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Double Anti-kaon Production in Nuclei by Stopped Anti-proton Annihilation

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Abstract

We propose to search for double strangeness production by $\bar{p}$ annihilation on helium nuclei at rest. The proposed experiment will provide significant information on double strangeness production and double strangeness cluster states.

1 Introduction

In view of the strongly attractive K^-N interaction below threshold, the importance to look for an even stronger attraction in nuclear clusters with more than one K^- is pointed out by Akaishi and Yamazaki [1], such as K^-K^-NN double anti-kaonic nuclear systems. Double anti-kaonic nuclear clusters are predicted to have binding energies up to 400 MeV and nuclear densities exceeding $\sim$ 5 - 6 times than that of the average one $\rho(0)=$ 0.17 fm^3, thus producing conditions in the phase diagram of hadronic matter for which phase transitions to Kaon-condensation [2] / colour superconductivity [3] or pre-cursor effects for these may be reached at low temperature. Thus the question comes up about possible processes by which several anti-kaons could be produced and transferred into nuclei under favourable kinematical conditions. Several processes have been discussed, such as double strangeness transfer in (K^-, K^+) reactions [4] or search for such clusters in residues of high energy heavy ion collisions [5]. Here we propose [7, 8, 9] to produce double K^- simultaneously at close distance in a nuclear target and explore the expected "strong attraction" mediated by double anti-kaons in the nuclear environment, leading to cold and dense Fermion matter. It may undergo a phase transition to a state with totally different properties similar to the ones recently observed in cold gases of Fermions [6].

The elementary anti-proton annihilation reaction, which produces two pairs of (K^+K^-), considered is

$$\overline{p} + p \rightarrow K^+ + K^+ + K^- + K^- - 0.098 GeV \quad (1)$$

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with a negative Q-value of 98 MeV, so it is forbidden for stopped antiprotons. However, if multi kaonic nuclear cluster exists with deep bound energy suggested by Ref. [5], following $\bar{p}$ annihilation reactions will be possible on ^{3}He and ^{4}He targets [7, 8, 9]:

$$\bar{p} + {}^4\text{He} \rightarrow K^+ + K^+ + pnnK^-K^- + B^{pnn}_{KK} - 126MeV \quad (2)$$
$$\bar{p} + {}^4\text{He} \rightarrow K^+ + K^0 + ppnK^-K^- + B^{ppn}_{KK} - 129MeV \quad (3)$$
$$\bar{p} + {}^3\text{He} \rightarrow K^+ + K^+ + pnK^-K^- + B^{pn}_{KK} - 106MeV \quad (4)$$
$$\bar{p} + {}^3\text{He} \rightarrow K^+ + K^0 + ppK^-K^- + B^{pp}_{KK} - 109MeV \quad (5)$$

This double kaonic nuclear cluster process occurs if the binding energy of the two K^- in a $pnnK^-K^-$ cluster B_{KK} exceeds 126 MeV (plus the Coulomb repulsion of the two kaons). This condition would be fulfilled for deeply bound double kaonic states [10, 11, 12]. Of particular interest is the production of double strangeness cluster states, such as $pnnK^-K^-$ (2), $ppnK^-K^-$ (3), pnK^-K^- (4), and ppK^-K^- (5) using antiproton annihilation in ^{3}He and ^{4}He targets.

In fact, recent reanalysis of the DISTO data indicate that the binding energy of the ppK- system can be as large as $B_K \sim 100$ MeV (T. Yamazaki et al EXA-LEAP08 Proceedings). Thus one could assume double binding strength for two K^-, namely $B_{KK} \sim 2B_K \sim 200$ MeV in the case of a two baryon double strangeness system.

2 Available data on double strangeness production

Experimental information of a possible mechanism to produce baryonic systems with strangeness $S = -2$ were reported recently [14] and at the EXA conference [15] by analyzing a sub-set of the OBELIX data, namely the data of stopped anti-protons in gaseous helium. The high production probability of strangeness $S = -2$ channels makes this reaction scheme favorable for the search of deeply bound antikaon nuclear states. The following possible production channels were found in their analysis normalized to antiproton annihilation:

$$K^+ + K^+ + p + \Sigma^- + \Sigma^- = (0.17 \pm 0.04) \cdot 10^{-4} \quad (6)$$
$$K^+ + K^+ + n + \pi^- + \Sigma^- + \Sigma^+ = (2.71 \pm 0.47) \cdot 10^{-4} \quad (7)$$
$$K^+ + K^+ + n + \Lambda + \Sigma^- = (1.211 \pm 0.29) \cdot 10^{-4} \quad (8)$$
$$K^+ + K^+ + n + n + K^- + \Lambda = (0.28 \pm 0.14) \cdot 10^{-4} \quad (9)$$

Zmeskal et al [16] have recently proposed the construction of a dedicated 4π detector with the capability to detect and identify charged particles, neutrons and photons with a sufficient momentum resolution for studying missing mass and invariant mass spectra in antiproton annihilation on gas targets of light nuclei such as ^{3}He and ^{4}He at the AD of CERN and in the future at the FAIR facility.

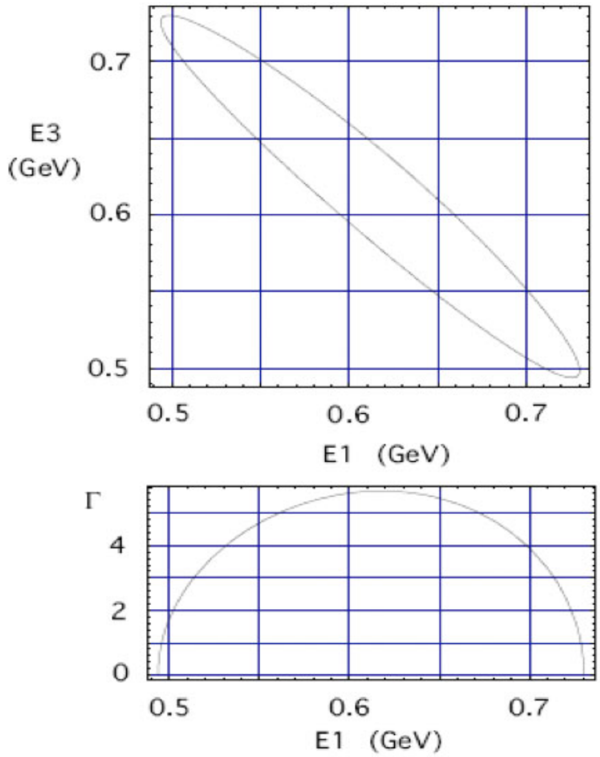

Figure 1: (Upper) Allowed kinematical region of $E_1 = E_{K^+}$ and $E_3 = E_{K^+}$ for $B_{KK} = 0.4$ GeV in the ^{4}He(stopped-$\overline{p}, K^+K^+$) reaction. Uniform event distribution is expected, if there is no pole (or resonance) in the region of interest. (Lower) The decay density distribution of K^+ versus $E_1 = E_{K^+}$.

3 Experimental approach

3.1 Search for double-strange states by two positive kaons

In the following, we discuss kinematical aspects of the anti-proton annihilation at rest in a ^{4}He target producing a $pnnK^-K^-$ cluster and two K^+, where the two K^+ are the particles to be measured. For this case, B_{KK} is expected to be larger than 200 MeV, most likely around 400 MeV, *i.e.* double the experimental value of $pnnK^-$ [13]. In the following, we assume that B_{KK} takes an arbitrary value. The kinematics of the three body final states are shown in Fig. 1 in which the correlation of the energy of the two K^+ ($E_3 - E_1$) is plotted for a binding energy $B_{KK} = 400$ MeV. Since $m_1 = m_3 = m_K$ is much smaller than m_X , the mass of the formed double strange cluster, the two K^+ carry away most of the released energy.

Fig. 1 shows also the statistically distributed decay density distribution Γ, proportional to the phase space, as function of the kaon energy E_1. In Fig. 2, the maximum energy and momentum of the K^+ is plotted as function of the binding energy B_{KK}.

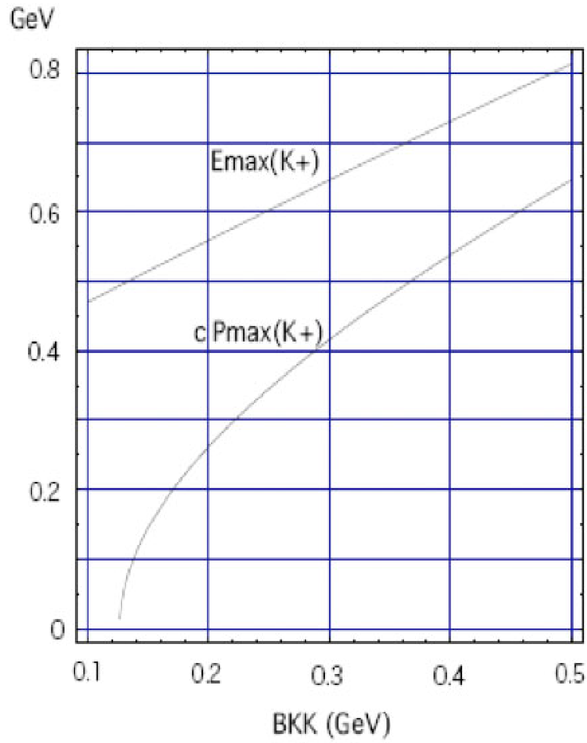

Figure 2: The maximum energy ($E_{K^+}^{max}$) and momentum ($cP_{K^+}^{max}$) of K^+'s versus B_{KK} in the ^{4}He(stopped-$\overline{p}, K^+K^+$) reaction.

The maximum recoil momentum P_{max}, which is transferred when the double strange cluster is formed, is about 500 MeV/c for $B_{KK} \sim 400$ MeV. This momentum transfer is not very small, but acceptable when K^- 's are bound in such a strong attraction. From momenta of the two K^+, the mass of the cluster X, M_X can be determined as follows:

$$\vec{P}_2 = -\vec{P}_1 - \vec{P}_3, \quad (10)$$

$$E_2 = M - E_1 - E_3 = M - \sqrt{m_K^2 + P_1^2} - \sqrt{m_K^2 + P_3^2}, \quad (11)$$

$$M_X = \sqrt{E_2^2 + P_2^2}, \quad (12)$$

where M is the initial energy, namely $M = m_{\overline{p}} + m_{\mathrm{He}}$. Note that the appearance of a discrete mass M_X in the spectrum of two K^+ is a unique signature of the formation of a double strange nuclear cluster. In addition, one can study the decay of the double kaonic cluster into the open Λ, Σ and nucleon channels to perform an exclusive experiment.

3.2 Search with K^+K^0 (or $\Lambda\Lambda$) pair

For reactions with a K^+ and a K^0 in the final state (3 and 5), one has no exclusive signal for the production of a $S = -2$ system, thus one has to resort to the detection of the decay of the cluster X into two $S = -1$ hyperons, such as two Λ particles. This is especially simple for the identification of the double strange ppK^-K^- system using the reaction (5). If one aims at such exclusive experiments, which measure the missing mass from the two K^+, and K^+K^0 energies and also the decay products in addition to reconstruct the invariant mass of the double kaonic nuclear cluster, a detector with 4π coverage and momentum acceptance up to 500MeV/c is required.

Especially in reaction (5), all particles in the finale can be charged ones if the ppK^-K^- intermediate state will decay to $\Lambda\Lambda$ in the final state, so one can detect all the particles rather easily. For the decay branching-ratio to the $\Lambda\Lambda$ final state, one needs detailed theoretical evaluation, although this coherent kaon absorption strength would not be small because of the favored isospin-zero channel. It is also preferable to detect all the possible decay particles including neutrons and photons, with the particle identification capability, so as to cover all the possible decay channels of the $S = -2$ system.

This double Λ channel has another remarkable point. This channel has also a very powerful kinematical feature, even if the binding energy of ppK^-K^- system is much shallower than we expected [11] and having B_{KK} at around 100 MeV. In such a case, the K^+K^0 pair should be produced almost at rest. From an experimental point of view, it is almost impossible to detect K^+ in such a condition, because the K^+ stops in the target quite easily. On the other hand, the $\Lambda\Lambda$ pair should have large internal motion between the two Λ. The K^0 decay can be observed using the $\pi^+\pi^-$ decay mode even at rest condition. From the missing mass analysis using $K^0\Lambda\Lambda$, one can select $K^+K^0\Lambda\Lambda$ final state rather clearly, in the case of ^{3}He target (5).

Therefore, in the case of reaction (5), one can achieve a wide-range search starting from the $\Lambda\Lambda$ threshold of ~2230 MeV ($B_{KK} \sim 530$ MeV) to the kinematical upper limit of ~2750 MeV ($B_{KK} = 0$). For the lower mass region, missing mass analysis using K^+K^0 is quite efficient, while $\Lambda\Lambda$ invariant mass analysis is promising for the higher mass region. For obtaining a clear signal, one needs to identify the final state to be $K^+K^0\Lambda\Lambda$.

It should also be pointed out that the ppK^-K^- system has the same quantum number with so called H-dibaryon. Thus, this exclusive channel study is equivalent to the unbound (excited) H-dibaryon search, which has never been done exclusively.

Let us focus on the $\overline{p} + {}^3$He reaction with a $K^+K^0\Lambda\Lambda$ final state.

$$\begin{aligned} \overline{p} + {}^3\text{He} &\rightarrow K^+ + K^0 + X \ (X = K^-K^-pp) \\ &\rightarrow K^+ + K^0 + \Lambda + \Lambda \qquad (13) \\ \overline{p} + {}^3\text{He} &\rightarrow K^+ + K^0 + X \ (X = H^*) \\ &\rightarrow K^+ + K^0 + \Lambda + \Lambda \qquad (14) \end{aligned}$$

If the mass is located near the K^-K^-pp threshold, the X is more like a double kaonic bound state (13) having a very small Q-value so the K^-K^-pp cluster should be produced at rest. This can happen if the binding energy of the K^-K^-pp cluster exceeds 109 MeV. On the other hand, if the pole exist close to the $\Lambda\Lambda$ threshold, then the X is more like a H-dibaryon (or a $\Lambda\Lambda$ unbound resonance like ^{2}He*, which is known to be a unbound pp resonance) having a large Q-value (14), thus the H^*-dibaryon is boosted strongly and the two Λ's having no internal kinetic energy between the two. This can happen if the H^*-dibaryon mass is near the $\Lambda\Lambda$ threshold.

From an experimental point of view, there is no clear criteria to discriminate the nature of the two except for the pole position in energy. However, one can clearly distinguish the two, in these extreme cases by reconstructing the $\Lambda\Lambda$ invariant mass and the Λ-Λ opening-angle distribution.

Possible background channels for the reactions (13) and (14) are direct $K^+ + K^0 + \Lambda + \Lambda$ production channels, like:

$$\bar{p} + {}^3\mathrm{He} \quad \rightarrow \quad K^+ + K^0 + \Lambda + \Lambda \tag{15}$$
$$\bar{p} + {}^3\mathrm{He} \quad \rightarrow \quad K^+ + K^0 + \Lambda + \Lambda + \pi^0 + \ldots \, . \tag{16}$$

The multi-body final state (16) caused by three-nucleon absorption reaction can be eliminated by the kinematical constraint in the offline analysis quite easily. However, there is no way to distinguish reactions (13 and 14) from (15) other than the invariant mass spectrum, so this channel can be the major background source.

4 Expected signal

To design the spectrometer for the double strangeness production search, the kinematical information is the most important issue. In this section, possible experimental signals from the K^-K^-pp cluster production and the $\Lambda\Lambda$ final-state are discussed, because the kinematics of other reaction channels are similar to this one.

4.1 K^-K^-pp production

The momentum spectra of the K^+, K^0 and K^-K^-pp cluster in the reaction (13) are shown in Fig. 3 with different binding energies. In the following calculation, the decay widths of K^-K^-pp cluster and H-dibaryon are assumed to be zero, and the angular distribution of the many-body decay is considered to be isotropic and proportional to the phase space. The kaons produced at the initial reaction have momentum of up to 300 MeV/c with a long tail to the lower momentum, even if the binding energy is deep enough such as $B_{KK} = 200$ MeV. The momentum correlation and opening angle of the decayed particles at $B_{KK} = 200$ MeV are plotted in Fig. 4, and Fig. 5, respectively. It should be pointed out that the kaons and K^-K^-pp are produced in a back-to-back direction in the laboratory frame.

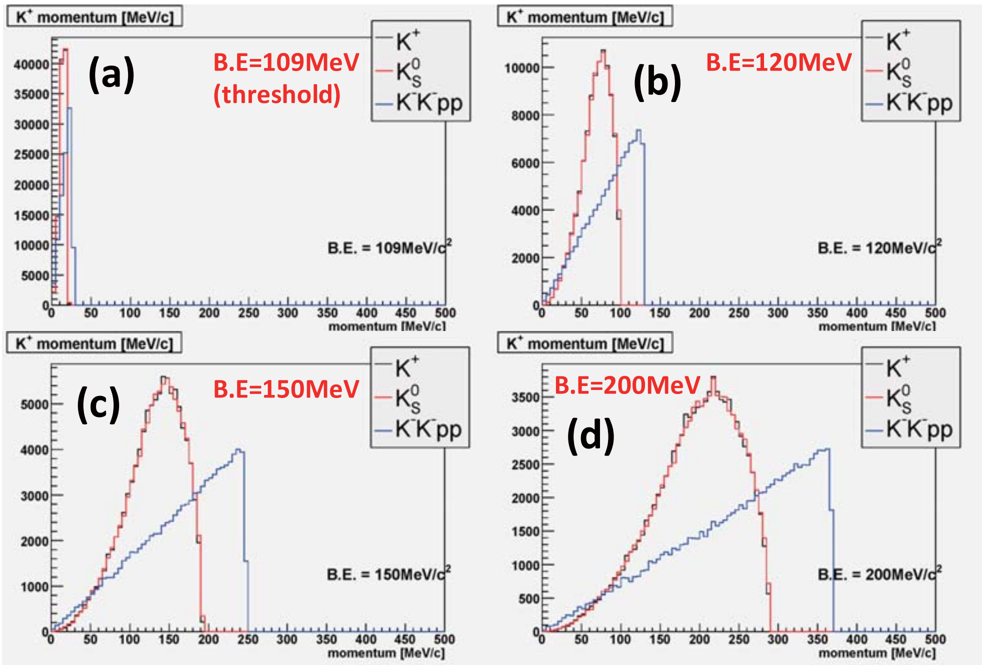

Figure 3: Momentum spectra of the K^+, K^0, and K^-K^-pp cluster in the reaction (13) with different binding energies, (a) B_{KK} = 109 MeV, (b) B_{KK} = 120 MeV, (c) B_{KK} = 150 MeV, (d) B_{KK} = 200 MeV.

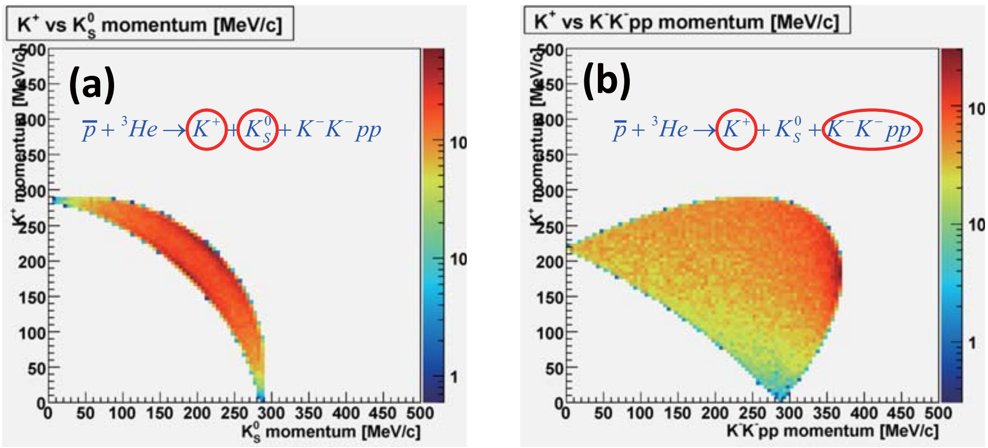

Figure 4: The momentum correlation of the decayed particles at B_{KK} = 200 MeV for (a) $K^+ - K^0$ and (b) $K^+ - K^-K^-pp$.

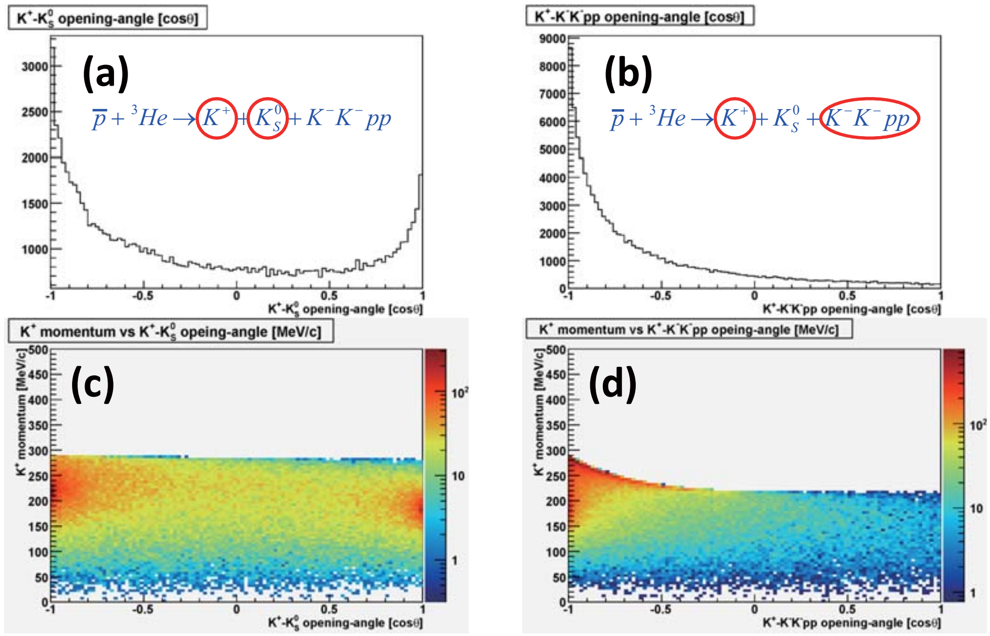

Figure 5: Opening angles of the decayed particles at $B_{KK} = 200$ MeV for (a) $K^+ - K^0$ and (b) $K^+ - K^-K^-pp$. The correlation between momentum(p) and opening-angle(θ) for (c) $p_{K^+} - \theta_{K^+-K^0}$ and (d) $p_{K^+} - \theta_{K^+-K^-K^-pp}$.

4.2 $\Lambda\Lambda$ final state

The momentum spectra of particles in the reaction (14) and (15) are shown in Fig. 6. In the kinematical calculation in (14), the mass of H-dibaryon is assumed to be $2M_\Lambda$ = 2231.4 MeV. Fig. 7 shows the comparison of the K^+ momentum spectra in the reaction (13), (14), and (15). The kaon momentum in the K^-K^-pp cluster production (13) is relatively small, even if B_{KK} is 200 MeV.

From the experimental point of view, the kinematical information of the decayed $\Lambda\Lambda$ help us to discriminate the exotic systems from the non-resonant $\Lambda\Lambda$ events. Figure 8(a) shows the momentum spectra of the Λ in the reaction (13), (14) and (15), where B_{KK} for the K^-K^-pp cluster and the mass of H-dibaryon are assumed to be 200 MeV and $2M_\Lambda = 2231.4$ MeV respectively. The Λ from the K^-K^-pp cluster has large momentum of about 700 MeV because of large decay Q-value of about 430 MeV under the assumption. Figure 8(b) shows the $\Lambda\Lambda$ opening angle distributions in the laboratory frame. The remarkable point is the back-to-back angular correlation between two Λ's in the reaction (13), whereas two Λ are produced in parallel direction in (14). In both cases, a formation of the K^-K^-pp cluster and H-dibaryon could be found as a mono energetic peak in the invariant mass spectrum of $\Lambda\Lambda$ as shown in Fig. 9, if the decay widths are narrow enough. If the pole exist in between the two extreme cases described above, the $\Lambda\Lambda$ correlation becomes week, but it can be seen

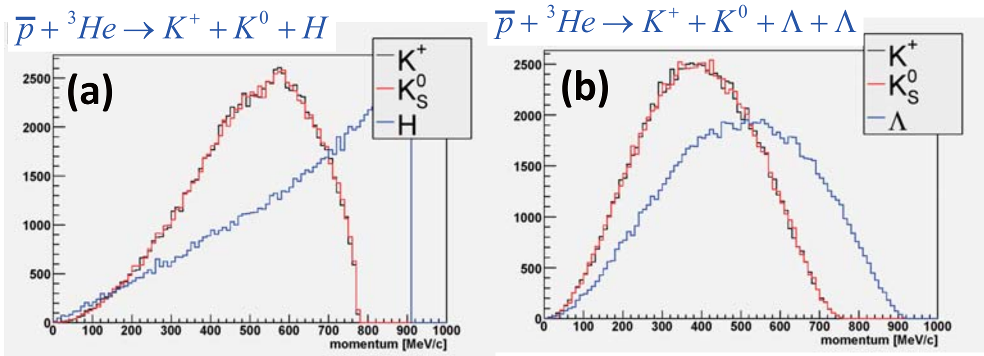

Figure 6: Momentum spectra of the K^+, K^0, and H-dibaryon in the reaction (14), and that of K^+, K^0, Λ, Λ in (15).

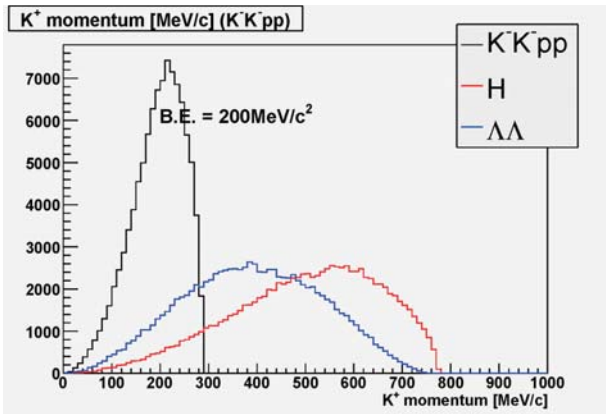

Figure 7: Momentum spectra of the K^+ in the reaction (13), (14) and (15).

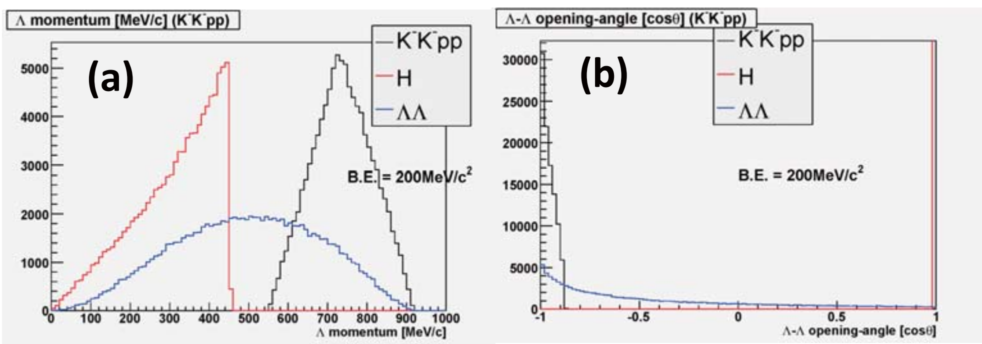

Figure 8: (a)Momentum spectra of the Λ in the reaction (13), (14) and (15). (b)Opening-angles between two Λ at the laboratory frame.

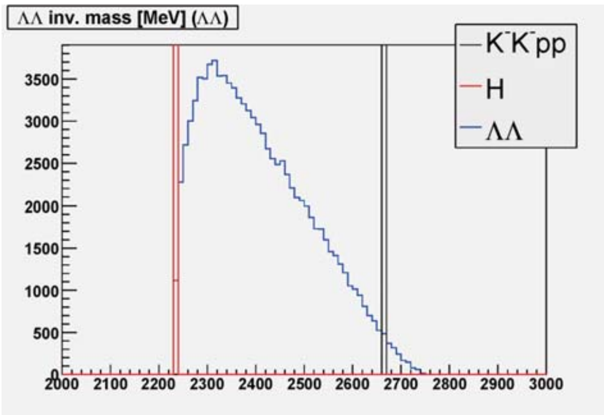

Figure 9: Invariant spectra of ΛΛ in the reaction (13), (14) and (15).

as a peak in the ΛΛ invariant mass spectrum.

5 Possible experimental setup

The experimental setup must be designed to detect low momentum particles and back-to-back events efficiently. The detectors with low mass material are essential for the low-momentum particle detection. If one tries to be sensitive all over the possible kinematical region from ΛΛ threshold to K^-K^-NN (or K^-K^-NNN) threshold, then the experimental setup should be designed so as to extend the detection efficiency of the low momentum particles as much as possible. If we take this criterion, then the low temperature gas target would be the natural choice. However there are many experimental difficulties to use the gaseous target, since the density of gaseous target is lower than the liquid one by two orders of magnitude which means the decrease in event rates as much as. For charged particle tracking and identification, the wide acceptance detector system is necessary for detecting Di-/Tri-baryon systems expected to be observed as the high-multiplicity events. It is very important also to detect a neutron from the $\Sigma^{\pm}$ decay, since the K^-K^-pn cluster would decay into $\Lambda + \Sigma^-$.

Here we point out that very first experiments for studying the fundamental double strange Di-baryon systems (ppK^-K^- and pnK^-K^-) using stopped antiproton annihilation can be done with the E15 set up of J-PARC using its 4π detector for charged particles and its liquid ^{3}He target (or a new gas ^{3}He target system) as shown in Fig. 10 [17]. In case of the double strange ppK^-K^- system, the missing mass is determined from detecting the momenta of the K^+ and K^0 with the latter being reconstructed from the $K^0 \to \pi^+\pi^-$ decays. As pointed out before in order to tag the formation of an S = -2 system we have to reconstruct the two Λ decay channels into two $p\pi^-$ vertices using the drift chamber. This data is also used for an invariant mass determination, thus giving a complete exclusive reconstruction of the formation and the decay of a double strange dibaryon, if it exists and if it is formed with the probability indicated by the OBELIX data.

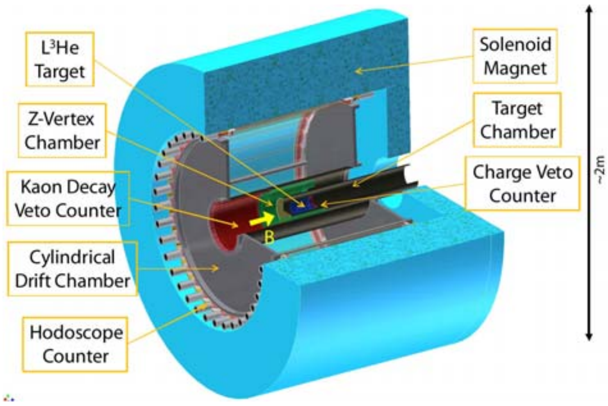

Figure 10: Schematic view of the E15 central spectrometer, CDS.

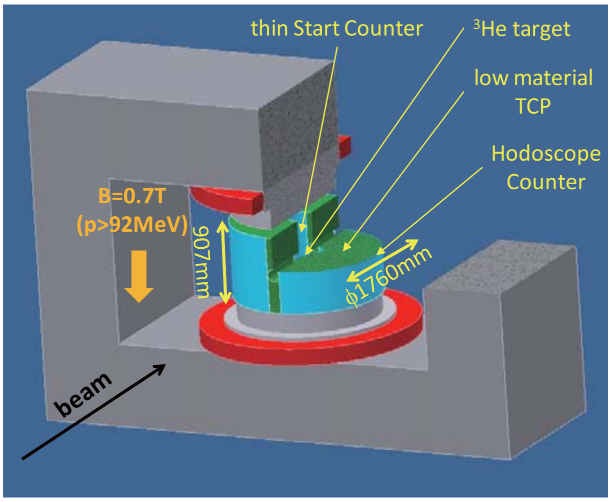

Figure 11: Conceptual design of the TPC setup.

Another possibility of experimental setup is using a large-acceptance Time Projection Chamber (TPC) with wide acceptance and low mass material. A TPC provides a 3D picture of the ionization deposited in a gas volume. The TPC's 3D localization makes it extremely useful in tracking charged particles in a high-track-density environment, and for identifying particles through their ionization energy loss (dE/dx). It is suitable for the proposed experiment, since the low momentum kaons which decay near the target volume can be tracked and identified. The conceptual design for the detector is shown in Fig. 11. In this setup, all detectors are installed in a large dipole magnet. The liquid (or gaseous) ^{3}He target is placed at the center of the spectrometer, and thin start counters surround the target. The TPC, which is the main tracker for the decay particles from the $\bar{p}^3$He annihilation with particle identification, is located around the target. For the charge multiplicity trigger and the particle identification using time of flight measurement, a hodoscope scintillation counter system is installed surrounding the TPC. With such a spectrometer, we can realize 4π detection for charged particles.

In both configurations, a search for a double strange deuteron, K^-K^-pn, using a missing mass spectrum with two K^+ mesons is possible in the same experiment. In this case, a tag for the formation of an S = -2 system is feasible. A Λ and a negative Σ final state would also be the signature. However it is more difficult to reconstruct, because the $\Sigma^- \rightarrow n\pi^-$ decay would require the detection of a neutron.

The main trigger for the proposed experiment is a simple charge multiplicity trigger, since a low-momentum kaon ($<$ 300 MeV/c) trigger using conventional techniques is almost impossible.

6 Yield estimation

The maximum $\bar{p}$ intensity is expected to be about 0.3×10^6 per spill (Spill duration: 3.5 [sec], Flat top: 0.7 [sec]) at 0.7 GeV/c $\bar{p}$ beam momentum at the 30 GeV operation of the proton synchrotron evaluated by empirical Sanford-Wang formula. To estimate the event rate of the double anti-kaon production, the following quantities are assumed:

- $\bar{p}$ beam intensity of 0.3×10^6 per spill at 0.7 GeV/c
- $\bar{p}$ stopping rate of 0.5% using liquid ^{3}He target, if we assume $\bar{p}$ stopping rate is same as K^-
- a formation probability of 10^{-4} indicated by the OBELIX data.

Then the interaction rate is estimated to be 1.5×10^3 per spill which is sufficiently triggerable. The expected production rate of the double strangeness is 1×10^5 events per month. With the following assumptions,

- acceptance of the double anti-kaon production is assumed to be 10%, loosely
- DAQ and analysis efficiency is assumed to be 70%,

the double strangeness production event will be obtained of 8×10^3 events per month. If the $\Lambda\Lambda$ production rate in the double strangeness events is assumed to be 10%, the expected double strangeness production event with $\Lambda\Lambda$ in the final state is obtained of 8×10^2 events per month, whereas the $\Lambda\Lambda$ production rate is not known at all.

	$R_a(\Lambda)$ [%]]	$R_a(K_S^0)$ [%]]
^{1}H		2.15 ± 0.07
^{2}H	0.30 ± 0.04	2.02 ± 0.10
^{3}He	0.55 ± 0.11	1.59 ± 0.20
^{4}He	1.12 ± 0.12	1.07 ± 0.11

Table 1: Experimental yields of $\Lambda(\Sigma^0)$ and K_S^0 with H and He nuclei at rest [18]. The yield of Λ is equal to zero on hydrogen, of course.

A Available data on single strangeness production at rest

It is worth revisiting the results of single strangeness production with light targets. The results provide important information to design the proposed experiment, especially the trigger scheme, and to understand the background from the multi-pion production.

The total rate of $\bar{K}K$ ($R(\bar{K}K)$) in $\bar{p}$ annihilation can be evaluated on the basis of the measured partial rates of the kaon productions, which were measured in mainly hydrogen bubble chamber experiments [18]:

$$R\left(K^0\bar{K}^0\right) = 1.733 \pm 0.067\% \quad (17)$$

$$R\left(K^+K^-\right) = 1.912 \pm 0.141\% \quad (18)$$

$$R\left(\bar{K}^0K^+\right) + R\left(K^0K^-\right) = 1.701 \pm 0.082\%. \quad (19)$$

Hence the total rate for the production of $\bar{K}K$ and K_S^0 can be written,

$$R\left(K_S^0\right) = {}^3\!/_4 R\left(K^0\bar{K}^0\right) + {}^1\!/_2\left[R\left(\bar{K}^0K^+\right) + R\left(K^0K^-\right)\right] = 2.149 \pm 0.065\% \quad (20)$$

$$R\left(\bar{K}K\right) = R\left(K^+K^-\right) + R\left(\bar{K}^0K^+\right) + R\left(K^0K^-\right) + R\left(K^0\bar{K}^0\right) = 5.35 \pm 0.18\%. \quad (21)$$

The Λ and K_S^0 production rates on He target is especially interesting for the proposed experiment. Table 1 shows experimental yields of $\Lambda(\Sigma^0)$ and K_S^0 with H and He nuclei, in which the He data were from a streamer chamber experiment at CERN-LEAR [19]. Figure 12 show the measured momentum spectra of Λ and K_S^0 in $\bar{p}^3$He and $\bar{p}^4$He at rest, respectively.

Note that charged particle multiplicities in $\bar{p}^3$He / $\bar{p}^4$He at rest were measured precisely as listed in Table 2,3. In addition, the ratio between the cross sections for the annihilation of $\bar{p}$ on neutron and on proton bound on ^{4}He nucleus at rest was obtained as:

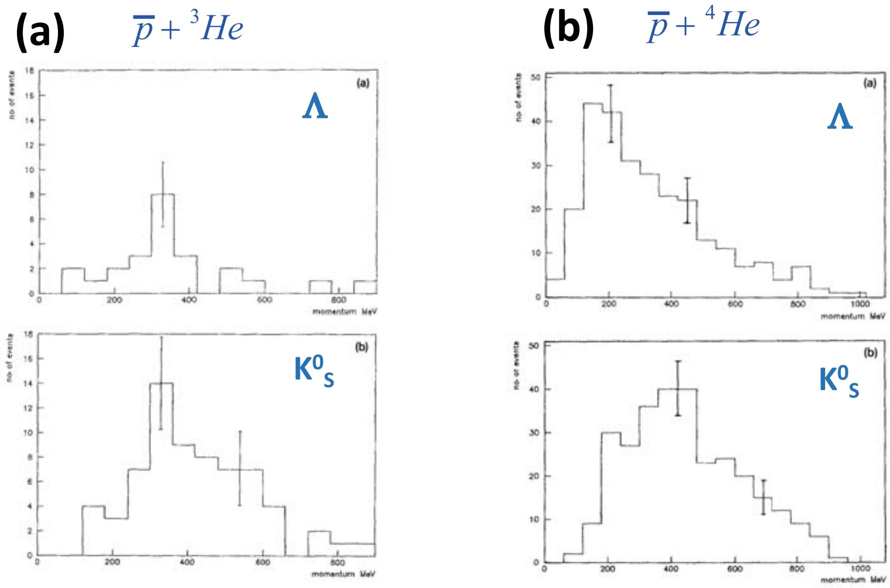

Figure 12: Momentum spectra of Λ and K^0_S in (a)$\bar{p}^3$He and (b)$\bar{p}^4$He at rest [19].

n_c	branch [%]
1	5.14 ± 0.40
3	39.38 ± 0.88
5	48.22 ± 0.91
7	7.06 ± 0.46
9	0.19 ± 0.08
$<n_c>$	4.155 ± 0.06

Table 2: Charged particle multiplicity in $\bar{p}^3$He at rest [20].

$$\sigma^a(\bar{p}p) = 70.4 \pm 2.5\% \quad (22)$$
$$\sigma^a(\bar{p}n) = 29.6 \pm 2.5\% \quad (23)$$
$$\rightarrow \sigma^a(\bar{p}n)/\sigma^a(\bar{p}p) = 0.42 \pm 0.05. \quad (24)$$

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n_c	branch [%]
1	3.36 ± 0.35
2	5.03 ± 0.42
3	33.48 ± 0.92
4	12.26 ± 0.63
5	35.68 ± 0.93
6	3.51 ± 0.36
7	6.24 ± 0.47
8	0.19 ± 0.08
9	0.24 ± 0.10
$\langle n_c \rangle$	4.097 ± 0.07

Table 3: Charged particle multiplicity in $\bar{p}^4$He at rest [21].

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