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Longitudinally segmented lead/scintillator hadron calorimeter with micro-pixel APD readout

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ABSTRACT

The construction and performance of a modular hadron calorimeter prototype is described. The prototype consists of 9 individual lead/scintillator sandwich modules with the sampling satisfying the compensating condition. The light from the individual scintillator tiles is captured and transported with the WLS-fibers embedded in the scintillator and extended along the lateral side to the rear end of the module. Set of 6 WLS-fibers from the neighboring tiles is grouped in one bundle and viewed by a $3\times3\,\text{mm}^2$ avalanche micro-pixel photodiode. The construction ensures a longitudinal segmentation of the module in 10 independent sections. The results of beam tests of the calorimeter prototype are presented. The energy resolution $\sigma/E \approx 53\%/\sqrt{E(GeV)}$ was obtained.

1. Introduction

A new generation of heavy-ion experiments (NA61/SHINE at CERN [1] and CBM at FAIR [2]) is focused on the search for the critical point of strongly interacting matter and analysis of the properties of deconfinement. A crucial goal of this experimental program is the study of event-by-event fluctuations as a function of collision energy, size of colliding nuclei and the collision centrality. The experimental extraction of the critical fluctuations requires a very precise control over the fluctuations caused by the variation of the number of interacting nucleons due to changes in the collision geometry. The number of non-interacting nucleons is measured by a very forward hadron calorimeter, the projectile spectator detector (PSD). Main requirements to PSD are good energy resolution ($\sigma/E{\sim}50\%/\sqrt{E(GeV)}$), transverse uniformity of this resolution and fine granularity, which is also requested for reaction plane reconstruction. Full compensating modular lead/scintillator hadron calorimeters [3,4] meet the above requirements.

2. Calorimeter module design

The calorimeter will consist of 108 individual modules arranged in a 12×9 array and placed at the distance of about 15 m downstream from the target. The single module with the dimensions $10\times10\times160\,\text{cm}^3$ consists of 60 lead/scintillator layers with 16 and 4 mm thickness, respectively. All lead/scintillator plates are tied together with 0.5 mm-thick steel tape and placed in box made of 0.5 mm-thick steel. Light readout is provided by the WLS-fibers embedded in round grooves in the scintillator plates and extended along the lateral side of module, Fig. 1. WLS-fibers from each 6 consecutive scintillator tiles are collected together in one optical connector at the end of the module. Each of 10 optical connectors at the rear side of module is viewed by a single photodiode. The longitudinal segmentation in 10 sections ensures the uniformity of the light collection along the module and the rejection of secondary particles from interaction in the target.

3. Signal readout

Longitudinal segmentation of calorimeter modules requires 10 individual photodetectors per module for the signal readout. Micro-pixel avalanche photodiodes, (MAPDs) are an optimum choice due to their remarkable properties such as high internal gain, compactness, low cost and immunity to the nuclear counter effect. At the rear side of the module 10 MAPDs per module are placed together with the front-end-electronics. MAPDs with active area $3\times3\,\text{mm}^2$, gain $\sim10^5$ and pixel density $10^4/\text{mm}^2$ were selected. These MAPDs with individual micro-wells are produced by the Dubna–Mikron collaboration [7]. The MAPD photon detection efficiency of ~20% for green light is similar to PMT performance. The linearity of MAPD response was checked up to

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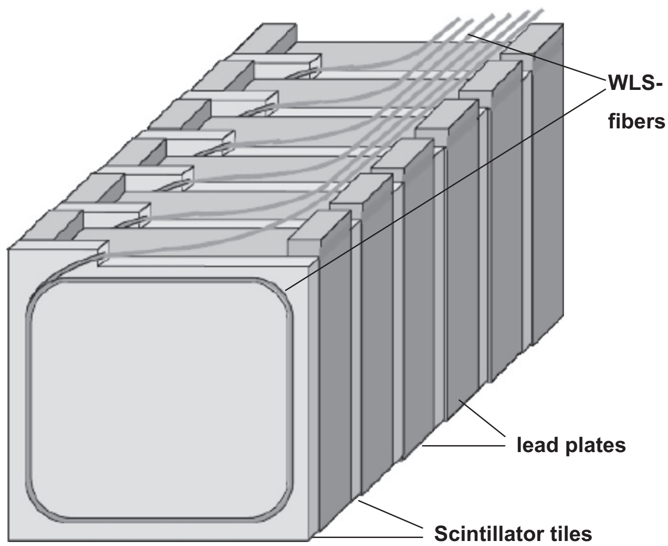

Fig. 1. Schematic view of scintillator light readout with WLS-fibers in calorimeter module.

10^4 photoelectrons and must be kept for larger amplitudes. Improved versions of MAPD with pixel density $4 \times 10^4/\text{mm}^2$, produced by Zecotek Photonics Inc. (Singapore) will be used for the readout of full calorimeter.

4. Beam test of super-module

Nine calorimeter modules were developed and assembled at INR in 2007. A first beam test of the PSD super-module (3×3 array) was performed at a hadron beam at SPS, CERN. The calibration of each readout channel was done with a muon beam. To obtain the full set of the calibration coefficients, the muon beam scan was performed for all 9 modules. After that the central module of the calorimeter was irradiated by a pion beam with 5 energies from 20 to 158 GeV. Pion beam at low energies contain significant fractions of muons and positrons. The spectrum of deposited energy in first section of central module for 30 GeV beam is shown in Fig. 2. The right peak in the spectrum corresponds to full positron energy absorption in first longitudinal section that might be regarded as an electromagnetic calorimeter with rough sampling.

The dependence of obtained energy resolution on beam energy is shown in Fig. 3. The fit of 5 experimental points provides a stochastic term of about 55% and a constant one of 3.6%. The calorimeter prototype with $30 \times 30\,\text{cm}^2$ front size is relatively too small to contain the entire hadron shower and non-negligible lateral shower leakage is expected. MC simulation confirms that about 16% of hadron shower escapes from the PSD super-module. The influence of shower leakage on energy resolution was considered in Refs. [5,6] where a third term together with the stochastic and constant ones in the parameterization of resolution is added. The fit of the experimental points with the three terms formula (Fig. 3) gives a stochastic term of 53.5% and a constant term of 1.9% at fixed leakage term of 16%. A non-zero constant term might indicate that selected lead/scintillator sampling does not provide full compensation. To avoid the influence of lateral shower leakage a larger calorimeter prototype of 25 modules is planed to be constructed.

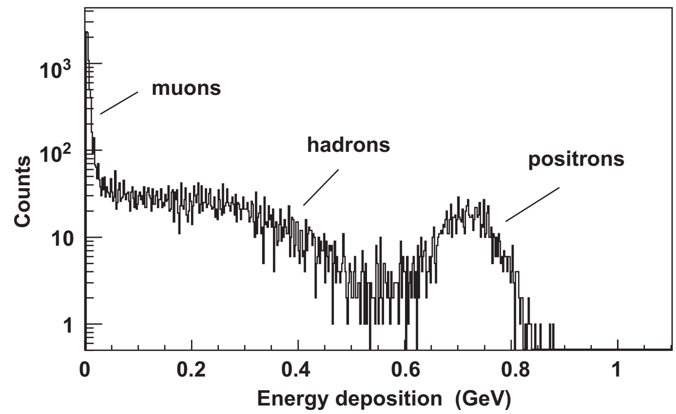

Fig. 2. Spectrum of energy depositions in first section of central module from 30 GeV pion beam that contains the fractions of muons and positrons.

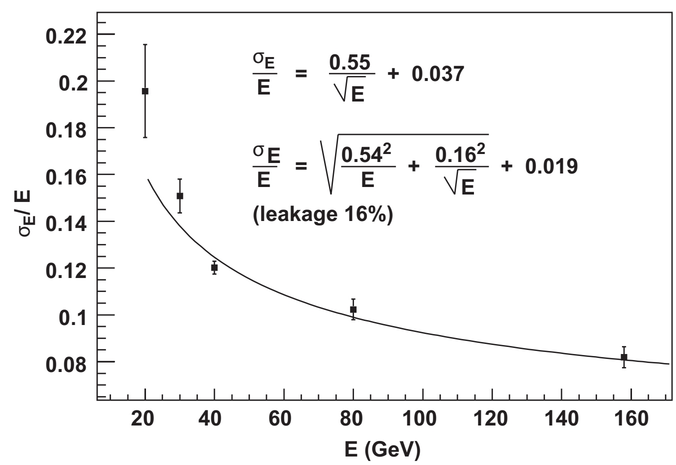

Fig. 3. Dependence of calorimeter prototype energy resolution on beam energy. Upper expression is the parameterization of experimental points with two-term formula. Down expression and solid line—third (leakage) term is added.

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