Validation of Hadronic Models using BNL and MIPP data

Geant4 Hadronic Working Group Meeting
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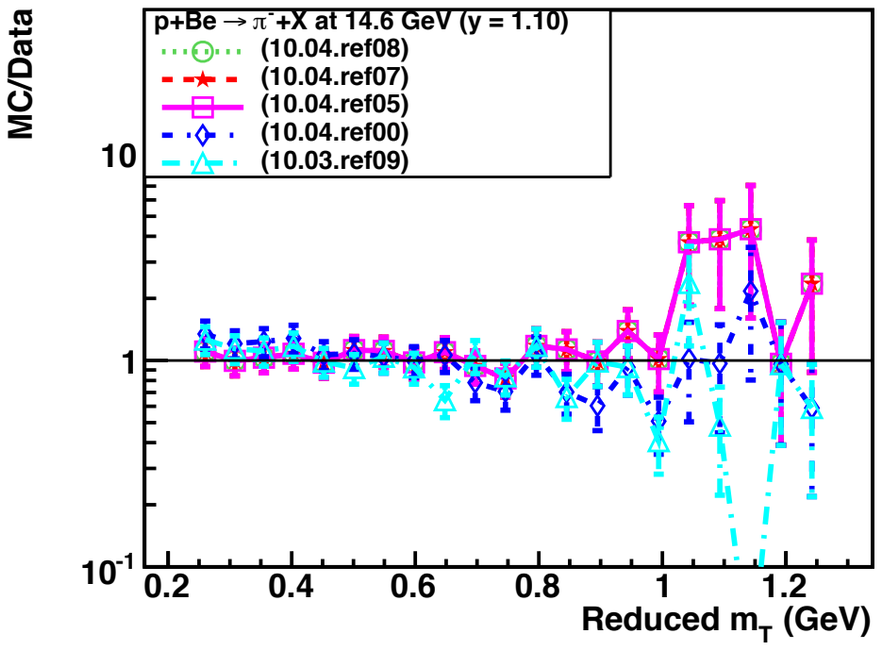
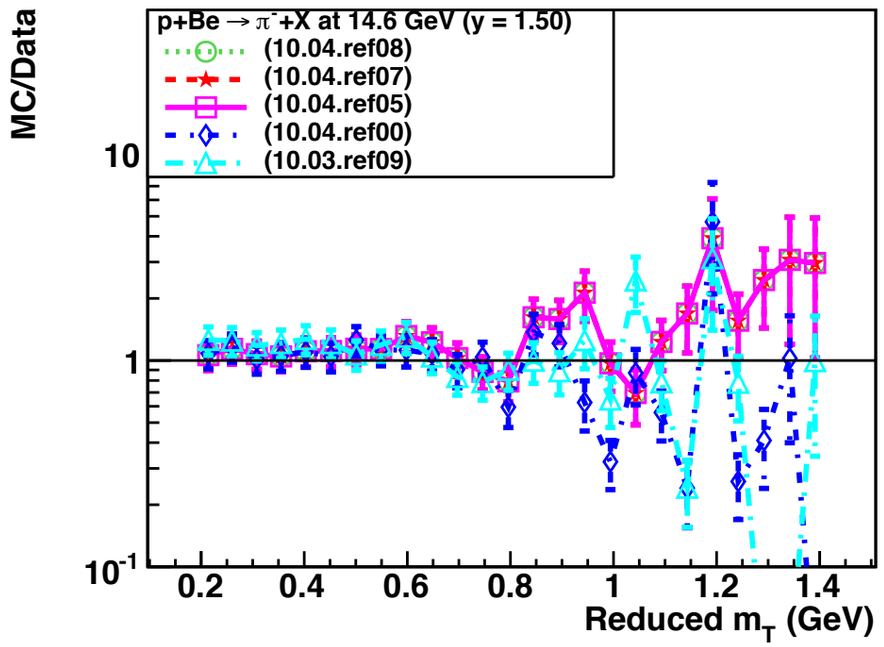
S. Banerjee
Fermilab

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
- Three Geant4 models are considered for the comparisons:
  - Bertini, FTFP and QGSP
- Five versions of Geant4 are used in the following plots:
  - 10.3.ref09, 10.4.ref00, 10.4.ref05, 10.4.ref07, 10.4.ref08

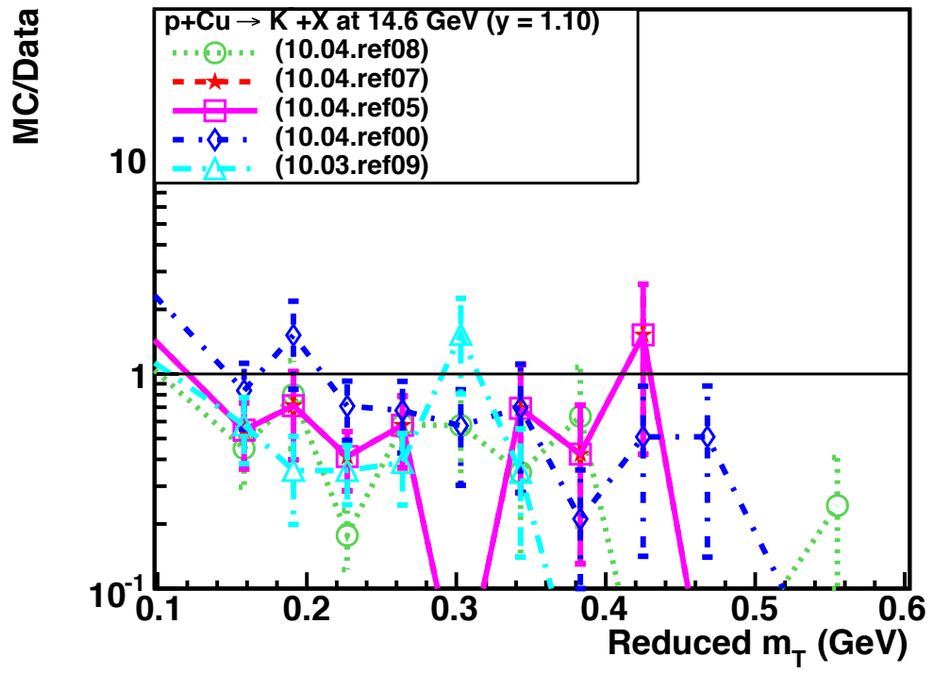
p + Be →π⁻ + X at 14.6 GeV/c (FTFP)

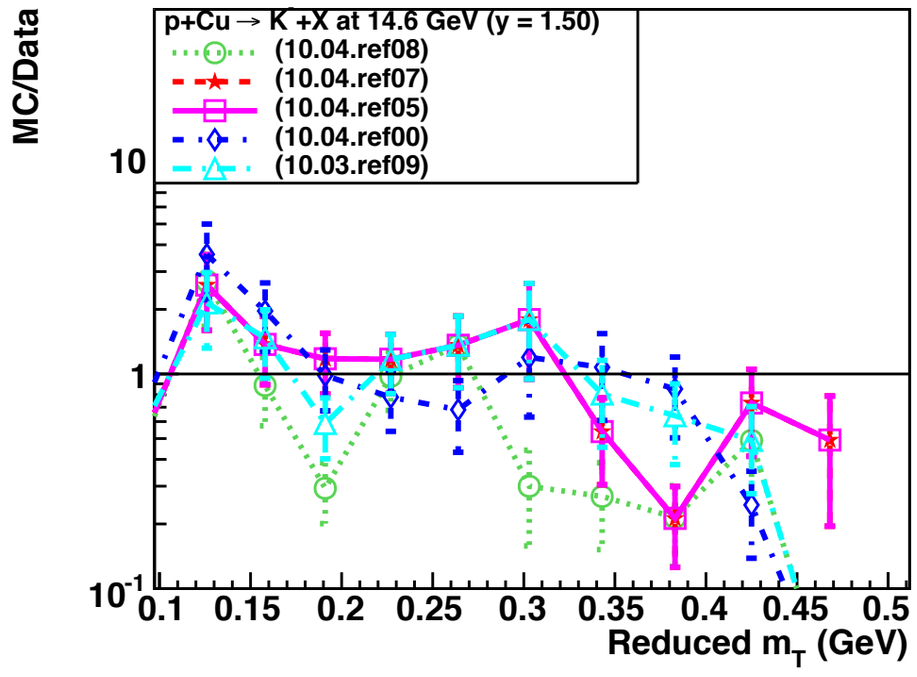


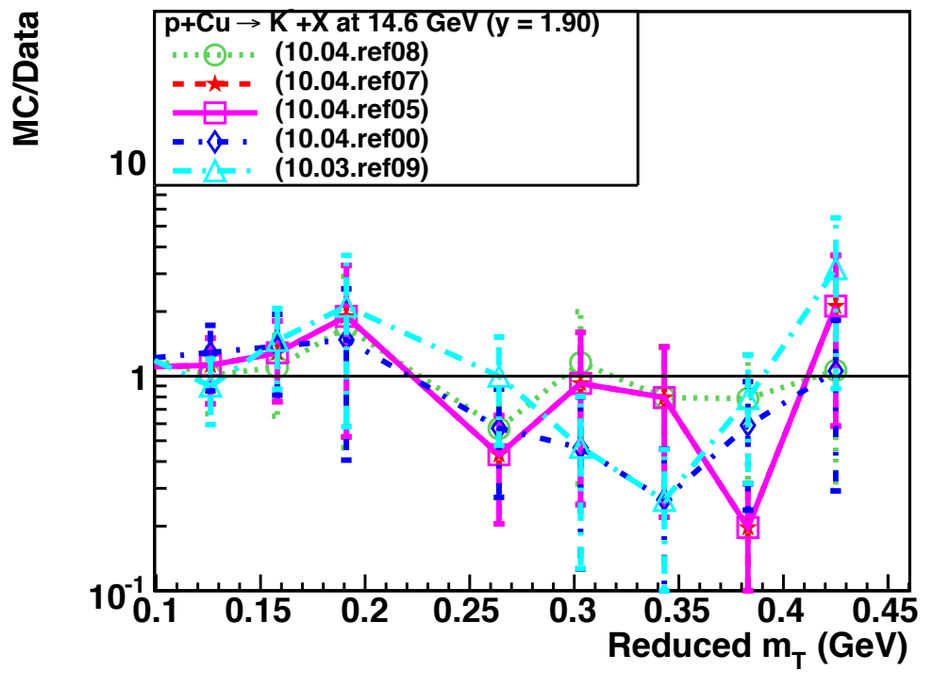


- There is some significant improvement in the predictions of the FTFP model from 10.3.ref09 to 10.4.ref00. But agreement deteriorates for subsequent reference versions of 10.4. ref09 is the same as ref08 for light target but worse for heavy targets

p + Cu → K^- + X at 14.6 GeV/c (FTFP)

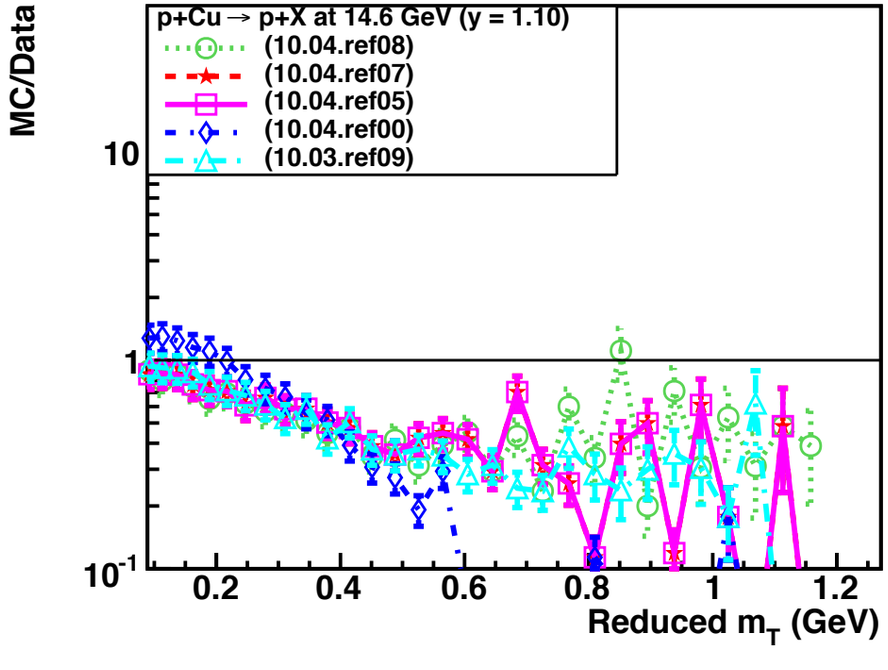


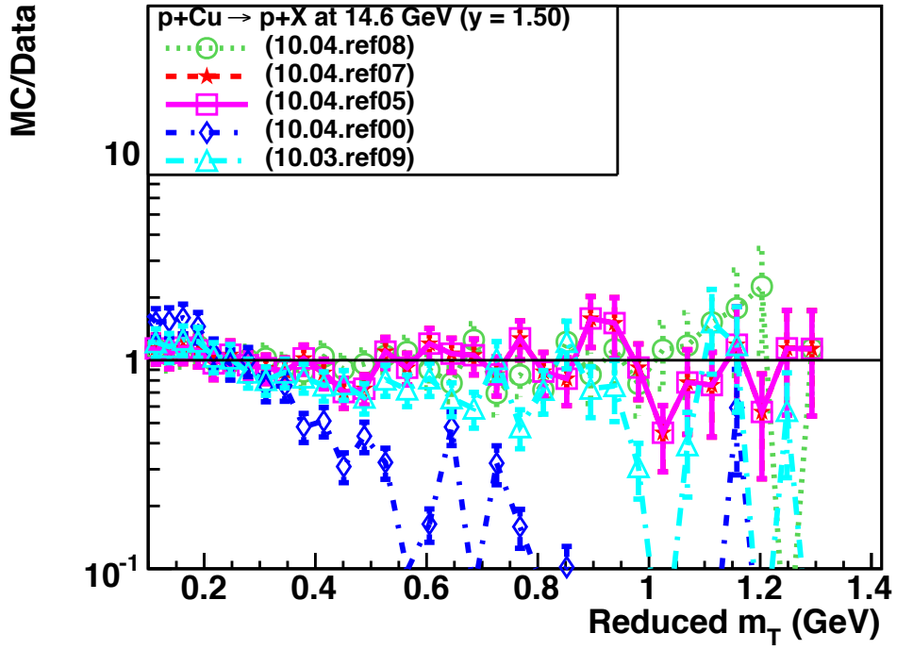


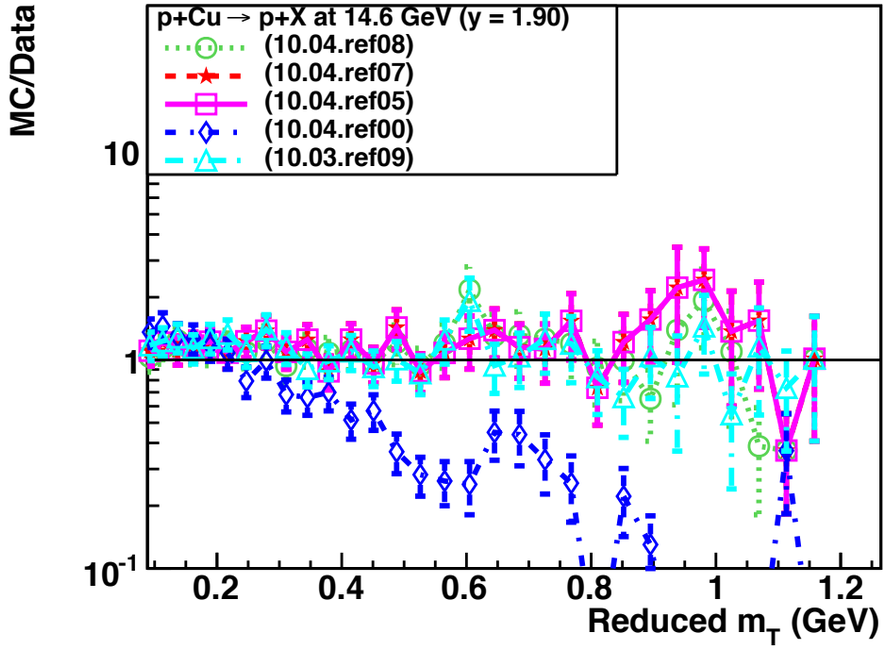


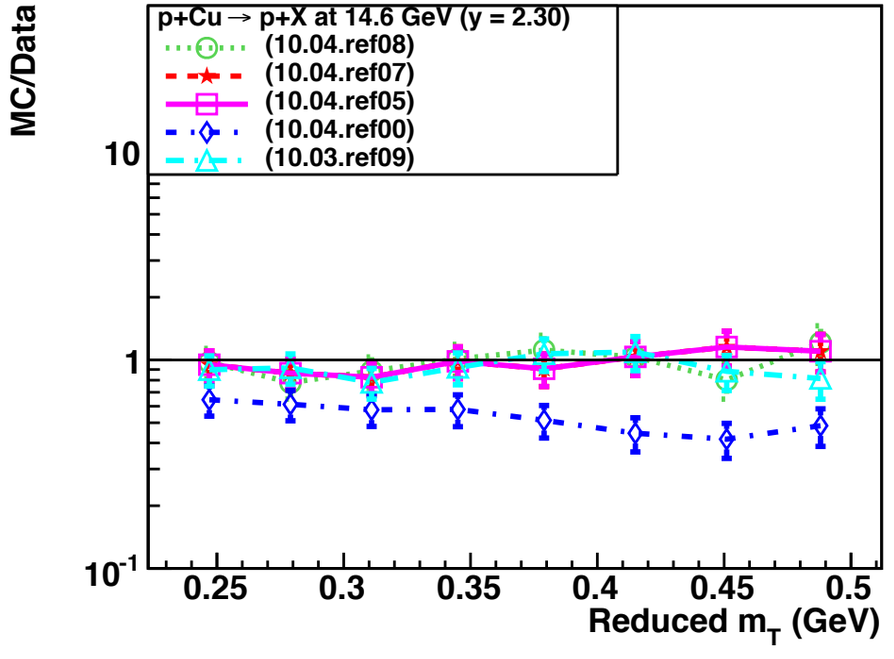
- All versions provide similar level of agreement for K^- production. All are better than 10.3.ref09

p + Cu →p + X at 14.6 GeV/c (FTFP)









- The version 10.4.ref00 provides the worst agreement for p production. 10.4.ref08 provide reasonable description of the data (better than 10.4.ref07)

ChiSq/Data for Final State Pions (FTFP)

- Using a flat systematic uncertainty for all measurements:

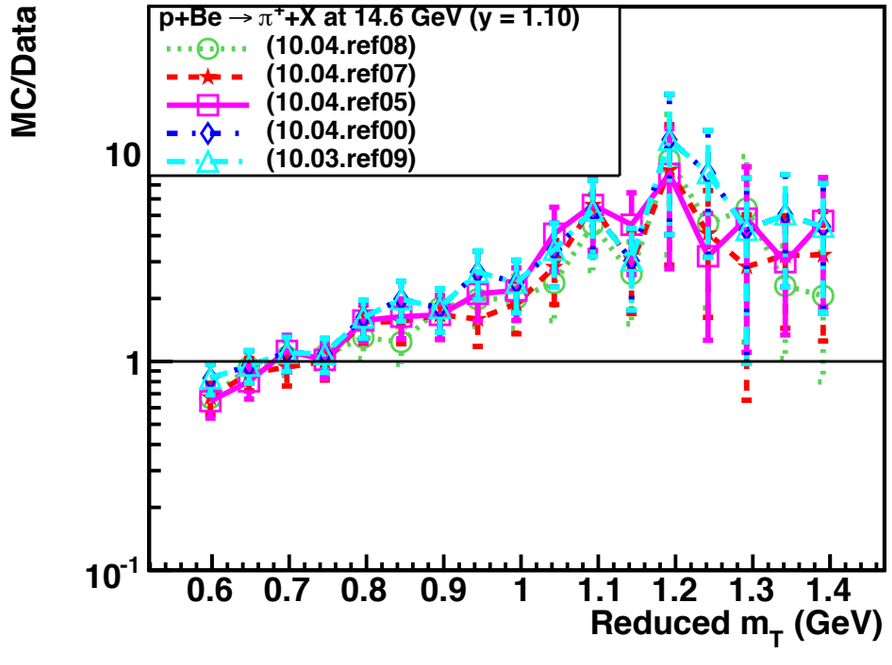
	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Be π^+ (1.1)	1.34	1.45	2.53	2.53	2.53
Be π^+ (1.5)	2.77	1.44	6.52	6.52	6.52
Be π^+ (1.9)	1.57	0.85	3.28	3.28	3.28
Be π^+ (2.3)	1.17	1.13	0.93	0.93	0.93
Be π^- (1.1)	1.26	1.24	4.56	4.56	4.56
Be π^- (1.5)	2.78	3.28	4.30	4.30	4.30
Be π^- (1.9)	4.42	1.62	4.13	4.13	4.13
Be π^- (2.3)	2.08	0.23	0.38	0.38	0.38
Au π^+ (1.1)	1.44	0.77	2.29	2.29	3.44
Au π^+ (1.5)	3.47	2.22	4.03	4.03	4.37
Au π^+ (1.9)	4.56	2.62	3.02	3.02	3.30
Au π^+ (2.3)	2.80	1.33	2.04	2.04	2.05
Au π^- (1.1)	2.47	2.27	3.58	3.58	4.47
Au π^- (1.5)	4.51	2.89	8.17	8.17	12.27
Au π^- (1.9)	6.29	1.84	8.41	8.41	9.62
Au π^- (2.3)	7.15	1.42	7.01	7.00	7.23

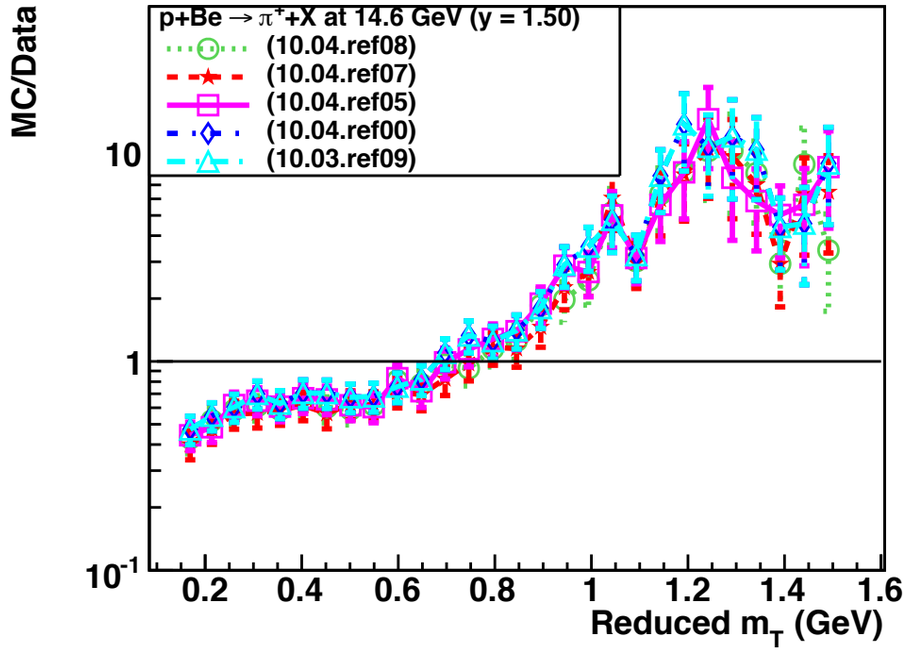
ChiSq/Data for Copper Target (FTFP)

- Using a flat systematic uncertainty for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Cu K^+ (1.1)	2.23	2.85	2.88	2.88	2.07
Cu K^+ (1.5)	2.33	2.00	1.82	1.82	2.66
Cu K^+ (1.9)	1.77	1.49	2.30	2.30	1.19
Cu K^- (1.1)	3.88	1.29	1.17	1.17	2.43
Cu K^- (1.5)	17.47	2.65	5.84	5.84	2.88
Cu K^- (1.9)	9.22	6.47	1.67	1.67	5.25
Cu p (1.1)	6.52	10.43	5.91	5.91	2.06
Cu p (1.5)	2.02	12.87	0.95	0.95	0.91
Cu p (1.9)	1.20	4.29	1.62	1.62	1.31
Cu p (2.3)	0.48	6.29	0.35	0.35	0.56

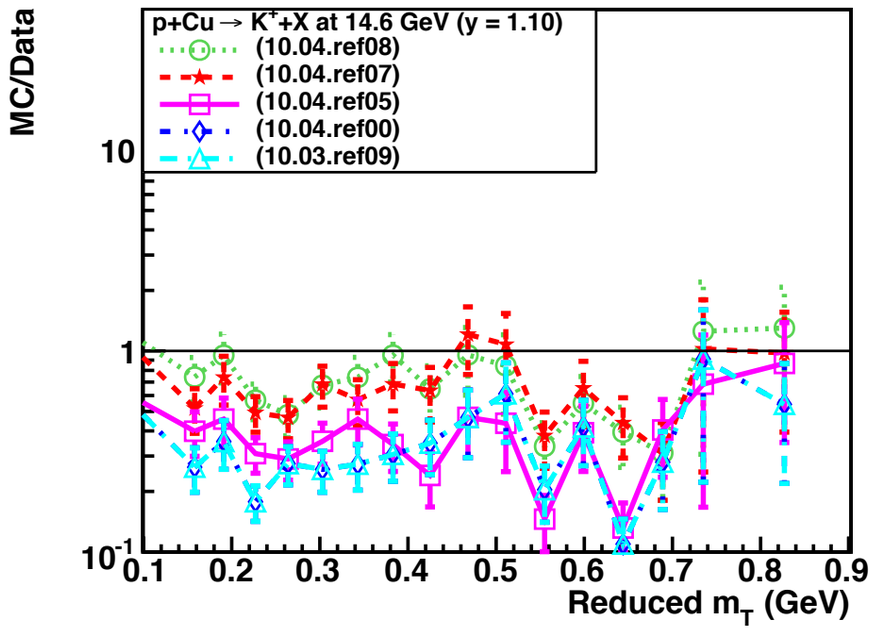
p + Be →π⁺ + X at 14.6 GeV/c (Bertini)

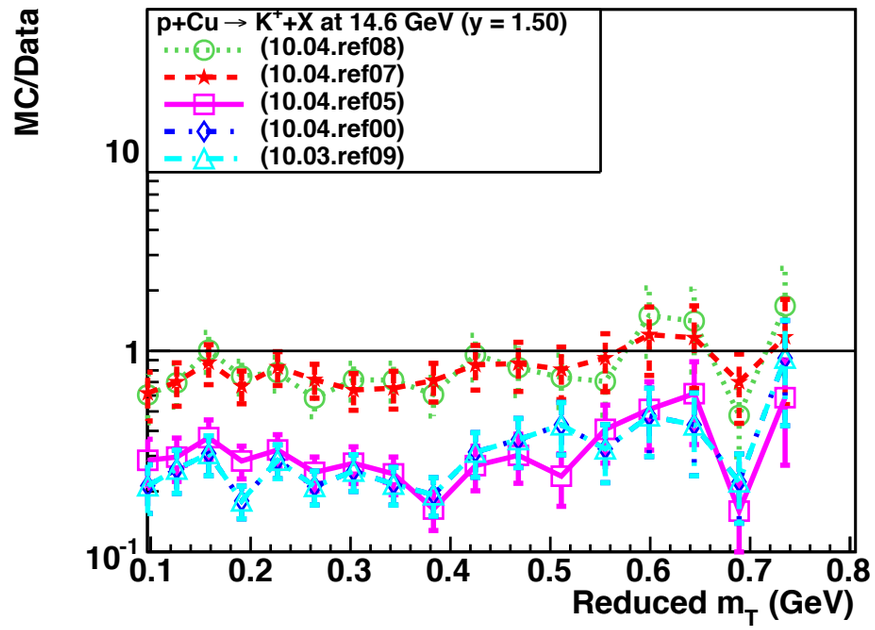




- Not much difference in the model predictions (all are bad).

p + Cu →K⁺ + X at 14.6 GeV/c (Bertini)





- Versions 10.4.ref08 and 10.4.ref07 provide better agreement with the data for K^+ production

ChiSq/Data for Final State Pions (Bertini)

- Using a flat systematic uncertainty for all measurements:

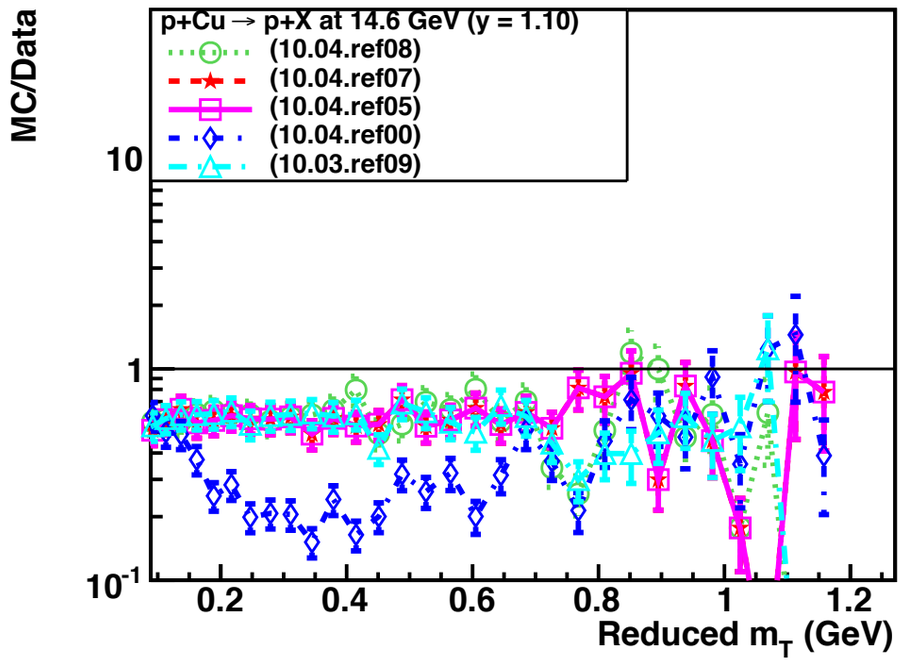
	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Be π^+ (1.1)	46.40	46.40	32.12	23.95	22.78
Be π^+ (1.5)	132.94	132.94	95.82	80.71	82.69
Be π^+ (1.9)	41.95	41.95	47.77	40.73	31.69
Be π^+ (2.3)	4.57	4.57	4.78	5.95	5.50
Be π^- (1.1)	546.63	546.63	484.55	372.79	442.89
Be π^- (1.5)	661.29	661.29	615.24	445.64	553.76
Be π^- (1.9)	228.01	228.01	213.80	156.49	178.50
Be π^- (2.3)	9.09	9.09	9.39	6.06	7.06
Au π^+ (1.1)	29.44	29.44	6.99	7.19	14.18
Au π^+ (1.5)	57.03	57.03	22.69	24.40	37.74
Au π^+ (1.9)	16.87	16.87	9.17	12.28	11.30
Au π^+ (2.3)	3.86	3.86	6.27	7.45	5.37
Au π^- (1.1)	122.54	122.54	86.25	52.67	133.07
Au π^- (1.5)	130.32	130.32	114.02	60.66	108.95
Au π^- (1.9)	97.55	97.55	120.56	63.83	118.41
Au π^- (2.3)	3.50	3.50	4.98	4.56	4.20

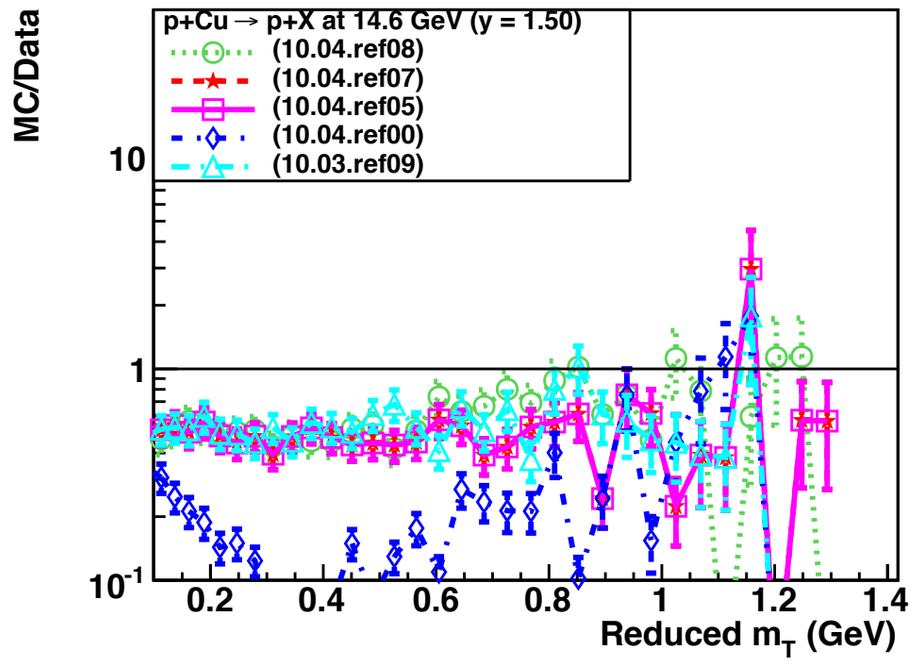
ChiSq/Data for Copper Target (Bertini)

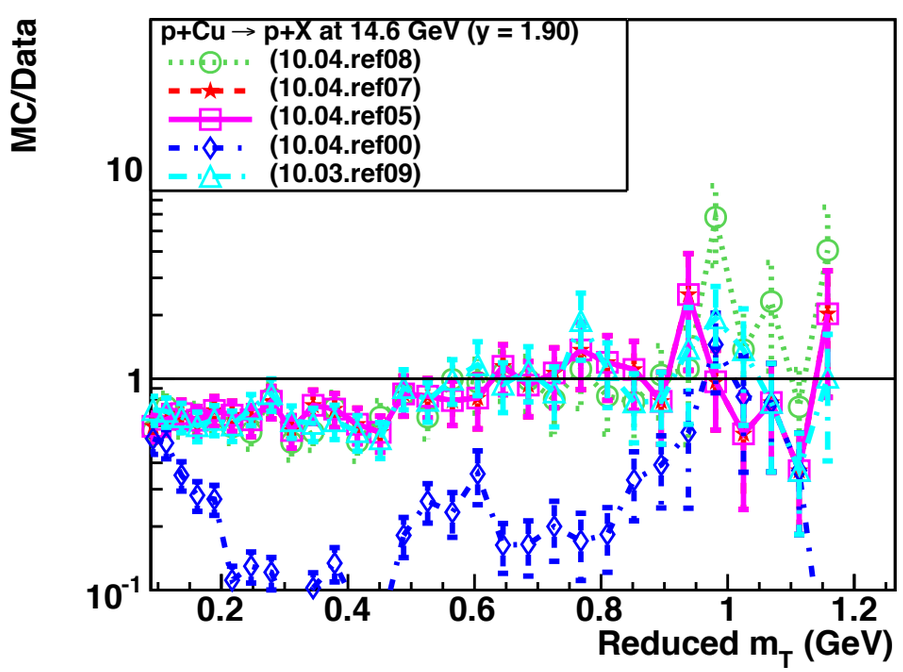
- Using a flat systematic uncertainty for all measurements:

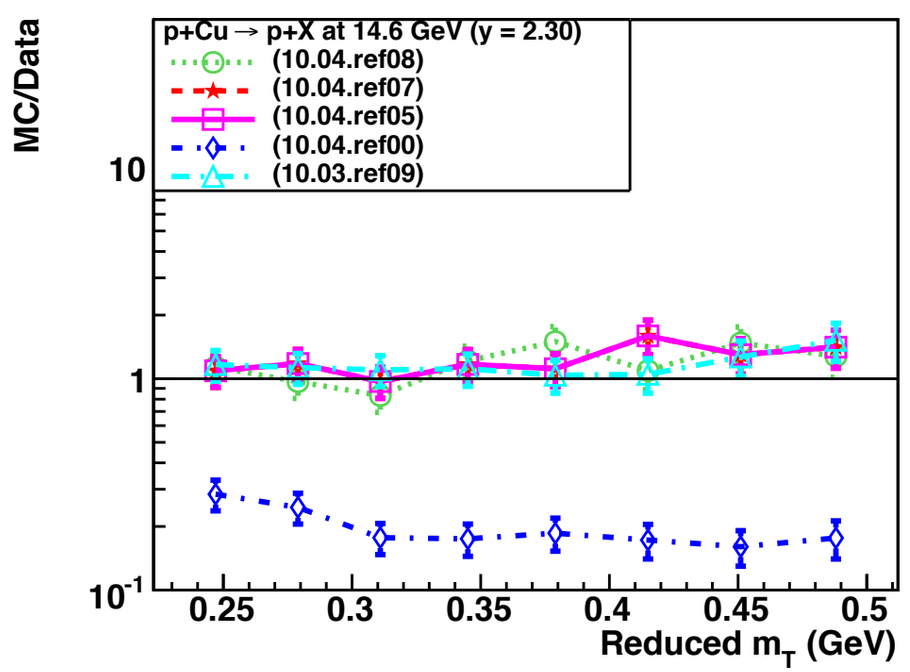
	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Cu K^+ (1.1)	5.53	5.53	4.69	2.00	1.61
Cu K^+ (1.5)	7.59	7.59	7.18	1.03	1.29
Cu K^+ (1.9)	8.53	8.53	7.88	1.63	0.88
Cu K^- (1.1)	1.90	1.90	2.15	1.31	1.54
Cu K^- (1.5)	2.61	2.61	2.51	1.08	1.28
Cu K^- (1.9)	2.84	2.84	2.79	2.57	2.28
Cu p (1.1)	54.34	54.34	68.07	69.31	56.52
Cu p (1.5)	161.65	161.65	181.52	197.24	156.12
Cu p (1.9)	126.31	126.31	148.37	140.16	120.87
Cu p (2.3)	1.61	1.61	1.36	1.78	1.43

p + Cu → p + X at 14.6 GeV/c (QGSP)



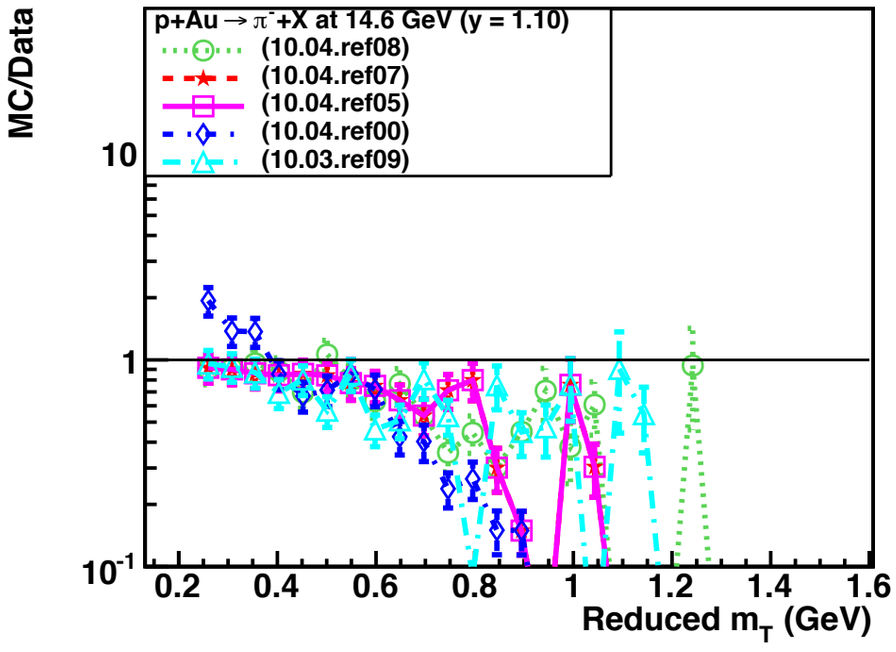


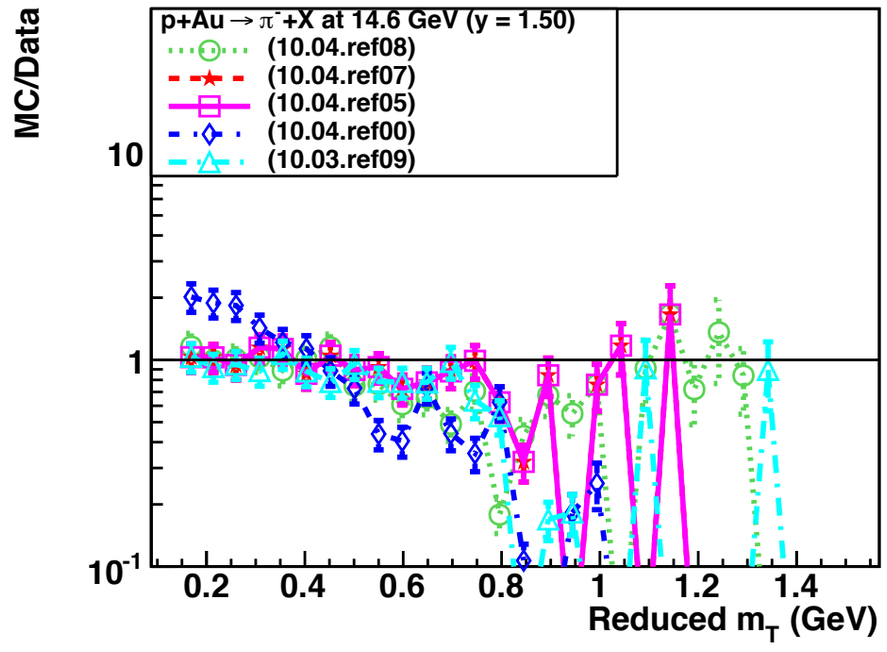


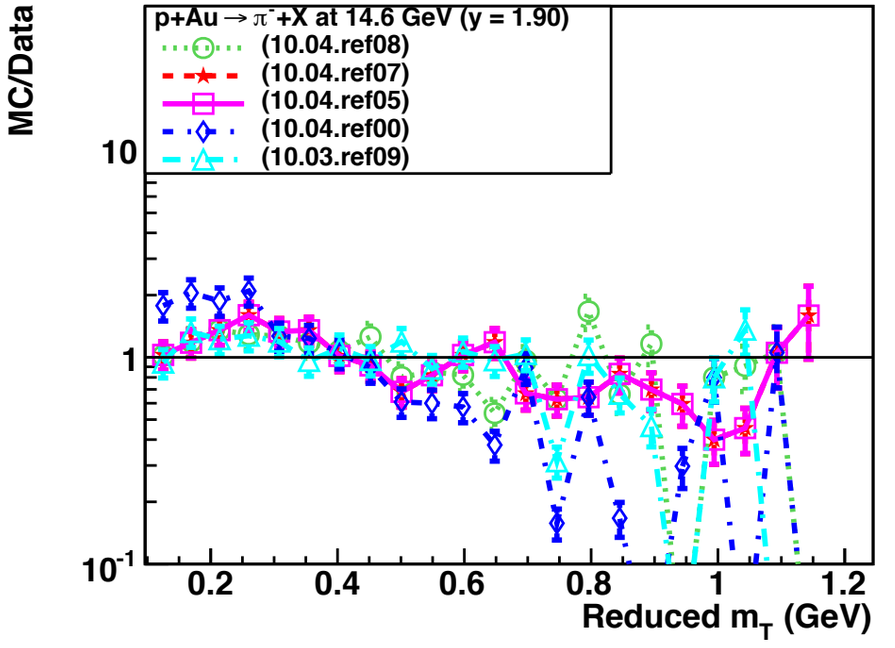


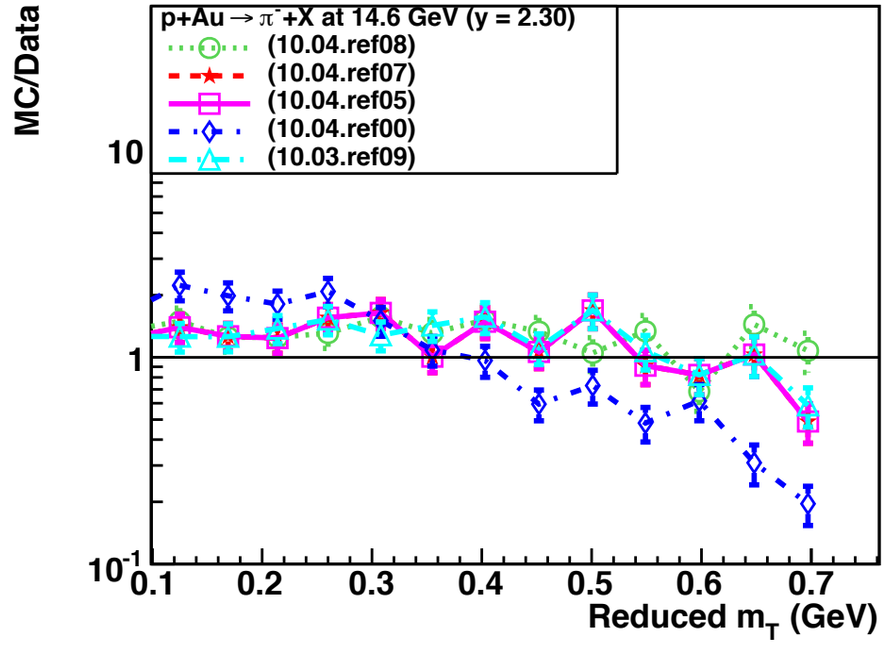
- Predictions from the version 10.4.ref00 provide the worst agreement

p + Au →π⁻ + X at 14.6 GeV/c (QGSP)









- The version 10.4.ref00 provides worst prediction while there is some improvement in the version 10.4.ref04 (ref05)

ChiSq/Data for Final State Pions (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Be π^+ (1.1)	4.17	7.30	2.33	2.33	2.33
Be π^+ (1.5)	2.91	7.21	1.81	1.81	1.81
Be π^+ (1.9)	3.91	8.88	2.36	2.36	2.36
Be π^+ (2.3)	2.49	6.28	2.04	2.04	2.04
Be π^- (1.1)	5.01	5.63	2.81	2.81	2.81
Be π^- (1.5)	4.50	7.49	3.20	3.20	3.20
Be π^- (1.9)	2.93	6.32	1.85	1.85	1.85
Be π^- (2.3)	0.74	3.19	0.42	0.42	0.42
Au π^+ (1.1)	4.71	8.35	3.38	3.38	5.29
Au π^+ (1.5)	4.19	13.40	3.22	3.22	1.49
Au π^+ (1.9)	3.57	16.33	3.17	3.17	3.29
Au π^+ (2.3)	1.84	30.40	1.35	1.35	2.32
Au π^- (1.1)	3.57	8.60	2.82	2.82	2.94
Au π^- (1.5)	2.51	11.52	1.41	1.41	2.71
Au π^- (1.9)	2.07	11.93	2.95	2.95	2.36
Au π^- (2.3)	4.05	15.87	4.59	4.59	3.90

ChiSq/Data for Copper Target (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
Cu K^+ (1.1)	6.75	4.34	6.33	6.33	6.78
Cu K^+ (1.5)	5.99	4.62	4.51	4.51	4.77
Cu K^+ (1.9)	2.45	3.32	4.01	4.01	3.69
Cu K^- (1.1)	2.02	3.59	1.82	1.82	1.74
Cu K^- (1.5)	1.58	6.13	2.38	2.38	3.43
Cu K^- (1.9)	1.49	0.82	0.78	0.78	0.28
Cu p (1.1)	5.52	11.20	5.01	5.01	4.97
Cu p (1.5)	5.78	16.32	6.94	6.94	5.36
Cu p (1.9)	2.28	11.82	2.22	2.22	7.78
Cu p (2.3)	1.28	18.74	2.28	2.28	2.25

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
- Five versions of Geant4 are used in the following plots:
  - 10.3.ref09, 10.4.ref00, 10.4.ref05, 10.4.ref07, 10.4.ref08

ChiSq/Data for 8 different processes

- Using a flat systematic uncertainty (as quoted in the paper) for all measurements:

	10.3.ref09	10.4.ref00	10.4.ref05	10.4.ref07	10.4.ref08
			FTFP		
p+H (56.8)	4.64	2.73	6.47	12.19	12.19
p+C (56.8)	16.01	4.31	11.83	11.83	11.86
p+Bi (56.8)	2.39	1.92	2.85	2.85	3.01
p+U (57.3)	2.48	1.85	2.94	2.94	3.03
p+H (82.6)	5.64	4.26	7.16	17.86	17.86
p+Be (120.0)	67.72	11.15	4.47	4.47	4.47
p+C (120.0)	79.19	10.03	32.34	32.34	32.39
p+Bi (120.0)	7.99	3.64	9.49	9.49	7.42
			QGSP		
p+H (56.8)	2.69	5.13	2.10	10.33	10.33
p+C (56.8)	6.00	3.03	3.29	3.29	3.30
p+Bi (56.8)	5.88	6.32	5.15	5.15	5.00
p+U (57.3)	13.38	11.30	10.65	10.65	10.75
p+H (82.6)	2.58	2.34	2.16	15.72	15.72
p+Be (120.0)	24.73	4.98	16.92	16.92	16.92
p+C (120.0)	22.35	5.33	10.59	10.59	10.47
p+Bi (120.0)	41.40	2.86	34.10	34.10	32.06

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.ref08 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, 10.4.ref07 and 10.4.ref08 provide similar level of agreement
  - Bertini cascade model predictions are far away from the measurements and it has improved a bit in 10.4.ref08
- 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.ref07/10.4.ref08 except for high momentum part of the neutron momentum distribution in interactions with heavier target where 10.4.ref00 provides better agreement

Additional Slides