The SBS SIDIS experiment (E12-09-018) with a novel (polarized ^{3}He) target

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So what is the SBS SIDIS experiment?

What does it measure?

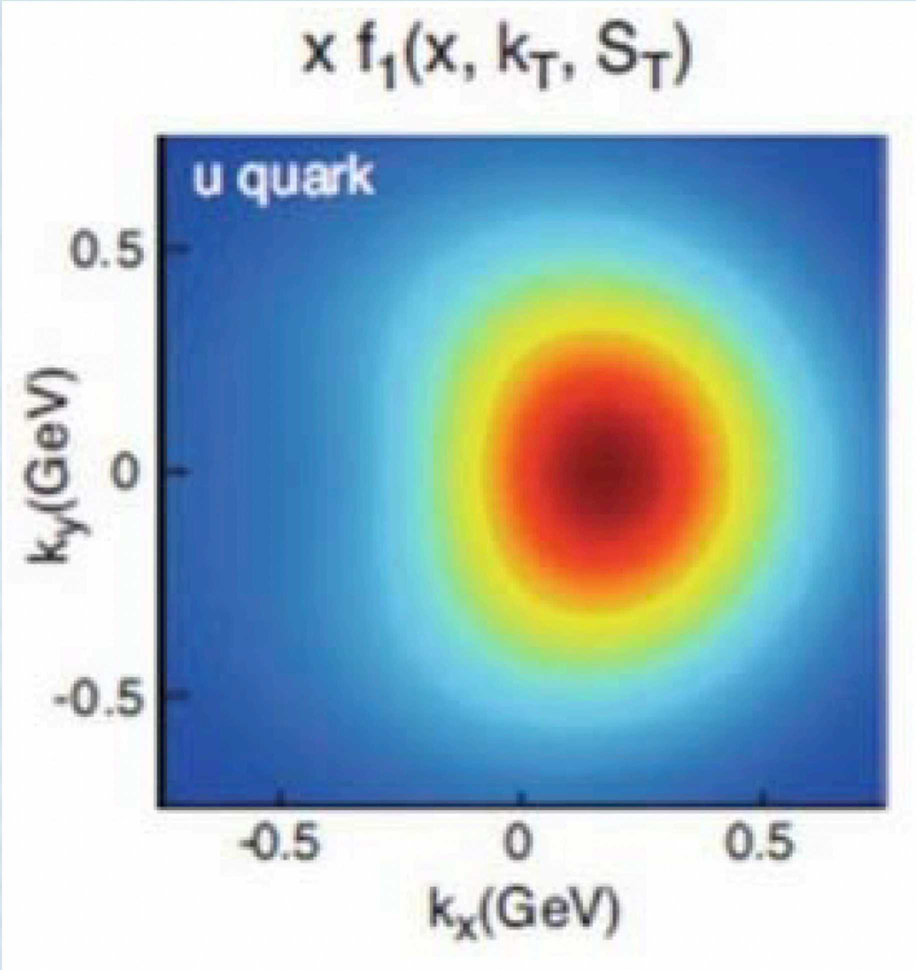
Why is it important?

How does it fit into the big picture?

The SBS SIDIS experiment is part of a larger campaign for…

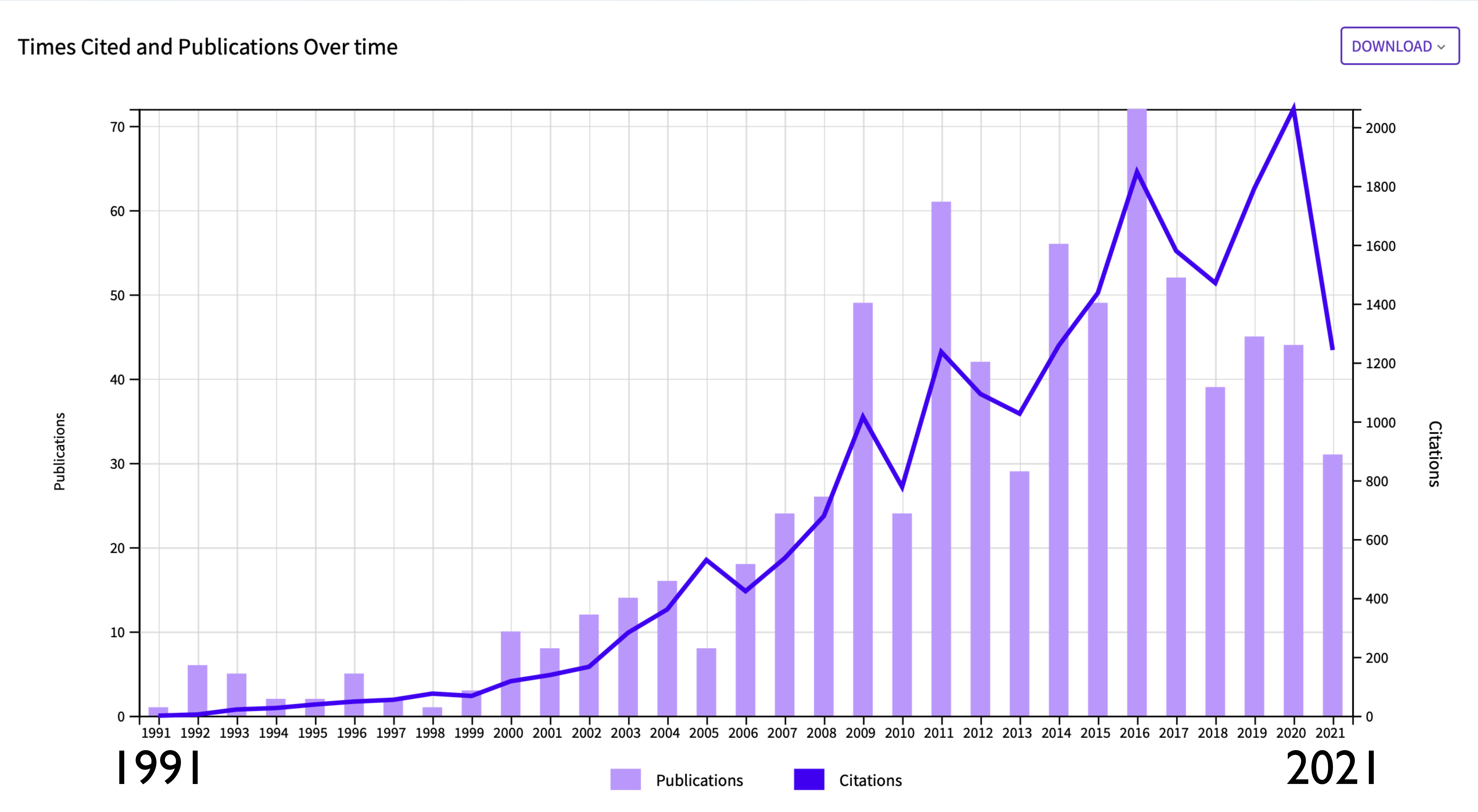
3D imaging of nucleons and nuclei

- Often cited as a key goal of JLab in the 12 GeV era
- The focus of the recently established Center for Nuclear Femtography
- Explicitly stated as a key element of the 2015 Long Range Plan (LRP) for nuclear science, including …
  - 3D spatial maps of the nucleon using GPDs and
  - 3D momentum maps of the nucleon using transverse momentum dependent distribution functions (TMDs)



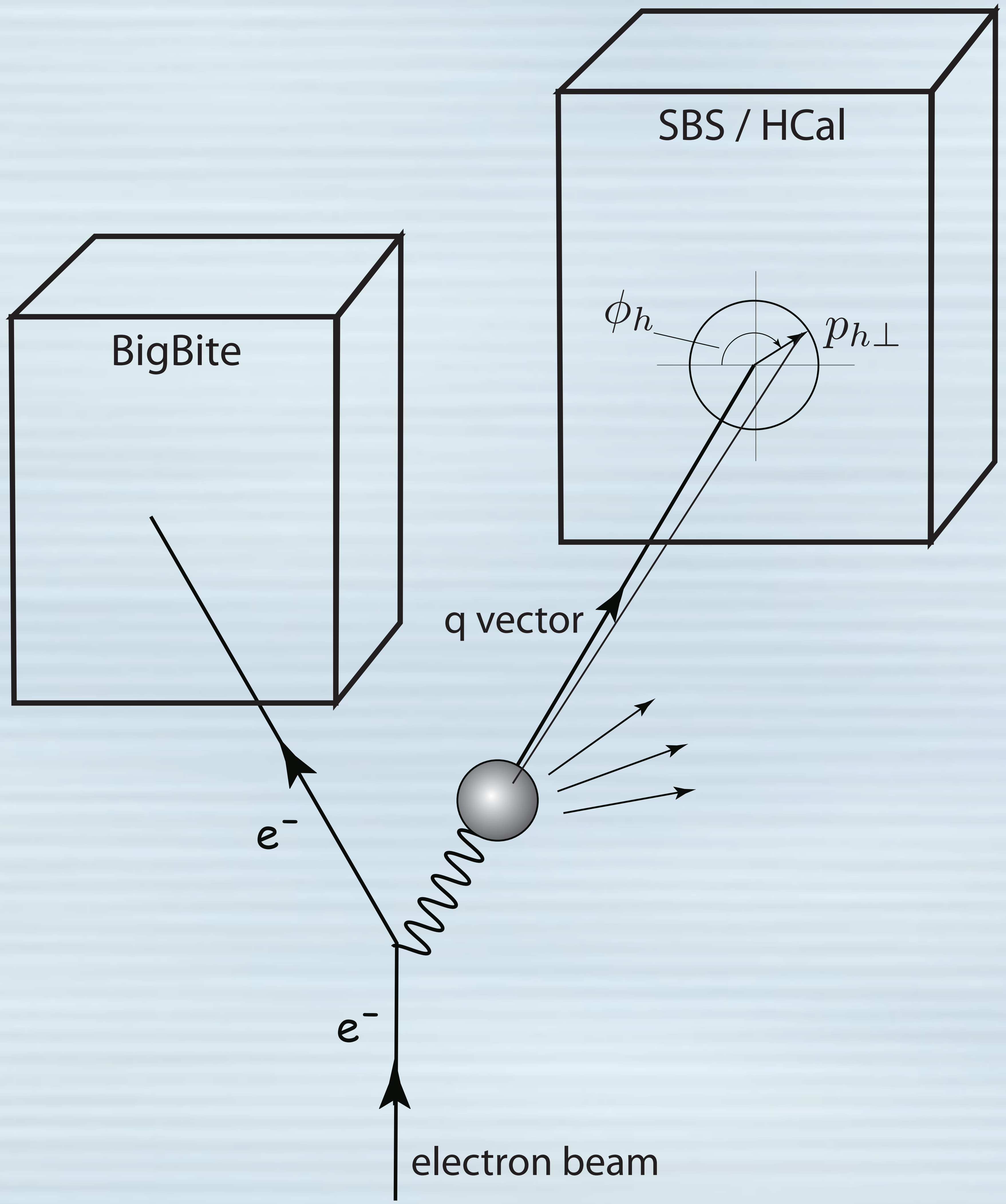
- At left is the Sivers function as a function of the transverse momentum in the x- and y-directions.
- The distribution is clearly biased in favor of positive transverse momentum in the x-direction.
- A non-zero Sivers function necessarily implies the importance of quark orbital angular momentum in nucleon structure.

The impact of TMDs on our understanding of the nucleon



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

The concept behind the SBS SIDIS experiment



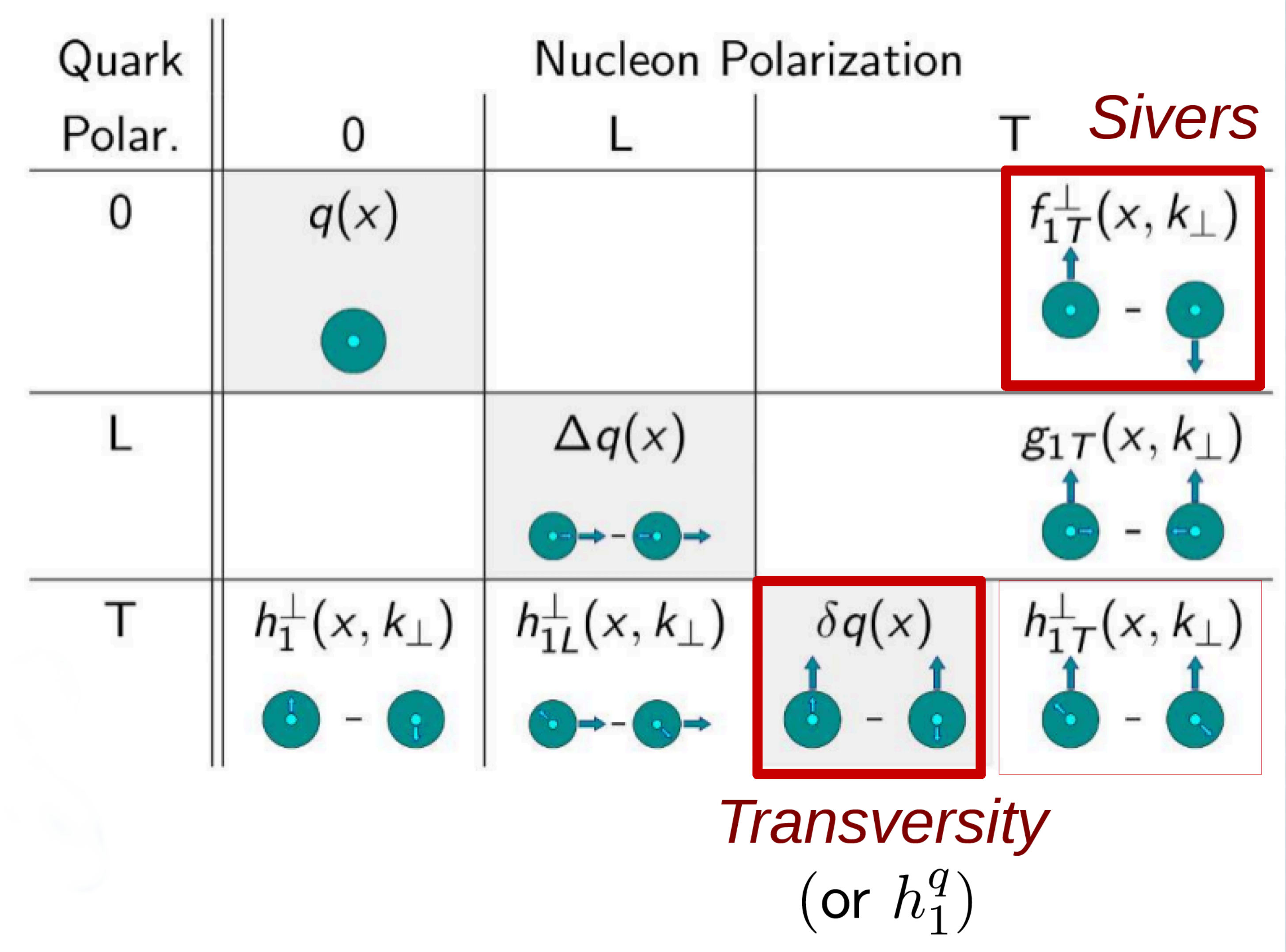
- The open-geometry dipole spectrometers allow wide kinematic coverage with a single setting.
- GEM-based tracking can handle huge singles rates.
- Center the hadron arm on q
- Exploit kinematic focusing along q
- Polarized ^{3}He target has flexibility to orient polarization relatively freely in the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

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

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

SBS SIDIS 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 units of angular momentum.



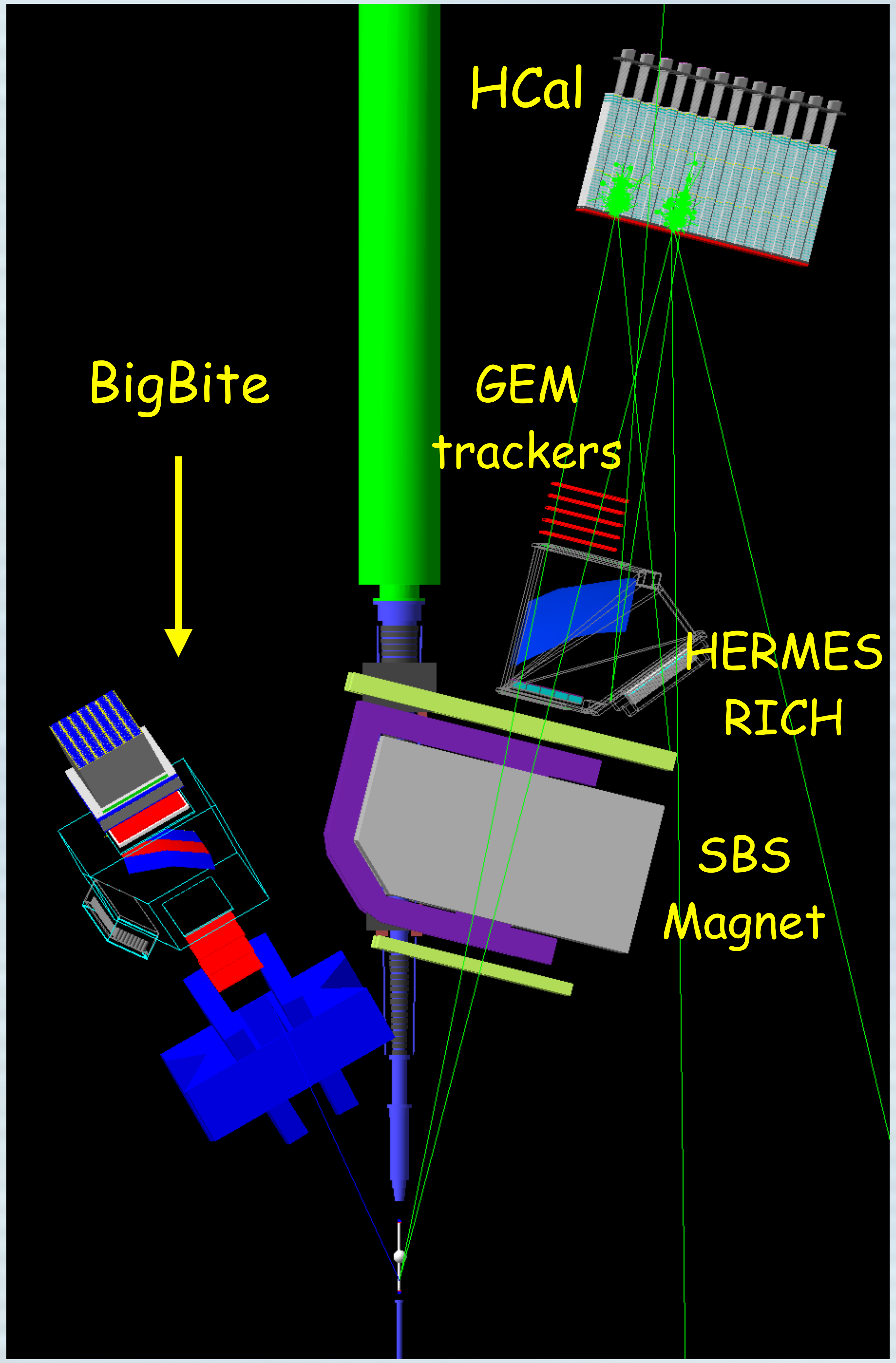
$$A_{UT} \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} - d\sigma^{\downarrow}}$$

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

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

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

The SBS SIDIS Experiment



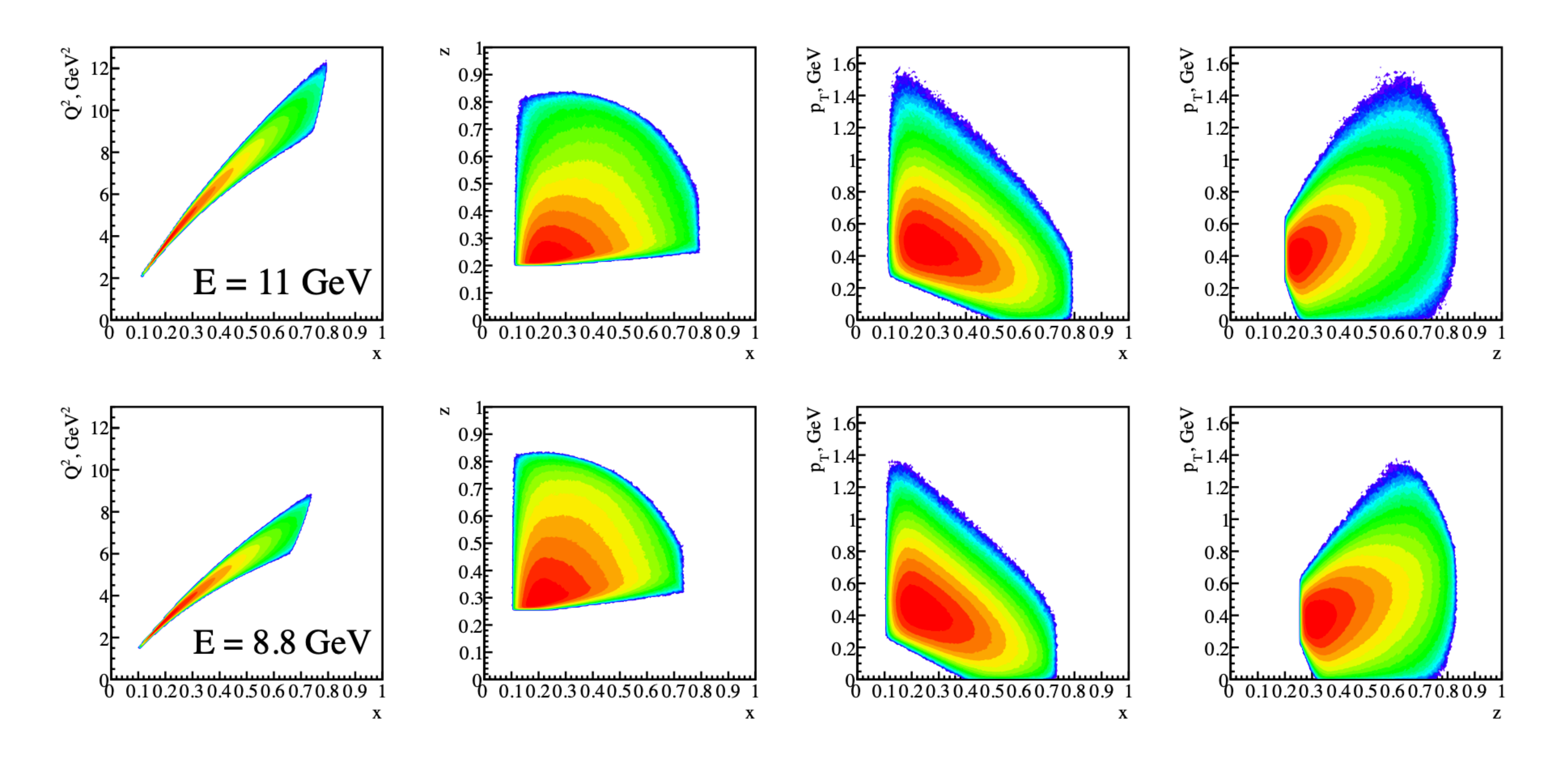
$$e + {}^3\mathrm{He}^{\uparrow} \rightarrow e' + \pi^0 + X$$

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

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

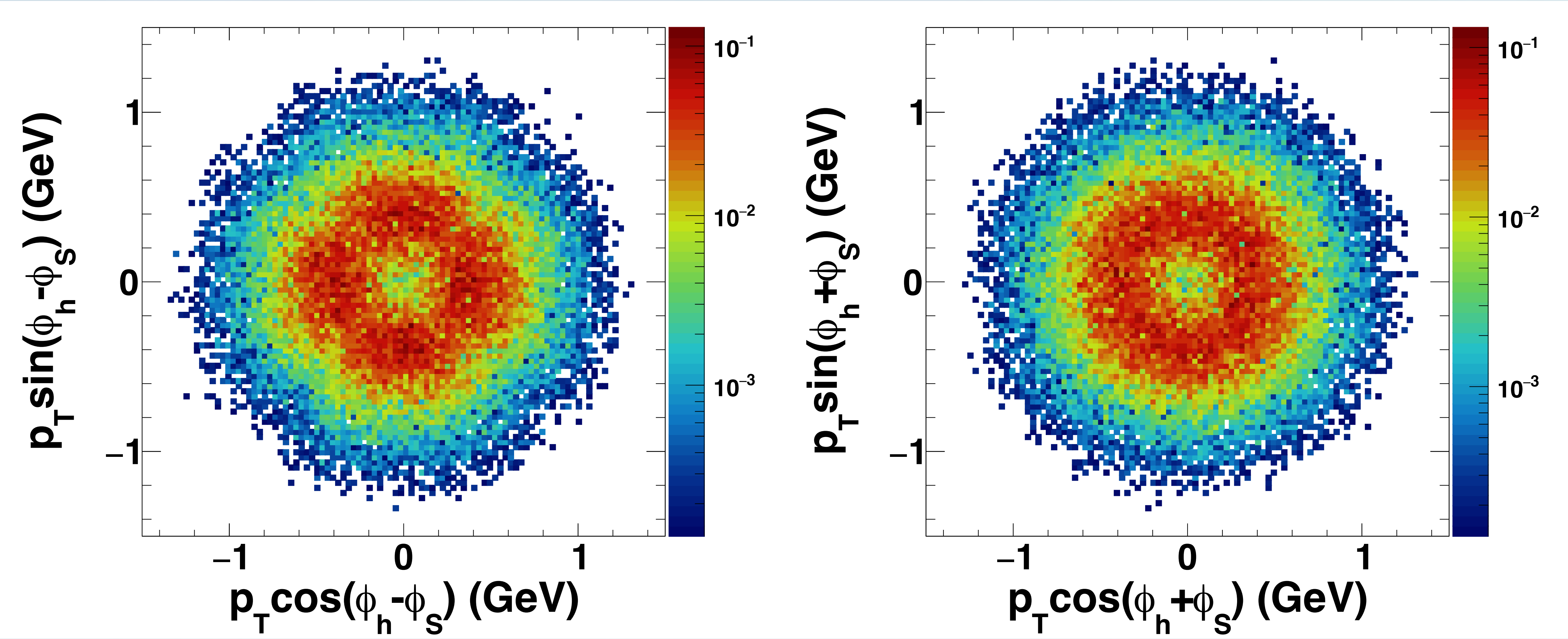
- Electron detected by BigBite.
- Pion or Kaon detected using the SBS magnet, the HERMES RICH for particle ID and HCal, a hadron calorimeter.
- High luminosity (~5x10^{36} cm^{-2}s^{-1}) polarized ^{3}He target, capable of rapid spin-flips in either the vertical or horizontal directions.
- ALL data collected with a single setting at each of two energies, 8.8 and 11 GeV.

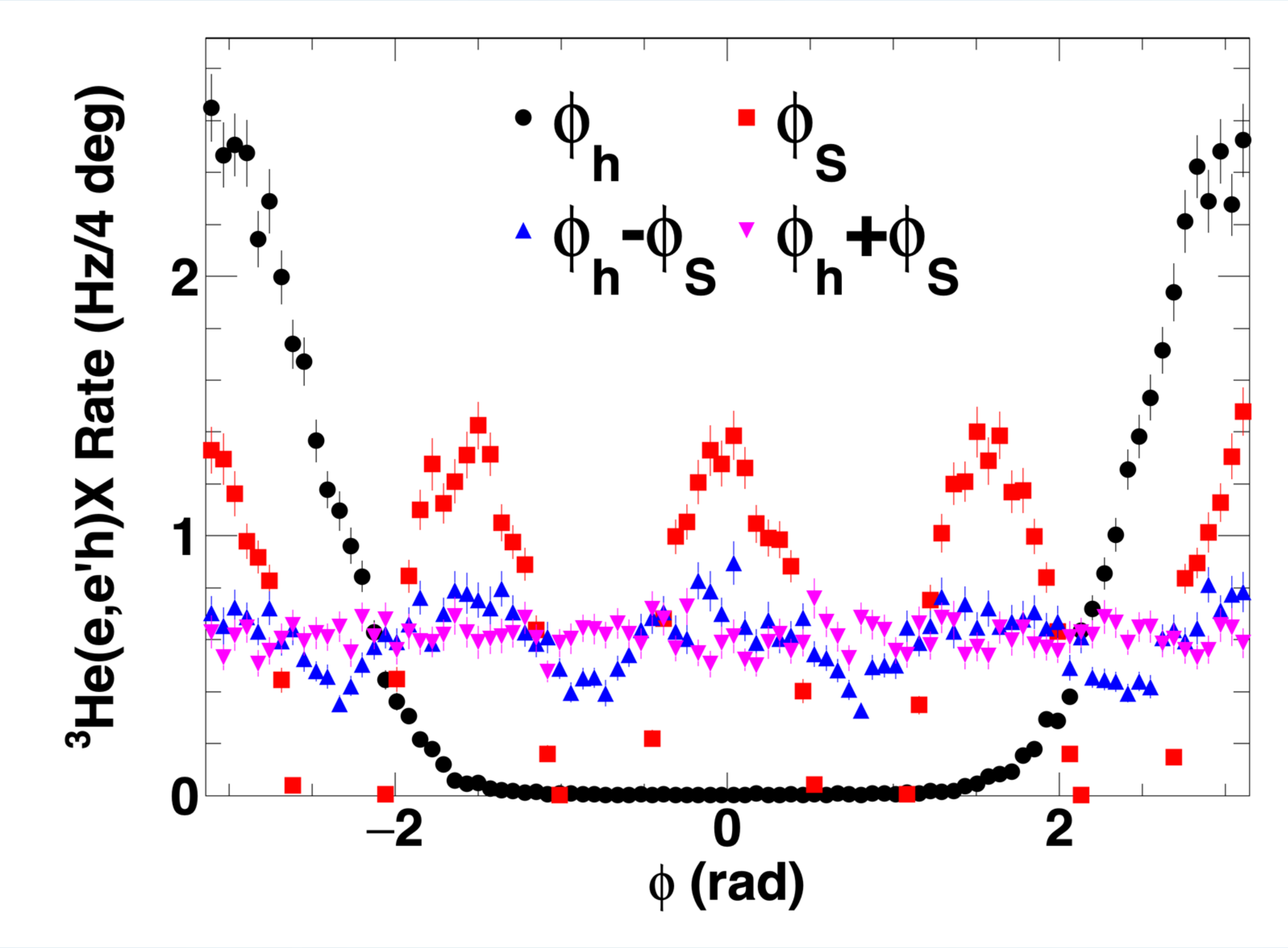
The SBS SIDIS kinematic coverage



- $Q^2 > 1$ 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

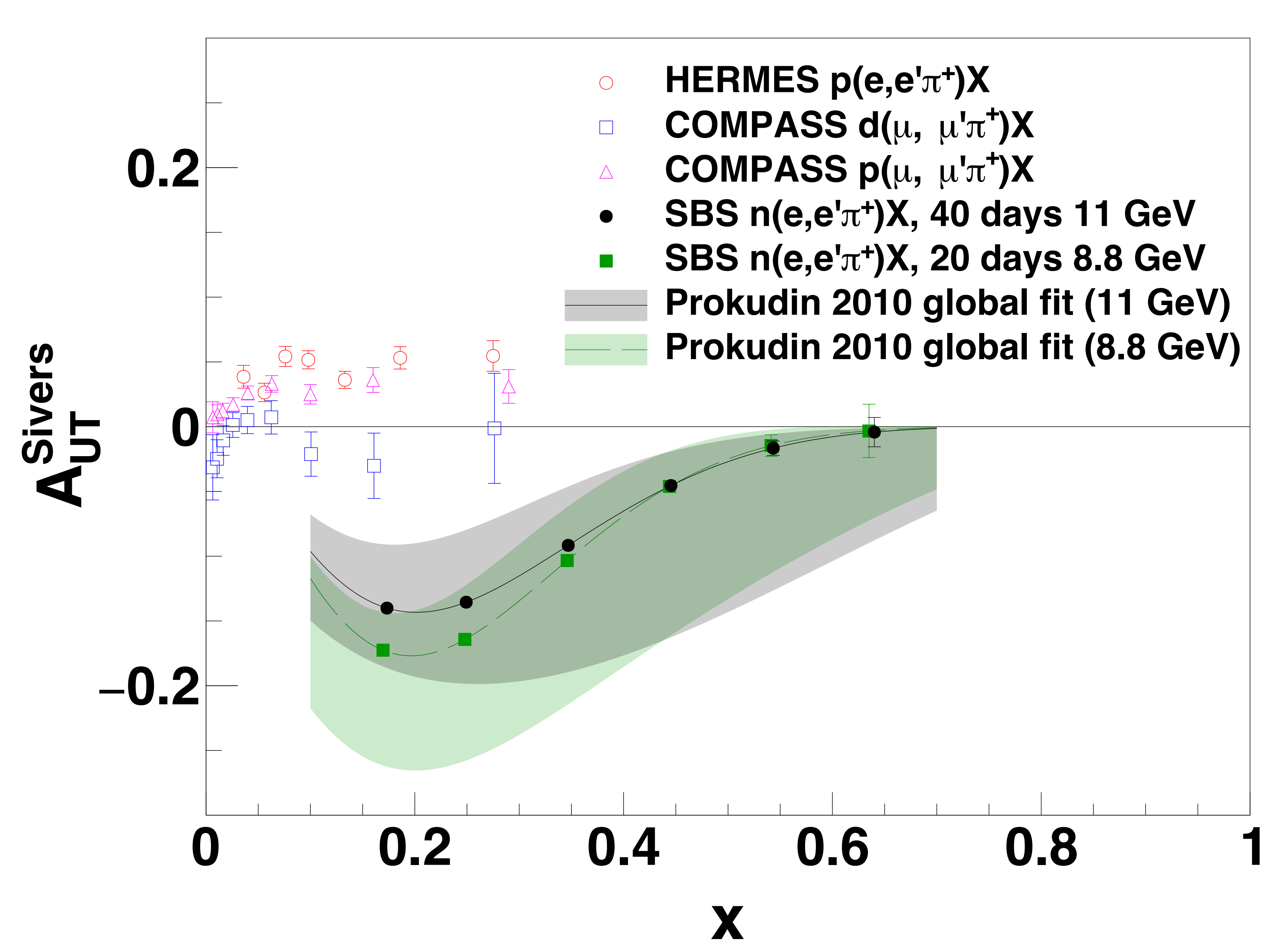
SBS SIDIS Azimuthal Coverage

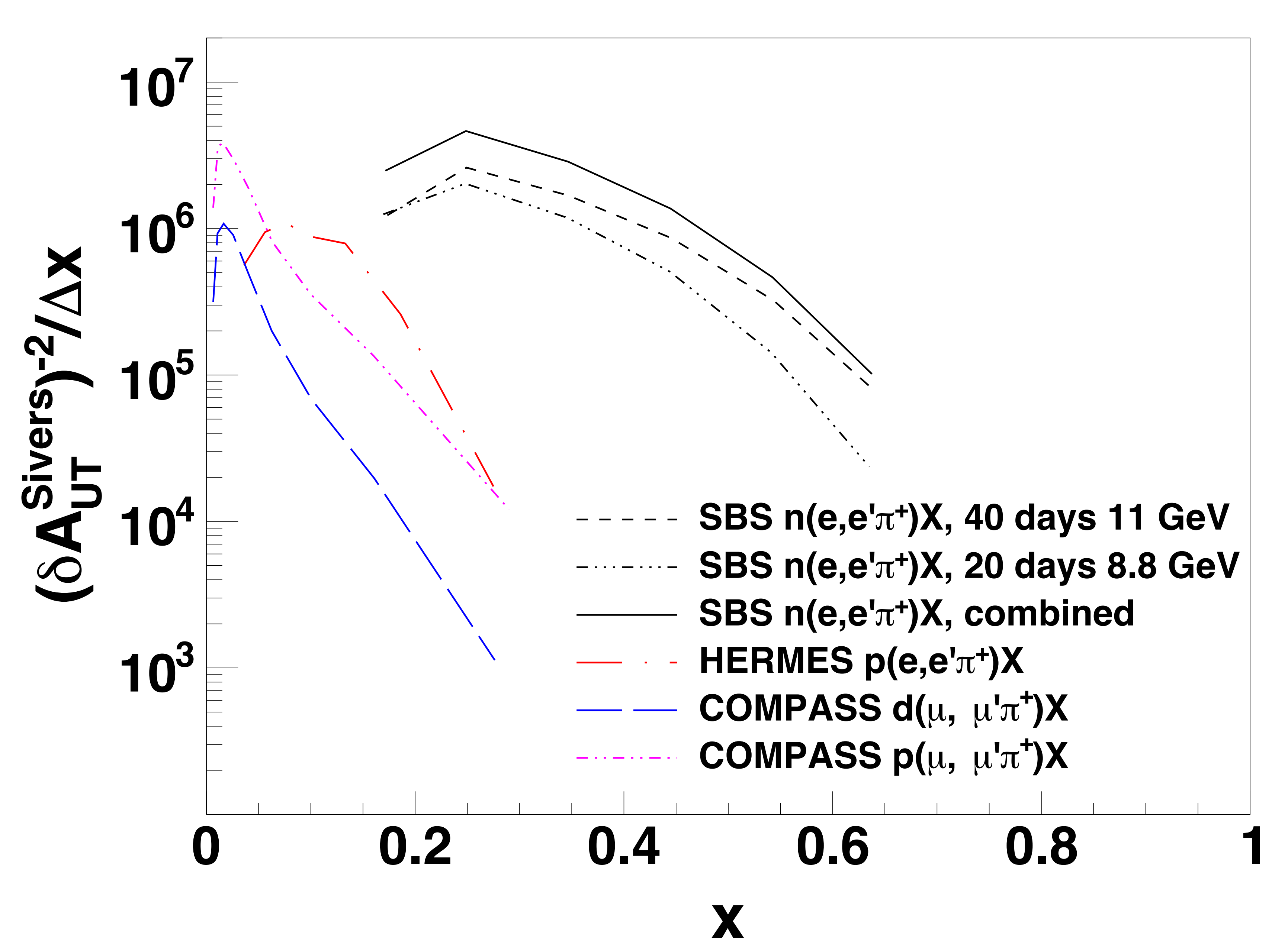




- Our original proposal envisioned eight spin orientations.
- We find virtually unchanged azimuthal coverage (and overall FoM) with four.
- Limiting to four spin orientations greatly simplifies the polarized target, enabling the use of major portions of the G_E^n target.

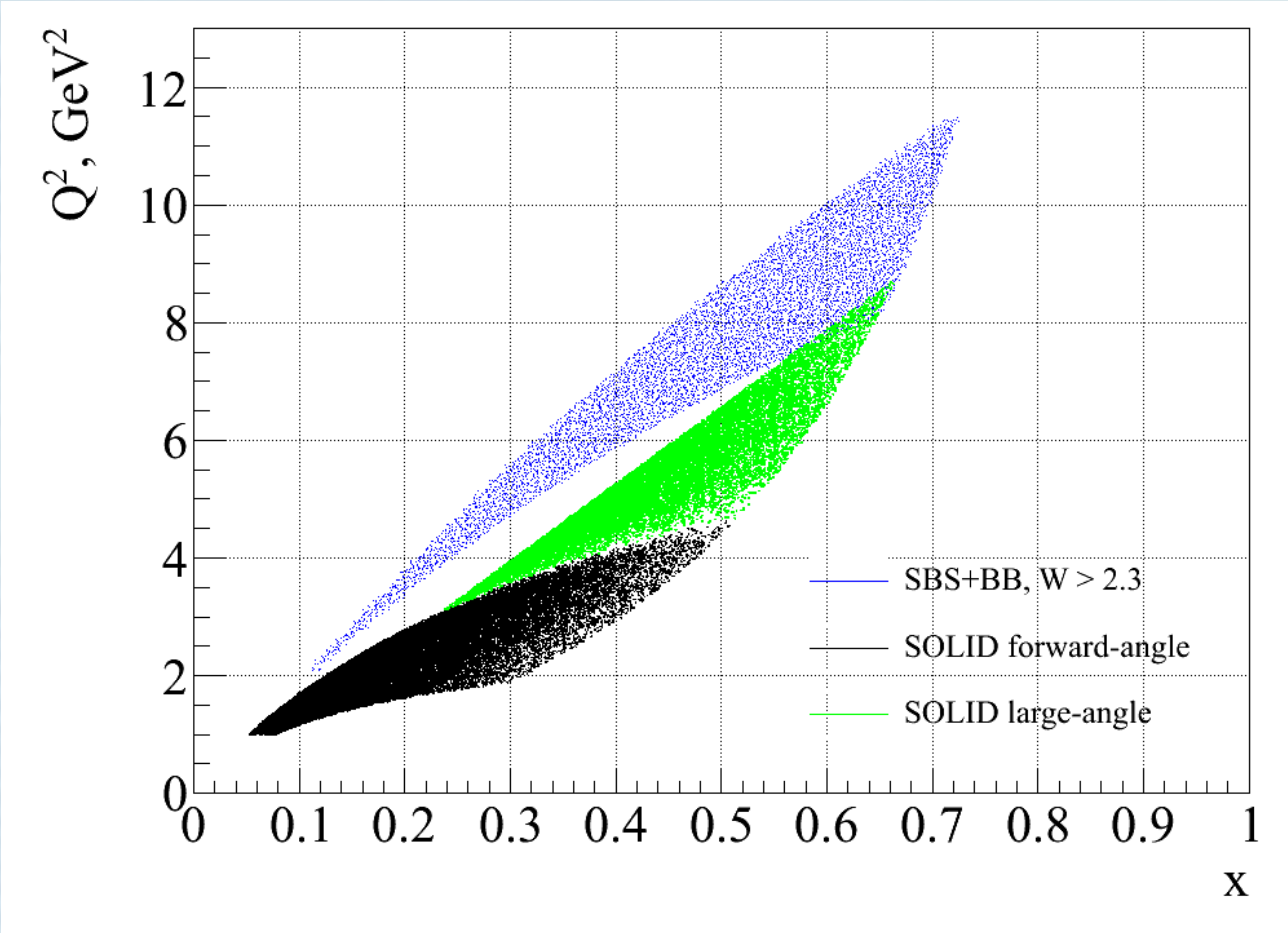
Comparing SBS SIDIS neutron data with existing data





- SBS SIDIS will increase the statistics of available TMD data by a factor of ~100 !!!
- At higher values of x, roughly x > 0.1, it will completely dominate TMD measurements for many years to come.

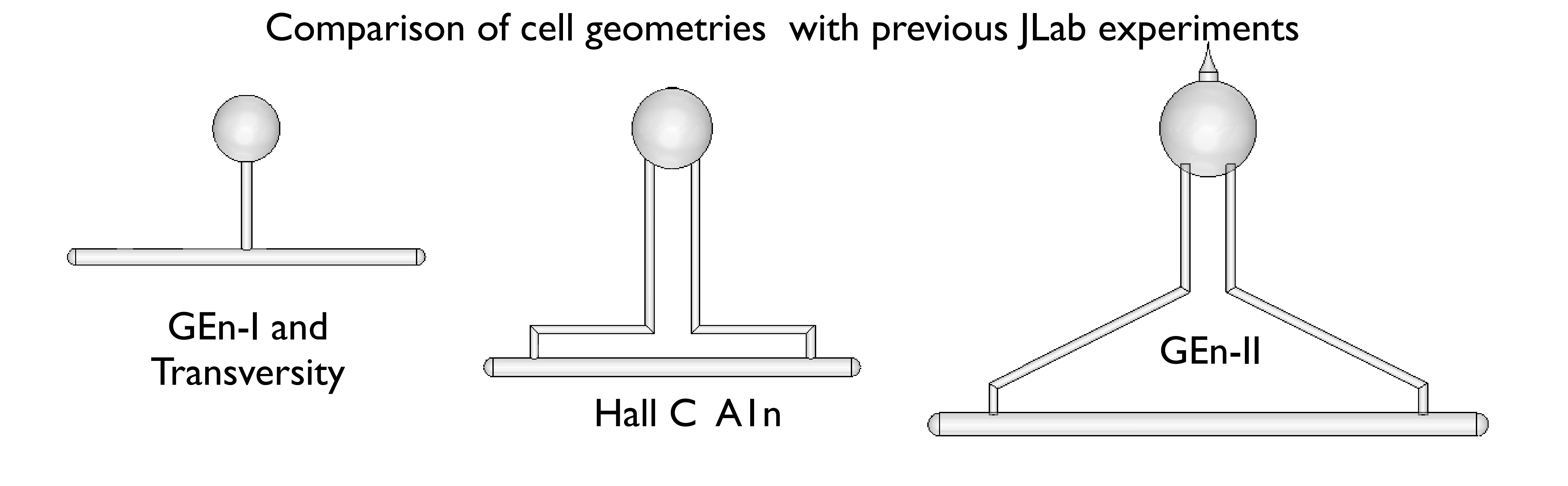
Comparison with SoLID



- 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.

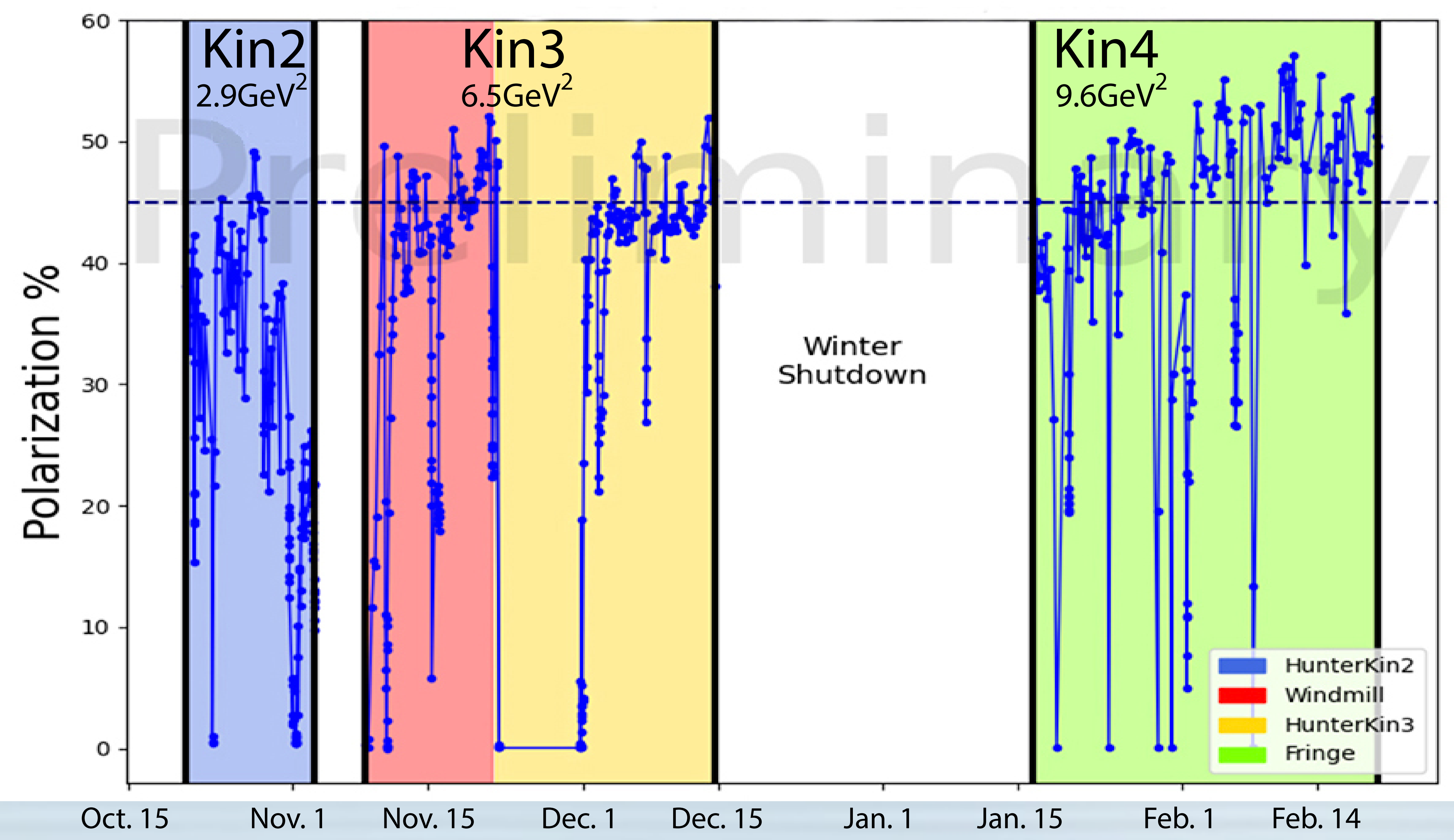
The SBS GEn-II target and modifications needed to run SBS SIDIS in Hall C

The polarized ^{3}He target for GEn-II



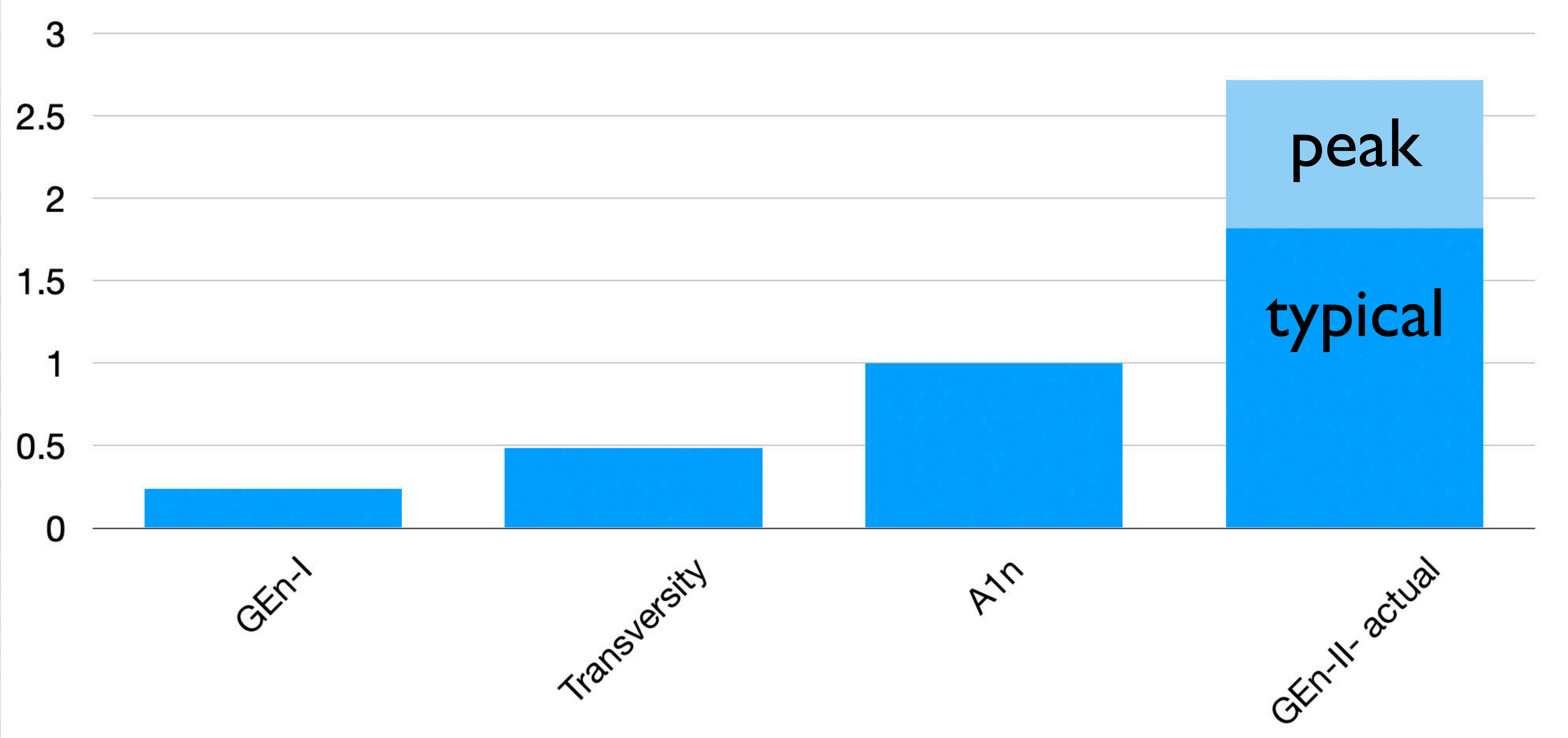
- Designed to handle luminosities 2-3 times higher than previous polarized ^{3}He targets.
- Target cells contain twice the volume of ^{3}He of previous target cells & target chamber is 60cm in length rather than 40cm previously.
- Cells are (for the first time) illuminated from two directions.
- Magnetic shielding protects the target from the fringe fields of the large SBS magnet.

GEn-II polarized ^{3}He performance



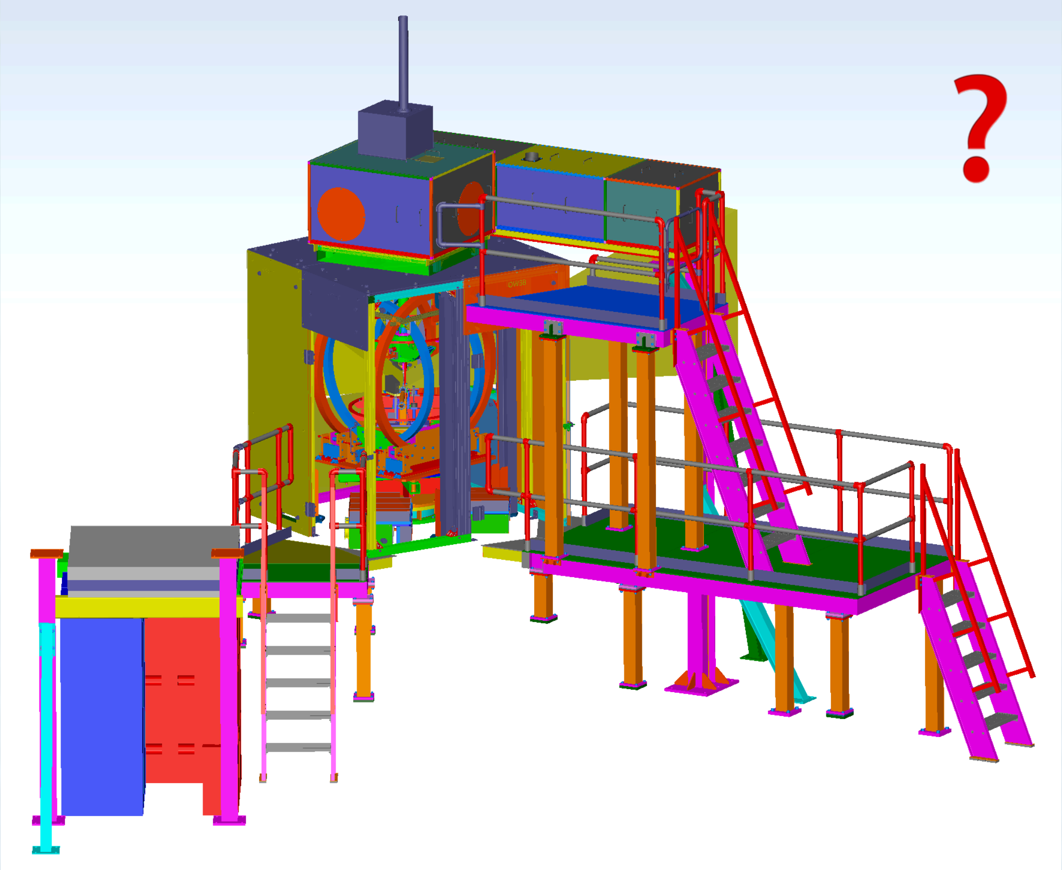
- At left is the polarization as a function of time for the three GEn-II kinematic settings.
- Note that we used Kin2 for commissioning which was possible because of the higher event rates at the lower value of Q^2 (2.9 GeV^2).
- Most data were taken with a beam current of 45μA (versus 30μA) previously
- With the 60 cm target chamber, the luminosity was a factor of 2.25 higher than all previous polarized 3He experiments at JLab.

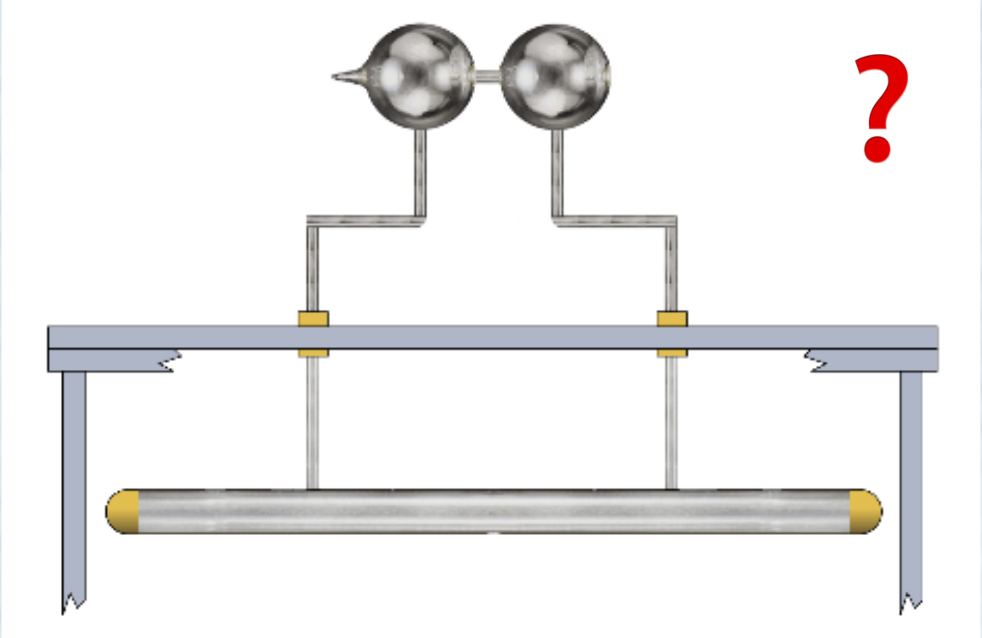
- At right is shown the figure-of-merit (FoM) achieved for several JLab experiments including GEn-II.
- We define the FoM as luminosity times polarization squared, shown in units where the Hall C A1n experiment is set equal to unity.
- Typical performance of the GEn-II target was nearly x2 higher than A1n, with peak performance nearly x3 higher.
- It is notable that the integrated luminosity of GEn-II (thus far) is roughly equal to all previous 3He experiments at JLab.



The SBS SIDIS Polarized ^{3}He Target for Hall C

Important changes in comparison to the GEn-II target





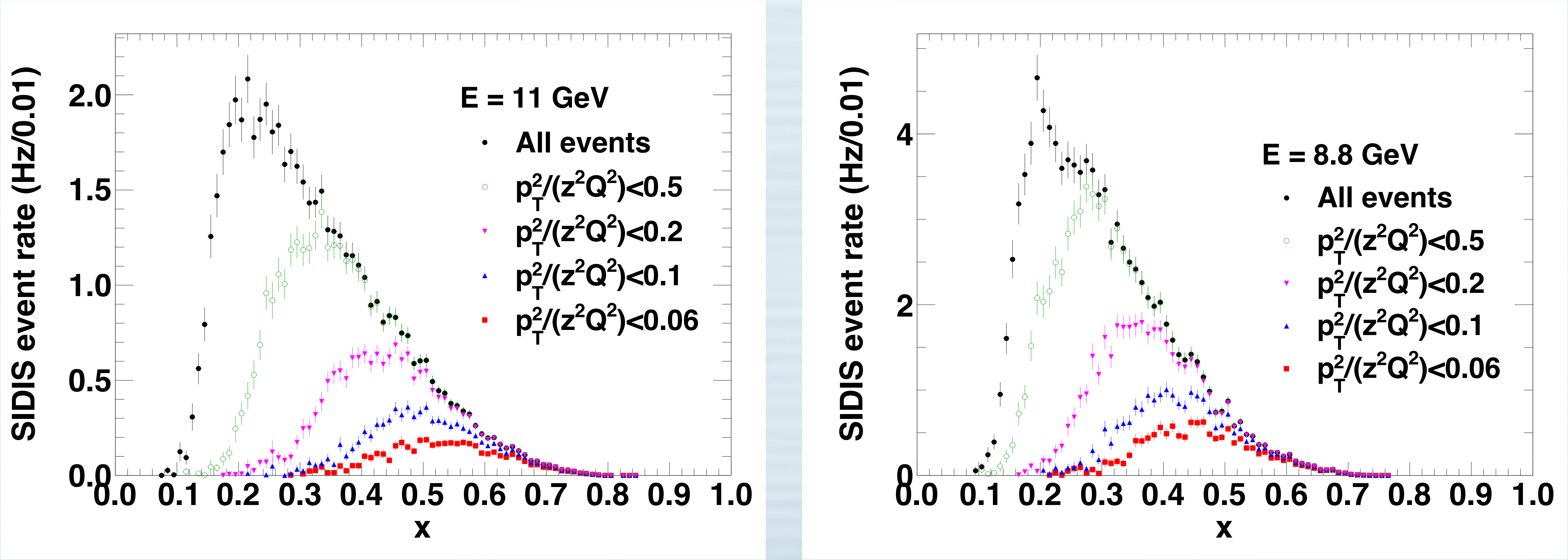
- Need to add capability for vertical polarization.
- Need to be capable of rapid flips of polarization direction.
- Optics system will need to accommodate vertical polarization.
- Perhaps worth considering some departure from current approach:
  - Two pumping chambers ?
  - Possibly polarize in a direction that is different from the polarization direction in beam?

Summary

- The move to Hall C looks (reasonably) straightforward.
- Target modifications are not trivial, but also reasonably straightforward.
- SBS SIDIS is arguably among the most important experiments that can be done at JLab.

Backup slides

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

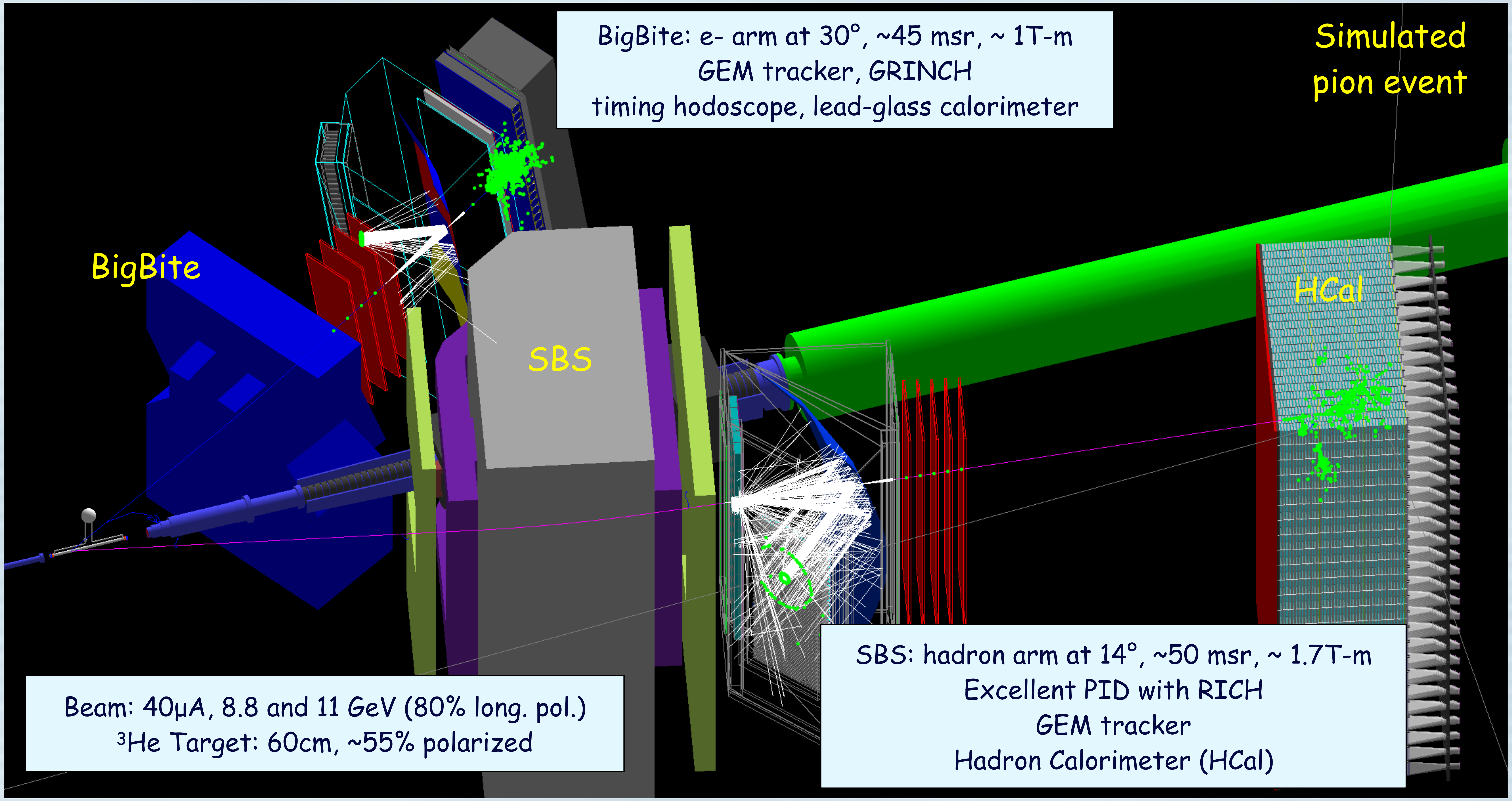


One global analysis by Scimemi and Vladimirov suggests a limit of $p_T^2/z^2Q^2 < 0.06$, which would exclude virtually all of HERMES data and much of the COMPASS data

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.

The SBS SIDIS Experiment
more details



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.

Projected data for SBS SIDIS

E_e (GeV)	Days	^{3}He$(e,e'\pi^+)X$ Events/10^6	^{3}He$(e,e'\pi^-)X$ Events/10^6	^{3}He$(e,e'K^+)X$ Events/10^6	^{3}He$(e,e'K^-)X$ Events/10^6	^{3}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}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.

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.