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An innovative approach to compact calorimetry in space, NEUCAL

S. Bottai [a,*], G. Castellini [a], P. Papini [a], G. Sguazzoni [a], E. Vannuccini [a], O. Adriani [b], L. Bonechi [b], M. Bongi [a], R. D'Alessandro [b], S. Ricciarini [a], G. Sorichetti [b], P. Sona [b], P. Spillantini [b], A. Viciani [b]

[a] INFN Sezione di Firenze, via Sansone, 1-I-50019 Sesto F. no (FI), Italy
[b] University of Florence, via Sansone, 1-I-50019 Sesto F. no (FI), Italy

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ABSTRACT

Neutron emission during the development of hadronic showers can be used to discriminate between electromagnetic and hadronic interacting particles impinging a calorimeter. A neutron detector based on a high efficiency 'active moderator' is presented and its performance is evaluated with the aid of Monte Carlo simulation.

1. Introduction

The development of techniques for the detection of neutrons in connection with the use of compact calorimeters (that may not be able to completely absorb the incident hadron), has become very important with the new generation of astroparticle space experiments, since these types of calorimeters must still discriminate, with a high rejection power, between electromagnetic and hadron showers.

2. Simulation of neutron emission

The idea of enhancing calorimeter discrimination by measuring the neutron component of the showers, was first tried with the PAMELA [1] experiment on satellite. There an 'old' style neutron detector was placed at the back-end of the calorimeter. Unfortunately, traditional neutron detectors are sensitive mainly to the low energy component of the neutrons produced in the calorimeters, the one that has been moderated by, for example, polyethylene and have very low efficiency. NEUCAL instead, will detect signals coming from the actual neutron moderation process (using a de facto active moderator), so as to significantly increase the performance of the detector. The detector itself will be a composite structure where various techniques are combined to produce an optimized detector for space applications. During the development of hadronic showers inside calorimeters, neutrons are expected to be produced both by nuclear excitations and by hadronic interactions. Electromagnetic showers can also produce neutrons via the giant resonance mechanism and via photo-nuclear interactions in general. In order to precisely characterize the neutron component associated with the different types of showers a detailed Monte Carlo simulation has been performed using the FLUKA simulation package [3]. As a 'test detector' the CALET [2] BGO homogeneous calorimeter, consisting of a BGO tower ($60\,\text{cm} \times 60\,\text{cm} \times 30\,\text{cm}$ height) with a vertical depth of approximately 30×0 has been simulated. For each simulated event the produced neutrons have been propagated till they reached the outside of the calorimeter. The energy, direction and arrival time of each neutron exiting the calorimeter from the bottom side where the NEUCAL moderator is placed are logged for further use. In Fig. 1 the number of neutrons exiting from the calorimeter is shown for 1 TeV interacting protons and for 400 GeV electrons (1 TeV proton showers on average give the same calorimetric signal as 400 GeV electrons in BGO). The rejection factor achievable for hadronic showers can be as high as $\approx 10^3$ just considering the neutron counting. The bulk of neutrons originate from the excitation and de-excitation of nuclei and exhibit a maximum in the MeV energy region (Fig. 2). Many neutrons undergo moderation before escaping and their energy is consequently degraded down to the eV energy region. Some neutrons can also be produced promptly in the hadronic interactions along the shower core, with an energy that can reach that of the primary proton. The highest energy neutrons ($E > 10\,\text{MeV}$) arrive close in time with respect to the charged component of the shower, while the low energy and more abundant component arrives in the neutron detector with a delay which ranges from 10 to 1000 ns and thus can be easily identified. The figure for electromagnetic showers is similar but with a much reduced contribution for the prompt neutron emission.

3. NEUCAL neutron detector

The NEUCAL neutron detector concept is presented in Fig. 3 and is based on the use of two active detectors: layers of plastic scintillators and arrays of 3He proportional counter tubes.

* Corresponding author.
E-mail address: bottai@fi.infn.it (S. Bottai).

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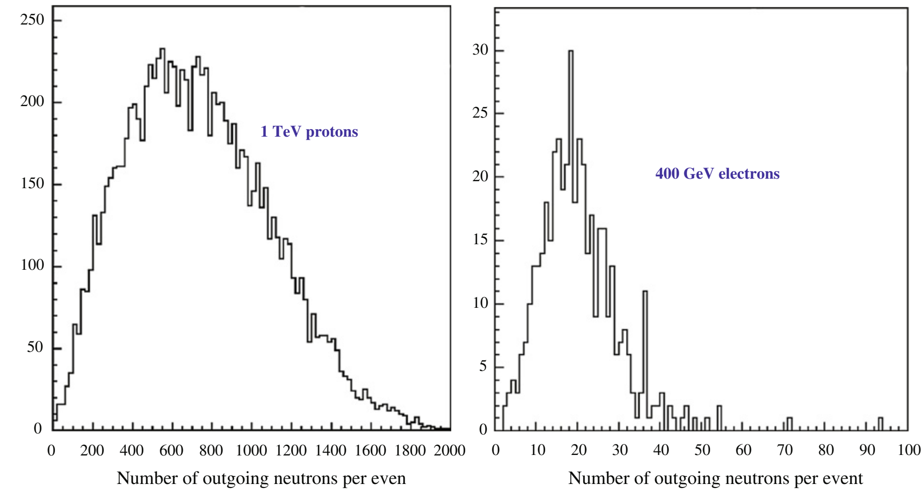

Fig. 1. Neutron yield outside the CALET calorimeter for 1 TeV interacting protons and 400 GeV electrons.

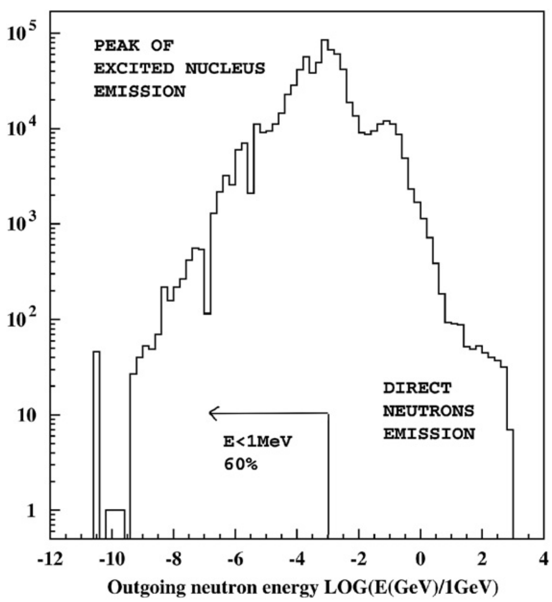

Fig. 2. Energy distribution of neutrons exiting from the CALET calorimeter in case of 1 TeV interacting protons.

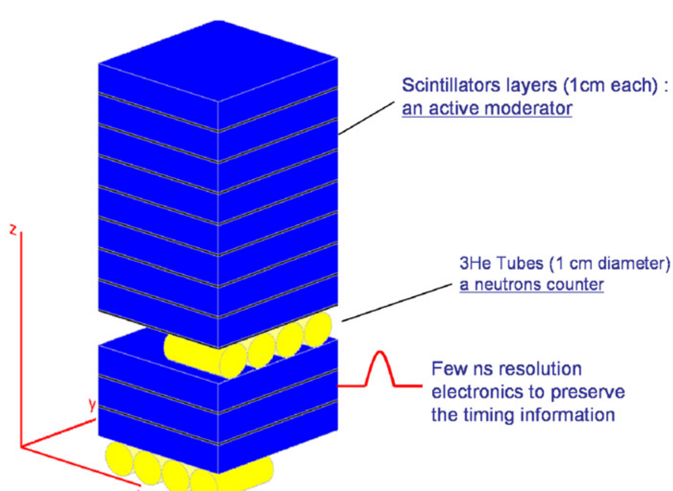

Fig. 3. A scheme of the proposed NEUCAL neutron detector.

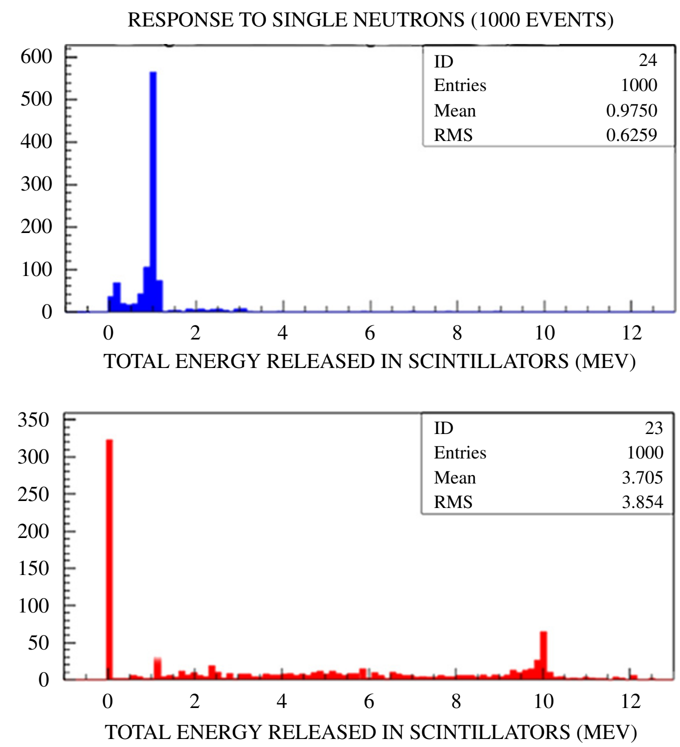

Fig. 4. Response of 12 scintillator layers to single neutron. The figure on top shows the energy released in all the scintillators by 1 MeV neutrons. The figure on the bottom refers to the response in case of 10 MeV neutrons.

Neutron–proton elastic scattering in the plastic scintillators provide the active neutron moderation. Scattered protons release their energy inside the scintillators and hence provide the signal associated with the neutron moderation process. The moderated neutrons can be detected by means of nuclear capture followed by 0.765 MeV proton emission in the 3He counters.

The response to single neutron has been simulated for neutron detector composed of 12 scintillators layers. As can be seen in Fig. 4 neutrons with energy up to few MeV are fully moderated and detected with high efficiency. In case of 10 MeV neutrons a detectable signal in the scintillators appear for 70% of the events but only 10% of them are fully moderated and detectable by the 3He tubes.

A prototype of NEUCAL composed of eight scintillators layers and five 3He tubes is under construction and is expected to be tested at CERN at the end of summer 2009. The test will be performed using a calorimeter in front of the neutron detector in such a way the whole process of neutron emission, transport and detection can be verified against the simulations that have already been performed.

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