EMMA: A new underground cosmic-ray experiment

T Enqvist¹, V Föhr¹, J Joutsenvaara¹, T Jämsén², P Keränen³, P Kuusiniemi¹, H Laitala¹, M Lehtola¹, A Mattila¹, J Narkilahti¹, J Peltoniemi¹, H Remes¹, M Reponen¹, T Räihä¹, J Sarkamo⁴, C Shen¹, M Vaittinen⁴, Z Zhang¹, L Ding⁵, Q Zhu⁵, M Roos⁶, I Dzaporova⁷, S Karpov⁷, A Kurenya⁷, V Petkov⁷, A Yanin⁷ and H Fynbo⁸

¹ CUPP, P.O. Box 22, FIN-86801 Pyhäjärvi, Finland
² SGO, FIN-90014 University of Oulu, Finland
³ Department of Physics, University of Jyväskylä, Finland
⁴ CUPP, P.O. Box 3000, FIN-90014 University of Oulu, Finland
⁵ IHEP, Chinese Academy of Sciences, Beijing, China
⁶ Department of Physical Sciences, University of Helsinki, Finland
⁷ INR, Russian Academy of Sciences, Moscow, Russia
⁸ Department of Physics and Astronomy, University of Aarhus, Denmark

E-mail: timo.enqvist@oulu.fi

Abstract. A cosmic-ray experiment of new type is under construction in the Pyhäjärvi mine in the underground laboratory of the University of Oulu, Finland. It aims to study the composition of cosmic rays at and above the knee region (energy above 1 PeV). The experiment, called EMMA, covers about 150 m² of detector area, and the setup is capable of measuring the multiplicity and the lateral distribution of underground muons, and the arrival direction of the air shower. The detector is placed at the depth of about 85 metres (corresponding about 240 m we) which gives a threshold energy of muons of about 45 GeV. The rock overburden filters out all other particles of the air shower except the high-energy muons. These high-energy muons originate at high altitudes close to the first interaction of the primary cosmic ray and they carry more information about the primary than low-energy muons. The full-size detector is supposed to run by the end of 2007.

1. Introduction

Due to a slight change observed in the cosmic-ray energy spectrum, it is believed that either the origin, modification in the chemical composition, acceleration mechanism or propagation of cosmic rays, or a combination of these, changes in the energy region of \(10^{15} - 10^{16}\) eV. Up to this energy, so called 'knee' region, most cosmic rays are supposed to originate inside the galaxy, and are also confined by the galactic magnetic field.

This topic has been one of the fundamental problems of cosmic ray physics, and it has been discussed for decades. Several models have been presented predicting different composition at the 'knee' energies, and could only be identified by the experimental evidence on the composition. Some new experimental efforts have been devoted to the study of cosmic rays in recent years. These experiments are based, for example, on multi-parameter measurement of extensive air-showers (EASs), on shower maximum measurement by Cerenkov radiation and on underground
multimuon measurements at a depth of about 1 km. Their conclusions, however, have so far been diverse, implying the need for further studies, especially using different approaches.

EMMA (Experiment with MultiMuon Array) is not the first underground cosmic-ray experiment (see, for example, Refs. [1, 2, 3]), but it differs significantly from the previous experiments with its ability to measure the lateral distribution function of underground muons.

2. Experimental details
The present experiment will be carried out at the depth of 85 metres in the Pyhäsalmi mine (owned by the Inmet Mining Corporation, Canada), which is situated in the middle of Finland.

The EMMA detector setup consists of muon barrel (MUB) chambers previously used in the LEP-DELPHI experiments at CERN [4]. The setup is able to measure the arrival direction of the air shower, the muon multiplicity and their lateral distribution. This is all done with an array of separate detectors with about 150 m$^2$ of the total detector area. Part of the array is in two layers with a vertical distance of 2.5 metres between the layers (for the direction information).

The active volume of each MUB chamber is 20 cm wide, 1.6 cm high and 3.65 m long. The drift chambers operate in the proportional mode, with Ar:CO$_2$ (92:8) nonflammable gas mixture. Due to the safety issues, the gas mixture does not contain CH$_4$. Each drift chamber can provide up to three signals, one anode signal and two delay line signals (near and far), which can be used to localise the points of particle passages through the chambers. The measured position resolution of the MUBs in our setup is about 1 cm and 3 cm along the drift direction and along the drift line, respectively.

A schematic detector layout at the depth of 85 metres is shown in Fig. 1. There a size of 15 m$^2$ is assumed for each of the nine units. The distance between the detector units is also 15 metres (the picture is not in scale). Other types of layouts are also considered.

Recycling the old muon barrel detectors gives the possibility to built the array at low costs. Also the use of existing caverns of the mine keeps the costs low. The data-acquisition electronics is built by ourselves or bought as new.

The underground array is under construction and the data recording can be started around middle of 2006 with a partial array. The full-size detector should be in operation by the end of 2007.
3. Expected results and simulations

With detailed Monte Carlo air-shower simulation-code CORSIKA [5] four samples of air showers in two energy regime were simulated: below the knee (3 PeV) with the spectral index of 2.7 for proton- and iron-initiated primary particles, and above the knee with the spectral index of 3.1. The simulated samples corresponds roughly the data of one year. All the showers were assumed vertical and the cut-off energy of 42 GeV has been used.

By using suitable selection criteria, those air showers having the energy in the interested interval (just below and above the knee) can be selected. If it is assumed that the measured data will be a linear combination of the pure proton and pure iron simulated data, the primary composition can be deduced from the selected showers with a good accuracy.

The energy resolution of EMMA according to this preliminary analysis is somewhat moderate. Due to contamination outside of the selected energy range, it is expected that the knee region can be divided to a two to three energy bins.

The main motivation of the EMMA experiment is clarifying the composition of the cosmic rays at the knee region. The first aim is to apply two-component composition model to the measured data, and to conclude the portion of light (proton) and heavy (iron) components. If the quality of the data allows, also more complicated analysis methods could be applied. The cosmic-ray composition at the knee region is important itself. The composition study is also supposed to give information about cosmic-ray sources and their origin, and about their acceleration and propagation mechanisms. It is very difficult to study the sources in direct way.

The composition analysis is strongly model dependent and the results obtained here could also help to improve the high-energy interaction models which are not well-known at these energies, as the EMMA experiment is sensitive to the upper part of an air shower.

4. Summary

A new underground cosmic ray experiment EMMA is under construction and it should start recording data in the full scale by the end of 2007. The preliminary analysis of simulated air showers shows that due to new method used, the EMMA experiment can provide comprehensive and also new information on the composition of the cosmic rays at the knee region within a few years of running.

Acknowledgments

The support from the Magnus Ehrnrooth Foundation, the Jenny and Antti Wihuri Foundation, and the Finnish Cultural Foundation is acknowledged. The work is funded by the European Regional Development Fund and it is also supported by the Academy of Finland (project #108991).

References

[1] Cebula D, Corbató S C, Daily T, Kieda D B, Lande K, Lee C K, Cherry M L 1990 The Astrophysical Journal 358 637–43
[2] MACRO Collaboration 1992 Physical Review D 46 895–902
[3] Avati V, Dick L, Eggert K, J. Ström, H. Wachsmuth, S. Schmeling, Ziegler T, Brünhl A, Grupen C 2003 Astroparticle Physics 19 513–23
[4] DELPHI Collaboration 1991 Nucl. Instrum. Methods A 303 233–76
[5] D. Heck et al. 1998 Report Forschungzentrum Karlsruhe 6019