Readiness of CMS Simulation towards LHC Startup

Outline

- Introduction
- Framework and Interface with GEANT4
- Detector specific components
- How have we fared
- Summary

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Sunanda Banerjee
CMS & Fermilab

Introduction

Monte Carlo samples in CMS will be used to

- Generate large amounts of signal and background events for use in physics analysis.
- Understand/Demonstrate analysis procedures and methods based on data to derive calibrations, efficiencies, resolutions for high level physics objects. (closure tests of data based methods).
- Directly derive calibrations, efficiencies, resolutions for high level objects in cases where data are biased or not available.

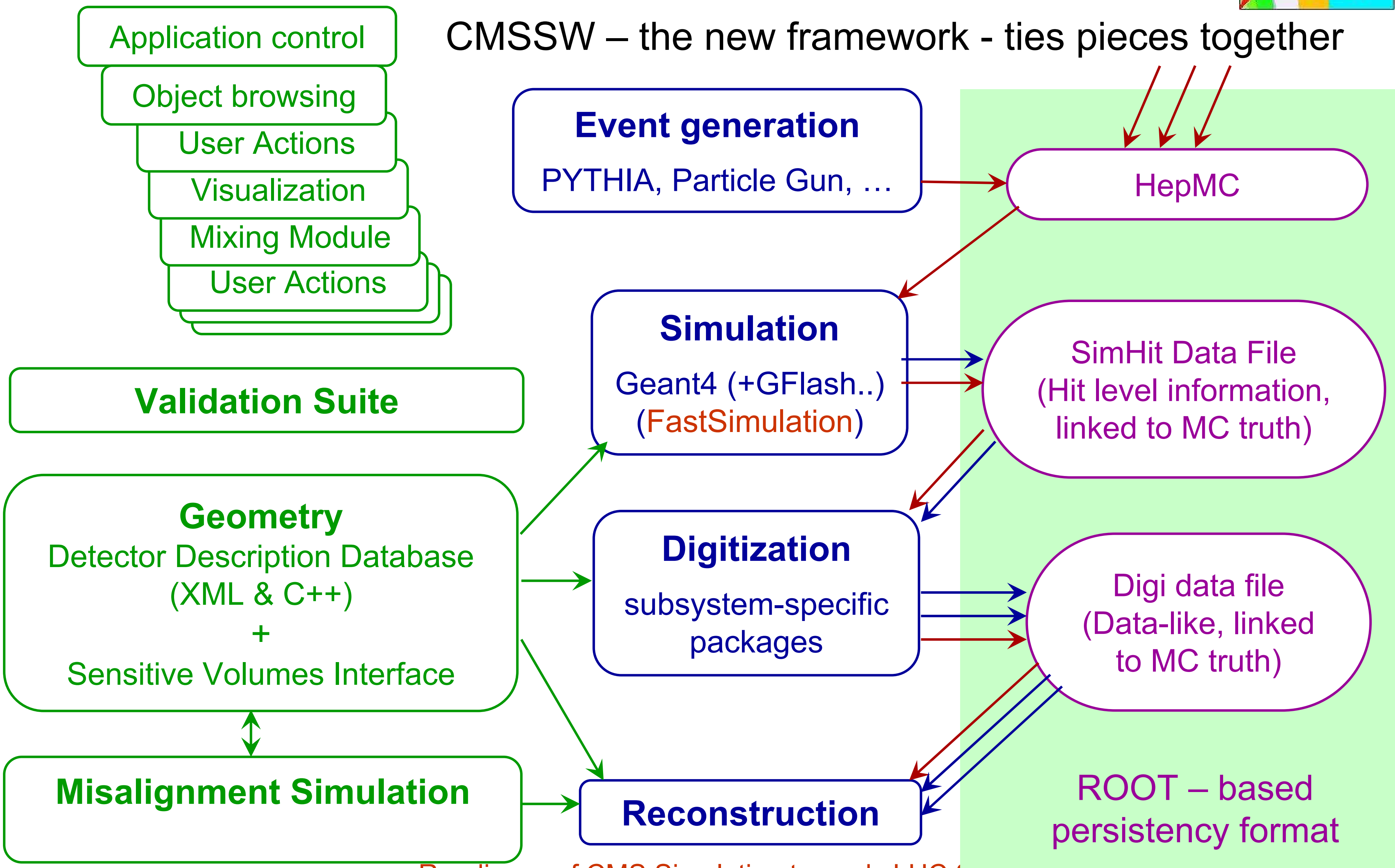
A data driven, realistic/accurate Monte Carlo, is an essential tool.

- Simulation effort started in CMS using GEANT3 more than a decade ago
- Evolved to the current design through 4 generations of Simulation Programs

Overview

- Though in operation for a number of years, it's a live system – goals, requirements, tools evolve throughout the lifetime of the experiment
- Based on Geant4 (8.2; in transition to 8.3/9.0):
  - **Physics processes: electro-magnetic and hadronic interactions**
  - **tools for detector geometry and sensitive element response**
  - **interfaces for tuning and monitoring particle tracking**
- New CMS offline framework and Event Data Model:
  - **Manages application control at run time**
  - **Relies on the concept of event processing module (EDProducer)**
  - **Interface to common tools (generators, magnetic field, MC truth handling, infrastructure for hits, event mixing, digitization, …)**
  - **Ensures provenance tracking and event immutability**

Simulation Software – CMS Solution



Interface to Geant4 (I)

- Core application = framework-based Event Data Producer + customized RunManager as interface between Geant4 and CMS Event Data Model
- Geometry record is available to either simulation or reconstruction via the framework EventSetup;
  - uses XML-based Detector Description machinery, configurable at run time via a hierarchy of XML files; converts DD solids and materials to Geant4 counterparts
- Sensitive detectors associated with geometrical volumes through XML configuration files at run time
- Magnetic field based on dedicated geometry of magnetic volumes; provided by independent subsystem via EventSetup; field selection, propagation tuning configurable at run time

Interface to Geant4 (II)

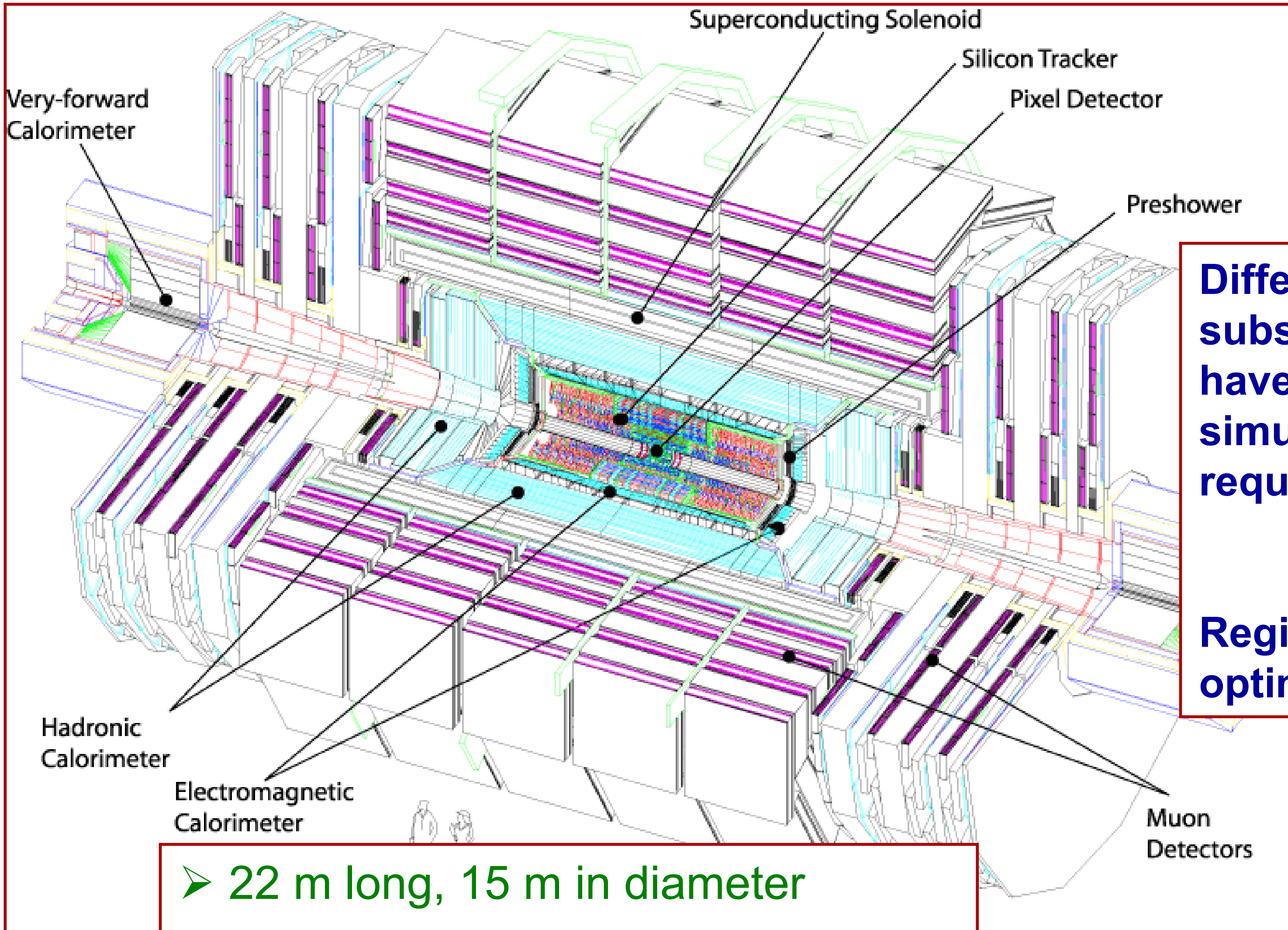
- Variety of lists (LHEP, QGSP/QGSP_EMV, QGSC, FTFP,…) for modeling physics processes; run-time selection of physics list and production cuts, activation/tailoring of individual processes;
- Variety of Physics event generators (particle guns, Pythia, Herwig,…); generator information stored in HepMC format and interfaced to G4Event
- User actions allow access to Geant4 objects at any stage (run, event, track, step); used for tuning, diagnostics, custom bookkeeping
- Monte Carlo truth record with decay/interaction history of the generator's particles and selected tracks from Geant4 simulation

Event Mixing and Digitization

- In-time pileup :
  LHC will produce ~3 (“low lum.”) or ~25 (“high lum.”) minimum bias interactions/crossing, on top of the trigger event
- Out-of-time pileup:
  Coming from bunch crossings before/after the trigger event
- Pileup events simulated separately from the physics events; merge of simulation outputs at hit level (reuse)
- Performed by a dedicated module, in a separate step
- Followed by simulation of the electronic readouts (Digi’s)
- Dedicated Digi module for each subsystem (separate steps)

Provide real data overlap tool for realistic pileup

The CMS Detector



Different subsystems have different simulation requirements

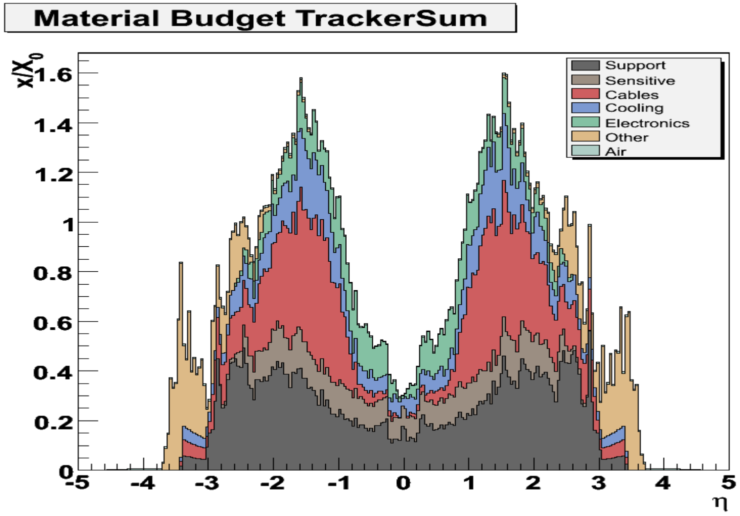
⇓

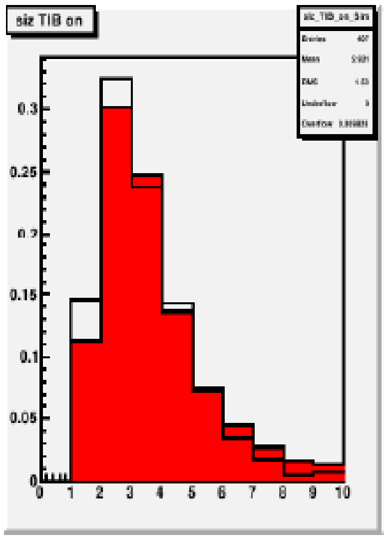
Region based optimization

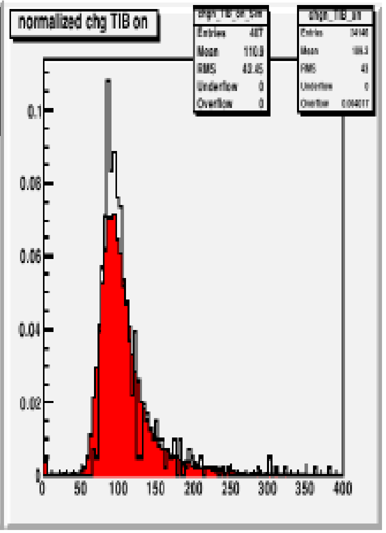
- 22 m long, 15 m in diameter
- Over a million geometrical volumes
- Many complex shapes

Tracker

- ❑ Demands a high degree of accuracy:
  - – Description of active and passive components
    - ➢ Review each component with full information from integration centres
    - ➢ Verify by weighing individual components
  - – Correct, navigable Monte Carlo truth
  - – Proper treatment of hard electron bremmsstrahlung
- ❑ Extensively validated in terms of signal simulation, tracking, dE/dx, …

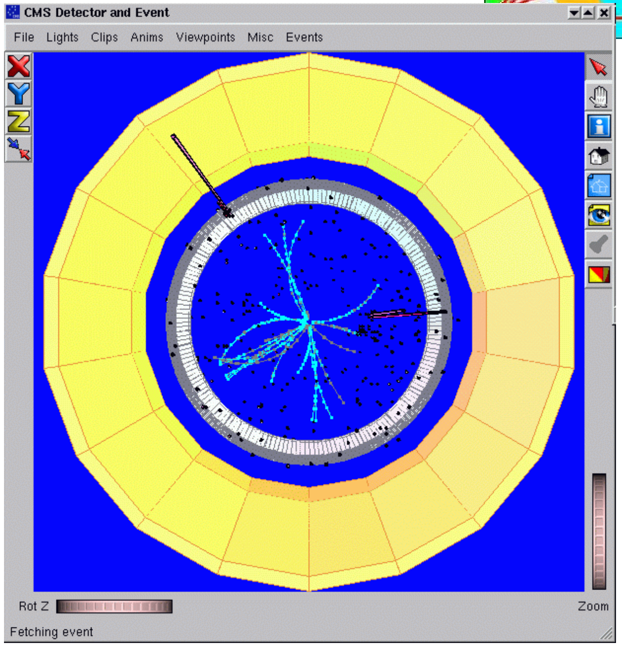


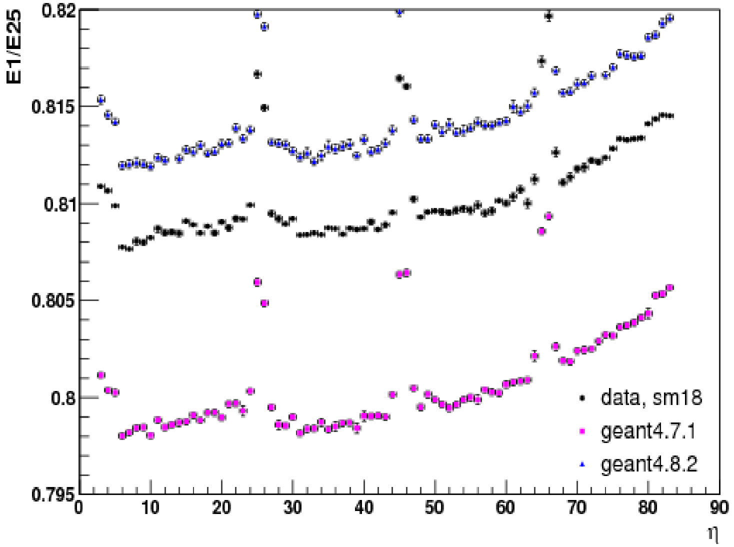




Electromagnetic Calorimeter

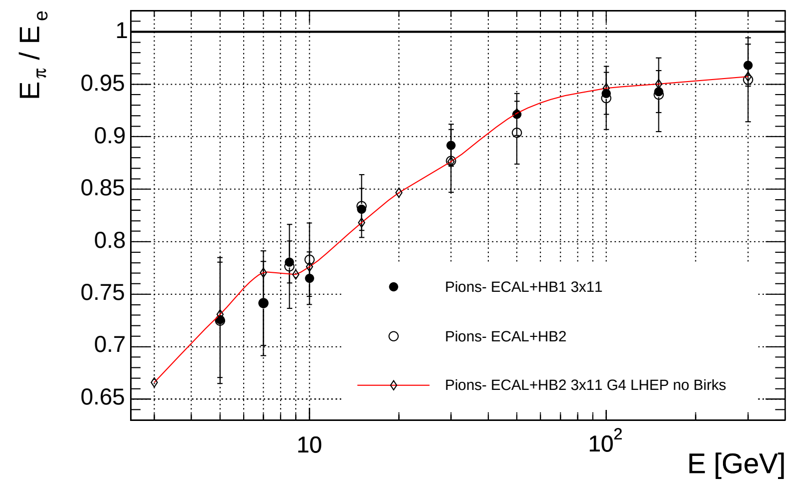
- Accurate description of geometry and material budget
  - Independent alignment of modules, super-crystals, wafers, …
  - Updated distribution of support, cooling, readout
- Good/complete implementation of physics process
  - Transverse shower profile (containment, calibrations)
  - Longitudinal shower profile (leakage, …)
- Validated extensively with test beam for energy measurement and transverse shower profiles

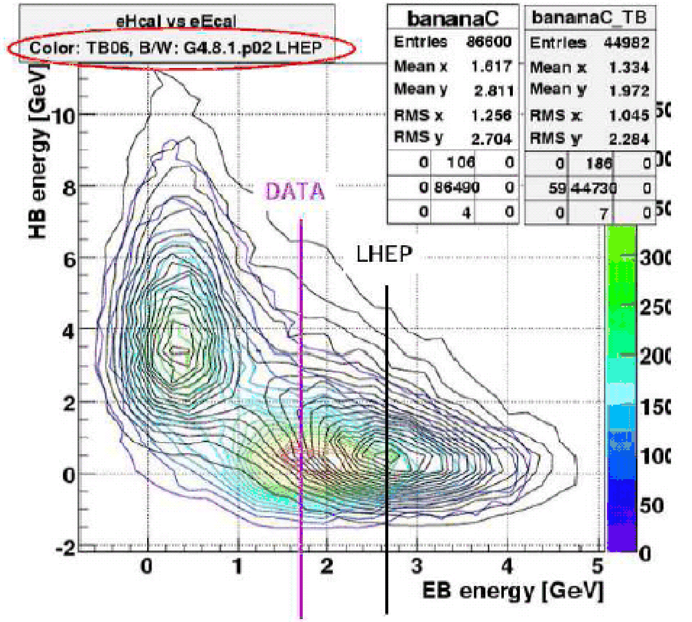




Hadron Calorimeter

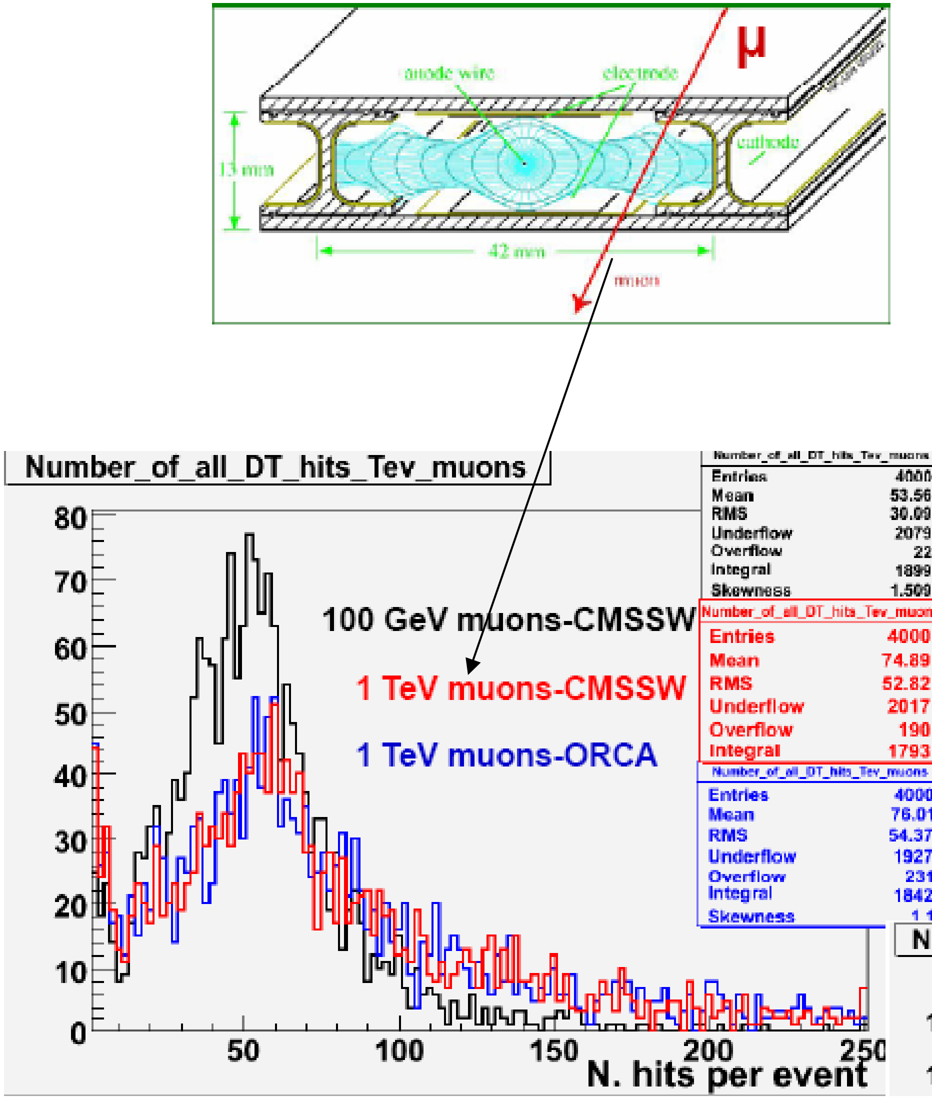
- Comparisons between single particle measurements in test beam: 2002-2007, with different HCAL modules, preceded by real ECAL super-module or prototype, to beams of π, e and μ over large energy range
- HCAL studies on energy resolution and linearity, e/π ratio, and shower profile instrumental in validating G4 hadronic physics models [parametric (LHEP) and microscopic (QGSP, QGSP_BERT,…)]
- Faithful description of timings, noise,
- Use of shower libraries, noise libraries, …





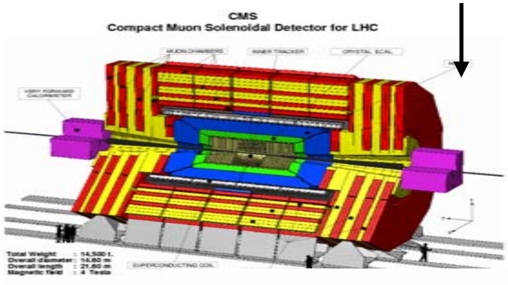
Muon System

- Geometry description verified using the Cosmic data collected during MTCC
- Muon physics in G4 is extensively tested and validated in the energy range 10 GeV – 10 TeV
  - Improved description of μ bremmsstrahlung, μ-nuclear effects, ..
  - Better description of multiple scattering (in agreement of data)
- Validate new descriptions with earlier simulation and with test data

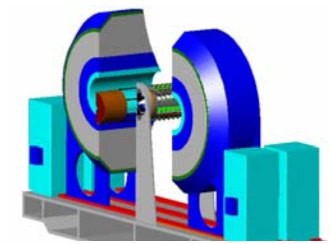


Forward Detectors

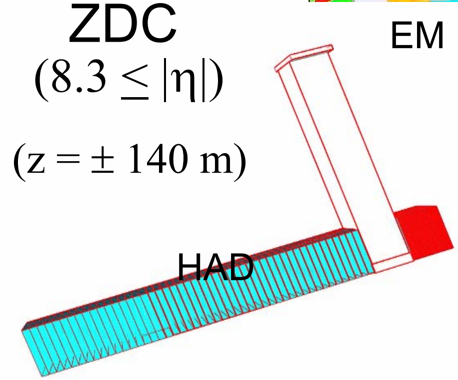
HF
$(3 \leq |\eta| \leq 5.2)$

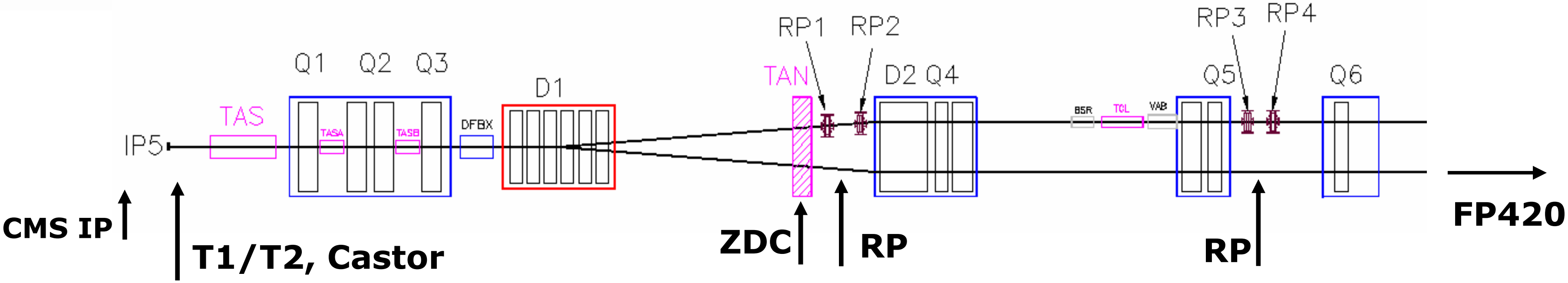


T1,T2
$(5.2 \leq \eta \leq 6.7)$
$(z = \pm\, 7.5, \pm\, 14.5$ m)

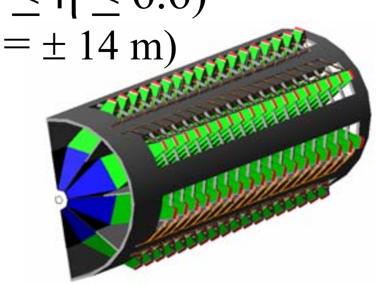


ZDC
$(8.3 \leq |\eta|)$
$(z = \pm\, 140$ m)

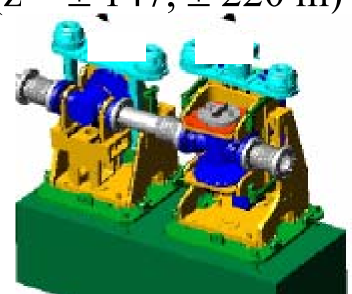




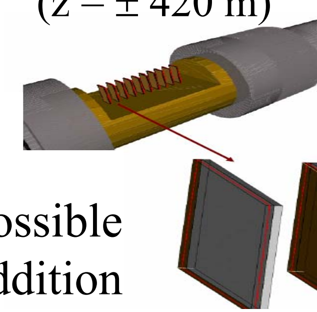
CASTOR
$(5.2 \leq \eta \leq 6.6)$
$(z = \pm\, 14$ m)



Roman Pots
$(z = \pm\, 147, \pm\, 220$ m)



FP420
$(z = \pm\, 420$ m)



possible addition

Forward Detector Simulation

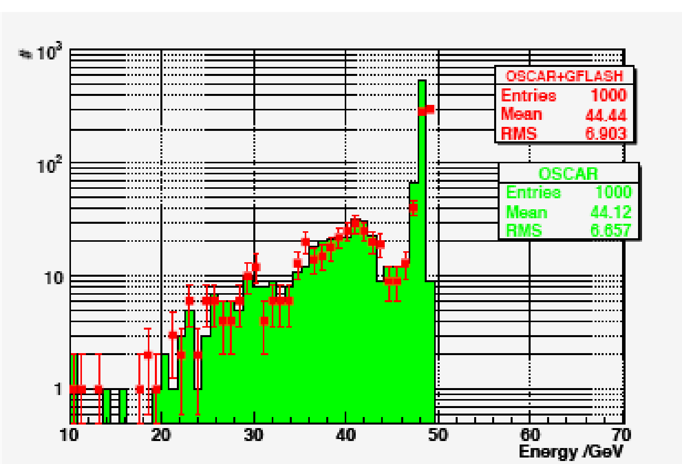
- ❑ Essential for diffractive and heavy ion programs
- ❑ Simulation of stand alone systems has been compared with test beam studies regarding energy resolution, leakage, …
- ❑ Simulation with central as well as forward detectors is foreseen:
  - Use filter to separate particles from event generators to be processed through central and forward detectors
  - Use a separate transport code Hector to transport particles within acceptance of forward detectors close to forward detectors
  - Also obtain beam interactions from a library obtained using MARS
  - Transport the particles in the central detector and also in the forward detector region using G4
  - Combine all the simulated hits to get the overall event

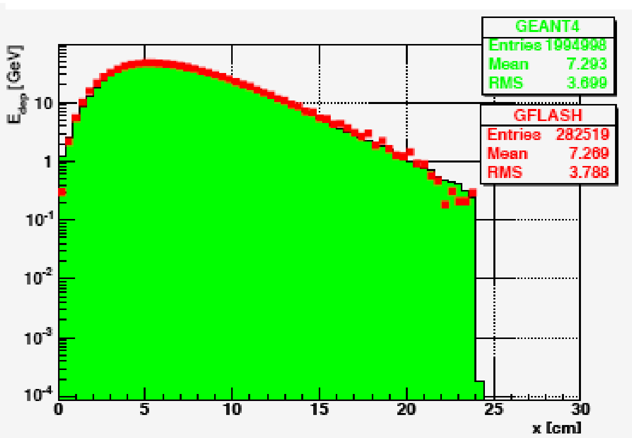
Parameterized Simulation

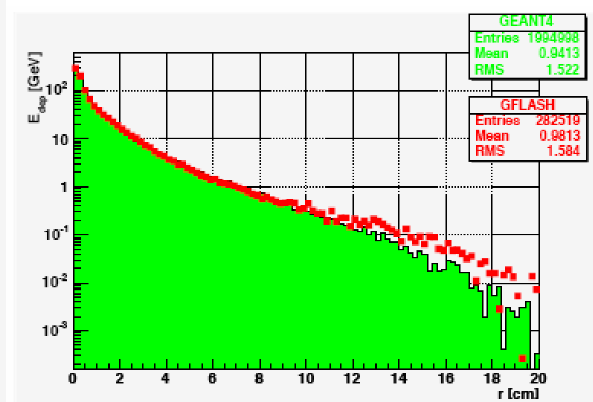
- GFlash model based on three probability density functions and used for parametrizing showers of electrons, positrons and photons in CMS barrel and endcap EM calorimeter allows speed up without compromising simulation accuracy
- Infrastructure is being built to parameterize hadronic showers and to tune it

Comparisons between GFlash-based and full simulation

- Energy deposits as well as shower profiles of parameterized and full simulations compare well
- Single e or γ with E=100 GeV in ECAL barrel: factor ~10 speed-up





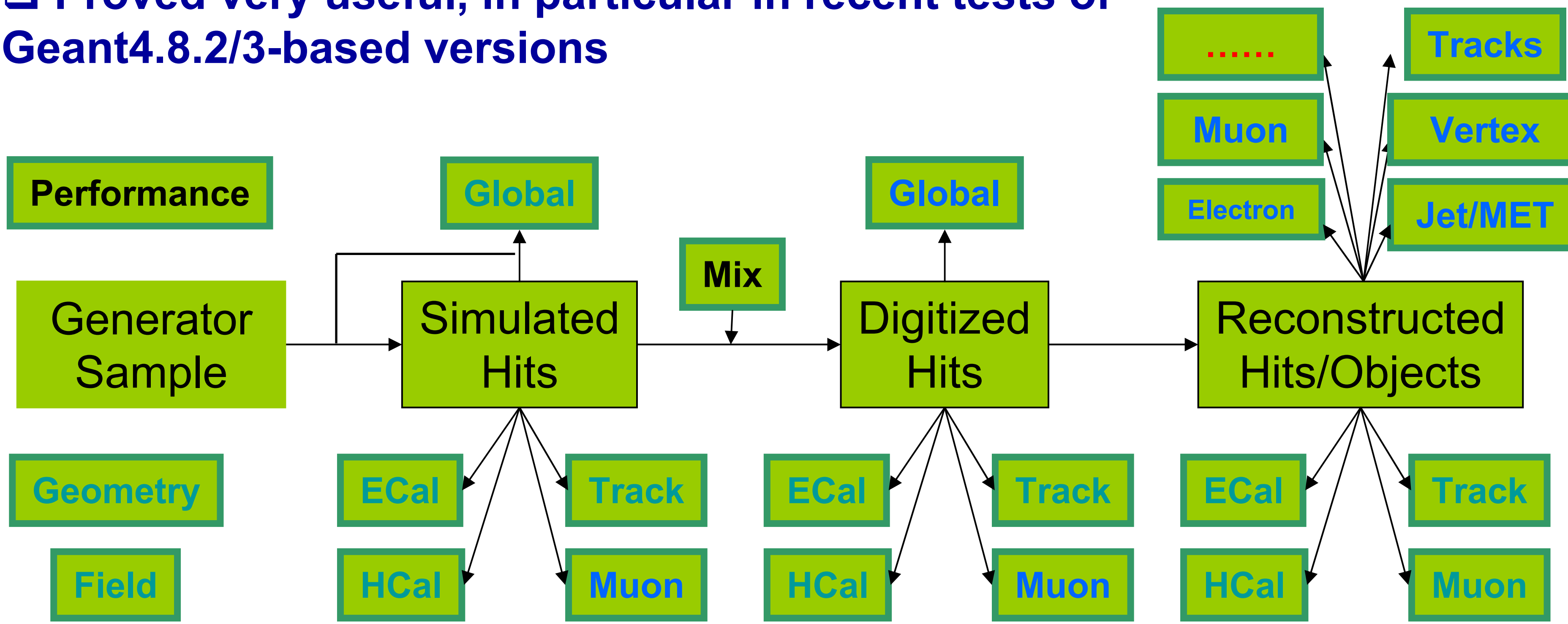


Software Validation

- Validation of physics processes modeling, via dedicated test beam setup simulation compared vs test beam data – feedback to Geant4

- Software Validation Suite, to ensure simulation (or other) software reliability, release-to-release, when changing Geant4 version, etc…

- Proved very useful, in particular in recent tests of Geant4.8.2/3-based versions



Performance and Production

- With the new/upgraded software: nearly 250 million events simulated by the production team since July 2006 (100 million with Geant 4.7.1 during CSA06 and validation efforts and 145 million with Geant 4.8.2.p01 during CSA07)
- Do extensive test/validation between G4 version changes
- Failure rate: <5% (arithmetic problem; trap NaN; skip event)

  expect to improve as we switch to Geant4.8.3 (in October)
- Speed [Intel(R) Xeon(R) CPUE5335 @ 2.00GHz, Geant4.8.2.p01 with QGSP_EMV physics list, interactive testing] very preliminary :

  Minimum bias events : 23 seconds per event

  t-tbar : 170 seconds per event
- CMS strategy:

  equal number of simulated and real events (~ $1.5x10^9$/year)

  Aim to achieve this with a mixture of full and fast simulation

Summary and Outlook

- In CMS, the Geant4-based Object Oriented simulation has been successfully implemented
- Ported to the new framework, widely validated (feedback reported to Geant4), used for physics and detector studies
- Proven to be robust, powerful, maintainable
- Capable to fulfill emerging requirements
- Further developments :
  - finalize geometry updates
  - simulate simultaneously central and forward detectors
  - include shower parametrization, real data overlap
  - Performance improvement (robustness, speed, memory usage,…)