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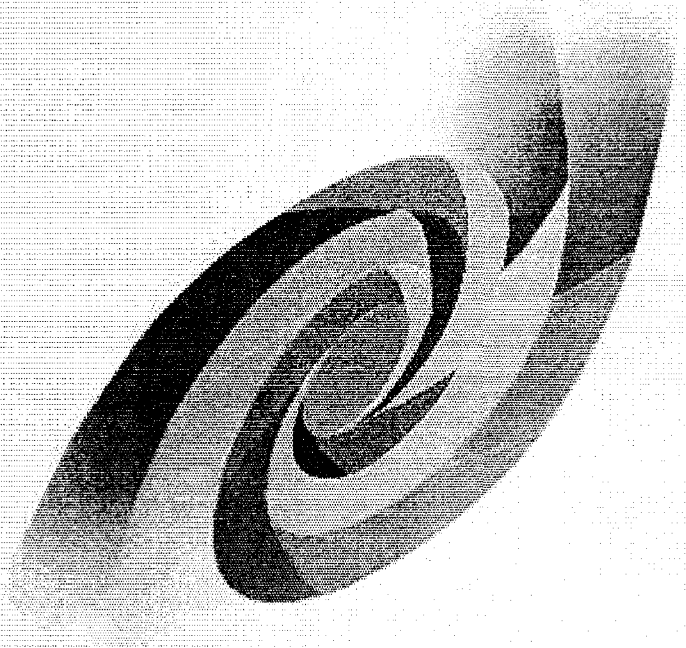

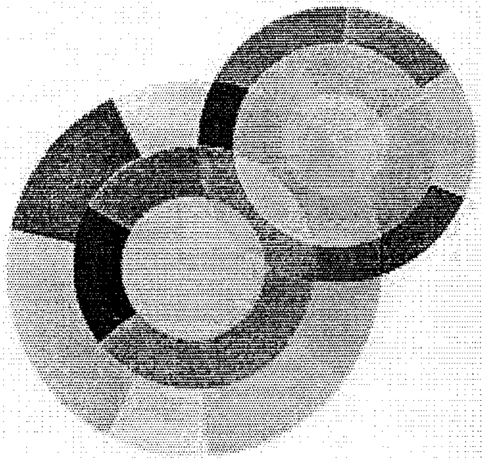

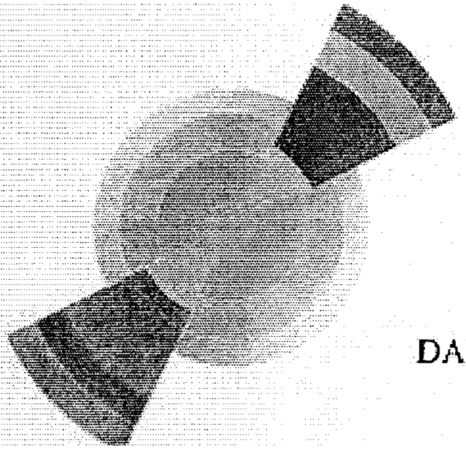

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Towards limits of excitation energy in the reaction ^{3}He(1.8 GeV) + ^{nat}Ag

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INTRODUCTION

The subject of hot nuclei draws a number of engaging problems. Broadly speaking one can divide the interest into three; the heating dynamics [1-3]; properties of hot nuclear matter [4] and the decay processes [5]. All this is within the confines of a relatively small number of nucleons interacting through an interplay of short and long range forces [5]. In this contribution we report on a study of hot nuclei, where through an appropriate choice of incident channel and event selection, dynamical effects are attenuated and multifragmentation is limited. Herein, we aim at giving three preparatory results; (i) the ^{3}He(1.8 GeV) + ^{nat}Ag can be described using an intranuclear cascade, INC, model; (ii) through a suitable selection of events we give a limit of the excitation energy that a nucleus can absorb without breaking into large pieces; (iii) we show that corresponding alpha decay is consistent with an evaporative process.

Before indulging in the experimental set-up, it is practical to adopt a general outlook of the reaction processes involved in light ion induced reactions at GeV. A incident energies. Within a BUU[6] description, the projectile nucleons are subject to n-n collisions and are then, more often than not, ejected over a time scale compatible with ~ 15 fm/c. This primary process leaves behind an abundant number of energetic π, Δ and nucleons. Over a time period covering say, 1.5 to 100 fm/c the residual system evolves through a sequence of dynamic evolutions with processes (π reabsorption, etc), in part, leading to thermalisation. As pointed out by Wang et al.[3], the coupling to the mean field could have a determining effect on the final channel through the formation of spatial density variation. However, we consider that at 1.8 GeV the consequences of these effects are less marked than at 4.8 GeV[3]. Beyond 100 fm/c the mean field settles down to give a predominantly thermalised hot nucleus. Herein we consider a INC description, where beyond ~ 30 fm/c the resultant complex is assumed to have normal sherical, uniform density distribuitions with the energy being shared between thermal and rotational degrees of freedom. On average at 1.8 GeV, the angular momentum is $20\hbar$ and the residual mass varies weakly with the calculated excitation energy[7]. As for the calculations presented, all impact parameters are considered with each event generated by the INC code[1] being fed into an evaporative routine, EUGENE[8]. Where necessary the events are filtered by the experimental acceptance (code FILTER). No effort was made to adjust the parameters of the INC and EUGENE.

Experimental Set-Up

The experiment was performed at the Laboratoire National Saturne using ^{3}He beam at 1.8, 3.6 and 4.8 GeV . In this contribution we present the lower incident energy data set. The target was natural Ag of thickness 1.08 mg/cm^2. Briefly, the experimental set-up consisted of essentially four parts. (i) ‘To measure leading protons ARCOLE was used 9 This consists of a forward plastic wall made up of 28 fast plastics and mounted so as to have a hole in the center for the beam. Light from each plastic was read out by two photomultipliers and gives the energy loss and impact position. This assembly covered an angular range of approximately 2.5 to 12” and was positioned to give a minimum flight path from the target of 4 meters. (ii) To detect heavy fragments, HF, a circular hodoscope, DELTA, which includes 30 high field Si detectors w-as used. The target-detector flight path was 60 cm and covered angles between 5 to 10°. (iii) Light charged particles ($Z \leq 2$), LCP, and intermediate mass fragments ($Z \lesssim 20$), IMF, were detected in an array called ISiS 10 which contains 162 triple detector telescopes in a tight geometry. Each telescope is composed of a gas-ionisation chamber, a fully depleted 500 μm ion-implanted silicium detector and a 28 mm CsI($T\ell$) crystal. The geometrical acceptance is typically 70% and thresholds are better than 1 MeV.A. The charge, Z, resolution ranged up to 20. Mass resolution is obtained for those particles which punch through the Si crystal. (iv) An active collimator assembly was employed to vetoe the beam halo particles reaching ISiS.

Possibly the only distinct signal of the reaction primordial time that we captured with our set-up are the fast leading protons. In fig. 1 we give the overall proton multiplicity in ARCOLE with a minimum trigger of 2 particles in ISiS. The lower energy threshold in ARCOLE is approximately 50 MeV for protons. The dashed histogram gives the filtered proton multiplicity from the INC calculations and illustrates the fair description of the data.

Analysis

Fig. ‘2 gives the superimposition of 26 mass vs velocity plots from DELTA for fragments under the minimum trigger condition. The mass was computed from the time between DELTA - ISiS and energy measurements. Correction due to time delay [11] and energy defect [12] were included. The latter was achieved through a coincident set-up with slowed down fission fragments in a separate measurement. Software velocity thresholds were set at 0.25 cm/ns. We remark that in light ion induced reactions it is expected that the highest yield of HF should be for mass values close to that of the target[13]. The shift seen in the figure towards a mean mass of ~ 70 amu is largely due

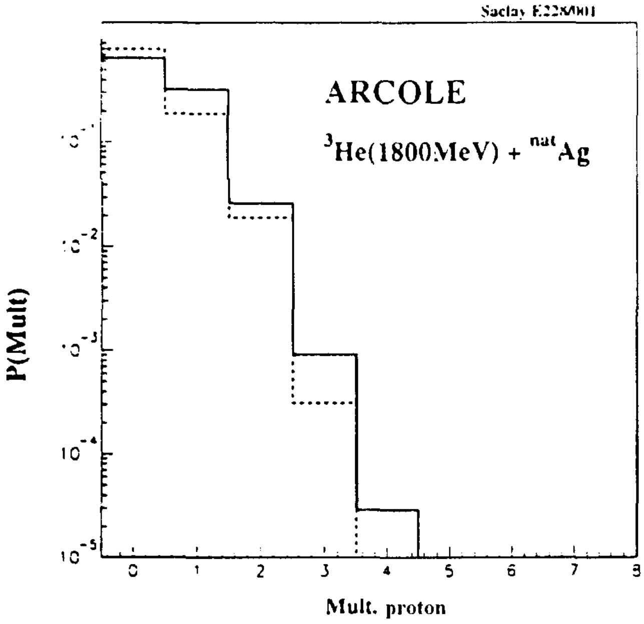

Figure 1. Probability for the multiplicity for high energy protons in the plastic wall ARCOLE with minimum trigger. The dashed histogram refers to the INC+EUGENE+ FILTER prediction.

to the target thickness energy threshold effects. It is important to note, however, that the fragments of interest here are the ones about (mass,velocity)=(45,0.6), which in fact are not strongly perturbed by the choice of target thickness.

Before detailing the analysis of how we assign excitation energies it is helpful to note and remark that: the data-model (INC+EUGENE+FILTER) comparison for events with minimum bias show a reasonable agreement for the global parameters. The total multiplicity, M_{tot}, is well described (fig. 3) for example, and this is also true for the total detected charge, IMF multiplicity, M_{IMF}, and so on. Less evident is the comparison of the linear momentum transfer. No inconsistency is found but the widths for the data and model are too wide to make a quantitive comparison. These results substantiate, in a circumstantial way, the model and allows us to examine our method to extract and correct the experimental excitation energies.

In this paragraph we describe the simple prescription we have employed to reconstruct what we call here, "thermal" excitation energy E_{th}, and mass, M_{th} . By thermal we refer to the energy and mass that is left over after the pre- equilibrium/cascade particles have escaped from the nuclear complex. Similarly, we consider Z_{th}. To compute these quantities experimentally we encounter three difficulties: (i) our set-up does not include a direct measure of neutron multiplicity and summed neutron kinetic energy. It is important to emphasise, that even with the present favourable choice of target, the calculated energy released through the neutrons can be as much as one half of E_{th}; (ii) detector geometrical acceptance and in particular the mass resolution at low energy; (iii) establishing a criteria of rejecting particles within an event which are considered of non-thermal descent. These points are of no revelation. Different groups have developed different techniques to reduce source of error. Item (i) and (ii), for example, have

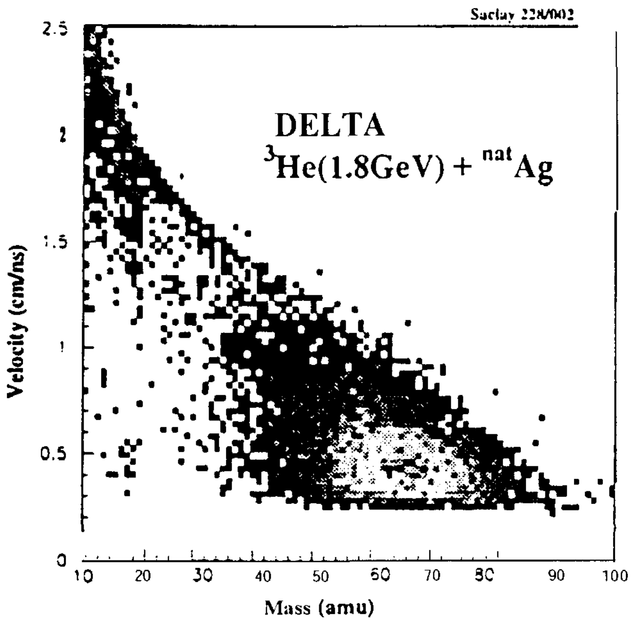

Figure 2. Residual mass versus velocity plot

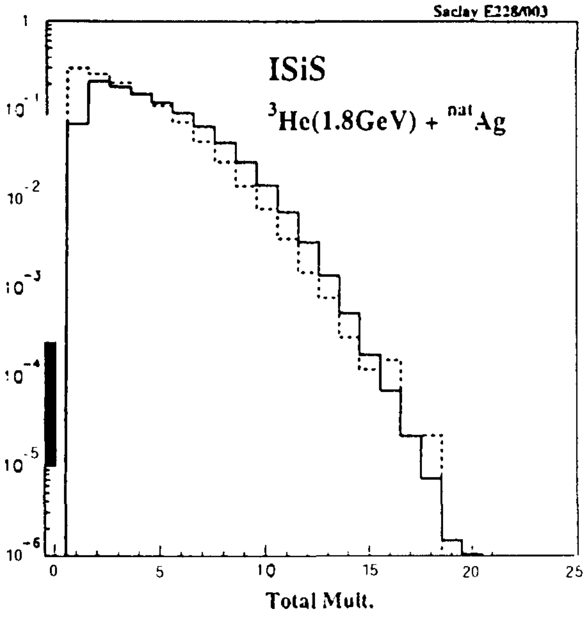

Figure 3. Probability for the total multiplicity data (solid histogram). The model predictions (dashed histogram) are normalised by a factor 1.2.

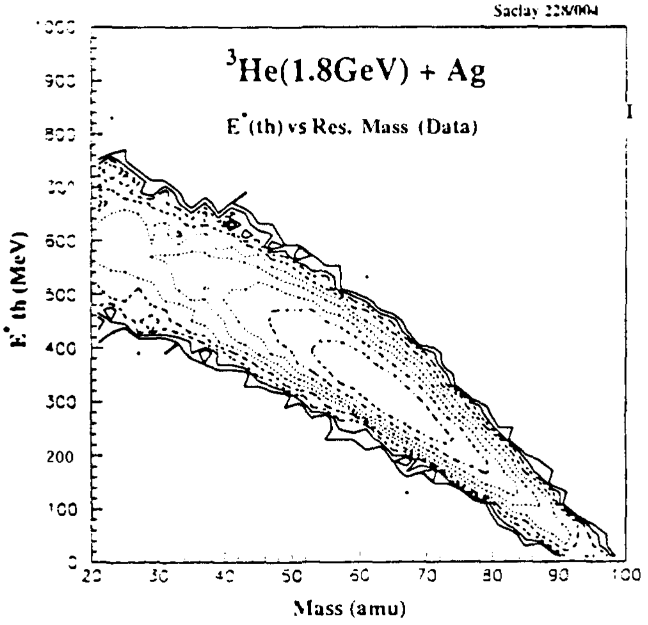

Figure 4. Experimental E_{th} as a function of residual mass.

been reasonably covered by the MBI + Ganil group at Cern [14]. The method employed here, and elsewhere [15,16], to account for (iii) is somewhat brutal; within an event, only those LCPs with KEs smaller than a given value are treated. As for the IMFs they have practically no pre-equilibrium component. The total detected M_{tot} mass, which includes the HF is then obtained event-by-event. Where only the charge is detected, the mass is derived through a function giving values in the valley of stability. In the case of low energy Z=1 these are given unit mass values. The total detected charge in ISiS and DELTA, Z_{th}, is obtained by transforming the HF mass into charge. The value of M_{th} is then obtained through a lookup table of ratios M_{th}/Z_{th} given by INC. The difference between M_{th} and M_{tot} gives the number of neutrons. Finally, E_{th} is obtained by summing over the KE of the selected particles and adding in the appropriate Q-values. For the neutrons we adopted a mean KE of 7.5 MeV/neutron, a value extracted from the INC+EUGENE code. It is important to stress that at this point we do not correct for geometrical acceptance. However with the above prescriptions and using the INC+EUGENE+FILTER as guide, we deduce the mean correction in extracted E_{th}. In the zone of interest, the correction in experimental E_{th} is of the order of 25%.

In fig. 4 we plot the residual mass as a function of E_{th}. This was obtained by demanding software triggers of a HF in DELTA for $M_{IMF} = 0$. Note that this condition on M_{IMF}, is equivalent to having ~40% probability to have, in the event, an undetected IMF. Further, the HF velocity and accompaning charge distribution for events which do have IMFs in coincidence indicates that fission is not a competing process for the higher E_{th}. Projecting a E_{th} spectrum with a window on the residual mass of (40,45) yields a Gaussian like peak. Correction for the acceptance gives a mean excitation energy of 625 MeV. As is evident from the figure, shifting the mass window to lower values increases this E_{th}.

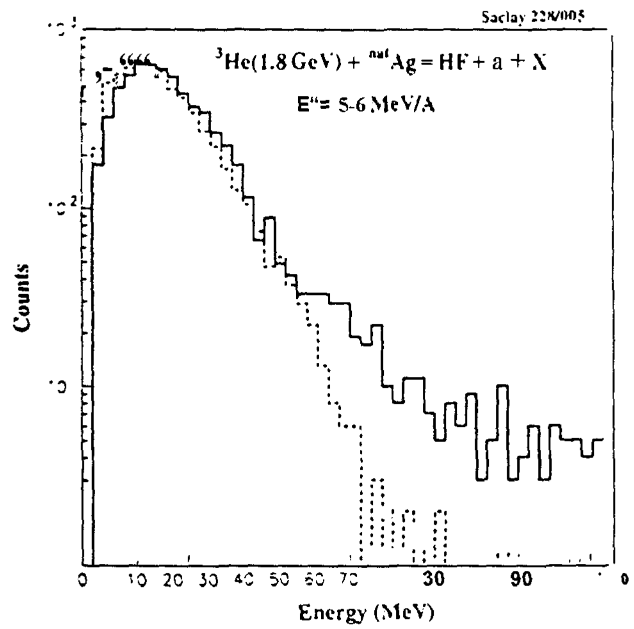

Figure 5. Energy spectrum for alphas in coincidence with HF for ϵ^* =5-6MeV/A.

The HF-coincident α (note no mass resolution in ISiS for Z=2 at low energy) particle spectra as a function of $\epsilon^* = E_{th}/M_{th}$ and $M_{th} \geq 35$ have been extracted and compared with the INC+EUGENE+FILTER calculations. In fig. 5 the spectra with a window of ϵ^* = 5-6 MeV/A are compared. Other comparisons, such as mass of the HF, HF-M_{IMF} or HF-M_{tot}, are of equivalent merit.

Conclusion

In conclusion, we report on an experimental study of ^{3}He(1.8 GeV)+^{nat}Ag where we detect LCP + IMF with a large geometrical coverage in conjuction with heavy fragments and fast protons in the forward direction. The global parameters with this configuration are effectively reproduced with an INC + EUGENE description. An attempt is made to extract the highest excitation energy reached that decays in a non-multifragmentary fashion. Values of ϵ^*/binding energy of 78% are obtained. The data-model comparison for the a-spectra indicate that at relatively high excitation energy the system can still decay through an evaporative process.

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