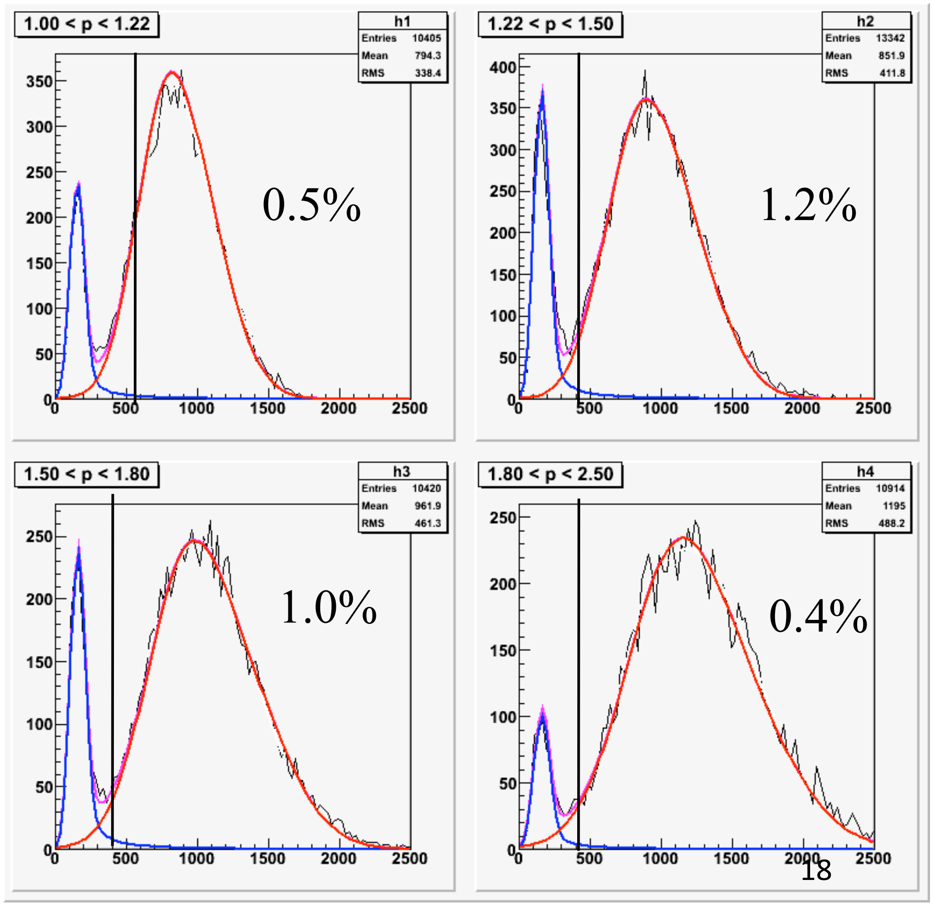
A bit more subtle…'bad' electrons will look just like 'good' electrons:

- good track
- same energy / momentum

Need 'positron' runs to estimate the contamination level

Contamination Studies

π^-



0.5%

1.2%

1.0%

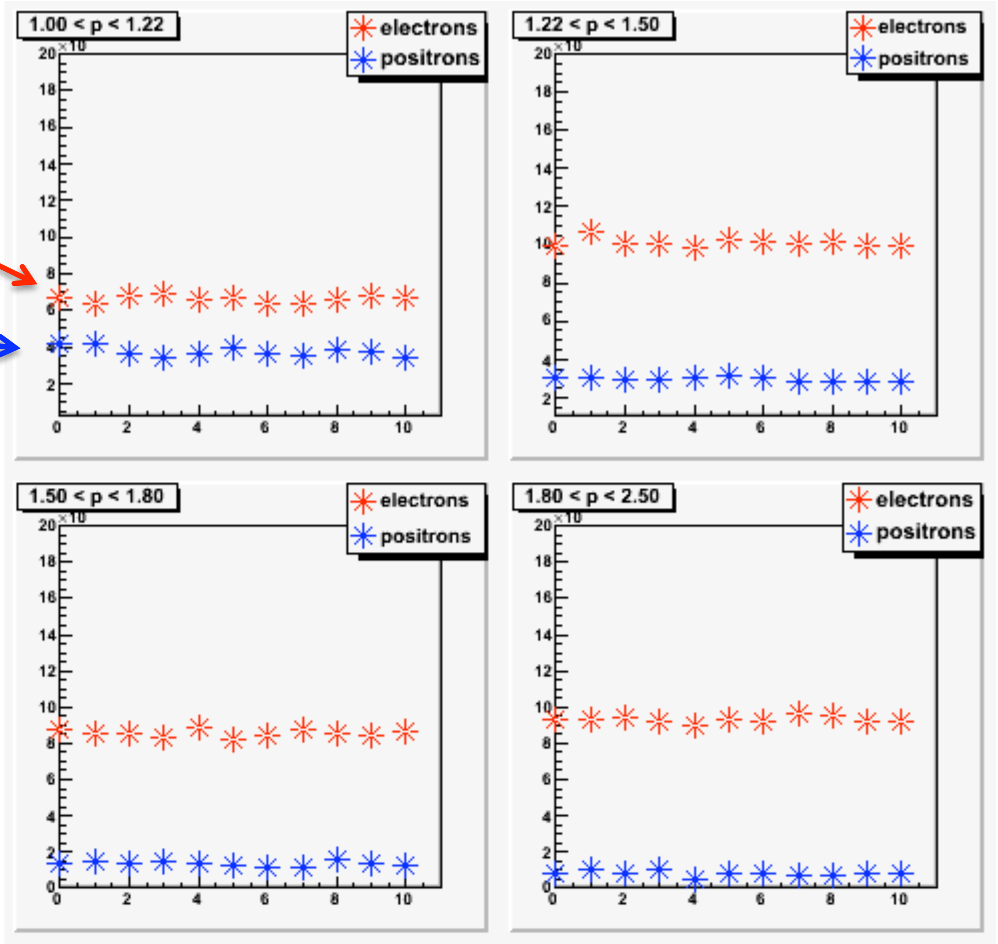
0.4%

Contamination Studies

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

Electron Yield

Positron Yield



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

Contamination Studies

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

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

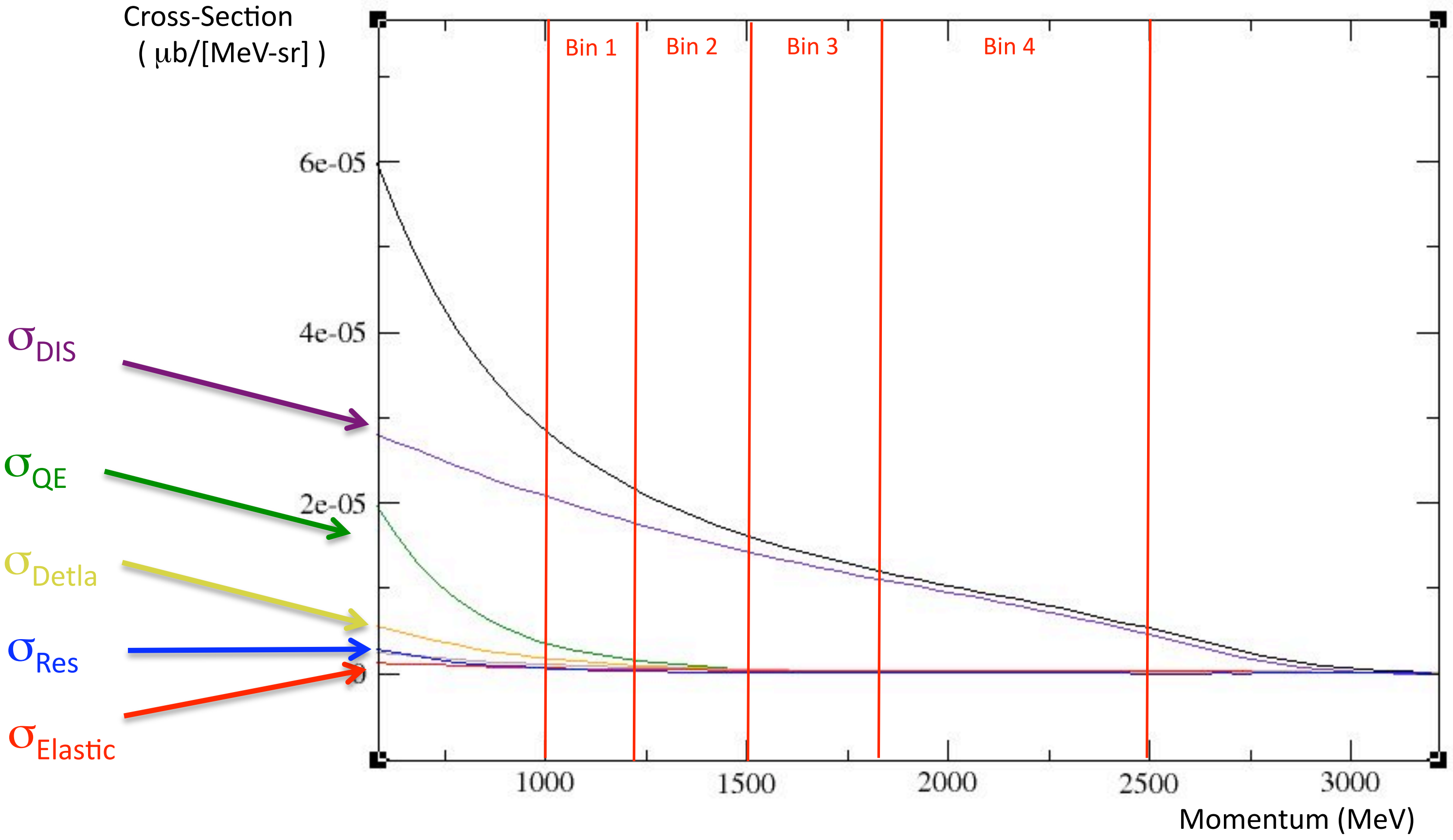
Physics Asymmetry Extraction

First, remove the background from the good data:

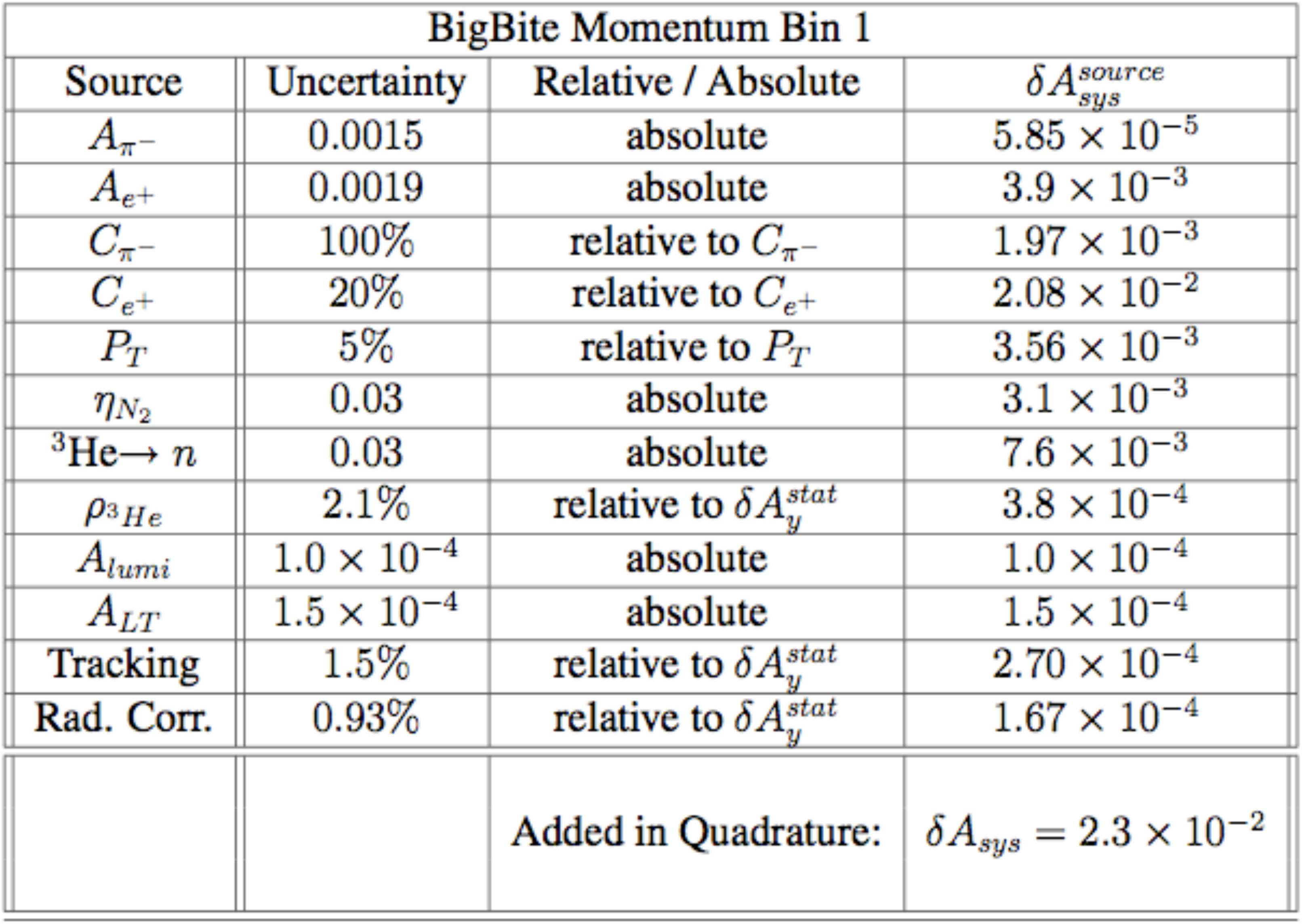
Define: $A^{meas} = \dfrac{Y^{meas,\uparrow} - Y^{meas,\downarrow}}{Y^{meas,\uparrow} + Y^{meas,\downarrow}}$; $\quad Y^{meas,\uparrow} = \dfrac{N^{e^-,\uparrow} + N^{\pi^-,\uparrow} + N^{e^+,\uparrow}}{Q^{\uparrow} * LT^{\uparrow}}$

$$A^{e^-} = \frac{A^{meas} - C^{\pi^-} A^{\pi^-} - C^{\pi^0} A^{e^+}}{1 - C^{\pi^-} - C^{e^+}}; \qquad \delta A^{e^-}_{stat} = \frac{\delta A^{meas}}{1 - C^{\pi^-} - C^{e^+}}$$

Radiative Corrections

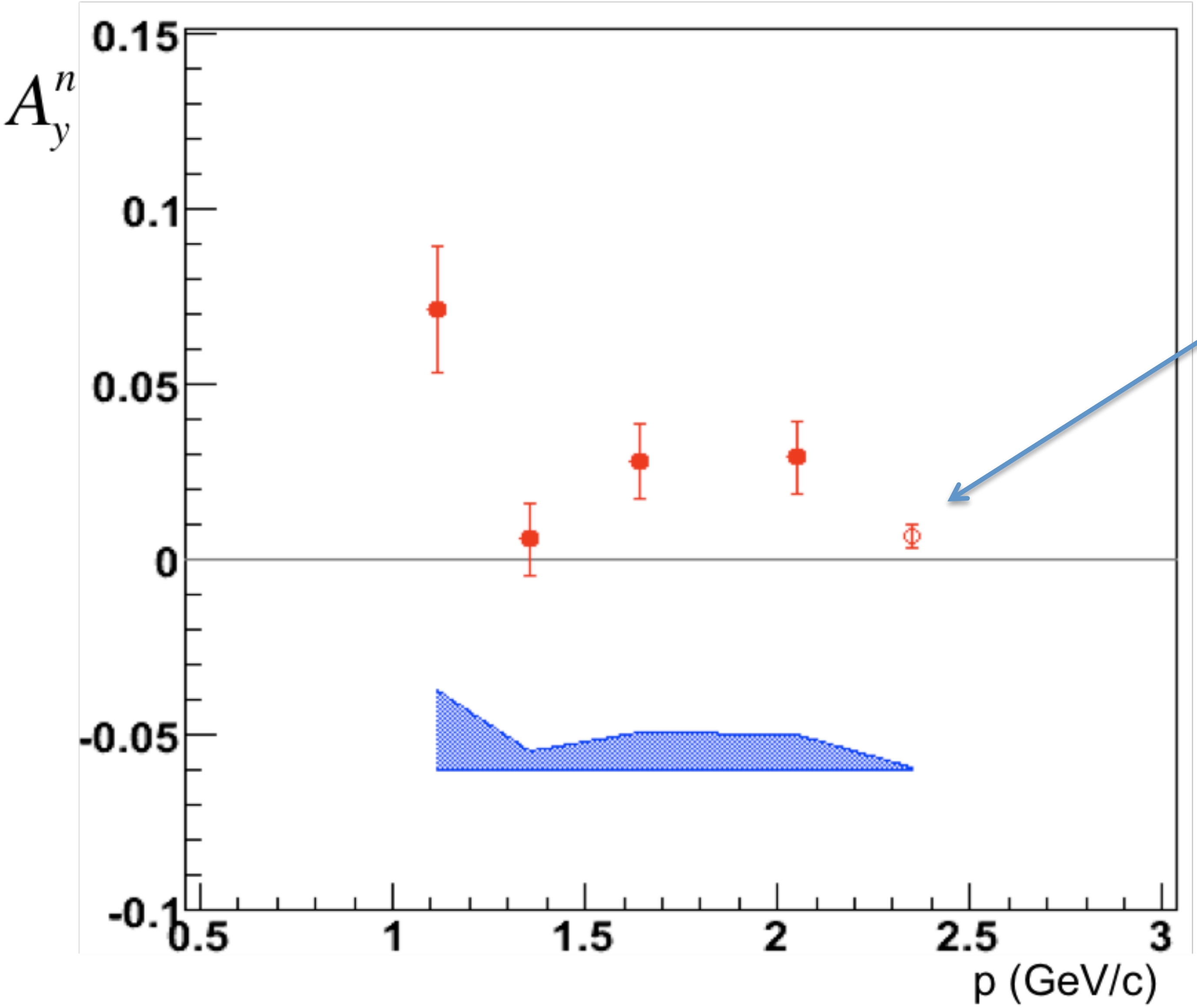


Summary of Systematic Error



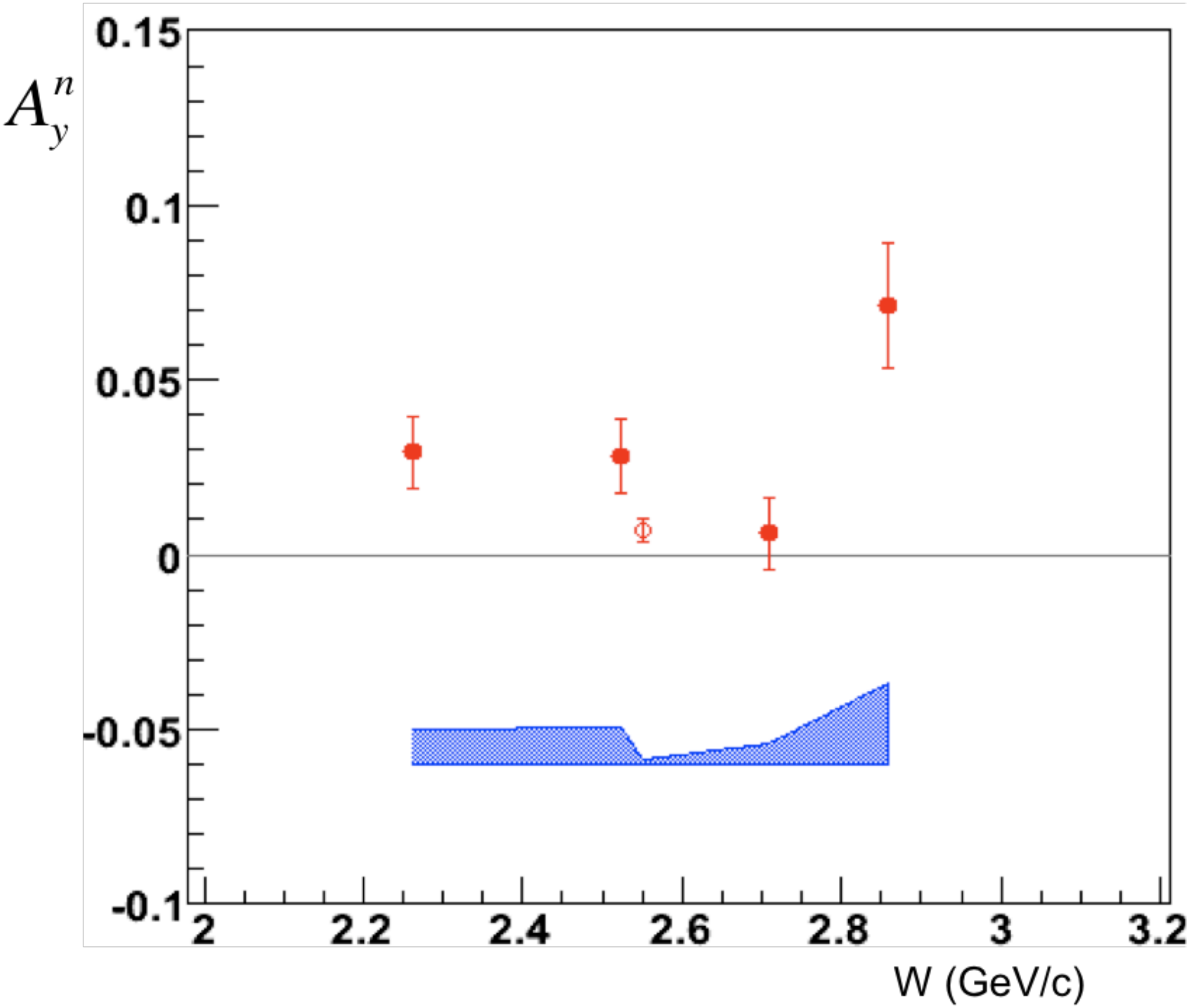
BigBite Momentum Bin 1			
Source	Uncertainty	Relative / Absolute	δA_{sys}^{source}
A_{π^-}	0.0015	absolute	5.85×10^{-5}
A_{e^+}	0.0019	absolute	3.9×10^{-3}
C_{π^-}	100%	relative to C_{π^-}	1.97×10^{-3}
C_{e^+}	20%	relative to C_{e^+}	2.08×10^{-2}
P_T	5%	relative to P_T	3.56×10^{-3}
η_{N_2}	0.03	absolute	3.1×10^{-3}
$^3\text{He} \rightarrow n$	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

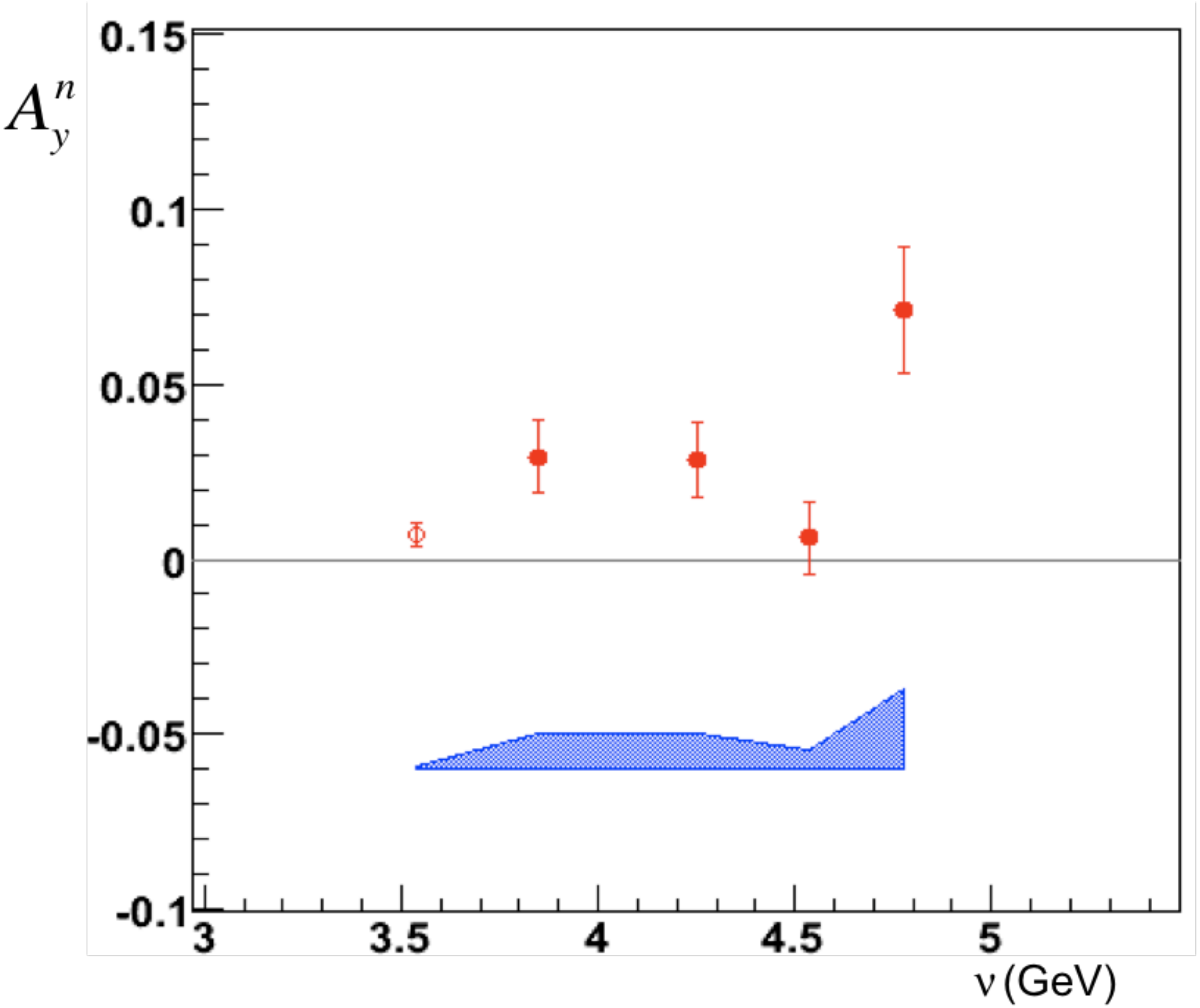


LHRS

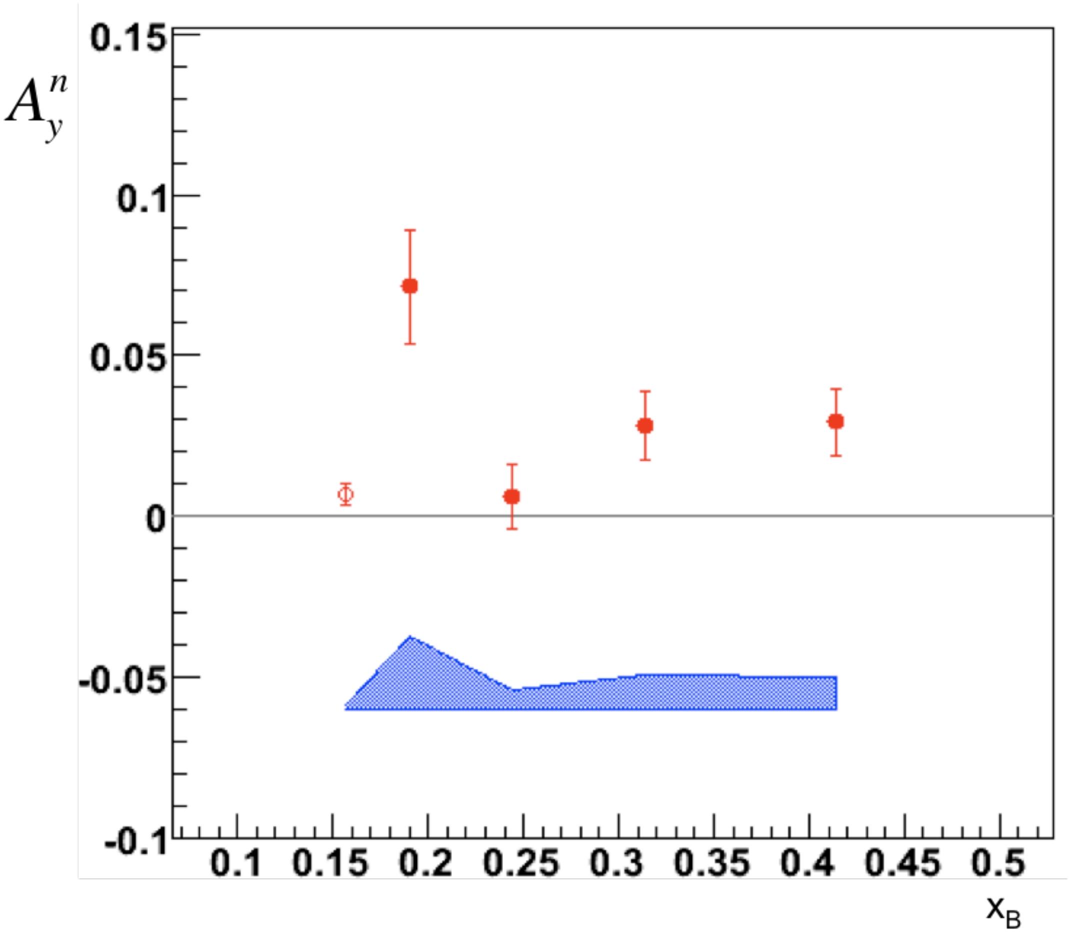
Preliminary Results



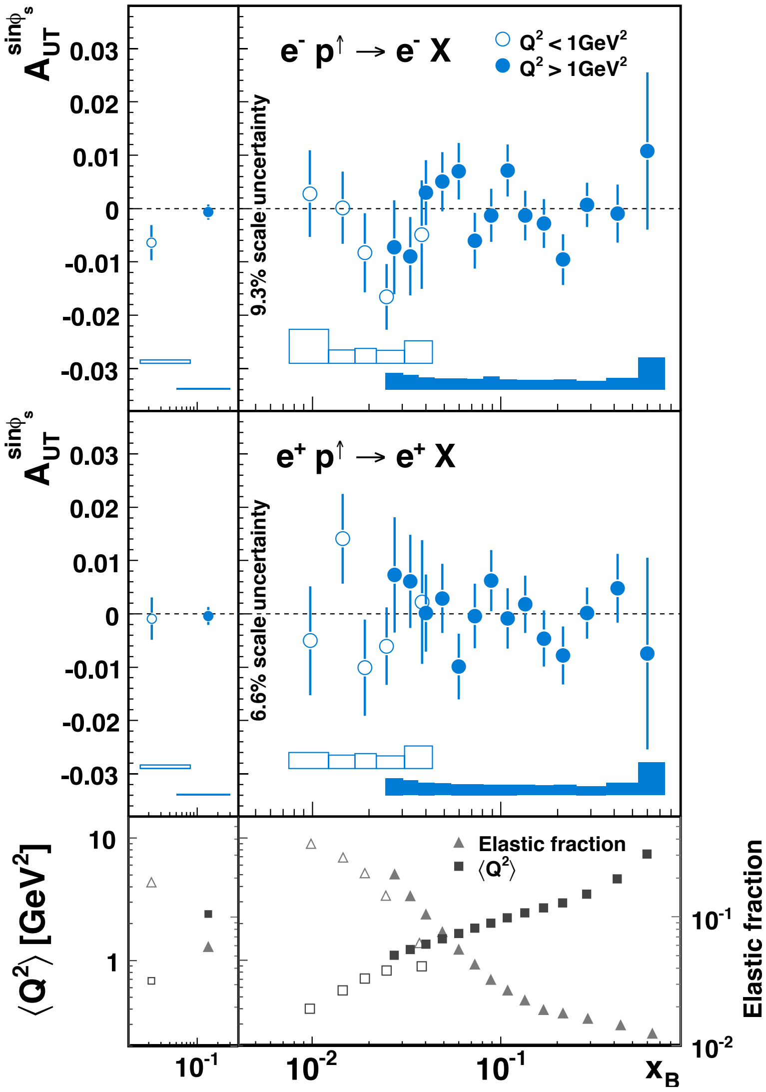
Preliminary Results



Preliminary Results



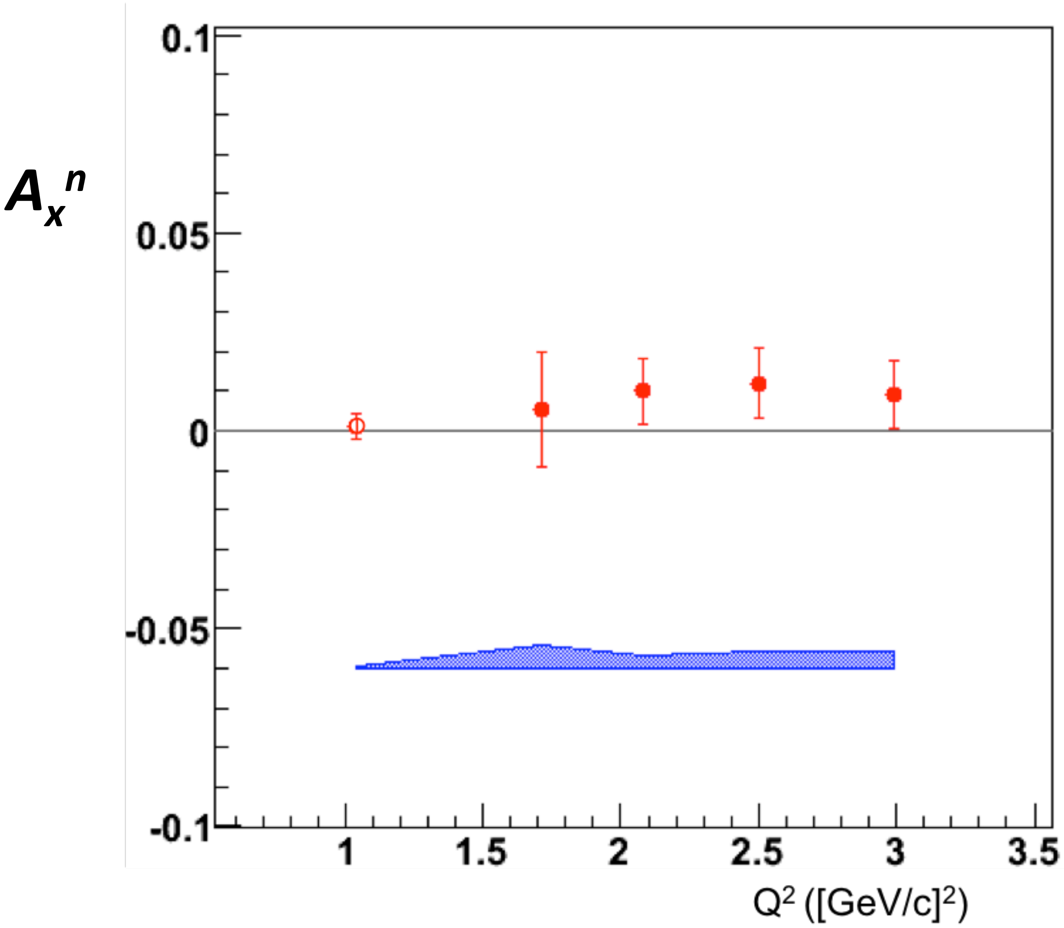
HERMES Proton



A. Airapetian et al,

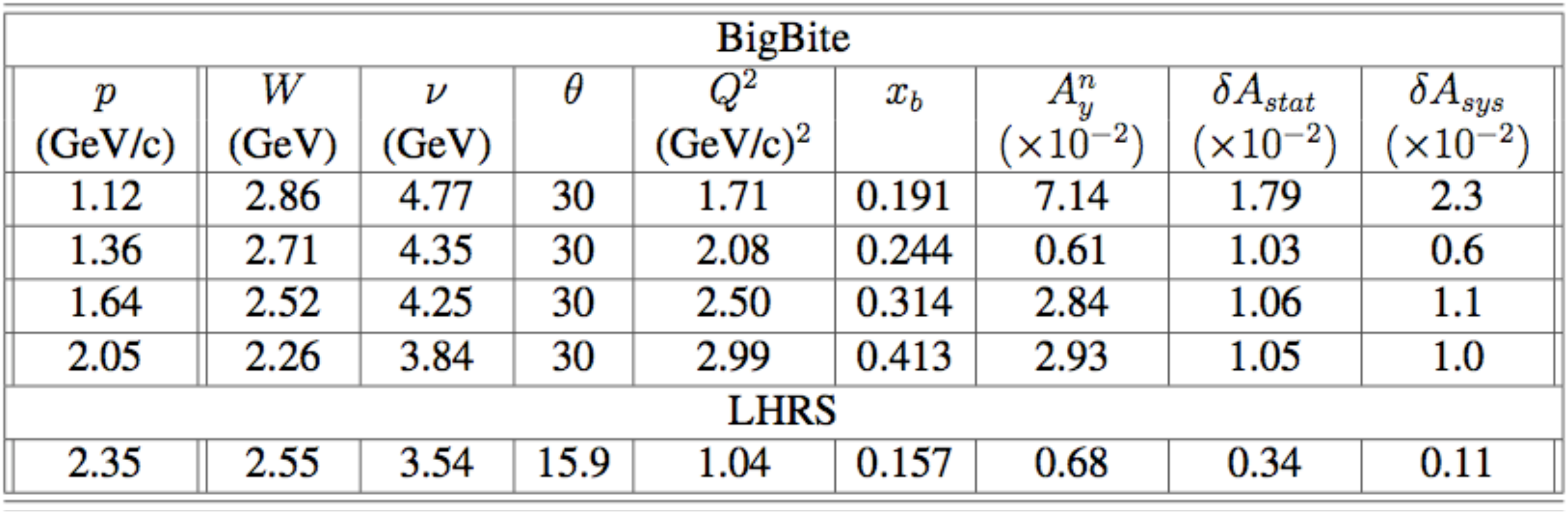
Phys. Lett. B682, 351 (2010)

Transverse SSA



Should be exactly zero

Summary of Final Results



p (GeV/c)	W (GeV)	ν (GeV)	θ	Q^2 (GeV/c)^2	x_b	A_y^n ($\times 10^{-2}$)	δA_{stat} ($\times 10^{-2}$)	δA_{sys} ($\times 10^{-2}$)
BigBite								
1.12	2.86	4.77	30	1.71	0.191	7.14	1.79	2.3
1.36	2.71	4.35	30	2.08	0.244	0.61	1.03	0.6
1.64	2.52	4.25	30	2.50	0.314	2.84	1.06	1.1
2.05	2.26	3.84	30	2.99	0.413	2.93	1.05	1.0
LHRS								
2.35	2.55	3.54	15.9	1.04	0.157	0.68	0.34	0.11

Ghost Track Background

No-track events can lead to false identification of good events!

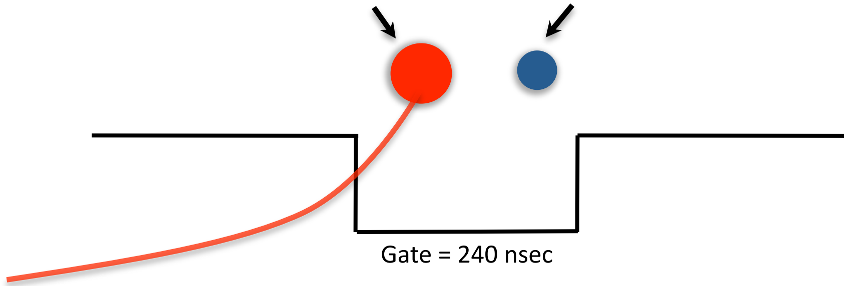
For Instance:

Low momentum particle
with a good track
(normally cut by PID)

+

Random particle,
no track, but extra
momentum

= False Good event !



An estimate of this contaminating occurrence can be made:

$\%C_{ghost}$ = Gate Time × Scaler Event Rate × % events with no track

T1 (<10% of statistics):

$\boxed{\%C_{ghost} \sim 1\%}$

T6 (>90% of statistics):

$\boxed{\%C_{ghost} < 0.5\%}$

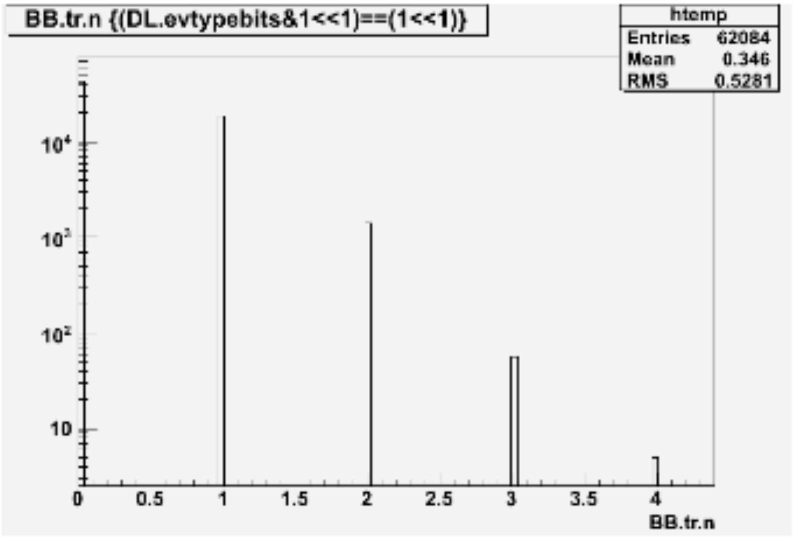


Figure 1: Trigger 1distribution of the number of tracks per event

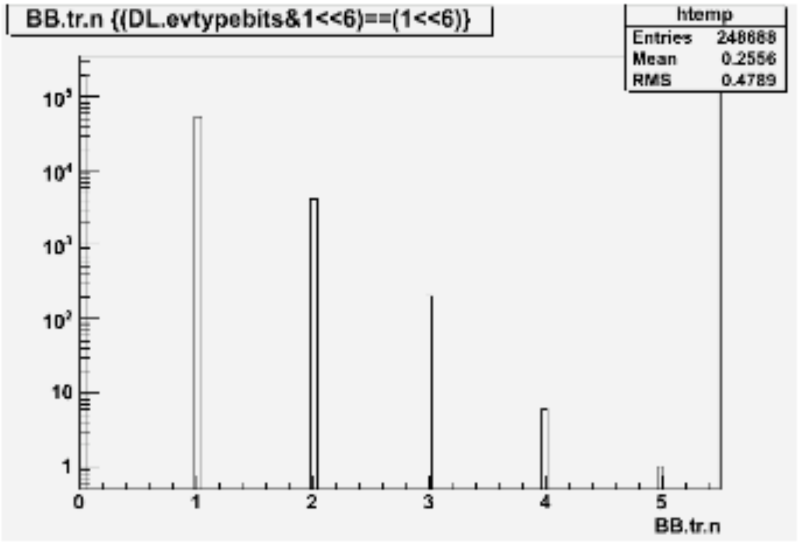


Figure 2: Trigger 6 distribution of the number of tracks per event

- Note: The no-track events have large asymmetry.

- Contamination small, so correction is small, but would make asymmetry larger……

A Few Remarks

- Values of A_y^n range from about 0.6 to 7 % with overall uncertainties on the order of a few percent
- Central values of A_y^n are much larger than the Afanasev *et al.* predictions of $\sim 10^{-4}$
- However, the results are of the same order as the quasi-elastic results from the May 2009 experiment ($\sim$2e10^{-2})
- These results should serve as excellent motivation for the proposal of an experiment which is dedicated fully to the measurement of A_y^n in the deep inelastic scattering region over a wide kinematic range

Summary

- First ever measurement of the target SSA, A_y^n , was performed in Jefferson Lab's Hall A
- Uncertainty is several times better than previous SLAC proton data, and an excellent compliment to recent HERMES data
- Greatly extended the kinematic range over which Ay has been measured $0.16 < x_b < 0.41$ and $1.0 < Q^2 < 3.0$
- First experiment to use a ^{3}He target that was polarized normal to the electron scattering plane
- First experiment to use both hybrid SEOP and narrow-band lasers, leading to record polarized ^{3}He target performance: $P_T > 60\%$

π^+ contamination in e^+ spectrum