Kaonic Atoms
and
Search for Kaonic Nuclei

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Physics with strangeness @ J-PARC

heavy ion / unstable nuclei
expanding nuclear chart
precise spectroscopy

Strangeness as impurity to nuclei
hyperon (Λ, Σ, Ξ, ...) = hypernuclei
K-meson = deeply bound kaonic state?

We need to view from various directions...
Why Kaonic Atoms?

- Kaonic Hydrogen Puzzle
  \( \Lambda(1405) : qqq \) or \( qqqq\bar{q} \)?
  inconsistent with scattering data

- Kaonic Helium Puzzle
  inconsistent with potential model
KN interaction?

Kp atom

Strongly attractive!
Weakly absorptive!

Why K-$^4$He x-ray measurement?

The Kaonic Helium Puzzle

Last orbit energy level shift and width of kaonic atoms

Very large repulsive shift

Exp. $\sim 40$eV

S. Hirenzaki, Y. Okumura, H. Toki, E. Oset, and A. Ramos
Phys. Rev. C 61 055205
$2p$ level shifts of the $K^- - ^4He$ atom

Shift: $\Delta E_{cc}^{2p} = -11$ eV (at a maximum)
Width: $\Gamma_{cc}^{2p} = 21$ eV

Repulsive shift for $K^- - ^4He < \sim 11$ eV

Y. Akaishi, EXA05 proceedings (2005)
Very preliminary x-ray data

K-He atom

stopped K with fiducial cut
better resolution

Previous data excluded...

Energy calibration → Using self trigger events
Dose meson form a bound state in nuclei?

π = YES! but ...

not by cascade, s-wave repulsive for N > Z
Dose K-meson form a bound state in nuclei?
Embedding K?

- Deep!
  \(~ 100 \text{ MeV} \)
  cf: \( B_N \sim 10 \text{ MeV} \)

- Narrow!
  \(~ 20 \text{ MeV} \)
  = meta-stable

- Shrink!
  = high density?


Deep!

Narrow!

Shrink!

astroonomical study

hadron mass

K\(^-\) p

K\(^-\) He

K\(^-\)\(^+\) He

!!!YES!!!
Why proton is heavy?

Quark-pair condensation?

Big bang

Higgs condensation

- $T \approx 100$ GeV
- Quark mass $\approx$ MeV

Quark-pair condensation

- $T \approx 200$ MeV
- Quark mass $\approx 300$ MeV
- Baryon formation

Present universe

- $T \approx 0$ eV
- Baryon mass $\approx 1000$ MeV

Baryon mass $\approx 0$
How to form deep K?

\[ Z : +1 \]
\[ T : 0 \text{ or } 1 \]

\( {^4}\text{He} \)

predicted

unpredicted

\[ Z : 0 \]
\[ T : 1 \]

\( pnnK^- \)

\( pnnnK^- \)

\( n \)

\( \rho \)
Experimental Method

M. Iwasaki et al.: NIM A473 (2001) 286-301

- **K^- injection**
- **n, p detector**
- **K^- meson detector**
- **π, p detector**
- **Liquid helium target**
- **p, n detection**
\textbf{distinct in proton} \\
- very narrow width \\
- semi-inclusive !

Strange tribaryon \\
\( S^0(3115) \)
Theoretical interpretation by Akaishi, Dote, Yamazaki

predicted $\sim 108$ MeV
observed $\sim 200$ MeV
($\sim 300$, if measured from excited core)

$$p + e^- \rightarrow K^- + p + \nu_e$$
Upgraded Experimental Setup

To confirm the state & with $K^{-}\,{}^4\text{He}$ x-ray measurement

$\uparrow n \times 5$!
$\downarrow p \times 20$!

Analysis is still in progress

enlarged NC volume
Another data from FINUDA @ DAΦNE

Concept of the further Exp. @ J-PARC

- Liquid $^3$He target
- Neutron counter in 0. degree
- Kaon beam sweeping magnet
- Detect production and decay (invariant mass)

$K^- + ^4$He $\rightarrow \langle K^- pp \rangle + n$

$\langle K^- pp \rangle \rightarrow \Lambda + p$

$\Lambda \rightarrow \pi^- + p$

$K^-$

1.0 GeV/c

Aerogel Cherenkov (beam $\pi$ veto)

$^3$He target

CDS

Magnet

Beam

neutron

15m

1.2 ~ 1.5 GeV/c

$n_{TOF}$ (E549 14×8)

Missing-mass resolution

$\sim 20$ MeV/c$^2$ (FWHM)
Summary

- Towards better understanding of KN int.

- Strange tribaryon $S^0(3115)$
  deeply bound Kaonic state?

- Preparing for J-PARC experiment

- New playground with strangeness = J-PARC
  Nagae will give us a talk tomorrow