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Secondary electrons detectors for beam tracking: micromegas and wire chamber

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J. Pancin,[a,b,1] **T. Chaminade,**[b] **A. Drouart,**[b] **B. Fernandez,**[c] **M. Kebbiri,**[b] **F. Naqvi**[d,e] **and M. Riallot**[b]

[a]*GANIL, bvd H. Becquerel, Caen, France*
[b]*CEA-DSM/IRFU, Gif Sur Yvette, France*
[c]*CNA, University of Sevilla,*
c/T. Edison, Sevilla, Spain
[d]*IKP, University of Köln,*
Zülpicher Str., Köln, Germany
[e]*GSI, Planckstr., Darmstadt, Germany*

E-mail: pancin@ganil.fr

ABSTRACT: SPIRAL2 or FAIR will be able to deliver beams of radioactive isotopes of low energy (less than 10 MeV/n). The emittance of these new beams will impose the use of beam tracking detectors to reconstruct the exact impact position of the nuclei on the experimental target. However, due to their thickness, the classical detectors will generate a lot of energy and angular straggling. A possible alternative is the SED principle (Secondary Electron Detector). It consists of an emissive foil placed in beam and a detector for the secondary electrons ejected by the passing of the nuclei through the foil. An R&D program has been initiated at CEA Saclay to study the possibility to use low pressure gaseous detectors as SED for beam tracking. Some SED have been already used on the VAMOS spectrometer at GANIL since 2004. We have constructed new detectors on this model to measure their performances in time and spatial resolution, and counting rate. Other detector types are also under study. For the first time, a test with different micromegas detectors at 4 Torr has been realized. A comparison on the time resolution has been performed between wire chamber and micromegas at very low pressure. The use of micromegas could be promising to improve the counting rate capability and the robustness of beam tracking detectors.

KEYWORDS: Wire chambers(MWPC, Thin-gap chambers, drift chambers, drift tubes, proportional chambers etc); Timing detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MICROMEGAS, InGrid, etc); Particle tracking detectors (Gaseous detectors)

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[1] Corresponding author.

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1 Introduction

New accelerators like SPIRAL2 (GANIL, Caen, France) or FAIR (GSI,Darmstatd, Germany) will be soon constructed. They will be able to provide beams of radioactive isotopes of energy lower than 10 MeV/n. They will be used to study the nuclear structure of new isotopes like super-heavy nuclei, neutron rich or neutron deficient nuclei or highly deformed nuclei. These beams have generally a large emittance, which impose to use tracking detectors before the target in order to reconstruct the exact trajectory of the incoming ions. The CATS (Chambre à Trajectoire de Saclay) have been used successfully at GANIL for 10 years [1] as Beam Tracking Detectors (BTD). However, they don't fit anymore with the new characteristics of the beam. Due to its low energy, they would generate a lot of energy and angular stragglings. One solution consists in placing an emissive foil in beam and detect the secondary electrons with a detector off-beam. This concept (SED) has been applied several times and has been working since 2004 at the focal plane of the VAMOS spectrometer at GANIL [2]. The emissive foil permits to really minimize material in beam with 130 μg/cm^2 (0.9 μm of aluminised mylar) compared to 600 μg/cm^2 in the case of CATS. The performance of this detector has too be slightly improved compared to the SED, notably in terms of counting rate. The detection efficiency has to be close to 100% for heavy to medium ions. Since this detector can used for triggering, its time resolution has to stay below 0.5 ns (FWHM). The spatial resolution has to match with the one of the other detectors (like MUST2 for instance) that is to say around 1 mm (FWHM). The intensity of the ion beams could go beyond 10^6 ions$/(cm^2.s)$, which is at least one order of magnitude more than the existing beam. Thus the detector should be able to cope with this flux.

Several detectors are good candidates to work with an emissive foil. Micro-channel plates are widely used as secondary electron detectors for their good time and spatial resolution [3]. Nevertheless, their size is quite limited (60×90 mm^2) and they are quite restrictive and expensive.

Diamonds detector could also be very interesting with very good timing properties and high robustness. However, the process is still very expensive for large surface with good homogeneity. Gaseous detectors at low pressure ($\simeq 10$ mbar) are another alternative. Their functioning is well known in nuclear physics since they have been widely used (proportional chamber, drift chamber, CATS, SED...), they are cheap and can be repaired quite easily. The first idea is to reduce the size of the actual SED used in VAMOS and to check the time and spatial resolutions. Moreover, a second gaseous detector called Micromegas [4] could achieve the same results as a wire chamber at low pressure. We have thus decided to test it at low pressure.

The first part of this article is dedicated to the tests performed with a mini-SED. The set-up to measure the time resolution is explained and the obtained results are given and commented. A second part is focused on the functioning of Micromegas at very low pressure and some results concerning the timing properties are also given.

2 The mini-SED detector prototype

2.1 Technical description and principle

The principle of functioning of a secondary electrons detector is fully described in [2]. In brief, an aluminised mylar foil of 0.9 μm inclined at 45° is positioned in front of the beam and polarized at -10 kV. A grid at ground is positioned at 1 cm from the foil. The incoming ions pull out electrons from the surface of the foil with a mean energy of about 10 eV. The number of secondary electrons depends on the nature of the projectile and also on the material of the foil. They are then immediately accelerated up to 10 keV and fly to the detector. In the case of the SED used on VAMOS, the detector is at 20 cm from the emissive foil. At this distance, it has been demonstrated that a magnetic field is mandatory in order to guide the electrons and to obtain a good spatial resolution. In our case, the detectors are just in front of the target, the beam tube is much smaller and the detector will be closer to the foil. Nevertheless, a magnetic field is still necessary to achieve good spatial resolutions.

The prototype is a copy of the SED but miniaturized. A shematic of this detector is shown in figure 1. It is a multi-wire gaseous counter which permits 2D position measurements and time measurement with an active surface of 70×70 mm^2. The gas, pure isobutane circulating at 4 Torr, is enclosed in between an aluminized mylar foil of 0.9 μm reinforced by a metal mesh (with 83% of transparency) and a printed circuit. The anode, polarized at about 550 V, is a plane of 20 μm diameter wires and is on top of the printed circuit at 1.6 mm or 3.2 mm depending on the prototype. Another wire plane, the cathode, perpendicular to the anode and placed on top of it, at 1.6 mm or 3.2 mm as well, gives the Y-position. It is composed of 50 μm diameter wires soldered every 1 mm and linked by three. The printed circuit is composed of 1D strips with 2.54 mm pitch separated by 100 μm to get the X-position information.

The accelerated electrons of 10 keV pass the entry foil with 70% efficiency. The energy deposit per electron is about 150 eV in the 3.2 mm of gas at 4 Torr which is giving around 6 ionization electrons. These electrons drift toward the anode wire plane and are amplified. Thanks to the very low pressure, the amplification takes place far from the wires in the drift region. This avalanche touches several wires because of transverse diffusion. The whole wire plane is equipped with a fast

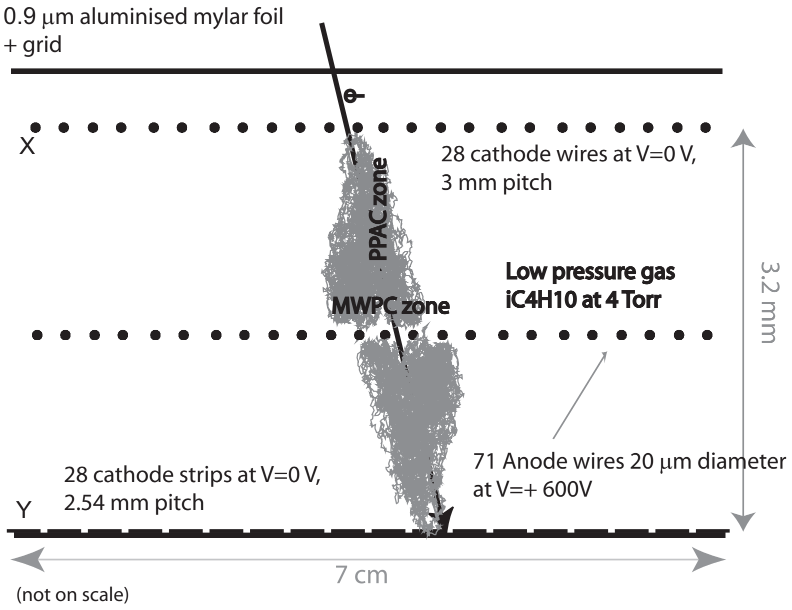


Figure 1. Shematic of the detector.

amplifier permitting to get a time signal. On the opposite, the two cathode planes (wires and printed circuit), are connected to slower charge amplifiers with higher gain and give the spatial information.

2.2 Time resolution

The time resolution is an important issue for these detectors, that are first intersected by the beam. It has to be measured in coincidence with two others detectors with an equivalent time resolution. A silicon detector and another SED detector were used. A ^{252}Cf source is placed at 45° from a square emissive foil (70×70 mm^2) with an extraction grid on each side. The silicon detector is positioned on the other side of the emissive foil in front of the source. On both sides of the foil, at equal distance, there are the two gaseous detectors, one forward that is to say on the same side with the silicon, and one backward. The detector for which the time resolution is wanted is forward like in real conditions. The forward detector will always receive about a factor of three more electrons because of a small kick given by the incident ions. The silicon detector is used as trigger since it is in front of the source pointing at the center of the foil. It permits also to separate light fission fragments from the heavy ones applying a selection on the signal amplitude. The time signal of each detectors is registered by a Matacq card that has a time resolution of 25 ps [5]. The analysis is then done off-line. Using a constant fraction of generally 20% on the amplitude, a start time is determined for each detector. The three time differences between the three detectors are calculated and it gives three time resolutions. Since the time resolution of each detector are uncorrelated, it is possible to get the resolution of each detectors. This set-up is also interesting because the time difference measured between the two gaseous detectors is independent of the time of flight of the fission fragments.

The first prototype used for these measurements was a 2×3.2 mm gap while the SED has only 1.6 mm. The gas pressure was 4 Torr. The calculated time resolution of the prototype is 260 ± 80

ps (σ) for the heavy fragments at 650 V while the calculated time resolution of the SED is 250 ± 80 ps at 600 V backward. The resolution is higher than the 250 ps (FWHM) quoted in [2] because the detector is backward. The resolution of the prototype is also acceptable considering that the gap is twice the one of the SED. In that case, the signal is seen later and thus the time resolution slightly degraded. The errors are quite important but it is normal considering the time resolution of the silicon detector (520 ± 40 ps). Another mini-SED prototype of 2×1.6 mm gap has also been tested. Its time resolution, measured with the same set-up, is 150 ± 80 ps at 550 V forward. It confirms the logical influence of the drift gap size on the time resolution. Finally, this result is validating the miniaturized version of the SED in terms of time properties.

3 The micromegas prototype

Micromegas are widely used in particle or nuclear physics. This gaseous detector has demonstrated its capabilities like high counting rate, good time and spatial resolution and robustness. Above all, what is interesting is its versatility. This detector is usually used close to atmospheric pressure with mixtures of a rare and a polyatomic gases. It has been introduced first in particle physics to avoid the drawbacks of wires chambers like space charge effects due to long ion drift length or limitation in spatial and time resolution. It is then interesting to see if the same advantages apply at low pressure. A comparison is made between the mini-SED and different prototypes of Micromegas in terms of gain and time resolution.

3.1 Technical description and principle

Micromegas detectors are composed of two zones separated by a micromesh, a drift gap of several millimeters and an amplification gap of several tens of microns [7, 8]. A weak electric field is applied in the drift gap while a strong field is applied in the amplification gap. In these conditions, the field lines make a funnel through the micromesh. If a charged particle passes through the gaseous detector, ionization electrons are created mainly in the drift zone. These electrons drift towards the micromesh, and are transferred to the amplification gap. They are multiplied by avalanche and a signal can be observed either on the micromesh or on some strips facing the mesh on the opposite side of the amplification gap. However, at a very low pressure of 4 Torr, the operation mode is different. It was demonstrated that pure isobutane was a good gas (high gain, good time resolution...) at very low pressure [6]. Then, the first test to do was to compare the gain capabilities of micromegas compared to mini-SED in isobutane at low pressure.

At this pressure of 4 Torr, there are two ways to do amplification using a micromegas detector. It is possible either to use large amplification gap [9] (more than 500 microns), in order to get a good stability and to compensate the decrease of the townsend coefficient, or to do a pre-amplification in the drift gap keeping a small amplification gap. To keep high counting rate capability, the second solution was investigated. The reduced critical electric field E_c/P in V$\cdot$cm$^{-1}\cdot$torr^{-1} is the field at which an avalanche begins. It is a characteristic value of the gas between 40 and 90 V$\cdot$cm$^{-1}\cdot$torr^{-1} for most gases [10]. It means that at 4 torr for example, a field of only 400 V/cm is enough to initiate the avalanche process. At 1 bar in a wire chamber, the avalanche takes place between 3 and 5 wire radius (about 50 microns). But at low pressure, it can take place for example at 1 mm from

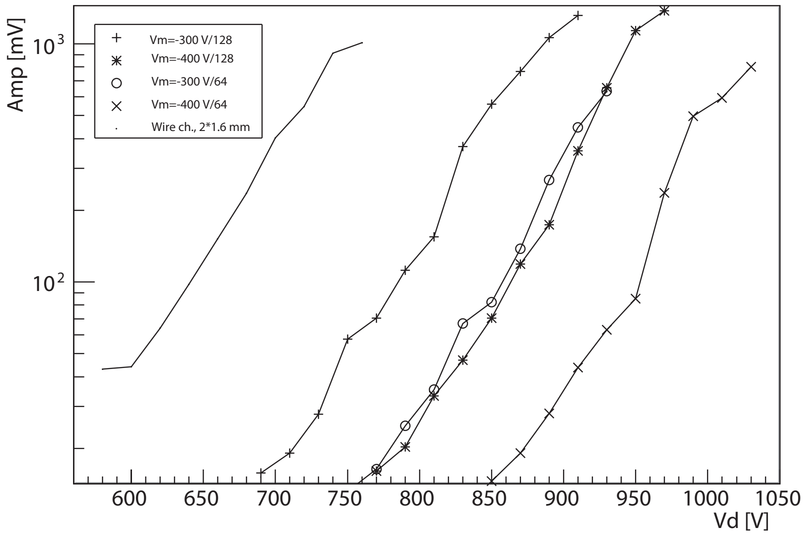


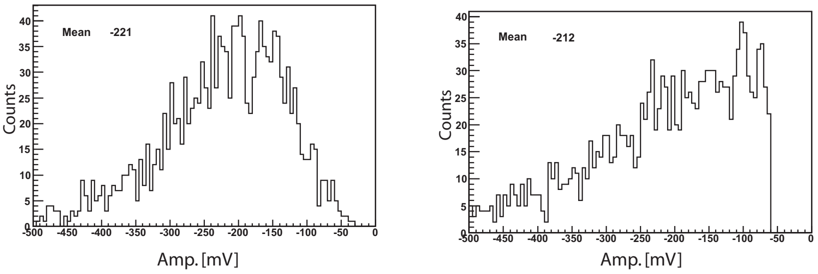
Figure 2. Signal amplitude versus drift voltage at 6 Torr for a beam tracking detector (of 2 × 1.6 mm gap) and 2 micromegas detectors of 128 and 64 μm for two different mesh voltages with an ^{241}Am source at normal incidence.

the wire where the field is lower. Thus, with only a small difference of voltage, it is possible to use the pre-amplification process in the drift gap.

Several micromegas geometries have been tested. Since the same performance as the mini-SED is demanded, the idea was to keep more or less the same gap of gas to get the same amount of ionization and diffusion. The micromegas were thus tested with drift gaps of 1 mm or 2 mm width. Concerning the amplification gap, we have tried first with 64 and 128 microns. It was either bulk micromegas with 30 μm thick micromeshes or the thin 5 μm thick Ni meshes used on the original micromegas [11].

The signals obtained with a wire chamber (classical Beam Tracking Detectors [1]) and the micromegas have been compared in amplitude and rise time. A collimated ^{241}Am alpha source was placed in front of the drift electrode in vacuum. The energy deposit is about 2 keV/mm. The signal was read directly from the printed circuit below the micromesh in the case of the micromegas or on the wire plane for the wire chamber. Both were connected to a fast voltage amplifier with a rise time inferior to 2 ns and a gain of 200. The signal amplitude as a function of the drift voltage is reported on figure 2. First of all, the amplitude between micromegas and BTD are comparable confirming the gain capability of micromegas at very low pressure. The maximum amplitude achievable with the 128 microns is more significant than with the 64 microns. Since the townsend coefficient saturates at high field and low pressures, the gain is still higher with the 128 microns, although the field in the amplification gap is twice lower than for the 64 microns at equal voltage. The fact that the amplitude remains the same when the mesh and drift voltages increase by 100 V, for the 64 or the 128 microns, has the same origin. The rise time (20 to 80%) was shorter in the case of the 64 microns with 7 ns instead of 8.5 ns for the 128 microns. The BTD is faster with a rise time of 6 ns.

Considering that an alpha of 5.5 MeV deposits 4 keV in 2 mm of isobutane at 6 torr, one gets a total number of ionization electrons of 170 (using 23 eV for the mean ionization energy of



(a) (b)

Figure 3. Signal amplitude at 4 torr with secondary electrons coming from the passing of fission fragments from a ^{252}Cf source through a mylar emissive foil with (a) mini-SED backward and (b) micromegas forward.

isobutane). The total maximal gain has been estimated to $3\cdot 10^4$, distributed between the drift gap and the amplification gap. It is bigger for the micromegas than for the BTD since the number of ionization electrons is lower in micromegas while the maximum signal is higher. The time resolution has now to be measured.

3.2 Time resolution

The same set-up as for the mini-SED is used. Three detectors are used: a silicon, a mini-SED prototype and a micromegas prototype. The first test was to check the gain properties just comparing the amplitude of mini-SED and of micromegas with secondary electrons (figure 3) at 4 torr.

A ^{252}Cf source is used to generate the secondary electrons. The mini-SED is with 1.6 mm between the strips and the anode and polarized at 610 V. The micromegas is a 128 micron bulk with a 2 mm drift space, polarized at -880 V for the drift and -400 for the micromesh. The figure shows that the mean amplitudes are comparable, confirming that the micromegas can be used with secondary electrons.

The time resolution has been measured for different micromegas prototypes (gap sizes, pad size. . .) and different voltages. The results are shown in table 1 where m denotes the micromesh type with amplification gap size and capacitance, d the drift gap size, P the pressure, V_d and V_m the drift and mesh voltages respectively, $< Amp >$ the mean amplitude and σ_t the time resolution (for both light and heavy fission fragments). The influence of the CFD (Constant Fraction Discriminator) value on the time resolution measurement has been studied and can be seen in figure 4. If the value is too low, the result is affected by the noise and if it is too high, it is the last electrons that are taken into account and their high diffusion length degrades the resolution. The value of 20% is a good compromise.

Before commenting this table, we recall what influences the time resolution. The time resolution is the temporal stability with which the signal begins. The longitudinal diffusion is important so that the electrons do not spread too much in time. The drift speed of the electrons plays also an important role, the faster or the earlier the signal appears, the less the electrons have diffused. These effects can be observed in the table. For example, the resolution improves by decreasing the pressure, because the electron drift speed increases and although the longitudinal diffusion increases. The resolution is also improving by decreasing the drift space from 2 to 1 mm. It is logical

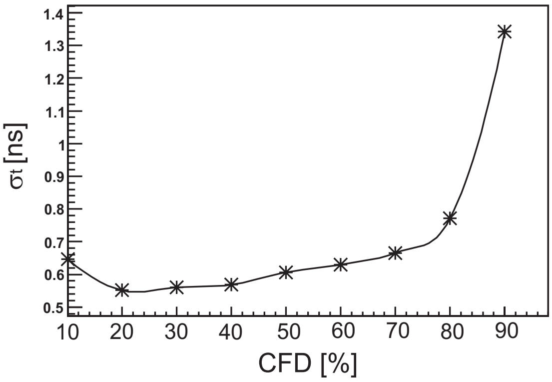


Figure 4. Standard deviation of the time difference between micromegas and miniSED signals versus value of the CFD on the signal amplitude.

Table 1. Time resolution for different micromegas prototypes, in secondary electrons detection configuration and at low pressure (*: with a selection on the events for which most of the amplification took place in the amplification gap).

m	d [mm]	P [torr]	V$_d$ [V]	V$_m$ [V]	$< Amp. >$ [mV]	$\sigma_t \pm 30$ [ps]
bulk 64 μm (120 pF)	2	4	-860	-350	100	720
bulk 64 μm (120 pF)	1	4	-740	-300	96	506
bulk 128 μm (60 pF)	2	6	-870	-400	141	862
bulk 128 μm (60 pF)	2	4	-840	-400	103	775
thin 128 μm (60 pF)	2	4	-760	-400	93	726
bulk 128 μm (30 pF)	2	4	-760	-380	161	1340
bulk* 128 μm (30 pF)	2	4	-760	-380	161	936

since the longitudinal diffusion is less important for a small drift space. The amplification gap size has only a small influence because of its small thickness. The difference observed in time resolution between thin and thick micromesh is not relevant, although an important influence has been observed on the transparency (at least a factor of 2).

The preliminary conclusion is that the time resolution for micromegas is not as good as the one of the mini-SED although it is the case at atmospheric pressures. At 1 bar for example, with a wire chamber, the electrons are multiplied in the vicinity of a wire. If there is a wire every millimeter, the path length to reach the wires are very different from one electron to another. It depends for example if the electron is in front of the wire or in the middle of two wires. On the contrary, with micromegas, there are holes in the micromesh every 50 microns. Then, all the electrons will experienced more or less the same path to enter in the amplification gap and the time resolution will be improved.

Nevertheless, the phenomemon is different at low pressure since the amplification takes place earlier, at the beginning of the drift gap. This avalanche is spread in space and implies several holes in micromegas as well as several wires for the mini-SED and there are not any more important differences in the electron path length. One hypothesis for the degraded time resolution is that with the micromegas, the strips are shielded by the micromesh and thus the amplified electrons in the drift gap have to drift before they become visible. The wire chamber sees the signal directly, as soon as it is amplified enough, with no extra-diffusion. However, some Garfield simulations seem to invalidate this idea. Another hypothesis is the capacitance influence. The table indicates that the bigger is the capacitance the better is the time resolution. The reason is that a non negligible part of the gain (10 to 20%) is made in the drift gap and it implies signal disturbance in the amplification gap by capacitive effects or by varying the voltage of the micromesh. For instance, we can select events for which most of the gain has taken place preferentially in the amplification gap, keeping only the signals with an important ion queue. The time resolution gets improved as can be seen in the two last lines of the table. This capacitance influence has to be investigated in detail if one wants to improve the time resolution of the micromegas.

4 Conclusion

A miniaturized version of the SED used on VAMOS has been constructed. Its time resolution has been measured and the performance is equivalent. Micromegas as a secondary electron detector has been also tested and it gives a S/N ratio equivalent to classical SED detector. This concept is very interesting to cope with the counting rate foreseen on SPIRAL2. However, the time resolution has still to be improved. The spatial resolution has also to be measured for both detector types. Moreover, a new detector with a 2D pad design has also been constructed and it has to be tested. All these detectors will be soon mounted in real conditions either at GANIL or at CNA, notably to estimate the maximum flux limits and its influence on the gain, the time and spatial resolution and the sparking rate if any.

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