SoLID SIDIS projections from transversely polarized ^{3}He target at 20+ GeV energies

Vlad Khachatryan for the SoLID collaboration

Physics Department, Duke University

The Next Generation of 3D Imaging, 7-8 July 2022

Let's start by outlining the following TMDs that describe confined motion inside the nucleon

Transversely Polarized Nucleon TMDs

→ Nucleon Spin

→ Quark Spin

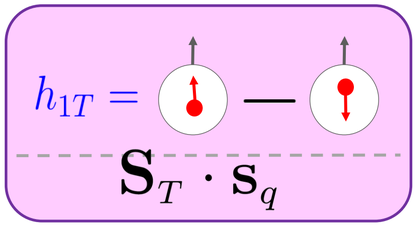
These TMDs will be measured by the SOLID SIDIS 12 GeV program

Experiments:
E12-10-006 (with trans. pol. ^{3}He ("neutron")
E12-11-108 (with trans. pol. NH_3 ("proton")

Relevant Vectors

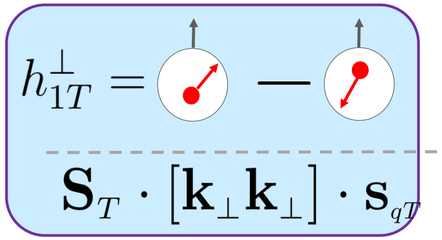
S_T: Nucleon Spin
s_q: Quark Spin
$k_\perp$: Quark Transverse Momentum
P: Virtual photon 3-momentum (defines z-direction)

Transversity



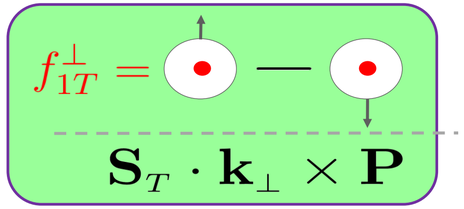
- h_{1T} (h_1) = g_1 (no relativity)
- h_{1T} → tensor charge (confronting lattice QCD calculations)
- Connected to nucleon beta decay and electric dipole moment

Pretzelosity



- Interference between components with quark orbital angular momentum (OAM) difference of 2 units (i.e., s-d, p-p) (model dependence)
- Signature for relativistic effect

Sivers

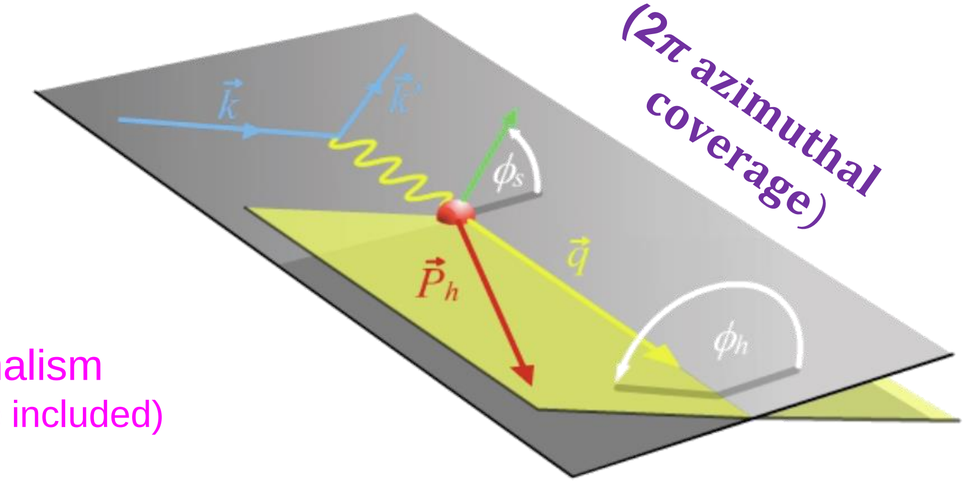


- Nucleon spin - quark orbital angular momentum (OAM) correlation
- Zero if no OAM (model dependence)

Separation of the transverse Collins / Sivers / Pretzelosity SSAs

Corresponding SIDIS SSAs depend on 4-D variables (x, Q^2, z, P_T);

Small asymmetries demand **large acceptance + high luminosity** allowing for measuring asymmetries in 4-D binning with precision!



$$A_{UT}(\phi_h, \phi_S) = \frac{1}{P_{t,pol}} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

Leading twist formalism
(higher-twist terms can be included)

$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

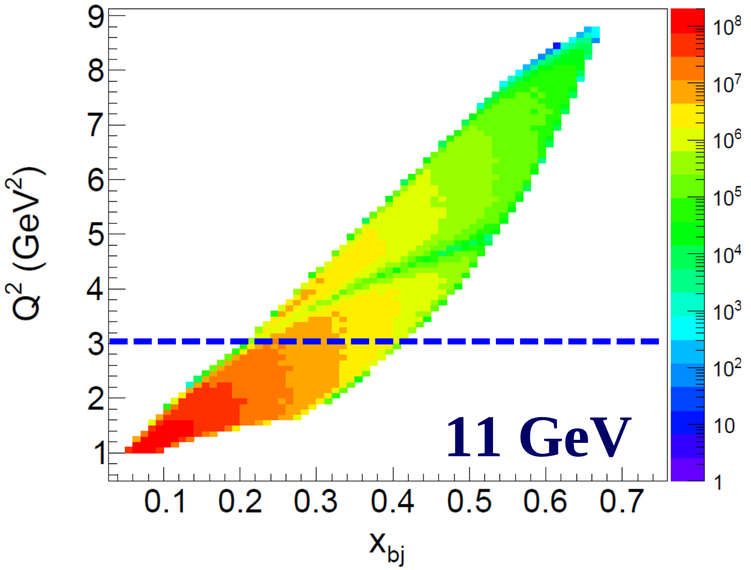
$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

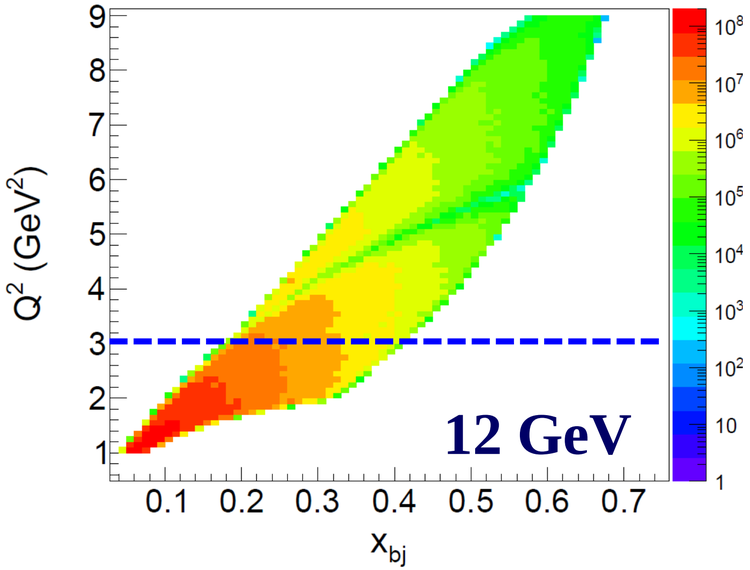
Collins fragmentation function from e^+e^- collisions

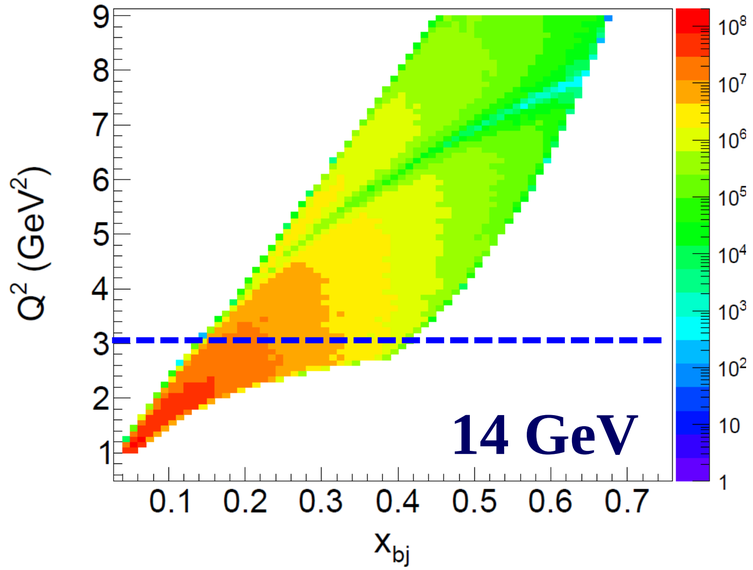
$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

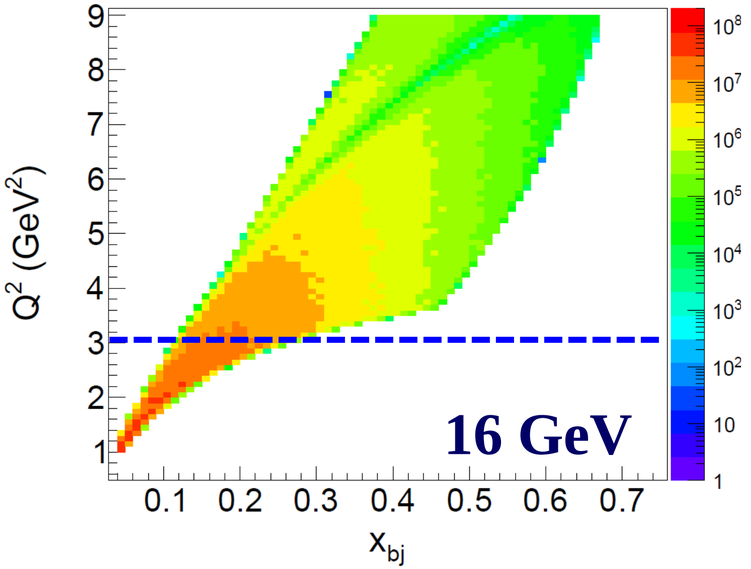
Unpolarized fragmentation function

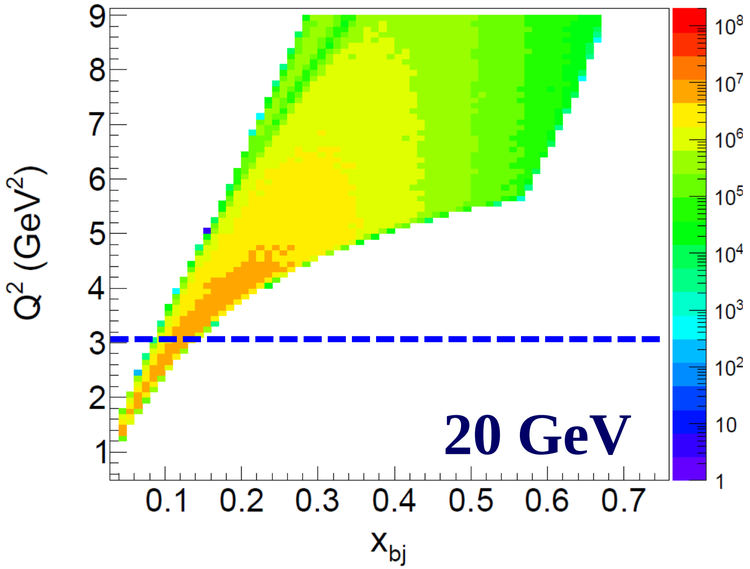
Phase - space examples obtained with the ^{3}He target at various beam energies: Q^2 vs. x_{bj}

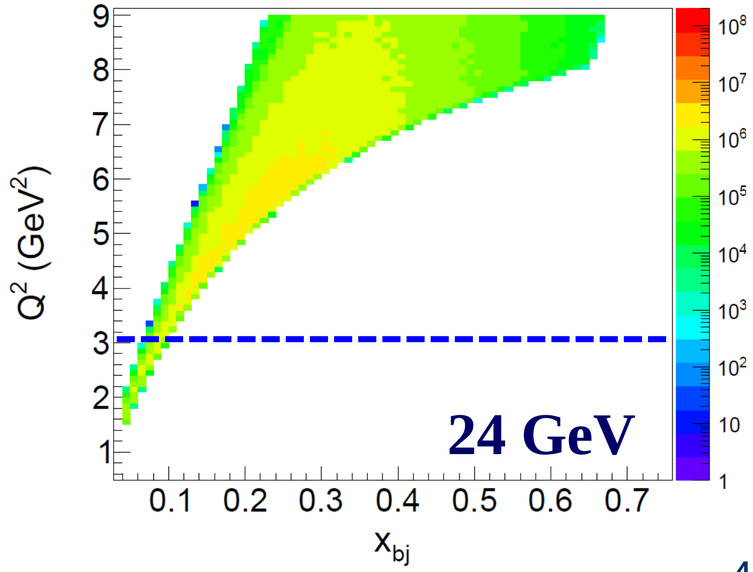








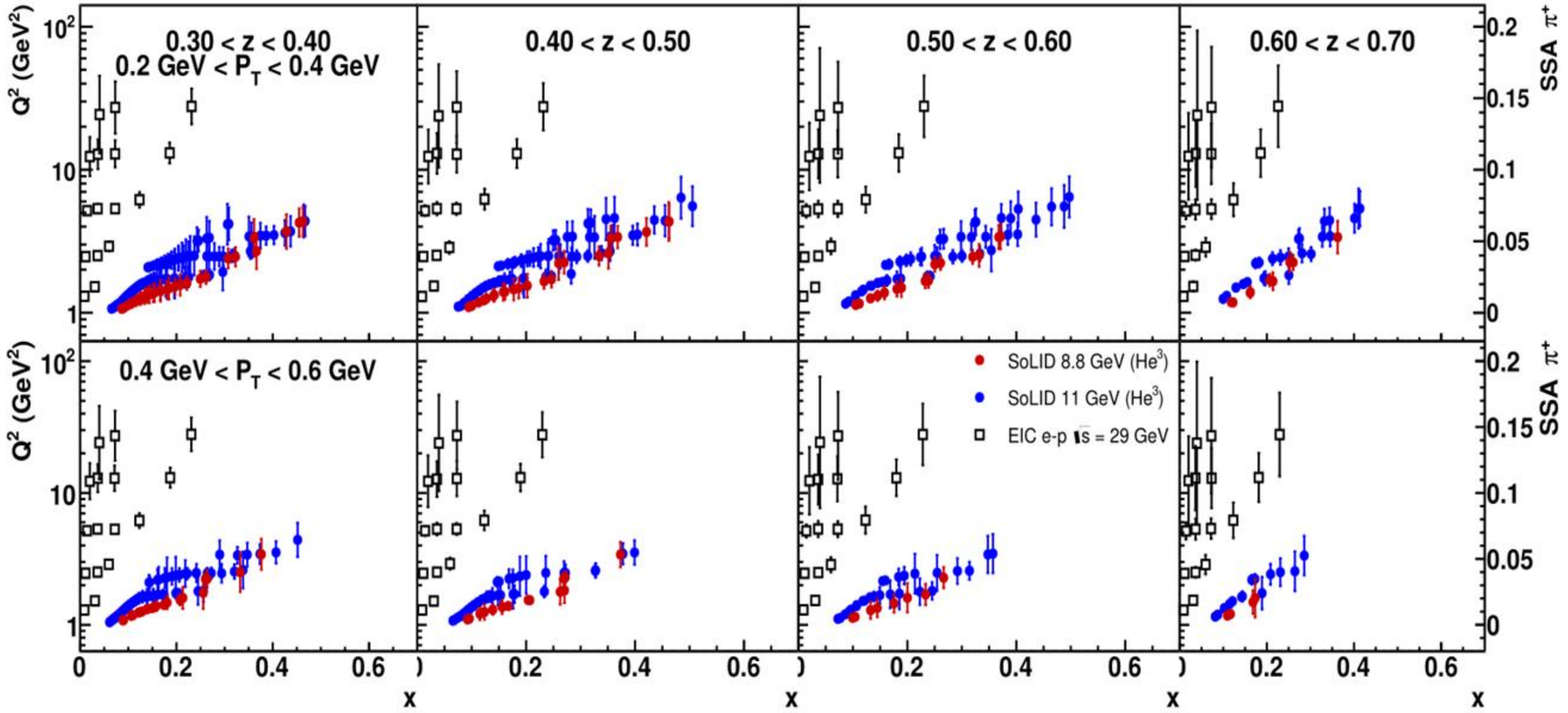




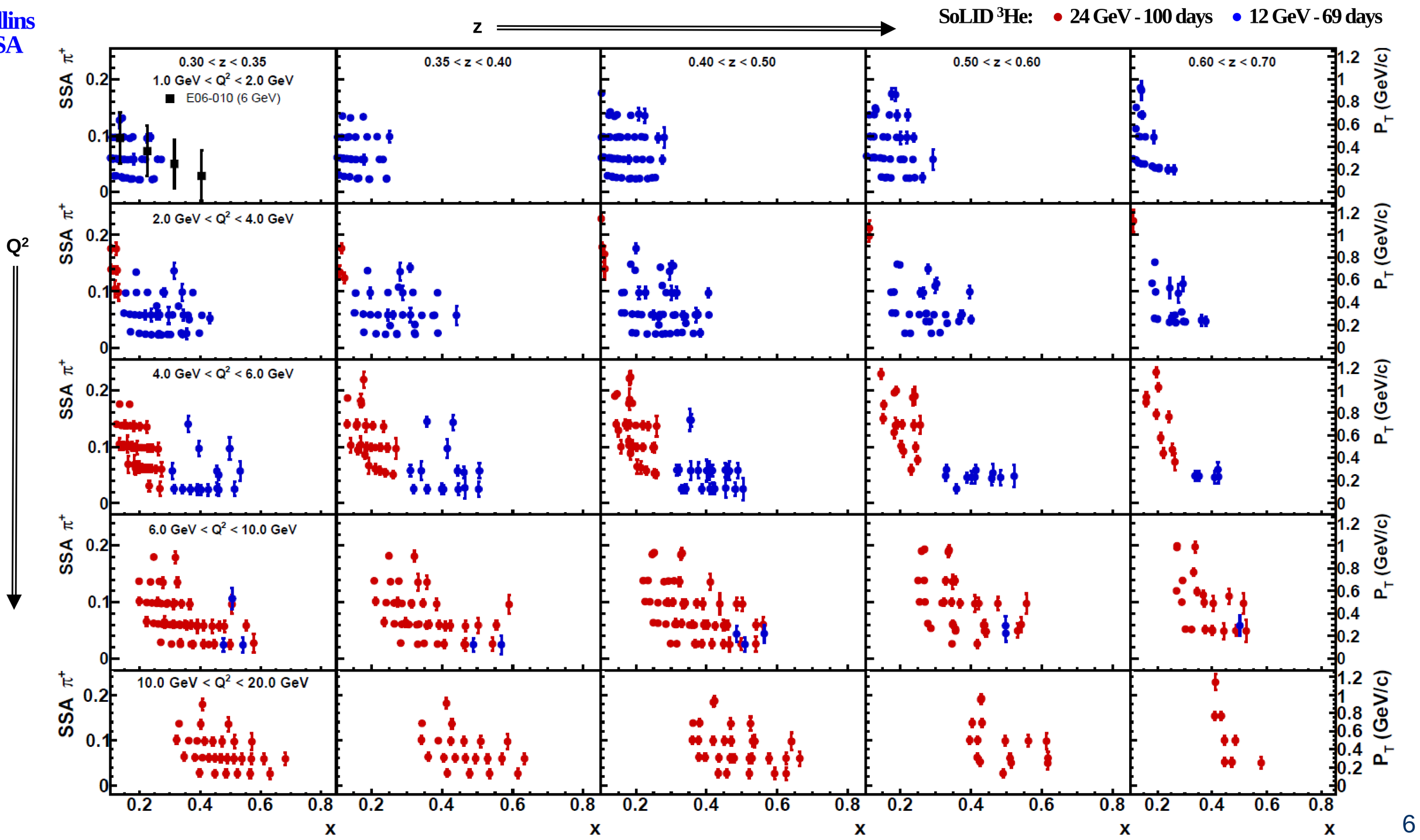
Just an example of the SOLID 12 GeV pseudo-data compared to that at EIC kinematics

- SoLID SIDIS projections of A_{UT} in various 4-D bins at 11 / 8.8 GeV beam energies from trans. pol ^{3}He target
- Projections at EIC kinematics for the same observable at 29 GeV center-of-mass energy
- SSA scale and uncertainties shown on the right-side axis of the figures
- SoLID and EIC projections synergistic towards each other, by covering different x and Q^2 ranges

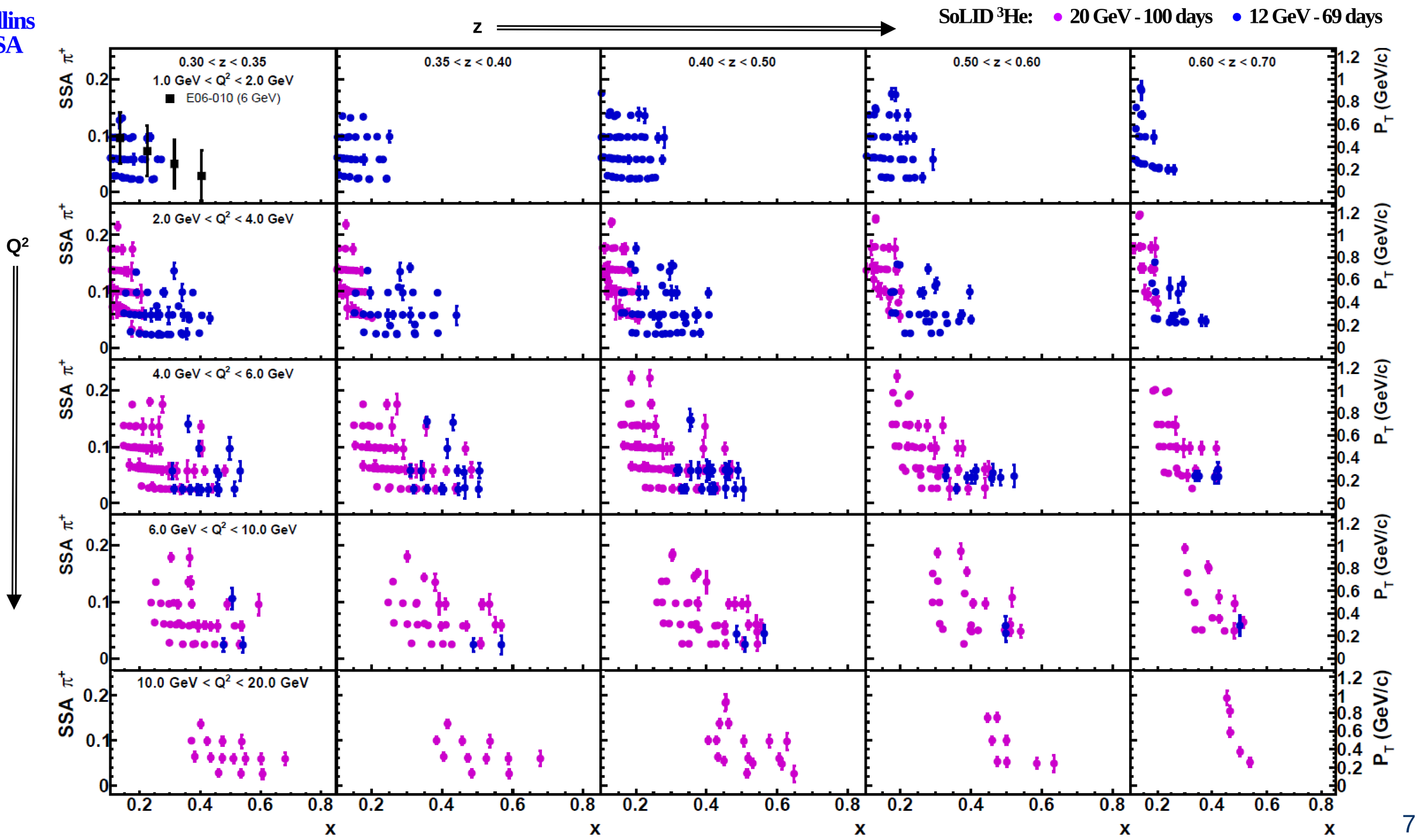
A_{UT} non-separated asymmetry of π^+ particles



Collins SSA

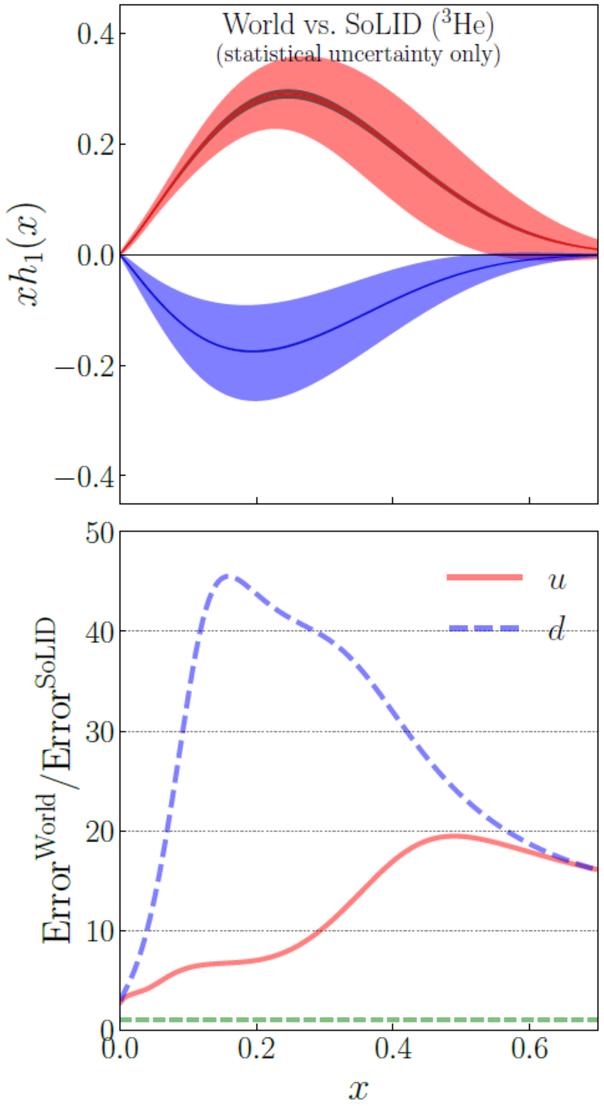

z
SoLID ^{3}He: 24 GeV - 100 days 12 GeV - 69 days
Q^2
0.30 < z < 0.35
0.35 < z < 0.40
0.40 < z < 0.50
0.50 < z < 0.60
0.60 < z < 0.70
1.0 GeV < Q^2 < 2.0 GeV
E06-010 (6 GeV)
2.0 GeV < Q^2 < 4.0 GeV
4.0 GeV < Q^2 < 6.0 GeV
6.0 GeV < Q^2 < 10.0 GeV
10.0 GeV < Q^2 < 20.0 GeV
SSA π^+
P_T (GeV/c)
x

Collins SSA


z
SoLID ^{3}He: 20 GeV - 100 days 12 GeV - 69 days
Q^2
0.30 < z < 0.35
0.35 < z < 0.40
0.40 < z < 0.50
0.50 < z < 0.60
0.60 < z < 0.70
1.0 GeV < Q^2 < 2.0 GeV
E06-010 (6 GeV)
2.0 GeV < Q^2 < 4.0 GeV
4.0 GeV < Q^2 < 6.0 GeV
6.0 GeV < Q^2 < 10.0 GeV
10.0 GeV < Q^2 < 20.0 GeV
SSA π^+
P_T (GeV/c)
x

Transversity projections

- Impact on the *u* and *d* quarks' Transversity TMD extractions by the SoLID SIDIS program

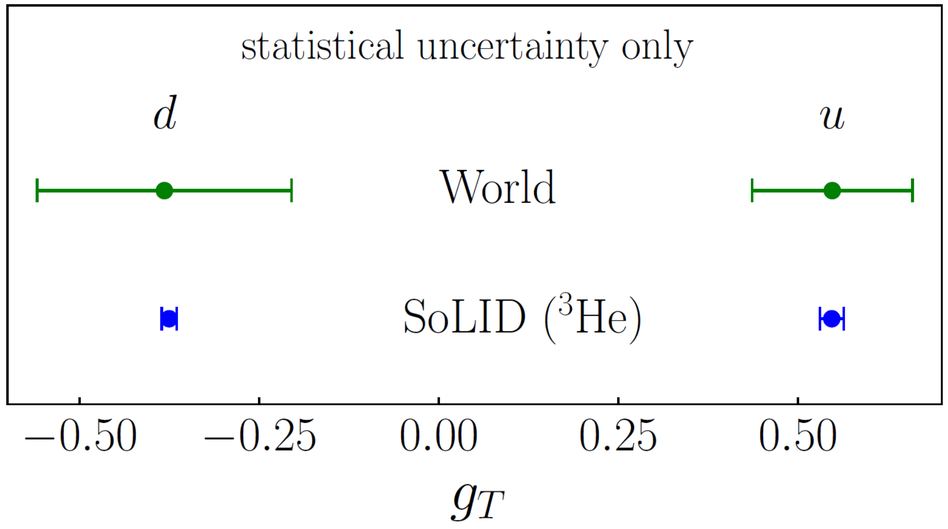


24-11-8.8 GeV

Tensor Charge projections

Tensor charge g_T:

$$g_T^q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x)\right] dx$$

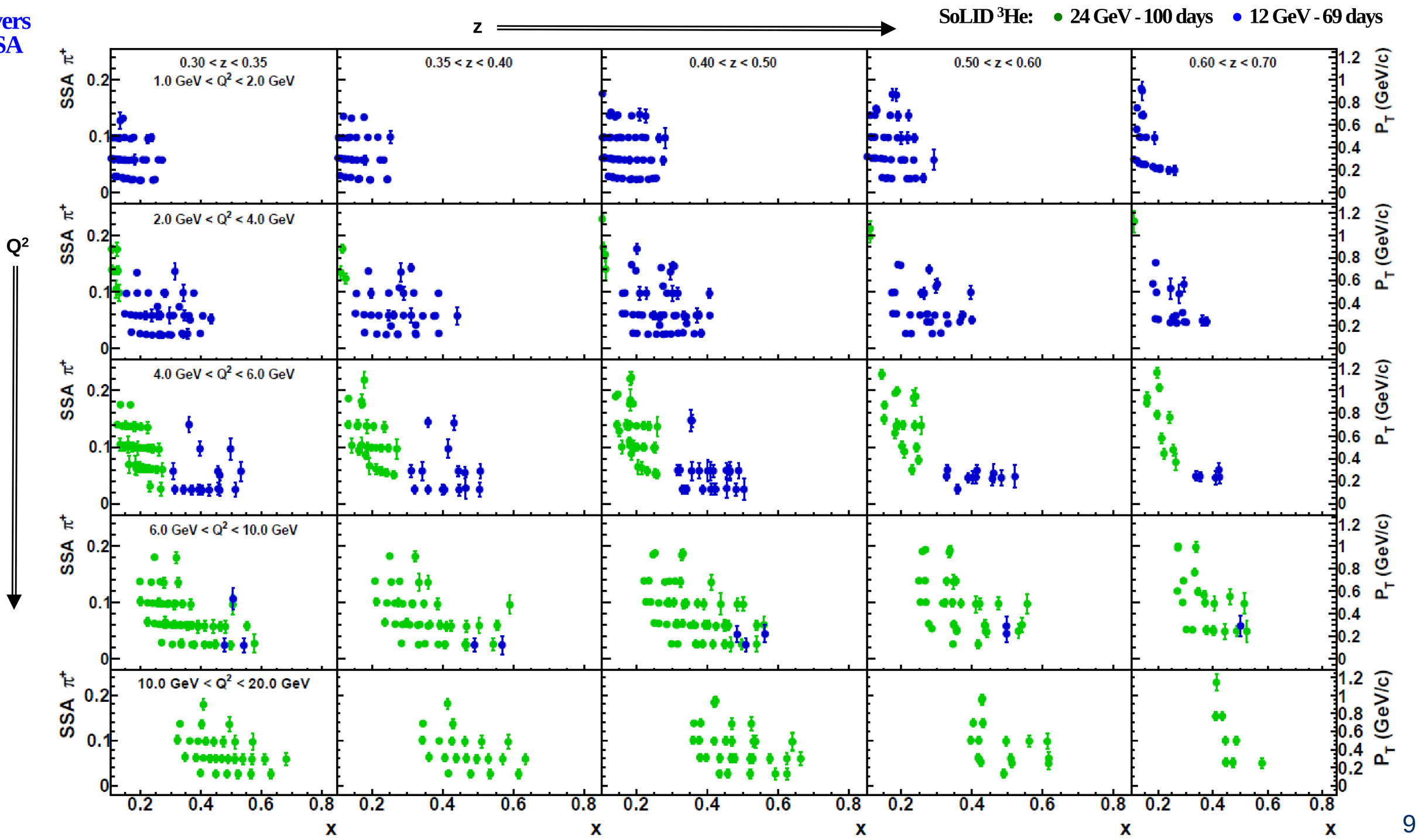


<u>World data</u> vs. <u>SoLID projections at 24 GeV

shown in the figure and table from ^{3}He target at 11 / 8.8 GeV energies

g_T flavor separation	World data	SoLID 12 GeV	SoLID 24 GeV
u / *d* value	0.548 / -0.382	0.547 / -0.376	0.547 / -0.375
u / *d* error	0.112 / 0.177	0.016 / 0.012	0.016 / 0.01

Sivers SSA

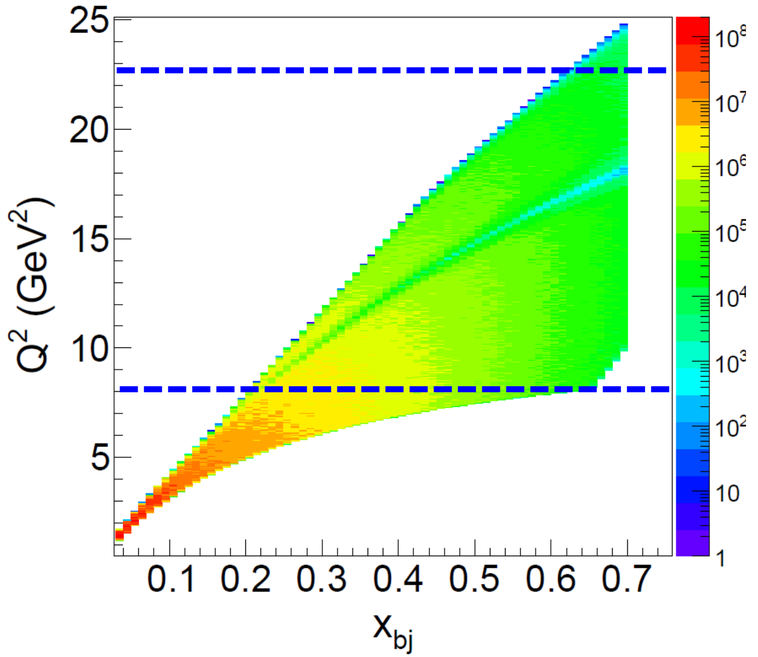

z
SoLID ^{3}He: 24 GeV - 100 days 12 GeV - 69 days
Q^2
0.30 < z < 0.35
0.35 < z < 0.40
0.40 < z < 0.50
0.50 < z < 0.60
0.60 < z < 0.70
1.0 GeV < Q^2 < 2.0 GeV
2.0 GeV < Q^2 < 4.0 GeV
4.0 GeV < Q^2 < 6.0 GeV
6.0 GeV < Q^2 < 10.0 GeV
10.0 GeV < Q^2 < 20.0 GeV
SSA π^+
P_T (GeV/c)
x

Let's do the following exercise when the SoLID ^{3}He acceptance is bypassed

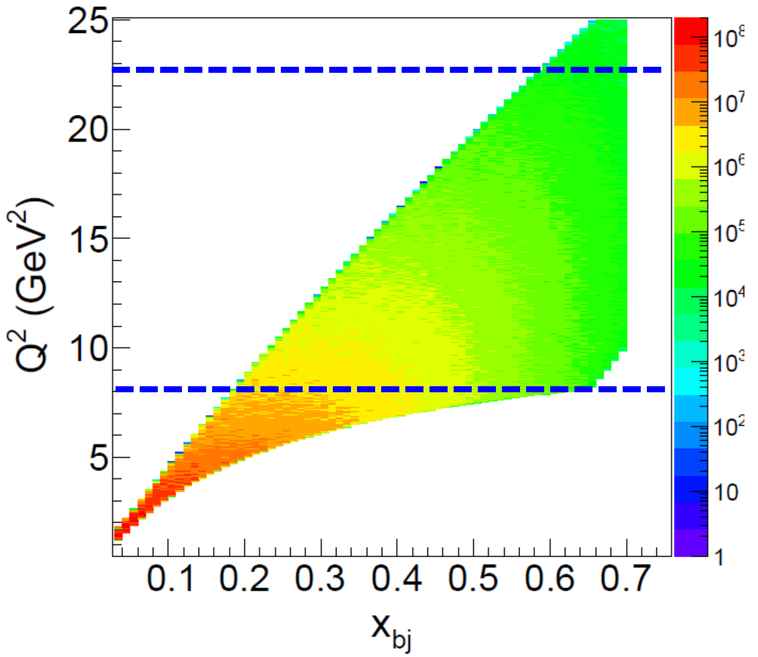
- The acceptance is in the polar angular coverage: $\theta = 8^\circ - 30^\circ$

- Bypass the acceptance in the range of $\theta = 8^\circ - 30^\circ$
- Bypass the acceptance in the range of $\theta = 5^\circ - 27^\circ$

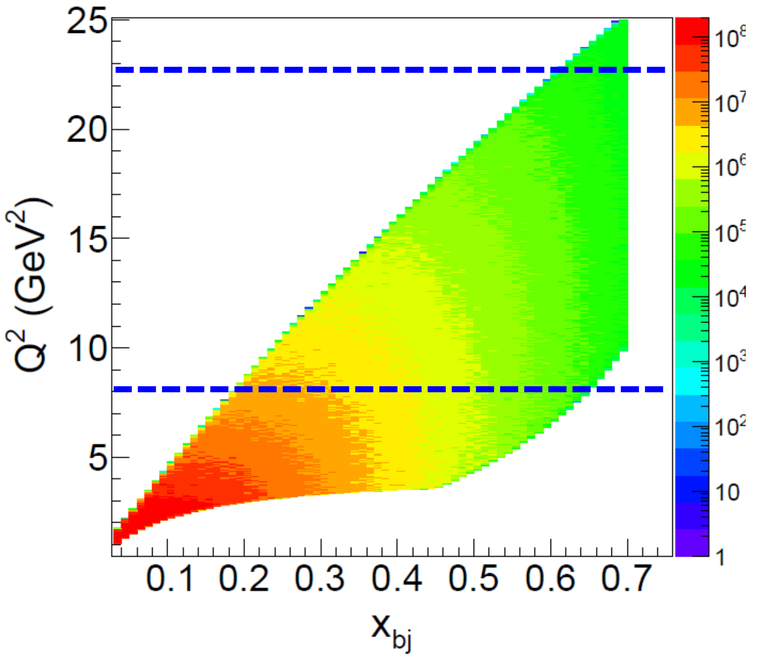
with 24 GeV acceptance
$\theta = 8^\circ - 30^\circ$



24 GeV acceptance bypassed
$\theta = 8^\circ - 30^\circ$



24 GeV acceptance bypassed
$\theta = 5^\circ - 27^\circ$



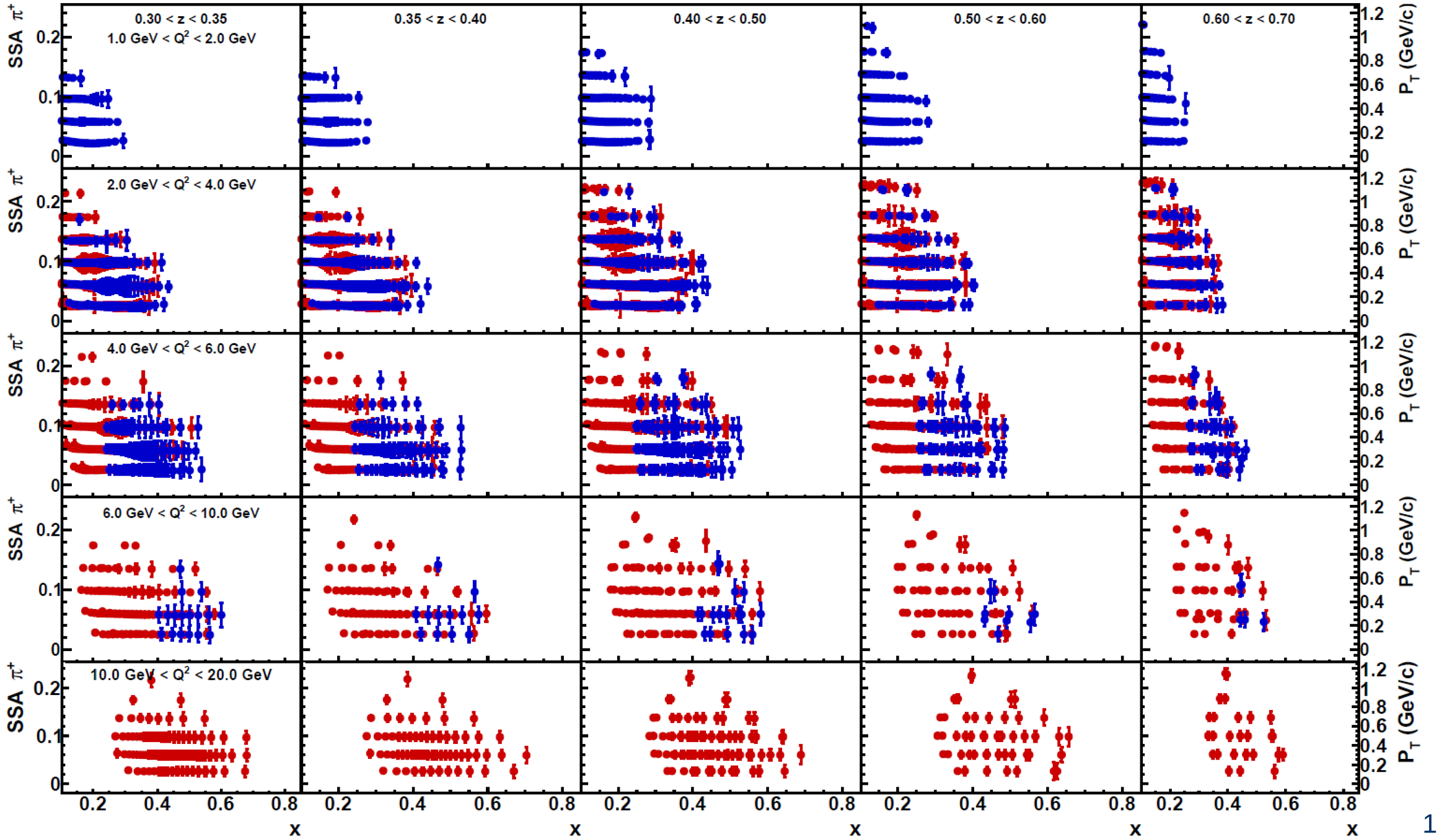
Acceptance bypassed for both 24 and 12 GeV

$\theta_{min} = 5°$

SoLID ^{3}He: ● 24 GeV - 100 days ● 12 GeV - 69 days

z →

Q^2 ↓



Collins SSA

- Produced the results with bypassed acceptance at **24 GeV** from ^{3}He and NH_3 targets
- Produced the results with bypassed acceptance at **20 GeV** from ^{3}He and NH_3 targets
- Produced the results with bypassed acceptance at **11 / 8.8 GeV** from ^{3}He and NH_3 targets
- Take the ratio (θ_{min} **= 5°** to θ_{min} **=** 8°) of the total rate in the entire 4-D binning, as shown below

Total rate ratio

SoLID ^{3}He

12 GeV, θ_{min} = 5°/θ_{min} = 8°	20 GeV, θ_{min} = 5°/θ_{min} = 8°	24 GeV, θ_{min} = 5°/θ_{min} = 8°
1.63	6.77	8.93

SoLID NH_3

12 GeV, θ_{min} = 5°/θ_{min} = 8°	20 GeV, θ_{min} = 5°/θ_{min} = 8°	24 GeV, θ_{min} = 5°/θ_{min} = 8°
1.19	3.67	4.5

Things to do next for 20+ GeV by the SoLID collaboration

- For the SIDIS pions, get also pseudo-data with the NH_3 target acceptance; combine with the ^3He pseudo-data to update the results on the Collins and Sivers SSAs

- Perform similar studies for the
  1) SIDIS kaons;
  2) g_T measurement (inclusive);
  3) SIDIS worm-gear TMD g_{1T};
  4) high-p_T inclusive pions.

- Make comparisons with observables at EIC kinematics