Validation of Geant4 version 10.7

Geant4 Hadronic Group Meeting
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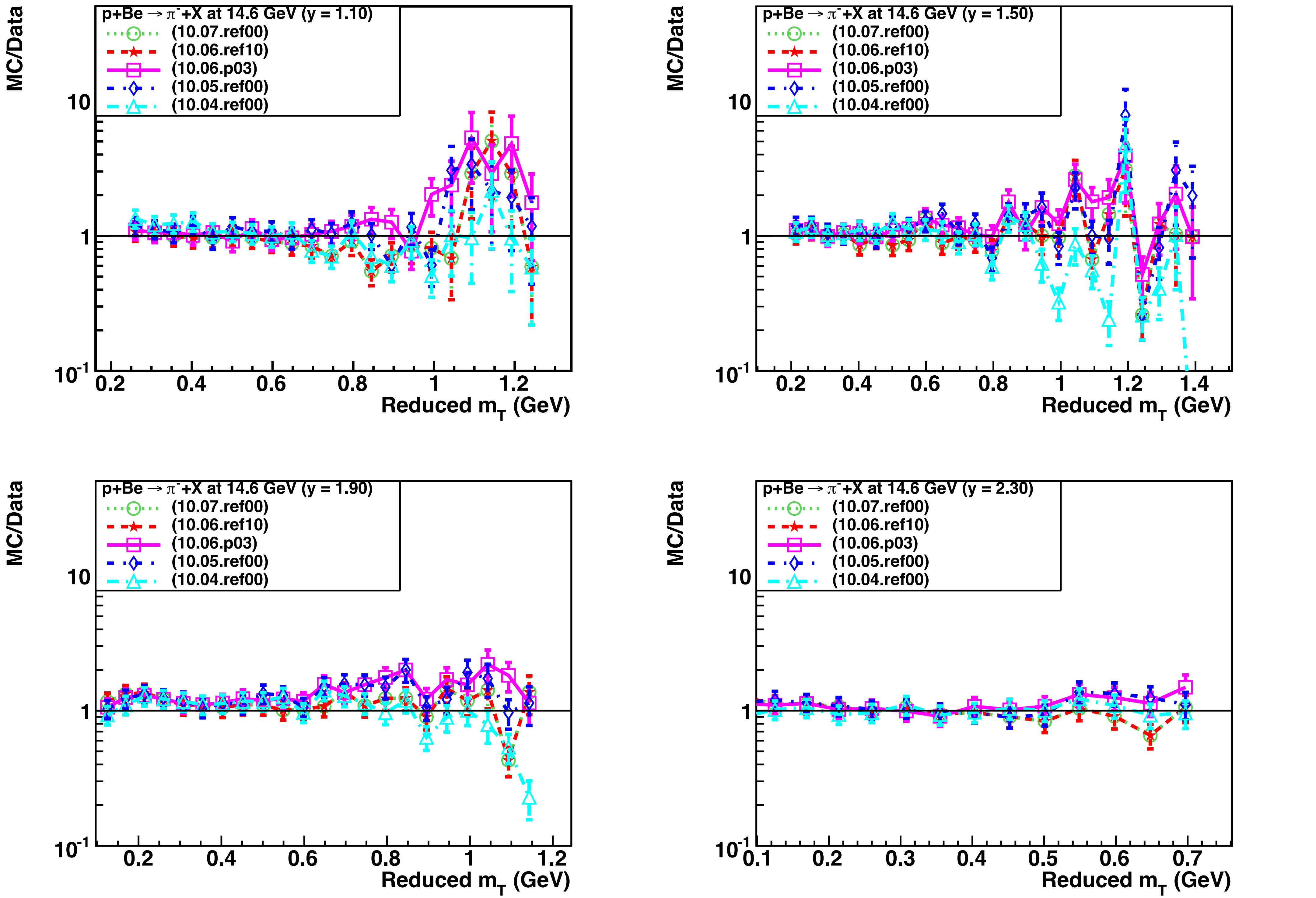
New Geant4 Version

- Geant4 released the version 10.7 during middle of December, 2020.
- CMS has integrated 10.6.p02 instead of 10.4.p03 with its production code and is planning to move to the version 10.7.
- 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
- Calorimeter data makes use of 2006 test beam at the CERN SPS facility and collision data from a low luminosity run in 2016
- CMSSW version 11_3_X is used for comparing with the CMS data for the new Geant4 version

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.p03, 10.6.ref10, 10.7.ref00

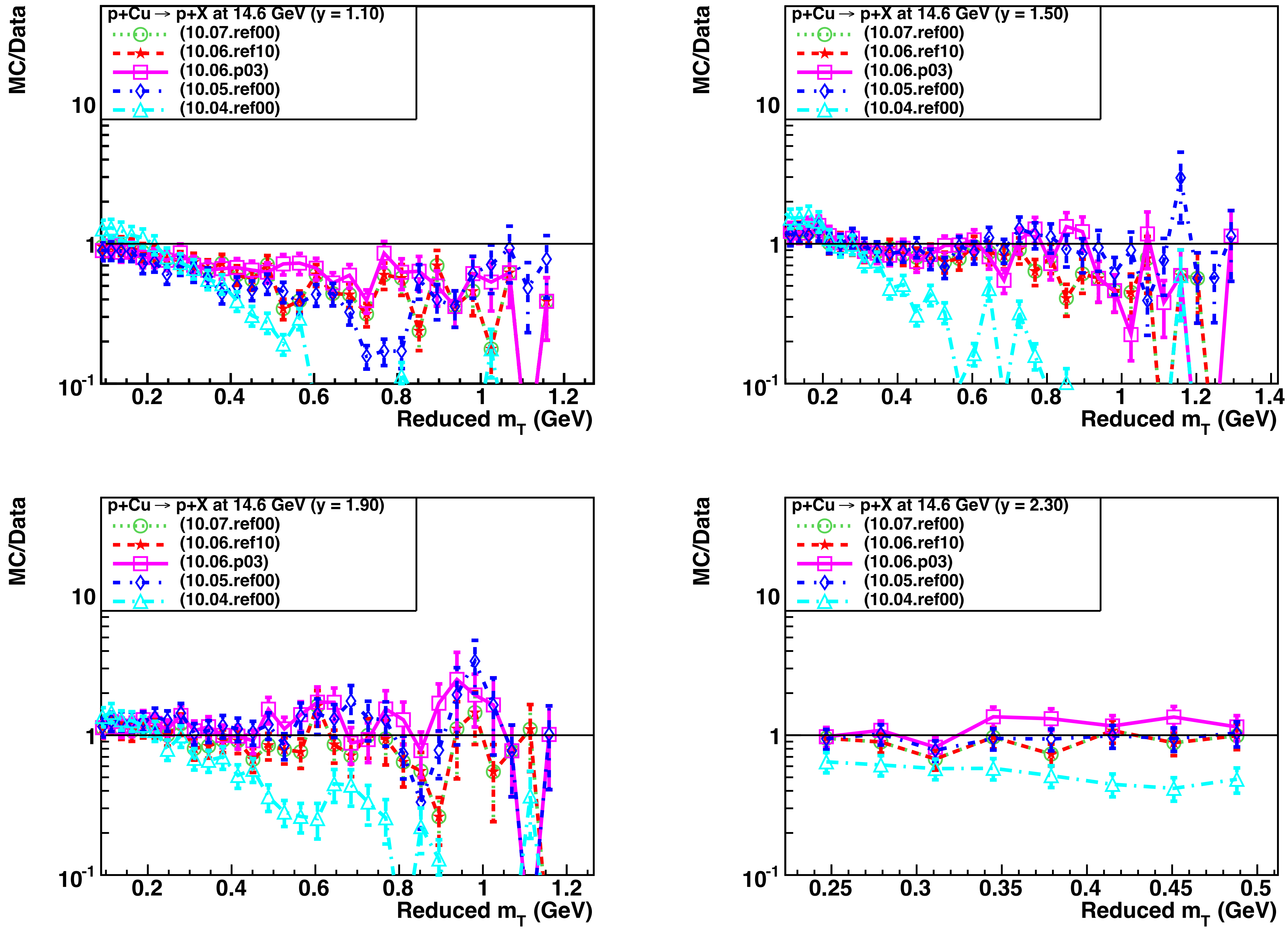
p + Be →π + X at 14.6 GeV/c (FTFP)



- The reference versions 10.5.ref00 and 10.6.p03 provide similar agreement with the data. The best agreements come from 10.4.ref00 and 10.7.ref00.

Geant 4

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 version 10.7.ref00 provides good 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	10.5.ref00	10.6.p03	10.6.ref10	10.7.ref00
Be π^+ (1.1)	1.45	0.87	1.34	1.21	1.06
Be π^+ (1.5)	1.44	4.77	4.66	8.76	1.60
Be π^+ (1.9)	0.85	4.53	2.97	2.52	1.28
Be π^+ (2.3)	1.13	0.77	1.08	0.86	1.65
Be π^- (1.1)	1.24	2.53	4.37	6.67	4.42
Be π^- (1.5)	3.28	8.70	2.12	4.05	1.81
Be π^- (1.9)	1.62	4.69	5.28	5.79	1.91
Be π^- (2.3)	0.23	1.06	0.99	0.97	1.01
Au π^+ (1.1)	0.77	5.71	2.13	1.74	2.04
Au π^+ (1.5)	2.22	8.06	3.05	3.01	3.85
Au π^+ (1.9)	2.62	3.68	3.17	2.66	2.56
Au π^+ (2.3)	1.33	2.94	3.06	2.76	5.25
Au π^- (1.1)	2.27	5.08	4.91	4.09	1.79
Au π^- (1.5)	2.89	8.63	7.42	7.14	2.27
Au π^- (1.9)	1.84	9.26	9.52	12.02	6.06
Au π^- (2.3)	1.42	8.35	7.40	7.26	12.59

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

ChiSq/Data for Copper Target (FTFP)

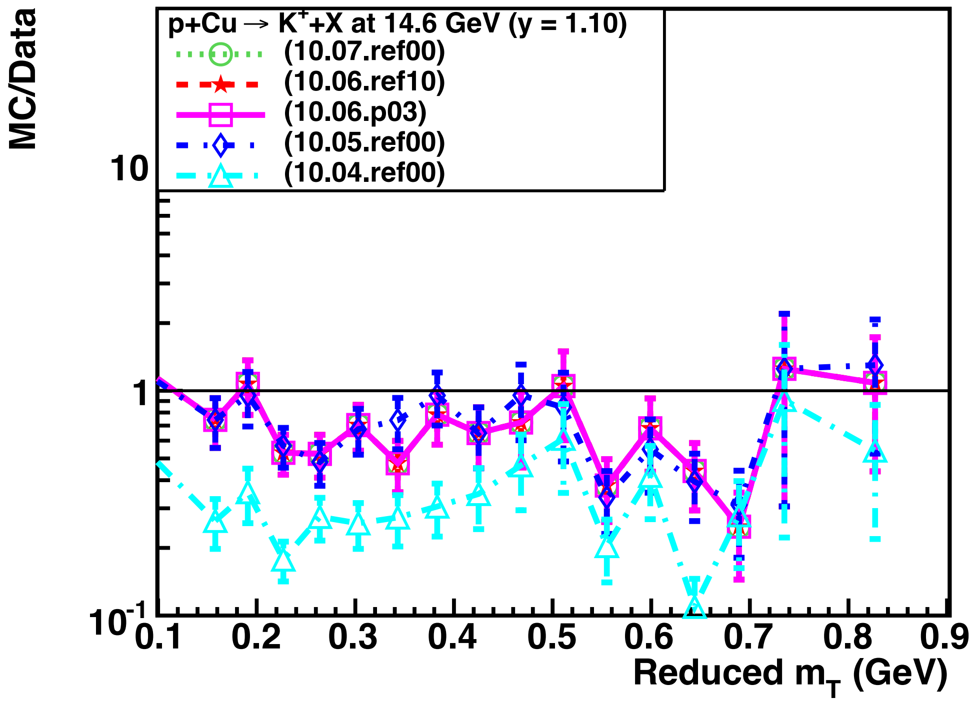
- Using a flat systematic uncertainty for all measurements:

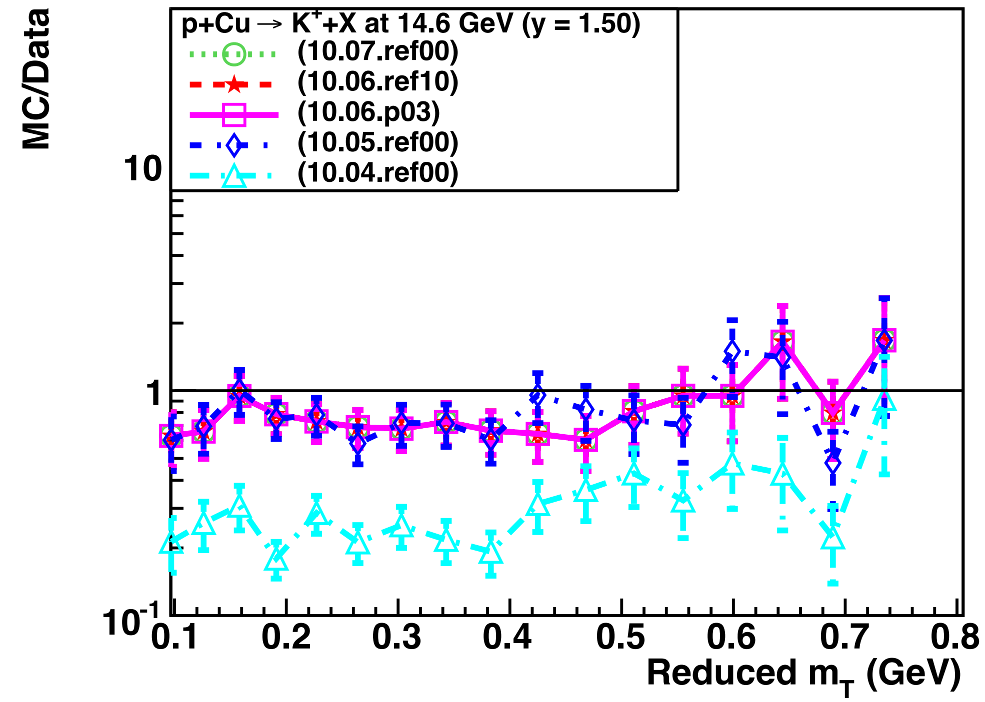
	10.4.ref00	10.5.ref00	10.6.p03	10.6.ref10	10.7.ref00
Cu K^+ (1.1)	2.85	4.46	5.27	5.44	6.69
Cu K^+ (1.5)	2.00	4.81	4.86	5.55	5.81
Cu K^+ (1.9)	1.49	3.30	2.88	3.79	4.04
Cu K^- (1.1)	1.29	1.73	1.57	1.40	2.01
Cu K^- (1.5)	2.65	1.93	1.44	2.25	1.10
Cu K^- (1.9)	6.47	2.42	0.73	1.46	0.98
Cu p (1.1)	10.43	5.28	3.22	2.49	3.10
Cu p (1.5)	12.87	1.43	1.69	1.69	1.88
Cu p (1.9)	4.29	2.82	3.82	2.00	1.01
Cu p (2.3)	6.29	0.25	1.69	1.54	0.93

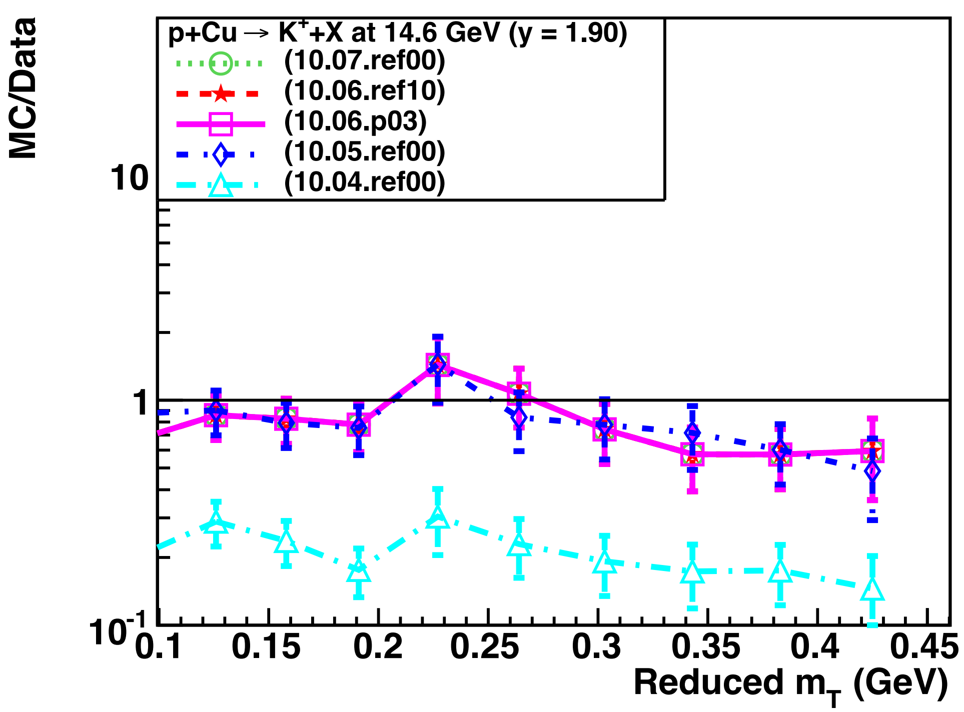
The first column refers to target/final state particle/mean rapidity value

Geant 4

$p + Cu \rightarrow K^+ + X$ at 14.6 GeV/c (Bertini)







- The new version provides the same level of agreement as 10.5.ref00. They provide better agreements 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.p03	10.6.ref10	10.7.ref00
Be π^+ (1.1)	46.40	22.79	23.70	28.73	28.73
Be π^+ (1.5)	132.94	82.69	81.59	85.50	85.50
Be π^+ (1.9)	41.95	31.69	29.24	24.56	24.56
Be π^+ (2.3)	4.57	5.50	5.65	5.48	5.48
Be π^- (1.1)	546.63	442.89	415.31	402.18	402.18
Be π^- (1.5)	661.29	553.76	485.78	541.02	541.02
Be π^- (1.9)	228.01	178.50	166.03	168.63	168.63
Be π^- (2.3)	9.09	7.06	6.71	6.87	6.87
Au π^+ (1.1)	29.44	14.18	15.01	16.34	16.34
Au π^+ (1.5)	57.03	37.74	39.58	40.32	40.32
Au π^+ (1.9)	16.87	11.30	8.47	14.95	14.95
Au π^+ (2.3)	3.86	5.37	5.30	5.00	5.00
Au π^- (1.1)	122.54	133.07	138.81	96.77	96.77
Au π^- (1.5)	130.32	108.95	111.15	141.29	141.29
Au π^- (1.9)	97.55	118.41	124.06	111.44	111.44
Au π^- (2.3)	3.50	4.20	4.31	3.73	3.72

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

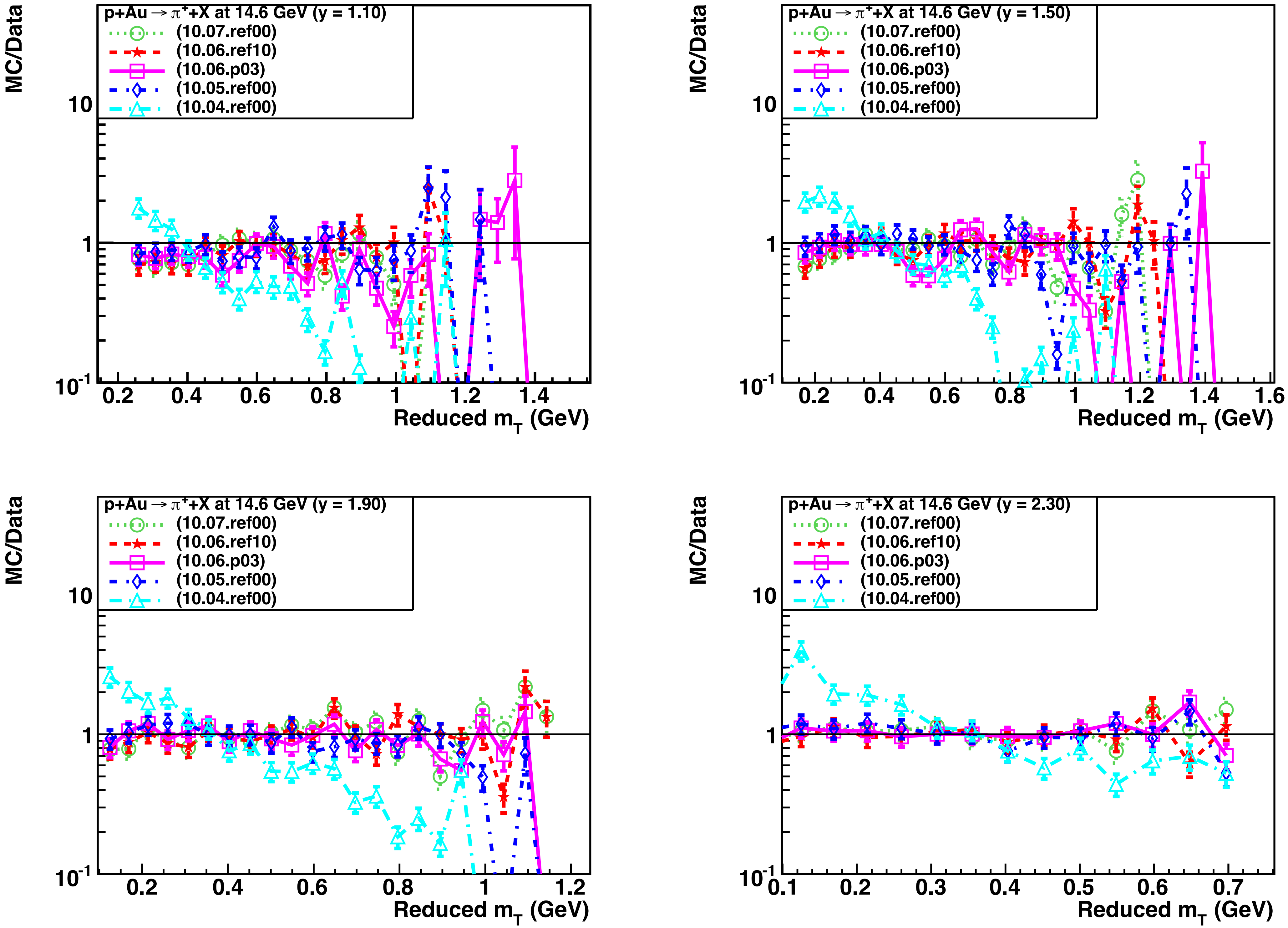
ChiSq/Data for Copper Target (Bertini)

- Using a flat systematic uncertainty for all measurements:

	10.4.ref00	10.5.ref00	10.6.p03	10.6.ref10	10.7.ref00
Cu K^+ (1.1)	5.53	1.62	1.62	1.75	1.75
Cu K^+ (1.5)	7.59	1.29	1.30	1.20	1.20
Cu K^+ (1.9)	8.53	0.88	0.86	1.06	1.06
Cu K^- (1.1)	1.90	1.55	1.55	1.36	1.36
Cu K^- (1.5)	2.61	1.28	1.21	1.51	1.51
Cu K^- (1.9)	2.84	2.28	2.29	2.47	2.47
Cu p (1.1)	54.34	56.52	56.81	58.68	58.68
Cu p (1.5)	161.65	156.12	155.86	140.76	140.76
Cu p (1.9)	126.31	120.87	122.89	106.42	106.42
Cu p (2.3)	1.61	1.43	1.44	1.60	1.60

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

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.p03	10.6.ref10	10.7.ref00
Be π^+ (1.1)	7.30	0.71	2.17	2.31	1.14
Be π^+ (1.5)	7.21	1.30	1.35	1.16	1.99
Be π^+ (1.9)	8.88	1.83	3.66	1.13	2.15
Be π^+ (2.3)	6.28	2.11	2.60	2.14	2.70
Be π^- (1.1)	5.63	2.54	4.15	3.41	4.11
Be π^- (1.5)	7.49	2.38	3.50	3.38	2.28
Be π^- (1.9)	6.32	1.74	2.18	1.52	2.42
Be π^- (2.3)	3.19	1.43	1.73	0.98	1.86
Au π^+ (1.1)	8.35	1.75	2.11	2.51	3.69
Au π^+ (1.5)	13.40	1.73	1.91	1.86	3.45
Au π^+ (1.9)	16.33	0.95	2.26	1.89	1.10
Au π^+ (2.3)	30.40	1.19	0.67	1.78	1.27
Au π^- (1.1)	8.60	2.06	2.76	2.32	3.44
Au π^- (1.5)	11.52	2.07	1.94	4.12	1.57
Au π^- (1.9)	11.93	4.50	2.99	4.06	3.52
Au π^- (2.3)	15.87	3.47	3.88	3.01	3.32

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	10.5.ref00	10.6.p03	10.6.ref10	10.7.ref00
Cu K^+ (1.1)	4.34	5.02	4.94	5.76	5.36
Cu K^+ (1.5)	4.62	3.83	4.46	4.72	5.40
Cu K^+ (1.9)	3.32	3.31	3.40	4.09	3.95
Cu K^- (1.1)	3.59	1.53	1.49	1.00	1.38
Cu K^- (1.5)	6.13	2.58	1.97	6.30	2.00
Cu K^- (1.9)	0.82	0.71	1.42	2.77	2.61
Cu p (1.1)	11.20	4.48	5.77	4.96	6.45
Cu p (1.5)	16.32	5.04	4.56	5.87	7.89
Cu p (1.9)	11.82	2.18	2.51	1.52	3.68
Cu p (2.3)	18.74	2.79	0.68	1.45	1.00

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

ChiSq/Data for Final State Pions

- Compiling for the 3 models in Geant4.10.7.ref00:

	FTFP	QGSP	Bertini
Be π^+ (1.1)	1.06	1.14	28.73
Be π^+ (1.5)	1.60	1.99	85.50
Be π^+ (1.9)	1.28	2.15	24.56
Be π^+ (2.3)	1.65	2.70	5.48
Be π^- (1.1)	4.42	4.11	402.18
Be π^- (1.5)	1.81	2.28	541.02
Be π^- (1.9)	1.91	2.42	168.63
Be π^- (2.3)	1.01	1.86	6.87
Au π^+ (1.1)	2.04	3.69	16.34
Au π^+ (1.5)	3.85	3.45	40.32
Au π^+ (1.9)	3.56	1.10	14.95
Au π^+ (2.3)	5.24	1.27	5.00
Au π^- (1.1)	1.79	3.44	96.77
Au π^- (1.5)	3.82	1.57	141.29
Au π^- (1.9)	6.06	3.52	111.44
Au π^- (2.3)	12.59	3.32	3.72

ChiSq/Data for Copper Target

- Compiling for the 3 models in Geant4.10.7.ref00:

	FTFP	QGSP	Bertini
Cu K^+ (1.1)	6.69	5.37	1.75
Cu K^+ (1.5)	5.81	5.40	1.20
Cu K^+ (1.9)	4.04	3.95	1.06
Cu K^- (1.1)	2.01	1.38	1.36
Cu K^- (1.5)	1.10	2.00	1.51
Cu K^- (1.9)	0.98	2.61	2.47
Cu p (1.1)	3.10	6.45	58.68
Cu p (1.5)	1.89	7.89	140.76
Cu p (1.9)	1.01	3.68	106.42
Cu p (2.3)	0.93	1.00	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.p03, 10.6.ref10, 10.7.ref00

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.p03	10.6.ref10	10.7.ref00
			FTFP		
p+H (56.8)	2.73	12.11	12.09	6.19	6.60
p+C (56.8)	4.31	11.90	11.89	11.65	10.42
p+Bi (56.8)	1.92	2.68	2.88	2.84	1.70
p+U (57.3)	1.85	3.30	3.62	3.39	2.13
p+H (82.6)	4.26	17.81	17.80	6.74	5.58
p+Be (120.0)	9.43	4.85	6.10	5.95	4.63
p+C (120.0)	8.45	28.06	27.04	28.01	27.27
p+Bi (120.0)	3.63	4.64	9.49	7.76	7.98
			QGSP		
p+H (56.8)	5.13	10.79	11.09	3.20	3.47
p+C (56.8)	3.03	3.36	3.68	4.34	5.89
p+Bi (56.8)	6.32	4.74	4.58	5.87	14.98
p+U (57.3)	11.30	9.88	9.59	11.67	33.43
p+H (82.6)	2.34	16.30	16.70	3.13	3.23
p+Be (120.0)	4.98	13.07	13.69	17.20	24.83
p+C (120.0)	5.33	8.29	8.45	11.17	17.92
p+Bi (120.0)	2.86	25.39	23.22	27.34	82.89

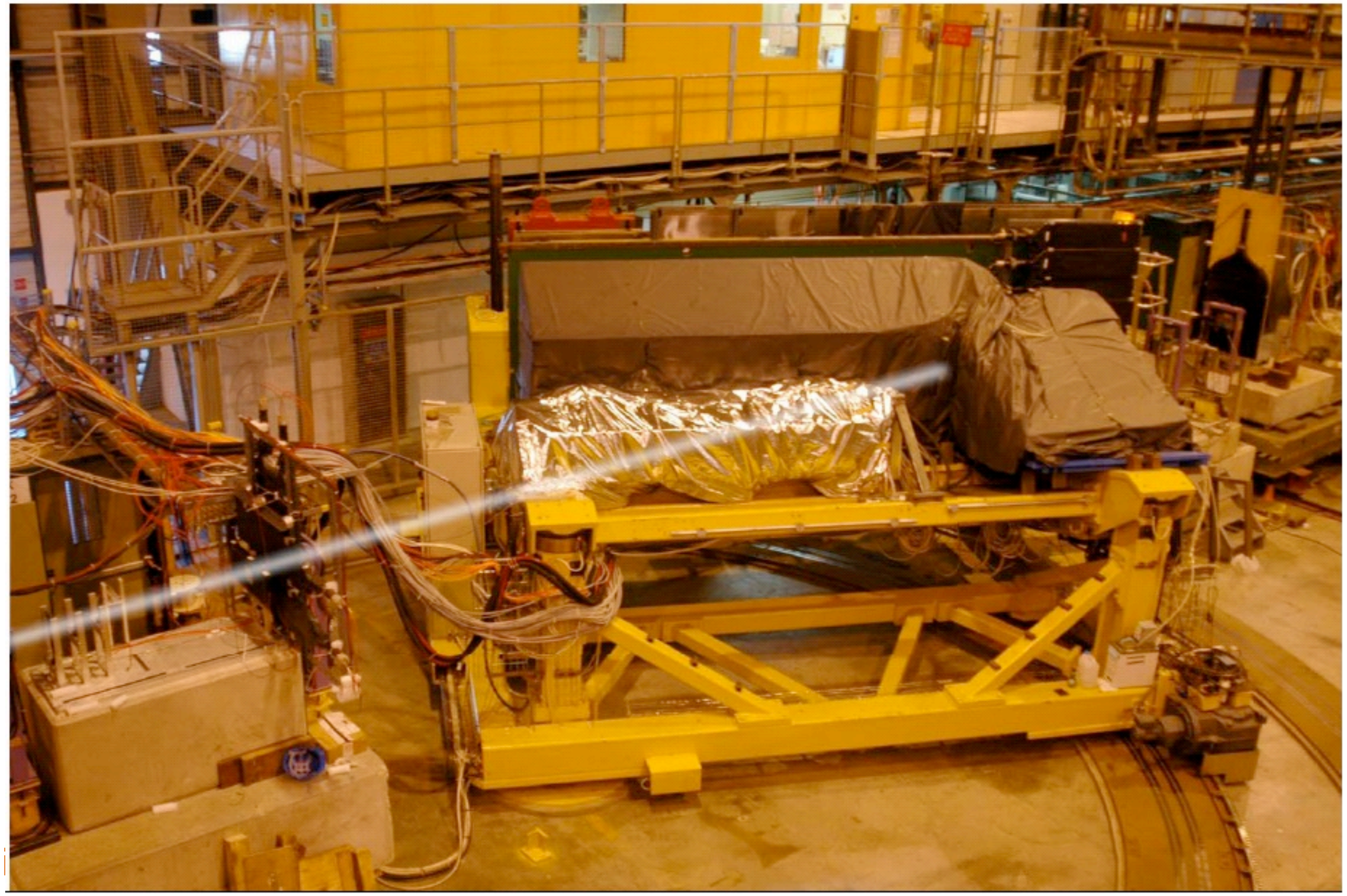
Physics List used in CMSSW

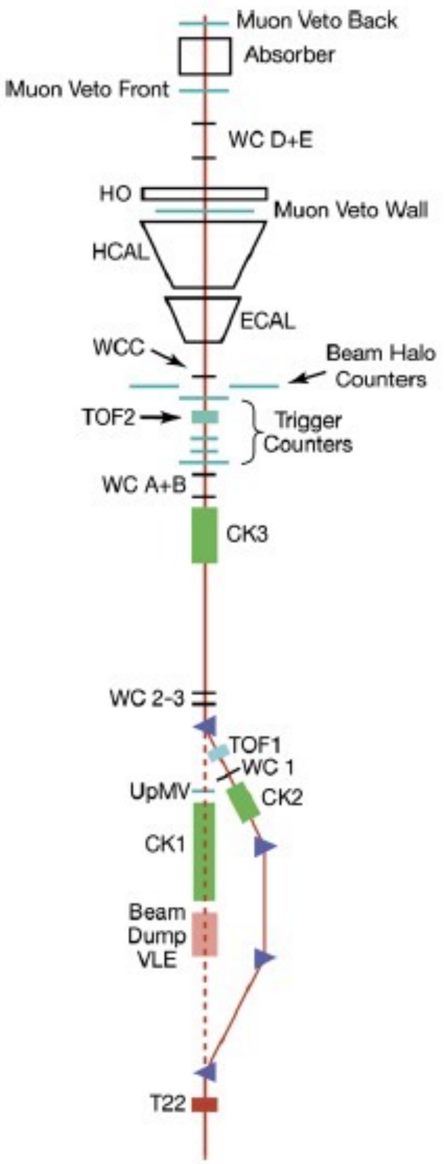
- Physics List FTFP_BERT_EMM has been CMS default:
  - FTFP_BERT is the Geant4 default
    - Geant4.10.4.p03: Transition energy Bertini-FTFP: 3-12 GeV
    - Geant4.10.6.p03, 10.7.beta, 10.6.ref08, 10.7.ref00: Transition energy Bertini-FTFP: 3-12 GeV for π and 3-6 GeV for other particles
  - EMM – configuration 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.p02 onward
  - 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

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- 10.4.p03	π- 10.6.p03	π- 10.7.r00	π+ 10.4.p03	π+ 10.6.p03	π+ 10.7.r00	p 10.4.p03	p 10.6.p03	p 10.7.r00
2 GeV	14.6±0.9	11.3±0.9	11.8±0.9	11.6±1.2	11.3±1.2	11.0±1.2	6.8±2.5	7.2±0.3	7.7±0.3
3 GeV	10.8±0.6	9.6±0.6	9.1±0.6	8.5±1.7	10.3±1.7	9.3±1.7	2.1±1.0	4.0±1.0	3.4±1,9
4 GeV	15.8±0.5	14.0±0.5	14.0±0.5	12.5±0.5	12.9±0.5	13.3±0.5	12.0±1.2	12.6±1.2	12.5±1.2
5 GeV	10.6±0.5	11.4±0.5	11.0±0.5	9.9±1.0	10.5±0.9	10.4±0.9	11.8±3.1	12.9±3.2	12.2±3.2
6 GeV	12.0±0.5	13.3±0.4	13.3±0.4	11.0±0.9	11.2±0.8	12.2±0.8	5.4±3.2	6.8±3.5	6.7±3.5
7 GeV	14.5±0.5	14.6±0.5	14.8±0.5	12.8±0.7	14.2±0.7	14.2±0,7	8.1±2.9	10.5±2.8	11.9±2.8
8 GeV	17.4±0.6	19.2±0.6	19.2±0.6	14.3±0.7	16.1±0.7	16.9±0.7	4.0±1.0	1.1±1.0	2.9±1.0

Comparison with CMS Test Beam Data

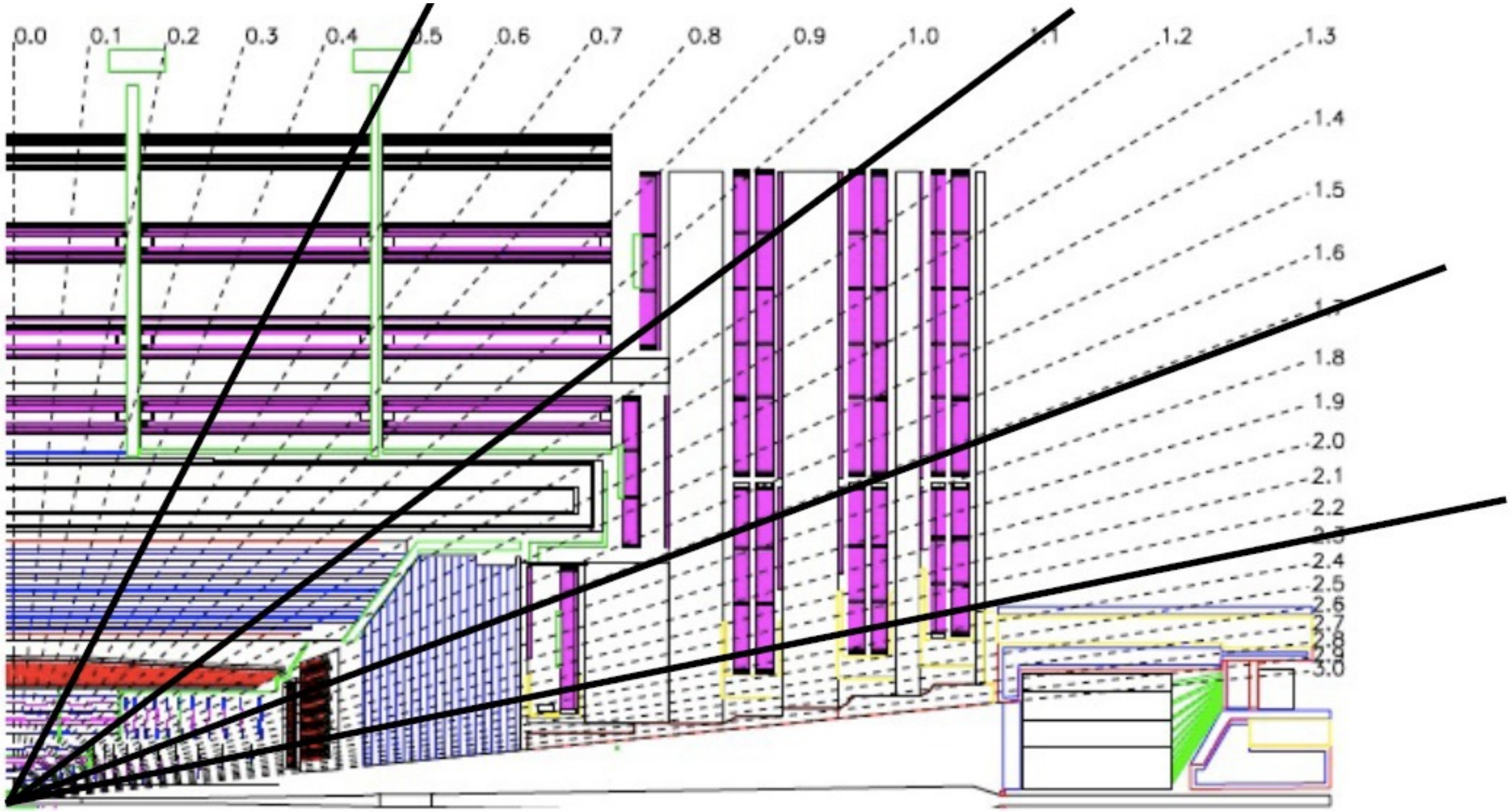
- Energy spectra for negative pions:
  - The data have a broader spectrum than what exist in the MC (for all versions of Geant4)
  - The mean level of disagreement vary between 9% and 19% for beam energies between 2 GeV and 8 GeV
- Energy spectrum for positive pions:
  - The level of agreement is similar to those for negative pions (data distribution is wider than MC)
  - The mean disagreement is between 9% and 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 3% and 12% for moment between 2 GeV and 8 GeV

Geant 4 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 1.3% and 3.5% for the Geant4 version 10.7, between 1.1% and 2.5% for the Geant4 version 10.6.ref10 and between 0.9% and 3.0% for the Geant4 version 10.6.p03 for FTFP_BERT_EMM.

Mean level of disagreement between MC and data

	$(E_{7x7}+H_{3x3})/p$ 10.4.p03	$(E_{7x7}+H_{3x3})/p$ 10.6.p03	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.6.p03
Barrel 1	(1.6±0.4)%	(2.5±0.4)%	(2.1±0.4)%	(2.6±0.4)%
Barrel 2	(4.0±0.4)%	(1.0±0.4)%	(2.8±0.4)%	(0.9±0.4)%
Transition	(5.3±0.5)%	(1.3±0.5)%	(3.6±0.5)%	(1.2±0.5)%
Endcap	(5.5±0.5)%	(3.0±0.5)%	(5.0±0.5)%	(1.9±0.5)%

	$(E_{7x7}+H_{3x3})/p$ 10.7.ref00	$(E_{7x7}+H_{3x3})/p$ 10.6.ref10	$(E_{11x11}+H_{5x5})/p$ 10.7.ref00	$(E_{11x11}+H_{5x5})/p$ 10.6.ref10
Barrel 1	(1.8±0.4)%	(2.4±0.4)%	(1.9±0.4)%	(2.5±0.4)%
Barrel 2	(1.8±0.4)%	(1.2±0.4)%	(1.5±0.4)%	(1.4±0.4)%
Transition	(3.5±0.5)%	(2.1±0.5)%	(3.0±0.5)%	(1.9±0.5)%
Endcap	(1.7±0.5)%	(1.7±0.5)%	(1.3±0.5)%	(1.1±0.5)%

Geant 4 Mean Level of Disagreement for QGSP_FTFP_BERT_EML

- The level of disagreement between data and MC is between 1.6% and 3.6% for the Geant4 version 10.7, between 1.2% and 2.5% for the Geant4 version 10.6.ref10 and between 0.6% and 4.0% for the Geant4 version 10.6.p03 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.p03	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.6.p03
Barrel 1	(1.6±0.4)%	(2.2±0.4)%	(2.1±0.4)%	(2.5±0.4)%
Barrel 2	(4.1±0.4)%	(0.9±0.4)%	(2.8±0.4)%	(0.6±0.4)%
Transition	(4.9±0.5)%	(2.5±0.5)%	(2.9±0.5)%	(2.5±0.5)%
Endcap	(4.7±0.5)%	(1.5±0.5)%	(4.0±0.5)%	(4.0±0.5)%

	$(E_{7x7}+H_{3x3})/p$ 10.7.ref00	$(E_{7x7}+H_{3x3})/p$ 10.6.ref10	$(E_{11x11}+H_{5x5})/p$ 10.7.ref00	$(E_{11x11}+H_{5x5})/p$ 10.6.ref10
Barrel 1	(1.8±0.4)%	(2.0±0.4)%	(2.2±0.4)%	(2.5±0.4)%
Barrel 2	(2.1±0.4)%	(1.7±0.4)%	(1.6±0.4)%	(1.5±0.4)%
Transition	(3.6±0.5)%	(1.9±0.5)%	(2.9±0.5)%	(1.7±0.5)%
Endcap	(2.3±0.5)%	(1.6±0.5)%	(2.1±0.5)%	(1.2±0.5)%

Geant 4

Comparison between 2 Physics Lists

- The level of disagreement between data and MC is between 1.5% and 3.5% for FTFP_BERT_EMM and between 1.6% and 3.6% for the physics list QGSP_FTFP_BERT_EML with the "VecGeom" builds depending on the region of the detector.
- The two physics lists FTFP_BERT_EMM and QGSP_FTFP_BERT_EML provide similar level of agreement with the data

	$(E_{7x7}+H_{3x3})/p$ 10.7.ref00 (FTFP)	$(E_{7x7}+H_{3x3})/p$ 10.7.ref00 (QGSP)	$(E_{11x11}+H_{5x5})/p$ 10.7.ref00 (FTFP)	$(E_{11x11}+H_{5x5})/p$ 107.ref00 (QGSP)
Barrel 1	(1.8±0.4)%	(1.8±0.4)%	(1.9±0.4)%	(2.2±0.4)%
Barrel 2	(1.8±0.4)%	(2.1±0.4)%	(1.5±0.4)%	(1.6±0.4)%
Transition	(3.5±0.5)%	(3.6±0.5)%	(3.0±0.5)%	(2.9±0.5)%
Endcap	(1.7±0.5)%	(2.3±0.5)%	(1.3±0.5)%	(2.1±0.5)%

Summary

- The release version of Geant4.10.7 has been tested with native geometry as well as with VecGeom version (v1.1.8) for thin target and CMS data

- Physics predictions from the new version agree well with the data from thin target experiments and also combined energy measurements in the CMS calorimeters: test beam setup as well as the final detector

- However, there are issues observed:

  - Individual energy measurements in the ECAL and in the HCAL show significant discrepancy (more energy in the ECAL and less in the HCAL)

  - The tracking efficiency is significantly smaller than in earlier reference versions (10.6.ref07 or earlier)

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
  - $Evis = E_{ECAL} * f_{ECAL} + E_{HCAL} * f_{HCAL}$
  - $f_{ECAL} = 1.01$, $f_{HCAL} \sim 105$ (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)%