Tests of Geant4.10.5 Candidate Versions

Geant4 Hadronic Group Meeting
December 12, 2018

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New Geant4 Version

- Geant4 came up with candidate versions 10.5.cand01 and 10.5.cand02 in quick successions during November following the reference release 10.4.ref09 version in October. Finally Geant4.10.5 was released by December 6.

- These versions are studied after integrating them with VecGeom library
  - They require newer versions of VecGeom library
    - Both the candidate Geant4.10.5 versions as well as the final ref00 version require v1.1 of VecGeom

- Thin target comparison is done by making specific builds for all 3 versions (no VecGeom build) and compared the predictions with BNL and MIPP data

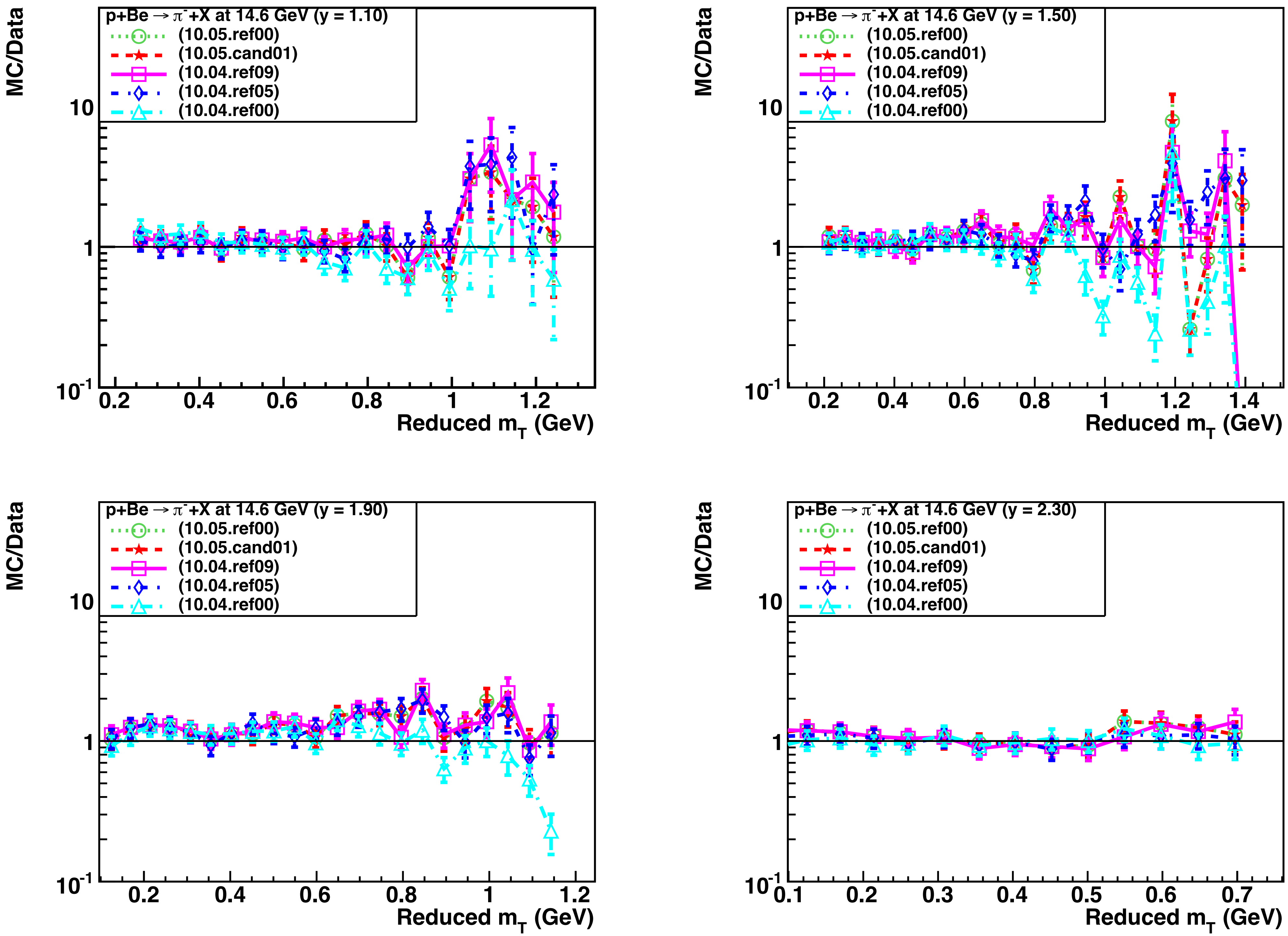
- These new versions are tested in special CMSSW builds based on version 10_2_3 for comparison with collision and test beam data of CMS

- Please note that these versions give large number of warning statements from the track propagation in B-field as noticed first with Geant4 version 10.4.ref07

Comparison with BNL Data

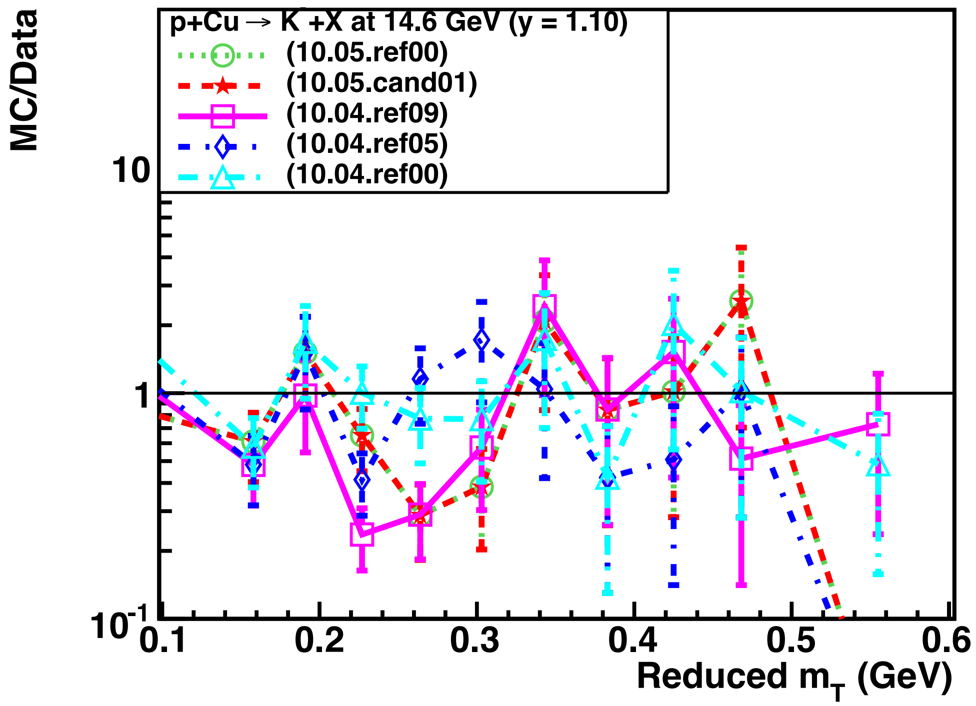
- Data set from BNL E802: (T. Abbott *et al.*, Phys. Rev. D45, 3906)
  - Inclusive $\pi^{\pm}$, $K^{\pm}$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets
  - Quantities measured are Lorentz invariant differential cross sections as a function of transverse mass (m_T) in 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.ref05, 10.4.ref09, 10.5.cand01, 10.5.ref00

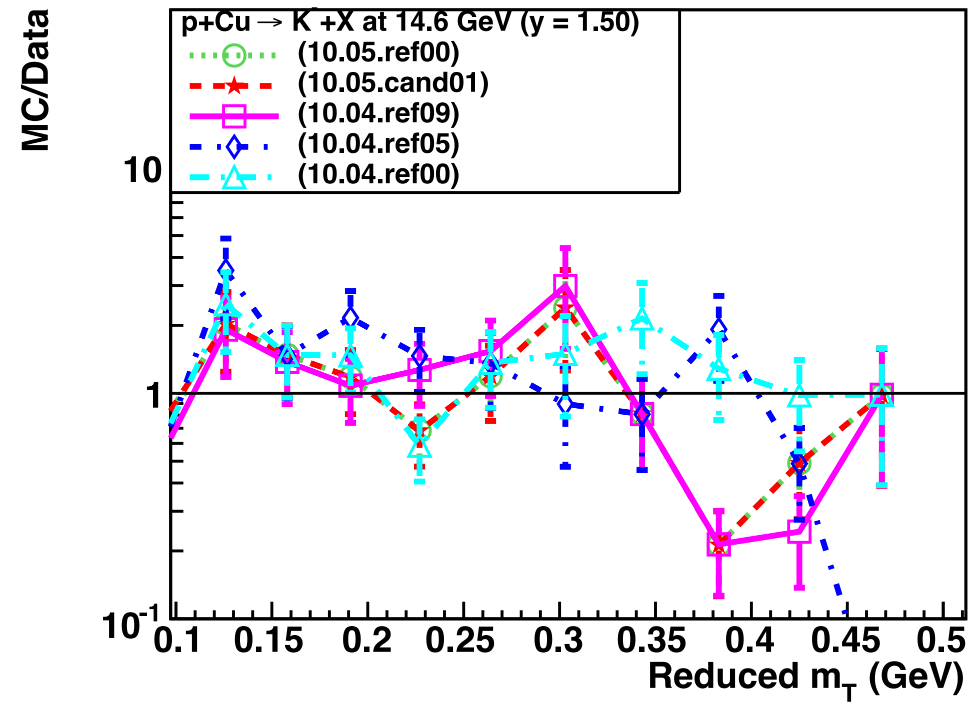
p + Be →π + X at 14.6 GeV/c (FTFP)

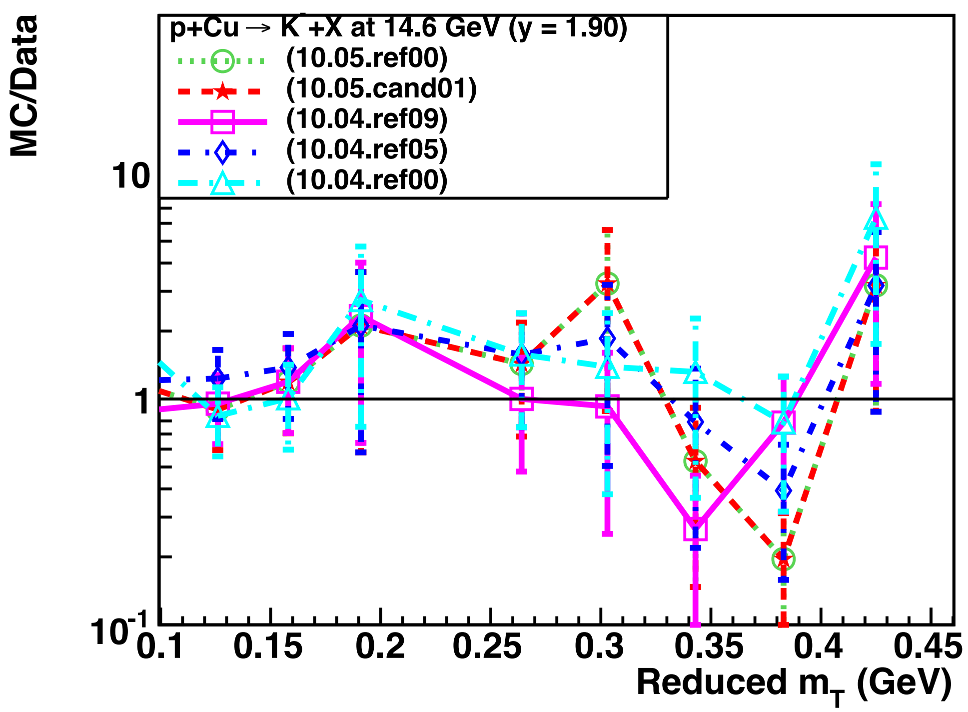


- There is some significant improvement in the predictions of the FTFP model from 10.3.ref09 to 10.4.ref00. Predictions are stable and slightly better in the recent versions in the very forward/backward directions and worse elsewhere.

p + Cu →K⁻ + X at 14.6 GeV/c (FTFP)

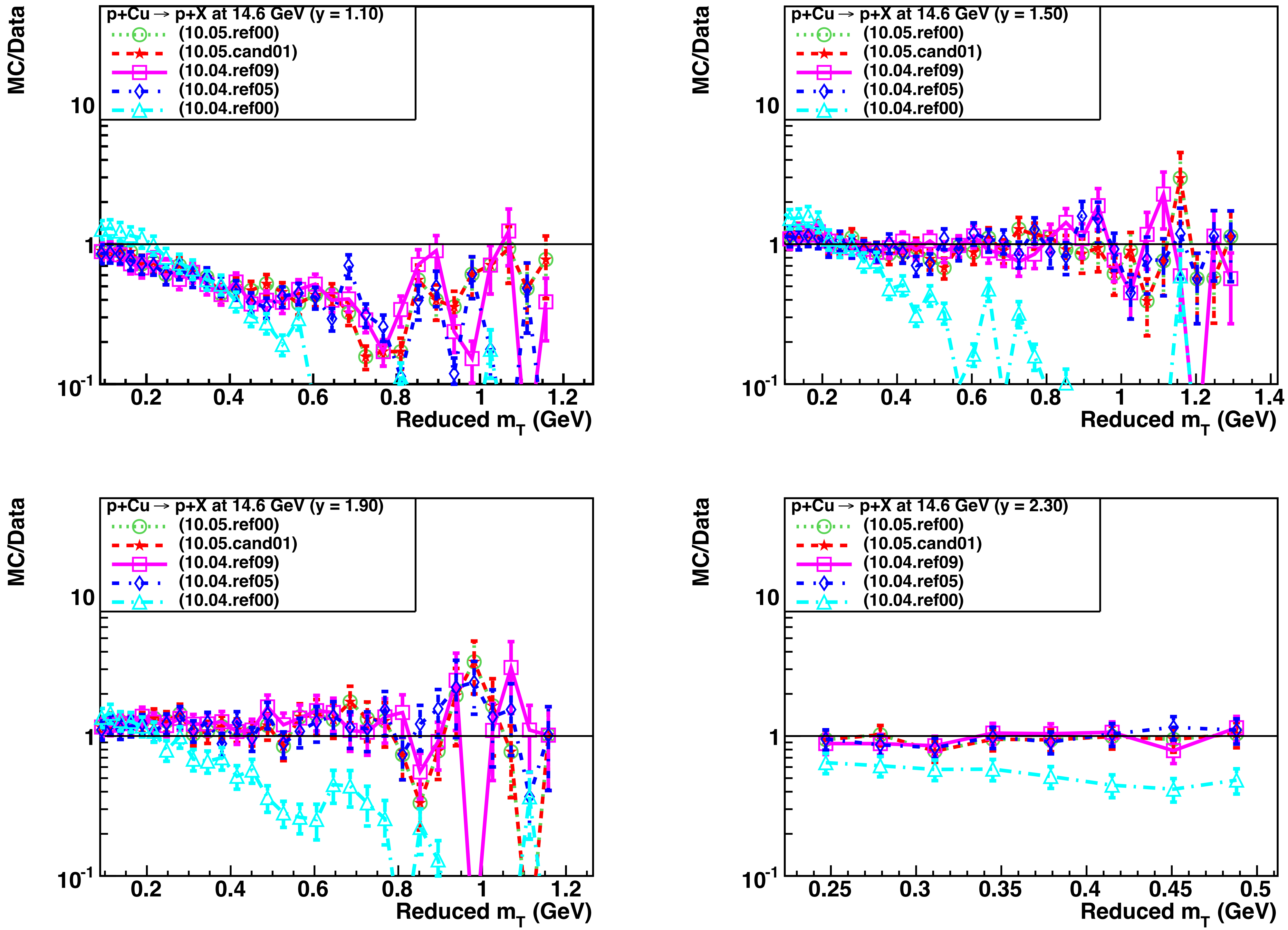






- All versions provide similar level of agreement for K^- production. All are better than 10.3.ref09

p + Cu → p + X at 14.6 GeV/c (FTFP)



- The version 10.4.ref00 provides the worst agreement for p production. 10.5.ref00 provides reasonable description of the data

ChiSq/Data for Final State Pions (FTFP)

- Using a flat systematic uncertainty for all measurements:

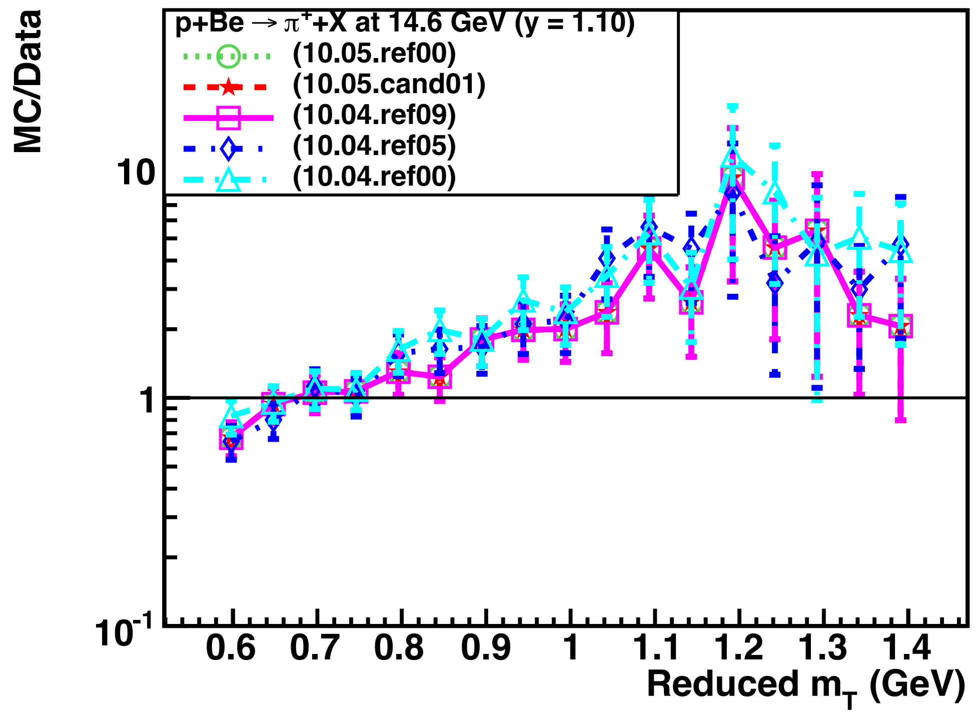
	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Be π^+ (1.1)	1.45	2.53	1.76	0.87	0.87
Be π^+ (1.5)	1.44	6.52	4.49	4.77	4.77
Be π^+ (1.9)	0.85	3.28	2.84	4.53	4.53
Be π^+ (2.3)	1.13	0.93	0.71	0.77	0.77
Be π^- (1.1)	1.24	4.56	4.88	2.53	2.53
Be π^- (1.5)	3.28	4.30	4.70	8.70	8.70
Be π^- (1.9)	1.62	4.13	5.41	4.69	4.69
Be π^- (2.3)	0.23	0.38	0.95	1.06	1.06
Au π^+ (1.1)	0.77	2.29	2.39	5.71	5.71
Au π^+ (1.5)	2.22	4.03	6.55	8.06	8.06
Au π^+ (1.9)	2.62	3.02	3.72	3.68	3.68
Au π^+ (2.3)	1.33	2.04	3.15	2.94	2.94
Au π^- (1.1)	2.27	3.58	4.62	5.08	5.08
Au π^- (1.5)	2.89	8.17	8.58	8.63	8.63
Au π^- (1.9)	1.84	8.41	10.86	9.26	9.26
Au π^- (2.3)	1.42	7.01	8.78	8.35	8.35

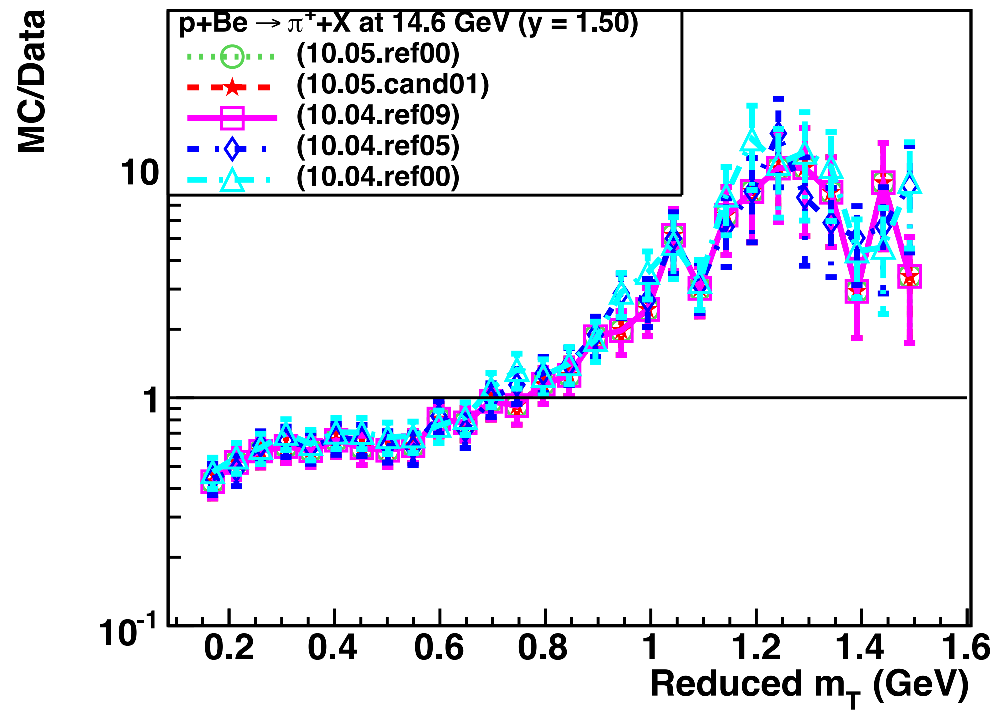
ChiSq/Data for Copper Target (FTFP)

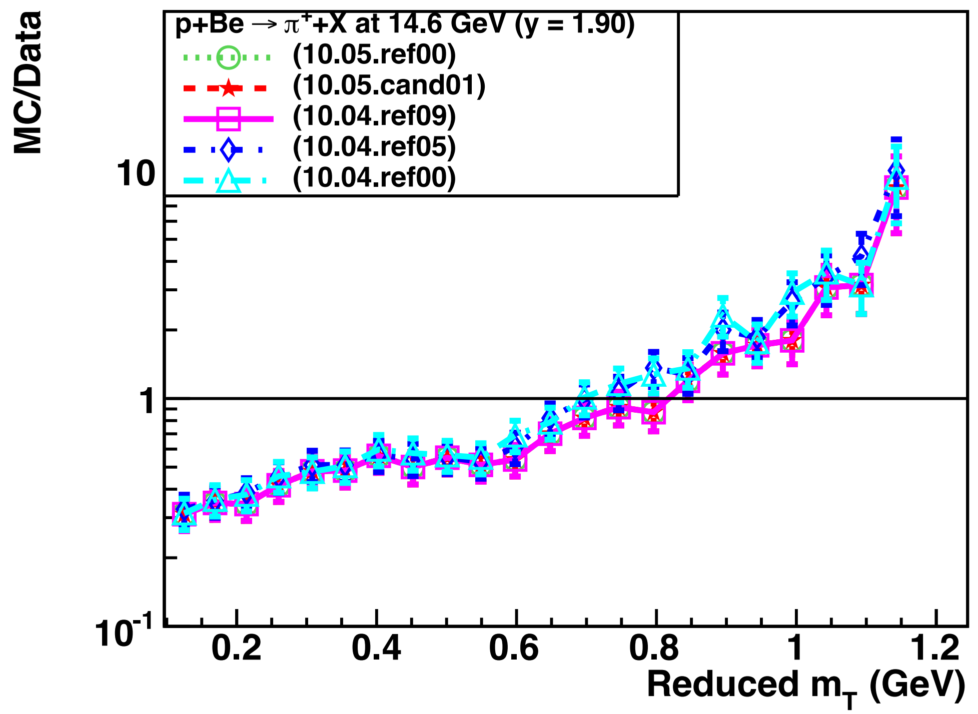
- Using a flat systematic uncertainty for all measurements:

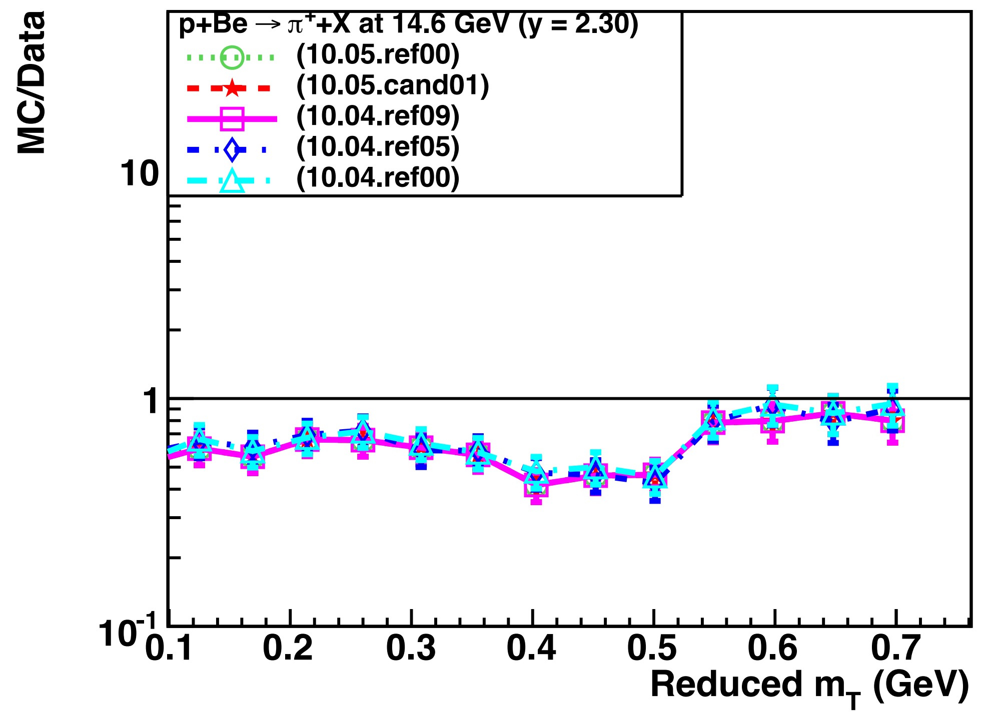
	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Cu K^+ (1.1)	2.85	2.88	4.48	4.46	4.46
Cu K^+ (1.5)	2.00	1.82	4.20	4.81	4.81
Cu K^+ (1.9)	1.49	2.30	3.93	3.30	3.30
Cu K^- (1.1)	1.29	1.17	1.83	1.73	1.73
Cu K^- (1.5)	2.65	5.84	2.63	1.93	1.93
Cu K^- (1.9)	6.47	1.67	2.62	2.42	2.42
Cu p (1.1)	10.43	5.91	5.55	5.28	5.28
Cu p (1.5)	12.87	0.95	1.36	1.43	1.43
Cu p (1.9)	4.29	1.62	2.31	2.82	2.82
Cu p (2.3)	6.29	0.35	0.44	0.25	0.25

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



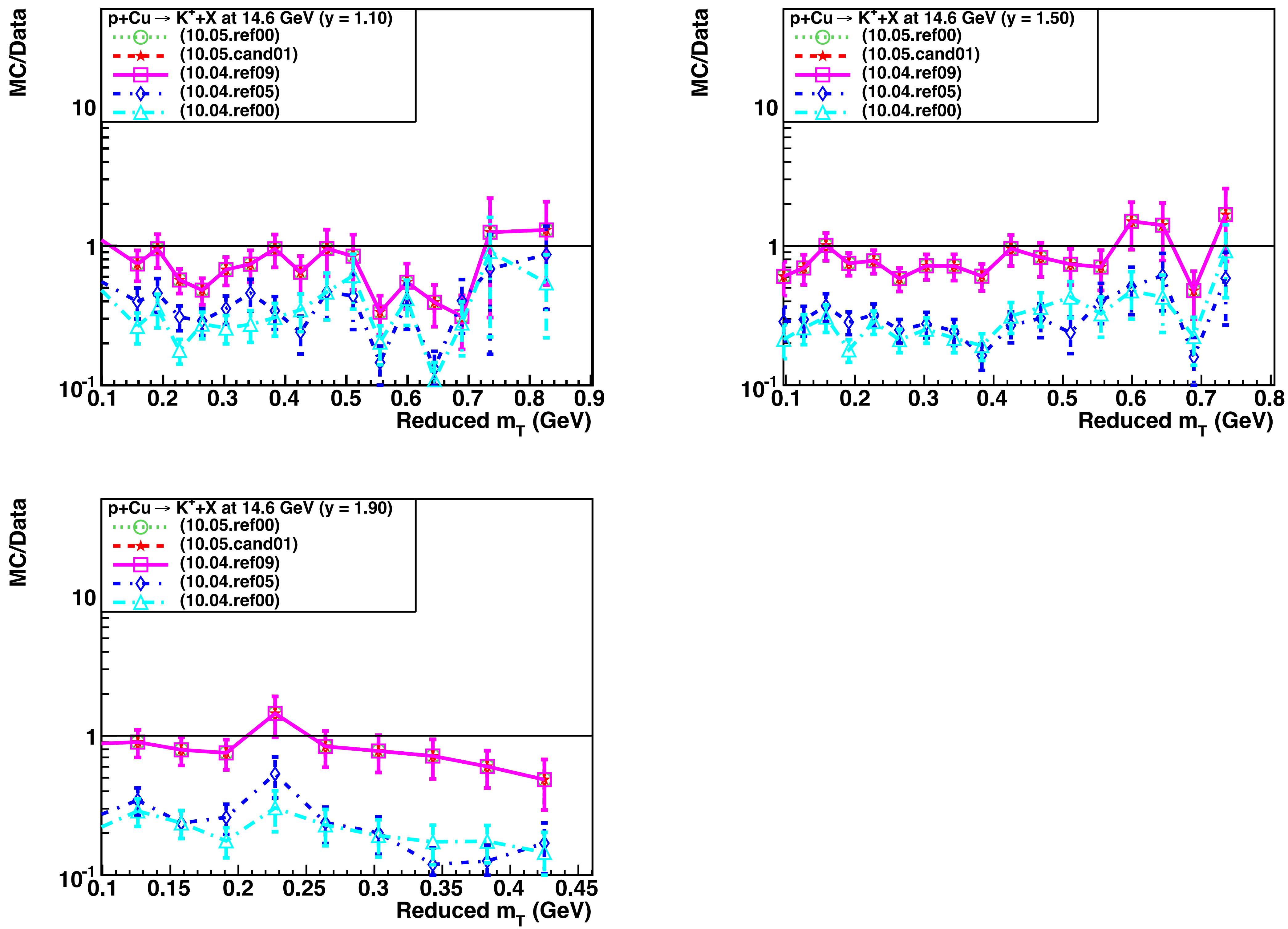






- Not much difference in the model predictions (all are bad).

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



- Versions 10.4.ref09 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:

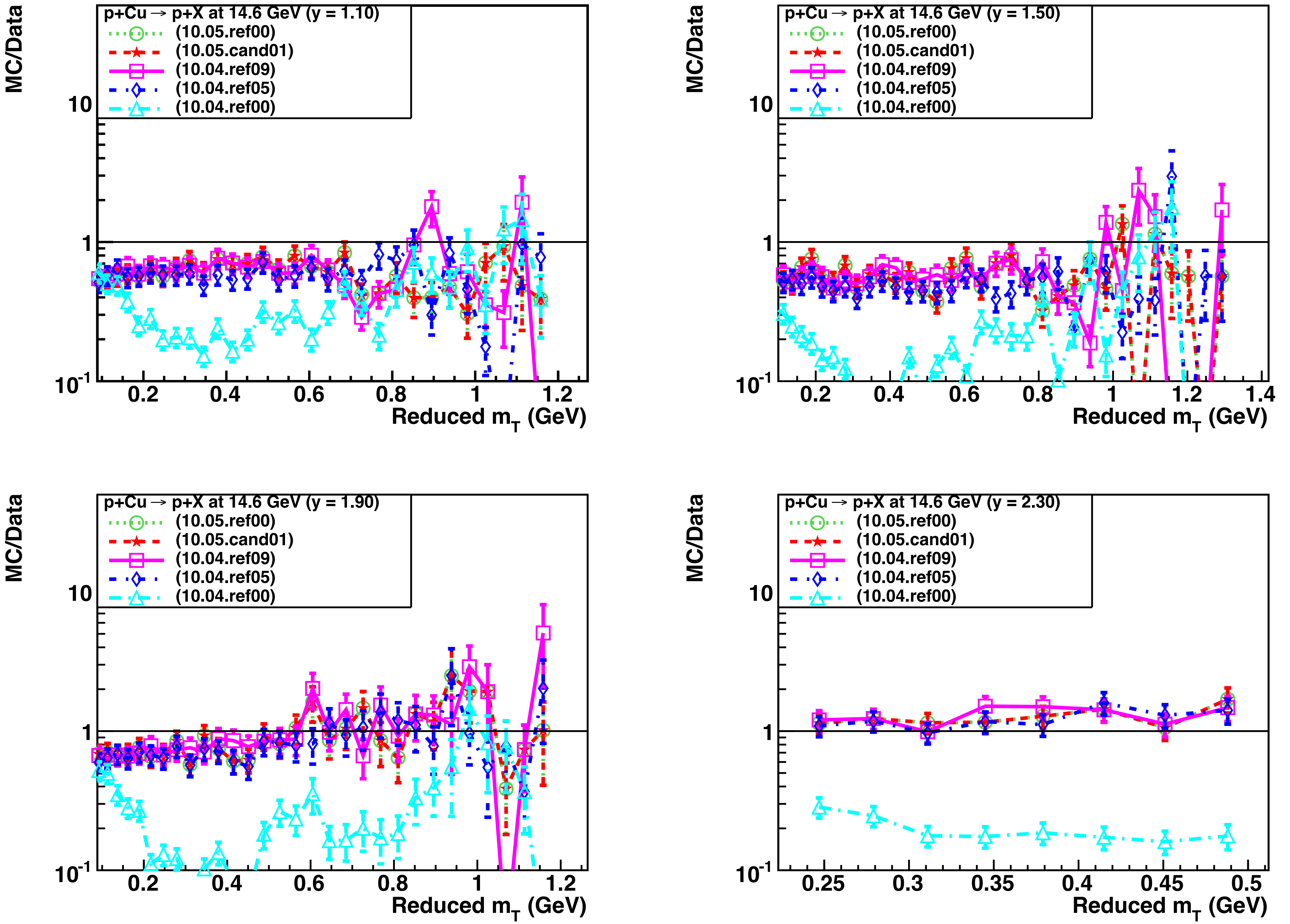
	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Be π^+ (1.1)	46.40	32.12	22.78	22.78	22.78
Be π^+ (1.5)	132.94	95.82	82.69	82.69	82.69
Be π^+ (1.9)	41.95	47.77	31.69	31.69	31.69
Be π^+ (2.3)	4.57	4.78	5.50	5.50	5.50
Be π^- (1.1)	546.63	484.55	442.89	442.89	442.89
Be π^- (1.5)	661.29	615.24	553.76	553.76	553.76
Be π^- (1.9)	228.01	213.80	178.50	178.50	178.50
Be π^- (2.3)	9.09	9.39	7.06	7.06	7.06
Au π^+ (1.1)	29.44	6.99	14.18	14.18	14.18
Au π^+ (1.5)	57.03	22.69	37.74	37.74	37.74
Au π^+ (1.9)	16.87	9.17	11.30	11.30	11.30
Au π^+ (2.3)	3.86	6.27	5.37	5.37	5.37
Au π^- (1.1)	122.54	86.25	133.07	133.07	133.07
Au π^- (1.5)	130.32	114.02	108.95	108.95	108.95
Au π^- (1.9)	97.55	120.56	118.41	118.41	118.41
Au π^- (2.3)	3.50	4.98	4.20	4.20	4.20

ChiSq/Data for Copper Target (Bertini)

- Using a flat systematic uncertainty for all measurements:

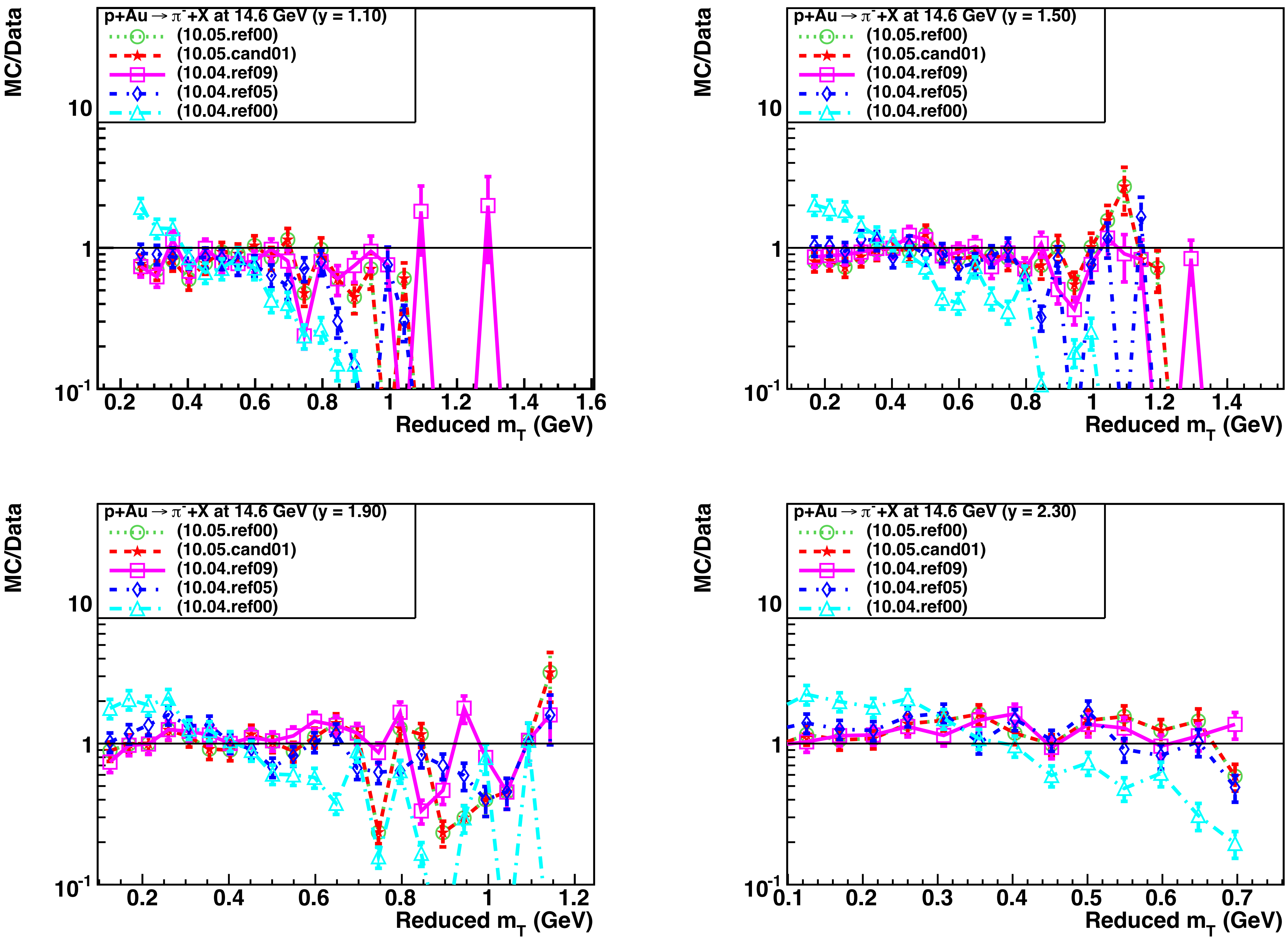
	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Cu K^+ (1.1)	5.53	4.69	1.62	1.62	1.62
Cu K^+ (1.5)	7.59	7.18	1.29	1.29	1.29
Cu K^+ (1.9)	8.53	7.88	0.88	0.88	0.88
Cu K^- (1.1)	1.90	2.15	1.55	1.55	1.55
Cu K^- (1.5)	2.61	2.51	1.28	1.28	1.28
Cu K^- (1.9)	2.84	2.79	2.28	2.28	2.28
Cu p (1.1)	54.34	68.07	56.52	56.52	56.52
Cu p (1.5)	161.65	181.52	156.12	156.12	156.12
Cu p (1.9)	126.31	148.37	120.87	120.87	120.87
Cu p (2.3)	1.61	1.36	1.43	1.43	1.43

p + Cu → p + X at 14.6 GeV/c (QGSP)



- Predictions from the version 10.4.ref00 provide the worst agreement. 10.5.ref00 provides 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 (better than in 10.5.ref00)

ChiSq/Data for Final State Pions (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Be π^+ (1.1)	7.30	2.33	1.25	0.71	0.71
Be π^+ (1.5)	7.21	1.81	1.30	1.30	1.30
Be π^+ (1.9)	8.88	2.36	2.49	1.83	1.83
Be π^+ (2.3)	6.28	2.04	2.04	2.11	2.11
Be π^- (1.1)	5.63	2.81	2.25	2.54	2.54
Be π^- (1.5)	7.49	3.20	2.63	2.38	2.38
Be π^- (1.9)	6.32	1.85	1.15	1.74	1.74
Be π^- (2.3)	3.19	0.42	1.40	1.43	1.43
Au π^+ (1.1)	8.35	3.38	2.11	1.75	1.75
Au π^+ (1.5)	13.40	3.22	3.04	1.73	1.73
Au π^+ (1.9)	16.33	3.17	2.43	0.95	0.95
Au π^+ (2.3)	30.40	1.35	0.92	1.19	1.19
Au π^- (1.1)	8.60	2.82	2.33	2.06	2.06
Au π^- (1.5)	11.52	1.41	1.11	2.07	2.07
Au π^- (1.9)	11.93	2.95	3.23	4.50	4.50
Au π^- (2.3)	15.87	4.59	2.46	3.47	3.47

ChiSq/Data for Copper Target (QGSP)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
Cu K^+ (1.1)	4.34	6.33	4.90	5.02	5.02
Cu K^+ (1.5)	4.62	4.51	4.30	3.83	3.83
Cu K^+ (1.9)	3.32	4.01	2.70	3.31	3.31
Cu K^- (1.1)	3.59	1.82	1.30	1.53	1.53
Cu K^- (1.5)	6.13	2.38	1.88	2.58	2.58
Cu K^- (1.9)	0.82	0.78	1.31	0.71	0.71
Cu p (1.1)	11.20	5.01	4.88	4.48	4.48
Cu p (1.5)	16.32	6.94	5.42	5.04	5.04
Cu p (1.9)	11.82	2.22	4.30	2.18	2.18
Cu p (2.3)	18.74	2.28	3.57	2.79	2.79

ChiSq/Data for Final State Pions

- Compiling for the 3 models in Geant4.10.5:

	FTFP	QGSP	Bertini
Be π^+ (1.1)	0.87	0.71	22.78
Be π^+ (1.5)	4.77	1.30	82.69
Be π^+ (1.9)	4.53	1.83	31.69
Be π^+ (2.3)	0.77	2.11	5.50
Be π^- (1.1)	2.53	2.54	442.89
Be π^- (1.5)	8.70	2.38	553.76
Be π^- (1.9)	4.69	1.74	178.50
Be π^- (2.3)	1.06	1.43	7.06
Au π^+ (1.1)	5.71	1.75	14.18
Au π^+ (1.5)	8.06	1.73	37.74
Au π^+ (1.9)	3.68	0.95	11.30
Au π^+ (2.3)	2.94	1.19	5.37
Au π^- (1.1)	5.08	2.06	133.07
Au π^- (1.5)	8.63	2.07	108.95
Au π^- (1.9)	9.26	4.50	118.41
Au π^- (2.3)	8.35	3.47	4.20

ChiSq/Data for Copper Target

- Compiling for the 3 models in Geant4.10.5:

	FTFP	QGSP	Bertini
Cu K^+ (1.1)	4.46	5.02	1.62
Cu K^+ (1.5)	4.81	3.82	1.29
Cu K^+ (1.9)	3.30	3.31	0.88
Cu K^- (1.1)	1.73	1.53	1.55
Cu K^- (1.5)	1.93	2.58	1.28
Cu K^- (1.9)	2.42	0.71	2.28
Cu p (1.1)	5.28	4.48	56.52
Cu p (1.5)	1.43	5.04	156.12
Cu p (1.9)	2.82	2.18	120.87
Cu p (2.3)	0.25	2.79	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.ref05, 10.4.ref09, 10.5.cand01, 10.5.ref00

ChiSq/Data for 8 different processes

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

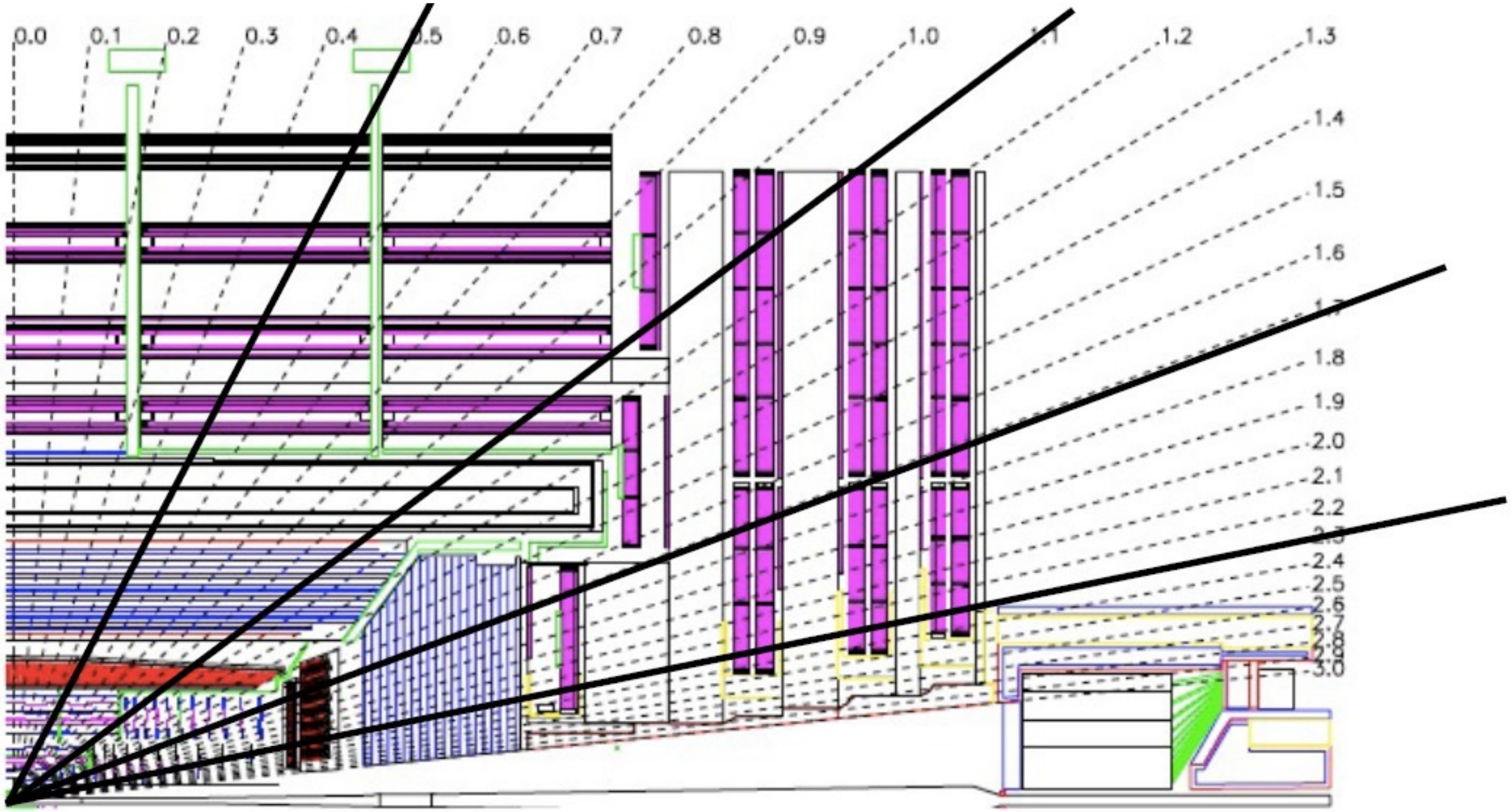
	10.4.ref00	10.4.ref05	10.4.ref09	10.5.cand01	10.5.ref00
			FTFP		
p+H (56.8)	2.73	6.47	12.11	12.11	12.11
p+C (56.8)	4.31	11.83	11.99	11.90	11.90
p+Bi (56.8)	1.92	2.85	2.80	2.68	2.68
p+U (57.3)	1.85	2.94	2.90	3.30	3.30
p+H (82.6)	4.26	7.16	17.81	17.81	17.81
p+Be	11.15	4.99	4.87	4.85	4.85
p+C (120.0)	10.03	27.72	27.64	28.06	28.06
p+Bi (120.0)	3.64	8.19	8.40	4.64	4.64
			QGSP		
p+H (56.8)	5.13	2.10	10.70	10.79	10.79
p+C (56.8)	3.03	3.29	3.36	3.36	3.36
p+Bi (56.8)	6.32	5.15	4.67	4.74	4.74
p+U (57.3)	11.30	10.65	9.62	9.88	9.88
p+H (82.6)	2.34	2.16	16.22	16.30	16.30
p+Be	4.98	16.92	12.95	13.07	13.07
p+C (120.0)	5.33	10.59	8.11	8.29	8.29
p+Bi (120.0)	2.86	28.50	23.26	25.39	25.39

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

- The mean level of disagreement between data and different MC versions 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) till 10.4.ref09 - slightly restored in 10.5.cand01(2)

	10.2.p02	10.4.ref00	10.4.ref09	10.5.cand01	10.5.cand02
Barrel 1	(2.4±0.4)%	(5.7±0.4)%	(3.1±0.4)%	(3.7±0.4)%	(3.7±0.4)%
Barrel 2	(3.6±0.4)%	(4.0±0.4)%	(6.0±0.4)%	(5.4±0.4)%	(5.4±0.4)%
Transition	(4.9±0.5)%	(4.8±0.5)%	(6.4±0.5)%	(5.7±0.5)%	(5.7±0.5)%
Endcap	(3.1±0.3)%	(3.0±0.5)%	(4.9±0.5)%	(4.6±0.5)%	(4.6±0.5)%

Comparison for Large Matrix

- 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 the worst for the 10.4.ref09 version and the versions 10.5.cand01(2) are slightly better

	10.2.p02	10.4.ref00	10.4.ref09	10.5.cand01	10.5.cand02
Barrel 1	(2.6±0.4)%	(4.0±0.4)%	(2.1±0.4)%	(2.2±0.4)%	(2.2±0.4)%
Barrel 2	(2.2±0.4)%	(2.6±0.4)%	(4.5±0.4)%	(4.0±0.4)%	(4.0±0.4)%
Transition	(2.2±0.5)%	(2.9±0.5)%	(4.8±0.5)%	(4.3±0.5)%	(4.3±0.5)%
Endcap	(1.5±0.3)%	(1.5±0.5)%	(4.9±0.5)%	(4.7±0.5)%	(4.7±0.5)%

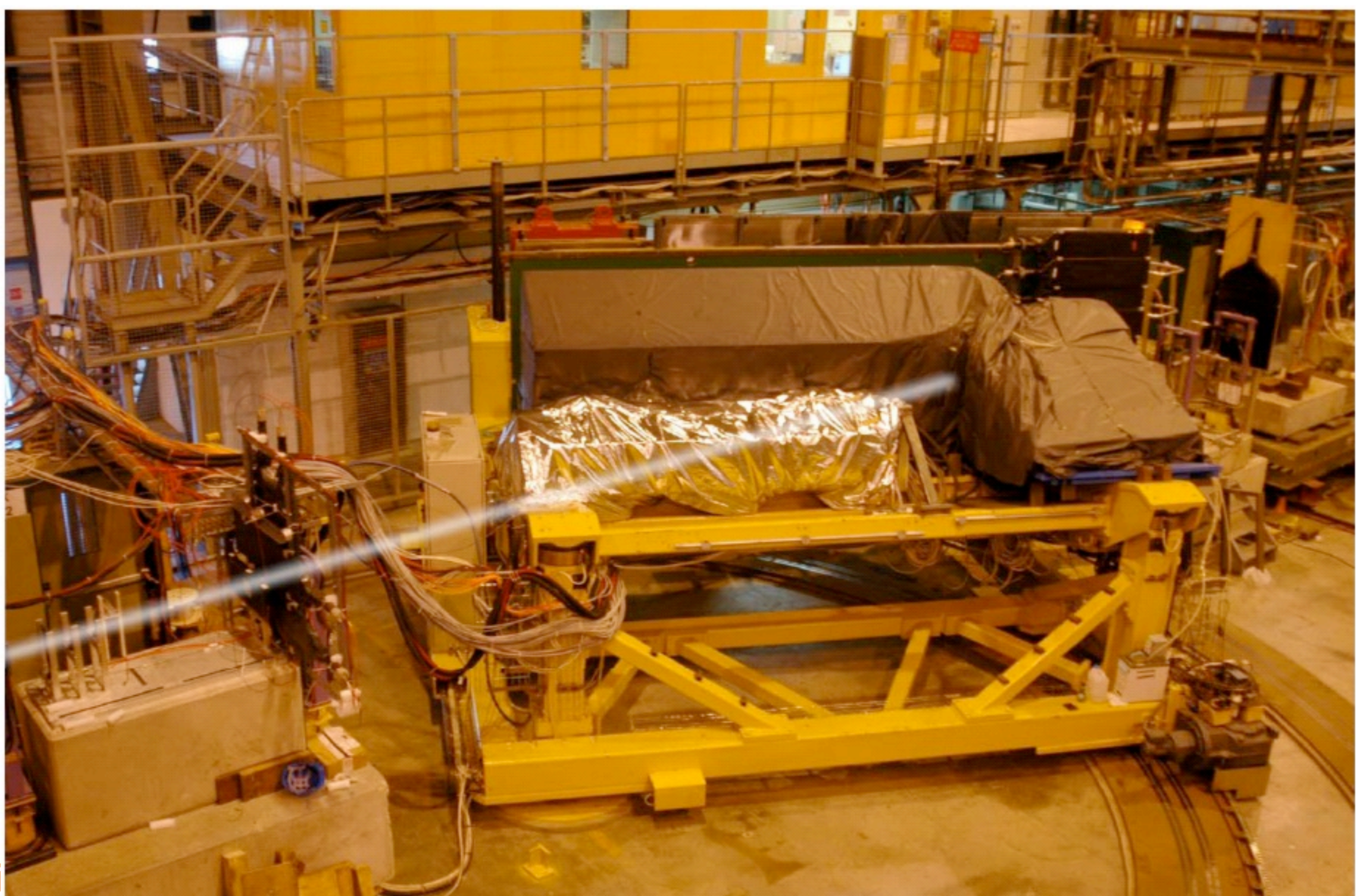
Comparison between 2 Physics Lists

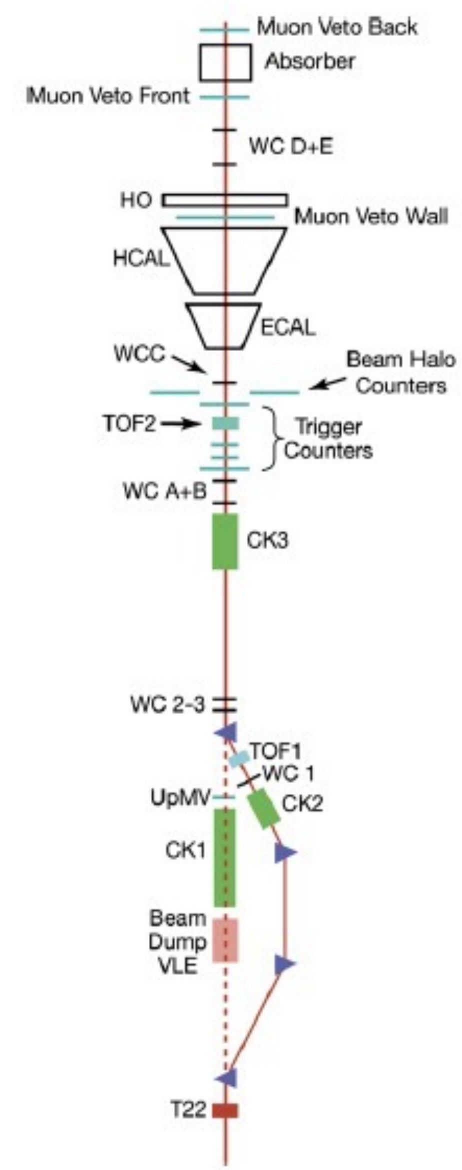
- The level of disagreement between data and MC is between 2.2% and 5.7% for FTFP_BERT_EMM and between 1.9% and 6.6% for the physics list QGSP_FTFP_BERT_EML with the "VecGeom" builds depending on the region of the detector.
- With the exception of transition region the physics list QGSP_FTFP_BERT_EML is performing better

	$(E_{7x7}+H_{3x3})/p$ 10.4.ref09 (FTFP)	$(E_{7x7}+H_{3x3})/p$ 10.4.ref09 (QGSP)	$(E_{11x11}+H_{5x5})/p$ 10.4.ref09 (FTFP)	$(E_{11x11}+H_{5x5})/p$ 10.4.ref09 (QGSP)
Barrel 1	(3.7±0.4)%	(2.7±0.4)%	(2.2±0.4)%	(1.9±0.4)%
Barrel 2	(5.4±0.4)%	(4.2±0.4)%	(4.0±0.4)%	(2.9±0.4)%
Transition	(5.7±0.5)%	(6.6±0.5)%	(4.3±0.5)%	(4.9±0.5)%
Endcap	(4.6±0.5)%	(4.2±0.5)%	(4.7±0.5)%	(4.1±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
  - $Evis = E_{ECAL}*f_{ECAL} + E_{HCAL}*f_{HCAL}$
  - $f_{ECAL} = 1.01$, $f_{HCAL} \sim 105$ (for FTFP_BERT_EMM Physics List)

Test Beam Data

Mean level of disagreement between MC and data

	π- 10.4	π- 10.4.ref9	π- 10.5.c01	π+ 10.4	π+ 10.4.ref9	π+ 10.5.c01	p 10.4	p 10.4.ref9	p 10.5.c01
2 GeV	9.4±0.9	11.7±0.9	11.8±0.9	13.4±1.2	11.7±1.2	12.0±1.2	8.1±2.5	6.9±0.3	7.4±0.3
3 GeV	12.2±0.6	9.1±0.6	8.0±0.6	10.0±1.7	10.3±1.7	9.1±1.7	3.1±1.0	2.9±1.0	2.2±1,9
4 GeV	11.8±0.5	14.3±0.5	14.1±0.5	14.8±0.5	12.0±0.5	13.1±0.5	9.6±1.2	12.3±1.2	12.5±1.2
5 GeV	10.8±0.5	10.7±0.5	10.7±0.5	9.7±1.0	10.9±0.9	10.6±0.9	13.4±3.1	13.1±3.2	13.0±3.2
6 GeV	10.4±0.5	11.6±0.4	11.7±0.4	8.2±0.9	12.2±0.8	12.5±0.8	9.4±3.2	5.9±3.5	6.2±3.5
7 GeV	12.3±0.5	14.5±0.5	14.4±0.5	10.6±0.7	14.2±0.7	13.7±0,7	8.0±2.9	11.0±2.8	9.6±2.8
8 GeV	17.8±0.6	17.3±0.6	17.4±0.6	14.2±0.7	17.1±0.7	15.4±0.7	6.1±6.0	5.2±1.0	6.7±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 17% 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 13% for moment between 2 GeV and 8 GeV

Summary

- The 10.5 candidate version of Geant4 has been tested with a newer VecGeom version (V.1.1.0) for CMS data
- Physics performance of the new versions does not make any significant change to the physics predictions
- The new versions have very large number of warning statements for tracking in B-field. The suggested changes reduce this but still the numbers are too large for production purpose.
- No longer finds killing of unstable particles like pions or kaons during tracking.
- The new version is as good as the earlier version (Geant4.10.4) which is used by CMS in its productions

Additional Slides

Performance Comparison

- The CPU and memory performance of CMSSW 10_2_3 with Geant4 versions with and without VecGeom:

	Change in CPU time VecGeom/Native	RSS (Native) (GB)	RSS (VecGeom) (GB)
50 GeV Muon	0.96	55.9	53.8
Muon (barrel)	0.96	55.0	53.5
Muon (endcap)	0.95	57.1	53.8
50 GeV Pion	0.97	56.0	56.5
Pion (barrel)	0.95	56.4	56.2
Pion (endcap)	0.90	56.0	56.2
50 GeV Electron	0.99	53.7	54.3
Electron (barrel)	0.98	52.9	53.4
Electron (endcap)	0.95	60.6	56.0
Minimum Bias	0.89	63.9	68.4
t-tbar	0.93	71.4	71.9

- VecGeom version shows better CPU performance with similar memory usage
- Tested with 3k events of single particle or minimum bias type and with 1.5 k t-tbar events

Warnings

- There are 2 types of messages which appear
  - More often one gets this message

```
*** G4Exception : GeomNav1002
      issued by : G4PropagatorInField::ComputeStep
 Unfinished integration of track (likely looping particle)
   of momentum (-13.3262,2.72214,132.395) ( magnitude = 133.092 )
 after 1000 field substeps  totaling 2930.79686268 mm  out of requested
   step 1000000 mm  a fraction of 0.2931 %
 in volume BeamVacuum11 with material Vacuum ( density = 1e-16 g / cm^3 )
 *** This is just a warning message. ***
-------- WWWW -------- G4Exception-END --------- WWWW -------
```

- Some of the thresholds during transportation (for reporting such messages) were relaxed by large factors

- The old thresholds are restored. This reduces the # of warnings by a factor of 4. But still there are a large number of warnings. Number of occurrences of these warnings are summarized

- The same configuration has been tried with two standard CMSSW versions using Geant4 version 10.4 + VecGeom version 00.05.00 within the releases 10_2_5_patch1 or 10_3_0_pre4. They show no warning messages.

Warnings of Type 1

- 3000 events were generated for single muon, pion, electron and minimum bias events and 1500 events for t-tbar events.

	10.5.cand01 (Native)	10.5.cand01 (VecGeom)	10.5.cand02 (VecGeom)
Muon	510	530	530
Muon (barrel)	227	286	286
Muon (endcap)	675	593	593
Pion	2194	2144	2144
Pion (barrel)	942	1053	1053
Pion (endcap)	2518	2519	2519
Electron	2523	2503	2503
Electron (barrel)	689	684	684
Electron (endcap)	4377	4547	4547
Minimum Bias	245 k	242 k	242 k
t-tbar	381 k	381 k	381 k

- The frequency does not depend on geometry type used within Geant4: Native/VecGeom
- Frequency is comparable to the last reference release

Second Type of Warning

- An example of the second type of warning:

```
*** G4Exception : Transport-001-ExcessSteps
      issued by : G4Transportation::AlongStepDoIt
 Transportation is killing track that is looping or stuck.
   Track is e+ and has 132.582 MeV energy  ( pre-Step = 132.582 )
   momentum = (-2.47961,-18.8804,131.723) mag= 133.092
   position = (36.934,22.1826,3481) is in volume 'BeamVacuum11',
   its material is 'Vacuum' with density = 9.99998e-17 g/cm^3
 Total number of Steps by this track: 13
 Length of this step = 2930.8 mm
 Number of propagation trials = 1 ( vs maximum = 10 for 'important' particles )
   ( Number of *calls* of Transport/AlongStepDoIt = 1971467 )
```

- Even high momentum used to be killed in some earlier reference versions
  - We no longer find evidence of such killed tracks in runs with similar statistics

Warnings of Type 2

- These warnings are less frequent than those of Type 1
- Please note that the native geant4 geometry versions using the same reference tag give warnings at similar rate

	10.5.cand01 (Native)	10.5.cand01 (VecGeom)	10.5.cand02 (VecGeom)
50 GeV Muon	0	0	0
Muon (barrel)	0	0	0
Muon (endcap)	0	1	1
50 GeV Pion	1	0	0
Pion (barrel)	0	0	0
Pion (endcap)	2	4	4
50 GeV Electron	1	1	1
Electron (barrel)	0	0	0
Electron (endcap)	1	2	2
Minimum Bias	1321	1319	1319
t-tbar	1778	1697	1697

Warnings of Type 2

- The second type of warning is associated with killing of the tracks. It is important to look into the properties of the tracks which are killed.
- Frequency of killing tracks is similar in the 10.5.cand01 and 10.5.cand02 versions
- Following characteristics are observed
  - The medium was always air or vacuum.
  - The tracks which are killed are electron or positrons of momentum around 100 MeV or slightly higher
  - Tracks of no other types are killed (unlike earlier reference releases)

	Native (Minbias)	VecGeom (Minbias)	Native (t-tbar)	VecGeom (t-tbar)
e^+	633	878	619	813
e^-	688	900	700	884
μ^+	0	0	0	0
μ^-	0	0	0	0
π^+	0	0	0	0
π^-	0	0	0	0
proton	0	0	0	0