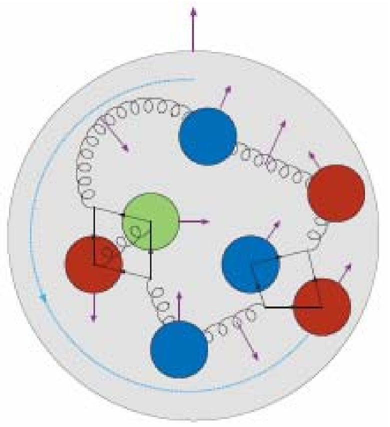
E-06-010

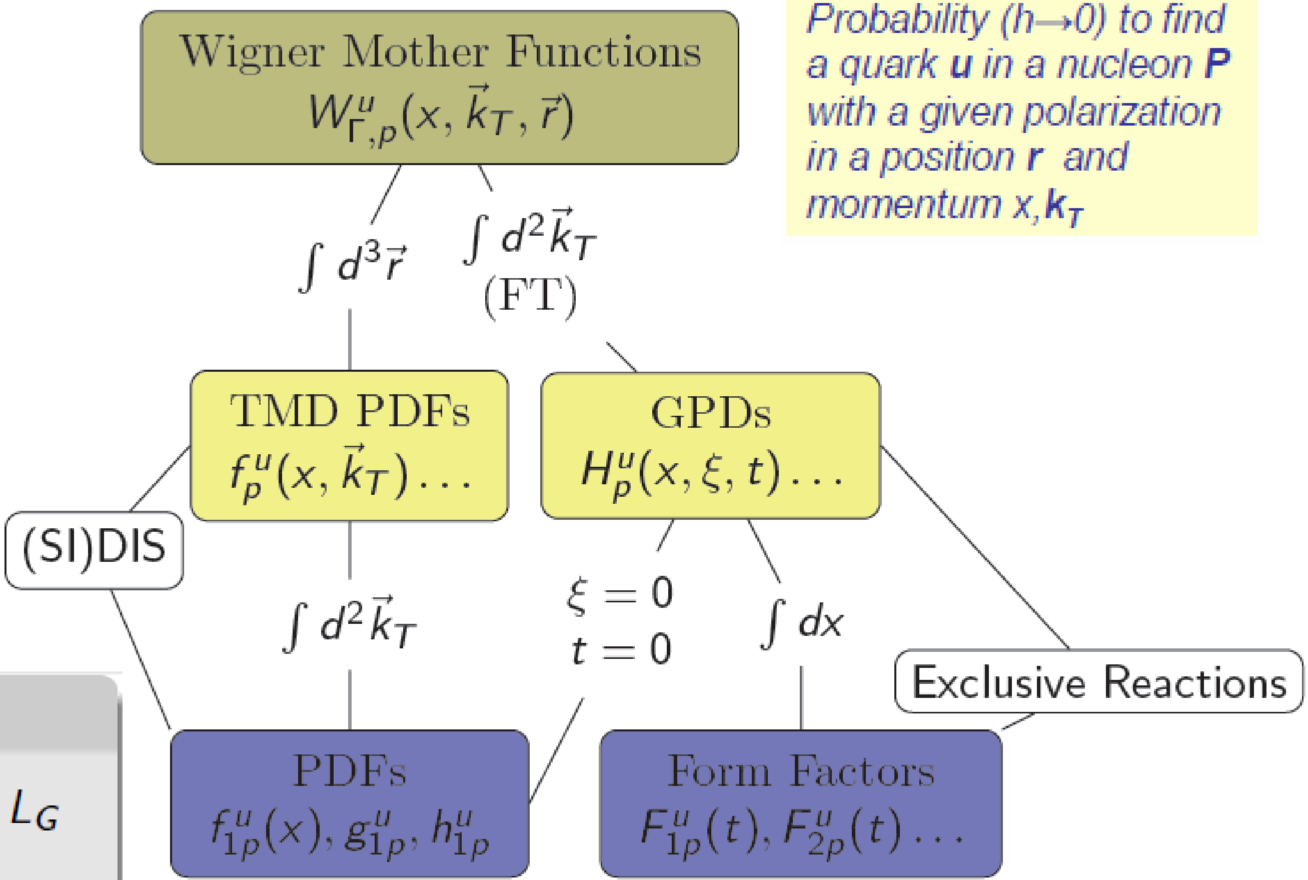
Measurement of Single Target-SpinAsymmetry in Semi-Inclusive $n^{\uparrow}(e,e'\pi)$ Reaction on a Transversely Polarized ^3He Target

E. Cisbani

http://hallaweb.jlab.org/experiment/transversity/

Struttura del nucleone





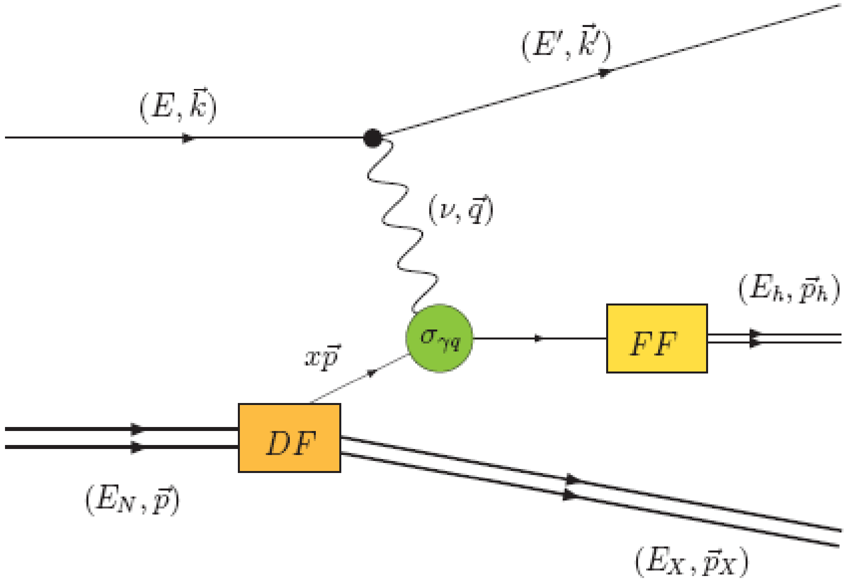
*Probability (h→0) to find a quark **u** in a nucleon **P** with a given polarization in a position **r** and momentum x,$\mathbf{k_T}$*

In termini di spin J_z^N ?

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_G$$

$\Delta\Sigma$: quark spin fraction
ΔG: gluon spin fraction
$L_q + L_G$: angular momentum

(Polarized) Deep Inelastic Scattering



Variabili cinematiche **Regione DIS**

$Q^2 = -(\nu, \vec{q})^2 \quad \gg M^2$

$\nu \overset{lab}{=} E - E' \quad \gg M$

$x = Q^2/(2M\nu) \quad$ finito

$z = E_h/\nu$

scale	lepton probe	strong interaction
space	$\hbar/|\vec{q}| \sim 10^{-2}$ fm	$R_N \sim 1$ fm
time	$\hbar/\nu \sim 10^{-25}$ s	$R_N/c \sim 10^{-24}$ s

Factorization Theorem

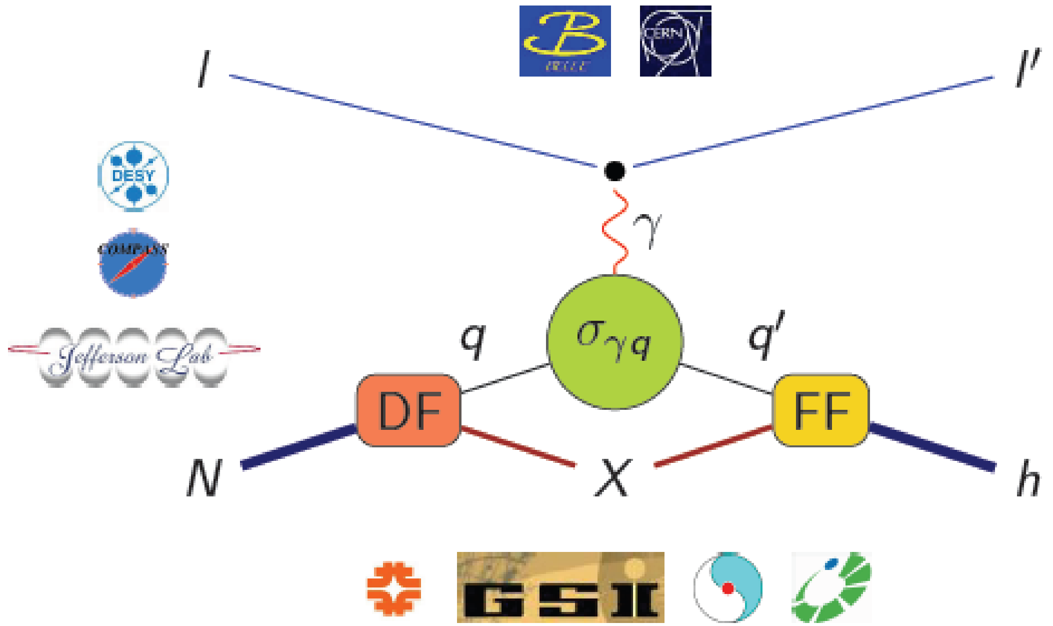
$$\sigma(lN \to lhX) \sim \sum_q e_q^2 \cdot DF_q(x) \otimes \sigma_{lq} \otimes FF_{q\to h}(z)$$

DF_q: quark distribution function

$FF_{q\to h}$: quark fragmentation function (solo per h rivelato)

- Natura universale: intervengono anche in altri processi
- Osservabili: debbono essere invarianti di gauge

Semi Inclusive Deep Inelastic Processes / Factorization and Universality



Q^2	γ 4-momentum
x	q long. mom. fraction
$k_\perp$	q trans. momentum
$K_\perp$	q' trans. momentum
z	h energy fraction
$P_{h\perp}$	h trans. momentum

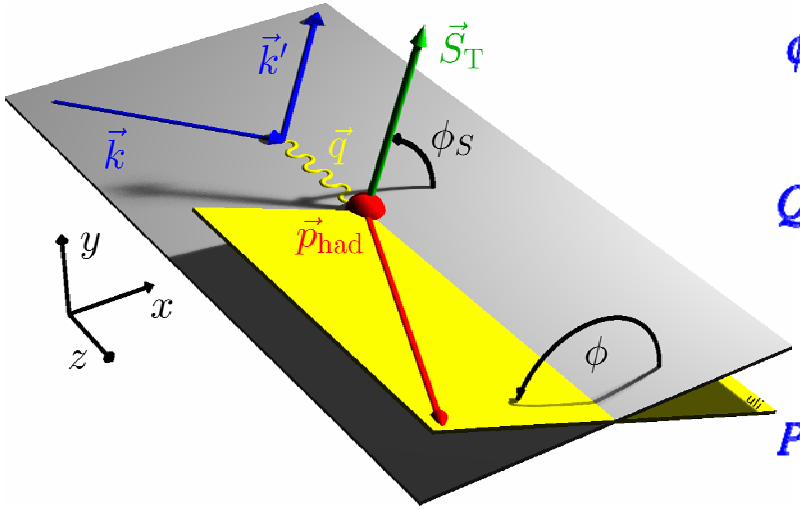
Long: $\parallel$ to γ
Trans: $\perp$ to γ

Nucleon/Hadron description at lowest twist

N \ q	U	L	T		h: U	L	T	q
U	$f_1(x)$		$h_1^\perp(x,k_\perp)$	$\otimes$	$D_1(z)$		$D_{1T}^\perp(z,K_\perp)$	U
L		$g_1(x)$	$h_{1L}^\perp(x,k_\perp)$			$G_1(z)$	$G_{1T}(z,K_\perp)$	L
T	$f_{1T}^\perp(x,k_\perp)$	$g_{1T}(x,k_\perp)$	$h_1(x), h_{1T}^\perp(x,k_\perp)$		$H_1^\perp(z,K_\perp)$	$H_{1L}^\perp(z,K_\perp)$	$H_1(z), H_{1T}^\perp(z,K_\perp)$	T

SIDIS cross section linear combination of convolutions of DF's and FF's, modulated by sin/cos of azimuthal angles

Method: from SIDIS to SSA to DF⊗FF



- ϕ_S Target spin azimuthal angle relative to virtual photon
- x Fractional long. momentum of the parton
- Q^2 Negative squared 4-momentum transfer
- ϕ Hadron azimuthal angle relative to virtual photon
- z Fractional energy of the observed hadron
- $P_\perp$ Hadron momentum perp. to photon direction

$$A_{UT} \equiv \frac{1}{|S_T|}\frac{d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S) + d\sigma(\phi,\phi_S+\pi)} = \frac{1}{|S_T|}\frac{d\sigma_{UT}}{d\sigma_{UU}}$$

$$d\sigma_{UT} = |S_T|\left([\delta q \otimes H_1^\perp]\sin(\phi+\phi_S)\right.$$ **Collins**

$$+[f_{1T}^\perp \otimes D_1]\sin(\phi-\phi_S)$$ **Sivers**

$$\left.+[h_{1T}^\perp \otimes H_1^\perp]\sin(3\phi-\phi_S) + O(1/Q)\right)$$

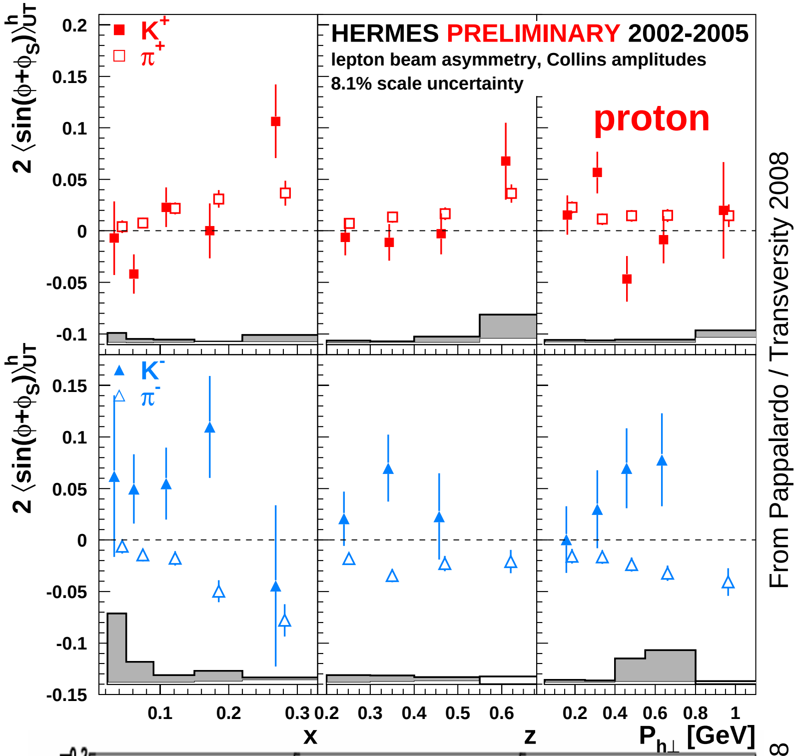
$$d\sigma_{UU} = [q \otimes D_1] + [h_1^\perp \otimes H_1^\perp]\cos 2\phi + O(1/Q)$$

where: $[d \otimes F] \equiv A_{d,F}\sum_q \int d^2p_T\, d^2k_T\, W_{d,F}\, d\, F$

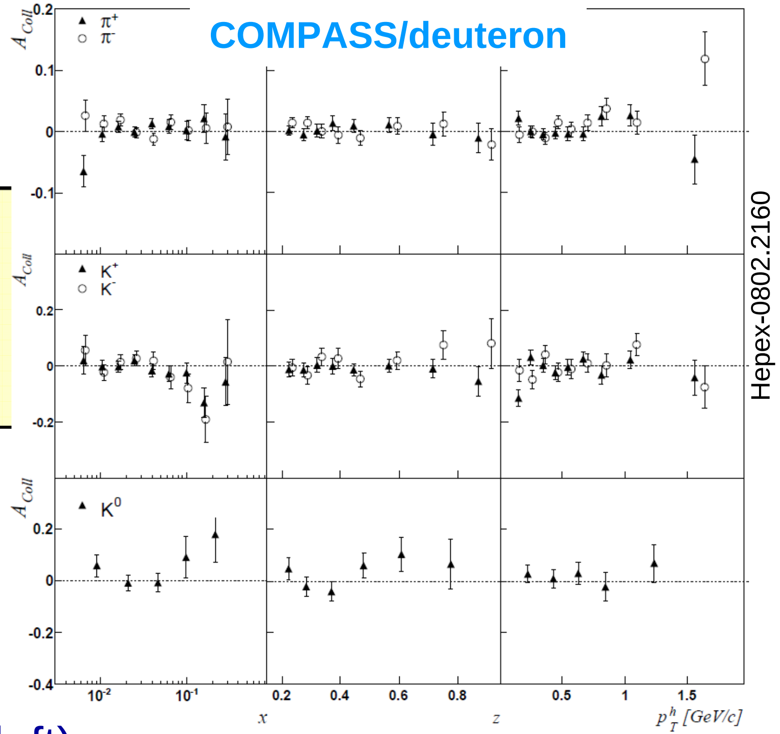
		quark		
		U	**L**	**T**
nucleon	**U**	q		$h_1^\perp$
	L		Δq	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	δq ; $h_{1T}^\perp$

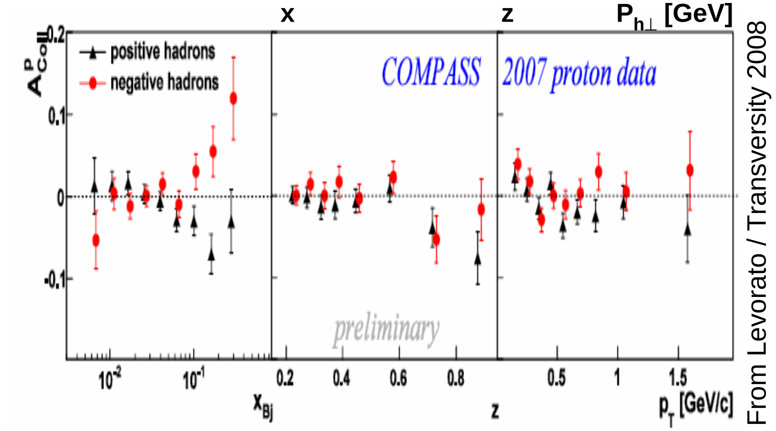
Pretzelosity

Collins Moments on proton/deuteron



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





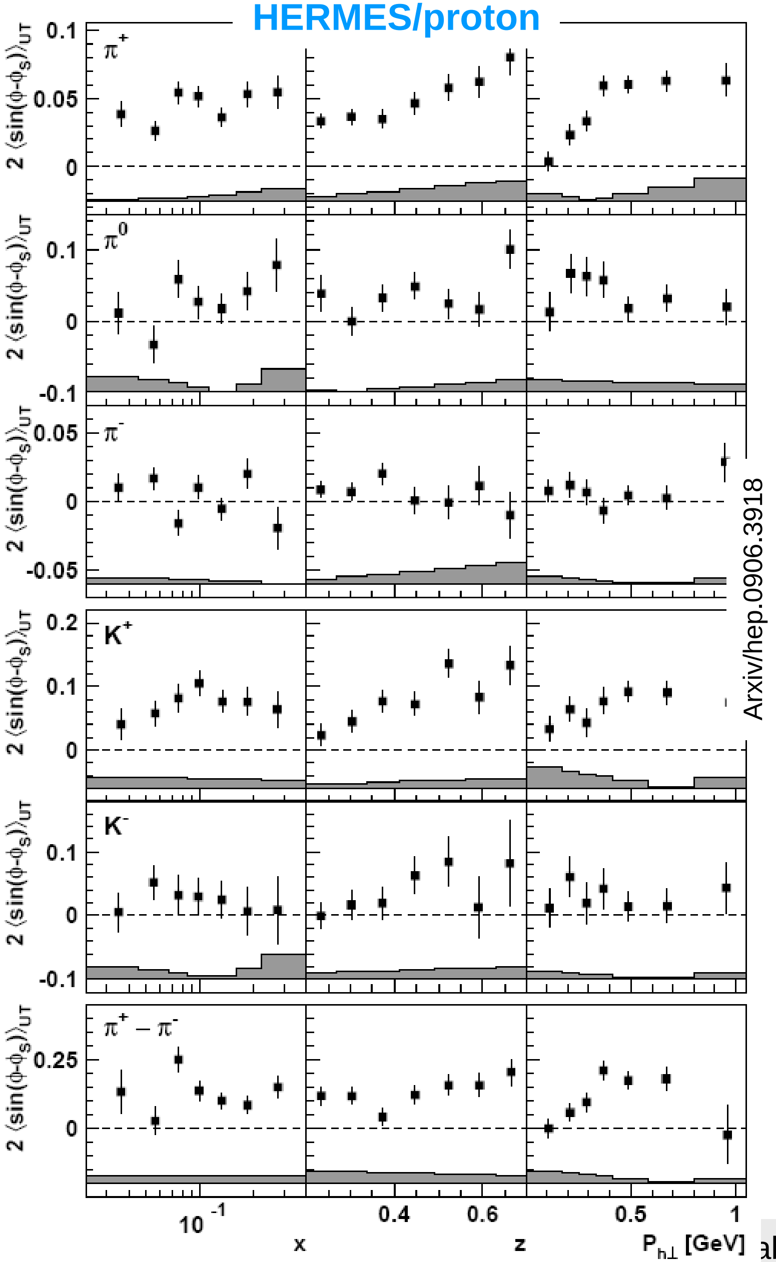
Larger effects at larger x

Proton (left)

- K- and π- with opposite sign, strong flavor dependence (but K errors significant)!
- K+ and π+ consistent with u dominance
- COMPASS compatible with HERMES

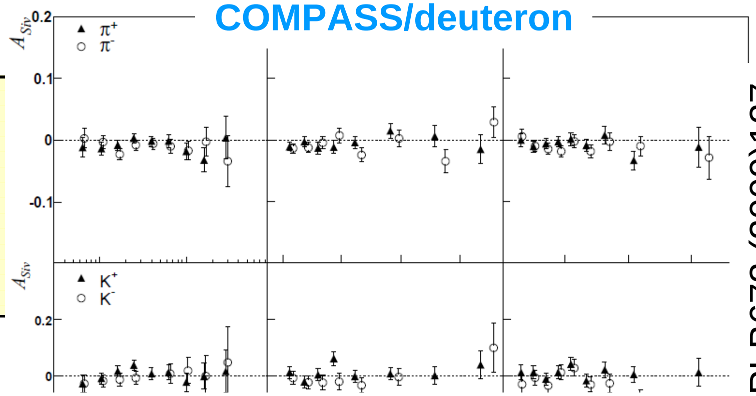
Deuteron (up): consistent with 0, expected asymmetry on neutron as large as on proton

Sivers Moments on proton/deuteron

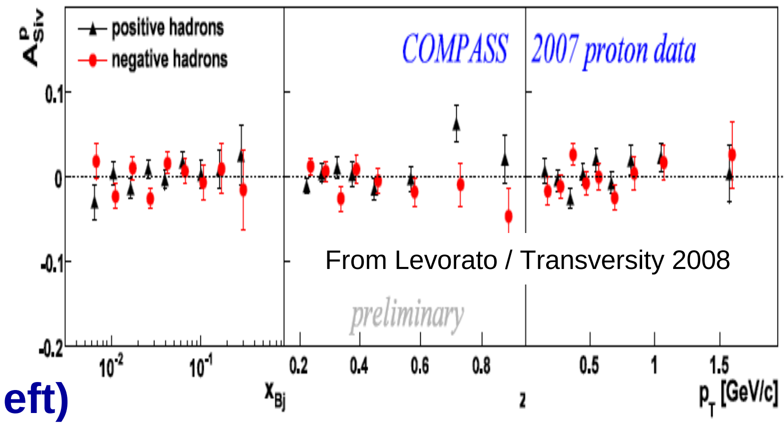


Arxiv/hep.0906.3918

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



PLB673 (2009)127



Proton (left)

- **K+ twice π+ conflict with u dominance expectation**
- **K- and π- consistent with 0**
- **COMPASS smaller than HERMES**

Deuteron (up): consistent with 0, expected asymmetry on neutron as large as on proton

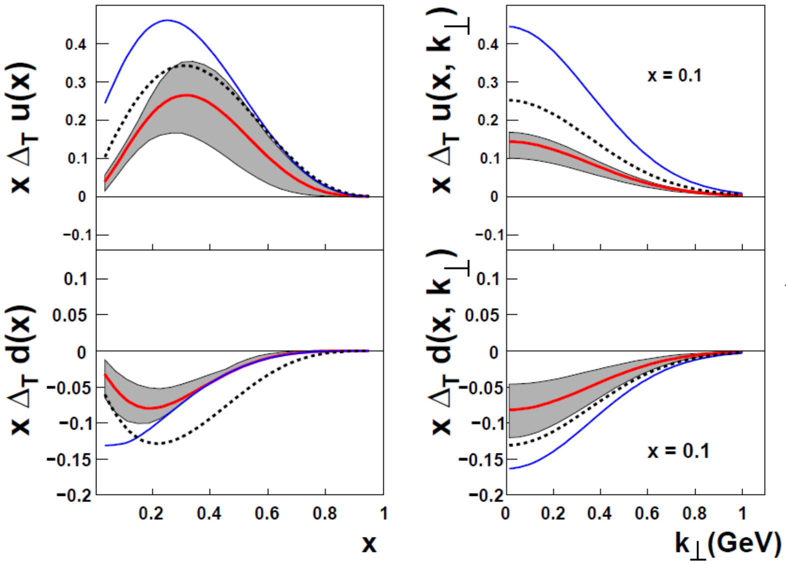
Extraction of DF and FF from a Global Fit

Transversity first moment (assume $\Delta_T$sea = 0)

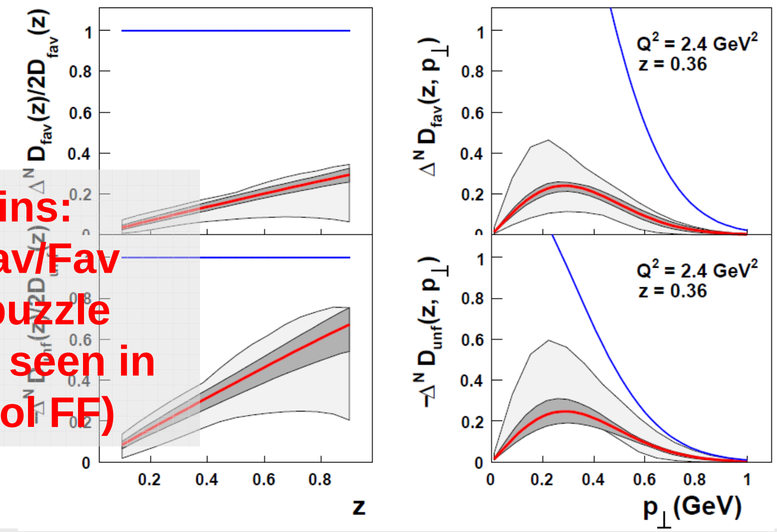
HERMES/p + COMPASS/d (Q^2~2.5 GeV^2)

e+e- from BELLE (Q^2=110 GeV^2)

Anselmino et al 12/08

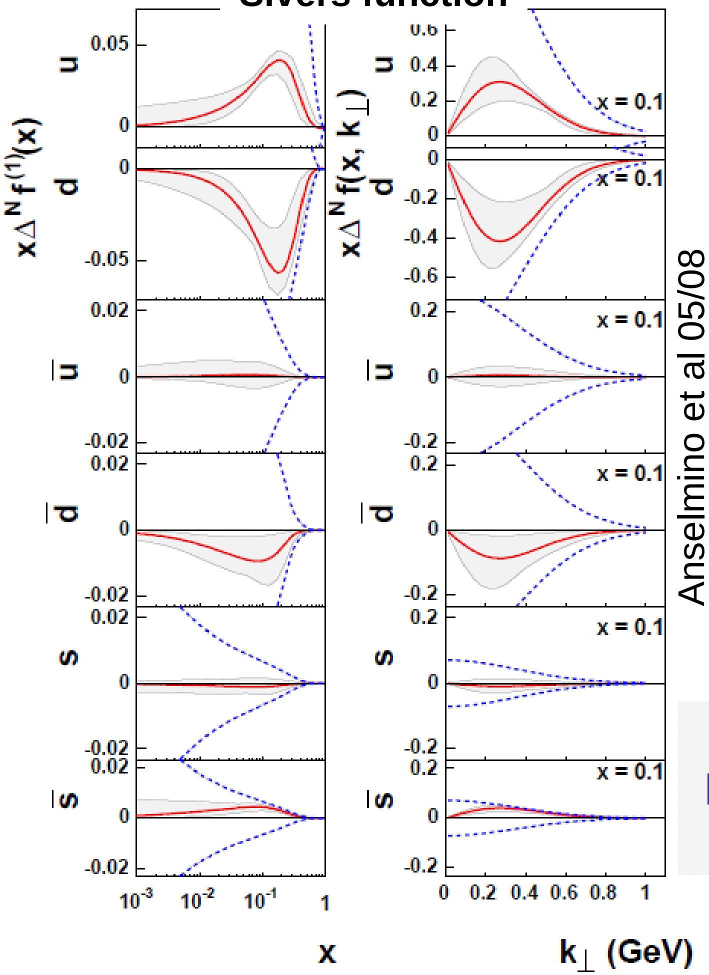


Collins Fragmentation Function



Collins: Unfav/Fav FF puzzle (not seen in Unpol FF)

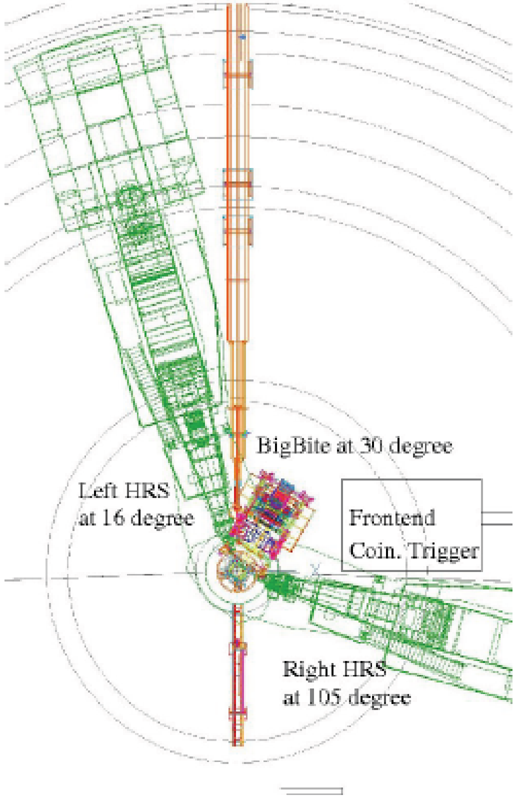
Sivers function



Anselmino et al 05/08

Sivers: large s-bar sea small

Transversity on neutron: Hall A Experimental Setup



Beam

6 GeV, 15 μA e^- (target limit)

Neutron Target

High pressure polarized ^{3}He, 50 mg/cm^2,

65% polariz./20 min, Lumi $\sim 10^{36}$/s/cm^2

Electron Detection: BigBite

$E' = 0.8 \div 1.9$ GeV, $\theta = 30^o$, $\Delta\Omega \sim 64$ msr

Hadron Detection: HRS Left

$P_h = 2.4$ GeV/c, $\theta = -16^o$, $\Delta\Omega \sim 6$ msr

π/K ID

Data taking

$\sim$ 30 beam days,
Oct-Dec 2008

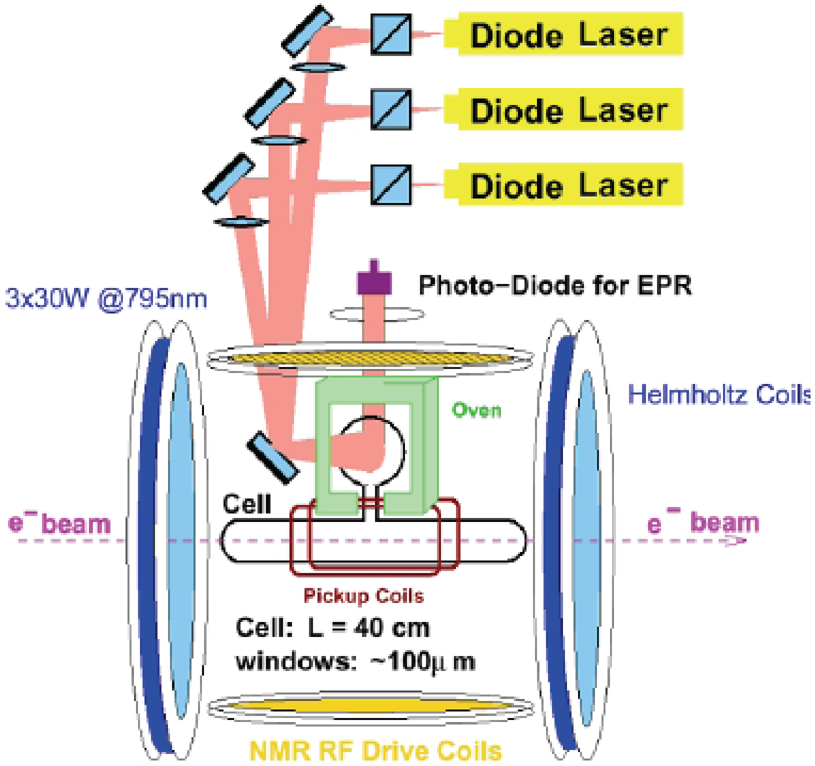
Kinematic Region

$\langle Q^2 \rangle = 2.2$ GeV^2, $x = 0.13 \div 0.4$, $z \sim 0.5$

More info:

http://hallaweb.jlab.org/experiment/transversity/

Polarized 3He Target

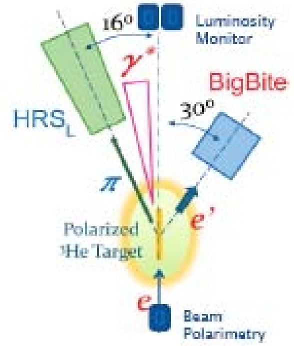


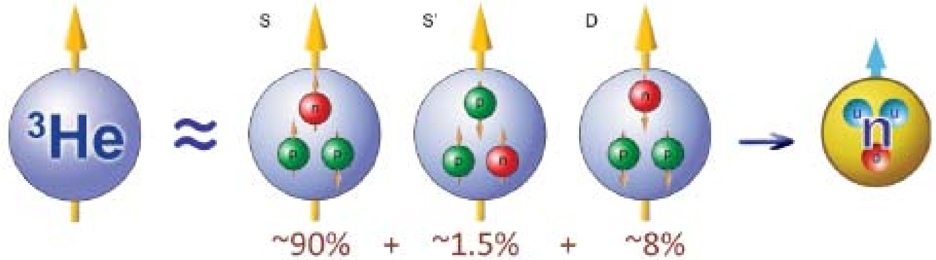
- Optically pumped Rb-K vapor polarizes ^{3}He nuclei by spin-exchange
- Polarization $\sim$ 45% (with beam) (along 3 directions)
- $<$ 4% relative polarization uncertainty (NMR and EPR polarimeter)

One more set of holding coil added for vertical polarization

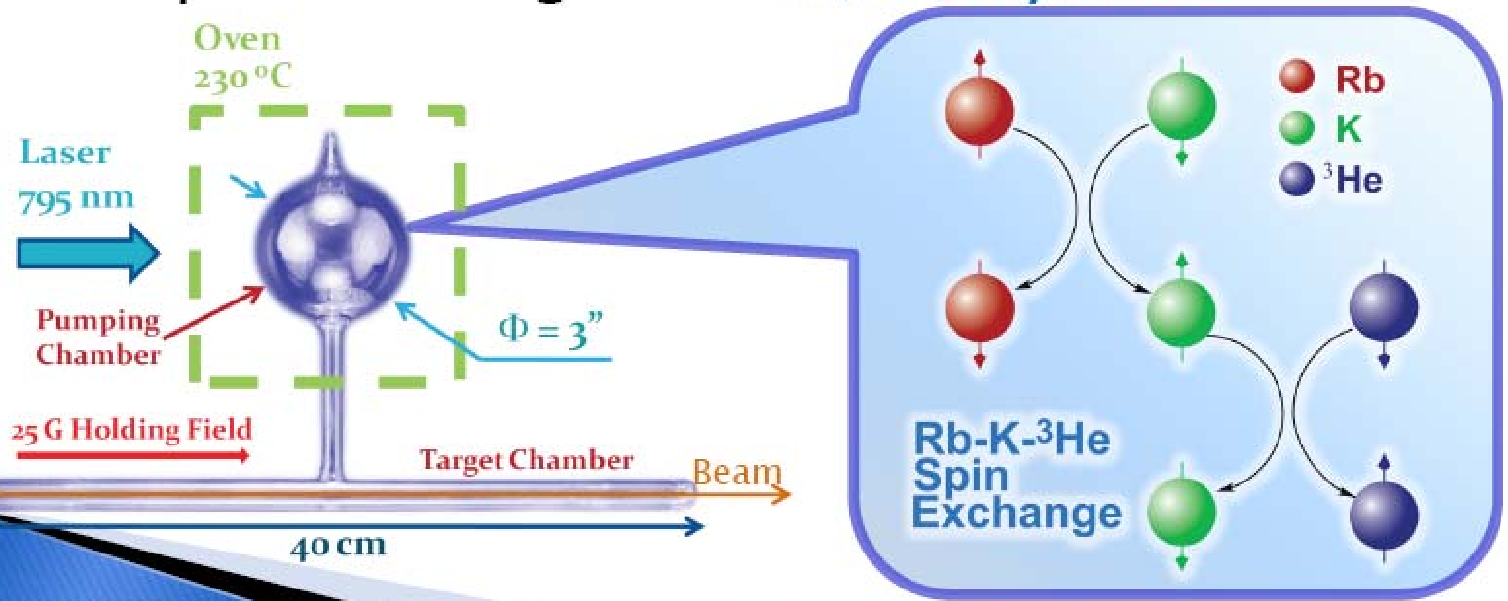
Near future: improve density for the 12 GeV era (metallic cell and two cell-target exchange tubes)

Polarized ^{3}He Target



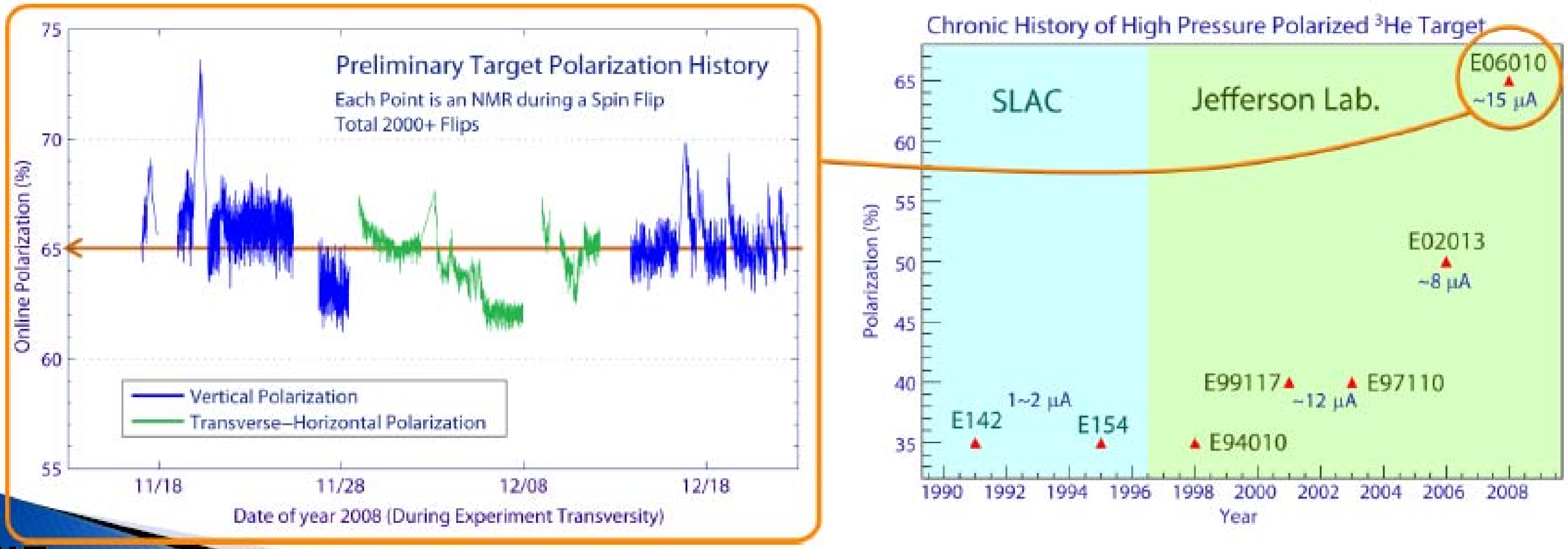
- 

- New narrow bandwidth COMET lasers
- Fast spin exchange with K/Rb hybrid cells



Performace of ^{3}He Target

- High luminosity: $L(n) = 10^{36}$ cm^{-2} s^{-1}
- Record high 65% polarization (preliminary) with automatic spin flip / 20min

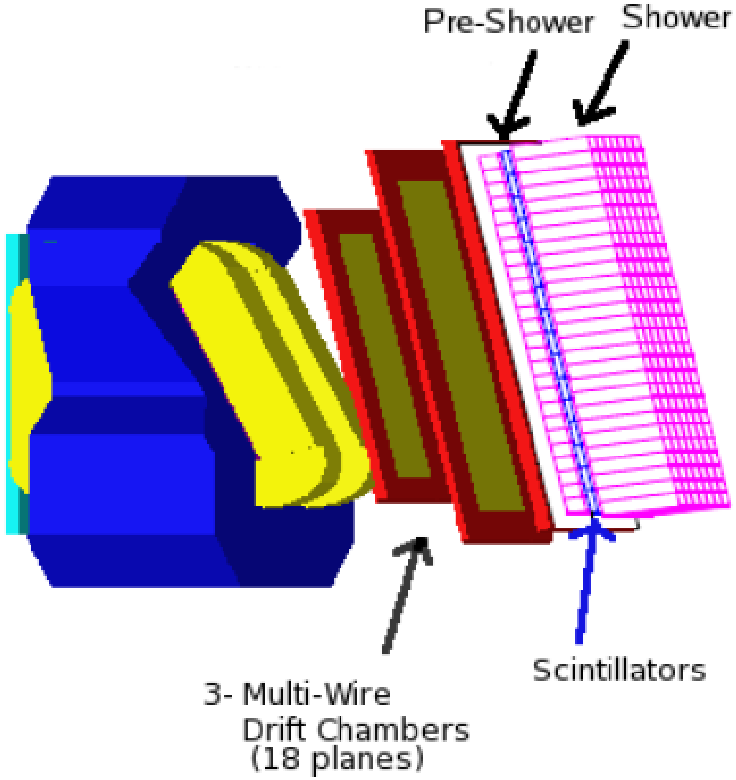


Jefferson Lab

Jin Huang <jinhuang@mit.edu> 2009 APS DNP Meeting 9

BigBite Spectrometer

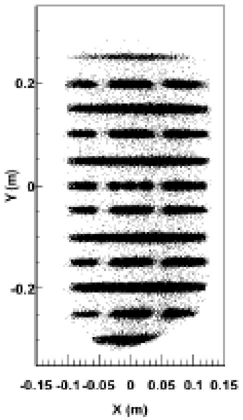
- Single dipole magnet.
- Detect scattered electrons
- 30^0 to the beam right
- Acceptance: $\Delta\Omega \simeq 64$ msr
- Momentum range: p = 0.8 GeV/c - 2.0 GeV/c
- 3 Wire chambers for precise momentum reconstruction
- Scintillator plane for timing
- Preshower and Shower (lead-glass) for PID

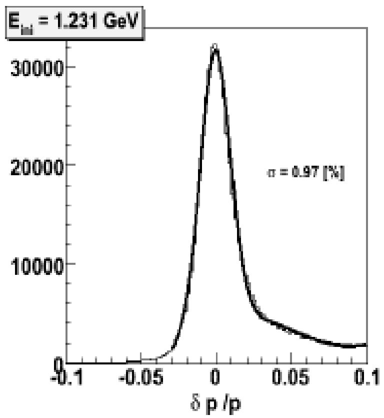


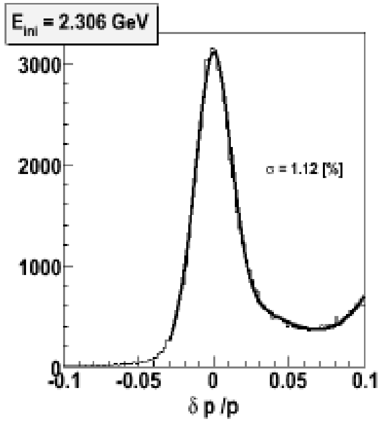
From Kalyan Allada

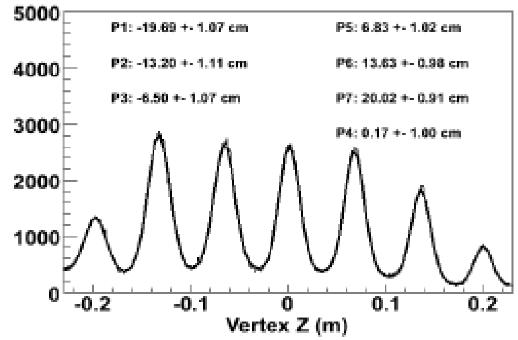
BigBite Analysis - Multi-Wire Drift Chambers

- Momentum reconstruction
- 1.5 inch Pb sieve-plate in front of the BigBite spectrometer
- Good reconstruction of the sieve pattern
- Vertex resolution: 1cm
- Wire chamber spacial resolution: 180 μm
- Momentum resolution $\frac{\delta p}{p} \simeq 1\%$.







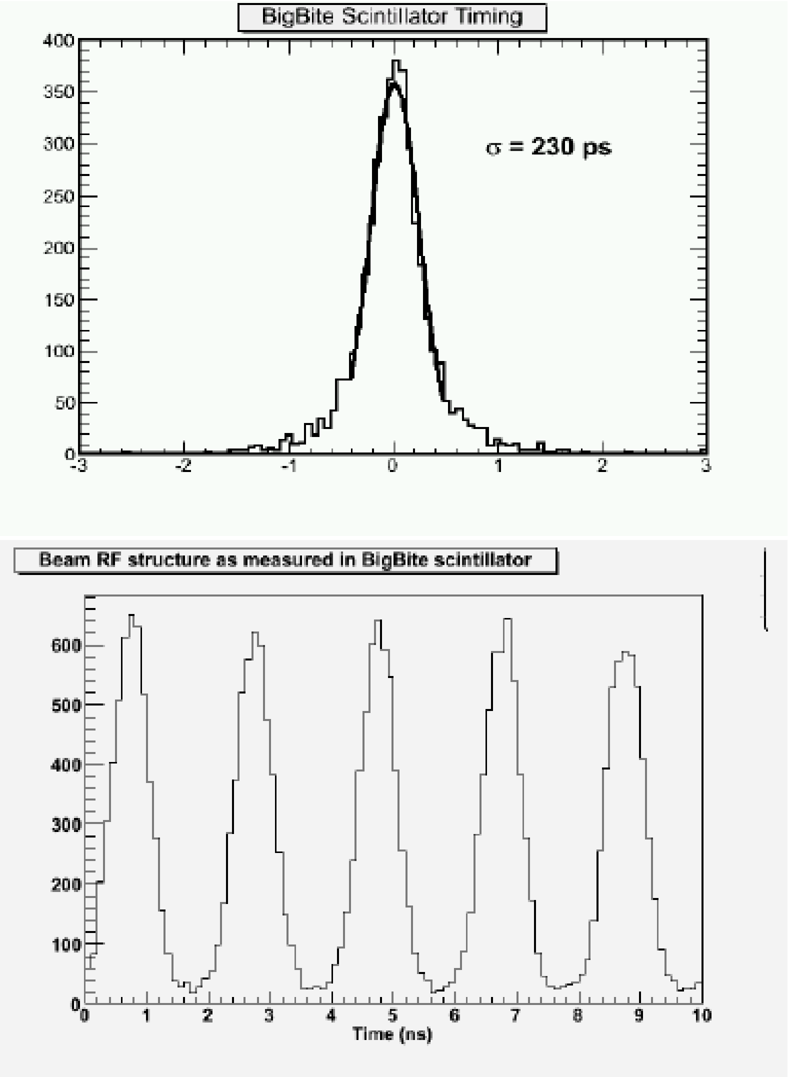


Multi-foil carbon target

From Kalyan Allada

BigBite Scintillator Plane - Timing

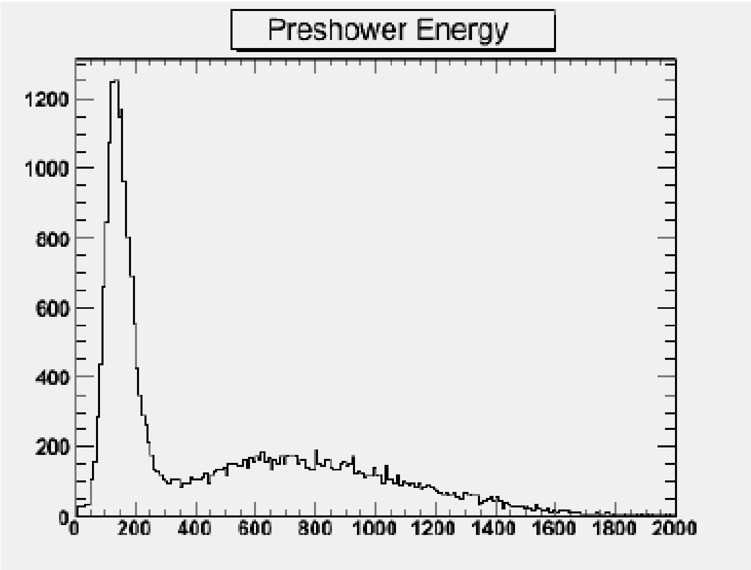
- Provides timing information, used in the coincidence TOF measurement.
- Coincidence TOF provides another handle on PID in hadron arm.
- Consists of 13 bars with two PMTs on each side.
- Good timing resolution $\sigma = 230$ ps

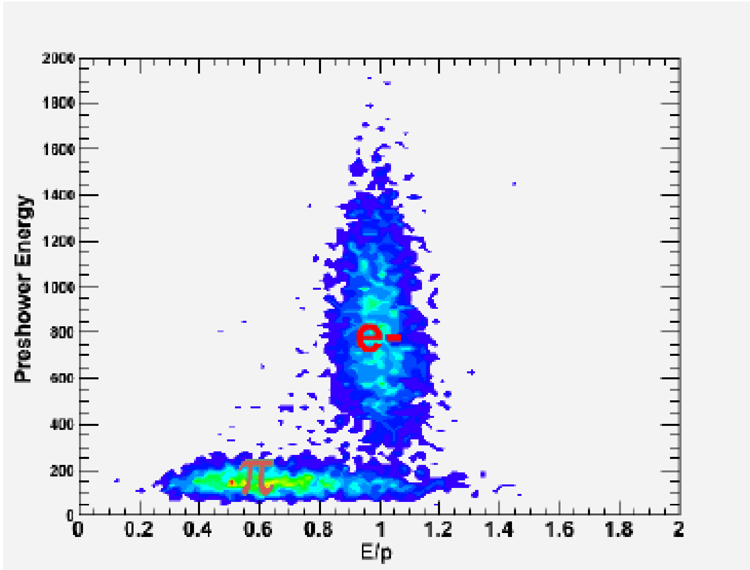


From Kalyan Allada

Pre-shower and Shower Detector - Particle Identification

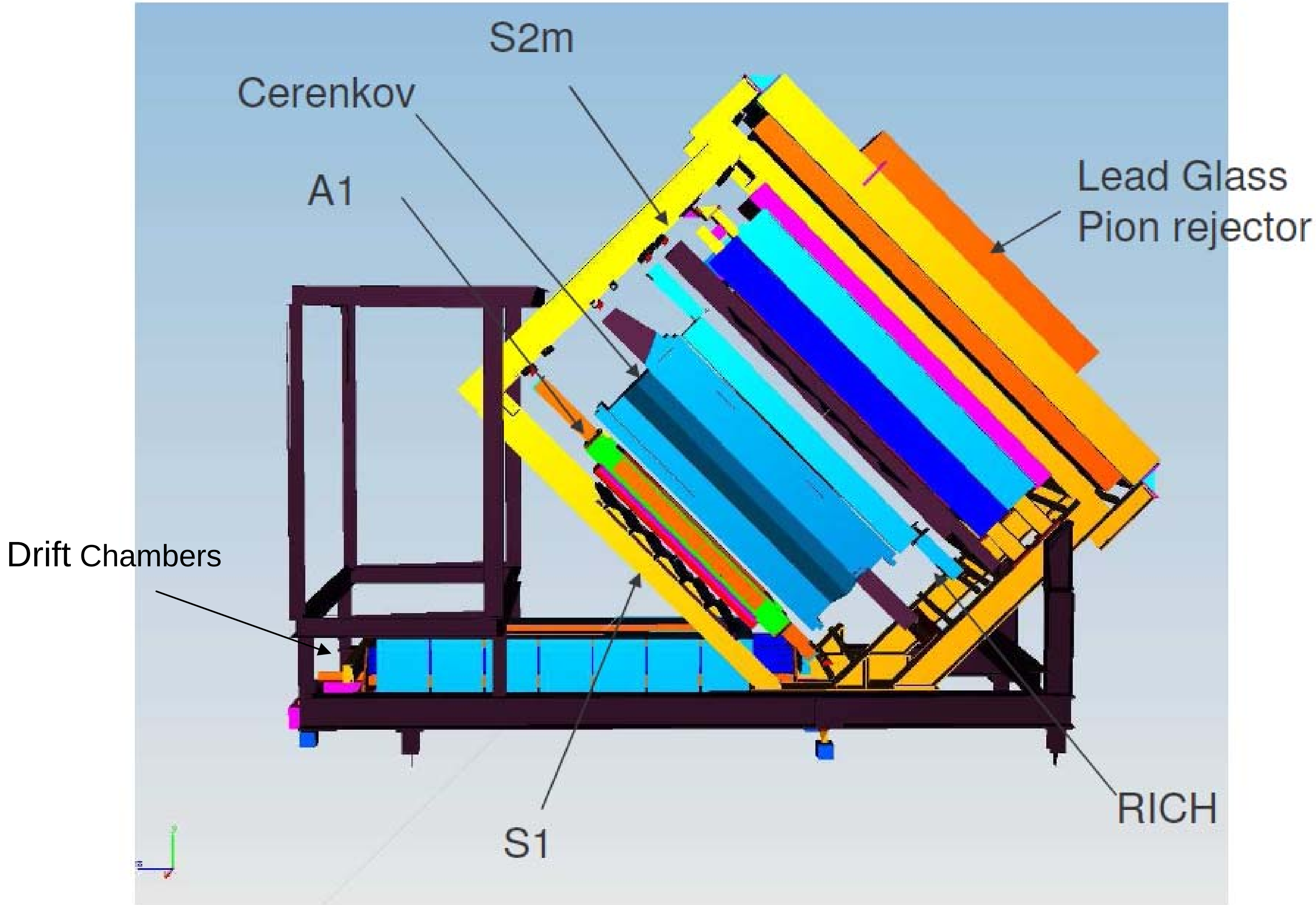
- Pions are major source of contamination.
- Well separated pions and electrons.



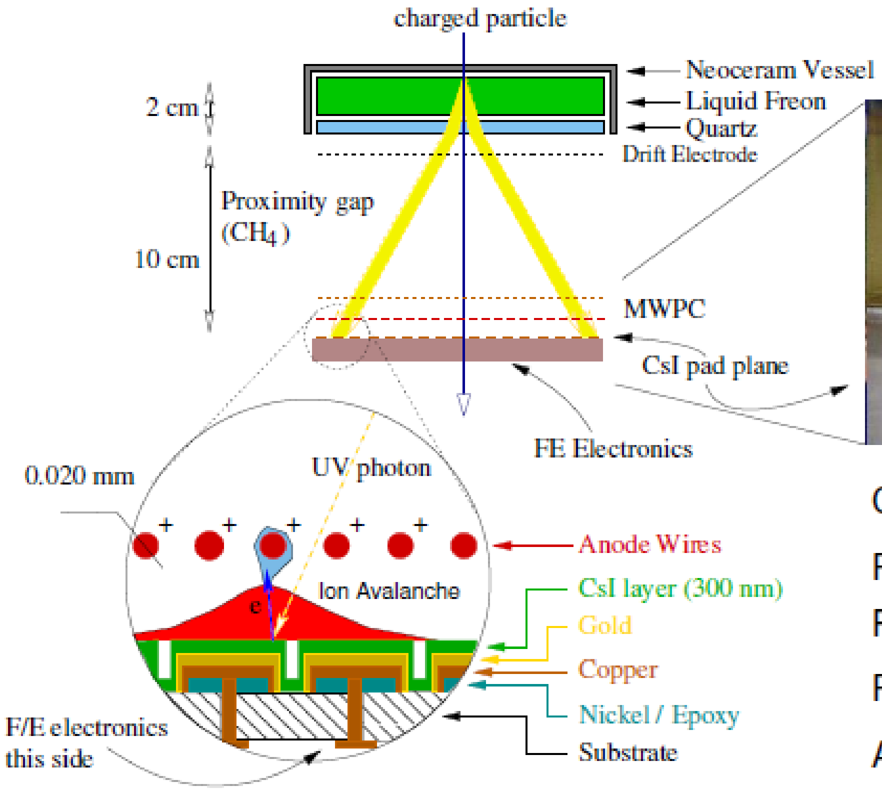


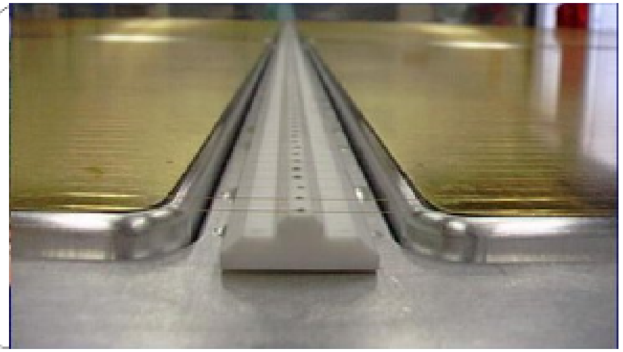
From Kalyan Allada

Apparato HRS-L



HallA RICH





CsI evaporated on 3 pad planes

Pad Plane size: 640 x 403 mm

Pad pitch: 8 x 8.4 mm

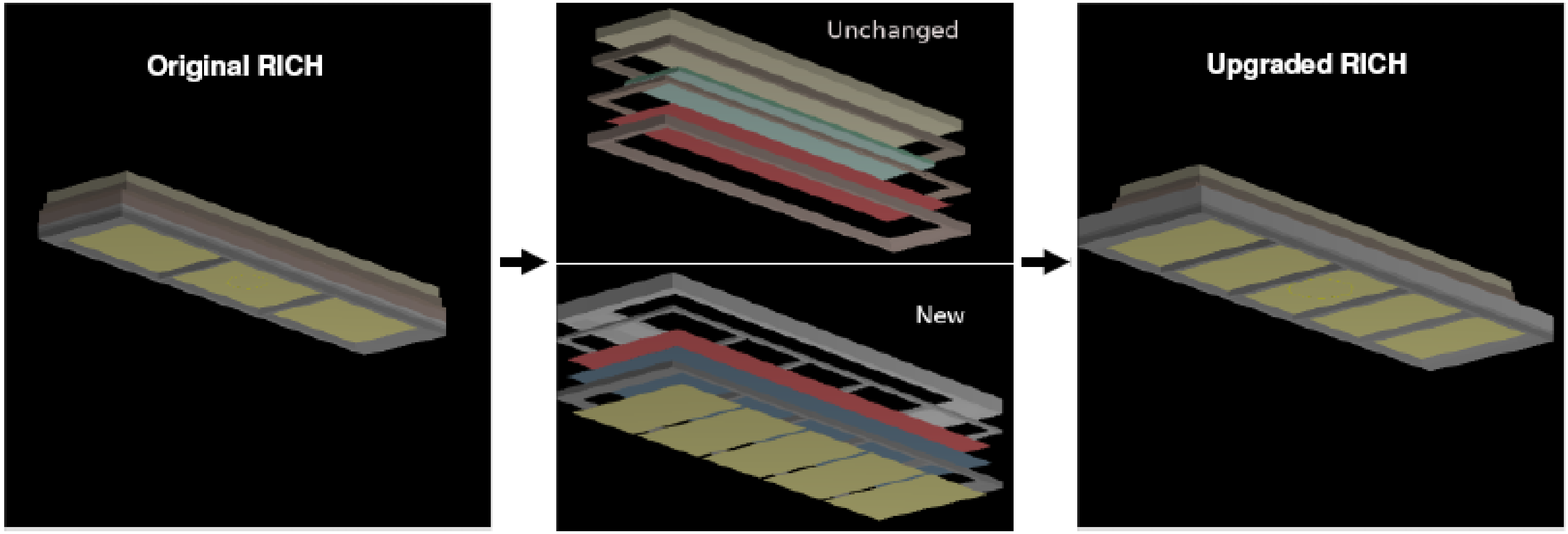
Pad to Pad gap: 35 mm

Anode–Pad distance: 2 mm

1. UV photon hits the CsI film and extracts one or more electrons
2. the induced charge of the MWPC is collected by the F/E electronics

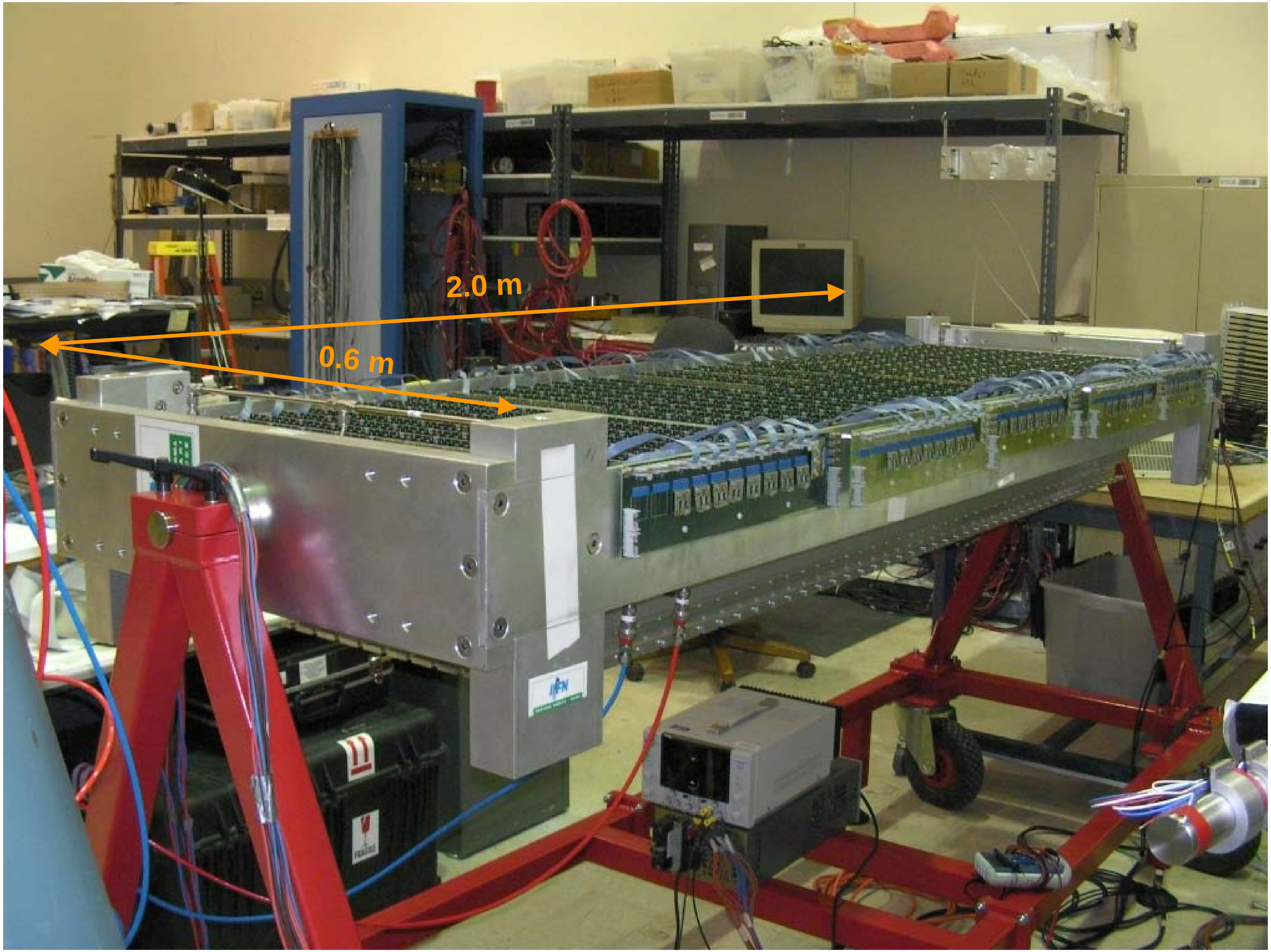
Upgraded Proximity Focusing RICH @ JLab

RICH originale utilizzato per Hypernuclei e Pentaquark



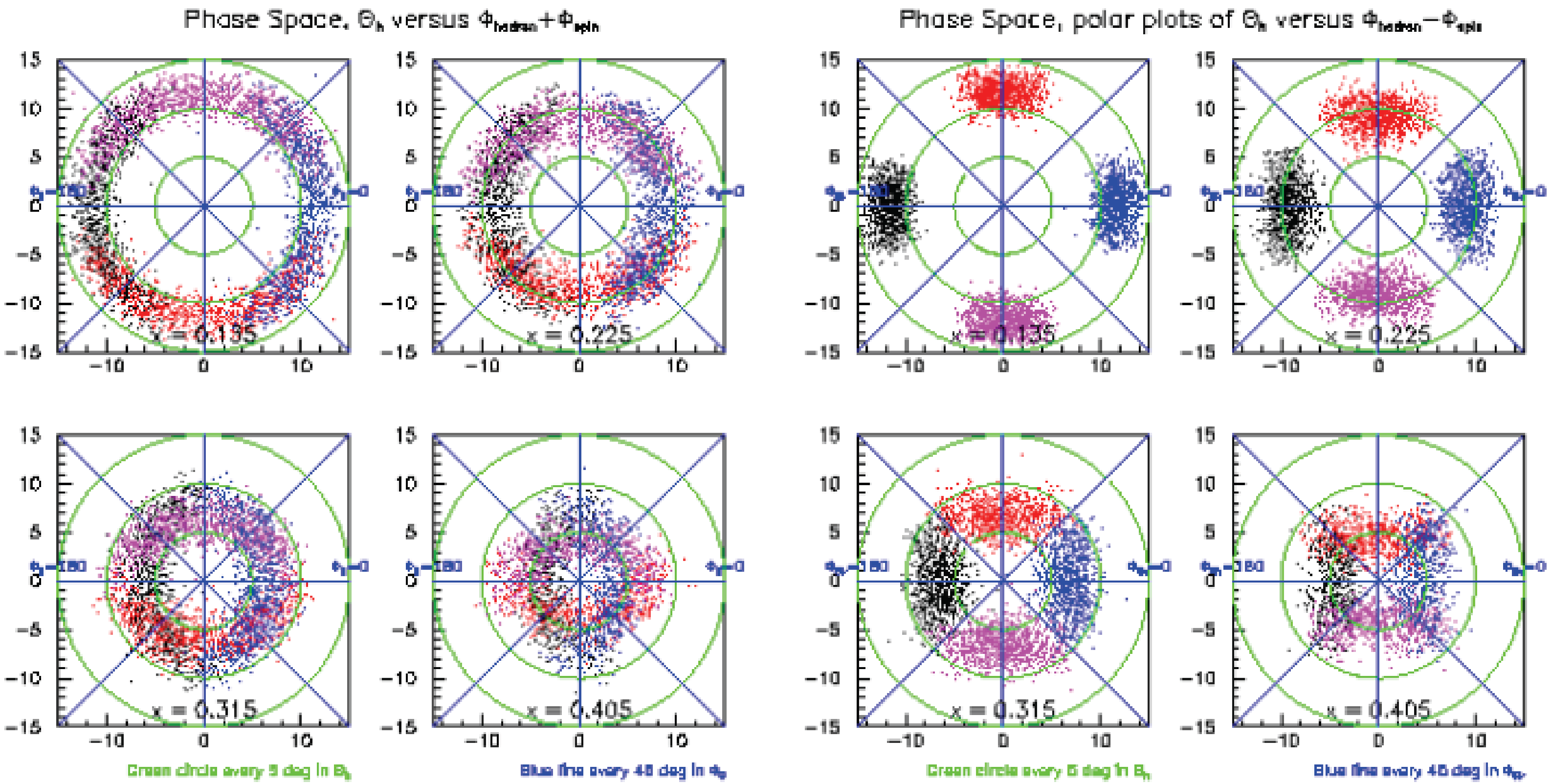
- ✔ 60% larger photon detection area (more photons collected)
- ✔ 75% longer proximity gap (smaller geometric error)

Radiator	15 mm thick Liquid Freon (C_6F_{14}, n=1.28)
Proximity Gap	100⟶ 175 mm, filled with Methane at STP
Photon converter	300 nm CsI film coated on Pad Planes
Position Detector	3⟶ 5 × pad planes = (3 × 645) × 403⟶ (5 × 403) × 645 mm^2 Multi Wire/Pad Proportional Chamber, HV= 1050 ÷ 1100 V
Pad Plane	403.2 × 640 mm^2 (single pad: 8.4 × 8 mm^2)
FE Electronics	11520⟶ 19200 analog chs, multiplexed S&H


2.0 m
0.6 m

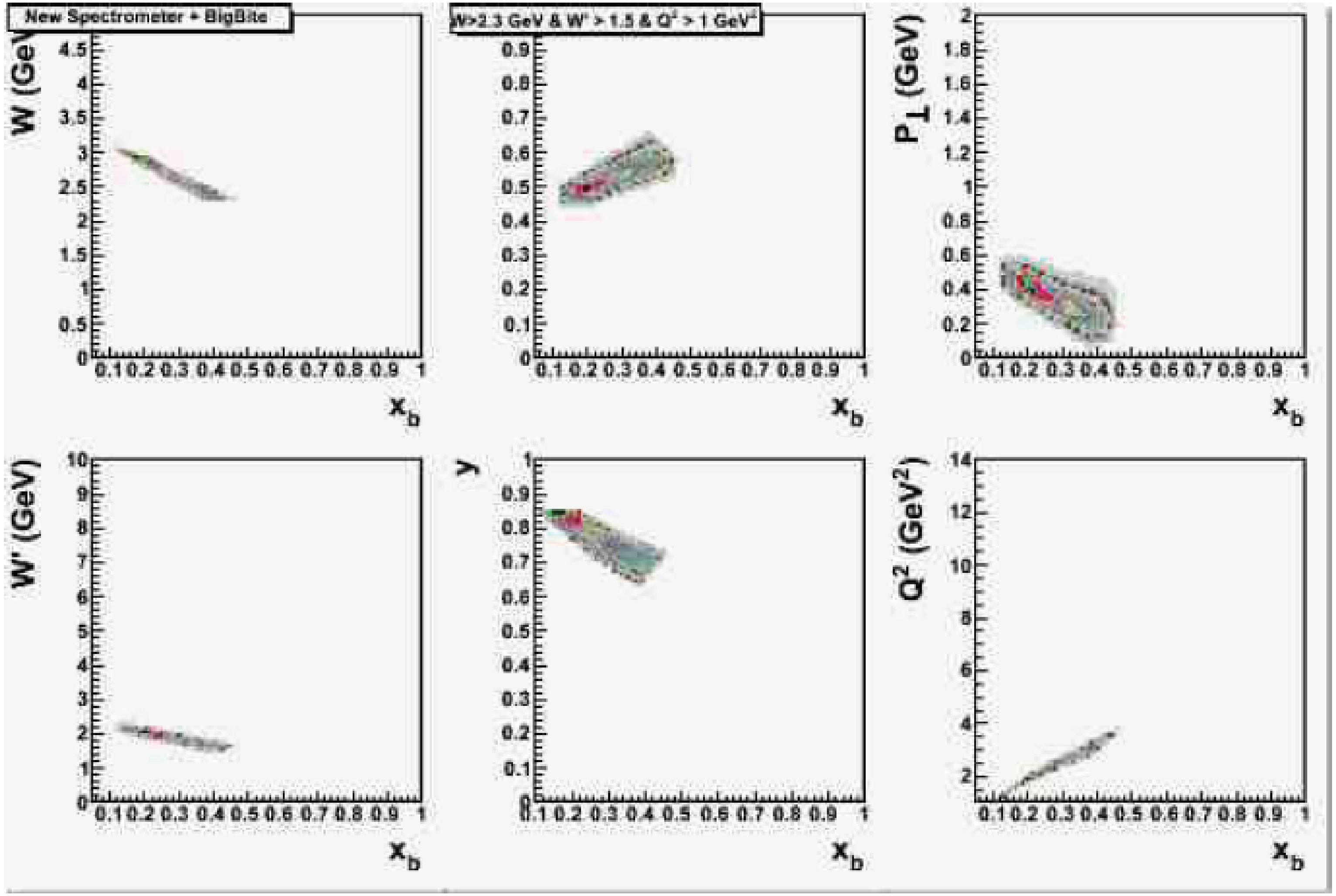
Spazio delle fasi angolare

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



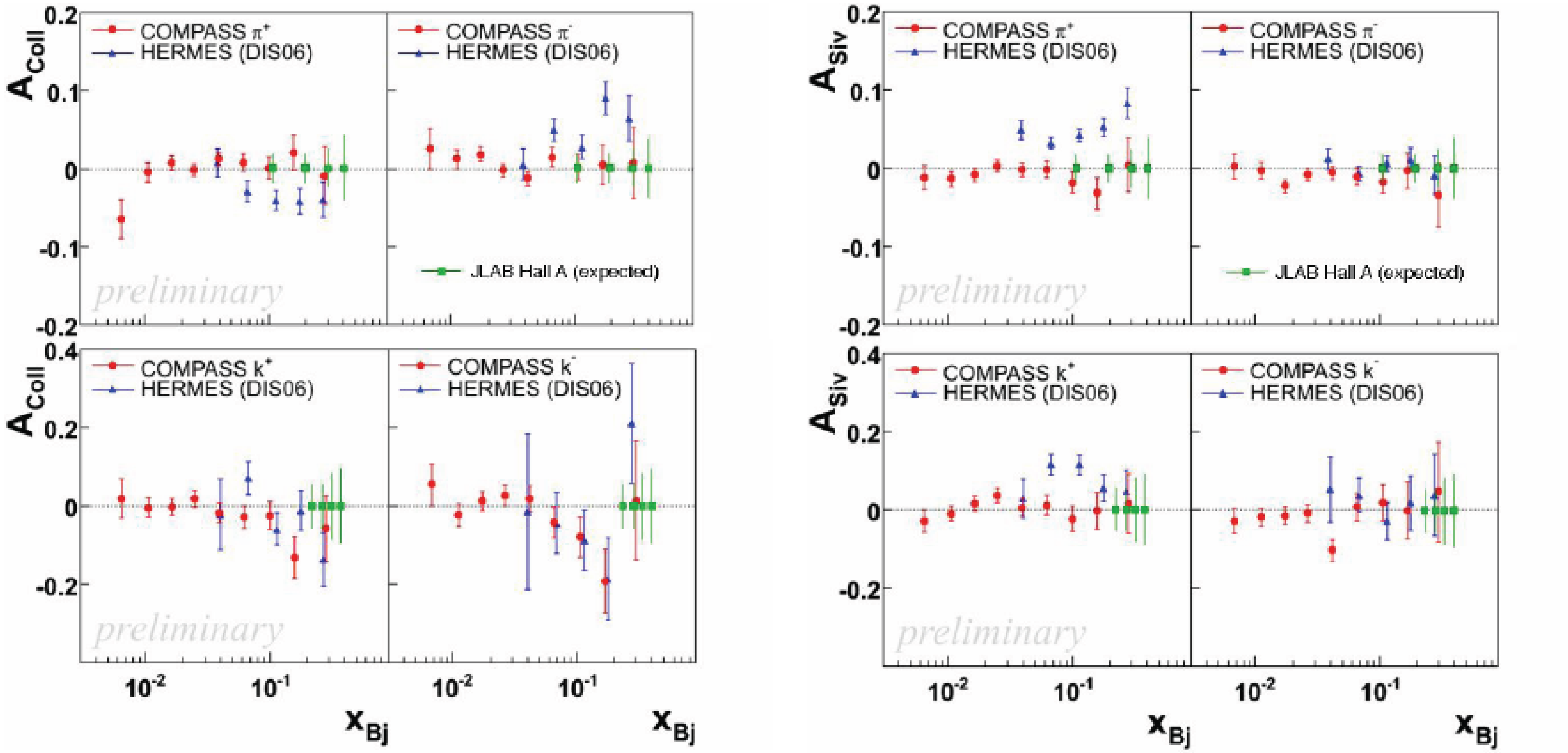
Black: $\phi_S^l = 0$, Red: $\phi_S^l = 90$, Blue: $\phi_S^l = 180$, Purple: $\phi_S^l = 270$

π SIDIS Phase space 6GeV JLab HallA



$\langle Q^2 \rangle = 2.2\ \text{GeV}^2,\ \langle z \rangle = 0.5,\ x = 0.1 - 0.4,\ P_\perp < 0.5\ \text{GeV}$

HERMES on p / COMPASS on d / JLab on neutron (proj. errors)



1 month data taking:

statistical errors comparable to HERMES(3 years)/COMPASS(2 years)

PR-09-018: SSA with SBS

Measurement of the Semi-Inclusive π and K electro-production in DIS regime from transversely polarized ^{3}He target with the SBS & BB spectrometers in Hall A

G. Cates, E. Cisbani, G.B. Franklin, B. Wojtsekhowski

and the SBS Collaboration

http://hallaweb.jlab.org/12GeV/SuperBigBite

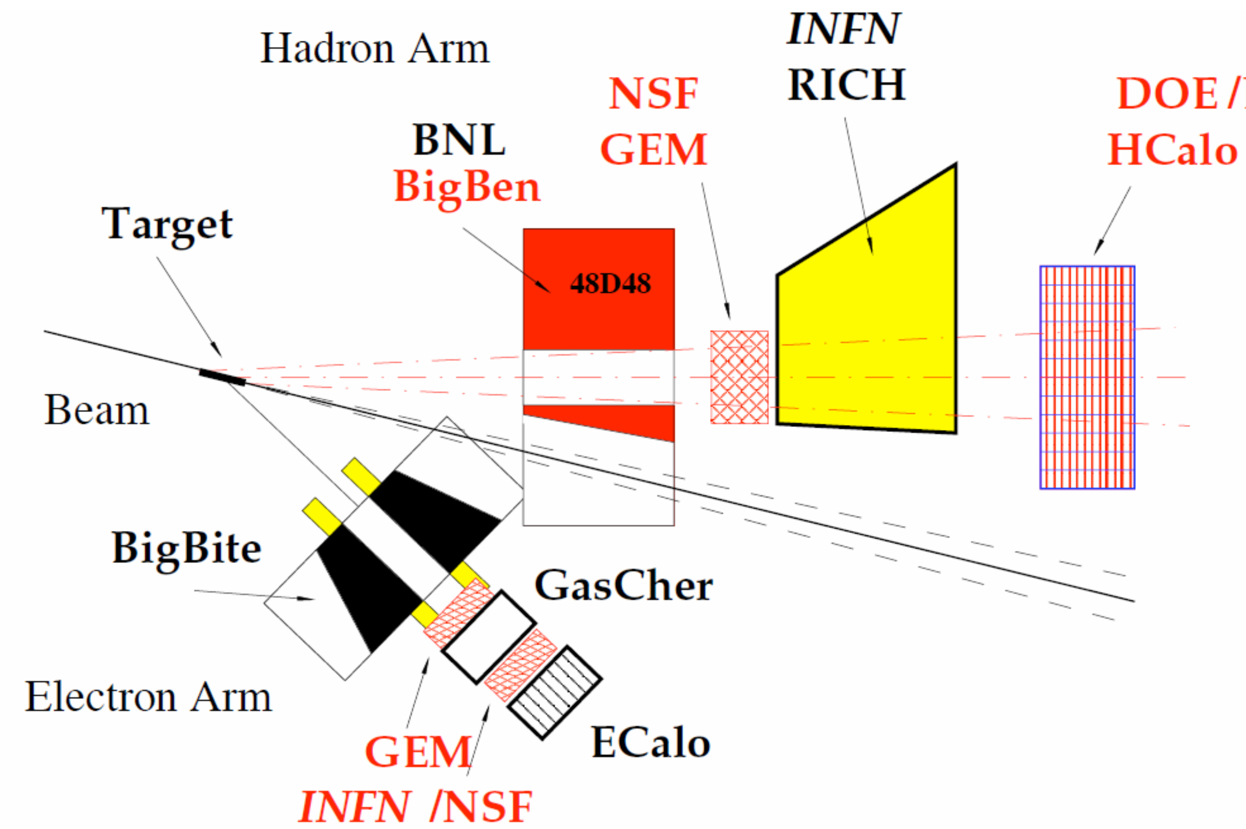
Propose to measure the SSA of SIDIS processes $n^{\uparrow}(e,e'\pi^{\pm})X$ and $n^{\uparrow}(e,e'K^{\pm})X$

- Extract Sivers and Collins (and Pretzelosity) asymmetries on π and K with high statistics
- Provide 2D binning (at least) on the relevant variables: x, $P_{\perp}$ and z, for both hadrons
- Provide Q^2 dependence
- Explore for the first time the high x valence region (with overlap to HERMES, COMPASS, JLab6 data)

  - Understanding of QCD dynamics in the nucleon by the Sivers effect
  - Improve knowledge of the nucleon structure in terms of parton distribution functions
  - Shed more light on the origin of the nucleon spin

Experimental Setup and parameters

$e + {}^3He^{\uparrow} \rightarrow e' + \pi(K)^{\pm} + X$



BB: e-arm at 30°
Ω = 45 msr
GEM Tracker
Gas Cherenkov
Shower
⇐ GMn/PR-09-019

SBS: h-arm at 14°
Ω = 50 msr
GEM tracker
excellent PID / RICH
Hadron CALO

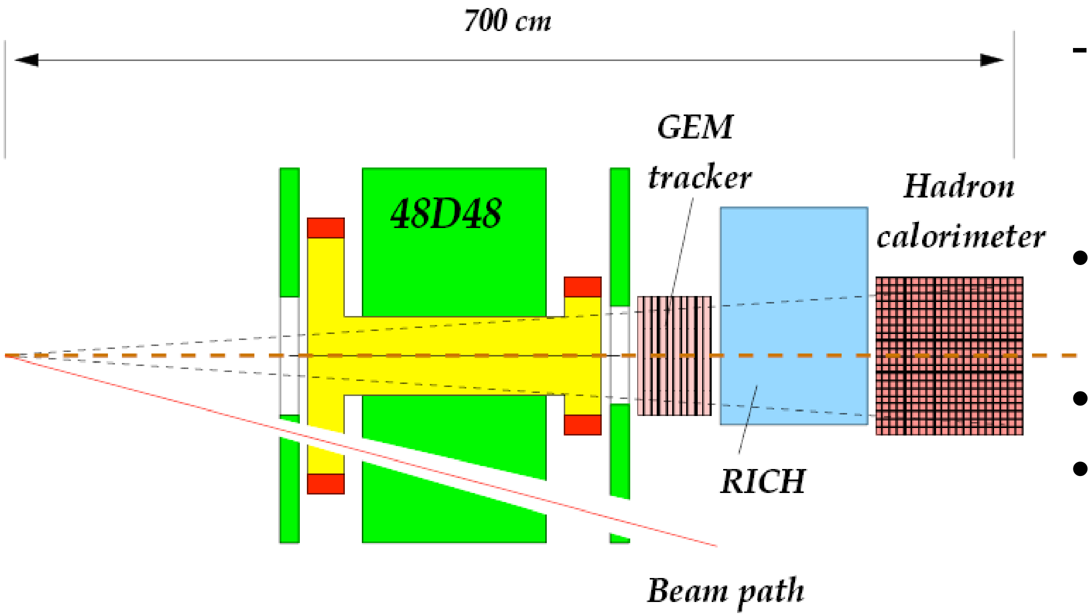
Beam: 50 μA, E=8.8 and 11 GeV (80% long. Pol.)
Target: 65% polarized 3He ⇐ GEn(2)/PR-09-016
⇨ Luminosity: 1.4×10^{37} $cm^{-2}s^{-1}$, 0.05 sr

Event rate: ~$10^4 \times$ HERMES
60 days of production
expected stat. accuracy:
1/10 of proton HERMES

What is special in this experiment

- High Luminosity:
  - 10^5 larger than in HERMES
  - High target polarization (65%)
  - Fast target polarization switch (120 seconds)
  - 4 (8) transverse polarization directions
- Use of SBS (and BB):
  - Large solid angle (50 msr), very good angular and vertex resolutions
  - Large momentum coverage (2-7 GeV/c)
  - Excellent hadron PID
- Reuse equipment from GEp(5) (approved), GEn(2) and GMn (proposals)

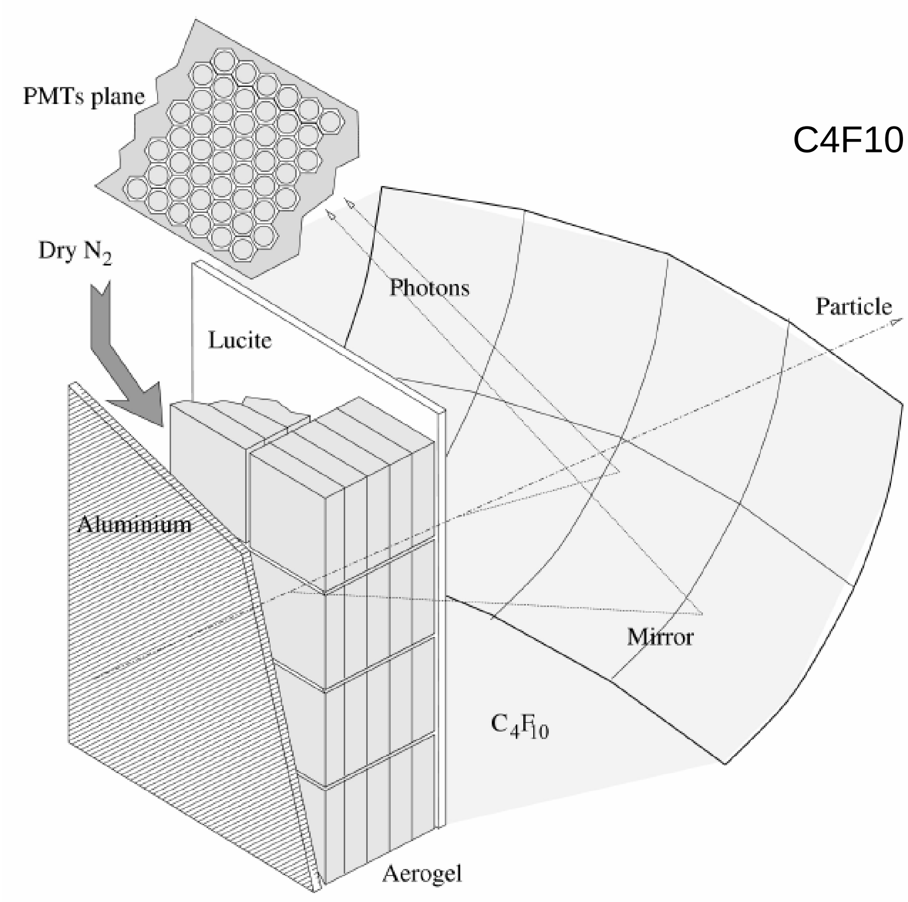
Hadron Arm: SBS

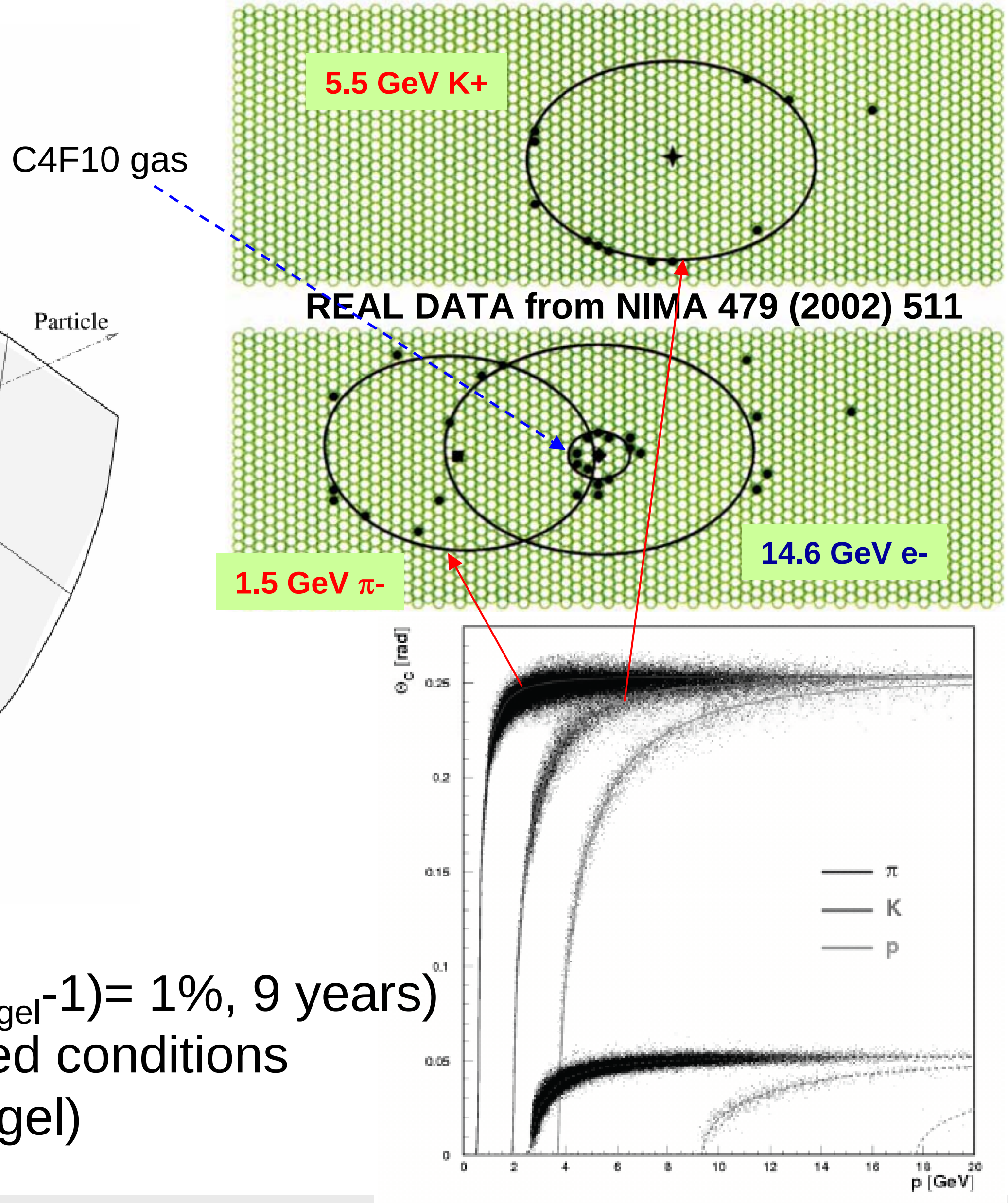


- Magnet: 48D48 - 46 cm gap
  - 2 Tm field integral -100 ton
  - Insert for beam pipe
- GEM chambers for tracking with 70 μm resolution
- HERMES RICH for hadron-ID
- Segmented Hadron CALO ($15x15\ cm^2$ blocks)

- Angular Resolution: (p = 4 GeV)
  - σ_{ϑ_h} = 0.09+0.59/p [mrad] (0.3 mrad)
  - σ_{ϑ_v} = 0.14+1.34/p [mrad] (0.4 mrad)
- Vertex Resolution: 0.53+4.49/p [mm] ($0.2\ cm/\sin\vartheta_{central}$)
- Momentum resolution σ_p/p = 0.03 p+0.29 % (0.4 %)
- CALO Trigger Threshold: 1.5 GeV (online), 2.0 (offline)

Hadron PID: HERMES RICH on SBS





Very stable performance ($\delta n/(n_{aerogel}-1)$= 1%, 9 years)
Stored at UVa under safe/controlled conditions
(also additional wall of spare Aerogel)

Background Rate and Trigger Logic

BB-Shower (1 GeV): 200 kHz

BB-Cherenkov (3-4 pe): 2.5 MHz

40 ns coinc./segmented accidental: **4 kHz**
DIS-e: **1 kHz**

SBS-HCalo (1.5 GeV): 3 MHz

Online 50 ns coinc.
real coinc: **100 Hz**
acc: **750 Hz**

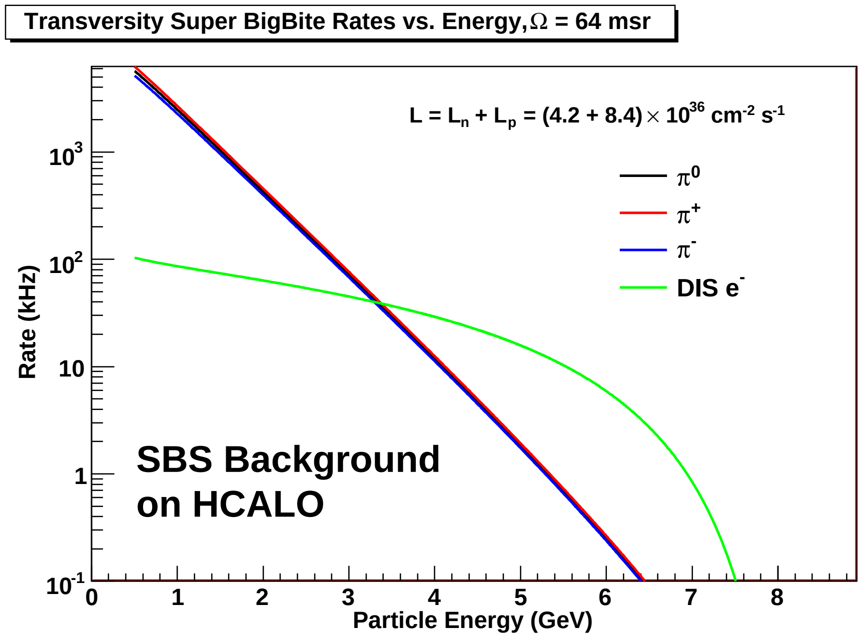
BB-Offline / Tracking
π^0 suppression: **1 kHz**

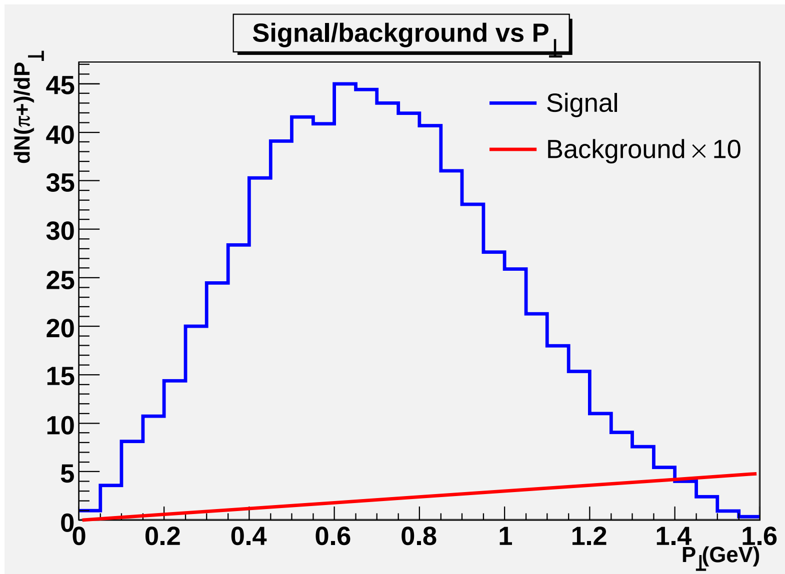
4 ns time gate
Total: 12 Hz

Vertex Correlation
(6σ=3 cm): 0.6 Hz

Momentum cut > 2GeV
Bck = 0.3 Hz

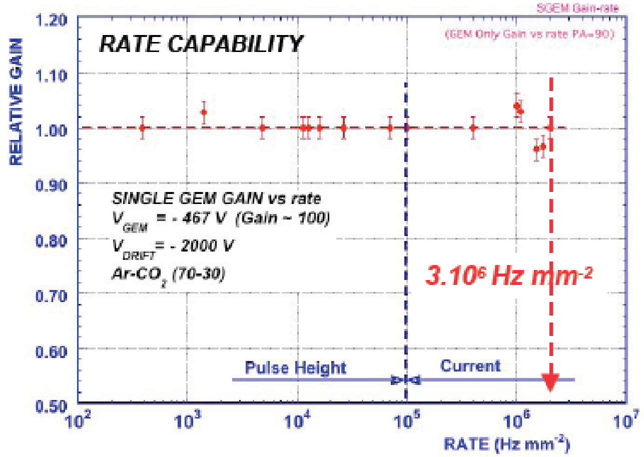
Signal = 67 Hz



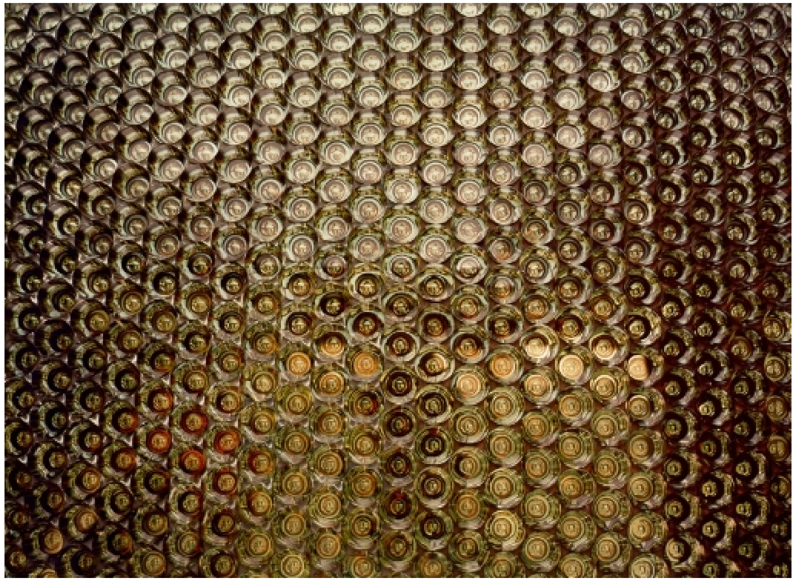


Challenges in large acceptance/high luminosity

- SBS Tracker rate 60 kHz/cm^2; 3xGEM support rate >10 MHz/cm^2
- Track reconstruction: BB first, SBS from vertex to segmented HCALO hit
- RICH PID: high segmentation of photon detector (2000 PMT) is the optimal solution:
  - Expected 35 extra hits/event from: soft photons $\rightarrow$ Compton electrons in aerogel (50 ns gate width) $\Rightarrow$ 2-5% occupancy

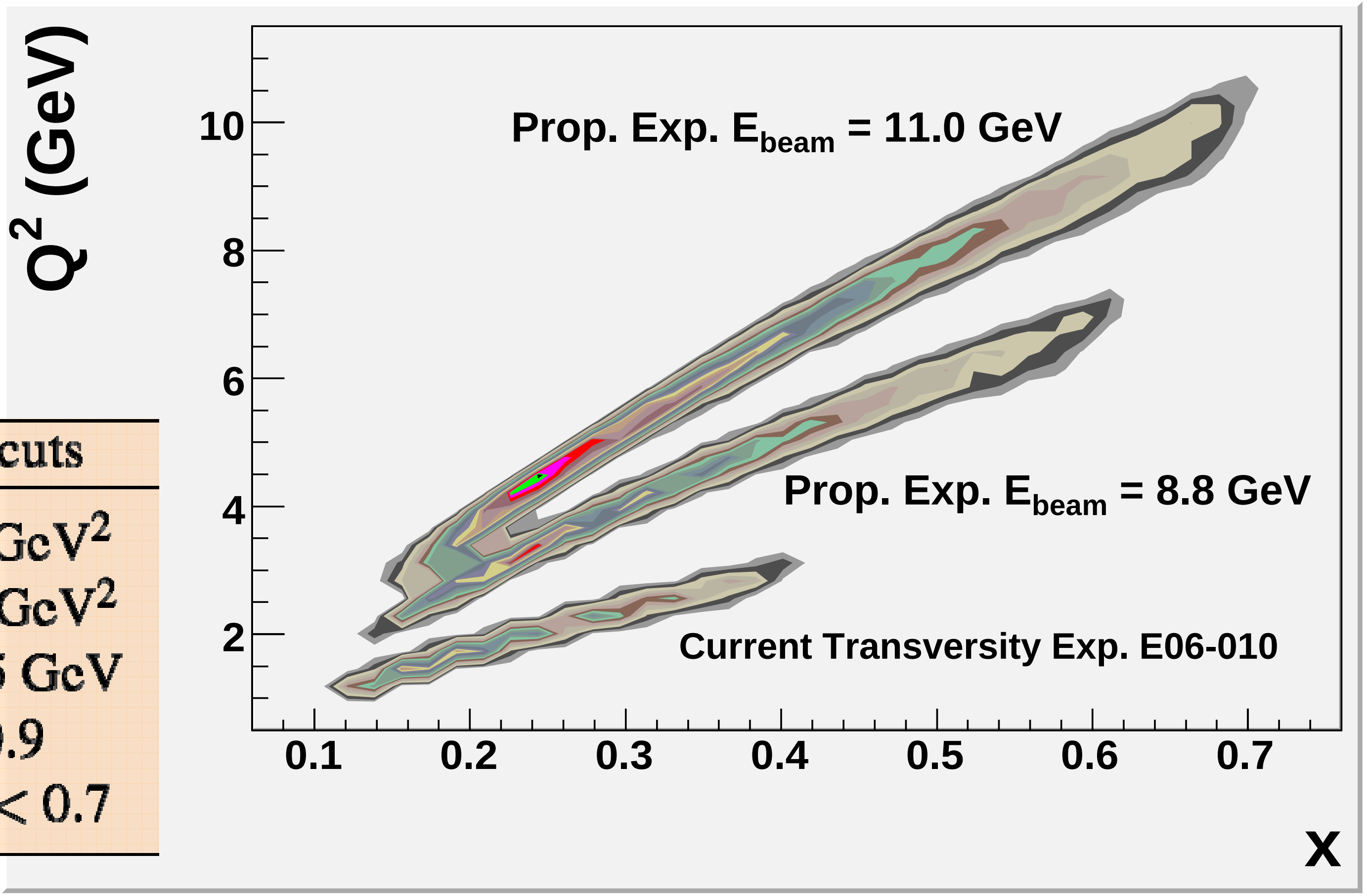


J. Benlloch et al, IEEE NS-45(1998)234



~20% of the HERMES RICH PMT array

Q^2 coverage

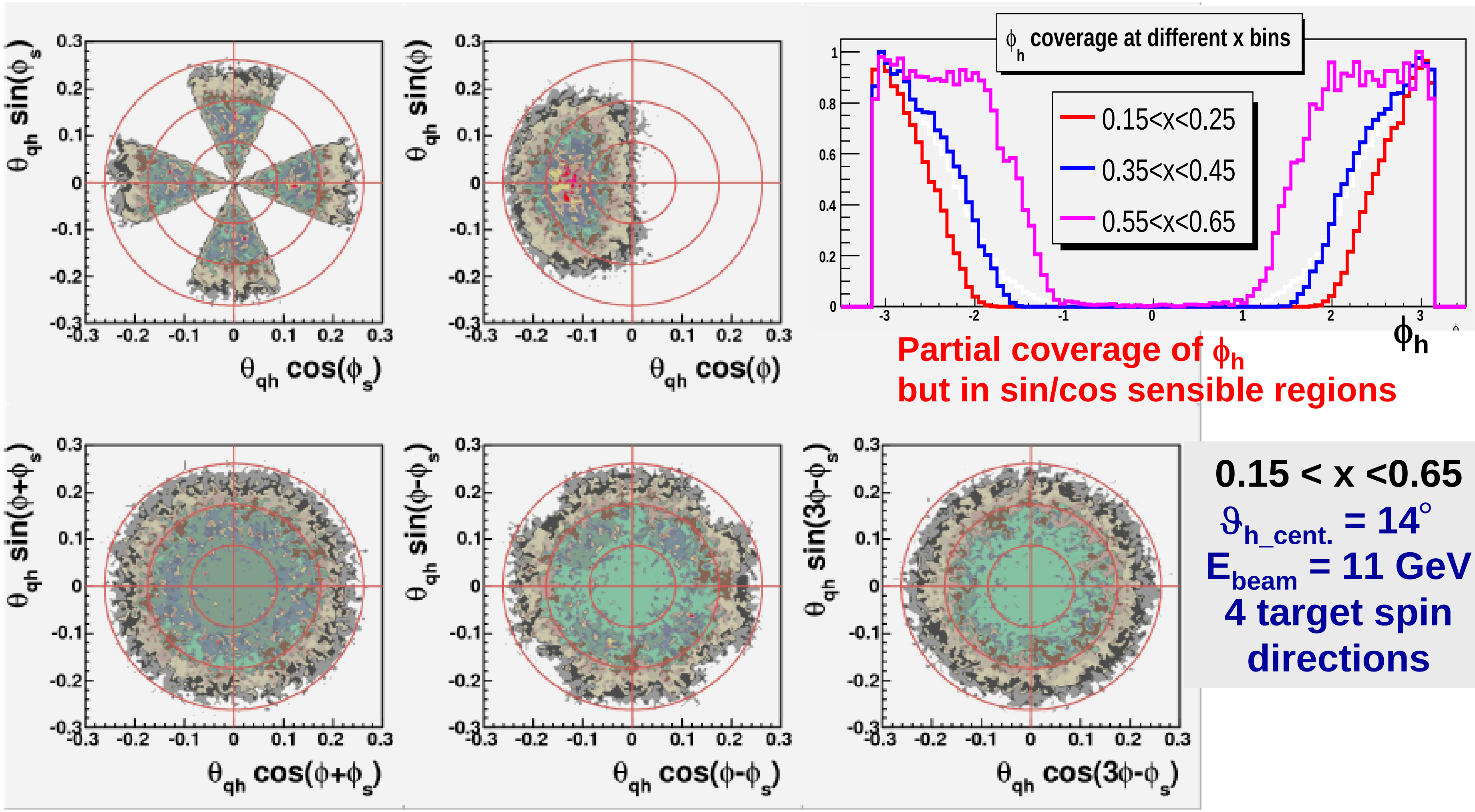


SIDIS cuts
$Q^2 > 1\ \mathrm{GeV}^2$
$W^2 > 5\ \mathrm{GeV}^2$
$W' > 1.5\ \mathrm{GeV}$
$y < 0.9$
$0.2 < z < 0.7$

We will investigate the Q^2 dependence of the Sivers and Collins functions, with overlap in the region of HERMES; reveal higher twist effects.

Analysis of the Q^2 effect will use also the results of presently running 6 GeV E06-010 Transversity experiment

Azimuthal Coverage



Partial coverage of ϕ_h
but in sin/cos sensible regions

0.15 < x <0.65
$\vartheta_{h\_cent.}$ = 14°
E_{beam} = 11 GeV
4 target spin directions

Complete coverage of the Collins, Sivers and "Pretzelosity" azimuthal angles with 4 target spin directions

(with 8 target spin directions even better uniformity)

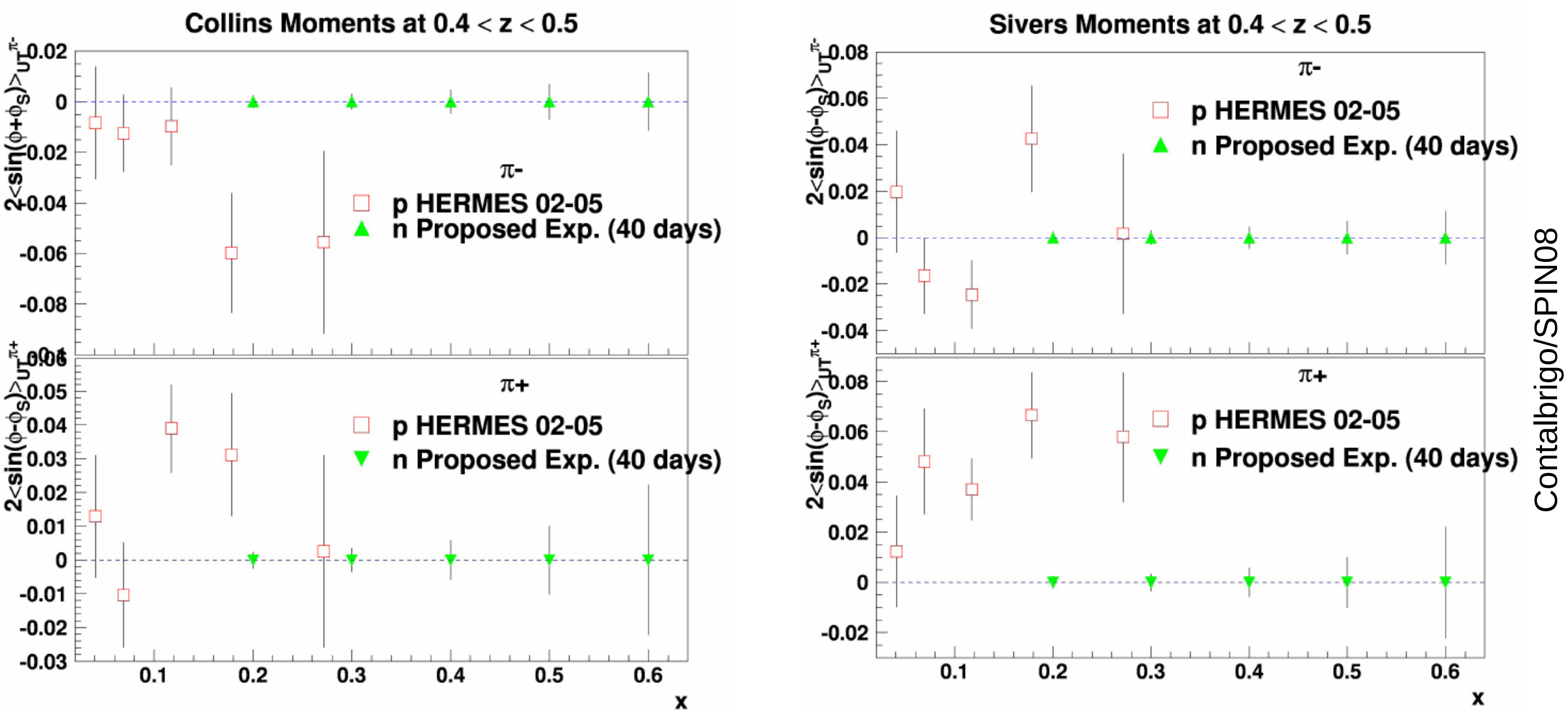
Figure of Merit

Parameter		Unit	HERMES	CLAS12	Proposed Exp.
Target			H	HD (×60 days)	^{3}He (×40 days)
Dilution factor	f		1	0.20	0.20
Nucleon Polarization	P	%	80	85	56
Cross Section $\sim s/Q^2$	σ	a.u.	4	1	1
Angular Acceptance	$\Delta\Omega$	sr	0.14	1	0.05
Integrated Luminosity	$\int L$	10^{38} cm^{-2}	1.5	260	4.6×10^5
$\mathrm{FOM} = f^2 P^2 \sigma \Delta\Omega \int L$			0.54	7.5	280

Two beam energy runs for Q^2 dependence studies:

E_{beam} GeV	Time days	Integrated Lumi 10^{43} cm^{-2}
8.8	20	2.4
11.0	40	4.6

Expected Statistical Accuracy on π



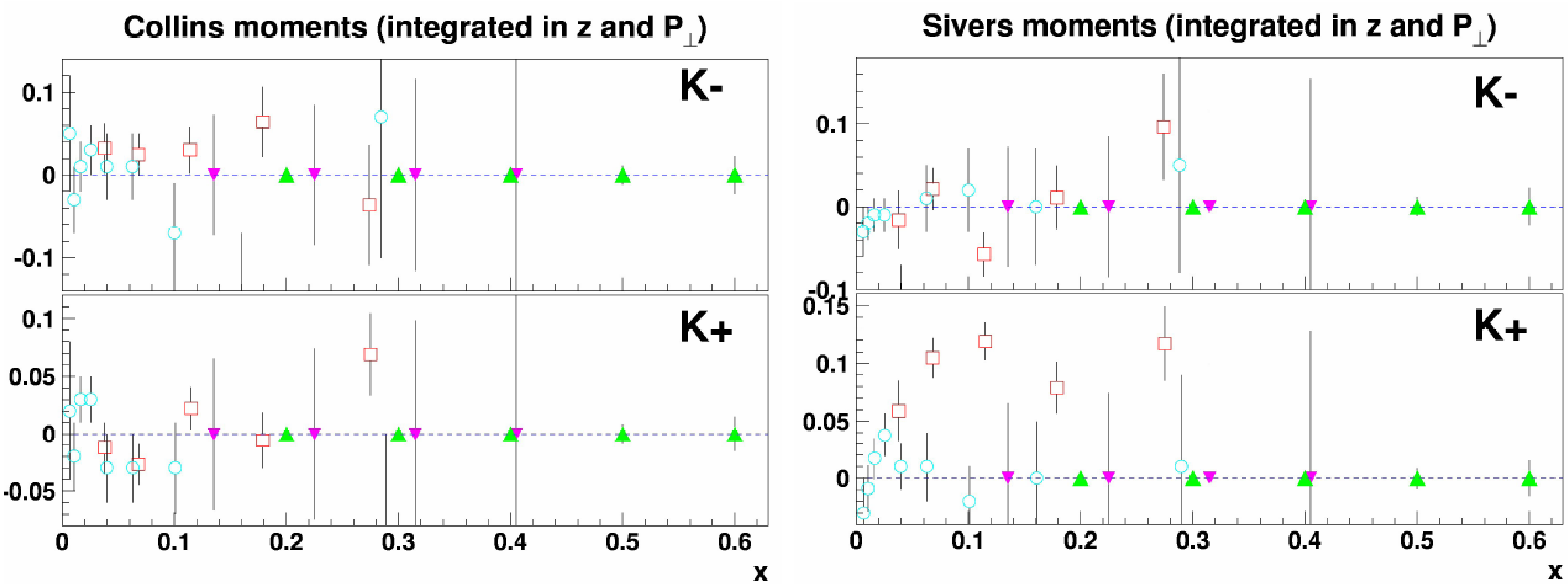
5 × 5 bins (0.15<x<0.65, 0.2<z<0.7) (only one shown)

High x region, with partial overlap with HERMES

2D binning in (x,z), (x,$P_\perp$) and (z,$P_\perp$) for π and K and Q^2 dependence

DF from CTEQ5M
FF from DSS

Expected Statistical Accuracy on **K**



- p - HERMES (2002-2005)
- d - COMPASS (2003-2004)
- n - JLab HallA 6Gev (24+24 days)
- n - Proposed Experiment (40 days)

- Superior quality of Kaon data
- Extend at higher x with partial overlap with existing data on proton, deuteron and expected results of HallA Transversity 6 GeV

DF from CTEQ5M
FF from DSS
Rate normalized to HERMES/p+d K production

Systematics

- Physics Effects:
  - FSI on nuclei
    - 3He: P_p~2%, $|\Psi_d|^2$~10%, P_{resc}~10-20%
    - D: P_p~85%, $|\Psi_d|^2$~6%, P_{resc}~5-10%
  - Higher Twist Terms of SIDIS asymmetries

- Experimental/Analysis:
  - Random background
  - Vector Meson
  - Particle ID
  - Acceptance Effects
  - Radiative Corrections

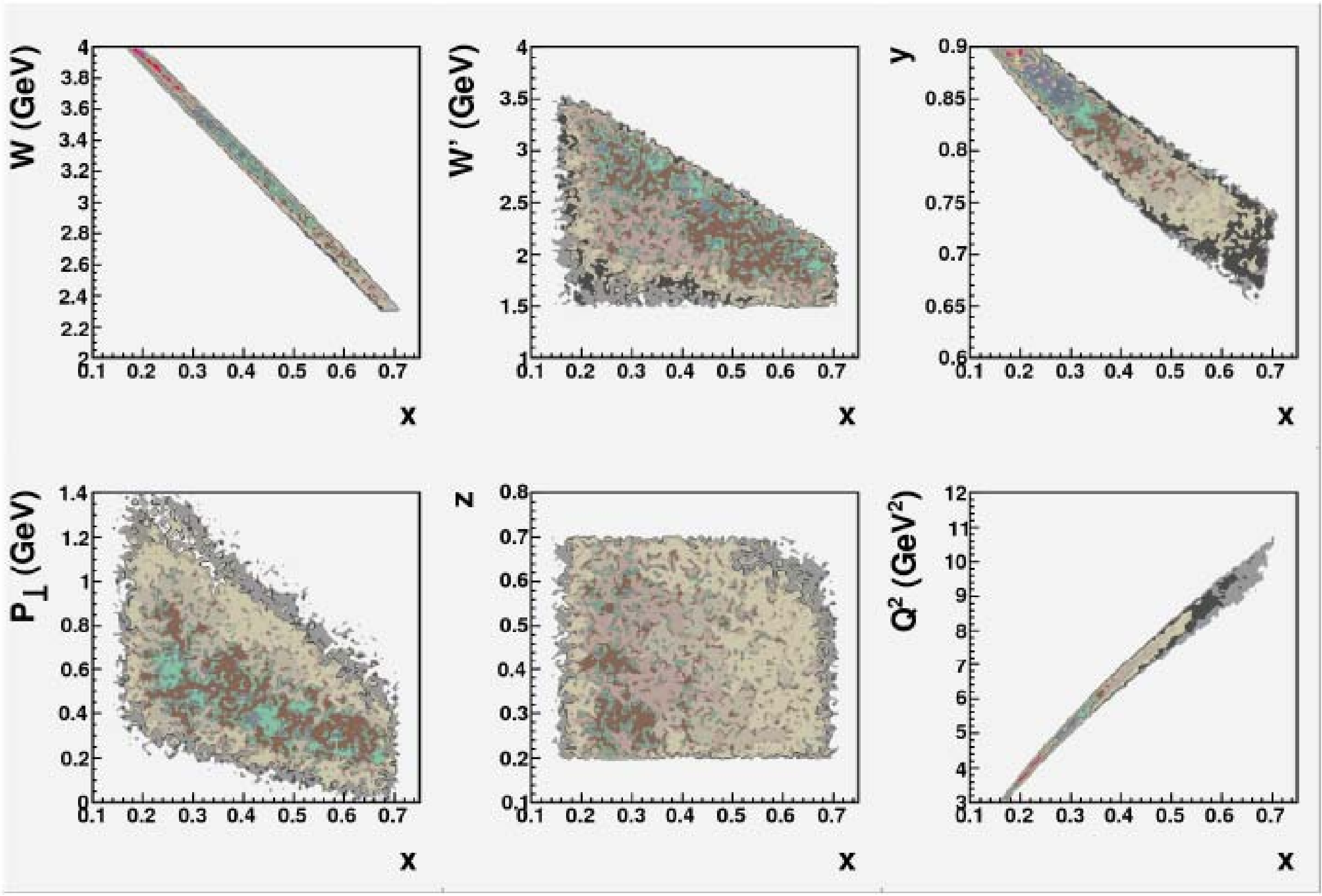
Summary

- We propose to measure the SSA in the transversely polarized SIDIS processes: **$n^{\uparrow}(e,e'\pi^{\pm})X$** and **$n^{\uparrow}(e,e'K^{\pm})X$** **at two Q^2**
- Experiment will re-use part of GEp(5) equipment and the HERMES RICH
- Will be ready to take data in 2014, with no significant extra costs respect to SBS apparatus for GEp(5)

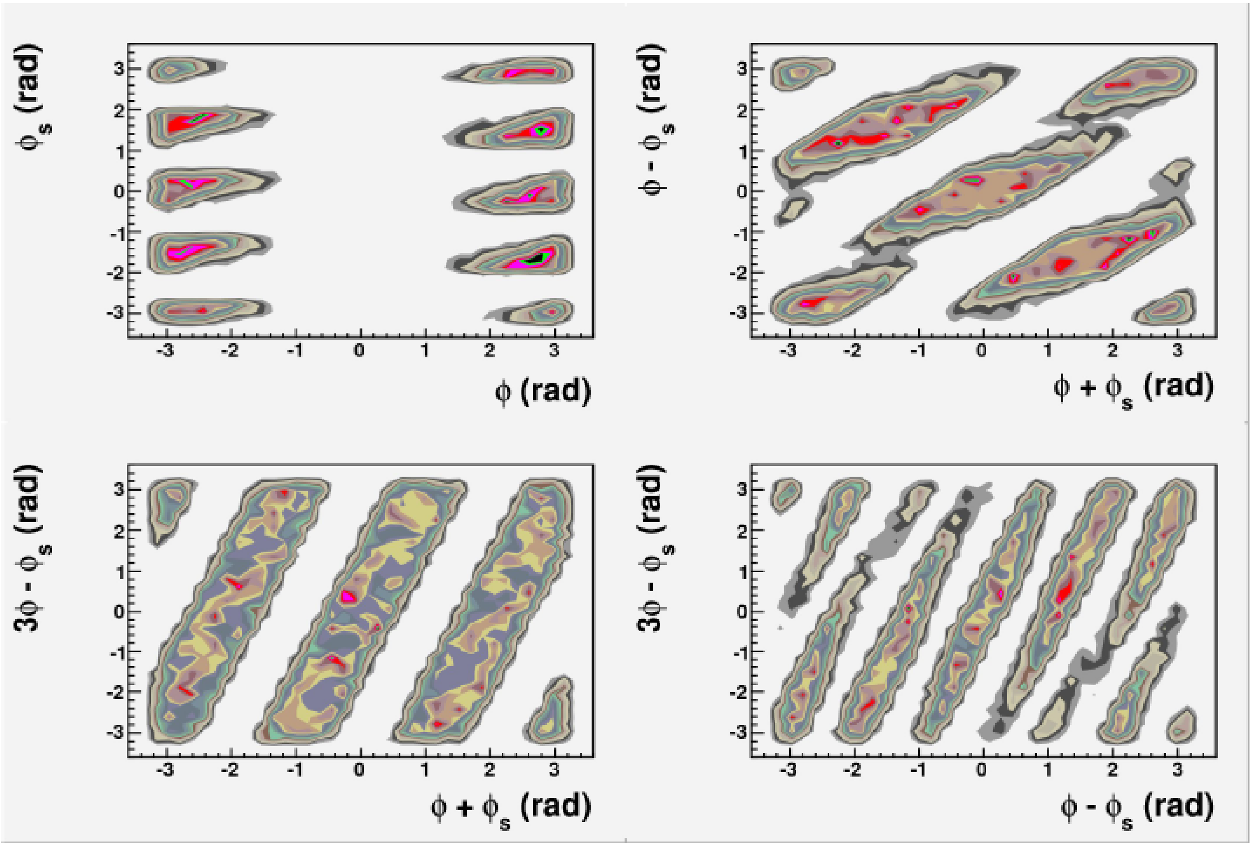
Beam Time Request	days
Production at $E_{beam} = 8.8$ GeV	20
Production at $E_{beam} = 11.0$ GeV	40
Calibration, Target Maintenance, Config. Changes	4
Total	**64**

Phase Spase of the Relevant Variables

Ebeam = 11 GeV

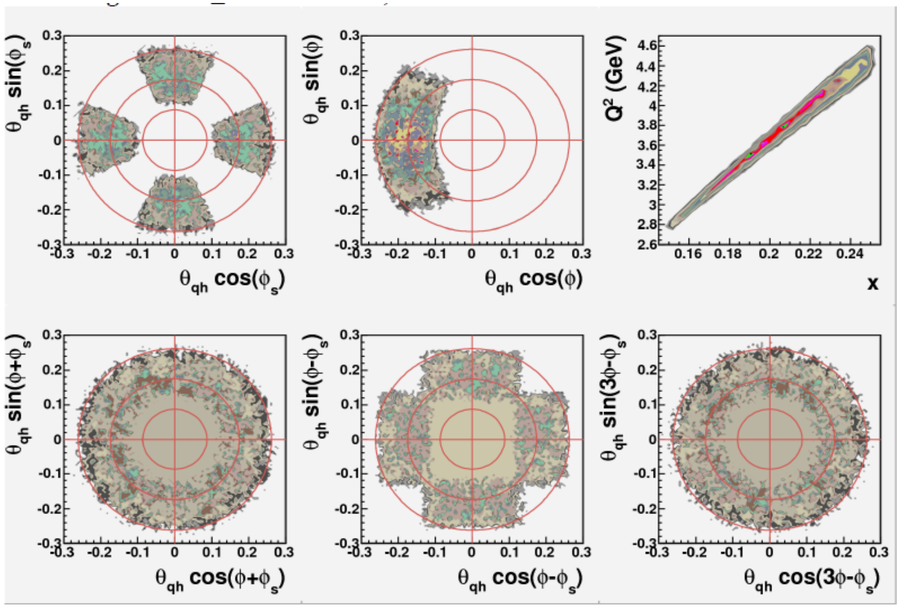


Azimuthal Angles Distributions



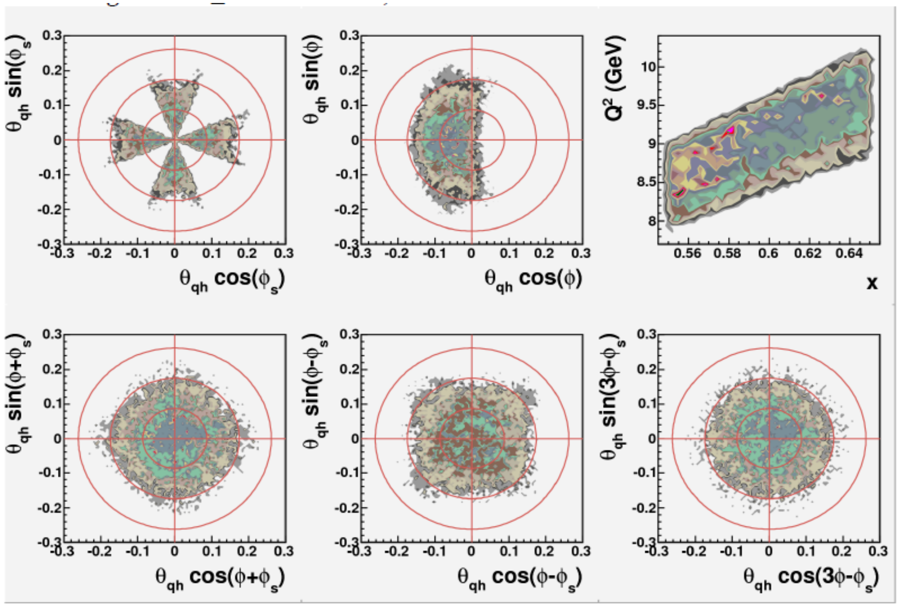
The coverage of ϕ can be extended moving forward SBS to $\vartheta_{central}$ ~ 10 degree (with a decrease of SBS acceptance) and/or changing (not dramatically) the BB settings

Azimuthal angles coverage vs x



Azimuthal angles coverage does not very significantly depend on x,Q^2

Number of target spin directions can be increased to have a better uniformity; 8 would be optimal in this respect.



Terms entering the measured asymmetry

Table 1: modulation terms in the "best model" of the measured asymmetry A_{UT}, in addition to the Collins and Sivers terms.

Modulation	Beam/Target Pol.	Twist	Comment
sin(3phi - phi_S)	U/T	2	Corresponding to the Pretzelosity amplitude
sin(2*phi-phi_S)	U/T	3	
sin(phi_S)	U/T	3	
sin(2phi + phi_S)	L/T	2	Small long. beam component along the photon
sin(2phi)	U/L	2	Small long. target component respect to the photon
sin(phi)	U/L	3	Small long. target component respect to the photon
cos(2phi)	U/U	2	Affect the denominator of A_{UT}, Boer-Mulders DF x Collins FF + Cahn Effect
cos(phi)	U/U	3	Affect the denominator of A_{UT}, Cahn Effect (+ Boer-Mulders)

Systematics/Physics

- Target FSI relative error: expected <7% following the analysis of Scopetta/Transversity/2008
- Higher Twists:
  - we will study the Q^2 dependence with high statistics;
  - terms will be included into the fit whose stability benefits again of the high statistics
  - Unpolarized analysis will also be carried on

Systematics/Exp. Apparatus

- Random
  - dilution factor expected to be small < 1% (S/N = 67/0.3)
  - Relative error well below 10%
- Vector Meson:
  - from PHYTIA prediction tuned on HERMES data below 2.5%; lower at higher x
  - can be studied at higher z
- Acceptances:
  - azimuthal angles are well covered even with partial ϕ_h coverage
  - X,z,$P\perp$,Q^2 effects suppressed by 2D (at least) binning
- Radiative QED Effects:
  - Influence x,Q^2 and azimuthal angles; PHYTIA can be used to estimate the correction factor (and systematic error)
  - According to HERMES we expect a systematic error <5%
- PID:
  - RICH detector with up to 5% occupancy expect to provide 4σ separation at least