Progress in the studies of low energy reactions by the TTIK method

A.K. Nurmukhanbetova,[1] N.A. Mynbayev,[1] V.Z. Goldberg,[2] G.V. Rogachev,[2] M.S. Golovkov,[3]
D. Nauryzbayev,[1] A. Rakhymzhanov,[1] A. Tikhonov,[1,4] and R.E. Tribble[2]
[1] *National Laboratory Astana, Nazarbayev University, Astana, Kazakhstan*
[2]*Cyclotron Institute, Texas A&M University, 77843 3366, Texas, USA*
[3]*Joint Institute for Nuclear Research, Dubna, 141980 Russia*
[4]*School of Science and Technology, Nazarbayev University, Astana, Kazakhstan*

An interest and achievements in detailed description of nuclear processes in stars stimulated new studies of nuclear reactions, especially resonance reactions, at low energies. The new data are needed on resonance interaction of rare as well as conventional beams. The needed measurements at low energies are difficult because of (1) low cross sections, and also because (2) of low energies of the detected particles. Inverse kinematics of the TTIK method [1,2] is an important factors to make the measurements easier.

DC-60 cyclotron was built in Astana (Kazakhstan) in 2006 [3]. The facility is capable of providing intense heavy ion beams from Lithium to Xenon in the energy range of 0.35–1.77 MeV/nucleon. Since 2010 groups from the Cyclotron Institute and the Nazarbayev University (Astana) initiated a joint program of an investigation of low energy resonance reactions of the special nuclear physics and astrophysics interest by the TTIK method. In this technique the incoming ions are slowed in the target gas (usually, methane or helium) and the light recoils (usually protons or α particles) are detected from a scattering event. These recoils emerge from the interaction with the beam ions and hit Si detector array located at forward angles while the beam ions are stopped in the gas, as p and α have smaller energy losses than the scattered ions. The TTIK approach provides for continuous excitation function as a result of slowing down the beam. Due to straggling effects, the energy and angular spread of the incoming beam increases as the ion traverses the scattering chamber.

The TTIK method cannot compete with the classic approach in the energy resolution of the excitation functions. The best cm resolution of the TTIK method is about 20 keV while it is an order of magnitude better for the conventional classic measurements. However, there are advantages of the TTIK method which are predominantly important in our case.

1. *The 180^0 degree (cm) measurements are simple.*

The TTIK measurements are easy at 180^0 degree (0^0 in lab. system) because the beam are stopped in the target before the detectors, and the detected energy of light recoils is relatively high due to high energy of the center of mass; for instance, for elastic scattering, the laboratory energy of scattered protons at zero degree, E~4Ecm (we neglected the mass of the proton to the mass of the heavy ion).

2. *Clean measurements with low abundance isotopes.*

There are well known difficulties of measurements when targets are low natural abundance isotopes (especially when elements are gases). It is difficult to separate the effect from the background related with admixtures of other isotopes, and these difficulties grow at low energy. On the contrary, there are no such difficulties in reverse kinematics because a cyclotron makes the perfect separation of the needed ions from a source material.

3. *High efficiency of the method.*

The whole excitation function is measured using a single energy of the cyclotron, the beam is slowed down and stopped using thick targets. Therefore, this method is the favorite approach to study resonance reactions with low intensity rare beams [4]. Due to high efficiency of the method and large cross sections for the resonance scattering, the main features of the excitation functions for exotic nuclei can be obtained with reasonable counting statistics and energy resolution. We additionally use the high efficiency as a possibility to improve time resolution of the beam for an application of the Time of Flight method (TF) with start signal provided by RF of the cyclotron. We are using TF to identify particle mass (as usual, by their velocities) and also to identify the different excitations in the same two particle final state processes (see details below). At low energy beams, the number of possible reaction channels is restricted, and due to low velocities TF can play an important role in the identification of the process without the deterioration of the energy resolution.

Fig.1 demonstrates 0^0 (180^0 cm) E-T spectrum obtained by bombarding the chamber filled by pure hydrogen with 1.8MeV/A ^{15}N beam. There are several loci corresponding to various channels of the reaction. Two loci corresponding to decay of the resonance states in ^{16}O to the ground and the first excited states in ^{12}C are evident at higher energies of the particles. The TTIK approach enabled us to observe α particle of the decay of the states at 12.4 and 12.9 MeV which had not been observed before because of the low energy of the particles. Intensive α particle decay to the first excited state in ^{12}C is well below the Coulomb barrier and evidences for the unnatural parity of the resonance levels in ^{16}O.

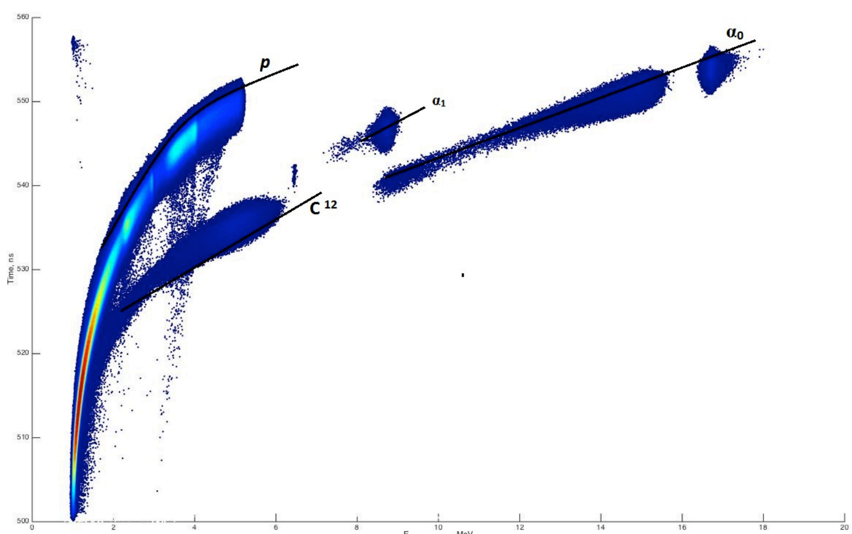

FIG. 1. 180^0 Time of Flight-Energy plot for the products of ^{15}N+p interaction.

At lower energies there is a loci corresponding to ^{12}C moving in forward direction after the ^{16}O decay into α +^{12}C. This curve is shifted relative to that of the α particle mainly because of the ^{12}C high energy loss. The observation both products of the decay of the same resonance eliminate many uncertainties of the experimental conditions. An at the lowest energies one can see protons of the elastic scattering.

[1] K.P Artemov *et al.*, Sov. J. Nucl. Phys. **52**, 406 (1990).
[2] G.V. Rogachev *et al.*, AIP Conf. Proc. **1213**, 137 (2010).
[3] B. Gikal *et al.*, Phys. Part. Nucl. Lett. **7**, 642 (2008).
[4] V.Z. Goldberg *et al.*, Phys. Lett. B **692**, 307 (2010).