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Factorization and Transverse Momentum in SIDIS at JLab

Peter BOSTED
Thomas Jefferson National Accelerator Facility
M/S 12H
12000 Jefferson Avenue
Newport News, VA 23606
U.S.A.

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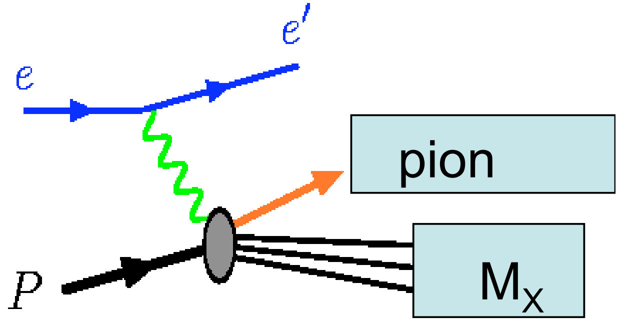
P. Bosted (JLab)

Fifth International Conference on Perspectives in Hadronic Physics
Trieste, Italy, May 2006

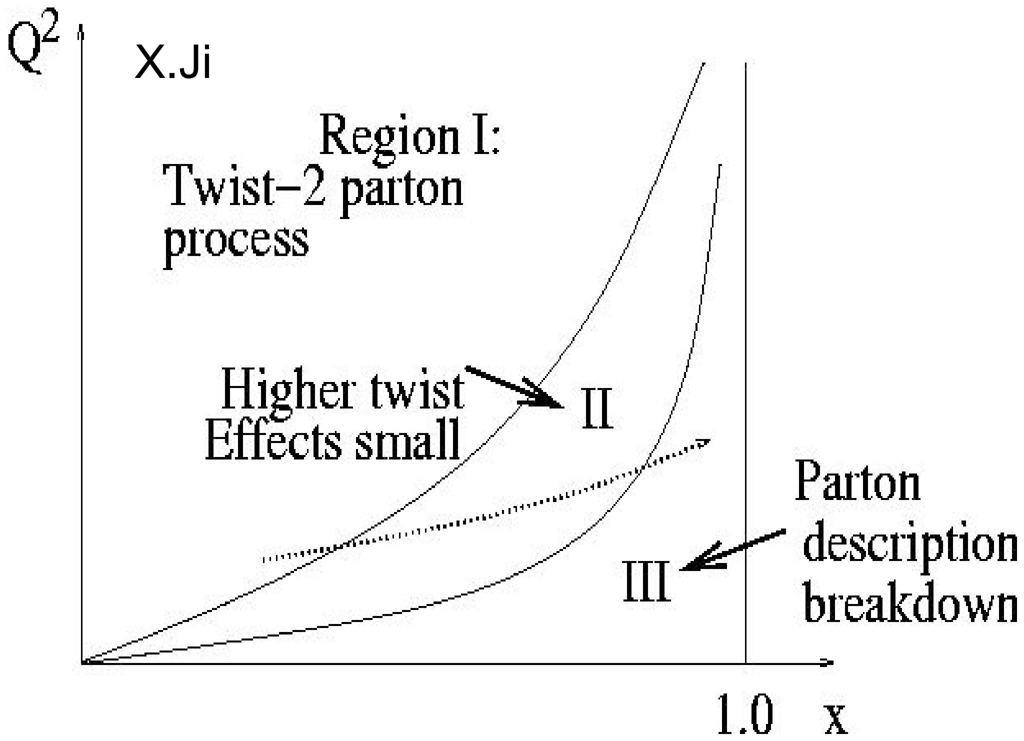
- **Semi-inclusive processes**
- **Factorization as a test of quark-hadron duality**
- **Factorization tests in unpolarized SIDIS**
- **Facorization tests in polarized SIDIS**
- **Tranverse momentum in fragmentation**

Semi-inclusive DIS



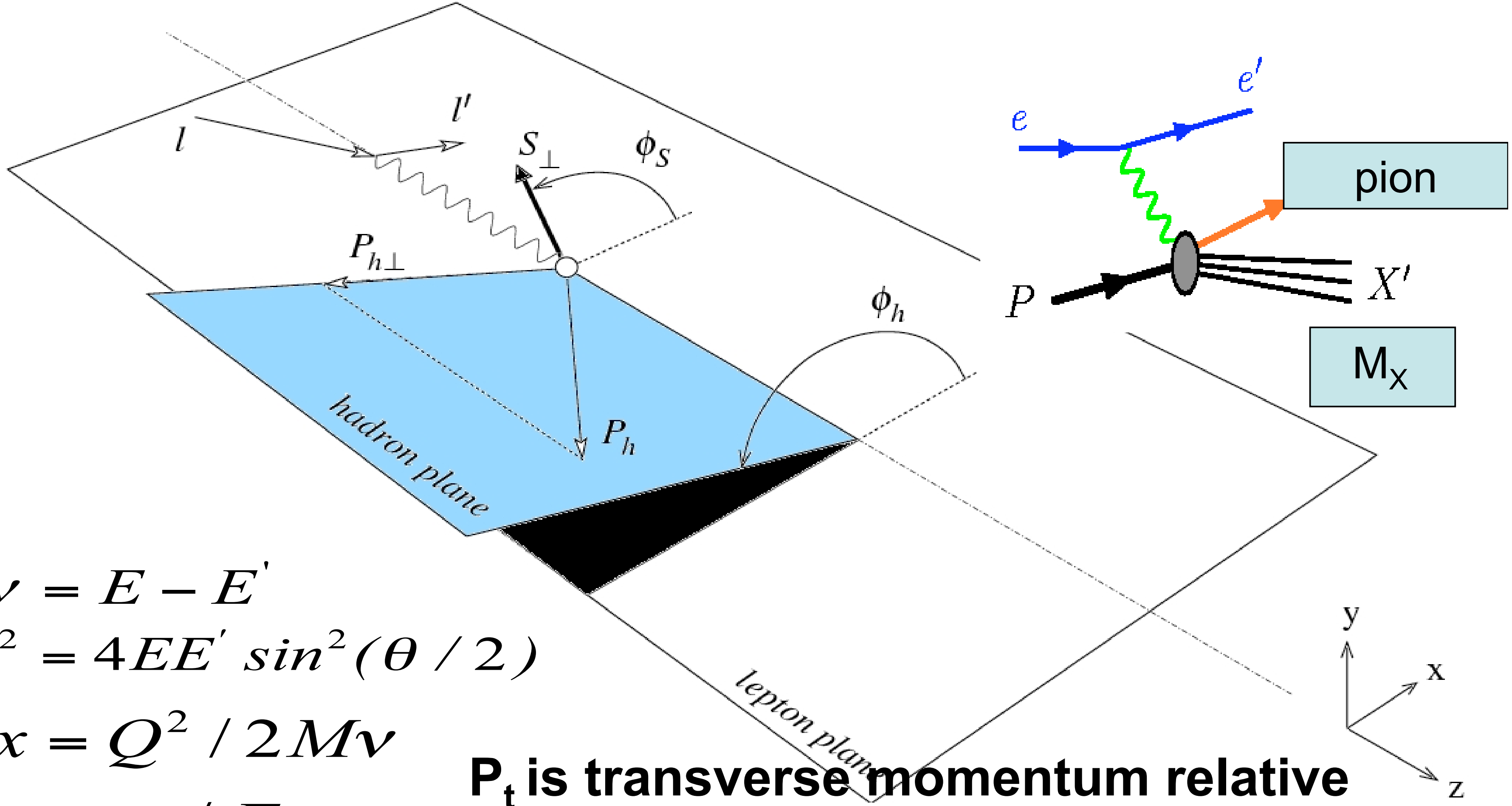
Main focus of SIDIS studies:

- **orbital motion of quarks (p_t, ϕ dependence)**
- **parton distributions (separate valence, sea)**



- **Where region I/II boundary?**
- **Can useful information come from Region II?**

SIDIS kinematic plane and relevant variables



$$\nu = E - E'$$

$$Q^2 = 4EE' \sin^2(\theta/2)$$

$$x = Q^2 / 2M\nu$$

$$y = \nu / E$$

$$z = E_h / \nu$$

P_t is transverse momentum relative to virtual photon

$W^2=M^2+Q^2(1/x-1)$ is invariant mass of total hadronic final state

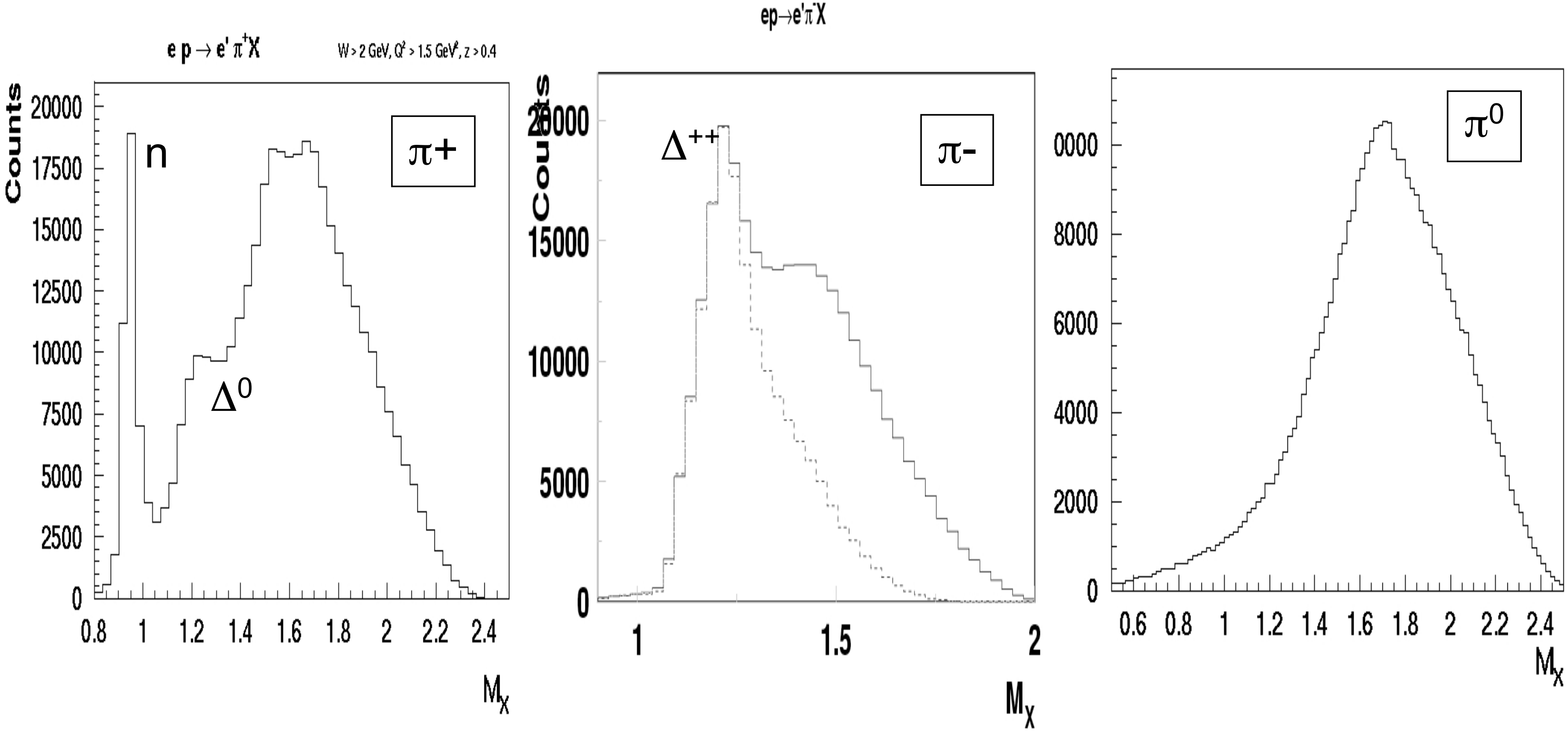
Factorzation

Basic idea: hit a single quark in nucleon which then hadronizes into a jet with negligible interaction with remenant quarks.

Factorzation

Cross sections factorize into product of parton distribution functions (depend on x and p_t) (i.e. $u(x,p_t)$, $d(x,p_t)$) and current fragmentation functions (depend on z and p_t) (i.e. $D^+(z,p_t)$, $D^-(z,p_t)$). High z used to distinguish current fragmentation from target fragmentation.

Missing mass of pions in ep->e'πX



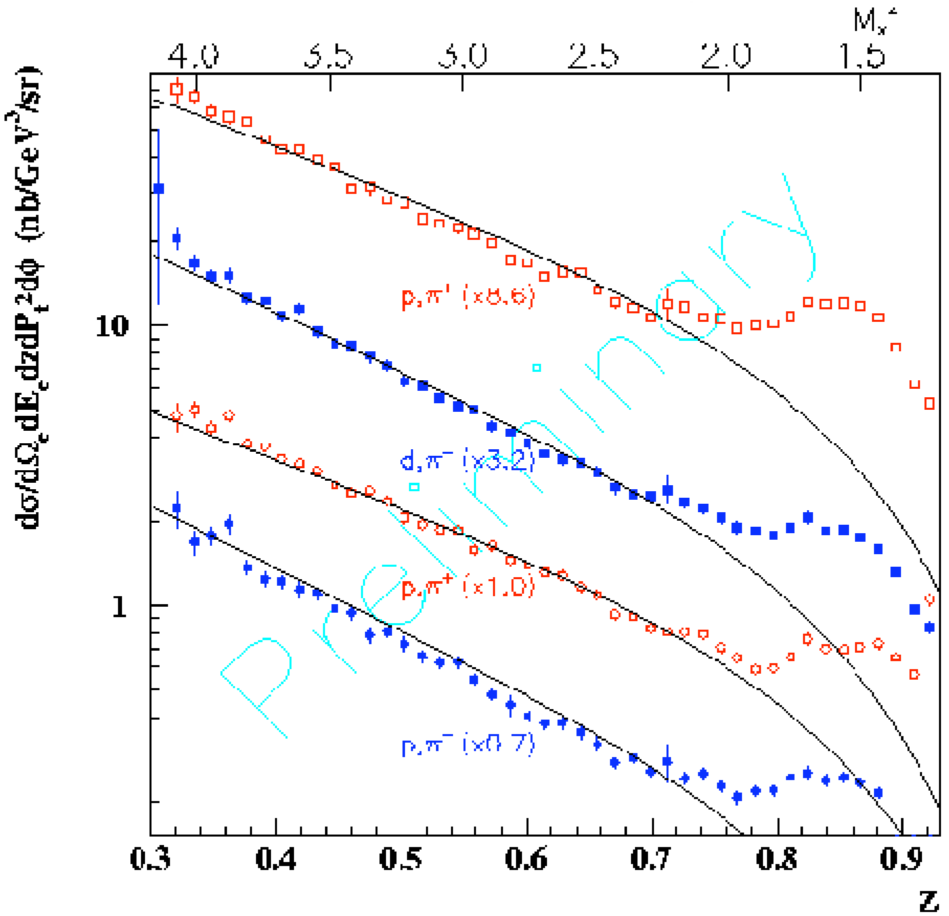
Duality question: will factorization work if M_x<2 GeV, even though Delta(1232) reonance Visible? For pi-, guess need M_x>1.4 GeV.

EXPERIMENT E00-108 at JLAB

- **Unpolarized electrons E=6 GeV**
- **Scattered electrons E'=1.6 GeV, 25 to 40 deg. Average Q^2 2.5 GeV^2.**
- **W about 2.5 GeV, but M_x<2 GeV.**
- **Detected positive and negative pions near 12 degrees**
- **Proton and deuteron targets**
- **Made scans in x, z. p_t<0.2 GeV**

Z-Dependence of cross sections

$$\sigma^{eH\to ehX} = \sum_q f^{H\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$$



X=0.3, Q^2=2.5 GeV^2, W=2.5 GeV

Good agreement with prediction using CTEQ5M PDFs and Binnewies fragmentation functions, except for z>0.7, or Mx>1.4 GeV.

In more detail, form super-ratios

$$\sigma^{eH\to ehX} = \sum_q f^{H\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$$

Simple LO picture in valence region:

$\sigma_p(\pi^+) = 4u(x,p_t)D^+(z,p_t) + d(x,p_t)D^-(z,p_t)$
$\sigma_p(\pi^-) = 4u(x,p_t)D^-(z,p_t) + d(x,p_t)D^+(z,p_t)$
$\sigma_d(\pi^+) = [u(x,p_t)+d(x,p_t)]\ [4D^+(z,p_t) + D^-(z,p_t)]$
$\sigma_d(\pi^-) = [u(x,p_t)+d(x,p_t)]\ [4D^-(z,p_t) + D^+(z,p_t)]$

$R_{pd+} = [\sigma_p(\pi^+) + \sigma_p(\pi^-)]\ /\ [\sigma_d(\pi^+) + \sigma_d(\pi^-)]$
$\quad = [4u(x,p_t) + d(x,p_t)]\ /\ 5[u(x,p_t)+d(x,p_t)]$
$\quad = \sigma_p(x)/\sigma_d(x)$ for any z, x, p_t (if d and u have same p_t depdendence)!

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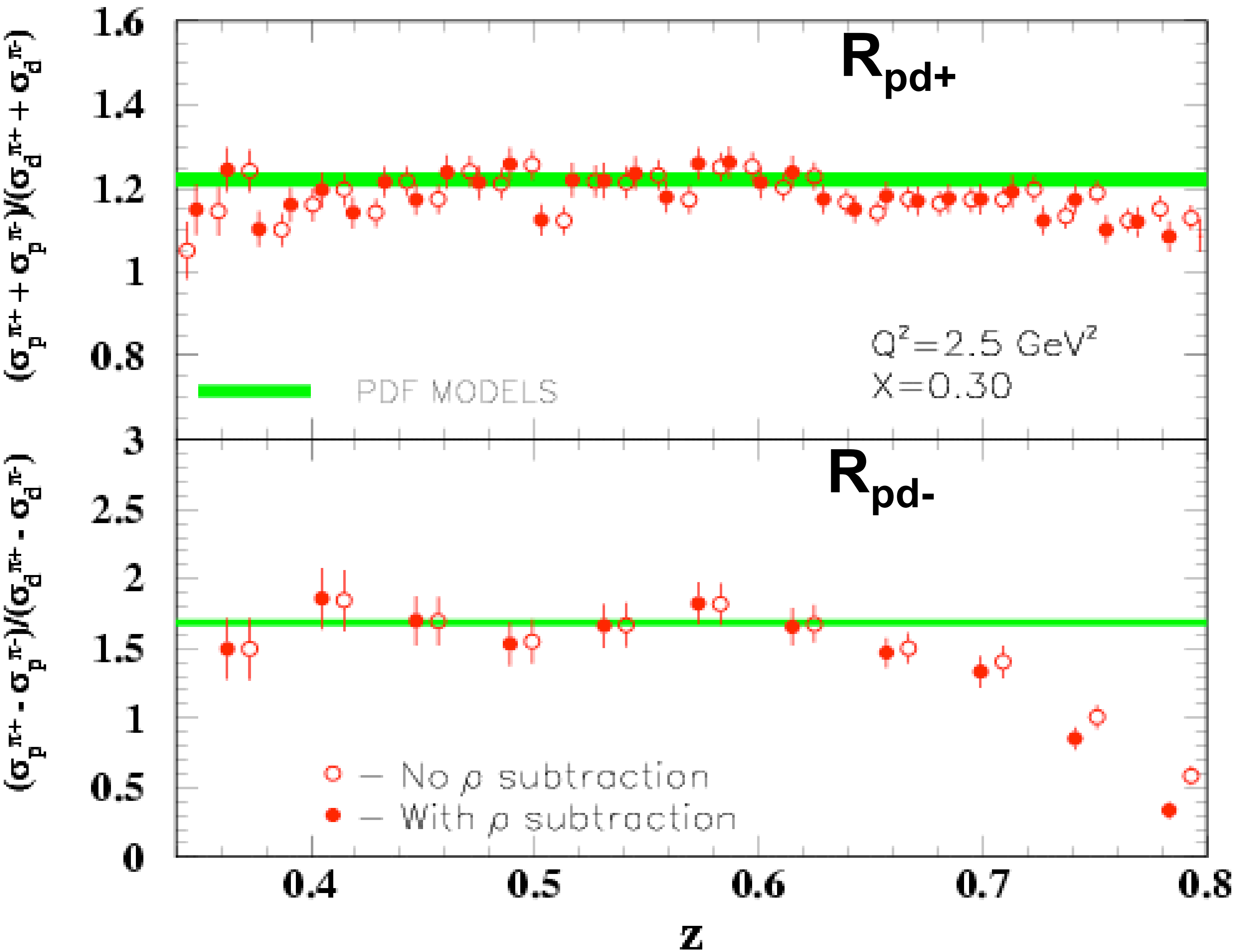
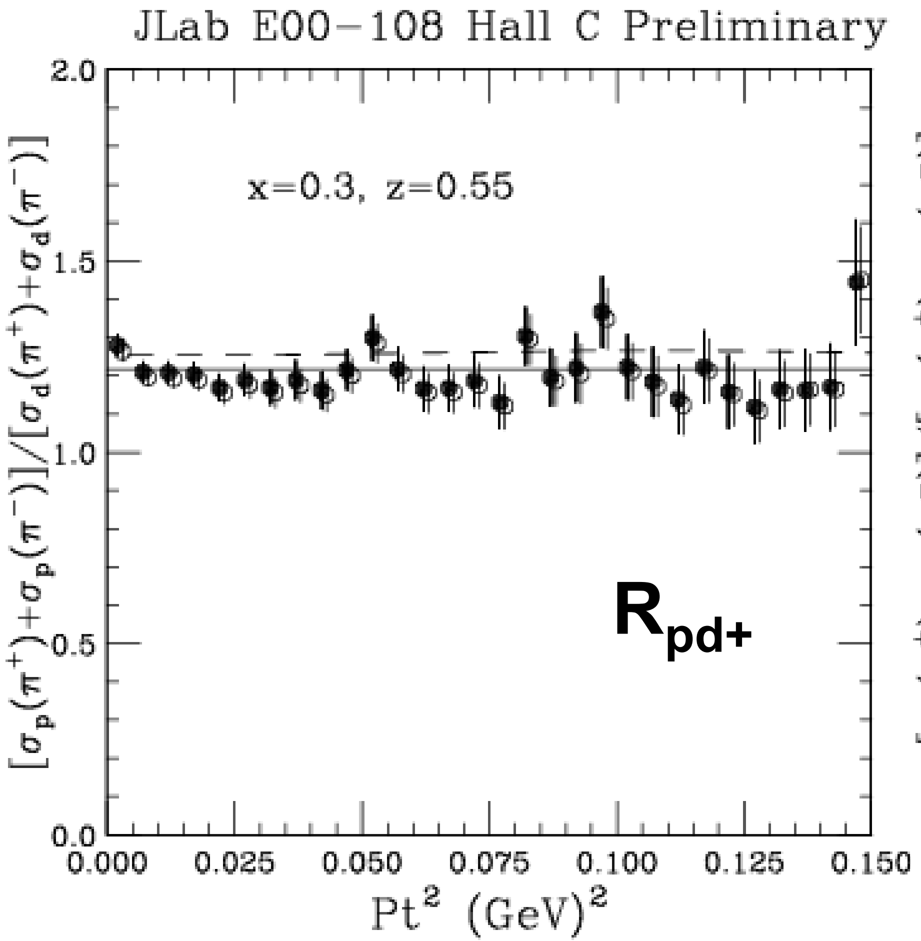
$\sigma_d(\pi^+) = [u(x,p_t)+d(x,p_t)]\ [4D^+(z,p_t) + D^-(z,p_t)]$
$\sigma_d(\pi^-) = [u(x,p_t)+d(x,p_t)]\ [4D^-(z,p_t) + D^+(z,p_t)]$

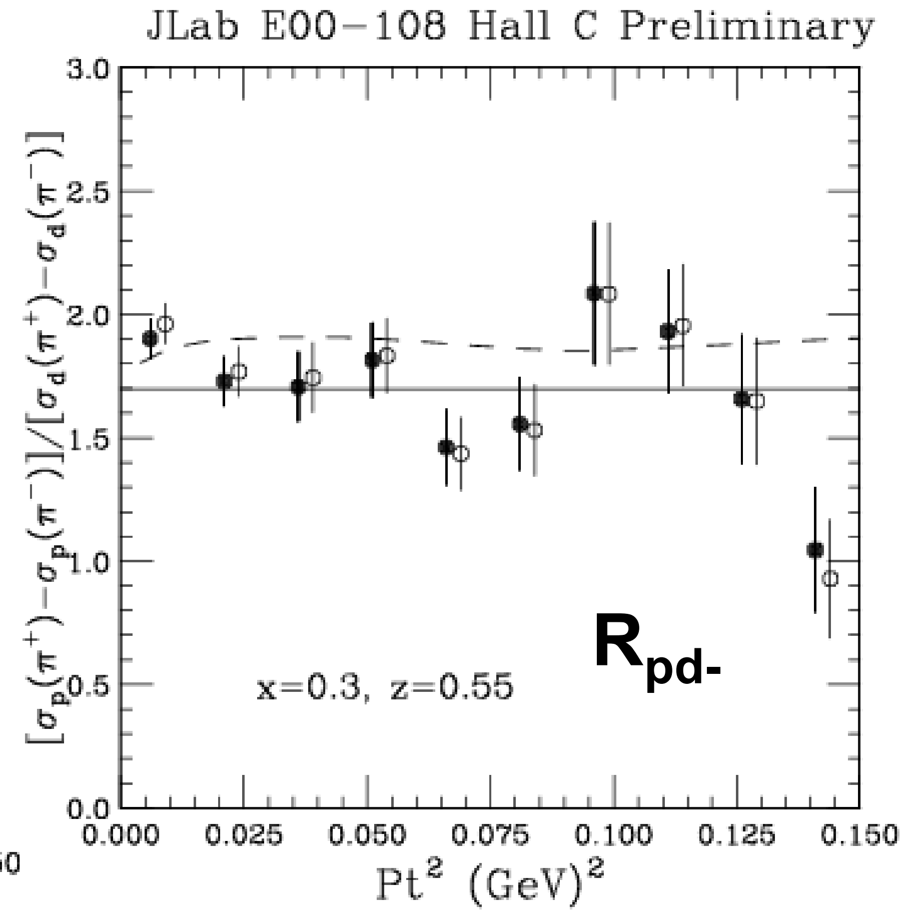
$R_{pd-} = [\sigma_p(\pi^+) - \sigma_p(\pi^-)] / [\sigma_d(\pi^+) - \sigma_d(\pi^-)]$
$= [4u_v(x,p_t) - d_v(x,p_t)] / 3[u_v(x,p_t)+d_v(x,p_t)]$

for any z, x!

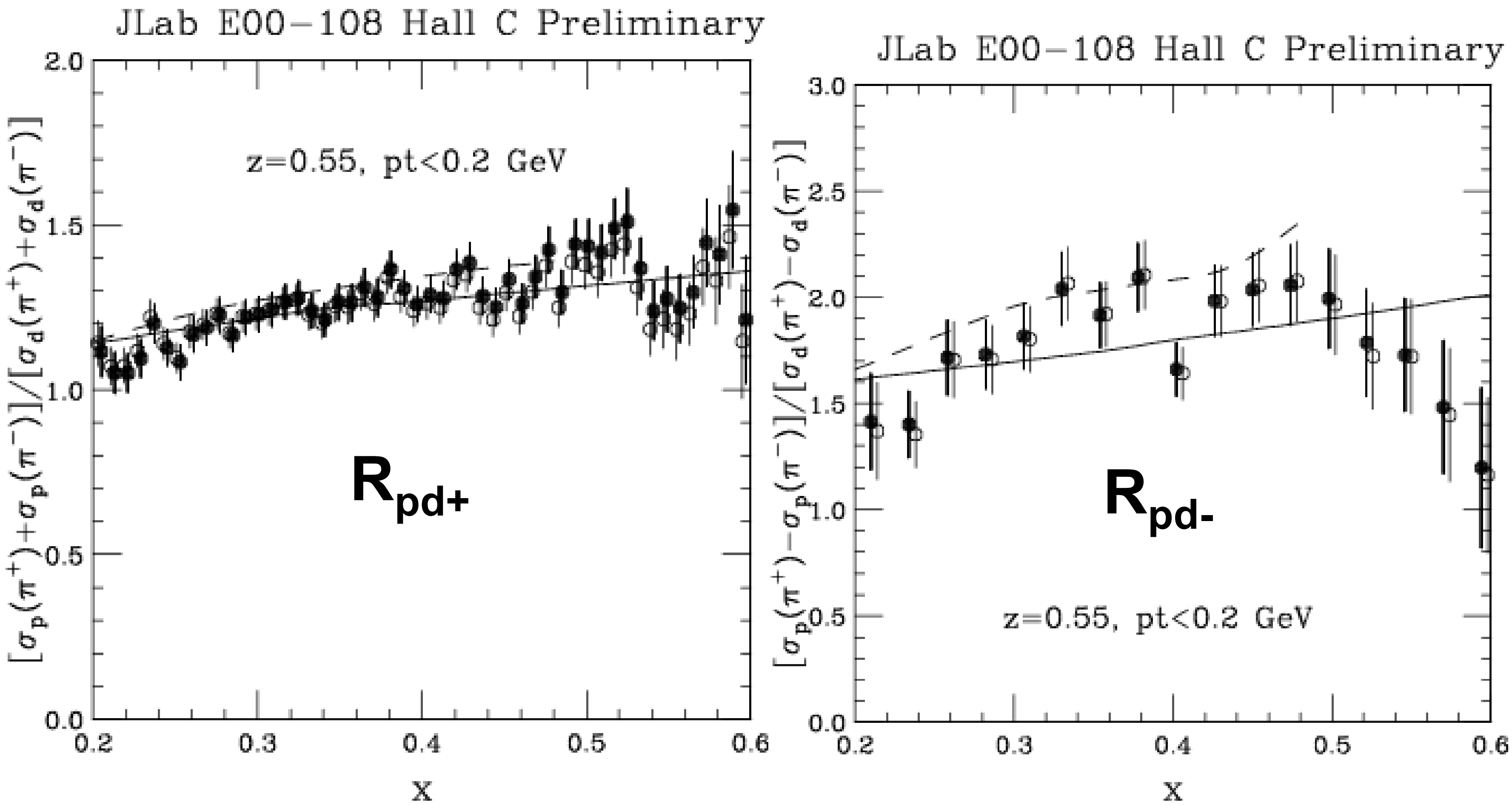


Both ratios agree PDF models for z<0.7 (Nx>1.4 GeV)



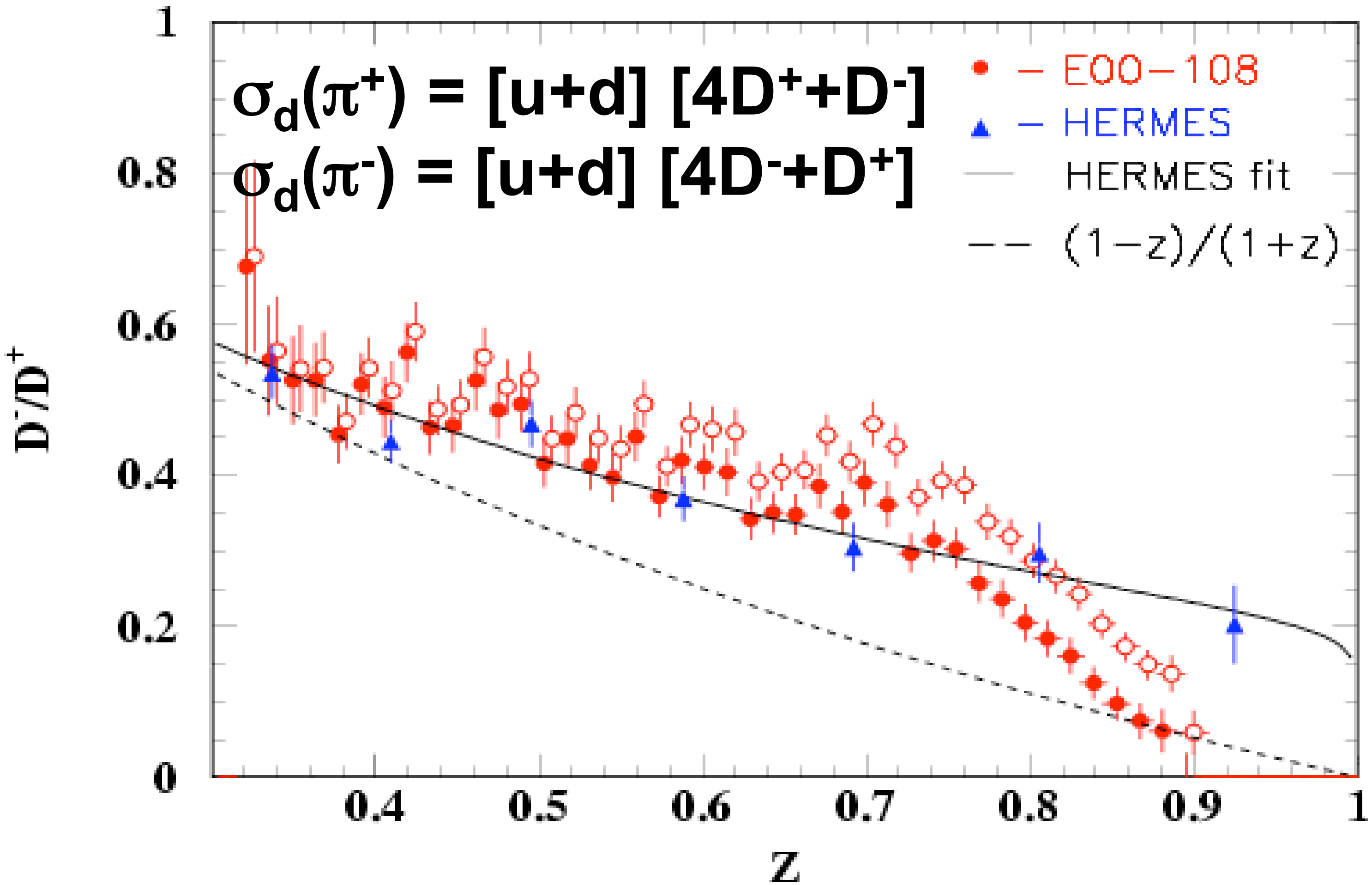


Both ratios independent of p_t (to 0.3 GeV) for z=0.55



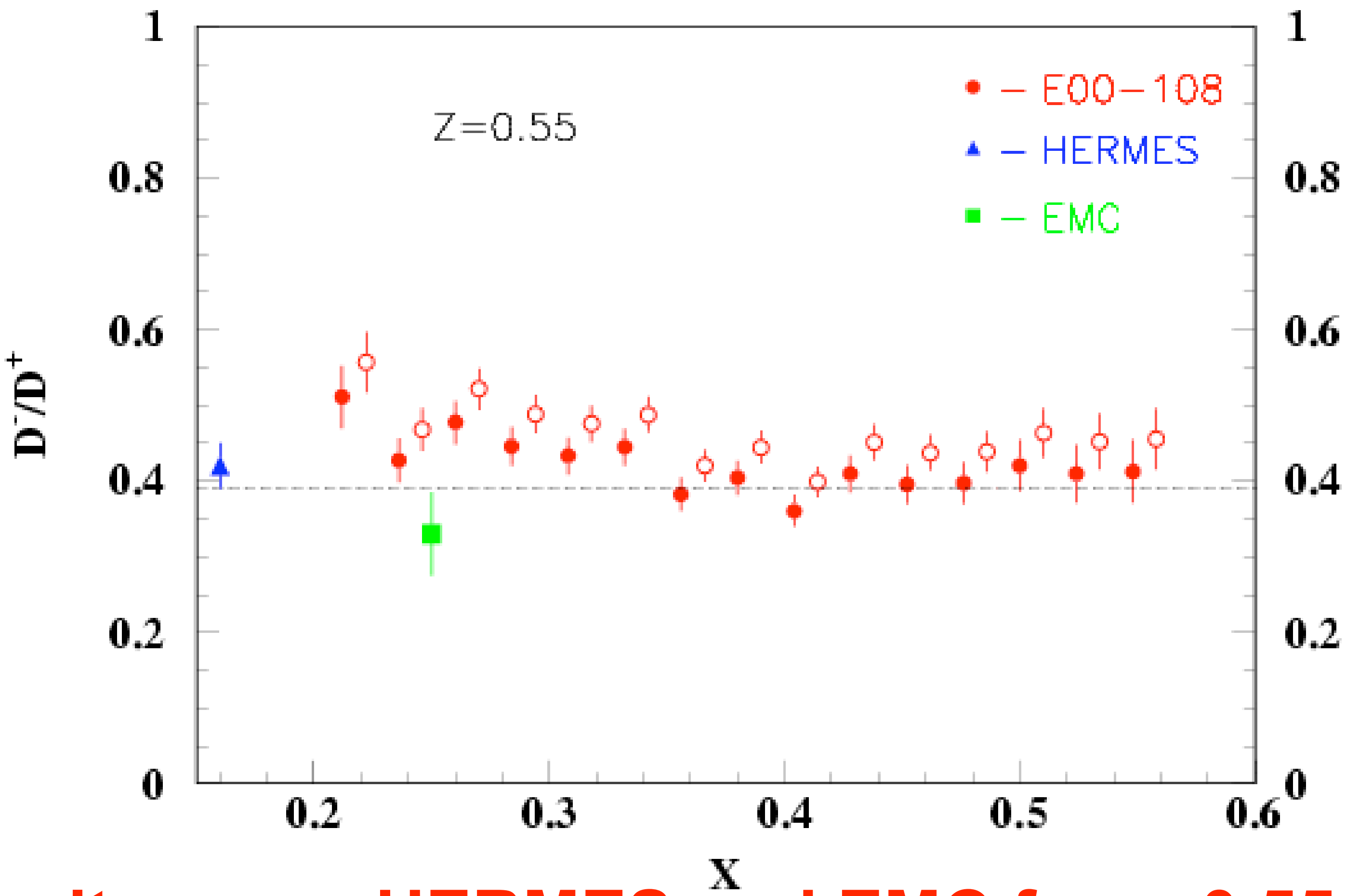
Both ratios agree PDF models 0.2<x<0.5 for z=0.55

Another test: D^-/D^+ from Deuteron π^+ to π^- ratio



Results agree HERMES (higher W, Mx>2 GeV) up to z=0.7 (Mx>1.4 at pt=0), after rho correction

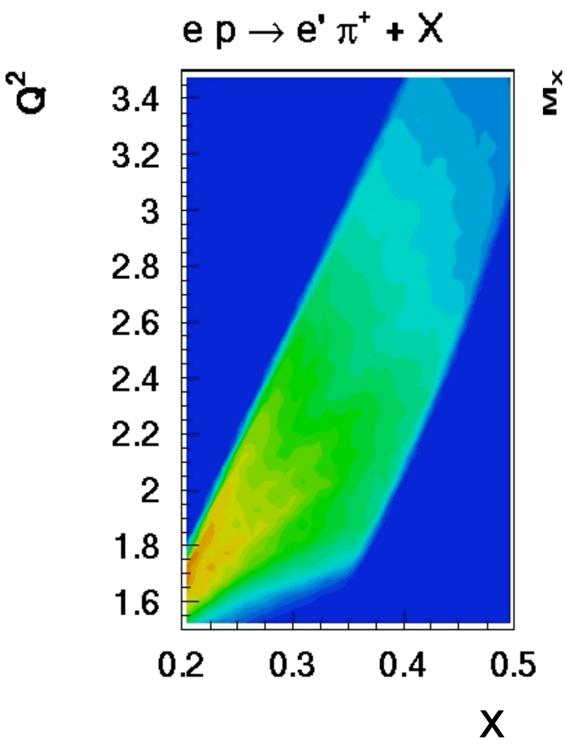
Another test: D^-/D^+ from Deuteron π^+ to π^- ratio

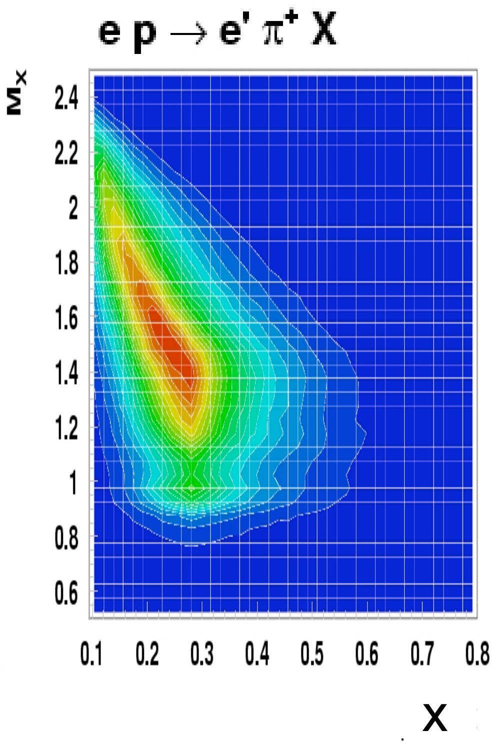


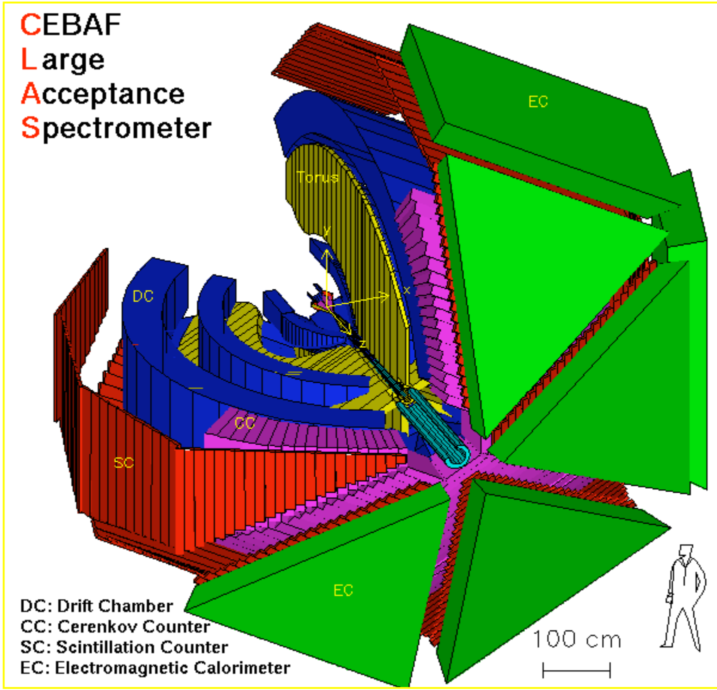
Results agree HERMES and EMC for z=0.55 and x>0.35. Maybe some x depdendence x<0.35 (sea quark correction?)

Now to polarized SIDIS at JLAB using CLAS

Scattering of 5.7 GeV polarized electrons off polarized NH_3, ND_3





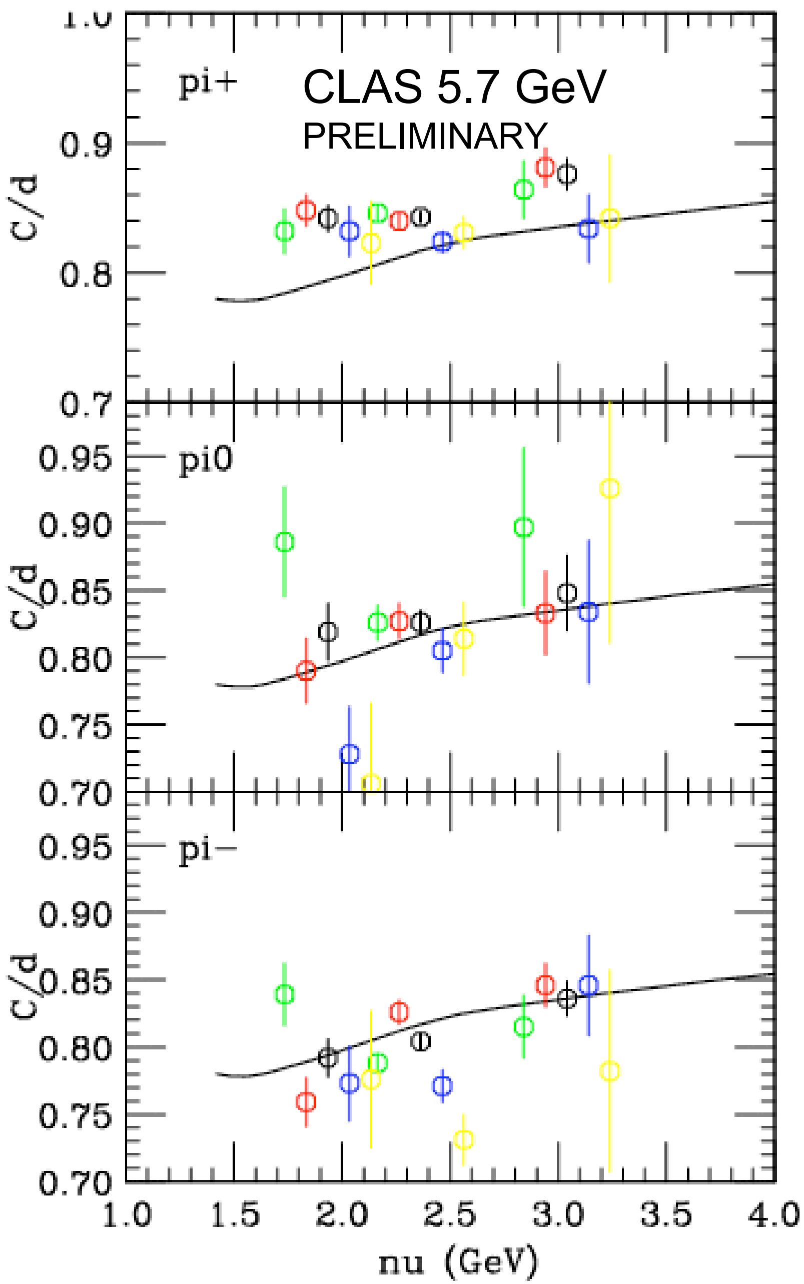


➢ ~8M π^+ in SIDIS kinematics

Determination of g_1/F_1 (approximately A_1)

$$A_1^p \approx \frac{1}{P_B P_T f D_{LL}(y)} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

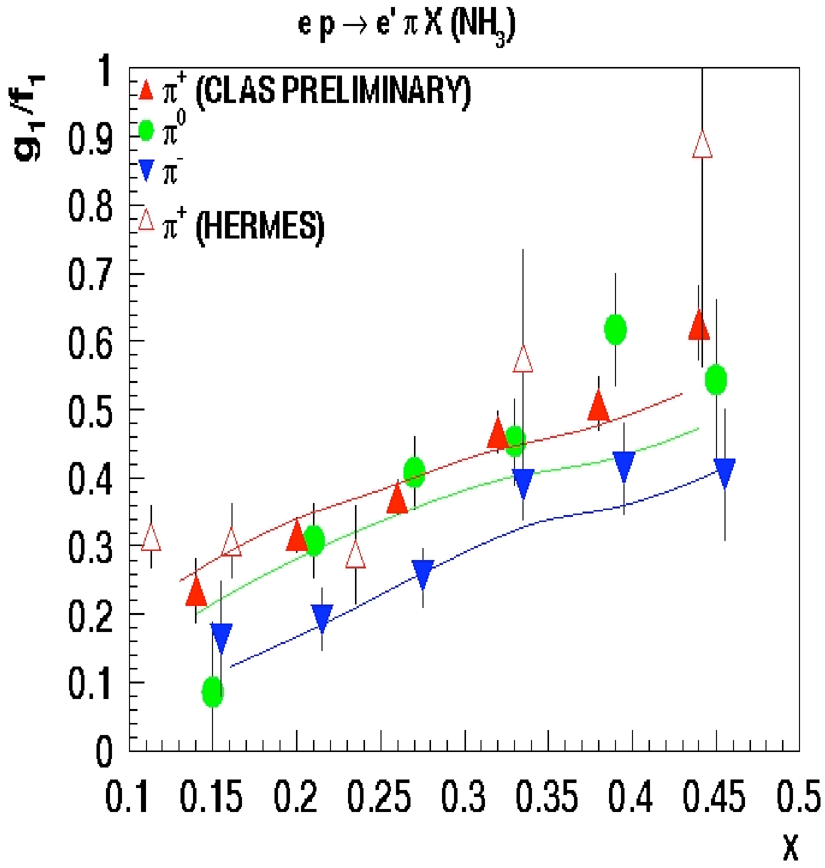
- Target polarization about 0.7 (0.3) for NH_3 (ND_3)
- Longitudinal beam polarization P_B about 0.7
- Dilution factor f varies from 0.1 to 0.3: used Lund model for n/p ratio (agrees with Hall C data) and preliminary Hall B data for A-dependence
- Depolarization factor $D_{LL}(y)$ evaluated assuming $R=\sigma_L/\sigma_T$ same as for inclusive.
- Assumed $A_{perp}=0$ (not measured)
- "π^+" and "π^-" include some K^+, K^- for P>1.5 GeV
- π^0 events cleanly identified with two photons



To obtain fraction of events from polarized protons (deuterons) in NH3 (ND3), used recent data for deuteron to carbon ratio in SIDIS from E02-104 (Will Brooks). Few representative points shown. MUCH MORE DATA coming soon over wide kinematic range. Studies quark propogation in cold QCD matter.

x-depenence of SIDIS proton g_1/F_1

W>2 GeV, Q^2>1.1 GeV^2, 0.4<z<0.7



- Good agreement with HERMES π+ data at higher W.
- x-dependence follows PEPSI (Lund) Monte Carlo using GRSV polarized PDFs (LO)
- Magnitude also in good agreement with simulation

Polarized SIDIS: factorization tests

Simple picture in valence region:

$\sigma_p(\pi^+) = 4u(x)D^+(z) + d(x)D^-(z)$
$\sigma_p(\pi^-) = 4u(x)D^-(z) + d(x)D^+(z)$
$\delta\sigma_p(\pi^+) = 4\delta u(x)D^+(z) + \delta d(x)D^-(z)$
$\delta\sigma_p(\pi^-) = 4\delta u(x)D^-(z) + \delta d(x)D^+(z)$

$(g_1/F_1)_{+-}=[\delta\sigma_p(\pi^+)+\delta\sigma_p(\pi^-)]/[\sigma_p(\pi^+)+\sigma_p(\pi^-)]$

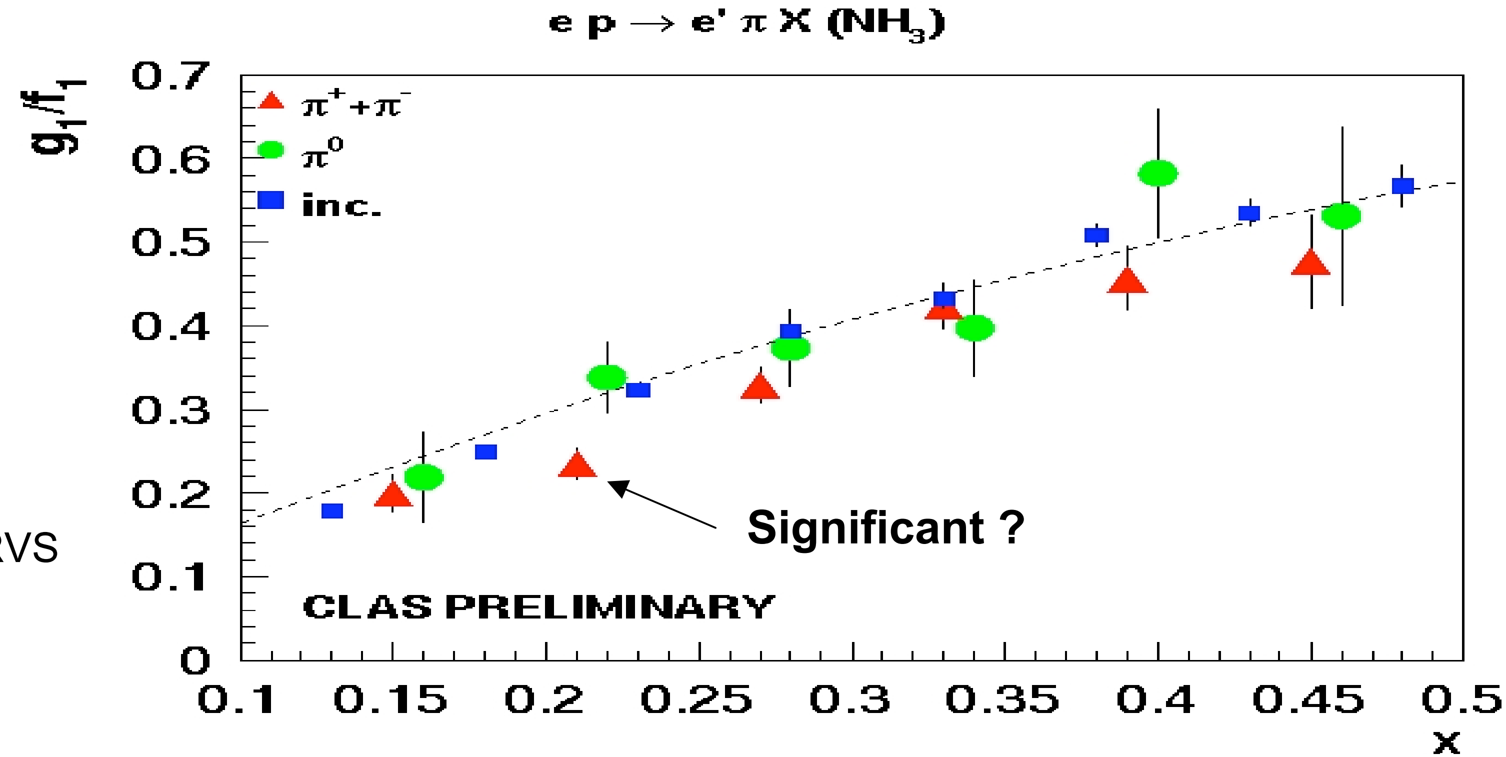
$= [4\delta u(x) + \delta d(x)] / [4u(x) + d(x)]$

$= (g_1/F_1)_{inclusive}$

Similarly for π^0 $(g_1/F_1)_0= (g_1/F_1)_{inclusive}$

$(g_1/F_1)_{+-}$ and $(g_1/F_1)_0$ should be independent of z and p_t, and equal to inclusive (g_1/F_1)

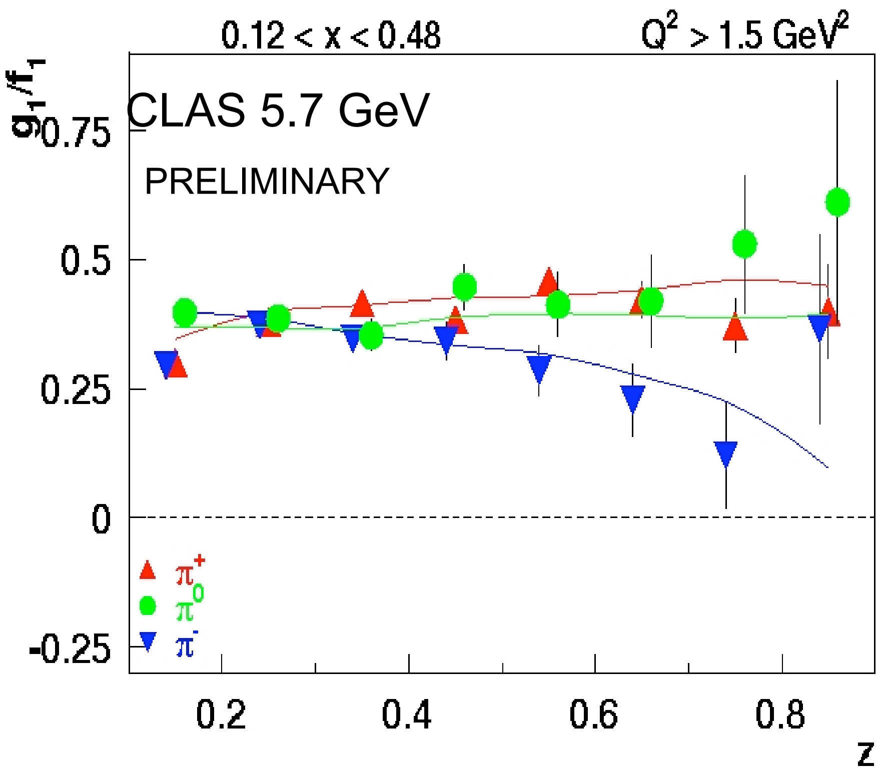
Polarized SIDIS factorization test



GRVS

g_1/F_1 for inclusive, for the sum of π^+, π^-, and for π^0 are fairly consistent with each other in the range $0.4<z<0.7$, as expected in LO if factorization works. Cuts used: $M_x>1.4$ GeV, $Q^2>1.1$ GeV^2, $W>2$ GeV

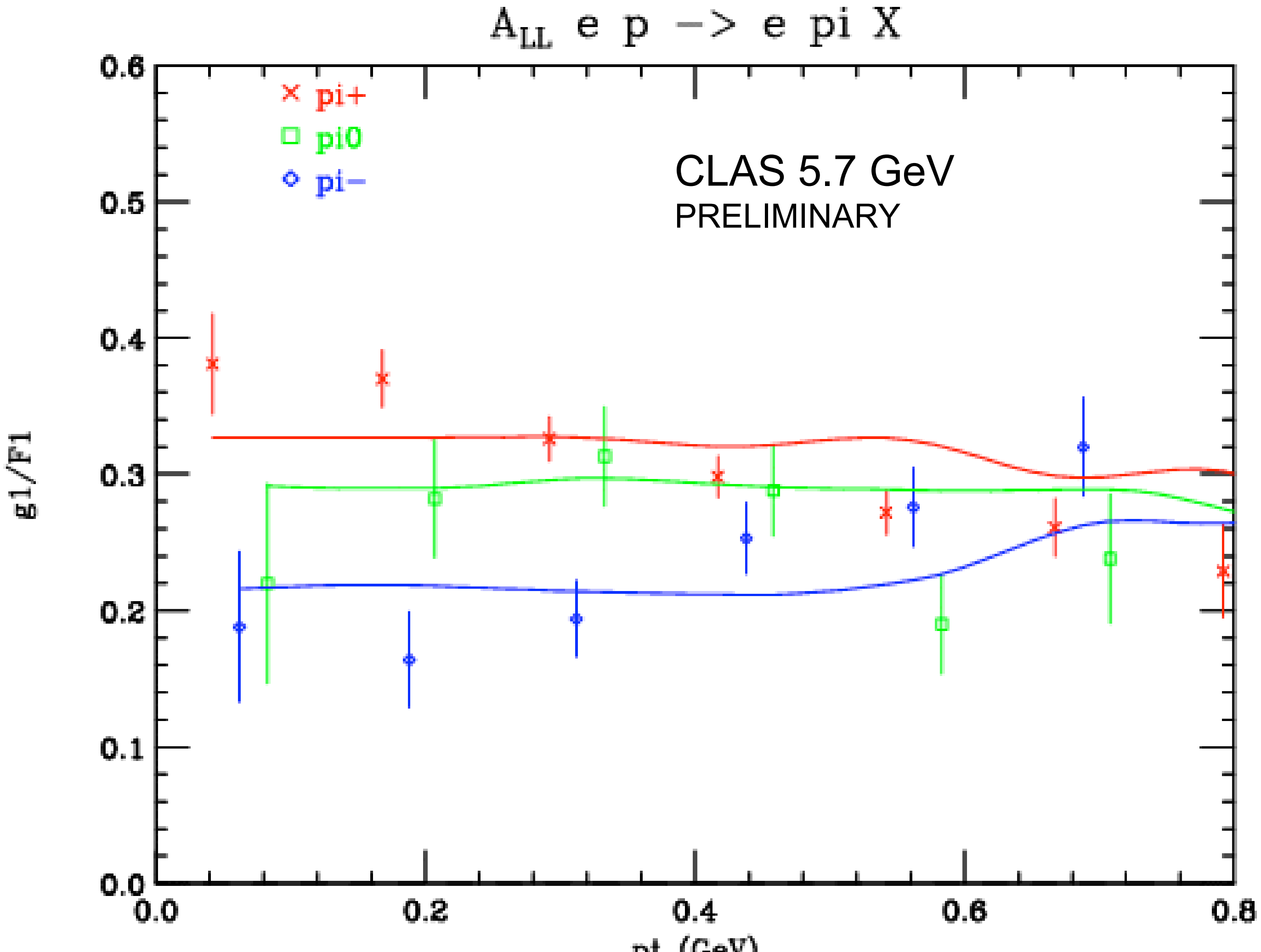
z-depenence of SIDIS proton g_1/F_1



No significant z-dependence seen for π^0 and $\pi^+ + \pi^-$ for 0.3<z<0.7, as expected if factorization holds

Good agreement with PEPSI predictions including dropoff at high z for π^-, due to increasing importance of $\delta d(x)$, in turn due to increase of D^+/D^- with increasing z

p_t-depenence of SIDIS proton g_1/F_1



p_t

No p_t dependence for π^0 (green), and average of π^+ (red) and π^- (blue) as expected if factorization works

p_t-depenence of SIDIS proton g_1/F_1

BUT, A_1 π^+ **decreases** with p_t at fixed x,Q^2,z while A_1 π^- **increases.**

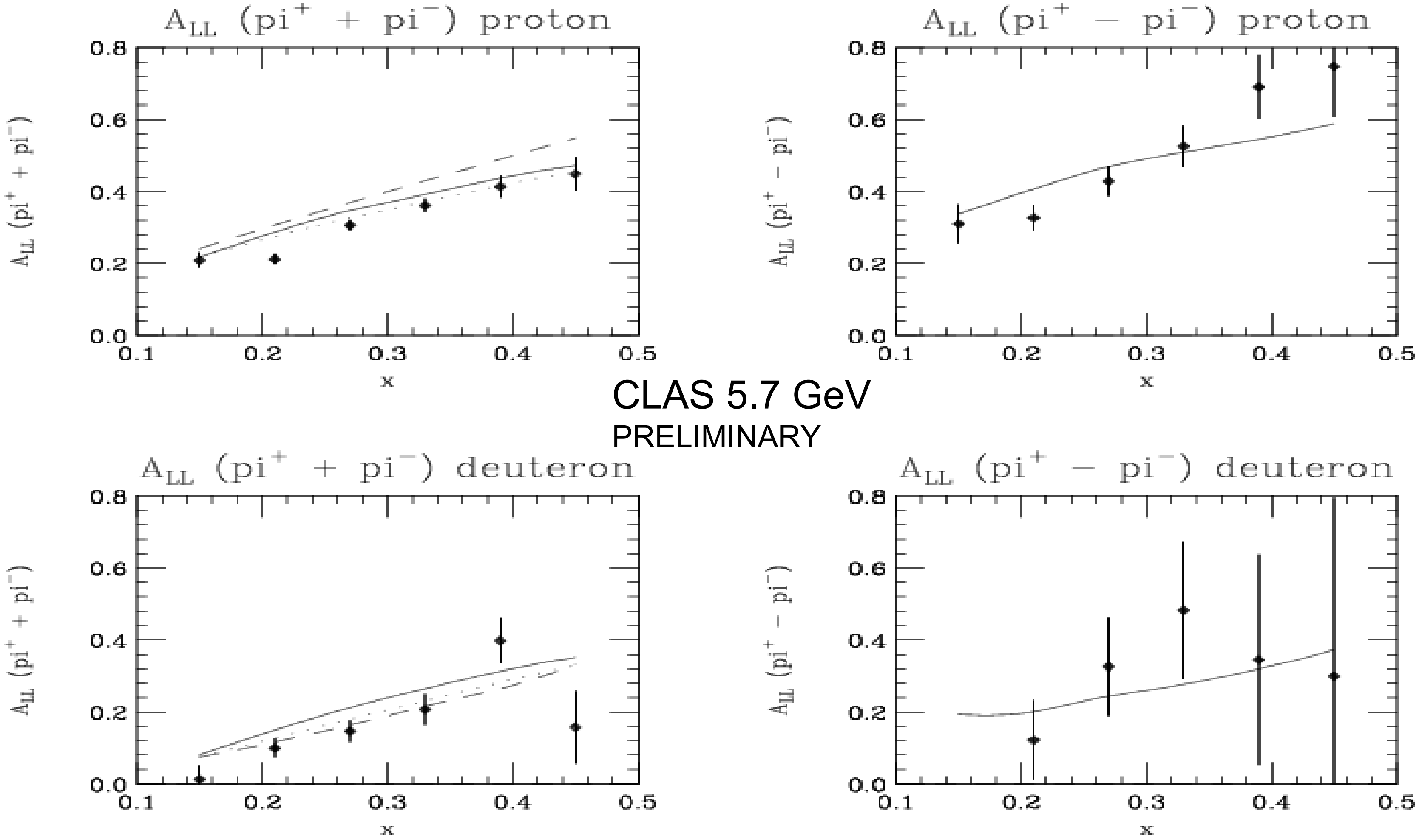
$$\delta\sigma_p(\pi^+) = 4\delta u(x,p_t)D^+(z,p_t) + \delta d(x,p_t)D^-(z,p_t)$$
$$\delta\sigma_p(\pi^-) = 4\delta u(x,p_t)D^-(z,p_t) + \delta d(x,p_t)D^+(z,p_t)$$

Hard to explain in terms of different p_t distributions for quarks, or influence of exclusive processes like diffractive rho production.

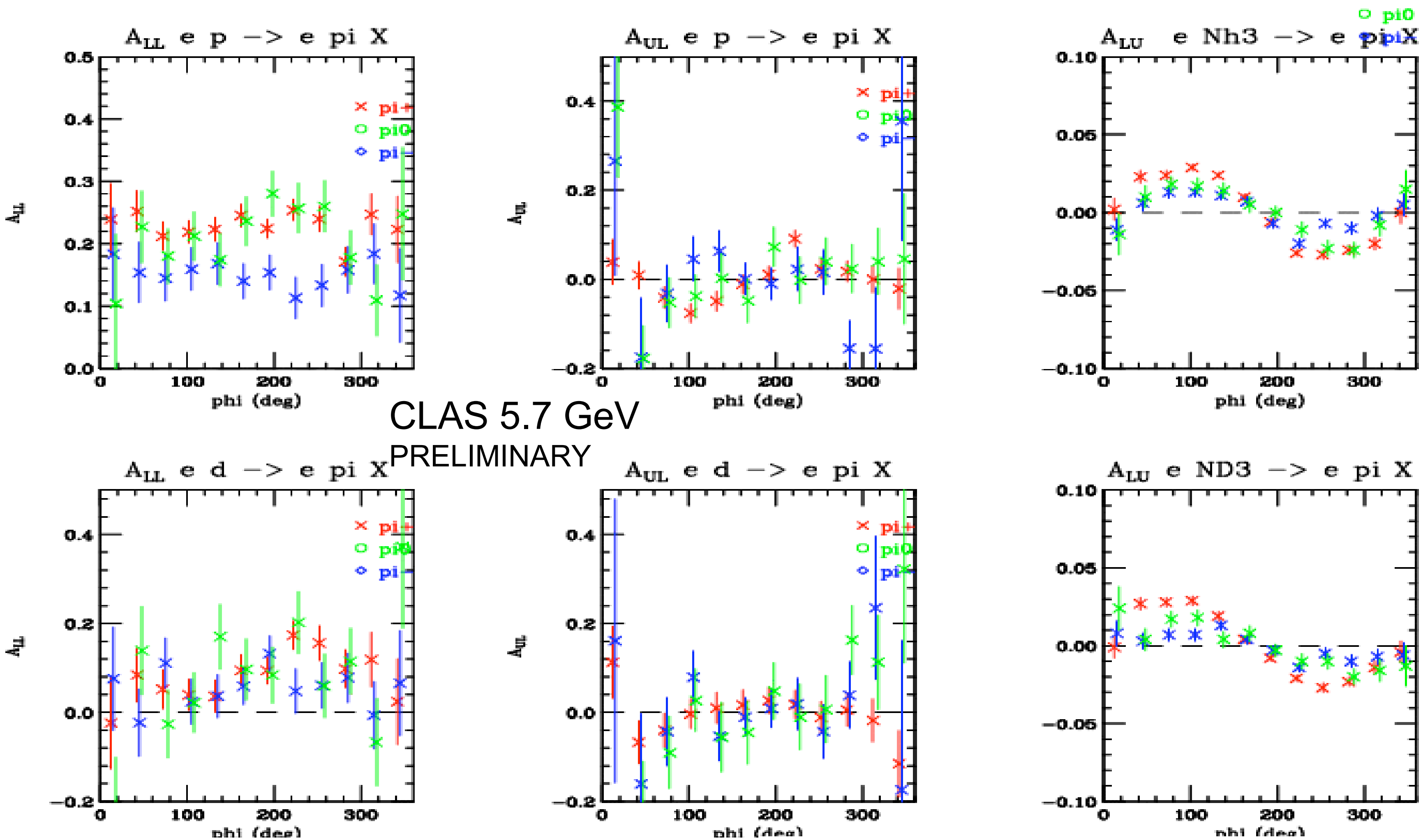
Simplest explanation is that D^-/D^+ increases with p_t (I.e. unfavored fragmentation has a wider transverse momentum dependence) **First hint?**

This effect magnified in g_1 compared to F_2 due to δd negative while δu positive

In region where factorization tests hold, can use data to constrain polarized PDFs in NLO analysis(separate out polarized up, down valence and sea quark parton distributions).



In region where factorization tests hold, analyze phi depdendence of A_{LL}, A_{LU}, and A_{UL} to learn about orbital motion of quarks, polarized fragmentation, and higher twist contributions.



Future

- 20x more π^+, π -, 40x more π^0 for g_1/F_1 at 6 GeV on proton (using CLAS)
- 3x more π^+ and π^- g_1/F_1 data on deuteron (Hall C)
- Jlab upgrade to 11 GeV electrons combined with major upgrade to CLAS will allow huge increase in kinematic coverage and statstical accuracy in SIDIS!

Summary

- Factorization in SIDIS pion production seems to work for $0.3<z<0.7$, $W>2$ GeV, $Mx>1.4$ GeV, $0.2<x<0.5$, $Q^2>1$ GeV^2.
- Opens opportunity for studies of PDF's, and orbital motion of quarks
- Jlab upgrade will allow definitive measruements for $x>0.1$
- Laat but not least, is p_t dependence of fragmentation function different for favored and unfavored?