Search for direct γ rays from the giant resonances in ^{12}C excited by the (p, p') reaction

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Introduction

An experiment (E398) to measure the γ rays emitted from giant resonances in ^{12}C was carried out at the Research Center for Nuclear Physics (RCNP), Osaka University [1]. Since, the giant resonances appear above the separation energy, they mainly decay hadronically via particle emission to the daughter nuclei but there is also a small probability ($\approx 10^{-3}$) [2] for electromagnetic (direct) decays. Due to this small decay probability, measurement of direct decay poses an extreme difficulty for experimentalists, yet its measurement is very important. As photon decay is extremely sensitive to multipolarities, it can shed some light on the micrscopic structures of giant resonances. This exercise can also be helpful in understanding the electromagnetic strengths of the resonances. Although these ideas have been discussed in past qualitatively, the quantitative studies, especially that for light nuclei are quite rare.

Concerning ^{12}C, there are some previous studies measuring the decay width Γ_{γ_0} or Γ_{γ_1} of the excited states of ^{12}C, namely, E_x=16.11 MeV (2^+, T=1), 17.26 MeV (1^-, T=0) and 19.2 MeV (1^-, T=1) [3, 4]. The width (Γ_{γ_0} or Γ_{γ_1}) below $E_x < 20$ MeV are all a few tens of eV. Gove et al. [5] studied the γ-ray emission from the giant resonance at E_x=22.5 MeV but only set the lower limit as Γ_{γ_0} >2.5 keV. No systematic data for direct decays exists for giant resonances above E_x >20 MeV.

In this work, we search for direct decays from the excited states of ^{12}C, including giant resonances in the energy region E_x = 16-32 MeV, excited by (p, p') reaction.

Experiment and Analysis

The γ rays were measured in coincidence with the scattered protons using a γ-ray detector made from an array of 2×5 NaI(Tl) counters. The descriptions of the experimental setup and backgroud subtraction are mentioned in detail in Ref. [1].

In Fig. 1, the two-dimensional histogram shows the γ-ray coincidence events for one of the ten NaI(Tl) counters. The line $E_x - E > 0$ marks the energy conservation limit as there should be no γ rays with energy higher than the excitation energy of ^{12}C. The region with E_x >16 MeV marks the giant resonance region. All the events in the region E_x >16 MeV and $E_x - E > 0$ are the γ rays from the giant resonances of ^{12}C. As no γ rays with E >11 MeV are possible from the hadronic decays [1] of giant resonances, the events in the region E >11 MeV and $E_x - E > 0$ are the direct electro-

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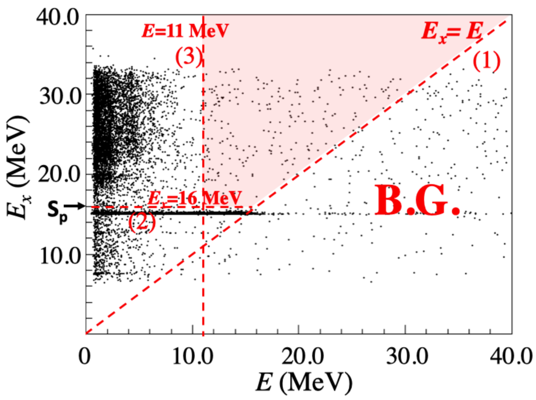

FIG. 1: Two-dimensional histogram with E_x (excitation energy of ^{12}C) at y axis and E (deposited γ-ray energy) at x axis.

magnetic decays probably to the ground state of ^{12}C.

Before the evaluation of the direct decay emission probability from the giant resonance region, validity of our measurements was checked and verified using discrete resonances of ^{12}C (12.71 MeV, 15.1 MeV, and 16.1 MeV) which decay electromagnetically and whose emission probabilities are well known [6].

The state 12.71 MeV decays to the ground state of ^{12}C by emitting γ-ray of energy 12.71 MeV with emission probability (Γ_{γ_0}/Γ = $(1.93\pm0.12)\times10^{-2}$) [6]. This state also decays the first excited state of ^{12}C (4.44 MeV) by emitting γ-ray of energy 8.27 MeV with emission probability ($\Gamma_{\gamma_1}/\Gamma = (2.93\pm0.99)\times10^{-3}$) which further decays to ground state by emitting γ-ray of energy 4.44 MeV with same emission probability. [6].

The measured γ-ray spectrum $[N_\gamma(E)]$ for $E_x = 12.55 - 13.0$ MeV can be expressed as:

$$N_\gamma(E) = N_{Ex}[r_0\ P(12.71\ MeV; E) + r_1\ P(8.27\ \text{MeV}, 4.44\ \text{MeV}; \text{E})] + \alpha \text{N}_{\text{bg}}(\text{E}), \quad (1)$$

where N_{Ex} is the number of excitation events in above mentioned E_x range, $P(E_\gamma; E)$ [1] are response functions of required γ-rays, $N_{bg}(E)$ is the background spectrum, and α is background normalization factor. The terms r_0 and r_1 are the γ-ray emission probabilities of 12.71 MeV state decaying to ground state and first excited state, respectively. These terms were set as free parameters and were obtained from fit. The fitted spectrum is shown if Fig. 2. This experiment accurately evaluated γ-ray emission probabilities of 12.71 MeV state which were of the order $10^{-2} - 10^{-3}$ within the sytematic uncertainty of 10%. We extend the same approach to evaluate emission probabilities of other discrete as well as giant resonances of ^{12}C. The improvements in analysis and better estimation of systematics are still ongoing.

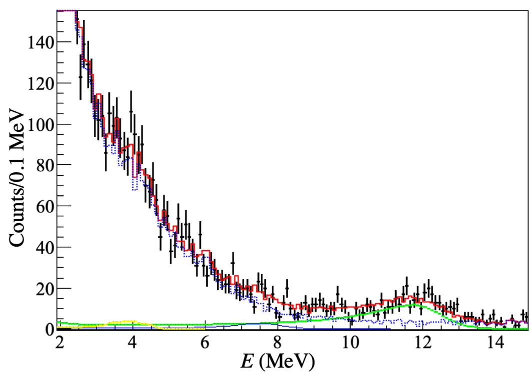

FIG. 2: The γ-spectrum (black data points), background spectrum (blue dashed-dotted line), total fit (red line) and γ-rays (colored lines) from the 12.71 MeV state of ^{12}C.

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