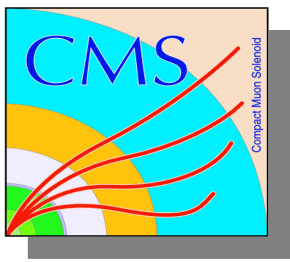


TUNING OF FAST SIMULATED ELECTROMAGNETIC SHOWER IN THE ECAL ENDCAP OF THE CMS DETECTOR

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13thDecember - 18thDecember, 2010, DAE conference,
Jaipur, India

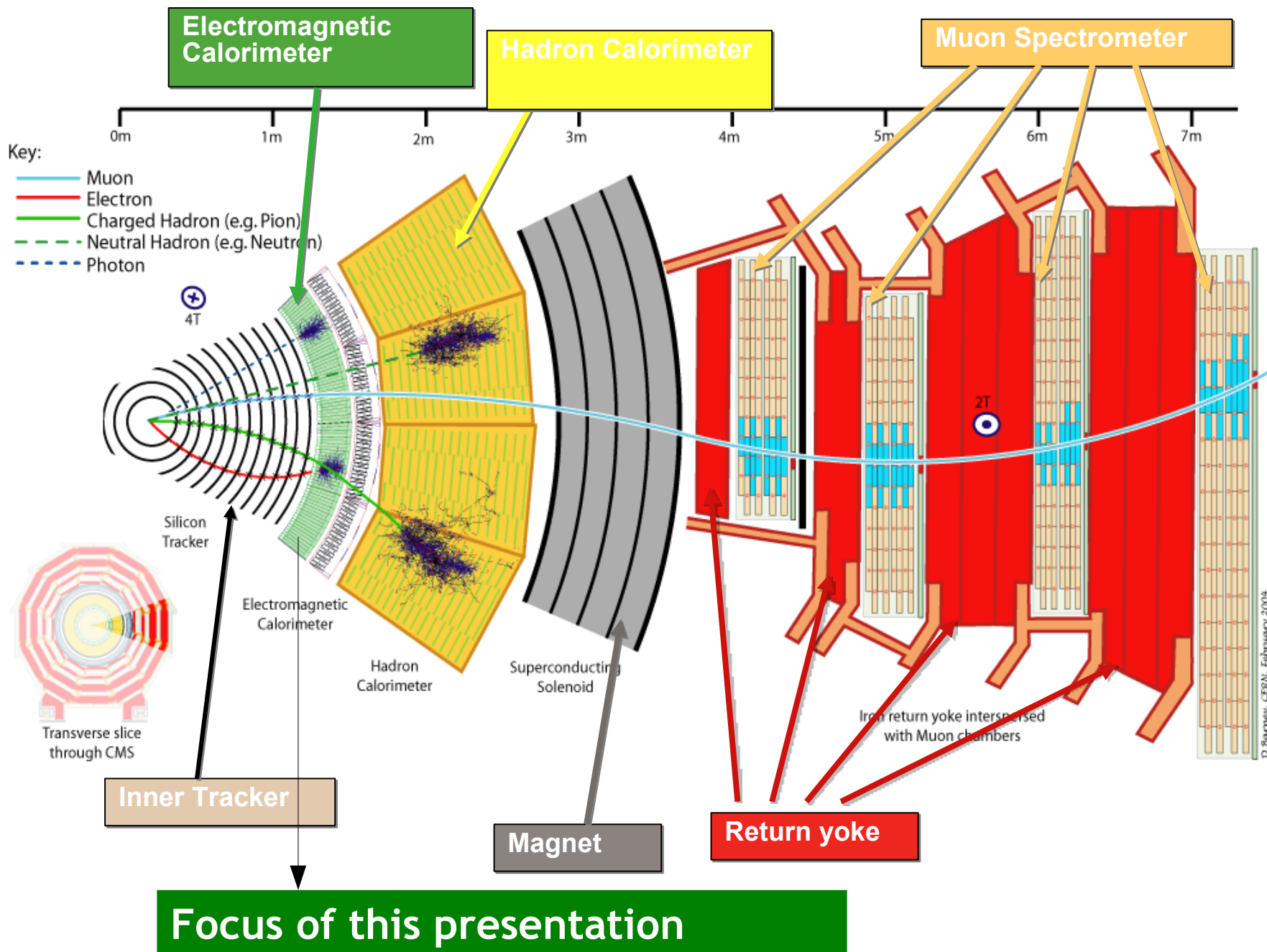


¹on behalf of the CMS collaboration

Outline

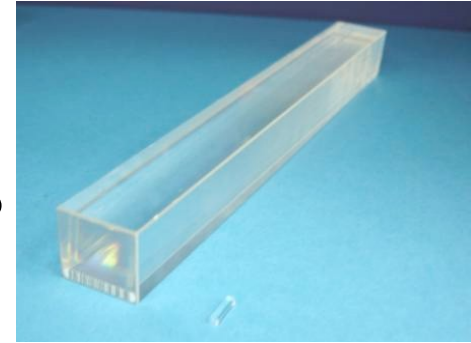
- Compact Muon Solenoid (CMS)
- CMS Electromagnetic Calorimeter
- CMS Preshower
- Brief introduction to Fast Simulation of CMS
- Electromagnetic Calorimeter in Fast Simulation
- Shower shape variable mismatch studies in Fast Simulation and in Full Simulation
- Tuning of Electromagnetic shower
- Summary

Compact Muon Solenoid (CMS)



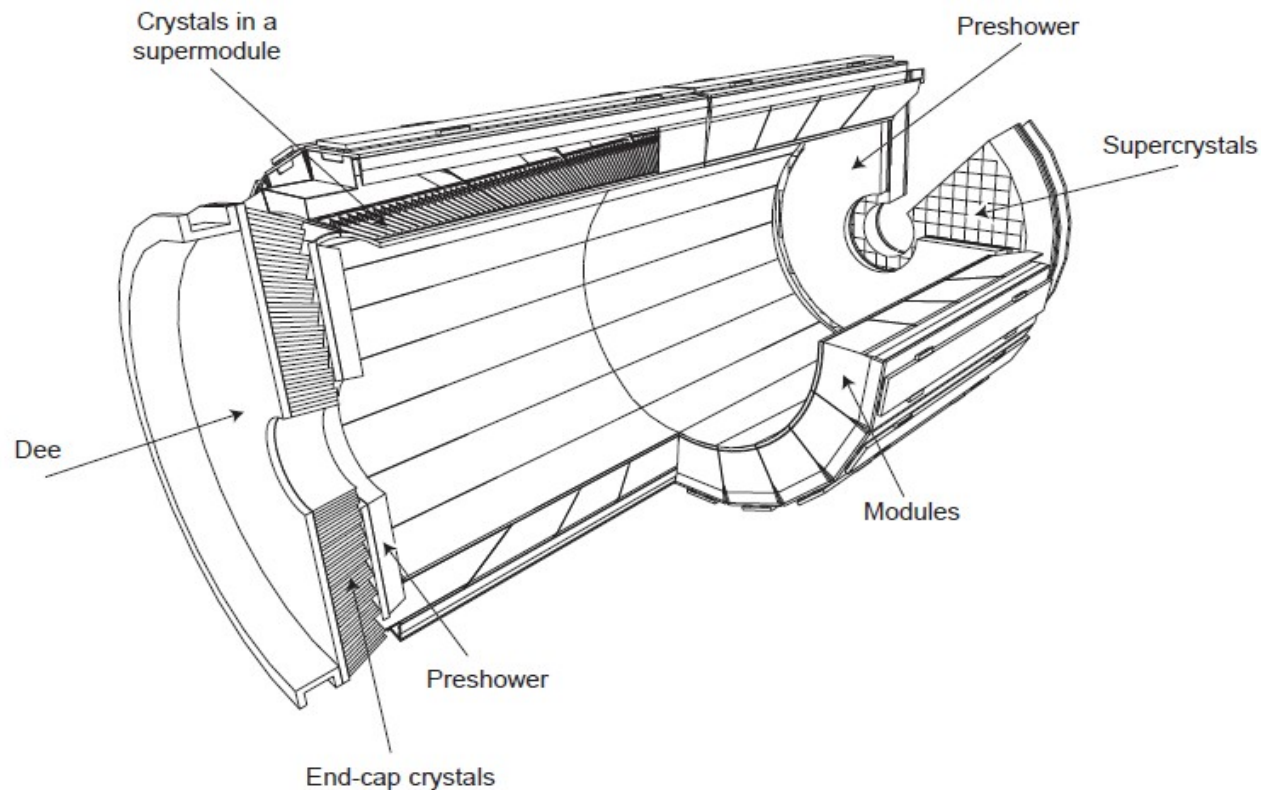
CMS Electromagnetic Calorimeter (ECAL)

- Made of 75848 lead tungstate crystals
- Photons and electrons produce EM showers in the crystals and the energy is the measure of the collected light
- Jets can fake photons or electrons
- Important variables in CMS to identify electrons and photons utilize their shower shape
- Necessary to have accurate description of these variables in the simulation software



CMS Preshower

- The main function of preshower is to provide π^0 - γ separation in the forward region
- It contains thin lead converters (two layers of respectively $2X_0$ and $1X_0$) followed by silicon strip detector planes, positioned in front of the ECAL
- The preshower measures the first part of the shower profile in two orthogonal planes of silicon strip sensors

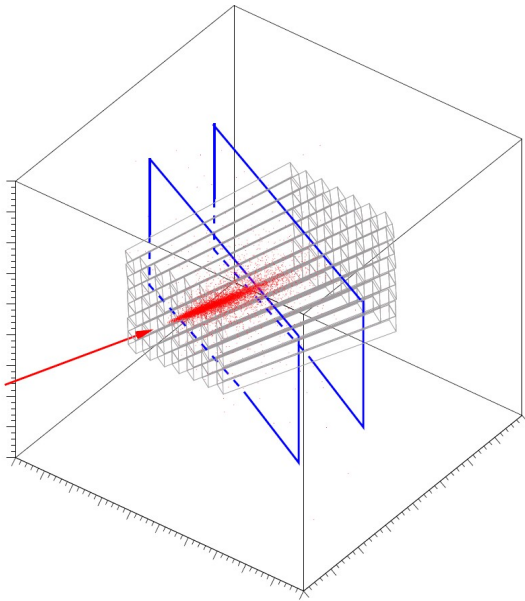


CMS Simulation software

- CMS uses two approaches for simulating detector response:
 - **Full Simulation (Fullsim)**
 - GEANT4 based full description of the detector geometry
 - Used for accurate detector studies
 - **Fast Simulation (Fastsim)**
 - Uses simplified geometry and detector response parameterizations
 - More than 100 times faster than Fullsim
 - Can be used in analysis in a regular way
 - Very useful for generating samples which are CPU time-intensive
 - are tuned using Fullsim and real data —► **Focus of this presentation**

A difference in an important electron/photon shower shape variable was observed between Fastsim and Fullsim. The difference corrected by tuning Fastsim is discussed

Simulation of the ECAL in Fastsim



- Fastsim: (two steps)
 - ✓ Shower is first simulated in a homogeneous medium
 - ✓ Then the generated shower is placed in a detector geometry

But how is the shower simulated?

- A parameterisation : GFLASH electron parameterization is used
- Longitudinal profile of each shower is represented by a gamma distribution. It is split into several longitudinal slices and the total energy of each slice is computed
- lateral profile : In each slice, the spots are distributed along the radial profile uniformly in ϕ . The lateral profile is modeled by :

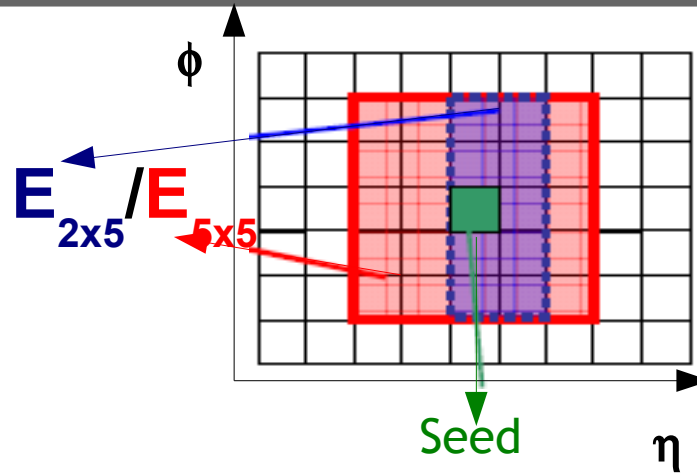
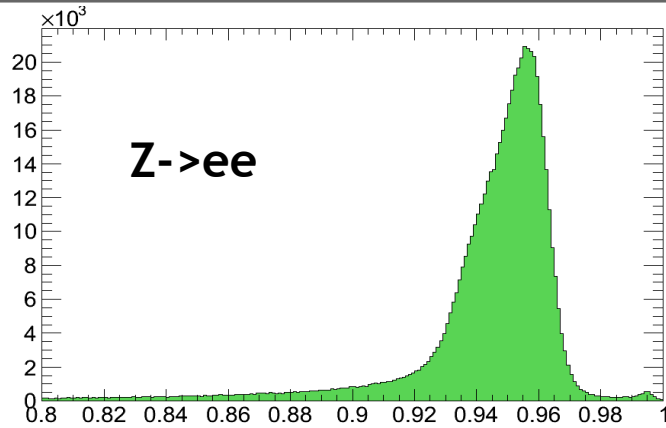
$$\begin{aligned} f(r) &= p f_C(r) + (1 - p) f_T(r) \\ &= p \frac{2r R_C^2}{(r^2 + R_C^2)^2} + (1 - p) \frac{2r R_T^2}{(r^2 + R_T^2)^2} \end{aligned}$$

with

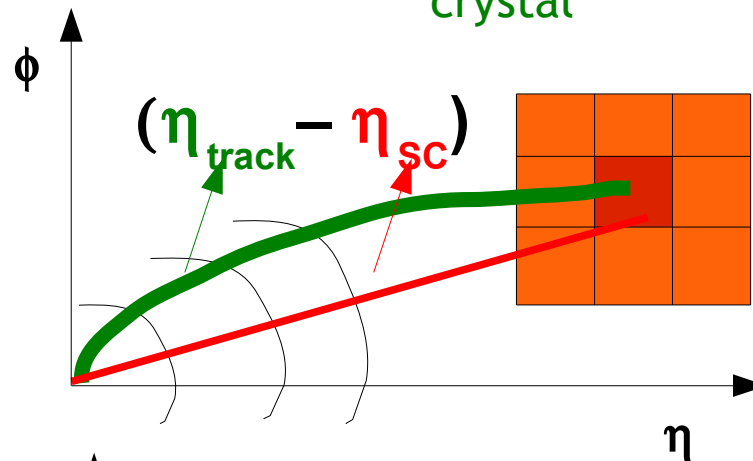
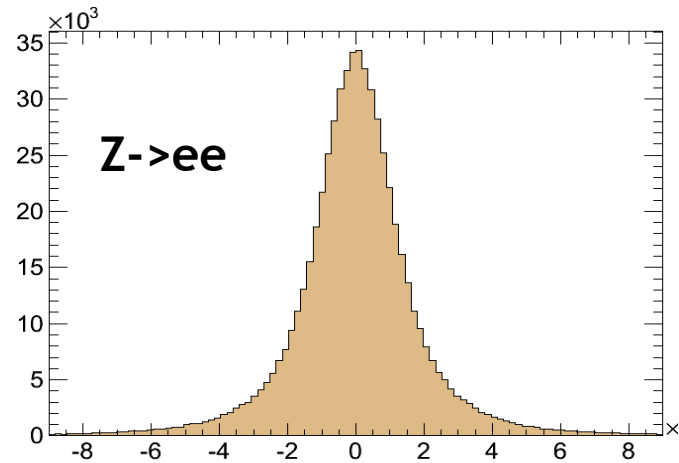
R_C is the radius of core of the shower and R_T is the radius of tail of the shower

$$0 \leq p \leq 1.$$

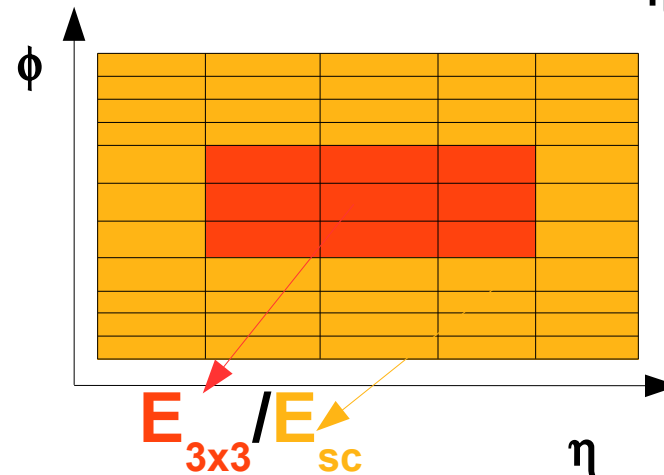
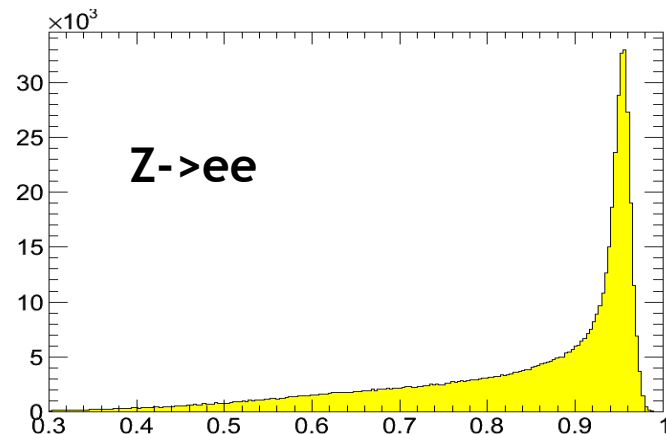
Some of the shower shape variables



$$E_{2 \times 5} / E_{5 \times 5}$$



$$\Delta \eta_{\text{in}}$$

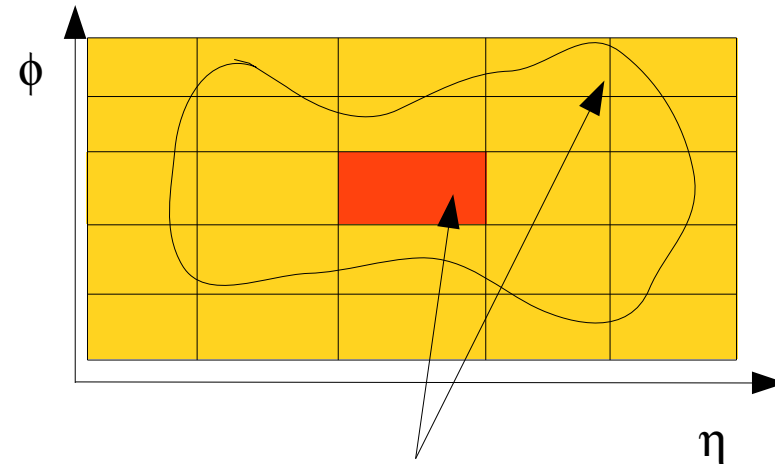
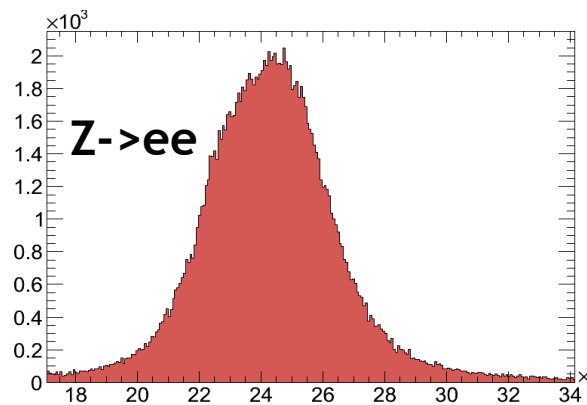


$$r9 = E_{3 \times 3} / E_{\text{sc}}$$

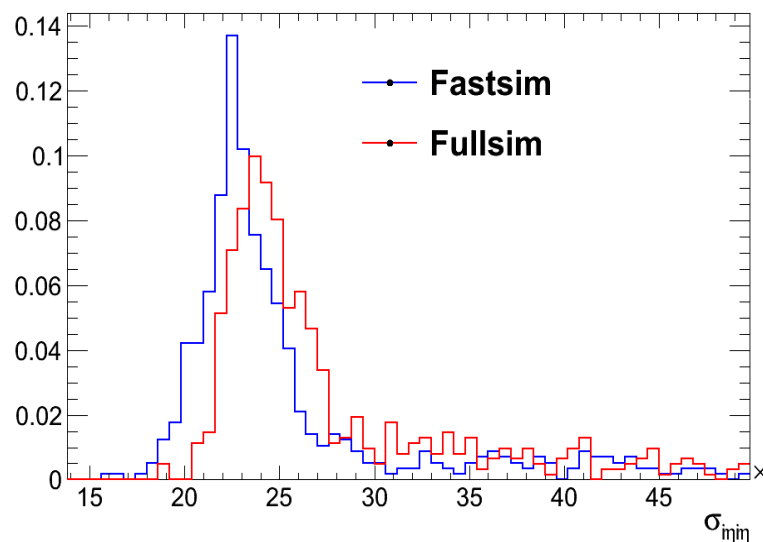
Shower shape variable $\sigma_{\eta\eta}$: mismatch

$$\sigma_{\eta\eta} = \sqrt{\frac{\sum_i^{5 \times 5} (\eta_i^{cryst. nr} \times 0.0175 + \eta^{seed\ cryst.} - \bar{\eta}_{5 \times 5})^2 \times W_i}{\sum_i^{5 \times 5} W_i}}$$

$$W_i = 4.2 + \ln \frac{E_i}{E_{5 \times 5}}$$

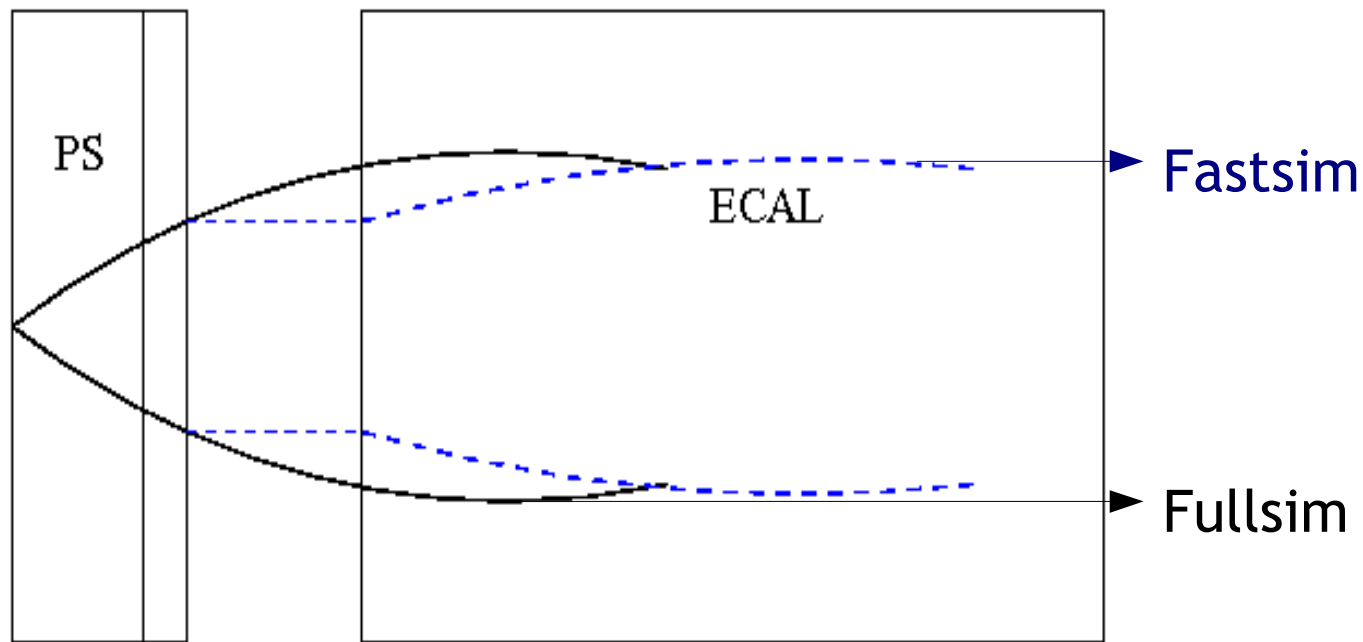


$\sigma_{\eta\eta}$ measures the energy weighted η width of the shower in an array of 5x5 crystals. Higher energy crystals get more weight.



This difference was observed in the preshower region of CMS in a physics process with high-energy electrons in the final state

Reason: Preshower in Fastsim

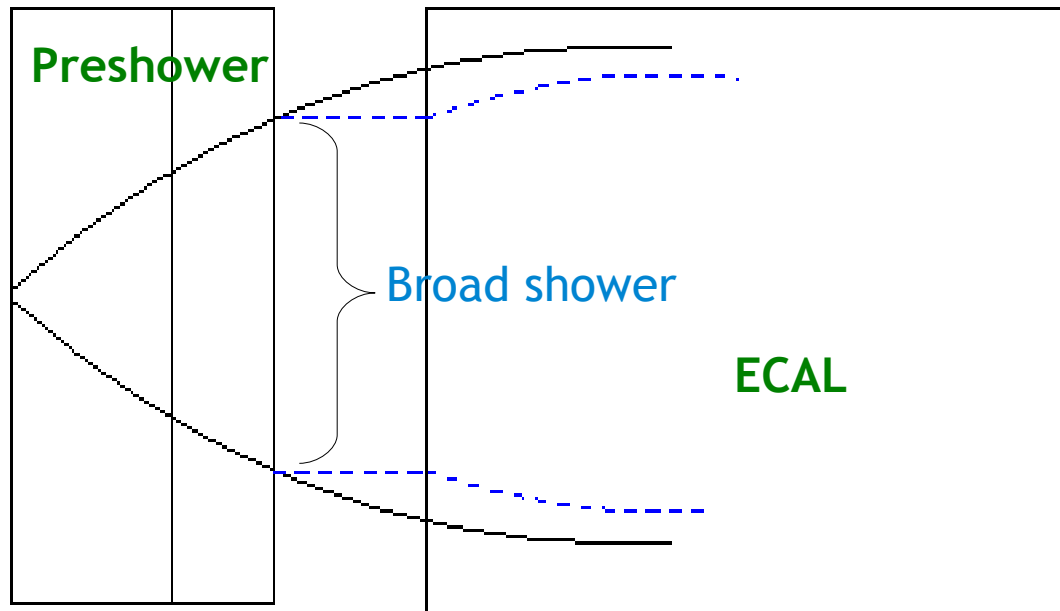


- In the Fastsim, the showers are divided in longitudinal slices of a few X_0 . In the preshower, one slice is made for the first layer, and another one for the second layer. Then, the next slice starts in the ECAL exactly where the previous one in the preshower ended
 - $0 X_0$ between the preshower and the ECAL
 - Everything is simulated as if the preshower were glued on the ECAL surface
- As a consequence the shower enlargement occurring between the preshower and the ECAL is not simulated
 - we try to recover from this effect by applying an enlargement factor to the showers in the ecal

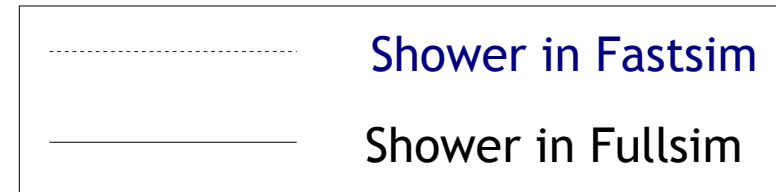
Tuning described - I

- Single photon samples with different energy values ($2 \text{ GeV} < p_T < 20 \text{ GeV}$; $E=50 \text{ GeV}$ & $E=100 \text{ GeV}$) were simulated using FastSim and FullSim
- Shower shape variable, $S1/S9$ of photon from each energy range from FastSim was compared with those from FullSim
- Various trials were done:
 - Increased the lateral shower shape profile by 5%, 10%, 15% ...
 - doesn't work for high energies (shown in the next slides)
 - The most **effective** one was making the lateral shower shape profile dependent on the depth of shower maximum
- The parameterization we used was :
$$a / (1 + b * \text{depthofShowerMax})$$
where 'a' and 'b' were obtained

Tuning described - II

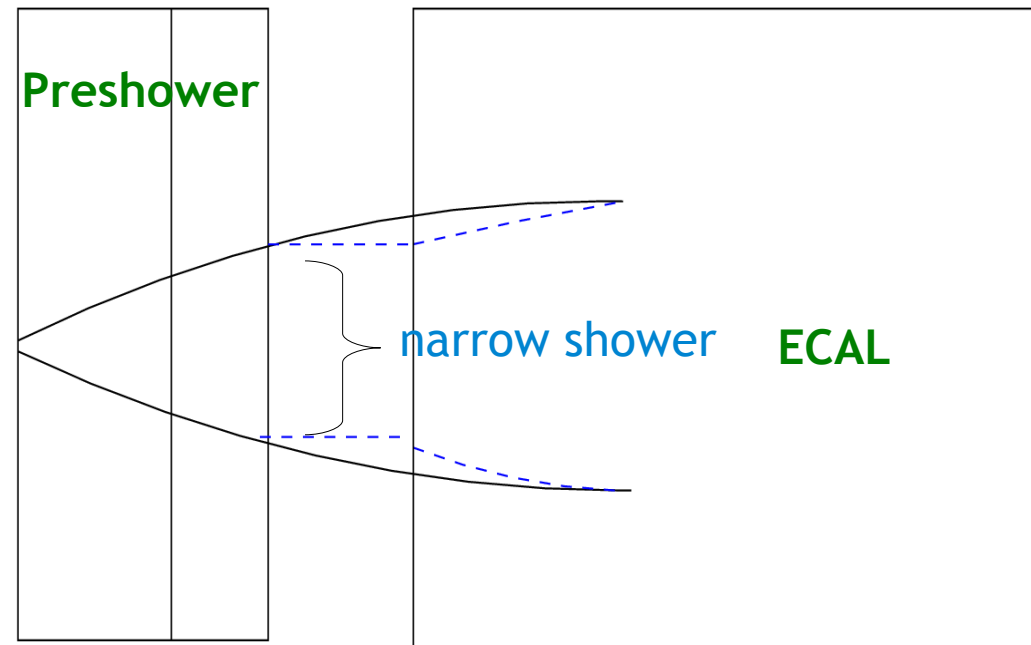


Shower maximum formed at smaller depth in Preshower

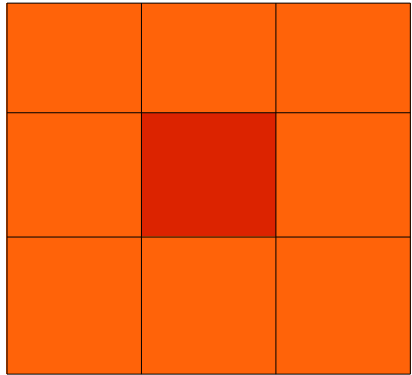


Shower maximum formed at larger depth in Preshower

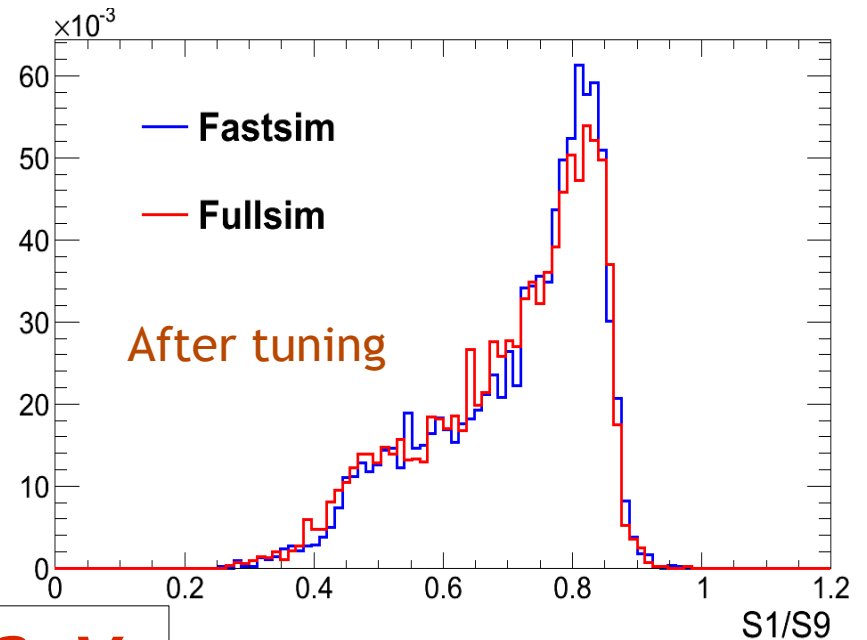
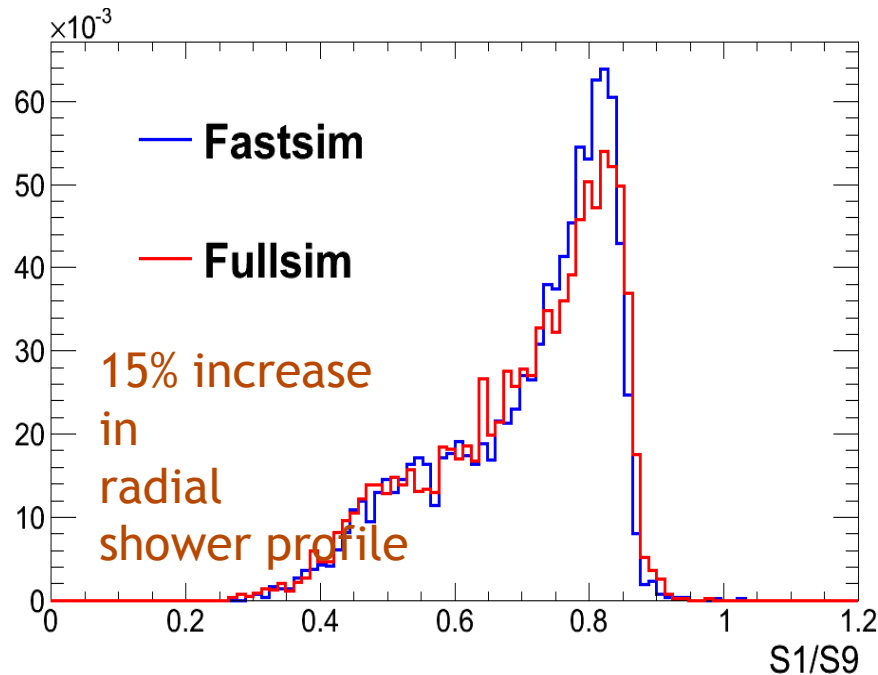
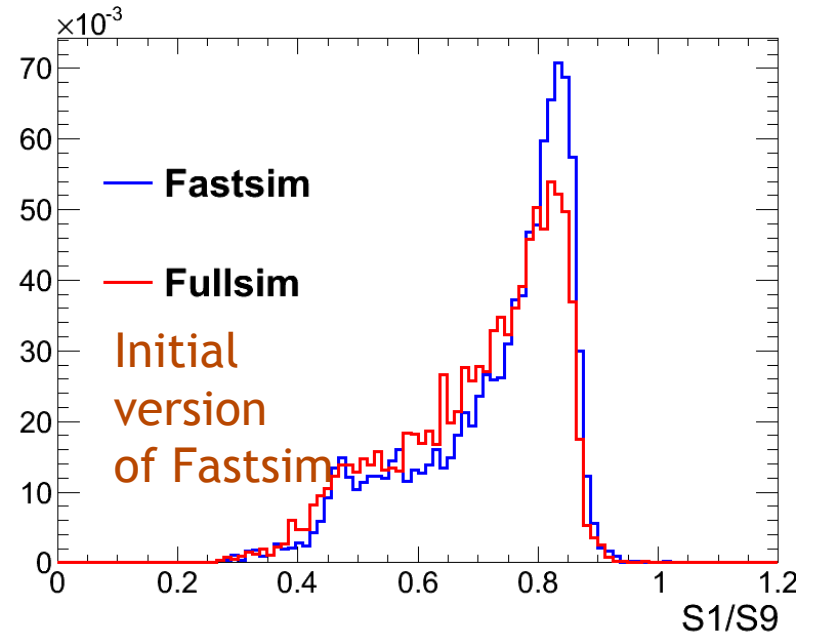
- If shower maximum occurs at smaller depth, the effect of preshower is more and hence the width of the shower is more at the preshower exit.
- If shower maximum occurs at larger depth, the effect of preshower is less and hence the shower is narrower at the preshower exit.



Shower shape variable: $S1/S9$ (photons)



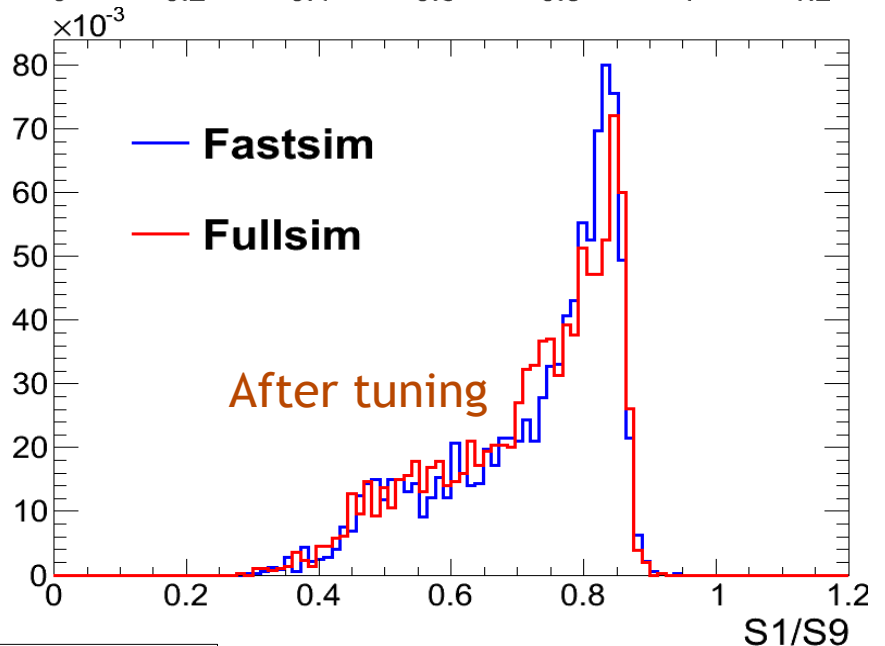
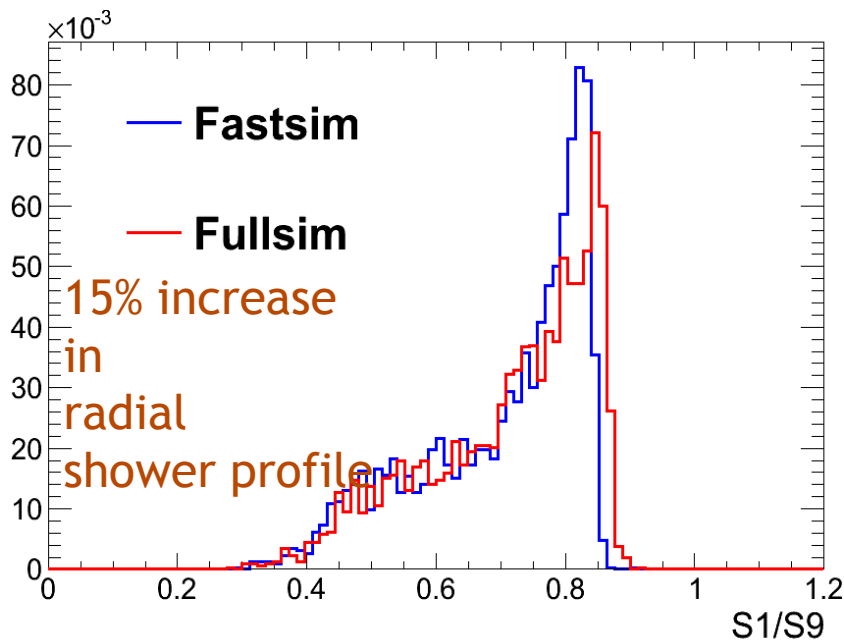
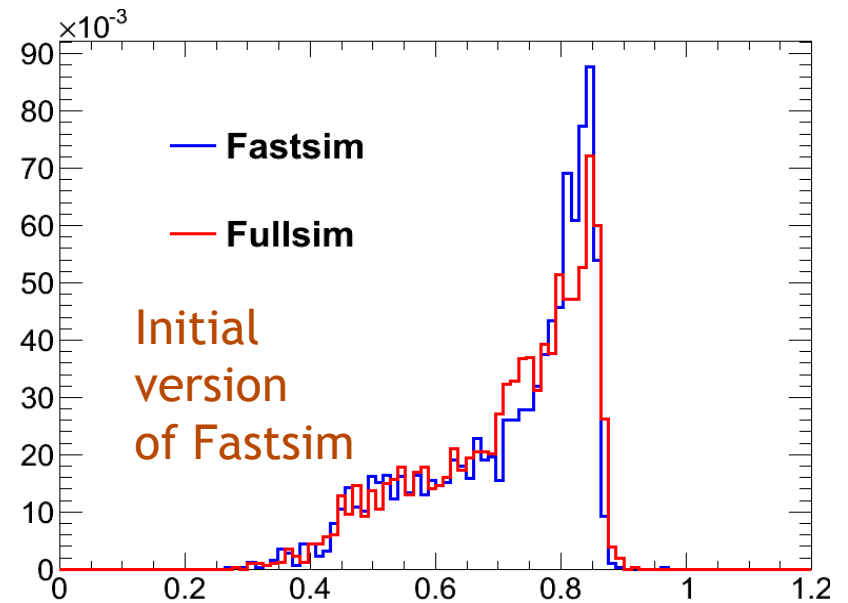
$S1/S9$ = ratio of energy of the central hit crystal to the nine crystals surrounding it



$2 < pt < 20 \text{ GeV}$

S1/S9: E = 250 GeV (photons)

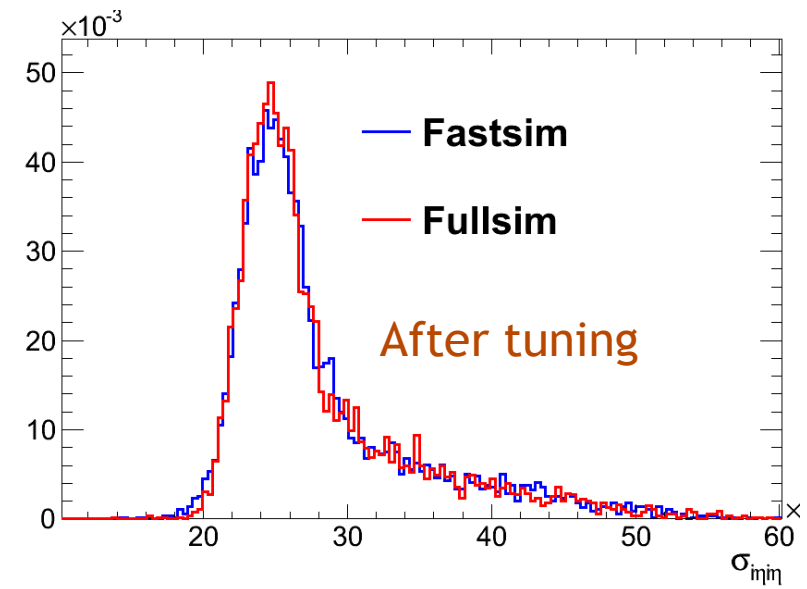
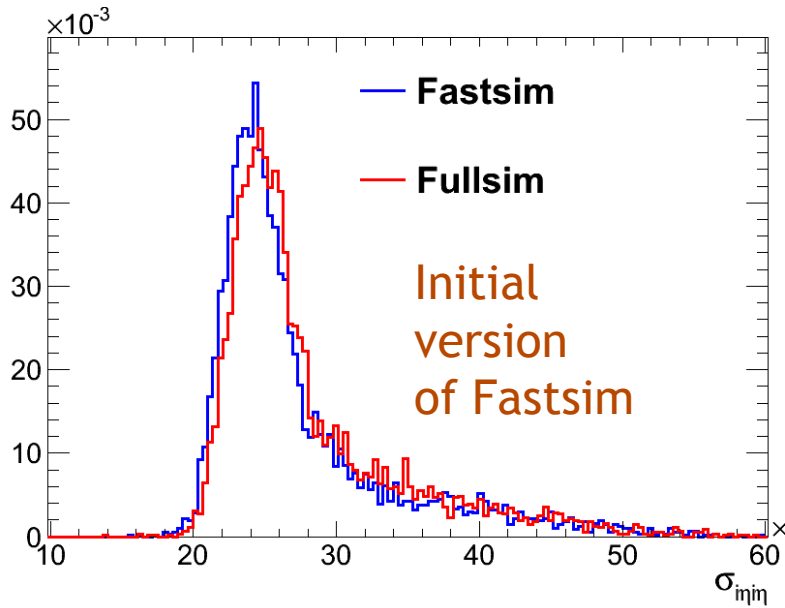
At higher energies, 15% increase in the shower profile didn't work well. Dependence of lateral shower profile on maximum depth of the shower seemed to work well even at higher energies



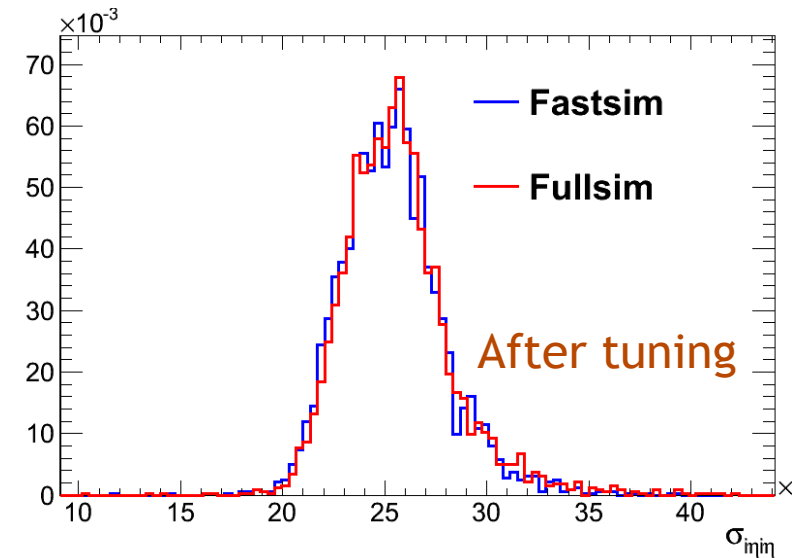
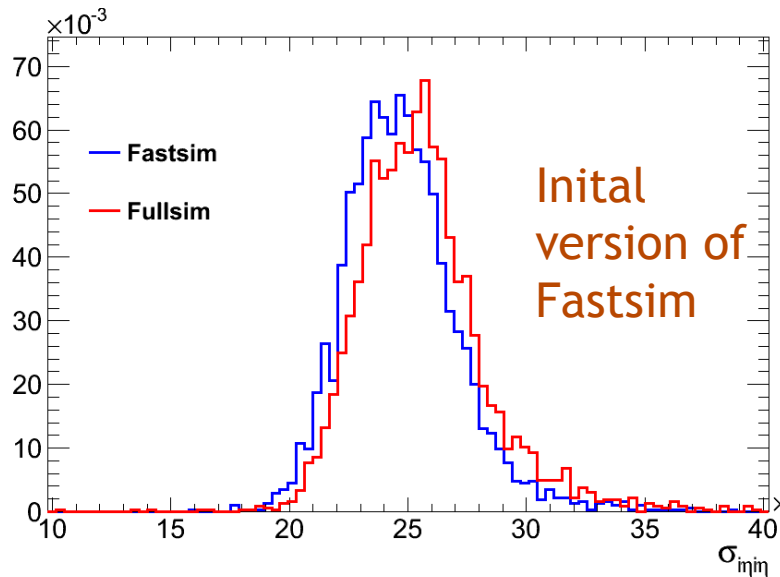
E = 250 GeV

Shower shape variable: $\sigma_{\eta\eta}$ (photons)

$2 < p_t < 20$
GeV

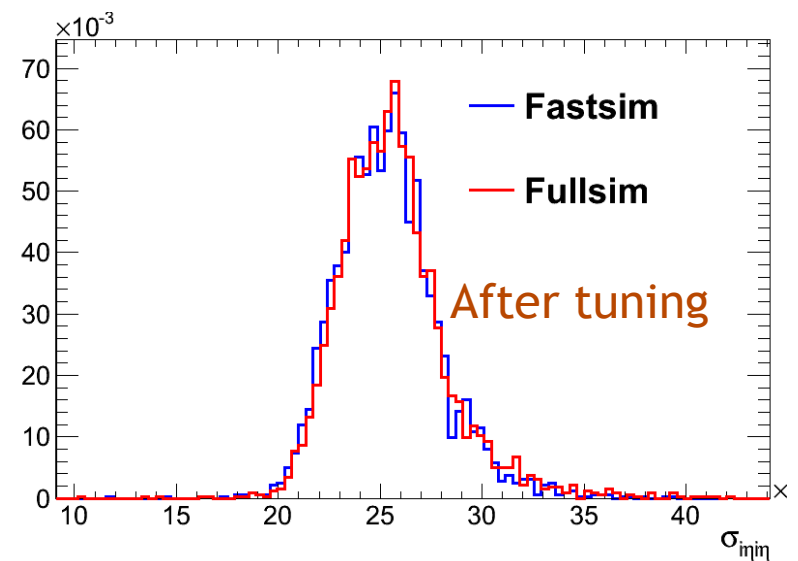
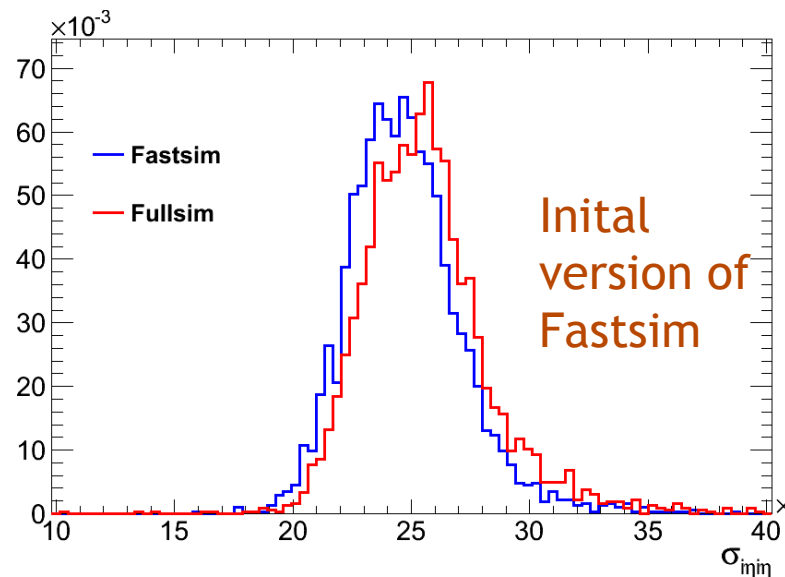


$E = 50$
GeV



Summary

- Tuning has worked and improved the description of shower variables in Fast Simulation
- These shower shape variables are used in all standard electron and photon ID and in every analysis which uses Endcap of the ECAL subdetector
- With a better description of shower variables in the Endcap, there is a good agreement between Fast Simulation and Full Simulation

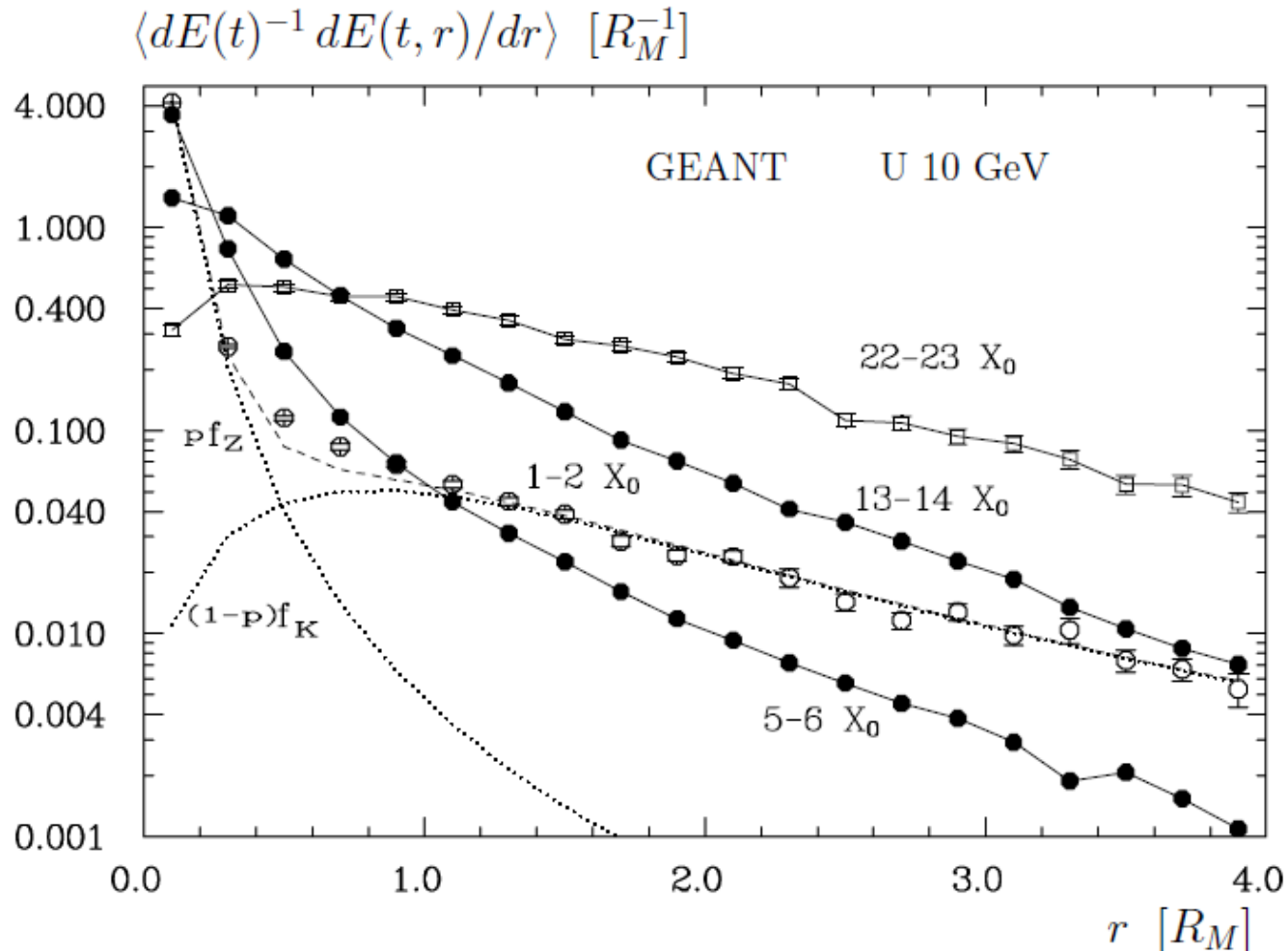


Acknowledgement

- I would like to thank Florian Beaudette of CMS Fast Simulation group with whom I worked on tuning of EM showers

BACKUP

Radial profile of the shower shape



Ref: The Parameterized Simulation of Electromagnetic Showers in Homogeneous and Sampling Calorimeters

Tuning described - II

Ref: Text book on Calorimetry by R. Wigman

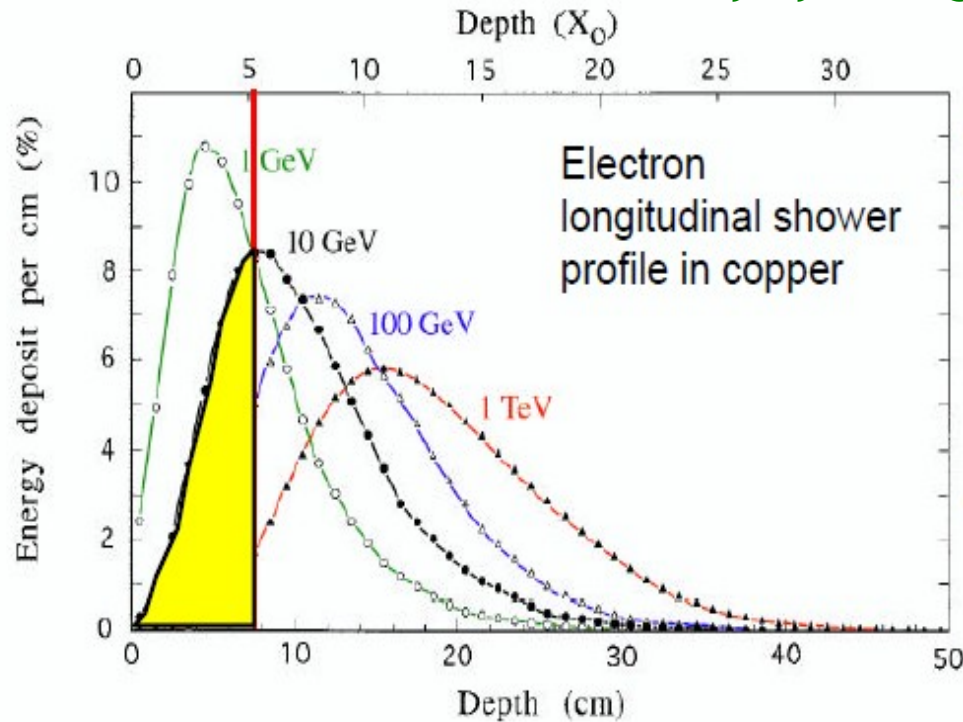


Fig. 1: Longitudinal shower profile

- High energy particles have larger depth of shower maximum and for $t/T \sim 1$, lateral shower profile parameters, R_c & R_T have minimal values, i.e. the spread in lateral shower is very small and so dependence of radial shower profiles on maximum shower depth works

Ref: The Parameterized Simulation of Electromagnetic Showers in Homogeneous and Sampling Calorimeters

$R_C [R_M], R_T [R_M], p$

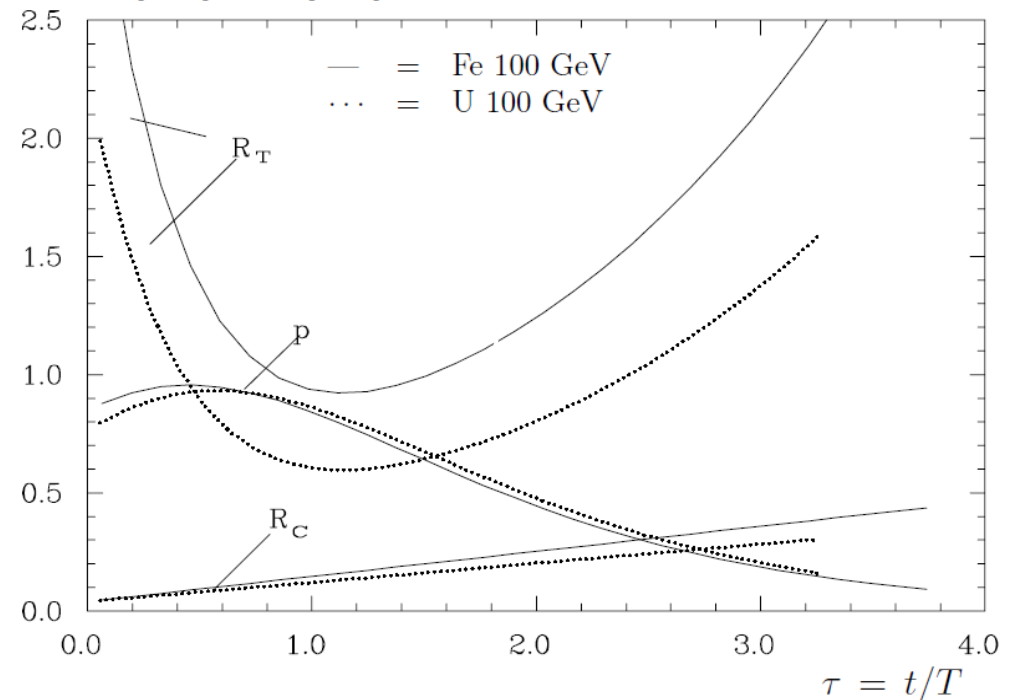
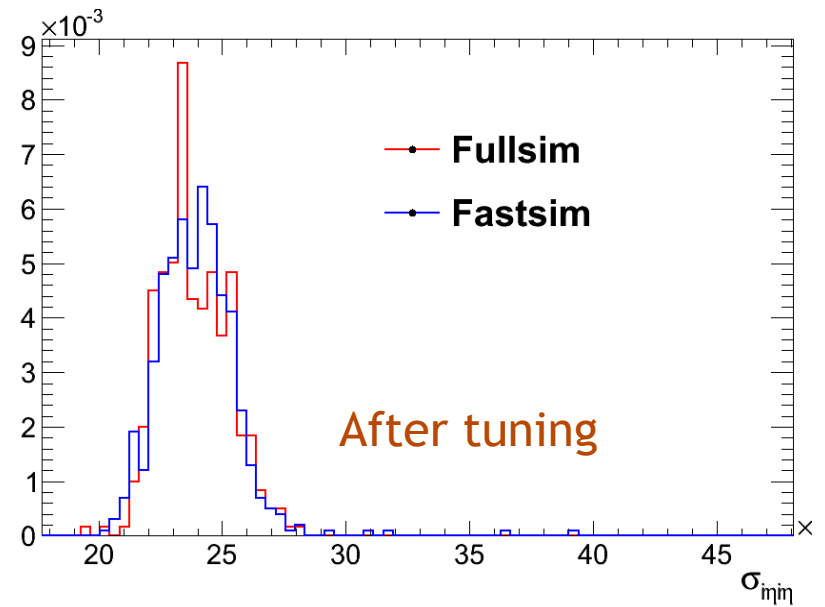
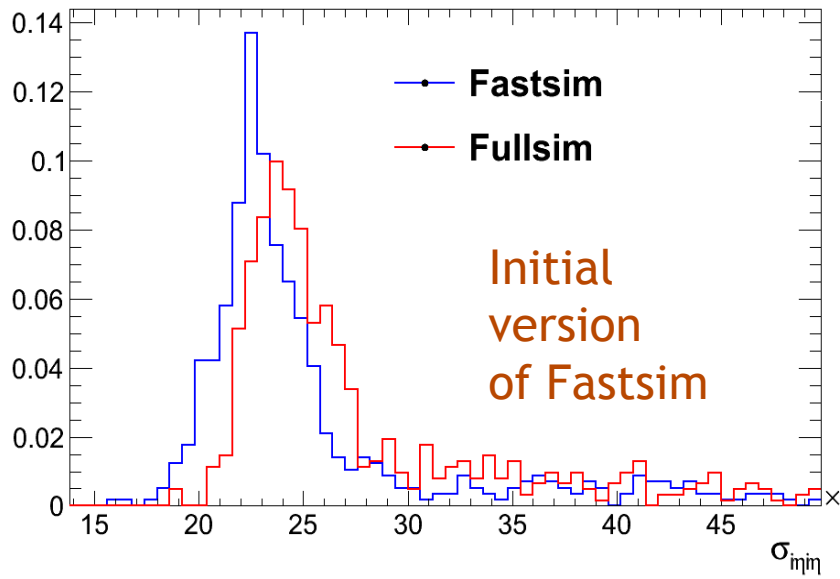


Fig. 2: Dependence of radial shower profile on shower depth

T = Depth of shower maximum
t = depth of shower



$\sigma_{\eta\eta}$ of high energy electrons