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LABORATORY ASSISTANTS FOR DATA ACQUISITION OF PISOLO EXPERIMENT

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1 Motivation and experiment

The laboratory activity was performed within the framework of a project investigating the hindrance phenomenon in $^{19}F +^{12}C$. The aim of this project is the measurement of the fusion excitation function of the cited reaction, using the PISOLO electrostatic deflector setup.

The motivations behind this research include the evaluation of fusion hindrance's features and the connection between its existence in light systems and astrophysical consequences.

1.1 Hindrance phenomenon and its astrophysical consequences

The hindrance phenomenon usually indicates a nuclear transition or decay which is slower than expected, with respect to theoretical predictions. This could be related to:

1. Structural differences between initial and final nuclear states;
2. Angular momentum and selection rules;
3. Reduced alpha-particle preformation;
4. Decreased electromagnetic transition probability.

Since the stellar evolution and nucleosynthesis are strictly connected to nuclear reactions and decay rates, if the hindrance effect occurs, major consequences can be observed in astrophysical environments [1], like:

- Changes in nucleosynthesis flow: for example, in r-processes, if a β-decay is hindered, the isotope involved becomes a waiting point, slowing the reaction flow. This can affect heavy elements abundances like Eu, Au, etc...;
- Changes in Supernovae and Kilonovae brightness: hindered β-decays or γ-decays alter how quickly nuclei return to stability and this affects the decay heat curve that powers luminosity in Supernovae and Kilonovae;
- Different yields of heavy elements and actinides: since if a decay is hindered, more nuclei survive long enough to capture additional neutrons and this alters the path to the actinides and the predicted age estimates using U/Th ratios.

In this respect, a very recent paper has concerned the fusion of 12C + 12C and 12C + 13C where the first case is well known to play a fundamental role in the stellar environment [2]. The results of this experiment are shown in Fig. 1.

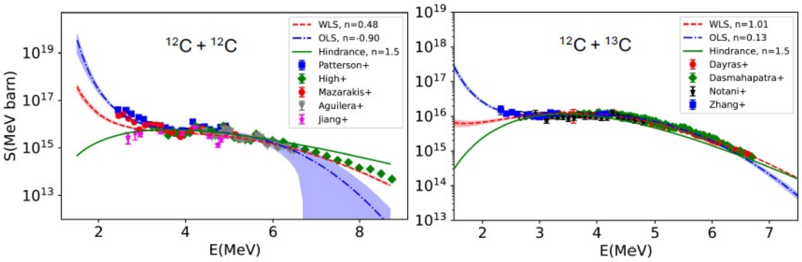


Figure 1: The astrophysical S factors for $^{12}C +^{12}C$ (left) and $^{12}C +^{13}C$ (right) obtained in Ref. [2]. The S factors from the hindrance model of Ref. [1] are also shown for comparison by the green solid line (see Ref. [2] for reference to the various data sets).

1.2 Setup apparatus

The ^{19}F beam was delivered by the XTU TANDEM accelerator at the Laboratori Nazionali di Legnaro (LNL), with beam energies ranging from 18 to 28 MeV [3]. The beam impinged on a ^{12}C target with a density of 50 µg/cm and an isotopic enrichment of 99.8 %. A set of interchangeable targets was employed to allow replacement in the event of target degradation during irradiation.

Evaporation residues produced in the nuclear reaction were detected using the electrostatic separator of PISOLO [4]. The detection system included two microchannel plate (MCP) detectors for time-of-flight (ToF) measurements, as well as four silicon detectors used for beam monitoring and cross-section normalization. The PISOLO schematic is shown in Fig. 2.

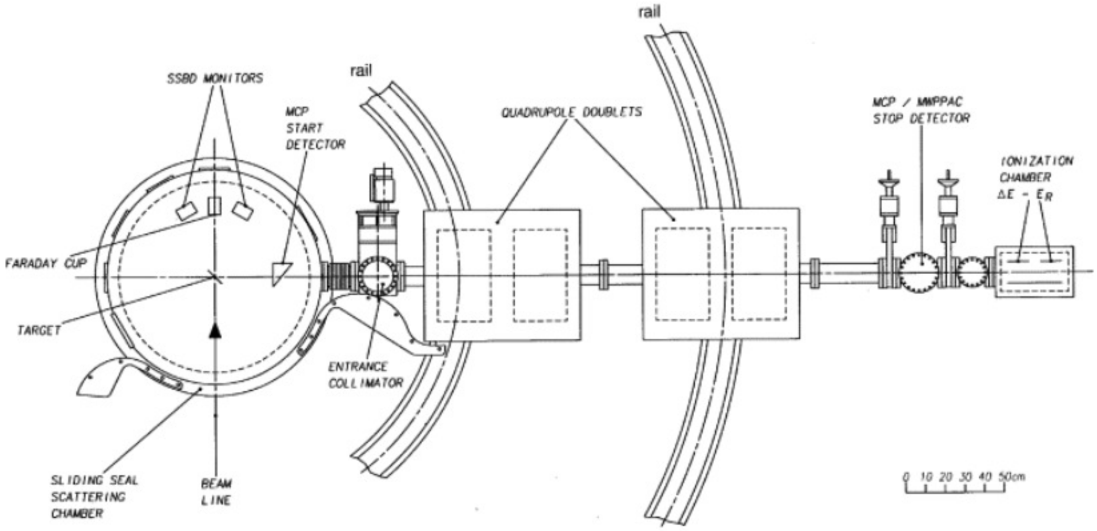


Figure 2: Schematic view of PISOLO spectrometer [4].

2 Data acquisition

During data acquisition, the PISOLO setup was rotated to measure the angular distribution of the evaporation residues. Since the ^{19}F beam impinges on a fixed target, the reaction fragments are predominantly emitted in the forward direction along the beam axis. Consequently, the angular distribution of the evaporation residues is expected to exhibit a maximum at 0° with respect to the beam axis. During the beamtime, the number of residues is measured as a function of the angle, in an approximate time interval of 1h 10 min. At the end of each run, the beam was stopped to allow manual reconfiguration of the apparatus to the subsequent angular setting. The measurements of angular distribution were repeated for different beam energies to investigate the energy dependence of the evaporation residue production rate.

Fig. 3 shows the angular distribution measured in the range from $10°$ to $-6°$, obtained from a run acquired prior to the present data-taking, with a beam energy of 23 MeV. The expected maximum around 0° is not clearly observed, likely due to the high background in the central angular region. Nevertheless, an increase in the number of detected events toward smaller angles is evident, in agreement with the expected forward-peaked emission of the reaction products.

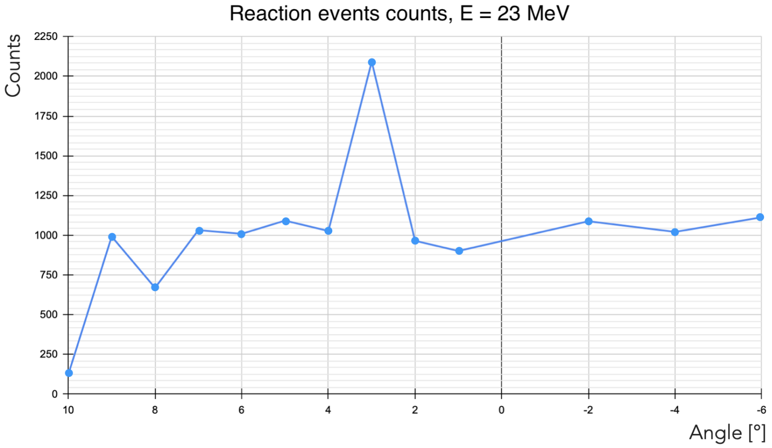
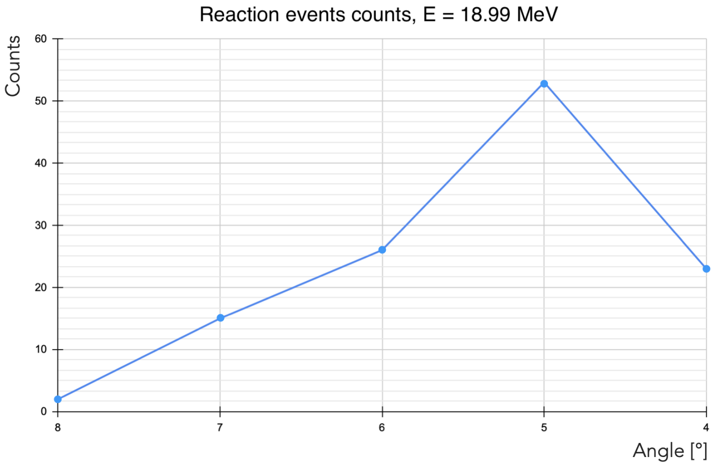


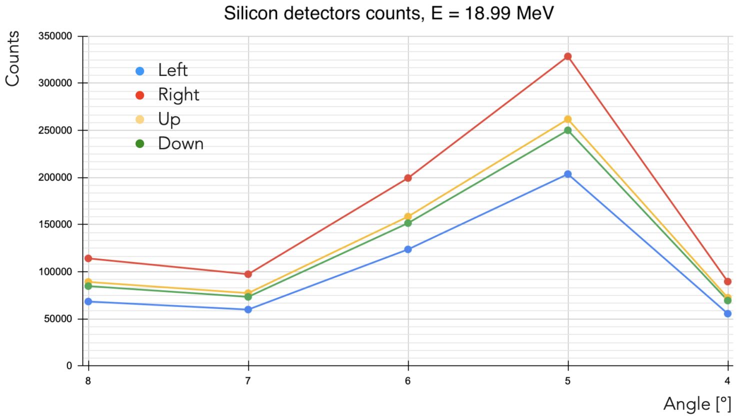
Figure 3: Counts of evaporation fragments of nuclear reaction $^{19}F + ^{12}C$, in the range $[10°\ ; -6°]$ with beam energy of 23 MeV (Lab frame).

Fig. 4a presents the angular distribution of evaporation residues measured during our data-taking shift over the angular range from 8° to 4°. The order of magnitude of measured events is lower than the previous one (Fig. 3) since this angular scan is performed with a lower beam energy of 18.99 MeV. As the angle decreases, the number of detected events increases down to 5°, in agreement with expectations. However, at 4° the number of recorded events is lower than the one obtained at the previous angular setting.

During data acquisition, beam behavior was monitored using four silicon detectors. The recorded count rates, presented in Fig. 4b, reflect the yield of evaporation residues produced in the nuclear reaction (Fig. 4a).



(a) Counts of evaporation fragments of nuclear reaction $^{19}F +^{12} C$.



(b) Counts of the four silicon detector (Left, Right, Up, Down) of PISOLO.

Figure 4: Angular distribution of nuclear reaction fragments, in the range [8° ; 4°] with beam energy of 18.99 MeV (Lab frame).

Since the beam parameters were within the expected operating ranges, the reduced number was initially attributed to possible degradation of the graphite target. The target was therefore replaced with a new one and the run was restarted. Nevertheless, the measured counts remained lower than expected, both at 4° and 3° angle configurations, as reported in Table 1. In response to these observations, the last run was stopped early and a series of tests were performed to verify the correct operation of the beam.

Run	Time	^{12}C target	Angle	Events
Run with old target	1h 02	4	4°	23
Run with new target, same angle	1h 10	3	4°	33
Run with new target, next angle	25 min	3	3°	10

Table 1: Comparison between evaporation fragments counts using old and new ^{12}C target.

3 Third mission

The presented experience was conducted within the framework of the INFN Third Mission program, which aims to reach the general public and to spread awareness of nuclear physics and related research. The program included a supervised visit to the Laboratori Nazionali di Legnaro (LNL) facility, under the guidance of Andrea Gozzelino. During this experience, we had the opportunity to collaborate with researchers during shift operations, gaining insight into standard operational procedures. We were involved in the data acquisition process and assisted in experimental decision-making, including adjustments to experimental parameters such as target replacement.

In addition, as part of the Third Mission initiative, the structure and objectives of experimental shift operations were presented to visiting high school students. So, we introduced students to fundamental concepts in nuclear and particle physics, such as reaction cross sections, and provided them with an overview of how a nuclear physics experiment is conducted. This included explanations of the accelerator configuration at LNL, the positioning of the PISOLO spectrometer and the operating principles of the detectors. The scientific goals of the experiment were also discussed. The students participated in selected shift activities, giving them first-hand experience in experimental research and the professional role of a physicist. We had the opportunity to facilitate these sessions and support the students throughout the process. In conclusion, this activity has been a good experience, not only from an academic point of view, but also to improve our personal transversal skills.

References

[1] C. L. Jiang, K. E. Rehm, B. B. Back, and R. V. F. Janssens, “Expectations for ^{12}C and ^{16}O induced fusion cross sections at energies of astrophysical interest”, Phys. Rev. C 75, 015803, 2007.

[2] K. Uzawa and K. Hagino, “Re-examination of fusion hindrance in astrophysical $^{12}C +^{12} C$ and $^{12}C +^{13} C$ reactions”, arXiv;2507.18065, 2025.

[3] A. M. Stefanini et al., “Investigation of the hindrance phenomenon in $^{19}F +^{12} C$”, Proposal for the XTU Tandem accelerator - October 2025, September 3, 2025.

[4] G. Montagnoli et al., “The time-of-flight spectrometer for heavy ions PISOLO”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 454, Issues 2–3, November 11, 2000.