Fast Simulation of Calorimeters for the CMS Experiment

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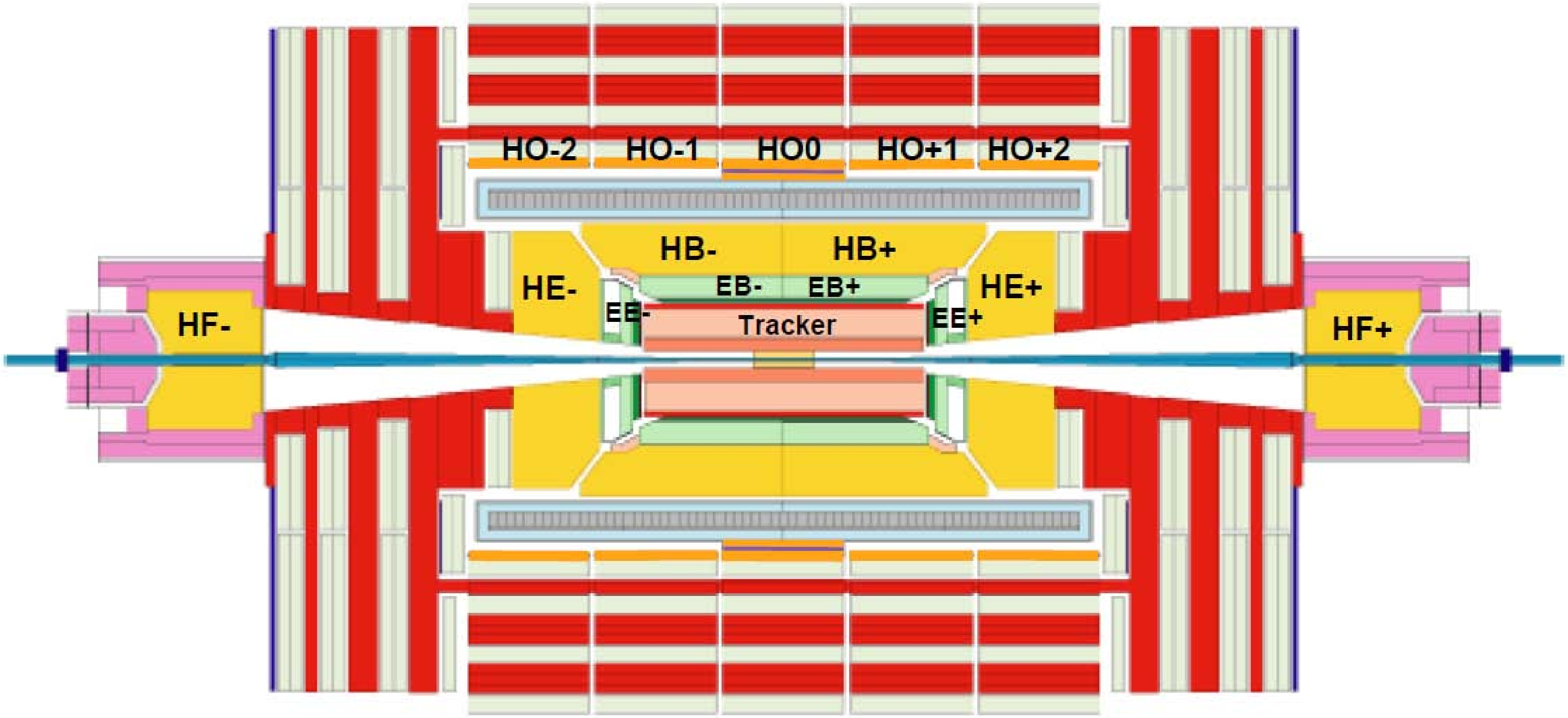
Outline

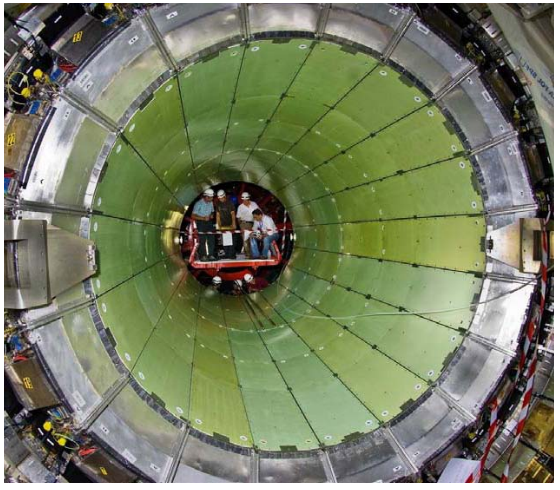
0) Description of the CMS calorimeters
1) Electromagnetic showers
    a) Shower parameterization & implementation
    b) Physics results (photons)
    c) Modifications for new detectors
2) Hadronic showers
    a) Shower parameterization & implementation
    b) Physics results (single particles, jets, MET)
    c) Modifications for new detectors
3) Conclusions, acknowledgements, references

CMS Calorimeters

Detector Schematic



Electromagnetic Calorimeter (ECAL)

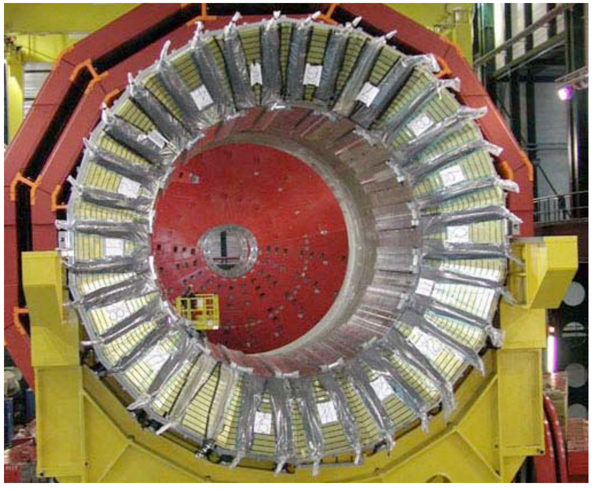


EB inside of HB.

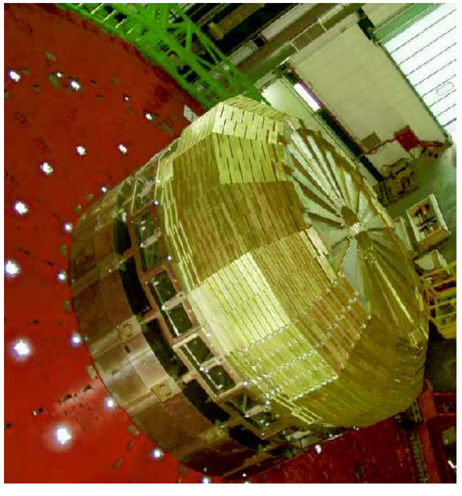
Half of one side of EE.

- Homogeneous medium: $PbWO_4$ crystals
  Sampling preshower: Lead absorber, silicon sensor
- Sections:
  EB (barrel, $0 < |\eta| < 1.479$)
  EE (endcap, $1.479 < |\eta| < 3.0$)
  ES (preshower, $1.653 < |\eta| < 2.6$), 2 layers
- Physics: measures photons and charged particles

Hadronic Calorimeter (HCAL)



One half of HB.



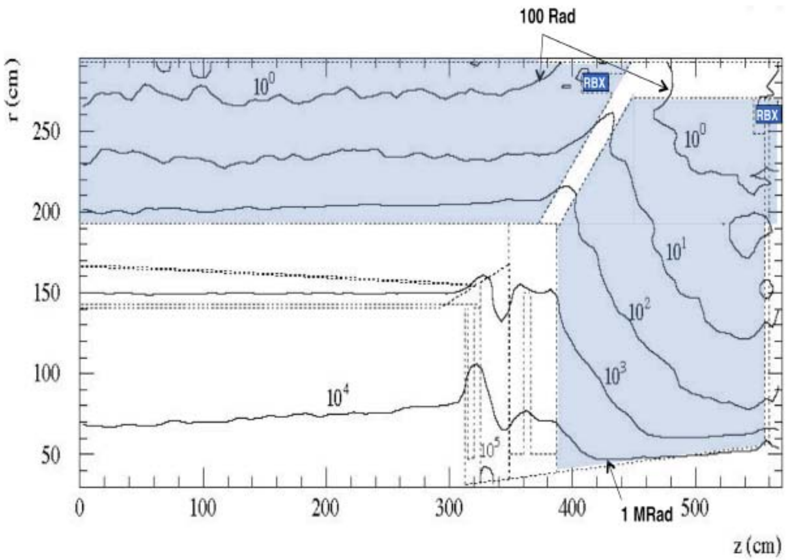
One side of HE.

- Sampling medium: Brass absorber, plastic scintillator
  Forward: Steel absorber, quartz fibers

- Sections:
  HB (barrel, $0 < |\eta| < 1.3$), 16+1 layers
  HE (endcap, $1.3 < |\eta| < 3.0$), 17+1 layers
  HO (outer, $0 < |\eta| < 1.3$), 1+1 layers
  HF (forward, $3.0 < |\eta| < 5.0$)

- Physics: measures charged and neutral hadrons

Calorimeter Upgrades



A radiation map of CMS at 500 fb^{-1} calculated by FLUKA, with doses in Gy. Shaded are HB (top) and HE (right).

The High Luminosity LHC upgrade (Phase 2) will increase the collider's luminosity by a factor of 10 above the final Phase 1 value. This will greatly increase the amount of data delivered, but it will also increase radiation damage to the detector.

Radiation levels will be particularly high closest to the beamline, affecting the endcap and forward detectors. The Forward Calorimetry Task Force is investigating possible replacements and upgrades for EE, HE, and HF.

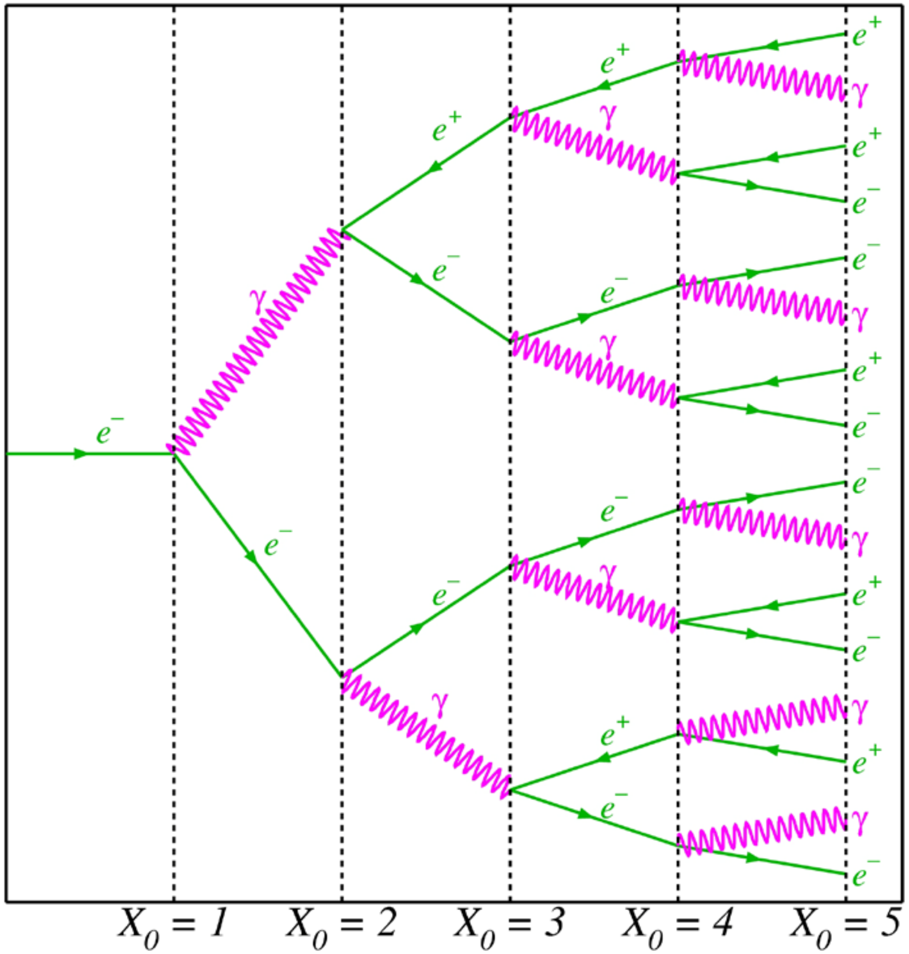
More details on the upgrade will be presented tomorrow in a talk by Silvia Tentindo.

Electromagnetic Showers

Electromagnetic Showers

At high energies (MeV and above):

- Charged particles enter a material and lose energy via bremsstrahlung (emitting photons as they decelerate)
- Photons interact with the material via pair production
- Below the critical energy, charged particles begin to lose more energy by ionization than bremsstrahlung
- At lower energies, other processes take over



Shower Parameterization

For fast simulation, the longitudinal and transverse distributions of energy in particle showers are approximated by analytical parameterizations.

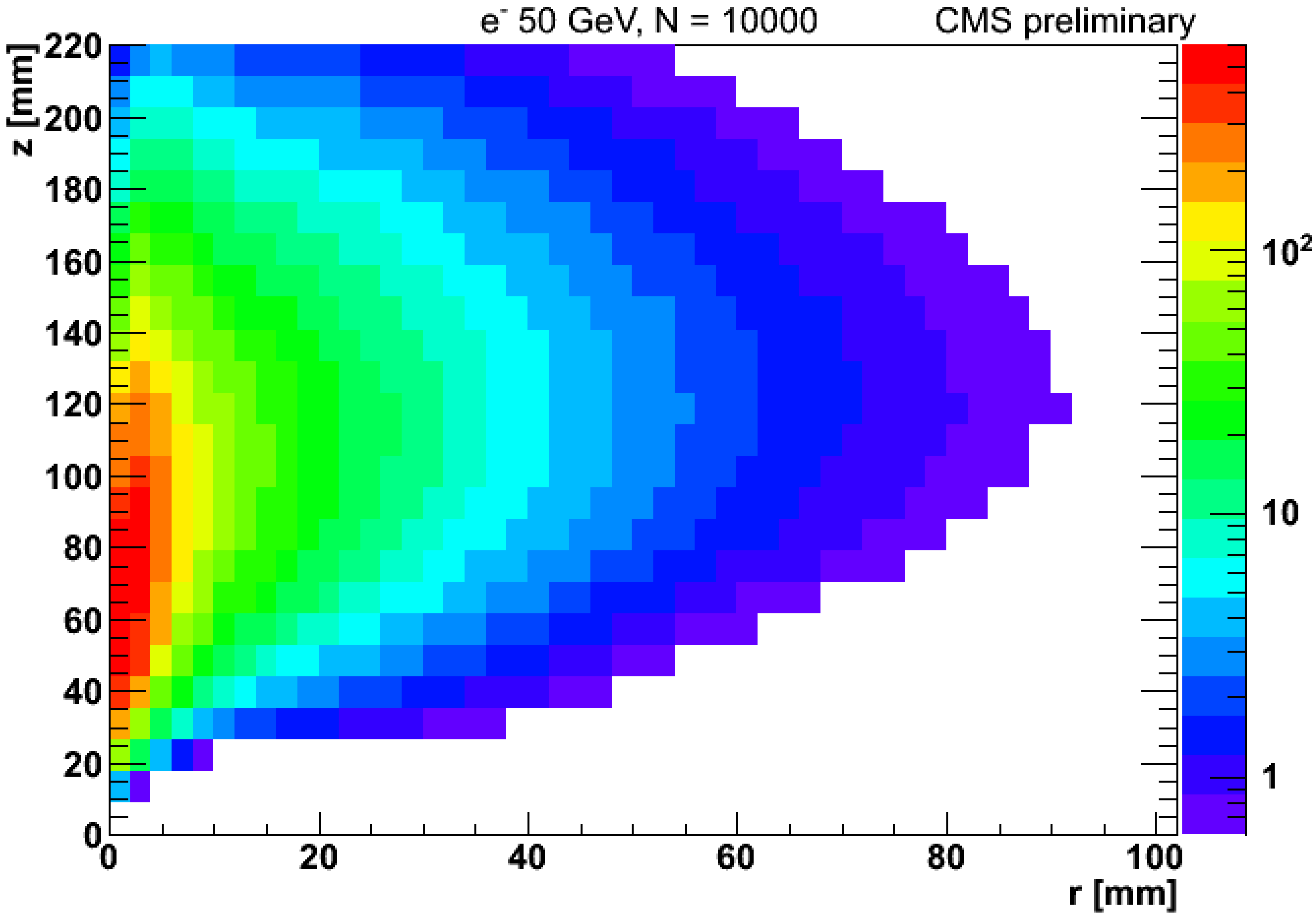
CMS uses the GFLASH parameterization for electromagnetic showers, developed extensively by Grindhammer and Peters. The energy distribution is:

$$dE(\vec{r}) = Ef(t)dtf(r)drf(\phi)d\phi$$

where E is the energy in units of critical energy E_c, t is the longitudinal shower depth in units of radiation length X_0, r is the transverse distance in units of Molière radius R_m, φ is the azimuthal angle. (Uniformity in φ is assumed.)

These physical, material-dependent quantities (E_c, X_0, R_m) are related to the progression of the shower. We eliminate most of the material dependence in the GFLASH parameters by working in units based on them.

Shower Parameterization



This plot shows the 2D (longitudinal-transverse) shower energy profile (in log scale) from the CMS fast sim of EM showers in ECAL.

Radiation Length

The radiation length X_0 is given approximately by:

$$1/X_0 = \frac{4\alpha N_A Z(Z+1) r_e^2 \log(183 Z^{-1/3})}{A}$$

Here α is the fine structure constant, N_A is Avogadro's number, r_e is the classical electron radius, Z is the atomic number, and A is the atomic weight.

This formula gives X_0 in units of g/cm^2. One can divide by the material density in g/cm^3 to find X_0 in units of cm.

An electron loses $(1 - e^{-1})$ of its energy on average after 1 X_0, and the mean free path for pair production of a high-energy photon is $\frac{9}{7}X_0$.

Critical Energy

The critical energy E_c has an approximation related to X_0:

$$E_c = 2.66 \left(X_0 \frac{Z}{A} \right)^{1.1}$$

As described previously, the critical energy is the point where bremsstrahlung and ionization contribute equally to energy loss for charged particles.

Above the critical energy, bremsstrahlung is the leading process; below the critical energy, ionization is the leading process.

Molière Radius

The Molière radius R_m can be expressed approximately in terms of X_0 and E_c:

$$R_m = \left(\sqrt{\frac{4\pi}{\alpha}}m_e c^2\right)\frac{X_0}{E_c} = (21.2\mathrm{MeV})\frac{X_0}{E_c}$$

The energy scale factor 21.2 MeV comes from multiple scattering theory.

This quantity describes the transverse size of a shower so that 90% of the spread is contained within a radius of 1 R_m.

R_m tends to vary less between materials because some of the Z and A dependence cancels between X_0 and E_c.

CMS ECAL Properties

The CMS ECAL has the following values for these material quantities:

$\rho = 8.28$ g/cm^3

$A_{eff} = 170.87$

$Z_{eff} = 68.36$

$X_0 = 7.37$ g/cm^2 = 0.89 cm

$E_c = 8.74$ MeV

$R_m = 2.19$ cm

A_{eff} and Z_{eff} are calculated by adding the A and Z of the component elements in $PbWO_4$ weighted by their mass fractions.

EB has a depth of 23 cm = 25.8 X_0, and EE has a depth of 22 cm = 24.7 X_0.

Longitudinal Parameterization

The average longitudinal profile can be modeled as a gamma distribution:

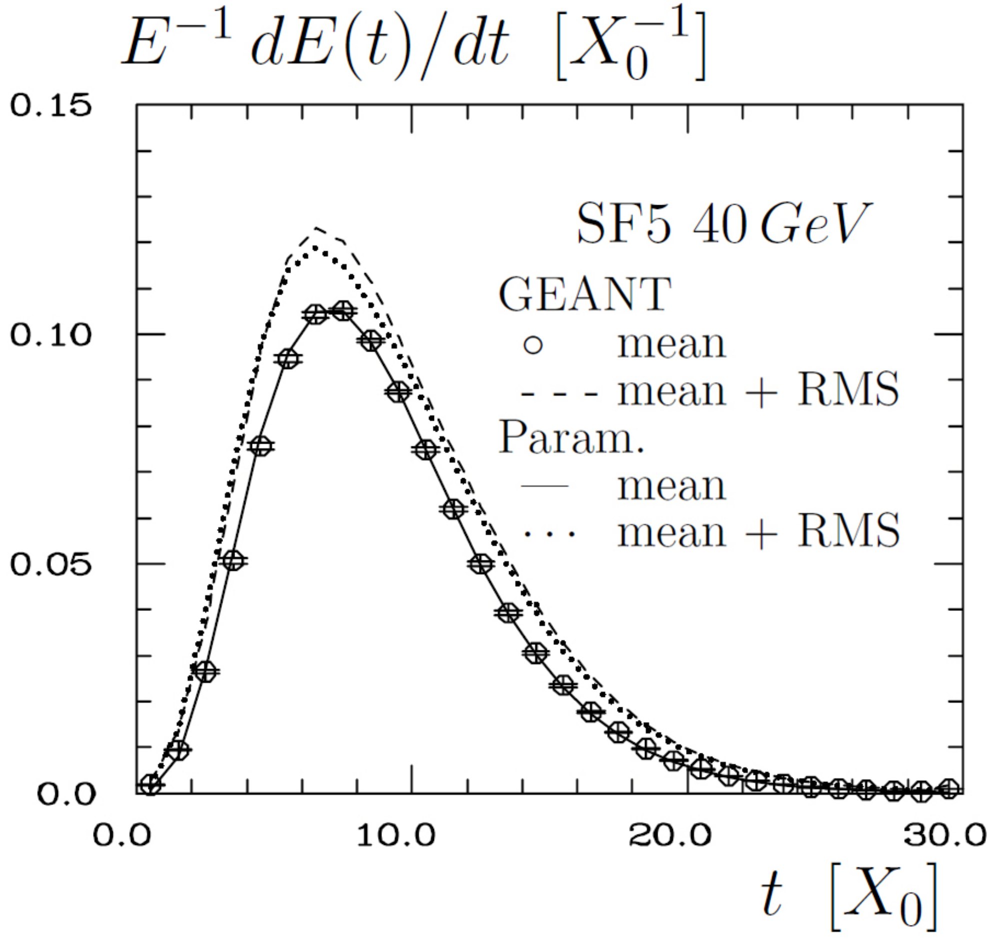
$$f(t) = \frac{(\beta t)^{\alpha-1}\beta\exp(-\beta t)}{\Gamma(\alpha)}$$

In practice, the parameters used are α and the shower maximum $T = (\alpha - 1)/\beta$.

The fluctuations and correlations of the parameters α and T are also parameterized. These are used with normally distributed random numbers in order to simulate different individual showers which deviate from the average.

All of the parameters are given functional forms that may depend on the particle energy E or atomic number Z of the material. The coefficients are determined by fits to full simulations using Geant.

Longitudinal Parameterization



A plot from Grindhammer and Peters, showing the longitudinal profile.

Transverse Parameterization

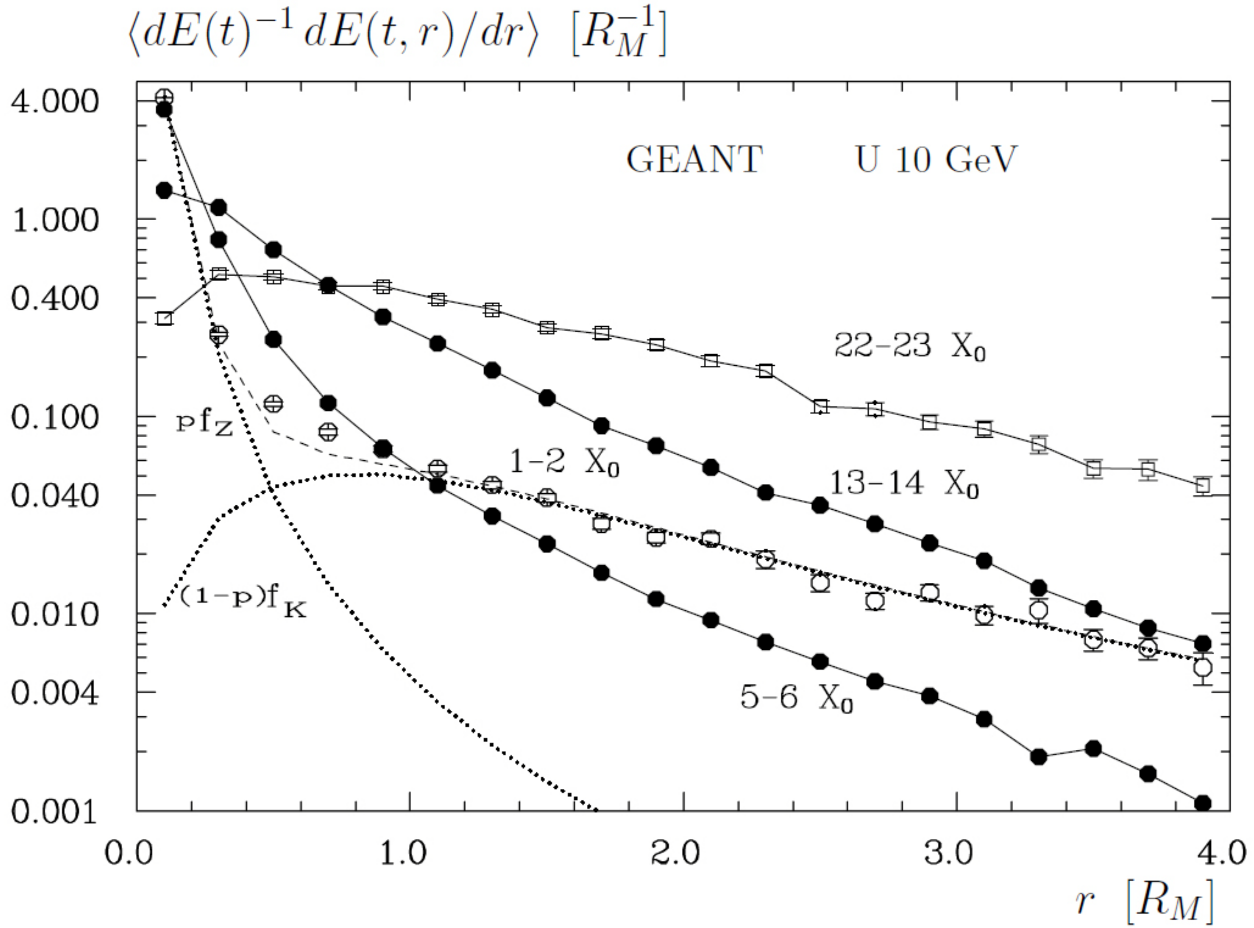
The average transverse profile varies depending on the longitudinal depth of the shower. The curves feature a maximum in the core and varying steepness in the tail. To capture this behavior, the average transverse profile is modeled with a two-term function:

$$f(r) = p\frac{2rR_C^2}{(r^2+R_C^2)^2} + (1-p)\frac{2rR_T^2}{(r^2+R_T^2)^2}$$

R_C is the median of the core, R_T is the median of the tail, and p weights the two contributions, so $0 \leq p \leq 1$. Like the previous parameters, these are fit to functional forms based on Geant results.

The longitudinal fluctuations must be taken into account for the transverse parameters, as they depend on a variable $\tau = t/T$.

Transverse Parameterization



A plot from Grindhammer and Peters, showing components of the transverse profile.

Energy Spots

Fluctuations in the transverse profile are included by dividing the energy in each longitudinal step, dE(t), into a number of “spots” $N_s(t)$ so that each spot has an energy $E_s = dE(t)/N_s(t)$.

The total number of spots per shower can be parameterized as follows:

$$N_{\mathrm{spot}} = 93\log(Z)E^{0.876}$$

The number of spots in each longitudinal interval, $N_s(t)$, can be parameterized as a gamma distribution, with parameters related to the longitudinal gamma distribution f(t).

The energy spots are distributed randomly in r according to the transverse distribution f(r), and uniformly in t and φ.

Algorithm Summary

1. Calculate dE(t) for an interval of length X_0 by integrating f(t).

2. Evaluate the number of energy spots needed for this interval, $N_S(t)$.

3. Randomly distribute the energy spots, each with energy $E_S = dE(t)/N_S(t)$, in r according to f(r) and uniformly in t and φ.

4. Transform from coordinates (E_S, t [X_0], r [R_m], φ) to (E_S, x, y, z).

Additional Details

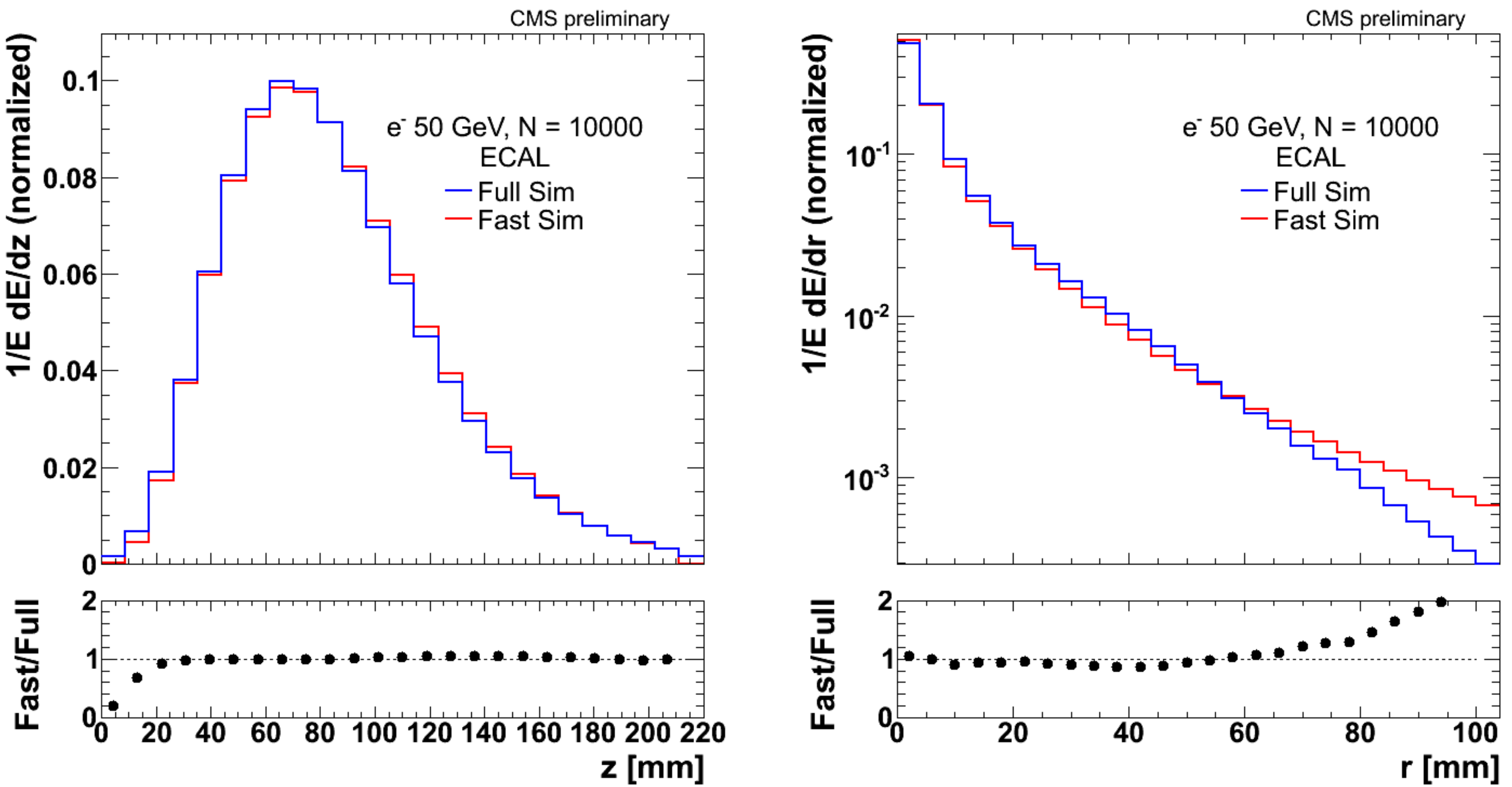
For particles in the appropriate η range, each layer of ES is simulated with a separate longitudinal step, and a step is added for the gap between ES and EE.

The CMS ECAL subdetectors are ~$25X_0$ in depth, which provides very good but not complete containment of EM showers. The leakage of showers outside of the ECAL is simulated by a straightforward continuation of the longitudinal gamma distribution. Integration of f(t) is carried out so any energy remaining after the end of the ECAL is deposited in HCAL.

The first pair production for photons is simulated separately (as a random value based on the mean free path), and then shower simulations are done for both particles in the resulting e^+e^- pair.

Light collection efficiency and nonuniformity for the photodetectors are also included in the simulation.

Validation



The longitudinal and transverse shower profiles can be compared between CMS full sim and fast sim, showing good agreement.

Photon Results

To check against data, the fast simulation was used to process 10 million 7 TeV minimum bias events generated using Pythia8.

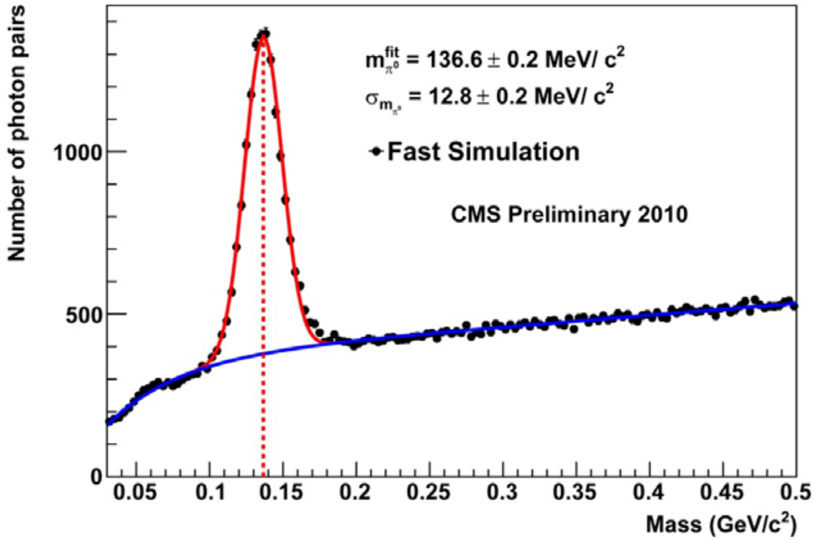
The results were compared against minimum bias samples from 2010 data and full simulation MC, as described in CMS PAS PFT-10-002.

The EM shower simulation can be checked by looking at the π^0 mass peak in a plot of di-photon invariant mass.

Photons were reconstructed using Particle Flow, with selection criteria:

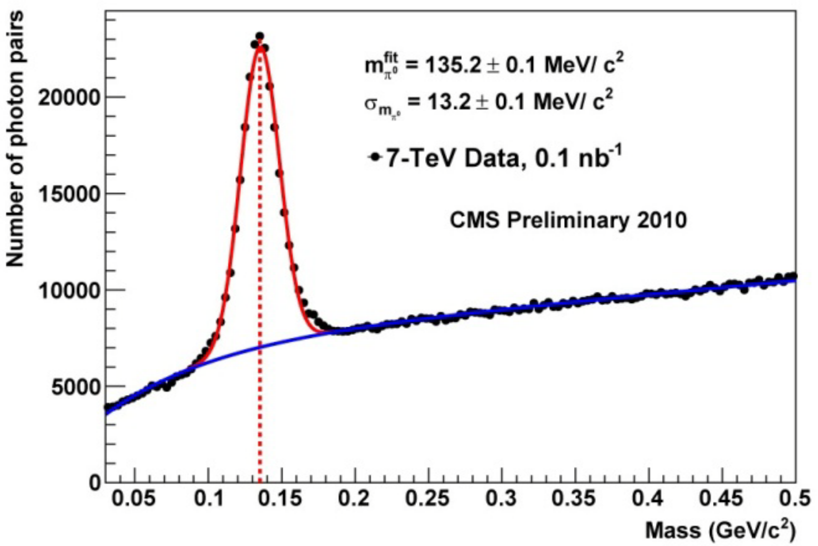
- $E_\gamma > 0.4$ GeV
- $E_{\gamma\gamma} > 1.5$ GeV (photon pair)
- $|\eta_\gamma| < 1$ (barrel)

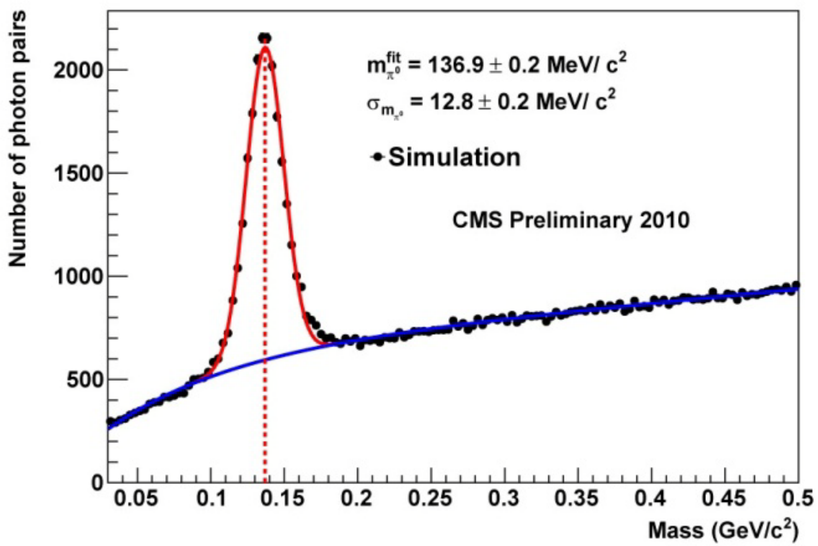
Photon Results



The fast simulation peak agrees with the data and MC peaks, in both the position and width.

	m [MeV/c^2]	σ [MeV/c^2]
Fast Sim	136.6 ± 0.2	12.8 ± 0.2
Full Sim	136.9 ± 0.2	12.8 ± 0.2
Data	135.2 ± 0.1	13.2 ± 0.1





Sampling ECAL

The EM shower parameterization described above is accurate for homogeneous calorimeters, like the current $PbWO_4$ ECAL. However, for the high luminosity LHC upgrade, new sampling ECALs are being considered to replace EE for improved radiation hardness.

In the CMS fast sim, the shower parameters can be easily modified via Python to simulate a new detector instead of the current ECAL. Simulating a sampling ECAL requires additional parameters which will be discussed.

New ECALs cannot be implemented easily in the CMS full sim geometry, which is a complex XML-based specification. The Forward Calorimetry Task Force has created a standalone Geant4 simulation with a simplified geometry, which can be used to validate the sampling ECAL fast simulation.

Effective Material

In GFLASH, sampling calorimeters are modeled as a single medium with effective material parameters (Z, A, X_0, E_c, R_m) calculated based on the properties of both the active (scintillator) and passive (absorber) materials. An example of this calculation for the effective radiation length:

$$w_i = \frac{\rho_i d_i}{\sum_j \rho_j d_j} \qquad \frac{1}{X_{0,\text{eff}}} = \sum_i \frac{w_i}{X_{0,i}}$$

Here i, j = {a, p} (active and passive), d_i is the depth of the *i*th part of one layer, ρ_i is the density, w_i is the weight.

However, it is not enough just to calculate the effective material parameters; effects of the sampling geometry must be included.

Sampling Fluctuations

The shower parameterization must be modified in several ways to account for the sampling structure. Sampling fluctuations (the amount of energy deposited in active vs. passive materials, which changes for each individual shower) are modeled as a normal distribution, with the σ parameter based on the sampling resolution c:

$$\frac{\sigma}{E} = \frac{c}{\sqrt{E}}$$

The energy in each longitudinal step, dE(t), is taken as the mean of the normal distribution and smeared based on this resolution (weighted by a random value generated according to this distribution).

Geometry Effects

The shower maximum occurs earlier for a sampling calorimeter than it would for the equivalent homogeneous calorimeter. To account for this, the functional forms of the various longitudinal and transverse parameters are modified to include extra terms based on the sampling frequency F_S and the ratio of signals from electrons vs. minimum ionizing particles, e/mip, which can be approximated as ê:

$$F_S = \frac{X_{0,\text{eff}}}{d_a + d_p} \qquad \hat{e} = \frac{1}{1 + 0.007(Z_p - Z_a)} \approx \frac{e}{\text{mip}}$$

In addition, the total number of spots will be smaller and depend on the sampling resolution c instead of the atomic number Z:

$$N_{\text{spot}} = \frac{10.3}{c} E^{0.959}$$

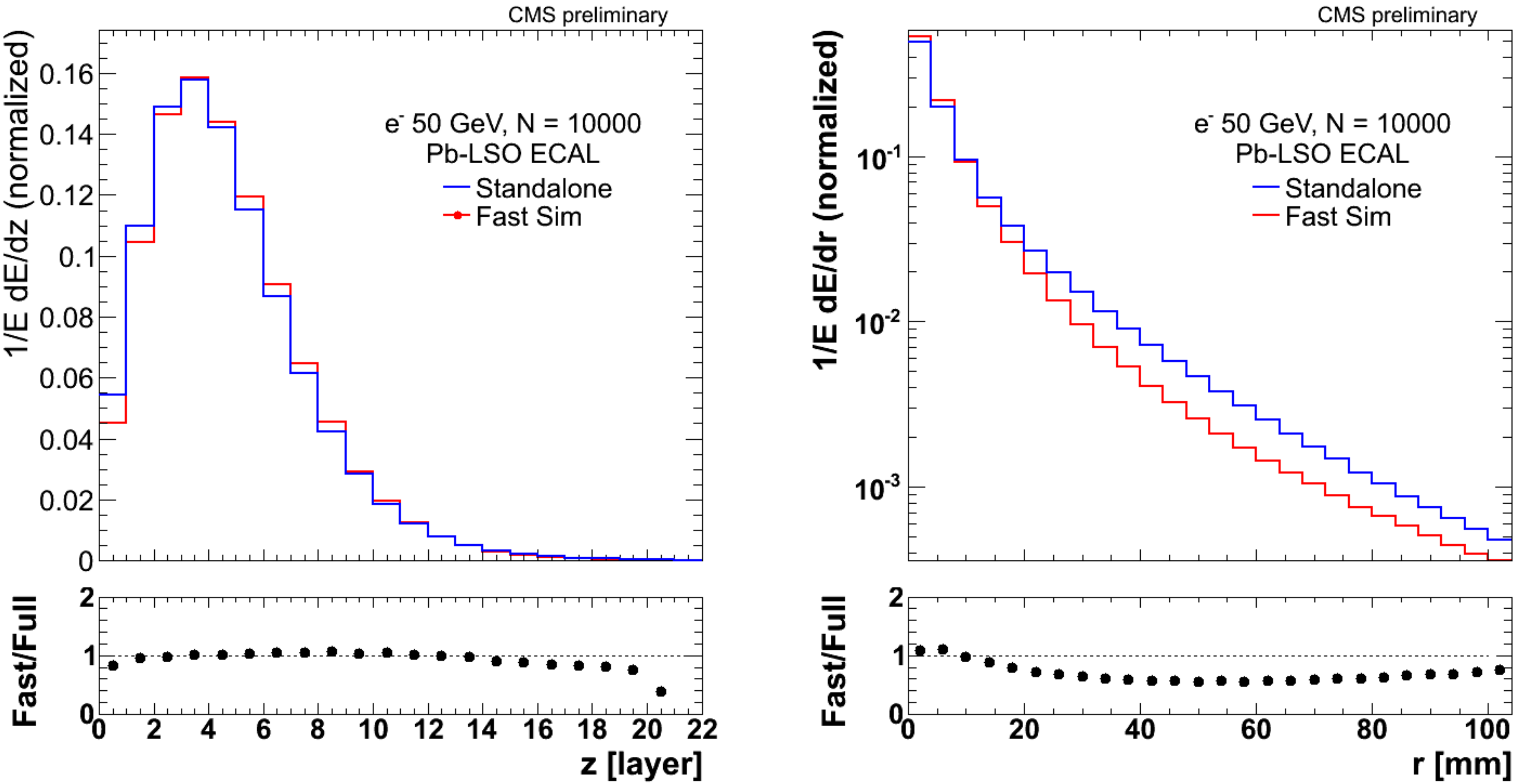
Sampling ECAL Example

One example of a sampling ECAL has 22 layers, each with 8 mm Pb absorber and 2 mm LSO scintillator. The effective medium has these properties:

ρ_{eff} = 10.55 g/cm^3		$X_{0,eff}$ = 6.59 g/cm^2 = 0.625 cm
A_{eff} = 197.52		$E_{c,eff}$ = 7.70 MeV
Z_{eff} = 78.44		$R_{m,eff}$ = 1.70 cm
F_S = 0.62	$\hat{e}$ = 0.85	c = 0.136 GeV$^{1/2}$

This example has the same depth as the current EE, 22 cm.

Validation



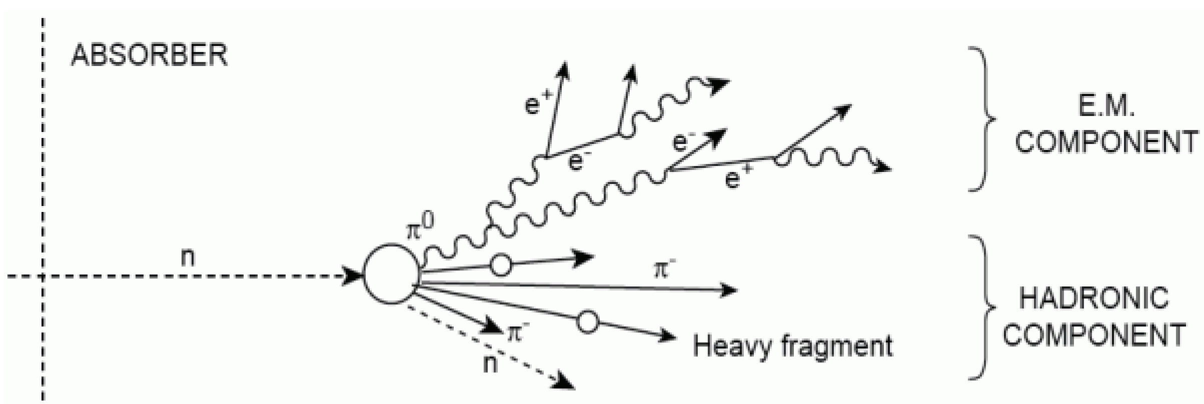
The longitudinal and transverse shower profiles can be compared between the FCAL standalone sim and CMS fast sim, showing good agreement.

Hadronic Showers

Hadronic Showers

Hadronic showers are more complicated than EM showers:

- Hadrons have many decay paths and interaction processes, which lead to greater fluctuations.
- Some decays can cause energy to leave the calorimeter in the form of muons or neutrinos.
- Neutral pions decay into two photons ~99% of the time, giving the showers a significant EM component.
- Evaporation neutrons can deposit energy in several ways, some of which (e.g. thermal capture) are slow.



Interaction Length

The nuclear interaction length λ_0 describes both the longitudinal and transverse spread of the hadronic component of hadronic showers:

$$\lambda_0 = \frac{A}{\sigma_I N_A} \approx 53(A)^{1/3}$$

Here, σ_I is the nuclear interaction cross-section, which can be found by subtracting the elastic and quasi-elastic cross-sections from the total nuclear cross-section σ_T.

This formula gives λ_0 in units of g/cm². One can divide by the material density in g/cm³ to find λ_0 in units of cm.

The interaction length for a material tends to be much larger than the radiation length, indicating that hadronic showers are much larger than EM showers.

Shower Parameterization

Grindhammer, Peters, and Rudowicz also developed a GFLASH parameterization for hadronic showers, but not as extensively as the version for EM showers. CMS uses the simplest version of the average shower parameterization, with custom fluctuations added to model individual showers.

As before, the energy distribution is:

$$dE(\vec{r}) = Ef(t)dtf(r)drf(\phi)d\phi$$

where E is the energy in units of critical energy E_c, t is the longitudinal shower depth (in units of λ_0 or X_0), r is the transverse distance (in units of λ_0 or R_m), φ is the azimuthal angle. (Uniformity in φ is assumed.)

CMS HCAL Properties

The CMS HCAL is simulated in the fast sim as an effective medium of copper. This is not too unrealistic, as the brass absorber is mostly copper, and the plastic scintillator makes up only ~5% of each layer. Copper has the following values for the important material quantities:

$\rho = 8.96$ g/cm^3	$X_0 = 12.86$ g/cm^2 = 1.43 cm
$A_{eff} = 63.546$	$E_c = 18.63$ MeV
$Z_{eff} = 29$	$R_m = 1.712$ cm
$\lambda_0 = 15.05$ cm	λ_0 (ECAL) = 18.5 cm

HB has an effective depth varying between 5 and 10 λ_0, and HE has a depth of 149.6 cm = 10 λ_0. Note the difference in size between ECAL and HCAL; the ECAL depth of ~25 X_0 corresponds to only ~1.1 λ_0.

Longitudinal Parameterization

The average longitudinal profile combines two gamma distributions, one for the hadronic part of the shower ($\mathcal{H}$, $\_{h}$) and one for the π^0 part ($\mathcal{E}$, $\_{e}$): :

$$dE_{dp} = E_{dp}[(1-c_{\pi^0})\mathcal{H}(x)dx+(c_{\pi^0})\mathcal{E}(y)dy]$$

$$\mathcal{H}(x) = \frac{x^{\alpha_h-1}e^{-x}}{\Gamma(\alpha_h)}, \quad x = \beta_h s_h$$

$$\mathcal{E}(y) = \frac{y^{\alpha_e-1}e^{-y}}{\Gamma(\alpha_e)}, \quad y = \beta_e s_e$$

Here, s_h is measured in interaction lengths λ_0 (for the hadronic part), s_e is measured in radiation lengths X_0 (for the π^0 part), and $c_{\pi 0}$ weights the two contributions, so $0 \leq c_{\pi 0} \leq 1$.

Longitudinal Fluctuations

The above parameterization actually requires two separate sets of parameters based on the incident particle energy:

- low-energy particles, 2 GeV < E < 10 GeV
- high-energy particles, 10 GeV < E < 500 GeV

For each individual shower, the location of the center of each longitudinal step is fluctuated according to a single uniformly distributed random number. This approximates the deviations from the average shower shape.

The starting depth of the shower is decided randomly according to an exponentially-falling distribution. This reflects the observation that most hadronic showers tend to start in ECAL, before HCAL. This is quantitatively accurate for incident particles in the range ~10 GeV < E < ~100 GeV.

Transverse Parameterization

The average transverse profile is modeled by a simpler version of the distribution used for EM showers:

$$f(r) = \frac{2rR^2}{(r^2 + R^2)^2}$$

The number of energy spots to distribute in each longitudinal step is calculated from an estimation of dE(t) and a spot size parameter which is chosen based on the total energy of the incident particle.

The size of the transverse shower is allowed to fluctuate according to a uniformly distributed random number.

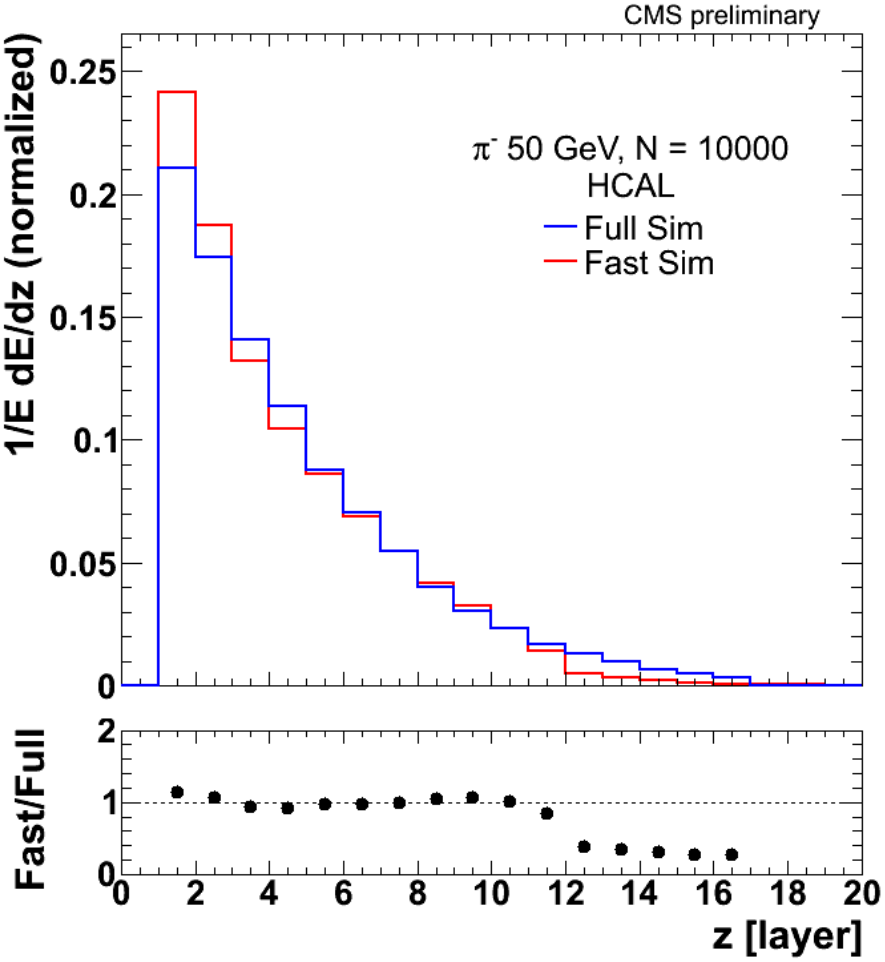
Inclusion of ECAL

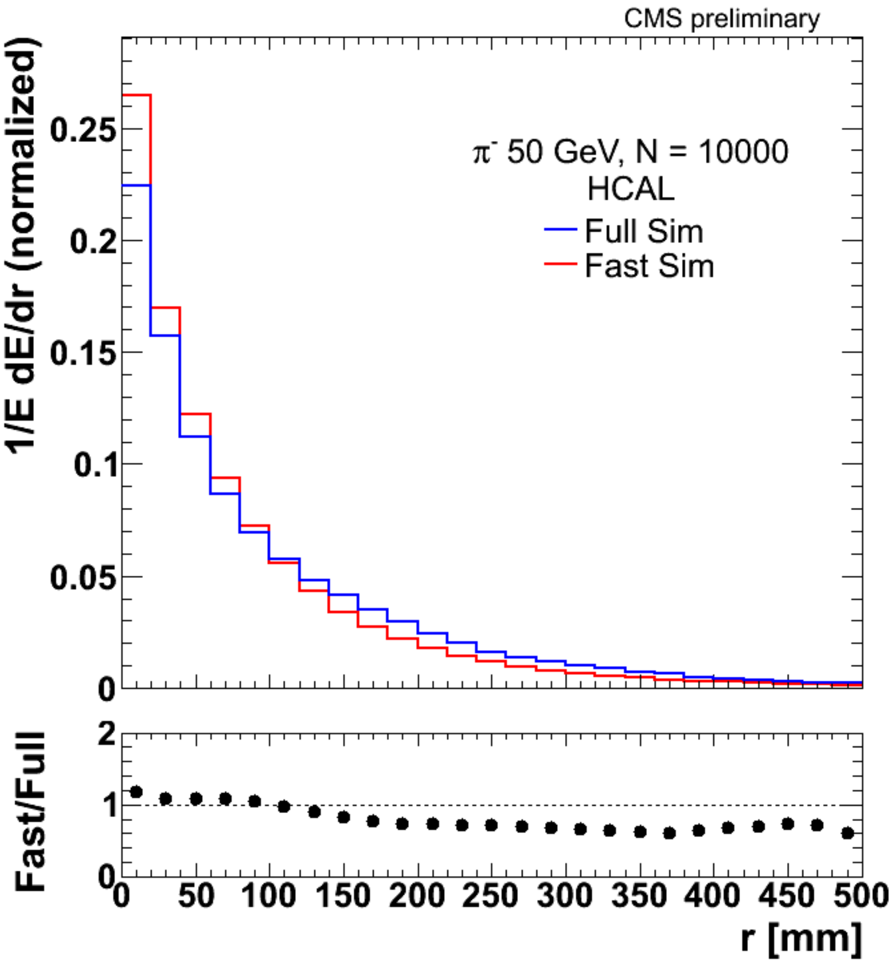
The evolution of hadronic showers in ECAL is simulated in a simplified way. If the starting depth of the shower is not too close to the back end of ECAL, a single step is taken. Otherwise, no step is taken, and no energy is deposited in ECAL.

Particles which deposit no energy in ECAL are called mips in the fast sim, although real mips deposit some small but non-zero energy in ECAL.

The amount of energy deposited by particles which do shower in ECAL is fluctuated according to a uniform random number and an ad-hoc factor which approximates the non-compensating nature of the calorimeter. ECAL (and HCAL, to a lesser extent) has a larger response to electrons than to hadrons, usually denoted as $e/h \neq 1$.

Validation





The longitudinal and transverse shower profiles can be compared between CMS full sim and fast sim, showing good agreement.

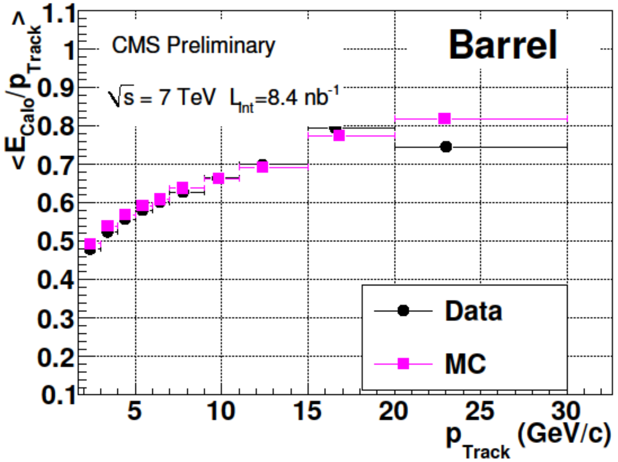
Response Nonlinearity

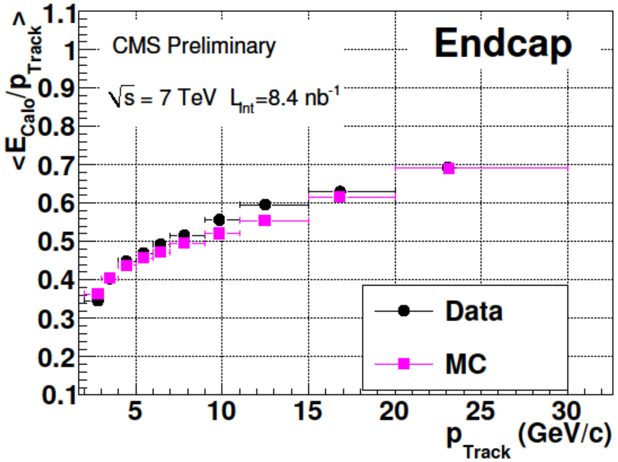
Though the above parameterization does a good job at reproducing the shower profiles in HCAL, it lacks several important features:

- Sampling fluctuations are not simulated, so no energy is lost
- Non-compensating behavior is only partially included
- Dead material between ECAL and HCAL ($\sim 0.6\lambda_0$ in depth) is not simulated

All of these factors play important roles in the observed nonlinearity of the calorimeter response to single particles and also contribute to the energy resolution.

Data vs. Full Sim





Response Smearing

To account for the detector effects listed above, once the energy spots are deposited in ECAL and HCAL, they are all smeared with normally-distributed random numbers (generated once per event) with parameters μ and σ corresponding to the energy response and resolution for single pions.

These parameters come from the CMS full sim, and are generated for a range of energy points from 1 GeV to 3 TeV at multiples of 0.1η. Parameters for pions with intermediate energies are calculated by linear interpolation between the two closest points. Other hadrons (nucleons, etc.) are treated as pions.

Smearing all of the energy spots in each event improves, on average, the accuracy of energy response and resolution for a large sample of particles.

Forward HCAL

Hadronic showers in the HF are simulated using the same procedure as described above, with a few small modifications (e.g. narrower transverse shower size to reflect the use of Cherenkov light instead of scintillation). The response is smeared using Gaussian parameters from full sim.

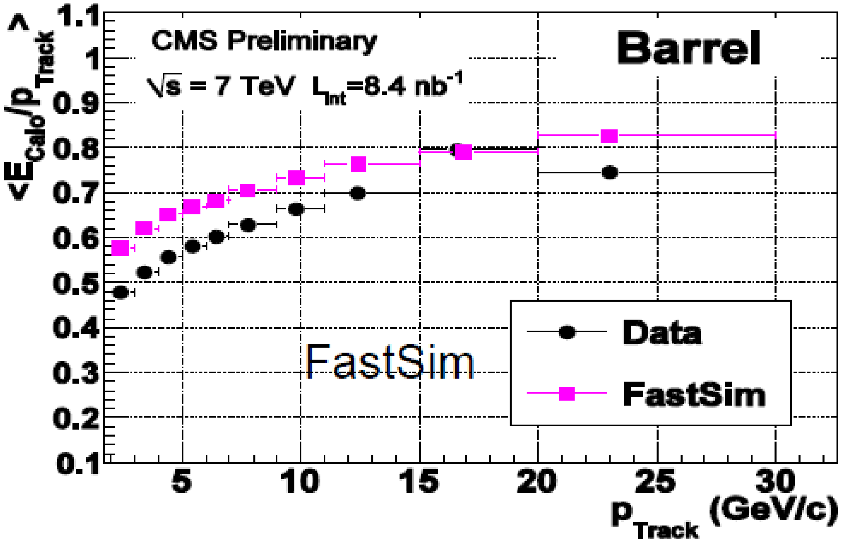
In addition, the response of HF to electrons and photons must be simulated, because there is no ECAL in front of it. This is done in a simple way: using similar smearing parameters calculated for electrons, a single smeared energy hit is deposited along the path of the particle track.

HF has a depth of 165 cm, or ~10 λ_0.

IsoTrack Results

To check against data, the fast simulation was used to process 50 million 7 TeV minimum bias events generated using Pythia6.

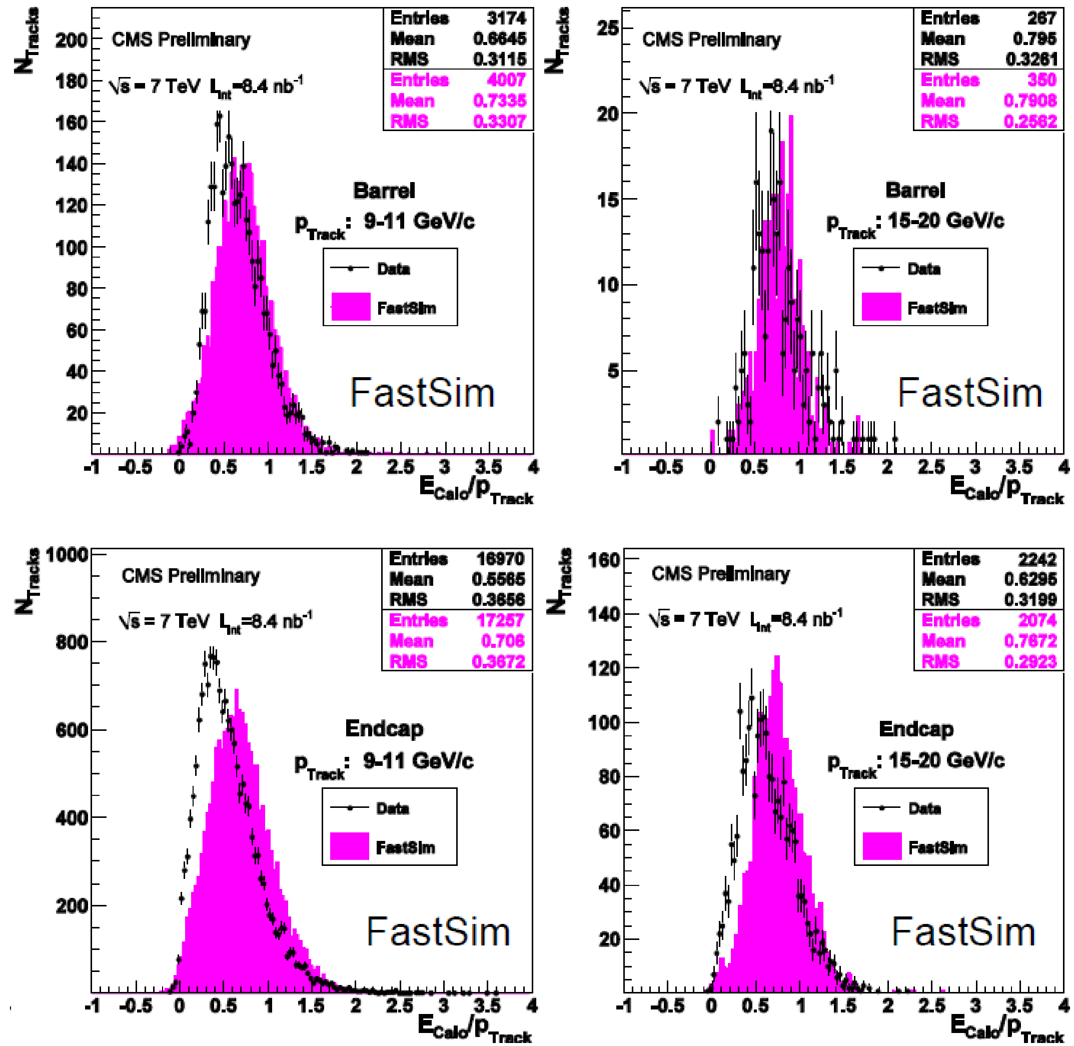
The results were compared against minimum bias samples from 2010 data and full simulation MC, with sample, event, and track selections as described in CMS PAS JME-10-008.



IsoTrack Results

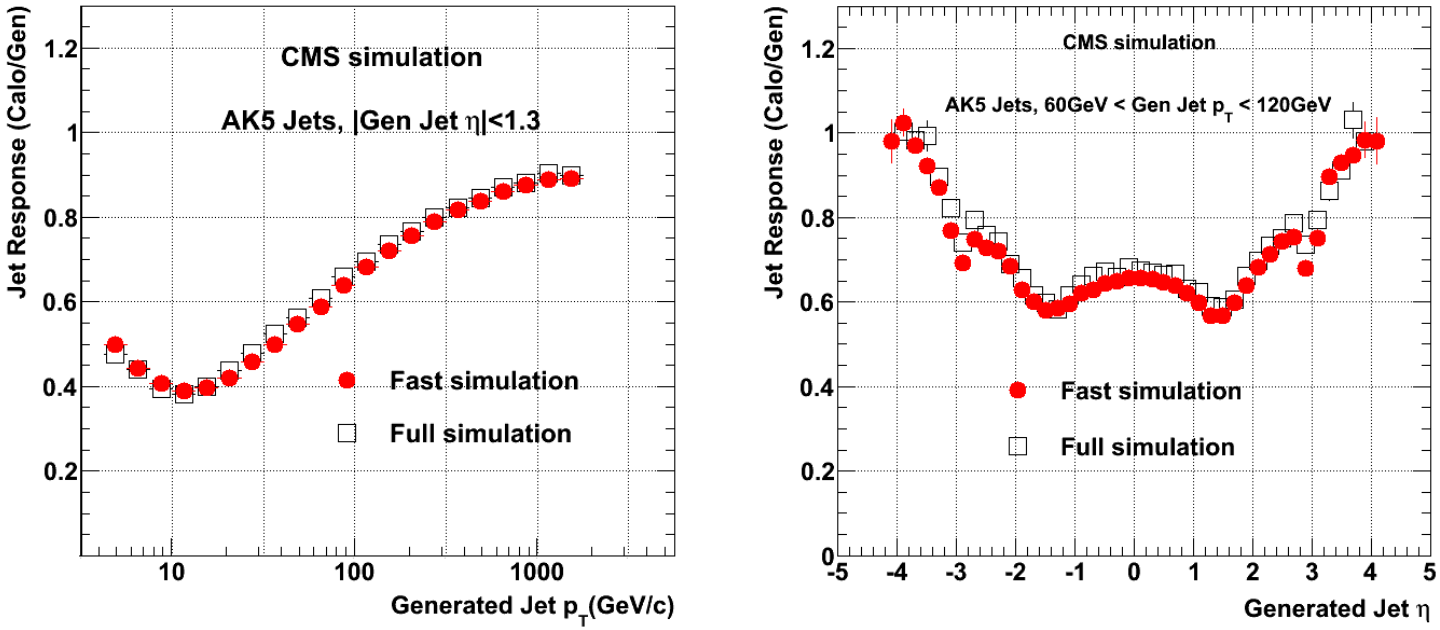
CMS fast sim deviates from data for the following reasons:

- Gaussian response smearing ignores tail behavior (esp. important at low energies)
- Modeling of mips in ECAL is inaccurate
- Showers tend to be too narrow (esp. at low energies)
- Magnetic field effects on shower not included
- HCAL zero suppression not included



Jet Results

The single-particle deviations do not seem to have a large effect on higher-level objects. For example, a comparison with simulated jets shows very good agreement:



samples from a CMSSW release used in 2010 data analysis (3.6.2)

MET Results

The agreement for missing transverse energy (MET) has also been tested.

The fast simulation was used to process 10 million 7 TeV minimum bias events generated using Pythia8.

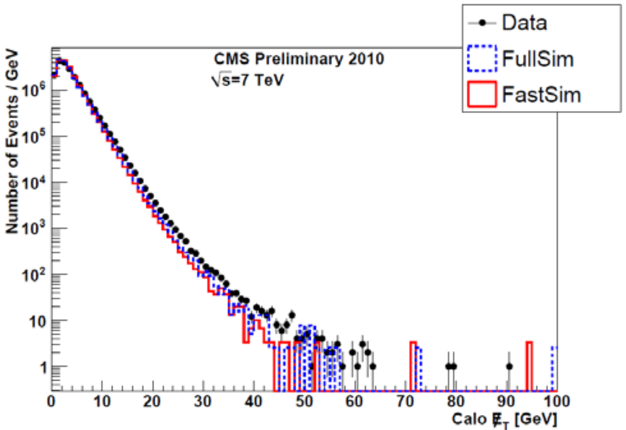
The results were compared against minimum bias samples from 2010 data (11.7 nb^{-1}) and full simulation MC, with sample, event, and particle selections as described in CMS PAS JME-10-004.

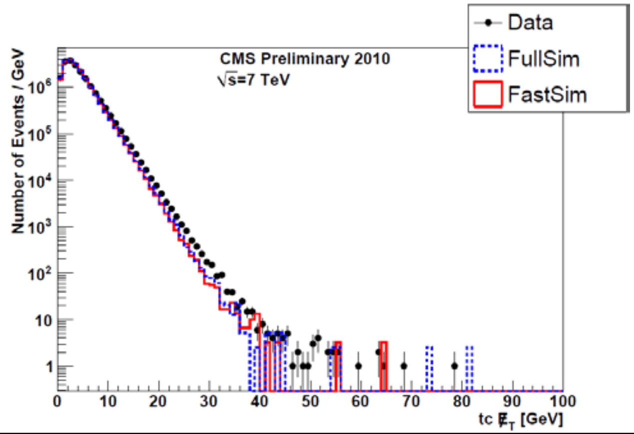
MET can be calculated using calorimeters only (Calo), calorimeters plus tracking (TC, track-corrected), or particle flow (PF).

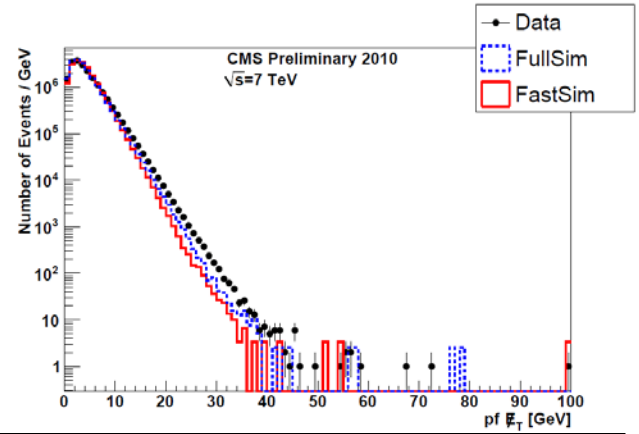
Since these plots were made, the agreement between data, full sim, and fast sim has improved due to better noise and bad-event filters.

MET Results

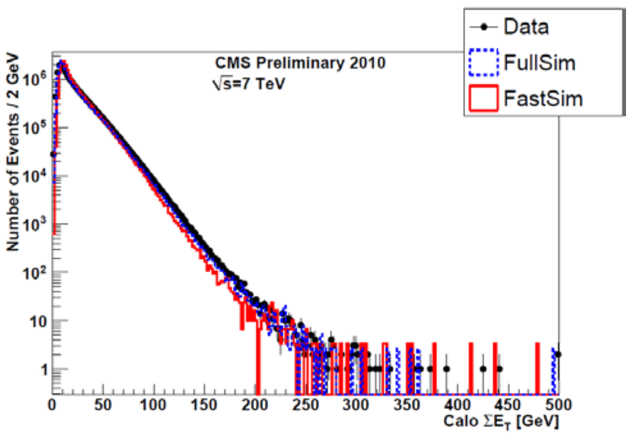
MET

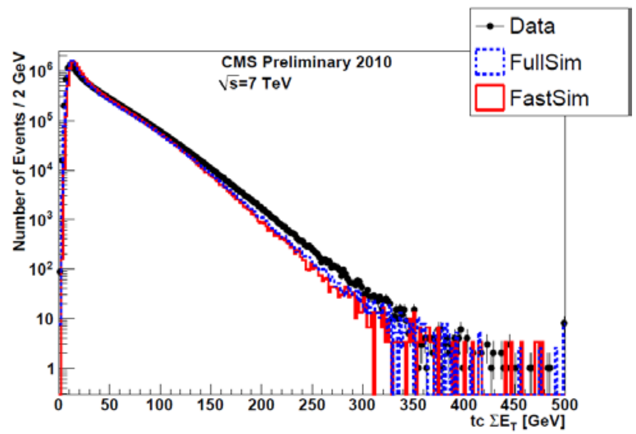


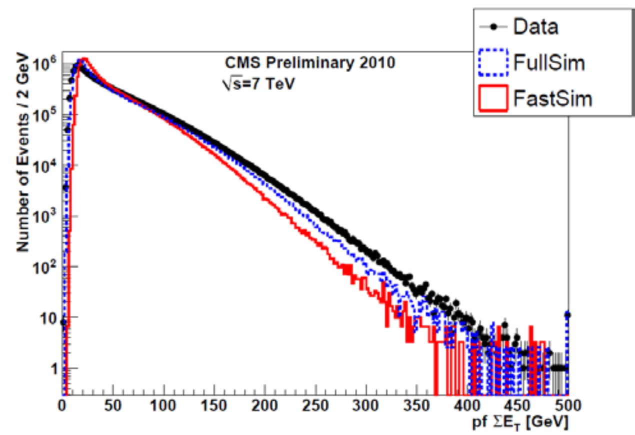




$\sum E_T$



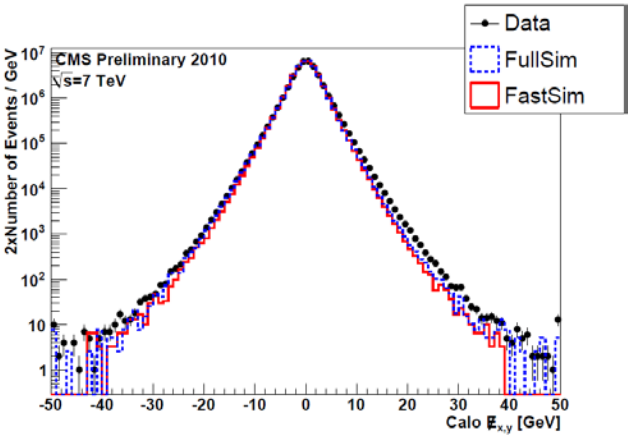




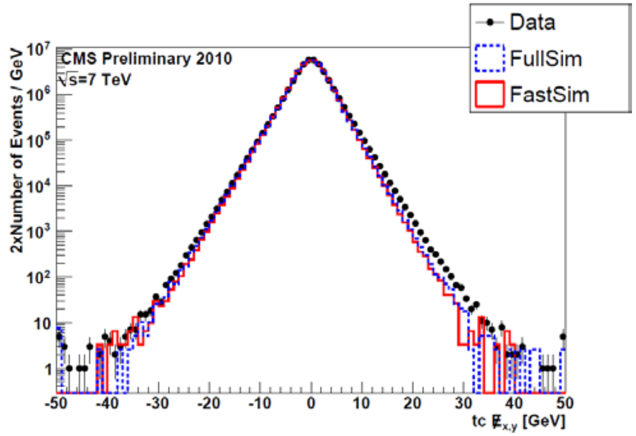
Calo	TC	PF

MET Results

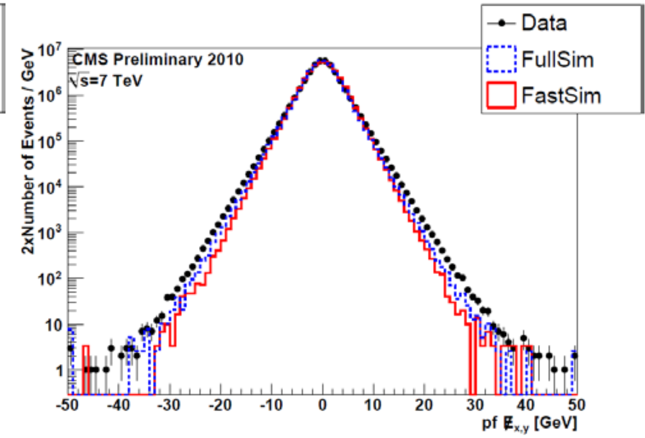
MET Resolution



Calo

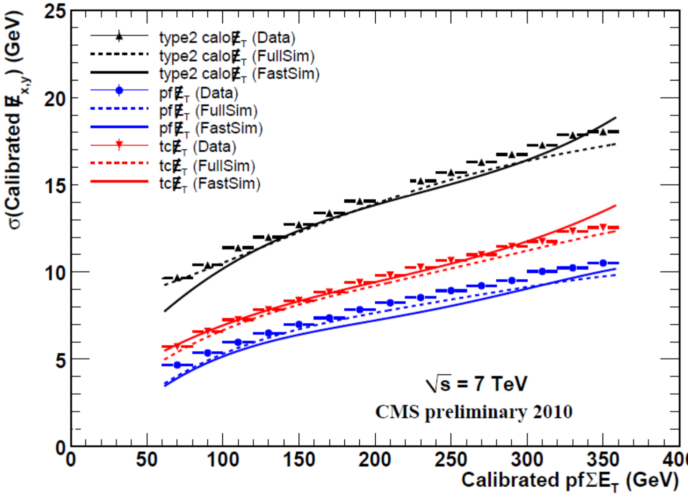


TC



PF

MET Resolution vs. PF $\sum E_T$ (calibrated with full sim)

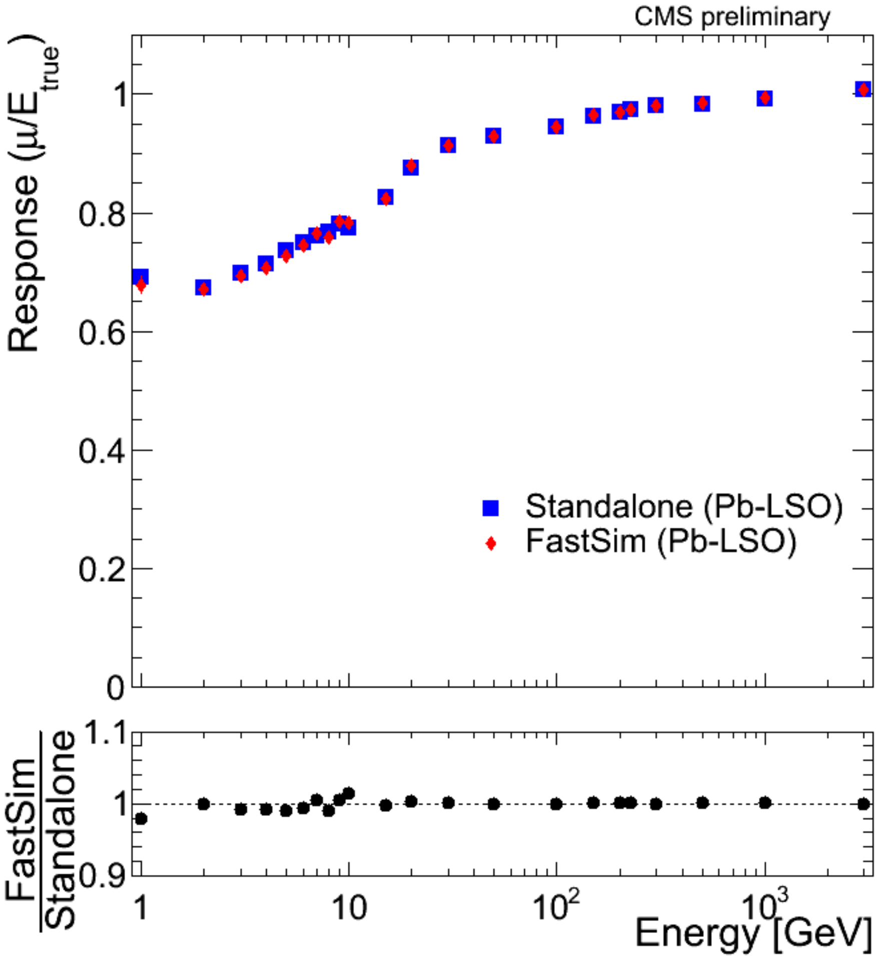


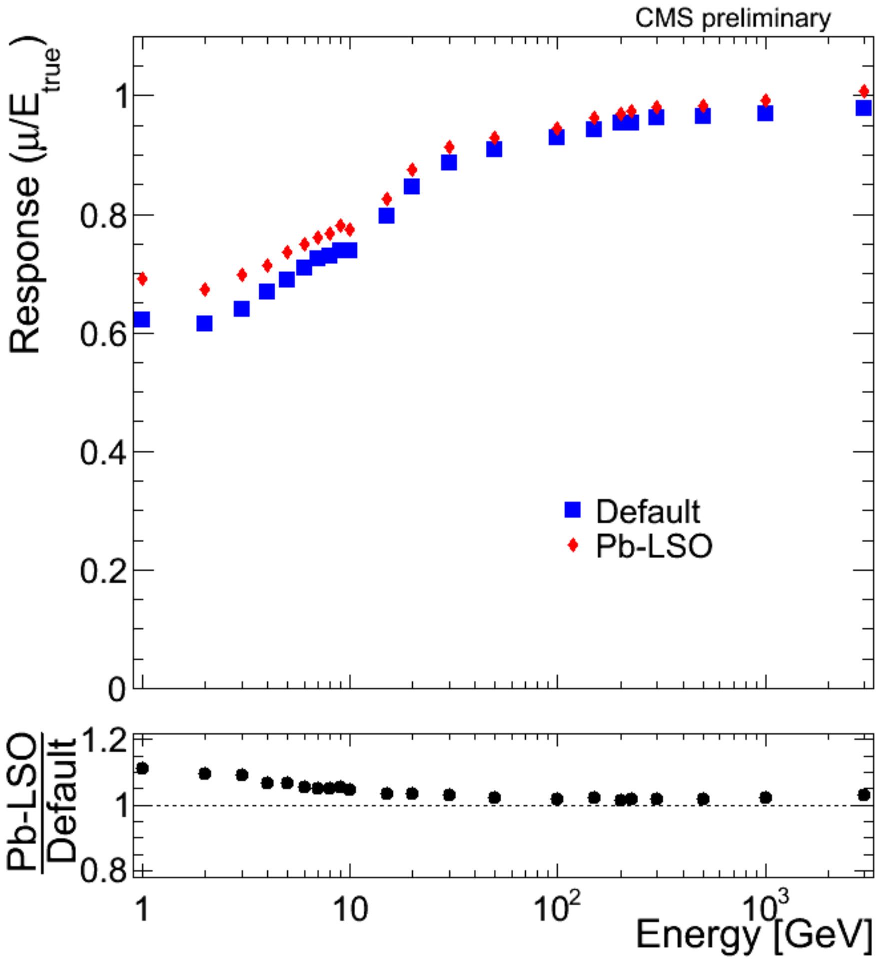
Sampling ECAL

Replacing the current ECAL with a sampling ECAL will change the combined calorimeter response to hadrons. The material properties of the effective medium are all that is needed for the hadronic shower fast sim, but the response smearing parameters will be entirely different to account for the detector effects (more sampling fluctuations, different e/h, etc.).

A new set of smearing parameters can be generated from the FCAL standalone simulation and easily input via Python. This allows for an accurate fast simulation of physics objects like jets and MET for investigation of calorimeter upgrades. This option could also be used to test replacement HCAL scintillators.

Validation





The response parameters can be compared between the FCAL standalone sim and CMS fast sim, showing good agreement. (A comparison between the default ECAL and new Pb-LSO ECAL is shown for reference on the right.)

Conclusion

Summary & Conclusions

- Fast simulation of calorimeters requires a careful understanding of detector geometry, material properties, and particle showers – lots of interesting physics!
- CMS Fast Sim gives accurate physics results and is useful for both current studies and upgrade studies
- There is room for improvement if any enterprising young students need a project…

Acknowledgements

Many thanks to:

- My advisor, Sarah Eno
- Fast Sim gurus, Andrea Giammanco and Salavat Abdoulline
- FCAL Task Force, including Alexander Ledovskoy, Maxime Gouzevitch, and Vladimir Andreev
- Everyone who worked on Fast Sim validation, tuning, and data comparisons
- All of you, for attending and listening!

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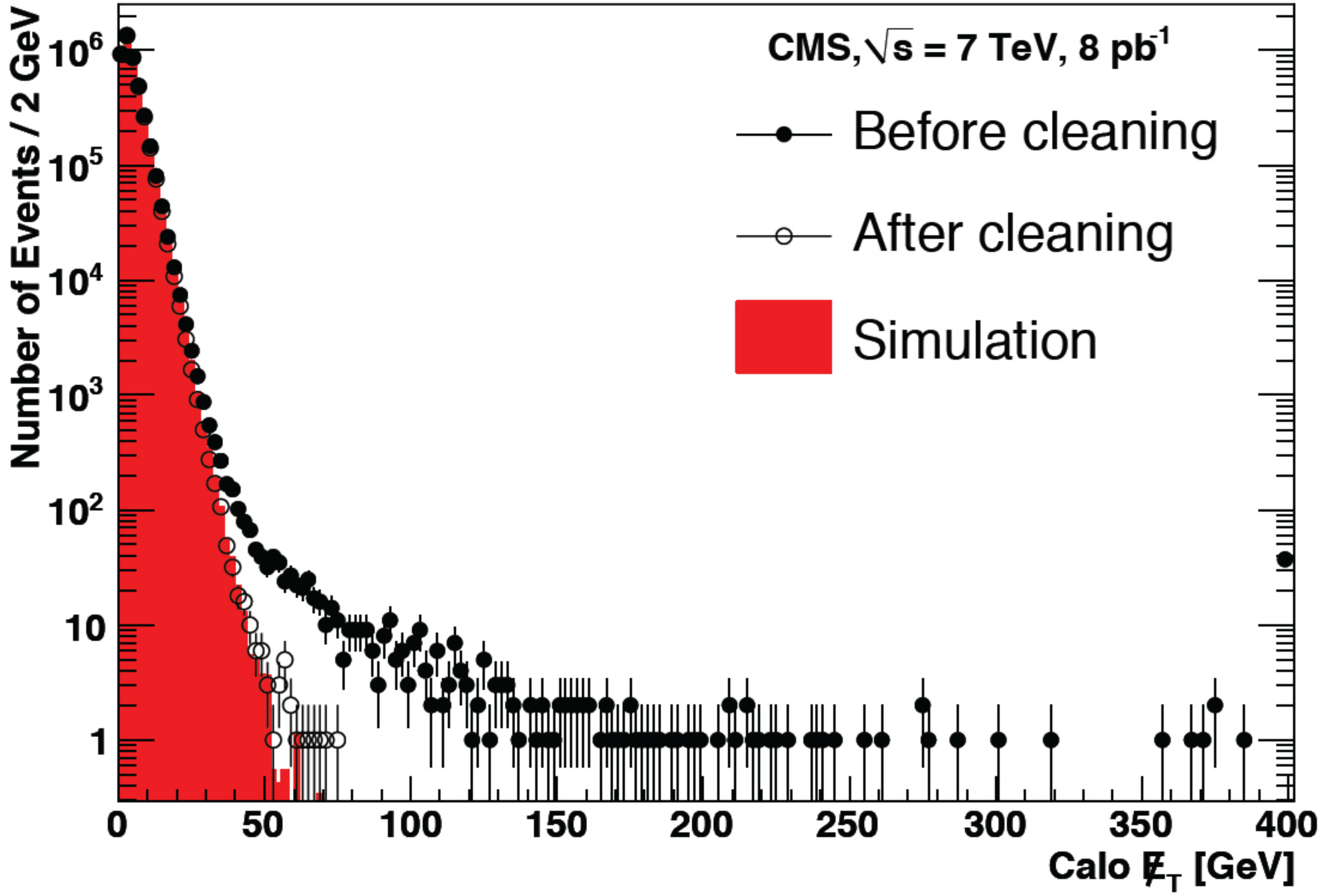
Backup

MET Results with Filters



This plot from JME-10-009 shows the effect of cleaning and filters on Calo MET as compared to full sim.

Particle Flow Patch

The discrepancy in energy scale between full sim and fast sim for PF jets and MET has been resolved by a patch to the fast sim.

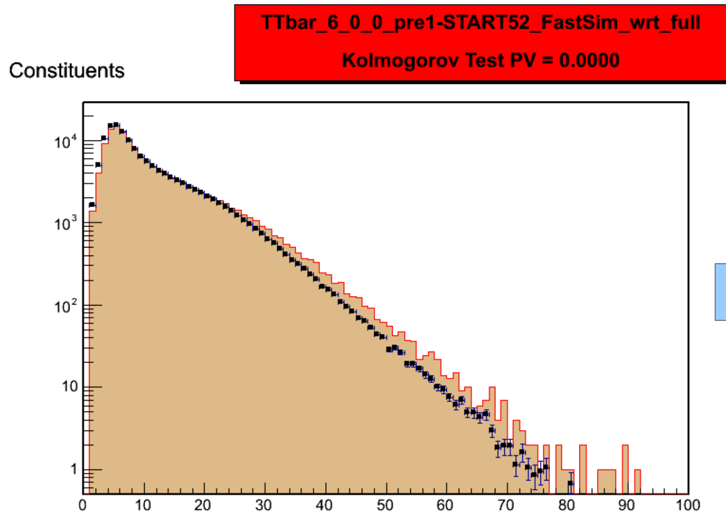
The current hadronic fast sim does not fully account for outliers, which caused the discrepancy. The patch works by adding additional neutral hadron clusters.

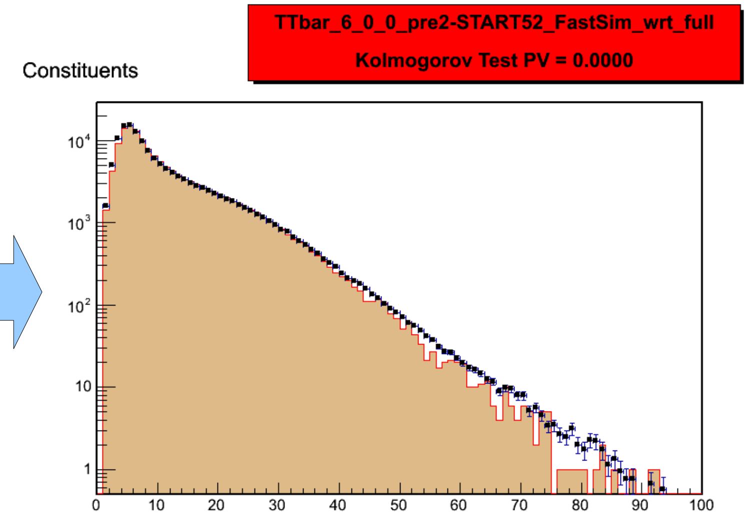
Details of the patch can be found on the public fast sim Twiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideFastSimFAQ#I_observe_a_discrepancy_in_energ

The following plots compare jet quantities for two CMSSW versions: 600pre1 has the patch turned off by default, and 600pre2 has the patch turned on by default. These plots were made by Kittikul Kovitanggoon.

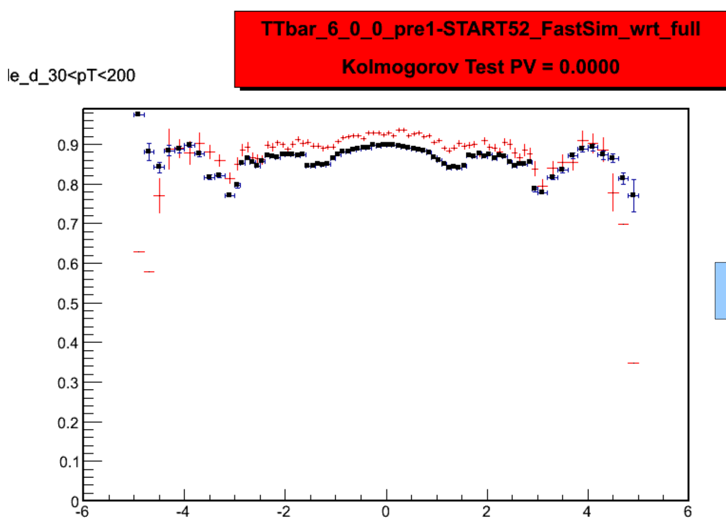
PF Patch Validation

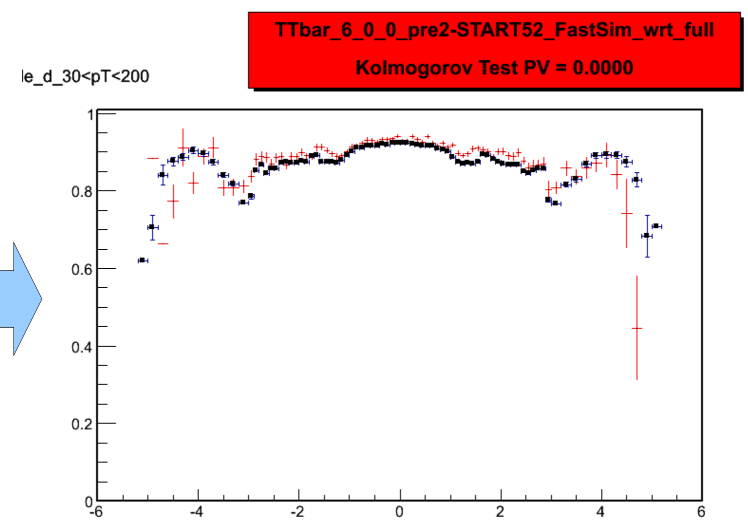
Jet Constituents:





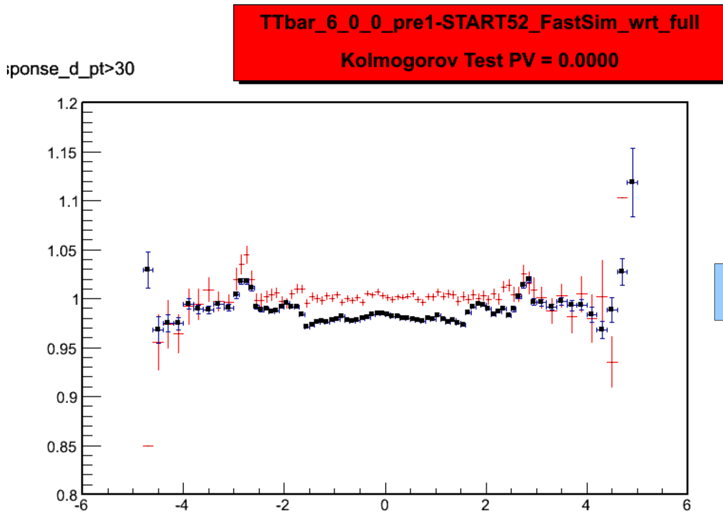
p_T scale vs. η:

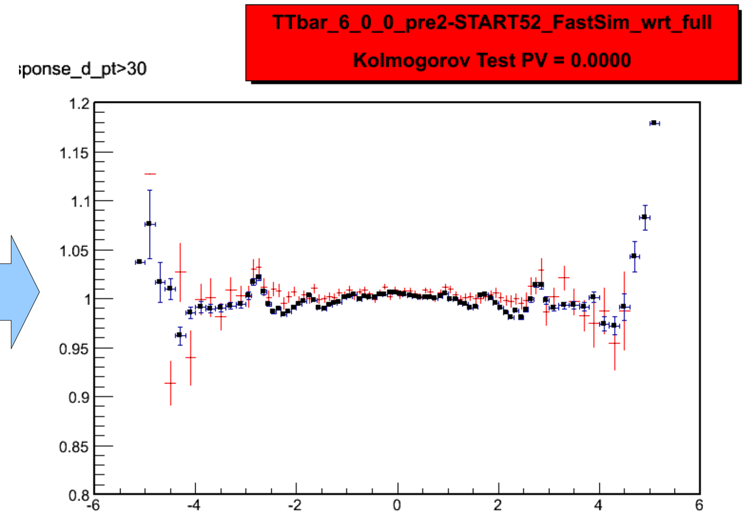




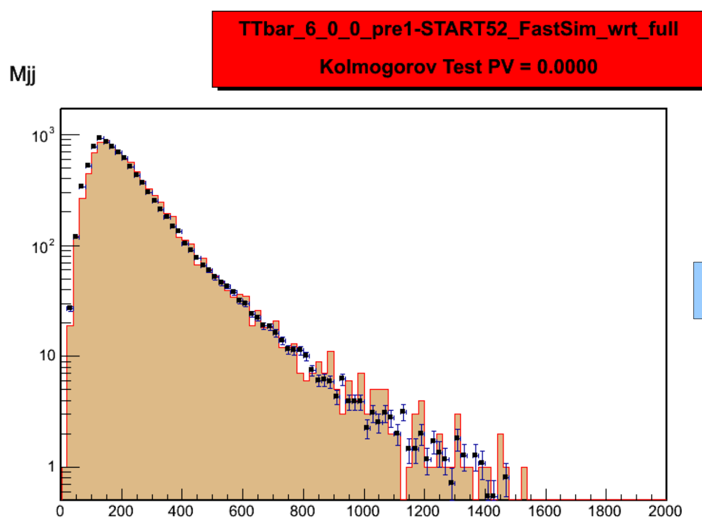
PF Patch Validation

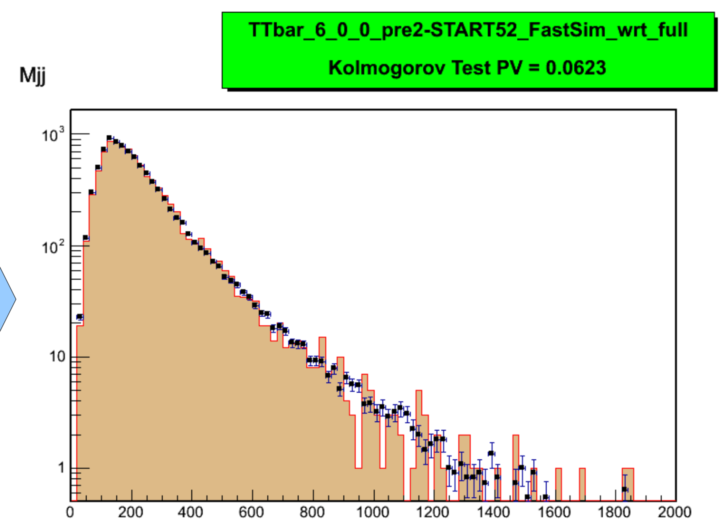
p_T response vs. η:





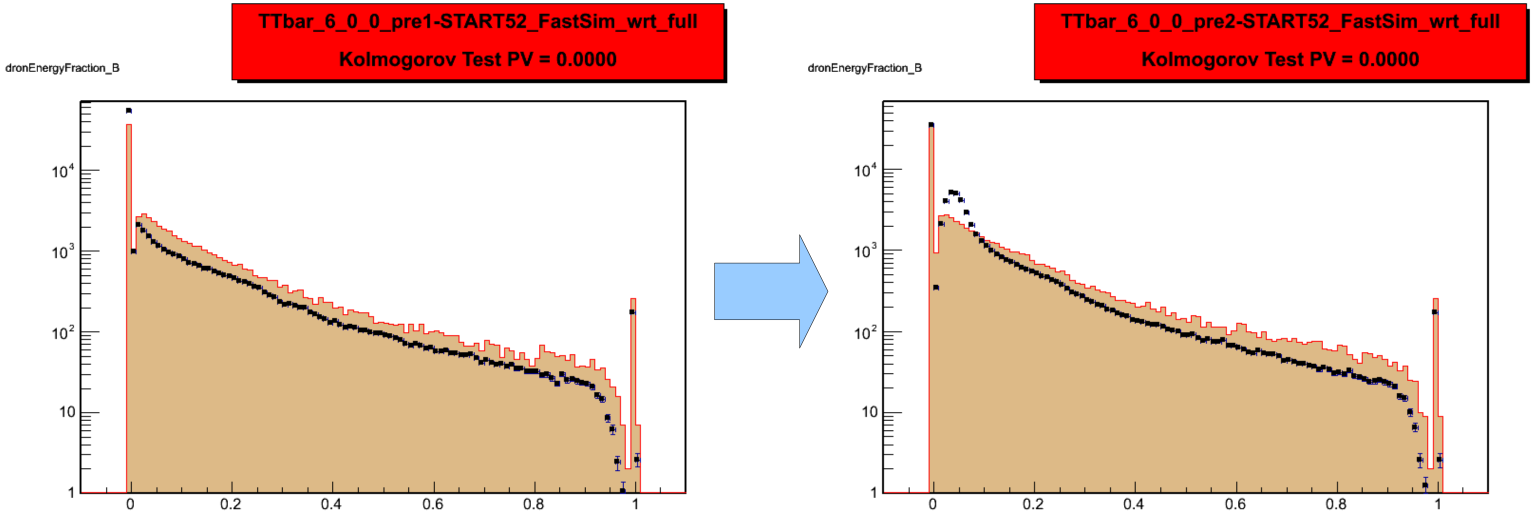
Dijet mass:



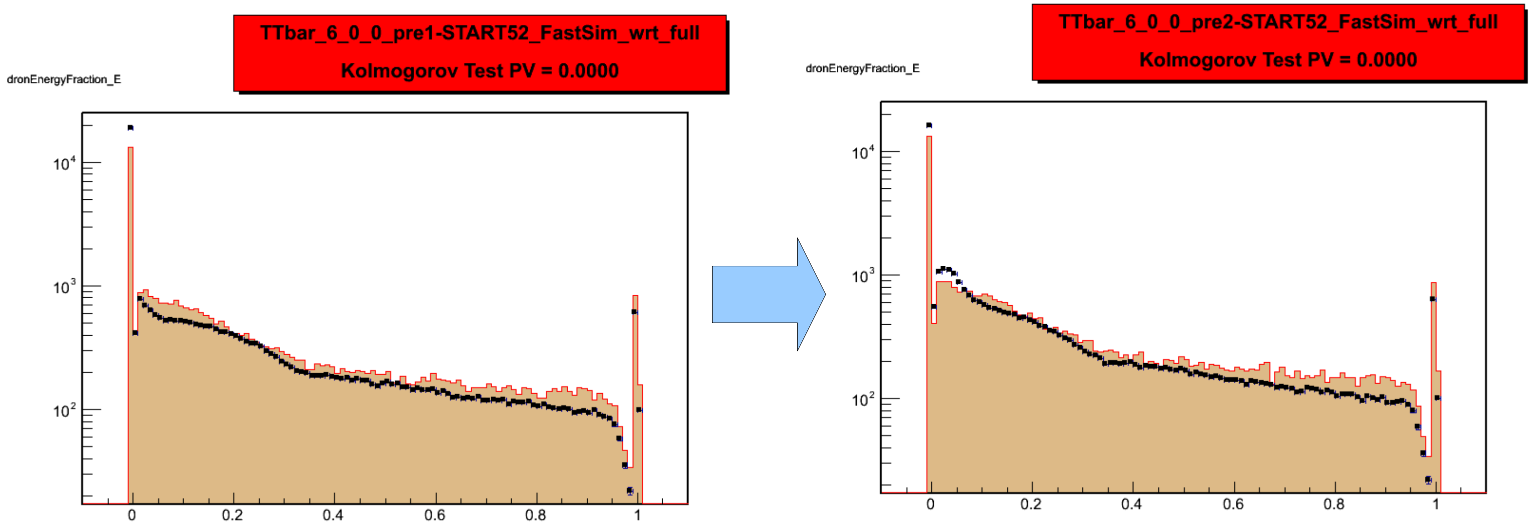


PF Patch Validation

Neutral hadron energy fraction (barrel):



Neutral hadron energy fraction (endcaps):



Note that the patch currently only moves events from the zero bin to the nearby bins.