The Farcos project

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INTRODUCTION

The study of correlations between particles emitted during a collision between two heavy ions provides information about the space-time properties and quantitative understanding of reaction dynamics. This in turn depends on the details of the nuclear interaction and the equation of state (EoS) of nuclear matter. The Eurisol facility will allow studying these problems with higher sensitivity to the isospin degree of freedom thanks to the capability of accelerating highly N/Z-asymmetric beams at intermediate energies. In this respect, detectors capable of detecting all reaction products on an event-by-event basis and measure their reciprocal correlations are mandatory [1,2]. Different observables need to be measured over a large solid angle coverage with high energy and angular resolution. The solid angle coverage guarantees a characterization of the collision event. The energy and angle resolution are important in order to measure the momentum vectors and kinetic energies of the detected particles and explore their correlations. Recent implementation of pulse-shape identification techniques promise to provide unique capabilities [3-5] that will allow studying nuclear dynamics even at low energies at facilities such as Spiral2 and Spes [6].

In this contribution we present the physics cases for the construction of a detector array meant to measure correlations between particles and fragments in coincidence with large solid angle arrays. The name of the project is Farcos, standing for Femtoscopy ARray for Correlations and Spectroscopy. It is expected to address topics in "femtoscopy" via intensity interferometry and spectroscopy with radioactive beams.

DYNAMICS AND TWO-PARTICLE CORRELATIONS

Heavy-ion collisions allow one to explore the properties of nuclear matter under extreme conditions. A clear understanding of the dynamics of heavy-ion collisions is required. Particles are emitted at different stages that are difficult to isolate. It is therefore important to disentangle particle and fragment emitting sources. Where and when are fragments produced? Understanding dynamics in heavy-ion collisions requires tracing-back particle and fragment emitting sources. Such challenge can be accomplished by using two-particle correlation function known to be sensitive to the space- time features of nuclear reaction mechanisms [7]. The shape of correlation functions probe important transport properties of nuclear matter and the density dependence of symmetry energy in the equation of state.

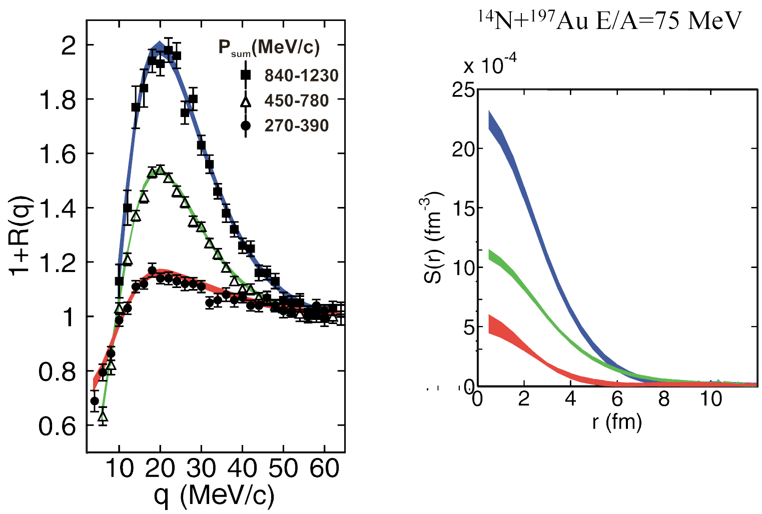

FIGURE 1. Left panel: Two-proton correlation functions measured in Ne+Au collisions at E/A=75 MeV. See Ref. [8] for details. Right panel: emitting source functions extracted by imaging.

Two-proton correlation functions, $1+R(q)$, is defined as the ratio between the two-proton coincidence and uncorrelated spectra, $Y_{coin}(q)$ and $Y_{unco}(q)$, respectively. q is the relative momentum between two protons in Y_{coin} and Y_{unco} spectra. Uncorrelated proton pairs are usually constructed by coupling protons from different events. Fig. 1 shows such a correlation function in the case of N+Au collisions at E/A=75 MeV [8]. The peak at q=20 MeV/c is due to the nuclear interaction between the two protons and determines the spatial extent of the emitting source, $S(r)$, defined as the probability of emitting two protons with a relative distance r recorded at the time when the second proton is emitted. Imaging techniques [8 and Refs. therein] have been successfully used to extract the emitting source function from the measured correlation function. This images represent sort of “space-time pictures” of the emission [7-9]. The right panel of Fig. 1 shows the source functions, S(r), extracted from the correlations represented on the left panel. The source function not only provides information about the size/volume of the emitting source, but also allows us to estimate the relative contributions between fast dynamical pre-equilibrium sources and slowly evaporating sources characterizing the later thermalized stages of the reaction [8]. This sensitivity of R(q) to the space-time features of the reaction becomes very useful as tool to explore transport properties of nuclear matter. Indeed microscopic transport models have shown sensitivity to the nucleon-nucleon (NN) collision cross section in the nuclear medium [9] and to the density dependence of the symmetry energy [10]. Such research program requires also the difficult task of measuring p-p, n-p and n-n correlation functions in the same experiment [10]. Coupling charged particle and neutron detectors is also a priority in this respect.

Extending these measurements to fragment-fragment correlation functions allows one to extract space-time information about the stage of heavy-ion collisions when nuclear matter at low density breaks-up into complex fragments possibly indicating the occurrence of a phase-transition [11] and carrying important signatures of the effects of the symmetry energy and its density dependence. The possibility of measuring fragment correlation functions is further enriched by the introduction of powerful pulse-shape capabilities that would allow identifying fragments at low kinetic energies [3,4]. These fragments can be identified only by a detailed study of the shape of the signal induced by their passage through the detector [2-4]. Another important application of intensity interferometry is represented by the study of correlations between unlike light particles, such as proton-alpha, deuteron-alpha, deuteron-^{3}He, etc. [7]. An extended study of all these correlation functions would allow a reconstruction of several emitting sources in the same reaction. These light particle correlations are usually characterized by the presence of several resonances and a precise measurement of their position and shape is mandatory in order to probe their emitting sources. High angular resolution is thus a key feature of an array meant to perform correlation measurements between light particles.

CORRELATION FUNCTIONS AS A SPECTROSCOPIC TOOL

During the dynamical evolution of the system several loosely bound nuclear species are produced for a very short time and decay. Their unstable states can be identified and explored by detecting all the products of their decay in coincidence. A typical example of this type of analyses has been shown in Ref. [12] where p-^{7}Be correlation functions were measured in order to study unbound states in ^{8}B nuclei and probe their spins [12]. In a more recent experiment, three- and four-particle correlation functions have been used to study highly lying unbound states in ^{12}C and ^{10}C nuclei [13]. Three-alpha particle correlation functions can be used to study the decay of internal states in ^{12}C. While two-alpha-two-proton correlation functions probe ^{10}C decay. In the case of ^{12}C these correlation studies allow one to disentangle the direct decay into three alpha particles from the sequential decay into ^{8}Be+alpha with a subsequent decay of ^{8}Be into two alphas. In the case of ^{10}C studies one can identify the decay sequence of unbound states that produce intermediate states in ^{6}Be, ^{8}Be and ^{9}B [13]. The techniques reported on Ref. [13] show that one single heavy-ion collision can provide access to some spectroscopic information of exotic unbound states. The availability of very proton-rich beams at Eurisol can enhance the possibility of producing even more exotic resonances and study their decay properties.

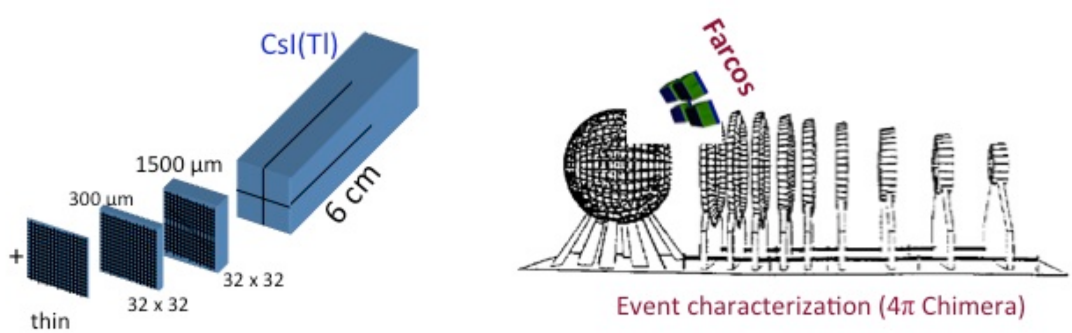

FIGURE 2. Left panel: Schematic view of the expected design of Farcos telescopes. Right panel: Coupling of the Farcos array to the Chimera detector at the LNS of Catania.

REQUIRED ARRAY FEATURES

Based on the physics cases outlined above, we plan to build an array of silicon strip and CsI(Tl) telescopes to be coupled to large detector arrays such as Chimera@LNS-Catania or Indra@GANIL. A minimum of about 15 telescopes is required in order to address a number of physics cases as outlined above. However a larger solid angle coverage would significantly increase the scientific reach of the project. The array will have a large geometric flexibility. Silicon strip detectors with thicknesses of 300 and 1500 μm (6.4 x 6.4 cm^2) will be followed by 6 cm –long CsI(Tl) crystals arranged in a square configuration 2 x 2 (each crystal will have a front face of 3.2 x 3.2 cm^2). This array will provide an angular resolution up to about 0.1^o at a distance of 1 m from the target. The left-end side of Fig. 2 shows a schematic view of the basic telescope. The geometry flexibility of the telescopes is expected to allow the use of an additional silicon strip detector aimed at lowering the identification threshold. Low thresholds will also be attained with pulse-shaping techniques [3-5]. Silicon nTD solutions are also under consideration to improve pulse-shaping capabilities. The required electronics will need to address the goal of obtaining high resolution, high dynamic ranges and high flexibility (programmability) in order to identify light and heavy fragments. Due to the large number of channels that will be employed in the array, an integrated electronics solution will be required. The right-end side of Fig. 2 shows a possible arrangement of the array inside the Chimera reaction chamber at the LNS of Catania. The use of the array in studying correlations between charged particles and neutrons is also envisioned and will require a specific study on the materials required in order to couple Farcos telescopes to neutron counters.

The high flexibility of the array will certainly allow applications at the Eurisol facility, especially when studying reactions induced by proton-rich beams. These beams will allow studying correlations between charged particles emitted by short-lived exotic nuclei abundantly produced close to the proton-drip line (two- and multi-proton emitters, etc.). Also, studying direct reactions induced by radioactive beams, such as (p,d), (d,p) etc. reactions, will be possible due to the envisioned high energy and angular resolution and to the geometric flexibility [14].

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