

The large-area micro-channel plate entrance detector of the heavy-ion magnetic spectrometer PRISMA

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Received 7 February 2005; received in revised form 14 March 2005; accepted 16 March 2005

Available online 13 May 2005

Abstract

This paper describes the entrance detector of the magnetic spectrometer PRISMA recently installed at Legnaro. The detector is based on rectangular ($80 \times 100 \text{ mm}^2$) Micro-Channel Plates (MCP). It provides a fast time signal and its position-sensitive anode allows to extract the X and Y information. It exploits an electrostatic field for the acceleration of secondary electrons from a thin Carbon foil ($\simeq 20 \mu\text{g}/\text{cm}^2$) onto the MCP assembly. The electrons are guided by a parallel magnetic field. Good performances were obtained in the laboratory tests. The detector is presently installed at the entrance of PRISMA and gives resolutions $\leq 400 \text{ ps}$ in time, and 1 mm in both X and Y -axes, with efficiency $\simeq 100\%$, in typical experiments with heavy-ion beams.

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PACS: 29.40.-n; 29.40.Gx

Keywords: Detectors for heavy ions; Micro-channel plates; Magnetic spectrometers; Low-energy heavy-ion reactions

1. Introduction

Detectors for heavy-ions based on Micro-Channel Plates (MCP) have been widely used for

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many years (see e.g. Refs. [1–9]) in experimental set-ups for nuclear physics studies at low and intermediate energies. These detectors yield fast time signals often used for measurement of Time-of-Flight (TOF) of nuclear reaction products. Accurate position sensitivity in one or two directions has been also achieved by suitable read-out systems. Possible sources of problems that have to be solved with MCP detectors (and especially for large-area detectors) are the background of X-rays, δ -electrons and (unwanted) light charged particles produced in the target, and the sensitivity to external magnetic or electric fields.

This paper describes in detail the construction and performance of the MCP detector used in the magnetic spectrometer PRISMA [10] of LNL [11]. This detector is based on rectangular large-size MCP, it gives time and X , Y position signals, and it is placed near the scattering chamber. Its characteristics and its carefully chosen installation between the target and the first magnetic element of the spectrometer make it very important for the performance of PRISMA.

The most interesting features of this spectrometer are a very large solid angle (80 msr) and momentum acceptance ($\pm 10\%$), good mass resolution (1/300) via (TOF) measurement, energy resolution up to 1/1000, and capability of rotation around the target in a wide angular range from -20° to 130° . PRISMA is based on a simple quadrupole-dipole magnet configuration, but the ion tracks are reconstructed event by event, via software, using the position, time and energy signals from the entrance MCP detector described here, and from the array of focal plane detectors [10,12] (FPD), on the basis of the detailed mapping of the magnetic fields.

Two possible schemes for trajectory reconstruction can be applied, in general: one can use position, energy and exit-angle information from the focal plane detectors plus TOF along the spectrometer, or one may substitute the exit-angle with entrance angle information. A start detector is required in both cases, but in the first hypothesis it can be rather simple. However, simulations show that only the second scheme (that we have chosen for PRISMA) allows to achieve the design mass resolution of 1/300. This puts stringent require-

ments on the start detector since (1) it should provide good timing (TOF resolution better than $\simeq 500$ ns), (2) the entrance angle resolution should be better than $\simeq 0.5^\circ$ in the dispersion plane (tolerance is somewhat larger in the vertical direction), (3) thickness should be kept at a real minimum in order to disturb the ion trajectory as little as possible and (4) the detector should withstand a high counting rate because of the large solid angle.

The position of the detector, half-way between the target and the magnetic quadrupole represents a compromise between angular resolution and the need to keep its size within reasonable limits. At that distance, the required angular resolution translates into a position resolution of about 1 mm. A vertical strip target is also used to limit the beam spot in the horizontal direction to 1 mm.

PRISMA was mainly designed for high-efficiency studies of elastic and inelastic scattering, and of few- and multi-nucleon transfer reactions induced by very heavy ions. PRISMA marks a significant step further for the experimental activity in this field, with its large efficiency and high mass, Z and energy resolutions. Those heavy-ion collisions at energies near or slightly above the Coulomb barrier are an interesting research area where reaction dynamics and nuclear structure influence each other to a large extent. They are also a valid tool for the population of moderately neutron-rich exotic nuclei where new structure effects are expected to show up. A γ -ray detector array [13] with 25 Clover detectors, called CLARA, from the Euroball collaboration is associated to PRISMA and allows for such nuclear structure studies.

The MCP entrance detector of PRISMA described here, gives the direction of the ions with an uncertainty smaller than 0.5° , and off-line ion tracking yields a careful determination of their velocity. Therefore, a very effective Doppler correction for the γ -ray energies can be performed.

2. The MCP detector

The entrance detector of the PRISMA spectrometer is based on a pair of large-area

($80 \times 100 \text{ mm}^2$) MCP¹, mounted in the chevron configuration. It provides a fast time signal, and position information of the reaction products in two directions X (along the PRISMA dispersion plane) and Y . Its high-counting rate capability allowed to install the detector close to the target where, usually, a very high background due to δ -electrons, X-rays and light charged particles is present. In its location between the target and the quadrupole magnet of PRISMA, it matches the whole solid angle covered by the spectrometer.

A schematic layout of the MCP detector is shown in Fig. 1, and a picture is reported in the following Fig. 2. The inner detector assembly is housed in a metal cage tilted at 45° with respect to the optical axis. Two faces of the cage consist of grids (entrance and inner grids), and are transparent to the ions. The other four faces consist of the MCP inner surface, and of three stainless-steel walls. All this box is biased at the same voltage of the MCP ($\simeq -2000 \text{ V}$).

The ions coming from the target cross a first grid of $20 \mu\text{m}$ gold-plated tungsten wires spaced 1 mm . Then the ions cross, sequentially, a second grid (inner grid), a thin self-supporting carbon foil ($\simeq 20 \mu\text{g}/\text{cm}^2$) biased to $\simeq -2300 \text{ V}$, and an outer grid in electrical contact with the inner one.

The inner/outer grids are placed symmetrically on either side of the foil, at 4 mm from it. The inner grid accelerates (to 300 eV) the secondary electrons produced in the foil and emitted backwards, toward the MCP, while the outer grid is used to balance forces on the very delicate foil. The accelerated electrons reach the MCP pair surface and undergo multiplication. The produced charge is collected by the position-sensitive anode described in Section 3.

In order to preserve the position information [1,2], a magnetic field, parallel to the accelerating electric field, is applied using an external coil (see Fig. 1) installed half-way between the carbon foil and the MCP. The electrons spiral around the magnetic field direction, drifting ($\simeq 10 \text{ cm}$) towards the MCP. The magnetic field at the center of the coil is $\simeq 120 \text{ Gauss}$. The preliminary tests (see

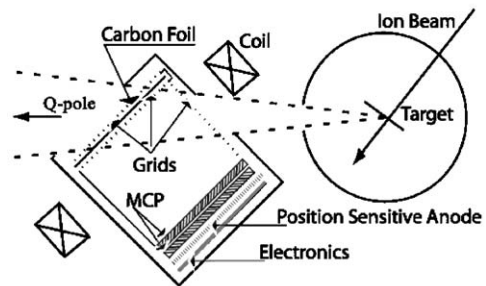


Fig. 1. Schematic view (from above) of the MCP detector. The carbon foil center is at 25 cm from the target.



Fig. 2. View of the MCP entrance detector.

Section 4) evidenced that the detector performance is only weakly affected by the intensity and uniformity of the magnetic field and/or by the accelerating electrostatic field. Both fields may be varied in a reasonably wide range [2].

Despite the short distance (25 cm) from the large-bore quadrupole magnet (30 cm diameter), the stray magnetic field is at most a few Gauss, thanks to a suitable shield placed in front of the quadrupole.

The MCP detector (see Fig. 2) is housed in a vacuum case, and fixed to a rectangular flange where the vacuum connectors for high voltage, DC-power for internal electronics, and for output signals are placed. Fig. 2 shows the detector as viewed from the target. The carbon foil is on the

¹GALILEO Corp., Galileo Park, P.O. BOX 550, Sturbridge, MA 01566-9979 (USA).

right; the electronics is fixed to the anode and to the MCP pair (not visible in the picture) and can be seen on the left.

3. The anode and the read-out system

The position-sensitive anode is composed of two orthogonal delay lines made of 100 μm gold-plated tungsten wire, each one wound around a frame of two plexiglas rods. The rods of the two lines have different diameters in order to keep them insulated from each other and both from the inner copper frame acting as a reflection plate for the electrons, according to Refs. [1,14] (see Fig. 3). The outer delay line is 3 mm from the MCP output face.

The scheme of the voltage divider (placed in vacuum) for the carbon foil, for the MCP and for the DC-voltage levels of the delay lines, is reported in the upper part of Fig. 4. The DC-voltage levels of the two delay lines are adjusted so as to collect half of the charge on each of them. Each delay line consists of two windings with 1 mm pitch as shown in detail in Fig. 3. Overall, they constitute a two-wire transmission line, where only one wire collects the charge (see Ref. [14] and Refs. therein for details). The two windings are connected to low-noise differential amplifiers [15] on one side (see Fig. 4), in order to minimize the influence of fast signals from the MCP. The whole anode structure is directly fixed to the printed circuit board where the voltage divider and the amplifiers are mounted (see Fig. 2).

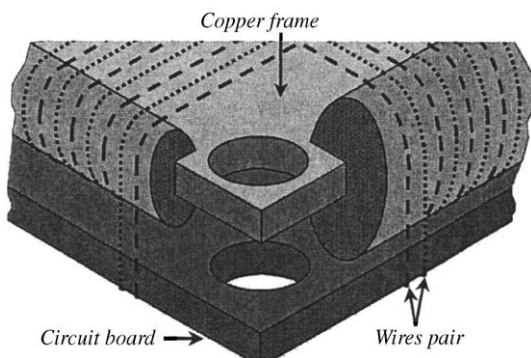


Fig. 3. An artist's view of one corner of the position-sensitive anode.

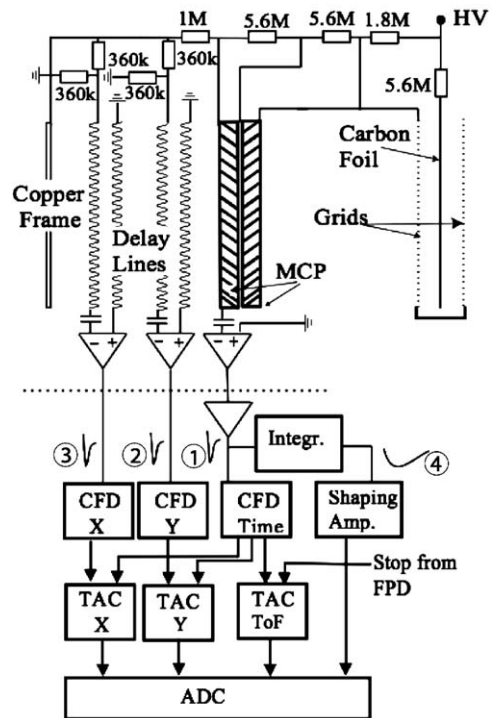


Fig. 4. A scheme of the MCP set-up, of the position-sensitive anode and of the electronics (see text). All items above the horizontal dashed line are in vacuum. The numbers just below the line identify the signals shown in Fig. 5.

Fig. 4 shows schematically how the X , Y position information is obtained from the difference in arrival time of the signal at one end of the delay line with respect to a reference time signal. This figure also shows that this fast time signal is derived from the second MCP through a capacitor. This signal is fed into a sequence of two fast amplifiers (risetime 1.5 ns, overall gain $\simeq 20$), in order to increase the counting rate capability of the detector. The second amplifier is placed outside the metallic box containing the whole detector. The time signal is also used as start reference for the TOF measurements through the spectrometer, while stop signals are supplied by the focal plane detectors.

Typical sets of signals are shown in Fig. 5. They were obtained during one of the tests with α -particles discussed in Section 5. From the top to the bottom, they are pairs of: time (blue),

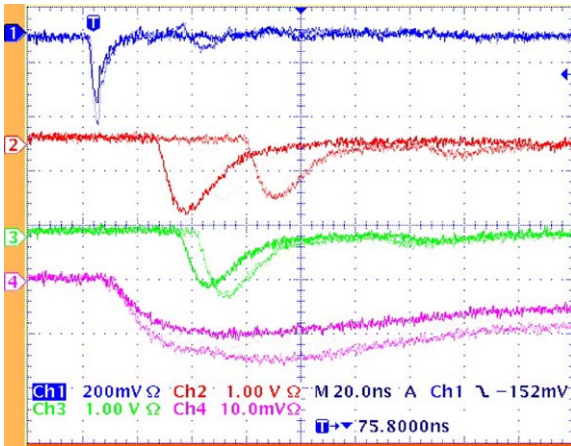


Fig. 5. Two sets of time, X , Y and time amplitude signals obtained with α -particles (see Fig. 4). The triggering signal is the fast time signal shown on channel 1 (in blue). The time base is 20 ns/div, and the sensitivities for the four channels are specified in the picture.

X (orange), Y (green) and time amplitude (pink) signals as seen on the scope. We notice that for a given time reference (the uppermost signal) triggering the scope, the X and Y signals appear with different delays (i.e. positions). The risetime of the fast time signal is $\simeq 1.5\text{--}2\text{ ns}$. For heavy-ions with $A \geq 20\text{--}30$, its amplitude is several hundreds of mV, typically. Comparable signals can be obtained with α -particles, by a suitable increase of the bias on the MCP.

In the lower part of Fig. 4 (below the horizontal dotted line), one sees the block scheme of the standard electronics placed outside the vacuum. The amplitude of the time signal is processed by an independent electronic line composed of an integrator and of a shaping amplifier. This allows to control the working conditions of the detector, and is used for further off-line analysis. Two examples of such integrated time signal amplitudes are shown in Fig. 5 (pink signals).

4. Tests with α -particles and UV rays

The position resolution of the MCP and read-out anode was tested illuminating directly the MCP surface with UV-photons emitted by a high

vacuum gauge. A mask with narrow slits was put in front of the MCP entrance surface and the image, we obtained, is shown in Fig. 6. One can appreciate that distortion effects are negligible and the position resolution is $\simeq 500\text{--}600\text{ }\mu\text{m}$.

Further tests of the position resolution were performed by irradiating the MCP directly with α -particles from a ^{241}Am source. As for the previous tests, a slotted mask was placed in front of the MCP. The result is reported in the upper panel of Fig. 7, where “PRISMA” appears, thanks to suitable cuts on the mask. The mask holes have $\varnothing = 1\text{ mm}$, with 5 mm separation.

The time resolution of the detector was extracted from a TOF measurement. To this end a smaller size MCP detector [16] ($20 \times 30\text{ mm}^2$), providing the start signal, was installed between the α -source and the large MCP (stop signal). The distance between the α -source and the small MCP detector was $\simeq 3\text{ cm}$, while the two MCP detectors

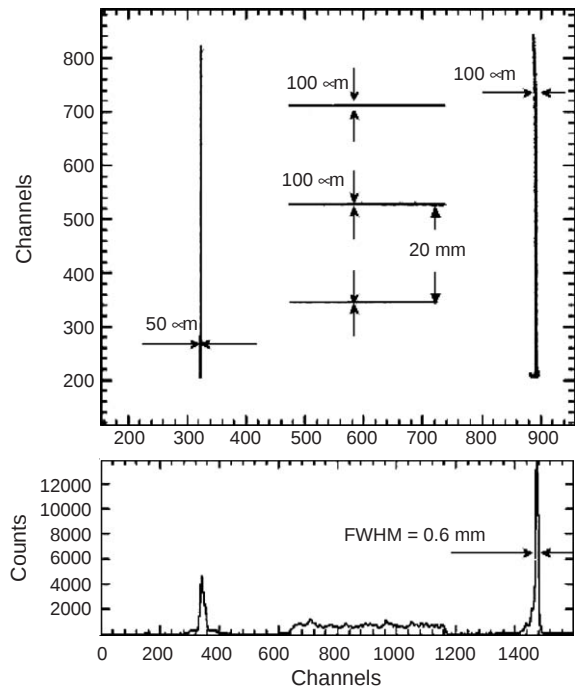


Fig. 6. X – Y two-dimensional spectrum obtained from the MCP detector illuminated by UV rays, and covered by a suitable mask. The projection on the X -axis is shown in the lower panel. The real widths of the open slits are reported in the upper panel.

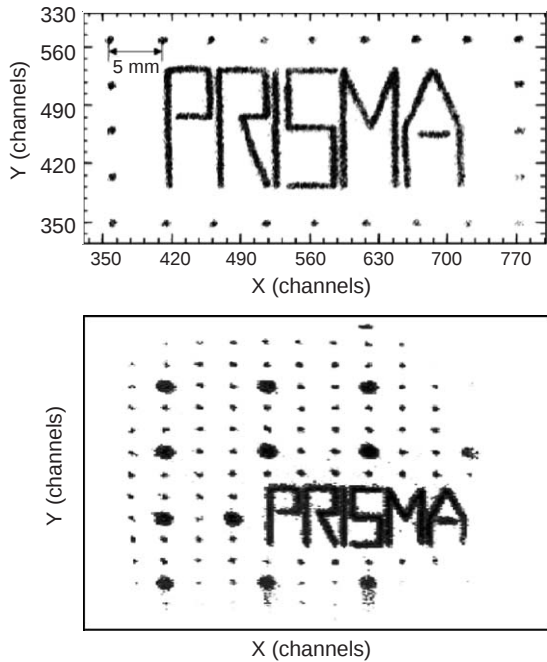


Fig. 7. Top: two-dimensional X – Y matrix of α -particles implanted into the MCP, through a mask of holes with diameter $\varnothing = 1$, and 5 mm apart from each other. Only a part of the whole matrix is shown. Bottom: the analogous X – Y plot obtained in the test with the ^{56}Fe beam as described in the text.

were at $\simeq 15$ cm from each other. The overall time resolution measured in this configuration is $\simeq 350$ ps FWHM (see Fig. 8).

5. In-beam performance

After installing the MCP detector at the PRISMA spectrometer, a first in-beam test of the position resolutions in X and Y was performed, with the $^{56}\text{Fe} + ^{197}\text{Au}$ reaction well below the Coulomb barrier (186 MeV of ^{56}Fe beam on a $200 \mu\text{g}/\text{cm}^2$ ^{197}Au target). The spectrometer was placed at $\theta_{\text{lab}} = 70^\circ$ and the elastically scattered ^{56}Fe ions were analyzed by PRISMA.

The same mask used for the laboratory tests (see Fig. 7, upper panel), was placed near the carbon foil (4 mm apart and downstream of it). In this case, a few holes were made larger ($\varnothing = 3$ mm). By triggering on ions that reach the focal plane of

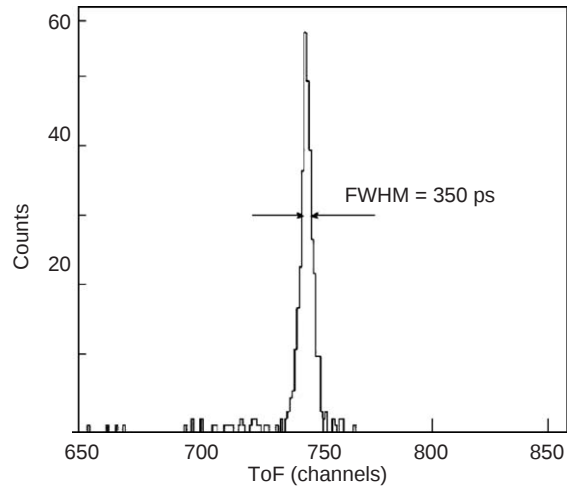


Fig. 8. Time-of-flight spectrum of α -particles obtained in the laboratory tests (see text).

PRISMA, one observed the structure reported in the lower panel of Fig. 7. This X – Y plot is quite comparable with the results of the tests with direct implantation of α -particles, i.e. the transport of the accelerated secondary electrons from the carbon foil to the MCP with the help of the magnetic field, keeps the position resolution better than 1 mm. The efficiency for the detected heavy ions was close to 100%. The long-term stability of the MCP detector (days of beam time) was also checked to be excellent. Further tests performed during test experiments with beams of ^{32}S and ^{64}Ni showed similar results as far as position resolutions, efficiency and stability are concerned.

We remark that, in this test as well as in the usual working conditions of PRISMA ($\theta_{\text{Prisma}} \geq 30^\circ$, beam intensity up to ≈ 20 pA, target thicknesses $\simeq 200$ – $400 \mu\text{g}/\text{cm}^2$), no particular problem for the MCP detector was caused by δ -electrons and other types of unwanted background coming from the target, in spite of the relatively short distance from it and of the large area of the MCP. This is the positive consequence of various conditions, i.e. (1) the detector is placed in a box separated from the small scattering chamber (see Fig. 1), (2) secondary electrons emitted backwards with respect to ion trajectories are detected, (3) the detector entrance grid, facing the target, has a high-negative voltage ($\simeq -2000$ V), (4) the applied

$\simeq 120$ Gauss magnetic field deflects unwanted electrons away from the MCP.

The timing performance of the MCP detector has also been checked in-beam, using a ^{40}Ca beam and a very thin ^{64}Ni target (a vertical strip, $18\mu\text{g}/\text{cm}^2$ thick and 1.5 mm wide, evaporated onto a $20\mu\text{g}/\text{cm}^2$ carbon backing).

The beam energy was 120 MeV, very near the nominal Coulomb barrier. The MCP detector was placed at $\theta_{\text{lab}} = 54^\circ$ (the central angle of PRISMA), in kinematical coincidence with a 50mm^2 ion-implanted silicon detector (SD) at $\theta_{\text{lab}} = 48^\circ$ on the other side of the beam direction. This SD was placed at 180 mm from the target, with a $\varnothing = 4\text{mm}$ collimator. Because of the wide horizontal angle subtended by the MCP ($54^\circ \pm 6^\circ$), the kinematical coincidence was insured both for scattered ^{40}Ca and recoiling ^{64}Ni ions detected by the silicon.

The TOF difference ΔTOF between the two ejectiles was measured by standard NIM electronics. In particular, the timing signals were fed into Constant Fraction Discriminators (Phillips Scientific, model 715), and the SD was overbiased by a factor 2.7. Fig. 9 shows the ΔTOF spectrum measured with a narrow gate on the energy spectrum of the ^{40}Ca ions detected by the SD. This procedure minimizes the kinematic contribu-

tion to the ΔTOF spectrum width. A ΔTOF time width $\simeq 400\text{ps}$ FWHM was obtained, as shown in Fig. 9.

It is reasonable to estimate that the SD contributed for the larger part of this width, since its time signal was intrinsically slower than the fast MCP signal (the two risetimes were 6–7 ns and $\simeq 2\text{ns}$, respectively, with comparable signal-to-noise ratios). Therefore, the time resolution of the MCP detector is much better than 400 ps. This refers obviously to only a part of the detector; however, the time resolution has to be good over all its surface, since the mass resolution is good for *all events* detected in real experiments (see the example here below). Actually, in PRISMA the mass A is derived, in a first approximation, from the position along the focal plane ($B\rho$) and from the TOF through the spectrometer, namely $A = B\rho \times \text{TOF}$, and the TOF of the ions to be analyzed is typically ≈ 200 –400 ns.

The first real experiments on grazing collisions between heavy ions were performed with PRISMA recently. Among them, a beam of ^{82}Se has been accelerated to 505 MeV by the Tandem-ALPI complex onto a ^{238}U target (a $400\mu\text{g}/\text{cm}^2$ U strip on a thin carbon backing). The scattered Se-like ions were analyzed by the magnetic spectrometer set at the grazing angle ($\theta_{\text{lab}} \simeq 64^\circ$). Fig. 10 shows the mass spectrum of germanium isotopes obtained after ion-track reconstruction, for a part of the total accumulated statistics of the experiment. The germanium isotopes were populated by two-proton stripping reactions, and several neutrons were transferred as well. In particular, we notice that a good mass resolution was reached ($\Delta A/A \simeq 1/280$). This is routinely achieved in the campaign of experiments presently being performed using the PRISMA-CLARA combined facility. Good time and position resolutions of the MCP detector (as well as of the focal plane detectors) are necessary ingredients for this successful performance.

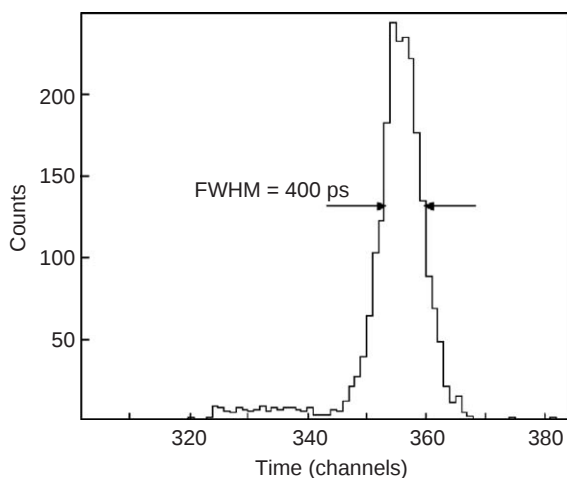


Fig. 9. Time spectrum measured using the in-beam kinematical coincidence set-up described in the text. The time calibration of the spectrum is 53 ps/cha.

6. Summary and conclusions

A large-area MCP detector for heavy ions has been installed at the entrance of the magnetic

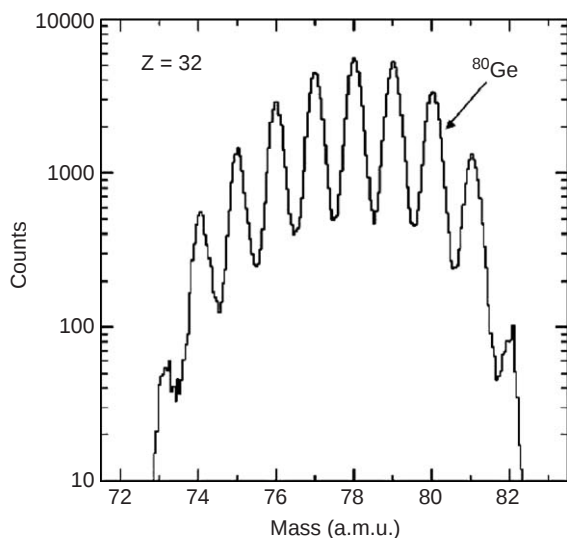


Fig. 10. Germanium isotopes populated by neutron transfer in the reaction 505 MeV ^{82}Se on ^{238}U , $\theta_{\text{lab}} = 64^\circ$, detected and identified by the magnetic spectrometer PRISMA.

spectrometer PRISMA at LNL. It provides X, Y positions and a fast time signal for the ions entering the set-up. The detector uses a pair of $80 \times 100 \text{ mm}^2$ MCP detecting secondary electrons produced in a thin carbon foil placed on the ion trajectories. The electrons are accelerated to $\simeq 300 \text{ eV}$ and a parallel magnetic field preserves the position information, on their way to the MCP pair.

The multiplied electrons are collected on an anode consisting of two pairs of thin wire grids, mounted orthogonally to each other on a common frame, and used as delay lines. A fast time reference signal is derived independently from the MCP. The time distance between this fast signal and the outputs of the delay lines, gives the X, Y positions. The detector set-up includes fast amplifiers for the time signal, for the signals produced in the wire grids, and a voltage divider, installed on a common board behind the anode structure.

Early laboratory tests were performed by direct implantation of α -particles from a ^{241}Am source, onto the MCP surface. Position resolutions $\simeq 0.5 \text{ mm}$ in X and Y , and a time resolution $\leq 350 \text{ ps}$ have been measured. Final tests have been performed by placing the detector in its

working site, i.e. at the entrance of the PRISMA spectrometer, between the small scattering chamber and the quadrupole magnet. Scattering of medium-heavy beams (^{32}S , ^{40}Ca , ^{56}Fe , ^{64}Ni , ^{82}Se) on heavy targets, has shown X, Y position resolutions $\leq 1 \text{ mm}$ with $\simeq 100\%$ efficiency over all detector surface, and an accuracy of the time signal better than $\simeq 400 \text{ ps}$. The background coming from X-rays, δ -electrons and light charged particles produced in the target, is not overwhelming in the usual working conditions of the spectrometer.

The large-area MCP detector described in the present paper is currently used in the heavy-ion experiments with the spectrometer PRISMA and the combined PRISMA-CLARA set-up. Its timing and position signals are fundamental for off-line reconstruction of the ion trajectories, and consequently for their mass identification with resolutions $\Delta A/A = 1/280\text{--}300$. Its precision allows a very accurate Doppler correction for the γ -ray signals detected in the Clover array.

Acknowledgements

We would like to acknowledge all other members of the PRISMA-CLARA collaboration, and all technicians of the Tandem-ALPI accelerators, who made possible the experiments with PRISMA. Grateful thanks are due to the staff of the Target Laboratory of the GSI, for producing the high-quality carbon foils used in the MCP detector, and to Mr. M.Negrello (INFN - Padova) for his professional work on electronics.

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