SBS SIDIS update

E12-09-018: Measurement of Semi-Inclusive pion and kaon electro-production in DIS regime from transversely polarized ^{3}He target with the SBS and BigBite spectrometers in Hall A

- Proposed and conditionally approved in 2009 by PAC 34
- Fully approved in 2011 by PAC 38
- Past jeopardy (with no changes) in 2021 PAC 39

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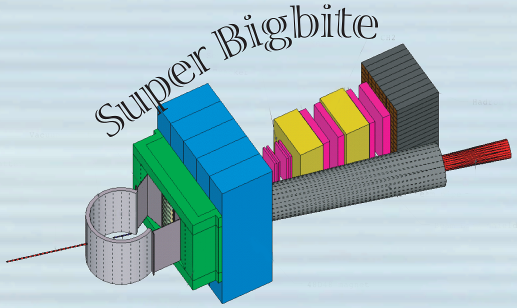
February 11, 2022

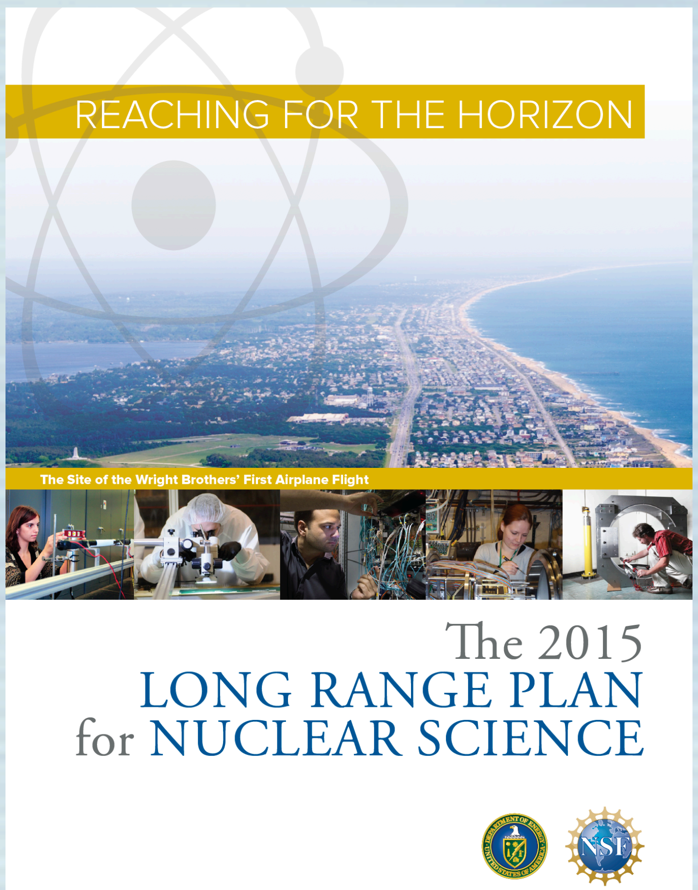


UNIVERSITY of VIRGINIA

Jefferson Lab
EXPLORING THE NATURE OF MATTER

SBS SIDIS is explicitly mentioned in the 2015 Long Range Plan

TMDs play a critical role in understanding the nucleon's properties and its dynamics.

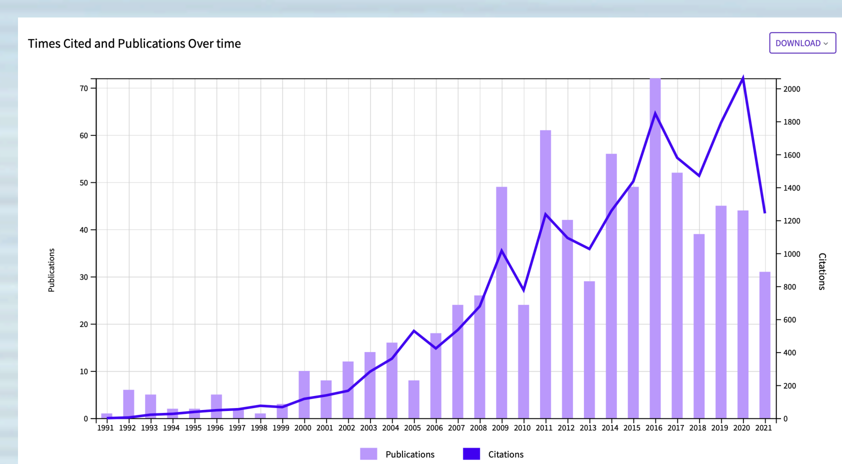


SBS SIDIS was explicitly mentioned in the 2015 Long Range Plan.

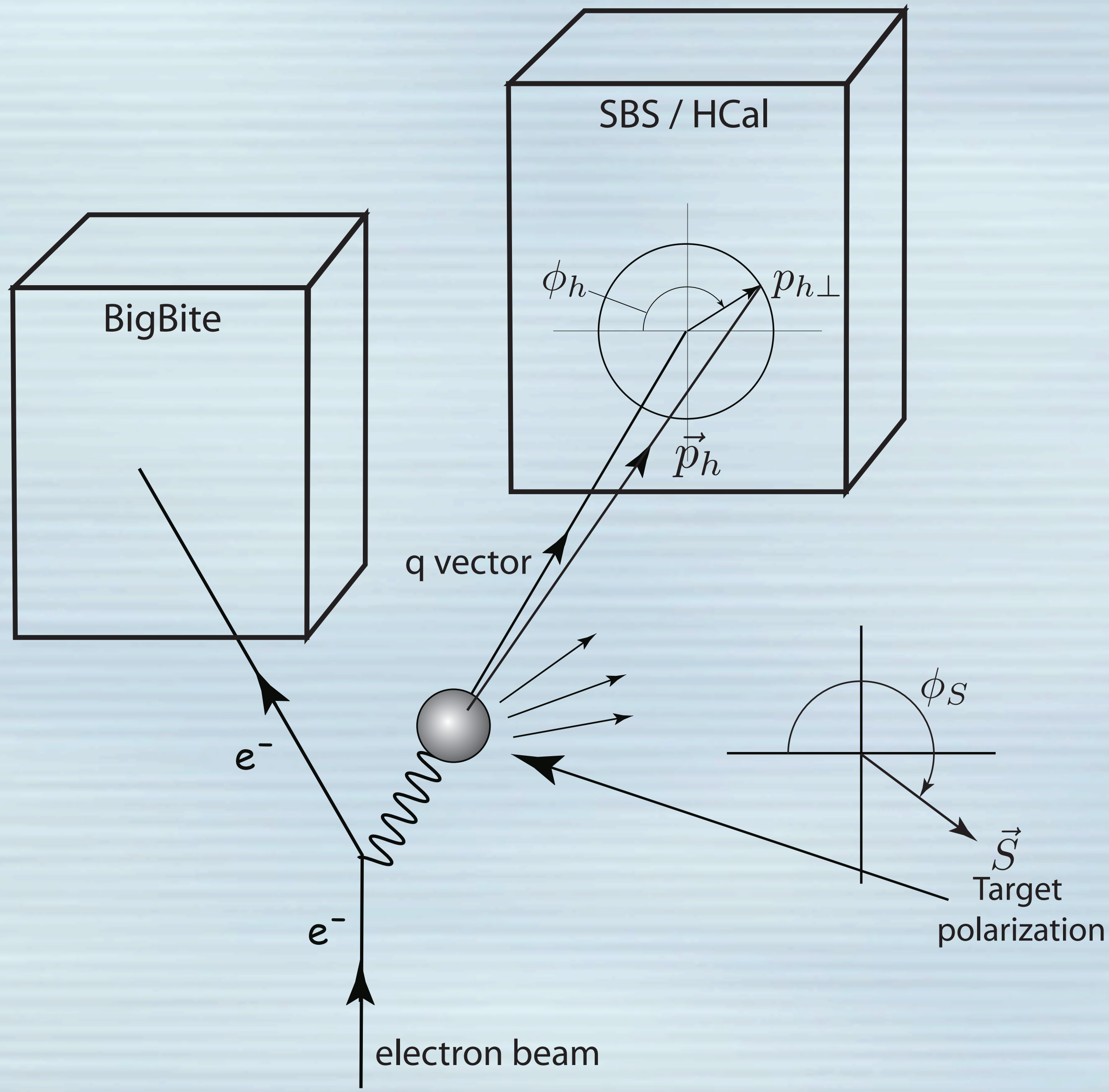
A nonzero Sivers function is considered to be strong evidence for the presence of quark orbital angular momentum. Indeed, it has been measured to be nonzero in the HERMES and JLab experiments.

Multiple instruments bring essential elements to this campaign: SBS, CLAS12, HMS-SHMS, and the proposed NPS. Finally, the proposed multipurpose SoLID detector (see Figure 2.6) would realize the full potential of the upgraded CEBAF.

Publications on TMDs have grown enormously since the 90's but may be dropping off with a dearth of data...



The concept behind the SBS SIDIS experiment



By judicious positioning of the hadron arm, even moderate solid angle results in excellent statistics.

$$e + {}^3\mathrm{He}^{\uparrow} \rightarrow e' + \pi^0 + X$$

$$e + {}^3\mathrm{He}^{\uparrow} \rightarrow e' + \pi^{\pm} + X$$

$$e + {}^3\mathrm{He}^{\uparrow} \rightarrow e' + \mathrm{K}^{\pm} + X$$

- Electron is detected in BigBite
- Leading hadron is detected in HCal
- ϕ_h is the angle of the leading hadron around q with respect to the scattering plane.
- ϕ_S is the angle of the target polarization around q with respect to the scattering plane.
- Polarized ^{3}He target has flexibility to orient polarization relatively freely in the plane perpendicular to q.

Single-Spin Asymmetries (flipping the target spin) contain several angular-dependent terms

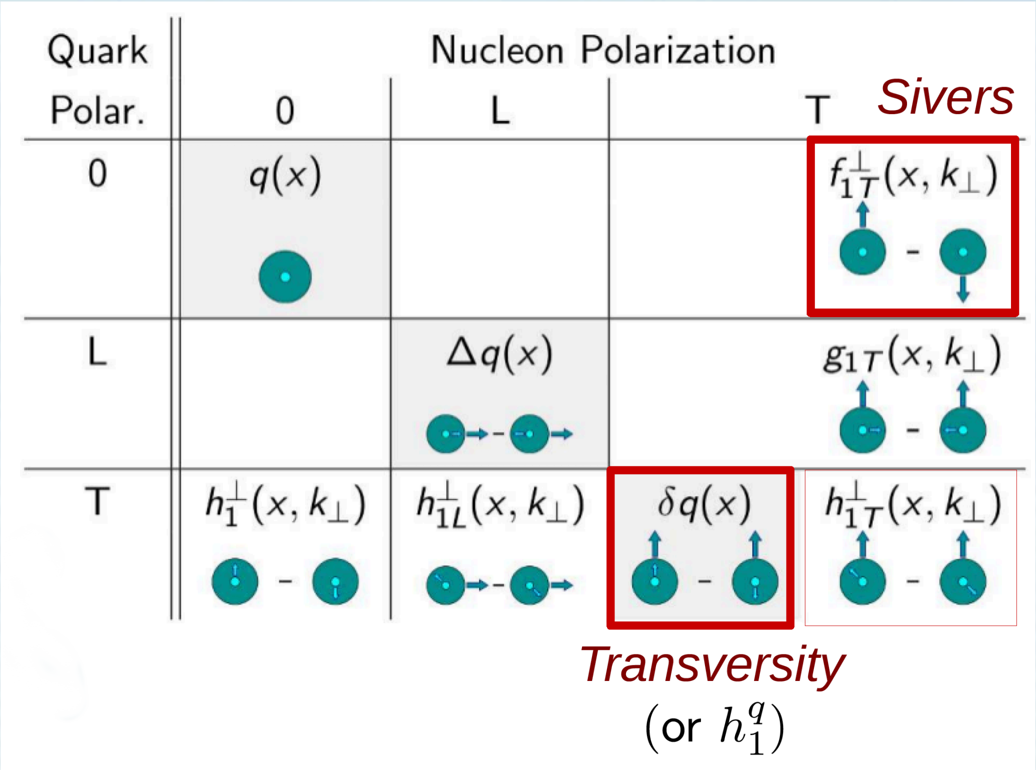
$$A_{UT} \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} - d\sigma^{\downarrow}}$$

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

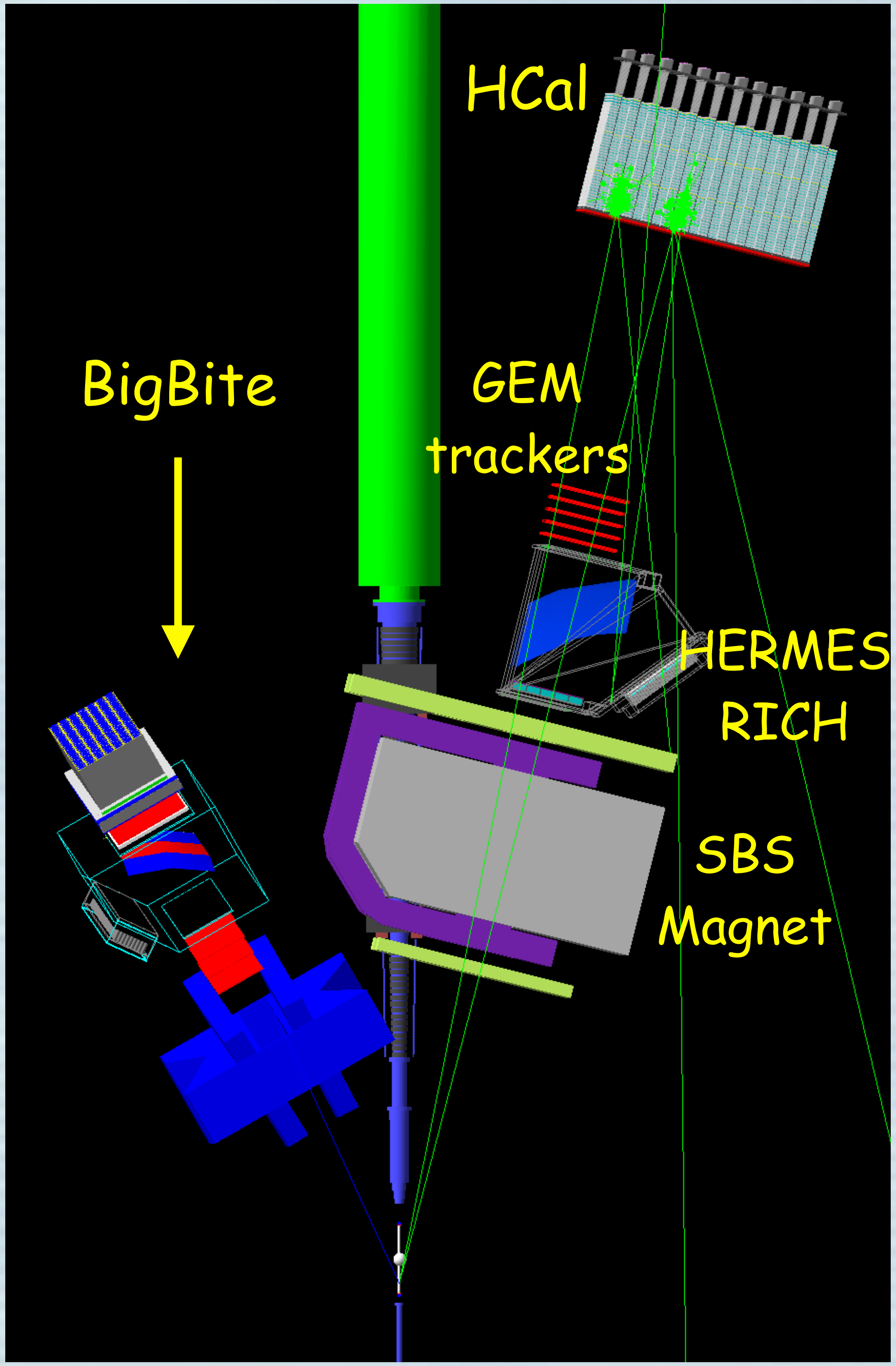
$$A_{UT}^{Collins} \sin(\phi_h + \phi_S) \sim \sum_q e_q^2 [\delta q^q \otimes H_{1q}^{\perp}]$$

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

- The Sivers function - correlations between transverse momentum and the nucleon spin.
- The Collins asymmetry - probing the transverse polarization of the quarks.
- Pretzelosity - interference between OAM wave functions differing by two units

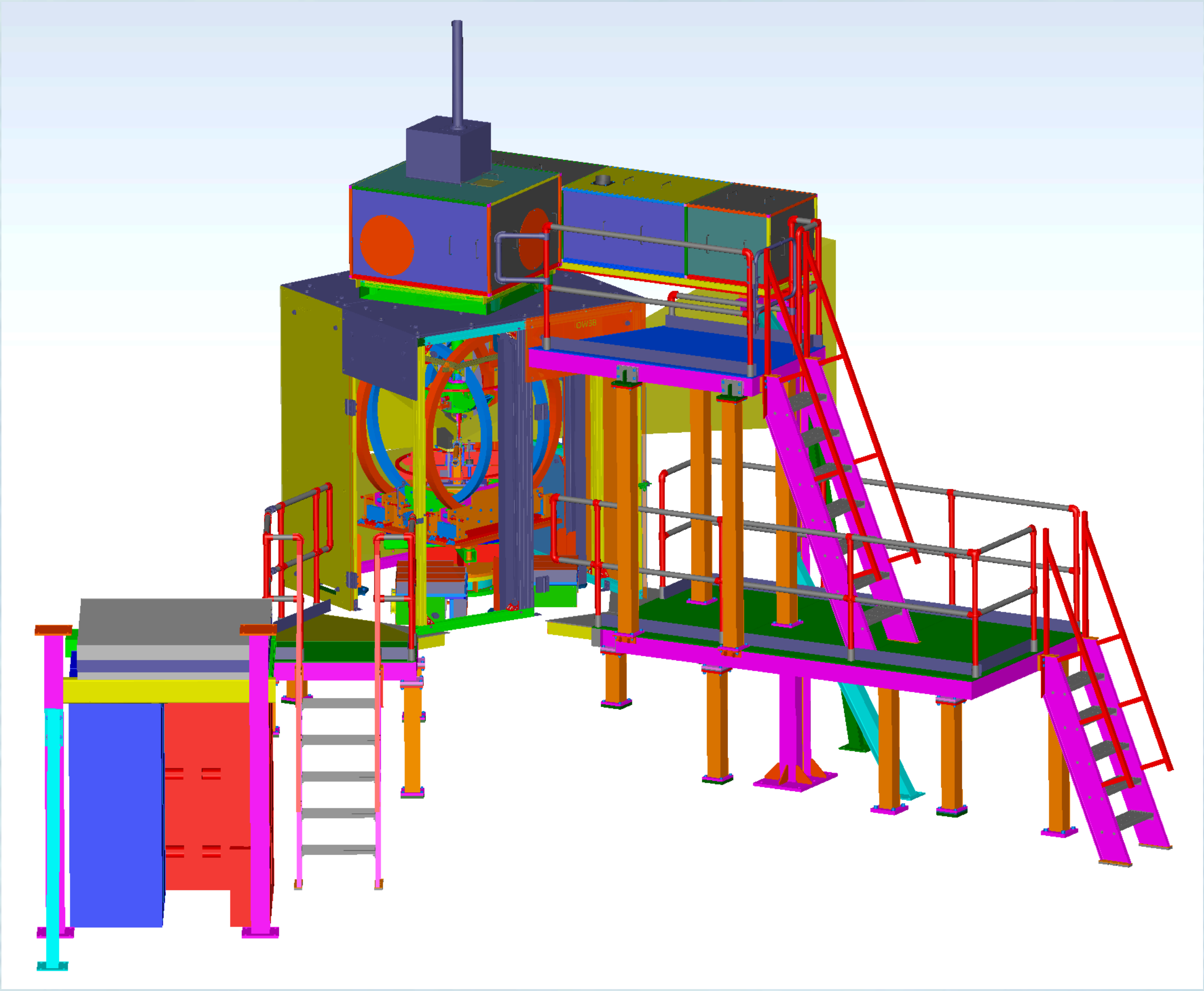


The SBS SIDIS Experiment



- Both the electron and hadron arms will use large open-geometry dipoles with large momentum acceptance and ~1% resolution.
- Electron arm, at 30 degrees, will use the BigBite spectrometer with ~45 msr acceptance.
- The hadron arm, at 14 degrees, will use the SBS magnet, the HERMES RICH for particle ID and HCal, a hadron calorimeter.
- Very-high luminosity (~5×10^{36} $cm^{-2}s^{-1}$) polarized ^3He target, capable of rapid spin-flips in either the vertical or horizontal directions.
- ALL data collected with a single setting at each of two energies, 8.8 and 11 GeV.

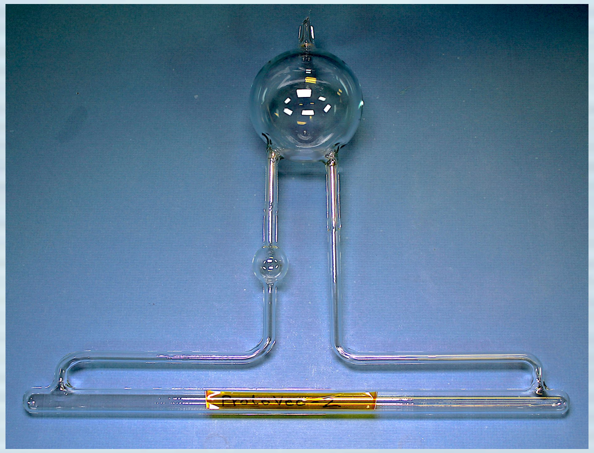
The SBS SIDIS
Polarized ^{3}He Target

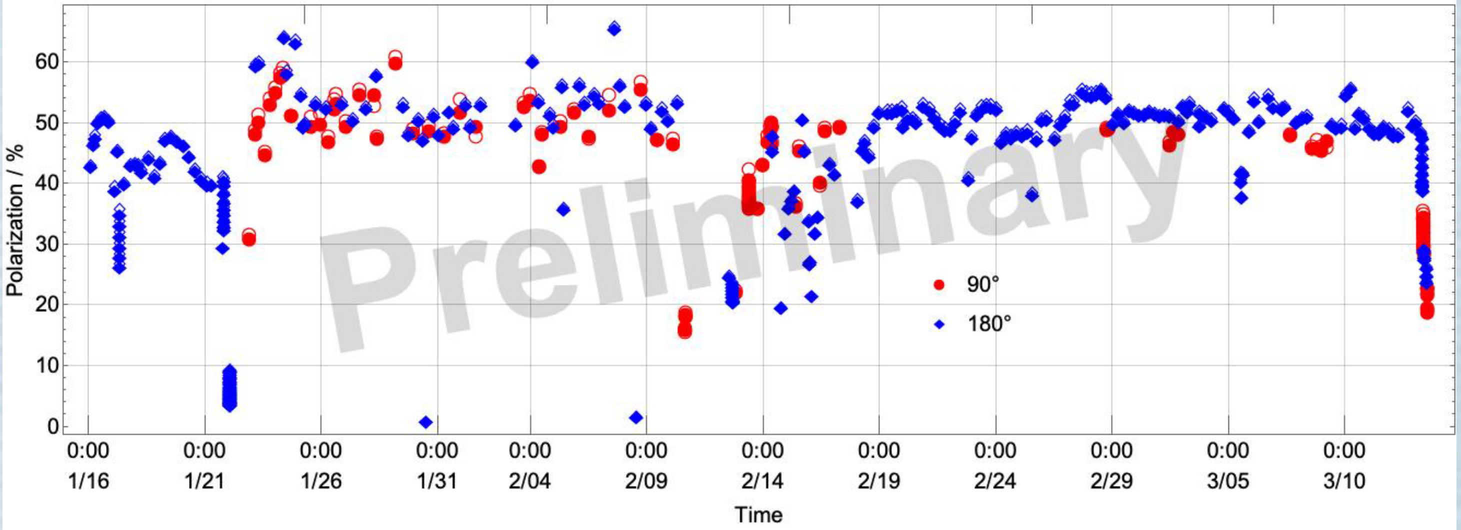


- Essentially the SBS G_E^n polarized ^{3}He target with small modifications
  - Will add capability for vertical polarization
- Magnetic shielding protects target from SBS and BigBite magnet fringe fields.
- For both SIDIS and G_E^n, the quantity of ^{3}He is twice what was used for recent Hall C experiments.
- Double the luminosity follows from twice the ^{3}He and twice the laser power.
- Note: Hall C A_1^n experiment, (with twice the luminosity of previous experiments) ran with performance essentially identical to expectations from simulated beam tests.

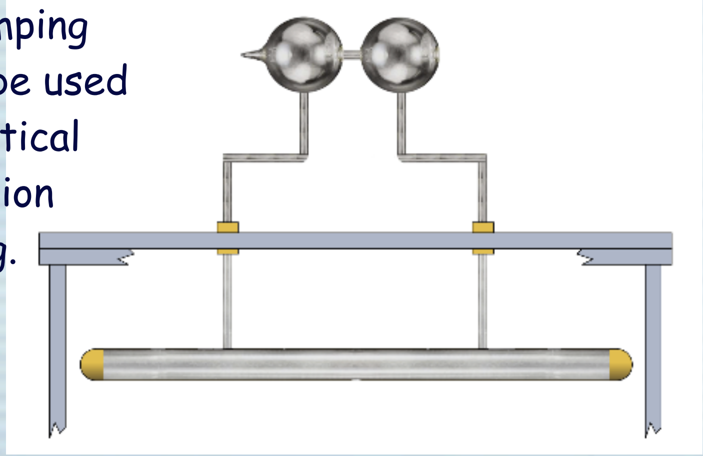
The SBS SIDIS
Polarized ^{3}He Target

Shown is Mike Souza, our Princeton glassblower, holding a G_E^n prototype target cell.





Double pumping chamber to be used during vertical polarization running.



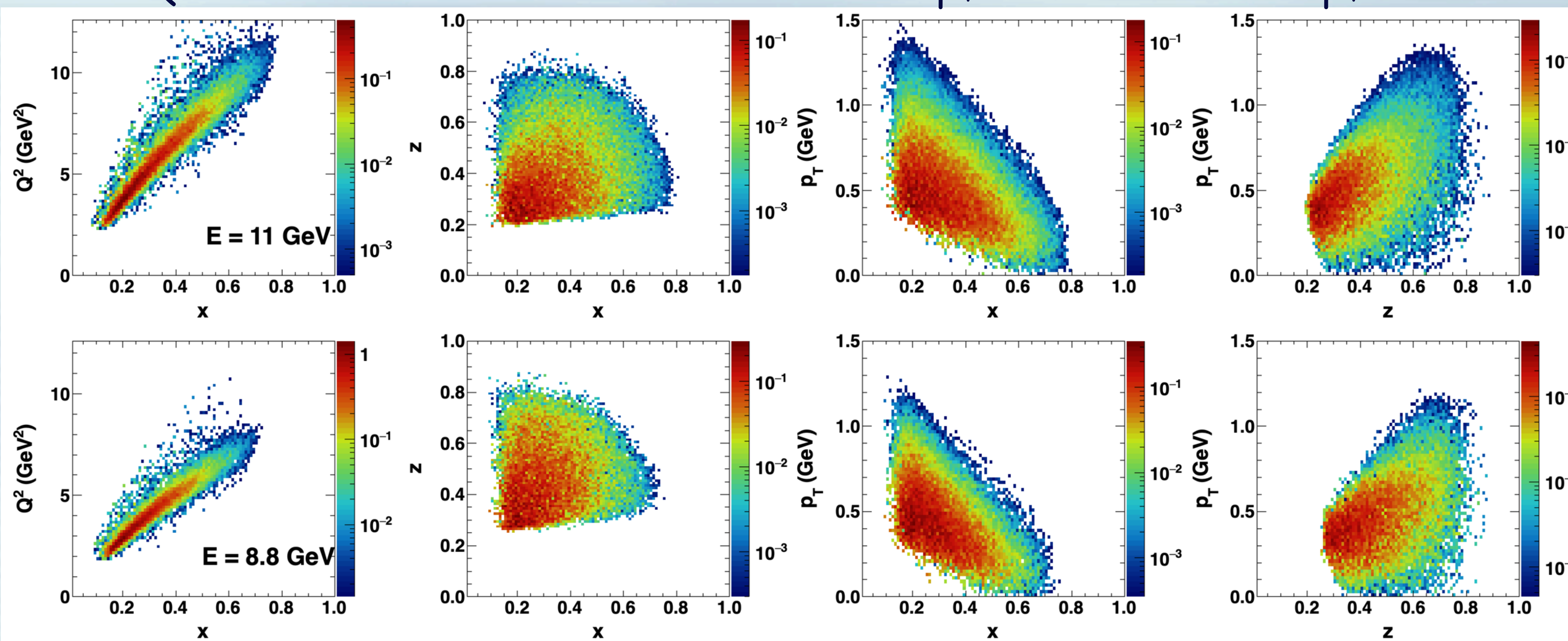
- The Hall C polarized ^{3}He target was the first used at JLab with the so-called "convection design", permitting full control of the movement of gas between the pumping and target chambers.
- The figure-of-merit of the Hall C A_1^n target was over twice that achieved with a polarized ^{3}He target anywhere.
- As noted earlier, it ran with performance essentially identical to expectations from simulated beam tests.

Requirements for TMD formalism to apply

- Large $Q^2 > 1$ GeV^2 and $W > 2$ GeV as in DIS
- Large but not too large $z = E_h/\nu$
  - 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.)
- Also want $p_\perp/z \ll Q$, but just how much less is as yet not clear.

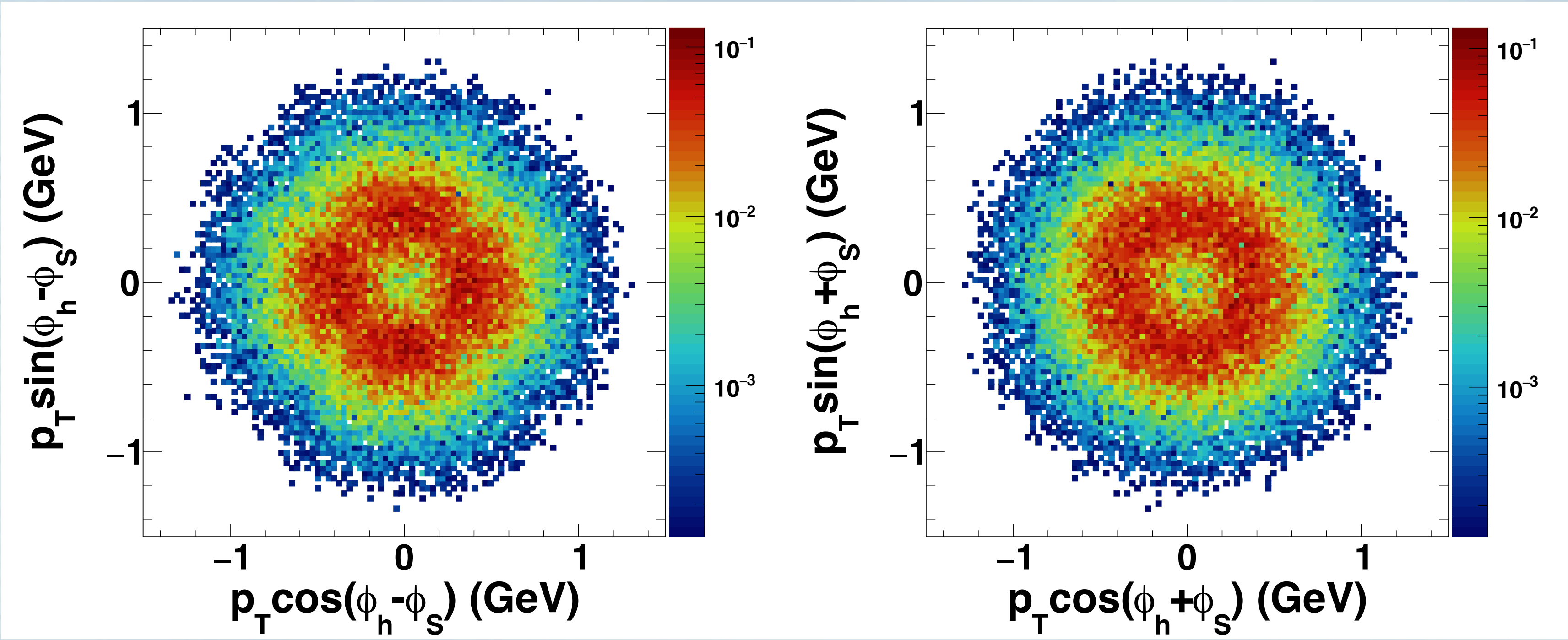
The SBS SIDIS kinematic coverage

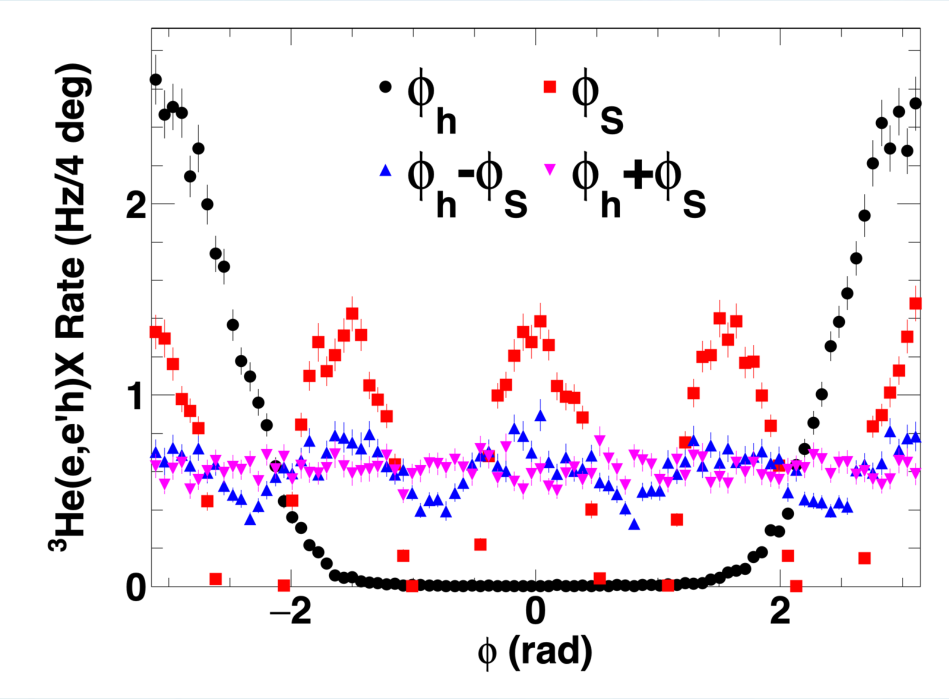
Q^2 vs. x | z vs. x | p_T vs. x | p_T vs. z



- $Q^2 > 1$ GeV^2
- $W^2 > 4$ GeV^2
- $M_X{}^2 > 2.3$ GeV^2
- $E'_e \geq 1$ GeV
- $p_h \geq 2$ GeV
- Good tracks on all relevant detectors

SBS SIDIS Azimuthal Coverage





- Our original proposal envisioned eight spin orientations.
- We find virtually unchanged azimuthal coverage (and overall FoM) with four.
- Limiting to four spin orientations greatly simplifies the polarized target, enabling the use of the G_E^n target with small changes.

Projected data for SBS SIDIS

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].

Compare, for example, with HERMES proton data

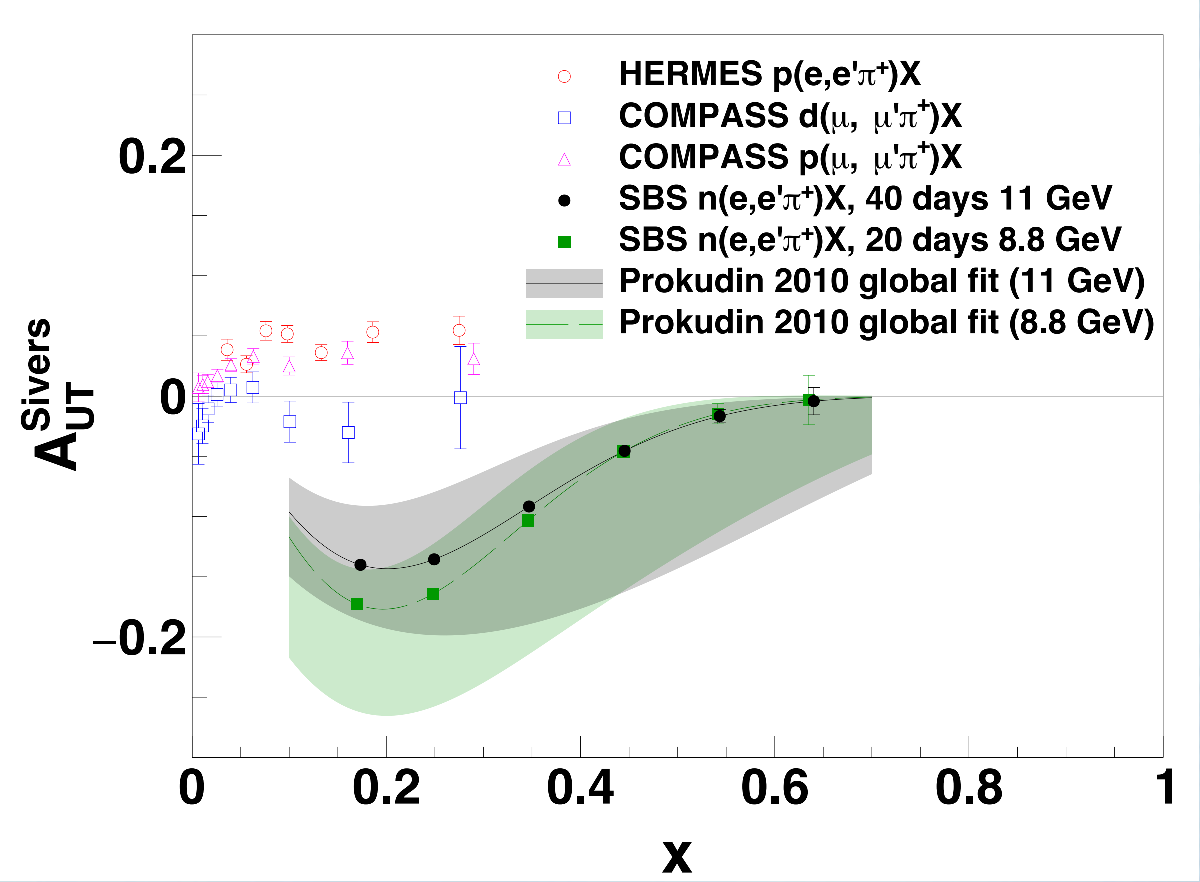
	π^+	π^0	π^-	K^+	K^-	p	$\bar{p}$
$0.2 < z < 0.7$	755k	158k	543k	136k	57k	94k	14k
$0.7 < z < 1.2$	68k	10k	40k	14k	1k	6k	<1k

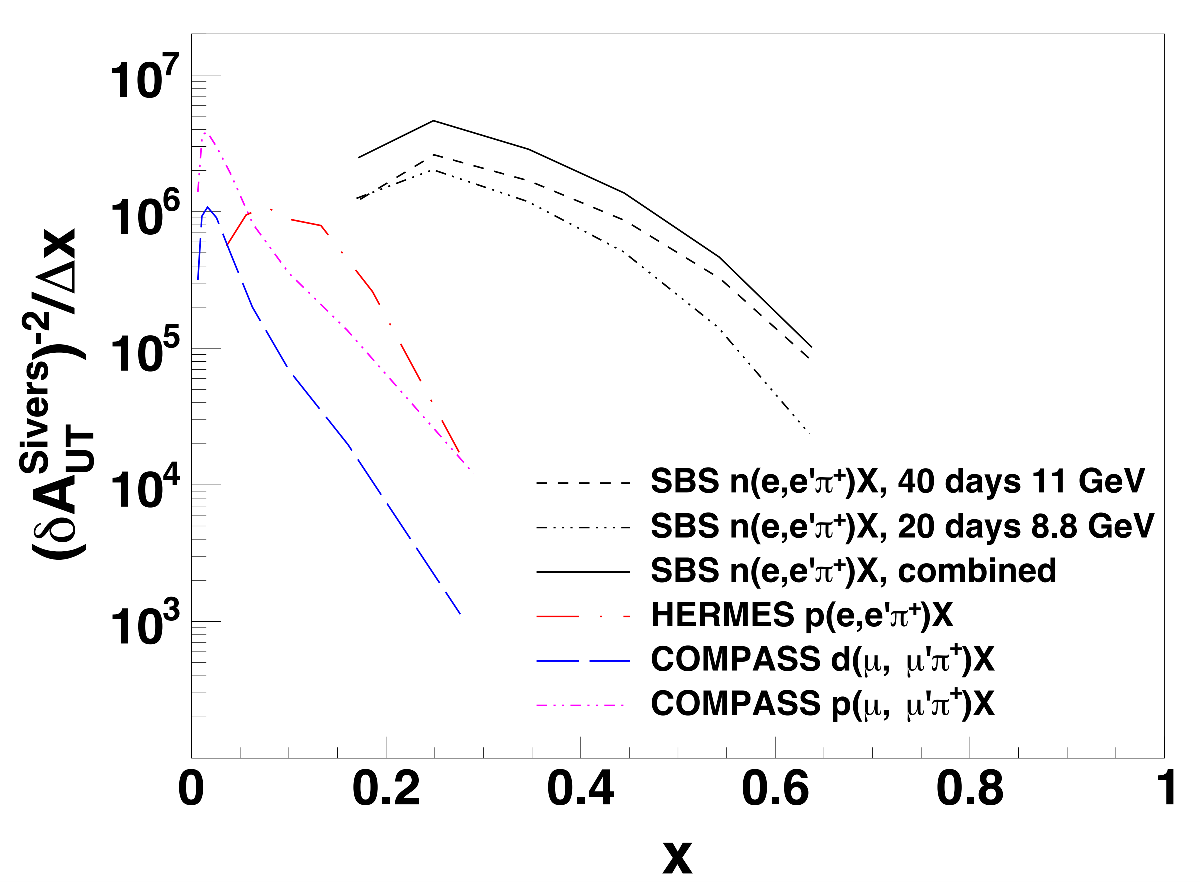
HERMES: from arXiv:2007.07755v1 [hep-ex] 15 Jul 2020

When dilution and polarization are taken into account, over all kinematics, the figure of merit is still more the x20 higher. For x > ~0.1, FoM is ~100 times higher

And of course, for the neutron, SBS dramatically changes the global picture.

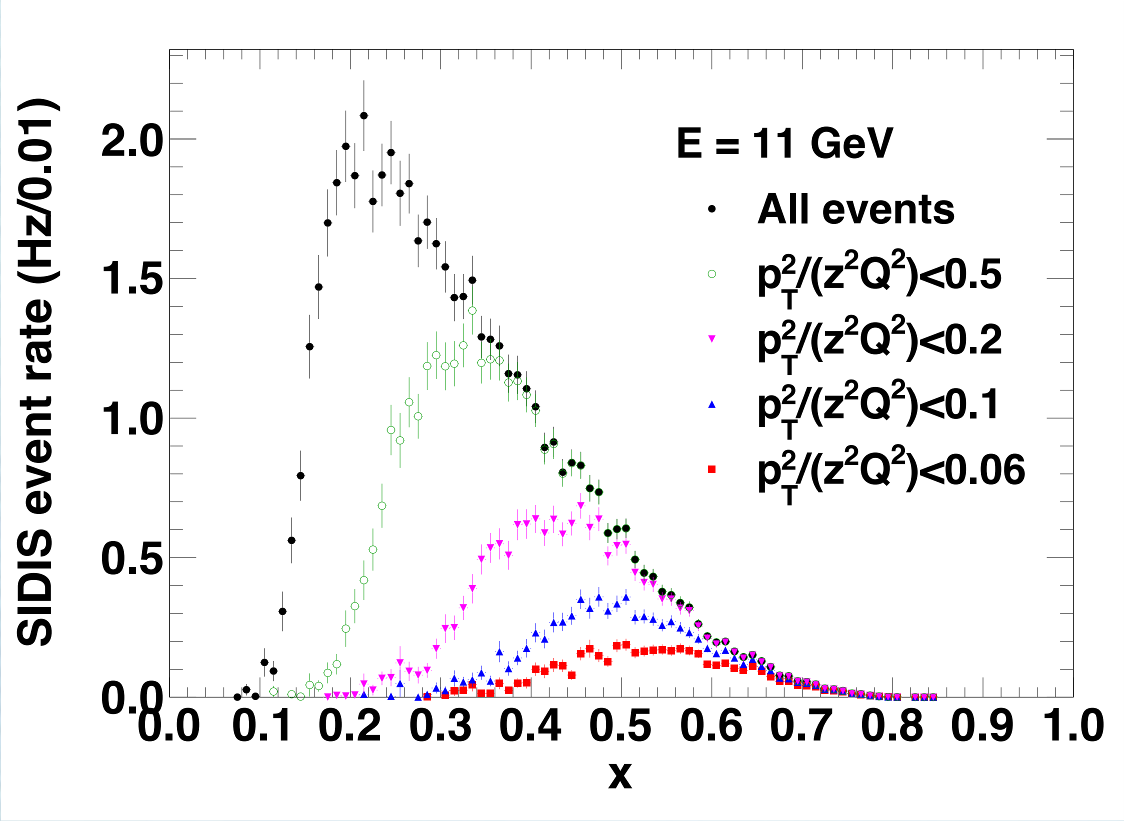
Comparing SBS SIDIS neutron data with existing data

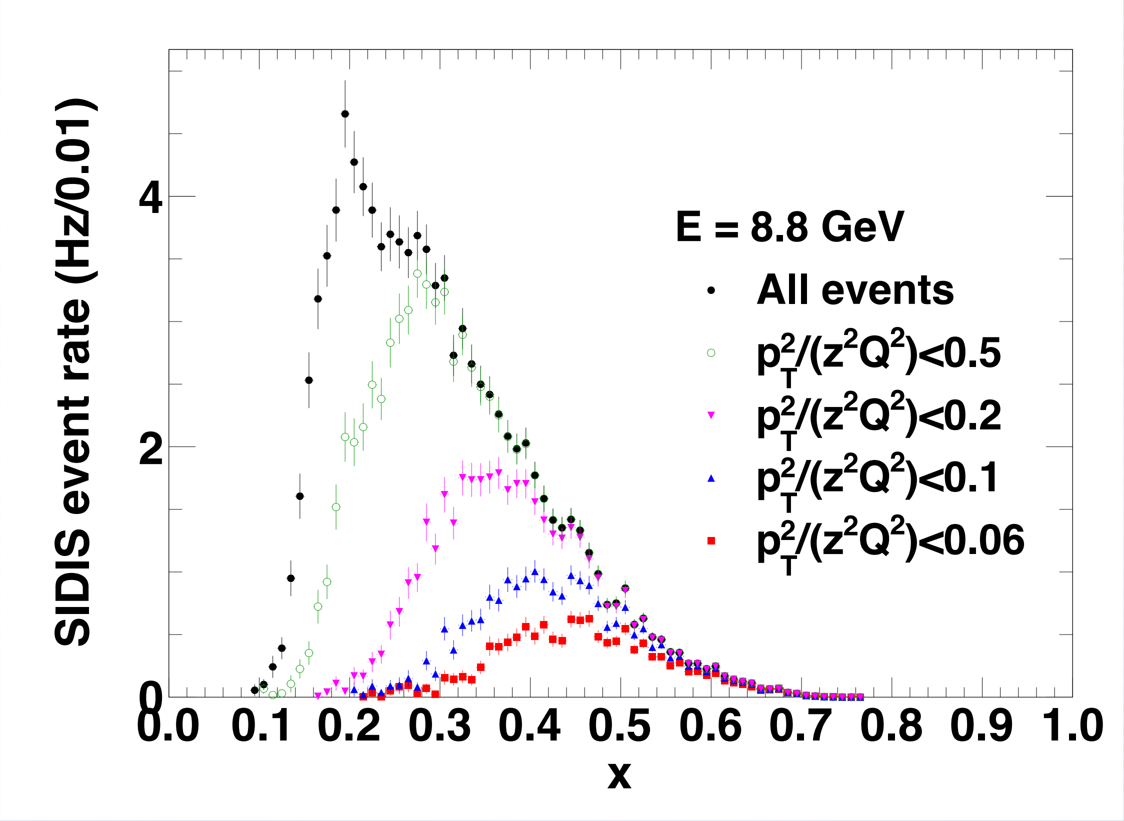




- SBS SIDIS will provide some of the most precise TMD data ever obtained on either the proton or the neutron.
- At higher values of x, roughly x > 0.1, it will completely dominate TMD measurements for many years to come.
- Note that once the new COMPASS deuteron data becomes available, the COMPASS neutron extraction should be roughly at the current level of their proton extraction.

Distribution of p_T^2/z^2Q^2 for SBS data



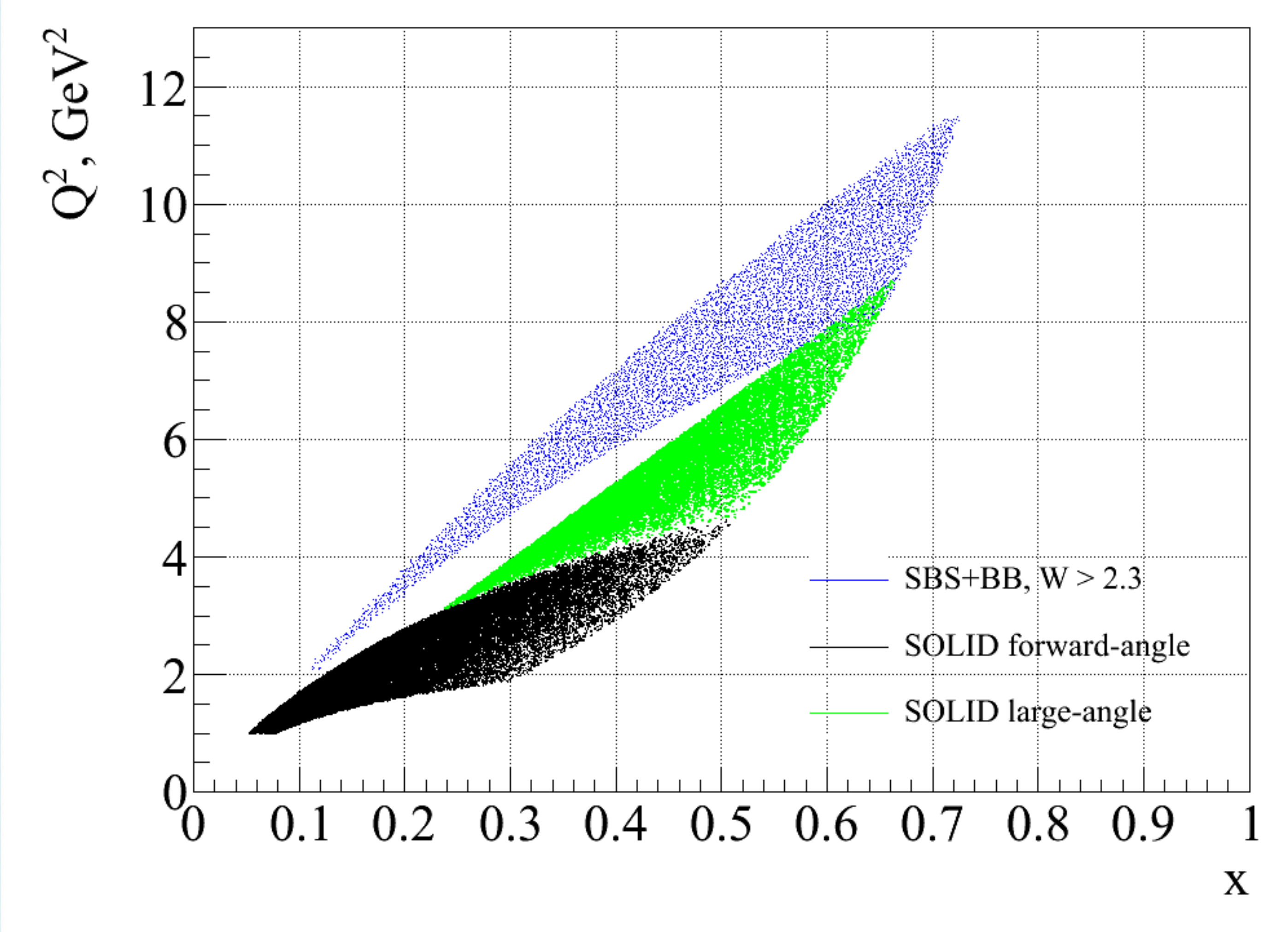


One global analysis by Scimemi[a] and Vladimirov suggests a limit of $p_T^2/z^2Q^2 < 0.06$, which would exclude virtually all of HERMES data and much of the COMPASS data

Other analyses, for example Bacchetta, suggest wider values are allowable.

SBS SIDIS will collect data over a range of values, permitting an empirical study of the dependence.

Complimentary to SIDIS with SoLID



- For each value of Bjorken x, SBS SIDIS will run at a higher value of Q^2
- Just as SBS SIDIS will increase statistics in transversely polarized TMD measurements for x > 0.1 by roughly x100, SoLID will increase statistics by another factor of roughly 100.
- We see SBS SIDIS as a critical step for progress in the field, as it will be the only game in town for transversely polarized TMDs for many years.

Most major components of SBS SIDIS are either already in use or will be shortly during GEn-II

Summary

- Prioritized in the 2015 Long Range Plan, the motivation to study single-spin asymmetries and TMDs in SIDIS has only gotten stronger
- There has been little to no experimental progress on transverse-polarized target single-spin asymmetries in SIDIS for over a decade.
- With the successful beginning of the SBS program, SBS SIDIS could run within the next few years.
- SBS SIDIS data would bring a new level of precision to the field, and would compliment both past and future (SOLID for example) experiments.
- SBS SIDIS NEEDS people - this is a great opportunity for the Hall A collaboration.

Backup slides

Details on projected π^+ data

8.8 GeV data

x	E' GeV	P_π GeV	W GeV	Q^2 GeV^2	z	$P_\perp$ GeV
0.20 ± 0.05	1.25 ± 0.16	3.40 ± 1.09	3.48 ± 0.08	2.93 ± 0.34	0.45 ± 0.25	0.61 ± 0.24
0.30 ± 0.05	1.65 ± 0.21	3.19 ± 1.02	3.21 ± 0.09	4.01 ± 0.33	0.45 ± 0.25	0.49 ± 0.21
0.40 ± 0.05	2.07 ± 0.23	3.02 ± 0.97	2.91 ± 0.09	5.03 ± 0.32	0.45 ± 0.25	0.37 ± 0.18
0.50 ± 0.05	2.44 ± 0.26	2.77 ± 0.88	2.62 ± 0.10	5.95 ± 0.33	0.44 ± 0.24	0.28 ± 0.14
0.60 ± 0.05	2.65 ± 0.22	2.53 ± 0.79	2.40 ± 0.06	6.70 ± 0.33	0.41 ± 0.24	0.23 ± 0.13

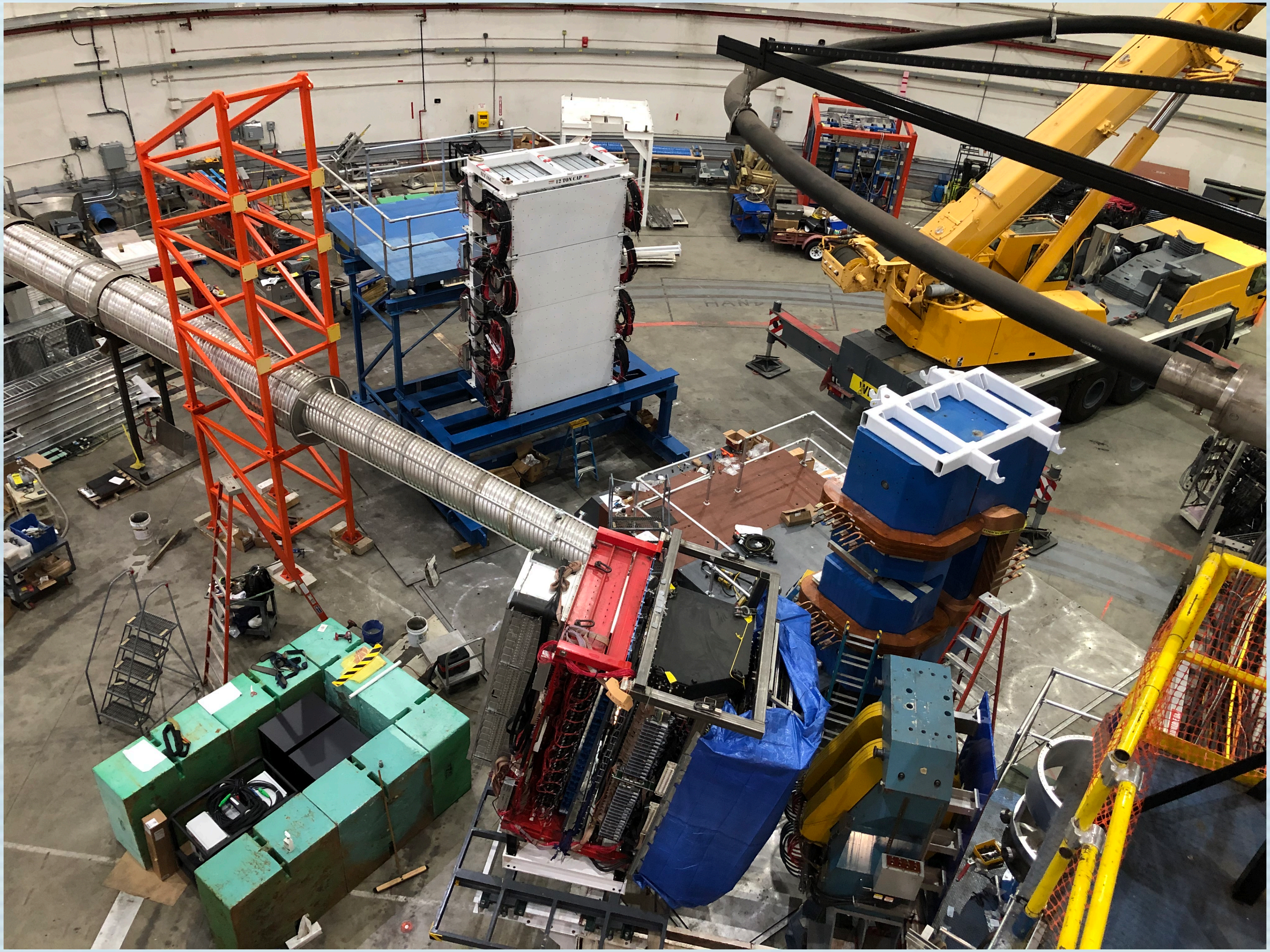
11 GeV data

x	E' GeV	P_π GeV	W GeV	Q^2 GeV^2	z	$P_\perp$ GeV
0.20 ± 0.05	1.32 ± 0.15	4.29 ± 1.37	3.91 ± 0.08	3.82 ± 0.43	0.44 ± 0.25	0.82 ± 0.30
0.30 ± 0.05	1.72 ± 0.23	4.11 ± 1.32	3.62 ± 0.10	5.20 ± 0.44	0.44 ± 0.25	0.69 ± 0.27
0.40 ± 0.05	2.17 ± 0.26	3.89 ± 1.24	3.30 ± 0.10	6.60 ± 0.42	0.44 ± 0.25	0.56 ± 0.24
0.50 ± 0.05	2.58 ± 0.28	3.71 ± 1.17	2.97 ± 0.10	7.86 ± 0.42	0.44 ± 0.25	0.45 ± 0.20
0.60 ± 0.05	2.97 ± 0.30	3.40 ± 1.08	2.64 ± 0.11	9.02 ± 0.44	0.42 ± 0.24	0.35 ± 0.17

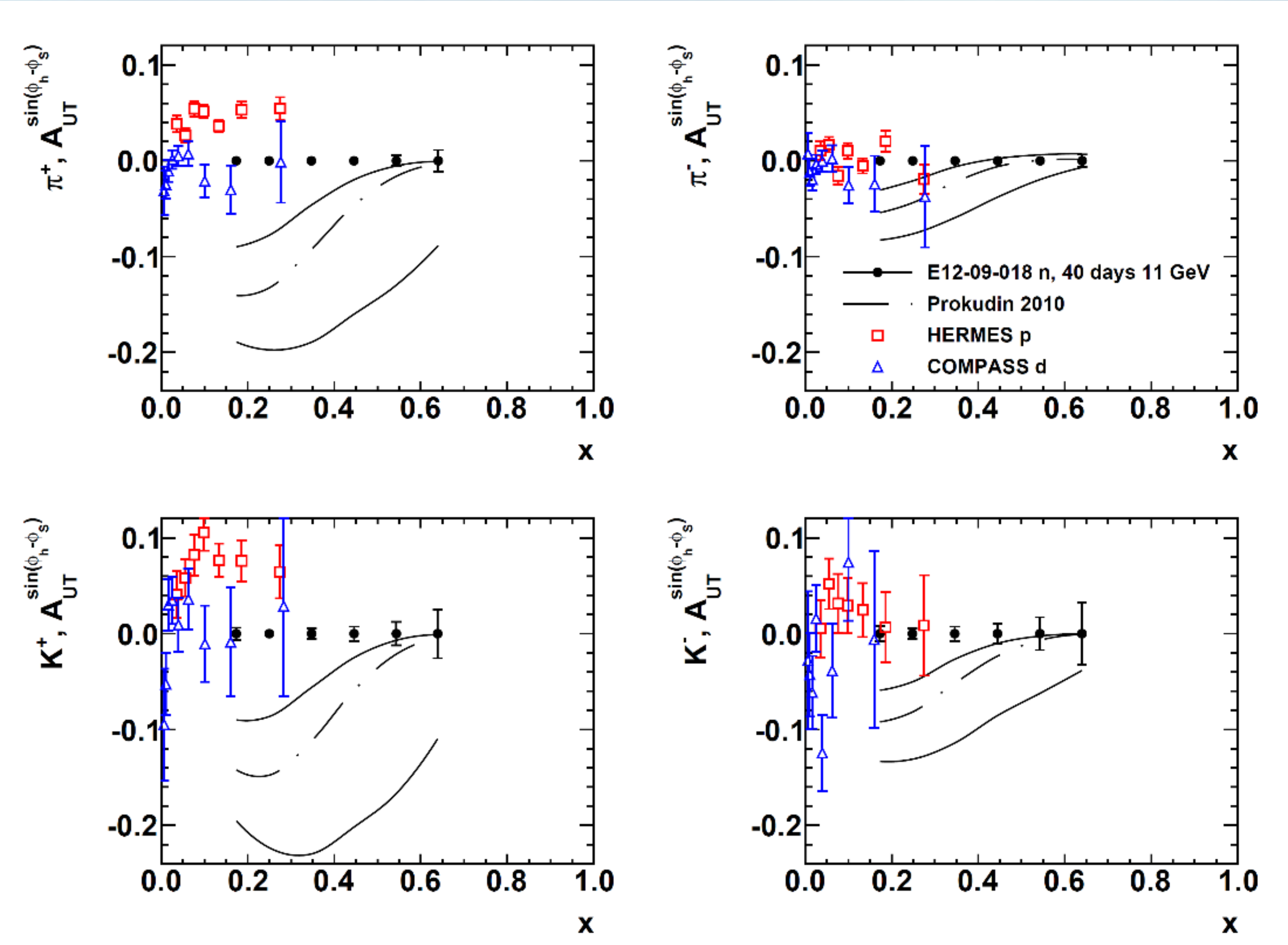
- $Q^2 > 1$ GeV^2
- $W^2 > 4$ GeV^2
- $M_X^2 > 2.3$ GeV^2
- $E'_e \geq 1$ GeV
- $p_h \geq 2$ GeV
- Good tracks on all relevant detectors

Progress and readiness:

the first SBS run group, which includes G_M^n/G_M^p (E12-09-019) is currently being installed in the hall.

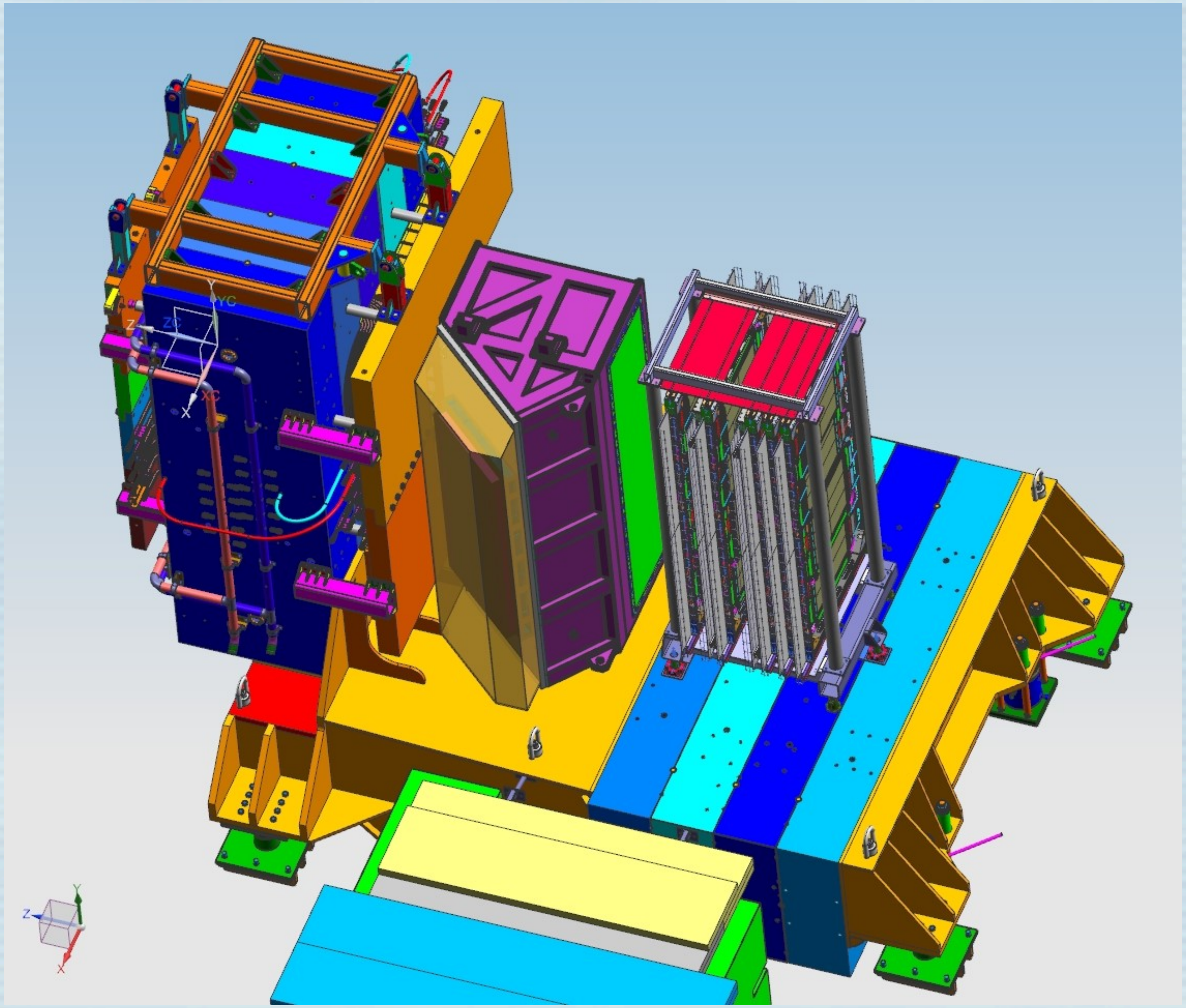


Projected data for SBS SIDIS

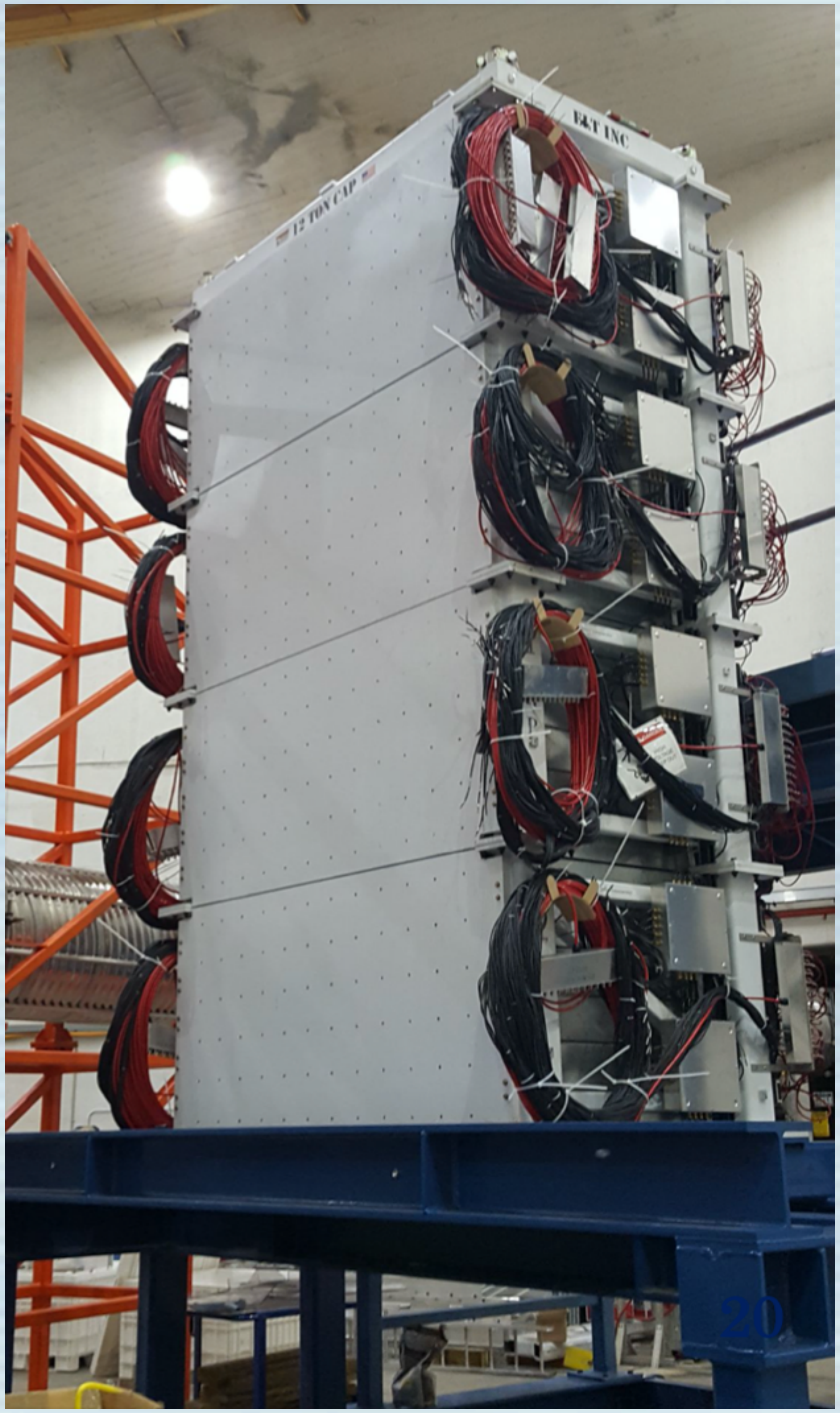


Example of E12-09-018 expected precision: neutron Sivers moments for charged pions and kaons.

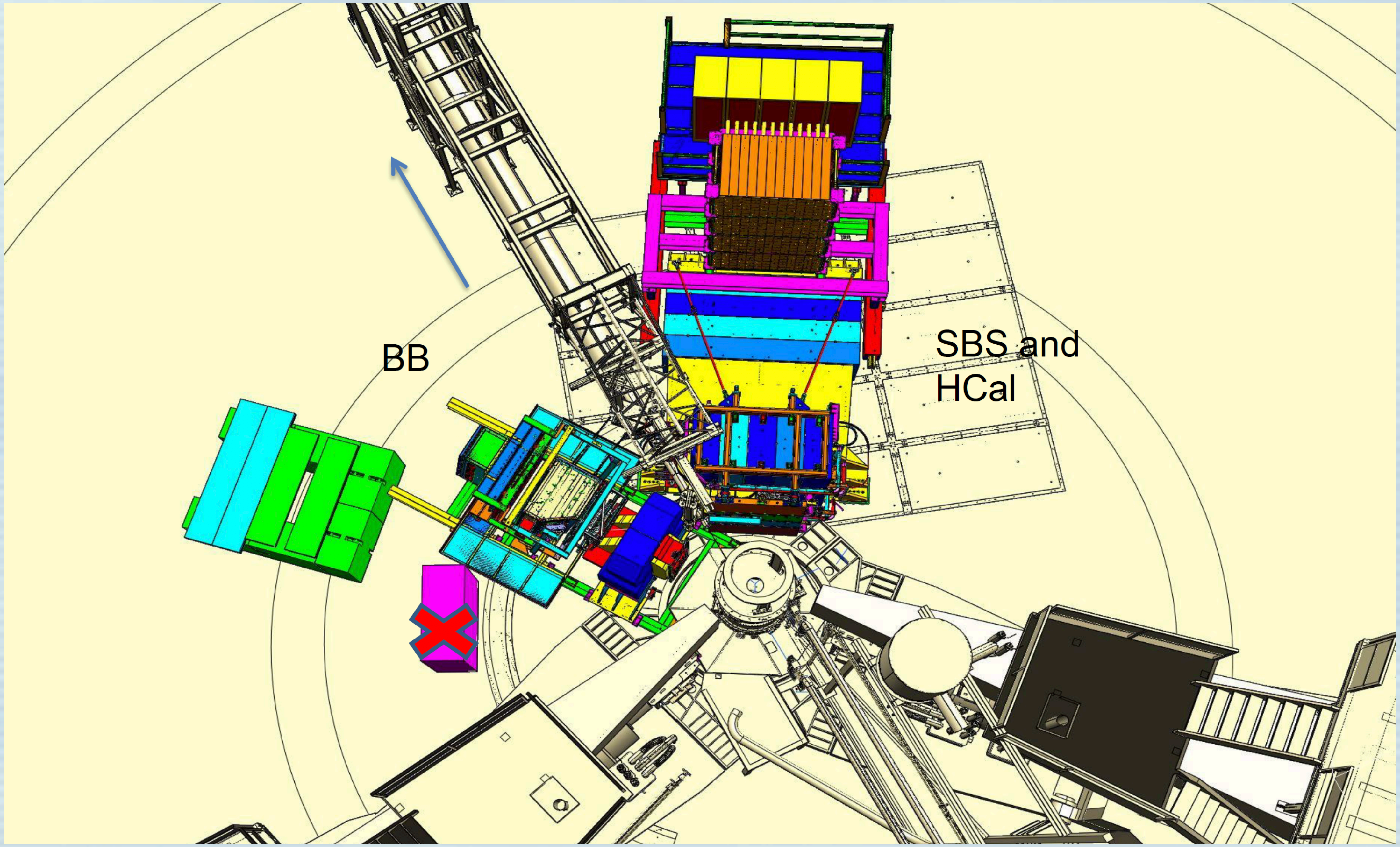
SBS SIDIS Hadron arm



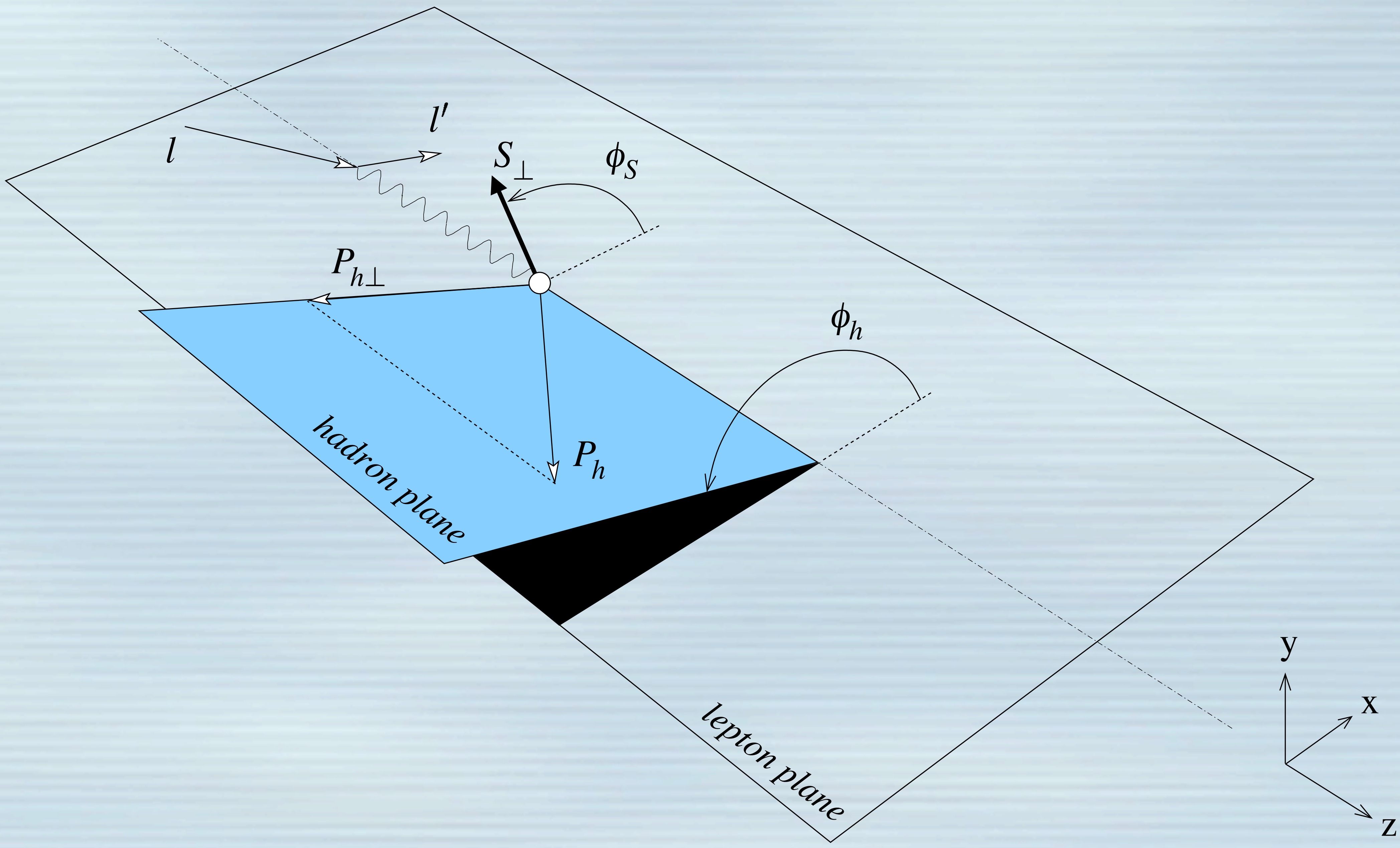
HCal - hadron calorimeter



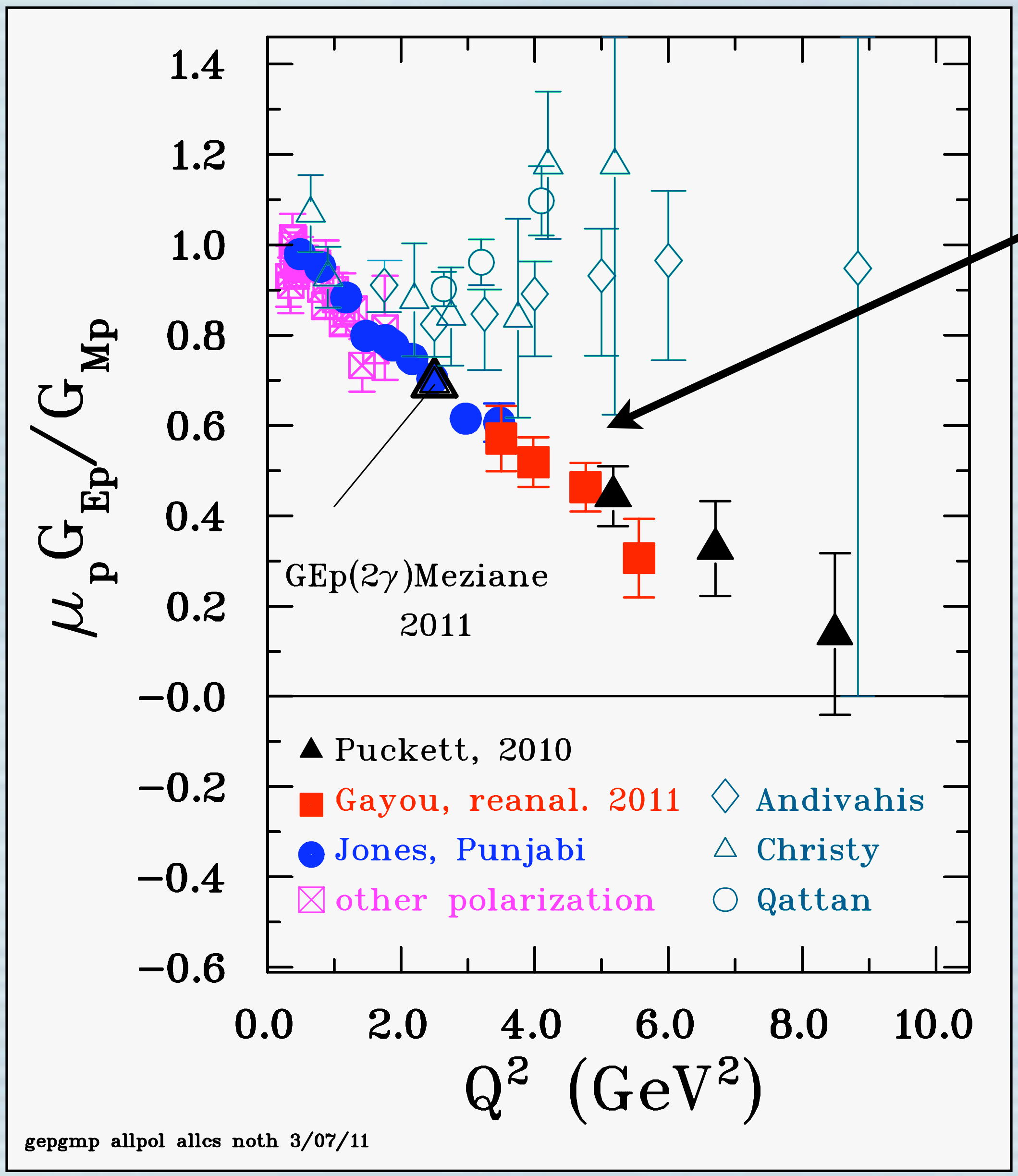
In the **first** SBS run group: measurement of the ratio G_M^n/G_M^p: E12-09-019



What is SBS ?



The ratio of the electric and magnetic FFs of the proton, $\mu_p G_E^p/G_M^p$, using the recoil polarization technique



Data from both Rosenbluth separations and the double-polarization technique.

Resulted in the 2017 Bonner Prize for Charles Perdrisat of William and Mary

- Explanations for the Q^2 behavior of G_E^p/G_M^p often emphasize the role of <u>quark orbital angular momentum</u>.
- It should be noted, however, that diquark correlations could also be responsible (not necessarily to the exclusion quark OAM).

The SBS SIDIS Experiment
more details