CMS Report

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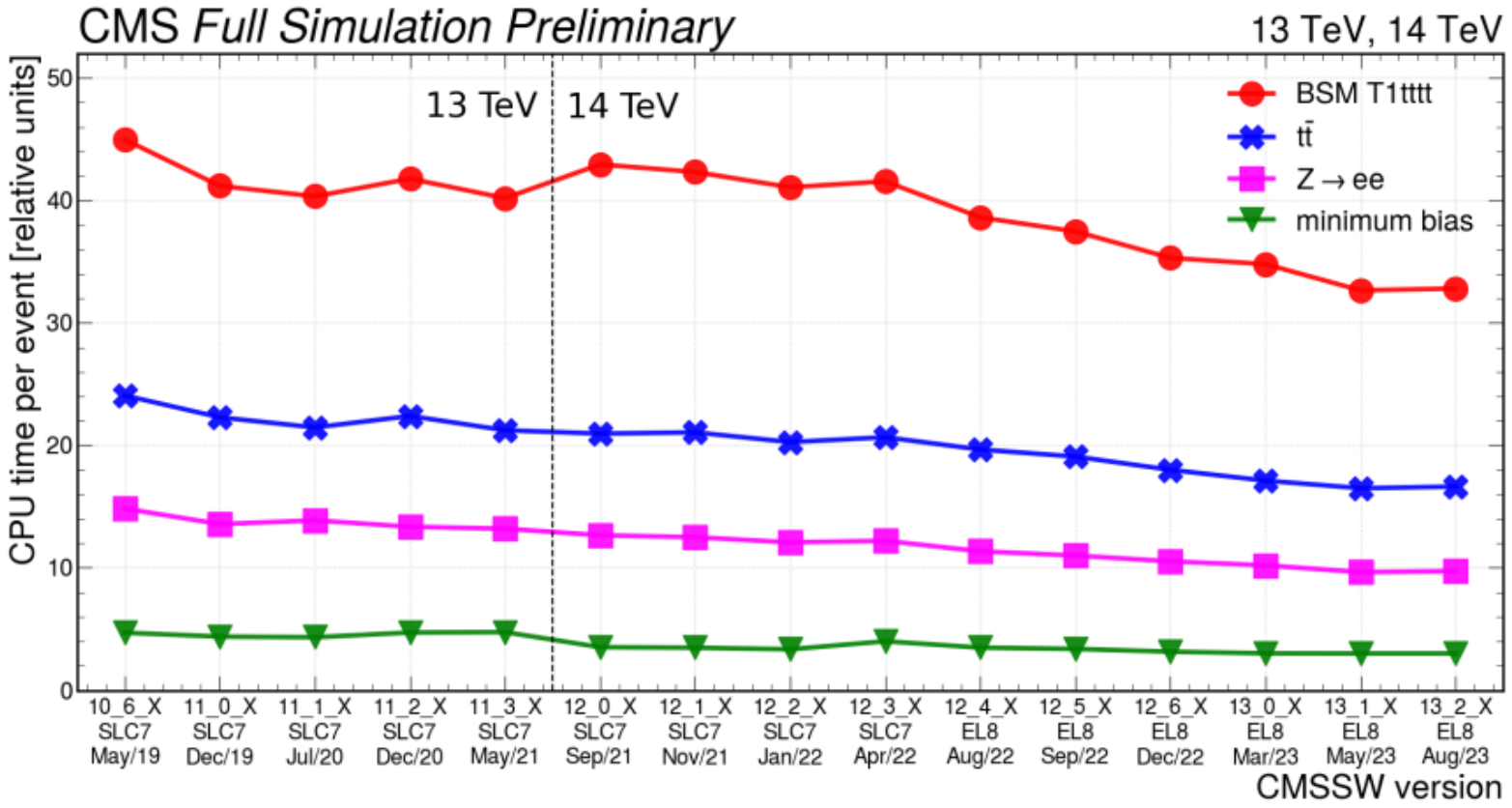
Current CMS Simulation Software

- CMS strategy for FullSim is to use the most recent public release of Geant4
  - It is shown that Geant4 physics between versions 10.6 and 11.2 is nearly the same
- New technical features in new version of Geant4 essential for the CMS Phase-2 simulation developments
  - For adaptation of each new Geant4 version number of tests are performed including 2006 test beam for the barrel
  - new 2018 test for Phase-2 endcap, and low pile-up data 2014

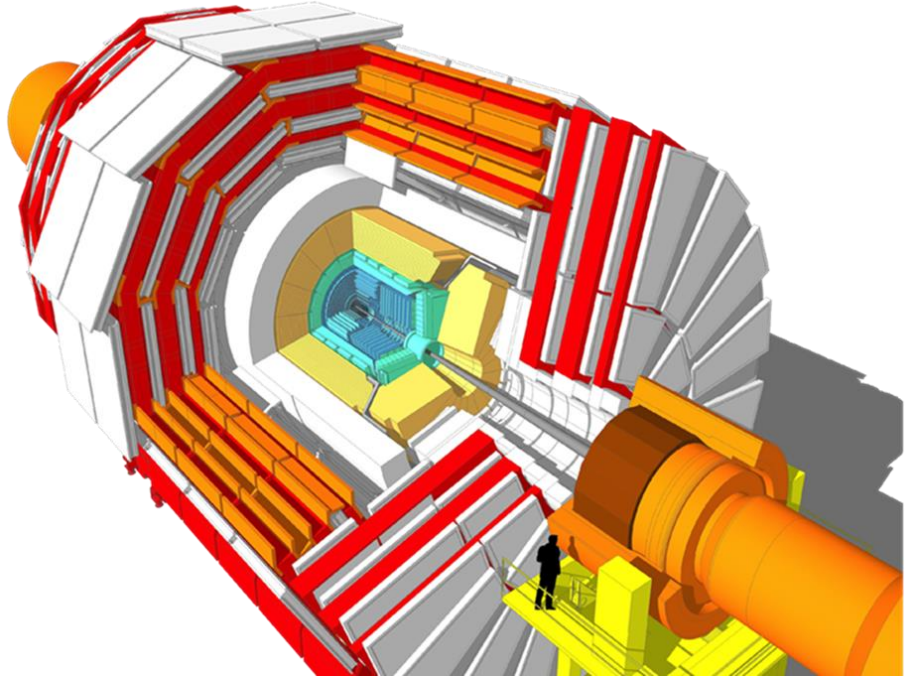
- Geant4 versions in CMSSW
  - Run2 – 10.4.2
  - Run3 2022-2023 – 10.7.2
  - Run3 2024 – 11.1.2
  - Run3 2024 HI – 11.2.2
  - The current Phase-2 -11.2.2
- External software
  - Celeretas v0.4.1
  - CLHEP 2.4.7.1
  - DD4hep v01-29-00
  - G4HepEm 20230309 – critical for Phase-2
  - VecGeom v1.2.7 – Critical for Phase-2

Performance monitoring for Run-3



During the ~4 years between the versions 10_6_X and 13_2_X the CPU time has improved for the processes: minimum bias by 36 %, ttbar by 32 %, BSM T1tttt by 27 % and Z -> ee by 32 %.

Phase-2 CMS experiment



- Old detectors
  - Barrel ECal and HCal calorimeters
  - Muon detectors
  - Magnet and magnet yoke
- New detectors
  - The new Tracker
  - The new endcap High Granularity Calorimeter (HGCal)
  - New barrel and endcap time detectors (MTD)
  - Additional GEM and RPC muon detectors for high eta regions
  - New PPS – proton scattering detectors in the LHC tunnel

Full Simulation for CMS Phase-2

- Run-2, Run-3, and Phase-2 simulation are performed using master branch of CMSSW
- Geometry for a particular run is plugged-in according to run configuration
  - Slight difference in geometry for each year of Run-2 and Run-3
  - ~20 variants of geometry for Phase-2
- Two way of geometry build
  - DD4Hep tool is the default since Run-3
  - DDD – legacy tool for Run-1 and Run-2
    - Is used for cross checks of geometry for Phase-2
- Geant4 Stepping action is different for Phase-2
  - Due to addition of new detectors
- Different list of Geant4 sensitive detectors for Phase-2

Geometry description for Run-3 and Phase-2

	Materials	Solids	Logical Vol	Physical Vol.	Touchables	Regions
Run3	489	3905	4229	21779	2317018	30
Phase-2	686	15808	16007	68608	13134654	26

- Counts are similar for the DDD and the DD4hep versions
- The increase in the number of touchable is primarily due to the description of the HGCal
- Summary of solids used in touchable volumes in the Run3|Phase2 scenarios:

	Standard	Reflected
Box	1208k | 1325k	434k | 429k
Tube	95.5k | 58.0k	1391 | 755
Trapezoid	240k | 158k	150k | 141k
Cone	1862 | 1862	0 | 0
Polycone	426 | 206	0 | 0
Polyhedra	1449 | 1572	0 | 0
ExtrudedPolygon	0 | 10845k	0 | 0
Torus	128 | 0	0 | 0
UnionSolid	175k | 614	0 | 0
SubtractionSolid	8325 | 173k	468 | 594
IntersectionSolid	0 | 360	0 | 0

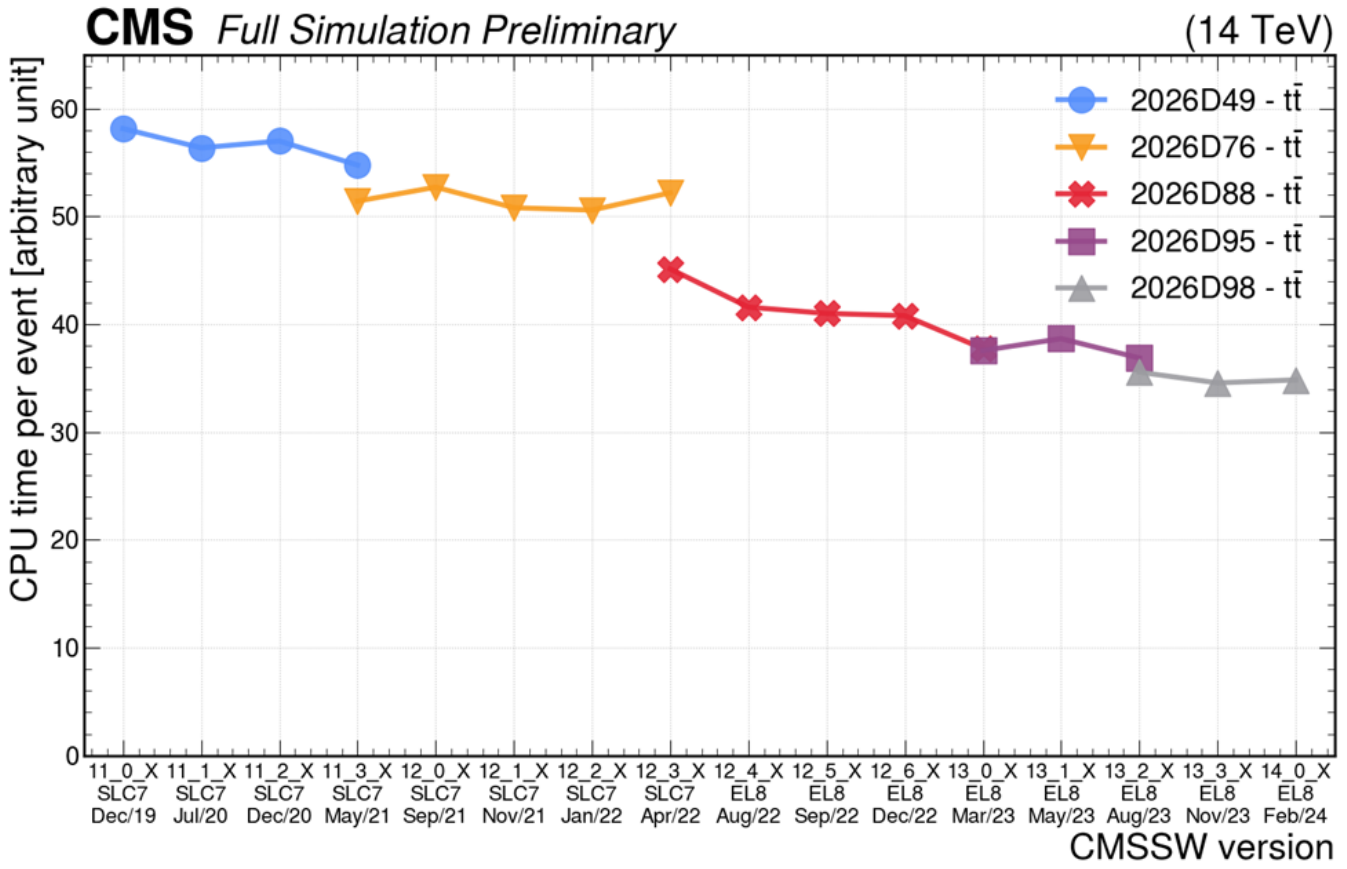
Geometry Overlap Summary

	DDD (1.0)	DDD (0.1)	DDD (0.01)	DDD (0.0)	DD4hep (1.0)	DD4hep (0.1)	DD4hep (0.01)	DD4hep (0.0)
Run3	0	0	84	566	0	0	4	475
Phase 2	0	0	36	344	0	0	0	348

- The 36 overlaps in the DDD version of the Phase2 geometry for a tolerance of 0.01 mm are all in Ecal barrel: precision lost in rotation of modules
  - Removed for Phase-2
  - The additional overlaps in the Run3 geometry are due to the description of the endcap pre-shower detector
- Most of the overlaps for tolerance of 0 mm come from the description of the return yoke
  - Our plan to remove all overlap in DD4hep case

Performance monitoring for Phase-2

- The average CPU time in arbitrary units for ttbar events
- The Phase-2 CPU performance have similar shape as Run-3 simulation performance
- The Phase-2 geometry updates affect CPU performance



Geant4 physics configurations

- The default Physics List FTFP_BERT_EMM was established for Run-2 and is used for both Run-3 and Phase-2.
  - It includes the FTFP string model and the Bertini Cascade model for hadronic processes, and CMS special combination EMM for electromagnetic processes.
- The alternative EM physics of Geant4 is implemented in the G4HepEm standalone library
  - FTFP_BERT_EMH Physics List is used.
- The difference with the CMS default FTFP_BERT_EMM physics List is in simulation of γ, e+, e- transport by G4HepEm.
  - Current G4HepEm is incomplete: no sampling of energy loss fluctuations of electrons and positrons and nuclear interactions

CPU performance of CMS Simulation Various EM physics Configurations provided by Geant4 and by CMSSW
In September 2024

		2021	Setup			2026D110	Setup	
	Min.	Bias	t-	tbar	Min.	Bias	t-	tbar
	CPU	RSS	CPU	RSS	CPU	RSS	CPU	RSS
EMM	1.000	1.22 GB	1.000	0.75 GB	2.154	1.68 GB	2.395	1.19 GB
EMN	1.044	1.30 GB	1.039	1.32 GB	2.816	1.95 GB	3.391	1.44 GB
EMY	1.547	1.51 GB	1.657	0.94 GB	2.869	1.93 GB	3.316	1.45 GB
EMZ	2.531	1.69 GB	2.971	1.20 GB	4.728	2.24 GB	5.950	1.78 GB
Standard	1.183	1.21 GB	1.237	0.76 GB	2.383	1.69 GB	2.723	1.20 GB

2006 Test Beam Data

- CMS collected data with a prototype of the Barrel Hadron Calorimeter and a super module of the barrel Electromagnetic Calorimeter in the H2 test beam area at CERN in 2006.
  - The analysis utilized particle identification using data from TOF counters and Cherenkov detectors up to an energy of 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, the energy resolution and some energy distributions for particles of a given type at a given momentum.
  - Results from this test beam were published and have been used in many comparisons presented in earlier notes.
- New results are obtained for comparisons of simulation predictions with Physics Lists FTFP_BERT_EMM and FTFP_BERT_EMH are presented.

Summary on test beam 2006

Chi^2/n_D analysis	negative pions	positive pions	negative kaons	positive kaons	protons	anti-protons
G4 11.2.2 FTFP_BERT_EMM	0.21	1.36	20.0	15.6	0.62	3.75
G4 11.2.2 FTFP_BERT_EMH	0.55	2.36	22.4	18.5	0.72	2.64

- The predictions from FTFP_BERT_EMM and FTFP_BERT_EMH are similar. The difference for any point is below ~1%.
- The level of agreement is good for pions and protons, while it is not good for kaons and some disagreement is seen for anti-protons.
- Results are compatible with those previously reported
- G4HepEM may be considered for CMS simulation

Summary

- CMS full simulation is under progress
  - Stable version for Run-3
  - Significant modifications for Phase-2
    - Geometry is under development
    - The goal is to have overlap free description
- CMS R&D efforts for Phase-2 are in progress
  - FTFP_BERT_EMM and FTFP_BERT_EMH provide similar results for 2006 test beam data
  - Significant interest to G4HepEm progress