Forward hadron calorimeter for measurements of projectile spectators in heavy-ion experiment

M. Golubeva,[1,*] F. Guber,[1,**] A. Ivashkin,[1,***] A. Kurepin,[1,****]
V. Marin,[1,*****] A. Sadovsky,[1,******] and O. Petukhov[1,*******]

[1] *Institute for Nuclear research RAS, Moscow, Russia*

The construction and performance of a modular hadron calorimeter for NA61 experiment at CERN is described. The calorimeter consists of 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 grooves. The light readout is done by avalanche micro-pixel photodiodes. The construction ensures a fine transverse granulation of the calorimeter and a longitudinal segmentation of each module in 10 independent sections. The results of beam tests of the calorimeter prototype are presented.

1. INTRODUCTION

NA61/SHINE heavy ion experiment at CERN [1] is focused on the search for the critical point of strongly interacting matter and possible deconfinement. A crucial goal of NA61 experimental program is the study of event-by-event fluctuations as the function of the collision energy and the size of colliding nuclei. The experimental extraction of the critical fluctuations requires a very precise control of the fluctuations caused by the variation of the number of interacting nucleons due to changes in the collision geometry. The number of

* Electronic address: marina@inr.ru
** Electronic address: guber@inr.ru
*** Electronic address: ivashkin@inr.ru
**** Electronic address: kurepin@inr.ru
***** Electronic address: marin@inr.ru
****** Electronic address: sadovsky@inr.ru
******* Electronic address: opetukhov@inr.ru

non-interacting nucleons or spectators is measured by a very forward hadron calorimeter, the Projectile Spectator Detector (PSD). Main requirement to PSD is a good energy resolution $\frac{\sigma_E}{E} < \frac{60\%}{\sqrt{E(\mathrm{GeV})}}$ and nice transverse uniformity of this resolution. Full compensating modular lead/scintillator hadron calorimeters [2, 3] meet the above requirements.

2. CALORIMETER DESIGN AND READOUT

The PSD calorimeter consists of 44 individual modules and covers the square of 120×120 cm^2. The distance between the target and PSD is varying between 17 m and 25 m depending on the beam energy and, respectively, the dimensions of the spectator spot. The central part of PSD consists of 16 small modules with the transverse sizes 10×10 cm^2 each, while 28 modules of outer calorimeter part have two times larger sizes 20×20 cm^2.

Each PSD module consists of 60 lead/scintillator layers with 16 mm 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 one 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.

Longitudinal segmentation of calorimeter modules requires 10 individual photodetectors per module for the signal readout. Micro-pixel avalanche photodiodes, MAPDs [4] are an optimum choice due to their remarkable properties such as high internal gain, compactness, low cost, and immunity to the nuclear counter effect. MAPDs with active area 3×3 mm^2, gain $\approx 5 \times 10^4$, and pixel density 10^4/mm^2 were selected. These MAPDs with individual micro-wells are produced by Zecotek Photonics Inc. (Singapore) [5]. 10 MAPDs per module are placed at the rear side of the module together with the front-end-electronics. The MAPD photon detection efficiency of 20% for green light is similar to PMT performance. The linearity of MAPD response was checked up to 10^4 photoelectrons and is kept for larger amplitudes.

3. BEAM TEST OF PSD CALORIMETER

At present, the central part of the PSD calorimeter is assembled at NA61 experimental area and includes 22 modules. Full construction of the detector will be finished in the beginning of 2011. To check the performance of the calorimeter a few beam tests at different hadron energies were performed. For this purpose the PSD module array of nine small modules (3×3 array) was assembled. The first beam test for high energies was done at NA61 hadron beam at SPS, CERN, while the second one at low energies was carried out at beam line T10 of proton synchrotron, CERN. In both tests 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 and for 10 longitudinal sections in each module. As a result, the set of 90 calibration coefficients was obtained. To estimate the energy resolution of PSD the central module of tested array was irradiated by a pion beam. The hadron energies at SPS test varied from 20 GeV to 158 GeV, while at T10 PS line the low energy scan from 1 GeV to 6 GeV was done. SPS 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 the first longitudinal section that might be regarded as an electromagnetic calorimeter with rough sampling. The energy resolution for positrons at 30 GeV is about 6.5%.

The dependence of obtained energy resolution on the pion energy is shown in Fig. 3. The calorimeter prototype with 30×30 cm^2 front size is relatively too small to contain the entire hadron shower. Therefore, non-negligible lateral shower leakage is expected. MC simulation confirms that about 16% of hadron shower escapes from the calorimeter array. The influence of shower leakage on energy resolution was considered in [6, 7], 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 three terms formula (Fig. 3) gives the coefficient of the stochastic term equals to 56.1%, of the constant term 2.1% at the 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 the beam test of calorimeter with larger size will be done soon. The described concept of PSD calorimeter might be used in other heavy ion experiments as NICA (Dubna, Russia) and CBM (Darmstadt, Germany).

ACKNOWLEDGMENTS

Authors thank all members NA61/SHINE collaboration for fruitful discussions and permanent attention. This work was supported by the Russian Academy of Sciences and by the Russian Foundation for Basic Research (grant 09-02-00664).

1. The NA61/SHINE homepage http://na61.web.cern.ch.
2. G. A. Alekseev *et al.*, Nucl. Instr. Meth. A **461**, 381 (2001).
3. Y. Fujii, Nucl. Instr. Meth. A **453**, 237 (2000).
4. Z. Sadygov *et al.*, Nucl. Instr. Meth. A **567**, 70 (2006).
5. The Zecotek homepage http://zecotek.com.
6. D. Acosta *et al.*, Nucl. Instr. Meth. A **308**, 481 (1991).
7. J. Badier *et al.*, Nucl. Instr. Meth. A **337**, 326 (1994).

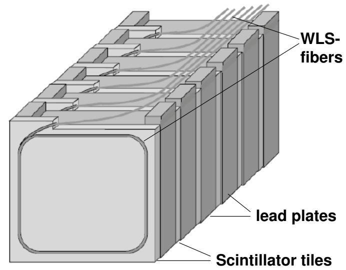

Figure 1. Schematic view of calorimeter module with WLS-fibers light readout.

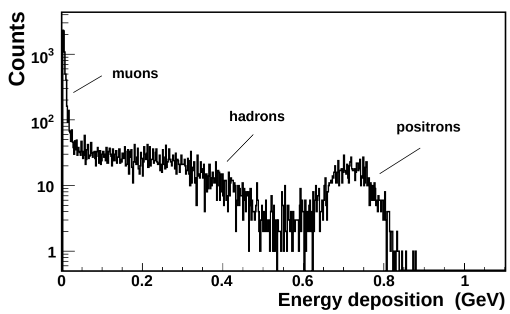

Figure 2. Spectrum of energy deposition in first section of central module for 30 GeV pion beam containing the fractions of muons and positrons.

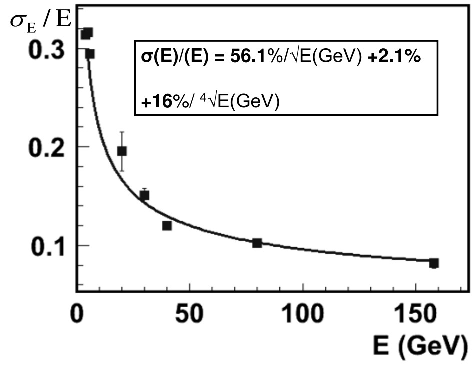

Figure 3. Dependence of PSD calorimeter energy resolution on beam energy. The solid line is the fit of experimental points by the function shown in the insertion.

FIGURE CAPTIONS

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

Fig. 2: Spectrum of energy deposition in first section of central module for 30 GeV pion beam containing the fractions of muons and positrons.

Fig. 3: Dependence of PSD calorimeter energy resolution on beam energy. The solid line is the fit of experimental points by the function shown in the insertion.