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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 $2.0*10^{-5}$ events/keV/cm^2/sec with better than 85% software efficiency.

Keywords: Micromegas; low background detector; micropattern detectors; X-Y readout; X-ray detection

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.

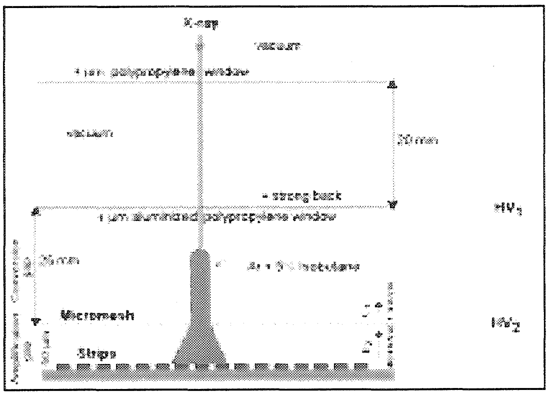

Fig. 1. Schematic of the structure of the Micromegas, showing the development of a cluster from an X-ray.

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.

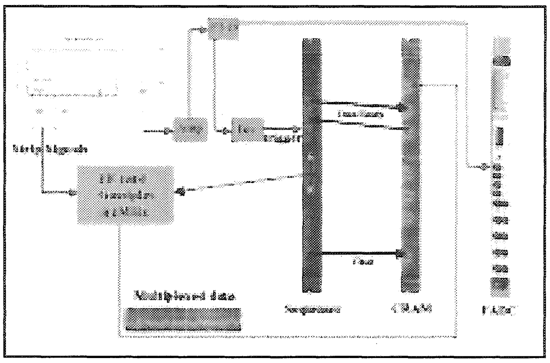

Fig. 2. Micromegas Data Acquisition schematic.

The features of this Micromegas detector also include the recording of the mesh signal and its processing via a flash ADC to record its time structure and reject signals without the expected shape. The Flash ADC is a 4-channel VME module, based on the MATRICE chip, designed by Saclay and LAL [8]. It has a 12 bit capacity and it is capable of handling up to 300 MHz input signals, with a sampling frequency of 2 GHz and very little noise (<200 μV RMS).

Fig. 3 shows one of the monitoring windows displaying one recorded event. The online X strips and Y strips activity can be seen together with the online Flash ADC analysis of the micromesh pulse.

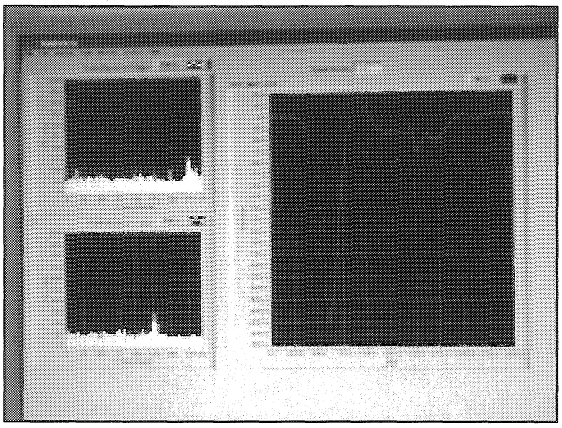

Fig. 3. Event Display showing one of the Micromegas events recorded.

3. Detector performance

This Micromegas detector has a linear response and a very good energy resolution by using either the micromesh signal or the X and Y strip depositions. It has excellent linearity and accurate position determination to better than 100 μm. Figure 4 shows the micromesh integrated charge as a response to 5.9 keV X-ray photons from a ^{55}Fe source, used for calibration purposes, where the Argon escape peak is also clearly observed. The energy resolution at 5.9 keV is best obtained from the integration of the micromesh pulse and it is 14% FWHM.

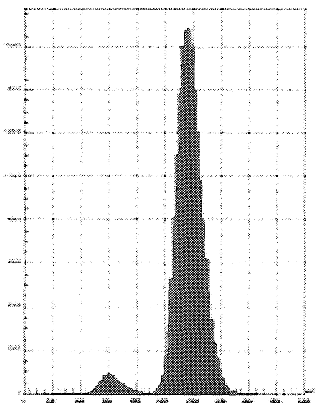

Fig 4. Integral of the mesh pulse from 5.9 keV γ's.

This device has been in stable operation since October 2002, taking data during the running periods of the CAST experiment. Its latest upgrade, at the end of summer 2003, with the flash ADC readout of the grid signal improved the background rejection capability by a factor of three.

Background data obtained during 476 hours of running with the Micromegas detector have been analysed. All events of 1-10 keV and within the fiducial area of 15.9 cm^2, with deviations from the expected time structure or energy balance or cluster size of an X-ray impinging perpendicularly to the polypropylene window into the detector were rejected (see cut details in table 1). The remaining X-ray-like events are shown in fig. 5. The features of the plot correspond to the photo peaks of the various materials present in the detector and their escape peaks. In descending energy order, one can 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 $2.0*10^{-5}$ events/keV/cm^2/sec with better than 85% software efficiency.

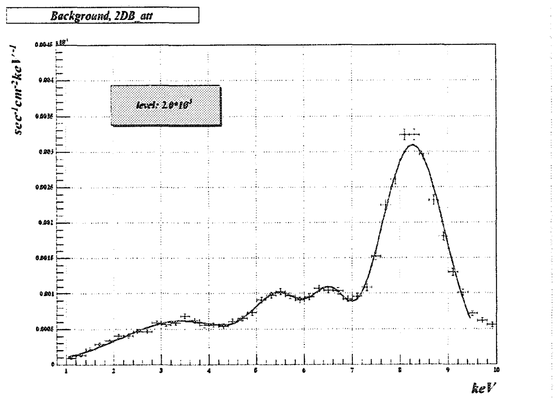

Fig. 5. Micromegas detector background data after cuts. The level achieved is $2.0*10^{-5}$ events/keV/cm^2/sec between 1-10 keV.

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 $2.0*10^{-5}$ events/keV/cm^2/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.

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References

[1] Y. Giomataris, Ph. Rebourgead, J. P. Robert and G. Charpak, NIM A376 (1996) 29, Y. Giomataris, NIM A 419 (1998) 239, J.I. Collar, Y. Giomataris, NIM A469 (2001)249.
[2] "MicroMegas Photon Detectors for CAST", by S. Andriamonje et al., CAST internal status report.
[3] R.D. Peccei, H.R. Quinn, Phys. Rev. D 16 (1977) 1791, R.D. Peccei, H.R. Quinn, Phys. Rev. Lett. 38 (1977) 1440.
[4] K. Zioutas et al., NIM A425 (1999) 480.
[5] S. Andriamonje et al, NIM A518 (2004) 252.
[6] J.-C. Santiard et al., CERN-ECP/95-17, NIM A 360 (1995).
[7] V551 C.A.E.N. Sequencer User Guide, V550 C.A.E.N. CRAM User Guide.
[8] The Flash ADC VME module is designed by E. Delagnes of CEA/Saclay and D. Breton of IN2P3/LAL.