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Nuclear detecting systems at LNL and LNS: foreseen experiments to provide basic data for heavy-ion risk assessment

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Abstract

The use of existing detecting systems developed for nuclear physics studies allows collecting data on particle and ion production cross-sections in reactions induced by Oxygen and Carbon beams, of interest for hadrontherapy and heavy-ion risk assessment, The MULTICS and GARFIELD apparatus, together with the foreseen experiments, are reviewed.

KEYWORDS: Radiation risk, nuclear reactions, heavy ions, fragmentation.

1. Introduction

Ion beams interacting with biological tissues undergo a series of nuclear reactions, which significantly modify the beam composition and its biological effects. Experimental data are required for developing models apt to provide reliable human risk assessments, of interest for space missions and hadrontherapy. To this purpose the use of existing ion accelerators and detecting systems, though developed for basic nuclear physics programs, can turn out to be quite effective.

In Italy the study of Heavy Ion Physics takes advantage of two facilities of the National Institute of Nuclear Physics (INFN), covering the range from low to intermediate energies:

– The Legnaro National Laboratories (LNL), mainly based on an 18 MV Tandem XTU and a linear booster, ALPI, with superconducting cavities. Available energies range from a few MeV/n up to 15-20A MeV.

– The National Laboratories of the South (LNS), which use a 15 MV Tandem Van de Graaff both for experiments at low energies and for injecting beams in the CS, a K=800 Cyclotron with superconducting coils. It could deliver light ions up to 100A MeV and very heavy ions up to 20A MeV.

Large detecting systems exist in both Laboratories. In Legnaro second-generation apparatus, as GARFIELD among others, have been developed to improve the understanding of nuclear reactions in the delivered energy range, where a lot has been more suggested than really demonstrated. In Catania, suitable to investigate a variety of phenomena mainly connected to the wide field of the fragmentation of large hot nuclear systems, the facility assembled by the OUVERTURE Collaboration and the CHIMERA device stand out.

Despite the variety of experiments performed worldwide at these energies, essentially no data can be found, for beams and target of biological interest, on the production cross sections of light particles and fragments, on their energy spectra and angular distributions. These data could be obtained taking advantage of existing detecting systems. In the following the apparatus and the measurements presently foreseen by a joint effort of STREGA, FORWARD and ATER/FIBI collaborations will be briefly reviewed.

2. Detecting systems

2.1. *Garfield*

This detecting system (General Array for Reaction Fragment Identification and Emitted Light particles in Dissipative collisions), used by researchers from LNL, Bologna, Firenze, Milano and Trieste, is based (Fig. 1) on two drift chambers [1], operated with CF4 and covering the forward ($30^o < \theta < 85^o$) and backward ($95^o < \theta < 150^o$) hemispheres.

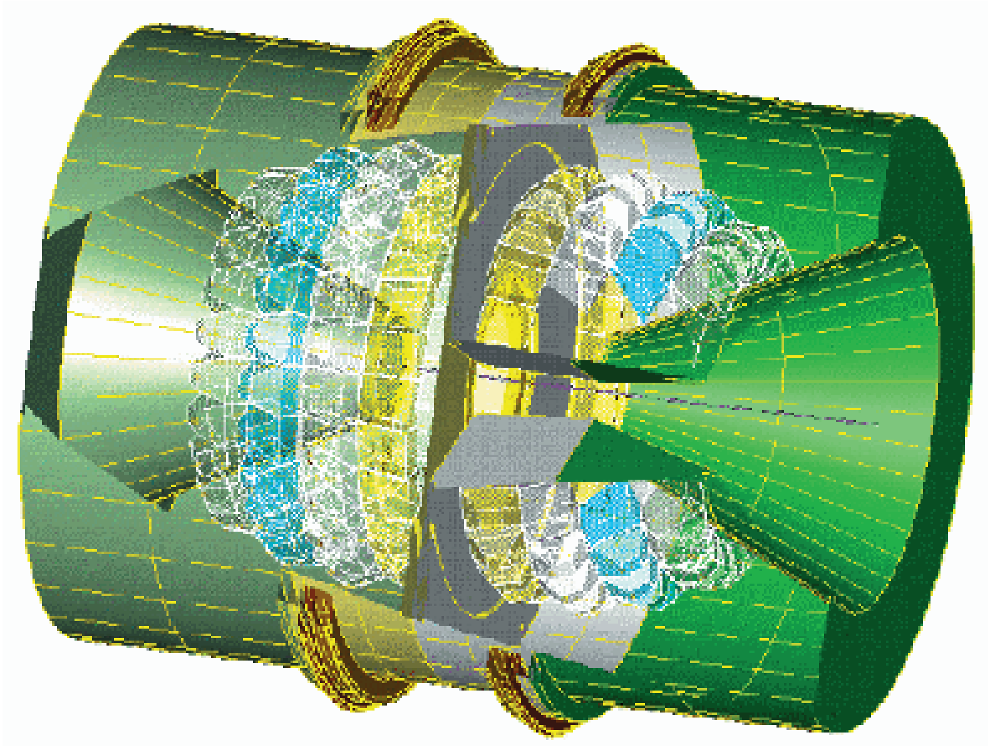

Fig. 1 – The two drift chambers of GARFIELD.

Their main peculiarity is the use of gas microstrips structures, that collect and multiply the electrons generated by the ions crossing the gas volume (Fig. 2).

The microstrip signal corresponds to the energy loss in the gas. The residual energy information is given by CsI(Tl) crystals, where the incoming ion stops. In-beam tests have shown the wide Z and E dynamical ranges that these relatively simple 2-stage telescopes can achieve. Low ionizing particles, as 70 MeV protons, and heavy ions can be identified with the same electronic set up, which has been specifically developed to optimize the Garfield performances. Energy thresholds are less than 1A MeV.

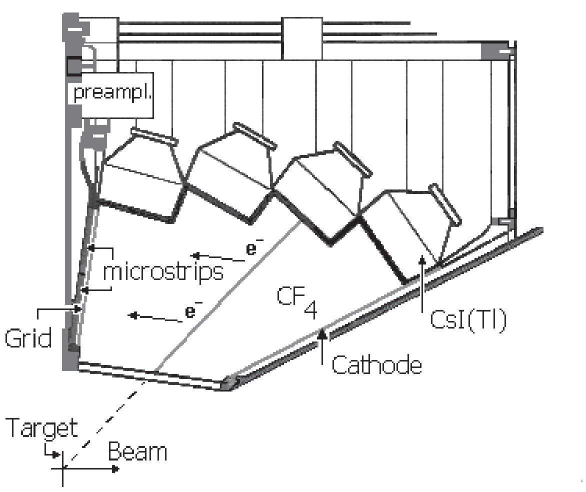

Fig. 2 – Cross section of the upper part of a drift chamber showing a track of an ion crossing the gas region, microstrips devices and CsI crystals.

The impinging angles of the incoming particles are given by the microstrips granularity ($\Delta\varphi$ = +– 3.75°) and by the drift times ($\Delta\theta$ = +–1°) in the gas.

Large-area two-dimensional position sensitive multi-wire proportional chambers (20 × 20 cm^2, 100 sensitive wires per plane) followed by thick Si(Li) detectors, are dedicated to the detection of projectile-like and target-like fragments in the appropriate angular ranges.

A segmented annular detector is placed at small angles. It is a three-stage system with ionization chambers, annular Silicon with 64 strips, apt to stop heavy fragments, and 16 CsI(Tl) crystals for long range light particles.

Some standard two-stage Silicon telescopes, covering the angular range between 16° and 30°, will be added for the measurements here considered.

2.2. *Multics-Medea-Maciste*

The coupling of the MEDEA and MULTICS apparatus at LNS (Fig. 3) resulted in a powerful facility with the distinctive capability of detecting both γ rays and charged ejectiles in a wide angular region. In particular, Heavy Ions and Fragments (3°< θ < ≈ 28°). Light Charged Particles ($Z \leq 2$, 3°< θ < ≈ 170°) and γ rays (0°< θ < ≈ 170°).

MULTICS [2] is an array of 56 telescopes, covering the forward angular region from about 3° to about 28° with a geometric efficiency of 72%, designed to detect light charged particles and heavy ions at intermediate energies. It has been widely used in experiments at GANIL (Caen, France) and at the NSCL facility of MSU (East Lansing, USA).

Each element of the array is a four-fold telescope

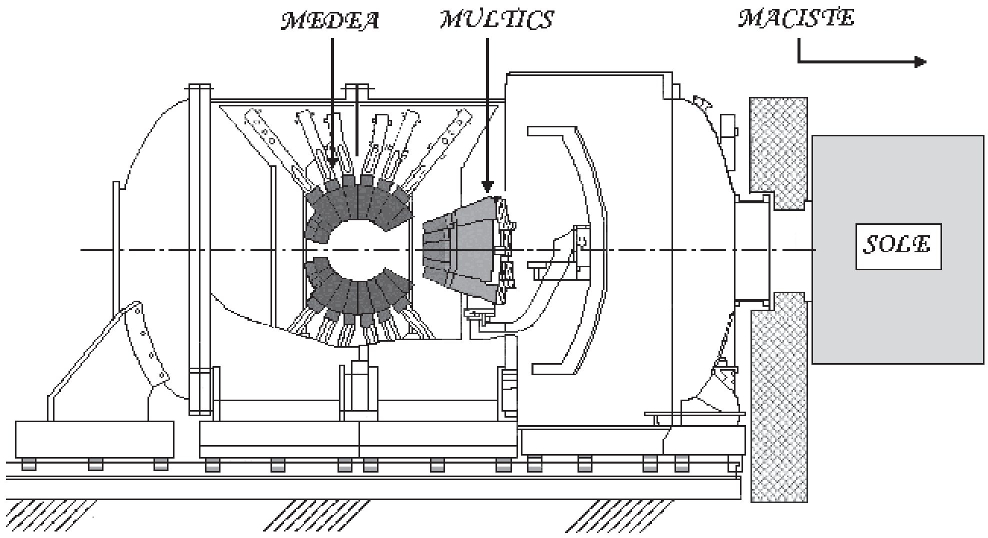

Fig. 3 – Sketch of the facility at LNS.

made up by an axial ionization chamber, a 5 × 5 cm^2 (500 mm thick) two-dimensional position-sensitive Si diode, a 3.5 mm Si(Li) detector and a 2.5 cm CsI crystal, read out by a photodiode. After MULTICS, the Si-CsI(Tl) coupling became the typical telescope in heavy-ion physics.

The angular resolution is about 0.1° in the central part (3 × 3 cm^2) of each detector and about 0.3° near the edges; charge identification has been proved to extend up to $Z = 83$ and the isotope separation up to oxygen ions: it is a detection system that combines a large dynamical range with good charge, energy and angular resolutions.

MEDEA [3], widely used in successful experiments in GANIL, is an array for γ rays and light charged particles, designed to operate in a large vacuum vessel. Its present configuration consists of 180 barium fluoride crystals, arranged in a ball shape of 22 cm inner radius.

The closely packed BaF2 ball covers polar angles from 30° to 170° and the whole azimuthal range. The typical thickness of each module is 20 cm, which is about 10 radiation lengths, and corresponds to the range of ≈300 MeV protons and ≈1 GeV alpha particles. The detection efficiency is higher than 97% for γ-ray energies from 1 to 300 MeV.

The discrimination of γ rays and light charged particles is achieved using a pulse-shape analysis method: the separate integration of the total output signal and the fast component allows for the identification of γ-rays, $Z = 1$ isotopes and $Z = 2$ particles from deposited energies as low as a few MeV. A good discrimination between γ-rays and neutrons is obtained combining the time of flight information and the pulse shape analysis.

At very forward angles MACISTE, 15 m far from the target, can identify the reaction products conveyed on it by SOLE, a superconducting solenoid placed just at the exit of the MEDEA-MULTICS reaction chamber. Sole presents an angular acceptance of about 5° and a moment acceptance of about 20%. MACISTE consists of 4 large modules with gas chambers, for energy loss and two-dimensional position information, followed by plastic scintillators for the residual energy measurement. The long flight path allows a superior detection and identification of projectile-like fragments and heavy residues emitted at very forward angles.

If necessary, standard telescopes, apt to improve the Z resolution and to lower the energy threshold, can substitute some MEDEA modules for reactions with a significant presence of $Z > 2$ ions above $\theta = 30^{o}$.

3. Foreseen experiments

Using the described facility at LNS and GARFIELD at LNL measurements are presently planned with Oxygen and Carbon beams impinging on targets as Carbon and Calcium, of interest for studying heavy ion effects on human tissues. For each Z value of the ejectiles (for each isotope whenever possible), the production cross-section, the energy spectrum and the angular distribution will be given. Energies at a few MeV per nucleon will be studied first, followed by experiments at higher energies, up to 15-20 A MeV at LNL and at 30, 50, 70 A MeV at the Superconducting Cyclotron.

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