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RECENT DEVELOPMENTS OF MICROMEGAS DETECTORS FOR HIGH ENERGY PHYSICS

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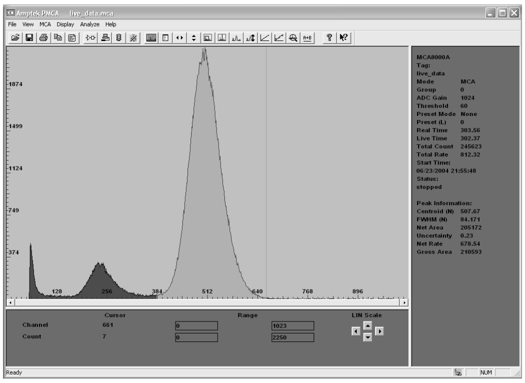
Since one or two years, Micromegas detectors have broken records in many respects: time and spatial resolution, single electron detection, low ion backflow, high rate capabilities, low energy threshold and low-noise detection. The recent achievements in these directions, obtained in the COMPASS, NA48 (KABES), and CAST experiments, and in R&Ds for the Linear Collider TPC and for low-energy neutrino detection, are presented. The reasons for such a success, inherent to basic properties of Micromegas, are explained.

1. Principle of Operation

The Micromegas Detector was invented by I. Giomataris, G. Charpak, and collaborators in 1995 [1]. The principle is very simple: the gas volume is separated by thin micromesh in two regions, one where the conversion and drift of the ionization electrons occurs and one, 50-100 micron thick, where the amplification takes place. In the amplification region, a very high field (40 to 70 kV/cm) is created by applying a voltage of a few hundred volts between the mesh and the anode plane, which collects the charge of the avalanche. The anode can be segmented into strips or pads.

The advantages of Micromegas follow from the smallness of the amplification gap and the particular configuration of the electric field on the two sides of the mesh, itself depending on the mesh pitch. The gap being very small, the size of the avalanche and hence the signal rise time are very small, leading to an electron signal of a few nanoseconds and an ion signal usually less than 50-100 ns, for most of the gas mixtures. Starting from the avalanche concentrated in the last few microns of the gap, the ions flow back to the mesh in the almost uniform amplification field. This avoids the ballistic deficit and the 1/t tails present in the wire chambers. Such a fast signal and ion collection allows high rates to be sustained. Thanks to the 'funnel-shaped' field lines configuration, an almost 100% electron collection efficiency is achieved, provided the field ratio between the two regions is large enough and the mesh thin enough. In addition, it can be shown that for a given voltage applied to the grid, the gas gain exhibits a flat maximum as a function of the gap, reached for a value of a few tens to hundred microns, depending of the gas mixture. These two properties are the ingredients of an excellent energy resolution, close to the statistical limit, as illustrated by the ^{55}Fe peak and its escape line in Argon shown in Fig. 1.



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Status:
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Peak Information:
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FWHM (N) 84.171
Net Area 205172
Uncertainty 0.23
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Gross Area 210593

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Count	7	0	2250

Figure 1. ^{55}Fe line and its escape line observed in a Micromegas detector filled with an Argon mixture. The resolution is 6.8% r.m.s.

For mesh pitches less than 20-50 microns, the extension of the avalanche is as large as the inter-hole space, forcing most of the ions to drift back to the mesh instead of drifting back to the drift volume. This reduction at the 3 per mil level of the ion backflow is very important for avoiding distortions due to ion space charge in a TPC, as demonstrated in Ref. [2].

All or some of these properties, privileging one or another, are used in the various applications of Micromegas.

2. Experiments in Progress

Micromegas has already been applied to several High Energy Physics experiments. Let us review them briefly.

2.1. *COMPASS*

The COMPASS experiment intends to measure spin-dependent structure functions of the nucleons and the relative contributions of u, d, s quarks and gluons. The detection of Minimum Ionizing Particles is done by Micromegas chambers 40x40 cm^2. These are the largest Micromegas chambers presently in operation. The segmentation of the anode into 350 µm strips allows a spatial resolution better than 70 µm. They sustain a high particle flow: 105 kHz/cm^2, with a dead time due to sparks kept below 1 per mil thanks to the choice of a Neon-based gas mixture. COMPASS is in operation at CERN since 2002 with efficiency in excess of 97%.

2.2. *CAST*

The CERN Solar Axion Telescope aims at detecting solar axions converted in the 8 tesla field of a LHC magnet. The expected spectrum of the X-ray signal peaks around 5 keV.

One of the detectors used at the focal point of the telescope is a Micromegas with a 50 micron gap stretched over an anode segmented in two overlayed crossed sets of strips, allowing a 2D readout [3]. The energy threshold of this detector is as low as 600 eV. The background is low (2 10^{-5} at ground level without shielding) and consists of well identified fluorescence lines of the constituents of the detector (copper and iron), and their escape lines (Fig.2).

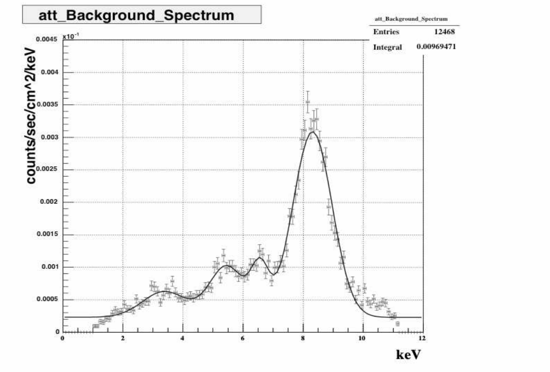

Fig. 2. Low-energy background spectrum from the CAST detector. The 8 KeV copper line and others are visible

2.3. *NA48/KABES*

KABES is a charged kaon beam spectrometer. It equips the NA48 experiment at CERN since 2003 [4]. The main goal of NA48 is to measure asymmetries in the $K^{\pm} \rightarrow \pi^{\pm}\pi\pi$ decays. Each station consists of a pair of head-to-tail 6-cm-drift TPCs with opposite drift fields, each being readout at one end by a Micromegas with anode strips. The space resolution obtained from the difference between the two drift times is 70 microns. The time resolution is better than 0.6 ns (Fig. 3).

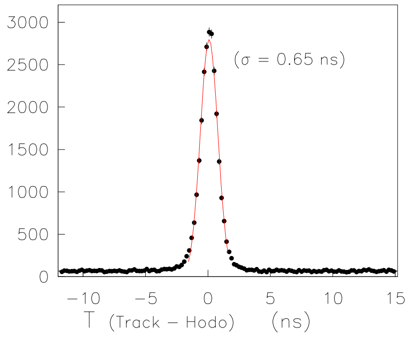

Fig. 3. Time difference distribution between the KABES spectrometer and the hodoscope; the hodoscope itself introduces a 0.3 ns contribution to the width of this distribution

The efficiency is kept close to 100% at a rate of 10^7 hadrons/cm^2/s, with no sign of aging. This is a step forward in the search for $K^\pm \rightarrow \pi^\pm \nu\nu$ decays at even higher beam intensities.

3. Developments in Progress

3.1. *TPC for the Linear Collider*

There are challenging requirements to fully exploit the outcome of the e+e- collisions at the linear collider. It has been early recognized that a large TPC is the best way of providing a fine granularity in the 3 dimensions at a relatively low cost and very low material budget, together with high redundancy for pattern recognition, including V0 reconstruction.

Disentangling the tracks in very narrow and dense jets as well as in high energy tau decays in three prongs requires O(8 mm) two-track separation both in z and in $r\phi$. The high photon and neutron background activity which prevails at the Linear Collider calls for a high granularity, low ion backflow and low Hydrogen content of the gas. The excellent jet resolution required to study, for instance, two-jet + missing energy final states requires a good particle flow analysis, which in turn calls for a low material budget of the endplate in front of the calorimeters. Particle identification requires a good *dE/dx* resolution. All these requirements are likely to be fulfilled by a Micropattern TPC, especially a Micromegas TPC.

The Berkeley-Orsay-Saclay collaboration has been taking cosmic-ray data with a large 1000-channel Micromegas TPC prototype in a 2T magnetic field [5]. Very accurate measurements of the diffusion coefficient of various gases are in progress and first results show that a point resolution better than 100 micron at zero-drift distance should be obtained at the collider.

A new technique for improving the resolution [6] has been successfully developed and tested. It makes use of a resistive coating over the anode pads to share the charge between neighboring pads, allowing a center-of-gravity determination of the space coordinates. A resolution 25 times smaller than the size of the pads has been achieved with a Micromegas device [7].

3.2. *NOSTOS, a Spherical TPC for Neutrino Detection*

The principle of neutrino oscillation measurement in a single experiment has been suggested in Ref. [8]. The authors suggest building a large (20 m diameter) spherical TPC read out by a Micromegas detector in the middle, surrounding a Tritium neutrino source.

Elastic interactions of the 10-15 keV electron neutrinos from the source can be localized in a large spherical TPC, making use of the strong dependence of the rise-time of the signal on the distance to the center of the sphere, in the $1/r^2$ drift field. The number of neutrino interactions as a function of this distance is expected to show a characteristic oscillation pattern with a half-period of about 7 meters, however significantly washed out by the presence of neutral current interactions of the other neutrino species with electrons from the gas.

Such a spherical TPC, or smaller copies, without the Tritium source, would also allow detection of nuclear plant neutrinos and of supernovae neutrinos from the recoil of nuclei in the gas, provided the N^2 enhancement of the neutral-current cross-section expected from coherent effects is present.

3.3. *Micromegas readout by Silicon Pixels*

A CERN-NIKHEF-Saclay-Twente collaboration recently demonstrated the detection of iron 55 quanta [9] and of minimum-ionizing particles [10] in a Micromegas detector read out by the Medipix2

CMOS chip. This chip has 65000 pixels, 55x55 microns each. This is a very powerful tool to study the charge flow in Micromegas, and this shows the possibility of making a digital TPC, with simple counting of ionization clusters.

3.4. *Bulk Micromegas*

A novel technique for manufacturing Micromegas detectors in a single process has been developed in 2004, by a CERN-Saclay collaboration [11]. A woven mesh is laminated on a PC board covered by a photo-imageable polyimide film, and the pillars are made by a photochemical technique with insolation through the grid. Such a detector ‘all-in one’, called ‘bulk’ Micromegas, is robust and will allow large areas to be made in one piece. A large variety of metals are available for the mesh.

3.5. *Neutron Detection*

Neutron detectors have been built by equipping a Micromegas detector with a converter (a ^{6}Li foil producing α rays for instance). Applications of such detectors include neutron tomography, which will allow observing hydrocarbon flows through a metal, or neutron detection in hostile environments, owing to the high robustness of such a detector.

4. Conclusions

Over the past one or two years, Micromegas has reached the statute of a mature technology. The infancy troubles encountered in the first prototypes (sparking) have been got around by improved manufacturing techniques and by suitable choices of operating gases. Micromegas offers exciting perspectives for high energy particle detection, as high granularity, suppressed ion backflow, single electron detection with a fast signal, record-breaking time resolution and low matter budgets.

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