Beam Test of the Neutron Detectors with the Prototype of the CMS Very Forward Calorimeter

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Introduction

We present the description and preliminary results of the neutron measurements performed during the August 1998 test run on the H4 beam line of the CMS test beam [1]. We have tested the neutron detectors, planned for use in the real CMS environment [2], and measured the neutron yields as a function of longitudinal and transverse coordinate. The data were taken in the negative pion beam with the energies 100 and 325 GeV. We compare our data to the predictions made with MARS'96 software. The preliminary results of this comparison are also presented.

1. Beam line and experimental setup

The described measurements have been performed during the August 1998 run on the H4 beam line of the CMS test beam. The layout of the experiment is shown in Fig. 1 (left). The copper prototype of very forward calorimeter — HAD95 [3] (total dimensions $330\,x\,330\,x\,1350$ mm^3), installed on the concrete block ($400\,x\,800\,x\,1800$ mm^3), served as a source of neutrons.

The scintillation telescope consisting of 6 scintillation counters ($S1-S6$) of various size (ranging from $2\,x\,2$ cm^2 to $5\,x\,5$ cm^2) was located in front of the calorimeter. The beam monitoring system also included scintillation hodoscope HX, HY (total dimensions $10\,x\,10$ cm^2, the cell size $1\,x\,1$ cm^2) and high spatial resolution drift chambers.

The measurements have been performed with two neutron detectors (noted as $N1$ and $N2$ in Fig. 1 (left), while the third detector ($N3$) was used to monitor the stability of the neutron background in the experimental hall. The data were taken in a negative pion beam (10^3 – 10^4 particles per 2.6 *sec* accelerator burst with a period of 14 *sec*) at the pion energy of 325 GeV and 100 GeV.

2. Detectors

The neutrons were detected by the sensors of thermal neutrons with the polyethylene moderators of the various size and shape as well as by the sensors without moderators.
We used the neutron counters of the SNM-14 type. The neutron detection is based on the reaction ^{10}B$(n,\alpha)^7$Li (the total cross section is 3837 *barn* at the neutron energy 0.025 eV). The sensor itself is a proportional counter (steel cylinder) filled with argon at the atmospheric pressure. The internal surface of the cylinder has a thin layer of boron-10.

Detectors D1 and D2 (with 10" and 6" moderators) were calibrated with Pu-Be source of neutrons [4]. The resulting calibration factors (integrated over the spectrum of the neutron source) are 0.69±0.03(4%) cm^2 and 0.8±0.04(5%) cm^2 for the detectors D1 and D2 correspondingly. The numbers in brackets represent the systematic error of the calibration measurements.

The response functions for the detectors were evaluated by the Monte Carlo based program MOSKIT [5] with sets of constants SADCO (neutron energy $E_n < 18$ MeV) and USCONS ($E_{n,\pi,p} >$ 18 MeV) [6]. The neutron source was described as a wide parallel neutron beam in the energy range from $2.53 \cdot 10^{-8}$ to 10^2 MeV. The scale factors were calculated separately for the detectors D1 and D2. The difference between these factors was found to be 3.1%, which is within uncertainties of the calibration measurements. The resulting response functions for detectors with 10", 6" and 2" moderators are shown in Fig. 1 (right).

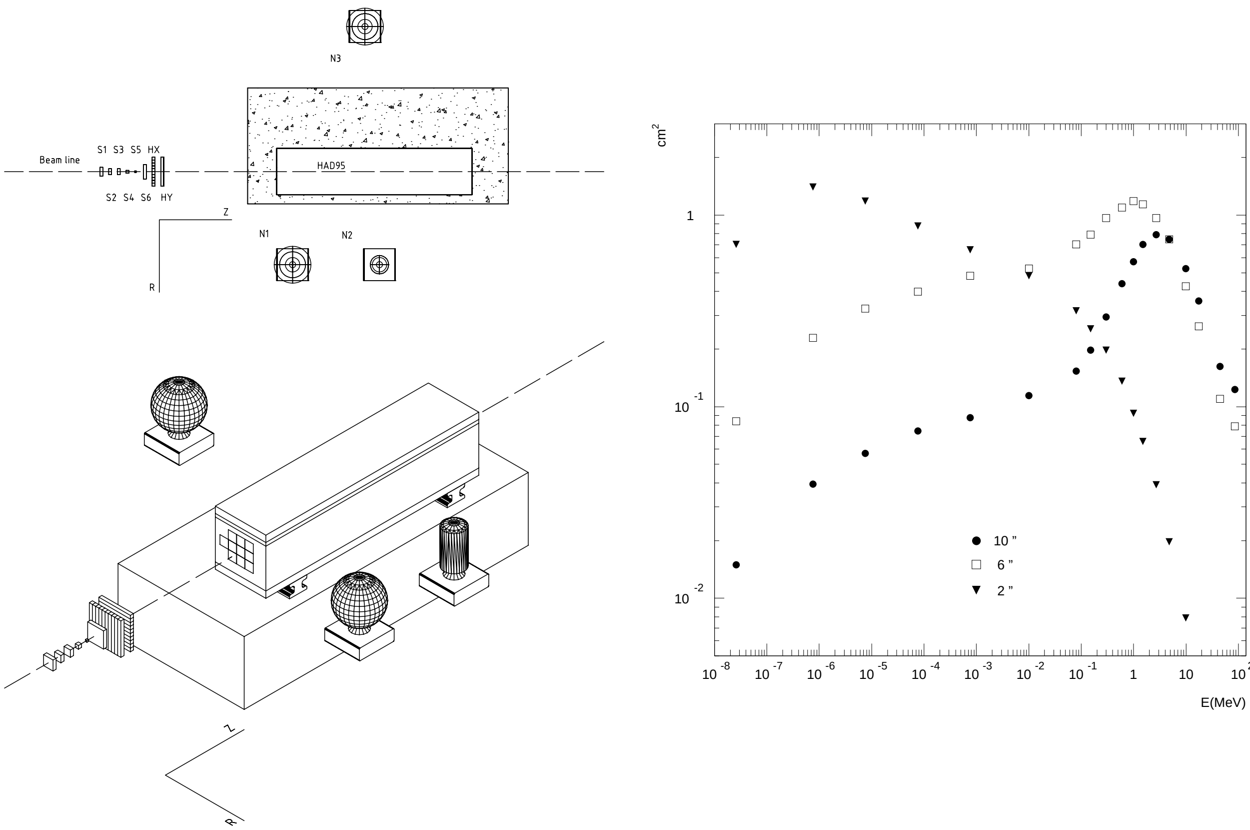

Figure 1: The layout of the experiment (left); Response functions for the detectors with 10", 6" and 2" moderators (right).

3. Measurements and data processing

We studied a longitudinal development of the neutron cascade, as well as attenuation of the neutron yields in the transverse direction. The data were taken with two neutron detectors simultaneously. The detectors were placed at the distance of at least 50 cm, in order to reduce interference between moderators. The coordinates of the detectors were measured from the longitudinal axis of the calorimeter (R-transverse coordinate) and from the front side of the calorimeter along the beam line (z-longitudinal coordinate).

The neutron information (as well as the beam intensity) was read out from the corresponding detectors once per accelerator burst. Under these circumstances, the neutrons can be produced by any beam particle intercepting the cross section of the calorimeter. This fact increases uncertainty in the beam definition since the largest beam detector available had dimensions of 5x5 cm^2. Therefore, the close attention has been paid to the monitoring of the stability of the geometrical position of the beam and its transverse size during the data taking.

The contribution of the detectors' own noise was estimated using the data from the empty accelerator bursts. An average value of the noise in the beam scintillation counters did not exceed the value of 4% of the total count rate in the given detector.

The muon contribution to the beam was estimated from the shape of the signal in the towers of the calorimeter. The beam particles, which were not producing hadronic/electromagnetic shower in the calorimeter, were considered to be muons. The upper estimate of the muon contamination, obtained in such a way, appeared to be 1% for 325 GeV beam and 3% for the beam energy of 100 GeV for the central part of the beam (>95% of the beam intensity).

4. Preliminary results

As it was mentioned before, the main goals of these studies include (1) experimental measurements of the fluence of neutrons, and (2) comparison of the experimental results with the Monte Carlo predictions, made with software used for the simulation of the real CMS environment. While the detailed analysis of the data is still in progress, we can present the first preliminary results comparing the measurements to the Monte Carlo calculations made with the MARS'96 code [7, 8].

The neutron spectra were calculated for each point of measurements with the geometry and beam parameters described above. The available set of detectors is insufficient for restoring the neutron spectrum. However, we can reverse the task, calculating the expected count rates for detectors with different polyethylene moderators and comparing them with the experimental values, thus probing the different parts of the neutron spectrum. By definition, the count rate $N(z, R)$ for a given combination detector-moderator at the measurement point (z, R) is a result of convolution of the calculated neutron spectrum $\frac{dn}{dE}(z, R)$ with the corresponding normalized response function $f(E)$ (see Fig. 1 (right)):

$$N(z, R) = \int_0^\infty \frac{dn}{dE}(z, R) f(E) dE,$$

where the actual limits of integration are defined by the hardness of the neutron spectrum and behavior of the response function.

We have also calculated the neutron fluence at the points of measurements. For this purpose, we used the results obtained with the detector D2 (6" cylindrical moderator), since its response function is the closest to a constant among the available ones. Therefore, these data are relatively less dependent on the shape of the initial neutron spectrum.

In order to obtain the neutron fluence, we corrected the measured count rate $N(z, R)$ by a factor $\varepsilon(z, R)$ calculated from the MARS neutron spectra as

$$\varepsilon(z, R) = \frac{\int_0^\infty \frac{dn}{dE}(z, R) \cdot f(E) dE}{\int_{E_{min}}^{E_{max}} \frac{dn}{dE}(z, R) dE}.$$

The values of $\varepsilon(z, R)$ are on average 20% higher than a factor obtained from the calibration with $Pu - Be$ source of neutrons. We attribute this increase to a difference between the spectrum of $Pu - Be$ source and that of the neutrons induced by the 100 and 325 GeV pions, as well as to the wider neutron energy range in case of the neutrons induced by the pion beam. The predicted values of the neutron fluence are obtained by integrating of the MARS calculated neutron spectrum up to the energy 15 MeV (the effective energy limit for the detector D2).

The resulting plots are shown in Fig. 2 (left and right). We can point out a good agreement of the calculated and measured values of the fluence of neutrons. The difference is within 20% for the longitudinal dependence and within 40% for the transverse dependence.

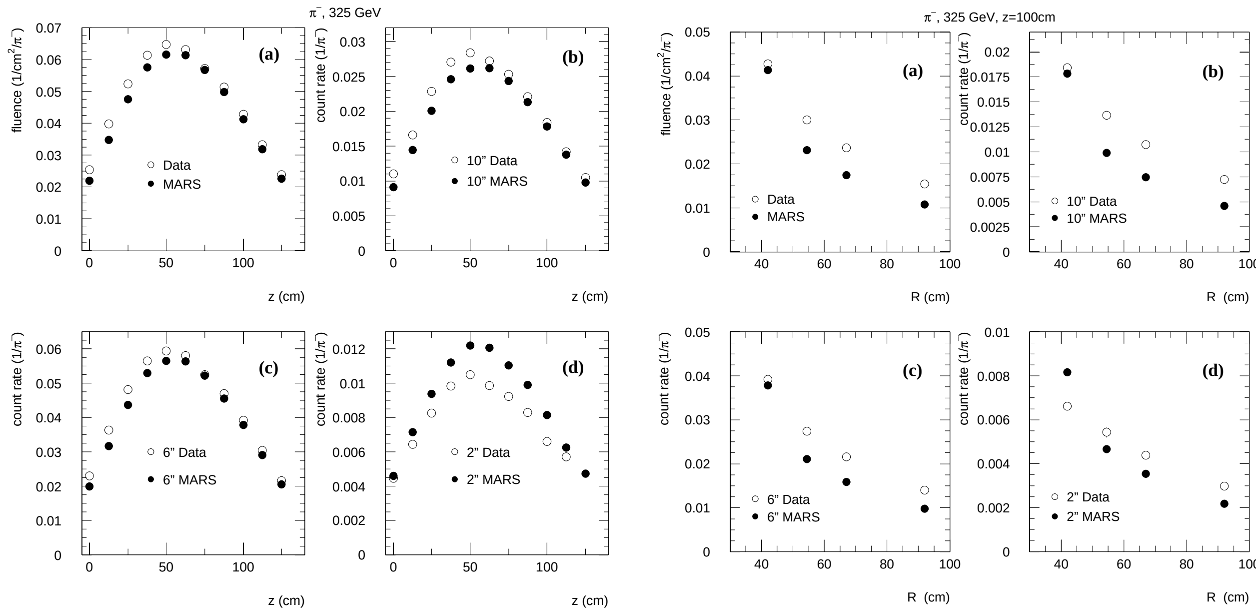

Figure 2: Longitudinal dependence of the fluence of neutrons (a) and count rates for detectors with different moderators (b-d) at the beam energy 325 GeV (left); Transverse dependence of the fluence of neutrons (a) and count rate per beam particle for detectors with different moderators (b-d) at the beam energy 325 GeV and longitudinal coordinate $z = 100\ cm$ (right).

Conclusions

We have tested the neutron detectors, which will be used for radiation monitoring in the vicinity of the very forward calorimeter during the CMS operation. The tests were performed in the conditions close to the ones expected in the real CMS environment (as regards the energy and composition of the secondary particles). For the first time, the results of measurements of neutrons induced by the high energy pions are directly compared with the Monte Carlo predictions. The preliminary analysis shows that MARS'96 reproduces within 20% the longitudinal dependence and within 40% the transverse dependence of the experimental neutron yield.

References

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