Isotope analysis in $^{32}S + ^{58,64}Ni$ at 14.5 AMeV

NUCL-EX collaboration: U. Abbondanno[1], S. Barlini[2], M. Bini[3] , M. Bruno[4], F. Cannata[4] , G. Casini[3], M. Chiari[3], M.D'Agostino[4], J. De Sanctis[4] , E. Geraci[4] , A. Giussani[5] , F. Gramegna[2], V. L. Kravchuk[2] , A. L. Lanchais[2], G. V. Margagliotti[1], A. Moroni[5], A. Nannini[3], A. Olmi[3] , A. Ordine[6], G. Pasquali[3] , S. Piantelli[3] , G. Poggi[3] , G. Vannini[4], L. Vannucci[2]

1 Dipartimento di Fisicadell'Universita' and INFN, Trieste,
2 INFN, Laboratori Nazionali di Legnaro,
3 Dipartimento di Fisica dell'Universita' and INFN, Firenze,
*4 Dipartimento di Fisica dell'Universita' and INFN, **Bologna**,*
5 Dipartimento di Fisica dell'Universita' and INFN, Milano,
6 Dipartimento di Fisica dell'Universita' and INFN, Napoli

I. INTRODUCTION

In recent years isospin effects in heavy ion nuclear reactions [1] and in particular in thermodynamical observables have been studied in several laboratories. The scientific program of the NUCL-EX collaboration concerns the investigation of these effects in particular at low energies, corresponding to the opening of the multifragmentation mechanism. At these energies, corresponding to the highest range of the Tandem-ALPI complex at the Legnaro Laboratories, the hot and excited composite systems formed in heavy ion nuclear reactions enter in the liquid-gas coexistence region [2]. A very interesting point is to extract the excitation energies and the temperatures for systems differing only in N/Z ratio since differences could be seen in the limiting temperature values [3], i.e. the maximal temperature a system can sustain while evaporating.

II. EXPERIMENTAL SET-UP

The experiment has been performed at INFN Laboratori Nazionali di Legnaro with the GARFIELD apparatus [4], a 4π array built to study thermodynamical and dynamical processes in the low energy region (E < 15 AMeV). This apparatus is designed to detect light charged particles and medium-light fragments emitted in the laboratory frame at angles between 30° and 85°. In this measurement the forward GARFIELD chamber has been coupled to the Ring Counter (RCo), a triple stage ionization chamber+silicon+CsI(Tl) apparatus, specially designed [5] to measure in the forward part not covered by the GARFIELD chamber.

The very good mass resolution of the RCo Si-CsI telescopes and the good coverage of the phase space of the whole apparatus allow for very accurate studies of the thermodynamics of excited systems with different isospin content (N/Z).

A beam of ^{32}S at 14.5 AMeV has been used for these measurements, impinging on two different targets (^{58}Ni and ^{64}Ni) to vary the isospin content of the final system.

III. EVENT SORTING

The data must be selected in order to isolate events keeping a negligible memory of the entrance channel dynamics. The centrality sorting can be obtained using many statistical methods [6]. One of the most effective is the flow-tensor [2]. Event by event one calculates the covariance matrix of the fragment momenta, for all the M detected products:

$T_{ij} = \Sigma_{(k)} p_i^{(k)} p_j^{(k)}$ (k = 1,M; i, j = 1, 3).

The direction of the main eigenvector with respect to the beam axis provides information about the average flow direction of the reaction products. By looking at the flow angle one can select rather central events that, due to the spherical symmetry, can be ascribed to the decay of a unique source [2].

This kind of kinematical selection is meaningful only if the detection of the decay products is almost complete. A first check on the measured data can be done by looking at the total detected charge. If one plots this quantity vs. the

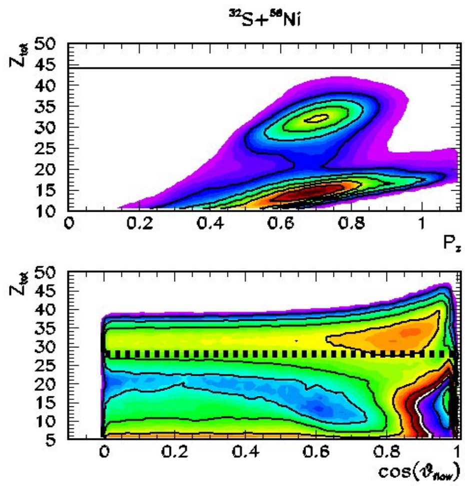

Figure 1 Upper panel: Total charge detected vs. total momentum detected in the beam direction.The line represents the system total charge (Z=44). Lower panel: Total charge detected vs. cos(θ_{flow}). The line represents the cut to get the most complete events.

total momentum P_z in the direction of the beam axis normalized to the beam momentum (see Fig.1 upper panel) one can see that the most complete detected events (Z_{tot}≥70% ot the total charge) have an average momentum of 75% of the projectile momentum. In Fig. 1 lower panel the total detected charged is plotted against cos(θ_{flow}). The line represents the cut to get the most complete events. Indeed with this cut the projection of the selected events on the cos(θ_{flow}) axis show a rather flat distribution at least for $\theta_{flow} \geq 60^o$, indicating a rather spherical source, which corresponds to the most central events.

IV. RESULTS AND DISCUSSION

Within the events which lie above the line drawn in Fig. 1 ($Z_{tot} \geq 28$) we extracted the events with at least three Intermediate Mass Fragments (IMF) in the final stage. This is a necessary, but not yet sufficient condition to select multifragmentation events. More work has to be done in order to have a better centrality selection.

Even though the previous sorting does not guarantee that a unique source has been selected, one can calculate its temperature with the method of double isotope ratio [7]. The results for 11 thermometers ranging from p,d to Carbon for the two systems $^{32}S + ^{58}Ni$ and $^{32}S + ^{64}Ni$ are shown in Fig. 2, where the apparent temperatures are presented together with the temperatures "corrected" for the secondary decay. The average values are $T_{iso}(58) = 3.20 \pm 0.05$ and $T_{iso}(64) = 3.27 \pm 0.05$ for the two systems, respectively.

In order to check if the data show a scaling behaviour, which is a necessary condition for chemical equilibration, a preliminary "isoscaling analysis" for light isotopes (gas phase) [8] is presented in Fig.3. Moreover, ratios characterizing relative population of different pairs of isotopes (mirror nuclei) allow to extract the relative neutron to proton density for the two reactions, providing information on the phenomenon of isospin distillation.

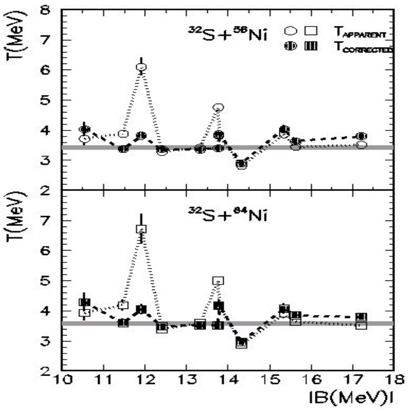

Figure 2 Double ratio apparent and "corrected" temperature for the two systems.

A further selection towards the most central events, can be done taking into account only the ones with $\theta_{flow} \geq 60^o$; one obtains the isoscaling parameter $\alpha = 0.42 \pm 0.04$, which is in agreement with the general trend discussed in Refs. [6,8]. When the corrected isotopic temperature is used, from mirror nuclei [6] one gets ρ_n/ρ_p (58) = 1.2 ± 0.1 and ρ_n/ρ_p (64) = 3.1 ± 0.3. These values are much larger than the ones expected for neutrons and protons homogeneously mixed at the break-up configuration, as found in Refs.[6,8]. The observed increase of neutron density may indicate a neutron enrichment in the gas phase, and a consequent proton depletion. If one considers only events with $\theta_{flow} \leq 30^o$ (not spherical events) the isoscaling parameter α is 0.67, far from the values of Refs. [6,8].

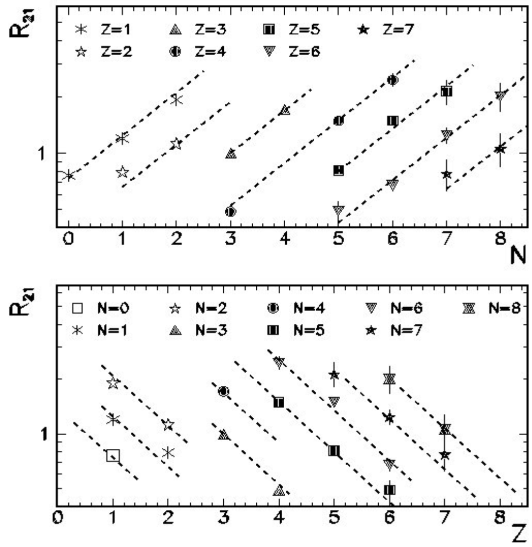

Figure 3 Isoscaling analysis for light isotopes.

These are very preliminary results. Further work is needed to better select central events, disentangle angular momentum effects, determine the characteristics of the source and perform a meaningful isoscaling analysis.

V. ACKNOWLEDGEMENTS

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1. *Isospin Physics in Heavy-Ion Collisions at Intermediate Energies*, edited by Bao-An Li and W. Udo Schroder, ISBN l-56072-888-4, Nova Science Publ. Inc., New York (2001).
2. M. D'Agostino et al. - Nucl. Phys. A734 (2004) 512.
3. J. B. Natowitz et al. - Phys. Rev. C 65 (2002) 34618.
4. F.Gramegna et al.- Nucl. Instr. Meth. A389(1997)474.
5. A. Moroni et al. - Nucl. Instr. Meth. A556(2006)516.
6. E. Geraci et al. - Nucl. Phys. A732 (2004) 173; Nucl. Phys. A 734 (2004) 524.
7. S. Albergo et al. – Nuovo Cim. A 89 (1985) 1.
8. M. B. Tsang et al. - Phys. Rev. Lett. 86 (2001) 5023; A. S. Botvina et al. – Phys. Rev. C 65 (2002) 044610.