Search of Deeply Bound Kaon States @ SuperB

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OUTLINE

- Deeply Bound Kaon States
- Physics Motivations for DBKS
- Direct decays of Υ into Baryons
  - Production of Baryons
  - Production of Bound States
- Search of DBKS @ SuperB

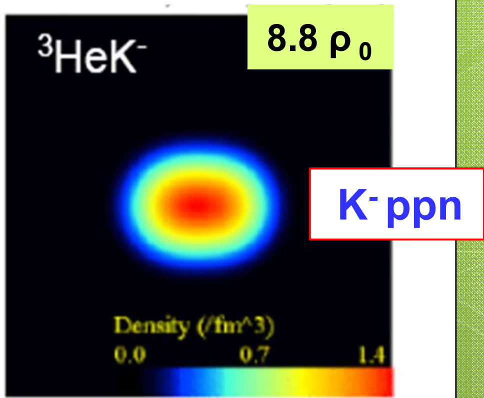
DEEPLY BOUND KAOON STATES

Existence of states with a $\bar{K}$ deeply bound to a few nucleons predicted by Akaishi-Yamazaki PLB535(2002)

phenomenological $\bar{K}$-N potential constructed by exp results

- **$\bar{K}$ N scattering length**
- **Kaonic Hydrogen X-Ray**
- **Energy and width of $\Lambda(1405)$**

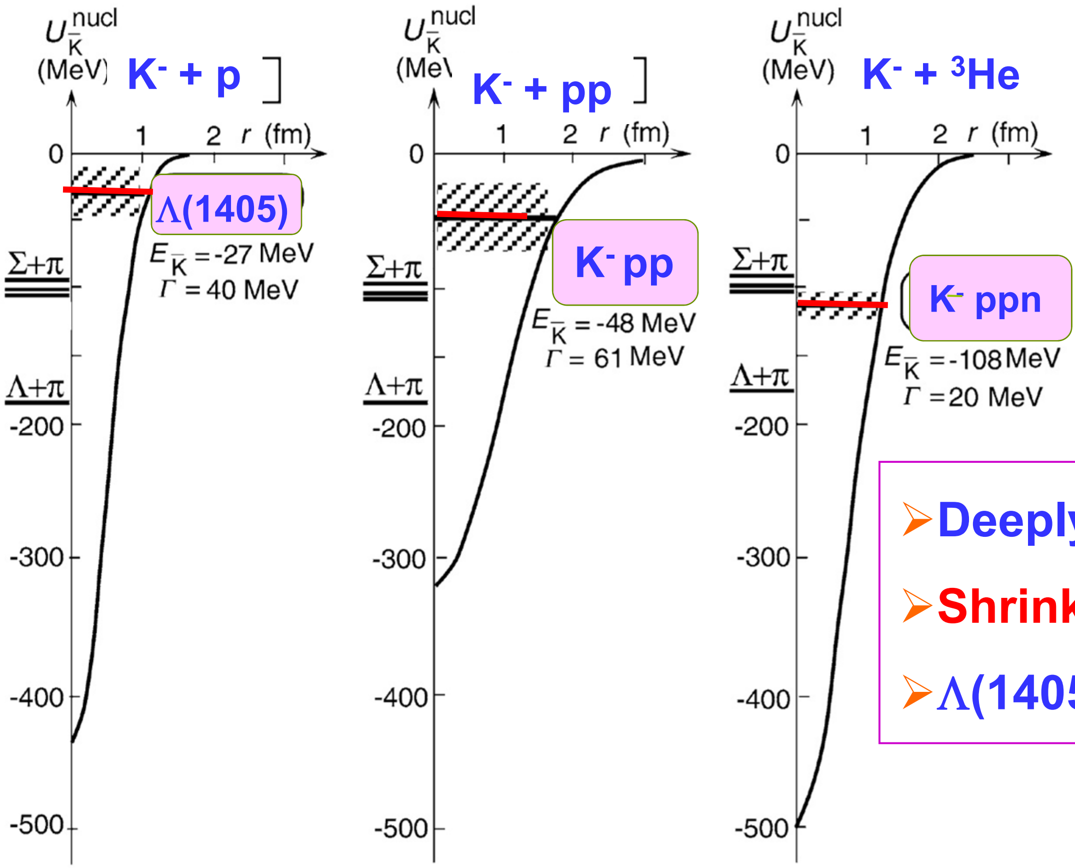
- **$\bar{K}$N strongly attractive interaction (I = 0)**
  - $\Rightarrow$ **Nuclear states strongly bound (~ 100 MeV)**



- **Very dense systems: $\rho > 3\rho_0$**
- **Clustering-structure → Strange Nuclear structure**

DEEPLY BOUND KAON STATES

The Λ(1405) is the simplest $\bar{K}N$ bound state in the model



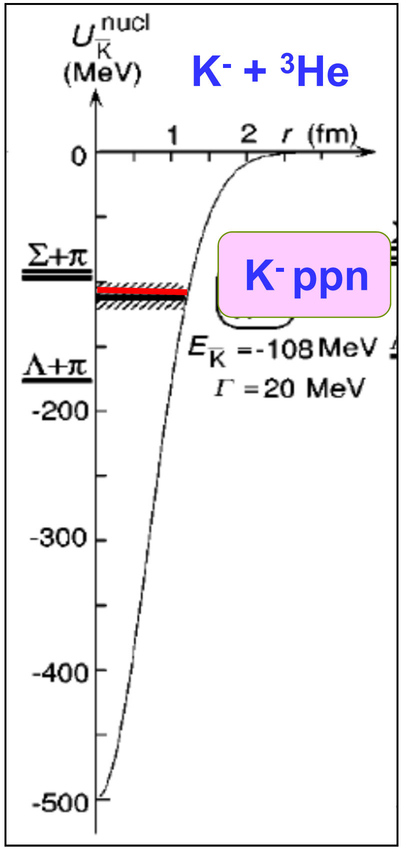
- Deeply Bound (> 100 MeV)
- Shrinkage of the core nucleus
- Λ(1405) as a $\bar{K}N$ bound system

Formation of Λ(1405) in a nucleus as a seed leads to $\bar{K}$ bound states

DEEPLY BOUND KAON STATES

Narrow widths of **20-40 MeV** because:

- below $\Sigma\pi$ emission threshold: ~~$\bar{K}N$~~ $\rightarrow \Sigma\pi$
- above $\Lambda\pi$ emission threshold
  BUT $\bar{K}N \rightarrow \Lambda\pi$ suppressed
  due to I = 0 attraction
- only Y+nN decay channels are allowed



DEEPLY BOUND KAON STATES

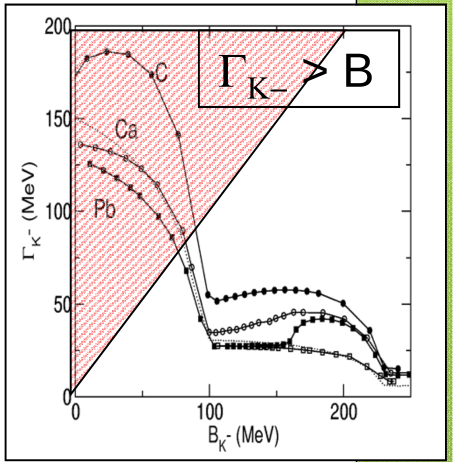
Different Theoretical Approaches

Deep potential ? (150-200 MeV)
Shallow potential ? (50-75 MeV)

- **Gal, Weise, Schaffner-Bielich, Wychech**
  - Possible existence of $\bar{K}$-nuclear aggregates, but potential is shallow and expected widths are large
  - Observation is difficult

- **Oset, Ramos, Toki**
  observed signals due to Final State Interactions

- **Mares et al.**
  high binding energy only for heavy nuclear targets

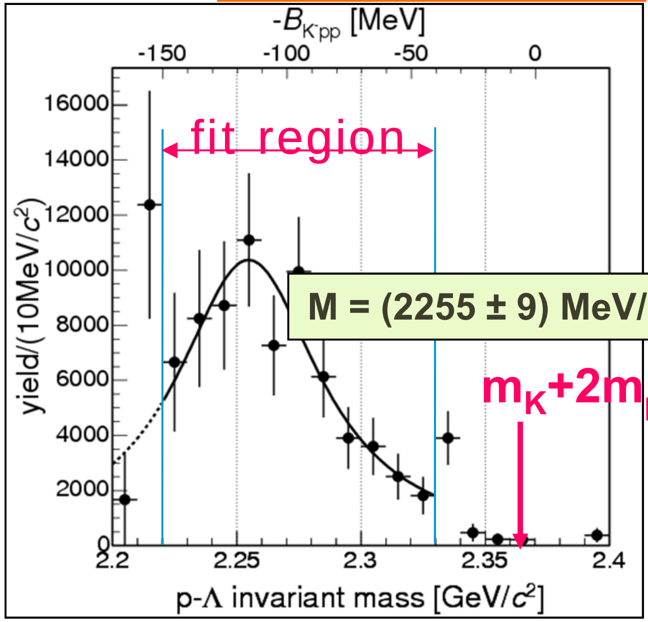


Their existence is not denied
But the possibility to observe them as narrow states is unlikely
Theoretical approaches: several attitudes but limited predictive power

DEEPLY BOUND KAON STATES

FINUDA @DAΦNE
first observation
of the lightest DBKS in pΛ spectrum

PRL 94(2005)212303



K^-pp

K^- stopped in Light targets ^{6}Li, ^{7}Li, ^{12}C

M = (2255 ± 9) MeV/c²

B = 115 $^{+6}_{-5}$ (stat) $^{+3}_{-4}$ (sys) MeV

Γ = 67 $^{+14}_{-11}$ (stat) $^{+2}_{-3}$ (sys) MeV

Yield ≈ 0.1 % / stopped K^-

Akaishi-Yamazaki, PLB535(2002)
B=48MeV, Γ=61MeV

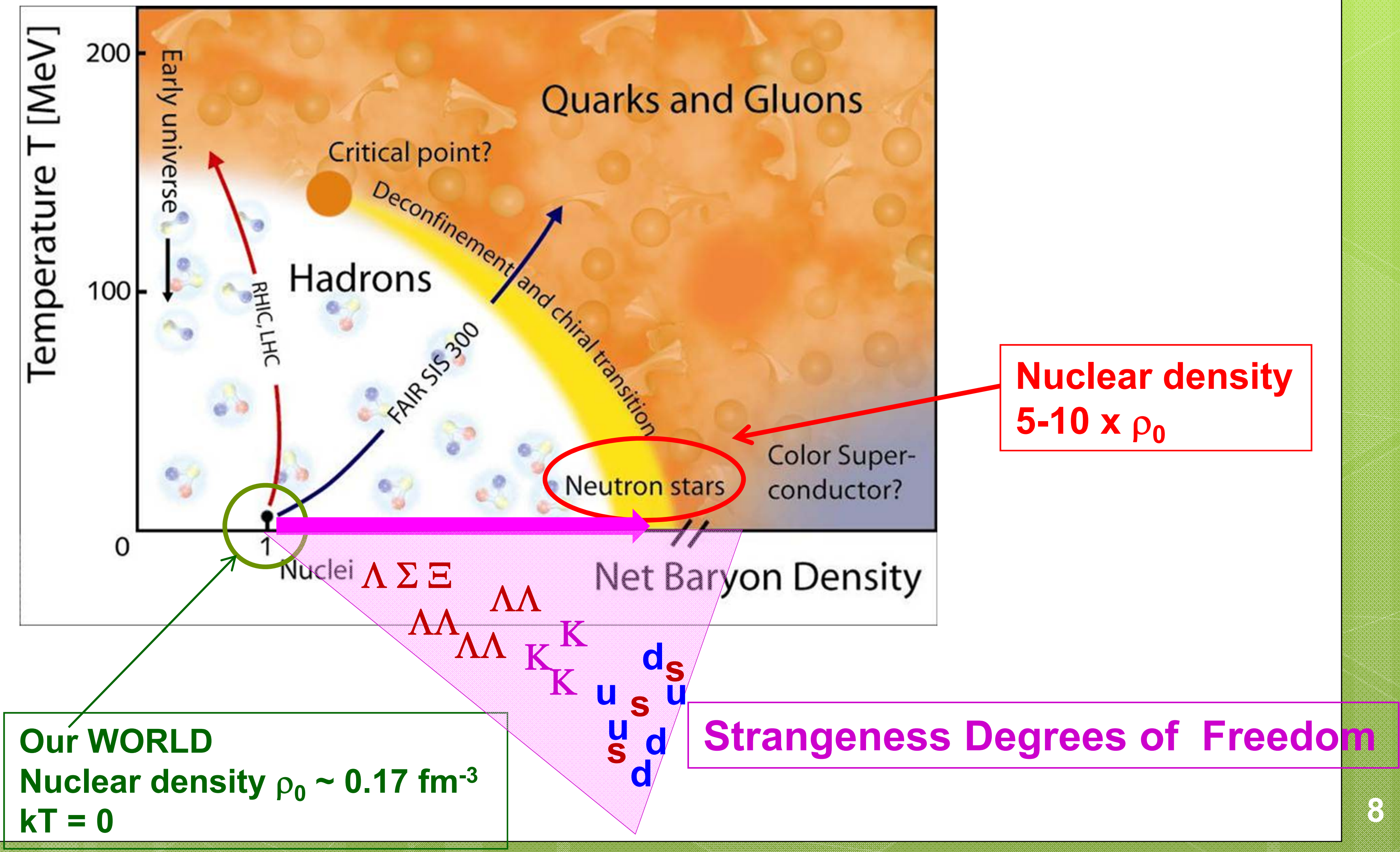
Shevchenko, PRL98(2007)
B=50-70MeV, Γ~100MeV

Ivanov, nucl-th/0512037
B=118 MeV, Γ~58MeV

$K^-(pp) \rightarrow X \rightarrow \Lambda p$
$\rightarrow \Sigma^0 p \rightarrow \Lambda\gamma\, p$

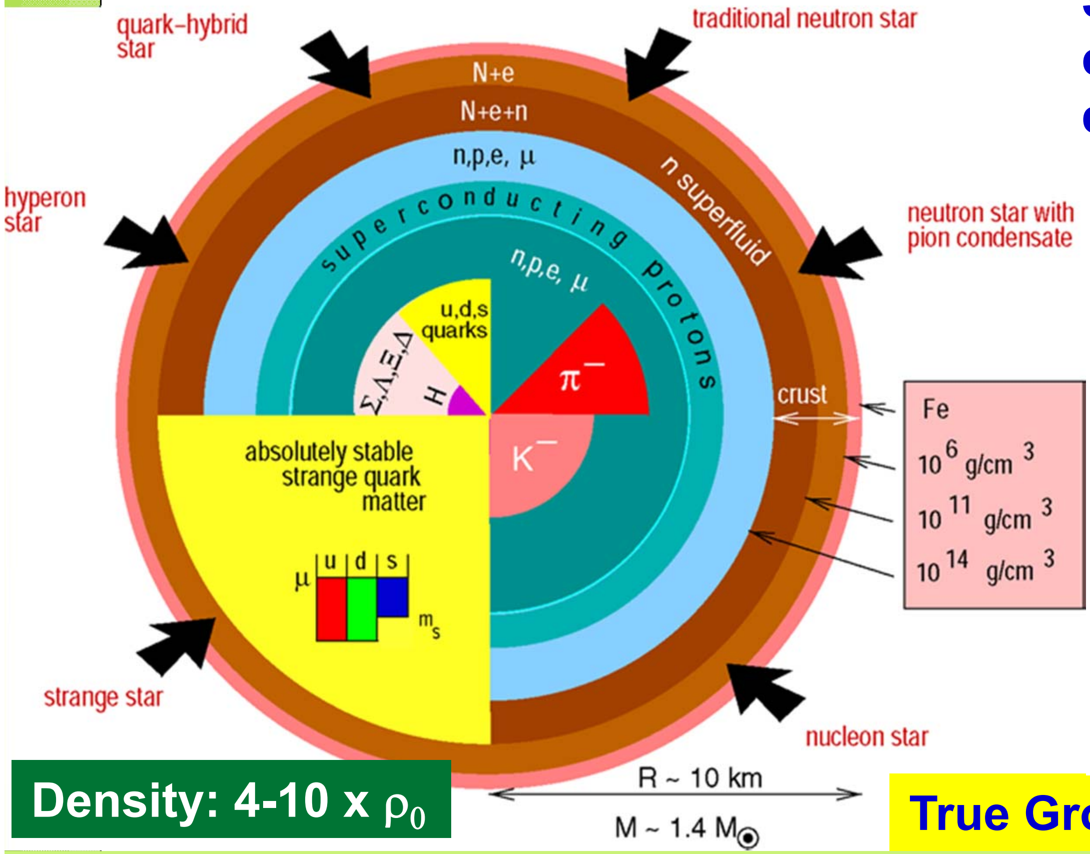
p Λ events strongly back-to-back correlated

Phase Diagram of Nuclear Matter



PHYSICS MOTIVATIONS

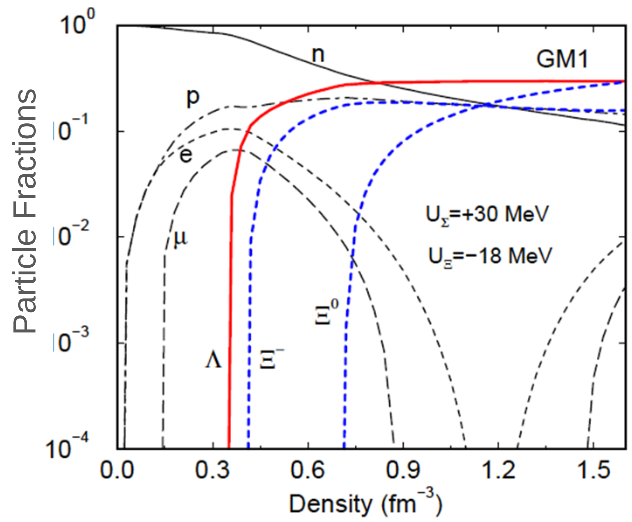
Neutron Stars or Strange Stars ?



Density: 4-10 x ρ_0

Strangeness/Baryon ratio ~ 1

Strangeness expected both confined (hyperons and kaons) and deconfined (strange quark matter)



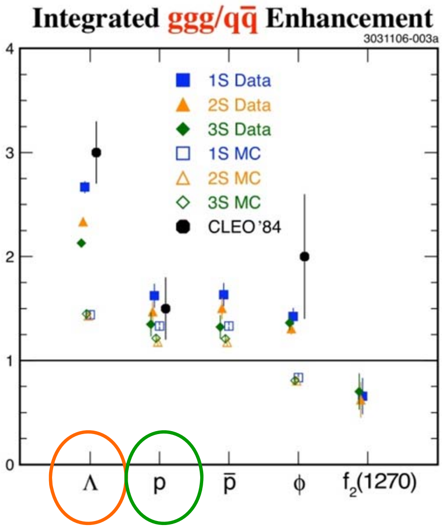
J. Schaffner-Bielich, , astro-ph/0703113

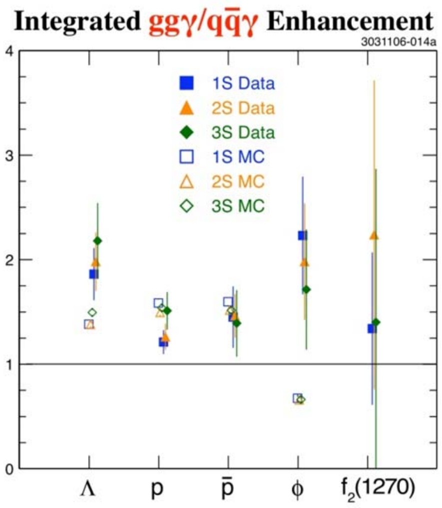
True Ground State of the Strong Interaction

Strongly attractive K^--nuclear potential of the order of 150-200 MeV could affect K^- condensation and evolution of strangeness in high-density nuclear matter in the core of Neutron Stars, where Y could be mixed with *N* in a stable system and could play crucial roles

Why to search for DBKS in Υ Decays ?

- **Baryon production** in $\Upsilon(nS)$ decays is known to be **enhanced** of about a factor of 2 relative to the continuum hadronization



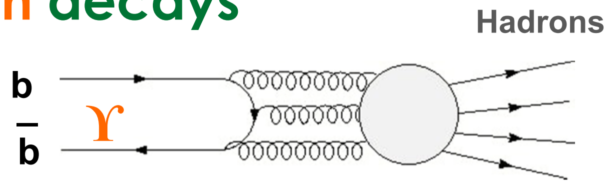


CLEO, Mitchell QCD2007

Baryon enhancements decrease in $gg\gamma/q\bar{q}\gamma$

- $\Upsilon(1S)$ decays ~80% via ggg $\Rightarrow$ glue-rich decays

  $\Rightarrow$ exotic multiquark states



$e^+ e^- \rightarrow q \bar{q}$

Baryon-AntiBaryon Production

Different experiments observe an Enhancement of

Correlated production

- $p\text{-}\bar{p}$
- $\Lambda\text{-}\bar{\Lambda}$
- $\Lambda_c\text{-}\bar{\Lambda}_c$

In contrast to inclusive single-particle production, compensation of Baryon and charm number is a more subtle aspect of quark fragmentation modelling

- **Local** compensation (small $|\Delta y|$, small opening angle)
  - e+e- annihilation in qqbar
- **Global/Primary** compensation (large $|\Delta y|$, large opening angle)
  - e+e- annihilation in diquark-antidiquark, which hadronize in jets containing a leading Baryon and a leading antiBaryon, respectively

Baryon-AntiBaryon Production

$\Lambda^+_c \overline{\Lambda}^-_c$

Charmed baryons 3x more likely to appear opposite an anti-charmed baryon than an anti-charmed meson

$e^+e^- \rightarrow c\bar{c} \rightarrow \Lambda_c \overline{\Lambda}_c X$ events @ Υ(4s) and below

CLEO PRD63 (2001) 112003

(3.35 ± 0.45 ± 0.42) times

TABLE III. Production rates; statistical errors only.

$\frac{\text{Double tags}}{\text{Single tags}}$	Data fraction
$2\times\frac{\Lambda_c^+\vert\overline{\Lambda}_c^-}{\overline{\Lambda}_c^-}$	$(7.19\pm1.08)\times10^{-3}$
$\frac{\Lambda_c^+\vert\overline{D}^0}{\overline{D}^0}$	$(2.05\pm0.16)\times10^{-3}$
$\frac{\Lambda_c^+\vert D^-}{D^-}$	$(2.03\pm0.26)\times10^{-3}$
$\frac{\Lambda\vert\overline{\Lambda}_c^-}{\overline{\Lambda}}$	$(19.3\pm1.1)\times10^{-3}$

BaBar PRD82 (2010) 091102(R)

~ 4 times

Particles in two opposite emispheres

→ Correlated production of $\Lambda^+_c \overline{\Lambda}^-_c$

Baryon # conserved by a leading Baryon and AntiBaryon, rather than locally along the hadronization chain

→ Primary diquark-antidiquark production and/or production of multiple intermediate mesons between a Baryon and antiBaryon

BARYON-ANTIBARYON PRODUCTION

$\Lambda\bar{\Lambda}$

3 σ excess has been found in the estimation of the primary correlated $\Lambda\bar{\Lambda}$ yield

CLEO

PRD636(2002) 052002

$e^+e^- \rightarrow q\bar{q}$ events @ Υ(4s) and below

872 ± 288 excess events

~ 3σ excess of particles produced in two opposite emispheres

→ Correlated production of $\Lambda\bar{\Lambda}$

Here the result is model dependent since JETSET event generator has been heavily used to estimate non primary contribution

NO significant statistical signal for primary ($\Lambda\bar{\Lambda}$) production was found in previous experiments at LEP

Anti-Deuteron Production

d $\bar{d}$

CLEO

- $B^*(\Upsilon(1S) \rightarrow \bar{d} + X) = (3.36 \pm 0.23 \pm 0.25)\times10^{-5}$ direct decays to ggg and γgg
- $B(\Upsilon(4S) \rightarrow \bar{d} + X) < 1.3\times10^{-5}$
- $B(\gamma^* \rightarrow q\bar{q} \rightarrow \bar{d} + X) < 1.3\times10^{-5}$ determined off resonance

➢ **ggg + γgg is at least about 3x more likely than $\gamma^* \rightarrow q\bar{q}$ to produce deuterons**

➢ **How often is an anti-d compensated by a d as compared to (n, p) combinations ?**

Roughly equal compensation by nn, pp, np relative to each other

3 $d\bar{d}$ events

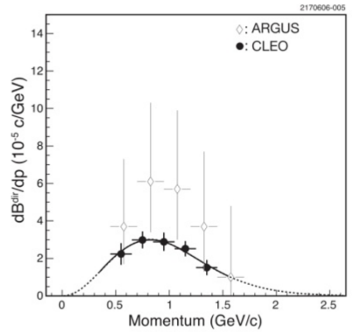
$R(e^+e^- \rightarrow \bar{d}\, d\, X) / R(e^+e^- \rightarrow \bar{d}\, N\, N\, X) \sim 1\%$

ANTI-DEUTERON PRODUCTION

Theoretical descriptions of antideuteron formation based on Coalescence Model

PLB98(1981)153 - PRep131(1986)223

$\bar{p}$ and $\bar{n}$ nearby to each other in phase space bind together



Fit to Maxwell distribution as used in fireball model

Coalescence disfavoured if anti-deuterons always compensated by deuterons, instead of n and p

Yield = $(5.9 \pm 1.8 \pm 0.5) \times 10^{-6}$ Z^0 into $\bar{d}$ @ Aleph

Yield < $(0.8 \pm 0.5) \times 10^{-6}$ Z^0 into $\bar{d}$ @ OPAL

$\bar{d} / \bar{p} \rightarrow (5.0 \pm 1.0 \pm 0.5) \times 10^{-4}$, $\sigma = (2.7 \pm 0.5 \pm 0.2)$ nb , in γp @ H1

High yields of anti-deuterons or anti-nuclei indirect signature of New Physics, such as Dark Matter

STAR

AntiNuclei & AntiHypernuclei

TABLE I: Particle ratios from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/c. The ^{3}He ($^{3}\bar{\mathrm{He}}$) yield have been corrected for $^{3}_{\Lambda}$H ($^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$) feed-down contribution.

Particle type	Ratio
$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}/^{3}_{\Lambda}\mathrm{H}$	0.49 ± 0.18 (stat.) ± 0.07 (sys.)
$^{3}\bar{\mathrm{He}}/^{3}\mathrm{He}$	0.45 ± 0.02 (stat.) ± 0.04 (sys.)
$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}/^{3}\bar{\mathrm{He}}$	0.89 ± 0.28 (stat.) ± 0.13 (sys.)
$^{3}_{\Lambda}\mathrm{H}/^{3}\mathrm{He}$	0.82 ± 0.16 (stat.) ± 0.12 (sys.)

Coalescence

$$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}/^{3}_{\Lambda}\mathrm{H} \propto (\bar{p}/p)(\bar{n}/n)(\bar{\Lambda}/\Lambda)$$

$$^{3}\bar{\mathrm{He}}/^{3}\mathrm{He} \propto (\bar{p}/p)^{2}(\bar{n}/n)$$

0.45 ~ 0.77*0.77*0.77

Ratios favour Coalescence

AntiHypernuclei produced with similar yields of AntiNuclei, unlike what happens at lower energies

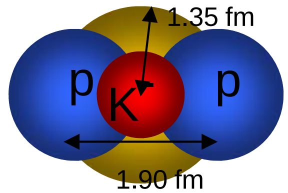
SEARCH OF DBKS @ SUPERB

$e^+e^- \rightarrow \Upsilon(1S) \rightarrow (K^- pp) + X$

$K^- pp \rightarrow \Lambda\, p$

$\rightarrow \Sigma^0\, p \rightarrow \Lambda\, \gamma\, p$

$\Upsilon(1S)$ Strong Decays ~ 80% through ggg hadronization



$I = 0$ Strong attractive potential

Very compact system

- Λ p Invariant Mass spectrum
  - Search for Mass m ~ 2.25 GeV/c^2 and narrow width Γ < 100 MeV
- Check Λ p Angular correlations

We rely in the high performance of the SuperB detector

- At least as frequent as Hypernucleus formation ($^3_\Lambda$H, $^4_\Lambda$H, $^4_\Lambda$He)
- No medium → different FSI → Identification easier than in HI exp

SUMMARY

- Kaonic Nuclear States have been predicted to be deeply bound due to the $\bar{K}N$ strong interaction in the I=0 term
- K^-pp, the lightest DBKS, has been first observed by FINUDA at DAFNE
- Study of DBKS is important to understand high density nuclear matter inside the neutron stars (kaon condensation)
- Nuclear bound systems, such as antideuterons, have been already observed in Υ decays at B-factories
- Search of DBKS in direct decays of $\Upsilon(1S)$ at SuperB can be pursued exploiting the high performance of the apparatus
- Measurements of the production yields could give important clues about both DBKS and hadronization processes in $\Upsilon(1S)$ decays

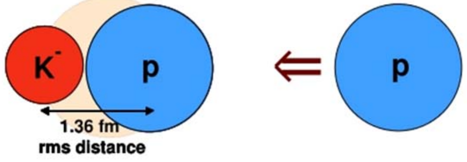
BACKUP SLIDES

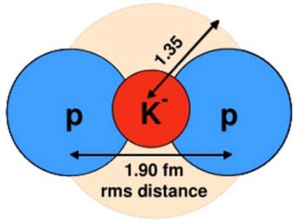
DEEPLY BOUND KAON STATES

K^-pp

K^- combines two protons into a strongly bound system

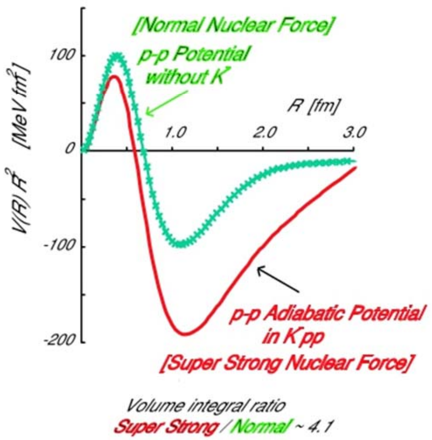
proton approaches
a bound K^-p "atom", $\Lambda(1405)$

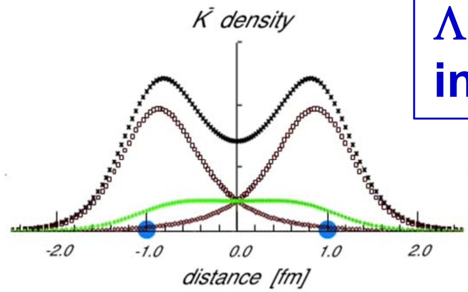


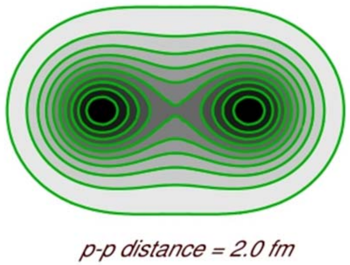


Kaonic hydrogen molecular ion

$\Lambda(1405)$ proton doorway in the formation process







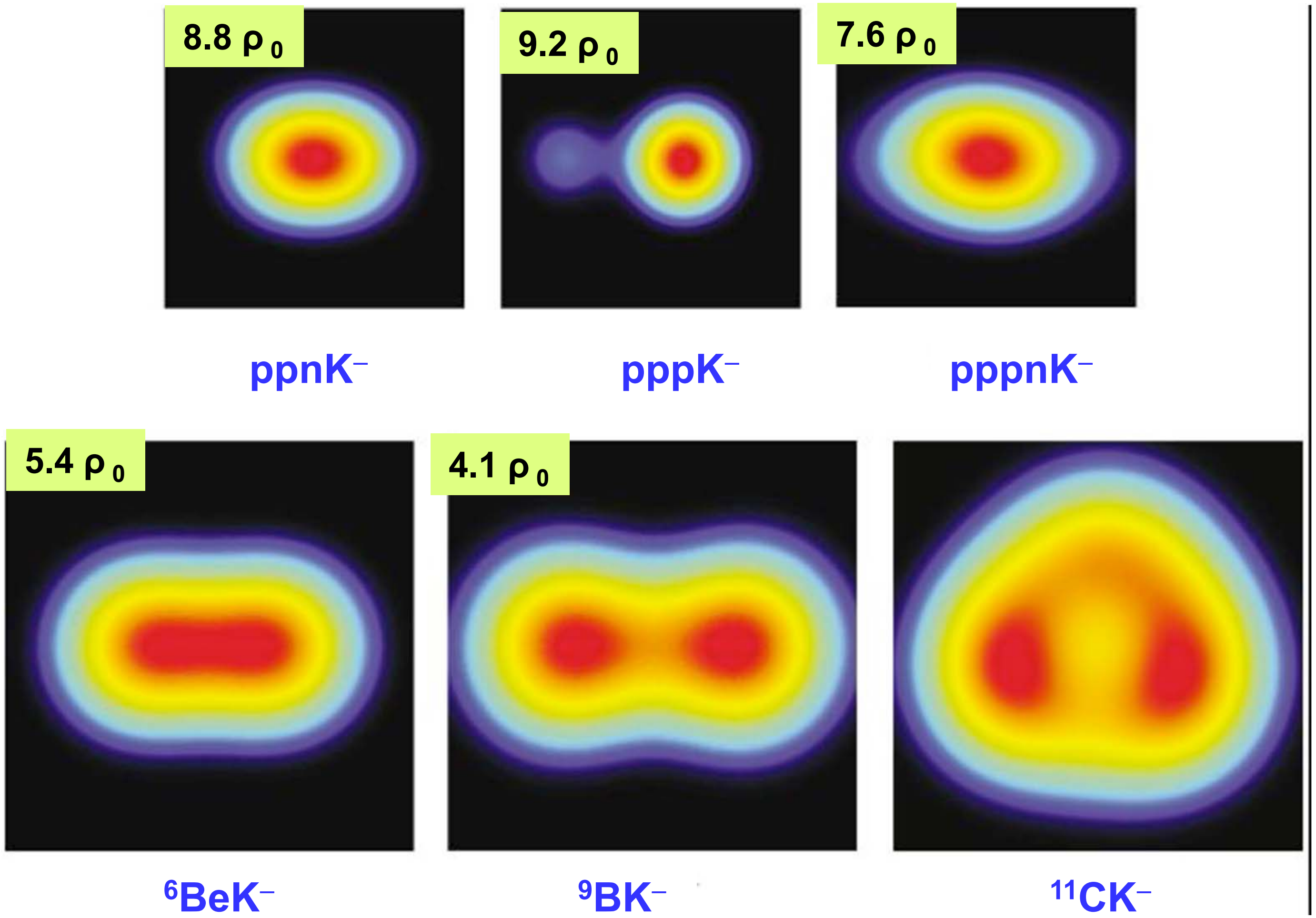
Yamazaki-Akaishi
nucl-th0706.3651v2(2007)

Despite the drastic dynamical change caused by the strong $\bar{K}N$ interaction, the identity of the constituent «atom», $\Lambda(1405)$, is preserved due to the presence of a short-range repulsion between the two protons

DEEPLY BOUND KAON STATES

AMD Calculations by Dote et al.
(Antisymmetrized Molecular Dynamics)

NPA738 (2004) 372



Dense Nuclear States