The Measurement of Energy Spectra for ^{9}Be(p,p′x) Reaction at 392 MeV

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Multistep direct processes in proton production reaction was investigated with proton beam of 392 MeV bombarding ^{9}Be target nuclei. Energy spectra were measured at ten laboratory angles from 20 to 105 degrees and compared with two theoretical models, the quantum molecular dynamics (QMD) and the intranuclear cascade (INC) model. Additionally, we modified the former model with improving the ground state in the code.

KEYWORDS: intermediate energy, proton, beryllium 9, double differential cross section, QMD, INC

I. Introduction

Recently, nuclear data which have been measured by using intermediate energy accelerators have been needed in many fields; science, engineering, medicine and so on . For example, they are cancer therapy with proton beam, the study of transmutation of nuclear waste and estimating the expose dose of spacemen etc.

A number of data were measured and studied for (p,p′x) and (p,nx) reactions at incident energies from several tens of MeV to 200 MeV. At around GeV region, systematic studies of (p,nx) reactions were made at some laboratories. However, only few studies have so far been made at the region from 200 MeV to 400MeV on (p,p′x) reaction.

We investigate double differential cross section energy spectra of (p,p′x) reactions at 392 MeV with target nuclei of ^{9}Be. We compare the data with two classical theories: QMD model + statistics decay model (SDM)[1)] and INC model.[2–4)] And we try to modify the former model with improving the ground state in the code.

II. Experiment

Measurements of proton production reactions were carried out at RCNP. Proton beams were accelerated by the ring-cyclotron. Proton beam of 392 MeV bombarded ^{9}Be target located at the center of a one-meter-diameter chamber. Energy spectra of emitted protons were measured by using stacked scintillators detectors[5,6)] placed out the chamber. A sketch of detectors is given in **Fig. 1**. The arrangement of them is shown in **Fig. 2**. Each detector size is shown in **Table. 1**.

The detectors are most suitable for investigating gross structures of energy spectra. Measurements were made at ten laboratory angles from 20 deg. to 105 deg. Energy calibrations were made with pp scatterings with a target of polyester foil. The particle identification was successfully done by a ΔE-E prescription in off-line analyses.

Table 1 The Size of Detectors of stacked scintillators detectors

Detector	Size	Number
Plastic	$44 \times 44 \times 5$ mm^3	2
Plastic	$20 \times 30 \times 0.5$ mm^3	2
Plastic	$20 \times 30 \times 2$ mm^3	2
GSO(Ce)	$43 \times 43 \times 43$ mm^3	5
GSO(Ce)	ϕ 62 $\times$ 120 mm	1

III. Results and discussion

The measured energy spectra were compared with the QMD and the INC models. In this work, we employed the JQMD code for the QMD model calculation. The INC code used presently was developed in our laboratory.

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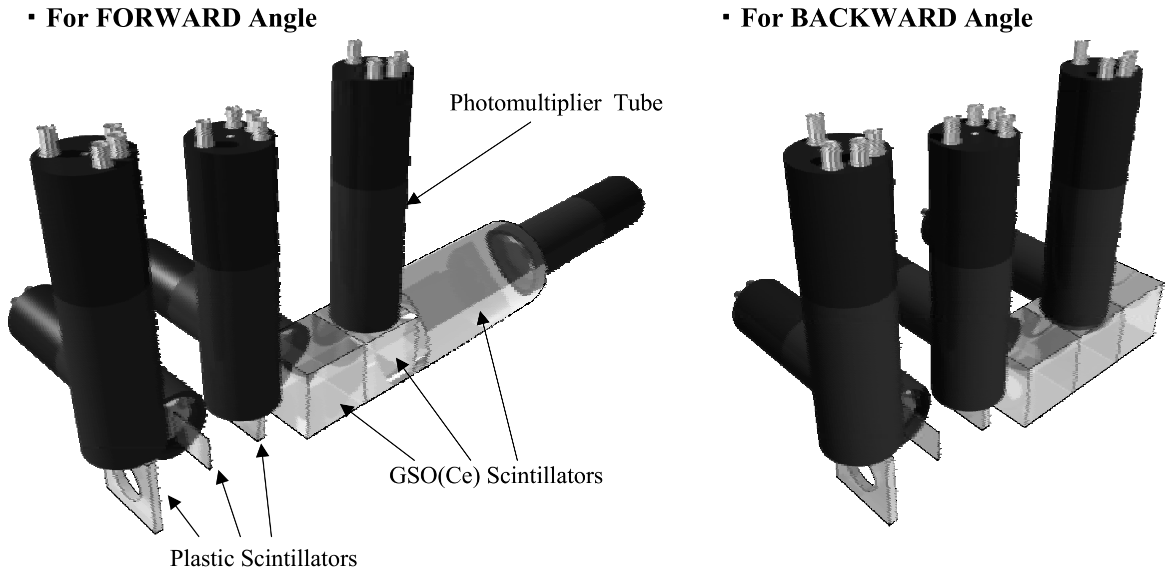

Fig. 1 A sketch of detectors

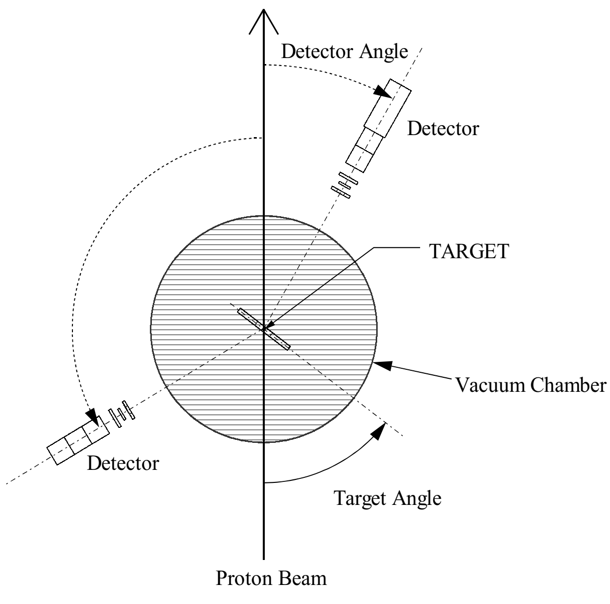

Fig. 2 Placement of the target, the chamber and detectors

At first, we compared the measured spectra with the QMD model but the shapes of them by the QMD do not have good reproducibility at each angles. At forward angles, the width of a quasi-free peak is narrower than that of experiment. At 50 and 45 degrees there are quasi-free peaks around 200 MeV and 150 MeV respectively but the measured spectra are smooth.

Then, we studied distributions of the momentum and the nucleon density of the target nuclear ground state generated by the QMD model. **Fig. 3** shows distributions for ^{9}Be ground state. With the standard JQMD which is shown by the dotted line, both of momentum and density distribute within narrower regions than that of local Fermi gas model. [7)]

To enlarge the distributions of QMD, we changed parameters of the density dependent potential for nucleon interactions. The code uses the local Skyrme type potential:

$$U_{Sky}(r) \quad = \quad A\frac{\rho(r)}{\rho_0} + \frac{B}{1+\tau}\left(\frac{\rho(r)}{\rho_0}\right)^{\tau}$$

We adjusted the parameters A and B. The resultant distributions are shown by solid lines in **Fig. 3**.

Energy spectra of ^{9}Be(p,p$'x$) with the standard and modified QMD and the INC are shown in **Fig. 4**. With the modified QMD, the shapes of spectra are better than standard one in all angles. But the absolute values of them are bigger than measured one. Especially the spectra of 50 and 60 degrees show good experiment reproducibility. With the INC, at forward angles in lower energy range the cross sections are close to experiment value. At backward angles they resemble to modified the QMD. In particular the spectrum of 25 degrees shows good experiment reproducibility.

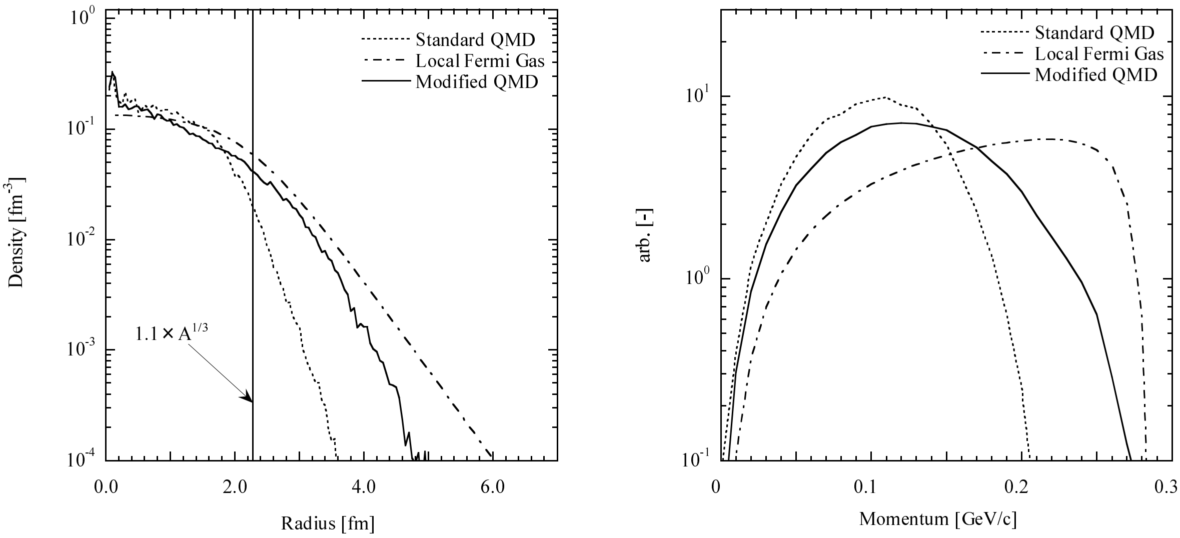

Fig. 3 Distributions of nucleon density(top) and momentum(bottom) for the ^{9}Be ground state

IV. Conclusion

We investigated energy spectra of (p,$p'x$) reactions at 392 MeV with ^{9}Be target. Experiment was carried out at the RCNP ring-cyclotron facility. The measured spectra were compared with the QMD and the INC models. In addition we modified the ground state in the QMD. It is found that the theoretical spectra are sensitive to ground state parameters of the target nucleus. And with the INC code that we developed the experiment reproducibility is better than the standard QMD.

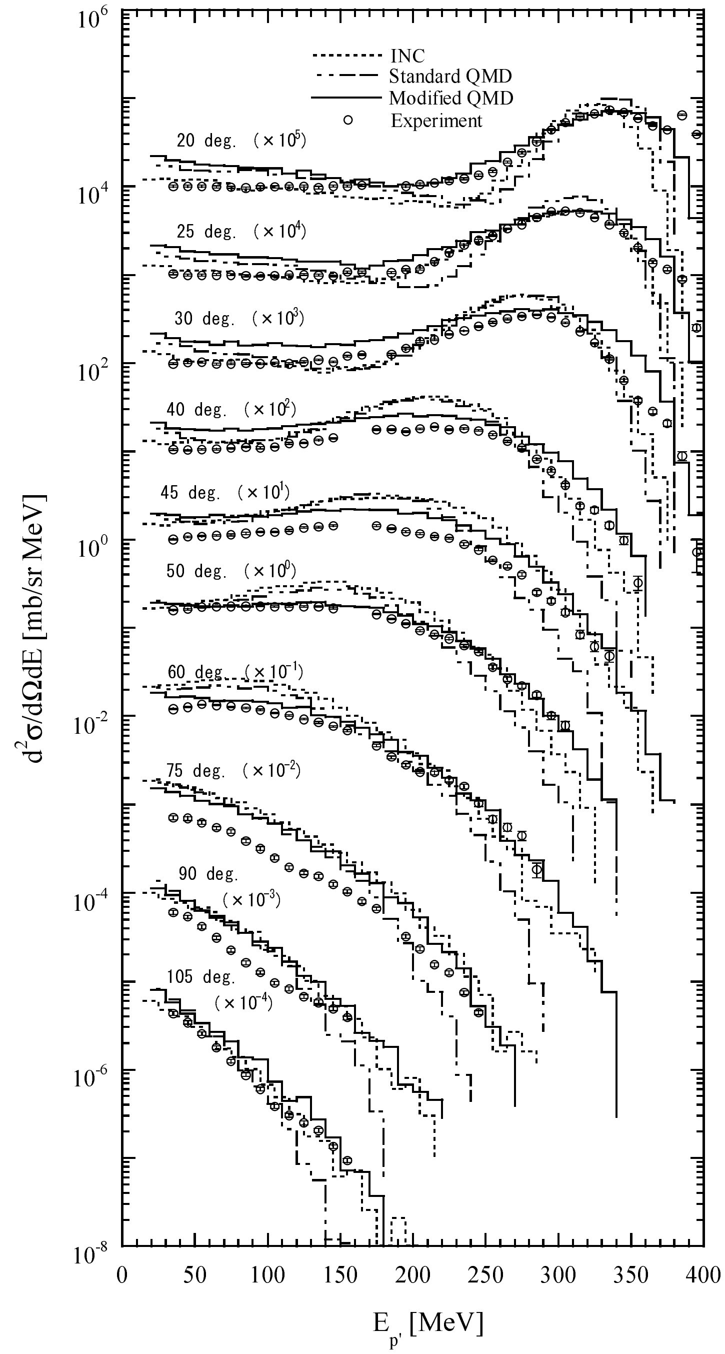

Fig. 4 Double Differential Cross Section of ^{9}Be(p,p′x)

References

1) K. Niita, S. Chiba, T. Maruyama, H. Takada, T. Fukahori, Y. Nakahara, and A.Iwamoto *Phys. Rev. C* **52**, 2620 (1995).
2) H. W. Bertini *et al.*, *Phys. Rev.* **131**, 1801 (1963).
3) Y. Yariv and Z. Fraenkel, *Phys. Rev. C* **20**, 2227 (1979).
4) J. Cugnon, *ibid.* **22**, 1885 (1980).
5) K. Anami, *et al.*, *J. Nucl. Instrum. Methods Phys. Res. A* **404**, 327 (1998).
6) H.Yosida, *et al.*, *J. Nucl. Instrum. Methods Phys. Res. A* **411**, 46 (1998).
7) J. W. Negele, *et al.*, *Phys. Rev. C* **1**, 1260 (1970).