Underground Multimuon Experiment in Pyhäsalmi Mine

T. Enqvist,[1,*] L. Ding,[2] A.-M. Elo,[3] T. Jämsen,[1] M. Lehtola,[1] K. Mursula,[3] M. Mutanen,[1] S. Nurmenniemi,[1] J.T. Peltoniemi,[1] J. Sarkamo,[1] C. Shen,[1,2] Q. Zhu[2]
(1) Centre for Underground Physics in Pyhäsalmi, P.O. Box 3000, FIN–90014 University of Oulu, Finland
(2) Institute of High Energy Physics, Beijing, China
(3) Department of Physical Sciences, University of Oulu, Finland,
(*) CUPP-project, P.O. Box 22, FIN–86801 Pyhäsalmi, Finland

Abstract

The CUPP project is preparing an experiment in the Pyhäsalmi mine in order to observe simultaneous, multiple muon events originated from extensive air showers. The detection of the multimuon events is motivated by partly unknown composition and origin of the primary cosmic rays in the energy region of 10^{15} – 10^{16} eV, i.e. the 'knee' region.

The experiment will be situated in shallow depths in the Pyhäsalmi mine, and it can be carried out with two or three detector units of an area of about 100 m^2 each and with mutual separation of about 30 m. The existing free caverns will be used. Detectors can be placed at different depths between 95 and 400 m (250 – 1000 mwe) for measuring different properties of the air shower.

1. Introduction

Due to a slight change observed in the cosmic ray spectrum, it is believed that either the origin, acceleration mechanism or propagation, or a combination of these, of cosmic rays 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 on multi-parameter measurement of extensive air showers (EASs) [1], shower maximum measurement by Cerenkov radiation [2] and underground multimuon measurements at a depth of about 1 km [3]. Their conclusions, however, have so far been diverse, implying the need for further studies, especially using

pp. 997–1000

different approaches.

2. Experiment

2.1. Underground Laboratory

The present experiment, including the prototype and the full detector system, will be carried out in the underground laboratory [4] of the CUPP project in the Pyhäsalmi mine of Inmet Mining Corporation. The mine is situated in the middle of Finland. It is the deepest operational base-metal mine in Europe, and provides excellent opportunities for the research of underground physics by having very stable bedrock, low background radiation level, modern infrastructure, and good traffic conditions all around a year [5].

In the first phase, the existing underground caverns are utilized, which is probably sufficient for the present experiment. However, excavation and construction works may be considered later if there is enough motivation to justify the cost. That would give the possibility for a more optimal setup for the detectors.

2.2. Underground Detector Array

The detectors to be used in the present experiment will consist nearly entirely of drift chambers formerly used in CERN as DELPHI barrel muon chambers (MUB) [6]. They have good enough spatial resolution; about 1 mm and 10 mm in horizontal directions. They can measure accurately the number and position of particles hitting the detectors.

The DELPHI-MUB consisted of 1372 drift chambers arranged into 146 planks. About 100 planks are now available for the multimuon experiment. The active volume of each chamber is 20 cm wide, 1.6 cm high and 3.65 m long. The drift chambers operate in the proportional mode, with Ar:CH_4:CO_2 (90:5:5) nonflammable gas mixture. 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 most interesting energy range is between 50 GeV and 100 GeV. To study this with sufficient statistics, the device must be placed at a suitable depth underground. Different depths can be used to measure different properties of the air shower. At higher energies the statistics to observe multiple muons gets smaller. Lower energies, instead, must be filtered out as they carry no valuable information on the composition. Hence we aim at setting the detectors at the depths from 100 m to 400 m (250 – 1000 mwe).

2.3. Surface Detector Array

A small extensive-air-shower surface-array will be set up to measure the direction and energy of the EAS with the accompanying underground multimuon event. The array will consist of low-cost scintillation counters.

2.4. Timetable

The experiment will first start by the construction of a prototype detector underground in summer 2003. The prototype includes about 70 drift chambers, and it will be expanded to a full system after the test period using the remaining DELPHI muon barrels. The multimuon experiment in full scale is expected to run in the beginning of 2006.

The surface detector may be constructed in connection with the proposed European or national wide-area cosmic-ray-array network.

3. Expected Results

From the observed underground multimuon events, combined with Monte Carlo simulations and the properties of the rock, we expect to be able to determine the direction, multiplicity, lateral distribution and energy of the muons in the extensive air shower. From this information we can make conclusions about the composition of the cosmic rays in certain energy range. This may help to solve the problem of their origin.

CosmoAleph group observed five cosmic ray muon events with very high multiplicity (about five or more events) [7]. It was preliminarily shown that Monte Carlo simulations using conventional interaction models could not interpret these multimuon events, suggesting some unknown physics processes. Because statistics was small for very-high multiplicity events observed by CosmoAleph, further observations with good statistics are required to study this phenomenon. Thus a large-area detector with good muon resolution set-up at a medium depth underground named CORAL was proposed [8].

The present multimuon experiment has qualifications to reach most goals proposed by CORAL. It is also able to observe much more CosmoAleph-like events (about 100 times more events than observed by CosmoAleph in one-year running), and to answer the presented questions.

Ref. [9] presented a mechanism of quark-gluon plasma (QGP) production in high-energy cosmic ray nucleus-nucleus collisions. The QGP production might be observed in the measurement of energetic cosmic ray muons at a medium depth underground. The experimental study of this process requires the measurement of the multiplicities of muons and their lateral distributions, as in the observed CosmoAleph-type events.

4. Conclusion

The CUPP project is starting the first large-scale experiment by constructing the multimuon detector system underground in the Pyhäsalmi mine. The prototype detector, consisting of about 70 drift chambers with the total area of about 50 m^2, is planned to run around middle of 2004. The full setup of ten times larger will be constructed after the prototype is proven functional.

5. References

1. KASCADE Collaboration
Nucl. Phys. B (Proc. Suppl.) 52B (1997) 92;
Proc. 25th ICRC 6 (1997) 97, 121, 141, 145;
Proc. 26th ICRC OG (1999) 1.2.11.
2. Boothby K et al. Proc. 25th ICRC 4 (1997) 33, 37; 5 (1997) 193.
Swordy S.P. and D.B.Kieda Astropart. Phys. 13 (2001) 137.
Fowler J.W. et al Astropart. Phys. 15 (2001) 49.
3. MACRO Collaboration
Phys. Rev. D46 (1992) 895;
Nucl. Phys. B (Proc. Suppl.) 35 (1994) 229;
Proc. 24th ICRC 1 (1995) 1031.
LVD Collaboration Nucl. Phys. B (Proc. Suppl.) 35 (1994) 243.
Jing C.L. et al. High Energy Phys. and Nucl. Phys. 9 (1985) 134.
4. Peltoniemi J. Physica Scripta 93 (2001) 102.
5. Enqvist T. et al. CUPP Report 01/2003.
6. DELPHI Collaboration Nucl. Instrum. Methods A303 (1991) 233.
7. Taylor C. et al. CosmoLEP proposal, CERN/LEPC 99-5 (1991).
8. Avati V. et al. CORAL A Cosmic Ray experiment in and above the LHC tunnel, CERN/2001-003, SPSC/P321 (2001).
9. Ridky J. Astropart. Phys. 17 (2002) 355.