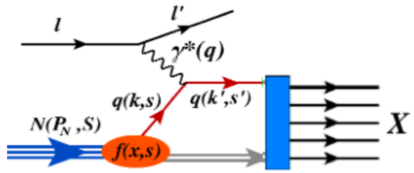
Present and Future of Polarized Target Experiment at CLAS12

Harut Avakian (JLab)

CLAS Collaboration Meeting
February 20th

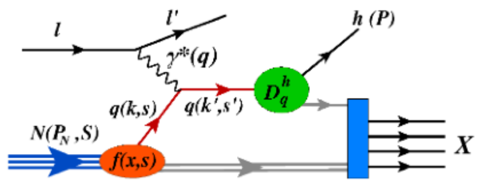
QCD: from testing to understanding

0h DIS

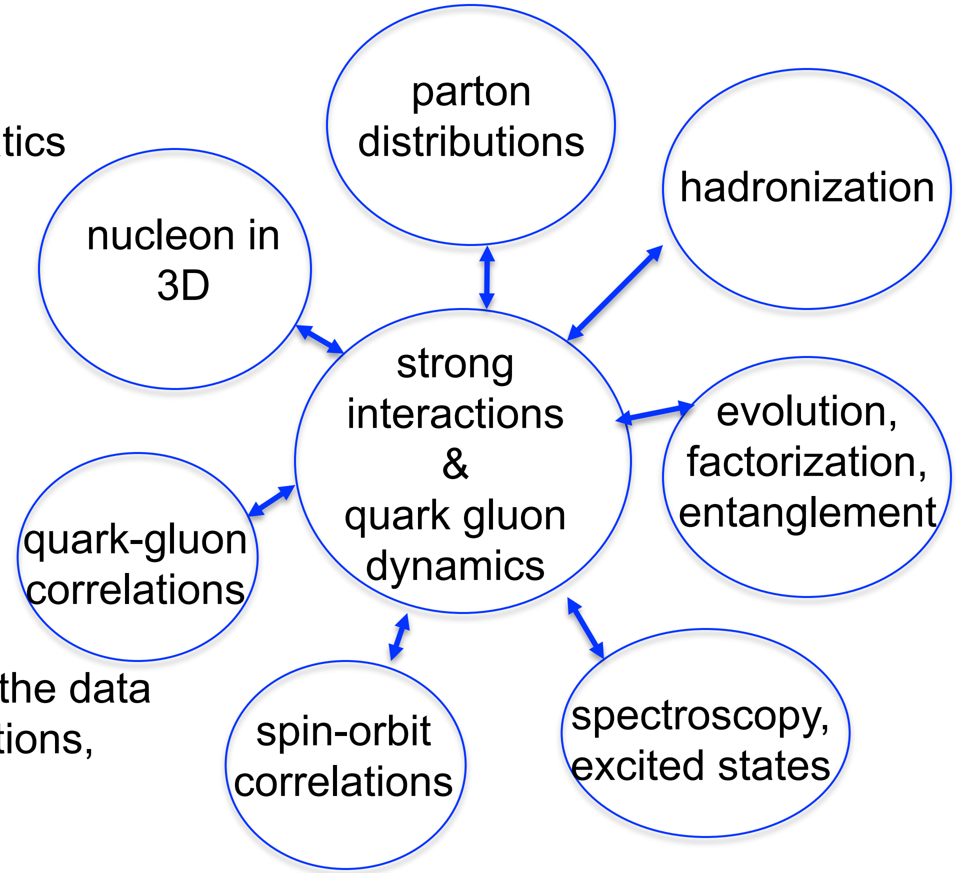


Testing stage:
pQCD predictions, observables in the kinematics where theory predictions are easier to get (higher energies, 1D picture, leading twist, current fragmentation, IMF)

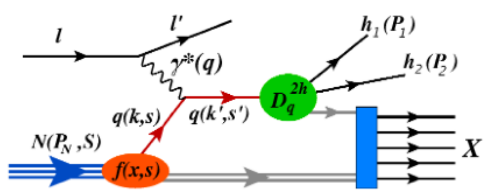
1h SIDIS/DVMP



Understanding stage:
non-perturbative QCD, strong interactions, observables in the kinematics where most of the data is available (all energies, quark-gluon correlations, orbital motion)



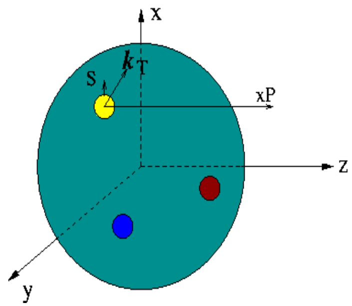
2h SIDIS/DVMP

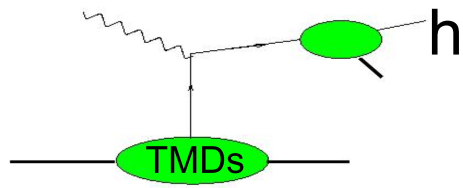


production in SIDIS provides access to correlations inaccessible in simple SIDIS

3D structure of the nucleon

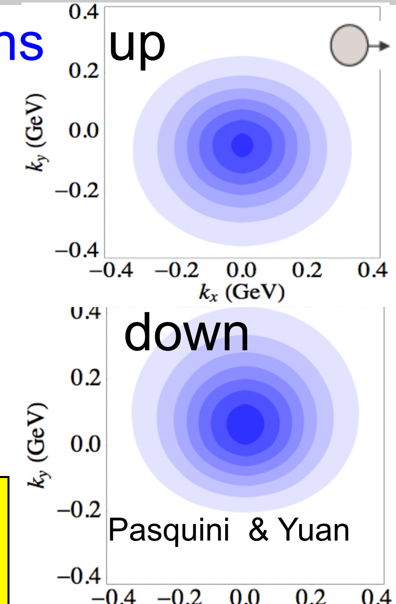
Semi-Inclusive processes and transverse momentum distributions





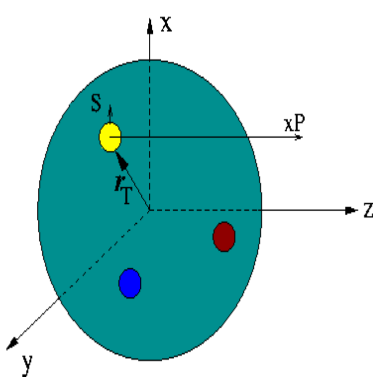
$$f_1^q(x,\mathbf{k}_\perp) \quad g_1^q \quad f_{1T}^{\perp q} \quad g_{1T}^q$$
$$h_1^q \quad h_{1T}^{\perp q} \quad h_{1L}^{\perp q} \quad h_1^{\perp q}$$

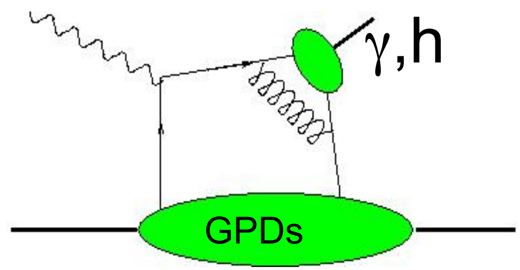
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$



Main goal of the upgraded JLab 3D program:
Study spin and flavor dependence of transverse space and transverse momentum distributions of quarks.

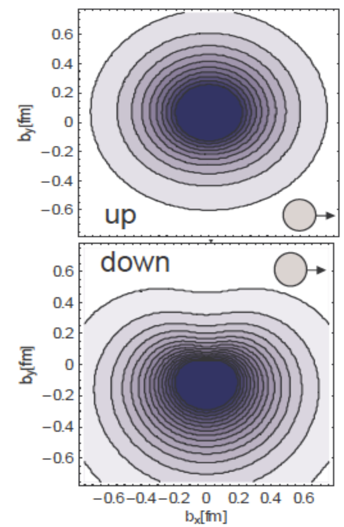
Hard exclusive processes and spatial distributions of partons





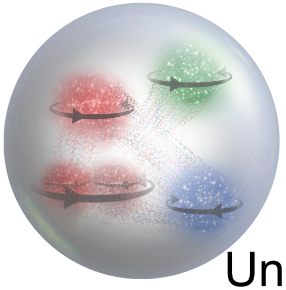
$$H^q(x,\xi,t) \quad \tilde{H}^q \quad E^q \quad \tilde{E}^q$$
$$H_T^q \quad \tilde{H}_T^q \quad E_T^q \quad \tilde{E}_T^q$$

	U	L	T
U	$\mathcal{H}$		$\mathcal{E}_T$
L		$\tilde{\mathcal{H}}$	$\tilde{\mathcal{E}}_T$
T	$\mathcal{E}$	$\tilde{\mathcal{E}}$	$\mathcal{H}_T, \tilde{\mathcal{H}}_T$



(QCDSF)

Features of partonic 3D non-perturbative distributions



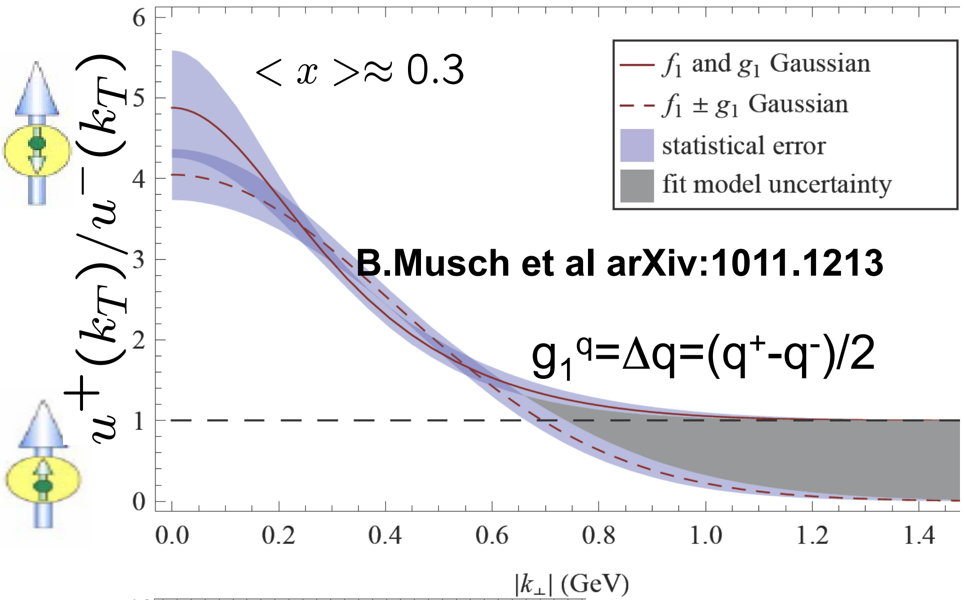
$$f^a(x, k_T^2; Q^2)$$

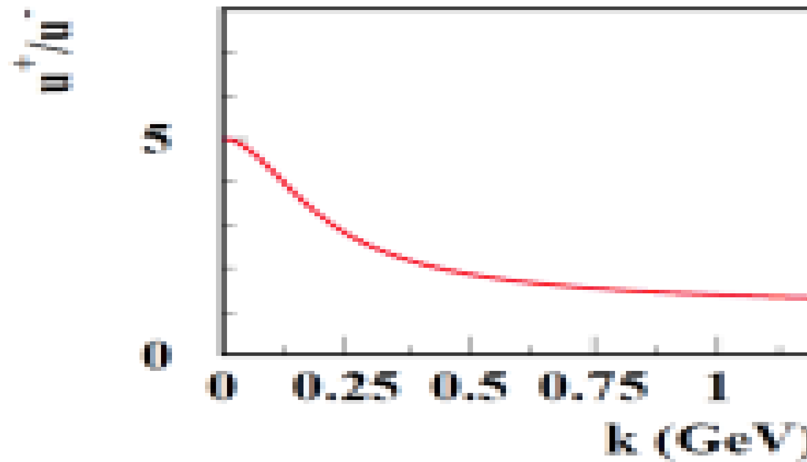
Ex. TMD PDF for a given combination of parton and nucleon spins

Understanding of the 3D structure of nucleon requires studies of spin and flavor dependence of quark transverse momentum and space distributions

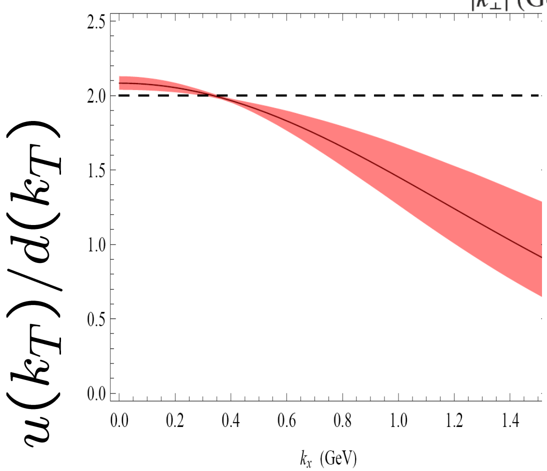
- transverse position and momentum of partons are correlated with the spin orientations of the parent hadron and the spin of the parton itself
- transverse position and momentum of partons depend on their flavor
- transverse position and momentum of partons are correlated with their longitudinal momentum
- quark-gluon interaction play a crucial role in kinematical distributions of final state hadrons, both in semi-inclusive and exclusive processes

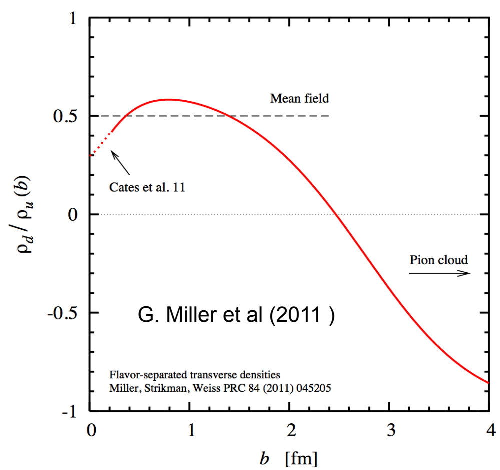
Quark distributions at large k_T: lattice

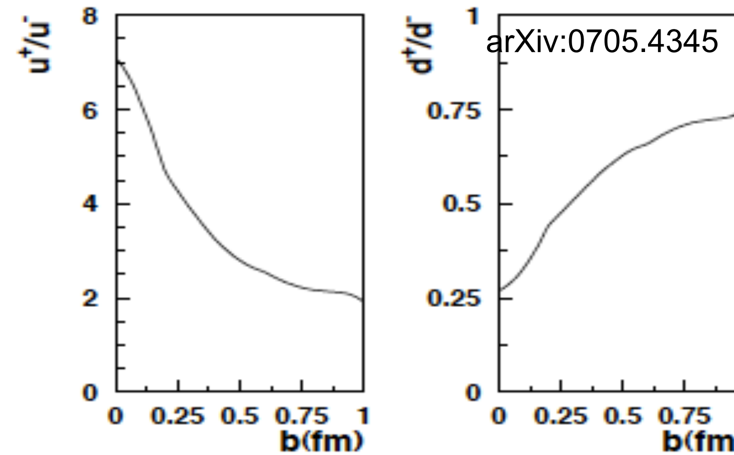




B.Pasquini et al





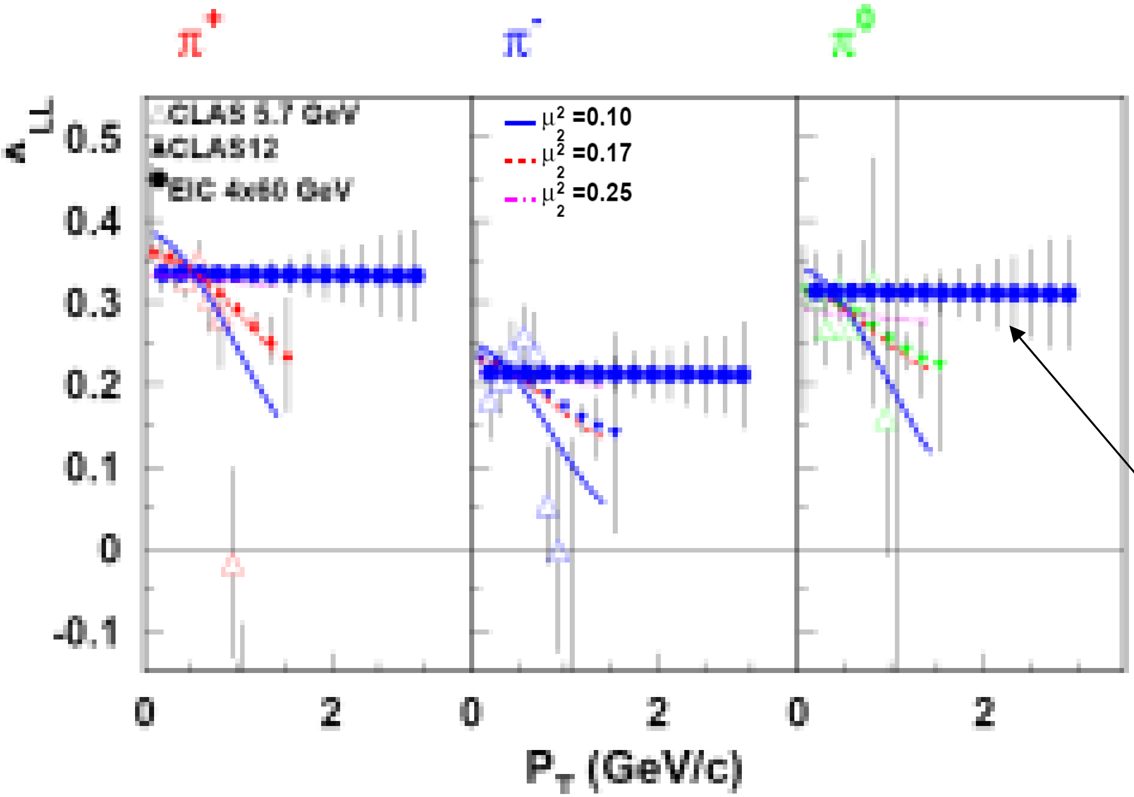


Distributions of PDFs may depend on flavor and spin (lower fraction aligned with proton spin, and less u-quarks at large k_T,b_T)

A_1 P_T-dependence in SIDIS

$$A_1(\pi) \propto \frac{\sum_q e_q^2 g_1^q(x) D_1^{q\to\pi}(z)}{\sum_q e_q^2 f_1^q(x) D_1^{q\to\pi}(z)} \; e^{-z^2 P_T^2 \frac{(\mu_0^2-\mu_2^2)}{(\mu_D^2+z^2\mu_0^2)(\mu_D^2+z^2\mu_2^2)}}$$

M.Anselmino et al
hep-ph/0608048



$$f_1^q(x,k_T) = f_1(x)\frac{1}{\pi\mu_0^2}\exp\left(-\frac{k_T^2}{\mu_0^2}\right)$$

$$g_1^q(x,k_T) = g_1(x)\frac{1}{\pi\mu_2^2}\exp\left(-\frac{k_T^2}{\mu_2^2}\right)$$

$$D_1^q(z,p_T) = D_1(z)\frac{1}{\pi\mu_D^2}\exp\left(-\frac{p_T^2}{\mu_D^2}\right)$$

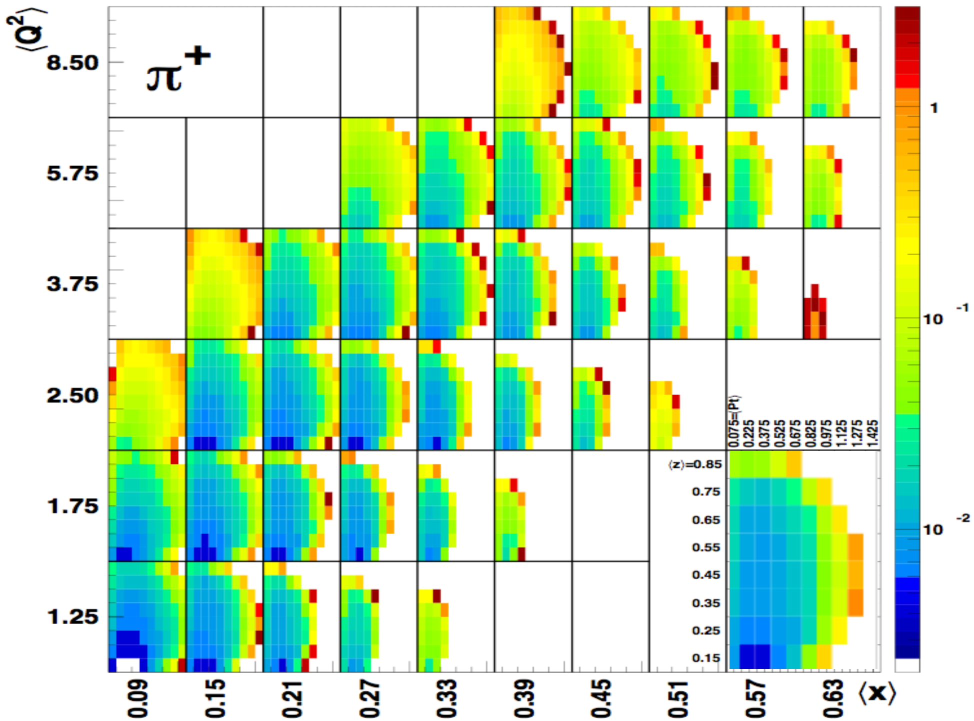
$\mu_0^2=0.25\text{GeV}^2$
$\mu_D^2=0.2\text{GeV}^2$

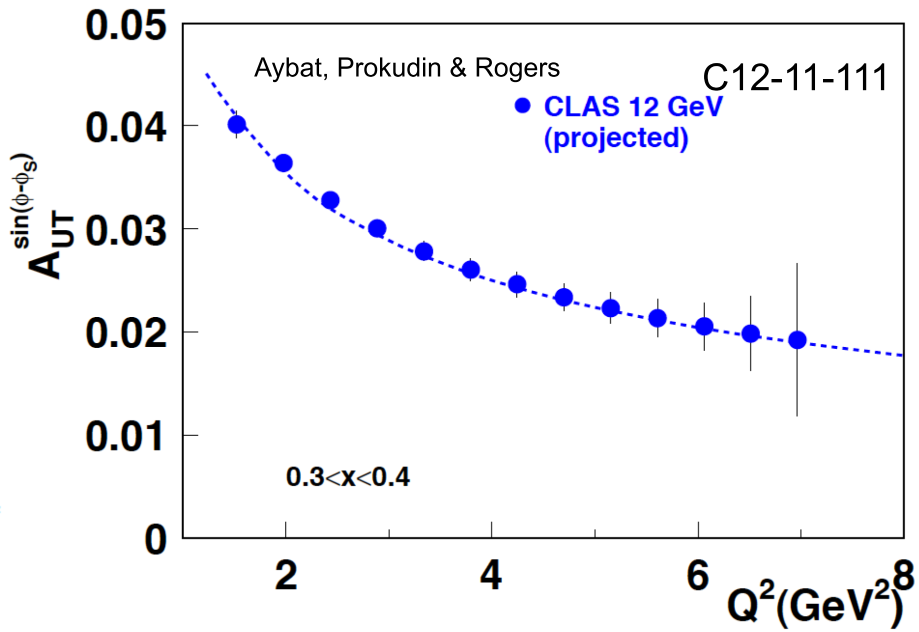
Perturbative limit calculations available for $g_1^q(x,k_T), f_1(x,k_T)$

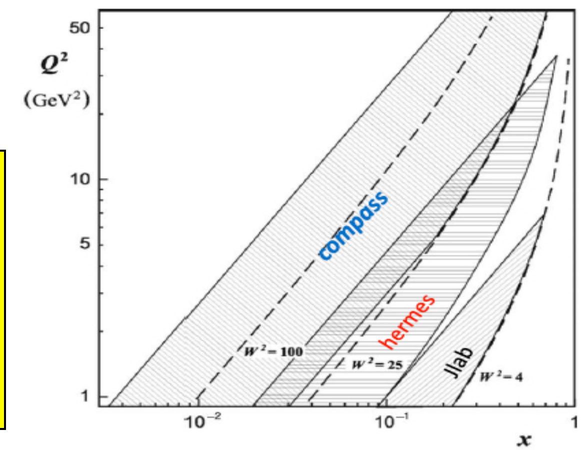
J.Zhou, F.Yuan, Z Liang: arXiv:0909.2238

- A_{LL} (π) sensitive to difference in k_T distributions for f_1 and g_1
- Wide range in P_T allows studies of transition from TMD to perturbative approach

CLAS12 A_{UT} with transverse proton target



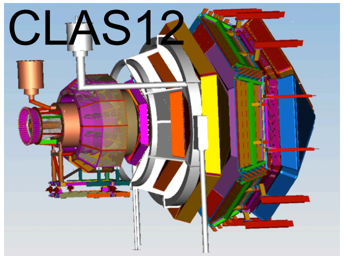




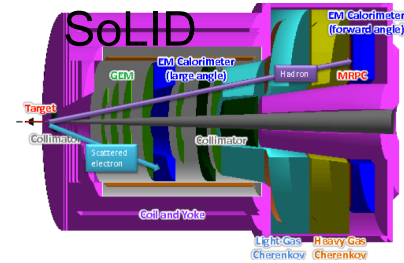
- Large acceptance of CLAS12 allows studies of P_T and Q^2-dependence of SSAs in a wide kinematic range
- Comparison of JLab12 data with HERMES, COMPASS (and EIC) will pin down the non-trivial Q^2 evolution of Sivers asymmetry.

Accessing transversity in dihadron production at JLab

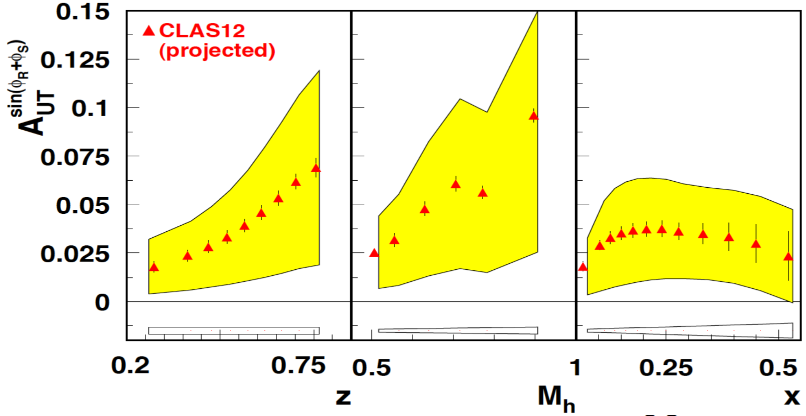
Measurements with polarized protons

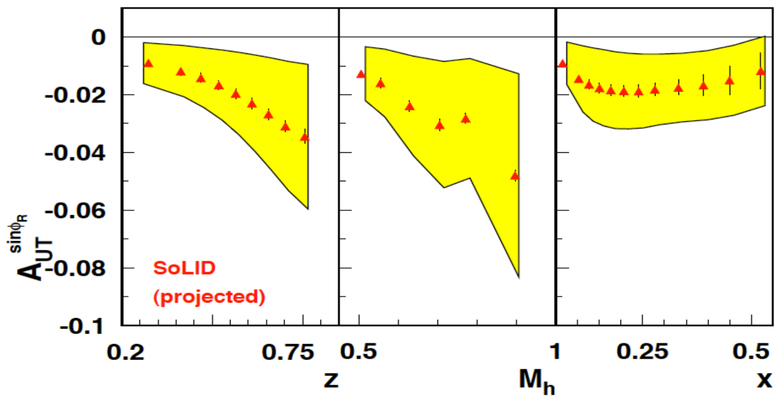


Measurements with polarized neutrons

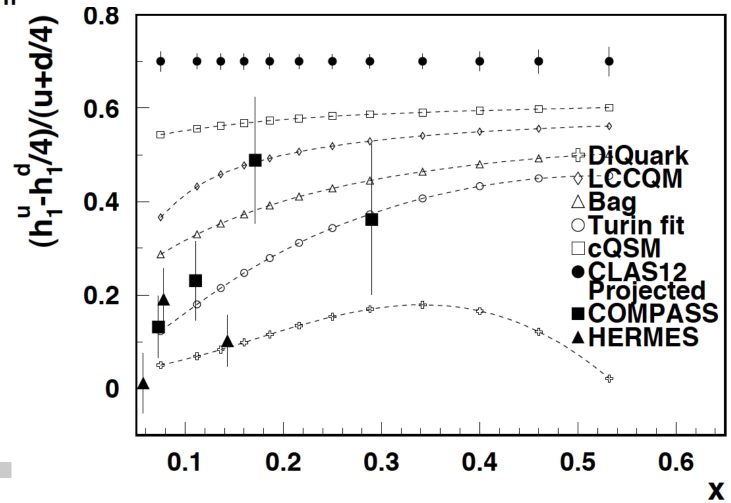


$$A_{UT}(\phi_R,\theta) = \frac{1}{fP_t}\frac{(N^+ - N^-)}{(N^+ + N^-)}$$



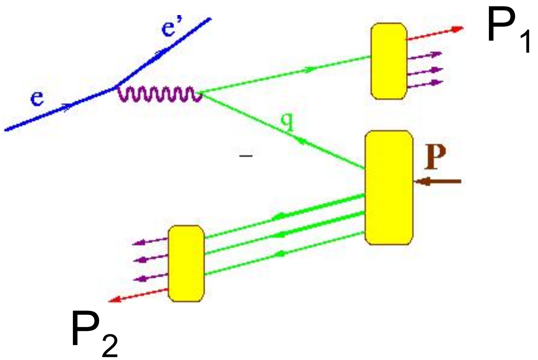


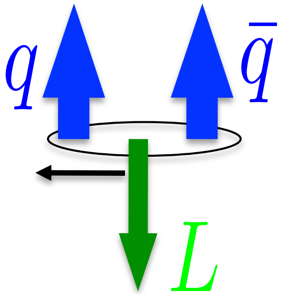
$$\frac{H_{1,sp}^{\sphericalangle,u}(z,M_h)[4h_1^u - h_1^d(x)]}{D_1^u(4f_1^u + f_1^d)}$$

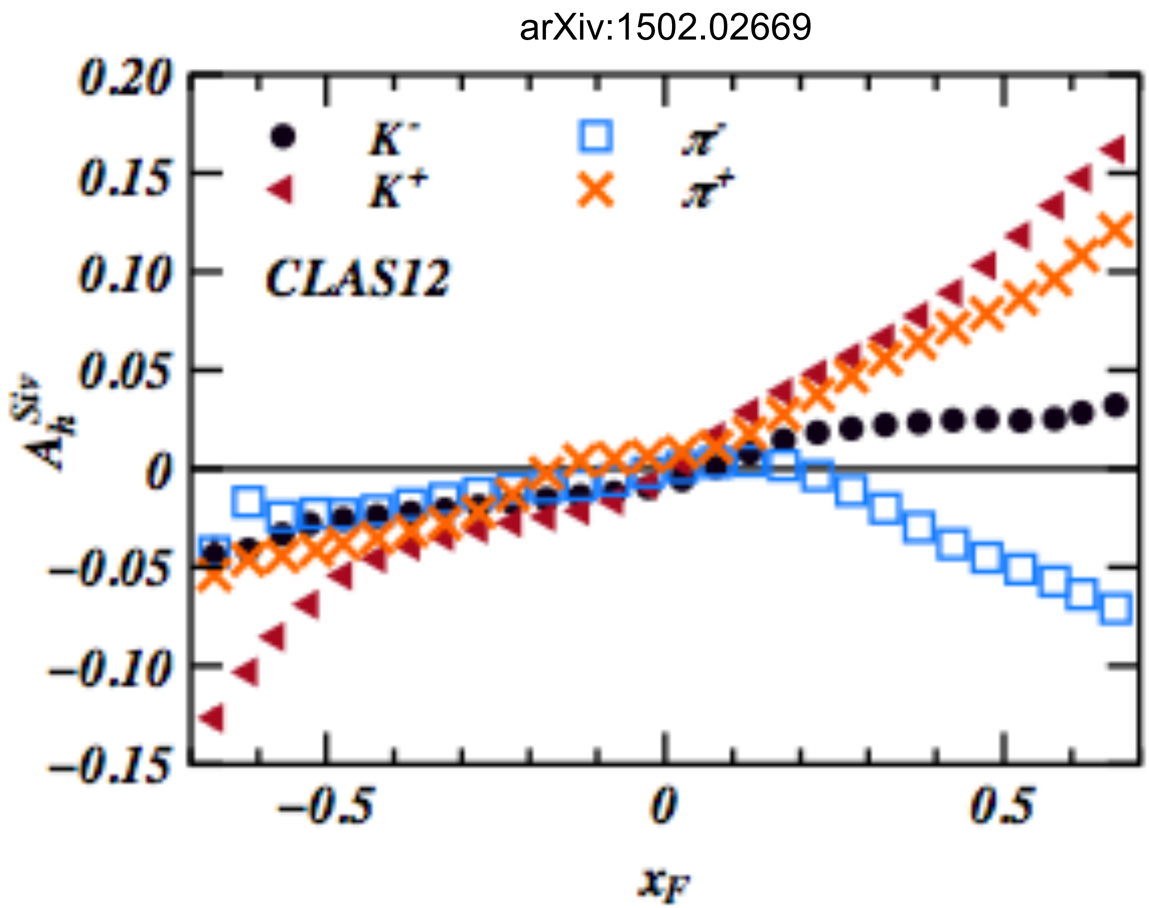


$$\frac{H_{1,sp}^{\sphericalangle,u}(z,M_{\pi\pi})\,\left(4h_1^d(x) - h_1^u(x)\right)}{D_1^u(z,M_{\pi\pi})\,\left(4f_1^d(x) + f_1^u(x)\right)}$$

Sivers effect in the target fragmentation



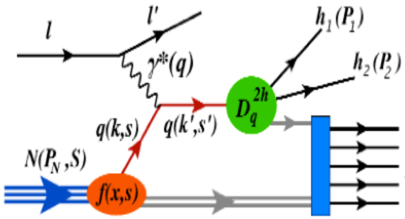




Wide coverage of CLAS12 will allow studies of kinematic dependences of the Sivers effect in target fragmentation region

Accessing Sivers TMD in dihadron production at JLab

A. Kotzinian, H. H. Matevosyan, and A. W. Thomas, Phys.Rev.Lett. 113, 062003 (2014), 1403.5562.



$$\frac{d\sigma^{h_1 h_2}}{dx\, dQ^2\, d\varphi_S\, dz_1\, dz_2\, d^2P_{1T}\, d^2P_{2T}} = C(x,Q^2)\,(\sigma_U + \sigma_S)$$

$$\sigma_2 \frac{P_{2T}}{M} \sin(\varphi_2 - \varphi_S) \qquad \sigma_1 \frac{P_{1T}}{M} \sin(\varphi_1 - \varphi_S)$$

$$\boldsymbol{P}_T = \boldsymbol{P}_\perp + z\boldsymbol{k}_T, \quad \boldsymbol{R}_T = \boldsymbol{R}_\perp + \frac{1}{2}(z_1 - z_2)\,\boldsymbol{k}_T$$

where σ_S, σ_1 and σ_2 depend on $x, Q^2, z_1, z_2, P_{1T}, P_{2T}$ and $P_{1T} \cdot P_{2T}$ (or $\cos(\varphi_1 - \varphi_2)$).

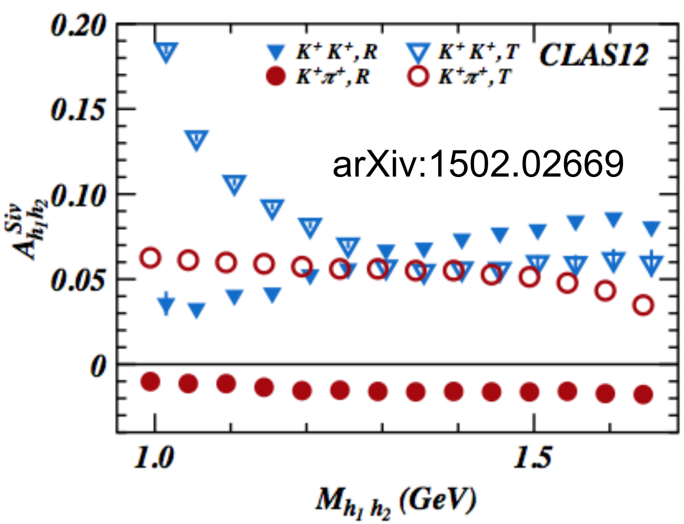
$\sigma_R \neq 0$ can be ensured, by choosing asymmetric cuts on the minimum values of **z**1 and **z**2.

After integration over the azimuthal angle of total transverse momentum

$$P_T = P_{1T} + P_{2T}$$

The asymmetry as a function of transverse momentum

$$R = \frac{1}{2}(P_{1T} - P_{2T})$$



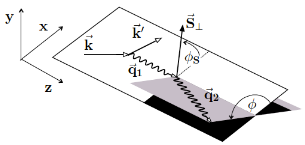
Proposal for PAC43

$$\frac{d\sigma^{h_1 h_2}}{P_T dP_T d^2R} = C(x,Q^2)\left[\sigma_{U,} + S_T\left(\frac{P_T}{2M}\sigma_{T,1} + \frac{R}{M}\sigma_{R,0}\right)\sin(\varphi_R - \varphi_S)\right]$$

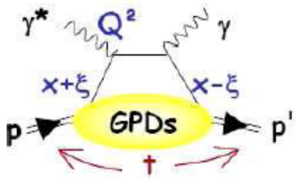
1st harmonic of the $\cos(\phi_T - \phi_R)$

$$\sigma_T = \frac{1}{2}(\sigma_1 + \sigma_2),\ \sigma_R = \sigma_1 - \sigma_2$$

- Measurements with polarized protons @ CLAS12
- Measurements with polarized neutrons @SOLID
- Measurements with EIC



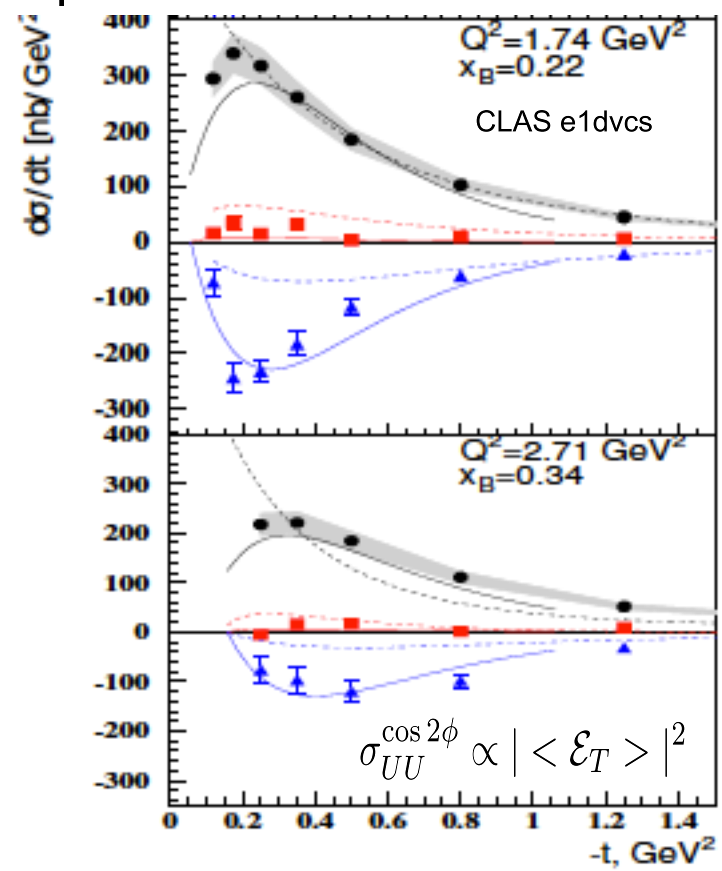
3D structure: GPDs



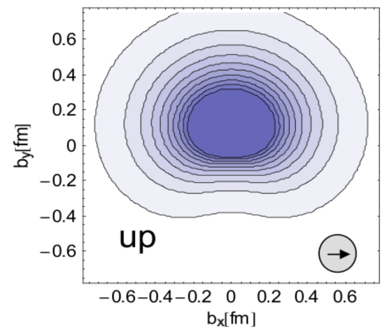
$\sigma_{LU}^{\sin\phi}$ $\sigma_{UL}^{\sin\phi}$ $\sigma_{UT}^{\cos\phi}$

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

ep➔e' pπ^0



DVCS asymmetries measured at HERMES & JLAB
More measurements at JLab, Compass



Lattice (QCDSF)

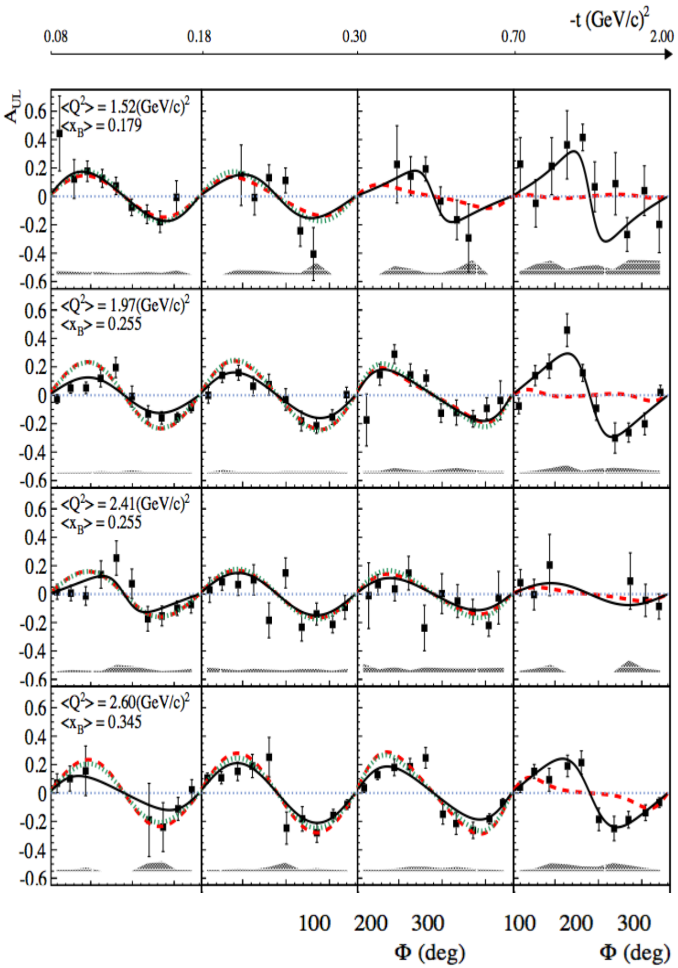
Transverse photon dominates the x-section for exclusive π^0 production

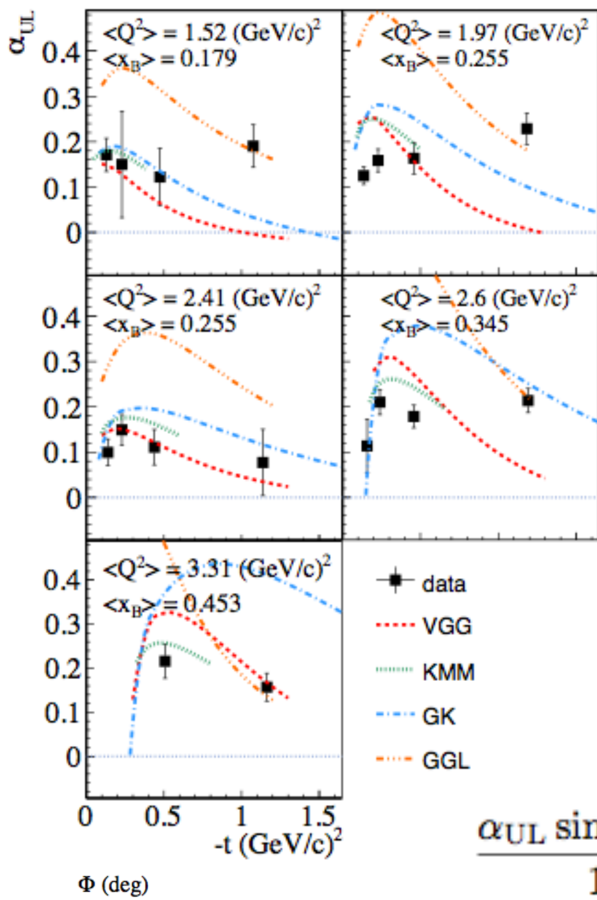
Spin-azimuthal asymmetries in hard exclusive production of photons and pions give access to underlying GPDs

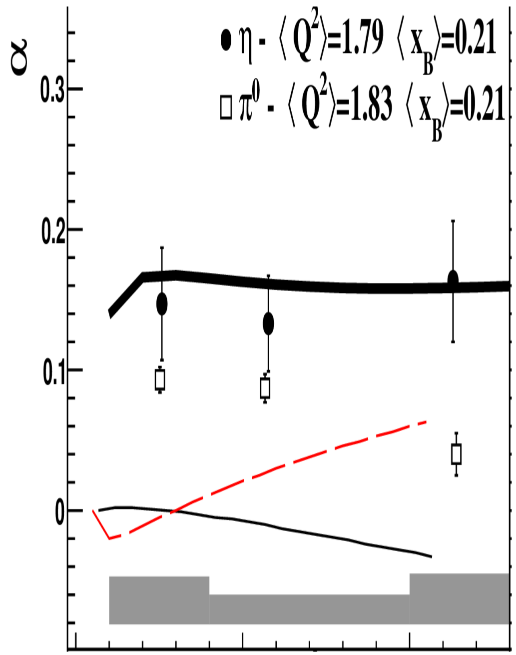
t-dependence of $\tilde{H}$

Unpolarized beam, longitudinal target (TSA) :

$$\Delta\sigma_{UL} \sim \sin\phi \, \mathrm{Im}\{F_1\tilde{\mathcal{H}}+\xi(F_1+F_2)(\mathcal{H}+x_B/2\mathcal{E}) - \xi k F_2 \mathcal{E}+\ldots\}d\phi \Rightarrow Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$



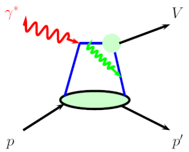




GK- $A_{LU}^{\sin\phi} \sim \mathrm{Im}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$

GL- $A_{LU}^{\sin\phi} \sim \mathrm{Im}\left[\langle E_T\rangle^*\langle\tilde{H}\rangle\right]$

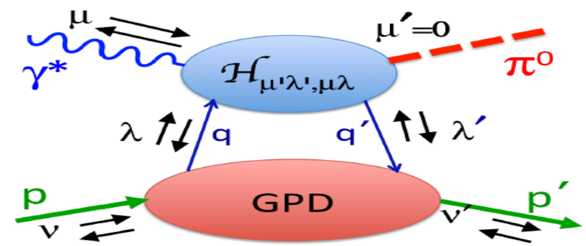
$$\frac{\alpha_{UL}\sin\phi + \gamma_{UL}\sin(2\phi)}{1+\beta\cos\phi}$$



t-dependences of HT

ep➔e' pπ^0

Goldstein, Liuti et al
P.Kroll & S. Goloskokov



helicity flip GPDs $(H_T, E_T, \widetilde{H}_T, \widetilde{E}_T)$

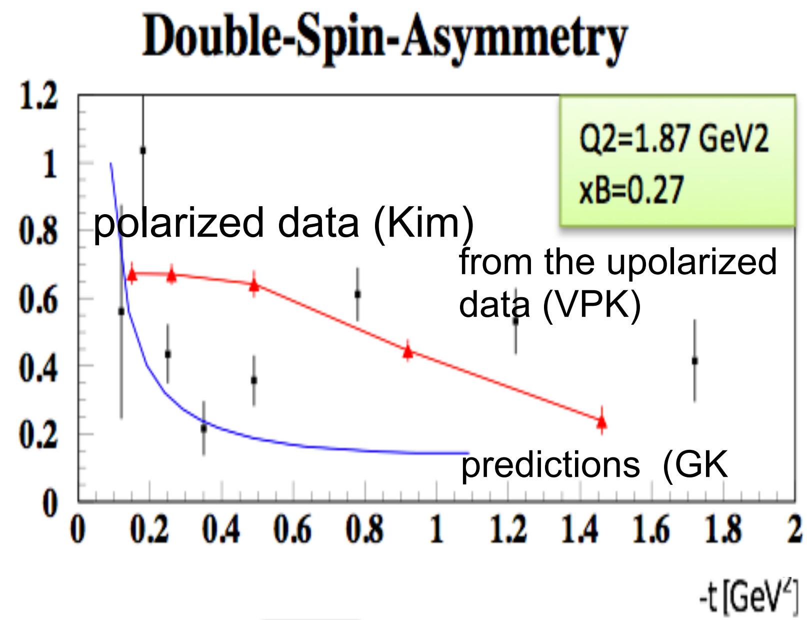
- The production amplitude at large **Q**^{2} factorizes into the hard subprocess and GPDs
- Within the handbag approach γ^*_T➔π transitions are related to transversity (helicity-flip) GPDs accompanied by a twist-3 pion wave function

$$\mathcal{M}^a_{\mu'\pm,\mu+} = \sum_a [\langle H^a \rangle + O(\langle \widetilde{H}^a \rangle)]$$

$$\langle H^a \rangle = \sum_\lambda \int_{xi}^1 d\overline{x} \mathcal{H}^a_{\mu'\lambda,\mu\lambda}(Q^2, \overline{x}, \xi, t) \hat{H}^a(\overline{x}, \xi, t),$$

Hard partonic subprocess

$$\sigma^{const}_{LL} = \frac{4\pi\alpha}{2k} \frac{\mu_\pi^2}{Q^8} (1-\xi^2) \, |\langle H_T \rangle|^2$$



$$A^{const}_{LL} = \frac{\sqrt{1-\epsilon^2}\sigma^{const}_{LL}}{\sigma_T + \epsilon \sigma_L}$$

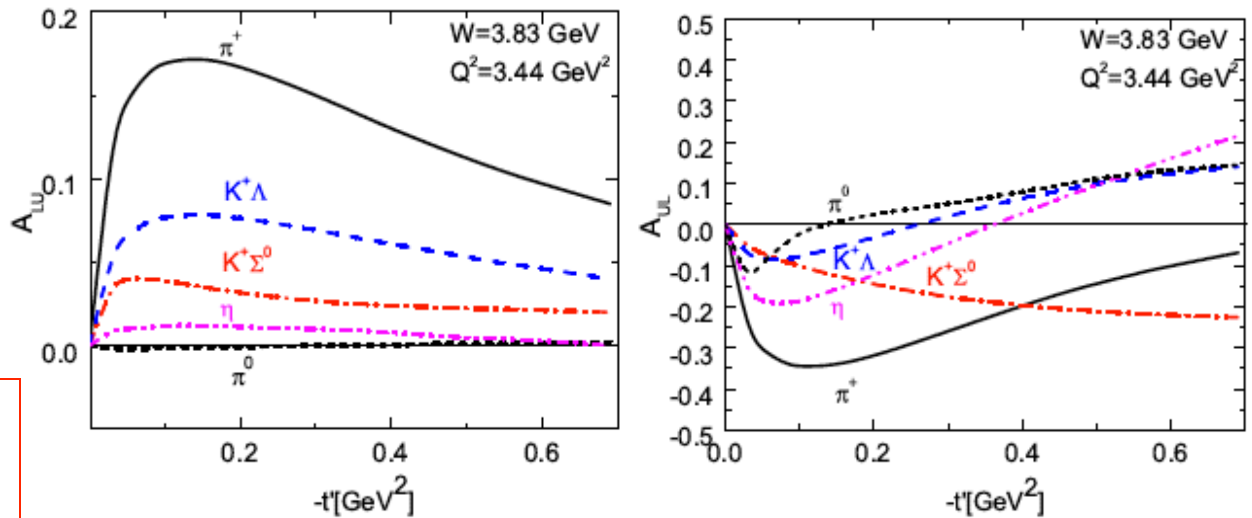
- CLAS12 can measure Q^2 dependence of HT SSAs significantly extending the range of CLAS

SSAs in exclusive kaon production

Proposal for PAC43 (A.Kim et al)

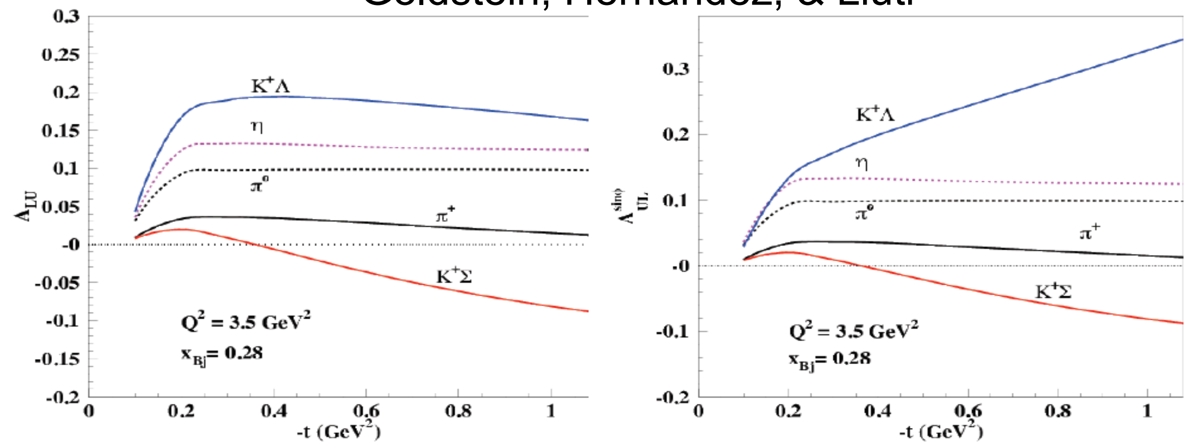
Goloskokov&Kroll

KΣ asymmetries are predicted to be large and with opposite sign to KΛ



Beam and target asymmetries in exclusive production of KΛ and KΣ are very sensitive to chiral-odd GPDs.

Goldstein, Hernandez, & Liuti



$$H_T^{\gamma^* p\to\pi^0 p} \sim [2H_T^u + H_T^d]$$

$$H_T^{\gamma^* p\to\eta p} \sim [2H_T^u - H_T^d]$$

$$H_T^{\gamma^* p\to K^+\Lambda} \sim [2H_T^u - H_T^d - H_T^s]$$

$$H_T^{\gamma^* p\to K^+\Sigma^0} \sim [H_T^d - H_T^s]$$

Exclusive production of KΛ and KΣ provide access to different combinations of chiral-odd GPDs

DVCS on the neutron with a longitudinally polarized ND_3 target

S. Niccolai

A combined analysis of DVCS observables for proton and neutron targets is necessary for flavor separation of GPDs

$$(H,E)_u(\xi,\xi,t) = \frac{9}{15}\left[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)\right]$$

$$(H,E)_d(\xi,\xi,t) = \frac{9}{15}\left[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)\right]$$

Continuation of the experimental program on nDVCS starting with the beam-spin asymmetry, the observable the most sensitive to the least constrained GPD, E ($\rightarrow J_q$) (E12-11-003)

Unpolarized beam, longitudinal target: target-spin asymmetry

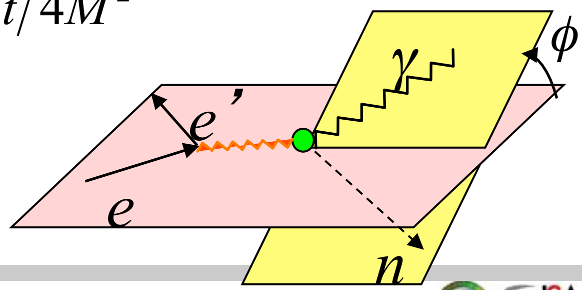
$$s^{I}_{1,UL} \sim \sin\phi\, \mathrm{Im}\{F_1\tilde{H} + \xi(F_1+F_2)(H + x_B/2E) - \xi k F_2 \tilde{E} + \ldots\} \Rightarrow Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$$

Polarized beam, longitudinal target: double-spin asymmetry

$$c^{I}_{1,LP} \sim (A + B\cos\phi)\, \mathrm{Re}\{F_1\tilde{H} + \xi(F_1+F_2)(H + x_B/2E)\ldots\} \Rightarrow Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$$

$$\mathrm{Im}\mathcal{H}_q = \pi e_q^2 \left[H_q(\xi,\xi,t) - H_q(-\xi,\xi,t)\right] \quad \xi = x_B/(2-x_B) \quad k = -t/4M^2$$

$$Re\mathcal{H}_q = e_q^2 P\int_0^{+1}\left(H^q(x,\xi,t) - H^q(-x,\xi,t)\right)\left[\frac{1}{\xi - x} + \frac{1}{\xi + x}\right]dx$$



Proposal for PAC43
(S. Niccolai, A. Biselli, C. Keith, S. Pisano, D. Sokhan)

Experimental setup

$ed \to e(p)n\gamma$

- $^{14}ND_3$ longitudinally polarized target (DNP) *(see C. Keith's talk):*

$L = f\ \rho\ L\ N_A I = 9.1 \times 10^{33}\ s^{-1}\ cm^{-2}$ *(per nA)*

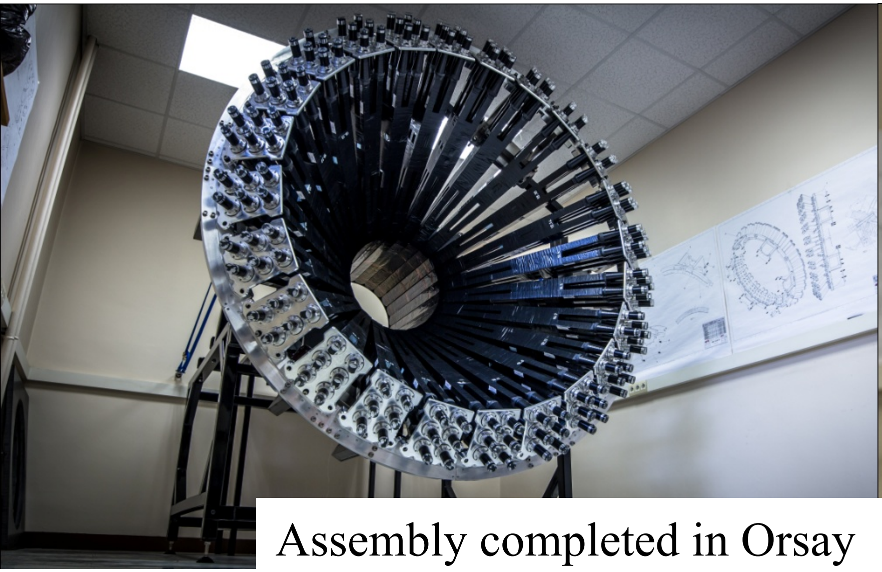
f = filling factor,0.6; $\rho(^{14}ND_3)$ = 1.007 g/cm^3; L = 4.0 cm; I = 6.24 x 10^9 e-/s *(per nA)*

Neutron polarization = ~40%

At 10 nA, to repair the target from radiation damage 1-2 anneals per week are needed

- CLAS12 + Forward tagger: detection of electron, γ ($\theta > 5°$) and γ ($2.5° < \theta < 5°$)
- Central Neutron Detector for the recoil neutron: ~10% detection efficiency

CND design: scintillator barrel, 3 radial layers, 48 bars per layer coupled downstream by "u-turn" lightguides, signals read upstream by PMTs at the end of 1.5-m-long lightguides



Assembly completed in Orsay
Shipping to JLab in June

Expected accuracy and coverage: TSA

$Im\{\mathcal{H}_n\}$

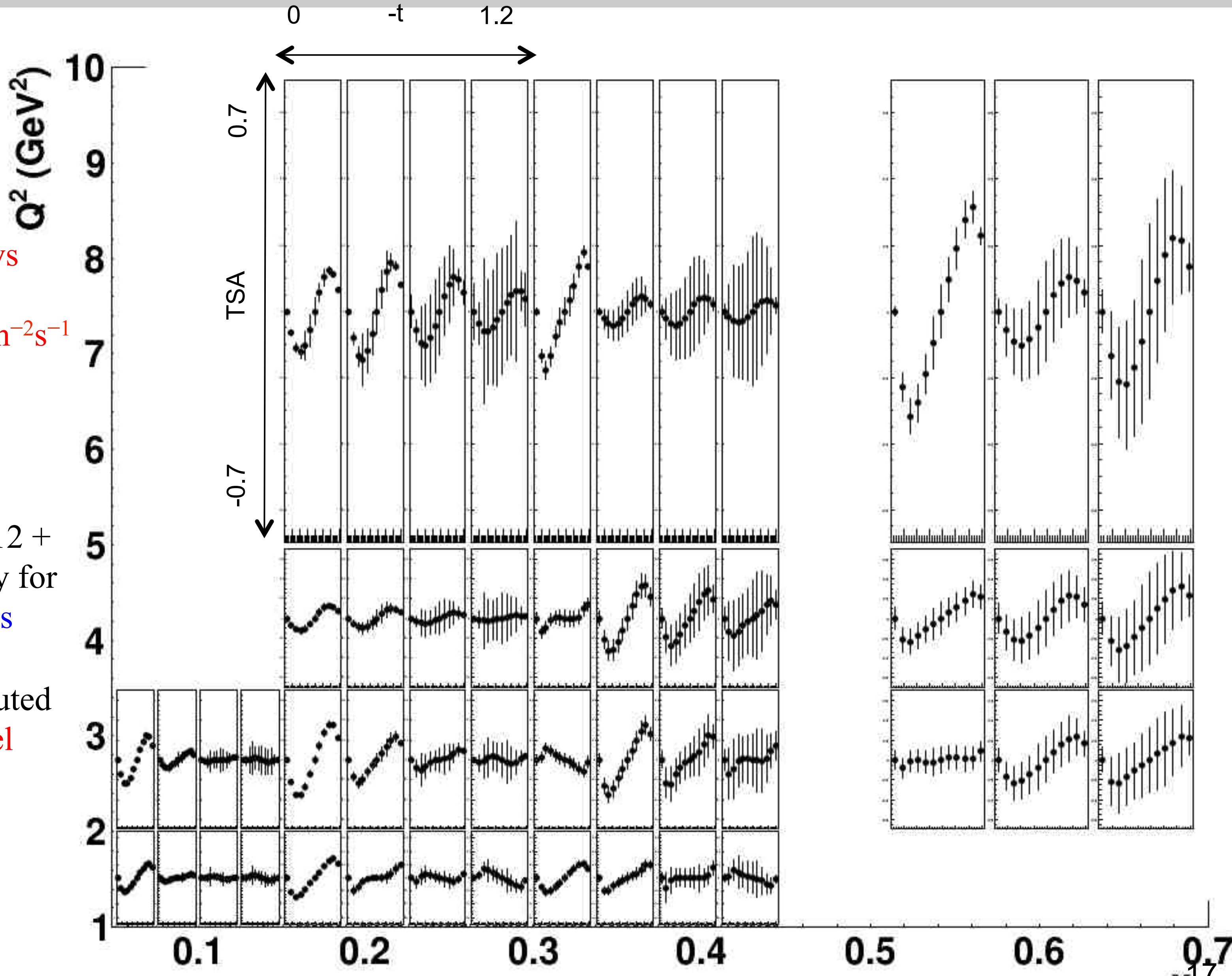
Beam-time: 160 days

$L = 3/20 \cdot 0.9\ 10^{35}\ cm^{-2}s^{-1}$

$P_n = 40\%$

nDVCS generator + Fast MC for CLAS12 + FT + 10% efficiency for CND, for count rates

Asymmetries computed with the VGG model



Summary

The main goal of the upgraded JLab 3D program is the study of spin and flavor dependence of transverse space and transverse momentum distributions of quarks.

•Understanding of transverse momentum and space distributions of polarized quarks is crucial for interpretation of semi-inclusive and exclusive production of hadrons and photons

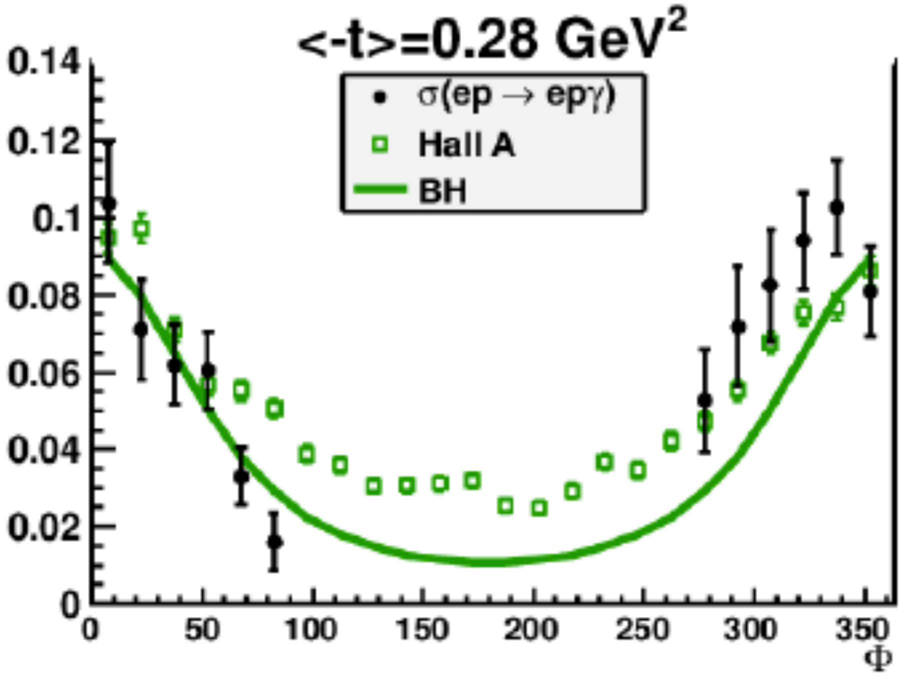
•Identification of Kaons will significantly enhance CLAS12 capabilities to study flavor dependence of transverse distributions in semi-inclusive and exclusive processes.

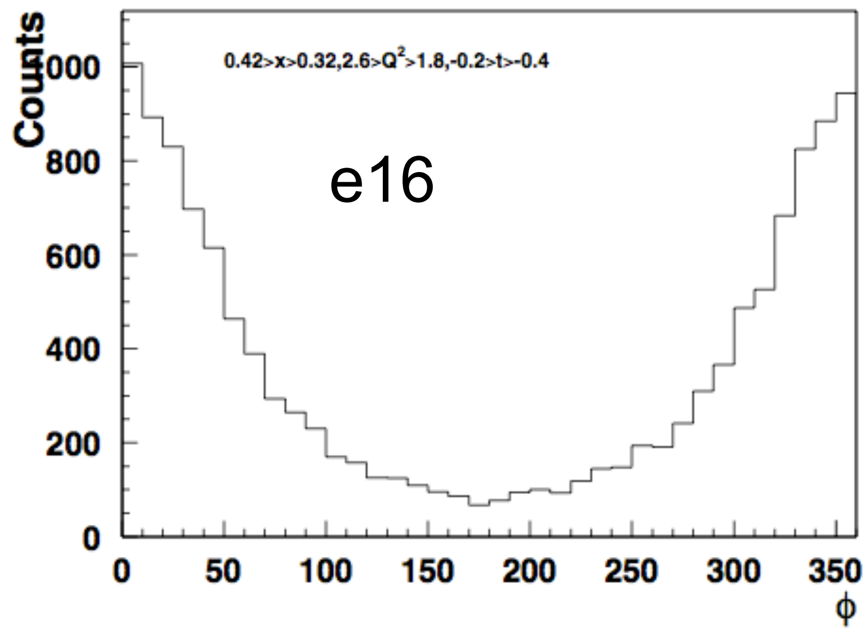
•Measurements with unpolarized, longitudinally and transversely polarized targets of hard exclusive and semi-inclusive processes will help to accomplish the CLAS12 program of studies of the 3D structure of the nucleon

Need TMD/CFF extraction framework with controlled systematics.

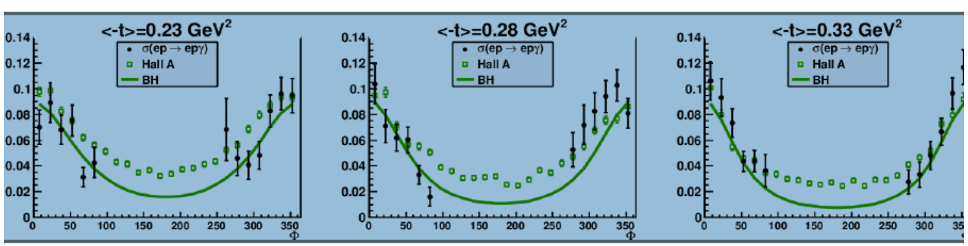
Support slides….

Studies of DVCS (IC vs EC)





The Hall A kinematics are: $Q^2 = 2.3$ GeV^2, $x_B = 0.36$, and different $-t$ values (0.23, 0.28,
GeV^2). Figure 297 shows the finite bin size corrections (see Section 13), as a function of ϕ, for
three bins in t. Figure 298 presents the comparison of the ϕ distributions between the unpolar
$ep \to ep\gamma$ cross sections that we extracted at the Hall A kinematics (black circles) and the Ha
results (green squares), for the three bins in t. The BH cross section is also shown, as a func
of ϕ, represented by the green curves.



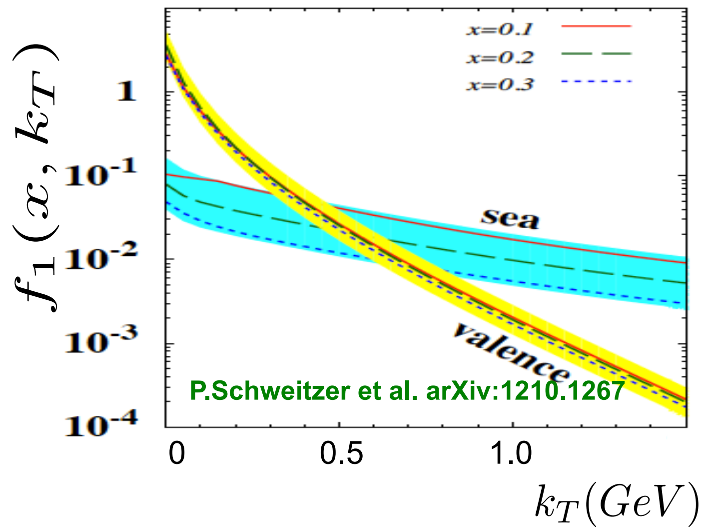
BH-> along the beam
DVCS-> γ^*
To study DVCS-> have to look around the virtual photon

Intrinsic k_T: Valence vs. sea quarks

Dynamical mechanisms creating nucleon sea?

Non-perturbative sea in nucleon due to chiral symmetry breaking

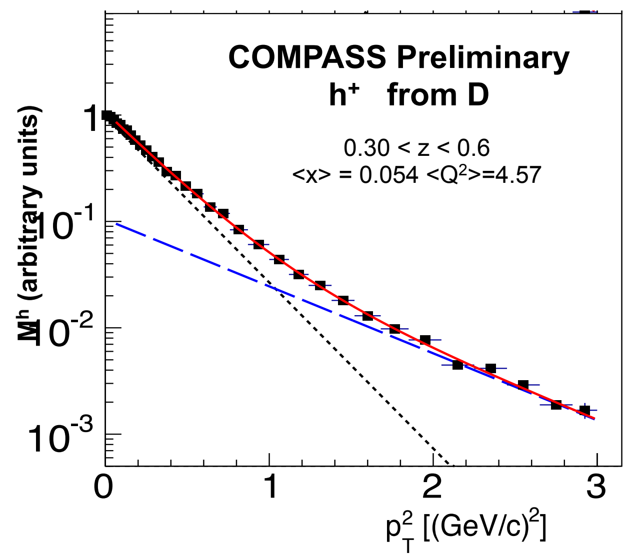
-- Large flavor asymmetry dbar > ubar as evidence
-- Partonic expression of q-qbar vacuum condensate?
-- Related to dynamical mass generation –



Higher probability to find more sea quarks at **large k_T**

- 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)
  -- directly observable in P_T-dependence of hadrons in SIDIS



Exclusive $\pi+/\pi^0$

arXiv:0906.0460

$$
\begin{aligned}
A_{UT}^{\sin(\phi-\phi_s)}\sigma_0 &= -2\epsilon\cos\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0-,0+}\mathcal{M}_{0+,0+}\Big] \\
&- \cos\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0+,++}\mathcal{M}_{0-,-+} - \mathcal{M}^*_{0-,++}\mathcal{M}_{0+,-+}\Big]\,, \\
&+\frac{1}{2}\sin\theta_\gamma\sqrt{\epsilon(1+\epsilon)}\,\mathrm{Im}\Big[(\mathcal{M}^*_{0+,++}+\mathcal{M}^*_{0+,-+})\mathcal{M}_{0+,0+} \\
&+(\mathcal{M}^*_{0-,++}+\mathcal{M}^*_{0-,-+})\mathcal{M}_{0-,0+}\Big] \\
A_{UT}^{\sin(\phi_s)}\sigma_0 &= \cos\theta_\gamma\sqrt{\epsilon(1+\epsilon)}\,\mathrm{Im}\Big[\mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+} - \mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+}\Big]\,, \\
A_{UT}^{\sin(2\phi-\phi_s)}\sigma_0 &= \cos\theta_\gamma\sqrt{\epsilon(1+\epsilon)}\,\mathrm{Im}\Big[(\mathcal{M}^*_{0+,-+}\mathcal{M}_{0-,0+} - \mathcal{M}^*_{0-,-+}\mathcal{M}_{0+,0+}\Big] \\
&+\frac{1}{2}\epsilon\sin\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0+,++}\mathcal{M}_{0+,-+}+\mathcal{M}^*_{0-,++}\mathcal{M}_{0-,-+}\Big]\,, \\
A_{UT}^{\sin(\phi+\phi_s)}\sigma_0 &= \epsilon\cos\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,++}\Big] \\
&+\frac{1}{2}\sin\theta_\gamma\sqrt{\epsilon(1+\epsilon)}\,\mathrm{Im}\Big[(\mathcal{M}^*_{0+,++}+\mathcal{M}^*_{0+,-+})\mathcal{M}_{0+,0+} \\
&+(\mathcal{M}^*_{0-,++}+\mathcal{M}^*_{0-,-+})\mathcal{M}_{0-,0+}\Big] \\
A_{UT}^{\sin(2\phi+\phi_s)}\sigma_0 &= \frac{1}{2}\epsilon\sin\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0+,++}\mathcal{M}_{0+,-+}+\mathcal{M}^*_{0-,++}\mathcal{M}_{0-,-+}\Big]\,, \\
A_{UT}^{\sin(3\phi-\phi_s)}\sigma_0 &= \epsilon\cos\theta_\gamma\,\mathrm{Im}\Big[\mathcal{M}^*_{0+,-+}\mathcal{M}_{0-,-+}\Big]\,. \qquad (44)
\end{aligned}
$$

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

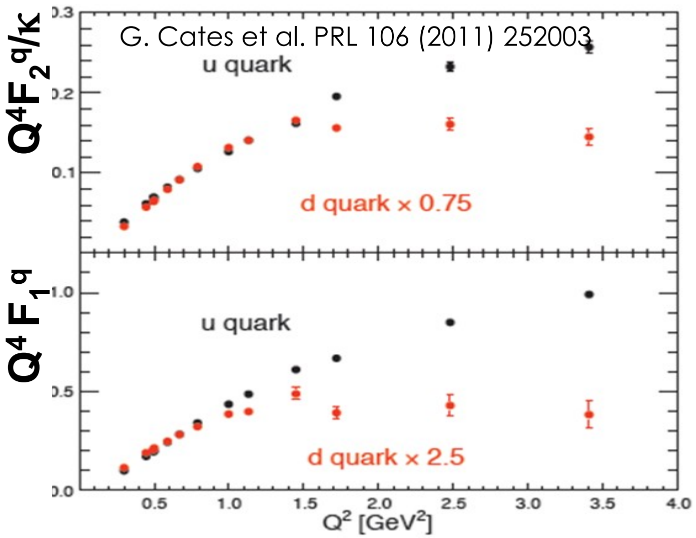
Different transverse moments will give access to different combinations of GPDs

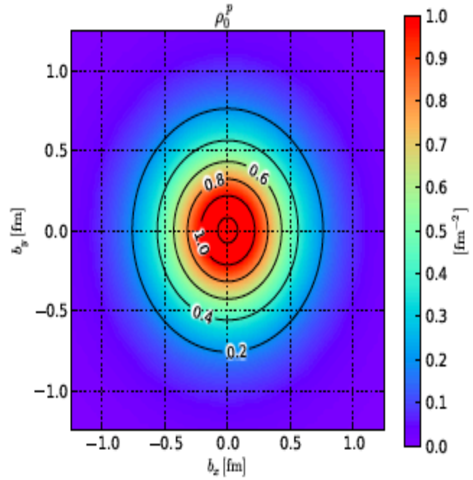
We propose a combination of measurements of cross sections, spin and azimuthal asymmetries with a longitudinally polarized beam and both unpolarized and longitudinally polarized proton target providing a flavor decomposition of underlying chiral-odd GPDs.

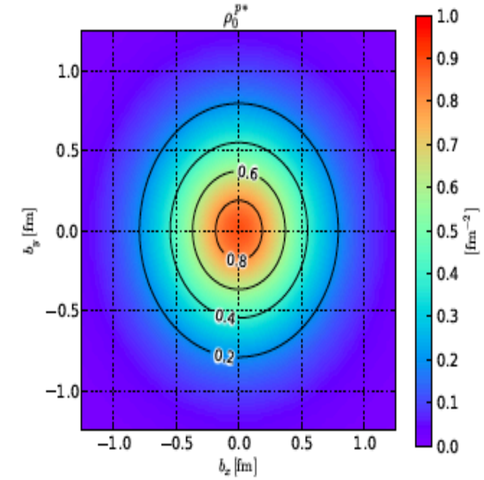
- Exclusive production of pseudoscalar mesons
- Chiral-Odd GPDs and transverse photon
- Studies of Transversity and GPD $\bar{E}_T$
- Exclusive kaon production and separation of different channels

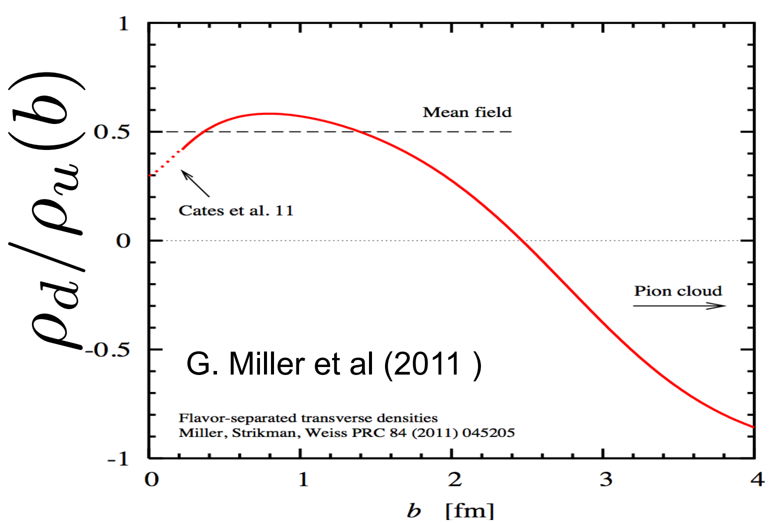
Flavor separation of form factors

Quark transverse charge densities inside an unpolarized proton arXiv:1304.5926





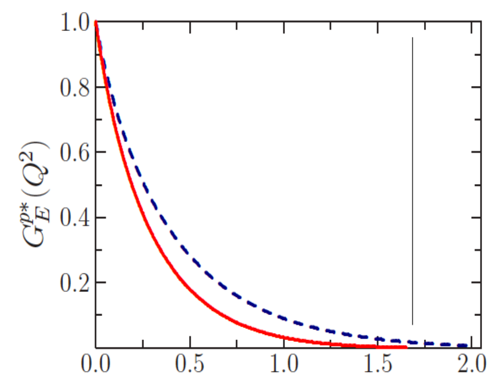




space distributions depend on flavor and spin (modify in medium)

$$\int_0^1 dx\, \mathcal{H}^q(x,t) = F_1^q(t)$$

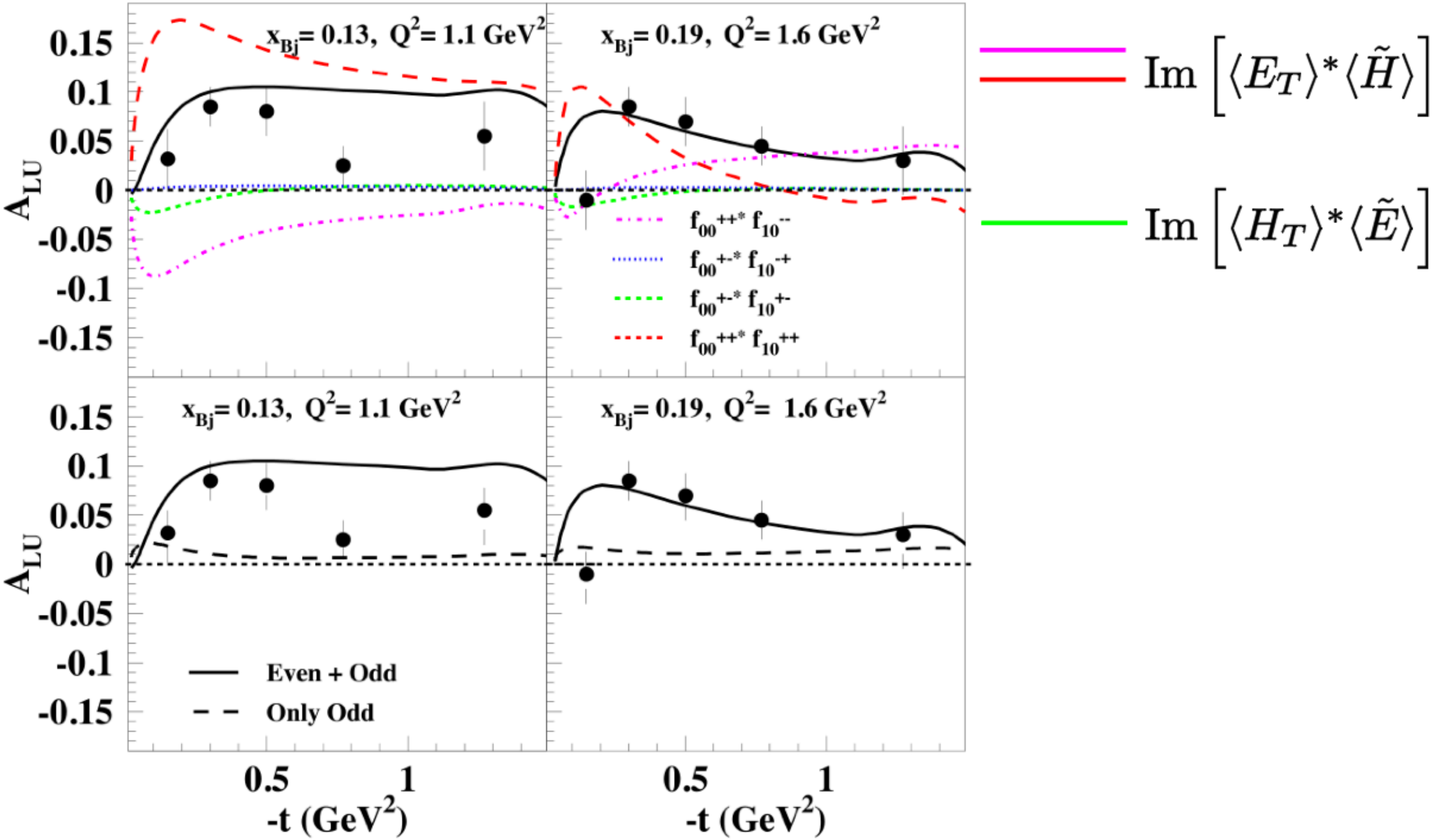
$$\int_0^1 dx\, \mathcal{E}^q(x,t) = F_2^q(t)$$



- form factors of the nucleon fell off faster in nuclear matter

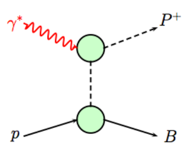
Beam Spin Asymmetries: $ep \to ep\pi^0$

GL model:

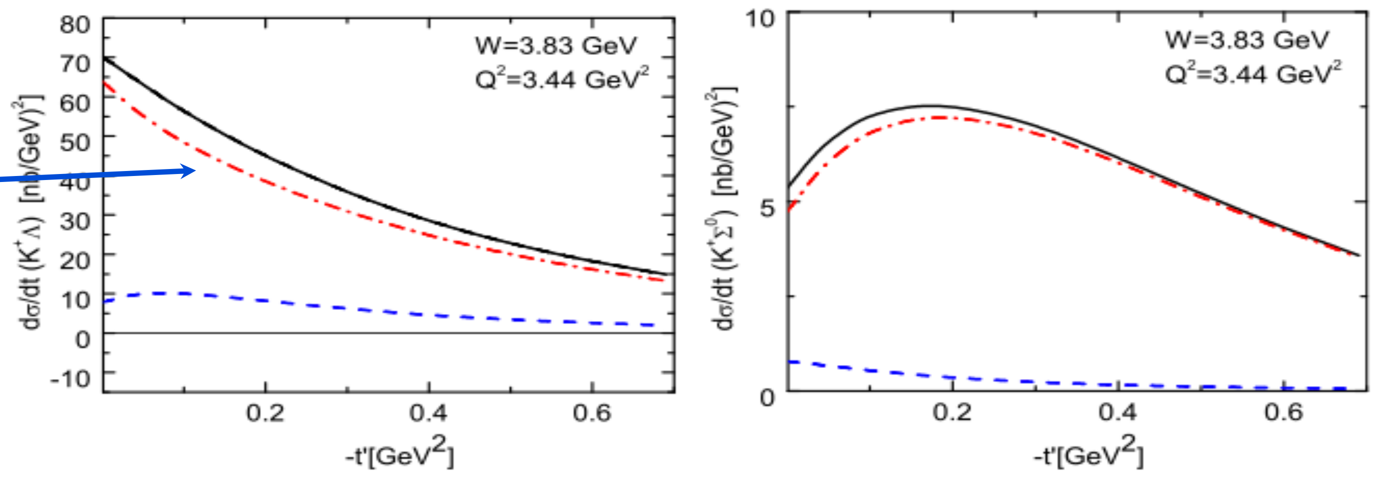


Exclusive kaon production

Unlike π+ the K+ x-section is totally dominated by the transverse photon



pole contribution negligible



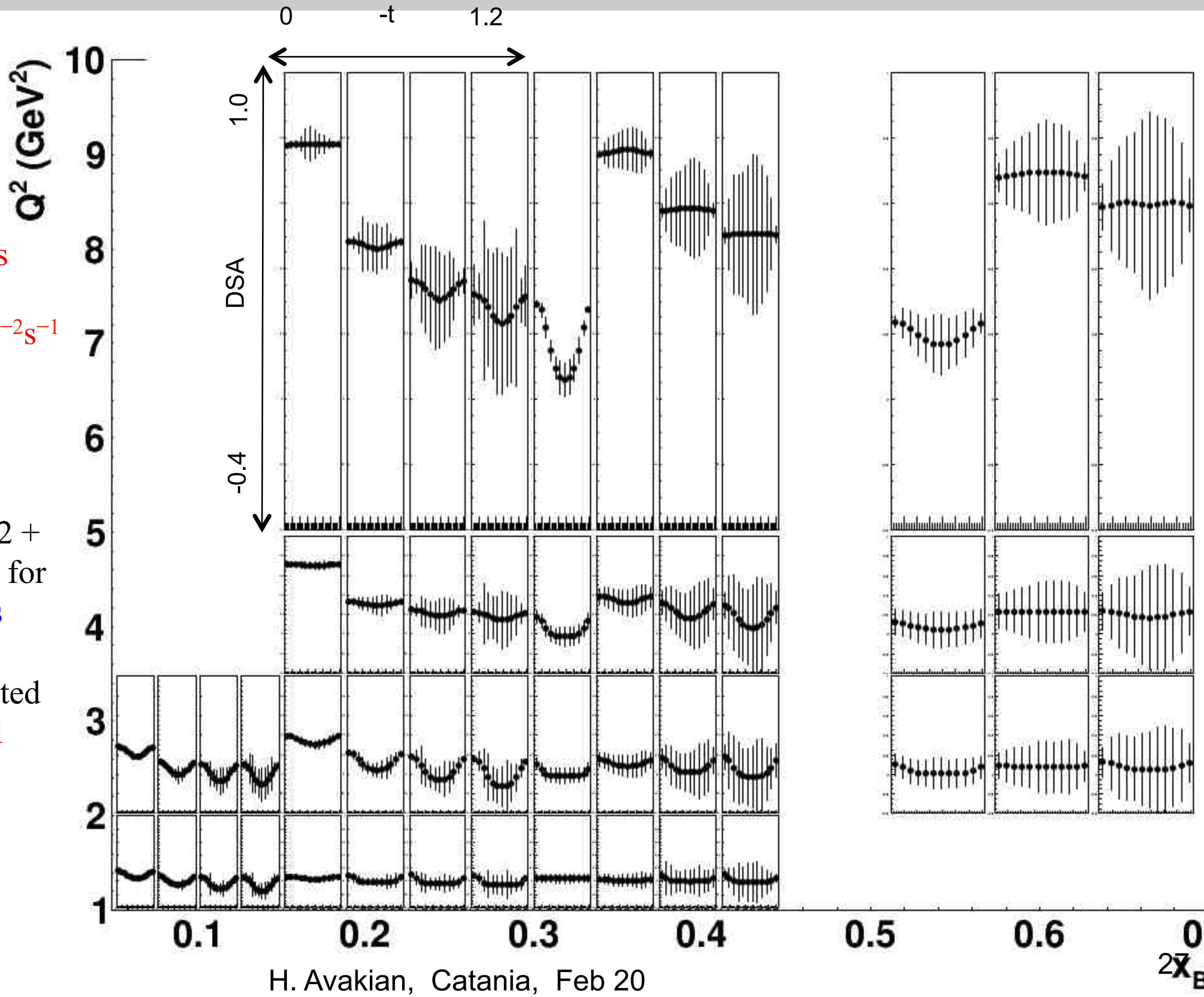
$$H_T^{\gamma^* p \to \pi^0 p} \sim [2H_T^u + H_T^d]$$
$$H_T^{\gamma^* p \to \eta p} \sim [2H_T^u - H_T^d]$$
$$H_T^{\gamma^* p \to K^+ \Lambda} \sim [2H_T^u - H_T^d - H_T^s]$$
$$H_T^{\gamma^* p \to K^+ \Sigma^0} \sim [H_T^d - H_T^s]$$

- $K^+\Lambda$ production. This channel should be predominated by transversity H_T contribution. This can be checked by the absence of forward dip in unseparated (or transverse if possible) cross section. From cross section, information about H_T transversity GPDs can be extracted.
- $K^+\Sigma^0$ production channel should be determined mainly by the $\bar{E}_T$ transversity GPD. This can be tested by the t' dependence of the cross section. Assuming the

Exclusive production of KΛ and KΣ provide access to different combinations of chiral-odd GPDs

Expected accuracy and coverage: DSA

Re{$\mathcal{H}_n$}



Beam-time: 160 days

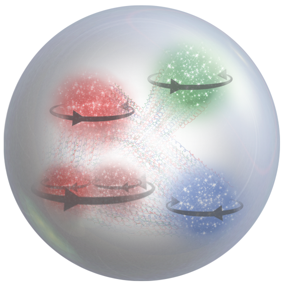
$L = 3/20 \cdot 0.9\ 10^{35}\ cm^{-2}s^{-1}$

$P_n = 40\%$, $P_e = 85\%$

nDVCS generator + Fast MC for CLAS12 + FT + 10% efficiency for CND, for count rates

Asymmetries computed with the VGG model

Transverse momentum dependence of sea quark distributions

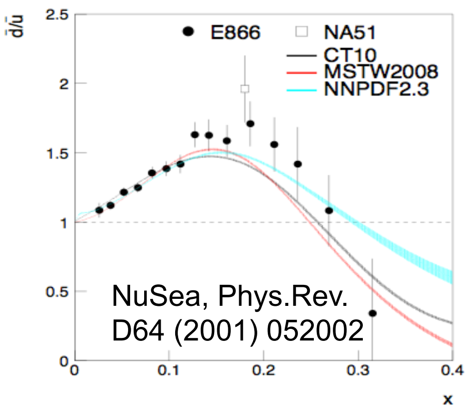


Understanding of the 3D structure of nucleon requires studies of spin and flavor dependence of quark transverse momentum distributions

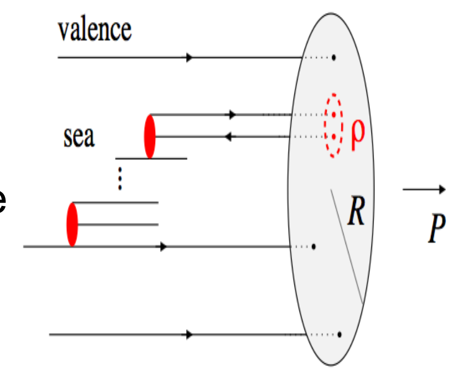
$f^a(x, k_T^2; Q^2)$ TMD PDF for a given combination of parton and nucleon spins

To apply the TMD formalism to data we need to understand the basic properties of the TMDs at a low scale, determined by non-perturbative QCD interactions

Nucleon could be regarded as a many-body system with short-range correlations induced by the chiral-symmetry breaking interactions.



Dynamical mechanisms producing intrinsic transverse momentum in the nucleon may be be very different for valence and sea quarks



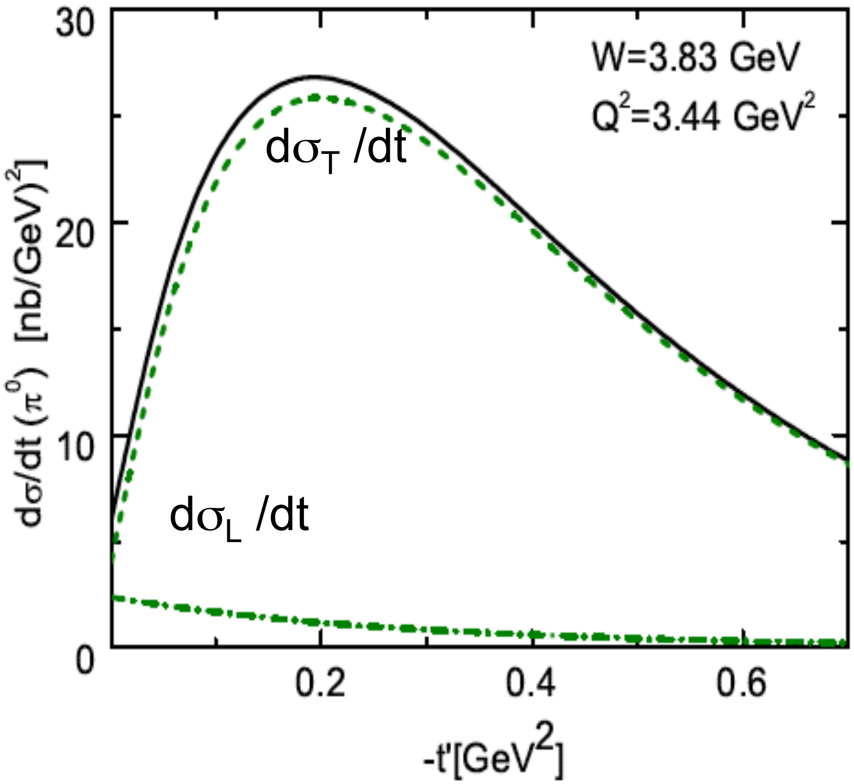
- k_T-distributions of valence quarks governed by the overall size of the nucleon of ~1fm (bag,light-front,..)
- sea k_T~vacuum fluctuations (0.3 fm), with significant contribution from short-range forces (ex. flavor structure of the sea)

- Short–range interactions $\rho \sim 0.3\,\mathrm{fm}$

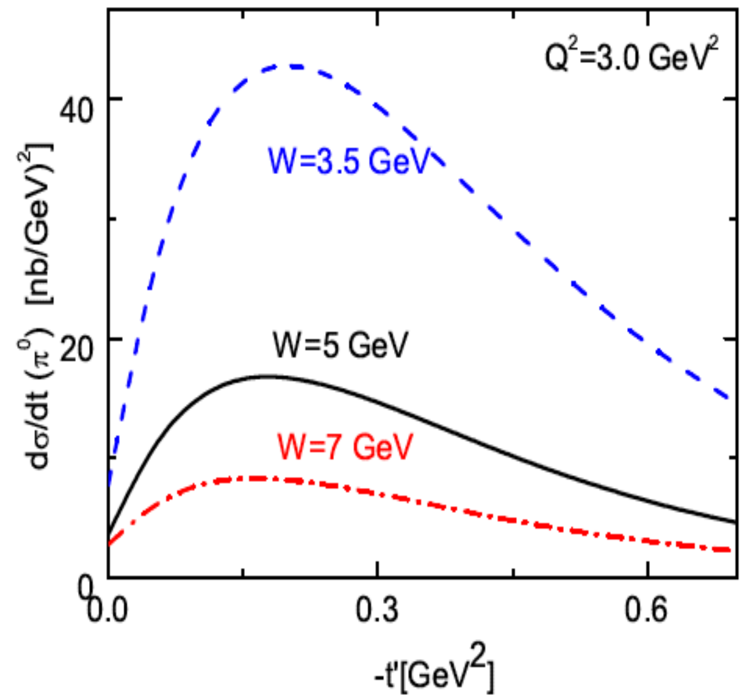
New dynamical scale $\rho \ll R$
Shuryak; Diakonov, Petrov 80's

Exclusive π^0

σ_T – dominates for π^0.



rates higher for small W



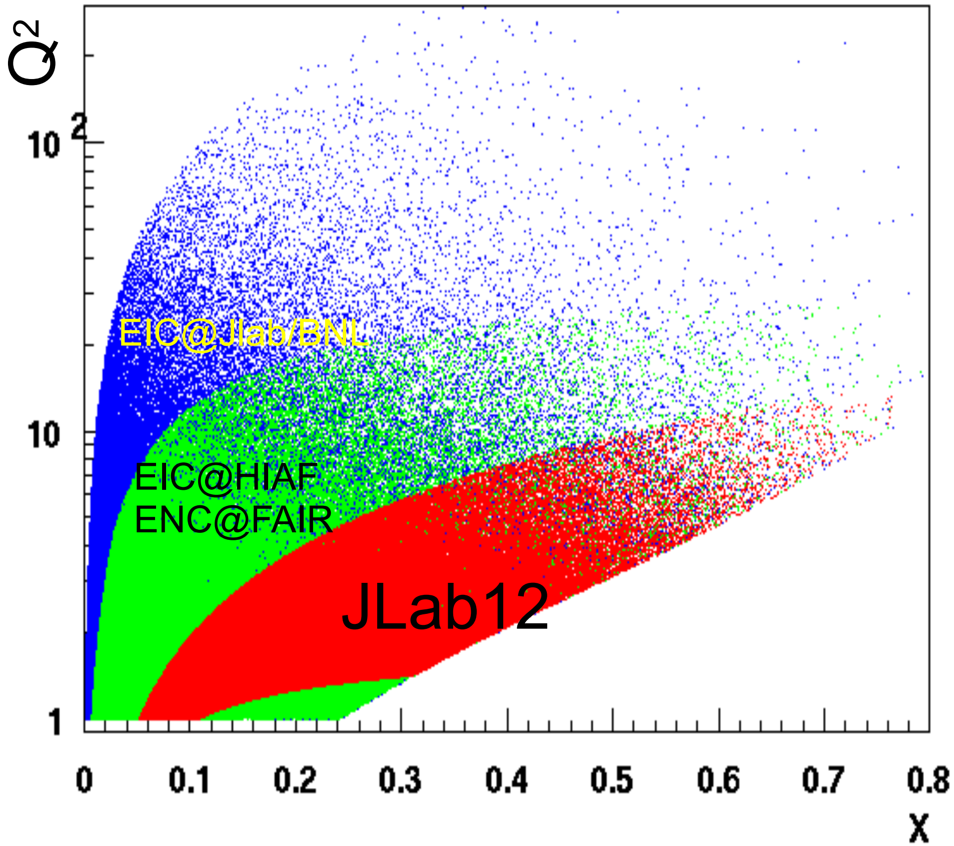
$$\mathcal{M}_{0+,\mu+}^{P,twist-3} \propto \frac{\sqrt{-t'}}{4m} \int_{-1}^{1} d\bar{x} \mathcal{H}_{0-,\mu+}(\bar{x}, ...)\ \bar{E}_T^P$$

$$\bar{E}_T^P = 2\,\tilde{H}_T + E_T.$$

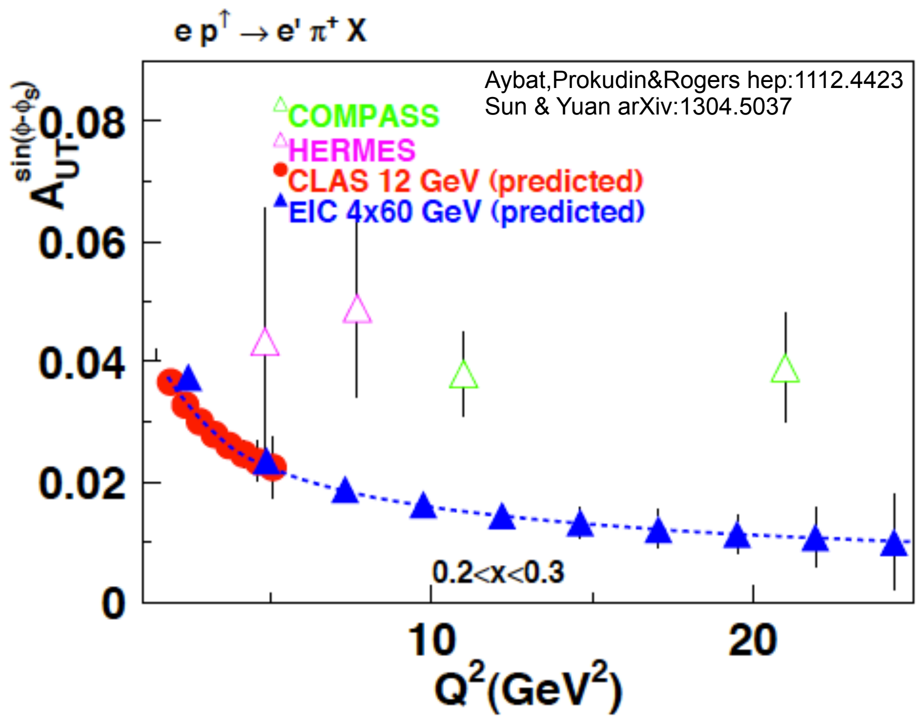
$\mathbf{K^2_\perp/Q^2}$ corrections in the propagators of the hard subprocess amplitude are essential in the description of the cross section at low $\mathbf{Q^2}$. They decrease σ by a factor of about 10 at $\mathbf{Q^2}$ ~ 3GeV²

M $_{0+,++}$ amplitude is important in σ_T .

Evolution Studies: from JLab12 to EIC

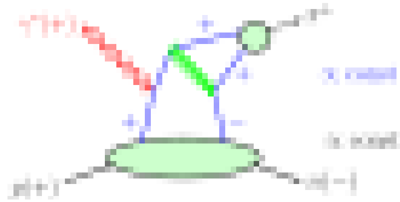


JLab@12GeV (25/50/75)
→0.1<x_B<0.7 : valence quarks
EIC √s = 140, 50, 15 GeV
→10^{-4}<x_B<0.3: gluons and quarks, higher P_T and Q^2.



- Q^2 – dependence of Sivers function is sensitive to the non-perturbative physics
- Wide range in Q^2 is crucial to study the evolution
- Study of large **x** domain requires high luminosity
- Overlap of EIC and JLab12 in the valence region will be crucial for the TMD program

Exclusive π+ cross sections in modified perturbative approach



- For **π+** production the **p** → **n** transition GPDs are required which are given by the isovector combination of proton GPDs **F**(3) = **F**u − **F**d **.**
- The **γ*q** → **πq** subprocess amplitudes within the modified perturbative approach is defined

Fourier transform to b space

$$\mathcal{H}_{0\lambda,0\lambda} = \int d\tau d^2b\, \hat{\Psi}_\pi(\tau, -\mathbf{b})\, \hat{\mathcal{F}}^{(3)}_{0\lambda,0\lambda}(\bar{x}, \xi, \tau, Q^2, \mathbf{b}) \times \alpha_s(\mu_R) \exp[-S(\tau, \mathbf{b}, Q^2)] \,.$$

momentum fraction of the quark defined with respect to the meson momentum

Longitudinal photons:

M_{0+0+} M_{0-0+}

Transverse photons:

M_{0+++} M_{0--+}

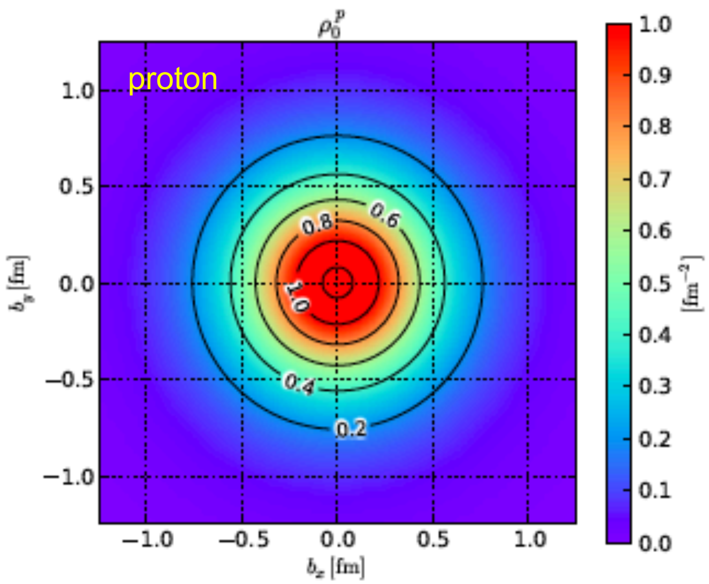
M_{0+-+} M_{0-++}

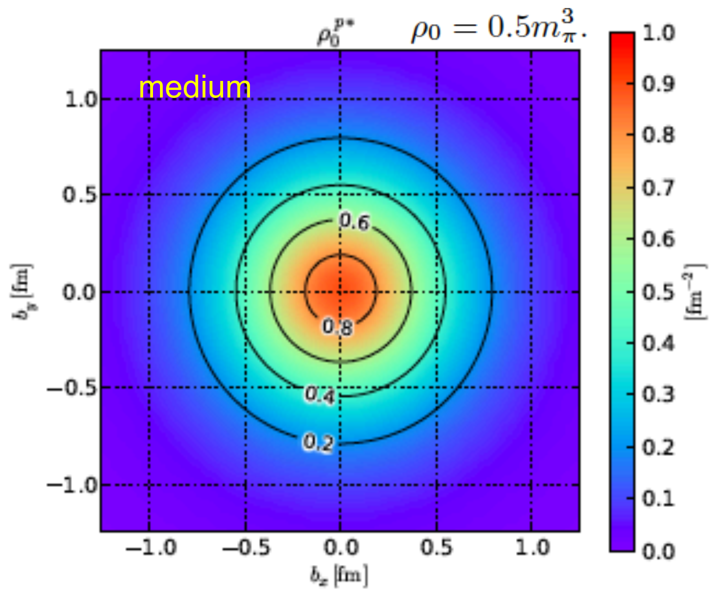
transverse cross section for large t (−t>~ 0.2 GeV2) is larger than the longitudinal one

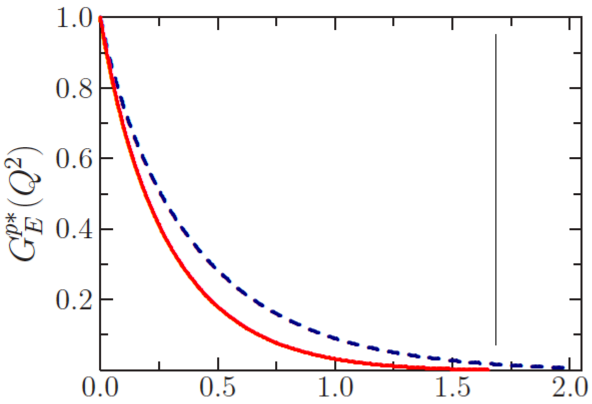
Transverse densities in the nucleon in nuclear matter

Quark transverse charge densities inside an unpolarized proton arXiv:1304.5926

Skyrme model

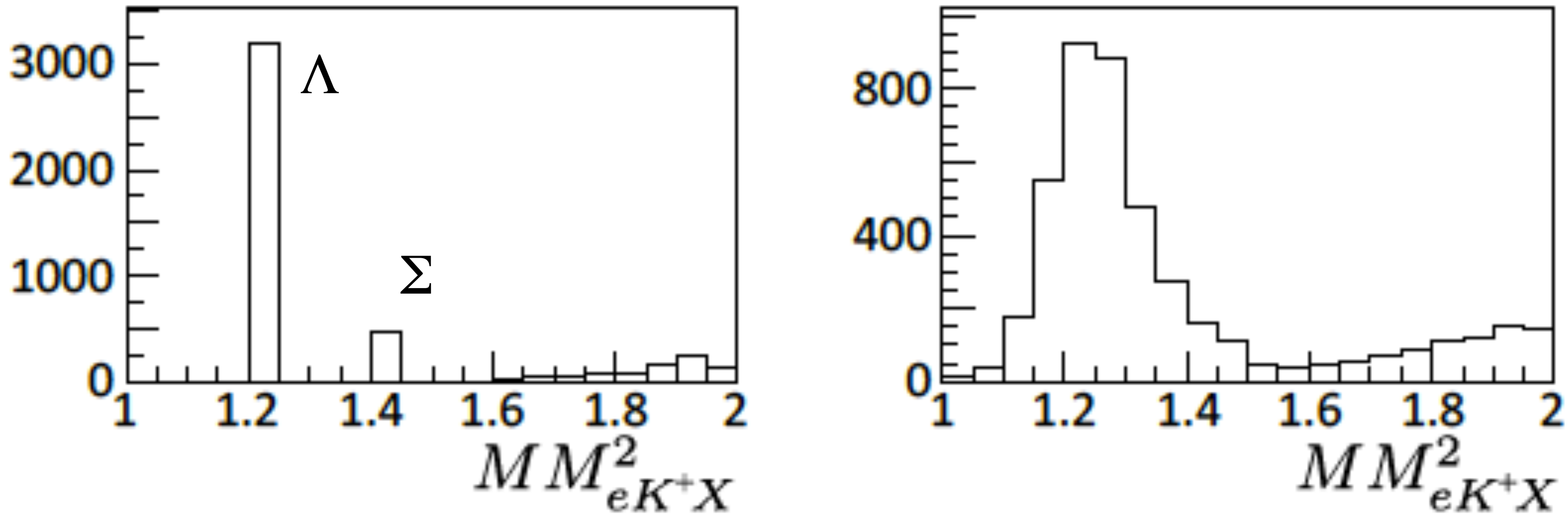






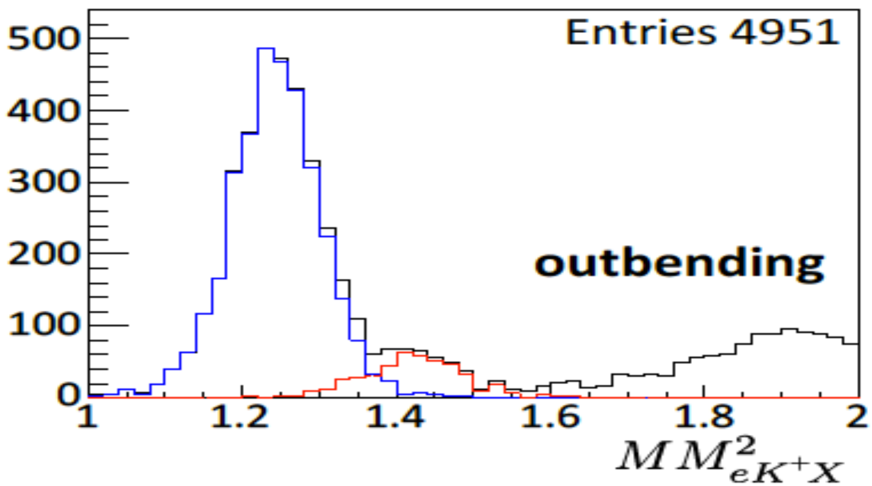
- form factors of the nucleon fell off faster in nuclear matter
- the size of the nucleon tends to bulge out in nuclear matter.

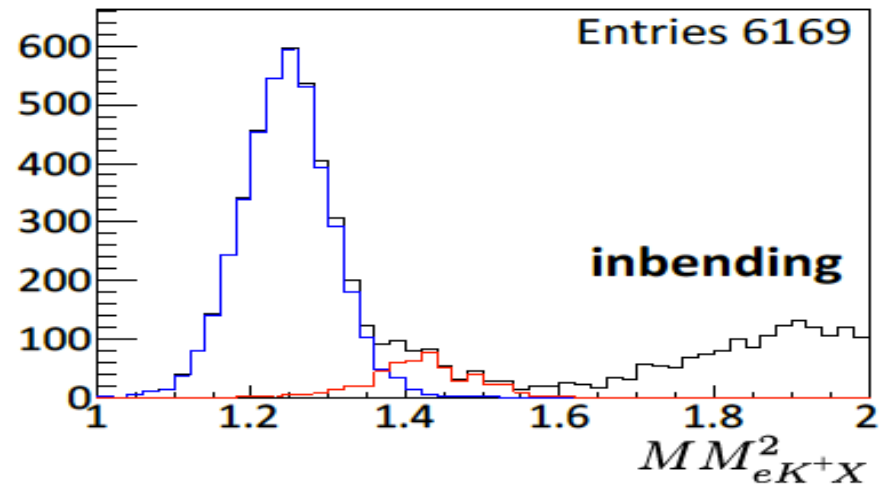
K/K* and Λ/Σ separation

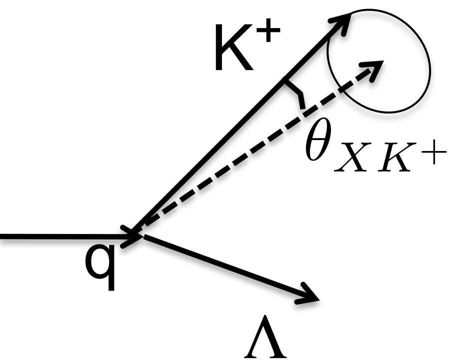


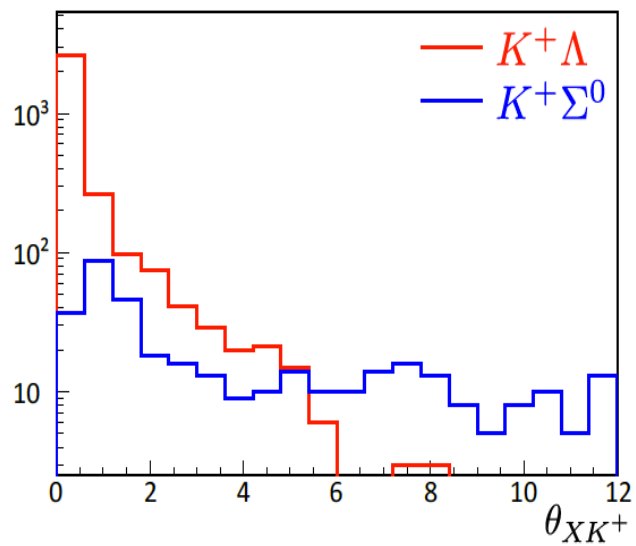
Due to detector resolution clean separation of different channels (Λ,Σ,K*) will require detection of 4 particles

K+ Λ/Σ separation





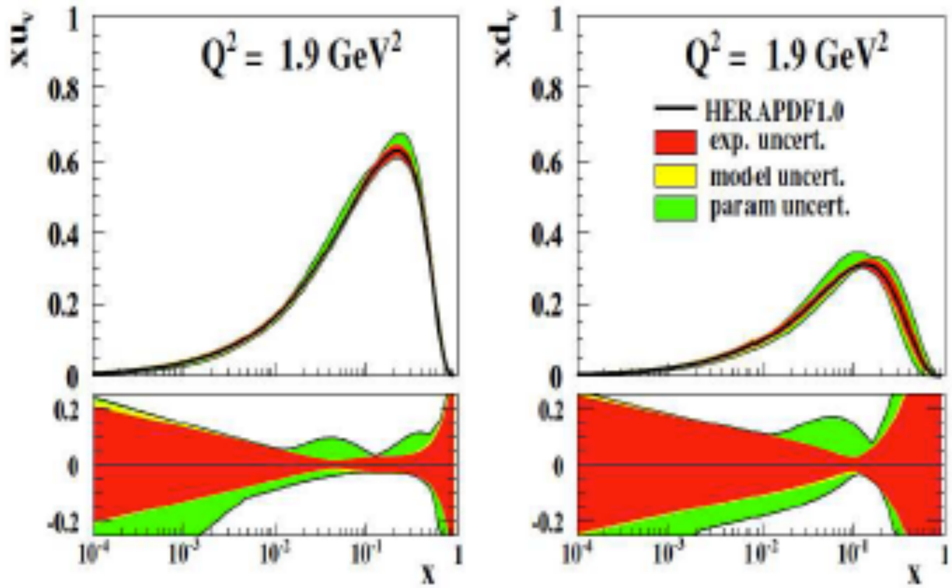




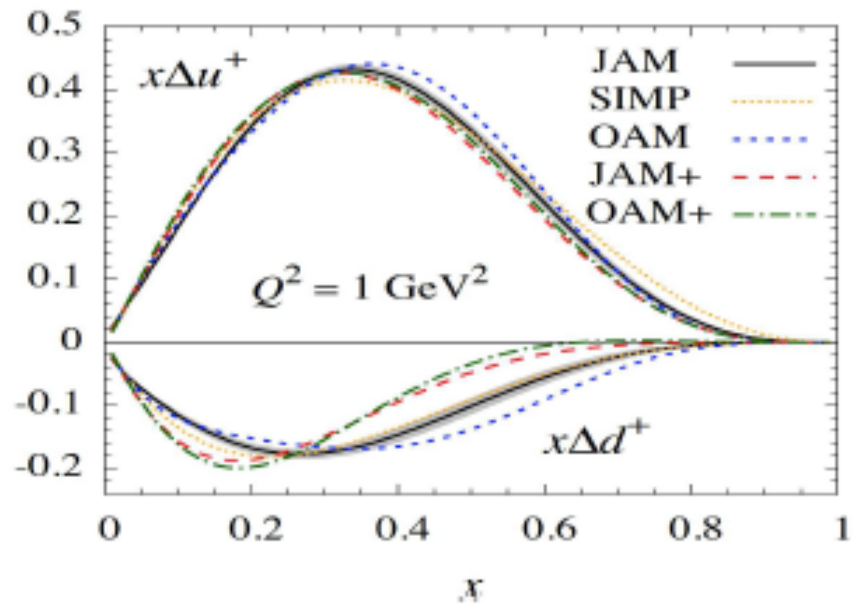
Detection of K+ p and π- would allow to separate of different final states (Λ,Σ,K*)

Studies of 1D PDFs

F. Aaron et al., JHEP 1001 (2010)

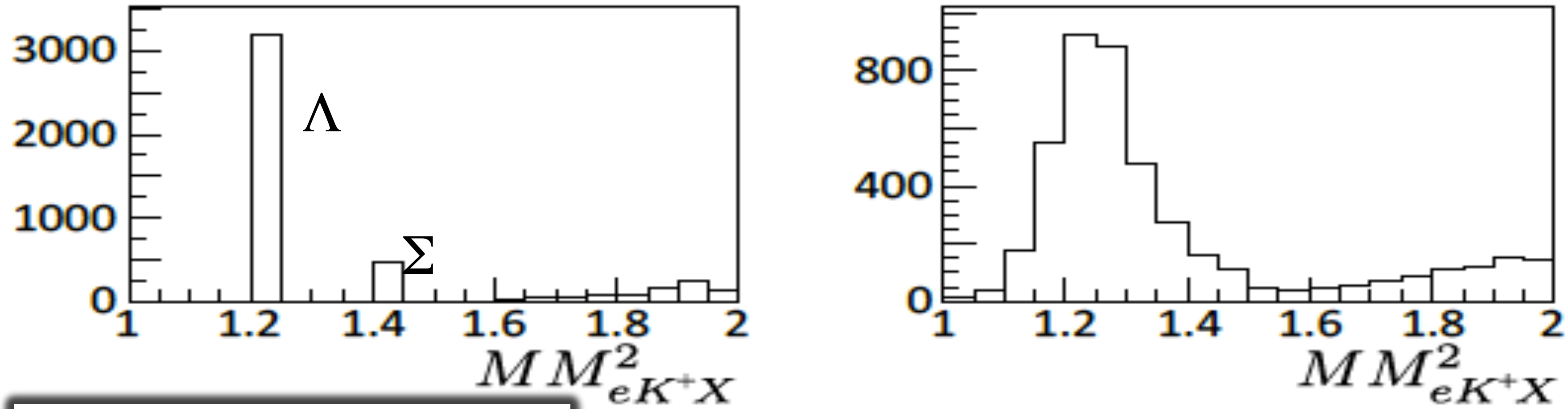


P. Jimenez-Delgado et al (2014), 1403.3355.

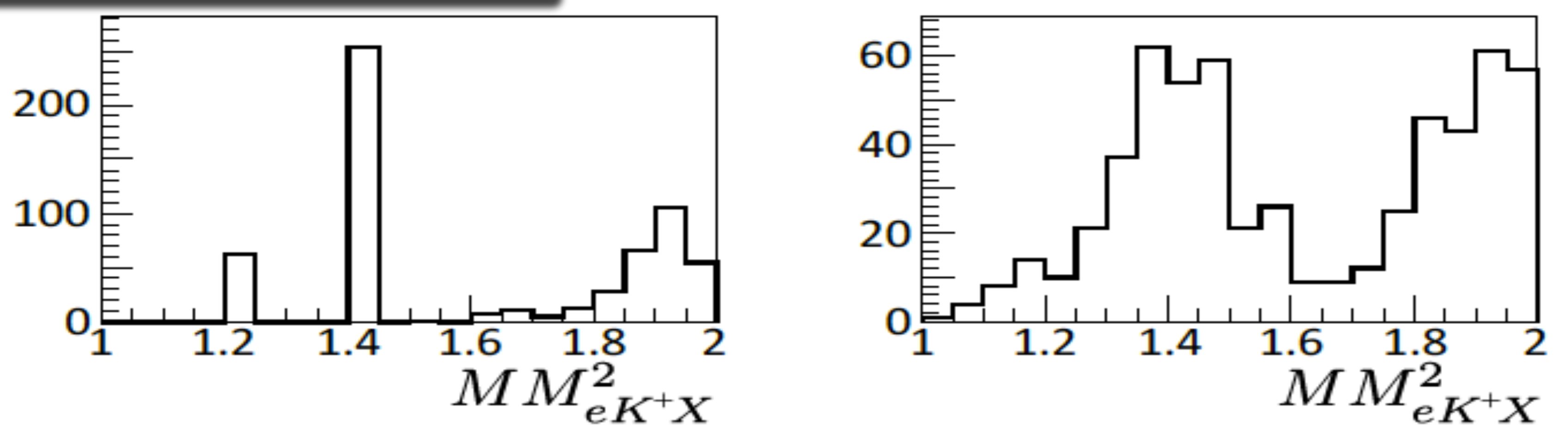


- Strong model and parametrization dependence observed already for 1D PDFs
- Positivity requirement may change significantly the PDF (need self consistent fits of polarized and unpolarized target data!!!)

Exclusive Λ/Σ separation



after the cut: $\theta_{XK^+} > 4°$



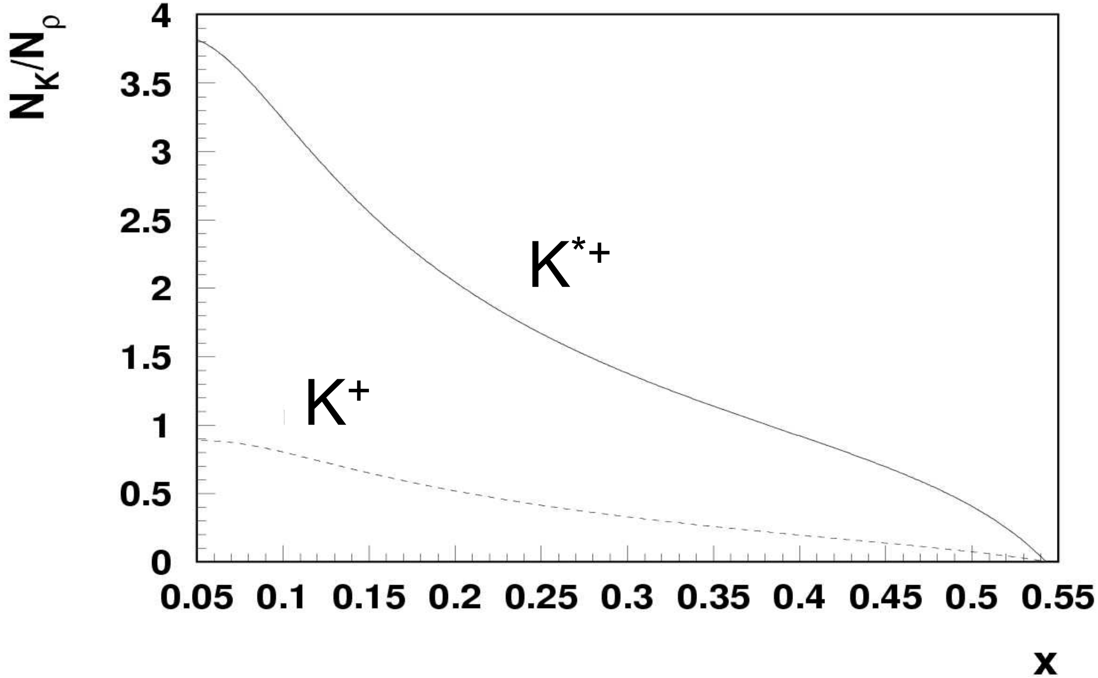
Detection of the complete final sate allow separation of exclusive Σs

GPDs from cross section ratios

$$\rho^+ n \propto [2H^u - H^d] - [H^{\bar{u}} - H^{\bar{d}}])$$

$$K^+\Lambda \propto -\frac{1}{\sqrt{6}}(2[2\tilde{H}^u - \tilde{H}^d - \tilde{H}^s] + [2\tilde{H}^{\bar{u}} - \tilde{H}^{\bar{d}} - \tilde{H}^{\bar{s}}])$$

$$K^{*+}\Lambda \propto -\frac{1}{\sqrt{6}}(2[2H^u - H^d - H^s] - [2H^{\bar{u}} - H^{\bar{d}} - H^{\bar{s}}])$$



M.Diehl et al. hep-ph/0506171

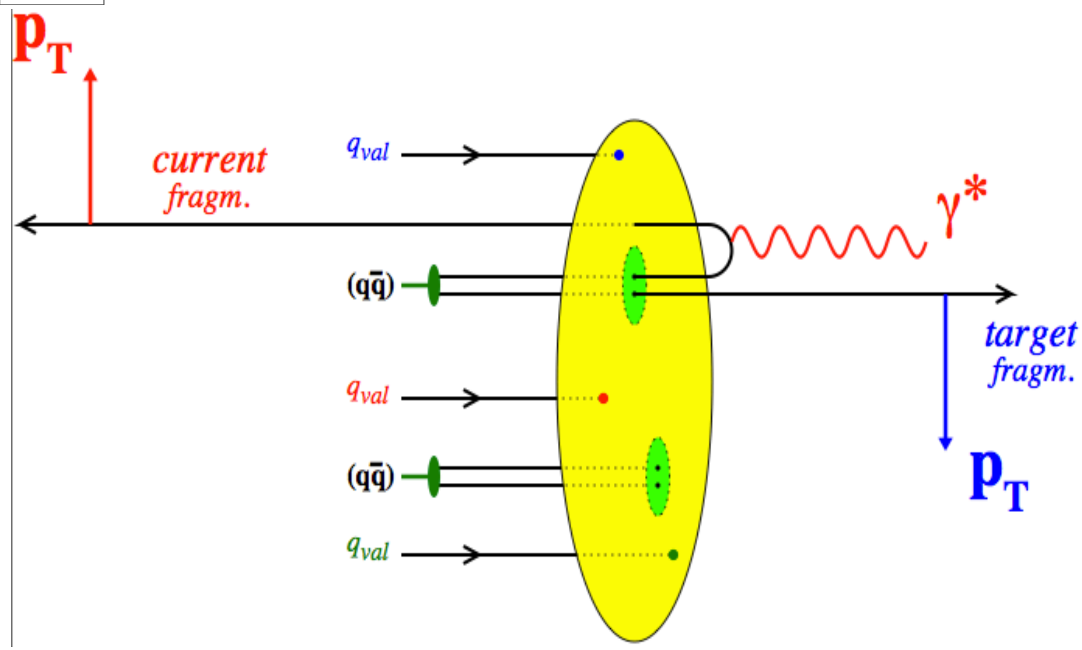
- L/T separation from $K^* \to K\pi$ decay + SCHC

•Study ratio observables: K/K*/ρ+,polarization transfer
•Different final state mesons filter out different combinations of unpolarized (H,E) and polarized (H,E) GPDs.

Correlations between target and current

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 $h_{1T}^\perp$

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



	U	L	T
U	M	$M_L^{\perp,h}$	$M_T^h, M_T^\perp$
L	$\Delta M^{\perp,h}$	ΔM_L	$\Delta M_T^h, \Delta M_T^\perp$
T	$\Delta_T M_T^h, \Delta_T M_T^\perp$	$\Delta_T M_L^h$ $\Delta_T M_L^\perp$	$\Delta_T M_T, \Delta_T M_T^{hh}$ $\Delta_T M_T^{\perp\perp}, \Delta_T M_T^{\perp h}$

- how the remnant system dresses itself up to become a full-fledged hadron
- correlation with the spin of the target or/and the produced particles