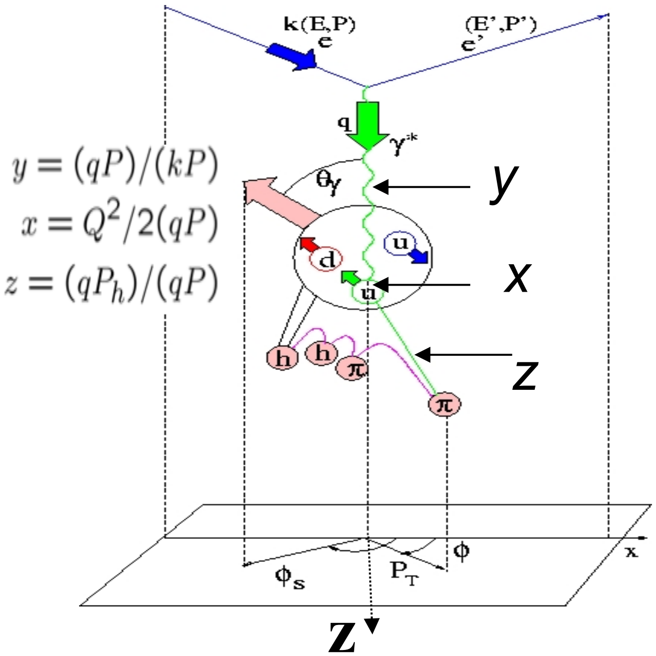
Correlations in di-hadron electroproduction

Harut Avakian (JLab)

CLAS Collaboration Meeting, November 24, 2019

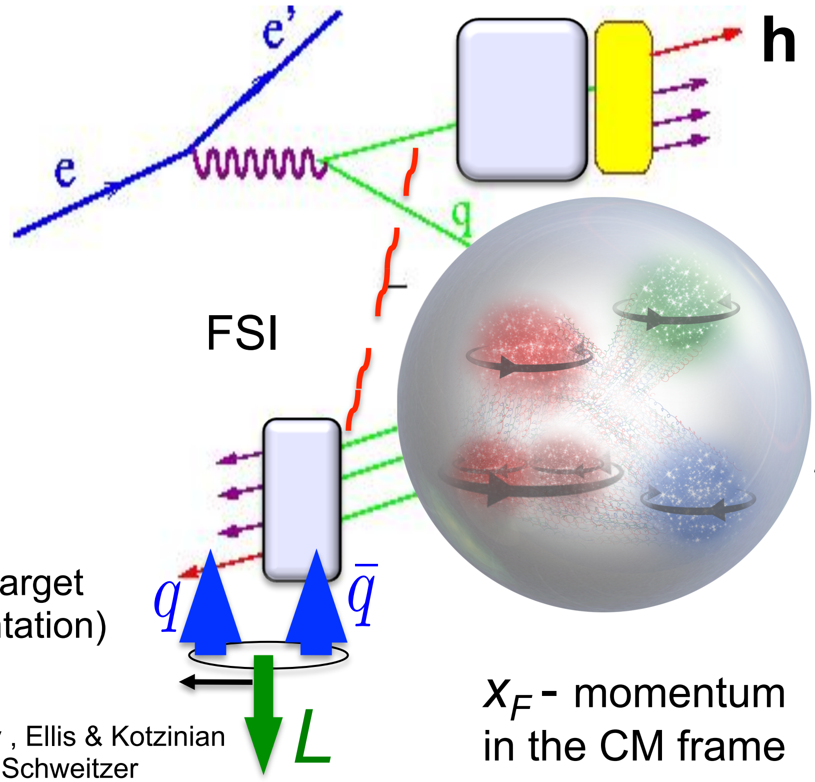
- TMDs: assumptions, measurements, extractions, interpretation
- Dihadron production at CLAS12
    - 2pion channels
- Spin observables as possible key to the source of SSAs
- Conclusions

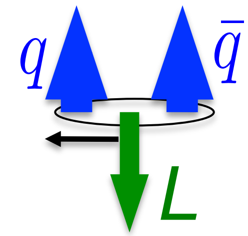
Hadron production in hard scattering



x_F>0 (current fragmentation)

X. Artru & Z. Belghobsi





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

x_F<0 (target fragmentation)

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

x_F - momentum in the CM frame

Modeling of q-q-bar correlations with spins and momenta in the process (not in PYTHIA) will be important for understanding of the dynamics

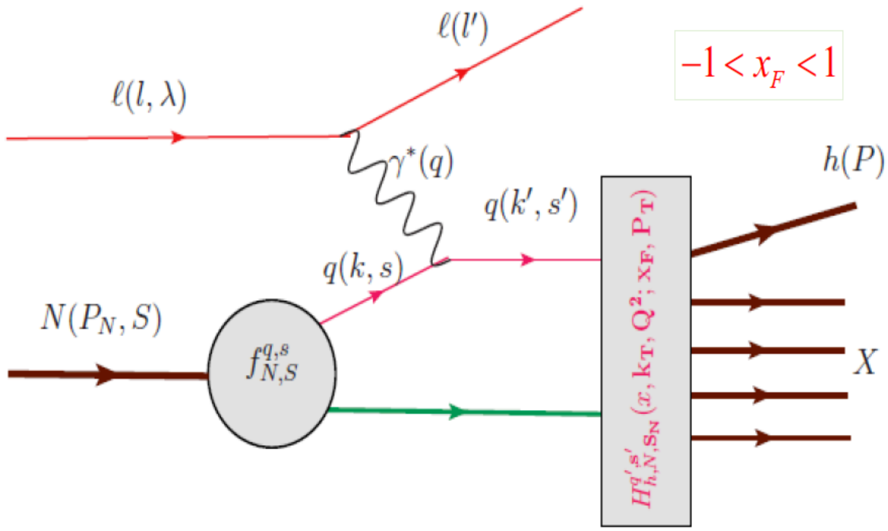
Hadronization and factorization

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

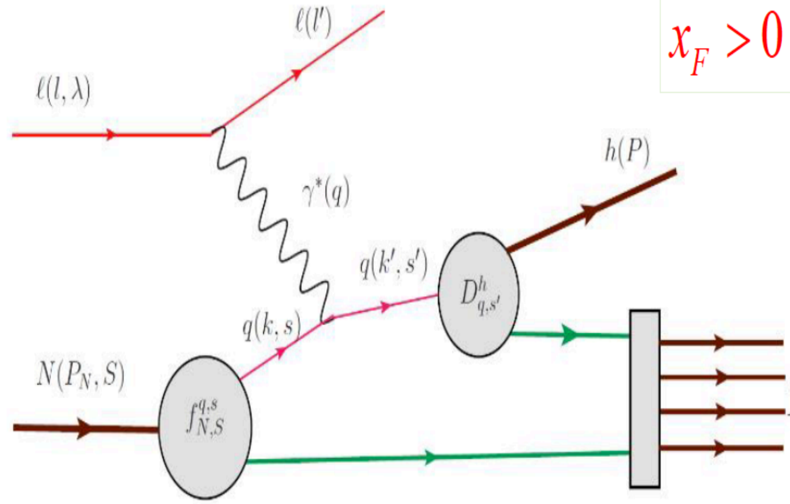
$$\int d^2\vec{k}_T d^2\vec{p}_T \delta^{(2)}(z\vec{k}_T + \vec{p}_T - \vec{P}_T)$$

$Q^2 \gg M_p^2$

$-1 < x_F < 1$



$x_F > 0$



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

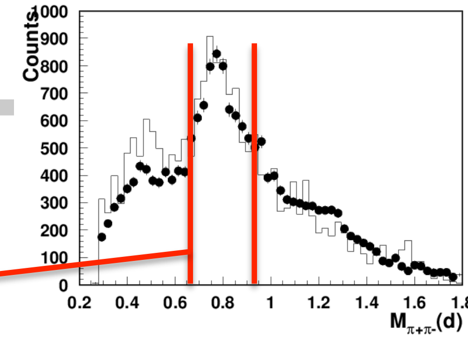
$$H^{q'}_{h/N}\left(x,\mathbf{k}_T,Q^2;x_F,\mathbf{P}^h_T;\mathbf{s}'_q,\mathbf{S}_N\right)$$

Quark Fragmentation Functions
(*universal and independent*)

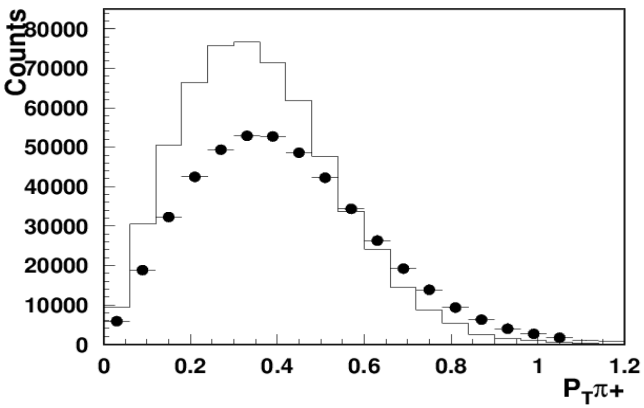
$$D^h_{q,s'}\left(z,\mathbf{p}_T,Q^2\right)$$

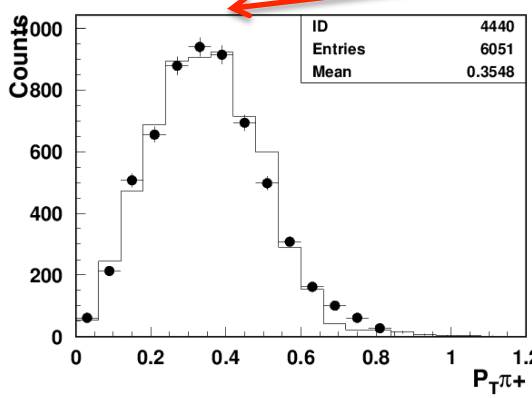
Where this works?

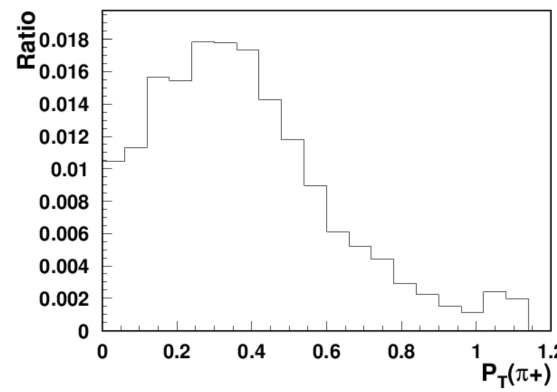
P_T distributions in the rho region

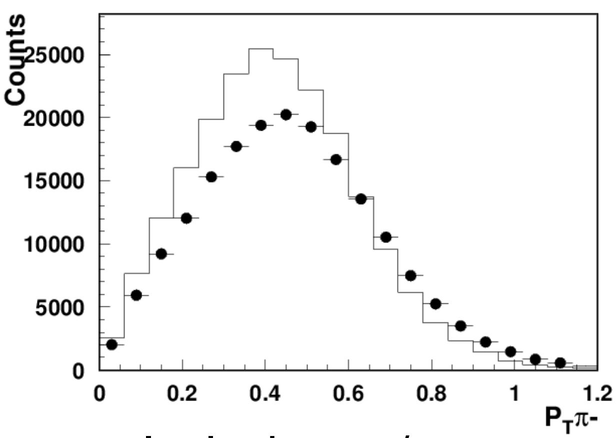


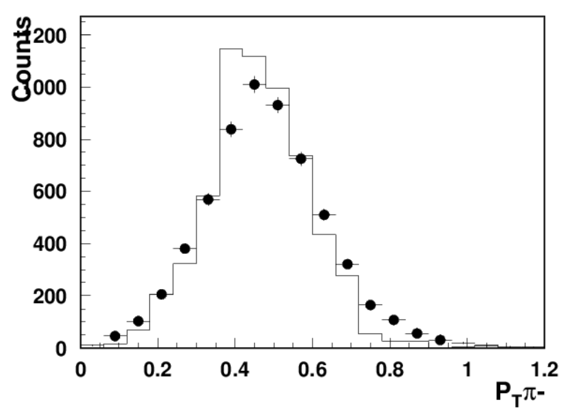
P_T- distributions of pions in the rho region
look like Gaussian

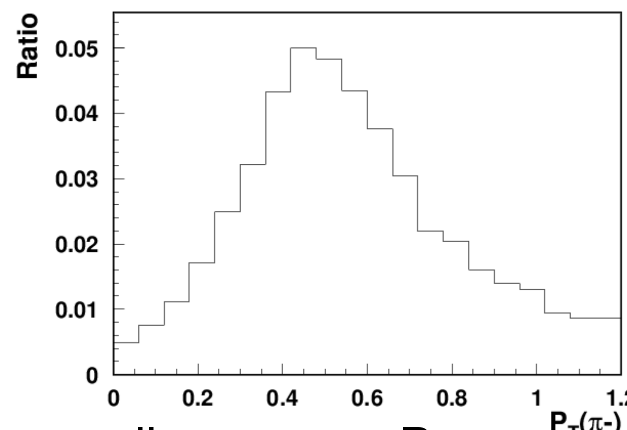








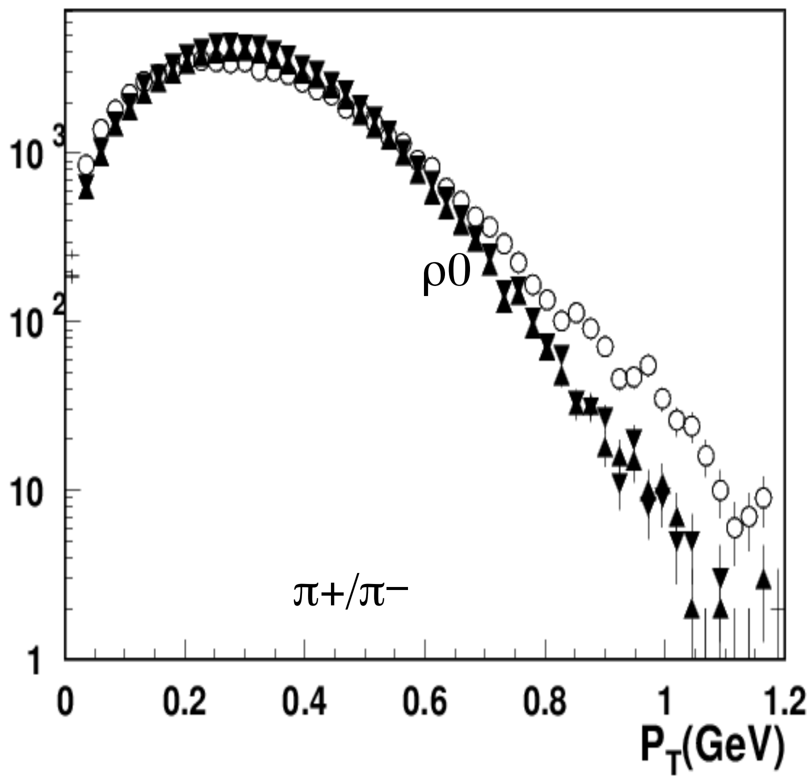


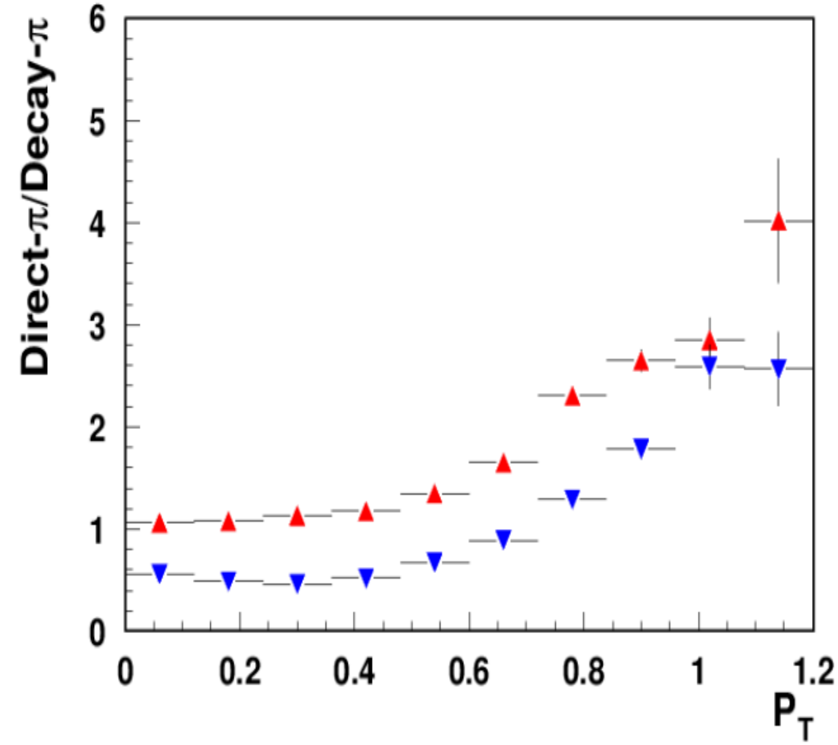


Inclusive $\pi+/\pi-$

$\pi+/\pi-$from ρ-region have smaller average P_T

P_T of pions from rho decays: LUND string fragmentation



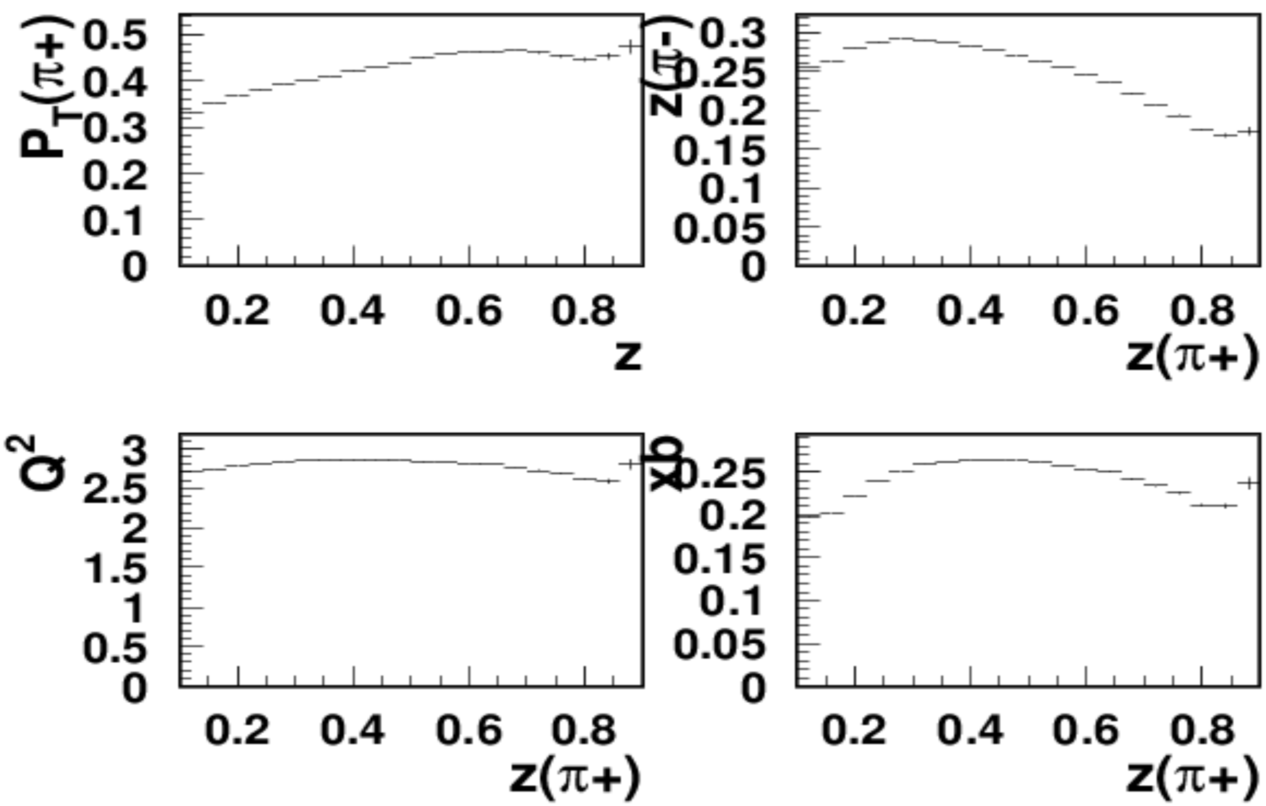


P_T-dependence of rho is similar to the one for decay pions at small P_T

Fraction of direct π+ increases with P_T

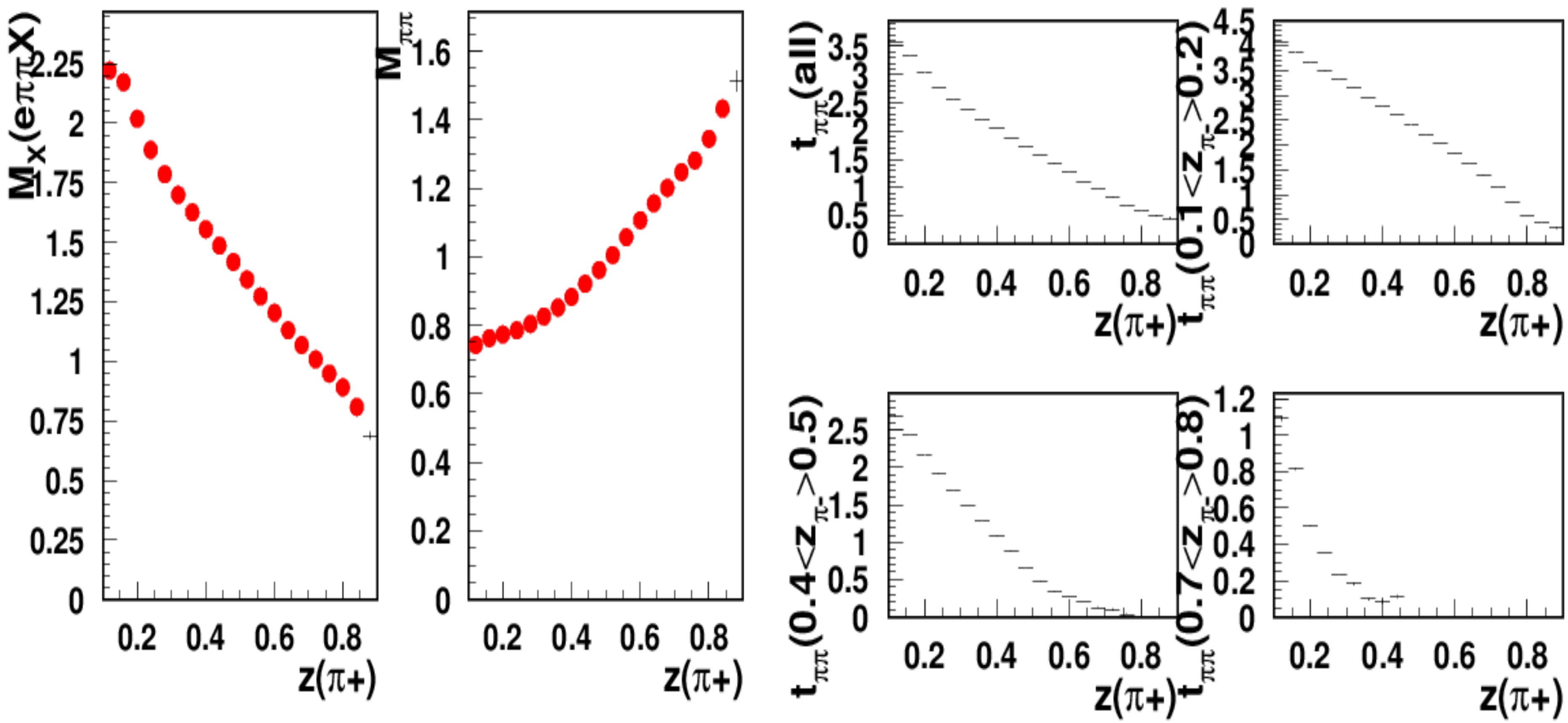
Kinematic correlations in pi+ SIDIS:CLAS12

ep→e'π+X from CLAS12 inbending data
(tight fiducial cuts on e-, EB ID for pions with Eπ>1GeV and angles>10 degree)



Averages of kinematical variables change with z of the pions, but not significantly

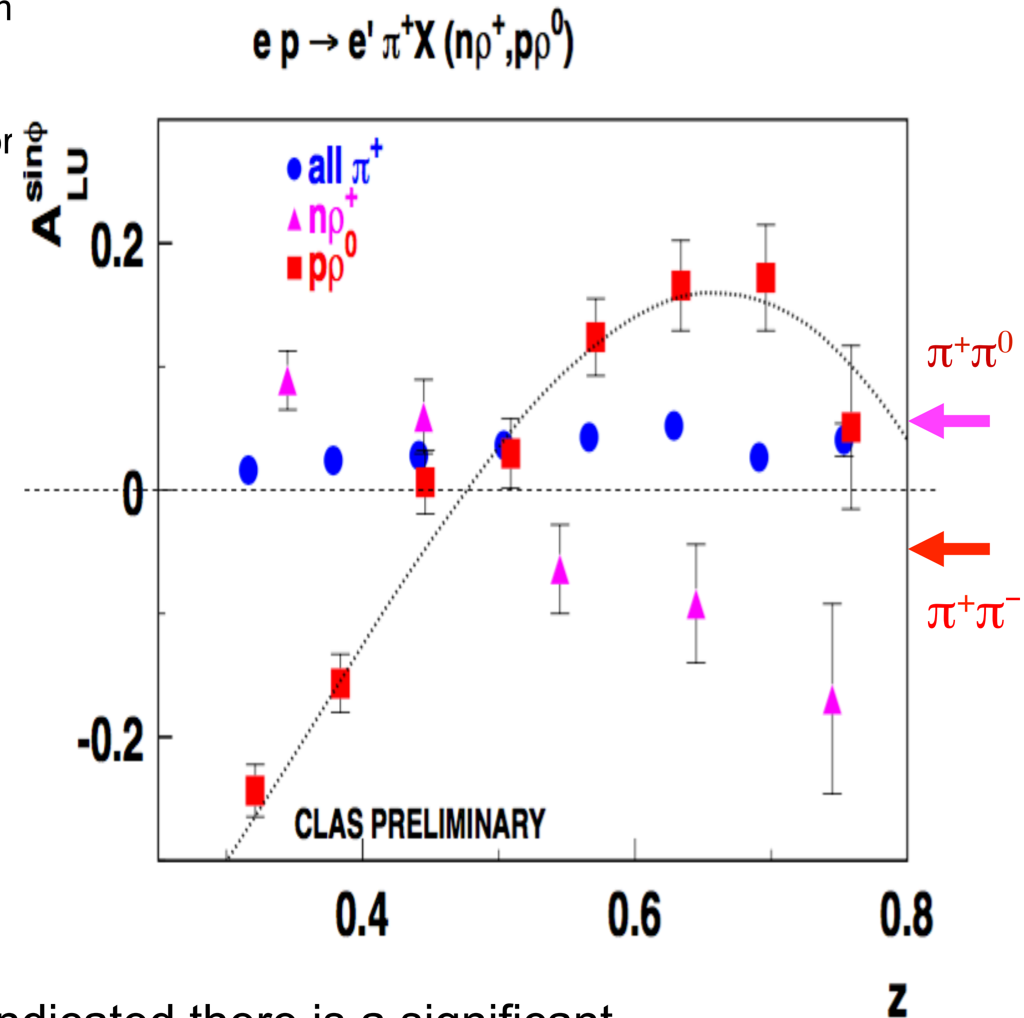
Kinematic correlations in pi+ SIDIS



Averages of missing mass and momentum transfer change significantly with z of the pions

The role of vector mesons and dihadrons in SIDIS

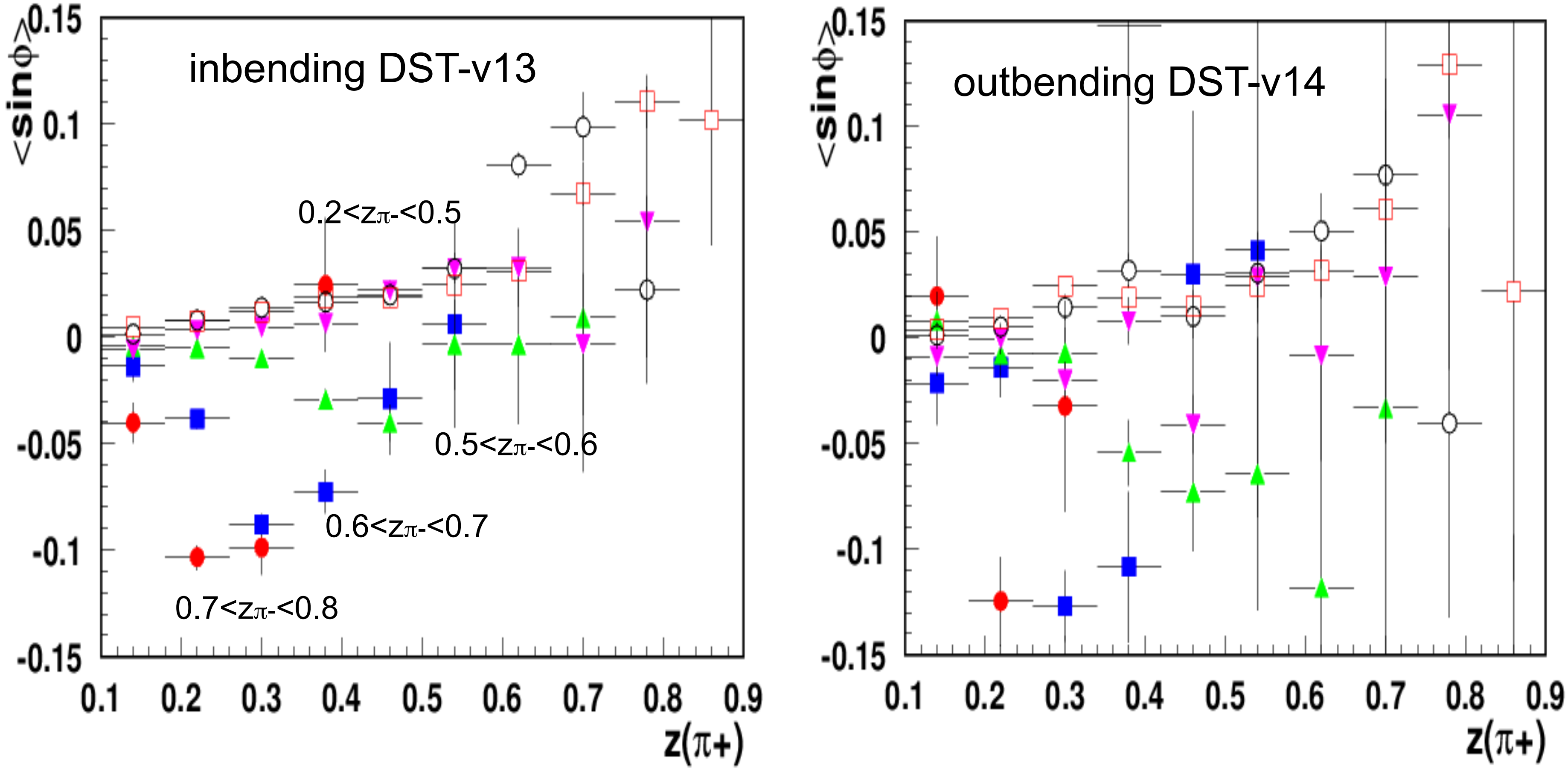
1) Should we worry about pions/kaons coming from vector meson decays?
2) What about $\rho+$ and $\rho-$
3) What do we know about relevant observables for pions specifically coming from vector meson decays
4) How correlated di-hadron affects SSAs in SIDIS (can we measure?)
5) What is radiative correction due to rho?
6) Vector meson as resonance in dihadron production?



Asymmetries more sensitive to the source of particles and can provide important info on the origin of SSA

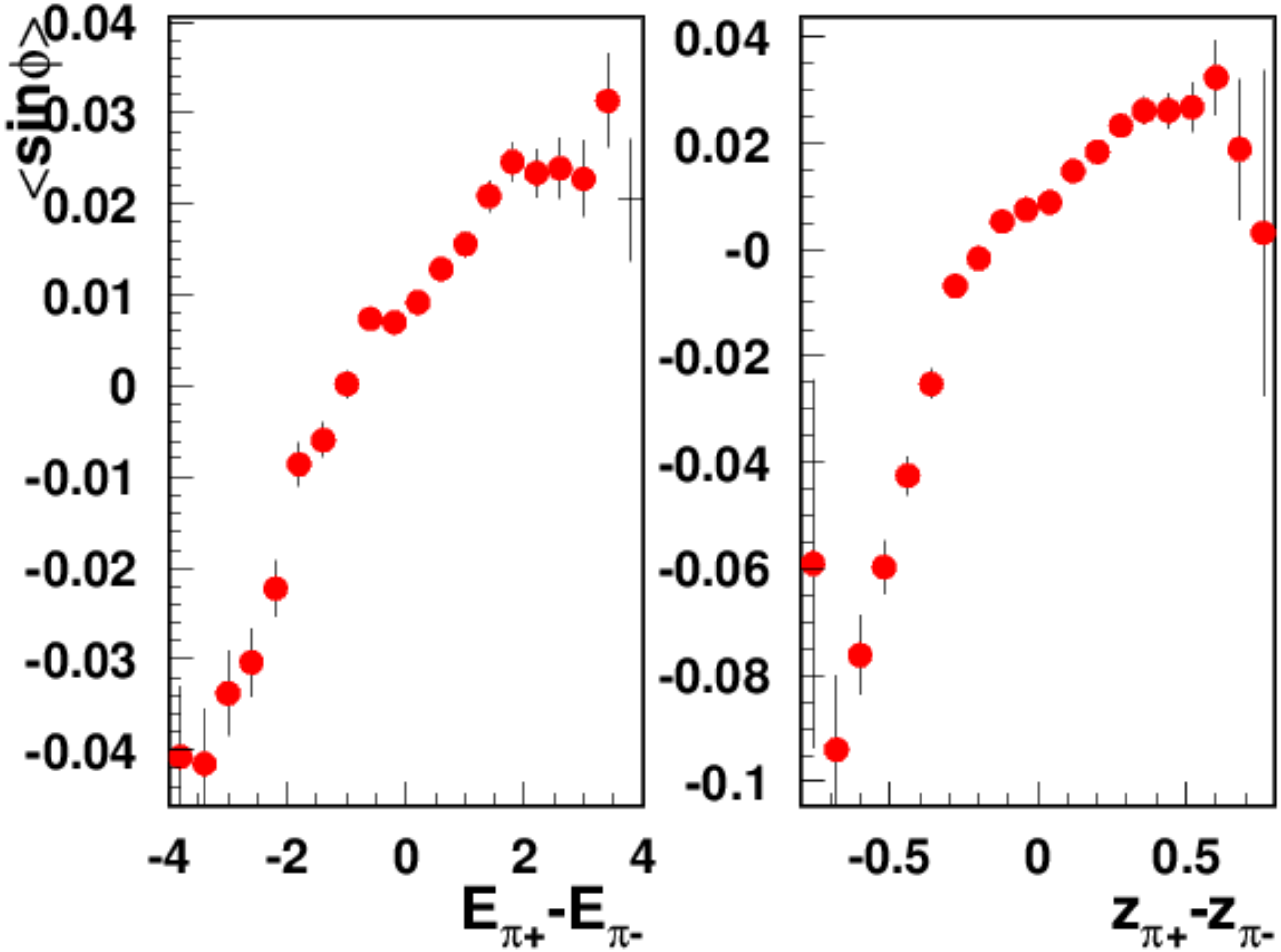
CLAS-6 data indicated there is a significant dependence of SSA on the source of the pion

Disecting the SSA in ep→e'π+X from CLAS12



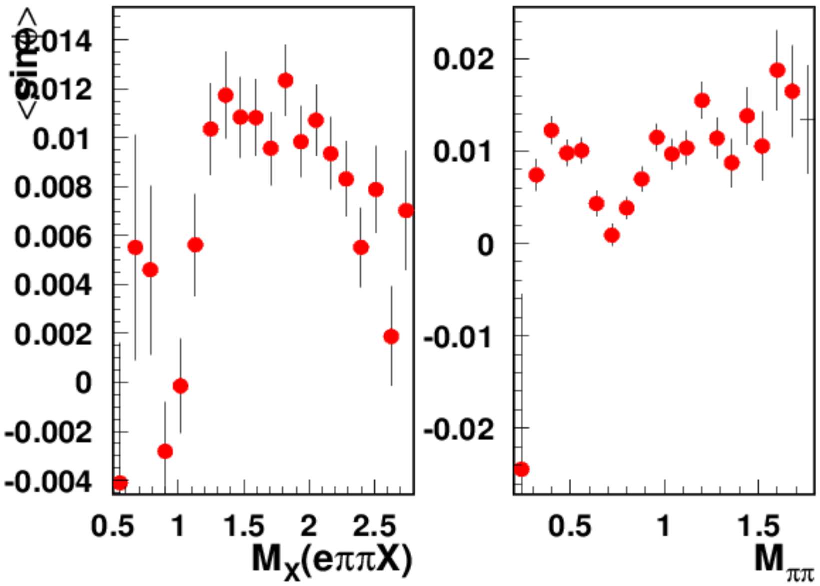
Observed SSA for the inclusive π+ changes significantly with the π- z

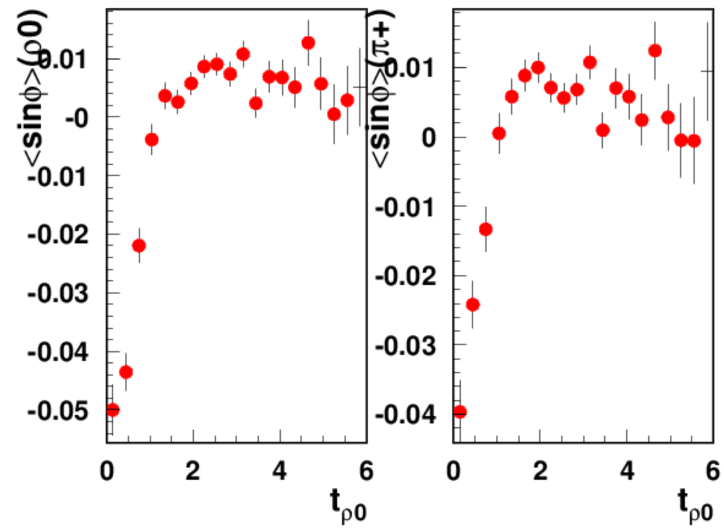
Kinematic correlations in π+ SSA

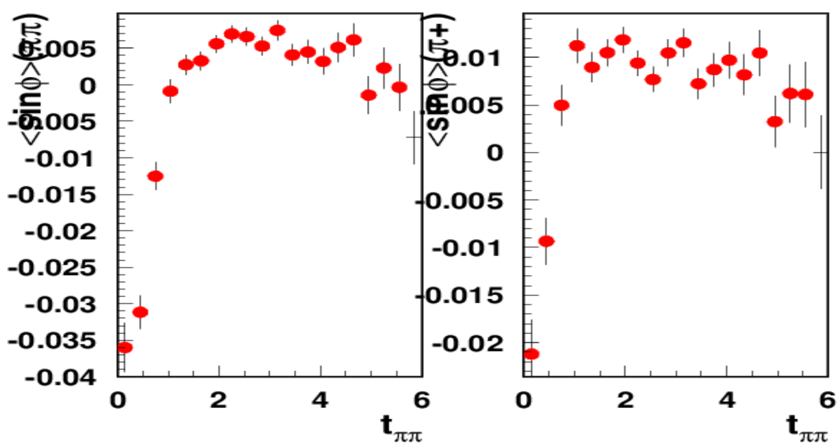


More asymmetric is the di-hadron bigger is the SSA for single pion

Kinematic correlations in π+ SSA







In the rho-region the pion SSA seem to be smallest (need more studies)

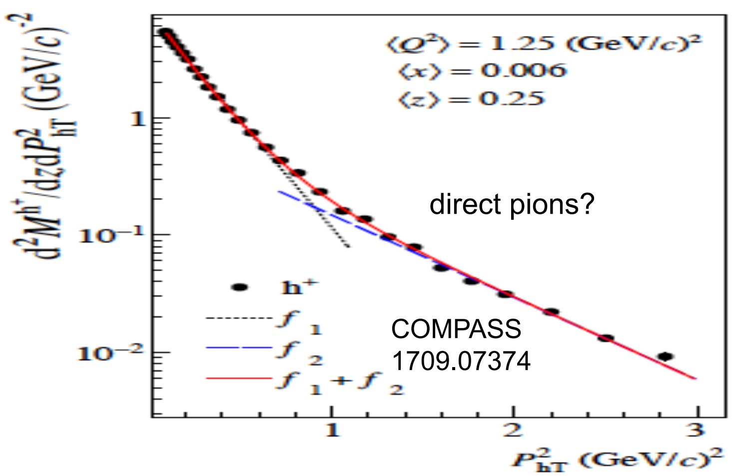
SUMMARY

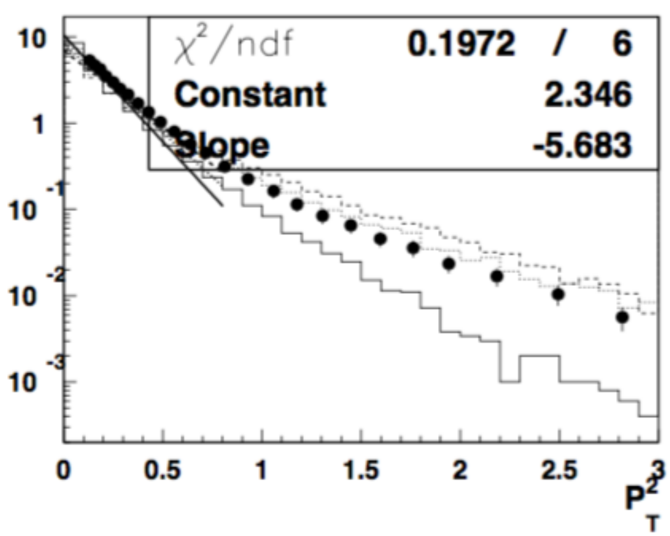
- The CLAS12 data supports predictions from different MCs of very significant fraction of inclusive pions coming from correlated dihadrons.
- Higher fraction of hadrons with spin-1 vs spin-0 in hadronization will have a number of implications
- The observables for pions from rhos have peculiar spin and momentum dependences and may <u>require different RC, modeling, and interpretation</u>
- Understanding of exclusive production of hadrons, in particular, at large t, where they show similar behavior, will be important for SIDIS
- Modeling of spin-orbit correlation will help to understand the dynamics and define the regions where independent fragmentation is most applicable

The interpretation of SIDIS multiplicities and SSAs in single-hadron production and di-hadron production, depends on understanding of contributions to those samples from correlated semi-inclusive and exclusive di-hadrons in general, and rho mesons, in particular.

Support slides

Dihadrons: key to hadronization?



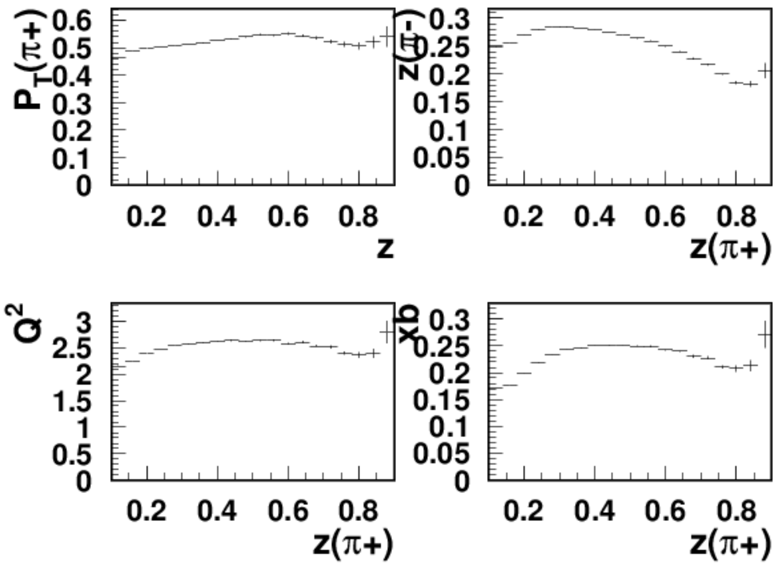


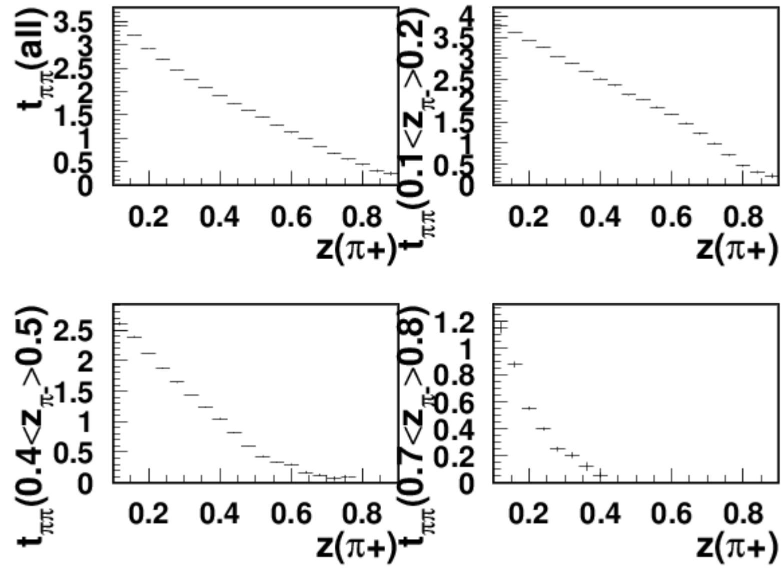
Origin of non-Gaussian tails

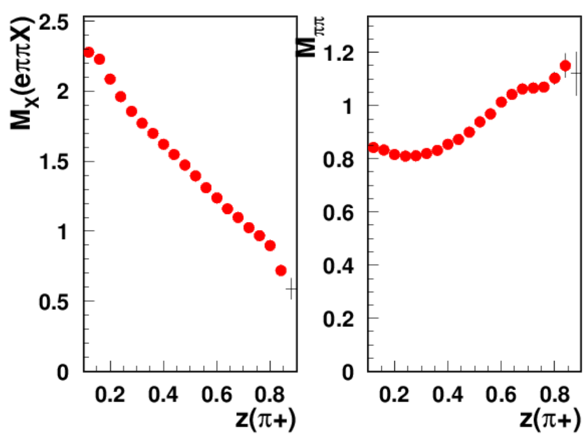
1) the "real" multiplicity may be lower with most hadrons produced from struck quark with large z, and low z fraction filled by VM decay pions
   - intrinsic k_T may be higher
   - the z-dependence enhanced at large z (may be tuned better to describe single and di-hadron distributions)
   - contributions to pions from target fragmentation may be less relevant

2) Combined increase of average transverse momentum and fraction of VMs allows description of non Gaussian tails at large P_T indicating most hadrons come from TMD region

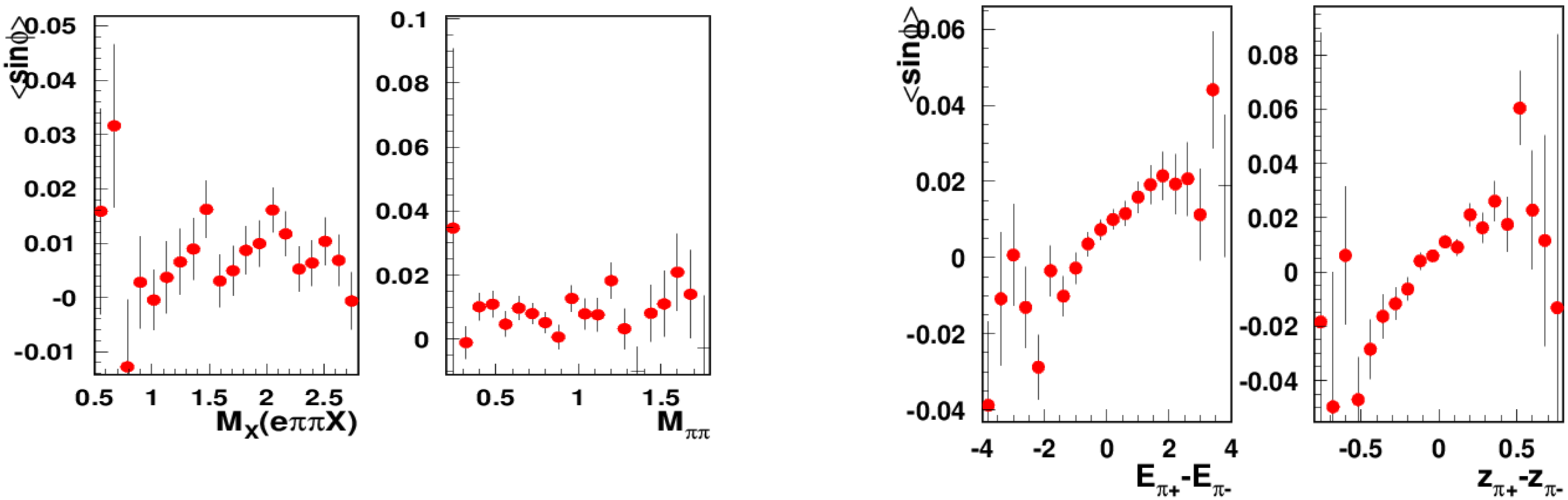
Kinematic correlations in pi+ SIDIS (outbending)



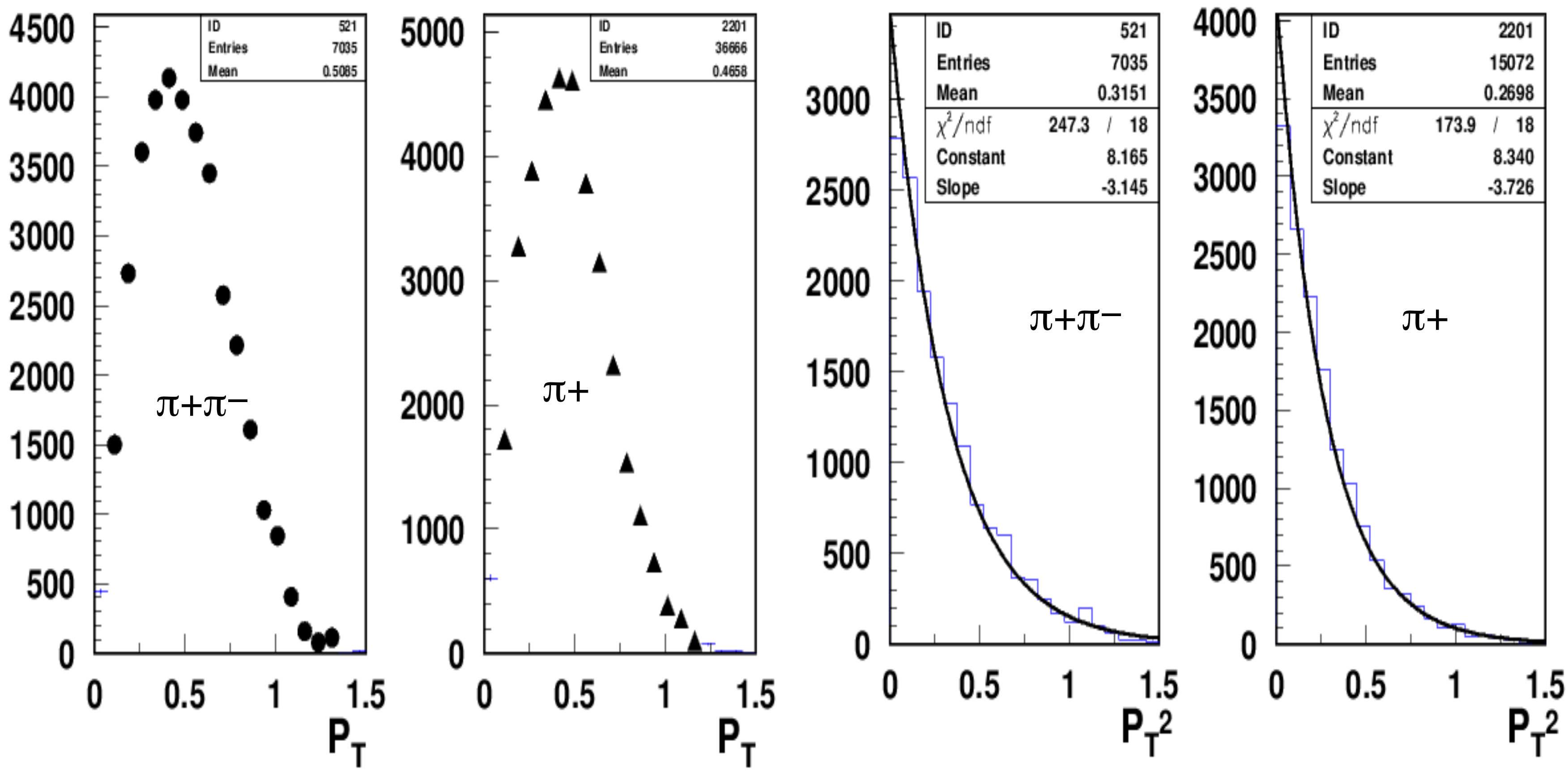




Kinematic correlations in pi+ SSA (outbending)

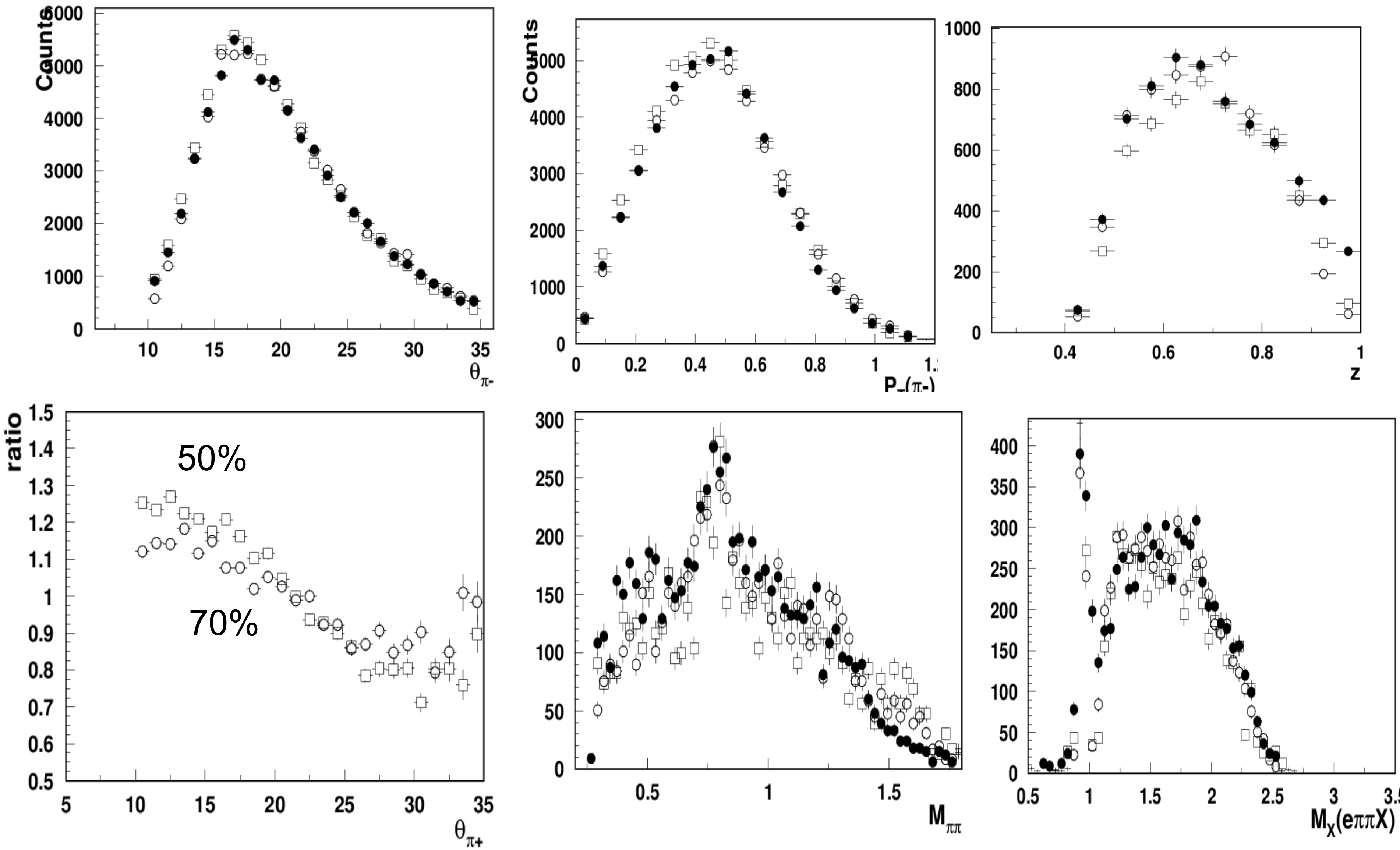


P_T of pions from VM decays: CLAS12 data



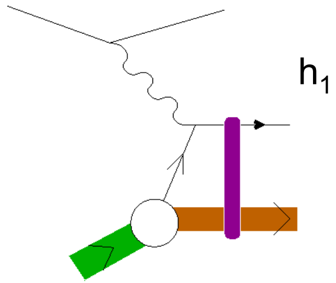
For the same average value of z, $\pi+\pi-$ pair has a wider P_T-distribution

compare different distributions: 70% vs 50%

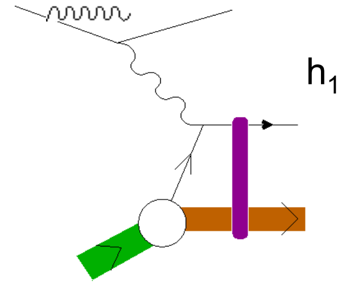


Sources of inclusive hadron electro-production

single hadron in CFR

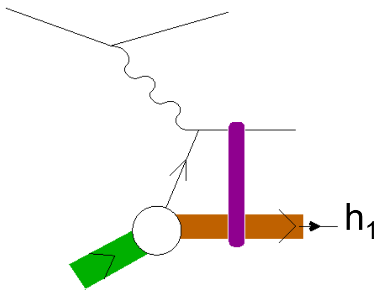


with additional radiation
single hadron in CFR

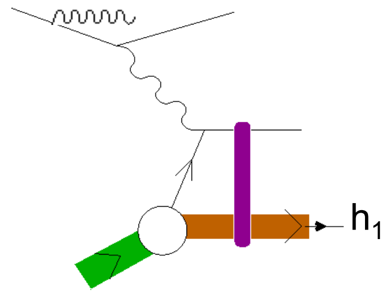


Does it matter what is the source of the single hadron, and if yes, where?

single hadron in TFR

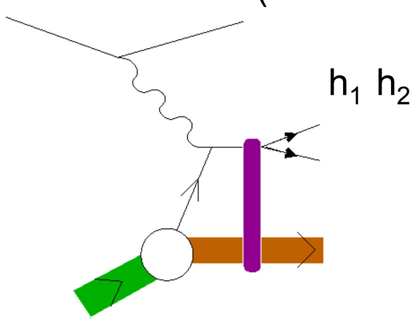


single hadron in TFR

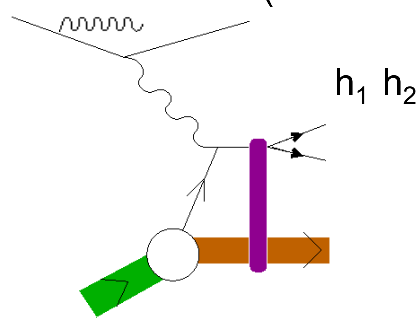


radiation mixes contributions from different structure functions and complicates separation of exclusive from semi-inclusive

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

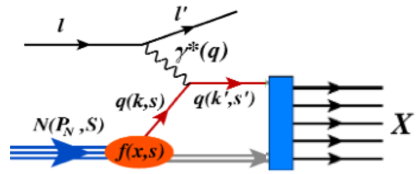


correlated hadrons(dihadron,rho,..) in CFR



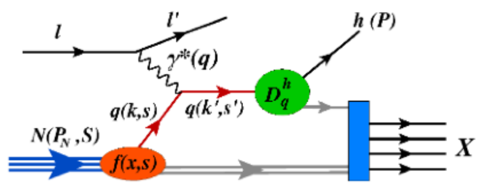
QCD: from testing to understanding

0h DIS



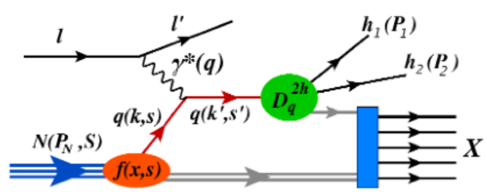
Testing stage:
pQCD predictions, observables in the kinematics where theory predictions are easier to get (higher energies, 1D picture, leading twist, current fragmentation, IMF)

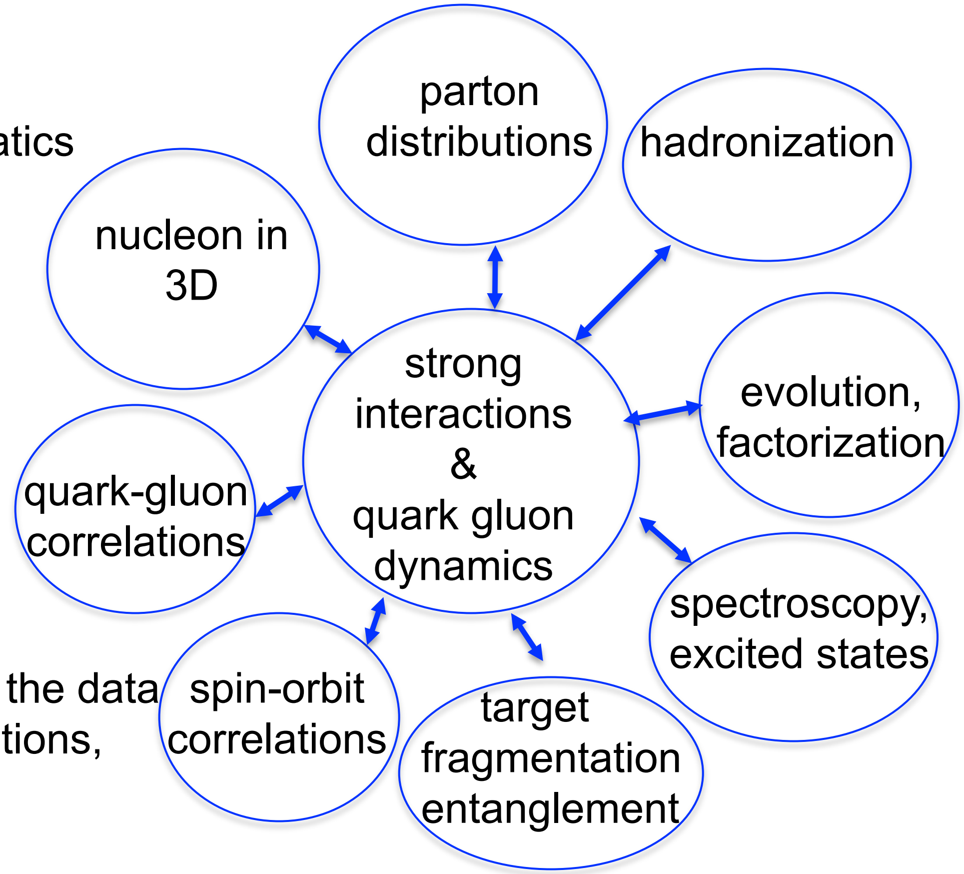
1h SIDIS/DVMP



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)

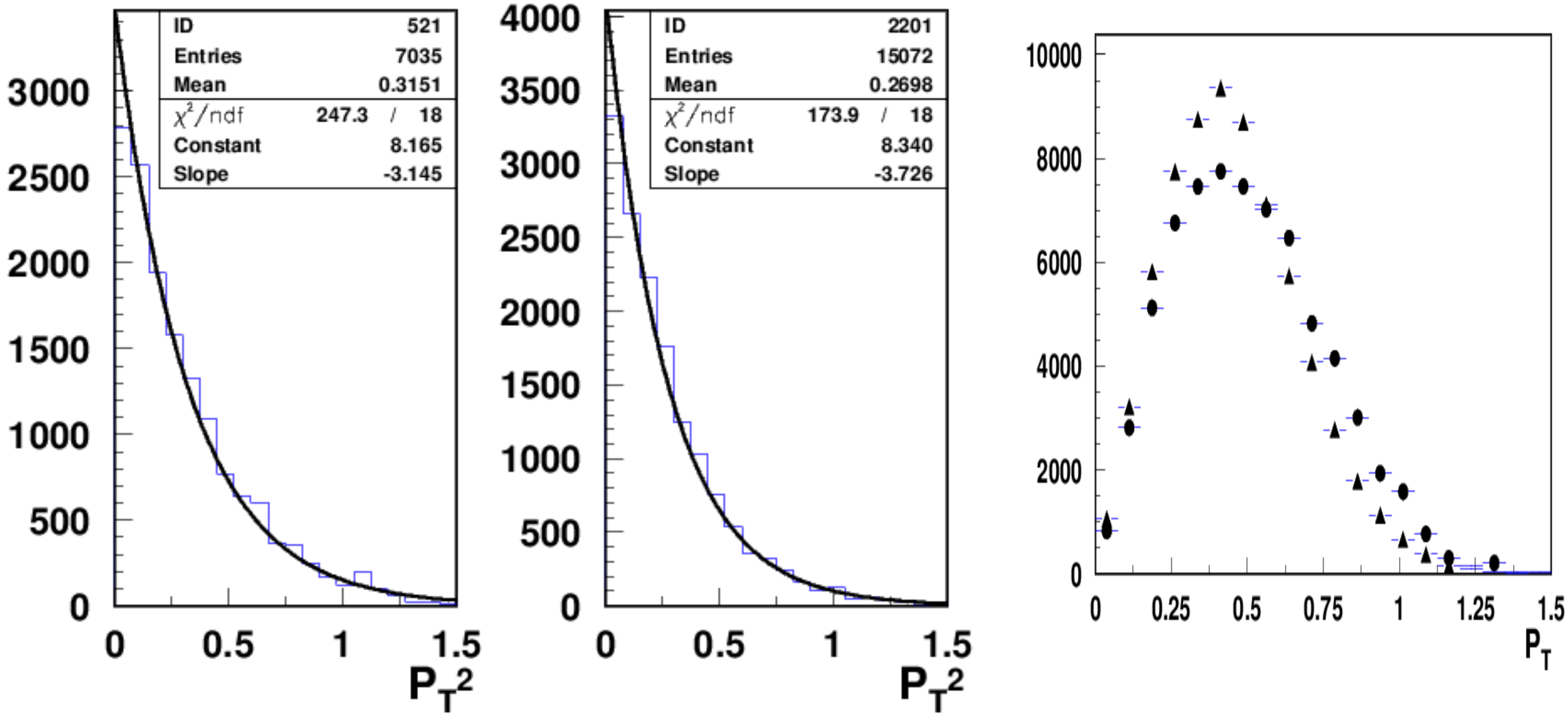
2h SIDIS/DVMP





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

P_T-widths



For the same <z> rho (pi+pi-) is wider than pi+

Quark flavours and transverse momenta in PYTHIA

field energy between them can be transformed into the sum of the two transverse masses $\mathbf{m}_T$. quarks created in one point and then tunnel out to the classically allowed region. The probability is given by

$$\exp\left(-\frac{\pi m_\perp^2}{\kappa}\right) = \exp\left(-\frac{\pi m^2}{\kappa}\right)\exp\left(-\frac{\pi p_\perp^2}{\kappa}\right)$$

the string tension $\kappa \approx 1\ \mathrm{GeV/fm} \approx 0.2\ \mathrm{GeV}^2$

The factorization of the transverse momentum and the mass terms leads to a flavour independent Gaussian spectrum for the **p**x and **p**y

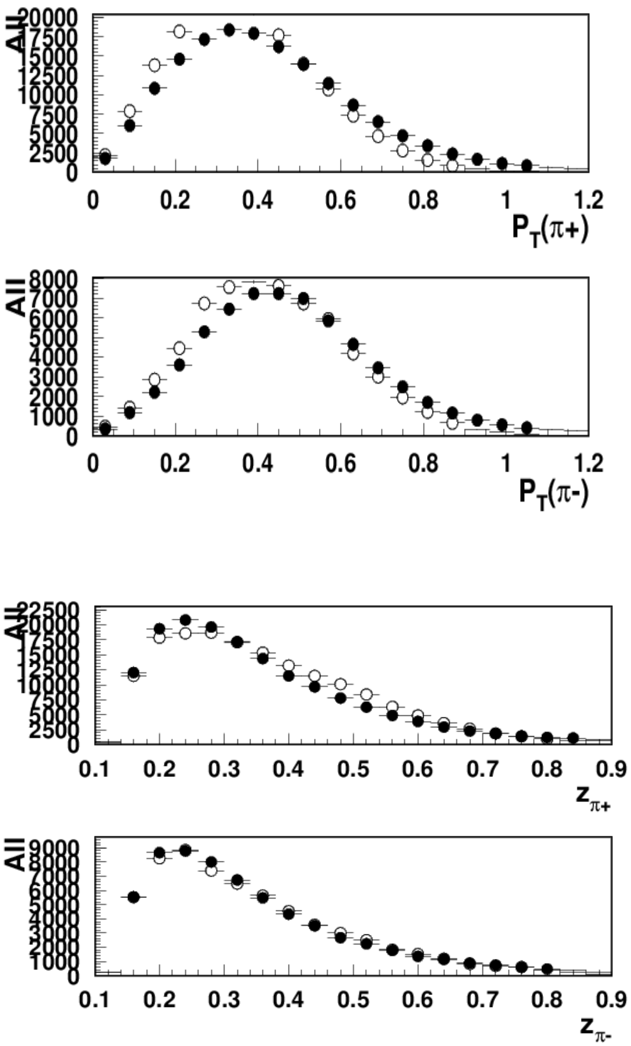
The **p**T of a meson $q_{i-1}\,q_i$ is given by the vector sum of the **p**T's of the q_{i-1} and q_i constituents, which implies Gaussians in $\mathbf{p}_x$ and $\mathbf{p}_y$ with a width \sqrt(2) that of the quarks themselves

flavor dependence u : d : s : c → 1 : 1 : 0.3 : 10^{-11}

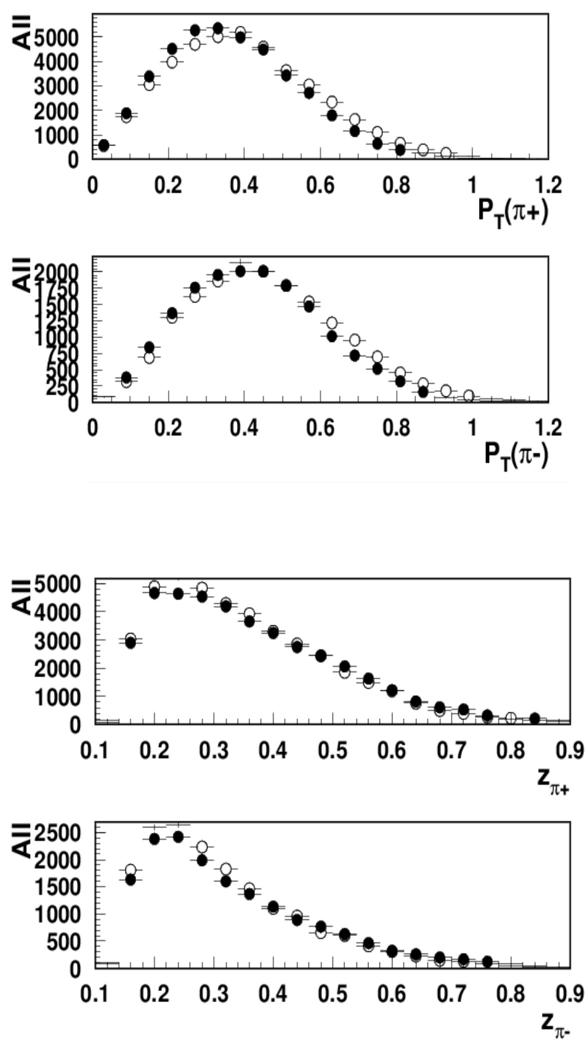
Spin counting arguments would then suggest a 3:1 mixture between the lowest lying vector and pseudoscalar multiplets. Wave function overlap arguments lead to a relative enhancement of the lighter pseudoscalar states

comparing clas12 data with MC

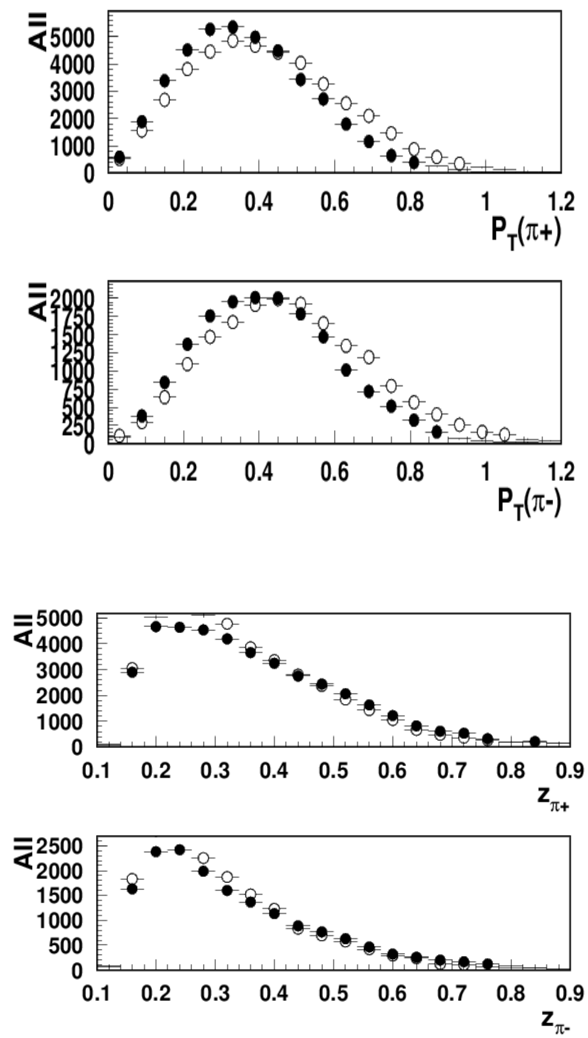
data vs parj41=0.3/parj21=0.4



parj21=0.4 parj41=0.3 vs parj21=0.5parj41=1.2



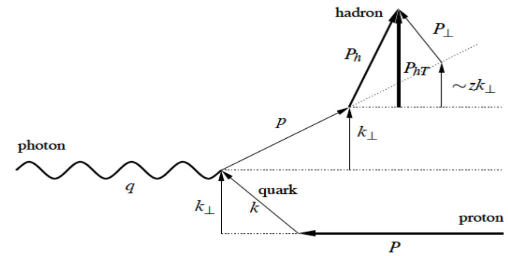
parj21=0.4 parj41=0.3 vs parj21=0.6, parj41=2.0

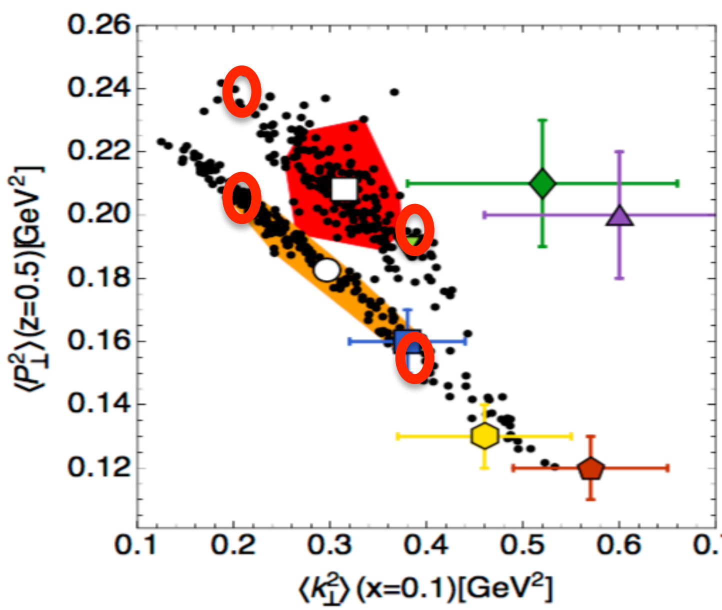


Extracting the average transverse momenta

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

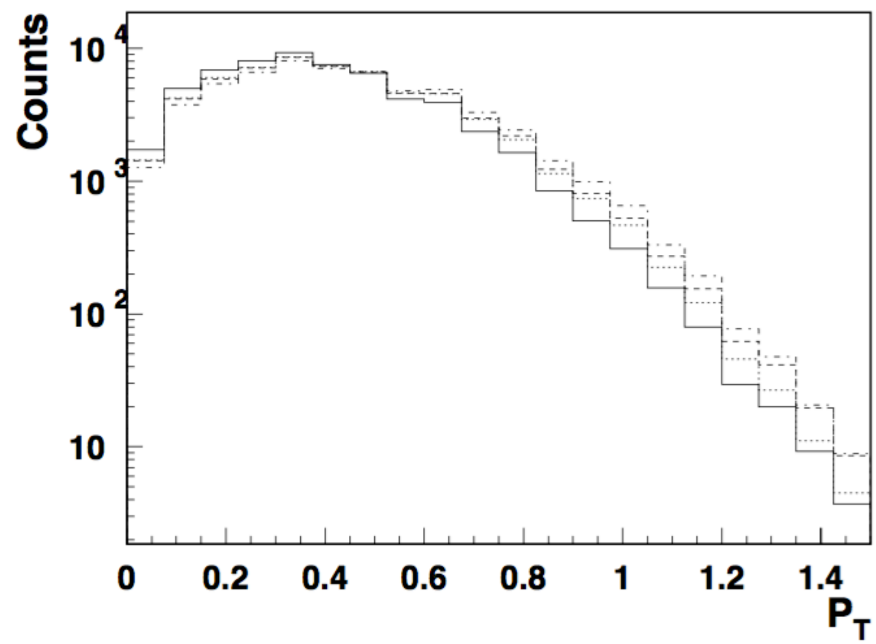
$$F_{UU,T}(x,z,P_{hT}^2,Q^2) = \sum_a \mathcal{H}_{UU,T}^a(Q^2;\mu^2) \int dk_\perp \, dP_\perp \, f_1^a(x,k_\perp^2;\mu^2)\, D_1^{a\to h}(z,P_\perp^2;\mu^2)\, \delta(zk_\perp - P_{hT} + P_\perp) + Y_{UU,T}(Q^2,P_{hT}^2) + \mathcal{O}(M/Q)\,.$$





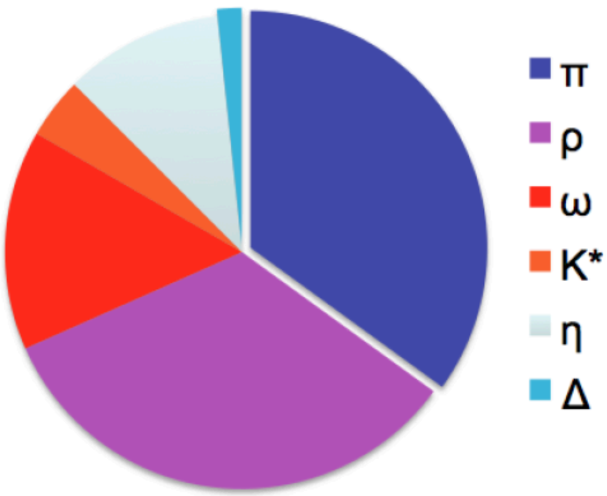
$$m_N^h(x,z,P_{hT}^2) = \frac{\pi}{\sum_a e_a^2 f_1^a(x)} \times \sum_a e_a^2\, f_1^a(x)\, D_1^{a\to h}(z)\, \frac{e^{-P_{hT}^2/\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}}{\pi\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}$$

Sea is not divided to perturbative and non-perturbative



- Extraction very sensitive to input (replicas)
- Most sensitive to parameters is the large P_T region
- Multiplicity alone may not be enough to separate $\langle k_T\rangle$ from average $\langle p_T\rangle$

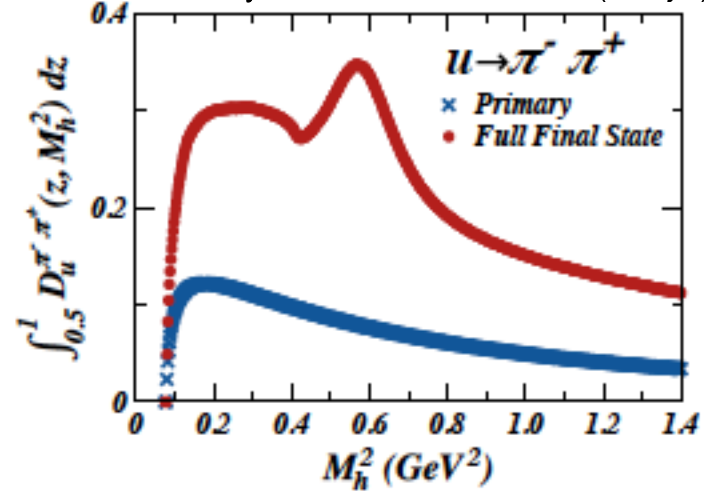
Dihadron production

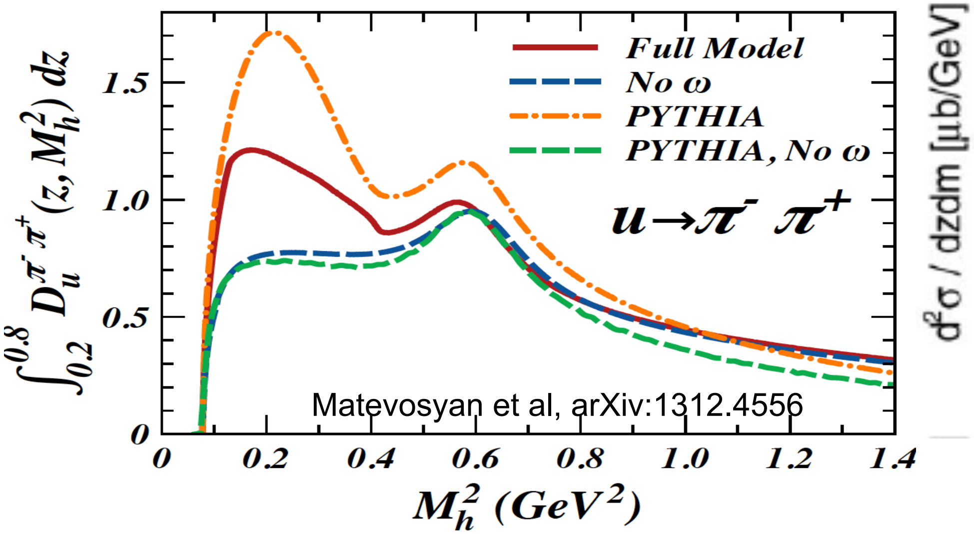


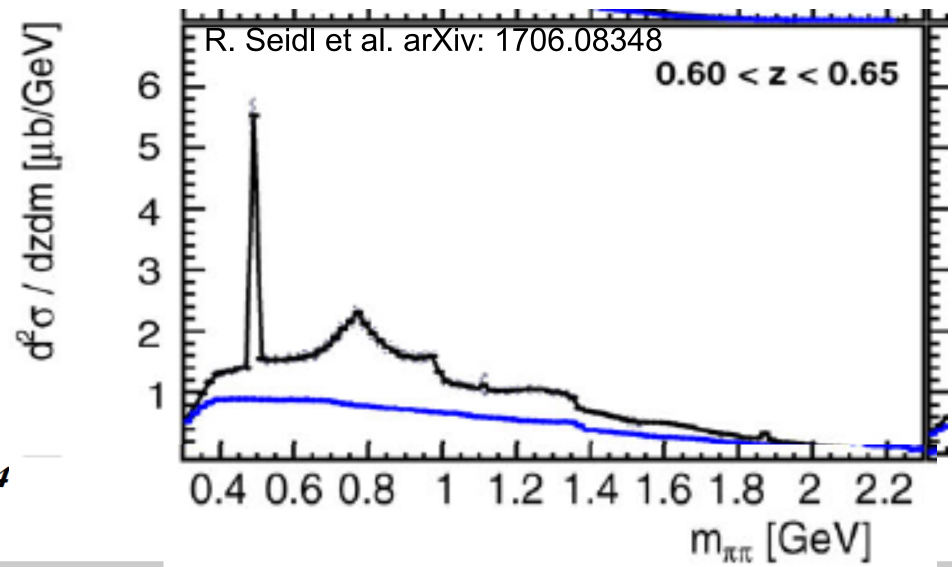
HERMES-note-96.059

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

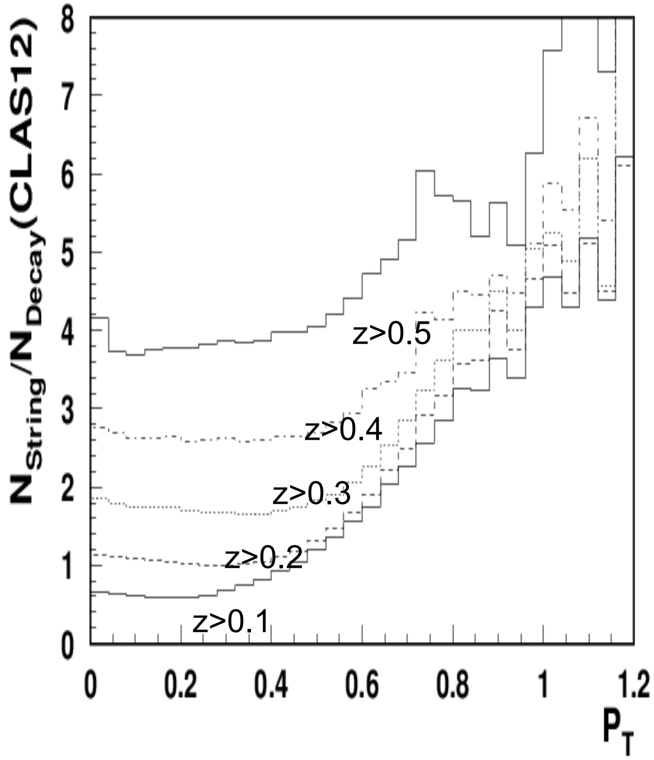
Matevosyan et al arXiv:1307.8125(NJL-jet)

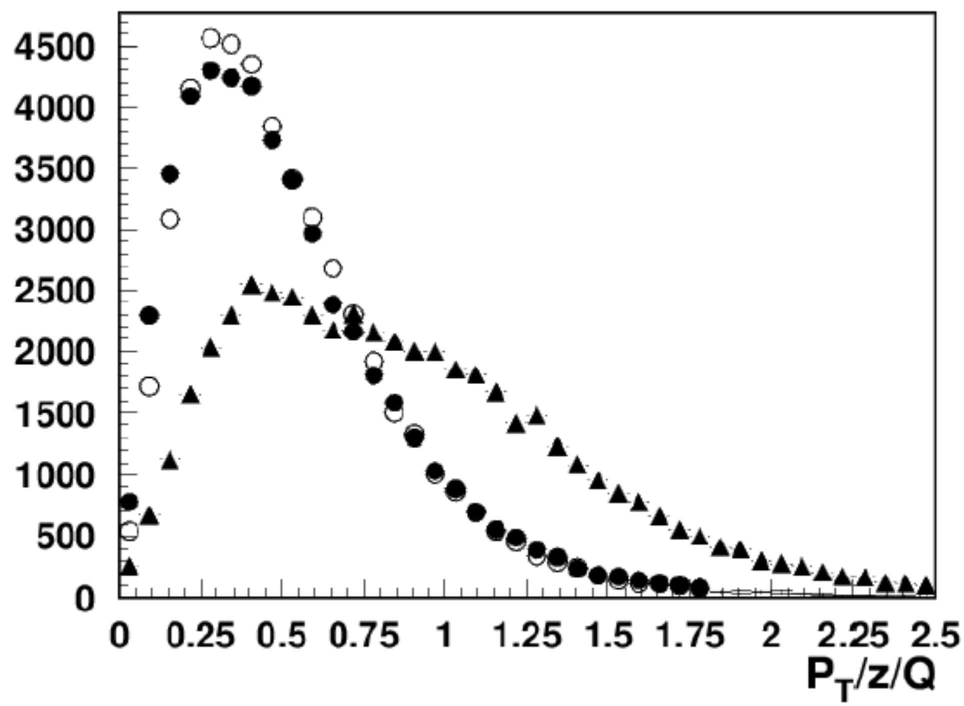






P_T of pions from rho decays: LUND string fragmentation

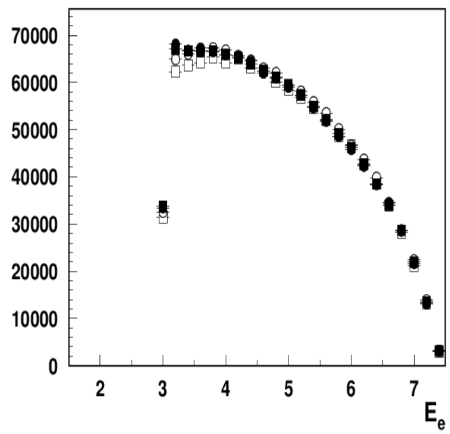


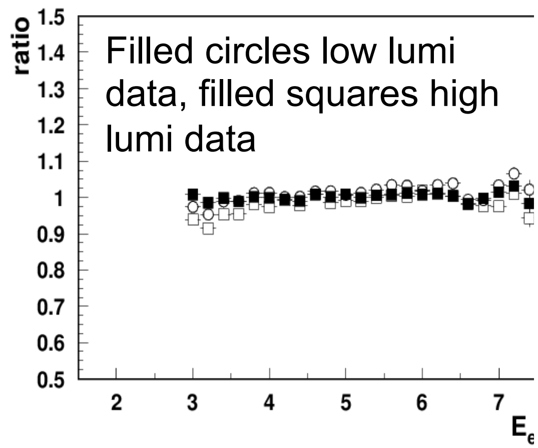


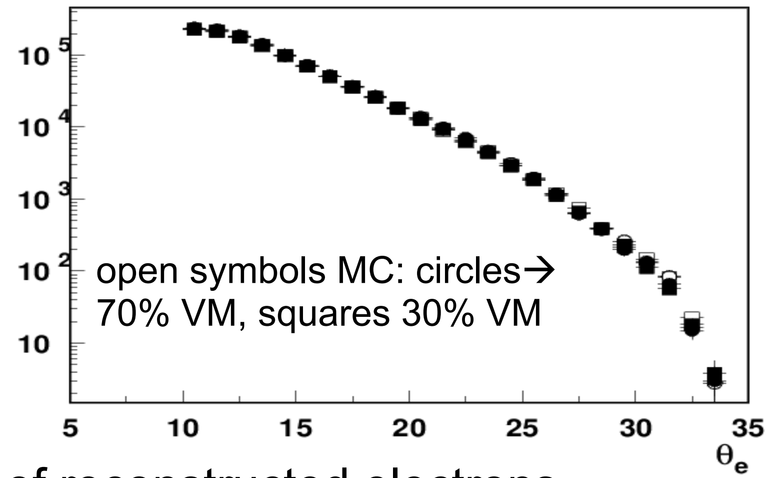
Fraction of direct π+ increases with P_T

Fraction of direct π+ decreases with P_T/z/Q

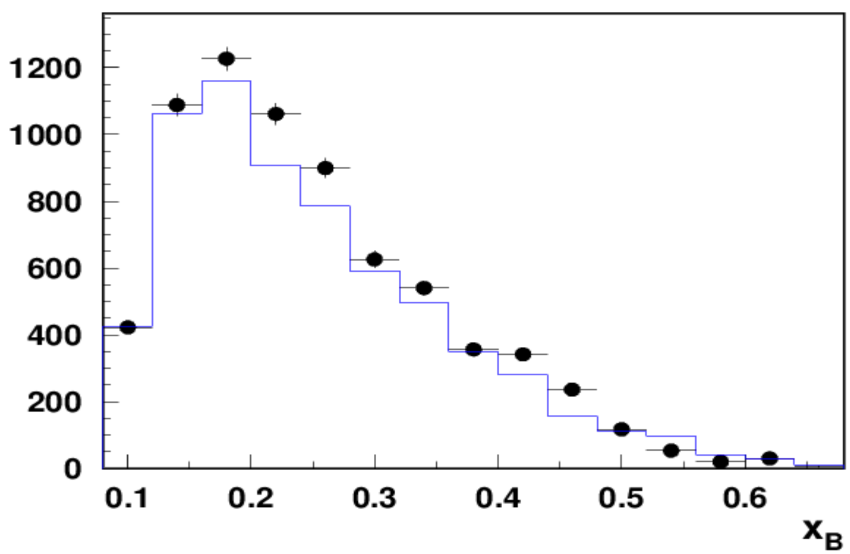
RGA: $ep \rightarrow e'\pi^+\pi^-X$

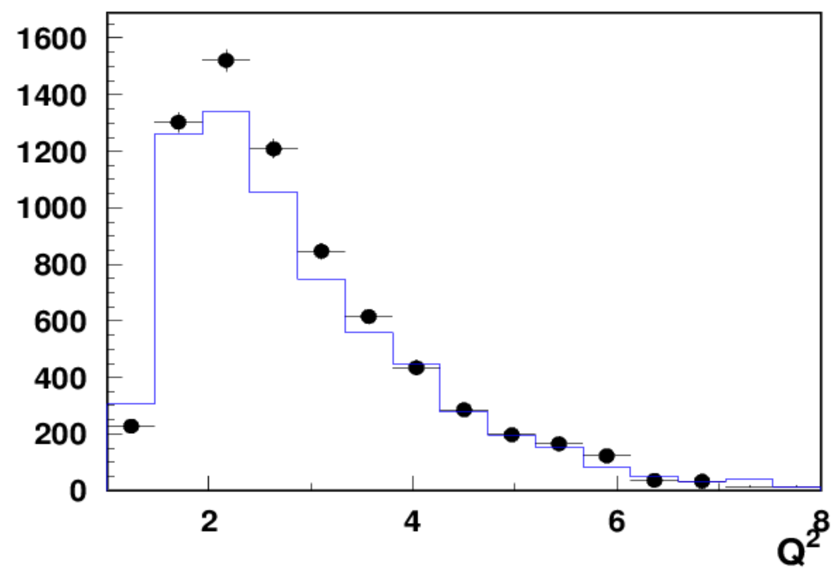






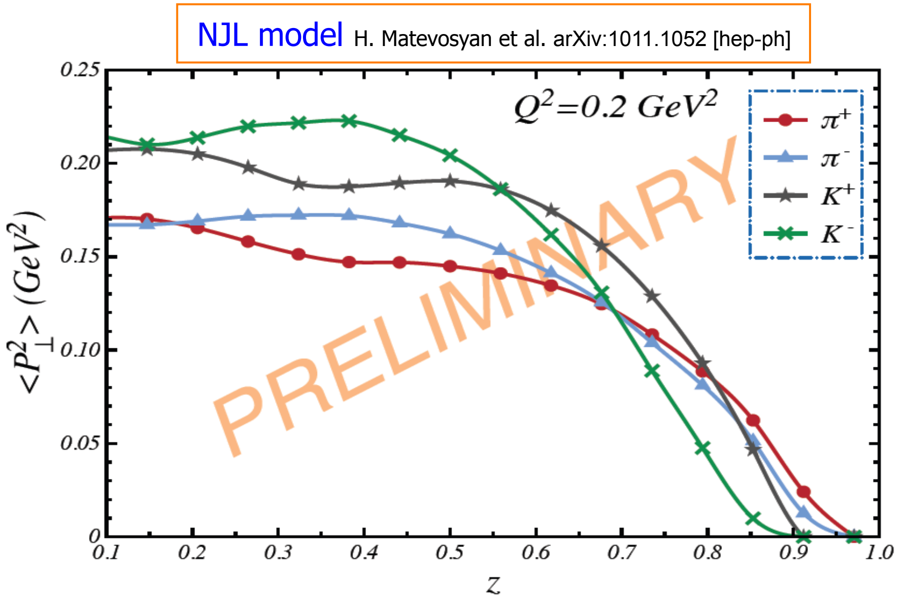
Normalizing all sets to the same number of reconstructed electrons





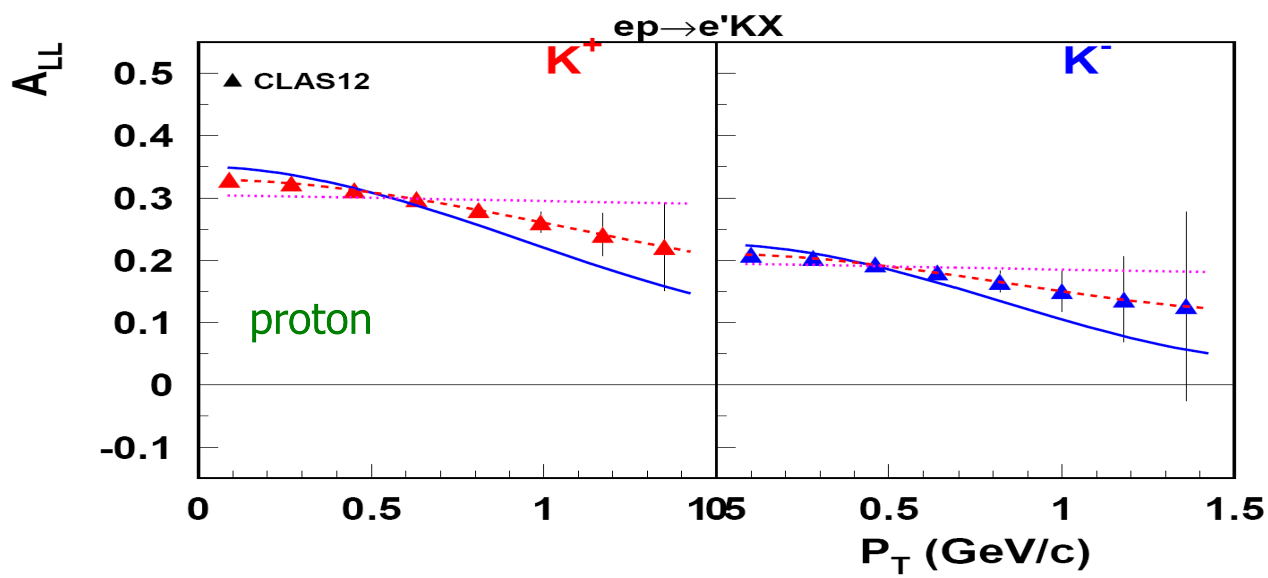
x, Q^2-dependences for $e'\pi^+\pi^-X$ MC (line) in good agreement with low lumi data

Transverse momentum distributions of partons

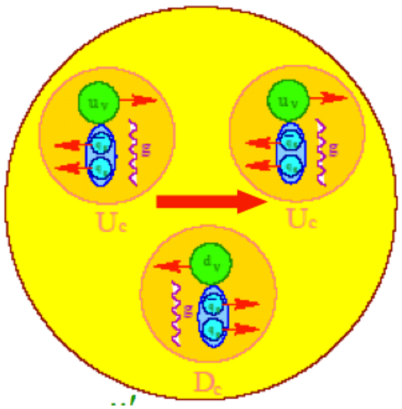


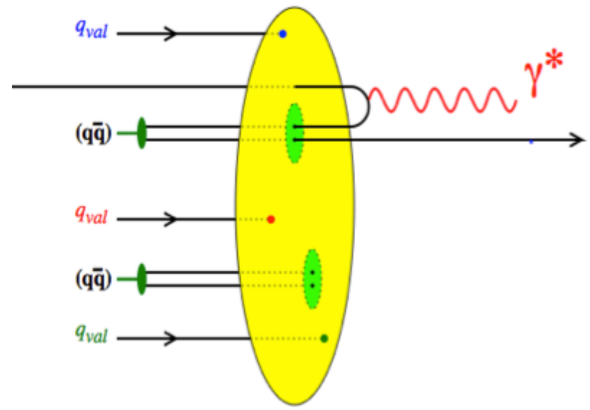
$$\langle P_T^2 \rangle \approx z^2 \langle k_\perp^2 \rangle + \langle p_\perp^2 \rangle$$

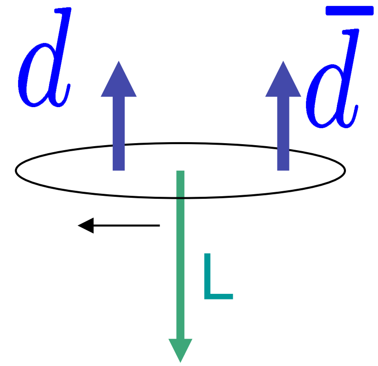
Transverse momentum distributions in hadronization may be flavor dependent => measurements of different final state hadrons required



Correlations between target and current





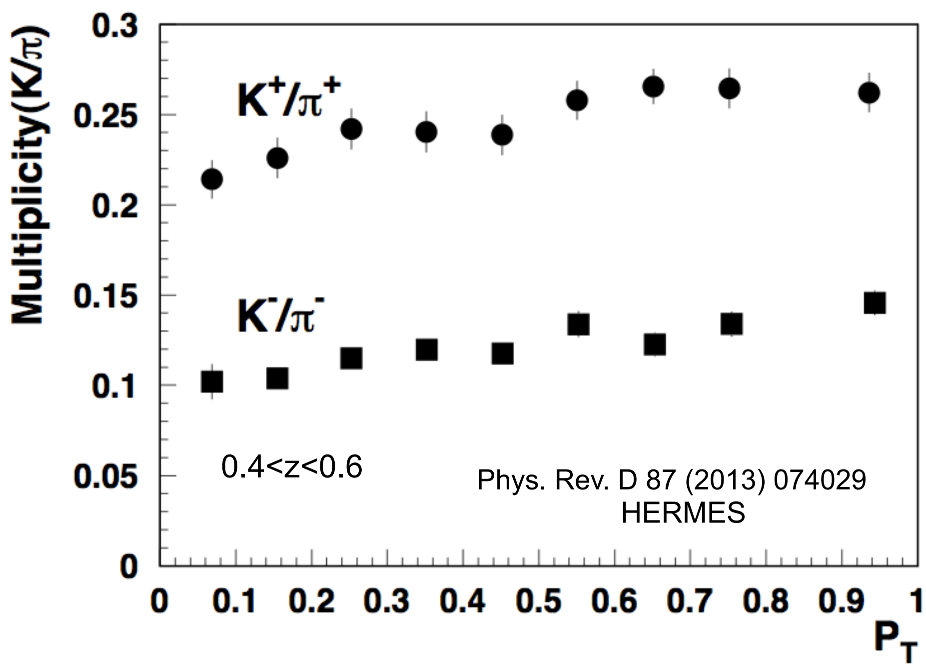


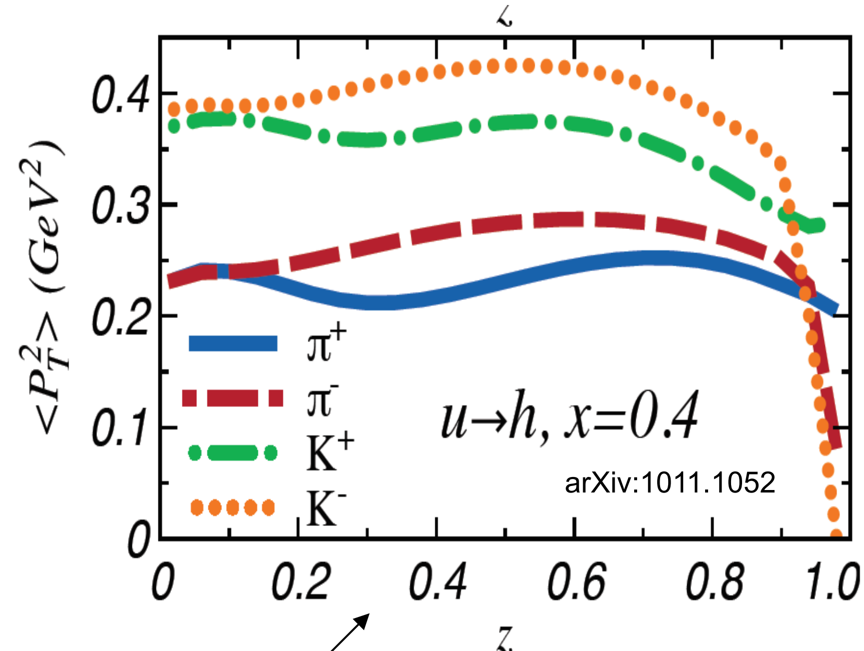
- how the remnant system dresses itself up to become a full-fledged hadron
- correlation with the spin of the target or/and the produced particles

Hadronization effects

$$f_1^q(x,k_T) \otimes D_1^{q\to h}(z,p_T) \quad \begin{matrix} D_1^{u\to\pi^+}(z,p_T) \\ D_1^{u\to K^+}(z,p_T) \end{matrix}$$

•Widths of fragmentation functions are flavor dependent. (H. Matevosyan, A. W. Thomas & W. Bentz)





Assuming u-quark dominance the increase with P_T of the fraction of kaons in the final hadron sample is consistent with wider $D_1^{u\text{->}K}$

Study of kaon multiplicities in SIDIS is crucial for understanding of spin-orbit effects in hadronization