CMS Use of Geant4.10.6

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Sunanda Banerjee
Vladimir Ivantchenko

Introduction

- CMS Simulation application in production is currently using Geant4 version 10.4.p03 and plans to go for the version10.6 and most likely with the release of patch01

- The version 10.6 (cand0) was available from December 6 (November 12), 2019 and it works with VecGeom version 1.1.5

- Adaptation of a new Geant4 version or a new Physics List requires validation of the model predictions using existing data

- The validation is carried out using 2 sources of data:
  - 2006 test beam with CMS calorimeter prototypes (hadron beams of different types and different energies)
  - Collision data from the CMS experiment utilizing zero bias or minimum bias triggers from low luminosity runs

- Use CMSSW version 10_5_0 with private installations of Geant4.10.6.ref00 with and without VecGeom and also a build with a development release of CMSSW_11_0_X with Geant4.10.6.cand0 and VecGeom

Warnings and Errors

- Several warning messages used to appear in some earlier versions, but they get substantially reduced or disappear in the new release:
  - Warnings about possible overlaps:
  - Warnings during tracking in B-field where some tracks are killed:
  - Error message from hadronic physics:
  - The EMZ physics lists run till end of the jobs but they do have several warnings where the energy deposit is a NaN
- In addition there used to be failures due to two possible sources
  - Miscalculation of step length during propagation
  - Tracks cannot be propagated after 25 attempts

The release still shows failures for some applications with tracks stopped after 25 attempts and showed some warnings (possible overlaps)

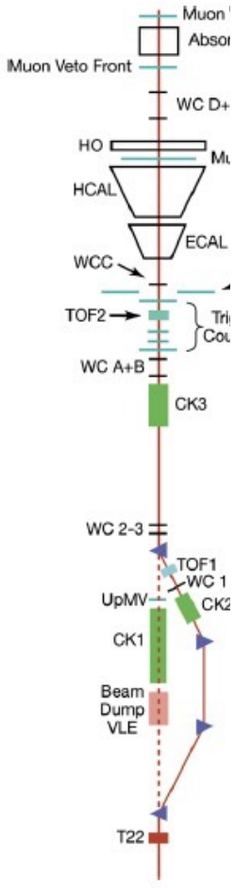
Effect of Physics Lists

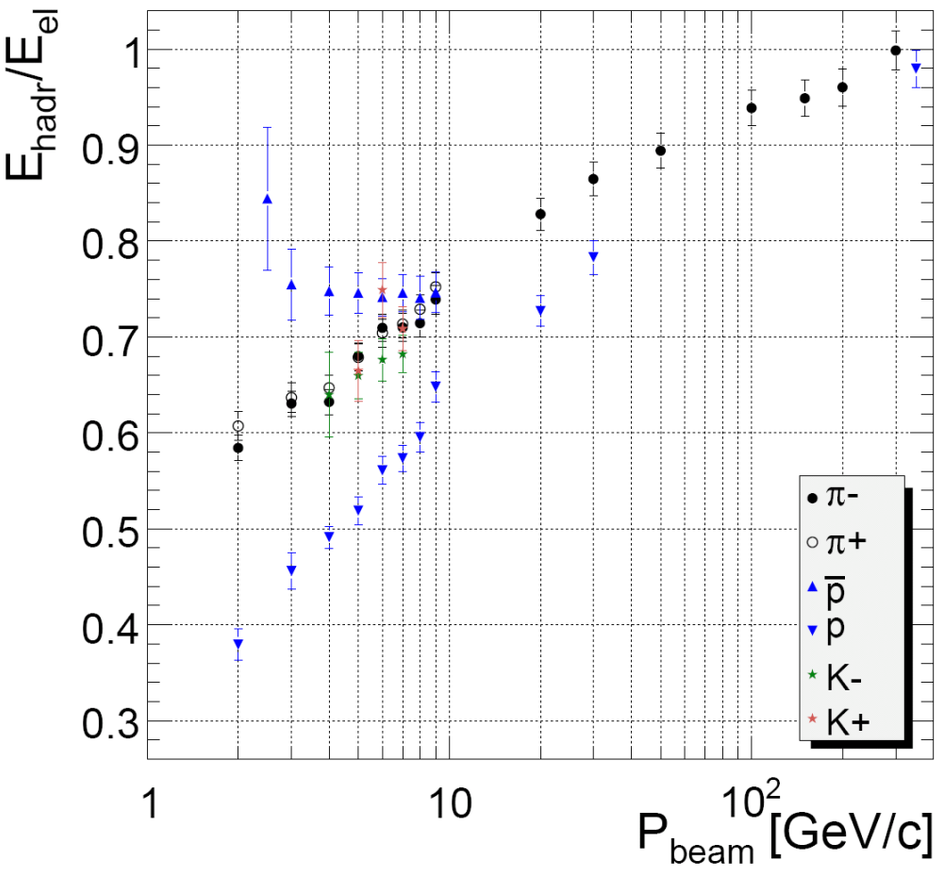
- FTFP_BERT_EMM is the default physics list for CMS
- A different physics list is also tried:
  - FTFP_BERT_EMN
    - uses Livermore model for P.E. effect and Klein-Nishina model for Compton scattering
    - uses Goudsmit-Saunderson model for multiple scattering and Seltzer-Berger model for bremsstrahlung

		2018	2023D17	2023D28
Minimum Bias	FTFP_BERT_EMM	1.00	1.29	1.45
(10.4.p03)	FTFP_BERT_EMN	1.09	2.12	1.76
(10.6.ref00)	FTFP_BERT_EMM	1.00	1.21	1.36
	FTFP_BERT_EMN	1.04	1.98	1.95
t-tbar	FTFP_BERT_EMM	1.00	1.69	1.76
(10.4.p03)	FTFP_BERT_EMN	1.09	2.92	3.21
(10.6.ref00)	FTFP_BERT_EMM	1.00	1.67	1.74
	FTFP_BERT_EMN	1.05	2.82	3.16

2006 TestBeam Data

- CMS collected data with prototype of Hadron Calorimeter Barrel and a supermodule of the barrel Electromagnetic Calorimeter in the H2 test beam area at CERN during 2006 with both positive and negative beams of momentum between 1 and 350 GeV
- The analysis utilized particle identification using data from TOF counters and Cherenkov detectors for beam momentum below 9 GeV
- The results consist of mean energy response (measured as the ratio of the total energy in the calorimeter to the beam momentum) as a function of beam momentum for different beam types and also the energy distribution for particles of a given type at a given momentum (all particles or particles which do not undergo inelastic interactions in Electromagnetic Calorimeter)





Comparison between data and MC

- Comparison is made to mean response, resolution, fraction of events which give MIP like signals in the ECAL and also at the energy spectrum for well identified particles with beam energies below 10 GeV
  - Input particles could be positive or negative pions, kaons, (anti-)protons

- Agreement between test beam data and simulation with Geant4.10.6 has degraded compared to similar study using Geant4.10.4.p03
  - Energy spectrum in the data is slightly broader and is shifted to higher values for energies above 5 GeV
  - Same is observed for positive pions
  - No significant shift is observed for protons

- Studied two possible variations:
  - Use transition between FTF and Bertini at 9-12 GeV rather than 3-6 GeV as suggested by ATLAS (FTFP_BERT_ATL_EMM)
  - Change the quenching coefficient of Birks law (from 0.0052 to 0.006)

Mean Energy Response

Geant4	π^+	π^-	proton	anti-proton	K^+	K^-
10.2.p02	1.02	0.61	0.51	1.69	19.0	20.7
10.4.p03	0.73	0.45	0.80	1.79	26.8	26.2
10.6.cand0	3.52	0.81	0.74	2.83	13.3	18.4
10.6.cand0 (ATL)	2.20	0.67	0.76	2.74	22.9	31.8
10.6.cand0 (BkC1=0.006)	1.92	0.68	0.67	1.94	17.3	18.2

- Geant4.10.6.cand0 demonstrates degradation for π, anti-proton, while some improvement for kaons
- FTFP_BERT_ATL_EMM improves for pions but degrades kaons
- Increasing BirksC1 from 0.0052 to 0.006 improves agreement for all particles

Energy Spectra

Mean level of disagreement between MC and data

	π- 10.2.p02	π- 10.4.p03	π- 10.6.ref0	π+ 10.2.p02	π+ 10.4.p03	π+ 10.6.ref0	p 10.2.p02	p 10.4.p03	p 10.6.ref0
2 GeV	14.4±0.9	14.6±0.9	11.9±0.9	11.1±1.2	11.6±1.2	12.0±1.2	6.4±2.5	6.8±0.3	7.4±0.3
3 GeV	10.4±0.6	10.8±0.6	8.3±0.6	9.7±1.7	8.5±1.7	9.2±1.7	3.1±1.0	2.1±1.0	3.4±1,0
4 GeV	14.0±0.5	15.8±0.5	16.1±0.5	11.5±0.5	12.5±0.5	13.3±0.5	10.7±1.2	12.0±1.2	13.2±1.2
5 GeV	13.9±0.5	10.6±0.5	15.7±0.4	12.5±1.0	9.9±0.9	14.3±0.9	10.2±3.1	11.8±3.2	12.5±3.2
6 GeV	16.2±0.5	12.0±0.4	24.2±0.4	15.1±0.9	11.0±0.8	22.2±0.8	8.7±3.2	5.4±3.5	6.4±3.6
7 GeV	18.0±0.5	14.5±0.5	29.8±0.5	18.7±0.7	12.8±0.7	28.1±0,7	10.4±2.9	8.1±2.8	10.6±2.8
8 GeV	21.2±0.6	17.4±0.6	34.8±0.6	19.0±0.7	14.3±0.7	28.6±0.7	0.1±1.0	4.0±1.0	0/1±1.0

Serious disagreement between data and MC for pions of energy above 5 GeV

Isolated Charged Particles

- Compare ratio of calorimeter energy measurement to track momentum for isolated charged hadrons between data and MC
- Select good charged tracks reaching the calorimeter surface
- Impose isolation of these charged particles
  - propagate track to calorimeter surface and study momentum of tracks (selected with looser criteria) reaching ECAL (HCAL) within a matrix of 31x31 (7x7) around the impact point of the selected track for charge isolation
  - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for neutral isolation
- Two versions of NxN matrix are defined for ECAL and HCAL
  - ECAL uses 7x7 or 11x11 matrix
  - HCAL uses 3x3 or 5x5 matrix
- The methodology was developed using 7 TeV data (PAS: JME-10-008) and this analysis is done using 2016 low pileup data.

Level of Agreement

- The level of agreement between data and MC is between 3.6% to 7.6% depending on the region of the detector and has significantly deteriorated in the current version

	$(E_{7x7}+H_{3x3})/p$ 10.2.p02	$(E_{7x7}+H_{3x3})/p$ 10.4.p03	$(E_{7x7}+H_{3x3})/p$ 10.6.ref00	$(E_{11x11}+H_{5x5})/p$ 10.2.p02	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.6.ref00
Barrel 1	(2.4±0.4)%	(1.6±0.4)%	(5.0±0.4)%	(2.6±0.4)%	(2.1±0.4)%	(3.6±0.4)%
Barrel 2	(3.6±0.4)%	(4.0±0.4)%	(6.1±0.4)%	(2.2±0.4)%	(2.8±0.4)%	(4.6±0.4)%
Transition	(4.9±0.4)%	(5.3±0.5)%	(7.6±0.5)%	(2.2±0.4)%	(3.6±0.5)%	(5.9±0.5)%
Endcap	(3.1±0.4)%	(5.5±0.5)%	(6.0±0.5)%	(1.5±0.4)%	(5.0±0.5)%	(5.8±0.5)%

Summary

- Predictions from the new Geant4 version10.6 using the physics list FTFP_BERT_EMM are compared with the data

- Test beam data with identified particle types are used as one source of validation while isolated charged particles from collision data are used as a second source

- There used to be good agreement between data and Monte Carlo for the physics list FTFP_BERT_EMM which is used as the default by CMS for its current and future event productions. However, the agreement for the version 10.6 is significantly worse than the earlier version 10.4.p03. It can be partly restored by tuning the overlaps among the models or constants for Birk's law.

- Many of the issues for track propagation in B-field which we observed in earlier reference releases are no longer seen within limited statistics
  - The frequent warnings for overlaps may be due to inadequacy in VecGeom for solids of shape CutTubs
  - The physics list EMZ needs attention
    - EMZ gives rise to NaN in the energy deposits

Backups

Dependence on Physics List

- The level of agreement between data and MC is between 3.6% and 7.6% for FTFP_BERT_EMM physics list and is between 3.4% and 7.1% for QGSP_FTFP_BERT_EML. The difference is small but overall the default physics list is slightly worse

	$(E_{7x7}+H_{3x3})/p$ QGSP_FTFP_BERT_EML	$(E_{7x7}+H_{3x3})/p$ FTFP_BERT_EMM	$(E_{11x11}+H_{5x5})/p$ QGSP_FTFP_BERT_EML	$(E_{11x11}+H_{5x5})/p$ FTFP_BERT_EMM
Barrel 1	(4.3±0.4)%	(5.0±0.4)%	(3.4±0.4)%	(3.6±0.4)%
Barrel 2	(6.7±0.4)%	(6.1±0.4)%	(5.2±0.4)%	(4.6±0.4)%
Transition	(7.1±0.4)%	(7.6±0.5)%	(5.1±0.4)%	(5.9±0.5)%
Endcap	(6.1±0.4)%	(6.0±0.5)%	(5.6±0.4)%	(5.8±0.5)%