UPDATE OF TRANSVERSE-SPIN AZIMUTHAL ASYMMETRIES FOR K^0 PRODUCTION IN SIDIS

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ON BEHALF OF THE COMPASS COLLABORATION

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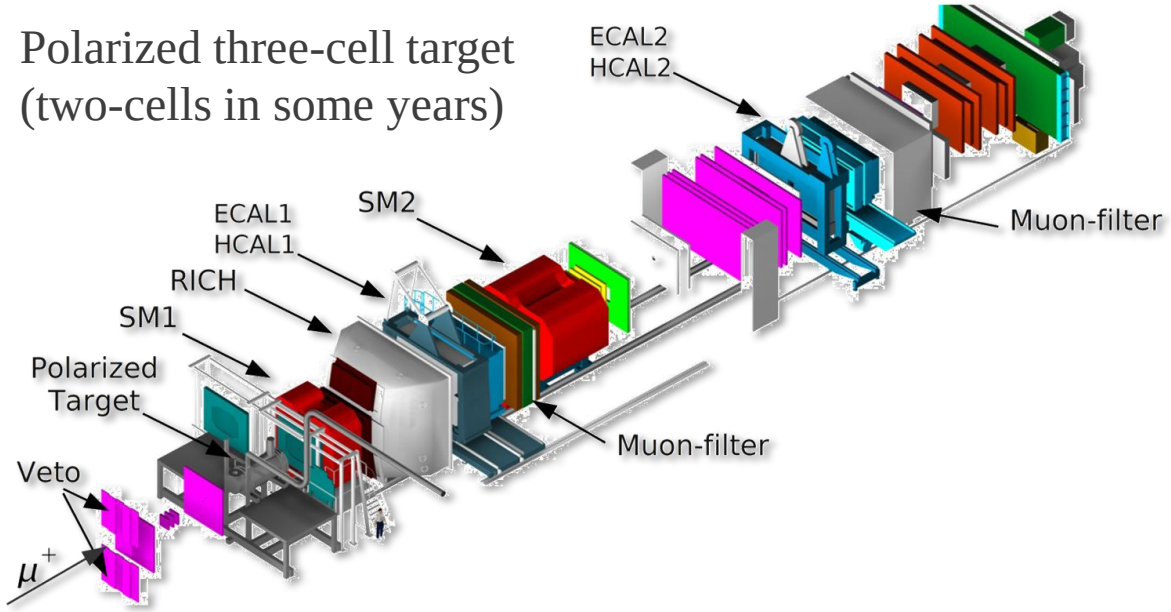
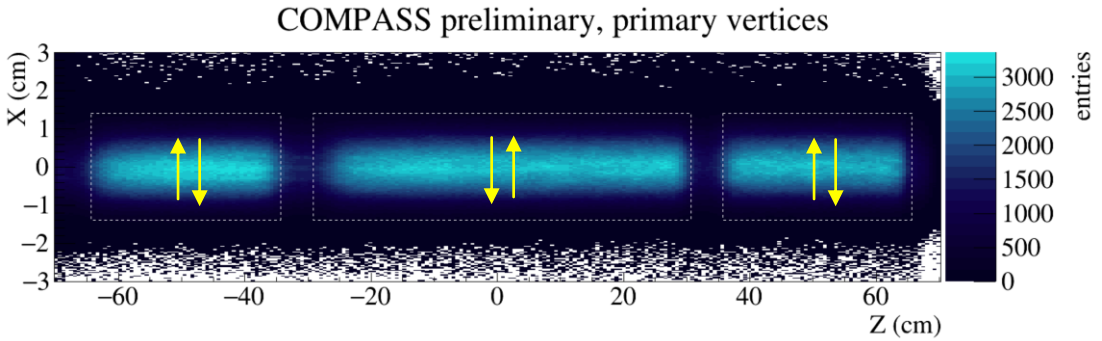
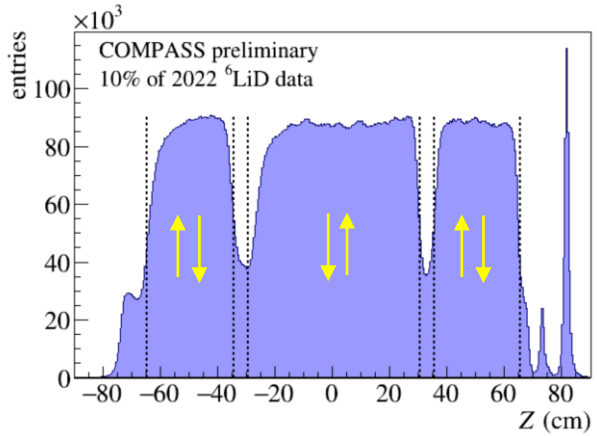
COMPASS EXPERIMENT

- Location: CERN SPS North Area at the M2 beamline.
- Two-stage spectrometer
- Large geometrical acceptance, wide kinematic coverage
- Comprises a variety of tracking detectors
- PID and calorimetry
- Trigger system (hodoscope stations)
- Polarized three-cell target (two-cells in some years)

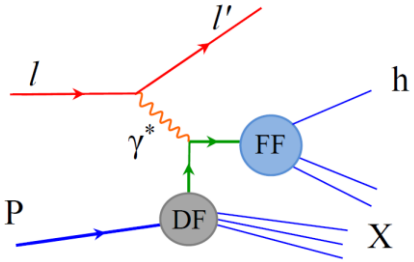


- COMPASS took data from 2002 to 2022.
- 2022 SIDIS data-taking: μ^+ high energy (160 GeV/c) beam
- Beam polarization: ~ - 80%
- Target material: Transversely polarized ^{6}LiD





SIDIS X-SECTION AND TMDS



COMPASS 25 years 1997 - 2022

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} =$$

$$\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)$$

15 asymmetries
all measured at COMPASS

$$\times\Big\{1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h$$
$$+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h$$
$$+S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right]$$
$$+S_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right]$$
$$+S_T\left[\begin{array}{l}A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)\\+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)\\+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)\\+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S\\+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\end{array}\right]$$
$$+S_T\lambda\left[\begin{array}{l}\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)\\+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S\\+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\end{array}\right]\Big\}$$

Twist-2

Twist-3

$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q}\otimes D_{1q}^{h}$ Sivers

$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^{q}\otimes H_{1q}^{\perp h}$ Collins

$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q}\otimes H_{1q}^{\perp h}$

$A_{UT}^{\sin(\phi_s)} \overset{WW}{\propto} Q^{-1}\left(h_1^{q}\otimes H_{1q}^{\perp h}+f_{1T}^{\perp q}\otimes D_{1q}^{h}+\ldots\right)$

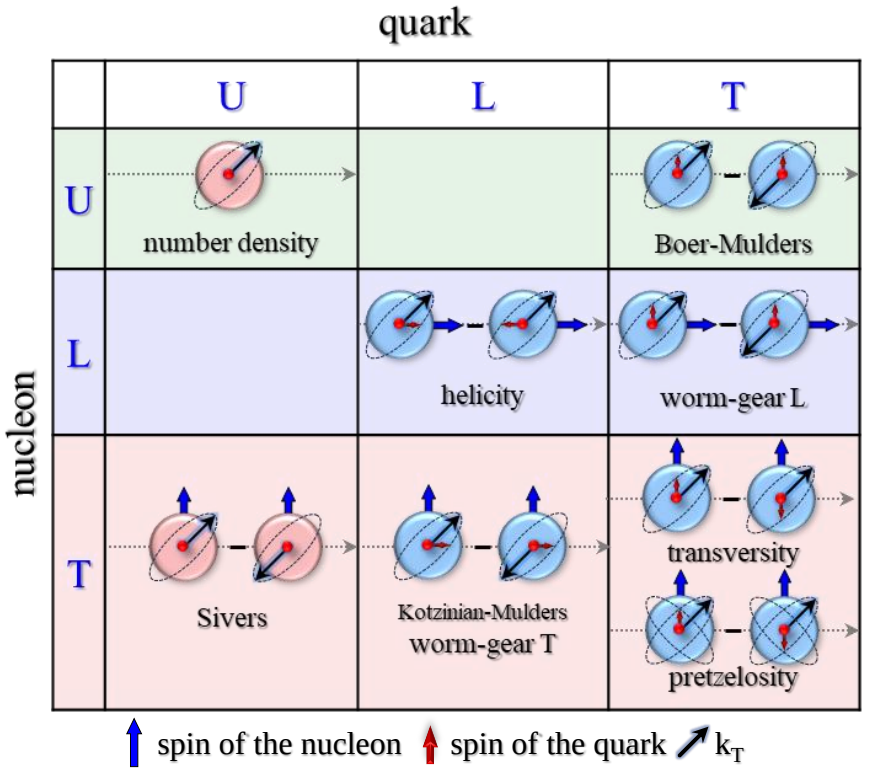
$A_{UT}^{\sin(2\phi_h-\phi_s)} \overset{WW}{\propto} Q^{-1}\left(h_{1T}^{\perp q}\otimes H_{1q}^{\perp h}+f_{1T}^{\perp q}\otimes D_{1q}^{h}+\ldots\right)$

$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^{q}\otimes D_{1q}^{h}$

$A_{LT}^{\cos(\phi_s)} \overset{WW}{\propto} Q^{-1}\left(g_{1T}^{q}\otimes D_{1q}^{h}+\ldots\right)$

$A_{LT}^{\cos(2\phi_h-\phi_s)} \overset{WW}{\propto} Q^{-1}\left(g_{1T}^{q}\otimes D_{1q}^{h}+\ldots\right)$

The 8 twist-2 TMD PDFs

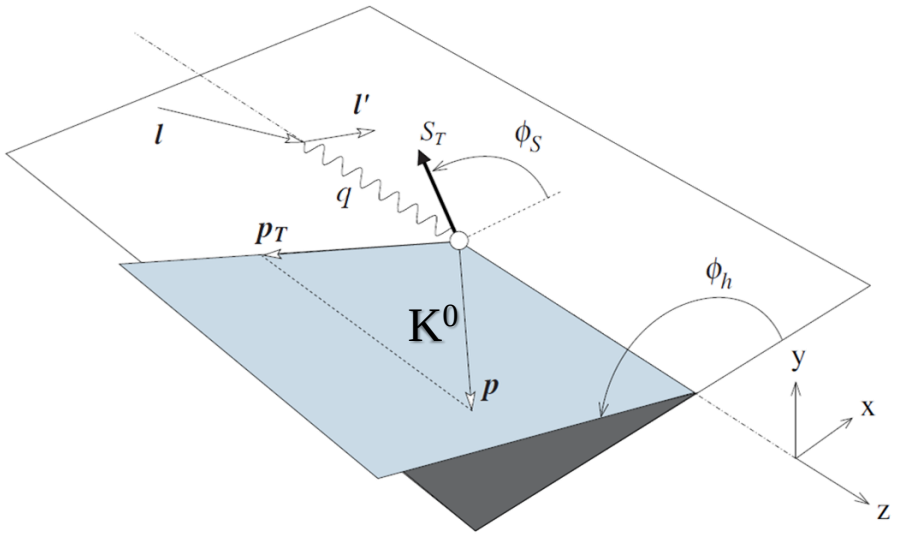


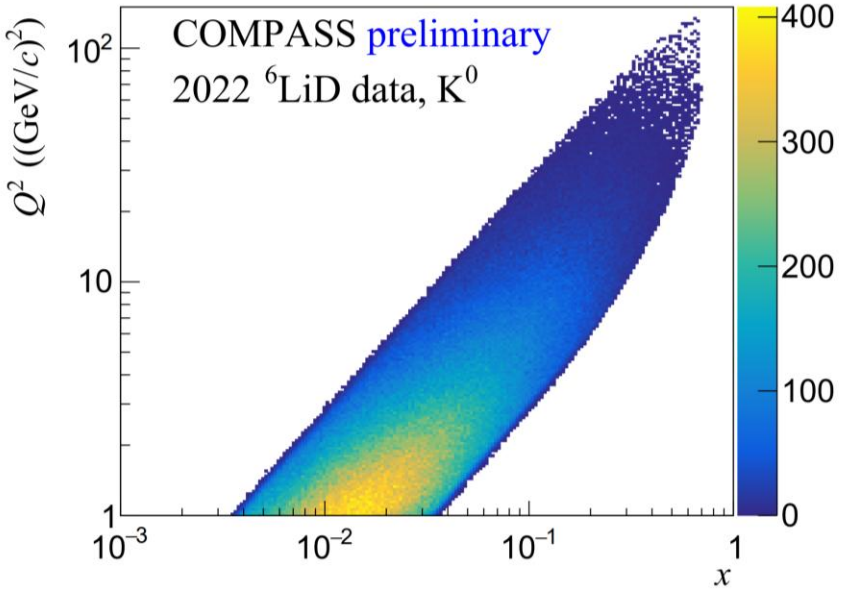
Different correlations between the spins of the nucleon and quarks and intrinsic transverse momentum of quarks

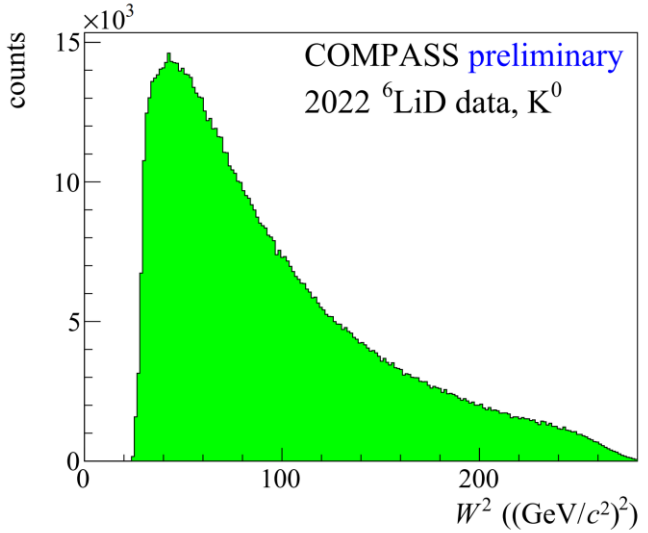
SIDIS EVENT SELECTION

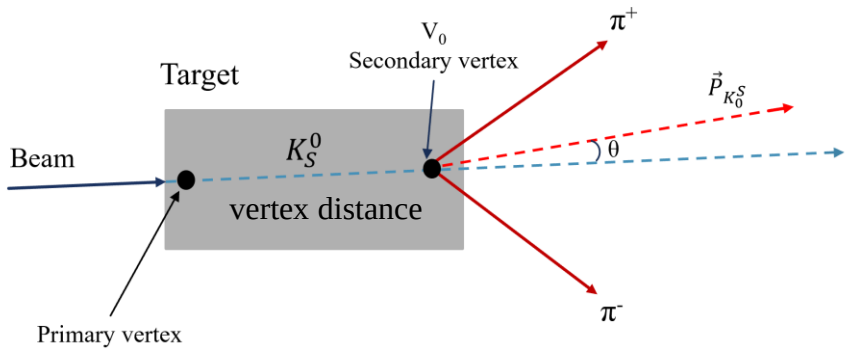
DIS cuts:

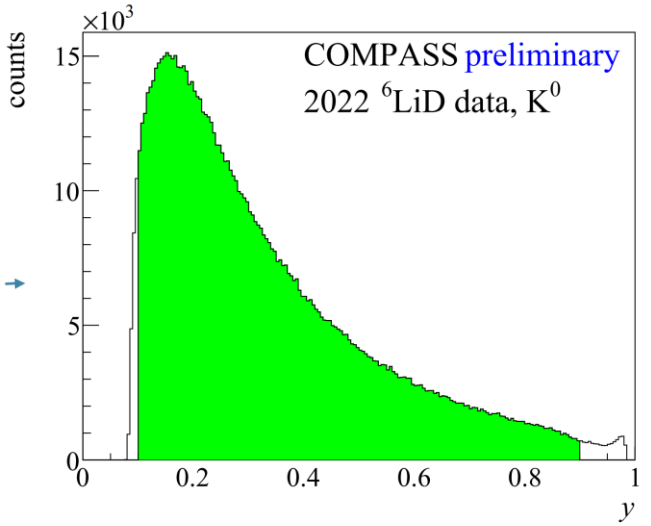
- $Q^2 > 1\ (\mathrm{GeV}/c)^2$
- $0.1 < y < 0.9$
- $0.003 < x < 0.7$
- $W^2 > 25\ (\mathrm{GeV}/c^2)^2$







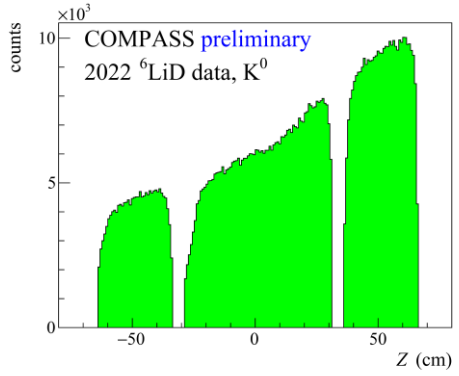


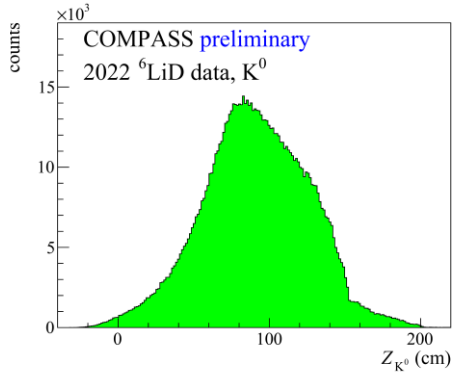


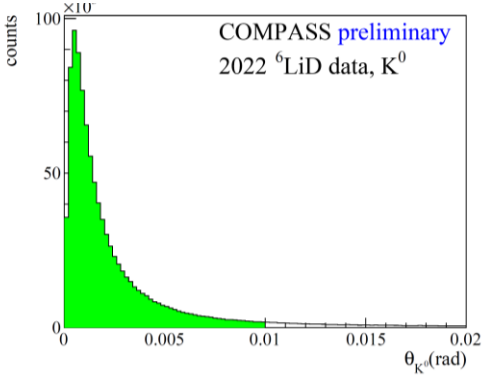
K^0 SELECTION

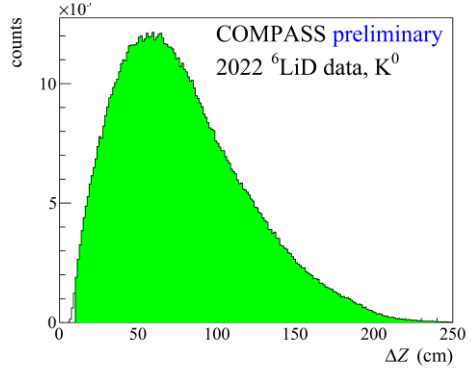
K^0 selection cuts

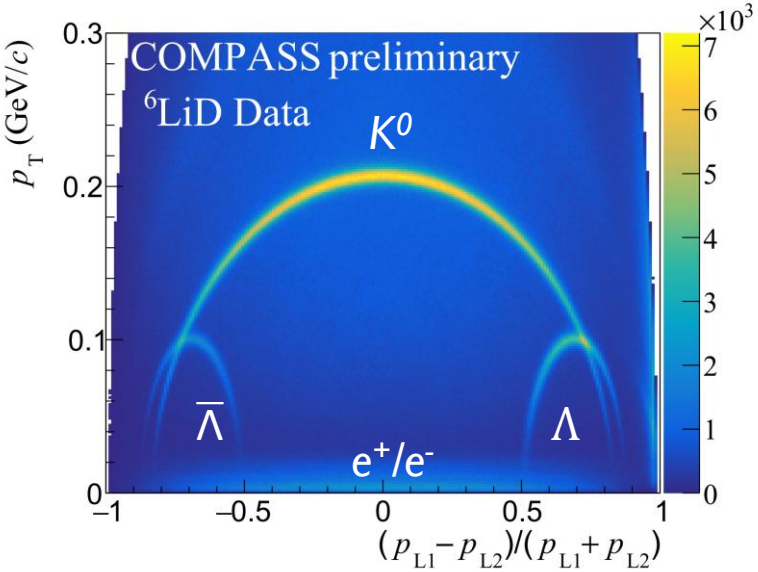
- Decay or pointing angle $\theta_{K^0} < 0.01$ rad
- Primary to V0 vertex distance > 10 cm
- $\Lambda/\bar{\Lambda}$ exclusion: 80 MeV/c < P_T < 110 MeV/c
- e^+/e^- background exclusion P_T > 40 MeV/c
- K^0 mass ± 20 MeV/c^2 of the PDG K^0 mass

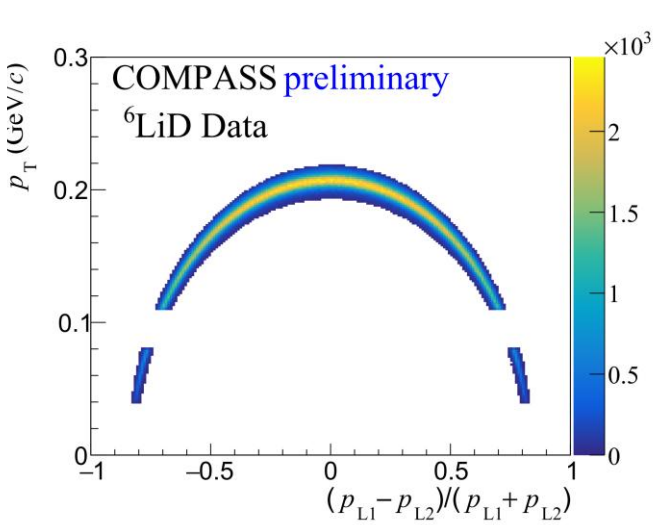


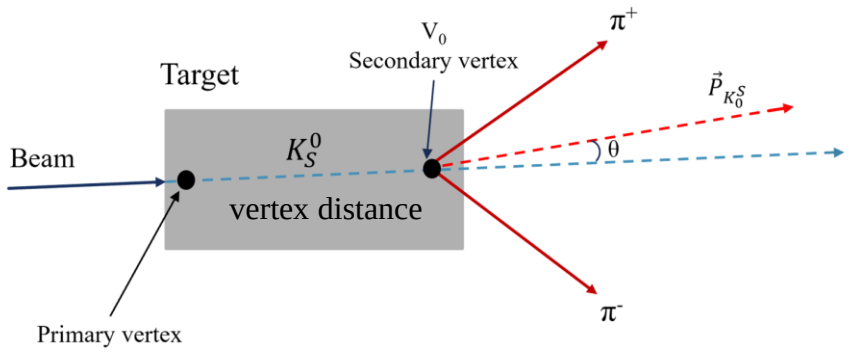


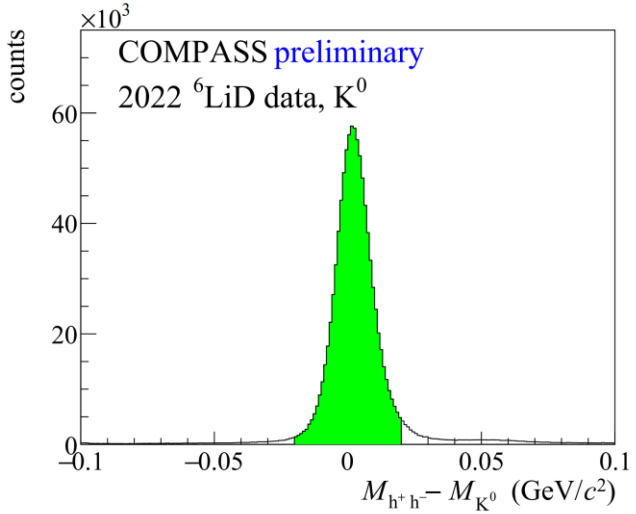








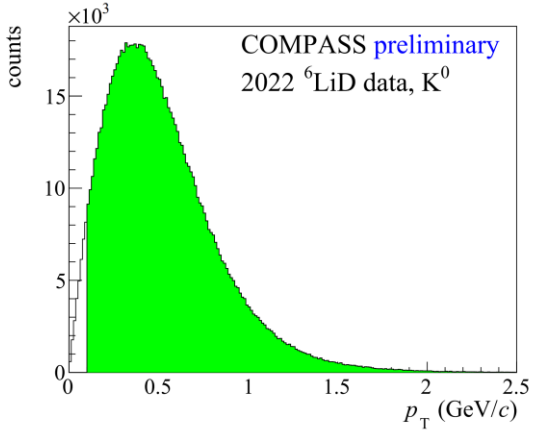


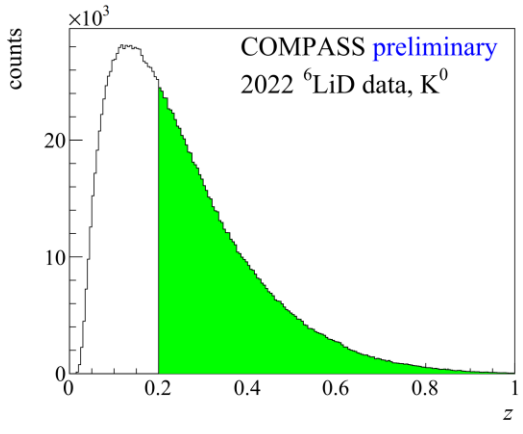


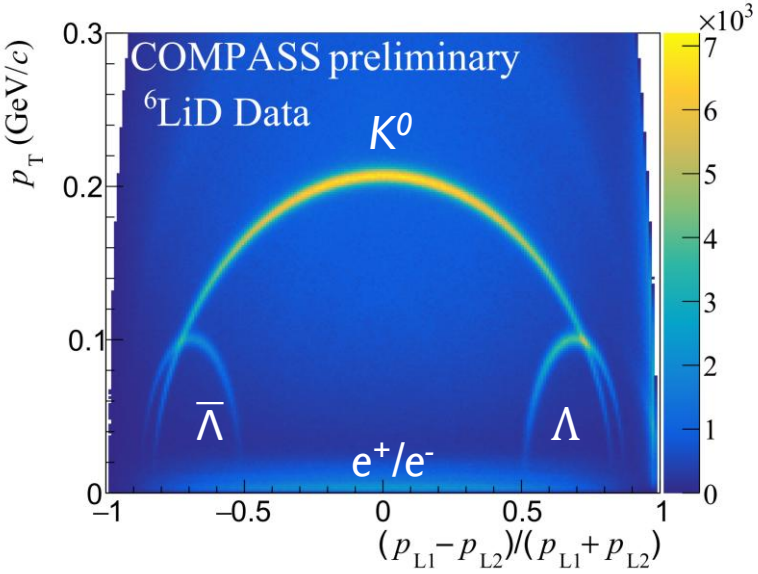
K^0 SELECTION

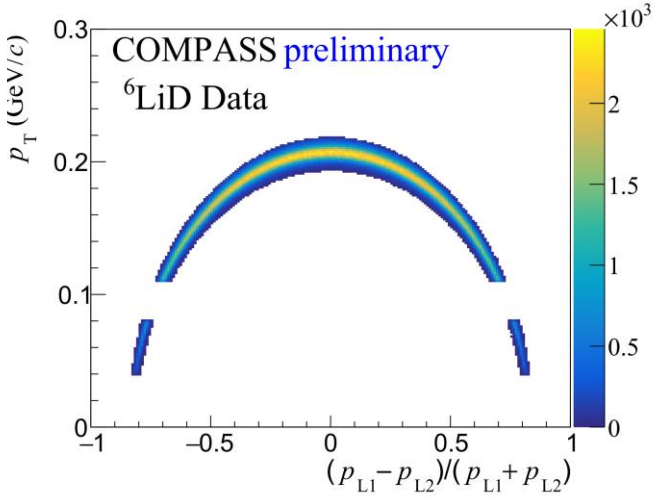
General Hadron selection cuts

- $0.2 < z < 1$ for the fractional photon energy transferred to the K^0
- Transverse momentum $p_T > 0.1$ GeV/c

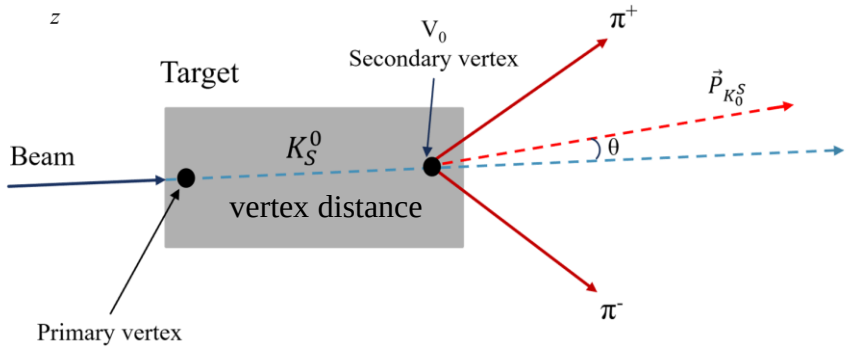


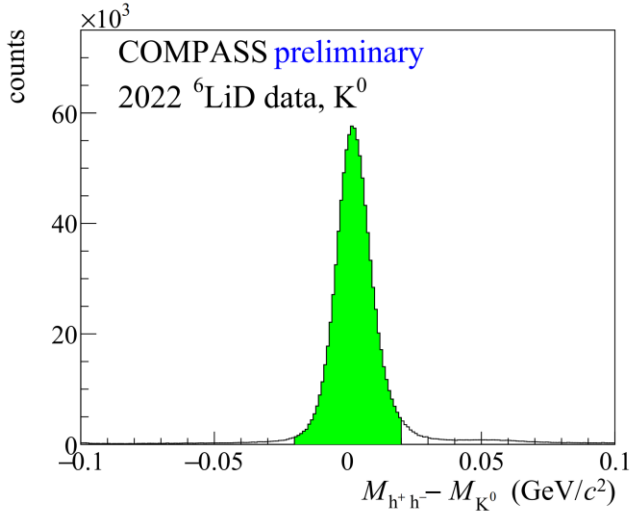






- Final 2022 K^0 sample: about 0.94 M
- Background fraction below 2%



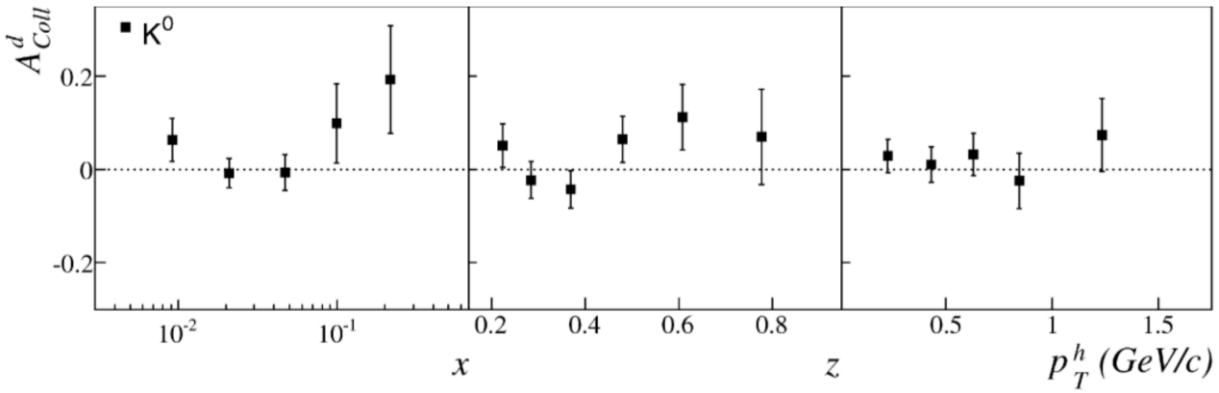


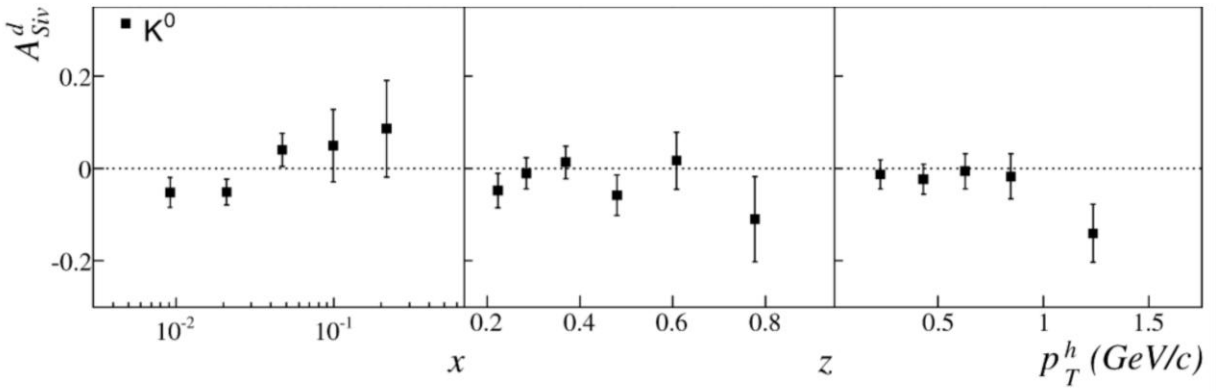
COLLINS AND SIVERS EFFECTS (DEUTERON 2002-2004)

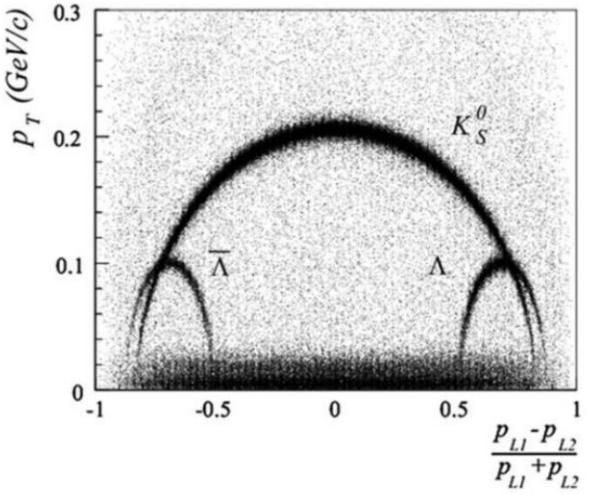
$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$

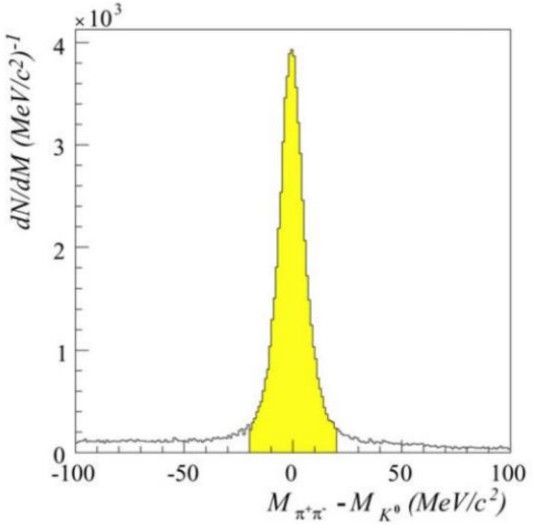
$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$

COMPASS Physics Letters B 673 (2009) 127–135









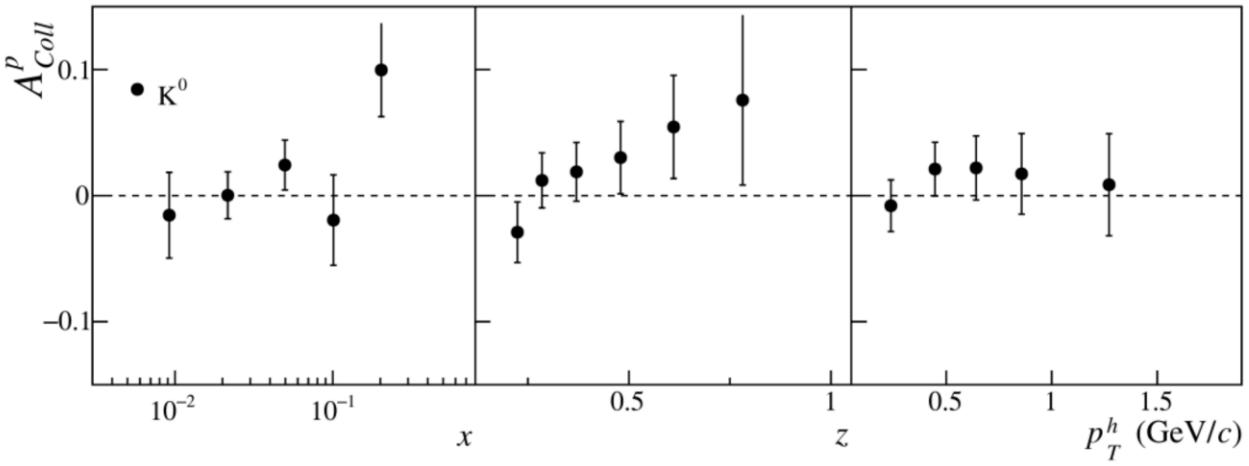
- 1st COMPASS deuteron measurements 2002-2004 (the only existing previous transverse deuteron target data up to 2022)
- Statistics: ~240·10³ K^0 events – large uncertainties
- Background fraction: ~ few percent
- Both Collins and Sivers TSAs are compatible with zero within uncertainties

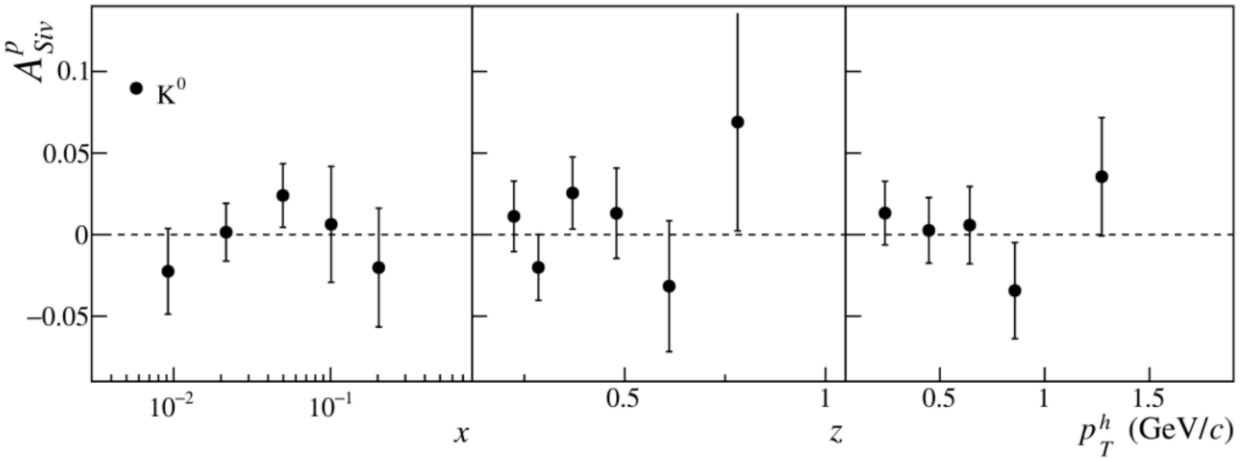
COLLINS AND SIVERS EFFECTS (PROTON 2010)

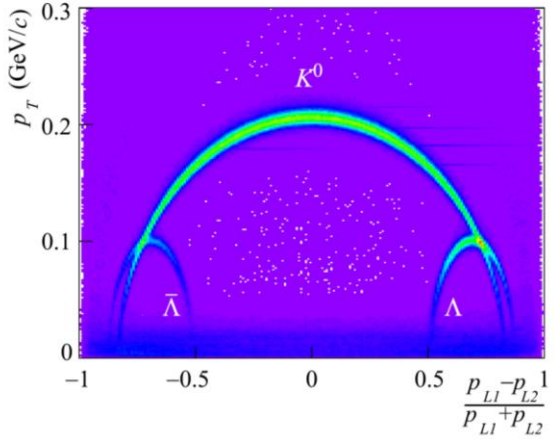
$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$$

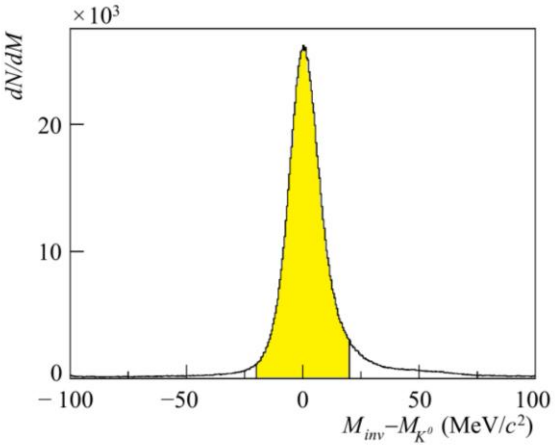
$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$$

COMPASS Physics Letters B 744 (2015) 250



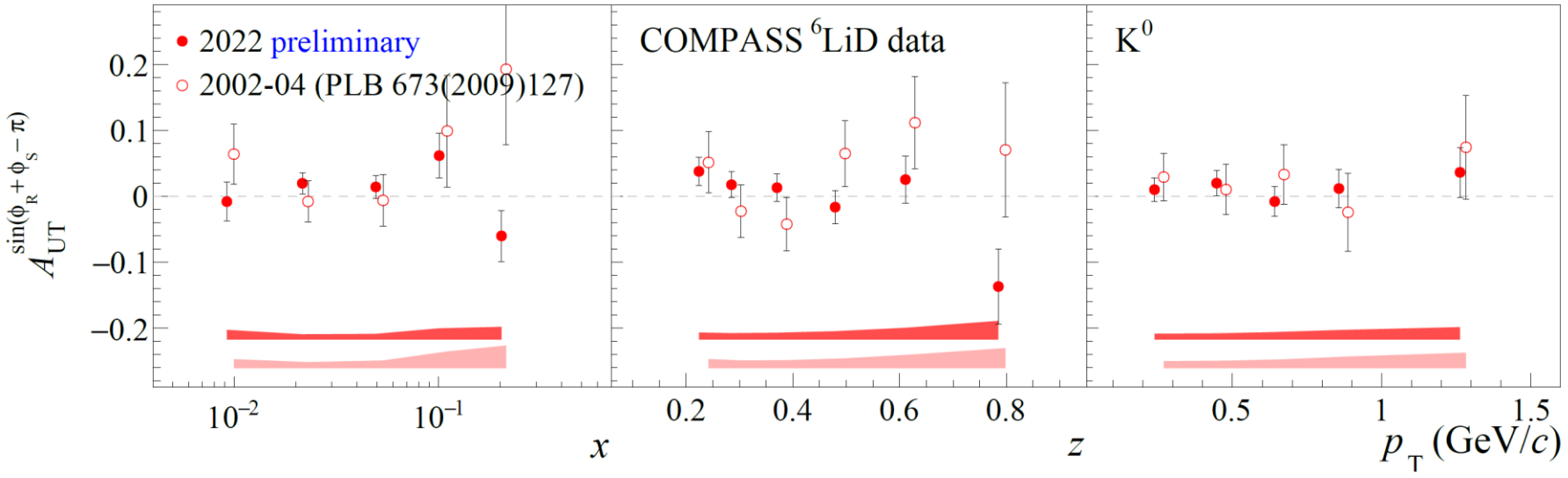


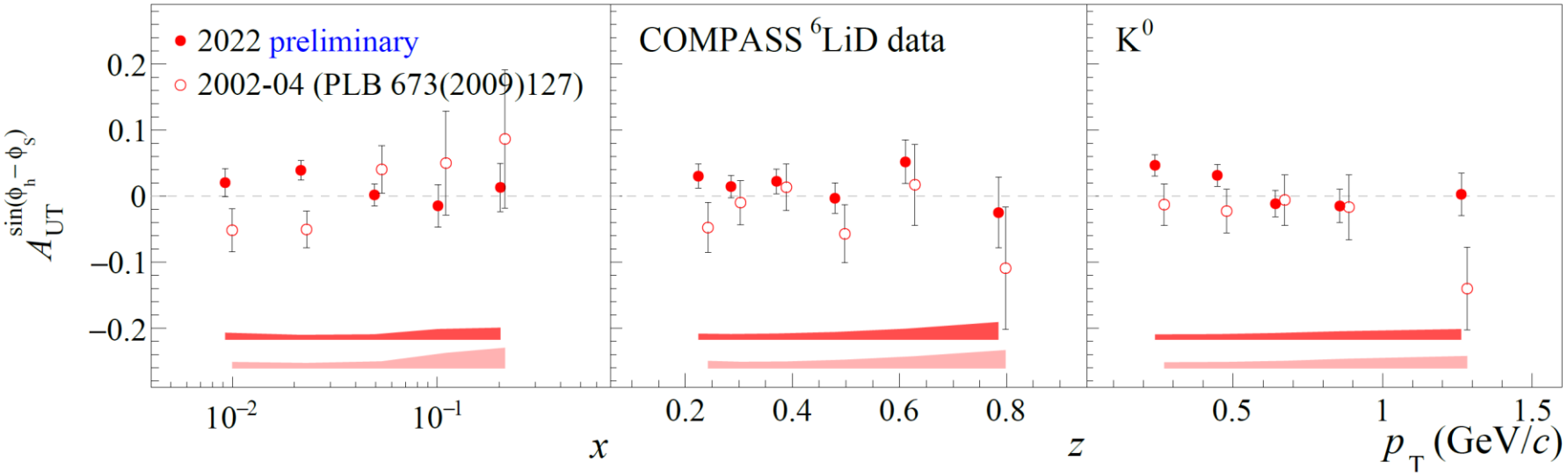




- Much larger sample with proton target (2010)
- Statistics: ~ 10^6 K^0 events
- Background fraction ~ 2%
- Systematic uncertainties about 50% of the statistical ones
- Both Collins and Sivers TSAs are compatible with zero within the uncertainties

COLLINS AND SIVERS EFFECTS WITH NEW 2022 RESULTS





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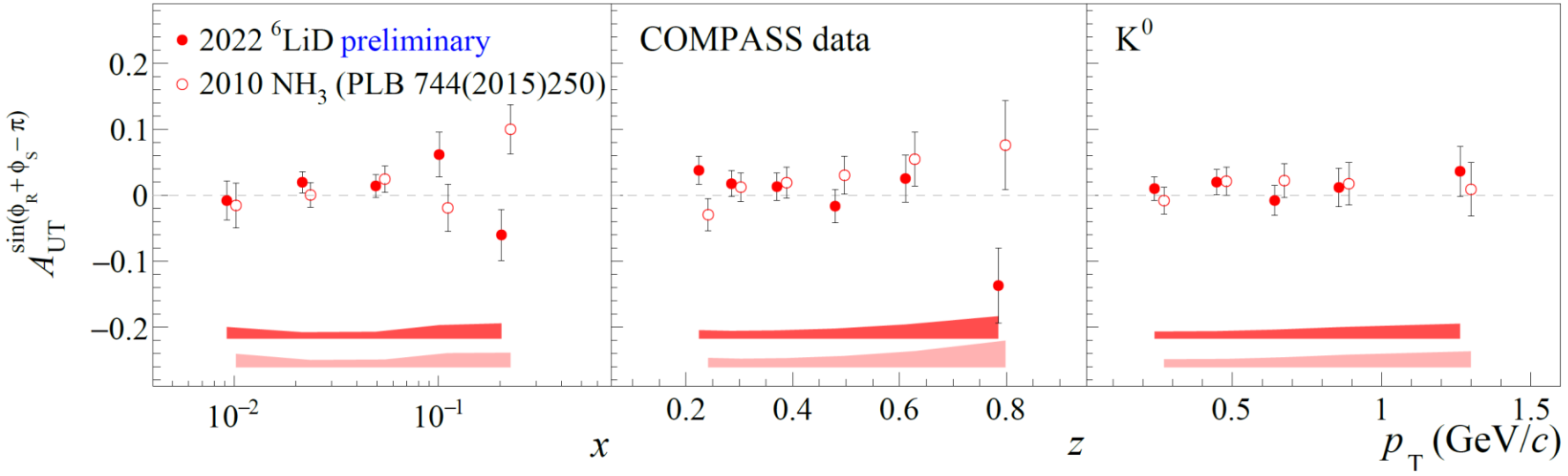
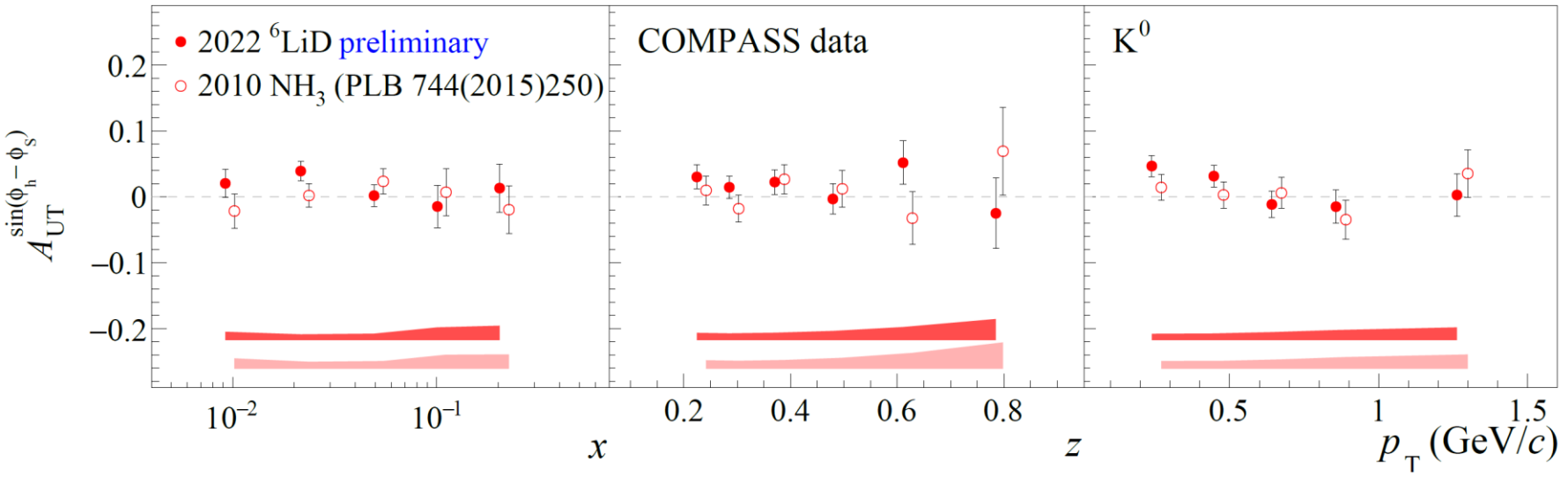
$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$$

- New deuteron target results from 2022 data-taking
- Statistics: 0.94 million K_0 events
- Background fraction < 2%.
- The systematic uncertainties are ~ 60% of the statistical ones
- Much higher precision compared to 2002-04 TSAs
- Some tensions are observed at small x for Sivers TSA.

COLLINS AND SIVERS EFFECTS WITH NEW 2022 RESULTS





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- New deuteron target results from 2022 data-taking
- Statistics: 0.94 million K_0 events
- Background fraction < 2%.
- The systematic uncertainties are ~ 60% of the statistical ones
- Much higher precision compared to 2002-04 TSAs
- Some tensions are observed at small *x* for Sivers TSA.
- Comparable precision with proton data
- proton 2010 and deuteron 2022 TSAs seems to be in agreement

CONCLUSIONS

- Collins and Sivers K^0 TSAs extracted from all of the SIDIS data collected in 2022.
- The asymmetries are evaluated as a functions of p_T , x and z for K^0.
- Significant precision improvement as compared to the old 2002-04 data; up to 4 times in some bins.
- Comparable accuracy when compared to the proton 2010 results.
- Both Collins and Sivers K^0 TSAs appear to be compatible with zero within the uncertainties.

THANK YOU!