# Performance of the PPB-BETS Confirmed by Accelerator Beam Tests

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## Abstract

We report on the performance of the PPB-BETS detector as an imaging calorimeter studied by the electron and proton beams at CERN-SPS accelerator in 2001. The PPB-BETS imaging calorimeter was designed to measure high energy cosmic-ray electrons up to $\sim 1$ TeV. As proved by the beam tests, we have confirmed that the performance of the PPB-BETS detector is consistent with simulation results.

## 1. Introduction

The BETS (Balloon-borne Electron Telescope with Scintillating fibers) experiment has successfully measured the cosmic-ray electron spectrum at the energies from 10 GeV to 100 GeV [2]. As a follow-up experiment of BETS, we are planning the Polar Patrol Balloon (PPB) experiment in Antarctica to observe high energy cosmic-ray electrons from 10 GeV to 1 TeV [3]. The design of the PPB-BETS detector is developed from the original BETS detector to extend observed energy up to 1 TeV. To verify the detector performance, we had beam experiments at CERN-SPS using 10-200 GeV electrons and 150-350 GeV protons in October, 2001.

## 2. PPB-BETS Detector

The detector of PPB-BETS is a sampling calorimeter. The calorimeter consists of 9 plastic scintillators and 36 scintillating fiber (SCIFI) belts between lead plates which have 9 radiation length (r.l.) thickness totally as shown in Fig. 1 (left). The plastic scintillators are employed to make event triggers for

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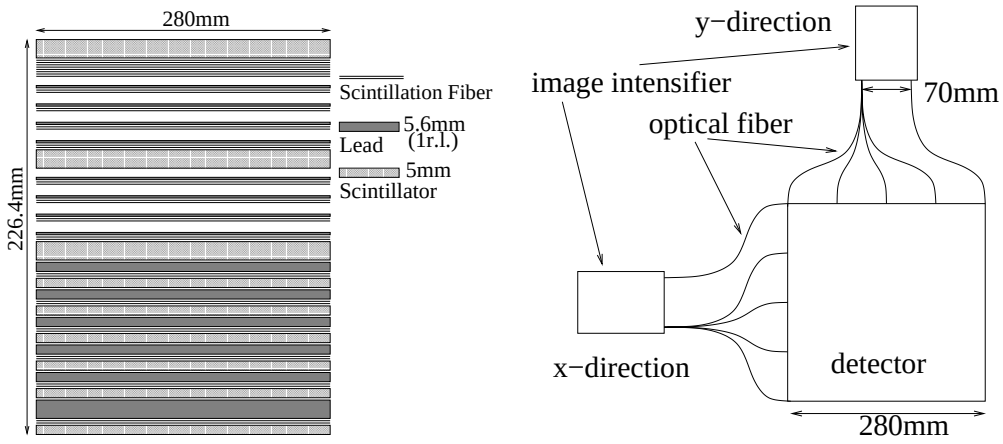


**Fig. 1.** The schematic view of PPB-BETS detector. The left is the side view of the detector and shows the layout of lead plates, plastic scintillators, and SCIFI belts. The right is the top view.

electron-like showers and to measure the energies. One SCIFI belt is composed of 280 fibers with a cross section of 1 mm square for each. These belts interleaved with lead plates are arranged alternatively in orthogonal direction. One end of SFIFIs is connected to optical fiber as used to be a light guide. For the readout with image intensifier (I.I) and CCD, optical fibers are bundled in each direction X and Y and coupled to I.I. optically as presented in Fig. 1 (right). The CCD has 1024×1024 pixels and signals of each pixel are digitized into 12 bit format by 40 MHz sampling. We developed the I.I and the CCD system which has a better spacial resolution and a wider dynamic range than that of the BETS detector.

## 3. Beam Experiment at CERN-SPS

We have carried out the beam test of the flight model for electrons from 10 GeV to 200 GeV and protons from 150 GeV to 350 GeV. In this beam test, we confirmed the performance of the data taking system and the detector response. Since the telemetry rate is very limited ($< 2$ kbps) in the balloon experiment, the data size of CCD images are adjusted by optimizing the gains of I.Is. As a result, the compressed data size of images is adjusted to 14 kByte for one 100 GeV electron shower.

## 4. Imaging Analysis

The development of the shower in the detector was clearly observed by the CCD system as presented in Fig. 2. To reduce the image size, the CCD images are obtained after the binning $4 \times 4$ pixels and presented in log scale. After the position calibration of SCIFIs in CCD images, the relative light yield in

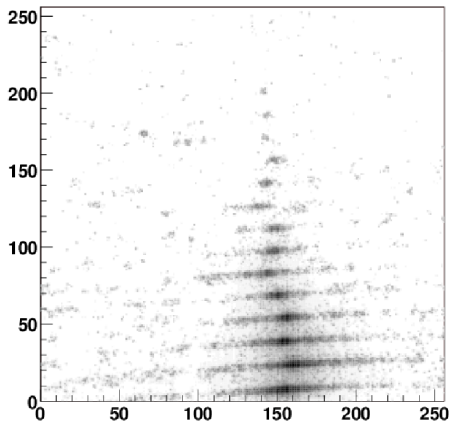


**Fig. 2.** Example of CCD image of a cascade shower induced by 200 GeV electron. Relative brightness is presented by darkness.

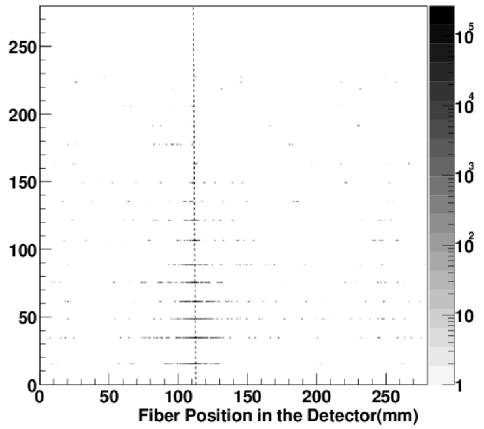


**Fig. 3.** Reconstructed image in the detector space. The dashed line is the shower axis estimated by the reconstructed image.

each SCIFI was obtained, and the shower image was reconstructed in the detector space as shown in Fig. 3.

### *4.1. Angular Resolution*

It is important to determine accurately a shower axis as mentioned below since the accuracy is crucial to determine the electron energy and the separation efficiency of electrons from background protons. We estimated the shower axis by using energy weighted center of lateral spread of the shower. The resolution is within $0°.6$ for perpendicular electron beams with energy from 10 GeV to 200 GeV. In Fig.4, we present the angular resolution at different energies. those resolutions are considerably better than those of the BETS detector ($\sim 1°$). However, they are worse than the simulated result ($< 0°.1$) for electrons over 30 GeV because errors of SCIFI positions in the detector space were not considered in this work. It will be improved by the corrections of SCIFI positions in future work .

### *4.2. Discrimination of Electrons and Protons*

For the rejection of background protons, we adopt the RE parameter defined as the ratio of energy deposit within 5mm from shower axis to total. Because of the difference of shower spreads, the REs for electrons concentrate around 0.85, but the REs for protons distribute widely. In the BETS experiment, this parameter were used for separating electrons and protons [2]. Figure 5 shows the distributions of RE for perpendicular electron 100 GeV beam and proton 250 GeV beam compared with simulated data after the correction of the CCD response which causes systematic error. We confirmed that electrons can clearly be sepa-

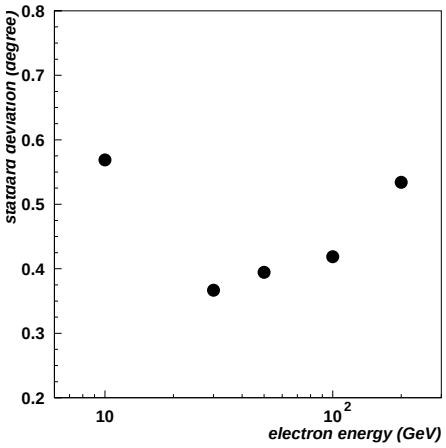


**Fig. 4.** Relations of angular resolutions and electron beam energies.

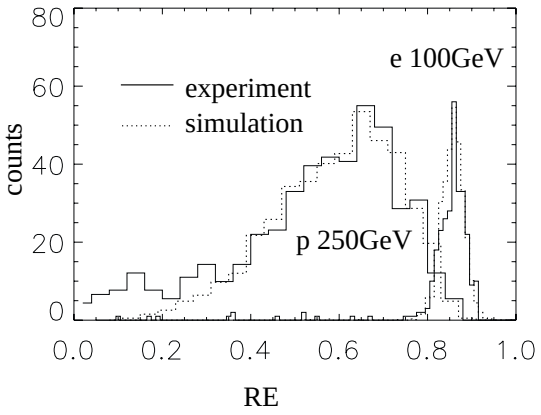


**Fig. 5.** RE distributions of 100 GeV electrons and 250 GeV protons. They are normalized by number of events.

rated from protons and simulations have good consistency with the experimental data.

## 5. Summary

The PPB-BETS detector was calibrated by accelerator beams. We confirmed that it has enough performance to measure cosmic-ray electrons over 100 GeV. The newly developed instruments such as the I.I-CCD system worked well and proved to have the better performance than the BETS instrument. Although we followed the analysis method of the BETS in this study, we are developing more suitable methods for the PPB-BETS experiment.

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