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MSGC test with fast neutrons

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Abstract

Results are presented from the exposure of a CMS performance prototype MSGC to a fast neutron beam having an average energy of 20 MeV and an intensity of 7 10^6 neutrons/mm^2/s. A fluence equivalent to 3 years of LHC operation has been accumulated without damages to the detector. The stability of the MSGC operation in a heavily ionising particle flux is reported and the estimation of their production by neutrons is discussed.

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1 Introduction

In the CMS setup, the outer part of the inner tracker will be equiped with MSGC counters and, in this region, one expects a flux of $\leq 10^4$ minimum ionizing particles (MIPS) per mm^2 and per second. The neutron flux in this region was estimated in [1] as $\sim 10^4$ n/mm^2/s ($E_n > 100$ KeV).

Although these neutrons cannot directly induce signals in the MSGC detectors, they can produce photons and highly ionizing charged secondaries (HIPS: e, p, d, α, ...) following neutron-induced nuclear reactions and/or the activation of the materials present in the tracker volume. These charged particles and the induced photons contribute to the occupancy of the detectors. In addition they could also induce streamers or sparks which can damage the MSGC's. Some neutron reaction cross sections on carbon and oxygen usually present in the MSGC building materials are shown in Figure 1. We can see that above 10 MeV the onset of (n,xα) reactions that can induce highly ionizing particles.

To tackle these problems, we irradiated MSGC detectors with a fast neutron beam. Its high intensity allows to reach within a couple of hours a fluence corresponding to 3 years of LHC operation (3 10^{11} neutrons/mm^2).

In this note we present the beam facility of Louvain-la-Neuve cyclotron and the first results obtained with a prototype MSGC.

2 The intense fast neutron beam

In order to reach the required fluence in a reasonable time with fast neutrons ($E_n > 1$ MeV), the neutron beam is generated by the reaction ^{9}Be(d,n)X induced by a 50 MeV primary deuteron beam (intensity up to 10 μA) hitting a 1 cm thick beryllium target (Fig. 2). To get the maximum neutron flux, the irradiations were performed very close to the Be target (at 9 cm). Downstream this target (not shown on the figure) and immediately after the stainless steel window we placed a filter made of a 1 cm thick polystyrene plate, a 1 mm cadmium and a 1 mm lead foils. This filter performs some hardening of the beam by decreasing the amount of thermal neutrons and also reduces the contamination by low energy charged particles.

The broad energy spectrum of the neutrons extends up to 50 MeV with an average energy of about 20 MeV. This energy domain is well above the threshold energies to produce low energy charged particles through nuclear reactions in the detector.

The neutron beam angular distribution is evaluated at a distance of 9 cm from the production target with a matrix of 50 thermoluminescent dosimeters (TLD) (Fig. 3). This angular distribution is forward peaked and 90$\%$ of the flux is located in a disc with a diameter of about 4 cm.

2.1 The absolute flux and the energy spectrum

The absolute neutron flux and its energy spectrum in the present setup are measured via the activation [2] of several metallic foils through nuclear reactions (table 1) with known cross sections (Fig. 4) [3]. Each activation reaction samples a specific part of the neutron energy spectrum.

Table 1: Production reactions, half life [3] of the induced radioactive nuclei and energy range of sensitivity.

Reaction	Energy range (MeV)	$T_{\frac{1}{2}}$
^{115}In(n,γ)^{116m}In	Thermal	54.15 min.
^{115}In(n,n')^{115m}In	1-14	4.49 h.
^{27}Al(n,α)^{24}Na	7-27	14.96 h.
^{58}Ni(n,p)^{58}Co	2-20	70.916 d.
^{58}Ni(n,2n)^{57}Ni	12-40	1.5 d.
^{59}Co(n,γ)^{60}Co	thermal	5.27 y.
^{59}Co(n,p)^{59}Fe	4-30	44.5 d.
^{59}Co(n,2n)^{58}Co	14-50	70.916 d.
^{59}Co(n,3n)^{57}Co	> 20	271.77 d.
^{93}Nb(n,2n)^{92m}Nb	9-30	10.15 d.

The neutron spectrum (Fig. 5) above 3 MeV is obtained by unfolding the measured activities of the different foils from the reaction cross sections [4].

The integration of the energy spectrum above 3 MeV gives an absolute neutron flux of 7.3 10^7 neutrons per mm^2 for a 1 μA incident deuteron beam. The relative error on the neutron flux is estimated to be about 20 %. These measurements are in agreement with the spectra measured by Meulders et al. [5].

In addition we measured, using dosimetric methods, the dose rate in the beam axis. Its measured value is 28 cGy per μC of deuteron charge on the production target. This correspond to 3836 Gy for a fluence of 10^{12} neutrons per mm^2 in this beam.

2.2 The beam contamination

To evaluate the energy deposition and response of the MSGC's to neutrons, we have to know the charged particle and γ ray contaminations in the neutron beam after the filter described before. The efficiency of this filter was evaluated by simulating the interaction of neutrons in the beryllium target and shielding materials located after it. This has been achieved with the GEANT software and allowed us to optimize the nature and thicknesses of the different shielding plates. Polystyrene moderates low energy neutrons; cadmium metal absorbs thermal neutrons while the lead foil decreases somewhat the gamma-ray and charged particle contamination. A preliminary result shows that this filter is useful for charged particles but not so much for γ rays (Table 2).

Table 2: Results of the simulation of the filter efficiency and on the contaminants.

Ratio	Before the filter	After the filter
γ/n	1.2 %	2.4 %
Charged particles/n	0.08 %	0.03 %

Particle	Fraction	Mean energy	Maximum energy
Neutron	1.0	16.54	50
Proton	1.5 10^{-4}	12.61	25
Electron	1.6 10^{-4}	1.57	6
Gamma	2.3 10^{-2}	1.93	10

3 MSGC test in a fast neutron beam

The performance prototype MSGC tested here was previously used at the CERN SPS with a high intensity hadron beam (T10) in april 97. At that time the aim was to study the stability of advanced passivated MSGC's at LHC-like counting rates and a fraction of HIPS [6]. The MSGC substrate is fabricated on the 0.3 mm thick Desag glass D263 ("ALENIA", Italy). This substrate is undercoated with the semiconductive glass S8900 with a surface resistivity of 4.8 10^{15} Ohm/sq. The 7 μm wide golden anode strips are separated from each other by 200 μm . The edges of the 90 μm wide cathode strips are passivated with a 6 μm wide layer of a polyimide material (thickness 2 μm). The useful sensitive area of 10x10 cm^2 is covered by 512 anode strips.

The MSGC substrate is glued on a 0.3 mm thick glass plate together with the readout electronics and the hybrid circuits for the high voltage supply. The drift electrode is made of the same D263 glass material but coated with a rather resistive, 5 nm thin Cr layer. It is placed 3 mm above the MSGC substrate. All electrodes are mounted in a flat carbon fiber box ("mini-banana") similar to the model proposed for the so-called "open design" for the CMS forward tracker [7]. The box is closed by a mylar window 100 μm thick. A sketch of the prototype is given in figure 6.

3.1 Experimental set-up and operation conditions

The detector is placed 9 cm after the neutron production target with the mylar foil looking upstream, i.e. serving as the neutron entrance window. The anode strip signals are read out by the Premux chips [8] with a measurement of their peak amplitude (without double correlated sampling). The data acquisition system is based on LabView operating on a VME+Mac platform. The readout sequence is initiated by trigger signals from a plastic scintillator 20x20 cm^2 and 1 cm thick located 2 cm behind the MSGC detector. In order to increase the efficiency of the trigger the cyclotron is operated in a pulsed mode and delivers beam spills lasting 2 ms every 10 ms. Within a spill the beam has a microstructure with the 5 ns bunches separated by 80 ns. The probability to get a trigger signal in the first bunch of the spill is close to 90%. The deadtime is essentially due to the acquisition system as each event is written on a hard disk. The trigger is thus randomly enabled with respect to the accelerator spill structure. We are thus left with a $\sim 20\%$ probability to release a trigger inside a spill: the recorded data could then be spoiled with pileup from previous signals coming from highly ionizing particles.

The cathode and drift currents in the range 1 to 10 μA were monitored by special trip modules with an accuracy of $\sim 5\%$. These modules have a time constant of about 20 ms. The 40 Hz sampling rate is asynchronous with the time structure of the beam. A PC-computer equipped with a multiplexing ADC card was used for the readout of currents.

Throughout the present test the detector was flushed with an Ar/DME (50/50) gas mixture with a flow rate corresponding to about 1 detector volume change every hour. The typical voltages were V_c = 580 V on the cathodes and V_d = 2 kV on the drift electrode. The absolute gas gain was estimated to be of the order of 1800. We did not succeed to bring V_d above 2 kV because of trips (trip level $\geq 10\mu$A) when beam was on. This problem was already seen before in the T10 beam test at CERN and seems related to the surface coating of the drift plane. Probably the Cr resistive coating ($\rho \geq 10$ kOhm$/sq$) could not sustain drift currents in excess of 1μA.

3.2 Results

We exposed the detector to the neutron beam during ~10 hours. The obtained fluence of 3 10^{11} neutrons/mm^2 is equivalent to about 3 years of LHC operation at high intensity. The average flux during irradiation was about 7 10^6 neutrons /mm^2/sec. We also tried fluxes 10 times higher during $\sim$ 1 hour.

Figure 7 shows typical "events", i.e. pulse heights at the anode strips for a given trigger, obtained in the neutron beam. We clearly see the saturation of the electronics near 1000 ADC counts (the saturation of the ADC depends on the pedestal) and we observe a negative crosstalk due to the cathode grouping in blocks of 16 strips. At high gas gains the pileup becomes significant. The comparison of the Landau distributions generated offline when recording cosmics with those observed in the neutron beam gives the relative ionization yield for the neutron secondaries with respect to cosmic muons(p $\geq$ 2 GeV/c). The figure 8 shows the Landau distributions generated by the cosmic muons at V_c = 580 V and in the neutrons beam at V_c = 300 V obtained with the same drift voltages and the same gas. As we knew beforehand the gain dependence on V_c we extract the ratio of ionization losses of neutron-induced highly ionizing particles (HIPS) to minimum ionizing particles (MIPS) $E_{HIPS}/E_{MIPS} \sim 65$. The dependence of the anode current I_a=$I_{cathode}$+I_{drift} versus V_c is shown in figure 9. Please note that I_a at V_c = 300 V in the neutron beam is equal to an LHC irradiation current at a rate of 10^4 mips/mm^2/s; let us also remark that the operation at V_c = 580 V generates an anode current equal to 30 times the LHC irradiation current. The linear dependence of the anode current on V_c (in logarithmic scale) proves that the undercoated MSGC gas gain does not saturate up to an anode current of 3 nA/mm^2.

As mentioned before the Landau distribution in the neutron beam is affected by pileup. The quality of the trigger is demonstrated in the figure 10 where the cluster multiplicity per event and the Landau distribution are shown side by side for the scintillator trigger and the random trigger. The number of clusters per event is rather high even with the scintillator trigger at this voltages V_c = 500 V due to pileup. It means that the Landau distribution is also spoiled and that the actual ratio of the energy deposits E_{HIPS}/E_{MIPS} could be higher. Indeed, for the shaping time of 50 ns set in the PreMux electronics, the HIPS contribute to the occupancy almost 4 times more then mips.

Taking into account the ratio E_{HIPS}/E_{MIPS} and the current measurement we can estimate the yield of the highly ionizing particles per neutron to 2 10^{-5} hips/neutron. Because of pileup and the unknown amount of beam contamination this value gives a upper limit for the neutron production cross section for HIPS in the open design detector of the CMS forward tracker.

We also monitored the $I_{cathode}$ and I_{drift} currents during the test. The leakage cathode current was about 150 nA at V_c = 500 V. The stability of the drift and cathode currents are shown in figure 11 during 3 hours of irradiation at a neutron flux of 7 10^6 neutrons/mm^2/s. At the operation voltages 25% of the ions are gathered by the drift plane and the remaining 75% by the cathode strips. The cathode current was quite stable. The few observed positive spikes in the $I_{cathode}$ do not exceed 5 μA. A negative current corresponds to a short shutdown of the cyclotron. On the contrary the drift current shows a very instable "ageing"-like behaviour. We believe that a resistive coating on the drift electrode is not suited for the operation at currents as high as we did here. The opening of the detector after irradiation clearly showed the indication of sparking near the edges of the drift plane. It is remarkable that this problem had a local influence only and did not affect the cathode current $I_{cathode}$. It is to be noted that, during the irradiation, the current was about 3 $nA/$mm^2 which is close to the aging current in addition to the large size of the avalanche.

After this beam test the inspection of the MSGC substrate showed no change of color and no spark tracks were found at the position of the beam spot. One damage found far away from the irradiation area was traced back to a HV mishandling which locally killed 13 anode strips.

We were not able to measure the activation of the detector after the irradiation. The induced activity of the whole detector as measured by a dosimeter was about 10 mrad/hour after 1 day decreasing to 1 mrad after 2 days. The stainless steel gas pipes were considered the main responsibles for this activity.

4 Conclusion

We operated the "performance prototype" MSGC in a neutron beam of 20 MeV average energy at a flux of 7 10^6 neutrons/mm^2/s. The corresponding fluence is 3 10^{11} neutrons/mm^2 and is close to the 3 years of LHC operation at a high luminosity. The average ionization loss of the neutron-induced highly ionizing particles was $\sim$ 65 times higher than for MIPS. The uncertainties in the neutron beam contamination gives us only an upper limit for the HIPS production yield which is 2 10^{-5} hips/neutrons. The detailed study of the beam contamination and the improvement of the trigger are foreseen.

It is obvious that we operated our detector in extreme conditions as far as the MSGC substrate is concerned: the avalanche size was $\geq 5.\ 10^6 e^-$ and the current during irradiation was $\sim$ 30 times higher than expected at the LHC. We did not observe serious problems with the MSGC substrate apart from a damaged area outside the beam spot and probably caused by a too fast HV ramping. The highly resistive drift plane did not support the high current ($\geq 1\ \mu$A/mm^2) during irradiation: this determined the maximum operational drift voltages V_d = 2 kV (3 mm drift gap). But this effect is peculiar to this irradiation: at lower rates it disappeared and we managed to operate at V_d = 3 kV when detecting cosmic muons. We plan to repeat these tests with more conductive drift planes.

In the present work we did not make a detailed study of the activation of the detector after irradiation. The dose rate of the activated detector dropped from 10 mrad, one day after exposure to the neutron beam to 1 mrad two days later.

5 Acknowledgement

We would like to thank Mr. M. Tavlet of the TIS-TE group at CERN for providing and reading some of the dosimeters and J.-M. Denis of the Neutron-Therapy group of Louvain-la-Neuve. We are grateful to the Cyclotron staff of Louvain-la-Neuve for the efficient operation of the accelerator.

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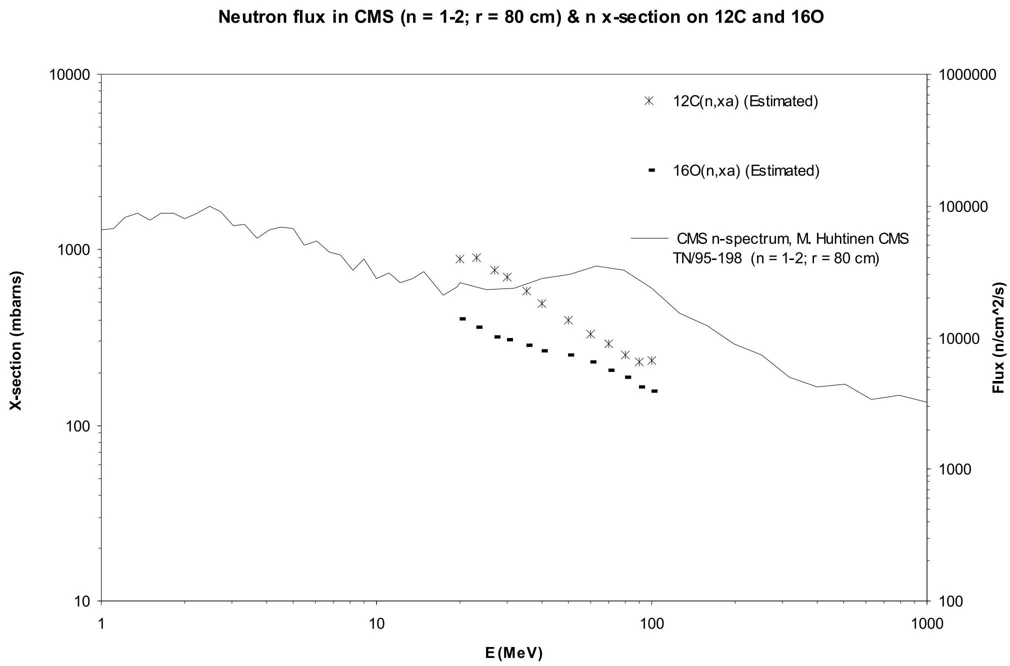

Figure 1: Energy spectrum of the expected neutrons in the CMS tracker and some neutron reaction cross sections on ^{12}C and ^{16}O. The values labelled "estimated" come from [9] and are based on measured datas.

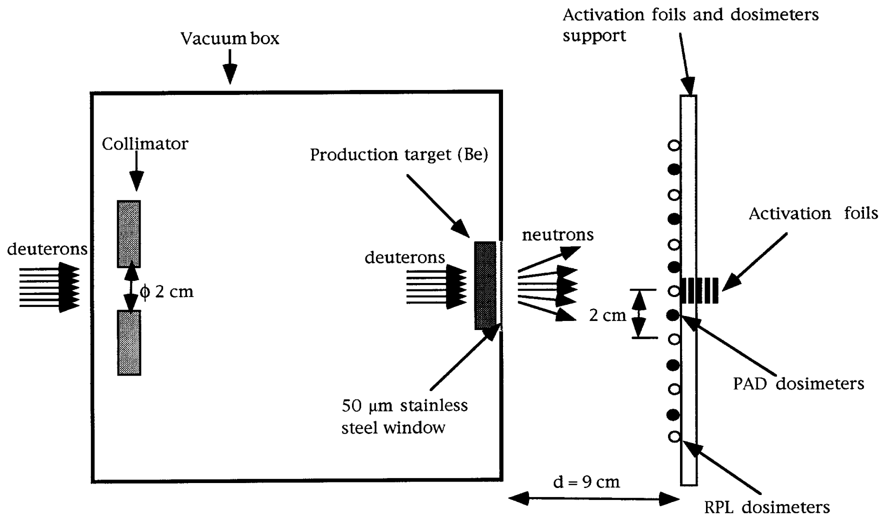

Figure 2: Schematic drawing of the neutron production set-up.

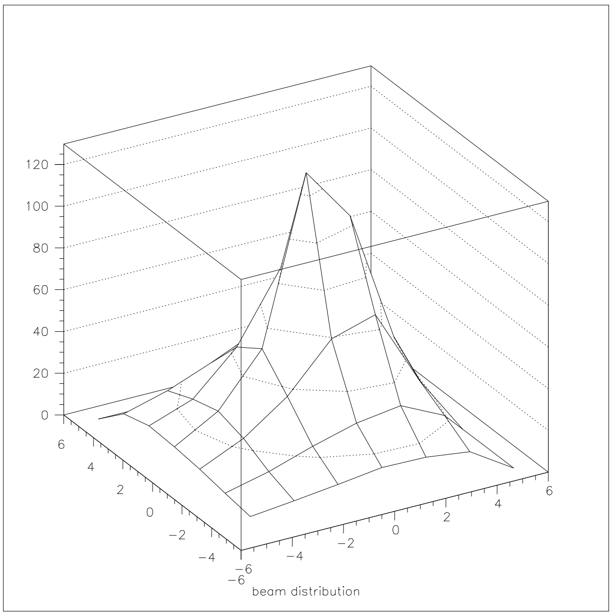

Figure 3: Beam profile at 9 cm from the production target using TLD dosimeters. The axes in the horizontal plane are labelled in cm.

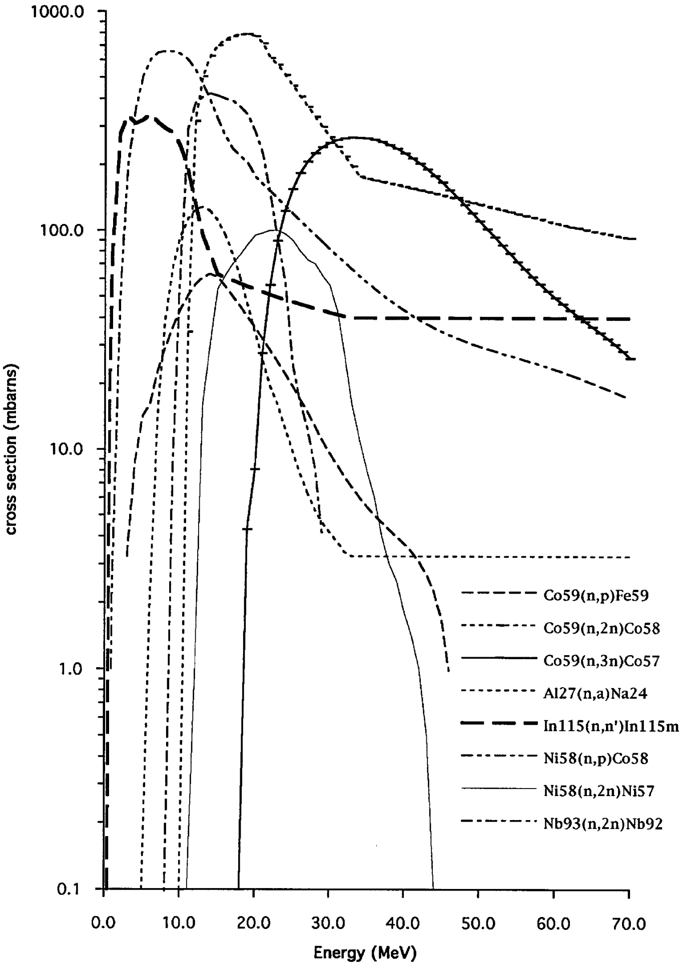

Figure 4: Neutron reaction cross sections [3] used for the measurement of the absolute neutron flux.

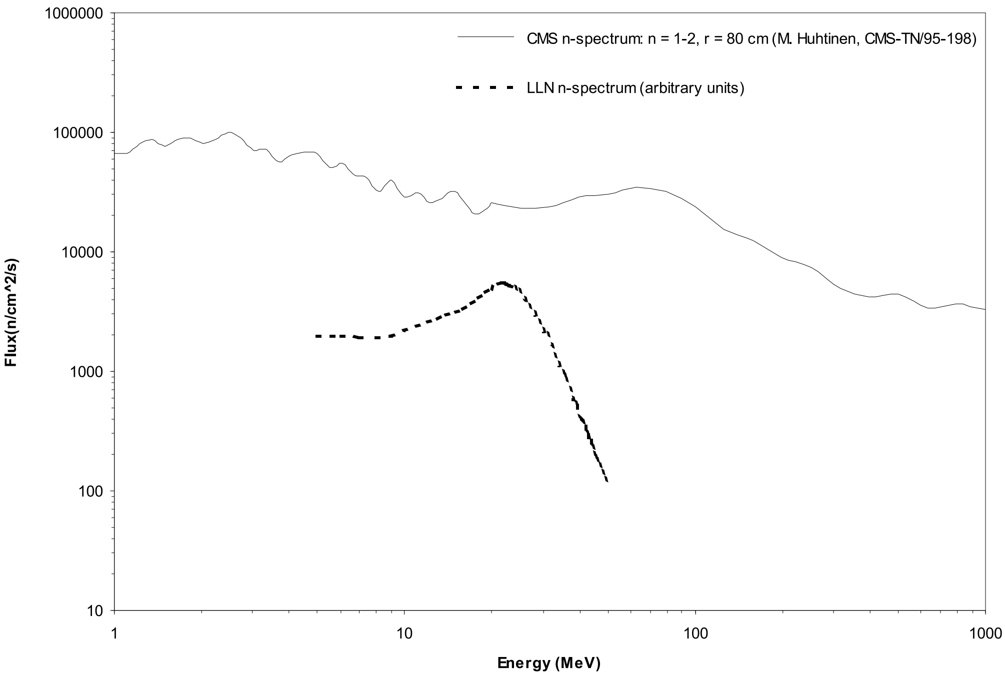

Figure 5: Energy spectrum of neutrons expected in the CMS tracker for a luminosity of 10^{-34} cm^{-2} [1] compared to the one produced in Louvain-la-Neuve (in arbitrary units).

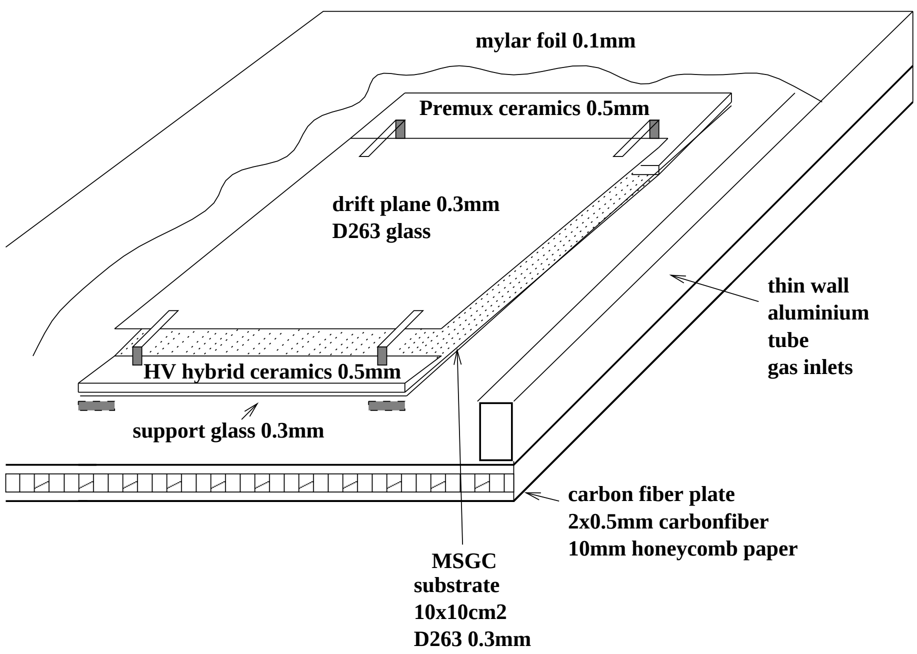

Figure 6: Schematic drawing of the open design prototype (banana box).

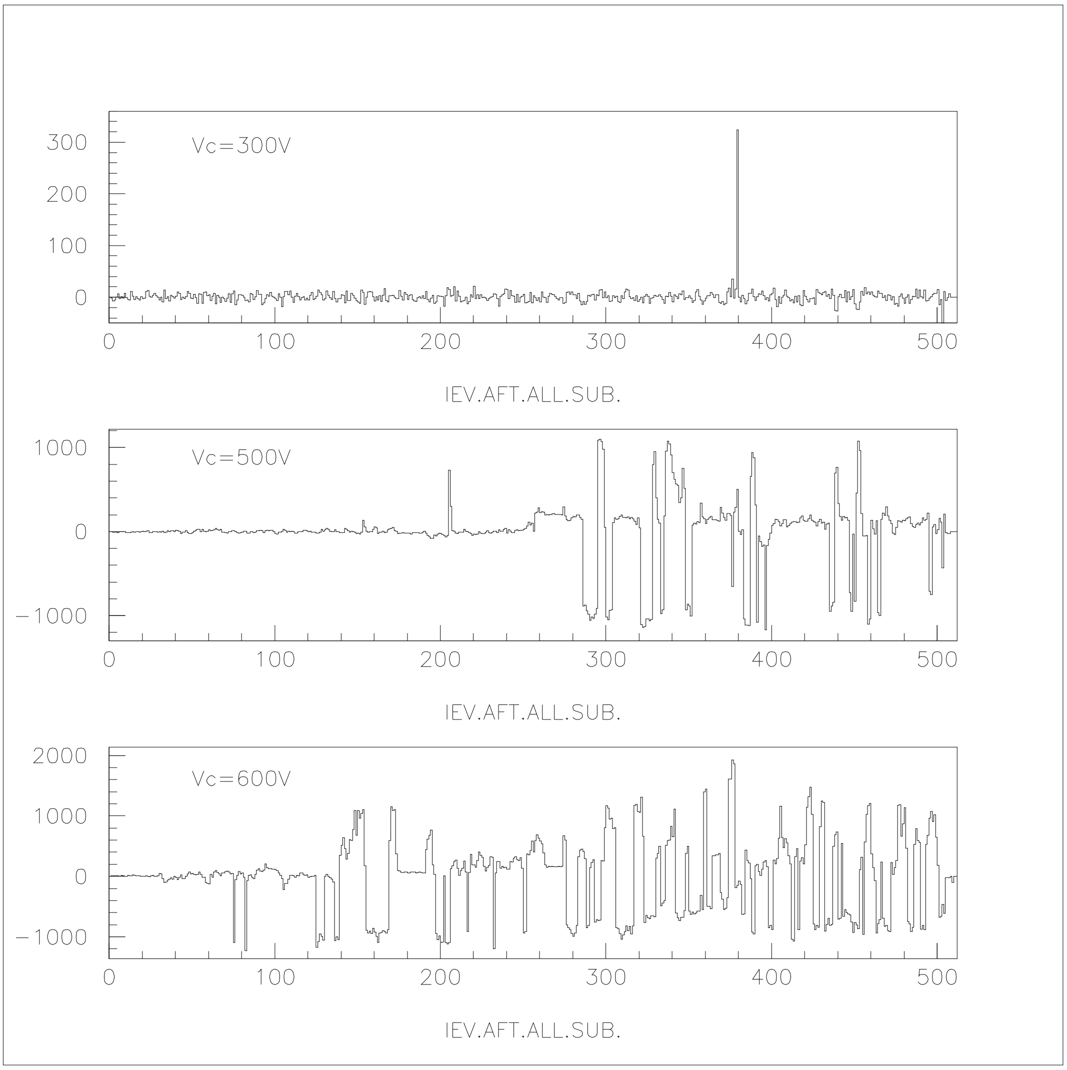

Figure 7: Pulse height at the anode versus strip number obtained in a neutron flux of 7 10^6 neutrons/mm^2/s at different cathode voltages. The pedestals are substracted.

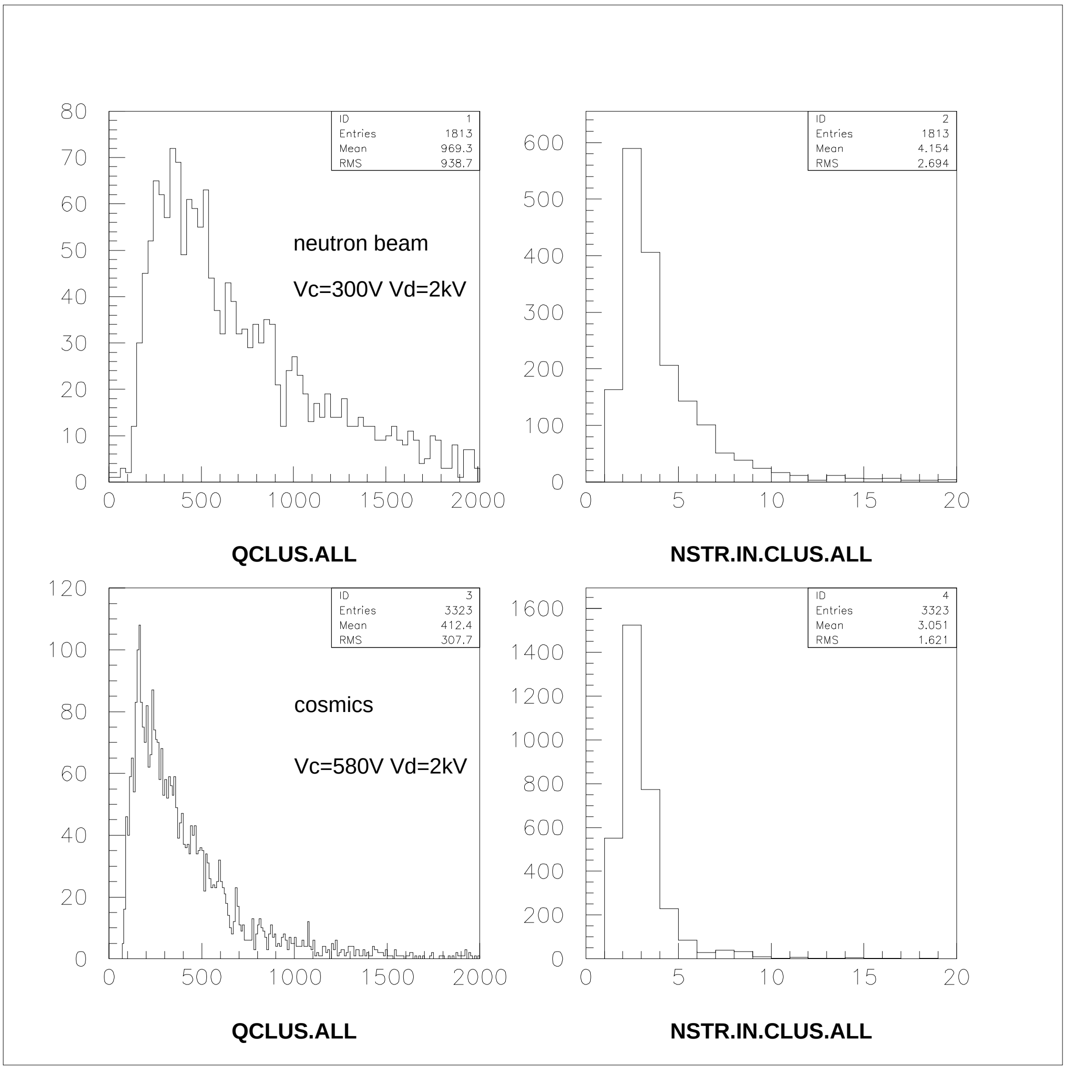

Figure 8: Landau distributions (left) and the cluster size distributions (right) during the neutron irradiation (top) and with cosmic rays (bottom) at different V_c in the gas Ar/DME(50/50).

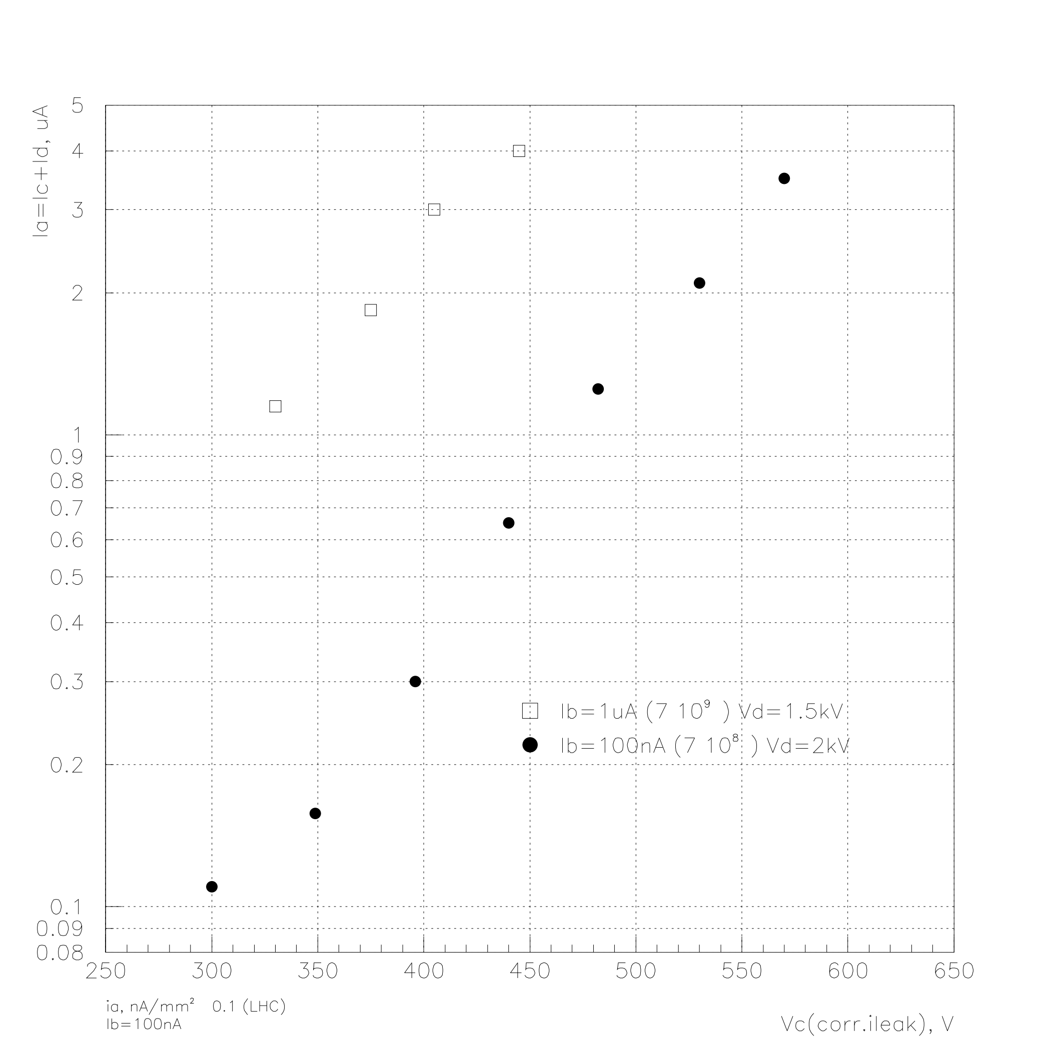

Figure 9: Anode current(as a sum of drift and cathode currents) versus V_c in the neutron beam with different intensities expressed in neutrons/cm^2/s.

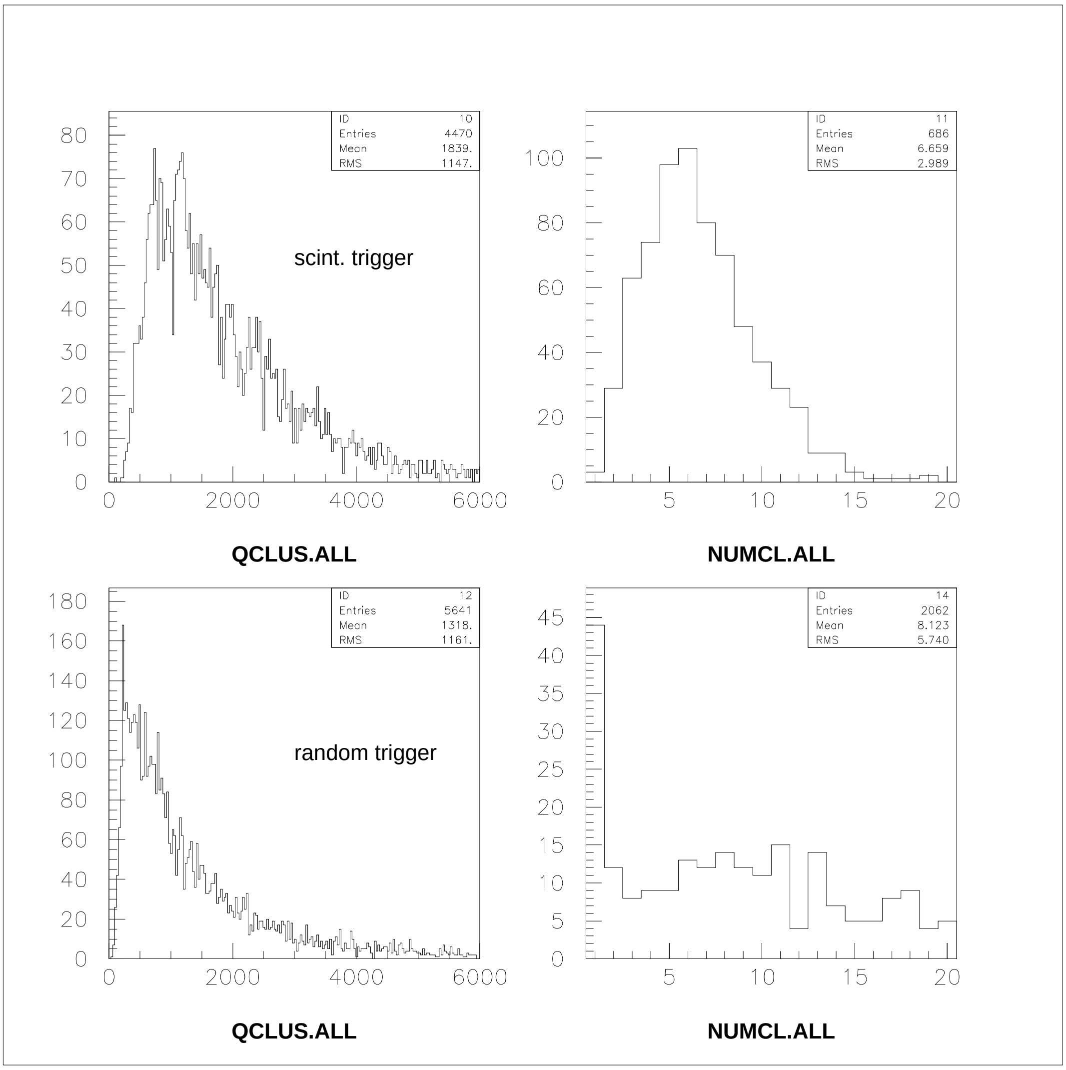

Figure 10: Landau distributions (left) and the cluster multiplicity distributions per event (right) for a scintillator (top) and for random trigger (bottom) at V_c = 500 V in a neutron flux of 7 10^6 neutrons/mm^2/s

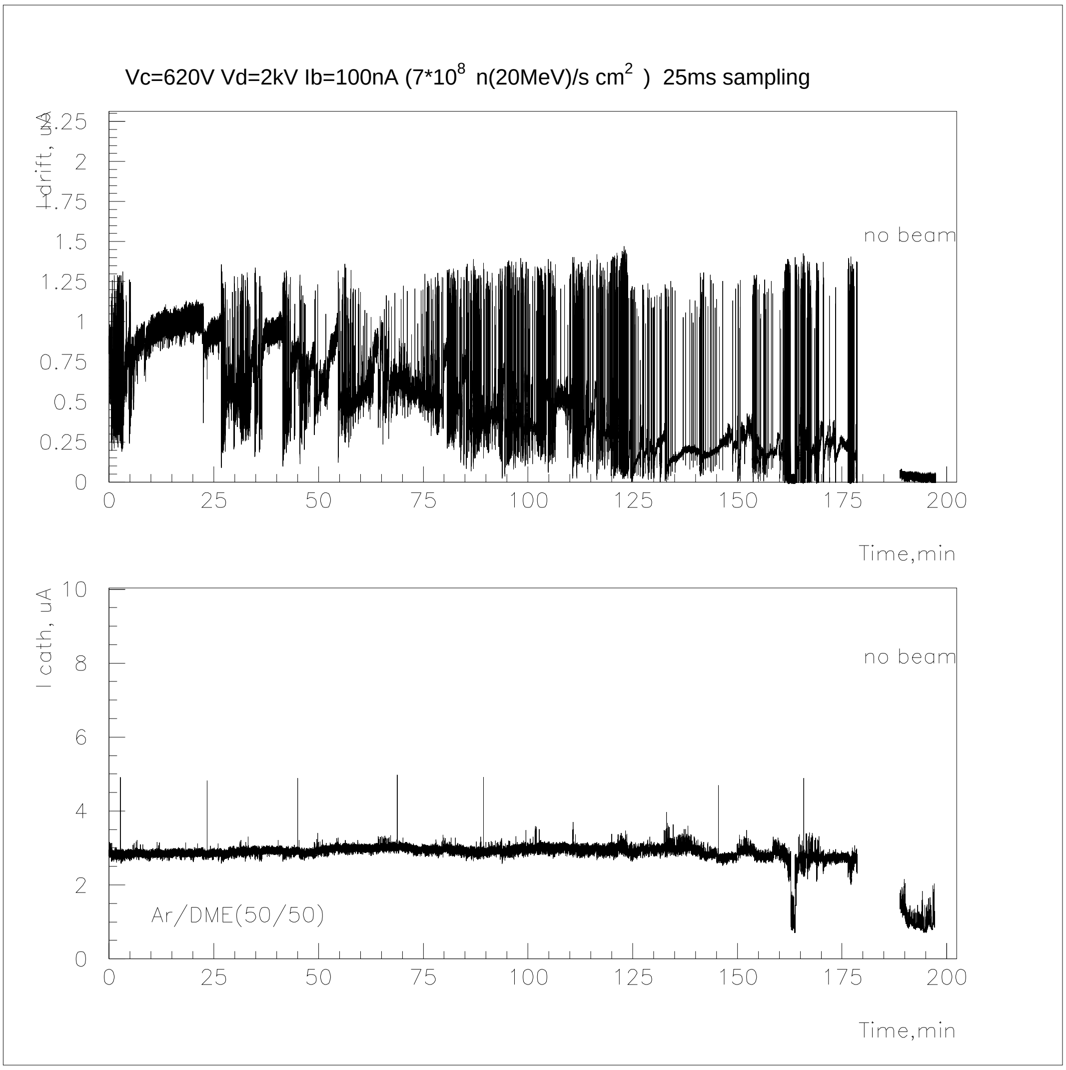

Figure 11: Drift and cathode currents during irradiation with a flux of 7 10^6 neutrons/mm^2/s. The diameter of the neutron beam spot is 4 cm. Cathode and drift voltages corrected for the leakage current are V_c=580 V and V_d = 2 kV.