29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

LHCf : A new experiment to study very forward particle emission at LHC

T. Sako[a], Y. Muraki[a], Y. Itow[a], K. Masuda[a], Y. Matsubara[a], H. Menjo[a], Y. Obata[a], K. Tanaka[a], H. Matsumoto[a], K. Kasahara[b], S. Torii[c], T. Tamura[d], K. Yoshida[d], M. Haguenauer[e], W. C. Turner[f], O. Adriani[g], L. Bonechi[g], M. Bongi[g], J. Velasco[h], A. Faus[h]

(a) Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya 464-8601, Japan
(b) Shibaura Institute of Technology, Japan
(c) Waseda University, Japan
(d) Kanagawa University, Japan
(e) Ecole-Polytechnique, France
(f) LBNL, Berkeley, USA
(g) INFN, Univ. di Firenze, Italy
(h) IFIC, Centro Mixto CSIC-UVEG, Spain
Presenter: T. Sako (sako@stelab.nagoya-u.ac.jp), jap-sako-T-abs2-he15-oral

A new accelerator experiment to study very forward particle emission in the LHC collider, LHCf, is presented. Because a collision of 7 TeV protons corresponds to 10^{17} eV in the laboratory system, our experiment can give a firm base for simulating air showers generated from ultra high energy cosmic rays. This is indispensable information for the ongoing large experiments like TA, Auger and EUSO for the near future. The LHCf detector is composed of three tower electromagnetic calorimeters and scintillating fibers (SciFi) to measure core position of the shower. To avoid multi particle hits, each tower has a small cross section (2cm×2cm, 3cm×3cm and 4cm×4cm). We have confirmed that we can measure shower energy with $< 5\%$ resolution even using such small calorimeters. A project overview and the results of a beam test carried out in August 2004 at CERN SPS are presented.

1. Introduction

Debate over the existence of super GZK cosmic rays has motivated a new set of modern experiments like TA, Auger and EUSO [1]. All of these experiments are designed to overcome the most crucial issue, namely statistics. Of course, large efforts are also expended to understand systematic effects of the detectors and the atmosphere in case of fluorescence observations. These experiments are believed to be capable of solving the GZK problem. However, one more important item, the particle interaction cross sections at this energy scale, must be clarified experimentally. To deduce the primary particle energy from air shower observations, Monte Carlo calculations must be carried out assuming a specific interaction model. As summarized by Knapp et al.(2003)[2], different interaction models give different results not only for the GZK problem but also for the chemical composition of cosmic rays in the 10^{17}eV energy range.

Models can be studied using accelerators, especially colliders to approach energies as high as possible in the laboratory system. Because the development of an air shower is dominated by very forward ($x > 0.05$; here x is the Feynman x) emitted particles, special detectors must be located near the colliding beam lines. So far, only one such experiment has been carried out by the UA7 collaboration at the laboratory equivalent energy of 2×10^{14}eV [3]. LHCf is a new such experiment to use Large Hadron Collider (LHC), where collisions of 7 TeV protons occur, corresponding to 1×10^{17}eV in the laboratory system.

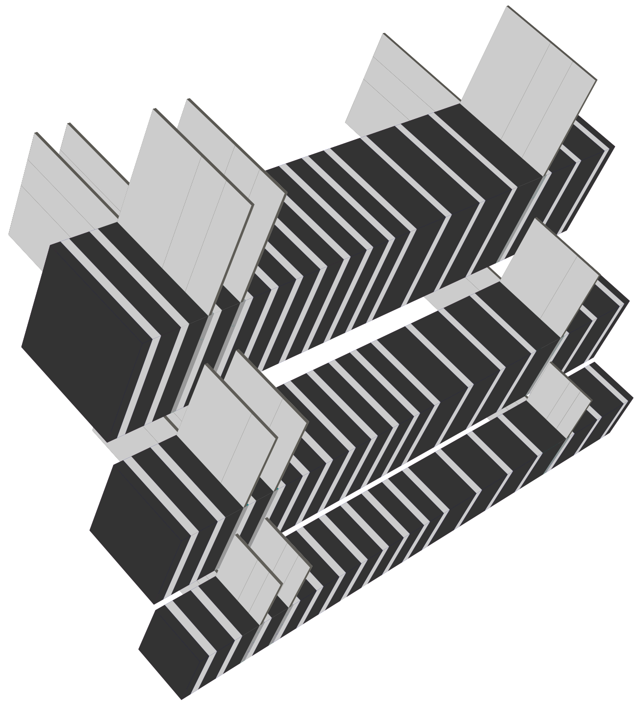

Figure 1. A schematic view of the LHCf calorimeters. We use 3 different sizes of calorimeter tower cross section. Each tower consists of tungsten plates (shown as black in the figure), plastic scintillator (gray) and SciFi (also gray but extended out, 3 pairs for each tower).

In this paper, we present the overview of the LHCf experiment together with the test beam results for the prototype detector carried out in August 2004 at CERN SPS.

2. LHCf

The goal of LHCf is to measure the x distribution (energy distribution in practice, where x is the Feynman parameter) in the very forward region of 7 TeV proton-proton collisions in the LHC. Because the LHC beam pipe is separated from one beam pipe into two with Y shape at 140 m from the interaction point, we can place a detector in the crotch of the Y and observe particle production near zero degrees[4][5]. Because the Y chamber is well outside the first beam separation dipole D1, only neutral particle production is observed. The gap between the separated beam pipes of the Y chamber is 96 mm, so our detector must fit in that limited space. The detector is composed of 3 towers of sampling shower calorimeters (Figure 1). Each calorimeter consists of 54 radiation lengths of tungsten plates and 17 plastic scintillators of 3 mm thickness for sampling. The dimensions of each tower are $2\mathrm{cm} \times 2\mathrm{cm}$, $3\mathrm{cm} \times 3\mathrm{cm}$ and $4\mathrm{cm} \times 4\mathrm{cm}$ in cross section and 25 cm in longitude. Separation into 3 small towers is chosen to reduce the probability of multi particle hits that would prevent us from obtaining the correct particle energy. At the same time, we can reconstruct the invariant mass of π^0 when the decay gamma-rays enter different towers. This enables us to obtain a good energy calibration of the detector. To measure the shower positions and to identify multi hit events, we also install scintillating fibers

(SciFi) in the calorimeters. The SciFi signals are read out by multi-anode PMTs (MAPMT H7546) while the scintillator signals are read by PMT H3164-10 through clear fibers. For the read out of MAPMT, a specially designed ASIC is applied [6].

One may question if we can really measure the shower energy correctly using such small calorimeters, especially with $2\mathrm{cm} \times 2\mathrm{cm}$. Actually, there is some fraction of leakage of shower particles out the side of the calorimeters. However in Monte Carlo and test beam measurements at the SPS, we found that this fraction is energy independent and a function of the shower position from the edge of a tower. SciFi is used to determine the shower position. We first predicted the fraction of shower leakage by using Monte Carlo calculations and verified these calculations experimentally with the prototype test at the CERN SPS in August 2004.

3. Prototype Test in 2004

Technical questions for LHCf were; 1) can we construct such a compact calorimeter in a limited volume? and 2) can we really measure the shower energy with such a small calorimeter? To clarify these points, we constructed a prototype LHCf detector and carried out a beam test at the CERN SPS from 26 July to 11 August 2004. The detector for these tests consisted of $2\mathrm{cm} \times 2\mathrm{cm}$ and $4\mathrm{cm} \times 4\mathrm{cm}$ towers with the $3\mathrm{cm} \times 3\mathrm{cm}$ absent. For both towers, SciFi were inserted in 3 places and the shower position was measured. To calibrate the SciFi positioning, we also placed a Silicon tracker in front of the detector and measured the position of each primary

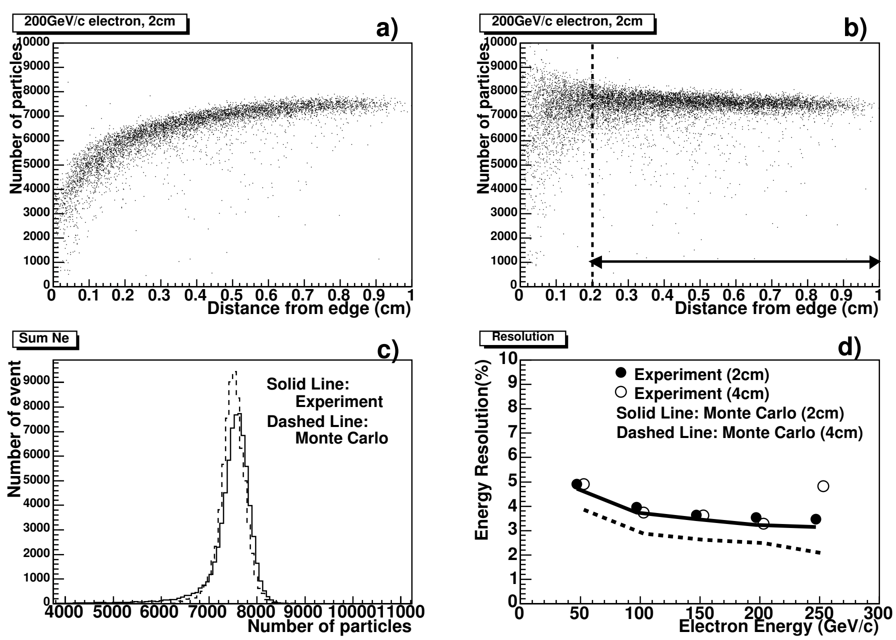

Figure 2. a) b) c) Analysis results for 200 GeV/c electron beam irradiated on the 2cm tower. a) Distance from edge versus total number of particles measured in each shower. b) Leakage corrected plot of a). Correction is done based on a MC calculation. c) Distribution of number of particles found in the marked area in b) 0.2 cm to 1.0 cm from the edge. d) Energy resolution as functions of the electron energy. See text for more detail.

particle. In the test experiment, we irradiated the calorimeter by muons of 150 GeV/c, electrons of 50, 100, 150, 200, 250 GeV/c and protons of 150, 300, 350 GeV/c.

In Figure 2, analysis results for electron beam are presented. For panels a) b) and c), the results for 200GeV/c electron are shown. The panel a) shows total number of shower particles for each shower as a function of the distance from the edge. As stated above, we can see the effect of leakage when the distance is small. However, the fraction of leakage can be predicted by Monte Carlo calculations as a function of distance from the edge but independent of shower energy. The panel b) shows the leakage corrected plot of a). The correction appears to work well. Because the scattering is large for the events near the edge, we decided to use events that are found to have their shower axes more than 0.2 cm from the edge. This region is indicated by a double arrow in panel b). The distribution of the number of particles after the distance cut is plotted in the panel c) together with the Monte Carlo result. Fitting this distribution with a Gaussian function and σ of the fit is defined as an energy resolution at that energy. Energy resolutions for all the primary electron energies, experiment and Monte Carlo, 2cm and 4cm towers are plotted in the panel d).

As expected from the panel c), we can find good agreement between the experiment and Monte Carlo in the case of the 2cm tower. In this sense, our prediction for the leakage correction in the small calorimeter is justified. However, there is a discrepancy between the Monte Carlo and the experiment for the 4cm tower. We speculate this is because of the non uniform read out of the scintillation light by the clear fibers. The effect of the non uniformity becomes larger for the larger scintillators. Although we corrected for this effect using muon data, the correction may be insufficient and the lateral spread of the shower particles may need to be taken into account. We are trying to understand the cause of this discrepancy and how to correct for it.

4. Summary

A new experiment, LHCf, has started. This experiment is motivated by the need to experimentally justify the interaction model used to estimate the primary energy of ultra high energy cosmic rays. LHCf is planned to run during the first stage of LHC operation in 2007. The concept of the experiment is already approved by the LHC Committee (LHCC) in 2004 and the first technical hurdles have been cleared by the prototype experiment carried out in 2004. We are now trying to understand the systematic effects found in the 2004 test in detail and improve the detector for the final setup. At the same time, we are investigating the possibility of installing another detector on the opposite side of the interaction point. The second detector would use silicon detectors in place of the scintillator. Monte Carlo calculations are also being developed and the expected LHCf results for different interaction models are being calculated.

We are grateful to the CERN staffs for the support of the beam test in 2004.

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