

Production mechanisms of isoscalar pseudotensor mesons in pion and kaon induced reactions

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(Received 23 November 2025; accepted 22 January 2026; published 11 February 2026)

The recent observation of the $X(2600)$ resonance by the BESIII Collaboration has motivated a renewed interest in the spectroscopy of light mesons, particularly pseudotensor states. However, a significant theoretical gap exists in the poorly explored spectrum of isoscalar pseudotensor mesons, where several predicted radial excitations remain unobserved. To address this, we investigate the production of four such states [$\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$] employing an effective Lagrangian approach combined with Regge trajectory phenomenology to describe the high-energy behavior of the reactions. Our calculations reveal a distinct production selectivity: the $\eta_2(4D)$ state is more prominent in pion induced ($\pi^- p \rightarrow \eta_2 n$) reactions, whereas the $\eta'_2(2D, 3D, 4D)$ states are preferentially produced in kaon induced ($K^- p \rightarrow \eta_2 \Lambda$) processes. Moreover, the total cross sections for these states exhibit characteristic peaks at specific beam momenta, providing clear kinematic windows for their discovery. This study provides the first comprehensive theoretical predictions for the production cross sections of these predicted mesons, offering crucial guidance for future experimental searches.

DOI: 10.1103/sz4b-11jz

I. INTRODUCTION

The study of light meson spectroscopy provides crucial insights into the nonperturbative regime of quantum chromodynamics (QCD). With the world's largest accumulated J/ψ data sample, the BESIII Collaboration has established an excellent platform for probing light hadrons. Their progressively enhanced experimental precision has led to the observation of several resonances, such as $X(1835)$, $X(2120)$, $X(2370)$, and the recently reported $X(2600)$, in the $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ decay [1–3]. Notably, the $X(2600)$ was observed in the $\eta' \pi^+ \pi^-$ invariant mass spectrum with a significance exceeding 20σ , based on approximately 10×10^{10} J/ψ events. Its measured mass and width are $2618.3 \pm 2.0^{+16.3}_{-1.4}$ MeV/ c^2 and $195 \pm 5^{+26}_{-17}$ MeV, respectively. Although its spin-parity quantum numbers J^{PC} remain undetermined, the observed decay channel suggests possible assignments of 0^{-+} (pseudoscalar) or 2^{-+} (pseudotensor).

The nature of the $X(2600)$ is actively debated, with interpretations including a $J^{PC} = 2^{-+}$ glueball within QCD sum rules [4] or a 2^{-+} tetraquark state [5]. Furthermore, as

discussed in Ref. [6], identifying the $X(2600)$ as a glueball or a conventional state may also depend on the internal structures of the $f_0(1500)$ and $f'_2(1525)$ resonances, adding further complexity to its interpretation.

From a conventional quark-model perspective, the previously observed resonances $X(1835)$, $X(2120)$, and $X(2370)$ in the $\pi^+ \pi^- \eta'$ mass spectrum were all identified as 0^{-+} pseudoscalar states [7,8]. This systematic pattern suggests a similar pseudoscalar nature for the $X(2600)$, leading to its interpretation as the $\eta(6S)$ isoscalar pseudoscalar state in Ref. [8]. However, a pseudotensor assignment cannot be entirely excluded. Crucially, the analysis in Ref. [9] demonstrates that the decay behaviors disfavor identifying the $X(2600)$ as the $\eta'_2(4D)$ state, effectively ruling out its classification as an isoscalar pseudotensor meson within this framework. This framework predicts four unobserved radial excitations of isoscalar pseudotensor mesons near 2.6 GeV: $\eta_2(4D)$ (2498 MeV), $\eta'_2(2D)$ (2238 MeV), $\eta'_2(3D)$ (2520 MeV), and $\eta'_2(4D)$ (2764 MeV). The existence of these predicted states naturally raises the question of how such highly excited pseudotensor mesons might be produced and observed experimentally.

To contextualize our study, we briefly review the known η_2 states listed by the PDG [10], which include the $\eta_2(1645)$ [11,12], $\eta_2(1870)$ [11,13,14], $\eta_2(2030)$ [15], and $\eta_2(2250)$ [16]. These states were primarily observed in $p\bar{p}$ annihilation processes and commonly decay via the $a_2(1320)\pi$ channel. Pion-proton and kaon-proton

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scattering have long served as effective tools for discovering light hadrons [17–21]. For instance, the $\pi_2(1670)$ was first identified in $\pi^+ p \rightarrow p\pi^+\pi^+\pi^-$ reactions [22], and the $K_2(1770)$ was initially observed in $K^- p \rightarrow pK^-\pi^+\pi^-$ and $K^- p \rightarrow p\bar{K}^0\pi^-\pi^0$ reactions [23]. As members of the same pseudotensor nonet, the predicted η_2 states could likewise be produced in similar processes, which forms the primary motivation for the present work.

Building upon this motivation, we investigate the production of the four predicted isoscalar pseudotensor mesons in pion and kaon induced reactions on a proton target, employing an effective Lagrangian approach. A Regge-based phenomenological treatment is applied to describe the high-energy behavior of these processes, successfully reproducing the expected energy and t -dependence of differential cross sections in the forward region [24]. Given the absence of experimental data for the specific reactions $\pi^- p \rightarrow \eta_2 n$ and $K^- p \rightarrow \eta_2 \Lambda$, our study focuses on predicting their energy-dependent cross sections within the Regge framework. These predictions are intended to provide concrete guidance for future experimental searches at facilities such as J-PARC [25], COMPASS [26], and SPS@CERN [27].

This paper is structured as follows. Following this introduction, Sec. II details the theoretical formalism, including the effective Lagrangians and scattering amplitudes. Section III presents our numerical results and discussion. Finally, the paper concludes with a summary in Sec. IV.

II. PRODUCTION MECHANISMS FOR η_2 MESONS IN PION AND KAON INDUCED REACTIONS

The reaction mechanisms for pion and kaon induced productions of isoscalar pseudotensor mesons are illustrated in the t -channel Feynman diagram of Fig. 1. We consider only the t -channel contributions, as the s channel is typically negligible and the u channel, which involves the exchange of a nucleon or hyperon, is dominant at backward angles—a region outside the forward-focused scope of this Regge-based analysis.

A. Lagrangians

The effective Lagrangian densities required for computing the processes in Fig. 1 are given by [28,29],

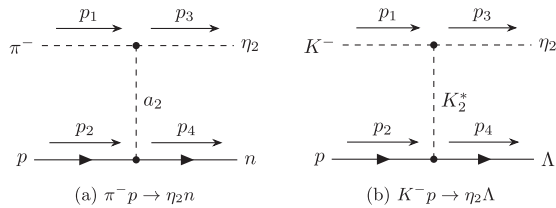


FIG. 1. Feynman diagrams for (a) pion induced and (b) kaon induced production of the η_2 meson. The t -channel exchange is dominated by the a_2 meson in (a) and the K_2^* meson in (b).

$$\mathcal{L}_{TXP} = g_{TXP} T_{\mu\nu} X^{\mu\nu} P, \quad (1)$$

$$\begin{aligned} \mathcal{L}_{TNN} = & -2i \frac{g_{TNN}^{(1)}}{M} \bar{N} (\gamma_\lambda \partial_\sigma + \gamma_\sigma \partial_\lambda) N T^{\lambda\sigma} \\ & + 4 \frac{g_{TNN}^{(2)}}{M^2} \partial_\lambda \bar{N} \partial_\sigma N T^{\lambda\sigma}, \end{aligned} \quad (2)$$

where T , X , P , and N denote the pseudotensor meson, tensor meson, pseudoscalar meson, and nucleon fields, respectively.

The coupling constants $g_{TNN}^{(1,2)}$ are determined using SU(3) flavor symmetry. For the $f_2 NN$ vertex, we adopt $g_{f_2 NN}^{(1)} = 6.45$ and $g_{f_2 NN}^{(2)} = 0$ from Ref. [30], values consistent with SU(3) predictions for parameters $\alpha_{(1,2)} = 2.25$ and $F/D = -1.8$. The corresponding couplings for $a_2 NN$ and $K_2^* N\Lambda$ vertices are determined through the SU(3) relations,

$$g_{f_2 NN}^{(1,2)} = \frac{1}{\sqrt{3}} (4\alpha_{(1,2)} - 1) g_{a_2 NN}^{(1,2)}, \quad (3)$$

$$g_{K_2^* N\Lambda}^{(1,2)} = -\frac{1}{\sqrt{3}} (1 + 2\alpha_{(1,2)}) g_{a_2 NN}^{(1,2)}, \quad (4)$$

where we use $g_{a_2 NN}^{(1)} = 1.4$ and derive $g_{K_2^* N\Lambda}^{(1)} = -4.45$ from these symmetry relations.

The coupling constants g_{TXP} are determined from the corresponding decay widths, which are expressed as,

$$\Gamma_{T \rightarrow XP} = \frac{k_f}{8\pi m_T^2} \frac{g_{TXP}^2}{45} \left(4 \frac{k_f^4}{m_X^4} + 30 \frac{k_f^2}{m_X^2} + 45 \right). \quad (5)$$

Here, $k_f = k_f(m_T, m_X, m_P)$ is the modulus of the outgoing momentum in the rest frame of T , given by,

$$k_f(m_T, m_X, m_P) = \frac{\lambda^{1/2}(m_T^2, m_X^2, m_P^2)}{2m_T}, \quad (6)$$

where $\lambda(x, y, z)$ is the Källén function, defined as $\lambda(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2xz - 2yz$. Utilizing the decay widths provided in Ref. [9], we calculate the coupling constants $g_{\eta_2 a_2 \pi}$ and $g_{\eta_2 K K_2^*}$, which are listed in Table I.

B. Amplitudes

With the above preparation, the amplitudes of these discussed reactions shown in Fig. 1 can be written as

TABLE I. Coupling constants for η_2 decays.

Parameter	Pseudotensor state			
	$\eta_2(4D)$	$\eta'_2(2D)$	$\eta'_2(3D)$	$\eta'_2(4D)$
$g_{\eta_2 a_2 \pi}$ (GeV)	1.104	0.955	0.698	0.566
$g_{\eta_2 K K^*}$ (GeV)	0.268	2.974	2.165	1.751

$$\begin{aligned} \mathcal{M}_{\pi^- p \rightarrow \eta_2 n} &= g_{\eta_2 a_2 \pi} \epsilon_{\mu\nu}(\eta_2) \frac{\Pi^{\mu\nu;\lambda\sigma}}{t - m_{a_2}^2} \bar{u}(p_4) \\ &\times \left[\frac{g_{a_2 NN}^{(1)}}{M_N} (\gamma_\lambda P_\sigma + \gamma_\sigma P_\lambda) + \frac{g_{a_2 NN}^{(2)}}{M_N^2} P_\lambda P_\sigma \right] \\ &\times u(p_2) F_{a_2}^2(t), \end{aligned} \quad (7)$$

$$\begin{aligned} \mathcal{M}_{K^- p \rightarrow \eta_2 \Lambda} &= g_{\eta_2 K_2^* K} \epsilon_{\mu\nu}(K_2^*) \frac{\Pi^{\mu\nu;\lambda\sigma}}{t - m_{K_2^*}^2} \bar{u}(p_4) \\ &\times \left[\frac{g_{K_2^* N \Lambda}^{(1)}}{M_N} (\gamma_\lambda P_\sigma + \gamma_\sigma P_\lambda) + \frac{g_{K_2^* N \Lambda}^{(2)}}{M_N^2} P_\lambda P_\sigma \right] \\ &\times u(p_2) F_{K_2^*}^2(t). \end{aligned} \quad (8)$$

The tensor propagator structure is given by,

$$\Pi_{\mu\nu;\lambda\sigma} = \frac{1}{2} (\bar{g}_{\mu\lambda} \bar{g}_{\nu\sigma} + \bar{g}_{\mu\sigma} \bar{g}_{\nu\lambda}) - \frac{1}{3} \bar{g}_{\mu\nu} \bar{g}_{\lambda\sigma}, \quad (9)$$

with

$$\bar{g}_{\mu\nu} = -g_{\mu\nu} + \frac{p_{t\mu} p_{t\nu}}{m_t^2}. \quad (10)$$

For the t -channel exchange, we employ a form factor of the type $F(t) = (\Lambda_t^2 - m_t^2)/(\Lambda_t^2 - t)$, where $t = (p_1 - p_3)^2$ is the Mandelstam variable. The cutoff parameter Λ_t in the form factor will be discussed in Sec. III.

C. Reggeized t channel

To describe the forward-angle behavior of the reactions at moderately high energies, we incorporate Regge phenomenology into the t -channel exchange. In this kinematic region, characterized by relatively large center-of-mass energy and small momentum transfer $|t|$ [31,32], Regge phenomenology has been widely and successfully applied to hadronic reactions [33–36]. Within this approach, the exchange of entire Regge trajectories provides a natural and economical way to incorporate high-spin contributions without introducing individual high-mass states explicitly. As a consequence, the Reggeized treatment yields a smooth energy dependence of the scattering amplitude and suppresses the unphysical growth associated with bare single-particle t -channel exchange.

This is achieved by replacing the standard Feynman propagators in Eqs. (7) and (8) with the corresponding Reggeized propagators,

$$\begin{aligned} \frac{1}{t - m_{a_2}^2} &\rightarrow \left(\frac{s}{s_{\text{scale}}} \right)^{\alpha_{a_2}(t)-2} \frac{\pi \alpha'_{a_2}(t)}{\Gamma[\alpha_{a_2}(t) - 1] \sin[\pi \alpha_{a_2}(t)]} \\ &\times \left(\frac{1 + e^{-i\pi \alpha_{a_2}(t)}}{2} \right), \end{aligned} \quad (11)$$

$$\begin{aligned} \frac{1}{t - m_{K_2^*}^2} &\rightarrow \left(\frac{s}{s_{\text{scale}}} \right)^{\alpha_{K_2^*}(t)-2} \frac{\pi \alpha'_{K_2^*}(t)}{\Gamma[\alpha_{K_2^*}(t) - 1] \sin[\pi \alpha_{K_2^*}(t)]} \\ &\times \left(\frac{1 + e^{-i\pi \alpha_{K_2^*}(t)}}{2} \right). \end{aligned} \quad (12)$$

Here s_{scale} is a mass scale, which is conventionally chosen as $s_{\text{scale}} = 1 \text{ GeV}^2$. The Regge trajectories for the a_2 and K_2^* exchanges are parametrized as [29,30],

$$\alpha_{a_2}(t) = 0.8(t - m_{a_2}^2) + 2, \quad (13)$$

$$\alpha_{K_2^*}(t) = 0.83(t - m_{K_2^*}^2) + 2, \quad (14)$$

with α'_M denoting the slope of the trajectory $\alpha_M(t)$.

III. NUMERICAL RESULTS

Using the formalism established in Sec. II, we calculate the cross sections for the production of the predicted pseudotensor mesons in the specific reactions $\pi^- p \rightarrow \eta_2 n$ and $K^- p \rightarrow \eta_2 \Lambda$ on a proton target. For a generic $2 \rightarrow 2$ process, the differential cross section in the center of mass frame is given by,

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s} \frac{1}{|p_{1\text{ cm}}|^2} |\overline{\mathcal{M}}|^2, \quad (15)$$

where $s = (p_1 + p_2)^2$ is the square of the center of mass energy, $p_{1\text{ cm}}$ is the momentum of incident pion or kaon in this frame, and $|\overline{\mathcal{M}}|^2$ denotes the squared scattering amplitude, averaged over initial spins and summed over final spins.

A. Cross section for $\pi^- p \rightarrow \pi_2^-(1670)p$ reaction

To validate our framework, we first calibrate it against the well-measured reaction $\pi^- p \rightarrow \pi_2^-(1670)p$, which involves a known pseudotensor meson. We optimize the cut-off parameter Λ_t by fitting the experimental total cross section data. The analysis employs nine data points from Ref. [37] spanning a beam momentum range of $P_{\text{Lab}} = 3.1\text{--}30.0 \text{ GeV}/c$, minimizing the χ^2 per degree of freedom (d.o.f.). Since the branching fraction of $\pi_2(1670) \rightarrow f_2(1270)\pi$ was suggested to be 56.3% by the PDG, the coupling constant $g_{\pi_2(1670)f_2(1270)\pi} \simeq 5.439 \text{ GeV}$ is obtained with $\Gamma_{\pi_2 \rightarrow f_2 \pi} \simeq 0.145 \text{ GeV}$.

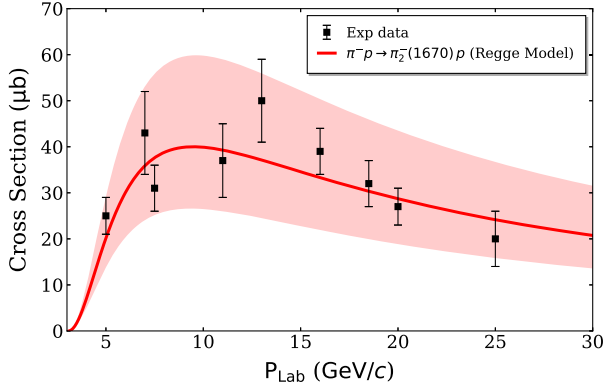


FIG. 2. Total cross section for the $\pi^- p \rightarrow \pi_2^-(1670)p$ reaction. The red solid line represents the central result of our Regge model calculation, while the shaded band denotes the uncertainty associated with the cutoff parameter. The experimental data are taken from Ref. [37].

The Regge trajectory for the exchanged f_2 meson is taken as $\alpha_{f_2}(t) = 0.9(t - m_{f_2}^2) + 2$ [38]. The resulting optimal cutoff is $\Lambda_t = 0.762 \pm 0.028$ GeV, yielding $\chi^2/\text{d.o.f.} = 1.006$, indicating good agreement with the experimental data.

Figure 2 shows the measured cross section for the reaction $\pi^- p \rightarrow \pi_2^-(1670)p$ as a function of beam momentum. As shown, the Regge theoretical prediction provides a reasonable description of the data. The cross section rises sharply from the reaction threshold, reaches a peak of approximately $40.0 \mu\text{b}$ around $9.5 \text{ GeV}/c$, and subsequently decreases slowly with increasing beam momentum. At lower momenta, specifically at $5 \text{ GeV}/c$, the theoretical prediction of $20 \mu\text{b}$ is slightly below the measured value of $25 \pm 4 \mu\text{b}$, but remains consistent within the experimental uncertainty and the expected theoretical systematic uncertainties. For higher momenta ($P_{\text{Lab}} > 16 \text{ GeV}/c$), the model agrees well with all data points within uncertainties. In particular, the prediction of $24 \mu\text{b}$ at $25 \text{ GeV}/c$ is consistent with the measured value of $20 \pm 6 \mu\text{b}$. This overall agreement supports the applicability of the Regge framework in the high-energy region considered here.

B. Cross section for $\pi^- p \rightarrow \eta_2 n$ reactions

We now present the calculated cross sections for the pion induced production of the predicted isoscalar pseudotensor mesons. Figure 3 shows the total cross sections for $\pi^- p \rightarrow \eta_2 n$ as a function of the pion laboratory momentum P_{Lab} . All four states exhibit a characteristic behavior: a rapid rise near threshold due to the opening of the production channel, followed by a gradual decrease at higher momenta, consistent with the typical energy dependence of Reggeized t -channel exchanges.

The four predicted pseudotensor meson states exhibit distinct production characteristics, with their thresholds and peak cross sections occurring at specific pion beam

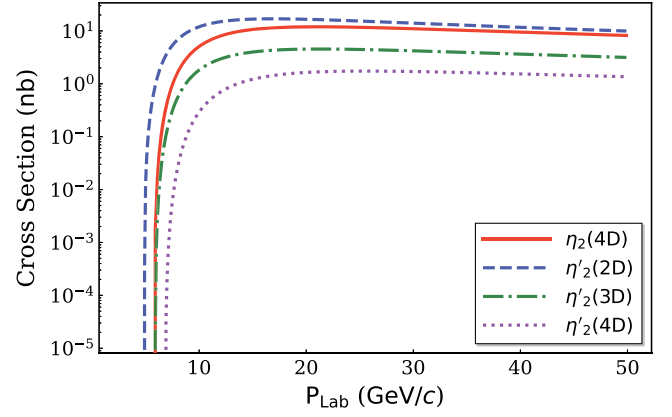


FIG. 3. Total cross section for the $\pi^- p \rightarrow \eta_2 n$ reaction in the Regge model via t -channel exchange with $\Lambda_t = 0.762$ GeV.

momenta, as detailed in Table II. A clear correlation exists between the mass of these states and their production requirements: higher-mass pseudotensor mesons require higher beam momenta to achieve their peak cross sections.

Specifically, the $\eta'_2(2D)$ state yields the largest cross section, while the $\eta'_2(4D)$ state attains the smallest. Notably, both the $\eta_2(4D)$ and $\eta'_2(3D)$ states reach their maximum at close beam momenta; however, the former exhibits a significantly larger cross section than the latter at this momentum, implying distinct production mechanisms. For experimental searches of these states via pion-proton scattering, the P_{Lab} values corresponding to the cross section peaks provide suitable momentum windows.

In addition to the total cross section, the predicted differential cross section for the $\pi^- p \rightarrow \eta_2 n$ reaction, calculated using the Regge trajectory model, is presented in Fig. 4. The results reveal a pronounced angular dependence on the scattering angle θ . As the energy increases, the reaction exhibits a progressively enhanced forward-peaking behavior, indicative of dominant Reggeized t -channel exchange processes. This energy-dependent forward peak suggests that experimental verification would be most effectively achieved through measurements at small scattering angles.

C. Cross section for $K^- p \rightarrow \eta_2 \Lambda$ reactions

The predicted production cross sections for the kaon induced reactions $K^- p \rightarrow \eta_2 \Lambda$ are presented in Fig. 5. Although the functional dependence on P_{Lab} is similar to that of pion induced reactions, the cross section magnitudes differ

TABLE II. Production characteristics in pion induced reactions.

Parameter	Pseudotensor state			
	$\eta_2(4D)$	$\eta'_2(2D)$	$\eta'_2(3D)$	$\eta'_2(4D)$
Production threshold (GeV/c)	5.9	4.9	5.9	6.9
Peak cross section (nb)	11.95	16.91	4.54	1.74
P_{Lab} at peak (GeV/c)	20.9	16.9	21.3	25.6

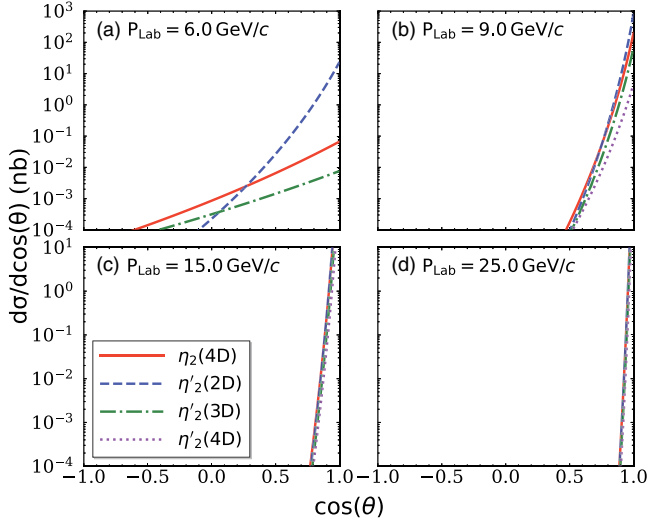


FIG. 4. Differential cross section $d\sigma/d\cos\theta$ of the $\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$ production for the $\pi^-p \rightarrow \eta_2n$ reaction at different P_{Lab} energies.

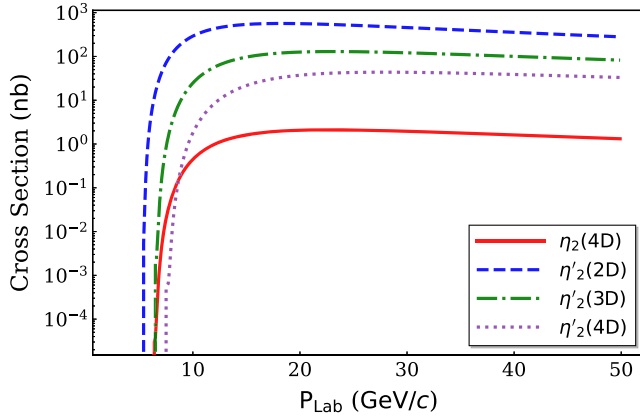


FIG. 5. Total cross section for the $K^-p \rightarrow \eta_2\Lambda$ reaction in the Regge model via t -channel exchange with $\Lambda_t = 0.762$ GeV.

significantly. Specifically, the cross sections for the $\eta'_2(nD)$ states are substantially larger in kaon induced processes. This enhancement is attributed to their stronger coupling to the KK_2^* channel compared to the πa_2 channel, as evident from the coupling constants listed in Table I. Conversely, the $\eta_2(4D)$ state exhibits the opposite trend, with a larger production cross section in pion induced reactions, consistent with its relatively stronger coupling to πa_2 .

Table III summarizes the thresholds and peak cross sections that characterize the production of the four predicted pseudotensor meson states in kaon induced reactions. A clear hierarchy is observed: higher-mass states generally require greater beam momenta to be produced and to reach their peak cross sections.

Notably, the $\eta_2(4D)$ state yields a peak cross section that is significantly smaller than those of the other states. The beam momenta at which the cross sections peak define

TABLE III. Production characteristics in kaon induced reactions.

Parameter	Pseudotensor state			
	$\eta_2(4D)$	$\eta'_2(2D)$	$\eta'_2(3D)$	$\eta'_2(4D)$
Production threshold (GeV/c)	6.4	5.4	6.5	7.5
Peak cross section (nb)	2.11	566.92	129.39	43.70
P_{Lab} at peak (GeV/c)	22.7	18.2	23.1	27.9

the optimal kinematic regions for detecting these states in future kaon beam experiments.

Furthermore, the predicted differential cross section for the $K^-p \rightarrow \eta_2\Lambda$ reaction, calculated within the Regge trajectory framework, is presented in Fig. 6. Consistent with the $\pi^-p \rightarrow \eta_2n$ case, the differential cross section shows a strong angular dependence on the scattering angle θ , with substantial contributions at forward angles that increase with beam momentum.

D. Experimental detection and uncertainty analysis

Based on the dominant decay modes of known η_2 family members [such as $\eta_2(1645)$], our predicted η_2 states are also likely to decay primarily through hadronic channels such as $a_2(1320)\pi$ or KK_2^* . Specifically, cascade decays like $\eta_2 \rightarrow a_2\pi \rightarrow (\pi\pi)\pi$ and $\eta_2 \rightarrow K_2^*K \rightarrow (K\pi)K$ can produce multiparticle final states (e.g., 3π , $K\bar{K}\pi$, etc.), which serve as characteristic signals reconstructible in experiments such as COMPASS and J-PARC.

Therefore, we propose that searches for η_2 in π^-p collisions should focus on the missing-mass spectrum of the final-state neutron (n) and look for resonance peaks in the invariant-mass spectrum of $a_2\pi$ near the specific beam-momentum windows listed in Table II. Similarly, in K^-p collisions, analyses should be conducted by combining the

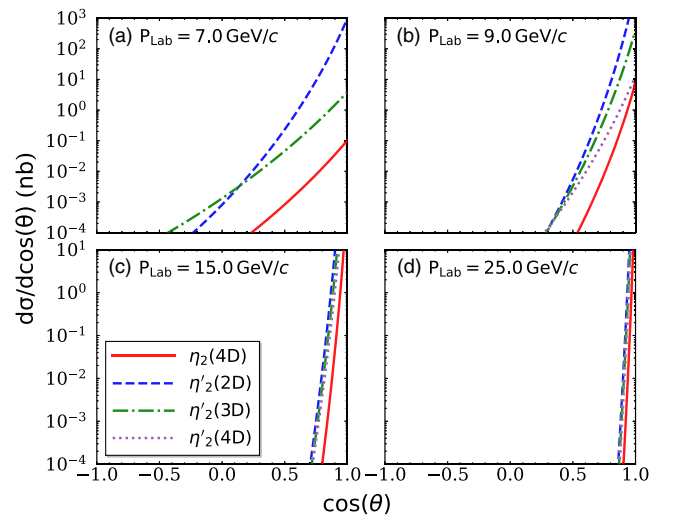


FIG. 6. Differential cross section $d\sigma/d\cos\theta$ of the $\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$ production for the $K^-p \rightarrow \eta_2\Lambda$ reaction at different P_{Lab} energies.

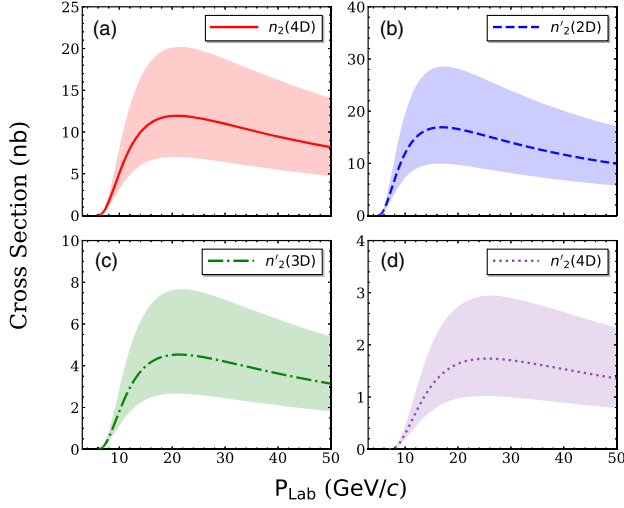


FIG. 7. Total cross sections for the $\pi^- p \rightarrow \eta_2 n$ reaction in the Regge model via t -channel exchange with $\Lambda_t = 0.762 \pm 0.028$ GeV; panels (a)–(d) correspond to the $\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$ states, respectively, and the shaded bands indicate the uncertainties from Λ_t .

reconstruction or missing-mass spectrum of the final-state Λ with decay channels such as KK_2^* .

In studies based on effective Lagrangians combined with Regge phenomenology, theoretical uncertainties are unavoidable. Our theoretical framework primarily relies on the effective Lagrangian approach, Regge trajectory phenomenology, and SU(3) flavor symmetry. Correspondingly, the uncertainties in our predictions mainly stem from the following aspects: (a) The coupling constants $g_{\eta_2 a_2 \pi}$ and $g_{\eta_2 K K_2^*}$ (see Table I) are derived by inverting Eq. (5) from theoretically calculated decay widths $\Gamma_{T \rightarrow X P}$. Theoretical calculations of such hadronic strong decays typically carry significant model dependence. (b) The coupling constants $g_{a_2 N N}^{(1,2)}$ and $g_{K_2^* N \Lambda}^{(1,2)}$ describing the meson-nucleon-nucleon (or hyperon) vertices are determined through the SU(3) relations. In actual physics, SU(3) flavor symmetry is broken, especially for vertices involving strange quarks (e.g., $K_2^* N \Lambda$). (c) We have adopted commonly used Regge-trajectory slopes and (d) a monopole form factor $F(t) = (\Lambda_t^2 - m_t^2)/(\Lambda_t^2 - t)$. For the pion induced reaction, the cutoff parameter Λ_t is determined by fitting data for the $\pi^- p \rightarrow \pi_2^-(1670)p$ reaction. This result is also applied to the kaon induced reaction, which directly affects the absolute magnitude of the predicted cross sections.

In our theoretical framework, the form-factor cutoff parameter Λ_t is uniquely determined by fitting experimental data, while other parameters such as coupling constants and Regge trajectory slopes are derived from existing phenomenological models or symmetry relations. Consequently, we have conducted an in-depth analysis of the impact of the cutoff parameter on the scattering cross sections of pion induced (Fig. 7) and kaon induced

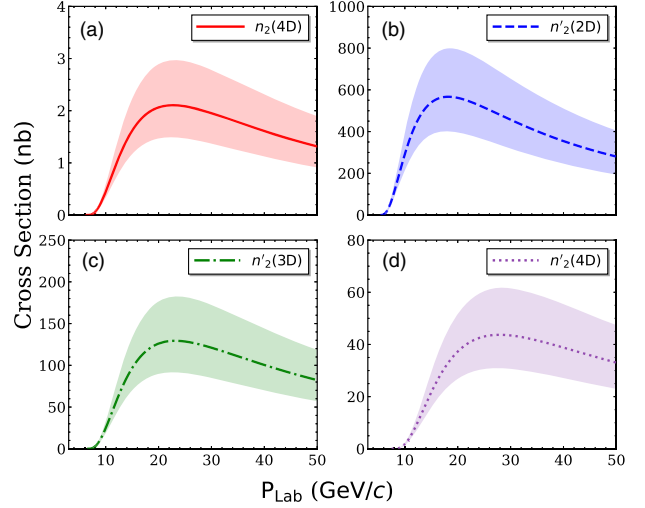


FIG. 8. Total cross sections for the $K^- p \rightarrow \eta_2 \Lambda$ reaction in the Regge model via t -channel exchange with $\Lambda_t = 0.762 \pm 0.028$ GeV; panels (a)–(d) correspond to the $\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$ states, respectively, and the shaded bands indicate the uncertainties from Λ_t .

reactions (Fig. 8). The value of Λ_t primarily affects the absolute magnitude of the cross sections, particularly in regions of larger momentum transfer.

As can be seen from Figs. 7 and 8, despite these uncertainties, they do not affect the core physical pattern revealed in this study—namely, the selective production mechanism where $\eta_2(4D)$ is more prominent in pion induced reactions, while η'_2 states exhibit enhanced production in kaon induced reactions, as well as the optimal kinematic windows defined by the peak positions of the total cross sections. These qualitative features are relatively robust.

IV. SUMMARY

We have systematically investigated the production mechanisms of four predicted isoscalar pseudotensor mesons, $\eta_2(4D)$, $\eta'_2(2D)$, $\eta'_2(3D)$, and $\eta'_2(4D)$, in pion and kaon induced reactions. Employing an effective Lagrangian approach with Regge trajectory phenomenology, we calculated both total and differential cross sections for the processes $\pi^- p \rightarrow \eta_2 n$ and $K^- p \rightarrow \eta_2 \Lambda$.

To validate our theoretical framework, we first calibrated the model parameters using existing data for the related $\pi^- p \rightarrow \pi_2^-(1670)p$ reaction, successfully reproducing its cross section within the Regge formalism. This established the reliability of our approach for predicting production cross sections of the unobserved states.

Our calculations reveal several key findings:

- (i) A clear production selectivity emerges due to the differing coupling strengths: the $\eta_2(4D)$ state, with its stronger coupling to πa_2 is significantly more

prominent in pion induced reactions, whereas the η'_2 states, with their stronger couplings to KK_2^* , are strongly enhanced in kaon induced processes.

- (ii) All states exhibit characteristic peaks in their total cross sections at specific beam momenta, defining optimal kinematic windows for experimental detection.
- (iii) The differential cross sections show pronounced forward angle enhancements, consistent with dominant t -channel Reggeized exchange mechanisms.

This work provides the first comprehensive theoretical predictions for production cross sections of these mesons, offering crucial guidance for future experimental searches at facilities such as J-PARC, COMPASS, and SPS@CERN. The distinct production patterns and kinematic dependencies identified here establish concrete pathways for discovering and characterizing these states in forthcoming meson-beam experiments.

ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China under Grant No. 12405104, the Natural Science Foundation of Hebei Province under Grant No. A2022203026, the Higher Education Science and Technology Program of Hebei Province under Contract No. BJK2024176, and the Research and Cultivation Project of Yanshan University under Contract No. 2023LGQN010.

DATA AVAILABILITY

The data that support the findings of this article are not publicly available upon publication because it is not technically feasible and/or the cost of preparing, depositing, and hosting the data would be prohibitive within the terms of this research project. The data are available from the authors upon reasonable request.

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