Status of SBS SIDIS E12-09018

G. Cates (UVa), E. Cisbani, **A.J.R. Puckett (UConn), B. Quinn (CMU), B. Wojtsekhowski (JLab), E12-09-018 and SBS collaborations**

Semi-Inclusive Deep Inelastic Scattering on a Transversely Polarized He-3 Target using the BigBite and Super BigBite Spectrometers in Hall A

9/July/2021 – HallA summer collaboration meeting

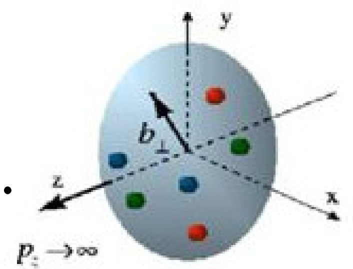
Toward a unified picture of the nucleon structure and its internal dynamics

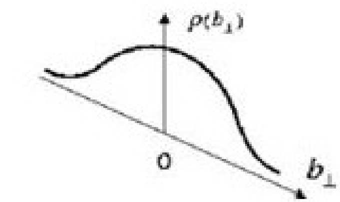
Large experimental "firepower" required:

- **Elastic Scattering**
- **WACS / DVCS**
- **SI-DIS / DY**
- **TDIS**
- **Lepton-Lepton**
- **...**

PDFs: $\mathrm{f}_n^q(x)\ldots$

FFs: $\mathrm{F}_n^q(t)\ldots$





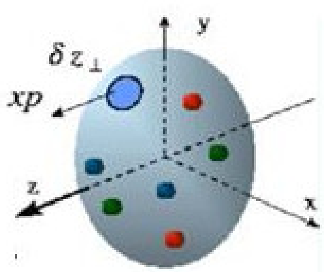
$\int d^2\vec{k}_\perp$

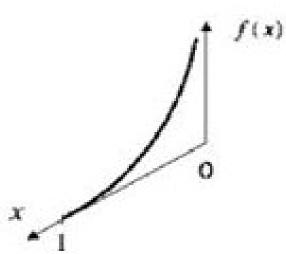
$\int dx$

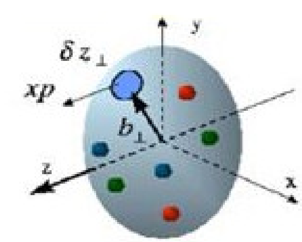
TMDs: $\mathrm{f}_n^q(x, \vec{k}_\perp)\ldots$

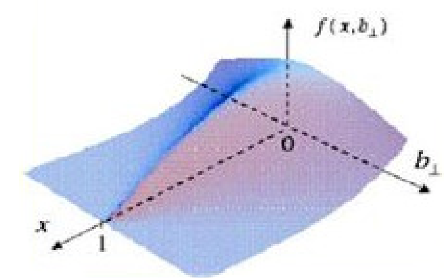
SBS

GPDs: $\mathrm{H}_n^q(x, \xi, t)\ldots$









$\int d^2\vec{b}_\perp$

$\int d^2\vec{k}_\perp$, FT $\vec{b}_\perp \leftrightarrow (\xi, t)$

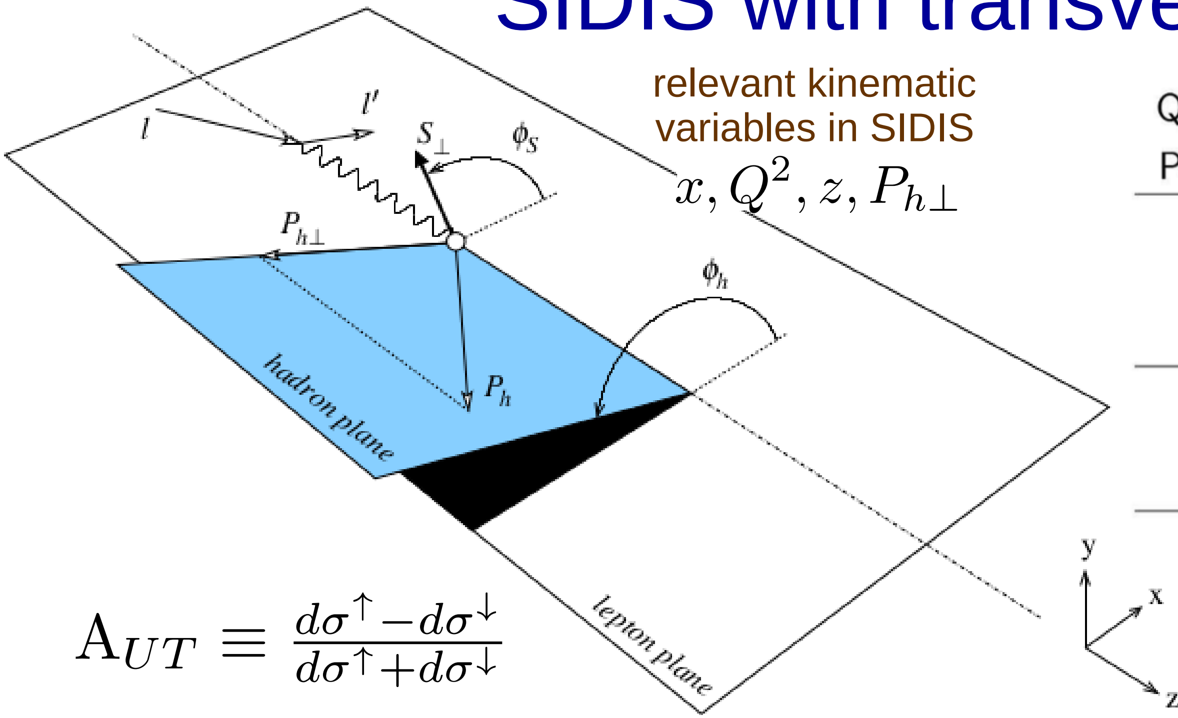
Wigner Functions:

$\mathrm{W}_{\Gamma,n}^q(x, \vec{k}_\perp, \vec{b}_\perp)$

SIDIS with transversely polarized target

relevant kinematic variables in SIDIS

$x, Q^2, z, P_{h\perp}$



$$A_{UT} \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

Quark Polar.	Nucleon Polarization 0	L	T
0	$q(x)$		$f_{1T}^{\perp}(x, k_\perp)$
L		$\Delta q(x)$	$g_{1T}(x, k_\perp)$
T	$h_1^{\perp}(x, k_\perp)$	$h_{1L}^{\perp}(x, k_\perp)$	$\delta q(x)$ / $h_{1T}^{\perp}(x, k_\perp)$

Sivers

Transversity
(or h_1^q)

(at leading twist-2)

$$A_{UT}^{Collins} \sin(\phi_h + \phi_S) \sim \sum_q e_q^2 \left[\delta q^q \otimes H_{1q}^{\perp}\right]$$

"Clean" probe of relativistic effects
Chiral-odd DF and FrF

$$A_{UT}^{Sivers} \sin(\phi_h - \phi_S) \sim \sum_q e_q^2 \left[f_{1T}^{\perp q} \otimes D_{1q}\right]$$

Link to quark Orbital Angular Momentum and QCD FSI mechanism; used to test DF universality

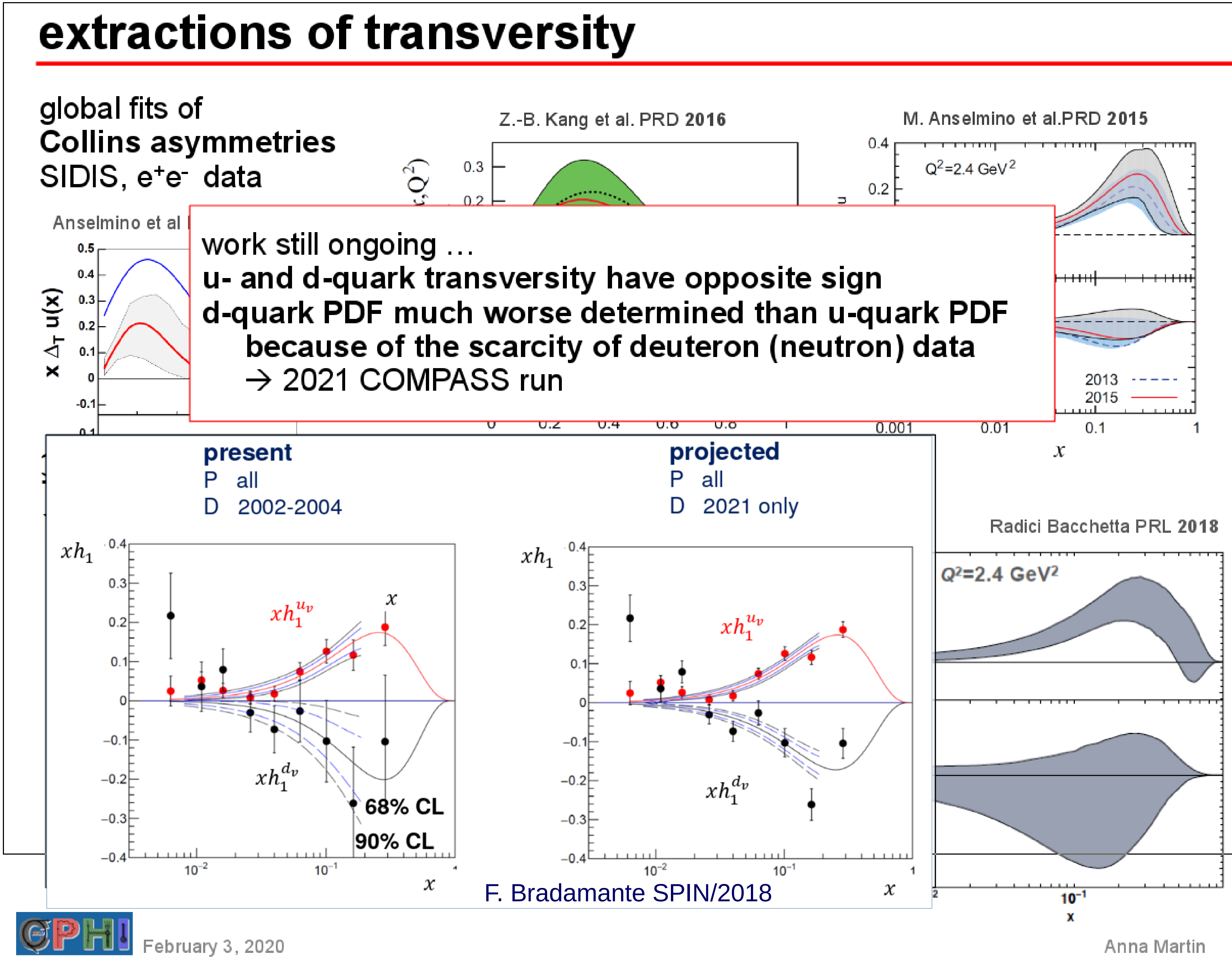
$$A_{UT}^{Pretz} \sin(3\phi_h - \phi_S) \sim \sum_q e_q^2 \left[h_{1T}^{\perp q} \otimes H_{1q}^{\perp}\right]$$

Transverse spin and momentum (~0)

$$\otimes \equiv \int \cdot \, d^2p_\perp \, d^2k_\perp$$

Convolution over unobserved transverse momenta

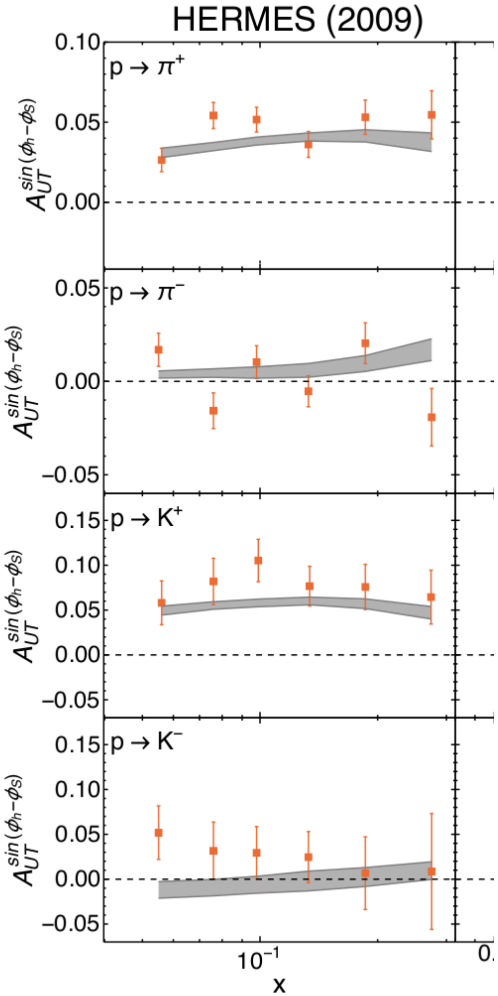
Why Transversity on neutron ?

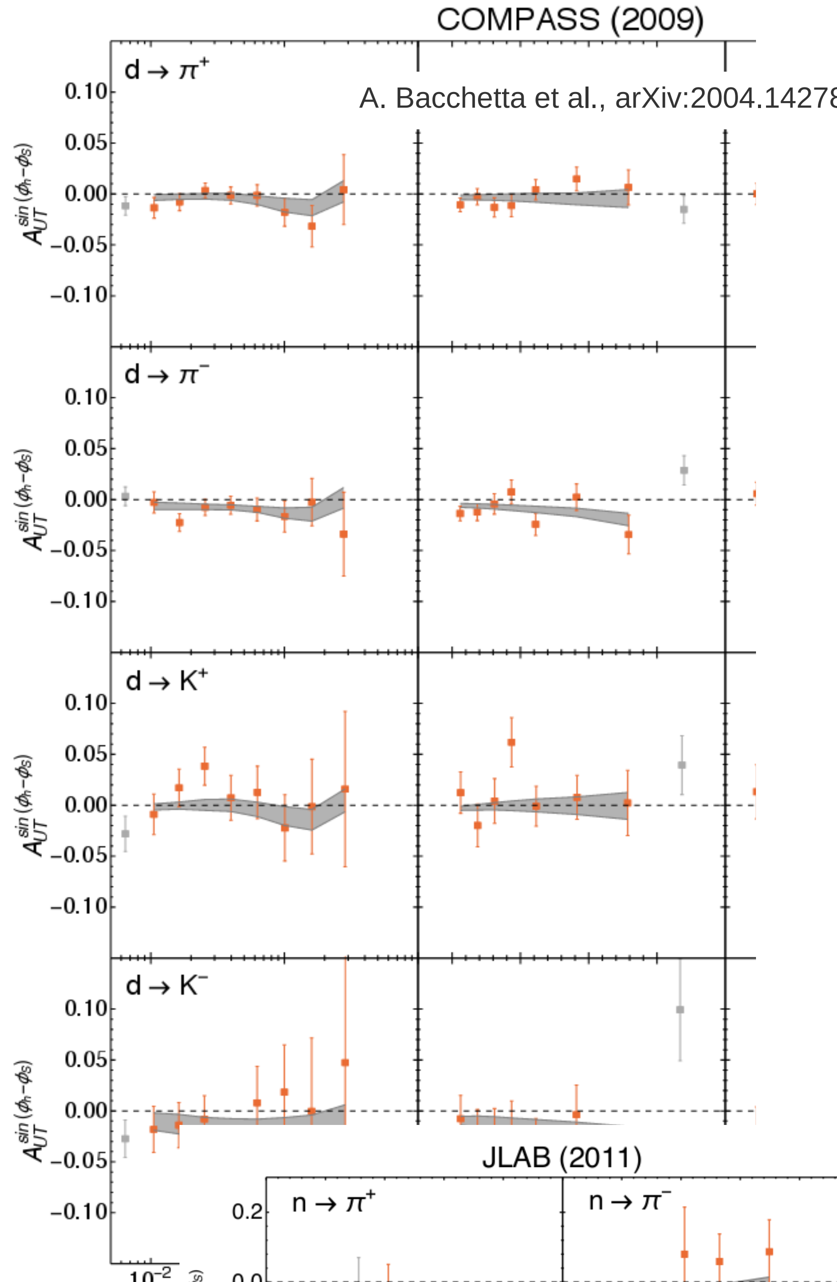


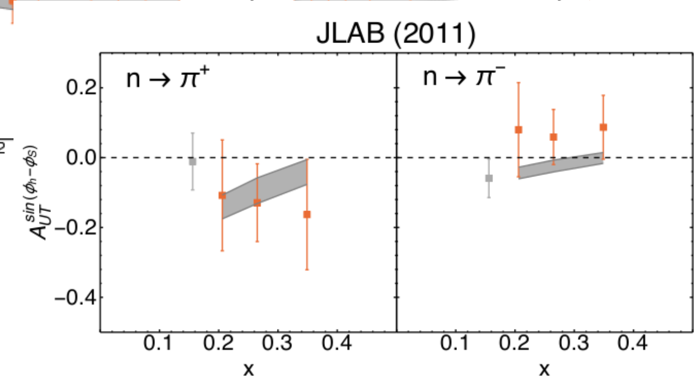
Why Sivert on neutron ?

Collab.	Ref.	Process	Q_{avg}	N_{data}	χ^2/N_{data}
COMPASS	[44]	$ld \to lK^0X$	2.52	7	0.770
		$ld \to lK^-X$	2.80	11	1.325
		$ld \to lK^+X$	1.73	13	0.749
		$ld \to l\pi^-X$	2.50	11	0.719
		$ld \to l\pi^+X$	1.69	12	0.578
	[43]	$lp \to lh^-X$	4.02	31	1.055
		$lp \to lh^+X$	3.93	34	0.898
	[46]	$\pi^-p \to \gamma^*X$	5.34	15	0.658
HERMES	[41]	$lp \to lK^-X$	1.70	14	0.376
		$lp \to lK^+X$	1.73	14	1.339
		$lp \to l\pi^0X$	1.76	13	0.997
		$lp \to l(\pi^+ - \pi^-)X$	1.73	15	1.252
		$lp \to l\pi^-X$	1.67	14	1.498
		$lp \to l\pi^+X$	1.69	14	1.697
JLAB	[45]	$lN \to l\pi^+X$	1.41	4	0.508
		$lN \to l\pi^-X$	1.69	4	1.048
RHIC	[47]	$pp \to W^+X$	M_W	8	2.189
		$pp \to W^-X$	M_W	8	1.684
		$pp \to Z^0X$	M_Z	1	3.270
Total				226	0.989

M.G. Echevarria et al., "Global analysis of the Sivers functions ...", JHEP01 (2021) 126







d-quark Sivers/Transversity are poorly constrained by existing data

- Proton data dominated by u-quarks
- Limited precision/sensitivity to d quark from COMPASS deuteron/JLab Hall A ^{3}He data

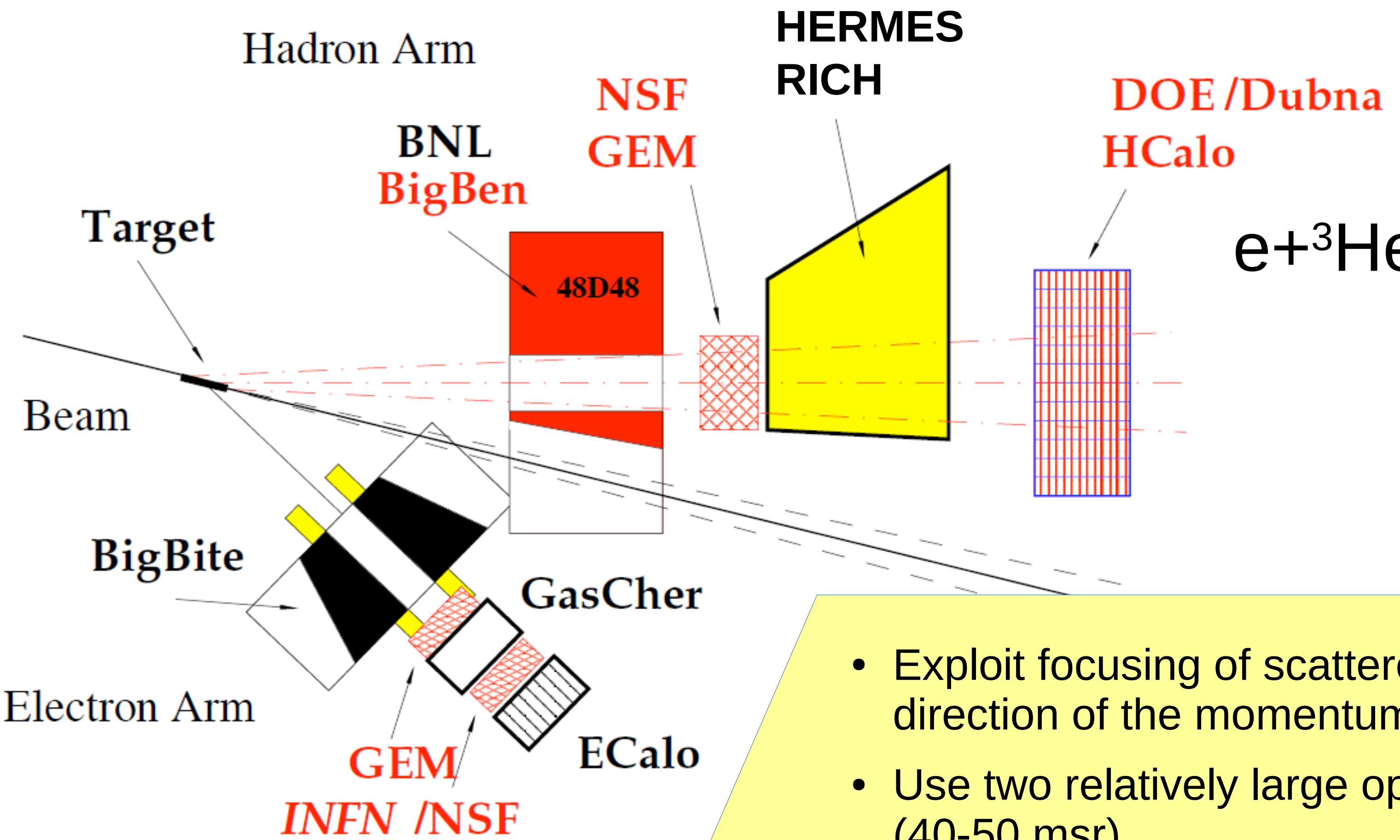
Conditions for TMD formalism applicability

- Large Q^2>1 GeV^2 and large W>2 GeV, as in DIS
- Large (but not too large) z:
  - High enough for dominance of “current quark” fragmentation over “target remnant” fragmentation
  - Low enough to avoid dominance of exclusive/resonance region contributions
- Requires small (but not too small) $p_\perp$:
  - Large enough for meaningful sensitivity to effects of quark transverse motion/spin:
  - Small enough for applicability of TMD formalism; i.e., dominance of TMD effects over collinear pQCD effects (gluon radiation, etc.)
- Experimentalist’s/phenomenologist’s rule of thumb: $$\frac{|\mathbf{P}_{h\perp}|}{z} \ll Q$$

➡ @ JLab-12 GeV: 0.3< z <0.7 for π's;
more restricted range for charged K's

Adapted from A. Puckett SBS weekly meeting 28/Jun/2021

SBS-SIDIS Experiment Concept



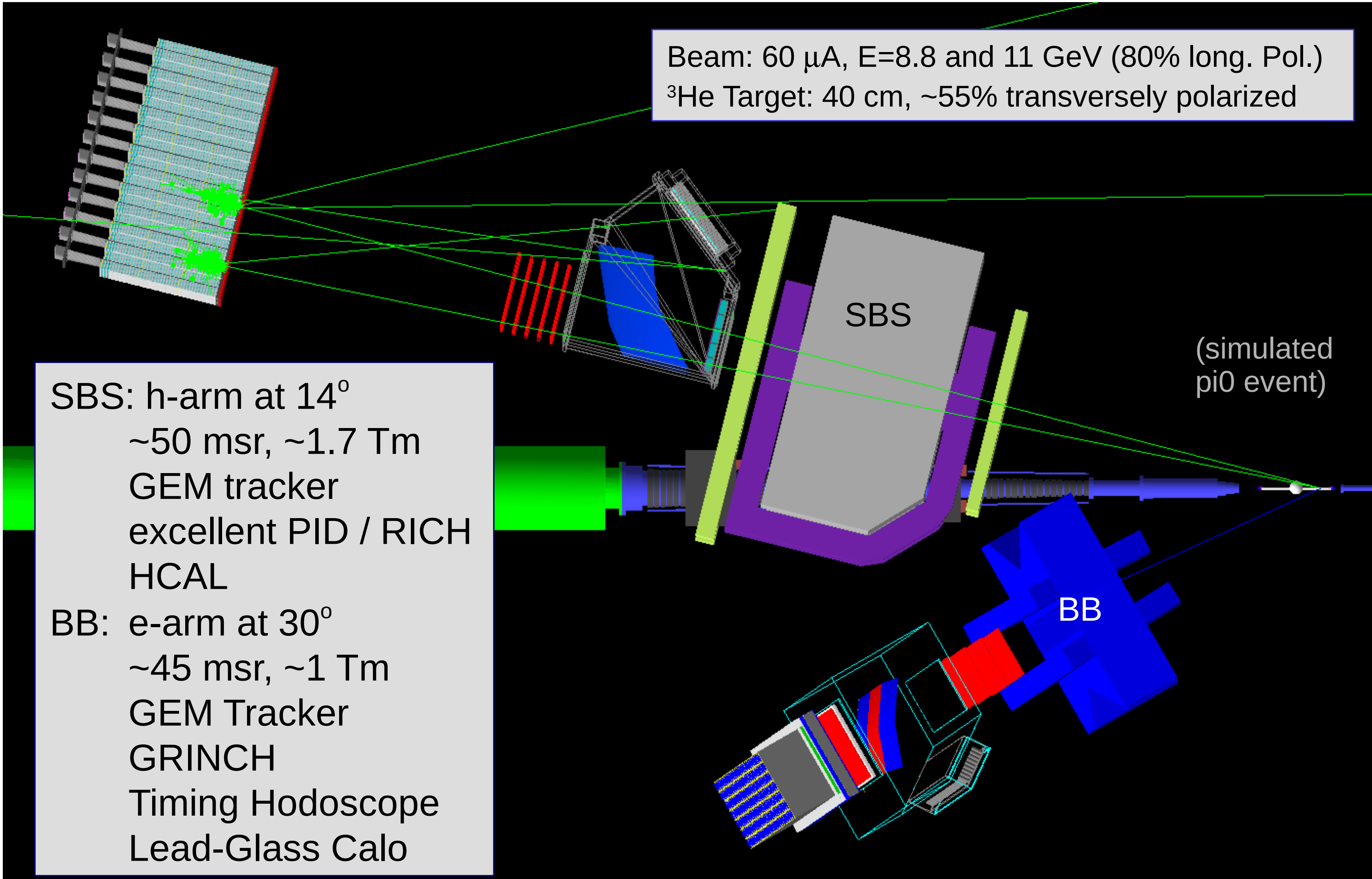
$e + {}^3He^{\uparrow} \rightarrow e' + \pi(K)^{\pm} + X$

Lumi > 10^{37} Hz/cm^2

(**HERMES unp. ≤$2.5 \cdot 10^{33}$ Hz/cm^2**)
Th. Benisch et al. NIMA 471 (2001) 314

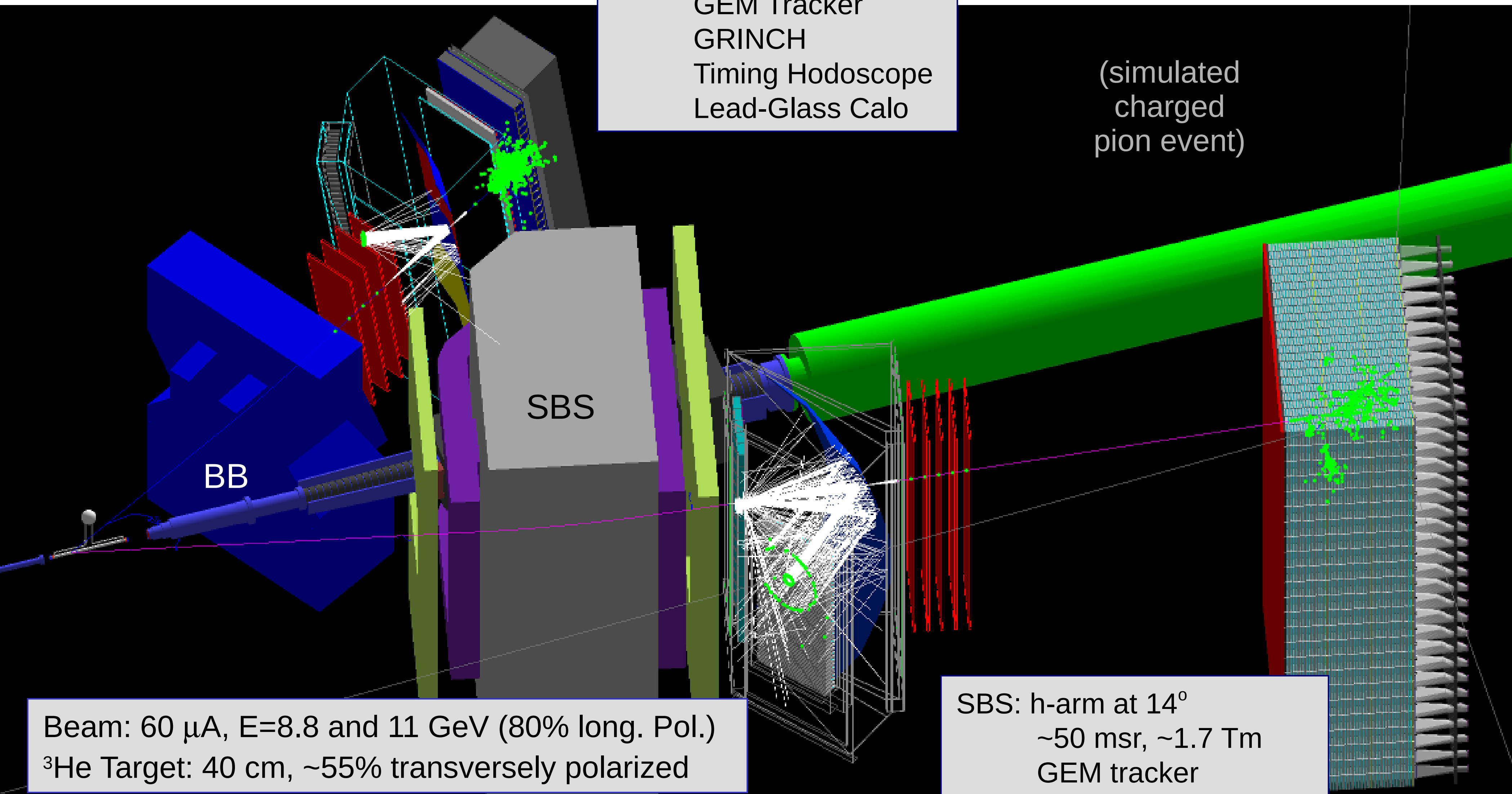
- Exploit focusing of scattered hadrons along the direction of the momentum transfer **q**
- Use two relatively large open-geometry dipoles (40-50 msr),
- Center the hadron arm along **q**
- Flexible orientation of the target polarization within the plane perpendicular to **q** thanks to the modest field (tens of Gauss) in the target region
- Dipoles sweep out low energy background

SBS-SIDIS Experiment Configuration (top view)



SBS-SIDIS Experiment Configuration (side view)

BB: e-arm at 30°
~45 msr, ~1 Tm
GEM Tracker
GRINCH
Timing Hodoscope
Lead-Glass Calo



Beam: 60 μA, E=8.8 and 11 GeV (80% long. Pol.)
^{3}He Target: 40 cm, ~55% transversely polarized

SBS: h-arm at 14°
~50 msr, ~1.7 Tm
GEM tracker
excellent PID / RICH
HCAL

^{3}He (SBS) polarized target

Evolution of the 3He polarized target HallA/C in latest years ending up to SIDIS:

Convection design → Hall C (A1n and d2n) (30 uA, 50% pol)

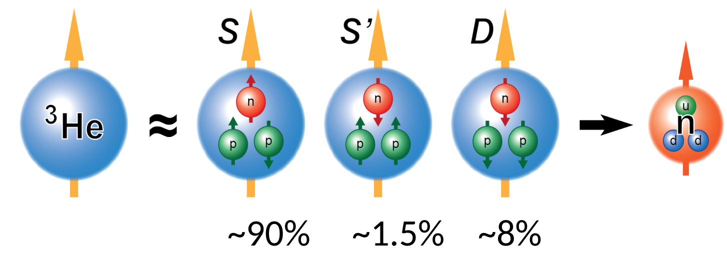
⇓

Twice target thickness → GEn (60 uA)

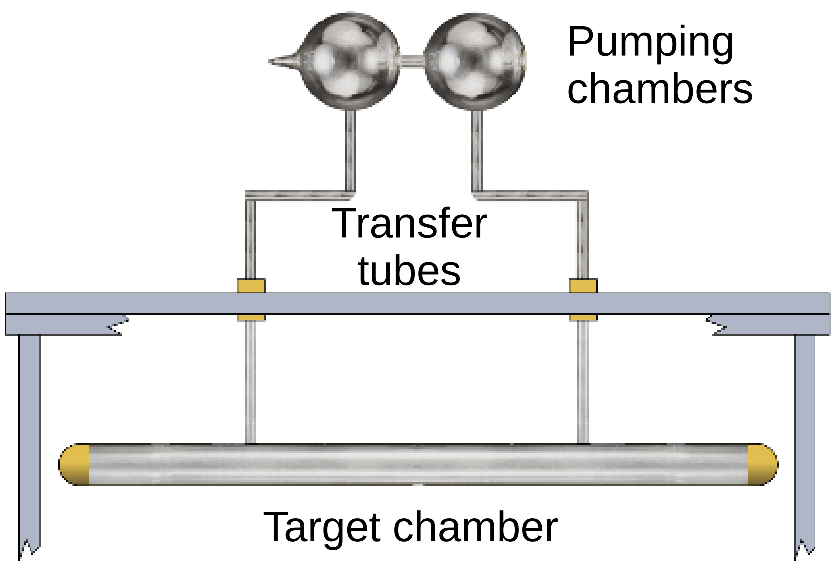
⇓

SIDIS will reuse most of the GEn target hardware including soft iron magnetic shield and to get different orientations will:

- rotate the magnetic-field coils (~ 1 week) for hor./ver. holding field
- use two pumping chambers, each served by one optics module pointing directly to it;
- install new forced-hot-air oven (for the 2 pumping chambers)



Effective polarized n target

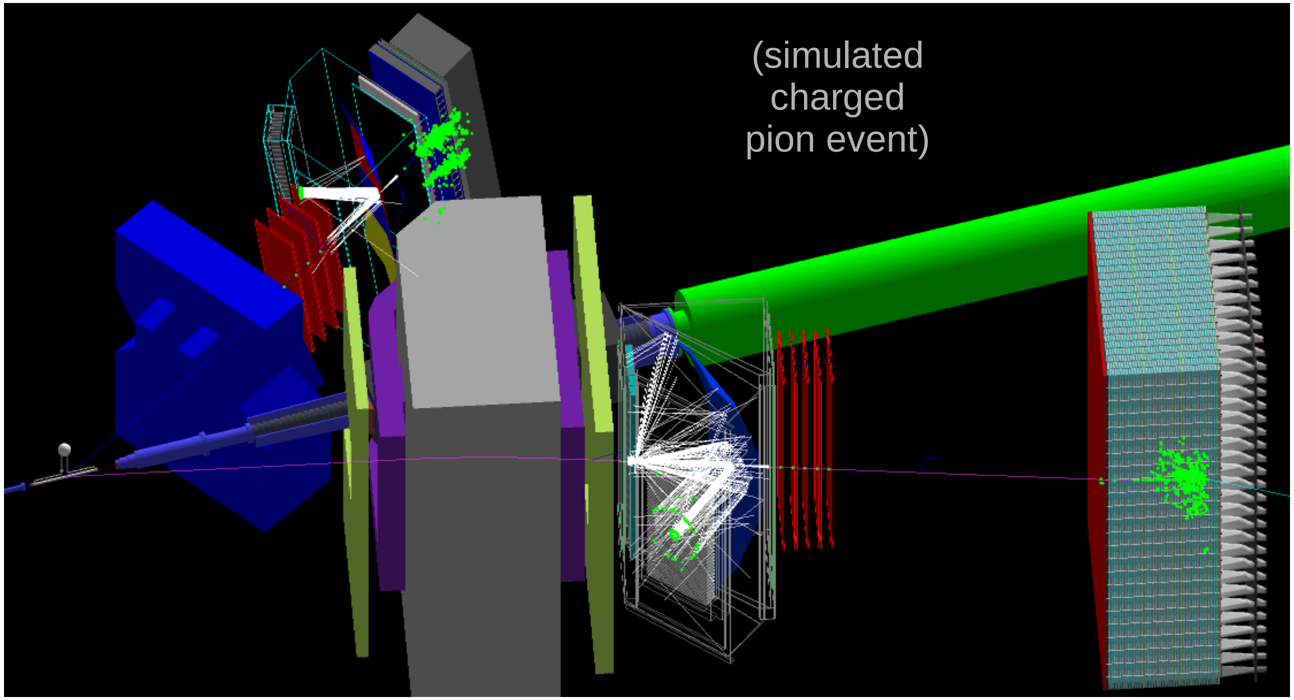


Only 4 spin directions (+/- hor. and +/- ver.) instead of original 8 (approach already validated in E06-010)

→ simplification in design, minimal changer relative to SBS-GEn)

→ no meaningful impact in physics

SBS-SIDIS Experiment Configuration Details



Trigger:

- BB Lead Glass ($E_{e'}$>1 GeV)
- HCAL (p_h>2.0 GeV)

Single spectrometer setting

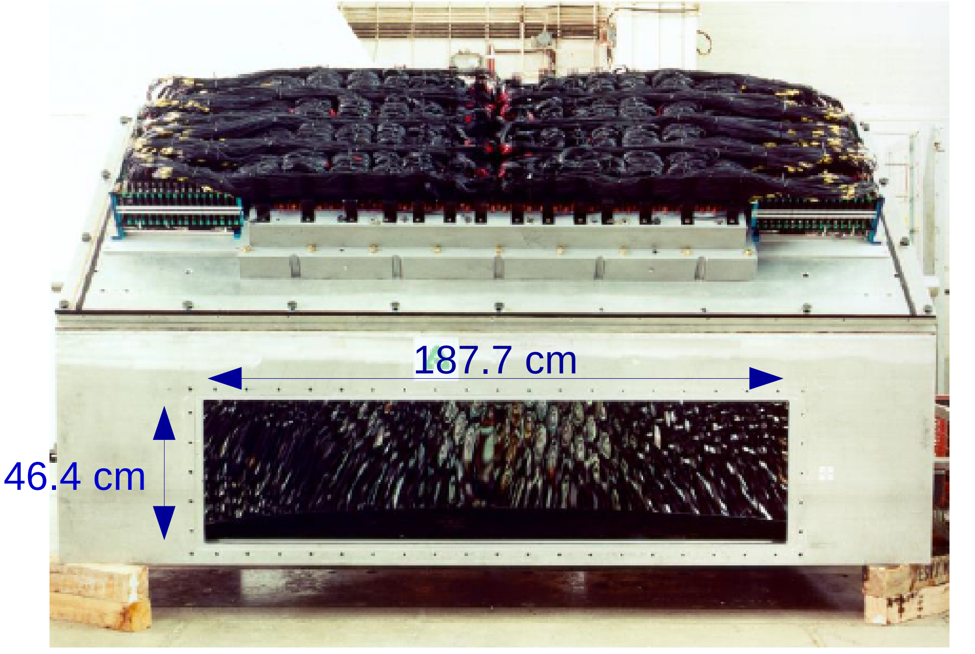
Two beam energy settings: 8.8 and 11 GeV (x 2 target orientations)

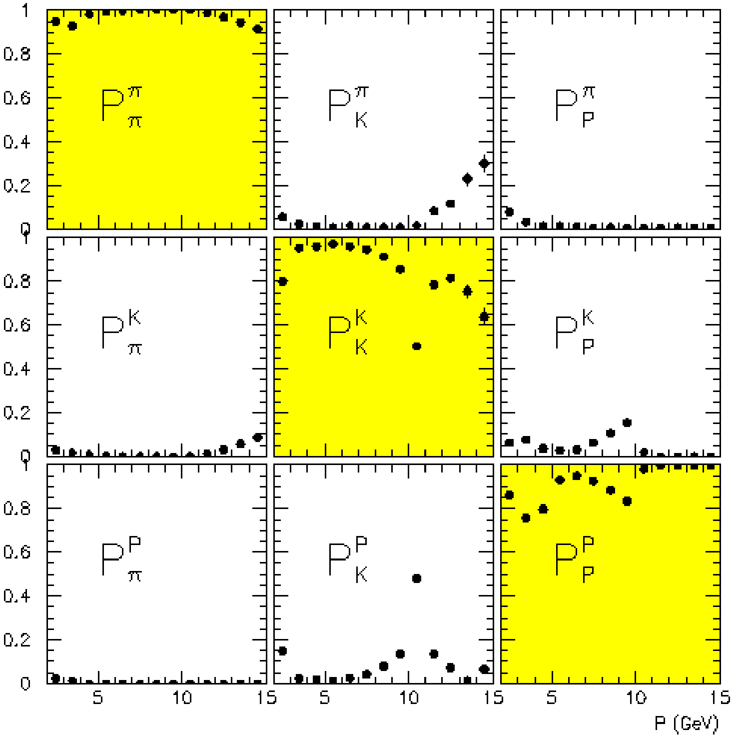
- **Electron Arm**: upgraded BigBite (exploited in upcoming FF SBS experiments)
  - GRINCH: pion rejection (and photon rejection in trigger)
  - Lead-glass calo: trigger and additional pion rejection
- **Hadron Arm**:
  - HERMES RICH: h-PID
  - HCAL (as far away from target as possible without compromising acceptance)
    - trigger, course spatial constraint for RICH and GEM
    - ToF for low momenta charged hadrons
    - neutral pion reconstruction

Move RICH in front of GEM (respect to original proposal) to increase acceptance

The HERMES RICH becomes the SBS RICH

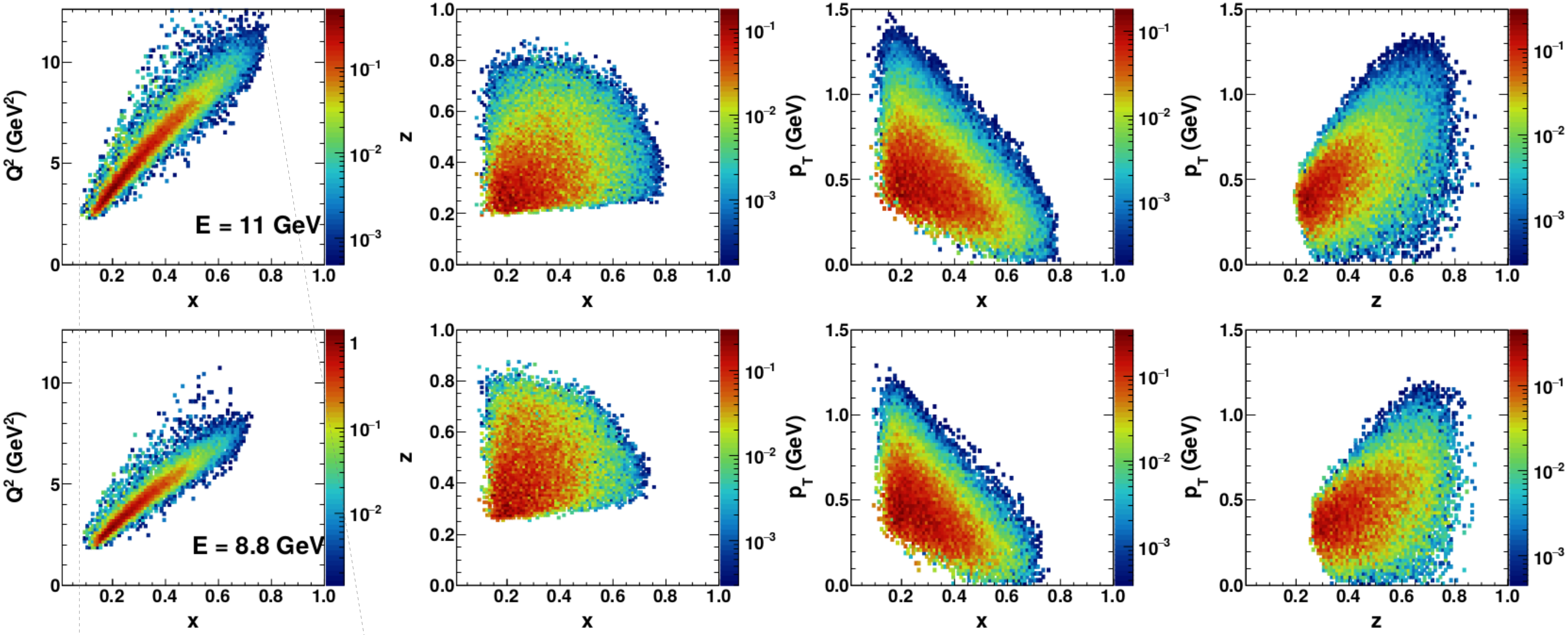
- The dual radiator HERMES RICH operated very well and stable from 2 GeV/c to more that 10 GeV/c
- We had chance to preserve one of the two HERMES RICH (and spare PMTs and aerogel tiles)
- HERMES RICH (rotated) fits reasonably well in SBS acceptance
- High segmentation (~2000 PMTs) with new NINO-chip based front-end electronics read out by VETROC back-end modules → estimated <0.1% PMT occupancy.
- Expected to provide excellent p-K-π separation

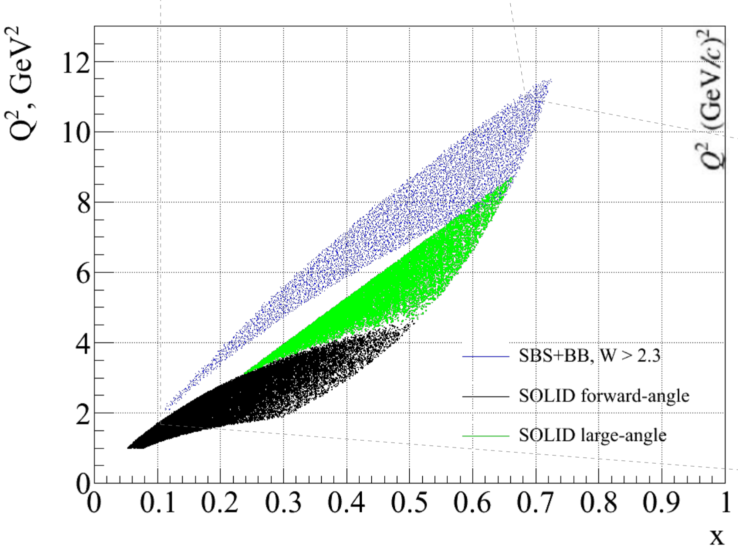


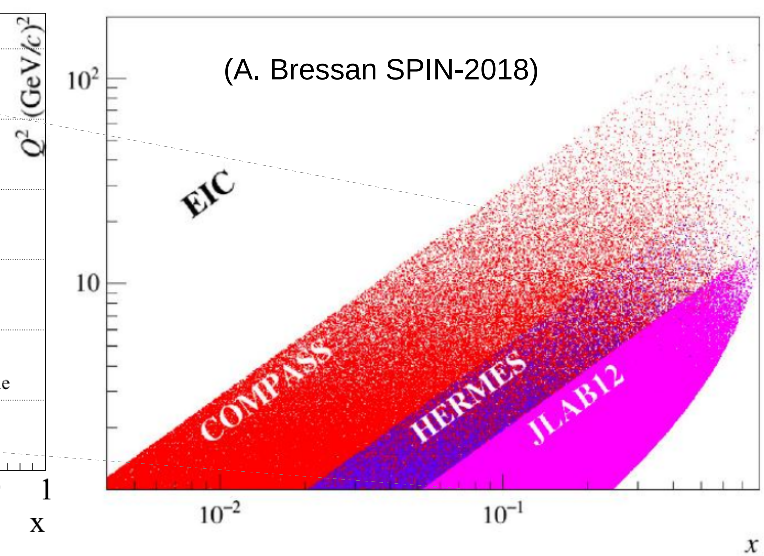


SBS SIDIS Kinematic Coverage

A.J.R. Puckett g4sbs





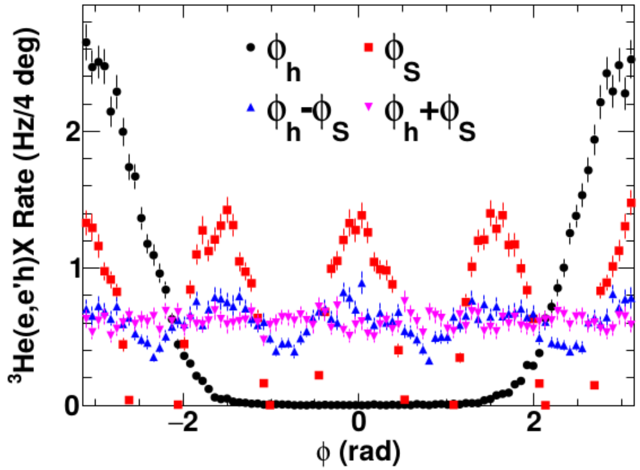


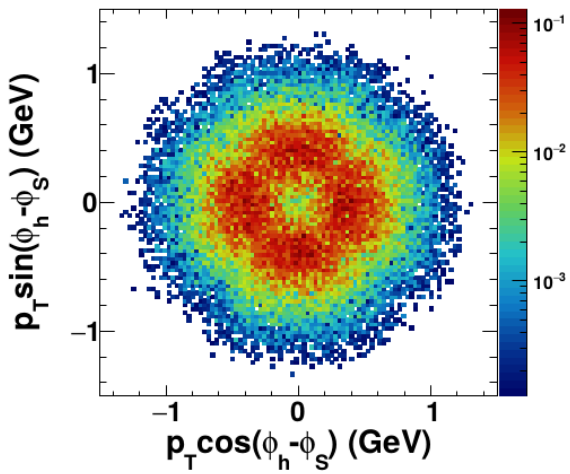
Cuts applied:
$Q^2 \geq 1$ GeV^2 ,
$W^2 \geq 4$ GeV,
$M^2_X \geq 2.3$ GeV^2,
$E'e \geq 1$ GeV,
$p_h \geq 2$ GeV,
and good tracks/signals required in all relevant SBS+BB detectors

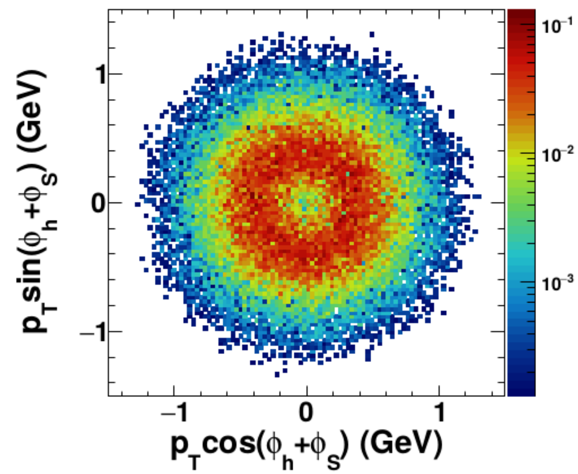
Azimuthal coverage

$h = \pi^+, \pi^-, K^+, K^-$

$^3\text{He}(e, e'h)X$ @ 11 GeV

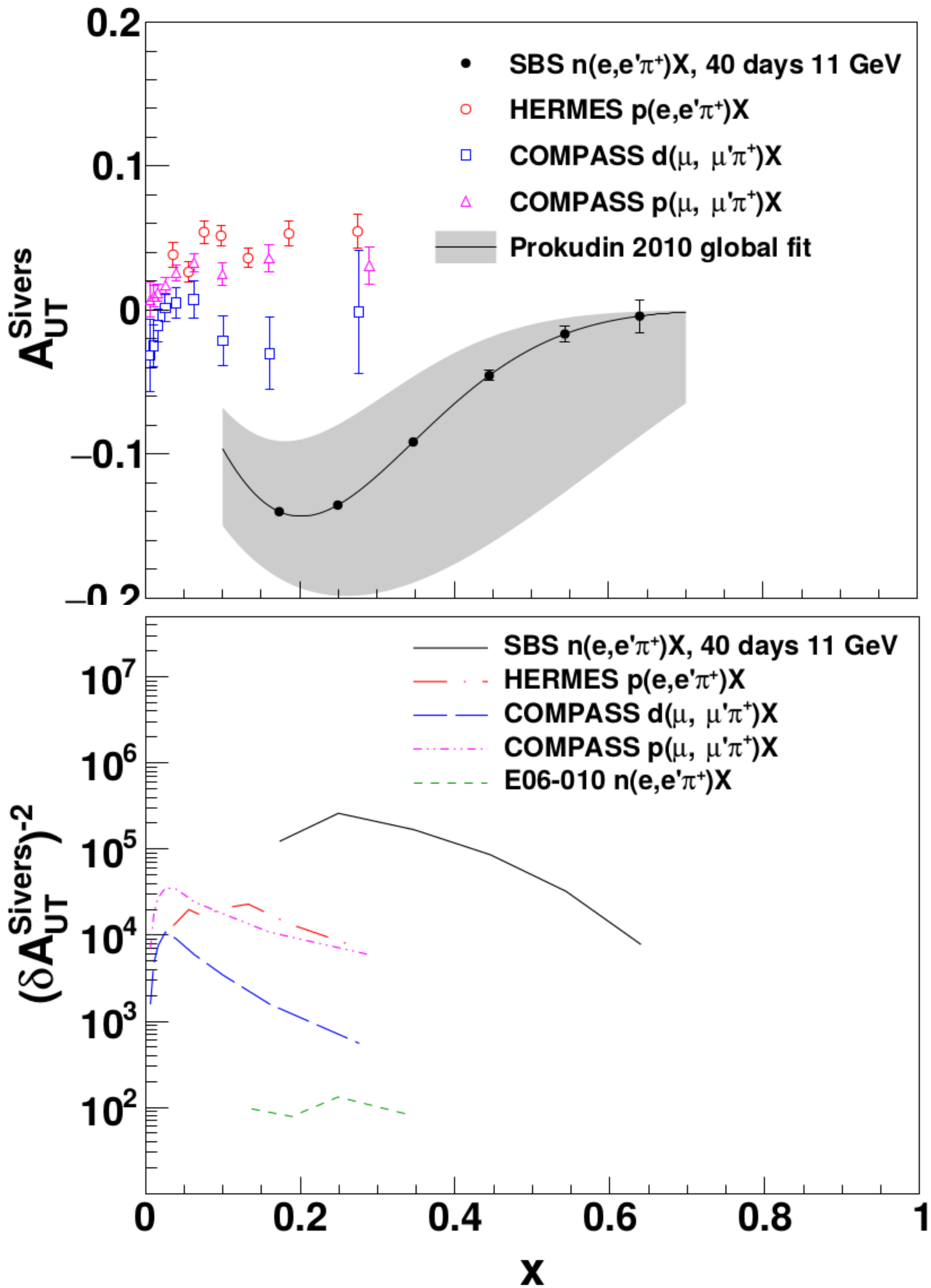






- Rate-weighted coverage with 4 target spin directions (instead of the 8 originally considered in the proposal) → no reduction of physics sensitivity
- Azimuthal coverage independent from the charged hadron species, slightly better in 8.8 GeV
- pi0 coverage slightly worse than charged hadrons due to reduced acceptance

Expected Physics Impact (on Sivers)



Projected statistics

($\Delta x = 0.1$, $0.1 \leq x \leq 0.7$)

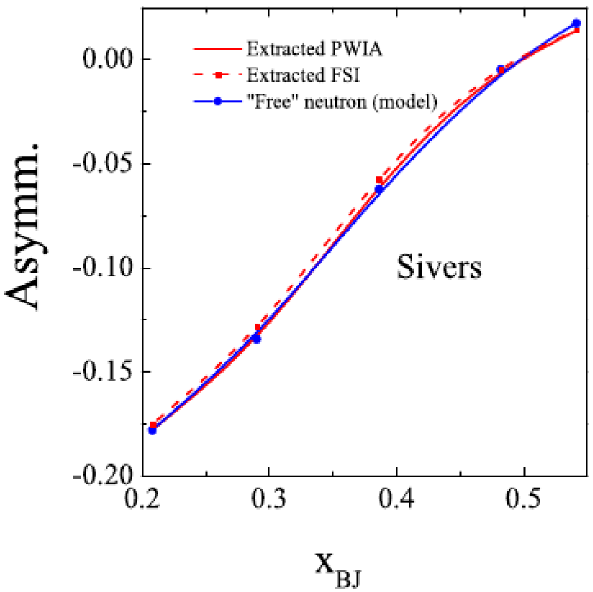
	Time (day)
Production run at $E = 11$ GeV	40
Production run at $E = 8.8$ GeV	20
Calibration Runs	2
Target maintenance and configuration changes	2
Total	64

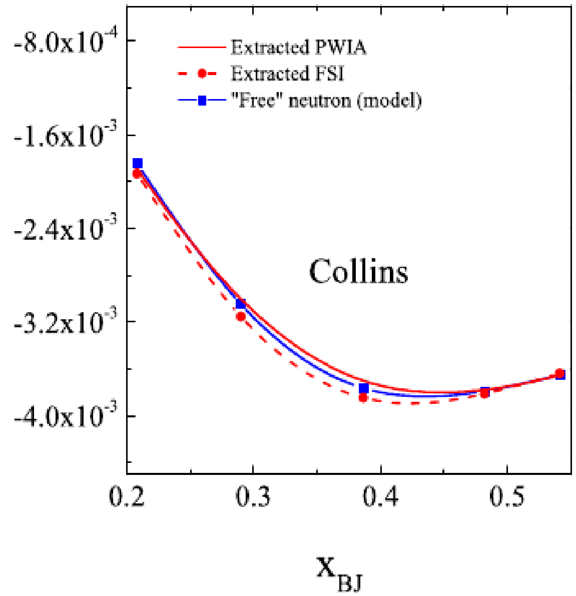
+ Target pol. change (no beam) 1 week (additional request)

Figure of Merit

not corrected for different x bin widths of published data, significantly understates SBS advantage for $x \geq 0.1$

FSI in ^{3}He distorted spectral function





1) **PWIA:** $\langle p_n \rangle = 0.876$, $\langle p_p \rangle = -0.0237$, $\theta_e = 30^o$, $\theta_\pi = 14^o$

E_{beam}, GeV	x_{Bj}	ν GeV	p_π GeV/c	$f_n(x,z)$	$\langle p_n \rangle f_n$	$f_p(x,z)$	$\langle p_p \rangle f_p$
8.8	0.21	7.55	3.40	0.304	0.266	0.348	-8.410^{-3}
8.8	0.29	7.15	3.19	0.286	0.251	0.357	-8.510^{-3}
8.8	0.48	6.36	2.77	0.257	0.225	0.372	-8.910^{-3}
11	0.21	9.68	4.29	0.302	0.265	0.349	-8.310^{-3}
11	0.29	9.28	4.11	0.285	0.25	0.357	-8.510^{-3}

2) **FSI:** $\langle p_n \rangle = 0.756$, $\langle p_p \rangle = -0.0265$, $\langle N_n \rangle = 0.85$, $\langle N_p \rangle = 0.87$, $\langle \sigma_{eff.} \rangle = 71\ mb$

E_{beam}, GeV	x_{Bj}	ν GeV	p_π GeV/c	$f_n(x,z)$	$\langle p_n \rangle f_n$	$f_p(x,z)$	$\langle p_p \rangle f_p$
8.8	0.21	7.55	3.40	0.353	0.267	0.405	-1.110^{-2}
8.8	0.29	7.15	3.19	0.332	0.251	0.415	-1.110^{-2}
8.8	0.48	6.36	2.77	0.298	0.225	0.432	-1.210^{-2}
11	0.21	9.68	4.29	0.351	0.266	0.405	-1.10^{-2}
11	0.29	9.28	4.11	0.331	0.250	0.415	-1.110^{-2}

$$\mathrm{A_n} \simeq \frac{1}{\mathrm{p_n^{FSI}\ f_n^{FSI}}}\left(\mathrm{A_3^{exp}} - 2\mathrm{p_p^{FSI} f_p^{FSI} A_p^{exp}}\right) \simeq \frac{1}{\mathrm{p_n\ f_n}}\left(\mathrm{A_3^{exp}} - 2\mathrm{p_p f_p A_p^{exp}}\right)$$

L. Kaptare et al. PRC 89 (2014)
A. DelDotto et al. PRC95 (2017)

- The effective polarizations $p_{p(n)}$ differs by 15-20%, but they have to be considered in combination with the dilution factor → the products in the asymmetries extraction change very little
- The extraction procedure seems to be safe
- The extraction procedure can be carefully tested in MC simulating the phase space of the JLab ^{3}He target dedicated experiments

Courtesy of Alessio Del Dotto

Conclusions

E12-09-18/SBS-SiDIS jeopardy proposal submitted to PAC49

It has progressed to an advanced stage of readiness: science case not changed since PAC38 (likely strengthened)

Its technical feasibility improved and grown stronger since PAC38

E_e (GeV)	Days	$^3\mathrm{He}(e,e'\pi^+)X$ Events/10^6	$^3\mathrm{He}(e,e'\pi^-)X$ Events/10^6	$^3\mathrm{He}(e,e'K^+)X$ Events/10^6	$^3\mathrm{He}(e,e'K^-)X$ Events/10^6	$^3\mathrm{He}(e,e'\pi^0)X$ Events/10^6
11	40	104	69	14	2.4	17
8.8	20	101	57	14	2.1	15

TABLE I. Total projected $^3\mathrm{He}(e,e'h)X$ statistics in the PAC38-approved E12-09-018 beam time at 11 and 8.8 GeV by hadron, after applying all relevant calorimeter, track, and Cherenkov cuts in both spectrometers. Kinematic cuts applied are $Q^2 > 1$ GeV^2, $W^2 > 4$ GeV^2, $M_X^2 > 2.3$ GeV^2, $p_T \geq 0.05$ GeV, $E_e' \geq 1$ GeV and $p_h \geq 2$ GeV. In addition, adequate signals in the BigBite and SBS detectors were required as described in the text. Full statistical projections for Collins and Sivers asymmetries $\vec{n}(e,e'h)X$, as evaluated for the original PAC38 proposal, are tabulated in Ref. [39].