A Micromegas detector for the CAST experiment

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A MICROMEGAS detector has been mounted on the CAST experiment at CERN. Performance results of the detector, based on the first period of data taking in November 2002 and in May 2003, are presented. Preliminary results on efficiencies, background rejection and axion sensitivity are shown. A novel pixel MICROMEGAS detector is being developed to be coupled to a focussing X-ray telescope.

1. Introduction

The CAST (Cern Axion Solar Telescope) Collaboration is using a decommissioned LHC dipole magnet to convert solar axions into detectable photons. Axions are light pesudoscalar particles that were introduced to solve the strong CP problem[1] and can be Dark Matter candidates[2]. Stars could produce axions via the Primakoff conversion of the plasma photons. The CAST experiment aims to track the Sun in order to detect solar axions. The detection principle is based on the coupling of an incoming axion to a virtual photon provided by the transverse field of an intense dipole magnet, being transformed into a real, detectable photon that carries the energy and the momentum of the original axion. The axion to photon conversion probability is proportional to $(BL)^2$, where B is the transverse field of the magnet and L is the active length of the magnet. Using an LHC magnet (9 T and 10 m long) improves the sensitivity by a factor 100 compared to previous experiments. The achievable sensitivity for light axion masses (< 1 eV) can be expressed as follows:

$$g_{a\gamma\gamma} \leq 1.4 \times 10^{-9} \frac{b^{1/8}}{t^{1/8} B^{1/2} L^{1/2} A^{1/4}} \mathrm{GeV}^{-1}, \quad (1)$$

where b is the background (in counts/day) of the X-ray detector, t is the time of alignment with the sun in days, B is the magnetic field in Tesla, L is the length of the magnet in meters, and A is the area of the magnet bore in cm^2. All parameters are already fixed for CAST, except for the background for the X-ray detectors that should be lowered as much as possible in order to gain on sensitivity. The limits on the axion photon coupling as a function of axion mass are shown in Figure 1. In this figure, the expected CAST limit can be seen as well as previous limits from the SOLAX[3], COSME[4] and Tokyo[5] experiments. The region favoured by theoretical axion models is shown in grey. Also represented are the bounds from red giant stars[6] (dashed line) and exclusion derived from the absence of an axion decay[7] quasi-monochromatic photon line from galactic clusters.

It can be seen that the CAST experiment will be able to improve previous laboratory limits and the experimental sensitivity will surpass the astrophysical axion constraints.

2. Overall view of the CAST Experiment

The decommissioned LHC test magnet is twin-aperture and has an effective cross section of

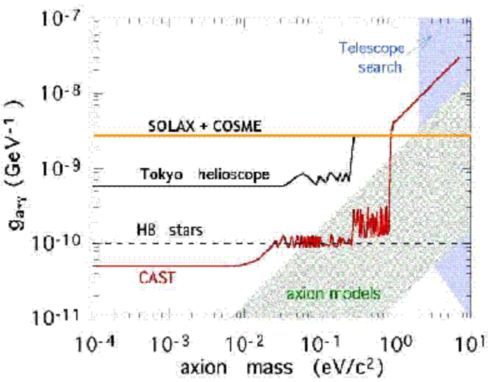

Figure 1. Limits on the axion photon coupling as a function of axion mass. The solid lines represent limits obtained by the SOLAX, COSME, Tokyo experiments and the expected limit for CAST. The dashed line is the bound from red giant starts.

2×14 cm^2. Detectors, at both ends, will look for the X-rays originated by the conversion of the axions inside the magnet when it is pointing the sun. The magnet is mounted on a platform allowing a mouvement of $\pm 8^o$ vertically and $\pm 40^o$ horizontally. This allows tracking of the Sun during about 1.5 hour at sunrise and the same time at sunset. The inclination of the magnet is limited by the cryogenic system that keeps it superconducting. A detailed description of the experimental setup can be found in [8].

Three different types of detectors have been developed to detect the X-rays originated by the conversion of the axions inside the magnet: a time projection chamber (TPC), a CCD and a Micromegas detector. The TPC is placed to be sensitive for X-rays from sunset axions. On the other side of the magnet, facing sunrise axions, a CCD detector and a Micromegas detector are working at the same time. For the moment the CCD detector is working in conjunction with a mirror system to focus X-rays coming out of the magnet bores. A Micromegas pixel detector, with higher rejection capability, is foreseen to replace the CCD. The mirror telescope focuses the X-rays induced from the magnet bore to a submillimeter spot. This allows the use of a very small detector and the improvement of the expected signal to background ratio by about two orders of magnitude.

3. The Micromegas detector

The Micromegas detector is a double gap chamber. It consists of a conversion gap separated from an amplification gap by a gauze-light electroformed conducting micro mesh. A full description of the detection principle can be found in [9]. For CAST, the conversion gap is 20 mm thick and the amplification gap is only 50 μm. The gas mixture is 95 % Argon and 5 % Isobutane. The field applied to the amplification gap is about 40 times higher than the conversion field so when an ionising particle goes through the conversion gap, electrons are released and they drift to the amplification gap where they are multiplied by an avalanche process. The charge is collected on X and Y strips of 350 μm pitch located on the same plane. The connections for the formation of the X strips are on the one side of the doubly clad Kapton, while connections for the Y strips are made on the other side, with the help of through plated holes on the Y-pads.

The Micromegas detector, which operates at atmospheric pressure, is interfaced with the LHC magnet, where the pressure is less than 10^{-6}mbar, by two thin vacuum windows. These two windows act as a buffer for the pressure gradient, to ensure that the leak rate is less than 10^{-5}mbar L^{-1} s^{-1} and at the same time to maximize the X-ray transmission in the energy range of interest for the axion search. The implemented setup is shown in Figure 2. Two thin windows of 4 μm polypropylene foil are used. The first window (Win 1 in Figure 2) lies between the magnet and the buffer vacuum. The second window (Win 2 in Figure 2) is made of aluminised polypropylene glued on a stainless steel strongback, defining the drift electrode. The volume between the magnet and the detector is continuously pumped.

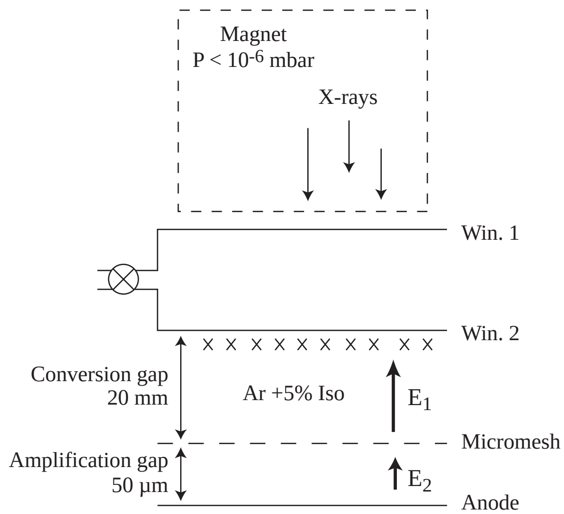

Figure 2. Schematic diagram of the Micromegas setup in the CAST experiment. E_1 is of the order of 1 kV/cm and $E_2 \simeq 40$ kV/cm.

The total X-ray loss in the solar axion energy range is of 15%. The advantage of using the double window with differential pumping is the very low leak of the detector gas into the magnet tube (3×10^{-9} mbar L^{-1} s^{-1}). The mechanical pieces of the detector are of Plexiglas due to its low natural radioactivity to limit as much as possible inherent background of the detector.

4. First Results

In May 2002 the Micromegas CAST detector was first characterized using a beam of photons at the PANTER X-ray facility at MPI Munich. The detector was mounted on the focussing mirror that is used for the CAST experiment. A focussed beam of photons of energies ranging from 1.5 to 8 keV was used. From these tests the mean efficiency of the detector was measured to be 50%. The resolution of the detector at 4.5 keV (the expected axion solar spectrum mean energy is 4 keV) was measured to be 18% (FWHM). The background rate was measured to be 3×10^{-6} counts keV^{-1} cm^{-2} s^{-1} with a photon efficiency of 47%.

In September 2002 the Micromegas detector was installed on the LHC magnet and the full electronics and acquisition system was tested. A special Faraday cage was designed in order to reduce the electronic noise. During November 2002 preliminary runs were taken in axion sensitive conditions (magnetic field at 9 T and tracking the sun during sunrise). These runs confirmed that the detector was working as expected.

The 2003 run of CAST was started on the 1st of May. Several runs have been already recorded. The electronics, acquisition and pumping system are working as expected. Micromegas records a data run at sunrise every morning, for the rest of the day a background run is recorded as well as calibration run with a ^{55}Fe source. The detector is showing good stability. In Figure 3 the distributions for the three types of runs can be seen after a preliminary sets of cuts for four days of data. The energy resolution at 5.9 keV is of 25% (FWHM).

The signal to background ratio optimisation is still in progress. Cuts to reduce background are based on strips multiplicities, well balanced energy deposition between the X and Y strips and search of a single cluster. First estimates are of the level of 3.6×10^{-5} counts keV^{-1} cm^{-2} s^{-1} with a photon efficiency of 57%.

A novel pixel Micromegas detector is being built to be coupled to the telescope. The active zone consists of 400 pixels with a pitch of 500 μm. The active zone is 1 cm^2. The mechanical elements are being constructed and the dectector will be assembled and tested by the autumn 2003. The expected sensitivity of this Micromegas detector coupled to the telescope should be 100 times better than the one obtained with the standard X-Y Micromegas detector.

5. Conclusion

The CAST experiment has entered the data taking phase since the beginning of May 2003 and for a period of three years under different running conditions. The very preliminary analysis of the data recorded during the first days of data taking shows that the initial expected sensitivity will be

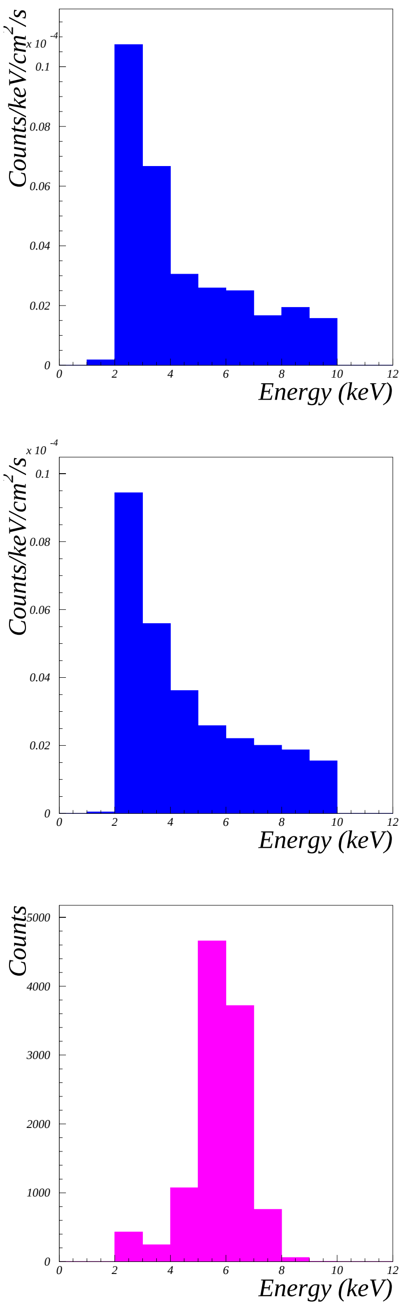

Figure 3. Distributions for the energy spectrum of solar tracking (top), background (middle) and calibration (bottom) runs using a ^{55}Fe source.

achieved. An improvement of about two orders of magnitude is expected by the use of the new pixel Micromegas detector in conjunction with the focusing telescope. A first test of the whole setup is expected for this autumn.

REFERENCES

1. R. D. Peccei and H. R. Quinn, Phys. Rev. Lett. **38**, 1440 (1977).
2. P. Sikivie, Int. J. Mod. Phys. **D3 S**, 1 (1994) and Phys. Rev. Lett. **51**, 1415 (1983).
3. F. T. Avignone *et al.* [SOLAX Collaboration], Phys. Rev. Lett. **81**, 5068 (1998).
4. A. Morales *et al.* [COSME Collaboration], Astropart. Phys **16**, 325 (2002).
5. Y. Inoue *et al.*, Phys. Lett. B **536**, 18 (2002).
6. G. G. Raffelt, Phys. Rev. D **33**, 897 (1986); G. G. Raffelt and D. S. Dearborn, Phys. Rev. D **36**, 2211 (1987).
7. M. T. Ressel, Phys. Rev. D **44**, 3001 (1991); M. A. Bershady, M. T. Ressel and M . S. Turner, Phys. Rev. Lett. **66**, 1398 (1991).
8. K. Zioutas *et al.*, Nucl. Instrul. Meth. A **425**, 482 (1999).
9. Y. Giomataris, P. Rebourgeard, J. P. Robert and G. Charpak, Nucl. Instrum. Meth. A **376**, 29 (1996).