# Fast Simulation of the CMS Detector

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## Why Fast Sim?

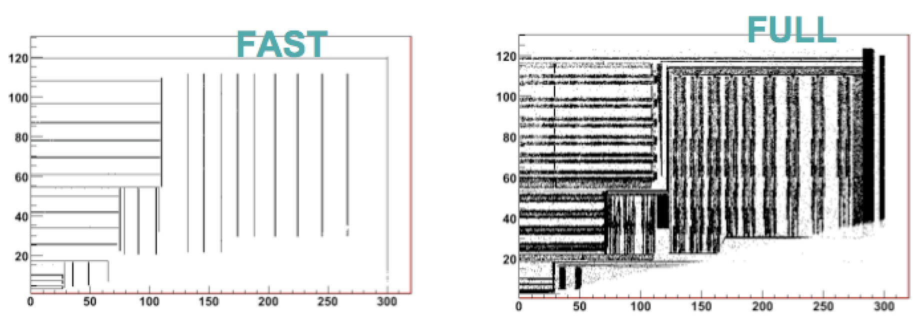
- CMS will need very high statistics Monte Carlo simulated data, with billions of events, to study backgrounds, account for systematic errors, search for new physics and optimize reconstruction algorithms.
- Quick - Fast Simulation is between 100 and 1000 times faster than the Geant4-based detector simulation. For instance, in the Fast Simulation a $t\bar{t}$ event with pile-up takes 441 ms to process. Compare that to 170,000 ms for the Geant4-based simulation.
- Tunable - A wide range of intuitive detector parameters can be set based on data from collisions.
- Thorough - Fast Simulation does not cut corners. All physically relevant material effects are included as the particles propagate through the entire detector.
- Usable - Fast Simulation produces the same format for all of the objects produced by the standard offline reconstruction. Analysis code that works on standard files automatically works on MC samples produced with the Fast Simulation. Fast Simulation has been successfully used for large scale productions (a few billion events) for Physics.

## Additional Features

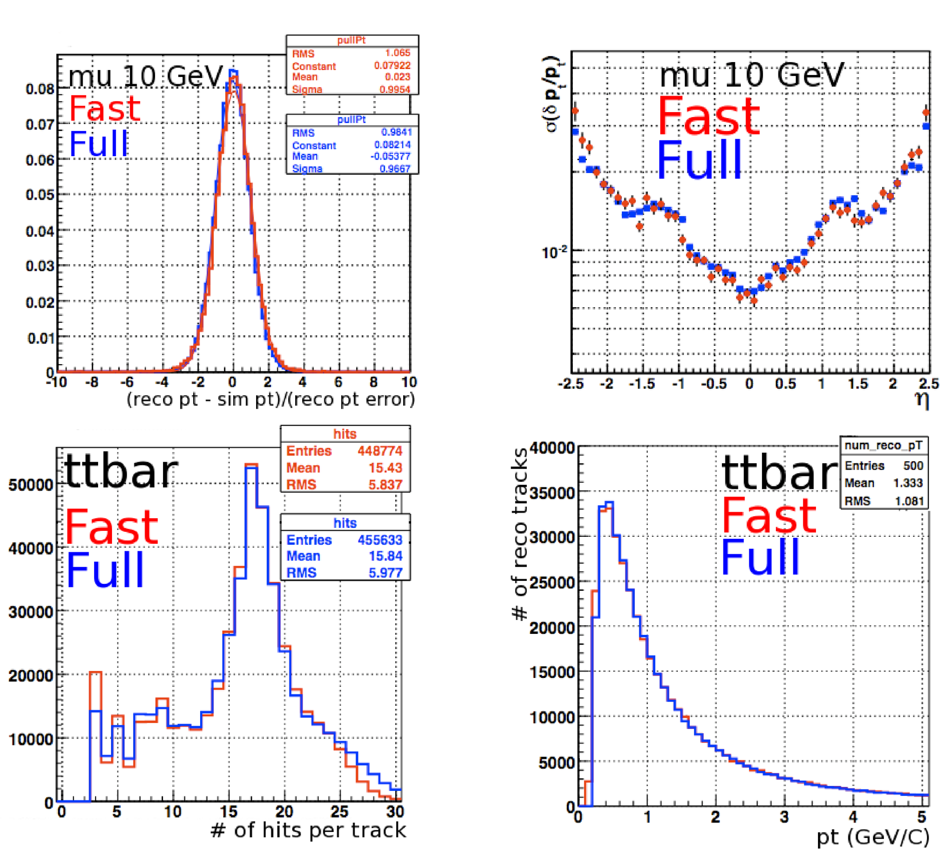
- Pile-Up - In-time pile-up is included for the Fast Simulation. Minimum-bias events, generated beforehand, are simulated together with signal events.
- Level 1 and HLT - The standard Level 1 and High Level Trigger configurations, taken from the database, are fully integrated into the Fast Simulation.
- Mis-Calibration - Mis-calibration of the ECAL and HCAL, and misalignment of the Tracker can be included to properly simulate conditions in the CMS.

## Tracking

- Resolutions of tracking hits are parameterized with input from the Geant4-based simulation and in the future data.
- Fast Simulation uses a custom pattern recognition emulation for tracking.



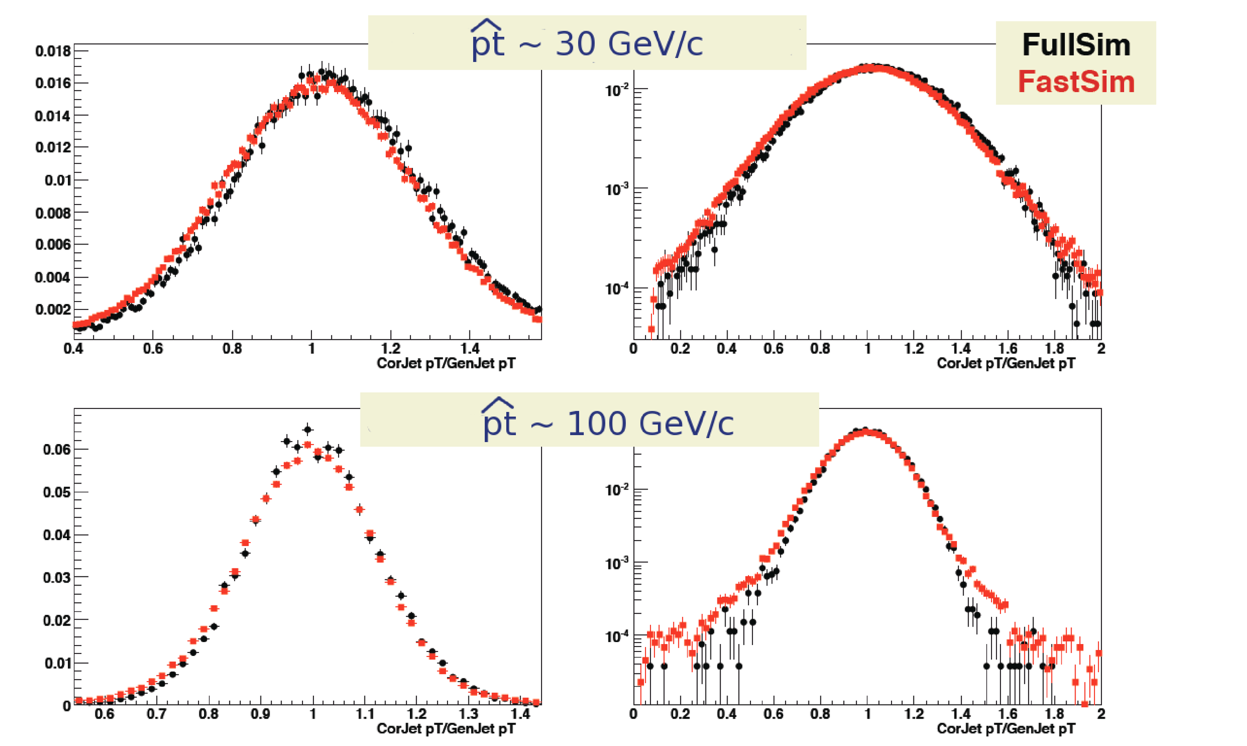

- Radiography of Tracker from vertices of converted photons in Fast Sim (left) and Full Sim (right).



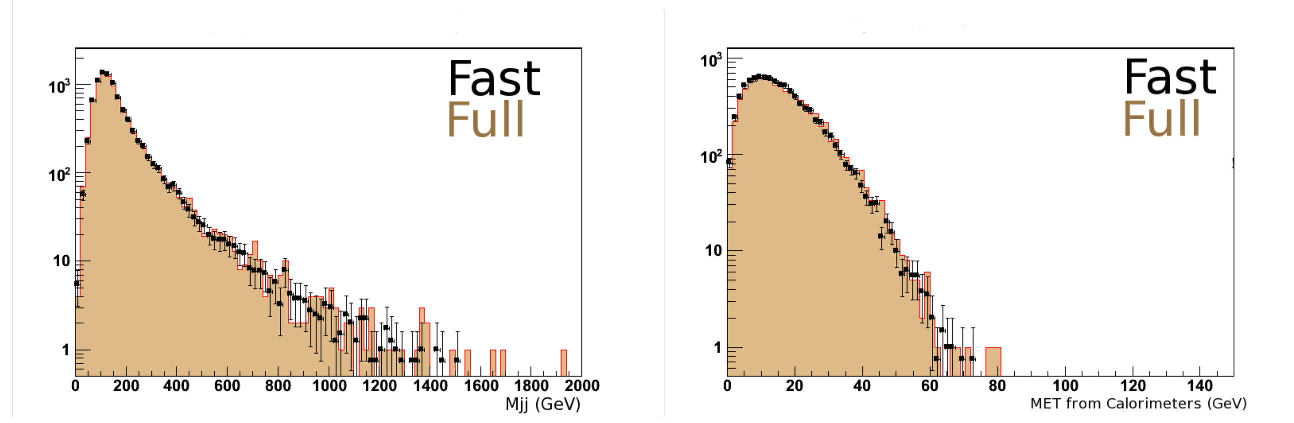

- Clockwise: Pull of $p_T$ for 10 GeV $\mu$, $p_T$ resolution for 10 GeV $\mu$, Number of tracks versus $p_T$ for $t\bar{t}$, Hits per track for $t\bar{t}$.

## Calorimetry

- Calorimeter showers are initiated with particles arriving from the tracker.
- Showers in the calorimeters are simulated using a parameterization that causes variations among showers, similar to GFLASH.



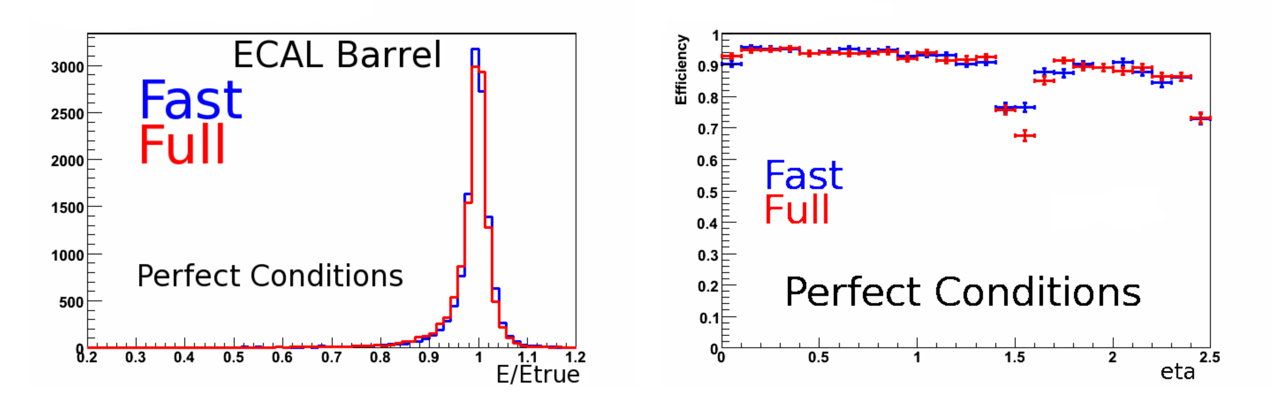

- Corrected jet energies over simulated jet energies for jets with $\hat{p}_T$ of $\sim$ 30 GeV/c (top) and jets with $\hat{p}_T$ of $\sim$ 100 GeV/c (bottom).




- $M_{jj}$ (left) and MET (right) for QCD jets with $\hat{p}_T$ = 80 - 120 GeV/c.

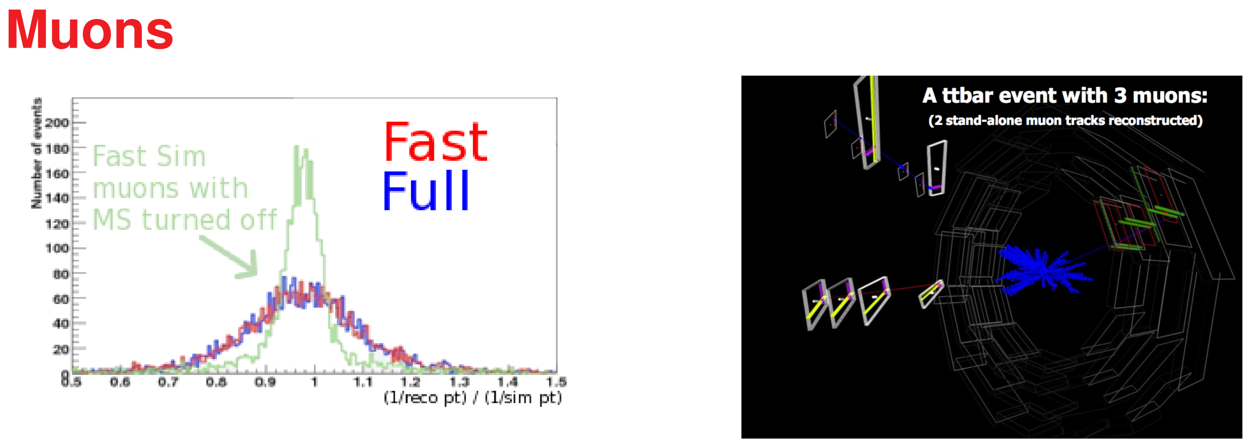
## Leptons

### Electrons




- Electron reconstructed energy divided by true energy in perfect conditions in the ECAL Barrel (left). Electron efficiency versus $|\eta|$ in perfect conditions (right).

### Muons

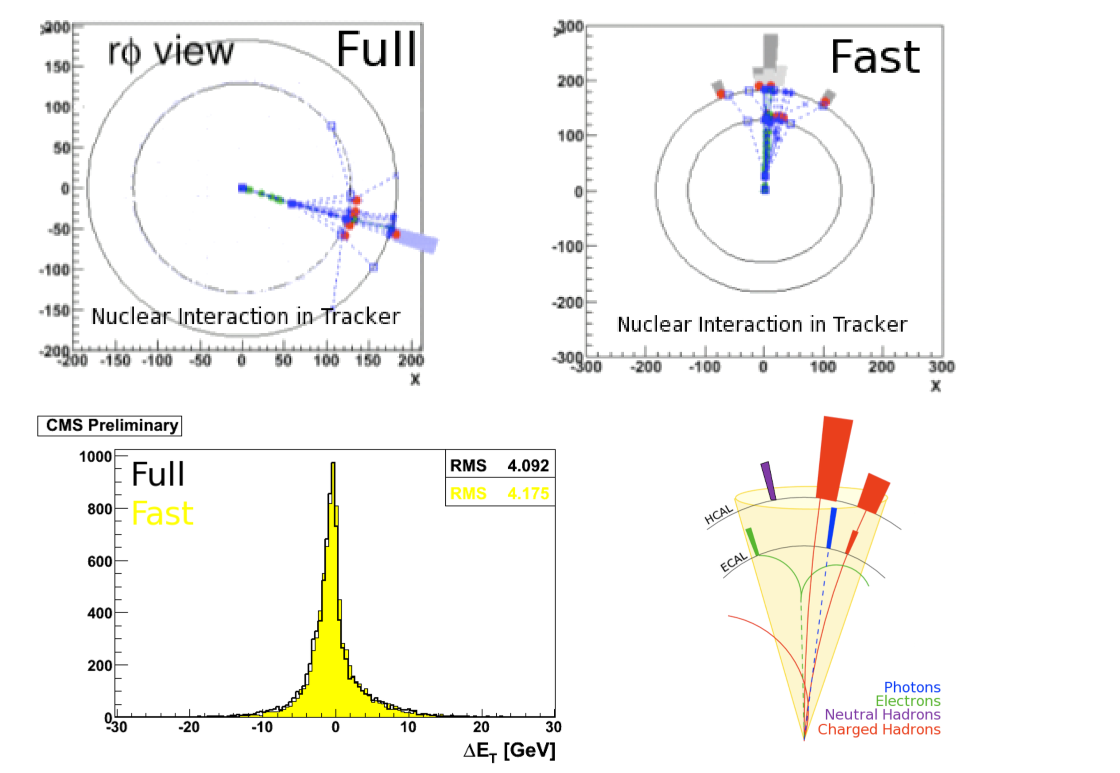



- Notice the good agreement in $1/p_T$ resolution between Fast Simulation and the Geant4-based simulation, and the large effect of multiple scattering (left). Event display of a $t\bar{t}$ event with muons (right).

## High Level Objects

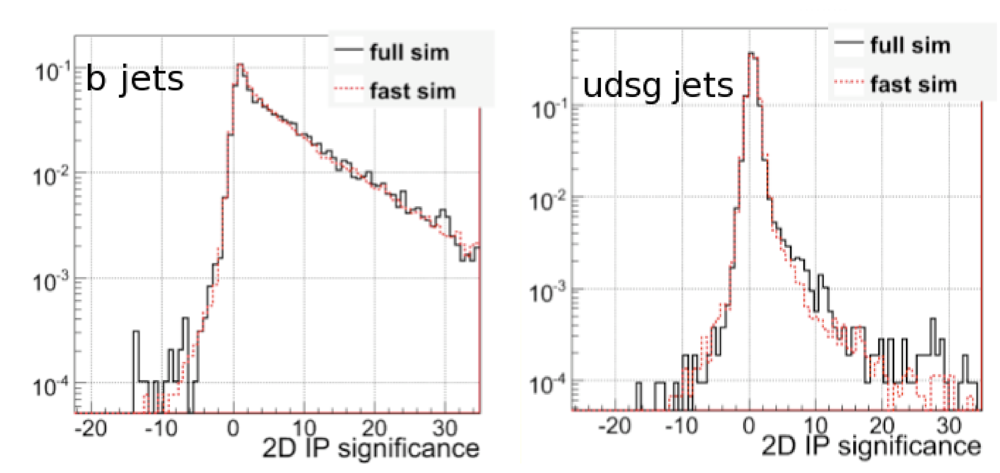
- Fast Simulation follows the propagation and interaction of the simulated particles through the entire detector. Therefore, complex reconstructed objects are in good agreement with the Geant4-based simulation.

### Tau Physics



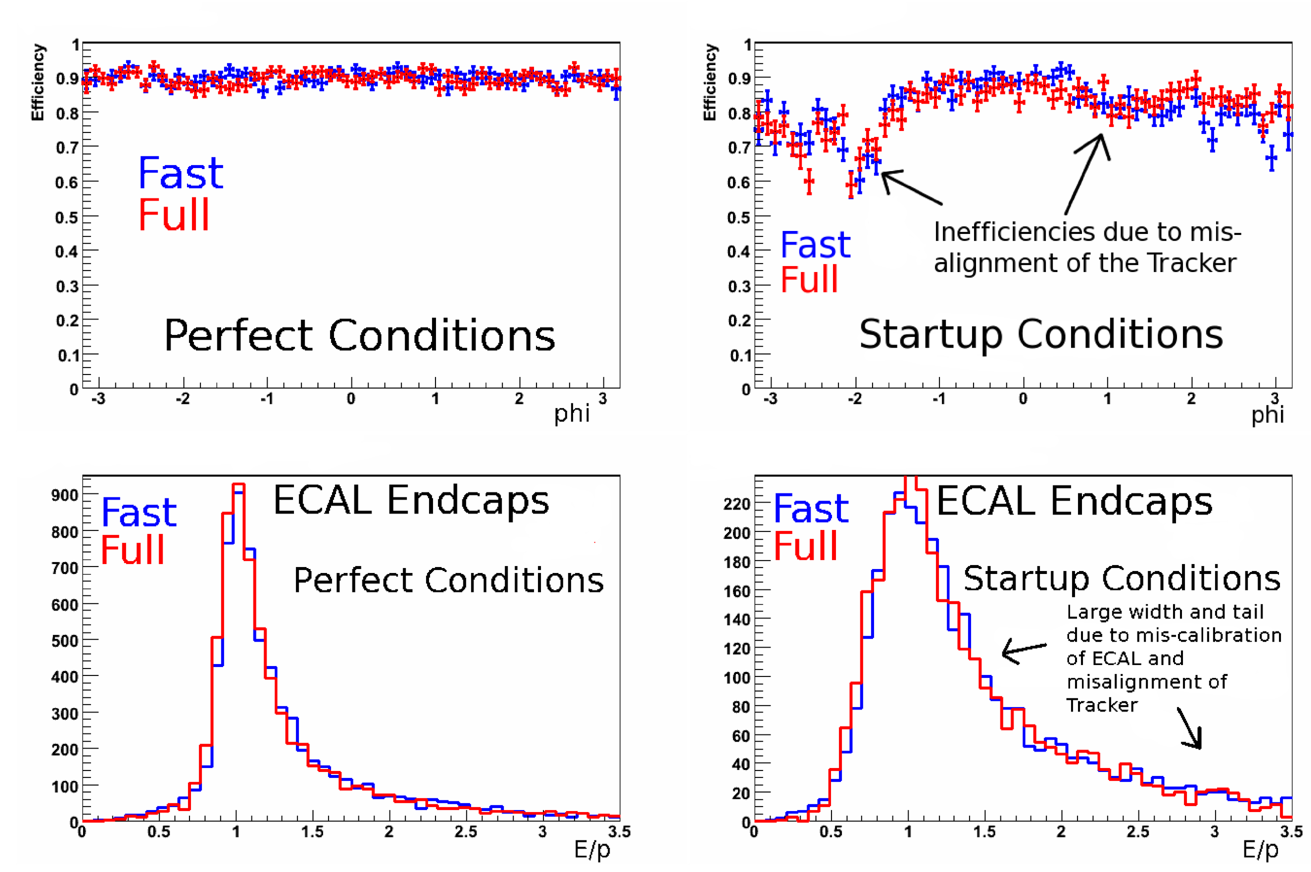

- Clockwise: $R\phi$ view of $\tau$ decay with a pion nuclear interaction in the Tracker for Full Sim and Fast Sim, Tau reconstruction is heavily dependent on the precise matching of reconstructed tracks and calorimeter clusters as illustrated in the diagram on the right, Reconstructed visible energy - simulated visibile energy in $\tau$ reconstruction.

### *b* Tagging




- Impact parameter significance for the second highest $p_T$ track in jets from $b$ quarks (left) and jets from uds quarks and gluons (right).

### Misalignment/Mis-calibration for Electrons




- The plots on the top show electron reconstruction efficiency versus phi in perfect (left) and startup (right) conditions. The plots on the bottom show electron energy over electron momentum in perfect (left) and startup (right) conditions in the ECAL Endcaps. The differences between the left and right plots are due to errors introduced by the misalignment of the Tracker and mis-calibration of the ECAL.


## Further Information and Acknowledgements

- CMS Collaboration, "The Physics Technical Design Report, Volume 1", CERN/LHCC 2006-001, (2006) (pp. 55-64)
- email: Doug.Orbaker@cern.ch
- Thanks to the Fast Sim group, especially Patrizia Azzi, Salavat Abdullin and Florian Beaudette.