The Performance for the TeV Photon Measurement of the LHCf Upgraded Detector Using Gd_2SiO_5 (GSO) Scintillators

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Abstract

The Large Hadron Collider forward (LHCf) experiment measures the forward particle production at the LHC to verify hadronic interaction models used in air shower experiments. We have developed the upgraded rad-hard calorimeters for p-p $\sqrt{s}$=13 TeV collisions. After the calibration through the beam test, we have completed the $\sqrt{s}$=13 TeV operation with the adequate performance of the detectors.

"Zero-degree" Measurement at the LHC

Two independent LHCf detectors were installed in the instrumental slots, the gaps between beam pipes, of the neutral particle absorbers located in 140m from the interaction point 1 (ATLAS point) (Fig .1). This configuration allows us to measure the neutral particles emitted in the pseudo-rapidity range from 8.4 to infinity. **LHCf is the only experiment dedicated to the very-forward EM measurement at the LHC.**

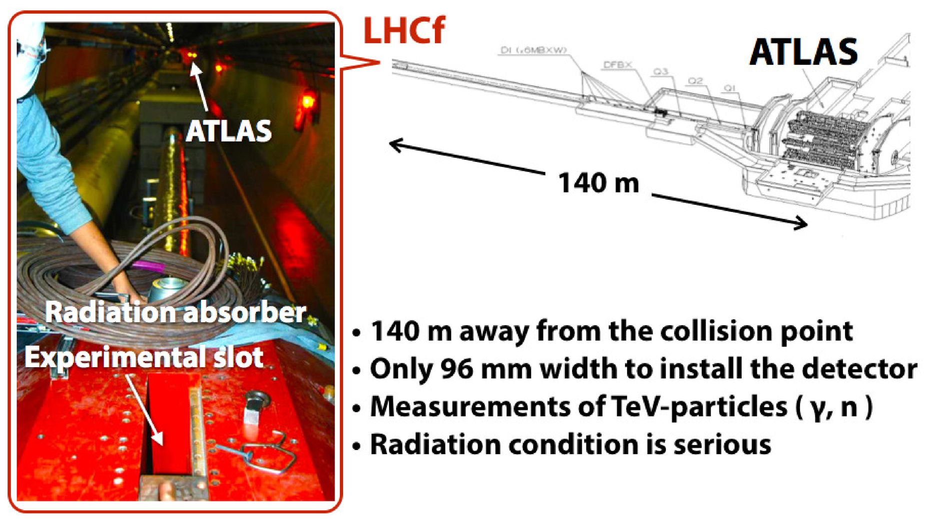


Figure 1: The location of LHCf

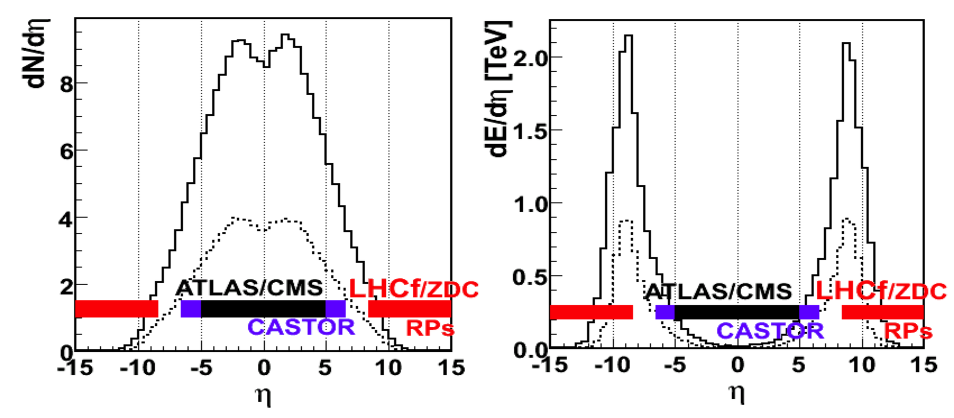


Figure 2: Particle and energy flux distributions

The Upgraded LHCf detectors

Why upgrade was necessary?

Once the LHC increases the collision energy to 13 TeV, maximum radiation dose to the detector was estimated about 30 Gy/nb^{-1}. Considering this irradiation rate, previous detectors [2] aren't suitable because plastic scintillators used in the detector begin its degradation of light yield for doses above 100 Gy. To deal the irradiation condition, Gd_2SiO_5 (GSO) scintillator was selected. **GSO is one of the most radiation-hard among known scintillators.** We have confirmed that properties, especially radiation tolerance, of GSO meet our requirement [3].

LHCf has two independent detectors, named Arm1 and Arm2. Each detector has two sampling and imaging calorimeter towers composed of tungsten interleaved with 16 sampling layers of 1 mm thickness GSO scintillator tiles (Fig. 5) by two radiation length steps. Radiation length of a calorimeter is 44 in total (Fig. 3). Four layers of position sensitive layers are inserted in a calorimeter, the GSO-bar hodoscope (Fig. 5,[4]) and the silicon strip detector for Arm1 and Arm2, respectively.

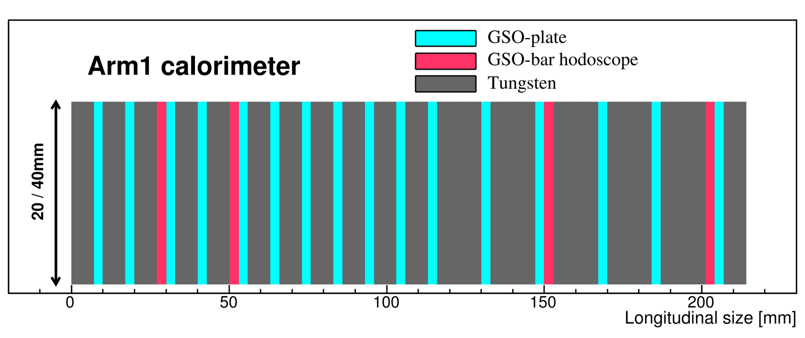


Figure 3: The Longitudinal layout of the calorimeter (Arm1).

The features of the LHCf detectors are,

- **Small sampling calorimeter with imaging layers**
- **Radiation-hard**
- **TeV-particle measurement**

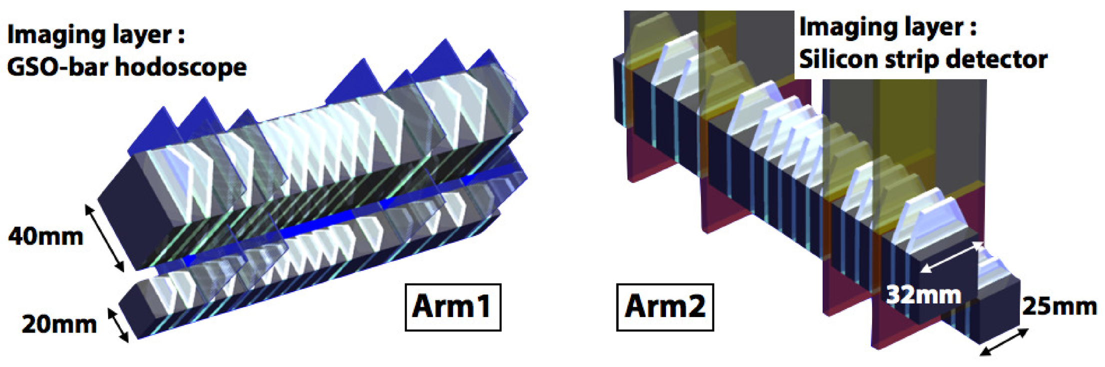


Figure 4: Arm1 and Arm2

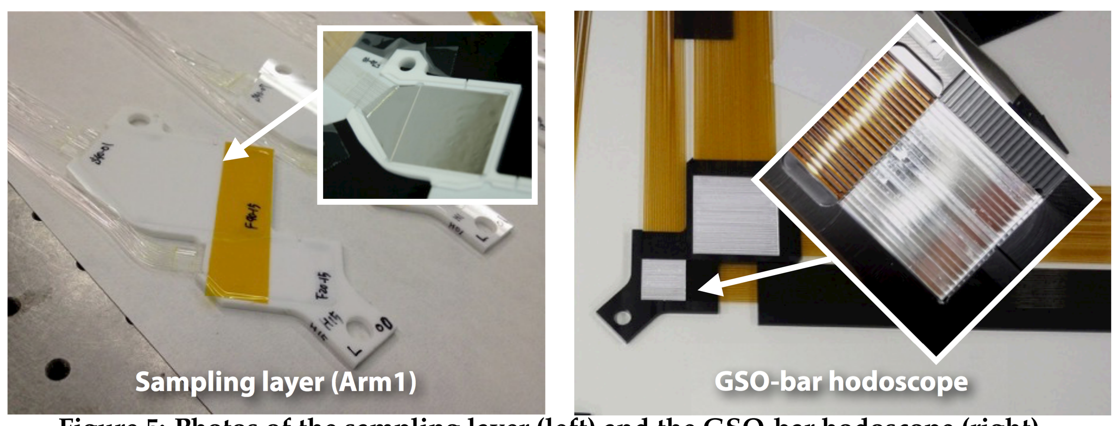


Figure 5: Photos of the sampling layer (left) and the GSO-bar hodoscope (right).

Calibration tests at the SPS

New detectors were calibrated at the Super Proton Synchrotron (SPS), CERN. In this beam test, SPS provided electron and muon beams from 100 to 250 GeV/c. These energies are close to the TeV-scale where we want to measure. Absolute gain calibration for sampling layers was performed with few percent of precision by comparison between data and MC distributions. Position resolution of shower-imaging layers were also evaluated in the test.

Performance of the upgraded detectors

After the absolute gain calibration of each component, performance such as energy resolution, position resolution and position dependence of the energy determination were evaluated.

Energy determination

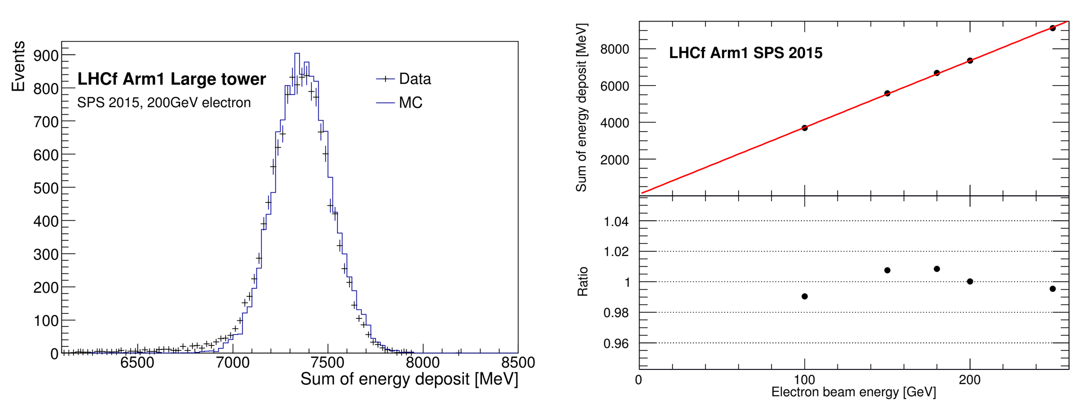
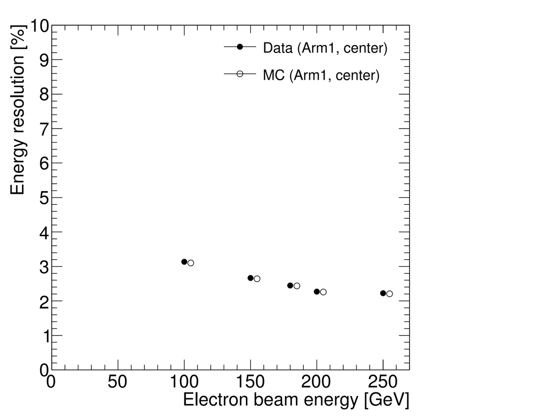


Figure 6: Distributions of total energy deposit (left) and the linearity (right)



- Good agreement between data and MC
- 3 % resolution above 100 GeV electron (left plot)
- Non linearity less than 1 %

Shower imaging

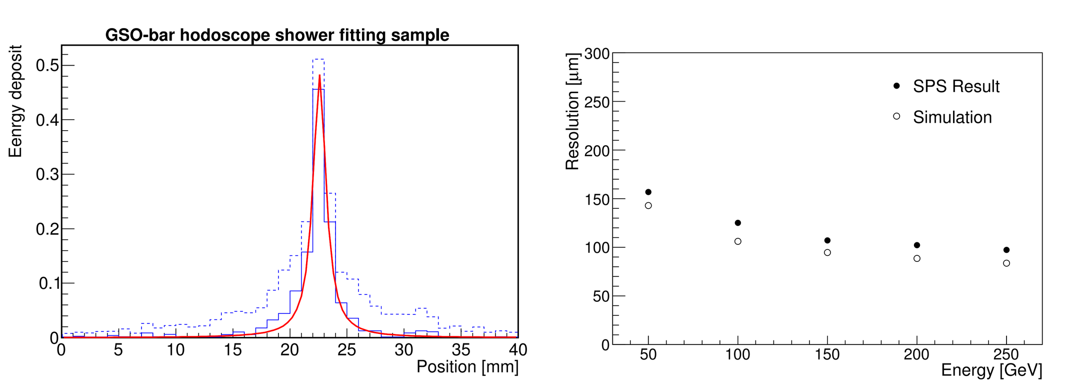


Figure 7: Performance plots of the GSO-bar hodoscope.

The unique shower-imaging detector, GSO-bar hodoscope can measure 100 GeV EM showers with resolution of 123 μm [4].

Summarizing the results above,

Energy resolution

3 % for 100 GeV electron

Position resolution

127 μm for GSO-bar hodoscope(Arm1),
$<$100 μm for Silicon strip (Arm2)

Others

Position dependence of the energy reconstruction was 1 % level among all fiducial area.

These results meet our requirements.

$\sqrt{s}$=13 TeV p-p at the LHC

On 8-12 June 2015, LHCf has successfully completed the operation during the LHCf special run in p-p $\sqrt{s}$=13 TeV collisions. After the operation, integrated luminosity of 5 nb^{-1} was collected. Trigger efficiencies of the detectors were 100% above around 200 GeV of photon energy. **We've measured more than 10^5 of π^0 candidates and a number of TeV gamma-rays.**

π^0 mass peak and the energy scale

Reconstructing the π^0 mass peak from two gamma-rays could be a good indication if our detector is working well or not. We have confirmed π^0, and moreover η, peaks in the invariant mass distributions in both of Arm1 and Arm2 (Fig. 8). π^0 mass resolution was 3.7 %. **Stability of π^0 was less than 1 % during the operation thanks to the radiation-hardness of the calorimeters** (Fig. 9).

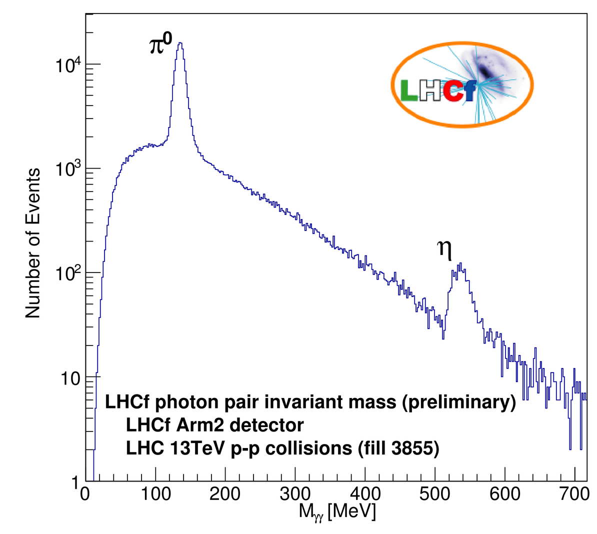


Figure 8: $M_{\gamma\gamma}$ distribution of Arm2

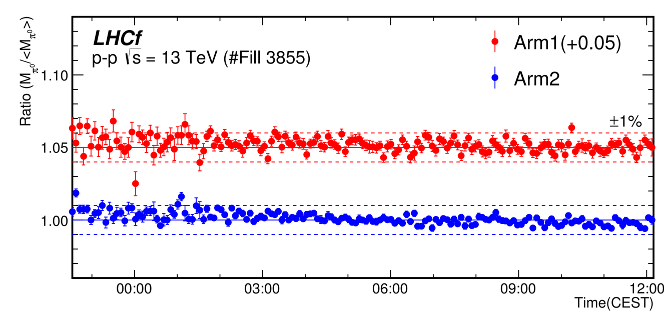


Figure 9: The stabilrity of π^0 mass peaks of Arm1 and Arm2

Forward gamma ray spectra

The plot bellow is the preliminary forward gamma-ray spectra. Two spectra, calculated by using data of Arm1 and Arm2 independently, show a good agreement and they are smoothly connecting from 200 GeV to around 6 TeV (Fig. 10).

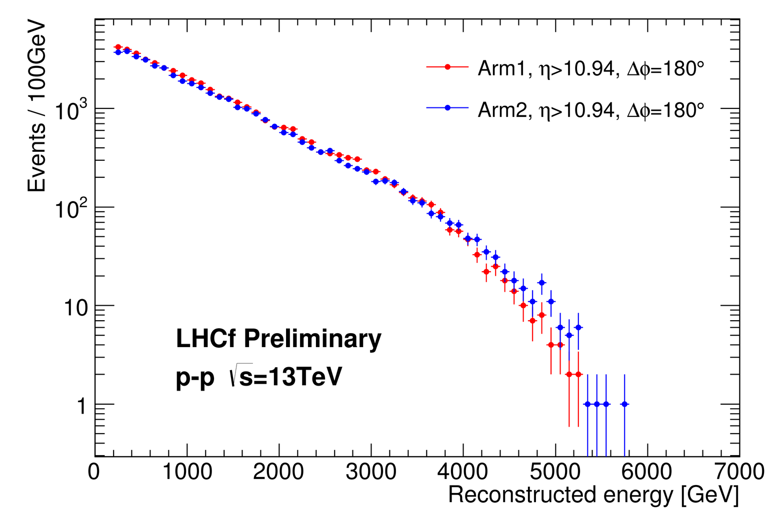


Figure 10: Forward γ-ray spectra at p-p $\sqrt{s}$=13 TeV

Summary

We have developed very small sampling and imaging calorimeters to measure the most energetic particles generated in p-p $\sqrt{s}$=13 TeV collisions at the zero-degree region, LHC. After calibrations performed at the SPS, the operation of p-p $\sqrt{s}$=13 TeV has been successfully completed with integrated luminosity of 5 nb^{-1}. Reconstructed π^0 peak with the mass resolution of 3.7 % and stability less than 1 % during the operation implies that our measurement was enough stable.

References

[1] O. Adriani et al., Phys. Lett. B **703** (2011) 128
[2] The LHCf collaboration, JINST **3** (2008) S08006
[3] K. Kawade et al., JINST **6** (2011) T09004
[4] Y. Makino et al., PoS (2014) 028