Open issues with SIDIS and future plans at JLab

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From observables to QCD dynamics
- Projections as motivation for future studies
- Studies of evolution properties
- Future studies of 3D

Summary

HIGH ENERGY WORKSHOP SERIES 2022

We are pleased to announce an upcoming series of summer workshops being organized jointly between the laboratory and the Jefferson Lab Users Organization (JLUO) to probe the science that would be opened up by a higher energy electron beam (~20-24 GeV) at Jefferson Lab. We are particularly interested in identifying key measurements that are not possible to access at 12 GeV, that initially utilize largely existing or already-planned Hall equipment, and that leverage the unique capabilities of luminosity and precision possible at Jefferson Lab in the EIC era.

https://www.jlab.org/conference/hews22

- **Hadron Spectroscopy with a CEBAF Energy Upgrade**
  June 16 & 17
- **The Next Generation of 3D Imaging**
  July 7
- **Science at Mid x: Anti-shadowing and the Role of the Sea**
  July 22 & 23
- **Physics Beyond the Standard Model**
  August 1
- **J/Psi and Beyond, August 17**

Mark your calendar !

More workshops on 3D of Jlab upgrade
Korea,July 18-23 :
https://indico.knu.ac.kr/event/566/
Trento, Sep 26-30
https://www.ectstar.eu/workshops/opportunities-with-jlab-energy-and-luminosity-upgrade/

Projections to motivate Jlab 20+ upgrade

Classify observables, summarize the set of projection from future facilities

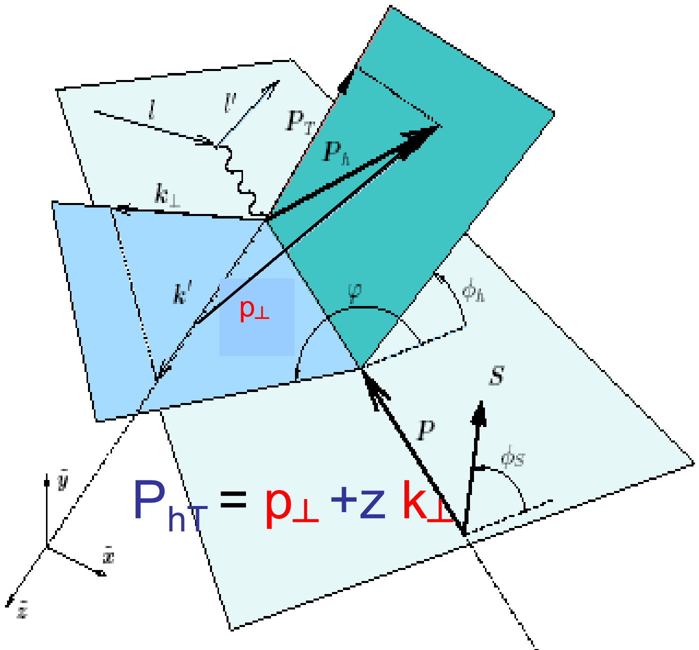
1) Identify the flagship measurements that can be done only with 20+ GeV

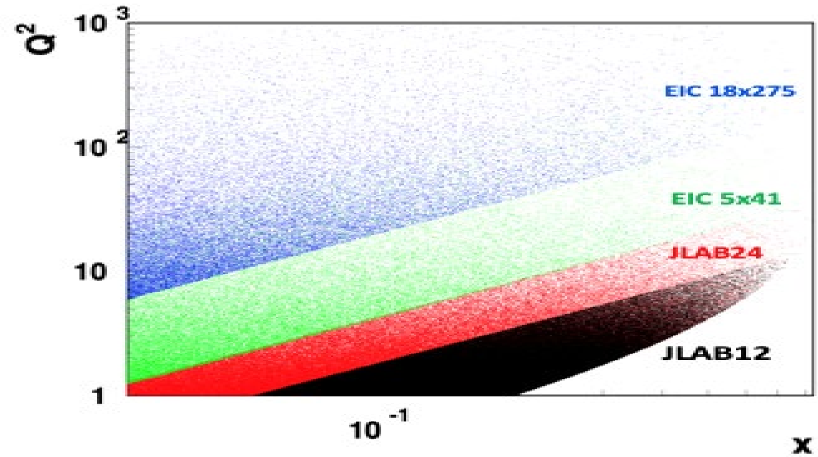
2)Identify the flagship measurements with 22 GeV that can extend, improve the 11 GeV, helping interpretation, multidimensional bins in extended kinematics

3)Identify the measurements with 22 GeV that can set the bridge between JLab12 and EIC (complementarity)

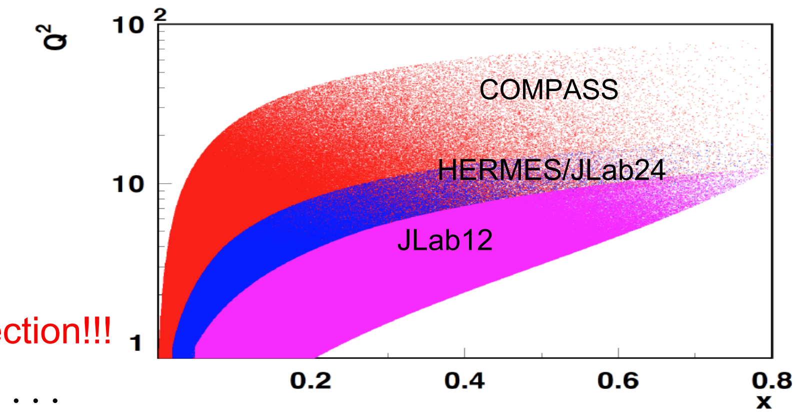
- Produce sets of event for relevant observables (SIDIS, DVCS, Large x,….) and process them using existing detector reconstructuion chains (ex. CLAS12, SoLID,Hall-A/C/D), evaluate count rates, define kinematical coverage and resolutions
  - Identify observables that can provide critical input without detector upgrades
  - Identify critical observables, that require certain detector upgrades

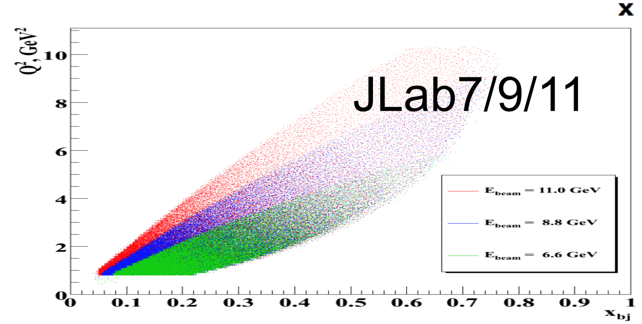
SIDIS kinematical coverage and observables





EIC





SIDIS experiments measure azimuthal dependence of the cross section!!!

$$\sigma \propto F_{UU} + P_b\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi + P_t\epsilon F_{UL}^{\sin 2\phi}\sin 2\phi + \ldots$$

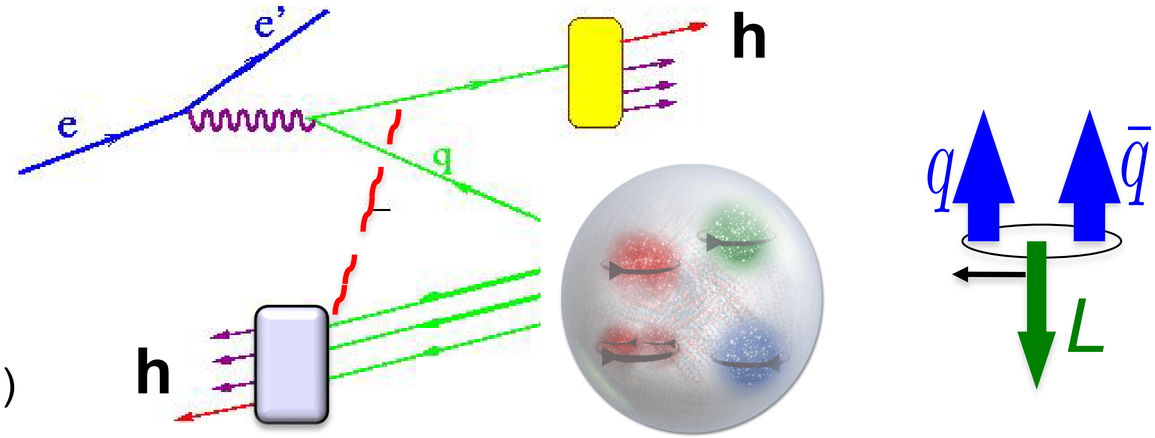
$$+F_{UU,L} + |S_\perp|[F_{UT}^{\sin\phi-\phi_S}\sin(\phi-\phi_S) + \sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin\phi_S}\sin\phi_S + \ldots]$$

- Studies of azimuthal modulations give access to underlying 3D partonic distributions
- QCD predicts only the Q^2-dependence of 3D PDFs

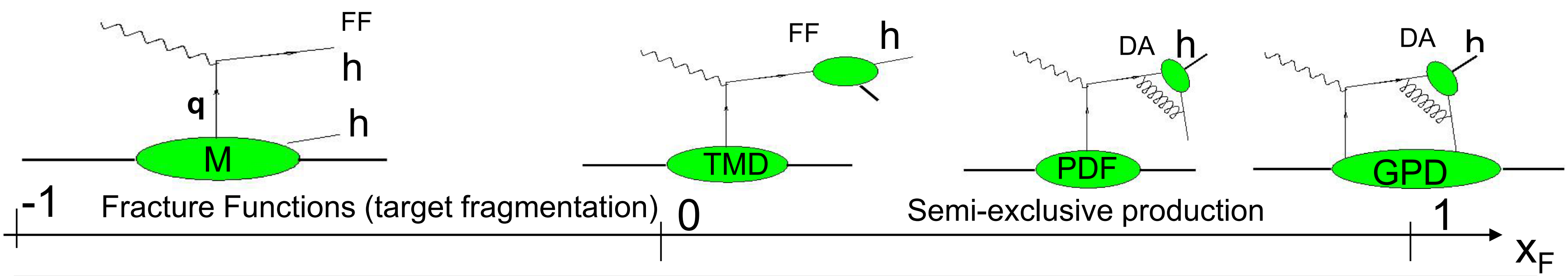
Hadron production in hard scattering in SIDIS

x_F – fractional momentum in the CM frame

$x_F>0$ (current fragmentation)



$x_F<0$ (target fragmentation)



Different non-perturbative objects may be involved in description, depending on kinematical conditions, introducing different dependence on Q^2

Understanding the systematics in 3D SIDIS

- SIDIS, with hadrons detected in the final state, from experimental point of view, is a measurement of observables in 5D space (x,Q^2,z,P_T,ϕ)
- Collinear SIDIS, is just the proper integration, over P_T,ϕ
- SIDIS observations relevant for interpretations of experimental results:
  - Understanding the kinematic domain where non-perturbative effects of interest are significant (ex. x,P_T-range)
  - Understanding of phase space effects is important (additional correlations)
  - Understanding of P_T-dependences of observables in the full range of P_T dominated by non-perturbative physics is important
  - Understanding the role of vector mesons is important
  - Understanding of evolution properties of observables is important
  - Understanding of radiative effects may be important for interpretation
  - Overlap of modulations (acceptance, RC,…) is important in separation of SFs
  - Multidimensional measurements with high statistics, critical for separation of different ingredients

Need a realistic chain for MC simulations of SIDIS to produce realistic projections with controlled systematics

Making projections: data set

Pseudo data set (counts)

Some prediction (parameterization?)

Extraction procedure

Projection for measurements

Data set

Full statistics

Fiducial volume

Full cuts (E_{min},y_{min},y_{max},…) may reduce the sample from ~50% to 1-2%

Quality

- Cross sections + geometrical cuts
- Generated events (real phase space)
- Generated + radiative effects
- GEANT simulation + resolutions+ID
- Reconstructed after GEANT (ideal)
- Reconstructed with real efficiencies (trigger, tracking, ID,….)

Making projections: extraction procedure

Pseudo data set (counts)

Some prediction (parameterization?)

Extraction procedure

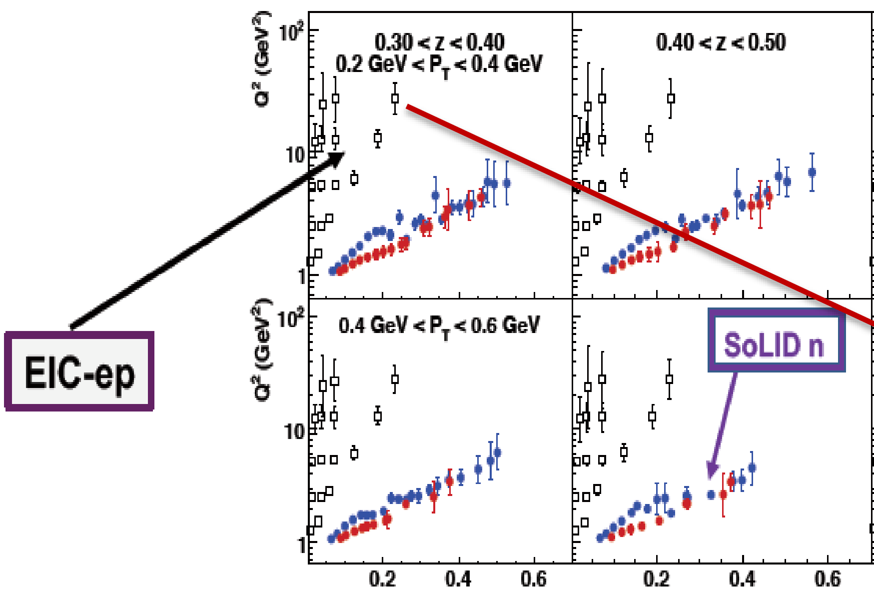
Projection for measurements

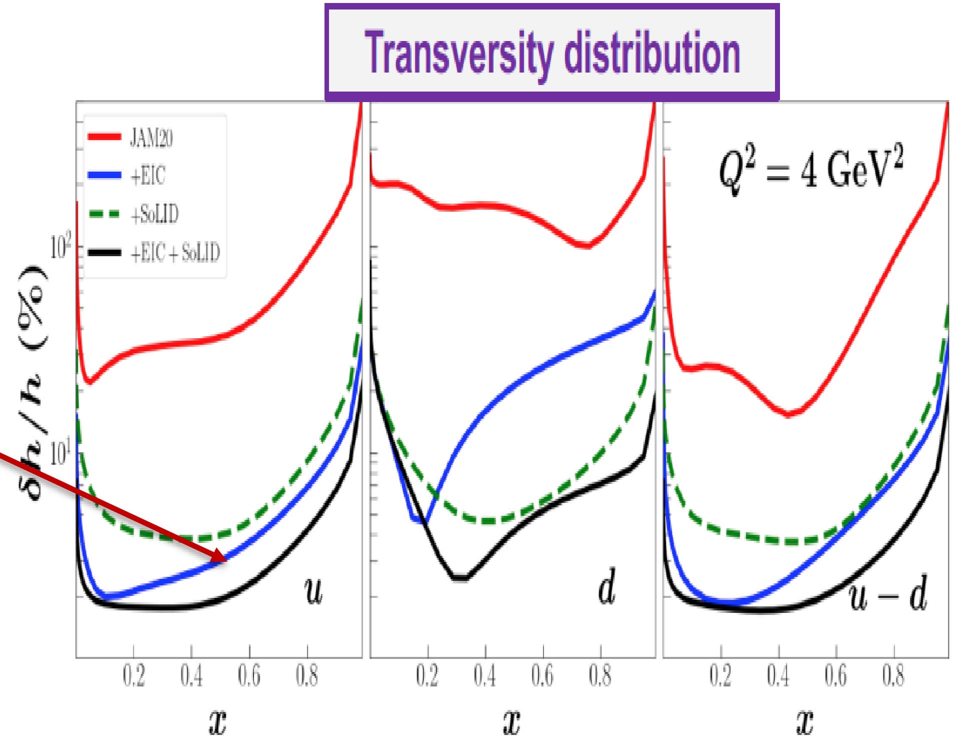
Extraction procedure should have clear definition of systematics

- The role of multidimensional measurements should be well defined, accounted in the extraction
    - The same parameterization used in production of data and extraction of TMDs will have practically unconstrained systematics
    - Using statistical errors from simulation to evaluate the errors on a given TMDs can produce absolutely unrealistic projections, in particular in boundaries.

TMDs sensitivity to transversity: large x

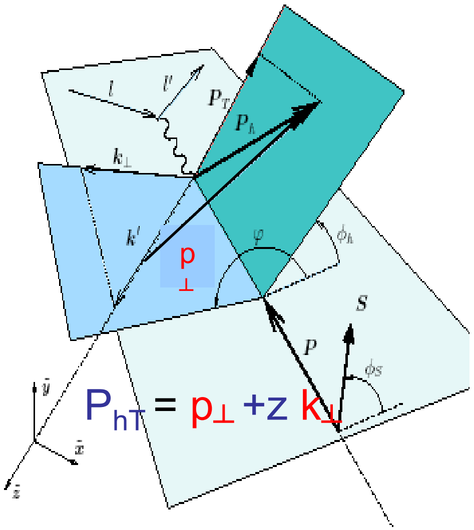
Plots from : “SoLID DOE review”

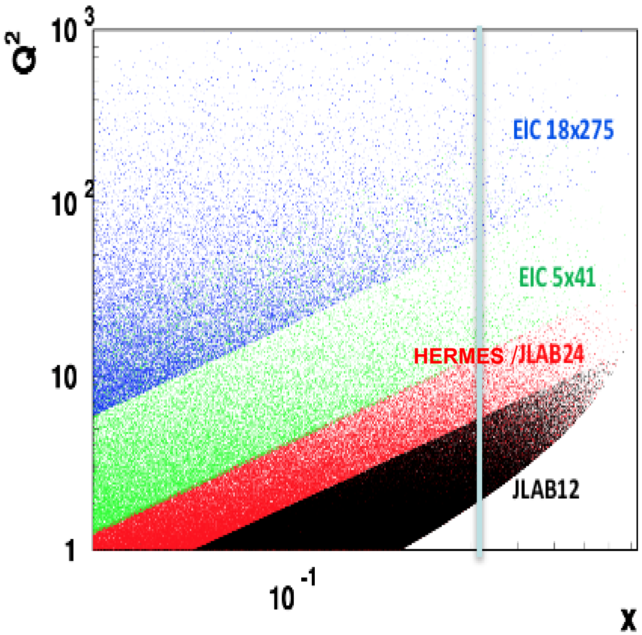


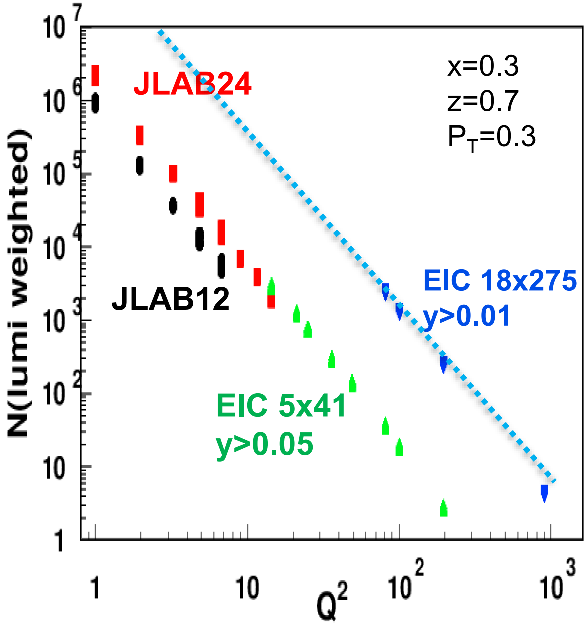


- SOLID measurements with transversely polarized targets will provide crucial input at large x
- Complementarity of JLab and EIC at large x should be carefully examined for better coordination (theory+experiment)
- Systematics from parameterizations, providing “sensitivity” to kinematical regions not covered by data should be carefully evaluated

SIDIS kinematical coverage and observables







Crucial to evaluate counts in the fiducial region (resolutions, acceptance,RC,…)

$$\sigma \propto F_{UU} + P_b\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi + P_t\epsilon F_{UL}^{\sin 2\phi}\sin 2\phi + \dots$$

- Higher energies open the phase space for large transverse momenta and Q^2, and lower x, but move events to lower y
- Wider range in Q^2- allows evolution studies of 3D PDFs
  - Higher statistics, better resolutions vs wider range in EIC (complementary)

“Only JLab” measurements (suppressed at EIC)

Twist-2

$$\boxed{A_{LL} = F_{LL}/F_{UU}}$$

Double spin asymmetries in single hadron production CFR and TFR

$$\boxed{\mathcal{F}_{LU}^{\sin(\phi_1-\phi_2)} \sin \Delta\phi}$$

Beam spin asymmetries in correlations of CFR and TFR

Twist-3

$$\boxed{\sin\phi_h\, F_{LU}^{\sin\phi_h}}$$

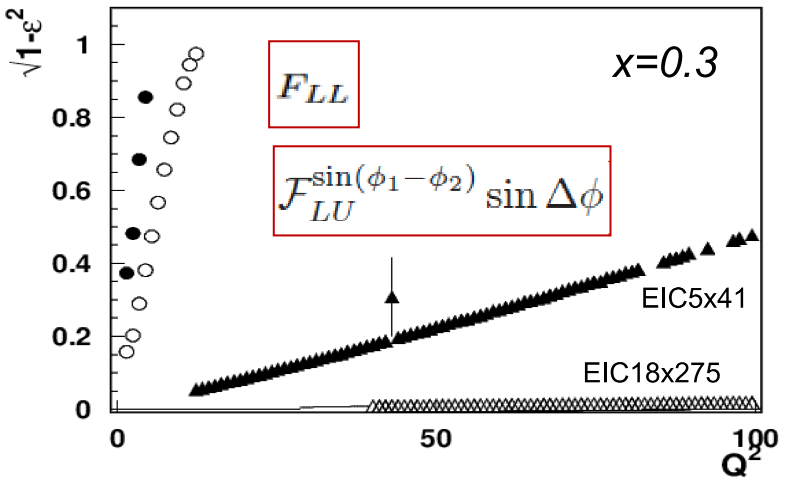
$$\boxed{\mathrm{A}_{\mathrm{LU}}^{\sin\phi_{R_\perp}}}$$

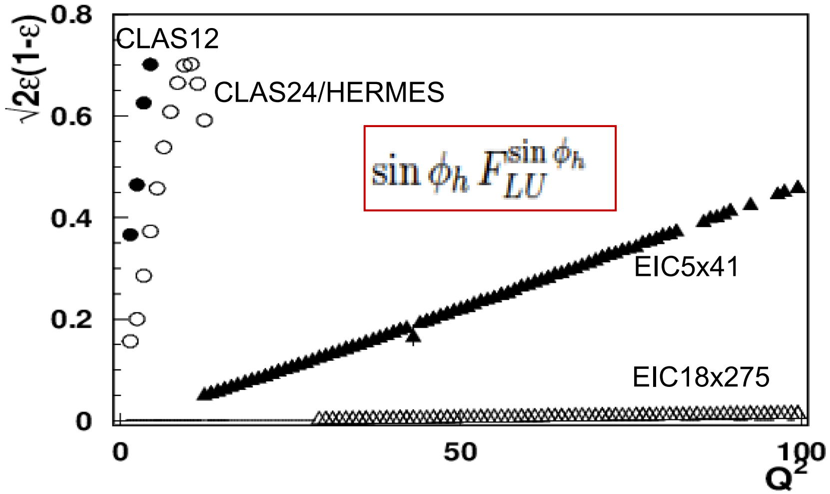
Beam spin asymmetries in CFR (single and dihedron)

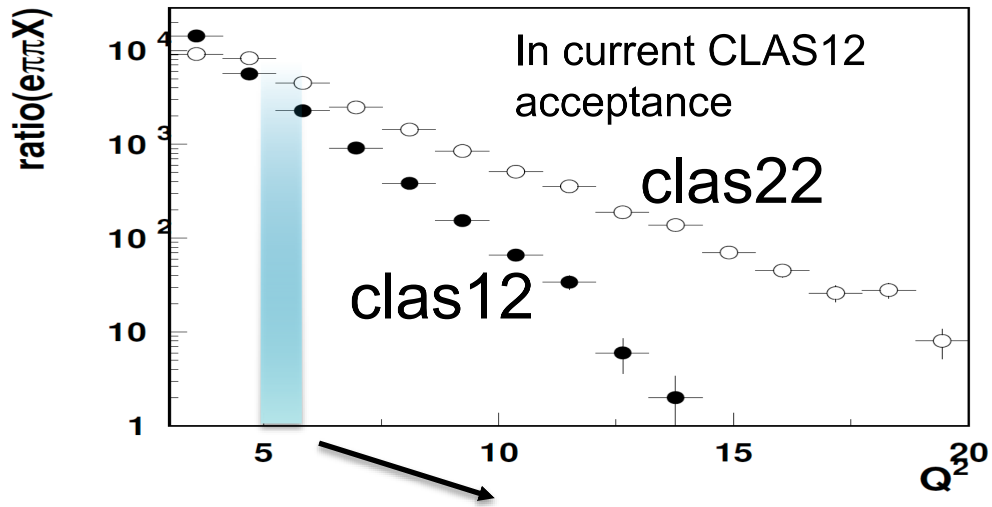
Examples in slides (10-15)

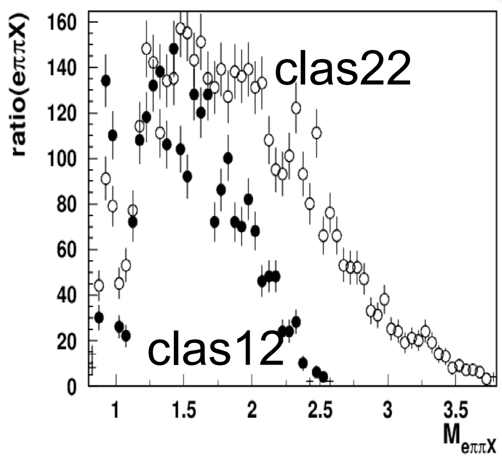
Exclusive processes in the x>0.1 domain, may most be in this category, due to resolutions and rapidly decreasing x-sections at higher energies

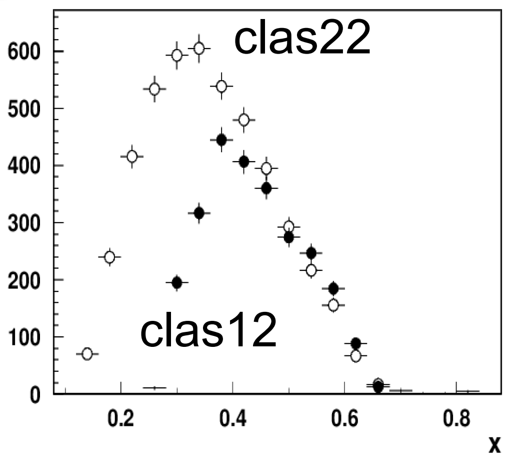
Beam SSAs & Kinematic suppression at large x











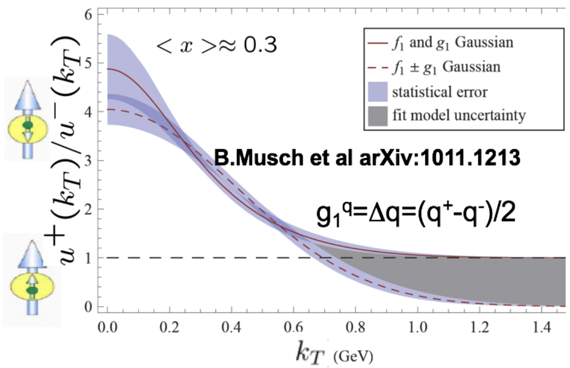
- Fixed target experiments are sensitive to all SSAs
- Higher energy opens up the phase space allowing access to, sea and large Q^2
- Measurements of beam SSAs (+some others) at large x, will be challenging at EIC

Unknown “known” f_1, g_1 TMDs

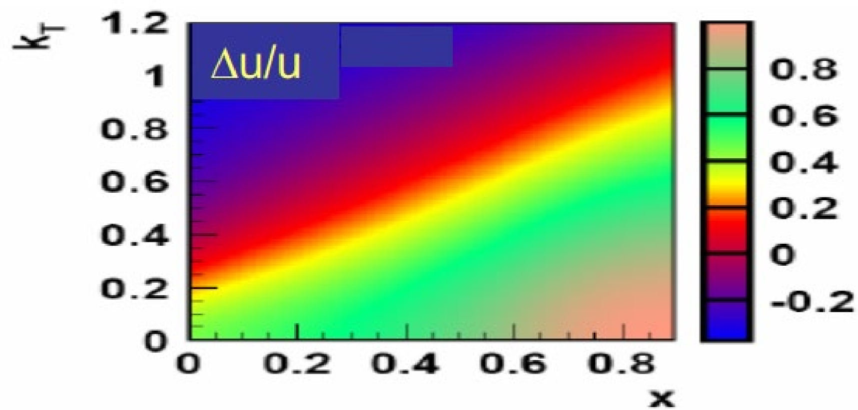
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

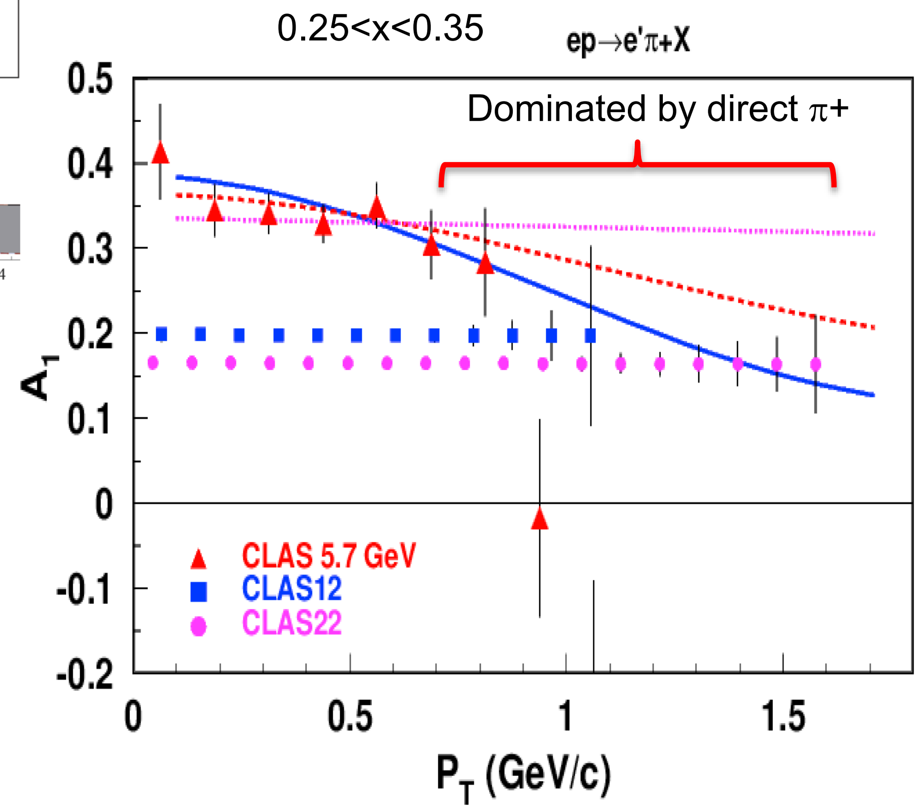
$$u^+(x,k_T) = f_1^u(x,k_T^2) + g_1^u(x,k_T^2)$$

$$u^-(x,k_T) = f_1^u(x,k_T^2) - g_1^u(x,k_T^2)$$



(dipole formfactor), J.Ellis, D-S.Hwang, A.Kotzinian

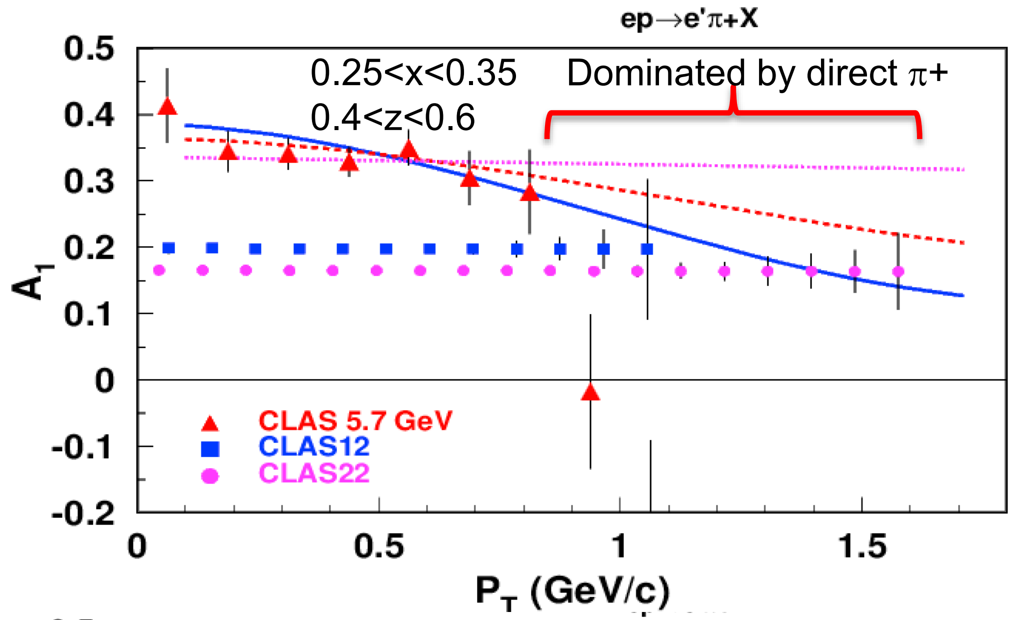




- Models and lattice predict very significant spin and flavor dependence for TMDs
- Large transverse momenta are crucial to access the large k_T of quarks
- Several CLAS12 proposals dedicated to $g_1(x,k_T)$-studies CLAS12
- Understanding of k_T-dependence of g_1 will help in modeling of f_1

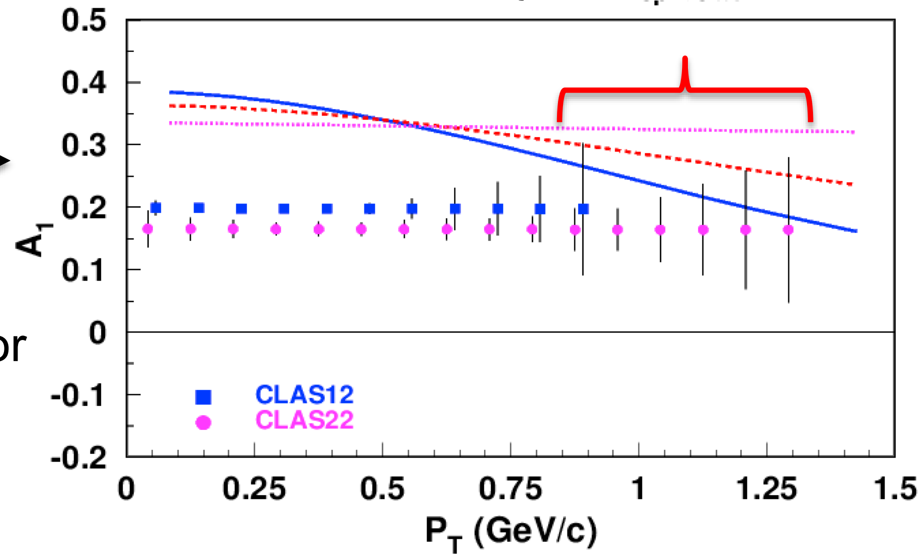
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

Impact of limitations from theory



- Gain with 22 GeV will be more critical with additional kinematical cuts imposed by theory

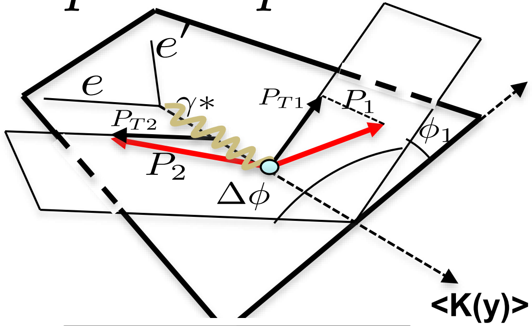
$P_T/z/Q<0.5$ →



More theory limitation, may convert the observable from major improvement (type 2) to only possible with 20+ GeV (type 1)

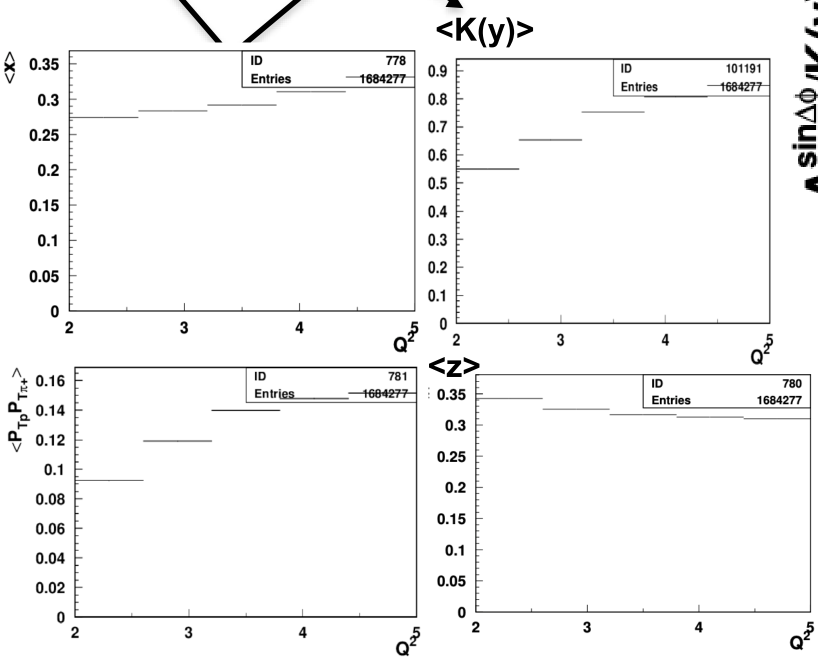
Back to back SSAs in ep→e'pπ+X

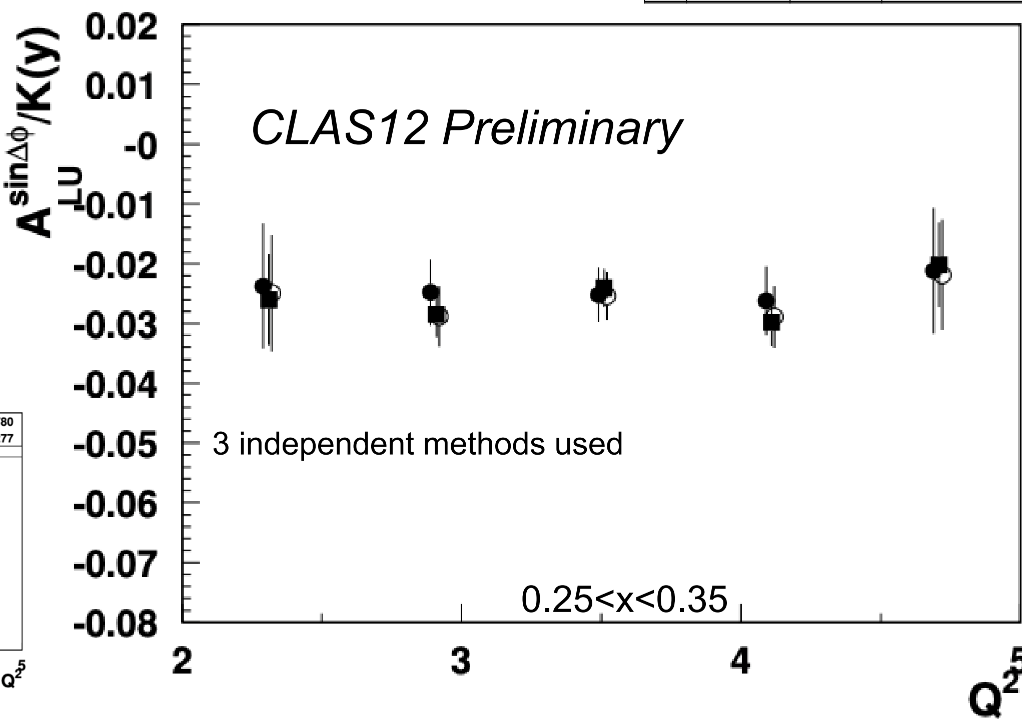
$$ep \to e'p\pi^+X$$



$$\mathcal{A}_{LU} = -\sqrt{1-\epsilon^2}\,\frac{\mathcal{F}_{LU}^{\sin\Delta\phi}}{\mathcal{F}_{UU}}\sin\Delta\phi$$

N/q	U	L	T
U	$\hat{u}_1$	$\hat{l}_1^{\perp h}$	$\hat{t}_1^h, \hat{t}_1^\perp$
L	$\hat{u}_{1L}^{\perp h}$	$\hat{l}_{1L}$	$\hat{t}_{1L}^h, \hat{t}_{1L}^\perp$
T	$\hat{u}_{1T}^h, \hat{u}_{1T}^\perp$	$\hat{l}_{1T}^h, \hat{l}_{1T}^\perp$	$\hat{t}_{1T}, \hat{t}_{1T}^{hh}, \hat{t}_{1T}^{\perp\perp}, \hat{t}_{1T}^{\perp h}$





No significant Q^2-dependence observed for B2B A_{LU}

- First indication in large x SIDIS of a LT observable
- Multidimensional measurements crucial for evolution studies

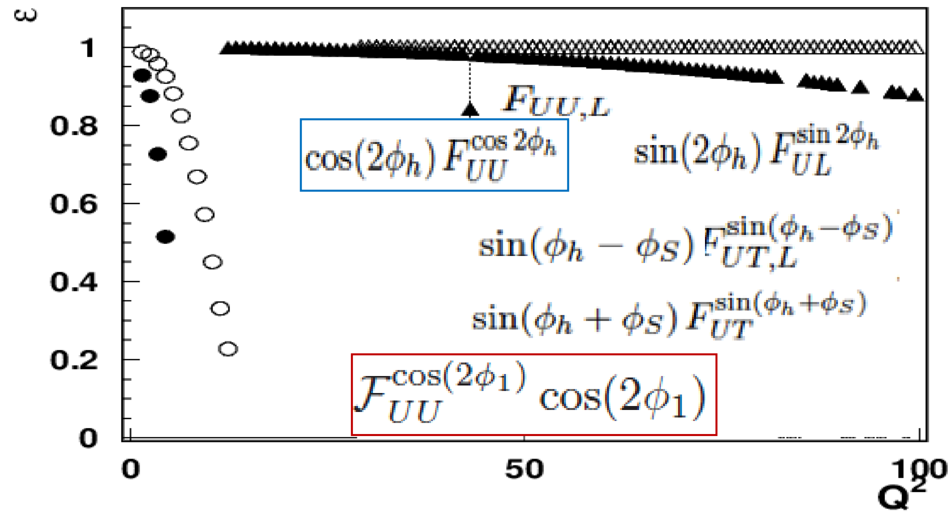
Complementarity between JLab and EIC

$F_{UU,T}$ Multiplicities, evolution of unpolarized SFs

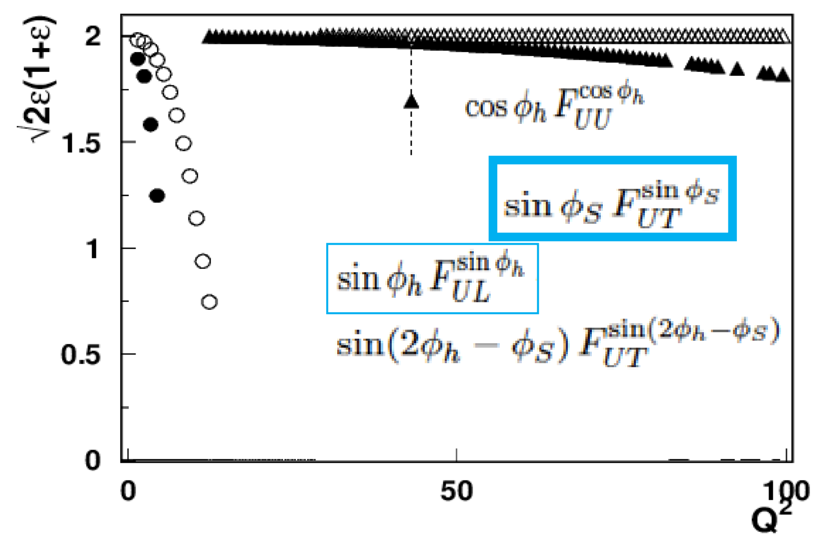
$F_{UT,T}^{\sin(\phi_h-\phi_S)}$ Sivers and Collins SSAs (Transverse target)

$\boxed{\mathcal{F}_{UL}^{\sin(\phi_1-\phi_2)} \sin\Delta\phi}$ Longitudinally polarized Target spin asymmetries in correlations of CFR and TFR (single and dihadron)

Observables with no ε-dependence or not suppressed at low ***y*** provide complementarity set



x=0.3



B2B correlations with long. Pol. Target

N/q	U	L	T
U	$\hat{u}_1$	$\hat{l}_1^{\perp h}$	$\hat{t}_1^h, \hat{t}_1^\perp$
L	$\hat{u}_{1L}^{\perp h}$	$\hat{l}_{1L}$	$\hat{t}_{1L}^h, \hat{t}_{1L}^\perp$
T	$\hat{u}_{1T}^h, \hat{u}_{1T}^\perp$	$\hat{l}_{1T}^h, \hat{l}_{1T}^\perp$	$\hat{t}_{1T}, \hat{t}_{1T}^{hh}, \hat{t}_{1T}^{\perp\perp}, \hat{t}_{1T}^{\perp h}$

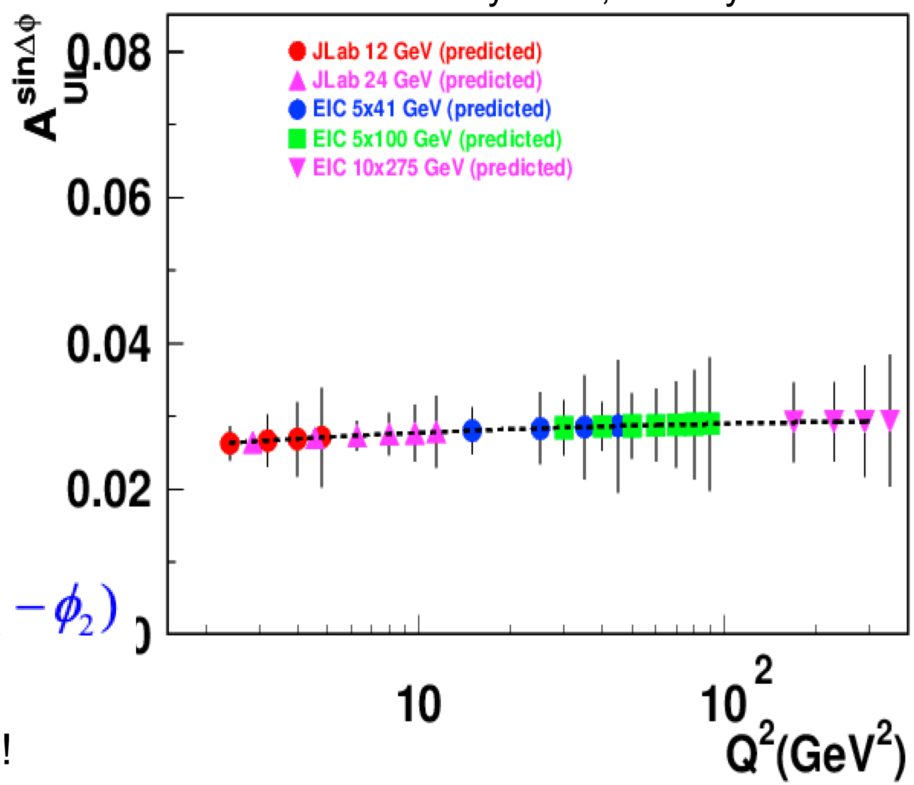
A. Kotzinian, arXiv:1107.2292

$$\sigma_{UU} = F_0^{\hat{u}\cdot D_1}$$

$$\sigma_{UL} = -\frac{P_{T1}P_{T2}}{m_2 m_N} F_{k1}^{\hat{u}_{1L}^{\perp h}\cdot D_1} \sin(\phi_1 - \phi_2)$$

No depolarization, like Sivers!

Lumi: JLab 10^{35}, EIC4x51/5x100/10x275 0.044,0.6,1x10^{34})
y>0.05,100 days



CL AS12 proposals

NH3/ND3
E12-09-009

E12-07-107
E12-09-007A

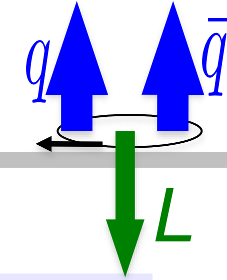
^{3}He
C12-20-002

^{7}LiD

E12-14-001

- Target SSA can be measured in the full Q^2 range, combining different facilities
- Advantages: Higher Lumi for JLab, less suppression at high Q^2 for EIC
- JLab24 will be crucial to bridge the studies of FFs between JLab12 and EIC in the valence region

3D PDFs: Common features



Rodini & Vladimirov, arXiv:2204.03856, J. O. Gonzalez-Hernandez, T. Rogers, N. Sato, arXiv:2205.0575,…

CS kernel discribes the interaction of out-going parton with the confining potential
Provides nonperturbative part of evolution for TMDs

$$Q^2 \frac{dF(x,b;Q)}{dQ^2} = -\left(\frac{\gamma_V(Q)}{2} + \mathcal{D}(b,Q)\right) F(x,b;Q)$$

quark AD
perturbative
known at N^{3}LO

CS kernel
nonperturbative

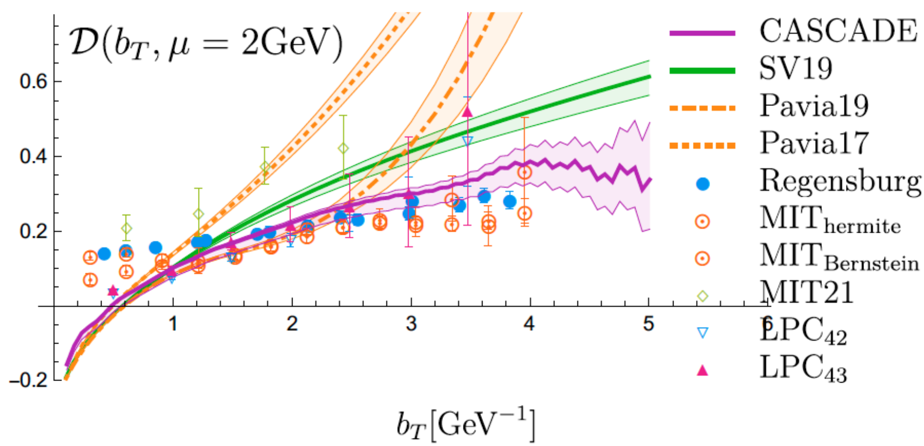
TMD distribution
any tw2
many **tw3**

Includes "e"

nonperturbative Q and x can be factorized

$$F(x,b;Q) = R[\mathcal{D},Q]F(x,b)$$

- R is known function
- $\mathcal{D}$ can de determined directly from data
  - requires dense coverage in p_T
  - requires proper adjustments of (x,z,Q)



The Collins Soper kernel, defining the evolution properties of TMDs related to non-perturbative q-q
Detailed studies of evolution properties of observables in different x-range will be needed

Projections for involved processes

Steps for making transparent, reproducible projections, to convince ourselves, first, before trying to convince others

- Define the cross sections for a given process
  - Collect realistic sets of Structure Functions (to be stored on common disk space)
  - Test with existing data (HERMES/CLAS/….)
  - Test with available full event generators (PYTHIA,…)
- Generate events of interest base on x-section defined by SFs
- Reconstruct particles in a given framework (CLAS12/SoLID/Hall-A/C/D) with actual resolutions and phase space (to be stored on common disk space)
- Make projections of extraction of relevant objects from the reconstructed data sets, with a well documented set of assumptions

Ex. of SIDIS with single hadron production for polarized targets

$$\frac{d\sigma_{\lambda\Lambda}^{eN\to e'hX}}{dx\,dQ^2\,dz\,dP_{hT}^2\,d\phi_h\,d\phi_l\,d\phi_s} = \sum_{l=1}^{L} SF_l$$

Summary

- Measurements of SFs from the azimuthal distributions of final state hadrons in electroproduction, requires high statistics in multidimensional bins (ex. Q^2-dep.)
- JLab has set a task force for preparation of the physics program to motivate the energy upgrade of the JLab to 20+ GeV

- The 3D physics with SIDIS and hard exclusive production processes can provide a set of flagship measurements
  – Measurements superior at JLab24, that are very challenging both at JLab12 and EIC
  – Measurements complementary between JLab12 and JLab24, increasing the coverage for multidimensional binning to large P_T and Q^2, and low x, as well as processes with Kaons
  – Complementarity between JLab12/24 and EIC for evolutions studies at large x,…

<u>Development of a procedure for making transparent and reproducible projections will be important for making a strong case for future experiments, and JLab24 in particular.</u>

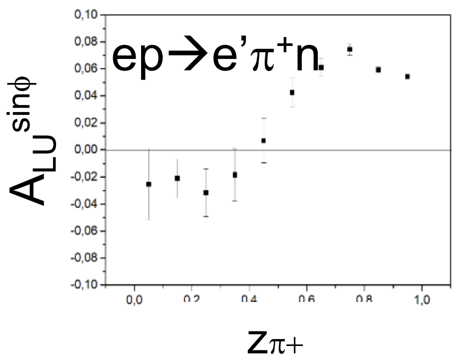
Support slides…

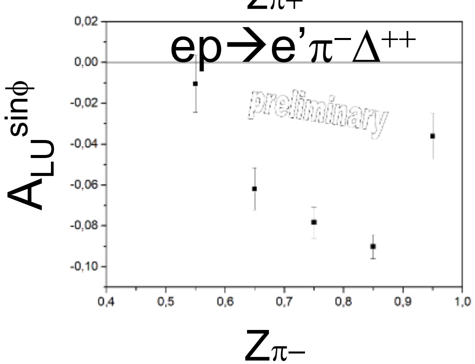
A_{LU}:New look at SSAs in ep→e'πX

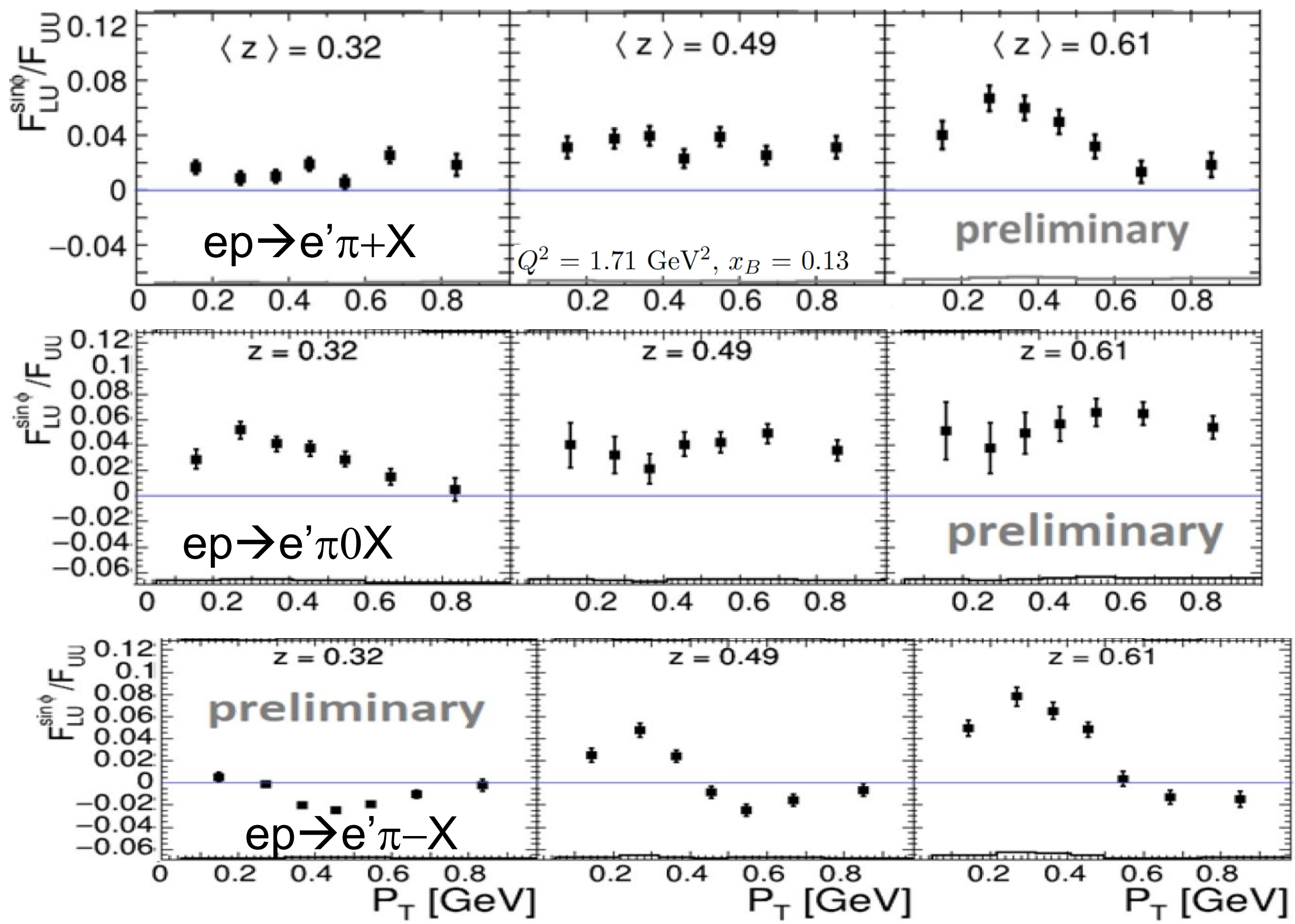
S. Diehl

Higher Twist PDFs

N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

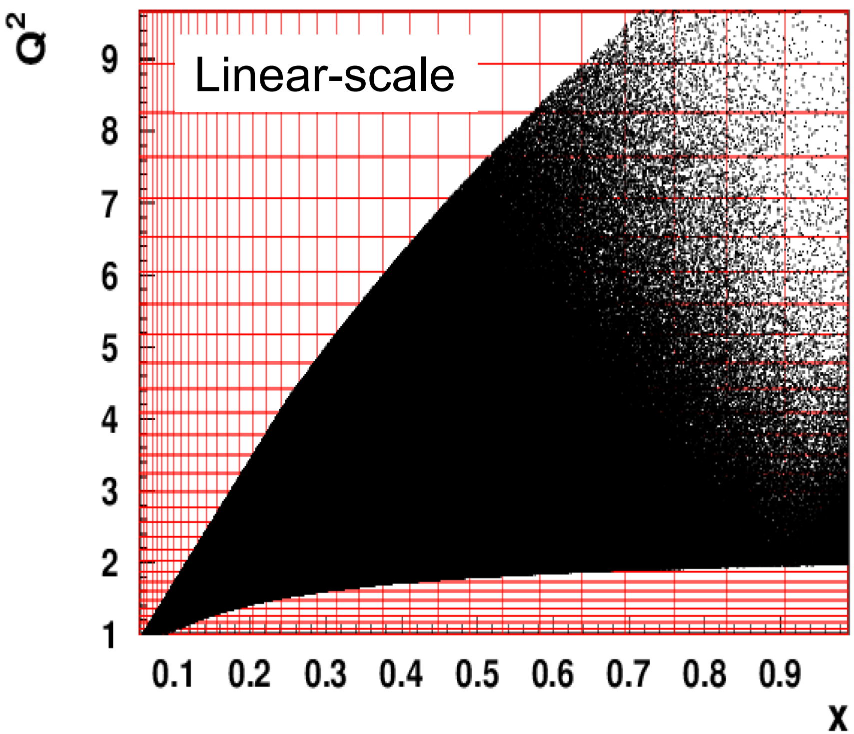


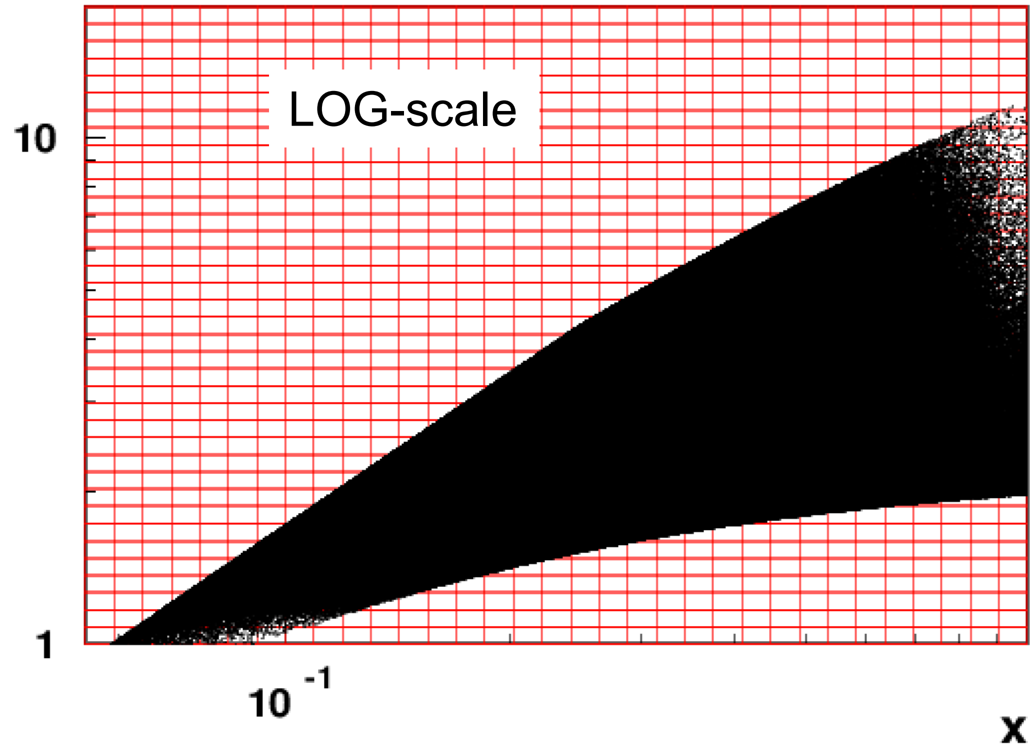




Single beam SSA tends to change the sign, when the observable is dominated by the struck u-quarks.
At small P_T the counts are dominated by VMs coming fro u-quarks

Coverage and binning





Grids for N+1 values from i=0,N

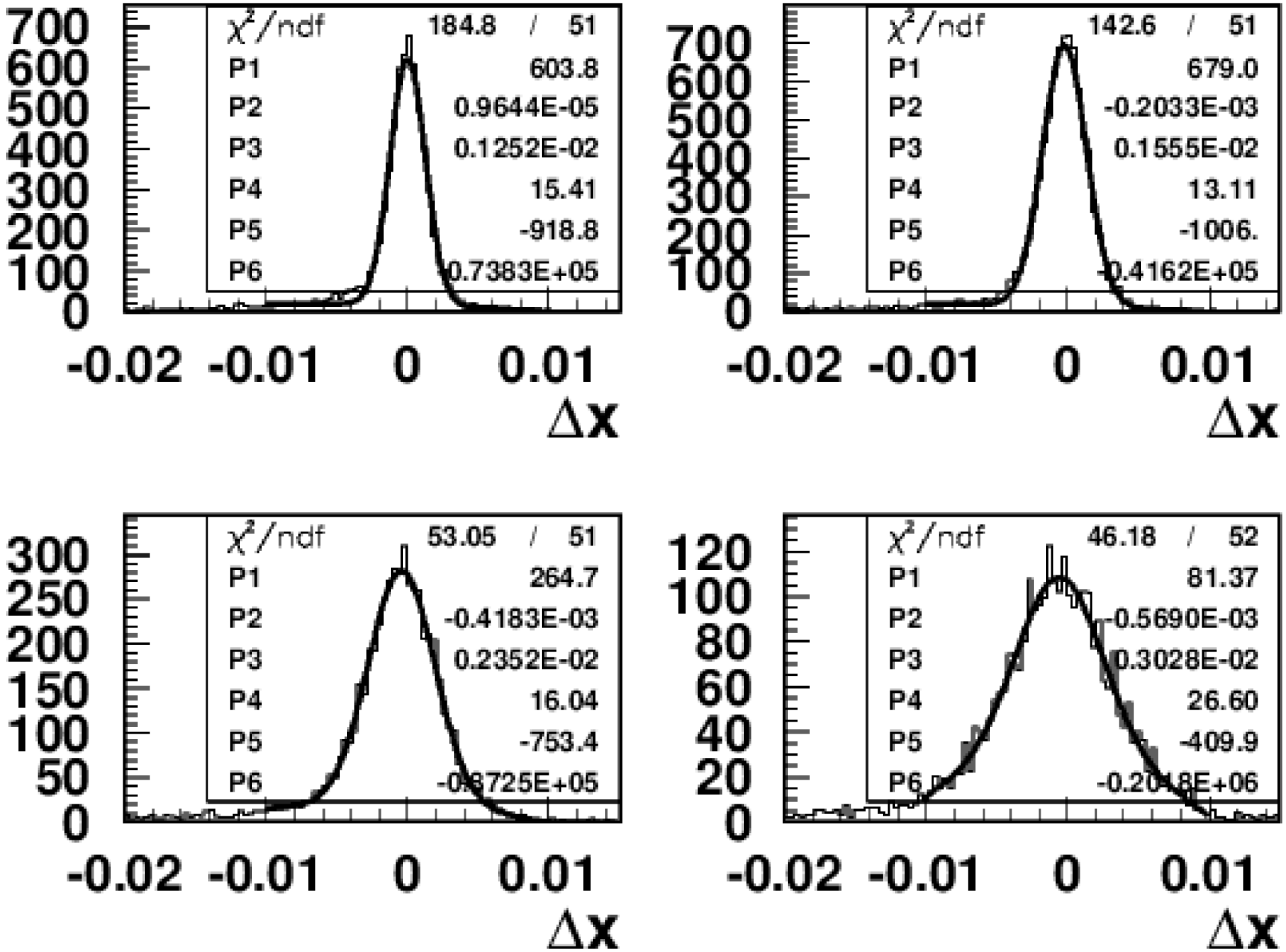
$$\Delta x = ln(x_{max}/x_{min})/N_x$$
$$\Delta Q^2 = ln(Q^2_{max}/Q^2_{min})/N_q$$
$$Q^2_i = Q^2_{min} e^{i\Delta Q^2}$$
$$x_i = x_{min} e^{i\Delta x}$$

$$\Delta z = (z_{max} - z_{min})/(2N_z)$$
$$\Delta P_T = (P_{Tmax} - P_{Tmin})/(2N_P)$$
$$z_i = z_{min} + (2i+1)\Delta z$$
$$P_{Ti} = P_{Tmin} + (2i+1)\Delta P_T$$

N_x=200,N_q=200
N_z=20,N_P=40
x_{min}/x_{max} (0.02 / 0.98)
Q^2_{min}/Q^2_{max}(1.0 / 40)
z_{min}/z_{max} (0.05 / 0.95)
P_{Tmin}/P_{Tmax}(0.0 / 2.0)

Resolutions in x

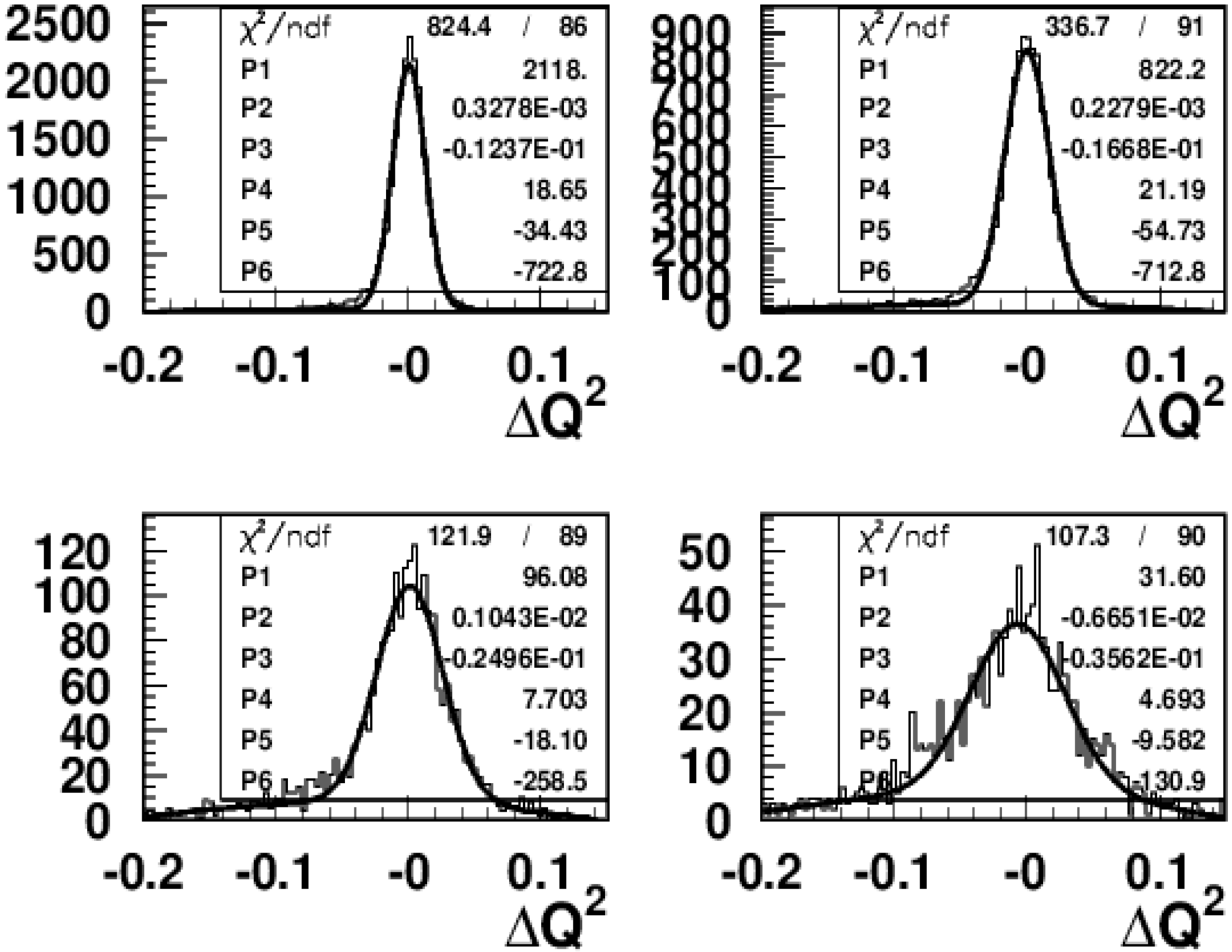
X-bins
0.0540
0.0590
0.0644
0.0704
0.0768
0.0839
0.0917
0.1001
0.1093
0.1194
0.1304
0.1424
0.1555
0.1699
0.1855
0.2026
0.2213
0.2417
0.2639
0.2882
0.3148
0.3438
0.3755
0.4101
0.4479
0.4891
0.5342
0.5834
0.6372
0.6959
0.7600



Bins ~4sigma

Resolutions in Q^2

1.000
1.0814
1.1694
1.2646
1.3675
1.4788
1.5991
1.7292
1.8700
2.0222
2.1867
2.3647
2.5571
2.7652
2.9903
3.2336
3.4968
3.7814
4.0891
4.4219
4.7818
5.1709
5.5917
6.0468
6.5389
7.0711
7.6465
8.2688
8.9418
9.6695
10.4564
11.3074
12.2276
13.2227
14.2988
15.4625
16.7209
18.0816



Bins ~5sigma

Projections for Sivers

arXiv:1208.1244

arXiv:1212.1701

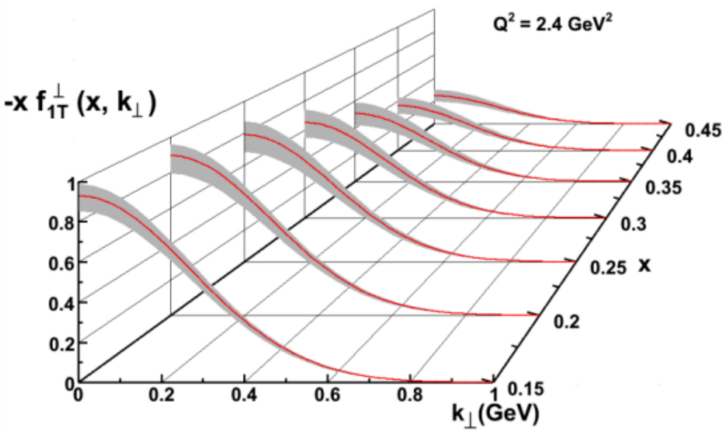


Figure 3.4 The Sivers function for the up quark as a function of $k_\perp$ at different values of x as determined by analysis of JLab 12 pseudo data generated for ^{3}He target. The central line is the model profile of [3-35]; real Jefferson Lab 12 GeV data will eventually reveal the actual shape of the distribution. The error bands have been projected about the model profile.

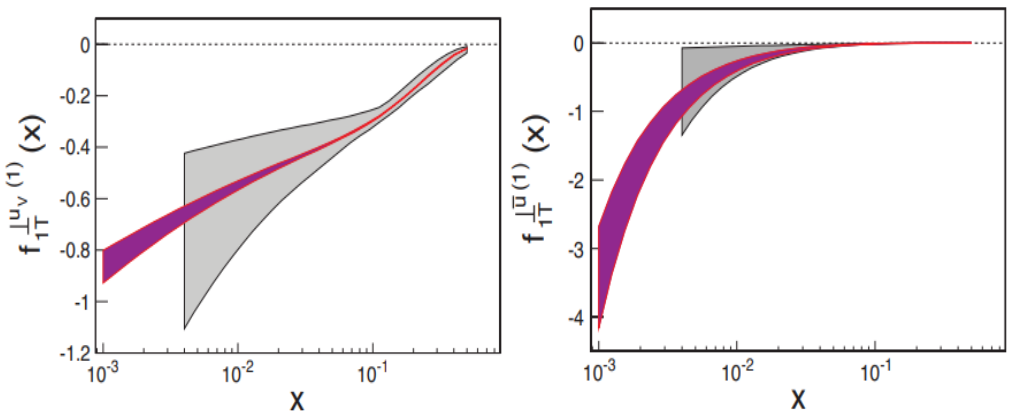
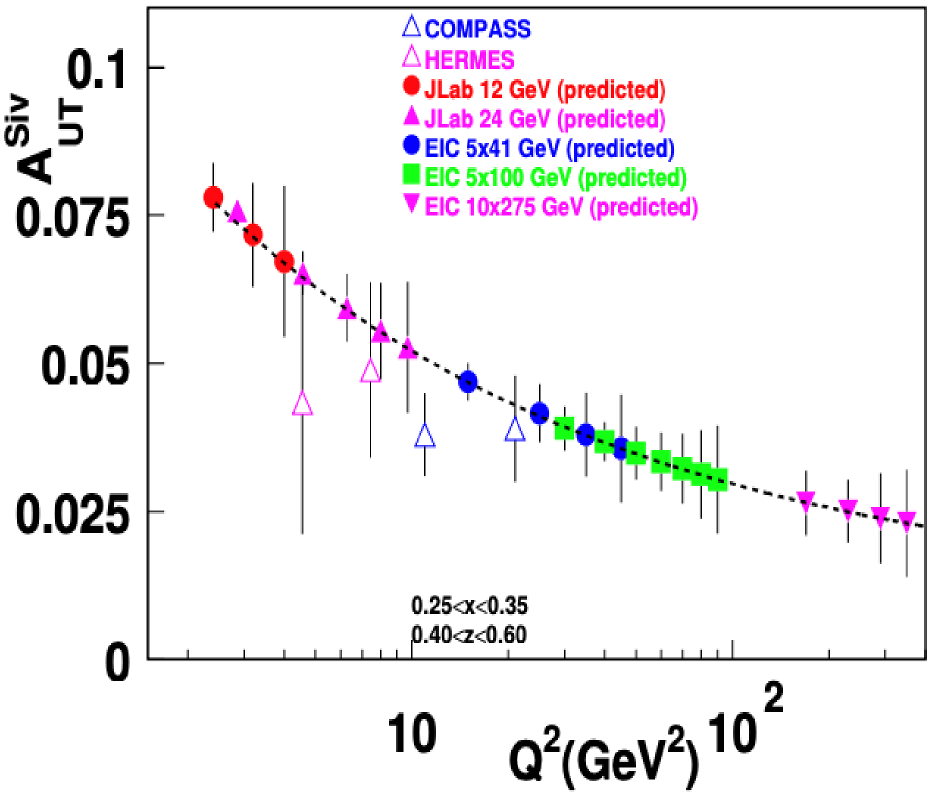


Figure 2.16: Comparison of the precision (2-σ uncertainty) of extractions of the Sivers function for the valence (left) $u_v = u - \bar{u}$ and sea (right) $\bar{u}$ quarks from currently available data [77] (grey band) and from pseudo-data generated for the EIC with energy setting of $\sqrt{s} = 45$ GeV and an integrated luminosity of 10 fb^{-1} (purple band with a red contour). The uncertainty estimates are for the specifically chosen underlying functional form.

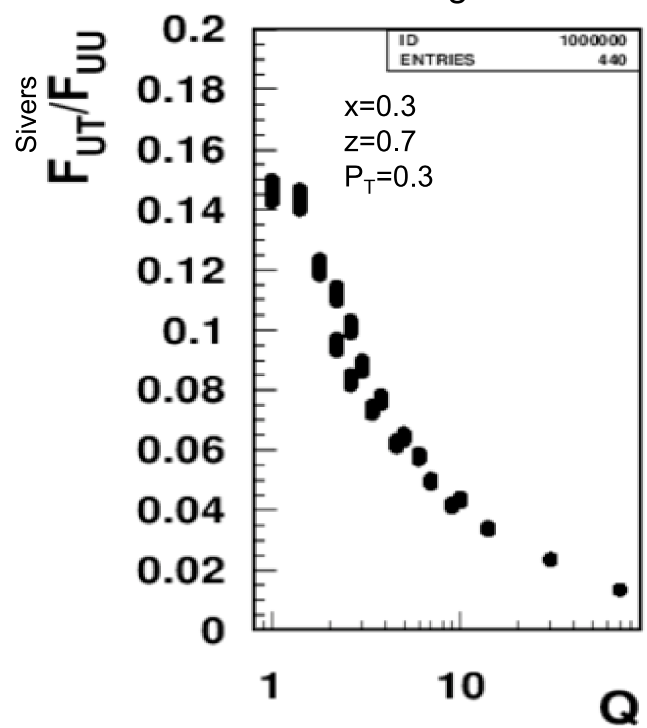
Contributions for 3D structure studies: Sivers

y>0.05,100 days (corrected for EIC official lumi)

H.A./C.Pecar/A.Vossen



Pavia grids

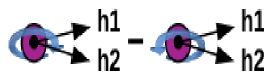


At large z drops faster

- Measurements of Q^2-dependence of SSAs will be crucial in validation of the theory
- JLab24 will be crucial to bridge the TMD studies between JLab12 and EIC in the valence region

Observation of SSAs in ep→e'$\pi^+\pi^-$X

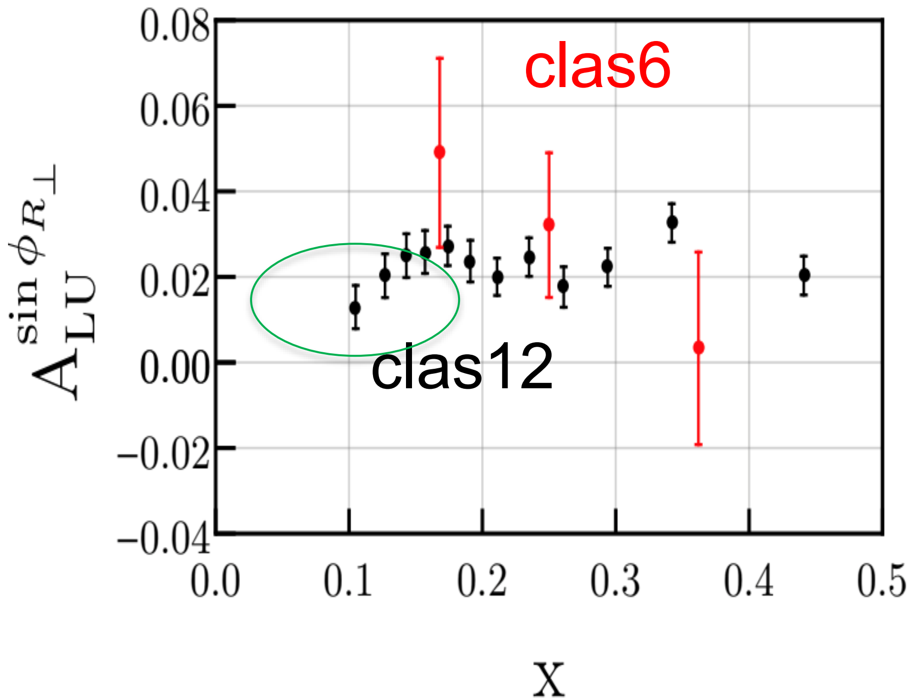
T. Hayward et al. Phys. Rev. Lett. 126, 152501 (2021)

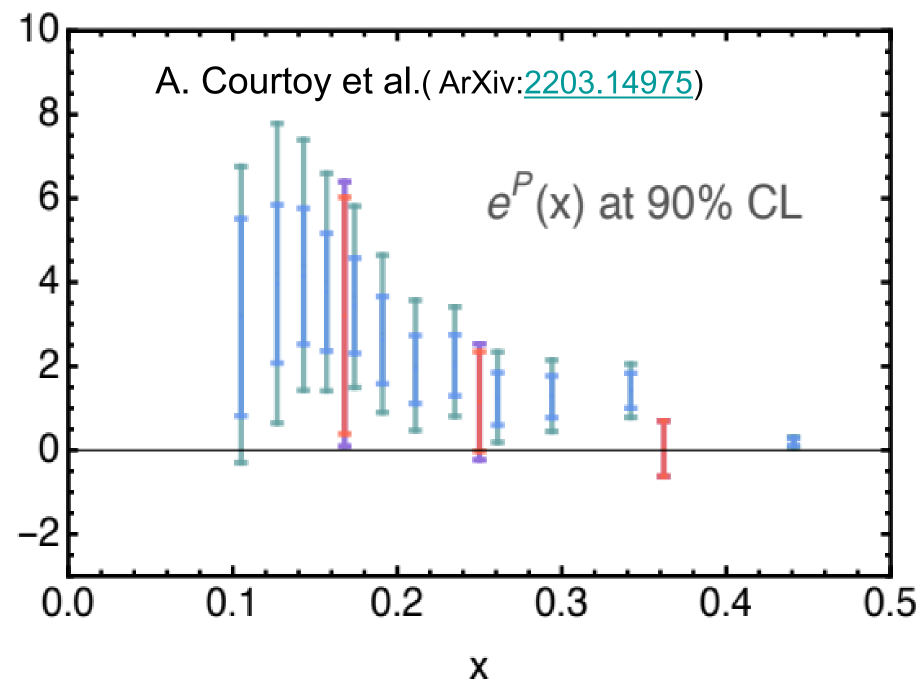
$H_1^{\sphericalangle}$ = 

$$d\sigma_{LU} \propto \lambda_e \sin(\phi_{R_\perp}) \left(x e(x) H_1^{\sphericalangle}(z, M_h) + \frac{1}{z} f_1(x) \tilde{G}^{\sphericalangle}(z, M_h) \right)$$

Bacchetta&Radici: arXiv:hep-ph/0311173

evolution→Rodini & Vladimirov, arXiv:2204.03856





- Doubling the JLab beam energy, opens the phase space for SIDIS dihadrons (low x)
- First extractions support: quark gluon correlations may be very significant,
- PDF e describes the force on the transversely polarized quark after scattering, factorization and evolution studies by Vladimirov et al (in preparation)

TMD extractions, parameterizations, grids

Important note from theorists: parametrizations should be used in the kinematics they are applicable. Validations mostly done for given Fragmentation Functions, by variations of experimental data within errors(TMD extraction talks).

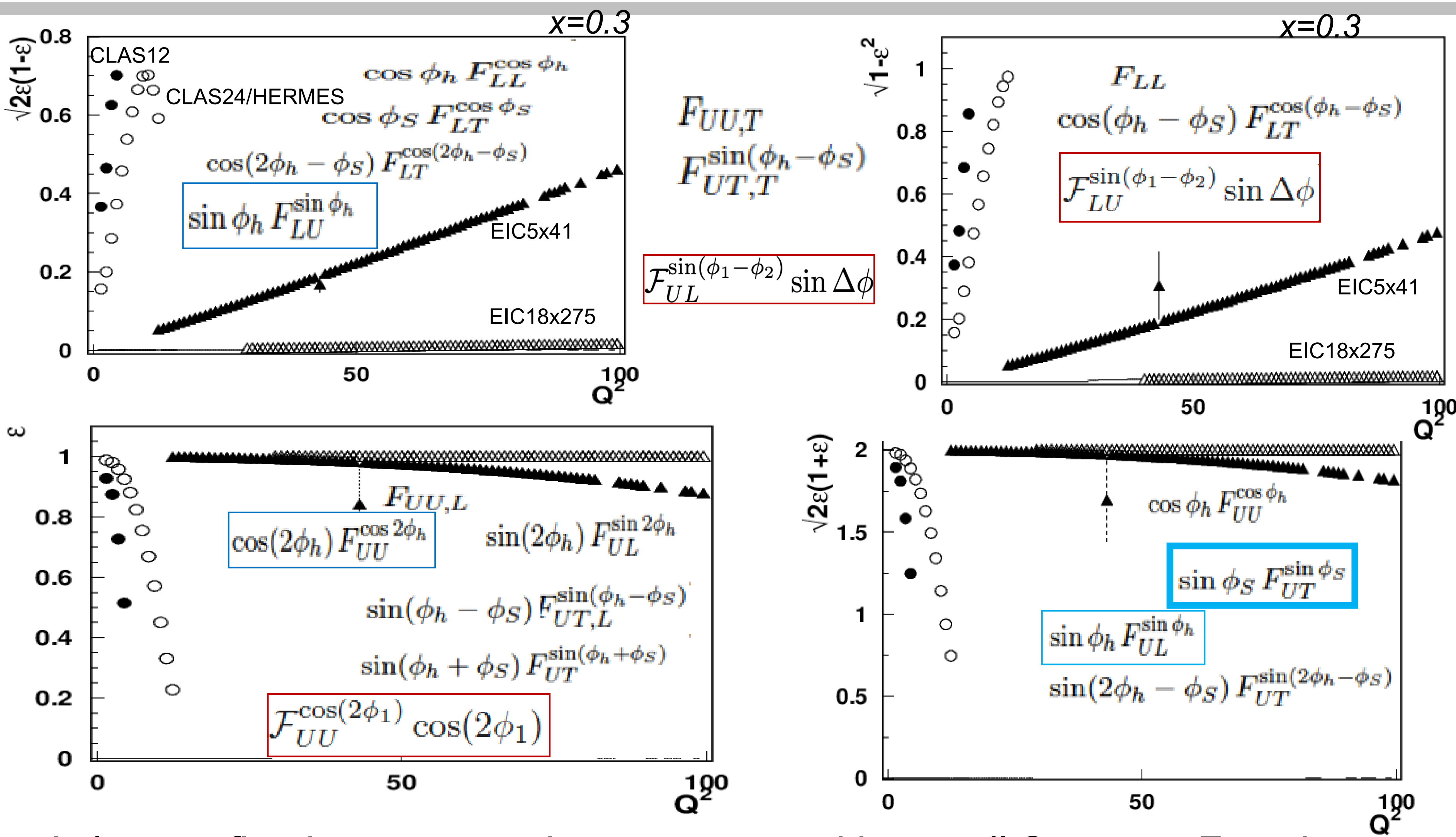
How to validate the TMD parameterization in 3D (discussion session):

- Compare kinematic dependences with new data (ex. P_T,Q^2-dependences)
- Compare kinematical dependences with direct calculations and lattice
- Compare kinematical dependences with other extractions
- Compare kinematical dependences with QCD inspired model predictions
- Common sense & intuition about non-perturbative kinematics

Use MC validation: generate pions with probabilities from extracted SFs for a given experiment, including the RC and compare multiplicities and SSAs with a given experiment (accounting phase space limitations & correlations between variables)

$$F^h_{XY}(x,z,P_T,Q^2) \propto \sum H^q \times f^q(x,k_T,..) \otimes D^{q\to h}(z,p_T,..) + Y(Q^2,P_T) + \mathcal{O}\big(M/Q\big)$$

SIDIS: Kinematic factors at large x



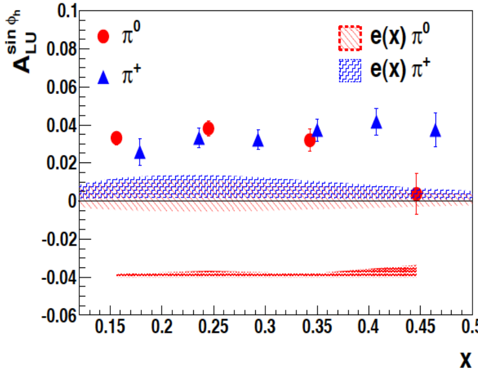
- At large x fixed target experiments are sensitive to all Structure Functions
- For EIC, observables surviving the $\varepsilon \to 1$ limit (F_{UU}, F_{UL}, Transversely pol. F_{UT})

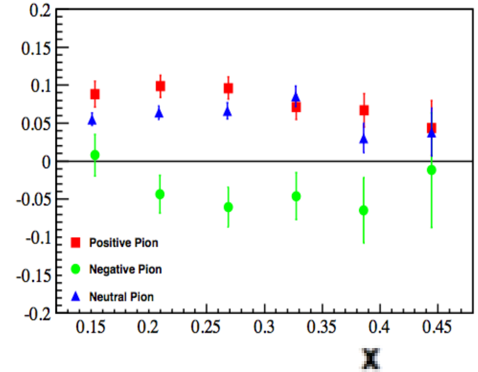
Quark-gluon correlations: flavor dependence

Higher Twist PDFs

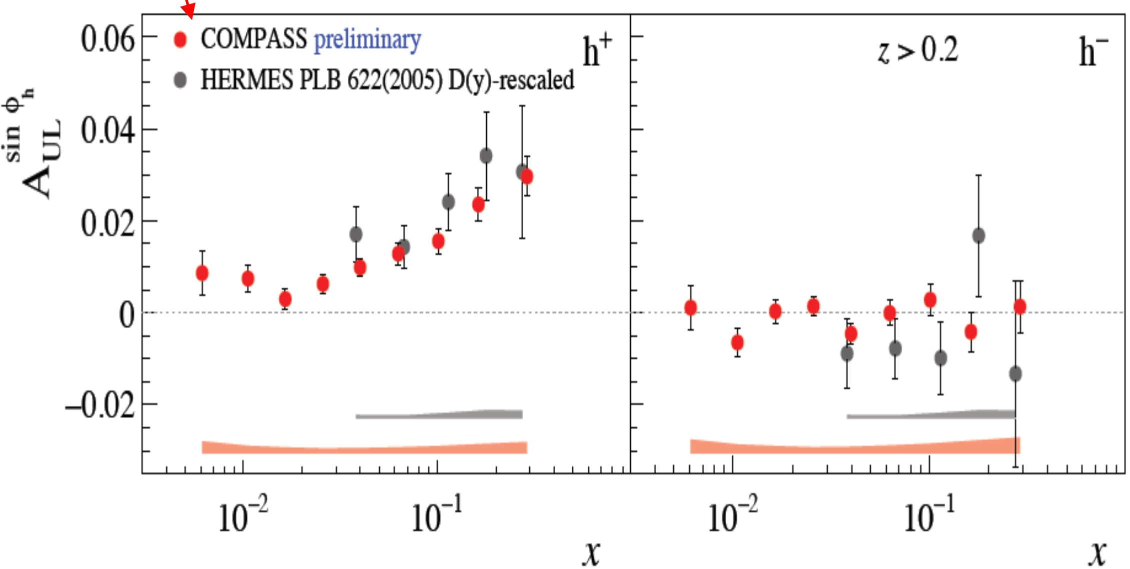
N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

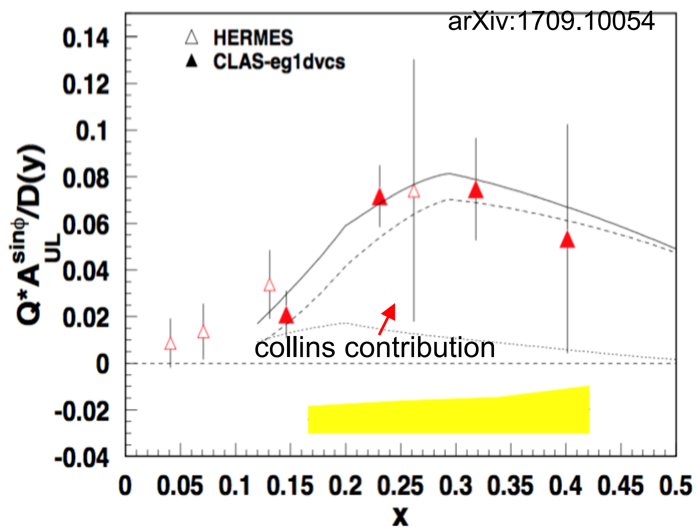
1) roughly equal $\pi^+\pi^0$ SSA
2) π^- SSA much smaller, consistent with 0 or<0





CLAS/HERMES



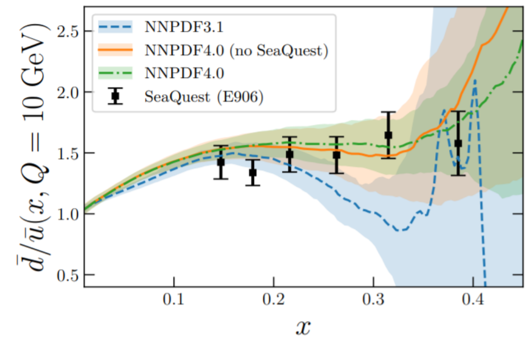


- Significant longitudinal beam and target SSA measured at HERMES, JLab and COMPASS may be related to higher twist distribution functions
- $\sin\phi$ modulations for $\pi^+\pi^0$ consistent with dominance of Sivers mechanism
- Subleading asymmetries comparable with leading ones (1/Q terms should be accounted)

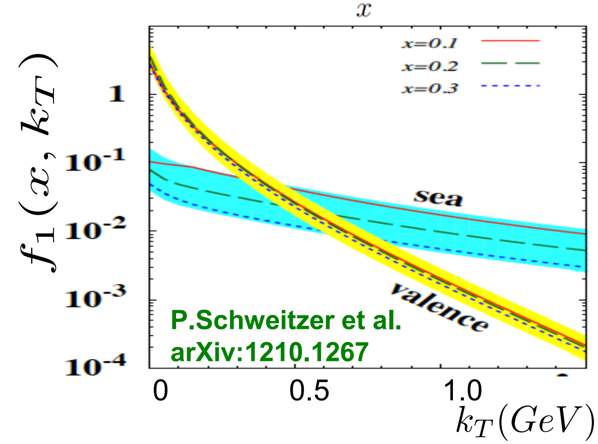
Non-perturbative contributions

Non-perturbative sea ("tornado"/$^3P_0$) in nucleon is a key to understand the nucleon structure

$$\bar{d} > \bar{u}$$

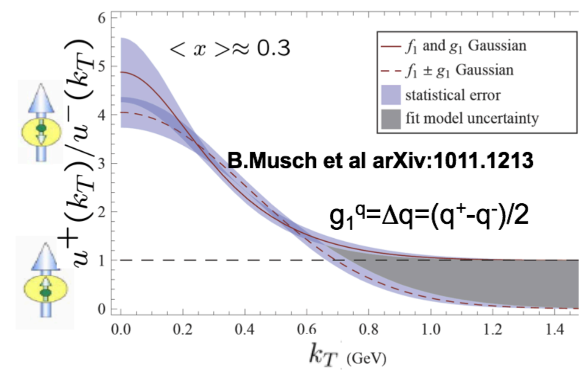


- Spin-Orbit correlations so far were shown (measurements and model calculations) to be significant in the region where non-perturbative effects dominate (x>0.02)
- Large transverse momenta of hadrons most relevant for understanding the non-perturbative QCD dynamics

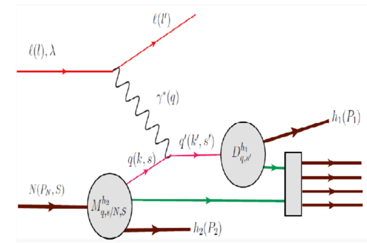


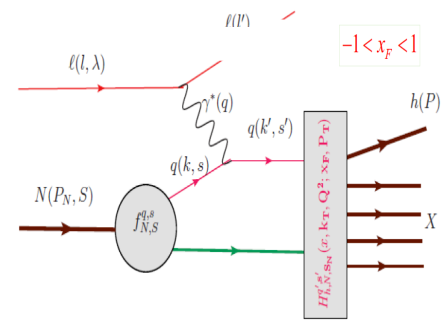
- Predictions from dynamical model of chiral symmetry breaking [Schweitzer, Strikman, Weiss JHEP 1301 (2013) 163]

  -- k_T (sea) >> k_T (valence)
  -- short-range correlations between partons (small-size q-qbar pairs)
  -- may be directly observable in P_T-dependence of hadrons in SIDIS



Hard scattering in e'hX and e'hhX



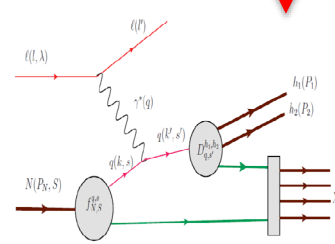


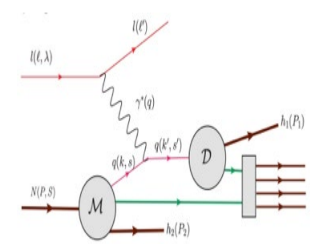
- A single-hadron MC with the SIDIS cross-section where widths of k_T-distributions of pions are extracted from the data is not reproducing well the data.
- LUND fragmentation based MCs were successfully used worldwide from JLab to LHC, showing good agreement with data.

LUND-MCs are more successful in description of hard scattering processes, and SIDIS in the first place.

- The hadronization into different hadrons, in particular Vector Mesons is accounted (full kinematics)
- Accessible phase space properly accounted
- The correlations between hadrons, as well a as target and current fragments accounted
- ….

subsamples





To understand the measurements we should be able to simulate, at least the basic features we are trying to study (P_T and Q^2,-dependences in particular)

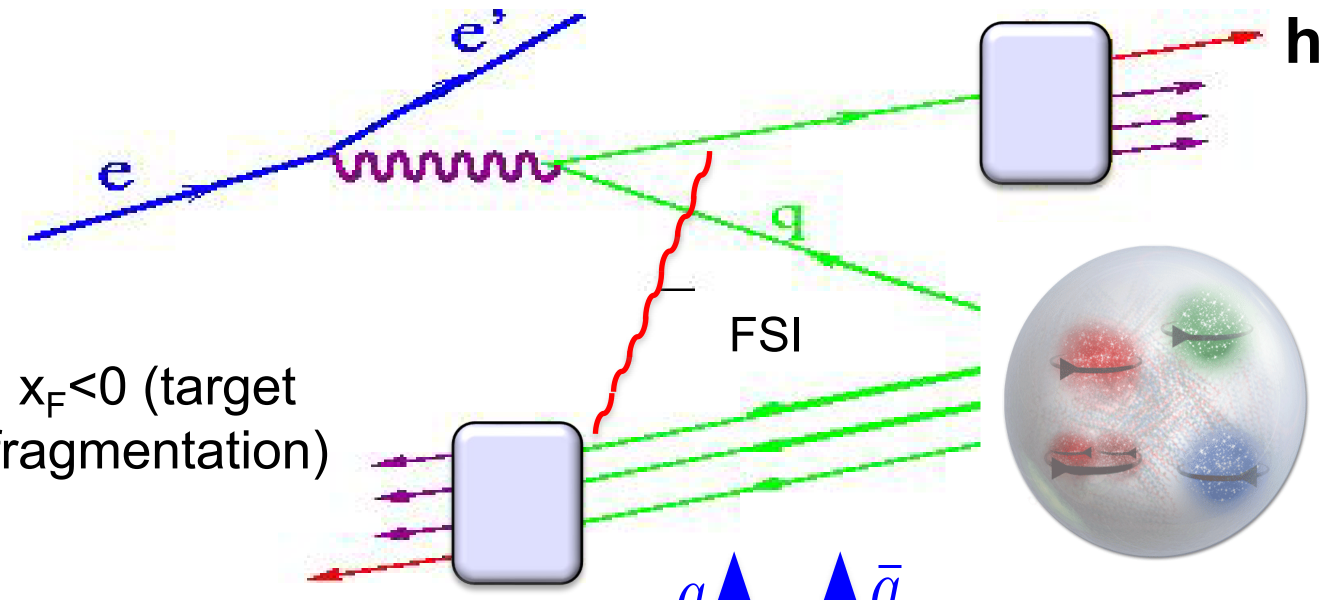
The studies of correlated hadron pairs in SIDIS may be a key for proper interpretation !!!

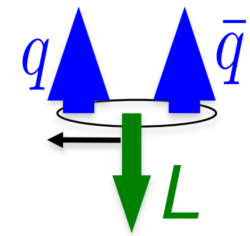
Hadron production in hard scattering

x_F – fractional momentum in the CM frame

$x_F>0$ (current fragmentation)

X. Artru & Z. Belghobsi

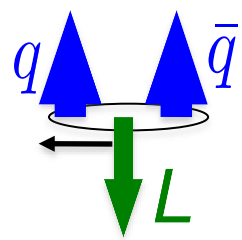




$x_F<0$ (target fragmentation)

2-hadron correlations in CFR studied in EMC(1986) and COMPASS(2015) CLAS12(2021)

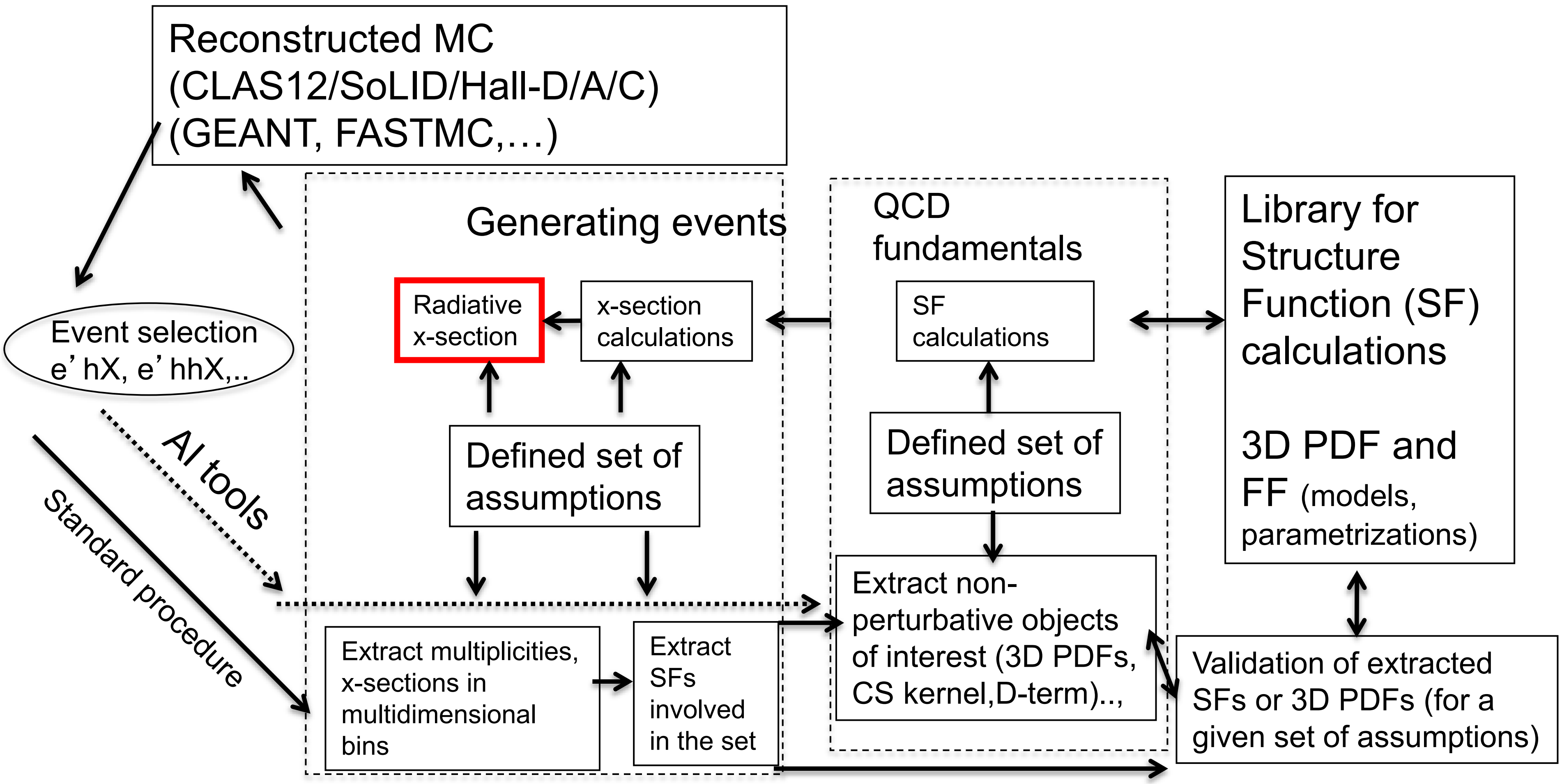
Karliner, Kharzeev , Ellis & Kotzinian
Strikman,Weiss & Schweitzer
Anselmino, Barone, Kotzinian



x_F - momentum in the CM frame

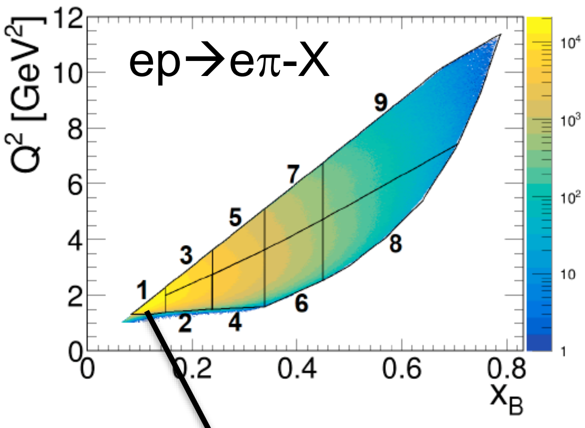
Correlations of the spin of the target or/and the momentum and the spin of quarks, combined with final state interactions define the azimuthal distributions of produced particles

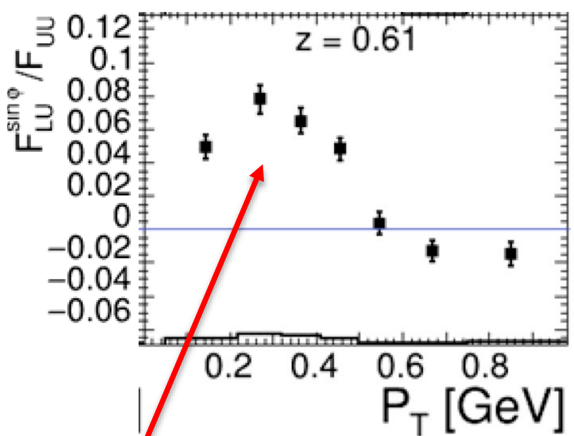
Framework: from SFs to projections



A procedure for realistic and reproducible projections for non-perturbative objects of interest (3D PDFs, FFs,FrF,…) from the multidimensional experimental observables with controlled systematics could be used by all interested

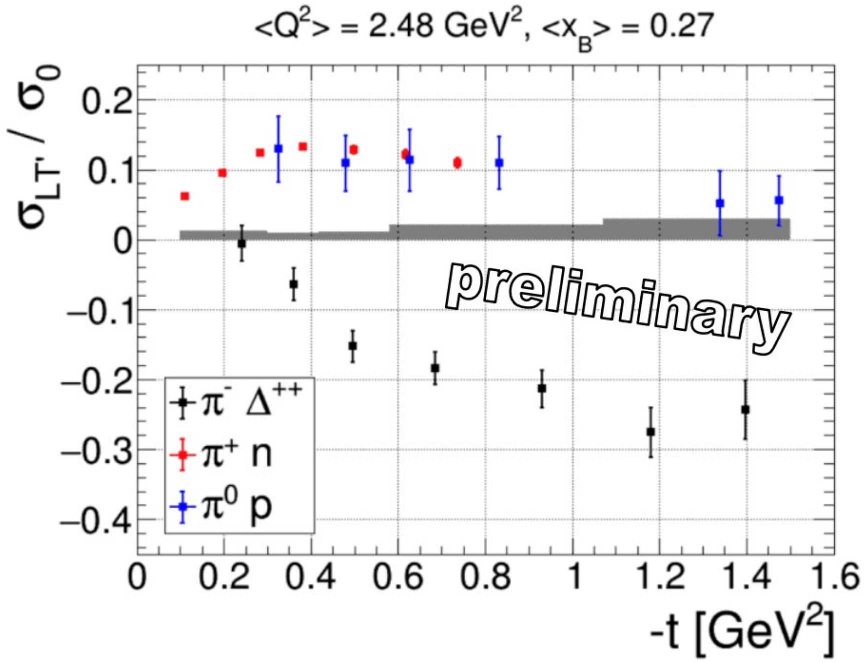
Multidimensional measurements





Low P_T dominated by VM decays from u-quarks

Beam SSAs as a tool to access the longitudinally polarized quarks



π- has sensitivity to polarized d-quarks, but require multidimensional measurements

From CLAS12 to CLAS24: Trento and focused workshops

ECT* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS
FONDAZIONE BRUNO KESSLER

Opportunities with JLab Energy and Luminosity Upgrade

Sep 26 – 30, 2022
ECT* - Villa Tambosi
Europe/Rome timezone

https://indico.ectstar.eu/event/126/

Physics Items

a)Measurements of evolution of 3D partonic distribution and fragmentation functions
b) Correlated hadrons and their impact on hadronization
c) Studies of 3D PDFs using combination of the Lattice QCD with the phenomenology and QCD based modeling needed for interpretation of the experimental data, and development of new observables.
d) Advances in the exploration of the structure of excited nucleon states.
e) In-medium modifications of fundamental QCD processes
f) Studies of light meson structure
g) Charm production near the threshold
h) Spectroscopy at the intensity frontier
i) Large x physics
j) Electroweak Physics at 24~GeV

Messina Workshop

Organizers

Harutyun Avagyan (Jefferson Lab, Newport News/US)
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John Arrington (Lawrence Berkeley National Laboratory, Berkeley/US)
JArrington@lbl.gov
Alessandro Bacchetta (Pavia University, Pavia/I)
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Kyungseon Joo (University of Connecticut (UConn), Storrs/US)
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Xiaochao Zheng (University of Virginia (UVa), Charlottesville/US)
xiaochao@jlab.org

Key speakers/physics items

1) Jianwei Qiu (QCD)
2) Jen-Chieh Peng (non-perturbative sea)
3) Pasquale Dinezza (the LHC fixed target experiments, large x)
4) Simonetta Liuti (GPDs)
5) Marco Battaglieri, Alessandro Pilloni (spectroscopy)
6) Moskov Amaryan/ Goldstein (charm)
7) Lubomir Penchev (Hall-D physics/detectors)
8) Ralf Gothe (Hall-B physics/detectors)
9) Jiang-Ping Chen (Hall-A/C physics/detectors)
10) Eric Voutie (positron beam)
11) Carlos Munoz Camacho (exclusive processes)
12) Gunar Schnell/Marco Contalbrigo (HERMES)
13) Moretti/Parsamyan (COMPASS)
14) Signori/Vladimirov/Yuan (TMDs)
15) Yong Zhao/Martha Constantinou (Lattice studies)
16) Misak Sargsian (Medium effects/theory)
17) Lamiaa el Fassi (Medium effects/experiment)
18) Barbara Pasquini (GTMDs)
19) Anselm Vossen (Complementarity with EIC)

Set of dedicated workshops/meeting to develop projections

Observation of SSAs in ep→e'$\pi^+\pi^-$X

evolution→Rodini & Vladimirov, arXiv:2204.03856

	U	L	$T_{J=0}$	$T_{J=1}$	$T_{J=2}$
U	$f_\bullet^\perp$	$g_\bullet^\perp$		$h_\bullet$	$h_\bullet^\perp$
L	$f_{\bullet L}^\perp$	$g_{\bullet L}^\perp$	$h_{\bullet L}$		$h_{\bullet L}^\perp$
T	$f_{\bullet T}$, $f_{\bullet T}^\perp$	$g_{\bullet T}$, $g_{\bullet T}^\perp$	$h_{\bullet T}^{D\perp}$	$h_{\bullet T}^{A\perp}$	$h_{\bullet T}^{S\perp}$, $h_{\bullet T}^{T\perp}$

Table 1. Quark TMD distributions of twist-three sorted with respect to polarization properties of both the operator (columns) and the hadron (rows). The labels U, H, and T are for the unpolarized, longitudinal and transverse polarizations. The subscript J differentiates different angular momentum for the transversely-polarized case. The bullet $\bullet$ stands for the $\oplus$, $\ominus$ labels.

$$\mu^2\frac{d}{d\mu^2}e = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)e\ ,$$

$$\mu^2\frac{d}{d\mu^2}e_T^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)e_T^\perp\ ,$$

$$\mu^2\frac{d}{d\mu^2}e_L = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)e_L\ ,$$

$$\mu^2\frac{d}{d\mu^2}e_T = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)e_T\ ,$$

$$\mu^2\frac{d}{d\mu^2}f_T = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)f_T - \frac{2a_sC_F}{x}\left(f_{1T}^\perp + \frac{b^2M^2}{2}\mathring{f}_{1T}^\perp\right)\ ,$$

$$\mu^2\frac{d}{d\mu^2}f_L^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)f_L^\perp\ ,$$

$$\mu^2\frac{d}{d\mu^2}f^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)f^\perp + \frac{2a_sC_F}{x}\mathring{f}_1\ ,$$

$$\mu^2\frac{d}{d\mu^2}f_T^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)f_T^\perp + \frac{2a_sC_F}{x}\mathring{f}_{1T}^\perp\ ,$$

$$\mu^2\frac{d}{d\mu^2}g_T = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)g_T + \frac{2a_sC_F}{x}\left(g_{1T} + \frac{b^2M^2}{2}\mathring{g}_{1T}\right)\ ,$$

$$\mu^2\frac{d}{d\mu^2}g_L^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)g_L^\perp + \frac{2a_sC_F}{x}\mathring{g}_1\ ,$$

$$\mu^2\frac{d}{d\mu^2}g^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)g^\perp\ ,$$

$$\mu^2\frac{d}{d\mu^2}g_T^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)g_T^\perp + \frac{2a_sC_F}{x}\mathring{g}_{1T}\ ,$$

$$\mu^2\frac{d}{d\mu^2}h_T^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)h_T^\perp + \frac{2a_sC_F}{x}\left(\mathring{h}_1 - h_{1T}^\perp - \frac{b^2M^2}{4}\mathring{h}_{1T}^\perp\right)\ ,$$

$$\mu^2\frac{d}{d\mu^2}h = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)h - \frac{4a_sC_F}{x}\left(h_1^\perp + \frac{b^2M^2}{2}\mathring{h}_1^\perp\right)\ ,$$

$$\mu^2\frac{d}{d\mu^2}h_L^\perp = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)h_L^\perp - \frac{2a_sC_F}{x}\left(h_{1L}^\perp + \frac{b^2M^2}{4}\mathring{h}_{1L}^\perp\right)\ ,$$

$$\mu^2\frac{d}{d\mu^2}h_T = \left(\frac{\Gamma_{\rm cusp}}{2}\ln\left(\frac{\mu^2}{\zeta}\right)+a_sC_F\right)h_T - \frac{2a_sC_F}{x}\left(\mathring{h}_1 + h_{1T}^\perp + \frac{b^2M^2}{4}\mathring{h}_{1T}^\perp\right),$$


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