Update on pT-SIDIS Experiment E12-09-017

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On behalf of **P. Bosted** (William & Mary)

- Brief review of motivation
- Results of Parameter Fit
- 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

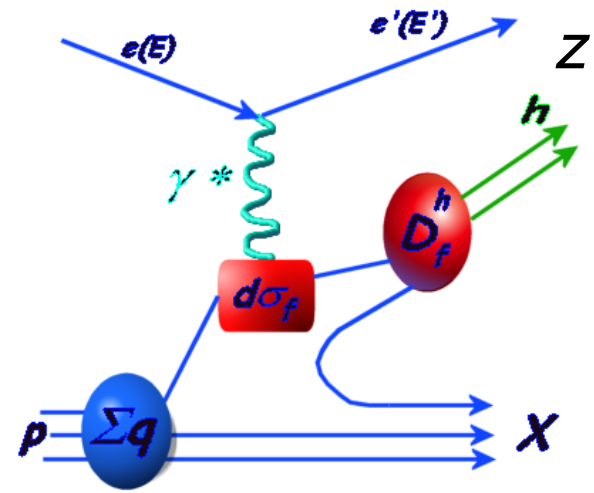
Do parton distributions and fragmentation functions factorize at Jefferson Lab energies?

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

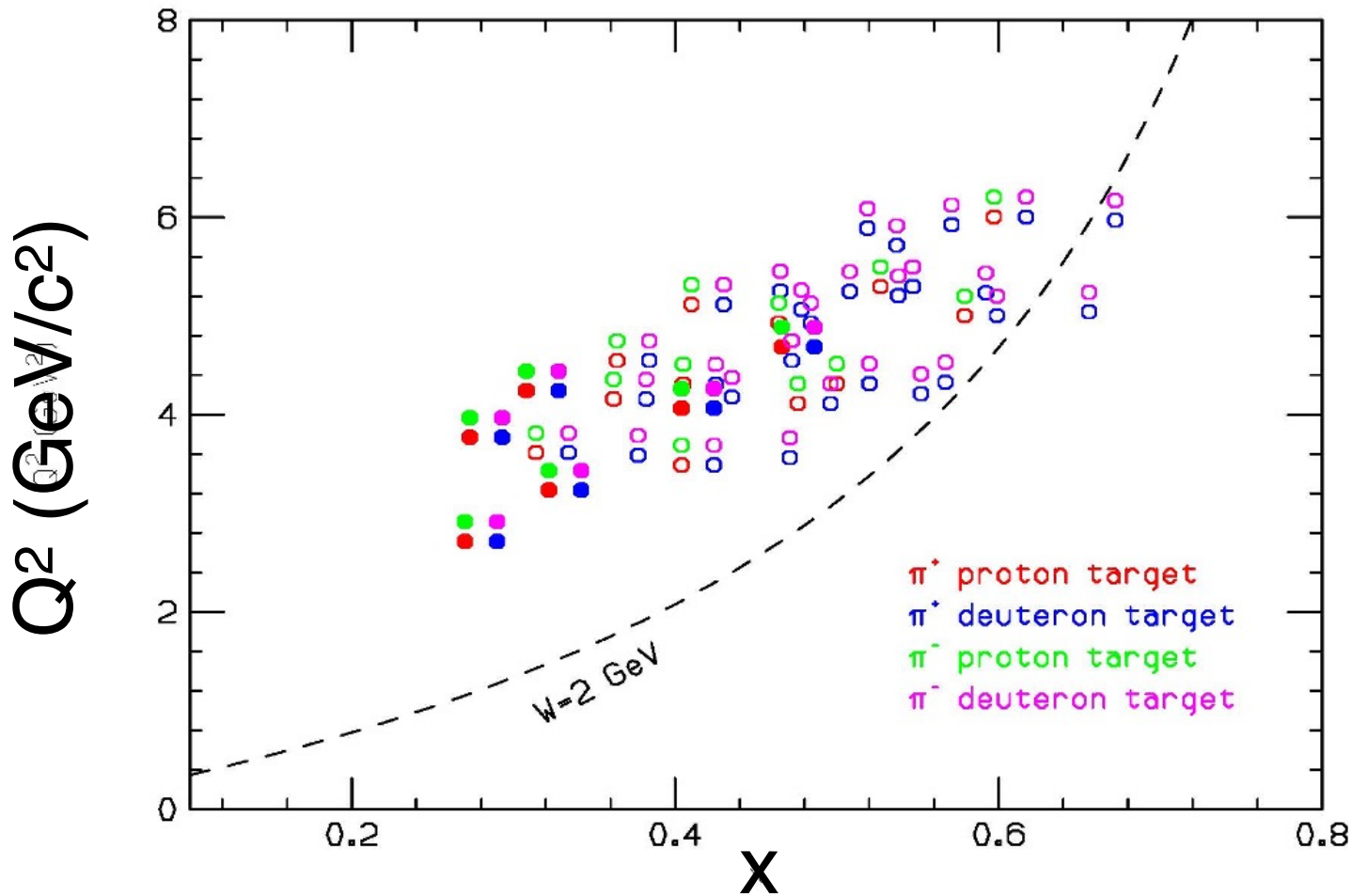
- W^2 = 5.08 GeV^2 and larger (up to 11.38 GeV^2)
- Used SHMS angle down to 6.6 degrees (for π detection)
  HMS angle down to 13.5 degrees (e^- detection)
  separation HMS-SHMS > 17.5 degrees
- $M_X^2 = M_p^2 + Q^2(1/x - 1)(1 - z)$ > 2.9 GeV^2 (up to 7.8 GeV^2)
- Improved coverage in all kinematic variables, 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)

Status of Pion SIDIS

- Table with 21,000 cross section and multiplicity results for charged pion SIDIS pretty much finalized.
- The table includes both the subtractive and multiplicative radiative corrections used.
- The table includes one estimate of diffractive rho(DVM) contributions, which can be applied to the results by the user if desired.
- The results ideally will be incorporated into large global analyses by groups such as JAM, updated with new results from CLAS12, COMPASS, NPS, and R_SIDIS as they become available.
- Meanwhile, have begun interpretation using our data only.

Kinematic Coverage in (x, Q2)

- Solid circles are from pt-SIDIS, open circles CSV SIDIS
- Each circle represents 10,000 to 1,000,000 events
- Dominated by valance quark distributions



SIDIS Differential Cross Section

Measurement of 6-fold differential cross section with unpolarized target has five structure functions (formalism from Bacchetta *et al.*, JHEP 0702, 93 (2007).)

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$
$$\left\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} \right.$$
$$\left. + \lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} \right\}$$

Virtual Photon Polarization: ϵ
Electron helicity: λ_e
Hadron azimuthal angle: ϕ_h

Structure functions depend on x, Q^2, p_T!

SIDIS cross section model with Transverse Momentum-dependent Parton and Fragmentation Distributions (TMDs)

$f_q(x, \mathbf{k}_\perp)$: *parton distribution function as function of intrinsic parton k_T*

$D_q^h(z, \mathbf{p}_\perp)$: *fragmentation function as a function of fragmentation p_T*

Cross section for SIDIS hadron of fractional energy z_h and transverse momentum P_T

$$\frac{d^5\sigma^{\ell p\to \ell h X}}{dx_B\, dQ^2\, dz_h\, d^2\boldsymbol{P}_T} = \sum_q e_q^2 \int d^2\boldsymbol{k}_\perp\; f_q(x, \boldsymbol{k}_\perp)\; \frac{2\pi\alpha^2}{x_B^2 s^2}\; \frac{\hat{s}^2+\hat{u}^2}{Q^4}$$

$$\times D_q^h(z, \boldsymbol{p}_\perp)\; \frac{z}{z_h}\; \frac{x_B}{x}\left(1+\frac{x_B^2}{x^2}\frac{k_\perp^2}{Q^2}\right)^{-1}$$

from Anselmino et al. (hep-ph/0412316v1)

Multiplicity Parameterization

Now perform $k_\perp$ integration and keep terms order $O(k_\perp/Q)$ on previous cross section expression to get

$$\frac{d^5\sigma^{\ell p\to \ell h X}}{dx_B\, dQ^2\, dz_h\, d^2\boldsymbol{P}_T} \simeq \sum_q \frac{2\pi\alpha^2 e_q^2}{Q^4}\, f_q(x_B)\, D_q^h(z_h) \Big[(1+(1-y)^2) - 4\,\frac{(2-y)\sqrt{1-y}\,\langle k_\perp^2\rangle\, z_h\, P_T}{\langle P_T^2\rangle\, Q}\,\cos\phi_h \Big] \frac{1}{\pi\langle P_T^2\rangle}\, e^{-P_T^2/\langle P_T^2\rangle},$$

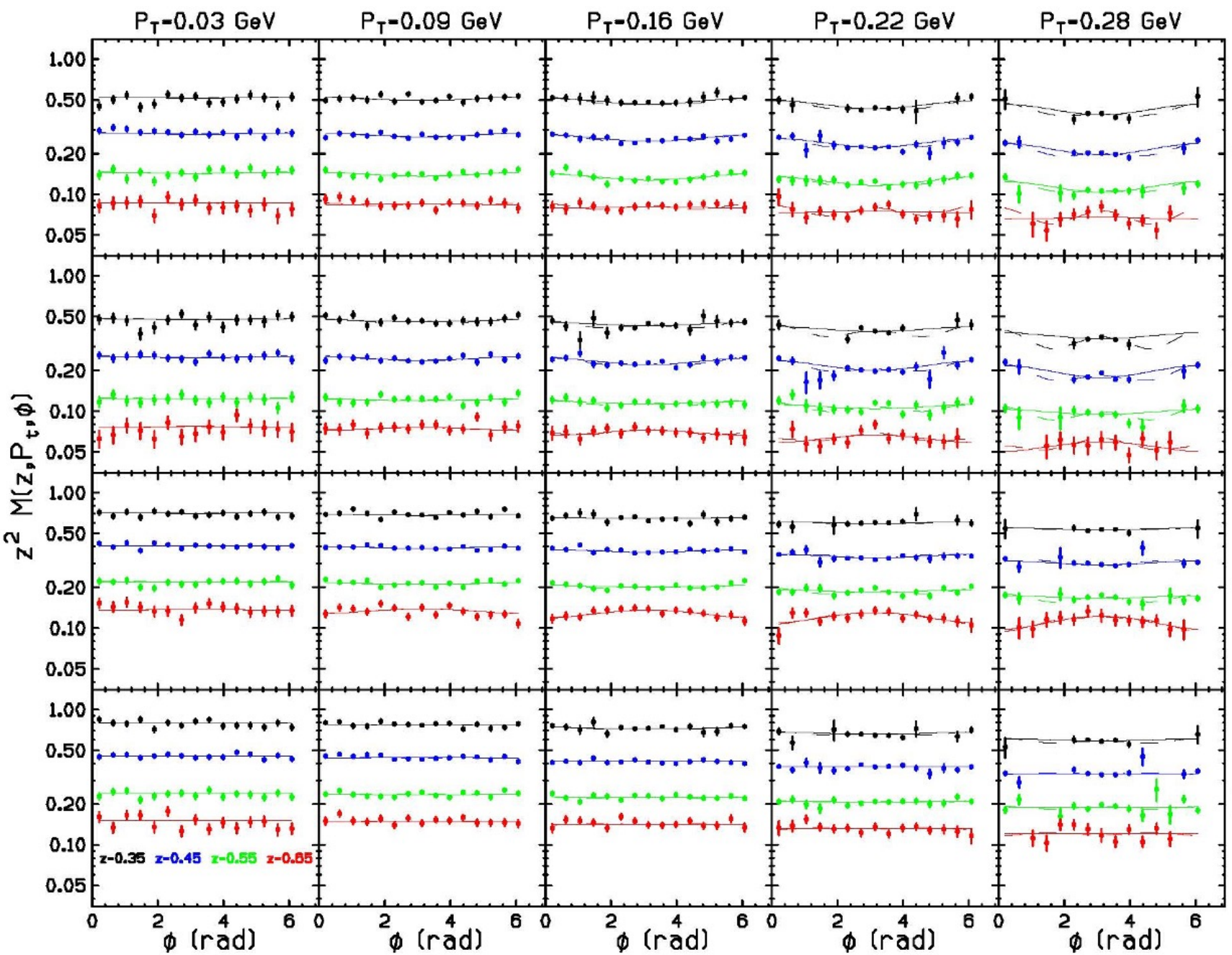
where $< P_T^2 > = < p_\perp^2 > + z^2 < k_\perp^2 >$

We divide by DIS cross section and fit the multiplicities with:

$$M(x, Q^2, z, P_{hT}, \phi) = \frac{d\sigma_{ee'\pi X}}{d\sigma_{ee'X}} = \frac{M_0}{2\pi < \mu^2 >} e^{-P_{hT}^2/<\mu^2>} (1 + A\cos\phi + B\cos 2\phi)$$

$M_0, < \mu^2 > , A, B$ are fit parameters

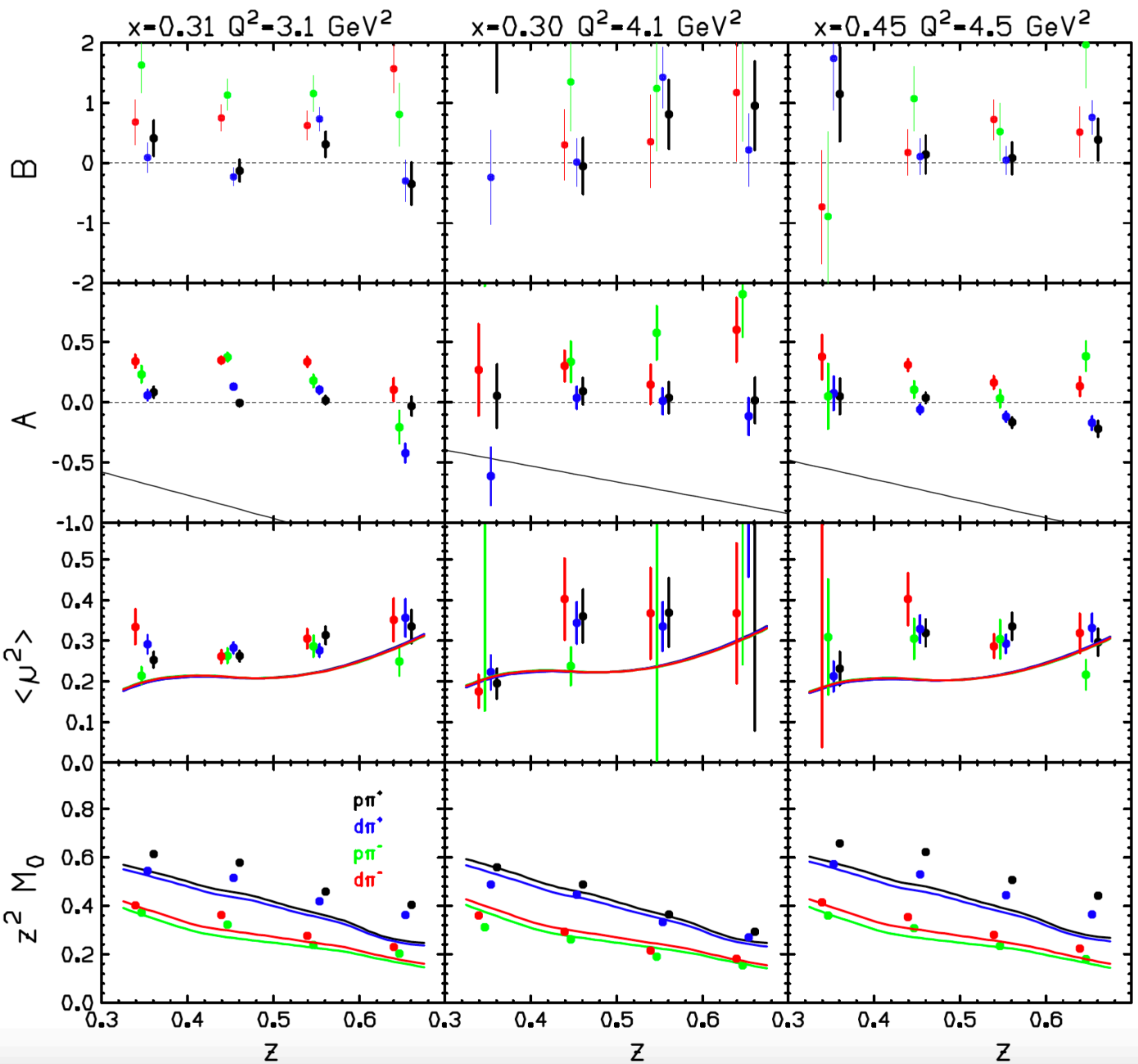
Azimuthal Dependence at x=0.3, Q^2 = 3.0 GeV/c^2



z=0.35
z=0.45
z=0.55
z=0.65

Also,
x =0.3,
Q^2=4.0
x =0.45,
Q^2=4.5

Four-parameter Fit Results (1st 5 p_T bins)



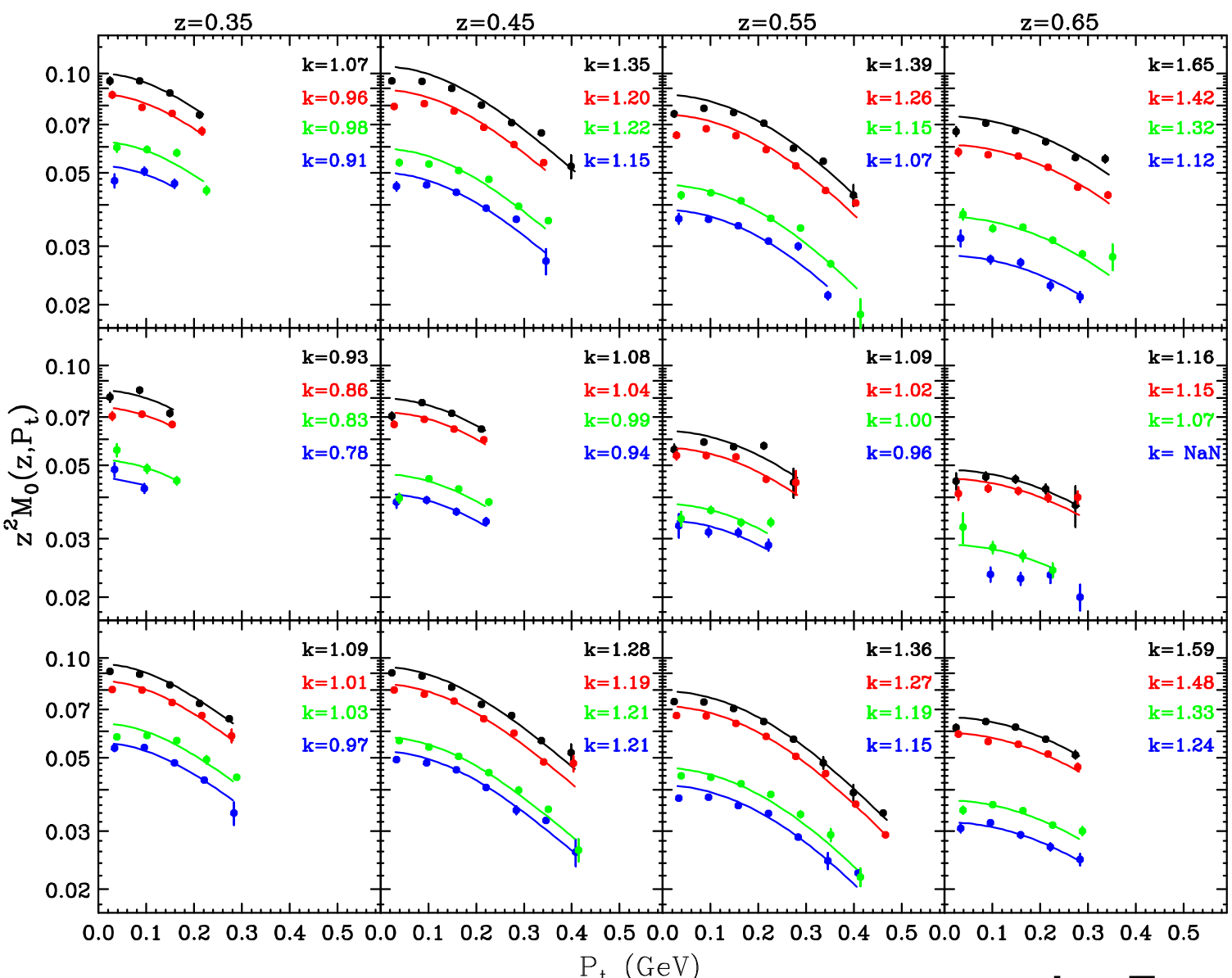
$p\pi^+$ $d\pi^+$ $p\pi^-$ $d\pi^-$

A,B ≈ 0 for π^+

A,B > 0 for π^-

Qualitative agreement with MAP (colored solid curves)

Multiplicities



$p\pi^+$ $d\pi^+$ $p\pi^-$ $d\pi^-$

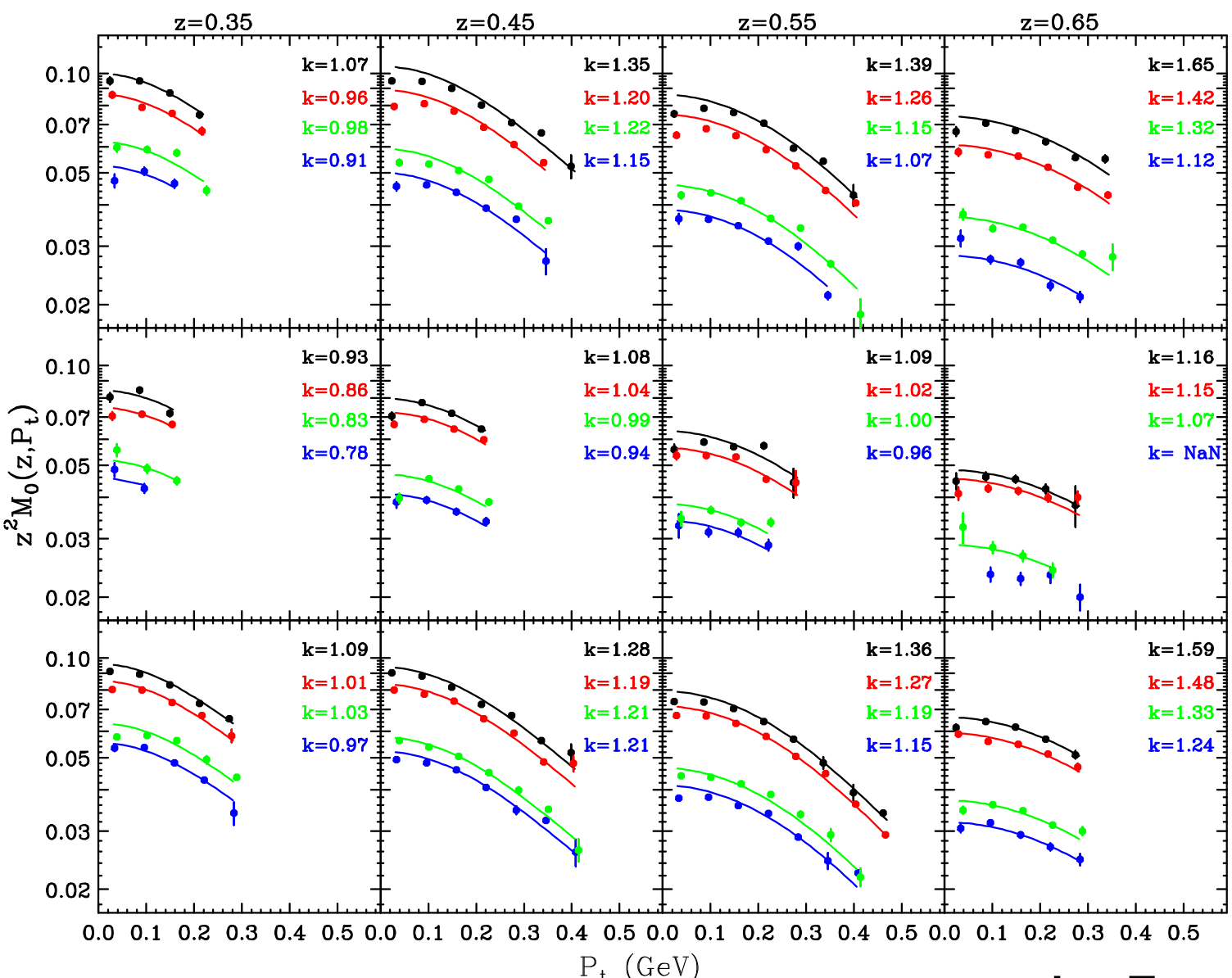
I x=0.45, Q2=4.5

II x=0.3, Q2=4.0

III x=0.3, Q2=3.0

k=Fit of MAPS to data

Multiplicities



$p\pi^+$ $d\pi^+$ $p\pi^-$ $d\pi^-$

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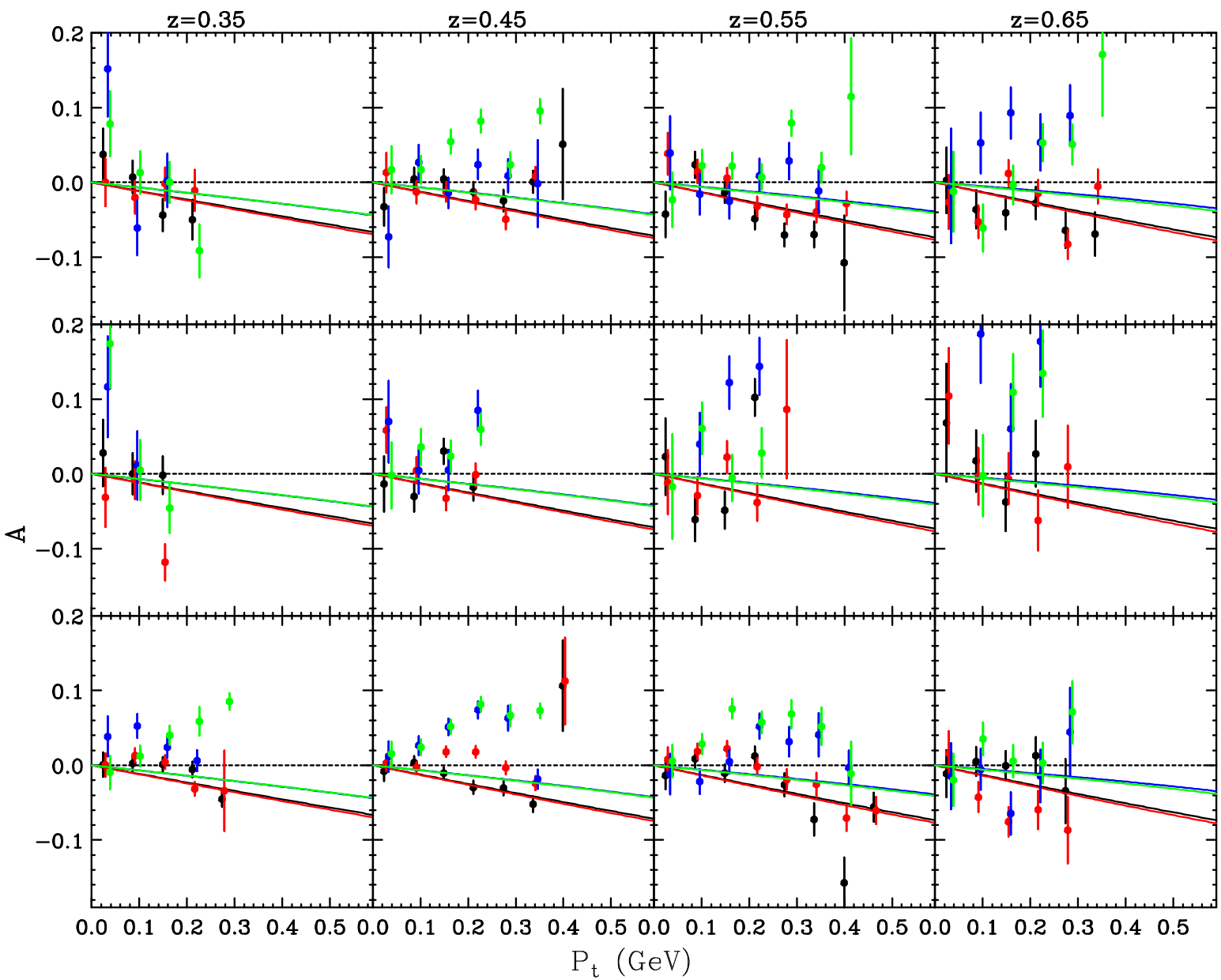
k=Fit of MAPS to data

Phi Coefficient (A)



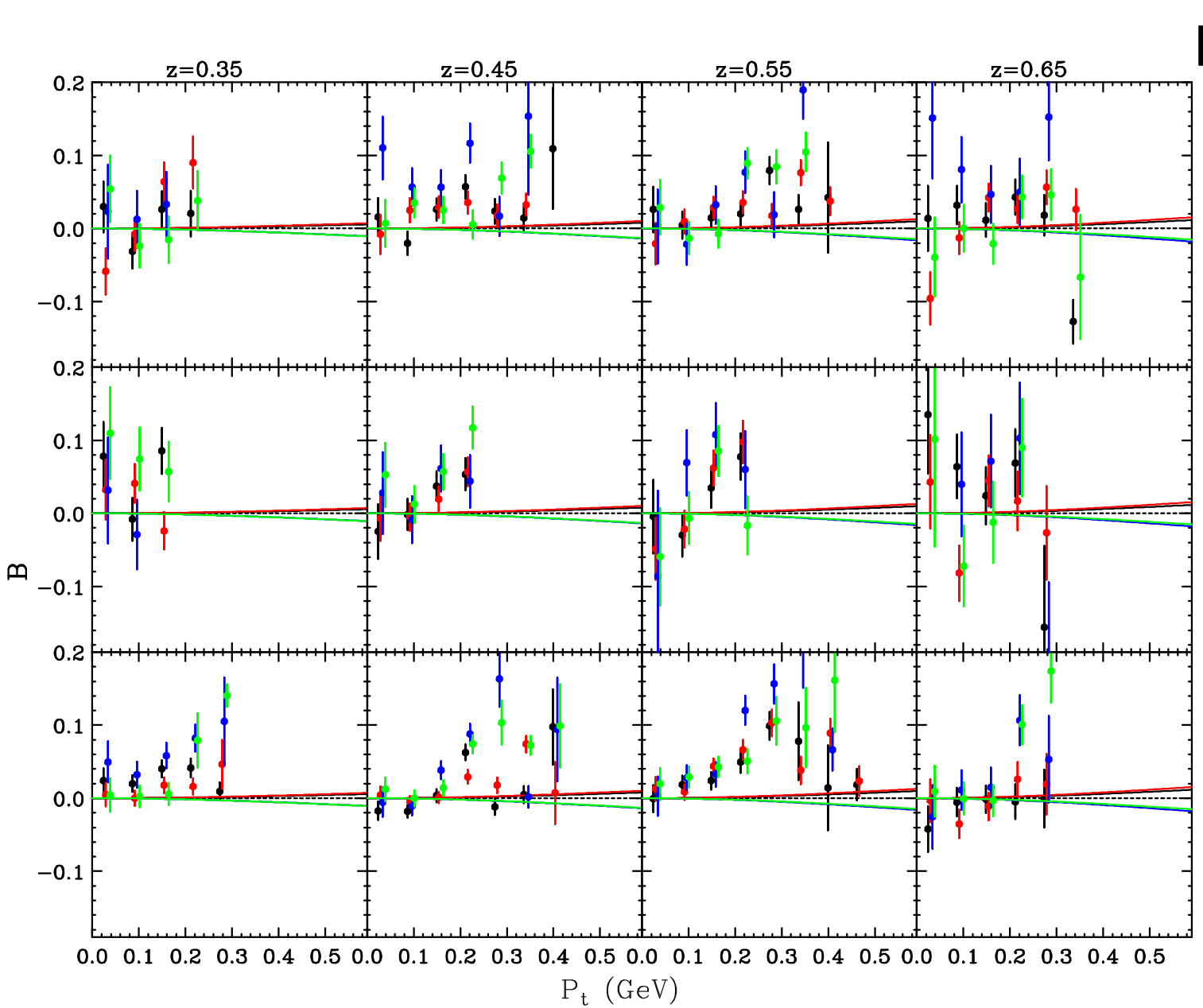
$p\pi^+$ $d\pi^+$ $p\pi^-$ $d\pi^-$

I x=0.45, Q2=4.5

II x=0.3, Q2=4.0

III x=0.3, Q2=3.0

2*Phi Coefficient (B)

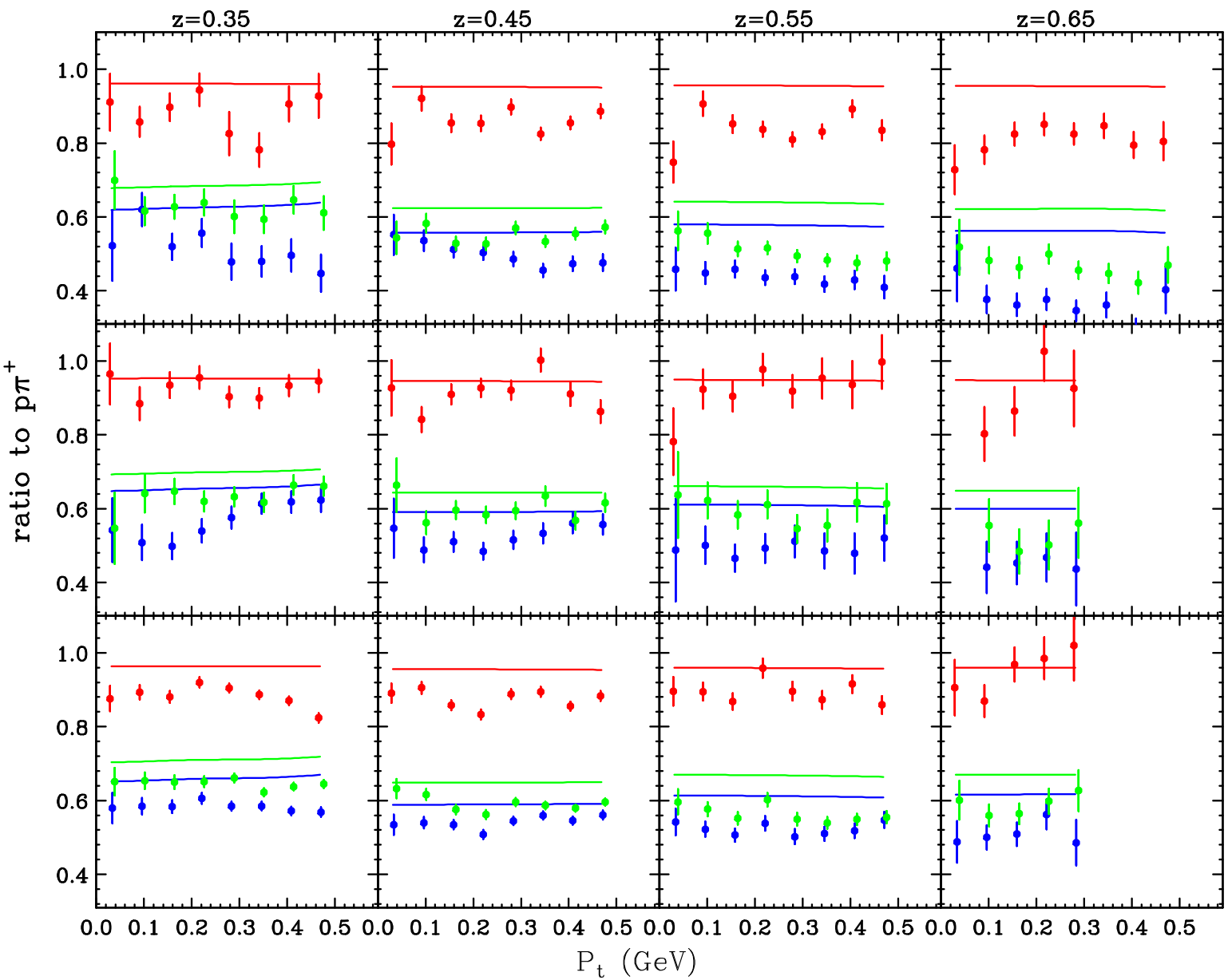


x=0.45, Q2=4.5

x=0.3, Q2=4.0

x=0.3, Q2=3.0

Ratio of Multiplicities



$p\pi^+$ $d\pi^+$ $p\pi^-$ $d\pi^-$

I x=0.45, Q2=4.5

II x=0.3, Q2=4.0

III x=0.3, Q2=3.0

Plans for future

- Develop pion fits further, understand systematics
- Understand 5% normalization difference between inclusive d cross section and world data parameterizations
- Determine kaon cross sections
- Manuscript in preparation for Phys Rev D containing all data with fits plus beam spin asymmetries. Goal to submit before start of R-SIDIS