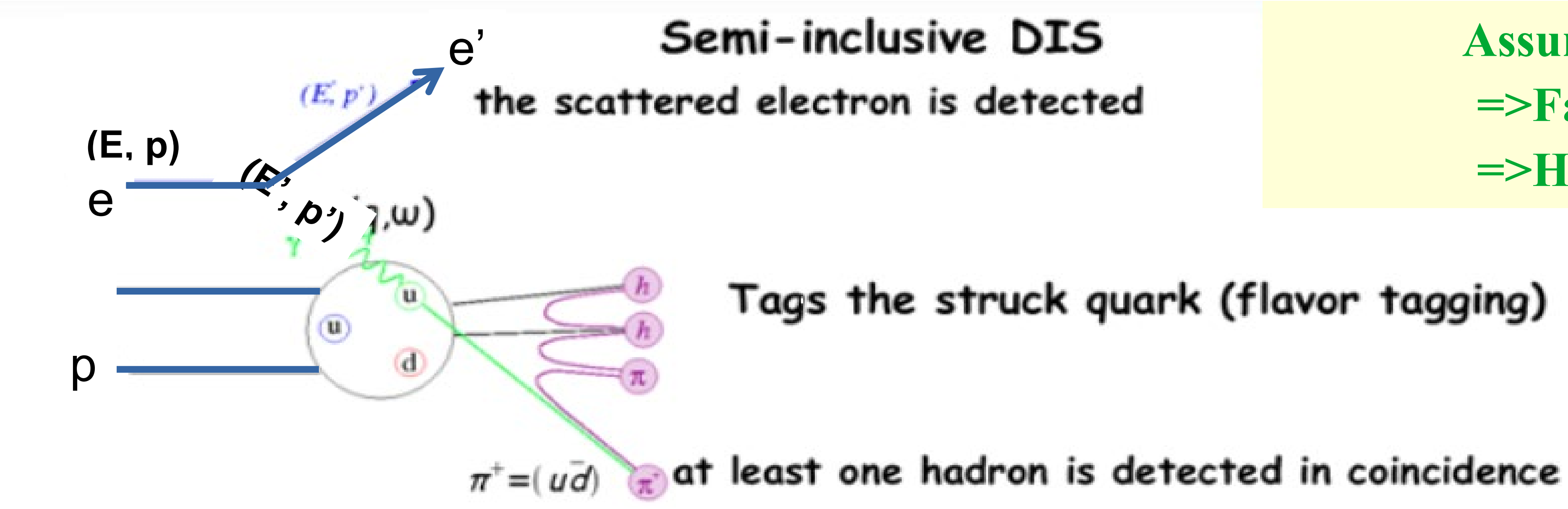
Update from 12-GeV era Hall C SIDIS experiments

Presenter: P. Bosted

Analysis from three Hall C experiments irun n 2018-2019

- Pt-SIDIS wide range of Pt for three (x,Q^2) settings with detection of SIDIS π^+, K^+, p, π^-, K^- from proton, deuteron, and aluminum, for 0.3<z<0.9. No graduate student , but Hem Bhatt analyzing one setting.
- CSV-SIDIS: 13 more settings in (x,Q^2) for π^+, K^+, p, π^-, K^- rom deuteron (and some proton) but limited Pt coverage, again 0.3<z<0.9. Graduate students Hem Bhatt and Shuo Jia. (see Whit's talk tomorrow morning).
- Kaon-LT: I exclusive and nelastic π^+ and K^+, p from proton target useful for rad. corr. models and measuring SIDIS at high z , including the rthe beam single-spin asymmetry (senitive to TMDs) and atso $R = \sigma_L/\sigma_T$

Semi-Inclusive Deep Inelastic Scattering (SIDIS)



Assumptions:
=>Factorization
=>Hadronization

u => π^+
d => π^-

Few kinematic quantities :

x = $Q^2 / 2M_p\nu$: Fraction of proton's momentum carried by the quark (Bjorken x)

M_p = mass of proton

ν = energy Transfer in lab frame (E - E')

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

z = fraction of energy transfer carried by outgoing hadron (pion) = E_h/ν $= \sqrt{(m^2_\pi + p^2_\pi)} / \nu$

Experiments overview

- HMS spectrometer detects electrons at scattering angles from 13 to 49 degrees, momenta from 1 to 6 GeV . Twenty-eight distinct settings: each can be divided into two (x,Q^2) bins.
- SHMS detects particles on opposite side of the beam line. At angles from 6 to 30 degrees, momenta from 2 to 7 GeV.
- Beam energy mostly 10.6 GeV, beam currents 2 to 70 μA
- Targets are 10 cm liquid hydrogen and deuterium, and “dummy’ to measure aluminum endcap contributions.
- Trigger was time coincidence between two spectrometers. Typical rate about 3000 Hz.
- Only one hadron per event (unlike open detectors such as CLAS)

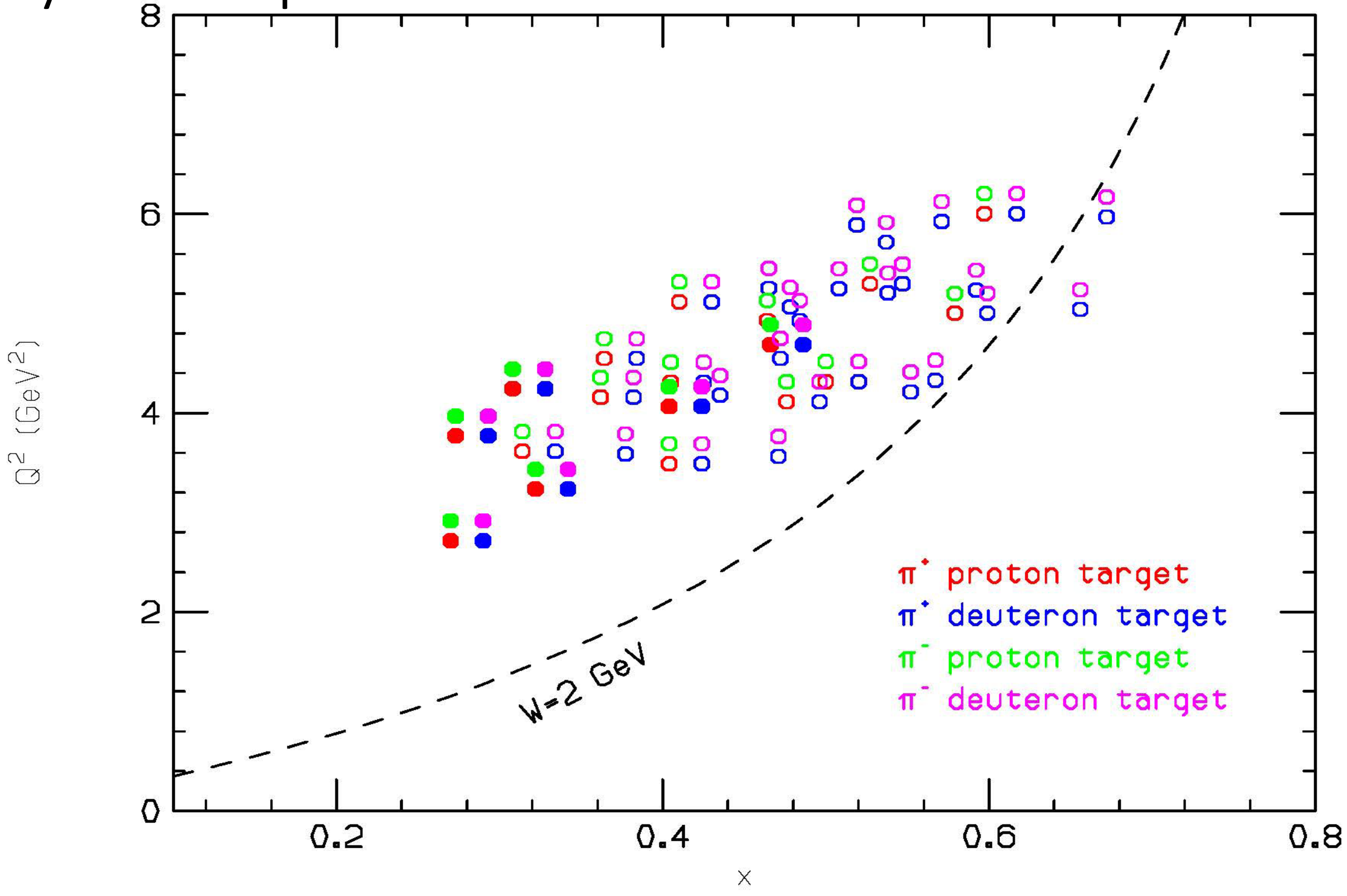
Kinematic coverage in (x,Q^2)

Solid circles are from pt-SIDIS, open circles CSV SIDIS

CLAS coverage extends to lower x and lower Q^2

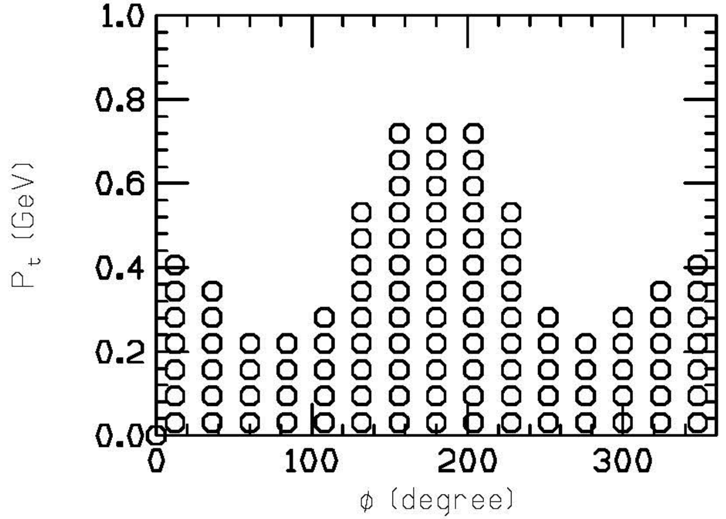
each circle has 10,000 to 1000,000 events

Dominated by valance quark distributions

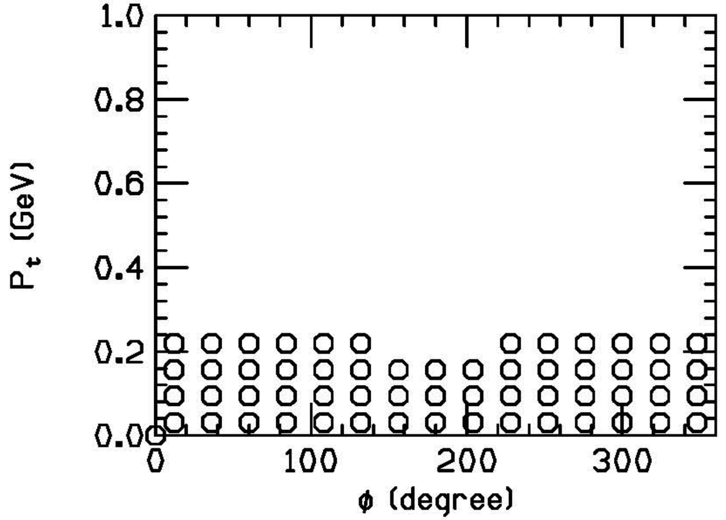


Kinematic coverage in P_t and ϕ

Typica pt-SIDIS setting
at z=0.5



Typica CSV-SIDIS setting
at z=0.5



Data Analysis Tasks Completed (more or less)

- Determination of beam energy and position
- Calibration of beam current monitors and target boiling corr.
- Computer and electronic dead time correction
- Debugging and improvements to tracking code
- Corrections for multiple trigger signals
- Calibration of spectrometer optics for -18<d<38% in SHMS
- Modifications to SIMC for better matching of data and simulation (shms_hut.f and hms_hut.f in particular))
- Calibration of all spectrometer detectors, including "hole" in heavy gas detector.
- Determination of pair-symmetric background (<1%)
- Optimization of PID for pions, kaons, and protons
- Improved models of exclusive pion and $\pi\Delta$ for rad. Corr.
- New model of diffractive rho contributions to cross sections.

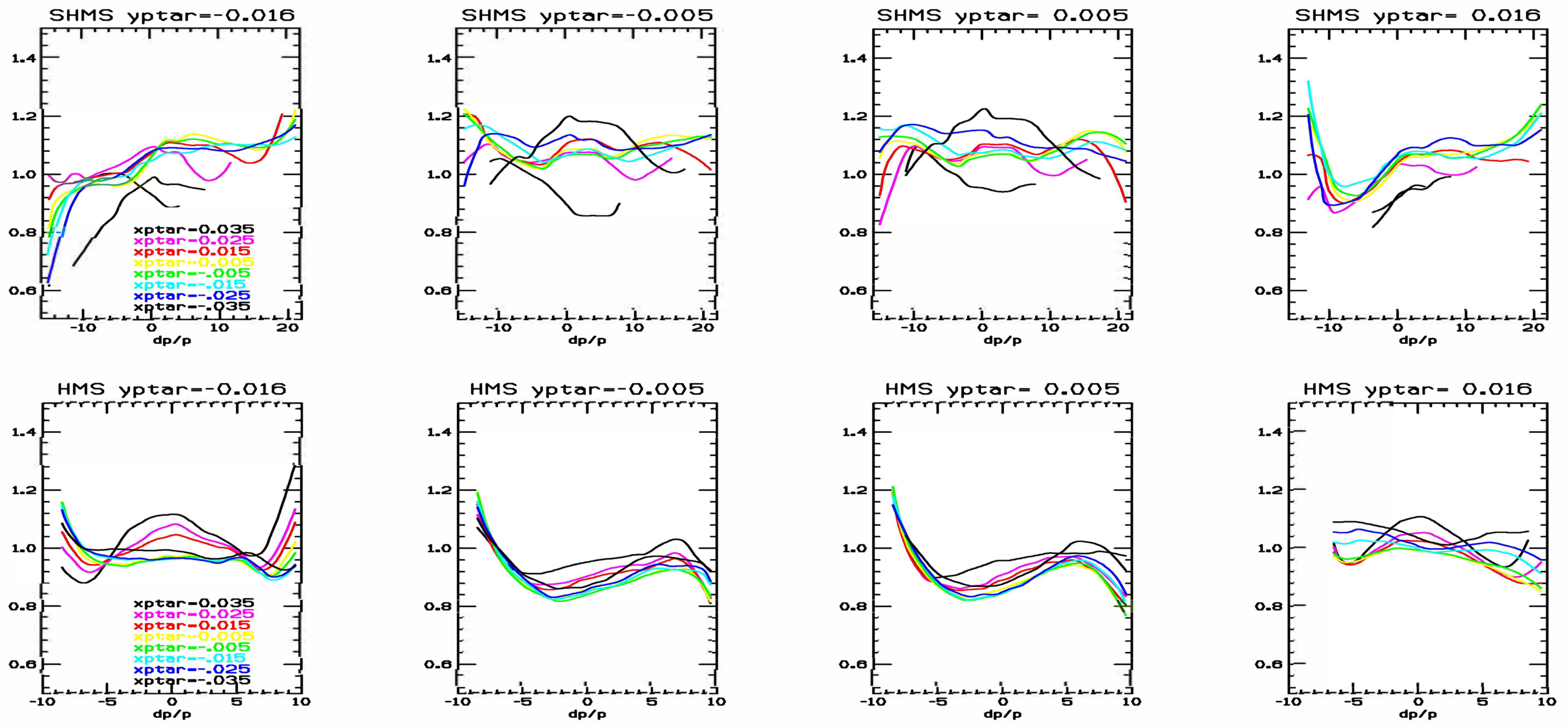
Particle ID improvements

- Modified SIMC to correctly take into account pion and kaon decays
- Calculated fraction of kaons that would be mis-Ided as pions
- Scaled by observed K/Pi ratio

- Improved RF (timing) for better K and p ID
- Accounted for fraction of particles passing kaon ID cuts that are actually pions or muons
- Added dector size cuts to SIMC , matched to data
- Took out “3/4” cut in SIMC hut routines: was cutting out too many events

Aceeptance corrections (2022)

Based on ratio data/SIMC for 100 million events. Big improvement in SHMS overlaps.
“dip” in HMS similar to what Bill Henry et al found, but notice yptar dependance.
Functions available if any wants to try it.



Binning

For each of 56 (x,Q^2) settings

With separate files for π, K , p

- 6 target/polity bins (p+, d+, Al+, p-, d-, Al-)
- 20 bins in z from 0 to 1 (bin 1 for excl. bin 2 for Delta)
- 15 bins in phi from 0 to 360 degrees
- 16 bins in Pt from 0 to 1 GeV
- Two hbeam elicity state bins
- Total: about 30,000 bins with meaningful results

For each bin:

- Pions, kaons, and protons
- Monte Carlo predicted rate for 4 processes, with and without radiation to get rad. corr.

Status of my SIDIS results for all 3 experiments

- Table with 21,000 cross section and multiplicity results for pion SIDIS ffinalized. Two versions: wide / narrow acceptance range.
- 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, COMASS, R_SIDIS as they become available.
- Meanwhile, have begun interpretation using our data only.

Formalism from Anselmino et al.

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

where $\langle P_T^2\rangle = \langle p_\perp^2\rangle + z_h^2\langle k_\perp^2\rangle$. The term proportional to $\cos\phi_h$ describes the Cahn effect [1].

By fitting the data [10] on unpolarized SIDIS we obtain the following values of the parameters: $\langle k_\perp^2\rangle = 0.25$ $(\mathrm{GeV/c})^2$, $\langle p_\perp^2\rangle = 0.20$ $(\mathrm{GeV/c})^2$. The results are shown in Fig. 1.

- Cahn effect predicts cos(phi) term proportional to <kt> of quarks
- Gaussian width has constant term from fragmentation plus quadric term in <kt>

Fit to pion SIDIS data from pt-SIDIS experiment

For each (x,Q^2,z) bin, pion polarity, and target, fit data using

$$M = M_0 \; [1 + A \; pt \cos(phi)] \; \exp(-pt^2 / \langle pt^2 \rangle)$$

With three free parameters:

M_0 is multiplicitaty at pt=0

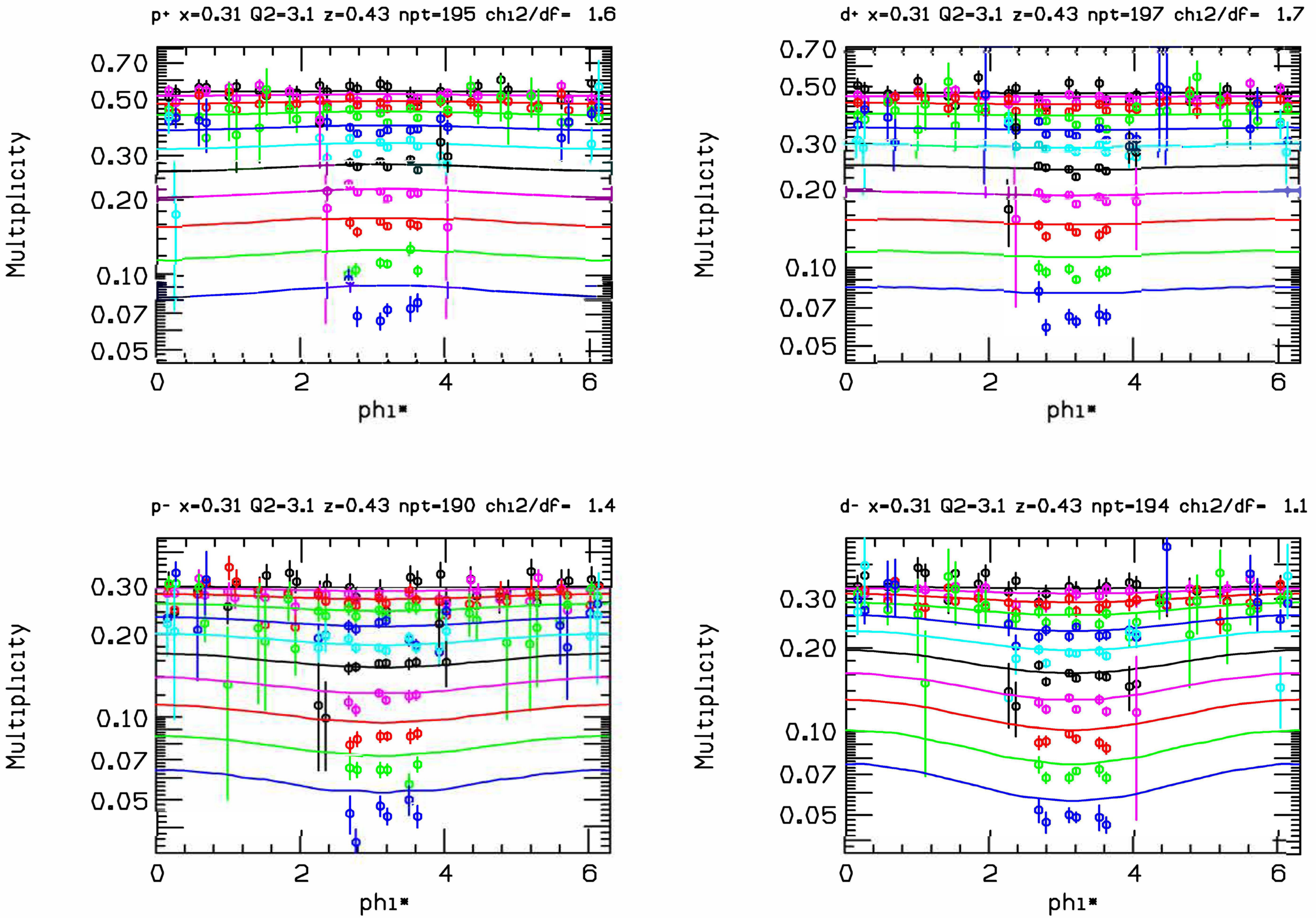
A is cos(phi) amplitute, assuming linear pt dependance

<pt2> is Gaussian width

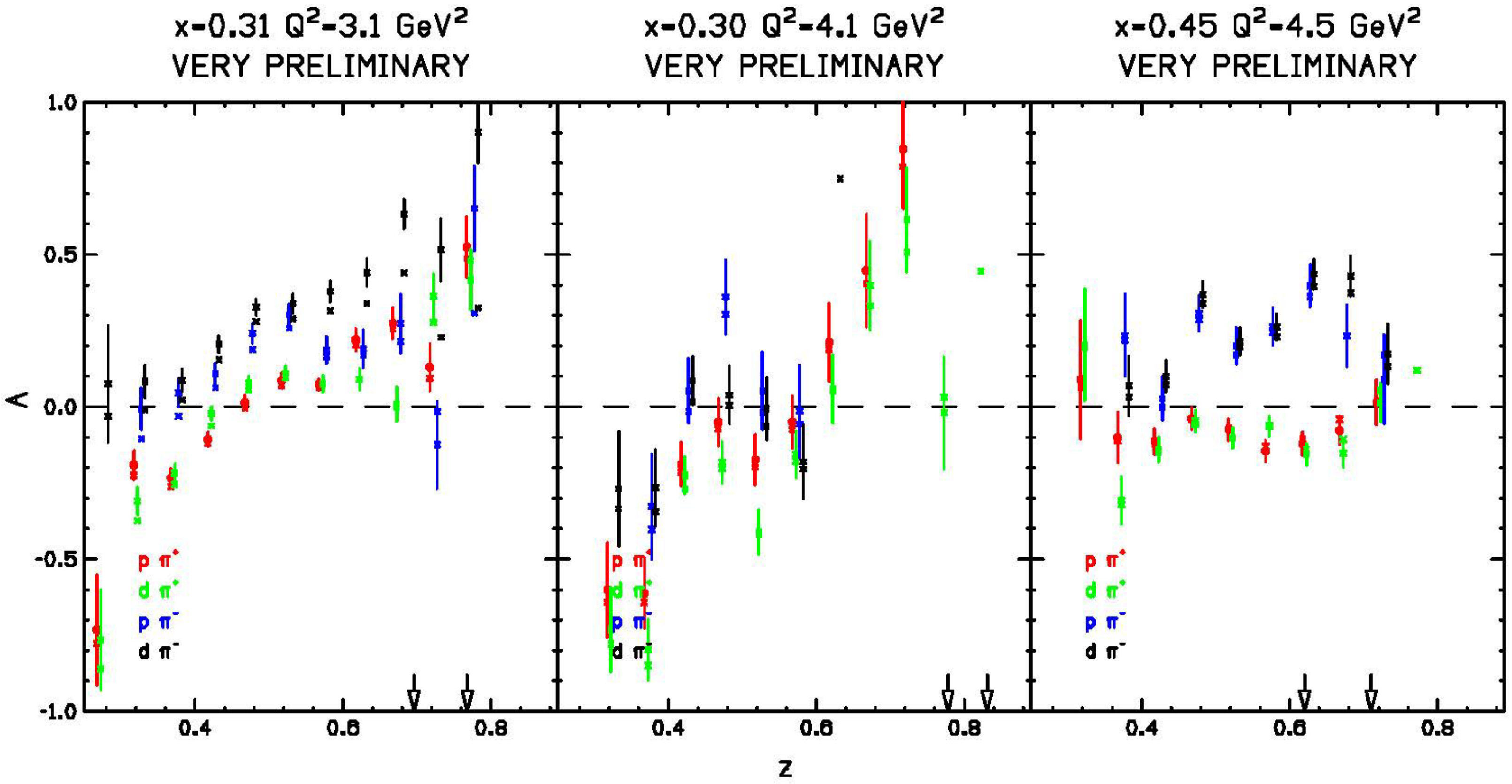
Where Multiplicity(z, pt, phi) is dfined by

SIDIS Cross Section = (Inclusive Cross Section) (Multiplicity)

Fits for one (x,Q^2,z) bin for the 4 cases

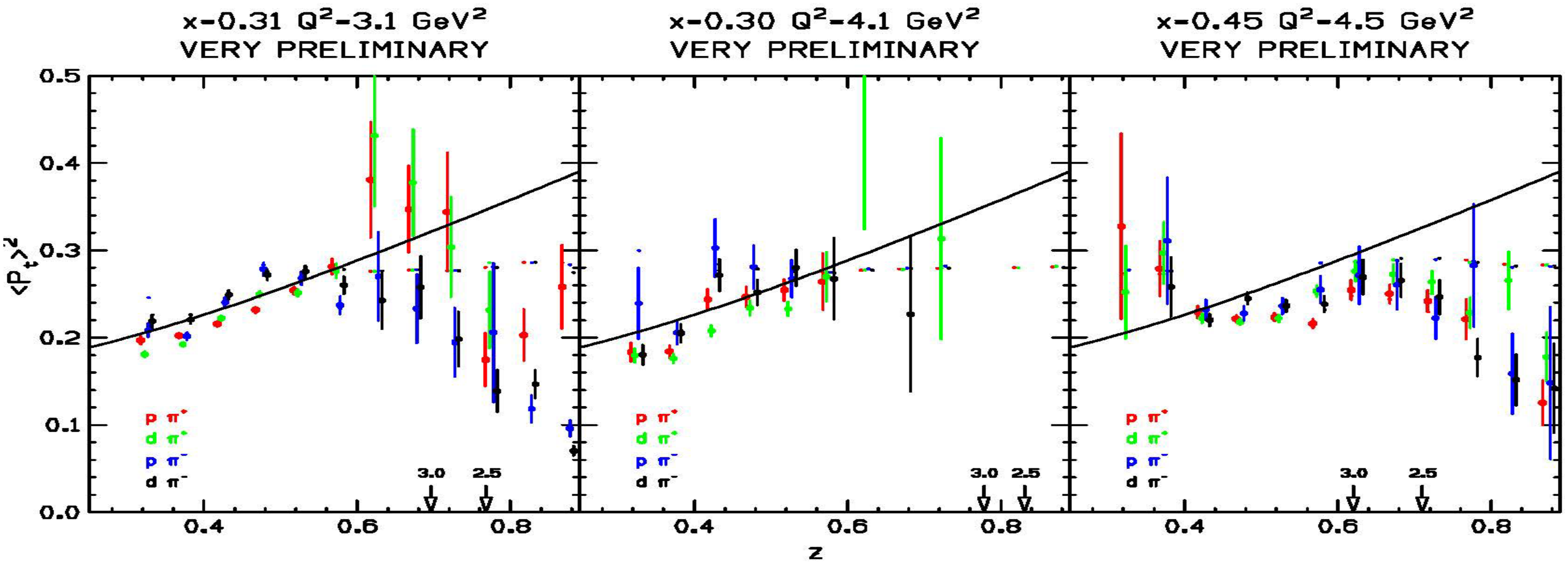


Full set of cos(phi) term results



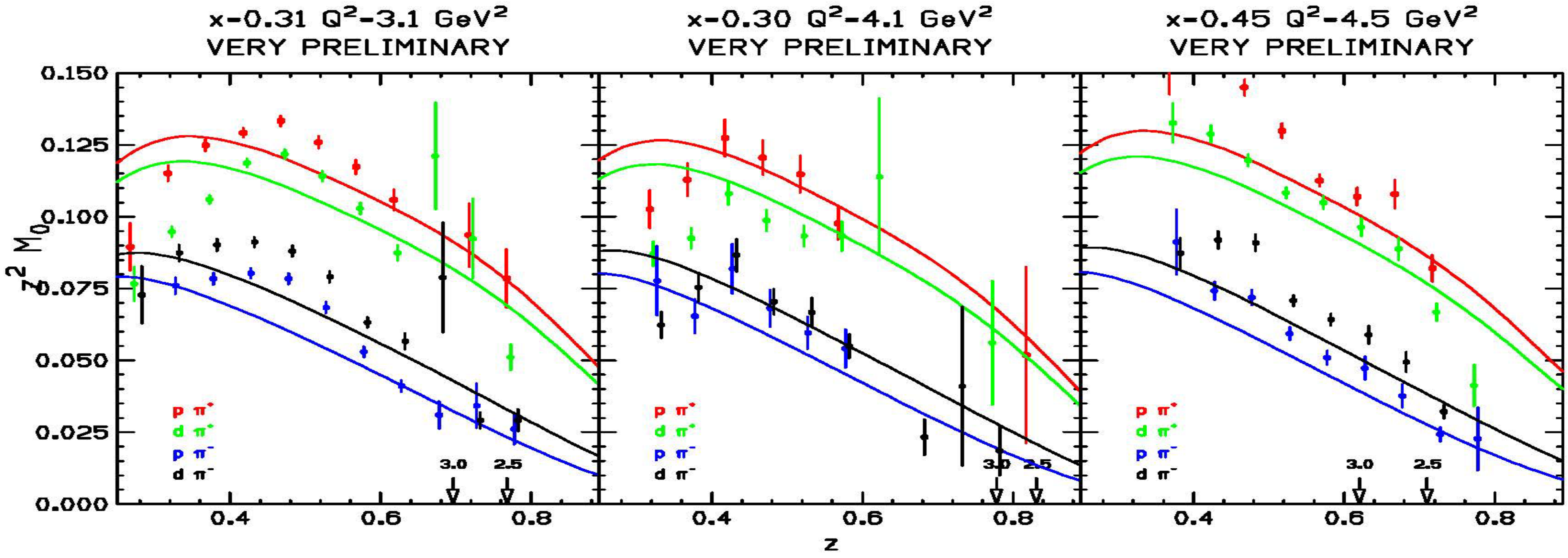
- Positive pion results close to zero.
- Negative pion results increase with z to signigicantly positive values
- Both in sharp disagreement with Cahn term (always <0).
- Contribution from other twist-3 terms must be significant.

Gaussian widths in transverse momentum vs z



- Results for pi- (blue, black) slightly higher than for pi+ (red, green)
- Results genarlly in agreement with simple eyeball fit (for $(M_x)^2 < 3$ GeV^2), given by
- $<pt^2> = \mathrm{sqrt}(0.16^2 + z^2\ 0.40^2)$ GeV^2

Integrated Multiplicity (M0) versus z



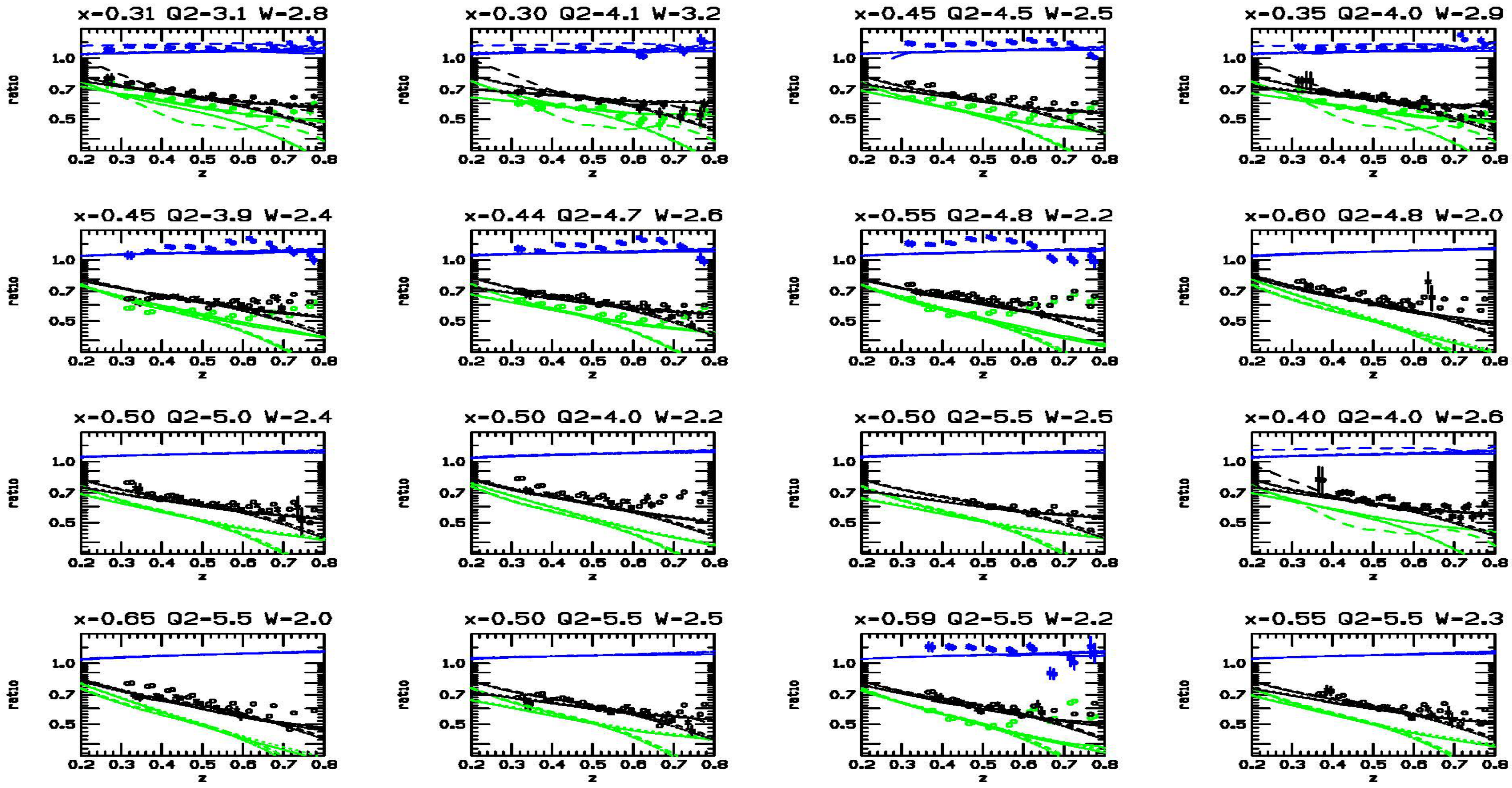
- The results are genearlly a bit higher than a prediction using DSS fragmentation functions and CTEQ quark distributions. The DSS framentation functions have a 15% ldifferentF for u -> pi+ than for d->pi-, which they found was needed to fit previous data.

Low Pt Multiplicity ratios to deuteron pi+

- Found average multiplicity for each pt-SIDIS and CSV (x,Q2) setting as a function of z for the four cases
- Average is for pt<0.25 GeV, all values of phi
- Plotted ratio to dueteron pi+ on next page.
- Blcack for deuteron pi-. Both mine a nd Shua's results shown.
- Blue for proton pi+
- Green for proton pi-
- Various curves use either JAM or DSS fragementation functions

(makes some differences) and either JAM or CTEQ PDFS (this makes almost no difference). The ong dashed curves are from the Lund String model (only shown for x<0.4).

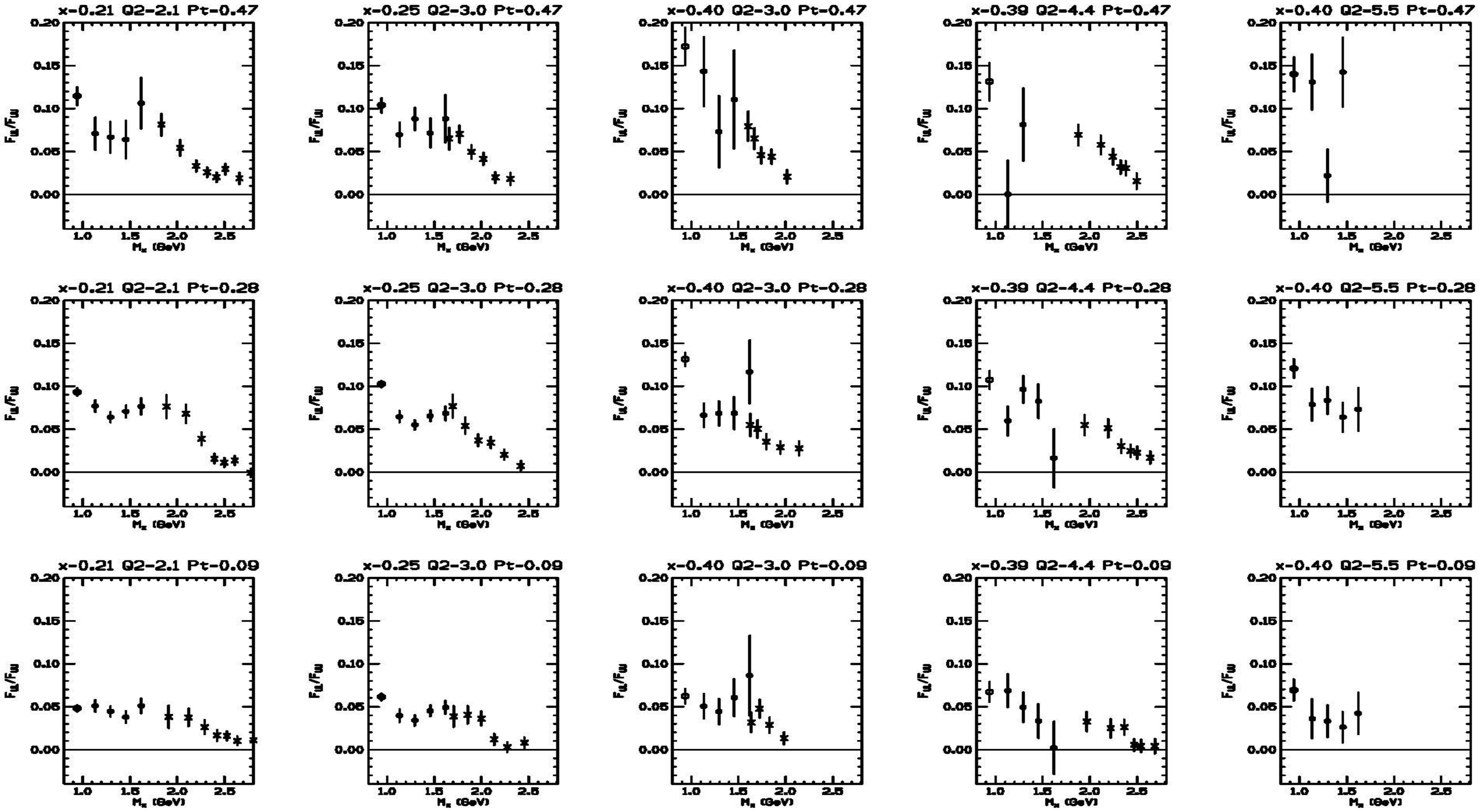
Low Pt Multiplicity ratios to deuteron pi+



Beam Single Spin Asymmetry

- With polarized beam, an L-T interfereance term gives rise to a sin(phi*) depenance in the helicity asymmetry.
- Twist-3 object with sensitivy to TMDs
- Very nice results published by CLAS12 recently, but cut Mx<1.5 GeV
- Only the 10.6 GeV Kaon LT data have enough statistical accuarcy and bood beam polarization to be competitive. So only pi+ from proton.
- Plot on next page shows my results for the exclusive channel (open circles) and inelastic pi+ (solid circles) as a function of pion missing mass Mx. Results divided into low, medium, and higher Pt bins.
- CLAS12 results shown as the crosses.

Beam Single Spin Asymmetry



R at high z

Used the inelastic pion data from the five KLT settings.

Each setting had a high and low epsilon setting.

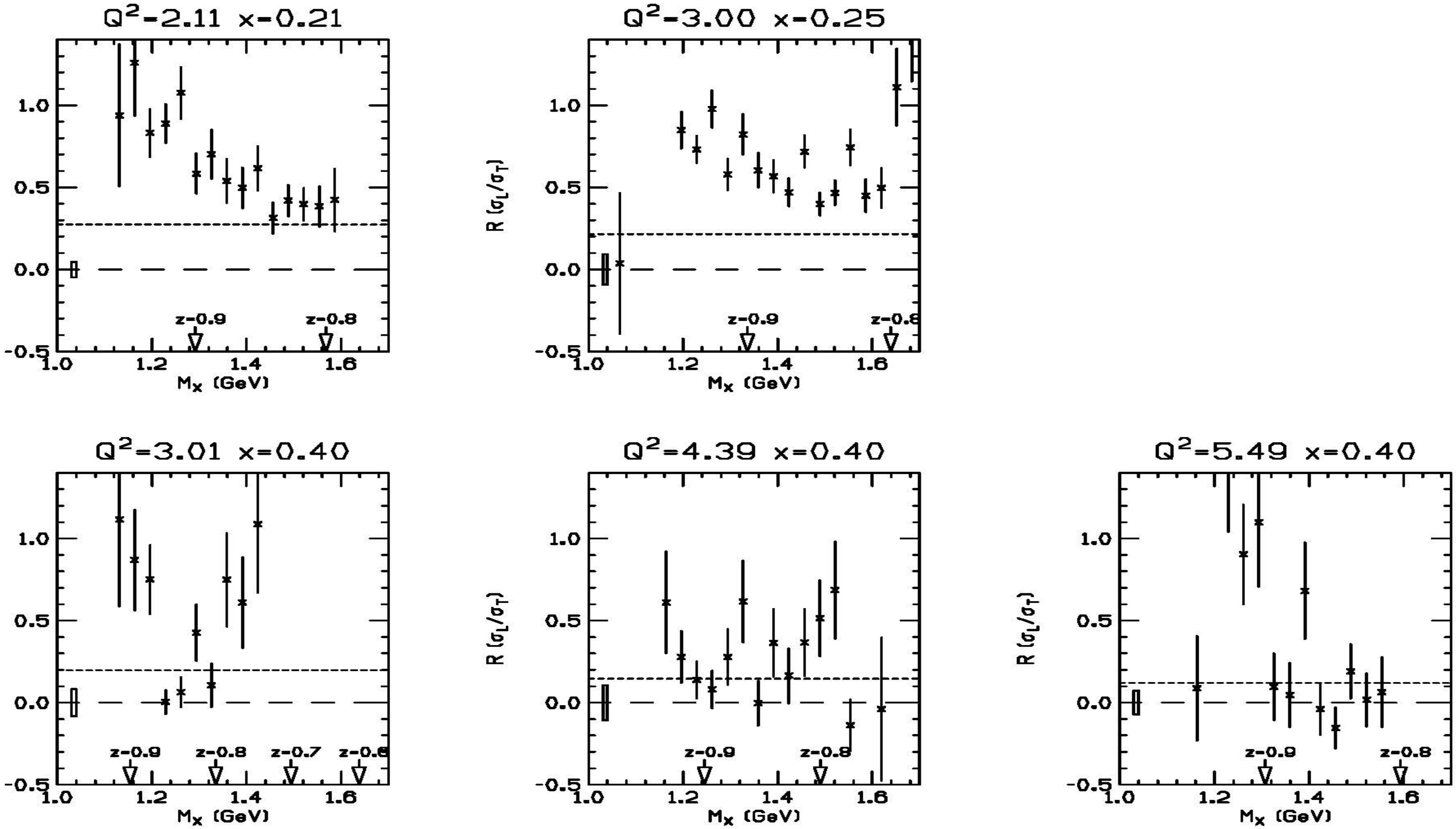
From the ratio of measured to predicted cross sections (using athe DIS model for R), can determine the values of R SIDIS.

The plot bon the next page shows the results as a function of Mx, averaged over pt and phi*

The results are clearly larger than R_DIS f(shown as short dashed lines) or the two lower x settings, and seem to decrease with increasing Mx

The results for the three x=0.4 settings have larger errors, but are consistent with R_SIDIS > R_DIS

R at high z


Q²=2.11 x=0.21
Q²=3.00 x=0.25
Q²=3.01 x=0.40
Q²=4.39 x=0.40
Q²=5.49 x=0.40
R (σL/σT)
Mx (GeV)
z=0.9
z=0.8
z=0.7
1.0
0.5
0.0
-0.5
1.2
1.4
1.6

To-do list

- Improve kaon and proton PID
- Improve the radiative corrections for the kaon and proton SIDIS results by iterating on global fits to results.
- Continue checking of pion results: compare with students.
- Write papers. Have started on pion results from pt-SIDIS experiment.