Fast Simulation of the CMS Detector at the LHC*

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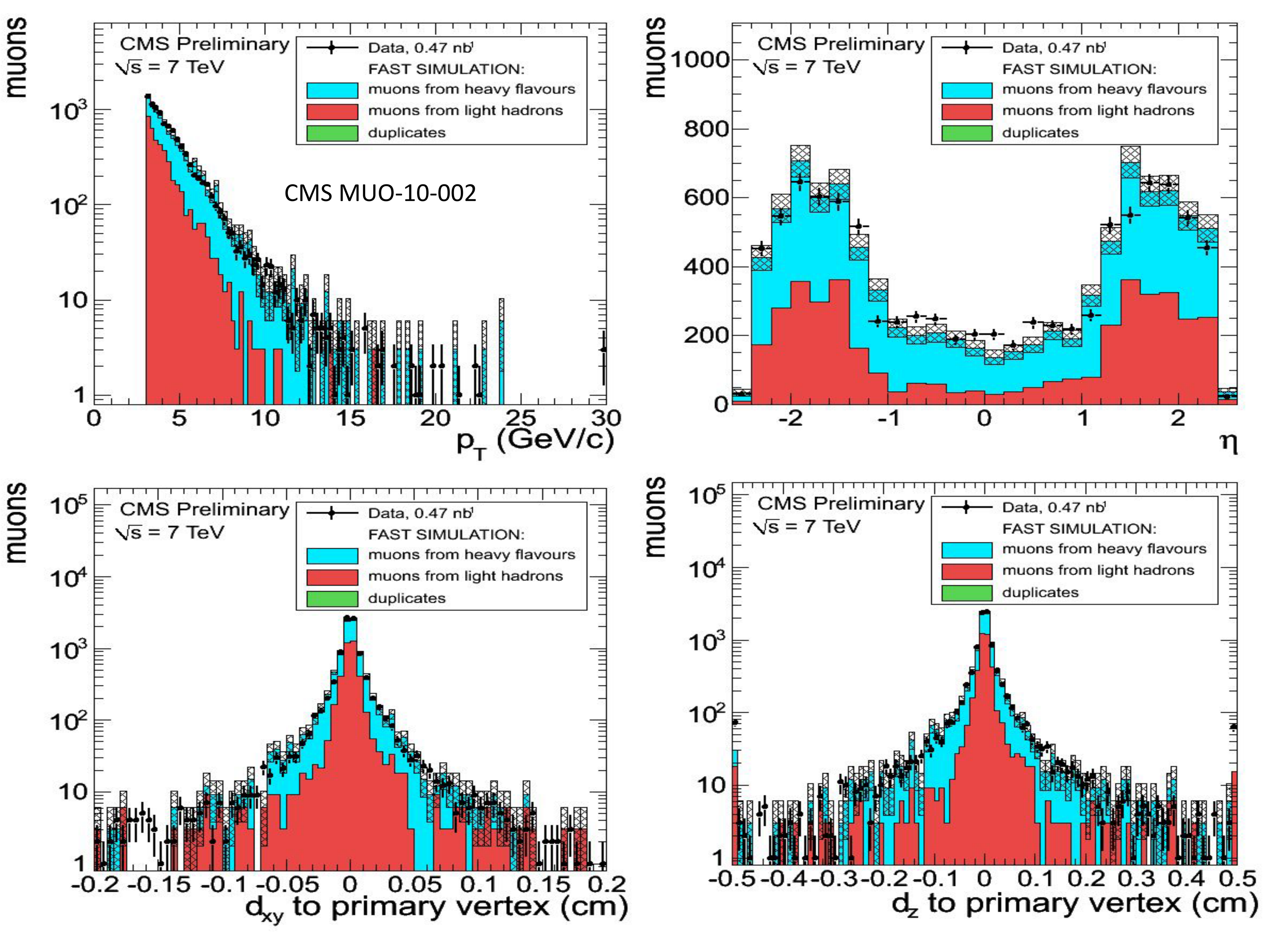
Fast Simulation* (***FastSim***) of particle interactions in the CMS detector has been developed and implemented in the overall simulation, reconstruction and analysis framework of CMS. It produces data samples in the same format as the one used by the Geant4-based (Full Simulation) and Reconstruction chain; the output of the ***FastSim*** can therefore be used in the analysis in the same way as other ones.
The Fast Simulation is intended, for example, for analysis requiring a generation of many samples to scan an extended parameter space of the physics model (e.g. SUSY), or analysis involving a consideration of large cross section backgrounds. The ***FastSim*** is an object-oriented subsystem of the general CMS C++ based software. The simulation part itself is typically 500-1000 times faster than the corresponding Full Simulation one (process dependent). We discuss here the basic and their implementation in the different components of the detector to demonstrate the level of accuracy achieved so far.

The physics processes

Input of the Fast Simulation are particles (from an event generator or a simple particle gun) characterized by their momentum and origin vertex, then propagated in the CMS magnetic field to the various CMS sub-detectors. The interactions simulated in the Fast Simulation are
1) electron Bremsstrahlung;
2) photon conversion;
3) charged particle energy loss by ionization;
4) charged particle multiple scattering;
5) nuclear interactions;
6) electron, photon, and hadron showering.
The first 5 are applied to particles crossing the thin layers of the tracker, while the latter is parameterized in the electromagnetic and hadron calorimeters. Muons propagate through the tracker, the calorimeters and the muon chambers with multiple scattering and energy loss by ionization taken into account in the propagation

Simulation of the Muon Detectors

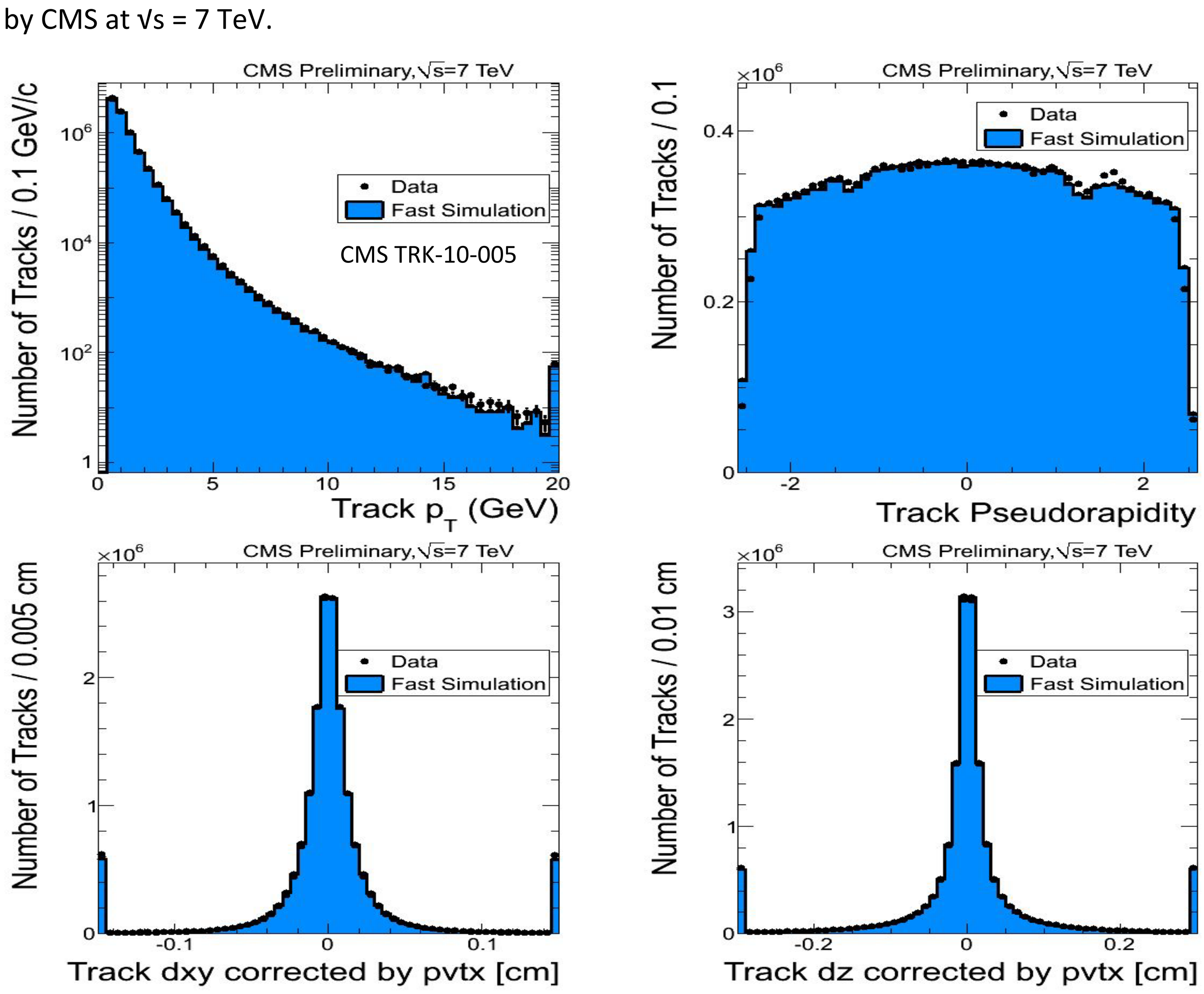
A muon is propagated in the CMS magnetic field through the tracker, the calorimeters, the solenoid and the muon chambers. The actual geometry of the CMS muon chambers (DT, CSC and RPC) is taken from a CMS database, and simulation hits are positioned in the detector whenever the track trajectory crosses an active layer of those chambers. Then, these simulated 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.



Transverse momentum (a), pseudorapidity (b), transverse (c) and longitudinal (d) impact parameters for Tight Muons, in data and Fast Simulation.

Simulation of the Tracker

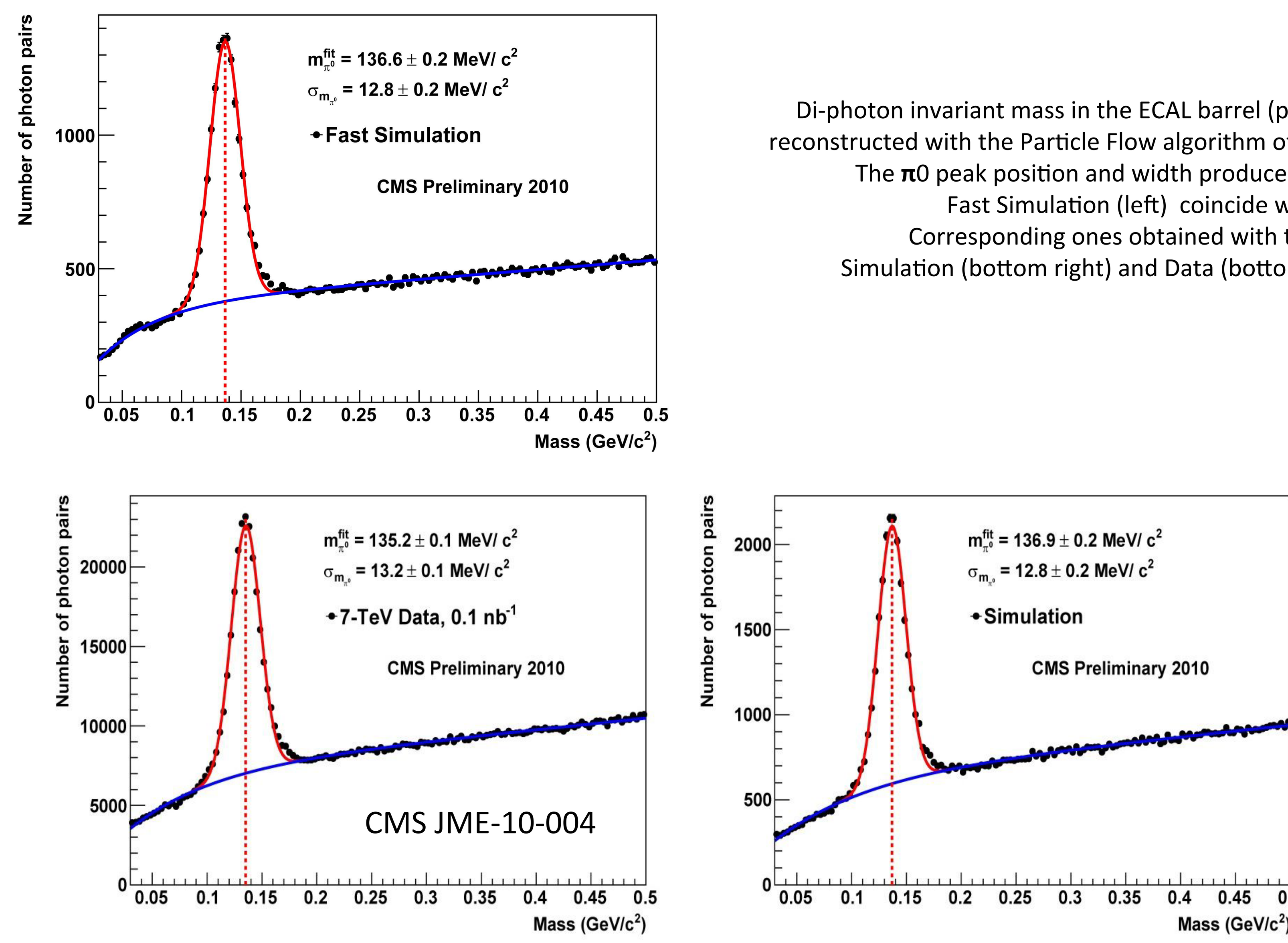
A simplified version of the tracker geometry is considered in the propagation of the simulated particles. Simulation hits are then created at the intersection of the track trajectory with the actual tracker geometry. To speed up the reconstruction of charged particle tracks, the reconstructed hits belonging to a given simulated charged particle are fit, with the same fitting algorithms as in the complete reconstruction. The quality of the FastSim reconstruction of tracks can be appreciated by looking at a few distributions obtained for Minimum Bias events in the Fast Simulation, compared with the data collected by CMS at √s = 7 TeV.



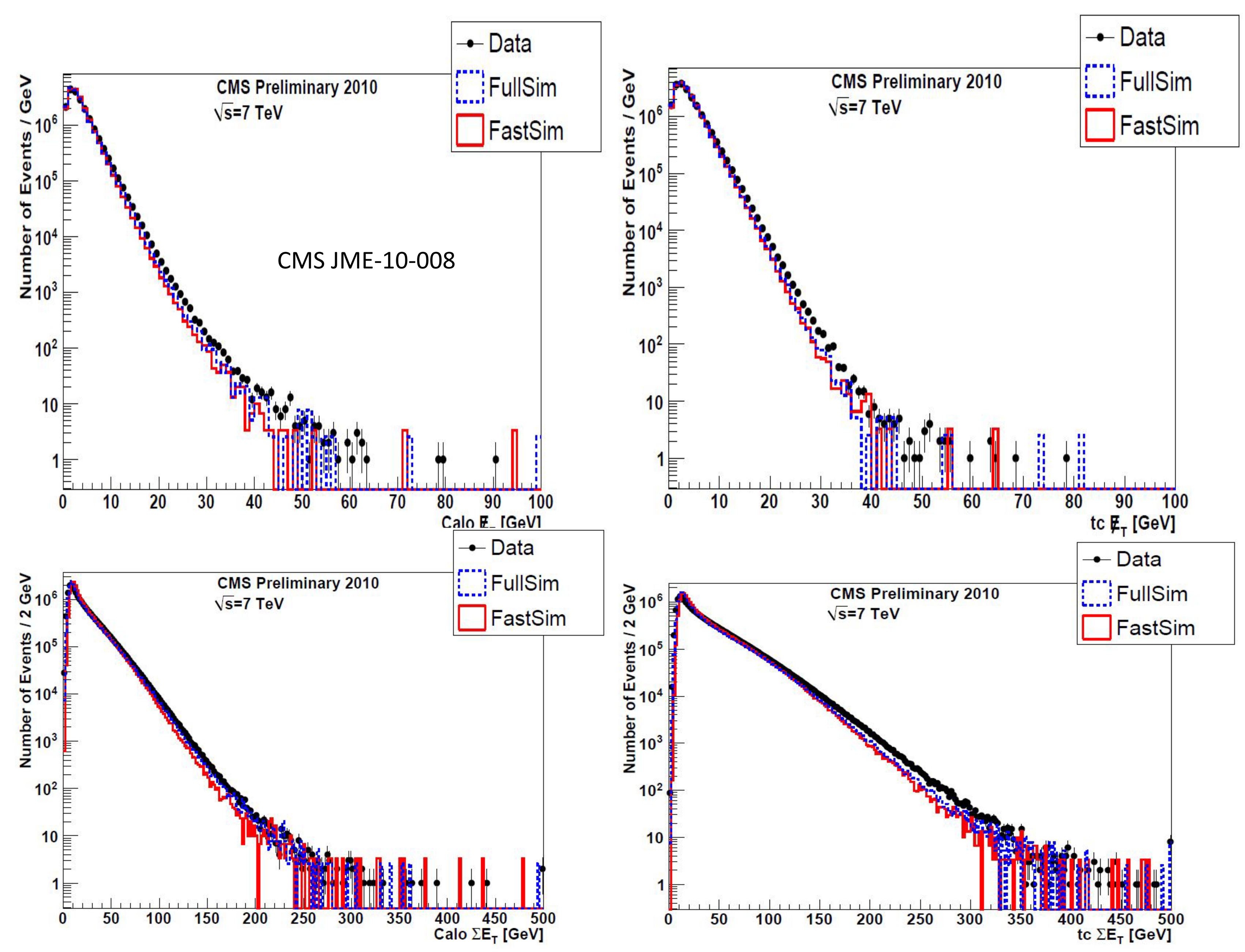
Distributions in pseudorapidity, transverse momentum, transverse and longitudinal impact parameters in the data and in the Fast Simulation of CMS

Simulation of the Calorimeters

Electromagnetic showers in the ECAL are simulated using well-tuned Grindhammer's GFLASH parameterization**, as if the ECAL was an homogeneous medium. In this parameterization, 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 properly. Then, in each slice the energy spots are distributed in space according to the radial profile and placed into the actual crystal geometry. Hadrons are propagated to the ECAL and HCAL surfaces after their interactions with the tracker layers. Their energy response is derived from the Full Simulation of charged pions. It is tabulated as a function of the hadron energy and pseudo-rapidity. This smeared energy is then distributed in the calorimeters using parameterized longitudinal and lateral shower profiles, following an approach similar to that of GFLASH.



Di-photon invariant mass in the ECAL barrel (photons reconstructed with the Particle Flow algorithm of CMS). The π0 peak position and width produced using Fast Simulation (left) coincide with the Corresponding ones obtained with the Full Simulation (bottom right) and Data (bottom left).



Missing ET (top) and sum of all ET (bottom) for calorimetric jets (left) and calorimetric jets corrected with the tracks (right) in the Data, Full Simulation and Fast Simulation.

Simulation of the Trigger

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 FullSim and real data. Those L1 primitives serve then as seed for the subsequent L2/L3 objects, which build up the HLT decision functions.

Reference:
* CMS Collaboration, CERN-CMS-DP-2010/039
** G. Grindhammer, M. Rudowicz, and S. Peters, Nucl. Instrum. Meth. A290, 469 (1990)