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A Low Background Micromegas Detector for Axion Searches

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Abstract

A micropattern low background detector based on the Micromegas technology has been designed and constructed for the CERN Axion Search experiment CAST. The detector is made of low natural radioactivity materials and has a two dimensional readout X-Y strip structure. It is operated with an Argon/Isobutane (95%/5%) mixture and it is controlled by a VME data acquisition system. The detector is sensitive to photons in the energy range of 1-10 keV, it has a linear response, excellent stability and a very good energy resolution (14% FWHM at 5.9 keV). This device has been in stable operation since October 2002, taking data during the running periods of the CAST experiment. By the end of summer 2003 the detector has been upgraded with a flash ADC readout of the grid signal to further improve its background rejection capability. The currently achieved background rate under normal operation is about $2.0 \cdot 10^{-5}$ events/keV/cm²/sec with better than 85% software efficiency.

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1. Introduction

The Micromegas [1] technique is based on the gaseous micropattern detector technology and it is

well known for its excellent stability, fast response, very good energy and position resolution, high efficiency and its potential for use in low background rare event experiments. A Micromegas detector [2], optimized for photon detection in the energy range of 1-10 keV, was specifically constructed to permit

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operation at very low background levels in order to be used in the solar axion search experiment CAST at CERN.

The axions are pion-like neutral particles required by the prevalent theoretical solution of the strong CP problem by Peccei and Quinn [3]. These particles are expected to be abundantly produced in the core of the sun by photons via the Primakoff mechanism. Their potential detection on earth relies on the reverse Primakoff mechanism i.e. their interaction with the magnetic field of a strong magnet and subsequent production of equal energy X-ray photons (1-10 keV). The CAST [4] experiment uses a 10 m long super conducting magnet, with a 9 Tesla field, which was initially built as a prototype magnet for the new under construction accelerator LHC of CERN.

The Micromegas detector is one of the three types of detectors employed for the detection of the X-rays from the axion flux, the other two technologies used being those of TPC and CCD. This detector is mounted at one end of one of the two apertures of the magnet such as the X-ray photons enter the detector active volume perpendicularly to the X-Y strip plane.

2. The detector features

The novel features of this Micromegas design aim at the reduction of the background radiation from cosmic rays or from surrounding materials. These features include firstly the use of low natural radioactivity materials for the construction of the detector. Secondly, a conversion region and a two dimensional charge collection structure help distinguish signals based on the transverse size and the balance of the X and Y clusters. The detector frame consists of Plexiglas disks held together via plastic bolts. The drift or multiplication electrodes are attached on these disks. Fig. 1 is a schematic of the structure and operation principle of the detector. The conversion region is 25 mm thick and is formed between a 4 μm thick aluminized polypropylene window glued on stainless steel strong-back, capable of holding vacuum at the magnet side [5], and the micromesh plane. The window of the conversion region also serves as the cathode of the drift field of the order of 1 KV/cm. The electrons created by an ionizing particle (a photoelectron in this case) drift

towards the multiplication region, which follows. The multiplication region is only 50 μm thick and is formed between the micromesh plane and the charge collection plane with the help of Kapton pillars, on the micromesh plane, spaced 1 mm apart. The electric field in the multiplication region, being 40 times stronger than that of the drift region, is strong enough for the creation of avalanches by the electrons entering. The charge collection plane consists of 192 X and 192 Y strips with a 350 μm pitch by interconnecting pads in the same plane with the help of through plated holes. An X-ray photon, coming from the direction of the magnet, deposits a cluster of charge with lateral a size of about 4-8 X and 4-8 Y strips.

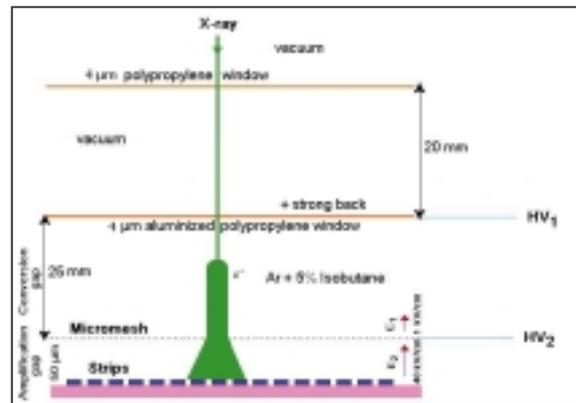


Fig. 1. Schematic of the structure of the Micromegas, showing the development of a cluster from an X-ray.

The detector is operated with an Argon/Isobutane (95%/5%) mixture. The charge on the X or Y strips is read out with the help of electronic cards based on the Gassiplex chip [6] controlled by a CAEN sequencer with two CRAM modules [7] in a VME crate. The micromesh signal is used to trigger the acquisition of an event. Because of the low rates involved (1 Hz) the zero suppression and pedestal subtraction capabilities of the CAEN modules are not utilized and all strip data are recorded. The data acquisition and monitoring system is based on National Instruments' LabView software running on a PC with Linux or Windows operating systems and the VME-MXI2 interface card. Fig. 2 is a schematic of the Micromegas data acquisition setup.

distinguish the photoelectric peak of the Copper from the X-Y strip plane, its Argon escape peak, the Iron photoelectric peak, coming from the strong back of the drift region window, and its Argon escape peak. These peaks are currently believed to be mostly due to excitations by cosmic rays. This is expected to be confirmed by the use of a scintillator wall, in the near future, to veto the cosmic rays out.

Table 1. Cuts applied and their effectiveness.

Cut applied	% events left (efficiency)
Rise time / width of grid pulse	10.8 (94%)
Only one X-Y cluster allowed	10.0 (91%)
Strip multiplicity/Energy balance	08.6 (86%)

The currently achieved background rate, as obtained by fitting the observed photo peaks and including a flat background, under normal operation is about $2.0 \cdot 10^{-5}$ events/keV/cm²/sec with better than 85% software efficiency.

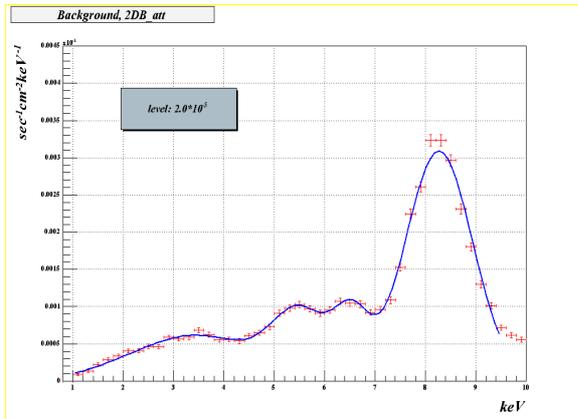


Fig. 5. Micromegas detector background data after cuts. The level achieved is $2.0 \cdot 10^{-5}$ events/keV/cm²/sec between 1-10 keV.

4. Conclusions and prospects

A Micromegas detector was constructed with X-Y strip readout and low background materials for the detection of 1-10 keV X-ray photons for the solar axion search experiment CAST at CERN. The last upgrade of the detector is the addition of a Flash

ADC VME module, which permits the recording of the time structure of the micromesh signal. The analysis of the events permit the rejection of a large fraction of cosmic ray related background using the observed properties of genuine photon events, like the rise time of the micromesh signal, the cluster size and the X-Y energy balance. The remaining background is under $2.0 \cdot 10^{-5}$ events/keV/cm²/sec with better than 85% software efficiency. This is expected to become better with the addition of a scintillator veto wall to reject cosmic rays at trigger level.

This Micromegas design has produced a powerful device for the detection of X-rays from axions in the energy range of 1-10 keV. Because of their excellent background rejection this type of detectors can be effectively used for other rare event searches.

Acknowledgements

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