Semi-Inclusive DIS with a longitudinally polarized neutron

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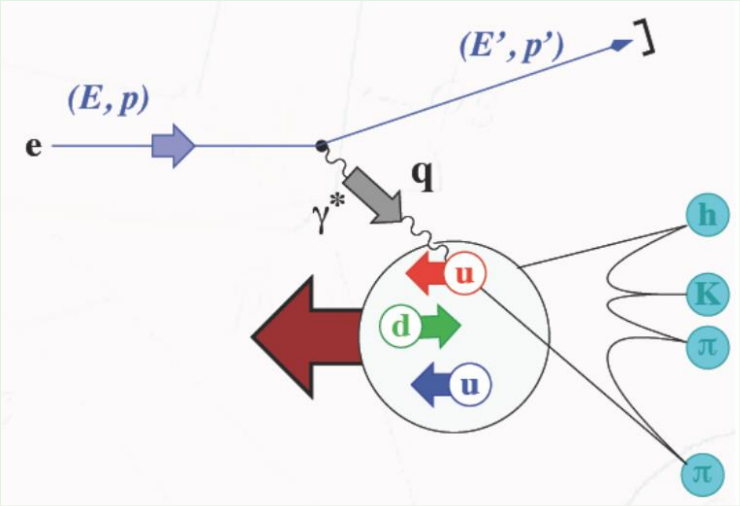
Transverse Momentum Distributions through Semi-Inclusive Deep-Inelastic Scattering



3D description of the nucleon structure in the momentum space → full 3D dynamics of the partons

Transition from hadronic to partonic degrees of freedom → Fragmentation Functions & Hadronization mechanisms

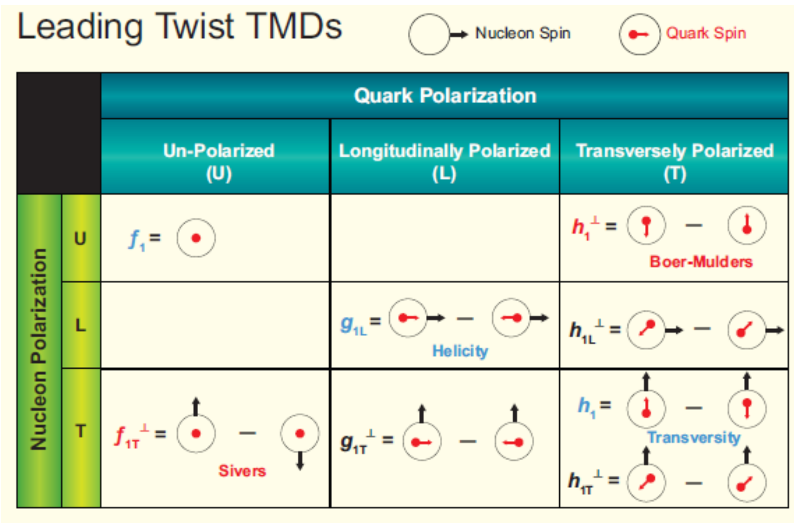
hidden strangeness in the nucleon

Access to quark-gluon-quark correlations through higher-twist observables

Transverse Momentum Dependent PDFs&FFs

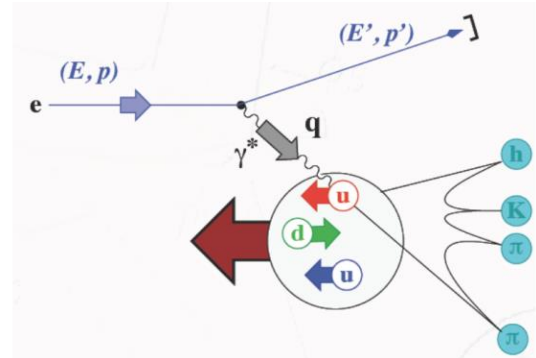
8 leading-twist TMDs

They depend on the parton longitudinal fraction x and on its transverse momentum k_T → ***full 3D dynamics***



Leading Twist TMDs — Nucleon Spin, Quark Spin

Nucleon Polarization	Quark Polarization: Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = − (Boer-Mulders)
L		g_{1L} = − (Helicity)	$h_{1L}^\perp$ = −
T	$f_{1T}^\perp$ = − (Sivers)	$g_{1T}^\perp$ = −	h_1 = − (Transversity); $h_{1T}^\perp$ = −



Fragmentation Functions → transition from partonic to hadronic degrees of freedom

q/H	U	L	T
U	$\boldsymbol{D_1}$		$H_1^\perp$
L		$\boldsymbol{G_{1L}}$	$H_{1L}^\perp$
T	$H_1^\perp$	G_{1T}	$\boldsymbol{H_1}$, $H_{1T}^\perp$

- different hadrons in the final state provide information on the hadronization of different flavors
- measurements on DIFFERENT TARGETS are essential to perform flavor separation and access TMDs of individual flavors

Single-hadron SIDIS cross-section

Depending on the degrees of freedom active in the process, various TMD&&FF can be accessed:

$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

Unpolarized target

$$\Big\{ \Big[F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{UU}^{\cos(\phi)} + \epsilon\cos(2\phi) F_{UU}^{\cos(2\phi)}\Big] + \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{LU}^{\sin(\phi)}\Big]$$

Longitudinally pol. target

$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{UL}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{UL}^{\sin(2\phi)}\Big] + S_L\,\lambda_l \Big[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{LL}^{\cos(\phi)}\Big]$$

Tranversely pol. target

$$+ S_T \Big[\sin(\phi-\phi_S)\Big(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\Big) + \epsilon\sin(\phi+\phi_S) F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{UT}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{UT}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{LT}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

18 structure functions appear in the cross-section

$$F_{ij,K} \propto DF \otimes FF$$

JLab TMD program explored the different terms:

1. Unpolarized contributions (Hall-B, Hall-C)
2. Longitudinally-polarized contributions (Hall-B)
3. Transversely-polarized contributions (Hall-A)

Longitudinal Target-Spin Asymmetry on deuterium

$$A_1 = A_{LL} \propto \frac{g_1 \otimes D_1}{f_1 \otimes D_1}$$

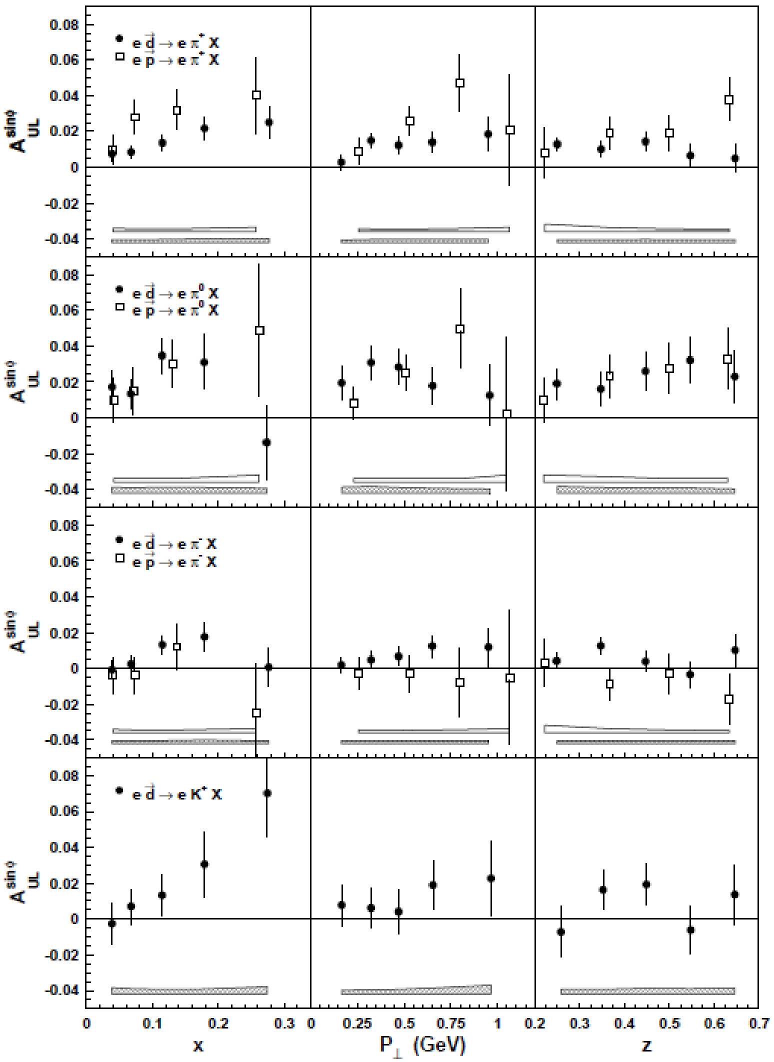
→ explore the k_T dependence of 1D PDFs

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(x h_L H_1^{\perp} + \frac{M_h}{M}\,g_{1L}\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(x f_L^{\perp} D_1 - \frac{M_h}{M}\,h_{1L}^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T) - \boldsymbol{k}_T\cdot\boldsymbol{p}_T}{M M_h} h_{1L}^{\perp} H_1^{\perp}\right],$$

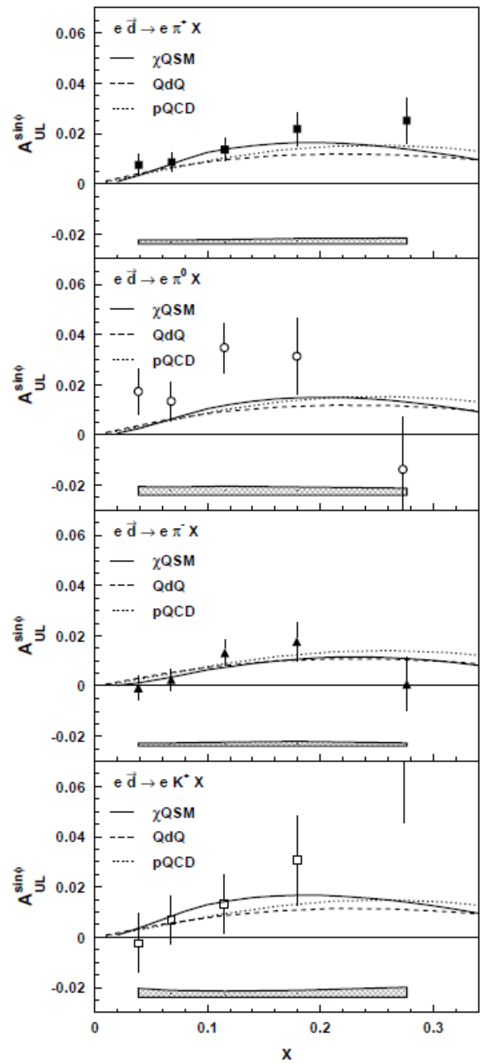
- Measurements on deuterium are available from HERMES and COMPASS, need to be (further) extended to VALENCE QUARK region
- low-Q^2 important to test the presence of possible evolution effects on TMDs & FFs
- CLAS12 will allow to explore both pions & kaons channel → *see M. Contalbrigo's contribution*
- Combining ND3 and NH3 measurement will allow to perform a flavor separation on the TMDs: compatible precision on hydrogen and deuterium is important to access flavor's TMDs → *see A. Courtoy's contribution*
- many semi-inclusive processes (single-hadron, di-hadron, back-to-back SIDIS), with the specific observables they granted access to, will benefit of additional ND3 days → *see H. Avakian's contribution*

HERMES measurements



Model comparison

- high-x region almost unexplored
- it is the region where models deviate greatly from data
- high-x region on kaon data deviates consistently from models → CLAS12 + RICH + ND3 can provide important constraints



Toward a 5D mapping of the nucleon

Transverse Momentum Dependent and Generalized Parton Distributions are reduction of the *Wigner Mother Functions,* encoding the 5D structure of the nucleon

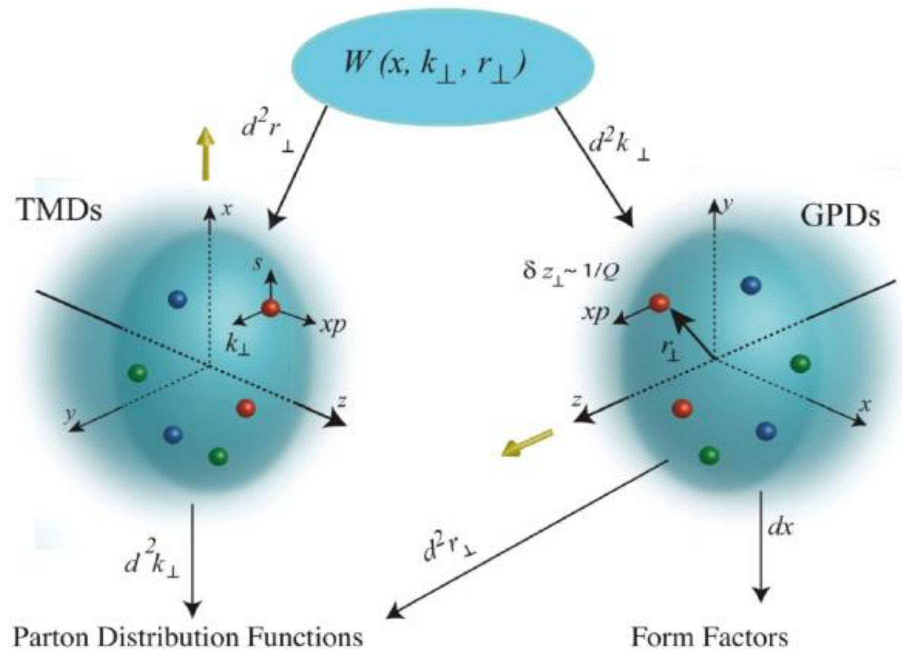
TMDs → Semi-Inclusive DIS: $e\,p \;\rightarrow e\,h\,X$

GPDs → Deeply-Virtual Compton Scattering: $e\,p \;\rightarrow e\,p\,\gamma$

CLAS12 is the perfect environment to access these two processes

Provide projections in the «5D space» in terms of DVCS variables $(x_B, Q^2, -t, \varphi)$ and SIDIS variables (x_B, Q^2, z, P_T) in the common electron (x_B, Q^2) kinematics

1D PDFs are the common part → to be constrained simultaneously from the two processes



- $r_\perp$: $-t$ from DVCS (at $\xi = 0$)
- $k_\perp$: P_T from SIDIS

Goal: provide a 5D data set

backup

Semi-Inclusive DIS and Transverse Momentum Distributions

$$F_{UU,T} = \mathcal{C}\big[f_1 D_1\big],$$

$$F_{UU,L} = 0,$$

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\Big[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\Big(xh\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{D}^{\perp}}{z}\Big) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\Big(xf^{\perp}D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{H}}{z}\Big)\Big],$$

$$F_{UU}^{\cos 2\phi_h} = \mathcal{C}\Big[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T) - \boldsymbol{k}_T\cdot\boldsymbol{p}_T}{MM_h}h_1^{\perp}H_1^{\perp}\Big],$$

$$F_{LU}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\Big[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\Big(xe\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{G}^{\perp}}{z}\Big) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\Big(xg^{\perp}D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{E}}{z}\Big)\Big],$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\Big[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\Big(xh_L H_1^{\perp} + \frac{M_h}{M}\,g_{1L}\frac{\tilde{G}^{\perp}}{z}\Big) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\Big(xf_L^{\perp}D_1 - \frac{M_h}{M}\,h_{1L}^{\perp}\frac{\tilde{H}}{z}\Big)\Big],$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\Big[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T) - \boldsymbol{k}_T\cdot\boldsymbol{p}_T}{MM_h}h_{1L}^{\perp}H_1^{\perp}\Big],$$

$$F_{LL} = \mathcal{C}\big[g_{1L}D_1\big],$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\Big[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\Big(xe_L H_1^{\perp} - \frac{M_h}{M}\,g_{1L}\frac{\tilde{D}^{\perp}}{z}\Big) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\Big(xg_L^{\perp}D_1 + \frac{M_h}{M}\,h_{1L}^{\perp}\frac{\tilde{E}}{z}\Big)\Big]$$

COMPASS measurement (on unidentified hadrons)