Spherical TPC development and trends

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Abstract. We present a new type of gaseous detectors, the spherical proportional counter. It consists of a small metallic ball, 16 mm in diameter, located at the centre of curvature of a large spherical vessel, acting as a proportional amplification structure. It allows high gas gains to be reached and operates from low to high gas pressure. This simple and robust structure allows large volumes to be read out with a single electronic channel. The detector performance presently achieved is already close to fulfil the demands of many challenging projects from low energy neutrino physics to dark matter detection with applications in neutron, alpha, gamma spectroscopy. Preliminary results of neutron flux measurements currently going on in underground laboratory will be presented.

1. Introduction

The Spherical Proportional Counter, recently developed, is a novel concept with very promising features, among which is the possibility of easily instrumenting large target masses with good energy resolution and low energy threshold. The natural radial focusing of the spherical geometry allows collecting and amplifying the deposited charges by a simple and robust detector using a single electronic channel to read out a large gaseous volume. Moreover the detector is robust and stable in time. Unlike in the conventional TPC special field cage is not needed.

There is increasing interest of such massive low-background, low-energy threshold detectors in particle astrophysics for searching the origin of Dark Matter in our universe or studying low-energy neutrino physics [1,4,5]. Large gaseous detectors located underground have been proposed to pursue such important new physics possibilities. In addition, for the search of Dark Matter in underground area, it is crucial to know with a good precision the contribution of the neutron background. At present a high efficiency and a good energy resolution neutron detector able to measure a very low neutron flux, expected to be at most $10^{-6}$ n/cm$^2$/s in a large energy range from thermal to several MeV, does

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not exist. The neutron detector based on the same geometry will use Helium-3 on a large mass scale. The resulting good resolution detector could provide the neutron energy spectrum at ground and underground installations. Good energy resolution is also required to obtain a low energy threshold and to identify lines from gamma background.

2. Detector description

A prototype of a spherical detector of 1.3 m diameter has been built, in the last two years at Saclay, as a demonstrator and its initial operation is quite promising. The design presents two basic innovations:

- A large spherical drift vessel, 1.3 meter in diameter and 6 mm thick
- A stainless-steel ball, 16 mm in diameter, is located at the centre of the drift vessel and is maintained by a metallic rod. Applying a positive voltage on the ball, while external sphere is grounded, a radial field is created.

The detector operates in a seal mode: the spherical vessel is first pumped out and then filled with an appropriate gas at a pressure from a few mbar up to 5 bar. In the simplest design the small spherical electrode acts as proportional amplification counter and is read by a single electronic chain. Figure 1 shows a schematic view of the device and describes the principle of operation; for more details we refer to previously published papers [2-3].

The amplification process is similar to other commonly used gaseous detectors: the Parallel Plate Avalanche Chamber (PPAC) [6] and the cylindrical proportional counter. Let us compare the three concepts in terms of electric field shape relevant for signal development and capacity relevant for electronic noise:

In the PPAC the electric field is constant and the capacity is given by \( C = \varepsilon_0 S / d \) where \( S \) is the detector surface and \( d \) is the thickness of the amplification gap. For large detectors (>1 m\(^2\)) the capacity, proportional to the surface, will exceed 10 nF.

In the cylindrical proportional counter the electric field is given by \( E = V_0 / r \) where \( V_0 \) is the applied voltage and \( r \) is the radius of the sense wire. The capacity is given by \( C = \varepsilon_0 L \log(r / R) \) where \( L \) is the length of the sense wire and \( R \) the external radius; for large detectors we get \( C > 100 \text{pF} \).

In the spherical proportional counter the electric field at a distance \( r \) is given by:

\[
E(r) = \frac{V_0}{r^2} \frac{1}{1/r_2 - 1/r_1}
\]  

(1)

where \( r_2 \) is the anode radius, \( r_1 \) cathode radius and \( V_0 \) the anode voltage. The capacity is given by:

\[
C = \frac{4\pi \varepsilon_0}{1/r_2 - 1/r_1}
\]

(2)

and since \( r_1 \gg r_2 \) \( C = 4\pi \varepsilon_0 r_2 \).

For a typical size of \( r_2=6 \text{ mm} \) the capacity is \( C = 0.05 \text{ pF} \). Such low capacity will provide a very low electronic noise and therefore low energy threshold even if the detector operates at moderate gains.
Notice also that the capacity depends only on the size of the ball radius and is roughly independent of the vessel volume.

In a previous paper [7] we have presented results of high resolution energy measurements obtained by this counter. In the following section we will describe another application where the spherical detector is optimized for neutron measurements.

3. Neutron detection

Gas detectors are widely used as neutron detectors and are superior to scintillation counters in terms of stability, price per unit, efficiency and suitability for mass production. Gas-filled cylindrical detectors typically employ $^3\text{He}$ or BF$_3$ as the primary constituent, at pressures of less than 1 to about 20 atm. Our detector will operate with $^3\text{He}$ gas to capture and detect neutrons.

Neutrons interact with $^3\text{He}$ as follows:

$$n + ^3\text{He} \Rightarrow p + ^3\text{H} + 764 \text{ keV}$$

In order to measure the neutron energy, both the charged particles $^3\text{H}$ and $p$ from the reaction must deposit all their energy in the drift volume. If the reaction takes place close to the vessel wall, it is likely for 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. The large volume with the possibility to operate at high gas pressure is an important advantage of our detector compared to the traditional cylindrical proportional counter.

Recently the detector has been installed in the LSM laboratory in Modane (Frejus). The goal was to measure thermal neutrons using 3 g of $^3\text{He}$ and evaluate the sensitivity for fast neutron measurements.
Figure 3 shows the amplitude of the signal versus the rise time (ms). The thermal neutron peak (ADC bin 1000) and the contamination due to $^{210}$Po (ADC bin 4500) are clearly seen. To avoid such contamination the new detector will be fabricated by using low-radioactivity materials.

A pulse shape cut (rejecting long rise time pulses > 0.04 ms) keeps 60% of thermal neutrons but the effect on the background is spectacular (Figure 3); as expected background from gamma and beta particles is highly reduced and most of Po alpha rays emitted from the internal vessel surface (largest distance giving rise to long time pulses), are rejected.

The rate of selected thermal neutrons was 350/day. From this result we have a first estimate of the thermal neutron flux at LSM: $2 \times 10^{-6}$/cm$^2$/s.

Despite such powerful background rejection it will be difficult to measure fast neutrons with present apparatus; the cross section of fast neutron capture is three orders of magnitude lower. We need to build a new detector using low background materials and possibly an appropriate shield to reduce
environmental backgrounds. Moreover we could anticipate by increasing the present (3 gr) amount of $^3$He; by using 50 g of $^3$He we expect a fast neutron capture rate of a few events a day.

4. Conclusions

We have developed a new detector based on the radial geometry with spherical proportional amplification read-out. The detector is robust, stable in time and is operating in seal mode. Another advantage of this structure is the use of a single electronic channel to read-out a large volume. This single information still allows the determination of the radial coordinate of the interaction point through the measurement of the time dispersion of the detected charge pulse. Such information is of paramount importance for localization of the interaction in depth and background rejection applying fiducial cuts.

Adding $^3$He gas the present detector becomes a powerful massive neutron detector. Preliminary neutron measurements at underground with 3 gr $^3$He gas are encouraging. Thermal neutron flux has been precisely measured and the detector operates in a stable fashion for many months. Prospects for measuring fast neutrons are open.

Several other applications are open arising from low energy neutrino physics, double beta decay to WIMP search.

5. References

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