Energy dependence of $\pi^-$ differential cross section in $^{28}\text{Si} + \text{In}$ with beam energies of 400, 600, and 800 MeV/nucleon


Information on the nuclear equation of state (EoS) within a broad density range is important for understanding the physics of neutron stars. However, the isospin-dependent term in EoS, i.e., the density dependence of the symmetry energy $E_{\text{sym}}(\rho)$ has a large model dependence in the supra-normal density region ($\rho > \rho_0$, the saturation density $\rho_0 \equiv 0.16fm^{-3}$). As a result, the relationship between the radius and the mass of a neutron star cannot be reliably calculated. According to a transport model calculation (IBUU04), detailed studies of the pion yield ratio, $Y(\pi^-)/Y(\pi^+)$, in central nucleus-nucleus collisions at intermediate energies can be conducted to obtain significant constraints on $E_{\text{sym}}(\rho)$ in the supra-normal density region.

The IBUU04 predicts that the beam energy dependence of the pion yield ratio is strongly related to the behavior of $E_{\text{sym}}(\rho)$ in the supra-normal density region. We performed a series of experiments using 400, 600, and 800 MeV/nucleon $^{28}\text{Si}$ beams accelerated at the Heavy Ion Medical Accelerator in Chiba (HIMAC) and an In target with a compact centrality filter and a pion range counter (RC).

The $\pi^+$ events can be clearly identified by the $\pi^+ \rightarrow \mu^+ + \nu_\mu$ decay after they are stopped at the RC. The $\pi^-$ events were selected using $\Delta E_i - \Delta E_j$ (energy deposition at each layers of RC) correlations obtained experimentally for $\pi^+$ events, because in-flight energy depositions are same between the $\pi^+$ and $\pi^-$ events. However, a pionic atom, which is created by the stopped $\pi^-$ and surrounding nuclei, decays various particles and some of them hit the next counter. Next we estimated a $\pi^-$ leak rate to the next counter.

The leak rate $\alpha$ at which the decayed particles hit the next elements was estimated with CsI($^{129}\text{Xe}, \pi^{\pm}$)X experimental data at 90° for which, the statistics is sufficient and the S/N ratio is large. We obtained a typical value of $\alpha$, $10.83^{+0.81}_{-0.99}$ (SYS) % For obtaining the production cross section of the $\pi^-$, the reduction rate by the decay in flight, nuclear reaction, and multiple Coulomb scattering until the $\pi^-$ reaches the RC from the production point was estimated using Geant4.

The Lorentz-invariant cross sections of the $\pi^-$ as a function of the kinematic energy in the mid-rapidity frame ($E_{\text{mid}}$) for In($^{28}\text{Si}, \pi^-$)X reaction with 400(top part), 600(middle part) and 800(bottom part) MeV/nucleon beam with statistical errors.

Fig. 1. Lorentz-invariant cross sections of the $\pi^-$ as a function of the kinematic energy in the mid-rapidity frame ($E_{\text{mid}}$) for In($^{28}\text{Si}, \pi^-$)X reaction with 400(top part), 600(middle part) and 800(bottom part) MeV/nucleon beam with statistical errors.

References