PHD Thesis Project proposal, 2022-2025
INFN Sezione di Firenze, Gruppo Nucleare

Frame: experimental Thesis
INFN financed experiment name: Nucl-ex (Nucl-ex national website: http://www.bo.infn.it/nucl-ex/)
Theme: **reconstructing the fragment origin in dissipative collisions at Fermi energies**
Apparatus: FAZIA+INDRA
Involved LABS: GANIL (Caen, F)
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General Physics Subject
The physics deals with the behaviour of nuclei far from stability, at conditions that can be reached on the Earth using energetic heavy-ion collisions. In particular the focus is on the Fermi energy domain (20-100 MeV/u) where NN-collisions play an important role during the nuclear reactions and very hot and deformed pieces of nuclear matter can be formed. The timescales of these systems are very short (<1zs) comparable with the interaction times. As a function of the reaction centrality, different outgoing channels can be populated, also depending on the size and the asymmetry of the incoming nuclei. Recently, the focus has been put on the formation and decay of clusters during these violent collisions because the accurate measurement of their properties can reveal details on the nuclear Equation of State (EoS) far from the equilibrium, in particular below/above the saturation density and towards the p or n drip lines. In turn, this has to do with the description of explosive and/or exotic astrophysical systems (e.g. SuperNovae explosion, NS-mergers, NS cooling process) which are currently the focus of strong interest thanks to the very recent multimessenger observation. The synergy between the information coming from terrestrial nuclear physics and astrophysical measurements is indeed welcome.

Specific proposed Physics goals
We want to address mainly this point: by means of particle correlation techniques, try to reconstruct the light fragment excited states that decay via particle emission. Indeed, during the collisions, the fragments are produced over a broad excitation energy distribution and with different spin values. The excitation E* of the fragment degrees of freedom depend on the very phase when they are produced (during the initial interaction, during the possible expansion or stretching in the overlap region, during the further decay from the primary sources): it is extremely interesting the experimental attempt to disentangle these various production phases and correlate the excitation energy spectra of fragments with the nuclear environment of their formation. The challenge is hard because one must separate different event classes and then, in various classes, establish the “candidate” origin of the measured fragments. Moreover, and this is the focus of this proposal, to extend the investigation, one can try to reconstruct the excitation spectrum beyond the separation energy of the various excited clusters. For example, excited 12C ions are not detected at all above about E*=7.65MeV because they soon decay in three alphas; 11C, similarly, can be reconstructed as a pair alpha-7Be above the separation energy. Therefore the particle correlation technique allows to greatly extend the exploration of the nature and the origin of excited fragments.
Of course, the experimental results as for the yield and the properties of the cold or resonant reconstructed fragments can be compared with performing nuclear reaction models. For some literature see for instance reff [1-5]

Methods
Our group is since years involved in experiments aiming at precisely measuring charged particles and fragments coming from Fermi energy reactions collecting data with well-performing detectors studied and assembled by the collaboration. Very briefly the methods consist in fixed-target experiments carried on with the FAZIA telescopes [6,7] coupled with the INDRA array at GANIL. The coupling permits to achieve large acceptance and thus to well characterize the detected events. Various reactions have been measured recently involving both symmetric and asymmetric reactions with ions of medium size (A<100). The well performing apparatus allows to to completely identify nuclei in mass and charge in the forward angular region up to Z=24-25. The event selection is very important to disentangle the various types of main sources (i.e. excited primary systems) that can break-up forming in turn smaller clusters. The experimental analysis is always guided and compared with simulated data, obtained running different reaction model codes.
The subject of the particle-fragment correlation method has been only recently attempted within our group but first studies demonstrated the capability for such investigation with FAZIA-INDRA. Thefore we propose to:

- characterize the clusters in violent collisions for different selected event classes
- reconstruct properties of cold fragments, ie. Identified as such in the detectors
- reconstruct fragment from resonances attempting 2- or 3-particle correlation analysis
- estimate the background contributions
- discuss the properties of cold and ‘hot’ fragments as function of relevant reaction parameters
- compare results and model predictions

The analysis can start using the data taken in recent experiments both with FAZIA-INDRA (large acceptance) and with previous reduced FAZIA stand-alone.

Candidate skills and operating conditions

The candidate will work in team (both local and french subgroups) and will be engaged in the analysis described before focussing on the various event selection criteria. He-She will then quantify the various event classes also checking the quality of the selections adopted. The the candidate will perform various analysis to characterize the role and the nature of the various emissions of light particles and fragments.

C++ and ROOT based packages are mainly used, thus a certain software knowledge is beneficial. Reaction model simulations will be also run. Geant-4 simulations and other simulation tools will be used to get rid of the bkg sources that are important to consider and correct for in correlation analysis techniques. The candidate must be available to travels and to mid-long stays in the labs where experiments are performed; indeed, he/she could also participate to new experiments that will be proposed by the collaboration for the next 2023 at GANIL.

The candidate will be involved in the possible writing and publishing of papers and in the participation to Conferences where results will be presented.

References:

[1] S.Piantelli et al.; C.Frosin et al.: two papers to be submitted to PRC
[2] A.Ono Prog.Part Nucl. Phys 105, 2019
[3] R. Han Phys. Rev. C 102 064617, 2020
[4] G. Tian Phys.Rev. C 97 034610, 2018
[5] E. De Filippo Phys Rev. C 86 014610, 2012
[6] R. Bougault et al Eur Phys. Journal A, 50, 2014
[7] http://fazia.in2p3.fr/?lang=en