2 - 10 Progress of the Nuclear Astrophysics Group in 2016

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The scientific program of the group covers big bang nucleosynthesis, hydrostatic burning in stars and explosive nucleosynthesis in supernova. By considering non-equilibrium statistics, we suggest a possible way to solve the Li problem in big bang nucleosynthesis. The ^{13}C(α,n)^{16}O is the major neutron source for the s-process happening in AGB stars. The ^{19}F(p, α)^{16}O is relevant to the production of fluorine. We are developing experimental platforms to study the important reaction for the first time directly at their stellar energies in Jinping Underground Laboratory. The ^{59}Fe stellar decay rate is important for the production of ^{60}Fe, an important isotope whose gamma ray has been observed by satellites. We determine its stellar decay rate for the first time using experimental B(GT) strength. The new rate reduces the discrepancy of the ^{60}Fe yields between the model predictions and the observations. The underground experiment is expected to begin in 2018. The ^{12}C+^{12}C reaction rate is highly uncertain By collaborating with IFNN at Romania, the fusion cross section of ^{12}C+^{13}C has been measured down to 0.9 nb. Our results rule out the existence of S-factor maximum predicted by the systematical study and confirm the predictions of other theoretical models, such as Equivalent Square Well mode and coupled channel calculation based on M3Y+Rep. As a result, the uncertainty of the ^{12}C+^{12}C is greatly reduced. The ambiguous ^{13}N(α, p) ^{16}O reaction rate is a limitation of the study of A+B grain produced by explosive nucleosynthesis in supernova. We are trying to determine the ^{13}N(α, p)^{16}O reaction rate by studying its inverse reaction ^{16}O(p, α)^{13}N.

The group is also developing active target to study the (α, p) process in X-ray burst and the fusion reactions in the crust of neutron star. While the incident particle continuously loses its energy within the gas of the active target, it has a possibility to react with the target nuclei, such as ^{4}He, ^{12}C or ^{16}O. Active target and its auxiliary detection systems record the detailed information of incident and outgoing particles with which the reaction energy and reaction channel are uniquely determined. We have developed a prototype with which the scattering and fusion reaction events have been observed. A full scale active target is being constructed. The first experiment is expected to take place in the late of 2017.

2 - 11 Stellar β-decay Rate of ^{134}Cs

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^{134}Cs a branching point in s-process path which is shown in Fig.1. The branching ratio is defined as $f_\beta=\lambda_\beta/(\lambda_\beta+\lambda_n)$. It could be deduced from the abundance of ^{134}Ba and ^{136}Ba since ^{136}Ba goes through both decay and neutron-capture of ^{134}Cs while ^{134}Ba only experiences decay channel[1].

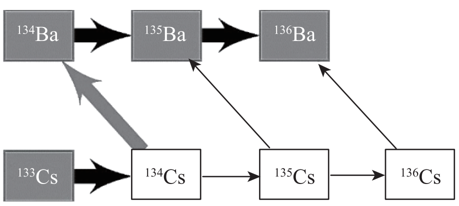

Fig. 1 s-process path in the vicinity of the branching point ^{134}Cs.

Due to both ^{134}Ba and ^{134}Ba are pure s-process nuclei, this branching point is a good approach to determine the s-process parameters. With temperature-dependent β-decay rate of ^{134}Cs, the temperature of s-process could be deduced.

At stellar temperature, the excited states could be thermally populated hence the decay rate is different to the terrestrial rate. ^{134}Cs has a 2.1 a half-life in laboratory. However, at 0.3 GK, a typical temperature of s-process, the decay rate would be ∼500 times faster according to Takahashi[2]. With this decay rate, a temperature T ∼0.18 GK of s-process is deduced. It is lower than that deduced from other branching points, *e.g.*, ^{151}Sm/^{154}Eu[3] and ^{176}Lu[4] both of which give a temperature at about 0.3 GK. Therefore, the better determination of the stellar β-decay rate of ^{134}Cs is essential for nucleosynthesis study.

The Takahashi's rates are based on outdated nuclear database and empirical transition strength. Here we employ shell model (SM) calculation to update ^{134}Cs stellar β-decay rates. Fig. 2 shows the ratio of the decay rates obtained by SM to Takahashi's rate. One can see that SM values are significantly smaller than Takahashi's rate.

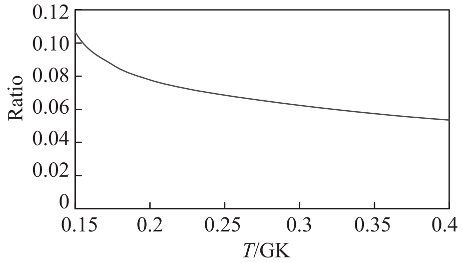

Fig. 2 The ratio of ^{134}C β-decay rate obtained by shell model to Takahashi's.

The impact on nucleosynthesis with new decay rates are investigated by NucNet code[5]with classical s-process calculation[6]. The abundance of Ba isotope with various ^{134}Cs decay rates are shown in Table 1. Note that the value is relative to solar abundance[7] and normalized to ^{136}Ba. With shell model rates, higher temperature (T=0.35 GK) scenario for s-process is preferred according to ^{134}Ba/^{136}Ba ratio. The more detailed study of ^{134}Cs β-decay rate and its impact on nucleosynthesis will be performed in the near future.

Table 1 Relative abundances with various ^{134}Cs β-decay rates.

		Ba-134	Ba-136
T=0.35 GK	Takahashi	1.16	1.00
	SM	0.99	1.00
T=0.17 GK	Takahashi	1.10	1.00
	SM	0.50	1.00

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2 - 12 Geant4 Simulation for the ^{14}O(α, p)^{17}F Measurement Using Time Projection Chamber (TPC)

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Type I X-ray bursts are the most frequent thermonuclear explosions in nature, resulting from thermonuclear runaway on the surface of an accreting neutron star[1]. The breakout reaction ^{14}O(α, p)^{17}F from the hot CNO cycle may have a prominent impact on the burst light curve and burst ashes[2]. However, insufficient experimental information is available to calculate a reliable, precise rate for this reaction[3]. We proposed to address the experimental investigation of the ^{14}O(α, p)^{17}F using Time Projection Chamber (TPC)[4].

The TPC operates with mixed gases of ^{4}He and CO_2. ^{4}He gas acts both as target and counter gas. The three-dimensional trajectories and the energy loss of the beam particle and the ejected charged particles from the reaction can be measured event by event, which makes it possible to identify the true reaction event. The energy-loss process of the beam particle is utilized to scan the center-of-mass energy to deduce the excitation function without changing the secondary beam energy. Emitted proton can be detected by the surrounding $\Delta E-E$ silicon telescope array.

A Geant4[5] simulation was performed to get the optimal condition for the ^{14}O(α, p)^{17}F measurement. A ^{14}O beam with an energy of 21 MeV was simulated to impinge on the mixture gas of 95% ^{4}He and 5% CO_2. The target gas at 200 torr pressure is confined in a chamber with an entrance window of 2.5-μm-thick Havar foil. The recoiling protons produced by ^{14}O(α, p)^{17}F were traced by the TPC and stopped in the Si telescope. A rectangle structure (8×5 mm) was chosen for the read-out pads, in order to reconstruct the projected trajectory. Once the trajectory is known, the angle of the out-going protons in the laboratory system are able to calculate and be compare with their corresponding "real" values given by Geant4. Then we are able to analyze the angular resolution of the TPC for a given gas, gas pressure, and pad information. Similarly, the position resolution can also be obtained by comparing the reconstructed reaction vertex Z-value with its "real" Geant4 value. Fig. 1 shows the Geant4 simulated results. Compared to the traditional thick-target method, the ^{14}O(α, p)^{17}F measurement with TPC can determine the reaction point with smaller uncertainty and distinguish the inelastic scattering protons clearly. A more realistic and considerate simulation is still in progress.