E12-09-018

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

The SBS SIDIS Experiment

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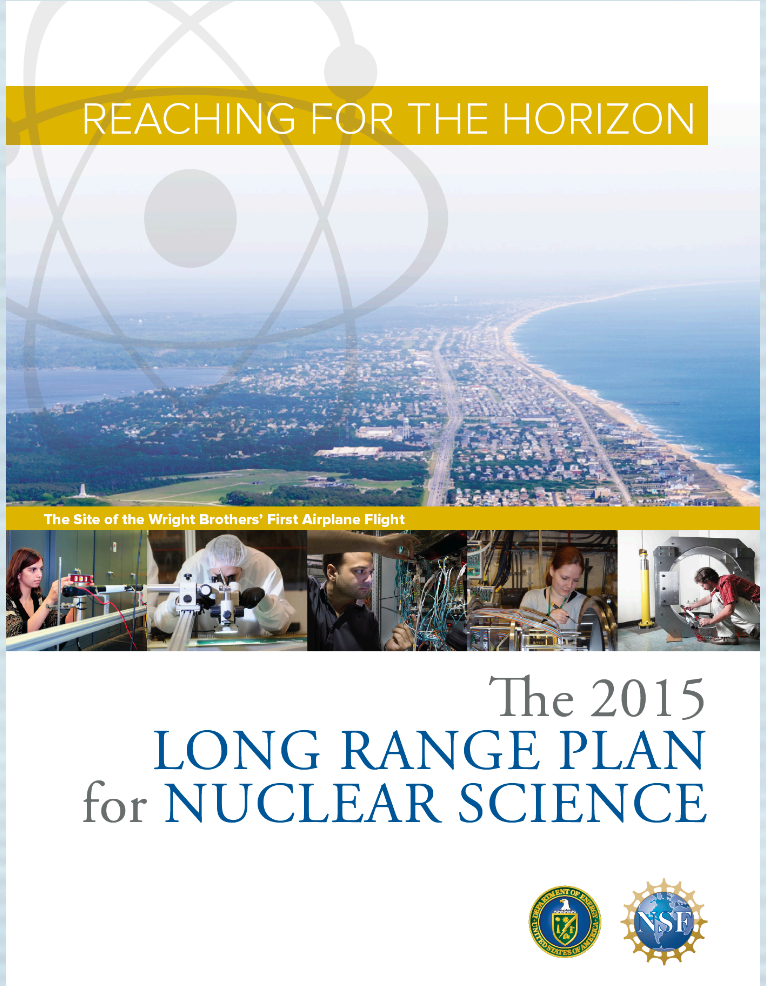
TMDs and understanding the nucleon

TMDs, along with GPDs, PDFs, Form Factors and other observables are playing a critical role in understanding the nucleon's properties and its dynamics.

From the 2015 LRP

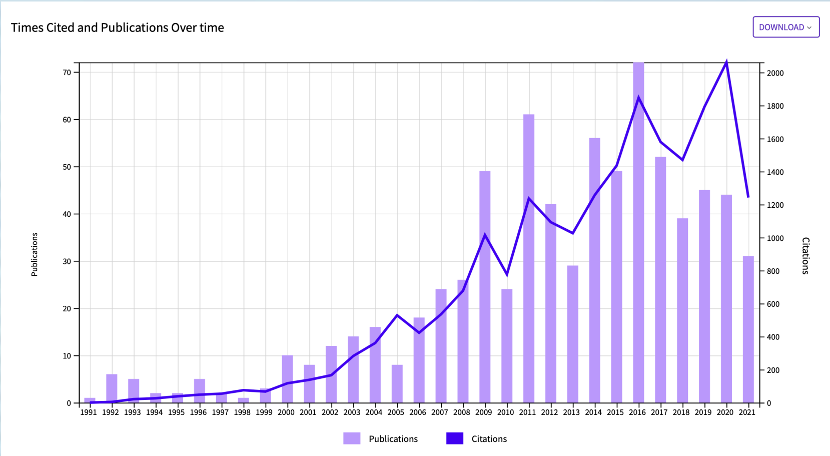


A nonzero Sivers function is considered to be strong evidence for the presence of quark orbital angular momentum. Indeed, it has been measured to be nonzero in the HERMES and JLab experiments.

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. RHIC will contribute by utilizing transversely polarized beams to make the first measurements in hadronic collisions to probe antiquark and gluon TMDs with the forward upgrades proposed for STAR and PHENIX.

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

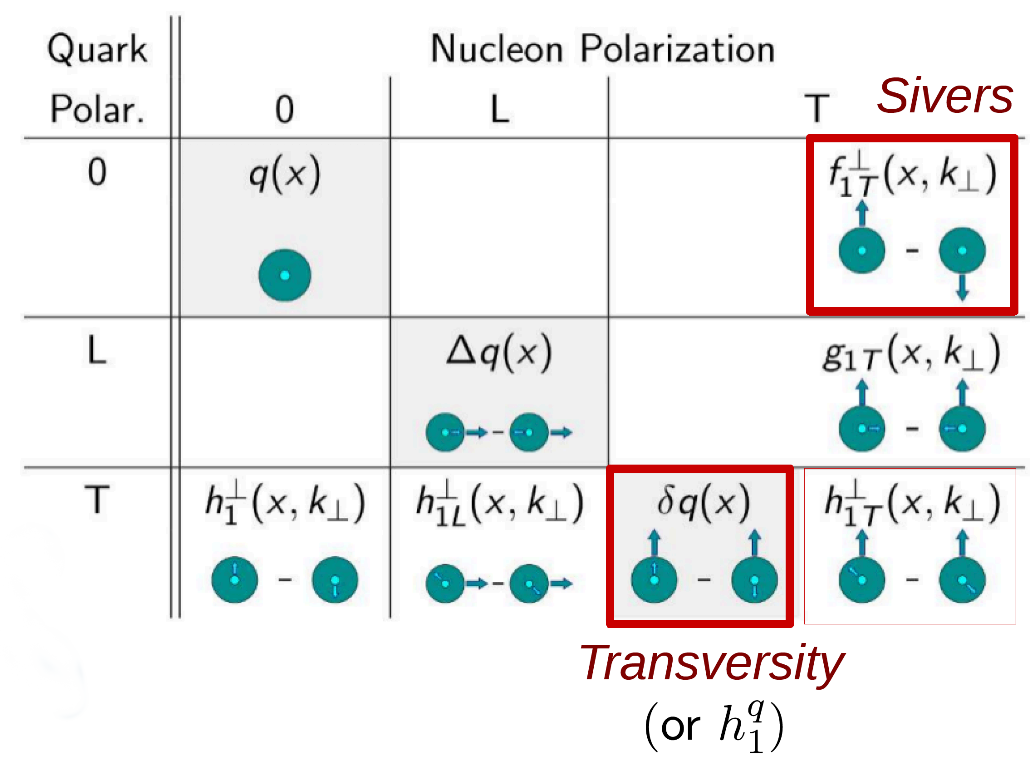
Publications on TMDs have grown enormously since the 90's but may be dropping off with a dearth of data...



E12-09-018 will measure single-spin asymmetries in SIDIS using a transversely polarized ^{3}He target

It will be sensitive to

- 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



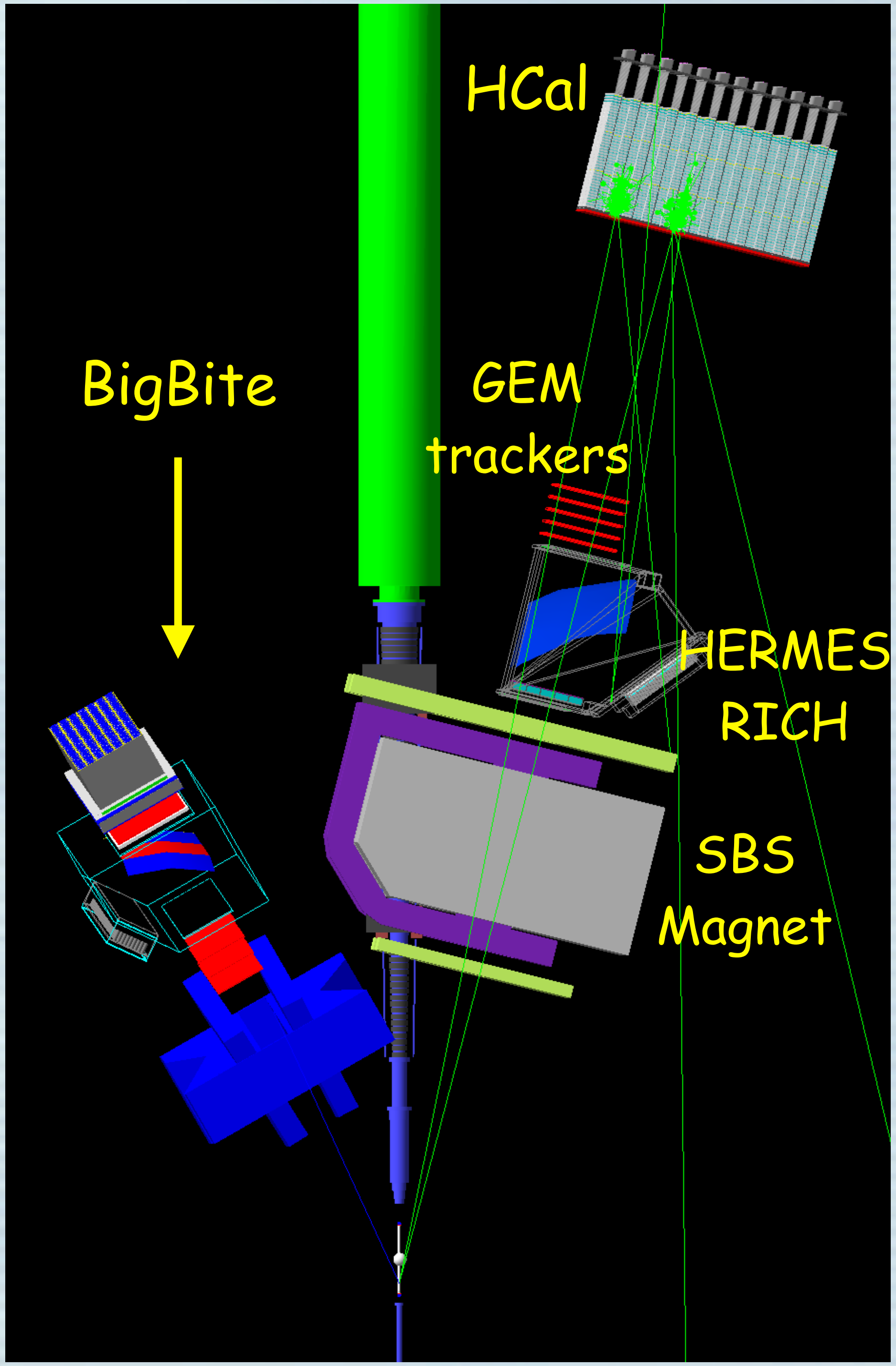
$$A_{UT} \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} - d\sigma^{\downarrow}}$$

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

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

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

The SBS SIDIS Experiment



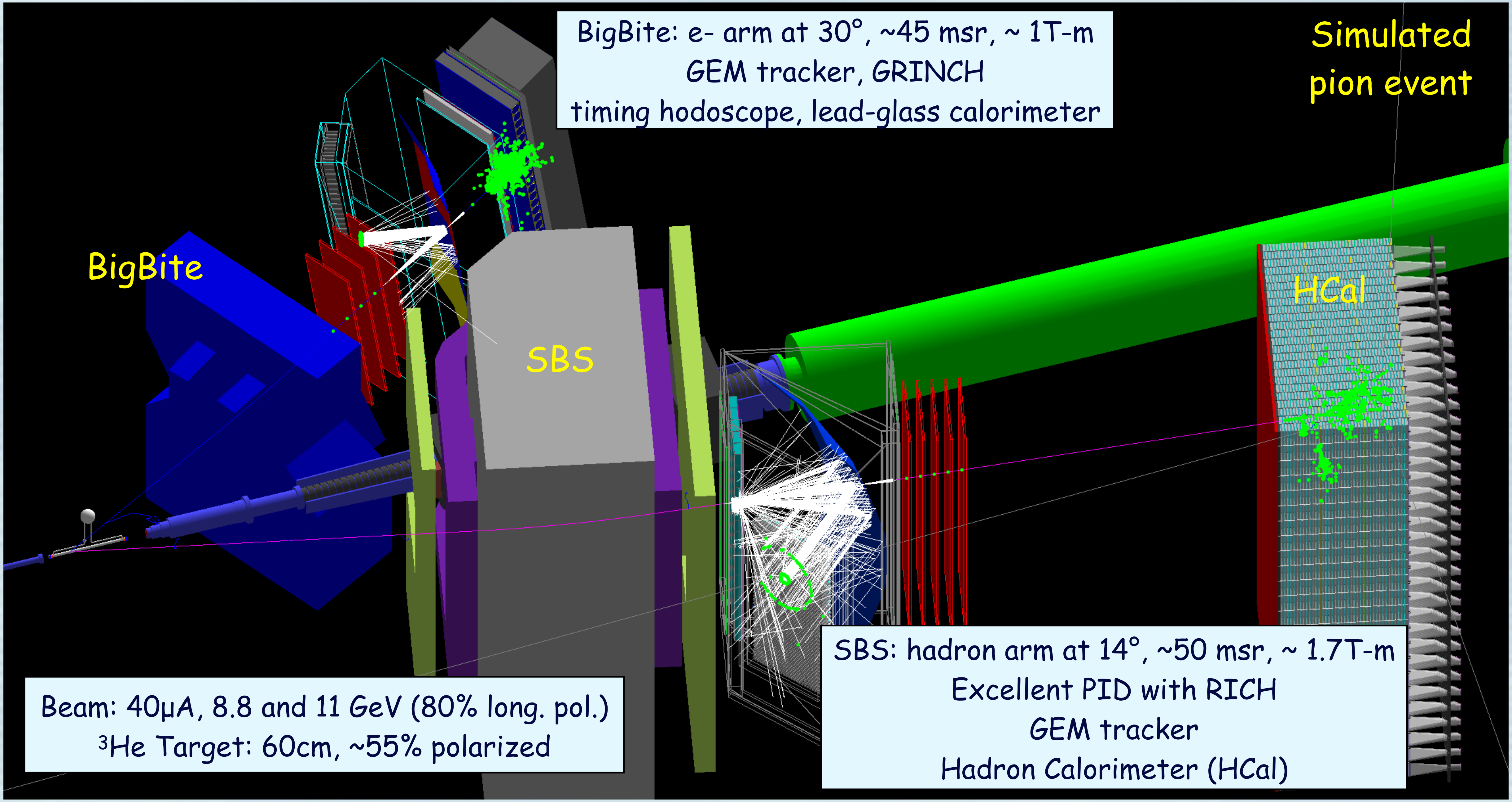
$$e + {}^{3}\mathrm{He}^{\uparrow} \rightarrow e' + \pi^{0} + X$$

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

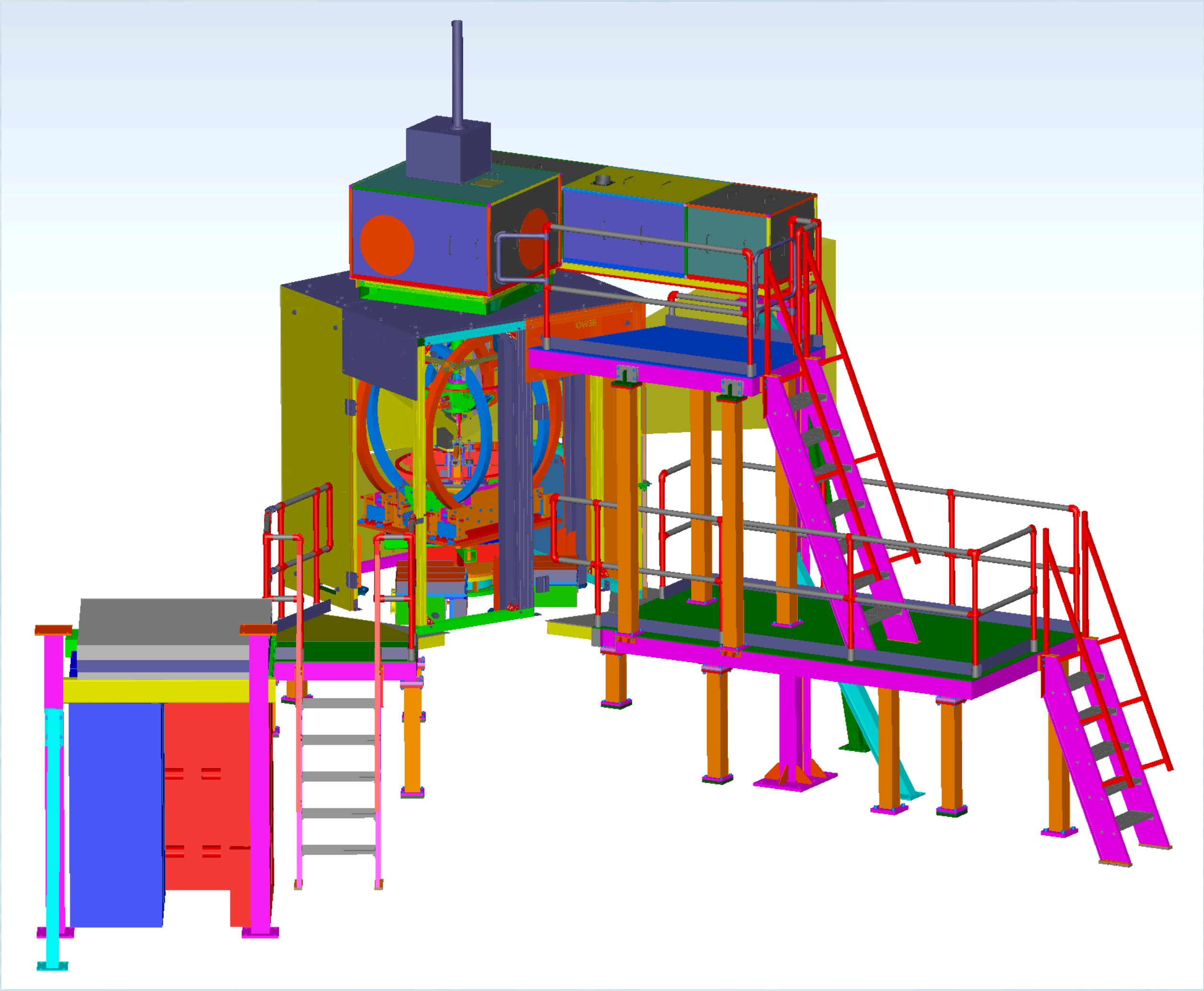
$$e + {}^{3}\mathrm{He}^{\uparrow} \rightarrow e' + \mathrm{K}^{\pm} + X$$

- 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 (~5x10^{36} $cm^{-2}s^{-1}$) polarized ^{3}He 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 Experiment
more details



The SBS SIDIS
Polarized ^{3}He Target

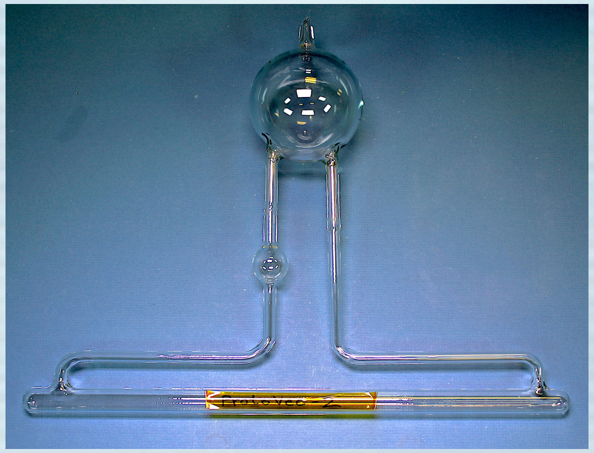


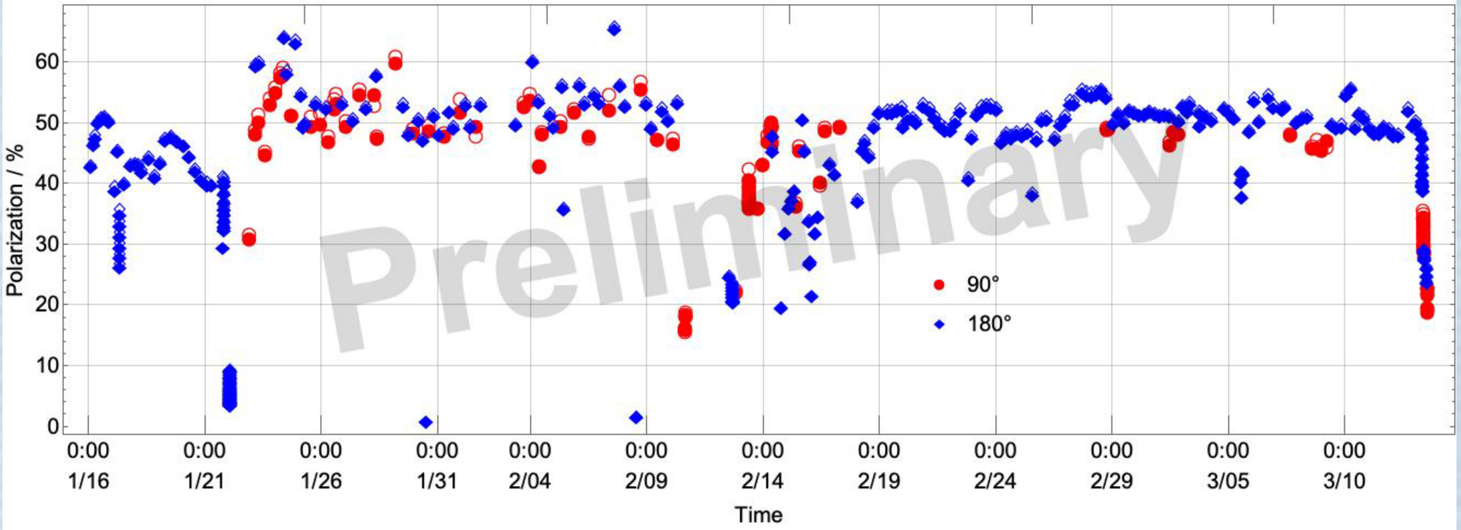
- Essentially the SBS G_E^n polarized ^{3}He target with small modifications
  - Will add capability for vertical polarization
- Magnetic shielding protects target from SBS and BigBite magnet fringe fields.
- For both SIDIS and G_E^n, the quantity of ^{3}He is twice what was used for recent Hall C experiments.
- 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

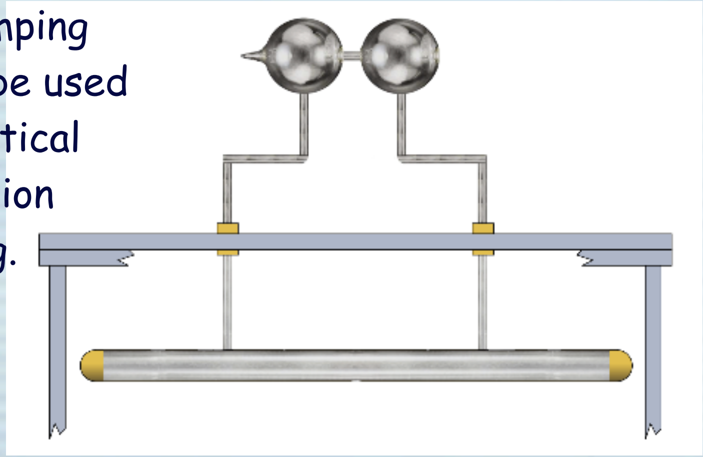
Polarized ^{3}He Target

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



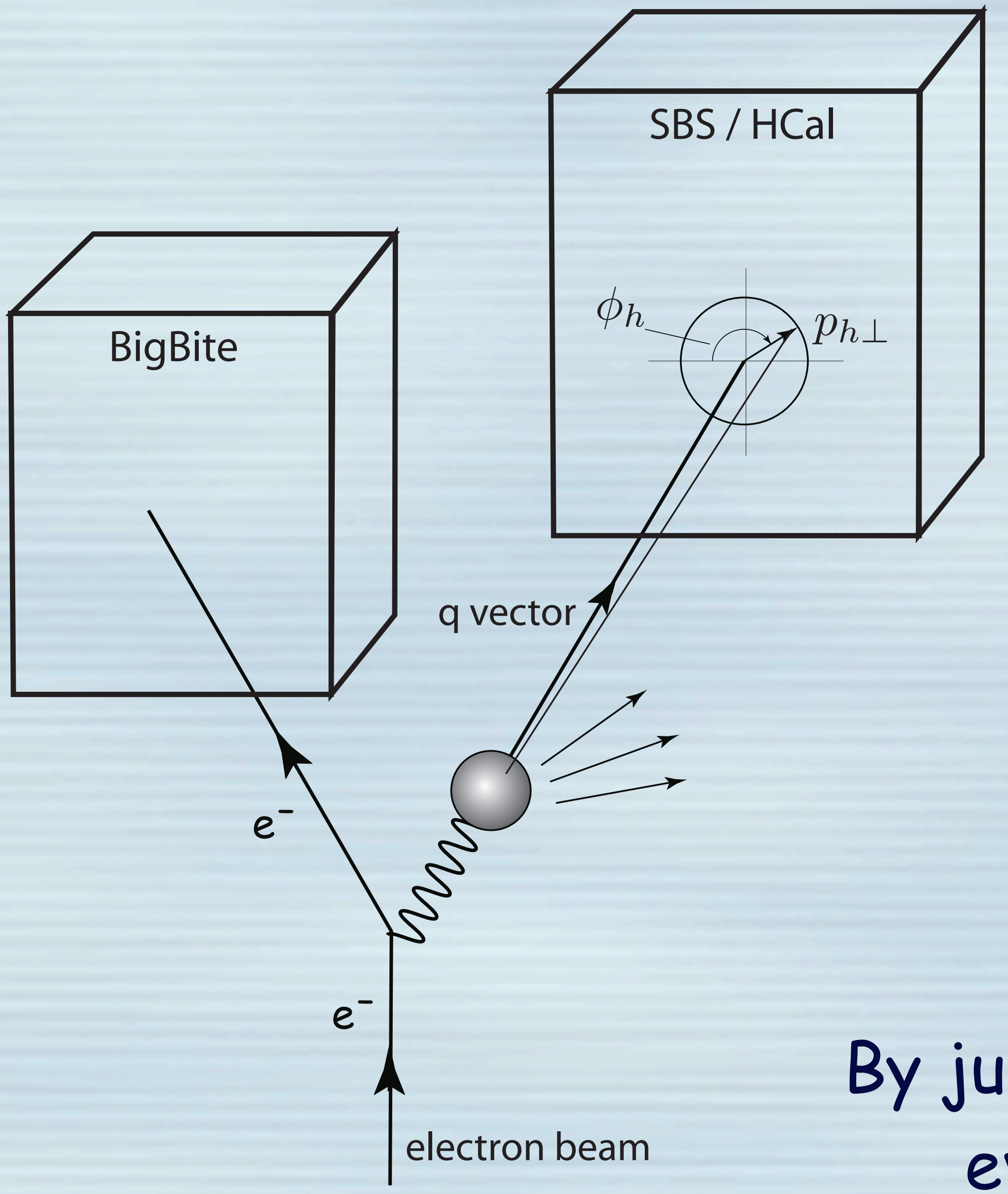


Double pumping chamber to be used during vertical polarization running.



- 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.

The concept behind the SBS SIDIS experiment



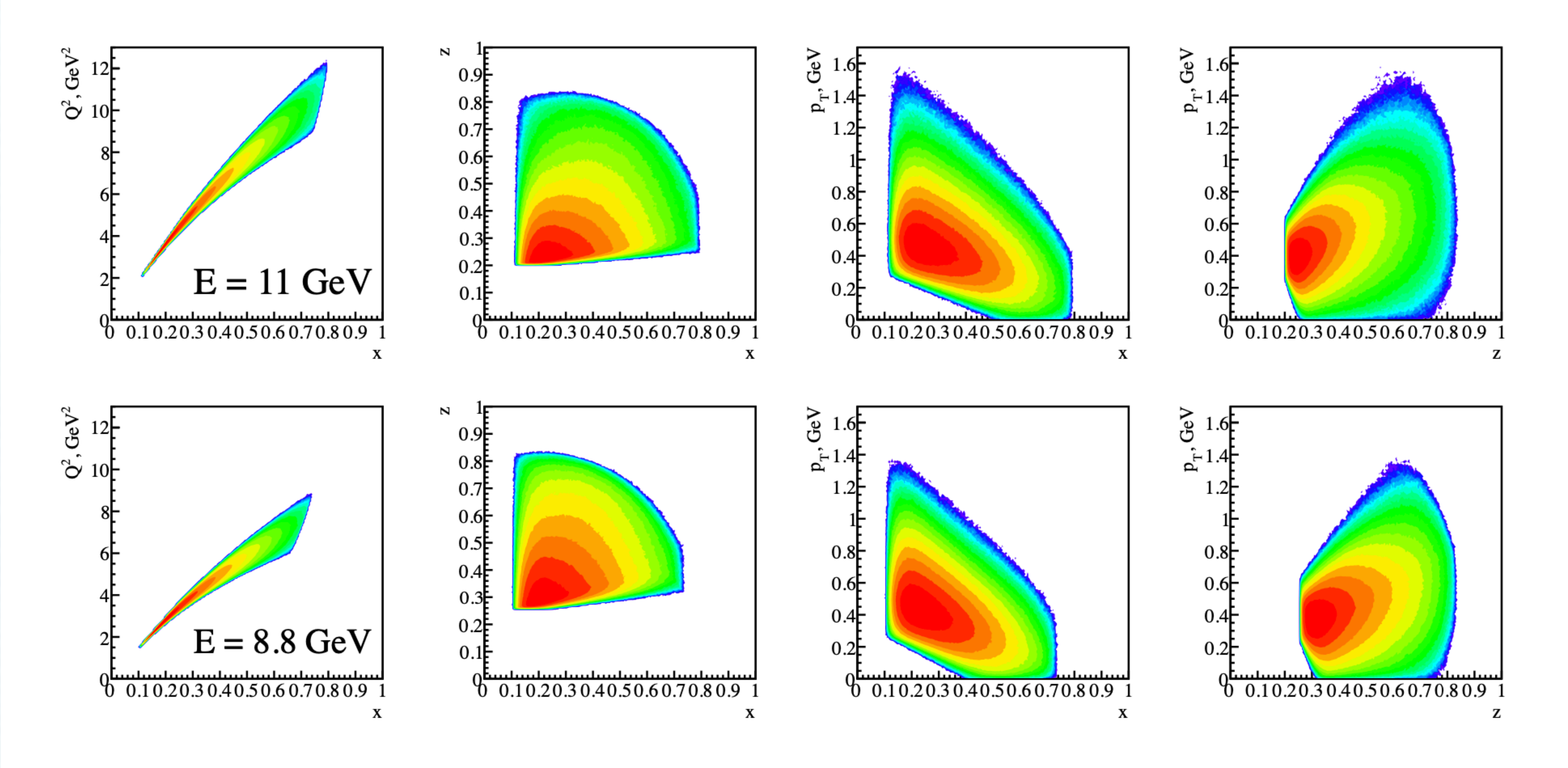
- The open-geometry dipole spectrometers allow wide kinematic coverage with a single setting.
- GEM-based tracking can handle huge singles rates.
- Center the hadron arm on q
- Exploit kinematic focusing along q
- Polarized ^3He target has flexibility to orient polarization relatively freely in the plane perpendicular to q.

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

Requirements for TMD formalism to apply

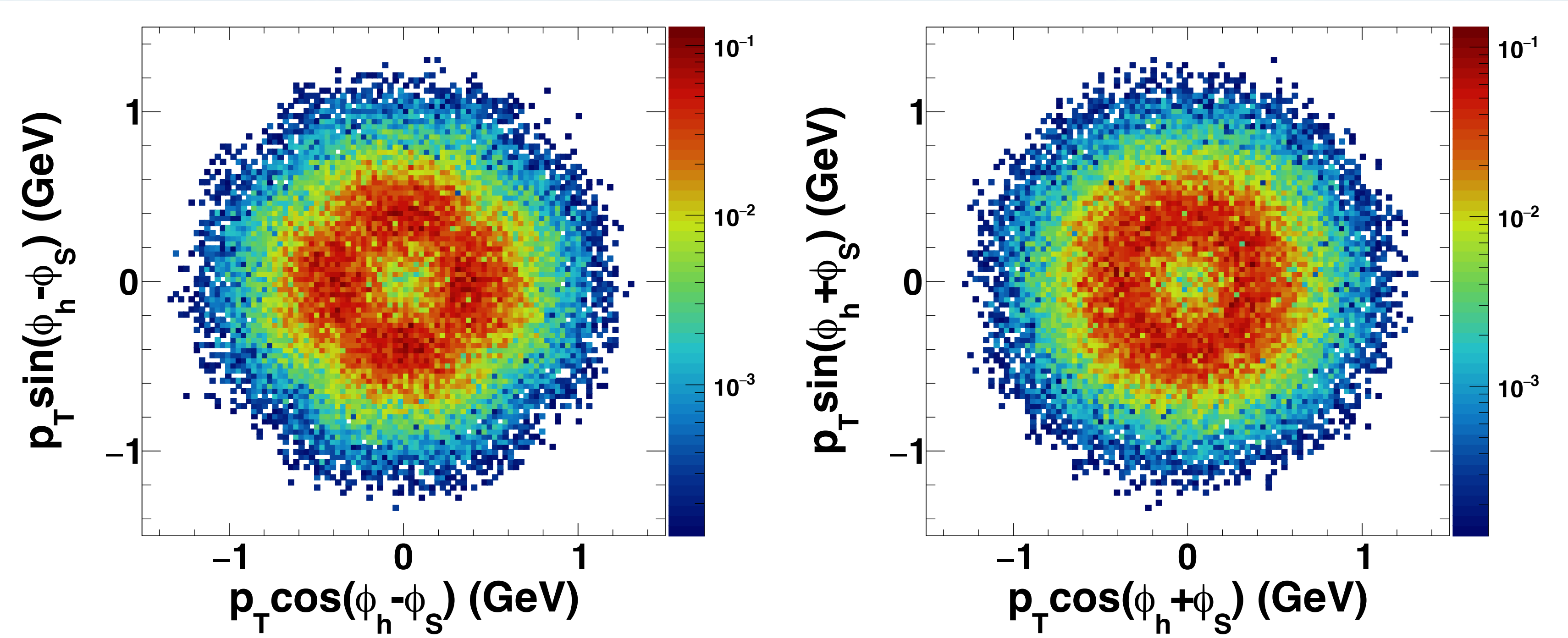
- Large $Q^2 > 1\ \mathrm{GeV}^2$ and $W > 2$ GeV as in DIS
- Large but not too large $z = E_h/\nu$
  - High enough for dominance of "current quark" fragmentation over "target remnant" fragmentation.
  - Low enough to avoid dominance of exclusive/resonance region contributions.
- Requires small, but 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.

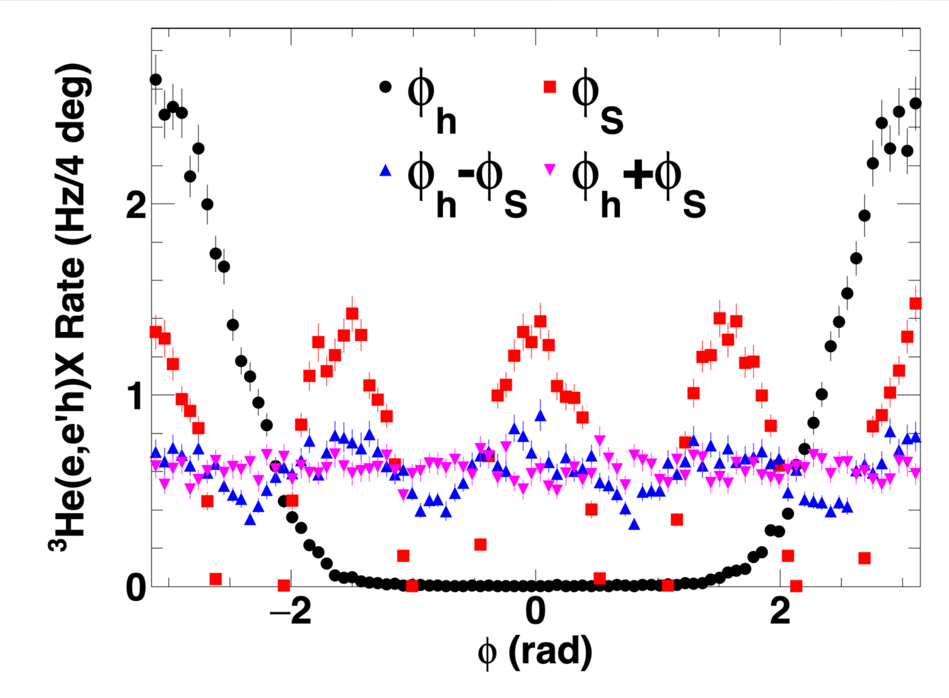
The SBS SIDIS kinematic coverage



- $Q^2 > 1$ 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

Compare, for example, with HERMES proton data

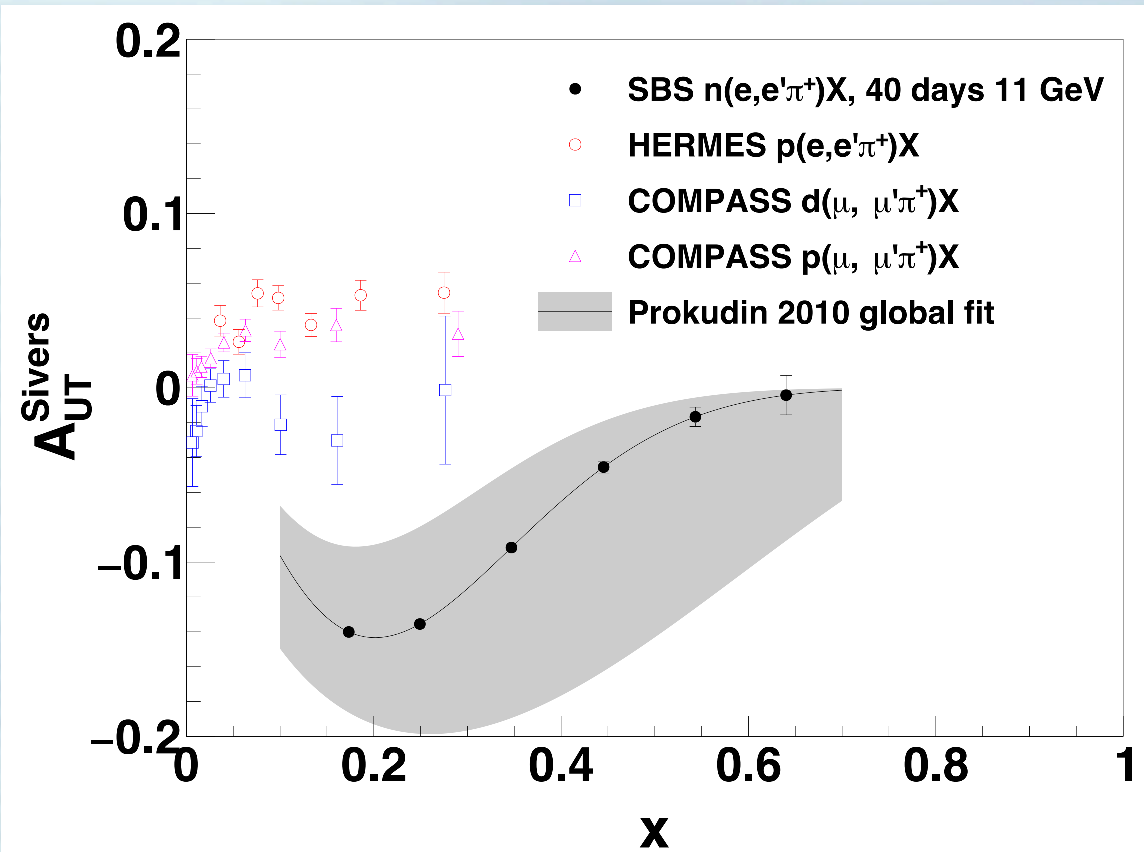
	π^+	π^0	π^-	K^+	K^-	p	$\bar{p}$
$0.2 < z < 0.7$	755k	158k	543k	136k	57k	94k	14k
$0.7 < z < 1.2$	68k	10k	40k	14k	1k	6k	$<$1k

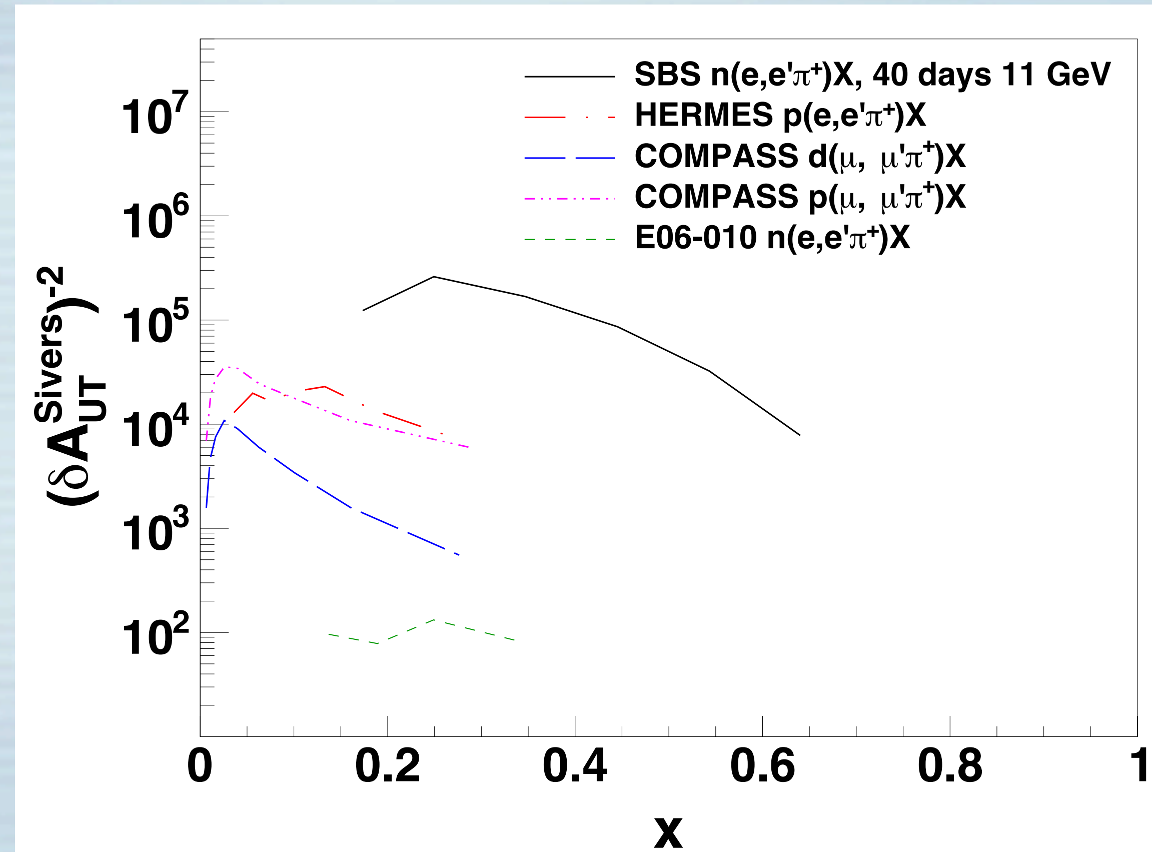
HERMES: from arXiv:2007.07755v1 [hep-ex] 15 Jul 2020

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.

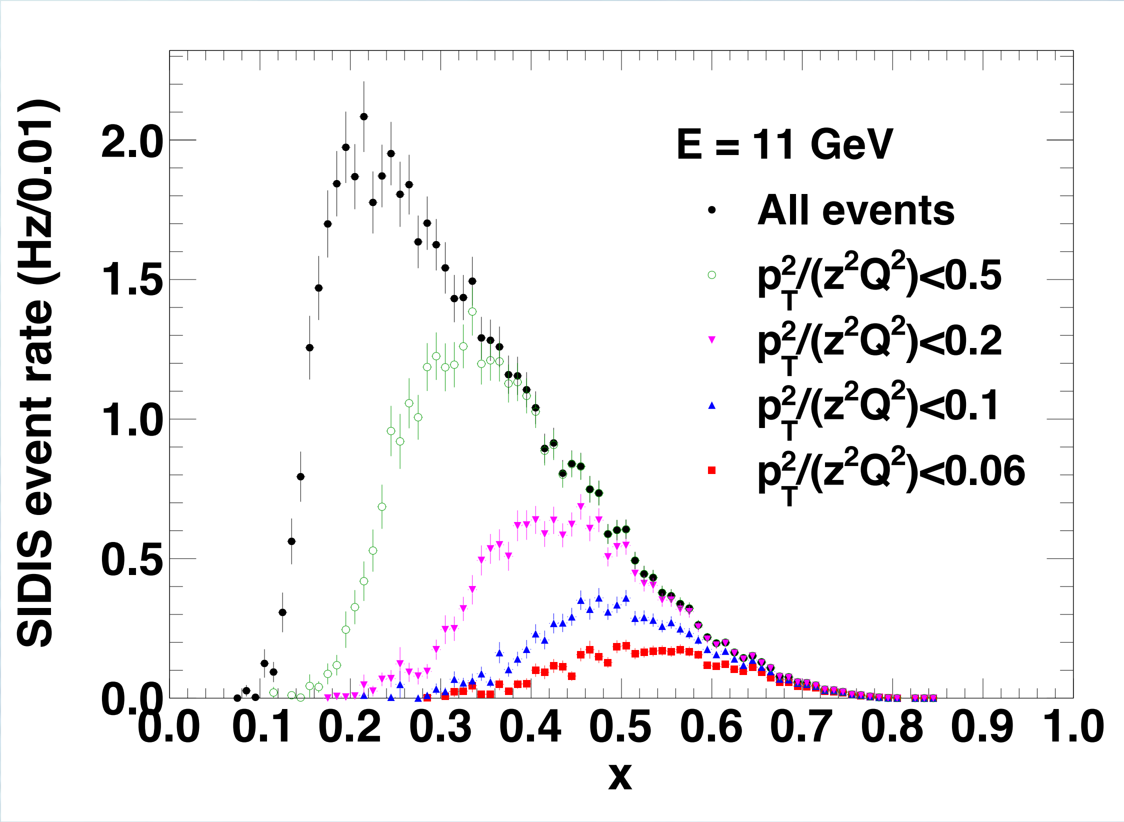
Comparing SBS SIDIS neutron data with existing data

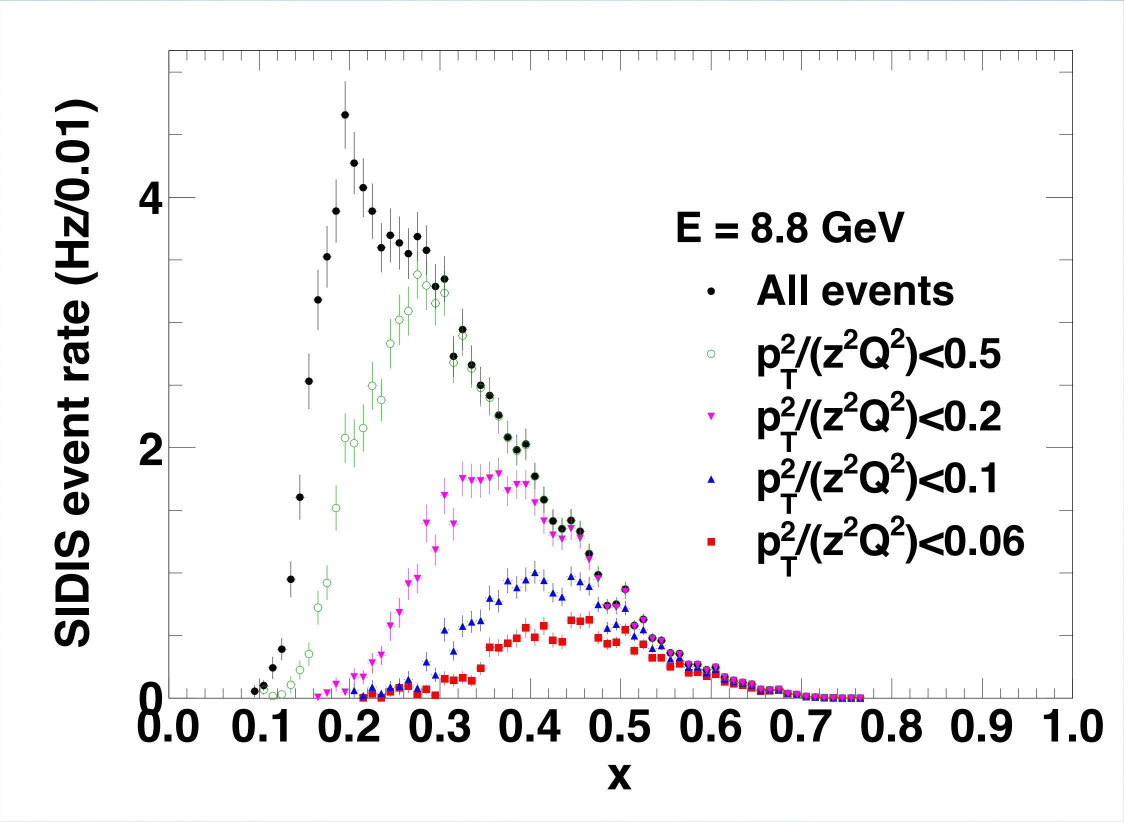




- SBS SIDIS will provide some of the most precise TMD data ever obtained on either the proton or the neutron.
- At higher values of x, roughly x > 0.1, it will completely dominate TMD measurements for many years to come.
- Note that once the new COMPASS deuteron data becomes available, the COMPASS neutron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

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



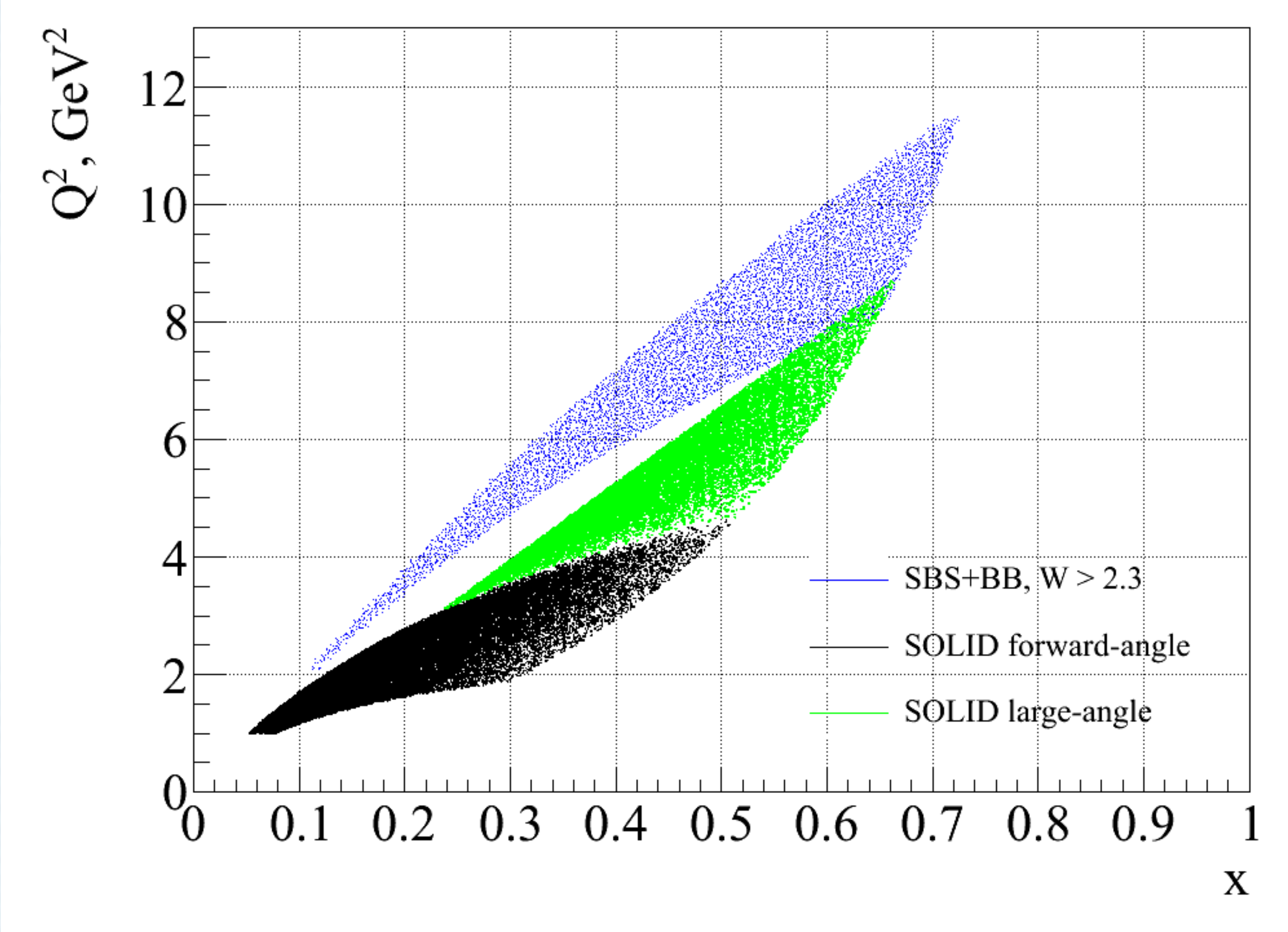


One global analysis by Scimemi[a] and Vladimirov suggests a limit of $p_T^2/z^2Q^2 < 0.06$, which would exclude virtually all of HERMES data and much of the COMPASS data

Other analyses suggest wider values are allowable.

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

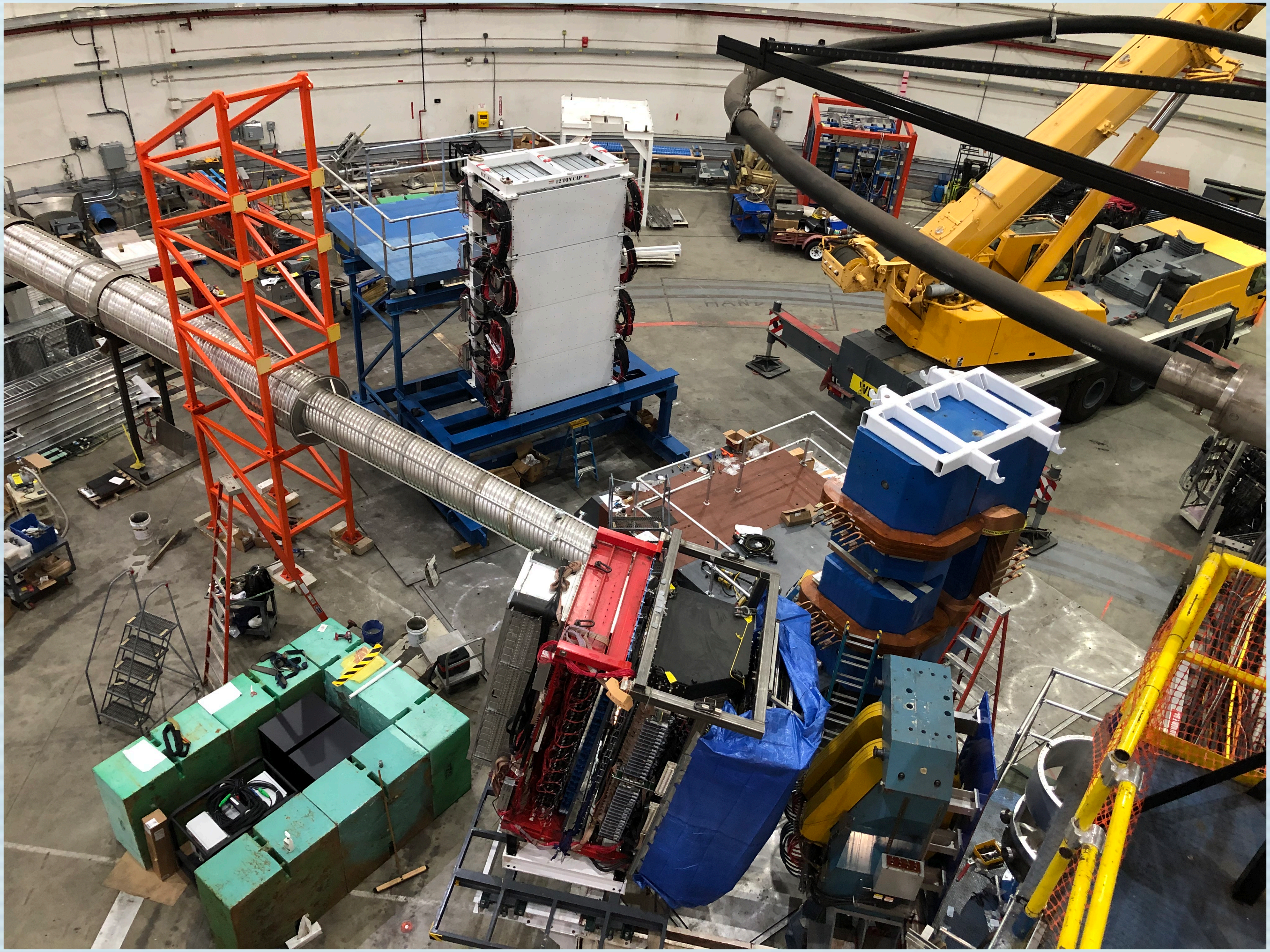
Comparison with SoLID



- 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.

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.



Summary and beam time request

- The motivation to study single-spin asymmetries and TMDs in SIDIS has grown significantly since E12-09-018 was first approved.
- Most components needed to run SBS SIDIS will be commissioned and used during the first two SBS run groups.
- The HERMES RICH will be a new piece of equipment, but it has been refurbished and has undergone testing both at UConn and at JLab.
- The high-luminosity polarized ^{3}He target will be used during G_E^n, and only minor modifications are needed for use during SBS SIDIS

	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

The table above is unchanged from that approved by PAC38. In keeping with PAC49 guidelines, we would also like to request the scheduling of one week without beam to change the target configuration from horizontal polarization to vertical polarization, which will allow us to avoid making major changes to the G_E^n target.