PR06-011

Neutron $(e, e'\pi^+)$ Transverse Target Single-Spin Asymmetry in Semi-Inclusive DIS on a Polarized ^{3}He Target

Spokespersons: Xiaodong Jiang (Rutgers), Haiyan Gao (Duke) and Evaristo Cisbani (INFN-Rome).

Beijing Univ., Univ. Sci. Tech. China, China Inst. Atomic Energy,

Duke, UIUC, INFN-Italy, JLab, Kentucky, Rutgers, Temple, Penn. State at Berks, UVa.

Goal: first data on single-spin asymmetries $A_{UT}^{Collins}$ and A_{UT}^{Sivers} in $n^\uparrow(e, e'\pi^+)$ (K^+ as by-products).

Provide information on the flavor dependence of neutron SSA.

- $A_{UT}^{n\pi^+}$ Collins: constrain the unfavored Collins frag. func. and d-quark transversity.
  When combined with $A_{UT}^{n\pi^-}$ and HERMES proton data, disintangle effects from four unknowns δu, δd, $H_1^{\perp fav}$ and $H_1^{\perp unfav}$.
- $A_{UT}^{n\pi^+}$ Sivers: constrain d-quark Sivers function $\Rightarrow$ d-quark angular momentum.
  When combined with $A_{UT}^{n\pi^-}$, JLab data can independently deduce Sivers function for both u and d-quark to cross check Sivers functions deduced from HERMES and COMPASS data.
- Request 24 days of 6 GeV beam, identical setup as in PR06-010.
  BigBite spectrometer is ready to take data for the Hall A G_E^n experiment.

Why neutron ?

Proton:	u	u	d	Notation: $d = u_n$			
e_q^2:	$\frac{4}{9}$	$\frac{4}{9}$	$\frac{1}{9}$				
Neutron:	d_n	d_n	u_n	$\Rightarrow$	u	u	d
e_q^2:	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{4}{9}$		$\frac{1}{9}$	$\frac{1}{9}$	$\frac{4}{9}$

Why π^+ ?

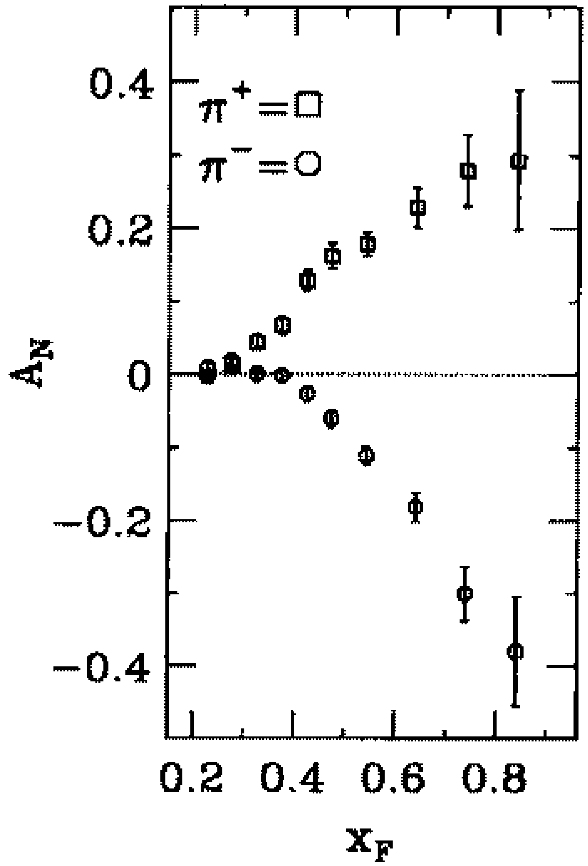
$\pi^+(u\bar{d})$ $\quad\quad$ $\pi^-(d\bar{u})$

$$D^{fav} = D_u^{\pi^+} = D_d^{\pi^-} \qquad D^{unfav} = D_u^{\pi^-} = D_d^{\pi^+}$$

$$\sigma_n^{\pi^+} \propto 4d \cdot D^{fav} + u \cdot D^{unfav} \qquad \sigma_n^{\pi^-} \propto 4d \cdot D^{unfav} + u \cdot D^{fav}$$

In $n(e, e'\pi^+)$ reaction, d-quark is the "chosen parton". At $z = 0.5$, $D^{unfav}/D^{fav} \approx 0.4$.

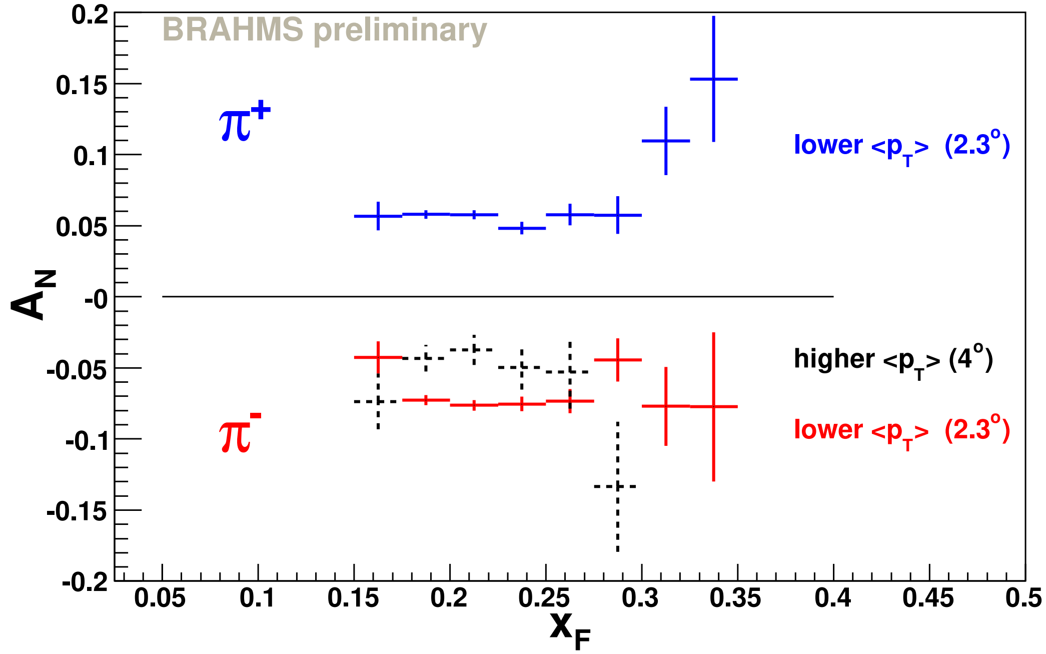
SSA in $pp^{\uparrow} \to \pi X$ has a strong flavor dependence



FNAL-E704: 200 GeV proton beam.

Phys.Lett. B264 (1991) 462.

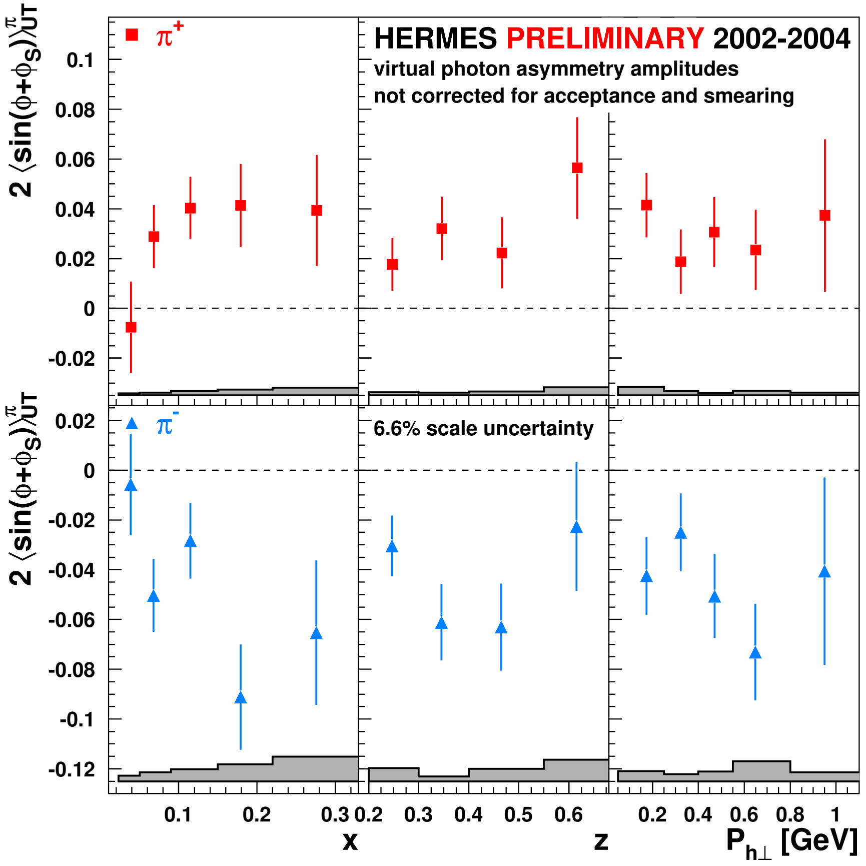
Large asymmetries with opposite sign !

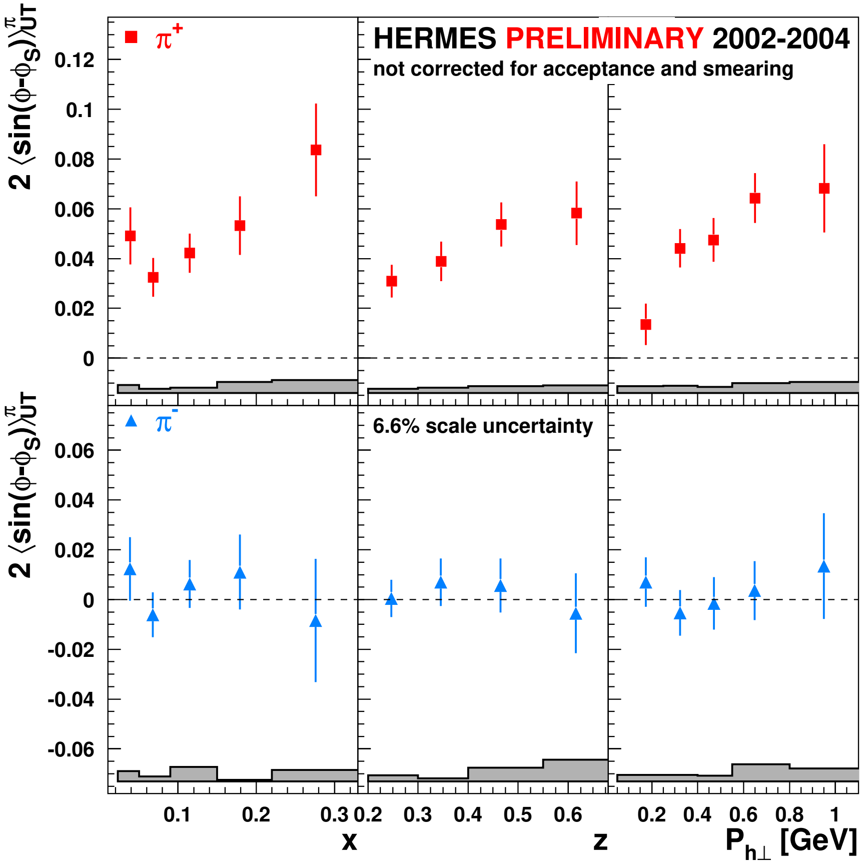


RHIC-BRAHMS: $\sqrt{s} = 200$ GeV nucl-ex/0601008.

In a transversely polarized nucleon, d-quark behave very differently compared to u-quark.

In SIDIS: HERMES proton data shows strong flavor dependence

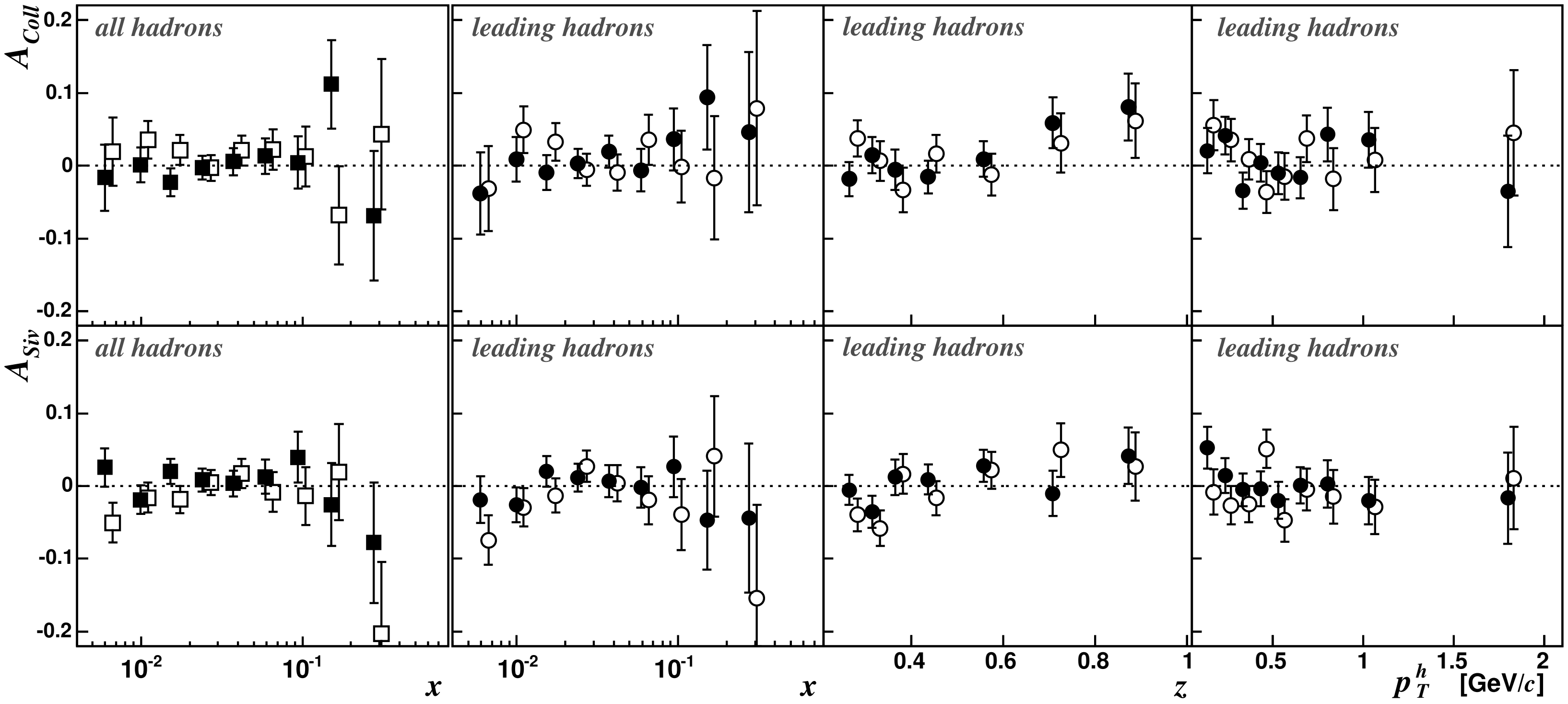




Both Collins and Sivers asymmetries are strongly dependent on the hadron flavor.

In a transversely polarized nucleon, u-quarks and d-quarks behave very differently.

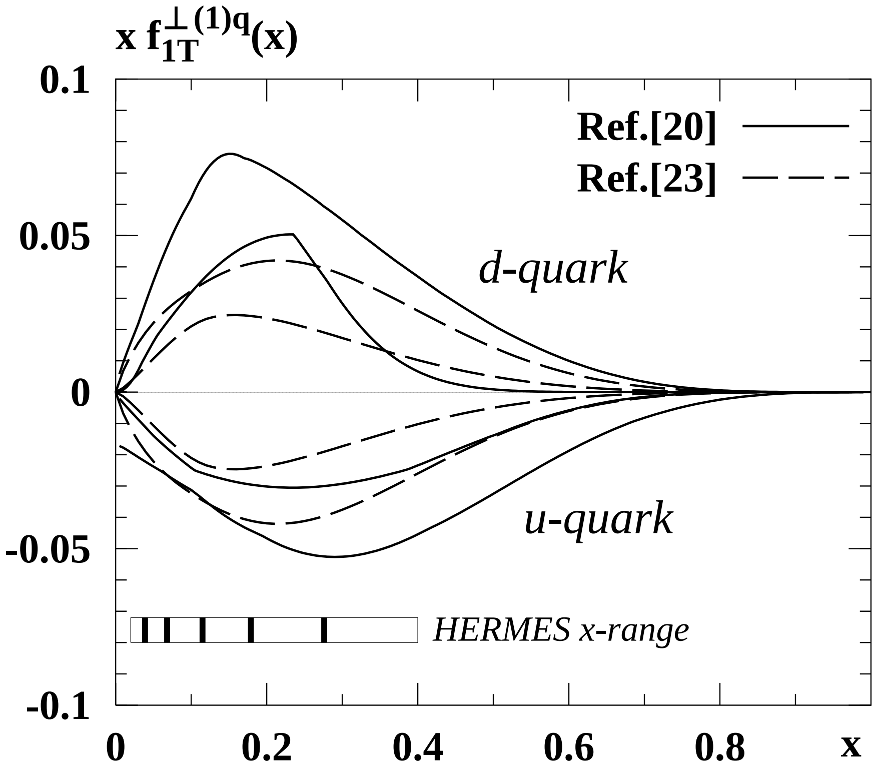
However, COMPASS deuteron data shows small SSA



⇒ Neutron SSA must have strong flavor dependence, in both Collins and Sivers asymmetries.

Compared to u-quark, d-quark makes a large and opposite contribution to SSA.

For example, d-quark Sivers function must be large !



M. Anselmino *et al.*, hep-ph/0511017. Fit to data.

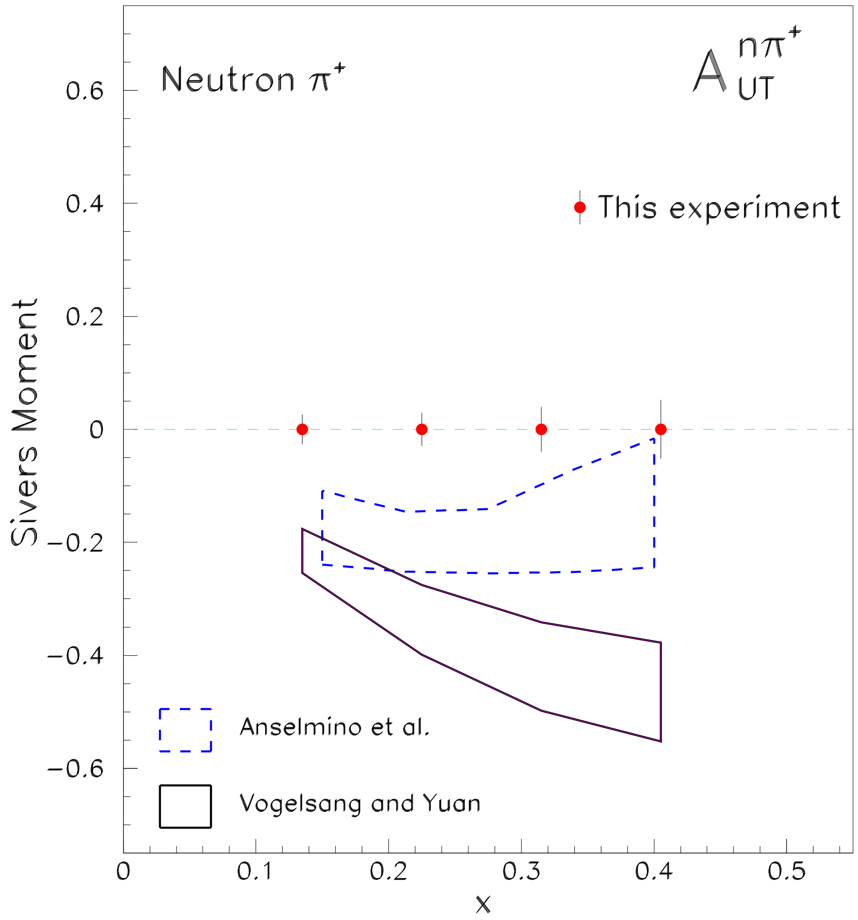
Sivers function: correlation between quark transverse momentum and nucleon's transverse spin.

- Consistent with a bag model calculation, F. Yuan.
- d-quark's angular momentum is opposite to u-quark's.

What happens when d-quark distribution is coupled with the favored frag. func. ?

Neutron Sivers $A_{UT}^{n\pi^+}$ must be large and opposite to $A_{UT}^{p\pi^+}$

Recall: $\sigma_n^{\pi^+} \propto 4d \cdot D^{fav} + u \cdot D^{unfav}, \qquad \sigma_p^{\pi^+} \propto 4u \cdot D^{fav} + d \cdot D^{unfav}$

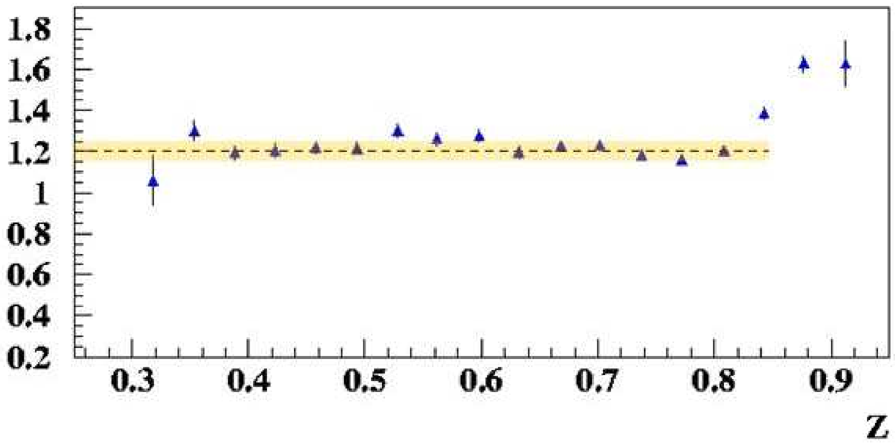


Anselmino *et al.*, Vogelsang and Yuan: fits to HERMES and COMPASS data, predicted Sivers asymmetries for this experiment.

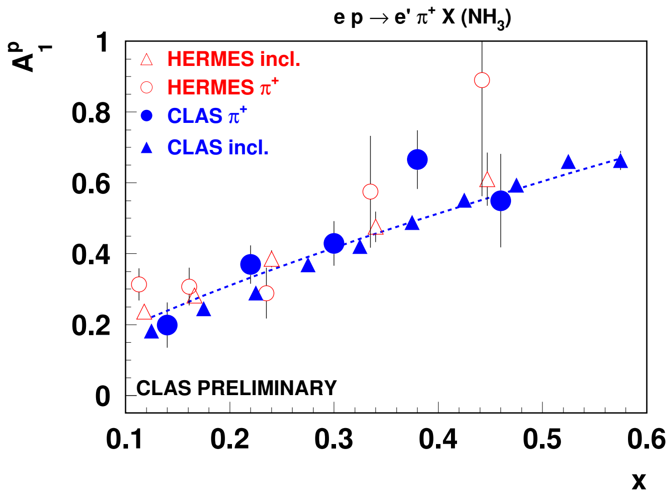
- Expect a larger Sivers asymmetry.
- Existing data do not have enough constrain on d-quark Sivers function.
- Data from this experiment can make a major impact.

Recent JLab Results in SIDIS at E_0=5.5 GeV

Data from Hall C (E00-108, unpolarized targets) and Hall B (eg1b, polarized proton target).



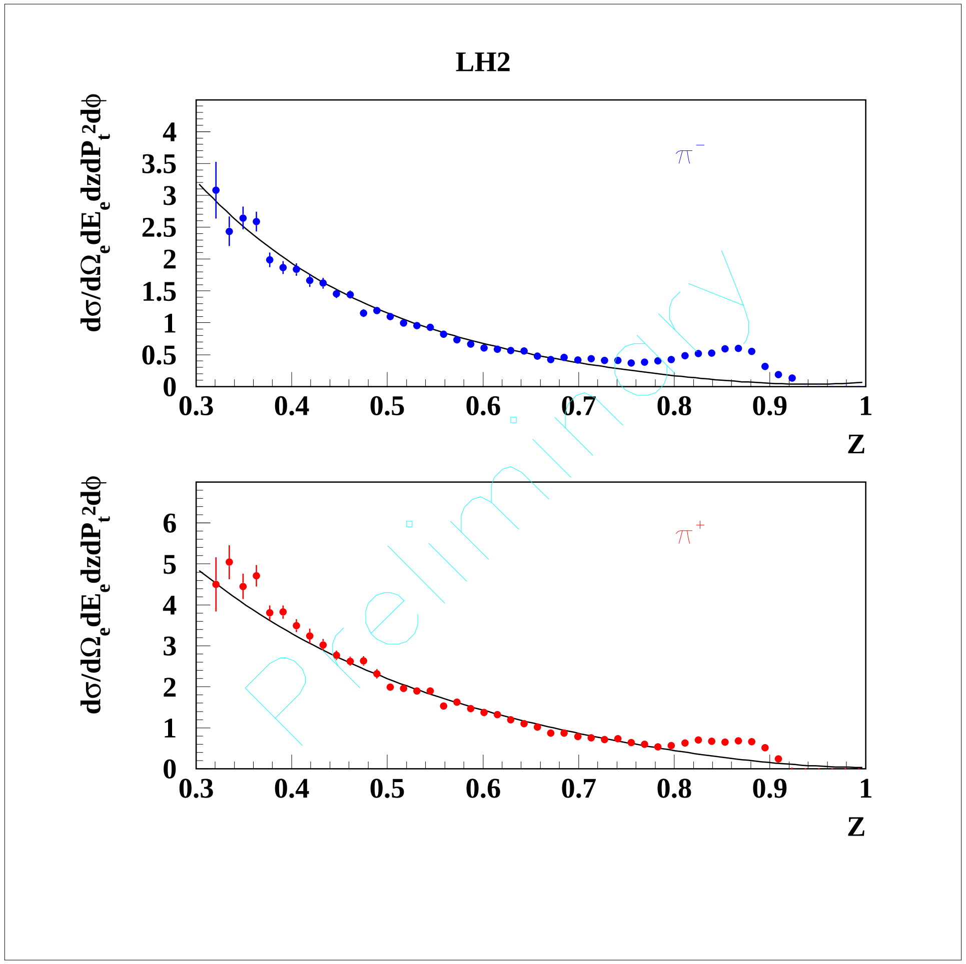
Cross section ratio $R(x,z) = \frac{\sigma_p^{\pi+}+\sigma_p^{\pi-}}{\sigma_d^{\pi+}+\sigma_d^{\pi-}}$ at $x = 0.3$, z-dependence agrees with a LUND based Monte Carlo $(z = E_\pi/\nu)$.



Double-spin asymmetry $A_{1p}^{\pi^+}$ agrees with HERMES and inclusive A_{1p}.

At 6 GeV, SIDIS experiments at JLab provide access to parton information.

... and the cross sections agree with Monte Carlo simulations



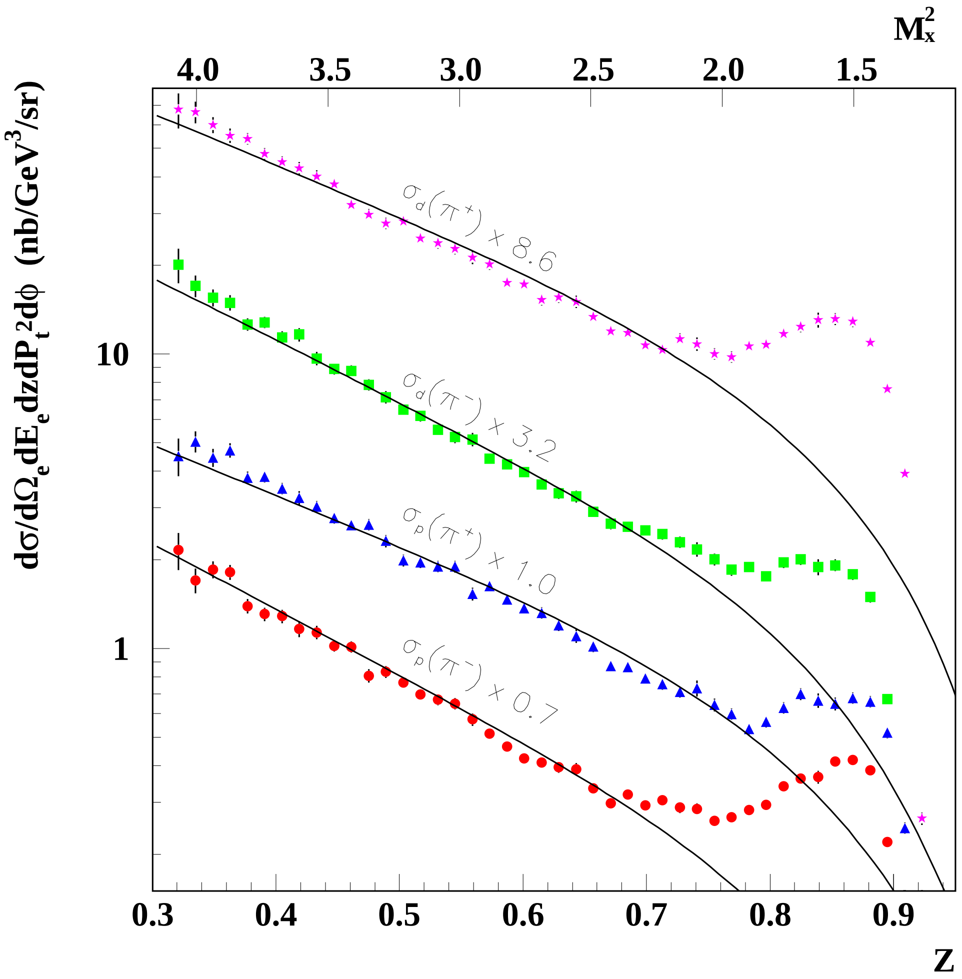
Hall C E00-108 data vs a Monte Carlo simulation (solid lines) which assumes:

$$\sigma_N^h(x,z) = \sum_q e_q^2 q(x) \cdot D_q^h(z).$$

- Uses standard parton distribution functions (CTEQ5) and fragmentation functions (BKK).

This experiment: z=0.5.

E00-108 cross sections on proton and deuteron

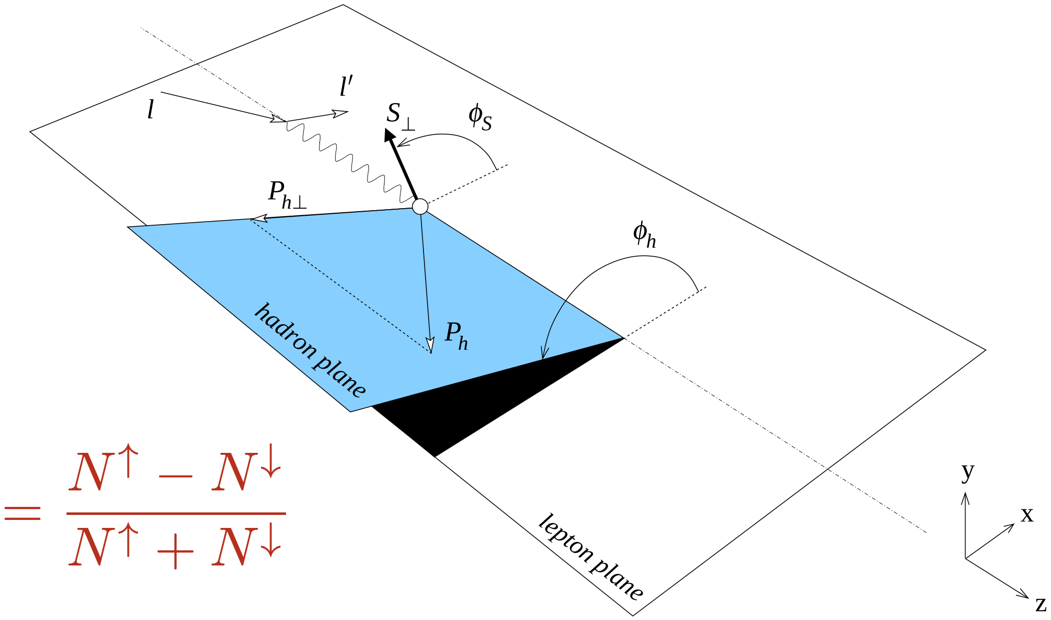


Monte Carlo (solid lines) assumes:

$$\sigma_N^h(x,z) = \sum_q e_q^2 q(x) \cdot D_q^h(z).$$

This experiment: z=0.5.

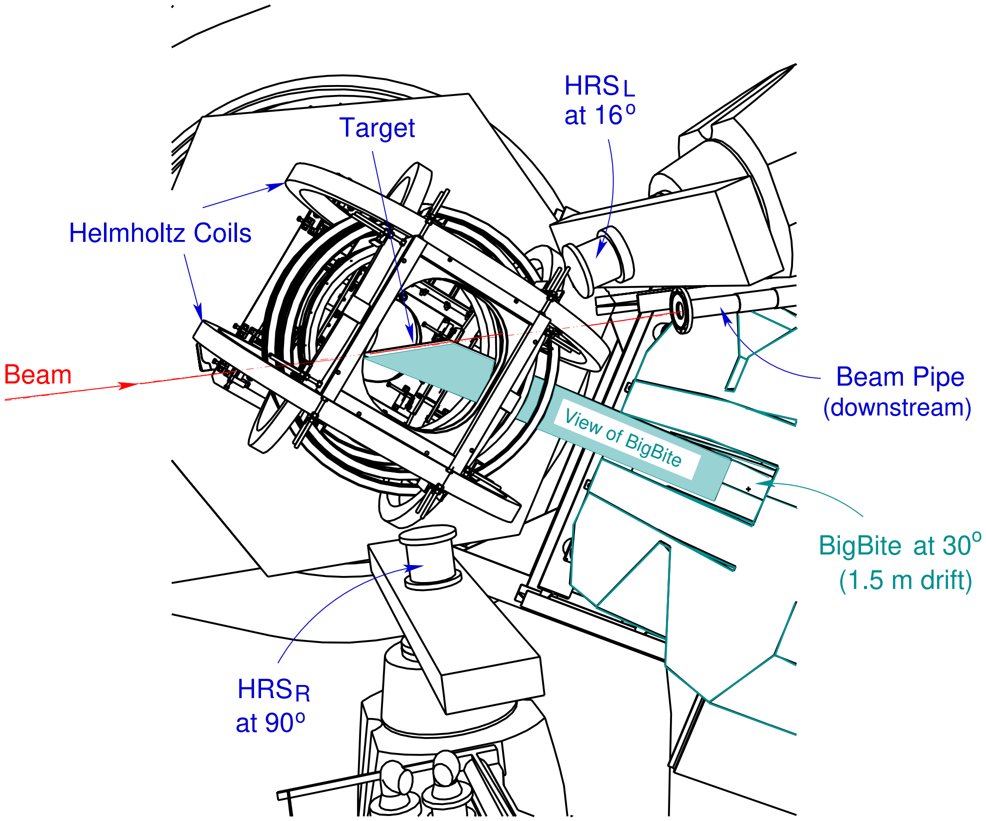
PR06-011: Target Single-Spin Asymmetry in ^{3}He$^{\uparrow}(e, e'\pi^+)$



$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$\begin{aligned}\sigma_{UT} \quad &\propto \quad S_T(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^\ell + \phi_S^\ell)\cdot\sum e_q^2\, h_1^q(x)\otimes H_{1q}^{\perp h}(z, P_{h\perp}^2) \\ &+ \quad S_T(1-y+\frac{y^2}{2})\frac{P_{h\perp}}{zM_N}\sin(\phi_h^\ell - \phi_S^\ell)\cdot\sum e_q^2\, f_{1T}^{\perp q}(x)\otimes D_{1q}^h(z_h, P_{h\perp}^2)\end{aligned}$$

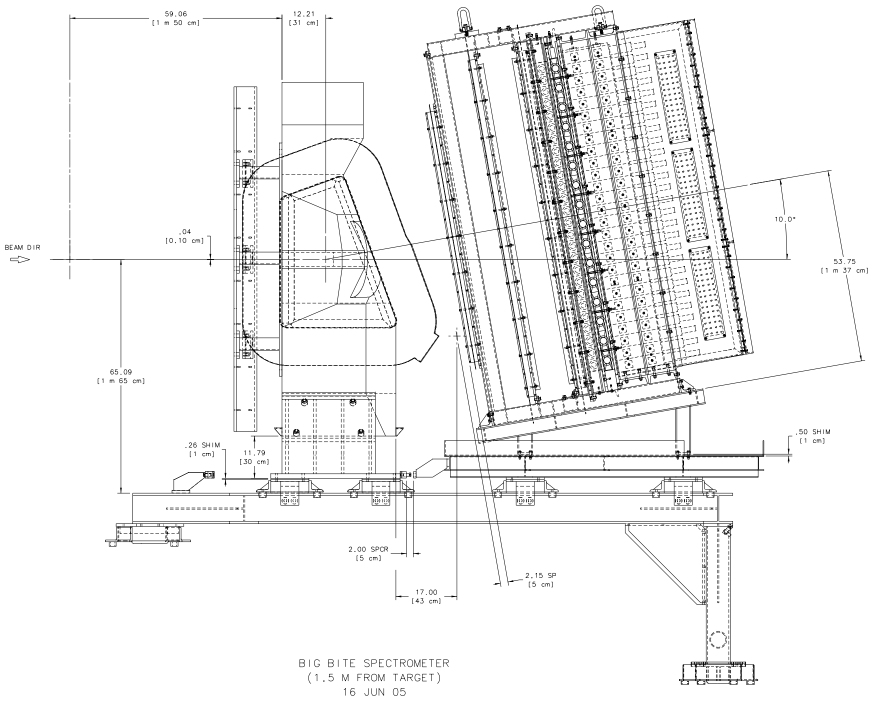
Freedom in target spin orientation ➡ separation of Collins and Sivers asymmetries.



Use existing equipments in Hall A.

- Identical setup as in PR06-010 (π^-).
- Two charge particle coincidence trigger.
- High pressure polarized ^{3}He target.
- HRS$_L$ at 16° as h-arm (π^+ or K^+). $p_h = 2.4$ GeV/c, $z = 0.5$.
- BigBite at 30° as e-arm. Identical detector configuration as in G_E^n but further away from the target, $\Delta\Omega = 64$ msr.

BigBite Spectrometer as e-Arm of the Coincidence

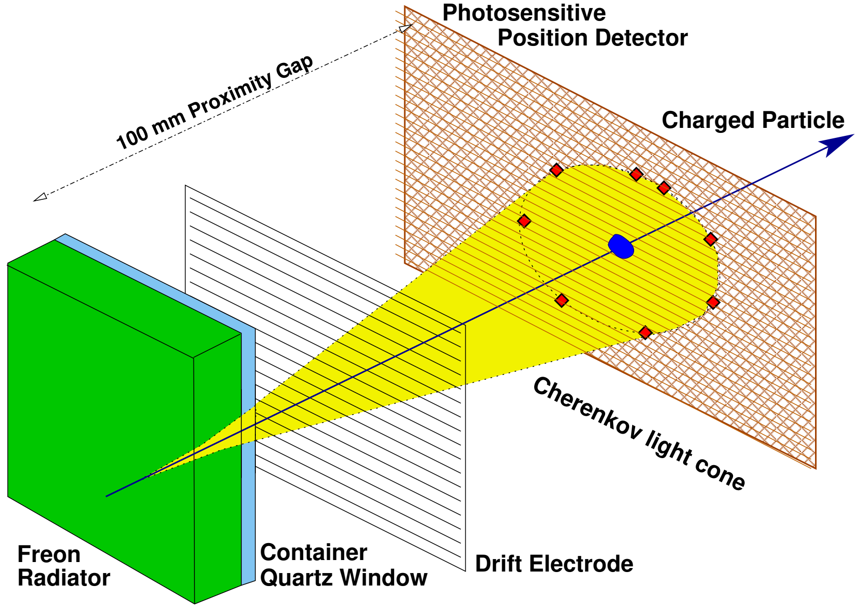


Ready to take data starting Feb. 24, 2006
for G_E^n experiment (E02-013).

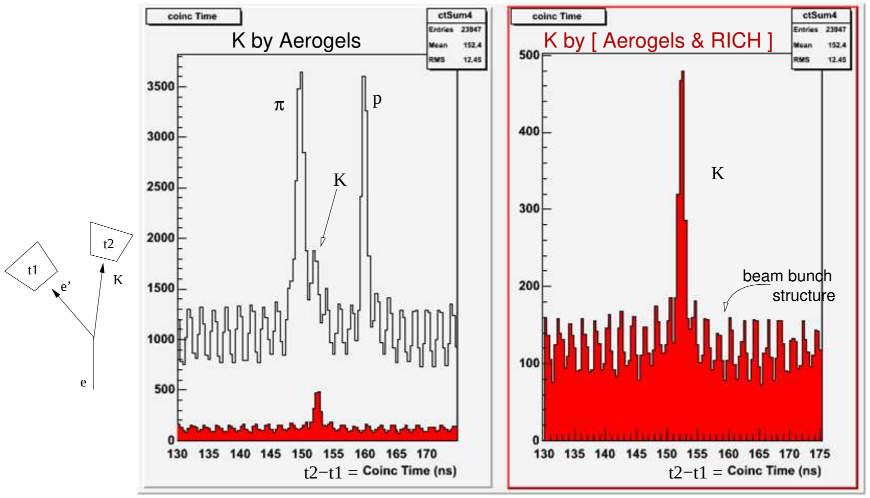
A 1.2 Tesla dipole magnet, 3 drift chambers,
a pre-shower+scintillator+shower package.

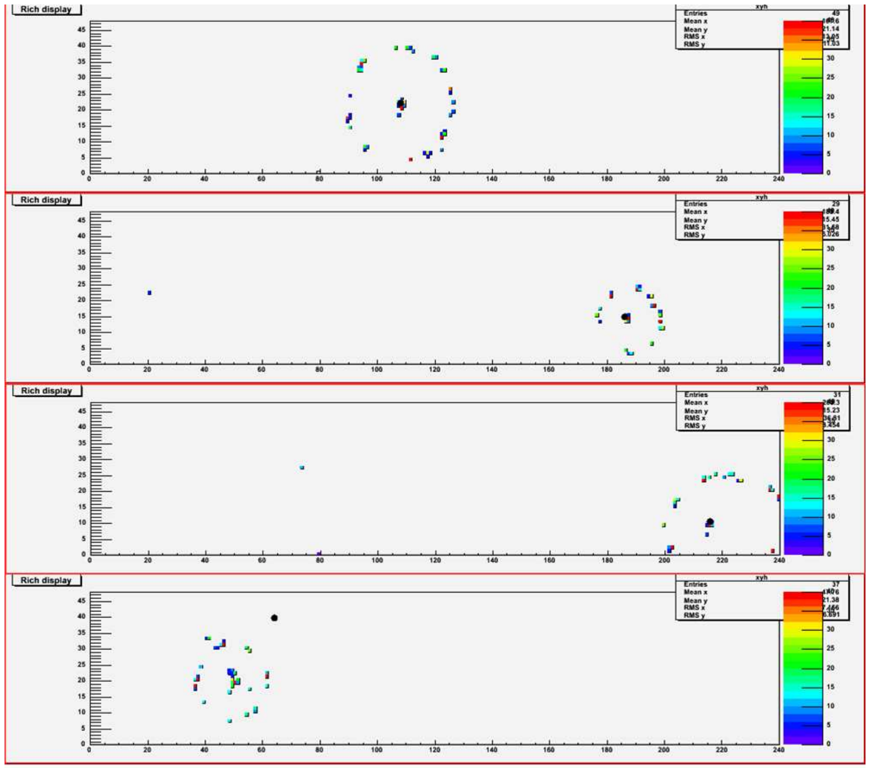
	PR06-011/010	Hall A G_E^n
Drift distance	1.5 m	1.0 m
Detector configuration	identical	
Background rates	similar	
Trigger mode	a part of coin.	BigBite single

Clean particle ID in HRS$_L$: the RICH detector



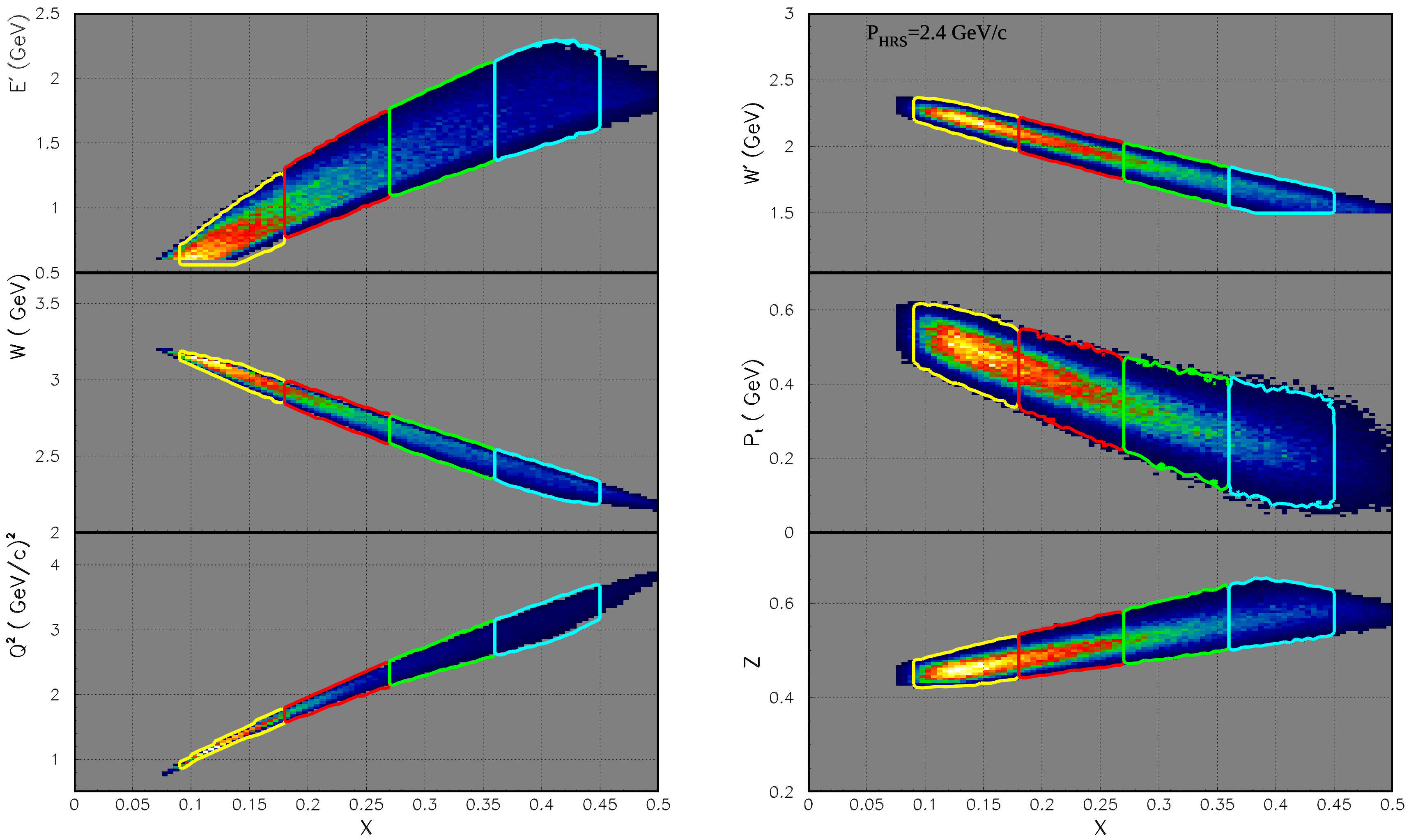
HRS$_L$ particle ID, free charged Kaon data





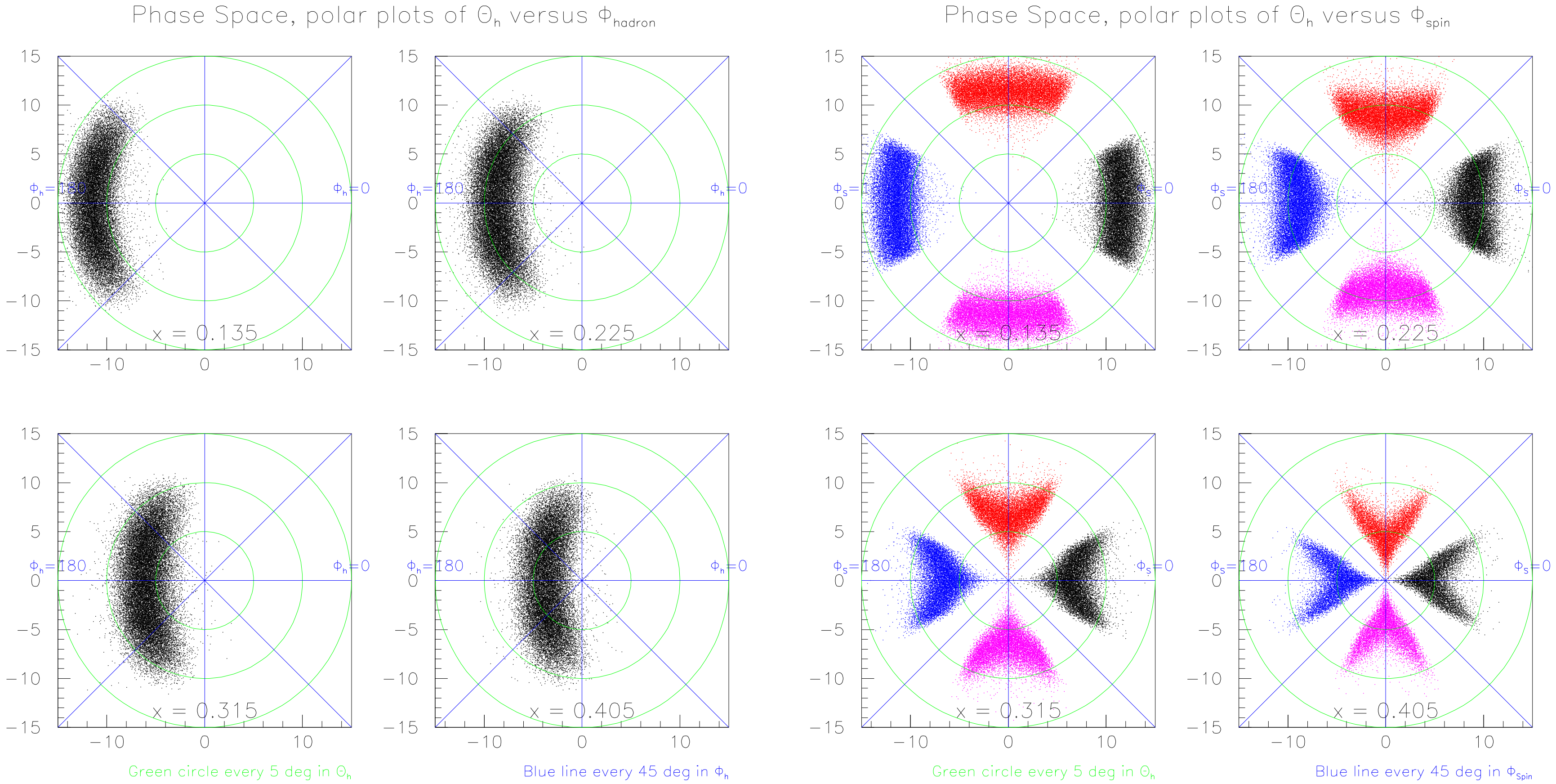
Coincidence time-of-flight. Data from Hall A experiment E94107.

Phase Space Coverage one setup covers four x-bins:



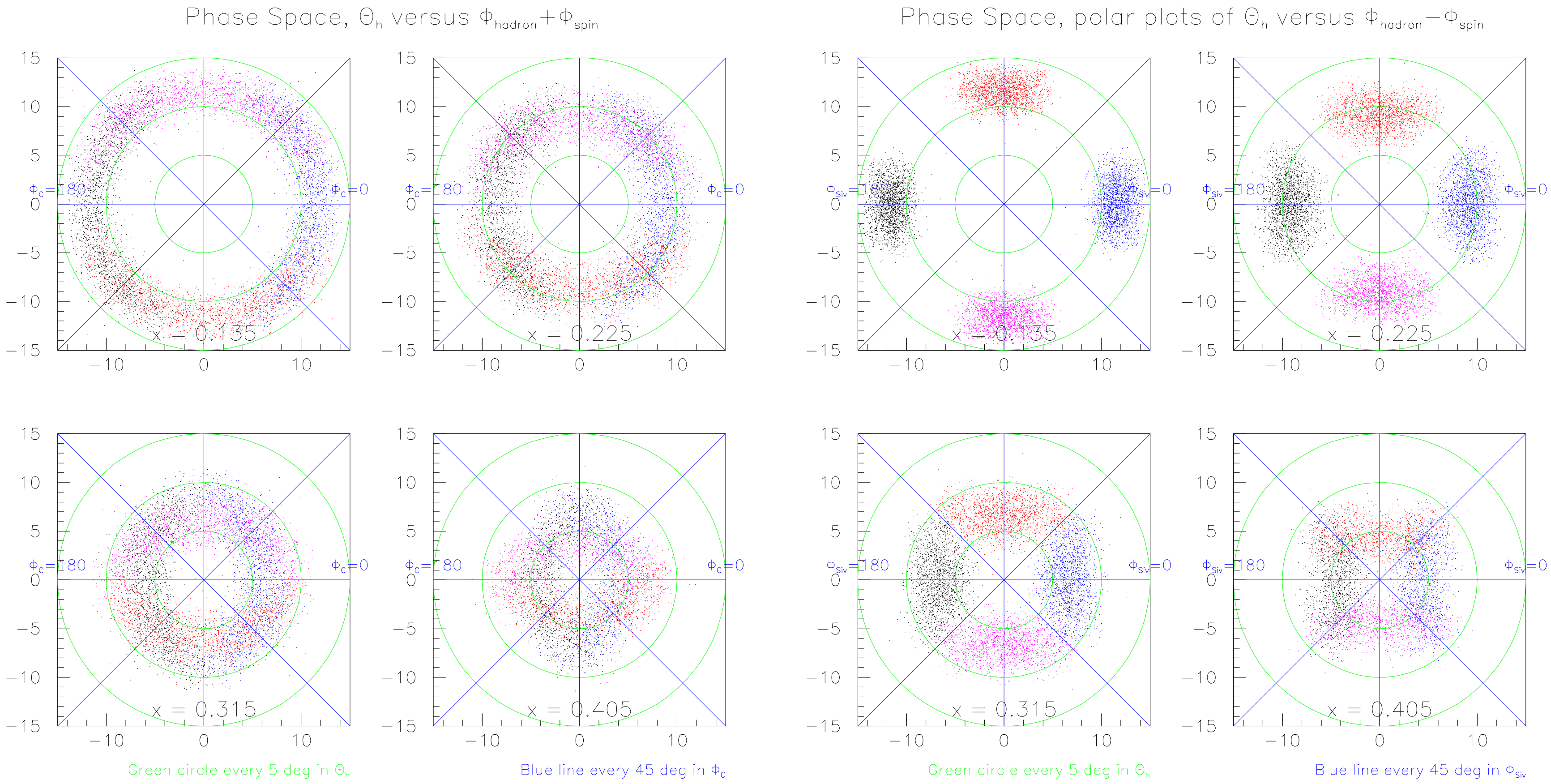
JLab: $\langle Q^2 \rangle = 2.2$ GeV^2, $\langle z \rangle = 0.5$. HERMES: $\langle Q^2 \rangle = 2.4$ GeV^2, $\langle z \rangle = \int_{0.2}^{0.8} = 0.36$.

Azimuthal Angle Coverage: ϕ_{hadron} and FOUR ϕ_{Spin}



Phase space of ϕ_{hadron} and four ϕ_{Spin}, up-down and left-right, for each x-bin.

$\phi_{Collins} = \phi_h + \phi_S$ **and** $\phi_{Sivers} = \phi_h - \phi_S$



Enough coverage on $\phi_{Collins}$ and ϕ_{Sivers} for A_{UT} separation.

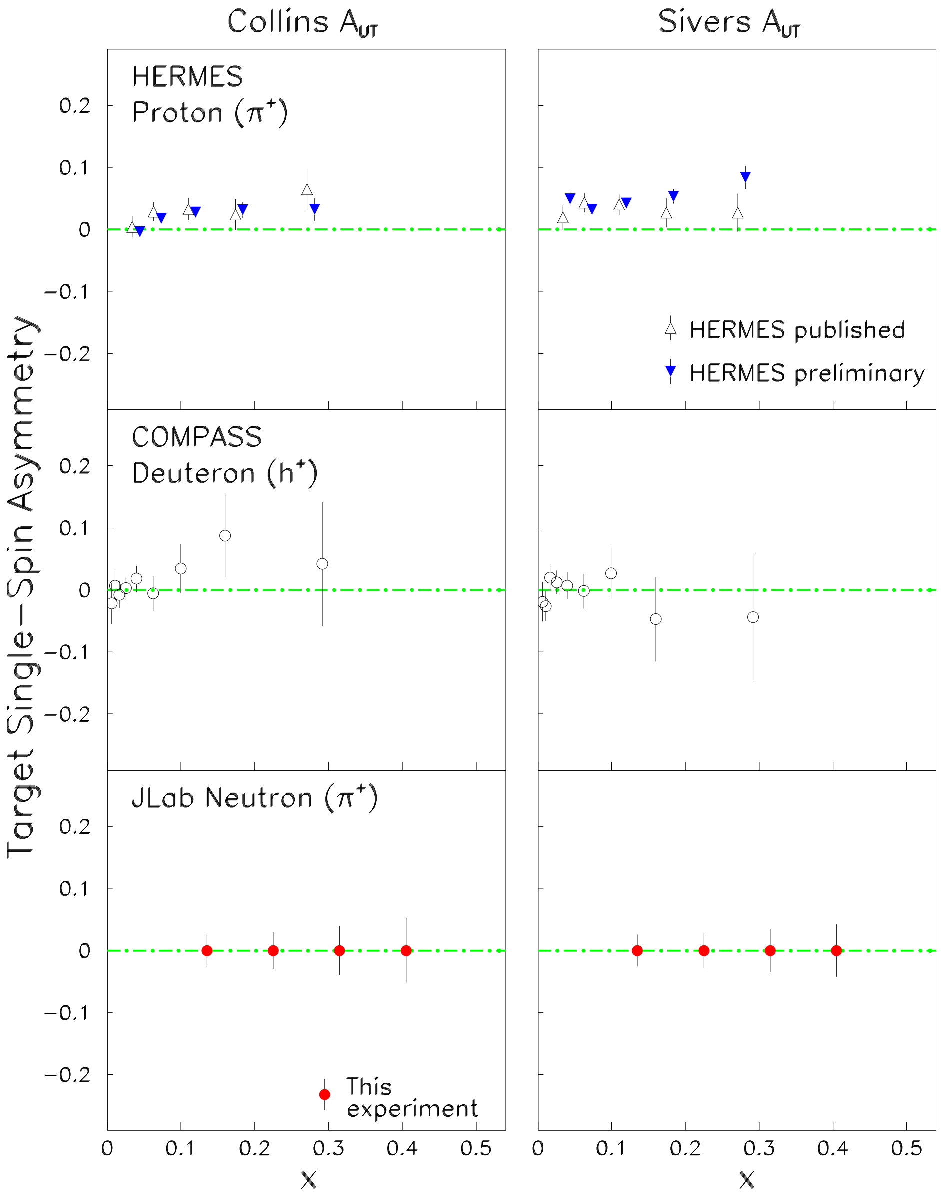
Beam Time Request: 24 days

One setting. Nothing changes except the target spin orientation.

	Time (Hour)
Production on Pol. ^{3}He	**528**
Reference cell runs, optics and detector check	16
Target Overhead: spin rotation, polarization measurement	32
Total Time Request	**576 (24 days)**

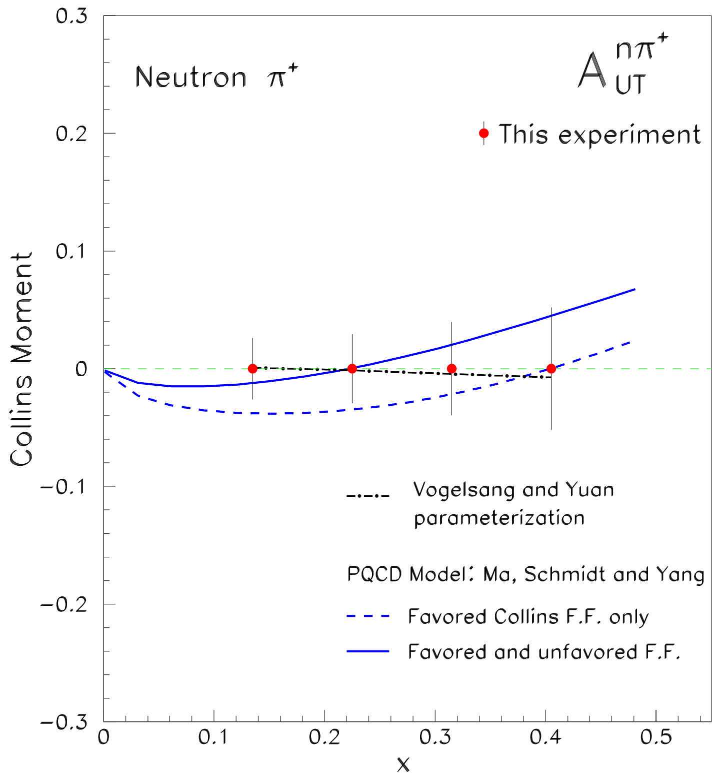
Switch-over time between PR06-010 (π^-) and PR06-011 (π^+): **FOUR** hours.

Expected Results: Neutron Single-Spin Asymmetry $A_{UT}^{n\pi^+}$



- First direct data on $A_{UT}^{n\pi^+}$
- At high-x.
- Clear separation of Collins and Sivers effects.
- Statistical uncertainty dominates.

Collins Asymmetry $A_{UT}^{n\pi^+}$ Compared with Expectations



Ma *et al.* assumed: $\frac{H_1^{\perp unfav}}{H_1^{\perp fav}} = \frac{D_1^{unfav}}{D_1^{fav}}$.

- Collins asymmetry is expected to be small ?
- Cancellations between δu and δd ?
- Collins F.F. $H_1^{\perp unfav} \approx -H_1^{\perp fav}$?

A combined analysis with HERMES proton data and $A_{UT}^{n\pi^-}$ allows a solution of four unkowns:

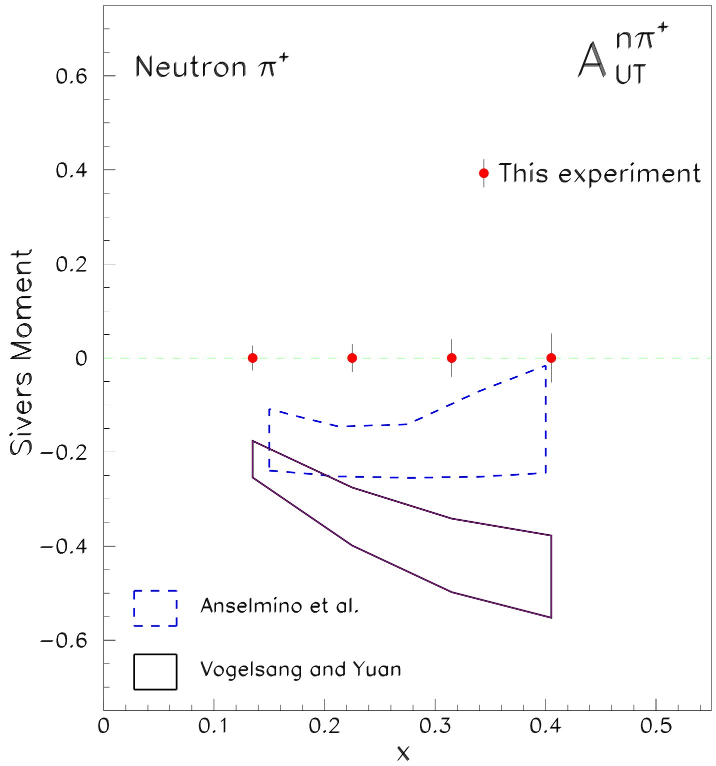
HERMES proton Collins:

$$A_{UT}^{p\pi^+} \propto 4\delta u \cdot H_1^{\perp fav} + \delta d \cdot H_1^{\perp unfav}$$
$$A_{UT}^{p\pi^-} \propto 4\delta u \cdot H_1^{\perp unfav} + \delta d \cdot H_1^{\perp fav}$$

JLab neutron Collins:

$$A_{UT}^{n\pi^+} \propto 4\delta d \cdot H_1^{\perp fav} + \delta u \cdot H_1^{\perp unfav}$$
$$A_{UT}^{n\pi^-} \propto 4\delta d \cdot H_1^{\perp unfav} + \delta u \cdot H_1^{\perp fav}$$

Sivers Asymmetry $A_{UT}^{n\pi^+}$ Compared with Expectations



- Sivers asymmetry is large and negative ?
- $f_{1T}^{\perp d} \approx f_{1T}^{\perp u}$? d-quark carries opposite angular momentum compared to u-quark ?

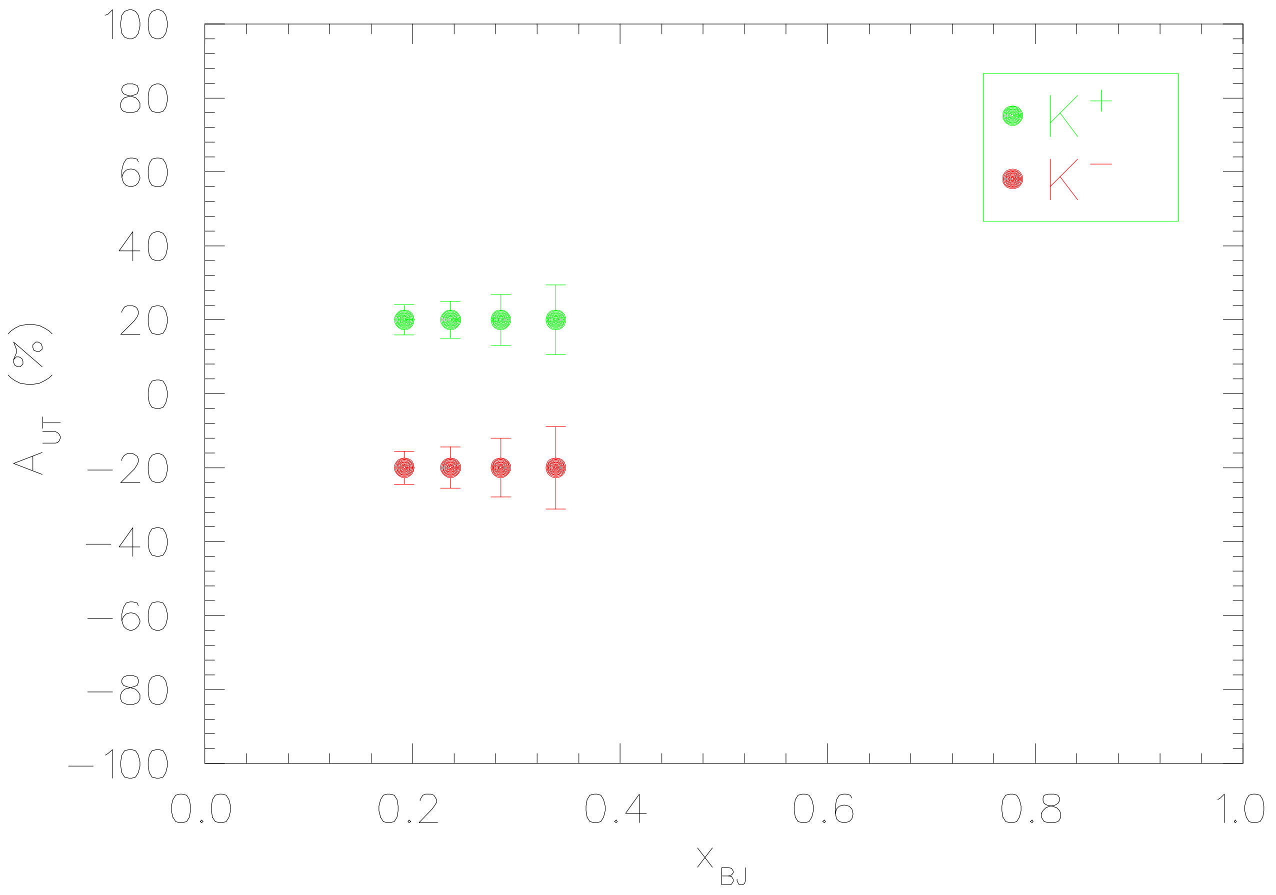
A combined analysis with $A_{UT}^{n\pi^-}$ allows an independent extraction of u and d-Sivers function form JLab data, to cross check with HERMS and COMPASS extracted Sivers functions.

JLab neutron Sivers:

$$A_{UT}^{n\pi^+} \propto 4 f_{1T}^{\perp d} \cdot D_1^{fav} + f_{1T}^{\perp u} \cdot D_1^{unfav}$$

$$A_{UT}^{n\pi^-} \propto 4 f_{1T}^{\perp d} \cdot D_1^{unfav} + f_{1T}^{\perp u} \cdot D_1^{fav}$$

Charged Kaon data comes free: A_{UT}^{nK}



For PR06-010 $K^-(\bar{u}s)$ and PR06-011 $K^+(u\bar{s})$.

Summary of PR06-011

Measurements of target SSA $A_{UT}^{n\pi^+}$ on a polarized ^{3}He target (24 days 6 GeV).

- Clear separation of Collins and Sivers effects.
- Provide urgently needed information on flavor dependence of neutron SSA.
  - $A_{UT}^{n\pi^+}$ Collins: When combined with $A_{UT}^{n\pi^-}$ and HERMES proton data, disentangle effects from four unknowns: δu, δd, $H_1^{\perp fav}$ and $H_1^{\perp unfav}$.
  - $A_{UT}^{n\pi^+}$ Sivers: When combined with $A_{UT}^{n\pi^-}$, JLab data can independently deduce Sivers function for both u and d-quark to crosscheck Sivers functions from HERMES and COMPASS data.

A very low cost experiment, uses existing equipments:

- Hall A polarized ^{3}He target, with modifications.
- BigBite spectrometer as in G_E^n, ready to take data.
- Identical setup for PR06-010/011.

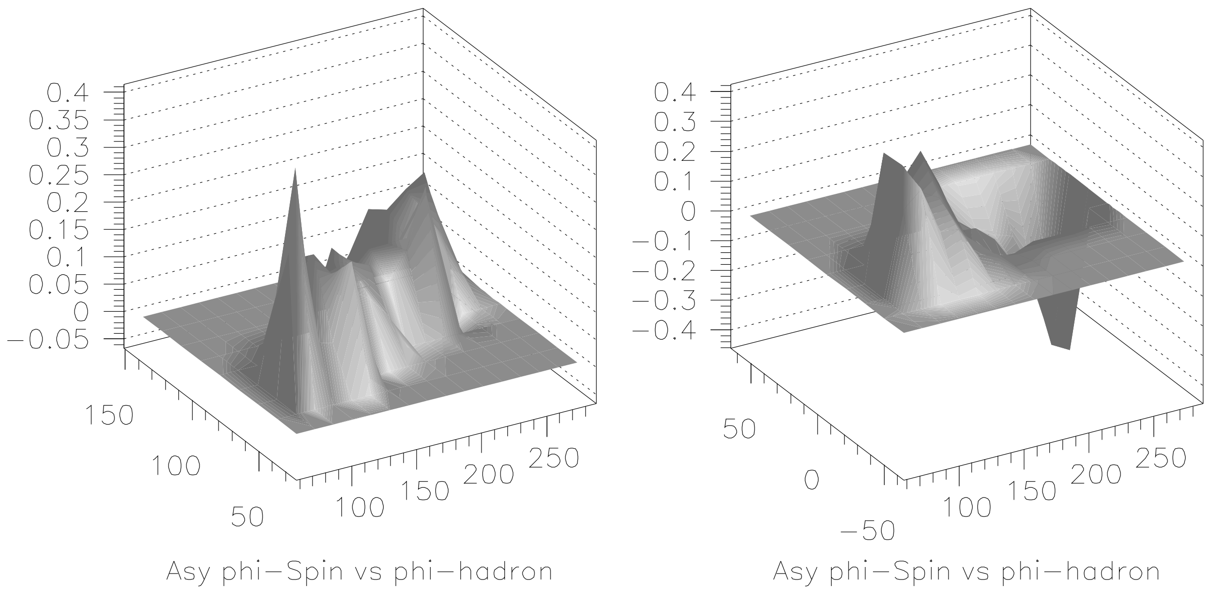
Backup Slides

Why do we need to measure both π^- and π^+ ?

- Nature is made up of two flavors in the light-quark sector, following SU(2) symmetry not U(1).
- A measurement with one charge only tells half of the story. A measurement with both π^- and π^+ is much more powerful:
  - Collins: When combined with HERMES proton data, disentangle effects from four unknowns.
  - Sivers: JLab data can independently extract Sivers function for both u and d-quark.

A Monte Carlo Demonstration: Separation of Asymmetries

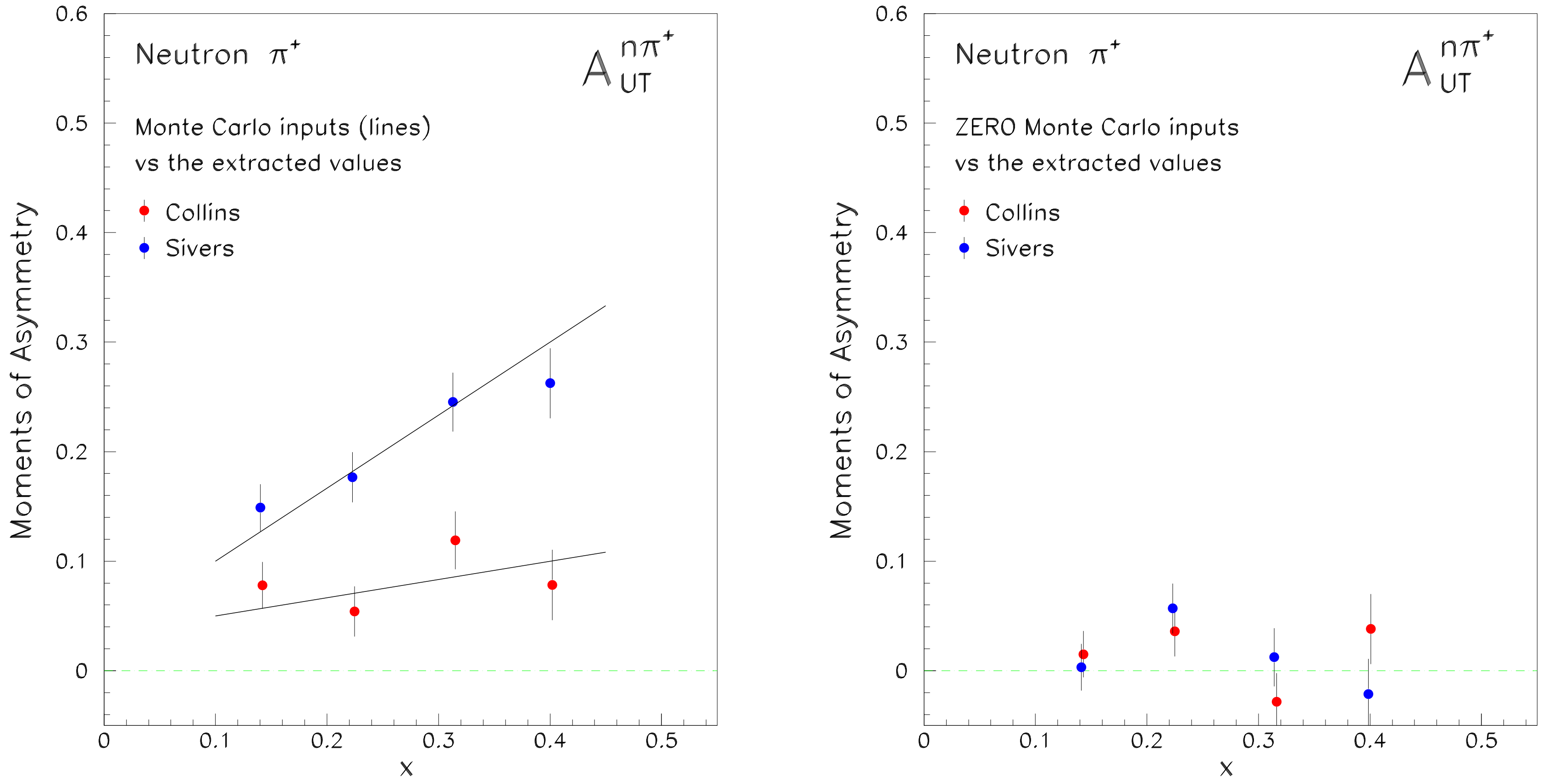
$$A_{UT} = a\sin(\phi_h + \phi_S) + b\sin(\phi_h - \phi_S)$$



Generate events according to A_{UT}.

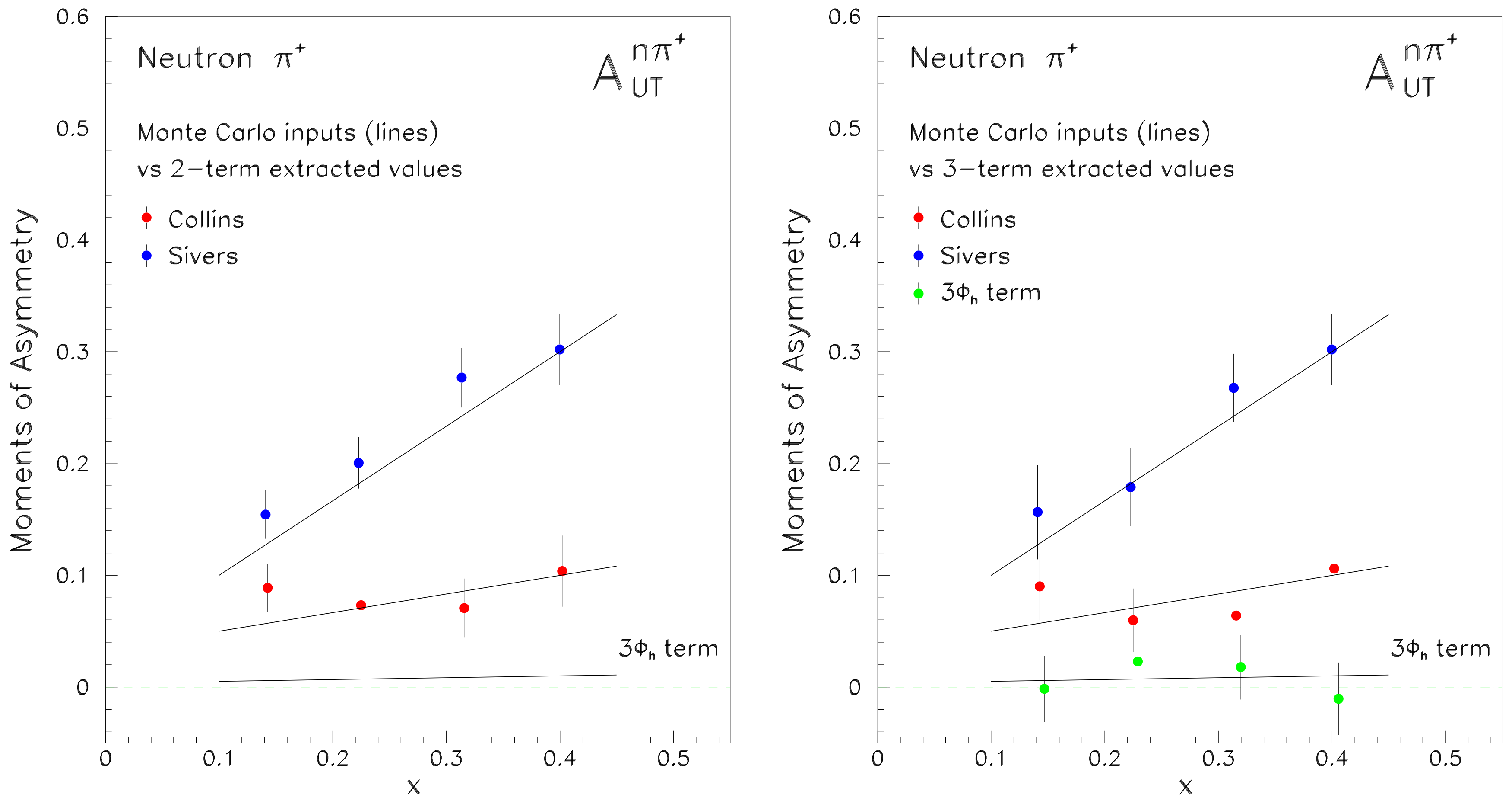
A_{UT} on (ϕ_S, ϕ_h) for up-down and left-right target spin asymmetries.

Monte Carlo: 2-Term Extraction



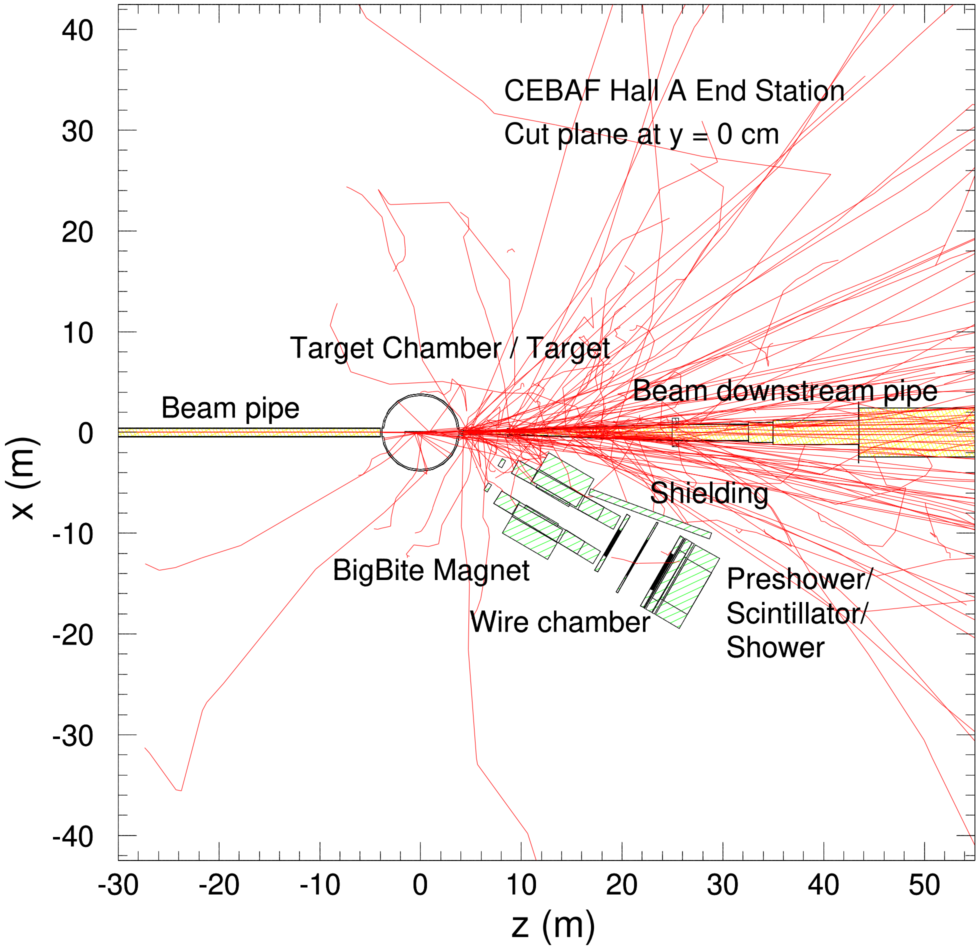
Recover the input values within statistical uncertainties.

Monte Carlo: add a small $\sin(3\phi_h - \phi_S)$ term

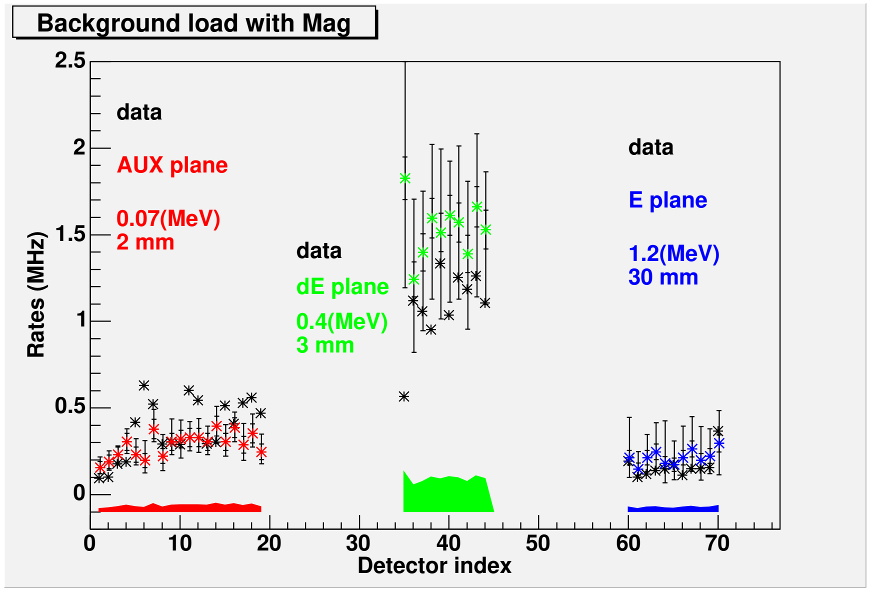


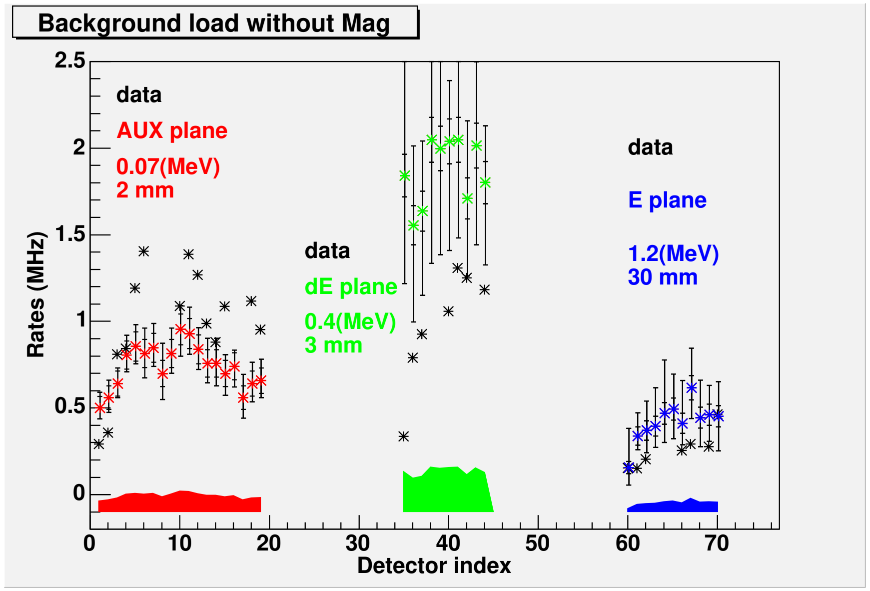
2-term extraction not affected. Can even extract the 3rd term.

BigBite Shielding Plan:



BigBite Rate Test Compared with Simulations:





Rates and Number of Events in ^{3}He$(e, e'\pi^+)$

E$'$	$\Delta E'$	θ_e	$\langle x \rangle$	$d\sigma_{(e,e')}$	$d\sigma_{(e,e'\pi^+)}$	Rate$_{\pi^+}$	N$_{\pi^+}$
GeV	GeV	deg.		nb/GeV/sr	nb/GeV^2/sr^2	Hz	k
					$\theta_\pi = 16.0^\circ, p_\pi = 2.4$ GeV/c		
0.815	0.431	30.0	0.135	29.64	8.17	0.24	461.0
1.246	0.398	30.0	0.225	19.37	7.19	0.20	374.5
1.612	0.340	30.0	0.315	12.95	5.53	0.13	246.1
1.925	0.381	30.0	0.405	8.37	3.63	0.10	181.0

Statistical Uncertainties on $A_{UT}^{n\pi^+}$

E′ GeV	$\langle x\rangle$	R	$B(x)/A(x,y)$	D_{nn}	z_π	f_{π^+}	$1/f_{\pi^+}P_T P_n\sqrt{N_{\pi^+}}$ %
0.815	0.135	0.32	0.249	0.267	0.46	0.27	1.50
1.246	0.225	0.26	0.375	0.398	0.51	0.23	1.93
1.612	0.315	0.21	0.485	0.501	0.55	0.20	2.77
1.925	0.405	0.18	0.584	0.582	0.59	0.18	3.69

Take target $P_T = 42\%$, effective neutron polarization in ^{3}He: $P_n = 86.5\%$.

Separation of current and target fragmentation: