Duality in Semi-Inclusive Deep Inelastic Scattering

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with thanks to my collaborators
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- Brief review of high energy model of SIDIS
- Hadron vs quark pictures
- SIDIS Duality Results from E00-108
- Precision $(e,e'\pi^{\pm})$,$(e,e'K^{\pm})$ cross sections at low $P_{h\perp}$
- Precision $(e,e'\pi^{0})$ cross sections at low $P_{h\perp}$
- L/T Separation of SIDIS $(e,e'\pi^{\pm})$ cross section

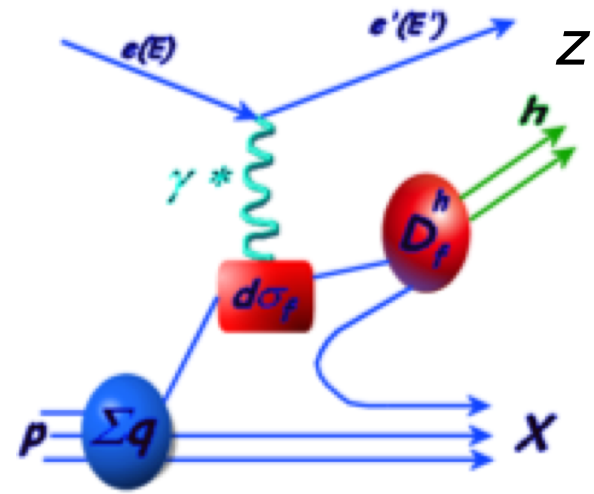
High Energy Model of SIDIS

Flavor Decomposition of SIDIS

$$\frac{1}{\sigma_{(e,e')}}\frac{d\sigma}{dz}(ep \to hX) = \frac{\sum_q e_q^2 f_q(x) D_q^h(z)}{\sum_q e_q^2(x) f_q(x)}$$

$f_q(x)$: parton distribution function

$D_q^h(z)$: fragmentation function



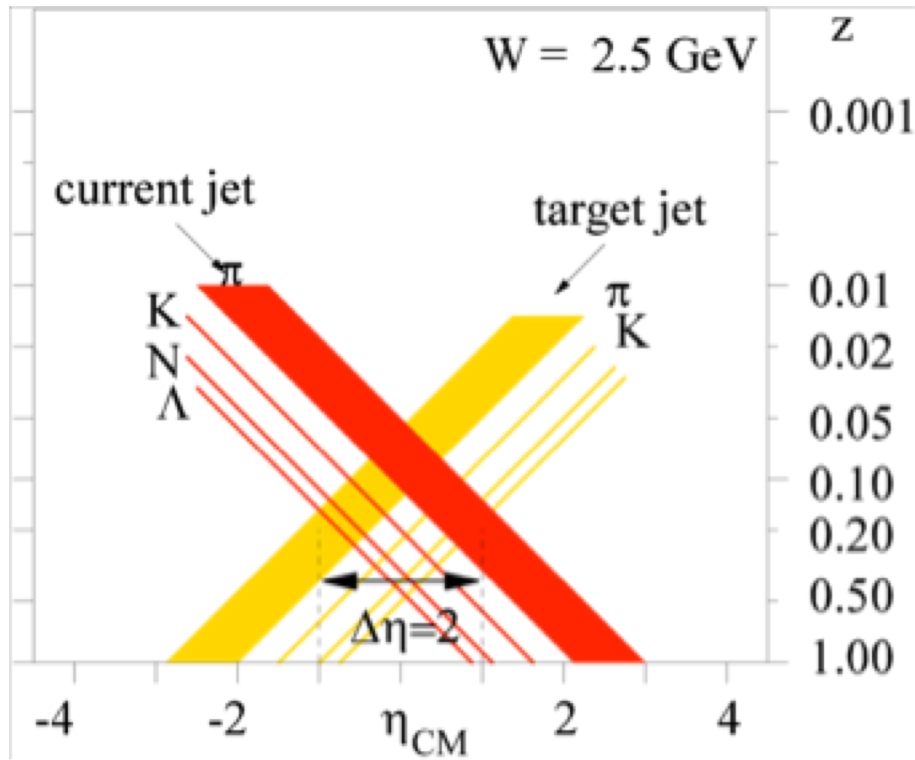
$z = E_h/\nu$

$M_x^2 = W'^2 \sim M^2 + Q^2\,(1/x - 1)(1 - z)$

- Leading-Order (LO) QCD
- after integration over $p_{h\perp}$ and Φ_h
- NLO: gluon radiation mixes
  x and z dependences
- Target-Mass corrections at large z
- ln(1-z) corrections at large z

With p_T and k_T dependences, some kind of convolution is necessary to obtain final $P_{h\perp}$

Current vs Target?



P.J. Mulders, hep-ph/0010199 (EPIC Workshop, MIT, 2000)

- Strict application of Berger “criterion” will limit useful range of kinematics; can we push our understanding to develop a more sophisticated measure?
- How do we expand this picture to handle large p_T?

Duality in Meson Electroproduction

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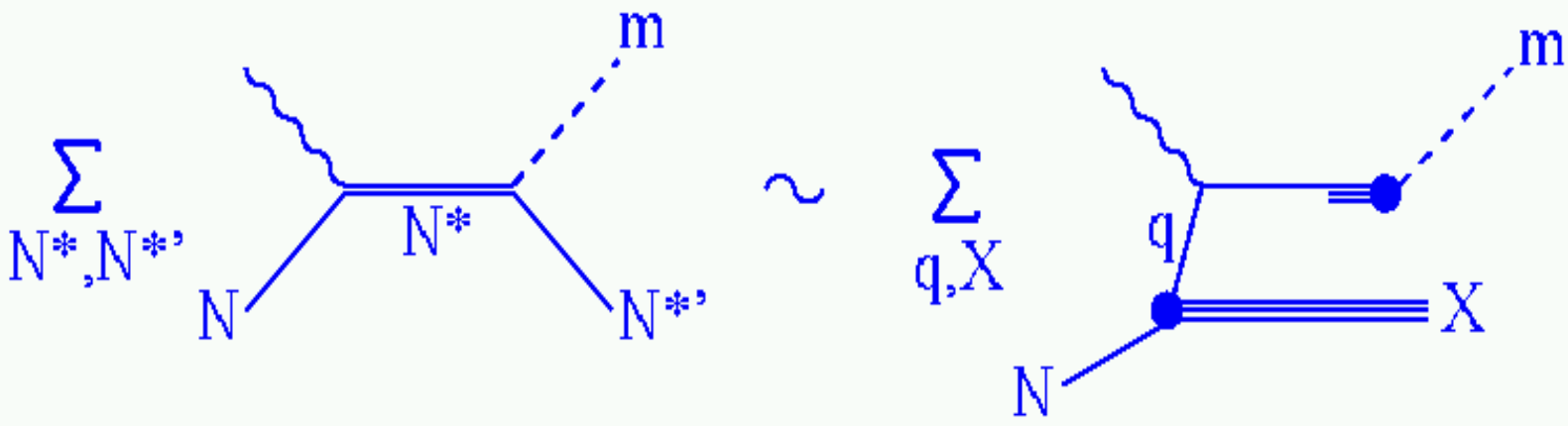
hadronic description ~ quark-gluon description



$$\sum_{N'^*} \left| \sum_{N^*} F_{\gamma^* N \to N^*}(Q^2, W^2)\, \mathcal{D}_{N^* \to N'^* M}(W^2, W'^2) \right|^2 \quad \sum_q e_q^2\, q(x)\, D_{q \to M}(z)$$

Transition Form Factor

Decay Amplitude

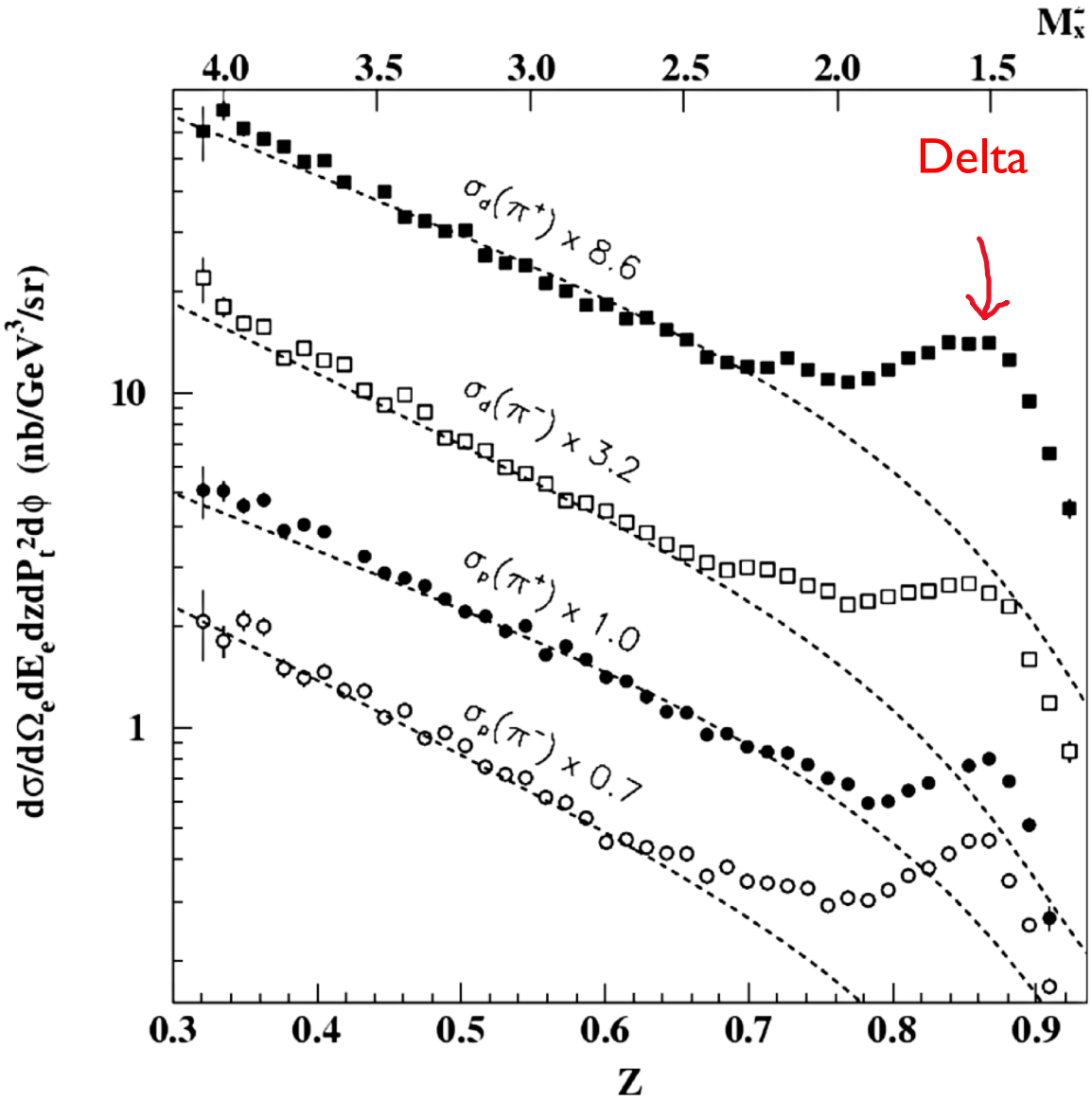
Fragmentation Function

SU(6) Model Expectation: Duality and factorization possible for $Q^2, W^2 \leq 3$ GeV^2 (Close and Isgur, Phys. Lett. B509, 81 (2001))

E00-108 Duality Results

T. Navasardyan et al., PRL 98 022001 (2007)

- Cross section/simulation based on factorization prediciton
- Clear Duality at low z
- Delta Resonance at high z



How Can We Verify Factorization?

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Neglect sea quarks and assume no p_t dependence to parton distribution functions

→ Fragmentation function dependence drops out in Leading Order

$$[\sigma_p(\pi^+) + \sigma_p(\pi^-)]/[\sigma_d(\pi^+) + \sigma_d(\pi^-)]$$

$$= [4u(x) + d(x)]/[5(u(x) + d(x))]$$

$$\sim \sigma_p/\sigma_d \quad \textit{independent of } z \textit{ and } p_t$$

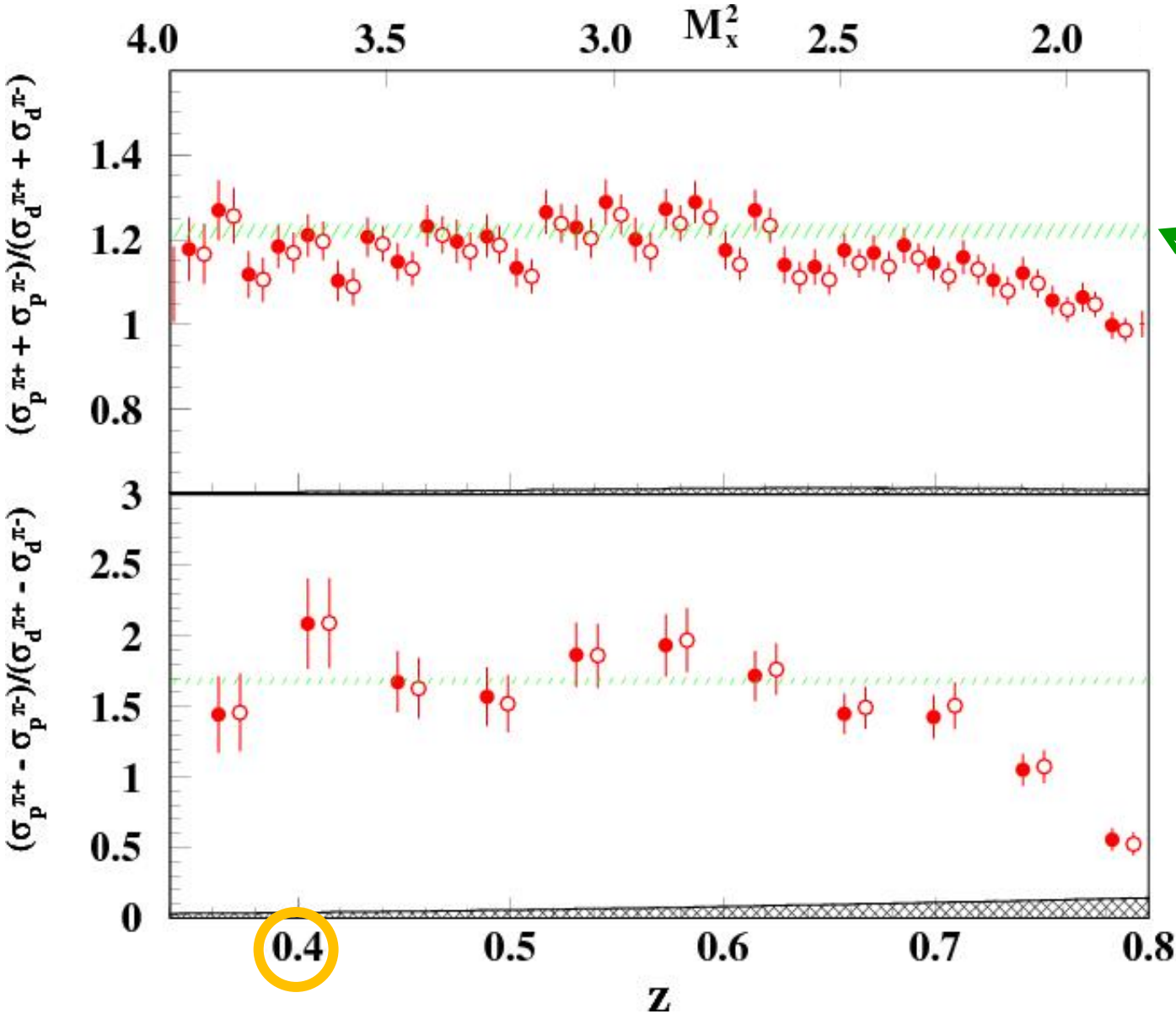
$$[\sigma_p(\pi^+) - \sigma_p(\pi^-)]/[\sigma_d(\pi^+) - \sigma_d(\pi^-)]$$

$$= [4u(x) - d(x)]/[3(u(x) + d(x))]$$

independent of z and p_t, but more sensitive to assumptions

E00-108: Onset of the Parton Model

R. Ent
Slide



Closed (open) symbols reflect data after (before) events from coherent ρ production are subtracted

GRV & CTEQ, @ LO or NLO

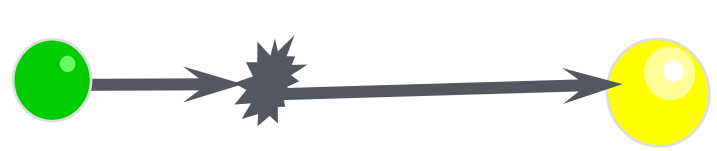
Good description for p and d targets for $0.4 < z < 0.65$

(Note: $z = 0.65 \sim M_x^2 = 2.5\ GeV^2$)

E00-108: Onset of the Parton Model

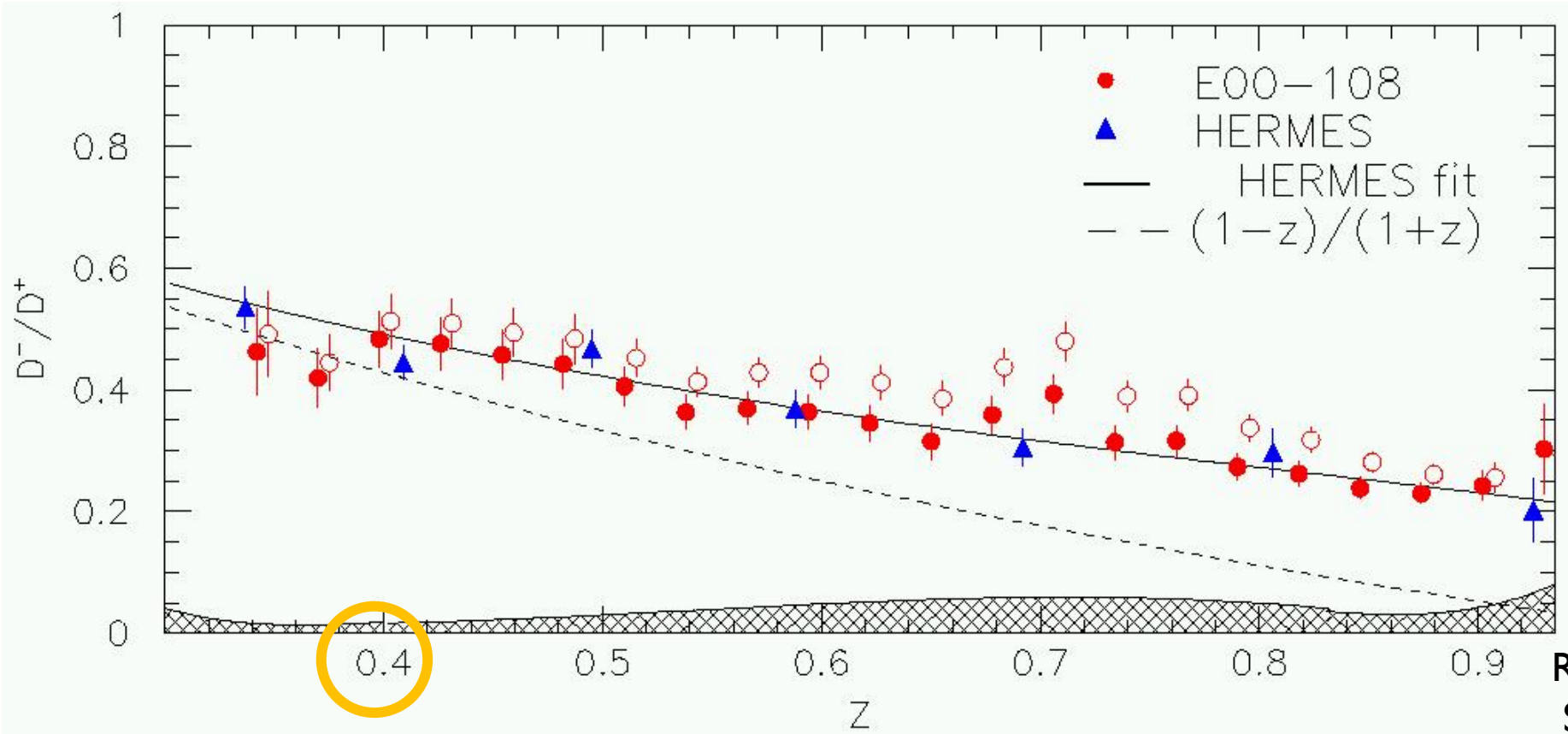
$$\Sigma e_q^2 q(x)\, D_q^{\pi}(z)$$

factorization



Collinear Fragmentation

$$\frac{D^-}{D^+} = \frac{4-R}{4*R-1} \qquad R = \frac{N_{\pi^+}}{N_{\pi^-}}$$ (Deuterium data)



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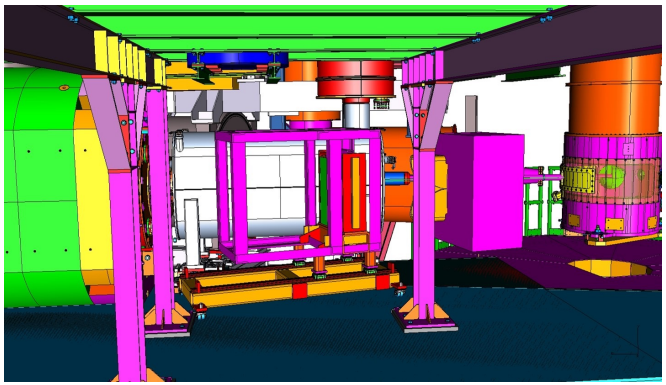
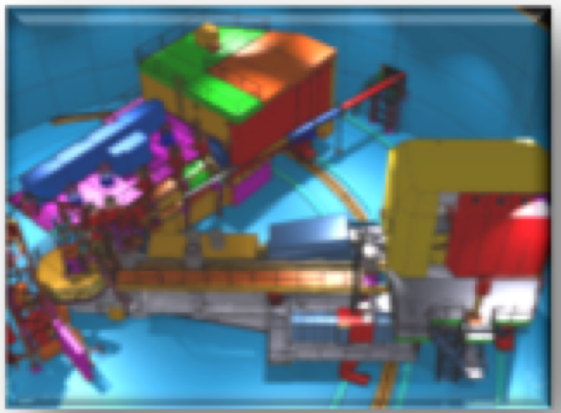
W′ = 2 GeV ~ z = 0.35 → data predominantly in "resonance region"

What happened to the resonances?

Precision SIDIS in Hall C

- Using magnetic spectrometers one can explore the highest luminosities! Hall C has SHMS and HMS.
- Common pivot allows most precise L/T separations
- New Neutral Particle Spectrometer adds π^0 capability with good acceptance.
- Precise cross sections/ratios for (e,e' $\pi^{\pm}$) and (e,e' $\pi^{0)}$ measurements at DIS kinematics
- New cross sections/ratios for (e,e' $K^{\pm}$)
- First direct determination of L/T ratio for SIDIS cross sections!





Precision (e,e'$\pi^{\pm}$),(e,e'$K^{\pm}$) cross sections at low $P_{h\perp}$

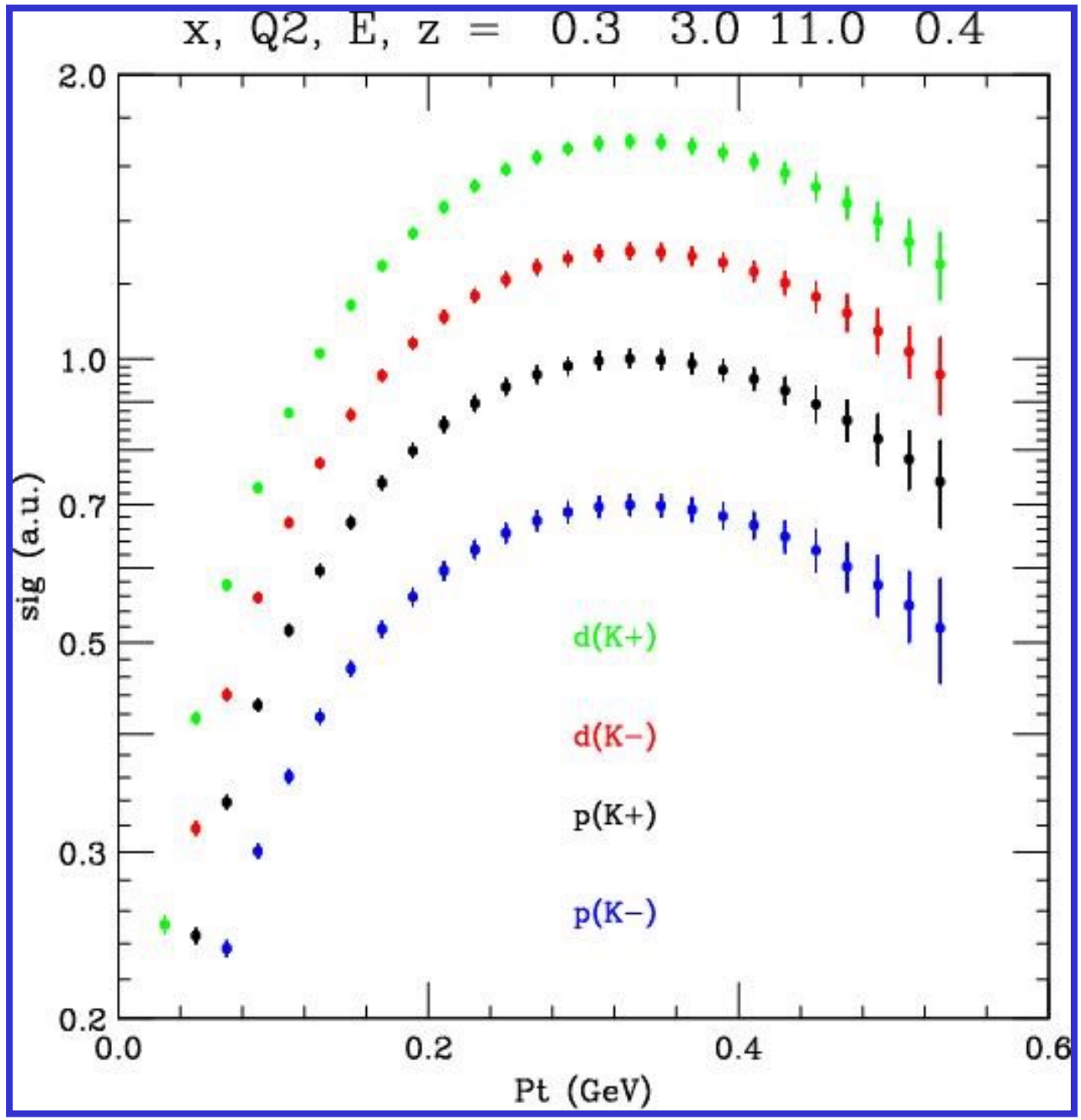
- Precision measurements to test the assumptions in factorization of SIDIS
- Explore assumptions of favored/disfavored fragmentation of different flavor quarks
- Look for target mass effects
- Higher twist effect
- Complementary to Hall B SIDIS measurements

Experiment E12-09-017

New experiment at 11 GeV: E12-09-17

- W^2 = 5.08 GeV^2 and larger (up to 11.38 GeV^2)
- Use SHMS angle down to 5.5 degrees (for π detection)
  HMS angle down to 10.5 degrees (e^- detection)
  separation HMS-SHMS > 17.5 degrees
- $M_X^2 = M_p^2 + Q^2(1/x - 1)(1 - z) > 2.9$ GeV^2 (up to 7.8 GeV^2)
- Improved coverage in all kinematic variables, especially ϕ and p_T
- Choice to keep Q^2/x fixed q_γ ~ constant (exception are data scanning Q^2 at fixed x)
- All kinematics both for π^+ (and K^+) and π^- (and K^-), both for LH2 and LD2 (and Aluminum dummy)

Example of Expected Charged Kaon Precision



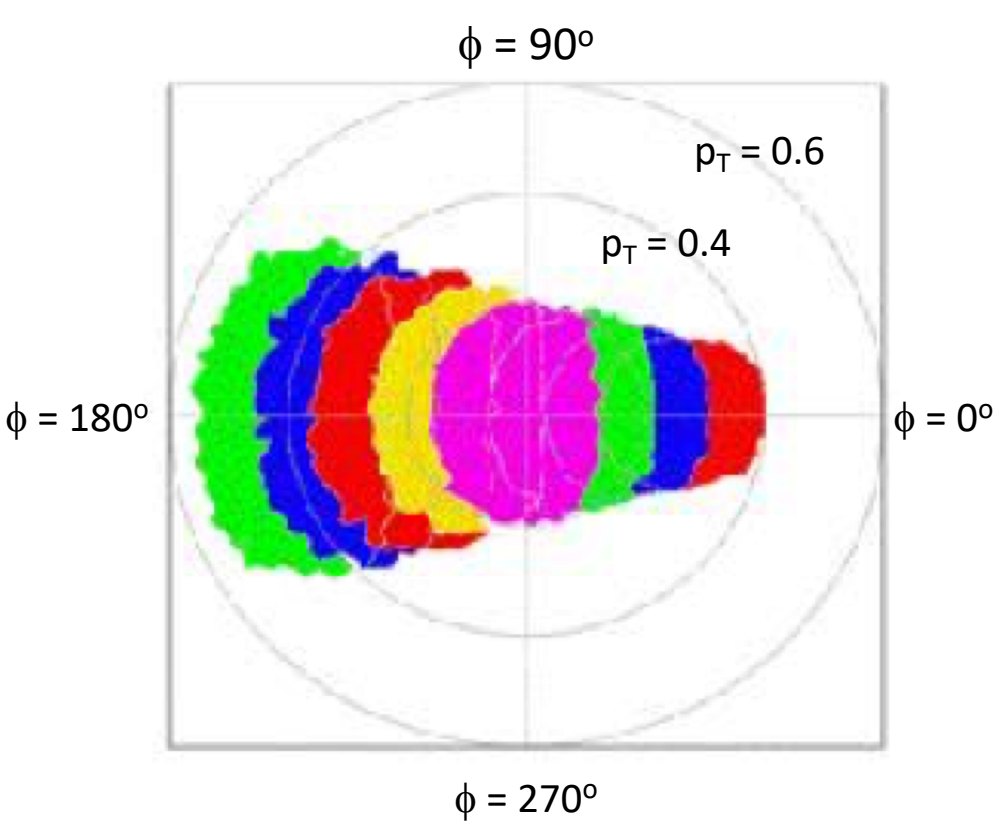
Precision $(e,e'\pi^0)$ cross sections at low $P_{h\perp}$

- Neutral pions are a good test and consistency check of flavor assumptions in extraction of TMDs with TM fragmentation
- Experimental measurement cleaner in terms of ρ (vector meson) contamination, exclusive pole contributions and hadron EM radiation effects
- Combined with charged pion/kaon data provides important constraint for analyzing future SIDIS experiments and TMD extraction

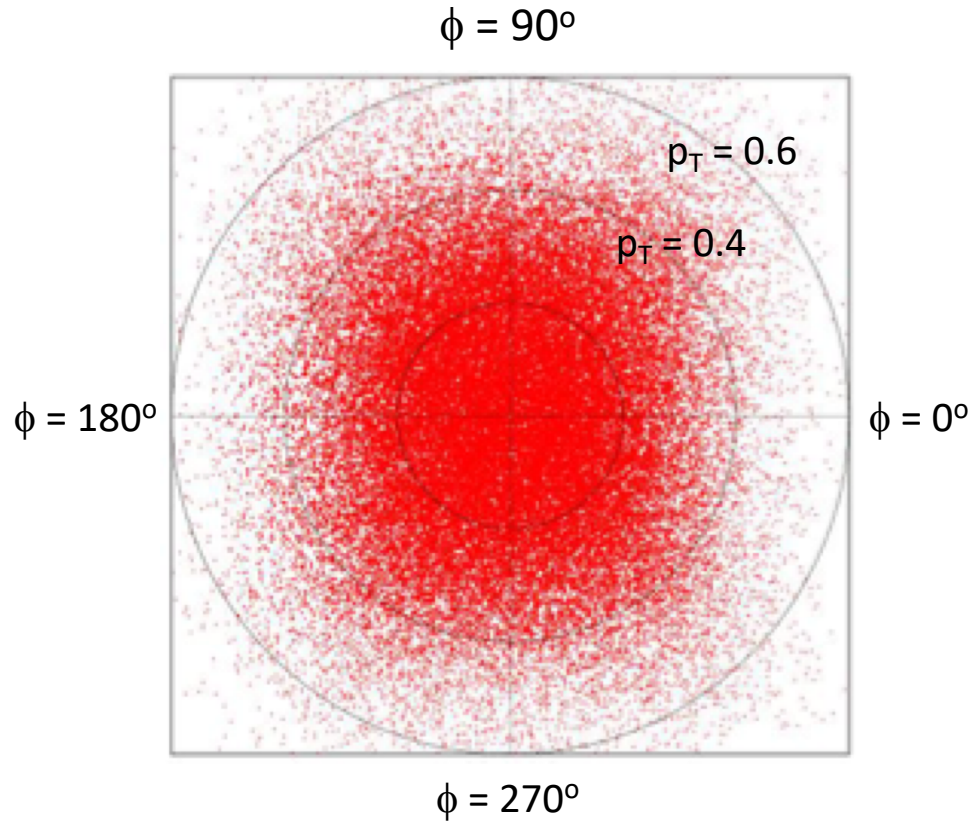
Experiment E12-13-007

$P_{h\perp}$ Coverage of SIDIS experiments

$(e,e'\pi^{\pm})$ with SHMS
E12-09-017



$(e,e'\pi^{0})$ with NPS
E12-13-007

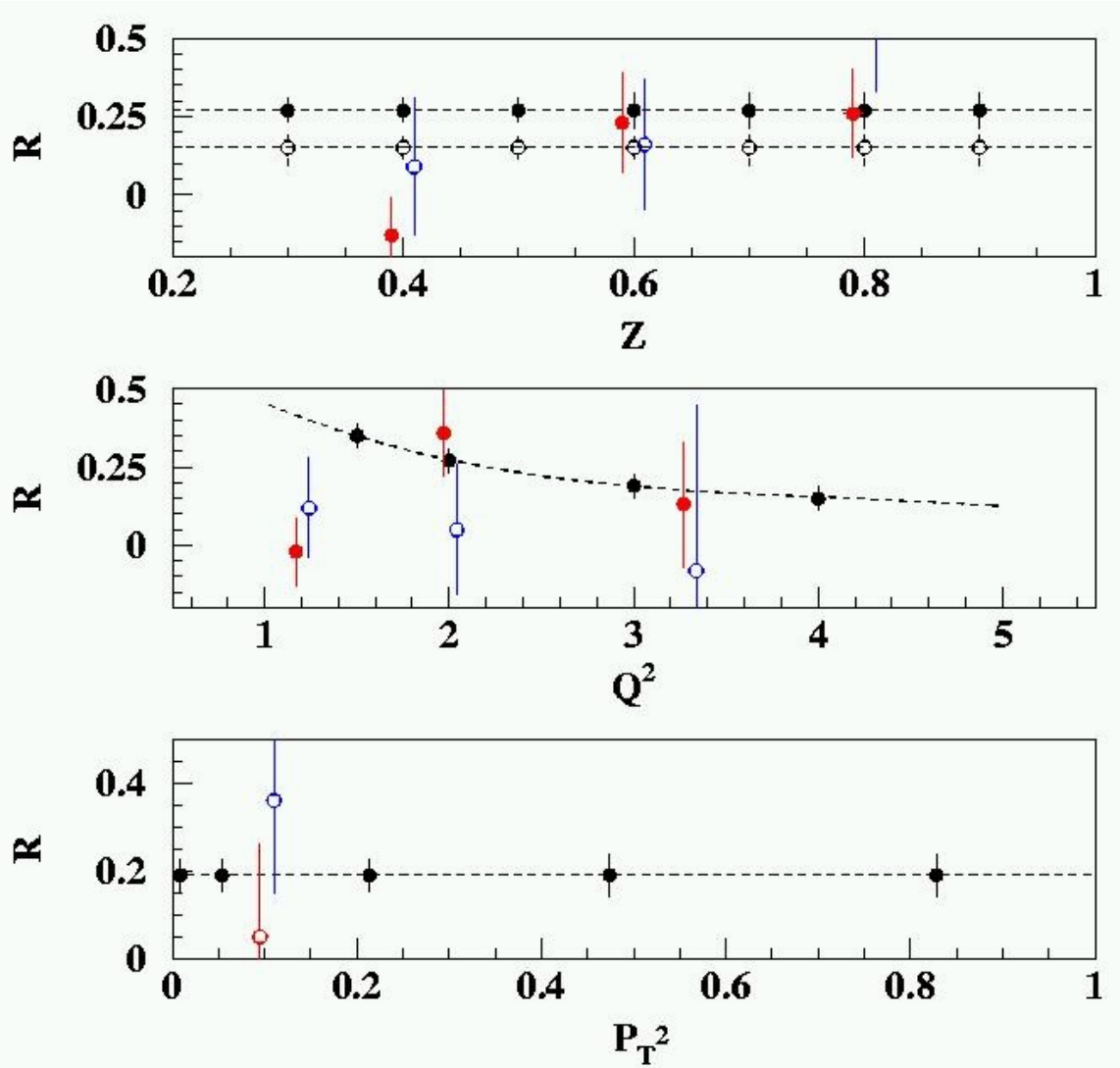


L/T Separation of SIDIS (e,e'$\pi^{\pm}$) cross section

- All SIDIS flavor analyses assume a value of $R_{SIDIS} = \sigma_L/\sigma_T$ as it has never been measured!
- Common assumption is $R_{SIDIS} = R_{DIS}$
- How does R_{SIDIS} depend on z?
- How does R_{SIDIS} depend on hadron type?
- How does R_{SIDIS} depend on $P_{h\perp}$?
- Do we understand Q^2 dependence in SIDIS and in Exclusive ($z \rightarrow 1$) regimes?
- Hall C spectrometers ideal for precise R measurement

Experiment E12-06-104

Expected R = σ_L/σ_T Results



Planned scans in z at Q^2 = 2.0 (x = 0.2) and 4.0 GeV^2 (x = 0.4)
→ should settle the behavior of σ_L/σ_T for large z.

Planned data cover range Q^2 = 1.5 – 5.0 GeV^2, with data for both H and D at Q^2 = 2 GeV^2

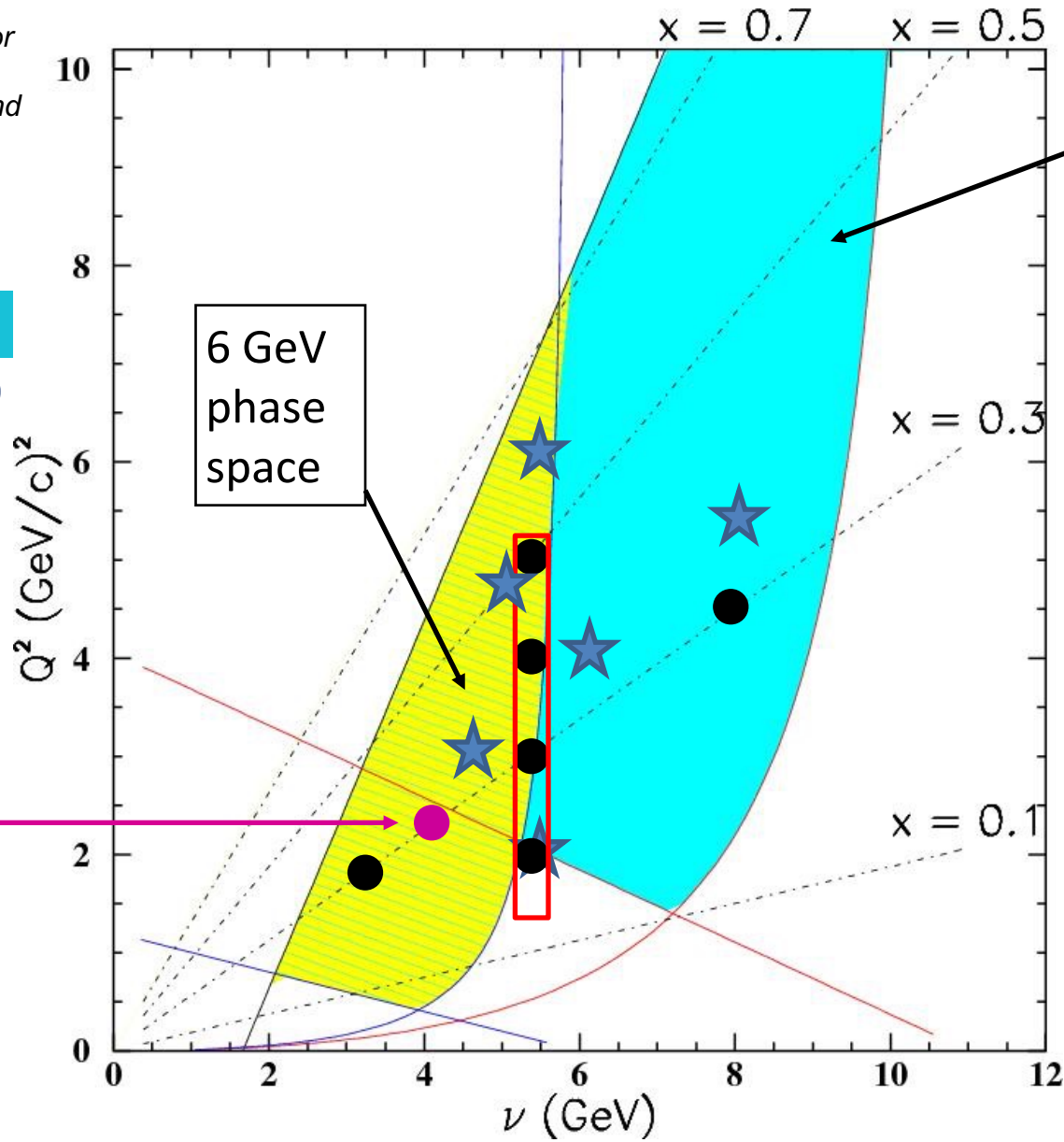
Planned data cover range in P_T up to ~ 1 GeV.
The coverage in ϕ is excellent (o.k.) up to P_T = 0.2 (0.4) GeV.

Solid black points are simulation results; colored points are from 70's experiments at Cornell.

Hall C Kinematic Reach

HMS + SHMS (or NPS) Accessible Phase Space for SIDIS

Accurate cross sections for validation of SIDIS factorization framework and for L/T separations



E12-13-007
Neutral pions:
Scan in (x,z,P_T)
Overlap with
E12-09-017

E00-108
(6 GeV)

Charged pions:

- E12-06-104
  L/T scan in (z,P_T)
  No scan in Q^2 at fixed x: $R_{DIS}(Q^2)$ known
- E12-09-017
  Scan in (x,z,P_T)
  + scan in Q^2 at fixed x

Choice of Kinematics – cont.

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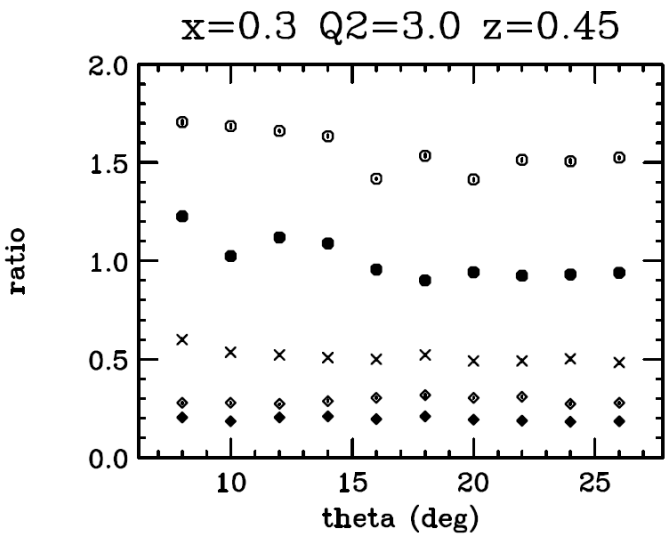
Kin	x	Q^2 (GeV^2)	Z	P_π (GeV)	Θ_π (deg)
I	0.2	2.0	0.3 -0.6	1.7 – 3.3	8.0 – 23.0
II	0.3	3.0	0.3 -0.6	1.7 – 3.4	5.5 – 25.5
III	0.4	4.0	0.3 -0.6	1.7 – 3.4	5.5 – 25.5
IV	0.5	5.0	0.3 -0.6	1.7 – 3.5	8.0 – 28.0
V	0.3	1.8	0.3 -0.6	1.1 – 2.1	8.0 – 30.5
VI	0.3	4.5	0.3 -0.6	2.5 – 5.0	5.5 – 20.5

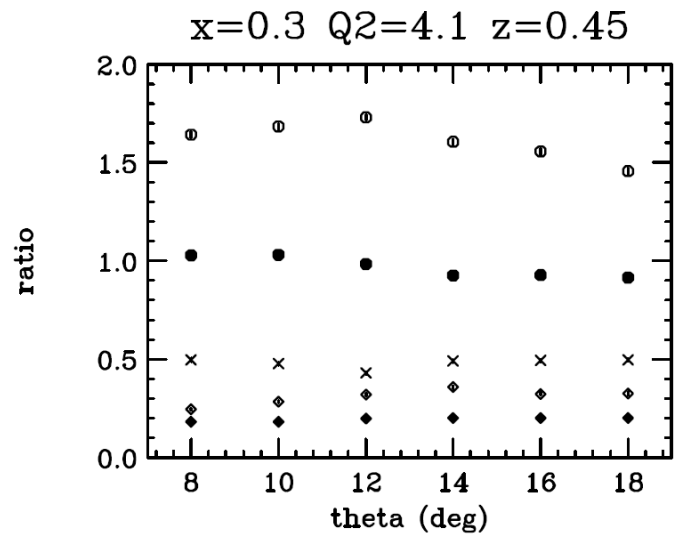
Map of p_T dependence in x and z, in Q^2 to check (p_T/Q) and (p_T^2/Q^2) behavior

Kinematics I, II, III, and IV are identical to those where this collaboration also plans to map R (= σ_L/σ_T) in SIDIS in E12-06-104. These are the priority for 2017 run.

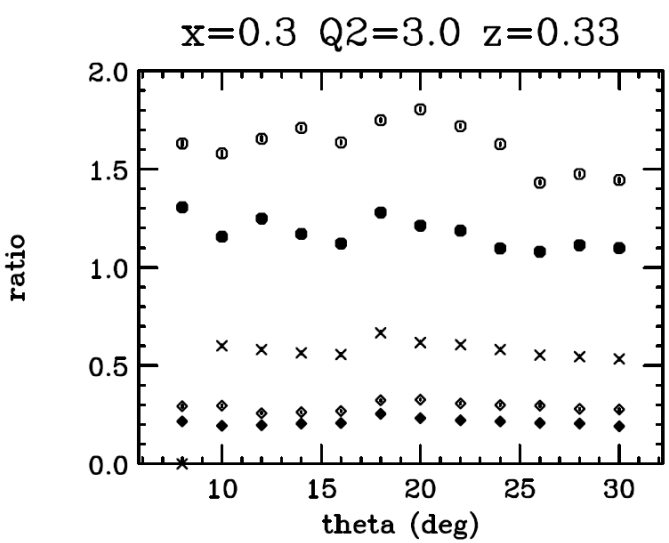
E12-09-017 Quasi-Online Results – Pions

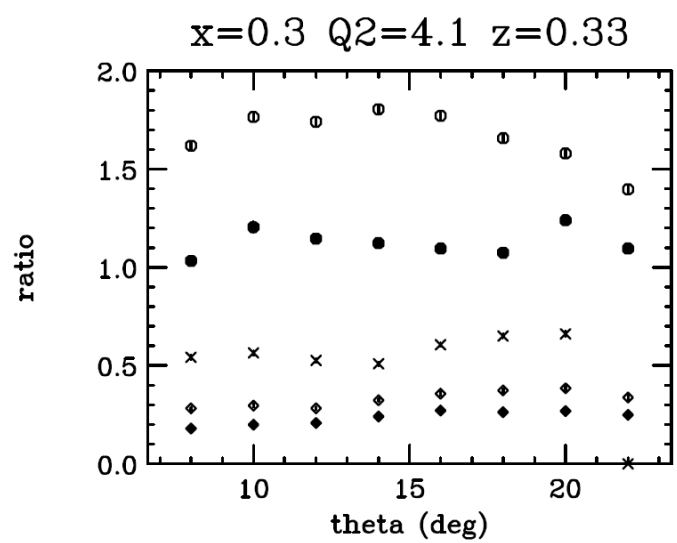
not normalized by target density: just ratios of counts/mC corrected for computer dead time.





Ratio to pi+ from LH2 of
pi+ from LD2 (open circles)
pi+ from Al (open diamonds)
pi- from LH2 (crosses)
pi- from LD2 (filled circles)
pi- from Al (filled diamonds)





Anashe Bandari & Peter Bosted

Timescales

- Charge pion, kaon measurements in 2018/2019
- Neutral pion measurements as soon as 2020
- R measurements to be scheduled after first commissioning Hall C measurements are analyzed in order to obtain the best accuracy

Summary

- E12-09-017, E12-13-007, and E12-06-104 will provide SIDIS charged pion+kaon data to allow tests of factorization and duality in meson electroproduction and will also explore new territory with (e,e'π^0) and R_{SIDIS} measurements.