Validation of Hadronic Models using BNL and MIPP data

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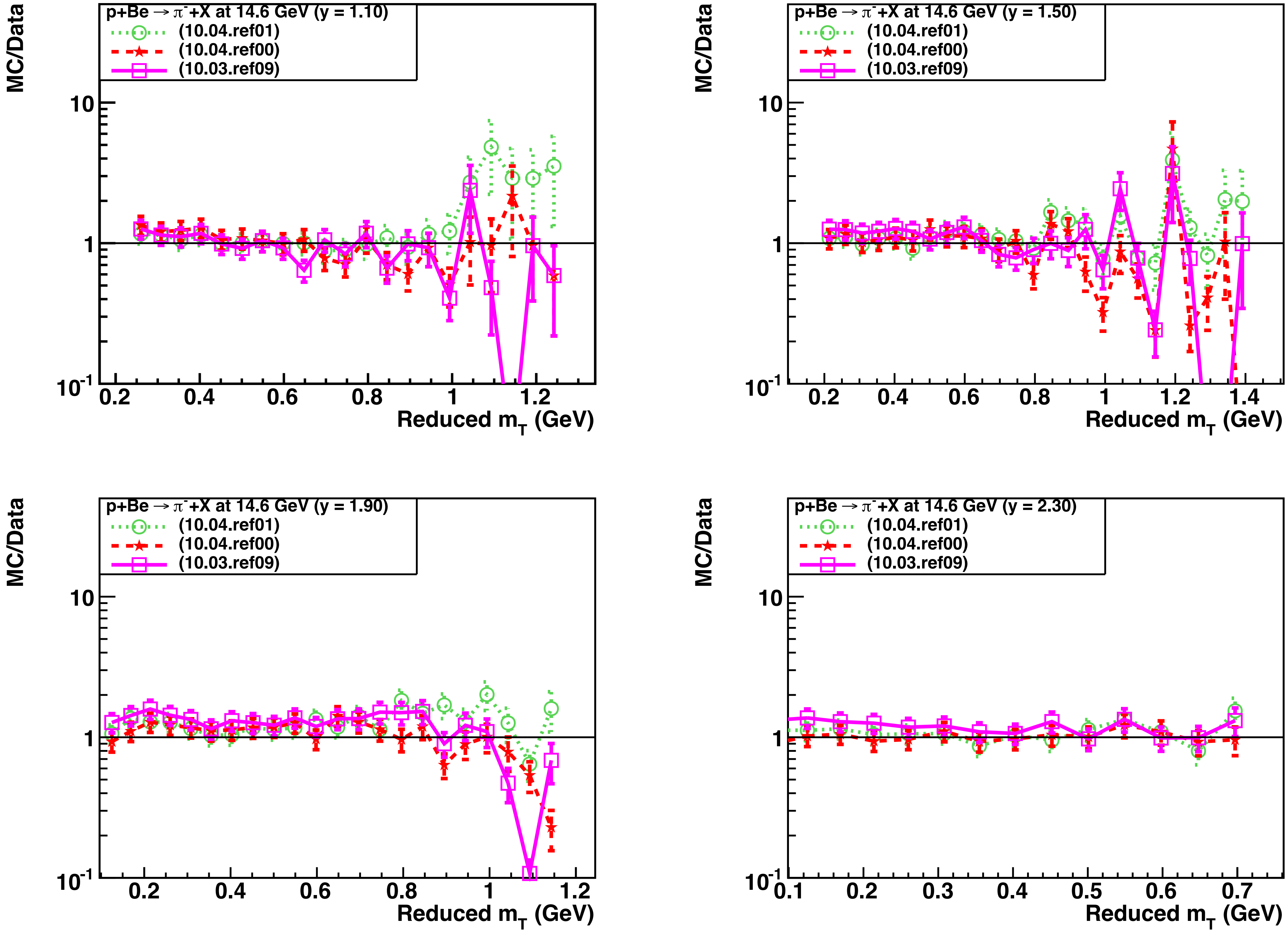
Comparison with BNL Data

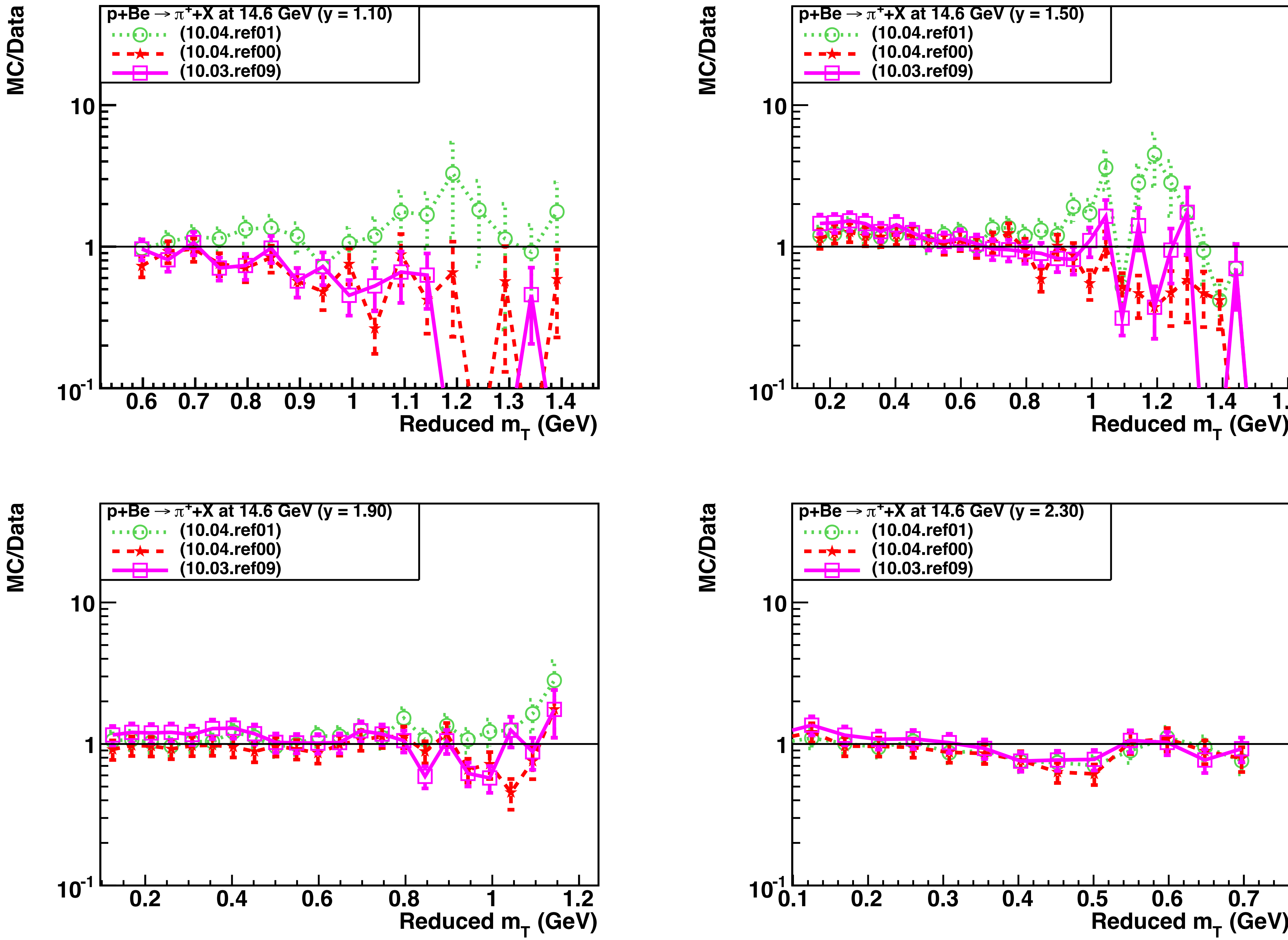
- Data set from BNL E802: (T. Abbott *et al.*, Phys. Rev. D45, 3906)
  - Inclusive $\pi^\pm$, $K^\pm$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets
  - Quantities measured are Lorentz invariant differential cross sections as a function of transverse mass (m_T) in bins of rapidity (y)
  - Data quality: statistical error 5-30%; systematic uncertainty 10-15%
  - Targets studied Be, Al, Cu, Au for all the final states available
- For calculation of invariant cross sections in the BNL data constant bin width of ($\Delta y = \pm 0.1$) is used
- Two Geant4 models are considered for the comparisons:
  - FTFP and QGSP models
- Three versions of Geant4 are used in the following plots:
  - 10.3.ref09, 10.4.ref00, 10.4.ref01

$p + Be \rightarrow \pi^- + X$ at 14.6 GeV/c (FTFP)



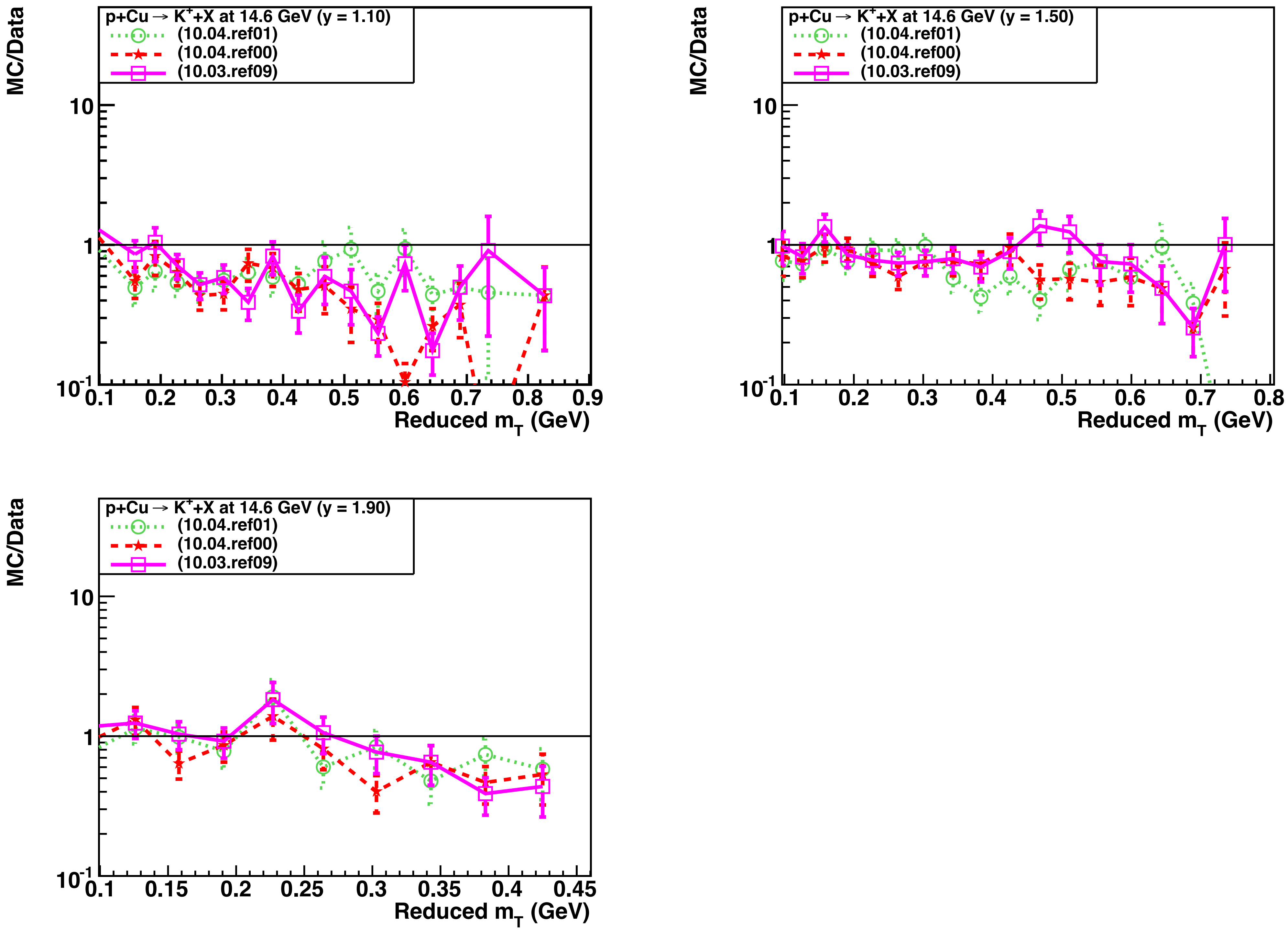
- There is some significant improvement in the prediction of FTFP models from 10.3.ref09 to 10.4.ref00.

p + Be →π⁺ + X at 14.6 GeV/c (FTFP)



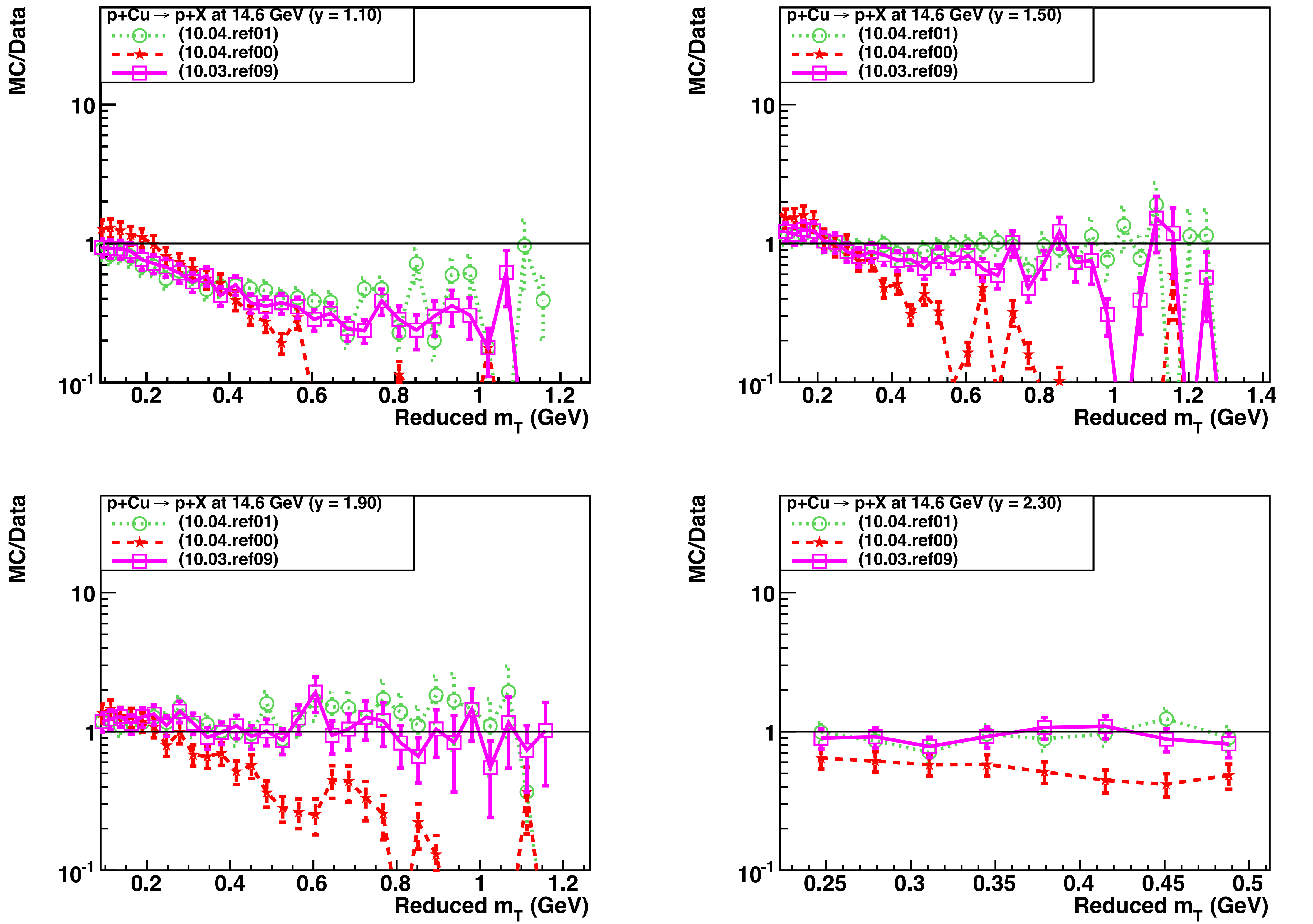
- Predictions are the best for the 10.4.ref00 version.

p + Cu →K⁻ + X at 14.6 GeV/c (FTFP)



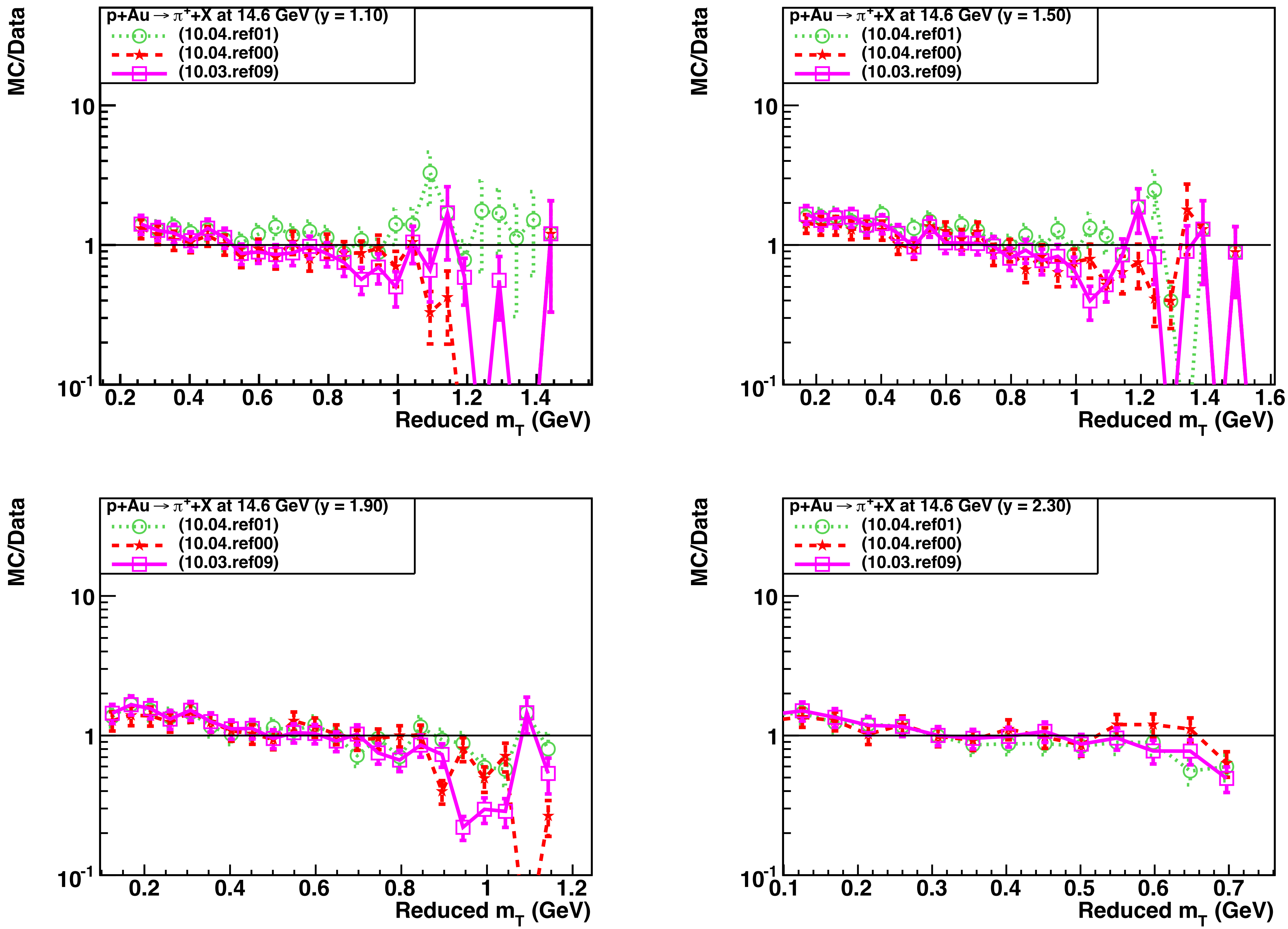
- All versions provide similar level of agreement for K⁻ production

p + Cu → p + X at 14.6 GeV/c (FTFP)



- The version 10.4.ref00 provides the worst agreement for p production

$p + Au \rightarrow \pi^{+} + X$ at 14.6 GeV/c



- Again the predictions from the version 10.4.ref00 is closest to the data

Geant 4 ChiSq/Data for Final State Pions (FTFP)

- Using a flat systematic uncertainty for all measurements:

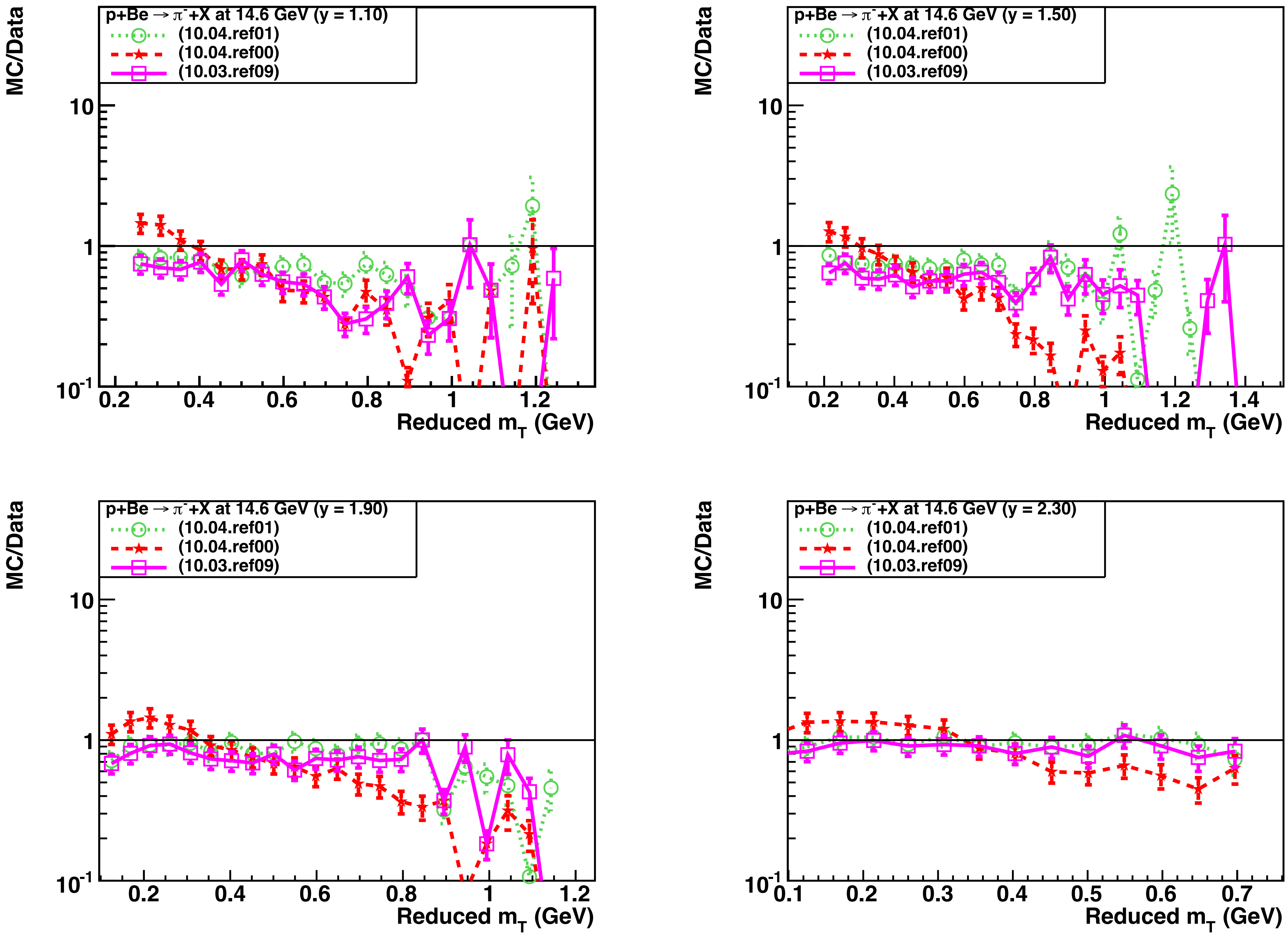
	10.3.ref09	10.4.ref00	10.4.ref01
Be π^+ (1.1)	1.34	1.45	1.80
Be π^+ (1.5)	2.77	1.44	9.69
Be π^+ (1.9)	1.57	0.85	2.27
Be π^+ (2.3)	1.17	1.13	0.78
Be π^- (1.1)	1.26	1.24	4.81
Be π^- (1.5)	2.78	3.28	2.35
Be π^- (1.9)	4.42	1.62	4.04
Be π^- (2.3)	2.08	0.23	1.00
Au π^+ (1.1)	1.44	0.77	2.69
Au π^+ (1.5)	3.47	2.22	4.62
Au π^+ (1.9)	4.56	2.62	2.90
Au π^+ (2.3)	2.80	1.33	3.00
Au π^- (1.1)	2.47	2.27	4.67
Au π^- (1.5)	4.51	2.89	7.01
Au π^- (1.9)	6.29	1.84	7.25
Au π^- (2.3)	7.15	1.42	6.99

ChiSq/Data for Copper Target (FTFP)

- Using a flat systematic uncertainty for all measurements:

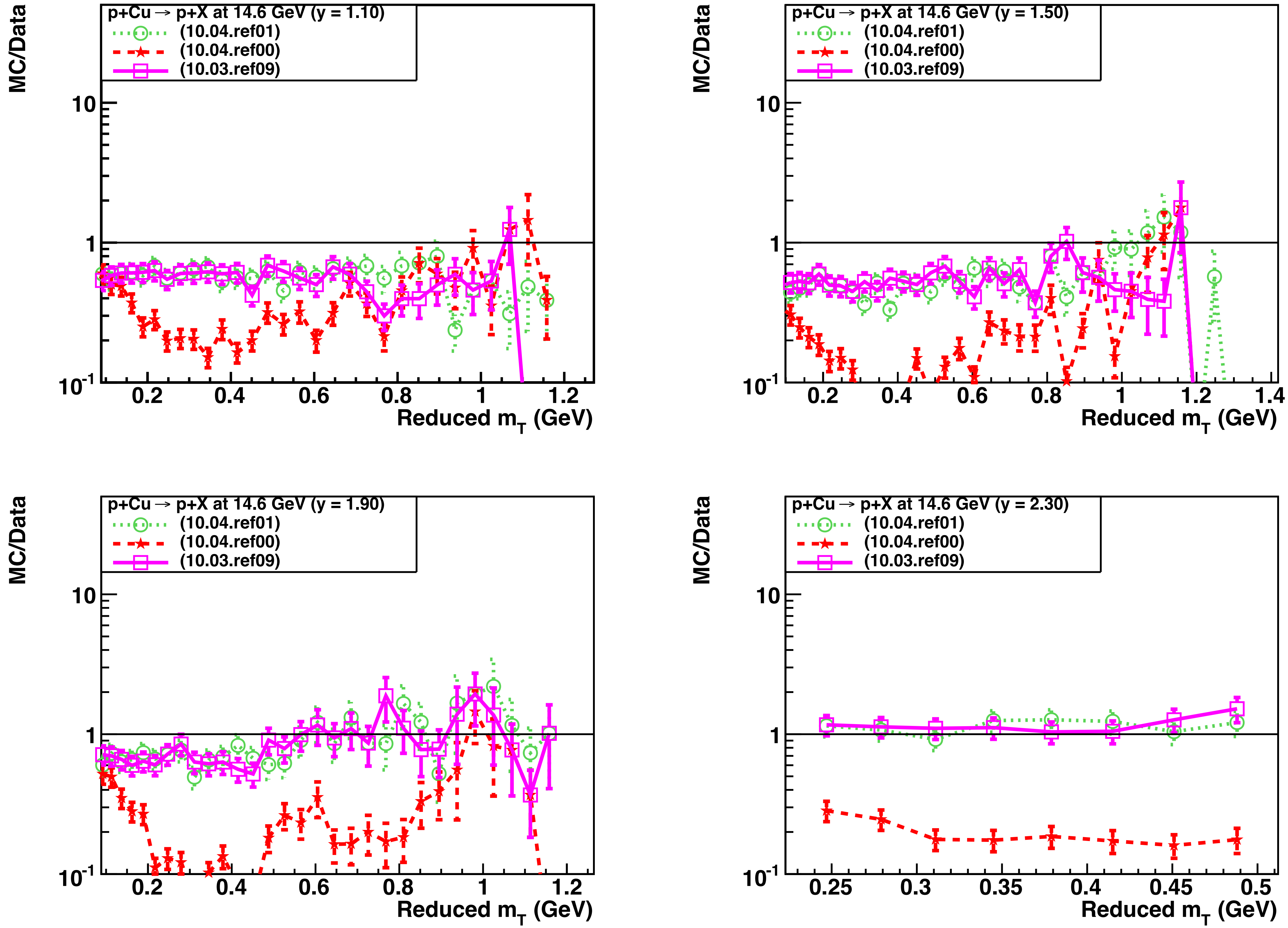
	10.3.ref09	10.4.ref00	10.4.ref01
Cu K^+ (1.1)	2.23	2.85	2.05
Cu K^+ (1.5)	2.33	2.00	2.13
Cu K^+ (1.9)	1.77	1.49	1.48
Cu K^- (1.1)	3.88	1.29	1.36
Cu K^- (1.5)	17.47	2.65	4.02
Cu K^- (1.9)	9.22	6.47	1.88
Cu p (1.1)	6.52	10.43	5.55
Cu p (1.5)	2.02	12.87	0.90
Cu p (1.9)	1.20	4.29	1.91
Cu p (2.3)	0.48	6.29	0.69

p + Be → π + X at 14.6 GeV/c (QGSP)



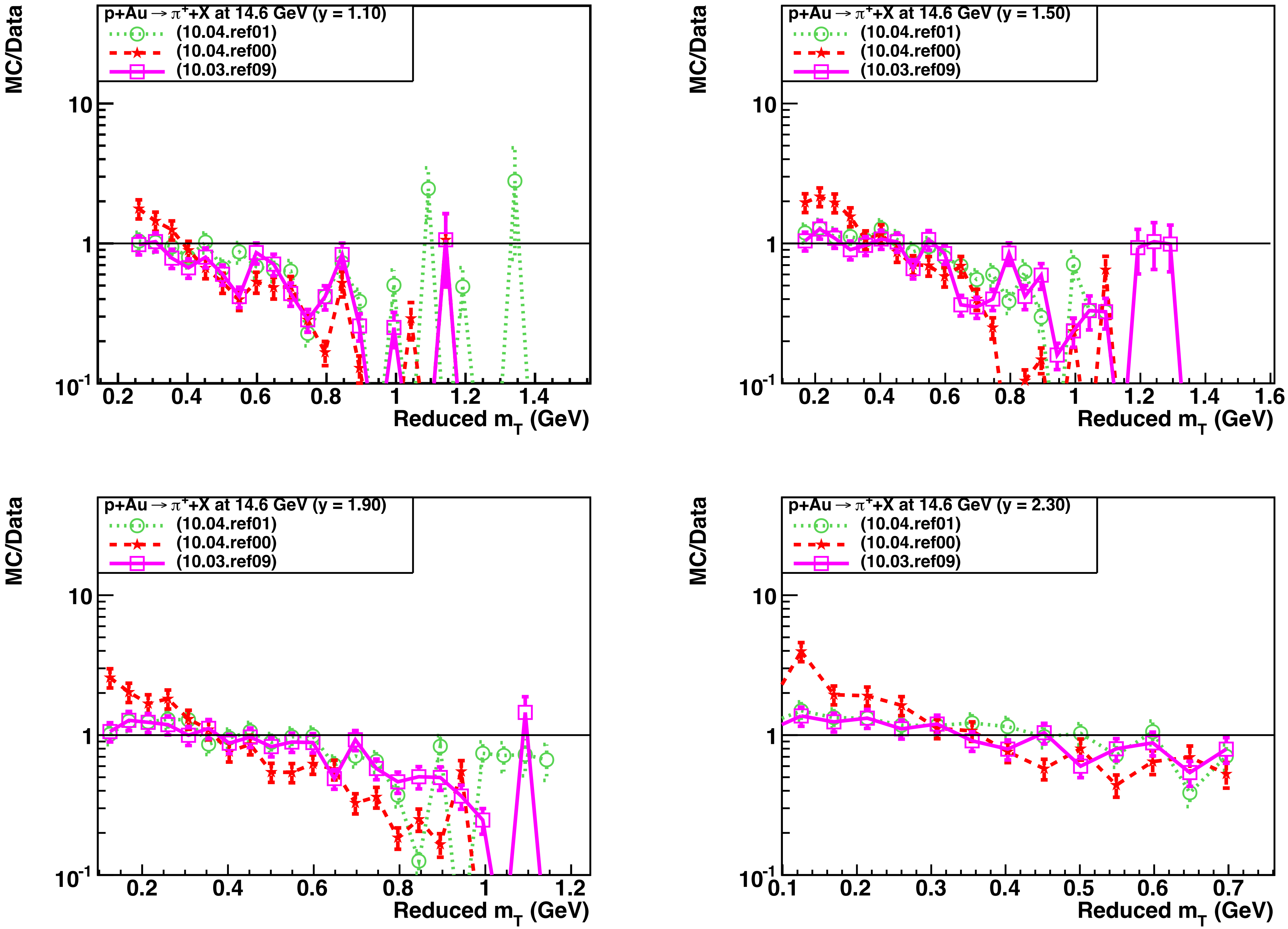
- Predictions from the version 10.4.ref01 provides the best agreement among the 3 versions

p + Cu → p + X at 14.6 GeV/c (QGSP)



- Predictions from the version 10.4.ref00 provide the worst agreement

p + Au → π^+ + X at 14.6 GeV/c (QGSP)



- The version 9.4.ref00 provides worst prediction while there is not much improvement in the version 9.4.ref01

ChiSq/Data for Final State Pions (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref01
Be π^+ (1.1)	4.17	7.30	2.64
Be π^+ (1.5)	2.91	7.21	1.17
Be π^+ (1.9)	3.91	8.88	2.44
Be π^+ (2.3)	2.49	6.28	1.71
Be π^- (1.1)	5.01	5.63	2.81
Be π^- (1.5)	4.50	7.49	3.22
Be π^- (1.9)	2.93	6.32	2.13
Be π^- (2.3)	0.74	3.19	0.44
Au π^+ (1.1)	4.71	8.35	4.10
Au π^+ (1.5)	4.19	13.40	3.37
Au π^+ (1.9)	3.57	16.33	3.05
Au π^+ (2.3)	1.84	30.40	2.48
Au π^- (1.1)	3.57	8.60	3.57
Au π^- (1.5)	2.51	11.52	3.41
Au π^- (1.9)	2.07	11.93	3.06
Au π^- (2.3)	4.05	15.87	4.56

ChiSq/Data for Copper Target (QGSP)

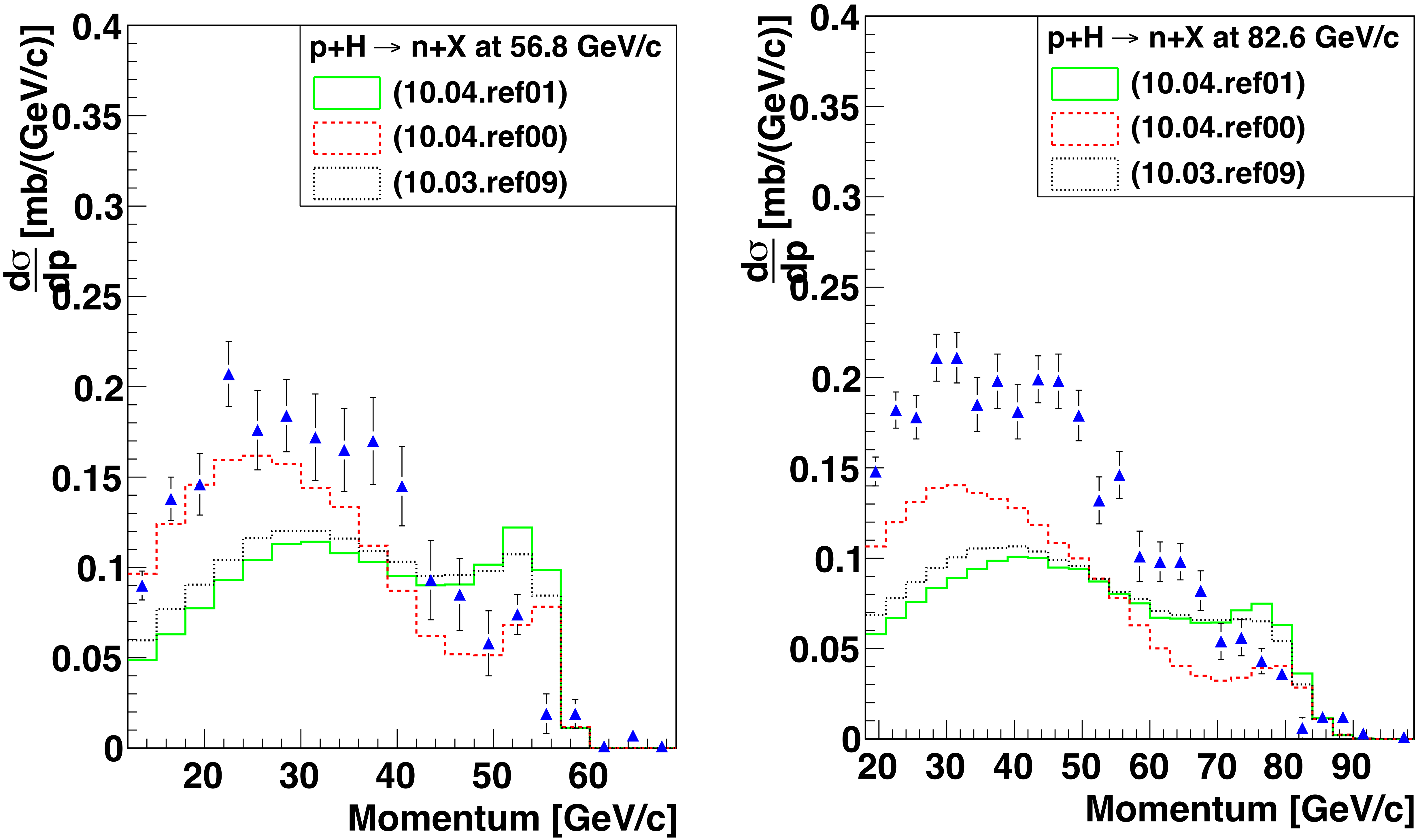
- Using a flat systematic uncertainty for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref01
Cu K^+ (1.1)	6.75	4.34	6.49
Cu K^+ (1.5)	5.99	4.62	5.60
Cu K^+ (1.9)	2.45	3.32	3.55
Cu K^- (1.1)	2.02	3.59	1.97
Cu K^- (1.5)	1.58	6.13	1.45
Cu K^- (1.9)	1.49	0.82	1.06
Cu p (1.1)	5.52	11.20	4.77
Cu p (1.5)	5.78	16.32	6.17
Cu p (1.9)	2.28	11.82	2.37
Cu p (2.3)	1.28	18.74	0.96

Comparison with MIPP data

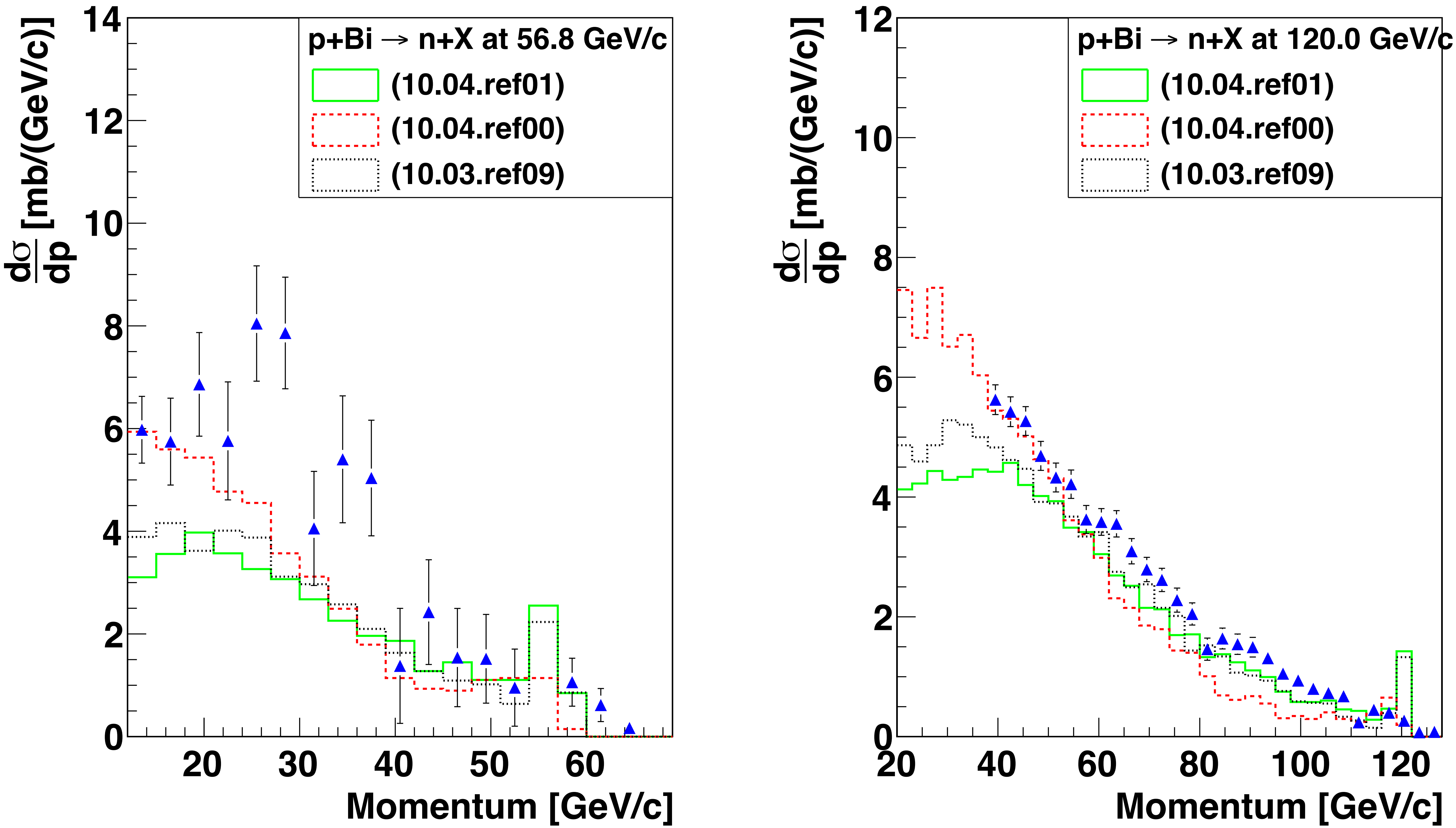
- Data set from Fermilab E907: (T.S. Nigmanov *et al.*, Phys. Rev. D83, 012002)
  - Inclusive neutron production with proton beams at high energies on a number of nuclear targets
  - Targets used: Hydrogen, Beryllium, Carbon, Bismuth, Uranium
  - Projectile: proton beam at: 56.8, 57.3, 82.6 and 120 GeV/c. Beam momentum and impact point at the target are measured using an upstream spectrometer
  - Neutrons detected in the hadron calorimeter and its energy is measured by subtracting energies of charged particles within the geometric acceptance of calorimeter
  - Inclusive neutron momentum distribution and Lorentz invariant cross section for neutron as a function of x_F without any geometric acceptance correction
- For calculation of invariant cross sections, finite target size, beam orientation, acceptance cut of the detector, beam momentum spread, etc. are taken into account
- Two Geant4 models are considered for the comparisons:
  - FTFP and QGSP models
- Three versions of Geant4 are used in the following plots:
  - 10.3.ref09, 10.4.ref00, 10.4.ref01

p + p → n + X at 56.8 and 82.6 GeV/c (FTFP)



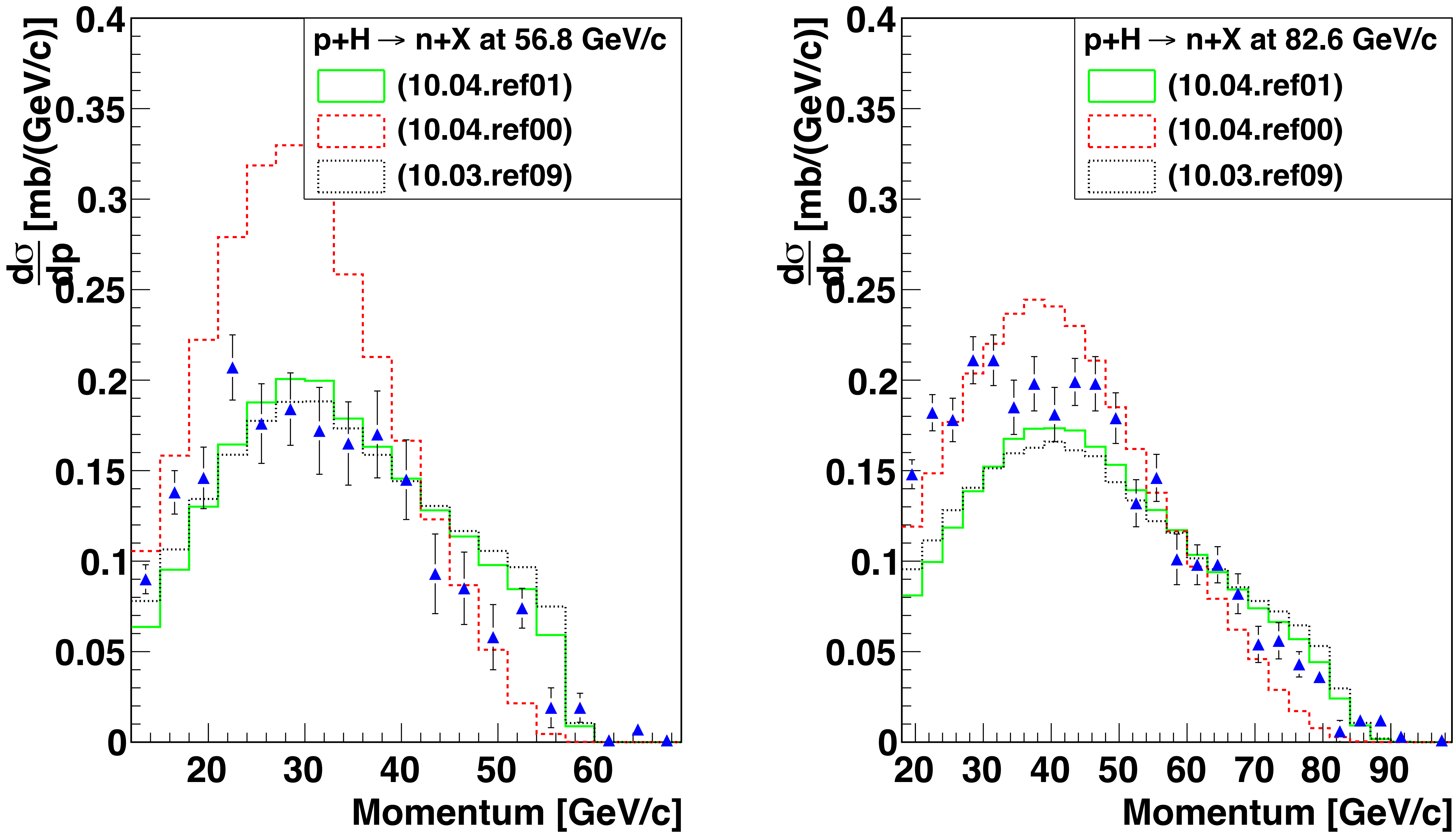
- FTFP predictions are closer to the data for the version 10.4.ref00

p + Bi →n + X at 56.8 and 120.0 GeV/c (FTFP)



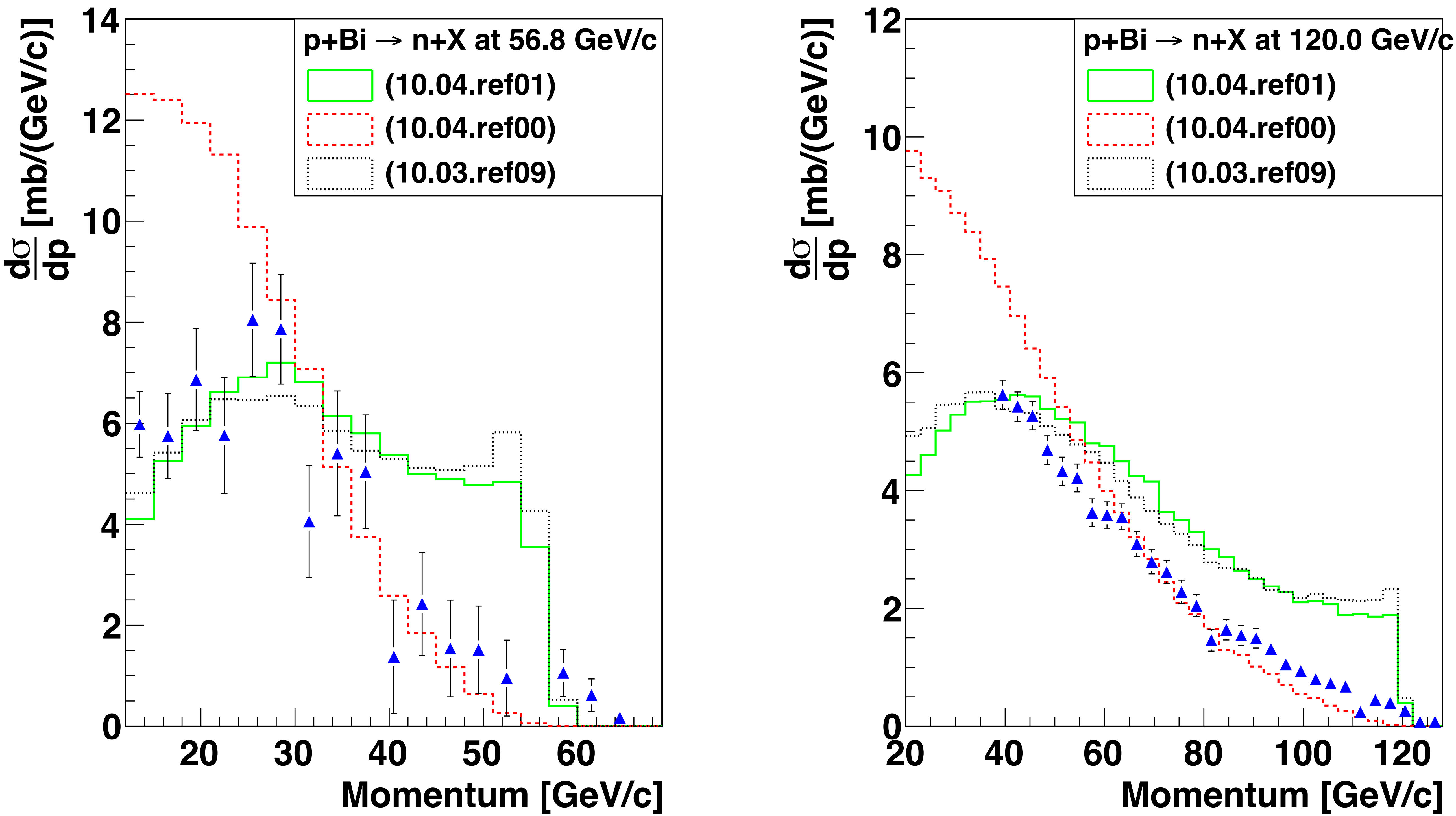
- Agreement is better for the version 10.4.ref00 for heavier targets as well

p + p → n + X at 56.8 and 82.6 GeV/c (QGSP)



- QGSP predictions are better in 10.4.ref01 at 56.8 GeV and in 10.4.ref00 version at 82.6 GeV

p + Bi → n + X at 56.8 and 120.0 GeV/c (QGSP)



- Version 10.4.ref00 provides better agreement on the high momentum end of the distribution while for momentum below 40 GeV is described better by 10.4.ref01

Summary

- Validation effort has been restarted with BNL E802 and MIPP experimental data
- Comparison with BNL data shows:
  - FTFP model provides the best agreement with 10.4.ref00 version for pion production data and with 10.4.ref01 version for proton or kaon production data
  - QGSP model provides the worst agreement with 10.4.ref00 and for proton or kaon production the versions 10.3.ref09 and 10.4.ref01 provide similar level of agreement
- Comparison with MIPP data shows:
  - FTFP model is better in the version 10.4.ref00 though the level of agreement is not very good
  - QGSP model is better in the version 10.4.ref01 except high momentum part of the neutron momentum distribution in interactions with heavier target where 10.4.ref00 provides better agreement

Additional Slides

ChiSq/Data for Final State Pions (10.4.ref01)

	FTFP	QGSP
Be π^+ (1.1)	1.80	2.64
Be π^+ (1.5)	9.69	1.17
Be π^+ (1.9)	2.28	2.44
Be π^+ (2.3)	0.78	1.71
Be π^- (1.1)	4.81	2.81
Be π^- (1.5)	2.35	3.22
Be π^- (1.9)	4.04	2.13
Be π^- (2.3)	1.00	0.44
Au π^+ (1.1)	2.69	4.10
Au π^+ (1.5)	4.62	3.37
Au π^+ (1.9)	2.90	3.05
Au π^+ (2.3)	3.00	2.48
Au π^- (1.1)	4.67	3.57
Au π^- (1.5)	7.01	3.41
Au π^- (1.9)	7.25	3.06
Au π^- (2.3)	6.99	4.56

- FTFP is slightly better for light target while QGSP is definitely better for heavier targets:

ChiSq/Data for Copper Target (10.4.ref01)

	FTFP	QGSP
Cu K^+ (1.1)	2.05	6.49
Cu K^+ (1.5)	2.13	5.60
Cu K^+ (1.9)	1.48	3.55
Cu K^- (1.1)	1.36	1.97
Cu K^- (1.5)	4.02	1.45
Cu K^- (1.9)	1.88	1.06
Cu p (1.1)	5.55	4.77
Cu p (1.5)	0.90	6.17
Cu p (1.9)	1.91	2.37
Cu p (2.3)	0.69	0.96

- FTFP has better agreement particularly for K^+ production