Supernova Neutrino Detection via Coherent Scattering

E. Bougamont[1], *P. Colas*[1], *A. Dastgheibi-Fard*[1], *J. Derre*[1], *I. Giomataris*[1], *G. Gerbier*[1], *M. Gros*[1], *P. Magnier*[1], *X.F. Navick*[1], *P. Salin*[2], *I. Savvidis*[3], *G. Tsiledakis*[1], *J.D. Vergados*[4]

[1]CEA-Saclay, France
[2]APC University of Paris, France
[3]University of Thessaloniki, Greece
[4]University of Ioannina, Greece

DOI: http://dx.doi.org/10.3204/DESY-PROC-2011-03/tsiledakis

Development of large mass detectors for low-energy neutrinos and dark matter may allow supernova detection via neutrino-nucleus elastic scattering. The Spherical Proportional Counter, recently developed, allows to instrument large target masses with good energy resolution and sub-keV energy threshold. This detector filled with a high pressure and high Z noble gas, can be employed to detect typical supernova neutrinos in our galaxy. Here we provide feasible measured signal rates and describe further developments optimizing the electric field configuration around the central electrode of the detector.

1 Introduction

The question of detecting and exploiting neutrinos from both terrestrial and extra terrestrial sources has become central to physics and astrophysics. Coherent neutrino-nucleus scattering is a famous but as yet untested prediction of the Standard Model [1, 2]. The process is mediated by neutral currents (NC), and hence is flavor-blind. Despite having relatively high rates, neutrino-nucleus scattering is difficult to observe because its only signature is a small nuclear recoil of energy $\sim$ keV (for MeV neutrinos). Because the neutrino is light, the nuclear recoil energy is extremely small leading to a signal below threshold for conventional solid or liquid state detectors. Thus, the challenge is to achieve a very low energy threshold (typically below 100 eV). Perhaps, the "ultimate" supernova detector involves neutrino-nucleus elastic scattering. The cound rate in such a detector could be very high because the coherent elastic cross section is large and all six neutrino components contribute to the signal. The detection might be feasible using large mass detectors [3].

A new gaseous detector based on a spherical geometry, the Spherical Proportional Counter (SPC), has been developed that combines large mass, sub-keV energy threshold and good energy resolution. This new concept has been proven to operate in a simple and robust way and allows reading large volumes with a single read-out channel. In the next session a short description and details of its performance will be provided. Then, new developments concerning the electrostatics of the SPC will be shown. Finally, we will present an estimation of the number of expected neutrino events for a typical supernova at 10 kpc, using this novel detector.

2 Detector description and performance

The detector consists of a large spherical copper vessel 1.3 m in diameter and a small metallic ball 16 mm in diameter located at the center of the drift vessel, which is the proportional counter. The ball is maintained in the center of the sphere by a stainless steel rod and is set at high voltage. A second electrode (umbrella-shaped) that is placed 24 mm away from the ball along the rod, is powered with an independent but lower high voltage, serving as electric field corrector. 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 few tens of mbar up to 5 bar. Detailed description of the detector, its electronics, its operation and its performance could be found in references [4, 5, 6].

Ultra low energy results taken with this counter are shown in reference [7, 8], leading to an energy threshold as low as 25 eV and a single electron detection sensitivity. The bench mark result is the observation of a well resolved peak at 270 eV due to carbon fluorescence, which is a unique performance for such large massive detector. Its moderate cost, simplicity and robustness, make this technology a promising approach to NC based detection of reactor and astronomical neutrinos and opens a new window in dark matter searches.

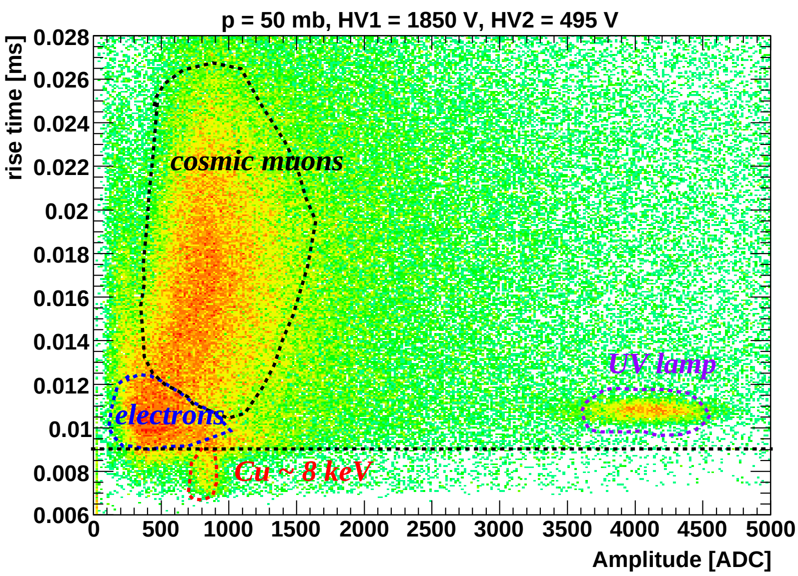

Figure 1: (color online) The rise time (rt) versus the amplitude for a gas mixture of Ar-CH_4 2% where a UV lamp is attached on the sphere.

A run is performed with the present detector, using a gas filling of Argon with 2% admixture of CH_4 and having a UV flash lamp installed in one of the sphere openings. The scatter plot of the rise time (rt) versus the amplitude of the signal is shown in Figure 1. The rise time of the signal actually provides the depth of the ionized electrons produced in the gas. We can observe on Figure 1 cosmic muons that are crossing the chamber having large rise time, electrons or low rise time X-rays that are absorbed in the periphery of the SPC, the photoelectrons created by the lamp which have the maximum drift time and the 8 keV line which is an induced fluorescence at the copper vessel. By applying a cut at rt $\leq$ 0.009 ms, we keep only volume events and observe a spectacular background reduction, from $\sim$300 Hz to $\sim$4.5 Hz, with $\sim$1.5 Hz in Cu (keeping $\sim$70% of the signal). The observed background at the relevant region for supernova neutrino detection (a few keV) is already quite low at ground. Keeping in mind that the needed mass to observe 100 events from a local SN is about 6000 times higher than the mass involved in present run, we anticipate that a shield might be needed.

2.1 Current developments configuring the electrostatics of the SPC

Current efforts focus on the design of an electrostatic structure that allows bringing the high voltage to the internal sphere with minimal distortion of the spherical field, both for purposes of drift and homogeneous amplification all around the small sphere [6]. The electric field configuration of the entire system has been numerically simulated and optimized, using COMSOL Multiphysics[1]. Figure 2 shows the electric field in a circle at a distance of 0.2 mm far from

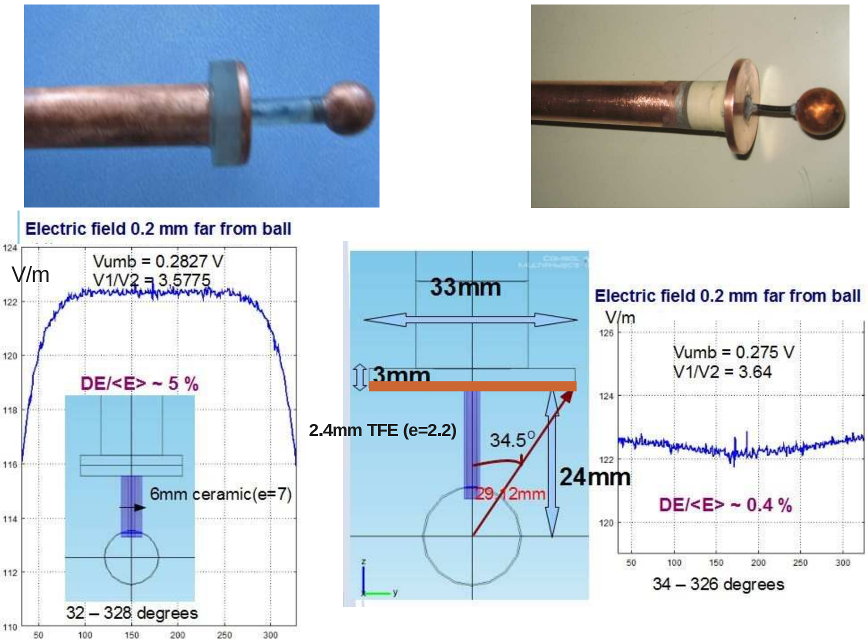

Figure 2: (color online) The simulated variation of the electric field 0.2 mm far from the ball for two different sensors.

the central electrode (ball) where an electric potential of 1 V is applied. In the first case the insulator that connects the two electrodes is made by ceramic of 6 mm thickness and in the second by teflon of 2.4 mm. The simulation proves that in the second case the variation of the electric field around the ball is significantly smaller, leading to a conclusion that material of low dielectric constant combined with a small thickness should be used. Preliminary results given in Figure 3 look very promising. The energy resolution in the 8 keV line of copper when a single cable is used is 6% (FWHM), compared to 11%.

[1] COMSOL Multiphysics, http://www.comsol.com

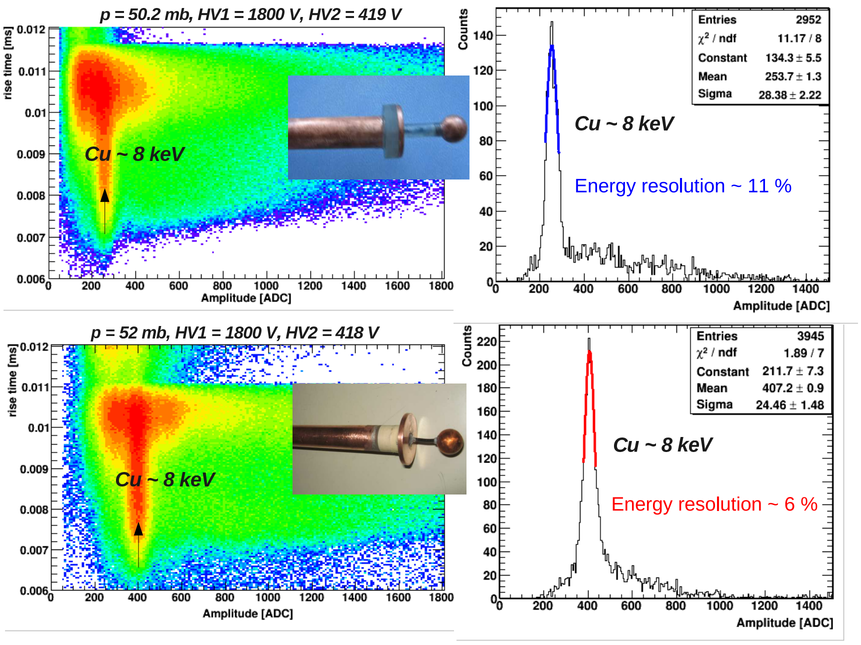

Figure 3: (color online) The rise time (rt) versus the amplitude as well as the energy spectra ($7 \leq$ rt $\leq 8\mu$s) for two different sensors where a gas mixture of Ar-CH_4 2% is used.

3 Supernova detection

In [9] it has been shown that it is feasible to detect typical supernova neutrinos in our galaxy. The idea is to employ the Spherical Proportional Counter filled with a high pressure noble gas. An enhancement of the neutral current component is achieved via the coherent effect of all neutrons in the target. The peak energies of the emitted neutrinos are approximately 15, 25 and 35 MeV for electron neutrinos, electron antineutrinos and all other flavors respectively. A detector of radius 2 m filled with Xe gas at a pressure of 10 Atm will detect about 100 events for a typical supernova explosion at 10 kpc. A world wide network of several such simple, stable and low cost supernova detectors is proposed [9].

References

[1] D.Z. Freedman *et al.*, Ann. Rev, Nucl. Sci. **27** 167 (1977).
[2] A. Drukier and L. Stodolsky, Phys. Rev. **D30** 2295 (1984).
[3] C.J. Horowitz, K.J. Coakley and D.N. McKinsey, Phys. Rev. **D68** 023005 (2003).
[4] S. Aune *et al.*, AIP Conf. Proc. **785** 110-118 (2005).
[5] I. Giomataris *et al.*, Nucl. Phys. Proc. Suppl. **150** 208-213 (2006).
[6] I. Giomataris *et al.*, JINST **3** P090007 (2008).
[7] E. Bougamond *et al.*, arXiv:1010.4132 [physics.ins-det], to be published at JMP (2010).
[8] E. Bougamont *et al.*, J.Phys. Conf. Ser. **309** 012023 (2011).
[9] I. Giomataris and J.D. Vergados, Phys. Lett. **B634** 23-29 (2008).