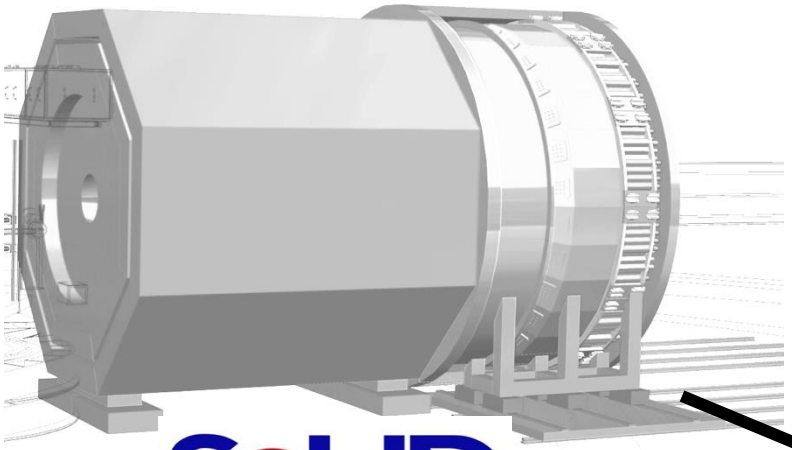
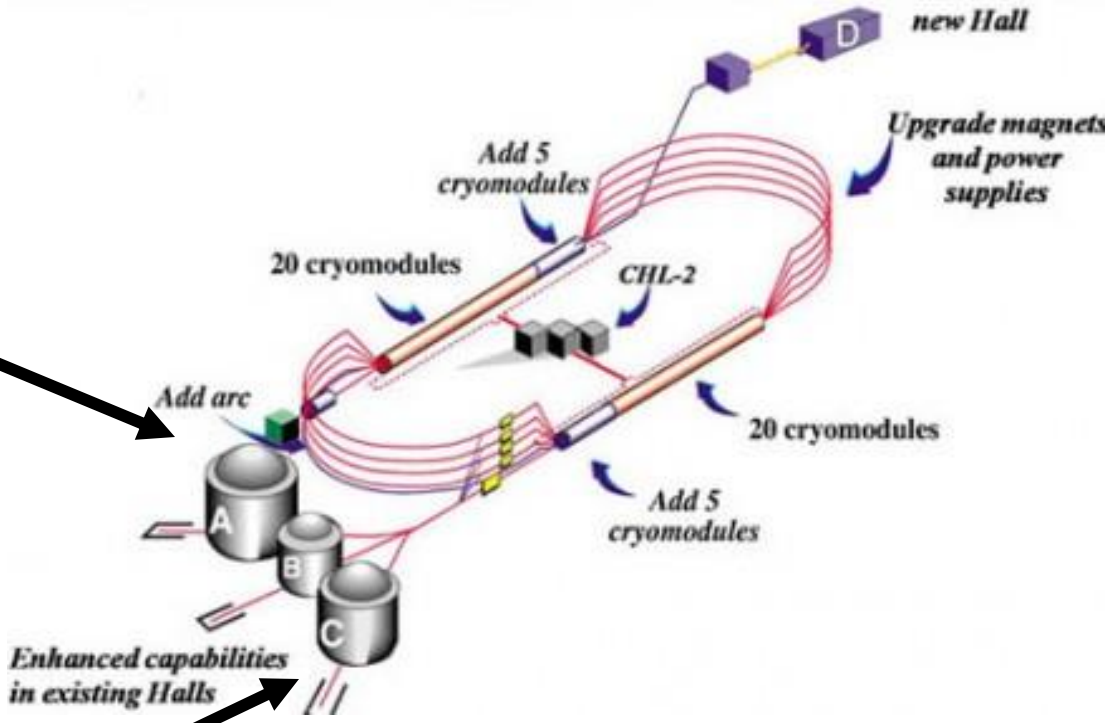
Study Light Sea with SIDIS @JLab22 in SoLID and Hall C

Workshop on Science at Luminosity Frontier: JLab at 22 GeV, 12/9-14, 2024

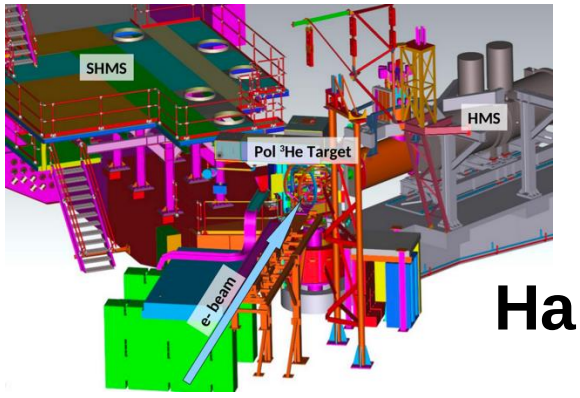
Jian-ping Chen, Jefferson Lab

In Collaboration with Dave Gaskell, Ching Him Leung, Arun Tadepalli and Ye Tian





JLab12 & Upgrade to JLab22



Hall C

Outline

1. Introduction: Parton Distributions and Light Sea

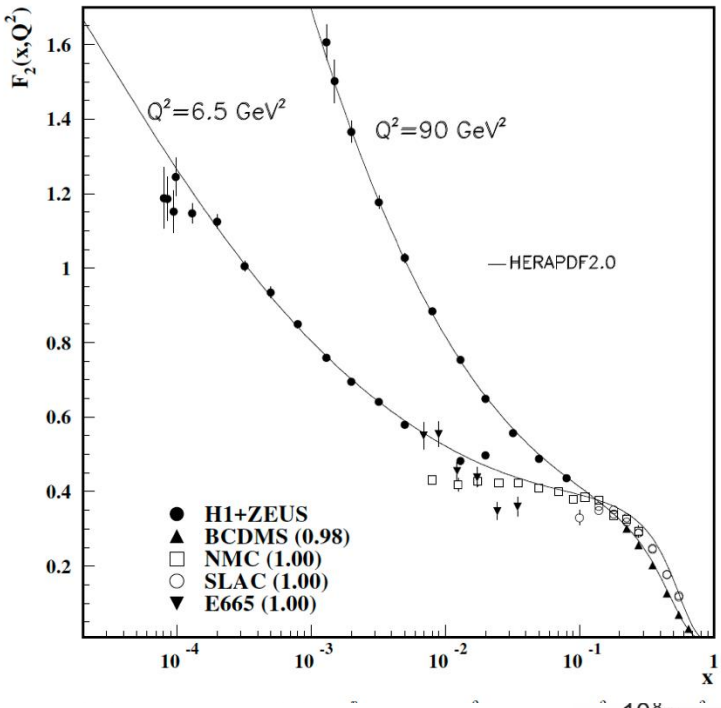
2. Unpolarized Light Sea: Projections for Hall C @ JLab22

3. Polarized Light Sea: Projections for SoLID @ JLab22
   also Projections on Pt Dependence of Longitudinal Asymmetries
   (Helicity TMDs)

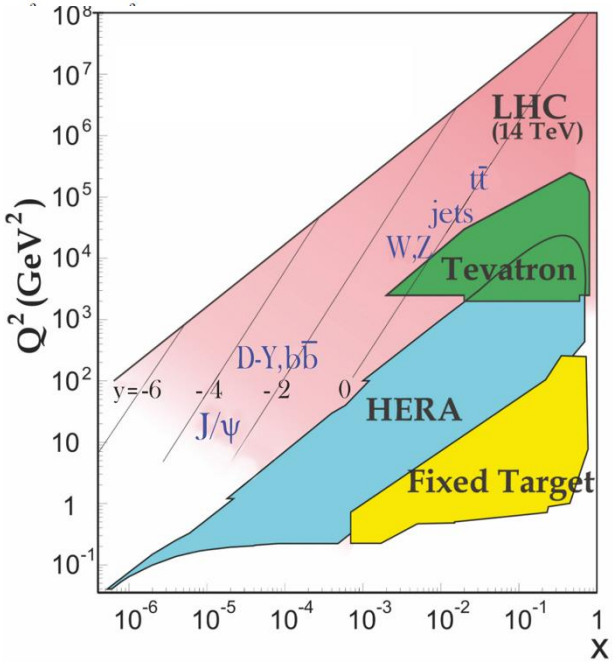
4. Summary

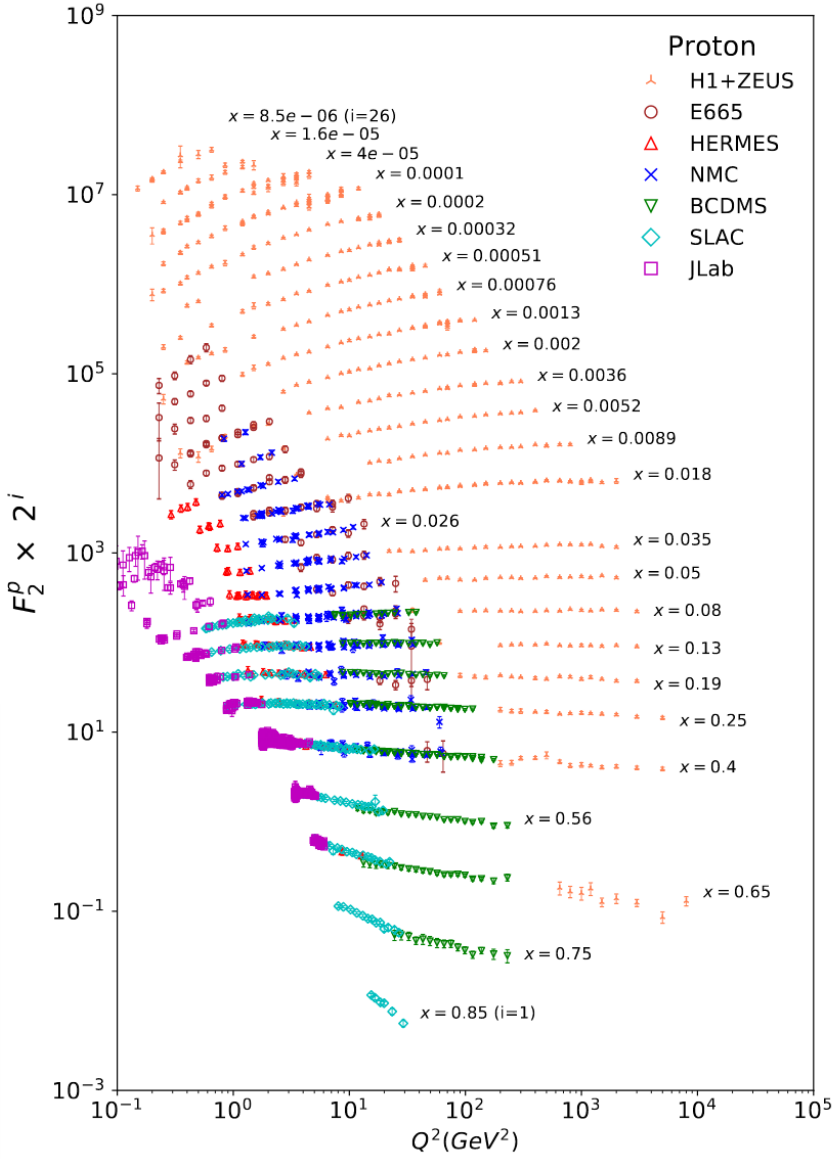
1. Introduction

Unpolarized Structure Functions

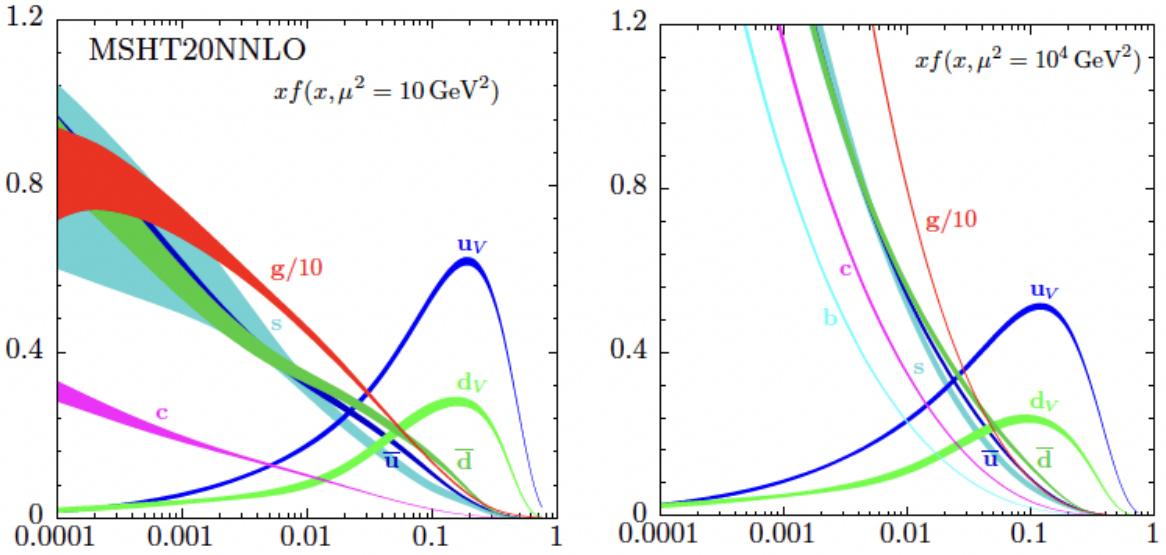


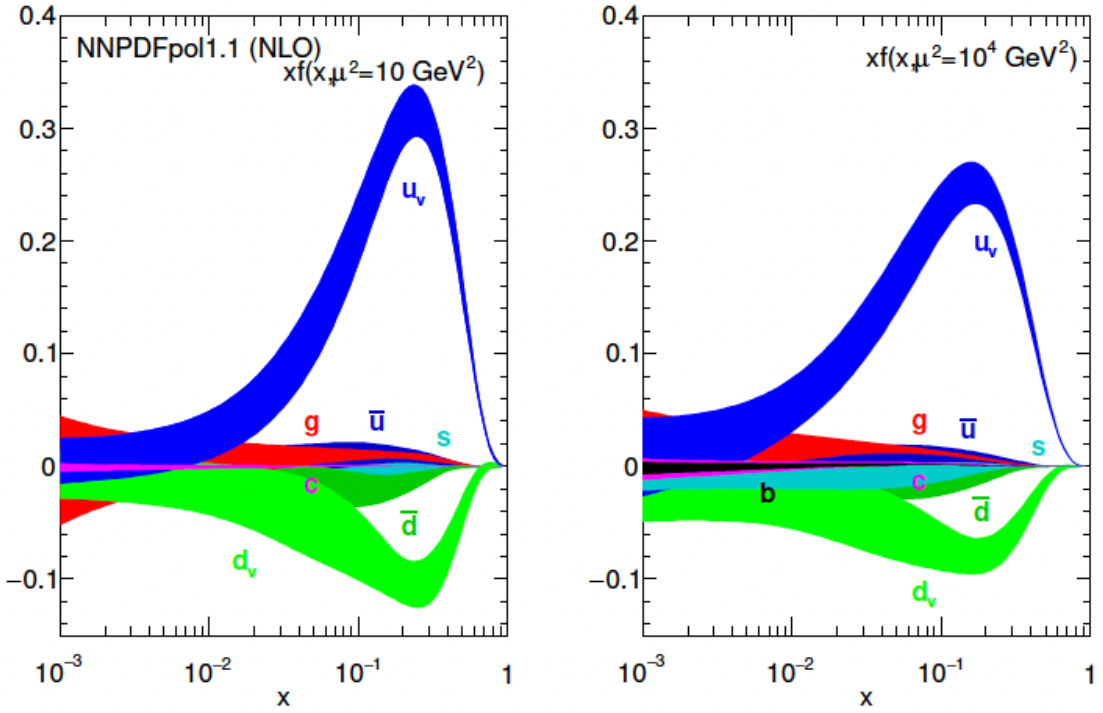
PDG
(online 2024)





Unpolarized Parton Distrobutions



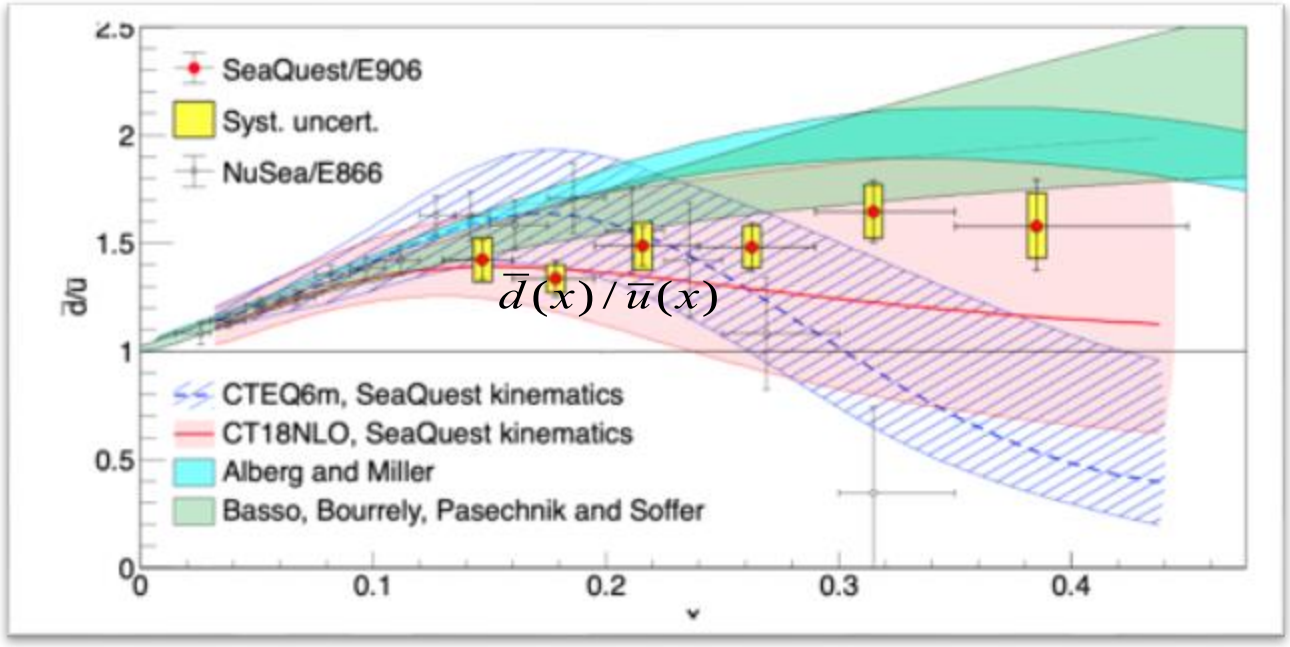


PDG
(online 2024)

SEAQUEST Results: Unpolarized Light Sea

- SeaQuest results show that nature prefers dbar over ubar in the proton sea
- Non-perturbative mechanism other than gluon splitting must be the source
- Trend consistent with meson baryon model and statistical parton distribution functions

Dove et. al. Nature 590, 561 – 565 (2021)



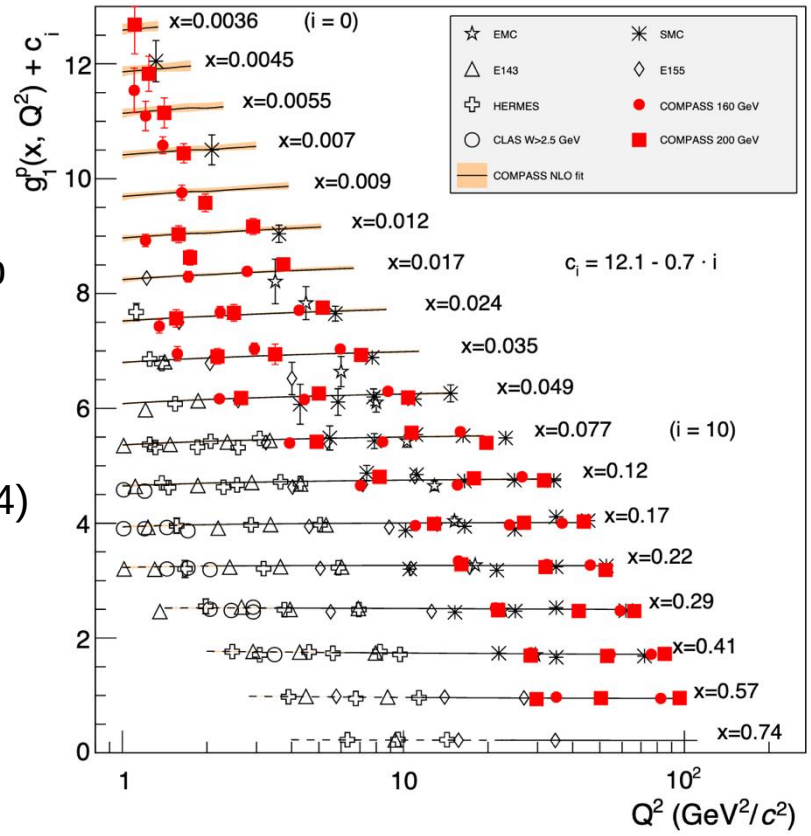
$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{(x_{beam}>>x_{targ})} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_{targ})}{\bar{u}(x_{targ})}\right]$$

Arun Tadepalli

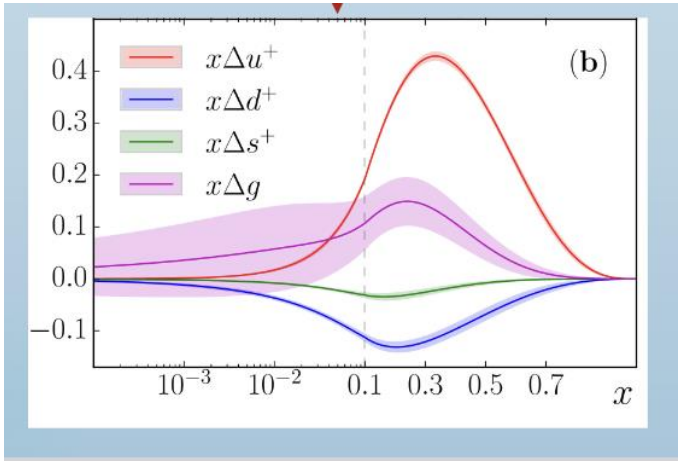
Polarized Structure functions

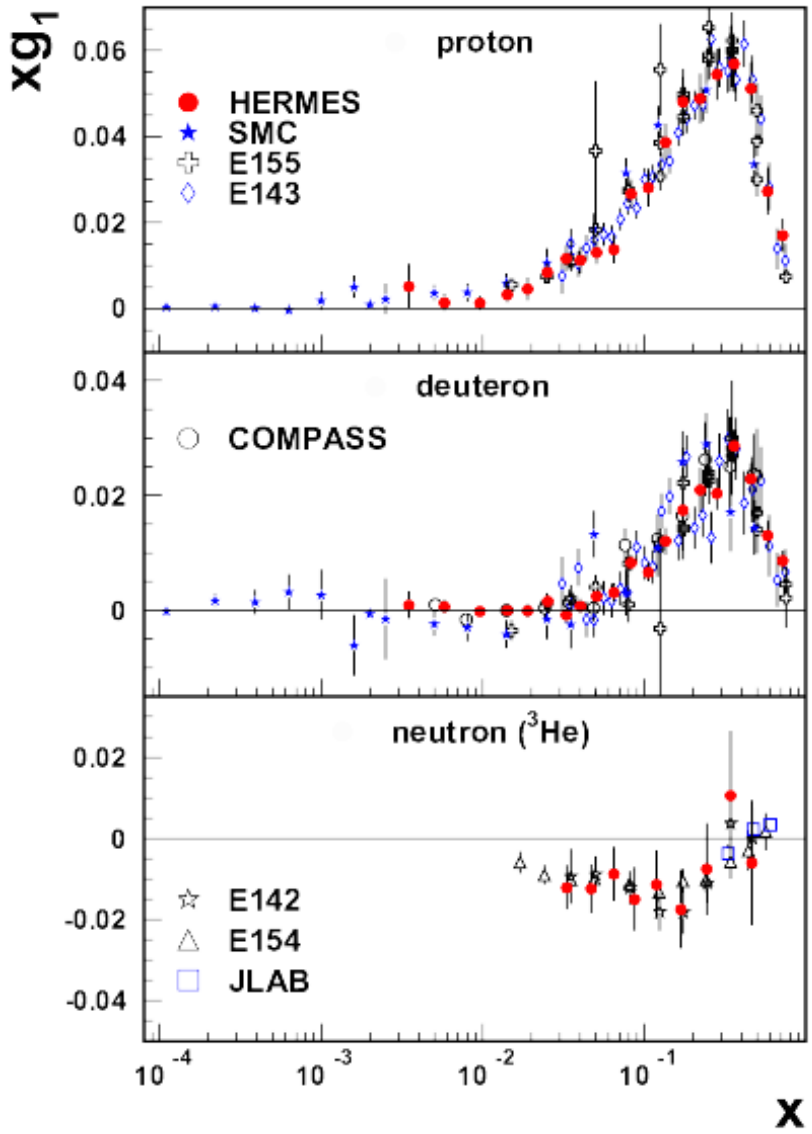
g_1^p

PDG
(online 2024)



JAM





RHIC-Spin W production → Polarized Light Sea

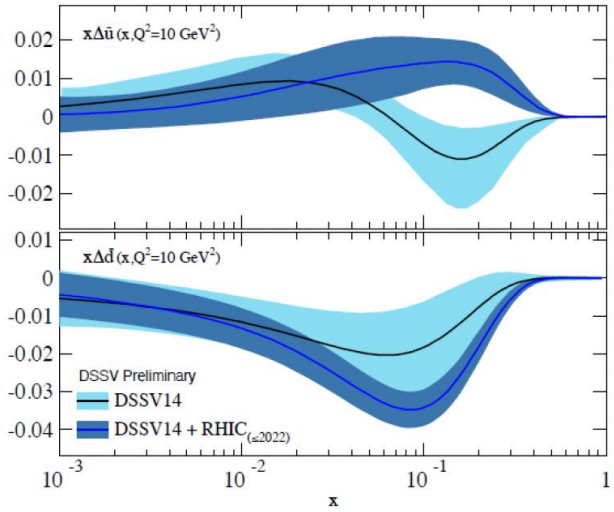
Ralf Seidl @ Diffraction2024

$\Delta q(x)$ $\Delta \bar{q}(x)$

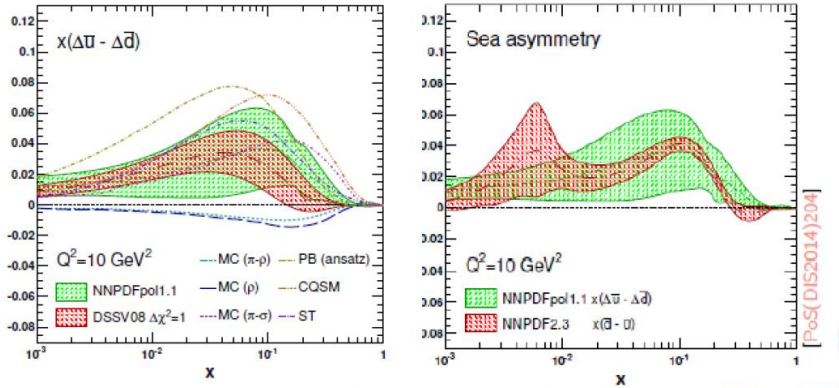
Sea quark helicites

- RHIC data at boundary of DSSV/NNPDFpol1.1 uncertainty bands
- Reweighted NNPDFpol1.1 and DSSV14 fits shows substantial polarized light sea asymmetry
- opposite sign to most pion cloud models (where polarized and unpolarized light sea asymmetries have same sign)

DSSV with and w/o RHIC



NNPDFpol1.1: arXiv:1406.7122

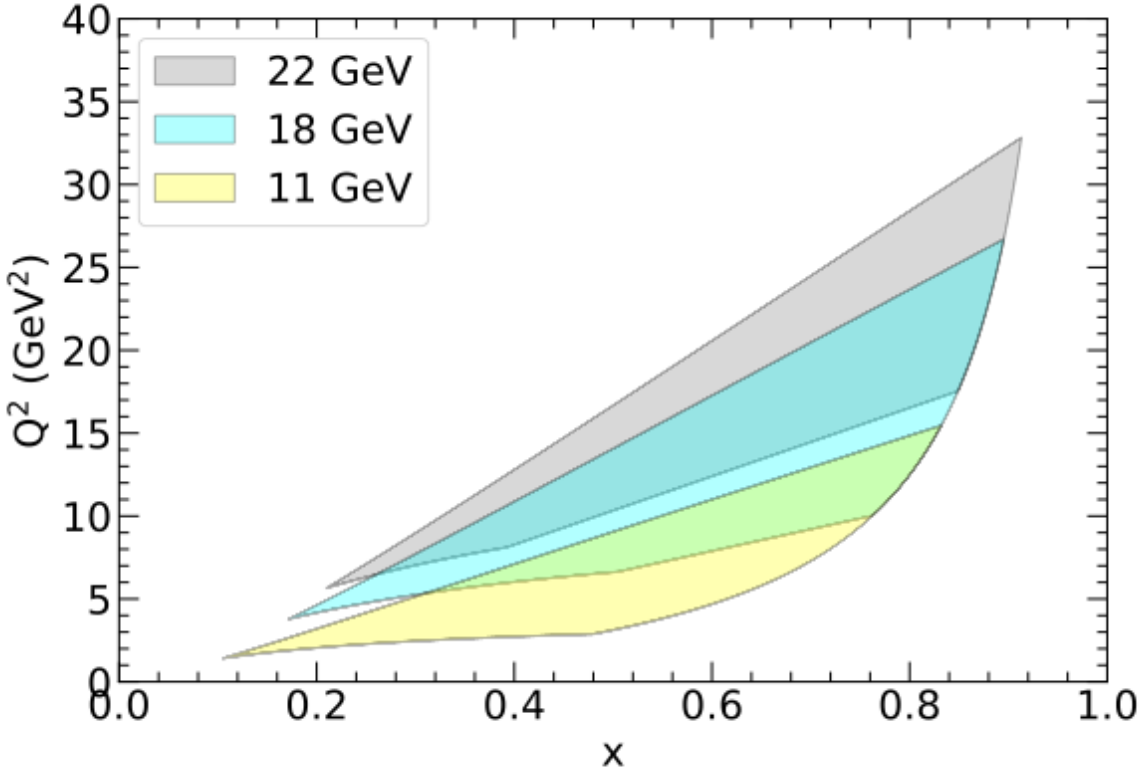


2. Unpolarized Light Sea

Projections for Hall C @ JLab22

Hall C @ JLab22 SIDIS Phase Space

Dave Gaskell



HMS-SHMS SIDIS phase space
→ Fixed z=0.5
→ Outgoing pion along q-vector
→ P_T acceptance up to 0.3 to 0.5 GeV

SHMS Properties
Min. angle 5.5 degrees
Max. momentum 11 GeV

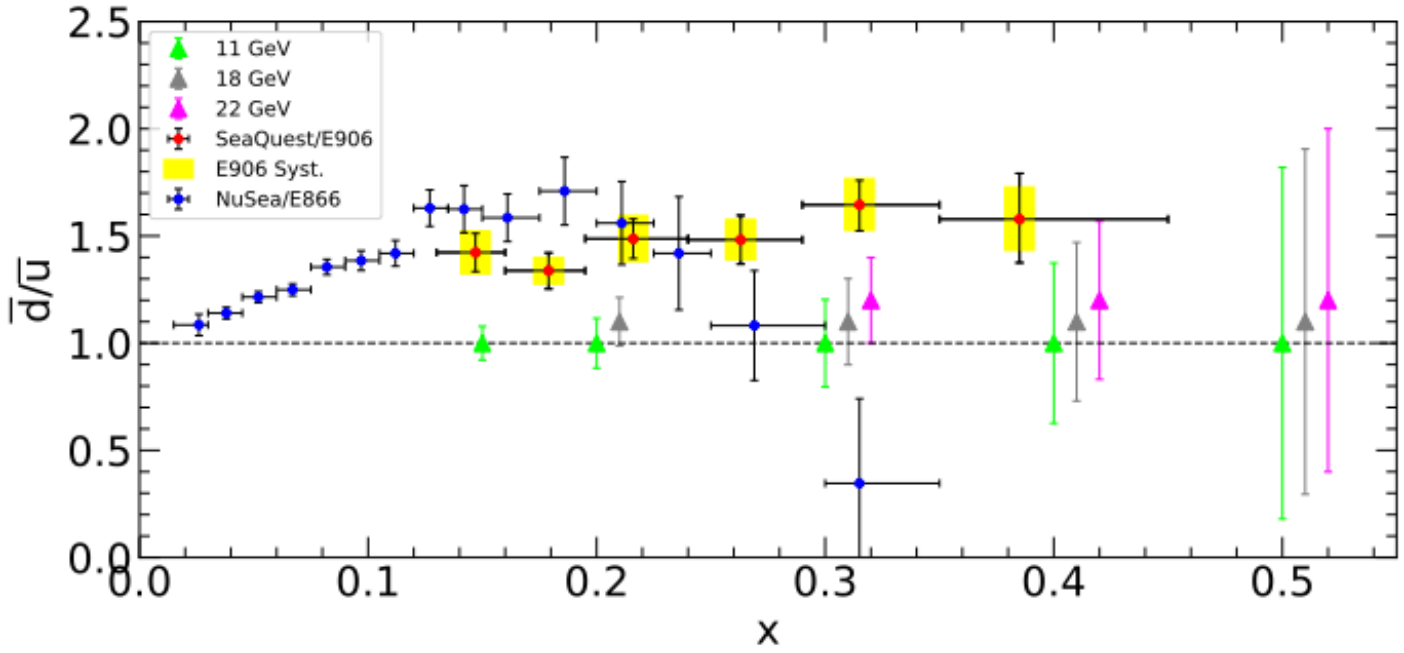
HMS Properties
Min. angle=10.5 GeV
Max. momentum=7.5 GeV

Hall C @ JLab22 SIDIS Projection

Dave Gaskell

30 days of running at 50 uA on 10 cm LH2 and LD2 targets
Assume 200k events for π+ and π- from LH2, 400k events from π+ and π- from LD2

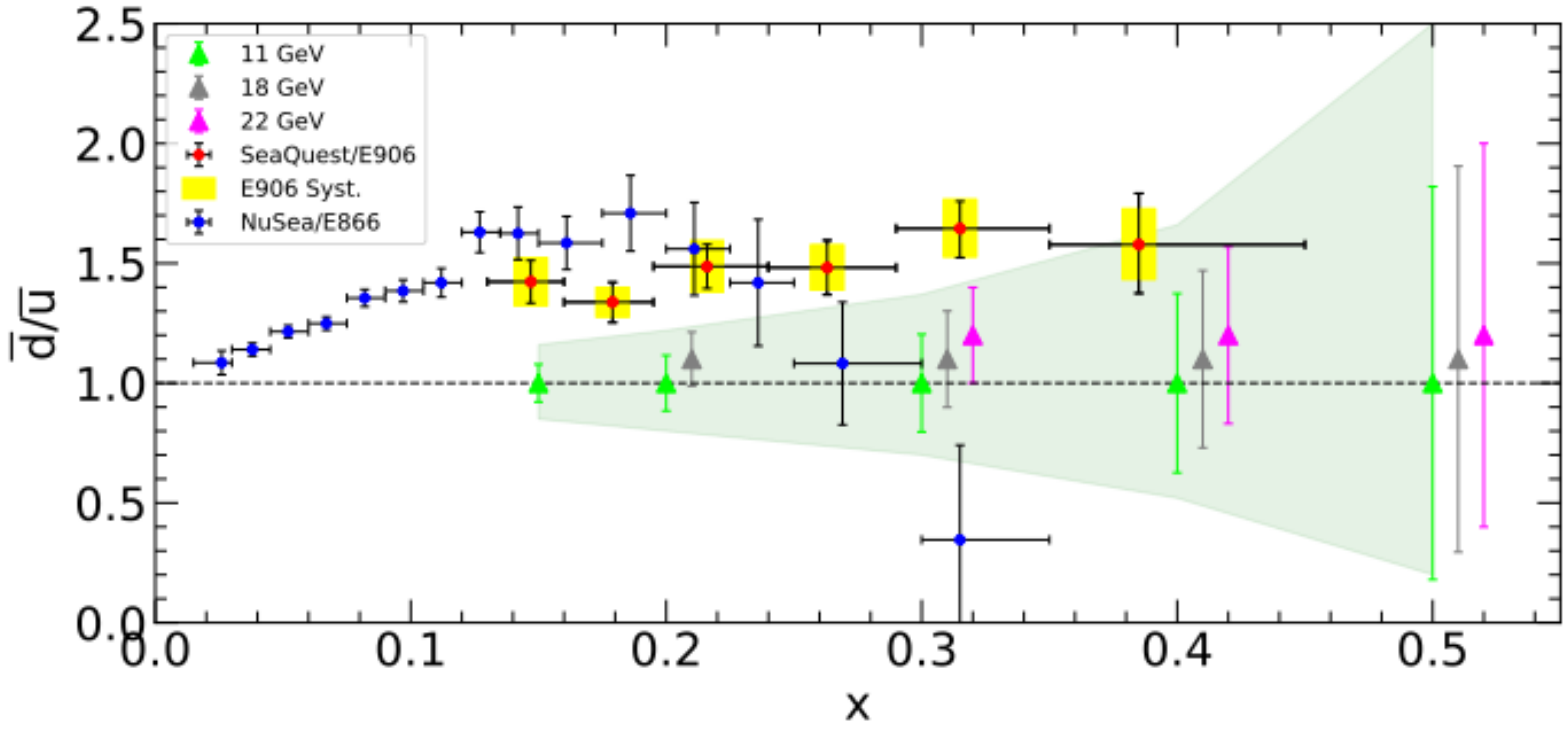
→ Error bars are statistics only – need excellent point-to-point systematics when combining π+ and π-



Study Experimental Systematics

Dave Gaskell

Including **only** the systematics related to LH2 and LD2 target thicknesses
Other systematics: study to be continued

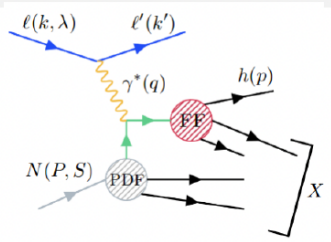


3. Polarized Light Sea

Projections for SoLID @ JLab22
and Projections on Helicity TMDs

COMPASS: Longitudinal Polarized SIDIS

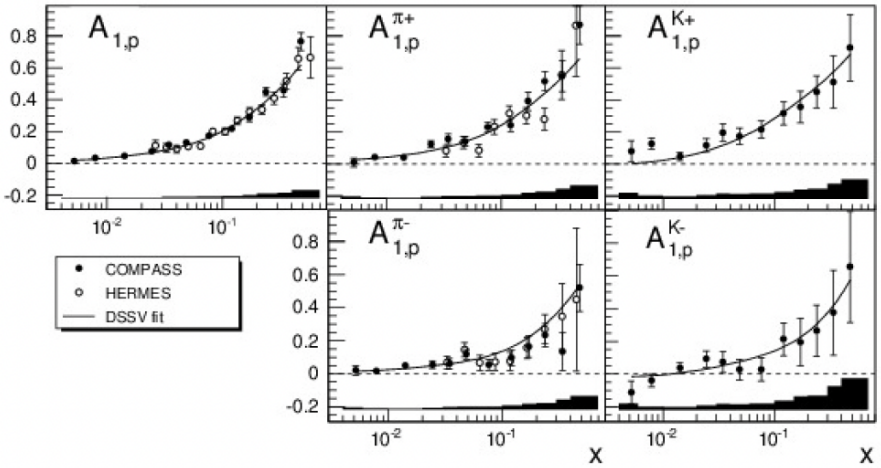
Semi-inclusive asymmetries and parton distributions

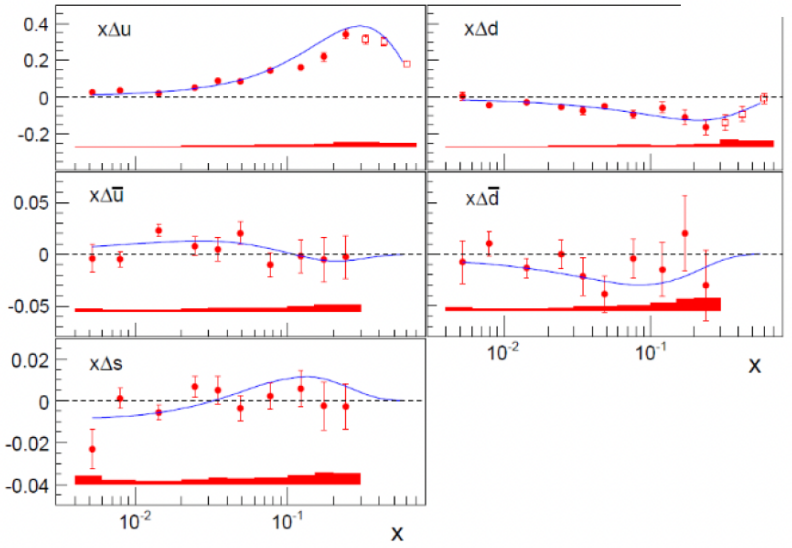


- COMPASS: measured on both proton and deuteron targets for identified π^+, π^- and (for the first time) K^+, K^-

COMPASS, Phys. Lett. B **693** (2010) 227

DSSV, Phys. Rev. D **80** (2009) 034030



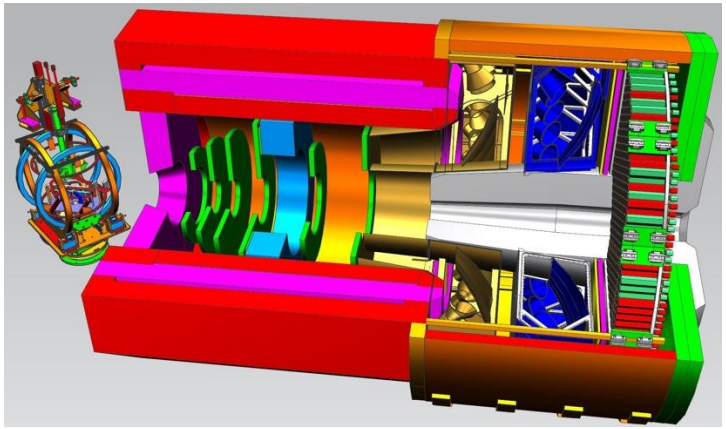


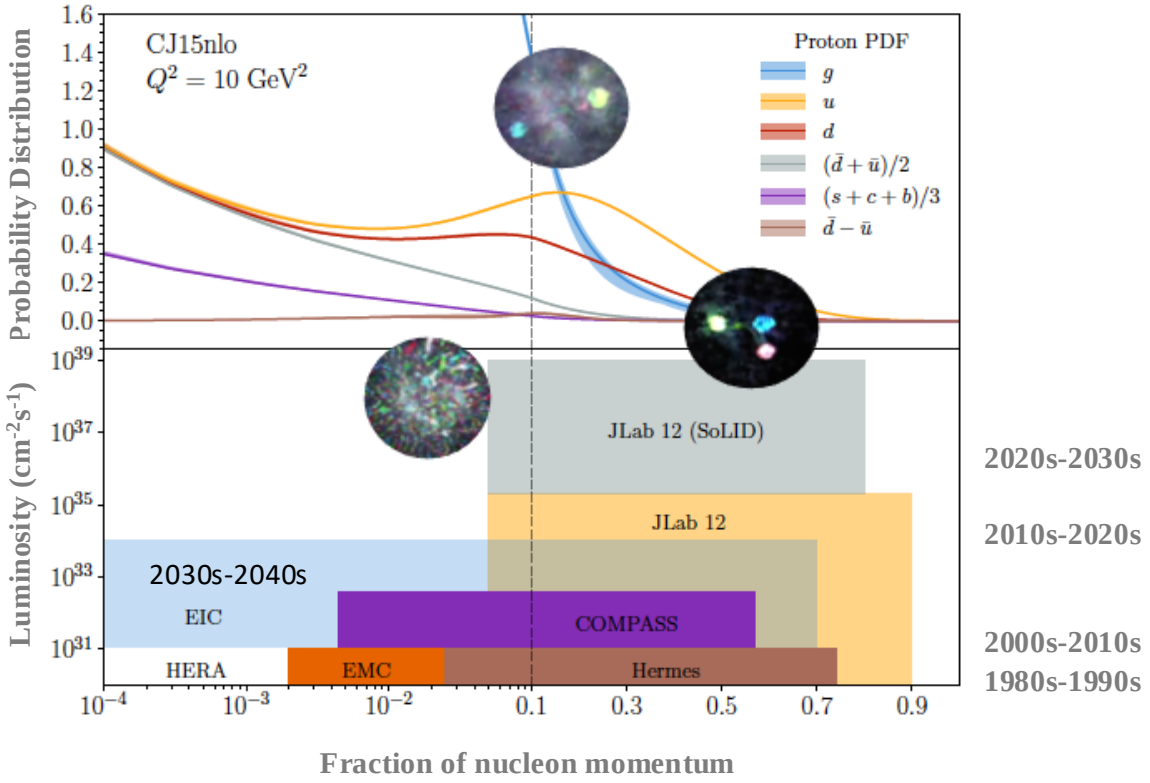
- COMPASS: LO DSS fragm. functions and LO unpolarised MRST assumed here.
- NLO parameterisation of DSSV (without these results) describes the data well.

SoLID@JLab: QCD Intensity Frontier

- Nucleon spin, proton mass, beyond standard model experiments require precision measurements of small cross sections and asymmetries, combined with multiple particle detection
  - ➢ critical need for high luminosity (10^{37}-10^{39} cm^{-2}s^{-1}) and large acceptance

- Science reach:
  - Precision 3D imaging of the nucleon in the valence quark region
  - Beyond Standard Model searches
  - Exploring the origin of the proton mass and gluonic force in the non-perturbative regime.

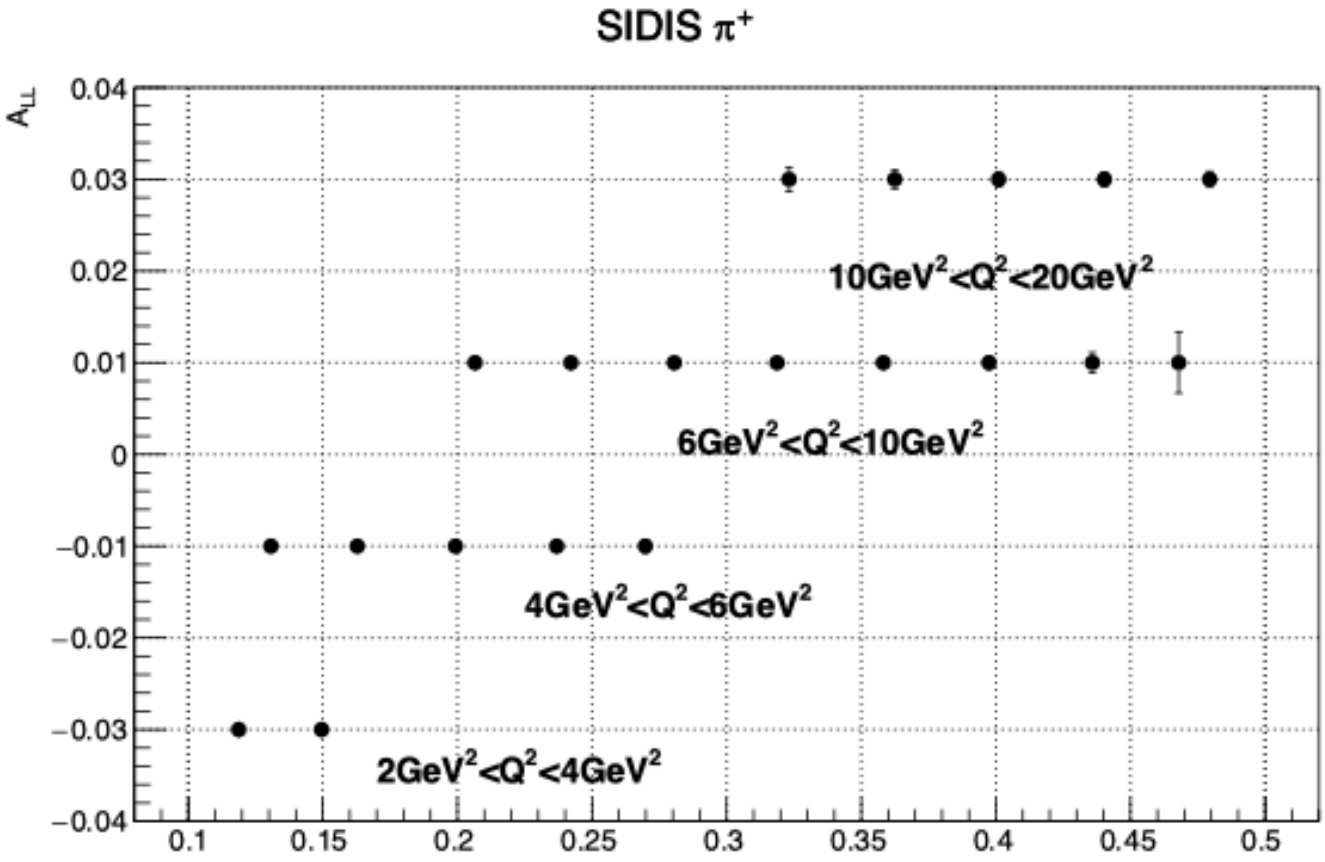




SoLID @ JLab22 SIDIS Polarized Asymmetries π+ on n

Ching Him Leung

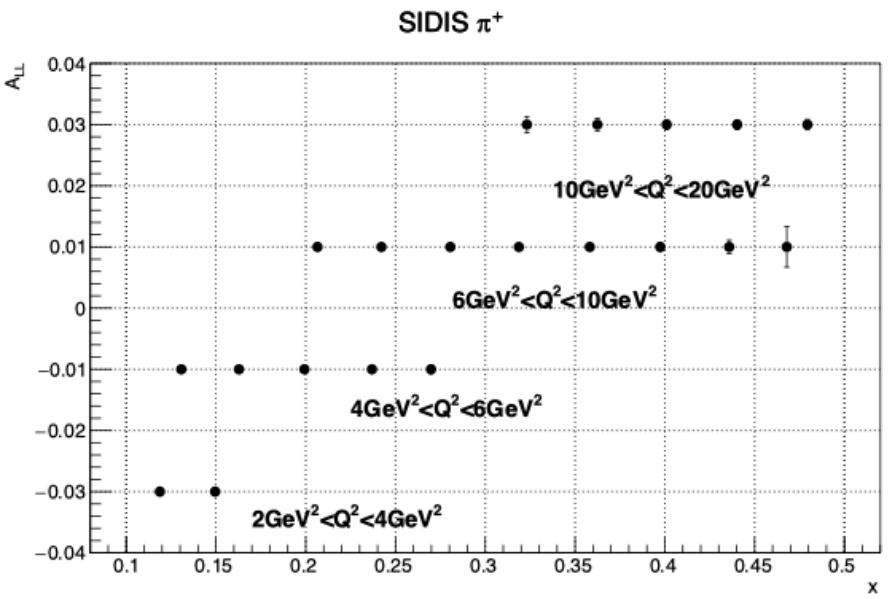
- Statistical uncertainty only (systematics to be studied in the next a few months)
- 100 PAC days; Luminosity = $10^{36}cm^2s^{-1}$, acceptance form EvneSoLID simulation
- Event generator (LO), PDF: CJ15lo; FF: DSSFFlo
- δALL = (1/fn * Pb * Pt * Pn) * SQRT ($Nacc$)
- Pb=85% beam polarization; Pt=60% pol ^{3}He target polarization (Pt=70% for pol proton target)
- Pn=86% neutron polarization in ^{3}He; neglecting the proton part
- fn is the dilution factor-fraction of neutron cross section relative to the nuclear cross section
- Summing over Pt and z ranges: 0 < Pt < 1GeV, 0.2 < z < 0.6

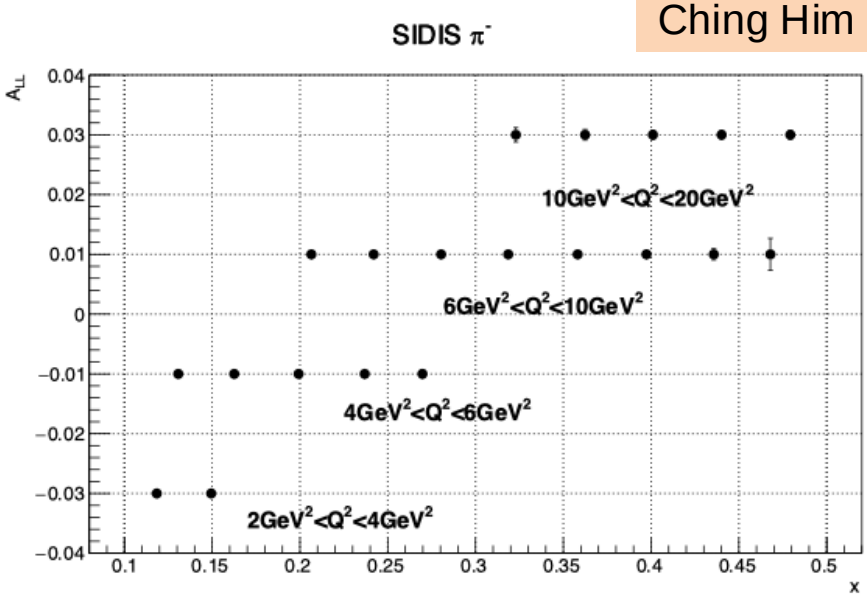


SoLID @ JLab22 SIDIS Polarized Asymmetries: π/K on n

Ching Him Leung

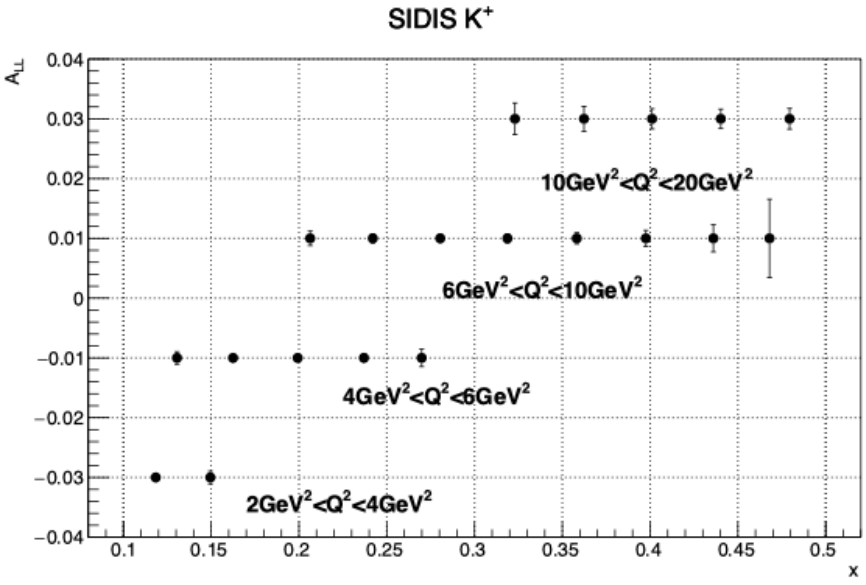
π+

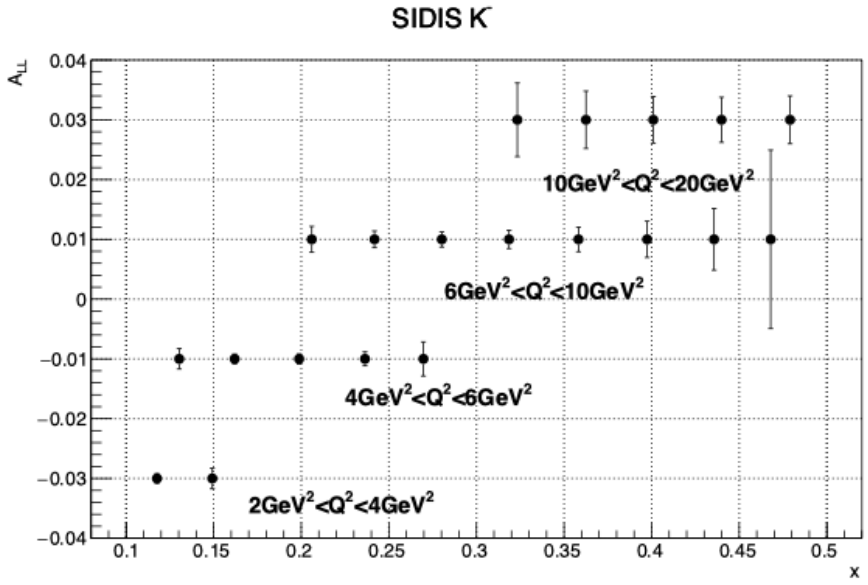




π-

K+



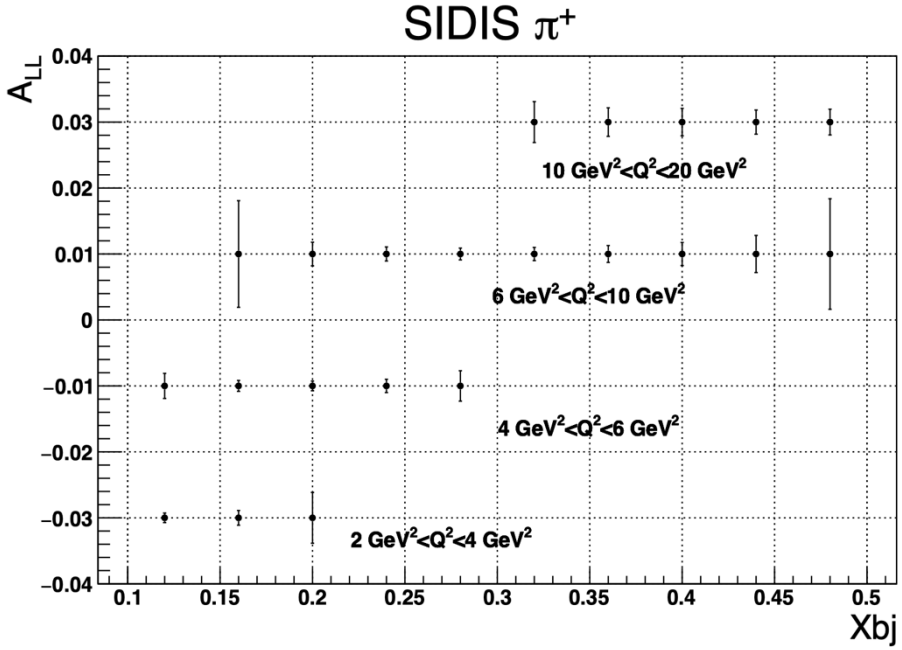


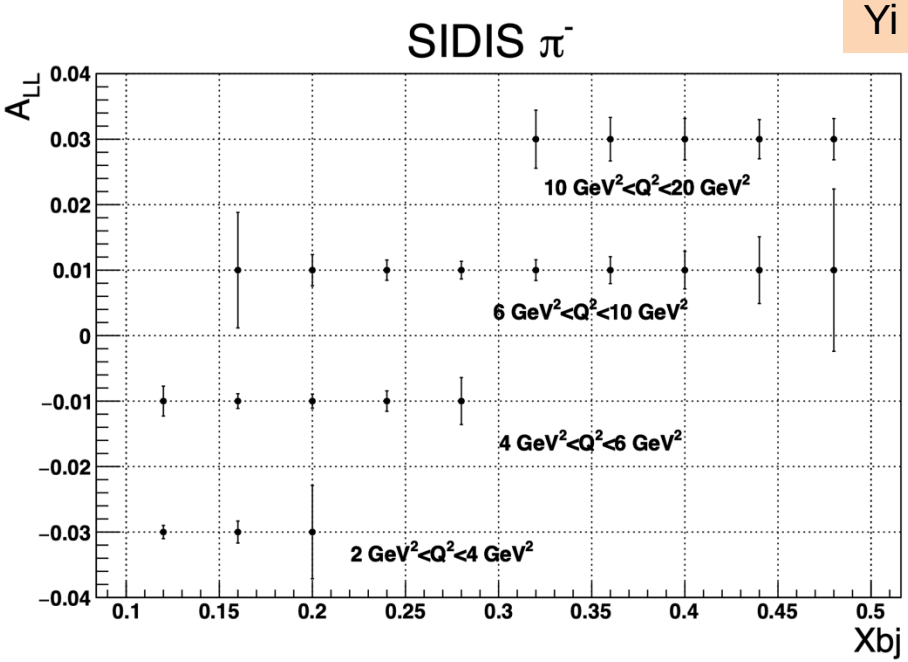
K−

SoLID @ JLab22 SIDIS Polarized Asymmetries: π/K on p

Yi Tian

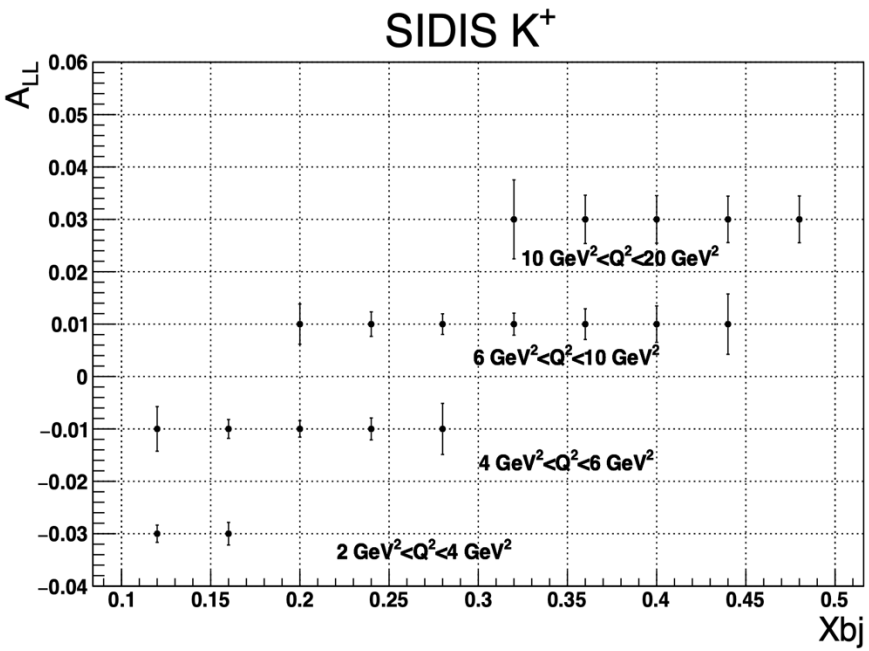
π+

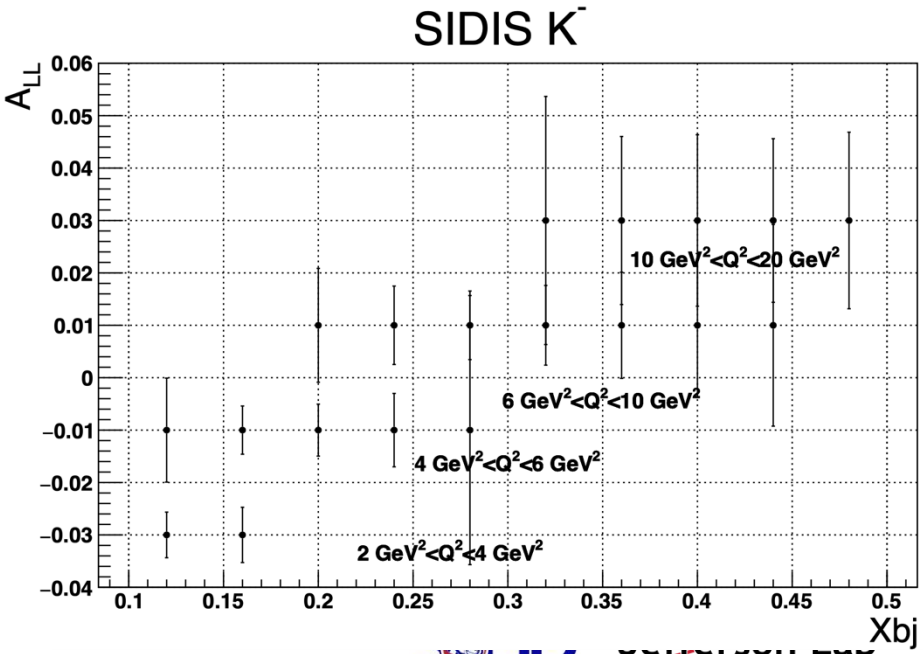




π-

K+





K−

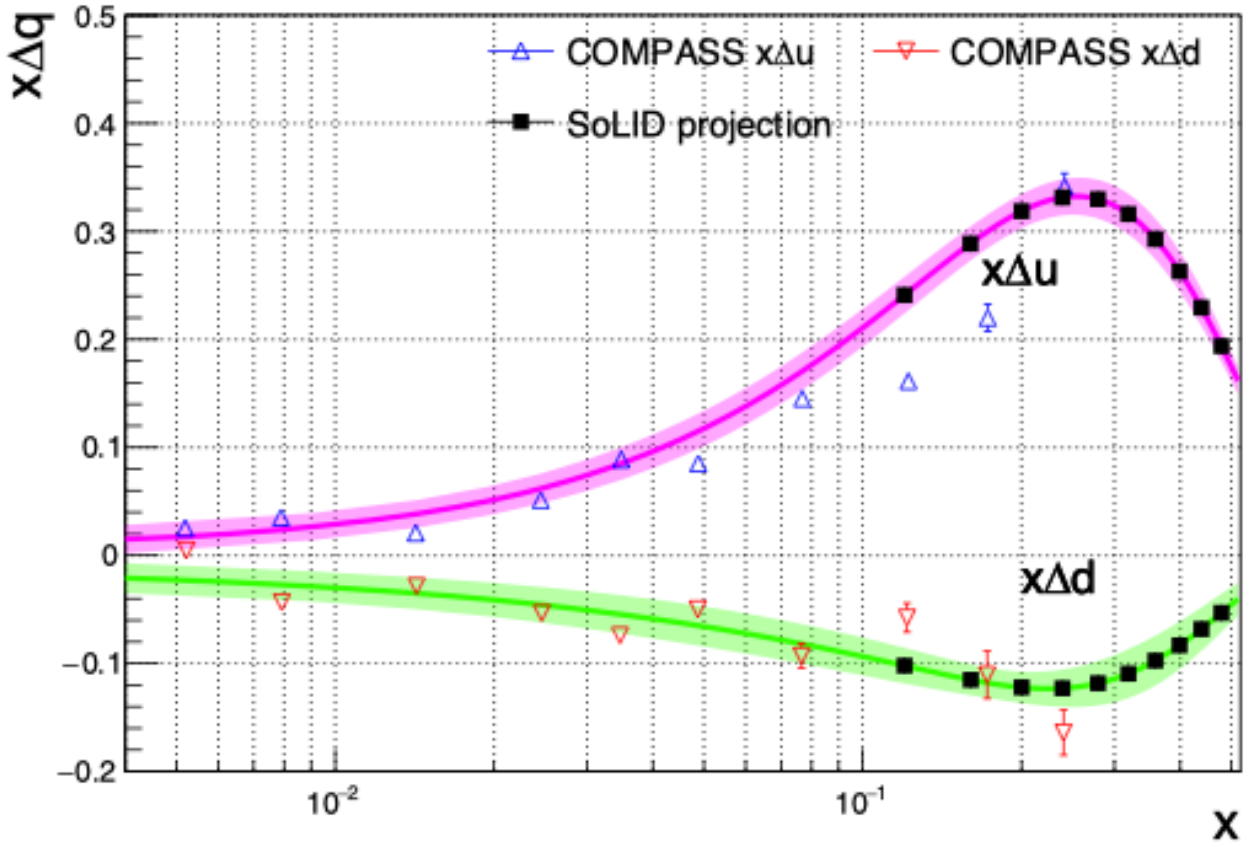
SoLID @ JLab22 SIDIS Polarized u/d PDFs

Ching Him Leung

LO extraction
(assuming x-z factorization)

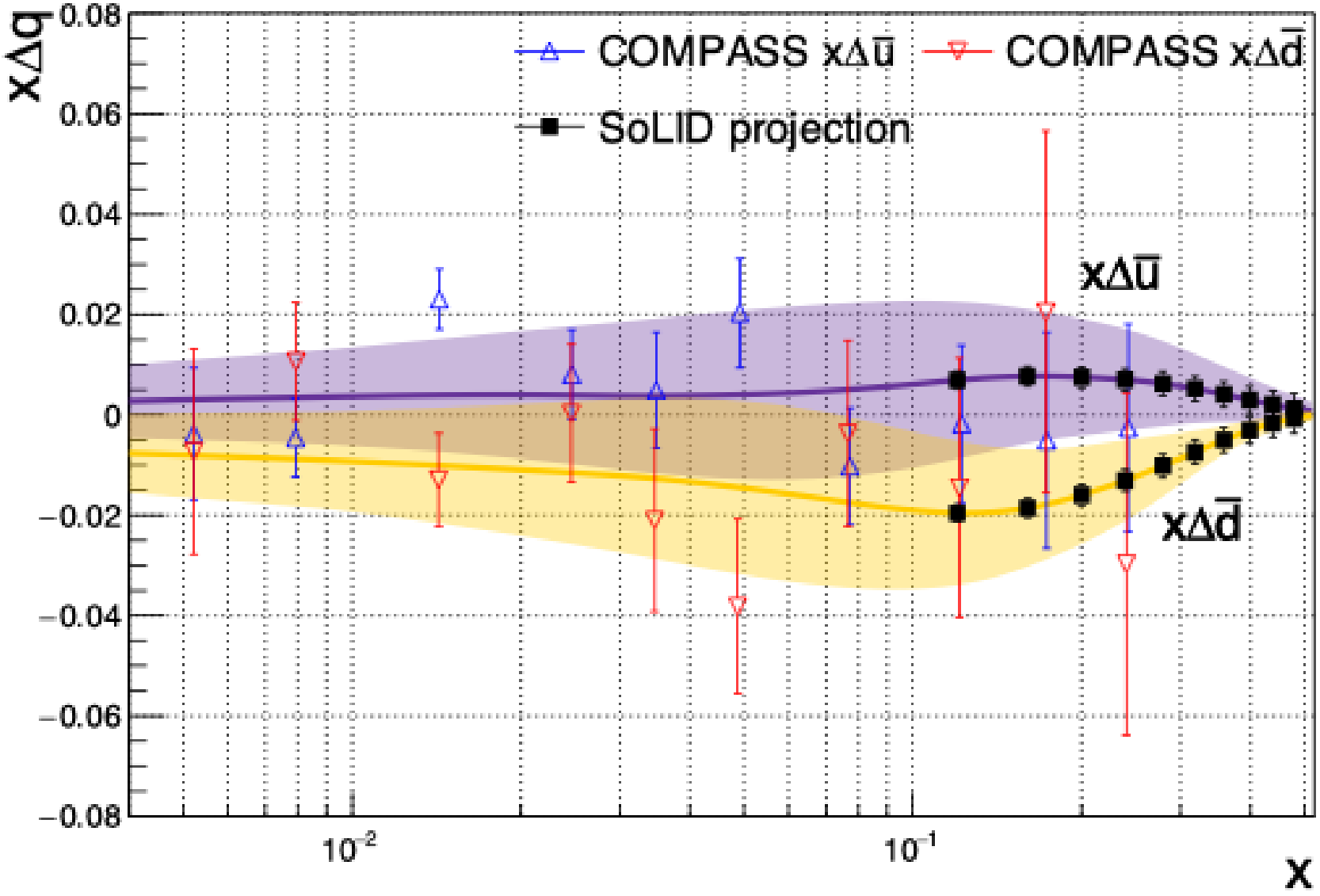
$$A_{LL}(x,Q^2,z) = \frac{\sum_f e_f^2 \Delta q_f(x,Q^2)\cdot D_f^h(z,Q^2)}{\sum_f e_f^2 q_f(x,Q^2)\cdot D_f^h(z,Q^2)}$$

Using LO Fragmentation Function DSSFFLO
Solving/ChiSQ fit all asymmetry data → polarized PDFs



SoLID @ JLab22 SIDIS Polarized ubar/dbar PDFs

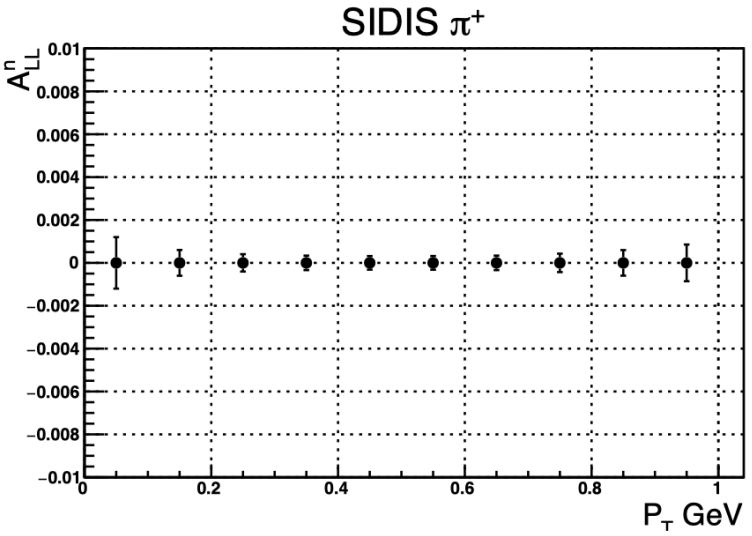
Ching Him Leung

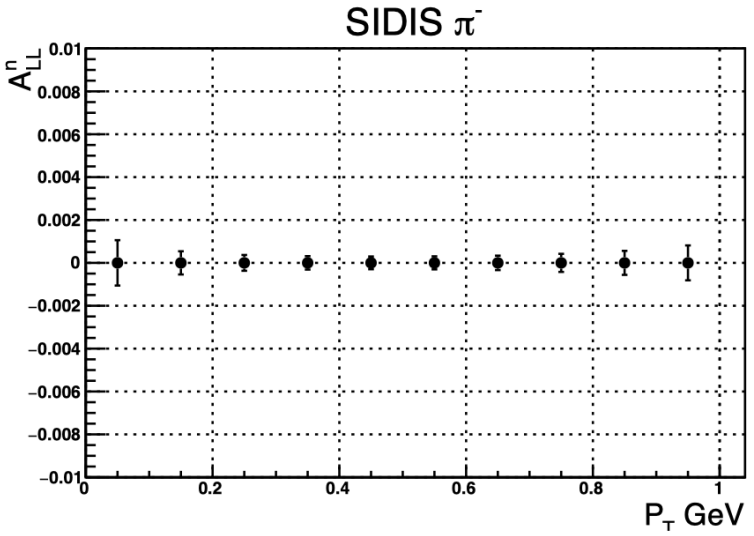


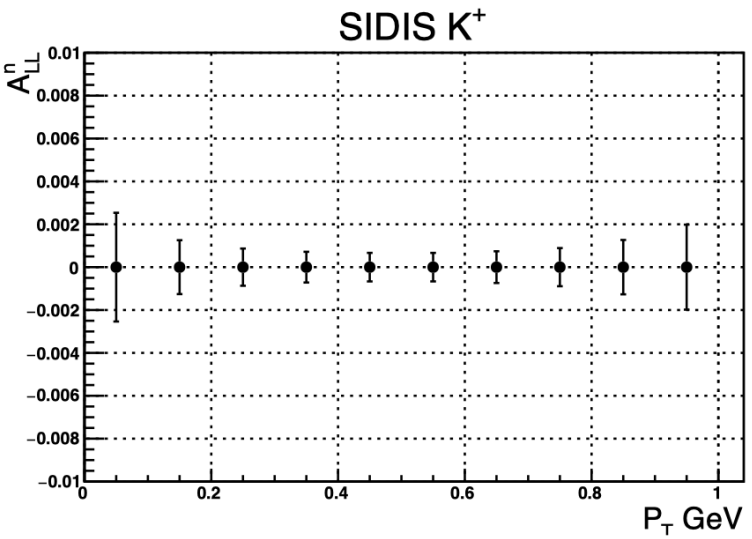
p_T Dependence of Longitudinal Asymmetries from n

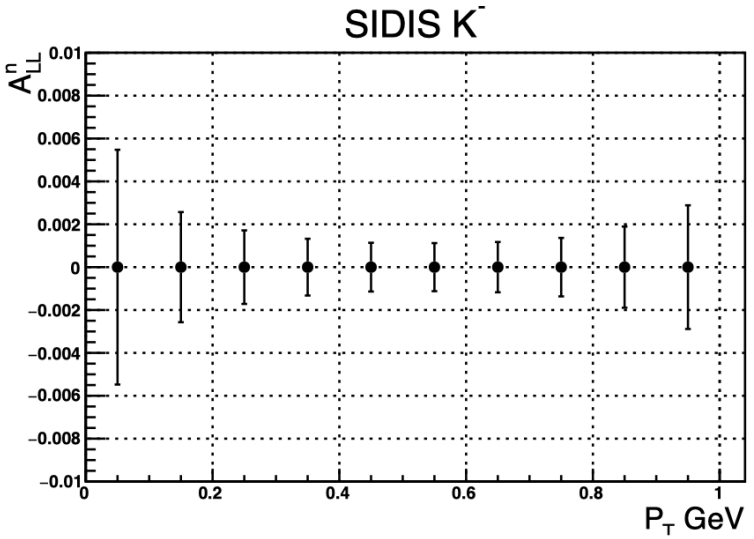
→ Helicity TMDs

Yi Tian









- 100 PAC days, statistic uncertainty only

Integrate over

- $0.2 < z < 0.6$
- $1\text{Gev}^2 < Q2 < 20\ \text{GeV}^2$
- $0 < x_{bj} < 1$

Systematic Uncertainties

- Next steps:
  1. evaluation of experimental systematic uncertainties
  2. evaluation of theoretical uncertainties: need help from theory and global fit groups.
- Experimental Systematics:

  similar to SIDIS-TMD study done for 11 GeV program?
- Theoretical Systematics:
  1. NLO extraction
  2. contamination from non-current fragmentation and higher-twist effects
  3. contamination from vector mesons
  4. effect from missing high high-Pt region
  5. assumptions of charge symmetry and isospin symmetry in FF
  6. nuclear effect for neutron extraction
  7. ……?

Summary

- Light sea (ubar/dbar) at intermediate x (0.1-0.5):

  of great interest and in need of high precision data
- High luminosity JLab22: ideal tool to study light sea at intermediate x
- Hall C @JLab22 projections -> potential to make an impact on unpolarized light sea; need careful systematic/theoretical studies.
- SoLID @ JLab22 projections show potential to make an impact on polarized light sea; need careful systematic/theoretical studies.

  Also projections on Pt dependence of longitudinal asymmetries

  (study helicity TMDs)
- Next steps: systematic uncertainty studies

  Δs?

Backups

Equations (leading order extraction)

$$\frac{\bar{d}}{\bar{u}}(x) = \frac{2(\bar{d}+\bar{u})(x)r_2 - (u+\bar{u})(x)(r_2 - r_1)}{(u+\bar{u})(x)(r_2 - r_1) + 2(\bar{d}+\bar{u})(x)}$$

Projections done using this formula

$$t_1(x) = \frac{Y_p^{\pi^+} + Y_p^{\pi^-}}{Y_n^{\pi^+} + Y_n^{\pi^-}} = \frac{4u(x) + d(x) + 4\bar{u}(x) + \bar{d}(x)}{4d(x) + u(x) + 4\bar{d}(x) + \bar{u}(x)}$$

$$t_2(x) = \frac{Y_p^{\pi^+} - Y_p^{\pi^-}}{Y_n^{\pi^+} - Y_n^{\pi^-}} = \frac{4u(x) - d(x) - 4\bar{u}(x) + \bar{d}(x)}{4d(x) - u(x) - 4\bar{d}(x) + \bar{u}(x)}$$

$$r_1(x) = \frac{4 - t_1(x)}{4t_1(x) - 1} = \frac{d_v(x) + 2\bar{d}(x)}{u_v(x) + 2\bar{u}(x)}$$

$$r_2(x) = \frac{4 + t_2(x)}{4t_2(x) + 1} = \frac{d_v(x)}{u_v(x)}$$

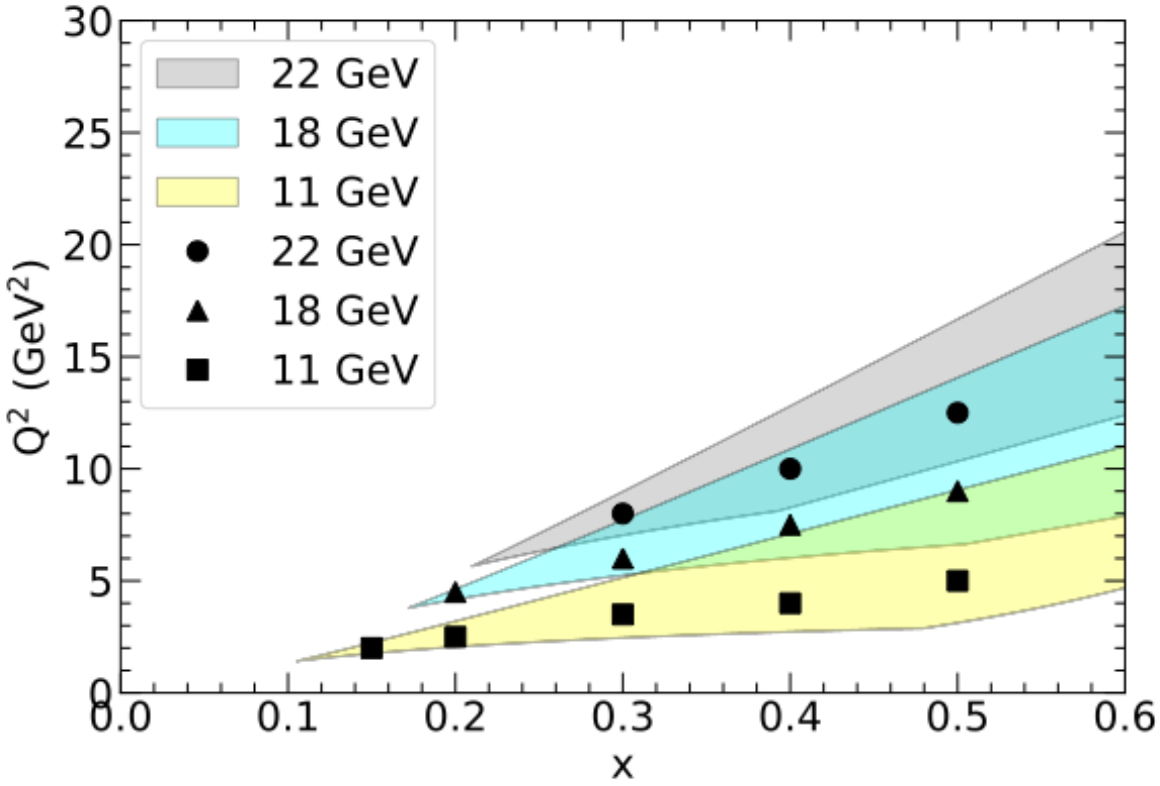
Points are kinematics of suggested measurements

11 GeV

x	Q^2	W	$(W')^2$
0.15	2.0	3.5	6.52
0.20	2.5	3.3	5.84
0.30	3.5	3.0	4.90
0.40	4.0	2.6	3.79
0.50	5.0	2.4	3.26

18 GeV

x	Q^2	W	$(W')^2$
0.20	4.5	4.4	9.84
0.30	6.0	3.9	7.82
0.40	7.5	3.5	6.42
0.50	9.0	3.1	5.25



22 GeV

x	Q^2	W	$(W')^2$
0.30	8.0	4.4	10.15
0.40	10.0	4.0	8.29
0.50	12.5	3.7	7.00

Z=0.5 for all settings

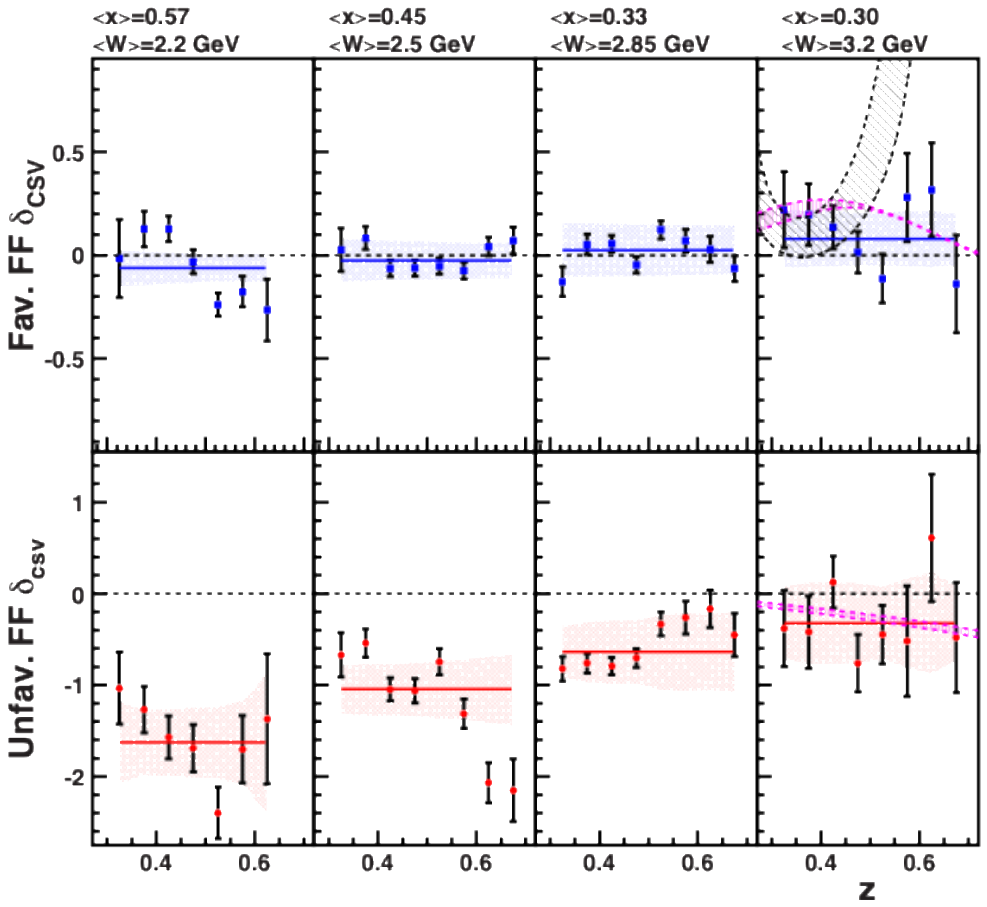
LO method assumes charge and isospin symmetry in Fragmentation Functions

$$D^+ \equiv D_u^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} = D_{\bar{d}}^{\pi^+}$$

$$D^- \equiv D_u^{\pi^-} = D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-}$$

$$\delta_{\mathrm{CSV}}^{f}(z) = \frac{D_d^{\pi^-} - D_u^{\pi^+}}{D_u^{\pi^+}}$$

$$\delta_{\mathrm{CSV}}^{uf}(z) = \frac{D_d^{\pi^+} - D_u^{\pi^-}}{D_u^{\pi^-}}$$



Preliminary Hall C results suggest this may not hold at large x or low W

SoLID@JLab: at the QCD Intensity Frontier

SoLID will ***maximize*** the science return of the 12-GeV CEBAF upgrade by **combining**

High Luminosity
$10^{37\text{-}39}$ /cm^2/s
[>100x CLAS12][>1000x EIC]

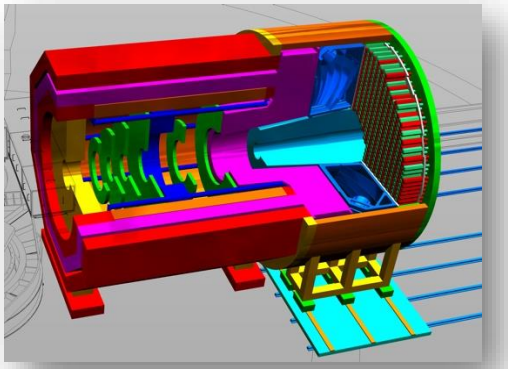
+

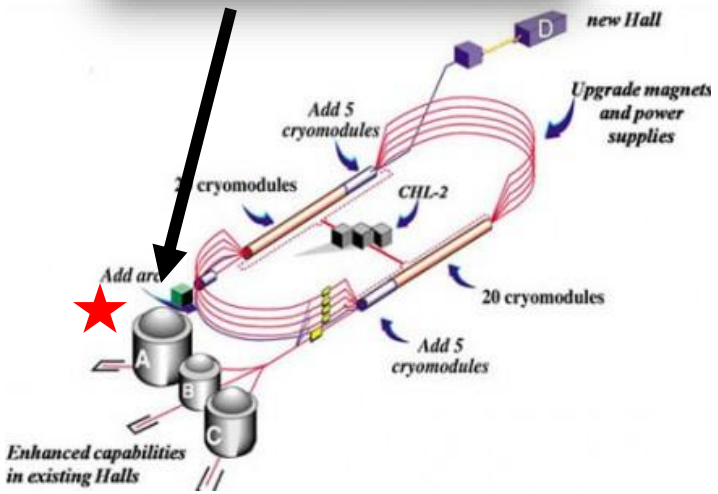
Large Acceptance
Full azimuthal ϕ coverage

Research at **SoLID** will have the ***unique*** capability to **explore** the QCD landscape while **complementing** the research of other key facilities

- 3D momentum imaging of a relativistic strongly interacting confined system - TMDs (**nucleon spin**)
- Superior sensitivity to the differential electro- and photo-production cross section of J/ψ near threshold (**gluon field and proton mass**)
- Pushing the phase space in the search of new physics and of hadronic physics

Synergizing with the pillars of EIC science (**proton spin** and **mass**) through high-luminosity valence quark tomography and precision J/ψ production near threshold



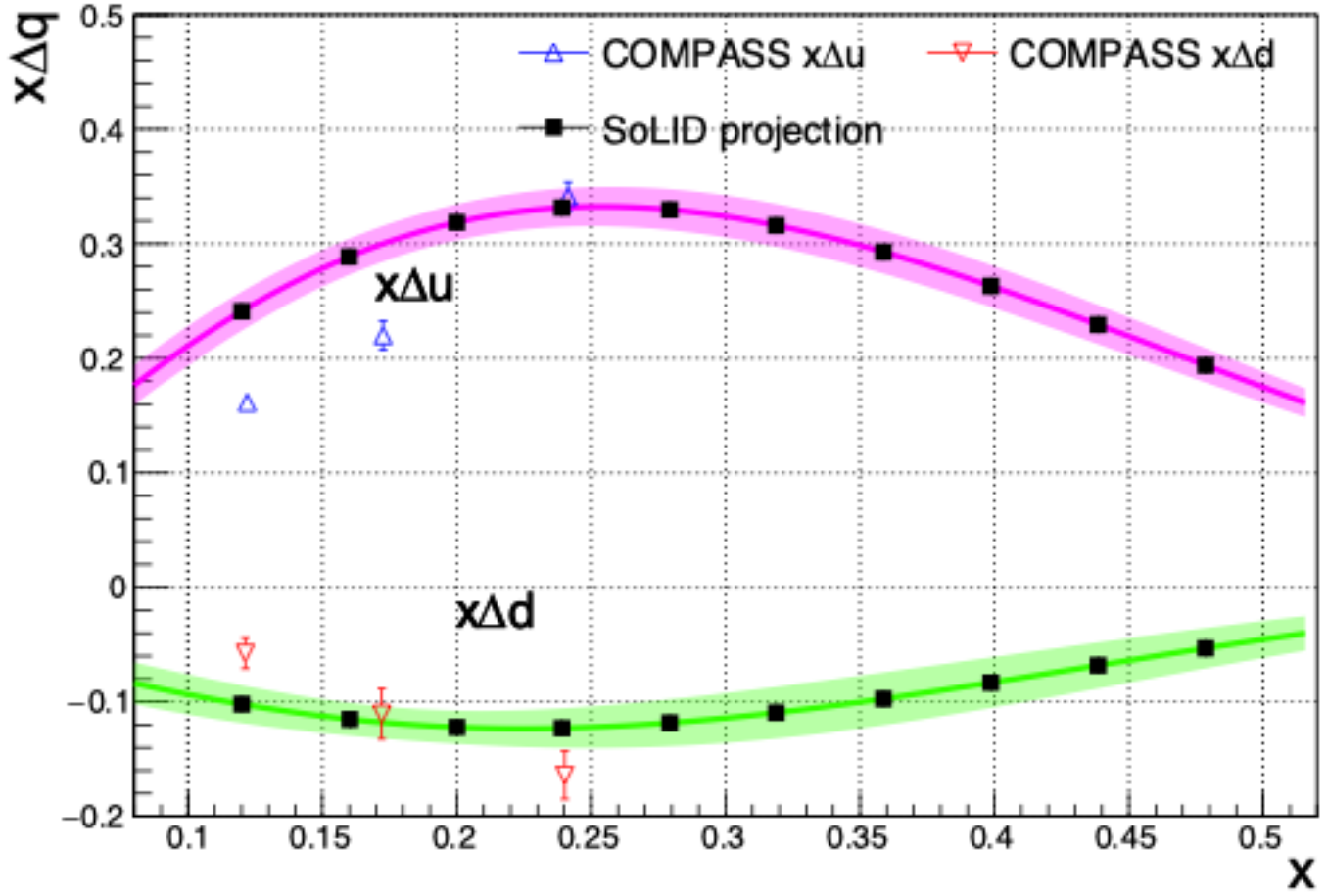


SoLID @ JLab22 SIDIS Polarized u/d PDFs

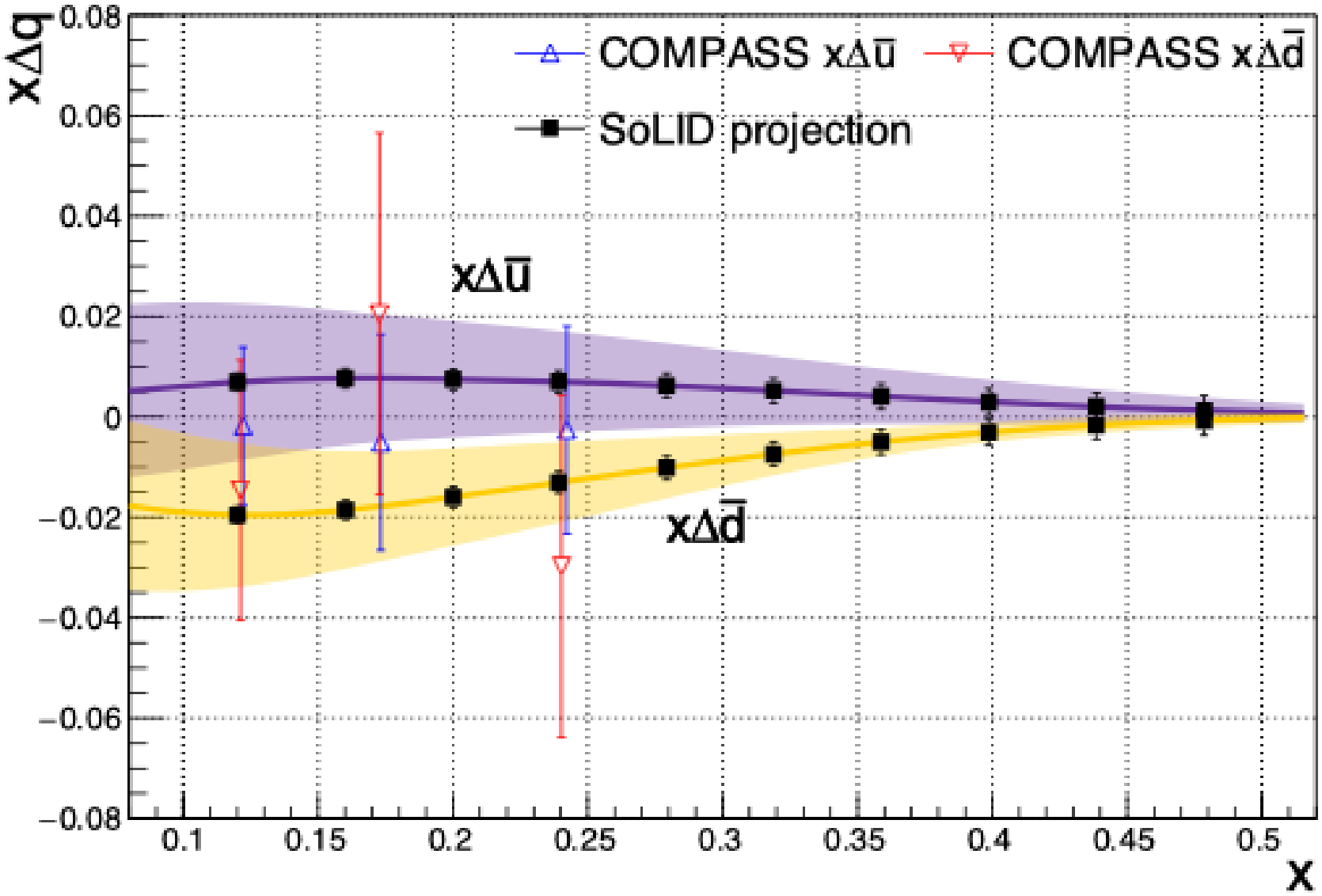
LO extraction
(assuming x-z factorization)

$$A_{LL}(x, Q^2, z) = \frac{\sum_f e_f^2 \Delta q_f(x,Q^2) \cdot D_f^h(z,Q^2)}{\sum_f e_f^2 q_f(x,Q^2) \cdot D_f^h(z,Q^2)}$$

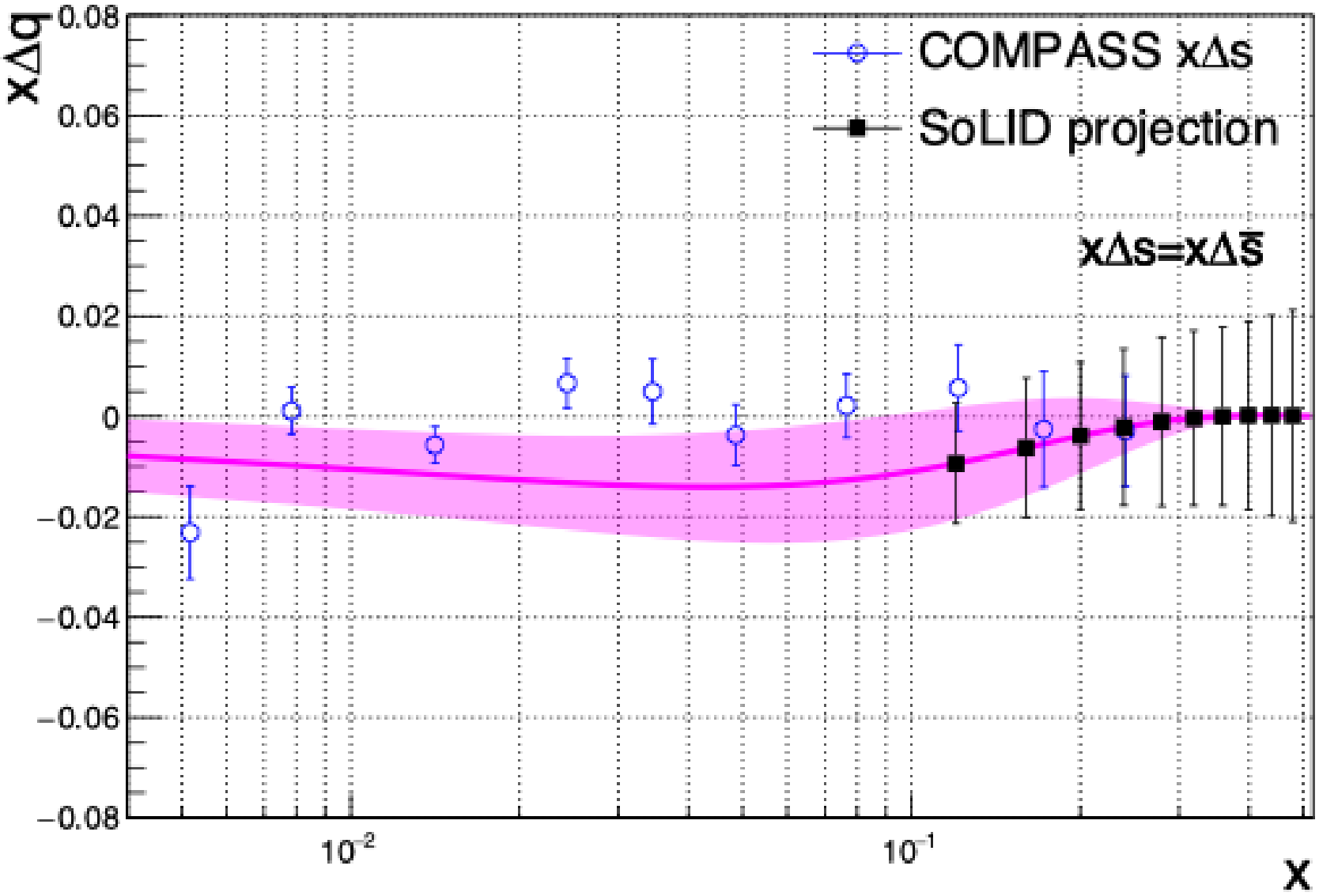
Using LO Fragmentation Function DSSFFLO
Solving/ChiSQ fit all asymmetry data → polarized PDFs



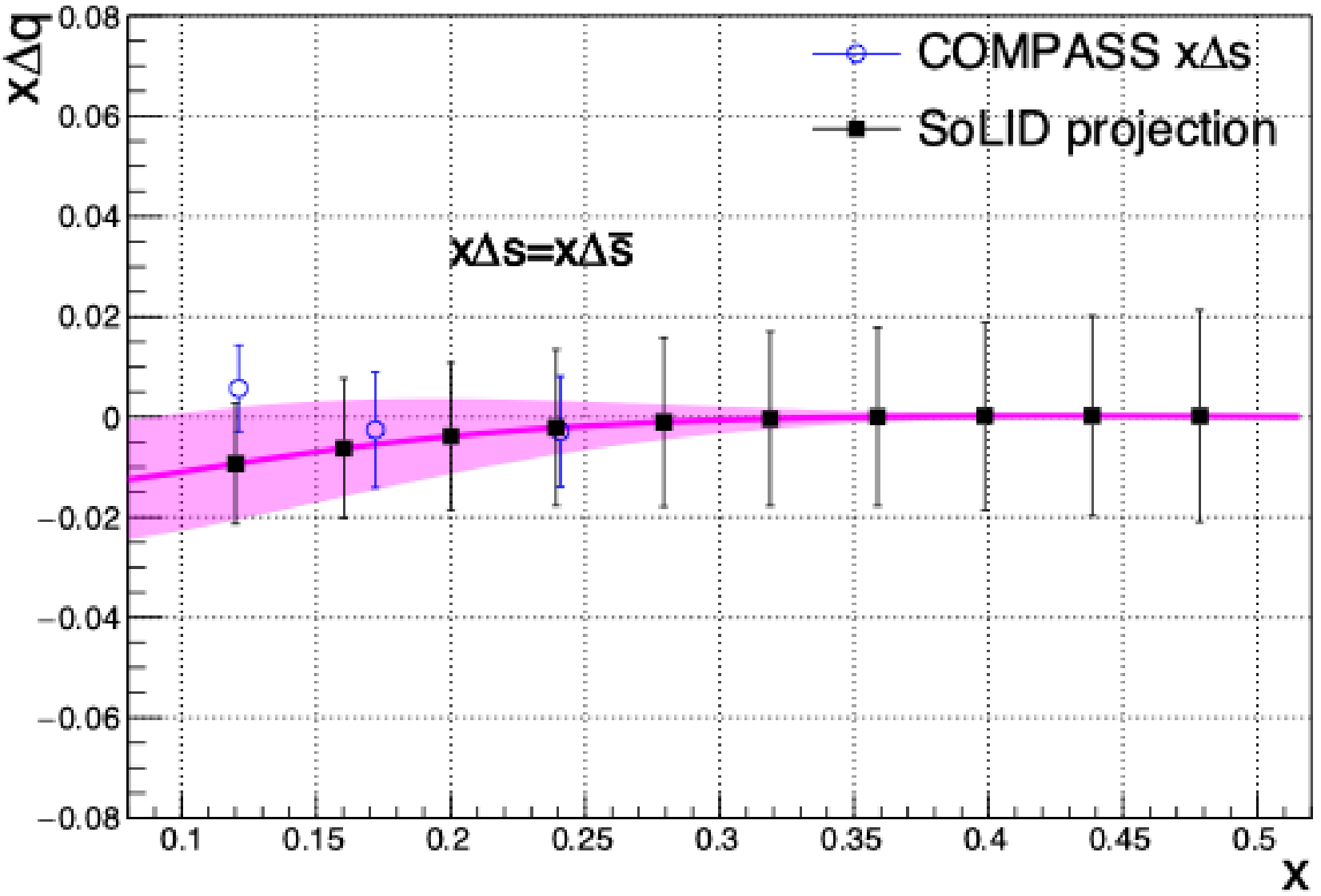
SoLID @ JLab22 SIDIS Polarized ubar/dbar PDFs



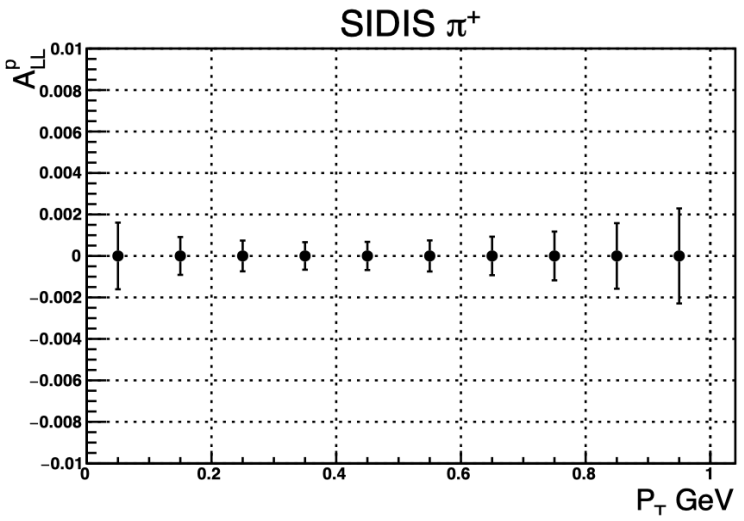
SoLID @ JLab22 SIDIS Polarized s PDFs

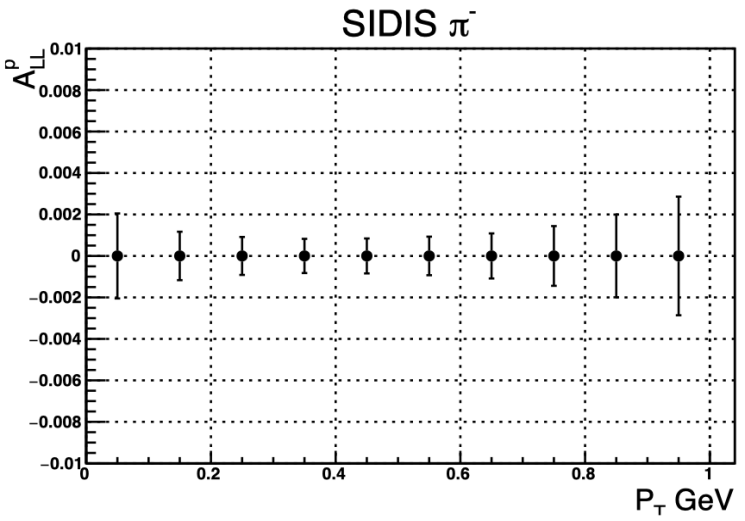


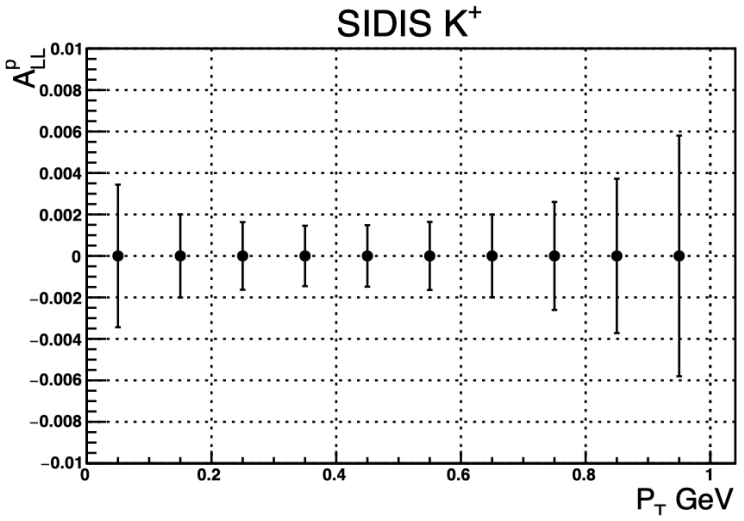
SoLID @ JLab22 SIDIS Polarized s PDFs

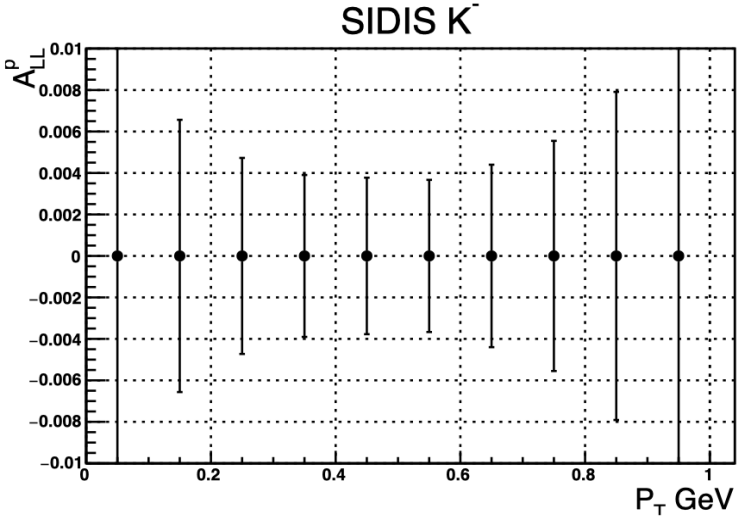


p_T Dependence of Helicity TMD Distributions from Proton





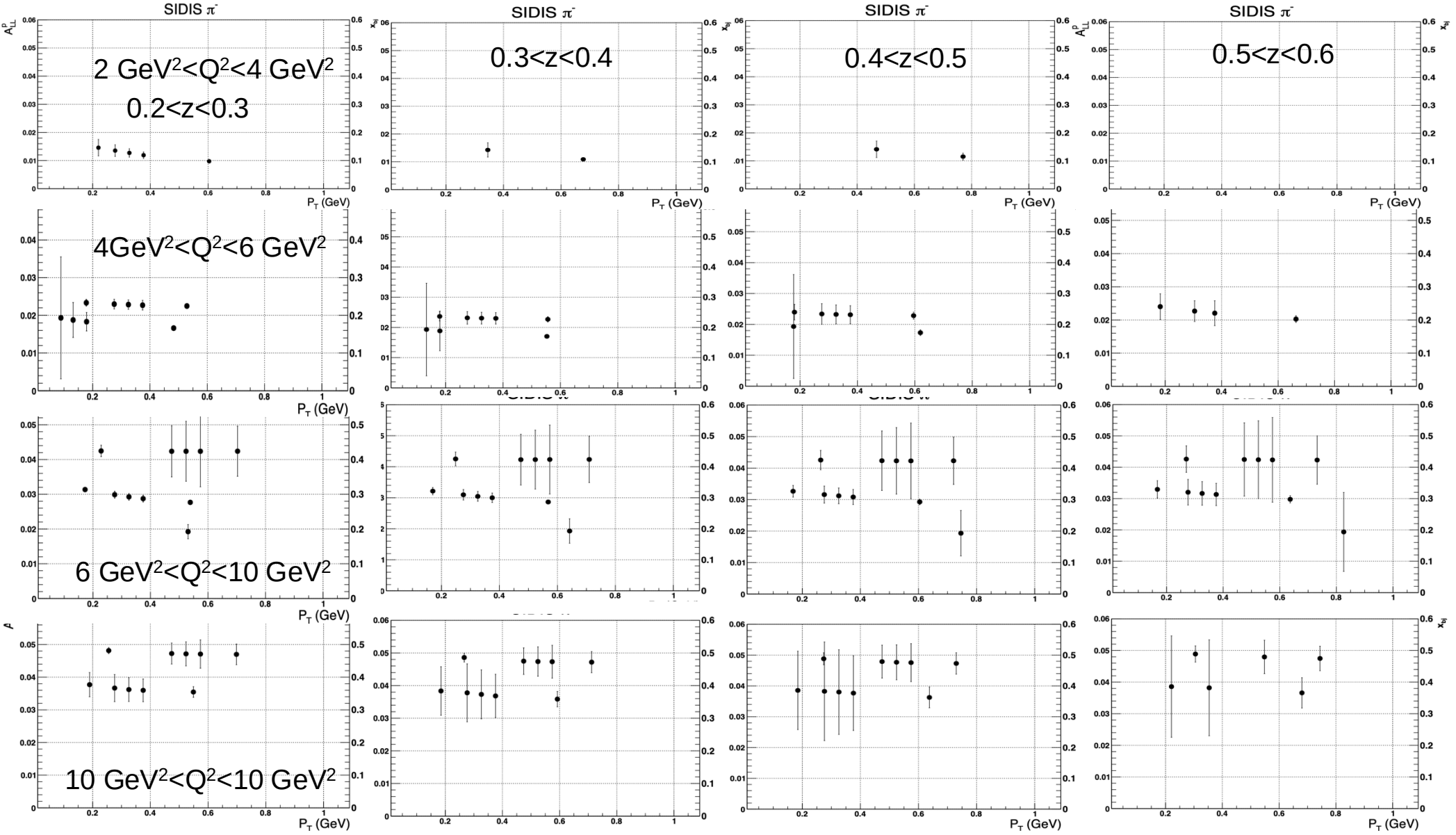




- 100 PAC days, statistic uncertainty only

Integrate over

- $0.2 < z < 0.6$
- $1\text{Gev}^2 < Q2 < 20\ \text{GeV}^2$
- $0 < x_{bj} < 1$


SIDIS π⁻
2 GeV²<Q²<4 GeV²
0.2<z<0.3
0.3<z<0.4
0.4<z<0.5
0.5<z<0.6
4GeV²<Q²<6 GeV²
6 GeV²<Q²<10 GeV²
10 GeV²<Q²<10 GeV²
P_T (GeV)