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A PROPOSAL TO STUDY THE PARTICLE PRODUCTION IN 86 MeV/N ^{12}C INDUCED HEAVY ION REACTIONS

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INTRODUCTION

The availability of 86 MeV/N beams of heavy ions up to Ne at the Synchrocyclotron of C.E.R.N. gives a unique opportunity to initiate a systematic study of nucleus-nucleus interactions at intermediate energies. At energies moderately above the Coulomb barrier (below 20 MeV/N) the nuclei interact dominantly by deep inelastic scattering [1]. On the other hand, at relativistic energies ($\geq$ 250 MeV/N) the mechanism is largely unknown. The available experimental data, mostly of inclusive type, is not sufficiently selective to distinguish between the large number of models [2].

The energy region 20-100 MeV/N is transitional because compression effects become increasingly important. Furthermore the relative speed between the ions passes in this region the Fermi speed, which gives a strong variation of the effect of the Pauli principle. Preliminary experiments with beam energy 90 MeV/N have been performed at the BEVALAC facility. They indicate momentum distributions which show an anomalous behaviour [3].

We suggest in this proposal an experiment where we want to study reactions with a ^{12}C beam at 86 MeV/N incident on various targets. We want to emphasize that if the beam energy can be degraded to the whole energy interval 20-86 MeV/N, we could extend our experiment into this completely unexplored region.

In a first stage we intend to measure:

1) The inclusive double differential cross sections of lighter fragments (up to the projectile mass).

2) Cross sections for emission of light particles in coincidence with a heavier projectile fragment.
3) The multiplicity dependence of the double differential cross sections of light particles and projectile fragments.

For the second stage of the experiment we intend to submit a new proposal which will extend the experiment to include also coincidence studies of how the low energy heavy target residuals ($E < 5$ MeV/N) are correlated to the emission of light particles or light projectile fragments. This coincidence measurements will however consume a substantial beam time which is difficult to estimate prior to the results from steps 1-3 in the proposed experiment.

Some Remarks about the Reaction Mechanism in the Energy Interval 20 MeV/N to 100 MeV/N.

In the beam energy interval 20 MeV/N - 100 MeV/N the available energy per nucleon is larger than the binding energy. This means that the reactions are expected to be dominated by multifragmentation processes in which several particles are emitted simultaneously in the initial stage of the reaction.

For the lowest energy in the interval at least two mechanisms for the prompt emission of fast particles (PEP) [4] have been suggested. When the two heavy ions are in close contact just after impact, a fast nucleon from one can penetrate into the other. This nucleon 1) either passes through the other nucleus, (Fermi jet, or PEP jet) or 2) it gives rise to local heating (hot spot) and subsequent emission of a fast light particle (knock out processes). By measuring nucleon momentum distributions it is in principle possible to select the two mechanisms.

At higher energies one has applied a model in which the colliding system is divided into two volumes with little communication between them, i) the highly excited overlap volume consisting of the participant nucleons, ii) the cold remaining parts of the projectile and target, called spectators. One of the aims of the present experiment is to investigate if this picture holds at or below 86 MeV/N. One consequence of the picture is that the presence of the colder spectator fragments would give rise to shadows in the spectra of lighter particles emitted from the participant region sometimes called the fireball [5]. It is worth mentioning that collective local correlations in the nuclei can give rise to backward emission of highly energetic particles.

The collective behaviour of nucleons may also give rise to a cumulative pion production [6]. Another interesting possibility arises for moderate bombarding energy and certain impact parameter and mass regions where the reaction time is so long that the energy from the hot region can spread to the whole nuclear system before it separates (total explosion). This phenomenon, which is indeed possible at 86 MeV/N, should be characterized by high multiplicity and no heavy spectator fragments.

It is worth mentioning that compression of the nuclear matter by a factor 2-3 is possible at 86 MeV/N which means that more exotic phenomena such as π-meson condensates may appear [7]. The fact that the temperature is much lower for an 86 MeV/N beam than in relativistic heavy ion reactions should be an advantage for condensation, but it is presently not possible to say what is the signature of condensation or even compression.

In conclusion we emphasize that coincidence experiments are very important. For all reaction models mentioned with the exception of total explosion, it is of essential importance to get specific information about the reaction plane. This can be obtained by measuring the momentum of the spectator fragments.

EXPERIMENTAL SETUP

In view of the preceding discussion we propose to build up our experiment in three steps.

1. For inclusive measurements of medium and high energy light particles (p,d,t,^{3}He,α; $30 \leq E_p \leq 100$ MeV) we propose to use a telescope consisting of a Si-transmission detector + a plastic stop detector.
2. For inclusive measurements of projectile fragments (α - ^{14}N; E > 10 MeV/N) we suggest to use intrinsic Ge detectors. Coincidence measurements between the projectile fragments and the medium energy light particles will be made by a combination of 1 and 2.
3. In order to measure the multiplicity dependence of the double differential cross section of light particles or projectile fragments we propose to build a movable ring of tag counters (~ 20 plastic scintillators) in order to be able to measure the backward angles.

The targets (at least four) and part of the detectors for 1 and 3 will be placed inside a vacuum scattering chamber. The exact design of this chamber will depend on the final experimental demands to be specified later.

TARGET THICKNESS

At least four targets (C-U) will be used. The energy resolution of the S.C. beam is assumed to be 0.5% corresponding to 5 MeV for ^{12}C at 86 MeV/N. The energy loss in the target

$$-\frac{dE}{dx} \approx 0.32\, Z_p^2\left(\frac{Z_T}{A_T}\right)\left(\frac{E}{A_p}\right)^{-0.7} \text{ MeV/mg.}$$

is for an Ag target ≈ 0.22 MeV/mg which means that a target thickness of 30 mg/cm^2 is possible to use without impairing the resolution seriously. For registrating of very heavy target residuals (4) we need a reduction of the target thickness of at least a factor 100.

REACTIONS IN THE DETECTORS

The thickness of the detectors makes it probable that the number of beam particle reactions in them will be noticeable. Using the interaction distance $R = 1.35(A_p^{1/3} + A_T^{1/3}) + 0.5$ fm we find an upper limit of the probability for direct beam interactions among the interesting events to be ~ 5% in (2). We find this mixture of unwanted reactions small enough to allow an effective use of Ge detectors.

NECESSARY AREA FOR THE SETUP

The most area consuming part of the experiment is the projectile fragment identification (2) which requires at least that the Ge-detector is placed 5 m from the target under assumption of a small emittance beam (6π mm) and a Gaussian distribution of the beam angles. Thereby a 1 cm^2 detector would intercept a fraction of $2 \cdot 10^{-3}$ of the useful fragment registration, when measuring at an emission angle of 30 mrad (~ the grazing angle for 86 MeV/N ^{12}C on Ag).

In case the beam will be more strongly divergent, we will have to consider the possibility to build a magnetic spectrometer for the fast fragment registration. The small angle scattering is further discussed in [9]. We conclude that the needed experimental area for our experiment is ~ 10x4 m^2.

BEAM TIME

1. Inclusive measurements of light particles:

The corrected $d^2\sigma/d\Omega dE$ distributions of p-α emitted from 250 MeV/N Ne+U reactions [10] have been reduced with a factor 2 due to the lower beam energy in the present experiment, to estimate various counting rates (Table 1). The beam intensity is taken to be 10^{11} s^{-1}, the target thickness to be 30 mg/cm^2 and the solid angle of acceptance for the detector to be 10 msr.

If we require 10^3 counts for protons at 150° we need a run time of 6 min for Al and 2 min for Cl. The corresponding times for α at 60° are 24 and 10 min respectively.

A measurement of p,d,t, spectra at 10°, 30°, 60°, 90°, 120°, 150° and ^{3}He, α at 10°, 20°, 40°, 60° for four targets requires ~ 14 h i.e. < 2 shifts.

Table 1. Estimated count rates for 75 MeV protons and α particles

		Al			U		
	Θ	$d^2\sigma/d\Omega dE$ (mb/(sr MeV/N))	Nr. of atoms (cm^{-2})	Counting rate (s^{-1})	$\frac{d^2\sigma}{d\Omega dE}$(mb/sr.MeV/N)	Nr of atoms (cm^{-2})	Counting rate (s^{-1})
p	30°	0.4	7×10^{20}	280	10	0.8×10^{20}	800
	150°	0.004		3	0.1		8
α	30°	0.01		7	0.4		32
	60°	0.001		0.7	0.32		1.6

2. The time for measurements of double differential cross sections of heavier beam fragments can be estimated if we use the fact that the cross sections for 400 MeV/N Ne+U reactions are on the average one order or magnitude lower than α production cross sections and that no large increase due to the beam energy is to be expected [11]. We find that ~ 28 shifts are necessary to measure Li-N spectra for four targets.
3. The multiplicity registrating experiment will require an additional run time which depends on the number of multiplicity bins we decide to use. An increase of time with a factor 10 is reasonable and thus we need ~ 20 shifts for the p-α measurements and ~ 10 shifts per fragment and target for the projectile fragment measurements.

In summation we can perform the first two stages of the experiment (four targets) including test runs (~ 5 shifts) within 35 shifts. The third stage can be carried through within 20 shifts + 10 shifts per projectile fragment and target. As a first allocation we ask for 50 shifts in order to carry through the first two steps of the proposed experiment and explore the third step.

SHIELDING

Based on computations for the GANIL project one may estimate that ≤ 4 m of standard concrete would be required around any place where the beam may be stopped. Shielding problems could be reduced if:

- The beam is well collimated already inside the SC main shielding.
- The ion source could be automatically switched off if ra-

diation levels at strategic places exceed a given value. In this case shielding could be conceived without consideration for accidental beam dump.

TECHNICAL SUPPORT FROM CERN

The experiment requires a standard multiparameter data acquisition system. A detailed request will be added later. In addition we would be grateful if CERN can provide us with the basic electronic units, for the detecting systems.

ADDITIONAL COMMENTS

In order to include financial provision already in the budget requirements of our laboratories for 1979 we would appreciate to have an agreement on fundamentals by the PSC Committee as soon as possible.

It is of essential importance for the experiment that the beam energy is degraded at least down to $\sim E_{Fermi}$, and we strongly emphasize that such efforts should be made. In September 1978 a preliminary investigation of how the charged particle multiplicity depends on the energy in ^{12}C induced heavy ion reactions (20 - 100 MeV/N) in nuclear emulsions will start in Lund.

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