Beam Tracking Detectors Developments

B. Fernández[a,b], Z. Abou-Haidar[a,b], A. Bocci[a,b], M. A. Cortés-Giraldo[a], A. Garzón[b], M. A. G. Alvarez[a,b], J.Pancin[c], A. Drouart[d], M. Kebbiri[d], M. Riallot[d]

[a]*Departamento de Física Atómica, Molecular y Nuclear (FAMN), Universidad de Sevilla, 41012 Sevilla, Spain.*
[b]*Centro Nacional de Aceleradores (CNA), Universidad de Sevilla, 41092 Sevilla, Spain.*
[c]*Grand Accelerateur National d'Ions Lourds (GANIL)14076 Caen - France.*
[d]*Commisariat a l'Energie Atomique (CEA) 91191 Saclay - France.*

Abstract: New generation of Radioactive Ion Beam (RIB) facilities are being constructed in Europe under the projects SPIRALII (GANIL, France) and FAIR (GSI, Germany). The new particle accelerators foreseen by these projects will be able to produce beams of radioactive isotopes with high intensities ($\geq 10^6$pps). These beams, at low energy, lower than 20 MeV/u, usually have large acceptance, which imposes the use of tracking detectors before the target in order to reconstruct the trajectory of the ions before a nuclear reaction. The group of Basic Nuclear Physics at the National Accelerator Center (CNA) in Seville, represents one of the institutions in charge of developing solutions of tracking systems for the low energy branch of FAIR (the HISPEC/DESPEC project). From this point of view, a collaboration with the Commissariat a l'Energie Atomique (CEA-SACLAY) was established, with the following objectives: to simulate, develop, build and test a low pressure Secondary electron Detectors (SeD) and its related fast electronics. The construction and experimental results of the first prototype as well as a first set of simulations are presented below. We also present a new Nuclear Physics Line, as a valuable tool, projected and mounted at the CNA with the aim of being able to perform tests on any kind of detector and on its related nuclear instrumentation.

Keywords: beam tracking detectors, fast electronics, low energy accelerators.

Corresponding author: malvarez@us.es

INTRODUCTION

Nuclear reactions are an important tool to investigate the nuclear structure and reaction mechanisms. These reactions have been extensively used in the past with stable nuclei. During the last decades, the nuclear reactions experiments grew to reach the biggest radioactive beam facilities such as the European laboratories GANIL (France), GSI (Germany), CRC (Belgium) or CERN (European Organization for Nuclear Research).

Two of these RIB laboratories, GANIL and GSI, have recently started expanding their facilities with the SPIRAL II (GANIL) and FAIR (GSI) projects. These projects foresee the construction of new accelerators that will allow studying the nuclear structure of new isotopes such as super-heavy nuclei, neutron-rich and neutron-deficient or highly deformed nuclei. Despite the fact that the current generation of tools allows successful measurements, it is clear that significant improvements can be reached regarding the efficiency, time and spatial resolutions and simultaneous detection of gamma rays and particles for a complete study of the reactions. Moreover, due to the characteristics of exotic nuclei beams (high acceptance and low resolution in energy) and in order to identify the initial conditions of the particles, it is important to detect and reconstruct the trajectory of the particles that produced the reaction.

This implies on developing a new generation of instruments that allows us to work under the parameters of the future radioactive beams, such as the high counting rate ($\geq 10^6$pps).

According to this framework, we present, in the following, the new Nuclear Physics Line of CNA, as a local facility, projected and mounted in order to test any kind of detector and its related nuclear instrumentation. Furthermore, we introduce the first mini-SeD (70x70mm) prototype constructed by a collaboration between the CEA-Saclay and the CNA. This detector has been built based on the concepts and parameters of the SeD (250x400mm) installed in the focal plane of the VAMOS spectrometer in GANIL [1,2]. The first idea was to guarantee the possibility of having a low pressure tracking detector system capable of working with position and time resolutions of around 1-2mm and 100-200ps, respectively, independent of its size. Afterwards the goal is to improve these resolutions by simulating and developing fast preamplifiers.

THE NEW NUCLEAR PHYSICS LINE OF CNA

A new line dedicated for developing Nuclear Physics instruments, is now available in the 3MV tandem of the CNA-Seville. This accelerator is able to accelerate protons and several heavy ions with a current range between 1pA and 1μA approximately, at energies between some keV and tens of MeV, depending on the charge state of the selected heavy ion.

With this tool we open the possibility of determining the particles trajectory, in an event by event basis, of low or high intensity of stable nuclear beams, at low energy, produced by the 3MV tandem accelerator. Therefore, the stable beams can be used to simulate the characteristics of radioactive beams (different counting rates with large acceptance).

The new installation includes two reaction chambers with high current and voltage connections, a gas control station, a cooling system as well as a high vacuum system, which allows working at pressures of around 10^{-6} mbar. Within the line, we are able to test different types of detectors that are used in the biggest RIB facilities around the world, nuclear instruments like fast electronics, as well as performing low energy nuclear reactions or training students under different academical or research proposals.

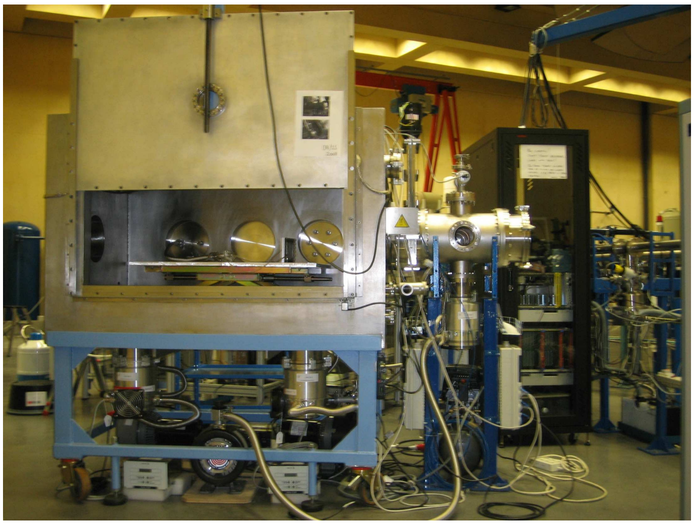

Figure 1: View of the new nuclear physics line in the CNA-Seville (Spain).

THE MINI-SED DETECTOR PROTOTYPE

Detector structure and operation principles

The mini-SeD is a low pressure gaseous detector. It is a mini-prototype (70x70mm) of the Secondary electron Detector (SeD) (250mm x 400mm) developed at CEA-Saclay and installed in the focal plane of VAMOS spectrometer in GANIL [1,2]. The ion beam passes through an emissive foil of aluminized mylar of 0.9 μm. The impact of ions on this emissive foil produces secondary electrons that are drained and focused towards the detector by a parallel electric (10KV) and a magnetic (100 G) field [3].

The mini-SeD is filled with pure isobutane at 4 torr. Once the secondary electrons pass through the 0.9 µm thick aluminized mylar window of the detector, the amplification occurs over two different zones: the "parallel-plate" zone where the field is constant and a zone of amplification around the anode wires where the gradient of the electric field is high [1,2].

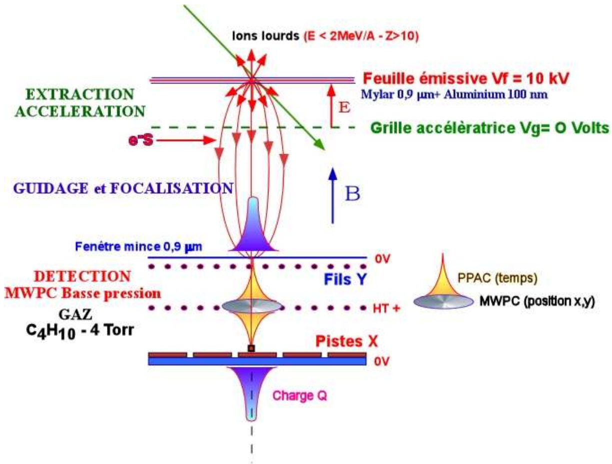

Figure 2: Operation principles of the SeD

The anode is a plane of goldened tungsten wires of 20µm diameter with 1mm pitch. The entire anode plane is at the same potential (600V). At 1.6mm of the anode, we have two cathodes, one on each side. The one located at the entrance of the detector is also a plane of goldened tungsten wires, with a diameter of 50µm, and a pitch of 1mm. They are linked by three and referenced to the ground through their electronics. The other cathode is an FR4, printed circuit board (PCB) with Copper strips. The strips are 2.34mm wide, and they are separated by 0.8mm. The active area of the mini-SeD is 70x70 mm^2.

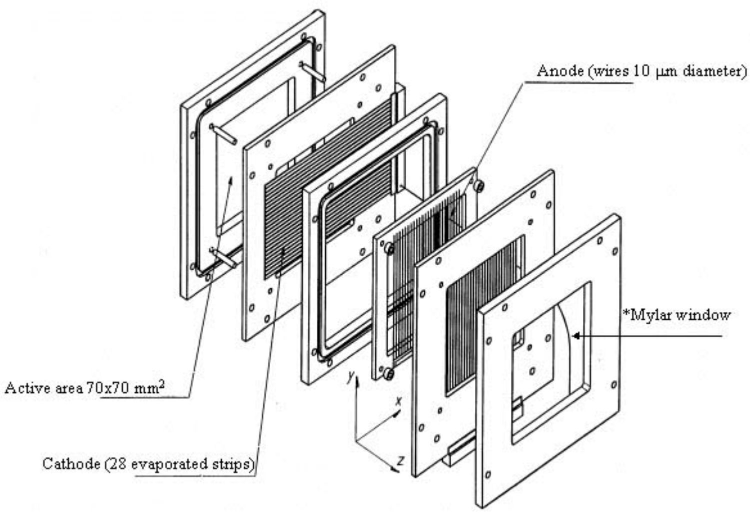

Figure 3: Different mechanical parts of the mini-SeD prototype.

CONSTRUCTION

In Figure 4, we present some steps of the (70x70mm) mini-SeD prototype construction. The mini-SeD was built to study the possibility of having a small and big active area tracking detector, based on the same technology, with comparable and reliable resolutions.

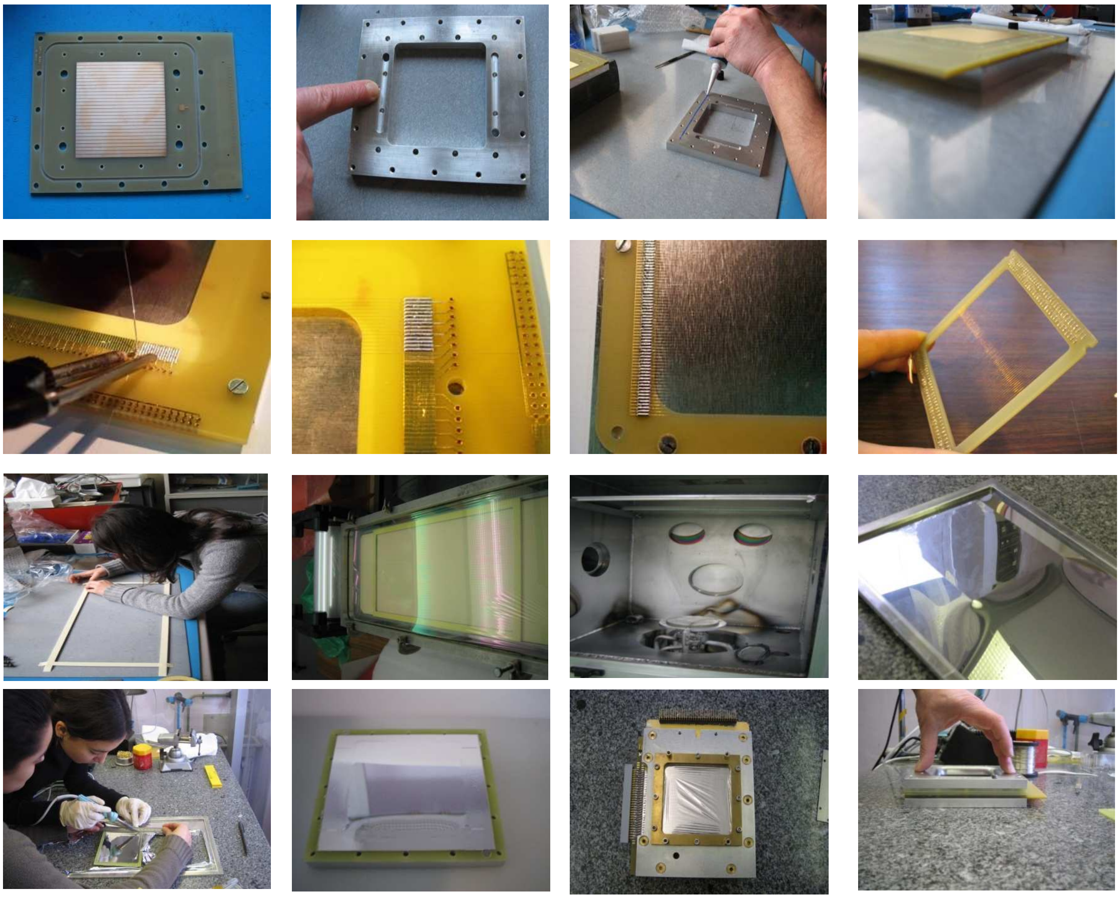

Figure 4: Details of the construction and assembly of the mini-SeD prototype.

TESTS AND RESULTS

The tests of the mini-SeD have been performed using a home made fast voltage amplifier (AR8) developed at CEA-Saclay to read out anode time signals and a MATACQ card [4] as the ADC. The cathodes are read out using the CPLEAR preamplifiers developed for SeD and a commercial QDC V792 model from CAEN.

Time Resolution

In order to measure the time resolution we use three detectors: a prototype of SeD, a surface barrier Si detector and the mini-SeD of which we want to measure the time resolution. The measurements are performed using a ^{252}Cf radioactive source. Figure 5 presents a scheme of the setup and Figure 6 presents typical anode signals. The time resolution (FWHM) obtained for the mini-SeD is 200ps, and it is the same value as the one obtained for the SeD.

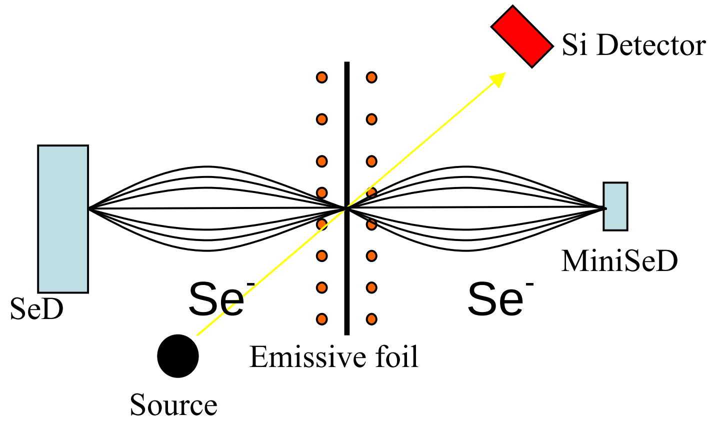

Figure 5: Scheme of the setup used to obtain the mini-SeD time resolution.

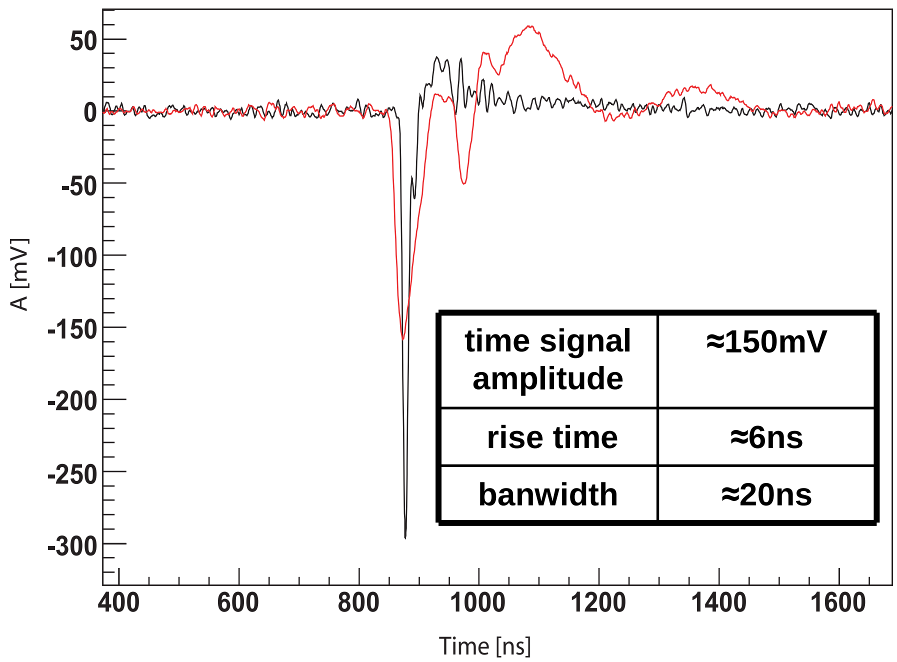

Figure 6: Typical time signals obtained from the anode of the mini-SeD prototype.

Spatial Resolution

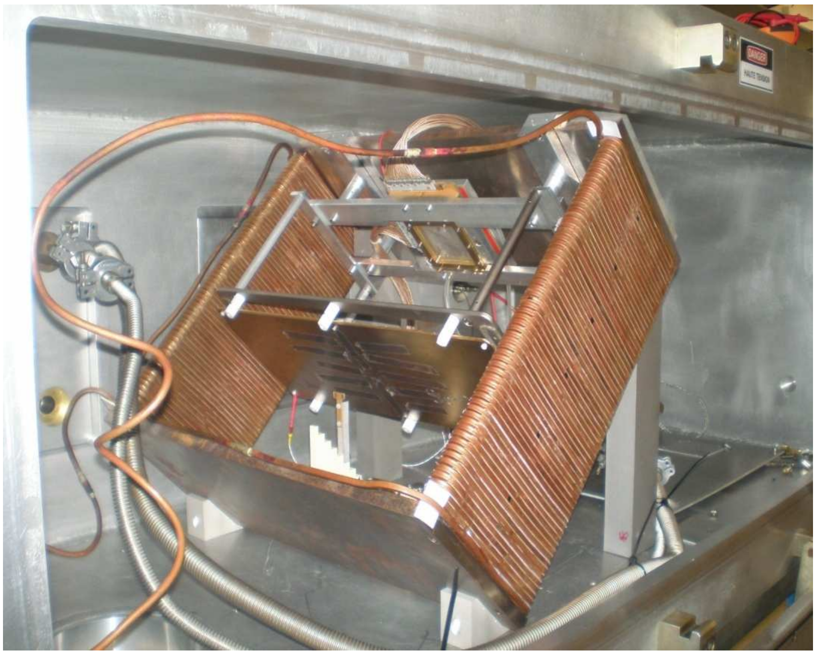

Figure 7: Setup used to obtain the spatial resolution of the mini-SeD.

In order to measure the spatial resolution, two methods of analysis, using different algorithms, were used. The first one consisted on calculating the geometric center of gravity of the measured charge on a given number of strips, as for the other, it consisted on approximating the distribution of charge with an analytic function (sechs) [5]. The best result obtained for the mini-SeD position resolution is 1.2mm (Figure 8), which is of the same order as the one obtained for the SeD, using the same preamplifiers.

Final Experimental Results

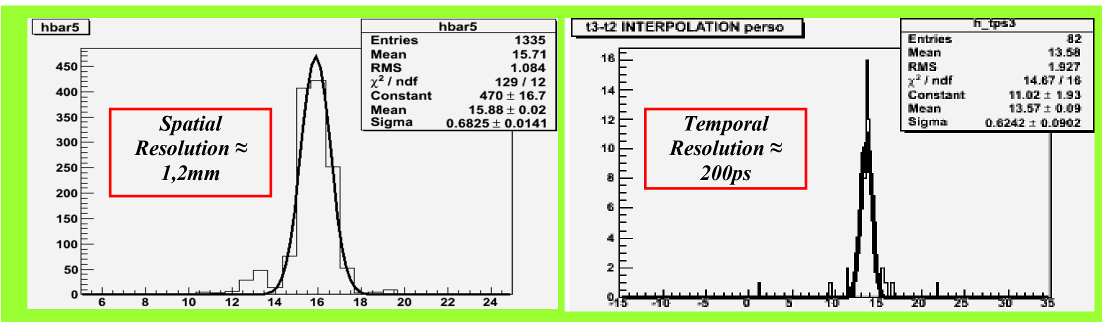

Figure 8: Final experimental results of the mini-SeD prototype: position resolution of 1.2mm and time resolution of 200ps. The results are comparable with the SeD installed in GANIL.

SIMULATIONS

Following the promising experimental results of the mini-SeD, and in order to improve them, we started a series of simulations using the Monte Carlo code GEANT4 (version 9.2). This code simulates the transport of the particles through matter. The geometry of the detector (mini-SeD) has been accurately reproduced in the simulations, especially the different parts and materials of the prototype (including the gas at low pressure) as well as the presence of the electric and magnetic fields. The so called "Physics List" used in the simulations is based on the QGSP-BIC-HP package provided in the GEANT4 official release. Some important data of the GEANT4 simulation are listed below:

- Energy of the incident beam = 1 MeV/u
- Aluminized mylar thickness = 0.9 µm
- Extraction voltage = 10KV
- Magnetic Field = 100G
- C_4H_{10} gas at ~4 Torr
- 20 µm goldened tungsten (anode)
- 50 µm goldened tungsten (cathode)
- 1.6 mm gaps
- FR4 PCB
- Cu strips (2.34 cm × 7.0 cm) (cathode)
- Electric field = 600 V/m

Thus, GEANT4 simulates the secondary electrons produced after the collision of the beam particle with the emissive foil, which is placed in the beam trajectory. These secondary electrons are extracted from the emissive foil by a 10-kilovolt high voltage and guided to the detector placed outside of the beam trajectory. Moreover, GEANT4 simulates the transportation of the electrons in the volume of the detector, as a result of the gas ionization. In addition, the fluence of the secondary electrons through the different electrodes is calculated in order to allow us to obtain the current produced in each strip or wire of each electrode (cathode or anode). The energy deposited in the Cu strips is calculated as well. We were mainly interested in the current produced in the cathodes, which will generate the position measurement and for which we develop new fast amplifiers.

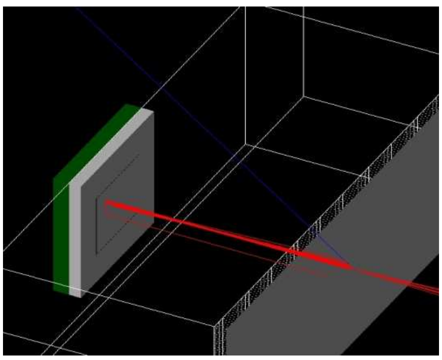

Figure 9: Illustration of charge produced in the emissive foil simulated by GEANT4.

So far, the simulations calculate a current of the order of 0.64µA in the cathodes. These current values, in the cathode, are our input source in the MULTISIM National Instruments code (Figure 10), which is used to simulate Trans-Impedance Amplifiers (TIA), RC filters and shaper-amplifiers elements and circuits.

The objective is to obtain the maximum performance of the system in terms of gain and bandwidth. The current of 0.64µA, given by the simulations, obtained from the electrons fluence in the detector cathodes implies on very fast signals. The signal rise time is of the order of 300ps (obtained by GEANT4 simulations), which gives, using the commercial tested TIA, a signal of 2.25mV. The bandwidth of the TIA is 240MHz, which means that up to this frequency the value of the gain is 10000. However, when the signal is faster, the gain decreases, in our case, the gain is of 3515 (Gain=2.25mV/0.64µA=3515).

On one hand, the simulations give the expected order of magnitude, with extremely good and fast signals; on the other hand the 300ps signals are very fast, and out of the range of the nominal gain and performance of the commercial TIA; this results in having an output signal amplitude, after the TIA, of the same order of the measured noise. Our research now is concentrated on improving the GEANT4 simulations, increasing the rise time and getting maximum gain performance, besides keeping the ideal compromise between gain and bandwidth (amplitude and velocity).

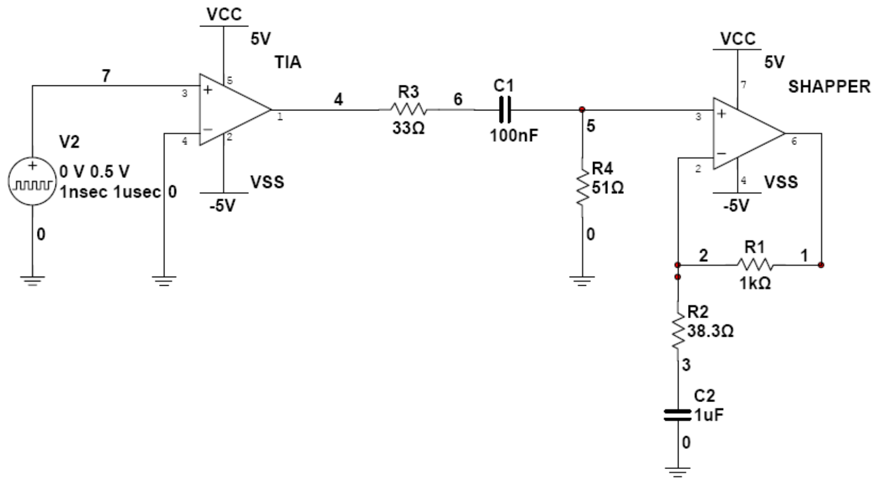

Figure 10: Circuit of the pre-amplifier: from left to right we can identify the current/voltage source, the trans-impedance amplifier (TIA), the RC filter and the shaper.

Cathode signal amplitude	≈50mV
Rise time	≈8ns
bandwidth	≈30ns

Cathode signal amplitude	**(Simulations) ≈2.25mV**
Rise time	**≈300ps**
banwidth	**BW x GAIN**

Table 1: Parameters of the experimental spatial signals (cathodes) compared to the parameters extracted from Geant-4 and the National Instrument Multisim simulations codes.

CONCLUSION

In a collaboration between CEA-Saclay, GANIL and CNA laboratories, we have built and tested, with a ^{252}Cf source, a first low pressure gaseous detector prototype as a candidate of tracking detector for FAIR, the mini-SeD. This (70x70 mm^2) detector, based on the characteristics of the SeD (250x400 mm^2) installed in the focal plane of VAMOS in GANIL, gives a temporal resolution of 200ps and a spatial resolution of 1.2mm. These results are consistent with the SeD. Therefore, we can say that this type of detector gives compatible and reliable results independently of the size of its active area. Never the less, these results can still be improved by coupling the mini-SeD to its fast adapted electronics. Within this framework, first simulations have been performed that gave better and faster signals. In addition, this detector is very cheap compared to Silicon or Diamond detectors and easy to repair. Now, the compromise between bandwidth and gain is under investigation in order to get maximum performance from preamplifiers circuits and from their coupling to the mini-SeD.

In the near future, the mini-SeD detector will be put under test at the ion beam facility of GANIL with the corresponding specific electronics and, later on, at the CNA. For this proposal a new structure is already working in the CNA. A new nuclear physics line has been prepared for the possibility of receiving several instrumental nuclear physics tests, including beam tracking and profile detectors or fast electronics.

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