Relativistic Calculations for Photonuclear Reactions (III): A Consistent Relativistic Analysis of the $(e, e'p)$ and $(\gamma, p)$ Reactions*

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Abstract

Relativistic calculations for the quasifree electron scattering process \((e, e'p)\) and the direct knockout contribution to \((\gamma, p)\) reactions are presented. The spectroscopic factors determined from the former reaction are used to fix the magnitude of the knockout contribution to the \((\gamma, p)\) reaction at 60 MeV. The results obtained for several nuclei indicate that the knockout contributions are much larger in magnitude and hence closer to the data than predicted in an earlier comparison based on non-relativistic calculations. We discuss the sensitivity of the results to the choice of parameters for the binding and final state interactions. We find these uncertainties to be more pronounced at the larger missing momenta explored by the \((\gamma, p)\) reaction. The implications of the present results for the size of contributions due to meson exchange currents are discussed.
1 Introduction

Reactions initiated by electromagnetic probes play a central role in our understanding of the structure-dynamics of nucleons and nuclei. In the latter case both quasifree \((e, e'p)\) and \((\gamma, p)\) reactions have been extensively studied. These two processes have a great deal in common in that both reactions result in the removal of a single proton from the target, via interaction with a photon, exciting essentially the same residual states. The first of the reactions is mediated by virtual photons, whereas the second is initiated by real ones. Moreover the two reactions complement each other in providing information about different momentum regions of single particle wave functions.

It has long been recognized that the similarity between the two reactions could be very useful in enhancing our understanding of the reaction mechanisms\cite{1, 2}. A recent study by Ireland and van der Steenhoven \cite{3} has compared results of non-relativistic DWIA calculations for \((e, e'p)\) and \((\gamma, p)\) reactions on a number of light and medium-weight nuclei. Under the reasonable assumption that the mechanism for the former reaction is well understood, calculations were performed first for this reaction and used in conjunction with the available data to determine the relevant spectroscopic factors and bound state parameters. The resulting parameters were then used to constrain similar calculations for the \((\gamma, p)\) reaction for a photon energy of 60 MeV. The objective was to quantify the importance of the direct knockout (DKO) mechanism to this process and hence to assess the extent of the contributions due to meson exchange current effects. The study revealed the surprising result that the constrained DKO calculations fell considerably below the data in most cases. The authors report an average value of 5.8 for the ratio between data and calculations.

The above results led Ireland and van der Steenhoven to explore possible contributions from meson exchange currents to the \((\gamma, p)\) reaction in a simple model. Using Seigert's theorem they estimated these contributions in the plane wave limit where they could determine a factor given by the ratio of the full cross section to the DKO cross section. When this factor was applied to the distorted wave DKO calculations, the agreement with data showed considerable improvement. The authors then concluded that meson exchange current contributions to \((\gamma, p)\) reactions, in this energy region, must be significant.

The purpose of the present paper is to report on similar comparative
calculations carried out within a relativistic mean field approach. We have recently carried out relativistic distorted wave calculations for the DKO contributions to \((\gamma,p)\) reactions \([4]\). There have also been several similar calculations for the \((e,e'p)\) reaction \([3,4,7,8]\). Moreover, recent studies by Hedayati-Poor et al. \([8,9,10]\) as well as other authors \([3,11,12]\) have concentrated on the question of the differences between relativistic and non-relativistic calculations for these two closely related reactions. In particular, the investigations reported in \([8,9,10]\) have pointed to the existence of subtle medium modifications to the interaction hamiltonians in the relativistic approach, which are absent in the corresponding non-relativistic treatment. This, in addition to the fact that the non-relativistic calculations referred to above require such large meson exchange contributions, suggests that a reanalysis in the relativistic framework is advisable. With the strong medium effects alluded to above, it is possible that the role of meson exchange currents could be strongly modified.

We carry out a comparison between the two reactions mentioned above along similar lines to those used by Ireland and van der Steenhoven. Relativistic calculations are carried out for \((e,e'p)\) reactions on a number of nuclei. The spectroscopic factors determined from comparison with the data are used to make predictions for \((\gamma,p)\) reactions on the same nuclei. These predictions are compared directly to the cross section data.

We outline the relativistic calculations for quasifree electron scattering and the direct knockout contribution to the \((\gamma,p)\) reaction in section 2. We then provide discussion of the specific ingredients of the models and results of the calculations for the two reactions in section \([3]\). Our conclusions are given in section \([4]\).

## 2 The Relativistic Calculations

The relativistic calculation of the amplitude in the one photon exchange model for the \((e,e'p)\) process is outlined in reference \([3]\). The main results are given briefly here with some change of notation in order to highlight the similarities between the two reactions considered here. We do not include the Coulomb distortion in the leptonic part of the amplitude. This will only be important for heavy nuclei \([4,13]\) which will not be considered in the present paper.
The relativistic expression for the differential cross section leading to a specific final state of the residual nucleus can be written as

$$\frac{d^3\sigma}{d\Omega_p d\Omega_f dE_f} = \frac{2}{(2\pi)^3} \frac{\alpha^2}{\hbar c} \left( \frac{(m_e c^2)^2}{q c^4} \frac{M c^2}{E_i} \right) \frac{1}{v_{rel} R} \times \frac{S_{J_i J_f}(J_B)}{2J_B + 1} \sum_{\mu M_B \nu_f \nu_i} \left| e_{\nu_f \nu_i}^\alpha N_{\alpha}^{\mu M_B} \right|^2,$$

(1)

where $\nu_i$ and $\nu_f$ are the spin projections of the incoming and outgoing electrons respectively, while $M_B$ and $\mu$ are the spin projections of the bound and continuum protons. The 4-momenta of the initial and final electrons are $p_i$ and $p_f$ respectively, while the final proton 4-momentum is $p_p$. The 4-momentum of the exchanged photon is $q$ and is calculated as the difference between the initial and final electron 4-momenta $q = p_i - p_f$. The 4-momentum of the recoil nucleus is $p_R$ and the initial 4-momentum of the struck proton is denoted $p_m$, which is often called the missing momentum.

The recoil factor $R$, was not included in reference [8] but we do include it here for completeness. $R$ is given in any frame by

$$R = 1 - \frac{E_p}{E_R} \left| \frac{1}{p_p} \cdot p_R \right|^2.$$

(2)

The function $N_{\alpha}^{\mu M_B}$ is

$$N_{\alpha}^{\mu M_B} = \int d^3x \, \Psi_{\mu}^\dagger (p_p, x) \Gamma_{\alpha} \Psi_{J_B, M_B} (x) \exp (i q \cdot x).$$

(3)

where the wave functions of the continuum and bound nucleons, denoted $\Psi_{\mu}$ and $\Psi_{J_B, M_B}$ respectively, are solutions of the Dirac equation containing appropriate potentials [4]. The $4 \times 4$ matrix $\Gamma_{\alpha}$, operating on the nucleon spinors is given in Eq. (2.8) of reference [8] and the four-vector which comes from the electron vertex $e_{\nu_f \nu_i}^\alpha$, is given in Eq. (2.9) of that same reference.

The distorted momentum distribution (referred to as ‘reduced cross section’ by Ireland and van der Steenhoven in reference [3]) is obtained from the cross section given above through division by a kinematic factor and the cross section for the elementary $e + p \rightarrow e + p$ process. We write [15, 16]:

$$\rho (p_m) = \frac{d^3\sigma}{d\Omega_p d\Omega_f dE_f} \left| \frac{1}{p_p} \right| d\sigma_{cc}^{e+}. $$

(4)
In the figures and the following discussion we refer to this simply as the momentum distribution. The space-like portion of the missing 4-momentum, in the impulse approximation, is the negative of the recoil nucleus 3-momentum in the lab frame $p_m = -p_R$. The free cross section, $d\sigma_{cc1}^{\text{free}}$, is that which de Forest denotes $cc1$ \cite{15} and is evaluated using the kinematics of the quasifree process with his prescription for the energy of the bound nucleon, $p_0^m = \left[ |p_m|^2 + M^2 \right]^{1/2}$. This prescription is used only in calculating the free cross section $cc1$ which divides our calculated cross section in Eq. (4) since $cc1$ divides the experimentally measured cross sections to obtain the momentum distributions which are presented as experimental data, see for example \cite{14, 18}. For the distorted wave calculations of the cross section given in Eq. (1) we use a slightly different prescription for the missing energy, namely, $p_0^m = \left[ |p_m|^2 + (M - E_s)^2 \right]^{1/2}$, where $E_s$ is the energy required to remove the bound nucleon from the target nucleus. Thus the bound proton is off-shell due to the modification of its mass by the separation energy.

The cross section for the $(\gamma, p)$ reaction in which the residual nucleus is left in a definite final state can be written as \cite{4}

$$
\frac{d\sigma}{d\Omega_p} = \frac{\alpha M c^2 |p_p|}{4\pi \hbar c} \frac{c}{E_\gamma} \frac{1}{v_{rel} R} \frac{S_{I, J_f}(J_B)}{2J_B + 1} \sum_{\mu M_B} \left| e^\alpha_r N^\mu M_B \right|^2
$$

where for the direct knockout contribution, the function $N^\mu M_B$ is the nuclear matrix element of Eq. (3). The 4-vector $e^\alpha_r$ is the photon polarization vector with two polarization states $r$. The recoil factor $R$, has exactly the same form as that of Eq. (3) but the kinematics are now those of the $(\gamma, p)$ reaction.

In the comparison with experimental data it is not necessary to define a common function for both the $(e, e'p)$ and $(\gamma, p)$ reactions. Ireland and van der Steenhoven presented their results in terms of common reduced cross sections in reference \cite{3}. The appeal of this procedure stems from the fact that the non-relativistic amplitudes for the two reactions reduce, in the plane wave limit, to simpler forms that depend on the momentum wave function of the struck nucleon. The relativistic amplitudes, however, do not lend themselves to a similar simplification. The important point in this regard, is that the two reactions probe complementary momentum regions of the nuclear wave function: the $(e, e'p)$ reaction for low momenta, and the $(\gamma, p)$ reaction for higher momenta. In that sense it is extremely interesting to
carry out a joint analysis of the two processes. This however does not restrict the way in which the individual data for each reaction is presented. Thus in the next section we compare our calculations for \((e, e'p)\) with data for the momentum distribution because that is the way the data are usually presented. Note that we are simply dividing our calculated differential cross section by the same factor by which the experimental differential cross section has been divided so the representation is irrelevant. We then compare the calculated and experimental cross sections for the \((\gamma, p)\) reaction and check whether the predicted relativistic results are in better agreement than those obtained non-relativistically.

3 Discussion

We begin our discussion with the elements common to calculations of the two reactions. The bound state protons are described by solutions of a Dirac equation containing the relativistic Hartree potentials of Horowitz and Serot [19]. These potentials, obtained through self-consistent calculations, usually underbind the protons in the states we consider by 1-3 MeV. The \textit{rms} radii, however, are in reasonable agreement with those found by Ireland and van der Steenhoven [3] as well as values obtained by other authors [17, 18, 21, 22].

The continuum proton in the final state is described by solutions of a Dirac equation containing complex phenomenological optical potentials obtained from fits to proton elastic scattering data [22]. There are several sets of potentials available, some of which are energy dependent (E-dep) and constructed from a fit to data for a specific nucleus, such as \(^{12}\text{C}\), \(^{16}\text{O}\), and \(^{40}\text{Ca}\), in the proton kinetic energy range of \(\sim 25\) MeV to 1 GeV. Other potentials are parameterized in terms of target mass as well as proton energy (E+A-dep) and can be used to generate potentials for which no proton elastic scattering data exist. We shall perform calculations using both types of potentials.

Given the potentials discussed above, the only parameters left to determine are the spectroscopic factors. In order to obtain spectroscopic factors \(S^R\), the relativistic calculations for quasifree electron scattering are normalized by eye to the right-hand peak of the experimental data, where the error bars tend to be smallest. Results of our calculations for \((e, e'p)\) reactions are plotted along with the experimental data in parts (a) of Figs. 1 to 5. In all cases the shape of the data is well described by our calculations indicating
that the Hartree wave functions are providing a reasonable description of the bound proton in the range of missing momenta considered. The spectroscopic factors obtained are recorded in Table 1.

Column 3 of Table 1 shows the spectroscopic factors extracted from calculations in which the final proton distortion is provided by E dependent potentials of Cooper et al. [22] for a particular target nucleus. Column 4 of Table 1 shows the spectroscopic factors extracted from calculations in which the final proton distortion is provided by ‘fit 1’ of the E and A dependent potentials of that same reference. The last column of Table 1 shows the spectroscopic factors obtained through the non-relativistic analysis of Ireland and van der Steenhoven [3]. The non-relativistic spectroscopic factor for knockout of the 1p3/2 proton from 16O is obtained from the analysis of Leuschner et al. [18] (the data for this state were not considered in reference [3]). These spectroscopic factors are in close agreement with others obtained through similar non-relativistic analyses [17, 18, 20, 21]. Note that the relativistic spectroscopic factors are slightly larger than those obtained non-relativistically, in agreement with other analyses (see for example Udias et al. [6] and references therein). One important feature of the present analysis is the difference in spectroscopic factors obtained from calculations involving the different relativistic potentials. This is a measure of our uncertainty in the knowledge of the continuum proton wave function. We see differences of up to fifteen percent between the spectroscopic factors obtained using the E dependent

| nucleus | nucleon state | S^R_{E-dep} | S^R_{E+A-dep} | S^{nR} |
|---------|--------------|-------------|----------------|-------|
| 12C     | 1p3/2        | 2.00        | 2.24           | 1.825 |
| 16O     | 1p1/2        | 1.26        | 1.38           | 1.124 |
|         | 1p3/2        | 2.24        | 2.60           | ~2.2  |
| 40Ca    | 1d3/2        | 3.24        | 3.12           | 2.698 |
| 51V     | 1f7/2        | n/a         | 0.46           | 0.384 |

Table 1: Spectroscopic factors extracted from (e, e’p) data. The superscripts R and nR on the spectroscopic factors refer to relativistic and non-relativistic calculations respectively.
potentials from those obtained using the E and A dependent potentials. We find similar differences when we use different bound state potentials with the E dependent optical potentials. Even though there are differences in the extracted spectroscopic factors arising from sensitivity to the input ingredients of the model, the resulting fits to the \((e,e'p)\) data are all of similar quality. These uncertainties should be kept in mind when drawing conclusions concerning the magnitude of the DKO contribution to \((\gamma,p)\) reactions.

Relativistic calculations of the direct knockout contribution to \((\gamma,p)\) reactions are carried out using the same relativistic Hartree potentials and distorting potentials used in the electron scattering calculations, as well as the same relativistic spectroscopic factors (see Table 1). We stress that there are no parameters left to adjust when comparing the results of the \((\gamma,p)\) calculations to the data. The resulting cross sections can be regarded as relativistic predictions for the knockout contribution to the \((\gamma,p)\) reaction. The results are shown in parts (b) of Figs. 1-5. The solid curves in all figures show the results of calculations for the reactions using the Hartree binding potentials and ‘fit 1’ of the E and A dependent optical potentials discussed earlier. The dashed curves in Figs. 2 and 3 use E dependent optical potentials along with Hartree binding, while the dotted curves result from utilizing a Woods-Saxon binding potential. The curves of Fig. 5 result from using three different E and A dependent potentials.

In order to emphasize the complementary momentum regions explored by the two reactions considered we have included an insert in Fig. 1(b) showing the missing momentum as a function of the proton lab angle for the \((\gamma,p)\) reaction with a \(^{12}\text{C}\) target. Note that the lowest missing momentum available in the \((\gamma,p)\) reaction is near the maximum of the missing momenta for which data are shown for the \((e,e'p)\) reaction. In moving to larger nuclei with the same incident photon energy in the lab the missing momentum simply scales upward slightly.

In comparing our relativistic calculations with the \((\gamma,p)\) data it is striking that our calculations lie slightly above the data in two cases (for the \(^{12}\text{C}\) and \(^{16}\text{O}\) targets shown in Figs. 1 and 3), and below in two cases (for the \(^{16}\text{O}\) and \(^{40}\text{Ca}\) targets shown in Figs. 2 and 4). In the fifth case in which the target is \(^{51}\text{V}\) the calculations lie within the error bars of the data. This is contrary to the results of the non-relativistic analyses of Ireland and van der Steenhoven who found that DKO calculations for \((\gamma,p)\) reactions lie consistently below the data; they reported an average factor of 5.8 for light nuclei \(^3\). The largest
differences between data and calculations occur for the lightest targets in both the non-relativistic and relativistic analyses. However the results of our relativistic calculations lie much closer to the data than the corresponding non-relativistic results for these light nuclei.

At this point it may be useful to comment on some aspects of the potential sensitivities in the present calculations. The Hartree potentials result in a binding energy that is slightly smaller than the experimental value. Alternate calculations for $^{16}$O were performed using Woods-Saxon binding potentials, which reproduce the experimental binding energy and also provide an rms radius for the bound state that is within one percent of that found from the Hartree potentials. We find little sensitivity to the results between the two potentials for the $(e, e'p)$ reaction (see part (a) of Figs. 2 and 3). This is because the momentum space wave functions for the bound states are very similar in the low momentum region explored by the $(e, e'p)$ reaction and only begin to show differences in the higher momentum region available via the $(\gamma, p)$ reaction. Figures 2(b) and 3(b) show that this is indeed the case, with a range of difference in the neighborhood of 30%. We have also done calculations in which the depth of the Dirac-Hartree scalar potential is varied in order to reproduce the experimental binding energy. This requires a change in depth of the potential of less than 3% but can yield a change in the $(\gamma, p)$ cross section of up to 30%.

Previously we pointed out some sensitivity to changes in the global optical potentials leading to different values of spectroscopic factors determined from $(e, e'p)$ data. We have done calculations for the $^{12}$C and $^{51}$V targets using the three available E and A dependent fits [22], and results are shown for the $^{51}$V target in Fig. 5. For the $(e, e'p)$ reaction the results change by less than five percent amongst the three potentials. The $(\gamma, p)$ reaction shows slightly more sensitivity particularly for angles larger than 90°, where the momentum transfer is large. However, there are no striking differences in shape or magnitude due to changes in the optical potentials. Similar results are obtained for $^{12}$C.

It is evident from the above discussion that relativistic calculations for $(\gamma, p)$ reactions do show some sensitivity to changes in the ingredients, and an estimate of these sensitivities combined leads to a possible variation in the magnitude of the cross sections by up to a factor of two, along with some variation in shape. It has also been noted by Harty et al. [23] that there are unexplained inconsistencies within the set of experimental $(\gamma, p)$ data leading
to differences of factors of up to two between differential cross sections at the same angle and photon energy while the systematic errors are quoted as 10% to 22%. Within these uncertainties our relativistic calculations are much closer to the \((\gamma, p)\) data than the non-relativistic calculations of Ireland and van der Steenhoven.

4 Conclusions

In this paper we have presented a comparative study of \((e, e'p)\) and \((\gamma, p)\) reactions for several nuclei. The objective is to make a quantitative assessment of the contribution from the direct knockout mechanism to the \((\gamma, p)\) reactions in the relativistic approach and to compare this with the non-relativistic results of Ireland and van der Steenhoven. The \((e, e'p)\) reaction was used to fix the spectroscopic factors which were subsequently used to make predictions for the \((\gamma, p)\) reaction.

In the course of our study we have looked at the dependence of the results, for both \((e, e'p)\) and \((\gamma, p)\) reactions, on the type of bound state used and on the optical potentials describing the final state interactions of the outgoing proton. We find little sensitivity to the choice of binding potential in the \((e, e'p)\) reaction; this is largely due to the low missing momenta covered by the present experimental data. The \((\gamma, p)\) reaction explores a higher range of missing momenta, and we find slightly more sensitivity to the choice of binding and optical potentials. Although the optical potentials we use are the best currently available there is clearly room for improvement in their precise specification. Note however that we find less variation amongst the potentials used here, as measured by the spectroscopic factor extracted via the \((e, e'p)\) reaction, than found in earlier calculations [4, 10].

With the above comments in mind, our relativistic analysis shows that the DKO contribution lies much closer to the data, compared to the non-relativistic calculations of Ireland and van der Steenhoven, who have found that the DKO calculations lie consistently below the data by an average factor of 5.8. The factors required to bring our calculations to the data are consistently less than 2. It should be noted that our present conclusions are in agreement with the findings of Ryckebusch et al. [24] (see also Bobeldijk et al. [25]) who have done non-relativistic RPA calculations of meson exchange contributions to \((\gamma, p)\) reactions. They have found that meson exchange is
not the dominant contributor for the \((\gamma, p)\) reaction leading to the ground state of the residual nucleus, while it can modify the DKO cross section by up to a factor of two when the residual nucleus is excited to some low lying states.

We conclude that the direct knockout contributions to the \((\gamma, p)\) reaction are much closer to the data than is indicated in the non-relativistic calculations of Ireland and van der Steenhoven. This implies that meson exchange currents may not play as dominant a role in our relativistic calculations, although they may certainly contribute significantly in obtaining the correct shape and magnitude of the cross section. In order to fully understand the role of the various competing mechanisms, it is desirable in this regard to carry out complete relativistic calculations, including meson exchange current corrections, and to compare the results with the data over a wide range of photon energies.

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Figure Captions

FIG. 1. Knockout of a $\text{1}p_{2/3}$ proton from a $^{12}\text{C}$ target leading to the $^{11}\text{B}$ ground state. Hartree bound state wave functions are used \[19\] and the proton optical potentials are E+A-dep, fit 1, from reference \[22\]. (a) Momentum distribution for the reaction $^{12}\text{C}(e,e'p)^{11}\text{B}_{\text{g.s.}}$. The energy of the incident electron is 481.1 MeV, and the kinetic energy of the detected proton is fixed at 70 MeV with parallel kinematics. The data are from reference \[17\]. (b) Cross section for the reaction $^{12}\text{C} (\gamma,p)^{11}\text{B}_{\text{g.s.}}$. The photon energy is 60 MeV. The data are from reference \[26\].

FIG. 2. Knockout of a $\text{1}p_{2/3}$ proton from a $^{16}\text{O}$ target leading to the $^{15}\text{N}$ ground state. (a) Momentum distribution for the reaction $^{16}\text{O}(e,e'p)^{15}\text{N}_{\text{g.s.}}$. The energy of the incident electron is 456 MeV, and the kinetic energy of the detected proton is fixed at 90 MeV with parallel kinematics. The data are from reference \[18\]. (b) Cross section for the reaction $^{16}\text{O} (\gamma,p)^{15}\text{N}_{\text{g.s.}}$. The photon energy is 60 MeV. The data are from reference \[27\]. Dashed curve — Hartree binding potential and E-dep optical potential for $^{16}\text{O}$. Dotted curve — Woods-Saxon binding potential and E-dep optical potential for $^{16}\text{O}$. Solid curve — Hartree binding potential and E+A-dep optical potential, fit 1.

FIG. 3. Same as Fig. 2 but for knockout of a $\text{1}p_{2/3}$ proton leading to the $^{3/2}−$ excited state at 6.3 MeV in $^{15}\text{N}$.

FIG. 4. Knockout of a $\text{1}d_{2/3}$ proton from a $^{40}\text{Ca}$ target leading to the $^{39}\text{K}$ ground state. Hartree bound state wave functions are used \[19\] and the proton optical potentials are E+A-dep, fit 1, from reference \[22\]. (a) Momentum distribution for the reaction $^{40}\text{Ca}(e,e'p)^{39}\text{K}_{\text{g.s.}}$. The energy of the incident electron is 460 MeV, and the kinetic energy of the detected proton is fixed at 100 MeV with parallel kinematics. The data are from reference \[20\]. (b) Cross section for the reaction $^{40}\text{Ca} (\gamma,p)^{39}\text{K}_{\text{g.s.}}$. The photon energy is 60 MeV. The data are from reference \[28\].

FIG. 5. Knockout of a $\text{1}f_{2/3}$ proton from a $^{51}\text{V}$ target leading to the $^{50}\text{Ti}$ ground state. Hartree bound state wave functions are used \[19\] and the proton optical potentials are E+A-dep, from reference \[22\]. (a) Momentum distribution for the reaction $^{51}\text{V}(e,e'p)^{50}\text{Ti}_{\text{g.s.}}$. The energy of the incident electron is 461 MeV, and the kinetic energy of the detected proton is fixed...
at 70 MeV for \( p_m < 140\text{MeV/c} \) and 100 MeV for \( p_m > 140\text{MeV/c} \), with parallel kinematics. The data are from reference [21]. (b) Cross section for the reaction \( ^{51}\text{V} (\gamma,p)^{50}\text{Ti}_{g.s.} \). The photon energy is 60 MeV. The data are from reference [29]. Solid curve — fit 1. Dashed curve — fit 2. Dotted curve — fit 3.
FIGURE 1.
\[ \frac{d\sigma}{d\Omega_p} \text{ (nb/sr)} \]

FIGURE 2.
FIGURE 3.
FIGURE 4.
**FIGURE 5.**