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INTERMEDIATE MASS FRAGMENT EMISSION FROM 8 TO 40MeV/u

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Of great interest in the intermediate energy regime (10-100 MeV/u) of heavy ion reactions is the origin of intermediate mass fragments. Theoretical models such as the liquid vapor phase transition and the cold fragmentation of a nucleus have been proposed to explain the production of these fragments. In this contribution, we are going to concentrate on an alternative mechanism; that of statistical decay of a compound nucleus-like system.

At low bombarding energies we have shown that intermediate mass fragments arise from the binary division of a compound nucleus[1-3]. Light particle evaporation and fission are two extreme examples of this more generalized decay mode. In this contribution we will show some more recent measurements which extend these studies to higher bombarding energies. Specifically we have studied the reactions ^{93}Nb + ^{9}Be,^{12}C and ^{27}Al from 8.5 MeV/u to 40 MeV/u. The data from 25 to 40 MeV/u were obtained with the LBL BEVALAC[4]; from 11 to 18 MeV/u with the GSI Unilac; and the lower energy data were obtained with the LBL SuperHILAC.

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In all measurements we utilized reverse kinematics reactions which have the advantage of producing a clear signature for statistical decay of a compound nucleus-like system; the spectra for each species show both a high and low velocity component arising from the forward and backward emission of fragments with Coulomb-like energies in the center of mass.

Fig.1. shows the singles-invariant cross section plotted in the velocity-Z plane for 25 and 30 MeV/u Nb + Be and Al for particles detected at angles from 3 to 8 degrees. These are similar to those obtained at other bombarding energies. In the cross sections one can identify three components. The first and strongest component consists of a large number of events near the projectile Z value (41) extending down to smaller values. This component is visible only at very small angles ($<5^{o}$) and consists of the tail end of the evaporation residue distribution from a highly excited compound system.

Another component is visible at small Z-values and low velocities and is apparently related to the target. It may be possible to explain these events in terms of a transfer of a few nucleons from the projectile to the target followed by evaporation.

The third component is visible at intermediate Z-values. For each Z-value there are two well separated groups of events; one at high velocities and one at low velocities. These events have the signature of binary decay from a compound nucleus-like system. The yields of the two groups are consistent with the expected $1/\sin\theta$ angular distribution.

From the average velocity of the two components one can derive the mean source velocity. At low bombarding energies (8.5MeV/u) these are consistent with full momentum transfer and thus correspond to binary decay following a complete fusion reaction. At the larger energies, the measured source velocities are larger than that for full momentum transfer and thus indicate that the fragments are emitted from a system formed in an incomplete fusion reaction. These velocities follow the well known systematics of momentum transfer.

From the difference of the high and low velocity components, the velocity of the fragments in the center of mass can be extracted. For all bombarding energies, these are well reproduced by assuming that the fragments possess Coulomb energies (two spheres sepated by 2 fm) and by correcting the observed charge of the fragment for sequential decay (see later).

Coincidence measurements confirm the binary nature of fragment production. The charges of coincidence events sum to a small range of Z-values which correspond to a large fraction of the total charge of the projectile and target. Fig.2. shows the mean sum of charges $<Z_1+Z_2>$ for binary events detected in the Nb + Al reaction as a function of bombarding energy. The sum $<Z_1+Z_2>$ decreases with increasing bombarding energy. This can be understood in terms of the charge lost in an incomplete fusion reaction and the sequential evaportion of charges from the excited primary fragments. The curve labelled Z_{CN} represents the average charge of a compound nucleus-like system formed in an incomplete fusion reaction. It was calculated from the systematics of momentum transfer assuming that momentum is transferred by mass transfer. By this method we also estimated the average excitation energies of the initial sytem from which we derived the excitation of the primary fragments. The evaporation of the primary fragments was calculated with the code PACE and the residual charge (Z_{CN}-$Z_{evaporated}$) of the two fragments, represented by the lower curve in Fig.2., is in excellent agreement with the experimental data.

In summary, our measurements imply, that over a large range of bombarding energies, intermediate mass fragments are produced by the binary decay of a compound nucleus-like system. At low bombarding energies, these systems are associated with a complete fusion reaction, whereas for the larger energies the initial system is formed in an incomplete fusion reaction. The measured momentum transfers are

consistent with the well known systematics and excitation energies derived from these are entirely consistent with observed total charge of coincidence events. For the higher bombarding energies, these excitation energies imply the formation of a very hot object.($E^* \approx$ 400MeV for the 30 MeV/u Nb + Al reaction) The data shows a smooth evolution from the lower energies, where the statistical emission of intermediate mass fragments is well established, to the higher, intermediate energy regime. Thus there is no need to include fragment production from new mechanisms.

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3. M.A. McMahan et al., Phy. Rev. Lett. 54, 1995 (1985)
4. R.J. Charity et al., LBL-20383, Submitted to Phy. Rev. Lett.

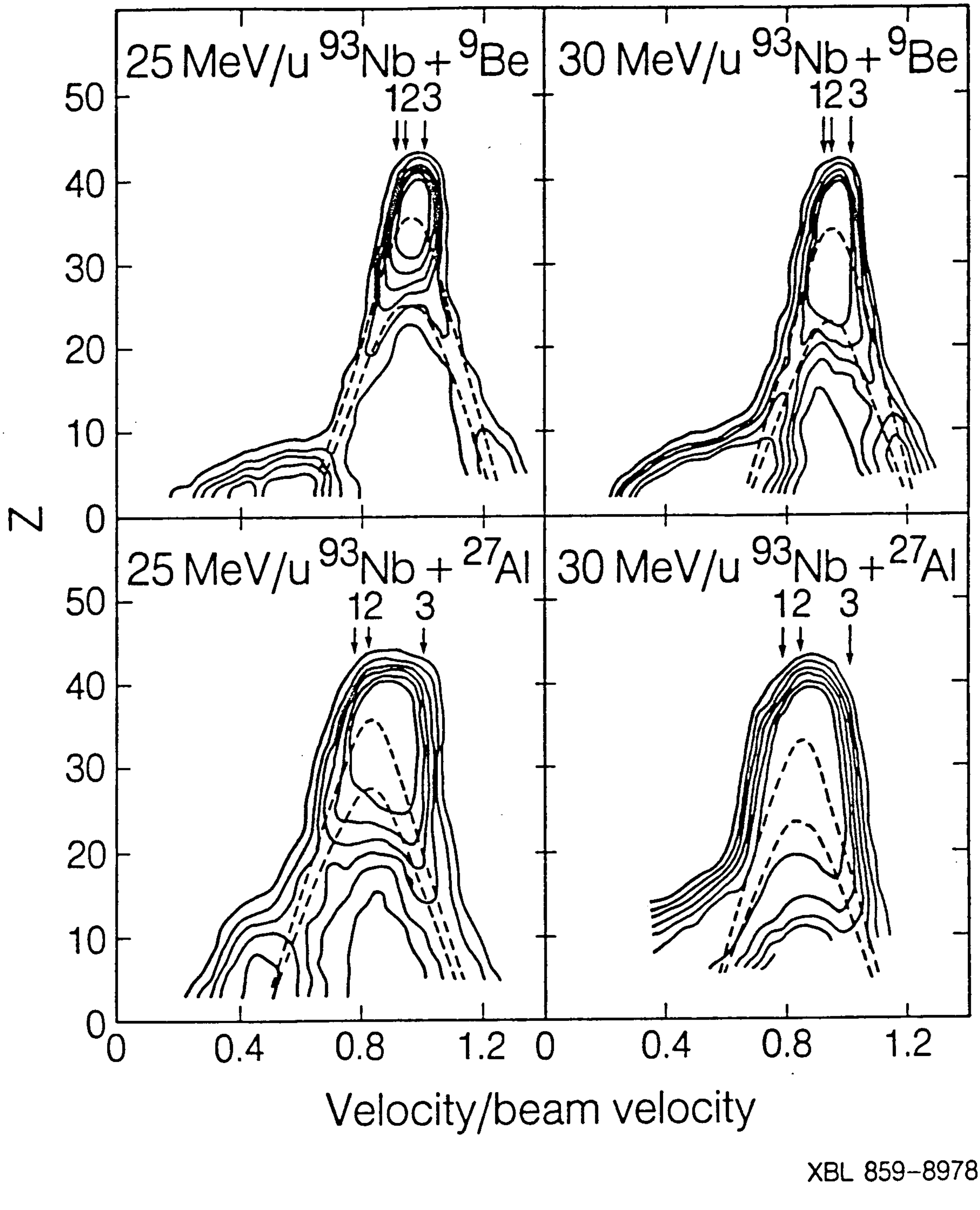
25 MeV/u 93Nb + 9Be
30 MeV/u 93Nb + 9Be
25 MeV/u 93Nb + 27Al
30 MeV/u 93Nb + 27Al
123
12 3
12 3
12 3
Z
0
10
20
30
40
50
0
0.4
0.8
1.2
Velocity/beam velocity
XBL 859-8978

Fig. 1

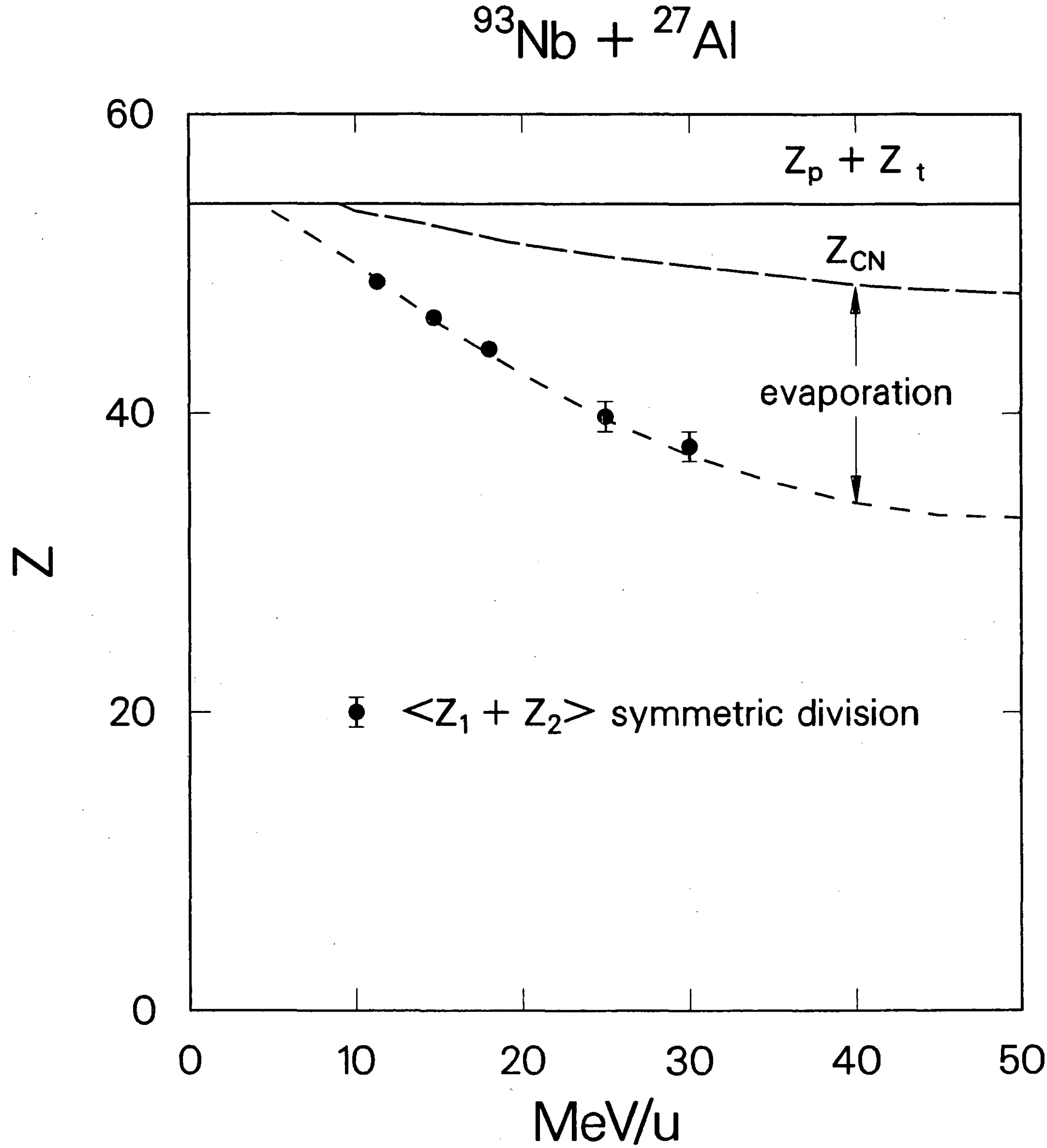
$^{93}Nb + ^{27}Al$
60
40
20
0
Z
$Z_p + Z_t$
Z_{CN}
evaporation
$\langle Z_1 + Z_2 \rangle$ symmetric division
0
10
20
30
40
50
MeV/u

Fig. 2

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