PRELIMINARY RESULTS AND FUTURE ACTIVITIES AT THE GARFIELD APPARATUS

F. GRAMEGNA, P.F.MASTINU, L.VANNUCCI

Laboratori Nazionali di Legnaro,Via Romea 4,35020 Legnaro(Pd)
Italy
E-mail: gramegna@lnl.infn.it

M. BRUNO, M.D'AGOSTINO, L. FIANDRI, A.LA NCHAIS, G.VANNINI

I.N.F.N.Sezione di Bologna e Dip. Fisica dell'Università di Bologna,Via Irnerio, Bologna
Italy
E-mail: dagostino@bo.infn.it

G.CASINI, M.CHIARI,A.NANNINI

I.N.F.N.Sezione di Firenze e Dip. Fisica dell'Università di Firenze, L.go E. Fermi, Firenze
Italy
E-mail: casini@fi.infn.it

A.BONASERA,S.CAVALLA RO,A.COSMANO

Laboratori Nazionali del Sud e Dip. Fisica dell'Università di Catania, Catania,
Italy
E-mail: Bonasera@lns.infn.it

A. MORONI

I.N.F.N.Sezione di Milano,Via Caloria 16, Milano,
Italy
E-mail: arialdo.moroni@mi.infn.it

A.ORDINE

I.N.F.N.Sezione di Napoli, Via Cinthia,Napoli,
Italy
E-mail: ordine@na.infn.it

U.ABBONDANNO, P.M. MILAZZO, G.M. MARGAGLIOTTI

I.N.F.N.Sezione di Trieste e Dip. Fisica dell'Università di Trieste,Via Valerio2, Trieste
Italy
E-mail: abbondanno@ts.infn.it

A new apparatus has been designed and built to study reaction mechanisms in the energy regime of the ALPI linear accelerator of the Laboratori Nazionali di Legnaro (E/A = 5 – 20 MeV). In this paper the importance of studying these mechanisms will be underlined, no more as a problem limited to a narrow energy range or a single process, but as a continuous trend from low to high energies and from the physics of stable nuclei to that one regarding instabilities. With this remarks in mind, a first experiment has been performed studying the reaction $^{32}S+^{58}Ni$ at 11AMeV. Preliminary results show that important information can be derived on multi-body emission, which can contribute to renew the interest in this energy regime.

1 Introduction

GARFIELD is a new 4π apparatus, which has been built and installed at the Laboratori Nazionali di Legnaro [1]. The main goal of the physics program to be performed with GARFIELD is to investigate the reaction mechanisms in the energy range accessible with the ALPI linear accelerator of L.N.L. and to revisit some processes. This energy range has been studied since a lot of time and in fact:

- All those phenomena which could be directly reached and characterized with few detectors and almost inclusive measurements has been already faced and solved;
- Nevertheless several open questions are still there, even if it may result very difficult to overcome the experimental difficulties needed to extract new, interesting and complete information;
- It is no more a world of fashion and often people consider worthwhile in this regime only to study γ-ray spectroscopy, mixing up the importance of studying the nuclear structure with an experimental technique.

The GARFIELD collaboration intends to stress that there are still things to be done, which, being deeply linked to processes found at higher energies, can be studied through new analysis methods and more complex and complete apparatuses.
The main topics of the GARFIELD programs are mainly devoted to:

- Dissipative mechanisms: they are still alive at higher energies (up to 100 MeV/n), where other kinds of phenomena are present (multi-fragmentation, pre-equilibrium emission, neck emission etc.). A better understanding at lower energy, where they predominate, can be helpful even for a comprehension of their role in the Fermi region, where they compete with other processes.
- Multi-body processes: their presence and their role are not yet well defined at low energy. Surely there are sequential processes strongly contributing to their cross-section, which have to be studied in a more detailed way. Moreover, a threshold of the many-body channel has in any case to be experimentally determined, especially for central collisions. Besides that, a new interest has grown up lately on the bases of recent statistical model calculations, which predict a possible low energy phase transition.

2 Experimental Set-Up

The GARFIELD apparatus, which is lodged in a large scattering chamber in the III Hall of the Laboratori Nazionali di Legnaro, is mainly composed by three parts:

1. An annular three stage telescope, covering from θ=3° to θ=18°. It is made by 8 Axial Ionization Chambers, an annular strip silicon detector (8 strips x 8 sectors), 16 CsI(Tl) crystals, with photodiode readout.
2. Three position sensitive parallel plate detectors (20x20 cm^2), some of which coupled to Si(Li) detectors, placed respectively at 150 cm from the target in the forward direction for Projectile-Like Fragment

detection and at almost 50 cm, at correlated angles for Target-Like Fragment detection.

3. Two drift chambers, which are made by 200 double stage telescopes, where the residual energy signal is given by CsI(Tl) crystals, while the ΔE signal is provided by metallic micro-strips edged on glass (Micro-strip gas chambers) [2], which collect and pre-amplify the primary ionization produced by the reaction products in the gas. Each sector is composed by four CsI(Tl) plus four micro-strips signals, so that the angular resolution is 7.5° in ϕ and 1° in θ (this last obtained from drift time measurements).

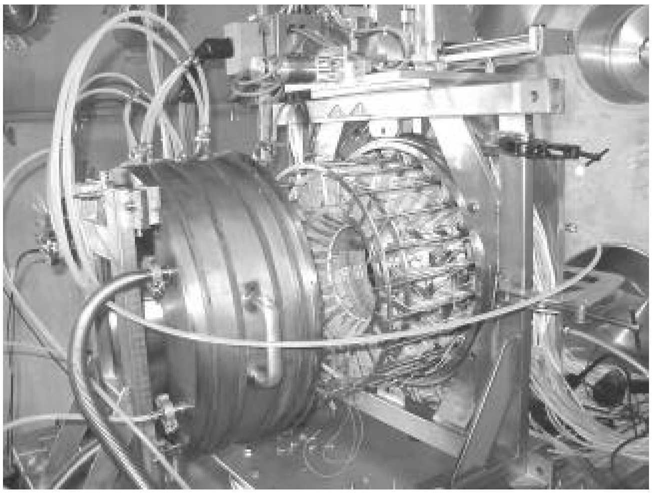

Figure 1. One of the GARFIELD drift chambers.

3 Experimental Motivation

The aim of the first experiment performed was to characterize, at low center of mass energy, the decay of systems formed in central collisions by the incomplete fusion of the two reaction partners, looking for the onset of multi-fragment production.
From a theoretical point of view, statistical multi-fragmentation models [3] predict anomalies of thermo-statistical observable, due to the opening of the phase space to the phase transition at about 1.5-2.5 AMeV excitation energy. The theoretical models predict also, in correspondence to this anomaly a huge increase in the variances of the experimental observable so far connected. When dealing with nuclei, which are finite and isolated systems, due to the conservation of charge,

mass and energy, the signal of a first order transition is given by an "S" shape in the caloric equation of state T (ε*). At a first order transition the system cools down with rising energy and this is explained by the opening up of new fragmentation (and so de-excitation) channels, which need more energy to open up.
Up to now, at lower energies, the experimental apparatuses were not complete enough to perform precise measurements.
By looking at the predictions of models working under different assumptions (prompt fragmentation or sequential emission), it is clear that the many IMF decay channel is a good probe, together with the study of the caloric curve through a precise excitation function, to investigate the population of the accessible phase space.
Indeed, let us consider a system of mass A=90 and Z=45 in the energy range above considered: multi-fragmentation models, for which all the fragments are supposed to be present at the same time, predict a non-negligible probability (P3/P2 4%) of multi-fragment emission at about the same energy where they predict an S-shape in the caloric curve.
On the contrary, if we consider binary sequential models [4], where at each step only two-body channels are permitted and the evaporation of light particles is the most probable, unless the decaying system is rotating (the system is there deformed and the probability of emitting fragments increases). For the GEMINI code at L=0 no three body events are then predicted and the charge distribution is U-shaped. Only for high values of angular momentum (L=Lmax) the elemental distribution N(Z), the probability distribution and the charged particle multiplicity result on the average quite similar to the prediction of Statistical Multi-fragmentation Model (SMM).
Nevertheless, the fact that the distributions are similar on average does not imply that these distributions will be similar even events by events.
Indeed, when looking at the higher momentum of the charge distribution connected with the fluctuations of the partitions or when studying the correlations among the charges of the three largest fragments in each event (Dalitz plots), it is clear that the different origin of the fragment production becomes distinguishable.
The same and complementary information can be given by correlation functions as a function of the relative velocity and/or angle between the fragments.

4 Preliminary results

Motivated by the above theoretical background, overall by the stimulating model predictions and by the lack of coincidence data at low energy, a first system leading to a compound system of A 100 has been studied to start exploring the phase space of decaying systems at ALPI.
In particular the ^{32}S + ^{58}Ni and ^{32}S + ^{64}Ni systems at 11 AMeV have been investigated. The data reduction has started by identifying the charge of the detected particles and by calibrating the energy of the micro-strip detectors.

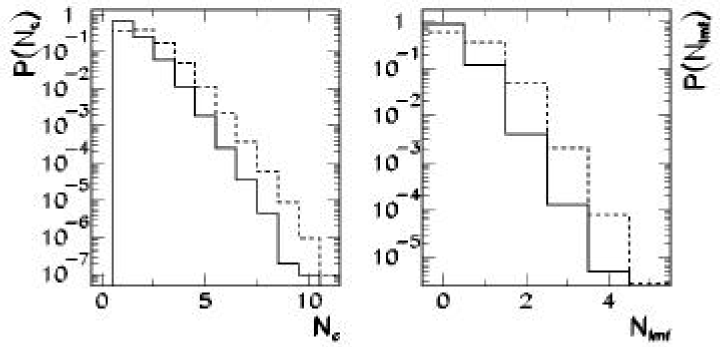

Figure 2: Charged particles (left panel – part a)) and Intermediate Mass Fragment (Z>2) (right panel – part b) probability distributions. Dashed lines are the distributions detected by the whole apparatus; solid lines represent the distribution detected by the GARFIELD drift chamber.

Fig. 2a shows the probability distribution of charged particles Nc. The dashed line means the whole apparatus (annular detector covering θcm=7°- 40° and drift chamber, covering θcm=50°-110°), while the continuous line is the GARFIELD drift chamber only. The distributions are almost similar to what is expected from the theory.
Looking at the probability distribution of the number of intermediate fragments emitted (Nimf), as shown in Fig. 2b, we still have a good agreement with the theory (SMM or GEMINI with L=Lmax), if we look only to the drift chamber (continuous line), while an overproduction is found when including also the annular detector (dashed line). This can be explained under the hypothesis that the drift chamber selects somehow the central collisions, while contributes of semi-peripheral collisions are present when the annular is included. Indeed this can be also evidenced by looking at the elemental distribution under the constrain Nimf 3.
The peak of the quasi-projectile is present in the distribution of the whole apparatus, while a more smooth distribution is observed for the GARFIELD drift chamber only, as shown in Fig. 3.

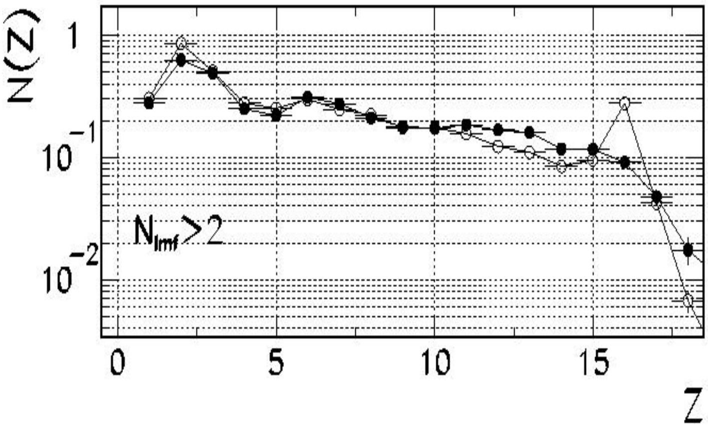

Figure 3. Charge distribution of light charged particles and fragments detected in the whole apparatus (open symbols) and in GARFIELD (full symbols), for events with at least three fragments. Both distributions are normalized to the total number of events.

If a further constrain is included on the total charge detected (Ztot 32), the distributions of the three largest fragments in each event become more and more similar one to the other. This can be seen in a powerful way by looking at the Dalitz plot, which results filled up in the central part.
The comparison with the theory show a quite impressive similarity with the SMM predictions, while rules out the GEMINI sequential emission, which, for high values of angular momentum, can only predicts very asymmetric events, essentially made by two Lithium plus a large fragment. The three distributions are compared in Fig 4, fig. 5 and Fig. 6 respectively.

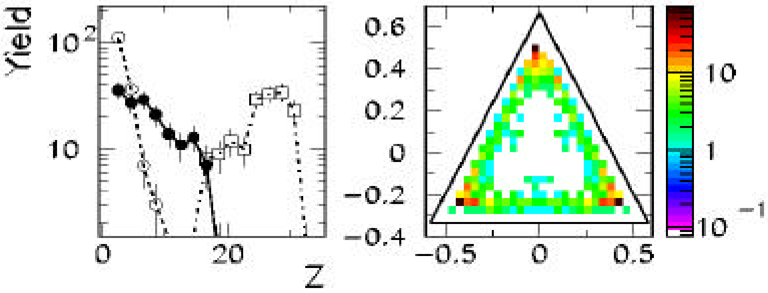

Figure 4. Left panel: Charge distribution of the three largest fragments in each events; Right panel: Dalitz plot from GEMINI prediction.

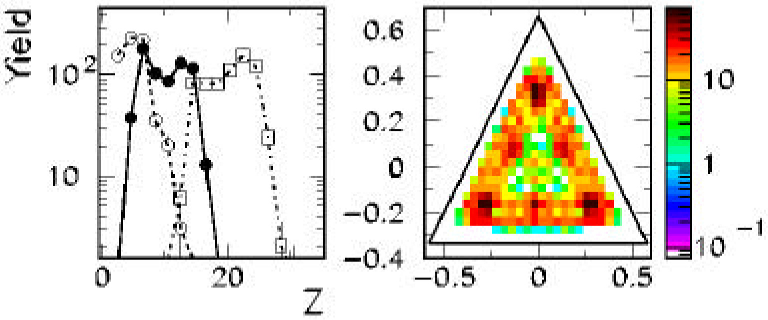

Figure 4. Left panel: Charge distribution of the three largest fragments in each events; Right panel: Dalitz plot from SMM prediction.

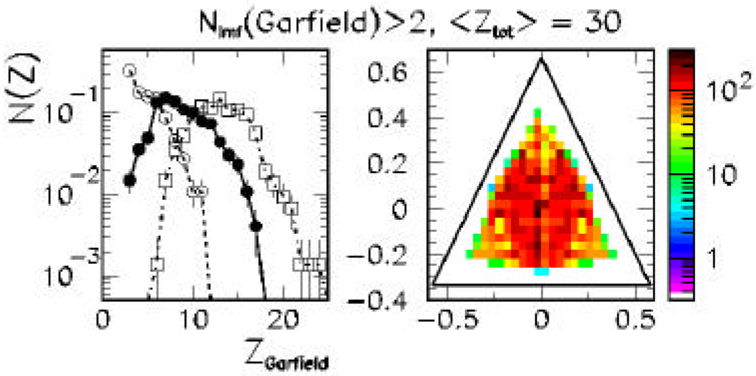

Figure 6. Left panel: Charge distribution of the three largest fragments in each events; Right panel: Dalitz plot from experimental data.

Multi-fragment events need, however, further investigation to be better characterized, in order to define both their emission source and their production mechanisms. Velocity and angular correlation are therefore necessary and will be performed in the next future. This part of analysis is still under development: it will give us more insight in the understanding of the nature of multi-fragment production at low energy.

Indeed other interesting findings come from the analysis of the charge distribution of fragments detected at large C.M. angles, by changing the neutron content of the system as shown in Fig. 7. As stated at the beginning, a small statistics was collected on the $^{32}S+^{64}Ni$ at the same incoming beam energy (11 AMeV) of the previous system. The two reactions measured $^{32}S+^{58}Ni$ and $^{32}S+^{64}Ni$, characterized respectively by a value of N/Z=1.05 and N/Z=1.18, showed a quite different behavior. In the first reaction, in fact, oscillations greater than the statistical errors around Z=6 and Z=12 are evident, while in the second case the oscillations are smoothed and the production of Z=3 is larger by a factor 2.

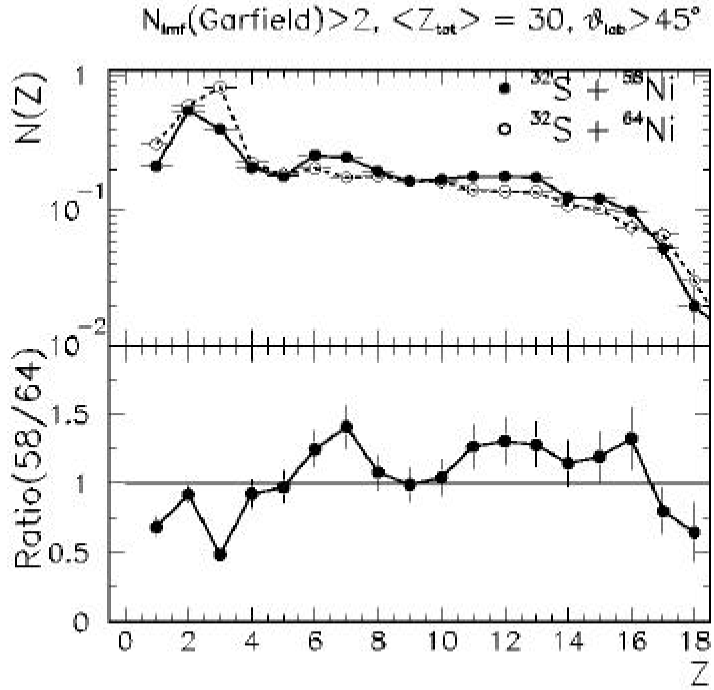

Figure 7. Charge distribution (upper panel) in the reaction 32S+58Ni and 32S+64Ni, for events with at least three fragments detected in GARFIELD. The lower panel shows the ratio of the two-charge distribution.

Effects of suppression/enhancement in the charge distribution could be ascribed to the opening/closure of decay channels, due to the energy conservation constraint on the phase space and have to be carefully investigated by means of models.

5 Conclusions

A new detector has been built and installed at LNL, Padua. Measurements performed at the ALPI accelerator with an 11 AMeV ^{32}S beam on Nickel targets have shown that interesting features exists at these energies, which can give more enthusiasm in the analysis and study of this energy range. Multi-fragment production has been evidenced and the characterization of the reaction mechanisms will be performed through a complete and exclusive analysis, by means of multi-correlation methods. Structure effects can also be responsible for the difference in the opening of decaying channels at low excitation energies, which can be evidenced in playing with the entrance channel N/Z ratio.

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