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Underground cosmic-ray experiment EMMA

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Abstract. EMMA (Experiment with MultiMuon Array) is a new approach to study the composition of cosmic rays at the knee region ($1 - 10$ PeV). The array will measure the multiplicity and lateral distribution of the high-energy muon component of an air shower and its arrival direction on an event-by-event basis. The array operates in the Pyhäsalmi Mine, Finland, at a depth of 75 metres (or 210 m.w.e) corresponding to the cut-off energy of approximately 50 GeV for vertical muons. The data recording with a partial array has started and preliminary results of the first test runs are presented.

1. Introduction

Prior to the present study several experiments have probed the cosmic-ray composition at the knee region. However, the composition puzzle remains unsolved as the results of these experiments are still inconclusive. In order to shed further light to the issue the EMMA experiment (Experiment with Multi-Muon Array) [1] uses yet another approach: it measures the lateral density distribution of high-energy muons at a shallow depth event by event.

CORSIKA simulation [2] of the muon lateral density distribution with muon energies in excess of 50 GeV reveals that the distribution is sensitive to the energy and mass of the primary cosmic-ray particle. Generally speaking the larger the muon energy cut-off the steeper the tails, and the larger the gap between proton and iron-initiated showers. In other words, the deeper underground the more low-energy muons dominating in tails are stopped in the rock overburden, and there are more muons available in iron-initiated showers than those of protons.

Figure 1 shows the average muon density distributions of 1, 3 and 10 PeV proton and iron-initiated air showers ($E_\mu > 50$ GeV). The figure reveals two important details for EMMA: i) the primary energy translates to the muon density at the shower core and is somewhat independent on mass, and ii) the muon tails of proton and iron-initiated showers are rather well separated and have measurable muon densities. Thus it seems justified to assume that the muon density at the shower core and the muon density gradient can be used to estimate the energy and mass of primary cosmic rays, respectively.

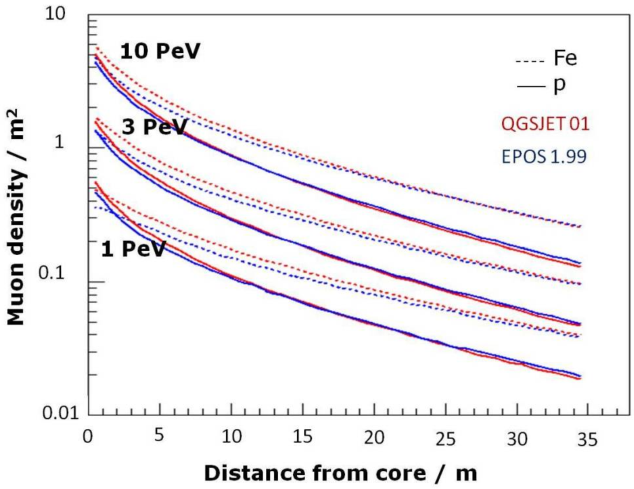

Figure 1. Simulated lateral muon density distributions of high-energy muons (E_μ > 50 GeV) of proton and iron-initiated air showers at 1, 3 and 10 PeV energies. CORSIKA+QGSJET 01 and CORSIKA+EPOS 1.99 models indicated by red and blue lines, respectively.

2. Experimental details

EMMA operates at a depth of 75 metres (or 210 m.w.e) in the Pyhäsalmi Mine, Finland. It is designed for cosmic-ray composition studies around the knee energy ($1 - 10$ PeV) by measuring the multiplicity and the lateral spread of high-energy muons initiated by an air shower. The muon tracking is used to extract the shower direction. The rock overburden results in average muon cut-off energy of approximately 50 GeV for vertical muons. Thus muons detected by EMMA are mostly generated in the upper part of air showers, or close to the primary interaction.

The array consists of detector stations arranged in a four-arm layout (see figure 2 for details). Each station has a detector area of approximately 15 m^2 on each detector layer. Currently seven stations are installed. EMMA employs three types of detectors. The bulk area is covered with the former LEP-DELPHI MUBs (or planks) [3] which are gas-filled with an Ar(92%):CO_2(8%)-mixture. Each plank consists of seven position sensitive drift chambers (365$\times$20 cm^2, 20 mm thick) arranged in lengthwise half-overlapping groups of 3 + 4 (area of 2.9 m^2 each). The position resolution (σ) of planks is approximately $\pm$1 cm^2 and the total area of planks is approximately 240 m^2. The gas mixture is delivered from ground via an approximately 100 metres long pipeline through the rock. The gas consumption of planks is rather high (in total more than 5 litres a minute, NTP) and thus the latter is both safety and practical issue allowing us to avoid the gas transportation through the rather narrow mine caverns.

The second type of detectors is a plastic scintillation detector [4]. These detectors are designed and manufactured by the INR/RAS, Moscow, and are equipped with APDs (Avalanche Photo Diodes). The scintillation detector (or SC16) consists of 4$\times$4 individual 12$\times$12$\times$3 cm^3 pixels. The SC16 covers the area of 0.5$\times$0.5 m^2. The total number of SC16s is 96 (or 24 m^2). The scintillators will be placed in the three central stations (C, F and G in figure 2) and as the total number of individual pixels is 1536 the scintillators set-up is an excellent tool for detailed muon multiplicity studies. Furthermore, the good time resolution (with σ better than 2 ns) provides a useful and independent initial guess for the shower arrival angles and verify muon tracking.

The third detector type is the Limited Streamer Tube (or LST) [5]. These detectors are gas-filled (with CO_2) position sensitive detectors dismantled from the KASCADE-Grande cosmic-ray

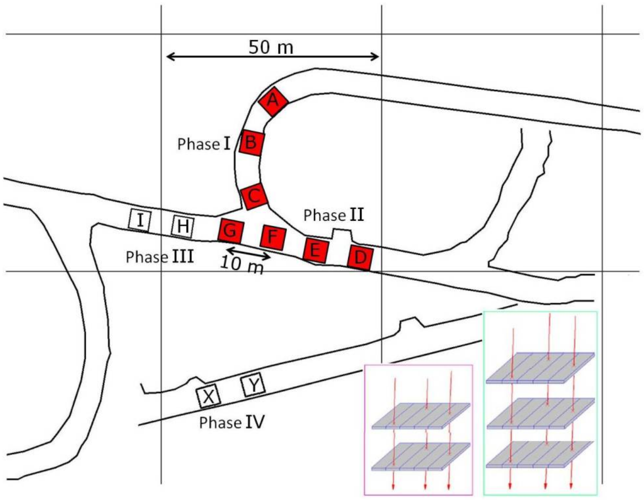

Figure 2. Layout of EMMA in the mine caverns 75 metres below ground. Phase I – IV refer to the four branches of the array and the detector stations are indicated by red rectangles (those of white have not been installed yet). The central stations C, F and G have three detector layers, each 1125 mm apart, while the rest have two, as illustrated in two insets bottom right.

experiment in Karlsruhe, Germany. One LST module has an area of 2.9 m^2 (1.0×2.9 m^2) and the number of modules is 60. Thus the total area of LSTs will be approximately 174 m^2. The detectors are designed for muon tracking and a pad (or a pixel) size of the LST-module is 2×8 cm^2. Furthermore, the gas consumption of LSTs is very small, or less than 1% that of planks. Therefore LSTs are particularly suitable for the satellite stations X and Y (see figure 2) placed in the cavern 30 metres above the main cavern connected only via two 50 metres long drill holes (Ø 75 mm) for (optical) cables and electricity.

The data acquisition uses the VME system, one VME unit placed on each arm (or on stations C, F, G and X, see figure 2) and all connected together via optical connection which, in addition, simplifies the electrical grounding of a rather large set-up.

3. Muon multiplicities – an example

While the last four stations are still to be constructed test measurements are already running in other stations. Test runs of three to four months were carried out in 2010 and 2011, and are also currently running. The first test run using one tracking station (three detector layers, each horizontally 1125 mm apart, dimensions are 3650×4220×2250 mm^3, see the insets in figures 2 and 3 for more details) and the second run using one tracking station together with one one-layer test station are completed. Currently the tests are running with two tracking stations.

So far all detectors in all stations have been drift chambers. The preliminary muon multiplicity distributions of Extensive Air Showers (EAS) recorded during 44 days in 2011 in a tracking station and CORSIKA simulation for protons are shown in figure 3 (for further details, see [6]). A schematic view of the tracking station with a shower of 16 tracks is shown in the inset.

4. Summary

The new underground muon array EMMA is under construction. The array has a four-arm layout. The three central tracking stations (C, F and G) are equipped with three layers of drift

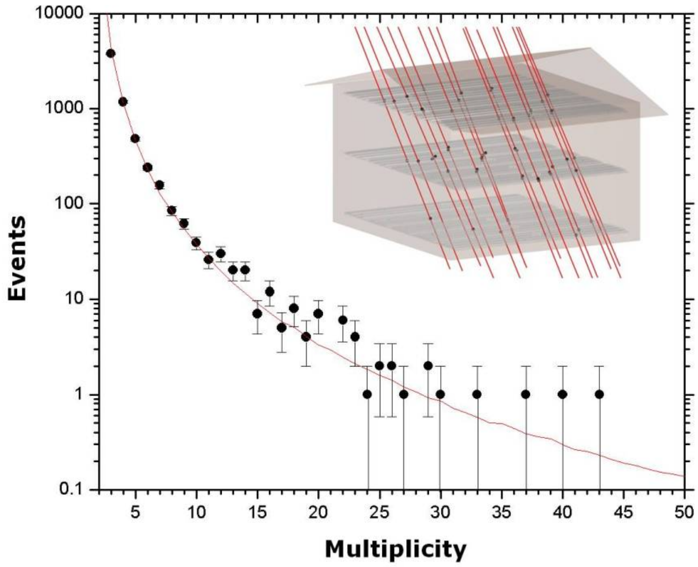

Figure 3. Preliminary muon multiplicity distribution extracted using one station (44 days of data, solid circles) and a CORSIKA simulation expectation for proton (red line, curve normalized to the muon multiplicity equal to five). A schematic view of the tracking station (dimensions are $3650\times4220\times2250$ mm^3) with a shower of 16 tracks is also illustrated.

chambers for the shower direction determination, and scintillators and LSTs for detailed muon multiplicity studies close to the shower core position, while the rest are two-layer stations, or sampling stations employing drift chambers and LSTs for sampling the muon densities. The data recording with a partial array has already started and the first results of test runs are presented. The preliminary result demonstrates that the tracking procedure is working as expected and the measured multiplicity distribution is in line with CORSIKA simulation.

Acknowledgments

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References

[1] Kuusiniemi P *et al.* 2011*Astrophys. Space Sci. Trans.* **7** 93
[2] Heck D, Knapp J, Capdevielle J N, Schatz G and Thouw T 1998 CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers, Report FZKA 6019
[3] Aarnio P et al. and the DELPHI Collaboration 1991 *Nucl. Inst. Meth. in Phys. Res.* A **303** 233
[4] Akhrameev E V *et al.* 2009 Nucl. *Inst. Meth. in Phys. Res.* A **610** 419
[5] Antoni T, Bercuci A, Bozdog H, Haungs A, Mathes H J, Petcu M, Rebel H, Zagromski S 2004 *Nucl. Inst. Meth. in Phys. Res.* A **533** 387
[6] Sarkamo J *et al.* 2012 EAS selection in the EMMA underground array *this proceedings*