IL NUOVO CIMENTO **48 C** (2025) 69
DOI 10.1393/ncc/i2025-25069-2

Colloquia: IWM-EC 2024

Performance of the AMD model for the low-energy reaction ^{18}O + ^{12}C at 16.7 MeV/nucleon

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received 26 November 2024

Summary. — This study investigates the performance of the antisymmetrized molecular dynamics (AMD) transport model in simulating the low-energy nuclear reactions ^{18}O + ^{12}C at 16.7 MeV/nucleon. The experimental data, gathered using the GARFIELD+RCo detector at Laboratori Nazionali di Legnaro, are compared with the AMD model coupled with the GEMINI++ decay code. The study found that the model accurately predicts the behaviour of fragments with $Z \geq 10$, while discrepancies were pointed out in the production of fragments with $4 < Z < 10$.

1. – Introduction

Nuclear reactions at low bombarding energies are crucial for understanding fusion mechanisms and compound nucleus decay. At energies just above 10 MeV/nucleon, processes beyond complete fusion, such as incomplete fusion and direct reactions, become significant. This is the case for the reaction $^{18}O+^{12}C$ at 16.7 MeV/nucleon, for which the systematics [1] predicts the fusion cross-section to be around 17% of the total. Therefore, in this case a large fraction of the reaction cross-section cannot be reproduced by a statistical code and another approach should be employed. In particular, we have used the antisymmetrized molecular dynamics (AMD) model [2], coupled with GEMINI++ [3, 4] as afterburner, which has been typically applied to higher energies for both intermediate mass [5-8] and light [9-13] systems. Instead, in this study, further discussed in [14], the model has been tested for the first time for a light system at this so lower energy.

2. – Experimental setup and theoretical simulation

The experiment was conducted using the ALPI Linac at Laboratori Nazionali di Legnaro, which delivered a 300 MeV ^{18}O beam on a ^{12}C target. The reaction products were detected with the GARFIELD+RCo setup [15], which provides high granularity and an approximately 80% geometrical efficiency. As anticipated, we used the AMD [2] transport model, which belongs to the quantum molecular dynamics (QMD) family. The reaction calculation has been stopped for each event at 500 fm/c. About 1.3×10^5 primary events were produced in the whole impact parameter range up to the grazing value (8 fm), with a triangular probability distribution. At the end of the dynamical phase, the excited fragments are allowed to decay towards the ground state; this evaporation phase is modelled via the afterburner (GEMINI++), producing 1000 events for each primary one. Before comparison with the experimental data, the simulated events were filtered through a software replica of the apparatus which reproduces the detection conditions.

3. – Experimental results and analysis

For this analysis, we selected the events where a significant part of the total ejectiles was experimentally identified by introducing the conditions $5 < Z_{tot} < 15$ and $0.3 < p_{tot}/p_{beam} < 1.1$, where Z_{tot} is the total detected charge and p_{tot} is the total detected momentum. Moreover, to avoid events of elastic scattering, we have considered only events with charge particle multiplicity greater than one.

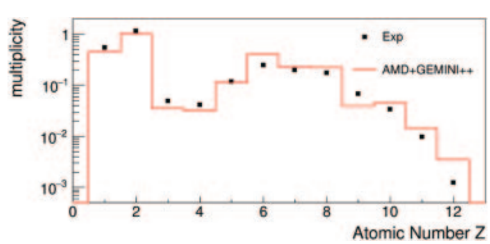

Fig. 1. – Charge multiplicity distributions of experimental data (black dots) and AMD+GEMINI++ results (red line).

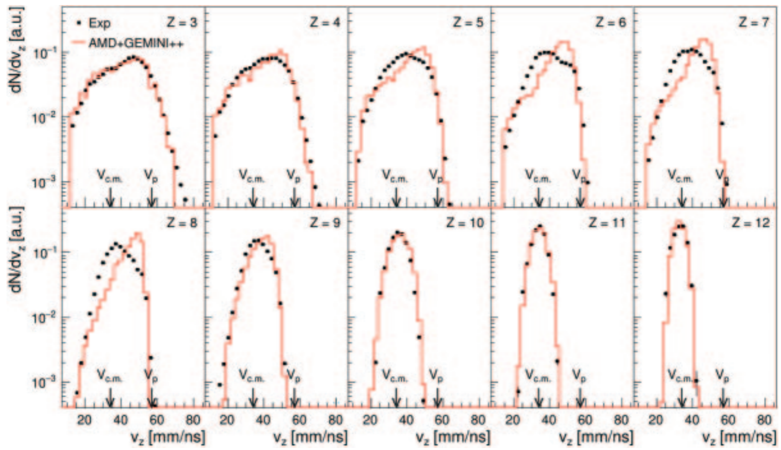

Fig. 2. – Laboratory velocity (beam axis component) distributions of fragments with $Z > 2$. Black dots represent the experimental distributions, while the red lines are the AMD+GEMINI++ results. The distributions are normalized to the unitary area.

To investigate how well AMD+GEMINI++ reproduces the experimental data, we compared the fragment charge distributions, which are presented in fig. 1. Each distribution is normalized to its number of events. The black dots represent the experimental data, while the red lines are the AMD+GEMINI++ results. Statistical errors are smaller than the marker size. The simulation code reproduces very well the experimental values, though some differences are present for $Z = 6,\ 9,\ 12$. In the following analysis, we have focused on fragments with $Z > 2$, which are mainly produced at forward angles. Therefore, we selected fragments detected in the RCo detector allowing for better angular, energy and mass resolution. In fig. 2, the comparison of the velocity distributions of these fragments is shown. For fragments with $Z = 3,\ 4$ and $Z \geq 10$, the AMD+GEMINI++ results are in good agreement with the experimental data. However, the model predictions are different from the experimental data for fragments $5 < Z < 9$, for which AMD favours less dissipative events than fusion-like ones.

The tendency of AMD model to underpredict fusion processes can be further investigated by observing the AMD+GEMINI++ velocity spectra as a function of the impact parameter b, as shown in fig. 3. In this case the simulation in 4π was used, requiring that the particles be emitted at angles compatible with the RCo. The heaviest fragments ($Z \geq 10$) are compatible with fusion-like processes for each impact parameter selection. Instead, fragments with $Z = 6,\ 7,\ 8$ produced in central collisions ($b =$ 0–2) are still emitted in phase-space regions typical of more peripheral reactions ($b =$ 6–8), which suggests scarce stopping in central collisions. This effect might be related to the NN cross-section, one of the parameters of AMD. Additionally, the inclusion of the clustering and interclustering interaction might be influencing this behaviour. In fact, the presence of clusters in an excited configuration may inhibit the interaction between the projectile and target nuclei, leading to an extra yield of fragments with velocities near the entrance channel. In this study, the AMD code was run with the standard parameters used in [9], but future work should include an optimization of the AMD parameters to improve the description of light systems.

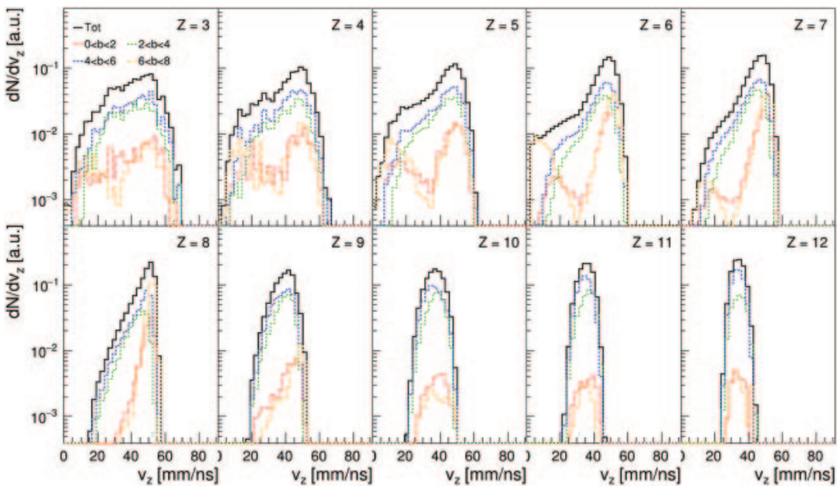

Fig. 3. – Model data: laboratory velocity (beam axis component) distributions for secondary fragments with $Z > 2$. The black lines represent the total spectra and the coloured lines represent the velocity spectra for different impact parameter b selections.

4. – Conclusions

We presented the first attempt at using the AMD model to simulate the low-energy reaction $^{18}O+^{12}C$ at 16.7 MeV/nucleon. Overall, the model successfully describes fragments with $Z = 3$, 4 and $Z \geq 10$, while it struggles with fragments with $4 < Z < 10$, for which it underestimates the very dissipative collisions that are expected for central impacts. This results in a lack of these ions at velocities around the compound nucleus velocity, with their production mainly occurring in phase-space regions close to the entrance channel. Future work will focus on refining the parameters related to the NN cross-section and the weight of the clustering and interclustering process to better reproduce our experimental data.

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