Production of K^-pp and $K^+\bar{p}\bar{p}$ in pp collisions at $\sqrt{s} = 7$ TeV

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The production of charged particles $K^{\pm}$, p, and $\bar{p}$ is simulated using the PACIAE model at scaled midrapidity $|y| < 0.5$ in proton-proton collisions at $\sqrt{s} = 7$ TeV. The simulation results are consistent with ALICE experimental data on $K^{\pm}$, p, and $\bar{p}$ yield, with the transverse momentum of kaon at 0.2–6 GeV/c and proton at 0.3–6 GeV/c. Furthermore, the production of K^-pp and $K^+\bar{p}\bar{p}$ is predicted in the dynamically constrained phase-space coalescence (DCPC) model, based on the hadronic final states produced in the PACIAE model. It is found that the yield of K^-pp is around 5×10^{-4}, much larger than the yield of the $K^+\bar{p}\bar{p}$ following the hypothesis that K^-pp and $K^+\bar{p}\bar{p}$ are formed in the way that a K^- (K^+) traps two protons (antiprotons) directly, without going through the so-called Λ^*p doorway state.

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I. INTRODUCTION

Theoretical studies [1–12] reveal that the $\Lambda(1405)$ might be identified as a K^-p bound state. The effective $\bar{K}N$ potential which reproduces the $\bar{K}N$ collision data and results in the K^-p bound state at a mass about 1400 MeV is strongly attractive [1]. This leads to the concept of deeply bound kaonic states in light nuclei such as K^-pp, K^-ppp, K^-ppn, and K^-ppnn. The study of the K^-pp system has been done intensively in both experiment and theory.

Theoretical studies in various approaches predict the binding energy and decay width of the $\bar{K}NN$ system varying in a big region [4–12]. In Ref. [4], the K^-pp cluster is studied comprehensively by solving the three-body system exactly in a variational method starting from the *ansatz* that the $\Lambda(1405)$ resonance ($\equiv\Lambda^*$) is a bound state of K^-p, the Λ^*p system which is formed as the compact doorway state by the unusually large self-trapping Λ^* with involved protons and finally the Λ^*p system propagates to K^-pp. The K^-pp bound state is evaluated to have a mass $M = 2322$ MeV, the binding energy of 48 MeV and width $\Gamma = 60$ MeV. The investigation of the K^-pp system has been done in variational methods by others, for example, in Refs. [5–7]. A weakly bound K^-pp state is found in Ref. [5], with a binding energy 19 ± 3 MeV, where the Argonne v18 NN potential and an energy-dependent $\bar{K}N$ effective interaction derived from chiral SU(3) coupled-channel dynamics are employed. The decay width $\Gamma(K^-pp \to \pi\Sigma N)$ is estimated to range between about 40 and 70 MeV. The same research group has studied the K^-pp system [6], employing as input several versions of energy-dependent effective $\bar{K}N$ interactions derived from chiral SU(3) dynamics together with the Av18 NN potential. The $\Lambda(1405)$, as an $I = 0$ quasibound state of $\bar{K}$ and a nucleon, appears to survive in the K^-pp, and the antikaonic dibaryon K^-pp is not deeply bound, with a binding energy $B(K^-pp) = 20 \pm 3$ MeV. With inclusion of the influence of p-wave $\bar{K}N$ interactions and the width from two-nucleon absorption ($\bar{K}NN \to YN$) processes and the dispersive corrections from absorption, the K^-pp binding energy is estimated to be in the range 20–40 MeV, whereas the total decay width can reach 100 MeV but with large theoretical uncertainties [6]. Deeply bound $\bar{K}NN$, $\bar{K}NNN$, and $\bar{K}NNNN$ states are studied together in Ref. [7], based on a phenomenological $\bar{K}N$ interaction. The lowest binding energy for $\bar{K}NN$ is derived by variational calculations to fall into 40–80 MeV.

Binding energies and widths of $\bar{K}NN$, $\bar{K}NNN$, and $\bar{K}\bar{K}NN$ quasibound states are calculated in Ref. [8] in the hyperspherical basis, using the Argonne Av4 potential and the same subthreshold energy-dependent chiral $\bar{K}N$ interactions as employed in Ref. [5]. Such calculations yield a relatively low binding energy $B(K^-pp) \approx 16$ MeV and a sizable conversion ($\bar{K}N \to \pi Y$) width $\Gamma \approx 40$ MeV.

The $\bar{K}NN$ three-body system has also been studied in the framework of the $\bar{K}NN - \pi YN$ coupled-channel equations. The first genuinely three-body $\bar{K}NN - \pi YN$ coupled-channel Faddeev calculation in search for quasibound states in the K^-pp system is reported in Ref. [9]. The calculation results in such a three-body quasibound state, bound in the range

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$B \approx 55$–70 MeV and with a width $\Gamma \approx 90$–110 MeV. A later work by the same group [10] investigated the dependence of the resulting three-body energy on the two-body $\bar{K}N \to \pi\Sigma$ interaction and confirmed the $B_{K^-pp} \approx 50$–70 MeV and width $\Gamma_{K^-pp} \approx 100$ MeV.

By solving the $\bar{K}NN - \pi YN$ coupled-channel Faddeev equation, where the $\bar{K}N$ interaction is constructed from the leading order term of the chiral Lagrangian using relativistic kinematics, Ref. [11] demonstrates that a three-body resonance of the strange dibaryon system is found at binding energy $B \approx 79$ MeV and width $\Gamma \approx 74$ MeV. The strange dibaryon is further studied [12], using two models with the energy-independent and energy-dependent potentials for the s-wave $\bar{K}N$ interaction, both of which are derived from the leading order term of the effective chiral Lagrangian. Solving the coupled-channel Alt-Grassberger-Sandhas (AGS) equations with the energy-independent potential leads to one resonance pole with $(B, \Gamma/2) = (44$–$58,\ 17$–$20)$ MeV, while for the energy-dependent potential two resonance poles are predicted, one with $(B, \Gamma/2) = (9$–$16, 17$–$23)$ MeV and another with $(B, \Gamma/2) = (67$–$89, 122$–$160)$ MeV [12].

The experimental evidence of the K^-pp bound state has been also reported [13–21]. The first experimental evidence of the K^-pp was reported by the FINUDA Collaboration through its two-body decay into a Λ and a proton [13]. The binding energy and the decay width of the bound state are determined from the Λp invariant-mass distribution to be $115^{+6}_{-5}(\text{stat})^{+3}_{-4}(\text{syst})$ MeV and $67^{+14}_{-11}(\text{stat})^{+2}_{-3}(\text{syst})$ MeV, respectively.

The DISTO Collaboration [14] reported another experimental evidence of the K^-pp by analyzing the experimental dada on the exclusive $pp \to p\Lambda K^+$ reaction at 2.85 GeV, with a binding energy of $103 \pm 3(\text{stat}) \pm 5(\text{syst})$ MeV and a width of $118 \pm 8(\text{stat}) \pm 10(\text{syst})$ MeV. However, they failed to observe the signal at 2.50 GeV [15], probably because of the lower production cross section of the $\Lambda(1405)$ at this energy. The data of the reaction $p(3.5\ \text{GeV}) + p \to pK^+\Lambda$ from the HADES Collaboration were analyzed by employing the partial-wave analysis to search for signals of the cluster of the hypothetical ppK^- [16]. The analysis suggests that a hypothetical ppK^- cluster signal need not necessarily show up as a pronounced feature. The hypothesis that the DISTO resonance [named $X(2265)$] is related to the kaonic nuclear bound state ppK^- is cross-checked in Ref. [17], based on the HADES data of the $p(3.5\ \text{GeV}) + p \to pK + \Lambda$ reaction. It is shown that the signal is missing at low ($E_{\text{kin}} < 2.85$) and high ($E_{\text{kin}} > 2.85$) beam kinetic energies. This cannot be explained by a depletion of the $\Lambda(1405)$. The KLOE Collaboration presented in Ref. [18] the analysis of the K^- absorption processes on two or more nucleons and the search for a signature of the $ppK^- \to \Sigma^0 + p$ kaonic bound state. The study concluded that although the measured spectra are compatible with the hypothesis of a contribution of the channel $ppK^- \to \Sigma^0 + p$, the significance of the result is not sufficient to claim the observation of this state.

The J-PARC E27 Collaboration [19] reported the observation of a K^-pp-like structure in the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c, where the $\Lambda(1405)$ resonance is assumed to serve a doorway to form the K^-pp through the process of $\Lambda^*p \to K^-pp$. The binding energy of the K^-pp system is $95^{+18}_{-17}(\text{stat})^{+30}_{-21}(\text{syst})$ MeV and the width is $162^{+87}_{-45}(\text{stat})^{+66}_{-78}(\text{syst})$ MeV. Additionally, the J-PARC E15 Collaboration reported about a structure near the K^-pp threshold in the $^3\text{He}(K^-, \Lambda p)n_{\text{missing}}$ reaction at 1.0 GeV/c [20]. Fit results show that the pole of the Λp invariant mass has $M_X = 2355^{+6}_{-8}(\text{ stat.}) \pm 12(\text{syst})$ MeV and $\Gamma_X = 110^{+19}_{-17}(\text{stat.}) \pm 27(\text{syst})$ MeV. The theoretical analysis [21] on the J-PARC E15 experiment suggests that the peak structure near the K^-pp threshold found in the $^3\text{He}(K^-, \Lambda p)n_{\text{missing}}$ reaction [20] could be a $\bar{K}NN$ bound state.

In summary, theoretical studies in various approaches predict a K^-pp bound state with the binding energy ranging from 20 to 80 MeV and the decay width from 40 to 100 MeV while the experiments send both positive and negative information of the existence of the K^-pp bound state.

The aim of the work is to construct K^-pp and $K^+\bar{p}\bar{p}$ which are formed without going through the doorway, and to calculate its yield using PACIAE+DCPC model. The paper is arranged as follows. In Sec. II, the production of charged particles, $K^\pm$, p, and $\bar{p}$, is simulated using the PACIAE model [22–24] at scaled midrapidity $|y| < 0.5$ in proton-proton collisions at $\sqrt{s} = 7$ TeV and compared with the ALICE experimental data [25]. In Sec. III we predict the production of kaonic nuclei K^-pp and $K^+\bar{p}\bar{p}$ by using PACIAE+DCPC model. Finally, in Sec. IV we summarize our findings.

II. PACIAE MODEL AND CHARGED-PARTICLE PRODUCTION

The PACIAE is a parton and hadron cascade model. It is developed from the PYTHIA6.4 model [26] which is a Monte Carlo event generator for relativistic hadron-hadron collisions. In the PYTHIA6.4 model a proton-proton (pp) (or hadron-hadron, hh) collision is decomposed into parton-parton collisions, and then the hard parton-parton collision is described by the lowest leading-order perturbative QCD (LO-pQCD) while the soft parton-parton collision (nonperturbative phenomenon) is considered empirically. The PACIAE model consists of four stages: parton initialization, parton evolution, hadronization, and hadron evolution:

(1) Parton initialization. In this stage the string fragmentation is switched off temporarily in PACIAE and di(anti)quarks are broken into (anti)quarks. This partonic initial state can be considered as quark-gluon matter (QGM) formed in the parton initialization stage of a pp collision.
(2) Parton evolution (parton rescattering). Here, the parton rescattering in QGM is taken into account by the $2 \to 2$LO-pQCD parton-parton cross sections [27]. Then the Monte Carlo method is used to simulate the total and differential cross sections in the parton evolution.
(3) Hadronization. This process follows the parton rescattering stage. Here, the hadron can be formed by either the Lund string fragmentation model [28] or Monte Carlo coalescence model [29]. The details about the hadronization stage is given in Refs. [30,31].

TABLE I. Charged particles $K^{\pm}$, p, and $\bar{p}$ yields (per event) at scaled midrapidity $|y| < 0.5$ in pp collisions at $\sqrt{s} = 7$ TeV.

Particle	ALICE data	PACIAE
K^+	0.286 ± 0.016	0.306
K^-	0.286 ± 0.016	0.302
p	0.124 ± 0.009	0.135
$\bar{p}$	0.123 ± 0.010	0.135

(4) Hadron evolution (rescattering) stage. The hadronic matter produced in the previous stage evolves and rescatters. It is performed by the usual two-body collision until the hadron-hadron collision pairs are exhausted (hadronic freeze-out). For details about hadron evolution, see Refs. [32,33].

PACIAE differs from PYTHIA in the addition of parton evolution (rescattering) and hadron evolution (rescattering) before and after hadronization, respectively. The PACIAE model is employed to calculate the yields of the charged particles ($K^{\pm}$, p, and $\bar{p}$) at midrapidity $|y| < 0.5$ in pp collisions at $\sqrt{s} = 7$ TeV. The capability of PACIAE to describe the production of charged particles in pp collisions can be seen in Refs. [23,24,34,35]. Table I shows our PACIAE simulated results of the yields of $K^{\pm}$, p, and $\bar{p}$, where the kaon and proton are measured with the transverse momentum of 0.2–6 and 0.3–6 GeV/c, respectively. In our calculations, the parameters of the PACIAE model are taken from Ref. [24]. It is found from Table I that the simulated results are consistent with the ALICE data for the production of the charged particles K^+, K^-, p, and $\bar{p}$.

III. DCPC MODEL AND PRODUCTION OF K^-pp AND $K^+\bar{p}\bar{p}$

In pp collisions, the K^-pp may be produced in the following processes [4]:

$$p + p \to K^+ + \Lambda^* + p,$$
$$\Lambda^* + p \to K^-pp. \qquad (1)$$

Here the Λ^* and the doorway state Λ^*p play crucial roles in the formation of the K^-pp bound state. As mentioned in Refs. [4,36], the structure of K^-pp shows a molecular feature, as shown in Fig. 1, where the K^- serves as the atomic center and plays a key role in producing strong covalent bounding with other protons. In other words, the strong attractive interaction between the K^- and proton is the key for the formation of the K^-pp bound state. Therefore, one may argue that the K^-pp bound state may be formed in the way that a K^- traps two protons directly without going through the so-called Λ^*p doorway state. In this work, we apply the dynamically constrained phase-space coalescence (DCPC) model to construct the K^-pp cluster which is formed without going through the doorway, and to calculate its yield following the PACIAE model simulations. The DCPC model has been used earlier to study the production of K^-p, $K^+\bar{p}$, light nuclei, light antinuclei, hypertritons, and antihypertritons in pp and Au + Au collisions [37–44].

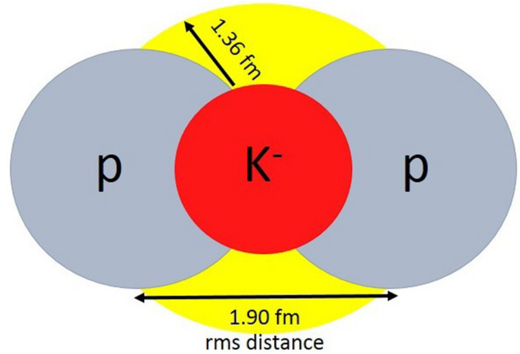

FIG. 1. Molecular structure of kaonic nucleus K^-pp [4].

Owing to the uncertainty principle in quantum statistical mechanics, $\Delta\vec{q}\Delta\vec{p} \geqslant h^3$ [45,46], one cannot exactly define both the position and momentum of a particle in the six-dimension phase space. Thus we can estimate the yield of a single particle by the following integral:

$$Y_1 = \int_{H\leqslant E} \frac{d\vec{q}d\vec{p}}{h^3}, \qquad (2)$$

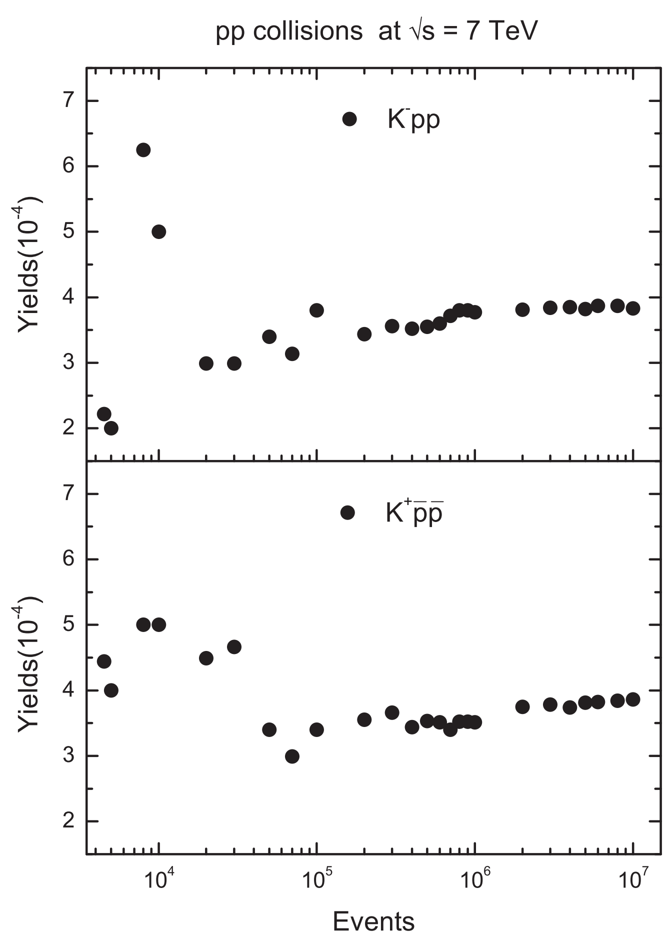

FIG. 2. Yield per event of K^-pp (upper) and $K^+\bar{p}\bar{p}$ (lower) as a function of the event number with $\Delta m = 0.03$ GeV in pp collisions at $\sqrt{s} = 7$ TeV.

TABLE II. Predictions of kaonic nuclei K^-pp ($\times 10^{-4}$) and $K^+\bar{p}\bar{p}$ ($\times 10^{-4}$) productions at scaled midrapidity $|y| < 0.5$ with Δm ranging from 0.02 to 0.05 GeV and m_0 (2.267, 2.269, 2.275, 2.322, and 2.355 GeV) for 1.3×10^7 events in pp collisions at $\sqrt{s} = 7$ TeV.

Δm (GeV)	$m_0 = 2.267$ GeV		$m_0 = 2.269$ GeV		$m_0 = 2.275$ GeV		$m_0 = 2.322$ GeV		$m_0 = 2.355$ GeV	
	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$
0.020	3.26	0.29	3.27	0.32	3.33	0.37	3.64	0.91	3.97	1.34
0.025	4.06	0.38	4.05	0.40	4.11	0.46	4.49	1.13	4.83	1.67
0.030	4.81	0.46	4.82	0.48	4.87	0.55	5.33	1.34	5.70	1.99
0.035	5.53	0.53	5.55	0.56	5.64	0.64	6.17	1.55	6.56	2.27
0.040	6.27	0.60	6.31	0.63	6.38	0.75	6.99	1.78	7.42	2.57
0.045	6.95	0.69	6.98	0.73	7.07	0.87	7.85	1.98	8.26	2.86
0.050	7.64	0.81	7.67	0.85	7.78	0.98	8.62	2.18	9.10	3.13

where H and E are the Hamiltonian and energy of the particle, respectively.

Among the exotic nuclei, K^-pp is the simplest kaonic nuclear bound state and it consists of a kaon and two protons. Therefore the yield of the kaonic nuclei can be obtained by the following integral:

$$Y_{K^-pp} = \int \cdots \int \delta_{123} \frac{d\vec{q}_1 d\vec{p}_1 d\vec{q}_2 d\vec{p}_2 d\vec{q}_3 d\vec{p}_3}{h^9}, \qquad (3)$$

where

$$\delta_{123} = \begin{cases} 1 & \text{if } 1 \equiv K, 2 \equiv p, 3 \equiv p, \quad m_0 - \Delta m \leqslant m_{\text{inv}} \leqslant m_0 + \Delta m, \quad q_{12} \leqslant D_0, q_{13} \leqslant D_0, q_{23} \leqslant D_0 \\ 0 & \text{otherwise.} \end{cases}$$

And m_0 is the rest mass of the kaonic nucleus, Δm refers to the allowed mass uncertainty, and D_0 stands for the diameter of the kaonic nucleus.

The invariant mass m_{inv} is defined as

$$m_{\text{inv}} = \sqrt{(E_{K^-} + E_p + E_p)^2 - (\vec{p}_{K^-} + \vec{p}_p + \vec{p}_p)^2}, \qquad (4)$$

where E_{K^-} (E_p) and $\vec{p}_{K^-}$ ($\vec{p}_p$) are the energy and momentum of K^- (p), respectively. Here the energies of K^- and p are defined as

$$E_{K^-} = \sqrt{\vec{p}_{K^-}^{\,2} + m_{K^-}^2}, \qquad (5)$$

$$E_p = \sqrt{\vec{p}_p^{\,2} + m_p^2}. \qquad (6)$$

By using the same set of parameters as fixed by comparing the production of charged particles from PACIAE with ALICE data, the cluster of K^-pp and $K^+\bar{p}\bar{p}$ yields are calculated in the DCPC model. In this work the m_0 of 2.267, 2.269, 2.275, 2.322, and 2.355 GeV are taken from [4,13,14,19,20]. The masses m_{K^-} and m_p are the effective masses of K^- and p, respectively. Please note that the cluster of $K^+\bar{p}\bar{p}$ can be obtained by replacing the K^- with K^+ and p with $\bar{p}$ in the DCPC model.

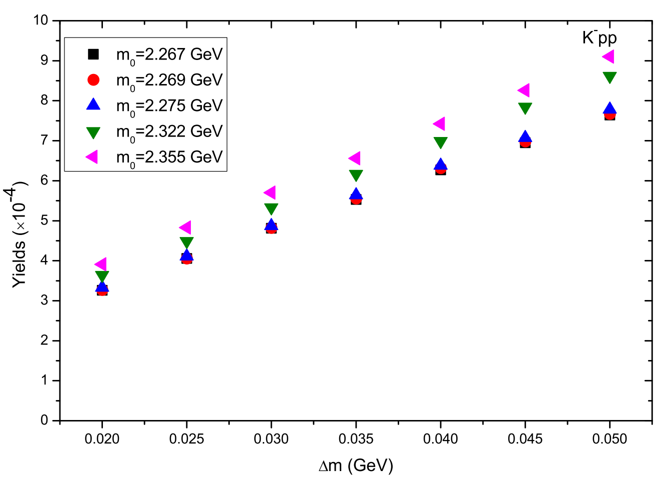

FIG. 3. Yield per event of K^-pp as a function of Δm ranging from 0.02 to 0.05 GeV in pp collisions at $\sqrt{s} = 7$ TeV. Results are taken from Table II.

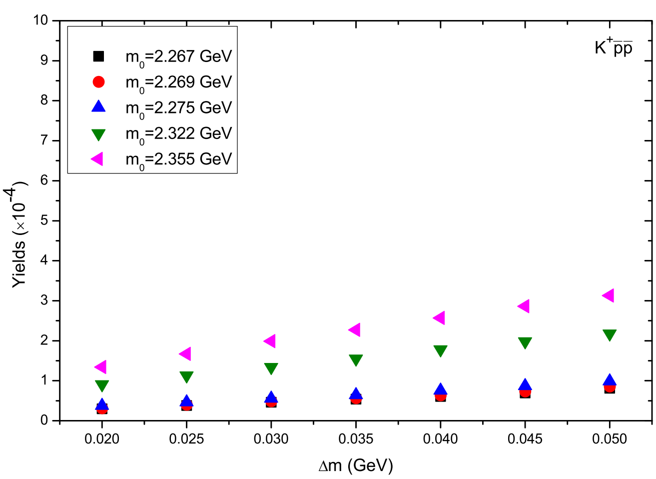

FIG. 4. Yield per event of $K^+\bar{p}\bar{p}$ as a function of Δm ranging from 0.02 to 0.05 GeV in pp collisions at $\sqrt{s} = 7$ TeV. Results are taken from Table II.

TABLE III. Predictions of kaonic nuclei K^-pp ($\times10^{-4}$) and $K^+\bar{p}\bar{p}$ ($\times10^{-4}$) productions at scaled midrapidity $|y| < 0.5$ with Δm ranging from 0.02 to 0.05 GeV, $D_0 = 1.5$, 2, 2.5, 3, 3.5, and 4 fm and $m_0 = 2.275$ GeV for 10^7 events in pp collisions at $\sqrt{s} = 7$ TeV.

Δm (GeV)	$D_0 = 1.5$ fm		$D_0 = 2$ fm		$D_0 = 2.5$ fm		$D_0 = 3$ fm		$D_0 = 3.5$ fm		$D_0 = 4$ fm	
	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$	K^-pp	$K^+\bar{p}\bar{p}$
0.020	2.08	0.21	3.33	0.37	3.78	0.40	3.86	0.41	3.89	0.40	3.89	0.39
0.025	2.58	0.28	4.11	0.46	4.66	0.50	4.76	0.51	4.78	0.50	4.80	0.49
0.030	3.09	0.34	4.87	0.55	5.51	0.60	5.63	0.61	5.66	0.60	5.68	0.60
0.035	3.62	0.40	5.64	0.64	6.39	0.71	6.52	0.72	6.57	0.71	6.60	0.71
0.040	4.10	0.47	6.38	0.75	7.21	0.83	7.36	0.84	7.42	0.83	7.44	0.83
0.045	4.54	0.53	7.07	0.87	7.97	0.93	8.15	0.94	8.21	0.95	8.23	0.96
0.050	5.05	0.62	7.78	0.98	8.76	1.07	8.94	1.08	9.02	1.07	9.06	1.08

The effective masses of K^- and K^+ in a nuclear medium are taken from the effective chiral Lagrangian work [47] to be about 0.393 and 0.513 GeV, respectively. For p and $\bar{p}$, their effective masses are defined in Ref. [48] as a function of kinetic energy E_{kin}. In this simulation the E_{kin} is around 140–180 MeV which leads to the effective masses of 0.75 GeV for p and 0.85 GeV for $\bar{p}$. The allowed mass uncertainty Δm varying from 0.02 to 0.05 GeV is used in this work.

The yield per event of K^-pp and $K^+\bar{p}\bar{p}$ as a function of the event number in pp collisions at $\sqrt{s} = 7$ TeV with $\Delta m = 0.03$ GeV, which is estimated by $\Delta m = \frac{\Gamma}{2}$ owing to the width Γ of K^-pp being 67 MeV [13], is given in Fig. 2. In the calculation, the diameter of the kaonic nuclei $D_0 = 2$ fm is taken from the rms distance calculated in Ref. [36]. One sees clearly that the fluctuation of the yield per event decreases with increasing analyzed event number. When the analyzed event number is larger than 10^6 events, the yield per event becomes stable. In this work the yields of K^-pp and $K^+\bar{p}\bar{p}$ are simulated using the PACIAE+DCPC model with 1.3×10^7 events to ensure sufficient statistics.

Shown in Table II are the predictions of the K^-pp and $K^+\bar{p}\bar{p}$ at scaled midrapidity $|y| < 0.5$ with Δm varying from 0.02 to 0.05 GeV for 1.3×10^7 events in pp collisions at $\sqrt{s} = 7$ TeV. The K^-pp masses (m_0) of 2.267, 2.269, 2.275, 2.322, and 2.355 GeV and the K^-pp widths of 103, 67, 95, 61, and 110 MeV are predicted or observed in Refs. [4,13,14,19,20]. By using these widths, the corresponding Δm (assumed as half of its decay width: $\Delta m = \Gamma/2$) are 51, 33, 47, 30, and 55 MeV, respectively. Then the Δm varying from 20 to 50 MeV are applied to cover the theoretical and experimental widths. The diameter of the kaonic nuclei $D_0 = 2$ fm is applied. To see the dependence of m_0 and Δm on the yield per event, the results in Table II are plotted in Fig. 3 for K^-pp and Fig. 4 for $K^+\bar{p}\bar{p}$. It is found at each m_0 that the yields of K^-pp and $K^+\bar{p}\bar{p}$ increase linearly with Δm. At each Δm, the yields of K^-pp and $K^+\bar{p}\bar{p}$ slightly increase with m_0 as well. The yield of the $K^+\bar{p}\bar{p}$ is smaller than the K^-pp by one order of magnitude at lower m_0 as 2.267, 2.269, and 2.275 GeV.

We show in Table III the productions per event of K^-pp and $K^+\bar{p}\bar{p}$ at scaled midrapidity $|y| < 0.5$ with Δm ranging from 0.02 to 0.05 GeV, $D_0 = 1.5$, 2, 2.5, 3, 3.5, and 4 fm and $m_0 = 2.275$ GeV in pp collisions at $\sqrt{s} = 7$ TeV. The yields of K^-pp and $K^+\bar{p}\bar{p}$ are increasing with D_0 from 1.5 to 3 fm but keep almost unchanged with D_0 from 3 to 4 fm.

IV. DISCUSSION AND CONCLUSIONS

In this work we have studied the production of charged particles $K^{\pm}$, p, and $\bar{p}$ at scaled midrapidity $|y| < 0.5$ in proton-proton collisions at $\sqrt{s} = 7$ TeV in the PACIAE model. The theoretical results are consistent with the ALICE experimental data. The clusters of K^-pp and $K^+\bar{p}\bar{p}$ are also simulated in this work using the PACIAE + DCPC model. It is found that the averaged yield of K^-pp is around 5×10^{-4}, much larger than the yield of the $K^+\bar{p}\bar{p}$ in the *ansatz* that the K^-pp and $K^+\bar{p}\bar{p}$ are formed in the way that a K^- (K^+) traps two protons (antiprotons) directly, without going through the so-called Λ^*p doorway state.

The study of the K^-pp and $K^+\bar{p}\bar{p}$ productions in pp collisions is under way, where the nuclei are formed through the Λ^*p doorway state. One may expect to derive a very different yield.

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