Two photon exchange in deep-inelastic scattering

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

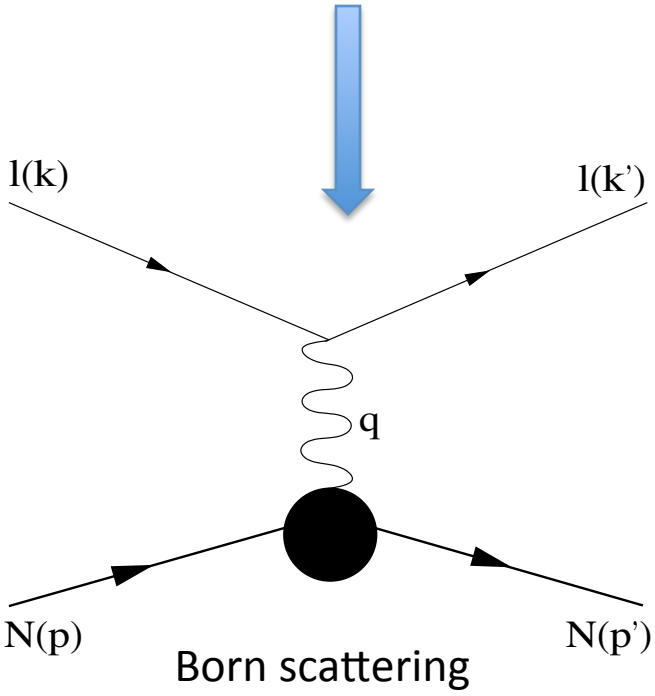
This analysis was done by Joe Katich, College of William and Mary

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)

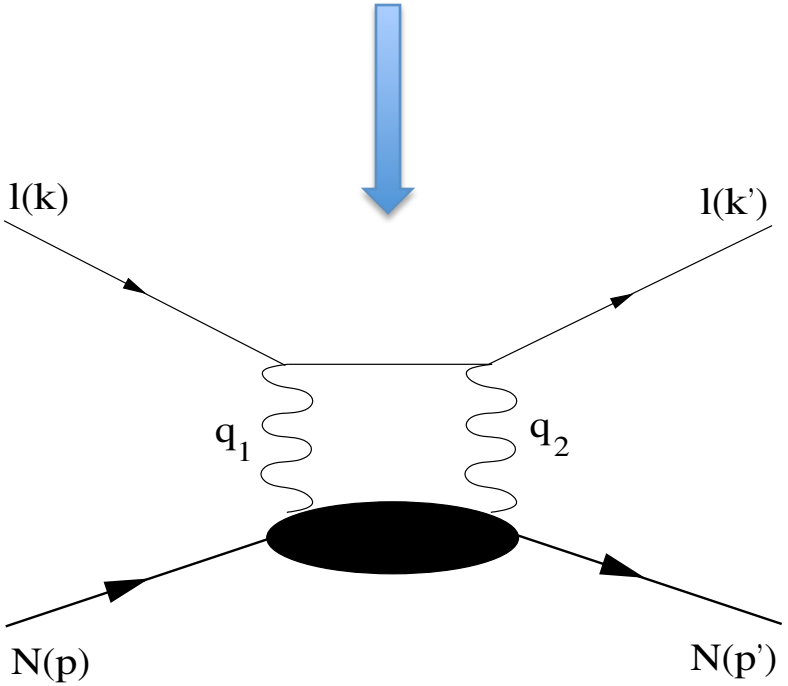
Born scattering and beyond

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



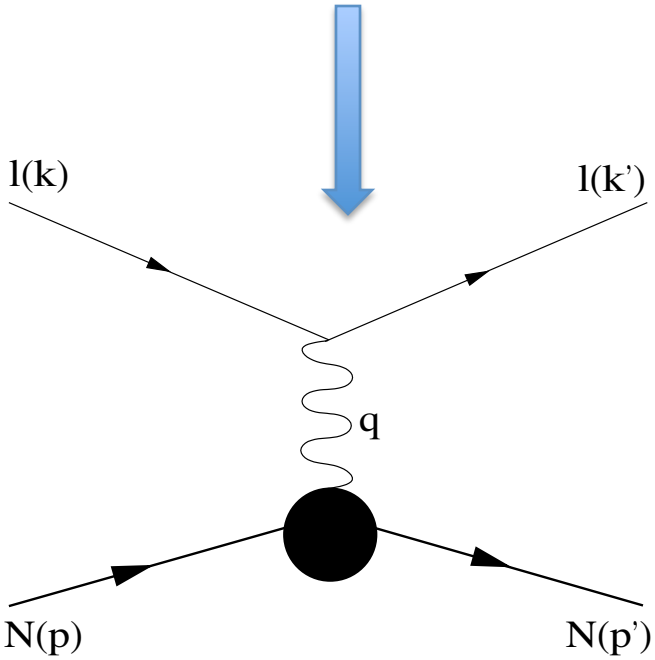
Born scattering

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

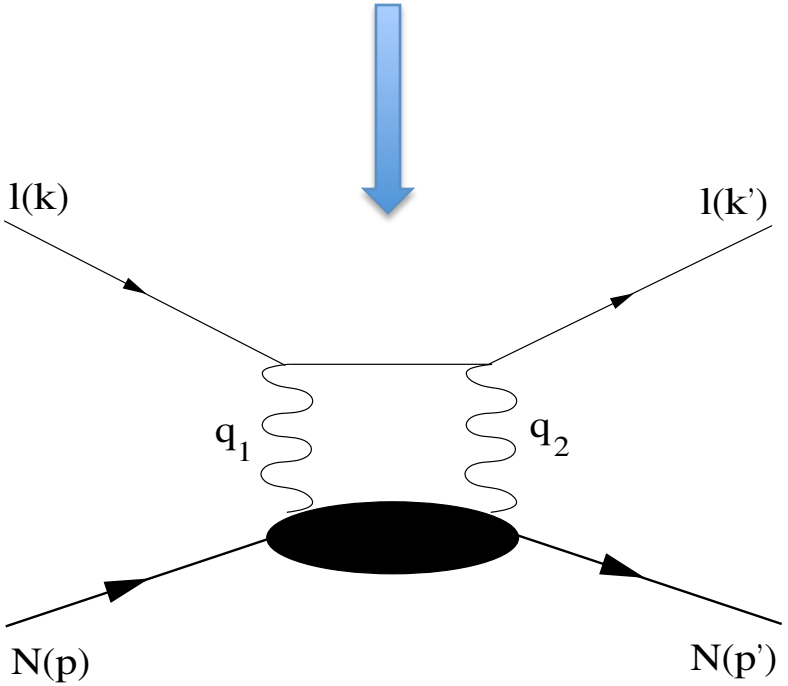


Born scattering and beyond

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



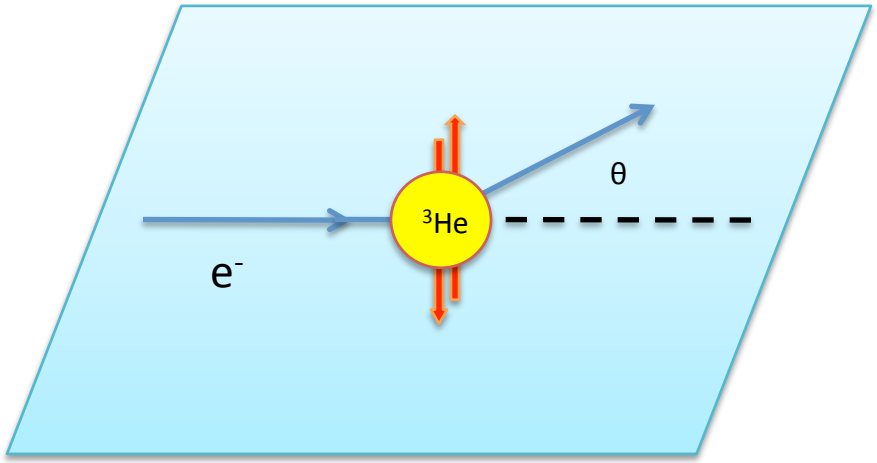
- How is it useful?
- Loop integral contains entire nucleon response.
- How do we observe this?



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

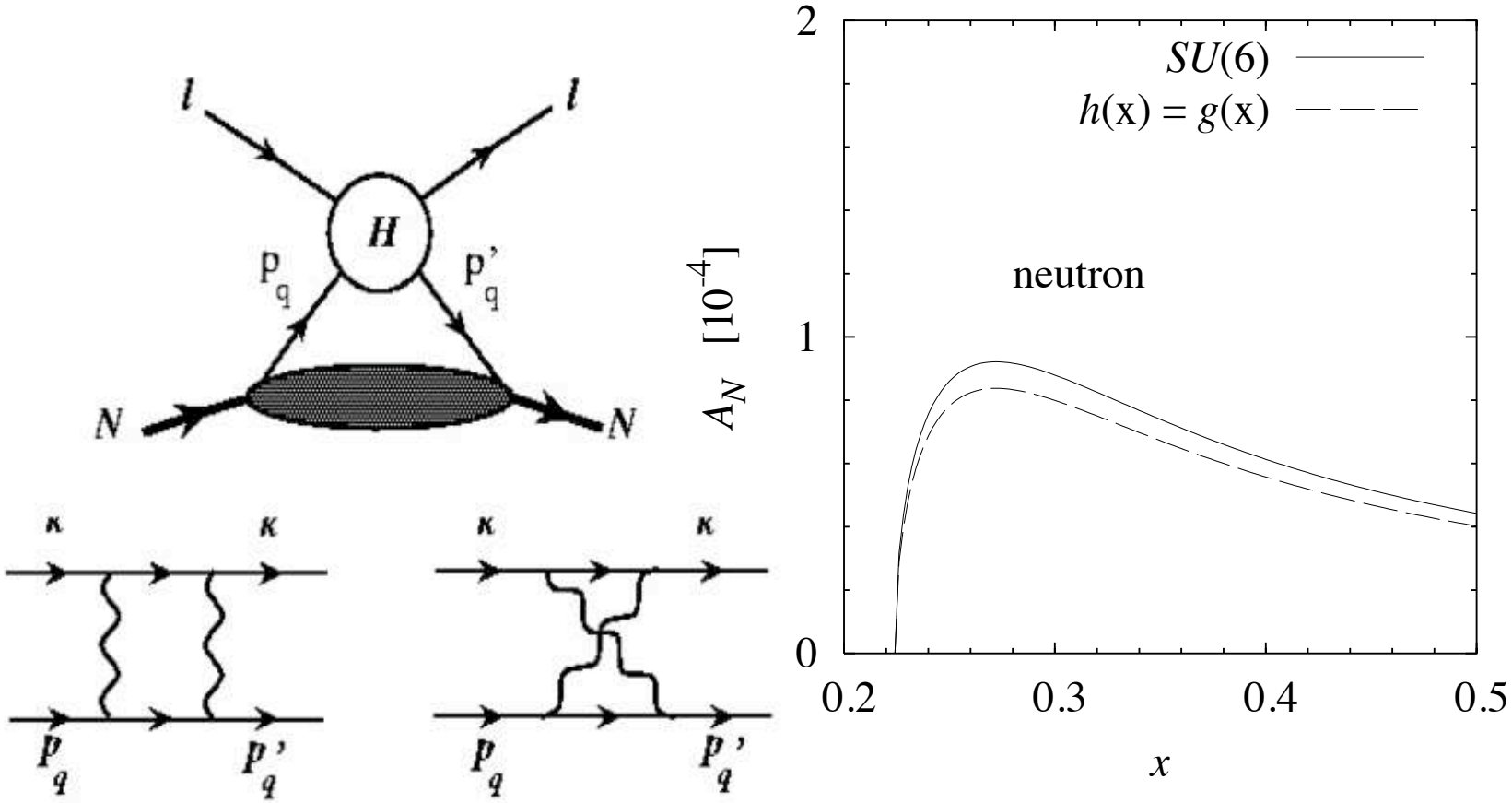
A. DeRujula *et al., Nuc. Phys. B35* (1971) 365

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

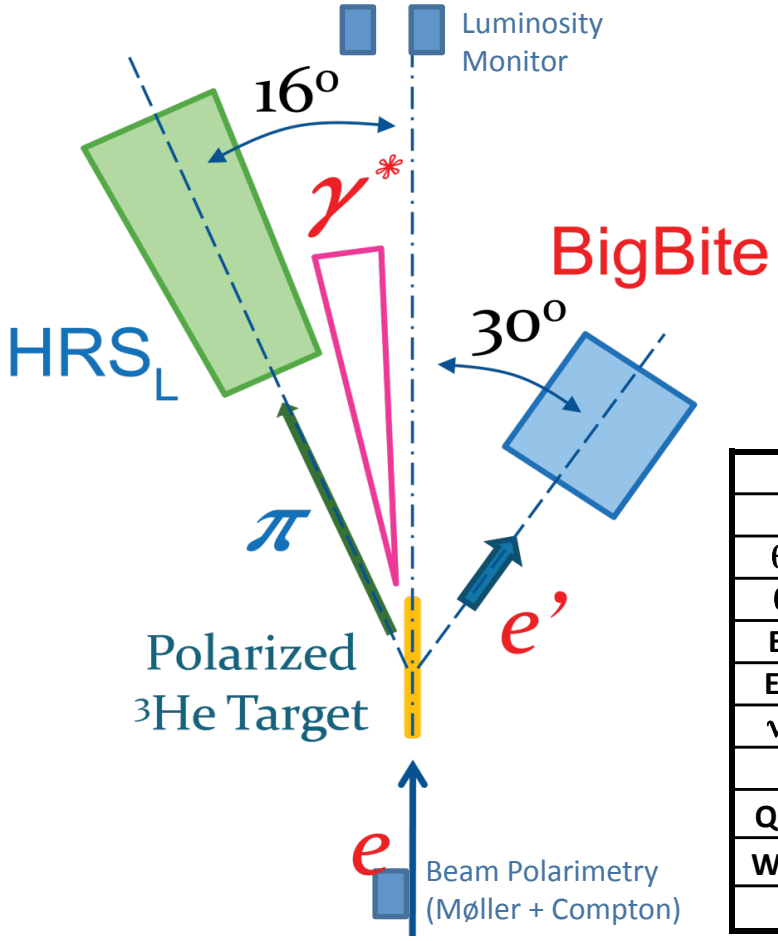


Afanasev, Strikman, Weiss (**Phys.Rev.D77:014028,2008)**

Physics Motivation

- Run concurrent with Transversity experiment. Perfect kinematics, target.
- Make 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 $A_y \sim 10^{-4}$ 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

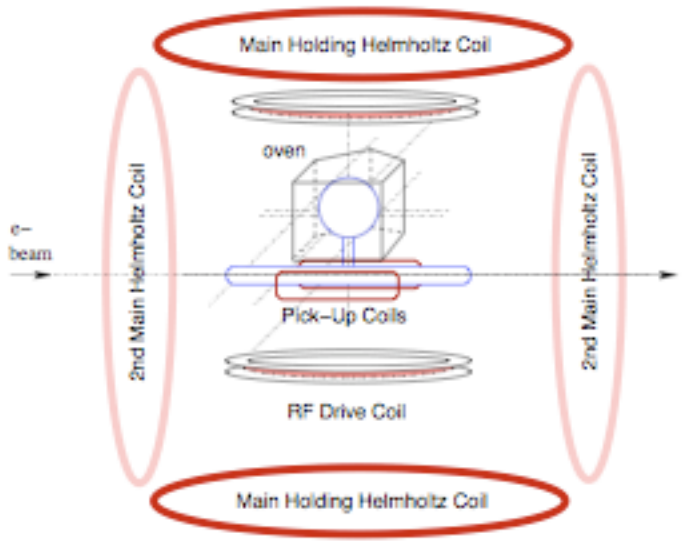


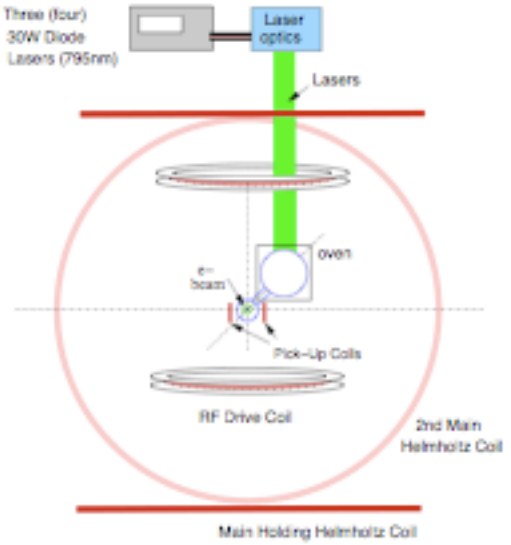
Measure ^{3}He(e,e') SSA using BB and LHRS in singles mode.

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

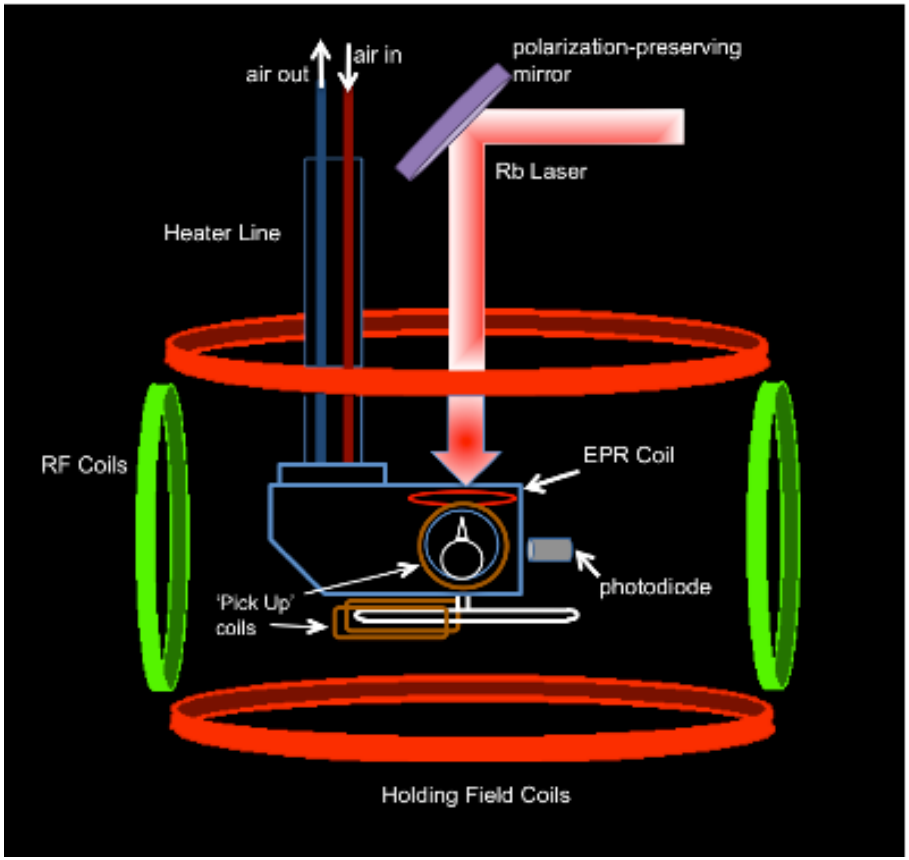
Vertically Polarized ^{3}He Target

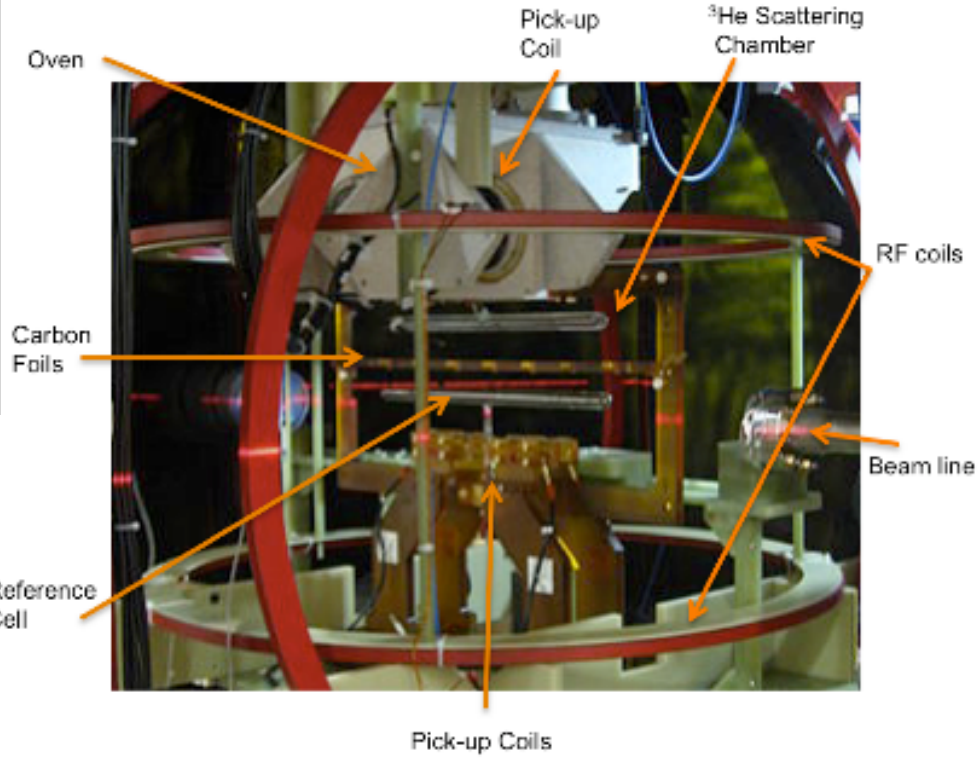




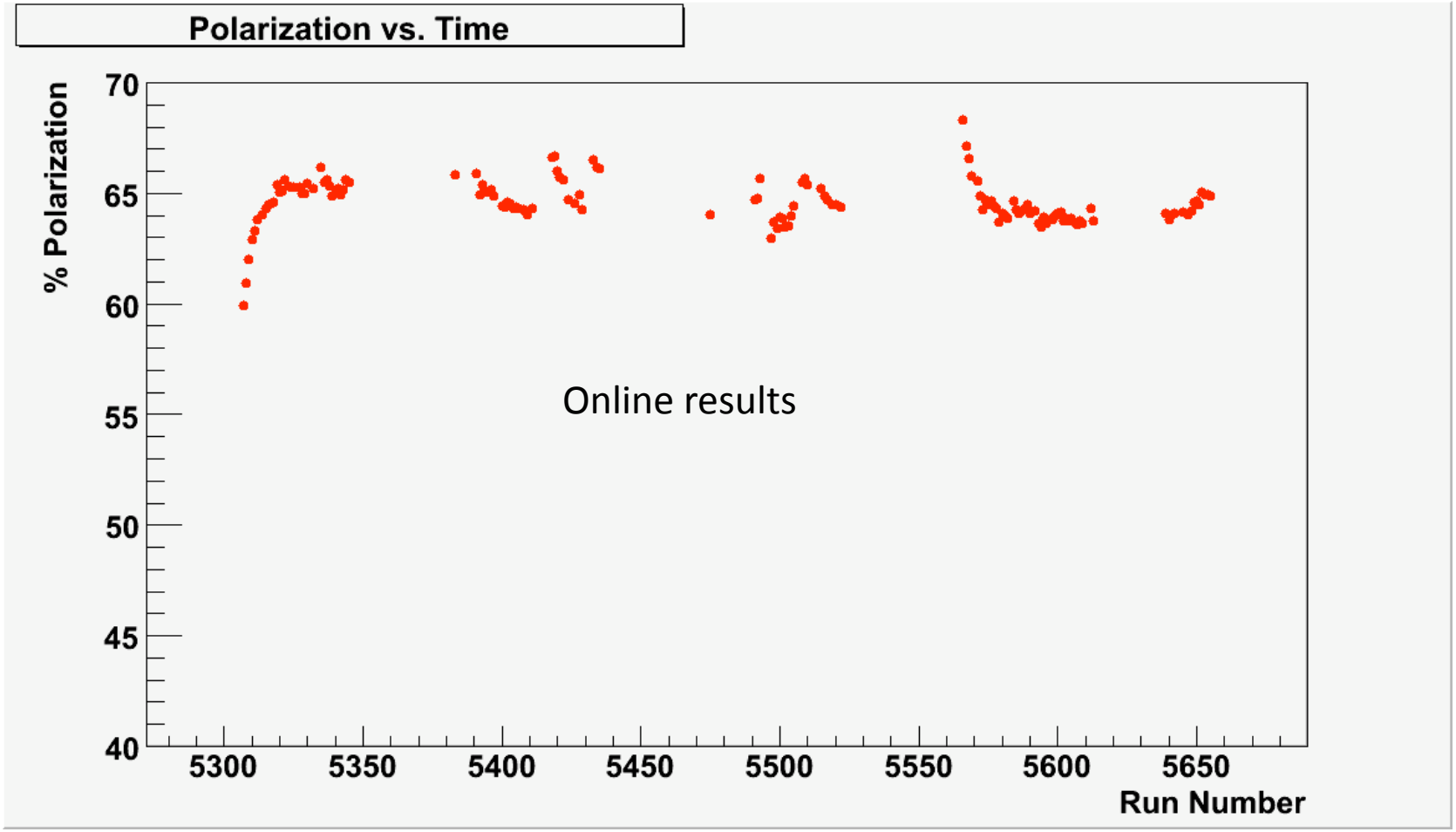
- Spin-exchange optically-pumped gas target. Now standard technology.
- New polarized target now achieving 65% in-beam polarization due to hybrid alkali and narrowed lasers.
- Reverse target spin direction every 20 minutes or less.

Vertically polarized ^{3}He target

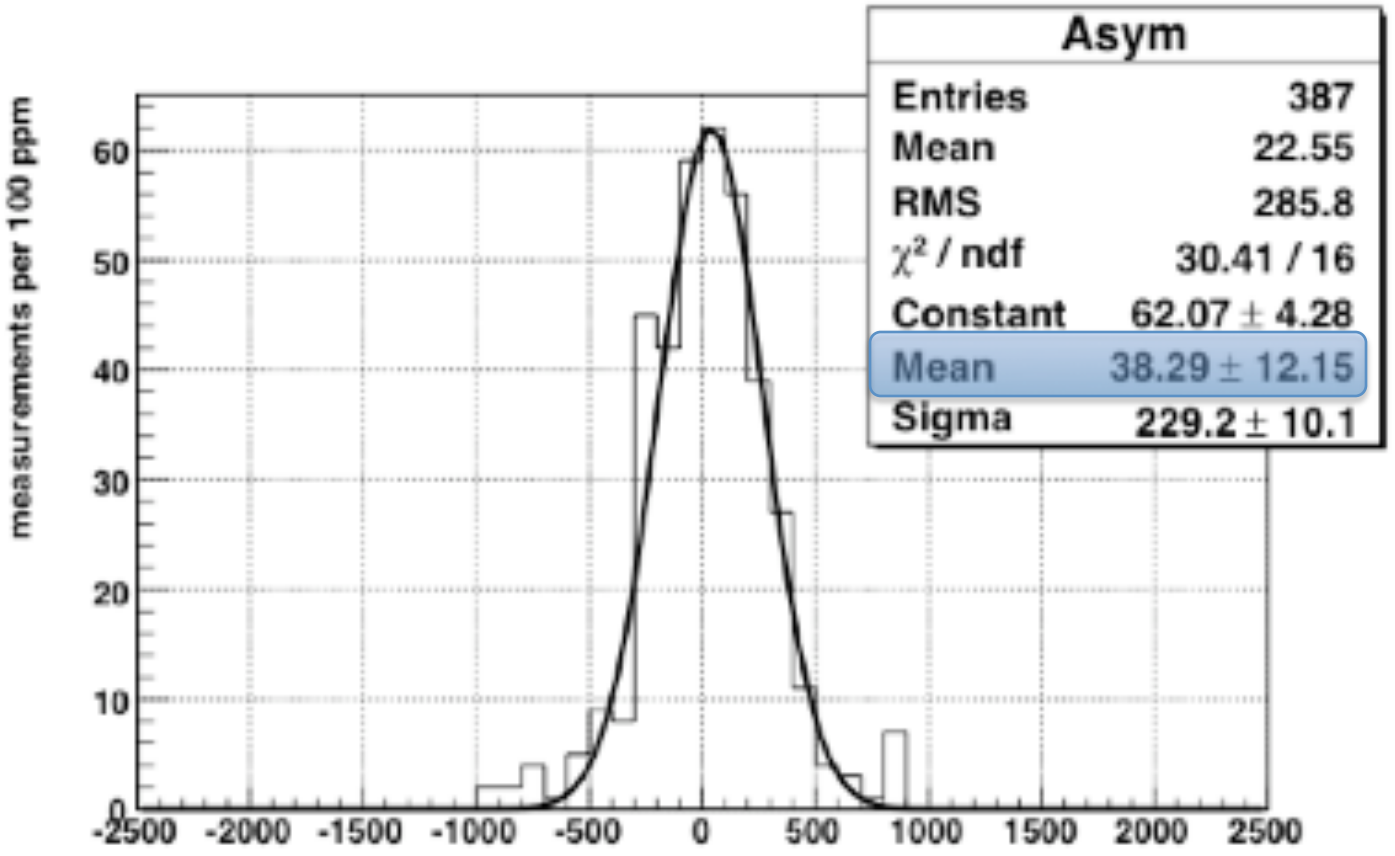




Target polarization for typical SEOP ^{3}He Hall A target



Luminosity Asymmetry



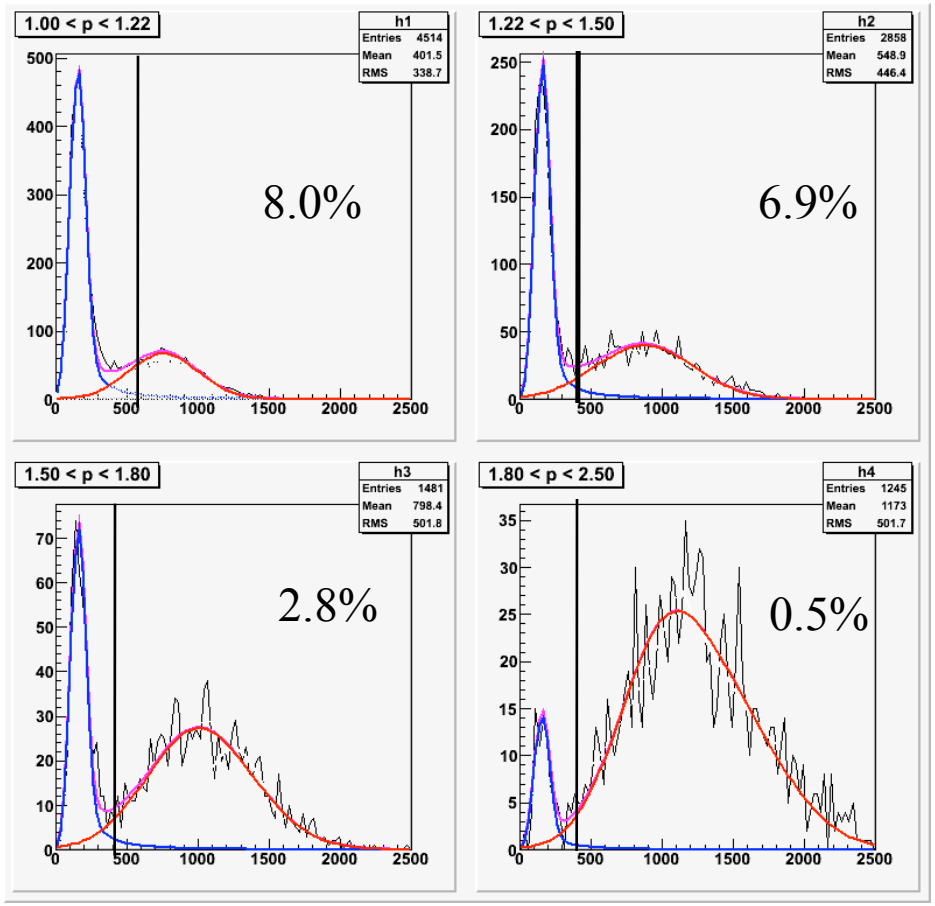
ppm

Backgrounds

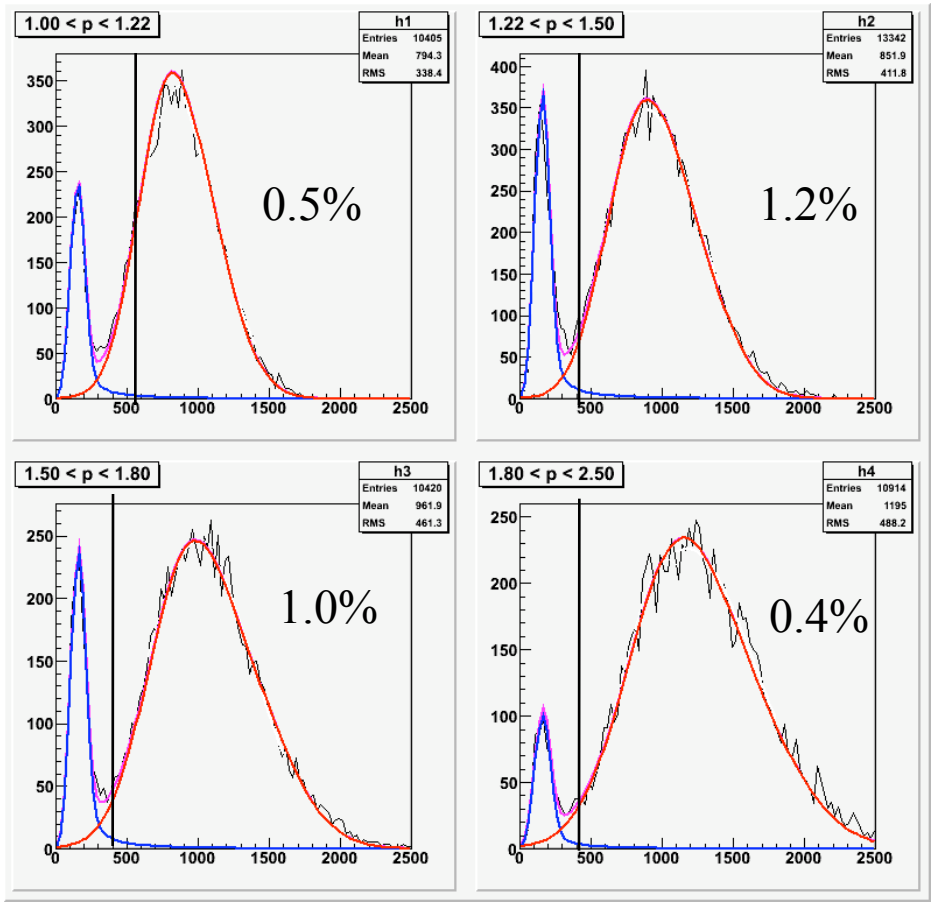
- $\pi^{-/+}$ in BB $e^{-/+}$ spectrum. Cherenkov in BB not yet working for PID.
- Pair produced e^+/e^- pairs from π^o decay.
  - Measure using positive polarity
  - 50% contamination in lowest momentum bin
    - Correct this for π^+ contamination….
  - Largest systematic uncertainty
  - LHRS data has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

Final pi- Contamination

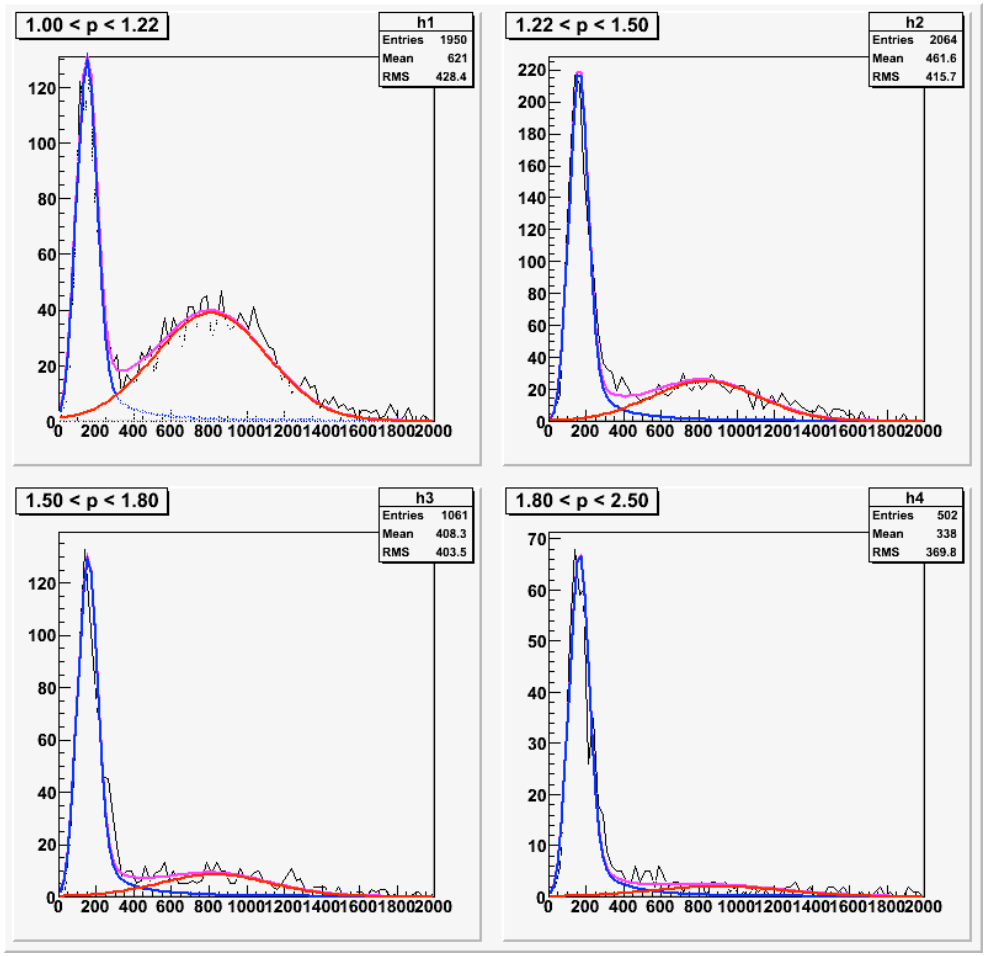
T1



T6

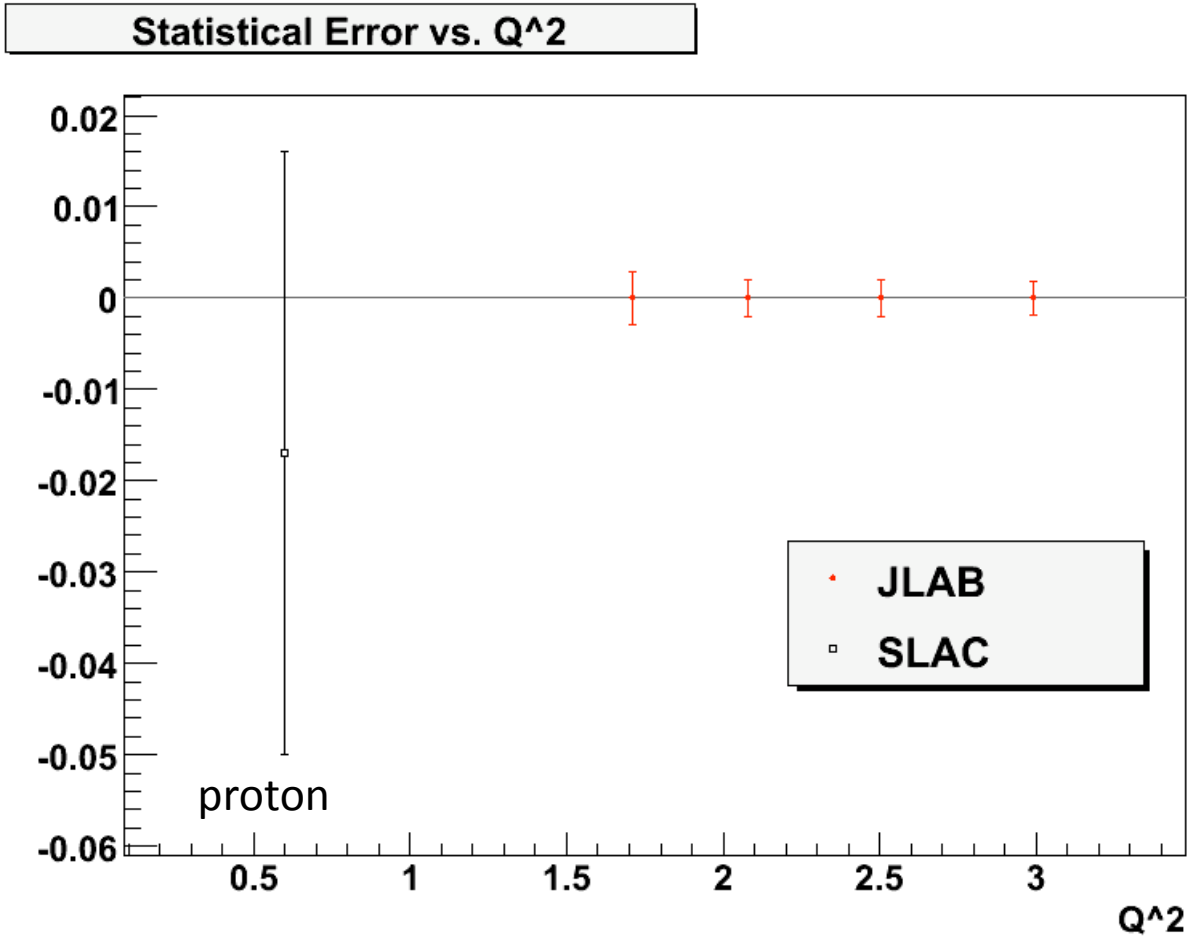


π^+ contamination in e^+ spectrum

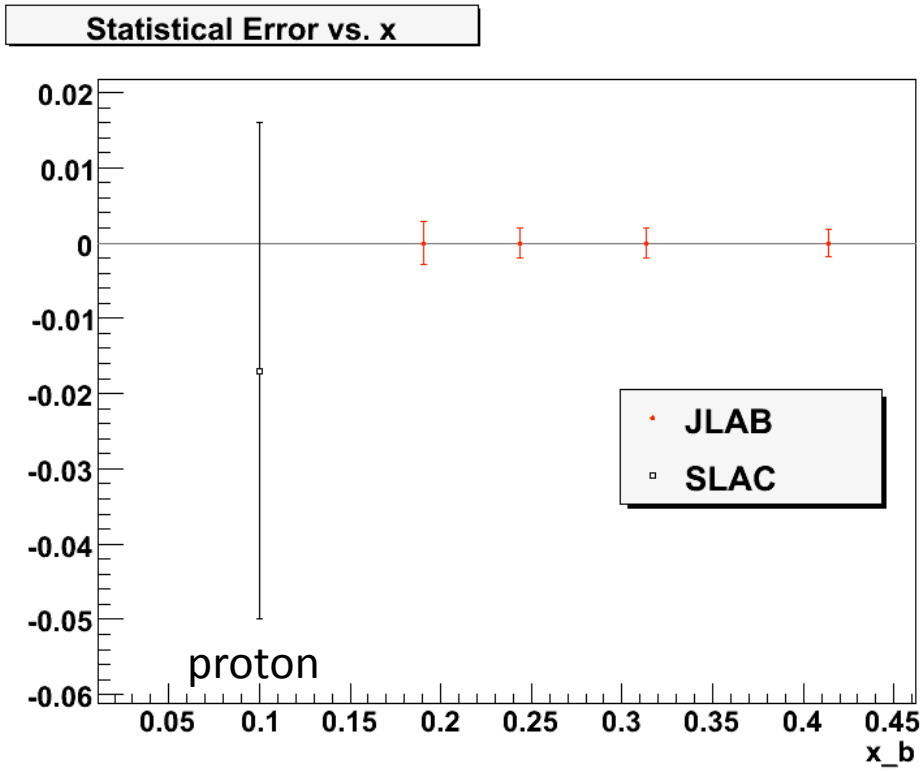


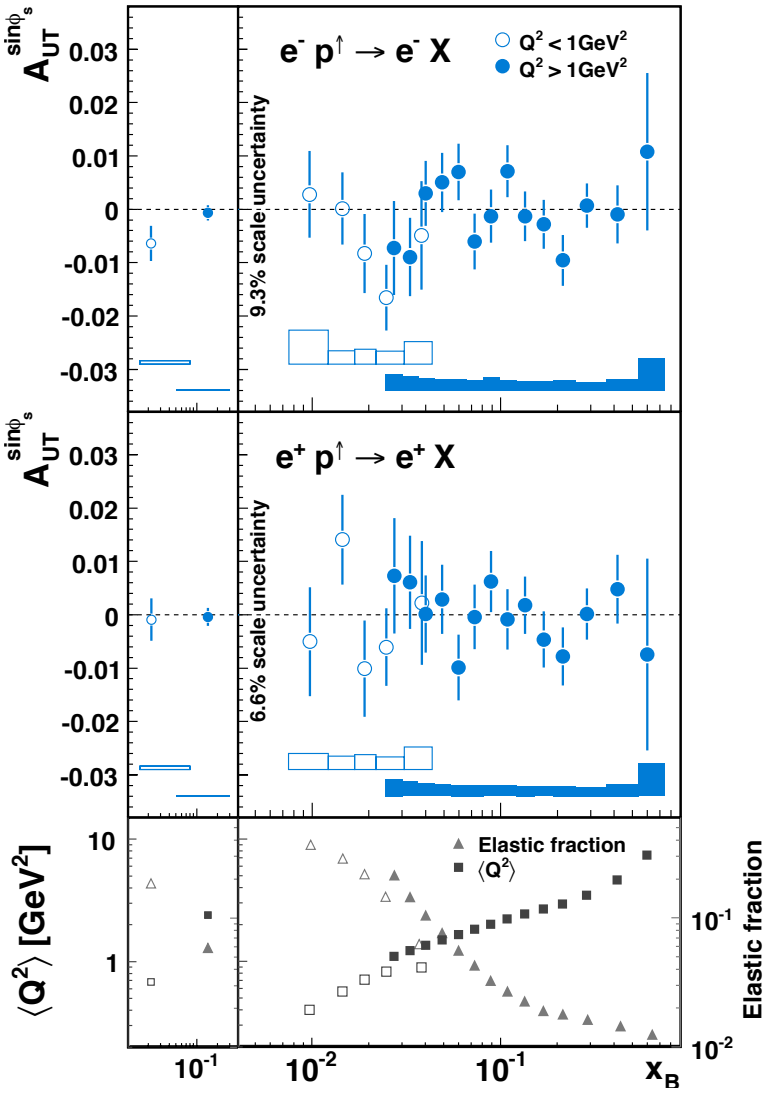
A_y for ^3He versus Q^2

Preliminary statistical uncertainties only



HERMES proton DIS data





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

Summary

- First measurements of the target SSA using vertically polarized ^{3}He in DIS
- Part of a broader program of nucleon structure studies using vertical target SSA
- Background studies underway.
  - LHRS data will help with backgrounds and give additional data at Q^2=1.0 GeV^2
- First DIS results for A_y on ^{3}He at Q^2=1.0-3.0 GeV^2.
  - Statistical precision comparable to HERMES proton results.