

# An overview of Hall A neutron transversity experiments

E-06-010 (ex E-03-004) and E-06-011

Evaristo Cisbani  
on behalf of the Transversity Collaboration

INFN-Rome and Italian National Institute of Health

Hall A Collaboration Meeting  
JLab

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- Introduction of the transversity
- Present status
- Experiment(s) in Hall A
- $\pi/K$  separation and RICH

# Quark DFs at leading twist

$$\Phi_{ij}(k, P, S) \sim \int d^4\xi e^{ix\cdot\xi} \langle PS | \bar{\phi}_j(0) \phi_i(\xi) | PS \rangle$$

$\phi$ ,  $k$  quark spinor and momentum fraction,  
 $P, S$  proton momentum and spin,

$i, j$  Dirac indices

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$$\Phi(x) \stackrel{\text{Twist } 2}{=} \frac{1}{2} [ q(x) \gamma^\mu P_\mu + S_{\parallel} \Delta q(x) \gamma_5 \gamma^\mu P_\mu + \delta q(x) \gamma^\mu P_\mu \gamma_5 \gamma^\mu (S_\perp)_\mu ]$$

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Quark	Nucleon		
	0	L	T
0	$q(x)$ 		

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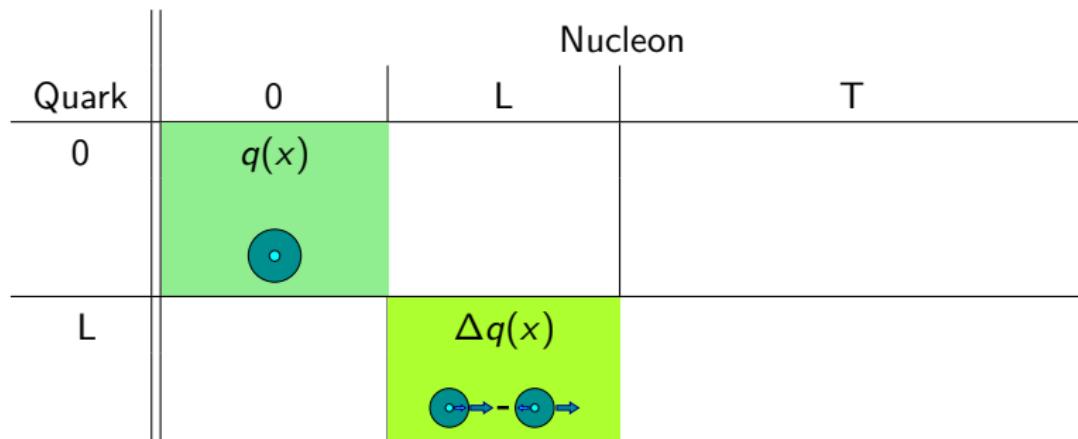
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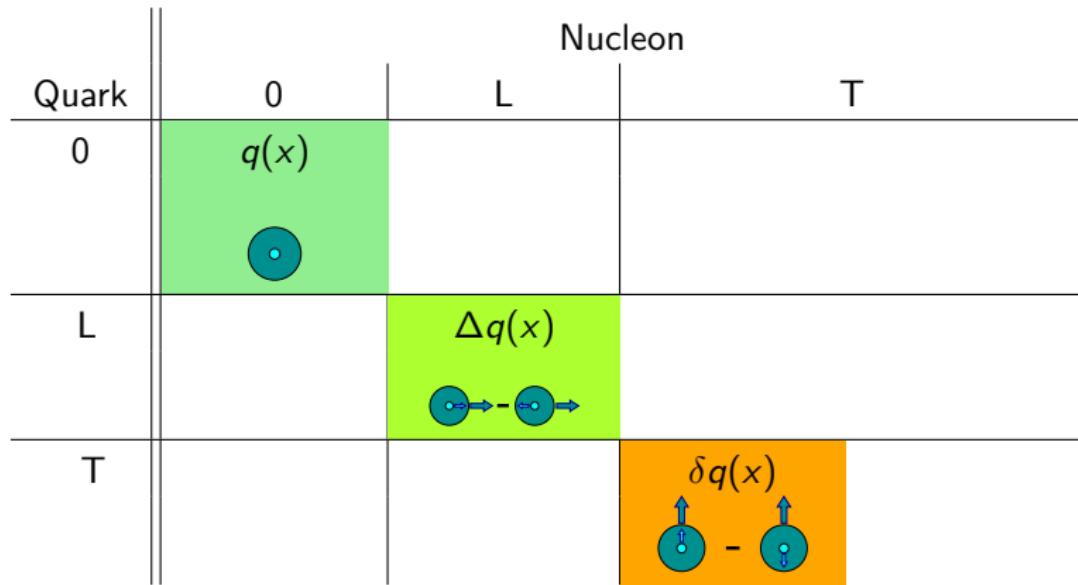
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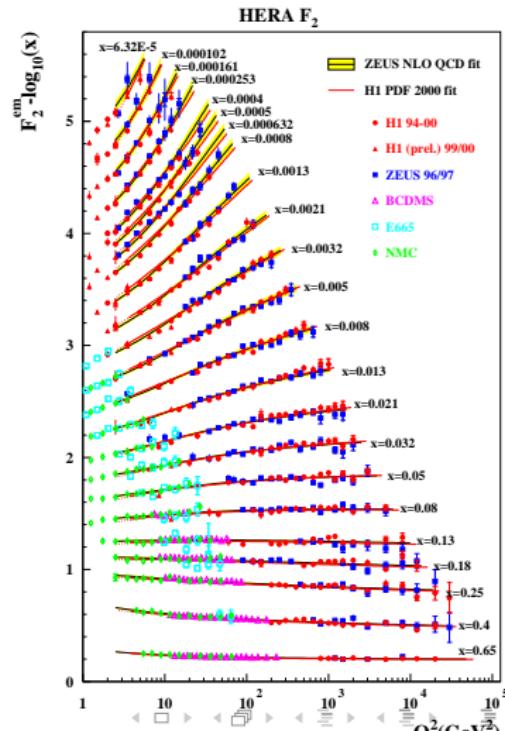
# Quark DFs at leading twist: data

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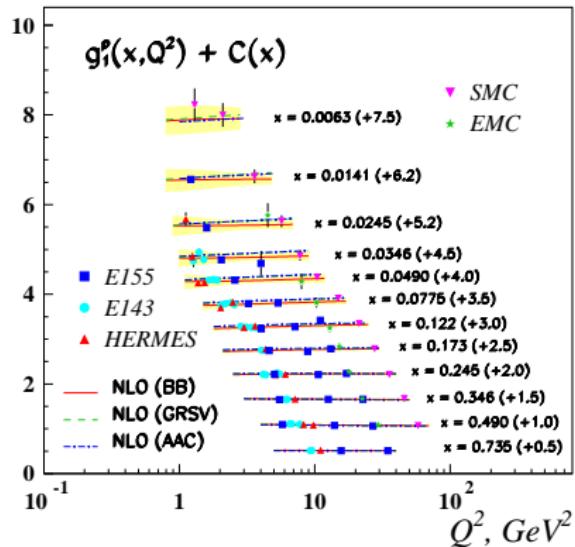
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- $\delta q(x)$  - transversity : *detected*,  
... next slides

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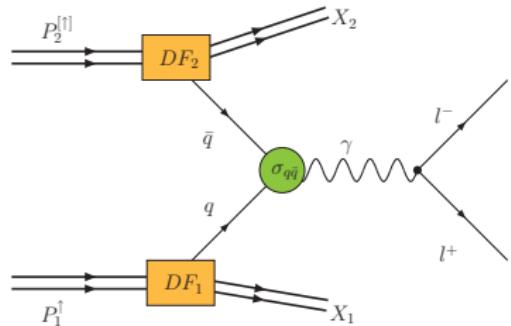
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- Theoretical knowledge on  $\delta q(x)$  similar to  $\Delta q(x)$

# Direct measurement of $\delta q(x)$ in polarized Drell-Yan

$$P_1^\uparrow + P_2^{[\uparrow]} \rightarrow l^+ l^- + X$$

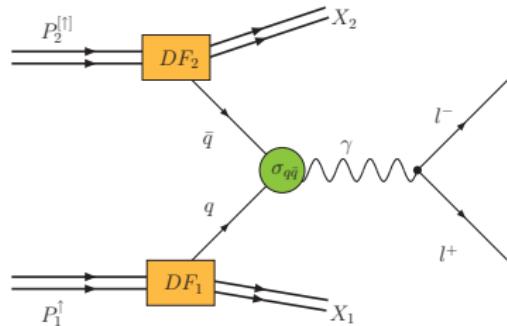
$P_1^\uparrow$  e  $P_2^{[\uparrow]}$  transverse polarized (anti)protons  
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Double spin transverse asymmetry, leading approximation

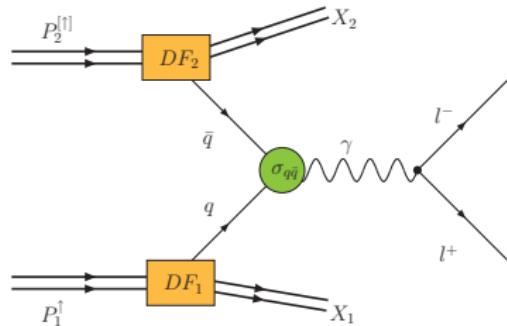
$$A_{TT}^{DY} \equiv \frac{\sigma(P_1^\uparrow P_2^\uparrow) - \sigma(P_1^\uparrow P_2^\downarrow)}{\sigma(P_1^\uparrow P_2^\uparrow) + \sigma(P_1^\uparrow P_2^\downarrow)} \sim \sum_q e_q^2 [\delta q(x_A) \delta \bar{q}(x_B) + \delta \bar{q}(x_A) \delta q(x_B)]$$

- only  $\delta q(x)$  involved (no fragmentation function)

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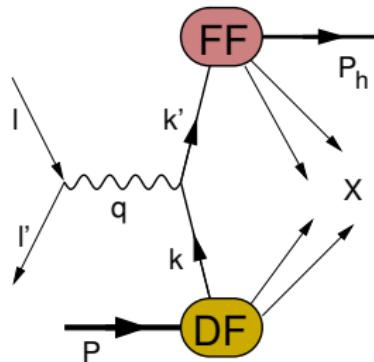
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- RHIC has a transversity program, but kinematics ( $\sqrt{s} > 100 \text{ GeV}$ ,  $x < 5 \times 10^{-3}$ ) unfavored:  $A_{TT}^{DY} \sim 1 \div 2\%$
- $(p^\uparrow, \bar{p}^\uparrow)$  at lower energies, higher  $x$  optimal process

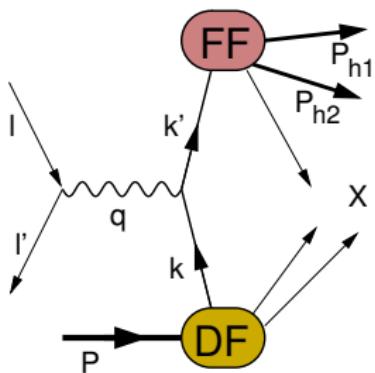
( $\Rightarrow$  PAX, next decennium?)

# $\delta q(x)$ from Semi Inclusive DIS



$$\sigma(IN \rightarrow lhX) \sim \sum_q \sigma(lq \rightarrow lq) \otimes DF(q) \otimes FF(q \rightarrow h)$$

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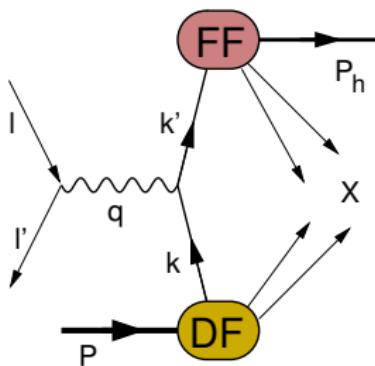


- Direct product of DF and FF
- No additional DFs
- Low statistics
- Unknown interference FF

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- Double Hadrons detected in final state

# $\delta q(x)$ from Semi Inclusive DIS



- 'Simpler' Exp. Setup
- Higher Statistics
- Additional DF involved
- Collins FF

$$\sigma(IN \rightarrow lhX) \sim \sum_q \sigma(lq \rightarrow lq) \otimes DF(q) \otimes FF(q \rightarrow h)$$

- Double Hadrons detected in final state
- One unpolarized hadron detected in final state  $\Rightarrow$  SSA

# Transverse Target Single-Spin Asymmetry (SSA)

$A_{UT}(\phi_h^I, \phi_S^I) \equiv \frac{1}{|S_T|} \frac{d\sigma(\phi_h^I, \phi_S^I) - d\sigma(\phi_h^I, \phi_S^I + \pi)}{d\sigma(\phi_h^I, \phi_S^I) + d\sigma(\phi_h^I, \phi_S^I + \pi)}$

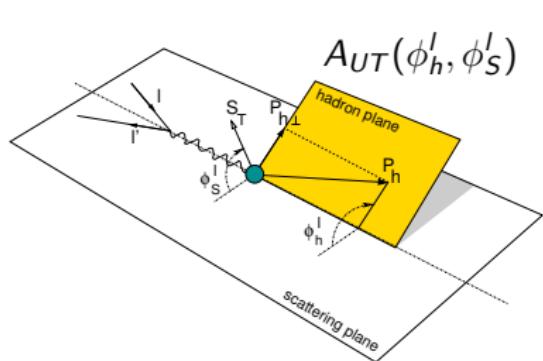
$\stackrel{\text{Twist2}}{=}$

$A_{UT}^{\text{Collins}} \sin(\phi_h^I + \phi_S^I) +$

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Twist<sup>2</sup>

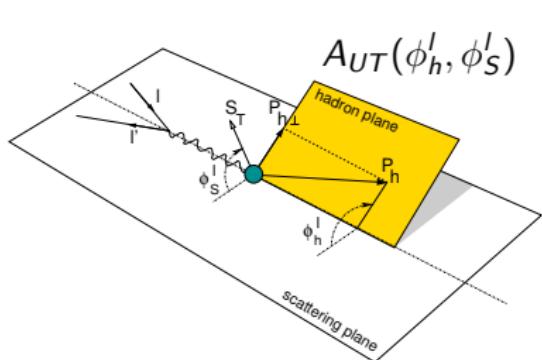
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$$A_{UT}^{\text{Collins}} \sim \sum_q e_q^2 \left[ \delta q \otimes H_{1q}^\perp \right]$$

Transversity  $\otimes$  Collins FF

$\otimes$  = convolution integral in initial and final quark transverse momentum

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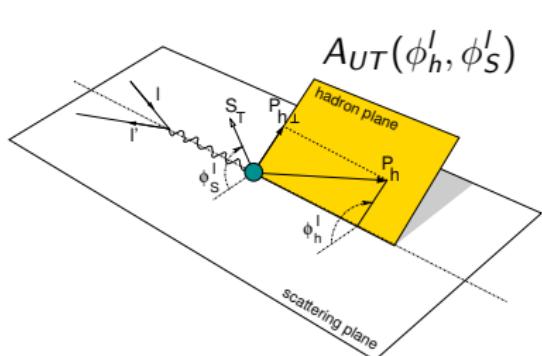
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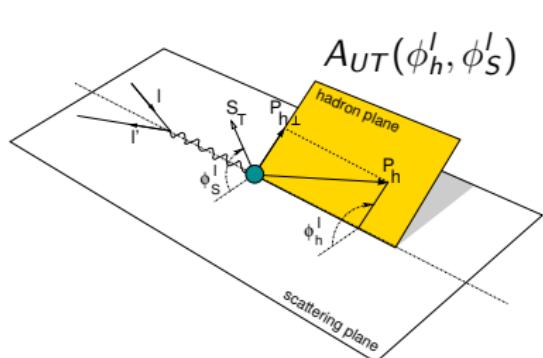
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Expected to be small

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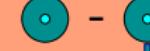
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**Collins and Sivers can be extracted by azimuthal fit**

# $k_\perp$ Dependent (TMD) Quark DF at Twist-2

Quark	Nucleon		
	0	L	T
0	$f(x, k_\perp)$		$f_{1T}^\perp(x, k_\perp)$
L		$g_{1L}(x, k_\perp)$	$g_{1T}(x, k_\perp)$
T	$h_1^\perp(x, k_\perp)$	$h_{1L}^\perp(x, k_\perp)$	$h_{1T}(x, k_\perp)$ $h_{1T}^\perp(x, k_\perp)$
			 

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$$\delta q(x) = h_{1T} + k_\perp^2/(2M)h_{1T}^\perp$$

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$f_{1T}^\perp(x, k_\perp)$ : Sivers DF, naive time-reversal odd,  $f_{1T}^\perp(x, k_\perp) \neq 0 \rightarrow$  I/FSI

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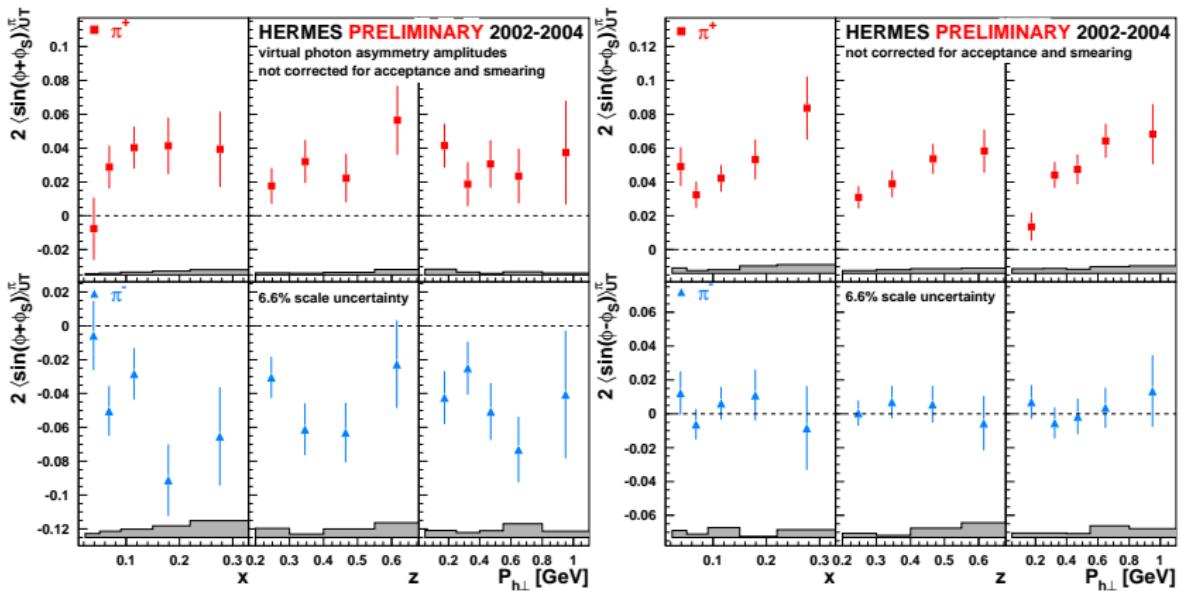
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information on quark angular momentum: if  $f_{1T}^\perp \neq 0 \rightarrow L_q \neq 0 !$

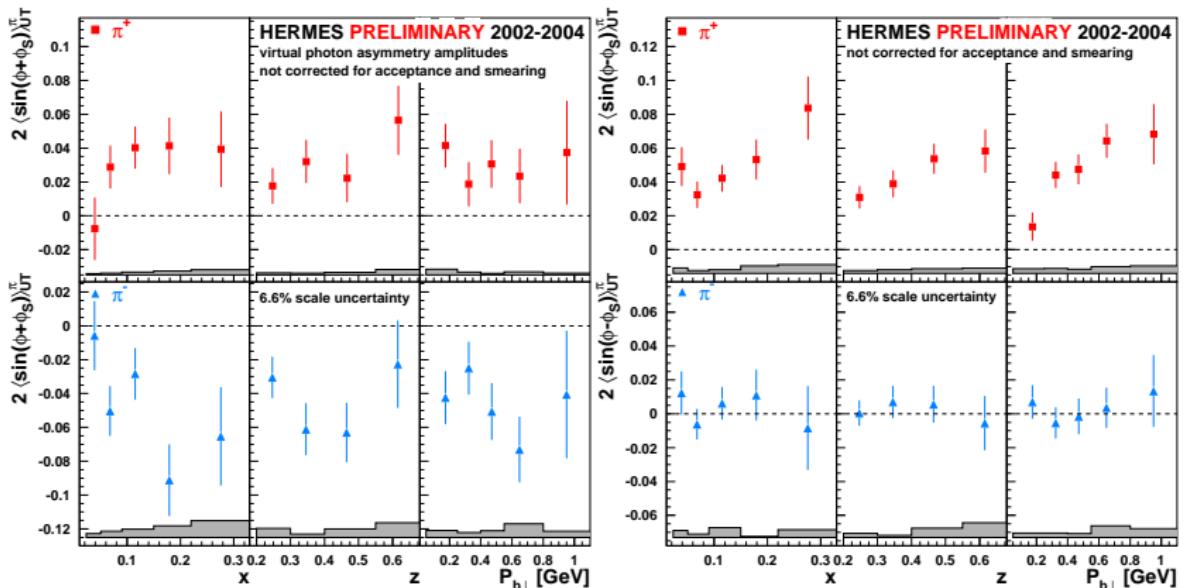
# HERMES SSA $\pi$ Proton Data [hep-ex/0507013]

$e + p^\uparrow \rightarrow e' + \pi^\pm + X$  with  $\pi^+/\pi^-$  Favored/Unfavored channels



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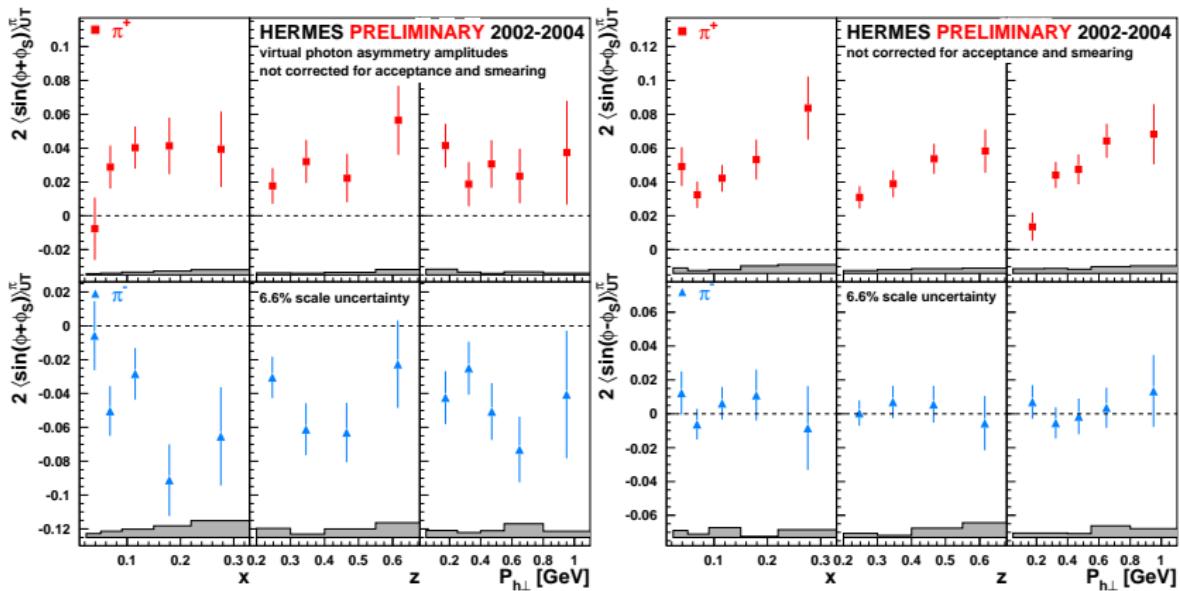
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Strong Flavor Dependence of the Collins and Sivers Asymmetries

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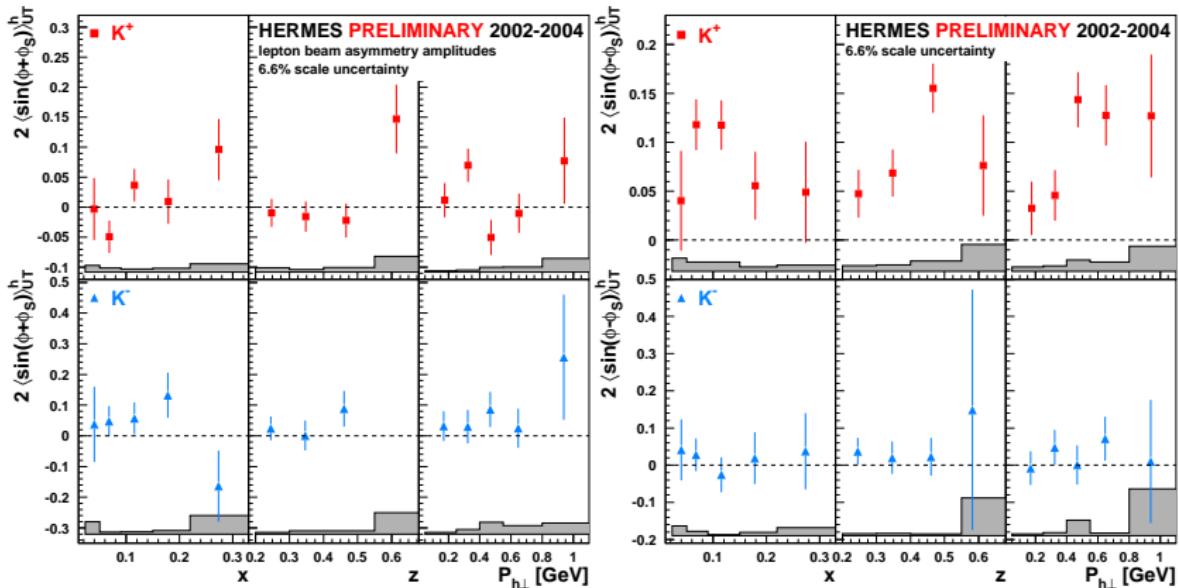
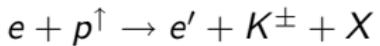
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**Strong Flavor Dependence of the Collins and Sivers Asymmetries**

Unfavored  $p(uud) \rightarrow \pi^-(d\bar{u})$  shows large Collins Asymmetry

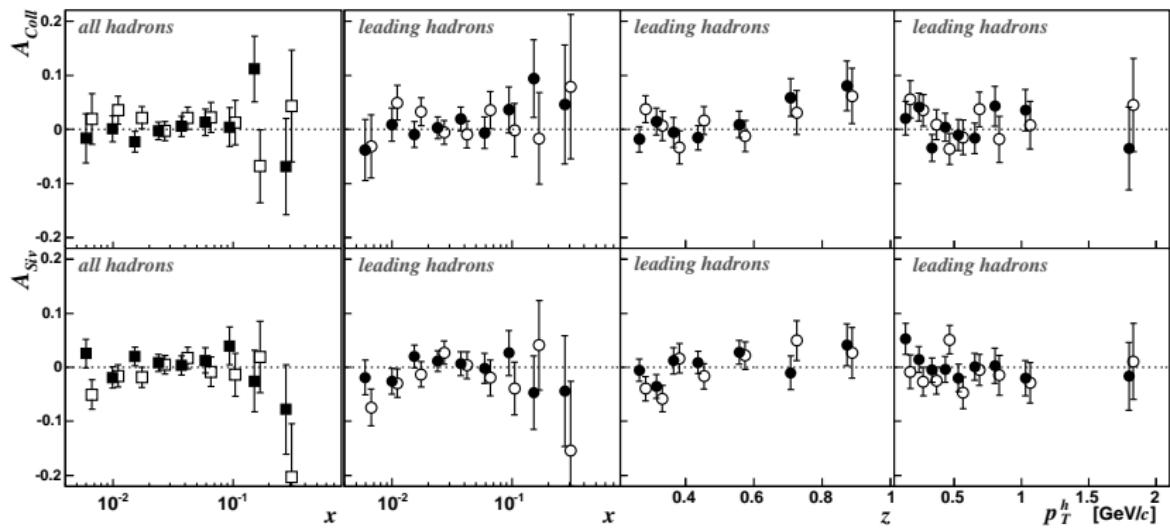
# HERMES SSA $K$ Proton Data



Contribution of sea quarks to Sivers function (?)

# COMPASS Deuteron Data [PRL 94 (2005) 202002]

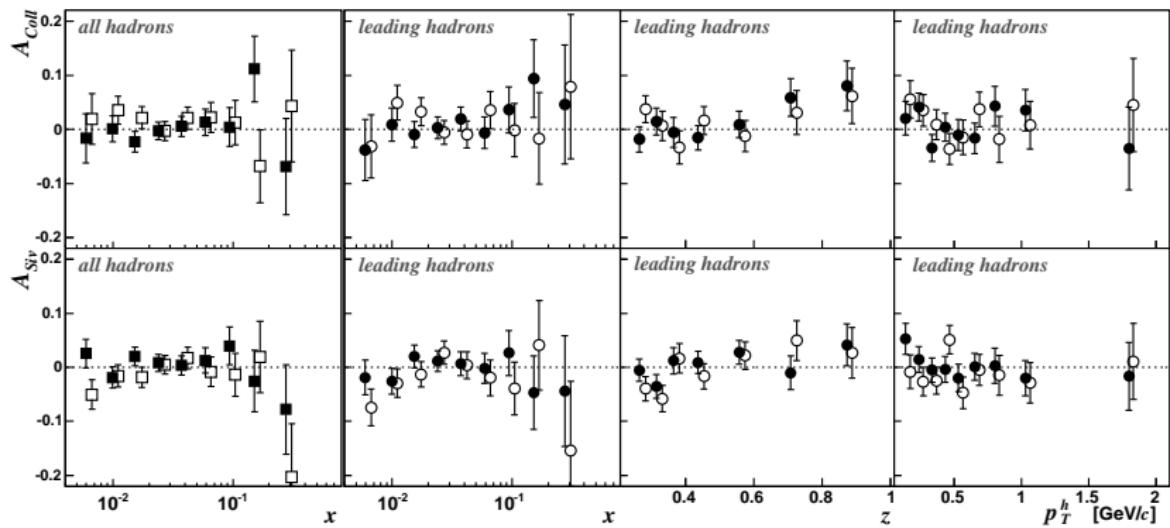
$$\mu + d^\dagger \rightarrow \mu' + h + X$$



( $\bullet = h^+$ ,  $\circ = h^-$ )

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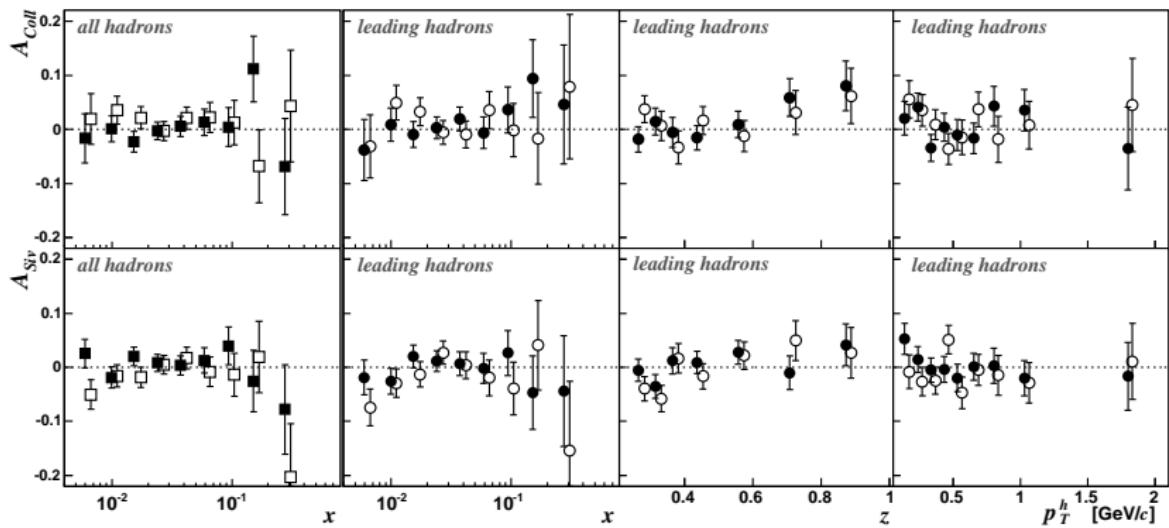


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- Both  $u$  and  $d$  quarks probed

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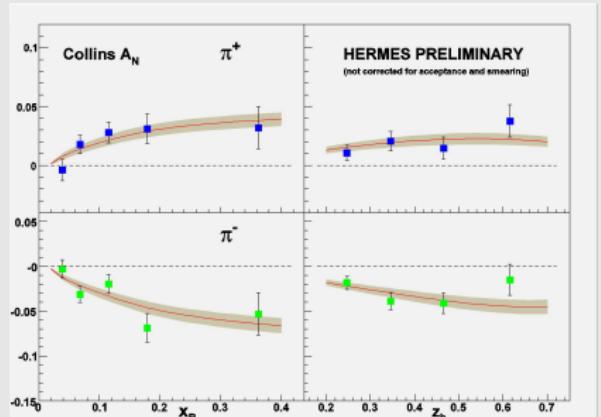
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- Both  $u$  and  $d$  quarks probed
  - Small SSA & HERMES data  $\Rightarrow$  large contribution to asymmetry from  $d$  quark (?)

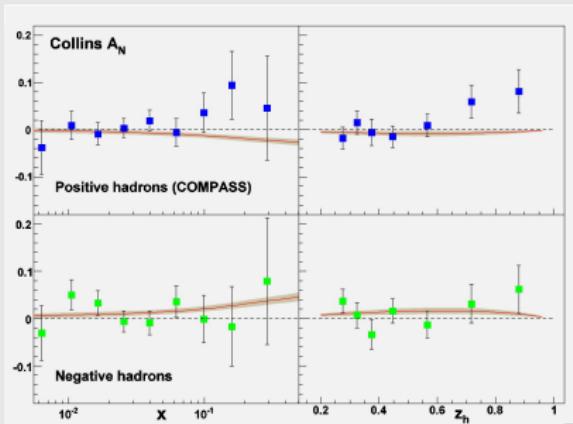
# Collins Functions from Data (hep-ph/0507266)

Assume:  $H_{1,fav}^\perp(z) = C_{fav} z(1-z) D_{1,fav}(z)$ ,  $H_{1,unfav}^\perp(z) = \frac{C_{unfav}}{C_{fav}} H_{1,fav}^\perp(z)$

Fit of HERMES data



Comparison to COMPASS data

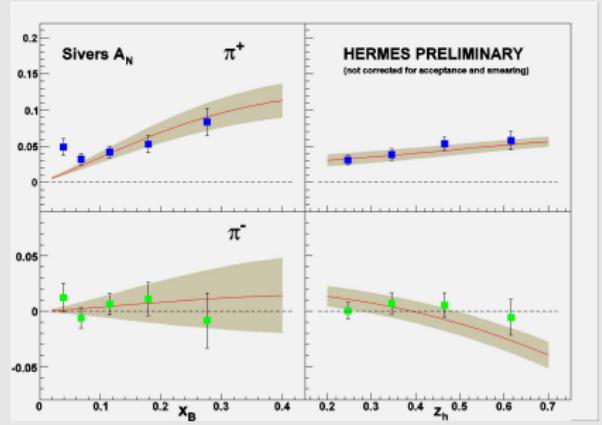


$$\Rightarrow H_{1,unfav}^\perp(z)/H_{1,fav}^\perp(z) \sim -1 !$$

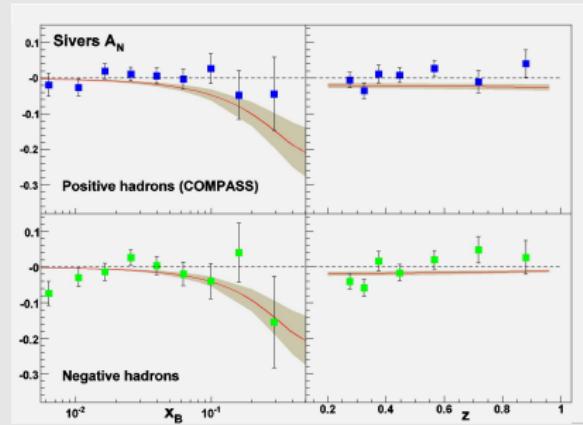
# Sivers Functions from Data (hep-ph/0507266)

Assume:  $f_{1T,u}^\perp(x) = S_u x(1-x)u(x)$ ,  $f_{1T,d}^\perp(x) = \frac{S_d}{S_u} f_{1T,u}^\perp(x)$

Fit of HERMES data



Comparison to COMPASS data



$$\Rightarrow S_u \sim -0.81, S_d \sim 1.86 !$$

High flavor dependence of Sivers functions

# Collins and Sivers Asymmetries Exp. Status

	Collins					Sivers				
	$\pi^+$	$\pi^-$	$K^+$	$K^-$	$h^\pm$	$\pi^+$	$\pi^-$	$K^+$	$K^-$	$h^\pm$
p	0.04	-0.06	0	0		0.06	0	0.1	0	
d				0					0	0

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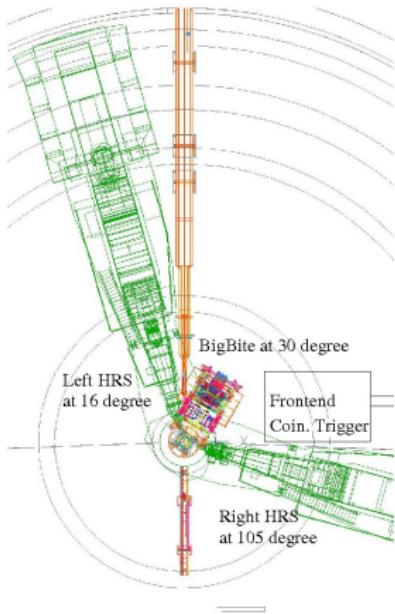
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⇒ Opportunity in Hall A @ JLab

E-06-010 (ex E-03-004) and E-06-011 / 29 PAC days

SSA in SIDIS  ${}^3He^\uparrow(e, e'\pi^\pm)X$  (and  $K^\pm$ )

# Hall A Experimental Setup for Transversity



Beam

6 GeV,  $15 \mu\text{A}$   $e^-$  (target limit)

Target

${}^3\text{He}$ ,  $50 \text{ mg/cm}^2$ ,  $\sim 42\%$  polar./ $15 \div 20 \text{ min}$   
trasversely polarized, tunable direction

Electron Detection: BigBite

$E' = 0.8 \div 1.9 \text{ GeV}$ ,  $\theta = -30^\circ$ ,  $\Delta\Omega = 64 \text{ msr}$

Charged Hadron Detection: HRS Left

$P_h = 2.4 \text{ GeV/c}$ ,  $z \sim 0.5$ ,  $\theta = 16^\circ$ ,  $\pi/K$  ID

Luminosity Monitor (Lumis fro HAPPEX)

Lumi up - Lumi down  $\sim 5 \times 10^{-5}$

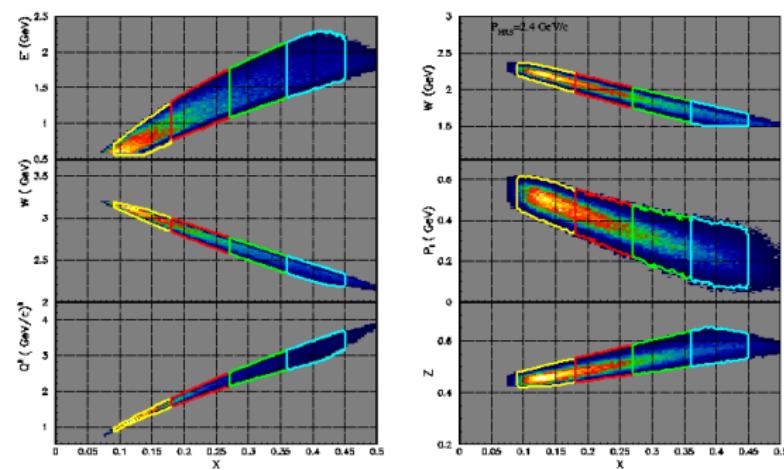
## Choice of the kinematics

- Largest invariant mass achievable at 6 GeV beam:  $W > 2.33$  GeV
- Detect hadron at  $z \sim 0.5$  (current fragmentation favored)
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**Phase Space Coverage** one setup covers four  $x$ -bins:

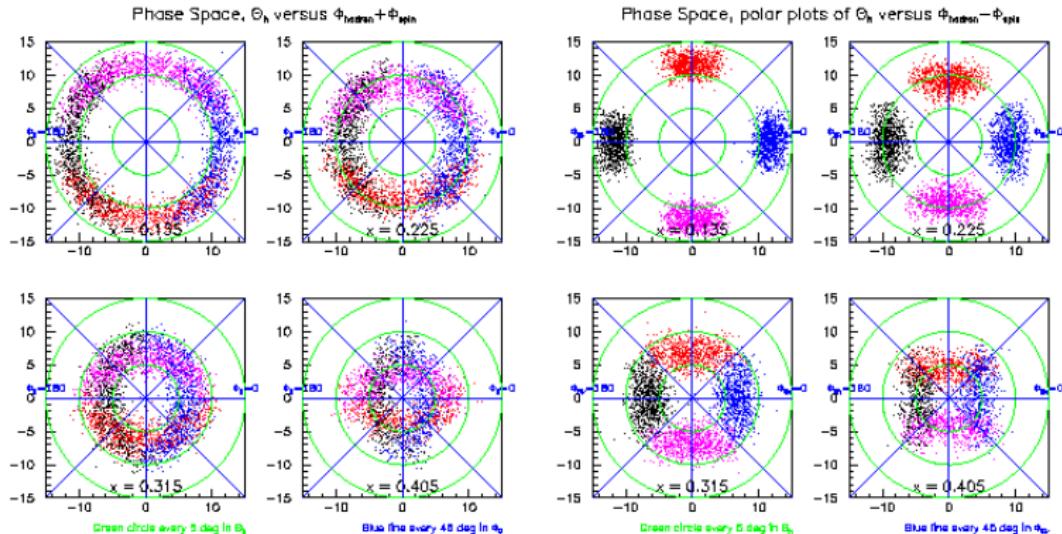


One BigBite setting  
One HRS<sub>L</sub> setting

	JLab	HERMES
$\langle Q^2 \rangle$	2.2	2.4
$\langle z \rangle$	0.5	$\sim 0.4$
$x$	0.13-0.4	0.02-0.3

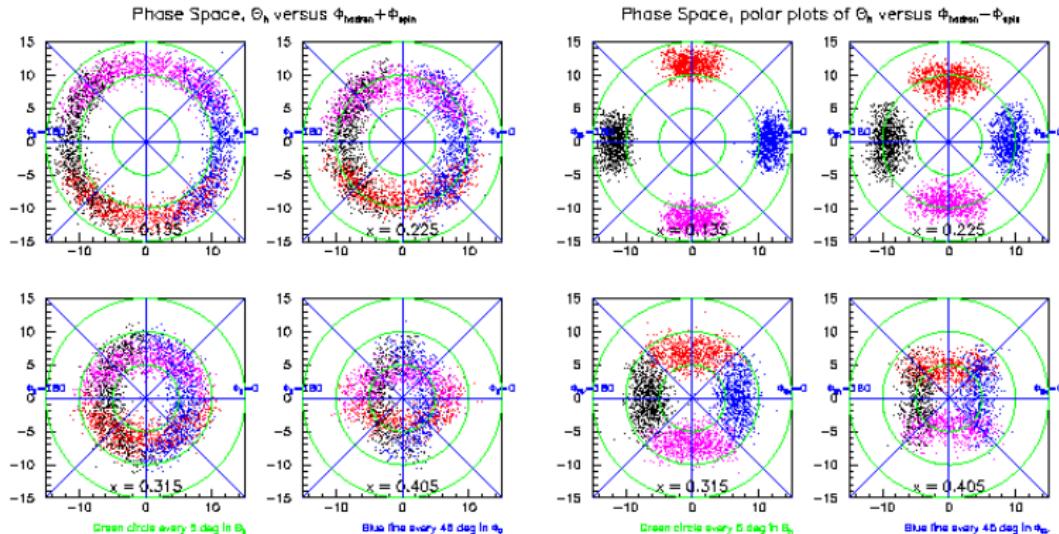
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$$\phi_{Collins} = \phi_h + \phi_S \text{ and } \phi_{Sivers} = \phi_h - \phi_S$$



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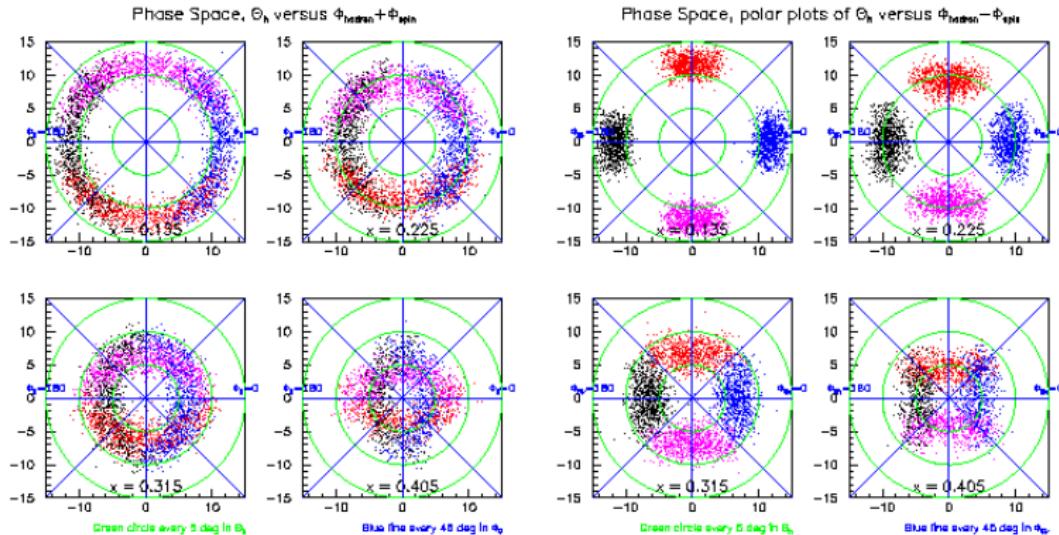
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3<sup>rd</sup> set of Helmholtz coils added for the vertical spin direction of the  ${}^3\text{He}$  target

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After online selection: few Hz

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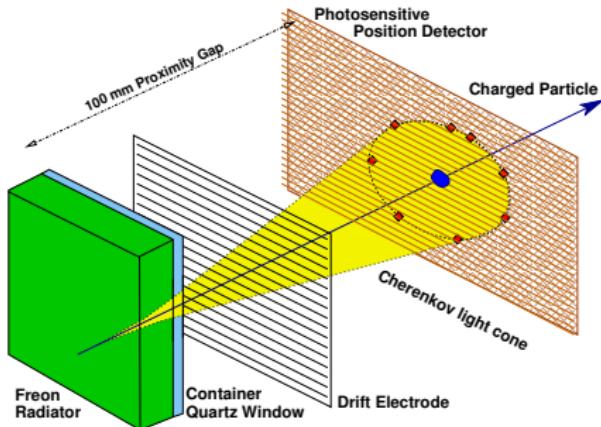
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- $\pi/K$  in hadron arm are identified by A1+A2 and independently (upgraded) RICH with rejection at  $\sim 1:1000$

# $\pi/K$ PID: Proximity Focusing RICH



Radiator

Photon converter

Position Detector

FE Electronics

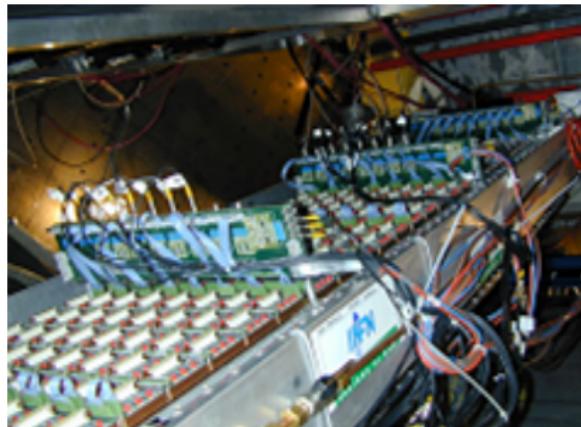
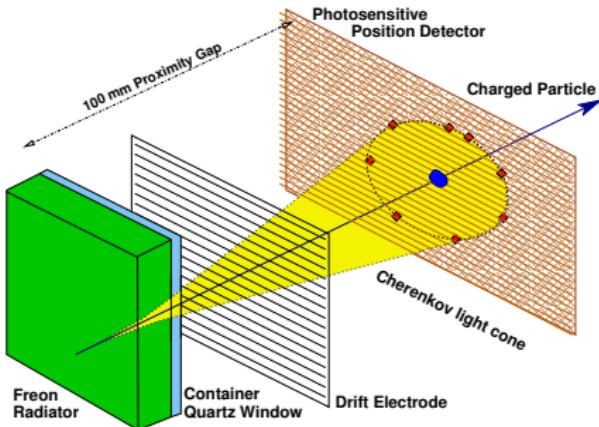
15 mm thick Liquid Freon ( $C_6F_{14}$ ,  $n=1.28$ )

300 nm CsI film coated on Pad Planes

$1940 \times 403 \text{ mm}^2$  - Multi Wire/Pad Proportional Chamber  
filled with Methane at STP, HV =  $1050 \div 1100 \text{ V}$

11520 analog chs, multiplexed S&H

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Successfully operated at 2 GeV/c in Hypernuclear Experiment with

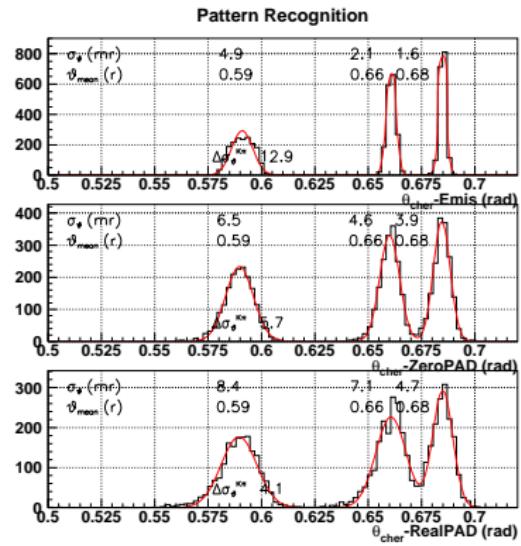
$\pi/K$  rejection < 1:1000

# RICH upgrade for 2.4 GeV/c

- add a inox frame spacer to increase the proximity gap of  $\sim 2$  cm

GEANT3 MonteCarlo prediction,  
normalized to Hypernuclear Experiment  
data

$$n_\sigma \sim 4.1 \Rightarrow \pi : K \sim 1 : 140$$



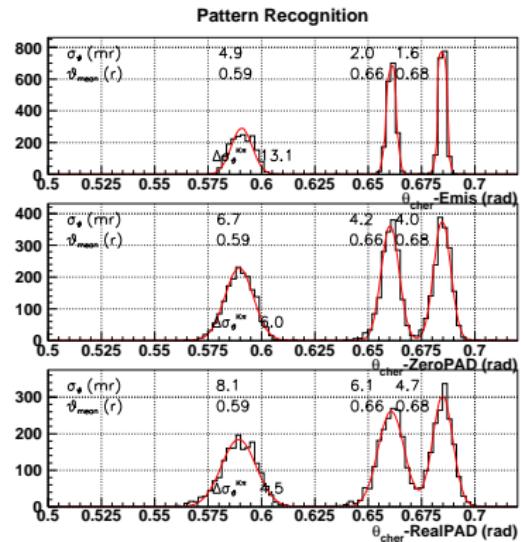
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$$n_\sigma \sim 4.4 \Rightarrow \pi : K \sim 1 : 500$$

better light collection (smaller charge  
particle phase-space)  
compatibility with A1 and A2 to be  
confirmed



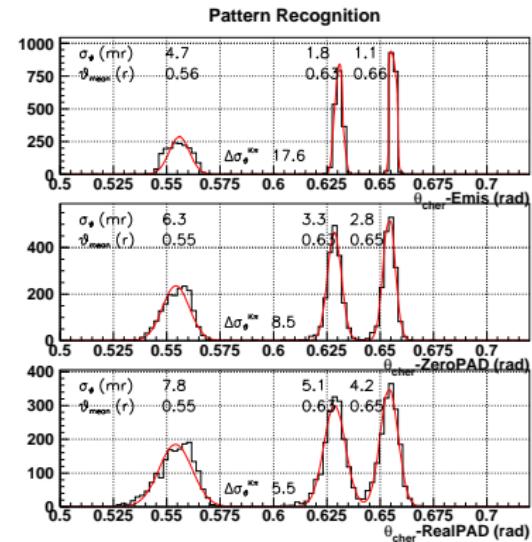
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**$C_5F_{12}$  boils at 30°C**  
**cooling system required**  
**this is the current direction of the**  
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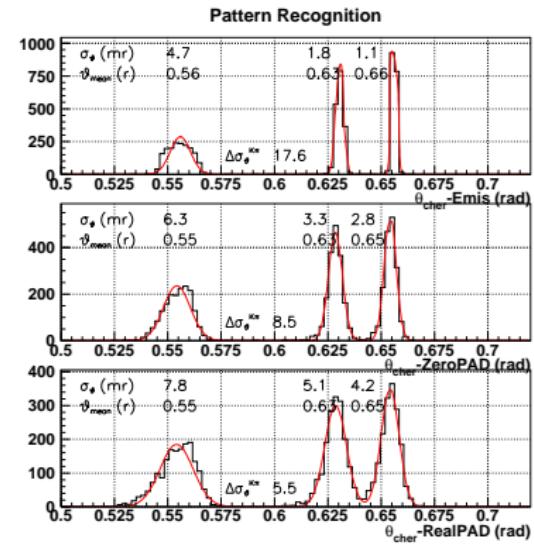
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- other options considered but rejected (cost/performance)

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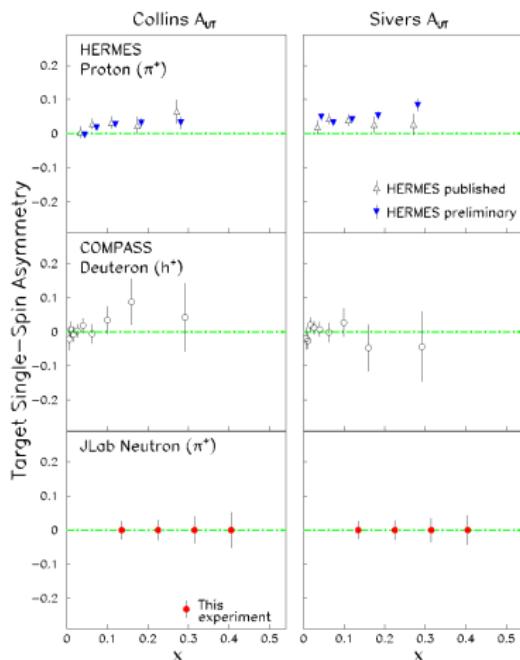
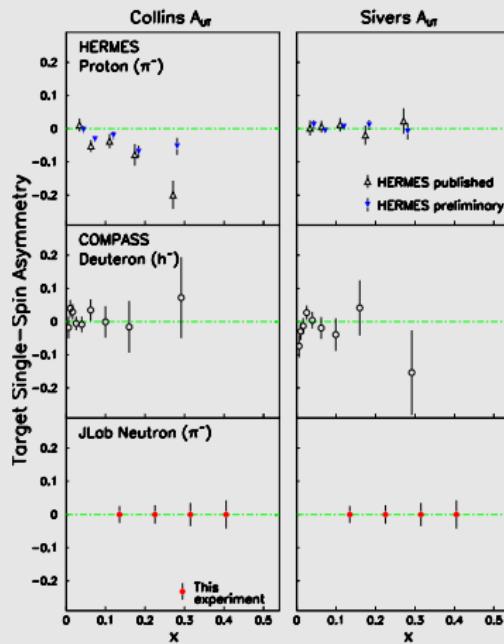
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# $A_{UT}$ Projected Performance (errors are $\sim 30\%$ larger)

Expected errors comparable to existing HERMES/COMPASS data



# Summary

- Transversity and TMD DFs and FFs are outstanding topic on nucleon structure investigation
- The Hall A facility offers a unique chance to perform the first SSA SIDIS measurements on the transversely polarized neutron, detecting  $\pi^\pm$  ( $K^\pm$ ) in the final state.
- Such measurements will provide new information, complementary to the existing data, with comparable errors (in much shorter beam time).