(Run Group Addition Proposal to Jefferson Lab PAC 51)

Measurements of the Ratio $R = \sigma_L/\sigma_T$, p/d ratios, $P_{h\perp}$ dependence, and azimuthal asymmetries in Semi-Inclusive DIS π^0 production form proton and deuteron targets using the NPS in Hall C

May 21, 2023

PR12-23-014

Spokespersons

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Hall C NPS Collaboration (see Appendix I)

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from Mark Jones: Hall C : Plan for next year (July 2023- July 2024)

Neutral Particle Spectrometer

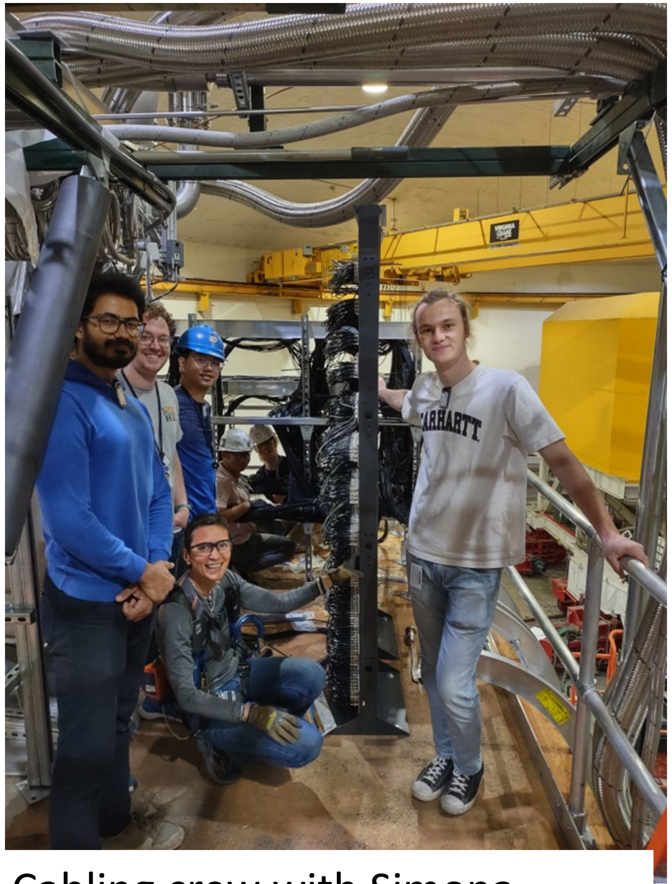
- Sweeping Magnet with calorimeter.
  - Magnet and power supply have been tested.
- NPS attached to SHMS carriage to allow easy angle change.
  - The calorimeter is on rails, cabled and taking cosmics.
- 1080 Lead-Tungstate blocks in calorimeter to detect γ and π^0

Three (four) experiments using the NPS

- E12-13-010/E12-13-007 are two concurrent experiments
  - Exclusive Deeply Virtual Compton on proton
  - SIDIS (e,e',π^0) cross section.
    - Map the transverse momentum dependence.
- E12-22-006
  - Exclusive Deeply Virtual Compton on deuteron
  - Subtract the proton data from deuteron data to get neutron.
- Proposal **PR12-23-014** would be a run group addition extending 90 PAC days to 97 PAC days that measures $R=\sigma_L/\sigma_T$ in SIDIS (e,e',π^0) cross section for both proton and deuteron, and p/d ratios.

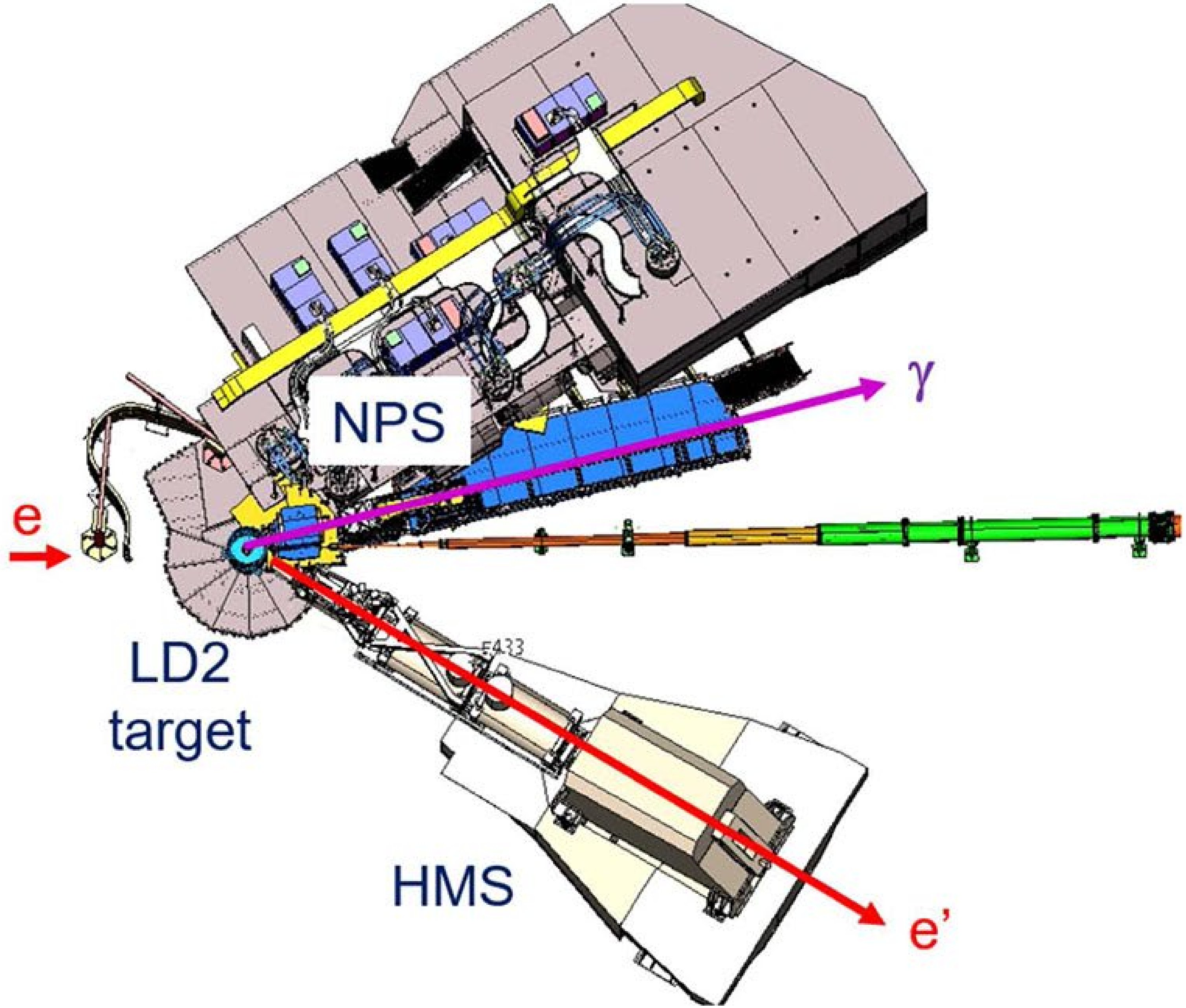
Students putting fiducial marks on Calo

NPS Calo craned onto the NPS platform



Cabling crew with Simona Malace who has led the installation of NPS Calo

Jefferson Lab



γ
NPS
e
LD2
target
E433
HMS
e'

The big picture

PR12-23-014 expands the scope of E12-13-007 to include

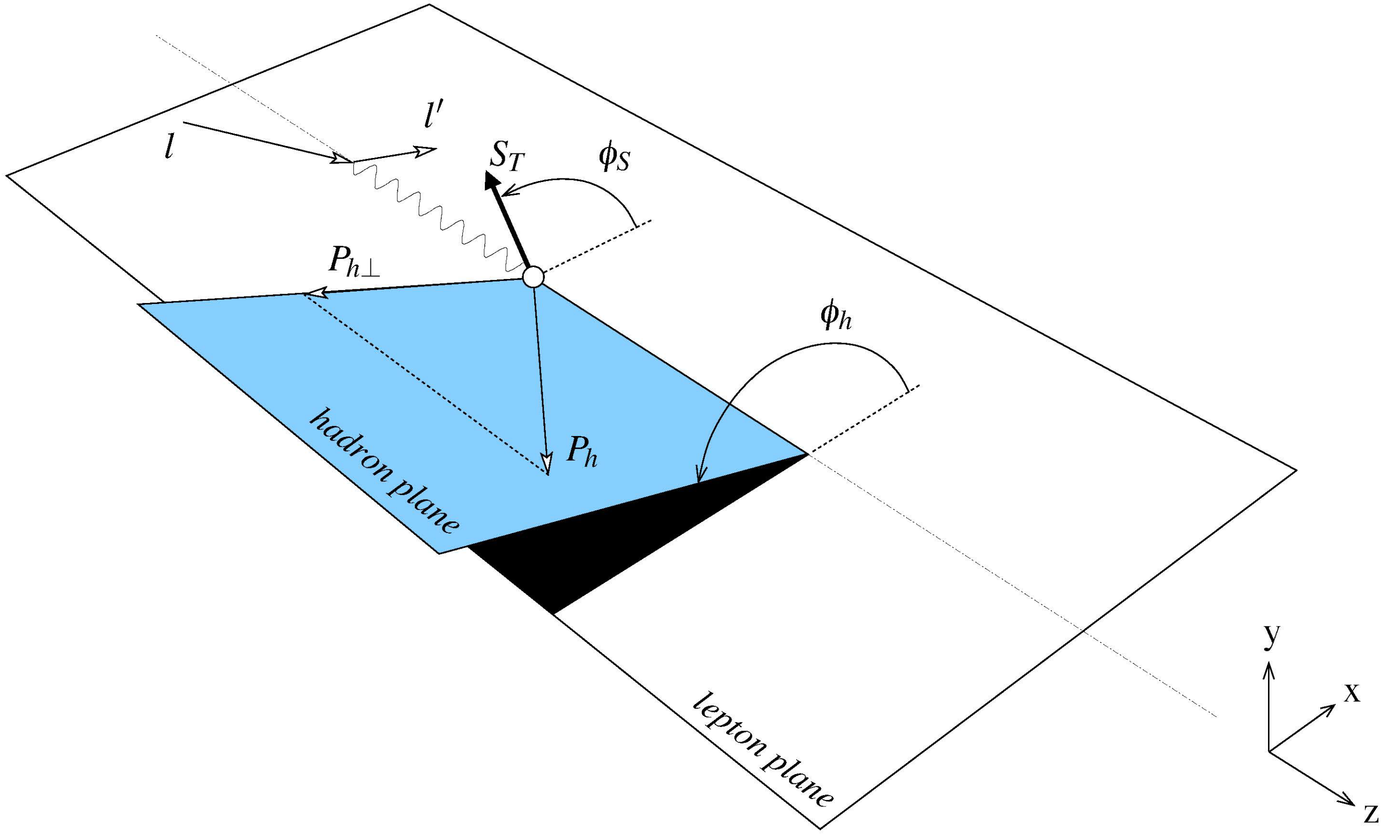
- All three beam energies (not just 10.6 GeV)
- Both proton and deuteron targets

What it adds to JLAB12 SIDIS program:

- Precision measurement of R_{SIDIS} on π^0
- Precision ratios of proton/deuteron
- Larger Q^2 compared to CLAS12 for beam spin asymmetry,…
- To accomplish these goals, augment approved 90 PAC days
- With 2 days for necessary background measurements
- Add deuteron running for lowest x setting
- Add 6.4 GeV running for middle x setting

SIDIS KINEMATICS

Bacchetta, Diehl, Goeke, Metz, Mulders, Schlegel, [hep-ph/0611265]



Q = photon virtuality

M = hadron mass

$P_{h\perp}$ = hadron transverse momentum = P_T $\qquad q_T^2 \approx P_{h\perp}^2 / z^2$

z = fraction of energy transfer carried by outgoing hadron (pion) = E_h / ν

We will measure 6-fold differential cross sections with polarized beam. There are contributions from five structure functions.

$$\frac{d\sigma}{dx\, dy\, d\psi\, dz\, d\phi_h\, dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})$$

$$\Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h}$$

$$+ \lambda_e \sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} \Big\}$$

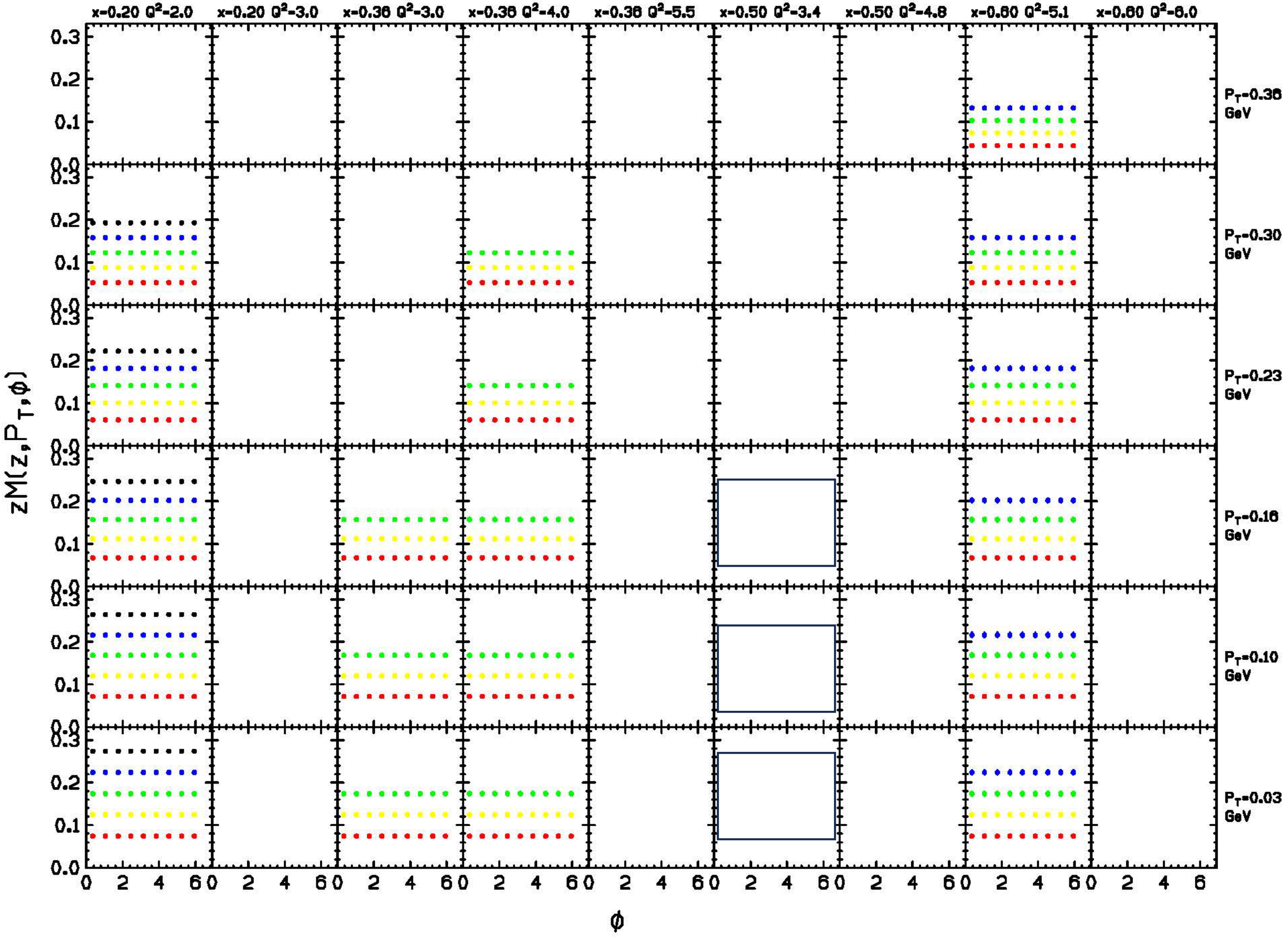
Define Multiplicity M as ratio of SIDIS cross section to DIS cross section.

Experimental overview

- HMS spectrometer detects electrons at scattering angles from 11 to 31 degrees, momenta from 1 to 6.9 GeV
- NPS detects neutral pions via decay to two photons. Mounted on SHMS carriage to cover angle range of 6 to 21 degrees.
- Targets are 10 cm liquid hydrogen and deuterium, and “dummy’ to measure aluminum endcap contributions.
- Electron beam energies of 6.4, 8.5, and 10.6 GeV, currents up to 50 μA, longitudinally polarized beam

Projected errors for beam energy 6.4 GeV. Proton or deuteron targets look same.

Values plotted using JAM PDF, JAM FF



without Extra Running time

Z=0.35

Z=0.45

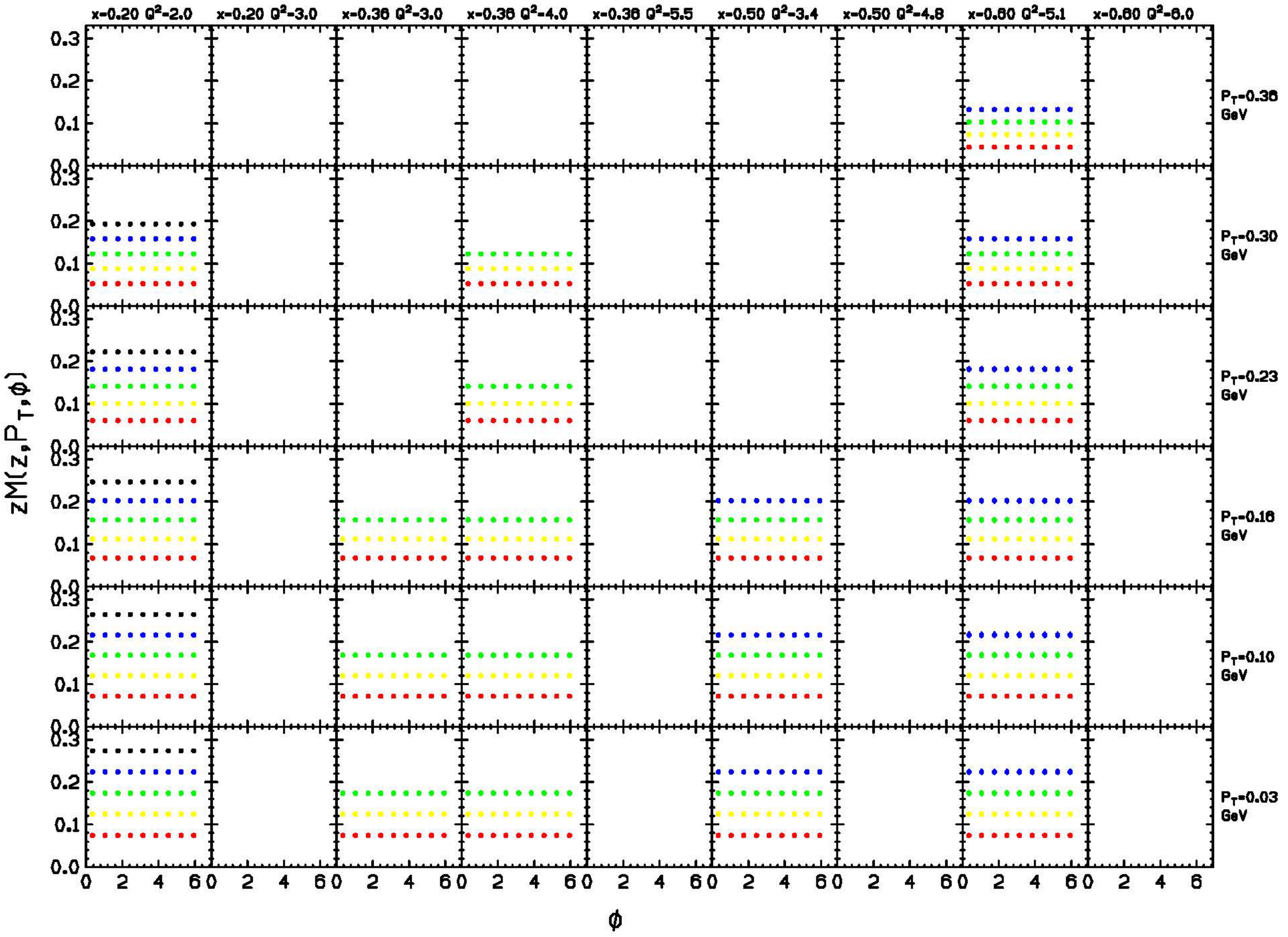
Z=0.55

Z=-0.65

Z-0.75

Projected errors for beam energy 6.4 GeV. Proton or deuteron target look same.

Values plotted using JAM PDF, JAM FF



with Extra Running time

Z=0.35

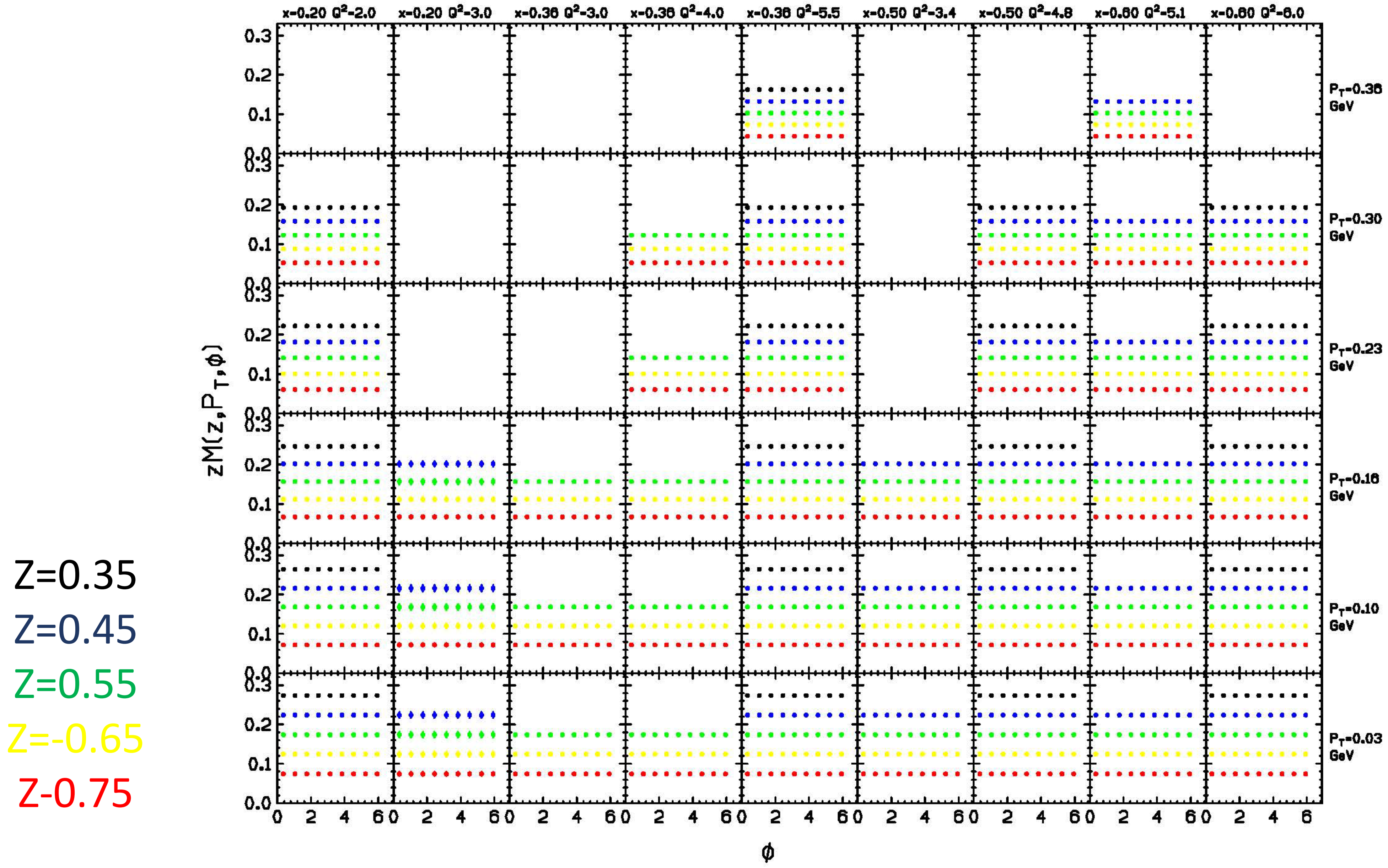
Z=0.45

Z=0.55

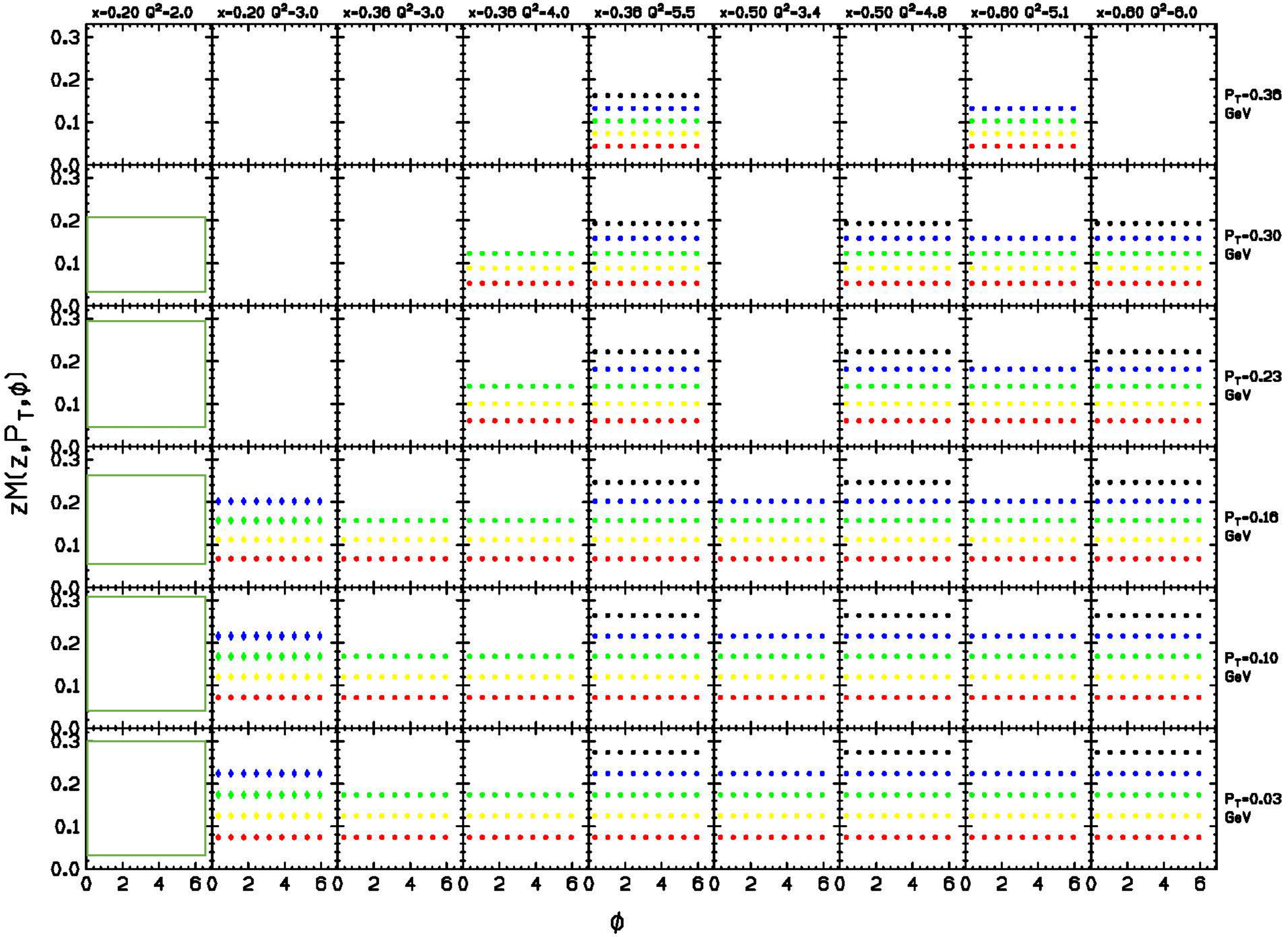
Z=-0.65

Z-0.75

Beam energy 10.6 GeV. Proton target



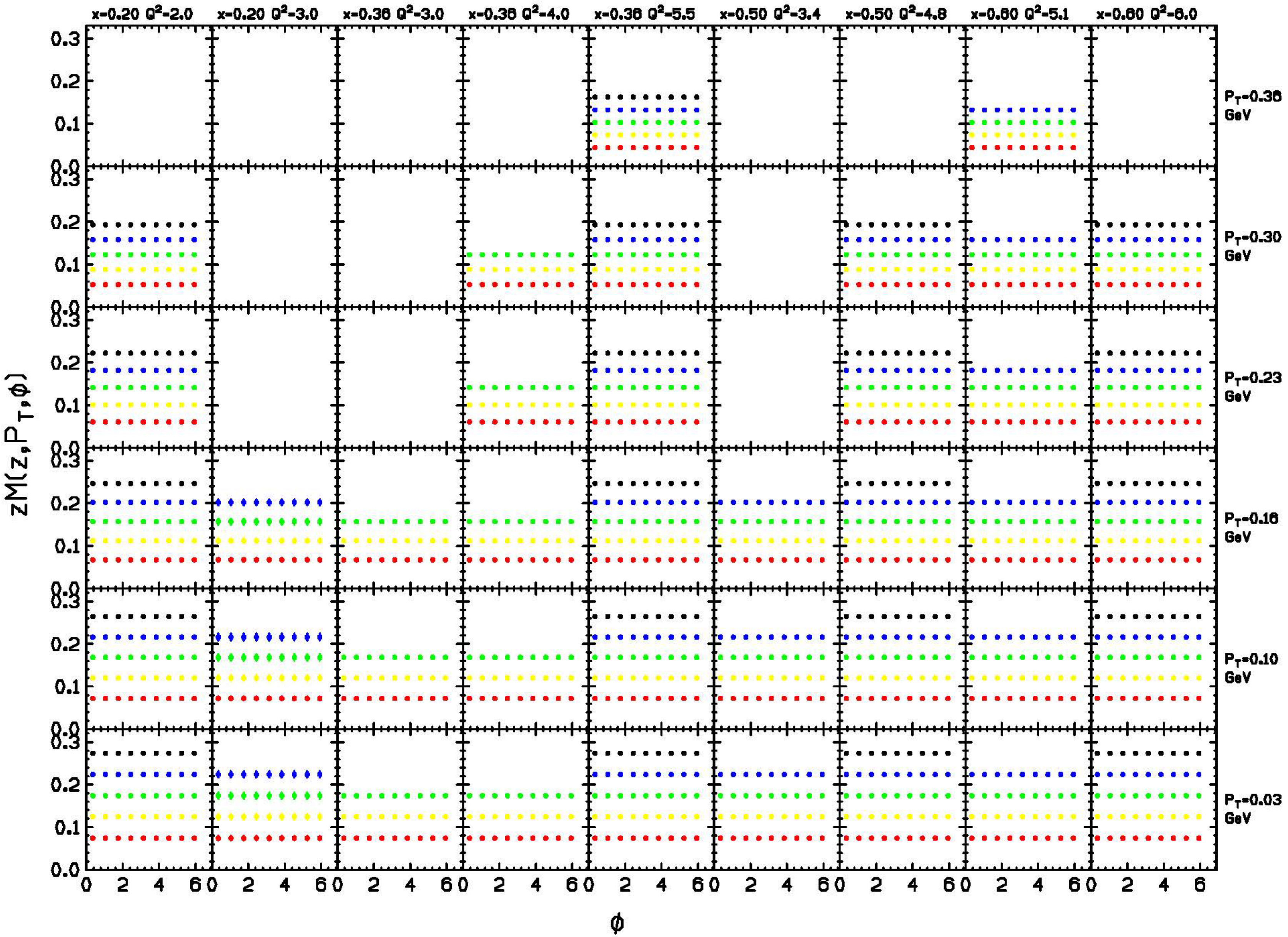
Beam energy 10.6 GeV. Deuteron target



Z=0.35
Z=0.45
Z=0.55
Z=-0.65
Z-0.75

without Extra Running time

Beam energy 10.6 GeV. Deuteron target



Z=0.35
Z=0.45
Z=0.55
Z=-0.65
Z-0.75

with Extra Running time

Kinematic dependence of Multiplicities

- Full 3D binning in (z, P_t, ϕ).
- $\cos(\phi)$ and $\cos(2\phi)$ as a function (z, P_t)
- P_t dependence as a function of z
- Beam single-spin asymmetry as a function of (z, P_t)
- All at 11 values of (x, Q^2), 1 to 3 energies

d/p ratios

- For every point in previous plots, can measure deuteron/proton ratio with typically <1% statistical precision, and small systematic error compared to CLAS because identical target, alternated frequently.
- Deviations from unity sensitive to breaking of LO factorization, isospin-dependent higher twist effects, charge symmetry assumption, …
- Will we see the same kind of deviations as we've seen for proton/deuteron for average pion $(\pi^+ + \pi^-)$?

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_{UU,L}}{F_{UU,T}}$$

$$\frac{d\sigma}{dx\, dy\, d\psi\, dz\, d\phi_h\, dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})$$

$$\Big\{F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h}$$

$$+ \lambda_e \sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

Use 3 beam energies to vary ε at fixed (x,Q^2)

POSSIBLE TERMS AT LOW TRANSVERSE MOMENTUM

see, e.g., Wei, Song, Chen, Liang, arxiv:1611.08688

R is zero at leading twist. Small values were pivotal in establishing quark spin ½.

$$F_{UU,L} = \frac{M^2}{Q^2}\mathcal{C}\left[\frac{4k_T^2}{M^2} f_1 D_1 + \frac{m^2}{M^2} f_1 D_1 + \tilde{f}_2 D_1 + f_1 \tilde{D}_2 + \ldots\right]$$

kinematic twist 4 (à la Wandzura-Wilczek)

mass corrections

dynamic twist 4

sometimes denoted with f_3

factorization breaking terms?

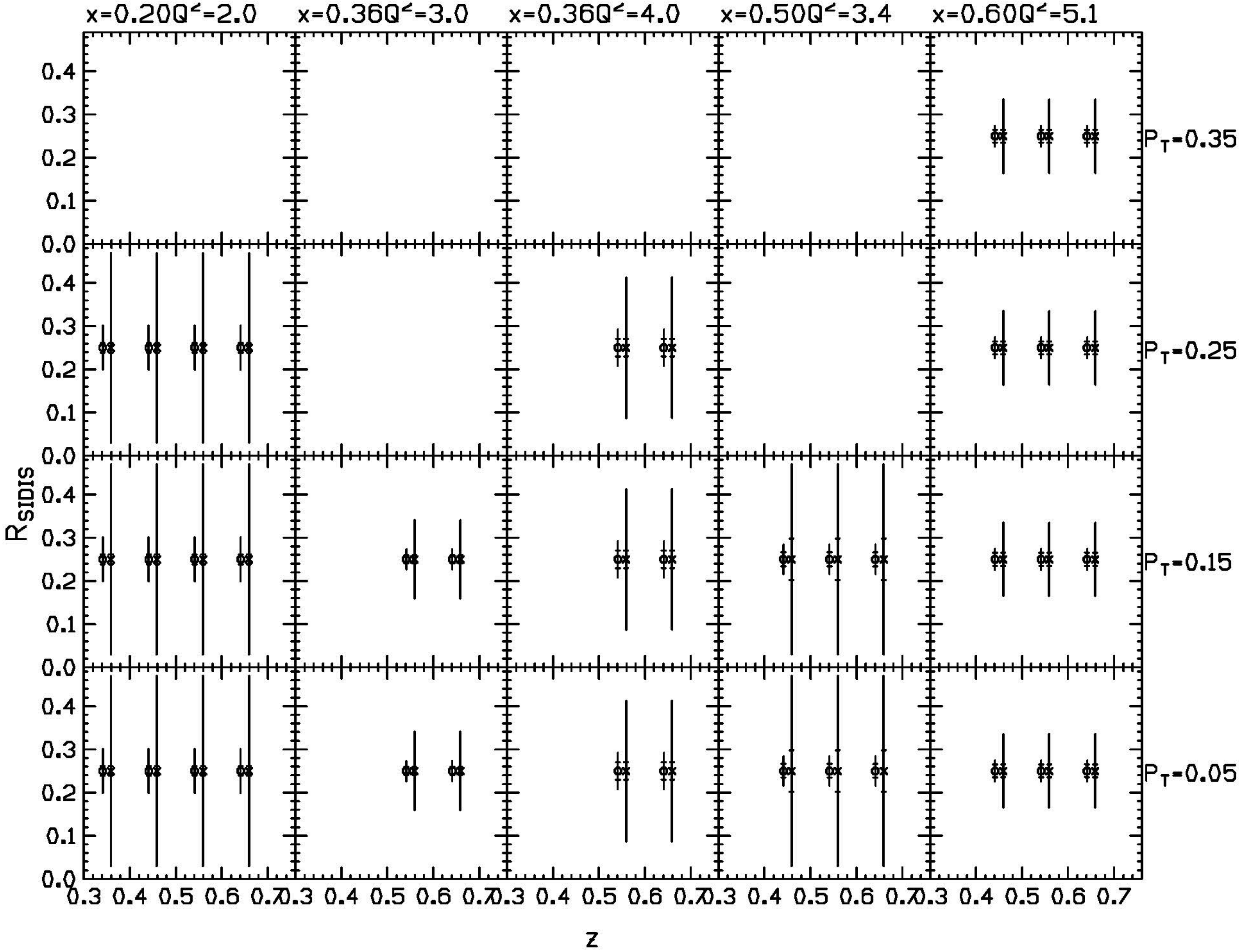
These and other contributions may grow to be very large at high z

Inner projected error bars statistical
Outer error bars include systematics

For each pair of points, left is with extra 7 requested days, right is without them.

Pair-symmetric measurements crucial

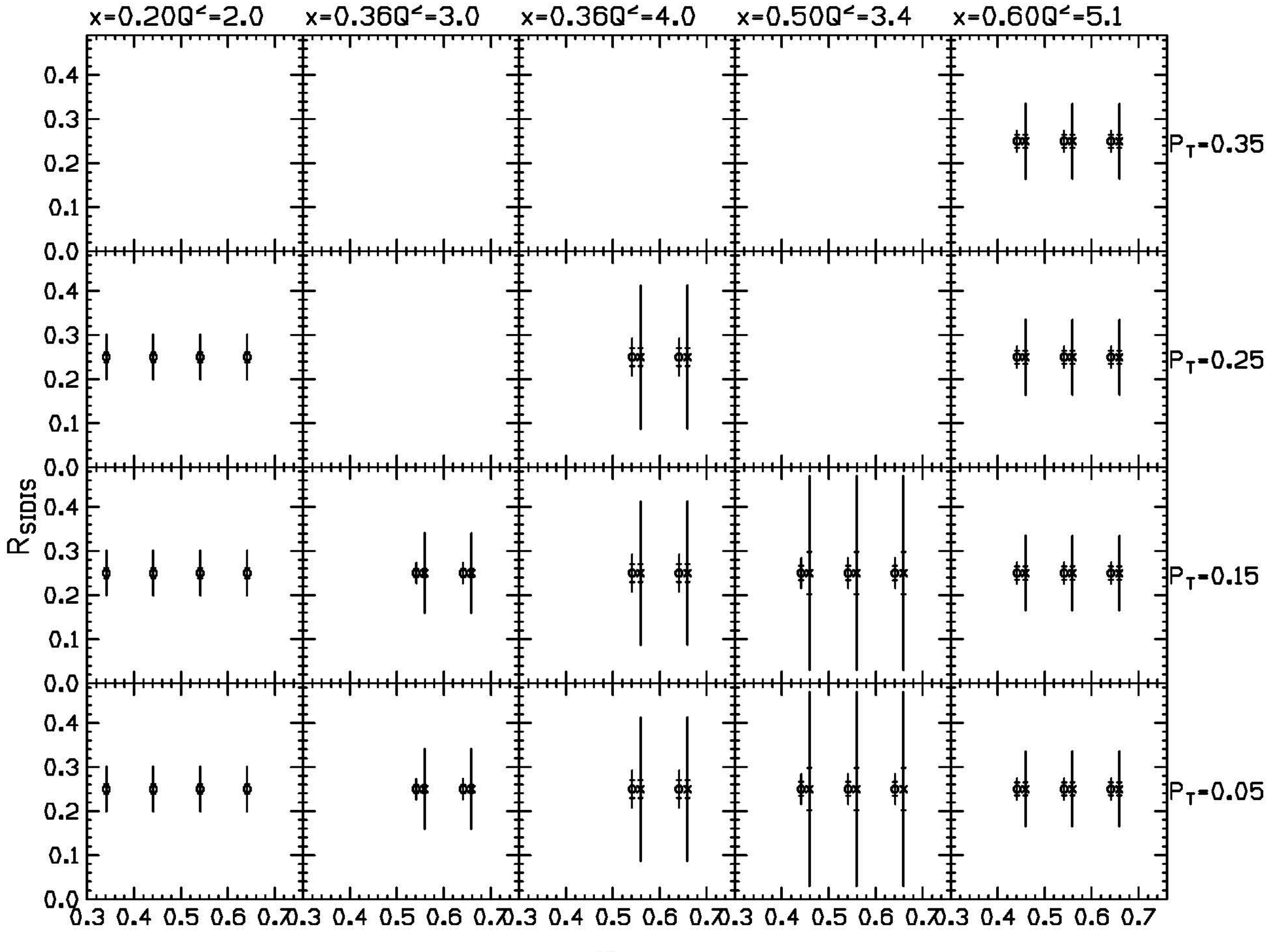
Proton target



For column 4, statistical error 3x bigger without extra beam time (both targets)

Column 1 would not exist for deuteron without extra time.

Deuteron target

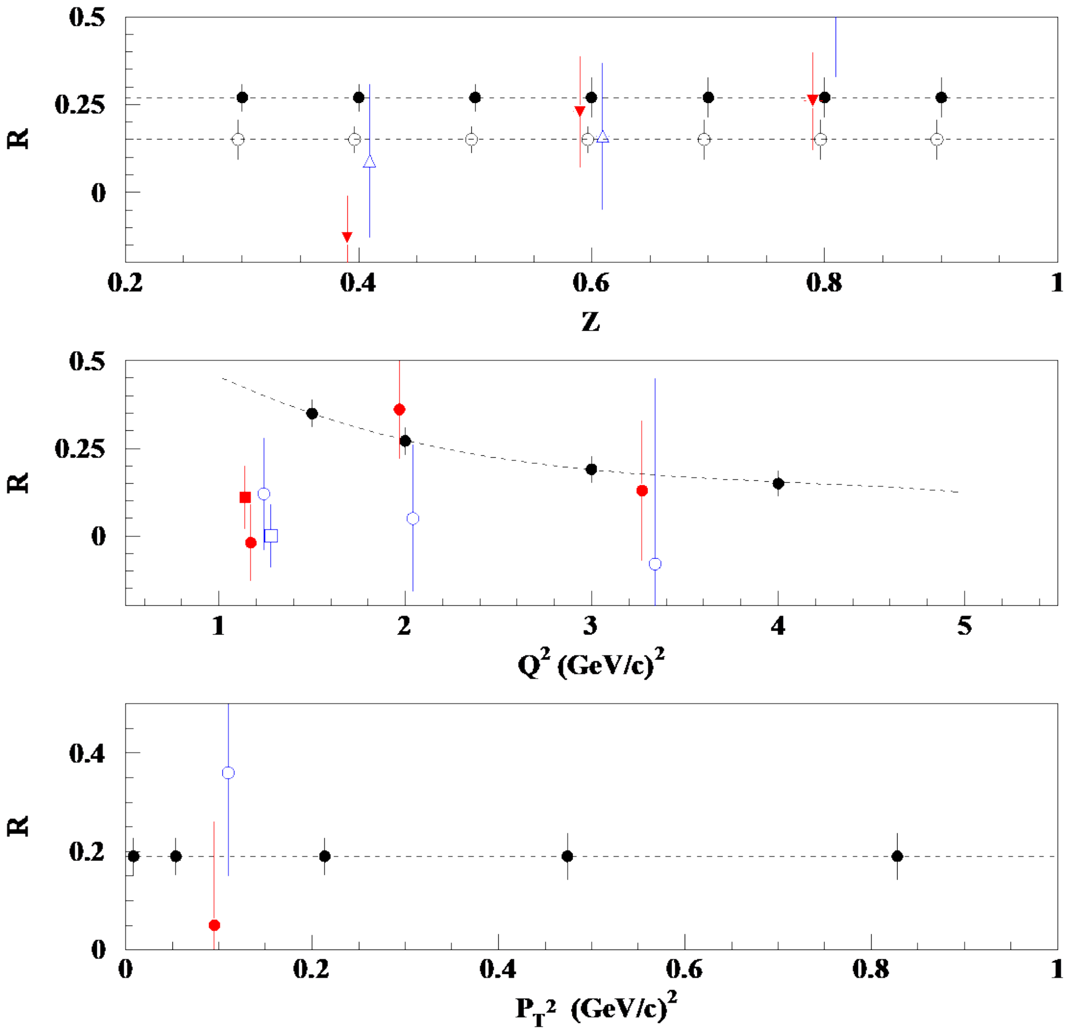


Complementary to E12-06-104 (charged pions) in 2024-2025

Advantages of this neutral pion proposal

- NPS has 6x bigger solid angle than SHMS
- NPS has full azimuthal coverage
- NPS covers all momenta at once (SHMS needs different central momentum settings).
- Pions from ρ^0 VDM production absent
- Larger range of (x,Q^2)

Projections for E12-06-104



Drawbacks

- P_t coverage limited to relatively small values

Pari-symmetric background

- Main source is photoproduction of 2 or more π^0.
- NPS detects one π^0, HMS detects an electron or positron from other π^0
- Measured by reversing polarity of HMS spectrometer
- Could be as large as 4% compared to SIDIS at the lower two beam energies, based on previous measurements with charged pions in 2018-19.
- Models not good enough to calculate background: need 2 PAC days dedicated beam time to do so.

Summary

PR12-23-014 expands on 12-13-007 (24 days) to include

- All three beam energies (not just 10.6 GeV)
- Both proton and deuteron targets

What it adds to JLAB12 SIDIS program:

- Precision measurement of R_{SIDIS} on π^0
- Precision proton/deuteron π^0 multiplicity ratios
- Larger Q^2 compared to CLAS12 for beam asymmetries, etc.
- To accomplish these goals, augment approved 90 PAC days
- With 2 days for necessary background measurement
- Add 2 days deuteron running for lowest x setting
- Add 3 days at 6.4 GeV for x=0.5 setting: 3x bigger ε range