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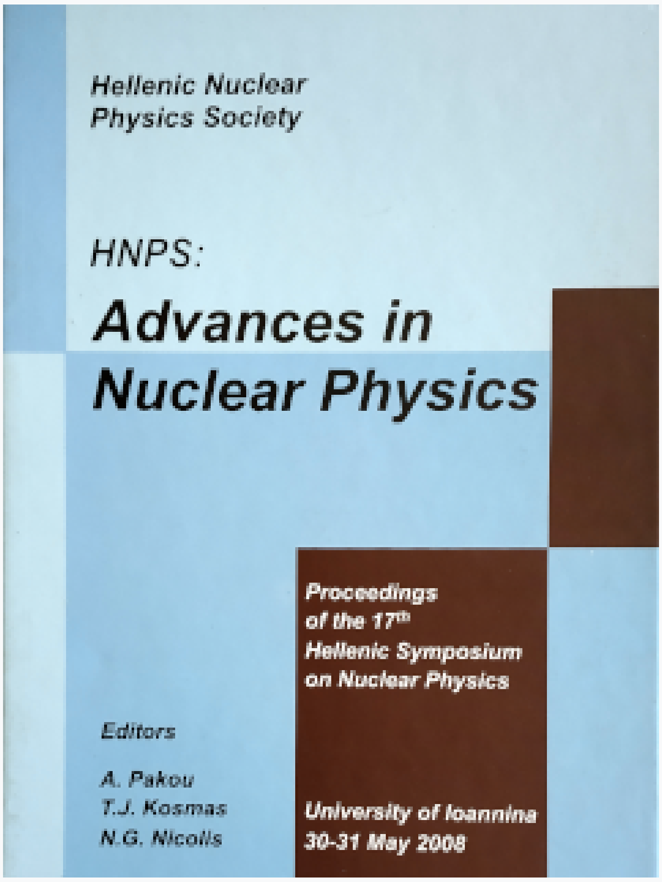

A Large Volume (1m3) Spherical Proportional Counter for Atmospheric Neutron Measurements

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A Large Volume ($1m^3$) Spherical Proportional Counter for Atmospheric Neutron Measurements

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Abstract: A large volume ($1m^3$) spherical proportional counter has been developed at CEA/Saclay, for low flux neutron measurements. Neutrons can be measured successfully, with high sensitivity, using ^{3}He gas in the detector. The proton and tritium energy deposition in the drift gaseous volume, from the reaction ^{3}He(n,p)^{3}H, can provide the neutron spectra from thermal neutrons up to several MeV. The α resolution of the detector has been measured using ^{222}Rn gas, in order to have the response of the total active volume of the detector. The three α peaks from ^{222}Rn decay and ^{222}Rn daughters decay have been measured with FWHM less then 2%, with gas mixture Ar 98% and CH_4 2% at a pressure of 200 mbar. The neutron sensitivity has been tested inserting in the sphere 100mgr of ^{3}He. The 0.765 MeV peak of p and ^{3}H is well separated form the cosmic ray background after irradiation with ^{252}Cf neutron source. The ground level atmospheric thermal neutrons have been also measured after several hours of exposure. The very low noise, the limited wall effect, the high resolution and the high sensitivity are some of the advantages of the detector.

1. Introduction

The atmospheric neutrons are produced by the interaction of the galactic and solar cosmic rays with the oxygen and nitrogen nuclei in the earth atmosphere. The flux of those neutrons depends on the atmospheric depth, the location and the solar activity but the shape of the energy spectrum does not change with the altitude or the latitude [1,2].

Although the flux at ground level is small, for high-density microelectronics cosmic ray neutrons are a source of soft upsets, since the ^{28}Si(n,n′α)^{24}Mg reaction release an energetic, heavily ionizing α particle[3,4,5]. Higher in the atmosphere, neutrons play a significant role in the assessment of radiation risks in aviation.

The ground level atmospheric neutrons represent one of the main backgrounds in the detection of Special Nuclear Material through passive or active neutron interrogation of cargo containers. The fissionable material produced penetrating neutron emission in the MeV energy range. So, the development of a detector with very high sensitivity and a very good energy resolution is important to the homeland security. Consequently, the flux of background neutrons at the search site must be known accurately, including the shape in the energy spectrum [6,7].

The investigation on the large volume spherical proportional counter [8] resulted in the development of a new neutron detector, based on the ^{3}He(n,p)^{3}H reaction. The low background of the detector and the possibility to separate the γ ray pulses from the protons and alpha particle pulses increases the sensitivity on the neutron detection. The detector can successfully measure very low neutron fluxes (10^{-6}n/cm^2/s, for thermal neutrons), providing the neutron energy spectrum from thermal up to several MeV at ground and underground level.

The large spherical geometry drift (1m^3), the very good energy resolution (<2% at 5.5 MeV alpha particles) and the simple electronics (one channel reading) are some of the advantages of the detector.

Other potential applications requiring large volume of about 10 m in radius are described in detail in reference [9,10,11,12]

2. The detector

The detector consist of a copper sphere, 1.3 m in diameter and 6mm thick (figure 1). The spherical vessel is well pumped (up to 10^{-8} mbar) and then is filled with a gas mixture at a pressure from several hundreds of mbars up to 5 bars. Out gassing in the order of 10^{-9} mbars/s is necessary for the amplification stability, because the present of the O_2 in the drift volume changes the detector characteristics.

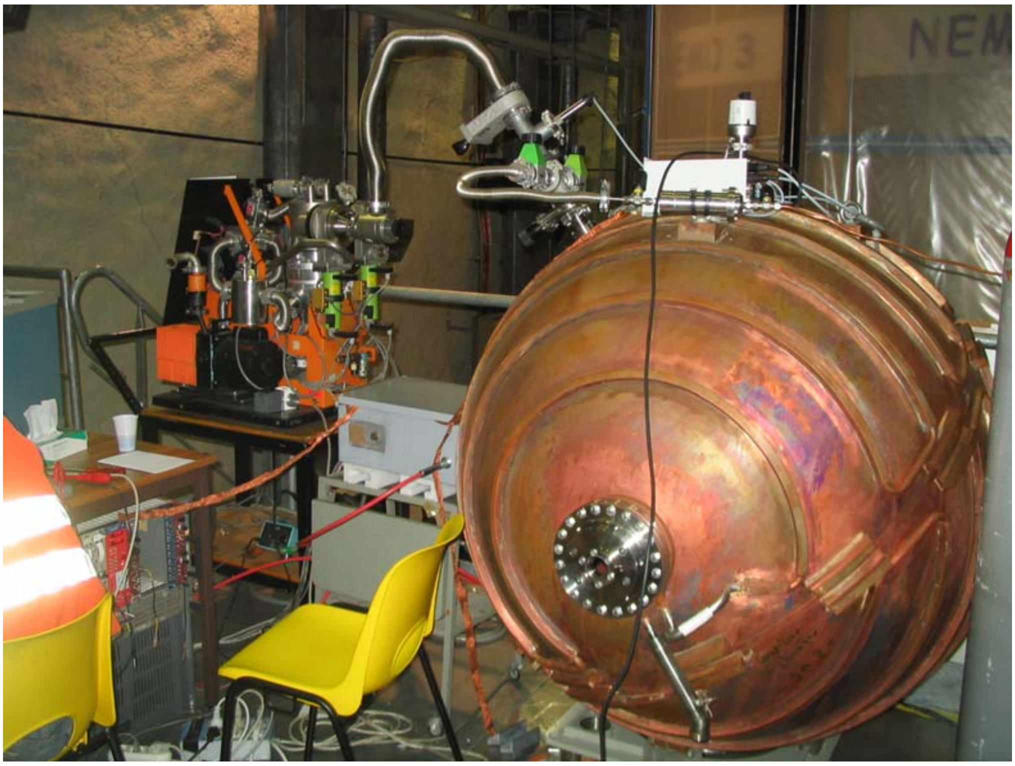

Figure 1. A photograph of the spherical vessel

A small stainless ball of 14 centimeter in diameter fixed in the center of the spherical vessel by a stainless steel rod, acts as an electrode with positive high voltage and as a proportional amplification counter. The detector was operated with positive bias applied to the anode (inner sphere) while the cathode (external sphere) remained at ground potential. A high voltage capacitor was decoupling the high voltage cable to protect the sensitive preamplifier.

Energetic charged particles, x-rays, or gamma rays or even neutrons entering the detector strip electrons from the gas atoms to produce positively charged ions and negatively charged electrons (figure 2). The electric field created across the electrodes drifts the electrons to the positive electrode. Near the inner anode sphere the electric field is high enough and electrons gain enough energy to ionize more gas atoms, a process that produces more electrons. Typical gases at atmospheric pressure required field strength on the order 10kV/cm to produce the avalanche of secondary electrons around the small anode ball. The avalanche is produced at a few mms distance from the anode and the positive ions drifting toward the cathode are inducing a pulse to the charge preamplifier. Since the avalanche takes place near the small ball and the electrons are attracted to it the positive ions travel a much greater distance. Therefore the induced pulse to the preamplifier is mainly due the ion movement; electrons produced during avalanche process have a negligible contribution to the signal.

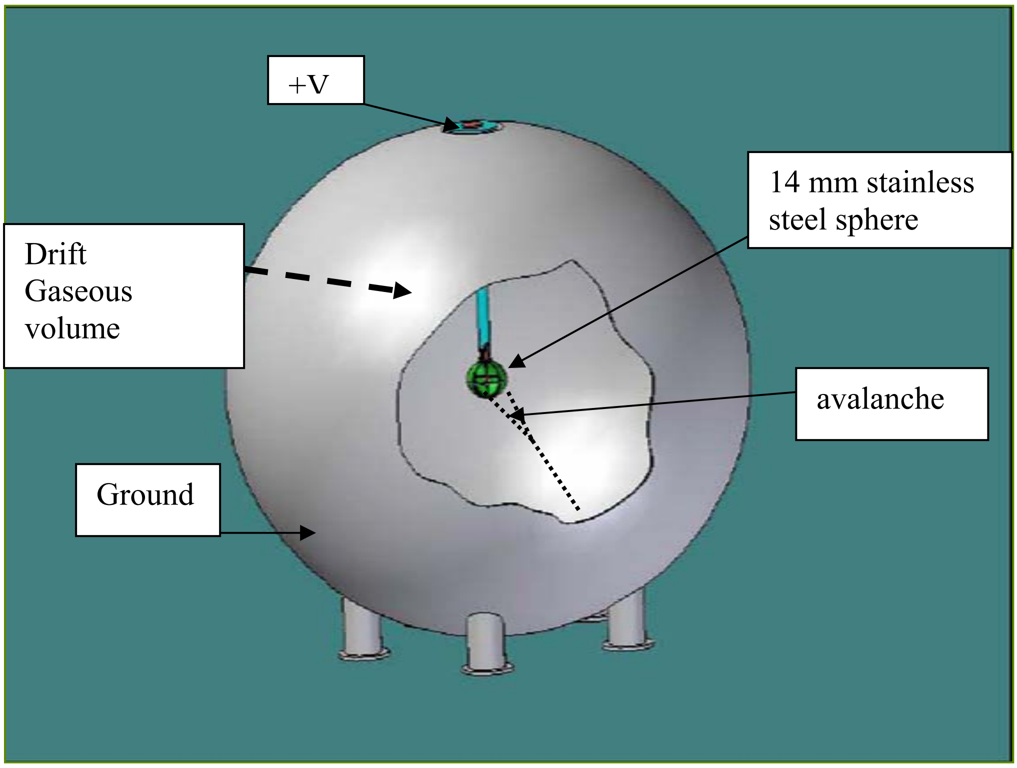

Figure 2. Sketch of the detector, showing the inner electrode and the avalanche formation from an electron, few mm far from the small ball. Positive ions moving backward are inducing a signal to the preamplifier.

3. The electric field

The electric field in the drift volume plays a very important role for the proportionality and the energy resolution of the detector. The ideal detector is a spherical capacitor with perfect radical symmetric electric field. In a real implementation of the spherical TPC concept, the ideal spherical symmetry is broken by the rod that supports the central electrode and that necessarily connects it to the front-end electronics, placed outside, to amplify and read the signals. In figure 3 the equipotential lines are plot for this simplest geometry, showing how the presence of this rod makes the electric field to be far from spherically symmetric. It means that the amplification depends on the direction and the position of the track of a charge particle in the drift volume and makes impossible the energy resolution.

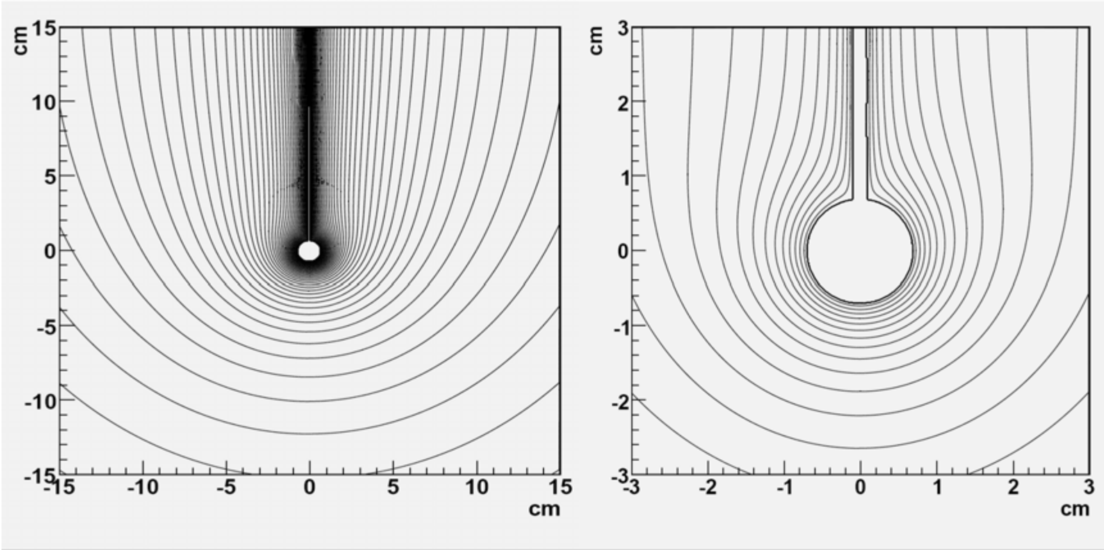

Figure 3. The epuipotential lines around the 14 mm sphere without any correction.

To solve the problem of field distortion due to voltage anode electrode, a cylinder around the high voltage rod, placed at 4 mm away from the central sphere and powered with an independent voltage V_2 (which can be zero, i.e., at ground). The equipotential lines for the described “corrected” configuration are shown in figure 4.

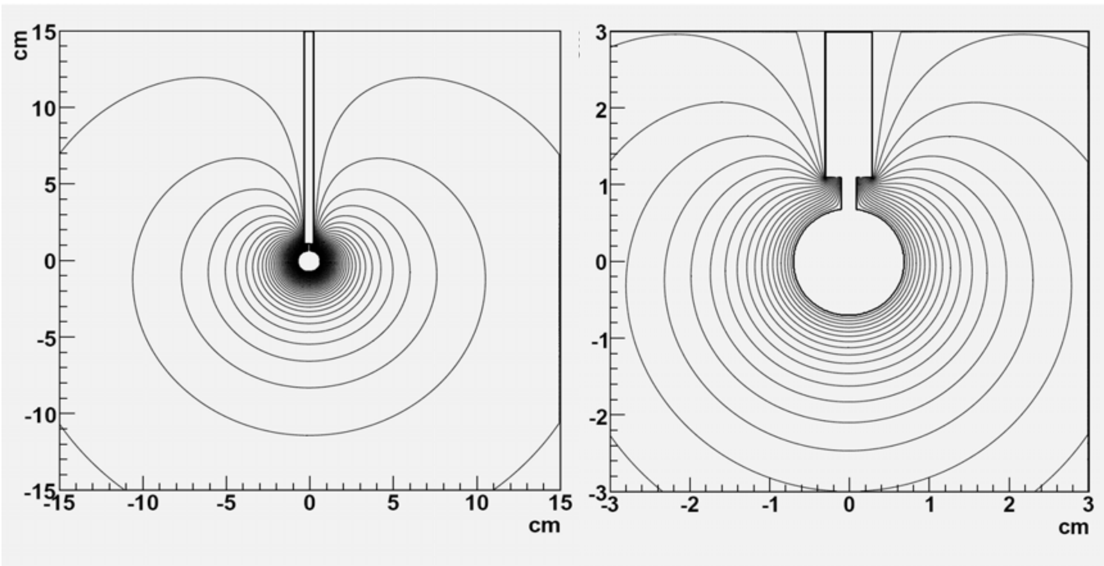

Figure 4. Electrostatic configuration for the readout electrode, with the "corrector" electrode consisting of a grounded cylinder surrounding the high voltage rod and placed <u>4 mm away</u> from the spherical electrode.
Sphere diameter=14mm.

4. The energy resolution

The energy resolution of the detector has been tested using ^{222}Rn gas and detecting the alpha particles from ^{222}Rn and ^{222}Rn daughters. Since the ^{222}Rn gas cover homogenously all the drift volume of the detector, we have alpha emission in every direction and in all the positions of the detector. So, charges from the alpha tracks arrive at the central positive electrode from every point and the amplification can be caused every ware on the surface of the 14 mm sphere.

The gas mixture consist of Ar (98%) and CH4(2%) at pressures, from 150 mbars up to 1 bar. The high voltage vary from 1.5 kV up to 5 kV depending on the gas pressure.

A charge preamplifier is connected to the central electrode and the signal is proportional to the charge particle energy.

In the figure 5 is shown the peaks observed from a ^{222}Rn radioactive source. From left to right we observe the ^{222}Rn peak at 5.5 MeV, the ^{218}Po and ^{214}Po at 6.0 MeV and 7.7 MeV respectively. The energy resolution was 2% FWHM at 200 mbar gas pressure and 2.8 kV High Voltage.

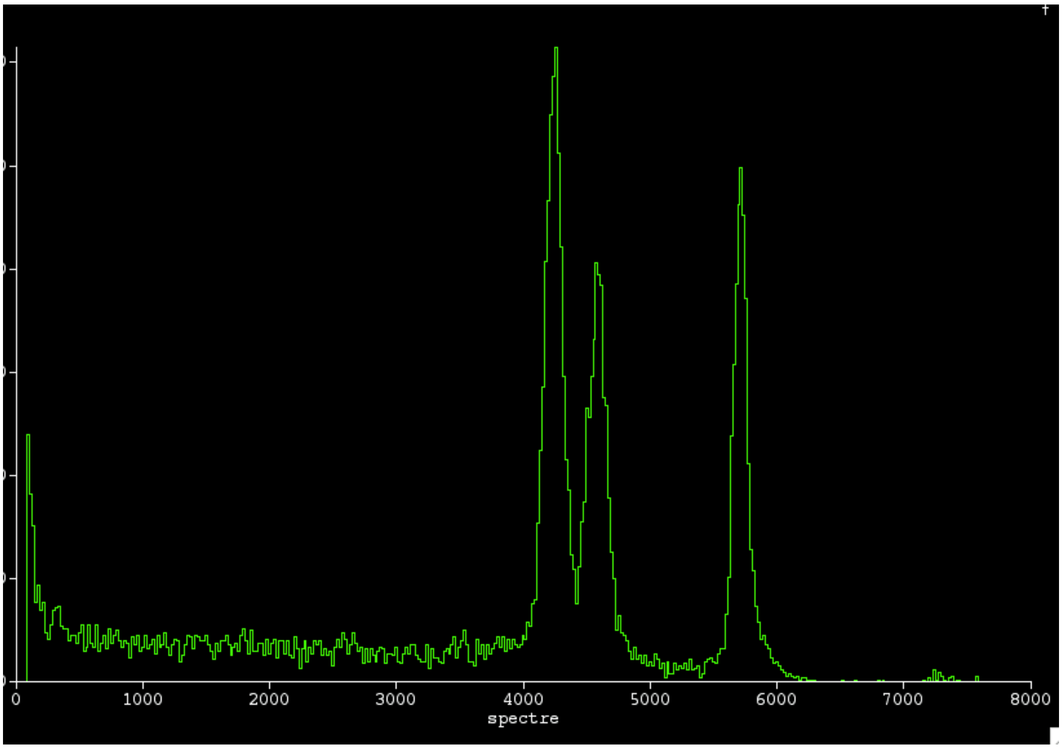

Figure 5. The peaks observed from a ^{222}Rn radioactive source. From left to right we observe the ^{222}Rn peak at 5.5 MeV, the ^{218}Po and ^{214}Po at 6.5 MeV and 7.7 MeV respectively. The energy resolution was 2% FWHM at 200 mbar gas pressure and 2.8 kV High Voltage.

5. The neutron detection and the wall effect

As we have shown, the spherical detector has a very good energy resolution to the alpha particles and consequently give us the possibility for easy detection of neutrons, using converters which give (n,p) or (n,α) reactions.

In the present work we have been used the ^3He gas as converter for thermal and fast neutron detection up to several MeV.

Neutrons interact with ^3He as follows

$$n + {}^3He \rightarrow p + {}^3H + 765 \text{ keV}$$

The signal is the sum of the p and ^3H energy deposition in the drift volume and depends on the neutron energy. In the case of thermal neutrons we measure one peak 765 keV and for the fast neutrons the energy peak is En + 765 keV, were En is the fast neutron energy.

The response of the detector follows the cross section curve of the reaction $^3He(n,p)^3H$ (figure 6) and depends on the ^3He amount in the drift volume of the detector.

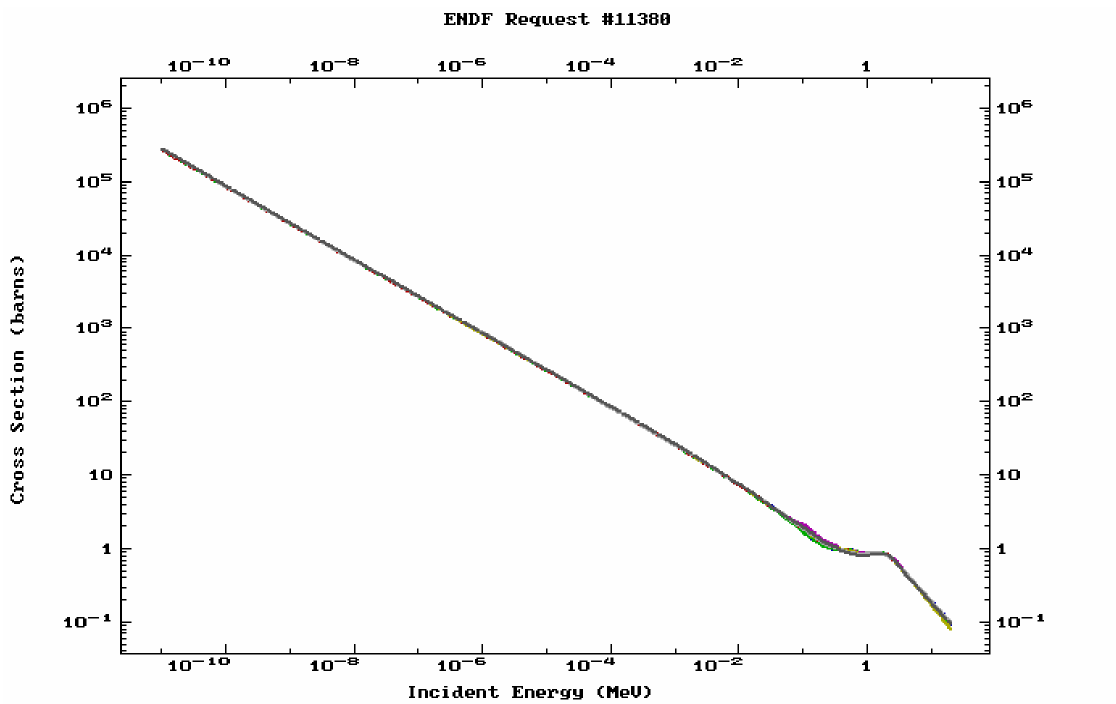

Figure 6. Cross section curve of the reaction $^3He(n,p)^3H$

In order to measure the neutron energy, both the charged particles ^3H and p from the (n,p) reaction must give all their energy in the drift volume . If the (n,p) reaction take place close to the vessel wall, it is possible one of the charged particles or both of them to hit the wall and to loose a part of their energy. This is known as the wall effect and leads to wrong estimation of the neutron energy (figure 7).

The wall effect depends on the range of the charged particles, which depends on the gas mixture and pressure, the neutron energy and on the dimensions of the detector. The large volume with the possibility to high gas pressure, is the advantage of the detector compared to the cylindrical proportional counters.

The wall effect of the detector has been calculated as a function of charged particles ranges (p range + ^3H range). In figure 8 is shown the sensitivity (%) of the detector. Sensitivity is the per sentence of the (n,p) reactions in the detector, were full the p and ^3H ranges are in the drift volume. The wall effect is (100 – sensitivity) %.

In the case of the thermal neutrons the proton energy is Ep= 573.75 keV and the ^3H is Et=191.25 keV. It is clear from this curve that the wall effect is small for the thermal neutrons but it is very important for the fast neutrons. In order to decrease the wall effect we have to decrease the charged particles ranges, which means to increase the gas pressure in the drift volume.

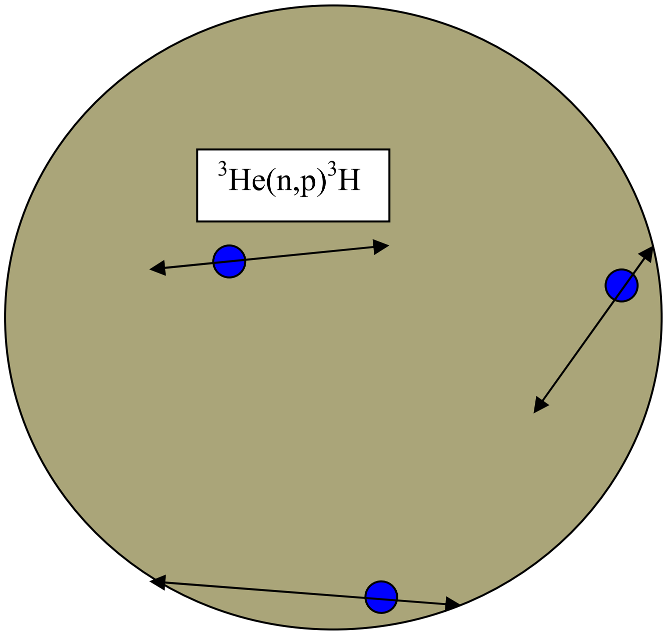

Figure 7. The wall effect of the detector

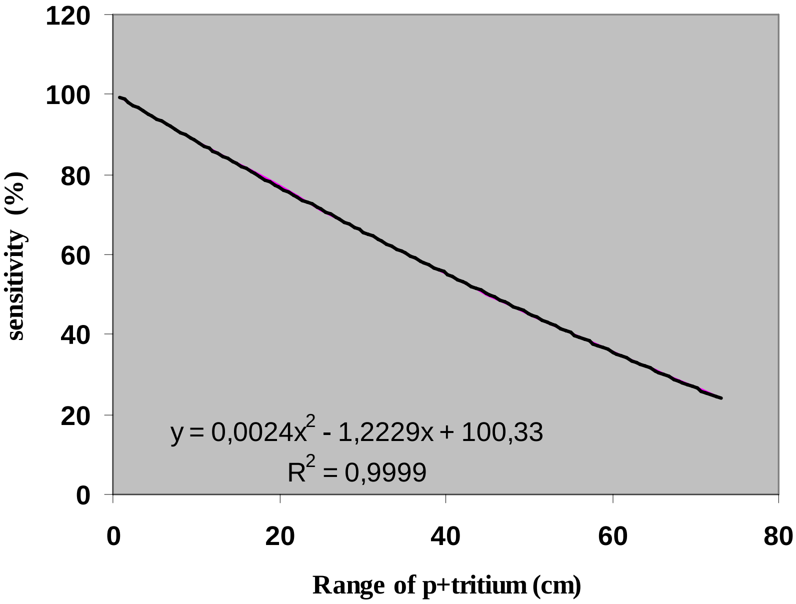

Figure 8. Sensitivity of the detector (%) as a function of the p+tritium range in the drift volume. Sensitivity = the per sentence of the (n,p) reactions were the full ranges of p and tritium are in the drift volume.

8. The atmospheric neutron measurements

The first time neutron measurements have been done in CEA (Saclay) using a gas mixture of Ar + 1% CH_4 + 100 mgr of ^{3}He. The gas pressure was 188 mbar and the high voltage 2880 V. The detector has been irradiated with an external ^{252}Cf neutron source, covered with paraffin moderator to increase the thermal neutron flux. The results are shown in the figure 9. The thermal neutron peak (765 keV) is well separated from the cosmic rays background.

The atmospheric neutrons have been measured removing the external neutron source from the detector. Because of the small amount of the ^{3}He the thermal neutron peak is small (count rate 3×10^{-2} counts/s) but well separated (figure 10).

The next step is the use of 3gr of ^{3}He and the measurement of the underground neutrons (10^{-6} neutrons/cm^2/s) in the LSM underground laboratory in Modane (France). The experiment is running and the results will be published soon.

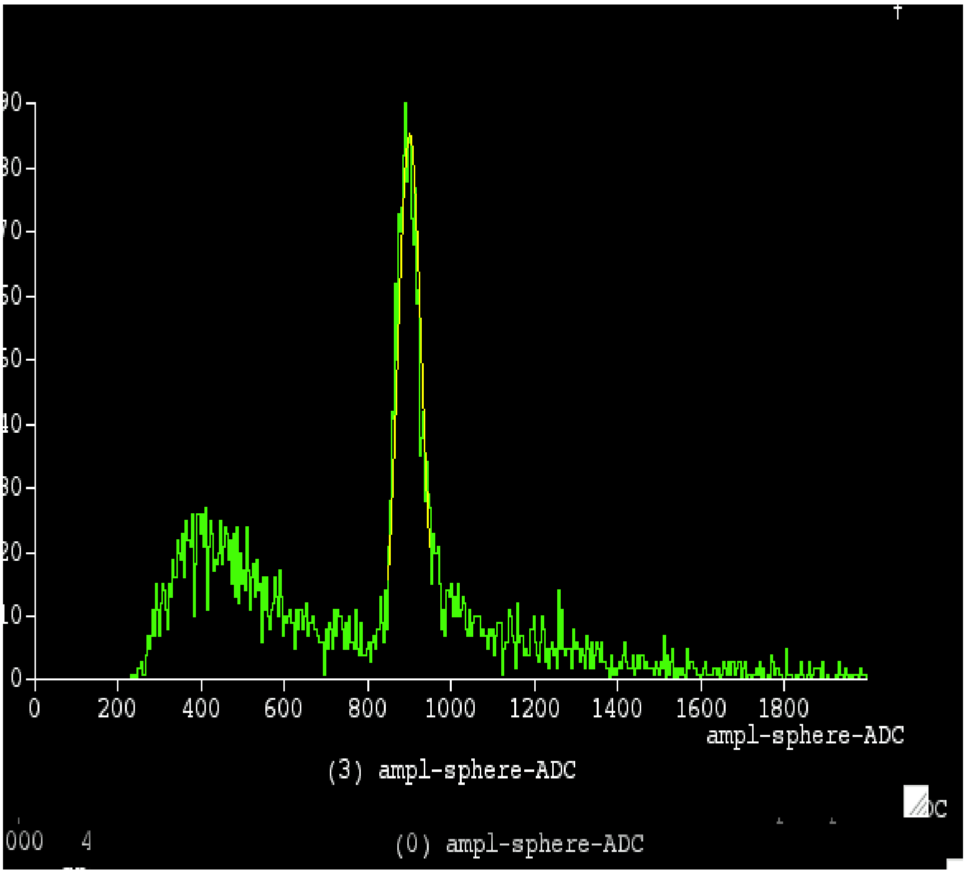

Figure 9. Thermal neutron peak from ^{252}Cf neutron source

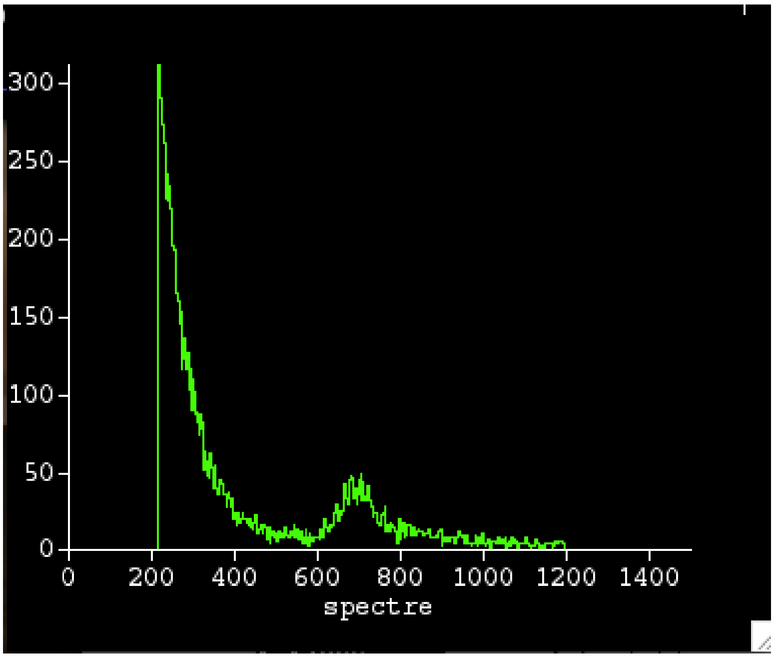

Figure 10. Atmospheric neutrons from the detector with 100mgr ^{3}He

9. Conclusions

We have developed a new neutron detector based on the radial geometry with spherical proportional amplification read-out. The main advantages of this structure are the following:

i. Single electronic channel to read-out.
ii. Low background
iii. Discrimination of the γ pulses from proton and alpha particle pulses
iv. Huge volume and large surface with very low wall effect
v. High energy resolution (2% for 5.5 MeV alpha particles)

Inserting several gr of ^{3}He in the drift volume the detector has the possibility to detect very low neutron fluxes (10^{-6} neutrons/cm^2/s).

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