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Thermal neutron detection with Resistive Plate Chambers via the $^{10}\text{B}(\text{n},\alpha)^7\text{Li}$ reaction

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Resistive Plate Chambers for thermal neutron detection have been developed and prototypes of the detector have been built. A $^{10}\text{B}_4\text{C}$ thin coating on the inner surface of one of the electrodes of the RPC is used as a thermal neutron converter via the $^{10}\text{B}(\text{n},\alpha)^7\text{Li}$ reaction. Monte Carlo calculations show that a conversion efficiency of about 2% for neutrons from a moderated beam can be achieved with a $3\ \mu\text{m}$ $^{10}\text{B}_4\text{C}$ layer. Converter coatings on glass plates have been tested with thermalised neutrons from a ^{252}Cf source (INFN Laboratori Nazionali Legnaro). The energy spectra, measured with a Si detector for different converter thicknesses, are well reproduced by simulation. A prototype RPC, with $10 \times 10\ \text{cm}^2$ glass electrodes and a 2 mm gap, has been built, characterised with cosmic rays and tested in avalanche mode with a low energy neutron beam at the european research centre IRMM (Geel, Belgium). A description of the prototype is presented, together with the results of experimental tests.

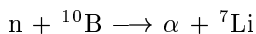
1. INTRODUCTION

Resistive Plate Chambers[1] are robust, position sensitive counters, whose adaptation to neutron detection would result in a multi-purpose detector to be used in beam profiling and field mapping for fundamental and applied[2] physics. Preliminary studies[3] show the feasibility of such a device.

2. DETECTION MECHANISM

Neutron detection by a Resistive Plate Chamber requires conversion into charged particles.

The chosen reaction is the following:



The cross section is proportional to the inverse square root of the neutron energy. Therefore,

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such a reaction is suitable for the detection of very low energy (thermal) neutrons. The cross section for thermal neutrons ($E \simeq 0.025\ \text{eV}$) is about 3.8 kbarn. The energy of the emitted α particle is 1.47 MeV in 94% of the events (when an excited state of ^7Li is produced), 1.78 MeV in the remaining 6%. RPCs can be adapted to detect thermal neutrons by adding a converter boron layer on one of the electrodes, on the surface facing the gas gap (Fig. 1).

Since atomic boron is not easily handled, the chosen converter material is $^{10}\text{B}_4\text{C}$ (boron carbide). B_4C can be enriched with ^{10}B up to more than 97%.

Monte Carlo calculations have been performed to define the optimum thickness of the $^{10}\text{B}_4\text{C}$ layer, and to evaluate the maximum achievable conversion efficiency, defined as the probability for a neutron to produce an α particle entering the gas gap. It has been assumed that Li ions cannot be detected because of absorption in

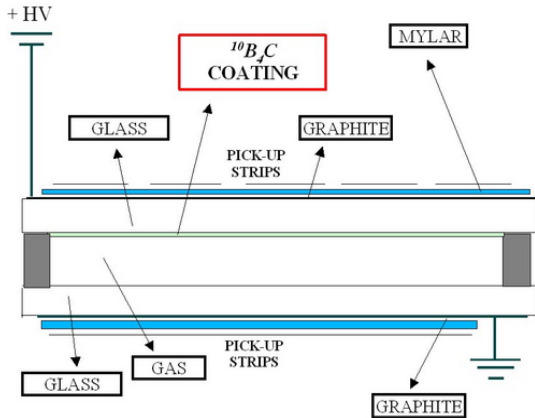


Figure 1. RPC for thermal neutron detection.

the $^{10}\text{B}_4\text{C}$ layer. The energy spectrum considered in such calculations is that available for the beam test at IRMM described in Sec. 4.1, with $E_n < 1$ eV. The results of the calculations are shown in Fig. 2: the conversion efficiency reaches its maximum value ($\approx 2\%$) for a $3\ \mu\text{m}$ layer. In the simulation (and in the tests described below) the converter is positioned between the neutron source and the gas gap: thus, for higher thickness values, absorption of the α particles in the layer itself becomes important and the efficiency decreases.

Converter samples have been developed (CERN EST Division), by depositing a $^{10}\text{B}_4\text{C}$ layer on glass using the magnetron sputtering technique. The choice of glass is due to the fact that bakelite, the most common material for RPC electrodes, cannot undergo magnetron sputtering without alterations. The drawback of glass electrodes is that they have high resistivity (about $10^{12}\ \Omega\text{cm}$), which limits the rate capability of the detector. The samples have been tested at the INFN Laboratori Nazionali Legnaro with thermalised neutrons from a ^{252}Cf source: the shape of the spectrum of charged particles coming out of the converter, measured with a Si detector for different converter thicknesses, shows good agreement with the expected one (Fig. 3).

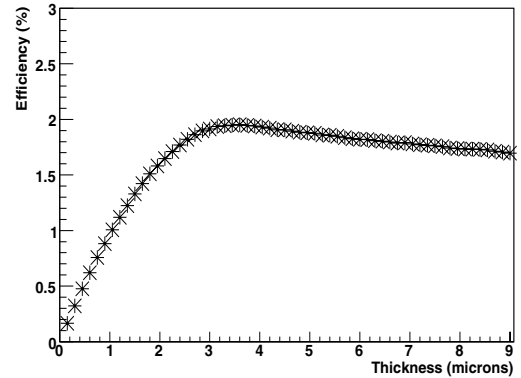


Figure 2. Conversion efficiency for neutrons ($E_n < 1$ eV), as a function of the $^{10}\text{B}_4\text{C}$ layer thickness.

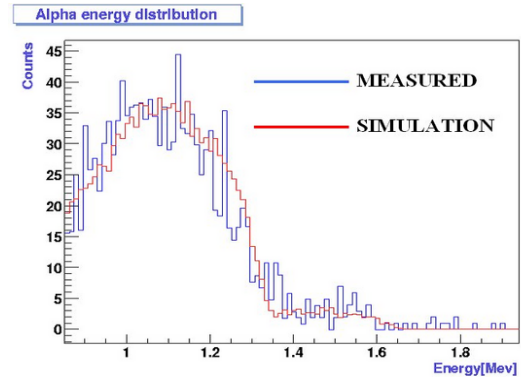


Figure 3. Energy spectrum of charged particles coming out of a $0.75\ \mu\text{m}$ $^{10}\text{B}_4\text{C}$ converter, simulated and measured with a Si detector at LNL.

3. PROTOTYPE DESCRIPTION AND CHARACTERISATION

A prototype RPC was built, with glass electrodes $10 \times 10\ \text{cm}^2$ in area and 2 mm thick, and a 2 mm gas gap. The resistivity of the elec-

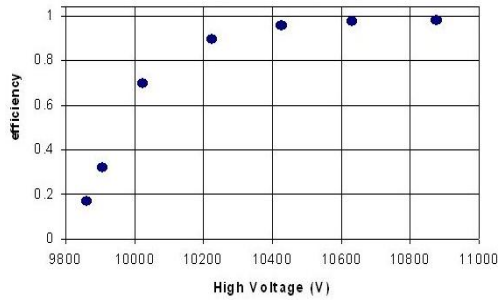


Figure 4. RPC efficiency curve, as measured in Torino with cosmic rays.

trodes is about $10^{12} \Omega \text{ cm}$. A circular area (diameter = 25 mm) on the inner surface of the anode plate has been coated with $^{10}\text{B}_4\text{C}$, to form a $3 \mu\text{m}$ thick converter. The surface has been previously roughened by a light sandblasting process, to facilitate adhesion of the material. Only the nominal thickness of the coating can be reported, because magnetron sputtering on sandblasted glass does not allow full control on the quantity of sputtered material. The gas gap is filled with a *saturated avalanche* gas mixture, consisting of 89.5% $\text{C}_2\text{H}_2\text{F}_4$ + 10% C_4H_{10} + 0.5% SF_6 : such a mixture was chosen because it provides stable signals with an amplitude of a few tens of mV.

The RPC prototype was equipped with 2 cm wide strips and tested with cosmic rays to measure its efficiency curve and to find the working point. The efficiency curve is reported in Fig. 4. Noise measurements were also performed: the background rate is lower than 0.1 Hz/cm^2 for all HV values.

4. TEST WITH NEUTRON BEAM

4.1. Experimental layout

The prototype was tested at the GELINA facility of the european Institute for Reference Material and Measurements (Geel, BE) in July 2005. The GELINA facility consists of a 100 MeV pulsed electron beam hitting a U target: *bremstrahlung* photons are emitted, which

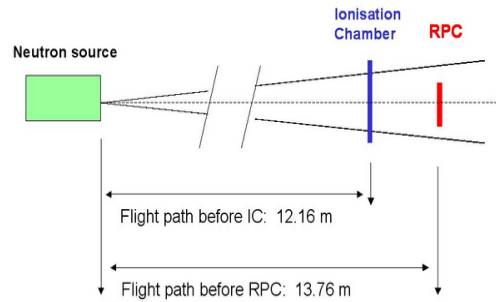


Figure 5. Experimental set-up for the beam test at IRMM.

produce neutrons by photonuclear reaction on U nuclei. The neutrons are then thermalised by a moderator. The resulting energy spectrum is approximately maxwellian, with a $1/E_n$ tail in the non-thermal region. During the test, GELINA was operated at a 40 Hz repetition frequency, resulting in a neutron rate of approximately 10^3 Hz/cm^2 at the distance of 12 m from the U target (the rate decreases as the inverse square of the distance). Filters were placed in front of the beam: Pb to reduce the γ flux, W and Ag to absorb neutrons of known energy, thus providing black resonances which can be used for background evaluation.

The prototype was equipped with two circular readout pads (diameter = 30 mm), one centered on the boron coating and the other outside the coating (background pad). An ionisation chamber was positioned in front of the beam, before the RPC, to be used as a reference counter (Fig. 5). The ionisation chamber detects neutrons via the same reaction as the RPC, with two $0.17 \mu\text{m}$ ^{10}B layers on the electrodes. A time of flight device allowed to measure the energy of detected neutrons.

Measurements were performed for two HV values: HV=9700 V minimizes the background rate, while HV=10100 V maximizes the signal to background ratio. Note that at HV=10100 V the detector is only 80% efficient for cosmic rays (see Fig. 4); measurements at higher voltages were

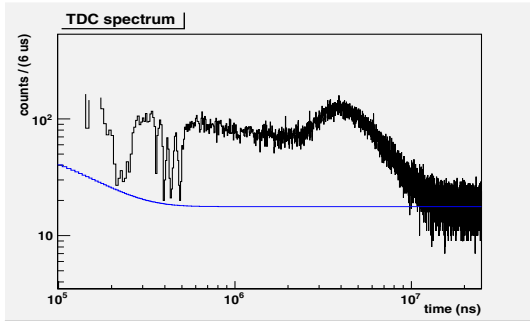


Figure 6. Time of flight spectrum measured with the RPC at $HV = 10100$ V. Holes can be seen, due to the black resonances of W (18 eV) and Ag (4 and 5 eV). The background fit is shown as well (continuous line).

not convenient because of the background due to the intense γ field associated with each bunch of GELINA: a huge number of *bremsstrahlung* photons hit the active area of the RPC all at once, almost ‘blinding’ it for part of the burst duration. However, since the products of the conversion reaction are highly ionising α particles, the detector can be operated at lower voltages, at which it is not fully efficient for photons and minimum ionising particles.

4.2. Data analysis and results

Time of flight spectra have been measured (Fig. 6). Background has been evaluated by fitting the spectrum obtained with the background pad and normalising it to the counts of the black resonances in the neutron spectrum.

The background subtracted energy spectrum of detected neutrons has been obtained from the time of flight spectrum. It is shown in Fig. 7, together with the one measured with the reference counter. The two differ by one order of magnitude because the two detectors have different area and distance from the U target (see Fig. 5).

In order to compare the two spectra, the RPC counts have been scaled to take into account the $1/L^2$ decrease of the beam intensity and the dif-

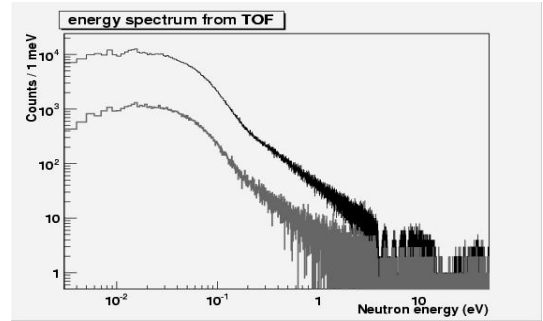


Figure 7. Energy spectrum of neutrons detected with the RPC (grey line) and with the ionisation chamber (black line). Counts are not normalised to the same neutron rate.

ference between active areas (the ionisation chamber coating is as large as the beam spot, which has a 6 cm diameter, while the $^{10}\text{B}_4\text{C}$ coating on the RPC only has a 2.5 cm diameter). The ratio of RPC to ionisation chamber counts has been calculated for six energy bins in the low energy region. The results in Tab. 1 show that such ratio is energy-independent up to $E_n = 1$ eV and that for $HV_{RPC} = 10100$ V the two detectors have comparable efficiencies.

Energy bin	RPC/IC 9700 V	RPC/IC 10100 V
(0.02 ÷ 0.05) eV	0.118 ± 0.007	0.81 ± 0.07
(0.05 ÷ 0.10) eV	0.118 ± 0.007	0.81 ± 0.07
(0.10 ÷ 0.20) eV	0.118 ± 0.007	0.81 ± 0.07
(0.20 ÷ 0.50) eV	0.125 ± 0.007	0.88 ± 0.14
(0.50 ÷ 1.00) eV	0.125 ± 0.007	0.88 ± 0.14
(1.00 ÷ 2.00) eV	0.125 ± 0.007	0.96 ± 0.14

Table 1

Ratio of the RPC to the reference counter (IC) counts for two different HV_{RPC} values. The RPC counts have been corrected for area and distance from the U target. Errors reflect the uncertainty in the background estimation.

Further analysis is needed to evaluate the actual neutron flux on the active area of the RPC, and thus its efficiency.

5. CONCLUSIONS

The RPC prototype described in Sec. 3 has correctly measured the time of flight and energy spectra of low energy neutrons in the beam. Preliminary analysis shows that the RPC response is comparable to the one of the reference counter up to $E_n=1$ eV. Further analysis is in progress, whose aim is to evaluate the RPC absolute efficiency.

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