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A telescope with microstrip gas chambers for the detection of charged products in heavy-ion reactions

F. Gramegna[a,*], U. Abbondanno[b], A. Andreano[c], R. Bassini[c], F. Bonutti[b], M. Bruno[d], G. Casini[e], M. D'Agostino[d], G. Manzin[a], G.V. Margagliotti[b], P.F. Mastinu[f], P.M. Milazzo[b], A. Moroni[c], M. Squarcini[e], F. Tonetto[a], G. Vannini[b], L. Vannucci[a]

[a]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro, Italy*
[b]*Istituto Nazionale di Fisica Nucleare, Sezione di Trieste and Dipartimento di Fisica dell'Università, Trieste, Italy*
[c]*Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milan, Italy*
[d]*Istituto Nazionale di Fisica Nucleare, Sezione di Bologna and Dipartimento di Fisica dell'Università, Bologna, Italy*
[e]*Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Firenze, Italy*
[f]*Istituto Nazionale di Fisica Nucleare, Sezione di Bologna and Dipartimento di Fisica dell'Università, Padova, Italy*

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Abstract

Prototypes of a ΔE–E telescope, designed to detect and identify with low-energy threshold both light charged particles and heavy fragments, are described. They are based on a gas drift chamber which conveys primary ionization electrons on gas microstrip devices where multiplication occurs and the energy loss signals are generated. Silicon detectors or CsI(Tl) crystals operate as residual energy detectors. The prototypes were tested both with a source and heavy ion beams. Performances, mainly related to energy resolution, charge identification and angle resolution, are reported.

1. Introduction

One of the most challenging performances required for a detecting system for studies on nuclear reaction mechanisms with heavy ions, at beam energies up to a few tens of MeV per nucleon, is the capability to identify the charge (and/or mass) of a large variety of reaction products and to measure their energies, typically ranging from 10^{-1} to 10^3 MeV. To somehow fulfil these requirements, many-stage telescopes (as ionization chamber + Si + CsI(Tl)) that use the ΔE–E technique or huge apparatuses based on the time-of-flight technique, have been built or proposed [1]. In the last few years a new possibility arose from the advent of microstrip gas chambers (MSGCs), formerly developed to meet the severe counting rate and position resolution requirements of high-energy physics experiments [2,3]: the ΔE–E technique using MSGCs in connection with plastic scintillators was in fact successfully used for heavy ion identification [4,5].

In designing GARFIELD [6,7], a new apparatus to be operated at the ALPI linear accelerator (5–20 A MeV) of the Laboratori Nazionali di Legnaro (LNL, Padua, Italy), the possibility of identifying light charged particles and heavy fragments using telescopes with only two stages, taking advantage of some of the MSGC peculiarities, was considered worth investigating.

We report here on the performances, namely the energy, charge and position resolution, obtained with telescope prototypes containing MSGCs as energy loss (ΔE) elements and silicon diodes or CsI(Tl) crystals as residual energy (E) detectors.

2. Description of the detector

A sketch of a prototype is shown in Fig. 1. The reaction products enter the gas region through a 6 μm-thick mylar window, lose energy in the gas and stop in one of the residual energy detectors, positioned 13 cm from the entrance window. The primary ionization electrons, created in the active gas volume, drift towards the Frisch grid under the action of a constant electric field between the cathode and the grid, which is 18 cm from the cathode. The dimensions of the active volume of the drift chamber have been chosen according to the GARFIELD layout, which in turn has been dictated by a compromise among many constraints including mechanical feasibility and budget availability. For instance, to reduce the cost of the residual energy detectors and the drift time, it was necessary to minimize the overall size, but still allow sufficient

* Corresponding author.

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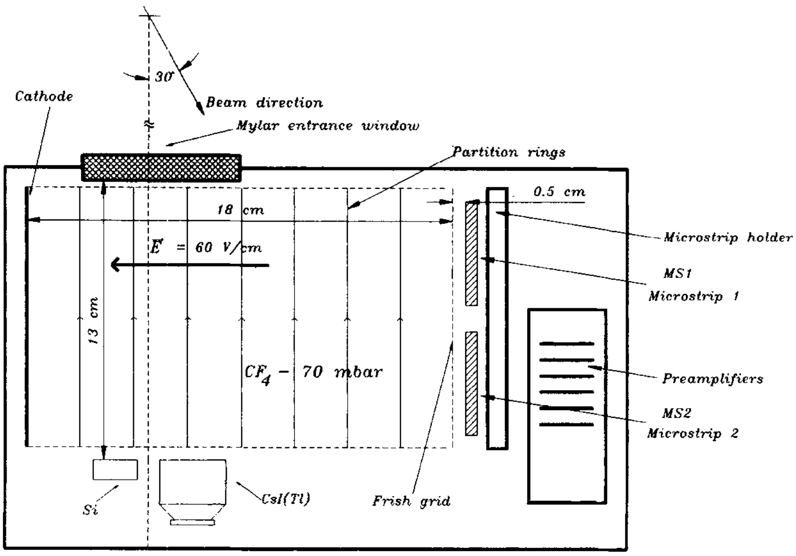

Fig. 1. Schematic drawing of the prototype used in the tests.

room to safely insert the entrance window and, at the same time, to keep the dead area below 10%.

A chain of 1 MΩ resistors connects the cathode to the grid through 70 partition rings, which assure the homogeneity of the electric field. The grid is grounded through a 11 MΩ resistor. This choice largely meets the conditions to minimize the capture of electrons on the grid [8].

The electrons reach the grid (95% geometric transparency) and the microstrip pads MS1 and MS2, where multiplication occurs and the $\Delta E1$ and $\Delta E2$ signals are generated.

Two 50×50 mm^2 Desag D263 glass microstrip pads (MS1 and MS2) [9], 0.5 mm thick, are mounted on a frame placed 5 mm after the grid. The microstrip 30×30 mm^2 chromium structure is deposited on the front plane (200 μm pitch, 80 μm wide cathodes, 10 μm wide anodes), while the back plane has a chromium continuous layer. The anodes of each pad have been connected together and biased in the 380–450 V range. Cathodes were also connected together and grounded. It has to be mentioned that connecting all the anodes together deprives the microstrips of one of their most interesting peculiarities, i.e. the high granularity due to the 200 μm pitch. This granularity could be used for precise position determination, as in the high-energy physics applications, or for ion identification by multisampling (50 samples per cm) the energy loss curve. These possibilities are not considered here, as the requirements for the experiments presently foreseen at the ALPI accelerator appear achievable without exploiting them.

Silicon diodes (50 mm^2 each, 700 μm thick) have been initially used as residual energy detectors. Later measurements have been made also with CsI(Tl) crystals (4×4 cm^2 front face and 52 cm^3) [10]. The back of each crystal has been shaped as in Fig. 1 to match, without any light pipe, the dimensions of the 18×18 mm^2, 500 μm thick S53204-05 photodiode [11] which reads out the emitted light. Further details on the CsI(Tl) preparation, calibration and tests will be given in a forthcoming paper.

Despite the worse energy resolution and linearity with respect to Si detectors, and the strong dependence of the light response on the charge of the interacting ion [12], CsI(Tl) crystals have many advantages for a detection system as GARFIELD, designed to cover a substantial part of 4π: namely they can be cut to any shape, can reach thicknesses suitable to stop all the particles with the kinetic energies of interest and are far less sensitive to radiation damage. Measurements performed with the two kinds of stop detectors will be compared.

3. Drift chamber and microstrip working conditions

A variety of tests, both with sources and heavy ion beams, was performed to identify the working conditions (gas pressure, drift electric field, microstrip anode voltage, back plane voltage, gas flow) best suited to our goals, namely charge identification from protons to heavy ions from $E \leq 1$ A MeV up to the highest energies available from ALPI and angle resolution $\Delta\theta \leq 2°$.

The main results and most relevant comments are hereafter reported:

- The CF_4 gas has been chosen, due to the high electron drift velocity and high stopping power. The typical gas pressure for the in-beam operation is 70 mbar. This value is a compromise between two opposing needs: on one hand the gas pressure should be reduced to decrease the identification threshold for heavy fragments, on the other hand it should be increased to have sizeable signal amplitudes and thus improve the detection of low ionizing particles like protons.

- The pressure has to be constant within 1%, in order not to affect the energy resolution.
- For the employed prototype, the gas flow has to be about 1 std l/min; reducing the flow to 0.1 std l/min results in worsening by about a factor of two the MSGC energy resolution after a few minutes. We are confident that a careful selection, which is in progress, of the materials to be used inside the detector [13] might reduce the needed flow.
- To maximize the electronic drift velocity to a value of ≈ 10 cm/μs at 70 mbar of CF_4, a drift electric field of ≈ 60 V/cm has to be applied. In the already described geometry, that implies a typical cathode bias of $V_c \simeq -1300$ V and a grid voltage of $V_g \simeq -170$ V.
- Microstrip anodes were found to break down at voltages between 500 and 550 V, depending on the various pads. The tests have been therefore made applying a voltage in the range 380–450 V. The electron multiplication gain, shown in Fig. 2 as a function of the anode voltage, is ≈ 90 at 400 V. This bias voltage, which is far enough from the breakdown region and guarantees a stable operation, has been used for all that follows.
- The microstrip signals were initially collected both from anodes and cathodes. Each microstrip has to feed three electronics chains, one handling a fast signal for timing purposes and, to exploit the large dynamical range, two with shaping amplifiers for the energy loss information (one with a gain value chosen for heavy ions and the other with a higher gain, about 10 times the previous one, for light particles). We compared the performances obtained using the anodic signal for the linear chains and the cathodic signal for the fast chain with the ones obtained using only one electrode (for instance, anodes) for the three chains. As no relevant difference was found for our purposes, the second solution, which requires half the number of preamplifiers, was chosen. All the signals from microstrips, Si detector and photodiodes, are fed to charge preamplifiers [14] located inside the prototype; sensitivities of 30 or 60 mV/MeV (silicon equivalent) have been used. Optimization of the connections and shielding of the electronics was also performed to avoid cross-talk between the detectors inside the prototype.
- The MSGC energy resolution for the α particles from a ^{241}Am source, entering the detector with an angular aperture of $\approx 3°$, goes from 5% to 9% FWHM, for energy losses from ≈ 600 keV to ≈ 240 keV corresponding to CF_4 pressures from 70 to 30 mbar.
- No significant dependence of the energy resolution on the position of the microstrip was found interchanging MS1 and MS2. Using different pads we also verified that the resolution is independent of the pad, within the errors.
- The back plane was biased in the range 0–100 V to check possible differences in the anode output signals due to the implantation of positive ions on the glass substrate [15]. As no effect turned out, suggesting that at a gain of 90 and counting rates below 1 kHz this effect is negligible, the back planes were grounded in all the subsequent measurements.

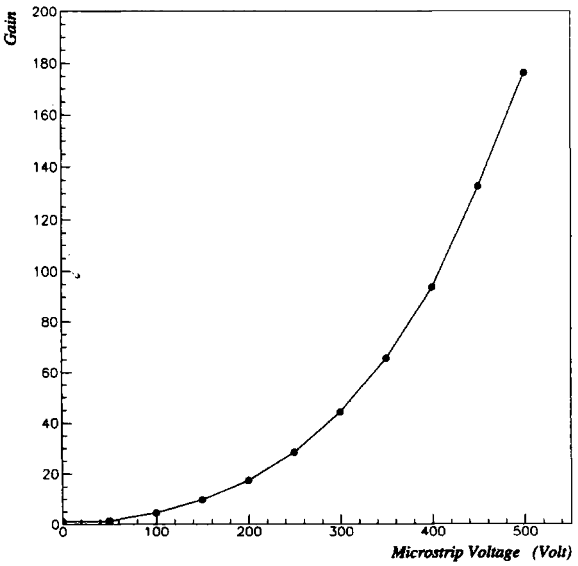

Fig. 2. Gain of the microstrips as a function of the applied voltage.

4. Telescope performances

Tests with heavy ion beams have been performed using 140, 180 and 200 MeV ^{32}S impinging on a variety of targets (^{56}Fe, ^{63}Cu, ^{92}Zr and ^{197}Au) and 250 MeV ^{58}Ni, 430 MeV ^{76}Ge on ^{92}Zr and ^{197}Au. The ^{32}S and ^{58}Ni beams were supplied by the XTU tandem accelerator, the ^{74}Ge one by the ALPI booster. For the 200 MeV ^{32}S + ^{63}Cu reaction the prototype was placed at an angle of 30° with respect to the direction of the incident beam, with the residual energy detectors metrically placed with respect to the 30° direction (see Fig. 1). The distance between the target and the Si or CsI(Tl) detector was 65 cm. In this geometry the angles subtended by the entrance window, Si detector and GsI crystal were 6.6°, 0.7° and 3.5°, respectively.

The possibility of Z-identification up to the beam value is demonstrated in Fig. 3 Fig. 4, where the calibrated ΔE–E scatter plots for the 200 MeV ^{32}S + ^{63}Cu reaction are shown. Fig. 3 corresponds to the low gain signals of MS 1 versus the silicon detector signals. The Z resolving power is $Z/\Delta Z = 34$ at $Z = 16$, constant in the whole energy range of the detected ions. The same values have been obtained from the MS2-Si plot and also for the

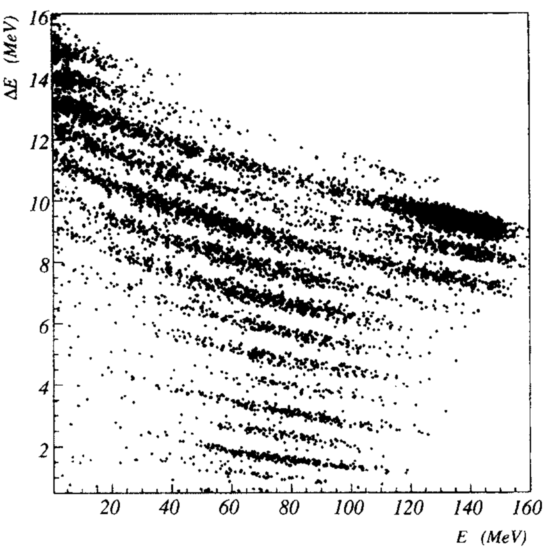

Fig. 3. ΔE–E calibrated scatter plot for the 200 MeV ^{32}S + ^{63}Cu reaction (MS1 versus silicon signals). Charge values Z from 4 to 18 are displayed.

microstrip-CsI telescope (Fig. 4). This is not surprising as the charge separation is largely due to the performances of the ΔE detector and the worsening due to the larger angular acceptance of the CsI detector is negligible in the present geometry.

The resolution of the energy loss signal (corresponding to $\Delta E \simeq 10$ MeV) for the ^{32}S elastic peak is 4.6%. For heavier beams, the resulting values are 3.7% for the ^{58}Ni beam and 4.6% for the ^{74}Ge beam (the energy losses were $\simeq 20$ MeV and $\simeq 30$ MeV, respectively).

Concerning the energy threshold, data demonstrate that the minimum energy an ion must initially have to be identified in GARFIELD is as low as 0.8 A MeV. Thus, the GARFIELD project requirements about ion identification and energy threshold are fully met.

The region of $Z = 1$ particles, from the high-gain chain of the microstrip, is shown in the inset of Fig. 4. Some separation between protons and deuterons can even be seen. Data demonstrate that protons can be identified in GARFIELD at least from 1 MeV to 70 MeV. The upper value, which can be considered the upper limit to be measured in GARFIELD at ALPI energies, is considered reachable as the energy loss equivalent to the measured noise level, smaller than 6 keV, favourably compares with the $\simeq 10$ keV energy loss expected for protons of that initial energy.

Information on the azimuthal angle θ of the impinging particle can be obtained from drift time measurements. In-beam tests have been performed to check the resolution achievable measuring the time difference between signals from the residual energy detector and one of the microstrips. The CsI(Tl) crystal used in these tests was collimated with a mask made by two strips 6 mm and 3 mm wide, placed 5 mm from one another. A sketch is shown in Fig. 5, with the time spectrum obtained with the products from 180 MeV ^{32}S on ^{197}Au. The resolution is clearly better than 3 mm. In the GARFIELD configuration, where the CsI crystals are at 15–22 cm from the target, this

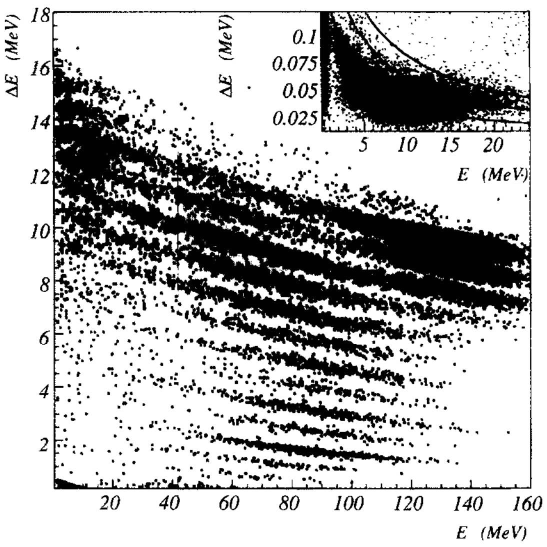

Fig. 4. ΔE–E calibrated scatter plot for the 200 MeV ^{32}S + ^{63}Cu reaction (MS1 versus CsI(Tl) signals). $Z = 1$ particles are shown in the inset.

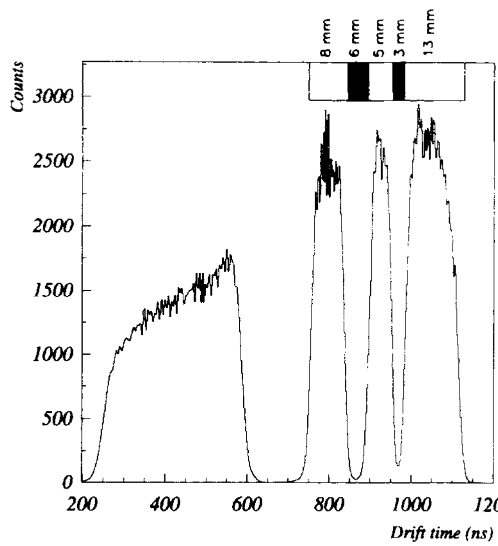

Fig. 5. Electron drift time distribution measured as the time difference between the CsI(Tl) and the microstrip signals. A mask, sketched in the upper part of the figure, is placed in front of one of the CsI(Tl) crystals.

corresponds to an angular resolution $\Delta\theta$ better than 1.1° and 0.8°, respectively. These values also satisfy the design goals for the GARFIELD project.

5. Conclusions

Gas microstrip pads were used in a two-stage telescope for Z identification and the detection of light and heavy charged reaction products. The advantages of using a microstrip gas chamber are mainly given by the signal-to-noise ratio for low ionizing particles, higher than for ionization chambers, and by a large dynamic range. These two characteristics allow the simultaneous identification both of light charged particles and of heavy ions with low energy thresholds.

Tests demonstrate that the Z resolving power values of 34 (at $Z = 16$), energy thresholds for heavy ion identification lower than 1 A MeV and angular resolutions of about 1° are achievable with operating MSGCs at low gain in CF_4 gas.

Light charged particles can be detected and, in particular, protons of kinetic energy ranging from 1 MeV up to 70 MeV can be identified.

The basic project requirements of the GARFIELD apparatus were fully satisfied.

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