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The Compact Muon Solenoid Experiment

CMS Performance Note

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Front-Non-Uniformity (”FNUF”) studies for $H \to \gamma\gamma$ mass measurement

CMS Collaboration

Abstract

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Front-Non-Uniformity (“FNUF”) studies for H→γγ mass measurement

The CMS Collaboration

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Introduction

In the CMS Higgs boson mass measurement, in the $H \rightarrow \gamma\gamma$ channel using 2016 data [1], one of the dominant systematic uncertainties is the non-uniformity of the light collection along the length of the ECAL crystals, which reflects into an uncertainty on the Higgs mass of 110 MeV.

In order to reduce the impact of the non-uniformity uncertainty, a new approach was pursued. In particular, an additional correction of the photon energy scale is computed using simulation, and applied to the data. A systematic uncertainty is associated to the mismodeling of the simulation. Thanks to this new approach the impact of the non-uniformity of the light collection on the photon energy scale is reduced.

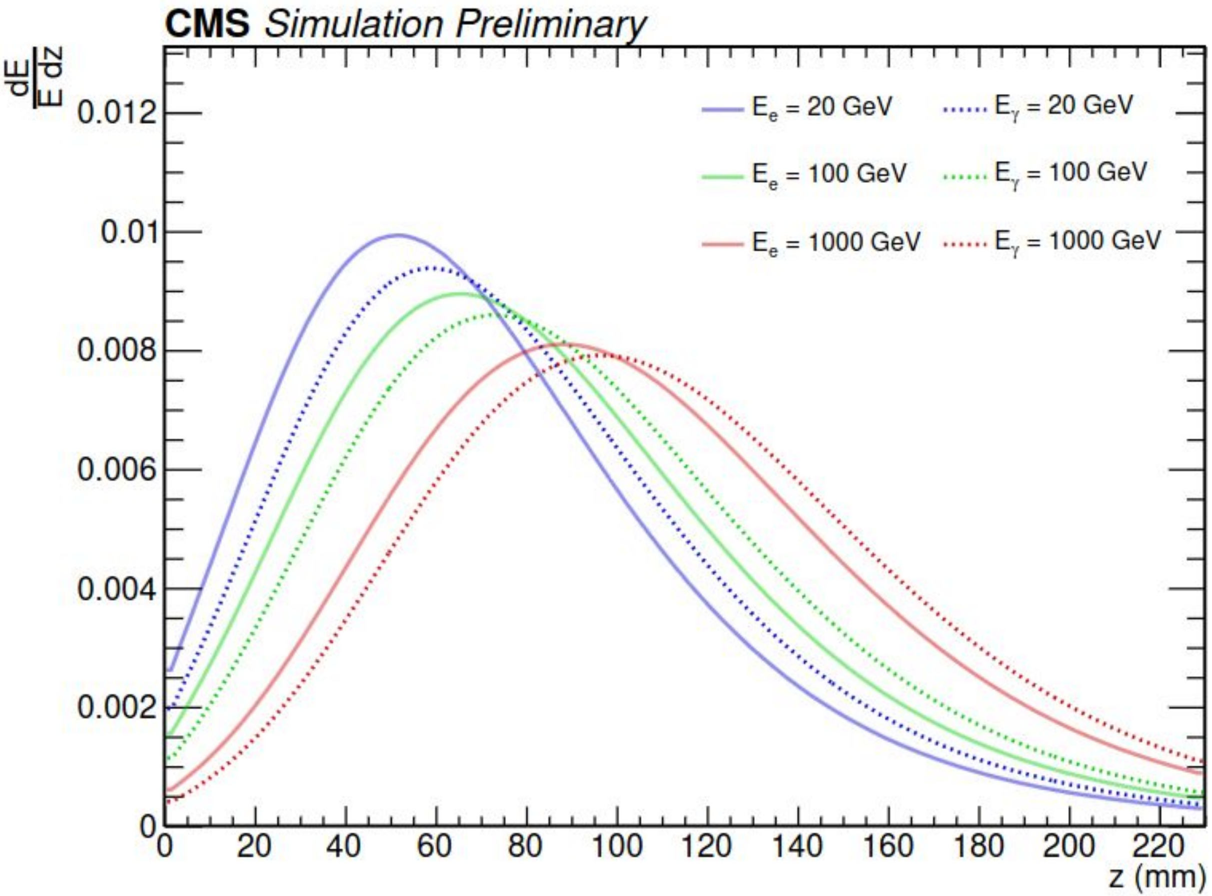
Front-Non-Uniformity corrections

Front-Non-Uniformity, “FNUF”, corrections are computed and applied to the fully calibrated photon energy in data to take into account the impact of the radiation on the difference of the shower profiles between electrons and photons inside the ECAL crystals. An additional energy scale correction is computed, to compensate for the non uniform profile of the radiation damage along the crystal axis. This induces on the light collection efficiency a bias dependent on the shower profile. The energy scale correction factor F is computed as follows:

$$F = \frac{\dfrac{\int E^{e}_{dep}(z)LCE(z)dz}{\int E^{e}_{dep}(z)dz}}{\dfrac{\int E^{\gamma}_{dep}(z)LCE(z)dz}{\int E^{\gamma}_{dep}(z)dz}}$$

where $E^{e,\gamma}$dep(z) is the shower profile inside non-irradiated crystals for electrons and photons, simulated using GEANT4. The radiation damage profile is based on fluences simulated by FLUKA and the light collection efficiency, LCE(z) is simulated with the optical-tracer framework called Litrani, for different scenarios of crystal transparency, R/R0, where z is the depth in the crystal along its axis. The correction is computed as a function of photon energy, impact point onto the detector and the crystal transparency measured with the laser-based monitoring system.

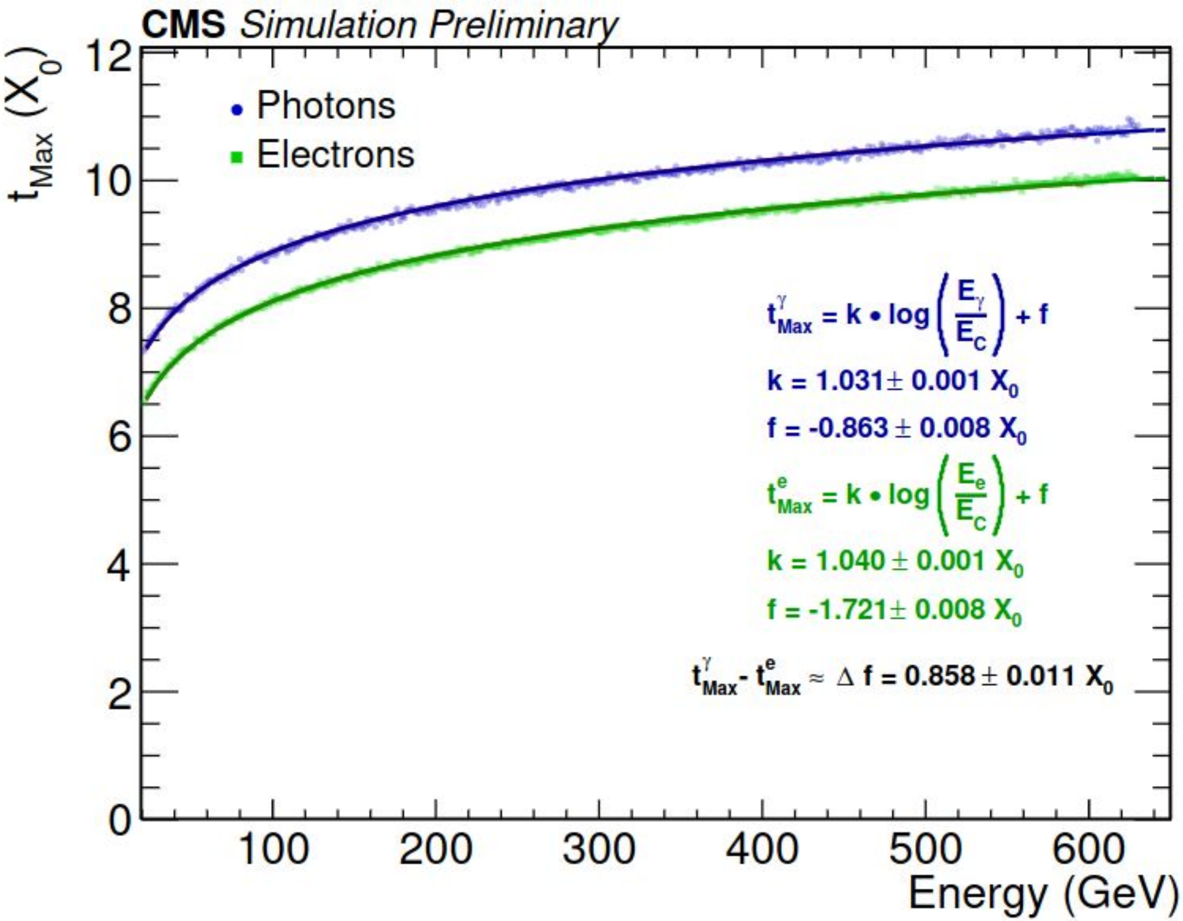
Electron and photon shower profiles



Electron and photon shower profiles

Simulated shower profiles for electrons and photons of different energies, measured with a 7x7 matrix of ECAL crystals centred in η = 1.03 and ϕ = 1.15 (ECAL barrel). Electrons and photons are generated from the nominal centre of CMS and points to the centre of the crystal matrix. The full CMS geometry and nominal magnetic field are used. Electrons are selected by requiring low emitted bremsstrahlung using the topology of the energy deposits, and photons are selected by vetoing conversions. As expected from first principles, photon showers start deeper in the crystals. The profiles were measured at different η, showing variations on the position of the maximum of less than 1%.

Estimation of electron and photon shower profiles difference



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The difference in shower profiles is estimated comparing the shower maximum (t_{Max}) for different simulated energies between photons and electrons. The shower maximum is estimated fitting the shower profile with the Longo-Sestili function [2]:

$$y = a \cdot z^{bt_{Max}} e^{-bz}$$

The resulting evolution of t_{Max} as a function of the energy is fitted with the empirical function:

$$t_{Max} = k \cdot log\left(\frac{E}{E_C}\right) + f$$

and the difference in shower maxima is estimated as: $\Delta t_{Max} \approx \Delta f = 0.85\ X_0$
where E_C = 7.94 MeV is the critical energy, and X_0 = 0.89 cm the radiation length of $PbWO_4$

Light Collection Efficiency

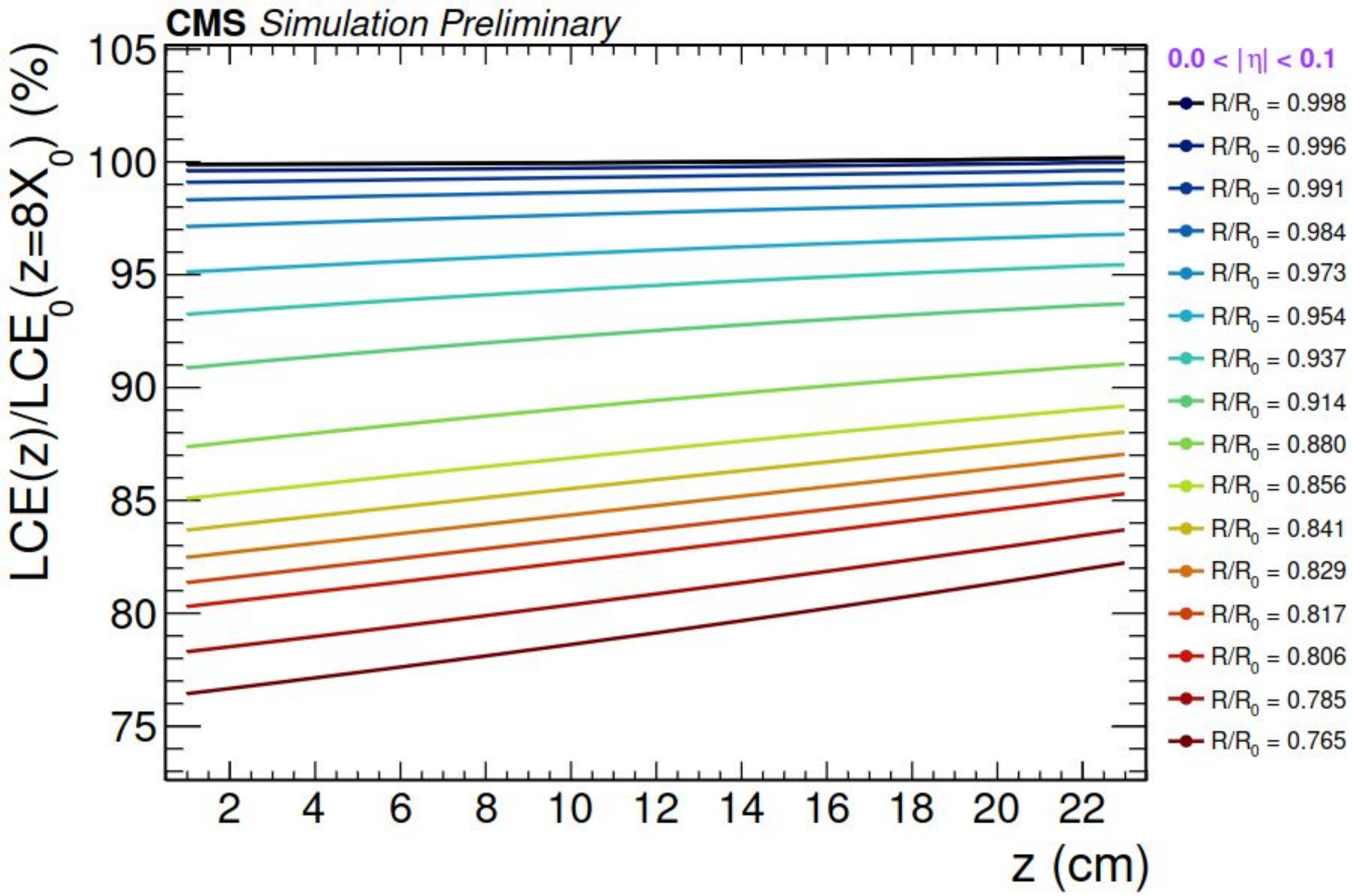
The Light Collection Efficiency (LCE) is the efficiency with which a scintillation photon, produced at point z in the crystal, is measured taking into account also the photodetector efficiencies.

The LCE is simulated for various values of the integrated luminosity, and therefore the change in the ECAL crystal transparency in different η bins is simulated using FLUKA+Litrani, including both electromagnetic and hadronic damage. This simulation is performed in different η bins since there are variations in the hadronic and electromagnetic doses, different photo-detectors in the barrel and the endcaps, and differences in the crystal geometry in η.

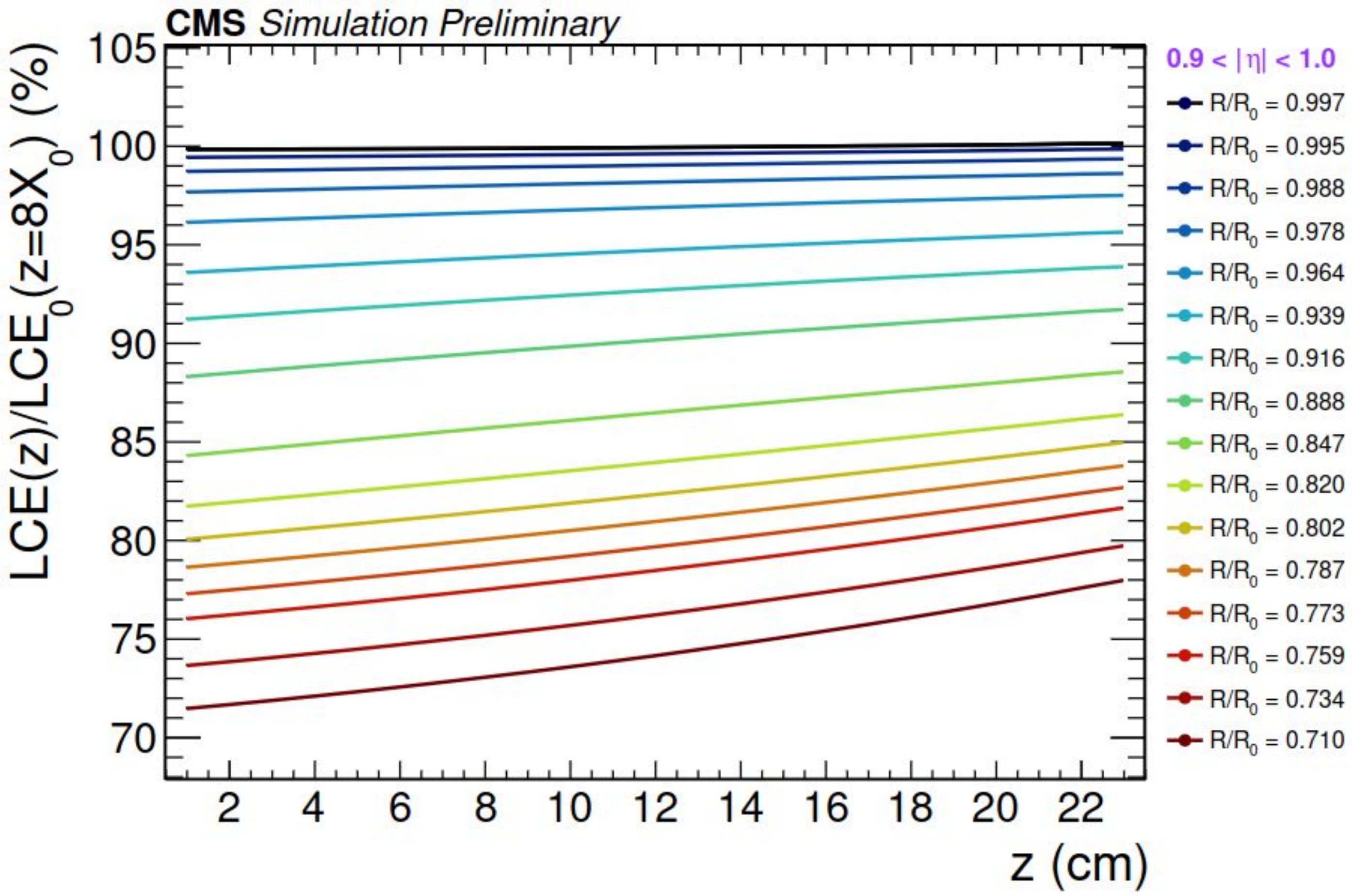
Thanks to the simulation, for any integrated luminosity scenario the ECAL crystal transparency is simulated and used as reference to predict the LCE in data. In particular, the crystal transparency measurements, R/R_0 , taken using the laser monitoring system [3] are used to evaluate the simulated crystal LCE to be used in the computation of the "FNUF" correction. The plots show the LCE as function of the crystal depth, where z=0 cm is the front of the crystal and z = 23 cm (22 cm in EE) is the back of the crystal, for the simulation of different R/R_0 scenarios and different η regions. In particular, the LCE is normalized to LCE_0 at $z = 8X_0$, where LCE_0 is the LCE for non-irradiated crystals.

The mismodeling of this simulation w.r.t. to the data is studied using measurements in [4], resulting in a relative systematic uncertainty of 20% (35%) assigned to the final "FNUF"-correction for EB (EE).

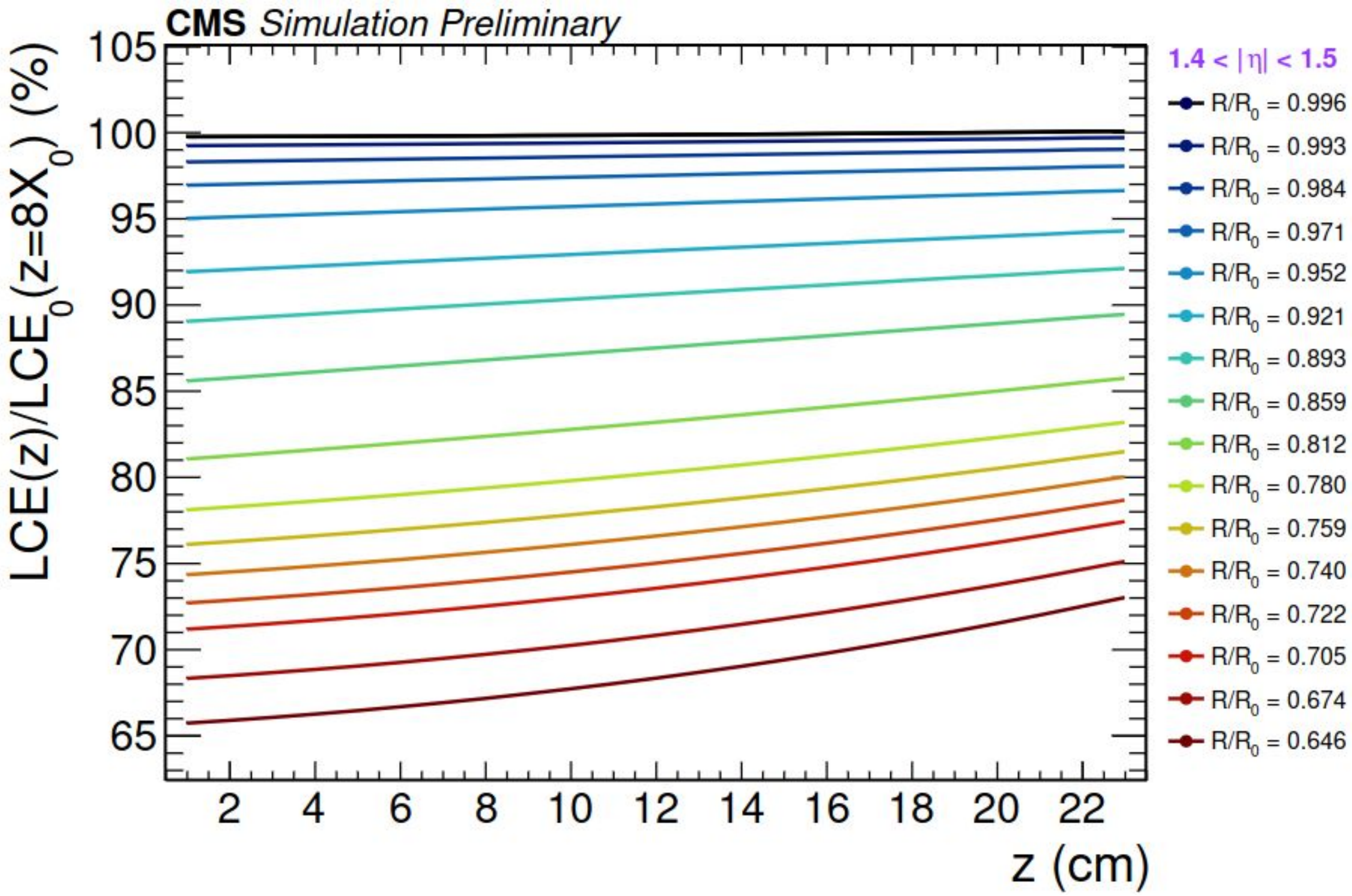
Light Collection Efficiency for 0.0<|η|<0.1



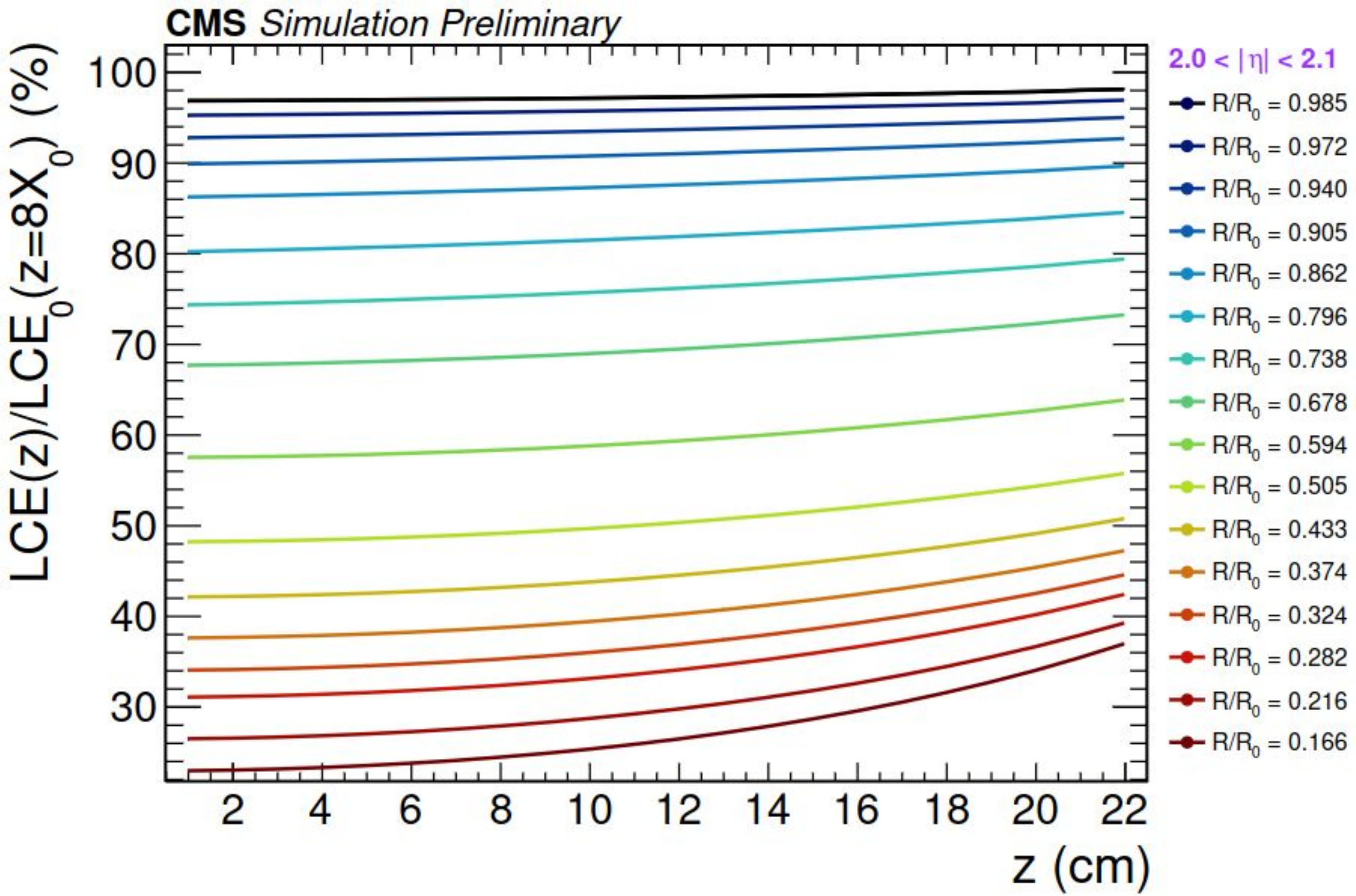
Light Collection Efficiency for 0.9<|η|<1.0



Light Collection Efficiency for 1.4<|η|<1.5



Light Collection Efficiency for 2.0<|η|<2.1



“FNUF”-corrections

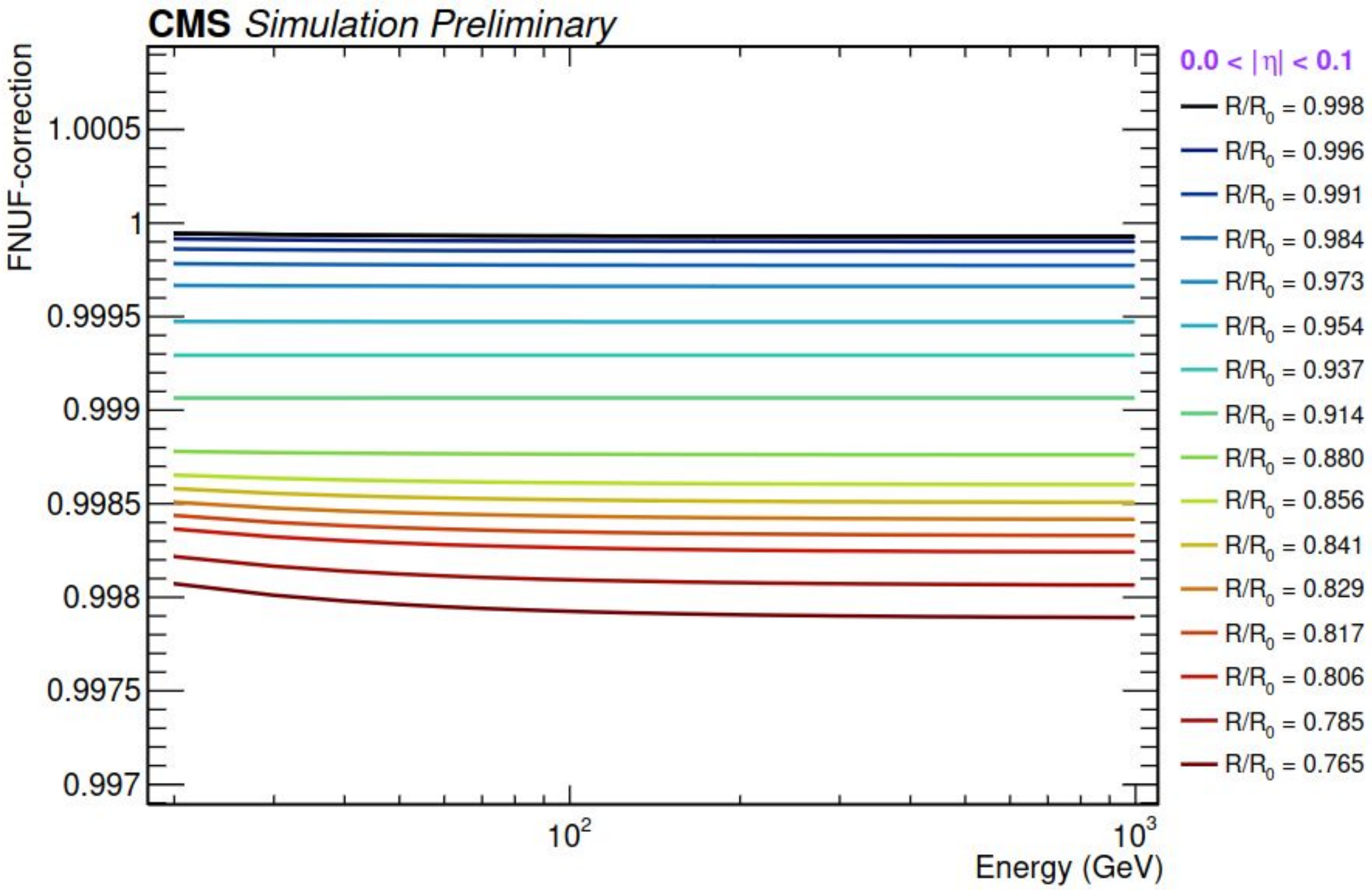
Final FNUF-correction is computed as follow:

$$F = \frac{\frac{\int E^{e}_{dep}(z) LCE(z) dz}{\int E^{e}_{dep}(z) dz}}{\frac{\int E^{\gamma}_{dep}(z) LCE(z) dz}{\int E^{\gamma}_{dep}(z) dz}}$$

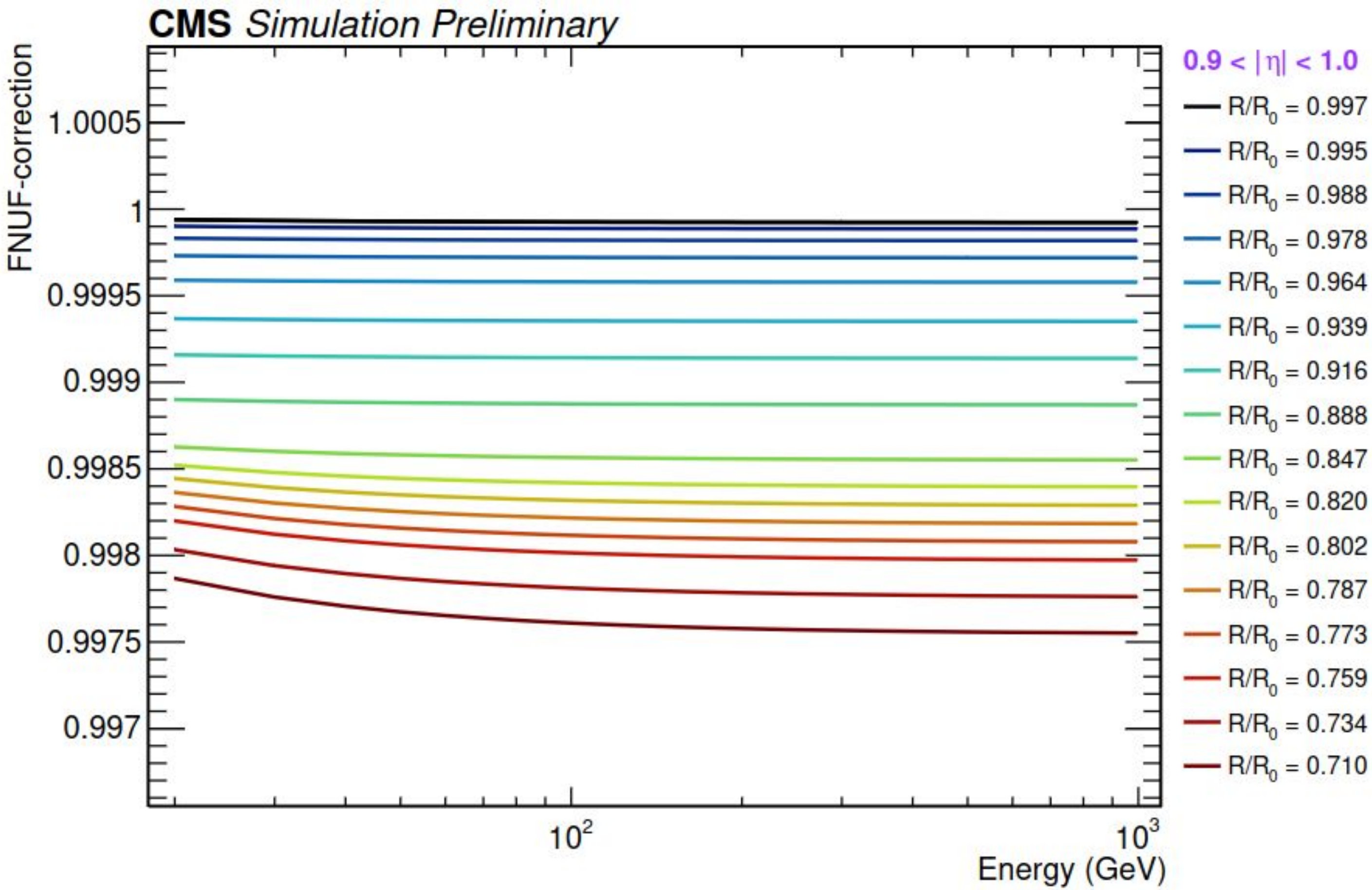
and applied to the calibrated energy of the photons in data. The correction is evaluated as function of the photon calibrated energy, η and the average R/R_0 of the crystals in the photon cluster, estimated using a transparency monitoring system based on laser light injection.

The plots show the FNUF-corrections as function of the particle energy for different R/R_0 scenarios and different η regions.

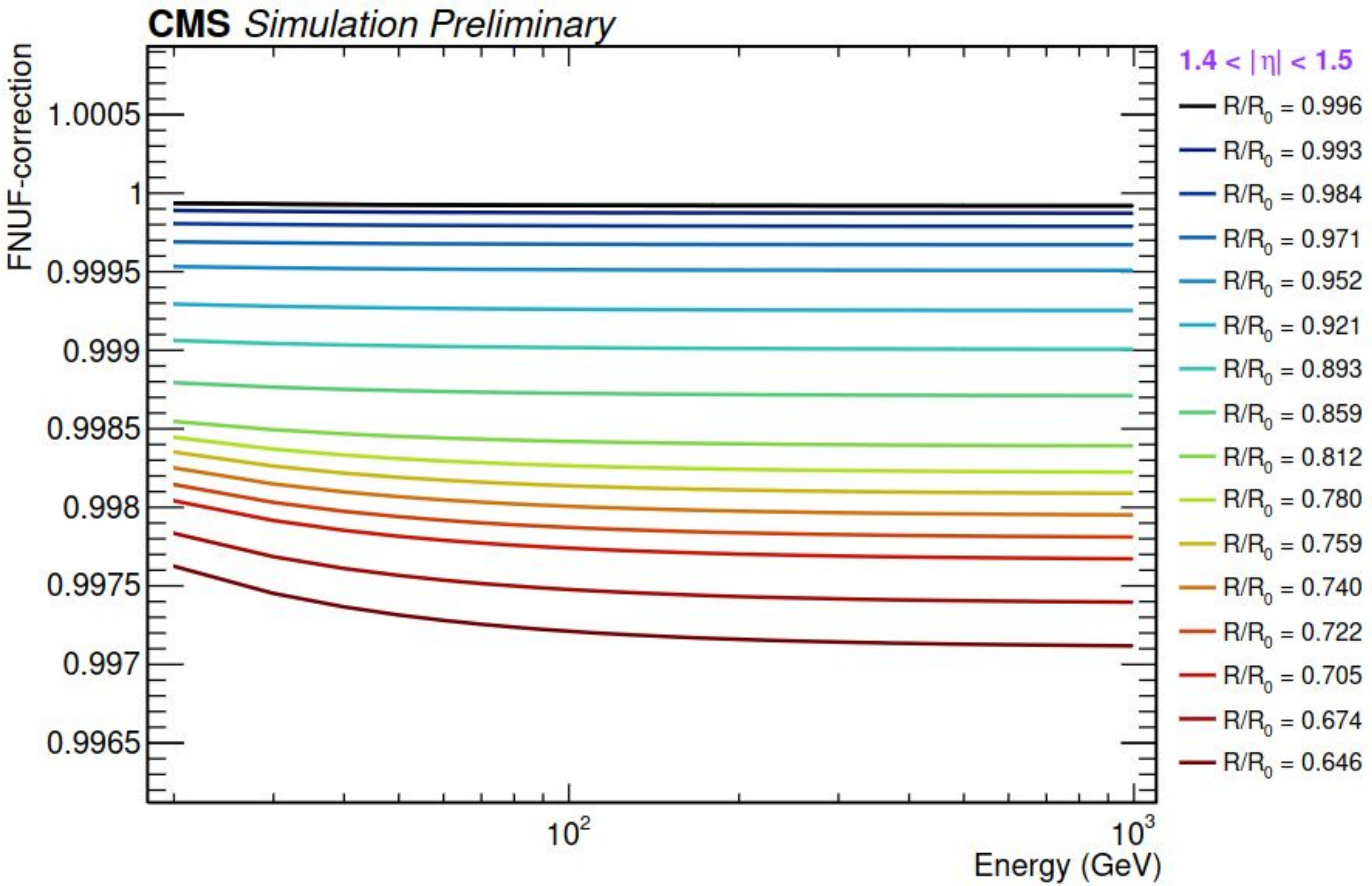
FNUF-correction for 0.0<|η|<0.1



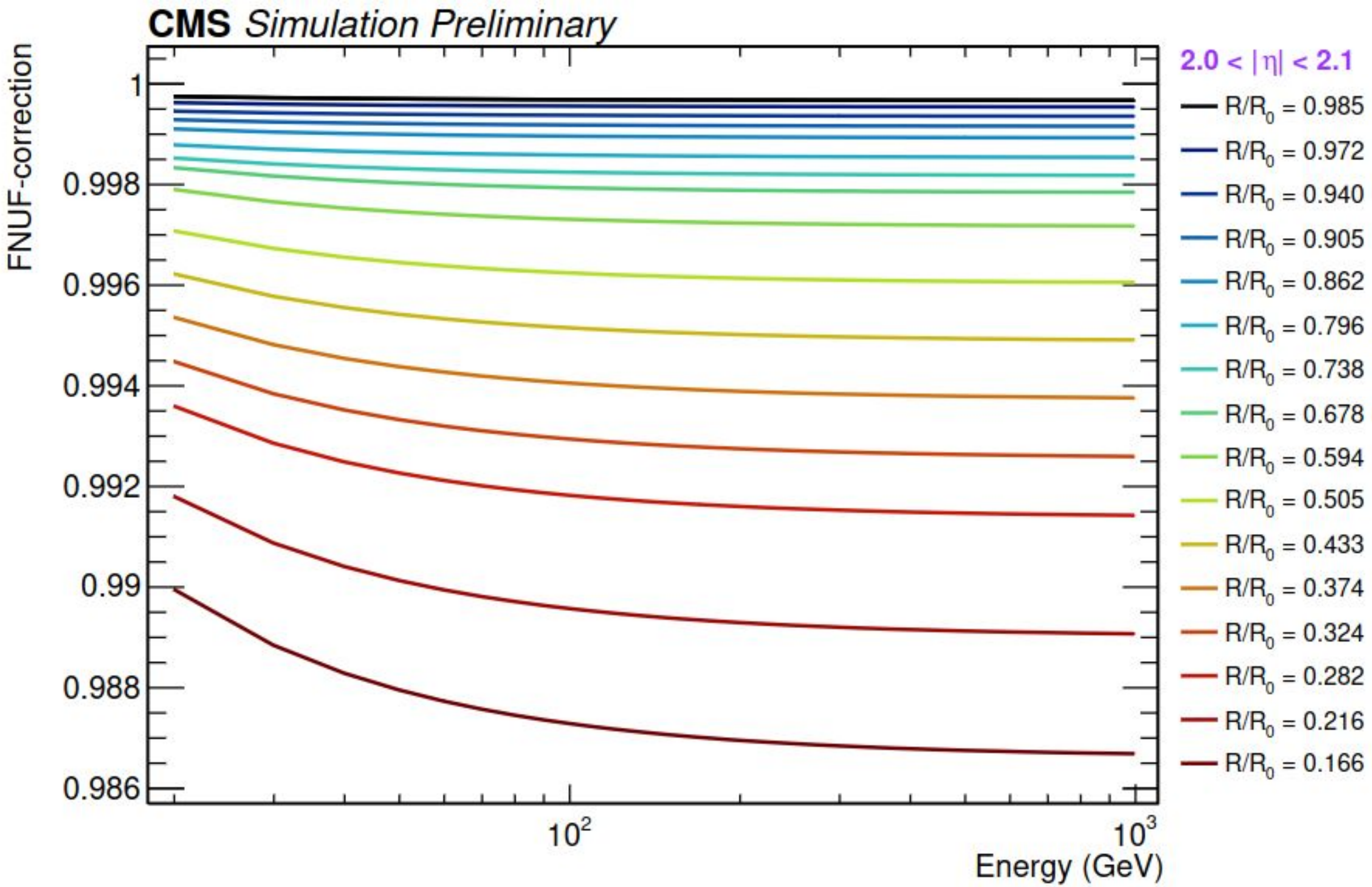
FNUF-correction for $0.9<|\eta|<1.0$



FNUF-correction for 1.4<|η|<1.5



FNUF-correction for 2.0<|η|<2.1



References

[1] CMS Collaboration, “A measurement of the Higgs boson mass in the diphoton decay channel”, Physics Letters B, Volume 805, 10 June 2020, 135425, DOI:10.1016/j.physletb.2020.135425

[2] E. Longo, I. Sestili, “Monte Carlo calculation of photon-initiated electromagnetic showers in lead glass”, Nuclear Instruments and Methods, 1 October 1975, Pages 283-307, DOI:10.1016/0029-554X(75)90679-5

[3] CMS Collaboration, “CMS ECAL Response to Laser Light”, CMS-DP-2019-005, https://cds.cern.ch/record/2668200

[4] P. Lecomte, D. Luckey, F. Nessi-Tedaldi, “High-energy proton induced damage study of scintillation light output from calorimeter crystals”, Nuclear Instruments and Methods in Physics Research Section A, Volume 564, Issue 1, 1 August 2006, Pages 164-168, DOI:10.1016/j.nima.2006.04.043