Three nucleon interaction in heavy ion collisions at intermediate energies

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Two and three nucleon interaction can be written in the Hamiltonian as [1]

$$H = \sum_i -\frac{\hbar^2}{2m_i}\nabla_i^2 + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk}, \qquad (2.1)$$

The three body interaction, *Vijk,* can be express as

$$Vijk = V^{\pi} + V^{R}$$

V^{π} is the sum of two and three pion exchange terms and V^{R} is an empirical medium range repulsive interaction. V^{π} is long and medium range attractive interaction and slightly decreases the binding energy for light nuclei. V^{R} is necessary to provide the enough strength of the massive neutron star against collapsing by the gravity.

The binding energy of the ground state and the energy scheme of the excited states provide the bench test of the attractive part of 3NF interaction. For V^{R}, Furumoto's elastic scattering theory may provide some evidence of the necessity of 3NF, using the diffraction pattern of near and far side scatterings [2].

As the first step, we incorporate 3NF into AMD code as a three nucleon (3N) collision term, which is incorporated into AMD-FM[3]. The new version is referred as AMD-FM (3N). The 3N collision

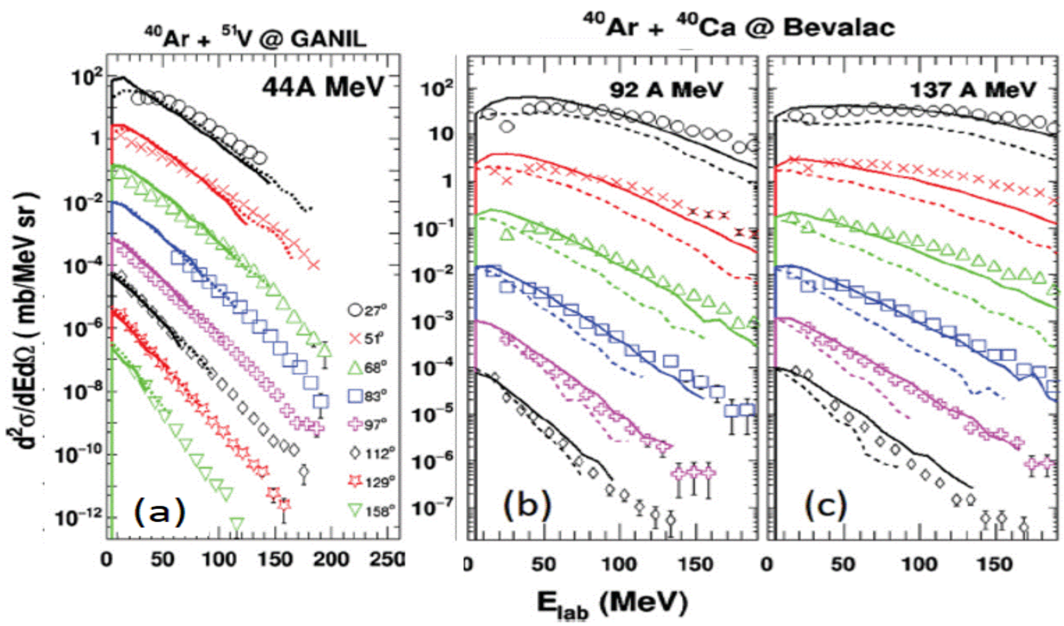

FIG. 1. Simulated results of proton energy spectra for the reactions $^{40}Ar+^{51}V$ reaction at 44*A*MeV 44 (a), at $^{40}Ar+^{40}Ca$ reaction at 92 A MeV (b), and 137A MeV (c). Data in (a) are taken from Ref. [5] and (b) and(c) are from Ref. [6]. Solid curves are for the results of AMD-FM(3N) and dashed curves are for those of AMD-FM. Data and results are plotted in an absolute scale. All results are multiplied by a factor of 10^{-n} from top to bottom for clarity.

is simply calculated by a succession of three binary collisions where one pair of nucleons interacts twice when three nucleons are within the collision distance each other. Pauli blocking is only examined at the final state. When the final state for the three nucleons are occupied, then the collision is canceled. A constant in-medium 3N collision cross section of 40mb is used.

AMD-FM(3N) is applied to the high energy proton energy spectra. The calculated results are compared with the available experimental data in Fig.1. Solid curves correspond to the results from AMD-FM(3N) and dashed ones from AMD-FM without 3N collisions. One can clearly see the role of the 3N collision term in the high energy slops and their angular distribution [4].

The calculations are further extended to a higher incident energy. In Fig.2, the calculations are compared with the high energy neutron data from a Bevalac experiment. As one can see, the experimental data are poorly reproduced by both calculations, except those at θ=60^o.

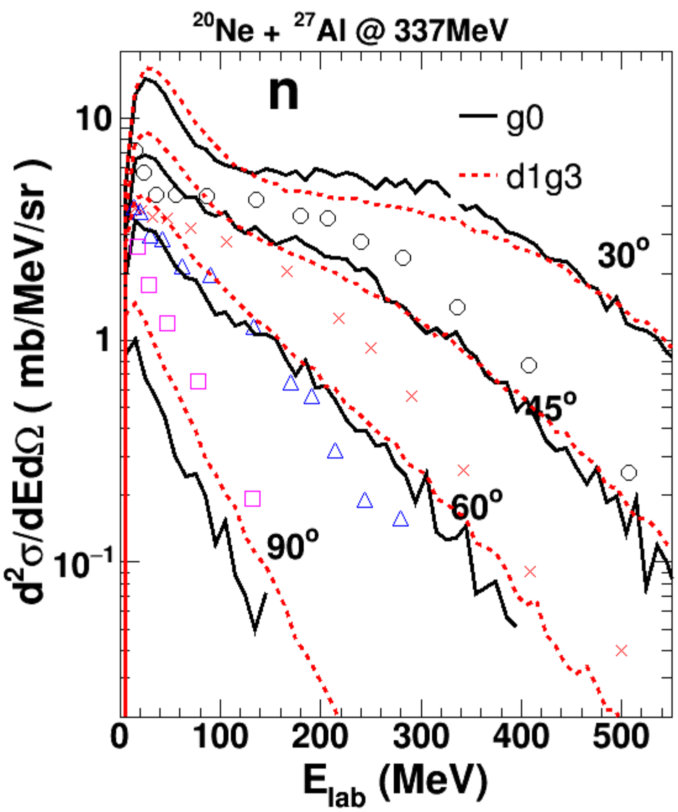

FIG. 2. Neutron energy spectra for $^{20}Ne+^{27}Al$ at 337 A MeV are compared in those between the AMD-FM(3N) and experiments [6]. Calculations are made with a standard Gogny interaction (K=228 MeV), g0, (black solid curve) and a modified version with K=380 MeV, d1g3,(red dashed one). Experimental data are shown by symbols, circles at 30^o, crosses at 45^o, triangles at 60^o and squares at 90^o.

Neutron energy spectra for $^{20}Ne+^{27}Al$ at 337 A MeV are compared in those between the AMD-FM(3N) and experiments [6]. Calculations are made with a standard Gogny interaction (K=228 MeV), g0, (black solid curve) and a modified version with K=380 MeV, d1g3,(red dashed one). Experimental data are shown by symbols, circles at 30^o, crosses at 45^o, triangles at 60^o and squares at 90^o.

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