Photoproduction of $a_2(1320)$ in a Regge model

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In this work, the photoproduction of $a_2(1320)$ off a proton target is investigated within an effective Lagrangian approach and the Regge model. The theoretical result indicates that the shapes of the total and differential cross sections of the $\gamma p \to a_2^+ n$ reaction within the Feynman (isobar) model are much different from that of the Reggeized treatment. The obtained cross section is compared with the existing experimental results at low energies. The $a_2(1320)$ production cross section at high energies can be tested by the COMPASS experiment, which can provide important information for clarifying the role of the Reggeized treatment at that energy range.

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I. INTRODUCTION

Within the past decades great progress has been achieved in hadron spectroscopy \cite{1,2}. Especially, inspired by the observation of exotic states \cite{1,2} (such as the candidate for the tetraquark \cite{3} or pentaquark \cite{4} state etc.), the underlying structure of these states attracts much attention both in theory and experiment. Observation of the exclusive photoproduction of exotic hadronic states off baryons, proposed in the Refs. \cite{5-8}, is the most direct way to get information about their nature. At higher energies such processes can be described in terms of Regge trajectory exchanges \cite{11,12}. In Ref. \cite{13}, the $\eta$ and $\eta'$ photoproduction were studied with the Regge model. It is found that the Reggeized model gives a good description for these reactions in and beyond the resonance region. Thus the photoproduction reaction at high energy may be appropriate to study the role of Reggeized treatment.

In the 1950s, Regge proved the importance of extending the angular momentum $J$ to the complex field \cite{14,15}. For more general reviews about the Regge theory, see Refs. \cite{16,18}. Later, the exchange of dominant meson Regge trajectories was used to successfully describe the hadron photoproduction \cite{19,22}. However, there is one question: has the Regge trajectory approach been well tested by experiment at higher energies?

In the past, the $a_2(1320) (\equiv a_2)$ photoproduction was extensively studied. The estimation of the exclusive photoproduction cross section for $a_2$ has been performed according to the one-pion exchange (OPE) mechanism with absorption in \cite{23}. The experimental results for the values and energy dependence of this cross section at relatively low ($< 20$ GeV) energies are quite consistent with the prediction of this model \cite{52}. Nevertheless the energy range covered by the existing experimental data is not enough to distinguish between the OPE prediction and the Regge trajectory approach \cite{10}.

The COMPASS experiment at CERN, uses the muon beam, can significantly enlarge the available energy range of virtual photons up to about 150 GeV. COMPASS has a good opportunity to contribute to the study of exotic charmonia via their photoproduction. However, the uncertainties of the theoretical description of photon-nucleon interaction at high energies complicate this task. The process of $\gamma^* p \to a_2^+ n$, where $\gamma^*$ is a virtual photon, has quite good experimental signature and can be used as a benchmark. Possibility to use $a_2$ photoproduction as a benchmark for study of exotic hadrons is discussed also in \cite{24}. It is also significant to carry out more theoretical studies on the $\gamma p \to a_2^+ n$ process in order to clarify the role of the Reggeized treatment.

Moreover, due to the vector meson dominance (VMD) assumption, a photon can interact with a vector meson, which means that the $\gamma p \to a_2^+ n$ reaction can also proceed through the vector meson dominance (VMD) mechanism \cite{25,27}. Thus the $a_2$ photoproduction mechanism is also an interesting issue.

In this work, the $\gamma p \to a_2^+ n$ reaction is investigated using an effective Lagrangian approach and the Regge model. In addition to the $\pi$ exchange, the contributions from the VMD mechanism is also considered. The differential cross section of the $\gamma p \to a_2^+ n$ reaction is also calculated, which could be tested by further COMPASS experiment.

This paper is organized as follows. After the introduction, we present the formalism and the main ingredients which are used in our calculation. The numerical results and discussions are given in Sec. III. In Sec. IV, we give a detailed illustration of the possibility of the experimental test at COMPASS. Finally, the paper ends with a brief summary.
II. FORMALISM

In the present work, an effective Lagrangian approach in terms of hadrons is adopted, which is an important theoretical method in investigating various scattering processes [28–33].

Figure 1 describes the basic tree-level Feynman diagrams for the \( a_2(1320) \) photoproduction process through general \( \pi \) exchange [Fig. 1(a)] and vector meson dominance (VMD) mechanism [Fig. 1(b)] [25–27].

![Feynman diagrams](image)

FIG. 1: (a): Feynman diagrams for the \( \gamma p \to a_2n \) reaction via \( \pi \) exchange. (b) same as in (a), but for the case in the frame of the VMD model.

To gauge the contribution of this diagram, we need to know the relevant effective Lagrangian densities. For the \( \pi NN \) interaction vertex we take the effective pseudoscalar coupling [34],

\[
\mathcal{L}_{\pi NN} = -i g_{\pi NN} \bar{N} \gamma_\tau \tau \cdot \vec{\pi} N
\]

where \( \tau \) is the Pauli matrix, while \( N \) and \( \pi \) stand for the fields of the nucleon and the pion, respectively. The coupling constant of the \( \pi NN \) interaction was given in many theoretical works, and we take \( g_{\pi NN}^2 / 4\pi = 12.96 \) [35, 36].

The commonly employed Lagrangian densities for \( a_2 \pi \gamma \) and \( a_2 \pi \rho \) couplings are [37, 40]:

\[
\mathcal{L}_{a_2 \pi \gamma} = \frac{g_{a_2 \pi \gamma}}{m_\rho^2} \epsilon^{\mu \nu \rho \sigma} a_2^\mu A_2^\nu \partial_\rho \phi_\sigma, \quad (2)
\]

\[
\mathcal{L}_{a_2 \pi \rho} = \frac{g_{a_2 \pi \rho}}{m_\rho^2} \epsilon^{\mu \nu \rho \sigma} a_2^\mu \rho_2^\nu \partial_\rho \phi_\sigma, \quad (3)
\]

where \( A^\rho, a_2^\rho, \rho_2^\rho \) and \( \phi_\rho \) are the photon, \( a_2 \) meson, \( \rho \) and \( \pi \) fields. \( m_\pi \) is the mass of the \( \pi \) meson. The coupling constant \( g_{a_2 \pi \gamma} \) and \( g_{a_2 \pi \rho} \) can be determined by the partial decay widths \( \Gamma_{a_2 \to \pi \gamma} \) and \( \Gamma_{a_2 \to \pi \rho} \), respectively.

With the above Lagrangian densities, we obtain

\[
\Gamma_{a_2 \to \pi \gamma} = \frac{g_{a_2 \pi \gamma}^2}{10\pi m_\pi^4} |\vec{p}_{\gamma}^{\text{c.m.}}|^5, \quad (4)
\]

\[
\Gamma_{a_2 \to \pi \rho} = \frac{g_{a_2 \pi \rho}^2}{10\pi m_\rho^4} |\vec{p}_{\rho}^{\text{c.m.}}|^5, \quad (5)
\]

with

\[
|\vec{p}_{\gamma}^{\text{c.m.}}| = \frac{\lambda_{1/2}(M_{a_2}^2, m_\pi^2, m_\gamma^2)}{2M_{a_2}}, \quad (6)
\]

\[
|\vec{p}_{\rho}^{\text{c.m.}}| = \frac{\lambda_{1/2}(M_{a_2}^2, m_\rho^2, m_\rho^2)}{2M_{a_2}}, \quad (7)
\]

where \( \lambda \) is the Källén function with \( \lambda(x, y, z) = (x - y - z)^2 - 4yz \). Using the partial decay widths of \( a_2(1320) \) as listed in the PDG book [41], we get \( g_{a_2 \pi \gamma} = 0.539 \times 10^{-2} \) GeV\(^{-1}\) and \( g_{a_2 \pi \rho} = 0.268 \) GeV\(^{-1}\).

For the \( a_2 \gamma \pi \) interaction vertex we can also derive it using the vector meson dominance (VMD) mechanism [25–27] on the assumption that the coupling is due to a sum of intermediate vector mesons. In the VMD mechanism for photoproduction, a real photon can fluctuate into a virtual vector meson, which subsequently scatters from the target proton. Under the VMD mechanism, the Lagrangian of depicting the coupling of the intermediate vector meson \( \rho \) with a photon is written as

\[
\mathcal{L}_{\rho \gamma} = -\frac{e m_\rho}{f_\rho} V_\mu A^\mu, \quad (8)
\]

where \( m_\rho \) and \( f_\rho \) are the mass and the decay constant of the \( \rho \) meson, respectively. With the above equation, we get the expression for the \( \rho \to e^+e^- \) decay,

\[
\Gamma_{\rho \to e^+e^-} = \left( \frac{e}{f_\rho} \right)^2 \frac{8\alpha |\vec{p}_{e^\pm}^{\text{c.m.}}|^3}{3m_\rho^3}, \quad (9)
\]

where \( \vec{p}_{e^\pm}^{\text{c.m.}} \) indicates the three-momentum of an electron in the rest frame of the \( \rho \) meson, while \( \alpha = e^2 / 4\hbar c = 1 / 137 \) is the electromagnetic fine structure constant. Thus, with the partial decay width of \( \rho \to e^+e^- \) [41]

\[
\Gamma_{\rho \to e^+e^-} = 7.04 \text{ keV}, \quad (10)
\]

we get the constant \( e / f_\rho \approx 0.06 \).

To account for the internal structure of hadrons, we introduce phenomenological form factors. For the vertex of \( a_2 \pi \rho \), the following form factor is adopted [30, 42, 43],

\[
F_{a_2 \pi \rho}(q_\rho^2) = \frac{m_\rho^2 - m_\pi^2}{m_\rho^2 - q_\rho^2}, \quad (11)
\]

For the vertices of \( \pi NN \) and \( a_2 \pi \gamma \), three types of the form factors are considered [30, 42, 43]: (i) the monopole form factor

\[
F_{\pi NN}(q_\pi^2) = F_{a_2 \pi \gamma}(q_\pi^2) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - q_\pi^2}, \quad (12)
\]
(ii) the dipole form factor
\[ F_{\pi NN}(q^2) = F_{a_2 \pi\gamma}(q^2) = \frac{(\Lambda_q^2 - m_n^2)}{q^2 - m_n^2} \left( \frac{\Lambda_d^2 - m_p^2}{q^2 - m_p^2} \right)^2, \]

(iii) the exponential form factor
\[ F_{\pi NN}(q^2) = F_{a_2 \pi\gamma}(q^2) = \exp \left[ R^2 \frac{(t - m_2^2)}{(1 - X_L)} \right], \]

where \( \Lambda_q, \Lambda_d \) and \( R \) are the free parameters, which can be determined from the data in this work. \( X_L \) is momentum fraction of the proton carried by the neutron.

With the effective Lagrangian densities as listed above, the invariant scattering amplitudes for the \( \gamma(p_1)p(p_2) \to a^+_2(p_3)n(p_4) \) process can be written as
\[
\mathcal{M}_a = \sqrt{2g_{\pi NN}g_{a_2 \gamma}} \frac{F_{\pi NN}(q^2)F_{a_2 \pi\gamma}(q^2)}{m_n^2}
\times \gamma_5 \epsilon_{\mu
u\rho\sigma} F^{\mu\nu\sigma}_{\pi\gamma}(p_3) p^\rho \epsilon^\sigma(p_1) (q_\pi)_{\alpha} \Gamma_{\alpha}(p_2) \]

for Fig. 1(a), and
\[
\mathcal{M}_b = \frac{1}{m_n^2} \epsilon_{\pi NN} a_2 \pi\gamma \frac{F_{\pi NN}(q^2)F_{a_2 \pi\gamma}(q^2)}{m_n^2}
\times \gamma_5 \epsilon_{\mu
u\rho\sigma} F^{\mu\nu\sigma}_{\pi\gamma}(p_3) p^\rho \epsilon^\sigma(p_1) (q_\pi)_{\alpha} \Gamma_{\alpha}(p_2) \]

for Fig. 1(b). Here \( \epsilon^\sigma(p_1) \) and \( T^{\mu\nu\sigma}(p_3) \) are the photon polarization vector and the polarization vector of the \( a_2 \), respectively, \( u(p_2) \) and \( \bar{u}(p_2) \) are the Dirac spinors for the initial proton and final neutron, respectively.

To describe the behavior at high photon energy, we introduce the Regge trajectories
\[
\frac{1}{q^2 - m_n^2} \to D_{\alpha} = \left( \frac{s}{s_{\text{scale}}} \right)^{\alpha_{\pi}(t)} \frac{\pi \alpha_0' e^{-i \pi \alpha_{\pi}(t)}}{\Gamma(1 + \alpha_{\pi}(t)) \sin(\pi \alpha_{\tau}(t))},
\]

where \( \alpha_0' \) is the slope of the trajectory and the scale factor \( s_{\text{scale}} \) is fixed at 1 GeV, while \( s = (p_1 + p_2)^2 \) and \( t = (p_2 - p_1)^2 \) are the Mandelstam variables. In addition, the kaonic Regge trajectory \( \alpha_K(t) \) is given by
\[
\alpha_{\tau}(t) = 0.7(t - m_n^2).
\]

With \( s = (p_1 + p_2)^2 \), the unpolarized differential cross section for the \( \gamma(p_1)p(p_2) \to a^+_2(p_3)n(p_4) \) process at the center of mass (c.m.) frame is given by
\[
\frac{d\sigma}{d\cos\theta} = \frac{1}{32\pi s} \left| p^c.m. \right| \left| p^c.m. \right| \left( \frac{1}{4} \sum_{\text{spins}} |\mathcal{M}_{a/b}|^2 \right),
\]

where \( \theta \) denotes the angle of the outgoing \( a^+_2 \) meson relative to the beam direction in the c.m. frame, while \( p^c.m. \) and \( p^c.m. \) are the three-momenta of the initial photon beam and the final \( a^+_2 \), respectively.

### III. RESULTS AND DISCUSSION

#### A. Cross section for the \( \gamma p \to a^+_2 n \) reaction

Energy dependence of the cross section calculated above for each of the models for the fixed parameter \( \Lambda_t = 1 \) GeV of the monopole form factor is shown in Fig. 2. One can see that the difference between the models is about an order of magnitude. Fine tuning of the parameter \( \Lambda_t \) can be performed on the basis of the experimental results.

The existing experimental data \([48-52]\) for \( a_2 \) photoproduction at low energies are summarized in Table I and Fig. 3. The original data from \([51]\) have been reanalysed in \([52]\) to take into account the actual branching ratio for \( a_2 \to 3\pi \) decay channel, since it was taken to be 100%. To fix the same problem we scale the result for the cross section and the error presented in \([43]\) by the factor of 1.5. We also skip the result for \( E_\gamma = 19.5 \) GeV, which seems are in tension with the shape of the expected theoretical curves. The MINUIT code of the CERNLIB library was used to perform one-parameter \( \chi^2 \) fits of the theoretical curves to the \( \sigma_{\gamma p \to a^+_2 n} \) data. The free parameters involved and their fitted values are listed in Table II.

### TABLE I: The experimental data for \( a_2 \) photoproduction cross section. Here the beam energy \( E_\gamma \) is in the units of GeV, while the cross section \( \sigma_{\gamma p \to a^+_2 n} \) is in the units of \( \mu b \).

| \( E_\gamma \) (GeV) | \( \sigma_{\gamma p \to a^+_2 n} \) (\( \mu b \)) | Data source |
|-------------------|---------------------------------|----------|
| 3.625 (3.25-4.0)  | 0.7 ± 0.3                       | [48]     |
| 4.2 (3.7-4.7)     | 1.2 ± 0.45                      | [49]     |
| 4.8 (4.3-5.25)    | 2.6 ± 0.6                       | [51, 52] |
| 5.1 (4.8-5.4)     | 0.81 ± 0.25                     | [50]     |
| 5.15 (4.0-6.3)    | 0.3 ± 0.3                       | [48]     |
| 5.25 (4.7-5.8)    | 0.9 ± 0.45                      | [49]     |
| 7.5 (6.8-8.2)     | 0.45 ± 0.45                     | [49]     |
| 19.5              | 0.29 ± 0.06                     | [52]     |

### TABLE II: The fitted values of the free parameter \( \Lambda_t \) of the monopole form factor, while the cutoff \( \Lambda_t \) is in the units of GeV.

| type                  | \( \Lambda_t \) | \( \chi^2/ndf \) |
|-----------------------|-----------------|-----------------|
| \( \pi \) exchange    | 0.99±0.07       | 2.23            |
| \( \pi \) exchange(Reggeized) | 3.58±0.66 | 2.73            |
| VMD                   | 0.35±0.02       | 2.05            |
| VMD(Reggeized)        | 0.46±0.04       | 2.04            |

The fitted parameter \( \Lambda_t \) satisfies the expectation with a reasonable \( \chi^2/ndf \). And yet, it is found that the cases with Reggeized treatment need a larger \( \Lambda_t \). For comparison, we also calculate the result with dipole or exponential form factor. The fitted parameter \( \Lambda_d \) and \( R \) are listed in Table III and Table IV, respectively. Fig. 3 show that the fitted results with the three types of form factor. It is found that the difference is small the result.
shapes of the differential cross section slowly with increasing energy. It is seen that the differential cross section with the Reggeized treatment is very sensitive to the angle $\theta$ and makes a considerable contribution at forward angles.

![Diagram](image)

**FIG. 2:** (Color online) Total cross section for the $\gamma p \rightarrow a_2^+ n$ reaction for the fixed parameter $\Lambda_t = 1$ GeV.

### B. Dalitz process $\gamma p \rightarrow \rho \pi n$

Considering the $a_2$ are usually detected in experiment via the $\rho\pi$ invariant mass, it would be useful to give the theoretical predictions of the differential cross section $d\sigma_{\gamma p \rightarrow a_2^+ n \rightarrow \rho \pi n} / dM_{\rho\pi}$ as a function of the beam energy $E_{\gamma}$, which could be tested by further experiment. Since the full decay width of the $a_2(1320)$ is small enough in comparison to its mass, the invariant mass distribution for the Dalitz process $\gamma p \rightarrow \rho \pi n$ can be defined with the two-body process

$$d\sigma_{\gamma p \rightarrow \rho \pi n} / dM_{\rho\pi} \approx \frac{\pi}{2m_{a_2}M_{\rho\pi}} \frac{\Gamma_{a_2 \rightarrow \rho \pi}}{\Gamma_{a_2}} \left( \frac{m_{a_2}^2 - M_{\rho\pi}^2}{m_{a_2}^4} \right)^2 \left( \frac{m_{\rho\pi}^2}{m_{a_2}^2} \right)^2.$$ 

where the full width $\Gamma_{a_2} = 107$ MeV and the partial width $\Gamma_{a_2 \rightarrow \rho \pi} = 75$ MeV are taken.

With the above equations and the fitted parameters as listed in Table II, the invariant-mass distribution $d\sigma_{\gamma p \rightarrow a_2^+ n \rightarrow \rho \pi n} / dM_{\rho\pi}$ for $E_{\gamma} = 3 - 200$ GeV is calculated, as shown in Fig. 7. It is seen that there exists an obvious peak at $M_{\rho\pi} \approx 1.32$ GeV.

### IV. POSSIBILITY OF THE EXPERIMENTAL TEST AT COMPASS

The COMPASS experiment\(^{[54]}\) is situated at the M2 beam line of the CERN Super Proton Synchrotron. Since 2002 it has obtained experimental data for positive muons scattering of $160\text{ GeV}/c$ (2002-2010) or $200\text{ GeV}/c$ momentum (2011) off solid $^6\text{LiD}$ (2002-2004) or $\text{NH}_3$ polarized targets (2006-2011). Particle tracking and identification is performed in a two-stage spectrometer covering a wide kinematical range. The trigger system comprises hodoscope counters and hadron calorimeters.

### TABLE III: The fitted values of the free parameter $\Lambda_t$ of the dipole form factor, while the cutoff $\Lambda_c$ is in the units of GeV.

| type        | $\Lambda_t$ | $\chi^2$/ndf |
|-------------|-------------|--------------|
| $\pi$ exchange | 1.53±0.11   | 2.26         |
| $\pi$ exchange (Reggeized) | 3.79±0.78   | 2.91         |
| VMD         | 0.54±0.03   | 2.07         |
| VMD (Reggeized) | 0.69±0.06   | 2.05         |

### TABLE IV: The fitted values of the free parameter $R$ of the exponential form factor, while $R$ is in the units of GeV$^{-1}$.

| type        | $R$         | $\chi^2$/ndf |
|-------------|-------------|--------------|
| $\pi$ exchange | 0.47±0.03   | 2.26         |
| $\pi$ exchange (Reggeized) | 0.10±0.02   | 2.66         |
| VMD         | 1.30±0.07   | 2.10         |
| VMD (Reggeized) | 1.06±0.09   | 2.06         |

of improvements in three types of form factor. Therefore, in the following calculation, we only consider the case of monopole form factor.

From Fig. 3(a) one can see that the experimental data (except the point at $E_{\gamma} = 4.8\text{ and }19.5\text{ GeV}$)\(^{[48][52]}\) for the total cross section of the $\gamma p \rightarrow a_2^+ n$ reaction are well reproduced with a small value of $\chi^2$/ndf. The shape of the total cross section via $\pi$ exchange is different from that of the VMD mechanism.

With the above equations and the fitted parameters as listed in Table II, the relevant physical results are calculated, as shown in Fig. 4-6.

In Fig. 4 we also present the variation of the total cross section of the $\gamma p \rightarrow a_2^+ n$ reaction within the typical uncertainties of the $\Lambda_t$ values. From Fig. 4 (a) it is seen that the total cross section via $\pi$ exchange is more sensitive than that of the VMD mechanism to the values of $\Lambda_t$. Moreover, a comparison of the results from Fig. 4 (a) and Fig. 4 (b) reveals that the total cross section becomes less sensitive to the $\Lambda_t$ values when the Reggeized treatment is added to the process of $\gamma p \rightarrow a_2^+ n$.

In Fig. 5, we show the differential cross section of $\gamma p \rightarrow a_2^+ n$ as a function of $-t$. It is obvious that there is a significant peak structure in the region of low $-t$, which increases rapidly near the threshold and then decreases slowly with increasing $-t$. However, it is seen, that the shapes of the differential cross section $d\sigma/dt$ with the Reggeized treatment are much different from that without the Reggeized treatment at higher $-t$. The Reggeized treatment can lead to that the differential cross section $d\sigma/dt$ decreases rapidly with increasing $-t$, especially at higher energies.

Figure 6 presents the differential cross section for the $\gamma p \rightarrow a_2^+ n$ reaction with or without the Reggeized treatment at different energies. It is seen that the differential cross section with the Reggeized treatment is very sensitive to the angle $\theta$ and makes a considerable contribution at forward angles.
FIG. 3: (Color online) Total cross section for the $\gamma p \rightarrow a_2^+ n$ reaction. The data are from [48–52]. Here, (a) is the result with monopole form factor, while (b) and (c) are the results related to the dipole and exponential form factors correspondently.

FIG. 4: (Color online) (a): The total cross section of the $\gamma p \rightarrow a_2^+ n$ reaction for the different values of cutoff parameter $\Lambda_t$. (b) Same as in (a), but for the case of the Regge trajectory exchange.

According to the presented calculations of the $a_2$ production cross section and previously published COMPASS results for exclusive photoproduction of $\rho^0$ [53] and $J/\psi$ [54], we can conclude that thousands of $a_2^\pm$ mesons could be produced per year of data taking via the exclusive charge-exchange reactions $\gamma^* p \rightarrow a_2^\pm n$ and $\gamma^* n \rightarrow a_2^- p$ (but the recoil nucleon cannot be detected). The energy of a virtual photon covers the range from about 20 GeV and up to 180 GeV. The obtained data can be used to clarify the mechanism of the $a_2$ production and the role of the Reggeized treatment at high energies. Nevertheless, most of the $a_2^\pm$ mesons at such energies are produced non exclusively via the pomeron exchange mechanism. Such events could produce strong background under poor exclusivity control. Additional systematics could come from the process $\gamma^* p \rightarrow a_2^- \Delta^{++}$ (the cross section of this reaction is of the same order of magnitude [57]) because the COMPASS setup is not
FIG. 5: (Color online) The differential cross section of $\gamma p \rightarrow a_2^+ n$ as a function of $-t$ at $E_\gamma = 3 - 200$ GeV.

FIG. 6: (Color online) The differential cross section $d\sigma / d\cos \theta$ for the $a_2(1320)$ photoproduction from the proton as a function of $\cos \theta$ at $E_\gamma = 3 - 200$ GeV.

able to reconstruct a decay of low-energy $\Delta^{++}$ in a regular way. Nuclear effects in $a_2$ photoproduction off the lithium-6, deuterium and nitrogen nuclei should also be taken into account in an appropriate way.

The forthcoming upgrade of the COMPASS setup related to the planned data taking within the framework of the GPD program could provide better conditions for experimental study of the reaction $\gamma p \rightarrow a_2^+ n$ and partially eliminate problems mentioned above. The new 2.5 m long liquid hydrogen target surrounded by a 4 m
long recoil proton detector will be used. Absence of the neutrons in the target will remove one exclusive production channel for \(a_2\). The recoil proton detector serves the double purpose: to reconstruct and identify recoil protons via time-of-flight and energy loss measurements. Since the reaction \(\gamma^* p \rightarrow a_2^+ n\) does not have a recoil proton in the final state, any activity in the recoil proton detector could be used as the veto in the offline analysis. In addition, the recoil proton detector will be able to detect the \(\Delta^{++} \rightarrow p\pi^+\) decay. Significant impact on the exclusivity control efficiency will be made by the planned upgrade of the electromagnetic calorimetry system.

V. SUMMARY

Within the framework of the effective Lagrangian approach and Regge model, the \(a_2(1320)\) photoproduction from the proton is investigated. The obtained numerical results indicate the following:

(I) The total cross section \(\gamma p \rightarrow a_2^+ n\) related to the experimental data \([48, 52]\) is well reproduced with reasonable value of \(\chi^2/ndf\). Although the monopole form factor was used in the calculations, the dipole and exponential form factors were also tested. It is found that the total cross section becomes less sensitive to the \(\Lambda_t\) values when the Reggeized treatment is added.

(II) The shapes of the differential cross section \(d\sigma/dt\) with the Reggeized treatment are much different from that without the Reggeized treatment at higher \(-t\). The Reggeized treatment can lead to that the differential cross section \(d\sigma/dt\) decreases rapidly with the increasing \(-t\), especially at higher energies.

(III) The differential cross section \(d\sigma/d\cos\theta\) with the Reggeized treatment is very sensitive to the angle \(\theta\) and makes a considerable contribution at forward angles.

(IV) The invariant mass distribution for the Dalitz process \(\gamma p \rightarrow \rho\pi n\) shows an obvious peak at \(M_{\rho\pi} \approx 1.32\) GeV, which can be checked by further experiment.

(V) For comparison, it is found that the cross section of the \(\gamma n \rightarrow a_2^+ p\) process is almost the same as that of the \(\gamma p \rightarrow a_2^+ n\) reaction. Thus, the above theoretical results are valid to the \(\gamma n \rightarrow a_2^+ p\) channel.

To sum up, we suggest testing our prediction for the cross section of the \(\gamma p \rightarrow a_2^+ n\) process at the COMPASS facility at CERN. Such a test could provide important information for clarifying the production mechanism of the \(a_2(1320)\) and the role of the Reggeized treatment at high energies. Nevertheless, the precise measurements near the threshold, where the difference between the predictions of the production models is maximal, are also important.

FIG. 7: (Color online) Differential cross section \(d\sigma_{\gamma p \rightarrow a_2^+ n \rightarrow \rho\pi n}/dM_{\rho\pi}\) as a function of \(M_{\rho\pi}\) at \(E_\gamma = 3 - 200\) GeV.
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