Understanding the “large” transverse momenta in SIDIS

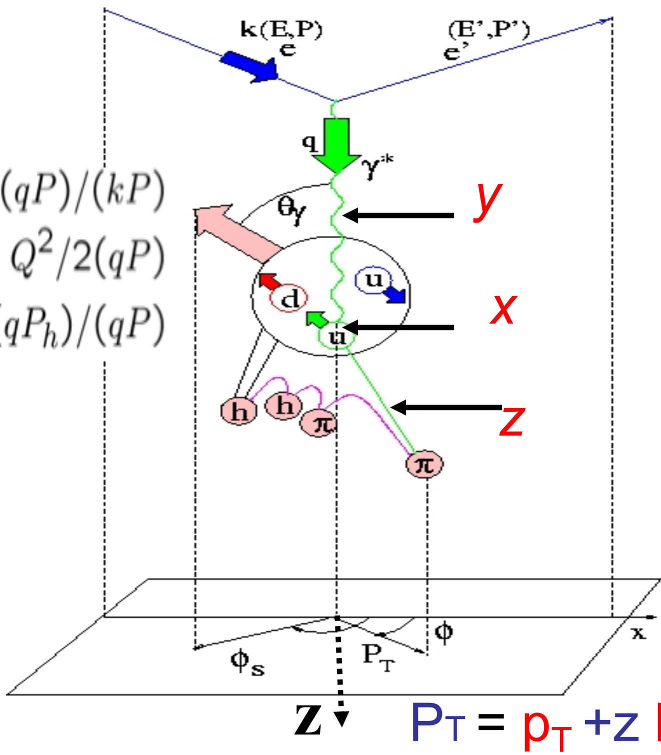
Giovanni Angelini (GWU) *

- Introduction
- Present some JLab12 (CLAS) data
- Studies of transverse momentum of hadrons
- Interpretations & challenges
- Summary

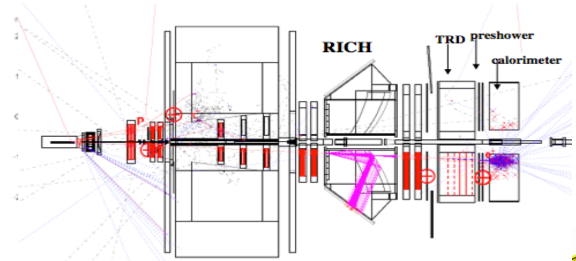
* In collaboration with Harut Avakian (JLab)

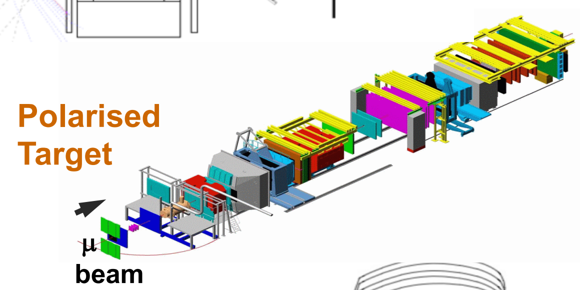
Semi Inclusive DIS

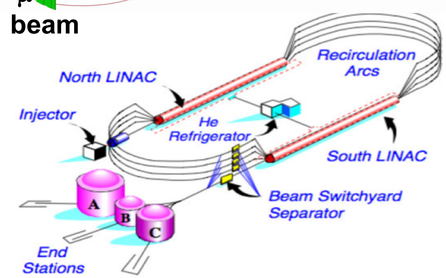
$$y = (qP)/(kP)$$
$$x = Q^2/2(qP)$$
$$z = (qP_h)/(qP)$$



$$P_T = p_T + z\, k_T$$







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

Azimuthal modulations depend on structure functions, providing information on underlying correlations of spins with partonic momentum distributions

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

beam polarization

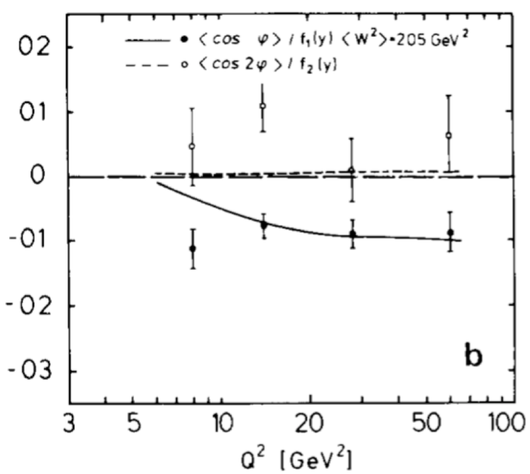
target polarization

Distribution & Fragmentation Functions

Azimuthal distributions in SIDIS (unpolarized)

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

EMC-1983 (PL,v130,118)



Observables: - Azimuthal Moments - Multiplicity

$$\boxed{\frac{d^4M^{\pi^\pm}(x,Q^2,z,P_T^2)}{dx\,dQ^2\,dz\,dP_T^2} = \left(\frac{d^4\sigma^{\pi^\pm}}{dx\,dQ^2\,dz\,dP_T^2}\right) \Big/ \left(\frac{d^2\sigma^{DIS}}{dx\,dQ^2}\right)}$$

$$m^h(x,z,P_T^2,Q^2) = \frac{\pi F_{UU,T}(x,z,P_T^2,Q^2) + \pi\epsilon F_{UU,L}(x,z,P_T^2,Q^2)}{F_T(x,Q^2) + \epsilon F_L(x,Q^2)}$$

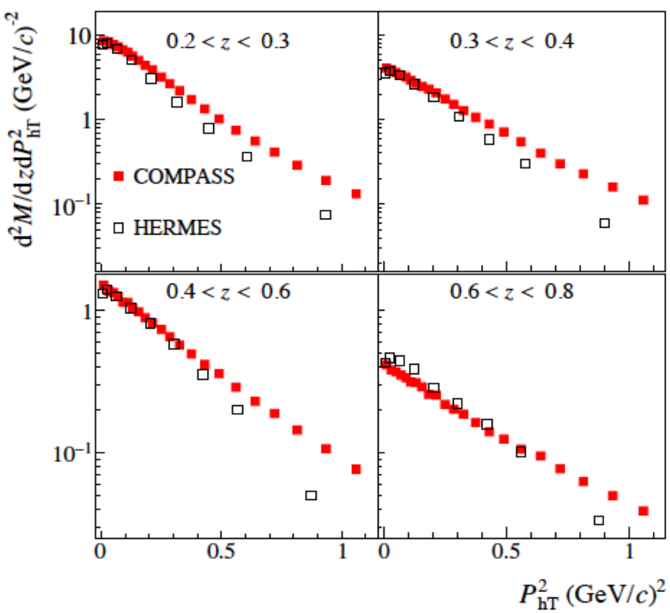
- Quark-gluon correlations are significant in electro production experiments (even if at high energy).
- Large cosϕ modulations observed in electroproduction (EMC, COMPASS, HERMES) may be a key in understanding of the QCD dynamics.

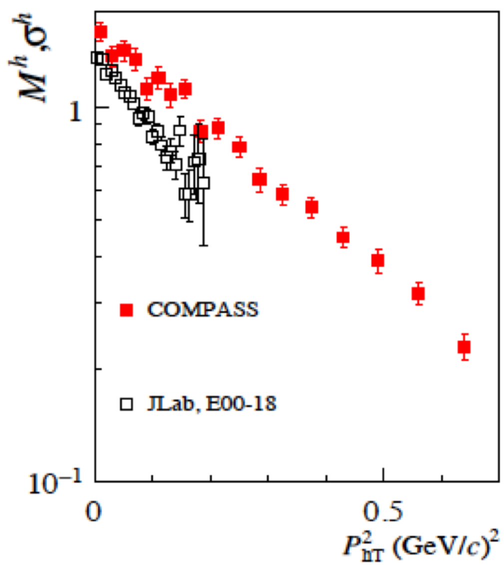
Multiplicities of hadrons in SIDIS

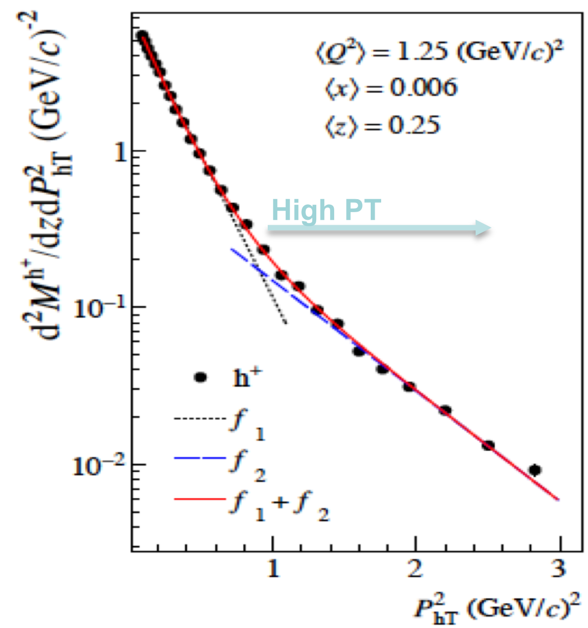
Gaussian Ansatz $\boxed{f_1^q} \otimes \boxed{D_1^{q\to h}} = x f_1^q(x)\, D_1^{q\to h}(z) \dfrac{e^{-P_{hT}^2/<P_{hT}^2>}}{\pi < P_{hT}^2 >}$

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

COMPASS:1709.07374







- TMDs evolution makes distribution wider
- Lower the beam energy, less phase space for high P_T

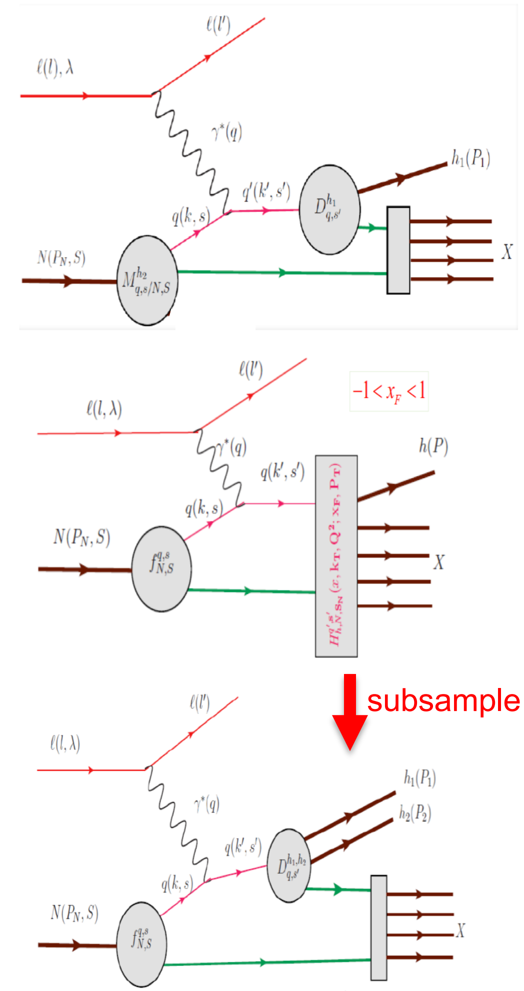
- What is the origin of the "high" PT tail?
  1) Perturbative contributions?
  2) Non perturbative contributions? (TMDs dependence not 1 Gaussian)

MC simulations: Why LUND works?

- A single-hadron MC with the SIDIS cross-section where widths of k_T-distributions of are extracted from the data is not reproducing well the data.
- LUND fragmentation based MCs were successfully used worldwide from JLab to LHC, showing good agreement with data.

So why the LUND-MCs are so successful in description of hard scattering processes, and SIDIS in the first place?

- The hadronization into different hadrons, in particular Vector Mesons is accounted (full kinematics)
- Accessible phase space properly accounted
- The correlations between hadrons, as well a as target and current fragments accounted
- ….



To understand the measurements we should be able to simulate, at least the basic features we are trying to study (P_T and Q^2,-dependences in particular)

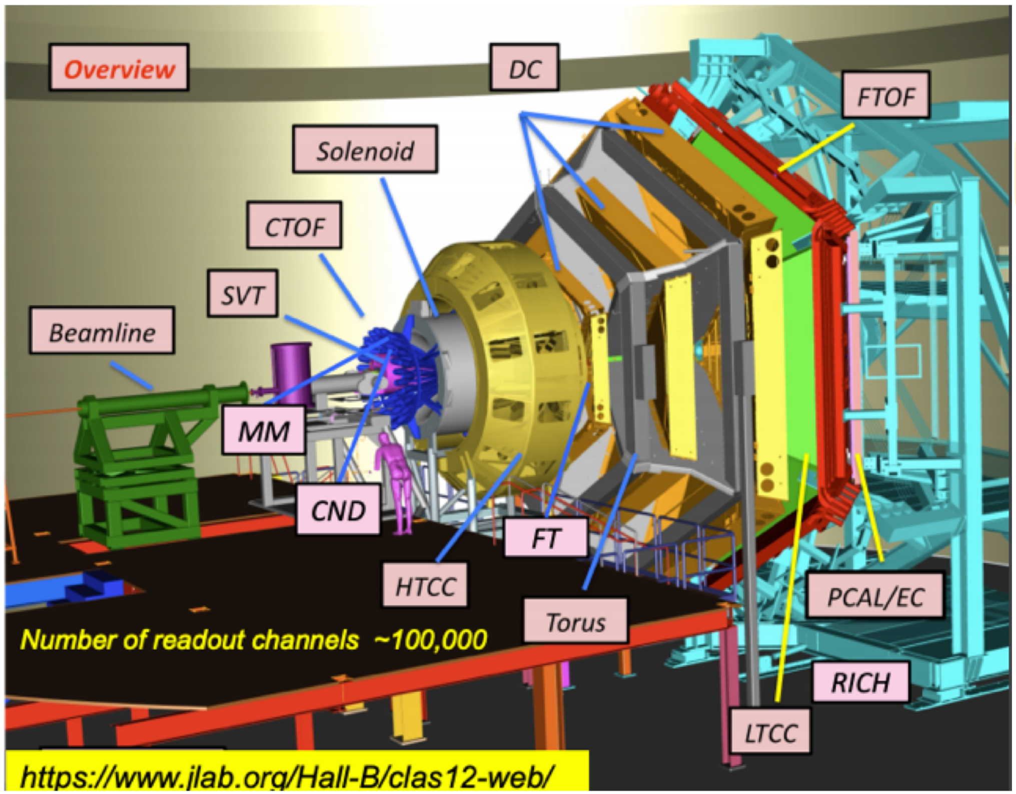
The studies of correlated hadron pairs in SIDIS may be a key for proper interpretation !!!

CLAS12 (JLAB) Detector

CLAS allows measuring multi-particle final state detection, opening unique possibilities to study correlation in hadron production.

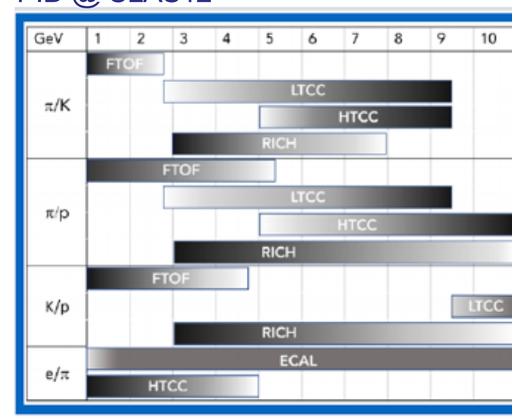
Forward Detector:
- *TORUS magnet*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *RICH detector*
- *Forward ToF System*
- *Pre-shower calorimeter*
- *E.M. calorimeter (EC)*
- *Forward Tagger*

Central Detector:
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Micromegas*
- *Central ToF system*
- *Neutron detector*
- *Backward Angle Neutron detector*



The CLAS12 Spectrometer at Jefferson Laboratory, V.D. Burkert, et al. Nucl. Instrum. Meth. A, Volume 959, 2020, 163419

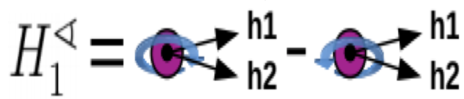
PID @ CLAS12



- Large acceptance detector
- Polarized beam (85% average polarization)
- Operates with polarized and unpolarized targets
- Luminosity up to $10^{35}\ cm^{-2} s^{-1}$
- Beam energy up to 10.6 GeV

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

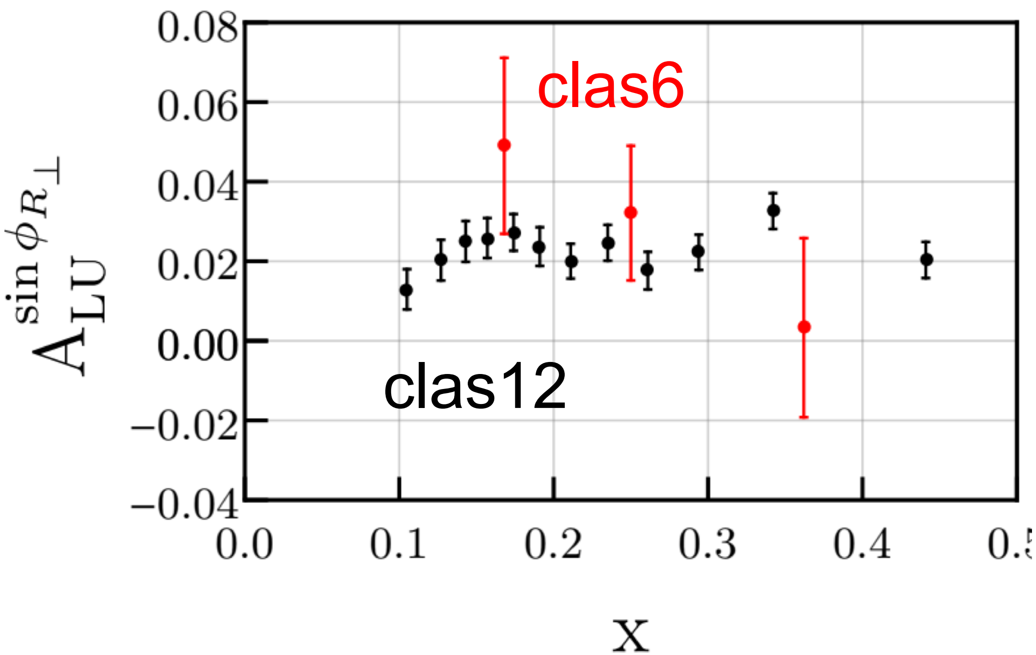
T. Hayward et al. Phys. Rev. Lett. 126, 152501 (2021)

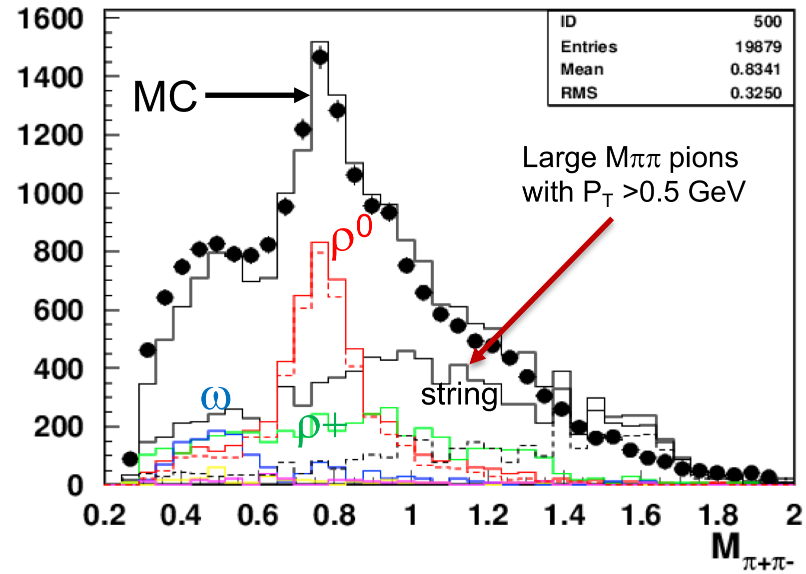


$$d\sigma_{LU} \propto \lambda_e \sin(\phi_{R_\perp}) \left(x e(x) H_1^{\sphericalangle}(z, M_h) + \frac{1}{z} f_1(x) \tilde{G}^{\sphericalangle}(z, M_h) \right)$$

Bacchetta&Radici: arXiv:hep-ph/0311173

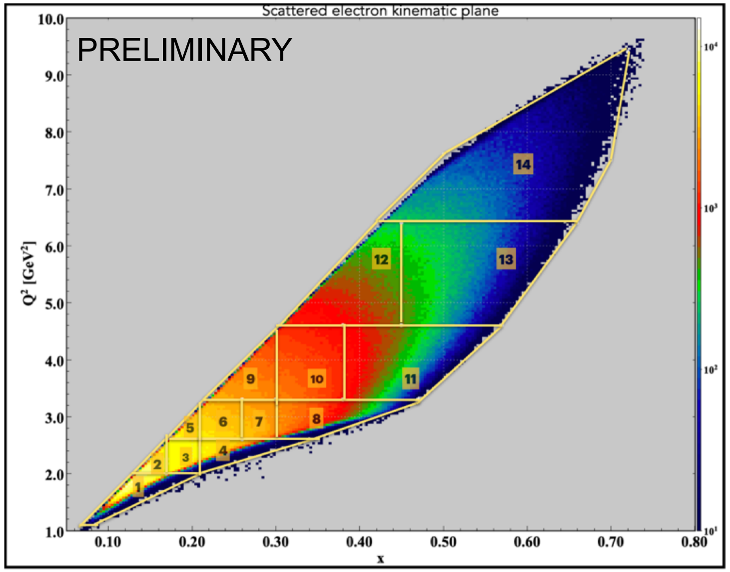
PDF e describes the force on the transversely polarized quark after scattering

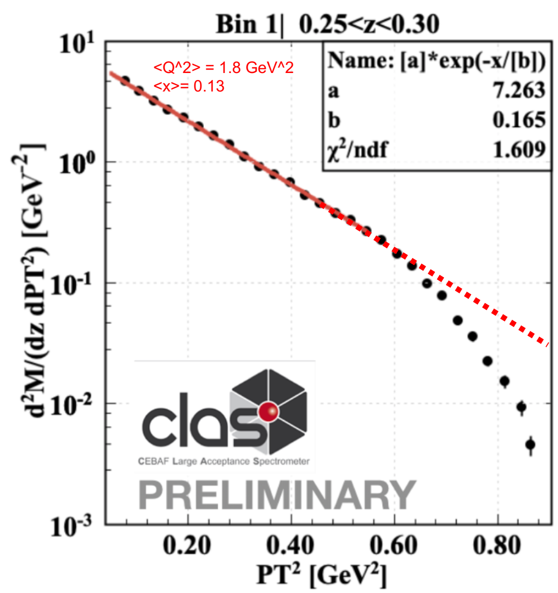


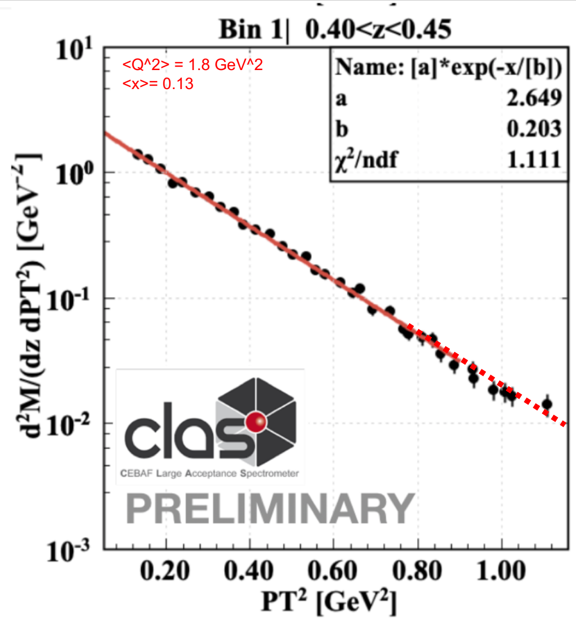


- Spin-azimuthal correlations in hadron pair production are very significant
- Hadron pairs in SIDIS (true from JLab to LHC) are dominated by VM decays (therefore single hadron channel too)

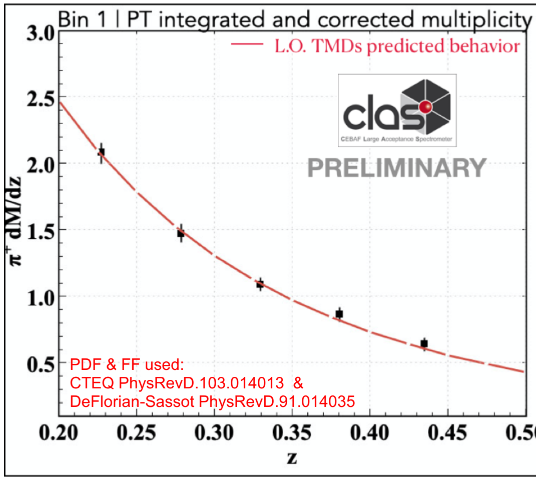
CLAS12 1h Multiplicities: high P_T & phase space

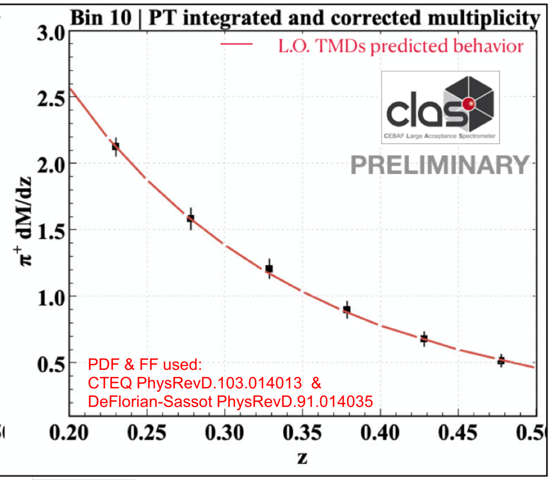




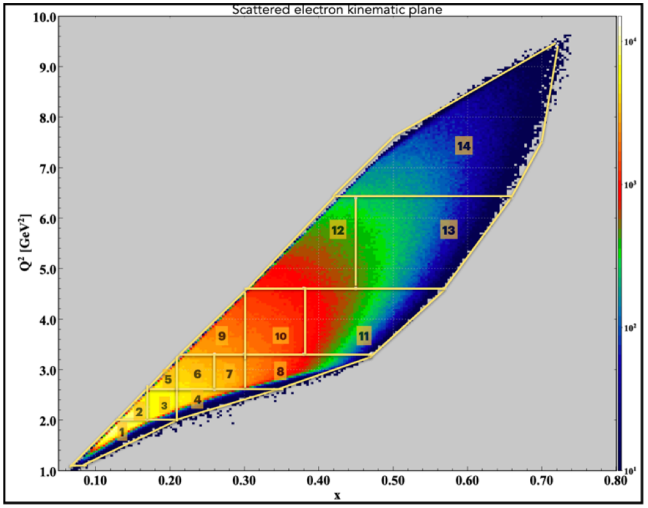


For some kinematic regions, at low z, the high P_T distribution appear suppressed: there is no enough energy in the system to produce hadron with high transverse momentum (phase space effect).
If the effect is accounted, the CLAS data follows global fits.

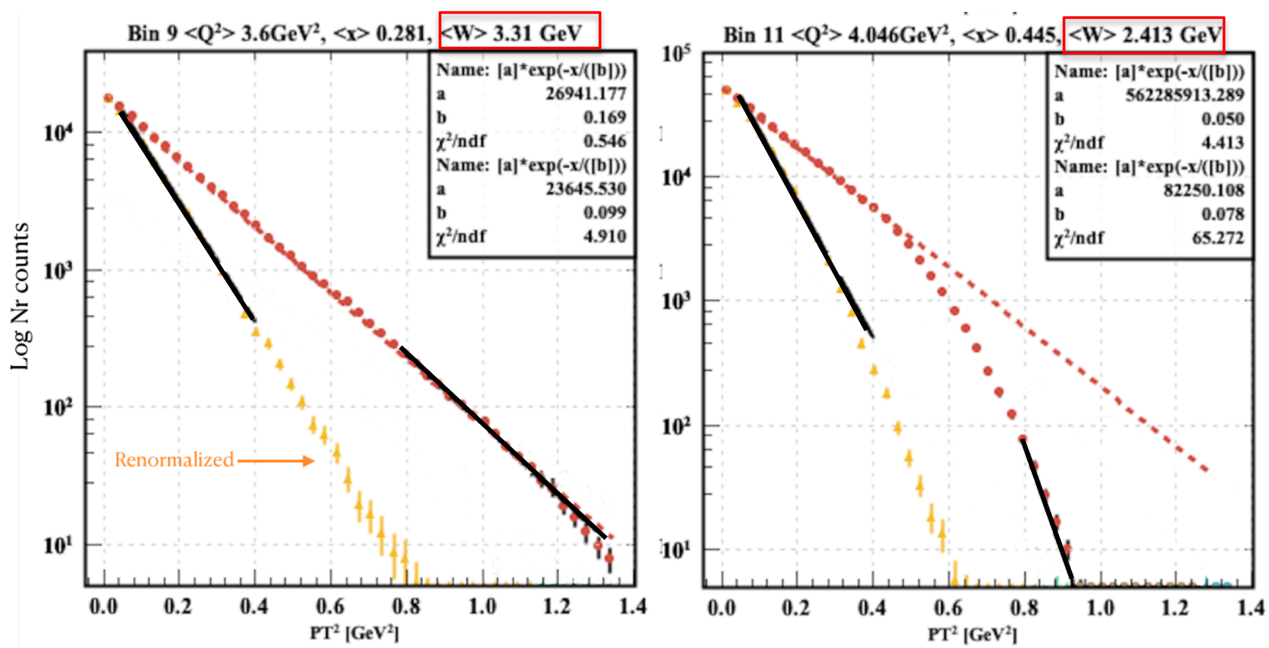




CLAS12 1h Multiplicities: high P_T & phase space



We binned the MC Phase space as for the CLAS12 multiplicity analysis, we used a single hadron generator with PDFs, FFs, and Gaussian Ansatz for transverse momentum and looked at the produced distribution.



Coded PT distribution in generator (0.2<z<0.25)

Directly Generated π+ (0.2 <z<0.25)

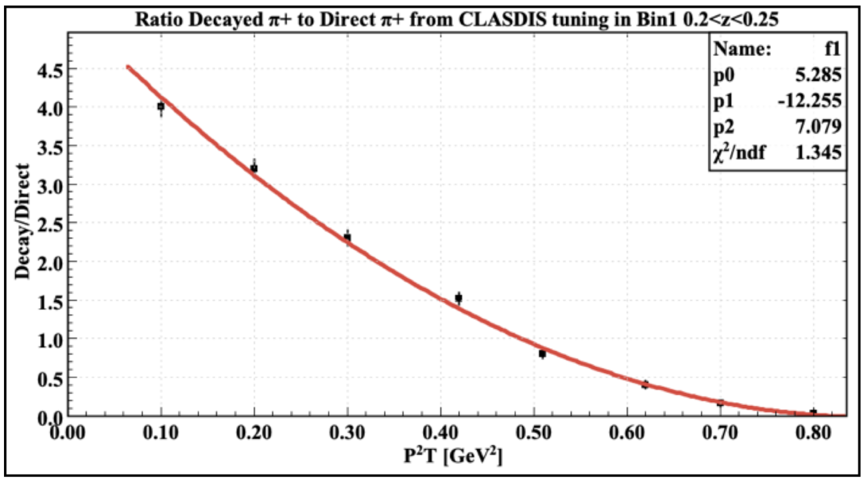
π+ decayed from ω (0.2 <z<0.25)

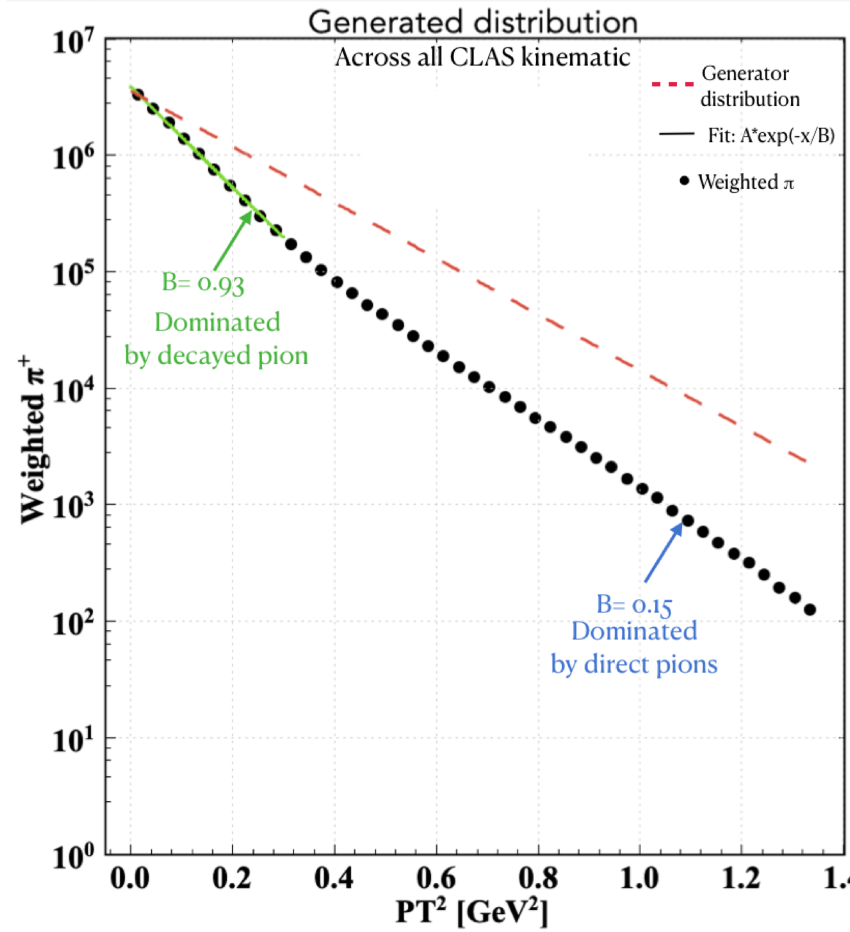
Gaussian Fit

- Phase space limitations for direct pion production more significant at low W, and low z
- Decayed pions have a much steeper P_T distribution at the same z

CLAS12 high P_T : impact of vector mesons

We consider the ratio of Decayed to Direct pions from the LEPTO MC (that well describes our data) and reweighted the distribution of pions accordingly.





By combining the directly produced pions and the decayed pions, two Gaussian slopes are effectively generated even if we started with one single gaussian

Summary

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. CLAS12 provides high statistical multidimensional measurements.

Extraction of multiplicities and spin-azimuthal asymmetries in multidimensional space is critical for interpretation of results and understanding of the systematics of TMD extractions

The extraction of universal 3D PDFs requires a clear understanding of the impact of the phase space in polarized electroproduction experiments, especially at JLab.

Understanding contributions from VM (with stronger phase space dependence) will be important to understand the systematics of TMD extraction and maybe provide a possible explanation for the single hadron PT distributions in SIDIS.