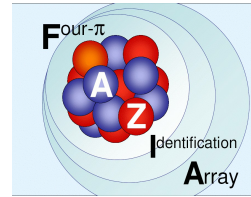


# Isospin dynamics and nucleon exchanges with Fribs

## LOI for the Fribs facility at the LNS

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### Introduction

In recent times many theoretical efforts have been made to address the role of the isospin dynamics in Heavy Ion Reactions (e.g. [bar02,riz08]). Several effects have been predicted which are related to the particular behavior of the symmetry energy as a function of the nuclear density: such a behaviour is largely unknown and on the other hand it plays a role in different environments both in microsystems (nuclear halo or skin, nuclear shape far from stability) and in macrosystems (crust of neutron stars, the explosions of SuperNovae).

From the experimental point of view the interest is also connected to the wider and wider availability of exotic beams by which one can form systems much poorer or richer in neutron than stable nuclei. In this way, the isospin degree of freedom (often measured by the  $N/Z$  value or by the  $I=(N-Z)/A$  parameter) can be highly excited and its evolution can be better investigated.

Very strong compression (high density) can be experienced by nuclear systems in central collisions at high energies; instead, densities lower than the saturation value can be reached during reseparation after peripheral interactions of nuclei even at moderate bombarding energies. With decreasing beam energies, isospin effects more and more show up on nuclear surface related phenomena and, in general, on the nuclear structure [sou07,ves06]. Therefore, at low beam energies, one can study how the exotic isospin content of the nuclei affects collision dynamics in particular in peripheral reactions, when the surfaces play a dominant role and the interplay of the dynamics with the underlying nucleon structure is relevant.

This is the realm of binary dissipative collisions, at different level of violence, from quasi-elastic interactions to more central impacts [pia06]. These reactions are characterized by the production of a Quasi-projectile (QP) and a Quasi-target (QT) whose properties are determined by the collision parameters and, among the others, by the  $N/Z$  value of the initial nuclei [sou07, hud05].

A good opportunity for this investigation is offered by the Fribs beam line at the LNS. Fribs mainly produces  $n$ -poor light species via in-flight fragmentation of fast ions. At present, according to the recent information spread during the "Fribs meeting" last March, the primary beams are those reported in the Table below (next page) together with some their characteristics.

Even in view of the foreseen upgradings of Fribs, in terms of new beams (e.g.  $^{32}\text{Ar}$ ), larger intensities and more powerful tagging detectors, the FAZIA collaboration manifests an interest with this very preliminary scientific program which can be better defined in future. We stress that this LOI is

closely related to the Physics program proposed by FAZIA at Spiral2 (LOI “Dynamics and Thermodynamics of exotic nuclear systems”) in particular as far as the fifth scientific case is concerned [fal06].

beam	Primary beam	rate (Hz/enA)	Beam line	beam purity	To date Primary intensity
$^{18}\text{Ne}$	$^{20}\text{Ne}$ 45 MeV/A	18	20°	9%	700 enA
$^{21}\text{Na}$	$^{20}\text{Ne}$ 45 MeV/A	44	20°	22%	700 enA
$^{11}\text{Be}$	$^{13}\text{C}$ 55 MeV/A	20	CHIMERA	55%	700 enA
$^{12}\text{B}$	$^{13}\text{C}$ 55 MeV/A	70	CHIMERA	85%	700 enA

We remind that FAZIA [faz06] is an international collaboration aiming at fully exploiting the intrinsic detector capabilities (scintillators and silicons) for charged products identification. To this goal an intense development of charge and current high-quality preamplifiers, of digital electronics and of Pulse Shape Analysis techniques has been undertaken together with specific data runs to study in details the behavior of signal production and collection in these detectors. Along the road towards a complete  $4\pi$  array, for the next 2-3 years FAZIA foresees to build a certain of final telescopes, of the order of 100-200 pieces, organized in clusters. The rather wide solid angle that can be covered with this set of telescopes and much more the performances which are expected from them will allow to produce some high-quality data on reaction mechanisms when suitably mounted at specific angles and coupled with presumably available arrays (e.g. INDRA, GARFIELD, CHIMERA).

A final remark concerns the coincident measurement of gamma rays. This aspect, which of course will need of an efficient gamma detector, can be very useful, for example, to extend the investigation of the dynamical dipole excitation, a nuclear mode closely related to the isospin dynamics [mar08]. In this case Fribs beams should be used towards lower energies when collective emission has more time to develop during the slower interaction.

## Scientific issues

At energies below 20-25 A MeV, the reaction dynamics for non central collision are described, with a certain success, through transport models in which the excitation of the nuclear degrees of freedom is given by exchange of nucleons in the potential felt during the interaction [tgo91]. Excitation of thermal and of rotational modes in dissipative collisions (DIC) has been, at least on average, fairly well described by these models. On the same ground the description was attempted of the isospin evolution (at that time often called charge equilibration) which was supposed to tend towards equilibrium with decreasing impact parameter,  $b$ . Essentially, the fate of the various degrees of freedom is given by the interplay of the excitation mechanism and relaxation time: for a given starting values of mass, charge and relative velocity of the incoming nuclei, the various observables of the reaction products smoothly

evolve with decreasing  $b$  since more and more nucleons are exchanged during the interaction, whose duration increases with increasing centrality.

Many studies on this field have been performed in the eighties and nineties [mar93, mad95, sha97]; the description based on transport models was not obviously tested with exotic nuclei, unavailable at that time. However, even in reactions between stable nuclei, it was observed that the proposed model, though catching the gross features, fails in describing many aspects and several details. Moreover, it is important to note that the experimental data are not always of high quality and in several cases they may bring to different, when not contradictory, conclusions. New specific measurements with a powerful array like FAZIA (A,Z identification in a wide dynamical range) and modern analysis tools may lead to some more definite results and more stringent comparisons with models.

Some of the questions which are not clarified are the following:

1. the question of the attainment of the equilibrium in the various degree of freedom (energy, spin, charge and mass);
2. the rapid increase of the variances of the distributions with decreasing  $b$  is not well reproduced by transport models; often models give average trajectory of a certain variable but correlations and fluctuations are either disregarded or poorly reproduced.
3. the possible role, in an exchange context, of cluster transfer;
4. the preequilibrium emission (yield and Z, A composition);
5. the shape deformation variable and its effect on the decay (fission).

In the framework of the modern nuclear science, all the listed points can be viewed as a testbench for isospin dynamics, in particular on the relationship between the isospin and the final properties of the reaction products.

For example, what is the isospin evolution of QP, QT with  $b$  in reactions with exotic beams? What are the effects due to the surfaces, expected to be amply diffused for n-rich nuclei? Can we evidence effects due to cluster exchanges? Can very exotic and loosely bound clusters be produced during these reactions induced by very N/Z-asymmetric beams? How does the preequilibrium emission (yield and chemical composition) change in exotic beam induced collisions? How does the isospin content influence the decay of the excited products in DIC?

We believe that an important step can be done in the next future to answer the above questions. However, it has to be considered that most theoretical efforts done in the past, at rather low energies, were aimed at describing the time evolution of the average trajectories of different degrees of freedom, easier to be measured. The knowledge of their widths and correlations requires inputs provided by extensive measurements over a wide range of incident energies, impact parameters and isospin asymmetries of projectile and target combinations. Such joint efforts between theory development and experimental measurements will enrich future perspectives in extending isospin and symmetry energy physics to the lower energy domain (e.g. at future facilities like SPES and Spiral2).

Experiments with Fribs, performed with a powerful detector, can permit to address some of these open problems, approaching the context from the

neutron-poor and light-mass side. In the following we cite some possible experiments. The idea of the FAZIA collaboration is to focus, in the future, on some specific experiment(s) and to prepare a final proposal fitting the conditions met at the end of 2010 as far as both the FAZIA project and the Fribs facility are concerned.

In any case, since at that time FAZIA will have reached the PhaseII, corresponding to the construction of a complete telescope module of about 100-200 units covering a restricted solid angle, it is quite reasonable that FAZIA must be coupled with other arrays in order to get some relevant scientific goal. The FAZIA group will consider and discuss all the possibilities along this roadmap to finalize a proposal.

We finally mention that this issue is the basis of an experiment proposal which the Nuclex collaboration (a group who almost completely merges into the italian part of FAZIA) is going to show at next LNL-PAC meeting (9-10 july) .

### **Preliminary examples of experiments using also Fribs beams**

The Table below simply shows a few systems that can be studied benefitting of Fribs beams. By using different asy-symmetric beam-target combinations one can investigate the degree of isospin equilibration during the interaction phase (fast emission) and at the end of the impact, both in case of binary channel (QP,QT properties) and in case of incomplete fusio-fission events (properties and decay of the hot heavy residue)

beam	target	E AM eV	N/Z P	N/Z T	theGr _lab deg	N/Z syst.	max L hbar	Rea Xsect barn	Vcm,Ecm cmns-1 MeV	Vrel cmns-1	Fusion Q- value MeV	id.
20Ne	100Mo	30	1	1.38	5.6	1.31	205	3.32	1.27, 500	7.61	-3.81	1
20Ne	92Mo	30	1	1.19	5.7	1.15	198	3.19	1.36, 493	7.61	-16.59	2
18Ne	100Mo	30	0.8	1.38	6.4	1.27	184	3.19	1.16, 458	7.61	+6.84	3
18Ne	92Mo	30	0.8	1.19	6.5	1.12	178	3.07	1.25, 452	7.61	-9.22	4
32Ar	100Mo	30	0.78	1.38	6.1	1.2	308	3.53	1.85, 727	7.61	-16.75	5
40Ar	92Mo	30	1.22	1.19	4.78	1.2	363	3.71	2.31, 836	7.61	-50.23	6

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