Duality in Meson Electroproduction
(E00-108)

- Introduction
- E00-108 Experiment
- Analysis
- Results
- First efforts to study cos(φ) terms
- Summary

(Hamlet Mkrtchyan, for the E00-108 Collaboration)

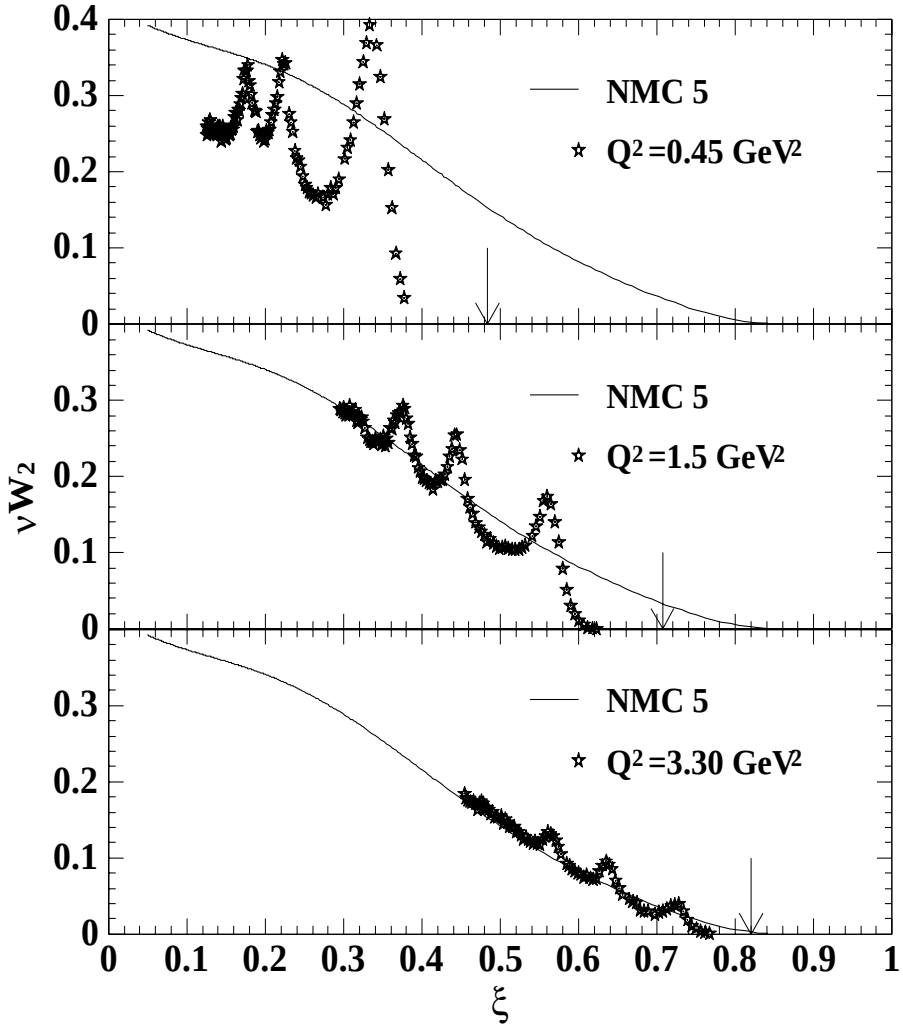
Hall C Meeting, January 25, 2007

Introduction

- At high energies: QCD allows for an efficient description in terms of quarks-gluons
- At low energies: more efficient description in terms of mesons-baryons
- Quark-hadron duality: relationship between the strong and week interaction limits of QCD
- The early observation of quark-hadron duality (Bloom-Gilman) was unexpected

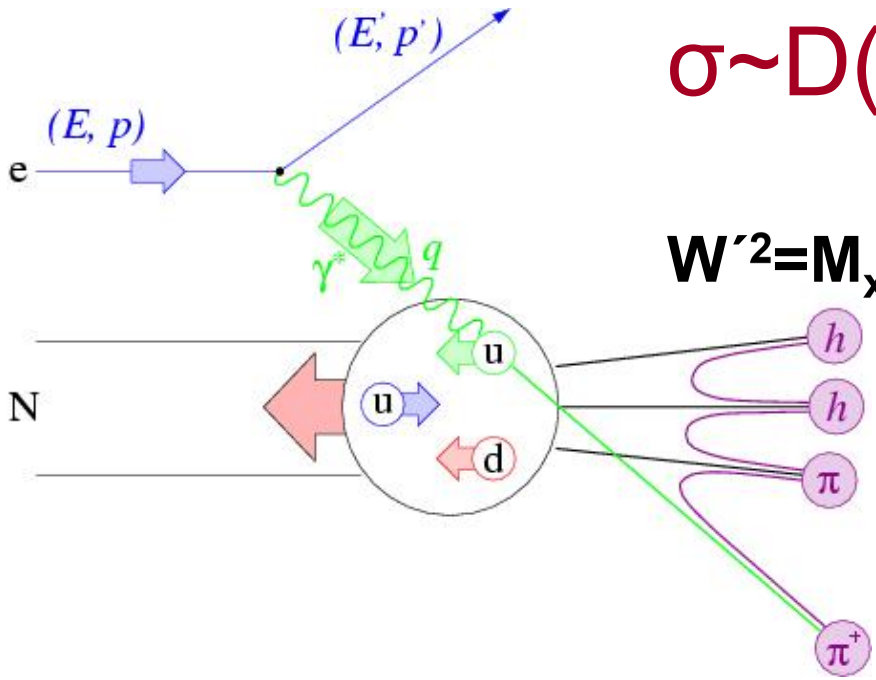
W_2 versus ξ for JLab resonance data

(e,e'x)



- Resonance peaks averaging to the NMC scaling curve
- DIS probes only the sum of quarks and anti-quarks
- The origin of quark-hadron duality poorly understood
- Small or cancelling High Twist contribution (In Operator Product Expansion framework)

Meson electroproduction in SIDIS



$$\sigma \sim D(z) \cdot q(x,Q^2)$$

$$W'^2 = M_x^2 = M_p^2 + Q^2(1/x-1)(1-z)$$

$\}$ W′

$$z = E_\pi / \nu$$

- At high energies SIDIS can be decomposed into part dependent on the quark hadronization, D(z), and on the quark-photon interaction, $q(x,Q^2)$.

- At low energies, this factorization ansatz is expected to brake down, due to effects of FSI, resonant excitations. (What will be at $W'^2 < 2$ GeV^2 ?)

E00-108 Experiment

- Goal: to study the duality concept to the unknown region of semi-inclusive pion electroproduction
- The experiment ran in the summer of 2003 in Hall C. SOS was used for e^- and HMS for $\pi^\pm$ detection
- Electron beam: I = 20-60 μA and energy ~5.5 GeV, Q^2~2.3 GeV^2/c^2 and W~2.5 GeV
- We took data on ^1H, ^2H and Al (dummy target).
- We mapped z-dependence at fixed x, x-dependence at fixed z and P_t at fixed z and x.

Analysis

- Acceptance, radiative corrections and the bin centering in cross-section is done using **SIMC**

- The meson yield arises in term of a fit to the normalized (e,e'x) DIS cross section:
  $\sigma_{SIDIS}=\sigma_{DIS}\cdot\sum e_i^2[q_i(x)D_i(z)]\cdot be^{-bp_t^2}\{1+A\cos(\varphi)+B\cos(2\varphi)\}$

- Used **CTEQ5M** parametrization for $q(x,Q^2)$, **average** $D^+(z)+D^-(z)$ from Binnewies and D^-/D^+ from HERMES

D^+ *is favoured* (*D^- is unfavoured*) *fragmentation function or probability for the struck quark* ***u*** (*d*) *rise to a* ***π^+***

Analysis

- In **x-scan** and **z-scan** data the φ-dependence was effectively integrated out (pions at $\mathbf{P_t \sim 0}$)

- Took in MC: $\sigma_{SIDIS} = \sigma_{DIS} \cdot \sum e_i^2 [q_i(x) D_i(z)] \cdot b e^{-b p_t^2}$

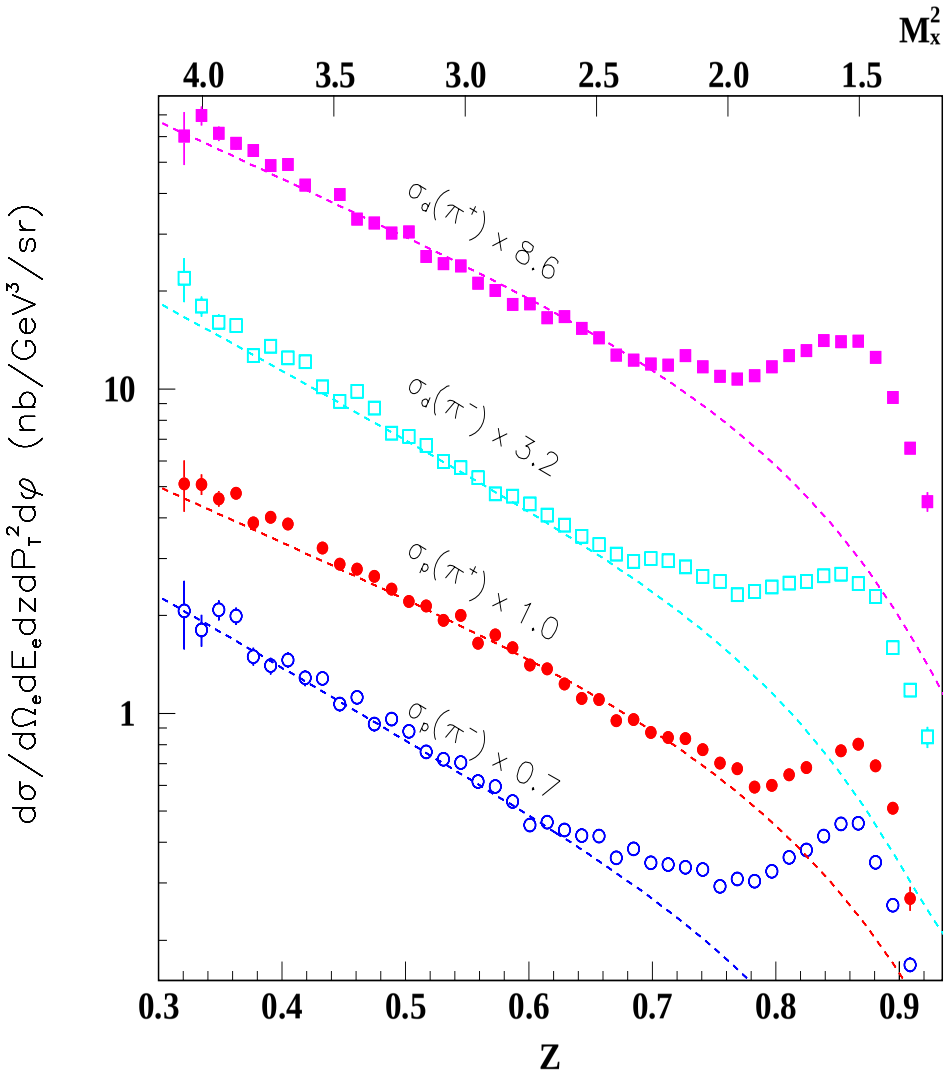
- We used parameter **b≈4.66** from **HERMES** (our own best estimate is b=4.0±0.4 for $\pi^{\pm}$)

- We estimated **Rad. Corrections** in two steps:
  - using peaking approximation in SIMC, and
  - exclusive π, from interpolation MAID & DESY.

- Subtracted **pions** from decay of **diffractive ρ**, using **PYTHIA** to estimate σ_ρ (similar to **HERMES**) .

Z-Dependence of cross section

$\sigma \sim D(z) \cdot q(x,Q^2)$



- Good agreement between data and high energy prediction at Z<0.65 (using CTEQ5M for PDFs and Binnewies for Fragmentation)
- Large excess in the data at Z>0.8 with respect to the prediction reflects the N–Δ region. ($m_\Delta^2 \approx 1.5$ GeV^2)

Super-Ratios

- To quantify factorization of **SIDIS** we formed the ratios insensitive to the fragmentation process.

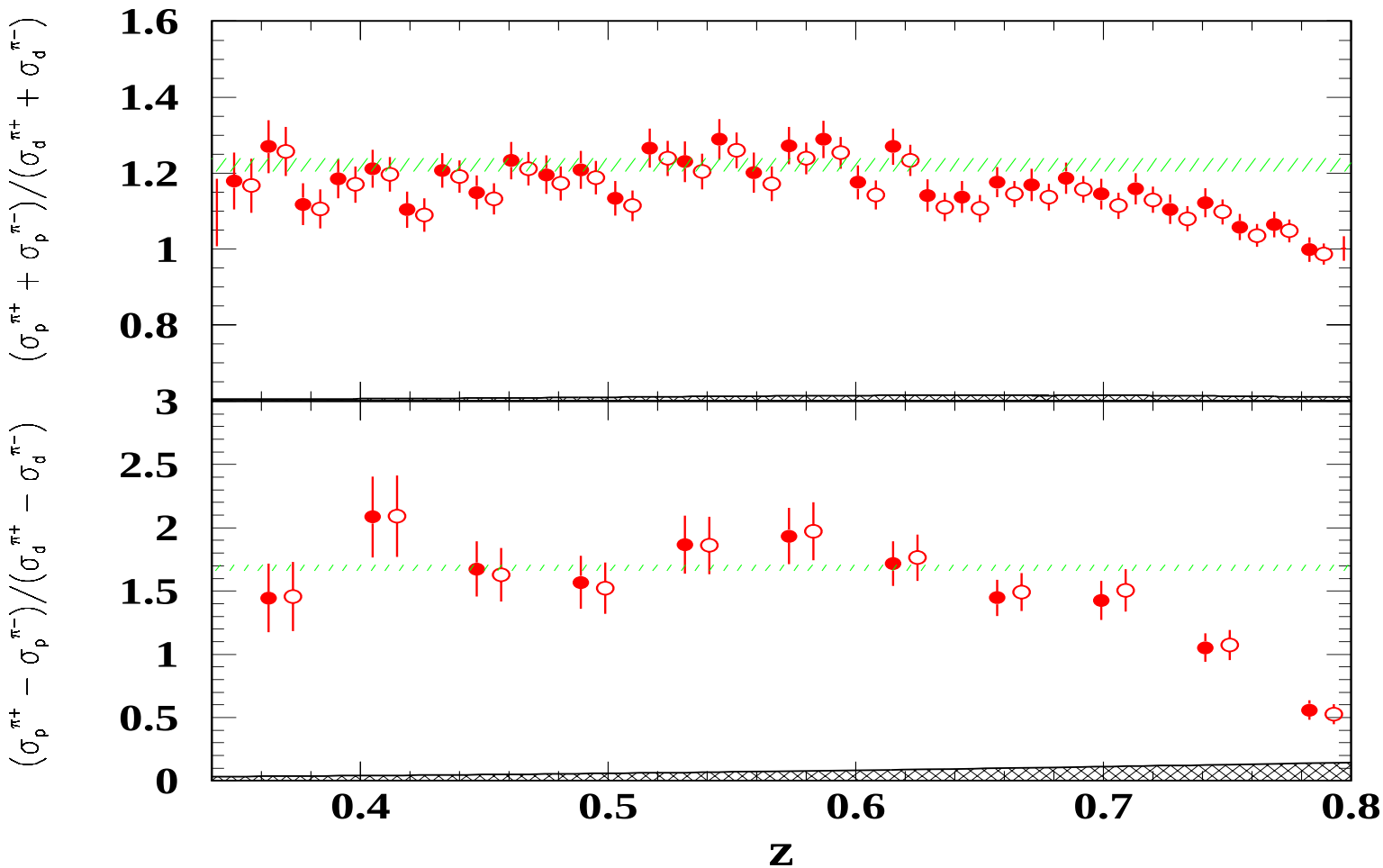
- Simple Leading Order picture in valence region:

$$R_{pd+} = [\sigma_p(\pi^+) + \sigma_p(\pi^-)] / [\sigma_d(\pi^+) + \sigma_d(\pi^-)]$$
$$= [4u(x,p_t) + d(x,p_t)] / 5[u(x,p_t) + d(x,p_t)]$$

for any z, x, p_t (if d & u have same p_t dependence)

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

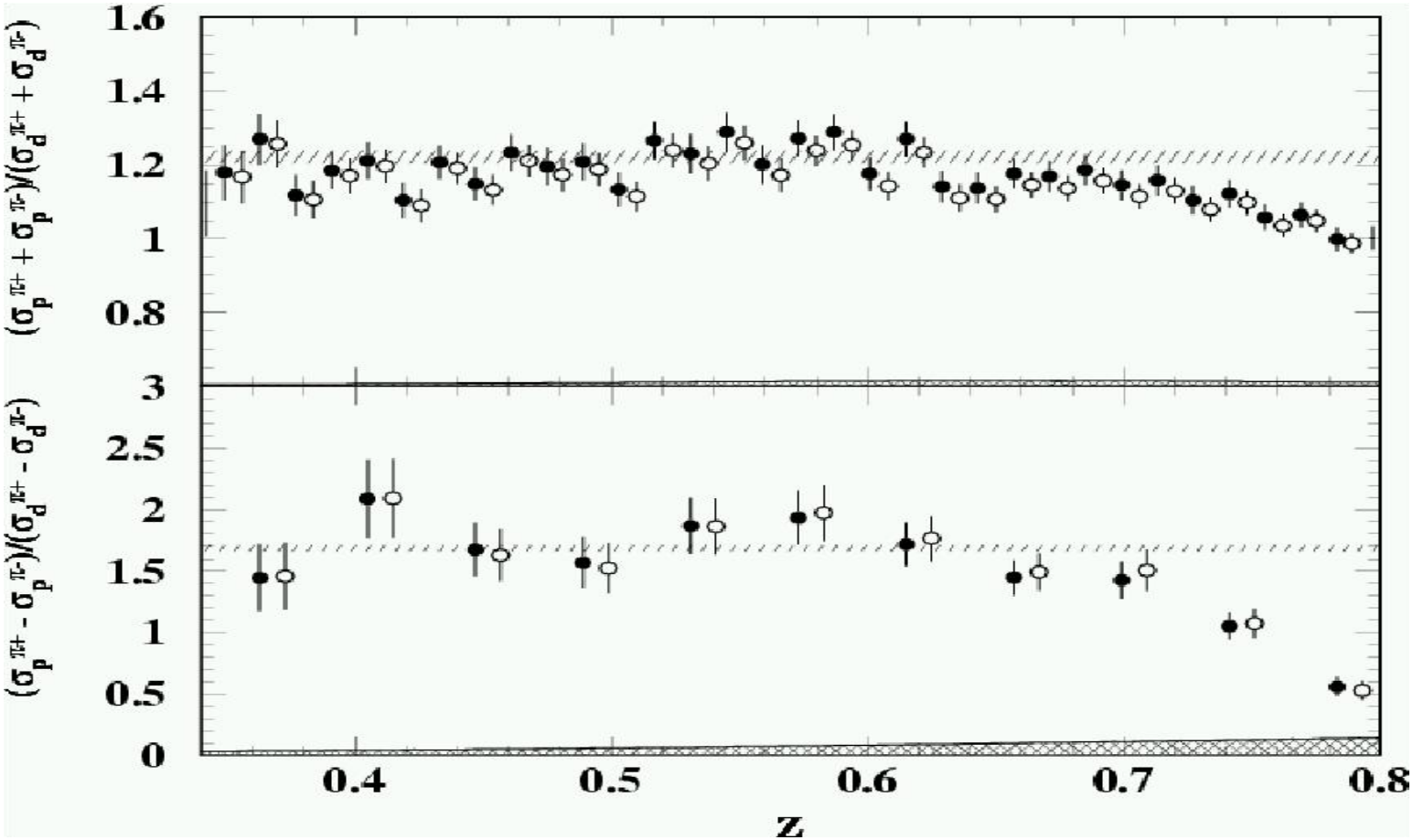
for any z, x !



Our data are close to the near-independence of z

The ratios agree PDF models predictions for z<0.7

Duality brakes down at z>0.7 (low Mx !)



Our data are close to the near-independence of z

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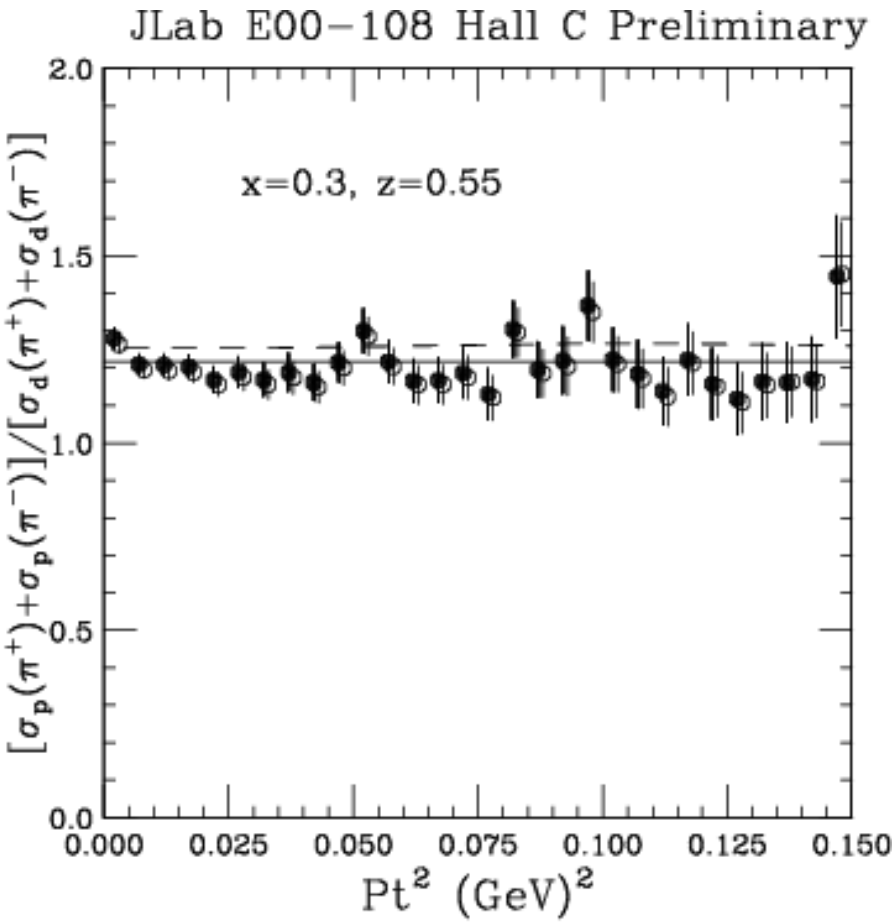
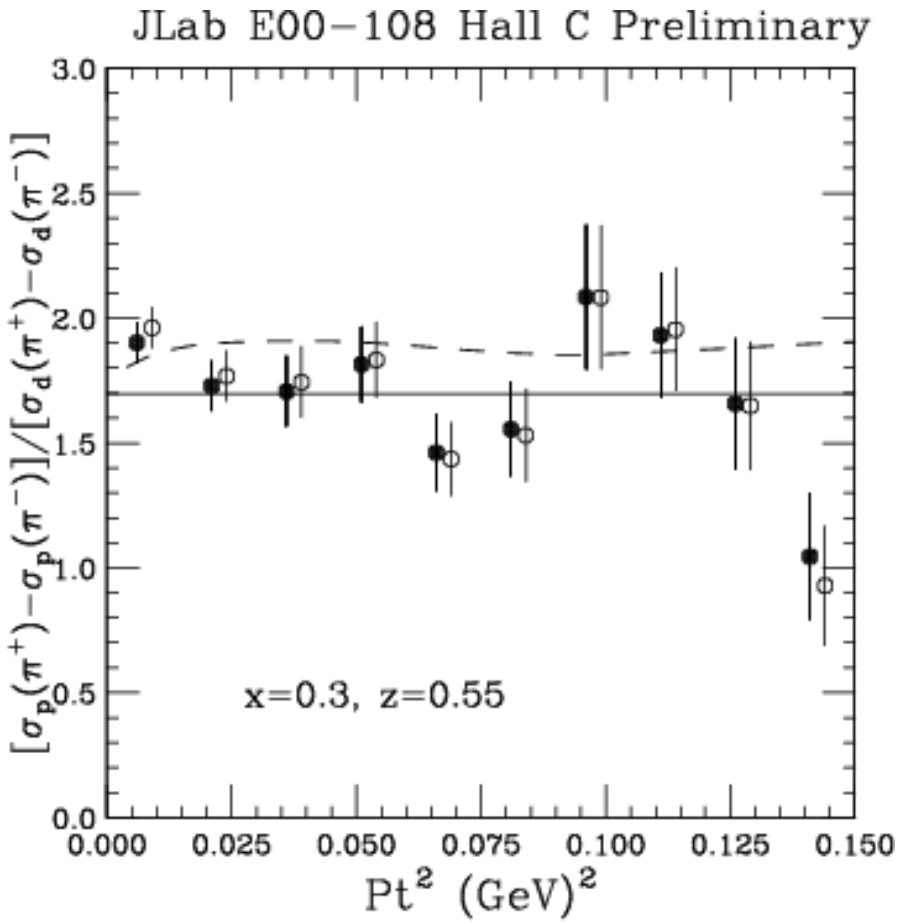
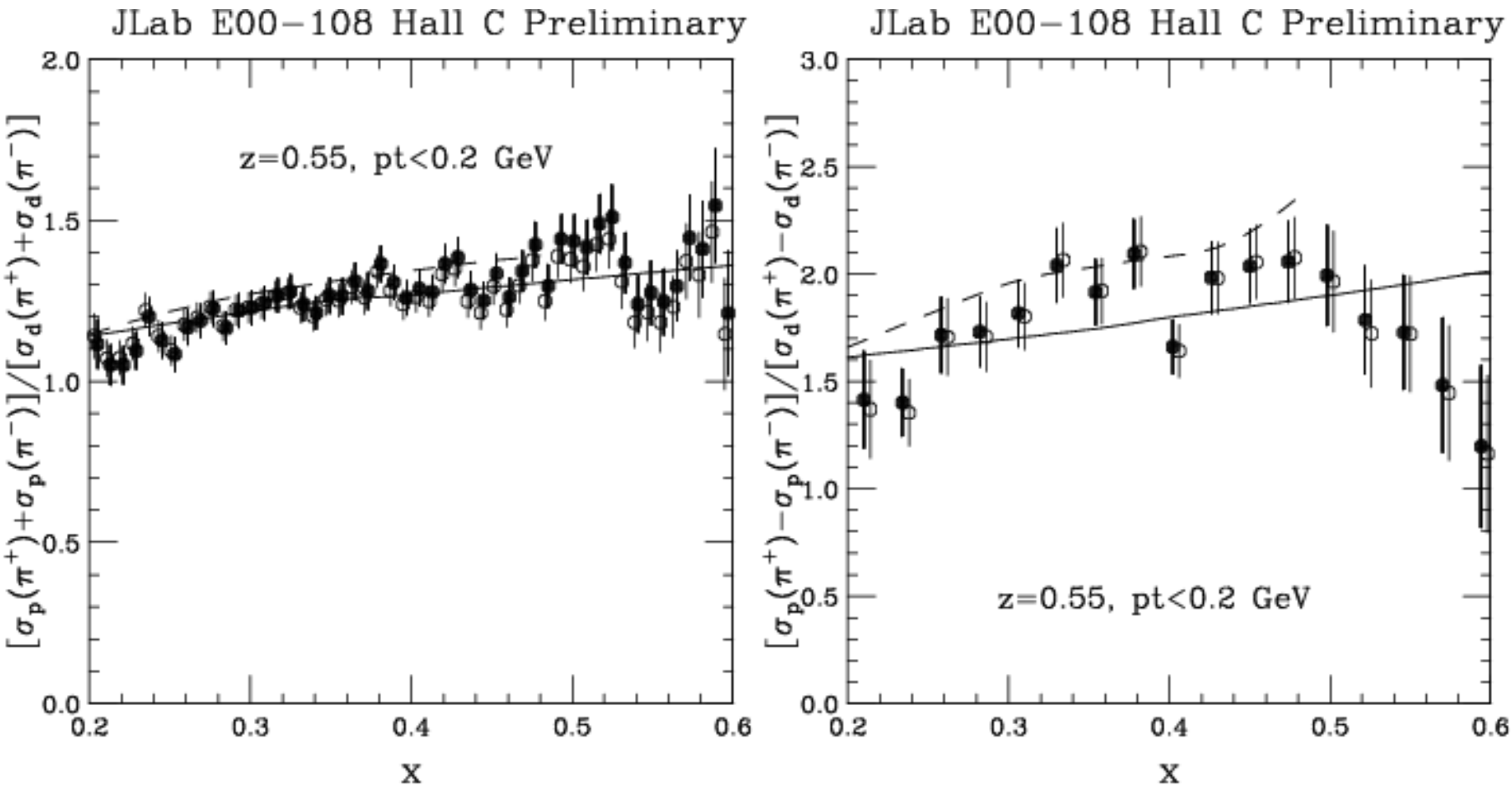
At low M_x (z>0.75) duality brakes down.





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**

Ratio D^-/D^+

(The Ratio unfavoured & favoured Fragmentation Functions)

- Assuming factorization & using the deuterium data only, the ratio D^-/D^+ can be extracted:

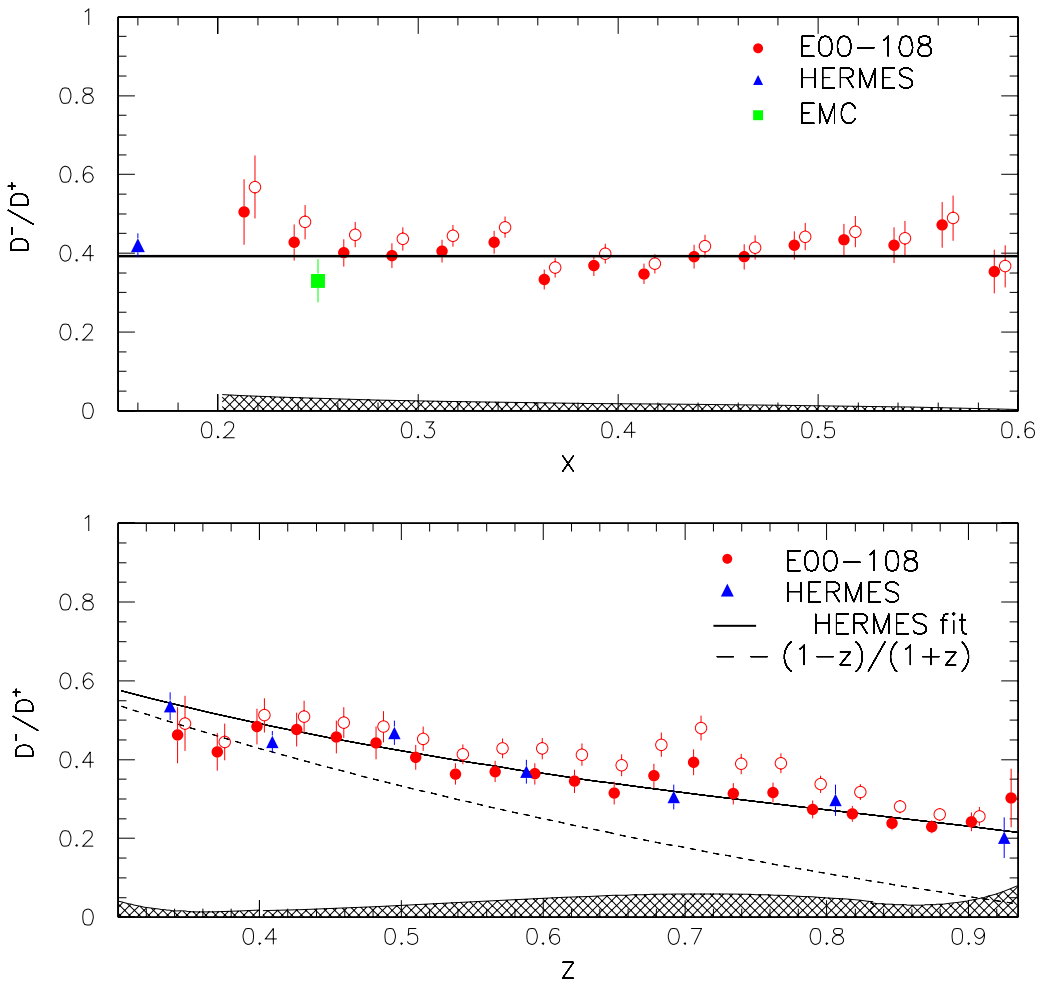
$$\sigma_d(\pi^+) = [u + d]\,[4D^+ + D^-]$$
$$\sigma_d(\pi^-) = [u + d]\,[4D^- + D^+]$$
$$D^-/D^+ = (4 - r) / (4r - 1)$$

were $r = \sigma_d(\pi^+)/\sigma_d(\pi^-)$

- **At high energy the ratio depend on z & Q^2**

- Will our results verify duality and this factorization assumption ?

D^-/D^+ from Deuteron π^+ to π^- ratio



- **Near-independence from x, as expected**
- **Our results agree with HERMES and EMC**
- **The resonant contribution at z>0.8 cancel out !**

First efforts to study cos(φ) terms

- In MC semi-inclusive cross in a simplest form:

$$\sigma_{SIDIS} \sim \sigma_{DIS}\,(dN/dz)\; b\, \exp(-bP_t^2)$$

- We found: Q^2-dependence in our data differs from the factorized high-energy expectation

- We did fine binning in Q^2, fitted the ratios of the yields with: $F(Q^2)=1+ C_1 \ln(Q^2)+C_2/Q^2+C_3/Q^4$

- For the analysis of cos(φ) terms in Monte Carlo we will use $\boldsymbol{\sigma_{SIDIS}}$ with this correction

First efforts to study cos(φ) terms

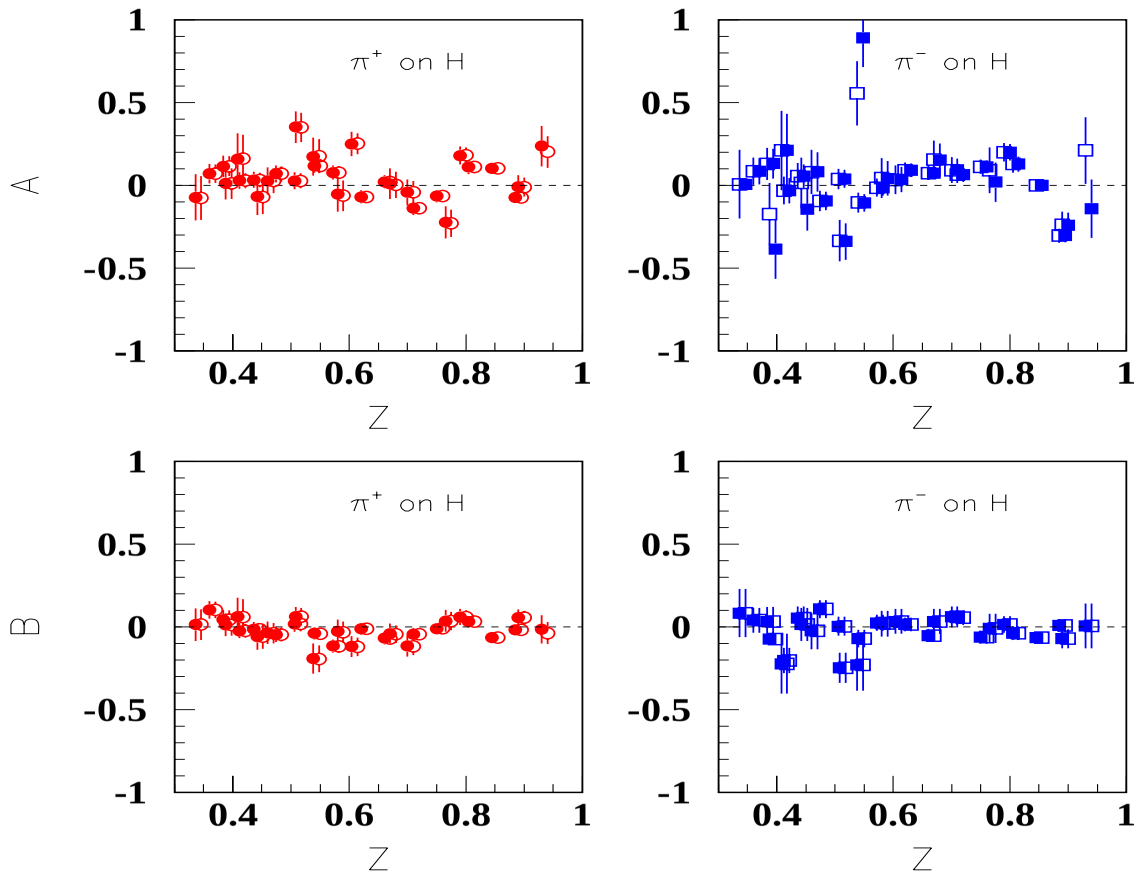
- We assume that all remaining difference data and MC can be addressed to the cos(φ) terms

- We did fine binning in φ and fitted the ratios of the normalized yields $\mathbf{Y_{data}/Y_{MC}}$ with function

$$\mathbf{F(\varphi)=P_3+P_1\cos(\varphi)+P_2\cos(2\varphi)}$$

- As a weights of cos(φ) and cos(2φ) terms in cross section one can use the the value:

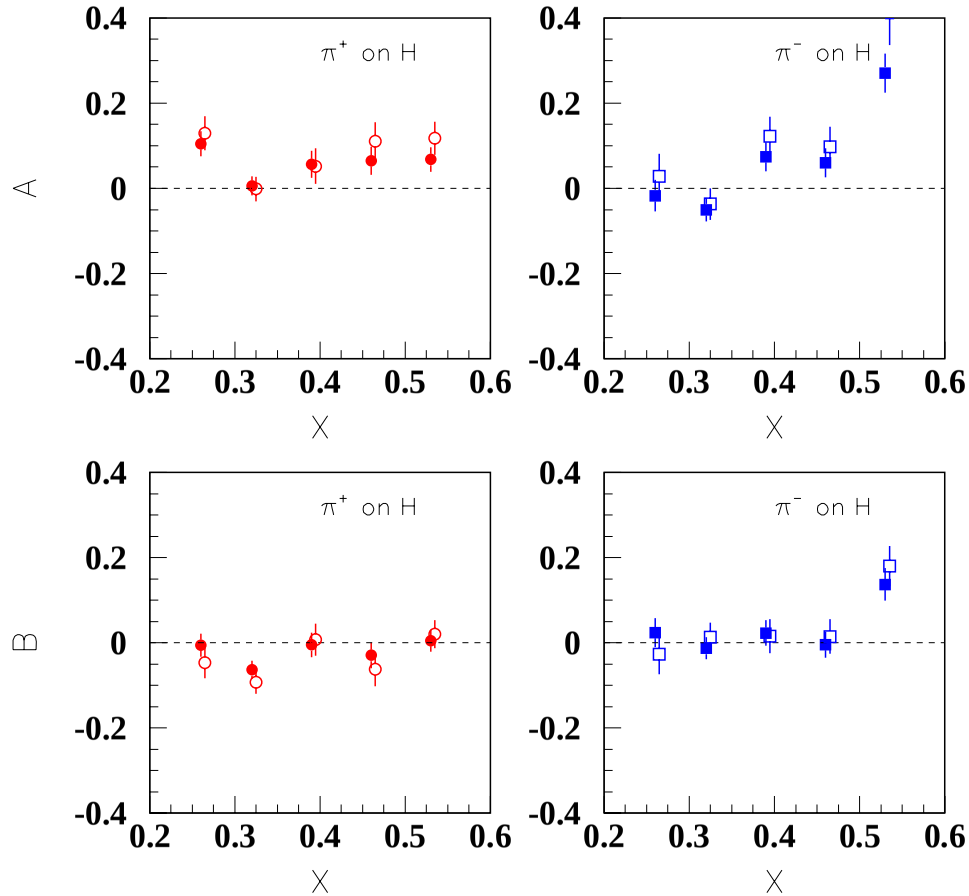
$$\mathbf{A=P_1/P_3} \text{ and } \mathbf{B=P_2/P_3}$$



$$\sigma_{SIDIS}=\sigma_{DIS}\cdot\sum e_i^2[q_i(x)D_i(z)]\cdot be^{-bp_t^2}\{1+A\cos(\varphi)+B\cos(2\varphi)\}$$

$$A\sim\sigma_{LT},\ B\sim\sigma_{TT}$$

Our very preliminary results: A≈B~0



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Our very preliminary results: A≈B~0

Summary

- Our data verify the onset of quark-hadron duality and factorization for $M_x^2>2$ ($z<0.7$) as predicted for high-energy.
- Factorization and duality brakes down at $z>0.7$
- First approach to study $\cos(\varphi)$ term implemented Preliminary results are: $A \approx B \sim 0$ for z-scan x-scan
- Detailed study effects of Radiation Corrections & physics background on φ terms of σ_{SIDIS} needed