CMS Full Simulation for Run-3
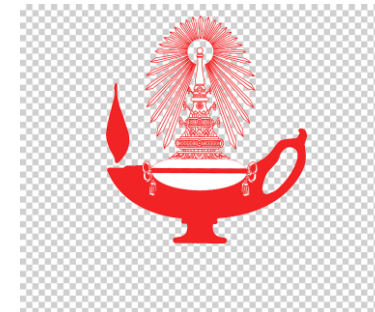
Vladimir Ivanchenko, *Sunanda* Banerjee, *Gabrielle* Hugo, *Sergio* Lo Meo, *Ianna* Osborne, *Kevin* Pedro, *Danilo* Piparo, *Dmitry* Sorokin, *Phat* Srimanobhas, and *Carl* Vuosalo on behalf of the CMS Collaboration

Outline

- CMS geometry upgrade
- Migration to DD4Hep
- Adaptation of Geant4 10.7
- Configuration of Geant4 Physics
- Fast parameterization of electromagnetic showers
- Summary
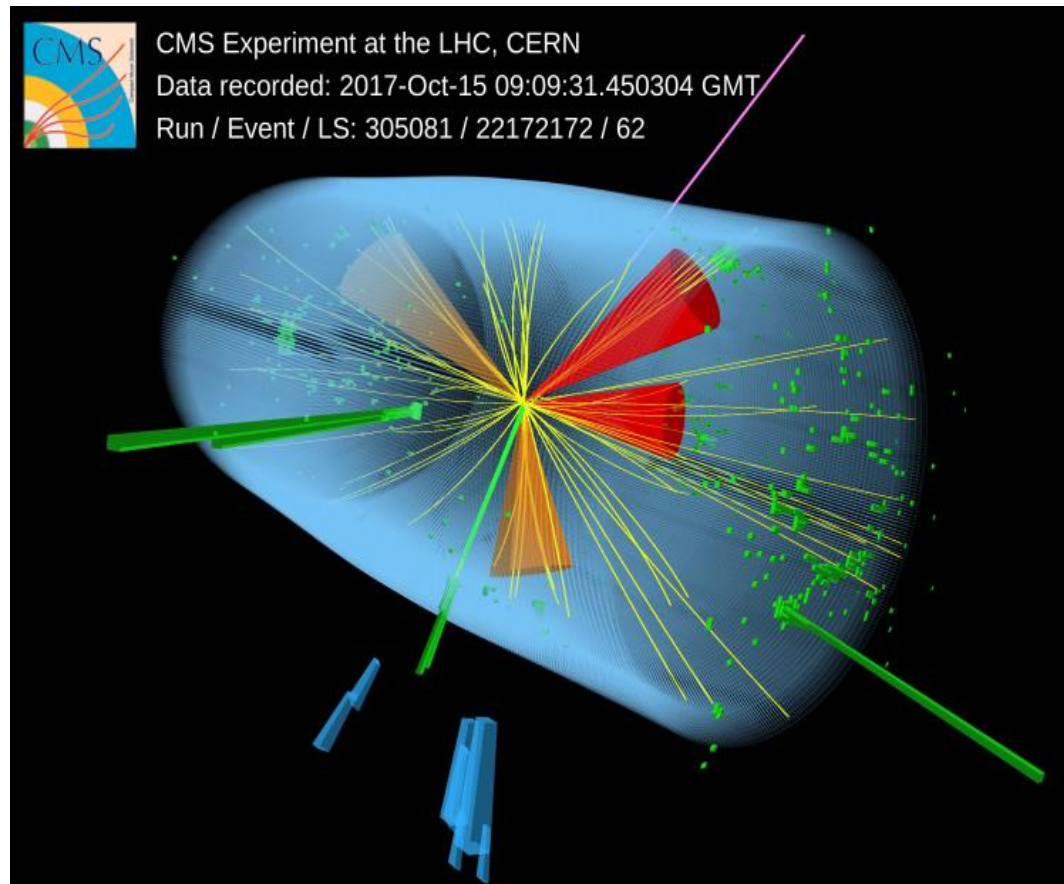
References for CMS FullSim for Run-2:
- D.J. Lange et al., J. Phys.: Conf. Ser. 608, 012056 (2015)
- M. Hildreth et al., J. Phys.: Conf. Ser. 664, 072022 (2015)
- M. Hildreth et al., J. Phys.: Conf. Series 898, 042040 (2017)
- V. Ivanchenko and S. Banerjee, EPJ Web of Conf. 214, 02012 (2019)
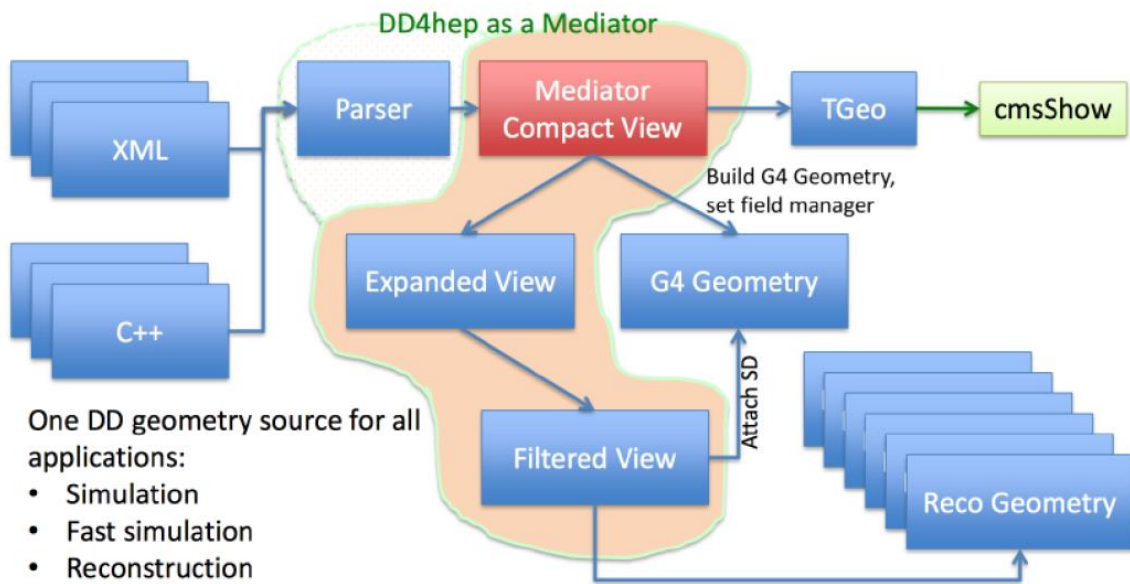
CMS geometry upgrade

- Geometry update for Run-3
  - New beam pipe
  - More accurate description of tracker support structure
  - Improved description of muon system, addition of GEM stations
  - Updated forward and very forward detectors

Tracker support

CMS central detector
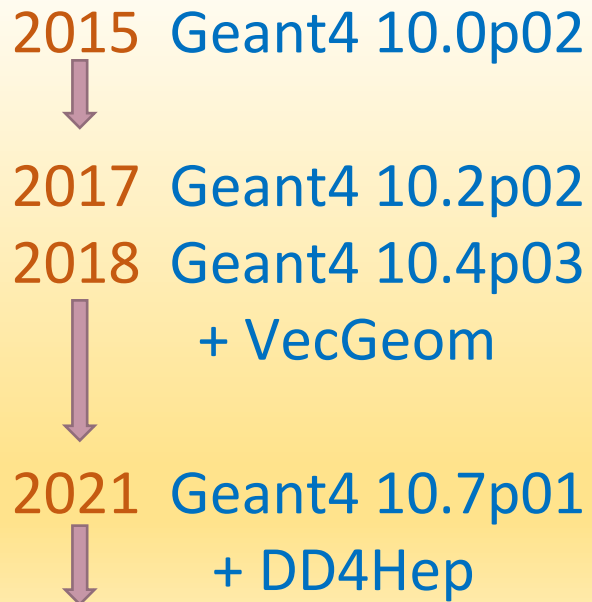
Migration to DD4Hep

DD4hep as a Mediator
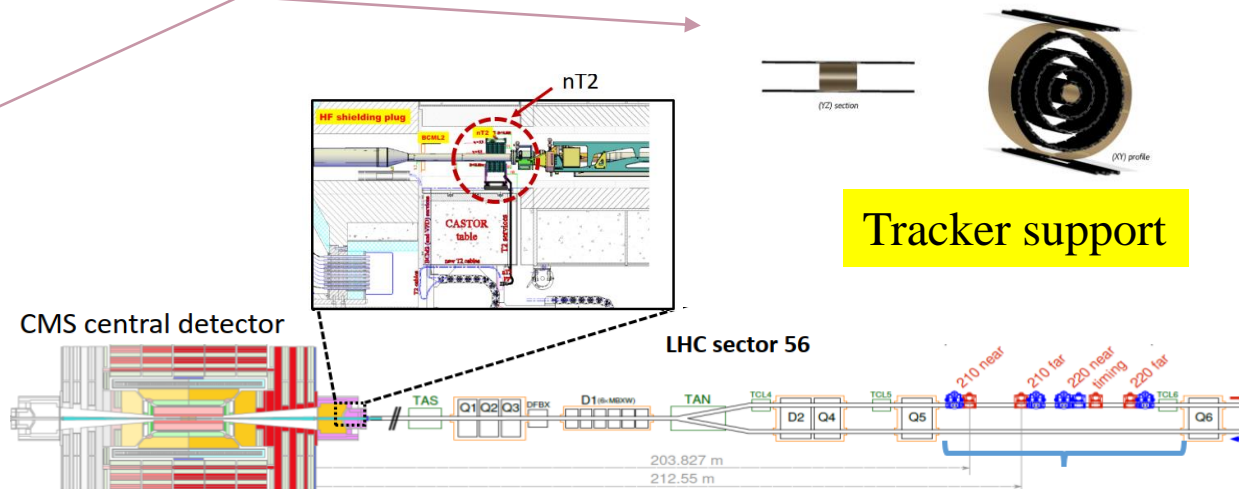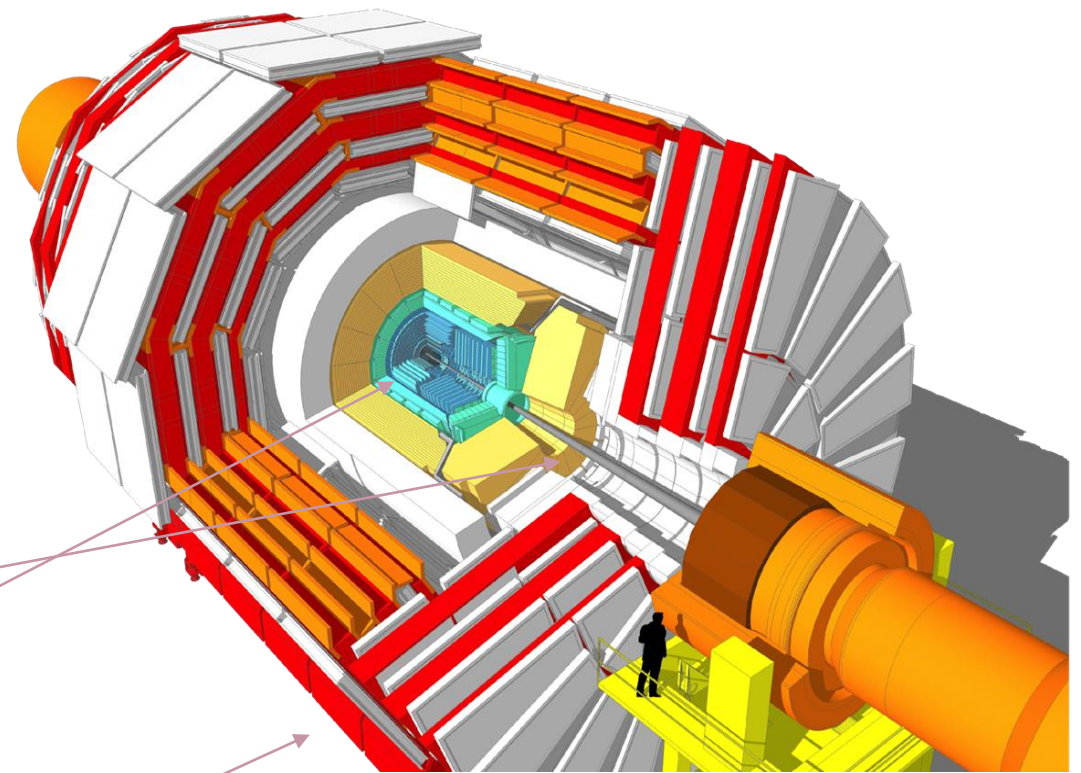
One DD geometry source for all applications:
- Simulation
- Fast simulation
- Reconstruction
- Alignment and Calibration
- Visualization

- For Run-1 and Run-2 CMS used custom detector description (DDD)
  - For each sub-detector original approach was developed by each sub-detector team
- For Run-3 a migration to the community developed tool DD4Hep was chosen
  - F. Gaede et al., EPJ Web of Conferences 245, 02004 (2020)
  - C. Vuosalo et al., EPJ Web of Conferences 245, 02032 (2020)
- Migration required contributions from several sub-detector teams
  - Was started in 2019 and included full review of the CMS geometry
    - XML files were reviewed and unified
  - Run-3 DD4Hep description is currently being validated by the CMS central testing team
  - The migration effort provided good opportunity to verify CMS geometry, remove overlaps, and improve accuracy of volume positions and representations
- We would like to thank Markus Frank (LHCb) and the DD4Hep team for prompt reactions to any our request
  - DD4hep code was also improved during this CMS campaign

Adaptation of Geant4 10.7

2015 Geant4 10.0p02

2017 Geant4 10.2p02

2018 Geant4 10.4p03
         + VecGeom

2021 Geant4 10.7p01
         + DD4Hep

CMS Geant4 version for Run-2 was updated

- Evolution of Geant4 version was possible, because CMS sub-detectors were modified for each new season
  - MT mode from 2017
  - Geant4 10.4p03 + VecGeom since 2018 – legacy MC production
- The configuration of physics was established during LS1 including FTFP_BERT_EMM Physics Lists, Russian roulette method, and HF shower library

Geant4 10.7 was the CMS target release for Run-3

- No change of sub-detectors is expected during Run-3
  - 10.7 is the most recent Geant4 version available during LS2
- The current version is 10.7p01
  - a new patch 10.7p02 is expected in June
- A procedure of validation for each new Geant4 version was established in CMS since Run-1
  - Validation started 6 months before the date of any Geant4 release, feedback to the Geant4 team is provided
  - Integrations tests, test-beam analysis, and comparisons with the detector data are performed
   - see talk of S.Banerjee today for more details

Configuration of Geant4 Physics

- Physics List for FTFP_BERT_EMM
  - The same for Run-2 and Run-3

- To achieve the agreement between CMS test-beam and detector data two revisions were introduced in simulation for Run-3:
  - Overlap energies between the Bertini Cascade and the FTFP string model for pions is set from 3 to 12 GeV
    - The default is from 3 to 6 GeV
  - The Birks coefficient for the HCAL scintillator is increased by about 15%

- Magnetic field driver G4DormandPrince745
  - both for Run-2 legacy processing and Run-3

- A smart configuration of Geant4 parameters for tracking in field is implemented with 3 sets of parameters
  - set 1 - for central detector region R < 8 m, |Z| < 11 m, and E > 200 MeV;
  - set 2 - for low-energy particles E < 15 MeV;
  - set 3 - for the rest.

- Dynamic switch between these 3 sets during tracking is performed
  - Providing accuracy for tracking of relativistic particle
  - Reducing tracking problems for low-energy sparing e^{+-}

Magnetic field parameters	Parameter set 1	Parameter set 2	Parameters set 3
DeltaIntersection (mm)	10^{-6}	0.01	10^{-4}
DeltaOneStep (mm)	10^{-4}	0.1	10^{-3}
DeltaChord (mm)	10^{-3}	0.1	$2 \cdot 10^{-3}$
MaxStep (cm)	150	150	50

Fast parameterization of electromagnetic showers

CPU effect as a function of the energy threshold
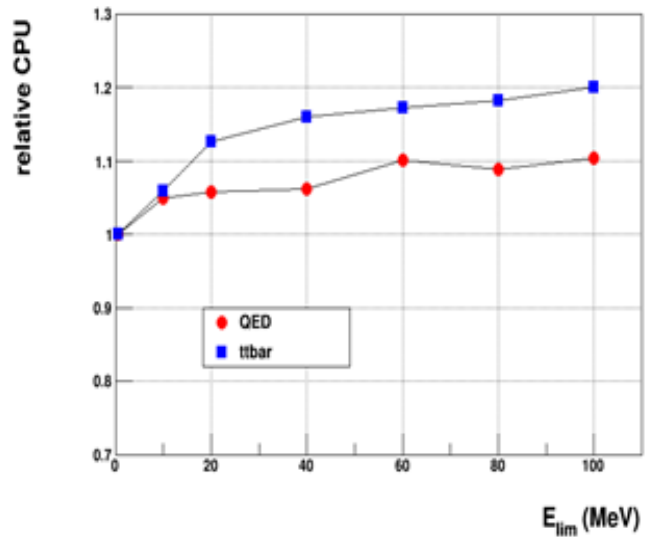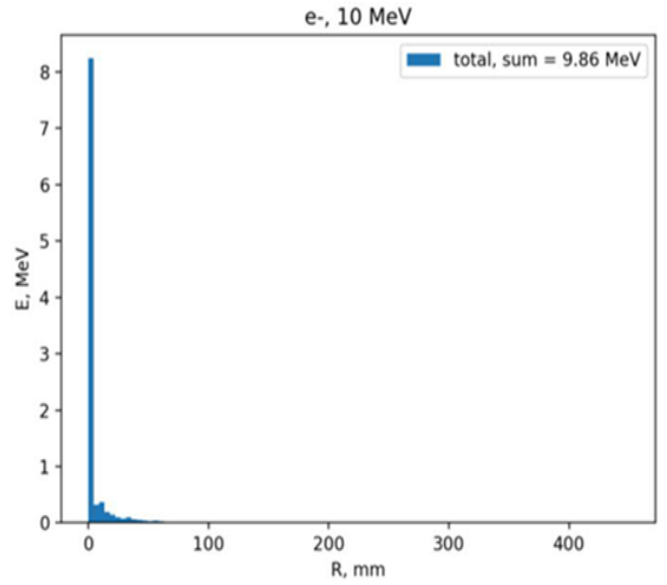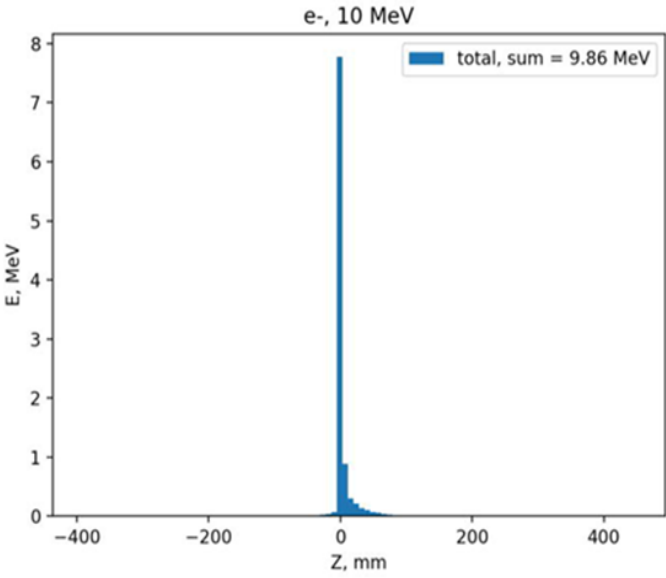
- Hybrid simulation of EM showers inside CMS ECAL
  - low-energy e^{+-} may be parameterized below 20 MeV
- Proposed method is currently under CMS testing

- Parametrized energy fraction deposited in-place E_0
- Parametrized $E_{tail}(Z)$, $E_{tail}(R)$
- In run time
  - Deposit E_0 in-place
  - Sample $Etail = E – E_0$ hits in space factorizing distributions for $Z \sim E_{tail}(Z)$ and $R \sim E_{tail}(R)$

vCHEP: V.Ivanchenko, CMS Simulation for Run-3

Summary

Intensive development carried out during LS2 for CMS FullSim

- Geometry for Run-3 was updated
- Run-3 geometry description migrated to DD4hep and currently being validated
  - Next step would be full migration to the DD4Hep tool for the Phase-2 detectors
- Geant4 10.7 is adopted
  - Required slight modification of physics configurations
  - Provides CPU advantage ~8 % compared to Run-2

Fast parameterization of low-energy e+- inside ECAL is introduced

- The method is under testing

CPU speed-up for Run-3 FullSim production is expected