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Highly segmented scintillator detector for underground cosmic ray experiments

Scintillator detectors designed and manufactured for the underground experiment EMMA in the Pihasalmi mine, Finland, are described. The whole detector has the total area of 135 mˆ2 covered by 1600 scintillator counters, 122×122 mmˆ2 and 3 cm thick, are arranged in 4×4 arrays, each of 16 counters, which form individual detectors of 50 cm × 50 cm in cross section. Polystyrene scintillator counters have been manufactured at IHEP, Protvino, Russia. Scintillating light in a counter is collected by a single Y11 (Kuraray) WLS fiber. The fiber is viewed from one end by a novel photosensor operating in a limited Geiger mode (MRS APD), the other end is covered by an aluminized mylar reflector. MRS APD's manufactured by CPTA, Moscow have unique features: high photon detection efficiency, low dark rate and cross-talk, and high gain. Detailed description of these devices is presented. The performance of EMMA counters was tested with cosmic ray muons. The light yield of about 150 photoelectrons was obtained for a 6 MeV energy deposited by cosmic muons in the 3 cm thick counter. The obtained time resolution is about 0.9 ns (sigma) and mainly determined by the slow decay time (9-12 ns) of the Y11 fiber. The photon background of the rock walls is suppressed keeping a high efficiency (> 95%) for cosmic muons.

Summary (Additional text describing your work. Can be pasted here or give an URL to a PDF document):

The goal of the EMMA experiment is to study the chemical composition of the primary cosmic rays around the "knee"region at the energy of about 3×1015 eV by measuring the multiplicity, lateral distribution and arrival direction of the underground cosmic ray muons. The EMMA detector will be constructed in the Pyhasalmi mine, Finland. It consists of drift chambers and plastic scintillator detectors and has the total area of about 135 mˆ2 at the depth of 85 m. In total, about 1600 scintillator counter arranged in 4x4 arrays, each of 16 counters, form individual modules of 50 cm x 50 cm in cross section.

An EMMA scintillator counter is a polystyrene based cast plastic scintillator of 122×122×30 mmˆ3. Outer surfaces of the scintillator were etched by a chemical agent that resulted in the formation of a micropore deposit over the plastic surface, which works as a diffuse reflector. Scintillating light is collected by a single Y11 (Kuraray) WLS fiber of 1 mm diameter glued into a spiral groove of 3.2 mm depth with the BC600 Bicron glue. The groove was carved by an engraving-milling machine which speed and cutting tools were optimized to make a clean groove to provide good transmission of the scintillating light through the cut surfaces. This technique was developed for scintillator counters manufactured for the near neutrino detector of the long baseline neutrino experiment T2K. The fiber is viewed from one end by a Geiger mode APD (MRS APD), the other end is covered by an aluminized mylar reflector.

The photosensor for EMMA detectors, MRS APD, multi-pixel avalanche photodiode with a metal-resistor-semiconductor layer structure operating in a limited Geiger mode manufactutered by CPTA, Moscow for EMMA detectors, consists of 556 independent sensitive pixels of 35 × 35 μmˆ2 each produced on a common p–type silicon substrate and has a sensitive area of about 1.1 mm2. The main parameters of these MRS APD's are measured and shown below. The photon detection efficiency is measured to be about 30% for green light region (WLS fiber emission spectrum) at the operating bias voltage while dark rate is kept below 1 MHz for a threshold of 0.5 photoelectron. It is demonstrated that the breakdown voltage is only weakly depends on the temperature that results in a weak temperature dependence of the photon detection efficiency and gain comparing with other Geiger mode APD's.

The performance of EMMA counters was tested with cosmic ray muons The light yield of about 150 photoelectrons and the time resolution of about 0.9 ns (sigma) were obtained for a 6 MeV energy deposited in a 3-cm thick counter that allows us to suppress the photon background from the surrounding rock (2.6 MeV) and keep a high efficiency (> 95%) for cosmic muons. A special electronics was developed and produced for automatic tuning of the operating bias voltage of MRS APD's in each counter taking into account an approximately constant counting rate from cosmic muons and the obtained in each counter value of the light yield.

The results of the measurements of the cosmic muon spectra and the background spectra from radioactive decays in the rock surrounding the EMMA detector will be presented.

Author: Prof. KUDENKO, Yury (Institute for Nuclear Research (INR), 117312 Moscow, Russia)

Co-authors: Mr IZMAYLOV, Alexander (Institute for Nuclear Research (INR), 117312 Moscow, Russia); KHOTJANTSEV, Alexei (Institute for Nuclear Research (INR), 117312 Moscow, Russia); YANIN, Alexei (Institute for Nuclear Research (INR), 117312 Moscow, Russia); SHAYKHIEV, Artur (Institute for Nuclear Research (INR), 117312 Moscow, Russia); SHAIBONOV, Bator (Institute for Nuclear Research (INR), 117312 Moscow, Russia); LUBSANDORZHIEV, Bayarto (Institute for Nuclear Research (INR), 117312 Moscow, Russia); ZYKOV, Dmitry (Institute for Nuclear Research (INR), 117312 Moscow, Russia); VOLCHENKO, Galina (Institute for Nuclear Research (INR), 117312 Moscow, Russia); Dr FYNBO, Hans (Department of Physics and Astronomy, University of Aarhus, DK-8000 Arhus, Denmark); Mr DAVITASHVILI, Irakly (Institute for Nuclear Research (INR), 117312 Moscow, Russia); Mrs DZAPAROVA, Irina (Institute for Nuclear Research (INR), 117312 Moscow, Russia); JOUTSENVAARA, Jari (CUPP/Pyhäsalmi, University of Oulu, FIN-90014 Oulu, Finland); SARKAMO, Juho (CUPP/Pyhäsalmi, University of Oulu, FIN-90014 Oulu, Finland); Mr BUTIN, Konstantin (Institute for Nuclear Research (INR), 117312 Moscow, Russia); Dr BEZRUKOV, Leonid (nstitute for Nuclear Research, 117312 Moscow, Russia); Mr GOLYSHKIN, Lev (Institute for Nuclear Research (INR), 117312 Moscow, Russia); Dr INZHECHIK, Lev (Institute for Nuclear Research (INR), 117312 Moscow, Russia); KHABIBULLIN, Marat (Institute for Nuclear Research (INR), 117312 Moscow, Russia); YERSHOV, Nikolai (Institute for Nuclear Research (INR), 117312 Moscow, Russia); MINEEV, Oleg (Institute for Nuclear Research (INR), 117312 Moscow, Russia); KUUSINIEMI, Pasi (CUPP/Pyhäsalmi, University of Oulu, FIN-90014 Oulu, Finland); POLESHUK, Roman (Institute for Nuclear Research (INR), 117312 Moscow, Russia); Prof. ENQVIST, Timo (CUPP/Pyhäsalmi, University of Oulu, FIN-90014 Oulu, Finland); RAIHA, Tomi (CUPP/Pyhäsalmi, University of Oulu, FIN-90014 Oulu, Finland); KALLIOKOSKI, Tuomo (Department of Physics, University of Jyväskylä, FIN-40351 Jyväskylä Finland); PETKOV, Valery (Institute for Nuclear Research (INR), 117312 Moscow, Russia); VOLCHENKO, Vladimir (Institute for Nuclear Research (INR), 117312 Moscow, Russia); TRZASKA, Wladyslaw (Department of Physics, University of Jyväskylä, FIN-40351 Jyväskylä Finland); Mr GULIEV, Zhamal (Institute for Nuclear Research (INR), 117312 Moscow, Russia)

Presenter: Prof. KUDENKO, Yury (Institute for Nuclear Research (INR), 117312 Moscow, Russia)