Production of the superheavy baryon $Λ_{c\bar{c}}^*(4209)$ in kaon-induced reaction

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Abstract. The production of superheavy $Λ_{c\bar{c}}^*(4209)$ baryon in the $K^-p \to ηcΛ$ process via $s$-channel is investigated with an effective Lagrangian approach and the isobar model. Moreover, the background from the $K^-p \to ηcΛ$ reaction through the $t$-channel with $K^+$ exchange and $u$-channel with nucleon exchange are also considered. The numerical results indicate it is feasible to search for the superheavy $Λ_{c\bar{c}}^*(4209)$ via $K^-p$ scattering. The relevant calculations not only shed light on the further experiment of searching for the $Λ_{c\bar{c}}^*(4209)$ through kaon-induced reaction, but also enable us to have a better understanding of the exotic baryons.

1 Introduction

At present, searching and explaining the exotic states has become a very interesting issue in hadron physics. These exotic states cannot be included in the conventional picture of $qqq$ for baryons and $q\bar{q}$ for mesons but are allowed to exist in the particle family when taking into account the color and flavor degrees of freedom in quark models.

With the development of experiments, a series of charmonium-like and bottomonium-like mesons (which were named as $XYZ$ states) have been observed [1,2]. Since these $XYZ$ mesons definitely cannot be accommodated into the frame of conventional charmonium $cc$ states, they are considered as the most promising candidate of the exotic states. Theoretically, abundant investigations were carried out on the nature and production mechanism of $XYZ$ states [1–4]. They are interpreted as a tetraquark, a hadron molecule or just a cusp effect, etc. [1,2].

In addition, the scientific study of multiquark baryons was already in full swing. In the early 1980s, Brodsky et al. proposed that there exist a few non-negligible intrinsic $uuds\bar{c}$ components ($\sim 1\%$) in the proton [5]. Later, a new measurement about parity-violating electron scattering (PVES) at JLab provided direct evidence for the existence of the multiquark components in the proton [6]. Moreover, in order to explain the phenomenon of the strong coupling of $N^*(1535)$ to the final states with strangeness and the mass order between $N^*(1535)$ and $Λ^*(1405)$ [7,8], the pentaquark picture was proposed by theorists [8–10], which makes the hidden strange $N^*(1535)$ with $|uuds\bar{s}\rangle$ be naturally heavier than the open strange $Λ^*(1405)$ with $|uudsq\bar{q}\rangle$. However, due to tunable ingredients and possible large mixing of various configurations, none of them can be clearly distinguished from the conventional $qqq$ or $q\bar{q}$ states. A hopeful solution for this problem is to extend the pentaquark to hidden charm and hidden beauty for baryons.

In refs. [11–13], within the framework of the coupled-channel unitary approach with the local hidden gauge formalism, several narrow hidden charm $N_{c\bar{c}}^*$ and $Λ_{c\bar{c}}^*$ resonances were predicted with mass above 4 GeV and width smaller than 100 MeV. Soon after, some hidden beauty $N_{b\bar{b}}^*$ and $Λ_{b\bar{b}}^*$ baryons were also proposed in ref. [14]. These predicted baryons are dynamically generated in the $PB$ and $VB$ channels, where $P$ and $V$ stand for the pseudoscalar and vector mesons, respectively [11–14]. In these predicted baryons, the production of $N^*(4261)$ resonance by $π^-p$ collision has been studied in our previous work [15]. Besides, one finds that the hidden charm $Λ_{c\bar{c}}^*(4209)$ and hidden beauty $Λ_{b\bar{b}}^*(11021)$ baryons all have a large coupling with $KN$ (detailed information about these two resonances are listed in table 1), which means that searching for these superheavy baryons via $K^-p$ scattering will be feasible and effective. Since a maximum $K$ beam of 20 GeV/$c$ can be produced at J-PARC, this allows one to observe the $Λ_{c\bar{c}}^*(4209)$ but not for the $Λ_{b\bar{b}}^*(11021)$ states. Thus we only focus on the production of $Λ_{c\bar{c}}^*(4209)$ in the present work.
Table 1. Informations of the $\Lambda^*_c(4209)$ and $\Lambda^*_b(11021)$ states from $PB \rightarrow PB$ as predicted in refs. [11–14]. $M$, $\Gamma$ and $\Gamma_i$ stand for the mass, total width, and partial decay width, respectively.

|             | $M$(MeV) | $\Gamma$(MeV) | $\Gamma_1$(MeV) |
|-------------|----------|---------------|-----------------|
| $\Lambda^*_c(4209)$ | 4209 | 32.4 | 15.8 |
| $\Lambda^*_b(11021)$ | 11021 | 2.21 | 0.65 |

![Diagram](image)

Fig. 1. (Color online) Feynman diagrams for the $K^- p \rightarrow \eta_c A$ reaction.

In this paper, with an effective Lagrangian approach and isobar model, we study the role and production of $\Lambda^*_c(4209)$ in the $K^- p \rightarrow \eta_c A$ process. Moreover, the feasibility of searching for the superheavy $\Lambda^*_c(4209)$ resonance is also discussed. It is shown that J-PARC [16] will be an ideal platform for searching for the superheavy $\Lambda^*_c(4209)$ baryon, which will hopefully confirm our numerical predictions for $\Lambda^*_c(4209)$ production.

This paper is organized as follows. After an introduction, we will present the formalism and the main ingredients which are used in our calculation. The numerical results and discussions are given in sect. 3. Finally, the paper ends with a brief summary.

2 Formalism

In this work, an effective Lagrangian approach and isobar model in terms of hadrons are used in our calculation, which is an important theoretical method in investigating various processes in the resonance region. Figure 1(a) describes the basic tree level Feynman diagrams for the production of $\Lambda^*_c(4209)$ in the $K^- p \rightarrow \eta_c A$ reaction through $s$-channel. The background contributions are mainly from the $t$-channel $K^*$ meson exchange and $u$-channel proton exchange, as depicted in fig. 1(b).

Since the spin-parity ($J^P$) quantum number of $\Lambda^*_c(4209)$ was determined to be $\frac{1}{2}^-$ [11–13], for the intermediate $\Lambda^*_c(4209)$ ($\Lambda^*$ for short) resonance contribution in the $s$-channel, we take the normally used effective Lagrangians for $K N \Lambda^*$ and $\eta_c \Lambda^*$ couplings as [17,18]

$$\mathcal{L}_{K N \Lambda^*} = g_{K N \Lambda^*} K \bar{\Lambda}^* N + h.c.,$$

$$\mathcal{L}_{\eta_c \Lambda^*} = g_{\eta_c \Lambda^*} \bar{\Lambda}^* \Lambda N + h.c.,$$

with~\(g_{K N \Lambda^*}\) and~\(g_{\eta_c \Lambda^*}\) determined by the partial decay widths of $\Lambda^*_c(4209)$,

$$\Gamma_{\Lambda^* \rightarrow N K} = \frac{g_{K N \Lambda^*}^2 (m_N + E_N)}{4\pi M_{\Lambda^*}},$$

$$\Gamma_{\Lambda^* \rightarrow \eta_c \Lambda} = \frac{g_{\eta_c \Lambda^*}^2 (m_{\Lambda^*} + E_{\Lambda^*})}{4\pi M_{\Lambda^*}},$$

where $\lambda$ is the Källen function with $\lambda(x, y, z) = (x - y - z)^2 - 4yz$. Using the predicted partial decay widths of $\Lambda^*_c(4209)$ [11,12] as listed in table 1, one gets $g_{K N \Lambda^*} = 0.369$ GeV$^{-1}$ and $g_{\eta_c \Lambda^*} = 0.557$ GeV$^{-1}$.

For the $t$-channel $K^*$ meson exchange, the effective Lagrangian for the $K^* K_{\eta c}$ coupling is

$$\mathcal{L}_{K^* K_{\eta c}} = ig_{K^* K_{\eta c}} K^*_\mu (\eta_{\mu \nu} \partial^\nu \bar{K} - \bar{K} \partial^\mu \eta_c) + h.c.,$$

where the isospin structure for $K^* K_{\eta c}$ is $K^* K_{\eta c}$, with

$$K^* = (K^{+-}, K^{*0}), \quad \bar{K} = \left(\begin{array}{c} K^- \\ \bar{K}^0 \end{array}\right).$$

With the partial decay width $\Gamma_{K^* \rightarrow K^*K} \leq 32.2 \times 1.28\%$ (MeV) [7], one obtains the upper limit of constant coupling: $g_{K^* \eta_c} = 0.203$ GeV$^{-1}$.

The effective Lagrangian for $K^* N A$ vertex is

$$\mathcal{L}_{K^* N A} = -g_{K^* N A} (\gamma_{\mu} K^{*\mu} - \frac{\kappa_{K^* N A}}{2m_N} \sigma_{\mu\nu} \partial^\nu K^{*\mu}) N + h.c.,$$

where the values of $g_{K^* N A}$ and $\kappa_{K^* N A}$ were given in many theoretical works. In refs. [19,20], two sets of these
coupling constants are obtained by the potential model, namely,
\[ g_{K^*N\Lambda} = -4.26, \quad \kappa_{K^*N\Lambda} = 2.66, \]
\[ g_{K^*N\Lambda} = -6.11, \quad \kappa_{K^*N\Lambda} = 2.43. \] (12)

Besides, one notice that the experiment data for the \( K^-p \to \pi^0\Lambda \) process were produced very well by taking \( g_{K^*N\Lambda} = -6.11 \) and \( g_{K^*N\Lambda} = -11.33 \) in ref. [21]. In this work, we take \( g_{K^*N\Lambda} = -6.11 \) and \( \kappa_{K^*N\Lambda} = 1.85 \) in order to obtain a more accurate estimates.

For the \( u \)-channel nucleon exchange, the effective Lagrangians for \( K\Lambda N \) and \( \eta_c N\eta \) couplings are
\[ \mathcal{L}_{K\Lambda N} = \frac{g_{K\Lambda N}}{m_N + m_A} \bar{N} \gamma_\mu \gamma_5 \partial_\mu K + \text{h.c.}, \] (13)
\[ \mathcal{L}_{\eta_c N\eta} = g_{\eta_c N\eta} \bar{N} \gamma_\mu \eta c N + \text{h.c.}, \] (14)
where \( g_{K\Lambda N} \) and \( g_{\eta_c N\eta} \) are determined from the partial decay widths of \( \eta_c \).

\[ \Gamma_{\eta_c \to pp} = (g_{\eta_c N\eta})^2 \left| \frac{\vec{p}_c^{\text{c.m.}}}{8\pi} \right|^2, \] (15)
with
\[ \left| \vec{p}_c^{\text{c.m.}} \right| = \sqrt{M_{\eta_c}^2 - 4M_N^2}. \] (16)
where \( \vec{p}_c^{\text{c.m.}} \) is three-momentum of nucleon in the rest frame of \( \eta_c \) meson. With \( \Gamma_{\eta_c \to pp} = 49.1 \text{ keV} \) [7], one obtains \( g_{\eta_c N\eta} = 3.26 \times 10^{-2} \text{ GeV}^{-1} \).

Considering the internal structure of hadrons, a form factor is introduced to describe the possible off-shell effects in the amplitudes. For \( s \)- and \( u \)-channels, we adopt the following form factors as used in refs. [18,21,24–26):
\[ F_s(u) = \frac{A_s(u) + (q_{ex}^2 - M_{ex}^2)^2}{A_s(u) + (q_{ex}^2 - M_{ex}^2)^2}, \] (17)
while, for the \( t \)-channel, we take
\[ F_t(q_{ex}^2) = \frac{A_t^2 - M_{ex}^2}{A_t^2 - q_{ex}^2}. \] (18)
where \( q_{ex} \) and \( M_{ex} \) are the four-momenta and the mass of the exchanged hadron, respectively. The values of cutoff parameters \( A_s \) and \( A_t \) will be discussed in the next section.

For the propagators with four-momenta \( q_{ex} \), we adopt the Breit-Wigner form [18,27],
\[ G_{A^*}(q_{ex}) = i \frac{q_{ex}^2 + M_{A^*}^2}{q_{ex}^2 - M_{A^*}^2 + iM_{A^*}\Gamma_{A^*}}, \] (19)
for the superheavy baryon \( \Lambda_{c\ell}^{(4209)} \), where \( \Gamma_{A^*} \) is the total decay width of \( \Lambda_{c\ell}^{(4209)} \) state.

For the \( K^* \) in the \( t \)-channel, we take the propagator as
\[ G_{K^*}(q_{ex}) = i \frac{-g^{\mu\nu} + q_{ex}^\mu q_{ex}^\nu/M_{K^*}^2}{q_{ex}^2 - M_{K^*}^2}, \] (20)
where \( \mu \) and \( \nu \) denote the polarization indices of vector meson \( K^* \).

For the nucleon propagator, we take
\[ G_N(q_{ex}^2) = \frac{i q_{ex}^2 + M_N}{q_{ex}^2 - M_N^2}. \] (21)

With the Feynman rules, the invariant scattering amplitude for the \( K^- (p_1) p(p_2) \to \eta_c (p_3) \Lambda (p_4) \) reaction as shown in fig. 1 can be constructed as
\[ M_i = \bar{\pi}_2 (p_4) A_{u_{r_1}} (p_2), \] (22)
where \( i \) denotes the \( s \)-, \( t \)-, or \( u \)-channel process that contribute to the total amplitude, while \( \bar{\pi}_2 (p_4) \) and \( u_{r_1} (p_2) \) are the spinors of the outgoing \( \Lambda \) baryon and the initial proton, respectively.

We define \( s = (p_1 + p_2)^2 \equiv W^2 \), then the unpolarized differential cross section for the \( K^-p \to \eta_c \Lambda \) reaction at the center-of-mass (c.m.) frame is given by
\[ \frac{d\sigma}{d \cos \theta} = \frac{1}{32\pi s |\vec{p}_3^{\text{c.m.}}|} \left( \frac{1}{2} \sum_{r_1r_2} |M_i|^2 \right), \] (23)
where \( \theta \) denotes the angle of the outgoing \( \eta_c \) meson relative to beam direction in the c.m. frame, while \( \vec{p}_3^{\text{c.m.}} \) and \( \vec{p}_3^{\text{c.m.}} \) are the three-momenta of initial \( K^- \) and final \( \eta_c \), respectively. Therefore, the total invariant scattering amplitude \( M \) is written as
\[ M = M_s^{V} + M_t^{K^*} + M_u^{\eta_c}. \] (24)
It is important to note that in phenomenological approaches, the relative phases between different amplitudes are not fixed. Since we do not now have experimental data, and we will see in the following that the magnitudes of signal and background contributions in the energy region that we considered are much different, the effect of the interference term should be small. Thus we take all the relative phases as zero in the present work.

3 Results and discussion

With the formalism and ingredients given above, the total cross sections for the \( K^-p \to \eta_c \Lambda \) reaction are calculated. Since the cutoff parameter \( \Lambda \) related to the form factor is the only free parameter, we first need to give a constraint on the value of \( \Lambda \).

From fig. 2 one notices that the cross section from the signal contributions is not sensitive to the values of cutoff \( \Lambda_s \), especially at the center of mass energy \( W \simeq 4.2 \text{ GeV} \), which is due to the fact that the form factor for \( \Lambda_{c\ell}^{(4209)} \) is close to 1 with the invariant mass \( W \) around 4.2 GeV in the present calculation. Therefore, we constrain the cutoff to be \( \Lambda_s = 2.0 \text{ GeV} \) as used in ref [18], which will be used as an input in the following calculations.
Figure 2. (Color online) The cross section for the production of $\Lambda^*_c(4209)$ through $s$-channel with the different typical cut-off $\Lambda_s$.

Figure 3(a) present the variation of cross section from the background contributions for $K^-p \rightarrow \eta_c \Lambda$ reaction with five typical $\Lambda_{t/u}$ values (namely, $\Lambda_t = \Lambda_u = 1.0, 1.5, 2.0, 3.0, 3.5$ GeV). It is seen that the cross section of background reach up to its maximum value when taking $\Lambda_{t/u} = 3.0$ GeV, while the cross section of background began to get lower when taking $\Lambda_{t/u} = 3.5$ GeV. In the spirit of seeking a larger limit for the cross section of the background, we take $\Lambda_{t/u} = 3.0$ GeV in our estimation, which may ensure a reliable estimation on whether the signal of $\Lambda^*_c(4209)$ can be distinguished from the background. Moreover, fig. 3(b) shows that the $t$-channel with $K^*$ exchange play dominant role in the background production and the contributions from $u$-channel with nucleon exchange is very small.

Figure 4 presents the total cross section for $K^-p \rightarrow \eta_c \Lambda$ reaction including both signal and background contributions by taking $\Lambda_s = 2.0$ GeV and $\Lambda_t = \Lambda_u = 3.0$ GeV. One notices that the line shape of the total cross section goes up very rapidly and has a peak around $W \simeq 4.2$ GeV. In this energy region, the cross section from the intermediate $\Lambda^*_c(4209)$ exchange is by two orders larger than that from the background related to the $K^*$ and nucleon exchange, which indicates that the signal can be clearly distinguished from the background. Accordingly, we conclude that $W \simeq 4.2$ GeV is the best energy window of searching for the $\Lambda^*_c(4209)$ baryon via $K^-p$ collision.

Considering the final state $\eta_c$ is a resonance and usually detected by its decay modes (such as $K\bar{K}\pi$, etc.),

1 It should be noted that the $K^-p \rightarrow \eta_c \Lambda$ reaction through $K^*$ and nucleon exchange is an OZI forbidden process, which is similar with the process of $\bar{p}p \rightarrow J/\psi \pi^0$ with nucleon pole exchange. In our previous work [28], we have concluded that the total cross section of $\bar{p}p \rightarrow J/\psi \pi^0$ by exchanging the nucleon pole are consistent with the E760 and E835 data by taking cut-off parameter $\Lambda_N = 1.9$ and 3.0 GeV, respectively. Thus it is reasonable to constrain the value of $\Lambda_{t/u}$ to be 3.0 GeV in the present work.
Fig. 5. (Color online) The differential cross sections for the process of \( \bar{K}^- p \to \eta_c \Lambda \) at different center-of-mass energies \( W = 4.1, 4.2, 4.5 \) and 5 GeV, where the “Total” denotes the differential cross section including both signal and background contributions.

### Table 2. The cross section for the \( K^- p \to K\bar{K}\pi\Lambda \) process at different beam momentum.

| Reaction                  | \( P_{\text{lab}} \) (GeV/c) | Cross section (\( \mu b \)) |
|---------------------------|-------------------------------|-------------------------------|
| \( K^- p \to \pi^0 K^+ K^- \Lambda \) | 2.58                          | 4.5                           |
|                           | 4.20                          | 84                           |
| \( K^- p \to \pi^0 K^+ K^- \Lambda \) | 6.0                           | 39                           |
|                           | 6.5                           | 39.3                         |
| \( K^- p \to \pi^- K^+ K^- \Lambda \) | 4.25                          | 25.2                         |
|                           | 14.3                          | 13                           |

In the \( K^- p \) system, center-of-mass energy \( W \approx 4.2 \) GeV corresponds to the \( K \) beam momentum of \( P_{\text{lab}} \approx 8.8 \) GeV. Thus we estimate that the total cross section of \( K^- p \to K\bar{K}\pi\Lambda \) is on the order of \( 40-80 \mu b \) at \( P_{\text{lab}} \approx 8.8 \) GeV. Accordingly, we get the ratio at \( W \approx 4.2 \) GeV as follows:

\[
\frac{\sigma(K^- p \to \eta_c \Lambda \to K\bar{K}\pi\Lambda)}{\sigma(K^- p \to K\bar{K}\pi\Lambda)} \approx 10-20\%.
\]

As mentioned above, the J-PARC facility is an ideal platform searching for the predicted \( \Lambda^*_c(4209) \) baryon via \( K^- p \) scattering [16]. Assuming the acceptance of \( K^- p \to K\bar{K}\pi\Lambda \) reaction at J-PARC is about 50% [16], one can expect about \( 4-8 \times 10^5 \) events per day for the production of \( K\bar{K}\pi\Lambda \) at \( W \approx 4.2 \) GeV, in which about \( 8 \times 10^4 \) events per day are related to the \( \Lambda^*_c(4209) \).

We also present the differential cross section for \( K^- p \to \eta_c \Lambda \) reaction including both signal and background contributions at different energy, as shown in fig. 5. It is seen that the differential cross section of background are sensitive to the \( \theta \) angle and gives a considerable contribution at forward angles. Besides, one notices that the shapes of the \( s \)-channel \( \Lambda^*_c(4209) \) and the background are much different, which can be tested in future experiments.

it is important to give an estimation about the ratio of \( \sigma(K^- p \to \eta_c \Lambda \to K\bar{K}\pi\Lambda)/\sigma(K^- p \to K\bar{K}\pi\Lambda) \). As presented in fig. 4, the cross section of \( \Lambda^*_c(4209) \) is on the order of 110 \( \mu b \) around center of mass energy \( W \approx 4.2 \) GeV. Using the branching ratio \( BR(\eta_c \to K\bar{K}\pi) = 7.3\% \), we obtain the cross section \( \sigma(K^- p \to \eta_c \Lambda \to K\bar{K}\pi\Lambda) \approx 8 \mu b \) at \( W \approx 4.2 \) GeV. For the total cross section of the \( K^- p \to K\bar{K}\pi\Lambda \) process, several experiment data are available [29], which are listed in table 2.
4 Summary

Within the frame of the effective Lagrangian approach and isobar model, the production of superheavy $A^*_c(4209)$ baryon in the $K^-p \rightarrow \eta_c A$ process is investigated via the $s$-channel. Moreover, the $t$-channel with $K^+$ and $u$-channel with nucleon exchange are also considered, which are regarded as the background for the $A^*_c(4209)$ production in the $K^-p \rightarrow \eta_c A$ reaction.

The numerical results indicate:

i) An obvious peak appears in the total cross section of the $K^-p \rightarrow \eta_c A$ reaction near the threshold of $A^*_c(4209)$ when the $s$-channel with intermediate $A^*_c(4209)$ are included. The cross section from the intermediate $A^*_c(4209)$ exchange is by two orders larger than that from the background around center-of-mass energy $W \approx 4.2$ GeV, which means it is feasible to search for the predicted $A^*_c(4209)$ baryon via the $K^-p \rightarrow \eta_c A$ reaction.

ii) The $t$-channel with $K^*$ exchange plays a dominant role in the background production and the contributions from $u$-channel with nucleon exchange is very small. Besides, the differential cross section of background are sensitive to the $\theta$ angle and gives a considerable contribution at forward angles.

iii) In the best energy window of $W \approx 4.2$ GeV, the signal can be clearly distinguished from the background, while there will be a sizable number of events related to the $A^*_c(4209)$ produced at the J-PARC facility.

As a final note, the near-future experiment at COMPASS@CERN [30] will also be enough to check our predictions. Thus we suggest that this experiment be carried out at the above experimental facilities, which not only helps in testing the existence of the $A^*_c(4209)$ baryon but also provides important information for better understanding of the production mechanism of the exotic baryons.

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References

1. X. Liu, Chin. Sci. Bull. 59, 3815 (2014).
2. N. Brambilla et al., Eur. Phys. J. C 71, 1534 (2011).
3. X.Y. Wang, J.J. Xie, X.R. Chen, Phys. Rev. D 91, 014032 (2015).
4. X.Y. Wang, X.R. Chen, arXiv:1503.02125 [hep-ph].
5. S.J. Brodsky et al., Phys. Lett. B 93, 451 (1980).
6. A. Acha et al., Phys. Rev. Lett. 98, 032301 (2007).
7. Particle Data Group (K.A. Olive et al.), Chin. Phys. C 38, 090001 (2014).
8. B.S. Zou, Nucl. Phys. A 827, 333C (2009).
9. C. Helminen, D.O. Riska, Nucl. Phys. A 699, 624 (2002).
10. B.S. Zou, Nucl. Phys. A 835, 199 (2010).
11. J.-J. Wu, R. Molina, E. Oset, B.S. Zou, Phys. Rev. Lett. 105, 232001 (2010).
12. J.-J. Wu, R. Molina, E. Oset, B.S. Zou, Phys. Rev. C 84, 015202 (2011).
13. J.-J. Wu, T.-S.H. Lee, B.S. Zou, Phys. Rev. C 85, 044002 (2012).
14. J.-J. Wu, L. Zhao, B.S. Zou, Phys. Lett. B 709, 70 (2012).
15. X.Y. Wang, X.R. Chen, EPL 109, 41005 (2015).
16. J-PARC LoI proposal, $\Xi^-$ Baryon Spectroscopy with High-momentum Secondary Beam, May (2014) http://www.jp-parc.jp/researcher/Hadron/en/Proposal_e.html?1301.
17. B.S. Zou, F. Hussain, Phys. Rev. C 67, 015204 (2003).
18. B.C. Liu, J.J. Xie, Phys. Rev. C 86, 055202 (2012).
19. V.G.J. Stoks, Th.A. Rijken, Phys. Rev. C 59, 3009 (1999).
20. Y. Oh, H. Kim, Phys. Rev. C 73, 065202 (2006).
21. P. Gao, B.S. Zou, A. Sibirtsev, Nucl. Phys. A 867, 41 (2011).
22. Y. Oh, K. Nakayama, T.-S.H. Lee, Phys. Rep. 423, 49 (2006).
23. Y. Oh, C.M. Ko, K. Nakayama, Phys. Rev. C 77, 045204 (2008).
24. T. Feuster, U. Mosel, Phys. Rev. C 58, 457 (1998).
25. T. Feuster, U. Mosel, Phys. Rev. C 59, 460 (1999).
26. V. Shklyar, H. Lenske, U. Mosel, Phys. Rev. C 72, 015210 (2005).
27. W.H. Liang et al., J. Phys. G 28, 333 (2002).
28. X.Y. Wang, X.R. Chen, Adv. High Energy Phys. 2015, 918231 (2015).
29. A. Baldini, V. Flamino, W.G. Moorhead, D.R.O. Morrisson, Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, Vol. 12, edited by H. Schopper (Springer-Verlag, 1988) Total Cross Sections of High Energy Particles.
30. COMPASS Collaboration (Ph. Abbon et al.), Nucl. Instrum. Methods A 779, 69 (2015).