3D partonic hadron structure from experimental measurement and lattice QCD calculations

Introduction

–Dissecting the SIDIS ep→e'pX, ep→e'π+X, ep→e'pπ+X, ep→e'$\pi^+\pi^-$X

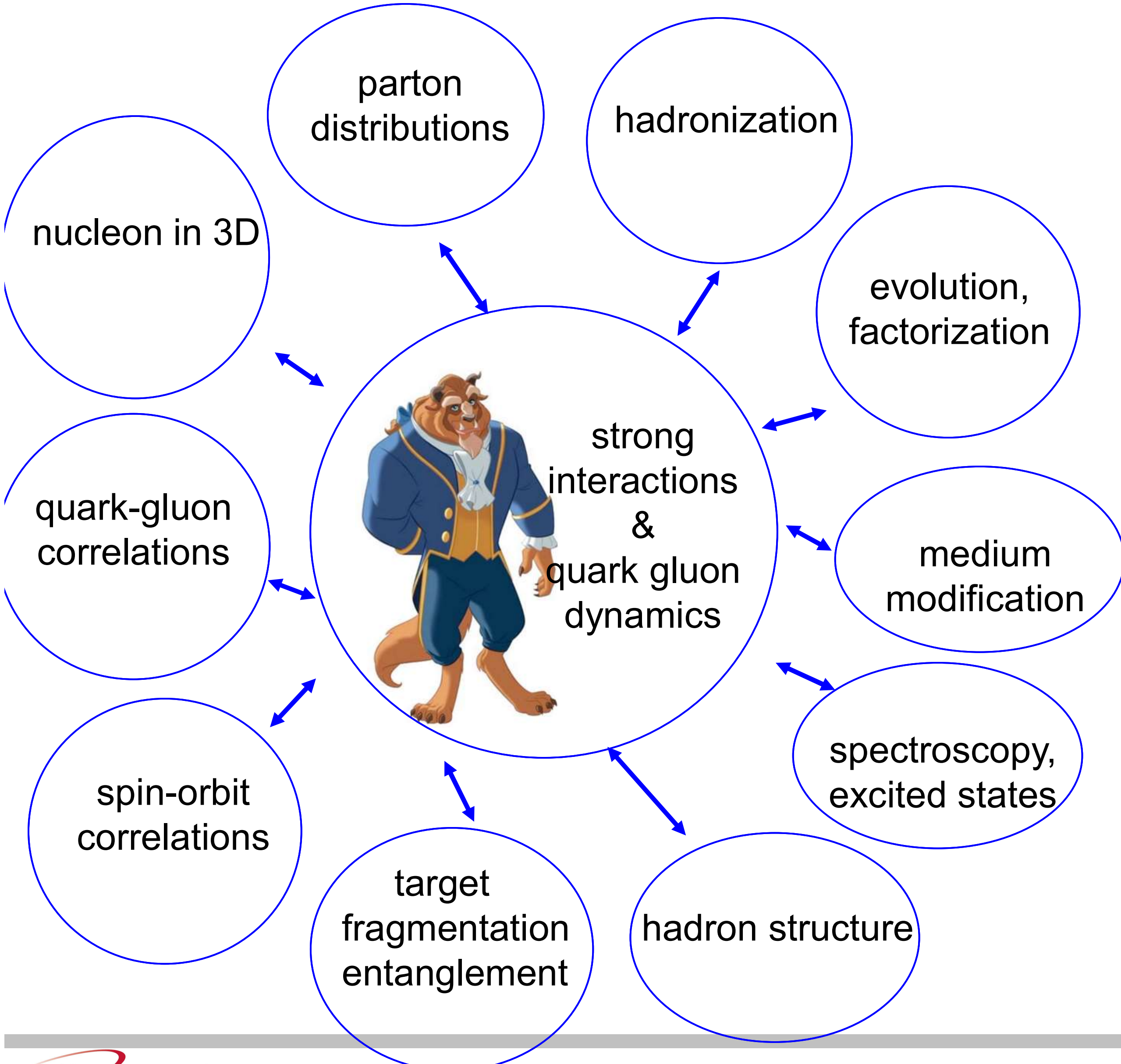
–Separating the kinematics of current and target fragmentation

–Separating dynamical contributions in exclusive and semi-inclusive processes

– Future plans

Summary

QCD: from testing to understanding

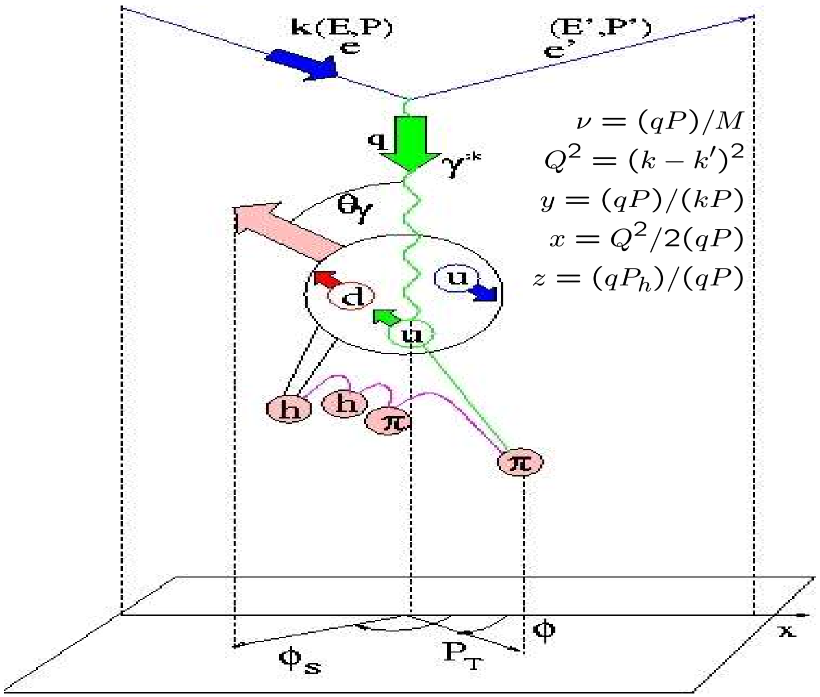


Testing stage:
pQCD predictions, observables in the kinematics where theory predictions are easier to get (higher energies, 1D picture, leading twist, IMF)

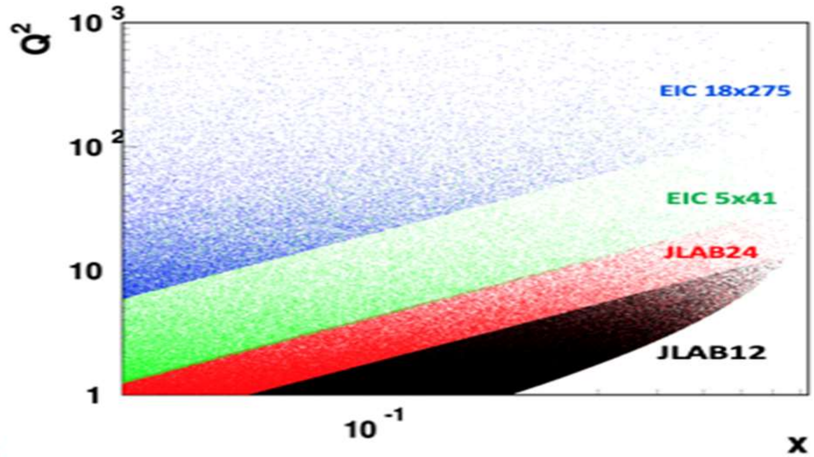
⇩

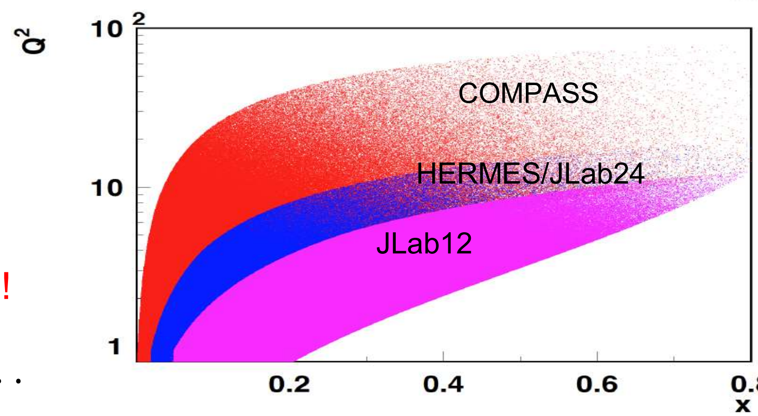
Understanding stage:
non-perturbative QCD, observables in the real life kinematics where most of the data is available and interactions are strong (more complex observables revealing details of the dynamics,…)

SIDIS kinematical coverage and observables



EIC

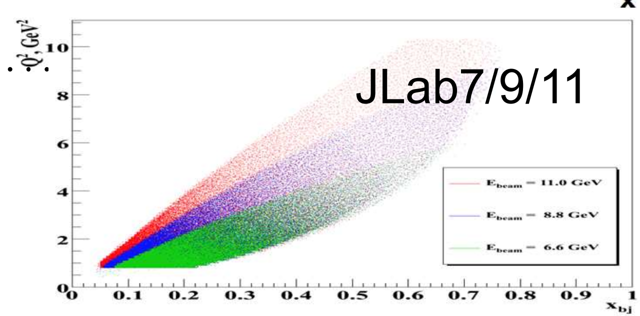




Experiments measure azimuthal dependence of the cross section!!!

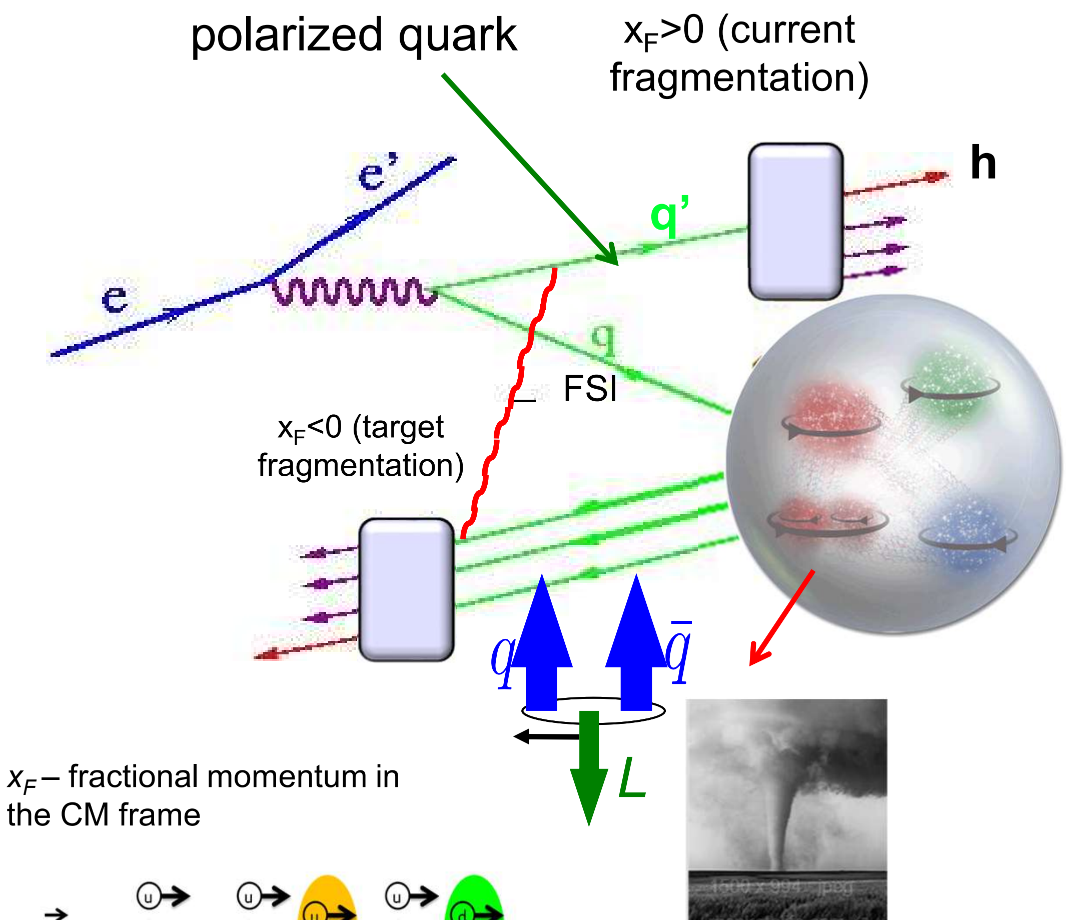
$$\sigma \propto F_{UU} + P_b\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi + P_t\epsilon F_{UL}^{\sin 2\phi}\sin 2\phi + \ldots$$

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

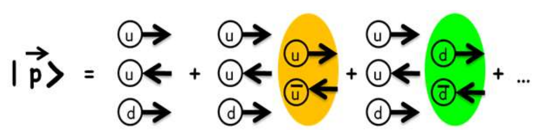


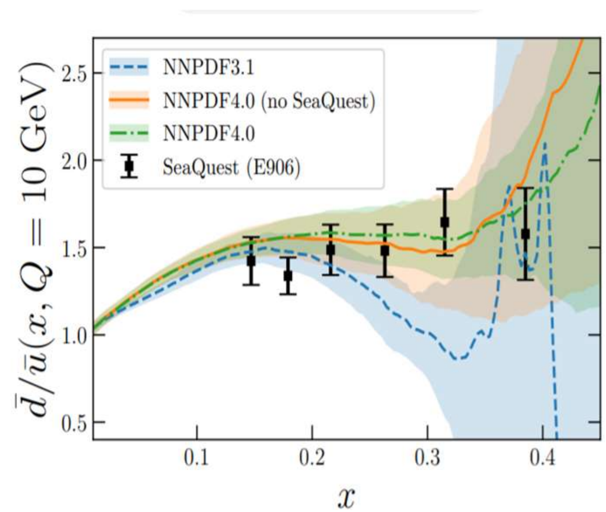
- Studies of azimuthal modulations give access to underlying 3D partonic distributions
- QCD predicts only the Q^2-dependence of 3D PDFs

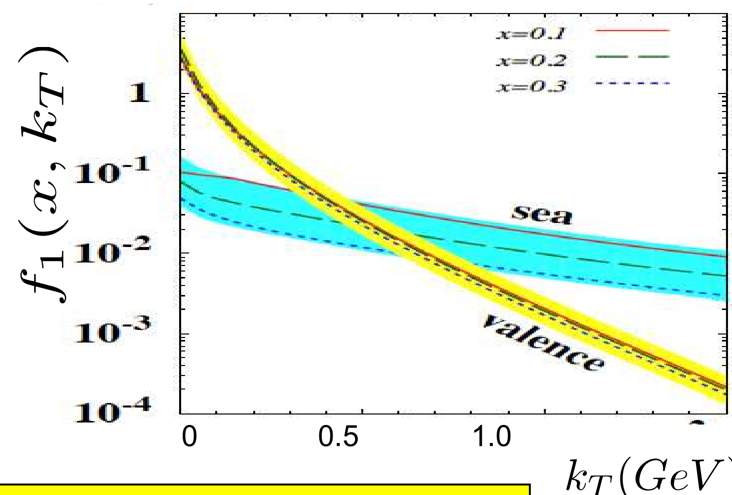
Hadron production in hard scattering



tornado

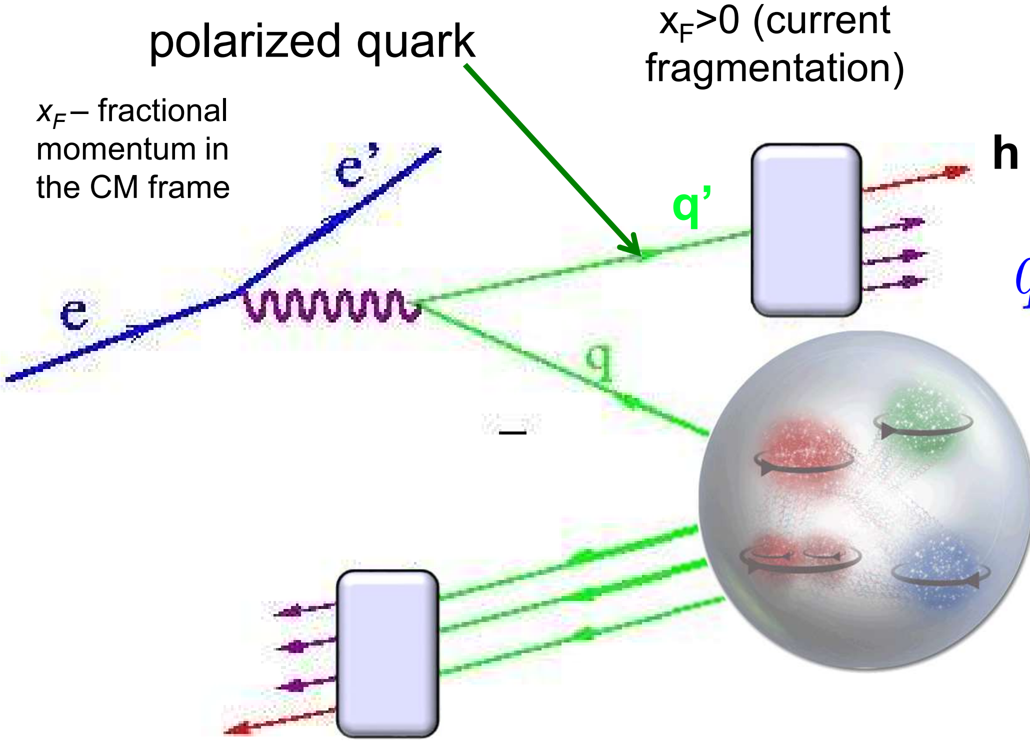


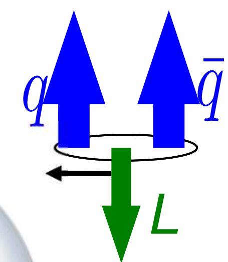




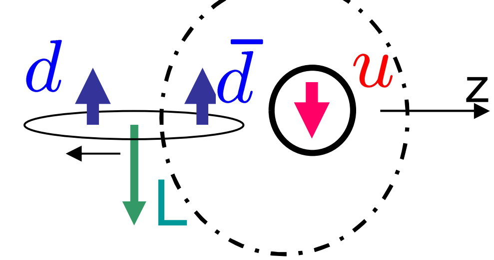
Non-perturbative sea is significant in the valence region
It contribute in spin-orbit correlations, more at large transverse momenta

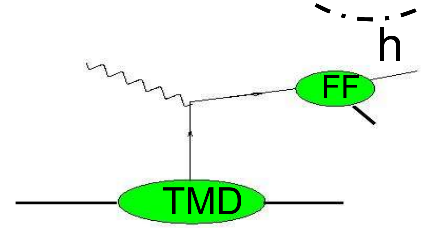
Hadron production in hard scattering: SIDIS





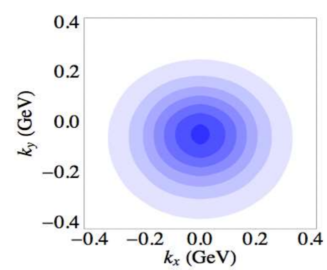
X. Artru (Collins effect)





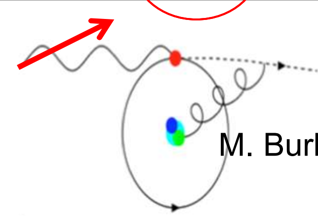
CFR/Current Fragmentation Region
→hadrons produced from struck quark

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 in SIDIS



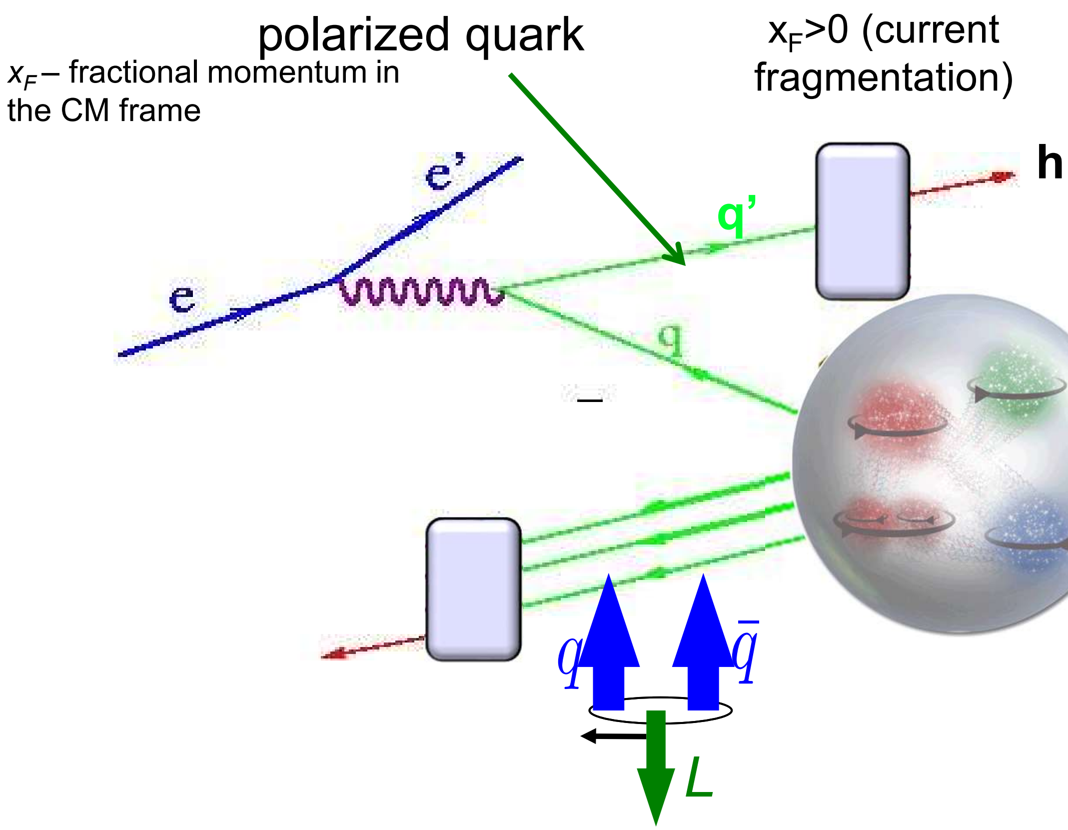
Transverse Momentum Distributions

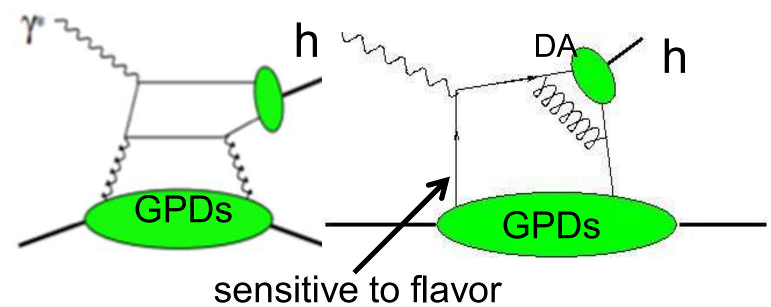
N/q	U	L	T
U	f_1	x	$h_1^{\perp}$
L	x	g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	h_1 $h_{1T}^{\perp}$



M. Burkardt (Sivers effect)

Exclusive hadron production in hard scattering

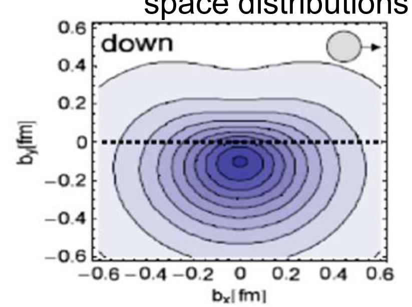




N/q

	U	L	T
U	H	X	$\mathcal{E}_T$
L	X	$\widetilde{H}$	X
T	E	X	$H_T, \widetilde{H}_T$

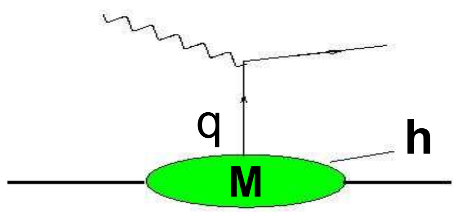
space distributions



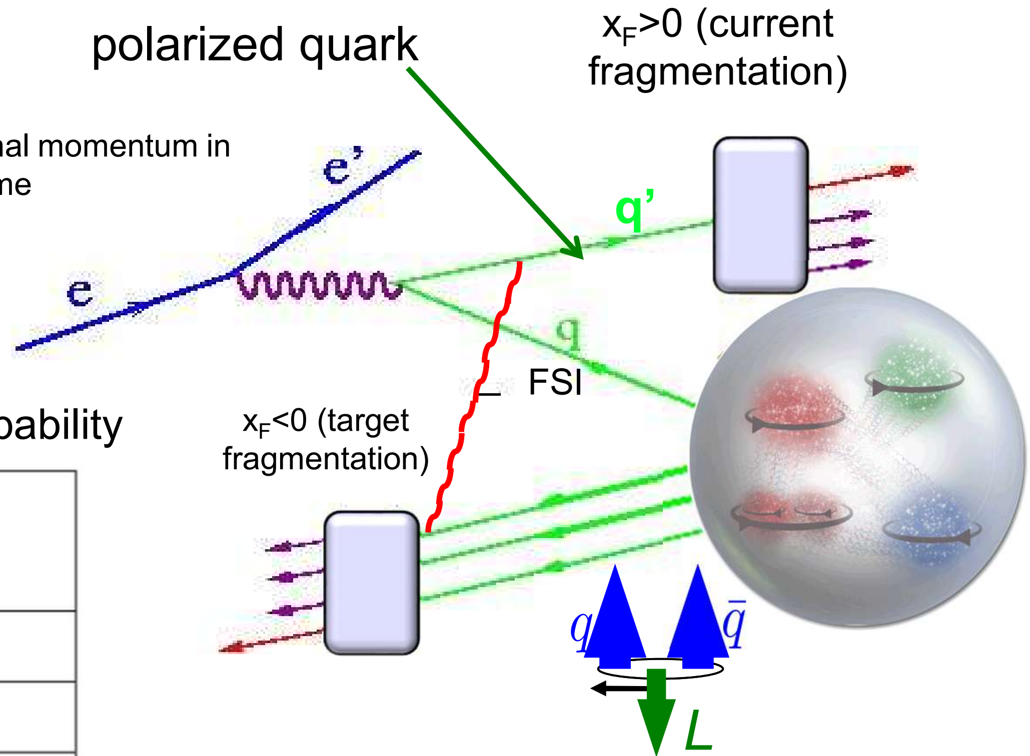
Current Fragmentation Region
→ nucleon and transition GPDs (⊥ space distributions)

Correlations of the spin of the target or/and the momentum and the spin of quarks define the azimuthal distributions of produced particles in hard exclusive production of hadrons

Hadron production in hard scattering: SIDIS



x_F – fractional momentum in the CM frame



Fracture Function→ conditional probability

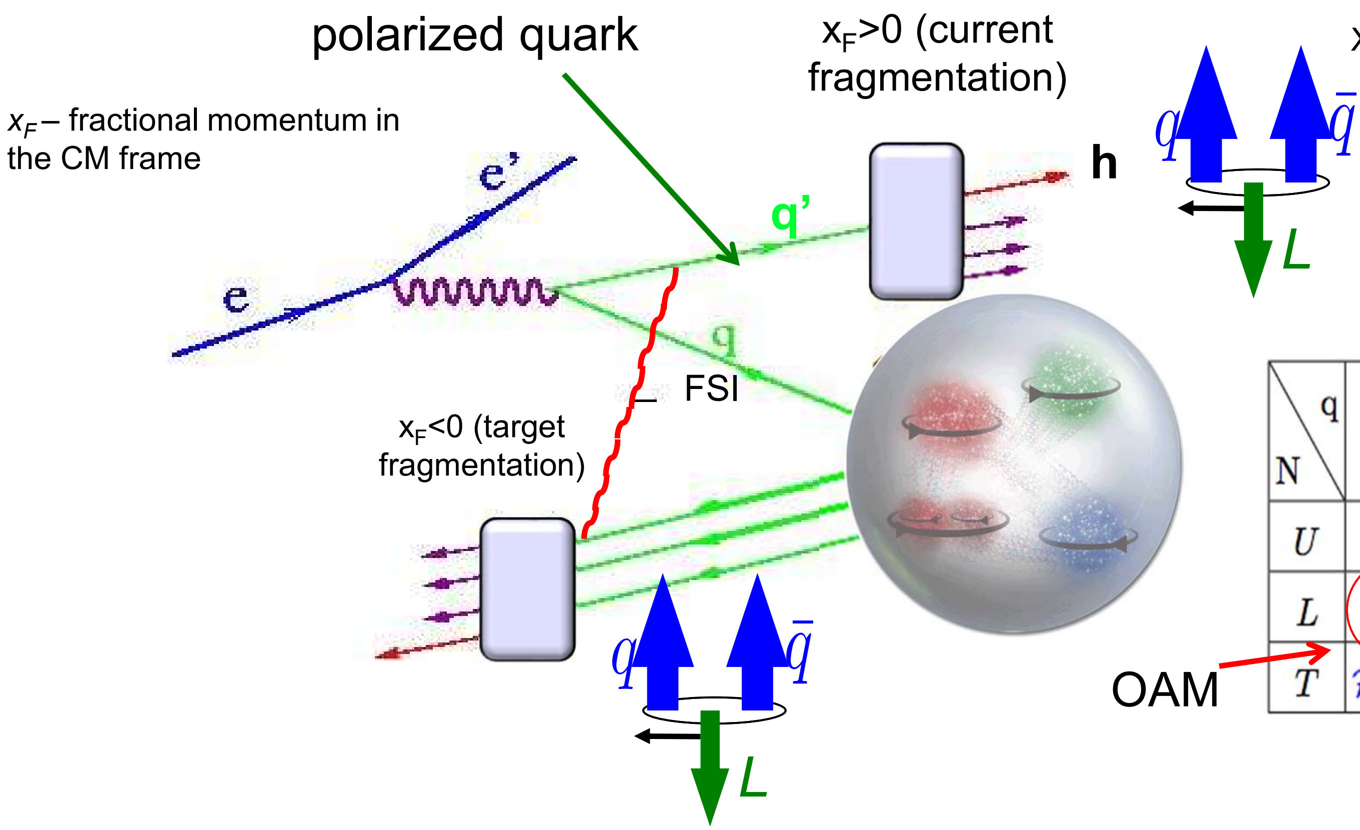
N \ q	U	L	T
U	$\hat{u}_1$	$\hat{l}_1^{\perp h}$	$\hat{t}_1^h, \hat{t}_1^\perp$
L	$\hat{u}_{1L}^{\perp h}$	$\hat{l}_{1L}$	$\hat{t}_{1L}^h, \hat{t}_{1L}^\perp$
T	$\hat{u}_{1T}^h, \hat{u}_{1T}^\perp$	$\hat{l}_{1T}^h, \hat{l}_{1T}^\perp$	$\hat{t}_{1T}, \hat{t}_{1T}^{hh}, \hat{t}_{1T}^{\perp\perp}, \hat{t}_{1T}^{\perp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

Anselmino, Barone, Kotzinian

TFR/Target Fragmentation Region
→hadrons produced from remnant
(do not contain the struck parton)

Correlations of the struck quark and the target remnant combined with final state interactions define the azimuthal distributions of particles in the backward hemisphere (TFR), providing complementary information on nucleon structure

Exclusive hadron production in hard scattering



Twist3 GPDs

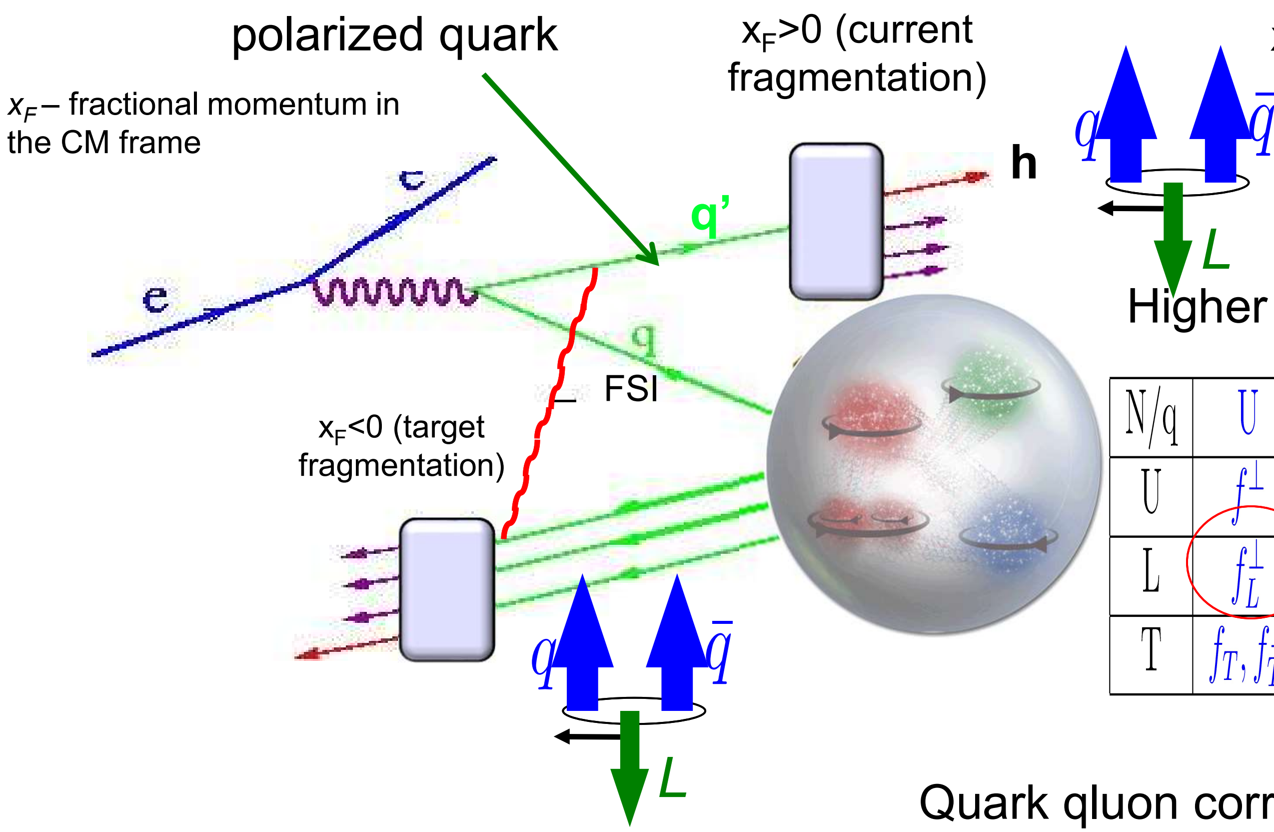
N \ q	U	L	T
U	$\mathcal{E}_{2T}$	$\mathcal{E}'_{2T}$	$\mathcal{H}_2, \mathcal{H}'_2$
L	$\tilde{\mathcal{E}}_{2T}$	$\tilde{\mathcal{E}}'_{2T}$	$\tilde{\mathcal{H}}_2, \tilde{\mathcal{H}}'_2$
T	$\mathcal{H}_{2T}, \tilde{\mathcal{H}}_{2T}$	$\mathcal{H}'_{2T}, \tilde{\mathcal{H}}'_{2T}$	$\mathcal{E}_2, \tilde{\mathcal{E}}_2, \mathcal{E}'_2, \tilde{\mathcal{E}}'_2$

OAM

Quark qluon correlations described by higher twist 3D PDFs

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

Hadron production in hard scattering: SIDIS



X. Artru & Z. Belghobsi

Higher Twist TMDs

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

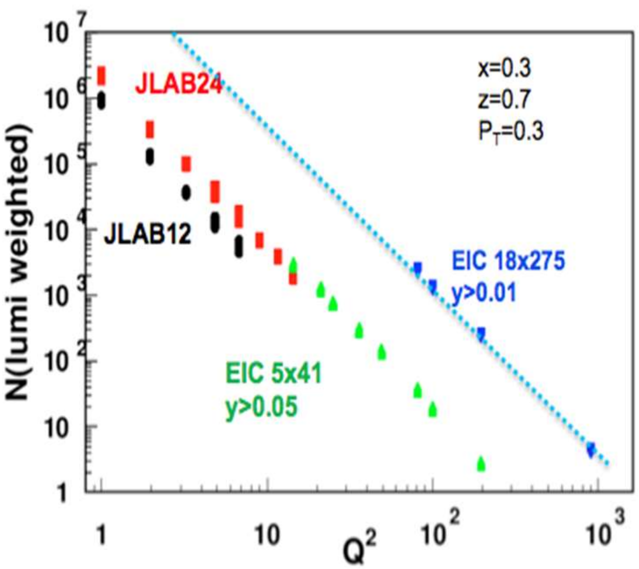
Quark qluon correlations described by higher twist 3D TMD PDFs

Final state interactions and quark-gluon correlations give rise to detectable spin-azimuthal modulations of produced particles

Structure functions and depolarization factors

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

$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{x\,y\,Q^2}\frac{y^2}{2(1-\varepsilon)}\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h}$$
$$+ \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} + S_L\Big[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h) F_{UL}^{\sin 2\phi_h}\Big]$$
$$+ S_L\lambda_e\Big[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\Big]$$
$$+ S_T\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) + \varepsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \varepsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S F_{UT}^{\sin\phi_S}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] + S_T\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

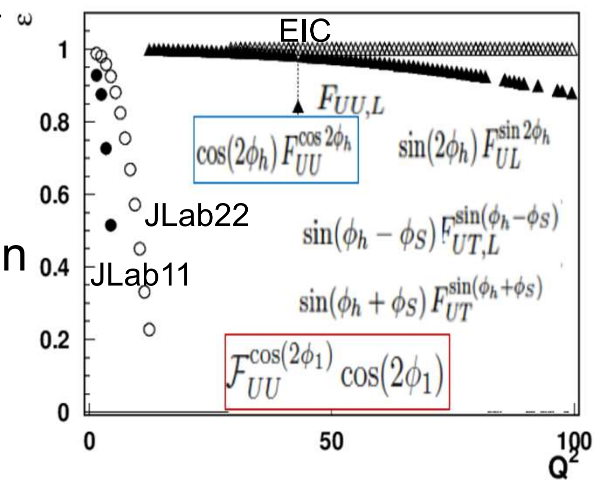


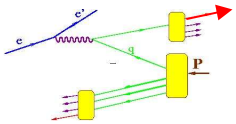
x-section from Bacchetta et al, 1703.10157

Combination of statistics and depolarization factors defines measurable SFs

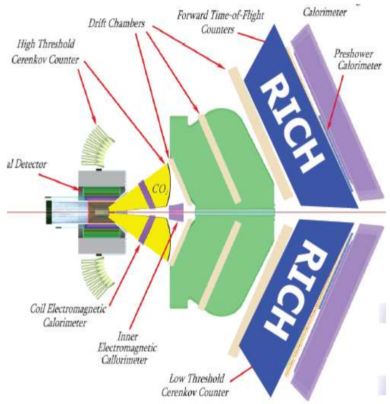
1) Measurements of $F_{UU,T}$ and Sivers requires separation, evaluation of longitudinal photon (JLab)

2) Meaningful interpretation of the Collins effects requires separation of VMs(JLab)





SIDIS at JLab12



Proton

CLAS12

- E12-06-112: π^+,π^-,π^0 / E12-09-008: K^+, K^-, K^0
- E12-07-107: π^+,π^-,π^0 / E12-09-009: K^+,K^-,K^0
- C12-11-111: π^+,π^-,π^0, K^+, K^-

H_2, NH_3, HD

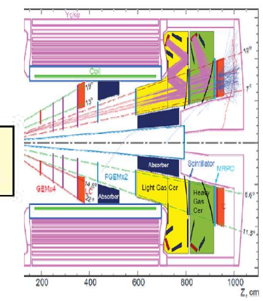
Quark spin polarization

Nucleon polarization (N \ q)	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Hall C | Hall A

- E12-09-017: π^+,π^-, K^+,K^- / C12-11-102: π^0 — HMS SHMS
- C12-11-108: π^+,π^- — Solid

H_2 NH_3



D_2

CLAS12

- E09-008: π^+,π^-,π^0, K^+, K^-,K^0
- E07-107: π^+,π^-,π^0 / E09-009: K^+,K^-,K^0

D_2, ND_3

C12-20-002 $\pi^+,\pi^-.\pi^0$,K+

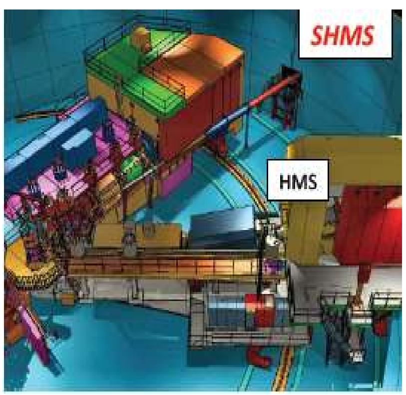
Quark spin polarization

Nucleon polarization (N \ q)	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Hall C

- E12-09-017: π^+,π^-, K^+,K^- / C12-11-102: π^0 — HMS SHMS

D_2



^3He

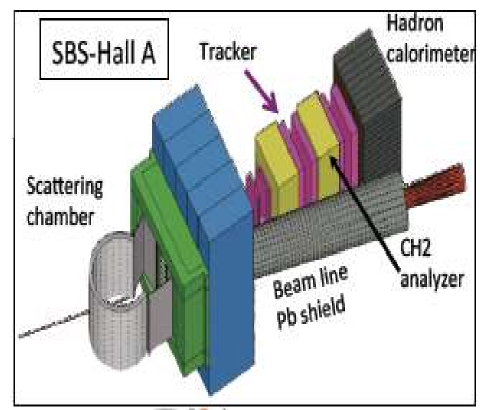
Quark spin polarization

Nucleon polarization (N \ q)	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Hall A

- E12-07-007: π^+,π^- — Solid
- E10-006: π^+,π^- — Solid
- E12-09-018: π^+,π^-, K^+,K^- — SBS

^3He



Proton polarization: x-sections

Semi-Inclusive:

Lepton helicity→ "+1" along the beam

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L} + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_{\|}\left[\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] + S_{\|}\lambda_e\,\sqrt{1-\varepsilon^2}\,F_{LL}\Big\}$$

Proton helicity→ "+1" opposite to the beam

NH3 – runs (~10%) from latest RGC run group with beam energy 10.55 GeV

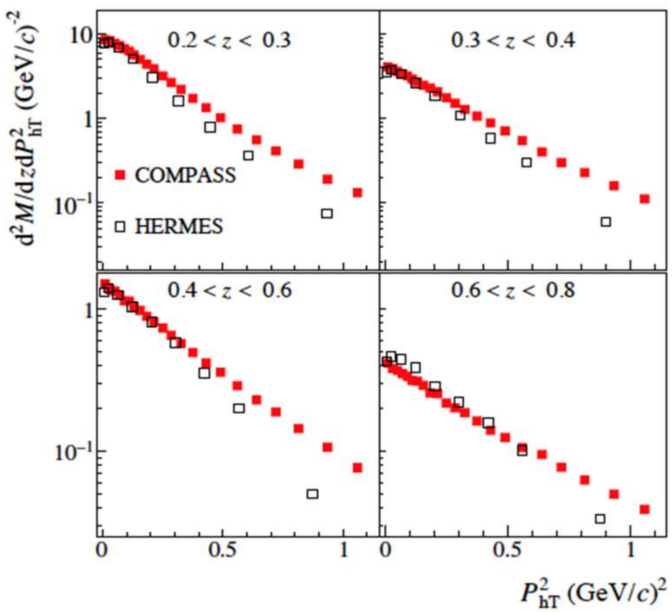
- Separation of contributions from longitudinal and transverse photons critical for interpretation
- Double polarized experiments allow studies of single beam-spin, single target-spin and double spin asymmetries

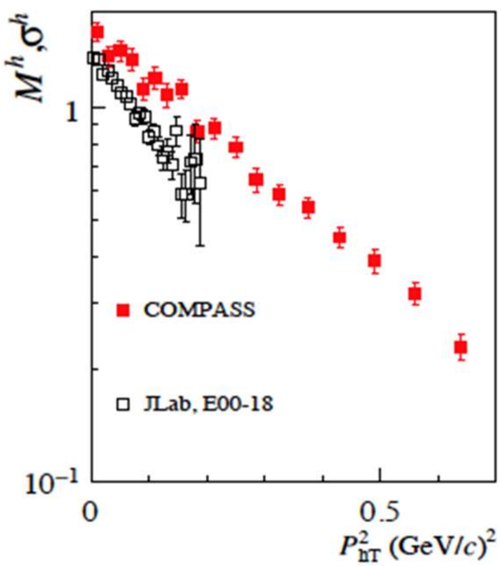
Multiplicities of hadrons in SIDIS

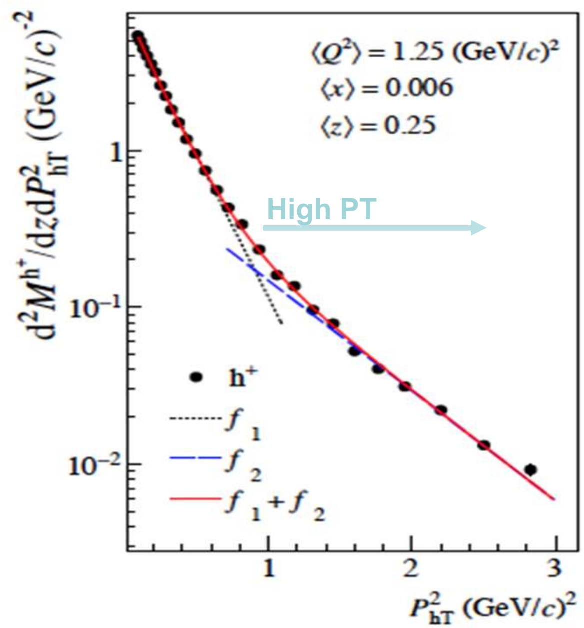
Gaussian Ansatz $$f_1^q \otimes D_1^{q\to h} = x f_1^q(x)\, D_1^{q\to h}(z) \frac{e^{-P_{hT}^2/<P_{hT}^2>}}{\pi < P_{hT}^2 >}$$

TMDs universal, so what is the origin of the differences observed ?

COMPASS:1709.07374



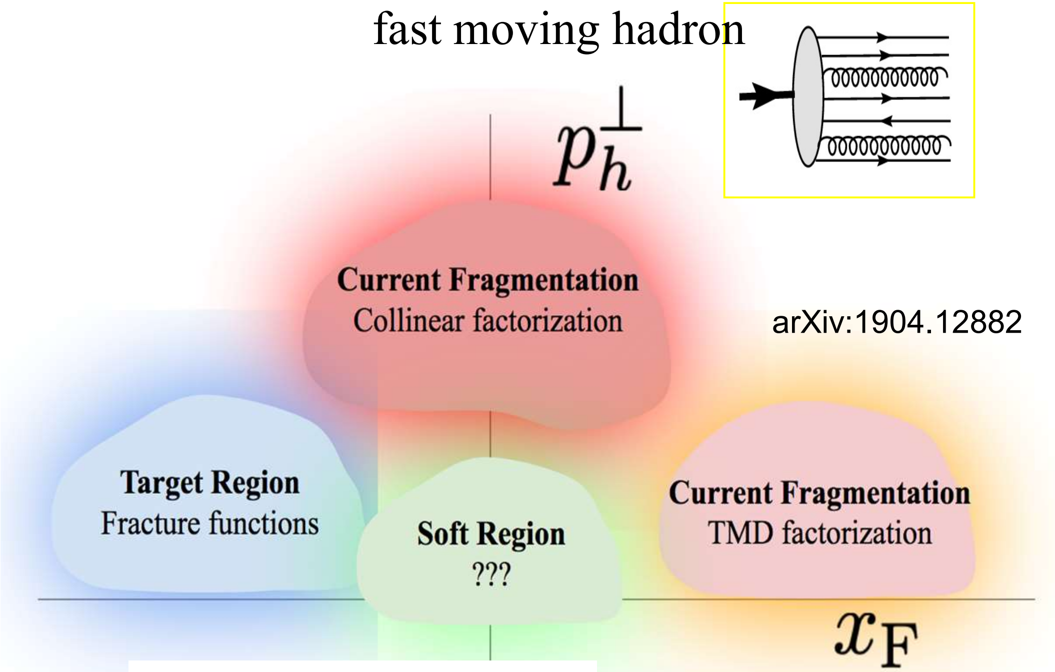




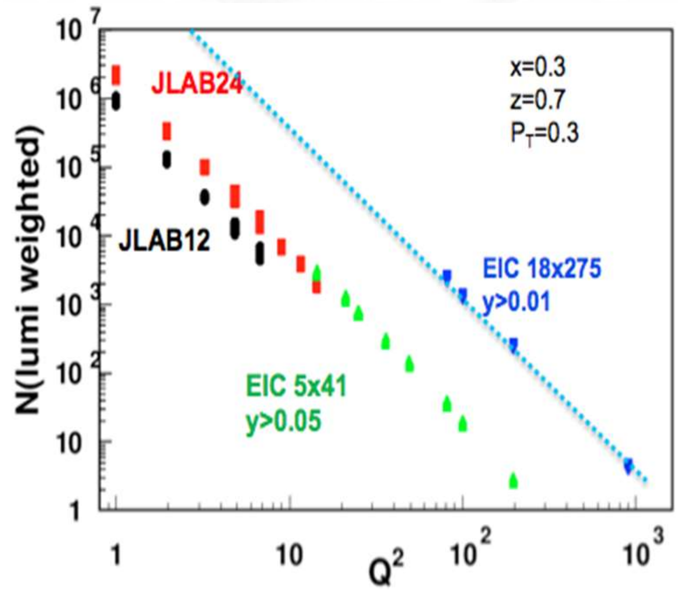
JLab: not enough energy to produce large P_T
HERMES: not enough luminosity to access large P_T

- What is the origin of the "high" P_T (0.8-1.8) tail?
  1) Perturbative contributions?
  2) Non perturbative contributions?

Structure functions and depolarization factors in SIDIS



x_F – fractional momentum in the CM frame



1) Theory works well for $P_T/Q<0.25$,
2) Kinematic regions not trivial to separate, in particular for polarized measurements
3) Multi-dimensional measurements critical, requiring high lumi
4) Theoretical separation of kinematic region requires some assumptions (no decays,…)

TMDs IN Semi-Inclusive DIS

TMD Parton Distribution Functions

TMD Parton Fragmentation Functions

$$F_{UU,T}(x,z,P_{hT}^2,Q^2) = x\sum_q \mathcal{H}^q_{UU,T}(Q^2,\mu^2)\int d^2\boldsymbol{k}_\perp\, d^2\boldsymbol{P}_\perp\, f_1^a(x,\boldsymbol{k}_\perp^2;\mu^2)\, D_1^{a\to h}(z,\boldsymbol{P}_\perp^2;\mu^2)\,\delta(z\boldsymbol{k}_\perp-\boldsymbol{P}_{hT}+\boldsymbol{P}_\perp) + Y_{UU,T}(Q^2,\boldsymbol{P}_{hT}^2)+\mathcal{O}(M^2/Q^2)$$

Hard scattering

Major advance in theory in last years

$$\hat{f}_1^a(x,b_T^2;\mu_f,\zeta_f) = \int \frac{d^2\boldsymbol{k}_\perp}{(2\pi)^2} e^{i\boldsymbol{b}_T\cdot\boldsymbol{k}_\perp} f_1^q(x,k_\perp^2;\mu_f,\zeta_f)$$

perturbative Sudakov form factor

$$\hat{f}_1^a(x,b_T^2;\mu_f,\zeta_f) = [C\otimes f_1](x,\mu_{b_*})\, e^{\int_{\mu_{b_*}}^{\mu_f}\frac{d\mu}{\mu}\left(\gamma_F-\gamma_K\ln\frac{\sqrt{\zeta_f}}{\mu}\right)}\left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\text{resum}}+g_K} f_{1\,NP}(x,b_T^2;\zeta_f,Q_0)$$

collinear PDF

matching coefficients (perturbative)

Collins-Soper kernel (perturbative and nonperturbative)

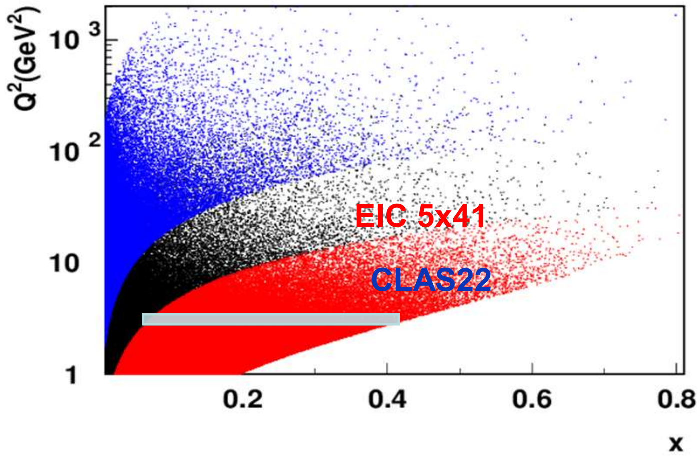
nonperturbative part of TMD

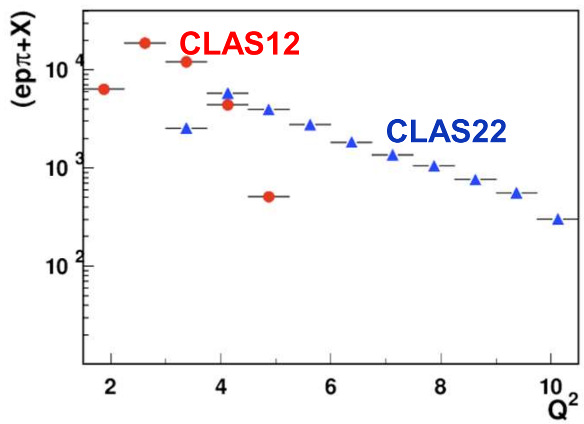
$$g_K(b_T^2) = -g_2^2\frac{b_T^2}{4}$$

CS-kernel→independent on any other variables

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

Accessing CS-kernel directly or through extraction of SFs





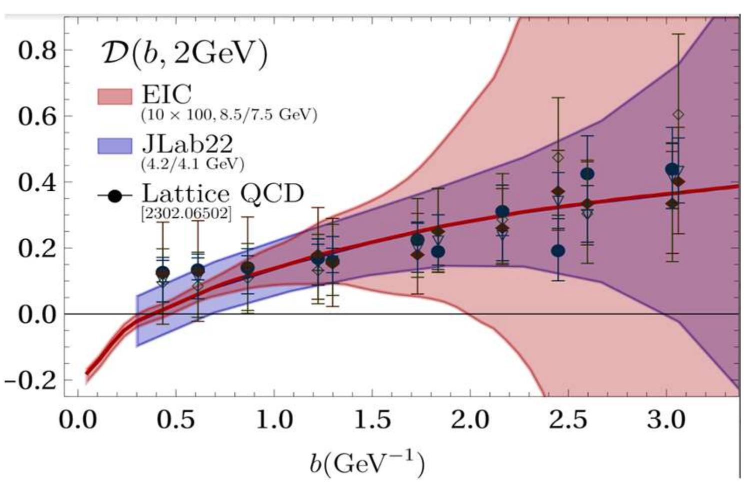
Different experiments most sensitive to different ranges in b

- JLab ~1<b<4
- EIC ~0.5<b<1.2
- LHC b<0.5
- COMPASS overlaps

Use slices in Q^2 (good resolution needed)

- Wide Q^2 range and high luminosity is the key for a validating separation of twist-2 contributions

A. Vladimirov



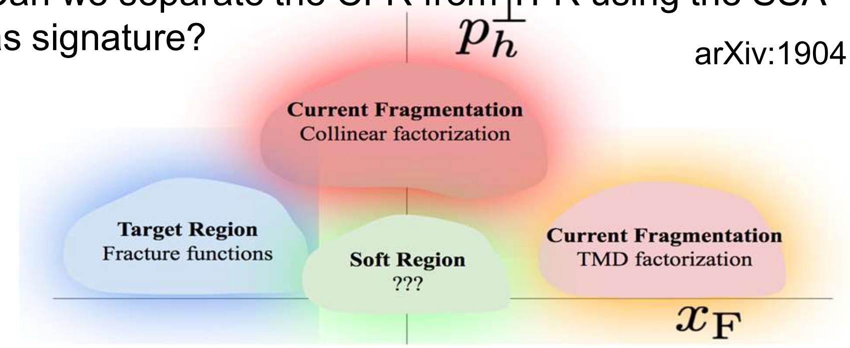
- Q^2 evolution studies possible, provide superior access to critical Collins-Soper (CS) kernel
- CLAS12 at JLab20+ can provide a wide range in Q^2 combined with high lumi and superior resolution

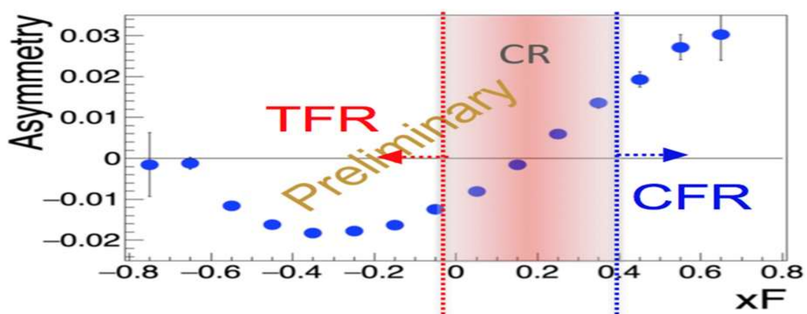
- Test the CS-kernel from different experiments, and for different kinematics in a given experiment
- Evaluate the systematics due to factorization violation and define possible reasons (some can be easy to fix)

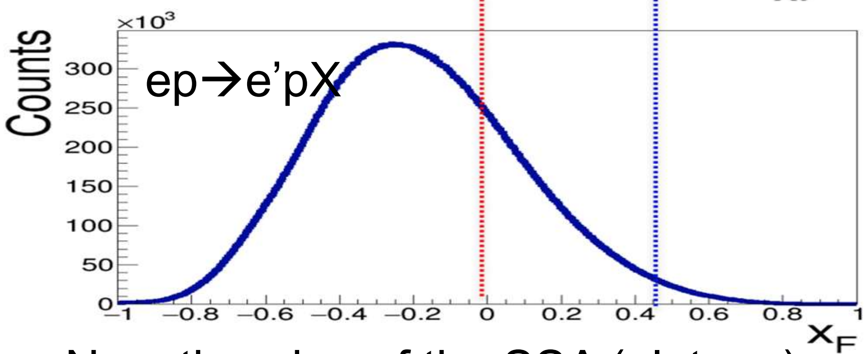
Beam SSAs: Where is the struck quark?

- Can we separate the CFR from TFR using the SSA as signature?

arXiv:1904.12882

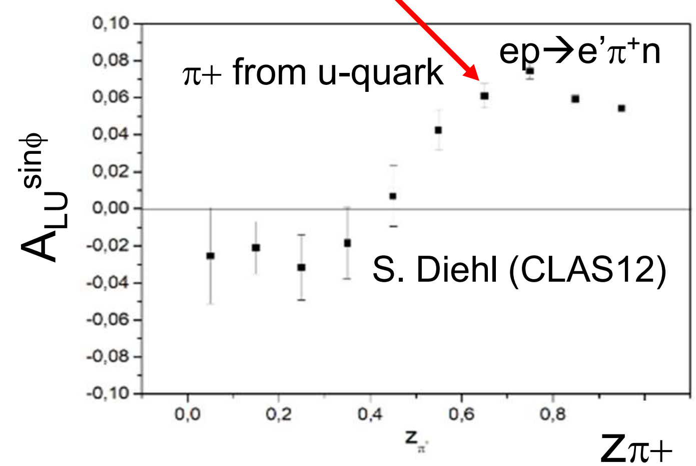


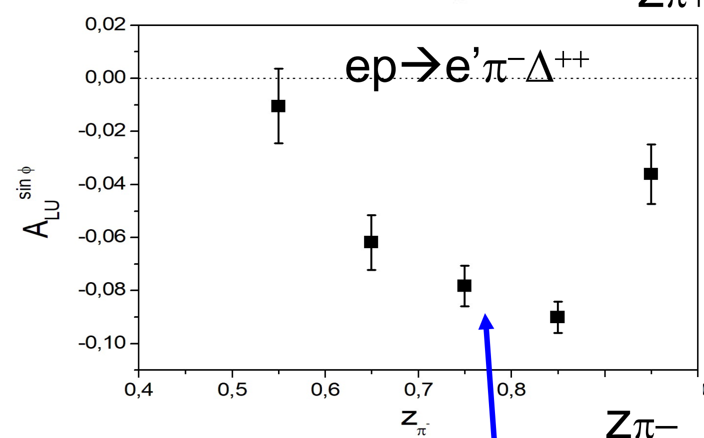




Negative sign of the SSA (plateau) defines the TFR dominance

Polarized u-quark, dominates
→ SSA positive



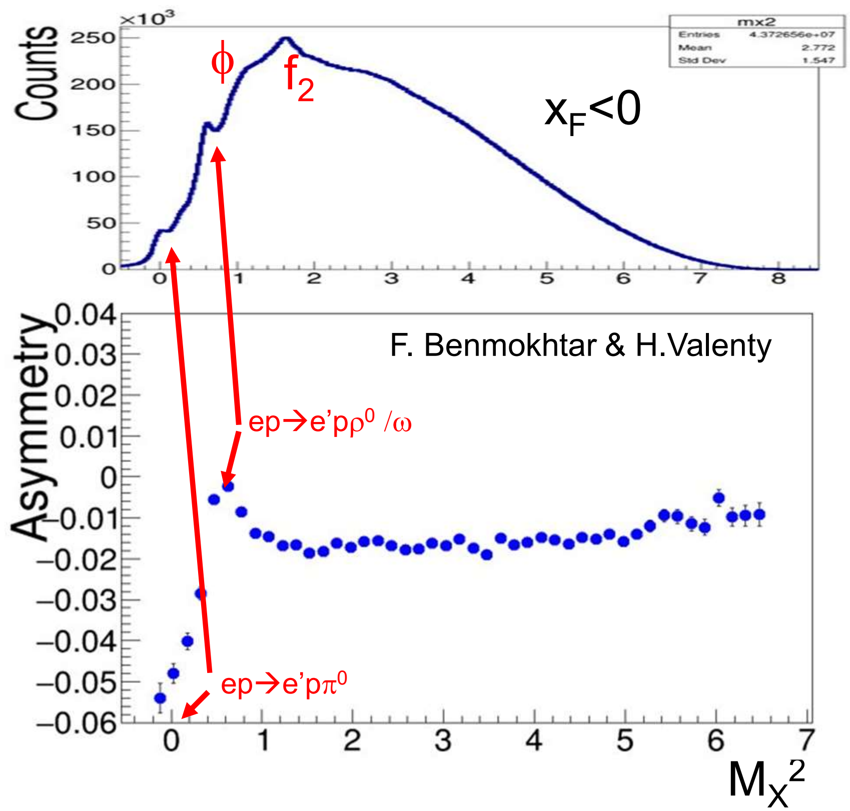


Polarized d-quark, is hard to locate, and one obvious process where we can guarantee it was hit, is the production of Δ++ (negative SSA)

Dissecting the beam SSA (A_{LU}) in ep→e'pX

- SIDIS is a sum over multiple exclusive states, but has to keep an eye to make sure it is not dominated by some dominant channel (extraction of Q2-dependence critical)
- The cut on the missing mass of the proton eliminates obvious exclusive channels, which tend to have higher positive or negative SSAs(ex. ep→e'pπ^0 or e'pρ^0)
- M_X>1.5 no structures and SSA goes to plato (no single channel dominates it) decreasing as the correlations get suppressed with multiple hadron production

What is SIDIS?



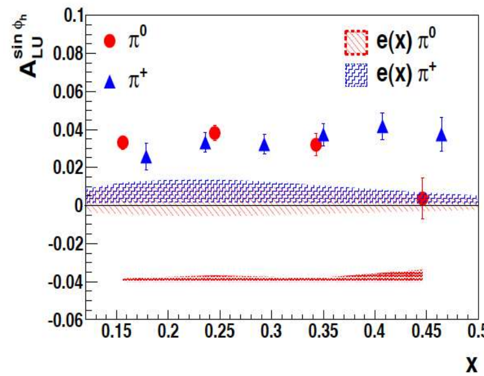
Significant beam spin SSAs observed for exclusive ep→e'pπ^0 (~8%) and ep→e'pρ^0 (~10-15%)

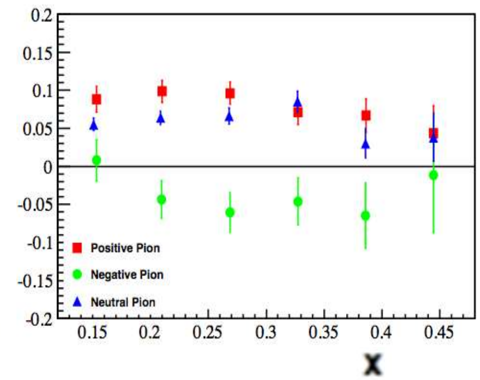
Quark-gluon correlations: flavor dependence

Higher Twist PDFs

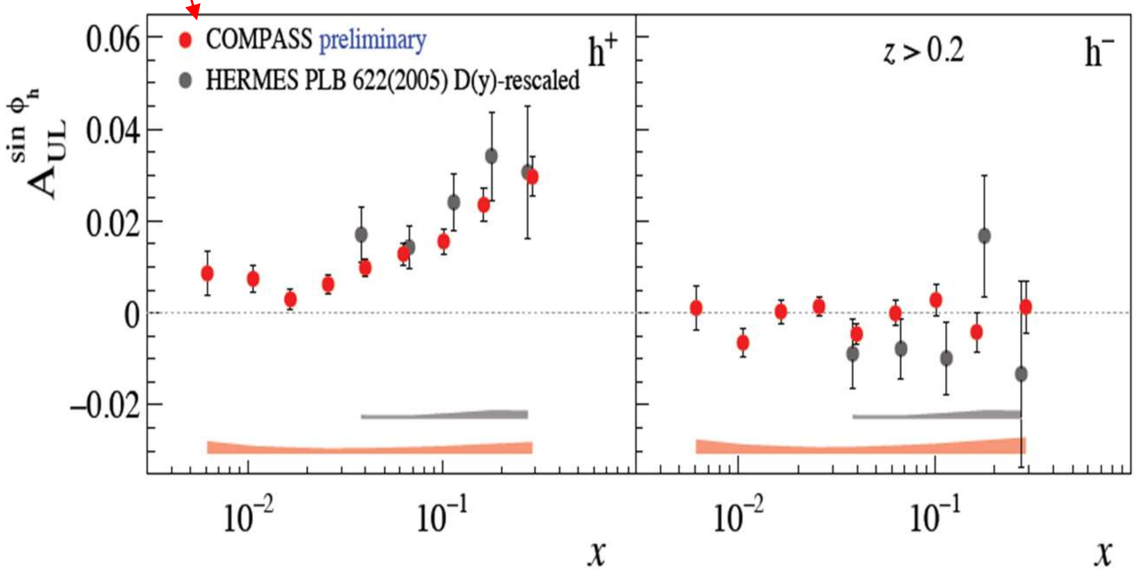
N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

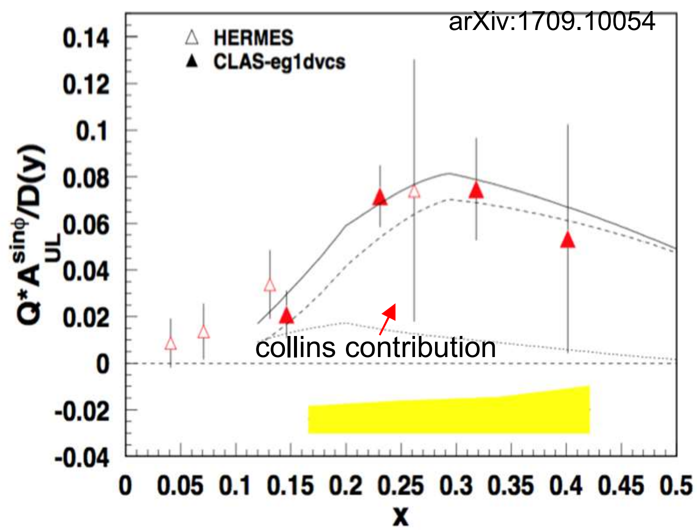
1) roughly equal $\pi^+\pi^0$ SSA
2) π^- SSA much smaller, consistent with 0 or<0





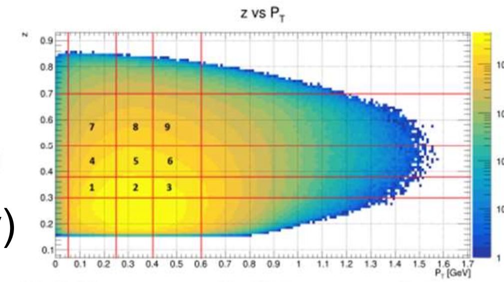
CLAS/HERMES





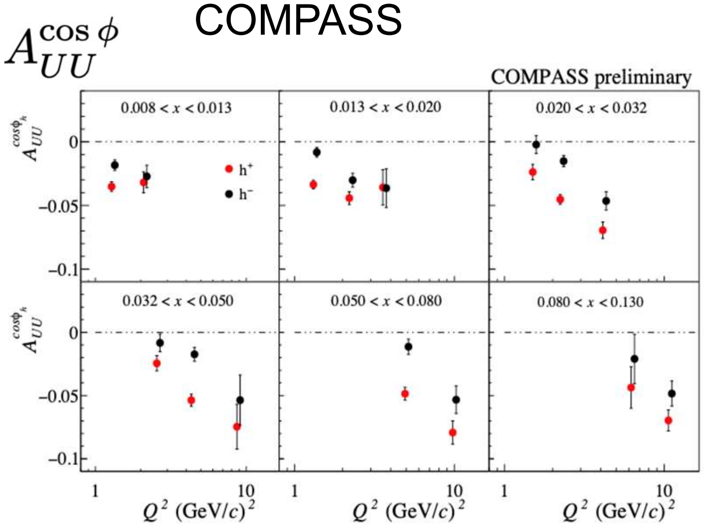
• Significant longitudinal beam and target SSA measured at HERMES, JLab and COMPASS may be related to higher twist distribution functions
• sinϕ modulations for $\pi^+\pi^0$ consistent with dominance of Sivers mechanism
• Subleading asymmetries comparable with leading ones (1/Q terms should be accounted)

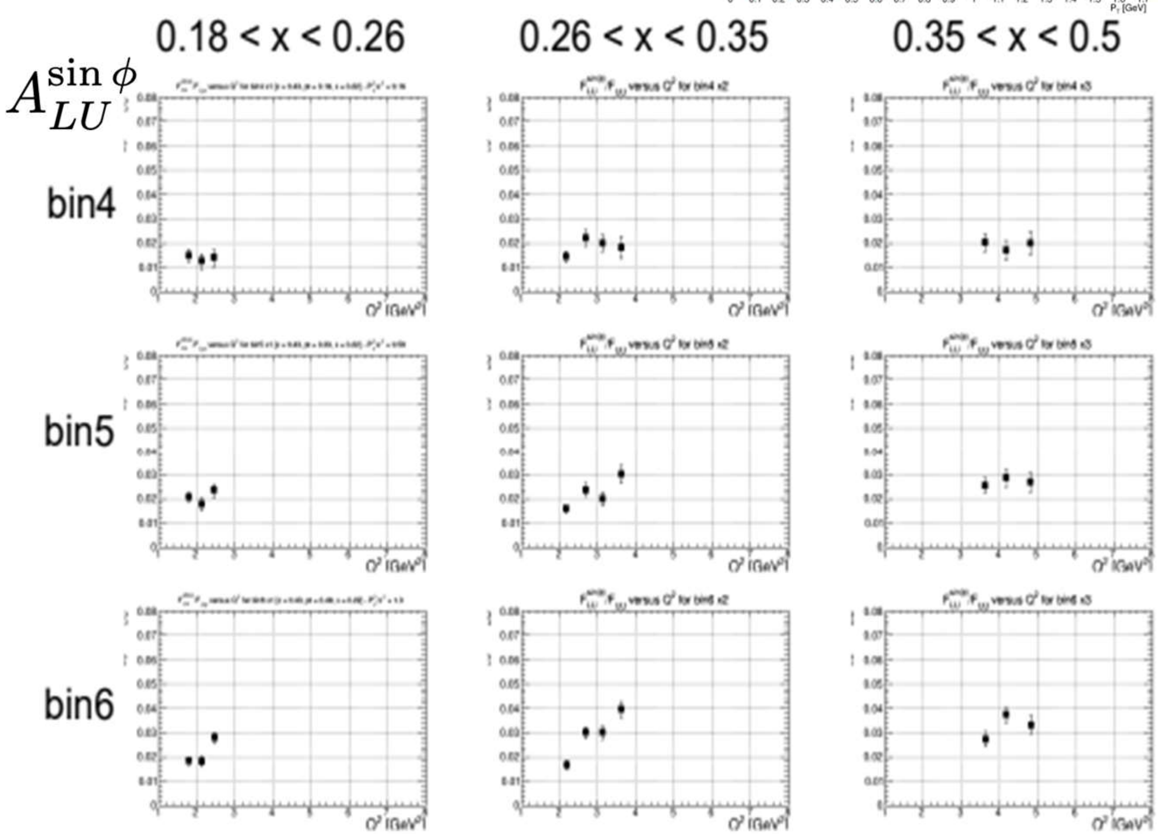
Attempts to understand Q^2-dependence of HT



CLAS12(preliminary)

COMPASS



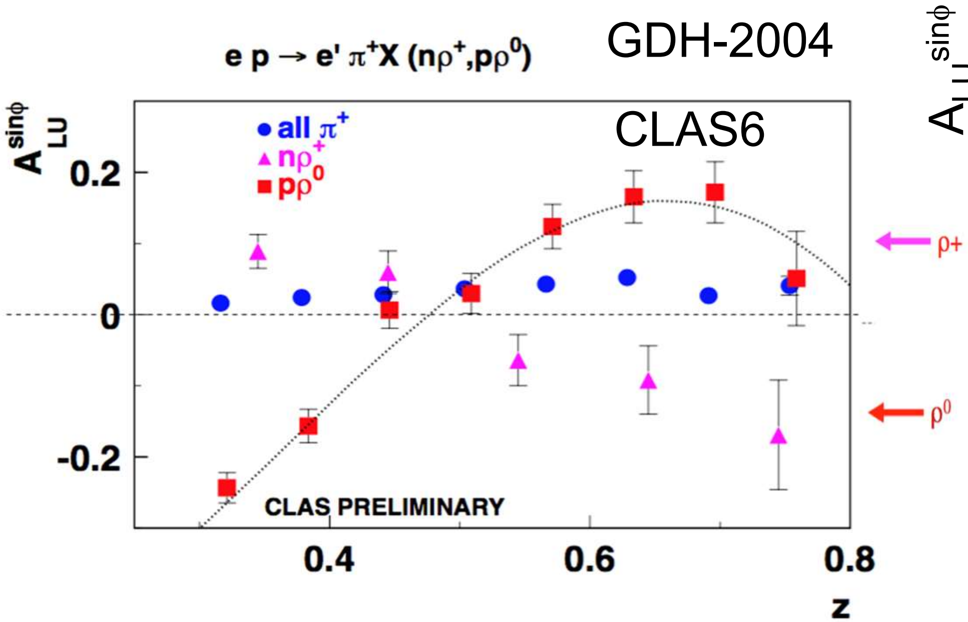


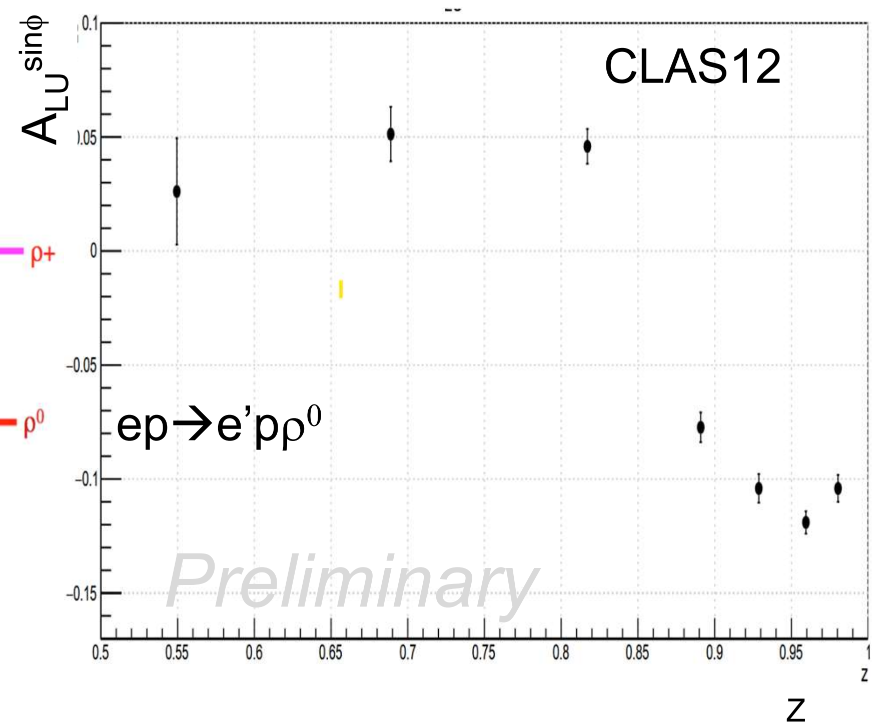
- We always measure ratio to

$$F_{UU,T}+\varepsilon F_{UU,L}$$

- The moments defined as a ratio to ϕ-independent x-section(to $F_{UU,T}$), are not decreasing with Q!!!
- The HT observables, don't look much like HT observables, something missing in understanding
- **Understanding of these behavior can be a key to understanding of other inconsistencies**
- Checking the Q^2 and P_T-dependences of the $F_{UU,L}$ may provide crucial input for validation

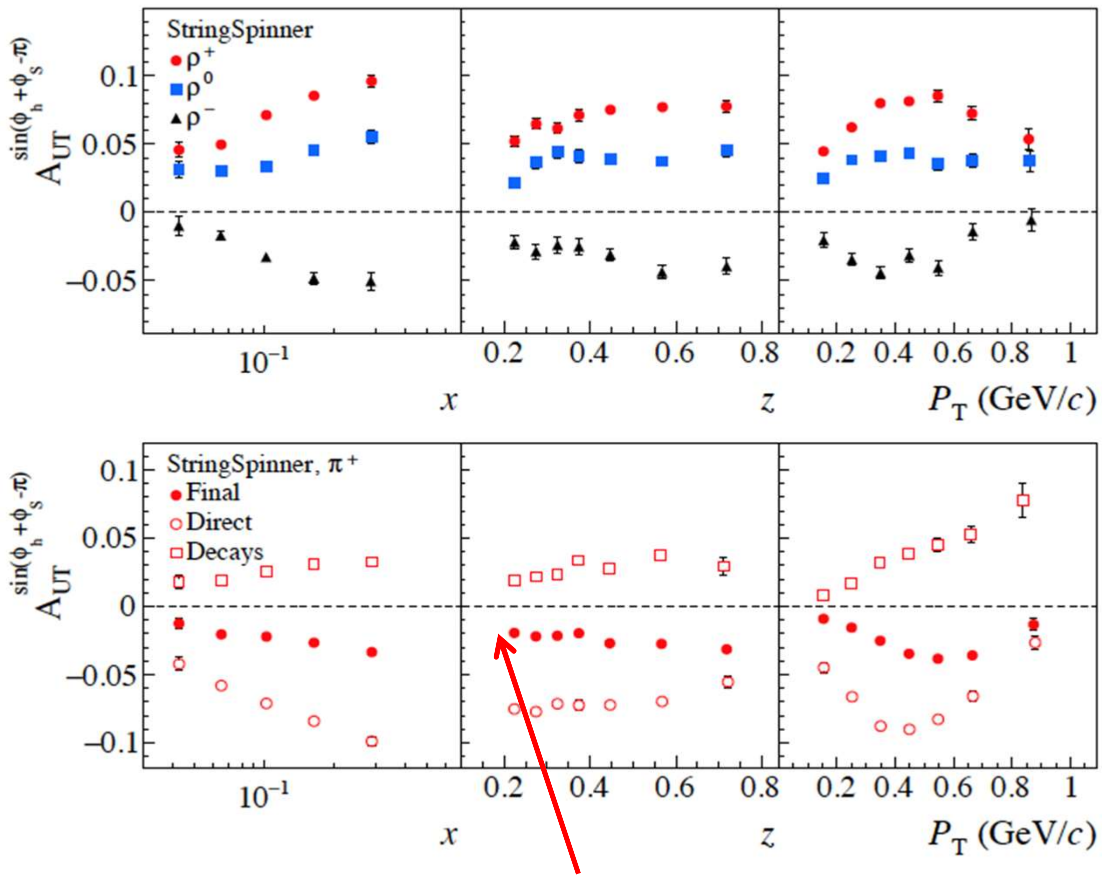
Quark-gluon correlations: flavor dependence





- CLAs 12 data confirm observation of significt r0 SSAs
- Understanding the SSAs of VMs is critical in interpretation of the pion SIDIS

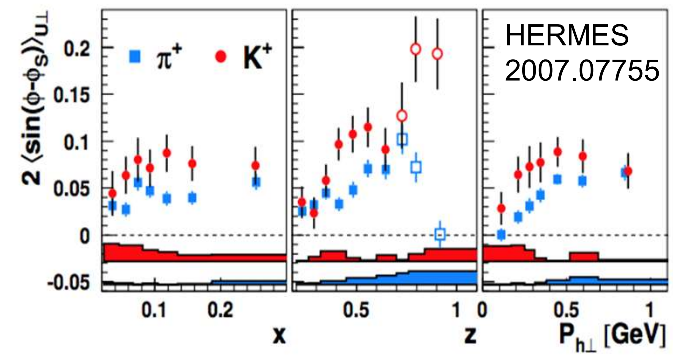
VM contributions



Strong dilution of SSAs due to VM decays

Are the differences in pions vs Kaons coming from VMs???

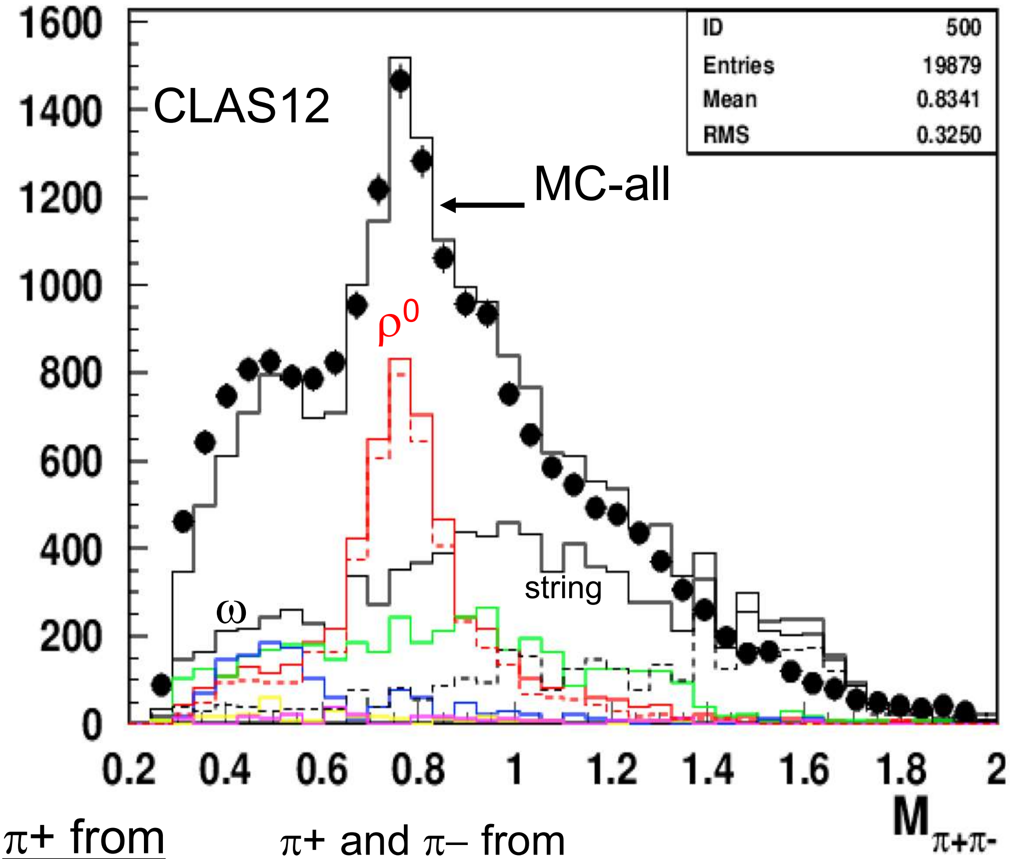
e+e- will have similar composition, and with high statistics may be able to describe the spectra

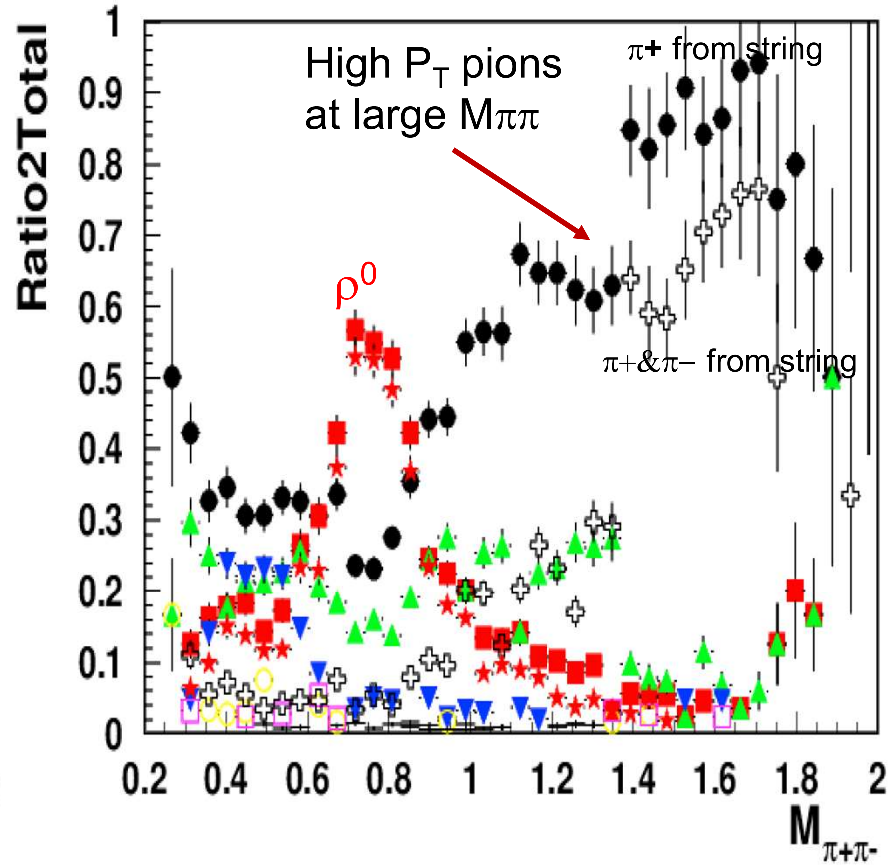


Understanding VMs is critical for interpretation

JLab can measure the SSA of VMs, and separate contributions

Sources of inclusive pions: CLAS12 vs MC





π+ from		π+ and π− from
—— (red)	ρ0	---- (red)
—— (black)	string	---- (black)
—— (green)	ρ+	
—— (blue)	ω	

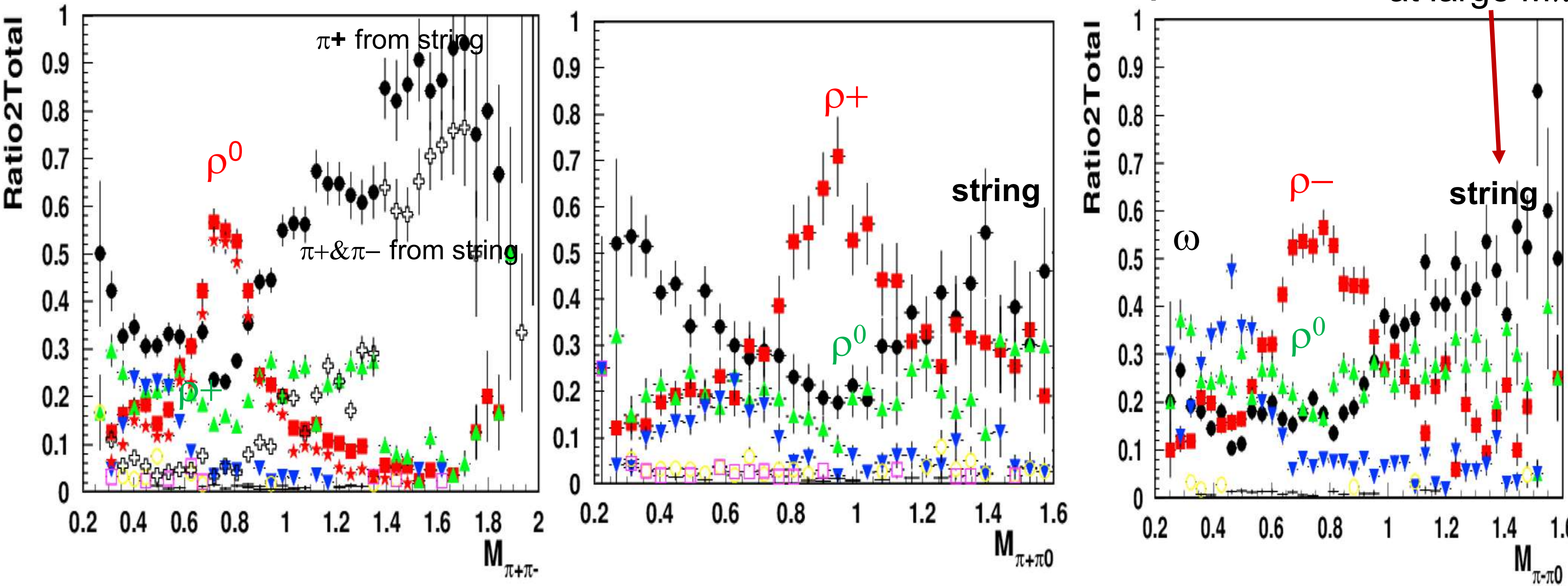
- Dominant fraction of inclusive pions come from VM decays
- Relative fraction by default in JETSET ~50%

Very important to have multidimensional TMD Fragmentation Functions!

Sources of inclusive pions: CLAS12 MC

Detection of π^0s allows also studies of $\rho^{\pm}$

High P_T pions at large $M\pi\pi$



Dominant fraction of 2 pion combinations come from VM decays

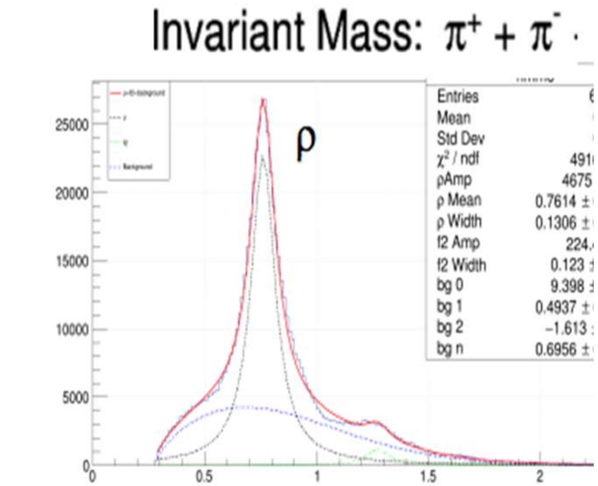
ρ

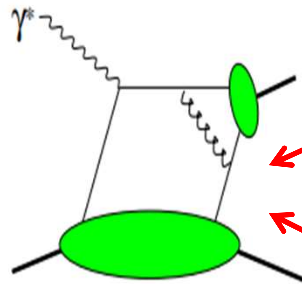
string

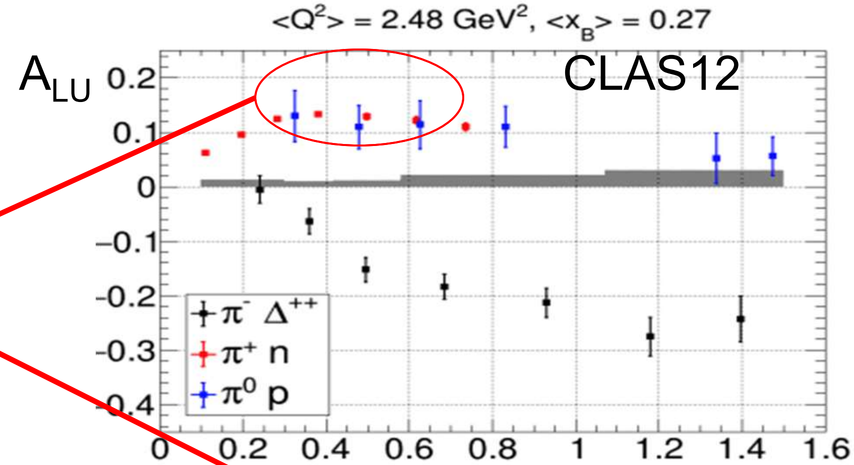
ω

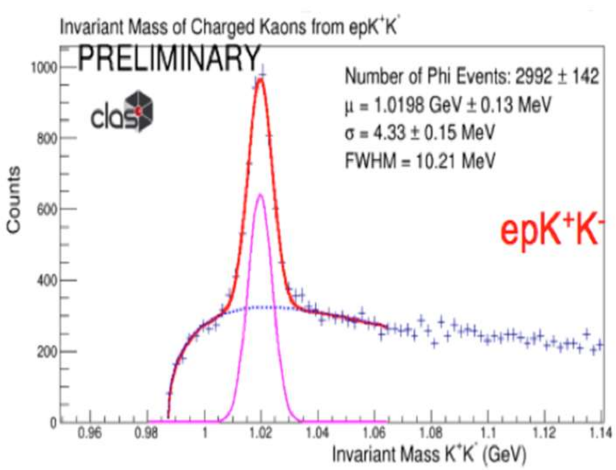
All measured 2 pion combinations are dominated by VM decays, indicate that all inclusive pions are dominated by VM decays at small P_Ts, and in particular at lower z!!!

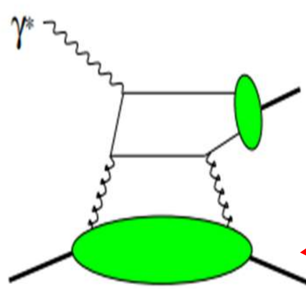
Current hadrons: exclusive limit

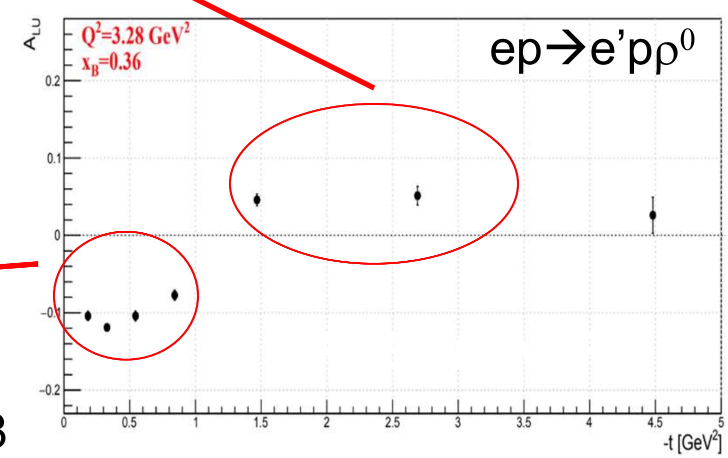












A_{LU}=-0.084+/-0.038

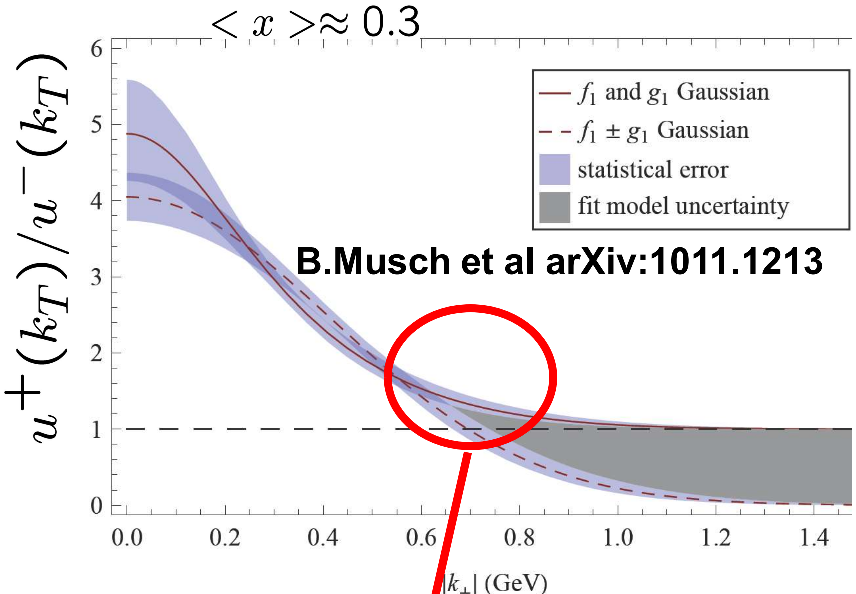
SSA negative→ΔG negative?

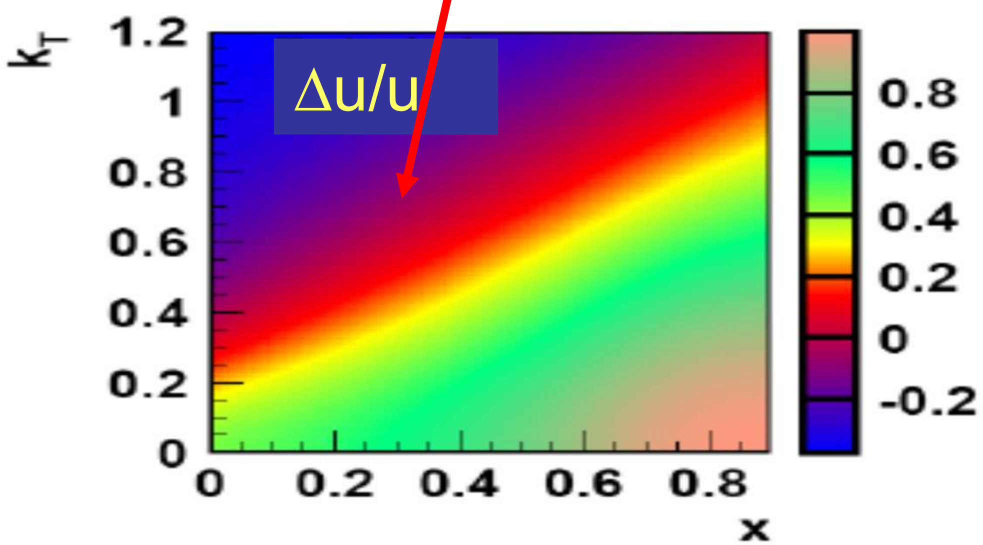
-t(GeV²)

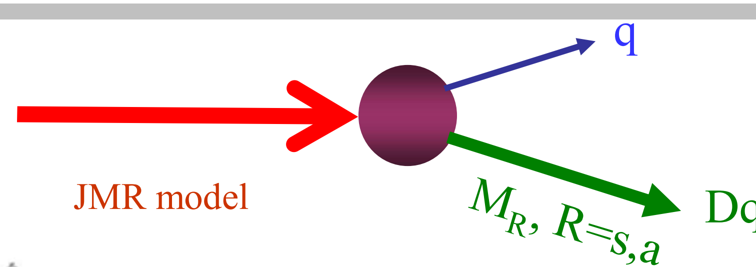
CLAS can measure all final states in exclusive production

Hadrons produced fro u-quark have positive SSA, d-quarks and gluons negative.

Quark distributions at large k_T: lattice







$$u^+(x,\mathbf{k}_T^2) \propto \frac{(xM+m)^2}{(\mathbf{k}_T^2+\lambda_R^2)^{2\alpha}},$$

$$u^-(x,\mathbf{k}_T^2) \propto \frac{\mathbf{k}_T^2}{(\mathbf{k}_T^2+\lambda_R^2)^{2\alpha}},$$

Sign change of Δu/u consistent between lattice and diquark model

$$\frac{1}{2}(q^+ + q^-) \equiv \quad q(x) \quad \equiv f_1^q$$

$$\frac{1}{2}(q^+ - q^-) \equiv \quad \Delta q(x) \quad \equiv g_1^q$$

More quarks with opposite to proton spin at large transverse momentum

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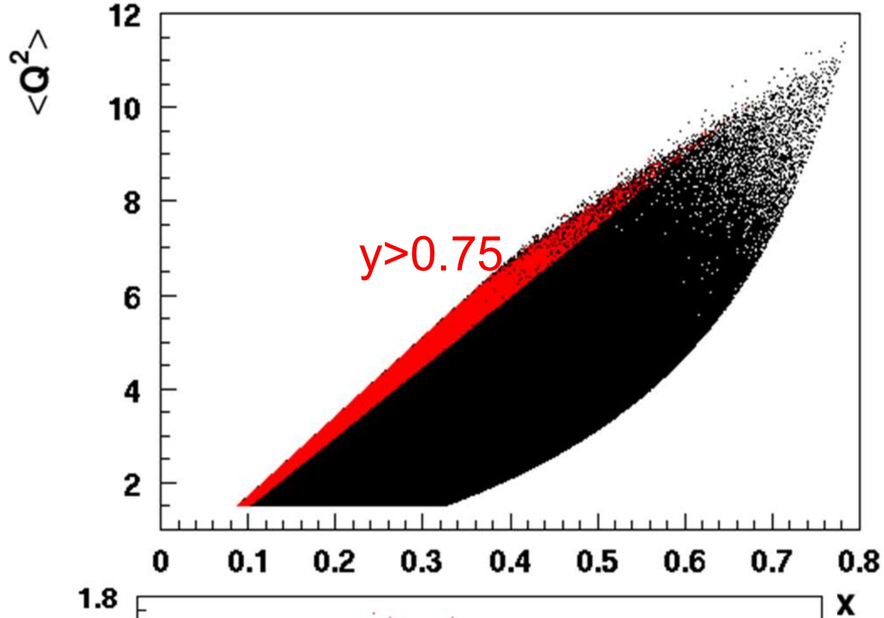
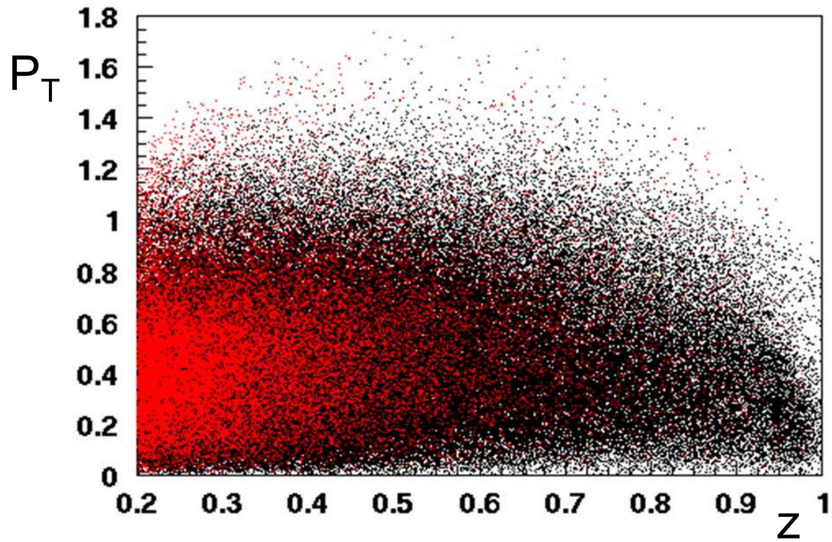
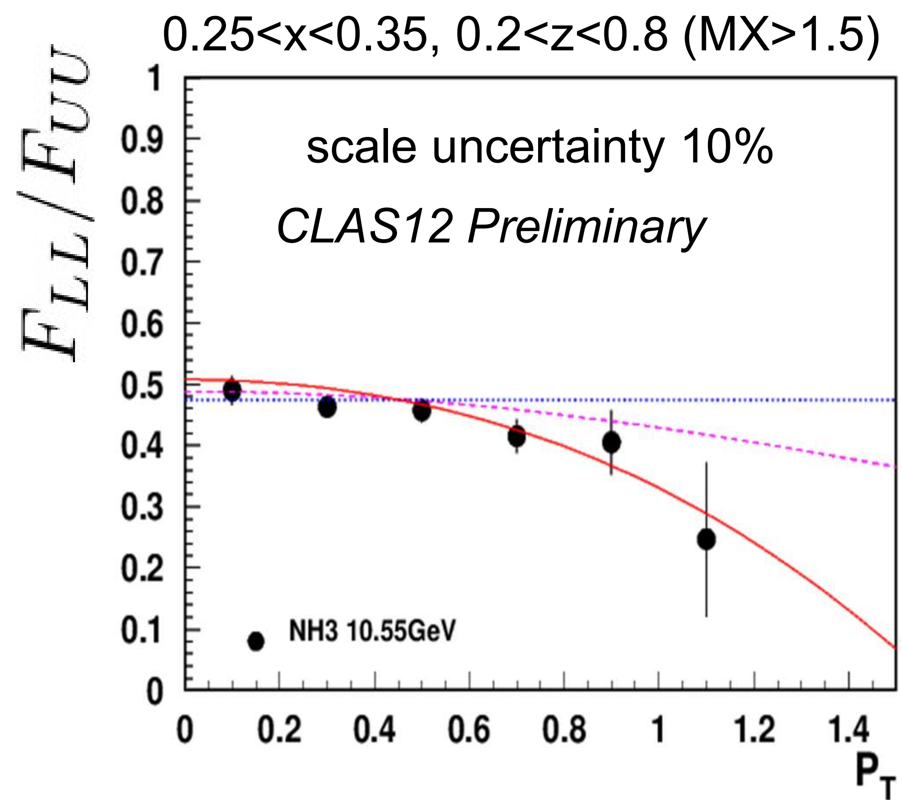
A_1 P_T-dependence





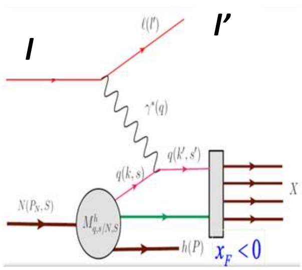


With more statistics can

- check with finer bins in P_T,
- extract the the same for dihadron sample

Red curve predictions from Lattice accounting different widths in $g_1(x,k_T)$ and $f_1(x,k_T)$

Hadron production in TFR



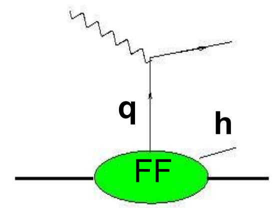
arXiv:2308.11251

$$F_{UL}^{\sin\phi_h} = -\frac{2|\vec{P}_{h\perp}|}{Q} x_B^2 u_L^h$$

unpolarized quarks in the longitudinally polarized proton

$$F_{LU}^{\sin\phi_h} = \frac{2|\vec{P}_{h\perp}|}{Q} x_B^2 l^h$$

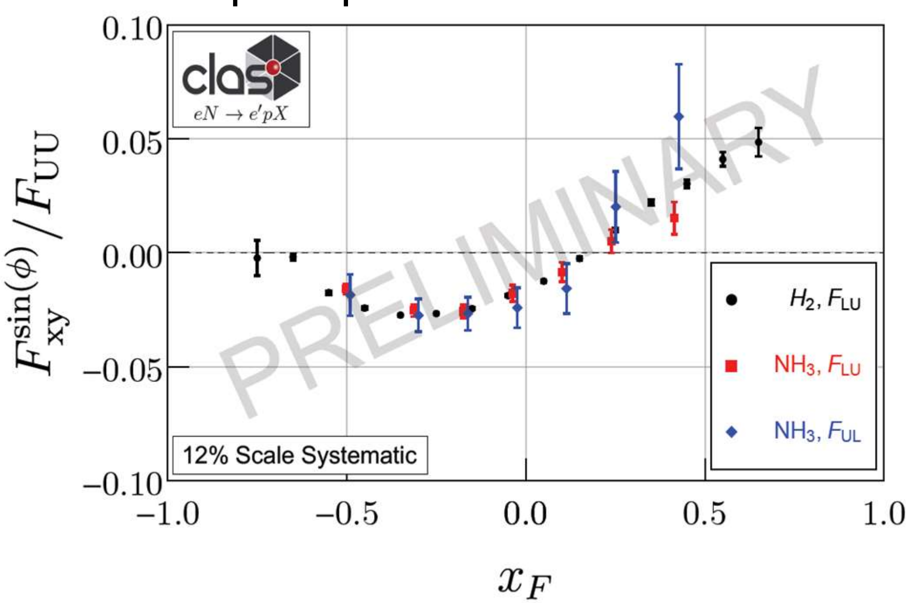
longitudinally quarks in the unpolarized polarized proton

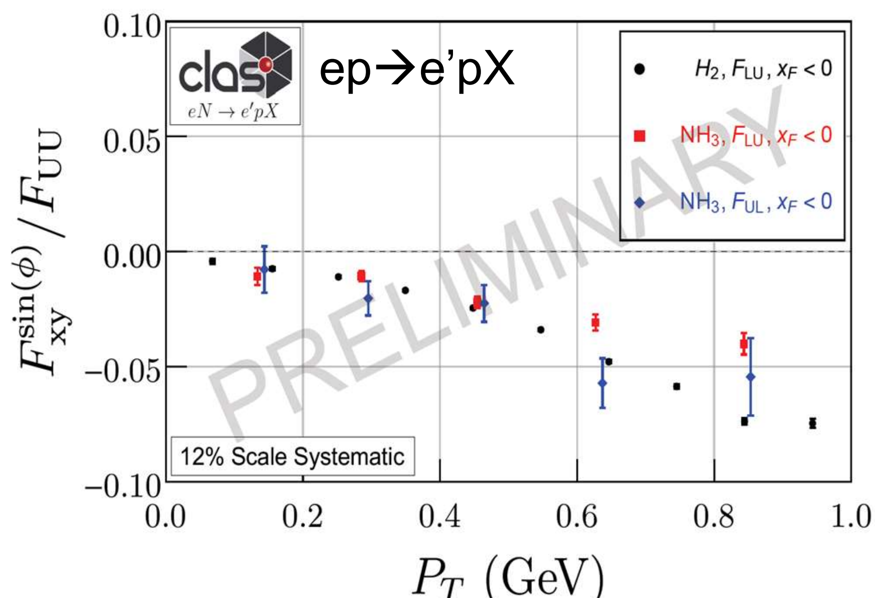


Conditional probability to produce a hadron ***h***, when kicking out quark ***q***

The Twist-3 Fracture Functions responsible for SSAs A_{LU} and A_{UL}

ep→e'pX

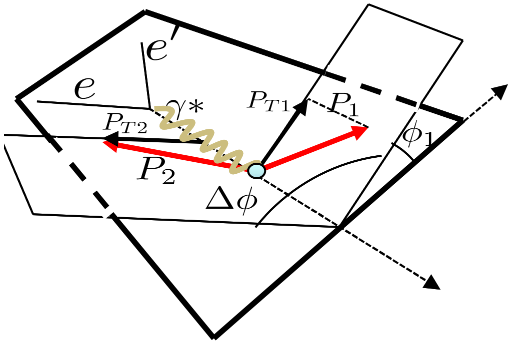


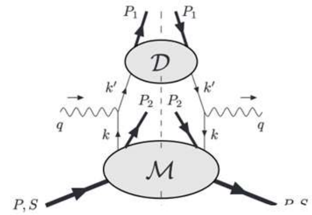


Asymmetries in epX described by the formalism based on Fracture Functions in Target Fragmentation Region (TFR) are generated by unpolarized quarks in the longitudinally polarized target (RGC) F_{UL} or longitudinally polarized quarks in the unpolarized target (RGA) F_{LU} (consistent with each other)

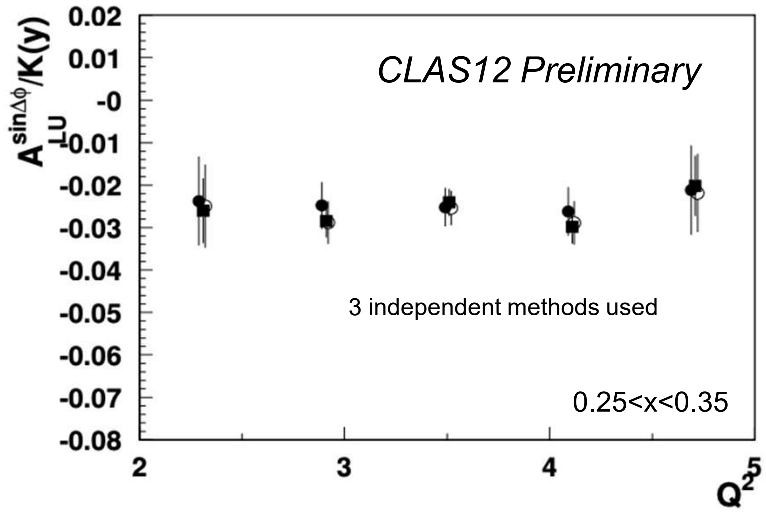
Correlations in back-to-back 2 hadron production

M. Anselmino, V. Barone and A. Kotzinian, Physics Letters B 713 (2012)





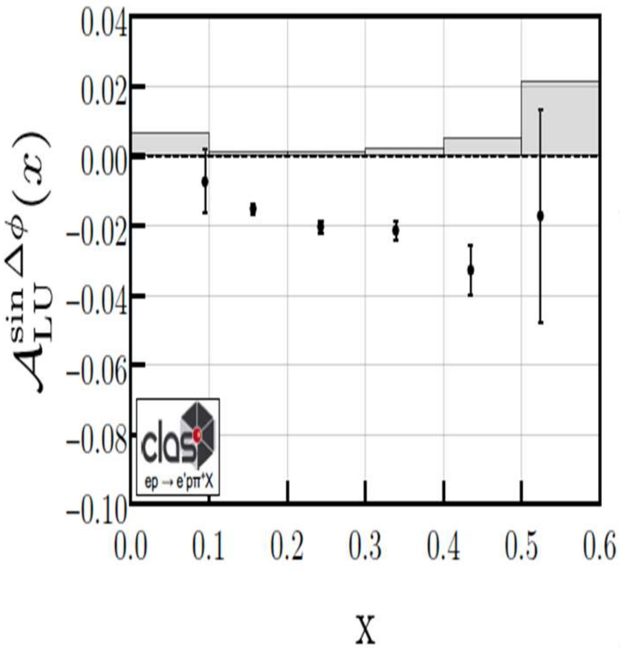
$$A_{LU} \propto \frac{\mathcal{C}[w_5\, \hat{l}_1^{\perp h} D_1]}{\mathcal{C}[\hat{u}_1 D_1]} \sin\Delta\phi$$



arXiv: 2208.05086

Twist-2 table
(Fracture Functions)

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	$\hat{u}_{1T}^h, \hat{u}_{1T}^\perp$	$\hat{l}_{1T}, \hat{l}_{1T}^\perp$	$\hat{t}_{1T}, \hat{t}_{1T}^{hh}, \hat{t}_{1T}^{\perp\perp}, \hat{t}_{1T}^{\perp h}$



- SSA significant at large x, where the valence quarks (non-perturbative sea) dominate?
- Correlation asymmetry is linked to Leading Twist(LT) distributions of longitudinally polarized quarks
- First indication in large x SIDIS of a LT observable
- Correlation between the struck quark and the remnant produces correlation between hadrons (entanglement)
- Multidimensional measurements crucial for evolution studies

SUMMARY

- Studies of QCD dynamics with controlled systematics involving Semi-Inclusive DIS, requires detailed understanding of the contributions into the measured cross sections/multiplicities/asymmetries as a function of all involved kinematical variables (including P_T and ϕ)
- For interpretation of the SIDIS data it is critical to separate contributions from different structure functions, as well as separation of different production mechanisms in a given structure function
- To evaluate the systematics of extracted 3D PDFs (TMDs and GPDs) , it is critical to validate the formalism, and understand main contributions violating the factorized picture based on the dominance of the leading twist contributions
- Measurements of azimuthal modulations of inclusive pions, and multiplicities of pion pairs indicate very significant part of hadrons come from decays of VMs (even more in kaon case)
- Evolution studies observables will require multidimensional coverage of all relevant kinematics (including depolarization factors) for observables with polarized beams and targets
- Progress in theory and lattice calculations in describing the higher twist observables will be crucial for future precision studies of the 3D structure of nucleon using the GPD and TMD formalisms.