Validation of Geant4 versions 10.6.p02 and 10.6.ref05

Geant4 Hadronic Group Meeting
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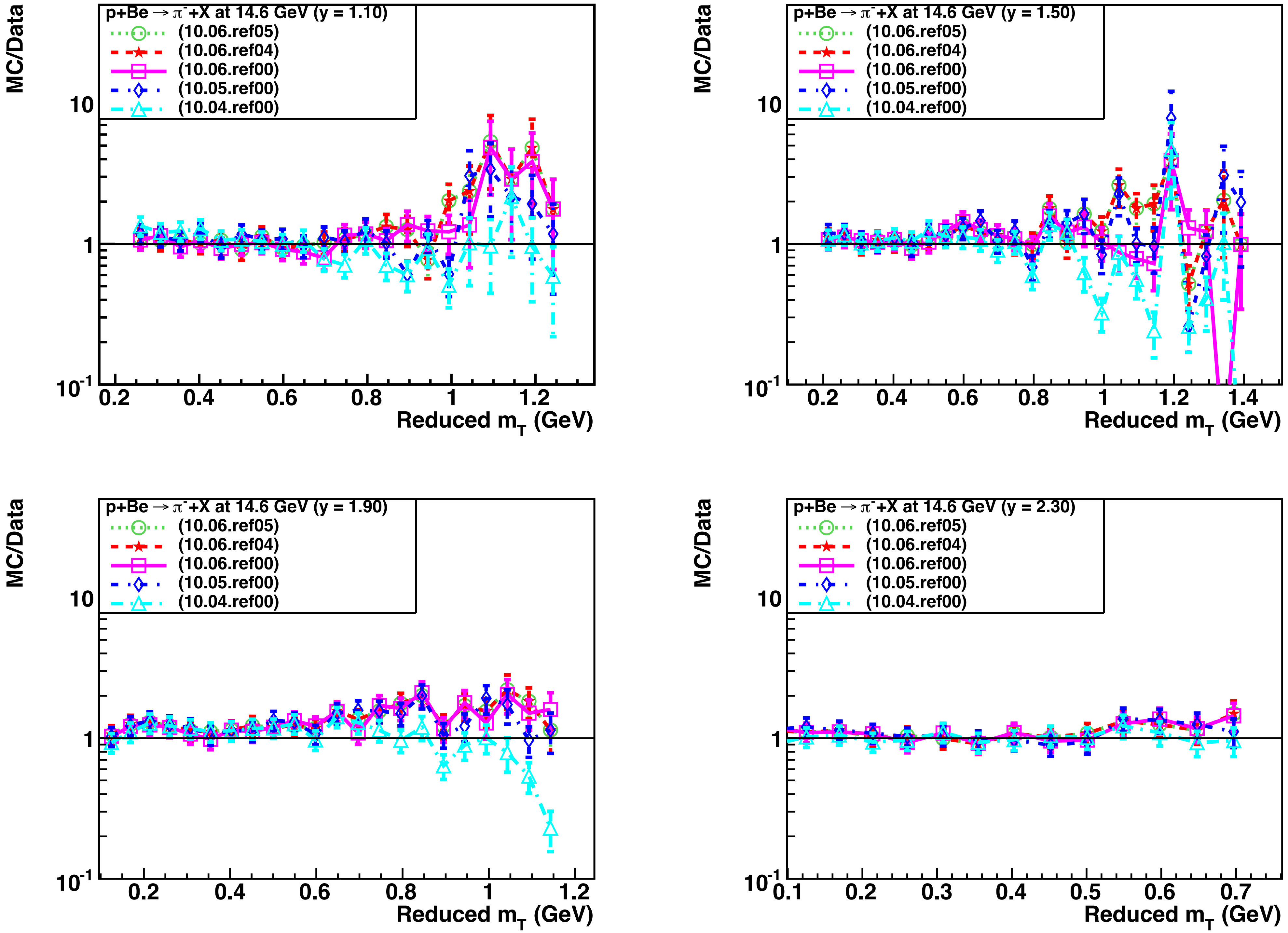
New Geant4 Version

- Geant4 came up with the version 10.6.p02 during May, 2020 and the version 10.6.ref05 in early June.
- CMS has currently integrated 10.6.p01 with its production code and is thinking of updating that to version 10.6.p02 for its future simulation production.
- For thin target comparison, Geant4 library is made with the native geometry version. For comparison with CMS collision and test beam data, Geant4 libraries are built with native as well as VecGeom geometry libraries.
- Thin target comparison is done against BNL and MIPP data utilizing test47 codes
- For comparison with CMS data (test beam as well as collision data) two Geant4 builds are made using native Geant4 geometry and also VecGeom (v1.1.6 or v1.1.7) replacing the native Geant4 geometry codes
- CMSSW versions 10_5_0 and 11_2_X are used for compare with the CMS data

Comparison with BNL Data

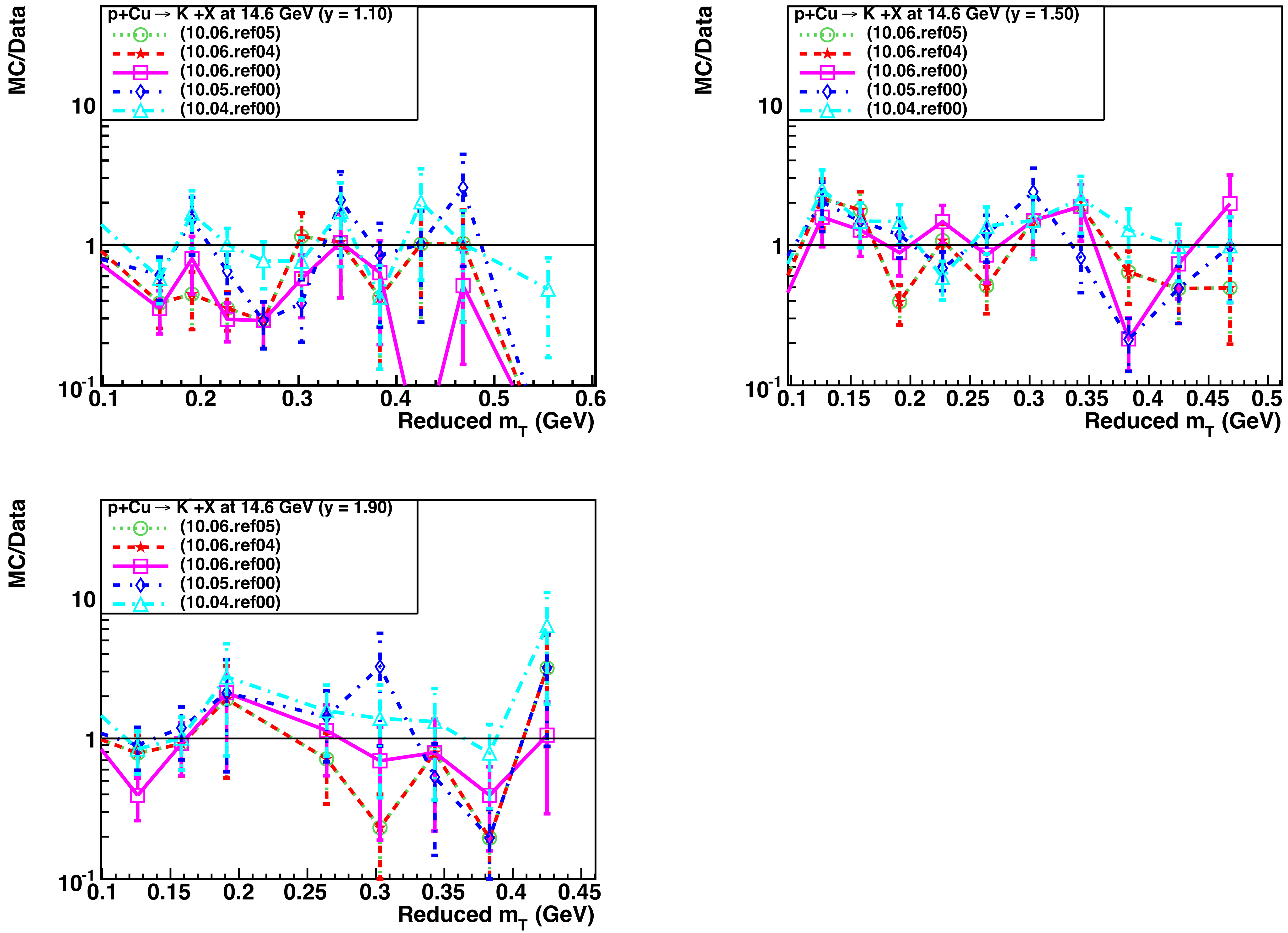
- Data set from BNL E802: (T. Abbott *et al.*, Phys. Rev. D45, 3906)
  - Inclusive $\pi^{\pm}$, $K^{\pm}$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets
  - Quantities measured are Lorentz invariant differential cross sections as a function of transverse mass (m_T) in 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:
  - 10.4.ref00, 10.5.ref00, 10.6.ref00, 10.6.ref04, 10.6.ref05

p + Be →π + X at 14.6 GeV/c (FTFP)



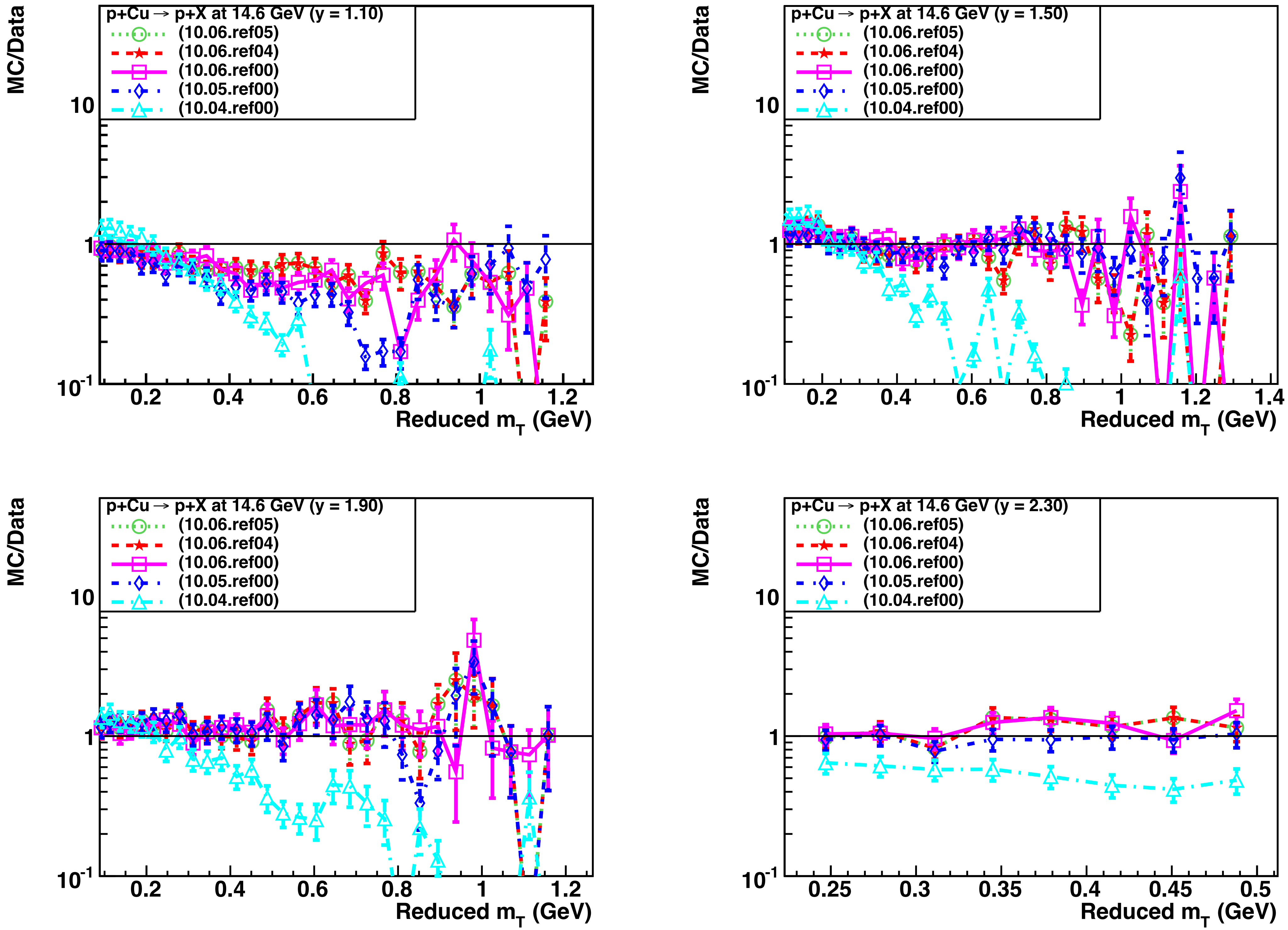
- The reference versions 10.6.ref05 and 10.6.ref00 provide similar agreement with the data. The best agreement comes from 10.4.ref00.

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 production of protons. The reference versions 10.6.ref05 provides good description of the data

Geant 4

ChiSq/Data for Final State Pions (FTFP)

- Using a flat systematic uncertainty for all measurements compute chi-square per data point:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Be π^+ (1.1)	1.45	0.87	1.34	1.44	1.21
Be π^+ (1.5)	1.44	4.77	4.66	3.62	8.76
Be π^+ (1.9)	0.85	4.53	2.97	2.09	2.52
Be π^+ (2.3)	1.13	0.77	1.08	1.01	0.86
Be π^- (1.1)	1.24	2.53	4.37	6.71	6.67
Be π^- (1.5)	3.28	8.70	2.12	2.26	4.05
Be π^- (1.9)	1.62	4.69	5.28	6.98	5.79
Be π^- (2.3)	0.23	1.06	0.99	1.33	0.97
Au π^+ (1.1)	0.77	5.71	2.13	1.80	1.74
Au π^+ (1.5)	2.22	8.06	3.05	4.75	3.01
Au π^+ (1.9)	2.62	3.68	3.17	3.09	2.66
Au π^+ (2.3)	1.33	2.94	3.06	2.39	2.76
Au π^- (1.1)	2.27	5.08	4.91	4.62	4.09
Au π^- (1.5)	2.89	8.63	7.42	6.34	7.14
Au π^- (1.9)	1.84	9.26	9.52	9.15	12.02
Au π^- (2.3)	1.42	8.35	7.40	7.70	7.26

The first column refers to target/final state particle/mean rapidity value

ChiSq/Data for Copper Target (FTFP)

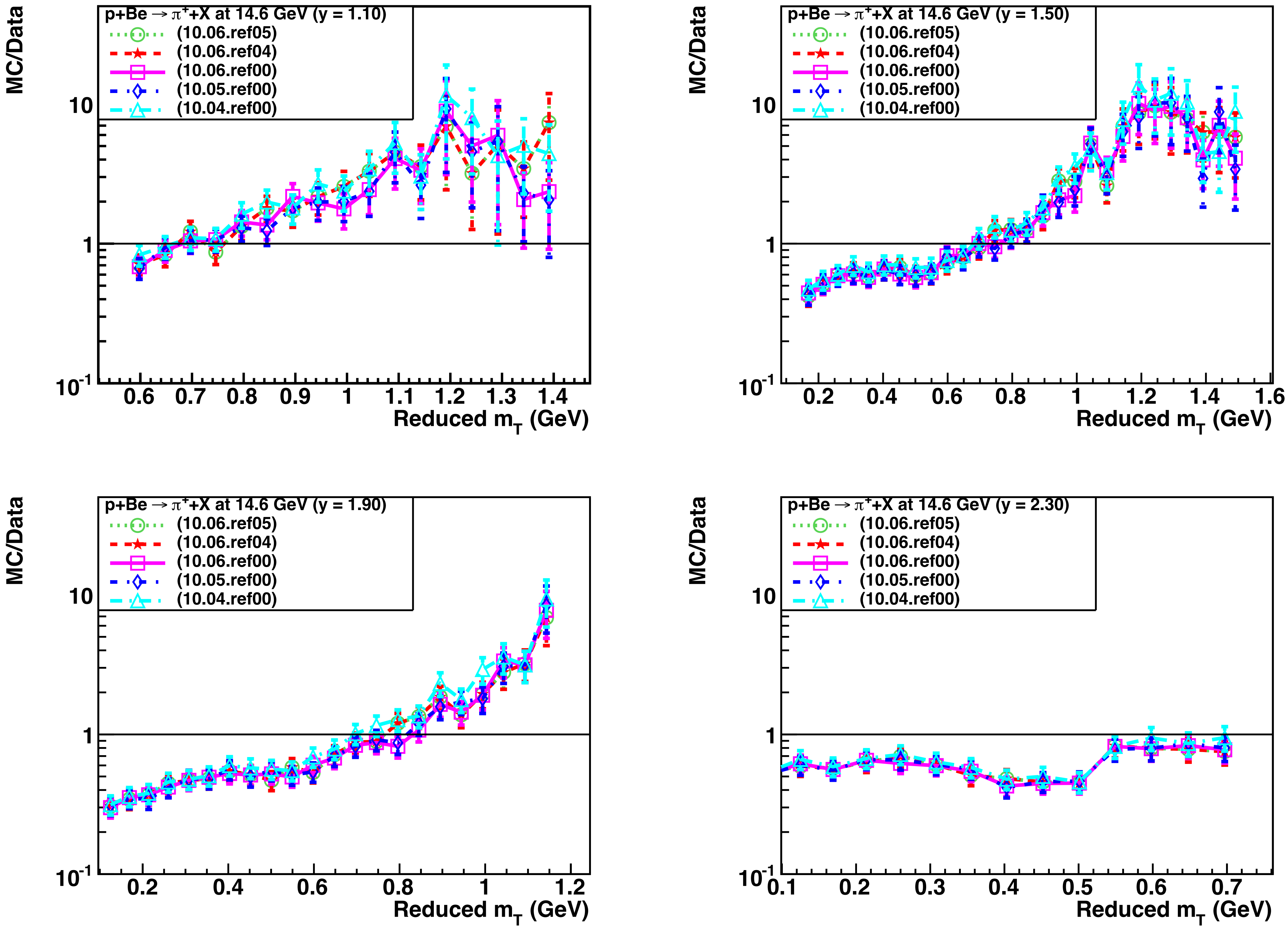
- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Cu K^+ (1.1)	2.85	4.46	5.27	6.21	5.44
Cu K^+ (1.5)	2.00	4.81	4.86	4.79	5.55
Cu K^+ (1.9)	1.49	3.30	2.88	3.23	3.79
Cu K^- (1.1)	1.29	1.73	1.57	1.26	1.40
Cu K^- (1.5)	2.65	1.93	1.44	1.28	2.25
Cu K^- (1.9)	6.47	2.42	0.73	1.08	1.46
Cu p (1.1)	10.43	5.28	3.22	3.28	2.49
Cu p (1.5)	12.87	1.43	1.69	1.69	1.69
Cu p (1.9)	4.29	2.82	3.82	2.34	2.00
Cu p (2.3)	6.29	0.25	1.69	1.56	1.54

The first column refers to target/final state particle/mean rapidity value

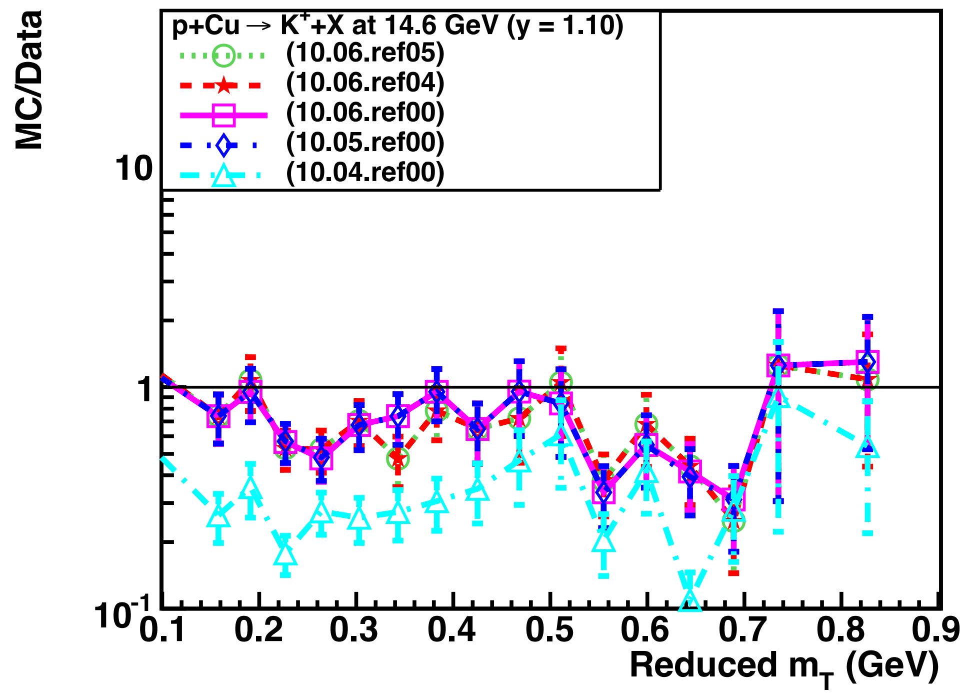
Geant 4

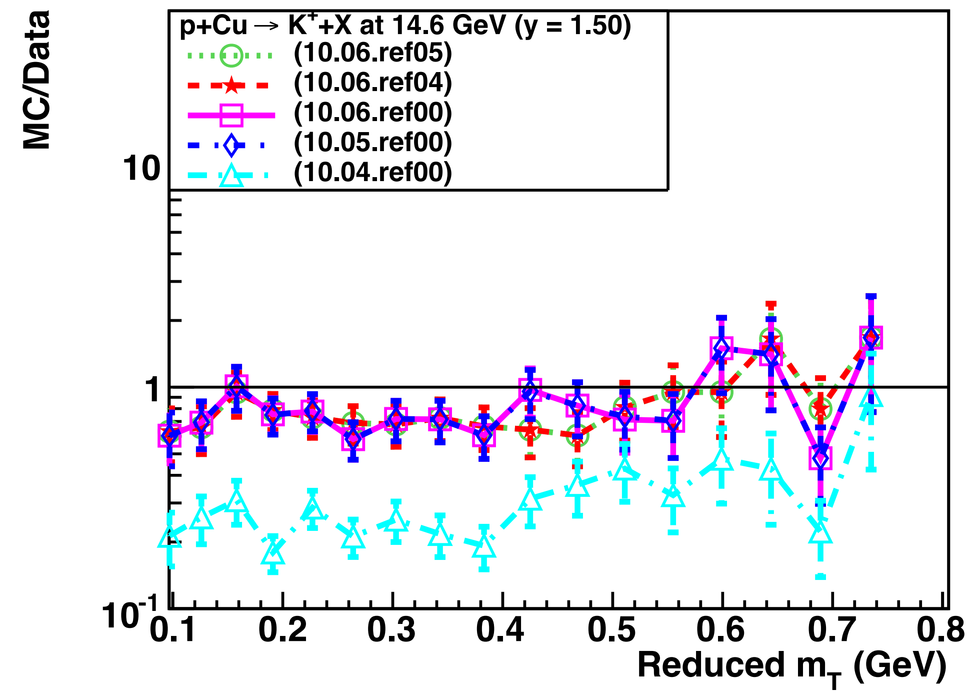
$p + Be \rightarrow \pi^+ + X$ at 14.6 GeV/c (Bertini)

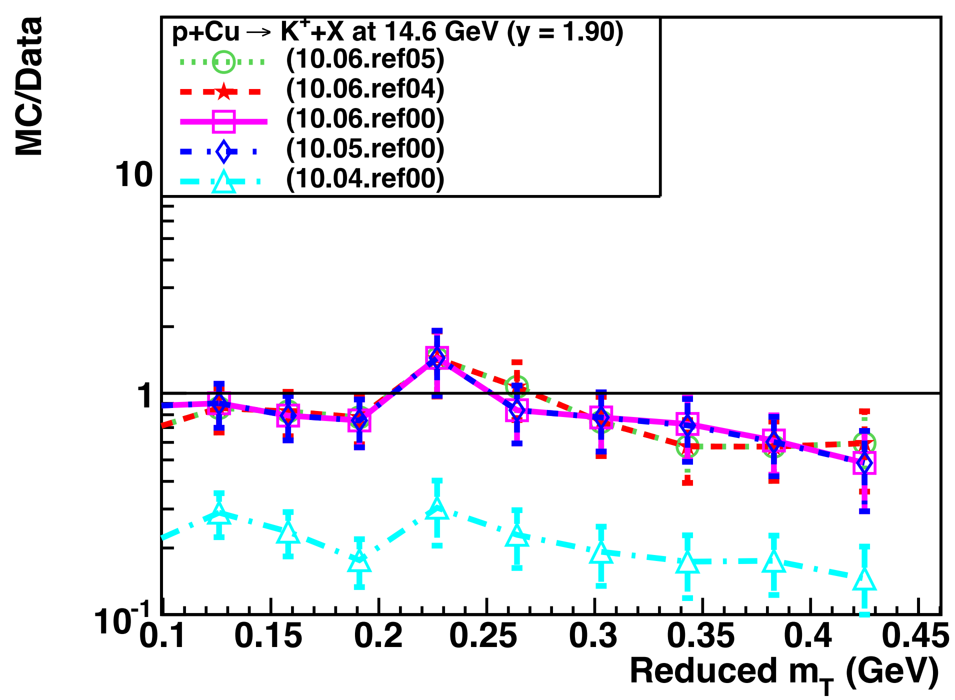


- Not much difference in the model predictions (all are bad).

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







- The new reference versions provide the same level of agreement as 10.5.ref00. They provide better agreement with the data for K^+ production than 10.4.ref00.

ChiSq/Data for Final State Pions (Bertini)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Be π^+ (1.1)	46.40	22.79	23.70	23.70	28.73
Be π^+ (1.5)	132.94	82.69	81.59	81.59	85.50
Be π^+ (1.9)	41.95	31.69	29.24	29.24	24.56
Be π^+ (2.3)	4.57	5.50	5.65	5.65	5.48
Be π^- (1.1)	546.63	442.89	415.31	415.31	402.18
Be π^- (1.5)	661.29	553.76	485.78	485.78	541.02
Be π^- (1.9)	228.01	178.50	166.03	166.03	168.63
Be π^- (2.3)	9.09	7.06	6.71	6.71	6.87
Au π^+ (1.1)	29.44	14.18	15.01	15.01	16.34
Au π^+ (1.5)	57.03	37.74	39.58	39.58	40.32
Au π^+ (1.9)	16.87	11.30	8.47	8.47	14.95
Au π^+ (2.3)	3.86	5.37	5.30	5.30	5.00
Au π^- (1.1)	122.54	133.07	138.81	138.81	96.77
Au π^- (1.5)	130.32	108.95	111.15	111.15	141.29
Au π^- (1.9)	97.55	118.41	124.06	124.06	111.44
Au π^- (2.3)	3.50	4.20	4.31	4.31	3.73

The first column refers to target/final state particle/mean rapidity value

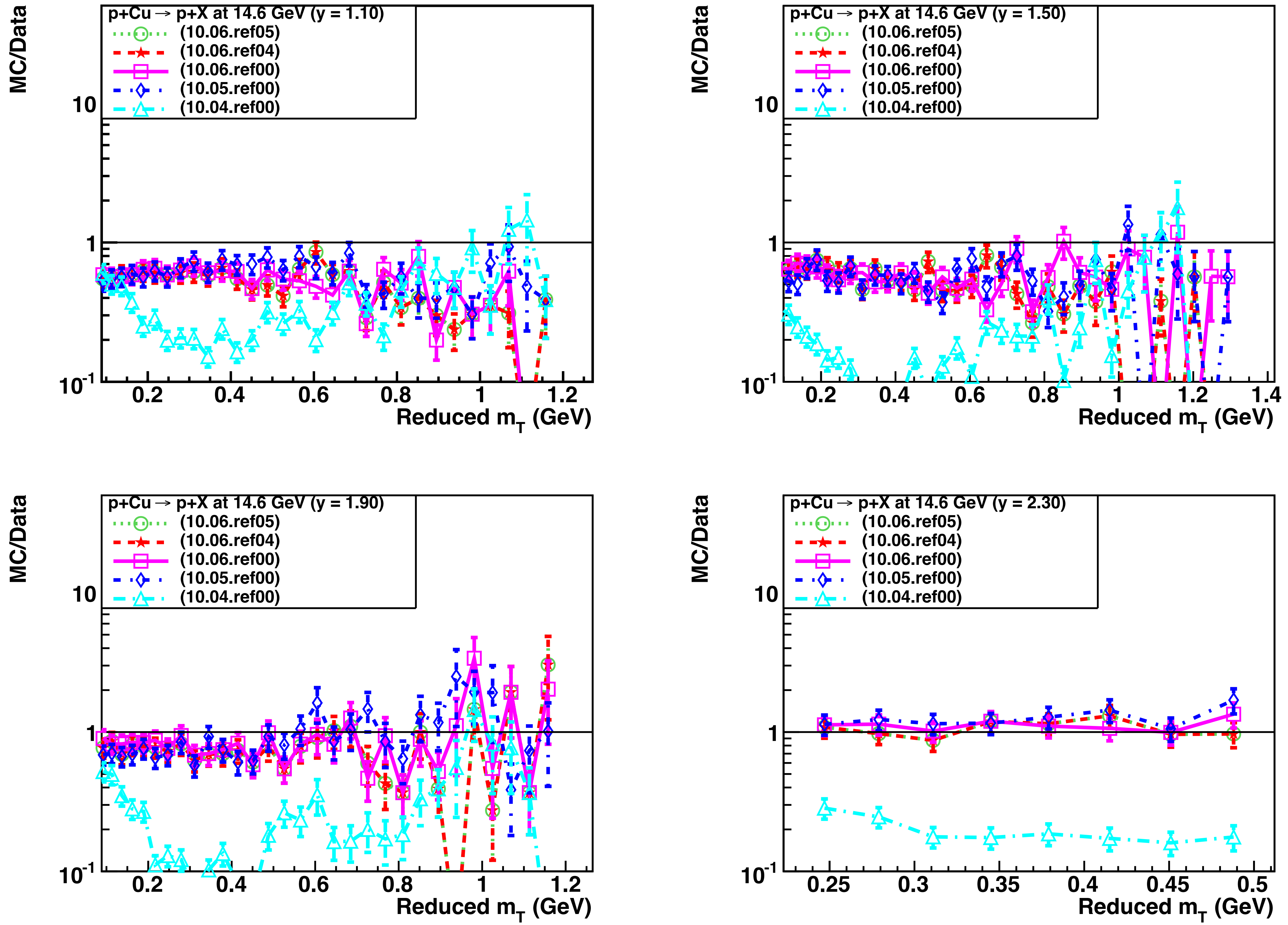
ChiSq/Data for Copper Target (Bertini)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Cu K^+ (1.1)	5.53	1.62	1.62	1.62	1.75
Cu K^+ (1.5)	7.59	1.29	1.30	1.30	1.20
Cu K^+ (1.9)	8.53	0.88	0.86	0.86	1.06
Cu K^- (1.1)	1.90	1.55	1.55	1.55	1.36
Cu K^- (1.5)	2.61	1.28	1.21	1.21	1.51
Cu K^- (1.9)	2.84	2.28	2.29	2.29	2.47
Cu p (1.1)	54.34	56.52	56.81	56.81	58.68
Cu p (1.5)	161.65	156.12	155.86	155.86	140.76
Cu p (1.9)	126.31	120.87	122.89	122.89	106.42
Cu p (2.3)	1.61	1.43	1.44	1.44	1.60

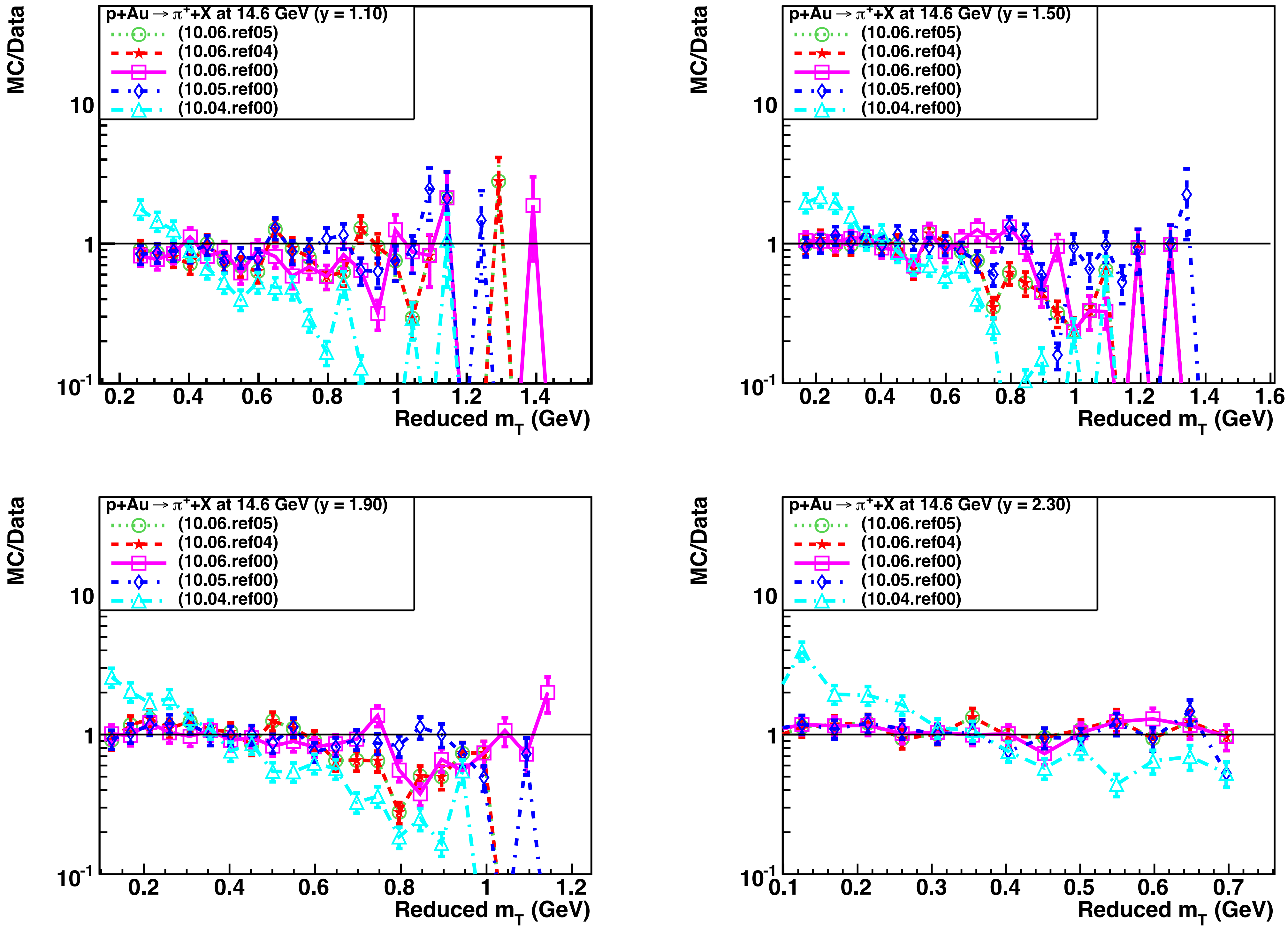
The first column refers to target/final state particle/mean rapidity value

p + Cu →p + X at 14.6 GeV/c (QGSP)



- Predictions from the version 10.4.ref00 provide the worst agreement. The new reference versions and 10.5.ref00 provide reasonable agreement with data

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 10.5.ref00, the same in the later versions

ChiSq/Data for Final State Pions (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Be π^+ (1.1)	7.30	0.71	2.17	1.97	1.59
Be π^+ (1.5)	7.21	1.30	1.35	1.68	1.67
Be π^+ (1.9)	8.88	1.83	3.66	2.36	1.85
Be π^+ (2.3)	6.28	2.11	2.60	3.08	2.66
Be π^- (1.1)	5.63	2.54	4.15	2.79	2.76
Be π^- (1.5)	7.49	2.38	3.50	3.42	3.49
Be π^- (1.9)	6.32	1.74	2.18	2.55	2.46
Be π^- (2.3)	3.19	1.43	1.73	1.79	1.81
Au π^+ (1.1)	8.35	1.75	2.11	2.51	2.59
Au π^+ (1.5)	13.40	1.73	1.91	1.86	2.96
Au π^+ (1.9)	16.33	0.95	2.26	1.89	2.96
Au π^+ (2.3)	30.40	1.19	0.67	1.78	0.78
Au π^- (1.1)	8.60	2.06	2.76	2.32	2.79
Au π^- (1.5)	11.52	2.07	1.94	4.12	1.16
Au π^- (1.9)	11.93	4.50	2.99	4.06	2.21
Au π^- (2.3)	15.87	3.47	3.88	3.01	2.63

The first column refers to target/final state particle/mean rapidity value

Geant 4

ChiSq/Data for Copper Target (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
Cu K^+ (1.1)	4.34	5.02	4.94	5.11	4.97
Cu K^+ (1.5)	4.62	3.83	4.46	4.68	5.03
Cu K^+ (1.9)	3.32	3.31	3.40	4.01	3.40
Cu K^- (1.1)	3.59	1.53	1.49	2.55	0.73
Cu K^- (1.5)	6.13	2.58	1.97	3.55	3.81
Cu K^- (1.9)	0.82	0.71	1.42	3.34	3.72
Cu p (1.1)	11.20	4.48	5.77	5.76	6.02
Cu p (1.5)	16.32	5.04	4.56	4.90	5.08
Cu p (1.9)	11.82	2.18	2.51	1.52	2.22
Cu p (2.3)	18.74	2.79	0.68	1.41	0.64

The first column refers to target/final state particle/mean rapidity value

ChiSq/Data for Final State Pions

- Compiling for the 3 models in Geant4.10.6.ref05:

	FTFP	QGSP	Bertini
Be π^+ (1.1)	1.21	1.59	28.73
Be π^+ (1.5)	8.76	1.67	85.50
Be π^+ (1.9)	2.52	1.85	24.56
Be π^+ (2.3)	0.86	2.66	5.48
Be π^- (1.1)	6.67	2.76	402.18
Be π^- (1.5)	4.05	3.49	541.02
Be π^- (1.9)	5.78	2.46	168.63
Be π^- (2.3)	0.97	1.81	6.87
Au π^+ (1.1)	1.74	2.59	16.34
Au π^+ (1.5)	3.01	2.96	40.32
Au π^+ (1.9)	2.66	2.96	14.95
Au π^+ (2.3)	2.76	0.78	5.00
Au π^- (1.1)	4.09	2.79	96.77
Au π^- (1.5)	7.14	1.16	141.29
Au π^- (1.9)	12.02	2.21	111.44
Au π^- (2.3)	7.26	2.63	3.73

ChiSq/Data for Copper Target

- Compiling for the 3 models in Geant4.10.6.ref05:

	FTFP	QGSP	Bertini
Cu K^+ (1.1)	5.44	4.97	1.75
Cu K^+ (1.5)	5.55	5.03	1.20
Cu K^+ (1.9)	3.79	3.40	1.06
Cu K^- (1.1)	1.40	0.73	1.36
Cu K^- (1.5)	2.25	3.81	1.51
Cu K^- (1.9)	1.46	3.72	2.47
Cu p (1.1)	2.50	6.02	58.68
Cu p (1.5)	1.69	5.08	140.76
Cu p (1.9)	2.00	2.22	106.42
Cu p (2.3)	1.54	0.64	1.60

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:
  - 10.4.ref00, 10.5.ref00, 10.6.ref00, 10.6.ref04, 10.6.ref05

ChiSq/Data for 8 different processes

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

	10.4.ref00	10.5.ref00	10.6.ref00	10.6.ref02	10.6.ref05
			FTFP		
p+H (56.8)	2.73	12.11	12.09	6.20	6.19
p+C (56.8)	4.31	11.90	11.89	11.72	11.65
p+Bi (56.8)	1.92	2.68	2.88	3.05	2.84
p+U (57.3)	1.85	3.30	3.62	3.56	3.39
p+H (82.6)	4.26	17.81	17.80	6.87	6.74
p+Be (120.0)	9.43	4.85	6.10	6.09	5.95
p+C (120.0)	8.45	28.06	27.04	28.12	28.01
p+Bi (120.0)	3.63	4.64	9.49	7.28	7.76
			QGSP		
p+H (56.8)	5.13	10.79	11.09	2.37	2.36
p+C (56.8)	3.03	3.36	3.68	3.74	3.75
p+Bi (56.8)	6.32	4.74	4.58	4.62	4.65
p+U (57.3)	11.30	9.88	9.59	9.53	9.41
p+H (82.6)	2.34	16.30	16.70	3.09	2.99
p+Be (120.0)	4.98	13.07	13.69	13.94	13.57
p+C (120.0)	5.33	8.29	8.45	8.49	8.53
p+Bi (120.0)	2.86	25.39	23.22	22.33	23.53

Physics List used in CMSSW

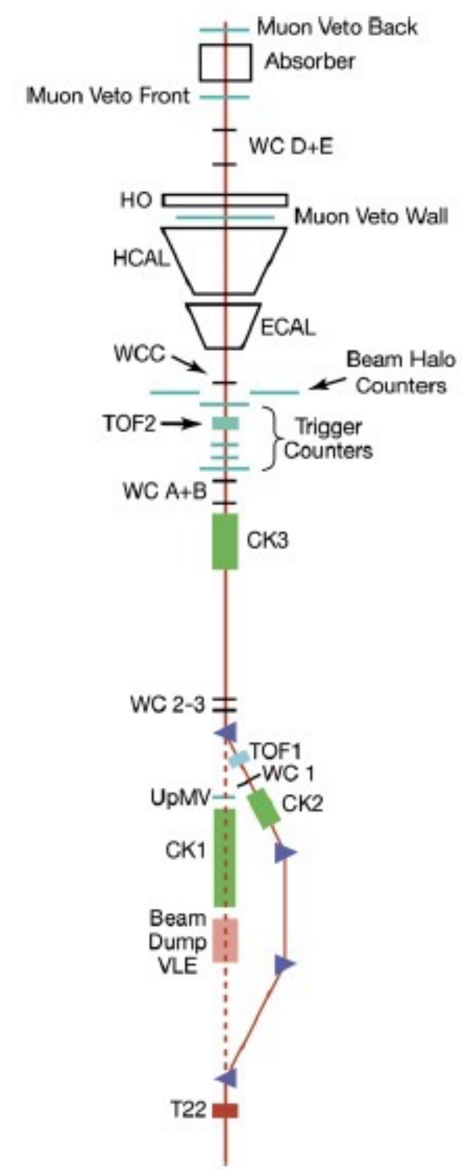
- Physics List FTFP_BERT_EMM has been CMS default:
  - FTFP_BERT is the Geant4 default
    - Geant4.10.4.p03: Transition energy Bertini-FTFP: 3-12 GeV
    - Geant4.10.6.p02, 10.6.ref05: Transition energy Bertini-FTFP: 3-12 GeV for π and 3-6 GeV for other particles
  - EMM – configuration of EM physics specific for CMS
    - Configuration different for crystal and sampling calorimeters like HCAL or HGCal

- Vladimir retuned the constants of Birk's law used for scintillators of HCAL using 2006 test beam data for Geant4 version 10.6.p01
  - Default values for Birk's constants for HCAL used to be
    - C1 = 0.0052; C2 = 0.142; C3 = 1.75
  - The tuned set is
    - C1 = 0.006; C2 = 0.142; C3 = 1.75

- Also the transition between FTF and Bertini was changed
  - Originally (10.4.p03): 3-12 GeV
  - CMS setting: 3-12 GeV for pions and 3-6 GeV for others

CMS 2006 TestBeam

- The data correspond to single particle response due to well identified particles over a large momentum range (2 to 350 GeV)
- The results consist of the energy distributions for well identified particles at a fixed momentum
  - Particle identification is rather good for beam momenta at or below 9 GeV
- Use the setup described within CMSSW to simulate events with single particles.
- Both the calorimeters are calibrated using 50 GeV electron beam



Test Beam Data vs 3 versions of Geant4

Mean level of disagreement between MC and data

	π- 10.6.p01	π- 10.6.p02	π- 10.6.ref5	π+ 10.6.p01	π+ 10.6.p02	π+ 10.6.ref5	p 10.6.p01	p 10.6.p02	p 10.6.ref5
2 GeV	11.7±0.9	11.3±0.9	11.7±0.9	12.0±1.2	11.3±1.2	11.5±1.2	7.2±2.5	7.2±0.3	6.7±0.3
3 GeV	8.4±0.6	9.6±0.6	9.8±0.6	10.2±1.7	10.3±1.7	9.8±1.7	2.5±1.0	4.0±1.0	3.2±1,9
4 GeV	13.3±0.5	14.0±0.5	15.1±0.5	13.3±0.5	12.9±0.5	13.2±0.5	12.9±1.2	12.6±1.2	13.7±1.2
5 GeV	11.5±0.5	11.4±0.5	12.7±0.5	9.7±1.0	10.5±0.9	10.7±0.9	12.0±3.1	12.9±3.2	12.4±3.2
6 GeV	13.4±0.5	13.3±0.4	13.1±0.4	11.8±0.9	11.2±0.8	12.6±0.8	7.8±3.2	6.8±3.5	7.4±3.5
7 GeV	15.3±0.5	14.6±0.5	16.3±0.5	15.0±0.7	14.2±0.7	14.6±0,7	11.9±2.9	10.5±2.8	12.1±2.8
8 GeV	19.8±0.6	19.2±0.6	20.1±0.6	15.6±0.7	16.1±0.7	16.2±0.7	0.6±1.0	1.1±1.0	3.0±1.0

Comparison with CMS Test Beam Data

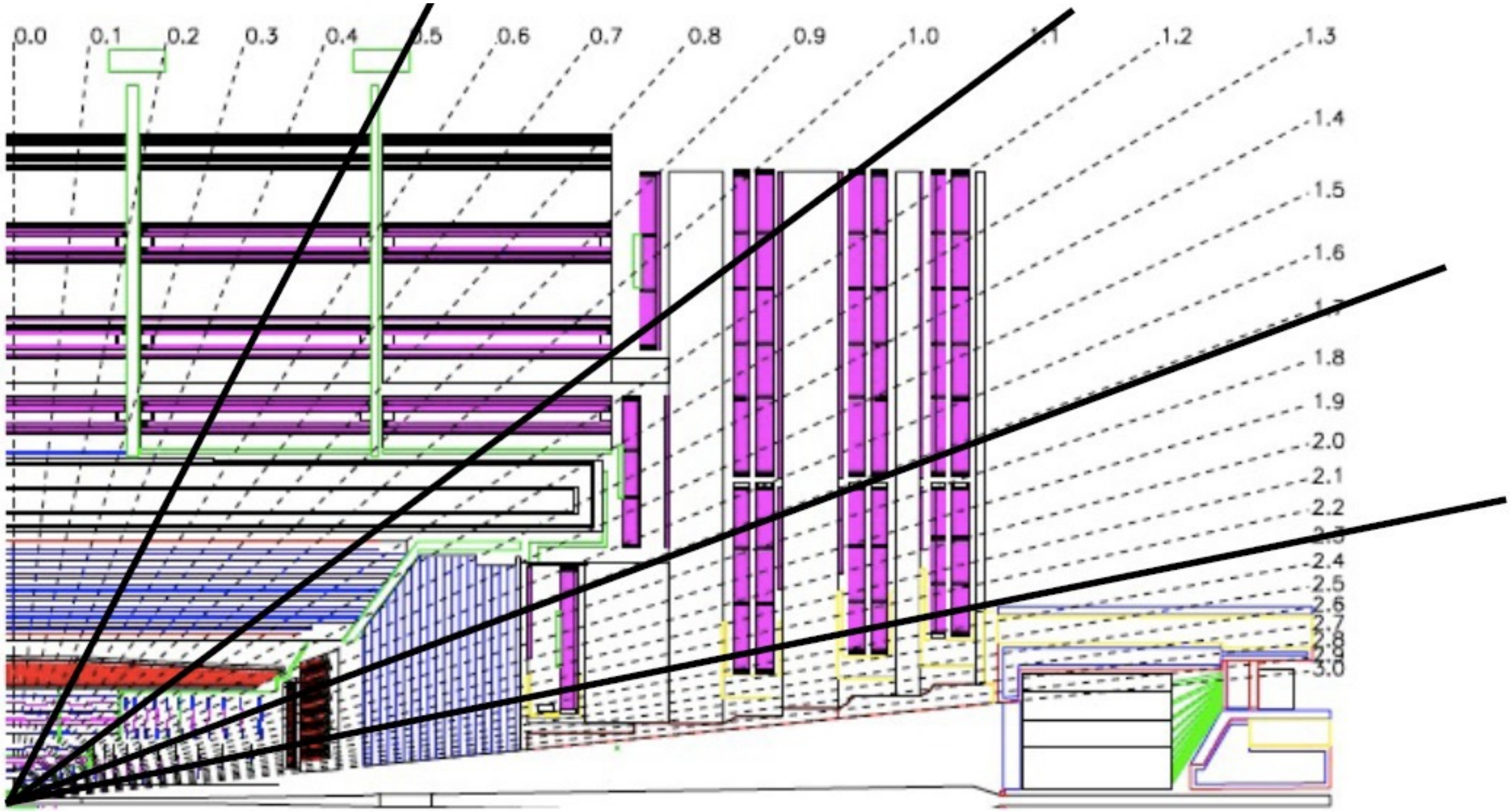
- Energy spectra for negative pions:
  - The data have a broader spectrum than what exist in the MC (for all versions of Geant4)
  - The mean level of disagreement vary between 10% and 18% for beam energies between 2 GeV and 8 GeV
- Energy spectrum for positive pions:
  - The level of agreement is similar to those for negative pions (data distribution is wider than MC)
  - The mean disagreement is between 9% and 15% for energies between 2 GeV and 8 GeV
- Energy spectrum for protons:
  - All versions of Geant4 used for the comparison provide a decent description of the data (the level of agreement is better than in the case of pions)
  - The mean level of disagreement is between 2% and 12% for moment between 2 GeV and 8 GeV

Isolated Charged Hadrons in CMS

- Compare ratio of calorimeter energy measurement to track momentum for isolated charged hadrons between data and MC

- Follow the analysis strategy developed for early data comparison and now applying to the Run-2 data
  - Select good charged tracks reaching the calorimeter surface
  - Impose isolation of these charged particles
    - propagate all tracks in the event to the calorimeter surface and study momentum of tracks (selected with a loose goodness criteria) reaching ECAL (HCAL) within a matrix of 31x31 (7x7) around the impact point of the selected track
    - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for isolation against neutral particles
  - Final cuts
    - No addition; tracks in the isolation region
    - Energy cut of 2 GeV for neutral isolation
    - No additional good primary vertex in the event (to reduce PileUp effect)

Energy Measurements



- Look at tracks in 4 different regions: two in the barrel, one in the endcap and one in the transition region

- Measure energy by combining energy measurements from a matrix of NxN cells around the cell hit by the extrapolated track to the calorimeter surface. Two versions of NxN matrix used:
  - 7x7 matrix for ECAL and 3x3 matrix for HCAL (better purity)
  - 11x11 matrix for ECAL and 5x5 matrix for HCAL (better containment)

- For the data use two low luminosity data sets from the 2016B run period
  - Distributions from Zero Bias and Minimum Bias triggers agree quite well
  - Combine these two data sets and compare that with Monte Carlo

Mean Level of Disagreement for FTFP_BERT_EMM

- The level of disagreement between data and MC is between between 1.9% and 5.9% for the Geant4 version 10.6.p02 and between 1.8% and 5.7% for the Geant4 version 10.6.ref05 for FTFP_BERT_EMM. Adjusting transition region between FTF and Bertini is crucial to get reasonable agreement for the 10.6 versions.

Mean level of disagreement between MC and data

	$(E_{7x7}+H_{3x3})/p$ 10.4.p03	$(E_{7x7}+H_{3x3})/p$ 10.6.p01	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.6.p01
Barrel 1	(1.6±0.4)%	(2.6±0.4)%	(2.1±0.4)%	(1.9±0.4)%
Barrel 2	(4.0±0.4)%	(3.9±0.4)%	(2.8±0.4)%	(2.6±0.4)%
Transition	(5.3±0.5)%	(5.4±0.5)%	(3.6±0.5)%	(3.8±0.5)%
Endcap	(5.5±0.5)%	(4.8±0.5)%	(5.0±0.5)%	(4.7±0.5)%

	$(E_{7x7}+H_{3x3})/p$ 10.6.p02	$(E_{7x7}+H_{3x3})/p$ 10.6.ref05	$(E_{11x11}+H_{5x5})/p$ 10.6.p02	$(E_{11x11}+H_{5x5})/p$ 10.6.ref05
Barrel 1	(2.2±0.4)%	(2.6±0.4)%	(1.9±0.4)%	(1.8±0.4)%
Barrel 2	(4.7±0.4)%	(4.7±0.4)%	(3.4±0.4)%	(3.6±0.4)%
Transition	(5.9±0.5)%	(5.7±0.5)%	(4.5±0.5)%	(4.8±0.5)%
Endcap	(3.5±0.5)%	(4.2±0.5)%	(3.2±0.5)%	(4.0±0.5)%

Geant4 Mean Level of Disagreement for QGSP_FTFP_BERT_EML

- The level of disagreement between data and MC is between 1.6% and 6.6% for the Geant4 version 10.6.p02 and between 2.2% and 6.6% for the Geant4 version 10.6.ref05 for the list QGSP_FTFP_BERT_EML

Mean level of disagreement between MC and data

	$(E_{7x7}+H_{3x3})/p$ 10.4.p03	$(E_{7x7}+H_{3x3})/p$ 10.6.p01	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.6.p01
Barrel 1	(1.6±0.4)%	(3.7±0.4)%	(2.1±0.4)%	(3.0±0.4)%
Barrel 2	(4.1±0.4)%	(5.2±0.4)%	(2.8±0.4)%	(3.5±0.4)%
Transition	(4.9±0.5)%	(6.6±0.5)%	(2.9±0.5)%	(4.7±0.5)%
Endcap	(4.7±0.5)%	(5.2±0.5)%	(4.0±0.5)%	(4.6±0.5)%

	$(E_{7x7}+H_{3x3})/p$ 10.6.p02	$(E_{7x7}+H_{3x3})/p$ 10.6.ref05	$(E_{11x11}+H_{5x5})/p$ 10.6.p02	$(E_{11x11}+H_{5x5})/p$ 10.6.ref05
Barrel 1	(2.2±0.4)%	(4.0±0.4)%	(1.6±0.4)%	(2.6±0.4)%
Barrel 2	(4.9±0.4)%	(4.9±0.4)%	(3.3±0.4)%	(3.5±0.4)%
Transition	(6.6±0.5)%	(6.6±0.5)%	(5.0±0.5)%	(4.8±0.5)%
Endcap	(5.7±0.5)%	(4.9±0.5)%	(5.7±0.5)%	(4.8±0.5)%

Comparison between 2 Physics Lists

- The level of disagreement between data and MC is between 1.6% and 5.7% for FTFP_BERT_EMM and between 2.6% and 6.6% for the physics list QGSP_FTFP_BERT_EML with the “VecGeom” builds depending on the region of the detector.
- The physics list FTFP_BERT_EMM provides systematically better agreement with the data than QGSP_FTFP_BERT_EML

	$(E_{7x7}+H_{3x3})/p$ 10.6.ref05 (FTFP)	$(E_{7x7}+H_{3x3})/p$ 10.6.ref05 (QGSP)	$(E_{11x11}+H_{5x5})/p$ 10.6.ref05 (FTFP)	$(E_{11x11}+H_{5x5})/p$ 10.6.ref05 (QGSP)
Barrel 1	(2.6±0.4)%	(4.0±0.4)%	(1.6±0.4)%	(2.6±0.4)%
Barrel 2	(4.7±0.4)%	(4.9±0.4)%	(2.6±0.4)%	(3.5±0.4)%
Transition	(5.7±0.5)%	(6.6±0.5)%	(4.8±0.5)%	(4.8±0.5)%
Endcap	(4.2±0.5)%	(4.9±0.5)%	(4.0±0.5)%	(4.8±0.5)%

Summary

- The releases p02 and ref05 of 10.6 of Geant4 have been tested with native geometry as well as newer VecGeom version (v1.1.6/v1.1.7) for thin target and CMS data
- Physics predictions from the new versions do not make any significant improvement with respect to those from 10.4.p03 when compared to the data. The version Geant4.10.4.p03 is used by CMS in its productions and is planning to move to Geant4.10.6.p02 for future productions.

Additional Slides

Test Beam Analysis

- Events are simulated only till the simulation hit level (including saturation effect as in Birk's law)

- Effect of electronics and detector noise is taken care of by adding Gaussian noise separately for ECAL and HCAL
  - $RMS_{ECAL} = 0.362$ GeV
  - $RMS_{HCAL} = 0.640$ GeV

- The detector components in the beam line are described in the simulation package and the cuts which are used for data analysis are also used for analyzing the Monte Carlo Sample

- Exclude hits in the outer hadron calorimeter and use a time cut of 100 ns

- Energy in the calorimeter is summed up around the beam spot
  - 7x7 matrix of crystals for ECAL
  - 3x3 towers for HCAL

- 50 GeV electrons are used for defining energy scales of ECAL as well as HCAL. Energy is measured as
  - $E_{vis} = E_{ECAL} * f_{ECAL} + E_{HCAL} * f_{HCAL}$
  - $f_{ECAL} = 1.01$, $f_{HCAL} \sim 105$ (for FTFP_BERT_EMM Physics List)

Use of Birk's Law in CMS

- CMS uses Birk's law which applies energy saturation correction depending on dE/dx in the current step.

- It makes use of 3 constants in the parametrization for plastic scintillators: birkC1, birkC2, birkC3 and the parametrization is best given by the C++ code

```
double rkb = birkC1 / density;
double c = birkC2 * rkb * rkb;
if (std::abs(charge) >= 2.) rkb /= birkC3;
weight = 1. / (1. + rkb * dedx + c * dedx * dedx);
```

where the factor weight is a multiplicative constant on energy deposit in the step

Comparison between 2 Physics Lists

- The same comparison for the version 10.4.p03 shows much closer agreement between the two physics lists FTFP_BERT_EMM and QGSP_FTFP_BERT_EML with a slight edge for QGSP_FTFP_BERT_EML

	$(E_{7x7}+H_{3x3})/p$ 10.4.p03 (FTFP)	$(E_{7x7}+H_{3x3})/p$ 10.4.p03 (QGSP)	$(E_{11x11}+H_{5x5})/p$ 10.4.p03 (FTFP)	$(E_{11x11}+H_{5x5})/p$ 10.4.p03 (QGSP)
Barrel 1	(1.6±0.4)%	(1.6±0.4)%	(2.1±0.4)%	(2.1±0.4)%
Barrel 2	(4.0±0.4)%	(4.1±0.4)%	(2.8±0.4)%	(2.8±0.4)%
Transition	(5.3±0.5)%	(4.9±0.5)%	(3.6±0.5)%	(2.9±0.5)%
Endcap	(5.5±0.5)%	(4.7±0.5)%	(5.0±0.5)%	(4.0±0.5)%