Tests of Geant4.10.5 Reference Versions (01 and 02)

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New Geant4 Version

- Geant4 came up with candidate versions 10.5.ref01 and 10.5.ref02 during the last 2 months following the release of Geant4.10.5 by December 6.

- Thin target comparison is done by making specific builds for these versions (with native Geant4 geometry) and compared the predictions with BNL and MIPP data and utilize test47 codes

- For comparison with CMS data (test beam as well as collision data) additional Geant4 builds were made using VecGeom (v01.01) replacing the native Geant4 geometry codes

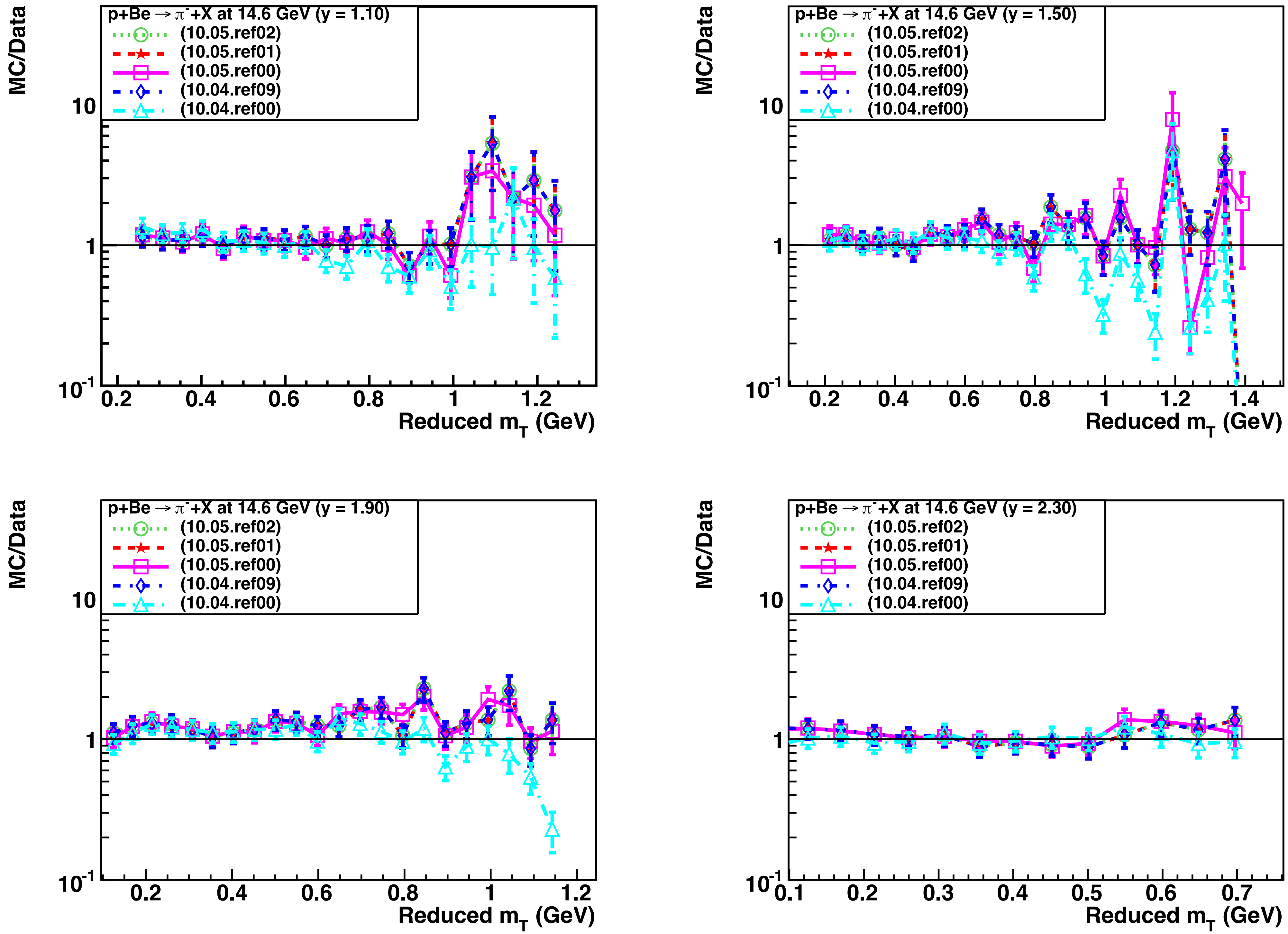
- CMSSW version 10_2_3 is used for compare with the CMS data

- Comparison with CMS data is also made with the patch release 10.4.p03

Comparison with BNL Data

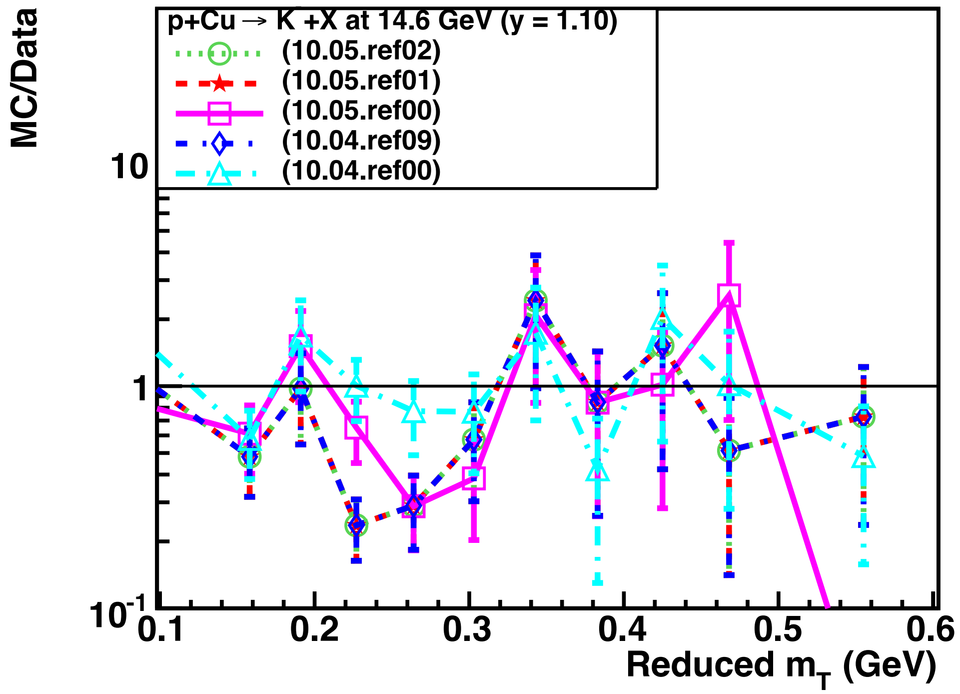
- Data set from BNL E802: (T. Abbott *et al.*, Phys. Rev. D45, 3906)
  - Inclusive $\pi^{\pm}$, $K^{\pm}$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets
  - Quantities measured are Lorentz invariant differential cross sections as a function of transverse mass (m_T) in 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, 10.4.ref09, 10.5.ref00, 10.5.ref01, 10.5.ref02

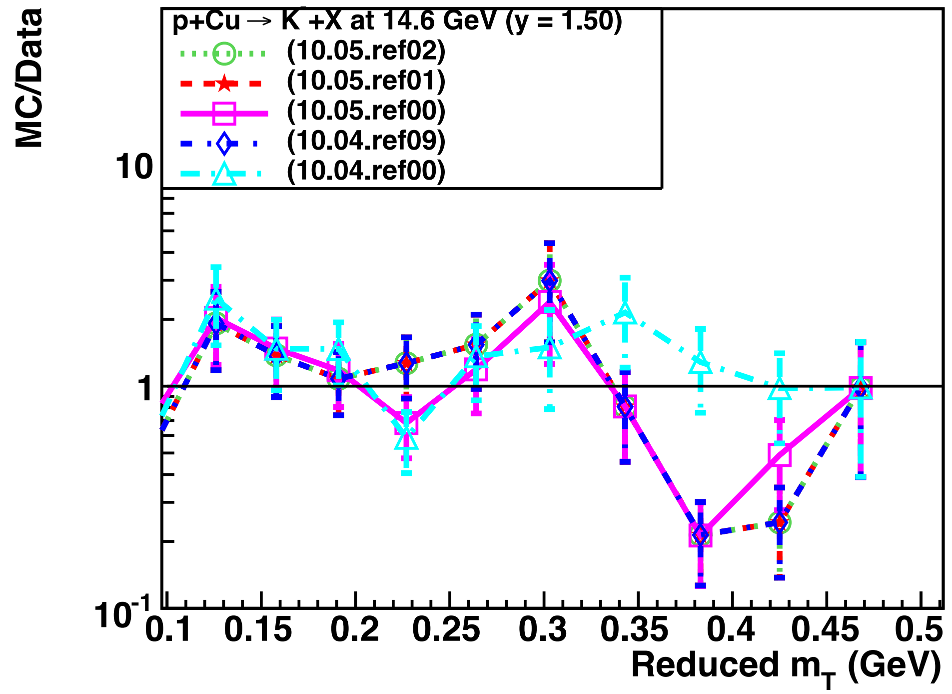
p + Be → π + X at 14.6 GeV/c (FTFP)

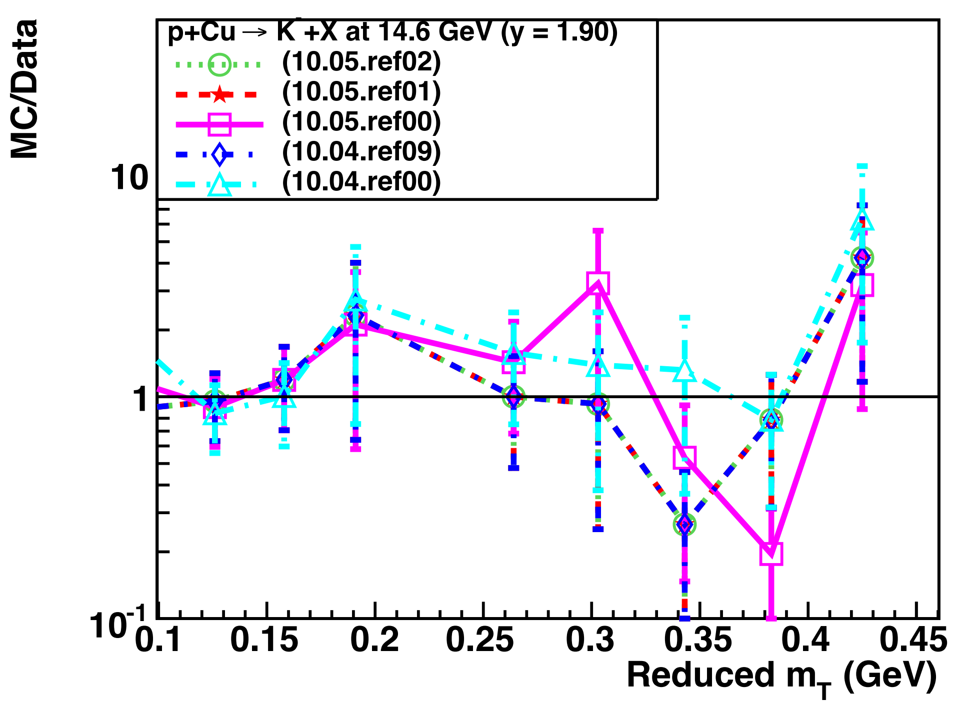


- The two reference versions give identical predictions and exactly the same as that of 10.04.ref09. All versions have reasonable agreement with the data.

p + Cu →K⁻ + X at 14.6 GeV/c (FTFP)

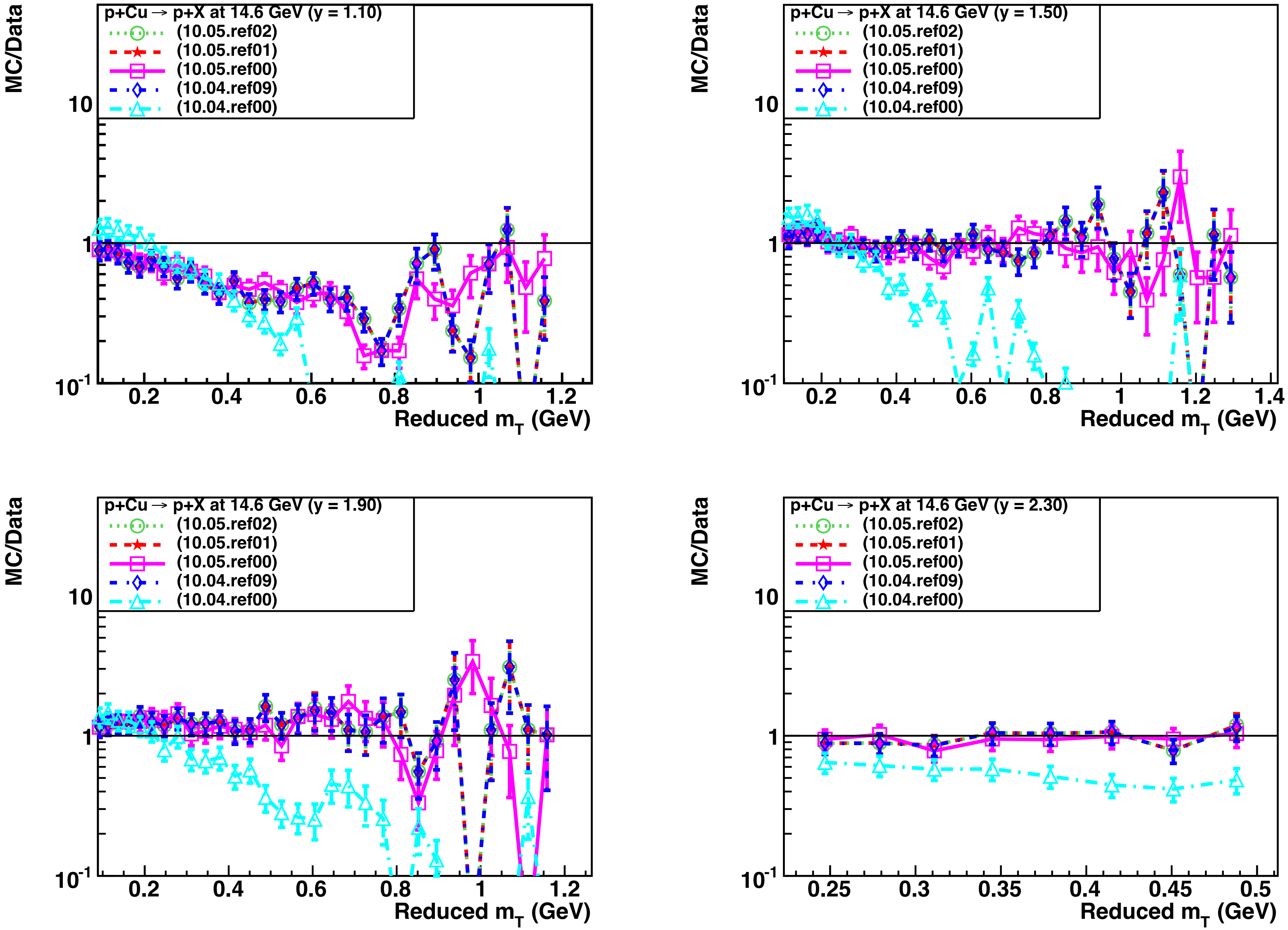






- All versions provide similar level of agreement for K^- production. Again the two reference versions give same predictions as 10.4.ref09

p + Cu → p + X at 14.6 GeV/c (FTFP)



- The version 10.4.ref00 provides the worst agreement for p production. The two new reference versions provide reasonable description of the data

ChiSq/Data for Final State Pions (FTFP)

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

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Be π^+ (1.1)	1.45	1.76	0.87	1.76	1.76
Be π^+ (1.5)	1.44	4.49	4.77	4.49	4.49
Be π^+ (1.9)	0.85	2.84	4.53	2.84	2.84
Be π^+ (2.3)	1.13	0.71	0.77	0.71	0.71
Be π^- (1.1)	1.24	4.88	2.53	4.88	4.88
Be π^- (1.5)	3.28	4.70	8.70	4.70	4.70
Be π^- (1.9)	1.62	5.41	4.69	5.41	5.41
Be π^- (2.3)	0.23	0.95	1.06	0.95	0.95
Au π^+ (1.1)	0.77	2.39	5.71	2.36	2.36
Au π^+ (1.5)	2.22	6.55	8.06	7.13	7.13
Au π^+ (1.9)	2.62	3.72	3.68	4.18	4.18
Au π^+ (2.3)	1.33	3.15	2.94	3.48	3.48
Au π^- (1.1)	2.27	4.62	5.08	4.46	4.46
Au π^- (1.5)	2.89	8.58	8.63	8.83	8.83
Au π^- (1.9)	1.84	10.86	9.26	9.63	9.63
Au π^- (2.3)	1.42	8.78	8.35	9.05	9.05

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

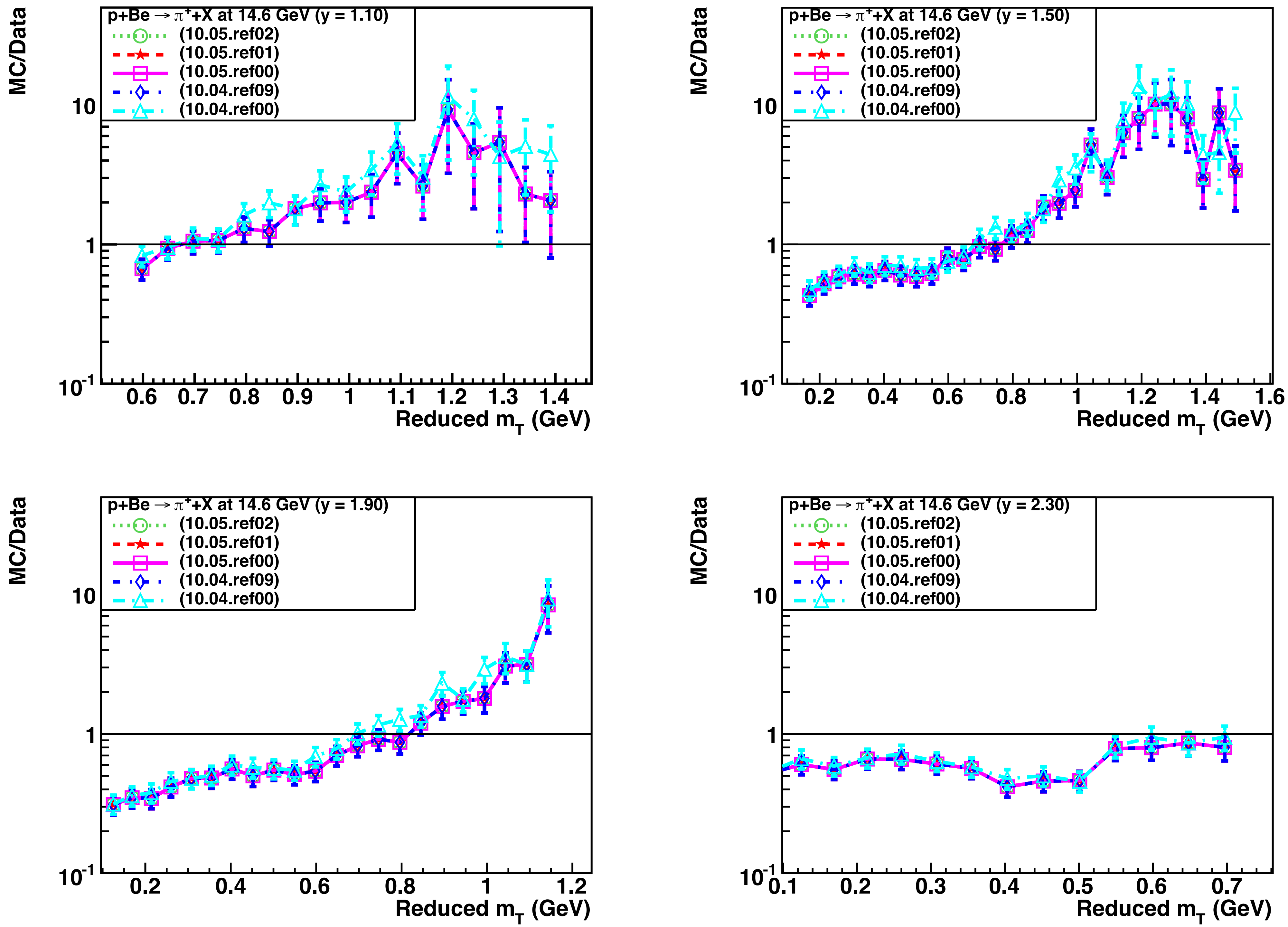
ChiSq/Data for Copper Target (FTFP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Cu K^+ (1.1)	2.85	4.48	4.46	4.48	4.48
Cu K^+ (1.5)	2.00	4.20	4.81	4.20	4.20
Cu K^+ (1.9)	1.49	3.93	3.30	3.93	3.93
Cu K^- (1.1)	1.29	1.83	1.73	1.83	1.83
Cu K^- (1.5)	2.65	2.63	1.93	2.63	2.63
Cu K^- (1.9)	6.47	2.62	2.42	2.62	2.62
Cu p (1.1)	10.43	5.55	5.28	5.56	5.56
Cu p (1.5)	12.87	1.36	1.43	1.36	1.36
Cu p (1.9)	4.29	2.31	2.82	2.34	2.34
Cu p (2.3)	6.29	0.44	0.25	0.47	0.47

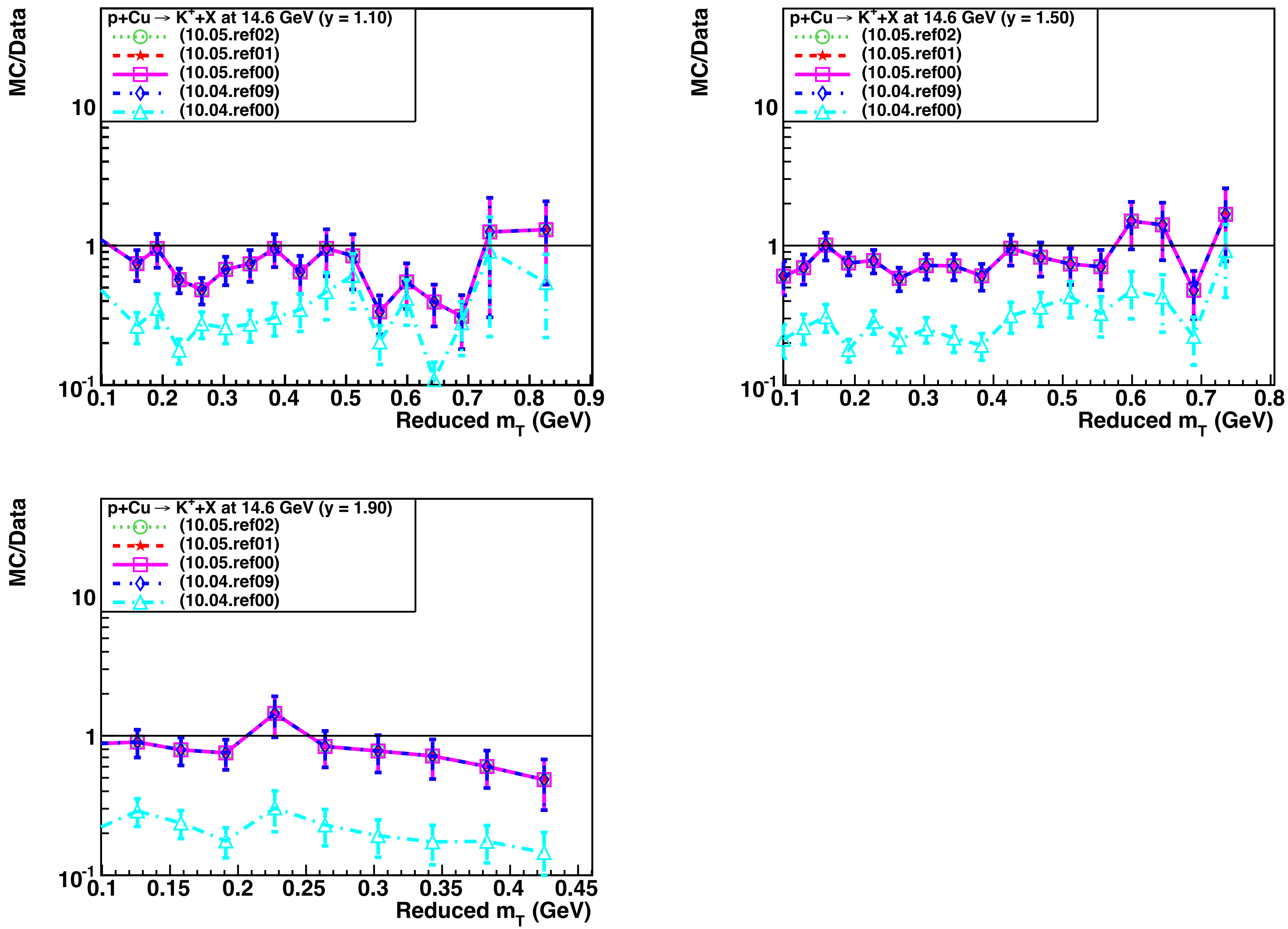
The first column refers to target/final state particle/mean rapidity value

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)



- The two new reference versions provide the same level of agreement as 10.4.ref09. They and 10.5.ref00 provide better agreement with the data for K^+ production

ChiSq/Data for Final State Pions (Bertini)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Be π^+ (1.1)	46.40	22.78	22.78	22.78	22.78
Be π^+ (1.5)	132.94	82.69	82.69	82.69	82.69
Be π^+ (1.9)	41.95	31.69	31.69	31.69	31.69
Be π^+ (2.3)	4.57	5.50	5.50	5.50	5.50
Be π^- (1.1)	546.63	442.89	442.89	442.89	442.89
Be π^- (1.5)	661.29	553.76	553.76	553.76	553.76
Be π^- (1.9)	228.01	178.50	178.50	178.50	178.50
Be π^- (2.3)	9.09	7.06	7.06	7.06	7.06
Au π^+ (1.1)	29.44	14.18	14.18	14.18	14.18
Au π^+ (1.5)	57.03	37.74	37.74	37.74	37.74
Au π^+ (1.9)	16.87	11.30	11.30	11.30	11.30
Au π^+ (2.3)	3.86	5.37	5.37	5.37	5.37
Au π^- (1.1)	122.54	133.07	133.07	133.07	133.07
Au π^- (1.5)	130.32	108.95	108.95	108.95	108.95
Au π^- (1.9)	97.55	118.41	118.41	118.41	118.41
Au π^- (2.3)	3.50	4.20	4.20	4.20	4.20

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

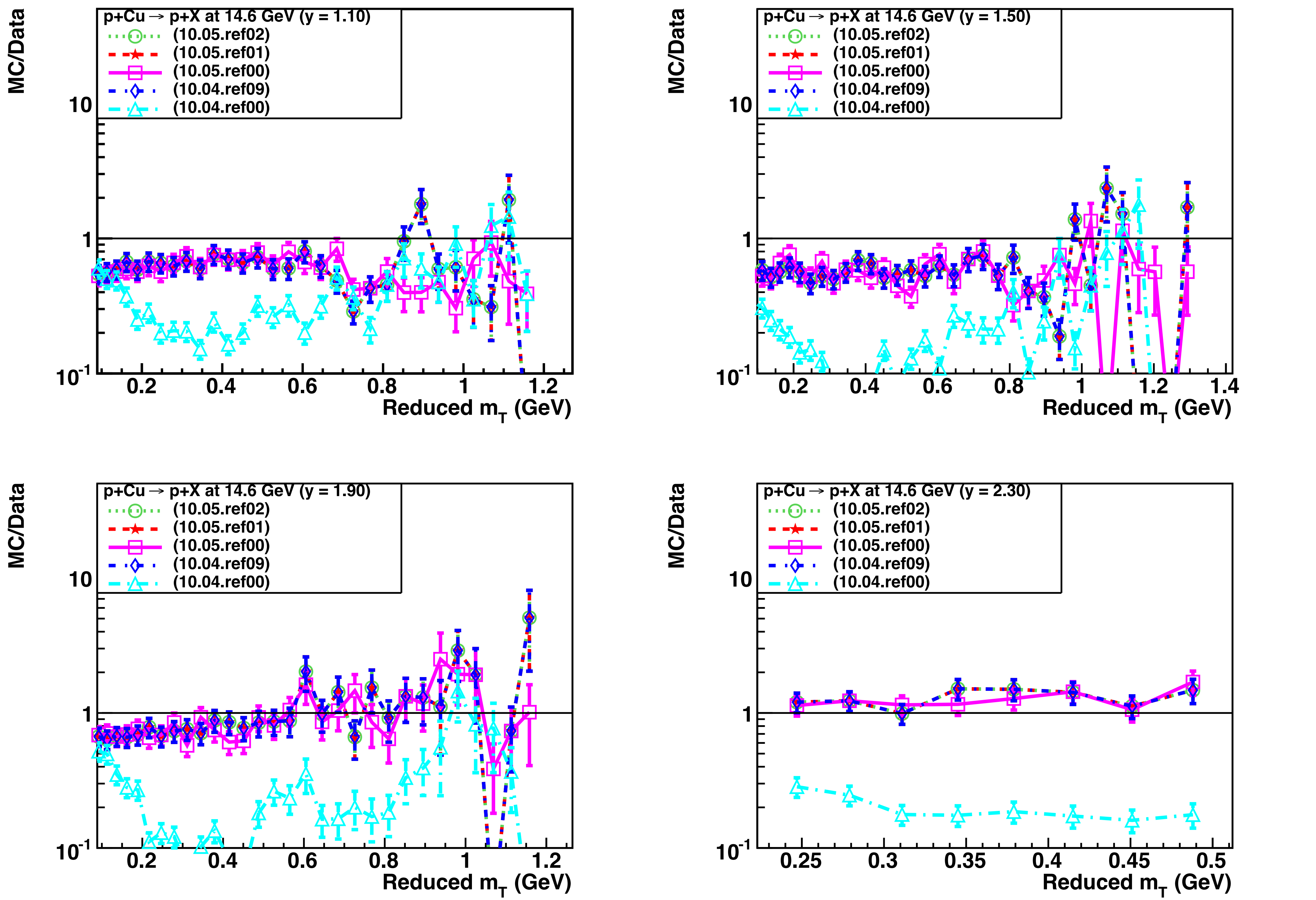
ChiSq/Data for Copper Target (Bertini)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Cu K^+ (1.1)	5.53	1.62	1.62	1.62	1.62
Cu K^+ (1.5)	7.59	1.29	1.29	1.29	1.29
Cu K^+ (1.9)	8.53	0.88	0.88	0.88	0.88
Cu K^- (1.1)	1.90	1.55	1.55	1.55	1.55
Cu K^- (1.5)	2.61	1.28	1.28	1.28	1.28
Cu K^- (1.9)	2.84	2.28	2.28	2.28	2.28
Cu p (1.1)	54.34	56.52	56.52	56.52	56.52
Cu p (1.5)	161.65	156.12	156.12	156.12	156.12
Cu p (1.9)	126.31	120.87	120.87	120.87	120.87
Cu p (2.3)	1.61	1.43	1.43	1.43	1.43

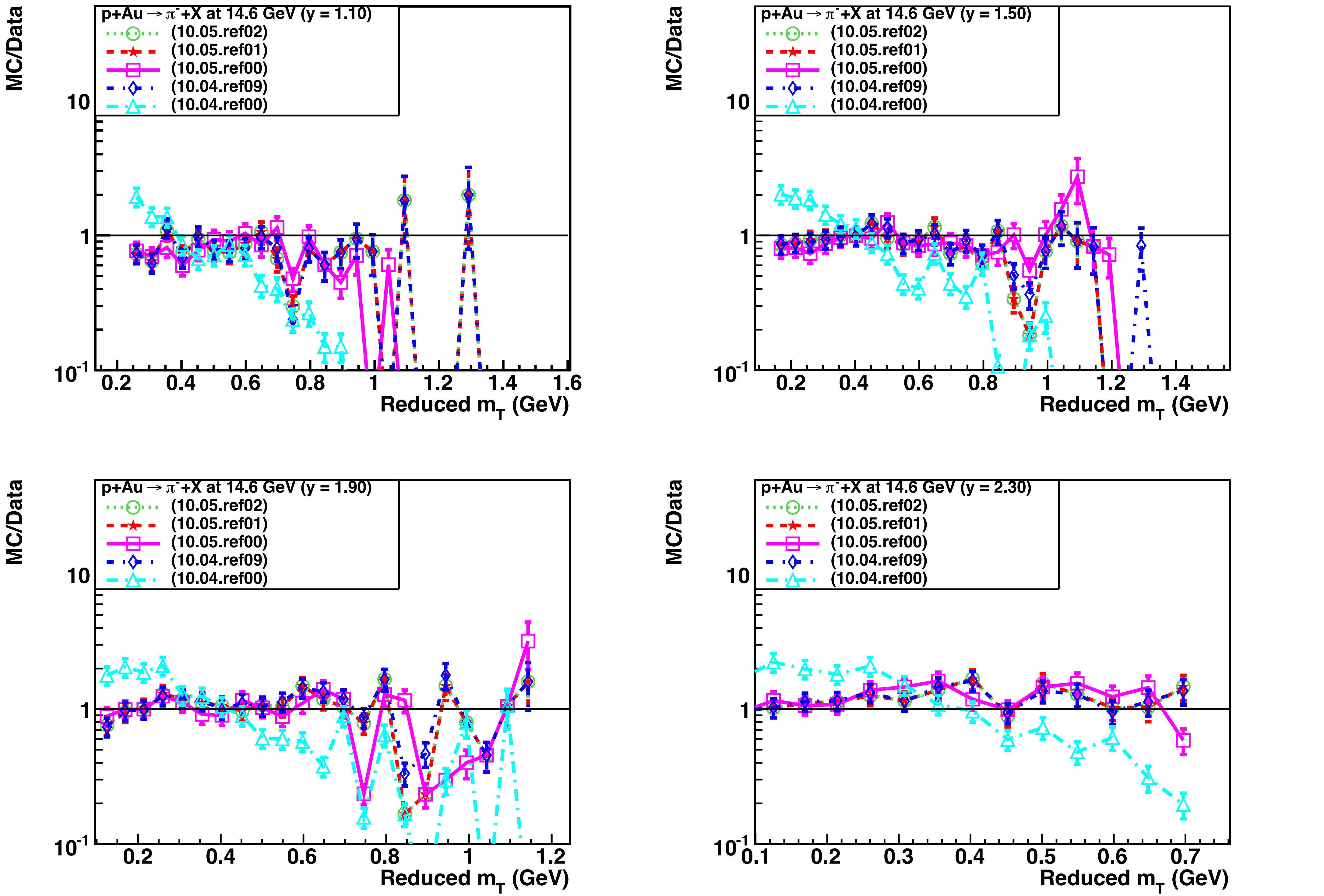
The first column refers to target/final state particle/mean rapidity value

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 10.4.ref09, the same in the 2 reference versions

ChiSq/Data for Final State Pions (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Be π^+ (1.1)	7.30	1.25	0.71	1.25	1.25
Be π^+ (1.5)	7.21	1.30	1.30	1.30	1.30
Be π^+ (1.9)	8.88	2.49	1.83	2.49	2.49
Be π^+ (2.3)	6.28	2.04	2.11	2.04	2.04
Be π^- (1.1)	5.63	2.25	2.54	2.25	2.25
Be π^- (1.5)	7.49	2.63	2.38	2.63	2.63
Be π^- (1.9)	6.32	1.15	1.74	1.15	1.15
Be π^- (2.3)	3.19	1.40	1.43	1.40	1.40
Au π^+ (1.1)	8.35	2.11	1.75	3.04	3.04
Au π^+ (1.5)	13.40	3.04	1.73	2.03	2.03
Au π^+ (1.9)	16.33	2.43	0.95	1.75	1.75
Au π^+ (2.3)	30.40	0.92	1.19	1.09	1.09
Au π^- (1.1)	8.60	2.33	2.06	2.23	2.23
Au π^- (1.5)	11.52	1.11	2.07	1.71	1.71
Au π^- (1.9)	11.93	3.23	4.50	3.36	3.36
Au π^- (2.3)	15.87	2.46	3.47	2.78	2.78

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

ChiSq/Data for Copper Target (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
Cu K^+ (1.1)	4.34	4.90	5.02	4.90	4.90
Cu K^+ (1.5)	4.62	4.30	3.83	4.30	4.30
Cu K^+ (1.9)	3.32	2.70	3.31	2.70	2.70
Cu K^- (1.1)	3.59	1.30	1.53	1.30	1.30
Cu K^- (1.5)	6.13	1.88	2.58	1.88	1.88
Cu K^- (1.9)	0.82	1.31	0.71	1.31	1.31
Cu p (1.1)	11.20	4.89	4.48	4.89	4.89
Cu p (1.5)	16.32	5.42	5.04	5.42	5.42
Cu p (1.9)	11.82	4.30	2.18	4.30	4.30
Cu p (2.3)	18.74	3.57	2.79	3.57	3.57

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

Geant 4

ChiSq/Data for Final State Pions

- Compiling for the 3 models in Geant4.10.5.ref02:

	FTFP	QGSP	Bertini
Be π^+ (1.1)	1.76	1.24	22.78
Be π^+ (1.5)	4.49	1.30	82.69
Be π^+ (1.9)	2.84	2.49	31.69
Be π^+ (2.3)	0.71	2.04	5.50
Be π^- (1.1)	4.88	2.25	442.89
Be π^- (1.5)	4.70	2.63	553.76
Be π^- (1.9)	5.41	1.15	178.50
Be π^- (2.3)	0.95	1.40	7.06
Au π^+ (1.1)	2.36	3.04	14.18
Au π^+ (1.5)	7.13	2.03	37.74
Au π^+ (1.9)	4.18	1.75	11.30
Au π^+ (2.3)	3.48	1.09	5.37
Au π^- (1.1)	4.46	2.23	133.07
Au π^- (1.5)	8.83	1.71	108.95
Au π^- (1.9)	9.63	3.36	118.41
Au π^- (2.3)	9.05	2.78	4.20

ChiSq/Data for Copper Target

- Compiling for the 3 models in Geant4.10.5.ref02:

	FTFP	QGSP	Bertini
Cu K^+ (1.1)	4.48	4.90	1.62
Cu K^+ (1.5)	4.20	4.30	1.29
Cu K^+ (1.9)	3.92	2.70	0.88
Cu K^- (1.1)	1.83	1.30	1.55
Cu K^- (1.5)	2.63	1.88	1.28
Cu K^- (1.9)	2.62	1.31	2.28
Cu p (1.1)	5.56	4.89	56.52
Cu p (1.5)	1.36	5.42	156.12
Cu p (1.9)	2.34	4.30	120.87
Cu p (2.3)	0.47	3.57	1.43

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, 10.4.ref09, 10.5.ref00, 10.5.ref01, 10.5.ref02

ChiSq/Data for 8 different processes

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

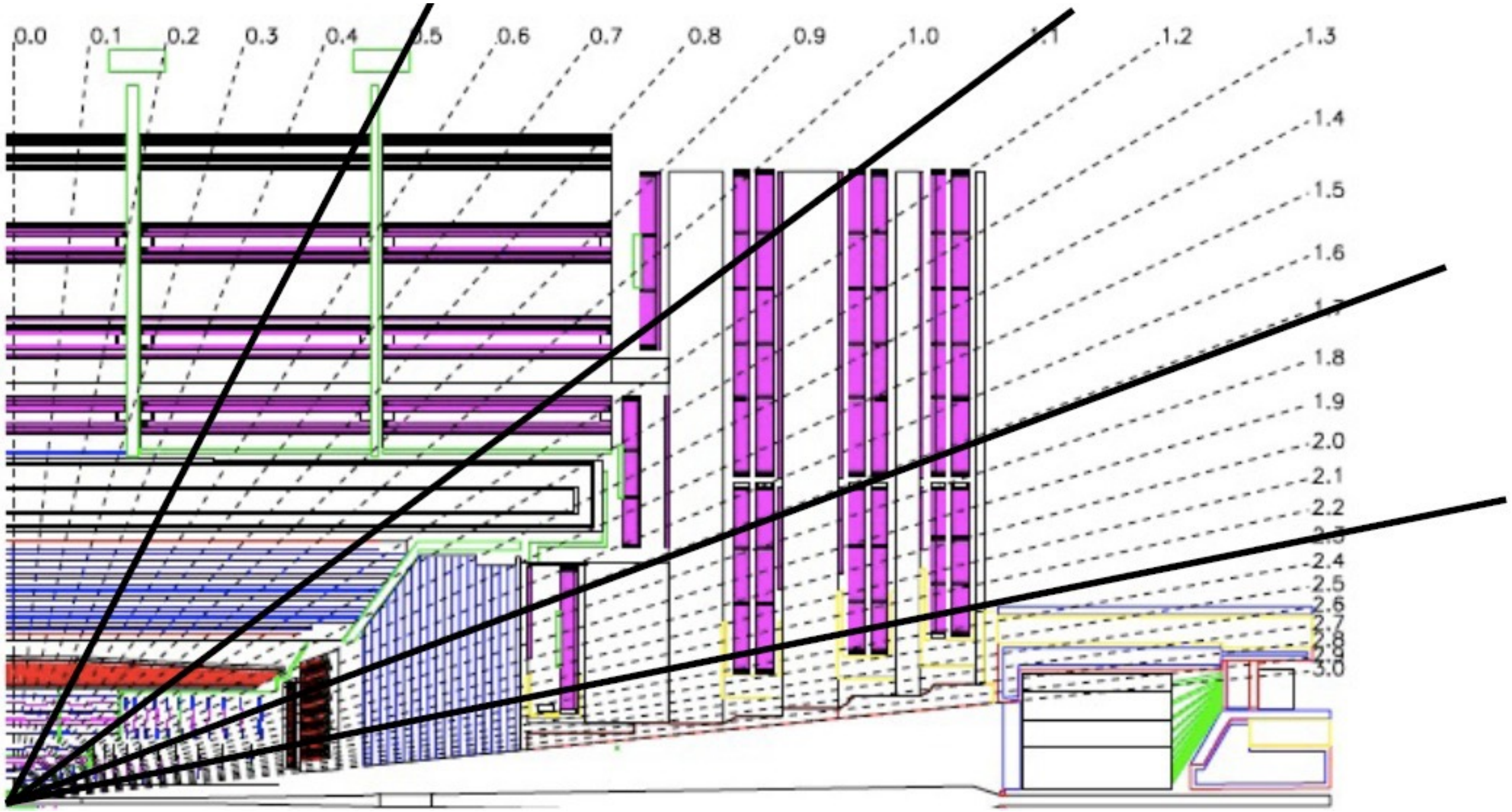
	10.4.ref00	10.4.ref09	10.5.ref00	10.5.ref01	10.5.ref02
			FTFP		
p+H (56.8)	2.73	12.11	12.11	12.11	12.11
p+C (56.8)	4.31	11.99	11.90	11.99	11.99
p+Bi (56.8)	1.92	2.80	2.68	2.90	2.90
p+U (57.3)	1.85	2.90	3.30	2.77	2.77
p+H (82.6)	4.26	17.81	17.81	17.81	17.81
p+Be	11.15	4.87	4.85	4.86	4.86
p+C (120.0)	10.03	27.64	28.06	27.81	27.81
p+Bi (120.0)	3.64	8.40	4.64	7.13	7.13
			QGSP		
p+H (56.8)	5.13	10.70	10.79	10.79	10.79
p+C (56.8)	3.03	3.36	3.36	3.36	3.36
p+Bi (56.8)	6.32	4.67	4.74	4.79	4.79
p+U (57.3)	11.30	9.62	9.88	9.73	9.73
p+H (82.6)	2.34	16.22	16.30	16.30	16.30
p+Be	4.98	12.95	13.07	13.11	13.11
p+C (120.0)	5.33	8.11	8.29	8.20	8.20
p+Bi (120.0)	2.86	23.26	25.39	23.47	23.47

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

Comparison for Small Matrix (FTFP_BERT_EMM)

- The mean level of disagreement between data and different MC versions for the physics list FTFP_BERT_EMM are studied for energy response in the small matrix: $(E_{7x7}+H_{3x3})/p$
- The difference got progressively worse in the endcap and transition region (and also in the second barrel region)

	10.2.p02	10.4.ref00	10.4.p03	10.5.ref00	10.5.ref01
Barrel 1	(2.4±0.4)%	(2.1±0.4)%	(1.6±0.4)%	(3.7±0.4)%	(3.5±0.4)%
Barrel 2	(3.6±0.4)%	(3.9±0.4)%	(4.0±0.4)%	(5.4±0.4)%	(5.6±0.4)%
Transition	(4.9±0.5)%	(4.8±0.5)%	(5.3±0.5)%	(5.7±0.5)%	(6.9±0.5)%
Endcap	(3.1±0.3)%	(5.6±0.5)%	(5.5±0.5)%	(4.6±0.5)%	(5.1±0.5)%

Comparison for Large Matrix (FTFP_BERT_EMM)

- The mean level of disagreement between data and different MC versions are studied for energy response in the larger matrix: $(E_{11x11}+H_{5x5})/p$
- The level of agreement improves for the larger matrix
- The difference is again progressively worse with newer versions

	10.2.p02	10.4.ref00	10.4.p03	10.5.ref00	10.5.ref01
Barrel 1	(2.6±0.4)%	(2.5±0.4)%	(2.1±0.4)%	(2.2±0.4)%	(2.2±0.4)%
Barrel 2	(2.2±0.4)%	(2.7±0.4)%	(2.8±0.4)%	(4.0±0.4)%	(4.4±0.4)%
Transition	(2.2±0.5)%	(3.1±0.5)%	(3.6±0.5)%	(4.3±0.5)%	(5.4±0.5)%
Endcap	(1.5±0.3)%	(4.8±0.5)%	(5.0±0.5)%	(4.7±0.5)%	(5.1±0.5)%

Comparison for Small Matrix (QGSP_FTFP_BERT_EML)

- The mean level of disagreement between data and different MC versions for the physics list QGSP_FTFP_BERT_EML are studied for energy response in the small matrix: $(E_{7x7}+H_{3x3})/p$
- The difference got progressively worse in the second barrel, endcap and transition region (and slightly recovered in the version 10.4.p03)

	10.2.p02	10.4.ref00	10.4.p03	10.5.ref00	10.5.ref01
Barrel 1	(1.5±0.4)%	(1.7±0.4)%	(1.6±0.4)%	(2.7±0.4)%	(2.7±0.4)%
Barrel 2	(3.8±0.4)%	(3.6±0.4)%	(4.1±0.4)%	(4.5±0.4)%	(4.5±0.4)%
Transition	(5.1±0.5)%	(5.7±0.5)%	(4.9±0.5)%	(6.6±0.5)%	(6.6±0.5)%
Endcap	(4.9±0.3)%	(5.1±0.5)%	(4.7±0.5)%	(4.0±0.5)%	(4.0±0.5)%

Comparison for Large Matrix (QGSP_FTFP_BERT_EML)

- The mean level of disagreement between data and different MC versions are studied for energy response in the larger matrix: $(E_{11x11}+H_{5x5})/p$
- The level of agreement improves for the larger matrix
- The difference is again progressively worse with newer versions with the exception of the version 10.4.p03

	10.2.p02	10.4.ref00	10.4.p03	10.5.ref00	10.5.ref01
Barrel 1	(2.7±0.4)%	(2.5±0.4)%	(2.1±0.4)%	(2.1±0.4)%	(2.1±0.4)%
Barrel 2	(2.2±0.4)%	(2.3±0.4)%	(2.8±0.4)%	(3.2±0.4)%	(3.2±0.4)%
Transition	(3.0±0.5)%	(3.7±0.5)%	(2.9±0.5)%	(4.7±0.5)%	(4.7±0.5)%
Endcap	(2.9±0.3)%	(4.0±0.5)%	(4.0±0.5)%	(3.9±0.5)%	(3.9±0.5)%

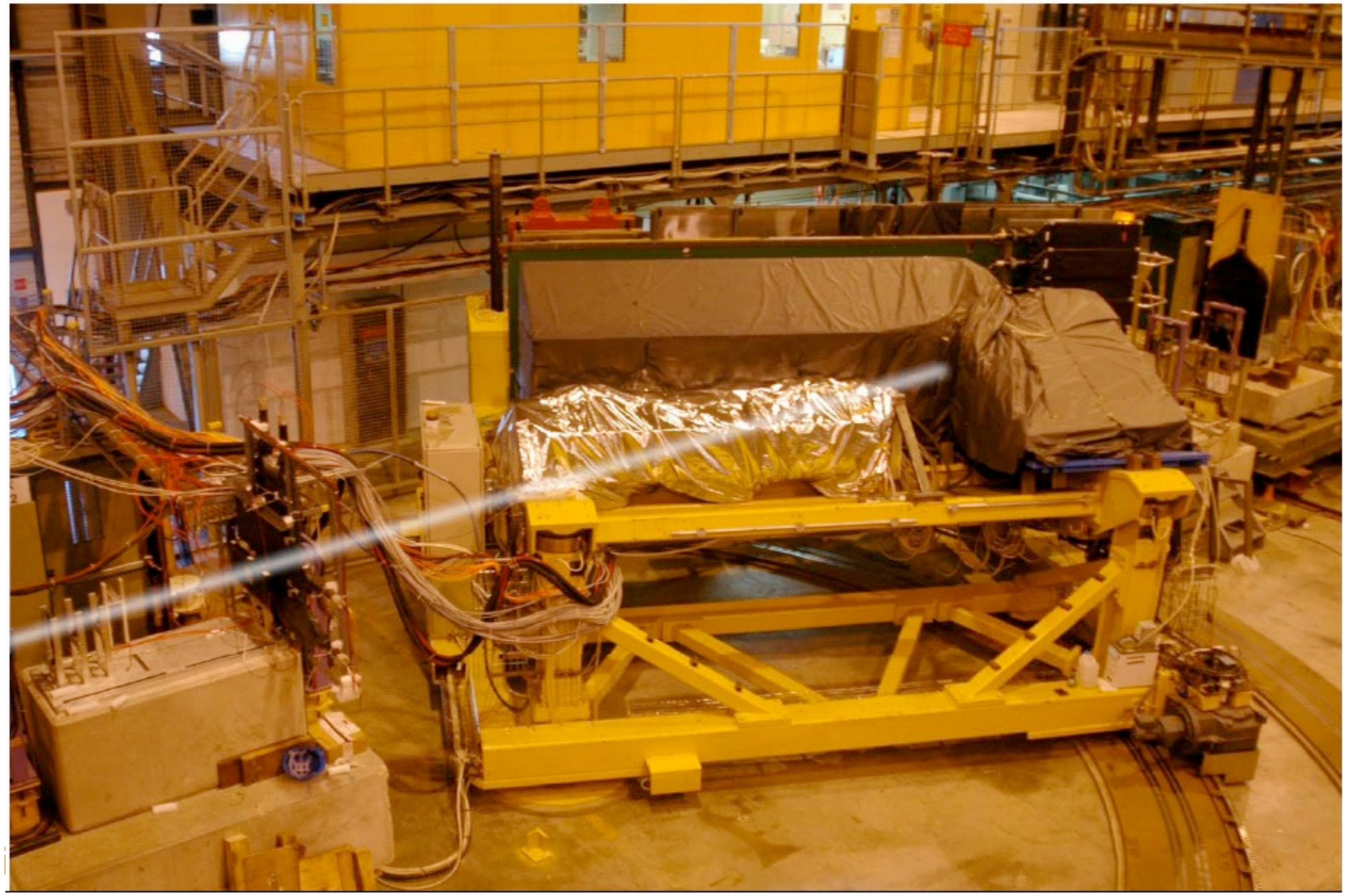
Comparison between 2 Physics Lists

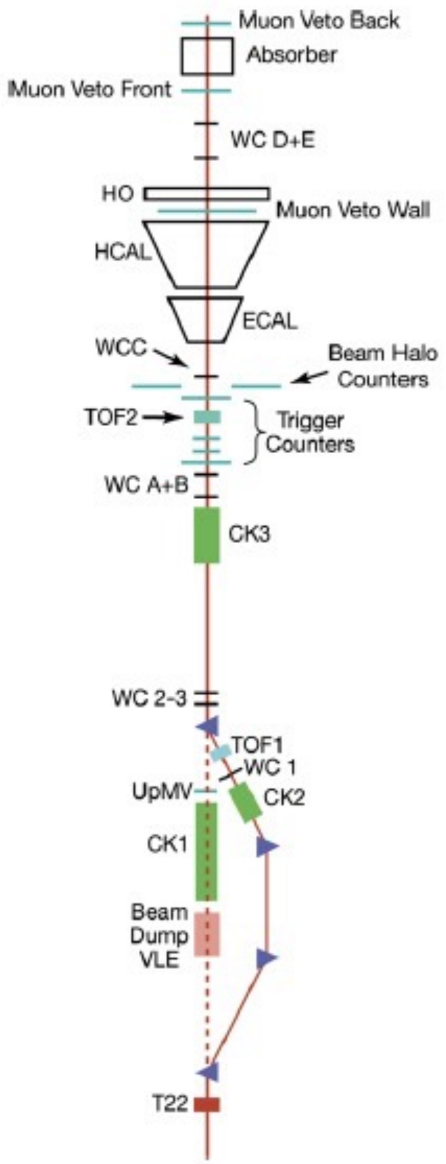
- The level of disagreement between data and MC is between 2.2% and 6.9% for FTFP_BERT_EMM and between 2.1% and 6.6% for the physics list QGSP_FTFP_BERT_EML with the “VecGeom” builds depending on the region of the detector.
- The physics list QGSP_FTFP_BERT_EML is in general performing better

	$(E_{7x7}+H_{3x3})/p$ 10.5.ref02 (FTFP)	$(E_{7x7}+H_{3x3})/p$ 10.5.ref02 (QGSP)	$(E_{11x11}+H_{5x5})/p$ 10.5.ref02 (FTFP)	$(E_{11x11}+H_{5x5})/p$ 10.5.ref02 (QGSP)
Barrel 1	(3.5±0.4)%	(2.7±0.4)%	(2.2±0.4)%	(2.1±0.4)%
Barrel 2	(5.6±0.4)%	(4.5±0.4)%	(4.4±0.4)%	(3.2±0.4)%
Transition	(6.9±0.5)%	(6.6±0.5)%	(5.4±0.5)%	(4.7±0.5)%
Endcap	(5.1±0.5)%	(4.0±0.5)%	(5.1±0.5)%	(3.9±0.5)%

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 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)

Test Beam Data

Mean level of disagreement between MC and data

Beam mom.	π- 10.4.r00	π- 10.4.p03	π- 10.5.r01	π+ 10.4.r00	π+ 10.4.p03	π+ 10.5.r01	p 10.4.r00	p 10.4.p03	p 10.5.r01
2 GeV	10.1±0.9	10.1±0.9	10.0±0.9	14.1±1.2	14.4±1.2	14.0±1.2	8.4±2.5	8.5±0.3	7.5±0.3
3 GeV	10.7±0.6	10.8±0.6	8.5±0.6	9.3±1.7	8.5±1.7	9.7±1.7	3.1±1.0	2.1±1.0	2.7±1,9
4 GeV	11.5±0.5	11.0±0.5	10.0±0.5	12.7±0.5	14.4±0.5	12.5±0.5	9.0±1.2	9.1±1.2	8.3±1.2
5 GeV	11.1±0.5	10.6±0.5	10.8±0.5	9.6±1.0	9.9±0.9	10.2±0.9	11.3±3.1	11.8±3.2	12.1±3.2
6 GeV	11.7±0.5	11.2±0.4	10.7±0.4	8.5±0.9	8.5±0.8	8.7±0.8	9.7±3.2	8.9±3.5	8.8±3.5
7 GeV	11.8±0.5	12.2±0.5	11.7±0.5	8.9±0.7	10.3±0.7	11.2±0,7	6.0±2.9	6.1±2.8	8.3±2.8
8 GeV	17.9±0.6	17.4±0.6	18.3±0.6	13.6±0.7	14.3±0.7	16.9±0.7	6.8±6.0	4.0±1.0	6.5±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 Genat4)
  - The mean level of disagreement vary between 8% 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 8% and 17% 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

Summary

- The two reference releases of 10.5 of Geant4 have been tested with a newer VecGeom version (V.1.1.0) for CMS data
- Physics performance of the new versions as well as from 10.4.p03 does not make any significant change to the physics predictions
- The new reference version is similar in performance as the earlier version (Geant4.10.4) which is used by CMS in its productions

Additional Slides