The status and preliminary results of the LHC forward experiment: LHCf

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The LHCf is one of the LHC forward experiments and the aim is to measure energy and transverse momentum spectra of gamma-rays and neutral hadrons emitted in the very forward region of LHC. In 2009, LHC started the operation and LHCf has taken data at $\sqrt{s}$ =900GeV. The measured spectra of gamma-ray like events and hadron like events are in good agreement with the Monte-Carlo simulation results generated by the QGSJET2 model within error. In 2010, LHC are delivering pp collisions at $\sqrt{s}$ =7TeV and LHCf are taking data with very low beam-gas background level of less than 1%.

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1. Introduction

The Monte-Carlo(MC) simulation is a part of essential tools for measurements of high energy cosmic rays. However hadron interaction models used in air shower simulations have an uncertainty due to the lack of experimental data in the energy range over 10^{15}eV. The Large Hadron Collider (LHC), which is the largest and the most powerful hadron collider, started the operation in 2009. The design collision energy is $\sqrt{s} =$14TeV, which corresponds to 10^{17}eV in the laboratory system. The LHCf experiment is one of the LHC forward experiments. The aim is to measure the energy and transverse momentum spectra of gamma-rays and neutral hadrons emitted in the very forward region of LHC and to provide critical data for calibration of hadron interaction models.

2. LHCf Experiment

The LHCf apparatus is composed of independent detectors (Arm#1 and Arm#2) with similar design but with slightly different configuration for background rejection and redundancy. Each detector have two sampling and imaging calorimeters with the transverse cross section of 20×20mm and 40×40mm in the Arm#1 detector and 25×25mm and 32×32mm in the Arm#2 detector. Figure 1 shows the schematic view of the Arm#1 and Arm#2 detectors. Each calorimeter is composed of 22 tungsten plates of 7mm thickness (2r.l.), 16 plastic scintillators and 4 position sensitive layers of X-Y SciFi hodoscopes and X-Y silicon strip detectors for Arm#1 and Arm#2, respectively. The plastic scintillators are inserted by 2 or 4 r.l. step for shower sampling and The position sensitive layers are inserted at 6, 10, 30 and 42 r.l. for the Arm1 calorimeters and at 6, 12, 30 and 42 r.l. for the Arm2 calorimeters to measure the shower position and identify the multiple showers in one calorimeter. The total thickness of each calorimeter is 44 r.l. and 1.7 interaction lengths. The calorimeters of each detector together with PMT's and front-end circuits are packed in the aluminum box of 92mm$^w \times 280$mm$^l \times 620$mm^h. The energy resolution is expected to be <5% and about 30% for gamma-rays with more than 100GeV and hadrons, respectively. The position resolution for gamma-ray showers is expected to be better than 0.2mm. These detector performances have been confirmed at the beam tests done in 2006 and 2007 at CERN SPS [1].
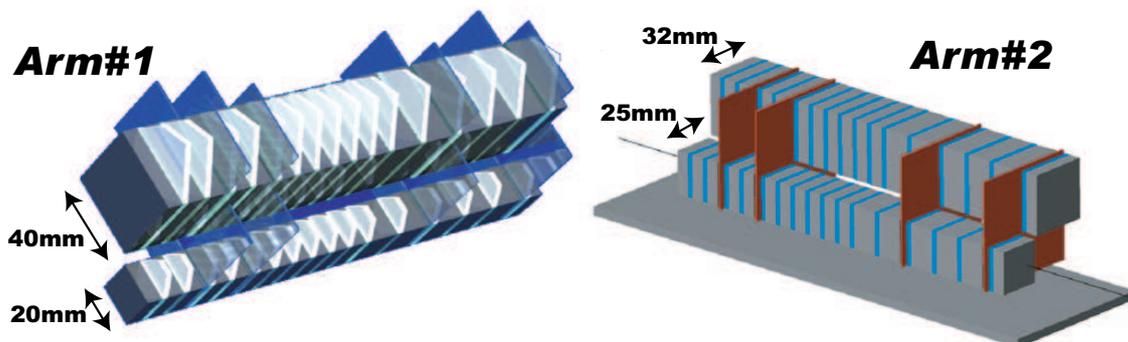

Figure 1: Schematic view of the Arm#1 and Arm#2 detectors.

At $+/-140$m from an LHC interaction point, IP1, zero degree neutral absorbers (TAN's) have been installed for preventing quenching of downstream superconducting magnets by neutral particles produced in *pp* collisions. Inside the TAN, the beam pipe makes a transition from a single common beam pipe facing IP1 to two separate beam pipes joining to the arcs of LHC (Y-chamber). In the crotch of the Y-chamber, there is an instrumentation slot with dimensions $96\text{mm}^w \times 1000\text{mm}^l \times 607\text{mm}^h$ for detectors of beam monitors and forward physics experiments. The LHCf detectors have been inserted in the slots of the both TAN's. The instrumentation slot allow to measure neutral particles produced at the interaction point at zero degree of collisions but not charged particles because they are swept away by the magnetic field of the beam separation dipoles located between IP1 and the TAN. The aperture is limited by the size of the TAN instrumentation slot and the aperture of the beam pipes located between IP1 and the TAN. The pseudo-rapidity coverage of the LHCf detectors is $\eta > 8.7$ and $\eta > 8.4$ with zero and 140μrad beam crossing angles, respectively.

3. Results at 900GeV in 2009

LHC have delivered proton beams with 450GeV beam energy in December 2009 and produced about 5×10^5 pp collisions without beam crossing angle at IP1. We have operated for 2.6 hours and 27.7 hours for detector commissioning and physics, respectively. We have collected about 2,800 and 3,600 shower events in total of operations in 2009 by Arm1 and Arm2 detectors, respectively. About 10% of the events are background events due to collisions between beams and residual gas in the beam pipes (beam-gas background). The background can be estimated by using events measured with non-colliding beams at IP1.

Electromagnetic showers induced by gamma-rays are discriminated from hadronic showers by using the longitudinal shower development measured by the 16 scintillator layers. To parameterize the transition shape of a shower event by event, we defined L90%, which is the longitudinal position containing 90% of the sum of the shower particles. Figure.2 shows the L90% distribution of data in 2009 measured by the smaller calorimeter of the Arm#1 detector. Electromagnetic showers develop
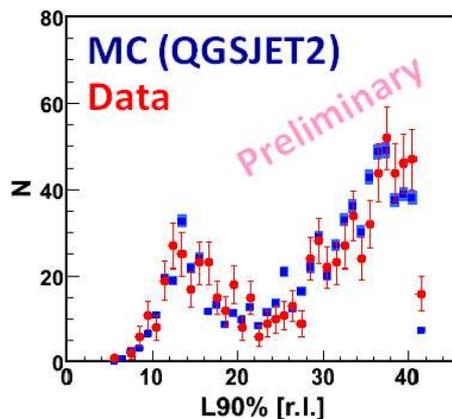

Figure 2: L90% distributions at the Arm#1 smaller calorimeter. The red and blue points indicate results of data and MC generated by the QGSJET2 model, respectively.

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more rapidly than hadronic showers and make the peak of L90% distribtion at around 12 r.l.. The L90% distribution expected by MC simulation data with 10^7 collisions generated by the QGSJET2 model [2] is also shown as blue dots in fig.2. The L90% distribution of data is in good agreement with that of MC. We set the criteria of L90% to discriminate between gamma-ray like events and hadron like events as a function slightly depending on total energy deposit (dE) in the calorimeter, $16 + 0.0002 \times dE$ r.l.. dE is total energy deposit normalized by MIP and it is about 4000 when a gamma-ray with 100GeV hits the calorimeter

Figure 3 shows the spectra of gamma-ray and hadron like events measured by the Arm#1 and Arm#2 detectors after the subtraction of beam-gas background estimated by using non-colliding beams at IP1. The blue dots in fig.3 shows MC results normalized by entries of gamma-ray like events. The measured spectra are in good agreement with MC results within statistical error. In the spectra for hadron like events, for the moment, the gamma-ray equivalent energy for are used instead of reconstructed hadron energy because still the detector response for hadrons is under study by using beam test data with 150GeV and 350GeV protons. The systematic errors are also under study. For the moment, we set +11%/-5% error of energy scale.
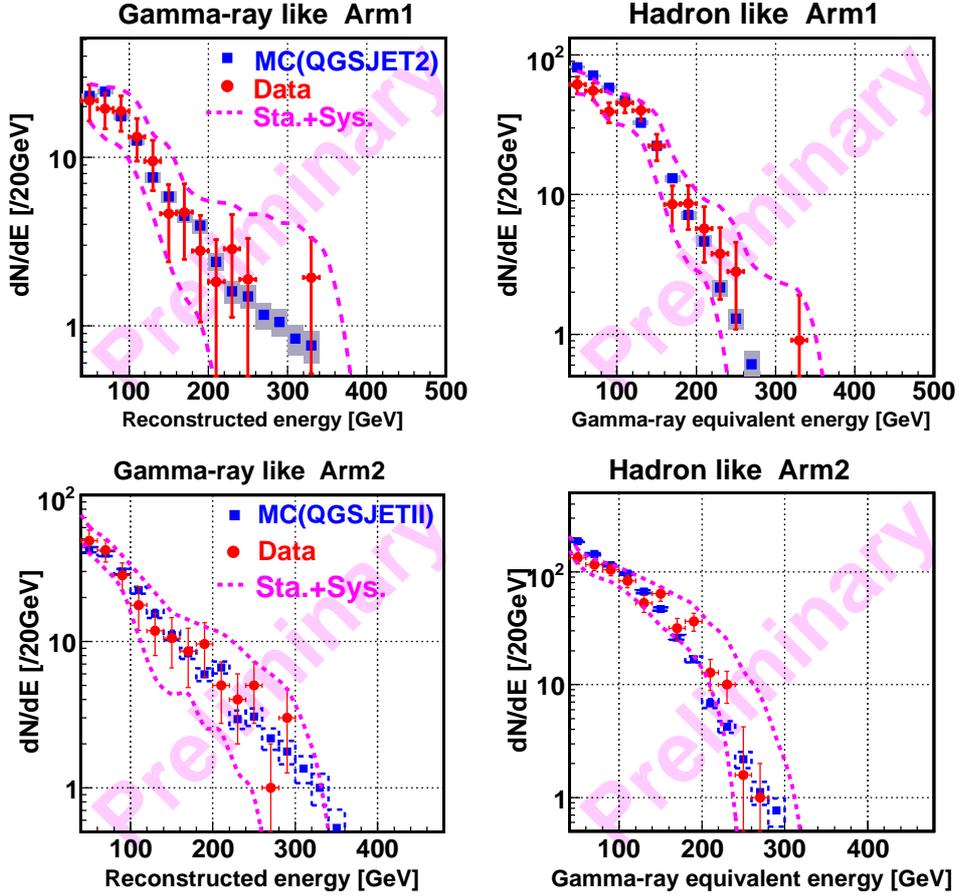

Figure 3: Energy spectra of gamma-ray like events and hadron like events measured by the Arm#1 and Arm#2 detectors. The red and blue dots show data and MC generated with the QGSJET2 model. The MC spectra are normalized by entries of gamma-ray like events in each detector.

4. Operation in 2010

On March 30, 2010, LHC had the first collision with 3.5TeV proton beams. The collision energy of $\sqrt{s} =$7TeV corresponds to 2.6×10^{16}eV in the laboratory system. LHCf has collected about 7×10^4 shower events for 3 hours at the day. Figure4 shows the spectra of gamma-ray like and hadron like events measured by the Arm#2 smaller calorimeter. The beam-gas background level at 7TeV collisions are less than 1%, which is much better than that at 900GeV collisions in 2009. After the day, LHC is delivering collisions at 7TeV with increasing the luminosity step by step and LHCf are taking data. The LHCf detectors will be removed from the LHC tunnel when the luminosity reaches $10^{30}cm^{-2}s^{-1}$ or the integral luminosity reaches $2nb^{-1}$. The LHCf detectors will be re-installed to the LHC tunnel in 2013 for operation at the LHC design energy of $\sqrt{s} =$14TeV.
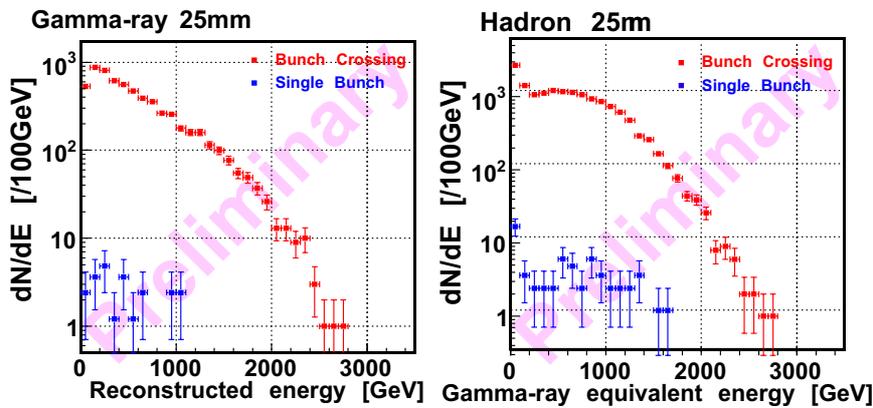

Figure 4: The energy spectra of gamma-ray like events and hadron like events measured by the Arm#2 smaller calorimeter on March 30, 2010. The red and blue dots indicate spectra of the events at colliding and non-colliding beams at IP1, respectively.

5. Summary

The aim of the LHCf experiment is to measure energy and transverse momentum spectra of gamma-rays and neutral hadrons emitted in the very forward region of LHC due to calibration of hadron interaction models. In 2009, LHCf has collected about 6,500 shower events at 900GeV *pp* collisions. The measured spectra of gamma-ray like events and hadron like events are in good agreement with the Monte-Carlo simulation results generated by the QGSJET2 model within error. In 2010, LHC are delivering *pp* collisions at $\sqrt{s} =$7TeV and LHCf are taking data with very low beam-gas background level of less than 1%. LHCf will continue operation at 7TeV until the luminosity reaches $10^{30}cm^{-2}s^{-1}$ or the integral luminosity reaches $2nb^{-1}$.

References

[1] The LHCf Collaboration, JINST, 3 (2008) S08006

[2] S. Ostapchenko, Phys. Rev. D74 (2006) 014026.