# A FAST IONIZATION CHAMBER FOR THE STUDY OF FUSION REACTIONS INDUCED BY RADIOACTIVE BEAMS*

G. Colucci[a], G. Montagnoli[a], A.M. Stefanini[b], P. Colović[c]
L. Corradi[b], E. Fioretto[b], F. Galtarossa[b], A. Goasduff[a]
G. Jaworski[b], M. Mazzocco[a], F. Scarlassara[a], E. Strano[a]
S. Szilner[c]

[a]Department of Physics and Astronomy, University of Padova
and INFN Sezione di Padova, 35131 Padova, Italy
[b]LNL INFN, 35020 Legnaro (Padova), Italy
[c]Ruđer Bošković Institute, 1002 Zagreb, Croatia

*(Received January 7, 2019)*

A new fast ionization chamber has been designed and built at the National Laboratories of Legnaro (LNL) to ensure a high counting rate particle identification for fusion studies involving exotic beams up to $10^5$ pps. To reduce the response time of the ionization chamber, a design using a series of tilted electrodes has been adopted. The readout of the fast IC was optimized and extensive tests using stable heavy-ion beams demonstrated its ability to operate at high counting rates. This feature and the much larger solid angle coverage will allow to detect fusion–evaporation residues with very high efficiency.

DOI:10.5506/APhysPolB.50.573

## 1. Introduction

The experimental set-up PISOLO at LNL has been largely employed in fusion reaction studies near and below the Coulomb barrier [1]. Fusion cross section is determined by the direct detection of the fusion–evaporation residues (ER) at small angles by separating out the beam and beam-like particles using an electrostatic beam deflector. The ER are identified downstream of the deflector by a double time of flight, energy loss and energy telescope (TOF-$\Delta E$–$E$) composed of two micro-channel plate time detectors

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 26–September 2, 2018.

(MCP), a conventional transverse field ionization chamber (IC) and a silicon detector placed inside the IC. The silicon detector measures the residual energy of the ER and gives the start signal for the two TOF as well as the trigger for the data acquisition.

However, this experimental set-up is not suitable for the radioactive beams of SPES [2], because of its low absolute efficiency, typically less than 1% for the ER detection. This low efficiency is due to *(i)* the geometrical structure of the apparatus whose effective solid angle is very small (around 0.04 msr), and *(ii)* to the low counting rate tolerated by the ionization chamber.

A new set-up has been developed and will be installed at LNL, especially designed for the low-intensity beams of SPES ($\sim 10^5$ pps). In the new configuration, the detection system will be placed at 0° with respect to the beam in the following sequence (see Fig. 1): two MCP position-sensitive detectors upstream of the target and a third position-sensitive MCP and a fast ionization chamber, placed very close to the third MCP, downstream of the target to identify ER events. In order to allow higher counting rates, a fast ionization chamber (Fast IC) has been developed at LNL, whose response time is shortened by using several tilted electrodes, see Fig. 2, following the original design of Chae *et al.* [3].

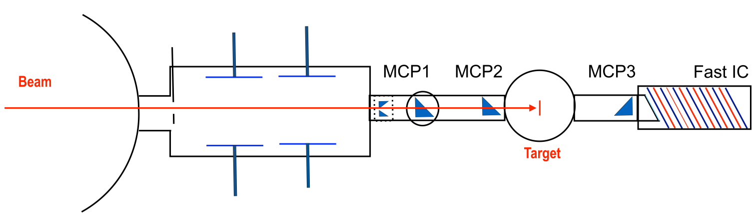


Fig. 1. Scheme of the upgraded PISOLO set-up for the SPES beams.

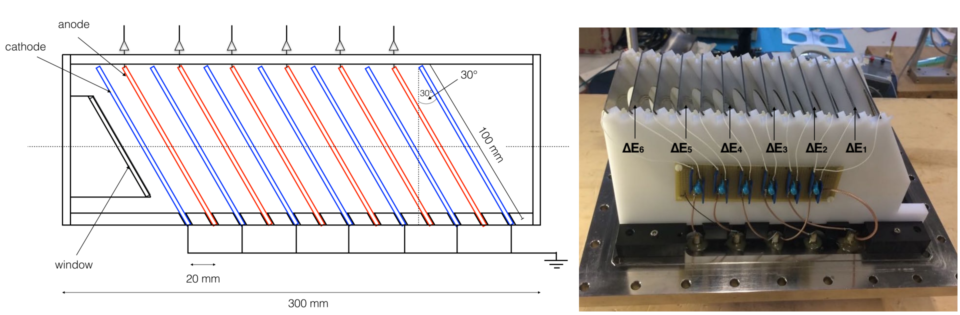


Fig. 2. Scheme (on the left) and picture (on the right) of the fast IC at LNL.

## 2. The detector

The fast IC is composed of 13 tilted electrodes. The electrodes are separated by 2 cm in the beam direction and the alternating arrangement of anodes and cathodes (6 and 7, respectively) results in a short drift time for the electrons to reach an anode. In addition, by tilting the electrodes at 30° from the perpendicular to the beam line, the electrons and positive ions produced in the gas drift away from the beam axis, reducing the probability of recombination. The entrance window is also tilted at 30° to avoid an unnecessary and position-dependent energy loss of the particles to reach the first cathode. The electrodes consist of copper coated fiberglass frames 10 cm × 10 cm with 6 cm circular openings and 20 $\mu$m gold coated tungsten wires soldered to the frame with 1 mm spacings. All the electrodes are fixed on a Delrin support. Each anode is connected to a separate BNC feedthrough, whereas all cathodes are grounded together. In this configuration, any section between two adjacent cathodes provides a $\Delta E_i$ measurement, so that the first several anodes can be combined together to give one or more energy loss signals $\Delta E$, while the remaining anodes will give the residual energy. The energy loss and the total energy signals will discriminate the ER from the beam and the beam-like particles.

## 3. Tests with stable beams

At LNL, heavy-ion beams are delivered by the Tandem-ALPI-PIAVE accelerator complex [4]. The performance of the fast ionization chamber has been tested in different fusion and transfer reactions with stable beams:

1. $^{28}$Si+$^{100}$Mo: $^{28}$Si beam at the energy of 125 MeV and an average current of 5 pnA. The target thickness was 150 $\mu$g/cm$^2$ on a 15 $\mu$g/cm$^2$ carbon backing;
2. $^{58}$Ni+$^{28}$Si: $^{58}$Ni beam at the energy of 190 MeV and an average current of 4 pnA. The target thickness was 50 $\mu$g/cm$^2$ on a 30 $\mu$g/cm$^2$ carbon backing.
3. $^{64}$Zn + $^{54}$Fe,$^{197}$Au: $^{64}$Zn beam at the energy of 275 MeV and an average current of 3 pnA. The $^{54}$Fe target was 40 $\mu$g/cm$^2$ thick on a 15 $\mu$g/cm$^2$ carbon backing. The $^{197}$Au target thickness was 200 $\mu$g/cm$^2$.

Tests 1 and 2 used fusion reactions at small or even 0°. The electrostatic deflector was used to reject the major part of the direct beam, and the rate into the IC was tuned by measuring at different angles and/or changing the primary beam intensity. In test 3, the set-up was placed at 30° and elastic and quasi-elastic scattering products were detected.

In all the measurements, the fast ionization chamber replaced the transverse field ionization chamber in the experimental set-up PISOLO.

### 3.1. Shaping time and the acquisition gate width

At the very high counting rates expected with SPES beams, pile-up effects and random coincidences may significantly deteriorate the quality of the acquired data. The employment of short shaping times reduces the probability that such effects occur. Moreover, the availability of fast signals allows to reduce also the width of the data acquisition gate, so far limited to values not shorter than $4\,\mu$s by the slow response of the transverse field IC. In that chamber, a shaping time of $1\,\mu$s was typically used.

Several tests have been performed using shorter shaping times and gate widths. Employing the reaction $^{28}$Si+$^{100}$Mo, a shaping time of the spectroscopy amplifier of $0.25\,\mu$s was used. A minimum width of the acquisition gate of $1\,\mu$s has been used in the fusion reaction $^{58}$Ni + $^{28}$Si in inverse kinematics. The quality of the spectra, judged by the resolution and separation of the ER from the beam-like particles was very good anyway. To estimate the improvement obtained using these short values, the ratio of the random background events to the total number of events (noise-to-total) has been estimated for both measurements. A 21% reduction of the noise-to-total ratio of detected events is obtained for the shaping time of $0.25\,\mu$s with respect to the $1\,\mu$s case. The gate width of $1\,\mu$s led to a further reduction of 20%, with respect to the $4\,\mu$s width [5].

### 3.2. Counting rate and veto

The collection time in the fast IC has been reduced by a factor of $\sim 5$ with respect to the transverse-field IC, as the distance between the anode and the cathode is smaller. This enables ER identification at high-rate.

High counting rates have been obtained by changing both the beam current and the detection angle. The shaping time of $0.25\,\mu$s was adopted in all the measurements and the DAQ was triggered by the MCP closer to the IC. The highest rate measured in the IC was 139 kHz, using the reaction $^{28}$Si + $^{100}$Mo. The detection system was placed at $0^\circ$ and the beam current was 5 pnA. Figure 3 (left panel) shows a 2D spectrum of this measurement. By selecting the ER detected by the first section $\Delta E_1$ the background is considerably reduced as shown in Fig. 3 (right panel) and the ER are clearly identified. In the tests performed at high counting rates, the pressure inside the IC was choosen in order to stop the ER before the fifth section, so that the signal provided by the sixth section of the IC could be used as veto of the DAQ. Figure 4 shows TOF$_2$ *vs.* $\Sigma_i^5 \Delta E$ measured without any veto condition (left) and imposing the veto (right). The ER are not affected by the use of veto, since the pressure of the gas inside the IC stops the ER within the fourth section. On the contrary, the most energetic part of the beam-like particles as well as a fraction of the background is removed.

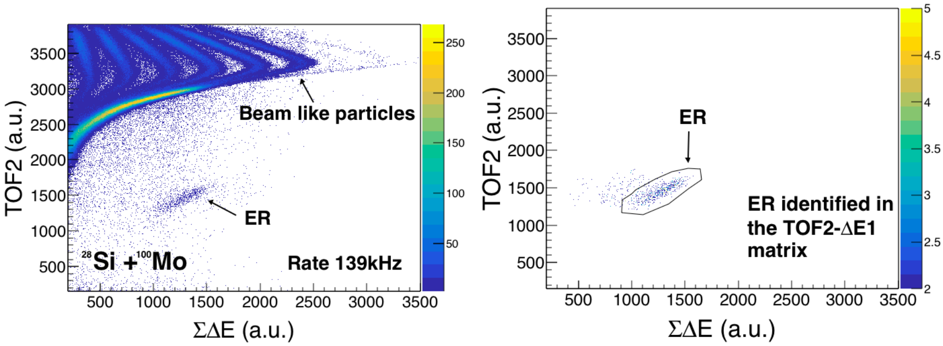


Fig. 3. Left: time of flight *vs.* total energy loss $\Sigma\Delta E$ at the rate of 139 kHz. Right: the same matrix obtained by selecting the ER detected by the first IC section, *i.e.* in the two-dimensional plot $\mathrm{TOF}_2$ *vs.* $\Delta E_1$ not reported here.

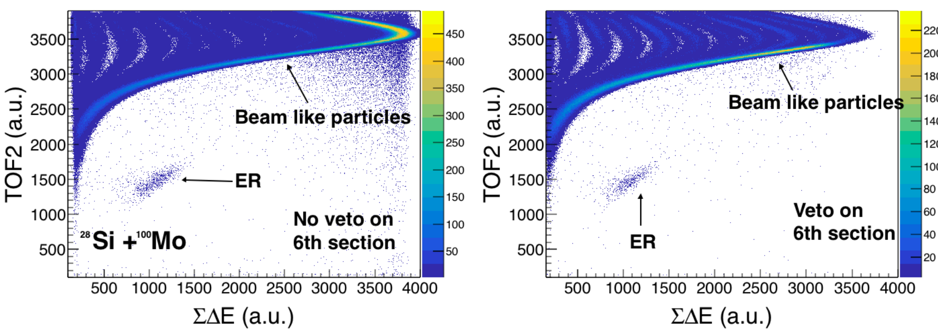


Fig. 4. Time of flight *vs.* the total energy loss $\Sigma\Delta E$ at a counting rate of 34 kHz, without any veto (left) and using the IC section $\Delta E_6$ as veto (right).

### *3.3. Z and energy resolution*

The $Z$ resolution of the fast IC has been estimated by detecting the quasi-elastic transfer channels of the reaction $^{64}\mathrm{Zn} + {}^{54}\mathrm{Fe}$. For this purpose, the whole set-up was placed at 30°, near the grazing angle of the reaction. At this detection angle, the direct beam was stopped inside the reaction chamber, so that the electrostatic deflector was not used. In this configuration, it has been possible to clearly identify and separate the scattered $^{64}\mathrm{Zn}$ from the stripping channel of two protons ($-2p$), as shown in Fig. 5 (left panel). The recoiling $^{54}\mathrm{Fe}$ ions are superimposed to the 4 protons stripping channel ($-4p$) location. The estimated $Z$-resolution of the IC is 1/38 for $^{64}\mathrm{Zn}$ ions of $\sim 3\,\mathrm{MeV}/u$.

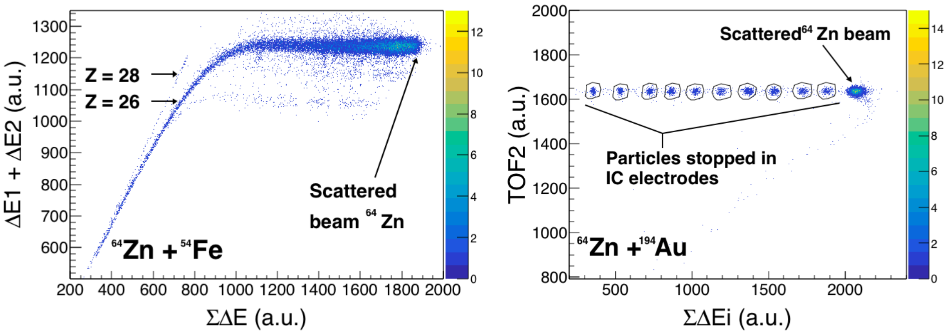


Fig. 5. Left: the energy loss $\Delta E_1 + \Delta E_2$ *vs.* the total energy $\Sigma\Delta E$. The scattered $^{64}$Zn ($Z = 30$) is separated by the stripping channels ($-2p$ and $-4p$) and the $^{54}$Fe recoiling ($Z = 26$). Right: time of flight *vs.* $\Sigma\Delta E$. The scattered beam particles of $^{64}$Zn stopped in the electrodes are in the small polygons.

The energy resolution has been obtained by measuring the elastic scattering of the beam in the $^{64}\mathrm{Zn} + {}^{197}\mathrm{Au}$ reaction. Also in this case, the detection angle was 30°. The pressure of the gas was chosen in order to stop the $^{197}$Au recoiling ions within the IC and separate them from the scattered beam. The MCP closer to the IC provided the trigger to the DAQ. Figure 5 (right panel) shows a 2D spectrum of the measurement. The energy resolution of the total energy signal is $(2.09 \pm 0.02)\%$.

## 4. Summary

The fast IC has been used with a shaping time of $0.25\,\mu$s in the amplifier and a DAQ gate width of $1\,\mu$s. The detector has been tested up to a rate of $\simeq 140$ kHz. A veto signal can be produced to reject the unwanted beam-like events and better identify the ER. The $Z$ and energy resolution of the IC are $1/38$ for $^{64}$Zn ions at about 3 MeV$/u$ and of $\sim 2.09\%$ with $^{64}$Zn ions at the energy of 2.3 MeV$/u$, respectively.

## REFERENCES

[1] G. Montagnoli *et al.*, *Phys. Rev. C* **97**, 024610 (2018).

[2] G. De Angelis *et al.*, *J. Phys.: Conf. Ser.* **527**, 012029 (2014).

[3] K.J. Chae *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **751**, 6 (2014).

[4] M. Mazzocco, LNL Annual Report, 2016.

[5] G. Colucci, Ph.D. Thesis, 2018.