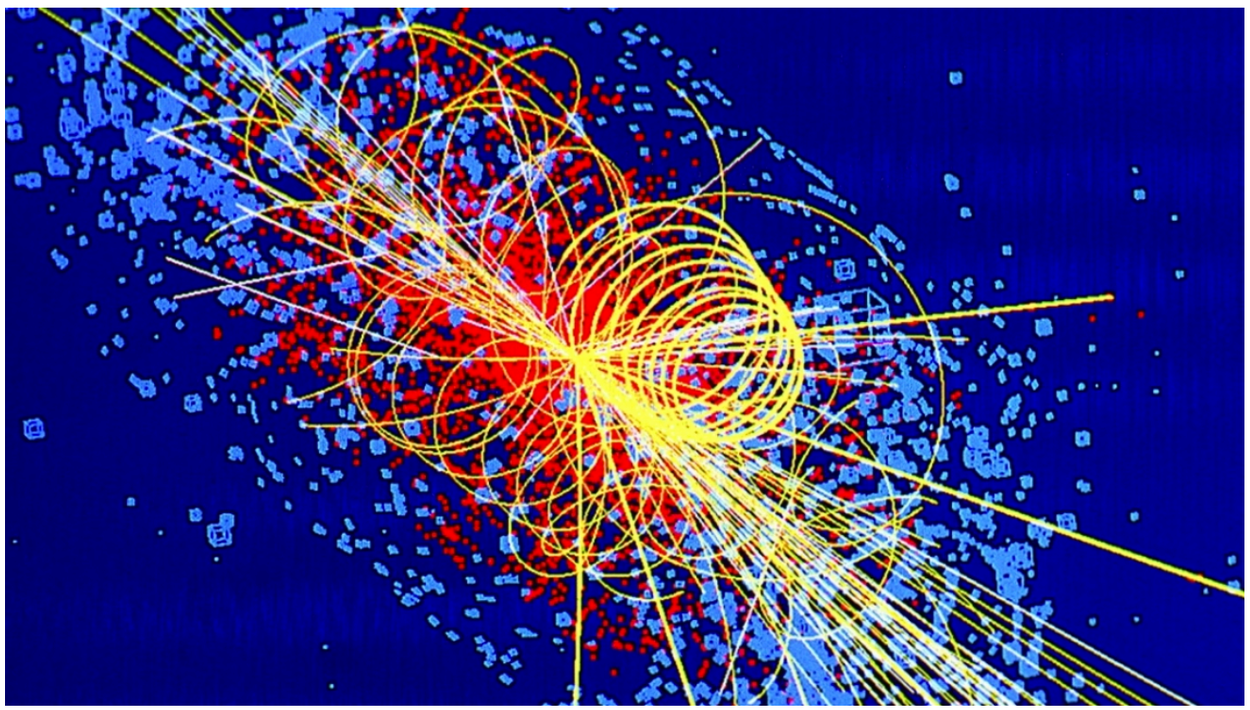
Common software for CMS simulation for the HL-LHC



HL-LHC Simulation Mini-Workshop
29 April, 2021

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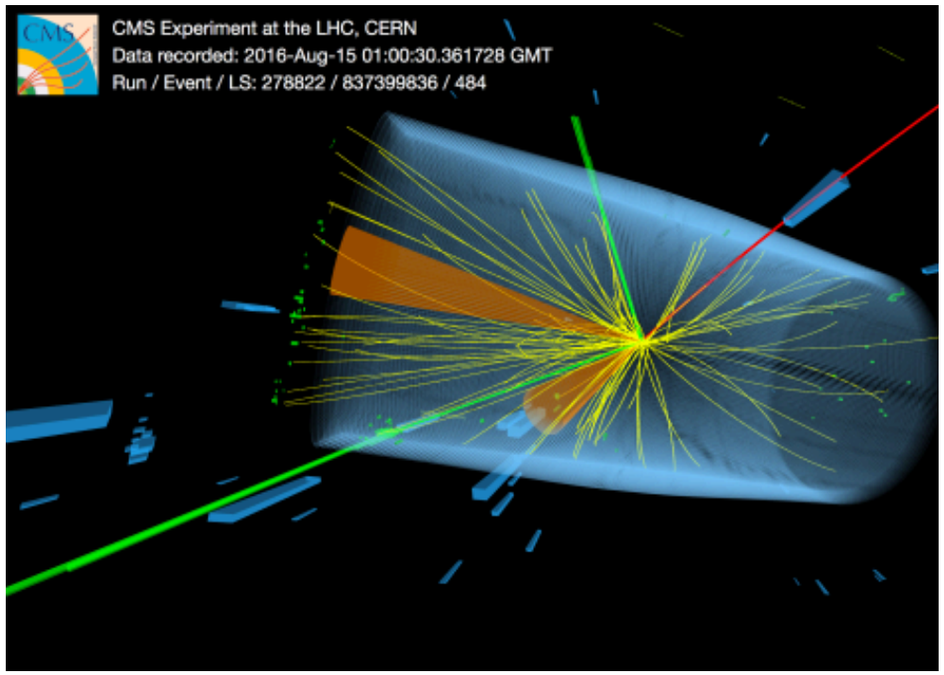
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

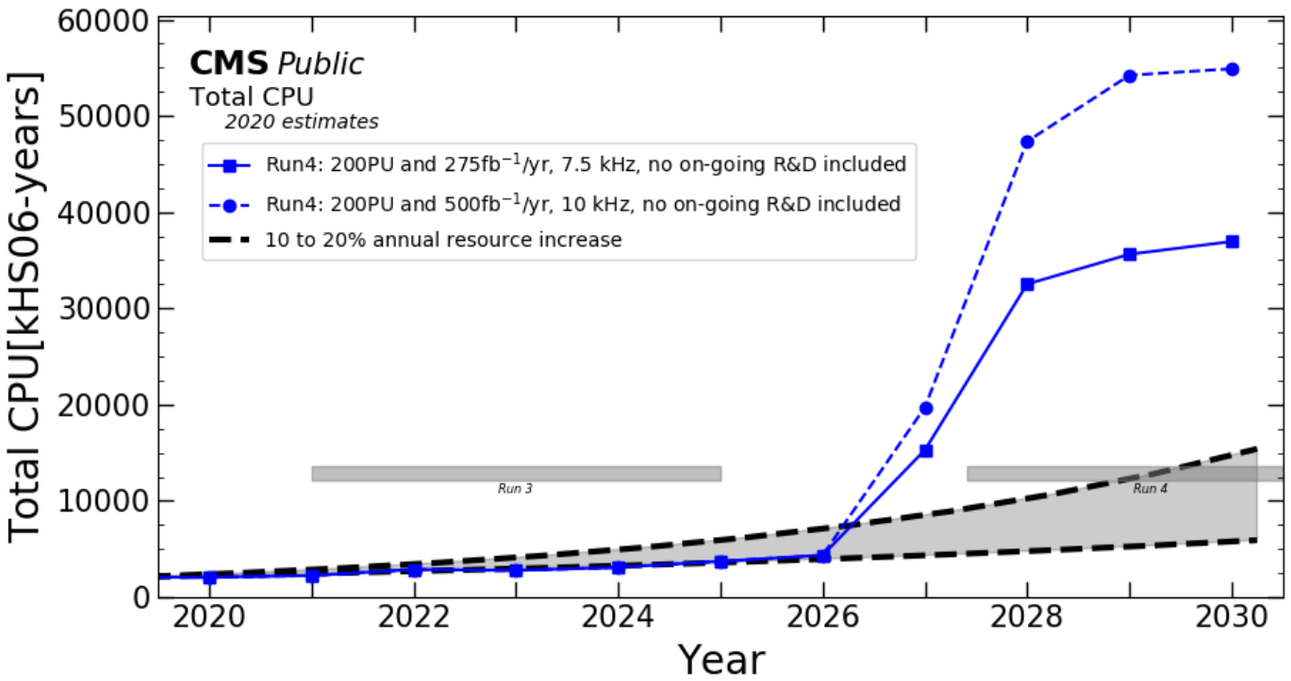
With input from Vladimir Ivantchenko, Danilo Piparo, David Lange, Kevin Pedro, Sunanda Banerjee

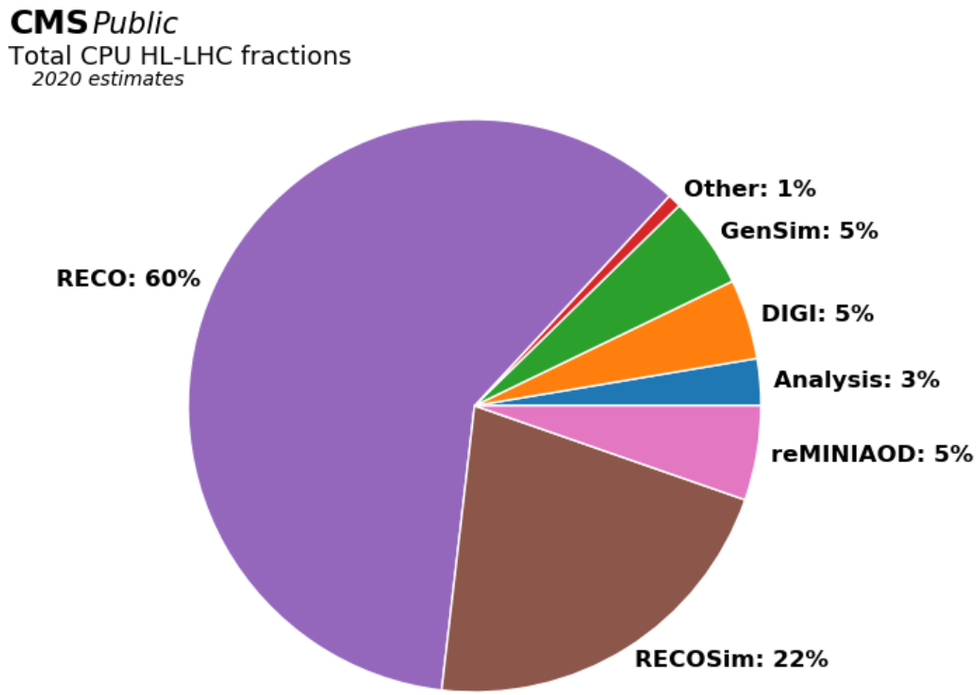
Simulation @CMS



- Vast spectrum of CMS physics analyses requires a large number of simulated events in order to achieve definitive physics results
- CMS has developed a detailed Geant4-based detector simulation framework (FullSim), with various CMS-specific optimisations (MC sampling, customised physics lists, etc)
  - D.J. Lange et al., J. Phys.: Conf. Ser. 608, 012056 (2015)
  - M. Hildreth et al., J. Phys.: Conf. Ser. 664, 072022 (2015)
  - M. Hildreth et al., J. Phys.: Conf. Series 898, 042040 (2017)
  - Geant4 10.4 is used for Run 2, 10.7 is being prepared for Run 3
- CMS continues to develop largely parametric fast simulation (FastSim) framework which will have an increased role in the future
  - arXiv:1701.03850 (2017)

Computing needs, budget





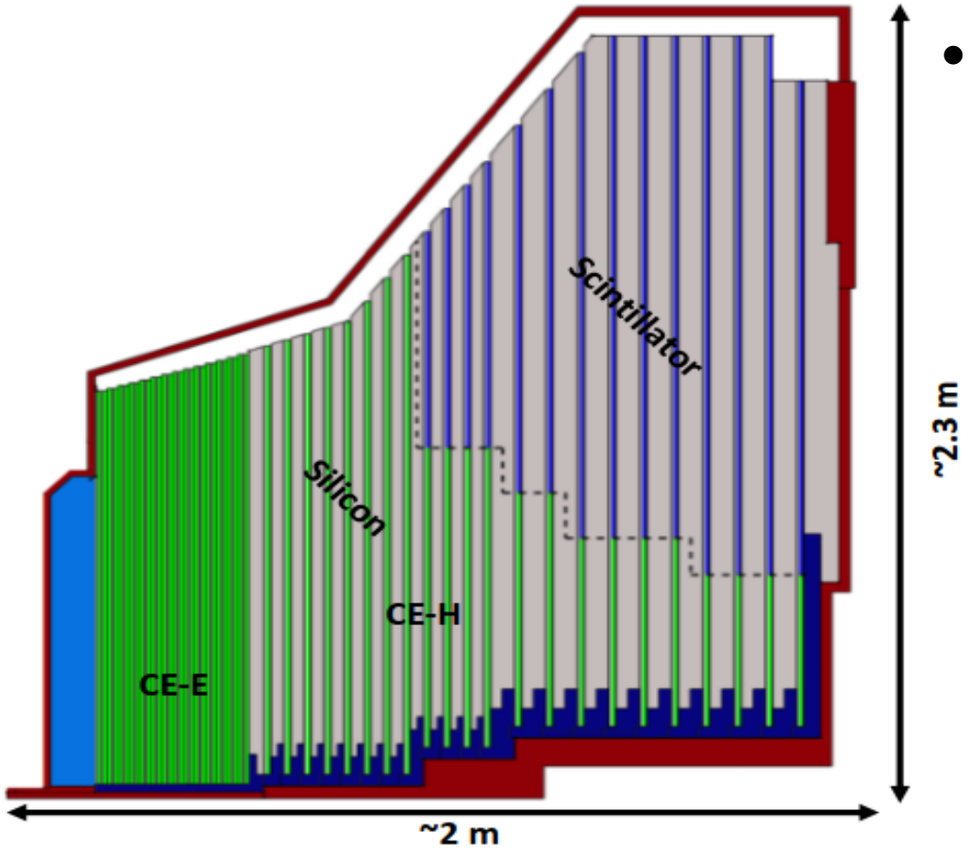
- Current projections of computing needs still above projected availability (ignoring the impact of R&D!): ramping up for Run 4
- Reconstruction currently shown to dominate the computation time; ongoing development should reduce this considerably
  - Note for the Fast MC chain, the RECO step is also customised

https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSOfflineComputingResults

FullSim Phase 2 upgrade

- Include new detectors with higher resolutions, radiation hardness
  - Phase-2 Tracker https://cds.cern.ch/record/2272264?ln=en
  - Time of flight (MTD) detector https://cds.cern.ch/record/2667167?ln=en
  - Endcap calorimeter (HGCAL) https://cds.cern.ch/record/2293646?ln=en
  - Muon detectors (GEM) https://cds.cern.ch/record/2021453?ln=en
- Use of DD4Hep for detector geometry beginning with Run 3
- Current FullSim for Phase-2 is about 2-3 times slower than simulation for Run-3
  - Factor of 2 from HGCal geometry complexity
  - Factor of 1.5 from more precise physics lists (try to match HGCal measurement accuracy)
    - https://arxiv.org/abs/2004.02327
- Will benefit from further software and accuracy improvements of Geant4, aiming for high quality simulation of response of new detectors

High Granularity Calorimeter Phase-2 CMS Endcap



- New endcap calorimeter under design and development for Phase 2
  - HGCal to provide better resolution, granularity than existing CMS calorimeters
  - 6M output channels
  - Possibility for high-quality particle flow analysis in the forward region

Electromagnetic calorimeter (CE-E):
Si/CuW/Pb absorbers 28 layers, 25.5 X_0, 1.7 λ

Hadronic calorimeter (CE-H):
Si & scintillator, steel absorbers, 22 layers, 9.5 λ

Simulation precision must meet the mark for new, high performing detector

Possible Geant4 improvements for CMS

- Specialized geometry and navigation components inside Geant4 for HGCAL simulation (navigation with knowledge of geometry structure)
  - Phase-2 CMS has ~2 times more physical volumes and ~1.5 more logical volumes mainly due to HGCAL
- Improved simulation of high and medium energy hadron/nuclei interactions for HGCal materials
  - Maximally explore high granularity for the particle flow analysis and pattern recognition
- Extended decay module of Geant4
  - More accurate branching ratios for baryons and mesons
  - Improved final state sampling
  - Addition of detailed tau, c-, and b- particle decays, native or via interface to generator packages

We welcome and encourage experts/developers of Geant4 actively engaged in the CMS simulation as CMS members

Fast MC Chain „FastSim“

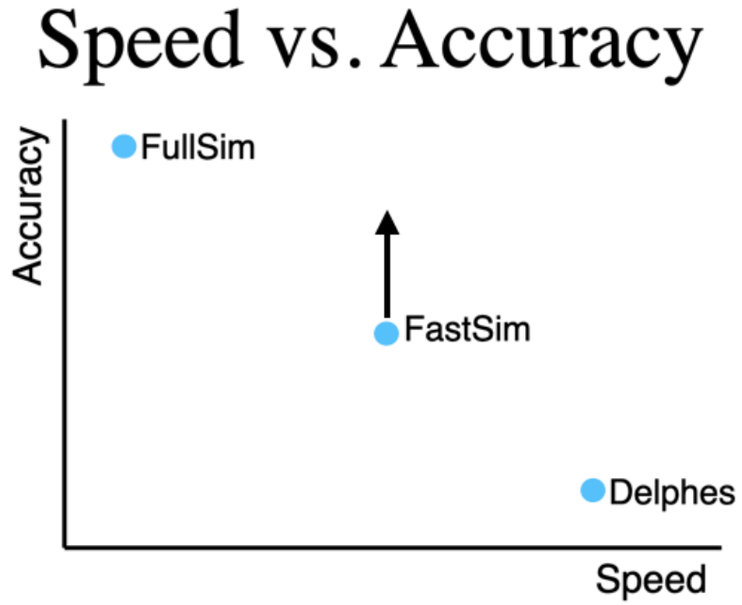
- Fast simulation package has been developed over years, used to produce ~15% of simulated events, aim to increase this in Run 3, Phase2
- Parametrization-based, tuned using Geant4 event samples
- Realistic model of low-level objects (hits and clusters), fast tracking

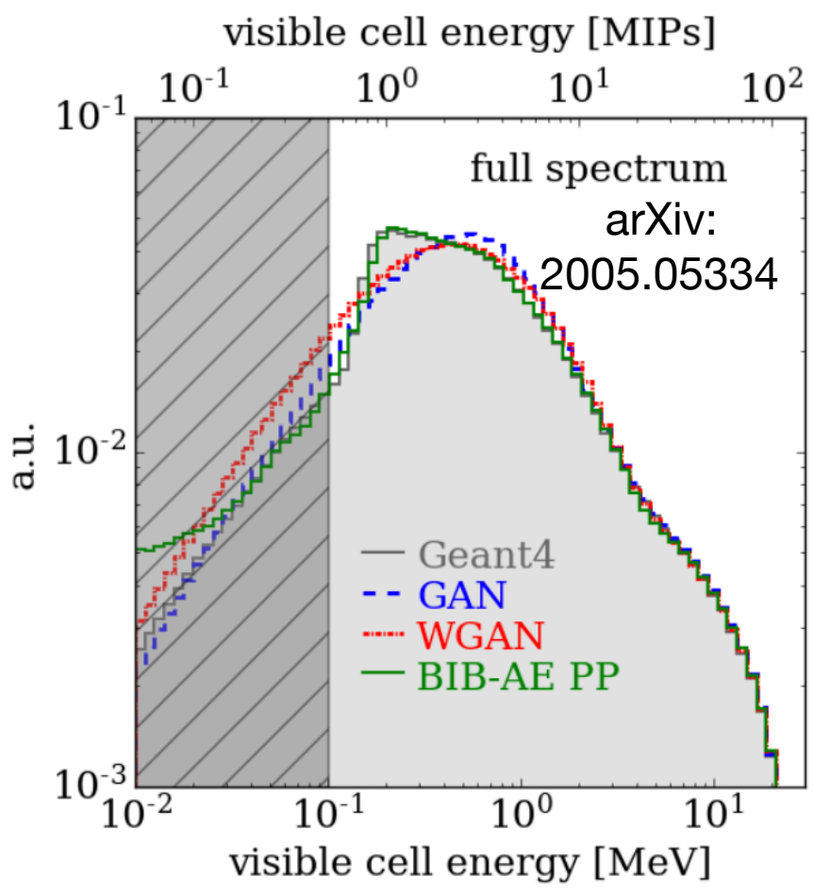
	Evt. generation (GEN)->	Detector simulation (SIM)->	Digitization (DIGI)->	RECO	Total s/event
FullSim chain	e.g., MG amc@NLO	Geant4	detector electronics	analyze digis as if data	-
FastSim chain	„“	param. en. loss, GFlash **x100 faster**	same as FullSim	use GEN+DIGI **x2.5 faster**	X10 faster
Delphes -like Chain	„“	simple 4-vector smearing	none	analytical efficiency	X1k faster

★ Numbers derived for ttbar events with Run-2 conditions and pileup

R&D for faster simulation

- Upgrade and validate -> more signatures
- Multi-faceted ML effort
  - Generative showering implementation using GAN, VAE
    - e.g., arXiv:2005.05334
  - FastSim refinement, e.g., WGAN, DCTRGAN
    - arXiv:2009.03796, arXiv:1802.03325
  - End-to-end simulation („FlashSim“)
    - arXiv:1901.05282, arXiv:2005.05334
  - Denoising coarse sim output, industry work
- Delphes arXiv:1307.6346 used for many upgrade sensitivity projections, e.g., CMS PAS FTR-16-005





Heterogeneity

- CMS is actively exploring heterogeneity
  - successful path to integrate new simulation engines has been demonstrated
    - https://arxiv.org/abs/2005.00949 and https://arxiv.org/abs/2004.02327 (GeantV)
  - for Run-3 a part of HLT code will run on GPUs
    - very interested in testing any new prototype for GPUs for Geant4
- Simulation applications that exploit accelerators can help CMS accessing and utilising future computing centres (e.g. HPCs, modernised WLCG tiers)
- Usage of ML algorithms for part of event simulation will naturally involve GPUs for full and fast simulation
  - carrying out several R&D projects to explore ML for simulation
  - any common solutions to use ML will be considered by CMS

Final remarks

- CMS working to satisfy enhanced computing needs for HL-LHC resulting from the large increases in event rates, luminosity and event complexity
- Will take advantage of many new optimisations afforded by the community e.g., with regards to simulation, geometry, heterogeneity, etc
- Ready to interface with new modes for event processing, e.g., GPU-based transport
- Simulation precision must meet the mark for new, high performing detector
- Plan to take advantage of Geant4 related improvements, including new physics lists, implementation of VecGeom, etc
- We very much welcome and encourage experts/developers of Geant4 actively engaged in the CMS simulation as CMS members
- Multi-pronged ML effort in collaboration with others in community, connection with CERN SFT ML4Sim group
    - Adequate mechanisms in G4 needed to allow seamless integration of such algorithms