The Fast Simulation of the CMS detector

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Abstract

A framework for Fast Simulation of particle interactions in the CMS detector has been developed and implemented in the overall simulation, reconstruction and analysis framework of CMS. It produces data samples in the same format as the one used by the Geant4-based (henceforth Full) Simulation and Reconstruction chain; the output of the Fast Simulation can therefore be used in the analysis in the same way as data and Full Simulation samples. The Fast Simulation has been used already for several physics analyses, in particular those requiring a generation of many samples to scan an extended parameter space of the physics model (e.g. SUSY) or for the purpose of estimating systematic uncertainties. Comparisons of the Fast Simulation results both with the Full Simulation and with the LHC data collected in the years 2010 and 2011 at the center of mass energy of 7 TeV are shown to demonstrate the level of accuracy achieved so far.

Physics processes

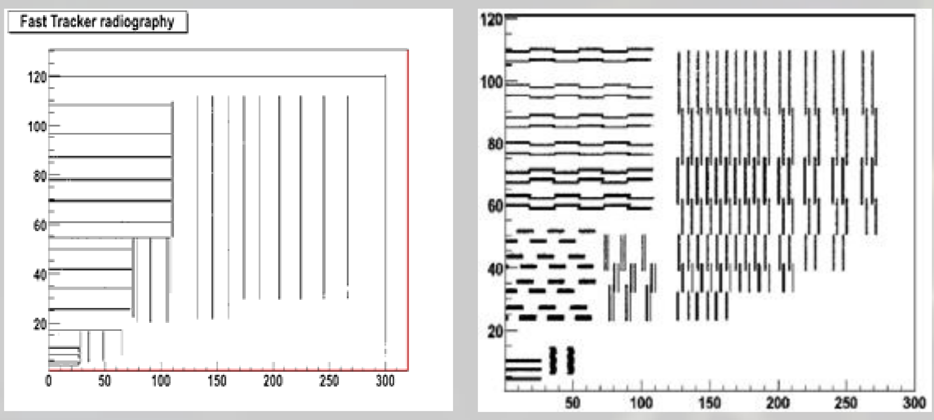
The simulation starts from a list of particles originating from an event generator. Particles are propagated in the CMS magnetic field to the different layers of the various sub-detectors, and are allowed to decay according to their known branching fractions and decay kinematics. The particles resulting from the interactions with the detector layers or from the decays in flight are added to the original list, and propagated/decayed in the same way. The interactions simulated at present in the fast simulation are:

- **electron Bremsstrahlung**
- **nuclear interactions**
- **photon conversion**
- **electron, photon, and hadron showering**
- **charged particle multiple scattering**
- **charged particle energy loss by ionization**

Pile-up is simulated by overlaying minimum bias pp collisions, randomly chosen from a pre-generated samples of one million events. The particles from PU events are treated in same way of these from main event. Only in-time PU is simulated in Fast Simulation, i.e., additional collisions in the same bunch crossing as the primary (hard) event.

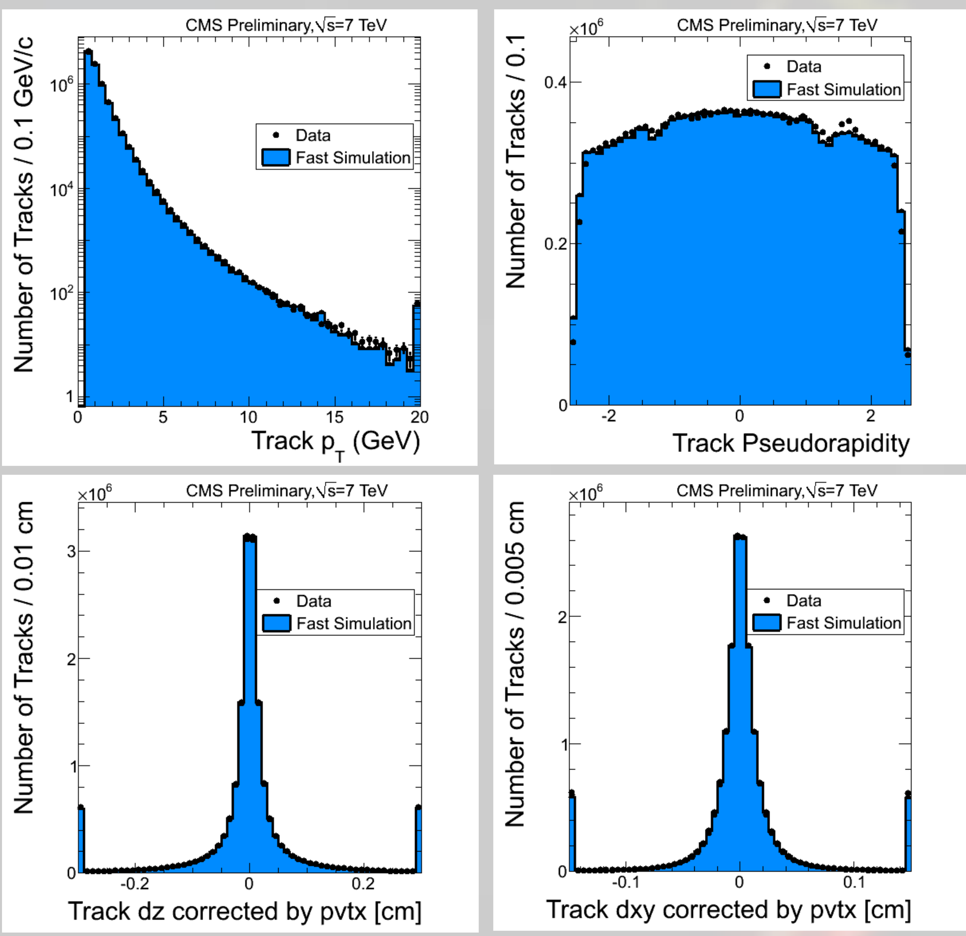
Tracker simulation

The interactions are simulated by exploiting a simplified version of the tracker geometry. The material, assumed to be pure silicon, is also assumed to be uniformly distributed over each cylinder barrel (respectively, endcap).



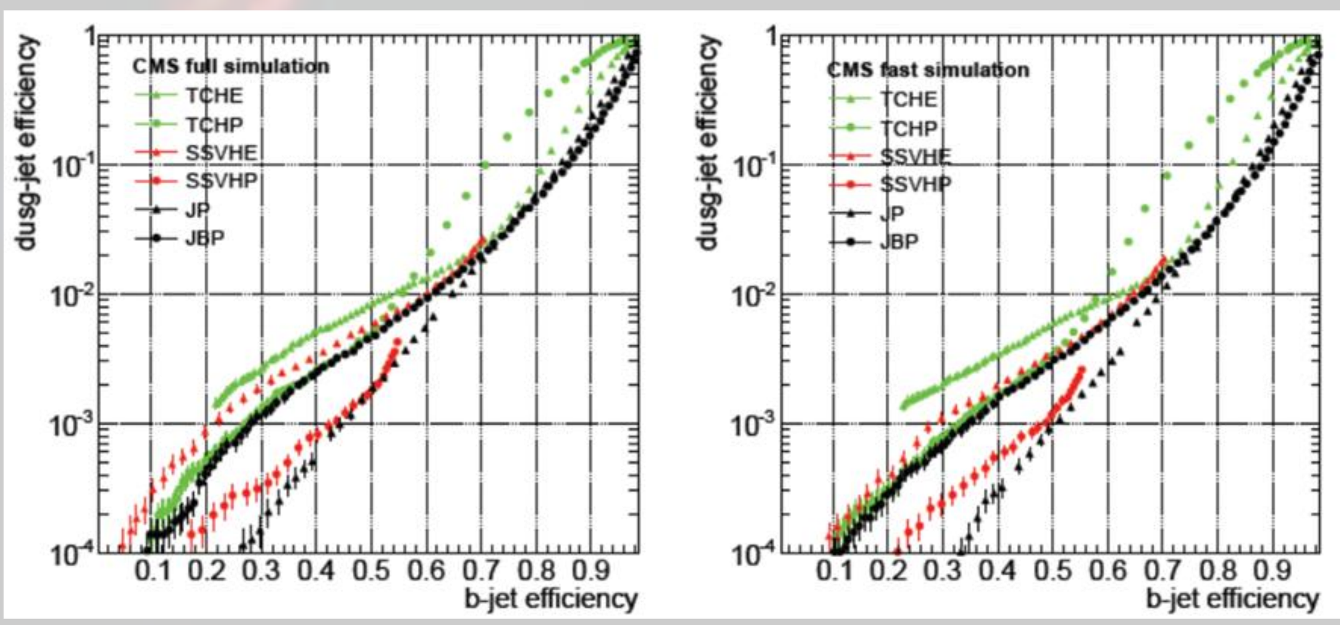
The complete magnetic field map is used for the track propagation between two surfaces. The "simulated hits" are created at the intersections between the modified trajectories and each tracker layer. Each of these is turned with a certain efficiency to a "reconstructed hit", the position of which is obtained from a Gaussian smearing of the simulated hit position.

The reconstruction is performed by a "fast tracking" algorithm: the reconstructed hits are fit with same fitting algorithms as in the full reconstruction; and the features of the full pattern recognition are emulated to reproduce the observed efficiency.



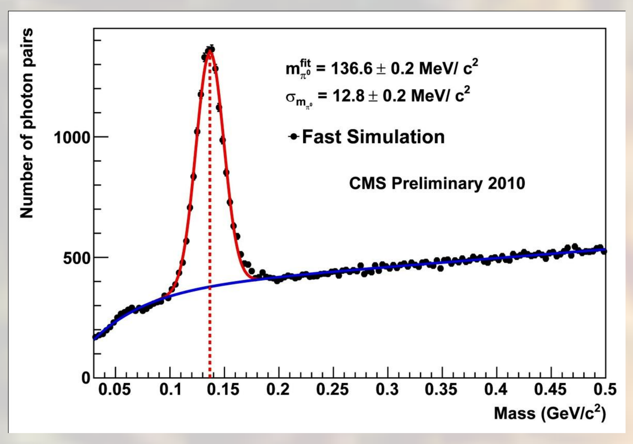
Comparison between the Data and Fast Simulation (top) for transverse momentum, pseudo-rapidity, transverse and longitudinal impact parameter for minimum bias events.

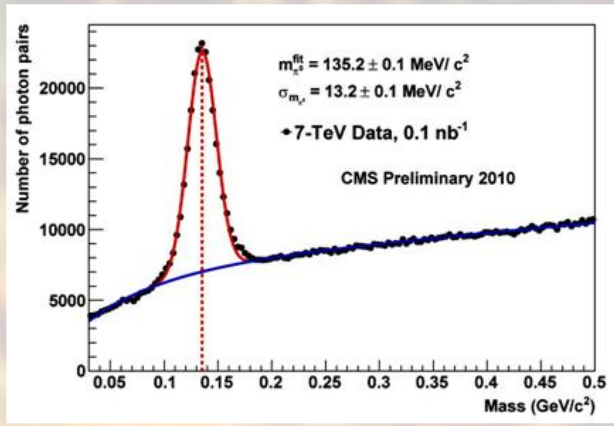
Comparison between Full and Fast Simulation for b-tagging efficiency (right).

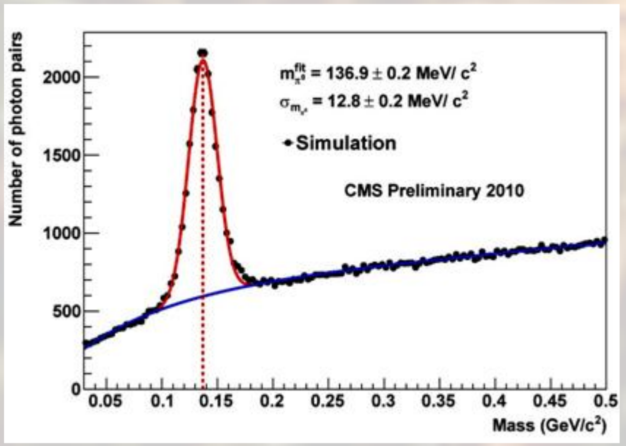


Calorimeters simulation

Electrons and photons make a shower in ECAL, which is treated as an homogeneous medium. The simulation exploits the GFLASH parameterization in which an electromagnetic shower consists of several thousand energy spots, longitudinally distributed according to a Γ function. The deposited energy is integrated over 2 X0-thick longitudinal slices, including uncertainties due to the limited photo-statistics and the longitudinal non-uniformity in the crystals. Then, in each slice the energy spots are distributed in space according to the radial profile and placed into the actual crystal geometry, under the realistic assumption that no energy is lost in the small inter-crystal gaps.



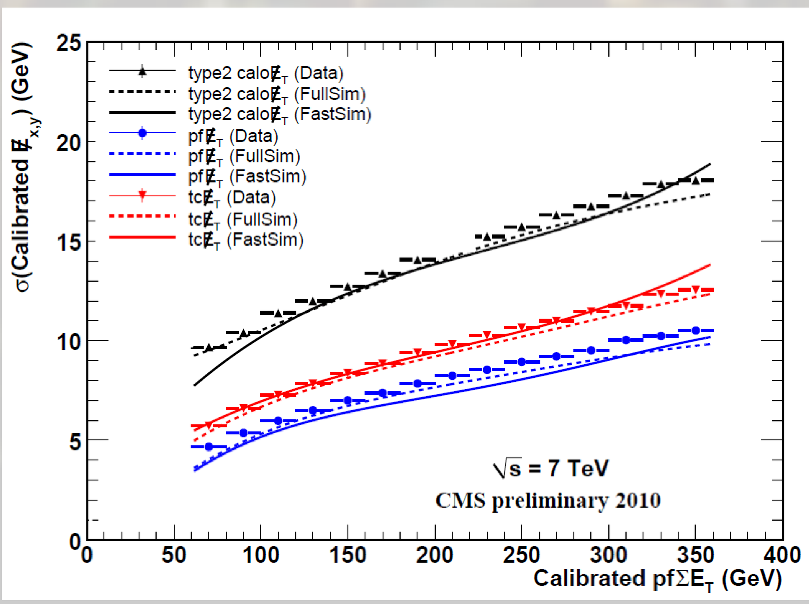




The plots of the π^0 di-photon mass show the impressive quality of the Fast Simulation (top left) low-energy Particle Flow reconstructed photons with respect to both Data (top right) and Full Simulation (bottom left).

Charged and neutral hadrons are also propagated to ECAL, HCAL and HF after the interaction with the tracker layers. Their energy response is obtained by fitting the energy response of single charged pions in Full Simulation. The parametrization is a function of energy in the range from 1 to 3000 GeV and, and of η in the whole acceptance sliced in 0.1 bins. This is used to simulate the gaussian hadron response that is then distributed in the calorimeters using parameterized longitudinal and lateral shower profiles, with shower-to-shower variations, following an approach similar to that of GFLASH. The same approach is followed for electrons and photons in the HF acceptance.

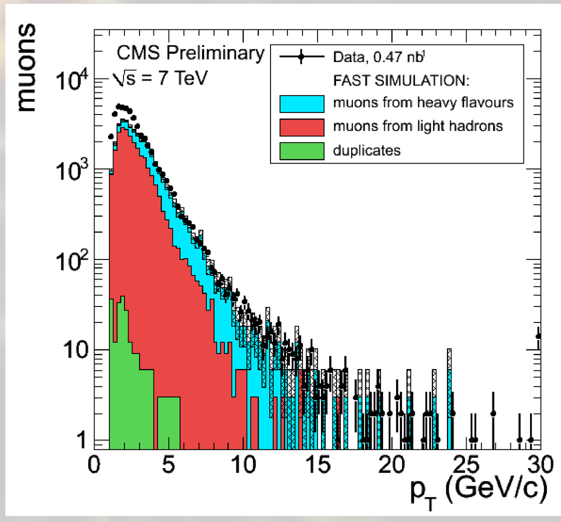
The plot shows that simulation is quite good for what concerns the energy resolution.



Muon chambers simulation

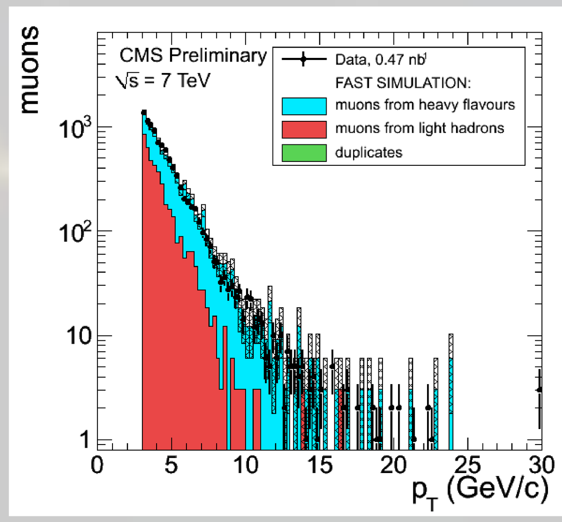
The muons are propagated in the CMS magnetic field through the tracker, the calorimeters, the solenoid and the muon chambers. The only simulated physics processes are the multiple scattering and the energy loss by ionization. The processes as bremsstrahlung or δ-ray production are taken into account in the hit mis-association efficiency in a probabilistic way. The actual geometry of the CMS muon chambers (DT, CSC and RPC) is taken from a CMS database. The simulated hits are created at the intersection of the track trajectories with the active layers of those chambers.

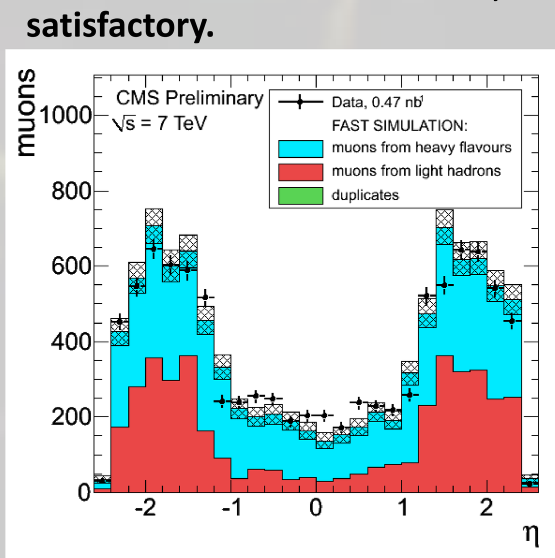
Then, the hits are digitized in the same way as in the Full Simulation chain, and the resulting digis (raw data equivalent) are fed to the normal local and global muon reconstruction packages, to end up with the final muon objects to be used in the physics analyses.

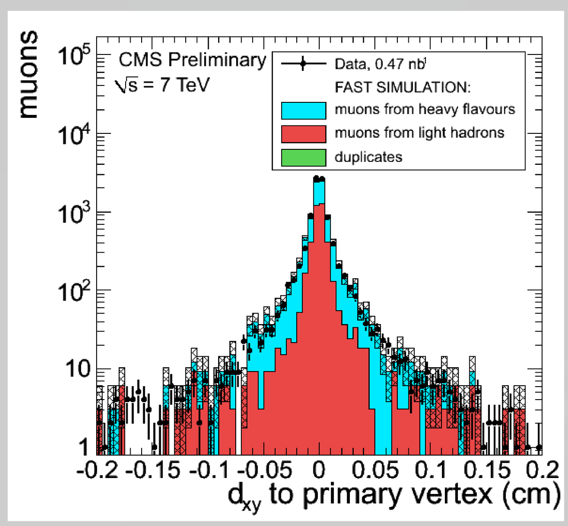


The comparison with Full Simulation and Data shows a deficit of muons in Fast Simulation, concentrated in the low p_T part of the spectrum. This is because the decays in flight of hadrons (K, π, …) are only allowed within the tracker volume; and also because the punch-through from hadron showers is not taken into account by Fast Simulation.

The typical muon selection in CMS has a higher p_T threshold and further quality cuts precisely to reduce the contribution from the punch-through and from muons originating far from the main interaction. For these so defined "tight muons" the agreement between the Fast Simulation and the data, and between the Fast and the Full Simulations, is satisfactory.







Trigger simulation

L1 trigger primitives are built in the ECAL, HCAL and Muon systems starting from the detector hits produced by the Fast Simulation, and used to generate the L1 decision functions as for Full Simulation and real data. These L1 primitives serve then as seed for the subsequent L2/L3 objects, which build up the HLT decision functions. Although there is some customized, Fast Simulation specific reconstruction of a few L3 objects, the HLT uses the same menus and algorithm as in the real data chain.

Recent and forthcoming evelopments

A tighter integration with the Full Simulation in:

- **simulation of the ECAL and HCAL electronic read-out** (digitization, as already done for the muon chambers);
- **simulation of the out-of-time PU events** from proton-proton collisions in the near bunch crossings to the one with primary (hard) event.