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Abstract

The photoproduction of Λ on ^{12}C is investigated by using the recently developed Saclay-Lyon amplitudes of $\gamma p \rightarrow K^+\Lambda$ reactions and the single particle wavefunctions from a relativistic mean-field model of nuclei and $\Lambda-$hypernuclei. In the impulse approximation, the predicted cross sections reproduce the energy-dependence of the data of the inclusive $^{12}C(\gamma, K^+)$ reaction up to 1.1 GeV, but overestimate its magnitudes by a factor of about 2. We discuss the extent to which this overestimation can be understood in terms of medium effects on the K^+ propagation.

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I. INTRODUCTION

It has been well recognized [1] that electromagnetic probes are complementary to hadronic probes in investigating the structure of hypernuclei. With the recent developments at several GeV electron facilities, the data of photoproduction and electroproduction of hypernuclei will soon be very extensive. To make progress, it is necessary to understand the reaction mechanism of these electromagnetic processes. In this paper, we will make an attempt in this direction by investigating the theoretical interpretation of recent $^{12}C(\gamma, K^+)$ reaction data [2].

Most of the previous theoretical investigations [3–6] of (γ, K) reactions on nuclei were carried out by using an approach similar to that developed in the study of (γ, π) reactions [7,8]. The transition amplitude of the reaction is calculated from a kaon photoproduction operator on the nucleon and the wavefunctions of the initial nuclear and the final hypernuclear systems. The outgoing kaon wavefunctions are calculated by using either an optical potential or the eikonal approximation. No data for 1p-shell and heavier nuclei were available for testing these earlier theoretical predictions.

Motivated by the recent $^{12}C(\gamma, \Lambda)$ reaction data [2], in this work we will test the validity of the theoretical scheme developed in Refs. [3–6] by taking the advantage of two recent developments. First, an accurate model of kaon photoproduction and electroproduction amplitudes has been developed by a Saclay-Lyon collaboration [9]. It is parameterized in terms of low-order Feynman amplitudes involving all identified resonances in the s-, u-, and t-channels. The parameters are determined by a global fit to all existing data of kaon photoproduction and electroproduction on the nucleon. Second, a relativistic mean-field model of hypernuclei has been developed [10] to reproduce accurately the binding energies of hypernuclei throughout the periodic table. The main objective of this work is to see the extent to which data of Ref. [2] can be understood by using these two theoretical inputs.

The data [2] of the $^{12}C(\gamma, K^+)$ reaction has two components. The first one is due to the bound-Λ production leading to bound $^{12}_{\Lambda}$B states. The second component is the production of a Λ in continuum states. In this work, we will focus on the simplest predictions with no adjustable parameters. This is accomplished by using the impulse approximation to calculate these two cross sections with all theoretical input fixed by the models developed in Refs. [9,10]. The difference between our predictions and the data will indicate the medium effects on the propagation of outgoing hadrons. We will discuss the extent to which the extracted medium effects can be understood in terms of Kaon distortion that can be estimated by using KN total cross sections.

Within the relativistic mean-field model developed in Ref. [10], we assume that the final $^{12}_{\Lambda}$B is an one proton hole-one Λ particle state of the ^{12}C ground state. This is clearly an oversimplification, but should be sufficient for the present calculation of inclusive process in which the contributions from all final states, bound or unbound hypernuclear states, are included.

In section II, we present formula for calculating the cross sections of $^{12}C(\gamma, K)$ reactions The results are presented and discussed in section III.

II. FORMULA FOR CROSS SECTION

Following the previous investigations [3–6], we assume that the (γ, K) reaction in the near Λ production threshold energy region can be described in terms of the elementary $\gamma N \to K\Lambda$ amplitudes. If we neglect the dependence on the Λ momentum (apart from the overall δ-function for three-momentum conservation) in evaluating the $\gamma N \to K\Lambda$ amplitude, the nuclear transition amplitude then takes a factorized form. In this factorization approximation, which is commonly used in the distorted-wave impulse approximation calculations of intermediate energy nuclear reactions, the transition amplitude for the (γ, K) reaction in the γ-nucleus center of mass frame (A-CM) is determined by the following production operator

$$A(k,q,\hat{\varepsilon}) = \sum_{i=1}^{A} O(k,q,\hat{\varepsilon},\sigma_i) e^{i(q-k)\cdot r_i} \quad , \tag{1}$$

where q and k are respectively the momenta of the initial photon and the final kaon, $\hat{\varepsilon}$ is the photon polarization vector, σ_i is the Pauli operator, and r_i is the position vector of the i^{th} nucleon. The interaction dynamics is contained in

$$O(k,q,\hat{\varepsilon},\sigma) = \Gamma(k,k_c,q,q_c) \sum_{i=1}^{4} F_i(W_c,\theta_c) O_i(q_c,k_c,\hat{\varepsilon},\sigma) \quad , \tag{2}$$

where $F_i(W_c,\theta_c)$ are the Chew-Goldberger-Low-Nambu(CGLN) amplitudes defined in the γN and $K\Lambda$ center of mass frame (2-CM), and

$$\begin{aligned} O_1(q_c,k_c,\hat{\varepsilon},\sigma) &= \sigma\cdot\hat{\varepsilon} \quad , \\ O_2(q_c,k_c,\hat{\varepsilon},\sigma) &= i(\sigma\times\hat{q}_c\cdot\hat{\varepsilon}) \quad , \\ O_3(q_c,k_c,\hat{\varepsilon},\sigma) &= \sigma\cdot\hat{q}_c\ \hat{k}_c\cdot\hat{\varepsilon} \quad , \\ O_4(q_c,k_c,\hat{\varepsilon},\sigma) &= \sigma\cdot\hat{k}_c\ \hat{k}_c\cdot\hat{\varepsilon} \quad . \end{aligned} \tag{3}$$

In the above expressions, we have used the frozen Λ approximation to define the relative momenta as

$$\begin{aligned} k_c &= \frac{E_\Lambda(p_\Lambda)k - E_K(k)p_\Lambda}{E_K(k) + E_\Lambda(p_\Lambda)} \quad , \\ q_c &= \frac{E_N(p_N)q - qp_N}{E_N(p_N) + q} \quad , \end{aligned} \tag{4}$$

where

$$\begin{aligned} p_\Lambda &= -\frac{k}{A} \quad , \\ p_N &= k + p_\Lambda - q \\ &= \frac{(A-1)}{A}k - q. \end{aligned}$$

The factor Γ in Eq.(2)is due to the transformation of the elementary amplitude from 2-CM to A-CM and is of the following form

$$\Gamma(k, k_c, q, q_c) = \left[\frac{E_K(k_c)E_\Lambda(k_c)E_N(q_c)q_c}{E_K(k)E_\Lambda(p_\Lambda)E_N(p_N)q}\right]^{1/2} \quad . \tag{5}$$

The invariant mass W_c and the scattering angle θ_c in 2-CM are defined by the final $K\Lambda$ subsystem

$$\begin{aligned} W_c &= E_K(k_c) + E_\Lambda(k_c) \quad , \\ \cos\theta_c &= \hat{k}_c \cdot \hat{q}_c \ . \end{aligned} \tag{6}$$

By using Eqs.(2)-(6), the Saclay-Lyon amplitudes can be used directly in our calculations. These equations define one of the possible off-shell extrapolations which are needed in any multiple scattering calculation of intermediate energy nuclear calculations. Here we are guided by the formulation developed in the (γ, π) study of Ref. [8].

To account for the shell structure of the initial nuclei and final hypernuclei, it is more convenient to cast Eq.(1) into the following second quantization form

$$O = \sum_{\alpha\beta} F^{JM}_{\alpha\beta}(k, q, \hat{\varepsilon})\left[b^\dagger_{l_\alpha j_\alpha}(\Lambda)h^\dagger_{l_\beta j_\beta}(N)\right]^{JM} , \tag{7}$$

where $b^\dagger$ and $h^\dagger$ are respectively the creation operators for a Λ-particle and a nucleon-hole states, and

$$\begin{aligned} F^{JM}_{\alpha\beta}(k, q, \hat{\varepsilon}) = & \sum_{n=0,1}\sum_{l}\Gamma(k, k_c, q, q_c)\left[\frac{4\pi}{2l+1}\right]\sqrt{\frac{2j_\alpha+1}{2L+1}}(-1)^{2j_\beta}N_{J,-M}(n, l, \hat{q}_c, \hat{k}_c, \hat{\varepsilon}) \\ & \times \langle l_\alpha \frac{1}{2} j_\alpha || T_J(\xi_n, Y_l(\hat{r})) || l_\beta \frac{1}{2} j_\beta \rangle \int_0^\infty r^2 dr R^*_{l_\alpha j_\alpha}(r) j_l(|q-k|r) R_{l_\beta j_\beta}(r) \ , \end{aligned} \tag{8}$$

where $\xi_0 = 1$, $\xi_1 = \sigma$, and $R_{lj}(r)$ is the radial wavefunction. All angle-dependence of the reaction is absorbed in

$$\begin{aligned} N_{JM} = & F_1(W_c, \theta_c)T_{JM}(\hat{\varepsilon}, Y_l(\hat{t})) - F_2(W_c, \theta_c)T_{JM}(\hat{k} \times (\hat{q} \times \hat{\varepsilon}), Y_l(\hat{t})) \\ & + F_3(W_c, \theta_c)(\hat{k} \cdot \hat{\varepsilon})T_{JM}(\hat{q}, Y_l(\hat{t})) + F_4(W_c, \theta_c)(\hat{k} \cdot \hat{\varepsilon})T_{JM}(\hat{k}, Y_l(\hat{t})) \ , \end{aligned} \tag{9}$$

where the angular tensor is defined, in the convention of Ref. [11], by

$$T_{JM}(V, Y_l(\hat{t})) = \sum_{m_v, m_l} < JM|1lm_v m_l > V_{1m_v} Y_{lm_l}(\hat{t}) \ .$$

The wavefunctions of the produced ${}^{12}_{\Lambda}$B states are assumed to be

$$|{}^{12}_{\Lambda}B\rangle_{[\alpha,\beta]^{JM}} = [b^\dagger_\alpha(\Lambda)h^\dagger_\beta(N)]^{JM}|{}^{12}C>_{g.s} \tag{10}$$

where $\alpha, \beta = 0s_{1/2}$ and $0p_{3/2}$ within the relativistic mean-field model [10] for A =12 systems. By using the above definitions Eqs.(7)-(10), the differential cross section of the bound-Λ production that leads to the bound states of ${}^{12}_{\Lambda}B$ can be written as

$$\left(\frac{d\sigma}{d\Omega}\right) = \frac{(2\pi)^4}{E^2} \frac{E_A(q) k E_K(k) E_{A-1,\Lambda}(k)}{2} \sum_{\lambda=\pm 1} \sum_{\alpha,\beta} \sum_{JM} |F^{JM}_{\alpha\beta}(k, q, \hat{\varepsilon}_\lambda)|^2 \,, \tag{11}$$

where $E_A(q)$ and $E_{A-1,\Lambda}(k)$ are respectively the energies of the initial ^{12}C and the final $^{12}_{\Lambda}$B states, J is restricted by $| j_\alpha - j_\beta | \leq J \leq j_\alpha + j_\beta$, and $E = q + E_A(q)$.

In the calculation of quasi-free production, we neglect all final state interactions and assume that the final state is a three-body system with two plane-wave states for K and Λ and a one proton hole state of ^{12}C. Explicitly, we define

$$|\Psi_f\rangle = a^\dagger_k b^\dagger_{p_\Lambda m_{s_\Lambda}}(\Lambda) |\Psi_{A-1}\rangle_\alpha \,, \tag{12}$$

where $a^\dagger$ is the creation operator for kaons, and $|\Psi_{A-1}\rangle_\alpha = h^\dagger_\alpha(P)|^{12}C\rangle_{g.s.}$. The differential cross section for quasi-free production can then be written as

$$\frac{d\sigma}{d\Omega} = \frac{(2\pi)^4 E_A(q)}{E} \int_0^{k_{max}} k^2 dk \int d\Omega_\Lambda \frac{p_\Lambda E_\Lambda(p_\Lambda) E_{A-1}(q-k-p_\Lambda)}{[E_{A-1}(q-k-p_\Lambda) + E_\Lambda(p_\Lambda)(1 - 2\hat{p}_\Lambda \cdot (q-k)/p_\Lambda)]} \times \frac{1}{2} \sum_{\lambda=\pm 1} \sum_{j_\alpha m_{j_\alpha}} \sum_{m_{s_\Lambda}} |T^\lambda_{j_\alpha m_{j_\alpha}, m_{s_\Lambda}}(k, q)|^2 \,, \tag{13}$$

with

$$T^\lambda_{j_\alpha m_{j_\alpha}, m_{s_\Lambda}}(k, q) = \sum_{l_\alpha m_{l_\alpha}} \sum_{m_{s_N}} \langle j_\alpha m_{j_\alpha} | l_\alpha \tfrac{1}{2} m_{l_\alpha} m_{s_N} \rangle Y_{l_\alpha m_{l_\alpha}}(\hat{p}_N) R_{l_\alpha j_\alpha}(p_N) (-1)^{j_\alpha - m_{j_\alpha}} \langle k p_\Lambda m_{s_\Lambda} | t(W) | q \lambda p_N m_{s_N} \rangle \,, \tag{14}$$

where k_{max} and p_Λ are restricted by

$$q + M_A = E_K(k) + E_\Lambda(p_\Lambda) + E_{A-1}(q - k - p_\Lambda) \,, \tag{15}$$

and

$$\begin{aligned} p_N &= p_\Lambda + k - q \,, \\ W &= E_K(k) + E_\Lambda(p_\Lambda) \end{aligned} \tag{16}$$

In Eq.(14), $R_{l_\alpha j_\alpha}(p_N)$ is the nucleon single-particle wavefunction in momentum-space. We evaluate the $\gamma N \rightarrow K\Lambda$ amplitude $< k p_\Lambda m_{s_\Lambda} \mid t(W) \mid q p_N m_{s_N} >$ exactly from the Saclay-Lyon amplitude by using the A-CM to 2-CM transformation defined in Ref. [8]. No frozen Λ approximation, such as that defined by Eq.(4), is assumed. This is important since the outgoing Λ in the quasi-free production is unbound.

III. RESULTS AND DISCUSSIONS

The most essential input to our calculations is the $\gamma p \rightarrow K^+\Lambda$ amplitudes defined by Eqs.(2)-(3). In this work we use the amplitudes developed by the Saclay-Lyon group [9]. The accuracy of this model is illustrated in Fig.1. We see that the $\gamma p \rightarrow K^+\Lambda$ data in the considered energy region can be described very well.

The $^{12}C(\gamma, K^+)$ data considered in this work were obtained from an experiment that was limited to measure the cross sections in the kinematic range where the outgoing kaons are within $10° \leq \theta_L \leq 40°$ with respect to the incident photons. By investigating the dependence of the averaged cross sections on the missing mass, the bound $^{12}_{\Lambda}$B states with total energies in the range of $11.2 \leq M_x \leq 11.4$ GeV were identified. However the data are not accurate enough for identifying individual states. The total bound-Λ production cross section of these unresolved bound hypernuclear states was estimated to be about 0.21 ± 0.05 $\mu b/sr$ in the $E_\gamma = 1.0 - 1.1$ GeV energy region. Within the relativistic mean-field model of Ref. [10], these bound-Λ cross sections are due to all possible transitions from the bound proton orbitals in ^{12}C to the bound Λ orbitals in $^{12}_{\Lambda}$B. The predicted single particle energies of these orbitals are listed in Table I. The corresponding single particle wavefunctions are shown in Fig.2. We see that $0p_{3/2}$ Λ is barely bound.

As seen in Eq.(8), the predicted bound-Λ cross sections depend on the Fourier-transform of the overlap of the initial proton and final Λ single-particle wavefunctions. Since the momentum-transfer $|k-q|(\sim 400$ MeV/c) is rather high in the considered kinematic region, the bound-Λ production cross sections are expected to be larger for the transitions that their wavefunction overlap is more concentrated in short distances. By inspecting Fig.2, we therefore expect that the cross section for the transitions to the final $0p_{3/2}$-state Λ must be smaller than that to the $0s_{1/2}$-state Λ. This is exactly the result from our calculations and is illustrated in Fig.3. Here the cross sections are the values obtained from taking an average of the calculated cross sections over the angle range $10° \leq \theta_L \leq 40°$. Since the $0p_{3/2}$-Λ state is barely bound(see Table I), it is more realistic to keep only the $0s_{1/2}$-state Λ contribution(dotted curve) in comparing our prediction with the data. The value from taking an average of the cross sections for producing the $0s_{1/2}$-state Λ over the energy range $1.0 \leq E_\gamma \leq 1.1$ GeV is 0.42 $\mu b/sr$. Thus our prediction of the bound-Λ production is about a factor of 2 larger than the experimental value 0.21 ± 0.05 $\mu b/sr$ of Ref. [2].

To compare our predictions with the data in the entire energy region up to $E_\gamma = 1.1$ GeV, we need to include the cross sections for producing a Λ in continuum states. This part of cross section is calculated by using the expression Eq.(12)-(16). The results are displayed in Fig.4. We see that the production from the $0p_{3/2}$ proton orbital is larger than that from $0s_{1/2}$ proton orbital. This is mainly due to the fact that there are more protons in the $0p_{3/2}$ orbital.

The sum of the total bound-Λ production(solid curve in Fig.3) and the total quasi-free production(solid curve in Fig.4) cross sections is found to be about a factor of 2 larger than the data. In Fig.5, these predicted cross sections divided by a reduction factor $R = 2.3$ are compared with the data. We see that the quasi-free contribution(dotted curve) is much larger than the bound-Λ production(dashed curve) except in the very near threshold region. The energy-dependence of the sum(solid curve) is in good agreement with the data of Ref. [2] within the assigned errors. The needed reduction factor is mainly controlled by the much larger quasi-free production cross section. This factor is not changed too much if we also assume here that the bound-Λ production only leads to a $0s_{1/2}$-Λ state.

The reduction factor $R \sim 2$ must be due to the medium effects on the incoming photons and outgoing hadrons. It is useful to first examine whether this factor can be understood by considering the reaction kinematics and kaon mean free path in nuclear medium. Since the momentum transfer is about $Q = |q-k| \sim 2$ fm^{-1} and the typical angular momentum transfer (L) involved is about 1, the place where the raction takes place is at $r \sim L/Q \sim 1/2 = 0.5$ fm. This means that the kaons are produced around the origin of ^{12}C and must be influenced by the strong absorption effect. Since the mean free path of kaon is $\lambda = r/(\sigma_{\Lambda N}\rho) \sim 5$ fm and the radius of ^{12}C is about $2.337 \times \sqrt{5/3} = 3.0$ fm, the probabilty for the produced kaon to leave the nucleus is, according to the the formula developed in Ref. [13], $\sim exp^{-3.0/5.0} = 0.55$. Hence about a half of the produced kaons are absorbed on their way out. This is consistent with the reduction factor $R \sim 2$. However, this estimate neglects the surface effect of a finite nucleus.

Alternatively, we can estimate the reduction factor by using the eikonal approximation [2,12] which makes use of the realistic density of ^{12}C. In this approximation, the reduction factor can be estimated by $R = Z_{eff}/Z$, where $Z = 6$ is the proton number of ^{12}C and the effective proton number is defined by

$$Z_{eff} = \int dr \rho_p(r) |\chi_\gamma^{(+)}(r)|^2 |\chi_{K^+}^{(-)}(r)|^2 \tag{17}$$

where

$$\chi_\gamma^{(+)}(r) = exp[iq \cdot r - \int_{-\infty}^{z} \frac{\sigma_{\gamma N}^{tot}}{2} \rho_(r) dr] \tag{18}$$

$$\chi_{K^+}^{(-)}(r) = exp[-ik \cdot r - \int_{z}^{\infty} \frac{\sigma_{K^+N}^{tot}}{2} \rho_(r) dr] \tag{19}$$

In above equations, $\rho_p(r)$ is the proton density normalized to Z=6, and $\rho(r)$ is the total density normalized to A=N+Z=12. By using the procedure of Ref. [12] to evaluate Eq.(18), we find that the effective proton number for a ^{12}C density defined in terms of harmonic oscillator wavefunctions can be calculated analytically

$$Z_{eff} \sim \frac{\pi}{2} \int dx T(x) exp[-\frac{\sigma_{\gamma N}^{tot} + \sigma_{K^+N}^{tot}}{2} T(x)] \tag{20}$$

with

$$T(x) = \frac{4}{\pi b^2} e^{-\frac{x}{b^2}} (\frac{5}{3} + \frac{4}{3}\frac{x}{b^2}) \tag{21}$$

Here the oscillator length $b = 1.587$ fm is chosen to reproduce the charge mean-square-radius($< r^2 >^{1/2} \sim 2.4$ fm) extracted from elastic electron scattering from ^{12}C. With the values $\sigma_{\gamma N}^{tot} \sim 0.2$ mb and $\sigma_{K^+N}^{tot} \sim 12.0$ mb, Eq.(21) yields $Z_{eff} = 4.38$. Thus the predicted reduction factor $R = Z_{eff}/Z$ is only 1.37 which is smaller than the value ~ 2 needed to reproduce the data. This suggests that the medium effect on K^+ is significant, but is not the whole mechanism for understanding the reduction factor $R \sim 2$. A more accurate estimate perhaps should include the the final Λ-nucleus interactions. However, this is a much more complex task and is beyond the scope of this work.

In conclusion, we have investigated the $^{12}C(\gamma, K^+)$ reactions by using the recently developed Saclay-Lyon amplitudes [9] of $\gamma p \to K^+\Lambda$ reaction and the wavefunctions from the relativistic mean-field model of nuclei and hypernuclei developed in Ref. [10]. In the impulse approximation calculations, the predicted cross sections reproduce the energy dependence of the data, but overestimate its magnitudes by a factor of about 2. In an eikonal approximation estimate, it is found that this overestimation can be attributed to some extent to the medium effect on the K^+ propagation. Our results suggest that the distorted impulse approximation approach developed in Refs. [3–6] can be used to give a good description of the data considered in this work and the forthcoming data. However, it is necessary to use more sophisticated approaches to account for the final state interactions and the structure of hypernuclei. This can be achieved by using appropriate kaon optical potentials, such as that developed recently by Gal and his collaborators [14]. It is also necessary to consider the configuration mixing in hypernuclei. This can be done by using the shell-model approach developed in previous investigations of the structure of hypernuclei [15–17].

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TABLES

TABLE I. Single particle energies(E) for the $0s_{1/2}$ and $0p_{3/2}$ states in ^{12}C and $^{12}_{\Lambda}B$ predicted by the relativistic mean-field model of Ref.[10]

$states$	$E(MeV)$
$N, 0s_{1/2}$	-38.639
$N, 0p_{3/2}$	-17.765
$\Lambda, 0s_{1/2}$	-10.800
$\Lambda, 0p_{3/2}$	-0.036

FIGURES

FIG. 1. The $\gamma p \to K^+\Lambda$ cross sections predicted by using the Saclay-Lyon amplitudes [9] are compared with the data.

FIG. 2. The single particle wavefunctions for the $0s_{1/2}$(S) and $0p_{3/2}$(P) states in ^{12}C and $^{12}_{\Lambda}B$ calculated from the relativistic mean-filed model of Ref. [10].

FIG. 3. The calculated bound-Λ cross sections for the $^{12}C(\gamma, K^+)$ reaction. The dotted(dashed) curve is due to the transitions from the proton orbitals in ^{12}C to the $0s_{1/2}(0p_{3/2})$ Λ states in $^{12}_{\Lambda}$B. The contributions from both the initial $os_{1/2}$ and $0p_{3/2}$ proton orbtals are included in the calculations. The solid curve is the sum of the two contributions.

FIG. 4. The calculated quasi-free cross sections for the $^{12}C(\gamma, K^+)$ reaction. The contribution from the initial $0s_{1/2}(0p_{3/2})$ proton orbitals in ^{12}C is the dotted(dashed) curves. The solid curve is the sum of the two contributions.

FIG. 5. The calculated cross sections devided by $R = 2.3$ are compared with the data[8]. The dashed and dotted curves are respectively the total bound-Λ and the total quasi-free productions. The solid curve is the sum of these two contributions..

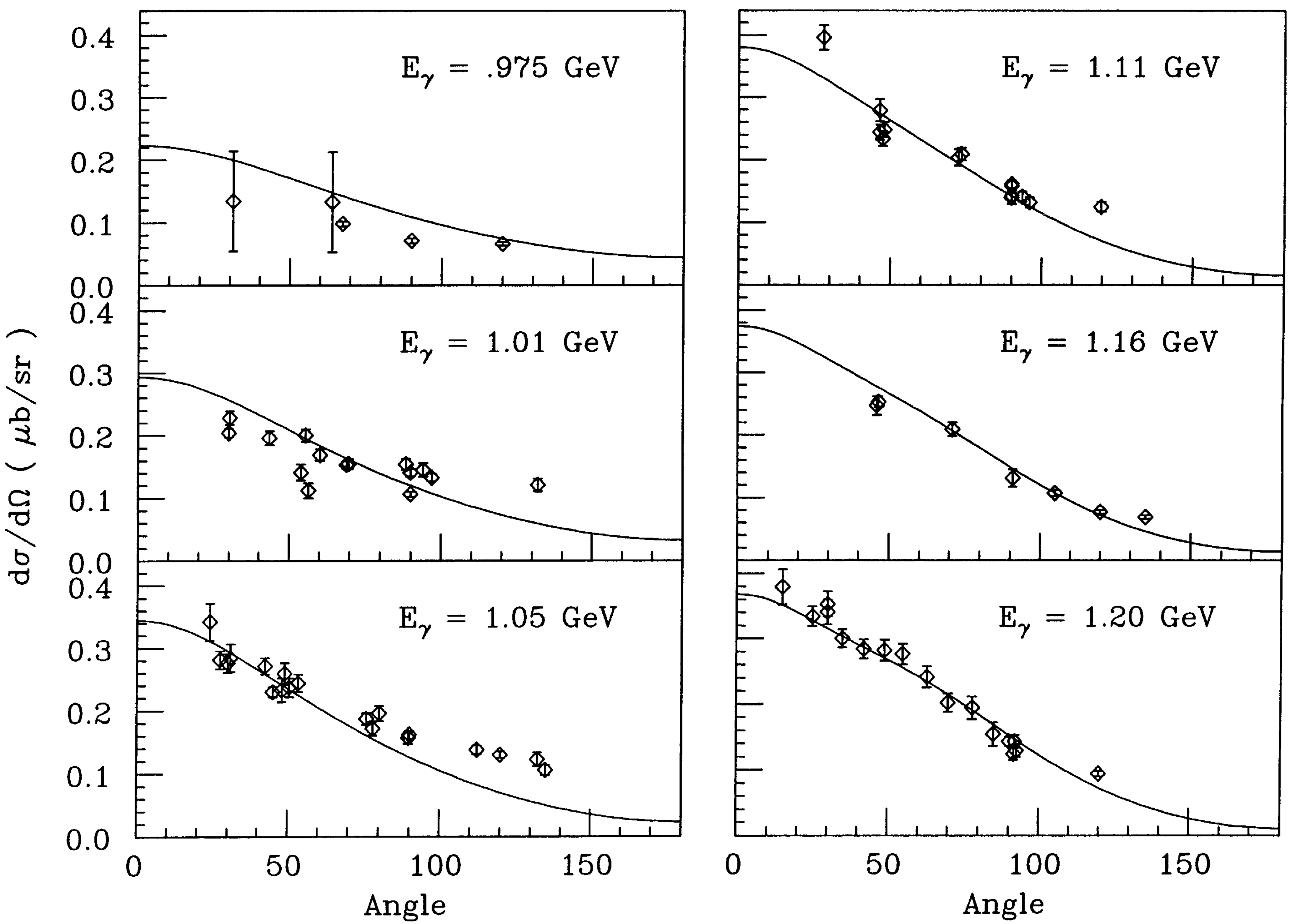

E_γ = .975 GeV
E_γ = 1.01 GeV
E_γ = 1.05 GeV
E_γ = 1.11 GeV
E_γ = 1.16 GeV
E_γ = 1.20 GeV
$d\sigma/d\Omega$ (μb/sr)
0.0
0.1
0.2
0.3
0.4
0
50
100
150
Angle

Fig. 1

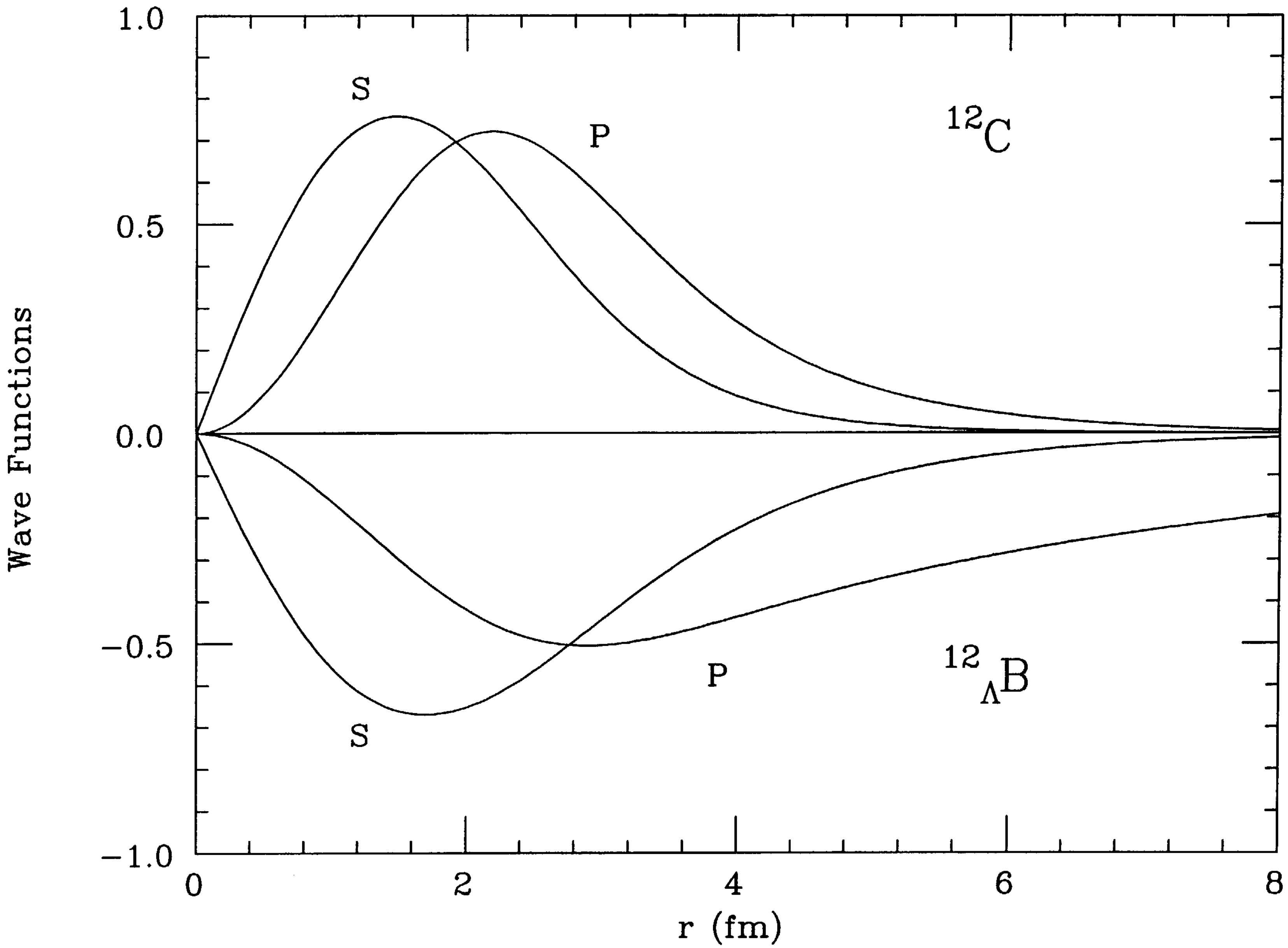
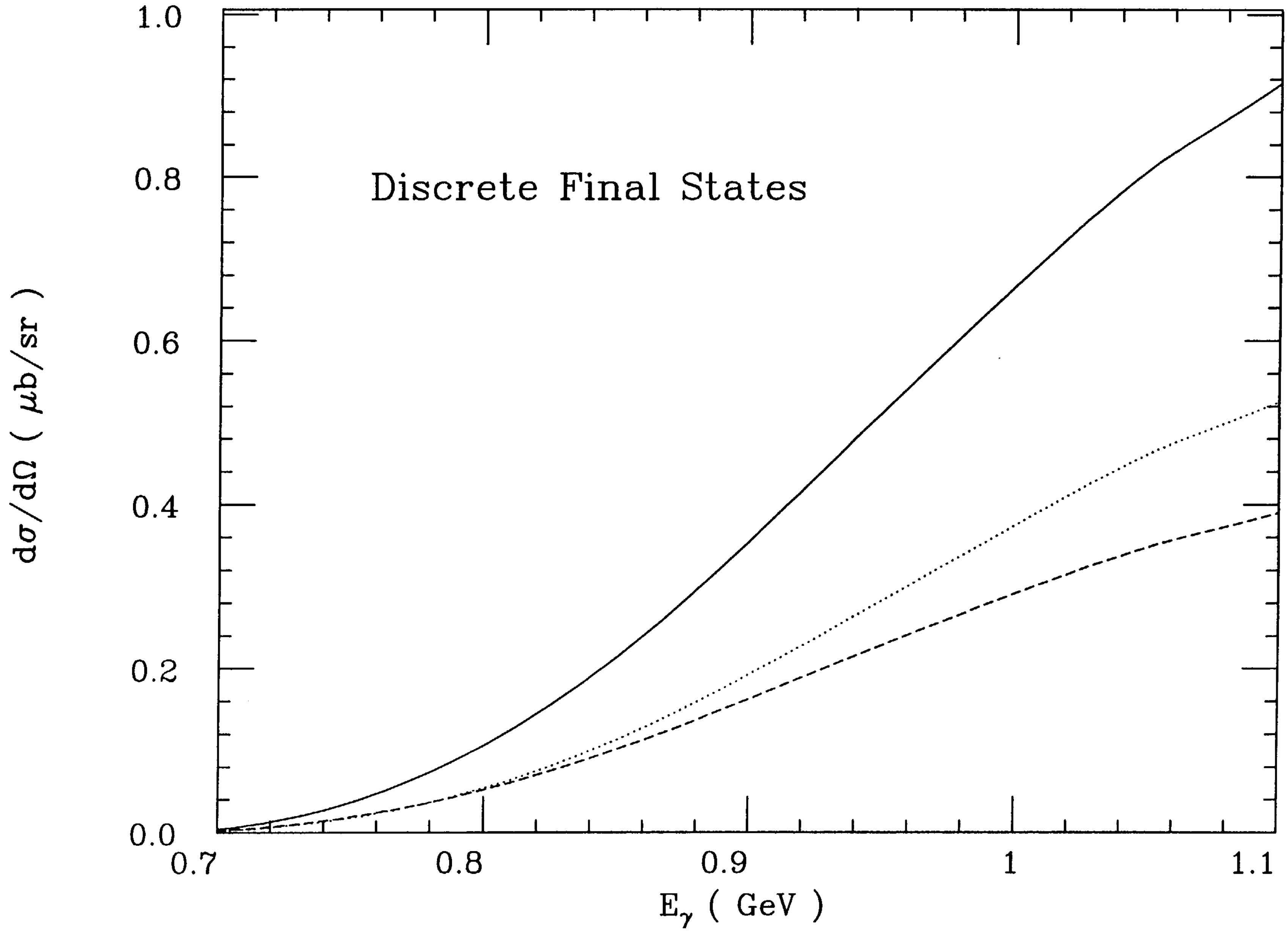


Fig. 2



Discrete Final States
dσ/dΩ (μb/sr)
E_γ (GeV)
0.0
0.2
0.4
0.6
0.8
1.0
0.7
0.8
0.9
1
1.1

Fig. 3

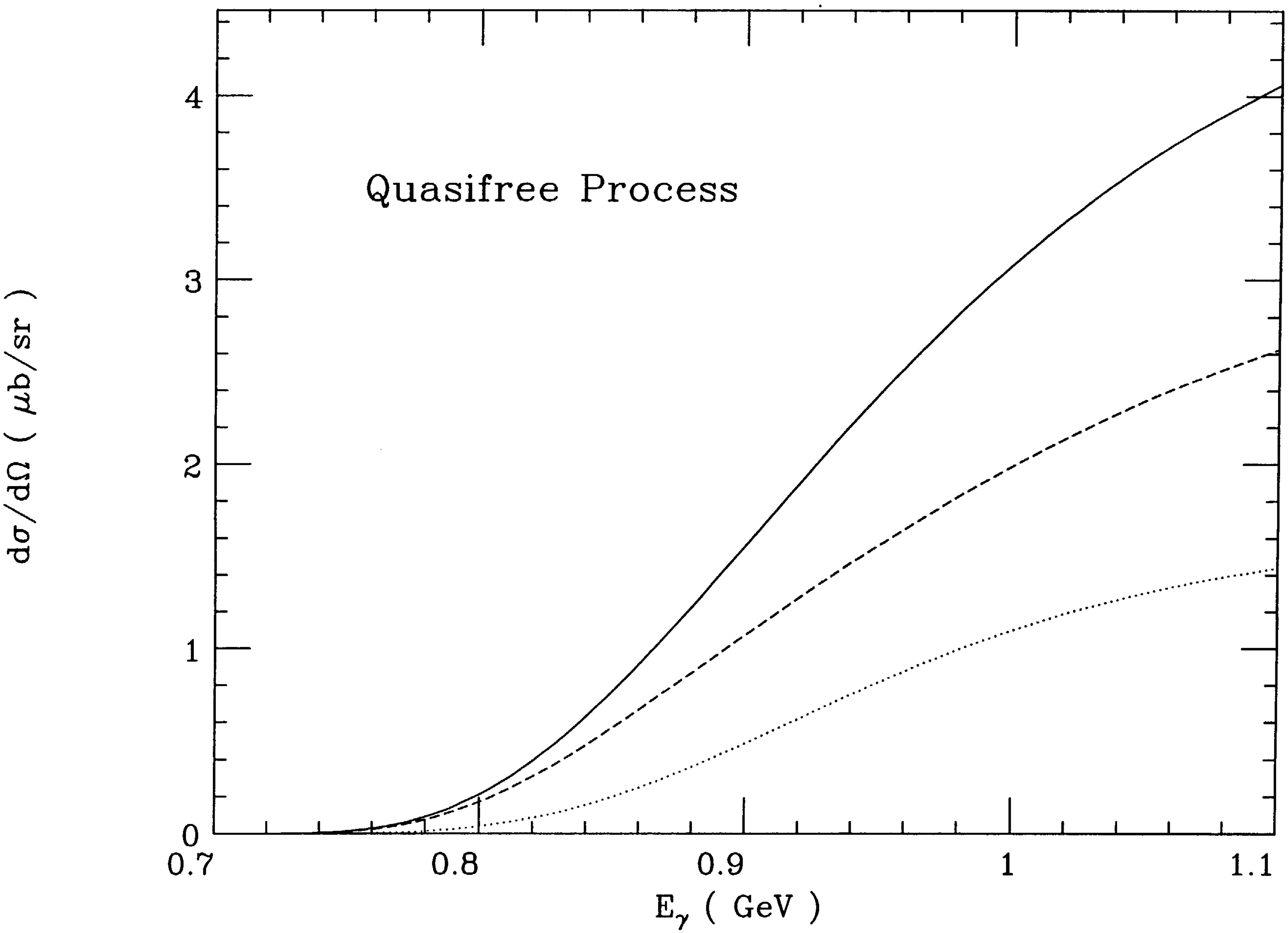


Fig. 4

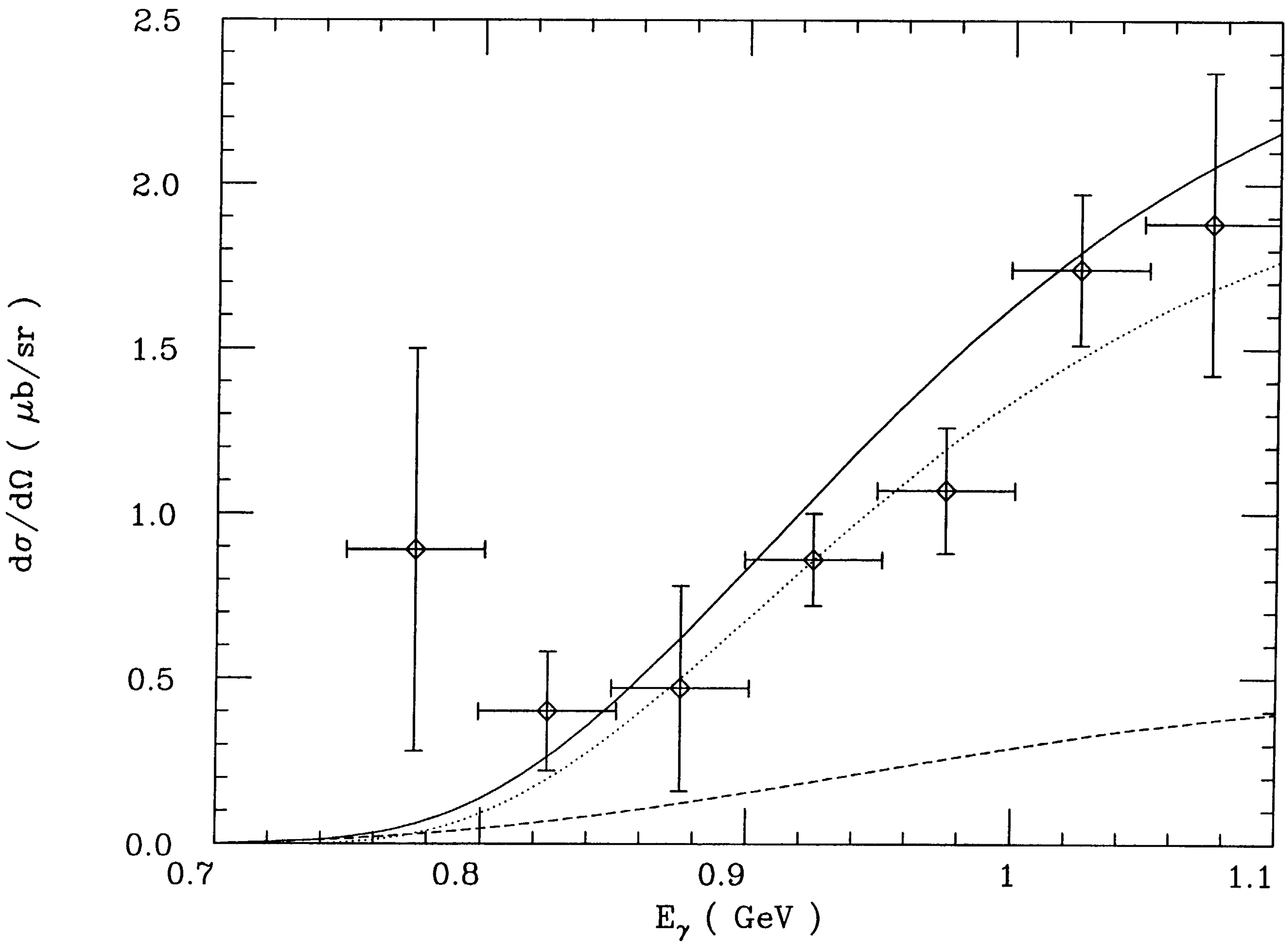


Fig. 5