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Concept and layout of the EAS muon arrival time distribution measurements on Mt. Aragats Observatory

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Abstract

The lateral and longitudinal profiles of the EAS development show specific features depending on the primary mass due to various particle interaction parameters influencing the development of the particle cascade in the atmosphere. The large muon detector of the ANI Cosmic Ray Observatory on Mt. Aragats gives a good opportunity to measure muon arrival times. In view of a possible extension of the muon underground installation EAS simulations have been performed. They consider various detector configurations with respect to the EAS core position. The observed muon time dispersion show specific trends with increasing radial distance and primary mass. Particularly, simulations based on the GEANT package had been done to study the faked detector signals due to secondaries generated in the surrounding material. A design for upgrading the muon detector array is presented which implies additional fast timing photomultipliers attached to the existing scintillation detectors.

1 Introduction:

The temporal structure of the Extended Air Shower (EAS) muon component maps rather directly the longitudinal shower development. The observed time dispersion of the EAS particles arises mainly from two sources: (1) Different transverse momenta of the secondaries produced in the hadronic cascade together with multiple scattering during transport in the atmosphere produce a transversal dispersion. (2) Differences in the velocities and in the path lengths. These dispersions are reflected by the variation of the arrival times of particular particles at a fixed radial distance. In sufficient large distances from the shower core arrival time quantities related to these effects become experimentally accessible, thus providing useful information for the identification of different primaries.

Proton and iron induced particle cascades behave differently in the atmosphere. On average, due to the smaller interaction length of iron primaries, their cascades will develop earlier at higher altitudes in the atmosphere. This feature together with the lower longitudinal momentum of the resulting secondaries as compared with proton induced showers of the same primary energy, lead to a higher probability for muons with longer path lengths. Due to different fluctuations, on observation level muons originating from proton primaries show broader arrival time distributions relative to the arrival time of the core as compared to iron induced showers and additionally they are shifted to slightly higher average values with respect to the shower front (Rebel et al., 1995). Such investigations had been carried out for example in the Haverah Park experiment (Ambrosio et al., 1997 and Agnetta et al., 1997). Most recently the KASCADE experiment studied various aspects of particle arrival times distributions (Haeusler et al., 1999, Badea et al., 1999 and Antoni et al., 1999).

2 The ANI cosmic ray observatory:

The ANI cosmic ray observatory is located at 3200 m a.s.l. on Mt. Aragats, Armenia. Presently it consists of two independently running EAS experiments (Fig. 1). The MAKET ANI experiment is instrumented with scintillation detectors for electron-photon detection and a calorimeter presently out of operation. The second experiment (GAMMA) consists of a surface e/γ detector array and an underground detector array equipped

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with scintillation detectors for muon detection. The threshold for muon detection has been determined to be between 2 and 5 GeV, independently by detector simulations (Zazyan & Haungs, 1998) as well as by flux measurements. The variation of the threshold energy values is due to the varying thickness of the material on top of the muon detectors location. This requires very detailed detector simulations to obtain precise results.

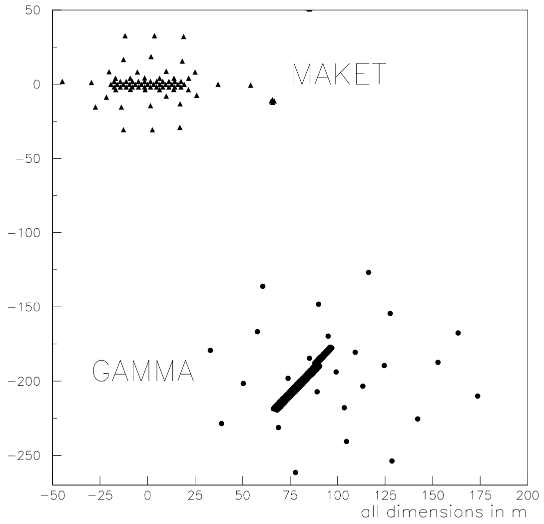

Figure 1: Schematic site map showing the two cosmic ray experiments of the ANI cosmic ray observatory located on Mt. Aragats, Armenia.

The detectors used for the muon underground detectors are built into pyramid-shaped housings as shown in Fig. 2. The dimension of the scintillator plate is $100 \cdot 100 \cdot 5$ cm^3. Currently the signal readout is done via Russian FEU-49 photomultipliers with a rise time of about 30 ns. The attached readout electronics is basically designed for the purpose of pulse height measurements. With a specially optimized readout electronics as it is used for timing requirements of the surface detectors (determination of shower arrival direction) an overall timing resolution of approx. 4 ns could be achieved. The presently obtainable timing resolution could be expressed as the Gaussian sum of the effects from the scintillator, the geometrical shape of the detector and of the electronic together with the currently used TDC (laboratory made) modules which have 5 ns digitalization steps (Erlykin et al., 1989).

3 Monte Carlo simulations:

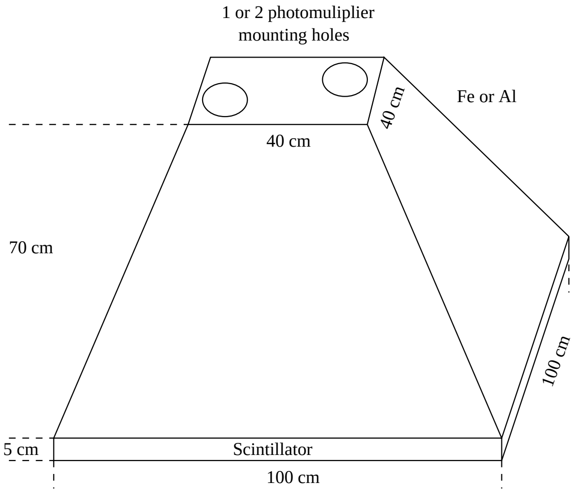

Figure 2: Sketch of the detector housing used for the ANI muon underground installation.

In view of a possible extension of the present detector setup to study muon arrival times a large number of MC studies were carried out. These studies mainly concentrate on the structure of the expected events under different external conditions. In the frame of these simulations the time resolution and the arrangement of the detectors are modeled. For the time resolution a hypothetical value of 2 ns is assumed. It is supposed that the muon underground detector array with its 150 detectors with $1\mathrm{m}^2$ each, is fully instrumented to measure muon arrival times. Furthermore, it is worth to stress that due to the large area of the muon detection system it is possible to subdivide the whole system in 3 subsystems with sufficient number of detectors. This allows us also to investigate correlated features of the observed arrival times (Badea et al., 1998). As possible trigger sources for an imaginary readout system the surface arrays of MAKET and GAMMA are considered, i.e. only showers are evaluated which have their core inside the detection area of these experiments and show up at least 2 muons in any of muon detector subarrays.

The particle output data delivered from the air shower simulation program CORSIKA (Capdevielle et al., 1992 and Heck et al., 1998) (version 4.60 with NKG, GHEISHA and VENUS option selected) with proton and iron primaries at fixed energies between $1 \cdot 10^{15}$ eV and $1 \cdot 10^{16}$ eV are used to feed the simulation program containing the described model. The choice of the experimental conditions leads to a range of possible core distances of 100 ... 120 m for showers triggered from the GAMMA installation (assuming not the full instrumentation of the GAMMA surface array) and of 190 ... 230 m for the MAKET installation respectively. The detectors register the arrival time of the first muon (τ_μ^i) at each detector position. On an event-by-event basis mean and median of the arrival times of all hit detectors are calculated. Finally τ_1, τ_{mean} and τ_{med} distributions are obtained and kept for further analysis for different primaries, energies and core distances.

4 The proposed timing experiment:

A realistic first phase of such an timing device installation is a prototype setup with the readout of 32 channels. In order to have a sufficiently large core distance such an installation has to be done with detectors at the end of the muon tunnel. Fig. 3 shows a block diagram of the proposed starting and testing phase of the timing experiment. The two running experiments at the ANI site use already the Camac readout system. So we decided to use also Camac based readout hardware. Other parts of the system could be implemented in any other appropriate standard or adapted for the specific needs.

We have chosen to use the model 3377 Camac TDC (LeCroy Research Systems) for the readout of the timing signals. However the choice implies the use of level translators to adapt the discriminators output signals to the ECL inputs of the TDC as it is only provided with ECL inputs for working in complex and fast readout setups. This TDC has 32 independent channels with a full scale range between 8 ns and 32 μs and with an programmable resolution between 0.5 ns and 4 ns. The full scale range has to be chosen according to the expected size of muon arrival times and dead time considerations. As this TDC is in addition multi-hit capable a new degree of freedom is introduced in this timing experiment. Up to now this is not considered by our simulation calculations.

The experiment plans to use constant fraction discriminators (CFD) to obtain the best timing resolution, though this is not the cheapest solution. It is planned to install these CFDs directly at the photomultipliers site. Eventually an additional fast pre-amplifier is needed in this setup. Tests must show if this can be avoided. The design of these CFDs is already done and a few test exemplars are available.

As the pulse height readout of the detectors is also necessary to estimate the muon number, the detectors have to be equipped with two different photomultipliers each one suited for a specific purpose. For some of the detector boxes this is feasible by the fact that they have two mounting holes for the photo-tube holders. For the remaining detector boxes another solution has to be found.

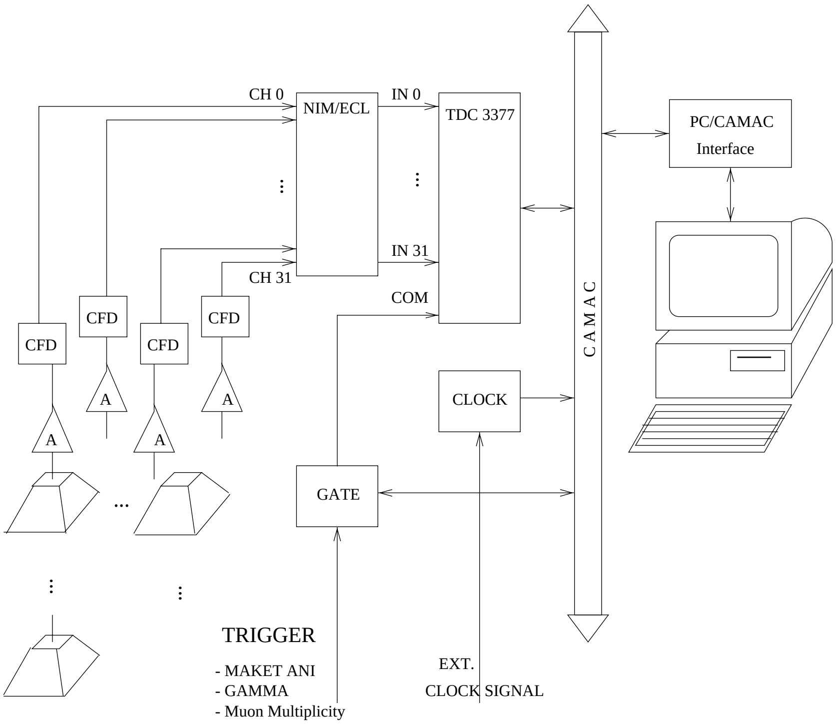

Figure 3: A block diagram of the electronics needed for a possible first phase (32 detectors instrumented) of the proposed timing experiment.

The MC simulations regarded both ANI e/γ-arrays as possible trigger source. Of course the use of the MAKET experiment for the trigger of the device will give us larger spreads of the arrival times which can be measured in an easier way. On the other side, due to the larger core distance the rate of events will be lower.

To simplify the setup in the first phase only the GAMMA experiment will be used as trigger source.

Any further online coupling with the GAMMA experiment is not planned in this phase. This would introduce additional complications for the time critical online software of the GAMMA experiment. Modifications may have some impacts on the actual data taking period. In the near future it is planned to use the coupling between MAKET and GAMMA. Then the merging of event data from the two experiments will become easier. But at the moment the low trigger rate allows us to use the PC's clock for event tagging.

The timing accuracy of the setup is an important aspect of the measurements and depends mainly on the detector properties. These effects have recently been studied more detailed with TDCs of higher resolution. In a setup with a $30 \cdot 30 \ \mathrm{cm}^2$ scintillator a few photomultiplier types are investigated with respect to their timing resolution. The obtained resolutions are σ_{opt} = 1.7 ns for FEU-30 and FEU-130 phototubes and σ_{opt} = 1.5 ns for EMI 9902 phototubes. The influence of the final detector geometry could not be measured. So this is the subject of tests presently carried out at the Yerevan physics institute. Considerations, based on simple MC simulations, show that the influence coming from the detectors geometry could be estimated to be about σ_D = 0.4 ns. So a timing resolution of about 2 ns or better seems to be achievable with the present setup just replacing photomultiplier and the discriminating electronics.

In Fig. 3 the schemes of additional electronics needed for the monitoring of the detectors and of the slow control system are missing. To guarantee a proper functioning of the timing detectors and of the CFD threshold settings they have to be monitored continuously. Assigning the timing data with the signal height information readout by the GAMMA experiment allows us to determine the actual thresholds without spending further ADC channels for the new experiment. After this a continuous monitoring of the rates will be done in order to check permanently the adjustments made.

5 Status and Conclusions:

The temporal structure of the EAS muon component reflects the features of the longitudinal shower development. For a proposed extension of the muon underground detectors of the ANI cosmic ray experiment a number of MC simulations were carried out in order to study these effects for this setup. The achieved timing accuracy of such a system turns out to be the crucial factor. For the ANI muon detectors the timing resolution has to be improved to reach this goals.

Presently detector tests are performed to obtain the actual detector performance and compare it with the expected values. When the experiment site will become accessible the installation of a few timing channels will be started.

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