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A new study for $^{16}O(\gamma,\alpha)^{12}C$ at the energies of nuclear astrophysics interest: The inverse of key nucleosynthesis reaction $^{12}C(\alpha,\gamma)^{16}O$

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Abstract

The key reaction $^{12}C(\alpha,\gamma)^{16}O$ in nuclear astrophysics is difficult to be performed experimentally at low energy because of the Coulomb barrier. But it is different if we use its inverse reaction $^{16}O(\gamma,\alpha)^{12}C$ because the cross-section of $^{16}O(\gamma,\alpha)^{12}C$ is almost 100 times larger than the cross-section of $^{12}C(\alpha,\gamma)^{16}O$ at the same center of mass energy ($E_{c.m.}$) based on our study. In the present work, we study the angular distributions and total cross-sections of $^{16}O(\gamma,\alpha)^{12}C$ which are induced by polarized photon using the resonance theory of low energy reaction. The differential cross-sections as well as E1 and E2 transition cross-sections at low nuclear astrophysics energies are also calculated. The feature of the future Shanghai Laser Electron Gamma Source (SLEGS) facility, a low energy γ-ray beam line with a high photon flux, is presented. The experiments of $^{16}O(\gamma,\alpha)^{12}C$ are simulated with a time projection chamber (TPC) and a realistic SLEGS layout. The lowest ($E_{c.m.}$), which can be obtained from the simulation, is 0.8 MeV with the 20–30% uncertainty for the one-month beam time of SLEGS. The extracted S factors of $^{12}C(\alpha,\gamma)^{16}O$ and their statistical uncertainties from the simulation are compared with the existing data and some theoretical calculations. It is shown that the promising $^{16}O(\gamma,\alpha)^{12}C$ experiment at SLEGS can largely reduce the statistical uncertainties of the $^{12}C(\alpha,\gamma)^{16}O$ experiment at low energies.

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Keywords: Nuclear astrophysics; Photonuclear reaction; $^{16}O(\gamma,\alpha)^{12}C$; γ-Ray beam facility; Experimental simulation

1. Introduction

The nuclear synthesis theory in astrophysics points out that many elements are produced in the stellar burning [1]. At the end of helium burning, the main production is ^{12}C, but the ^{12}C will capture α particle through the reaction channel $^{12}C(\alpha,\gamma)^{16}O$ and then form ^{16}O and emit photon. The abundance ratio of ^{12}C and ^{16}O is the beginning condition of the continuing stellar evolution, and determines the destiny of a star. Therefore, the reaction rate of $^{12}C(\alpha,\gamma)^{16}O$ is a very important parameter in astrophysics [2,3].

The temperature when the reaction $^{12}C(\alpha,\gamma)^{16}O$ occurs in stellar is about 0.2×10^9 K, correspondingly, the $E_{c.m.}$ of the reaction is about 0.3 MeV according to the Gamow theory. The cross-section is about 10^{-17} barn at $E_{c.m.} = 0.3$ MeV, so it is too small to be measured. In the last three decades, about thirty experiments for $^{12}C(\alpha,\gamma)^{16}O$ have been performed to determine the cross-section. However, there is no experimental data available below $E_{c.m.} = 0.9$ MeV around. On the other hand, there are many theoretical works such as R-matrix formula have been employed to fit the experimental data and to extrapolate them down to $E_{c.m.} = 0.3$ MeV and lower. Unfortunately, the cross-sections at $E_{c.m.} = 0.3$ MeV deduced from various works are very different from each other. The extracted $S(300)$ factors cover a range from 1 to 300 keVb. The calculated reaction rate of $^{12}C(\alpha,\gamma)^{16}O$ at astrophysics

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temperature is also diverse. In our previous paper, we give a general result about $^{12}C(\alpha,\gamma)^{16}O$ reaction rate [4].

The photonuclear reaction of $^{16}O(\gamma,\alpha)^{12}C$ is the inverse reaction of $^{12}C(\alpha,\gamma)^{16}O$. To the best of our knowledge, no experimental data and theoretical calculations of $^{16}O(\gamma,\alpha)^{12}C$ are available at $E_{c.m.} < 2.2$ MeV. In this paper, the differential cross-sections, as well as E1, E2, and total cross-section of $^{16}O(\gamma,\alpha)^{12}C$ at the energies of nuclear astrophysics interest are calculated and discussed in Section 2. Based on the features of the future Shanghai Laser Electron Gamma Source (SLEGS), the experimental proposal of $^{16}O(\gamma,\alpha)^{12}C$ is presented, and the results of experimental simulation are given and compared with other works in Section 3. In Section 4, we summarize the obtained results and draw several conclusions.

2. Theoretical study of $^{16}O(\gamma,\alpha)^{12}C$ induced by polarized photon beam

2.1. Theory of the cross-section calculation

The angular distribution of the photonuclear reaction with the incident linear polarized photon beam is given by [5]:

$$\frac{d\sigma}{d\Omega}(E,\theta,\phi) = \sum_{pq} A_{pq}(E,\theta)t_{pq}(\phi) \tag{1}$$

where

$$A_{pq}(E,\theta) = \frac{\lambda_\gamma^2}{24\pi^2}\sum_{kk'p'q'} B_{pq}^{p'q'} R_k R'_{k'} P_{p'}^{|q'|}(\cos\theta). \tag{2}$$

In Eq. (1), E and θ are the reaction energy in the center of mass system and the scatting angle of an emitting particle, respectively. ϕ is the azimuthal angle between γ-ray polarization orientation ε (see Fig. 4) and the reaction plane. The tensor moments $t_{pq}(\phi)$, the coefficient $B_{pq}^{p'q'}$, and the reduced transition matrix elements R_k and $R'_{k'}$ are defined in Ref. [5]. $P(\cos\theta)$ is the associated Legendre function.

After the relationship between the reaction collision matrix U and the reduced transition matrix elements is employed, the differential cross-section is deduced as:

$$\frac{d\sigma}{d\Omega}(E,\theta,\phi) = \frac{\left|\sum_l \frac{2l+1}{\sqrt{l(l+1)}} U_l(E)P_l^L(\cos\theta)\right|^2}{8k_\gamma^2} \times (1+\Sigma\cos 2\phi). \tag{3}$$

Here, k_γ is the photon wave number. The factor $(1+\Sigma\cos 2\phi)$ presents the asymmetry property of the angular distribution, where

$$\Sigma = \frac{\sigma^{\parallel}-\sigma^{\perp}}{\sigma^{\parallel}+\sigma^{\perp}} \tag{4}$$

can be obtained from an experiment.

The total cross-section of σ_{El} is the integral of the differential cross-section with respect to θ and ϕ. Assuming $\Sigma = 1$, σ_{El} can be simply given by:

$$\sigma_{El}(E) = \frac{\pi(2l+1)|U_l(E)|^2}{k_\gamma^2}. \tag{5}$$

Here, the collision matrix U_l can be written as

$$U_l(E) = u_l(E)i^l \exp\left(i\left(\delta_{\text{coulomb}}(E) + \sum_r \delta_{lr}(E)\right)\right) \tag{6}$$

where u_l is a real number determined by the interaction system. δ_{coulomb} is the coulomb phase shift and δ_{lr} is the resonance phase shift. Using the Breit–Winger formula approximation, the collision matrix U_l can be described as:

$$|U_l(E)|^2 = \sum_r \frac{\Gamma_{l,r}^{\text{Total}}\Gamma_{l,r}^{\gamma}}{(E-E_{l,r})^2 + (\Gamma_{l,r}^{\text{Total}})^2/4}. \tag{7}$$

In Eqs. (6) and (7), r is the index of a resonance at the lth partial wave contribution, and $E_{l,r}$ is the peak energy of a resonance. In our calculation of the cross-section of $^{16}O(\gamma,\alpha)^{12}C$, the time reversal principle is employed, i.e., the resonance width of (γ,α) reaction is equal to the resonance width of (α,γ) reaction. The data of the resonance width of $^{12}C(\alpha,\gamma)^{16}O$ are chosen from Refs. [6] and [7].

2.2. Result and discussion

For $^{16}O(\gamma,\alpha)^{12}C$, the p and d wave contributions dominate in the total cross-section at $E_{c.m.} < 2.5$ MeV, so only the E1 and E2 transitions are considered for the transition matrix elements. In this energies region, the E1 transition is mainly contributed from the 1^- states of ^{16}O at 9.582 and 7.117 MeV transferring to the ground state, and the E2 transition is mainly contributed from the 2^+ state at 6.917 MeV transferring to the ground state. Here, the 1^- state of ^{16}O at 7.117 MeV and the 2^+ state at 6.917 MeV are below the threshold of $^{16}O(\gamma,\alpha)^{12}C$. In addition, because of very small contributions of the cascade transitions, they are neglected in our calculation.

Based on the reaction theory mentioned before, the polarized differential cross-sections of $^{16}O(\gamma,\alpha)^{12}C$ are calculated at different $E_{c.m.}$ of nuclear astrophysics interest. The results are shown in Fig. 1, where the scattering angle θ and the azimuthal angle ϕ for the photon polarization orientation are illustrated in Fig. 4. From Fig. 1 we can see the differential cross-sections for a certain scattering angle reach the maximum value as $\phi = 0$, i.e., the photon polarization orientation vector locates in the reaction plane, which is composed of the orientation of the induced photon beam and the outgoing α particle. On the other hand, the differential cross-sections for a certain scattering angle are equal to zero as $\phi = \pi/2$, i.e., the photon polarization orientation vector is vertical to the reaction

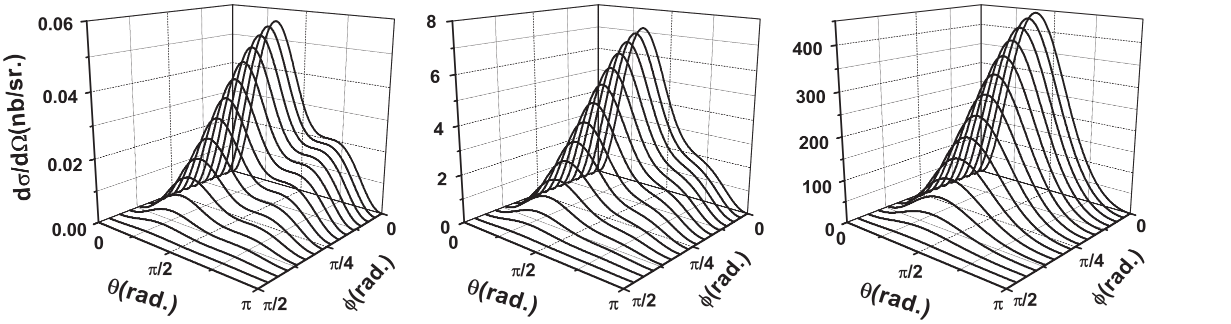

Fig. 1. The differential cross-sections of $^{16}O(\gamma,\alpha)^{12}C$ at $E_{c.m.} = 0.8$ MeV (left panel), $E_{c.m.} = 1.4$ MeV (middle panel) and $E_{c.m.} = 2.2$ MeV (right panel).

plane. Therefore, the experimental yield largely distributes around the plane, which is determined by the orientation of the photon incidence and polarization. This conclusion will be helpful to arrange a measurement on the differential cross-sections of $^{16}O(\gamma,\alpha)^{12}C$. In addition, the angular distribution of the photonuclear reaction induced by unpolarized photon is symmetric with respect to the azimuthal angel ϕ. From Eq. (3), we also can draw a conclusion that polarized differential cross-section at $\phi = \pi/4$ is the same as the differential cross-section of the photonuclear reaction induced by unpolarized photon.

As for a certain azimuthal angel ϕ, there are two peaks in the differential cross-sections against the scattering angle θ at $E_{c.m.} = 0.8$ MeV. Whereas, the shape of the differential cross-section only includes one peak for the same ϕ at $E_{c.m.} = 2.2$ MeV. The reason is that in the range of the scattering angle θ from zero to π, the shape of the angular distribution of the pure E1 transition has one peak while the shape of the pure E2 transition angular distribution has two symmetric peaks. Also, the contributions from E1 and E2 to the differential cross-sections are comparable at $E_{c.m.} < 1.0$ MeV but the E1 contribution becomes much larger than the E2 contribution at $E_{c.m.} > 1.0$ MeV. The results shown in Fig. 2 confirm this argument. Here the cross-section of the E1 transition (E1 cross-section), the E2 transition (E2 cross-section) and total cross-section are calculated based on Eq. (5).

Due to the resonance of the 1^- state at 9.582 MeV of ^{16}O, we can see that the contribution of the E1 transition to total cross-section is more than 95% at $E_{c.m.} > 2$ MeV. However, below the threshold of $^{16}O(\gamma,\alpha)^{12}C$, there are the 1^- state at 7.117 MeV and the 2^+ state at 6.917 MeV of ^{16}O. Both of them can affect the cross-section at $E_{c.m.} < 1.0$ MeV where the E1 and E2 cross-sections are in the same order. Another noticeable result in Fig. 2 is that the total cross-section of $^{16}O(\gamma,\alpha)^{12}C$ is approximately larger by a factor of one hundred than the cross-section of $^{12}C(\alpha,\gamma)^{16}O$ [8] at the same $E_{c.m.}$ because of no Coulomb barrier in the photonuclear reaction. This is the reason why we propose the experiment of $^{16}O(\gamma,\alpha)^{12}C$ for extracting the cross-section of $^{12}C(\alpha,\gamma)^{16}O$.

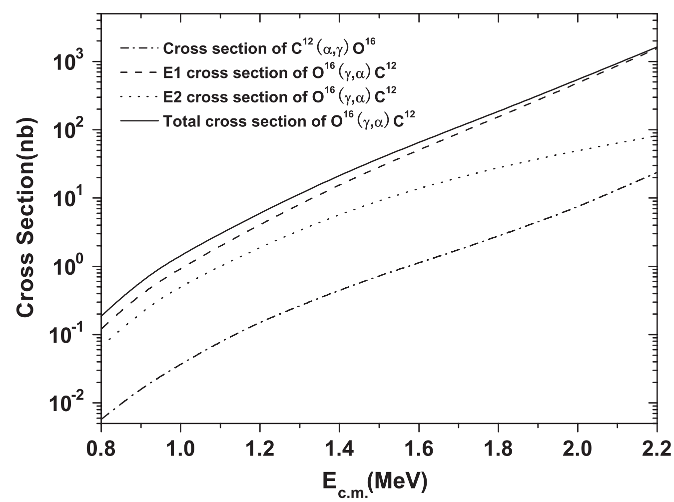

Fig. 2. The E1(dash line), E2(dot line), and total(solid line) cross-sections of $^{16}O(\gamma,\alpha)^{12}C$. The cross-section of $^{12}C(\alpha,\gamma)^{16}O$ [8] (dash-dot line) is also shown for comparison.

3. Experiment proposal and simulation of $^{16}O(\gamma,\alpha)^{12}C$ based on SLEGS

3.1. SLEGS facility

The future SLEGS provides a great opportunity to carry out an experiment of the reaction of $^{16}O(\gamma,\alpha)^{12}C$. SLEGS, a γ-ray beam line, can produce quasi-homochromous and partially polarized γ-rays of 10 MeV order. The expected photon flux of SLEGS could reach up to 10^{11} s^{-1} [9]. The γ-rays beam are generated by the backward Compton scattering between 3.5 GeV electrons in the storage ring at Shanghai Synchrotron Radiation Facility (SSRF) and a 10 KW CO_2 laser. The schematic layout of the future SLEGS at SSRF facility is show in Fig. 3.

The CO_2 laser beam is generated and polarized in the optical chamber, then focused and injected into the SSRF storage ring. Once the laser beam overlaps electron bunches, Compton backscattering occurs between relativistic electrons and laser photons. γ-rays with a small energy spreading and a narrow divergence angle are generated. The remaining laser light through the

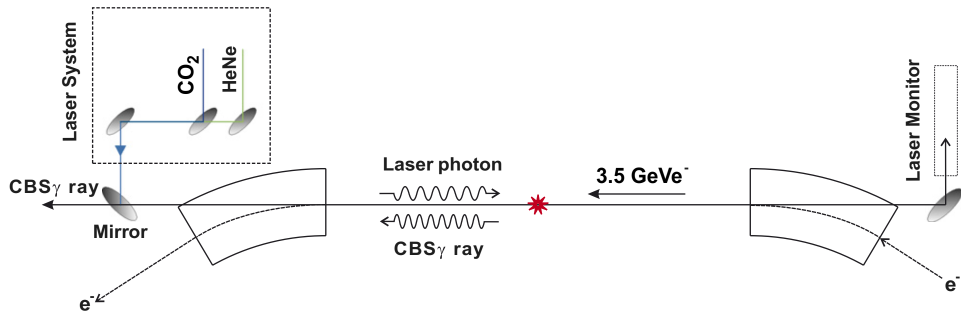

Fig. 3. The schematic layout of the future SLEGS at SSRF facility.

Table 1
The features of HIγS and the future SLEGS for the $^{16}O(\gamma,\alpha)^{12}C$ experiment

	Recent proposal of HIγS	Future SLEGS
Laser type	Free Electron Laser	CO_2 laser
Energy region	2–58 MeV	1–22 MeV
Total flux	$10^9\ s^{-1}$(below 20 MeV)	$10^{11}\ s^{-1}$(use 10 KW laser)
Resolution	2% or 5%	
Flux in bin	$3\times10^7\ s^{-1}$ or $8\times10^7\ s^{-1}$	$5\times10^8\ s^{-1}$(bin of 0.1 MeV)

interaction region is inspected by a set of monitors, which provide feedback and control signals as well. The generated γ-ray passes through the laser mirror and enters into the experimental area. The prototype of SLEGS is under construction at 100 MeV LINAC in Shanghai Institute of Applied Physics, Chinese Academy of Sciences [10]. We expect that the SLEGS facility will be completed in three years.

The features of γ-rays at SLEGS are obtained by a Monte Carlo simulation [9] and are shown in Table 1. The features of γ-rays written in a recent proposal of HIγS in Duke are also listed here.

For a $^{16}O(\gamma,\alpha)^{12}C$ experiment, a collimator will be used in SLEGS to choose γ-rays within the energy range from 7.5 to 10 MeV, and the total flux of γ-ray will therefore decrease to some extent. However, a higher power CO_2 laser is still available which can remedy the flux of γ-rays.

3.2. Experiment proposal

Because the energy of an outgoing particle in the low energy reaction of $^{16}O(\gamma,\alpha)^{12}C$ is too low to come out of a solid or liquid target and reach to detectors, the traditional target–detector system cannot satisfy this experimental requirement. Recently, an optical readout time projection chamber (O-TPC), a united target–detector technique, is developed to perform experiments just like a low energy photonuclear reaction. Using an O-TPC and HIγS, an experiment of $^{16}O(\gamma,\alpha)^{12}C$ has been suggested at Duke [11]. The TPC technique has been successfully applied in experiments of ^3He and ^4He photodisintegration [12]. Here, we propose to use a TPC, a target–detector system, to carry out $^{16}O(\gamma,\alpha)^{12}C$ experiment in the future SLEGS. The sketch of the reaction of $^{16}O(\gamma,\alpha)^{12}C$ which occurs in TPC with a polarized photon is shown in Fig. 4.

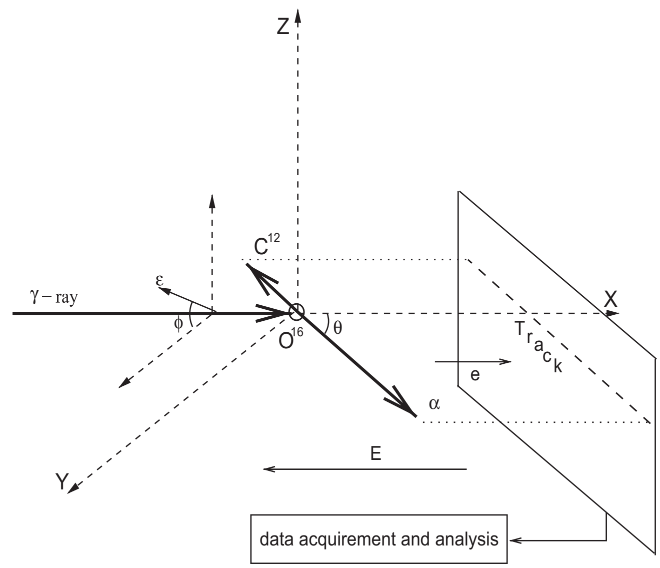

Fig. 4. The sketch of the reaction of $^{16}O(\gamma,\alpha)^{12}C$ in a TPC.

The polarized photon beam enters into a TPC and most likely induces the photodisintegration of ^{16}O. The produced ^{12}C and α particle emit back to back from a reaction point. These charged particles can induce secondary ionization electrons, which drift along the electric field in the TPC. These electrons are eventually collected in the detection area. Thus, the total energy loss, the yields, the track and the dE/dx of charged particles can be measured. The electrons produced by the Compton effect and the electron pairs effect, as well as the photodisintegration production of various nuclei existed in the TPC mixture gas, cause the main backgrounds. However, the dE/dx of an electron is about 100 eV/mm [12] which is much lower than the value of charge particle, it can be cut off by setting a proper threshold during an off-line analysis. Another background is the photodisintegration production of various nucleus existed in the TPC. For example, the reactions of $^{17}O(\gamma,\alpha)^{13}C$ and $^{18}O(\gamma,\alpha)^{14}C$ can occur in the γ-ray energy range from 7.5 to 10 MeV. Because of the low abundance of ^{17}O and ^{18}O in the natural isotope of oxygen, the yields of these reactions can be neglected comparing to statistical uncertainties of a future $^{16}O(\gamma,\alpha)^{12}C$ experiment with 100 h long and the photon flux of $10^{11}\,s^{-1}$ at SLEGS. Furthermore, the total energy loss equals to the Q-value of a reaction, and it can be measured to remove the event of $^{17}O(\gamma,\alpha)^{13}C$ and $^{18}O(\gamma,\alpha)^{14}C$ from $^{16}O(\gamma,\alpha)^{12}C$. After taking care of these backgrounds, the events of $^{16}O(\gamma,\alpha)^{12}C$ can be identified.

3.3. Simulation

For $^{16}O(\gamma,\alpha)^{12}C$, we simulate the energy spectrum of the outgoing α particle at different $E_{c.m.}$ as an example. The α particle yield is plotted against the energy of the outgoing α particle and the results are shown in Fig. 5.

In the simulation, we assume no inefficiency for both detectors and beam. The experimental formula of the α particle yield at a certain $E_{c.m.}$ is therefore employed and given by:

$$Y(E_\alpha) = W \times d \times t \times \int_{E_{c.m.}} \int_\phi \int_\theta n_\gamma(E_{c.m.}) \times \frac{d\sigma}{d\Omega}(E_{c.m.}, \phi, \theta)\, dE_{c.m.}\, d\phi\, d\theta \quad (8)$$

where the differential cross-sections in Eq. (3) are used and the two body kinematics relationship of the reaction of $^{16}O(\gamma,\alpha)^{12}C$ between θ and E_α is employed. In Eq. (8), W is the power of CO_2 laser and $W = 10\,kW$ is chosen, d is the density of ^{16}O in the TPC which is taken from [11], the running time t is 100 h, the bin width of $E_{c.m.}$ is 0.1 MeV, and $n_\gamma(E_{c.m.})$ is the photon flux of future SLEGS which is simulated. Here, $n_\gamma(E_{c.m.})$ in the $E_{c.m.}$ range from 0.5 to 2.5 MeV are plotted in Fig. 6. Notice that from Eq. (8), the total yields are not relevant to the polarization of photon beam. In addition, for a low energy photonuclear reaction, relativistic effects between the center of mass frame and the lab frame of the reaction are negligible. Therefore, our simulated results in the center of mass frame are valid for the lab frame as well.

Then, we calculate the total photon flux in term of $E_{c.m.}$ with the bin width of 0.1 MeV for various experimental

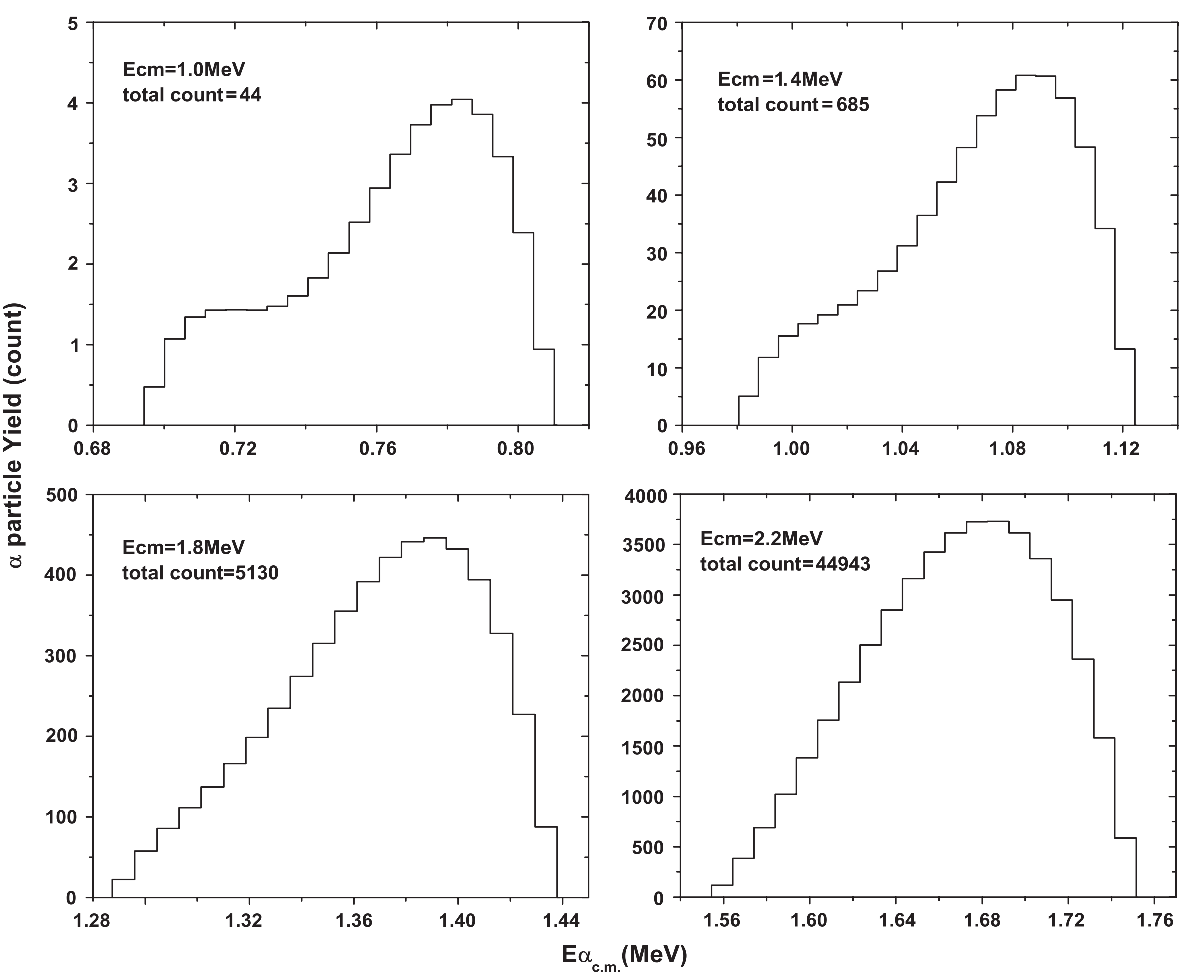

Fig. 5. The simulated energy spectra of outgoing α particle of $^{16}O(\gamma,\alpha)^{12}C$ experiment at different $E_{c.m.}$.

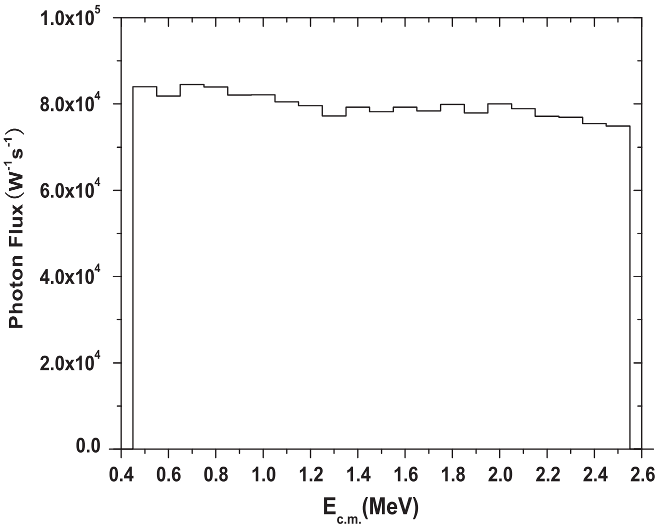

Fig. 6. Photon flux of the future SLEGS as a function of $E_{c.m.}$ of $^{16}O(\gamma,\alpha)^{12}C$.

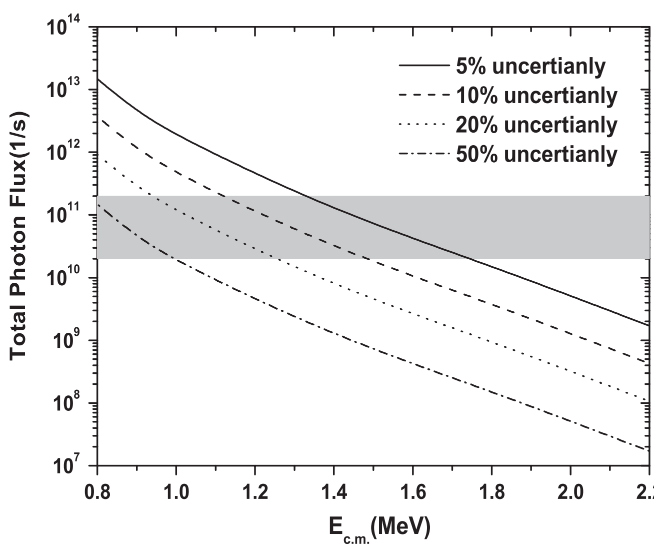

Fig. 7. To reach various statistical uncertainties for $^{16}O(\gamma,\alpha)^{12}C$ experiment (5% uncertainty (solid line), 10% uncertainty (dash line), 20% uncertainty (dot line) and 50% uncertainty (dash-dot line)), the required total photon flux are plotted against the measured reaction $E_{c.m.}$. In this simulation, the bin width is 0.1 MeV and the beam time are assumed to be 100 h. The gray band is the range of the total photon flux which the future SLEGS can possibly attain.

uncertainty. The inputs of above simulation are also used for the calculation here. The results are shown in Fig. 7 where the gray band is the range of the total photon flux which the future SLEGS can possibly attain. Only statistical errors for the total yields are taken into account. For an example, the cross-section at $E_{c.m.}$ of 0.9 MeV can be measured with the 20% uncertainty when the photon flux of SLEGS attains $10^{11}\,s^{-1}$. Furthermore, we can also increase the beam time of SLEGS to lower the statistical uncertainty and therefore reach to $E_{c.m.}$ below 0.9 MeV with the same uncertainty. Actually, we can measure the yield at $E_{c.m.} = 0.8$ MeV with the 20–30% uncertainty if the running time is one month. It is a great significance because no experimental data of $^{16}O(\gamma,\alpha)^{12}C$ is available under $E_{c.m.} = 0.9$ MeV around. Whereas, continuously increasing the running time is not a practical approach for $E_{c.m.}$ below 0.8 MeV.

3.4. Comparisons and discussion

The total α particle yield is obtained by integrating over the entire energy range of outgoing α particle at each $E_{c.m.}$ in Fig. 6. The count per day (cpd) and the time for the 10% error are obtained, and are compared with Duke's [13] in Table 2. In each energy bin of γ-ray, the flux of SLEGS is about 15 times larger than HIγS's. So we can spend less time for reaching the 10% error at the same $E_{c.m.}$ than Duke's does. In another word, the experiment of $^{16}O(\gamma,\alpha)^{12}C$ will carry out more accurately based on the future SLEGS.

In Fig. 8, we extract the S factor of $^{12}C(\alpha,\gamma)^{16}O$, a very important parameter in nuclear astrophysics. Its uncertainty is estimated from the simulation with the $E_{c.m.}$ bin width of 0.1 MeV, the total photon flux of $10^{11}\,s^{-1}$ and the 100 h running time. The relationship between the cross-section and the corresponding S factor is given by:

$$S(E_{c.m.}) = \sigma(E_{c.m.}) \times E_{c.m.} \times \exp(2\pi\eta). \quad (9)$$

The E1 and E2 cross-sections of $^{12}C(\alpha,\gamma)^{16}O$ are obtained from the E1 and E2 cross-sections of $^{16}O(\gamma,\alpha)^{12}C$ in Fig. 2 based on the detailed balance. The experimental data and some theoretical fit values of $^{12}C(\alpha,\gamma)^{16}O$ [14–21] are also plotted in Fig. 8. The gray band illustrates the uncertainties of extracted S factors in our calculation and they become smaller as $E_{c.m.}$ increases owing to the larger yield at higher $E_{c.m.}$. We can conclude that the experiments of $^{16}O(\gamma,\alpha)^{12}C$ will bring a significant improvement of the status of $^{12}C(\alpha,\gamma)^{16}O$ studied because it is shown that our simulated results can restrict the uncertainty of the $^{12}C(\alpha,\gamma)^{16}O$ experiment evidently. We can also see that the theoretical fit and the experimental data of S factor do not agree with each other very well. In addition, S factor cannot be well determined at $E_{c.m.} < 0.9$ MeV due to no existing

Table 2
Comparison of the experimental yield and time between present work and Duke's proposal

$E_{c.m.}$ (MeV)	Experimental yield (cpd)		Time for 10% error (h)	
	Duke	Present work	Duke	Present work
1.0		11		220
1.4	12	165	300	14
1.8	81	1239	50	2
2.2	630	10 863	10	0.2

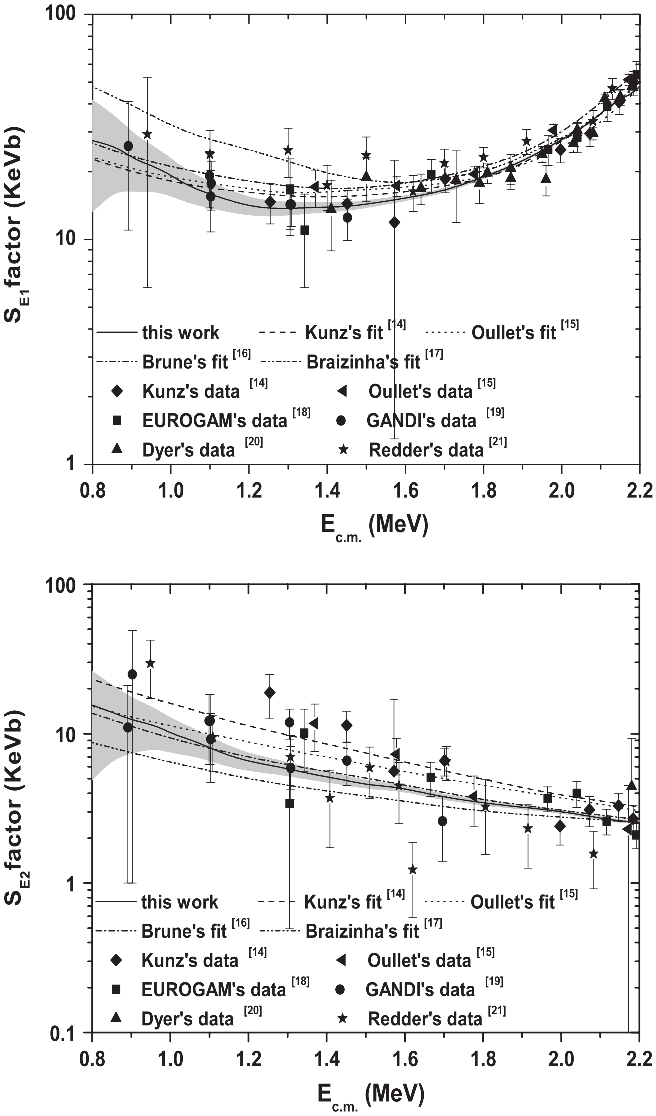

Fig. 8. The extracted S factors with their statistical uncertainties of $^{12}C(\alpha,\gamma)^{16}O$ compared with the existing data and some theoretical calculations. The gray band illustrates the statistical uncertainties of extracted S factors based on the simulation of the 100 h beam time.

experimental data. Therefore, performing a precision $^{16}O(\gamma,\alpha)^{12}C$ measurement down to $E_{c.m.} = 0.8$ MeV is indeed necessary to determine the S factor of the crucial reaction of $^{12}C(\alpha,\gamma)^{16}O$ in nuclear astrophysics.

4. Summary and outlook

The photonuclear reaction of $^{16}O(\gamma,\alpha)^{12}C$, the inverse of the key reaction of $^{12}C(\alpha,\gamma)^{16}O$ in nuclear astrophysics, is studied through theoretical calculations and experimental simulations. The total and differential cross-sections are calculated based on the resonance theory of low energy reaction in the case of the induced polarized photon. It is found that the yield is concentrated around the plane, which is determined by the incident photon orientation and the photon polarization orientation. Taking into account of 1^- and 2^+ resonance states of ^{16}O for the reaction of $^{16}O(\gamma,\alpha)^{12}C$, the E1 and E2 cross-sections are comparable below $E_{c.m.}$ of 1.0 MeV, and the E1 cross-section becomes dominant above $E_{c.m.}$ of 1.0 MeV.

The $^{16}O(\gamma,\alpha)^{12}C$ experiment at the energies of nuclear astrophysics interest is simulated based on the features of the future SLEGS and our theoretical calculation for the differential cross-section of $^{16}O(\gamma,\alpha)^{12}C$. We find that the lowest $E_{c.m.}$ which can be obtained from simulation is about 0.8 MeV with the 20–30% uncertainty for the one-month beam time of SLEGS, while there is no experimental data of $^{12}C(\alpha,\gamma)^{16}O$ below $E_{c.m.} = 0.9$ MeV around so far. For $^{16}O(\gamma,\alpha)^{12}C$ experiment, the simulated total yields and their statistical uncertainties are compared with Duke's simulation results. The proposed experiment of $^{16}O(\gamma,\alpha)^{12}C$ for the future SLEGS has more advantages due to a higher photon flux. The extracted S factor of $^{12}C(\alpha,\gamma)^{16}O$ and its uncertainty simulated are compared with the existing data and some theoretical calculations. It seems to us that the experiments of $^{16}O(\gamma,\alpha)^{12}C$ will bring a significant improvement of the status of $^{12}C(\alpha,\gamma)^{16}O$ studied. It is suggested that the future experiments of $^{16}O(\gamma,\alpha)^{12}C$ for different low $E_{c.m.}$ at SLEGS are quite promising.

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