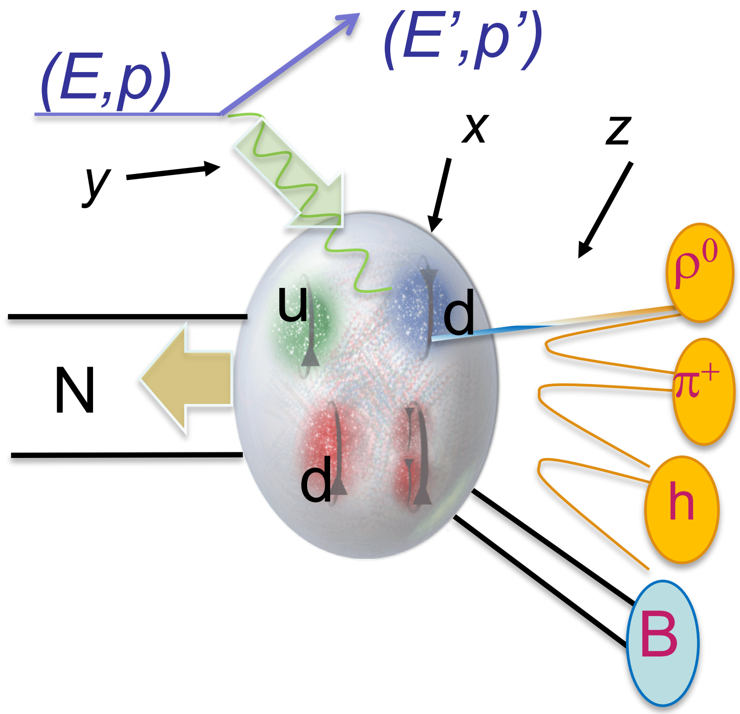
SIDIS/TMD Program at 24 GeV

Harut Avakian (JLab)

CLAS Collaboration Meeting 2021
June 2, 2021

- Introduction
- Main achievements of CLAS12 in SIDIS
- Limitations in theory description
- Impact of limitations due to energy
- JLab12 at large x and overlap with EIC
- JLab24 vs HERMES 27
- Summary

SIDIS kinematical coverage and observables



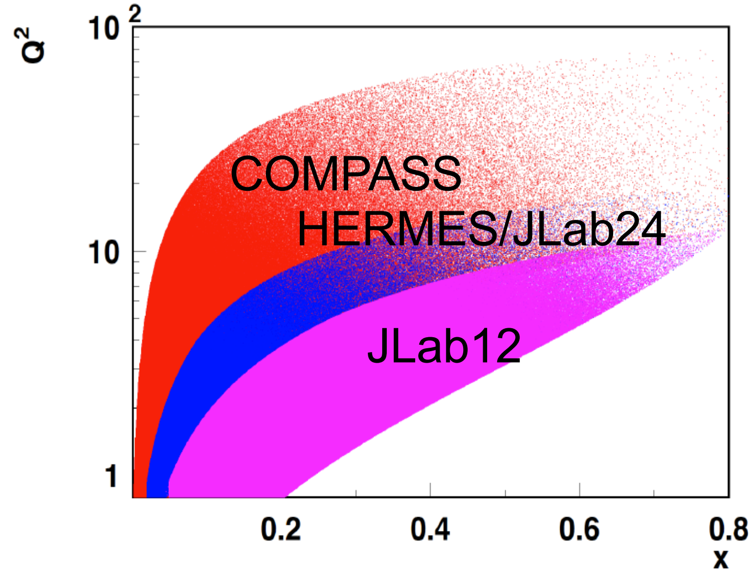
hermes

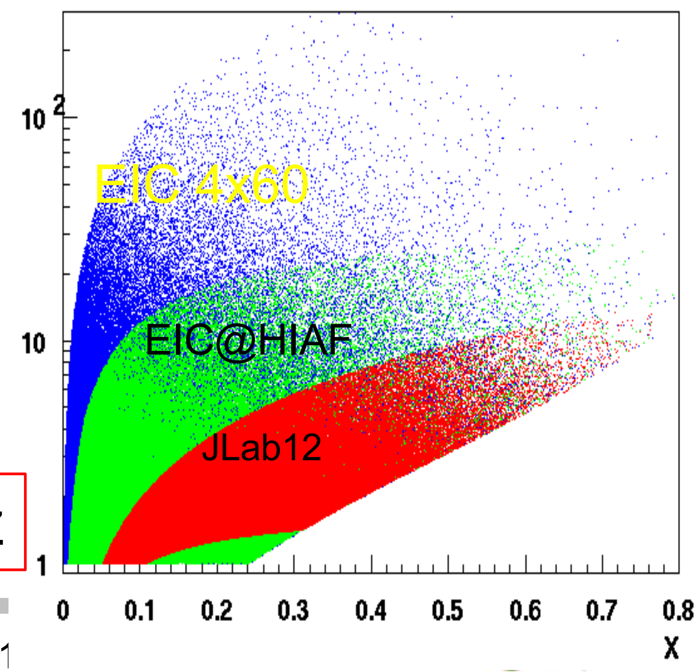
COMPASS

Jefferson Lab

EIC^2 EIC Center at Jefferson Lab

EIC





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

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

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

beam polarization

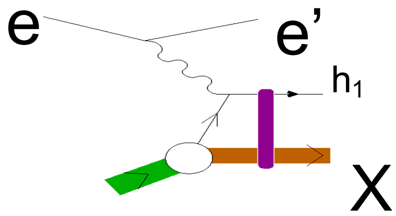
target polarization

corrections for the region of large kT~Q

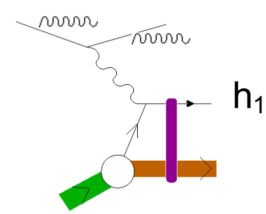
$q_T = P_T/z$

Electro-production of hadrons

single hadron in CFR (Current Fragmentation Region)

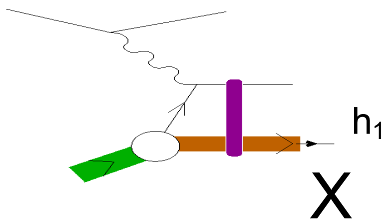


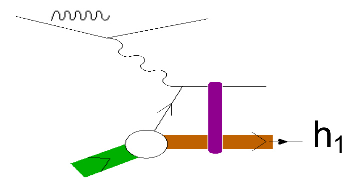
with additional radiation



Does it matter what is the source of the single hadron, and if yes, where?

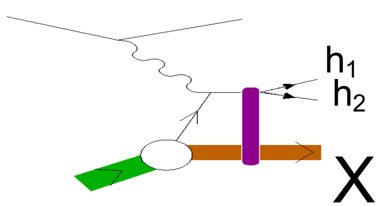
single hadron in TFR(Target Fragmentation Region)

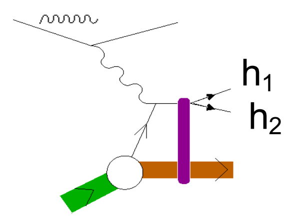




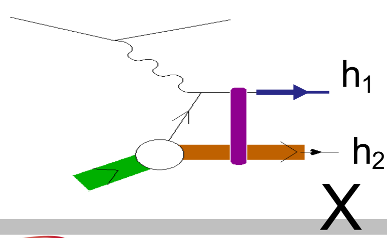
radiation mixes contributions from different structure functions and complicates separation of exclusive from semi-inclusive

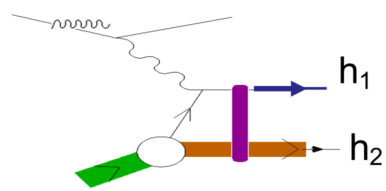
correlated hadrons(dihadron,rho,..) in CFR





correlated hadrons in CFR+TFR

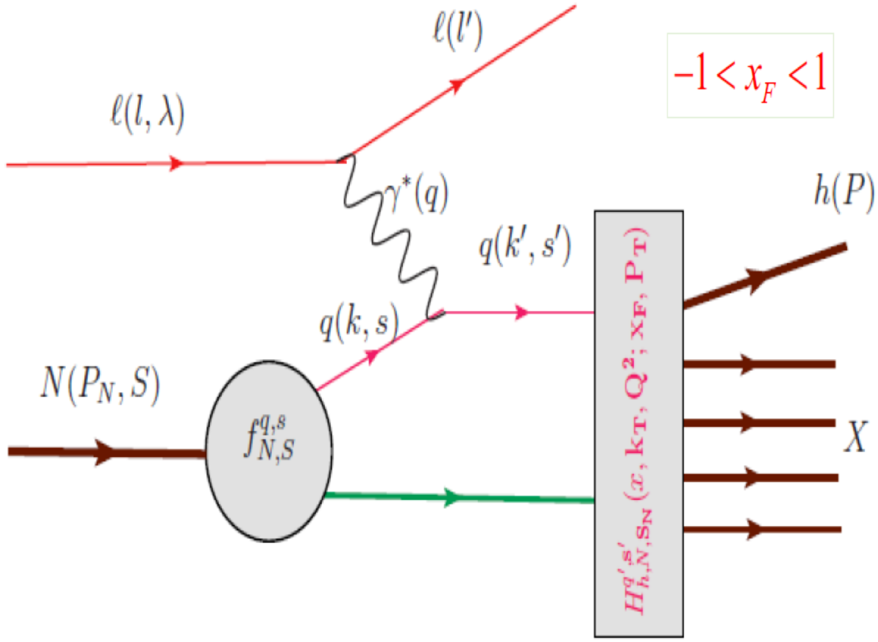


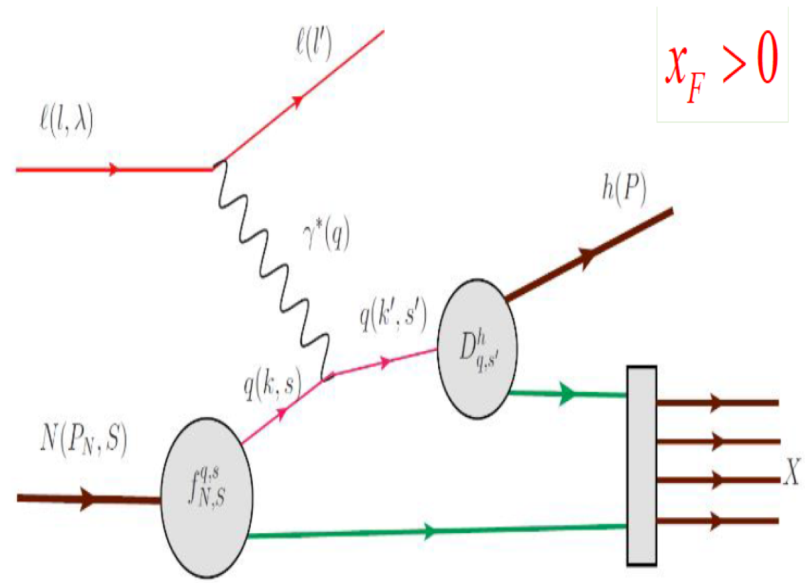


Hadronization

$Q^2 \gg M_p^2$

A.Kotzinian FF2019





Hadronization Function
→ conditional probability to produce hadron ***h***

$$H_{h/N}^{q'}\left(x,\mathbf{k}_T,Q^2;x_F,\mathbf{P}_T^h;\mathbf{s}_q',\mathbf{S}_N\right)$$

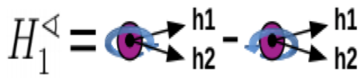
Quark Fragmentation Functions

$$D_{q,s'}^h\left(z,\mathbf{p}_T,Q^2\right)$$

Where this works?

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

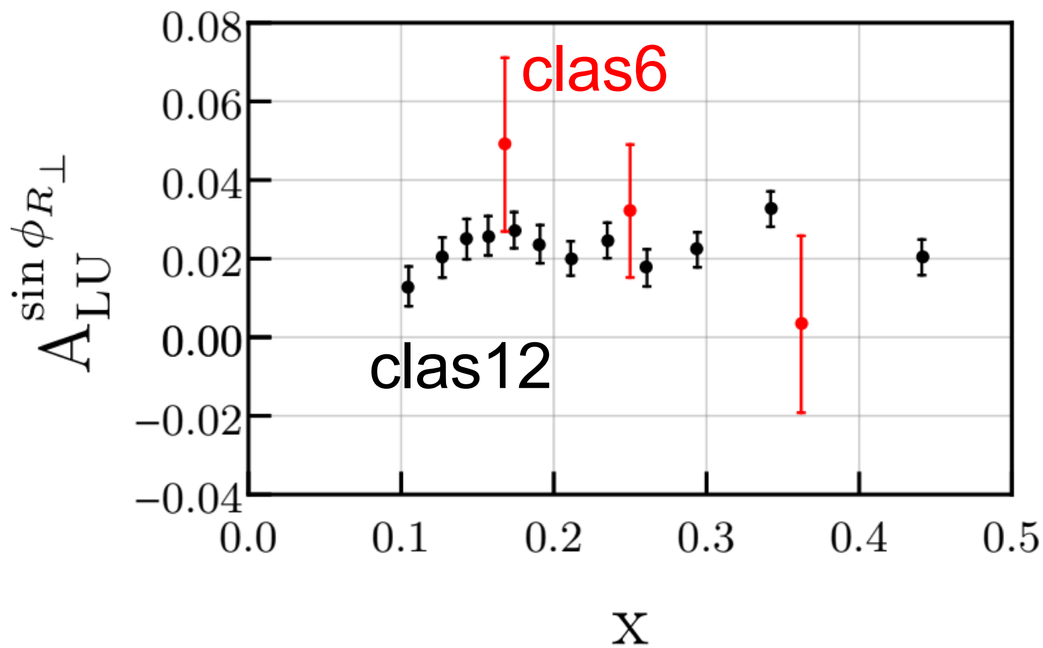
T. Hayward et al. Phys. Rev. Lett. 126, 152501 (2021)

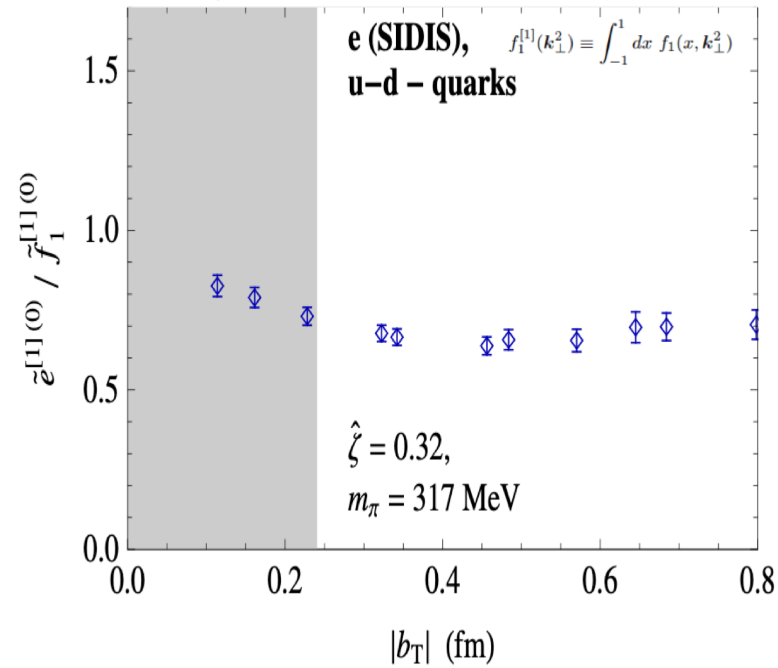


$$d\sigma_{LU} \propto \lambda_e \sin(\phi_{R_\perp}) \left(xe(x)H_1^{\sphericalangle}(z, M_h) + \frac{1}{z} f_1(x)\tilde{G}^{\sphericalangle}(z, M_h) \right)$$

Bacchetta&Radici: arXiv:hep-ph/0311173

Engelhardt: TMDs from JLab to EIC

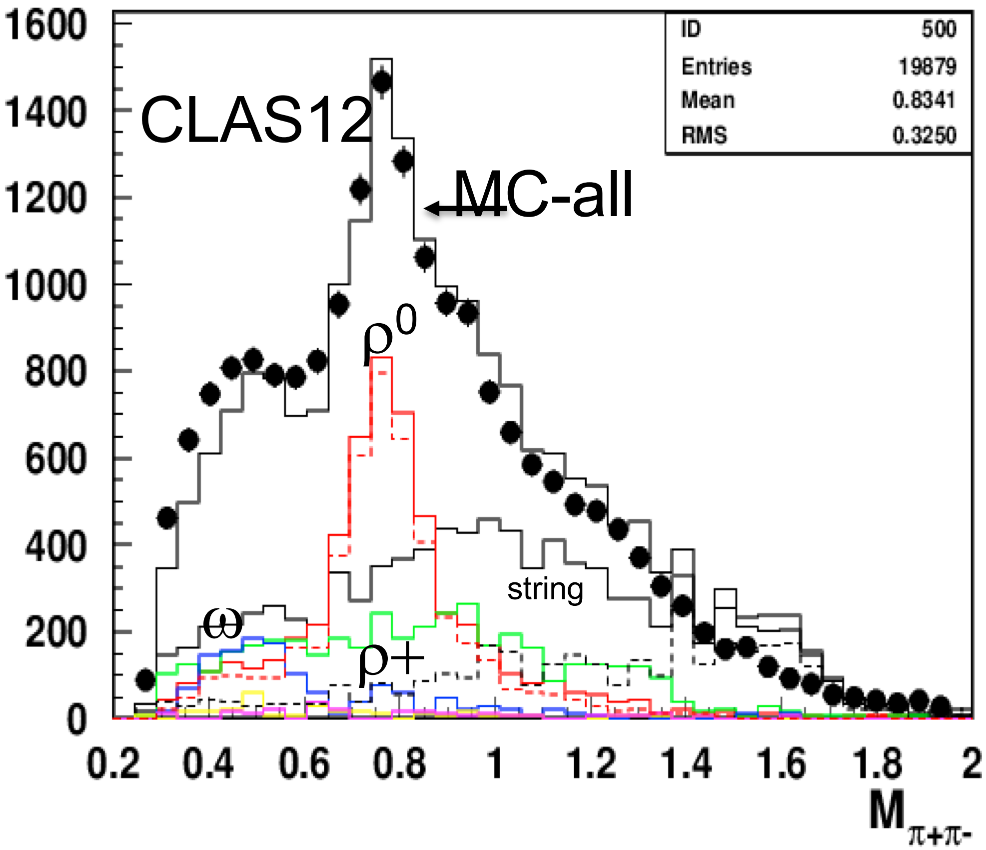




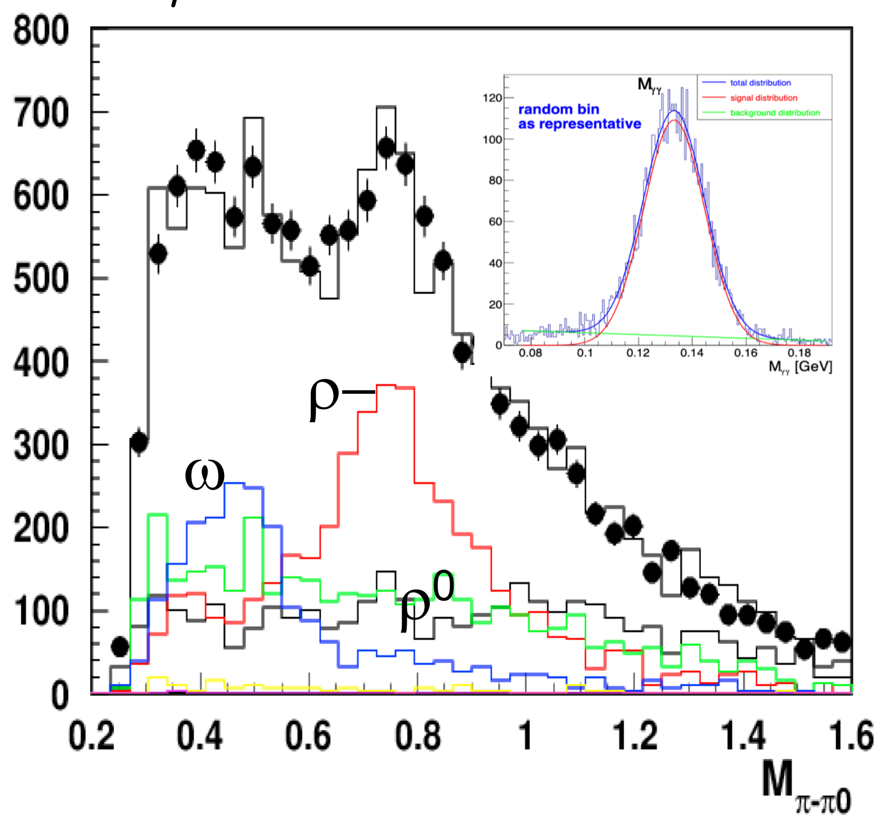
Doubling the JLab beam energy, opens the phase space for SIDIS dihadrons

Quark gluon correlations may be very significant

Sources of inclusive pions: CLAS12 vs MC



$\rho^{\pm} \rightarrow \pi^0 + \pi^{\pm}$



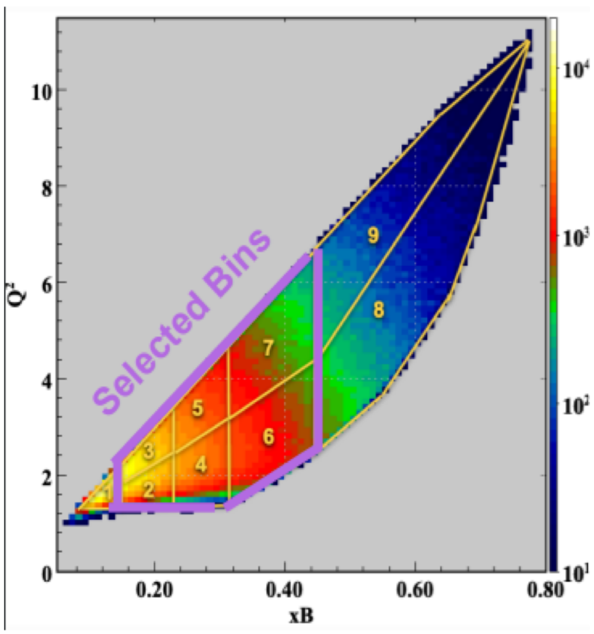
- Dominant fraction of inclusive pions come from VM decays
- Detection of π0s opens a new avenue to study charged ρ multiplicities
- Experimentally study relative fractions of π from ρ (default in JETSET ~50%)

Very important to have multidimensional TMD Fragmentation Functions!

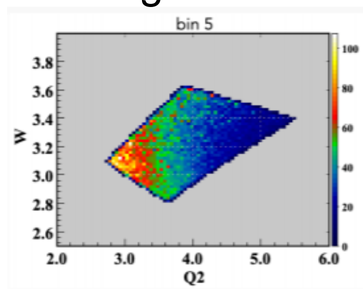
CLAS12 Multiplicities: high P_T & phase space

G. Angelini (GW)

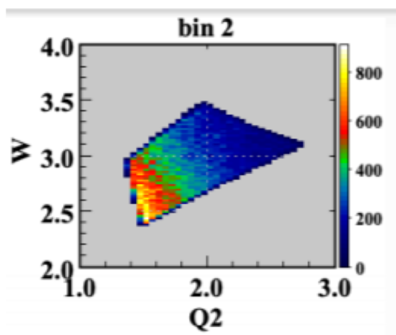
Generate direct pions with Gaussian

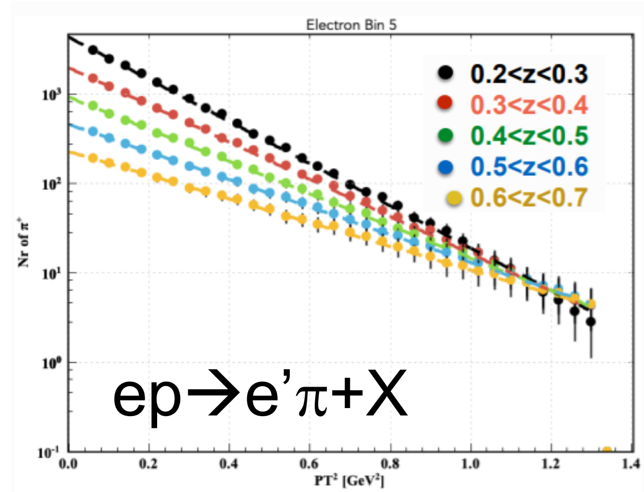


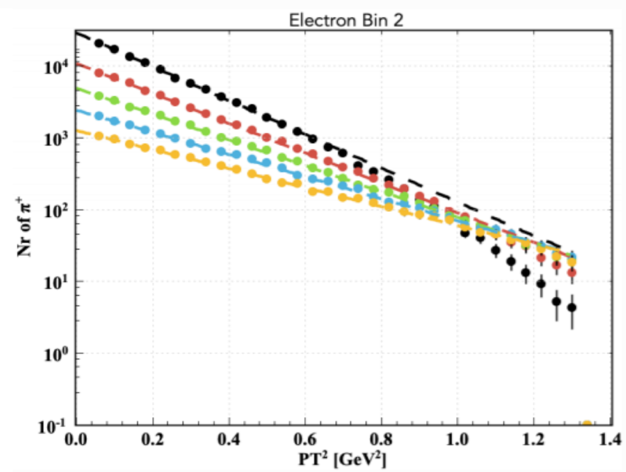
Higher W



Lower W







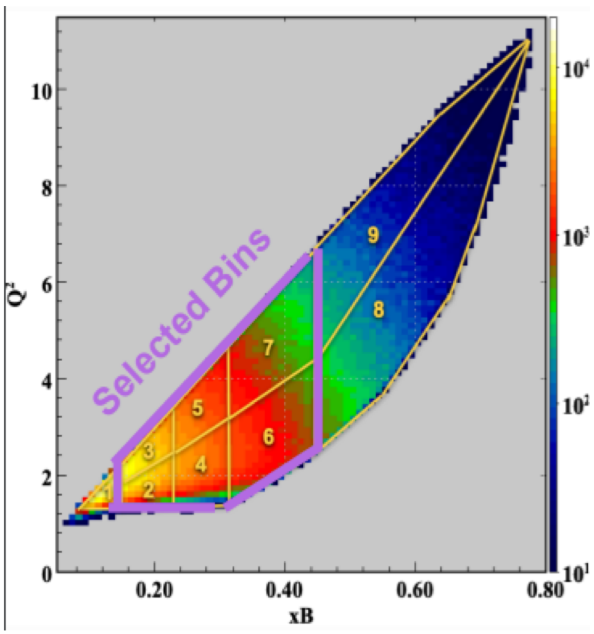
- Phase space limitations for direct pion production more significant at low W, and low z

At low z, and high P_T there is no enough energy in the system even for reproducing the Gaussian fall of (problem for studies of high P_T tails)

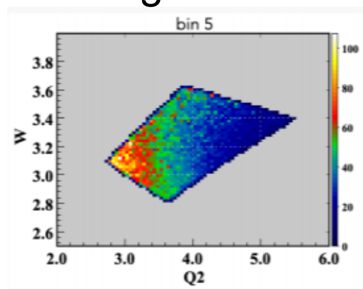
CLAS12 high P_T : impact of vector mesons

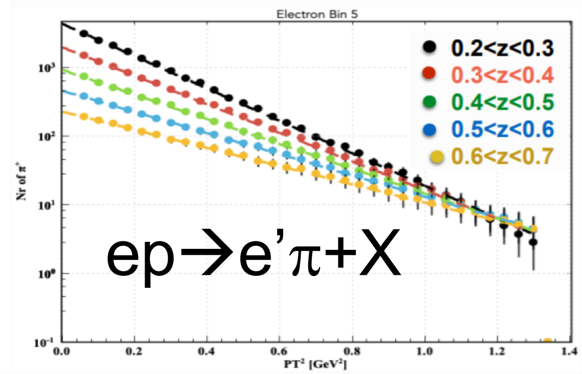
G. Angelini (GW)

Generate direct pions with Gaussian



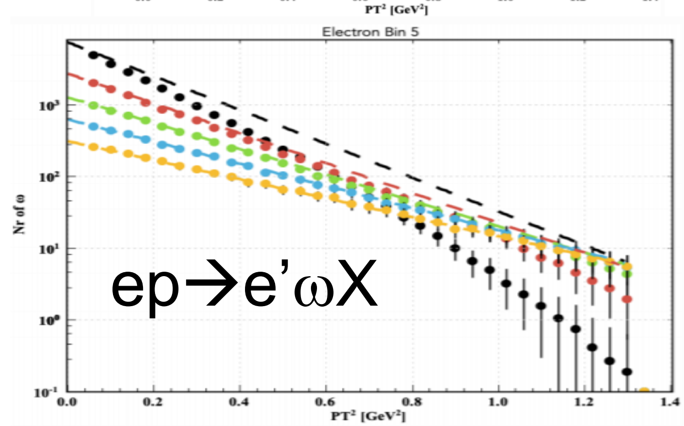
Higher W





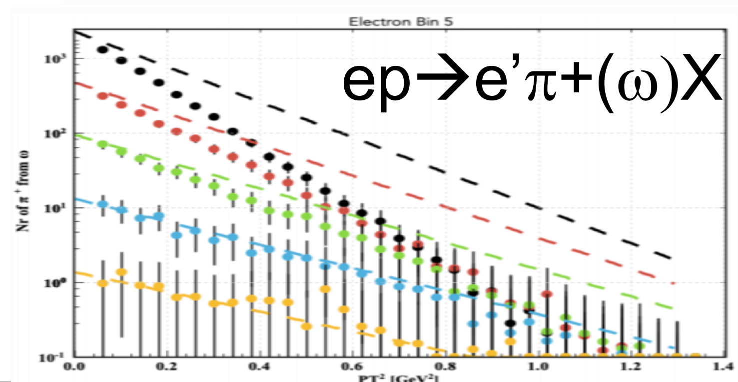
Generate pions from ω produced with the same Gaussian

Phase space effects more pronounced

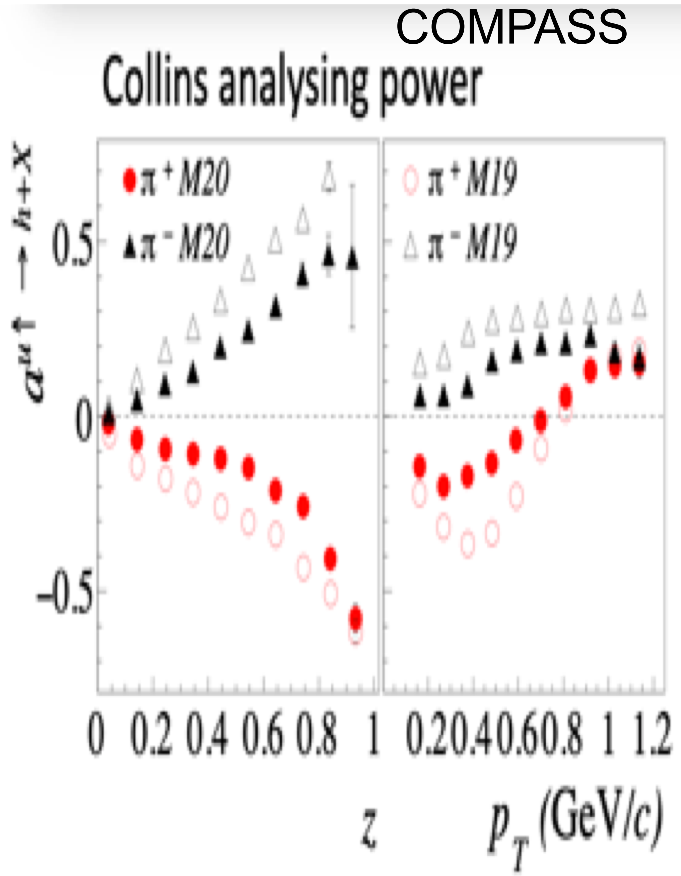


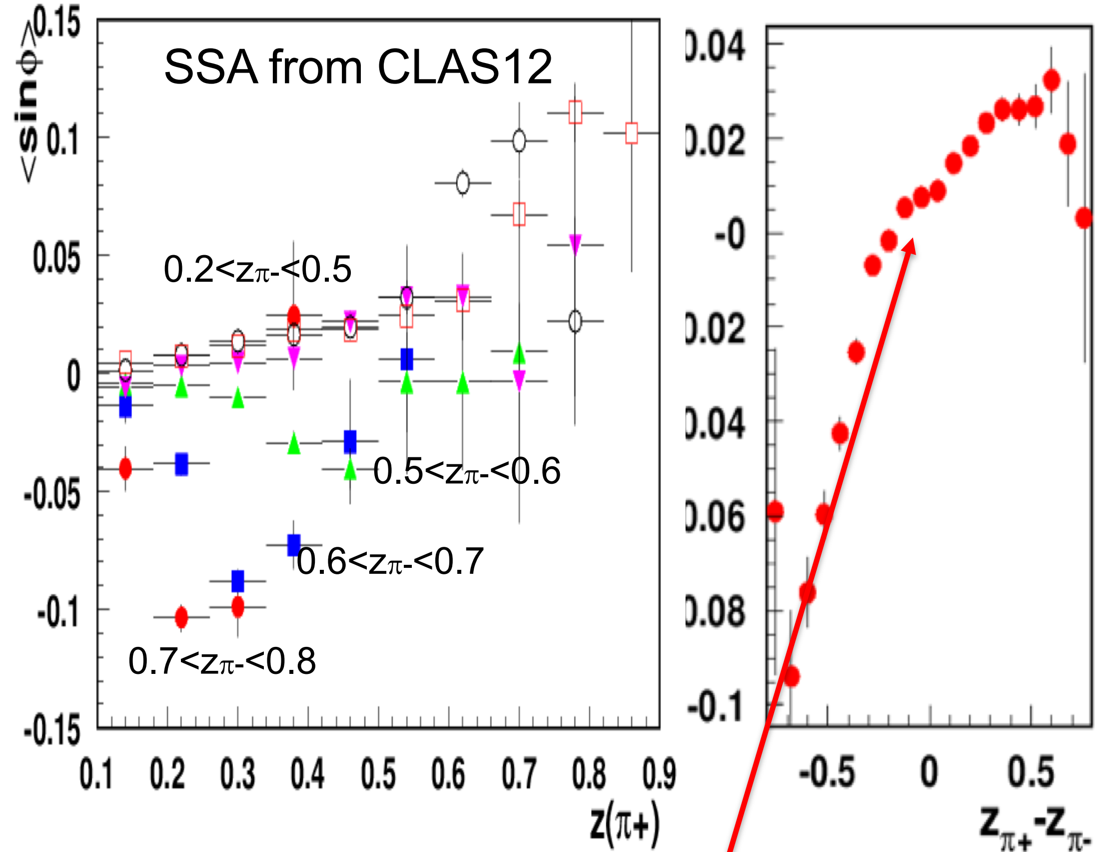
- The low P_T sample of pions is dominated by VM decays

Decay pions from ω have significantly lower transverse momentum for the same z



Disecting the SSA in ep→e'πX





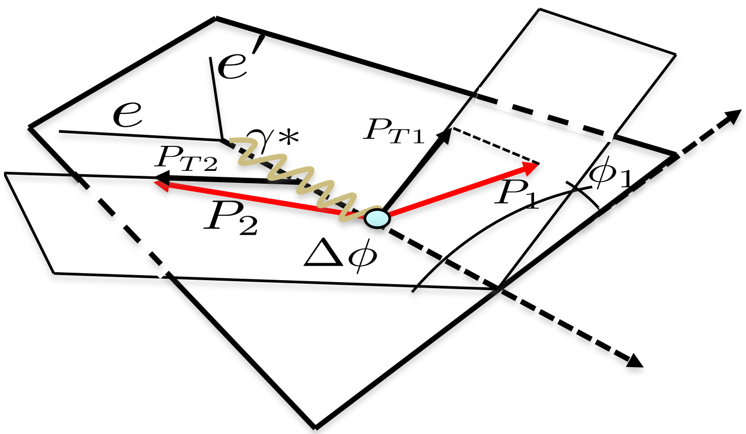
VM contributions may change significantly the interpretation of Collins analyzing power
A. Kerbizi: TMD Studies: from JLab to EIC

Observed SSA for the inclusive π+ changes significantly with the π- z
The polarization of the ρ itself may be relevant (no SSA for symmetric case)

B2B hadron production in SIDIS: First measurements

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

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



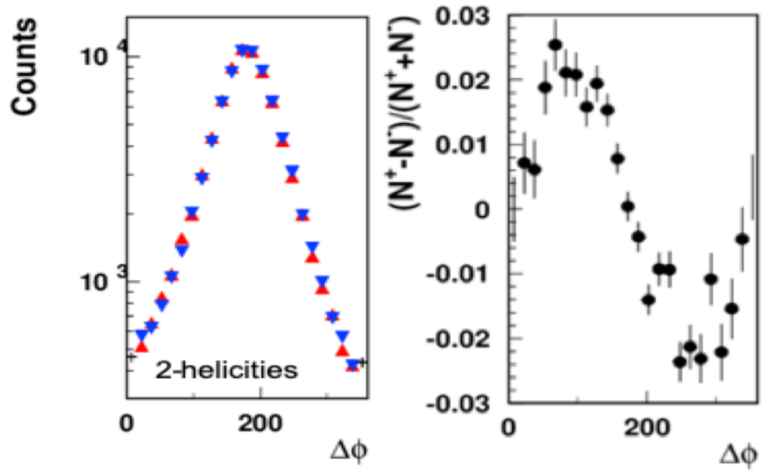
$$A_{LU} = -\frac{y(1-\frac{y}{2})}{(1-y+\frac{y^2}{2})}\frac{\mathcal{F}_{LU}^{\sin\Delta\phi}}{\mathcal{F}_{UU}}\sin\Delta\phi$$

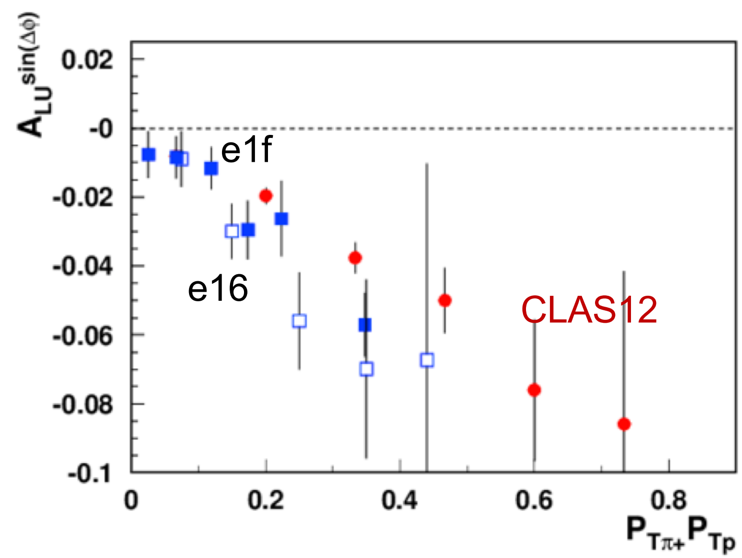
$$= -\frac{|\boldsymbol{P}_{1\perp}||\boldsymbol{P}_{2\perp}|}{m_N m_2}\frac{y(1-\frac{y}{2})}{(1-y+\frac{y^2}{2})}\frac{\mathcal{C}[w_5 \hat{l}_1^{\perp h} D_1]}{\mathcal{C}[\hat{u}_1 D_1]}\sin\Delta\phi,$$

kinematics

modulation

Correlation

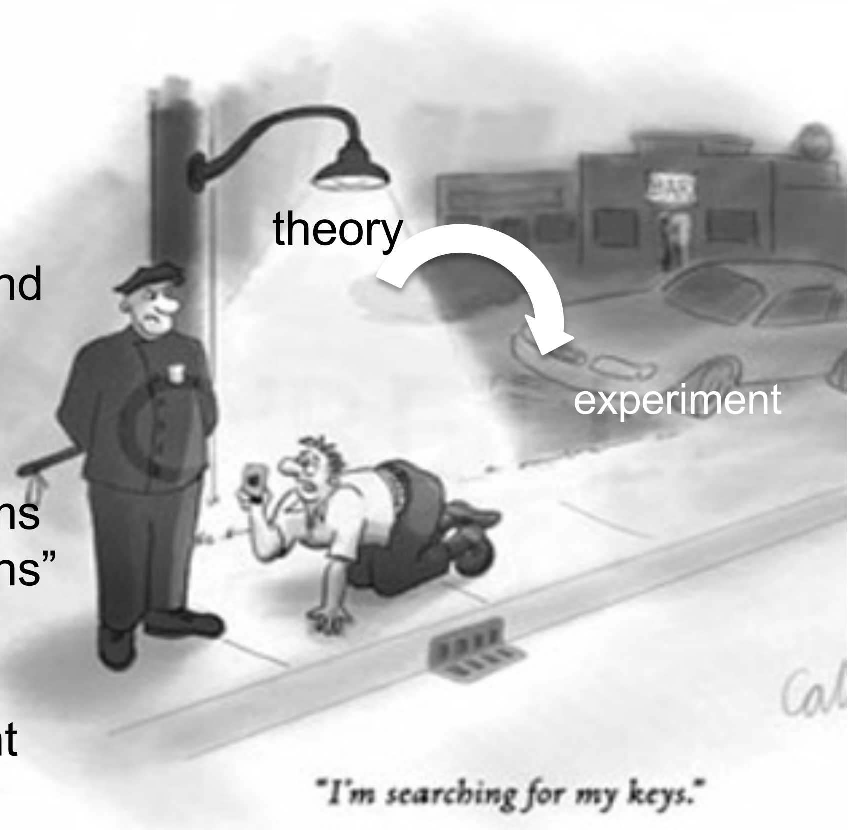




Significant single-spin asymmetries observed by CLAS12 (talk by T. Hayward) indicating strong correlations between hadrons

Nucleon structure, TMDs and SSAs

- Large effects observed at relatively large x, relatively large P_T and relatively low Q^2
- Theoretical framework works better, and is "trustworthy" at higher Q^2 and lower P_T
- TMD Fragmentation functions poorly known and understood, systematics not controlled well
- Higher twist SSAs are significant, indicating strong quark-gluon correlations, issues theory has, may become a key to resolve the problems
- Real experiments have "phase space limitations" due to finite energies, introducing correlations between kinematical variables
- Impact of radiative corrections with full account of azimuthal moments in the polarized x-sections still in development



The main goal is the study of non-perturbative QCD, through spin-orbit correlations, where they are significant enough to be measurable

Understanding of the limitations of the current TMD framework with all its assumptions and approximations, is important for predictions, and projections for future experiments

Current theory limitations (q_T/Q)

JLab/HERMES/COMPASS/EIC talks

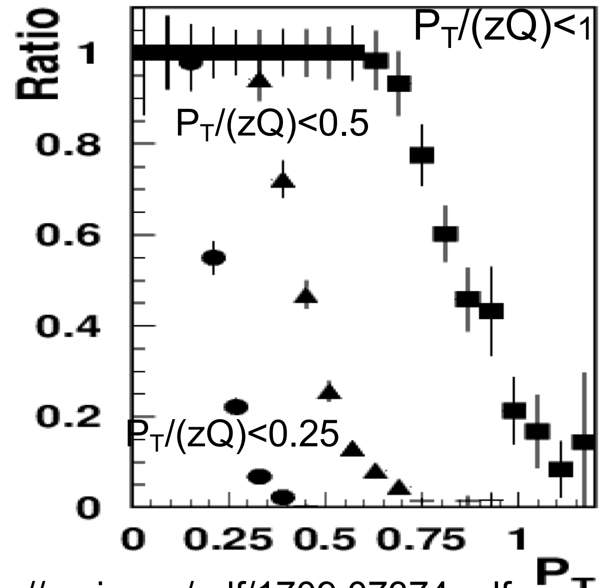
estimates of their effects. For example, the TMD description of SIDIS is valid in the small-p_T regime when $p_T^2/(zQ)^2 \ll 1$, and in a recent study [JHEP 06 (2020) 137] finding that $p_T^2/(zQ)^2 \lesssim 0.06$ approximately demarcates the boundary to large p_T, where a description in terms of TMD PDFs may not be trustworthy. By comparison, values for this ratio as

The $q_T=P_T/z$ cut, as formulated:

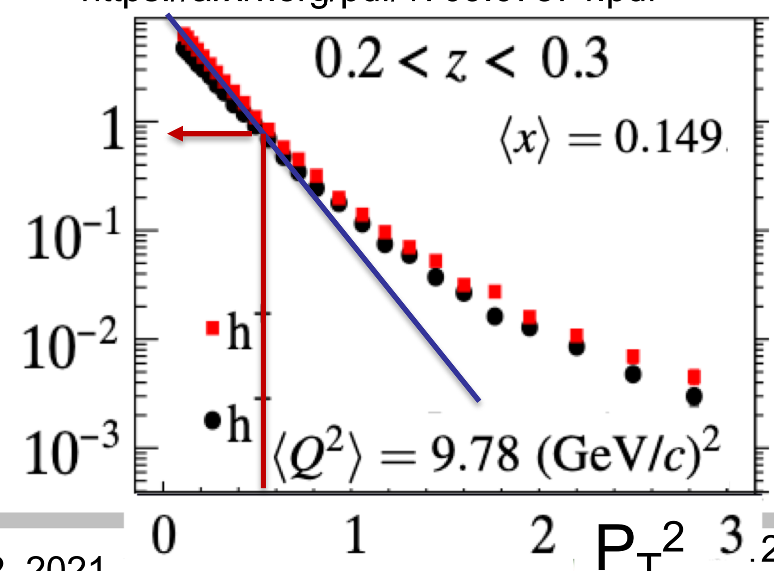
1) Enhances large z region (ex. Exclusive Events)
2) Suppresses high P_T (sensitive to k_T), where all kind of azimuthal modulations are large
3) Cuts not only most of the JLab data, but practically all accessible in polarized SIDIS large P_T samples , including ones from HERMES (Schnell) COMPASS (Martin) and EIC(Dilks).

https://indico.jlab.org/event/439/

JLab12



https://arxiv.org/pdf/1709.07374.pdf



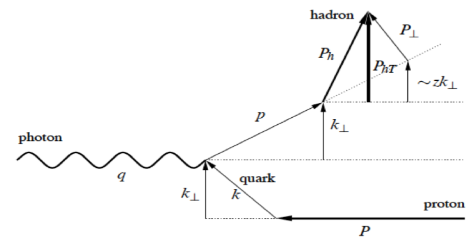
Limitations of current TMD theory

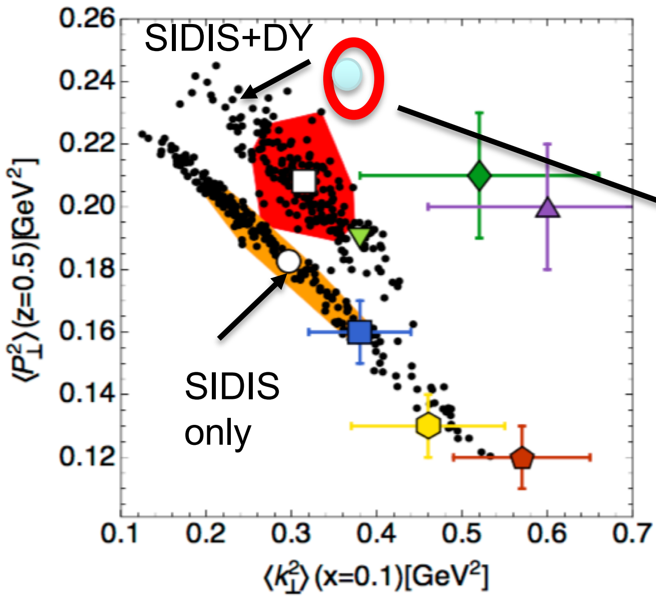
Andrea Signori,[1,*] Alessandro Bacchetta,[2,3,†] Marco Radici,[3,‡] and Gunar Schnell[4,5,§]

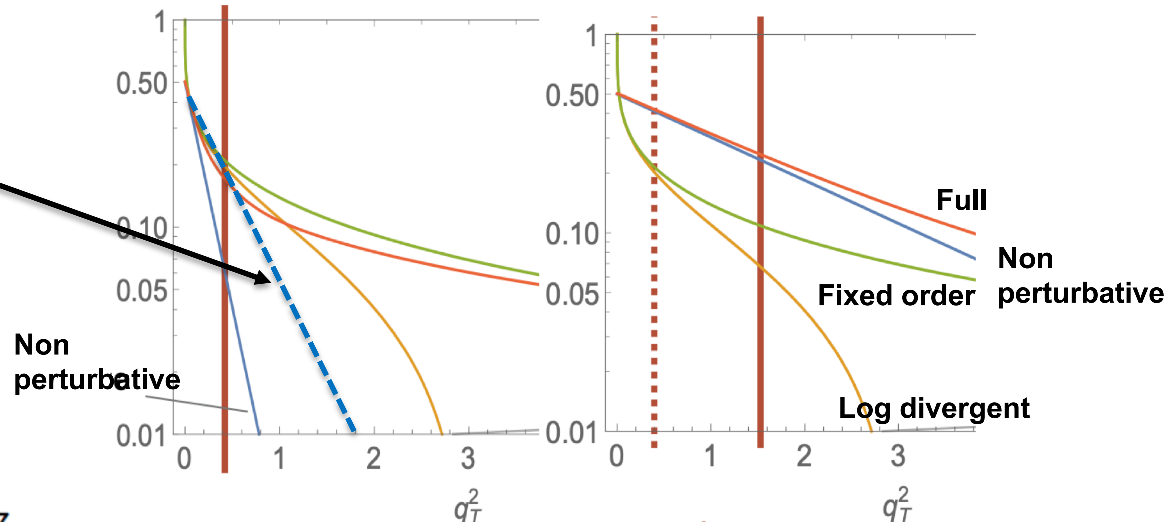
$$F_{UU,T}(x,z,P_{hT}^2,Q^2)=\sum_a \mathcal{H}^a_{UU,T}(Q^2;\mu^2)\int dk_\perp\, dP_\perp\, f_1^a(x,k_\perp^2;\mu^2)\, D_1^{a\to h}(z,P_\perp^2;\mu^2)\,\delta(zk_\perp - P_{hT}+P_\perp)$$

$$+Y_{UU,T}(Q^2,P_{hT}^2)+\mathcal{O}(M/Q).$$

$$\langle \boldsymbol{P}^2_{hT,a}\rangle = z^2\langle \boldsymbol{k}^2_{\perp,a}\rangle + \langle \boldsymbol{P}^2_{\perp,a\to h}\rangle$$

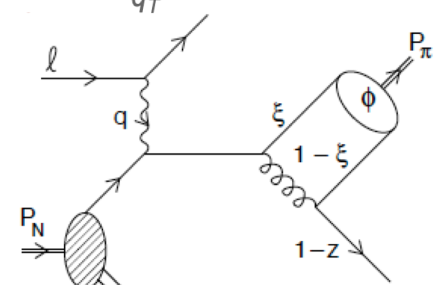






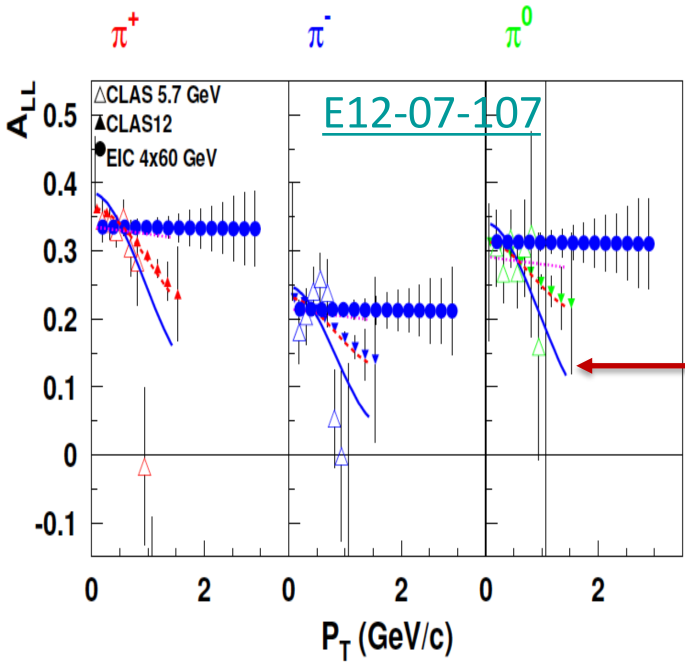
- Crucial to extend the theory to large q_T
- Higher Twist account may help
- Linking SIDIS with exclusive

Sea is not divided to perturbative and non-perturbative

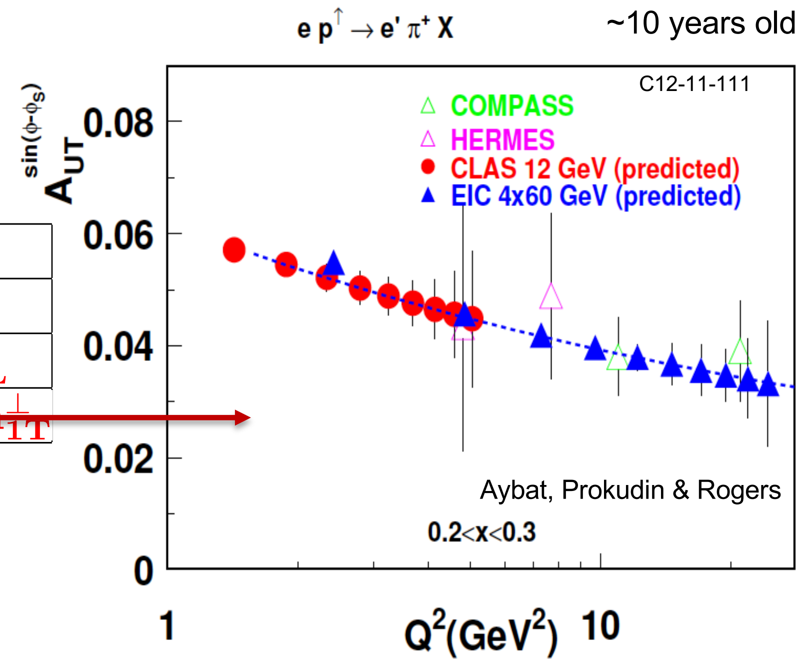


Semi-exclusive production

CLAS12: Evolution and k_T-dependence of TMDs



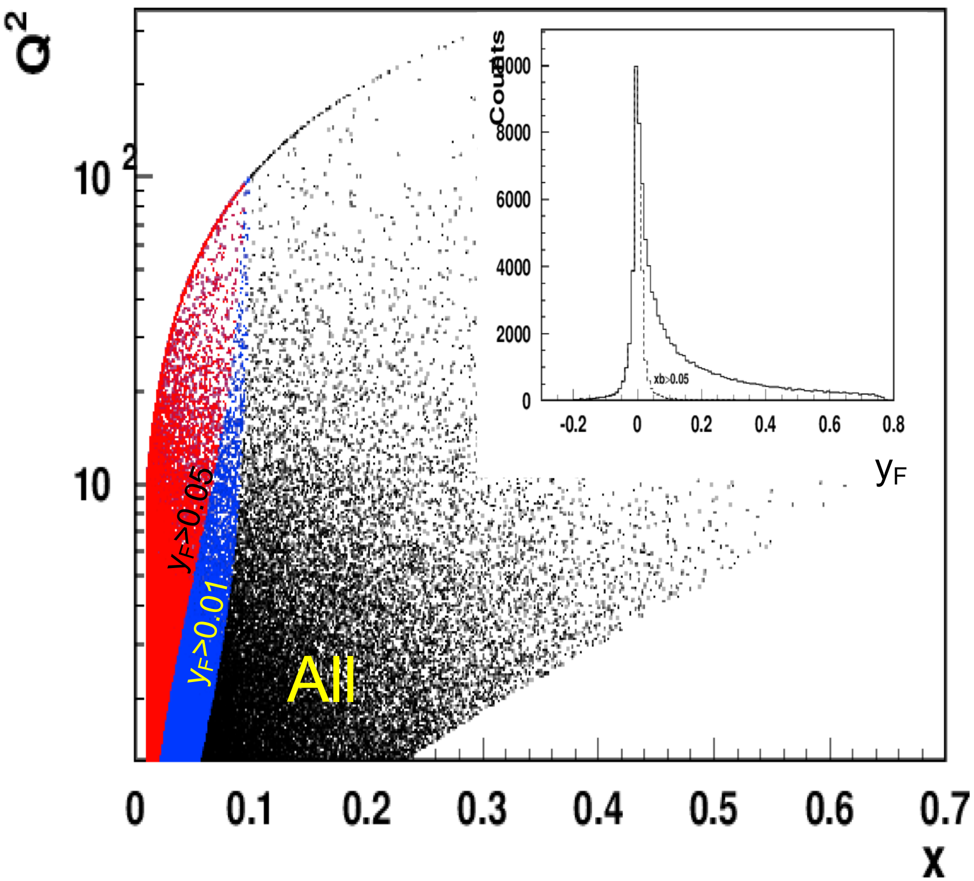
N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$

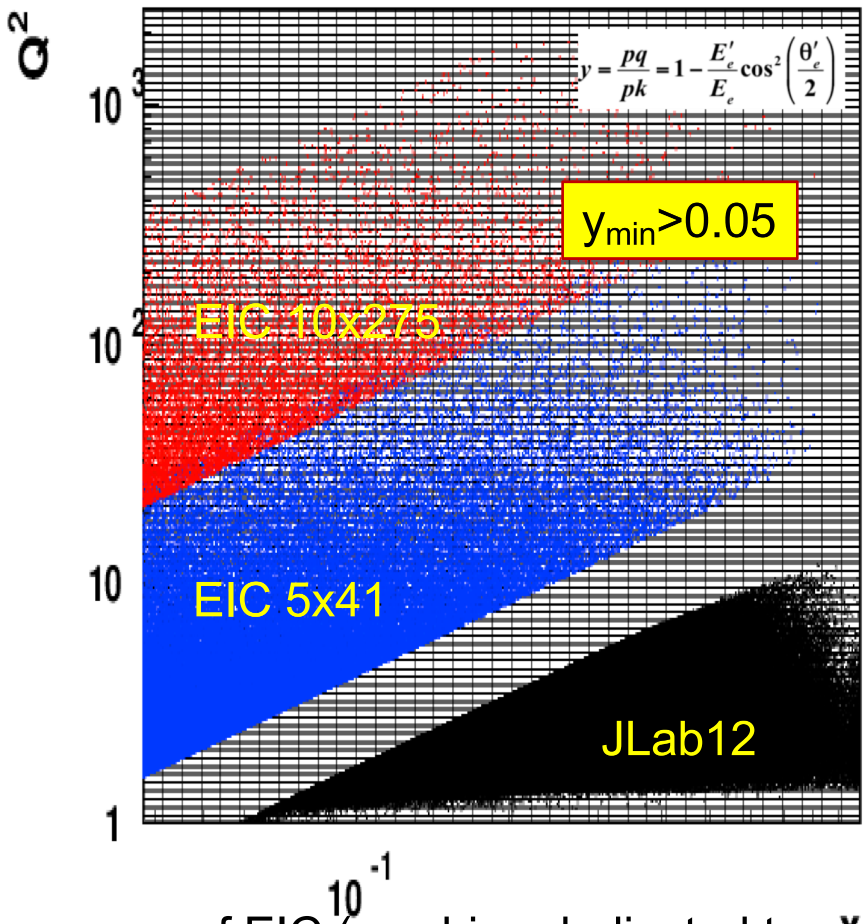


CLAS12 kinematical coverage k_T-dependence of $g_1(x, k_T)$ Q^2-dependence of Sivers, $f_1^\perp(x, k_T)$

- Large acceptance of CLAS12 allows studies of P_T and Q^2-dependence of SSAs in a wide kinematic range (most critical for TMD studies)
- Comparison of JLab12 data with HERMES, COMPASS and EIC will pin down transverse momentum dependence and the non-trivial Q^2 evolution of TMD PDFs in general, and Sivers function in particular.

X vs Q^2 from JLab to EIC

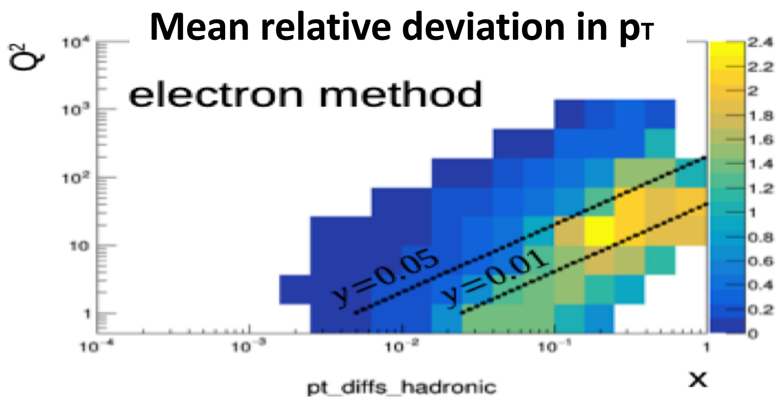


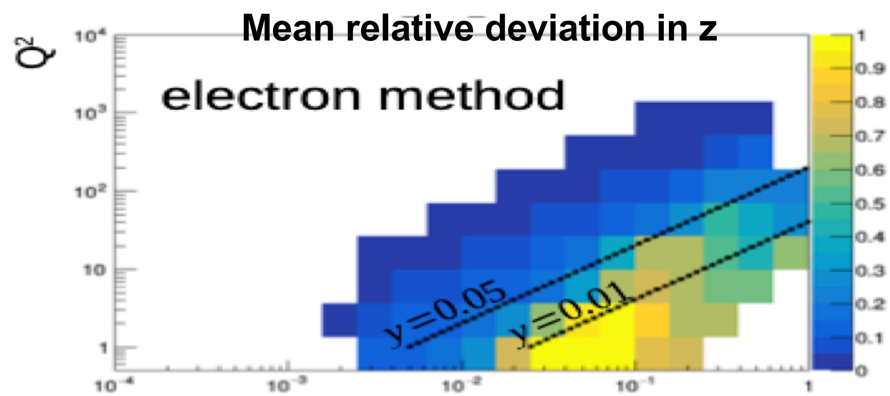


Large x events all in region of small y_F=1.0-E'/Ebeam

Non overlapping ranges of EIC (machine dedicated to gluon studies) and JLab may be a problem for evolution studies, which are most critical for the 3D structure

EIC: Major challenges at large x



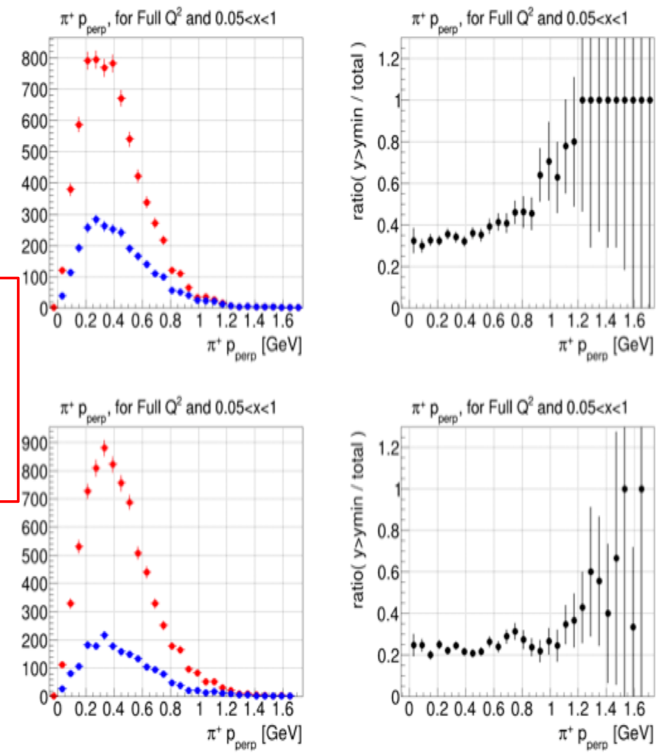


p_T Distributions for varying y_{min} in 2 bins of z

y_{min} = 0.05

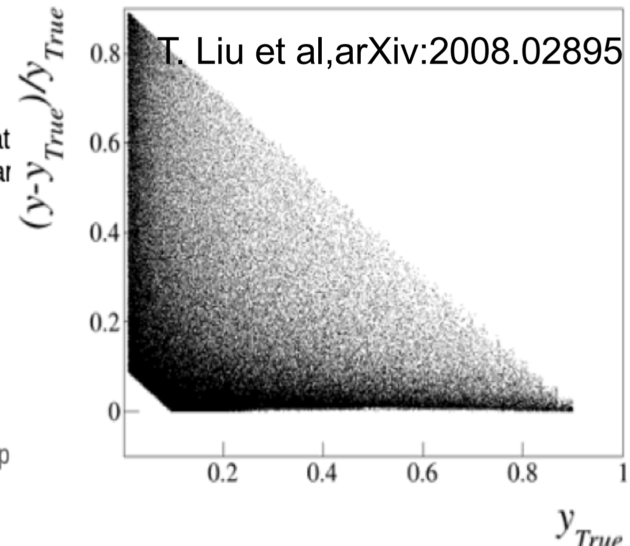
0.2 < z < 0.3 →

0.3 < z < 1 →



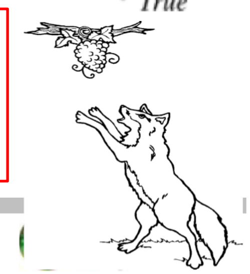
suppression worse at higher y_{min}, but similar relative trend

note: suppression trends for q_T look similar (see backup slides)

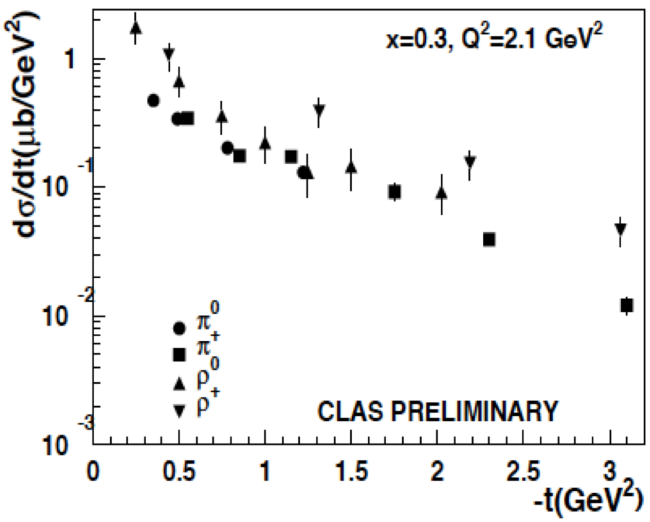


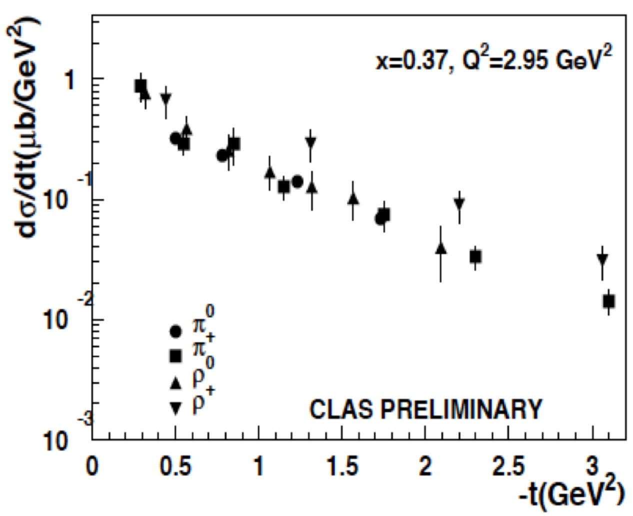
Significant loss of events in relevant P_T range at large x

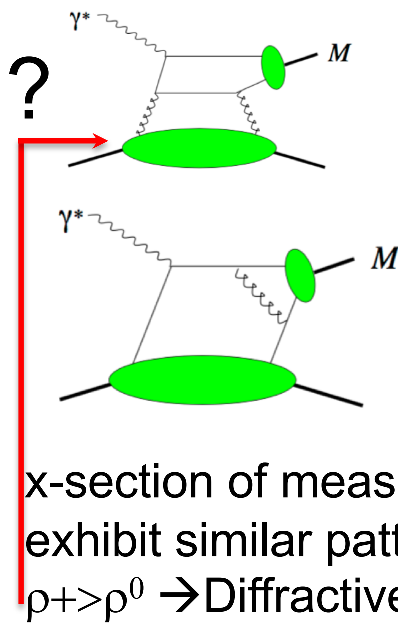
Resolutions out of control for large x, and relatively low Q^2 dominated by small y

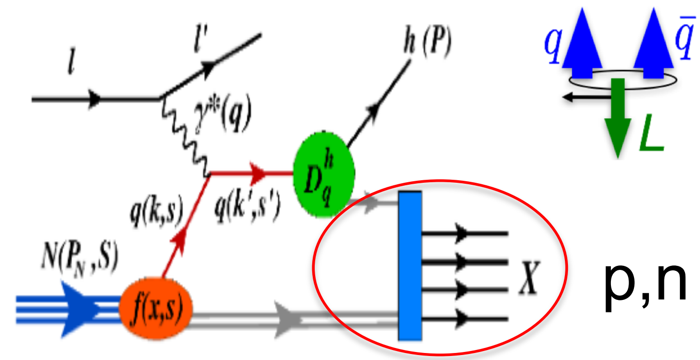


Exclusive π/ρ production at large t









Implications

x-section of measured exclusive process at large t exhibit similar pattern

- ρ+>ρ⁰ →Diffractive production suppressed
  at large t production mechanism most likely is similar to SIDIS
- Slightly higher rho x-sections indicate the fraction of SIDIS pions from VM > 60%
- consistent with LUND-MC in fraction of pions from VMs
- Integrating in total counts (different Q^2-dependence)?
- ………

Opportunities with 24 GeV

Significantly wider phase space would allow

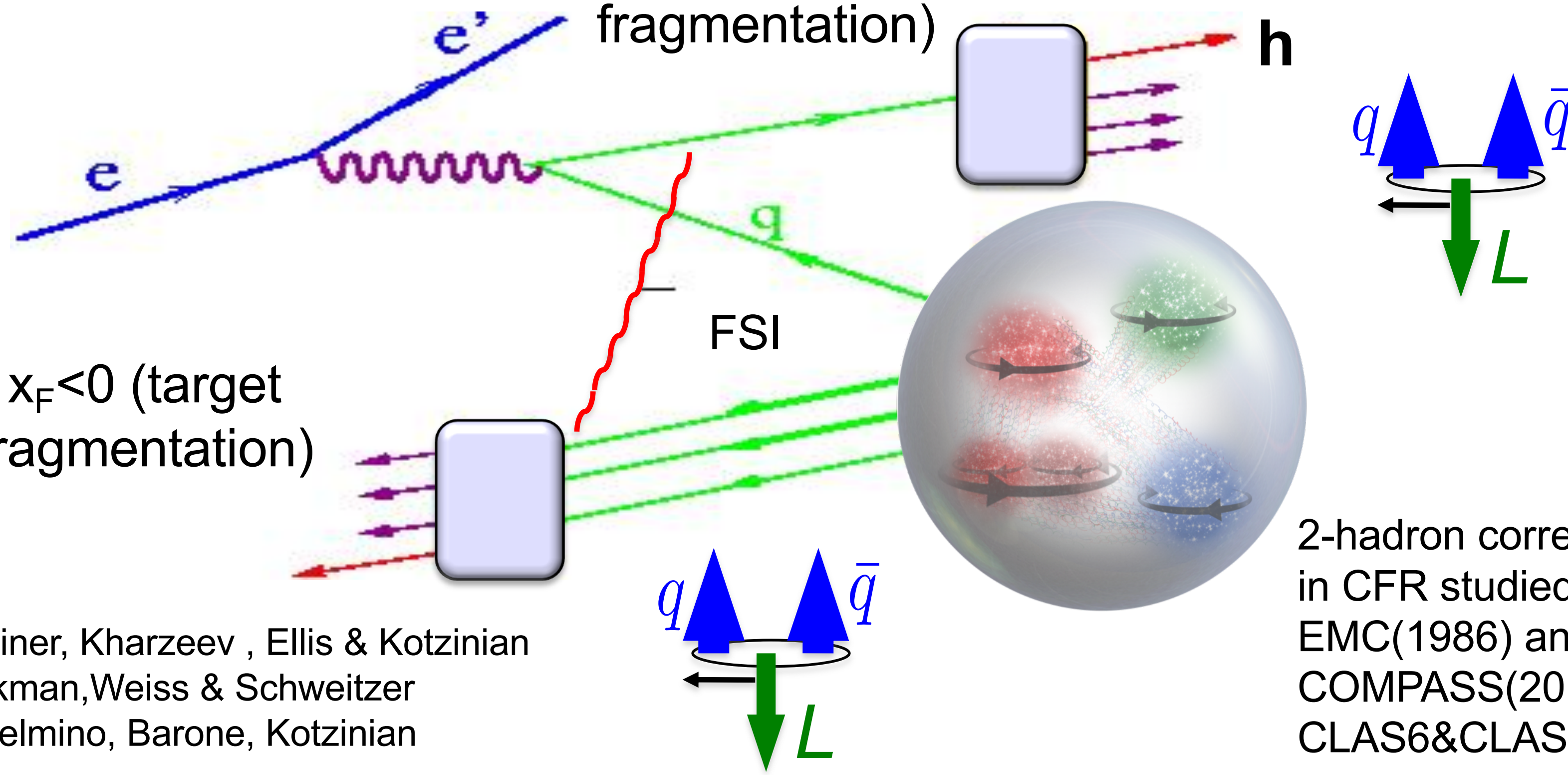
- Enhance the range in transverse momentum P_T of hadrons
  - Access to P_T-region where the dependence of the k_T-dependences of different flavors (valence and sea) and polarization states is most significant
- Enhance the Q^2 range
  - Increase significant the range of high Q2, where the theory is supposed to work better, and allow studies of evolution properties
- Enhance the x-range
  - Access the the full kinematical range (x>0.03-0.04) where the non-perturbative sea is expected to be significant

Hadronic long-range correlations

x_F - momentum in the CM frame

$x_F = p_{L(CM)}/p_{Lmax} > 0$ (current fragmentation)

X. Artru & Z. Belghobsi



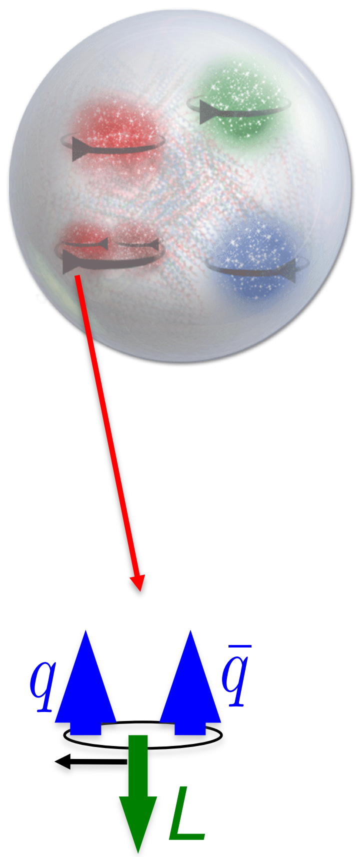
$x_F < 0$ (target fragmentation)

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

2-hadron correlations in CFR studied in EMC(1986) and COMPASS(2015) CLAS6&CLAS12

What is a "pion tornado"?
Modeling of q-q-bar correlations with spins and momenta in the process (not in PYTHIA) will be important for understanding of the dynamics

Measuring Spin-Orbit correlations

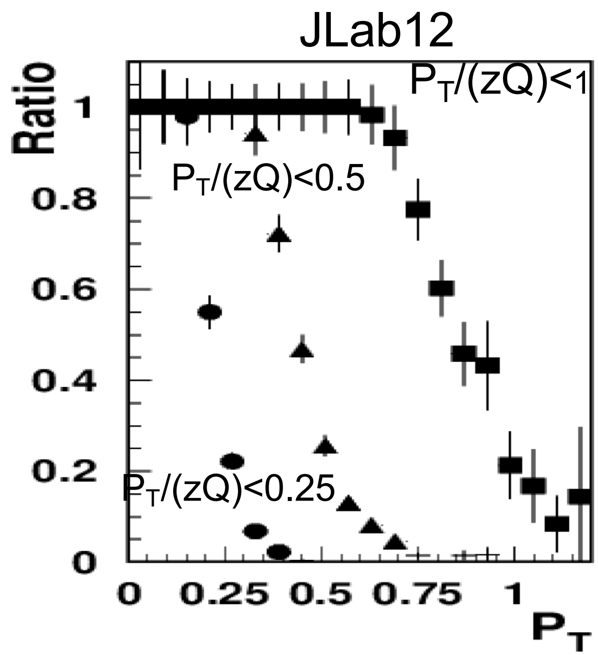


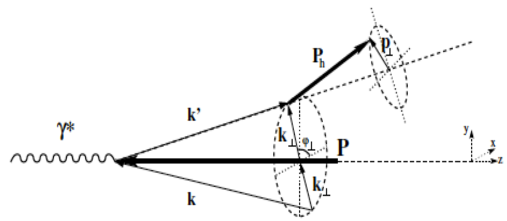
"pion tornado"

Spin-Orbit correlations so far were shown (measurements and model calculations) to be significant in the region where non-perturbative effects dominate

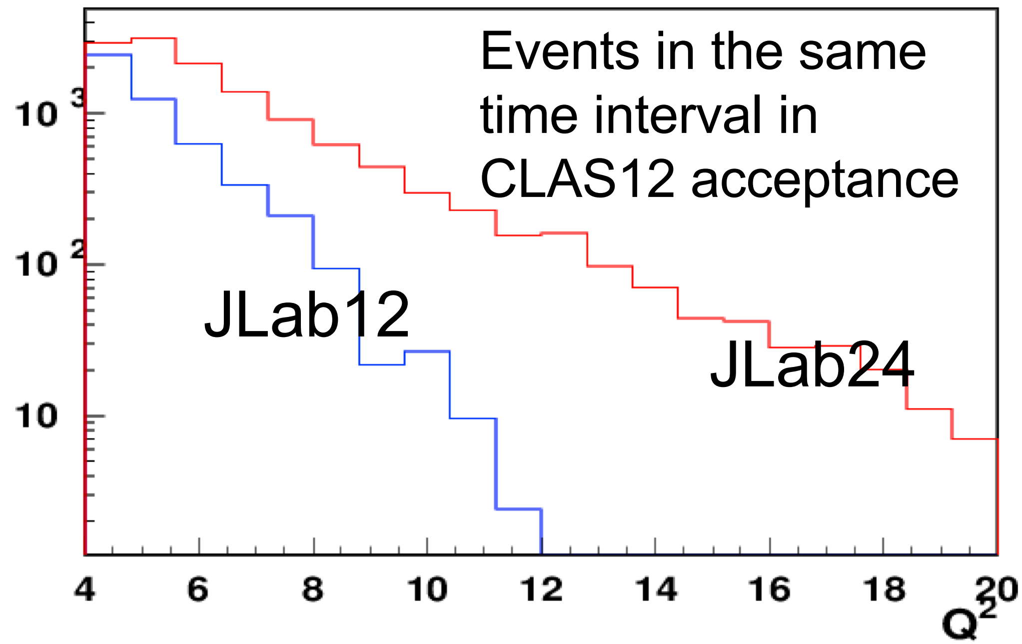
- Relatively large x (x>0.02)
- Relatively low Q^2 (Q^2<40-50 GeV^2)
- Relatively large z of hadrons (z>0.2-0.3)
- Medium P_T of hadrons ($0.3<P_T<1.5$)

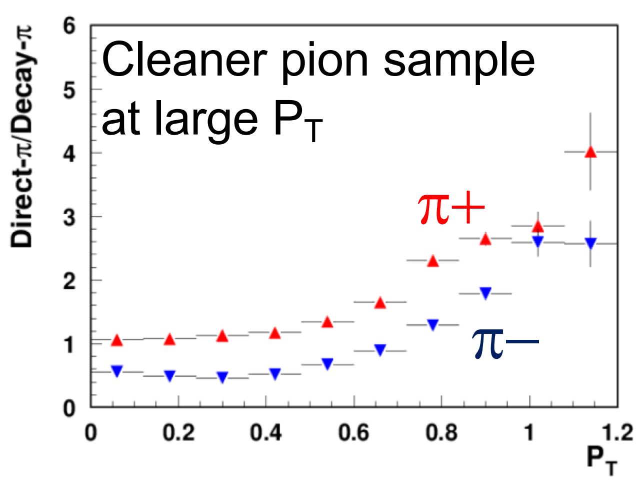
From JLa12 to JLab24 Larger Q^2 at large P_T





$$f_1^q(x, k_T) \otimes D_1^{q\to h}(z, p_T)$$

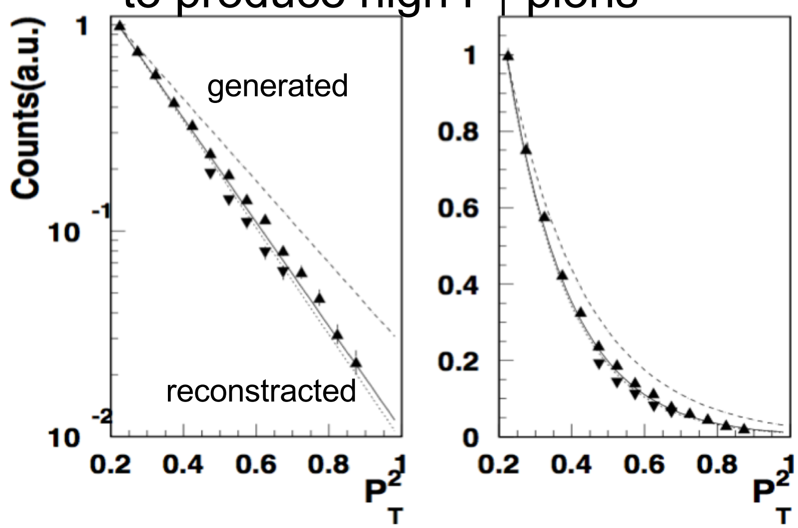


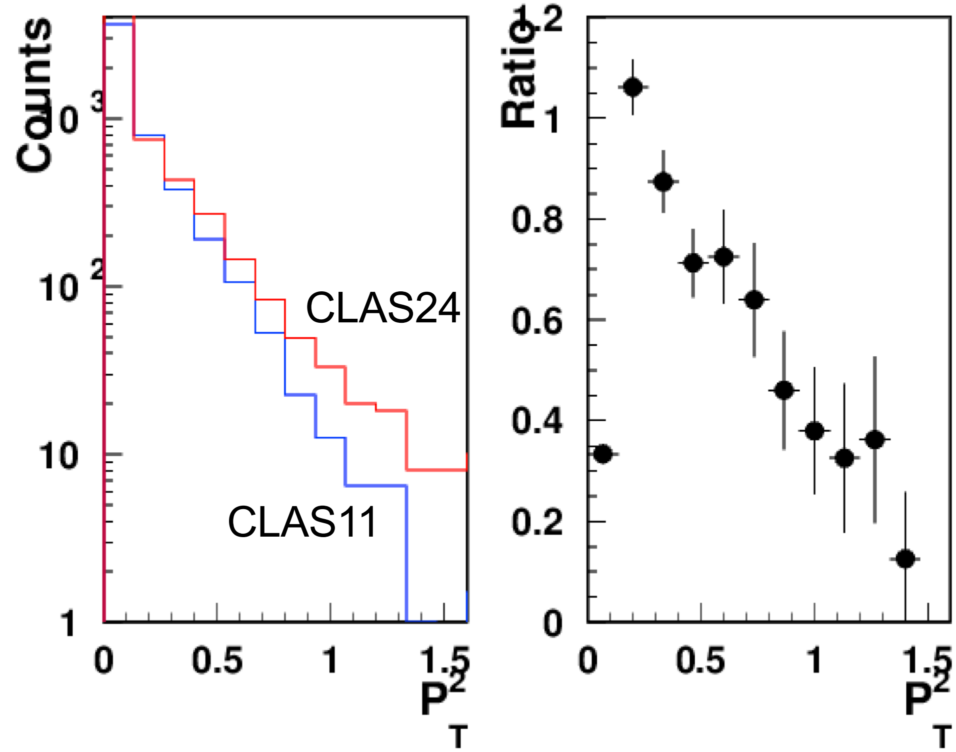


JLab24 will significantly increase the the Q^2 range, allowing detailed separation of higher twist SFs, needed for understanding the QCD

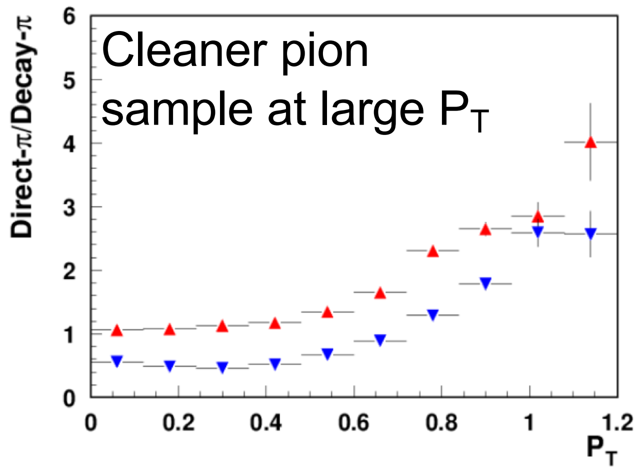
The large P_T dominated by direct pions

Not enough phase space
to produce high P_T pions



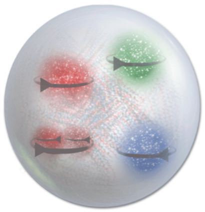


Cleaner pion
sample at large P_T



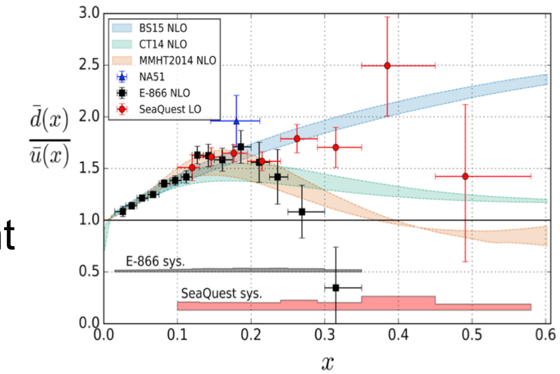
JLab24 will significantly increase the phase space providing access to complete P_T range where spin-orbit effects are significant ($0.4<P_T<1.5$)

Extending to small x and large P_T

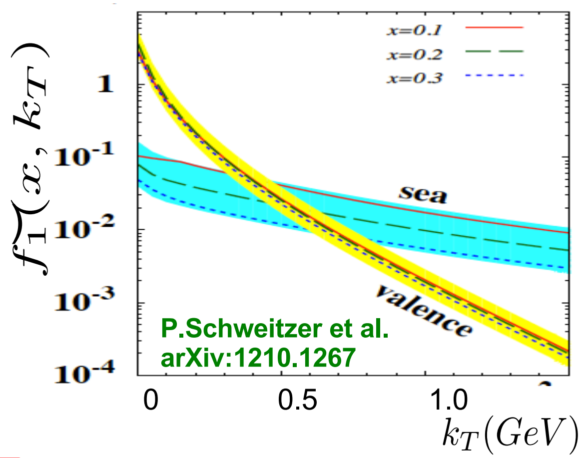


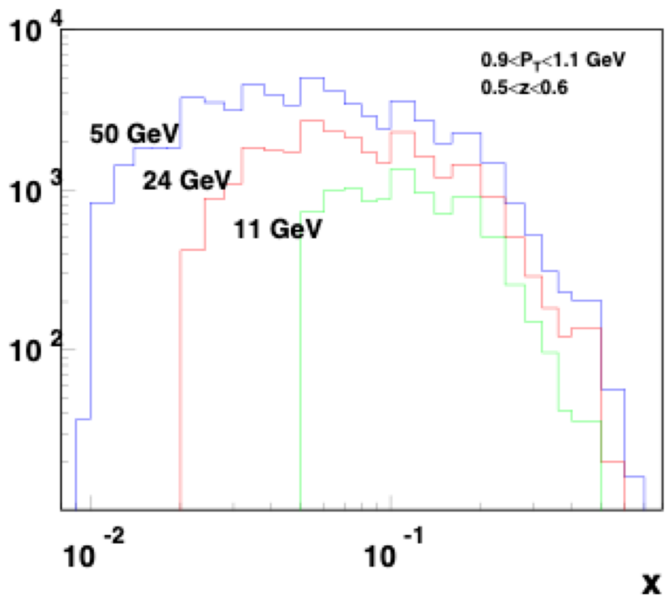
Non-perturbative sea in nucleon is a key to understand the nucleon structure

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



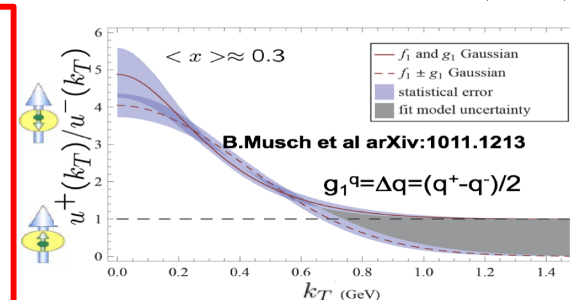
- Spin and momentum of struck quarks are correlated with remnant
- Correlations of spins of q-q-bar with valence quark spin and transverse momentum will lead to observable effects
- Spin-Orbit correlations so far were shown (measurements and model calculations) to be significant in the region where non-perturbative effects dominate



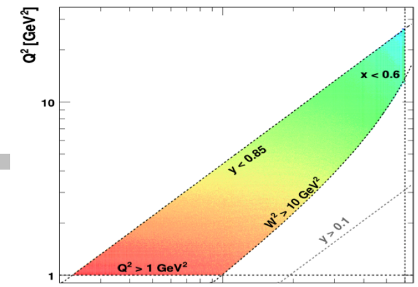


Relatively large x (x>0.02)
Relatively low Q^2 ($Q<5$-7 GeV^2)
Relatively large z of hadrons (z>0.2-0.3)
Medium P_T of hadrons ($0.3<P_T<1.5$)

JLab24 will fully cover the kinematical range where the non-perturbative sea is relevant



CLAS24 as HERMES++

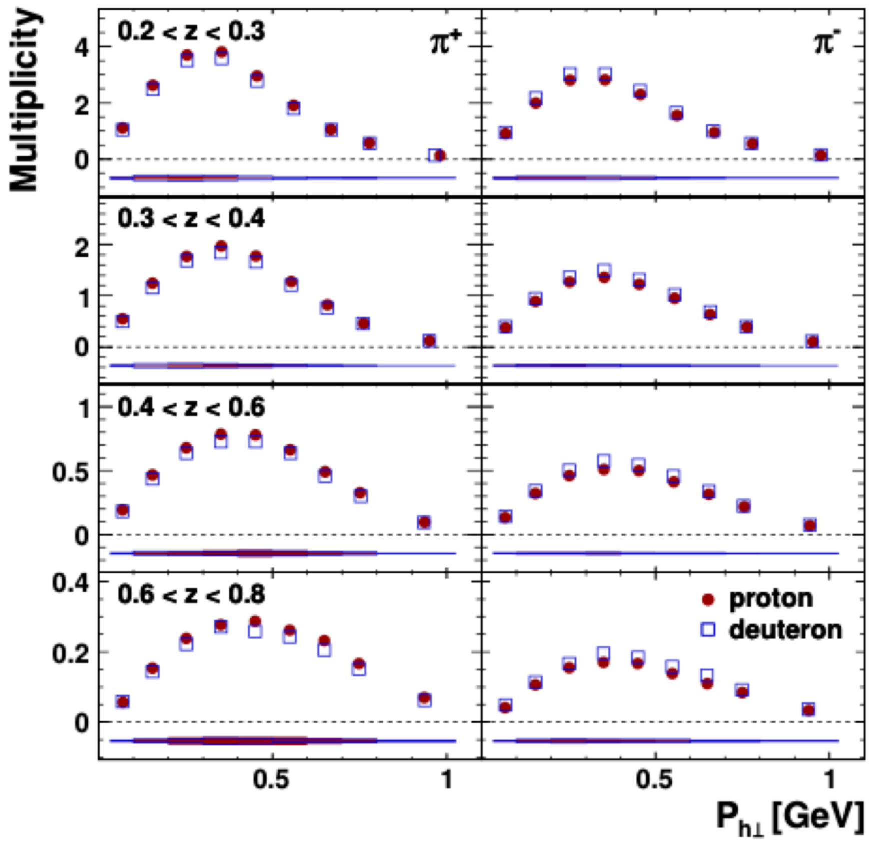


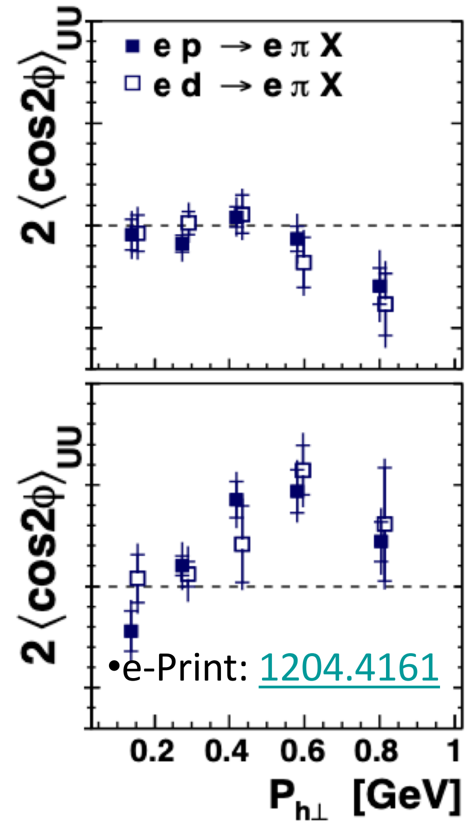
https://arxiv.org/abs/1006.4221

HERMES, out for 10 years, still dominates the 3D landscape

https://arxiv.org/pdf/1212.5407.pdf (2013)

Max<Q²>~3-4 GeV²





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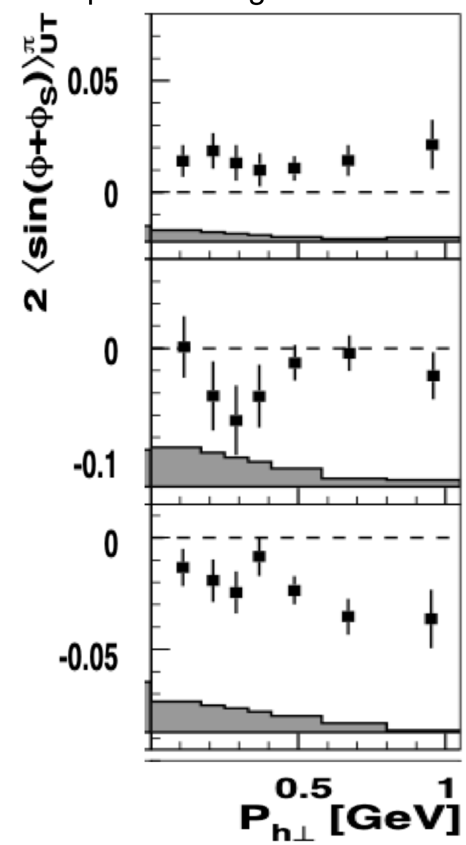


- Due to limited luminosity HERMES was not able to collect enough statistics in the region most relevant for understanding of non-perturbative structure of the nucleon (P_T>0.8 GeV)
- CLAS24 could collect years of HERMES data in days, even without a major detector upgrade

Summary

CLAS12 measurements of dihadron multiplicities and asymmetries provide qualitatively new possibilities for understanding the structure of the nucleon and the process of hadronization, allowing experimental studies of the fractions and distributions of pions coming from vector meson decays

Studies of JLab at large x will be the main source of the information on the kinematical dependences of spin-orbit correlations in the valence region, and the underlying non-perturbative functions, also in the EIC era.

The spin-orbit correlations, providing access to the 3D structure of the nucleon are significant in the kinematics of large x (x>0.03-0.04), low Q^2 (Q^2<20-30) and medium P_T (P_T<1.5) accessible at JLab12, and significantly improved at JLab24.

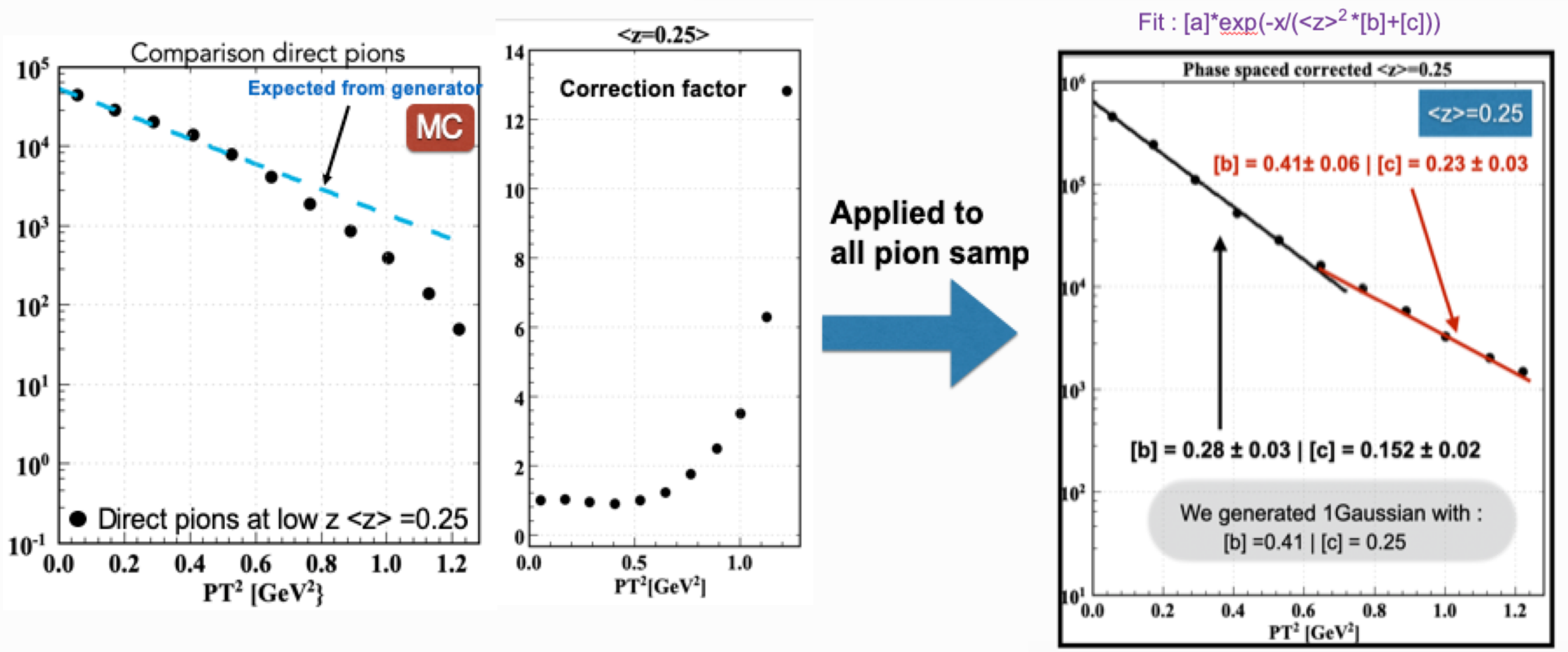
Upgraded to 24 GeV JLab will increase dramatically the phase space, providing the missing part of the mosaic, accessing much wider range of Q^2 and P_T allowing studies of evolution properties and flavor dependence of transverse momentum distributions, allowing access to kinematical region, where the non-perturbative sea is measurable, and also providing important information on kaon SIDIS.

Support slides

CLAS12 Multiplicities: the role of high P_T

LUND MC at 12 GeV using a single Gauss for all hadrons

G. Angelini (GW)

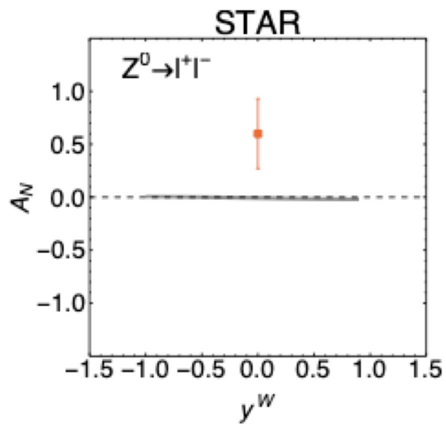


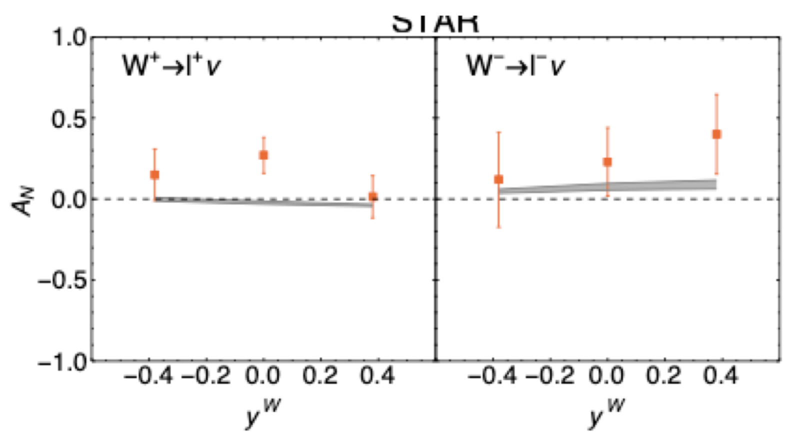
- Corrections due to phase space (energy needed to produce a hadron with a given z,P_T at given x,Q^2) are detector and model independent
- Corrections due to fraction of fragmentation VMs and diffractive VMs are model dependent, but can be extracted from MC (work in progress)

At low z, only the high P_T shows the generated Gaussian transverse momentum distribution.

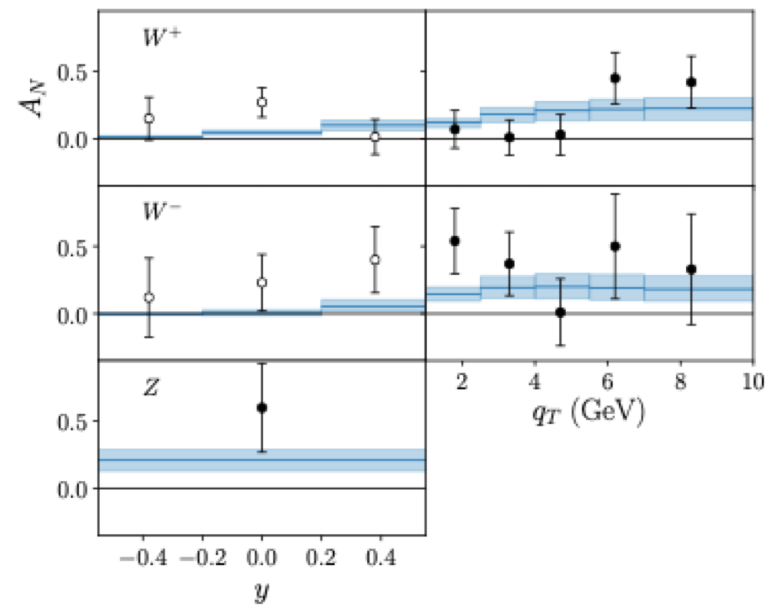
COMPARISON WITH DRELL-YAN DATA

Bacchetta





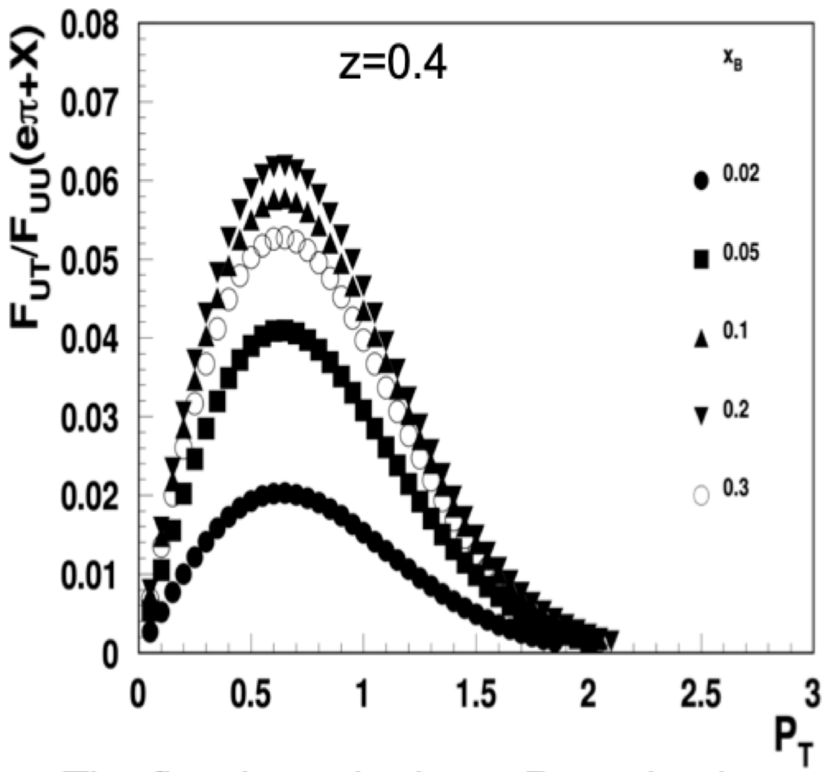
Vladimirov



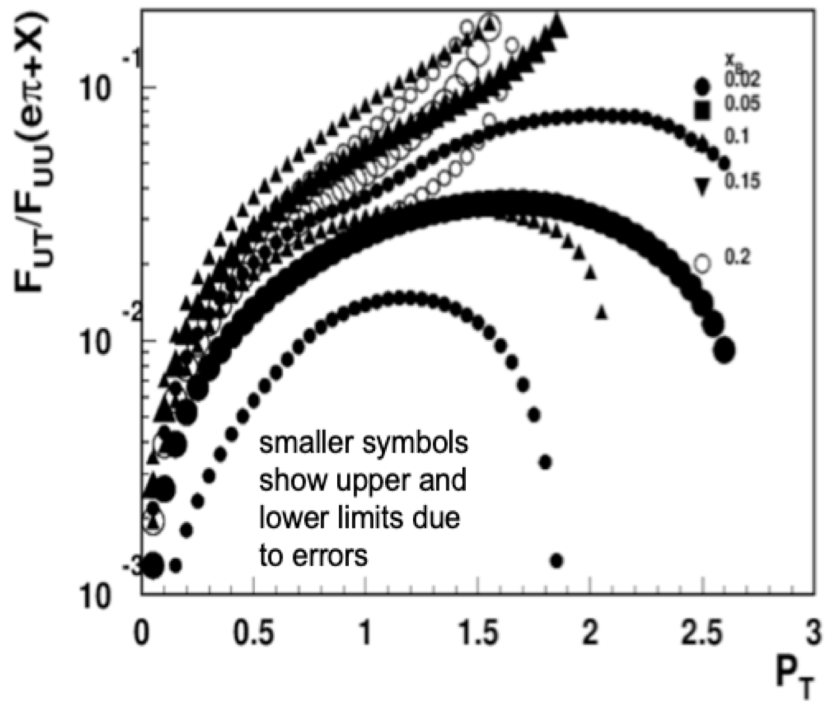
Fitting STAR data seem to require leaving out all high P_T SIDIS data with $q_T/Q<0.25$!!

Comparing Sivers: P_T-dependences

Boglione et al (consistent with JAM)



Vladimirov



The fit, where the large P_T region has unrealistically large contributions, <u>may emulate "sensitivity" at large x and large s</u> with larger Q^2 (inconsistent with other Sivers extractions)

All TMD extraction, including Sivers, were done using the accessible kinematical range, and should be used with care outside of those limits

PAC request for reevaluation

From PAC review of CLAS12 Long.Pol. experiment:

…the [DIS/SIDIS] proponents should come back to the PAC after the significance of the different experiments addressing PDFs, helicity PDFs and TMDs has been reevaluated.

estimates of their effects. For example, the TMD description of SIDIS is valid in the small-p_T regime when $p_T^2/(zQ)^2 \ll 1$, and in a recent study [JHEP 06 (2020) 137] finding that $p_T^2/(zQ)^2 \lesssim 0.06$ approximately demarcates the boundary to large p_T, where a description in terms of TMD PDFs may not be trustworthy. By comparison, values for this ratio as large as ~ 2 are often found for the kinematics covered in JLab TMD-oriented proposals. Such observations do not negate the value and importance of the measurements, but they should be addressed directly in the proposals, and their potential impact on interpretation should be discussed more explicitly.

Indication of a gap between theory and experiment?

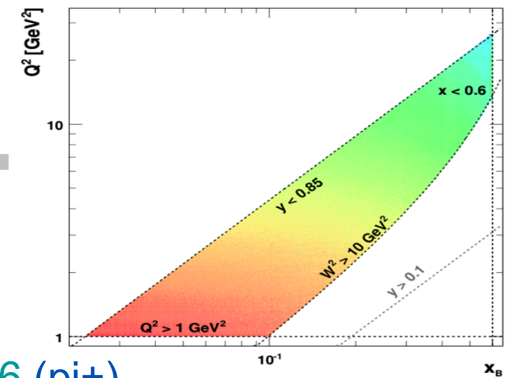
Understand the source, and evaluate the impact of q_T limitations!

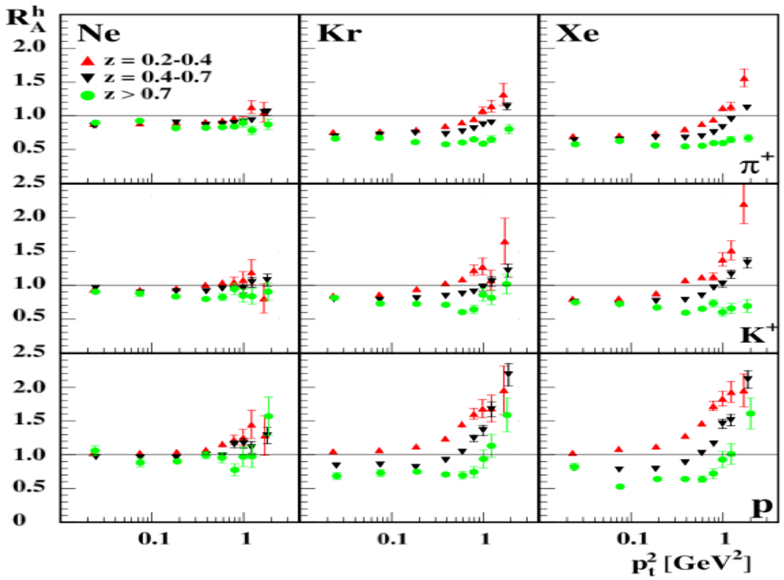
Discussed in the workshop TMD Studies: from JLab to EIC--> need a development of theory and more realistic projections

https://indico.jlab.org/event/439/

CLAS24 as HERMES++

HERMES out for 10 years, still dominates the 3D landscape





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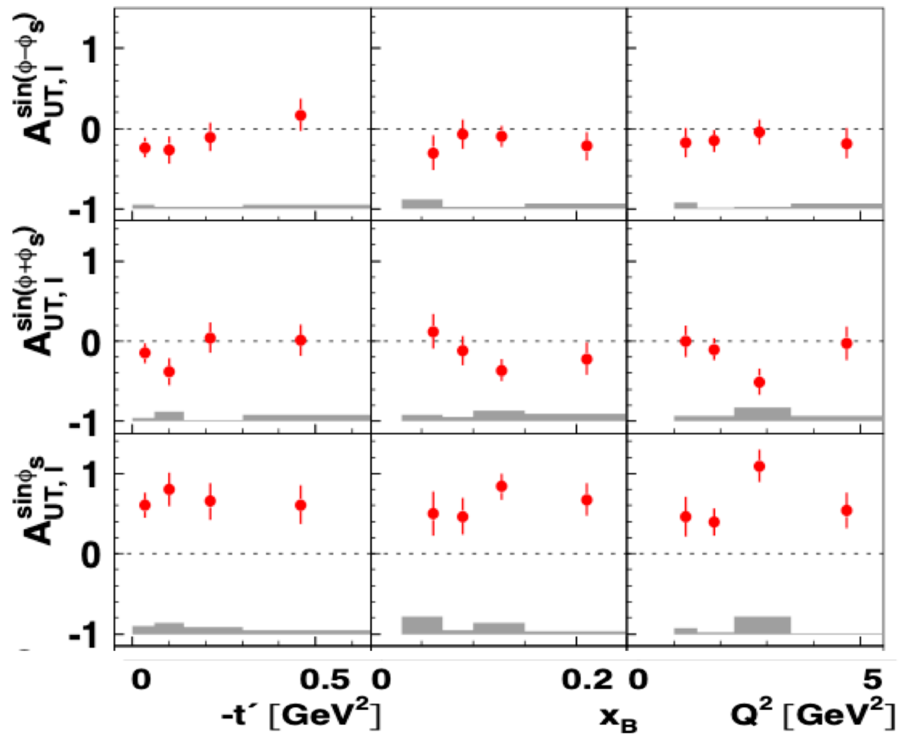
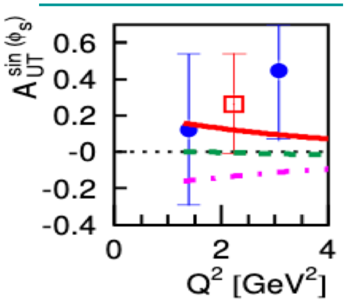
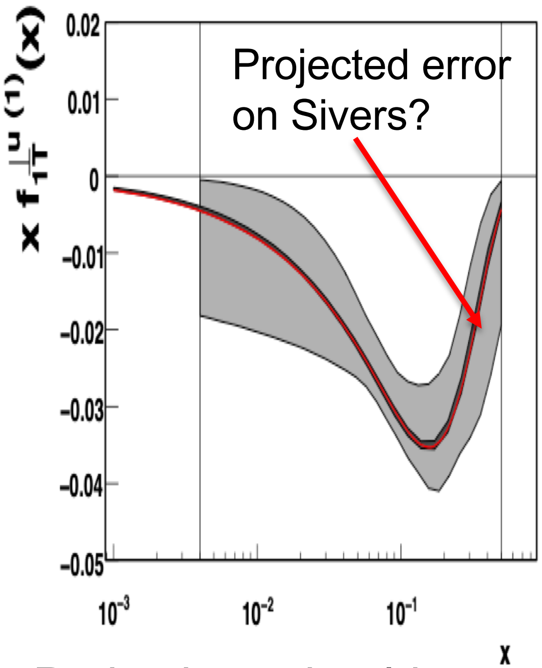


1508.07612 (omega)

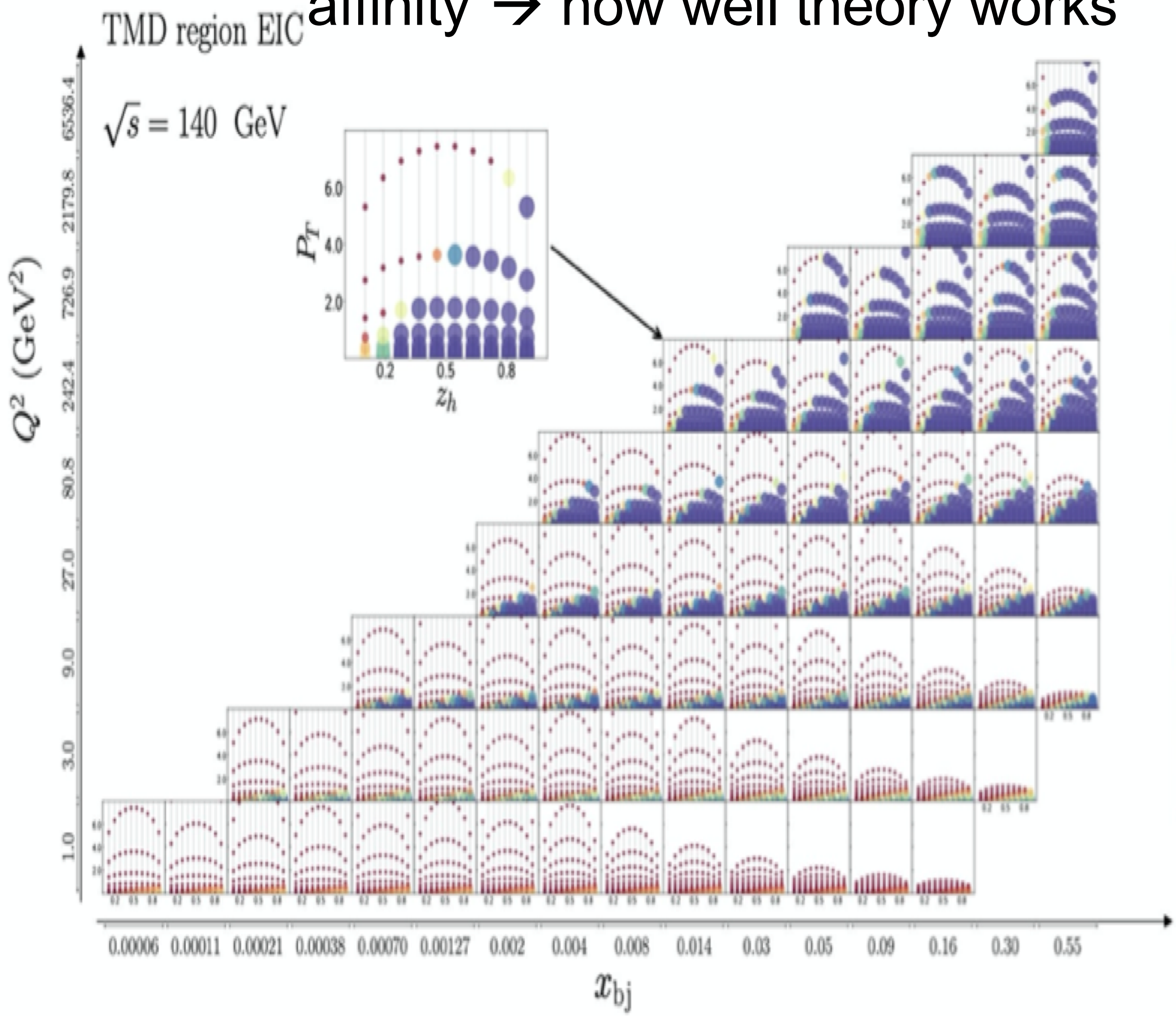


Huge asymmetry $\sin\phi_S$ (higher twist)

Projections from 1D to 4D

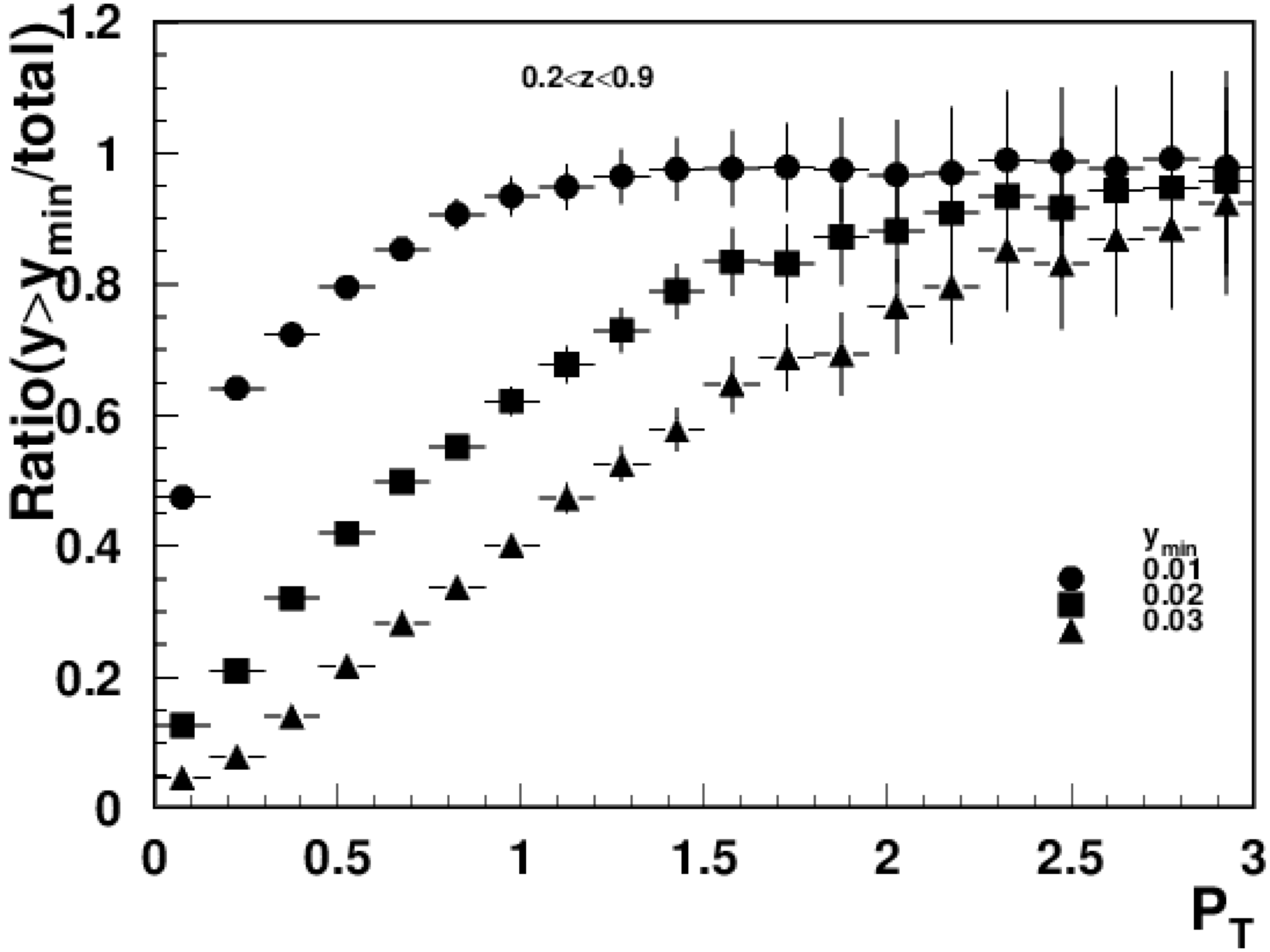


“affinity”→ how well theory works



Projections should contain the size of the effect and the counts for a given interval of time
For SIDIS the x-section is defined by F_{UU}, for Sivers effect F_{UT}/F_{UU}

Low Q^2 and large x kinematics in EIC: P_T-distributions

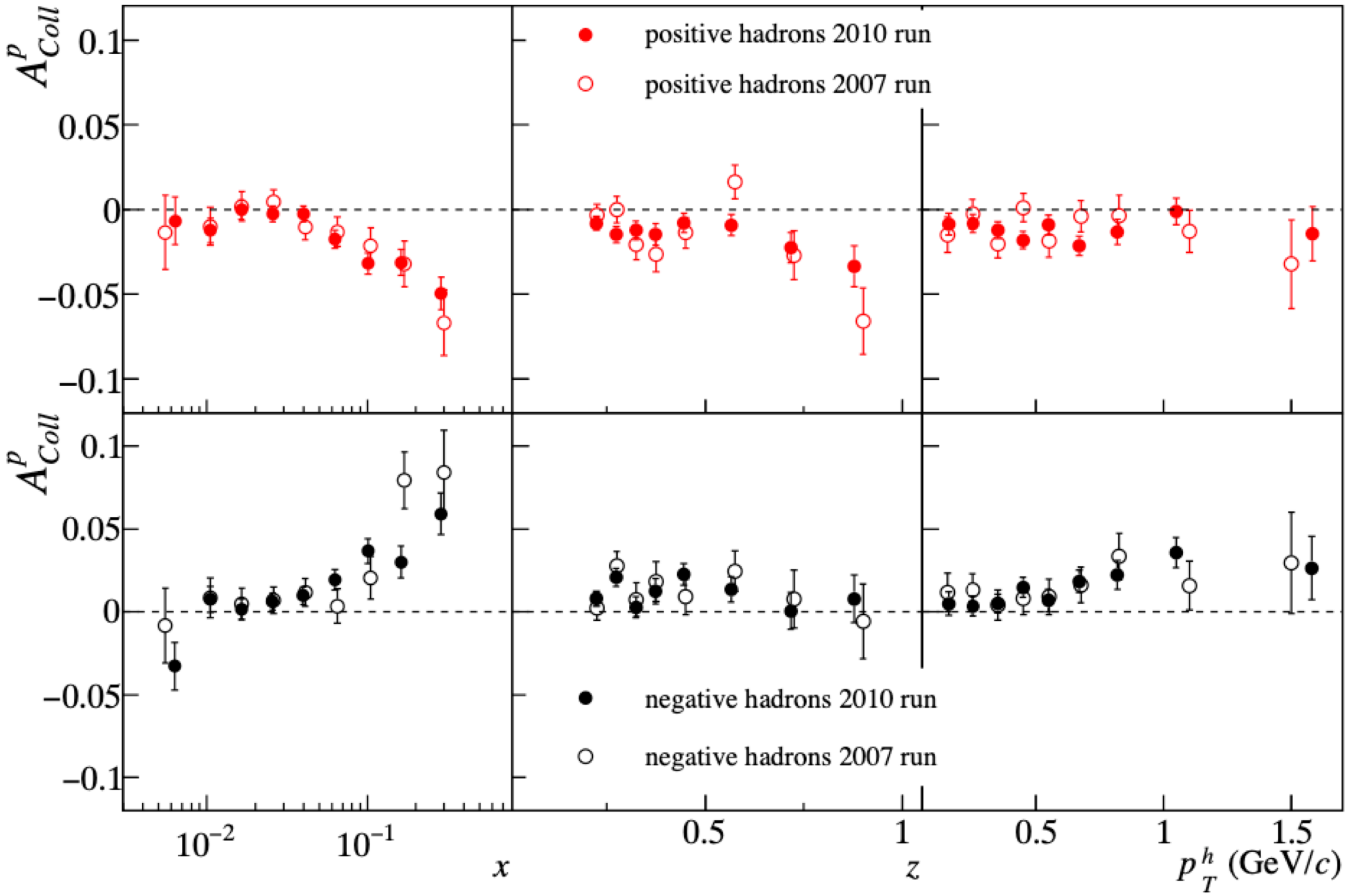


EIC 5x41
x>0.01

For large x(x>0.05) large y cuts can significantly change P_T-distributions

Experimental data: Collins

https://arxiv.org/pdf/1005.5609.pdf



No indication of significant effects for x<0.05

RC in the low y region (large x and low Q2)

$$r_c(y) = \frac{\mathrm{d}\sigma/\mathrm{d}y|_{O(\alpha)}}{\mathrm{d}\sigma/\mathrm{d}y|_{Born}} - 1$$

EIC-white-paper.1108.1713

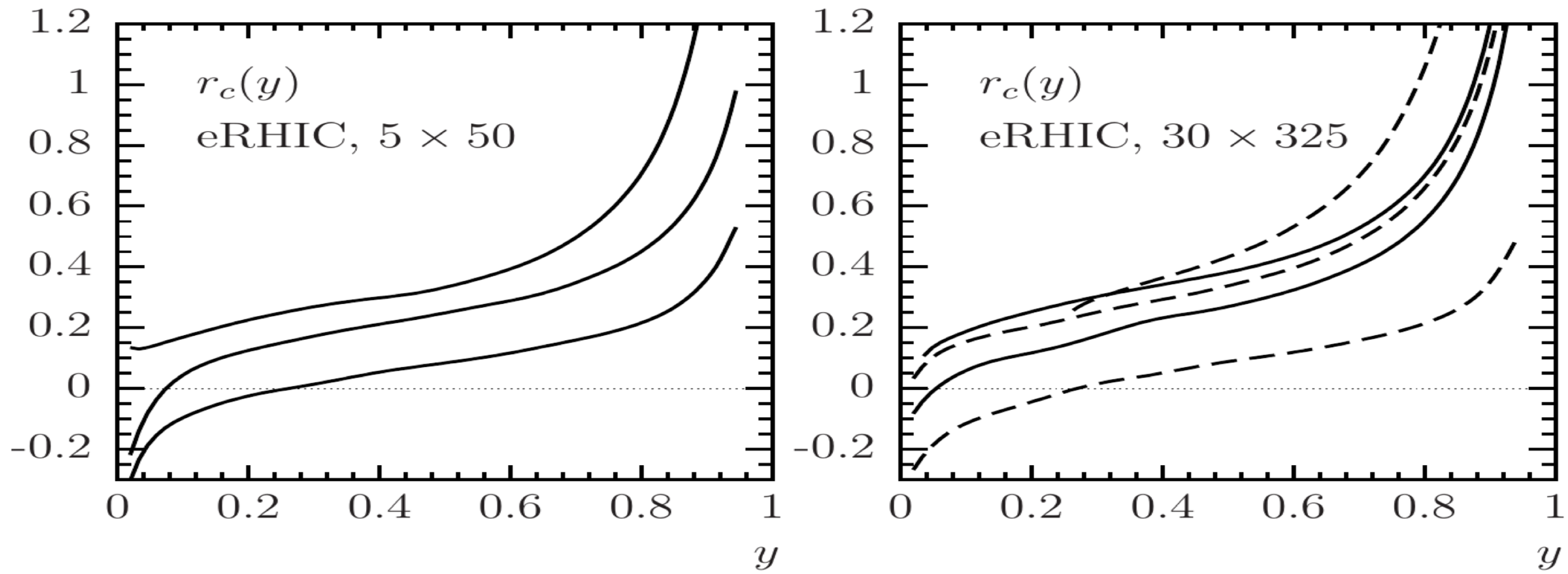


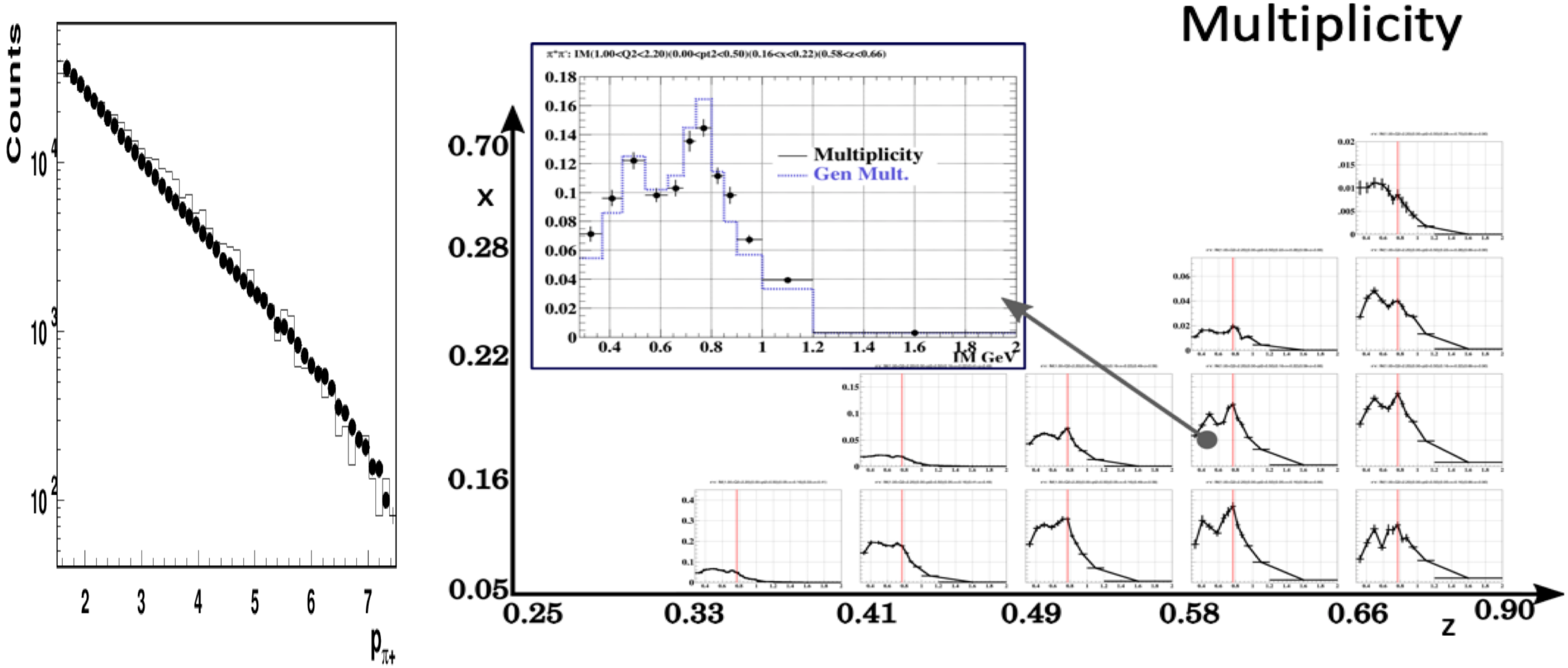
Figure 7.25. y-dependence of the leptonic radiative correction factor for electron proton scattering with different beam energies and in different x_B ranges. Left: $E_e = 5$ GeV, $E_p = 30$ GeV and the curves from the bottom up correspond to $0.1 < x_B < 0.4$, $10^{-2} < x_B < 10^{-1}$, $10^{-3} < x_B < 10^{-2}$; Right: $E_e = 30$ GeV, $E_p = 325$ GeV and $0.1 < x_B < 0.4$, $10^{-2} < x_B < 10^{-1}$, $10^{-3} < x_B < 10^{-2}$, $10^{-4} < x_B < 10^{-3}$, $10^{-5} < x_B < 10^{-4}$ (full and dashed lines alternating for better visibility).

What are the RC in the region of y<0.05 (x>0.02) for SIDIS case ?

CLAS12 ehhX mutliplicities in a wide range

ep→e'hX (RGB/RGA CLAS12 Data/MC <u>normalized to the same number of electrons</u>)

O.Soto



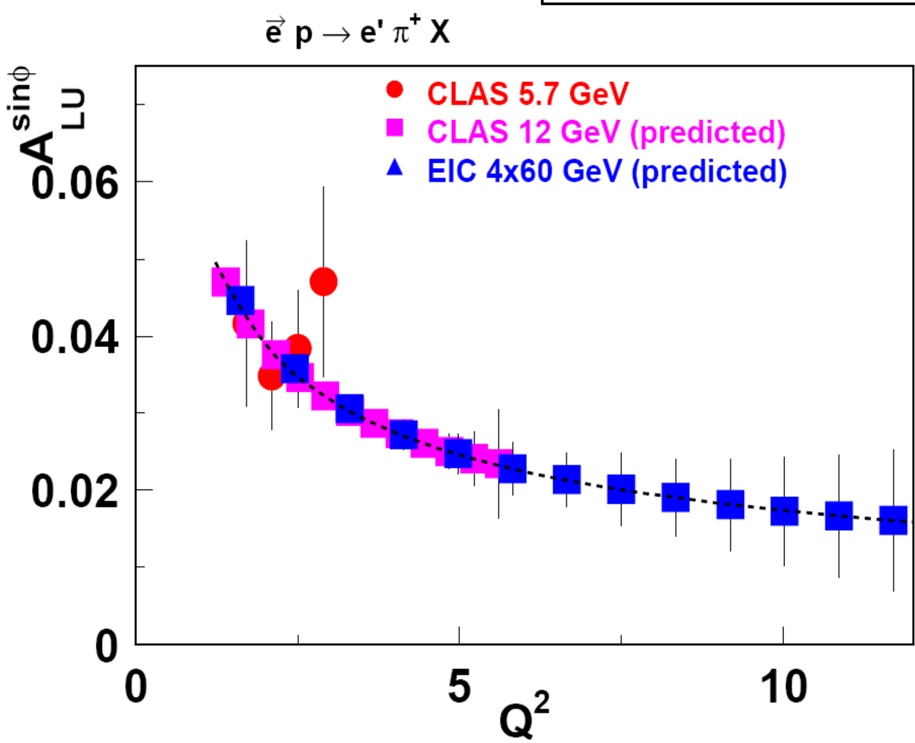
- Most of the single hadron sample (from 50-70%) is coming from VM decays
- Pion counts for normalized e'X events are consistent with clas12 LUND MC (VM 70%)
- Simulation describes well both single (e'hX) and di-hadron (e'hhX) counts in CLAS12
- MC data can be used to make conclusions about the source of hadrons

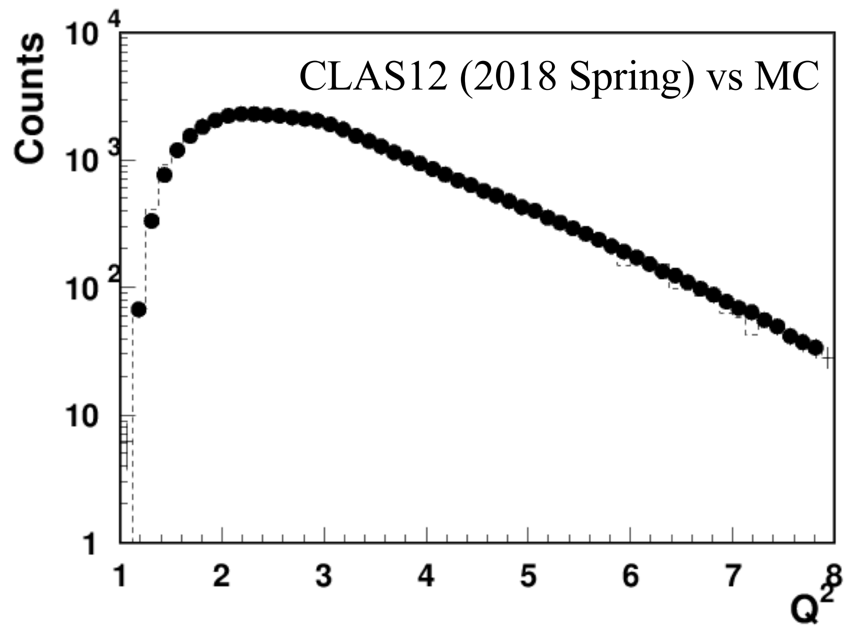
N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

From JLab12 to EIC

$$A_{LU} \propto g^{\perp}(x) D_1(z)$$

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.





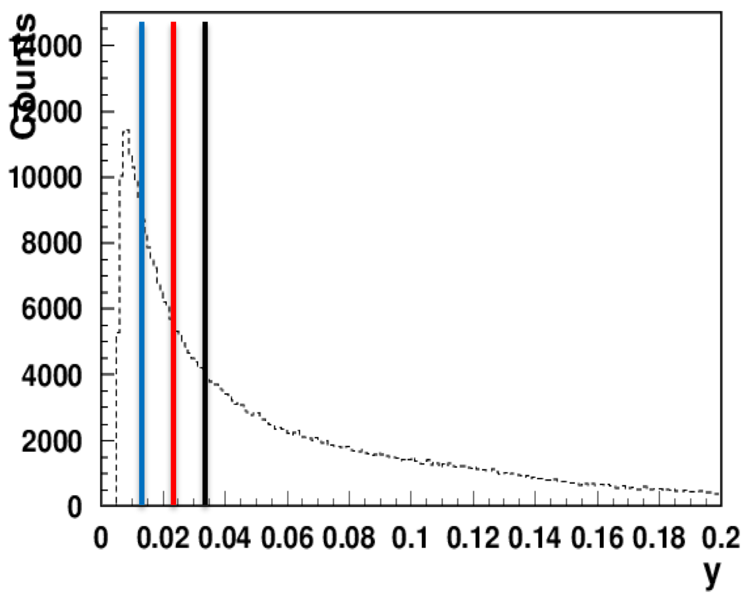
- Understanding of quark-gluon correlations is crucial for precision studies of the structure of the nucleon.
- At medium energies all experiments measure very significant HT contributions
- Large HT effects may indicate the breakdown of the theory
- Overlap of EIC and JLab12 in the valence region will be crucial for the TMD program

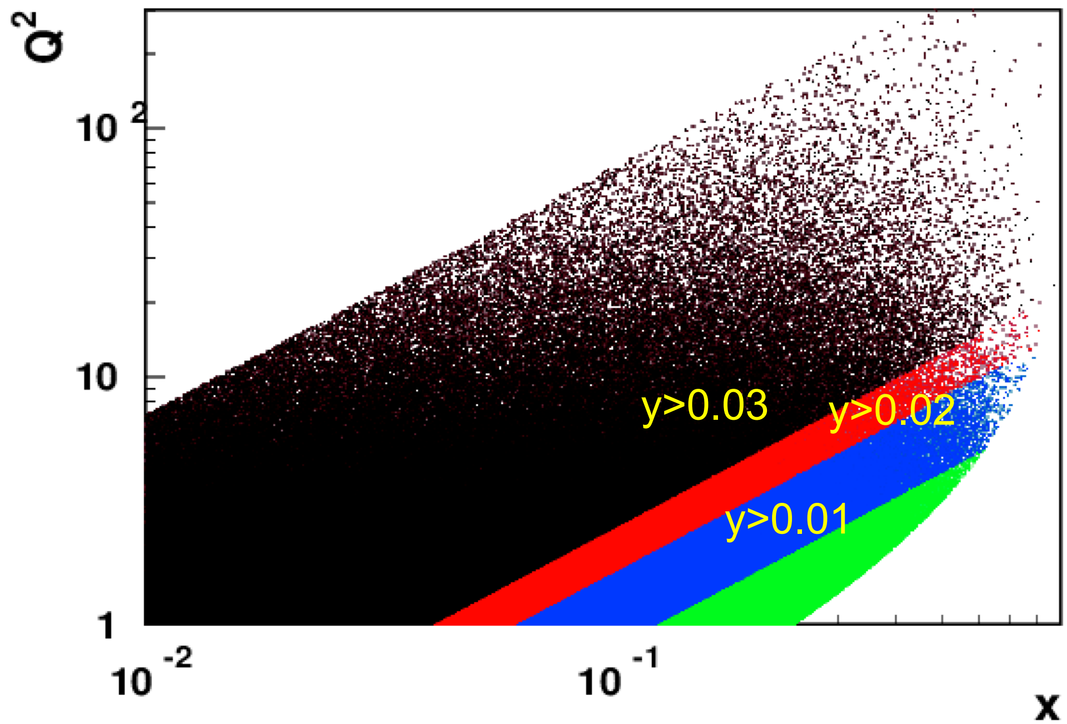
Low Q^2 and large x kinematics in EIC

The same binning covers JLab and EIC

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

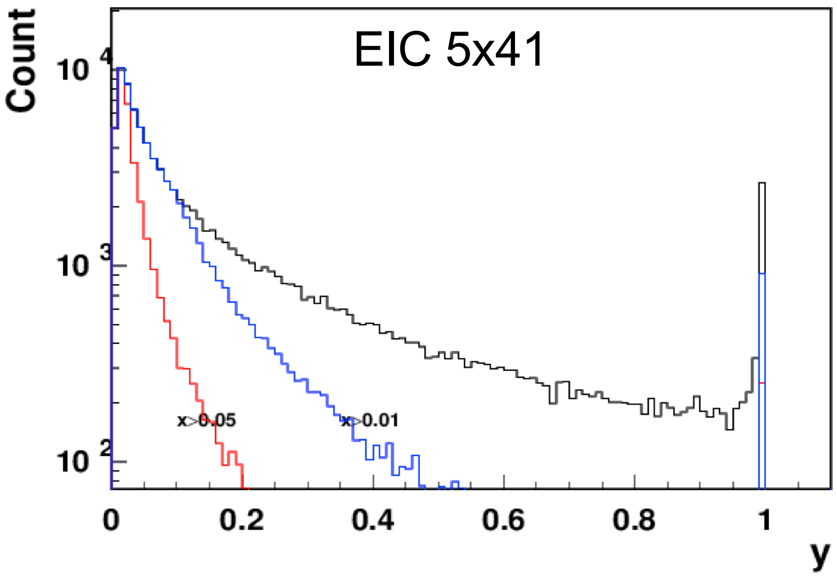
EIC 5x41



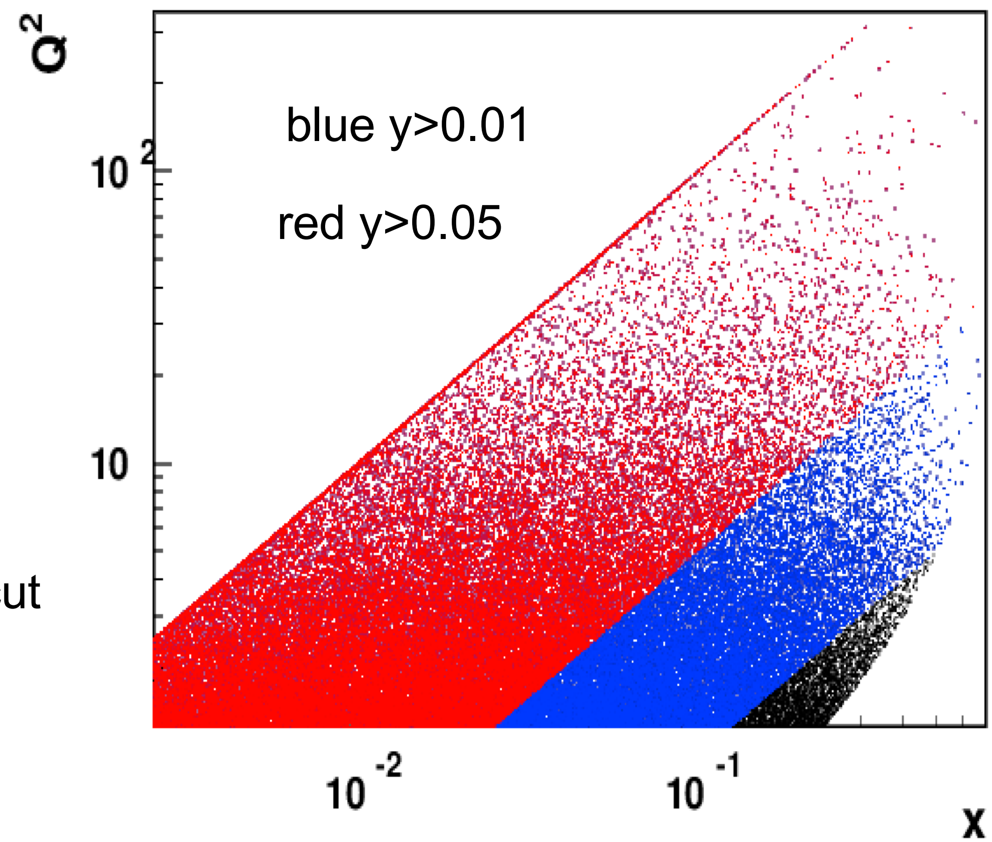


Small y are critical to access wide range in Q2 for large x, where the non-perturbative effects are relevant

Low Q2 events for evolution studies



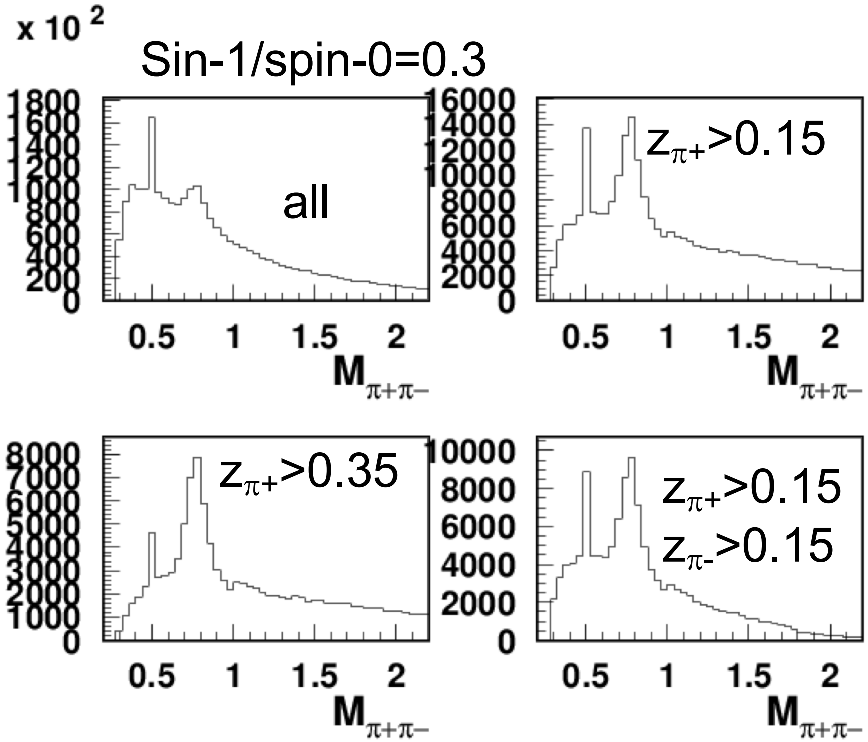
Large x events all in region of small y=1.0-E'/Ebeam*$\cos^2(\theta_e/2)$



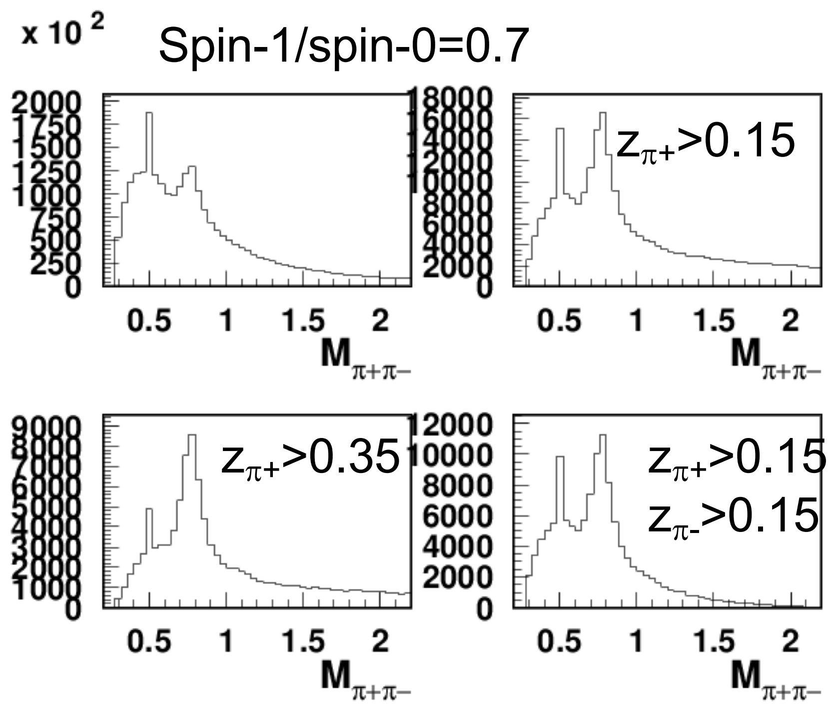
Large x are washed out with y cut

JLEIC (5x50) 2-hadron mass spectra

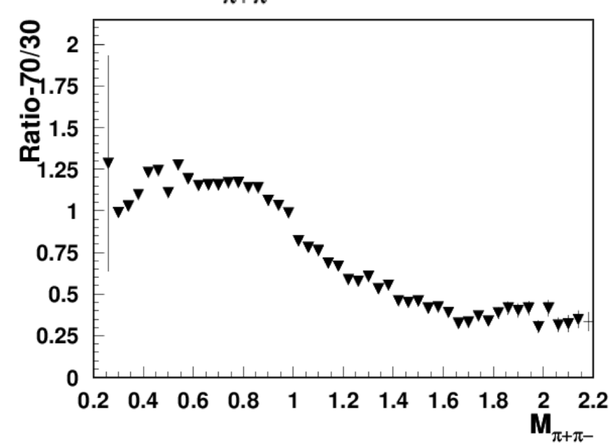
Sin-1/spin-0=0.3



Spin-1/spin-0=0.7

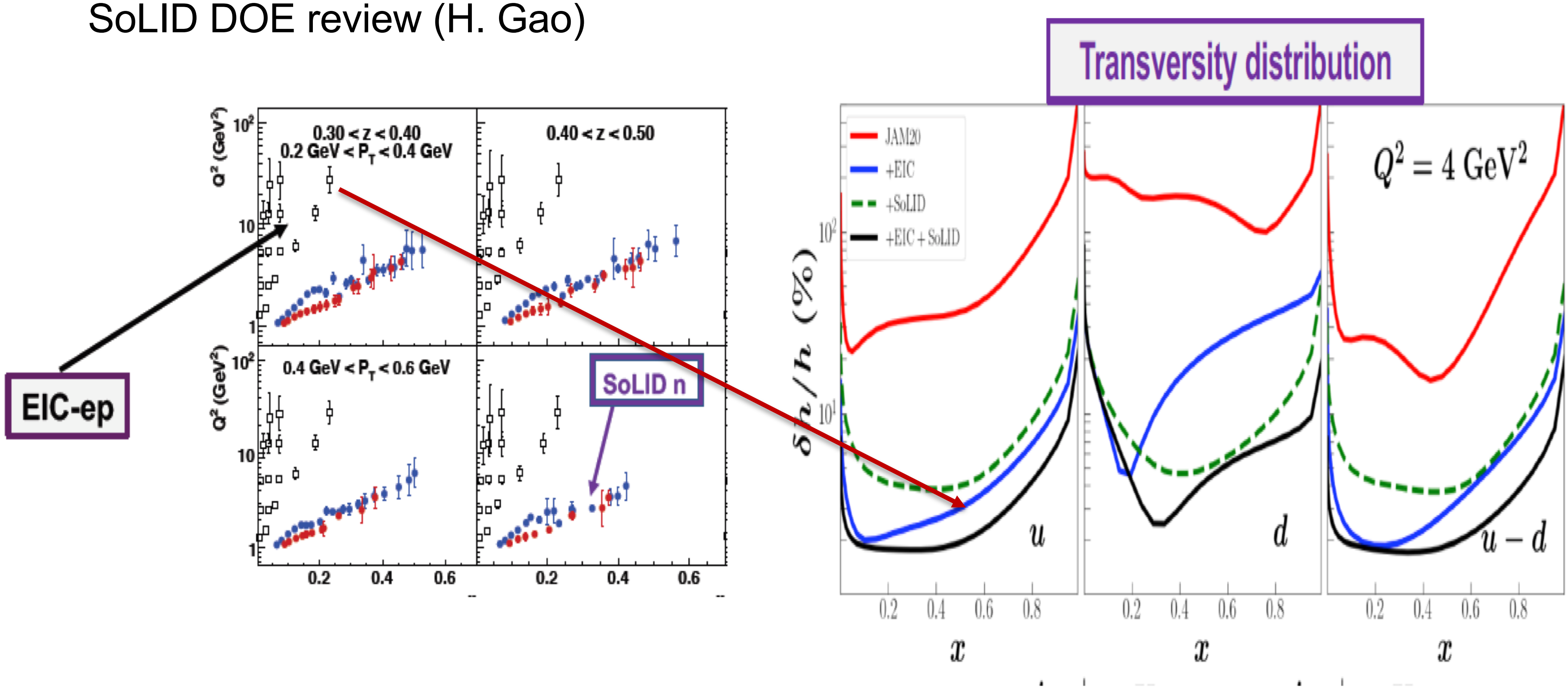


The rho peak is not increasing visually with increase of the fraction of VMs, as most of the background comes from low momentum particles at large $M_{\pi\pi}$



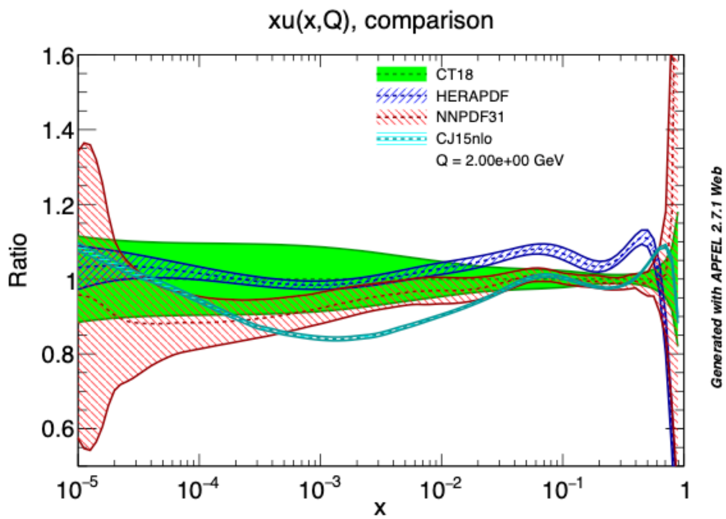
TMDs and sensitivity for high energy

SoLID DOE review (H. Gao)



"Incredible extractions and projections" with EIC at large x, providing more sensitivity to TMDs without even covering the large x region

The role of PDFs in the systematics (Vladimirov)



Result of a TMD fit is 100% dependent on PDF in use!

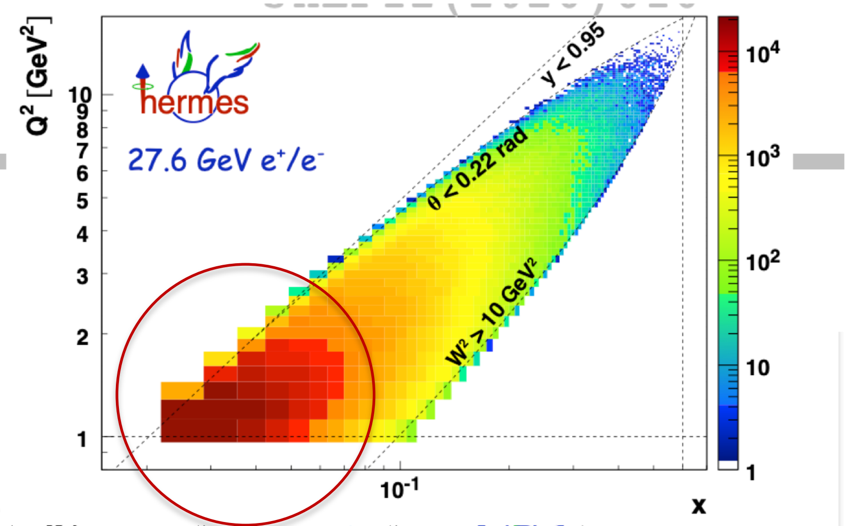
- Different PDF set are different
  - Especially in a "TMD-important" region $x \sim 0.1 - 0.5$
  - Different flavor decomposition
- As the result:

PDF & FF sets	χ^2/N_{pt}
HERA20 & DSS	0.76
HERA20 & JAM19	0.93
NNPDF31 & DSS	1.00
NNPDF31 & JAM19	1.65
HERA20 & DSS (N^3LO)	0.88
NNPDF31 & DSS (N^3LO)	1.31

SIDIS+DY fit [SV19]

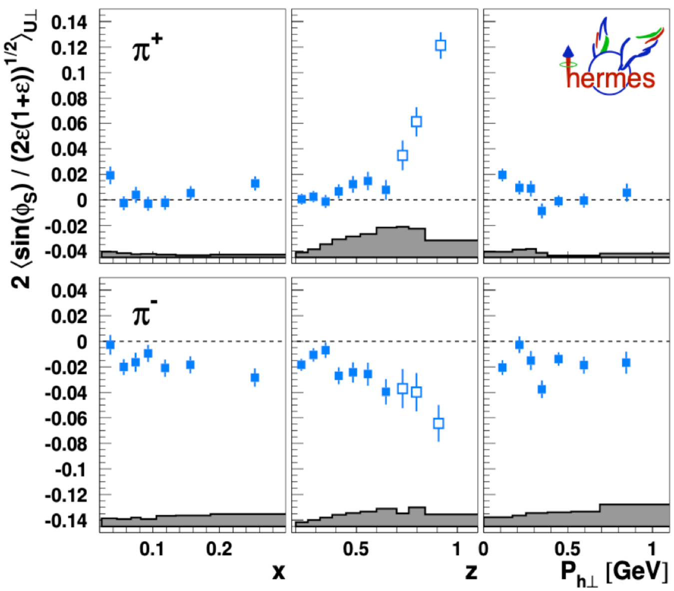
https://indico.jlab.org/event/439/contributions/8353/attachments/6927/9459/JLab2EIC-2021_gunar.schnell.pdf

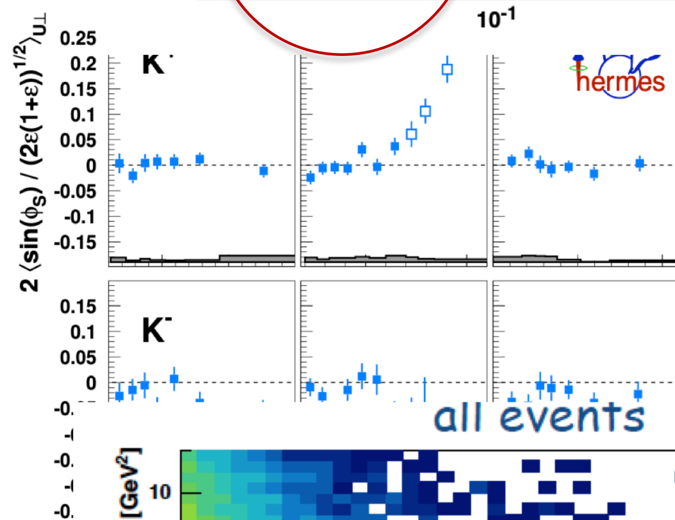
(G.Schnell)

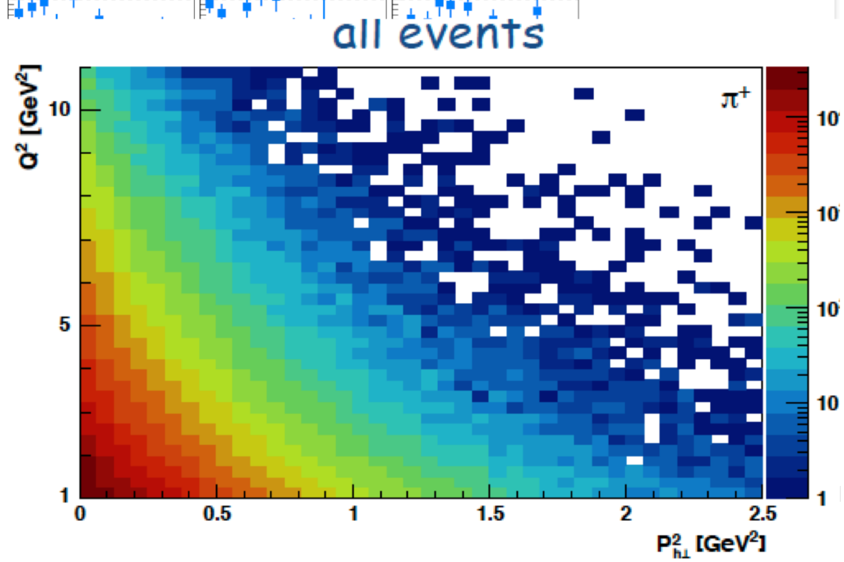


JLab25 will provide the same kinematics x100 more events

subleading twist — $\langle \sin(\phi_S) \rangle_{UT}$



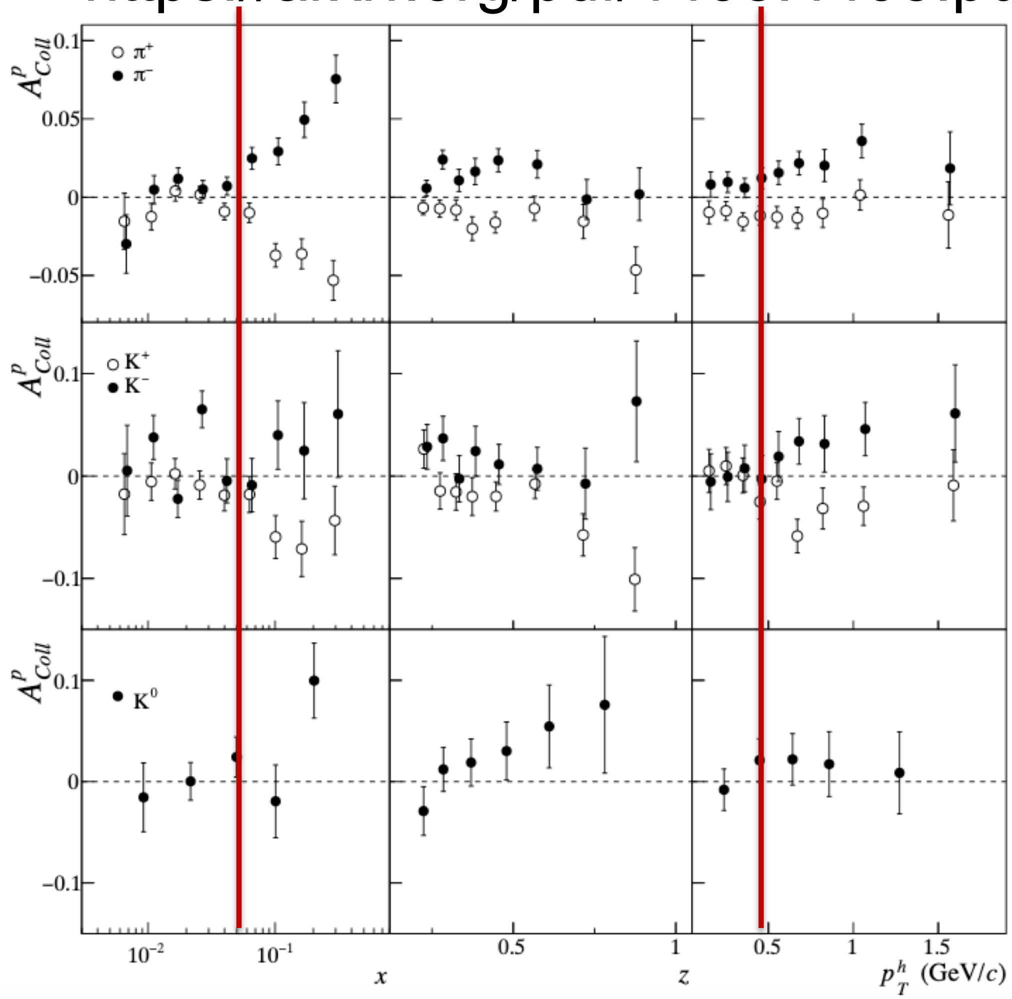




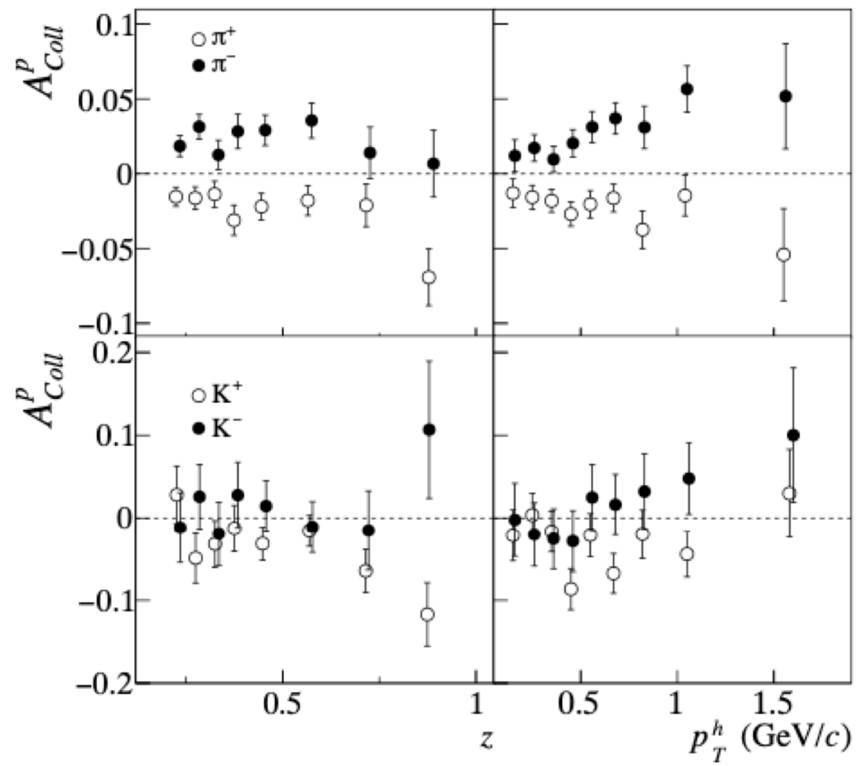
- clearly non-zero asymmetries
- opposite sign for charged pions (Collins-like behavior)
- striking z dependence and in particular magnitude
- similar observation at COMPASS

COMPASS transversity

https://arxiv.org/pdf/1408.4405.pdf

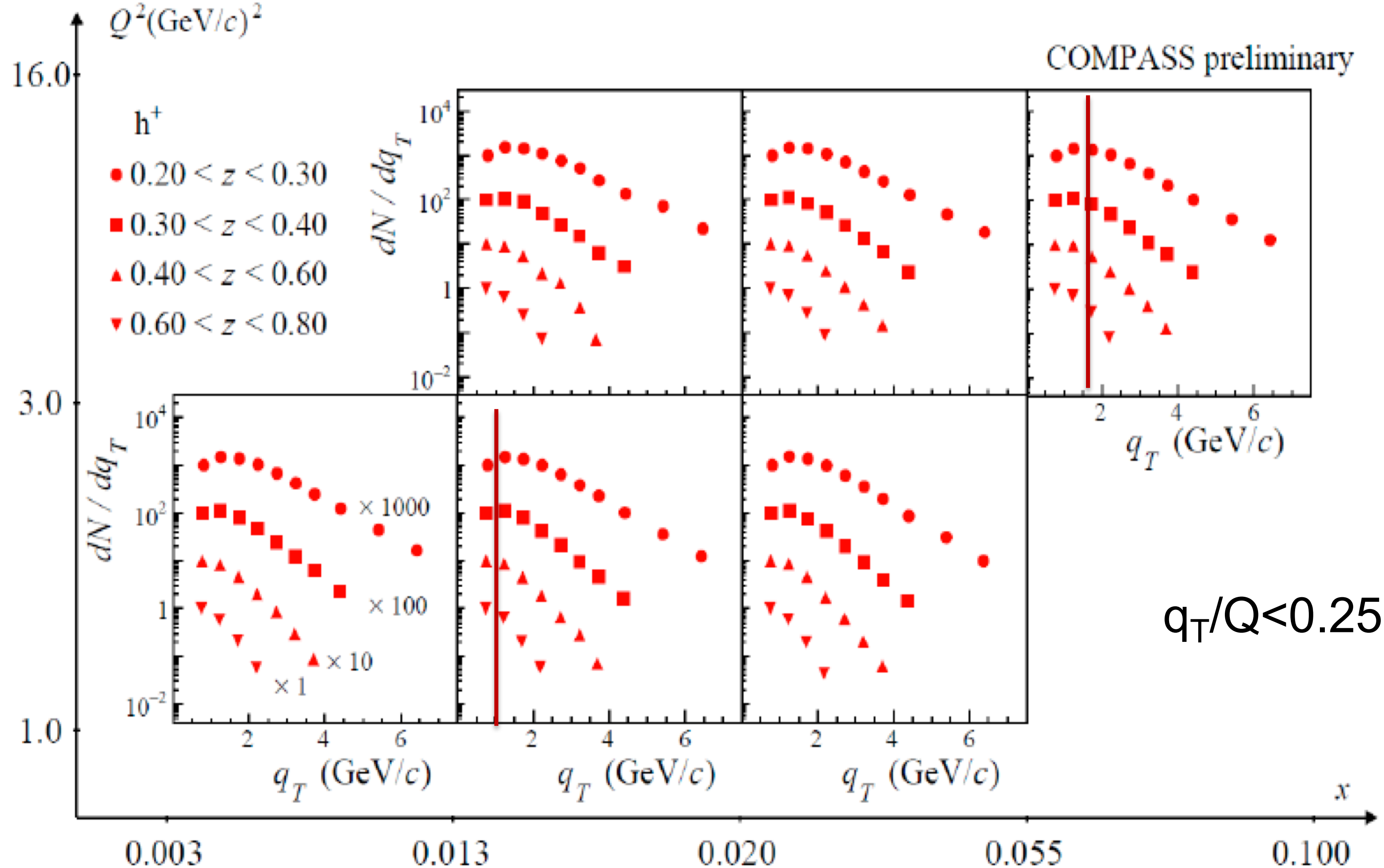


x>0.03



No significant effects for x<0.05, and P_T<0.5

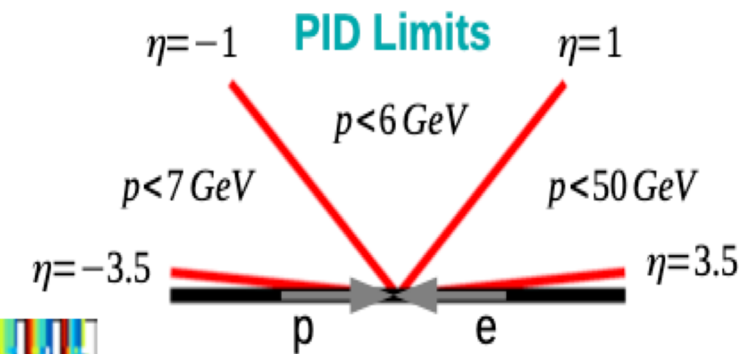
A. Martin COMPASS vs q_T-cuts

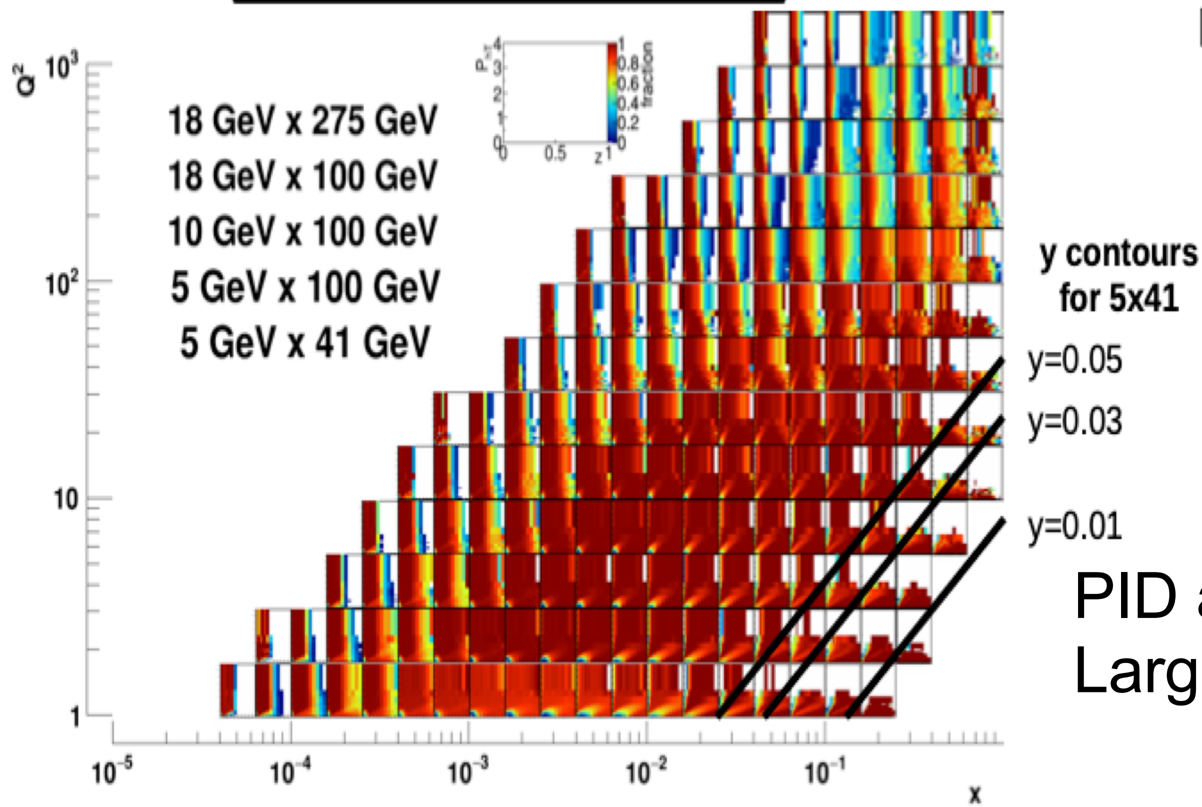


$q_T/Q<0.25$

EIC Coverage Limits

Chris Dilks





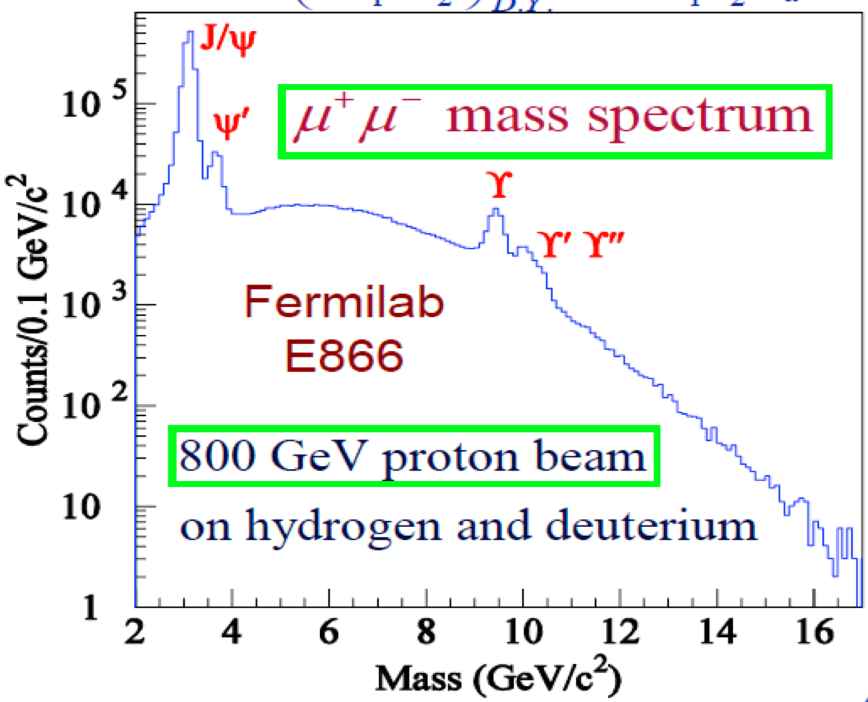
PID at smaller P_T
Large x at smaller y

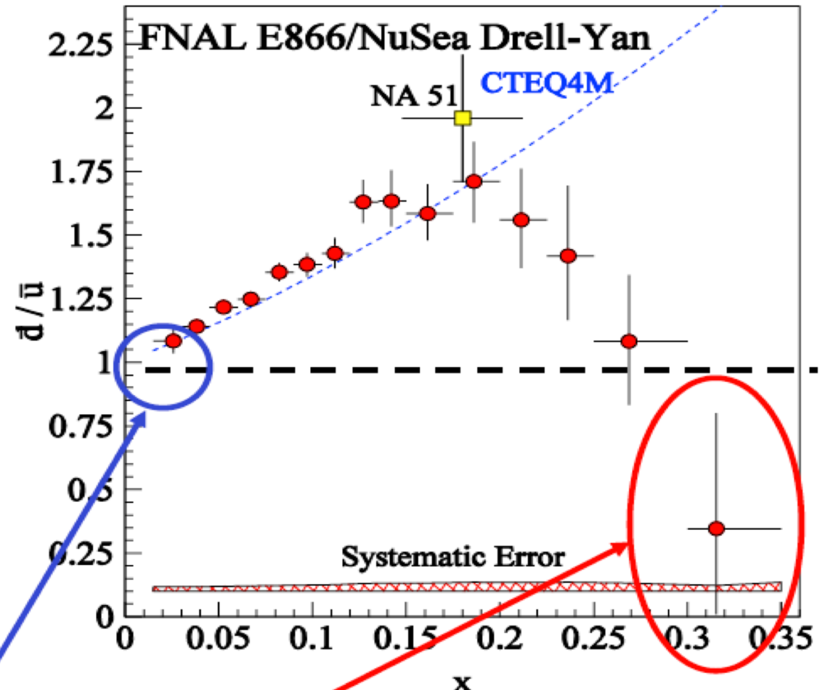
C. Dilks

20

$\bar{d}/\bar{u}$ flavor asymmetry from Drell-Yan

- J.C. Peng $\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2[q_a(x_1)\bar{q}_a(x_2)+\bar{q}_a(x_1)q_a(x_2)]$





The data suggest $\bar{d}/\bar{u} \to 1$ at small x, but more data are needed

The data suggest $\bar{d}/\bar{u} < 1$ at large x, but better data are needed

No significant effects expected below x~0.03 (within JLab25)

summary

To address in details some of the raised question there was a proposal to have 3 dedicated meetings

1) Discussions on details of TMD extractions, and validation of parameterizations, in particular in the kinematics used for projections for the new measurements

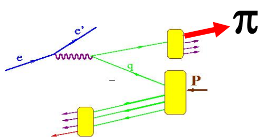
a) The role of PDFs and TMD FFs in the systematics of TMD PDF extraction
b) assumptions and cuts (ex. q_T/Q<0.25 leading to dominance of DY in the large x,P_T-kinematics
c) the role MC can play in understanding different limitations and approximations
d) comparison of parameterizations used for projections, and availability of grids in public access

2) The Radiative Corrections in hard scattering

a) advantages and disadvantages of "old RC"
b) advantages and disadvantages of new RC (JLab)
c) impact of RC on the SIDIS at small y of EIC (y<0.05)
d) impact of RC on large y for EIC and JLab
e) impact of RC on e+e- extractions at large P_T
d) impact of radiative photons on detector performances, which may require having the radiative photons properly accounted in MC, both for internal and external radiation

3) The scope of events to be considered when studying x-sections, multiplicities, and asymmetries. The main items could be:

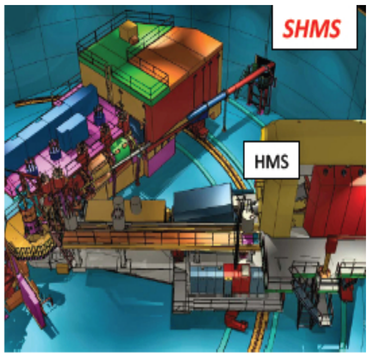
a) Diffractive exclusive vector mesons, may or may not be properly accounted for in the fragmentation functions
b) Does the current SIDIS framework allow to properly account for exclusive processes, and diffractive VMs, in particular, Nobuo and Ted are suggesting to keep in the data sample?
b) The role of VMs, and possibilities to study experimentally VMs separately from pions, and using the VM multiplicity and SSA data in the interpretation of the pion data

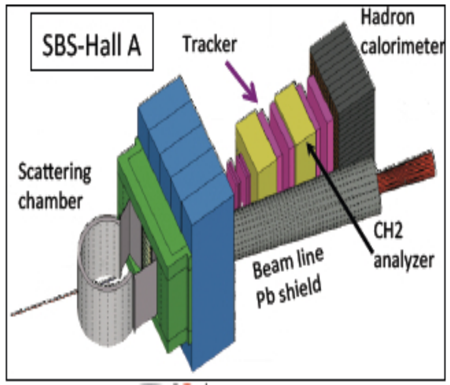


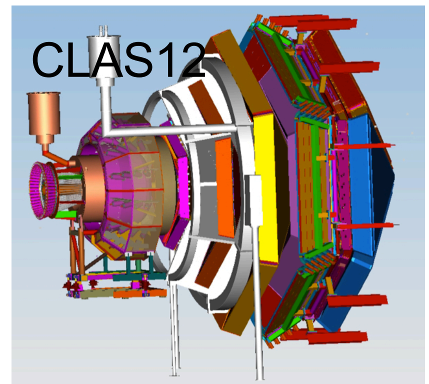
SIDIS at JLab12

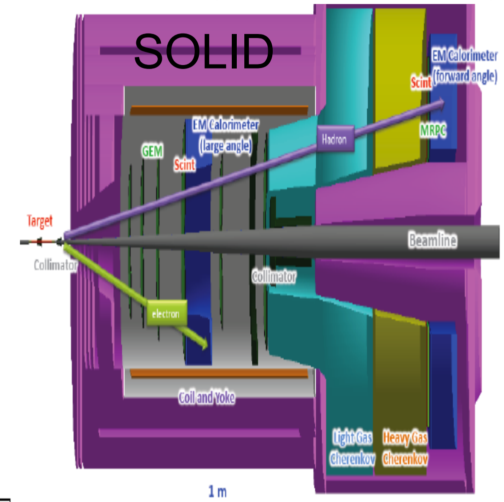
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

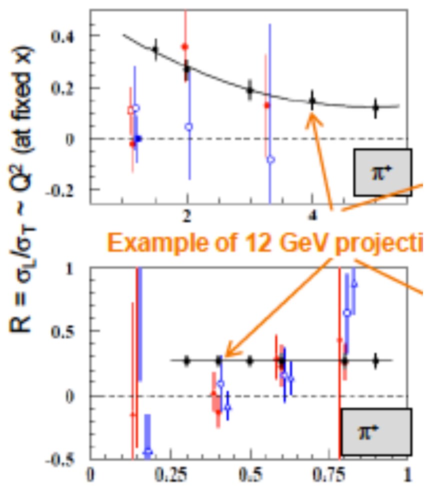
Complementary measurements with different targets

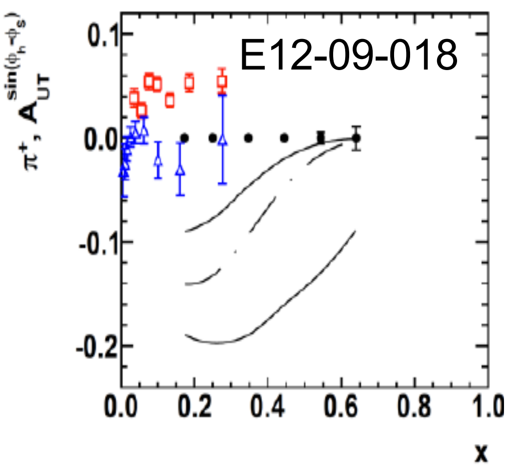


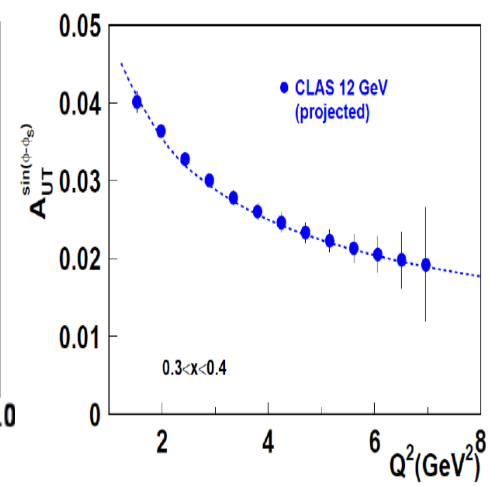


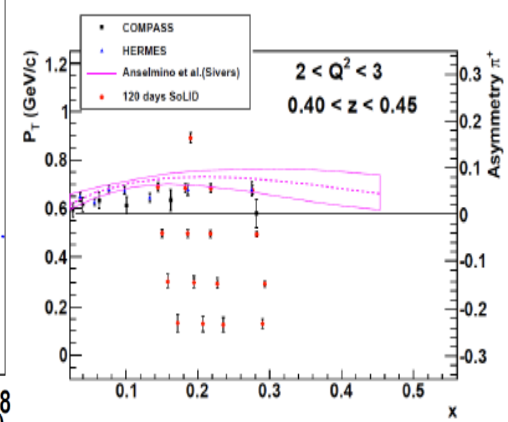








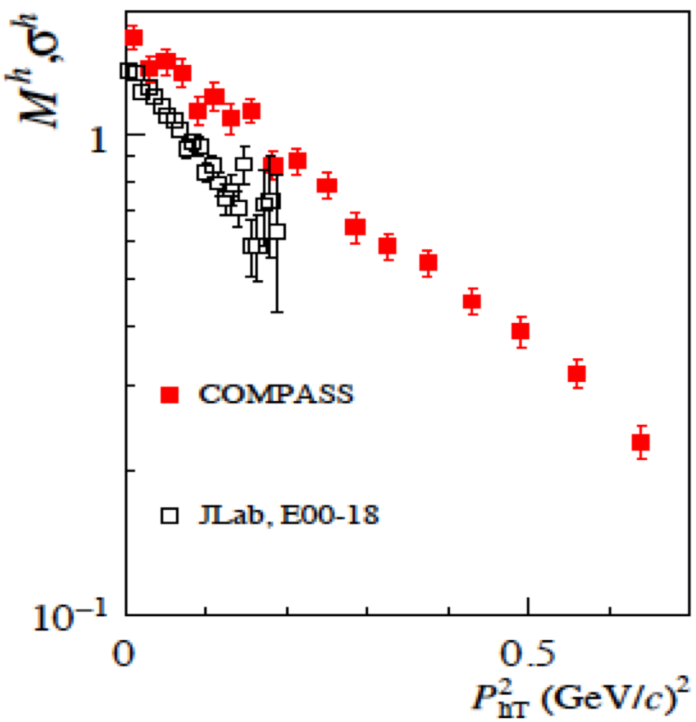




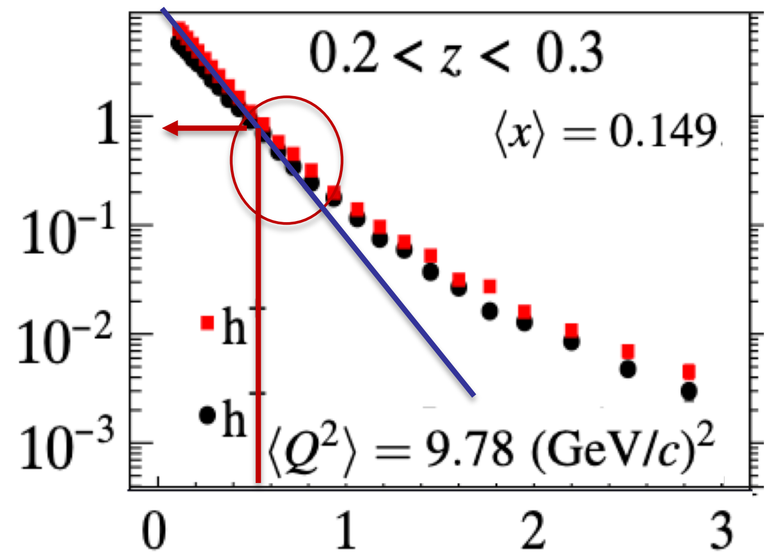
Combination of high resolution measurements from spectrometers combined with large acceptance data from CLAS12 and SOLID would allow to pin down all TMDs in the valence region

Multiplicities in SIDIS

COMPASS:1709.07374



Theory only describing low P_T

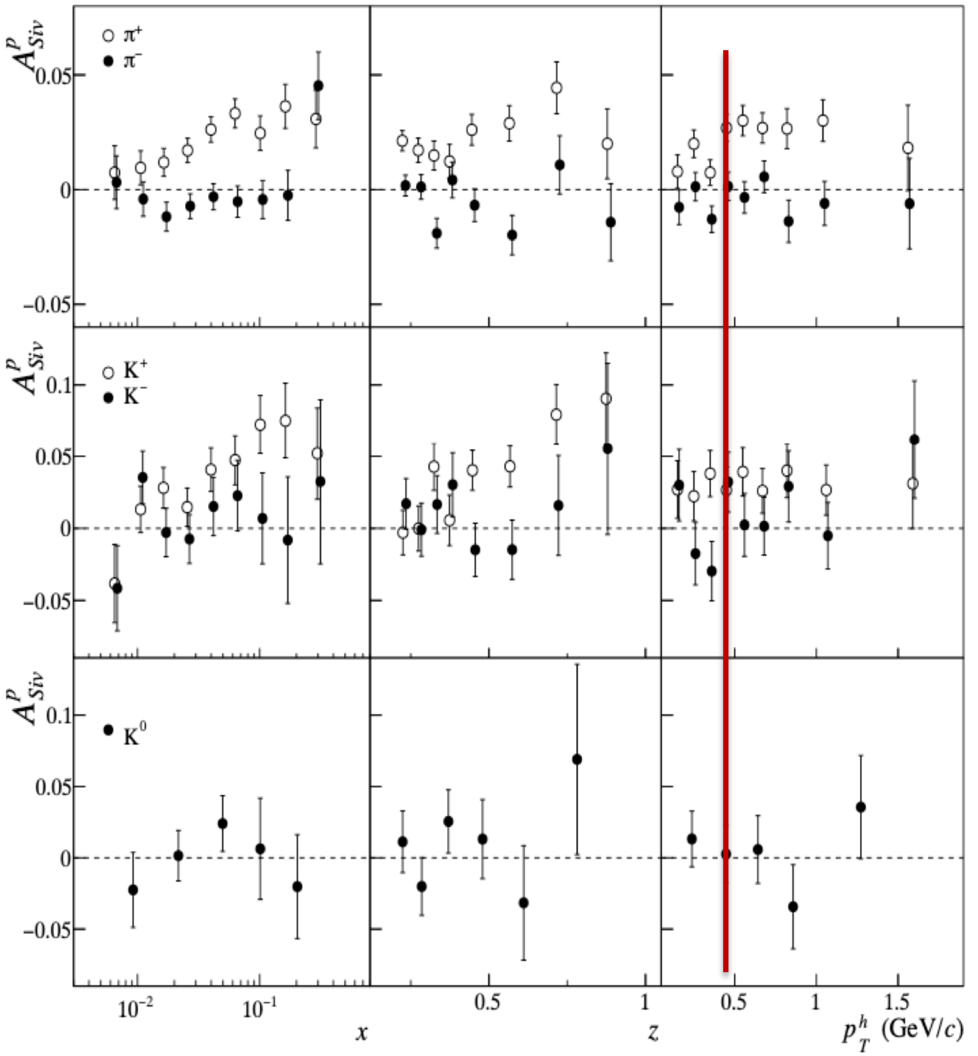


Lower the beam energy, less phase space for high $P_{T,}$ Impact can be simulated, more significant for heavier VMs

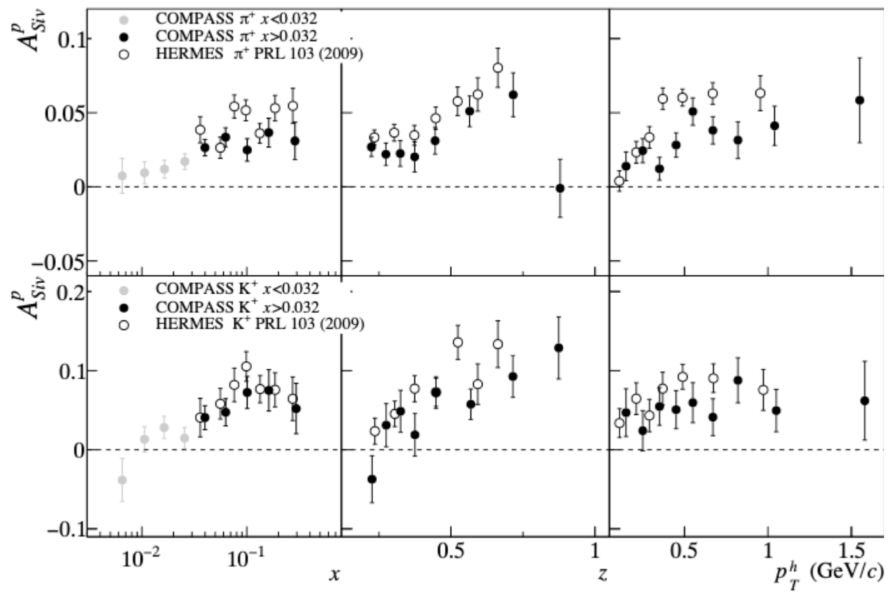
Main question: What is the origin of the tail starting at P_T~0.6-0.7?

COMPASS Sivers

https://arxiv.org/pdf/1408.4405.pdf



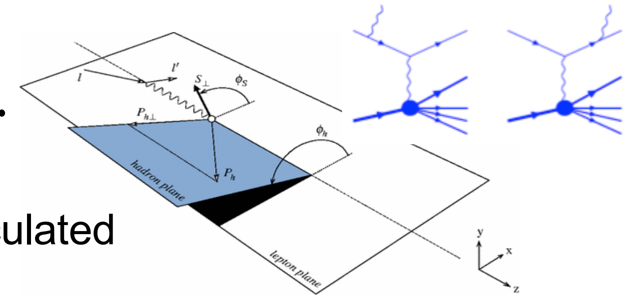
x>0.03



Experiment measure the full x-section with RC

I. Akushevich et al (LDRD-2018)

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



Due to radiative corrections, ϕ-dependence of x-section will get multiplicative R_M and additive R_A corrections, which could be calculated from the full Born (σ_0) cross section for the process of interest

$$\sigma_{Rad}^{ehX}(x,y,z,P_T,\phi,\phi_S) \to \sigma_0^{ehX}(x,y,z,P_T,\phi,\phi_S) \times R_M(x,y,z,P_T,\phi) + R_A(x,y,z,P_T,\phi,\phi_S)$$

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

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

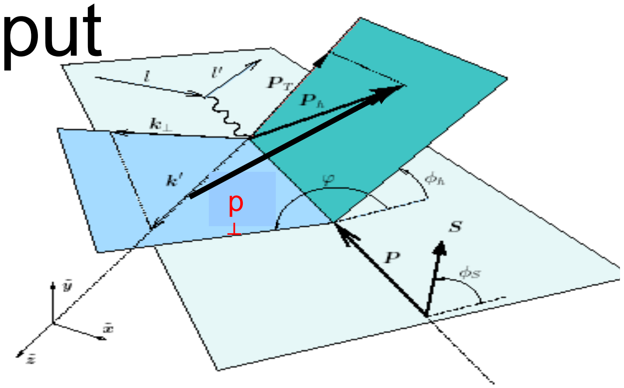
$$\sigma_0(1 + sS_T\sin\phi_S)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + sr/2S_T\sin(\phi_h - \phi_S) + sr/2S_T\sin(\phi_h + \phi_S))$$

Correction to DSA

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

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

MC Generator to simulate SIDIS output



SIDIS MC in 7D (10D)

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

Theory

Provide a set of SF_l

For a given model/theory based on underlying non-perturbative input and assumptions calculate SF_l

$$F_l(x_1, x_2, x_3, ...x_N, P_1, P_2, ...P_M)$$

step-1 $x_i, Q_i^2 z_i P_{hT}^{i2} \phi_h^i \phi_l^i \phi_s^i$

step-2 (for a given $E_{beam}, \lambda, \Lambda$) P_i^{el}, P_i^h

step-3 (detected for a given Detector configuration)

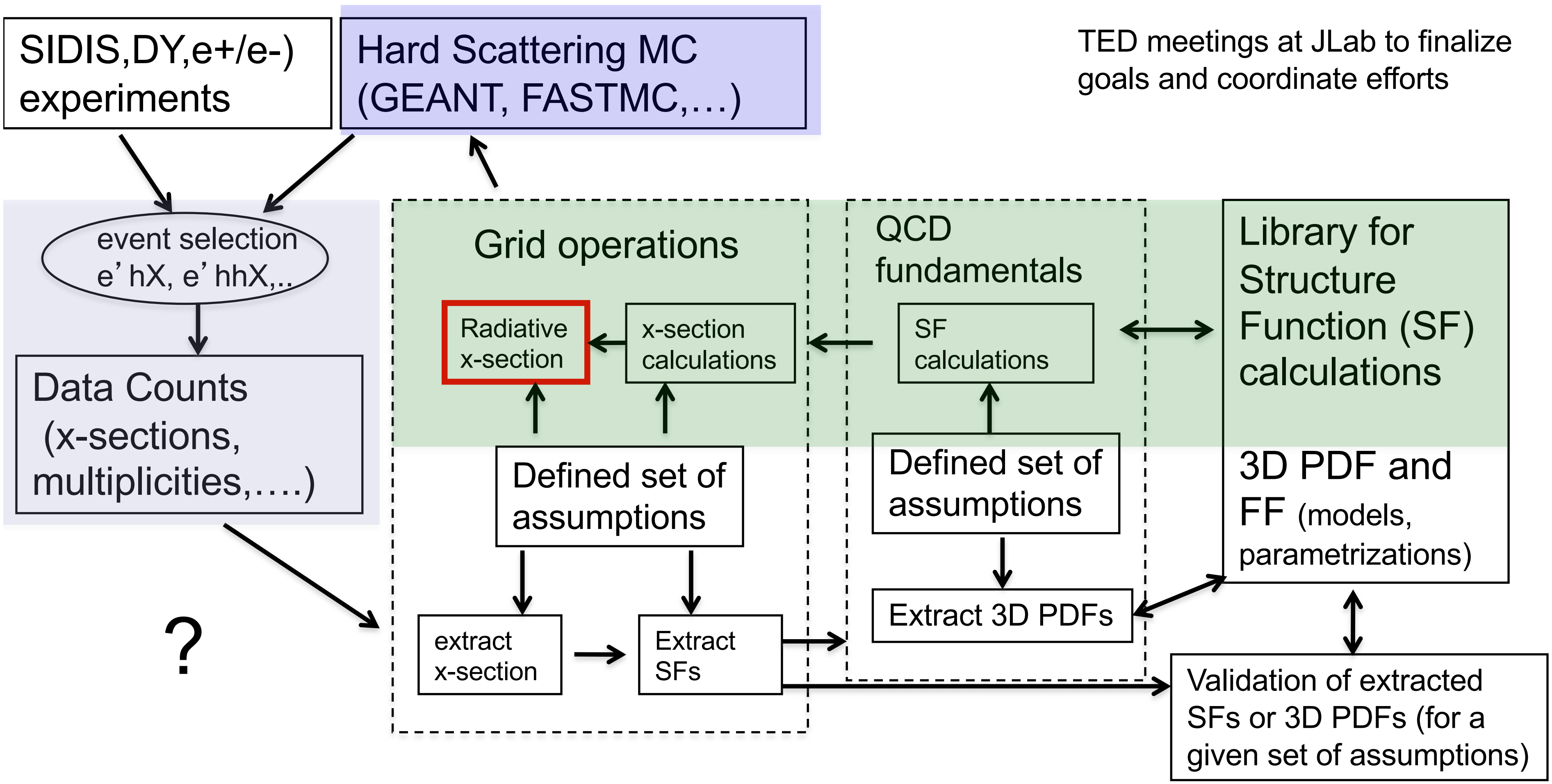
$$x_j, Q_j^2 z_j P_{hT,j}^2 \phi_h^j \phi_l^j \phi_s^j$$

$$F_l(x_1, x_2, x_3, ...x_N, P_1^*, P_2^*, ...P_M^*)$$

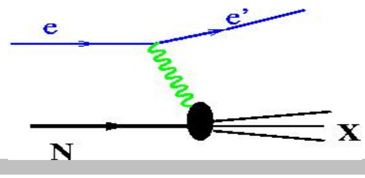
Need criteria to compare the input and output parameter spaces (validate)

3D PDF Extraction and VAlidation (EVA) framework

TED meetings at JLab to finalize goals and coordinate efforts

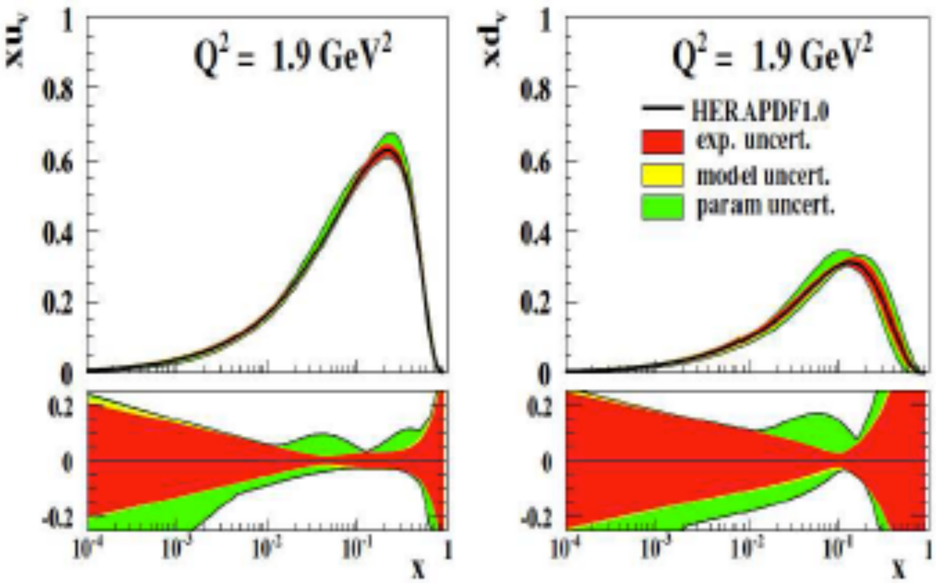


Development of a reliable techniques for the extraction of 3D PDFs and fragmentation functions from the multidimensional experimental observables with controlled systematics requires close collaboration of experiment, theory and computing

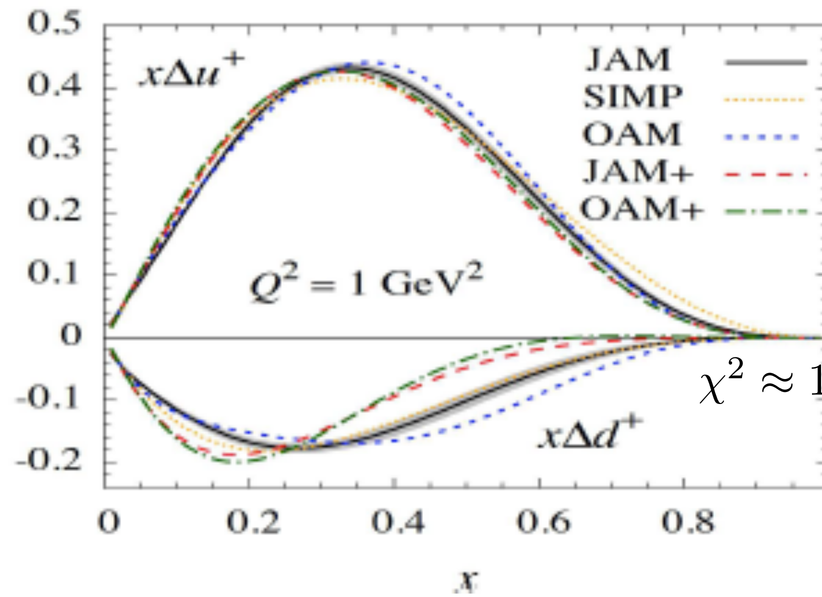


Studies of 1D PDFs

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



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



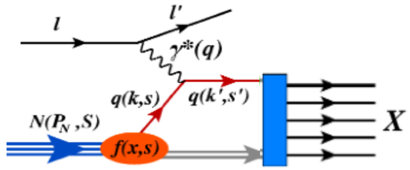
JAM (standard) $x\Delta q^+(x, Q_0^2) = N\, x^\alpha (1-x)^\beta \left(1 + \epsilon\sqrt{x} + \eta\, x\right),$

inspired by the OAM
Avakian et al $x\Delta q^+ = N\, x^\alpha (1-x)^\beta + N'\, x^{\alpha'} (1-x)^{\beta'} \log^2(1-x).$

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

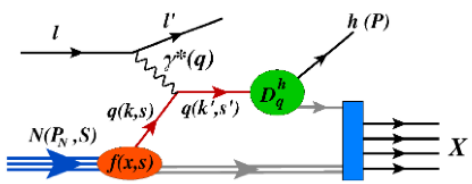
QCD: from testing to understanding

0h DIS

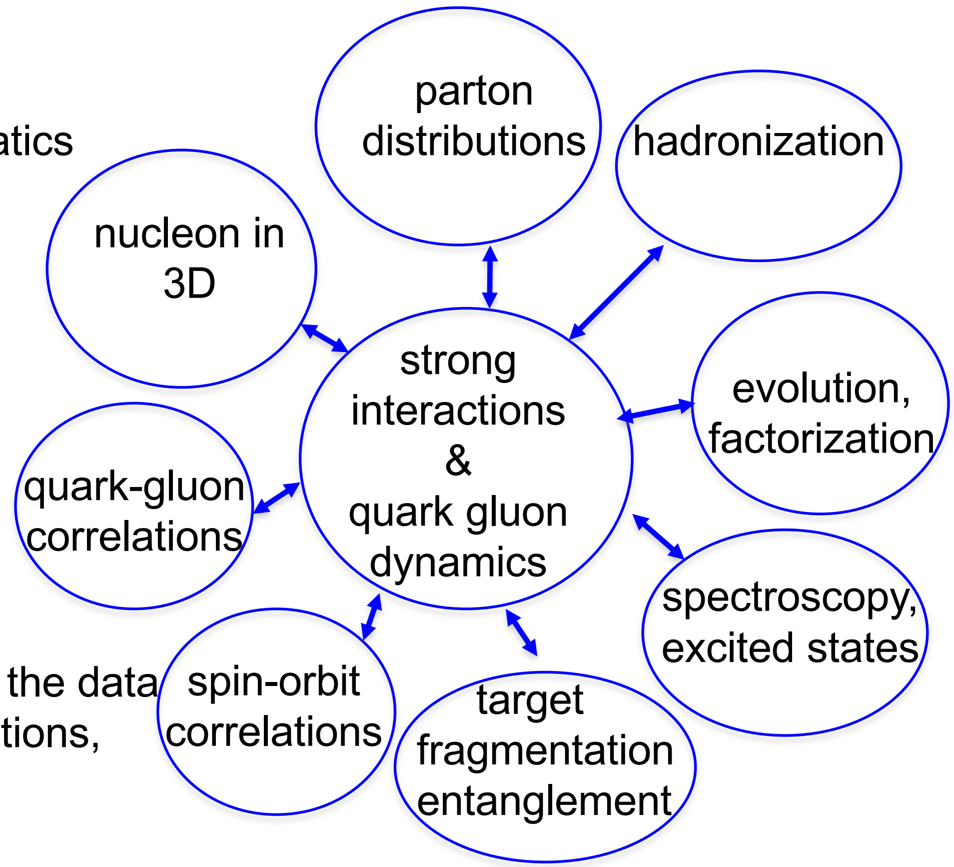


Testing stage:
pQCD predictions, observables in the kinematics where theory predictions are easier to get (higher energies, 1D picture, leading twist, current fragmentation, IMF)

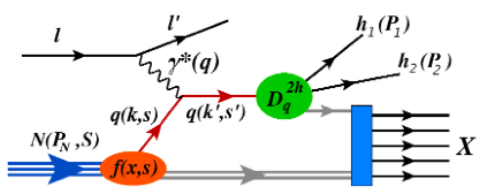
1h SIDIS/DVMP



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)

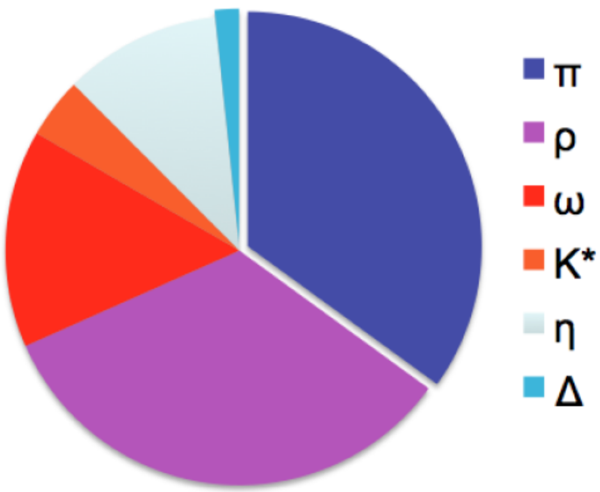


2h SIDIS/DVMP



production in SIDIS provides access to correlations inaccessible in simple SIDIS (BEC,dihadron fragmentation , correlations of target and current regions, entanglement....)

Dihadron production



HERMES-note-96.059

What is the origin of dihadrons?
What is a single hadron?

Matevosyan et al arXiv:1307.8125(NJL-jet)