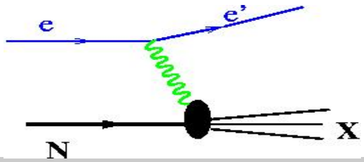
Development of a framework for TMD extraction from SIDIS data

Harut Avakian (JLab)

DPWG, JLab, 2015, Oct 22

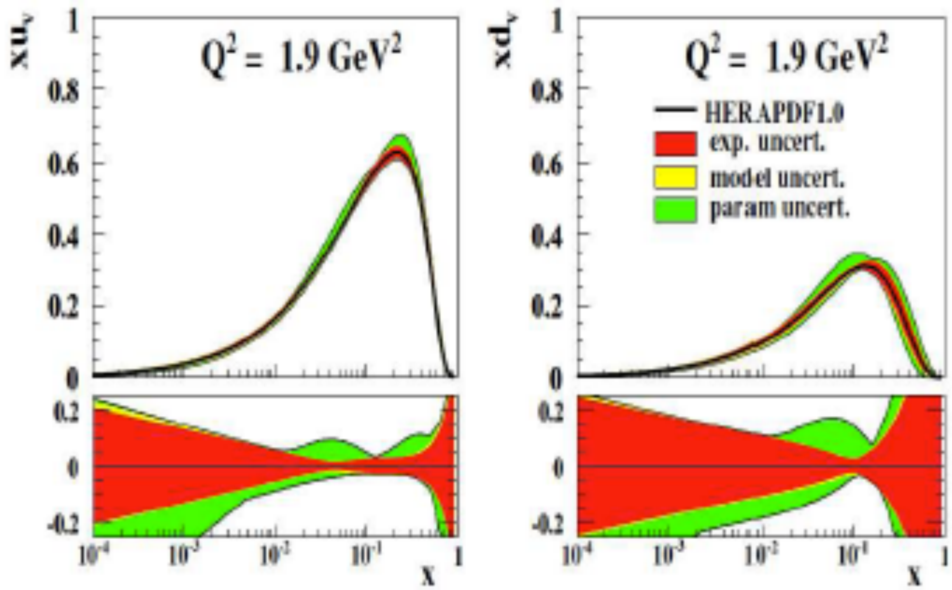
Spin-Azimuthal asymmetries in SIDIS
- Defining the output (multiplicities, asymmetries,…)
- Examples from 6 GeV analysis
- Combination of different experiments
- Radiative corrections in 5D (x,y,z,P_T,ϕ)

MC and validation of the framework
Summary

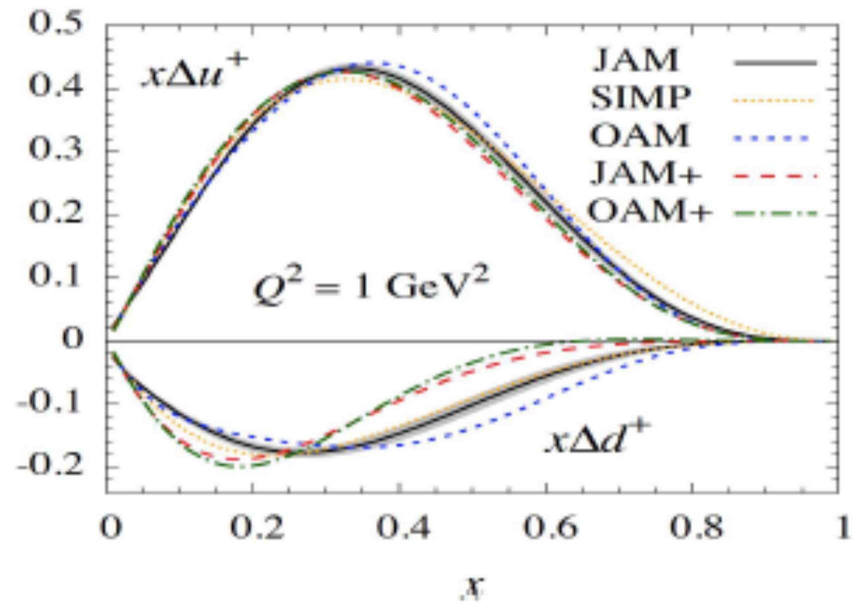


Studies of 1D PDFs

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



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

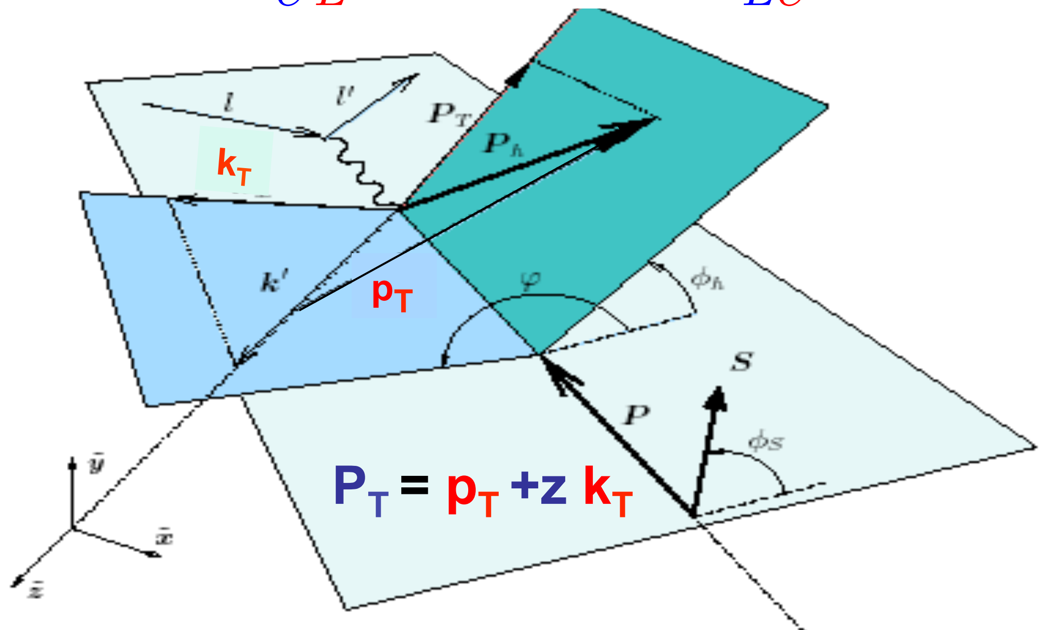


- Strong model and parametrization dependence observed already for 1D PDFs
- Positivity requirement may change significantly the PDF (need self consistent fits of polarized and unpolarized target data!!!)

SIDIS: partonic cross sections

$$\nu = (qP)/M$$
$$Q^2 = (k - k')^2$$
$$y = (qP)/(kP)$$
$$x = Q^2/2(qP)$$
$$z = (qP_h)/(qP)$$

$$\sigma = F_{UU} + P_t F_{UL}^{\sin\phi} \sin 2\phi + P_b F_{LU}^{\sin\phi} \sin\phi \ldots$$



Azimuthal moments in hadron production in SIDIS provide access to different structure functions and underlying transverse momentum dependent distribution and fragmentation functions.

$$\int d^2\vec{k}_T d^2\vec{p}_T \delta^{(2)}(z\vec{k}_T + \vec{p}_T - \vec{P}_T)$$

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

beam polarization

target polarization

corrections for the region of large k_T~Q

QCD fundamentals for TMD extraction

TMD factorization theorem separates a transversely differential cross section into a perturbatively calculable part and several well-defined universal factors

$$d\sigma_{\text{SIDIS}} = \sum_f \mathcal{H}_{f,\text{SIDIS}}(\alpha_s(\mu), \mu/Q) \otimes F_{f/H_1}(x, k_{1T}; \mu, \zeta_1) \otimes D_{H_2/f}(z, k_{2T}; \mu, \zeta_2) + Y_{\text{SIDIS}}$$

corrections for the region of large $k_T \sim Q$

TMDs may in general contain a mixture of both perturbative and non-perturbative contributions

$$b_*(b_T) \equiv \frac{b_T}{\sqrt{1 + b_T^2/b_{\max}^2}}.$$

Aybat,Collins,Qiu,Rogers 2012
Collins&Rogers 2015

non perturbative

$$\tilde{F}_{H_1}(x, b_T; Q, Q^2) = \tilde{F}_{H_1}(x, b_*; \mu_b, \mu_b^2) \exp\left\{ -g_1(x, b_T; b_{\max}) - g_K(b_T; b_{\max}) \ln\left(\frac{Q}{Q_0}\right) + \ln\left(\frac{Q}{\mu_b}\right) \tilde{K}(b_*; \mu_b) + \int_{\mu_b}^{Q} \frac{d\mu'}{\mu'} \left[\gamma_{\text{PDF}}(\alpha_s(\mu'); 1) - \ln\left(\frac{Q}{\mu'}\right) \gamma_K(\alpha_s(\mu')) \right] \right\}$$

parameterize

perturbatively calculable

$$P_T \sim \Lambda_{QCD} \ll Q, \quad \Lambda_{QCD} \ll P_T \ll Q, \quad P_T \sim Q, \text{ and } P_T > Q.$$

Azimuthal moments in SIDIS

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = {} & \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
& + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
& + S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] \\
& + S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
& + |\boldsymbol{S}_\perp|\left[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)\right. \\
& \quad + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& \quad \left. + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\right] \\
& + |\boldsymbol{S}_\perp|\lambda_e\left[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}\right. \\
& \quad \left. + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\right]\Big\},
\end{aligned}
$$

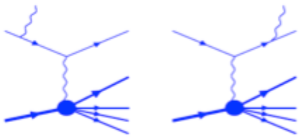
quark polarization

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

Higher Twist PDFs

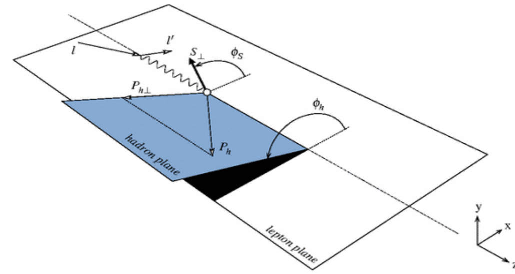
N/q	U	L	T
U	$f^\perp$	$g^\perp$	$h, \mathbf{e}$
L	$f_L^\perp$	$g_L^\perp$	$\mathbf{h_L}, e_L$
T	$f_T, f_T^\perp$	$\mathbf{g_T}, g_T^\perp$	$h_T, e_T, h_T^\perp, e_T^\perp$

Experiment for a given target polarization measures all moments simultaneously



QED radiative corrections in SSA

$$\sigma = \sigma_{UU} + \sigma_{UU}^{\cos\phi} cos\phi + S_T \sigma_{UT}^{\sin\phi_S} \sin\phi_S + ...$$



Due to radiative corrections, ϕ-dependence of x-section will get more contributions

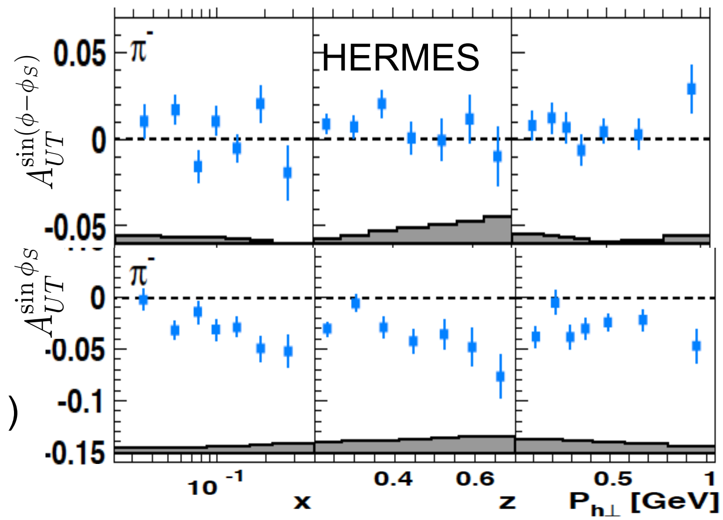
$$\sigma_{XY}^{h}(x,z,P_T) \to \sigma_{XY}^{B,h}(x,z,P_T) \times R(x,z,P_T,\phi_h) + \sigma_{XY}^{R,h}(\dots).$$

using a simple approximation

$$R(x,z,P_T,\phi) = f_{XY}(x,z,P_T) * (1 + a_{XY} * cos\phi + ...)$$

we can get correction factors to moments (ex. for RC for $\sigma_{UT}^{\cos\phi}$)

we can get new moments



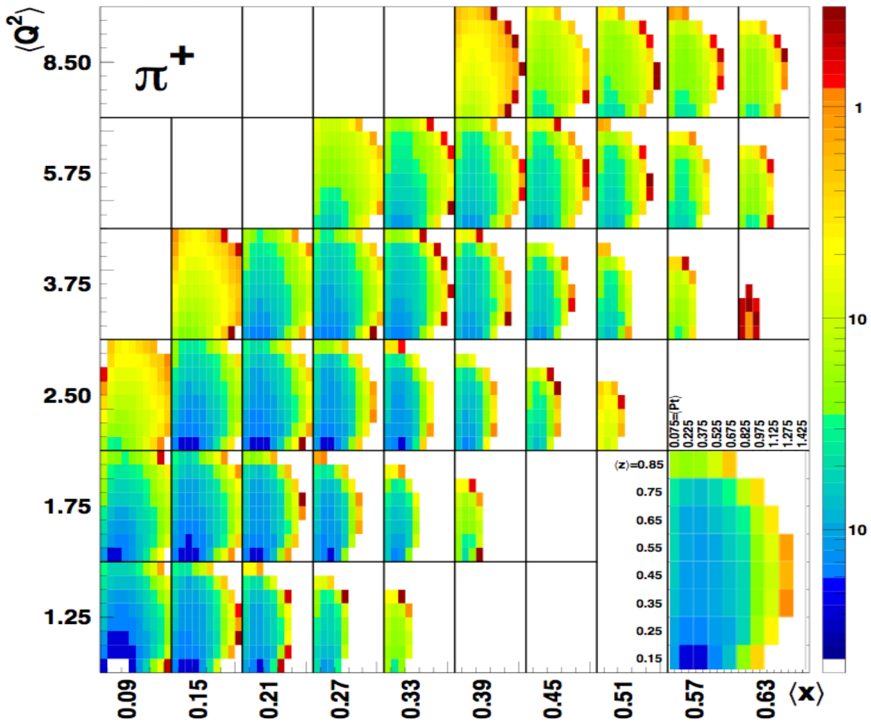
In reality contributions will me more complicated

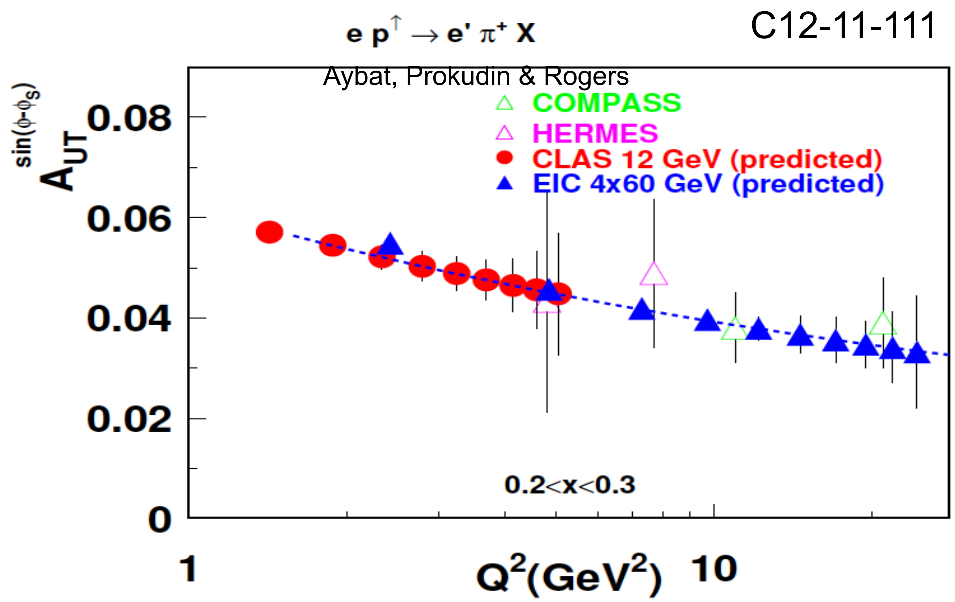
$$\sigma_{UU} -> \sigma_{UU} + 1/2\sigma_{UU}^{\cos\phi} f_{UU} a_{UU}$$

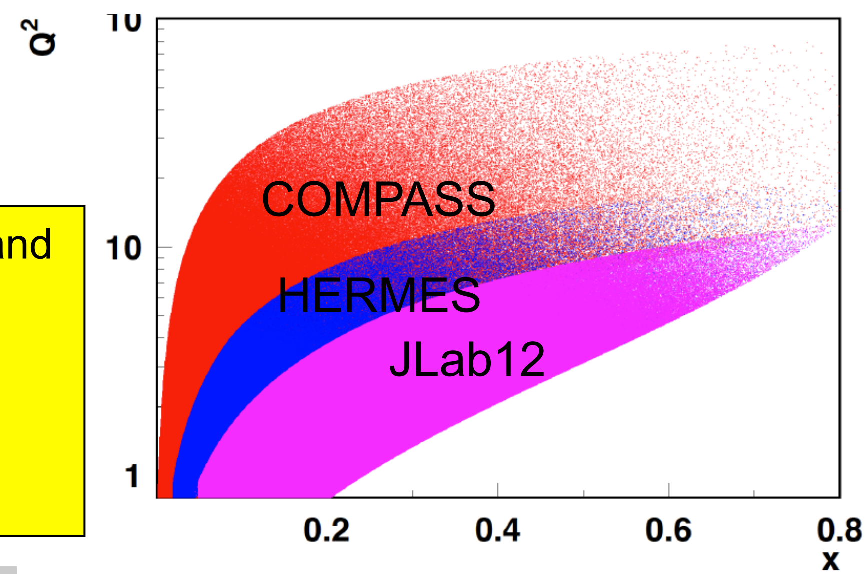
$$\sigma_{UT}^{\sin(\phi-\phi_S)} = 1/2\sigma_{UT}^{\sin\phi_S} f_{UT} a_{UT}$$

Due to radiative corrections, ϕ-dependence of x-section will get more contributions
- Some moments will modify
- New moments may appear, which were suppressed before in the x-section

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 be important in understanding the Q^2 evolution and checking the theory framework.

Extraction of 3D PDFs

ThePEG framework, HERWIG++,PYTHIA

TMDlib and TMDplotter version 1.0.0"
Hautman et al Preprint 1408.3015

Hard Scattering MC
(SIDIS,DY,e+/e-)

3D PDFs Library
(models,parametrizations,..)

QCD fundamentals

Hard Scattering Data
(x-sections,
multiplicities,
asymmetries,...)

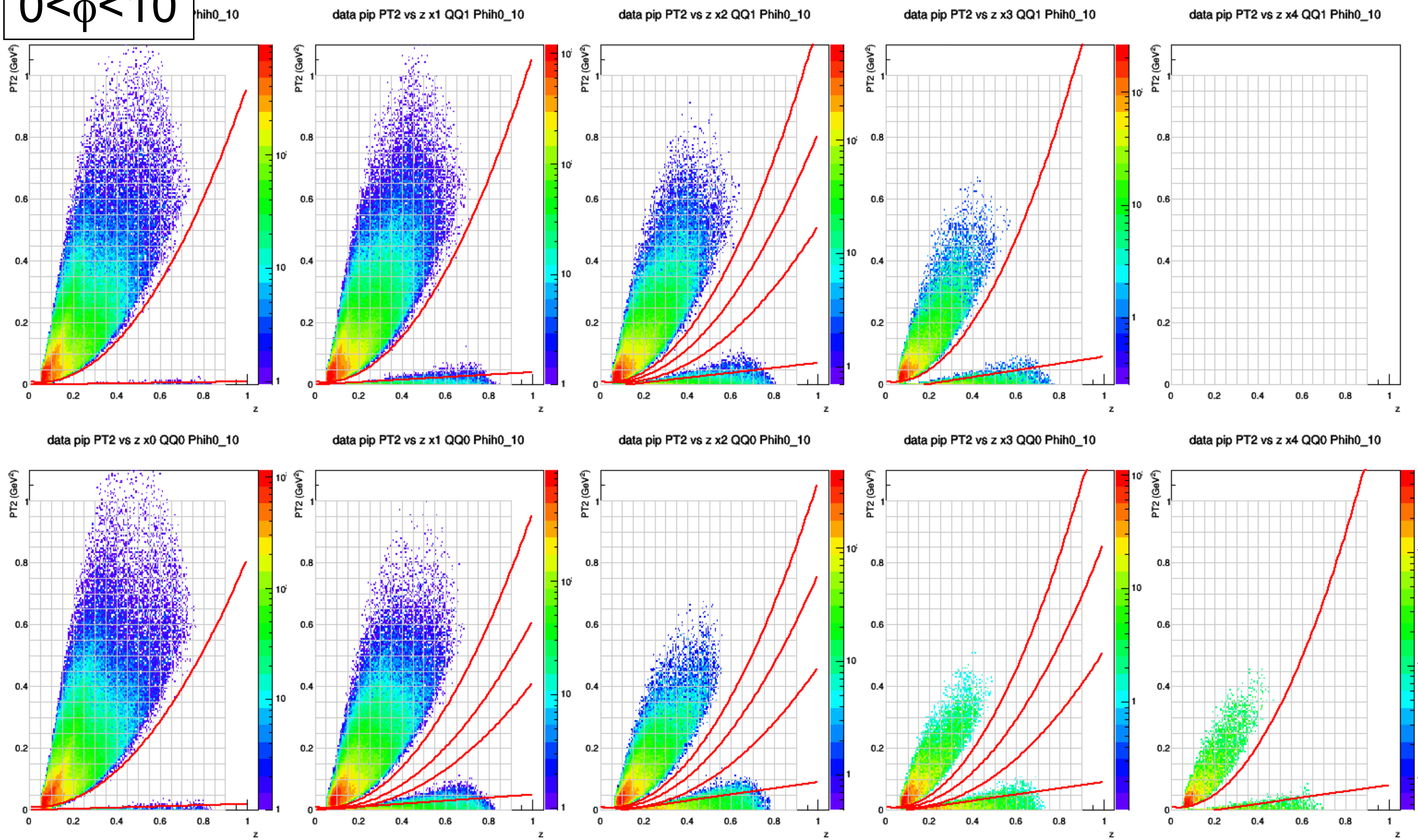
3D analysis
framework,
phenomenology

3D PDFs

Develop reliable and model independent techniques for the extraction of 3D PDFs and fragmentation functions from the multidimensional experimental observables.

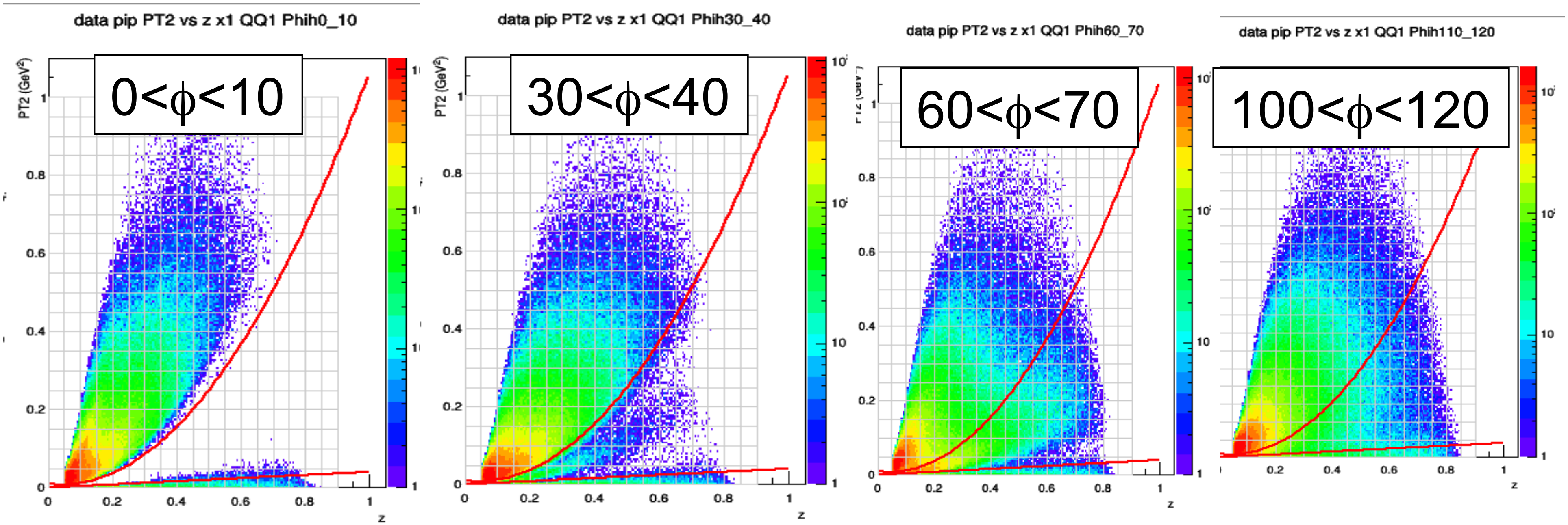
Microscopic bins (N. Harrison,e1f-set)

$0<\phi<10$



fixed bin in ϕ,x,Q^2)

Microscopic bins (N. Harrison,e1f-set)



Precision studies of azimuthal distributions require

- good description of data by MC(resolutions, kinematic distributions…)
- Microscopic binning to minimize edge effects, typically getting out of control

Output tables

e1f (N.Harrison) tables with mutiplicities fitted by $A_0+A_1\cos\phi+A_2\cos2\phi$

bin#	<x>	<Q^2>	<z>	$\langle P_T^2\rangle$	<y>	A_0	ΔA_0	A_1	ΔA_1	A_2	ΔA_2	$A_{0(RC)}$	$\Delta A_{0(RC)}$	$A_{1(RC)}$	$\Delta A_{1\ (RC)}$	$A_{2\ (RC)}$	$\Delta A_{2(RC)}$
0 0 1 0	0.147328	1.16379	0.0762828	0.026808	0.77197	543541	853.533	-0.162717	0.00247702	-0.0200227	0.00243121	516500	812.846	-0.152185	0.00248606	-0.0162215	0.00242759
0 0 2 0	0.151031	1.16925	0.122463	0.0275494	0.75789	231532	493.001	-0.103776	0.00340326	0.028234	0.00306469	224535	479.781	-0.0863418	0.0034032	0.0264976	0.00306648
0 0 2 1	0.150379	1.16783	0.122796	0.0731165	0.760156	175718	371.285	-0.230244	0.0033067	0.0097803	0.00326033	164948	349.555	-0.19372	0.0033142	-0.000968785	0.00326021

……………………………… 1331 lines for pi+/ 1134 lines for pi- (~150Kb)

eg1dvcs (S. Koirala) tables with asymmetries ALU, AUL,ALL

Index	Flav	Q2Num	Q2BinAvg	XbNum	XbBinAvg	ZzNum	ZzBinAvg	PtNum	PtBinAvg	PhNum	PhBinAvg	MxAvg	YyAvg	EeAvg	DpAvg	DiAvg	Alu	AluError	Aul	AulError	All	AllError
63	0	0	1.14772	0	0.135591	0	0.349046	5	0.886265	2	77.6354	1.7382	0.763591	0.420486	0.842163	0.138502	-0.00956366	0.0328709	0.0450115	0.292196	0.23585	0.345479
64	0	0	1.14337	0	0.136228	0	0.347242	5	0.888113	3	104.958	1.71881	0.757405	0.430883	0.835993	0.138236	0.0494798	0.0269866	0.104973	0.24706	-0.0210623	0.291505
65	0	0	1.14175	0	0.135597	0	0.349518	5	0.887756	4	137.776	1.7291	0.759641	0.427246	0.838135	0.138388	0.00275549	0.0276319	0.380788	0.256311	-0.172219	0.302168

…………………….. 20737 lines 6.5 Mb

bin#	x	Q^2	y	W	M_X	ϕ	z	P_T	λ	Λ	N(counts)	RC
1 … N												

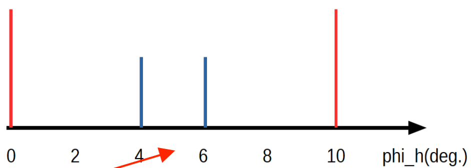
Tables with acceptance corrected mutiplicities in 5D bins may serve as input for the framework

Input data for analysis framework

- Differential input (SIDIS):

M. Aghasyan et al arXiv:1409.0487 (JHEP)

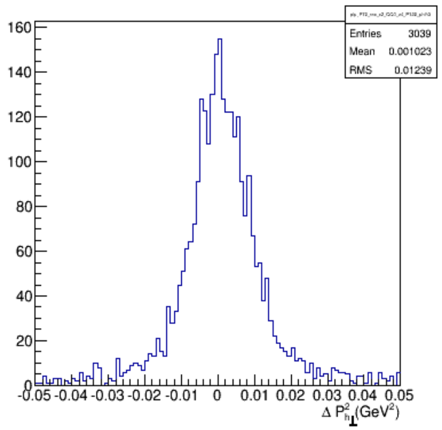
bin#	x	Q^2	y	W	M_X	ϕ	z	P_T	λ	Λ	N(counts)	RC
1 ... N												

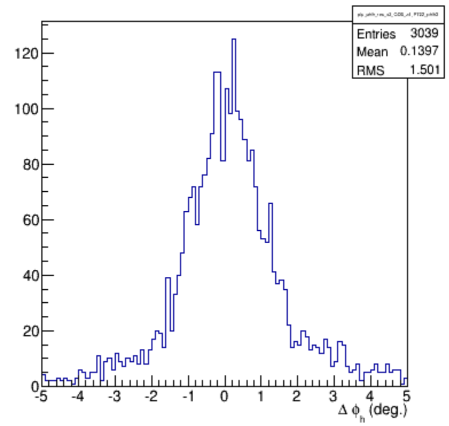


Microscopic vs macroscopic bins

Pros:
1) can go to wider bins,
2) smaller bin centering corrections
3) smaller acceptance/radiative correcions.

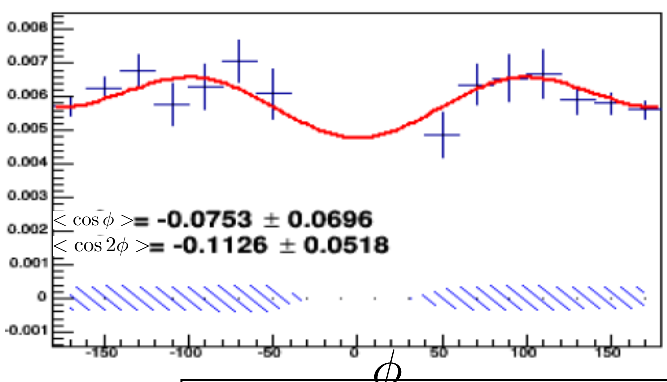
Cons:
1)Requires huge MC sample
2)…………
…………

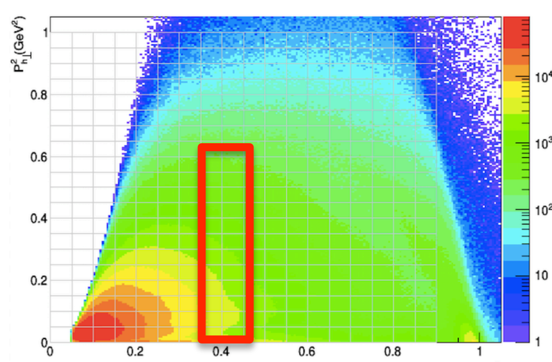


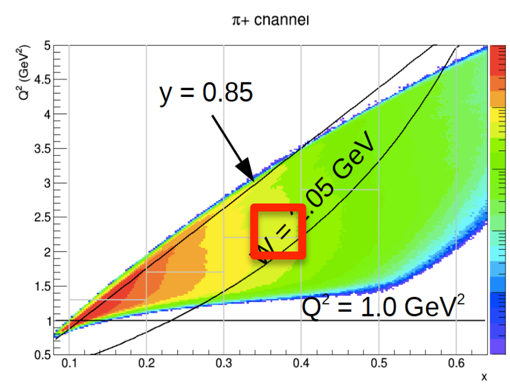


bin sizes limited by resolutions

N.Harrison (preliminary e1f)





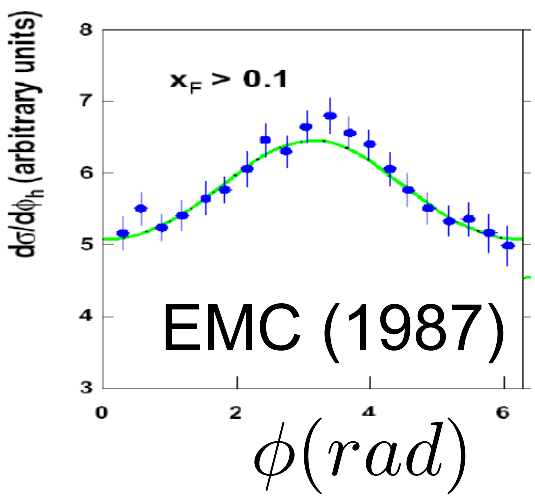


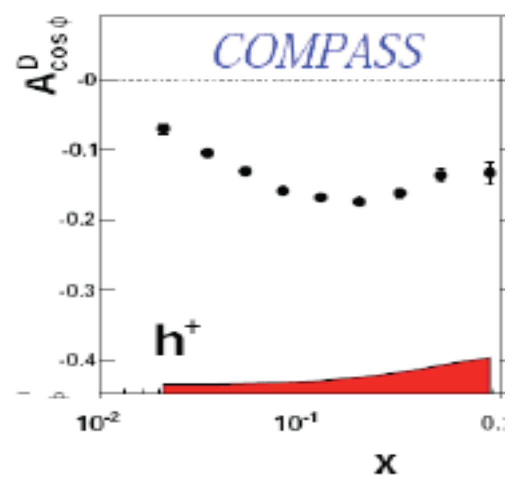
Realistic MC is crucial for acceptance!!!

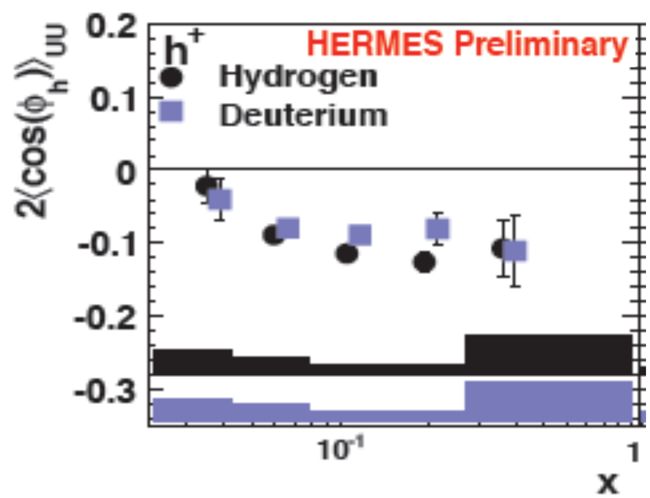
Higher twists in azimuthal distributions in SIDIS

HT

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

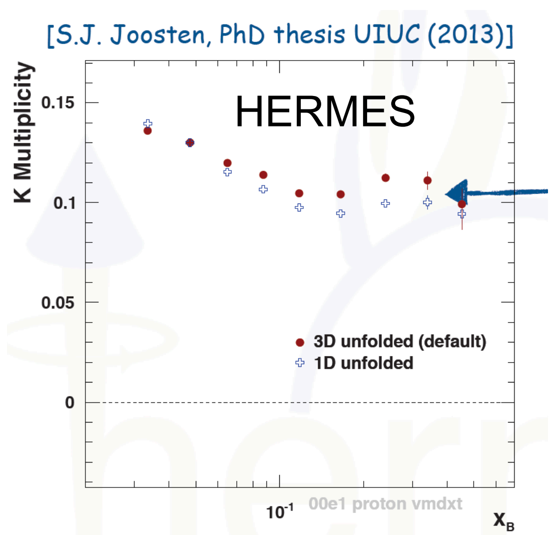


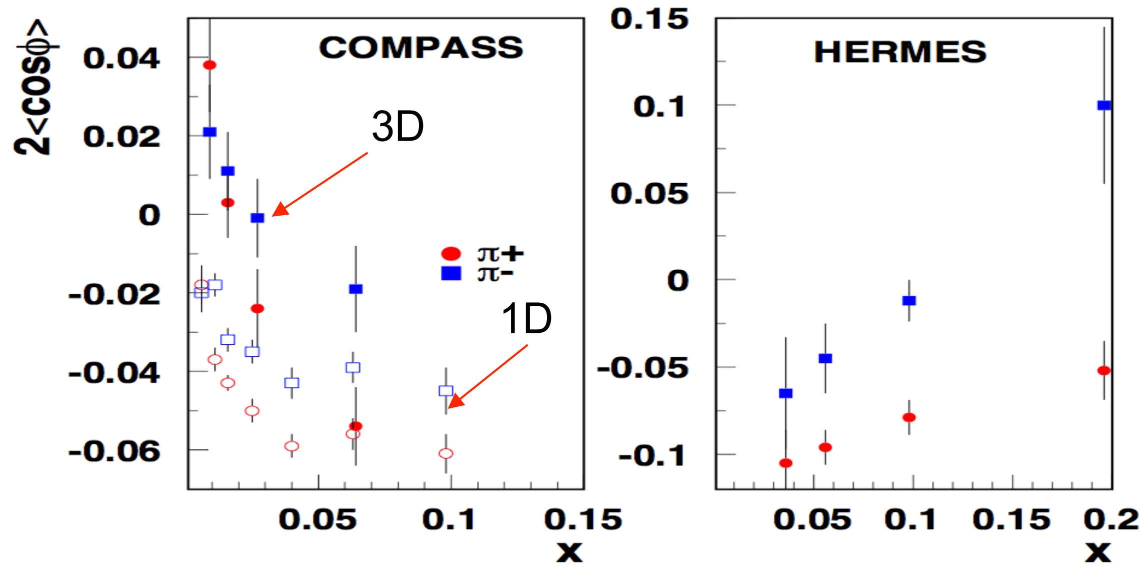




Large cosϕ modulations observed by EMC were reproduced in electroproduction of hadrons in SIDIS with unpolarized targets at COMPASS and HERMES

From 1D to 3D





COMPASS multi-dimensional bins

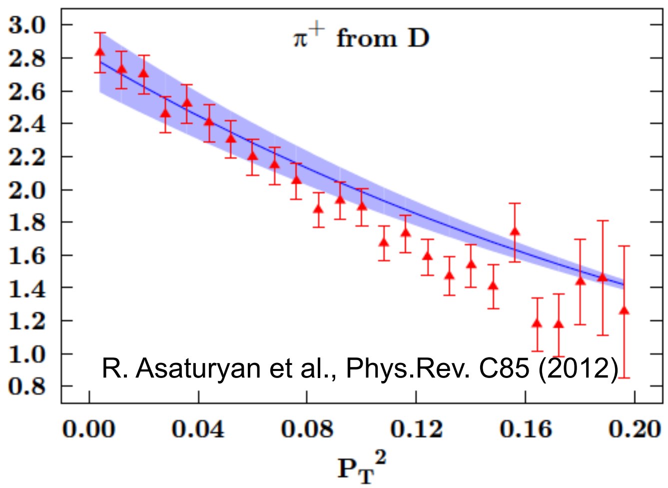
$0.003 < x < 0.008$	$0.20 \leq z < 0.25$	$0.10 < p_T^h \leq 0.20$ GeV/c
$0.008 \leq x < 0.013$	$0.25 \leq z < 0.30$	$0.20 < p_T^h \leq 0.30$ GeV/c
$0.013 \leq x < 0.020$	$0.30 \leq z < 0.35$	$0.30 < p_T^h \leq 0.40$ GeV/c
$0.020 \leq x < 0.032$	$0.35 \leq z < 0.40$	$0.40 < p_T^h \leq 0.50$ GeV/c
$0.032 \leq x < 0.050$	$0.40 \leq z < 0.50$	$0.50 < p_T^h \leq 0.60$ GeV/c
$0.050 \leq x < 0.080$	$0.50 \leq z < 0.65$	$0.60 < p_T^h \leq 0.75$ GeV/c
$0.080 \leq x < 0.130$	$0.65 \leq z < 0.80$	$0.75 < p_T^h \leq 0.90$ GeV/c
$0.130 \leq x < 0.210$	$0.80 \leq z < 1.00$	$0.90 < p_T^h \leq 1.30$ GeV/c
$0.210 \leq x < 1.000$		$1.30 < p_T^h$

- Observables extracted in 1D bin and 3D bins (with same average values in z,P_T) may be quite different.
- No consistency between different experiments

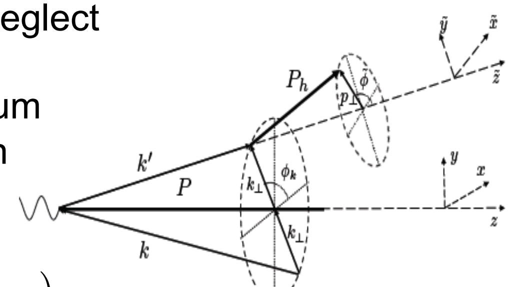
Understanding of cosϕ moment is crucial for understanding the theory

Finite phase space (including target, hadron mass) corrections

M. Anselmino et al., JHEP 1404 (2014)



In real life (also MC) one can't neglect nucleon mass, hadron mass and transverse momentum, momentum and baryon number conservation



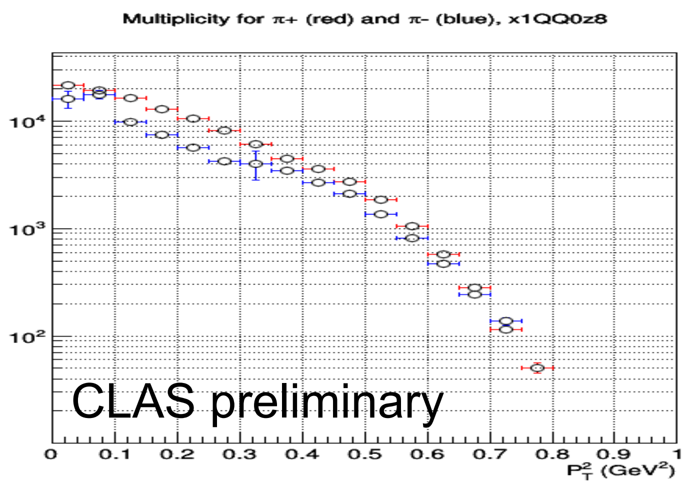
$$f^q(x, k_T, ..) \otimes D^{q\to\pi^+}(z, p_T, ..)$$

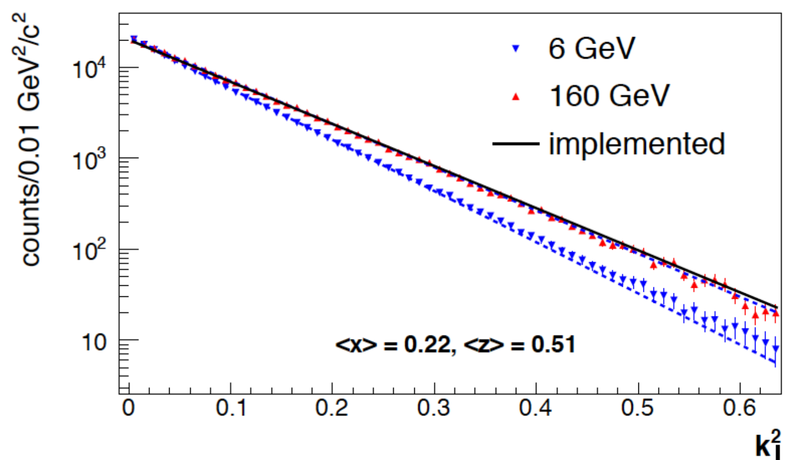
$$\downarrow$$

$$f^q(\xi, k_T, ..) \otimes D^{q\to\pi^+}(\zeta, p_T, ..)$$

$$\xi = \frac{2x_B}{1+\sqrt{1+4x_B^2 M^2/Q^2}},$$

$$z_h = \frac{p_h \cdot p}{q \cdot p} = \frac{x_B}{\xi}\left(\zeta_h + \frac{\xi^2}{\zeta_h}\frac{M^2 m_{h\perp}^2}{Q^4}\right)$$

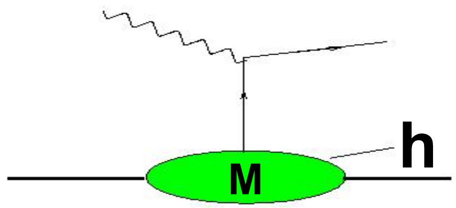




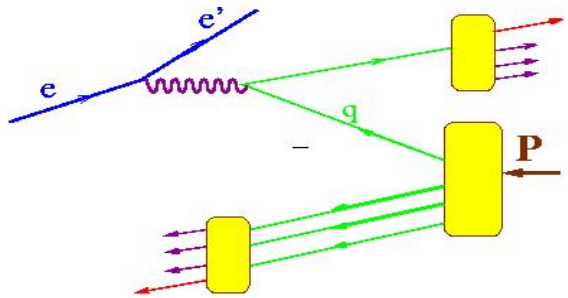
Phase space at low beam energies limits high P_T

MC: Aghasyan et al, JHEP 1503 (2015) 039

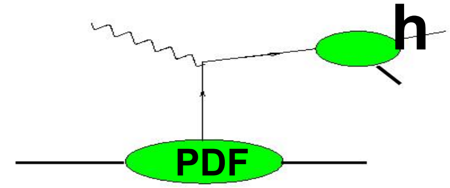
Target Fragmentation



x_F<0 (target fragmentation)



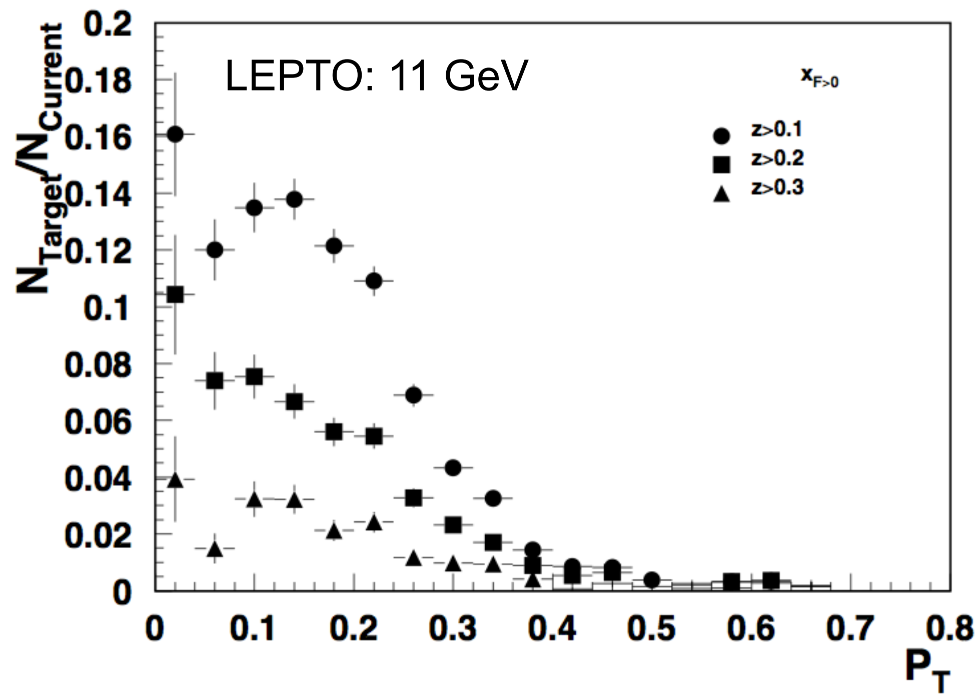
x_F>0 (current fragmentation)



Fracture Functions: probabilities to produce the hadron h when a quark q is struck in a proton target

	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	$\Delta_T M_T^h, \Delta_T M_T^\perp$	$\Delta_T M_L^h$ $\Delta_T M_L^\perp$	$\Delta_T M_T, \Delta_T M_T^{hh}$ $\Delta_T M_T^{\perp\perp}, \Delta_T M_T^{\perp h}$

•Hadrons produced in target fragmentation are correlated with hadrons in the current fragmentation and may introduce SSAs missing in current fragmentation.



Goals and requirements

The unambiguous interpretation of any SIDIS experiment (JLab in particular) in terms of leading twist transverse momentum distributions (TMDs) requires understanding of evolution properties and large k_T corrections(Y-term), control of various subleading $1/Q^2$ corrections, radiative corrections, knowledge of involved transverse momentum dependent fragmentation functions, understanding of hadronic backgrounds not originating from current quarks.

- Leading twist QCD fundamentals (Y-term, matching at large P_T..)
- higher twist effects
- TMD fragmentation functions
- target fragmentation correlations with current fragmentation

- Finite energies, finite phase space (target and hadron mass corrections,..)
- radiative corrections including the full list of structure functions

Summary

For precision studies of TMD(CFF) we need

Theory:

- Extraction framework with controlled systematics (build in validation mechanism) to define requirements for the input
- Better understanding of higher twists (indispensable part of SIDIS analysis) is crucial for interpretation of SIDIS leading twist observables
- Better understanding of Radiative Corrections (in 5D)
- Understanding of kinematic corrections (finite phase space,target mass,…)
- Understanding of target fragmentation and correlations between hadrons in target and current fragmentation
- Understanding of relative scales, sizes and kinematic dependences of different contributions

Experiment:

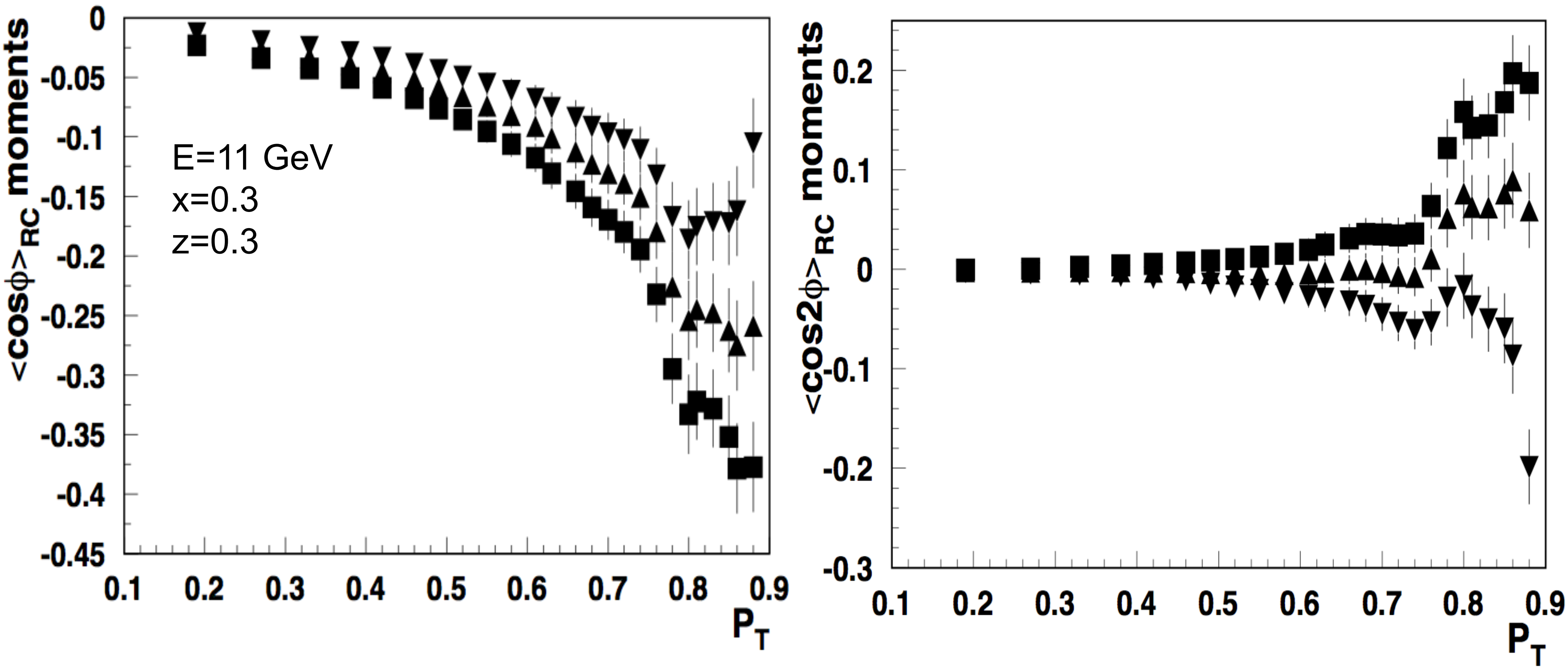
Realistic MC description of measured distributions to minimize acceptance effects

Need a new MC generator "PYTHIA with spin-orbit correlations"
to simulate azimuthal and spin correlations in final state hadronic distributions.

Proposal for topical collaboration: https://www.overleaf.com/2474182rxzqcg#/6457247/

Support slides….

P_T -dependence of Radiative Corrections to F_{UU}



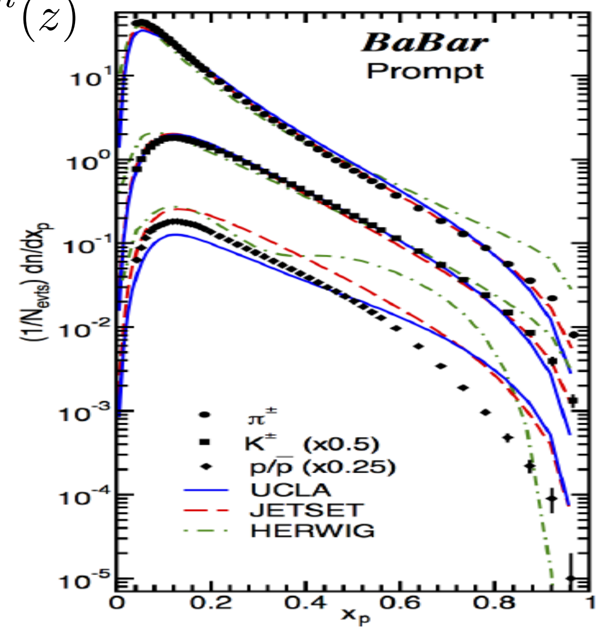
Azimuthal moments from radiative effects are large and very sensitive to input structure functions (3 different SFs plotted)

Flavor dependent TMD Fragmentation functions

https://www.phy.anl.gov/nsac-lrp/Whitepapers/StudyOfFragmentationFunctionsInElectronPositronAnnihilation.pdf

$$F_{UU} \propto \sum_q f_{1,q}(x,k_\perp) \otimes D_1^{q\to h}(z,p_\perp)$$

$D_1^{q\to h}(z)$

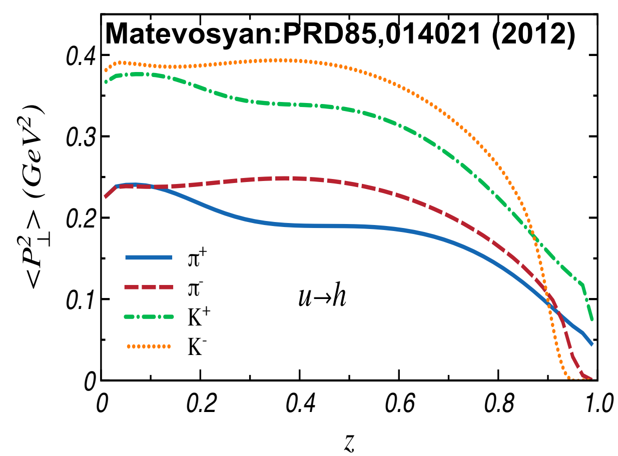


Even simple approximations require an additional set of parameters

$$D_1^{q\to h,fav}(z,p_\perp) = D_1^{q\to h}(z) \times \frac{e^{-\frac{p_\perp^2}{\langle p_{\perp,fav}^2(z)\rangle}}}{\pi\langle p_{\perp,fav}^2(z)\rangle}$$

$$D_1^{q\to h,unf}(z,p_\perp) = D_1^{q\to h}(z) \times \frac{e^{-\frac{p_\perp^2}{\langle p_{\perp,unf}^2(z)\rangle}}}{\pi\langle p_{\perp,unf}^2(z)\rangle}$$

$$\langle p_{\perp,unf}^2(z)\rangle > \langle p_{\perp,fav}^2(z)\rangle$$



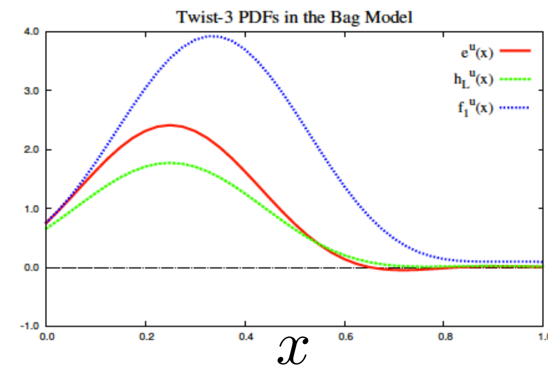
Measurements of flavor and spin dependence of transverse momentum dependent fragmentation functions will provide critical input to TMD extraction

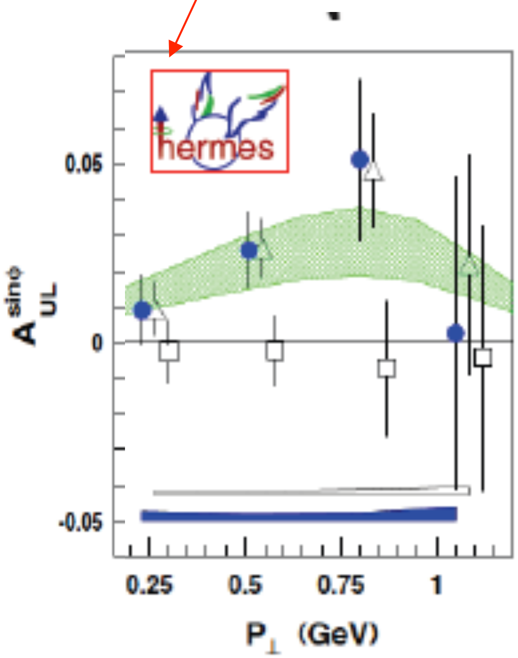
Quark-gluon correlations: Models vs Lattice

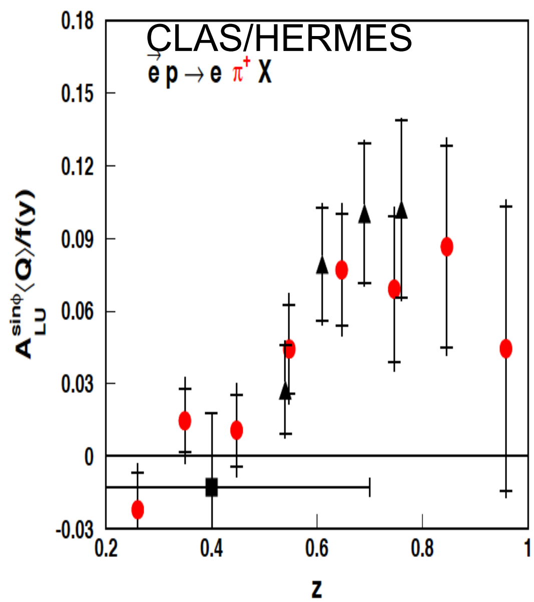
N/q	U	L	T
U			e
L			h_L
T		g_T	

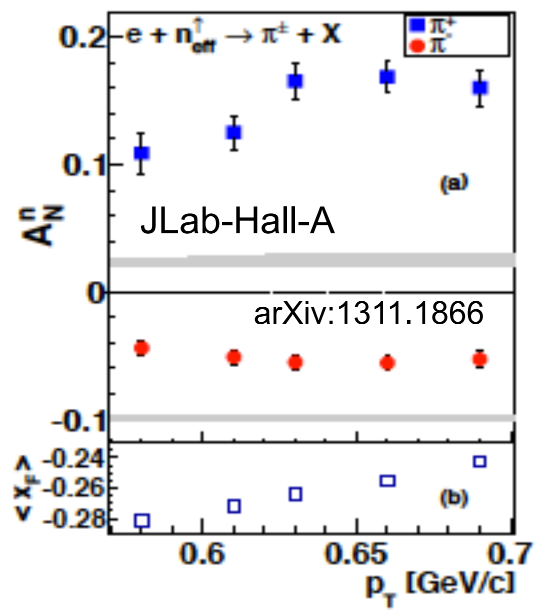
$$e_2 \equiv \int_0^1 dx x^2 \bar{e}(x)$$

Force on the active quark right after scattering (Burkardt)



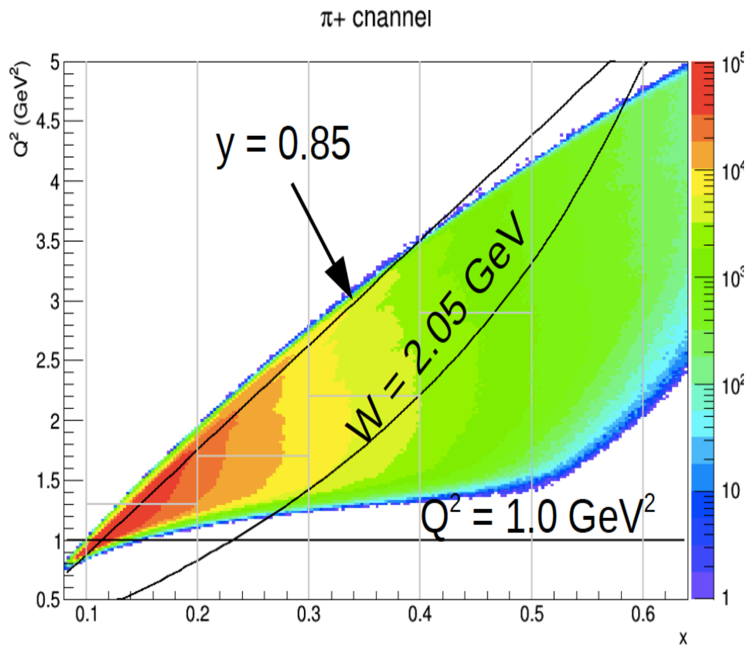




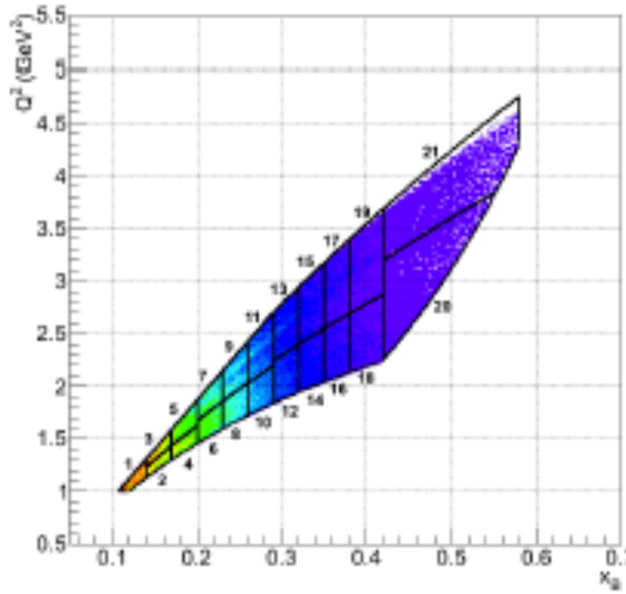


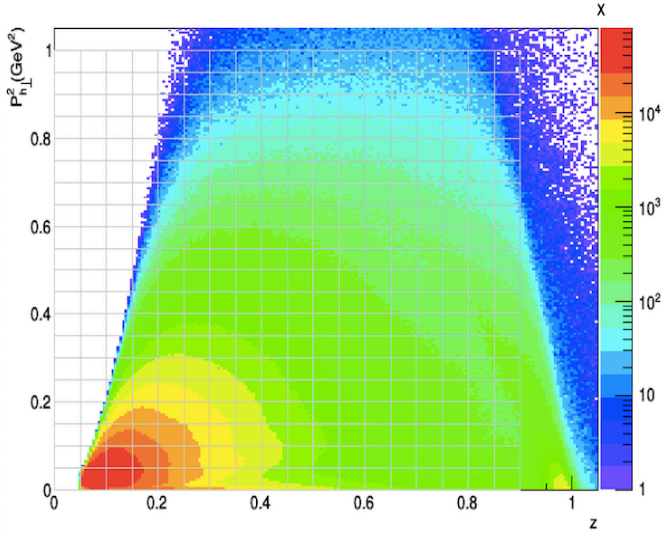
- Significant longitudinal target SSA measured at JLab and HERMES may be related to HT and color forces
- Large transverse spin asymmetries observed in inclusive pion production (Hall-A, HERMES)
- Models and lattice agree on a large e/f1 -> large beam SSA

Multidimensional binning (e1f-SIDIS vs e1dvcs)



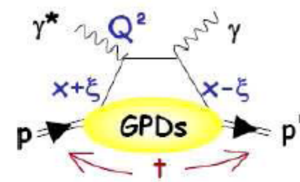
	x_B	θ_e (deg)	% of the dataset
bin 1	0.1 − 0.14	21 − 45	6.96%
bin 2	0.14 − 0.17	21 − 25.5	5.48%
bin 3	0.14 − 0.17	25.5 − 45	5.94%
bin 4	0.17 − 0.2	21 − 25.5	6.48%
bin 5	0.17 − 0.2	25.5 − 45	7.43%
bin 6	0.2 − 0.23	21 − 27	7.89%
bin 7	0.2 − 0.23	27 − 45	6.57%
bin 8	0.23 − 0.26	21 − 27	6.69%
bin 9	0.23 − 0.26	27 − 45	6.77%
bin 10	0.26 − 0.29	21 − 27	5.16%
bin 11	0.26 − 0.29	27 − 45	5.90%
bin 12	0.29 − 0.32	21 − 28	4.27%
bin 13	0.29 − 0.32	28 − 45	4.19%
bin 14	0.32 − 0.35	21 − 28	3.12%
bin 15	0.32 − 0.35	28 − 45	3.20%
bin 16	0.35 − 0.38	21 − 28	2.33%
bin 17	0.35 − 0.38	28 − 45	2.50%
bin 18	0.38 − 0.42	21 − 28	2.14%
bin 19	0.38 − 0.42	28 − 45	2.40%
bin 20	0.42 − 0.58	21 − 33	2.38%
bin 21	0.42 − 0.58	33 − 45	2.20%





5 x bins in x_i= 0.1+0.1*(i-1) i=1-6
4 Q^2 bins are: 1.3, 1.7, 2.2, and 2.9 GeV^2.
18 bins in z_j=0.0+(j-1)*0.05 j=1,19
20 bins in P_T^2_l= 0.0+0.05*(l-1) l=1,21

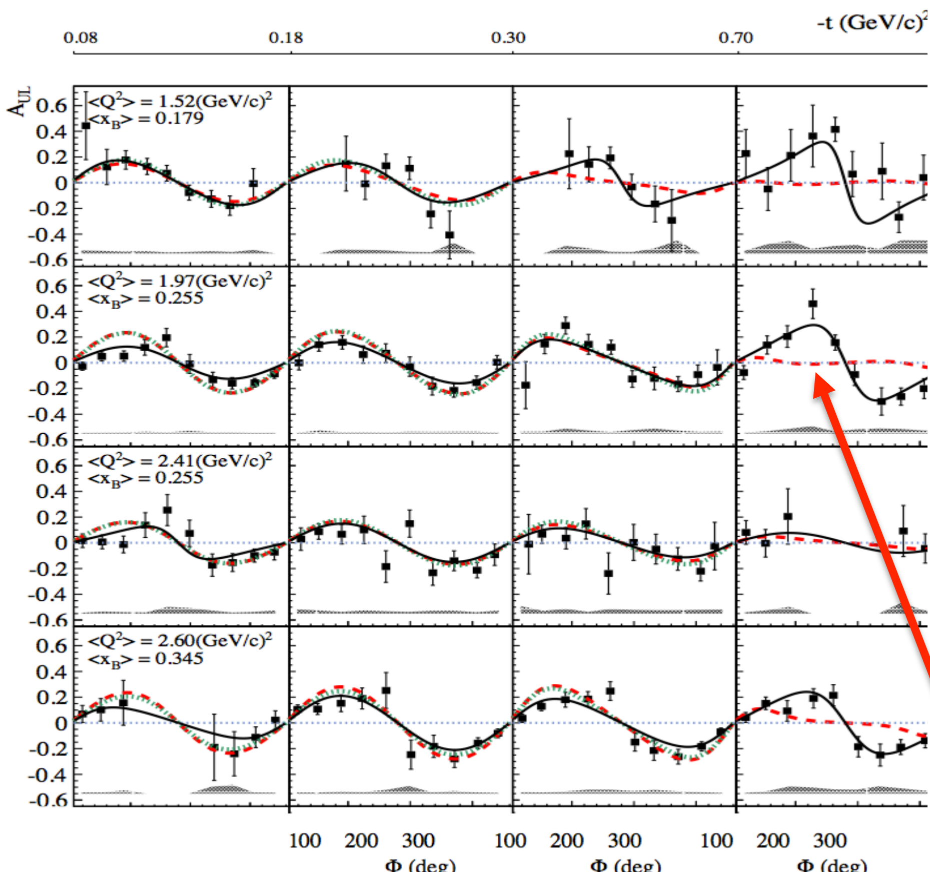
Polarized SSAs in DVCS



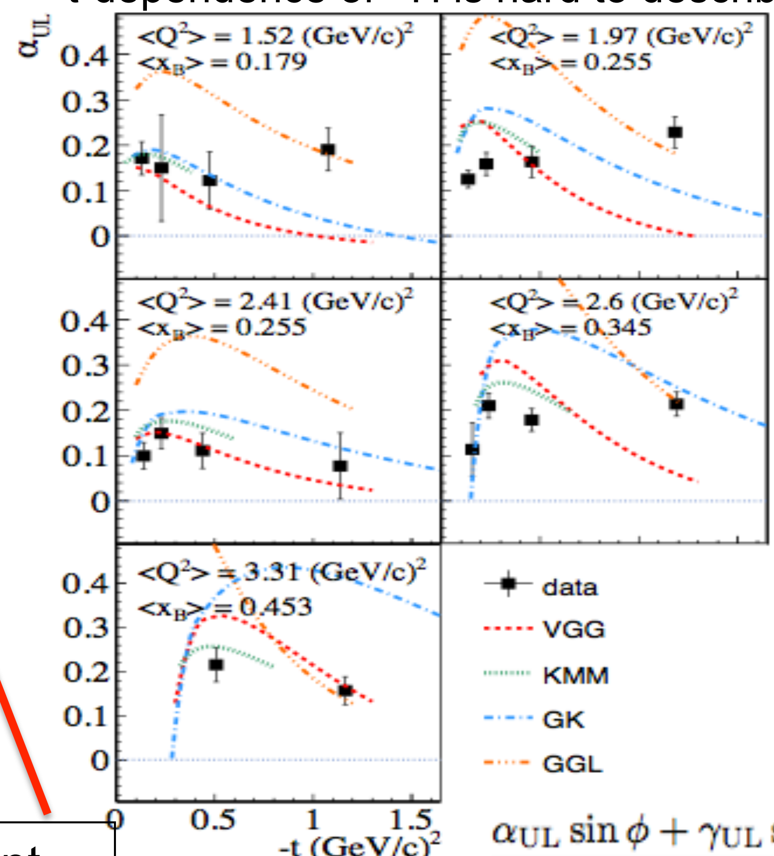
Unpolarized beam, longitudinal target (TSA) :

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

$\Rightarrow$ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$



t-dependence of $\tilde{H}$ is hard to describe



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

Higher twist contributions may be significant for polarization SSA in DVCS

Higher Twists

http://arxiv.org/abs/arXiv:1506.07302

quark polarization	nucleon polarization	TMD PDFs	if $\mathcal{L}=1$	integrated over $\vec{k}_\perp$
U	U	$e(x,k_\perp)$, $f^\perp(x,k_\perp)$	0, $f_1(x,k_\perp)/x$	$e(x)$, $\times$
	T	$e_T^\perp(x,k_\perp)$, $f_T^{\perp 1}(x,k_\perp)$, $f_T^{\perp 2}(x,k_\perp)$	0, 0, 0	$\times$ $\times$ $\times$
L	L	$e_L(x,k_\perp)$, $g_L^\perp(x,k_\perp)$	0, $g_1(x,k_\perp)/x$	$\times$, $\times$
	T	$e_T(x,k_\perp)$, $g'_T(x,k_\perp)$, $g_T^\perp(x,k_\perp)$	0, 0, $g_{1T}(x,k_\perp)/x$	$\times$ $g_T(x)$
T	U	$h(x,k_\perp)$	0	$\times$
	$T(\parallel)$	$h_T^\perp(x,k_\perp)$	$h_{1T}^\perp(x,k_\perp)/x$	$\times$
	$T(\perp)$	$h_T(x,k_\perp)$	$h_{1T}(x,k_\perp)/x+k_\perp^2 h_{1T}^\perp(x,k_\perp)/M^2x$	$\times$
	L	$h_L(x,k_\perp)$	$k_\perp^2 h_{1L}^\perp(x,k_\perp)/M^2x$	$h_L(x)$
U	L	$f_L^\perp(x,k_\perp)$	0	$\times$
L	U	$g^\perp(x,k_\perp)$	0	$\times$

Higher Twist PDFs

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

L = 1 , i.e. if we neglect the multiple gluon scattering and simply take a nucleon as an ideal gas system consisting of quarks and anti-quarks

Extracting the moments with rad corrections

Moments mix in experimental azimuthal distributions

Simplest rad. correction $$R(x, z, \phi_h) = R_0(1 + r\cos\phi_h)$$

Correction to normalization

$$\sigma_0(1 + \alpha\cos\phi_h)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + \alpha r/2)$$

Correction to SSA

$$\sigma_0(1 + sS_T\sin\phi_S)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + sr/2S_T\sin(\phi_h - \phi_S) + sr/2S_T\sin(\phi_h + \phi_S))$$

Correction to DSA

$$\sigma_0(1 + g\lambda\Lambda + f\lambda\Lambda\cos\phi_h)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + (g + fr/2)\lambda\Lambda)$$

Generate fake DSA moments (cos)

$$\sigma_0(1 + g\lambda\Lambda)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0 gr\cos\phi_h$$

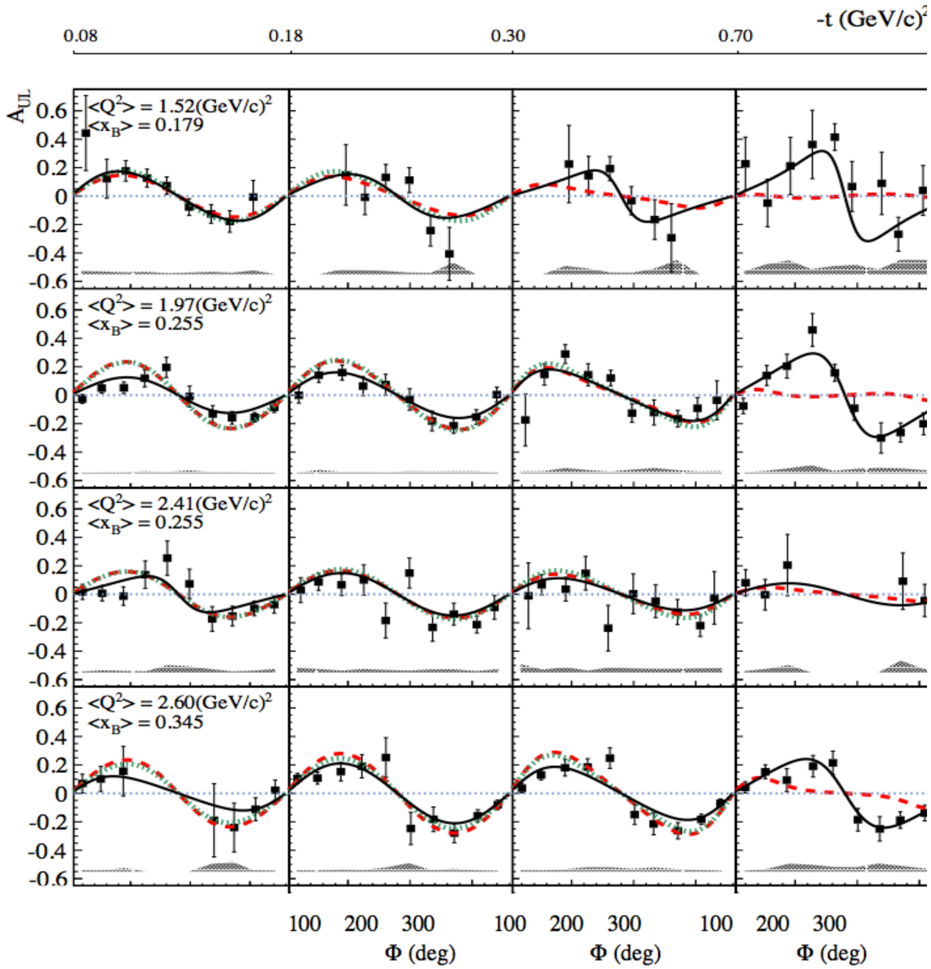
Simultaneous extraction of all moments is important also because of correlations!

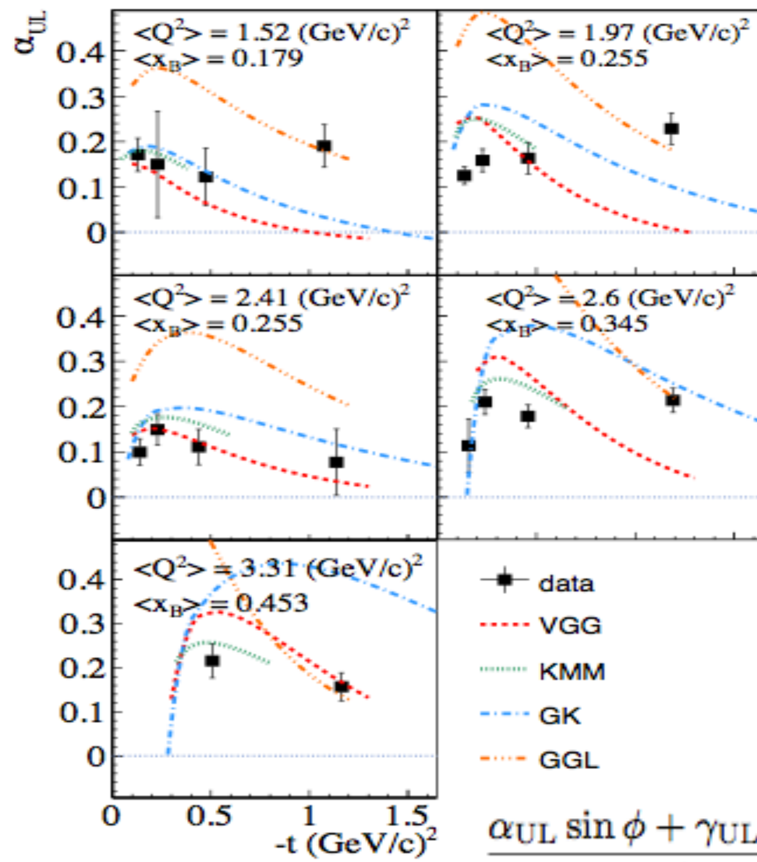
t-dependence of $\tilde{H}$

Unpolarized beam, longitudinal target (TSA) :

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

$\Rightarrow$ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$





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

HERMES AUT