Event Spectra from Neutron Background in the ME1/1 Chamber on the CMS

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Introduction

The ME1/1 muon chambers on the CMS experiment at LHC are awaited to operate in the conditions of very high neutron background ($\sim 10^{12}$ cm^{-2} ten year fluence) [1]. These neutrons produce large number of charged secondaries in the chamber volume to be discriminated from muons. The problem of background discrimination is supposed to be decided by using six sensitive planes of the chamber working in coincidence. The main part of background charged particles will be rejected by this method resulting, however, to some decrease of the chamber efficiency.
The other problem of neutron background is associated with the relatively rare high local ionization events in the sensitive volumes which may cause the following negative effects:

- decrease of the chamber efficiency due to the long dead time and recovery time;
- transition of the chamber to the streamer or spark regime with possible burn out of the readout electronics or destruction of the anode wires [2].

To estimate the chamber efficiency, its tolerance to the background radiation and possible ways to protect the readout channels, event spectra from the neutron background are to be known.

The initial spectra of heavy charged particles produced by neutrons in the chamber gas were calculated in [3]. It was shown that the main contribution give He, C and O ions from elastic and inelastic neutron collisions with carbon and oxygen nuclei. The maximum energy deposition per wire for such events was estimated as 20 MeV approximately that is 4 orders of magnitude higher compared to high-energy muons (few keV).

The final results are given in a scale of ionization energy deposition per wire proportional to the number of initial ion pairs liberated in a sensitive volume.
The event spectra presented in this paper include energy depositions from secondary charged particles heavier than pion.

1. Model of calculation

1.1. Geometry

The ME1/1 chamber [1] consists of the six 7 mm thick gas sensitive planes with a gas composition of (50% CO_2 – 40% Ar – 10% CF_4) by volume and 0.0021 g/cm^2 density. Each plane contains 600 anode wires 50 cm long, on an average, positioned in 2.5 mm from each other. It may be considered as a set of 600 sensitive volumes with average dimensions of 0.25x0.7x50 cm^3. The chamber walls are made from G10 0.8 mm thick laminated by 18 μm Cu layer (cathode). Anode wires are made from tungsten $\oslash$ 30 μm coated by gold (5% of the total wire mass). The walls of neighbourhood sensitive planes are separated by 1.44 cm thick honeycomb structure made from G10 as well.

Calculations were made in an approach of isotropic irradiation of the chamber gas, walls and environment by the neutron spectrum calculated by MARS [4] for the conditions of full LHC luminosity (10^{34} Hz/cm^2). The neutron energy distribution at the centre of chamber is shown in Fig. 1. The high-energy cascade peak of the neutron spectrum is much more important as a source of secondary heavy charged particles which may be divided into the following main groups:

- high-energy protons and pions produced mainly in the chamber walls and environment;
- elastic and inelastic recoils from neutron interactions with gas nuclei;
- light complex particles (d, t, ^{3}He, α);
- fission fragments emitted from wires.

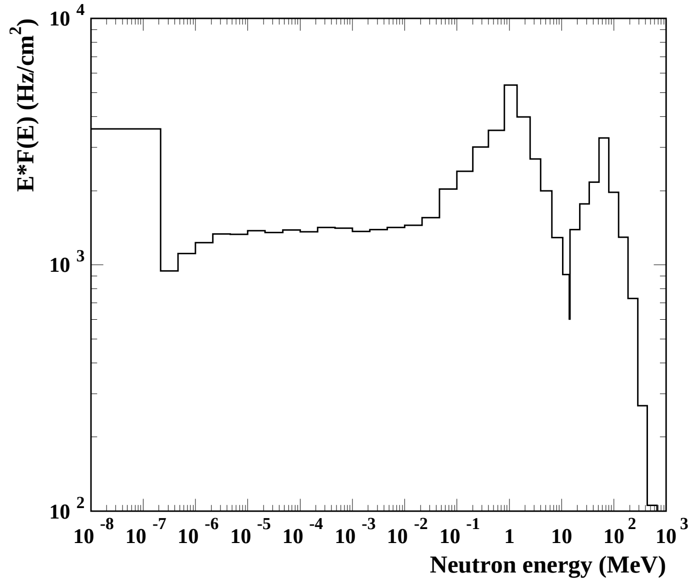

Figure 1: Neutron energy spectrum in the ME1/1 chamber slot.

It should be noted that considerable part of charged particles is produced in inelastic collisions with multiple charged particle emission. The most important of them are ^{12}C$(n,n')3\alpha$ and ^{16}O$(n,n')4\alpha$ with high enough cross sections in the neutron energy range of interest. Another important channel providing extremely high local ionizations is fission events in the anode wires.

1.2. Generation of charged particles

Calculations were made using the high-energy transport code HADRON [5] based on the cascade-exciton model of nuclear reactions. Its essential distinction from widely used high-energy codes is more accurate physics of nucleon-induced reactions below 100 MeV. Cascade stage of a nuclear reaction is calculated taking into account refraction of particles by the mean-field nuclear potential. The process of nucleus deexcitation after the cascade stage is considered in frame of preequilibrium exciton model including an equilibrium approach as a final stage. Inelastic collisions with chamber nuclei were simulated by HADRON at all neutron energies above the thresholds. The total inelastic and elastic cross sections above 20 MeV are calculated in HADRON using parametrisation [6]. For simulation of elastic scattering at $E_n > 20$ MeV, the modified Ranft formula [7], adjusted to experimental data for light nuclei, is used. The total cross sections and elastic recoil energy spectra for low-energy neutrons were generated from the ENDF/B-VI library [8].

For description of fission process, we have used a simple semi-empirical model based mainly on the experimental and theoretical proton fission data from [9]. The effective fission cross sections for our neutron spectrum above the fission threshold ($\sim$100 MeV) have been estimated as 22 mb for ^{197}Au and 1.2 mb for ^{184}W.

2. Results and discussion

Particle transport is simulated in HADRON in frame of the well-known step method in which particle trajectory is divided into small segments to take into account such physical processes as multiple scattering, energy loss straggling etc. Charged particle deviation in a magnetic field is easily calculated as well in this approach. Magnetic field with a flux density of 3 T was taken to be normally directed to the chamber planes.

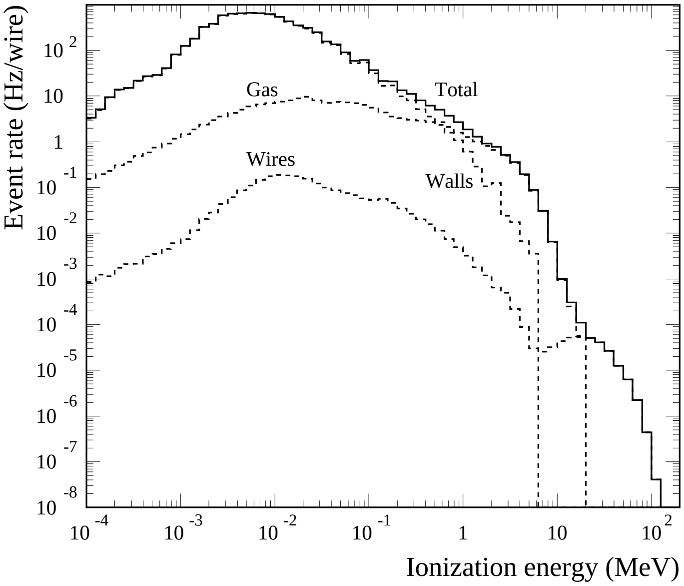

Figure 2: Total event spectrum and its components at the center of chamber.

The scoring procedure included calculation of total ionization energy deposited by all secondary charged particles from each neutron collision in different sensitive volumes. The term "ionization energy" means that only ionising part of the total stopping power included in energy deposition.

The total event spectrum and contributions of walls (including environment), gas and wires are presented in Fig. 2. The scale of ionization energy can be easily transformed into the scale of ion pairs number using the value of $W = 25$ eV per ion pair accepted for the ME1/1 gas. The main part of events is produced by high-energy long-range protons and pions emitted from the chamber walls. This component peaking at some keV is important for the problems of background discrimination and chamber efficiency. As regards to high ionizations, the region of 1–20 MeV is defined by charged particles from gas nuclei.

The event spectrum from wires above 10 MeV, where this component is essential, is fully defined by the fission channel. These high ionization events are created mainly by fission fragments emitted from the gold layer. The tungsten contribution above 10 MeV is less than 10% due to much lower fission cross section and absorption of short-range fission fragments in wires.

The expected uncertainties of the calculated total event spectrum are defined as follows. Assuming the above considerations, the spectrum region below 20 MeV originates mainly from elastic and inelastic interactions of high-energy neutrons (cascade peak of the neutron spectrum). The accuracy of HADRON calculations is estimated in this case as better than 50% for all important components of the event spectrum. Above ionization energy of 20 MeV, where only fission channel contributes to the total spectrum, possible systematical error reach up a factor of 2–3. The main source of this uncertainty is due to the use of proton fission cross sections instead of neutron ones.

In Table 1, the integral event numbers for planning ten years of work (assuming 180 working days per year) is shown for reader convenience. In this presentation, each bin gives the total rate of events above the corresponding ionization energy E_{ion}. In the same Table, the integral event rates for the whole chamber, including 3600 wires in 6 planes, are given. These results clearly indicate that even highest possible ionization energy events with E_{ion} >100 MeV can not be neglected since the most part of wires (or readout channels) may be destroyed due to such events during the working time of the ME1/1 chamber.

Table 1: Integral event numbers above the ionization energies E_{ion}.

E_{ion}(MeV)	10^{-4}	10^{-2}	0.1	1	10	100
$N^{>E_{ion}}$(event/wire)	$2.70 \cdot 10^{11}$	$9.07 \cdot 10^{10}$	$4.87 \cdot 10^{9}$	$2.17 \cdot 10^{8}$	$5.51 \cdot 10^{4}$	$1.45 \cdot 10^{0}$
$N_{tot}^{>E_{ion}}$(event)	$1.07 \cdot 10^{15}$	$3.59 \cdot 10^{14}$	$1.93 \cdot 10^{13}$	$8.61 \cdot 10^{11}$	$2.18 \cdot 10^{8}$	$5.75 \cdot 10^{3}$

3. Summary and conclusions

The calculated total ionization event spectrum shows that the main part of events is produced by high-energy protons and pions emitted from the chamber walls. The total event rate is equal to 1740 Hz/wire. This value should be compared with the muon and electron backgrounds for which only fluence rates were calculated [4]. In case of muons, this estimate can be made in an assumption of normal exposure of the chamber planes that is enough realistic. Each muon hits in this situation only one wire providing the scaling factor from fluence rate to event rate equal to the square of sensitive volume: 0.25x50 cm^2 = 12.5 (Hz/wire)/(Hz/cm^2).

In case of the main background charged particles – electrons – this scaling can not be easily obtained due to their wide spectrum, isotropic source and strong influence of the magnetic field, that requires to perform additional calculations. One more factor to be taken into account in the analysis of the chamber efficiency and of the relative contributions of different background components is the dead time and recovery time roughly proportional to the pulse amplitude. This factor will strongly enhance the relative importance of heavy charged particles compared to light ones (e, μ).

The problem of high ionization events and of their influence to the readout channels requires to perform experimental studies. In our calculations, we did not consider some physical effects which may strongly decrease the effective charge collected on wires in case of high local ionizations. As was stated above, the calculated event spectrum is nearly fully produced by the cascade peak of the neutron spectrum. Its shape is enough representative and can be easily simulated outside shields irradiated by high-energy hadrons above a few hundreds of MeV.

If the problem will be found to be important, the methods of the chamber protection and the ways of background decrease are to be considered. One possible way of strong suppression of very high fission ionization events is seen from our results. It consists in the substitution of the gold wire coating by lighter metal if this is possible from performance requirements.

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