Search for double anti-kaon nuclear bound states at J-PARC

F. Sakuma, RIKEN

● (brief) Introduction of “Kaonic Nuclear Cluster”
● “Double-Kaonic Nuclear Cluster” search
  ✓ using $p^{\bar{\text{bar}}} + ^3\text{He}$ annihilation at rest
  ✓ using $p+p$ reaction
  ✓ using anti-duetron beam?
● Summary
Kaonic Nuclear Cluster (KNC)

- $K^\text{bar-N}$ interaction is clarified to be strongly attractive by Kaonic-atom experiments in 20th.
- This leads the prediction of deeply-bound kaonic nuclear cluster (KNC), as many theorists pointed out.

Some predictions show the density of the KNC is high density more than normal nuclear-density.


We will open new door to the high density matter physics, like the inside of neutron stars.
Experimental Situation of KNC

stopped-$K^- + A \to (\Lambda + p) + X$

Because there is a discrepancy between THEORETICAL PREDICTIONS and EXPERIMENTAL OBSERVATIONS...

We need more evidences in various channels!
J-PARC E15 Experiment

search for the $K^-pp$ using $^3\text{He}(\text{in-flight } K^-,n)$ reaction

The latest results will be given in M. Iwasaki’s talk
What will happen to put one more kaon in the kaonic nuclear cluster?

“Double-Kaonic Nuclear Cluster”
The double-kaonic nuclear clusters have been predicted theoretically.

<table>
<thead>
<tr>
<th>K cluster</th>
<th>$M_{c^2}$ [MeV]</th>
<th>$E_K$ [MeV]</th>
<th>$\Gamma_K$ [MeV]</th>
<th>$\rho(0)$ [fm$^{-3}$]</th>
<th>$R_{\text{rms}}$ [fm]</th>
<th>$k_p$ [fm$^{-1}$]</th>
<th>$k_K$ [fm$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>pK$^-$</td>
<td>1407</td>
<td>27</td>
<td>40</td>
<td>0.59</td>
<td>0.45</td>
<td>1.37</td>
<td>1.37</td>
</tr>
<tr>
<td>ppK$^-$</td>
<td>2322</td>
<td>48</td>
<td>61</td>
<td>0.52</td>
<td>0.99</td>
<td>1.49</td>
<td>1.18</td>
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<tr>
<td>pppK$^-$</td>
<td>3211</td>
<td>97</td>
<td>13</td>
<td>1.56</td>
<td>0.81</td>
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<tr>
<td>ppnK$^-$</td>
<td>3192</td>
<td>118</td>
<td>21</td>
<td>1.50</td>
<td>0.72</td>
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<td></td>
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<tr>
<td>ppppK$^-$</td>
<td>4171</td>
<td>75</td>
<td>162</td>
<td>1.68</td>
<td>0.95</td>
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<tr>
<td>pppnK$^-$</td>
<td>4135</td>
<td>113</td>
<td>26</td>
<td>1.29</td>
<td>0.97</td>
<td></td>
<td></td>
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<tr>
<td>ppnK$^{-}$</td>
<td>4135</td>
<td>114</td>
<td>34</td>
<td>1.12</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ppK$^-K^-$</td>
<td>2747</td>
<td>117</td>
<td>35</td>
<td>2.97</td>
<td>0.69</td>
<td></td>
<td></td>
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<tr>
<td>ppnK$^-K^-$</td>
<td>3582</td>
<td>221</td>
<td>37</td>
<td>2.33</td>
<td>0.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


The double-kaonic clusters have
- much stronger binding energy
- much higher density than single ones. (AMD calc.)
Two New Calculations

M. Hassanvand, Y. Akaishi, T. Yamazaki


IV. CONCLUSION

In this paper we have presented the results of our calculations on the formation of the basic double-\(K\) cluster, \(K^-K^-pp\), in \(pp\) collisions. Since \(K^-pp\) is well approximated by \(\Lambda^* - p\), we have employed a \(\Lambda^*\) doorway model for \(K^-K^-pp\) formation. We have found that the \(p + p \rightarrow K^+ + K^0 + K^-K^-pp\) reaction takes place at a large probability, so that the bound-state peak dominates the spectral shape. We have studied the dependence of the spectral intensity on the bound-state energy and the compactness of \(K^-K^-pp\) and confirmed that the large bound-state cross section results from its compactness probed by the colliding \(p + p\) with a large momentum transfer and a short collision length. Adding the

4. Conclusion

In conclusion, we have performed calculations of three-body \(KNN\) QBS

For the four-body QBS systems \(\bar{K}NNN\) and \(\bar{K}\bar{K}NN\) we found relatively small binding, of order 30 MeV in both, with widths that range from about 30 MeV for the lowest \(\bar{K}NNN\) QBS to about 80 MeV for the lowest \(\bar{K}\bar{K}NN\) QBS. These systems are not as compact as suggested by Yamazaki et al. [17, 18, 19]. Their \(\bar{K}N\) r.m.s. distances do not fall below that of the \(\Lambda(1405)\)-like \(\bar{K}N\) QBS, and their \(NN\) r.m.s. distances exceed that of nuclear matter \((\approx 1.7\ \text{fm})\).
Experimental Approaches to Search for DKNC

How to produce the double-kaonic nuclear cluster?

- heavy ion collision
- \((K^-,K^+)\) reaction
- \(p^{\bar{\text{b}}}A\) annihilation  \(\rightarrow ①\) K1.8BR
- \(p+p\) reaction  \(\rightarrow ②\) primary
- ...
- \(d^{\bar{\text{b}}}A\) annihilation  \(\rightarrow ③\) K1.8BR

We would like to perform exotic states search at J-PARC!
① “Double-Kaonic Nuclear Cluster” search
Using
p^{bar}_+^{3}He annihilation at rest
The elementary $p^\bar{b} p$ annihilation reaction with double-strangeness production:

$$\bar{p} + p \rightarrow K + \bar{K} + K + \bar{K} \quad -98\text{MeV}$$

This reaction is **forbidden for stopped $p^\bar{b}$**, because of a negative Q-value of 98MeV

If multi kaonic nuclear exists with deep bound energy, following $p^\bar{b}$ annihilation reactions **will be possible**!?

**e.g.** $\bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + K^- K^- pp + B_{KK}^{pp} \quad -109\text{MeV}$

**final state:** $K^+ + K^0 + \Lambda + \Lambda$

- $\pi^+ \pi^-$
- $p \pi^-$
- $p \pi^-$

Then we can **investigate the DKNC with exclusive or semi-inclusive measurement**
Past Experiments of Double-Strangeness Production in Stopped-$p^{\text{bar}}$ Annihilation

several groups reported double-strangenessness production in $p^{\text{bar}}+A$ annihilation

hydrogen bubble-chamber experiment @ BNL

in association with the H-dibaryon search

They did NOT observe any double-strangenessness event in $p^{\text{bar}}$ - C, Ti, Ta, Pb annihilation ($\sim 80,000$ events, $p < 400$ MeV/$c$)


<table>
<thead>
<tr>
<th>Reaction</th>
<th>Frequency (90% C.L.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p^{\text{bar}}A \rightarrow \Lambda^0\Lambda^0X$</td>
<td>$&lt; 4 \times 10^{-4}$</td>
</tr>
<tr>
<td>$p^{\text{bar}}A \rightarrow \Lambda^0K^-X$</td>
<td>$&lt; 5 \times 10^{-4}$</td>
</tr>
<tr>
<td>$p^{\text{bar}}A \rightarrow K^+K^+X$</td>
<td>$&lt; 5 \times 10^{-4}$</td>
</tr>
<tr>
<td>$p^{\text{bar}}A \rightarrow HX$</td>
<td>$&lt; 9 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
Past Experiments of Double-Strangeness Production in Stopped-\(\bar{p}\) Annihilation

<table>
<thead>
<tr>
<th>experiment</th>
<th>Channel</th>
<th># of events</th>
<th>yield (x10^{-4})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIANA@ITEP</strong></td>
<td>(K^+K^+X)</td>
<td>4</td>
<td>0.31+/-0.16</td>
</tr>
<tr>
<td>[(p^\bar{b}ar+Xe)]</td>
<td>(K^+K^0X)</td>
<td>3</td>
<td>2.1+/-1.2</td>
</tr>
<tr>
<td><strong>OBELIX</strong></td>
<td>(K^+K^+\Sigma^-\Sigma^-\rho_s)</td>
<td>34+/-8</td>
<td>0.17+/-0.04</td>
</tr>
<tr>
<td><strong>@CERN/LEAR</strong></td>
<td>(K^+K^+\Sigma^-\Sigma^+n\pi^-)</td>
<td>36+/-6</td>
<td>2.71+/-0.47</td>
</tr>
<tr>
<td>[(p^\bar{b}ar+^4He)]</td>
<td>(K^+K^+\Sigma^-\Lambda n)</td>
<td>16+/-4</td>
<td>1.21+/-0.29</td>
</tr>
<tr>
<td></td>
<td>(K^+K^+K^-\Lambda nn)</td>
<td>4+/-2</td>
<td>0.28+/-0.14</td>
</tr>
</tbody>
</table>

Although observed statistics are small, their results have indicated a high yield of \(\sim 10^{-4}\)
--- the \( K^-K^-\)pp is assumed to be produced by \( \Lambda^*\Lambda^* \) collision ---

**double-strangeness production yield in \( p^{\text{bar}}A \): \( \sim 10^{-4} \)**

**free \( \Lambda^* \) production yield: \( \sim \Lambda x0.1 \)**

**free \( \Lambda^*\Lambda^* \) production yield: \( \sim \Lambda\Lambda x0.01 \)**

**\( \Lambda^*\Lambda^* \) production yield in \( p^{\text{bar}}A \): \( \sim 10^{-6} \)**

*even if all \( \Lambda^*\Lambda^* \) become the \( K^-K^-\)pp state,*

**\( K^-K^-\)pp production yield in \( p^{\text{bar}}A \): \( \sim 10^{-6} \)**

small production yield is expected ...

*moreover, \( Q \)-value of \( \Lambda^*\Lambda^* \) production in \( p^{\text{bar}}^3\text{He} \) reaction is negative (\( Q = -55\text{MeV} \))
Experimental Strategy

I. investigation of “double-strangeness production” in $p^\text{bar} + ^3\text{He}$ annihilation at rest

- $\bar{p} + ^3\text{He} \rightarrow K^+ + K^+ + \Lambda + \Sigma^-$
- $\bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + \Lambda + \Lambda$

II. toward search for “double-kaonic nuclear cluster” in $p^\text{bar} + ^3\text{He}$ annihilation at rest

- $\bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + K^- K^- pp \rightarrow \Lambda + \Lambda$
Experimental Setup

We will perform the experiment at J-PARC K1.8BR beam line

stopped-\(p_{\text{bar}}\) beam

initial beam mom. : 0.7GeV/c
w/ tungsten degrader (t=31mm)
460/spill(6s) @ 30kW, Pt-target

Engineering run (2012, Jun.)
Double-Strangeness Measurement

\[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^+ + \Lambda + \Sigma^- \]
\[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + \Lambda + \Lambda \]

acceptances of \(K^+K^+\) and \(\Lambda\Lambda\)

- evaluated using GEANT4 toolkit
- Many-body decay are considered to be isotropic decay.
- branching ratios of \(K^0 \rightarrow K_s^0/K_s^0 \rightarrow \pi^+\pi^-/\Lambda \rightarrow p\pi^-\) are included.
- acceptance is defined by CDC

<table>
<thead>
<tr>
<th>(K^+K^+) channel</th>
<th>(K^+K^0) channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K^+K^+) detection</td>
<td>(\Lambda\Lambda) detection</td>
</tr>
<tr>
<td>24%</td>
<td>4.1%</td>
</tr>
<tr>
<td>(K^+K^+\Lambda) detection</td>
<td>(\Lambda\Lambda\LambdaK^+) detection</td>
</tr>
<tr>
<td>4.4%</td>
<td>2.1%</td>
</tr>
<tr>
<td>(K^+K^+\Lambda\pi^-) detection</td>
<td>(\Lambda\Lambda\LambdaK^+K^0) detection</td>
</tr>
<tr>
<td>2.8%</td>
<td>0.29%</td>
</tr>
</tbody>
</table>

CDS @ K1.8BR
Double-Strangeness Measurement (Cont’d)

**sensitivity**

- $\sigma = S/\sqrt{S+B}$
- backgrounds are assumed to be,
  - $K^-\, S:B=9:1 \rightarrow K^+K^+: S:B=8:2$
  - $\Lambda\, S:B=7:3 \rightarrow \Lambda\Lambda\, S:B=5:5$
- backgrounds are assumed to be,
  - $K^-\, S:B=9:1 \rightarrow K^+K^+: S:B=8:2$
  - $\Lambda\, S:B=7:3 \rightarrow \Lambda\Lambda\, S:B=5:5$

from engineering run, and the S/N ratio is NOT depend on the production ratio

- duty factor of the accelerator and apparatus: 21h/24h
- DAQ and analysis eff.: 0.7

30kW, 3 weeks

- $K^+K^+: 1100$
- $\Lambda\Lambda: 200$

DIANA/OBELIX

**Engineering run (2012, Jun.)**

$\Lambda \rightarrow p\pi^-$
Experimental Strategy

present situation of the double-strangeness production in \( \bar{p} + A \) (\( A>2 \)) annihilation at rest:

- NO results with a dedicated spectrometer and high intensity beam except for bubble chamber experiments.
- high-statistics measurement is NOT performed!

I. investigation of “double-strangeness production” in \( \bar{p} + ^3\text{He} \) annihilation at rest

- \[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^+ + \Lambda + \Sigma^- \]
- \[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + \Lambda + \Lambda \]

II. toward search for “double-kaonic nuclear cluster” in \( \bar{p} + ^3\text{He} \) annihilation at rest

- \[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + K^-K^- pp \rightarrow \Lambda + \Lambda \]
Procedure of the K⁻K⁻pp Search

\[ \bar{p} + ^3\text{He} \rightarrow K^+ + K^0 + K^-K^- \text{pp} \rightarrow \Lambda + \Lambda \]

**methods of the measurement**

- (semi-inclusive) \( K^0K^+ \) missing-mass w/ \( \Lambda \)-tag
- (inclusive) \( \Lambda\Lambda \) invariant mass
- (exclusive) \( K^0K^+\Lambda\Lambda \) measurement

**acceptance**

- evaluated using **GEANT4** toolkit
- \( \Gamma(K^-K^-pp) = 100 \text{ MeV} \)
- isotropic decay
- branching ratios of \( K^0 \rightarrow K^0_s/K^0_s \rightarrow \pi^+\pi^-/\Lambda \rightarrow p\pi^- \) are included.
Assumptions

evaluate sensitivity to the $K^-K^-pp$ observation using these assumptions

**production yield:**
- $K^-K^-pp$ bound-state = ?
- (3N) $K^-K^-ΛΛ$ phase-space = 5x10^{-5}
- (3N) $K^+K^0Σ^0Σ^0π^0$ phase-space = 5x10^{-5}
- (2N) $K^+K^0K^0Σ^0(n)$ phase-space = 3x10^{-4}

**branching ratio:**
- $BR(K^-K^-pp \rightarrow ΛΛ) = 0.25$
- $BR(K^-K^-pp \rightarrow Σ^0Σ^0) = 0.25$
- $BR(K^-K^-pp \rightarrow Σ^0Σ^0π^0) = 0.5$

- total yield: upper limit of $p^\text{bar}A \rightarrow KKKX$, 5x10^{-4}
- 3N: 20% of yield, and 3N:2N = 1:3
- $K^-K^-pp$ yield: parameter
- non-mesonic : mesonic = 1 : 1
Expected $K^-K^-pp$ production yield in $p^{\text{bar}}A$: $\sim 10^{-6}$

$\rightarrow$ We have less sensitivity to the $K^-K^-pp$ with the assumptions.
Expected Spectra @ 50kW, 6 weeks

assumptions:
- **K^-K^-pp production yield** = $10^{-4}$/stopped-\(p^{\text{bar}}\)
- B.E. = 200 MeV
- \(\Gamma = 100\) MeV

\(3\text{He}(p^{\text{bar}}, \Lambda\Lambda/K^+K^0)X\) measurements give us some hints?
Related Topics in $p^{\text{bar}}A$ annihilation

We can also search for H-dibaryon (H-resonance) by using $\Lambda\Lambda$ invariant mass / missing mass.

$$\bar{p} + ^3\text{He} \rightarrow K^0 + K^+ + H \rightarrow \Lambda + \Lambda$$

Of course we can measure $K^-pp$ production with the dedicated detector, simultaneously.

$$\bar{p} + ^3\text{He} \rightarrow K^0 + K^- pp \rightarrow \Lambda + p$$

The exclusive H search with stopped-$p^{\text{bar}}$ beam has never been done.

Our experiment can check the OBELIX results of the $K^-pp$ with a dedicated spectrometer.
② “Double-Kaonic Nuclear Cluster” search using p+p reaction
Experimental Principle

8GeV \( p + p \rightarrow K^+ + K^+ + \Lambda^* + \Lambda^* \)

\( \Lambda^* \Lambda^* \rightarrow K^- K^- pp \)

\( \Lambda \Lambda \)

the produced K^-K^-pp can be identified by both

- missing-mass spectrum \( \Delta M(K^+K^+) \)
- invariant-mass spectrum \( M(\Lambda \Lambda) \)
The free \( \Lambda \) production CS in \( p+p \) collision is known to be
\[
\sigma_\Lambda \sim 10^{-3} \times \sigma_{\text{total}} \sim 50\mu b
\]
The free \( \Lambda^* \) production CS at 2.83GeV is known to be
\[
\sigma_{\Lambda^*} \sim 4.5\mu b \sim 0.1 \times \sigma_\Lambda
\]
The double-\( \Lambda \) production CS is expected to be
\[
\sigma_{\Lambda+\Lambda} \sim 10^{-3} \times 10^{-3} \times \sigma_{\text{total}} \sim 50\text{nb}
\]
Thus, the double-\( \Lambda^* \) production CS is expected to be
\[
\sigma_{\Lambda^*+\Lambda^*} \sim 0.1 \times 0.1 \times \sigma_{\Lambda+\Lambda} \sim 0.5\text{nb}
\]
The DISTO result indicates the \( K^-pp \) production CS is as much as \( \Lambda^* \) production CS, so we simply assume \( K^-K^-pp \) production CS to be
\[
\sigma_{K^-K^-pp} \sim \sigma_{\Lambda^*+\Lambda^*} \sim 0.5\text{nb}
\]

Of course, these are very rough estimations and depend on incident energy
If yield of proton is assumed to be as same as that of pion,

$\sim 10^8$ proton/spill(6s) is expected with $p_p \sim 8-10$ GeV
Expected Production Yield

- CS : $\sigma_{K^-K^-pp} \sim 0.5 \text{nb}$
- Beam : 8 GeV proton $10^8 / 6\text{s} \times 1 \text{ month} (30\text{d}) = 4 \times 10^{13}$
- Target : LH$_2$ target 0.85 g/cm$^2$
  (= SKS target, 0.0708 g/cm$^3$ 12 cm)

\[\sim 10^4 / \text{ month } K^-K^-pp\]
Kinematics

$K^+$
[momentum vs. $\cos(\theta_{\text{lab}})$]

$\Lambda$
[momentum vs. $\cos(\theta_{\text{lab}})$]

$8\text{GeV} \quad p + p \rightarrow K^+ + K^+ + X$

B.E. = $200\text{MeV}$

$\Lambda \Lambda \rightarrow pp\pi^-\pi^-$

Production & decays are assumed to be isotropic.
E16 spectrometer + hadron-spectrometer upgrade

**E16 experiment:**
- investigation of vector meson modification in medium (p+A)
- precise di-lepton measurement with high statistics
- $10^{10}$ proton /spill with thin targets
Detector Acceptance

Generated events

$8\text{GeV} \quad p + p \rightarrow K^+ + K^+ + X$

$B.E. = 200\text{MeV}$

$\Lambda\Lambda \rightarrow pp\pi^-\pi^-$
Detector Acceptance (Cont’d)

**double-K⁺ accepted event**
acceptance = 16% → 1600 / month

**double-Λ accepted event**
acceptance = 0.7% → 30 / month

- ΛΛ decay: 100%
- ppπ⁻π⁻ decay: 40%

π⁻ from Λ
[ mom vs. cos(θ_lab) ]

p from Λ
[ mom vs. cos(θ_lab) ]

π⁻ from Λ
[ mom vs. cos(θ_lab) ]

p from Λ
[ mom vs. cos(θ_lab) ]

K⁺ cos(θ_lab) vs. K⁺ momentum [GeV/c]

π⁻ cos(θ_lab) vs. π⁻ momentum [GeV/c]

proton cos(θ_lab) vs. proton momentum [GeV/c]

π⁻ from Λ
[ mom vs. cos(θ_lab) ]

p from Λ
[ mom vs. cos(θ_lab) ]

π⁻ from Λ
[ mom vs. cos(θ_lab) ]

p from Λ
[ mom vs. cos(θ_lab) ]

acceptance for the exclusive measurement is 0.0%

measurement of p(p, K⁺K⁺)X reaction could be feasible
③ “Double-Kaonic Nuclear Cluster” search using $d^{\text{bar}}$ beam?
**dbar+A annihilation?**

Anti-deuteron (d$^{\text{bar}}$) beam has never been realized. Using high-power proton accelerator (~270kW), we could use the world's first d$^{\text{bar}}$ beam at J-PARC!

**Why d$^{\text{bar}}$+A annihilation?**

- Nobody has done, and nobody knows.
- In baryonic number B=0 annihilation, four nucleon masses are released in small region, followed by creation of the highly energetic/excited blob.
- In B>0 annihilation, more exotic matter could be produced.
- Increase of strangeness production could be observed as same as QGP/hadronic-gas formation in A+A reaction.
- Such anomalous condition, exotic state such as H-dibaryon and K-K-pp could be generated.
**d^{bar} beam @ J-PARC?**

**d^{bar} production in p+A reaction**

At AGS, d^{bar} production was studied in 30GeV p+Be reaction in 1960’s
- production angle: 4.5 degrees
- \( d^{bar}/\pi^{-} = (5.5 \pm 1.5) \times 10^{-8} \) @ 5GeV/c after \( \pi^{-} \) decay & d^{bar} abs. correction
  \( \rightarrow d^{bar}/\bar{p} \sim 10^{-6} \)

**d^{bar} beam @ J-PARC K1.8BR**

- p^{bar} intensity in 30GeV p+Pt reaction at 6 degrees is \( 7 \times 10^{3} /1kW/\text{spill}(6s) \) from the commissioning result in 2012 Feb.
  \( \rightarrow 2 \times 10^{5} \) p^{bar}/spill(6s) @ 30kW, Pt-target

- Assumptions:
  - \( d^{bar}/\bar{p} \sim 10^{-6} \)
  - decrease of d^{bar} yield caused by absorption in 60mm Pt-target is twice of p^{bar} yield

**d^{bar} intensity @ K1.8BR = 0.1 d^{bar}/\text{spill}(6s) @ 30kW, Pt-target**

<table>
<thead>
<tr>
<th>Mom. (GeV/c)</th>
<th># of events</th>
<th>( d^{bar}/\pi^{-} ) yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>41</td>
<td>( (3.0 \pm 1.5) \times 10^{-8} )</td>
</tr>
<tr>
<td>5.0</td>
<td>118</td>
<td>( (3.9 \pm 0.8) \times 10^{-8} )</td>
</tr>
<tr>
<td>5.4</td>
<td>55</td>
<td>( (2.4 \pm 1.0) \times 10^{-8} )</td>
</tr>
<tr>
<td>6.0</td>
<td>17</td>
<td>( (6.0 \pm 3.0) \times 10^{-8} )</td>
</tr>
</tbody>
</table>

D.E.Dorfan, et al., PRL14(1965)1003

**d^{bar} production @ K1.8BR will be checked toward realizing d^{bar} beam**
Summary

- **Single-Kaonic Nuclear Cluster Search (K⁻pp):**
  The E15 experiment will finally start physics run in this FY.

- **Double-Kaonic Nuclear Cluster Search (K⁻K⁻pp):**
  - $\bar{p}^3\text{He}$ annihilation at rest @ K1.8BR
    - double-strangeness measurement will be conducted as a first step
    - measurement of $^3\text{He}(\bar{p}, \Lambda\Lambda/K^0K^+)X$ reaction will be given us some hints of the $K^-K^-pp$
  - 8 GeV/c $p+p$ reaction @ primary
    - $p(p, K^+K^+)X$ measurement using the E16 spectrometer could be feasible
  - $d^\text{bar}$ beam @ K1.8BR
    - expected yield: 0.1 $d^\text{bar}$/spill(6s) with 30kW, Pt-target
Thank you!
<table>
<thead>
<tr>
<th>Year (JFY)</th>
<th>K1.8BR ( (p^{\text{bar}},d^{\text{bar}}) )</th>
<th>high-pt ( (p) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>beam-tune</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>beam-tune</td>
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</tr>
<tr>
<td>2011</td>
<td>recovery</td>
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</tr>
<tr>
<td>2012</td>
<td>E15</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>E15/shutdown</td>
<td>construction?</td>
</tr>
<tr>
<td>2014</td>
<td>E17/E31/here?</td>
<td>construction?</td>
</tr>
<tr>
<td>2015</td>
<td>...</td>
<td>E16?</td>
</tr>
<tr>
<td>2016</td>
<td>...</td>
<td>E16?</td>
</tr>
</tbody>
</table>
Backup
$p^\bar{b}ar$ Beam @ J-PARC K1.8BR

$p^\bar{b}ar$ stopping-rate evaluation by GEANT4

Incident Beam
- momentum bite: +/-2.5% (flat)
- incident beam distribution: ideal

Detectors
- Tungsten Degrader: $\rho=19.25\,g/cm^3$
- Plastic Scintillator: $l=1\,cm$, $\rho=1.032\,g/cm^3$
- Liquid He3 target: $\phi=7\,cm$, $l=12\,cm$, $\rho=0.080\,g/cm^3$

$p^\bar{b}ar$ production yield with a $p^\bar{b}ar$ CS parameterization

$p^\bar{b}ar$ stopping-rate by GEANT4

250 stopped $p^\bar{b}ar$/spill @ 0.7GeV/c, $l_{\text{degrader}} \sim 3\,cm$
Trigger Scheme

expected stopped-\(p^{\text{bar}}\) yield = 250/spill @ 50kW

All events with a scintillator hit can be accumulated

\(p^{\text{bar}}+^3\text{He} \) charged particle multiplicity at rest

<table>
<thead>
<tr>
<th>Nc</th>
<th>Branch (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14 +/- 0.04</td>
</tr>
<tr>
<td>3</td>
<td>39.38 +/- 0.88</td>
</tr>
<tr>
<td>5</td>
<td>48.22 +/- 0.91</td>
</tr>
<tr>
<td>7</td>
<td>7.06 +/- 0.46</td>
</tr>
<tr>
<td>9</td>
<td>0.19 +/- 0.08</td>
</tr>
</tbody>
</table>

\(<\text{Nc}>\) 4.16 +/- 0.06

expected \(K-K-pp\) event
Backgrounds

(semi-inclusive) $\bar{p}^\text{stopped} + ^3\text{He} \rightarrow K^0 + K^+ + K^- + \text{pp}$

*signal*

- $\bar{p}^\text{stopped} + ^3\text{He} \rightarrow K^0 + K^+ + \Lambda + \Lambda$
- $\bar{p}^\text{stopped} + ^3\text{He} \rightarrow K^0 + K^+ + \Lambda + \Lambda + \pi^0$ ...
- $\bar{p}^\text{stopped} + ^3\text{He} \rightarrow K^0 + K^+ + K^0 + \Sigma^0 + (n)$
- $\bar{p}^\text{stopped} + ^3\text{He} \rightarrow K^0 + K^+ + \Xi^0 + (n)$ ...

*3N annihilation*

*2N annihilation*

*each spectrum is obtained with the same production yield*
Backgrounds (Cont’d)

(inclusive) $\Lambda\Lambda$ invariant mass

**signal**
- $\text{stopped-}p^{\text{bar}} + ^3\text{He} \rightarrow K_0^0 + K^+ + K^- + p + p$
  $\rightarrow \Lambda + \Lambda$

**missing 2$\gamma$**
- $\text{stopped-}p^{\text{bar}} + ^3\text{He} \rightarrow K_0^0 + K^+ + K^- + p + p$
  $\rightarrow \Sigma^0 + \Sigma^0$

**missing 2$\gamma$+$\pi^0$**
- $\text{stopped-}p^{\text{bar}} + ^3\text{He} \rightarrow K_0^0 + K^+ + K^- + p + p$
  $\rightarrow \Sigma^0 + \Sigma^0 + \pi^0$

*each spectrum is obtained with the same production yield*

**Graph:**
- $\Lambda\Lambda$ invariant mass

- $B.E. = 200$ MeV
- $\Gamma = 100$ MeV

Yield (arbitrary units) vs. $\Lambda\Lambda$ invariant mass [MeV]
Kaon identification

Hydrophobic silica aerogel production at KEK

Makoto Tabata, Ichiro Adachi, Hideyuki Kawai, Takayuki Sumiyoshi, Hiroshi Yokogawa

Abstract

We present herein a characterization of a standard method used at the High Energy Accelerator Research Organization (KEK) to produce hydrophobic silica aerogels and expand this method to obtain a wide range of refractive index ($n = 1.006$–$1.14$). We describe in detail the entire production process and explain the methods used to measure the characteristic parameters of aerogels, namely the refractive index, transmittance, and density. We use a small-angle X-ray scattering (SAXS) technique to relate the transparency to the fine structure of aerogels.
Past Experiment ...

KEK-PS E248 (AIDA)

12GeV p+p → K^+ + K^+ + X

KEK-PS E248 AIDA Asymmetrically Installed Double Arm Spectrometer
An antideuteron beam at JHF

F. Iazzi

*Politecnico di Torino and INFN, Sez. di Torino, Torino, Italy

The future japanese hadronic machine (JHF) could offer the possibility not only to continue experiments with the antiproton in both the low and high energy ranges but also to start to study the antinuclei physics. In the present paper the production of antinuclei is reviewed and first results of a design for an antideuteron beam line at JHF are reported. Moreover, some particular aspects of the antideuteron physics are discussed together with the basic features of the experimental apparatuses involving an antideuteron beam and the antideuteron annihilation detection.

6. Acknowledgements

The author wish to thank Prof. T. Bressani for many helpful discussions.
ANTIDEUTERON BEAM LINE

Table 1
Parameters of the $\bar{d}$ line components

<table>
<thead>
<tr>
<th>Component</th>
<th>Effective Length (cm)</th>
<th>Angle (deg)</th>
<th>Magnetic field (KGAuss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1, B2</td>
<td>140, 175</td>
<td>43° 18', 57° 15'</td>
<td>18, 19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Electric Field Gradient (kV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep1, Sep2</td>
<td>400, 300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Aperture (cm) at pole tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1, Q2</td>
<td>80, 40</td>
</tr>
<tr>
<td>Q3, Q4</td>
<td>10, 10</td>
</tr>
<tr>
<td>Q5, Q6</td>
<td>30, 30</td>
</tr>
<tr>
<td>Q7, Q8</td>
<td>25, 30</td>
</tr>
<tr>
<td>Q9, Q10</td>
<td>60, 30</td>
</tr>
</tbody>
</table>

~ 30 $d^{\text{bar}}$/pulse @ 50GeV (full power?)
30kW, 30GeV
Pt-target (50% loss)
pulse = 6sec