科研費 新学術領域「多彩なフレーバーで探る新しいハドロン存在形態の包括的研究」
2010年度 領域研究会

Λ(1405) and Kaonic Few-body States in Chiral Dynamics

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Status report of research project (No. 22105507)
ハドロン分子状態としてのハドロン励起状態

original papers http://www2.yukawa.kyoto-u.ac.jp/~jido/NewHadron/NewHadron_Jido.html

1) **Study of the KKKbar system and dynamical generation of the K(1460)resonance**
A. Martinez Torres, D. Jido, Y. Kanada-En'yo, arXiv:1101.1505 [nucl-th].
2) **Structure of Λ(1405) and threshold behavior of πΣ scattering,**
Yoichi Ikeda, Tetsuo Hyodo, Daisuke Jido, Hiroyuki Kamano, Toru Sato, Koichi Yazaki, arXiv:1101.5190 [nucl-th].
3) **Internal structure of resonant Λ(1405) state in chiral dynamics,**
Takayasu Sekihara, Tetsuo Hyodo, Daisuke Jido, arXiv:1012.3232 [nucl-th].
4) **Multi-quark hadrons from Heavy Ion Collisions,**
Sungtae Cho et al. (the ExHIC collaboration), arXiv:1011.0852 [nucl-th].
5) **Kaon induced Λ(1405) production on a deuteron target at DAFNE,**
D. Jido, E. Oset, T. Sekihara, accepted in *Eur. Phys. J. A*, arXiv:1008.4423 [nucl-th].
6) **Theoretical study of incoherent φ photoproduction on a deuteron target,**
Takayasu Sekihara, Alberto Martinez Torres, Daisuke Jido, Eulogio Oset, arXiv:1008.4422 [nucl-th].
7) **Nature of the σ meson as revealed by its softening process,**
Tetsuo Hyodo, Daisuke Jido, Teiji Kunihiro, *Nucl. Phys. A* 848, 341-365 (2010).
8) **KΛ(1405) configuration of the KbarKN system,**
A. Martines Torres, D. Jido, *Phys. Rev. C* 82, 038202 (2010).

What are effective constituents in hadrons ?

✓ quarks and gluons are fundamental constituents of hadrons, but not effective degrees of freedom in many-body systems of quarks and gluons

Success of constituent quark models for low-lying baryons

- **magnetic moments of octet baryons**
- **Gell-Mann Okubo Mass Formula** SU(3) flavor symmetry with a small breaking by quark masses

Octet baryon (N, Λ, Σ, Ξ)

$$m_\Sigma - m_N = \frac{1}{2}(m_\Xi - m_N) + \frac{3}{4}(m_\Sigma - m_\Lambda)$$

254 MeV 248 MeV

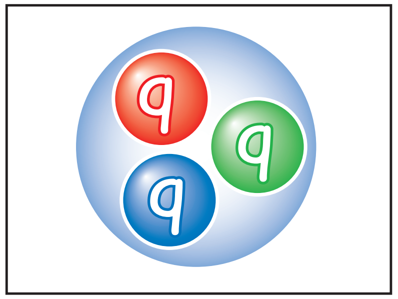
3% level agreement

Typical mass scale >> SU(3) breaking

Decuplet baryon (Δ, Σ*, Ξ*,Ω)

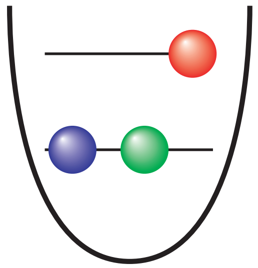
$$m_{\Sigma^*} - m_\Delta = m_{\Xi^*} - m_{\Sigma^*} = m_\Omega - m_{\Xi^*}$$

152 MeV 149 MeV 139 MeV



Symmetry of quarks is realized in baryon properties through constituent quarks

baryon resonances are described by excitation of quarks in constituent quark models



Hadronic molecular states

✓ composite vs elementary ?? they are mixed. Let us consider one extreme side.

Hadronic molecular state

hadrons are constituents （nesting-box structure, Verschachtelung）

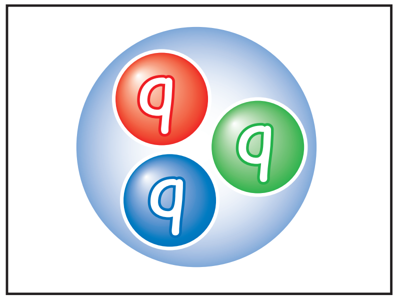
governed by hadron dynamics, not inter-quark dynamics (confinement force)

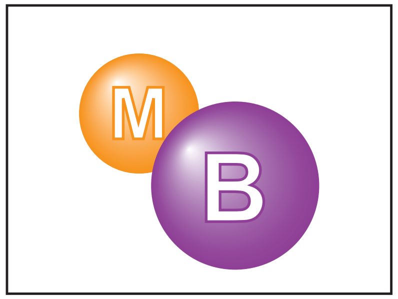
inter-hadron distance > confinement size

larger than typical size of hadron

ex） nucleus ： bound state of baryons

deuteron, ^{3}He, triton (NNN), hypertriton (Λpn)





Meson constituents

resonance with decay width (quasibound state)

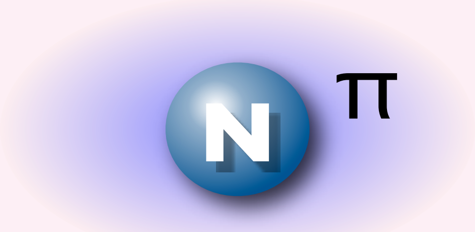
transition to lighter mesons (pion)

absorptive decay modes, no meson number conservation

real particles are constituents

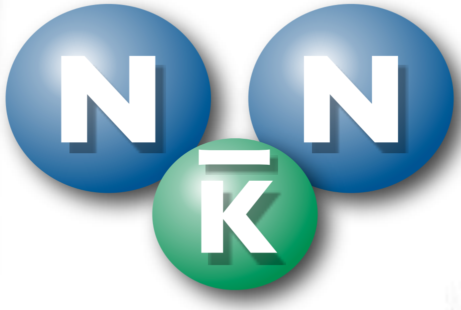
different from virtual pion cloud

physics of threshold



Λ(1405)

K^{bar}NN



Peculiarities of K meson

Y. Kanada-En'yo, DJ, **PRC78, 025212 (2008)**
DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

pion is too light to be bound in range of strong interaction

kaon has moderate mass and interaction strength

- Nambu-Goldstone boson

smaller mass compared with typical hadron mass scale

chiral effective theory can be applied

strong s-wave attraction in $K^{bar}N$ and $K^{bar}K$ ⇒ two-body quasibounds

- heavy particle

half of nucleon mass

small kinetic energy in bound systems (BE ~ 10-30 MeV)

non-relativistic potential model with decay channels

isospin averaged mass

$$\begin{aligned} m_K &= 495.7 \text{ MeV} \\ m_N &= 938.9 \text{ MeV} \end{aligned}$$

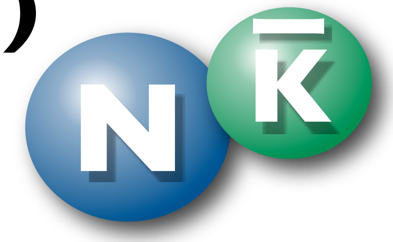
Kaons are different from pions in the energies of our interest !!

Kaonic few-body nuclear system

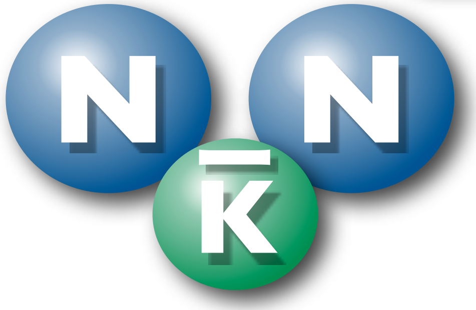
few body nuclear systems with one kaon

Nogami, PL7, 288 (1963)
Akaishi, Yamazaki, PRC64,044005 (02)

Λ(1405)



K^{bar}NN



BE: 10 or 30 MeV

single or coupled channel

achievement in theory : bound with a large width

biding energies of K^{bar}NN system

	single channel		**coupled channel**		
	ATMS	Variational	Faddeev	Faddeev	Variational
	Akaishi, Yamazaki	Dote, Hyodo, Weise	Shevchenko, Gal, Mares	Ikeda, Sato	Wycech, Green
B.E. [MeV]	48	17-23	50-70	60-95	40-80
Width[MeV]	61	40-70	90-110	45-80	40-85

issue is whether πΣ is active or not

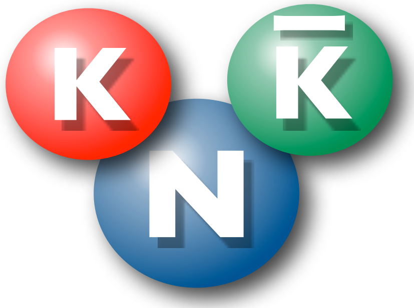
$K\bar{K}N$ system with I=1/2, J^P=1/2$^+$

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

A prediction of KK^{bar}N quasibound state as an N* resonance

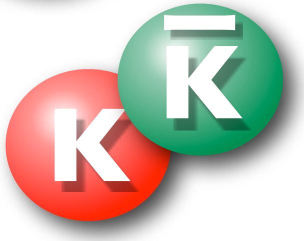
N*

J^P=1/2$^+$



Λ(1405)

f₀(980), a₀(980)



Interactions in KK^{bar}N system

		I=0	I=1	threshold	open channels
$\bar{K}N$	attraction	$\Lambda(1405)$	weak attraction	1434.6 MeV	$\pi\Sigma, \pi\Lambda$
$K\bar{K}$		$f_0(980)$	$a_0(980)$	991.4 MeV	$\pi\pi, \pi\eta$
KN	repulsion	very weak	strong repulsion	1434.6 MeV	no

if 3-body BS << 2-body BS + hadron molecular picture broken down

Theoretical studies of KK^{bar}N system

N*

$J^P=1/2^+$

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

fix two-body interaction → calculate three-body system

1) non-relativistic potential model

KK^{bar}N single channel

two-body interaction

K^{bar}N	Λ(1405) as a quasibound state
K^{bar}K	$f_0(980)$ and $a_0(980)$ as quasibound states
KN	adjust repulsive scattering length

2) relativistic Faddeev approach

Martinez Torres, Khemchandani, Oset, **PRC79**, 065207 (2009)

Martinez Torres, DJ, **PRC82**, 038202 (2010)

coupled channels, **KK^{bar}N, KπΣ, KπΛ**

two-body subsystem

scattering amplitudes obtained by chiral unitary model in full coupled-channels

meson-baryon	dynamically generated Λ(1405)
meson-meson	dynamically generated $f_0(980)$ and $a_0(980)$

non-resonant background

Results of $KK^{\rm bar}N$ system   N* at 1910 MeV

$K\bar{K}N$ is bound blow thresholds of $\Lambda(1405)+K$, $a_0(f_0)+N$

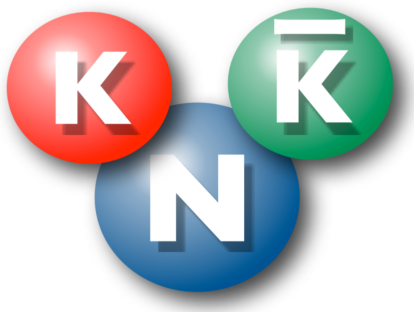
- loosely bound system   threshold of $KK^{\rm bar}N$ 1930 MeV

1) non-relativistic potential model

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

	B.E. from $KK^{\rm bar}N$	width	mass
HW:	**19 MeV**	**88 MeV**	**1911 MeV**
AY:	**39 MeV**	**98 MeV**	**1891 MeV**

N*



2) relativistic Faddeev approach

read peak position and width

$(K\bar{K}N, K\pi\Sigma, K\pi\Lambda)$

mass: 1922 MeV, width ~25 MeV

1426 MeV in $K^{\rm bar}N$, 988 MeV in $K^{\rm bar}K$

$(K\bar{K}N)$ same result

Martinez Torres, Khemchandani, Oset, **PRC79**, 065207 (2009)

Martinez Torres, DJ, **PRC82**, 038202 (2010)

also found in calculation with fixed centre approximation

Xie, Torres, Oset, arXiv:1010.6164

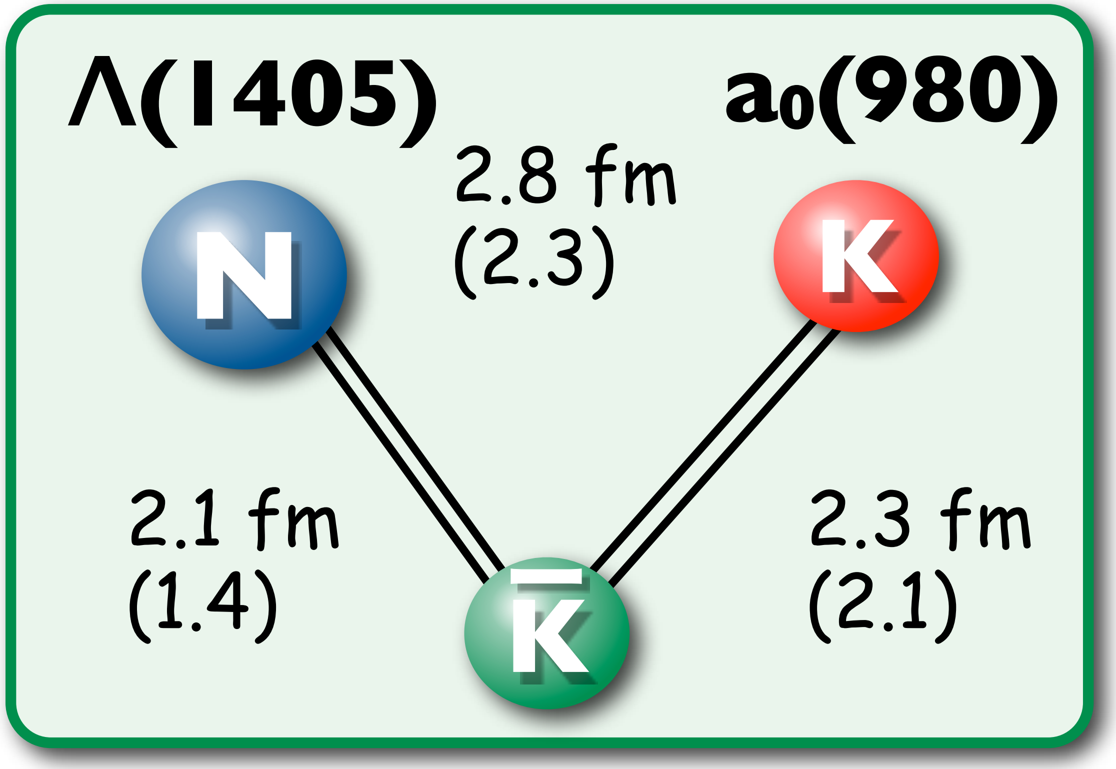
This state is essentially described by $KK^{\rm bar}N$ single channel in three-body configuration

Structure of N*(1910)

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

1) relativistic potential model

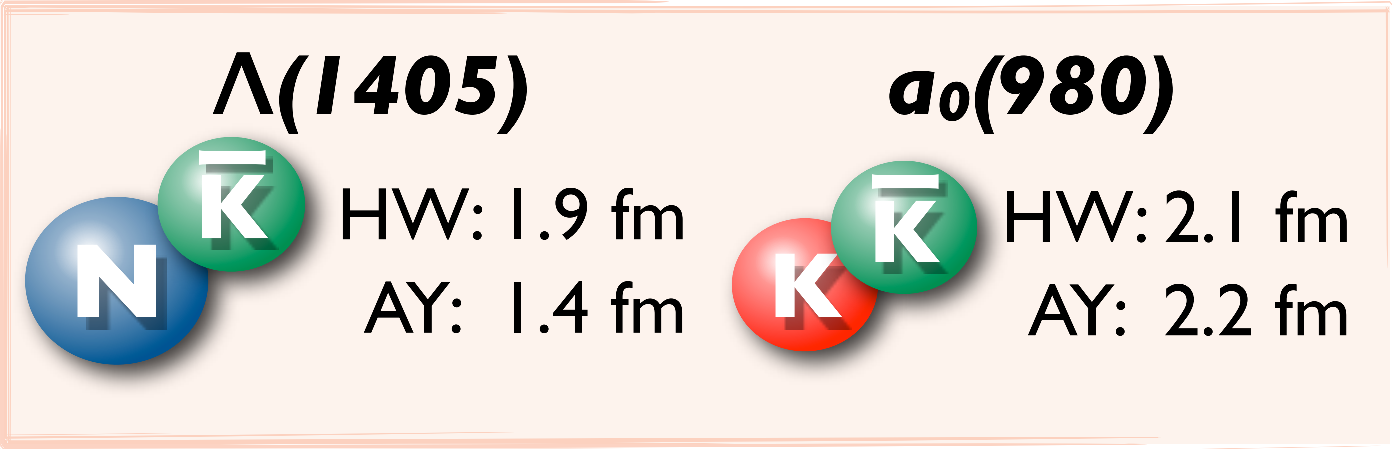
spatial structure



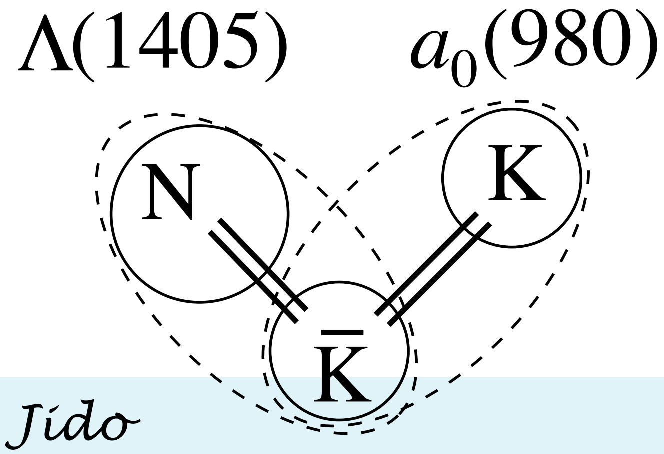
r.m.s radius: **1.7 fm** cf. 1.4 fm for ^{4}He

hadron-hadron distances are comparable with nucleon-nucleon distances in nuclei

mean hadron density: **0.07 hadrons/fm^3**



- coexistence of two quasi-bound states keeping their characters



Λ(1405)+K

a₀(980)+N

- main decay modes

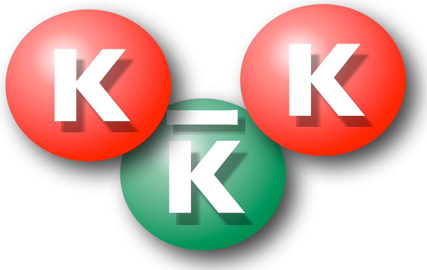
$\pi\Sigma K$	from Λ(1405)
$\pi\eta N$	from a₀(980)

$K^{\mathrm{bar}}KK$ system

Kaon Ball

K^*

$J^P=0^-$



A. Martinez Torres, DJ, Y. Kanada-En'yo,
arXiv:1102.1505 [nucl-th]

threshold: 1488 MeV

potential model **1467 MeV (BE: 21 MeV), width 110 MeV**

Faddeev **1420 MeV, width ~50 MeV**

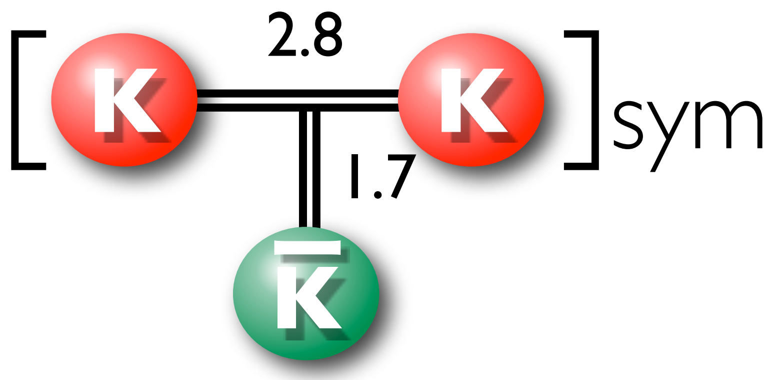
$K^{\mathrm{bar}}K$ Inv.Mass : 983 MeV (I=0), 950 MeV (I=1)

spatial structure obtained in potential model

r.m.s radius: **1.6 fm**

K-K distance: **2.8 fm**

(KK)-K^{bar} distance: **1.7 fm**

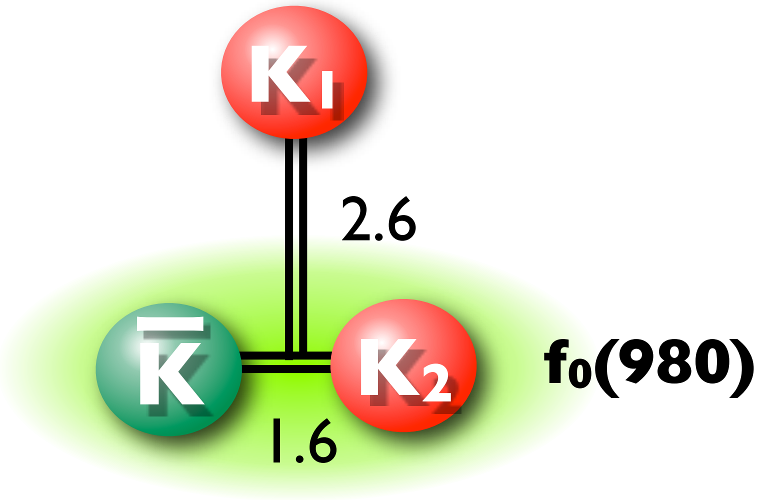


role of repulsive KK interaction

before symetrization ...

K_2-K^{bar} distance: **1.6 fm**

K_1-(K_2K^{bar}) distance: **2.6 fm**

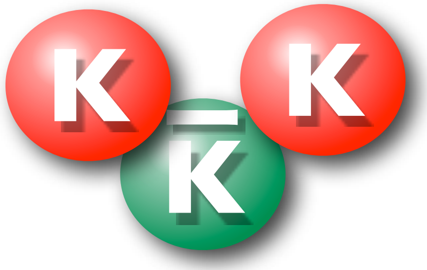


K^{bar}KK system

Kaon Ball

K*

$J^P=0^-$



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K^{bar}K Inv.Mass : 983 MeV (I=0), 950 MeV (I=1)

- also found in $f_0(980)K$, $a_0(980)K$ two-body systems

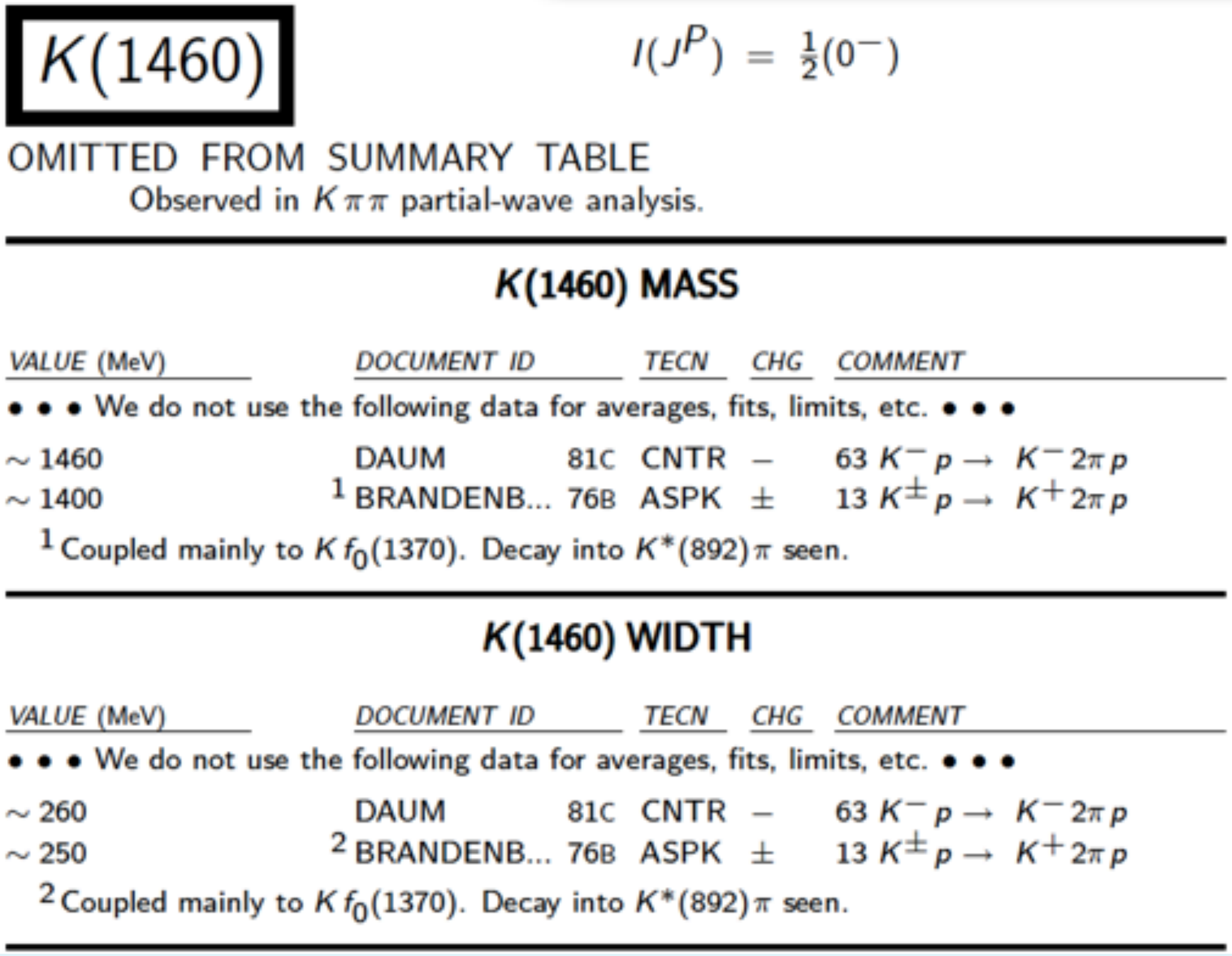
Albaladejo, Oller, Roca, PRD82, 094019 (2010)

PDG

K(1460) seen in Kππ partial wave analyses

omitted from summary table

large width



$K(1460)$ $\qquad$ $I(J^P) = \frac{1}{2}(0^-)$

OMITTED FROM SUMMARY TABLE

Observed in $K\pi\pi$ partial-wave analysis.

$K(1460)$ MASS

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
~ 1460	DAUM	81C	CNTR	−	63 $K^- p \to K^- 2\pi p$
~ 1400	[1] BRANDENB...	76B	ASPK	±	13 $K^\pm p \to K^+ 2\pi p$

[1] Coupled mainly to $K f_0(1370)$. Decay into $K^*(892)\pi$ seen.

$K(1460)$ WIDTH

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
~ 260	DAUM	81C	CNTR	−	63 $K^- p \to K^- 2\pi p$
~ 250	[2] BRANDENB...	76B	ASPK	±	13 $K^\pm p \to K^+ 2\pi p$

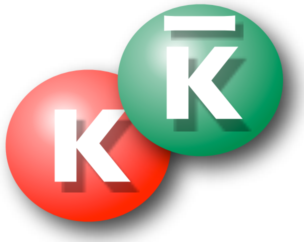
[2] Coupled mainly to $K f_0(1370)$. Decay into $K^*(892)\pi$ seen.

Family of kaonic few-body systems

Λ(1405)

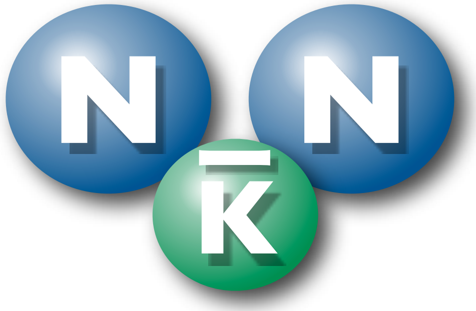
BE ~10 MeV
(or more)

f_0(980), a_0(980)



BE ~10 MeV

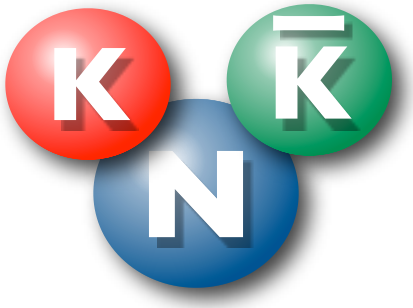
K^{bar}NN



BE ~20 MeV
(or more)

N*
$J^P=1/2^+$

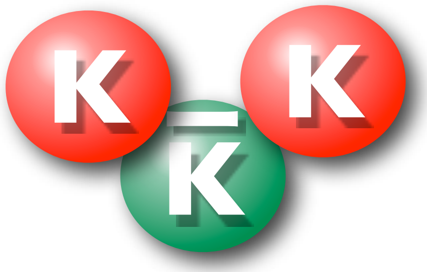
K^{bar}KN



BE ~20 MeV

K*
$J^P=0^-$

K^{bar}KK



BE 20~60 MeV

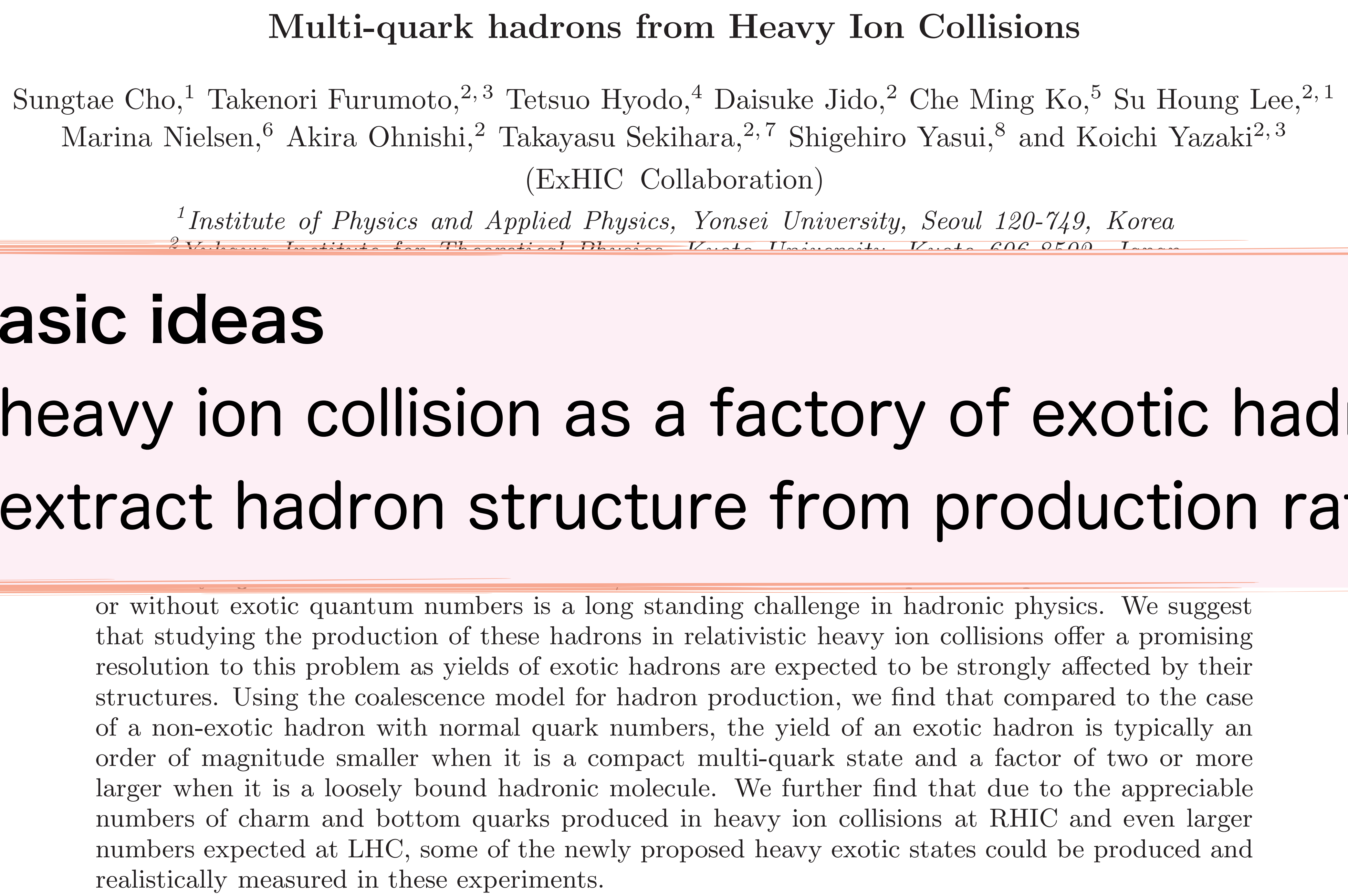
K^{bar}N and **K^{bar}K** interactions are "similar" in a sense of chiral dynamics

Λ(1405) f_0(980), a_0(980)

pion is too light to be bound in range of strong interaction

ExHIC (Exotic Hadrons from Heavy Ion Collision)

arXiv:1011.0852



Multi-quark hadrons from Heavy Ion Collisions

Sungtae Cho,[1] Takenori Furumoto,[2,3] Tetsuo Hyodo,[4] Daisuke Jido,[2] Che Ming Ko,[5] Su Houng Lee,[2,1]
Marina Nielsen,[6] Akira Ohnishi,[2] Takayasu Sekihara,[2,7] Shigehiro Yasui,[8] and Koichi Yazaki[2,3]
(ExHIC Collaboration)

[1] *Institute of Physics and Applied Physics, Yonsei University, Seoul 120-749, Korea*

or without exotic quantum numbers is a long standing challenge in hadronic physics. We suggest that studying the production of these hadrons in relativistic heavy ion collisions offer a promising resolution to this problem as yields of exotic hadrons are expected to be strongly affected by their structures. Using the coalescence model for hadron production, we find that compared to the case of a non-exotic hadron with normal quark numbers, the yield of an exotic hadron is typically an order of magnitude smaller when it is a compact multi-quark state and a factor of two or more larger when it is a loosely bound hadronic molecule. We further find that due to the appreciable numbers of charm and bottom quarks produced in heavy ion collisions at RHIC and even larger numbers expected at LHC, some of the newly proposed heavy exotic states could be produced and realistically measured in these experiments.

Basic ideas

- heavy ion collision as a factory of exotic hadrons
- extract hadron structure from production rates

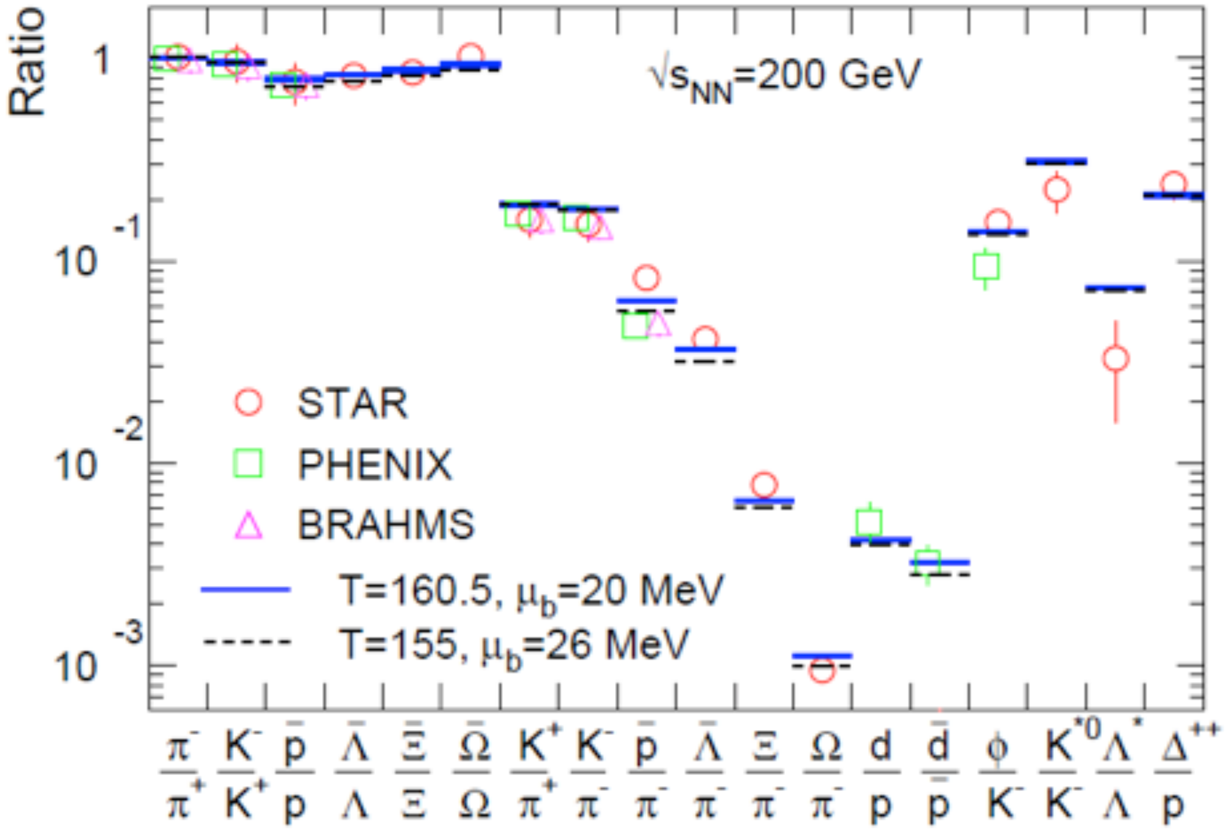
ExHIC (Exotic Hadrons from Heavy Ion Collision)

compact multi-quark system

vs

loosely bound hadronic molecular system

- Yield of Normal and Exotic Hadrons
  - Statistical model
    - Successful to describe yield of normal hadrons at RHIC
    - Only sensitive to the mass (not quark content, size, …)
  - Coalescence model
    - Successful to describ baryons & v2 at RHIC
    - Sensitive to quark content and hadron size



A. Andronic, P. Braun-Munzinger, J. Stachel, NPA772('06)167.

Hadron coalescence vs Quark coalescence

arXiv:1011.0852

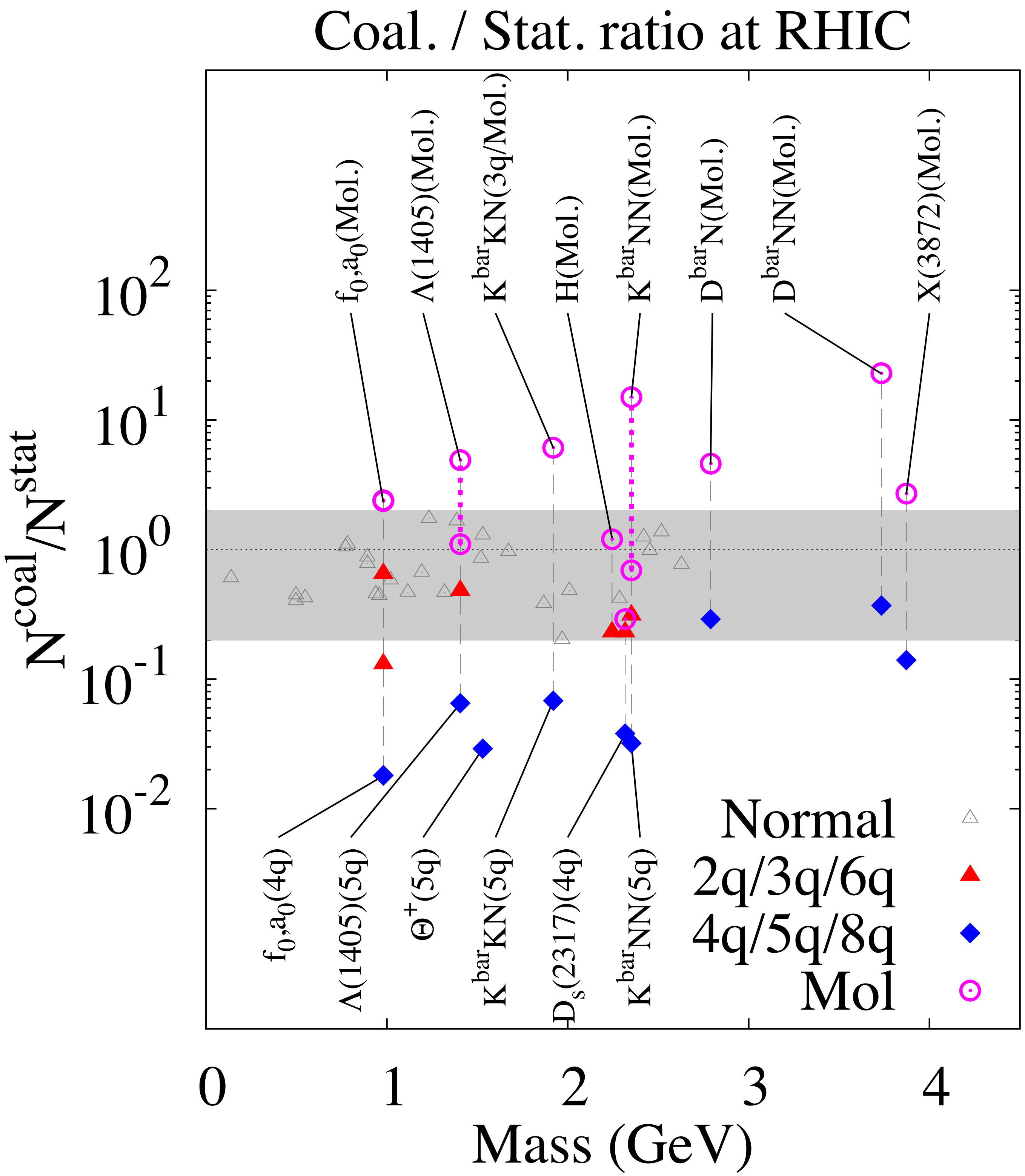
Coal./Stat. ratio: $R_h = N^{coal}/N^{stat}$

Normal hadrons
→ $0.2 < R_h < 2$ (Normal band)

Multi-quark states
→ $R_h < 0.3$

Hadronic molecules
→ Large yields (Rh > 2)
for weakly bound states

hadron coalescence after hadronization



Summary

effective constituents in baryons structure

constituent quarks in low-lying baryons

hadrons can be effective constituents in some hadron resonances

hadronic molecular states

hadron resonances composed by low-lying hadrons

unique role of Kaon

new category of resonance

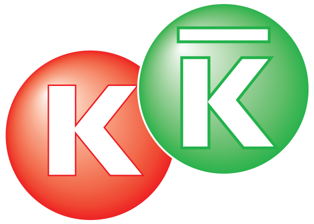
heavy ion collision

factory of exotic hadrons

production rates

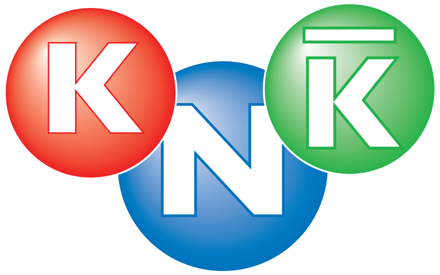
Λ(1405)

$f_0(980)$, $a_0(980)$



$K^{bar}KN$

N*



$K^{bar}KK$

K*