GARFIELD:a General ARray for Fragment Identification and for Emitted Light particles in Dissipative collisions

2004 IEEE Nuclear Science Symposium, Medical Imaging Conference, and Workshop of Room-Temperature Semiconductor Detectors

F. Gramegna*[1], A. Moroni[5], G. Casini[4], M. Bruno[3], U. Abbondanno[2], R. Bassini[5], S. Barlini[1], A. Boiano[6], C. Boiano[5], S. Brambilla[5], R. Cavaletti[3], M. Chiari[4], A. Cortesi[5], M .D'Agostino[3], P. Del Carmine[4], M. Falsiroli[1], E. Geraci[3], M.Giacchini[1], A. Giussani [5], V.L. Kravchuk[1], A.L. Lanchais[1], M. Malatesta[5], G.V. Margagliotti [2], P. F. Mastinu[1], P.M. Milazzo[2], A. Nannini[4], A. Ordine[6], G. Tobia[4], F. Tonetto[1], L. Travaglini[1], G. Vannini[3], L. Vannucci[1].

1 *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro*
2 *Istituto Nazionale di Fisica Nucleare, Sezione di Trieste and Dipartimento di Fisica dell'Università, Trieste*
3 *Istituto Nazionale di Fisica Nucleare, Sezione di Bologna and Dipartimento di Fisica dell'Università, Bologna*
4 *Istituto Nazionale di Fisica Nucleare, Sezione di Firenze and Dipartimento di Fisica dell'Università, Firenze*
5 *Istituto Nazionale di Fisica Nucleare, Sezione di Milano and Dipartimento di Fisica dell'Università, Milano*
6 *Istituto Nazionale di Fisica Nucleare, Napoli*

***Abstract*--GARFIELD, an apparatus designed to study complex nuclear events produced in the medium-low energy range (5-20 A MeV) heavy ion induced reactions, is presented. Its main components are two newly conceived drift chambers, based on the ΔE-E technique, for fragment and light charged particle identification (θ=30°-150°). The ΔE signals are delivered by 180 micro-strip detectors that amplify the primary ionization produced along the track left by the particle in the gas. The residual energy signals are given by 180 CsI(Tl) crystals. Details both on the main characteristics of the single parts and of the whole apparatus are given. The drift chambers are complemented by a Ring Counter, an annular three element multi-telescope for forward emitted reaction products (θ= 6°-18°), and a set of Position Sensitive Parallel Plate Detectors (20x20 cm^2 each), used mainly for PLF or evaporation residues detection and mass measurements in dissipative collisions.**

Manuscript received October 31, 2004.

L. Travaglini is now at private company (e-mail: laura.travaglini @libero.it).
F. Tonetto is now at private company (e-mail: tonetto @tin.it)
M. Falsiroli is now at private company
(e-mail: falsiroli @accenture.infostrada.it)
M. Malatesta is now at private company

I. Introduction

The experimental nuclear physics with heavy-ion has opened up in the last decade to a large variety of new processes, moving in a quite large incident beam energy range, from few MeV/n up to many GeV/n. A continuous development, from low energy typical processes to the very complex and disruptive events found at the high energy side, has to be considered in order to obtain a deeper comprehension of the entire phenomenon. The energies in between the extreme regions, which somehow strongly characterize different kinds of processes (compound nucleus – multi-fragmentation, multi-fragmentation - vaporization, vaporization - production of sub-nuclear particles etc.), are those of particular relevance, because they permit the study of the behavior of the system while it is developing from one stage to another, due to particular changes of the nuclear matter characteristics.

The ALPI linear accelerator of the LNL (Padua, Italy) is designed to operate in the energy range from 6 to 20 MeV/n. Among the various possible themes of research in this energy region, the interest of our group was focused mainly on the search for non-equilibrium signatures in deep inelastic collisions, for the onset of three body processes at low excitation energies and for the experimental evidences of a low energy liquid-gas phase transition.

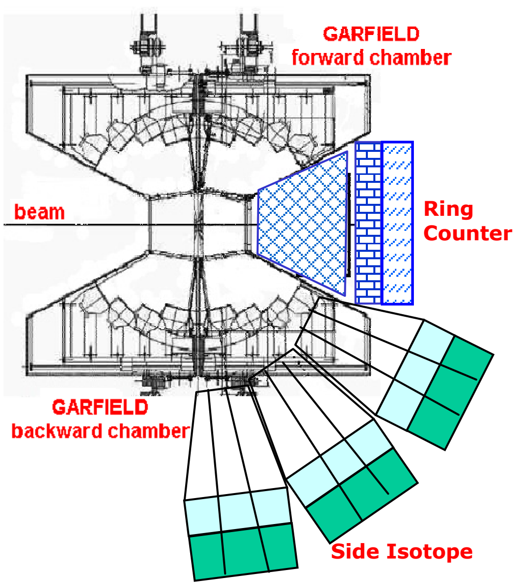

Fig. 1 – Sketch of on of the possible set-up with the GARFIELD apparatus

II. Experimental Set-up

We designed and realized a composite general purpose apparatus especially tailored to be used in measurements aiming to investigate the physics described above [1]. It is composed by three main parts, namely:

a) Two newly designed drift chambers, covering a large solid angle region, for intermediate mass fragments and light charged particles identification, taking advantage of the performances of gas micro-strips and scintillating crystals[2].

b) The Ring Counter: an annular three element telescope placed at forward angles, for light charged particles and fragments identification.

c) A set of three element telescopes of the same kind used in the MULTICS apparatus (actually installed at the Laboratori Nazionali del Sud in Catania). The set up which can be coupled with GARFIELD is made by 15 telescopes, each of which is composed by a 8 cm long Bragg ionization chamber, a 300 μm Si detector, one 5cmx5cm, 4 cm thick CsI crystal [3].

d) A time of flight system composed by four large Position Sensitive Parallel Plate Avalanche Counters (PSPPACs), for fragment mass identification.

A sketch of the whole apparatus is shown in Fig. 1.

The structure and the performances of the apparatus are described in the following. One of the most important requirements that a complete apparatus should fulfill, when used for studies of nuclear reaction mechanisms with heavy ions, is the capability of measuring the energy values and of identifying the charge and/or the mass of a large variety of reaction products.

a) Drift Chambers

The use of gas detectors is of great importance to somehow fulfill these requirements on a large dynamical range, allowing an easy selection of the effective ΔE thickness, which often becomes a compromise between the requirement of low identification thresholds and the necessity to handle quite large dynamical ranges of detected products. New possibilities for the gas ΔE section arose a few years ago with the development of micro-strip gas chambers (MSGC), initially designed to meet the severe needs of high energy physics experiments as far as regards the counting rate, the high gain and the position resolution. Using the ΔE/E technique with the MSGCs in connection with scintillators, both plastic and inorganic, as CsI(Tl) crystals, was shown to be very promising.

The advantages of using MSGC's are mainly due to the large dynamical range and to the signal-to-noise ratio for low ionizing ions, which is much higher as compared to ionization chambers. These two characteristics allow the simultaneous identification, with low energy threshold, of both light charged particles and heavy ions with an only two-stage telescope.

Two drift chambers (GARFIELD) with cylindrical symmetry have been therefore designed. They are placed back to back, arranged at forward and backward angles with respect to the target. In Fig. 1 the cross section view along the beam axis is shown. The forward chamber covers the angular region from θ=30° to θ=85°, while the region from 95° to 150° is covered by the backward detector respectively. The coverage of the azimuthal angle is almost complete except for a side opening of ~45° in the forward chamber to permit the allocation of specialized telescopes or different detectors like the PSPPAC.

The drift chambers, filled with CF_4 at 50-80 mbar, are divided in 21 and 24 sectors respectively. In each sector four micro-strip pads [4] and four CsI(Tl) are present. In the single cell every CsI crystal covers 15° in θ and ϕ, while the micro-strip detectors, which are positioned almost perpendicular to the beam axes are structured so that an angular resolution of about 7.5^{o} in ϕ and 1^{o} in θ, through the measurements of the drift time of the electrons, can be obtained. The identification threshold is about 0.8 MeV/n, while the detection threshold is much lower.

A total of 84 micro-strips and 84 CsI(Tl) are then present in the forward chamber, while 96 micro-strips and 96 crystals are there in the backward chamber. The micro-strip detectors provide the ΔE signals, multiplying and collecting the primary electrons of the ionization tracks. The energy resolution of the chambers is about 2% for 1 $A\cdot$MeV fragments (up to Z=28).

The CsI(Tl) crystals, which geometrically define the boundary of the sensitive volume of the drift chambers, are in the same gas volume. They provide the measurement of the residual energy with ~3% precision. Due to the micro-strip amplification of the primary charge and to the low energy threshold, the detector is characterized by a wide acceptance in Z (from 1 up to at least 28).

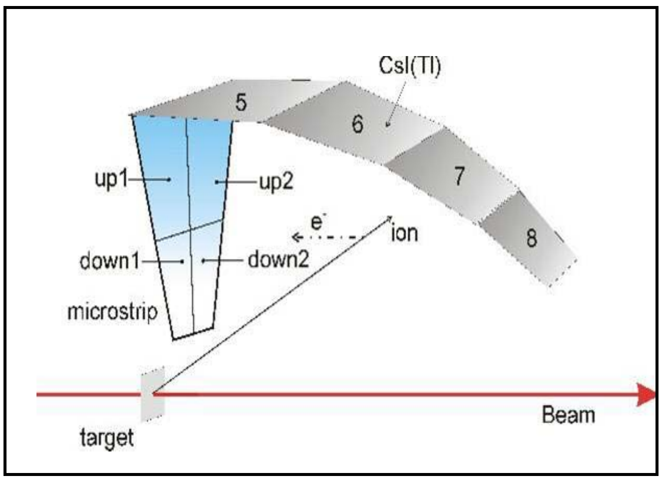

Fig.2 – 3D Sketch of the GARFIELD drift chamber cell.

The sketch of a 3D cell of the GARFIELD detector is shown in Fig. 2: charged particles entering the active volume loose energy in the CF_4 gas and stop in the CsI(Tl) crystals. Primary electrons created in the gas drift towards the Frish grid and then towards the micro-strip plates where are multiplied and collected on the anode strips.

Each micro-strip detector is divided in 4 parts: it is made by hundreds of very small alternated electrodes which are prepared through photolitography technique on glass: the anodes, which are 10 μm large, are biased at 400 V and connected into 4 groups, while the cathodes are all connected together and grounded.

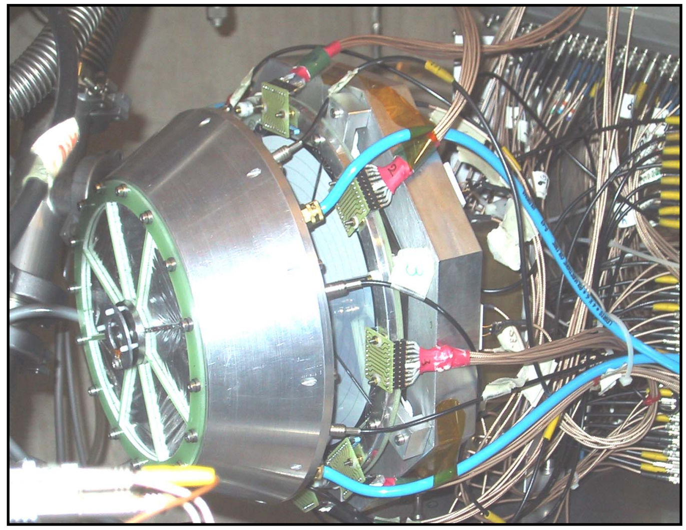

Fig. 3 – The Annular detector

b) The Annular Detector

The annular detector, shown in Fig. 3, is a three stage telescope: it consists of a Ionization Chamber, which is divided in 8 sectors, which is followed by 8 silicon detector (300 μm thick), each of which is still divided in 8 strips (custom design by Canberra [5]) and 2 CsI(Tl) scintillators. The annular detector covers the forward region from about 6° to 18 ° and it is used for fragments and light charged particle measurements.

e) The PSPPAC

The detectors are assembled in square shapes, 20x20 cm^2 active area. The core of the detectors consists of two gas regions, 3 mm thick, separated by a central cathode consisting of a Mylar foil, 1.5 μm thick, double aluminized. The anodes are made, for each coordinate X and Y, by 200 parallel tungsten golden wires, of 20 μm diameter, tightened at a distance of 1mm one from the other. The X-Y information is obtained using the method of delay line partition: wires are connected two by two and the resulting signals are fed, through a delay line, to preamplifiers, directly mounted on the detectors to optimize the timing performances. The detectors are operated with flowing heptane (C_7H_{16}), at a typical pressure of 3.5 hPa. The overall detector thickness is about 0.8 mg cm^2. The prototypes have been tested in laboratory using fission fragments and α-particles emitted from a ^{252}Cf source: the position resolution resulted to be better than 2 mm for fission fragments and the time resolution, from the fast cathode signal, about 700 ps. A picture of a couple of PSPPAC is shown in Fig.3.

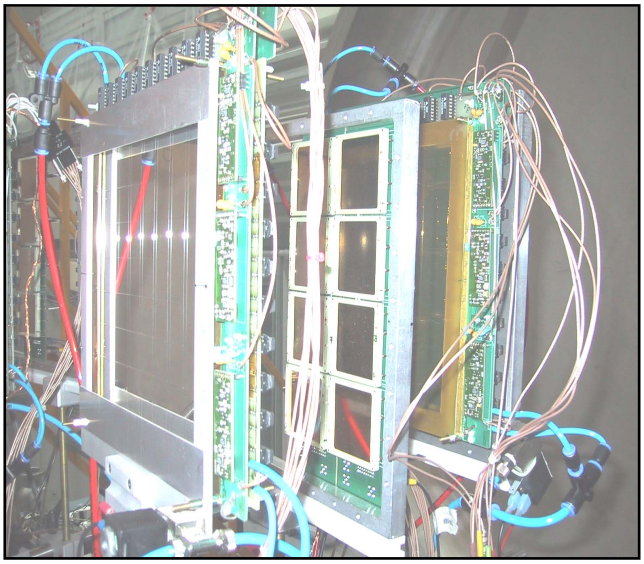

Fig. 4 – Couple of PSPPAC – SiLi in between al large angles.

A set up which was used in the experiment related to the study of the damping mechanisms of the giant dipole resonance in highly excited nuclei was composed coupling the GARFIELD apparatus (for fragment and light charged particle detection) and the Hector apparatus for high gamma rays [6]. The position sensitive parallel plates were used for evaporation residues detection through TOF measurements.

Fig. 4 is a view of the ensemble of PSPPAC for the Evaporation Residues detection. At small angles where silicon could suffer for big radiation damage the residues had been detected through an anticoincidence mode between a sandwich of PPAC, while at larger angles Lithium Drift Silicon detectors were used, coupled with the forward PPAC.

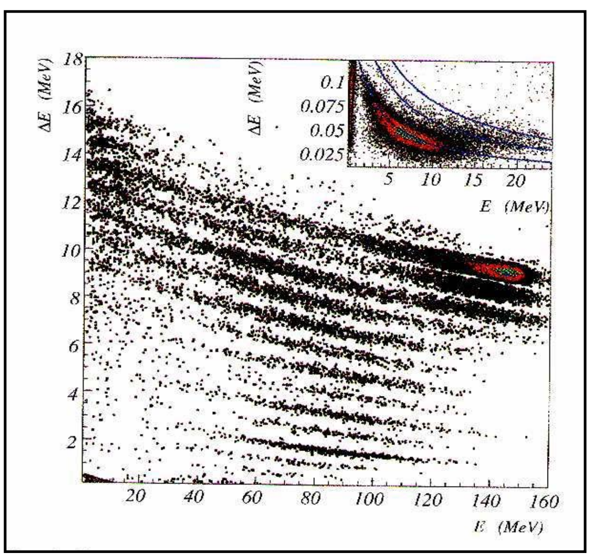

Fig. 5 – ΔE-E calibrated scatter plot for Garfield drift chamber.

The calibration procedure for the drift chambers and the annular detector is quite long and several cross checks have to be performed. In particular CsI crystals have been calibrated, through a dedicated measurement, which permitted to determine a functional expression of the Light Output as a function of the energy and charge of the reaction products. This expression permits, then, to calibrate all the data [7].

For the micro-strip detectors a linear calibration can be used. An example of the result obtained is shown in the Fig. 5 were p, d, t can be seen in the small windows together with sulphur beam and other reaction products in the drift chamber.

The experimental results obtained also in the annular detector are shown in Fig. 6 and Fig. 7:in the first picture (Ic vs Si) the ER are seen together with all other production products. Fig. 7 shows a very good isotopic resolution which can be obtained from the Si-CsI couple up to at least Oxygen isotopes.

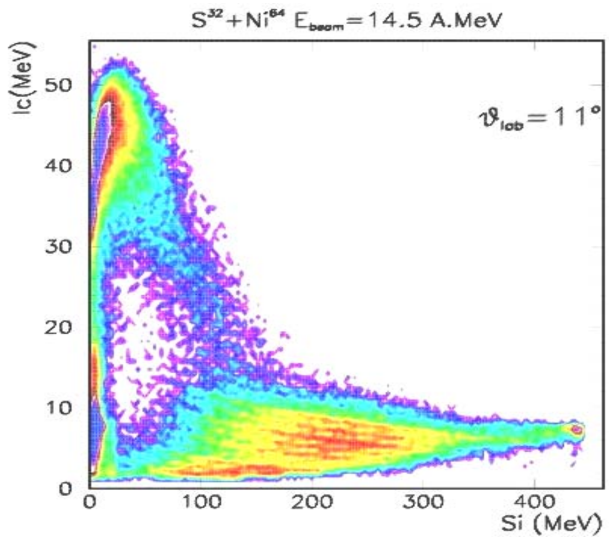

Fig. 6 – ΔE-E calibrated scatter plot for the annular detector (IC vs Si).

This would permit the study of the isospin degree of freedom as a function of the reaction mechanism, through correlation functions between the reaction products.

A further development of the apparatus is in progress related to the upgrading of electronics, through the digitalization of the signal, which would permit a good isotopic resolution also coming from CsI signal in the GARFIELD drift chambers [8].

III. Conclusions

A complex apparatus has been designed, built and installed at the Laboratori Nazionali di Legnaro in a big scattering chamber (6m long, 3.2 m of diameter) in the III experimental Hall.

The apparatus is designed for measurements dedicated to the study of the dynamics of collisions between heavy ion at low-medium energy. A detailed program is in particular devoted to the study of the thermodynamics of nuclei at medium and high excitation, within the framework of the study on phase transition in nuclear matter.

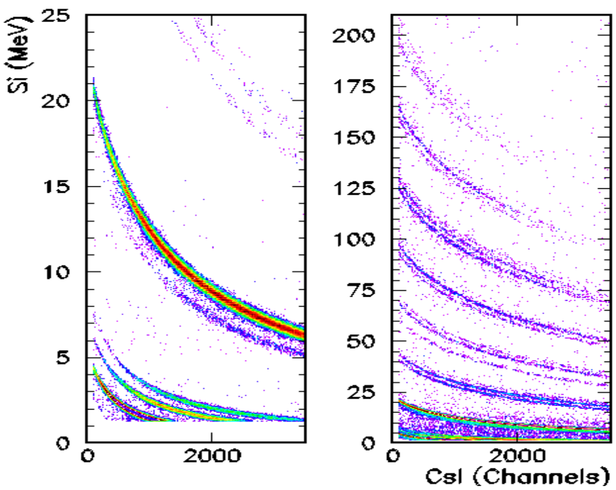

Fig. 7 – ΔE-CsI (L.O.) scatter plot for the annular detector (Si vs CsI).

IV. References

[1] F. Gramegna et al. – *New Perspectives for studies of reaction mechanisms at low-medium energies* – Acta Phys. Polonica 34(2003)2353

[2] F. Gramegna et al. -*A telescope with micr-strip gas chambers for the detection of charged products in heavy ion reactions* – NIMA389(1997)474

[3] I. Iori et al. – *A multi-element detector array for heavy fragments emitted in intermediate energy nuclear reacitons* – NIMA 325(1993)458

[4] M. Chiari et al - *Performances of keyston geometry micro-strip gas chambers,* NIMA484(2002)111.

[5] Canberra – www.canberra.com

[6] F. Gramegna et al. - *Light Charged Particle Emission and the Giant Dipole Resonance* – submitted to Acta Physica Polonica

[7] in Ce Nuclei P.F.Mastinu – *Energy and Charge Calibration of CsI(Tl) Crystals of the GARFIELD apparatus* – APH N.S., Heavy Ion Physics 11(2002)463 and U. Abbondanno et al. - , " *Calibrating the CsI(Tl) detectors of the Garfield apparatus* , NIMA 488(2002)604

[8] L. Bardelli - *Application of digital sampling techniques to particle identification in scintillation detectors*, NIM A 491 (2002) 244-257