Update on SIDIS-PT Experiment E12-09-017

Edward R. Kinney, University of Colorado at Boulder

with thanks to my collaborators

*A. Bandari, **P. Bosted** (William & Mary), R. Ent (Jefferson Lab), H. Mkrtchyan, V. Tadevosyan (Yerevan)*

- Brief review of motivation
- Tasks completed
- Ratio Results
- To-Do List

E12-09-017:
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 effects
- Complementary to Hall B SIDIS measurements

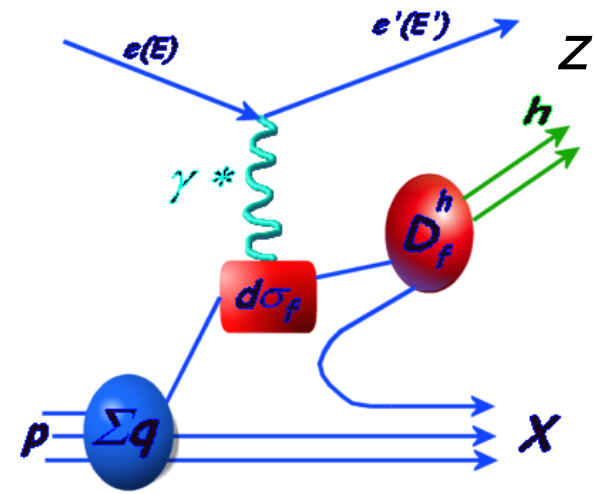
Do parton distributions and fragmentation functions factorize at Jefferson Lab energies?

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 $P_{h\perp}$

Kinematic Plan at 11 GeV

- W^2 = 5.08 GeV^2 and larger (up to 11.38 GeV^2)
- Used SHMS angle down to 6.6 degrees (for π detection)
  HMS angle down to 13.5 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)

Completed Tasks - 1 -

- Found and fixed several error in standard.kinematics using several methods including singles rates, coincidence rates, and overlaps between runs with adjacent SIMC angles or momenta.
- Determined BCM corrections using HMS singles rates.
- All detector calibrations done.
- Fixed a problem in the tracking code that was limiting tracking efficiency at high rates.
- Improved track pruning. Now includes more criteria.
- Determined tracking parameters that give high efficiency even at high rates.
- Tried to fix poor resolution in double arm timing in Fall 2018 with not much success. However, found that one can use TOF using RF signal to separate kaons and pions using timing.

Completed Tasks - 2 -

- Found problem with TDC versus ADC timing window. Implemented a code to fix this using best time from the hodoscopes, and applying it to the other detectors. This increased Aerogel efficiency to close to 99% at high rates (was as low as 90% before).

- Found problems with matching SIMC to data on edges of acceptance. Partially fixed by removing a 5 mr offset in the vertical angles of HMS (left over from 6 GeV era).

- Determined a "fiducial region" in p/theta/phi space for each spectrometer where the ratio of data/SIMC is smooth and reasonable. This keeps about 50% of events.

- Changed random number in SIMC to one that does not repeat.

- In process of adjusting SIDIS model in SIMC to agree better with data

Preliminary Analysis Results - 1 -

- Basic method of analysis is to determine normalized rates, defined as accidental-subtracted counts divided by beam charge, target thickness, and detector efficiencies to obtain counts per mC per gm/cm**2

- The same thing is done for the simulated SIMC events. In all plots, the SIMC model has a single slope parameter (versus pT**2) of 4 (no dependence on quark flavor or z)

- The SIDIS rates for SIDIS and radiated exclusive pion events are summed.

- Rates for runs at identical kinematics are averaged together and checked for agreement. Disagreements were used to correct the run information list and fix the problems mentioned above for runs at different beam currents.

- Pion ID is mainly done by requiring a signal in Aerogel, but not in Noble Gas (Spring18 only). And E/P in calorimeter < 0.7 or so. For P>3 GeV, also the Heavy Gas is required to have a signal.

Ratios to Hydrogen π+ -1-

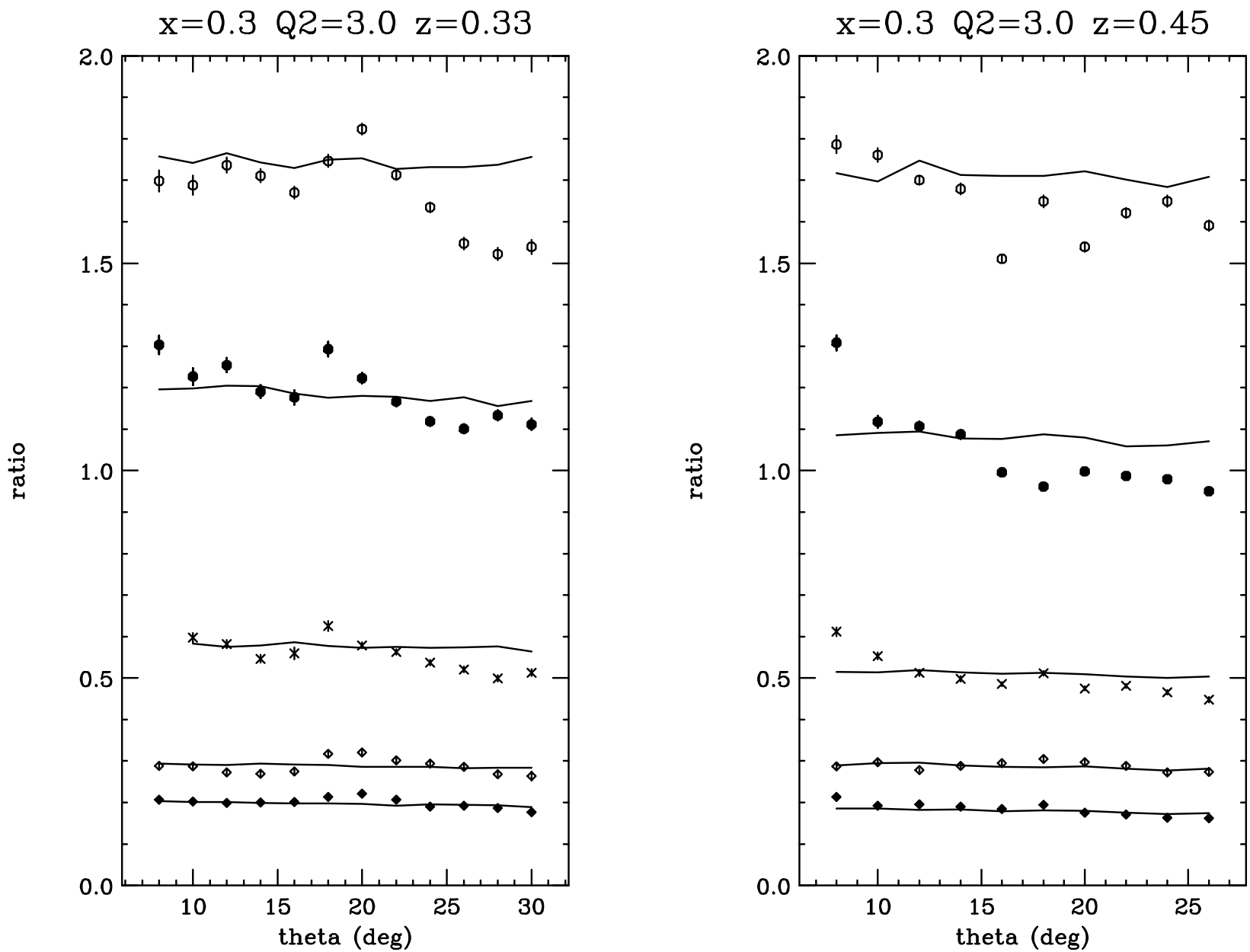
^{2}H(π+)

^{2}H(π-)

^{1}H(π-)

Al(π+)

Al(π-)



Curves: SIMC

Ratios to Hydrogen π+ -2-

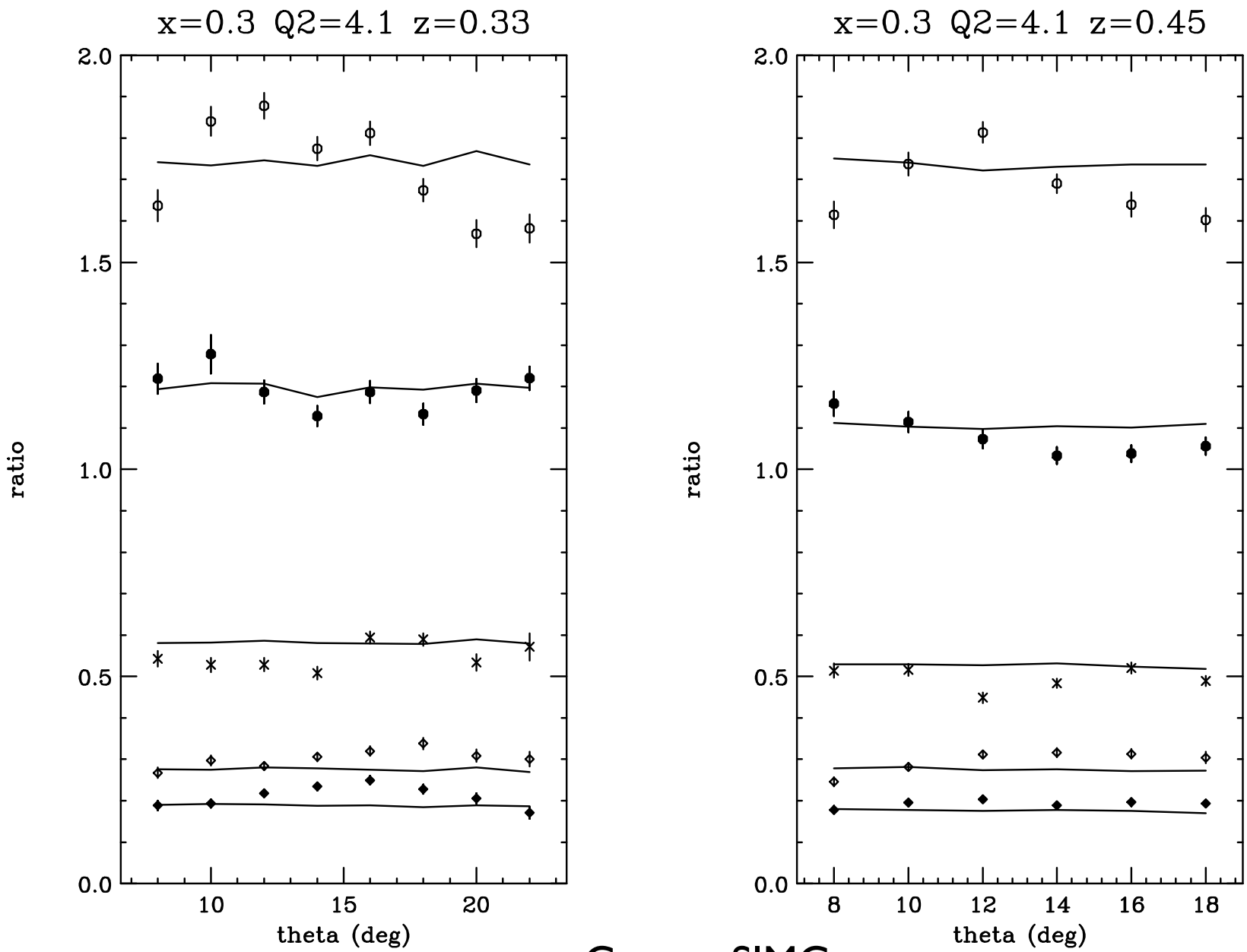
^{2}H(π+)

^{2}H(π-)

^{1}H(π-)

Al(π+)

Al(π-)



Curves: SIMC

Ratios to Hydrogen π+ -3-

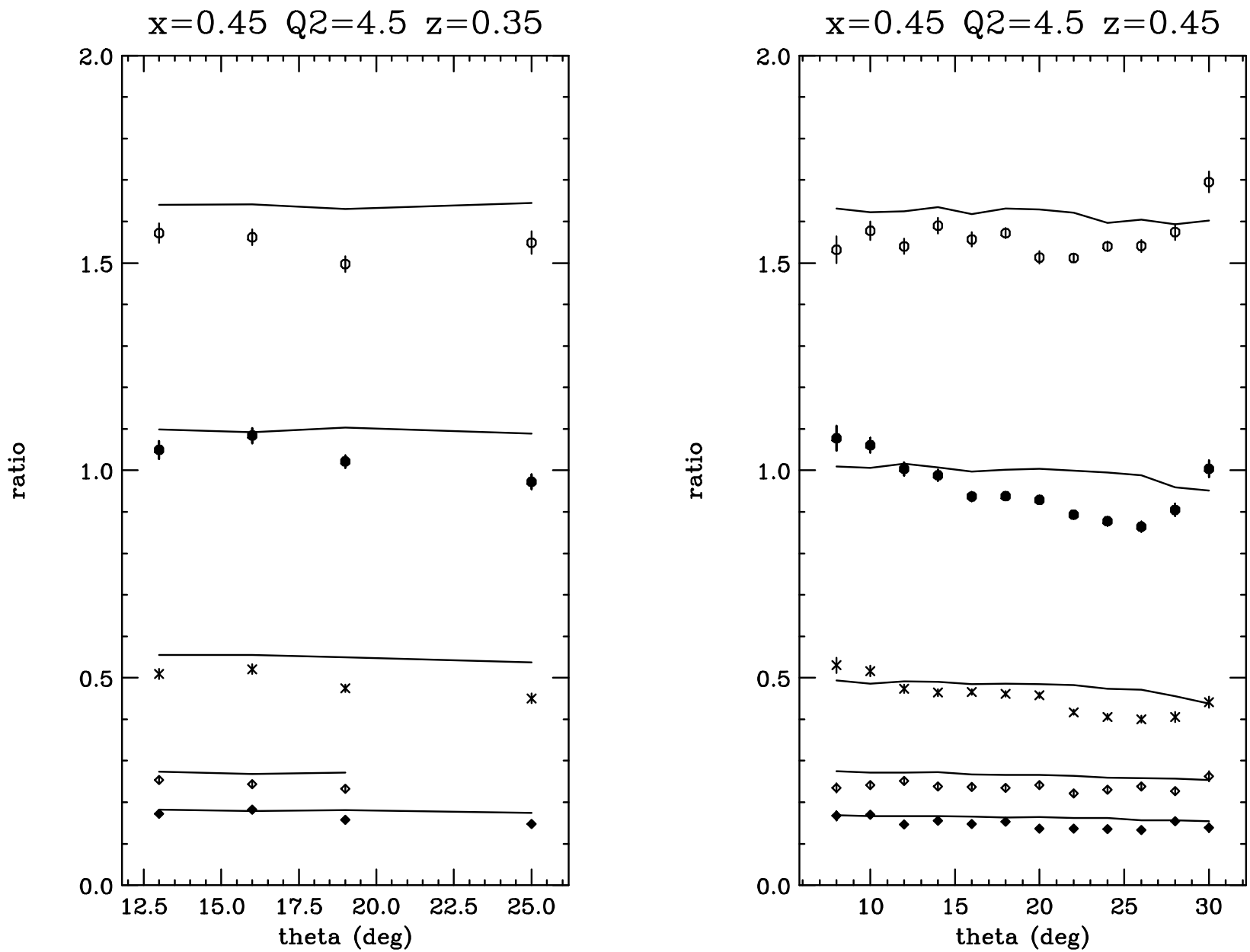
^{2}H(π+)

^{2}H(π-)

^{1}H(π-)

Al(π+)

Al(π-)



Curves: SIMC

Ratio Discussion

- Overall, the magnitude of the data ratios is in reasonable agreement with SIMC ratios. There is a slight trend for the ratios to be smaller than SIMC at larger SHMS angles (larger pt). Note, the model assumes no difference in the phi*-dependence for pi+ or pi+, nor proton or neutron.

- However, one has to be careful before interpreting these plots, because the range of phi* changes: at low pt the coverage is close to 360 deg., while at high pt, it is a narrow range around 180 deg. Hence a difference from SIMC could be due to a combination of pt-dependence and phi* dependence for pi+/pi+ and/or p/d.

- Also, one can see an upturn in the data ratios at the highest SHMS angles for the high Q2 setting. At these kinematics,the exclusive pion tails are large, of order 20%. Peter thinks the reason is that his model for e p -> Delta++ pi- is too small by a large amount.

Exclusive Tail Study

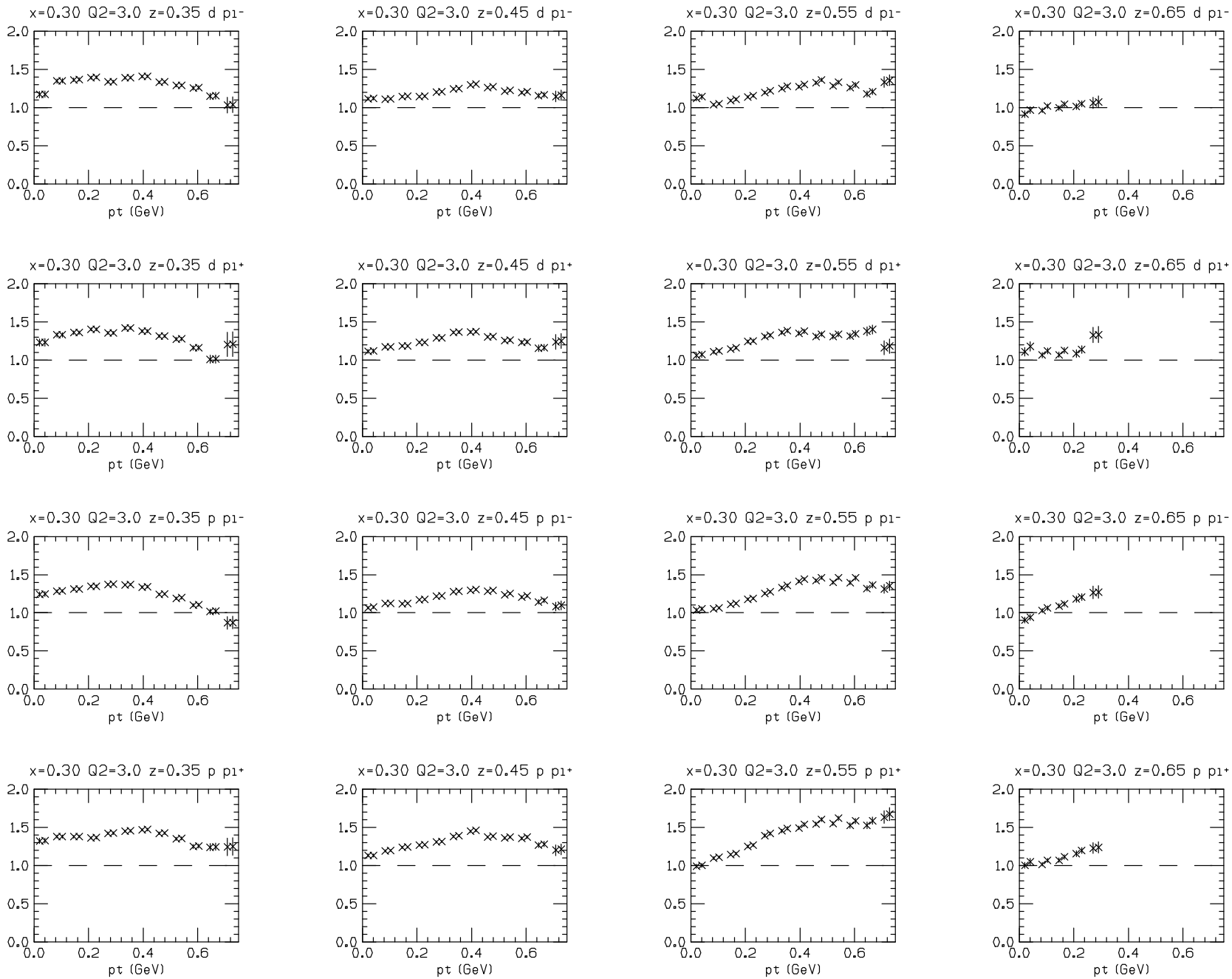
- To study the exclusive tail in more detail, ratios of data/SIMC are obtained for each run in bins of x/Q2, pt, z, and phi*. The ratios for a given target and pion polarity are averaged over all runs for each of these bins.

- With no fiducial acceptance cuts, the agreement between runs at different SHMS momenta and angles started off being very poor, but after fiducial cuts and fixing the rate dependencies as mentioned above, the agreements are reasonable, although there is evidence for non-statistical systematic effects on the few percent level.

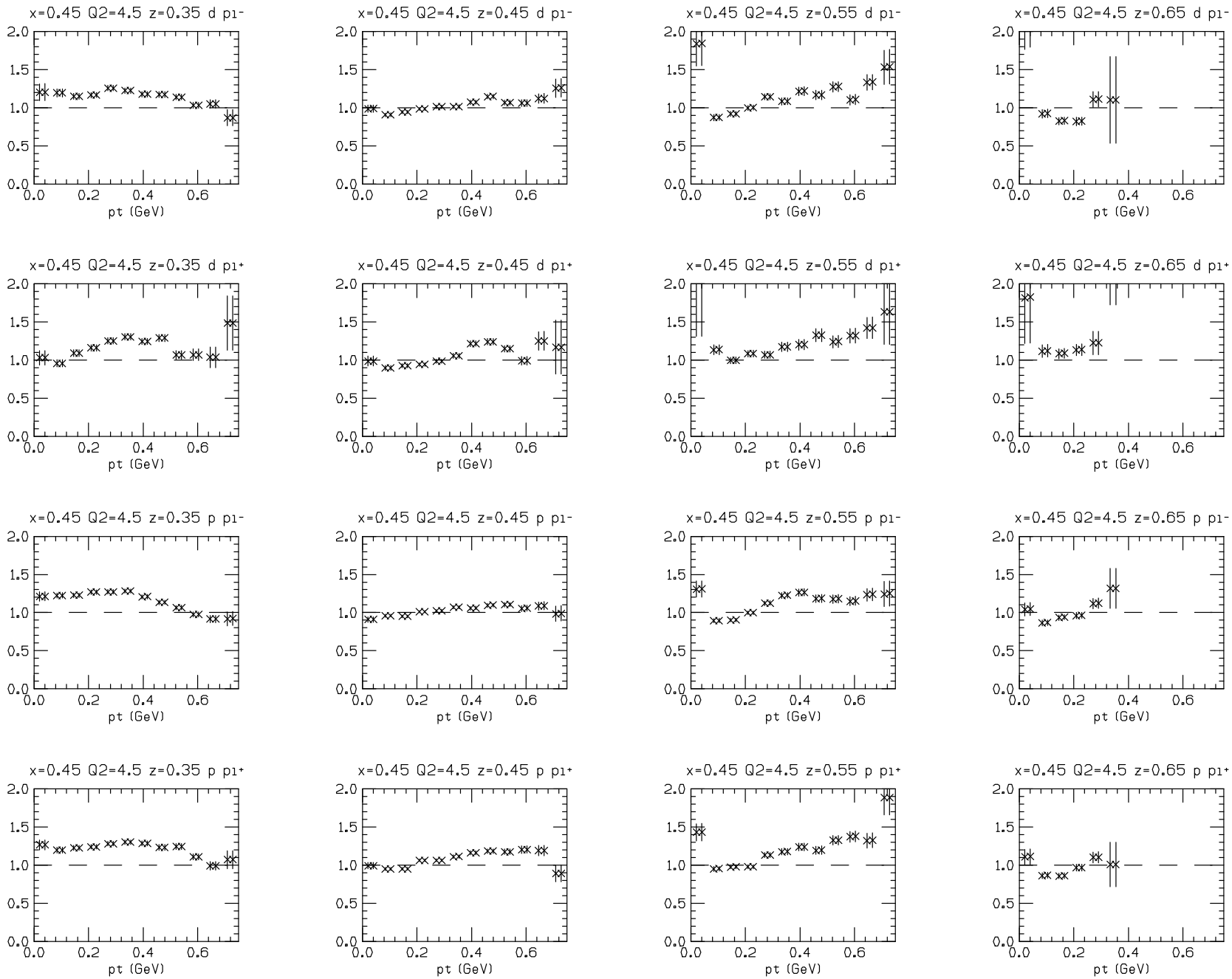
- In the following slides, the ratios of data / SIMC are plotted as a function of pt, averaged over the 120<phi*<240 deg., for four bins in z, and our three main kinematic settings in x/Q2

- Each data point is plotted twice: slightly offset in pt. The right-hand ones are ratios of data to SIMC without exclusive tail, while the left hand ones include the exclusive tails. In most kinematics, the tail is small, but in others it is of order 20%.

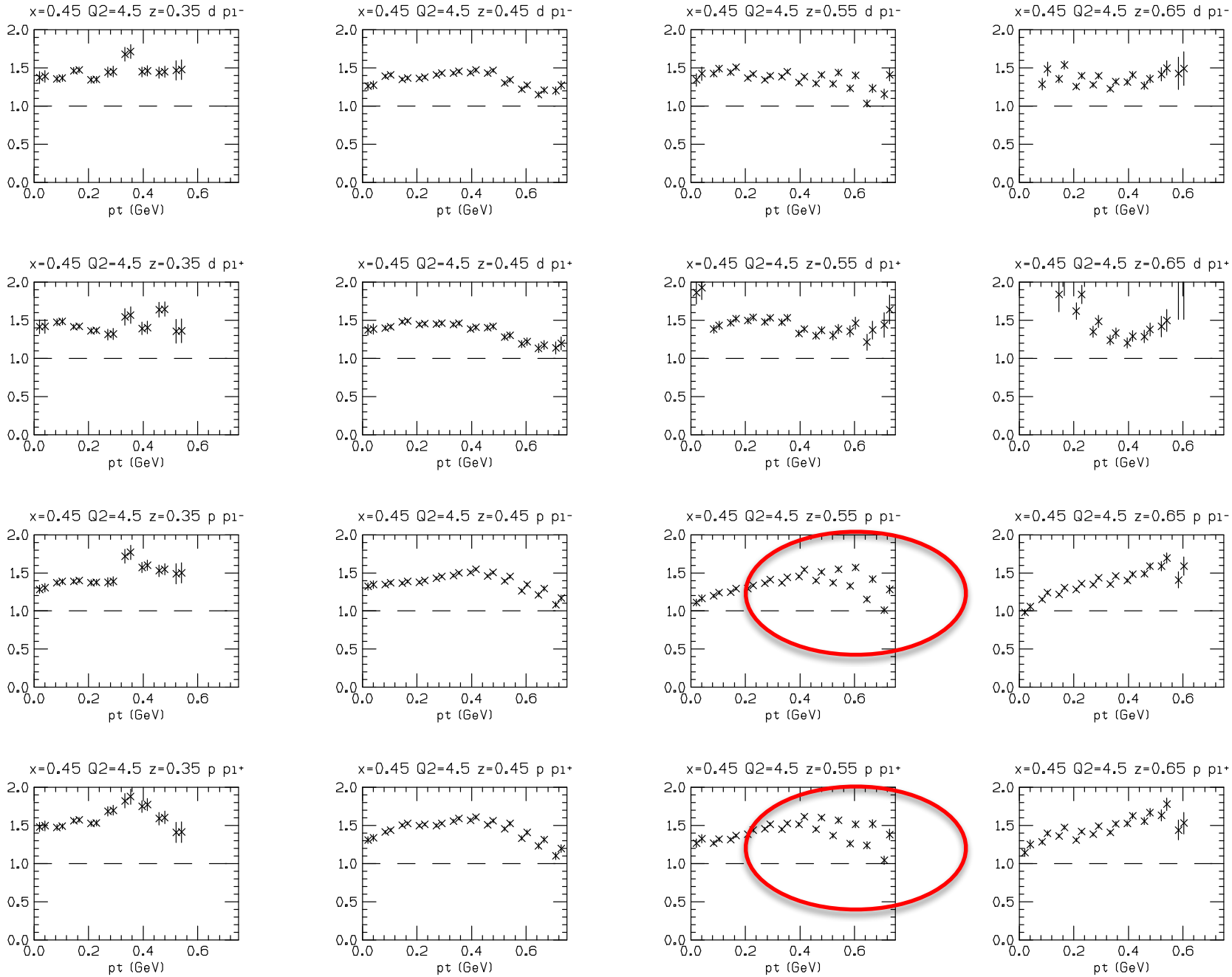
Tail Studies -1-



Tail Studies -2-



Tail Studies -3-



To Do List -1-

- Figure out the big fluctuations in some of the Q2=3, x=0.3 settings (early in Spring18 when things were less stable).

- Improve the models for exclusive npi+ and ppi- final states (they seem to be too low at present) compared to data from this experiment (pt-SIDIS) as well as CSV. Include data with electron in SHMS and pi- in HMS.

- Improve the Delta++pi- model by comparing to data from pt-SIDIS and CSV. I have included all CSV runs from Fall18 in my run list, and electrons in both HMS and SHMS, so ready to start on this comparison soon.

- Double check all detector calibrations and efficiencies, especially early in Spring18.

- Iterate on SIDIS model in SIMC until data and model agree well. This can only be done once the exclusive pion radiative tails are correct, however.

To Do List -2-

- Finally, at long last, see if pt-dependence of u and d quarks, and/or favored and unfavored fragmentation functions are significantly different.

- Also, look at target and pion charge dependence of cos(phi) and cos(2phi) terms (at low pt)

- Examine kaon to pion ratios and compare to models.

- Study L/T dependence of SIDIS at high z using Kaon LT data (just for pi+ on proton). This can help prepare for the upcoming R-SIDIS experiment.

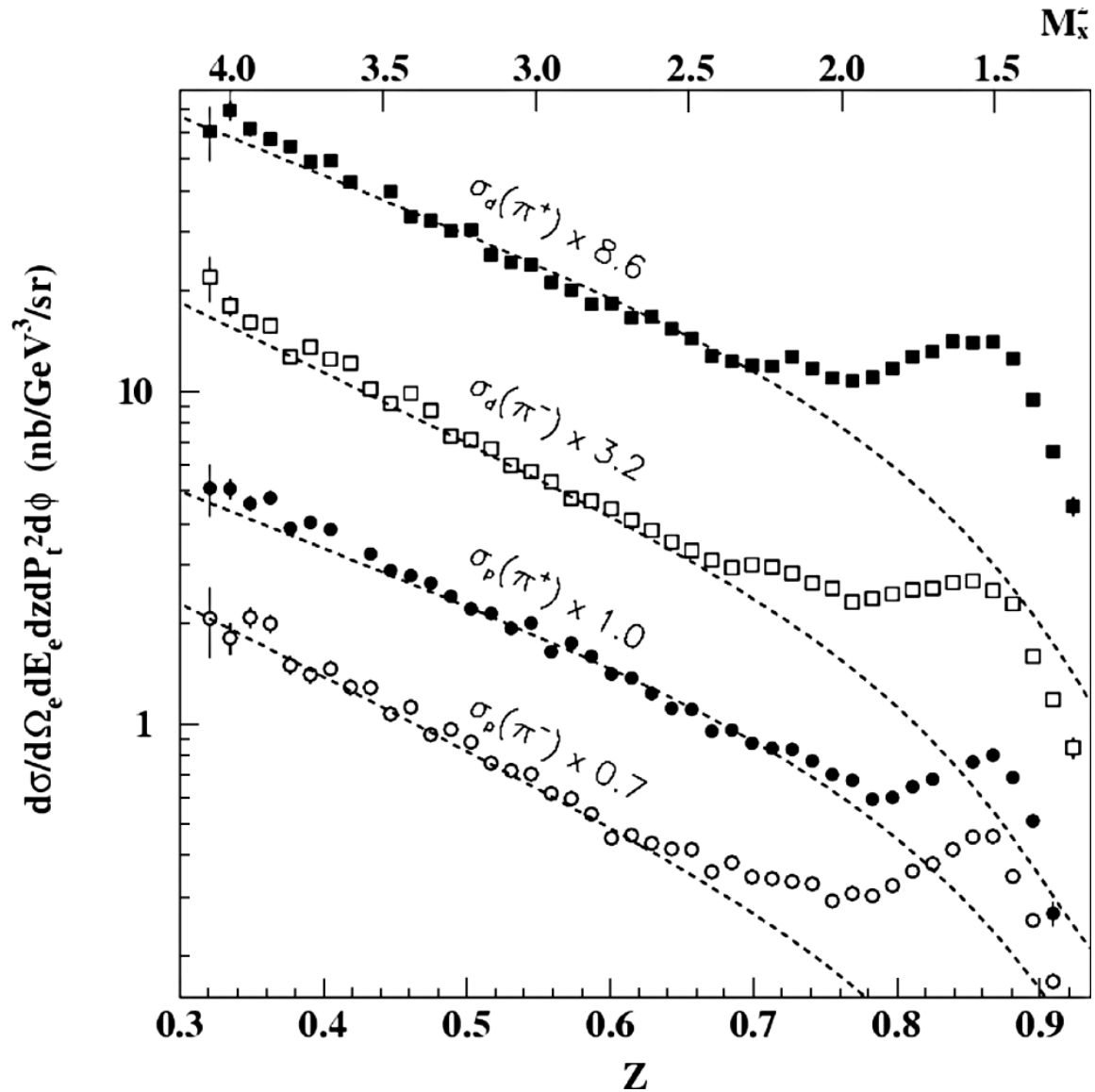
- Try to understand disagreement of data/SIMC on edges of acceptance (for example, due to beam position or spectrometer offsets and mis-pointing corrections).

Backup

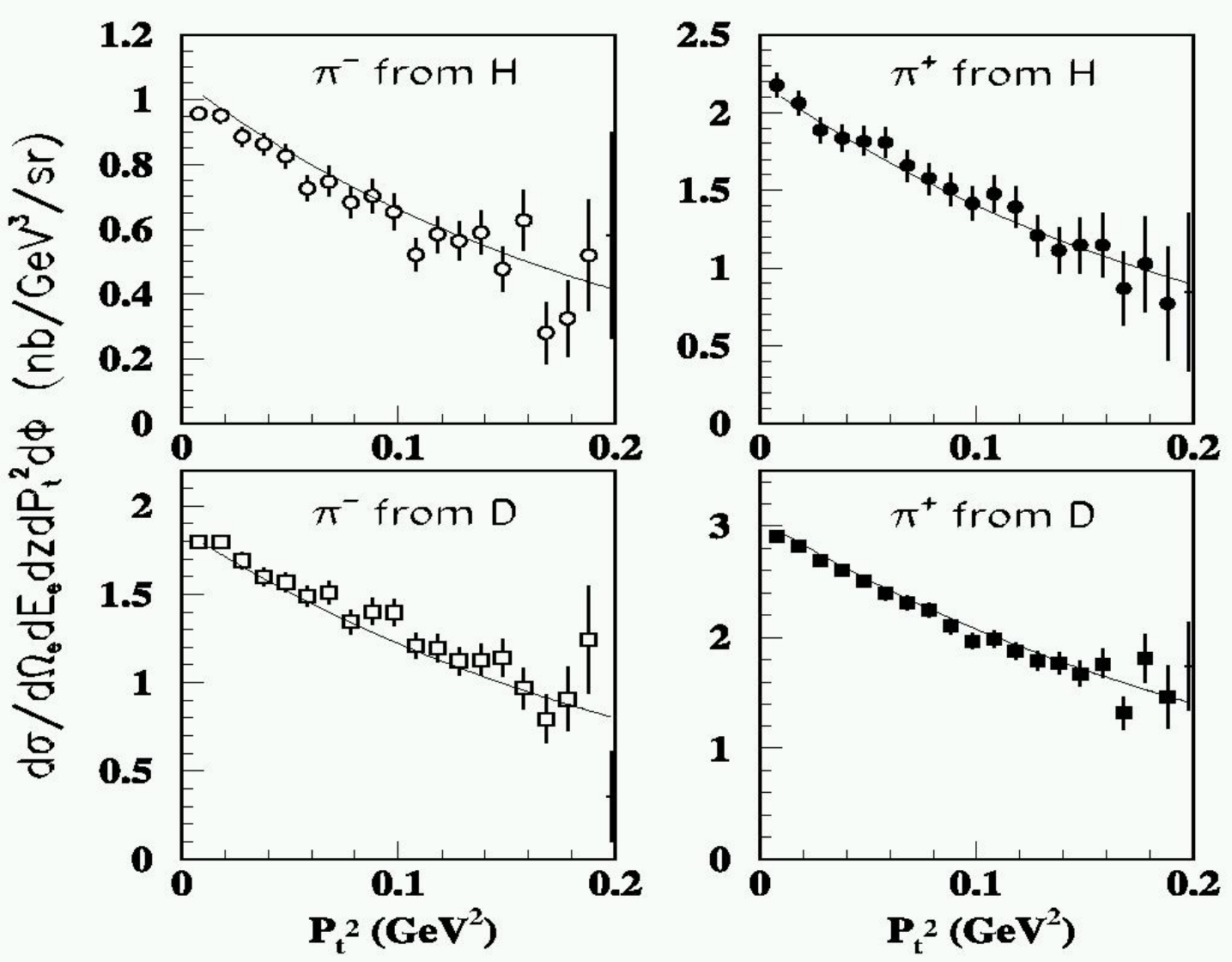
Jlab E00-108 Results

- Cross section/simulation based on factorization prediction
- Good Agreement at low z
- Delta Resonance at high z

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



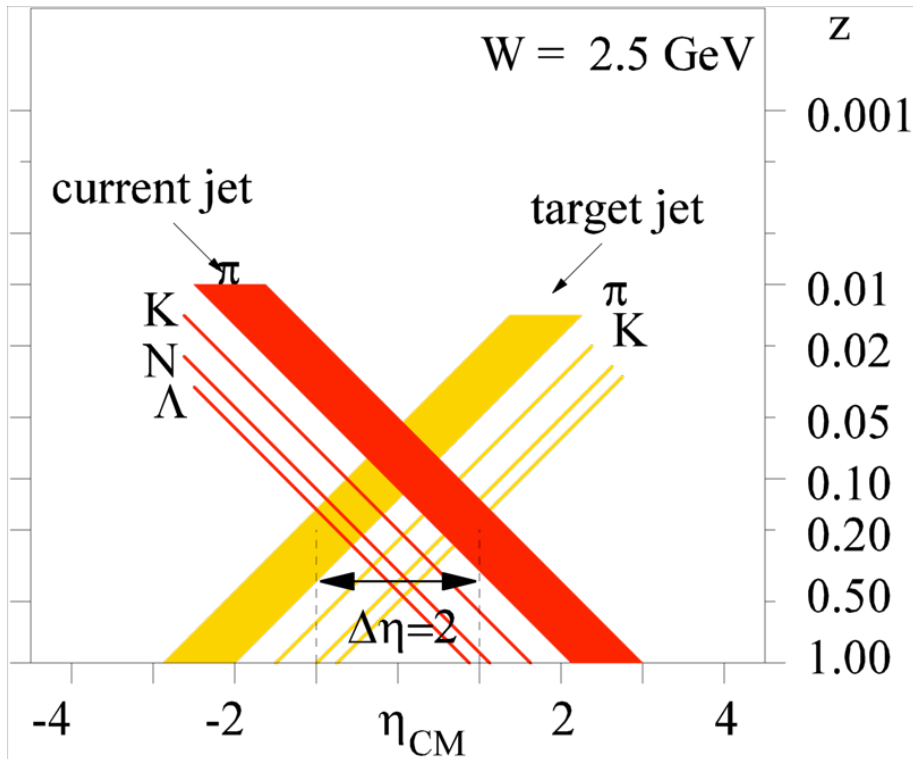
Earlier JLab Measurements: E00-108



- E= 5.5, x=0.3, Q^2=2.3
- Similar, but different slopes for H, D
- Using simple gaussian+Cahn model, combined data yields momentum widths of pdf and fragmentation functions

from Phys. Lett. B665 (2008) 20

Current vs Target?

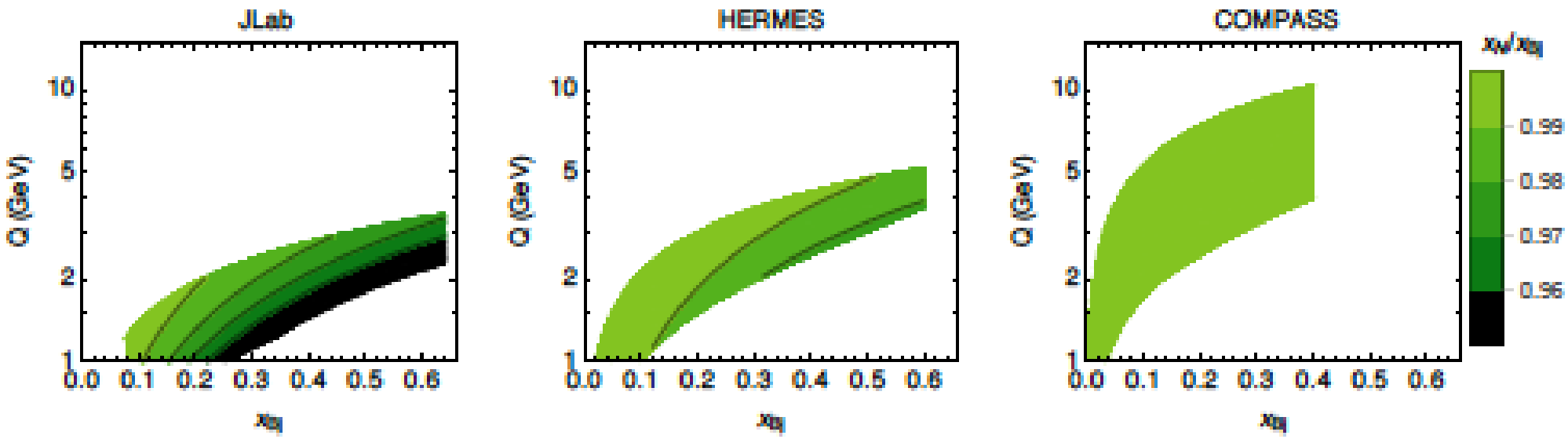


P.J. Mulders, hep-ph/0010199 (EPIC Workshop, MIT, 2000)

- 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?

New Theoretical Guidance

Mapping the Kinematical Regimes of Semi-Inclusive Deep Inelastic Scattering,
M. Boglione, A. Dotson, L. Gamberg, S. Gordon, J.O. Gonzalez-Hernandez, A. Prokudin, T.C. Rogers, and N. Sato, (2019), ArXiv:1904.12882



Example: Study of kinematic deviation between Nachtmann and Bjorken x

SIDIS Cross Section

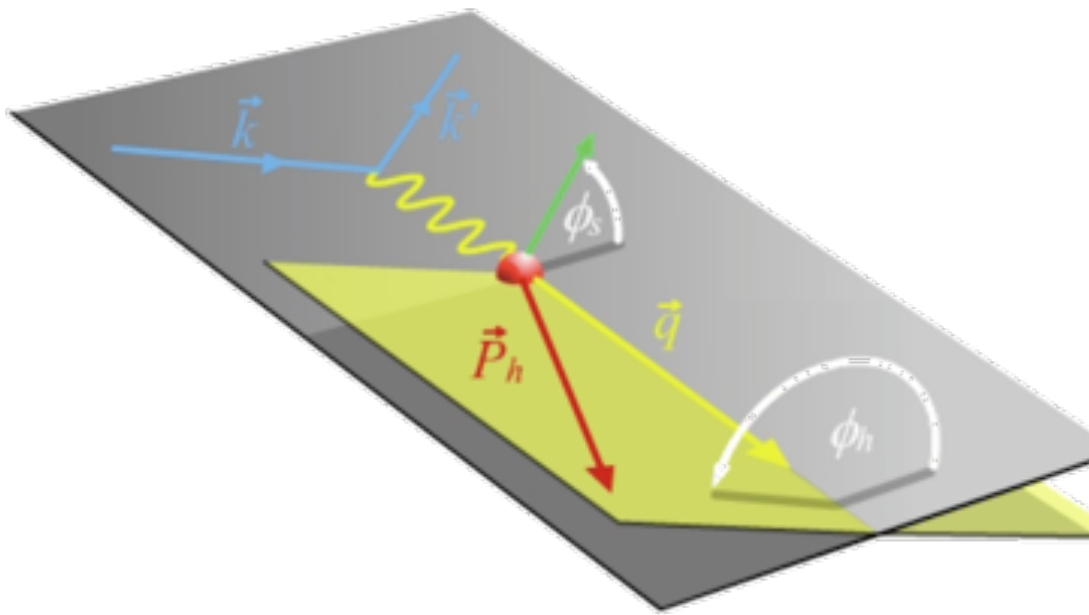
$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h,t}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} +$$

$$\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)} + \lambda_e\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

Q^2 = Virtual Photon Mass

ε = Virtual Photon Polarization

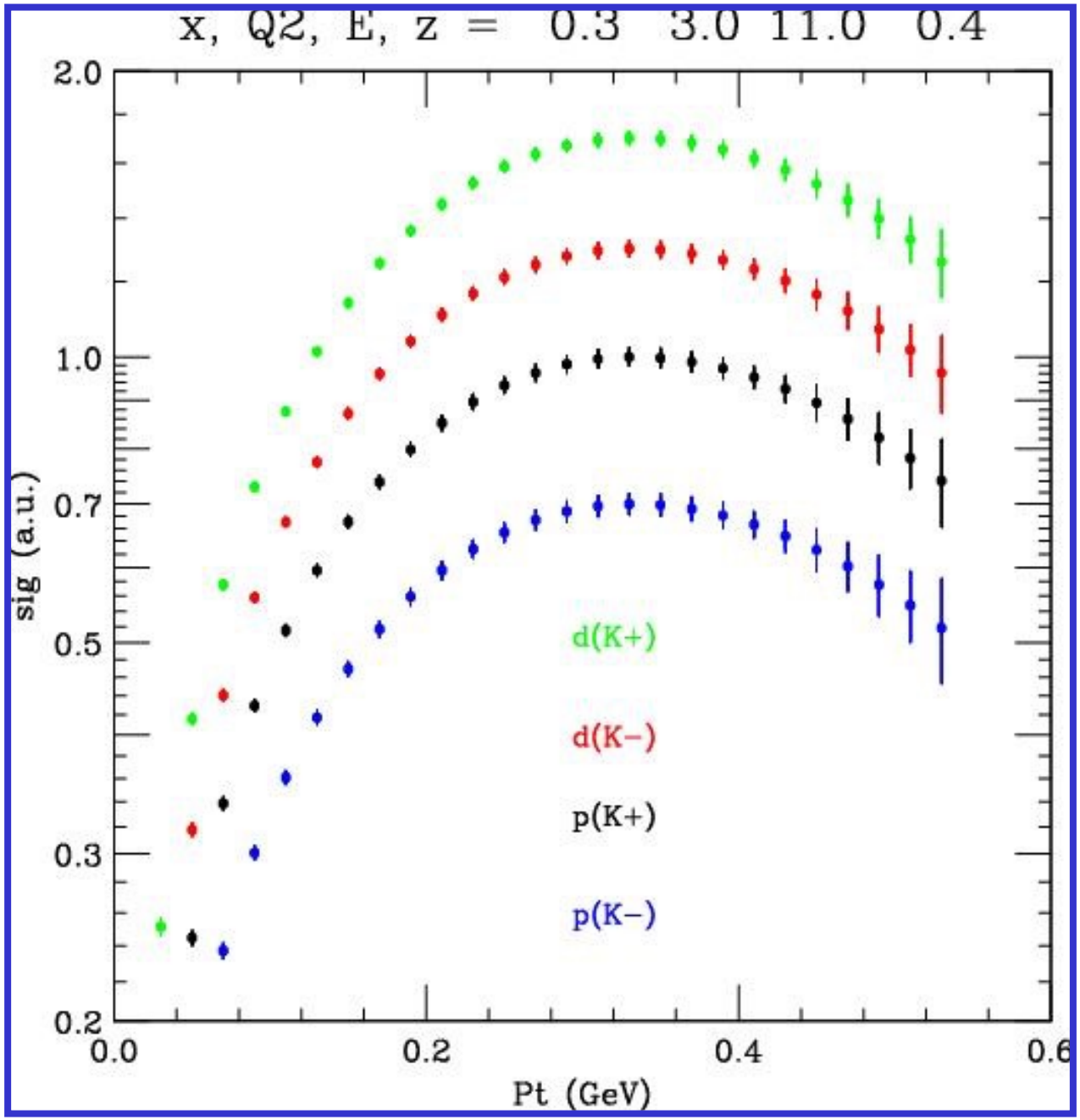
λ = Long. Beam Polarization



General formalism for (e,e'h) coincidence reaction w. polarized beam: [A. Bacchetta et al., JHEP 0702 (2007) 093]

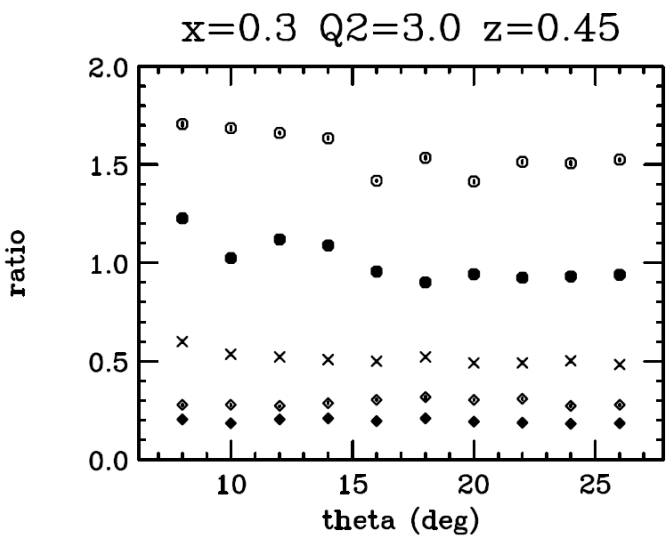
(Ψ = azimuthal angle of e' around the electron beam axis w.r.t. an arbitrary fixed direction)

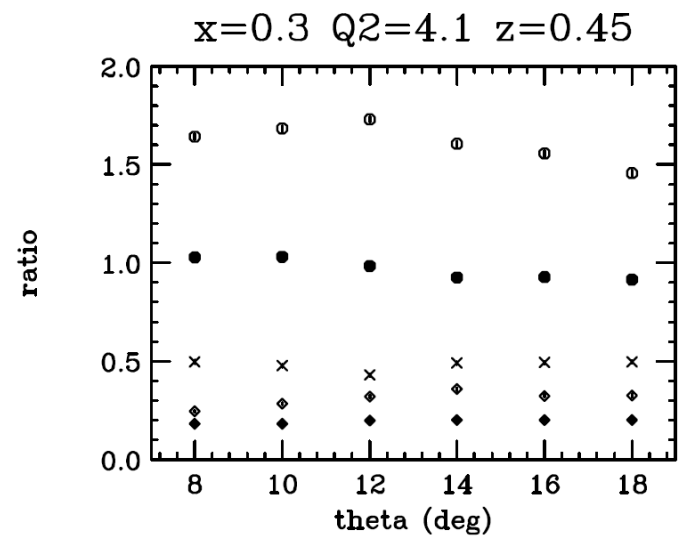
Example of Expected Charged Kaon Precision



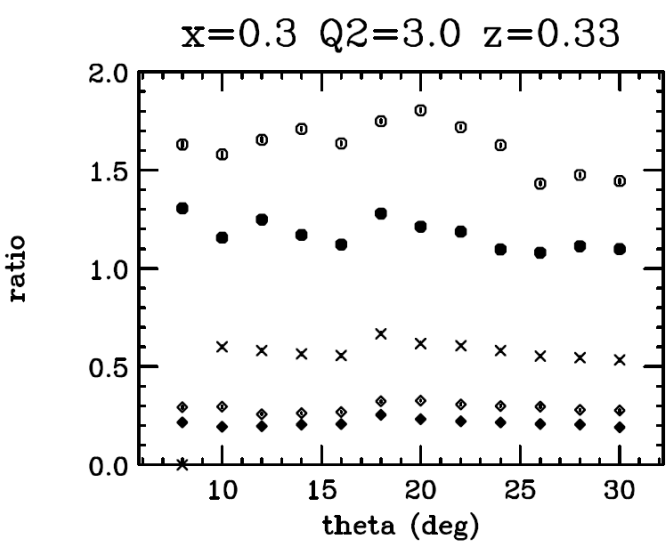
E12-09-017 Quasi-Online Results – Pions

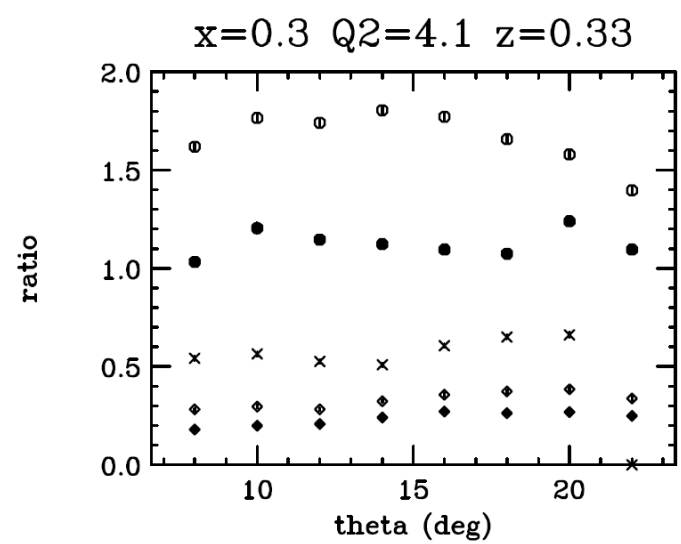
not normalized by target density: just ratios of counts/mC corrected for computer dead time.





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)

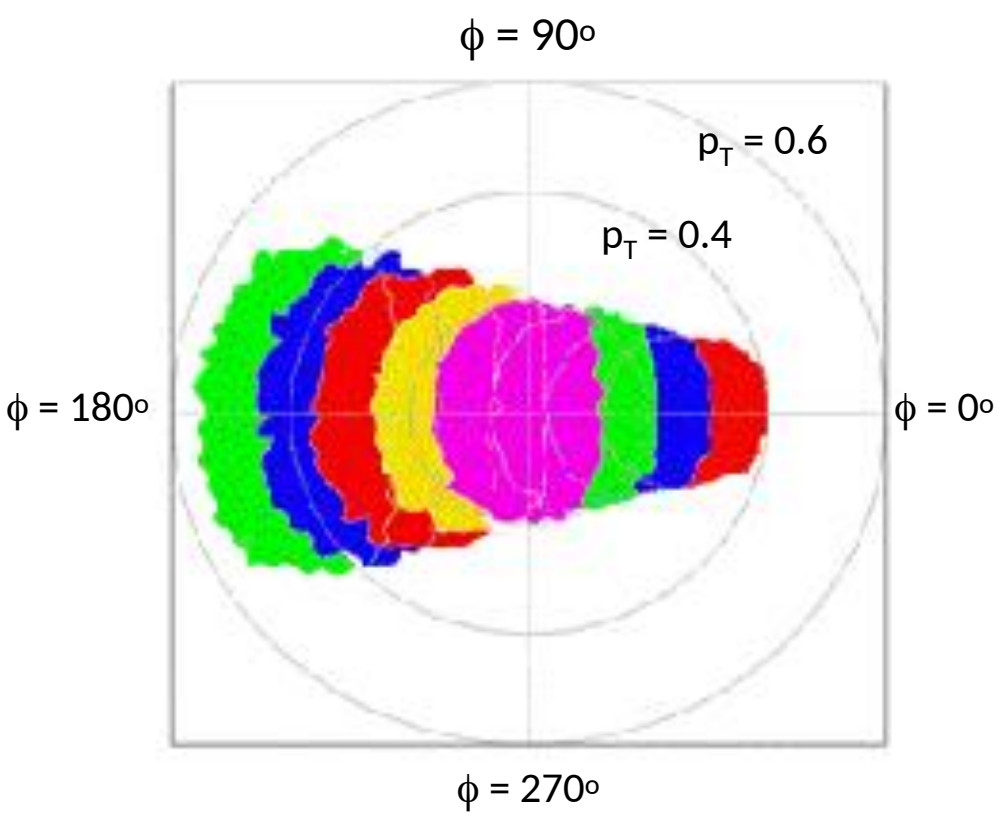




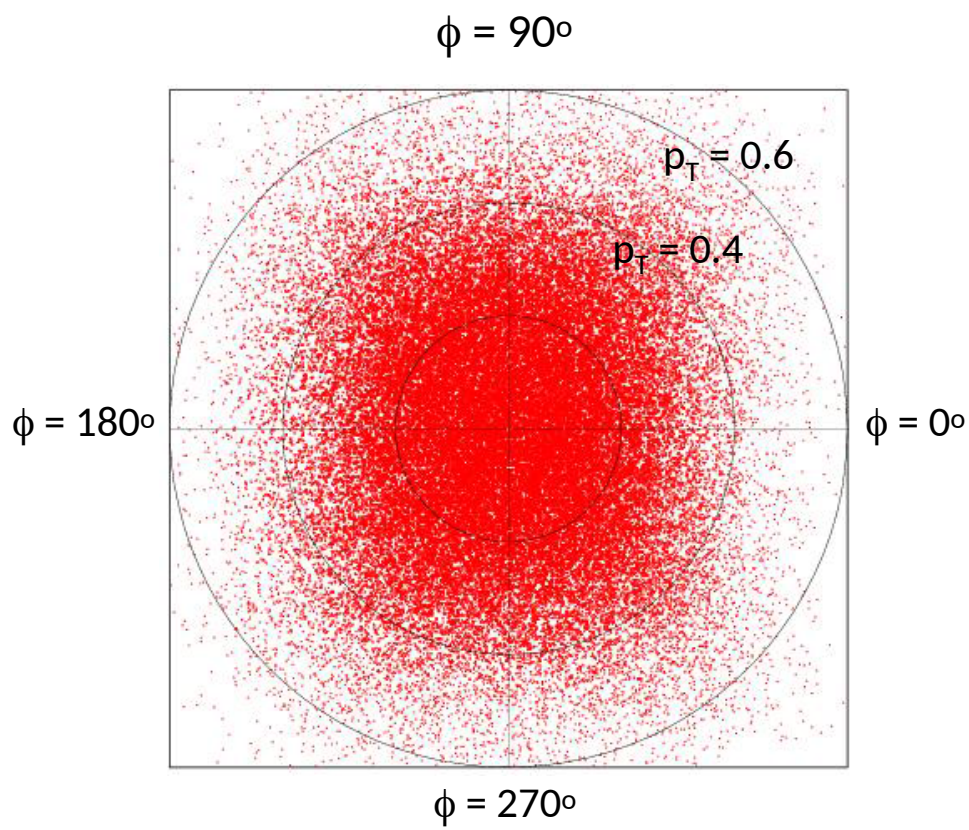
Anashe Bandari & Peter Bosted

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

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



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



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

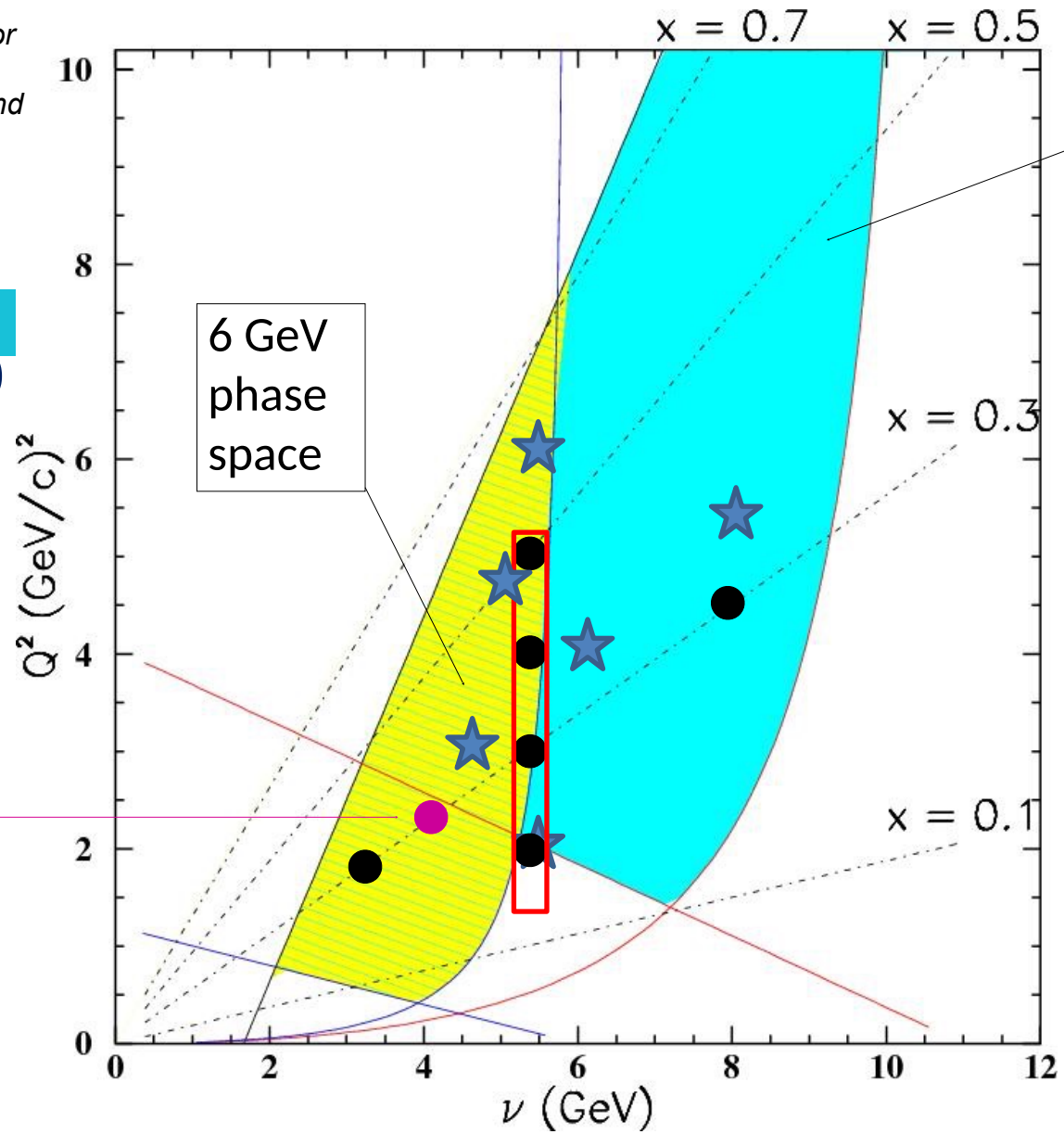
E12-13-007

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