RPC sensitivity to low energy neutrons and γ rays:preliminary results

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Abstract: A double gap Bakelite Resistive Plate Chamber (RPC) with common readout has been exposed to the radiation emitted from a ^{252}Cf source to measure its neutron and γ sensitivity. RPC signals were triggered by fission events detected using BaF_2 scintillators. A GEANT 3.21 Monte Carlo code with MICAP interface estimated the γ and neutron contributions to the total number of collected RPC signals. A neutron sensitivity $s_n = 0.46 \times 10^{-3}$ at ≈ 2 MeV and a γ sensitivity $s_\gamma = 12.6 \times 10^{-3}$ at ≈ 1.5 MeV have been measured for the double gap configuration.

1. Introduction and experimental setup

Bakelite Resistive Plate Chambers (RPCs) are part of the CMS muon sub-detector for the experimentation at the Large Hadron Collider (LHC). Our collaboration has investgated several properties of any of their components, as well as several features of their behavior[1].

They are expected to operate in a hostile environment made of neutrons and γ rays. To evaluate the effect of these background radiations on the detector functionality, we present measurements of γ and neutron RPC sensitivities using the spontaneous fission events from a ^{252}Cf source emitting low energy γ rays (mostly below 1 MeV) and neutrons (mean energy of about 2 MeV).

Fig. 1a shows a schematic of the the experimental setup. A double gap RPC was placed 30 cm from a ^{252}Cf source. The ^{252}Cf fission events were counted by detecting the source prompt γ rays with two BaF_2 scintillators (chosen for their fast response of ≈ 1

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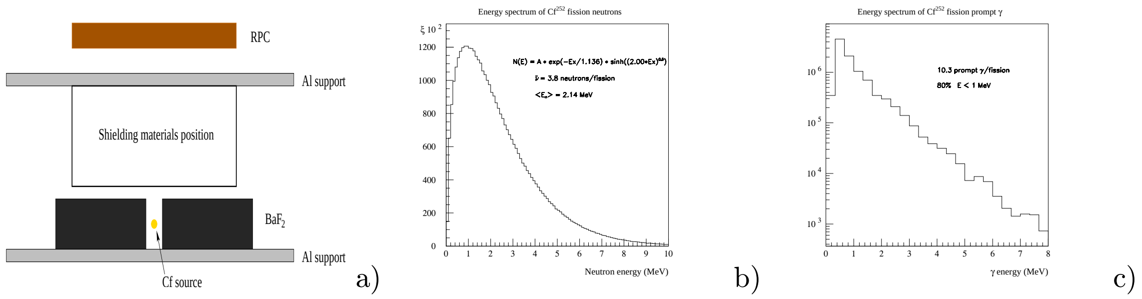


Figure 1: a- Experimental setup; b- prompt neutron energy spectrum; c- prompt γ energy spectrum.

ns). Lead and polyethylene slabs were used to modulate the γ and neutrons fluxes. The detector is an RPC made of two single gaps with central common readout strips. Only one gap underwent the traditional surface treatment of the internal electrodes with linseed oil. The detector active area was 35×35 cm^2. The used gas mixture was 97% $C_2H_2F_4$ and 3% i-C_4H_{10}. The bakelite volume resistivity was 4×10^{10} Ωcm at room temperature. The detector was equipped with the CMS 16- channel front-end board (FEB) containing two 8 channels chips. The chip charge sensitivity 2 mV fC^{-1}. Data were taken at two different front end input thresholds, i.e.: 130 mV and 230 mV.

The ^{252}Cf source has both a prolific isotropic neutron emission rate (2.34×10^{12} s^{-1} g^{-1}) and an important γ emission rate ($6.41 \times 10^{12}\gamma$ s^{-1} g^{-1}). Both radiations have a prompt and a delayed component. The source activity (23.8 μ Ci), corresponds to a fission rate $r = 2.6 \times 10^4$ s^{-1}. On average, each fission emits about 3.8 prompt neutrons and 10.3 prompt γ rays. Fig.s 3b,c show their energy spectra, taken from the literature [2][3][4]. The neutron spectrum (fig. 1b) is well described by the Watt model[2]b-d: it shows a peak at ≈ 0.7 MeV and an average energy $E_n^{av} \approx 2.14$ MeV. To our knowledge there is no model for the prompt γ spectrum (fig. 1c); the total energy carried by each prompt γ is ≈ 8.2 MeV per fission.

All prompt neutrons are emitted in less than 10^{-12} s; all prompt γ rays in less than 10^{-9} s. The delayed γ rays represent only the 6% of the prompt radiation and are emitted after few hundred ns. Delayed neutrons are about 1% and their emission time might reach seconds.

2. Data taking and experimental results

Several setup conditions were possible: switch on only one gap; both gaps switched; change the front-end chip threshold for any of the previous selections.

The signal from the OR of 16 strips was taken as the RPC response. The RPC was considered efficient to a fission event when a detector signal appeared in coincidence with the trigger signal from the BaF_2 scintillators. The coincidence gate was 50 ns wide. The trigger rate was very low (about 3 kHz), so there was no pile-up problem for two consecutive triggers.

Accidental coincidences between trigger and RPC signal, due to the detector noise, have been taken into account and properly subtracted from the measured coincidence rates.

The direct experimental result is a measurement of the probability to see the ^{252}Cf spontaneous fission event with the RPC detector. The events were counted in coincidence with a trigger signal inside a 50 ns time window, thus only the prompt radiations contribute to the measured rates. As shielding materials lead and polyethylene (PE) slabs of different thickness were used to isolate neutron and γ components. Lead attenuates γ rays and leaves the neutron component almost unchanged. The PE slab has an important effect both on the number of neutrons reaching the RPC surface and on the neutron energy spectrum. Due to the neutron interactions in the shielding material, the production of a secondary γ component must be taken into account, mainly in presence of PE.

Fig. 2a shows the 4 shielding setups corresponding to different number of *equivalent interaction lengths* X_{eq} defined as:

$$X_{eq} = \frac{\mathrm{X}_{Pb}}{\lambda^*_{Pb}} + \frac{\mathrm{X}_{PE}}{\lambda^*_{PE}} \tag{2.1}$$

where X_{Pb} and X_{PE} are the lead and polyethilene thickness respectively while λ^*_{Pb} and λ^*_{PE} are the corresponding neutron effective interaction lenghts, which account for the shielding configuration effect on the neutron attenuation.

Fig. 2b shows the probability to see a fission event as a function of X_{eq}. Secondary γ rays are not separated here. As easily expected, the sensitivity doesn't depend upon the surface treatment.

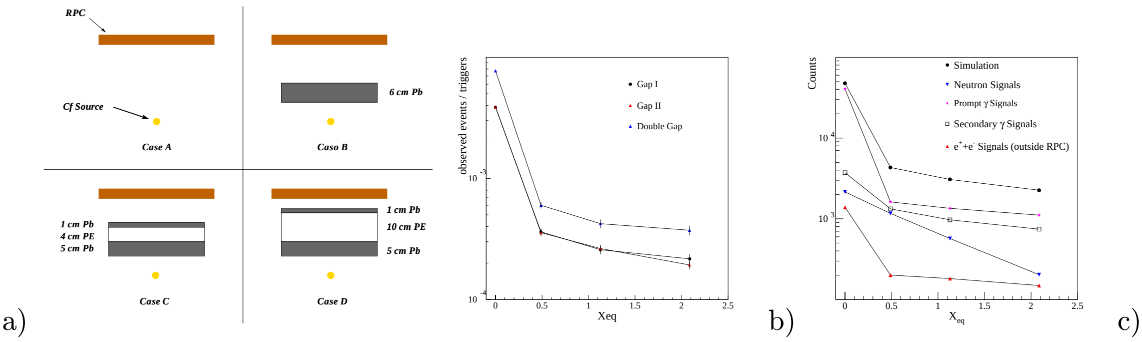


Figure 2: a- sketch of 4 shielding setups: Case A (top left): no shielding material between source and detector. $X_{eq} = 0$; Case B (top right): 6 cm Pb $X_{eq} \approx 0.5$; Case C (bottom left): 5 cm Pb+4 cm PE+1 cm Pb. $X_{eq} \approx 1.1$; Case D (bottom right): 5 cm Pb+10 cm PE+1 cm Pb. $X_{eq} \approx 2.1$ (the biggest lead shield always placed nearest to the Cf source); b- probability of fission detection for the double gap (top triangular points) and the single gap configurations (bottom points); c- relative contributions of the different components to simulated fissions; total rate: black squares; prompt γ: stars; secondary γ: open squares; neutrons: downwards triangles. The bottom data (upwards triangles) show the contributions of secondary electrons from any γ conversion.

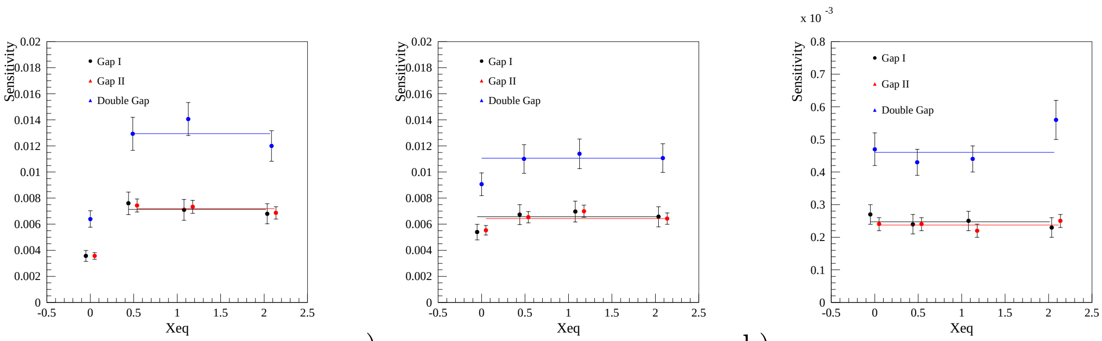
A significant drop in fig. 2b is visible moving from case A to case B. This is mainly due to the prompt γ attenuation of the first 6 cm of lead. Cases C and D, show a minor decrease, due to neutron attenuation in PE, only partially compensated by secondary γ emission.

3. Simulations

In order to separate the prompt neutron and γ components, the setups shown in fig. 2a were simulated using the GEANT 3.21 code with MICAP interface to describe low energy neutron interactions; simulation of all materials surrounding both the RPC and the source is necessary to evaluate the effects of secondary interactions, i.e.: neutron scattering, radiative captures and other inelastic processes. The energy spectra shown in fig. 2a were used in the simulation. Each fission event was simulated by the emission of four neutrons followed by 10 γs. Isotropic emission has been assumed for both neutrons and γ rays. The effect of the 50 ns trigger window was accounted for by using the particles time of flight from the generation to the interaction in the RPC gas gap. For secondary particle production, the time of flight is calculated starting from the primary particle generation. The 3 components: neutrons, prompt and delayed γ rays, are kept separated.

Fig. 2c shows the total simulated counting rates in 10^7 fissions as well as the partial contributions coming from neutrons, prompt γ, secondary γ and electron or positrons reaching the surface of the RPC detector.

In all four configurations the contribution from prompt γ rays is the largest one.



a) b) c)

Figure 3: Prompt γ (a), secondary γ (b) and neutron (c) sensitivity as a function of the shielding composition for gap I, gap II and double gap.

Table 1: Summary of sensitivity results.

Single gap	Sensitivity (x10^{-2})	Double gap	Sensitivity (x10^{-2})	E_{av} (MeV)
prompt γ	0.36 ± 0.04	prompt γ	0.64 ± 0.06	0.9
prompt γ	0.72 ± 0.05	prompt γ	1.26 ± 0.07	1.5
secondary γ	0.63 ± 0.04	secondary γ	1.05 ± 0.05	1.4
neutrons	0.025 ± 0.002	neutrons	0.046 ± 0.002	1.9

Comparison between simulated and experimental counted signals shows that in all four configurations the simulated number is larger than the experimental one. This systematic difference is 20% $\div$ 25% and is constant within the experimental errors. Part of this systematic might be attributed to the fact that the RPC efficiency was less than 100%.

Moreover the simulation did not take into account the effect on the signal charge of the position where the discharge development started.

4. Conclusions

A simultaneous measurement of γ and neutron RPC sensitivity has been done using a ^{252}Cf source. Results are summarized in Table I. It is well known that RPC sensitivity is a function of particle energy. However, for the secondary from γs and neutrons, the mean energy of the simulated spectra has been found to be constant. For this reason a fit to the four configuration results has been performed and the result is shown in Tab. I. For the prompt γ case, a significant change in the mean energy has been observed between case A and case B. In case A the mean energy is about 0.88 MeV while in the remnant cases is around 1.54 MeV. As it has been pointed out, this difference is an effect due to low energy γs stopped in the first lead slab.

The general increasing behavior with the γ energy is in agreement with the previous results [5]. Neutron sensitivity appears to be at least a factor ten less than γ sensitivity. It is important to notice that in the present work only signals due to neutrons that enter in the detector contribute to the neutron sensitivity measurement. Secondary γ contribution, due to neutron interactions in the experimental area but outside the RPC volume, has been treated separately. Comparison between the measurements done at different electronic threshold has not been shown any dependence of neutron and γ sensitivity from this parameter. The same consideration can be done about the internal surface treatment with linseed oil.

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