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The use of the Micromegas technology for a new imaging system

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Abstract

The Micromegas (Micromesh Gaseous) detector technology was developed by I. Giomataris and G. Charpak, in the mid 90s, for applications in the field of experimental Particle Physics. The most recent development is a novel Micromegas detector designed to detect photons of energies 1–10 keV (X-ray range), for a discovery experiment of the hypothetical particles called axions, installed and currently taking data at CERN (the European Laboratory for Particle Research in Geneva). This detector has an X-Y readout capability of resolution less than 100 µm, an energy resolution down to 14%, for this energy range, and an overall efficiency of 70%. With planned modifications, similar performances can be achieved for operation in the energy regime of the technetium gammas. This could lead to a novel γ -ray imaging device with spatial resolution in the submillimeter range. Initial results are presented obtained using the current detector with a parallel hole collimator to image thin capillary phantoms filled with a ^{99m}Tc water solution. © 2004 Elsevier B.V. All rights reserved.

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1. Introduction

The Micromegas [1] (Micromesh Gaseous) detector technology was developed by I. Giomataris and G. Charpak, in the mid 90s, for applications in the field of experimental Particle

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Physics. A recent development is the novel Micromegas detector [2] designed to detect photons of energies 1–10 keV (X-ray range), for the CAST experiment [3] searching for the so far undiscovered particle axion, generated in the sun's core, currently taking data at CERN, the European Laboratory for Particle Research in Geneva. This detector has an X-Y readout capability with a spatial resolution of less than 100 µm, and an energy resolution better than 14%, for this energy range. This paper investigates the current

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capability of this detector to record the position of Technetium gammas and initiates the work on the modifications needed to construct a detector appropriate for use in medical imaging applications.

With planned modifications excellent performance could be achieved for operation in the energy regime of the 141 keV (the energy of the technetium gammas). This would lead to a novel γ ray imaging device with spatial resolution in the submillimeter range. We present initial results obtained using the current detector with a parallel hole collimator to image thin capillary phantoms filled with ^{99m}Tc water solution.

2. Description of the Micromegas detector

The principle of operation of the Micromegas detector as applied to the CAST experiment is shown in Fig. 1. The X-rays, after going through a buffer region filled with He (or being in vacuum), enter the active volume of the detector, consisting of the conversion space and amplification gap. The active volume of the detector is filled with an argon/isobutane (95%/5%) gas mixture. Most of the low-energy photons convert, via the photo-electric effect, into an electron which ionizes the gas medium. The secondary electrons drift towards the amplification gap where electron ava-

lanches are produced and collected by the X and Y strips of the anode. The innovation of the Micromegas detector technology is in the amplification gap design. The essential ingredient is a metallic micromesh with 25 µm holes, 50 µm apart, where the secondary electrons funnel through. The high field region is formed between the micromesh and the X-Y readout strips with the help of 50 µm high pillars etched on the micromesh. The X and Y strips have a pitch of 350 µm. The thickness of the amplification gap is maintained uniform throughout its active area resulting in a uniform gain and stability of operation. The detector is operated with a gain of about 10⁴.

The charge cluster, obtained from an X-ray photon converted to electron via the photoelectric effect, is distributed among about three to six X and Y strips. The barycenter of the X or Y cluster gives the X or Y position with an accuracy of the order of 70 µm.

The readout of the charge of the X and Y strips is obtained via four readout cards [4] based on the Gassiplex chip.

The signal for triggering the Micromegas device is obtained through the use of a preamplifier, which provides the high voltage for the micromesh (grid) as well. The data acquisition system is based on the VME technology with a National Instruments interface to PC and the LabView software (see Fig. 2). The readout cards are read via a CAEN sequencer and CRAM modules. The number of channels read in each event is about 400 and the speed of the event acquisition is about 150–200 Hz.



Fig. 1. The Micromegas principle of operation as used for the construction of this type of CAST X-ray detectors.



Fig. 2. The Micromegas DAQ system.

3. Operational characteristics of the Micromegas detector

The Micromegas X-ray detector is routinely calibrated and monitored using a ⁵⁵Fe source. Two detectors, constructed for the CAST experiment, were thoroughly tested with various energies of X-ray photons in the range of 1–10 keV (the range of operation in the CAST experiment) in the PANTHER facility of the Max Planck Institute in Munich. The tests showed the excellent proper-



Fig. 3. X-Y profile of a 4.5 keV X-ray focused beam.

ties of the detector in this energy range and determined the appropriate to the CAST experiment operational parameters.

Fig. 3 shows the positional capabilities of the detector which reproduces the beam shape in X and Y directions. An X-ray grazing incidence telescope focuses the X-ray beam. The core of the beam is less than 1 mm in one direction and the plot with the logarithmic scale exemplifies the properties of the focusing device.

The energy measurement performance of the Micromegas detectors for 6.4 keV X-ray photons is shown in Fig. 4. The photoelectric peak at 6.4 keV is seen together with the Argon escape peak at 3.4 keV. The total energy resolution is about 14% in this energy range.

The Micromegas detector setup has been successfully recording data in the CAST experiment, at CERN, since October 2002.

4. Micromegas for medical imaging

The Micromegas detector as developed for the CAST experiment is quite efficient for low energy X-ray detection. However, when the energy of the photons increases, the efficiency of the current design of the detector drops and reaches values below 1 per thousand for energies of the order of 141 keV (see PDG). This is expected since the



Fig. 4. X and Y energy distributions for focused 6.4 keV X-rays.

photoelectric cross-section decreases with energy. It is obvious that for efficient use in medical imaging instrumentation, the detector needs to be modified. Suggested modifications include heavier gases (e.g. xenon), higher pressure and insertion of proper converter materials. As the energy increases the Compton scattering becomes more important. The advantage of this detector is that events initiated by Compton scattering can be used for the position determination after proper filtering to select only the forward going tracks. This selection is based on restricting the strip multiplicity of the X and Y clusters.

The positional accuracy required for medical imaging is also much less than the specifications of this detector. A capability of less than 1 mm will be obtained by increasing the X and Y strip width and consequently decreasing the number of channels to be read by a factor of ten. This will result in a much faster event acquisition expected to exceed the 1 kHz rate.

5. Results with technetium phantoms

We have investigated the current capability of this detector to 'see' a technetium capillary phantom despite its low efficiency and relatively slow event acquisition due to the large size of the events. We used capillaries with internal diameter of 1.15 mm filled with a 99m Tc water solution. The technetium gammas entered the Micromegas chamber after going through a 2 cm thick lead collimator block with hole diameter of 1.5 mm and hole pitch of 2.5 mm.

Because of the geometry of the setup, the apparent thickness of the capillary as measured on the X-Y readout plane of the detector is expected to be about 6.8 mm (see Fig. 5). However, selecting events with clusters of restricted strip multiplicity results in selecting more forward-going gammas. As a result, the apparent thickness of the capillary phantom will be less than the geometrically expected one.

We used a prototype Micromegas detector, for these tests, with the following operational parameters: A 90%/10% gas mixture of argon/



Fig. 5. The apparent thickness D=6.8 mm of the phantom capillary on the readout plane of the detector ($\delta = 1.15 \text{ mm}$, d = 1.5 mm, h = 2 cm, H = 4 cm).



Fig. 6. The data acquisition and Micromegas setup for the tests.

isobutane, a grid voltage of 330 V and a drift voltage of 1000 V.

The experimental setup used is shown in Figs. 6 and 7.

Only one quadrant of the active area of the detector was instrumented for these tests. Fig. 8a shows the X and Y plot of a single phantom capillary while Fig. 8b shows the distribution of the events transverse to the capillary axis. The events were selected so that the clusters had multiplicities between 6 and 14 strips and the energy was more than 150 channels. There was a small inactive area of several X-strips, as seen in the scatter plot of Fig. 8a.

The resulting FWHM of the apparent transverse distribution of the single capillary phantom is 5.3 mm. This can be improved by bringing the



Fig. 7. The technetium phantoms with the lead collimator on the detector.



Fig. 8. (a) X and Y distribution of the events from single phantom. (b) Transverse distribution of events from single capillary phantom. The FWHM of the fit is 5.3 mm.



Fig. 9. X distribution (transverse) of the two phantom capillaries. The left phantom is too close to the edge of the instrumented region.

collimator closer to the detector active volume and also by using a finer collimator (smaller hole diameter).

Two capillary phantoms were also used placed along the X-strips and 7.5 mm apart. The X projection of the X-Y distribution of these events is shown in Fig. 9.

The observed distance of the two capillaries is 7.6 ± 0.3 mm, quite consistent with their real distance.

6. Discussion of the results and future prospects

We have investigated the medical imaging capabilities of a prototype Micromegas detector designed for use in the CAST experiment at CERN searching for solar axions. We used single and double technetium sources in the form of medical capillary phantoms. Given the measured positional resolution of the detector and the geometry of the setup, and despite the low efficiency for 141 keV X-ray photons, excellent agreement was obtained on the expected sizes and distances.

Obviously, further development is needed to improve the total efficiency of the detector to acceptable values. The introduction of thin converters is one of the main routes to be followed. However, higher pressure gases and heavier gases are also among the possible solutions. Moreover, the planned introduction of time readout for the strip signals will provide three-dimensional information of the track and help determine the direction of the incoming X-ray thus eliminating the use of the collimator and further improving the overall efficiency.

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