Le 26 janvier 2009

Test of a beam profile monitor on IPHI

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Introduction:

In the framework of IFMIF, some beam profile monitors have to be designed. The beam will be a 40 MeV deuteron beam with a high intensity of 125 mA. The detectors will have to be robust to deal with such intensity and radiation, and also reliable to avoid any technical problem on the beam line or on the target [1].

Detection principle:

The solution studied at CEA Saclay is a residual gas ionization monitor. It has the interest to be a non intercepting detector. With a pressure of about 10^{-5} mbar, it is possible with high beam intensities to detect the ionization of the residual gas by the beam [1].

The detector designed for this test is a parallel plate detector shown on figure 1. The detector is 5 cm height with a drift electrode in the upper part and a strip plane at the bottom. The strip plane is composed of 32 strips along the beam with 1.25 mm pitch and 32 mm length. A field degrador is placed between the upper and the lower planes to ensure the field homogeneity. The strips are grounded through an electronic card registering the current of each strip. When the high voltage is applied on the drift electrode, the ions (if positive) or the electrons (if negative) are drifting towards the strips generating a current proportional to the beam intensity and the residual gas density.

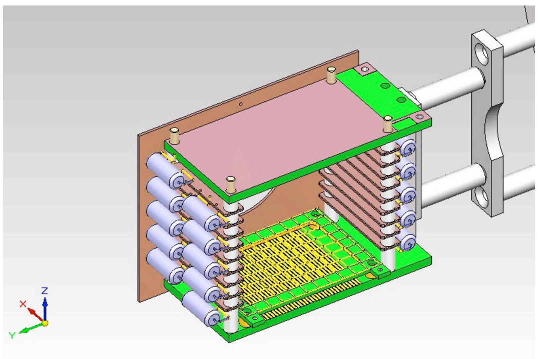


Fig. 1: Detector prototype with beam parallel to the X axis.

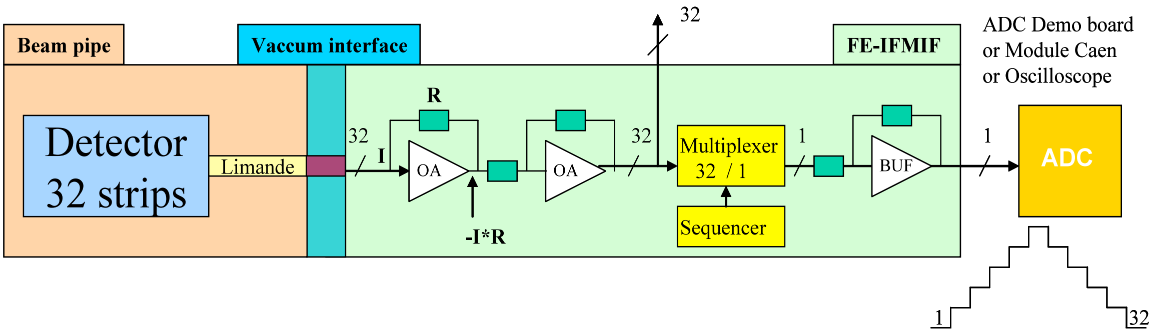


Fig. 2: scheme of the electronic.

An electronic scheme is shown on figure 2. This electronic reads the current on the strips with a bandwidth of 3 MHz. Thanks to high gain of $12x10^5$ V/A with a noise of 0.8 nA, it is sensitive to 1 nA input currents. The strip can be seen separately, or multiplexed and read every 1060 ns. To have a constant mean profile, it was necessary to average over at least 10 multiplexed profiles. It means that currently 10 µs are necessary to get a profile.

This detector has been tested at IPHI. (Injecteur de Protons à Haute Intensité in Saclay) during 2 weeks in July 2008. The beam energy was a proton beam of 75 to 95 keV with an intensity varying from 1 to 100 mA.

Current of the HV module:

A high voltage module is used to supply the high voltage to the drift electrode. It can be positive or negative if one wants to be sensitive more to ions or electrons, respectively. This current has several origins. A field degrador is used with 20 resistors of about 60 MΩ. It implies a current of 1.7 µA at 1000 V for example. However, whatever is the polarity, the current is much higher, showing that the contribution of the field degrador can be neglected (see Fig. 3). The beam is a proton beam. It is thus a positive beam, imposing an image charge which is negative on all the conductive materials surrounding the beam. When the drift voltage is positive, the beam image charge has to be compensated to impose the voltage. It explains why the high voltage current increases with the beam intensity while it remains more or less independent of the intensity for negative high voltage. It is also the reason why the current in positive is much higher than in negative. Moreover, the high voltage current is sensitive to the ionization current in negative polarisation since it increases with the voltage, while in the positive case it is hidden in the high compensation current.

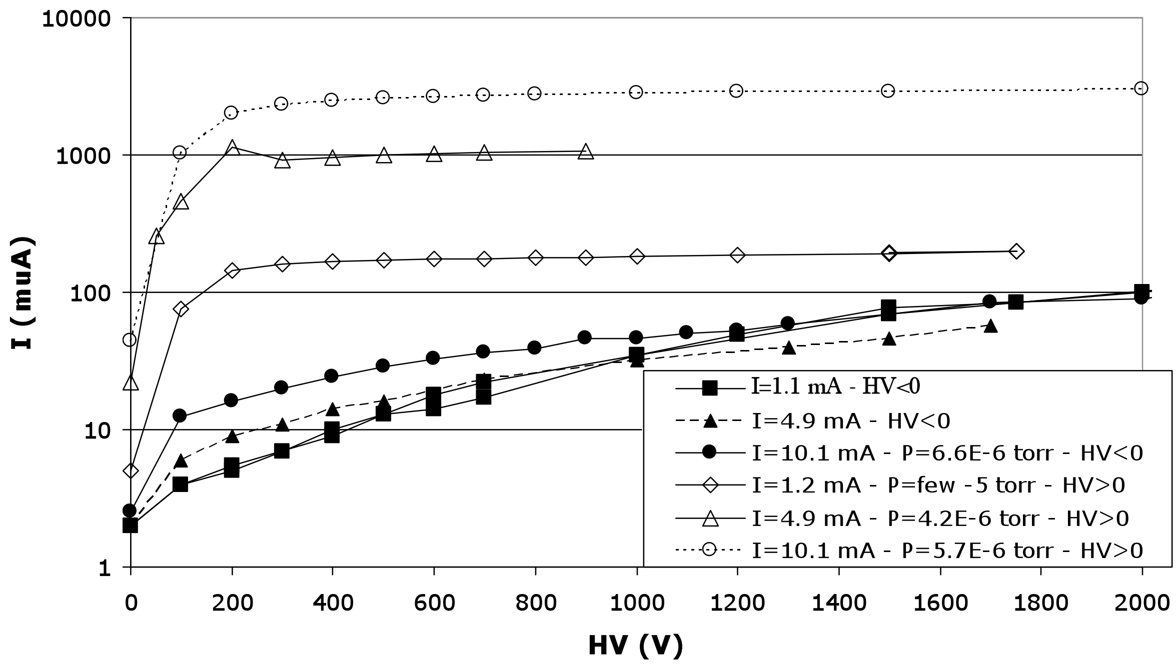


Fig. 3: Absolute value of the current read on the high voltage module in positive and negative potentials and for different beam intensities.

Field simulations:

Some field simulations has been realised using GARFIELD [2], with a positive beam generating a 100 V/cm cylindrical electric field. The results of the simulations can be seen on Fig. 4 and 5. The voltage is applied on the top electrode and the bottom electrode is kept at ground. The drift lines of the ions and electrons created by the ionization process are drawn.

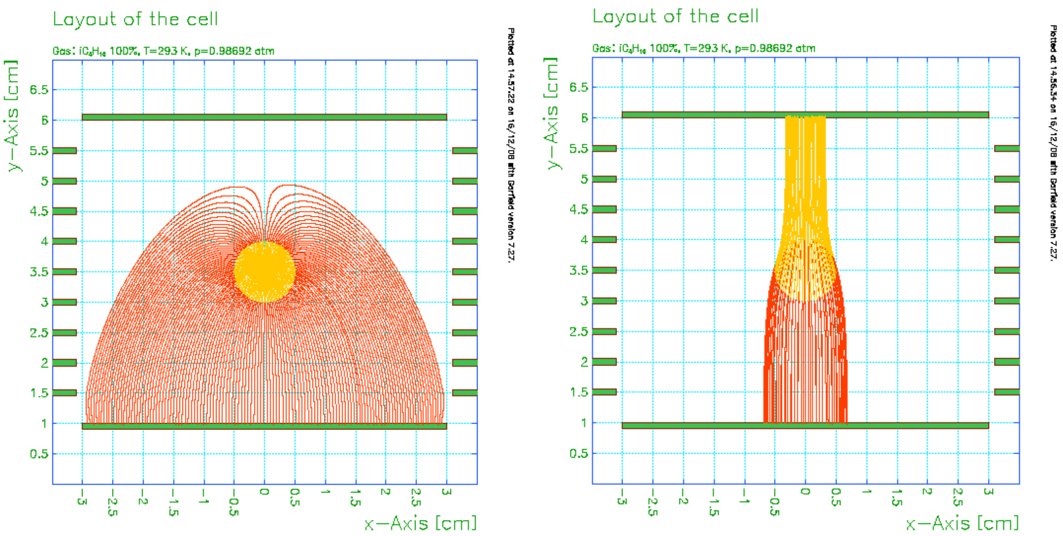


Fig. 4: Electric field lines at +200 V on the left and +2000 V on the right with the ions in red and the electrons in yellow.

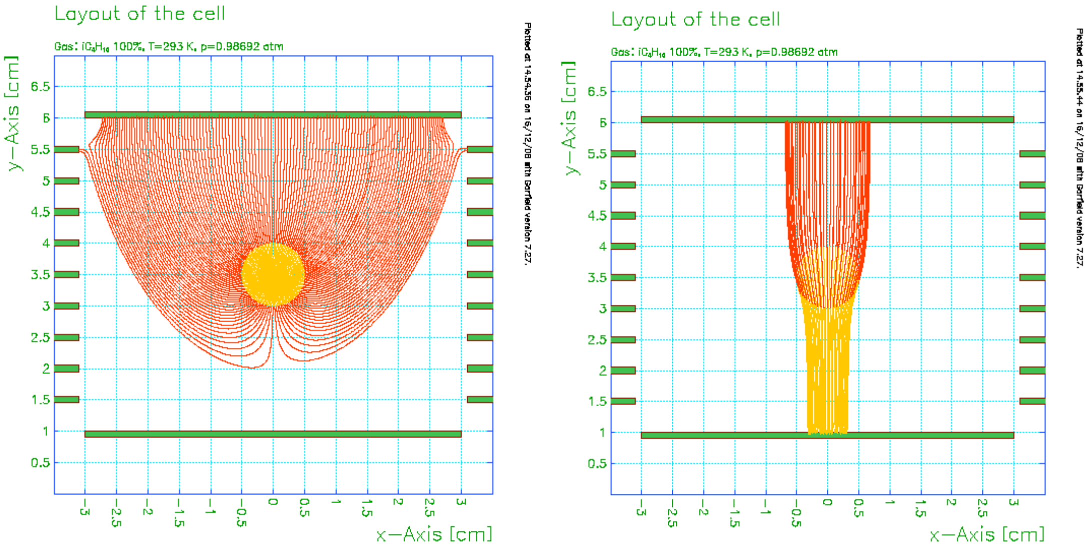


Fig. 5: Electric field lines at -200 V on the left and -2000 V on the right with the ions in red and the electrons in yellow.

The electric field behaviour is of course symmetric in negative and positive. However, the current is read only on the bottom electrode. The ions are easily extracted from the beam, which is normal since the beam is positive. One has to apply a higher voltage to extract the electrons. They are captured by the beam if the drift field is too low. It is the reason why no electron is seen at 200 V in positive or negative.

Now, if one looks a strip in the center of the bottom electrode. In positive voltage, one sees that the ion drift lines are more concentrated at higher voltage. Hence, the current read by the strip should increase and reach a steady state. In negative, it should behave differently since at low voltage, the electrons are not seen and only the ions drifting toward the top are generating a current, while at higher voltage, the ions are hidden by the beam and it is the electrons which are generating a current on the strip. Hence, two phases should be observed in negative voltage.

Current on the strips:

The current is read on the strips thanks to a pico-ammeter.

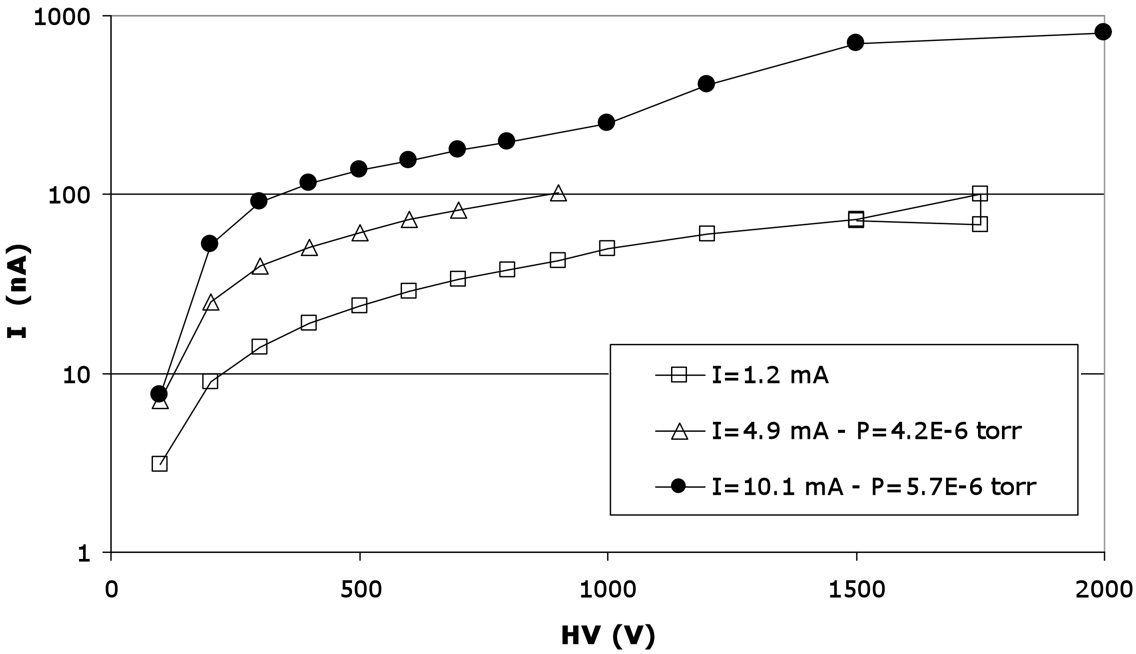


Fig. 6: Current read on 2 central strips for a positive polarisation.

The current read on 2 strips for a **positive polarisation** is shown for several beam intensity as a function of the drift high voltage on Fig. 6. As expected, it is proportional to the beam intensity since the ionization rate increases. Moreover, it increases also with the drift high voltage in two stages. The first stage, at low voltage, corresponds to the establishment of the field lines around the beam (until about 500 V depending on the beam intensity) and the second stage corresponds to the increase of the ion velocity.

The current read on 2 strips for a **negative polarisation** is shown for several beam intensity as a function of the drift high voltage on Fig. 7. It has not the same behaviour than in positive since it presents a peak (for example at 400 V for 4.9 mA). This peak is shifted in voltage with the beam intensity indicating it is beam related. An explanation could be that in negative, with a positive beam, the first voltages are not high enough to read the electronic current. It is a distorted ion current which is read as explained by the simulations.

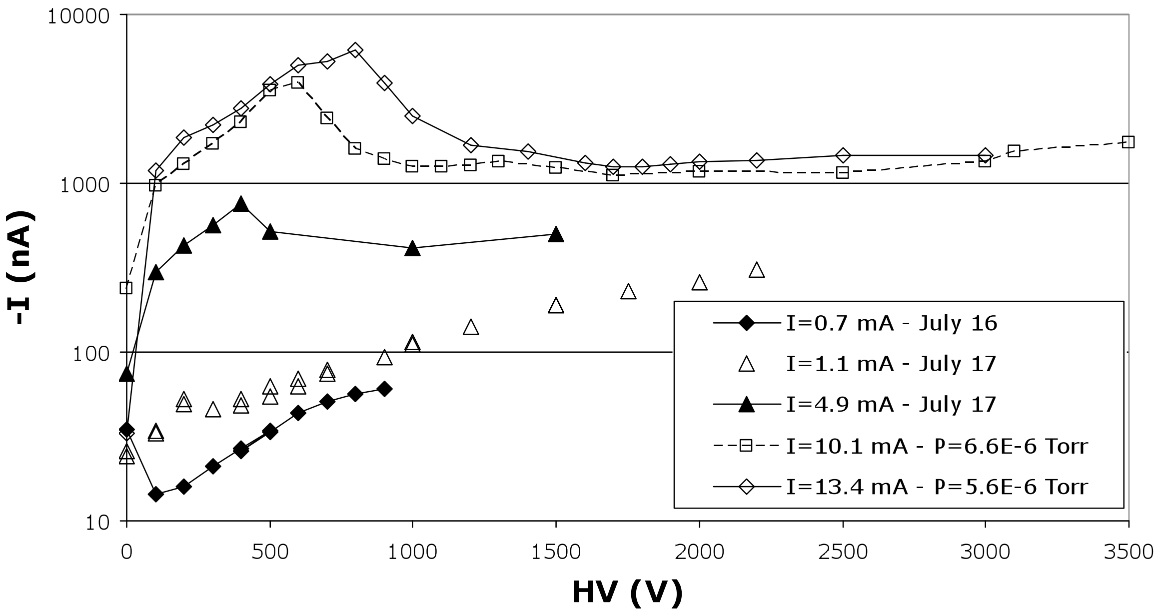


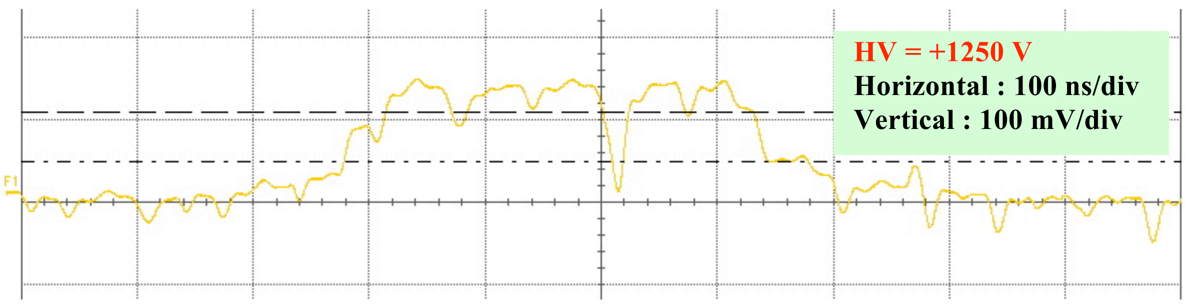
Fig. 7: Current read on 2 central strips for a negative polarisation.

When the voltage is high enough, the beam field becomes negligible and the electrons leave the beam. The electronic current becomes detectable and stable like the ionic current in positive polarisation. It increases with the beam intensity like the ionization process and also with the voltage like the electron drift speed. The increase with the voltage should be the same whatever is the beam intensity which is more or less the observed phenomenon.

The electron current is always higher than the ion current at same beam intensity. This is not really understood since below 150 keV of proton energy, more ions than electrons are produced by the ionization process because of electronic capture. However, the electron drift speed is higher than the ions drift speed and it could explain higher current. Moreover, if the signal is higher with electrons then it could be possible to obtain profiles at lower pressures.

Beam profiles:

The electronic connected to the 32 strips of the detector permits to observe beam profiles directly on the oscilloscope. Beam profiles can be observed on Fig 8.



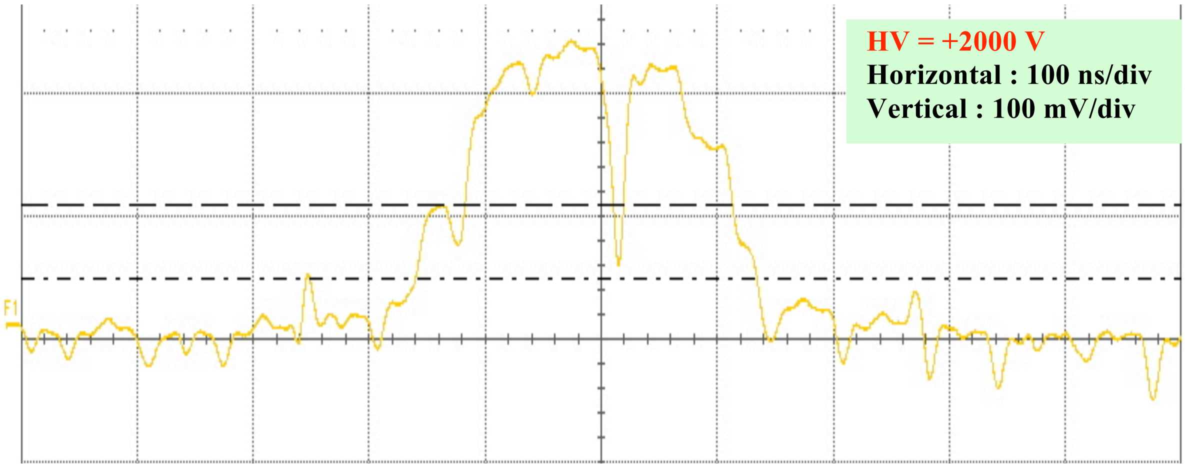


Fig. 8: Oscilloscope beam profiles.

The second beam profile is higher than the first one. As before with the pico-ammeter, the current is higher with the voltage, improving the amplitude and the measured profile. One can see also that the profile is thinner increasing the voltage. The FWHM of the profile is decreasing with the voltage since the homogeneity of the field gets better and the field line straighter.

Influence of the pressure:

The pressure influence is another strong proof that the detector is sensitive to ionization. On figure 9 is shown the maximum amplitude of two beam profiles for two different pressures with exactly the same beam conditions. On this figure, it is clear that the more the pressure is important, the more the signal amplitude is high. Moreover, on figure 10, the ratio corresponds exactly to the ratio of the pressure, indicating a linear dependence of the signal with the pressure, which is the case for the ionization process. It confirms that the detector sees the residual gas ionization.

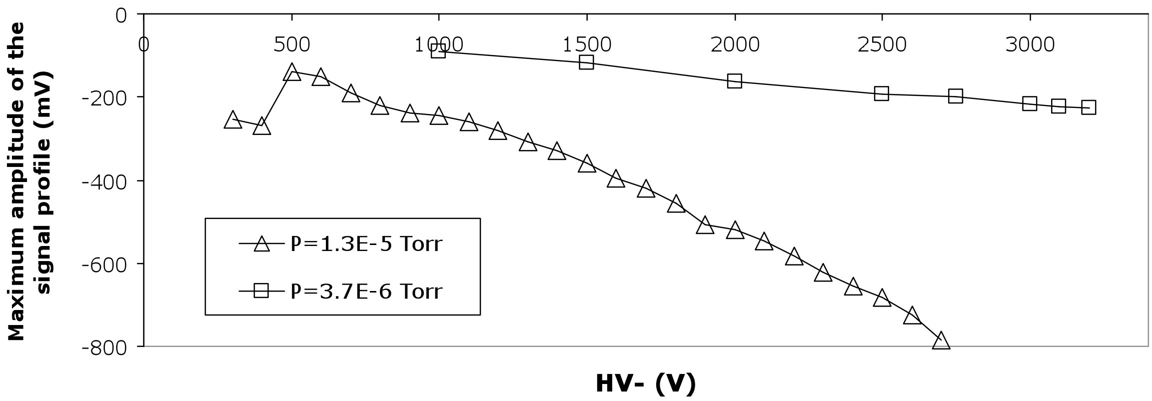


Fig. 9: Amplitude of two beam profiles at different pressures as a function of the drift voltage.

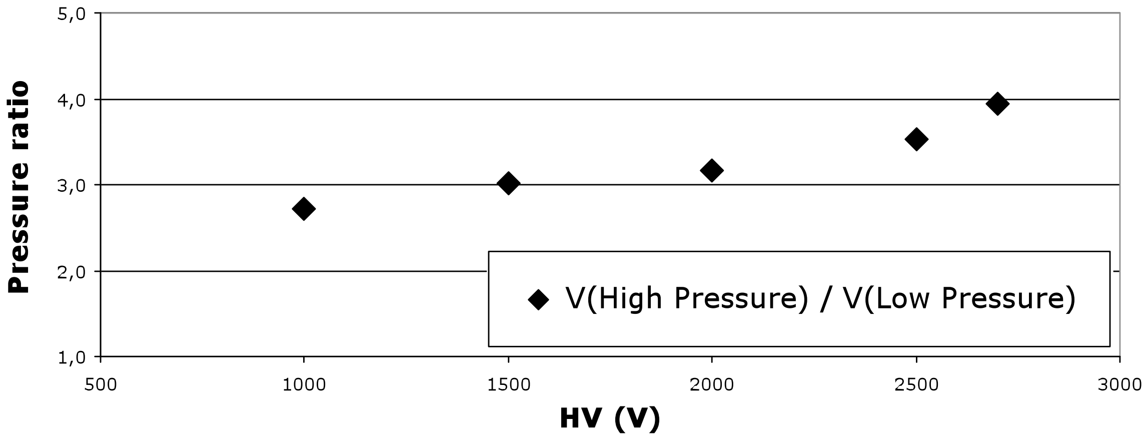


Fig. 10: Ratio between the amplitude of fig 9.

Beam width estimations:

As seen before, an increase in the voltage decreases the beam width measurement. It means that the beam profile has to be measured at high field. The first reason is that the field lines are straighter, less disturbed by the beam at high voltage. Thus, the ions or electrons are detected exactly where they have been produced. Moreover, there is a difference between the ions and the electrons during the ionization process [3]. The electron emission is in the forward direction with a probability of high energy transfers (δ electrons). It means that to compensate this angle of emission, a high electric field is needed in the case of the electrons. Concerning the ions, they are emitted at high impact parameters, thus at very low energy. It is then obvious that the electrons will undergo a higher shift than the ions. In the ion case, the profile width is less disturbed and should be better even at lower fields. One can see on table 1 the improvements in the beam width increasing the voltage (in positive).

HT (V)	1000	1250	1500	1750	2000	2500
Δ (mm)	17	15	12	11	10	8

Table 1 : FWHM of beam profile as a function of the voltage (positive)

The same results are not given in negative, that is to say using electrons. It was possible to reach the same values but without the same steady behaviour. In fact, usually in this kind of applications, the strips are covered with a 1 cm width window perpendicular to the strips. The advantage is that it limits the length over which the detector is sensitive to ionization, thus limiting side effects due to the field. It permits also to select only a short region of the detector rejecting the electrons of too high energies. However, it limits the amount of ionization detected, reducing the signal.

Use of a grid :

A grid had been placed at 5 mm from the strip plane (to see on figure 1). The idea was to reduce the influence of the beam field and to be sensitive only to the electrons or ions drifting between the grid and the strip plane. The grid had a pitch of 0.5 mm with some square holes of 0.4x0.4 mm^2. Some field simulation had permitted to determine the voltage to apply on the grid to force all the field lines to cross it. However, the current measurements have remained more or less unchanged with or without the grid. The high transparency of the grid is responsible for this. One could have used a grid with a much smaller pitch (like a micromegas micromesh for instance), but the grid voltage would have been very important.

Use of a slit:

The spatial resolution of the detector is a key issue of this study. Two copper slits of 5 mm width separated by 12 mm have been placed in the beam in front of the detector. The beam was then pulsated to avoid the heating of the slits. An image of the collimated beam is shown on figure 11.

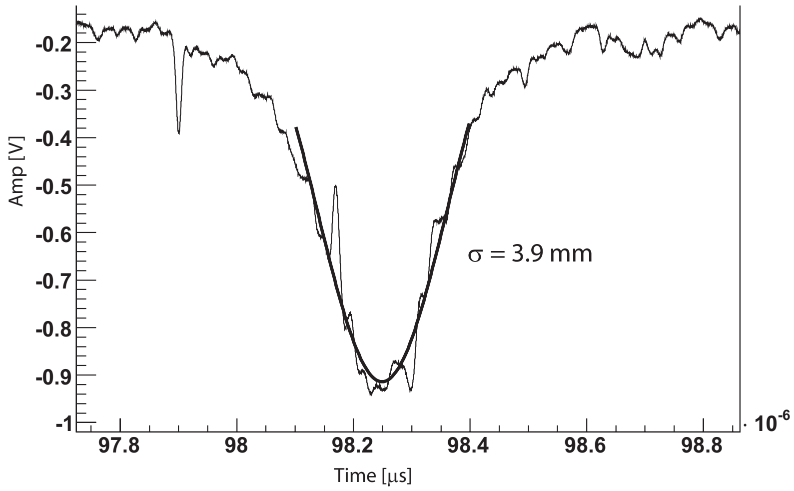


Fig 11: Image of the beam with slits

It has not been possible to obtain a correct image of the slit with for example a 5 mm flat part in the middle. The possible reasons could be the misalignment of the two slits, the divergence of the beam and the shape of the beam itself. This has to be investigated during the next measurements.

Application to IFMIF characteristics:

The beam condition as said before will be totally different with 40 MeV and 125 mA, to be compared to 90 keV at 1 mA on IPHI. The cross section is falling by a factor of 100 from 100 keV to 40 MeV, but since the beam intensity increases also by a factor 100, it should be possible to deal with the ionization on IFMIF.

Conclusion and perspectives:

A second prototype is currently designed for experiments in 2009. It will have to be more robust and less sensitive to charging and sparks. Only metal and ceramics will be used for the construction. It will be coupled to a SEM (Secondary Emission Monitor) in order to compare the results. Some higher beam current will also be tested and new spatial resolution measurements will be realised. A first test is already planned in June on IPHI and a second should take place before the end of 2009 at higher energy for example at GSI.

Acknowledgements:

We would like to thank all the people of IPHI and the GANIL team for beam diagnosis.

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