Kaonic

nuclei

Kaonic nuclei at J-PARC

Prototype system = K^-pp

Kaonic nuclei at J-PARC

Theoretical situation of K^-pp study

KEK Theory Center / IPNS/ J-PARC branch
Akinobu Doté

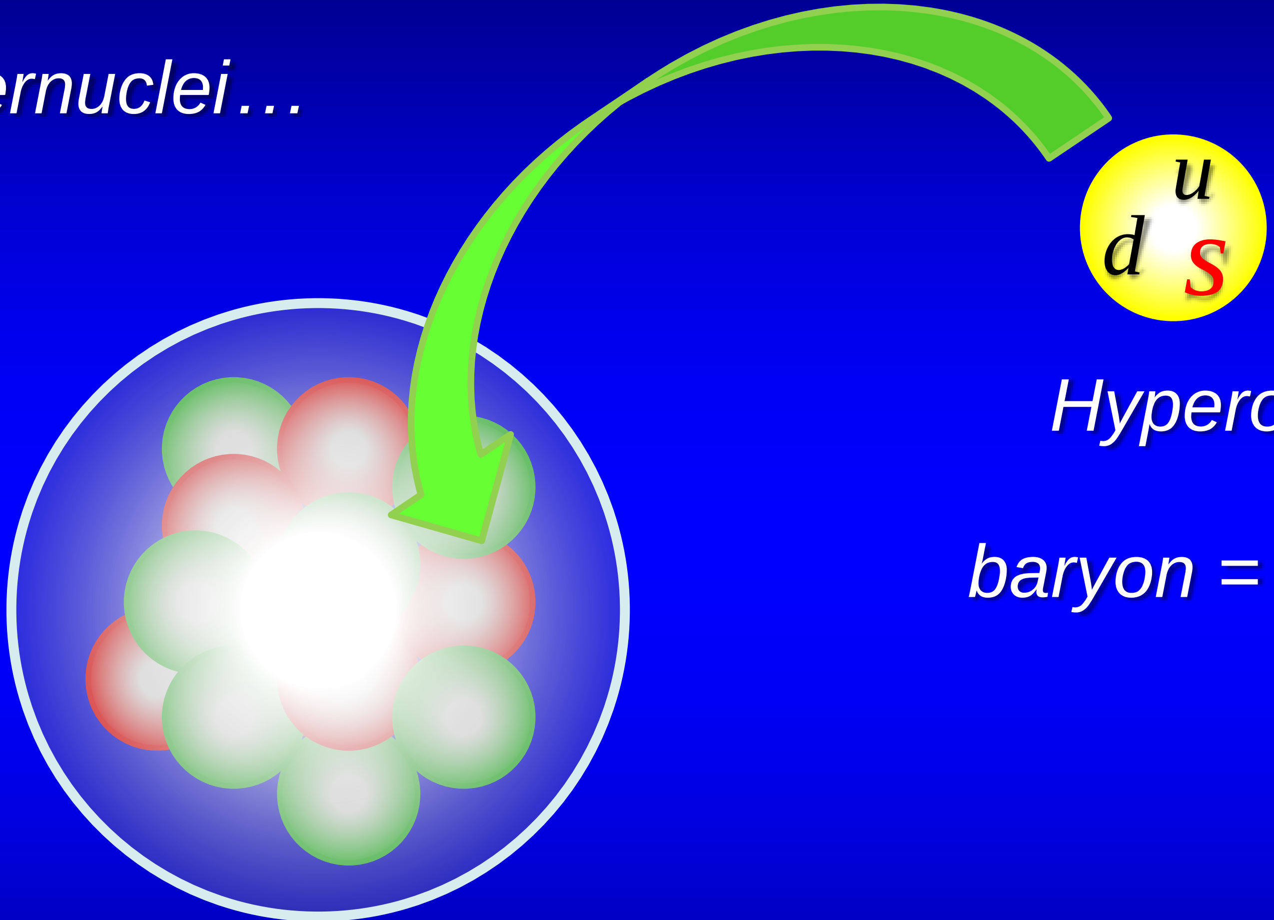
1. Introduction
2. Recent theoretical studies of K^-pp
3. K^-pp studied with
   "coupled-channel Complex Scaling Method + Feshbach method"
4. Issues on kaonic nuclei
5. Summary

Workshop on J-PARC hadron physics in 2014,
10.Feb.'14 @ IQBRC, Tokai, Ibaraki, Japan

1. Introduction

Strange nuclear physics

Hypernuclei…



Hyperon

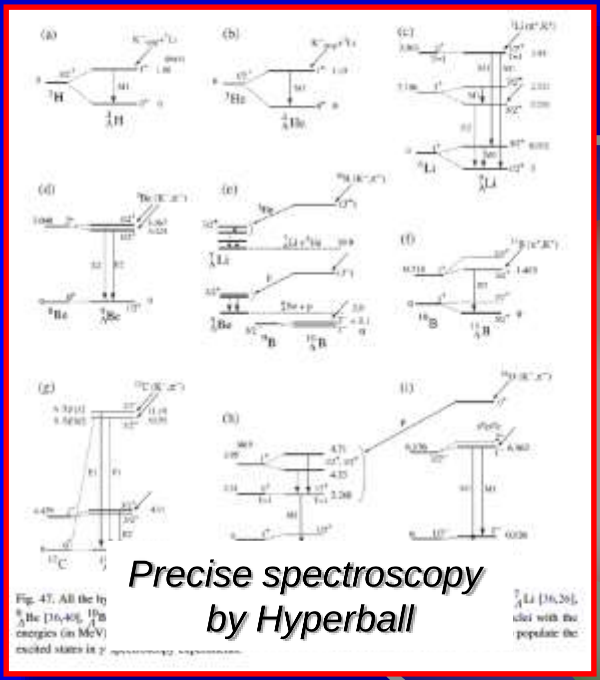
baryon = qqq

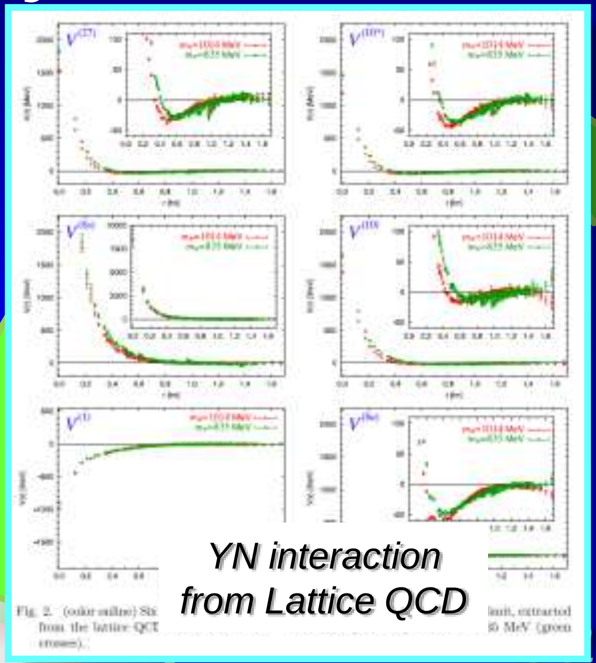
Nucleus

Strangeness is introduced through baryons.

Strange nuclear physics

Hypernuclei…

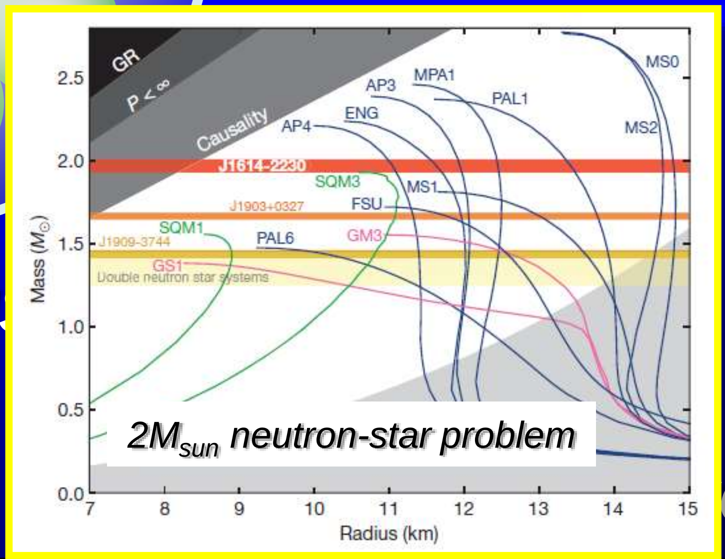




Hyperon

aryon = qqq

Nucleus

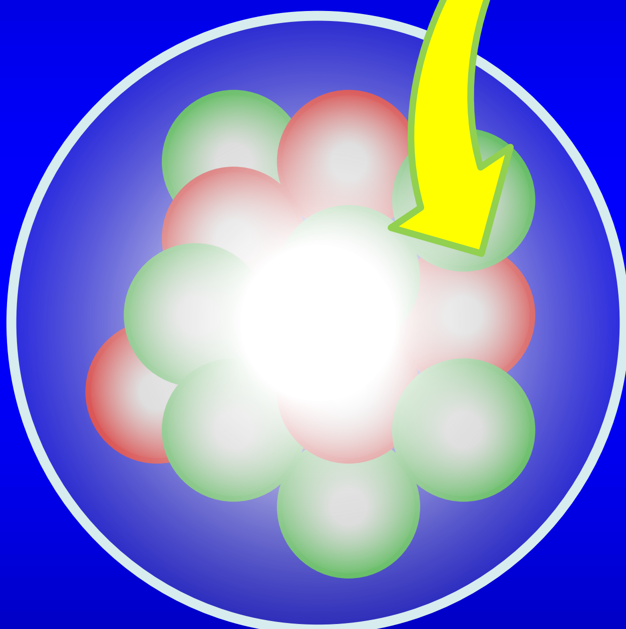


is introduced

ons.

Strange nuclear physics

Strangeness is introduced through *mesons …*



Nucleus

K^- meson
(anti-kaon, K^{bar})

meson = qq^{bar}

Kaonic nuclei !

Kaonic nuclei = Nuclear system with Anti-kaon "K^{bar}"

Attractive $K^{bar}N$ interaction!

Excited hyperon Λ(1405) = a quasi-bound state of K^- and proton

- ✓ *Difficult to explain by naive 3-quark model*
- ✓ *Consistent with "repulsive nature" indicated by $K^{bar}N$ scattering length and 1s level shift of kaonic hydrogen atom*

Λ(1405) 1/2⁻ $I(J^P) = 0(\frac{1}{2}^-)$

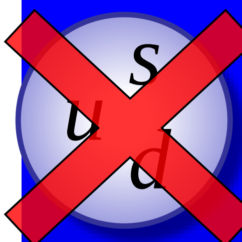
Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV

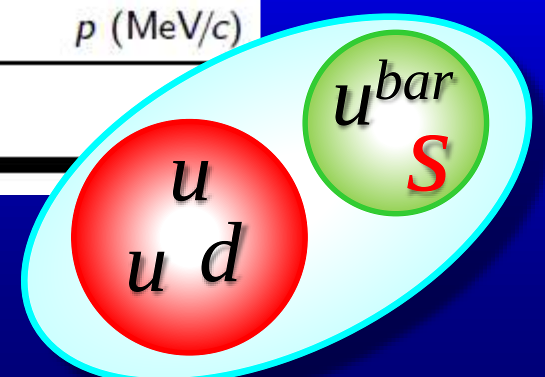
Full width $\Gamma = 50 \pm 2$ MeV

Below $\overline{K}N$ threshold

$K^{bar}N$ threshold = 1435MeV

Λ(1405) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	

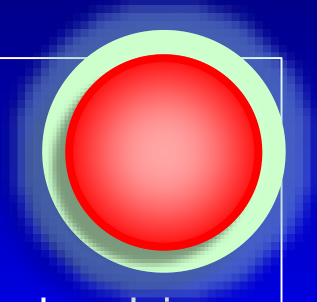




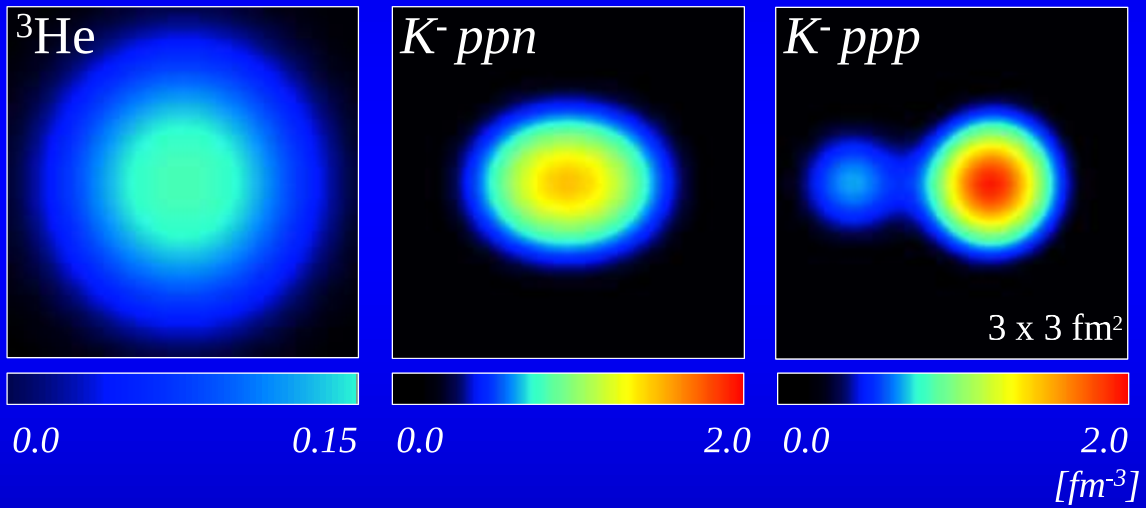
T. Hyodo and D. Jido,
Prog. Part. Nucl. Phys. 67, 55 (2012)

Kaonic nuclei = Exotic system !?

Phenomenologically derived I=0 $K^{bar}N$ potential … Very attractive



Deeply bound (Total B.E. ∼100MeV)
Highly dense state formed in a nucleus
Interesting structures that we have never seen in normal nuclei…

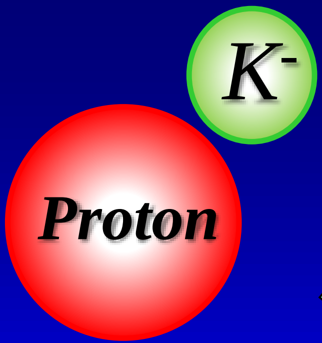


Antisymmetrized Molecular Dynamics method with a phenomenological $K^{bar}N$ potential

A. Dote, H. Horiuchi, Y. Akaishi and T. Yamazaki, PRC70, 044313 (2004)

Relate to various interesting physics such as …

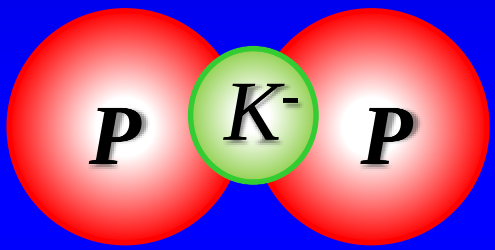
- *Restoration of chiral symmetry in dense matter*
- *Interesting structure*
- *Neutron star*



$\Lambda(1405)$ *"Building block of kaonic nuclei"*

… used to determine $K^{bar}N$ interaction

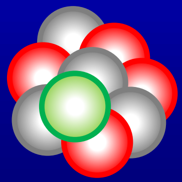
K^-pp



Most essential kaonic nucleus

"Prototype of kaonic nuclei"

Nuclear many-body system with K^-



$^3HeK^-$, $pppK^-$,
$^4HeK^-$, $pppnK^-$,
…, $^8BeK^-$, …

2. Recent theoretical studies of K^-pp

Theoretical studies of K^-pp

"K^-pp" = Prototype of K^{bar} nuclei

$K^{bar}NN$ – $\pi\Sigma N$ – $\pi\Lambda N$, $J^p=1/2^-$, $T=1/2$

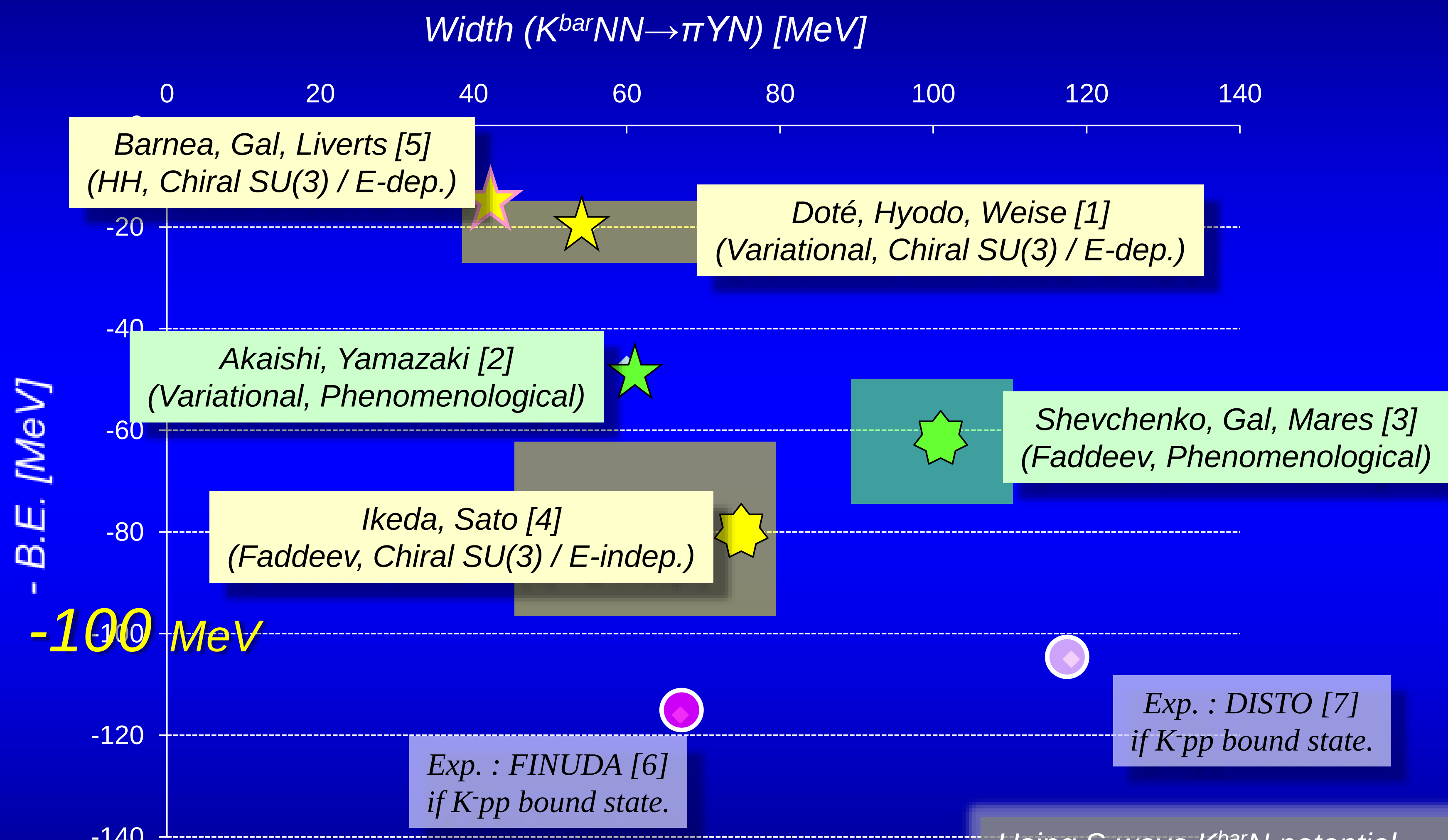
- Doté, Hyodo, Weise — PRC79, 014003(2009)
  Variational with a chiral SU(3)-based $K^{bar}N$ potential
- Akaishi, Yamazaki — PRC76, 045201(2007)
  ATMS with a phenomenological $K^{bar}N$ potential
- Ikeda, Sato — PRC76, 035203(2007)
  Faddeev with a chiral SU(3)-derived $K^{bar}N$ potential
- Shevchenko, Gal, Mares — PRC76, 044004(2007)
  Faddeev with a phenomenological $K^{bar}N$ potential
- Barnea, Gal, Liverts — PLB712, 132(2012)
  Hyperspherical harmonics with a chiral SU(3)-based $K^{bar}N$ potential

- Wycech, Green — PRC79, 014001(2009)
  Variational with a phenomenological $K^{bar}N$ potential (with p-wave)

- Arai, Yasui, Oka/ Uchino, Hyodo, Oka — PTP119, 103(2008) /PTPS 186, 240(2010)
  Λ* nuclei model
- Nishikawa, Kondo — PRC77, 055202(2008)
  Skyrme model

All studies predict that K^-pp can be bound!

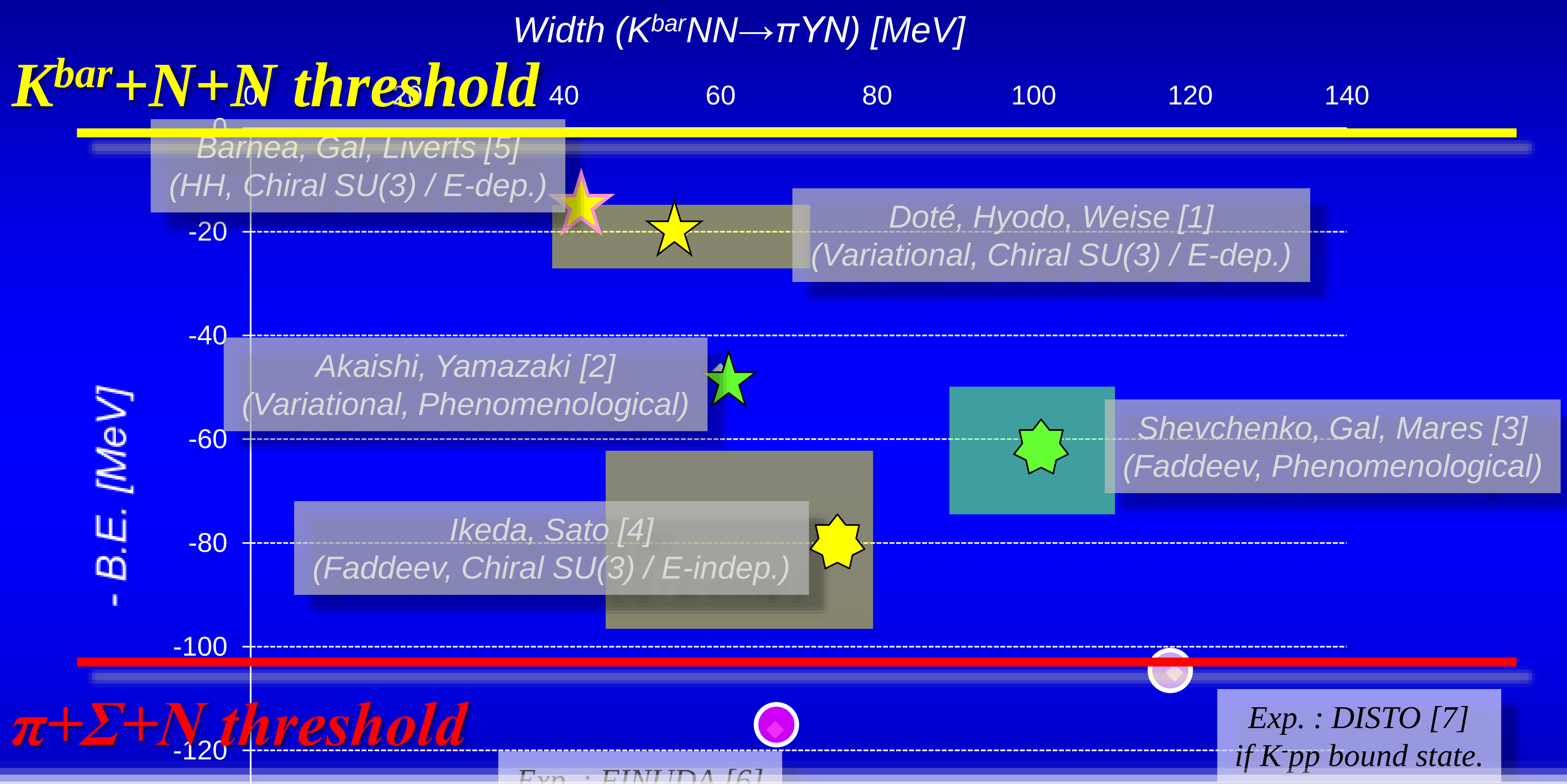
Typical results of theoretical studies of K^-pp



Using S-wave $K^{bar}N$ potential constrained by experimental data.
… $K^{bar}N$ scattering data,
Kaonic hydrogen atom data,
"Λ(1405)" etc.

[1] PRC79, 014003 (2009)
[2] PRC76, 045201 (2007)
[3] PRC76, 044004 (2007)
[4] PRC76, 035203 (2007)
[5] PLB94, 712 (2012)
[6] PRL94, 212303 (2005)
[7] PRL104, 132502 (2010)

Typical results of theoretical studies of K^-pp



From theoretical viewpoint,
K^-pp exists between K^{bar}-N-N and π-Σ-N thresholds!

[4] PRC76, 035203 (2007)

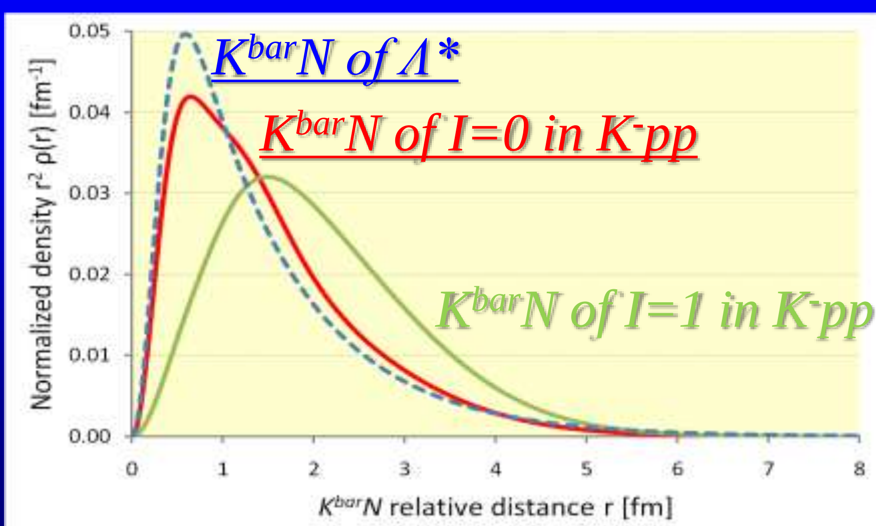
"Λ(1405)" etc.

Typical results of theoretical studies of K^-pp

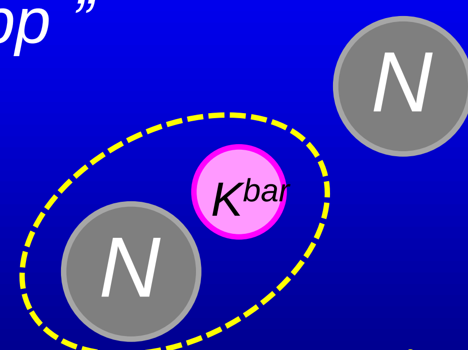
	DHW	AY	BGL	IS	SGM
B(K^-pp)	20±3	47	16	60 ~ 95	50 ~ 70
Width Γ	40 ~ 70	61	41	45 ~ 80	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Potential	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (E-indep.)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	Rel.	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in K^-pp"*



"K^-pp "



Isospin-0 ~ Λ* !

Typical results of theoretical studies of K^-pp

	DHW	AY	BGL	IS	SGM
$B(K^-pp)$	20±3	47	16	60 ~ 95	50 ~ 70
Width Γ	40 ~ 70	61	41	45 ~ 80	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Potential	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (E-indep.)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	Rel.	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in K^-pp"*

DHW vs BGL

DHW is checked by BGL with a different base (Hyperspherical Harmonics)

Typical results of theoretical studies of K^-pp

	DHW	AY	BGL	IS	SGM
$B(K^-pp)$	20±3	47	16	60 ~ 95	50 ~ 70
Width Γ	40 ~ 70	61	41	45 ~ 80	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Potential	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (E-indep.)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	Rel.	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in K^-pp"*

DHW vs BGL

DHW is checked by BGL with a different base (Hyperspherical Harmonics)

Variational (DHW, AY, BGL) vs Faddeev-AGS (IS, SGM)

- *πΣN three-body dynamics included in Faddeev-AGS*
- *Decay width: perturbative in variational cal., non-perturbative in F-A*

Typical results of theoretical studies of $K^{-}pp$

	DHW	AY	BGL	IS	SGM
$B(K^{-}pp)$	20±3	47	16	60 ~ 95	50 ~ 70
Width Γ	40 ~ 70	61	41	45 ~ 80	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Pot.	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (E-indep.)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	Rel.	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in $K^{-}pp$"*

DHW vs BGL

DHW is checked by BGL with a different base (Hyperspherical Harmonics)

Variational (DHW, AY, BGL) vs Faddeev-AGS (IS, SGM)

- *πΣN three-body dynamics included in Faddeev-AGS*
- *Decay width: perturbative in variational cal., non-perturbative in F-A*

Further study of IS

Y. Ikeda, H. Kamano, T. Sato, PTP124, 533 (2010)

Typical results of theoretical studies of K^-pp

	DHW	AY	BGL	IS	SGM
$B(K^-pp)$	20±3	47	16	44 ~ 58	50 ~ 70
Width Γ	40 ~ 70	61	41	34 ~ 40	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Pot.	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (E-indep.)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	***Non-rel.***	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in K^-pp"*

DHW vs BGL

DHW is checked by BGL with a different base (Hyperspherical Harmonics)

Variational (DHW, AY, BGL) vs Faddeev-AGS (IS, SGM)

- *πΣN three-body dynamics included in Faddeev-AGS*
- *Decay width: perturbative in variational cal., non-perturbative in F-A*

Further study of IS

Y. Ikeda, H. Kamano, T. Sato, PTP124, 533 (2010)

- *Kinematics: Rel. → Non-rel. ⇒ (B, Γ)=(44~58, 34~40)*

Typical results of theoretical studies of K^-pp

	DHW	AY	BGL	IS	SGM
$B(K^-pp)$	20±3	47	16	9 ~ 16	50 ~ 70
Width Γ	40 ~ 70	61	41	34 ~ 46	90 ~ 110
Method	Variational (Gauss)	Variational (Gauss)	Variational (HH)	Faddeev-AGS	Faddeev-AGS
Potential	Chiral (E-dep.)	Pheno.	Chiral (E-dep.)	Chiral (***E-dep.***)	Pheno.
Kinematics	Non-rel.	Non-rel.	Non-rel.	***Non-rel.***	Non-rel.

DHW vs AY

- *Difference of the potential: chiral (E-dep.) = shallow, phenomenological = deep*
- *"Survival of Λ* in K^-pp"*

DHW vs BGL

DHW is checked by BGL with a different base (Hyperspherical Harmonics)

Variational (DHW, AY, BGL) vs Faddeev-AGS (IS, SGM)

- *πΣN three-body dynamics included in Faddeev-AGS*
- *Decay width: perturbative in variational cal., non-perturbative in F-A*

Further study of IS

Y. Ikeda, H. Kamano, T. Sato, PTP124, 533 (2010)

- *Kinematics: Rel. → Non-rel. ⇒ (B, Γ)=(44~58, 34~40)*
- *Energy-dependence of chiral potential: E-indep. → E-dep. ⇒ (B, Γ)=(9~16, 34~46)*
  (B, Γ)=(67~89, 244~320) … another pole

3. K^-pp studied with

"coupled-channel Complex Scaling Method + Feshbach method"

Takashi Inoue (Nihon univ.)
Takayuki Myo (Osaka Inst. Tech. univ.)

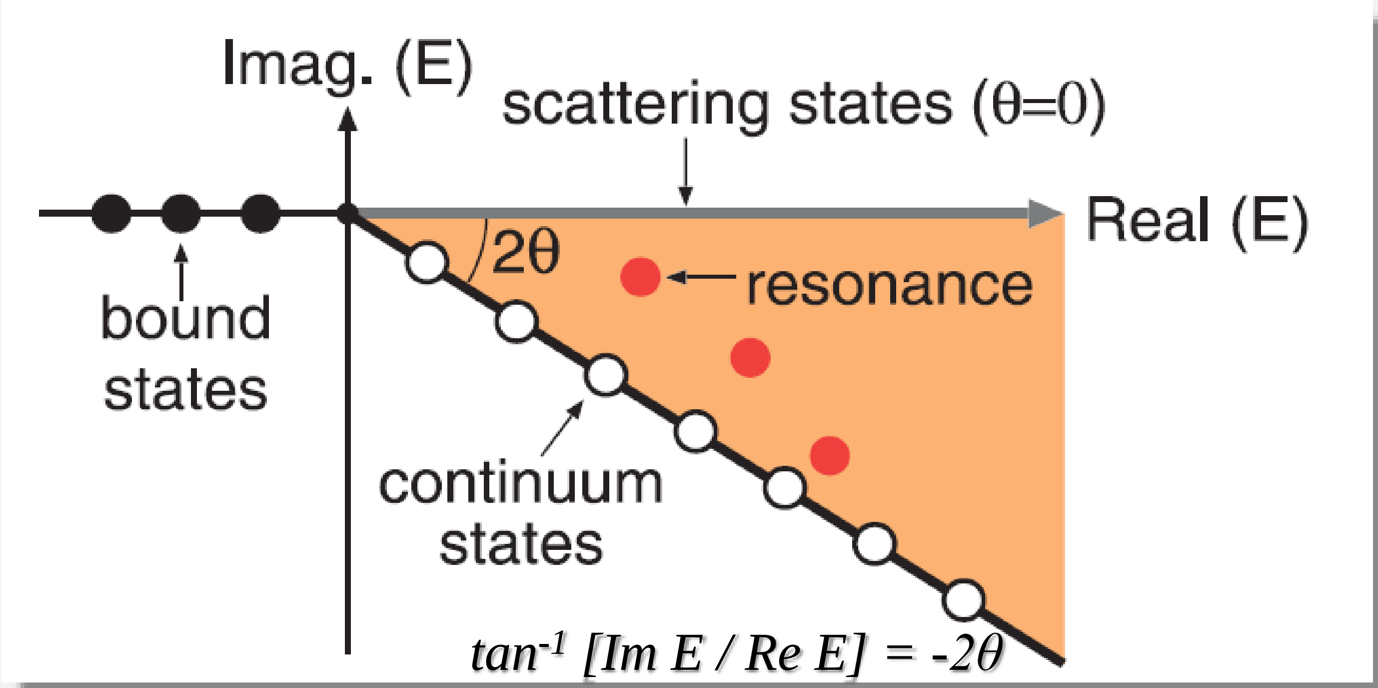
Complex Scaling Method

= Powerful tool for resonance study

Complex rotation of coordinate
(Complex scaling)

$$U(\theta): \quad \mathbf{r} \to \mathbf{r}\, e^{i\theta}, \quad \mathbf{k} \to \mathbf{k}\, e^{-i\theta}$$

Diagonalize $H_\theta = U(\theta)\, H\, U^{-1}(\theta)$ with Gaussian base,



- *Continuum state appears on 2ϑ line.*
- *Resonance pole is off from 2ϑ line, and independent of ϑ.*

S. Aoyama, T. Myo, K. Kato and K. Ikeda, PTP116, 1 (2006)

ccCSM + Feshbach method

Elimination of channels by Feshbash method

Schrödinger eq.
in model space "P" and out of model space "Q"

$$\begin{pmatrix} T_P + v_P & V_{PQ} \\ V_{QP} & T_Q + v_Q \end{pmatrix} \begin{pmatrix} \Phi_P \\ \Phi_Q \end{pmatrix} = E \begin{pmatrix} \Phi_P \\ \Phi_Q \end{pmatrix}$$

Schrödinger eq. in P space :

$$\left(T_P + U_P^{Eff}(E) \right) \Phi_P = E \Phi_P$$

Effective potential for P-space

$$U_P^{Eff}(E) = v_P + V_{PQ} G_Q(E) V_{QP}$$

Q-space Green function:

$$G_Q(E) = \frac{1}{E - H_{QQ}}$$

Extended Closure Relation in Complex Scaling

$$H_{QQ}^{\theta} \left| \chi_n^{\theta} \right\rangle = \varepsilon_n^{\theta} \left| \chi_n^{\theta} \right\rangle$$

$$H_{QQ}^{\theta} = U(\theta) H_{QQ} U^{-1}(\theta)$$

$$\int_C \sum_{R+B} \left| \chi_n^{\theta} \right\rangle \left\langle \chi_n^{\theta} \right| = 1$$

Diagonalize H^{θ}_{QQ} with Gaussian base,

$$\sum_n \left| \chi_n^{\theta} \right\rangle \left\langle \chi_n^{\theta} \right| \approx 1$$

Well approximated

T. Myo, A. Ohnishi and K. Kato, PTP99, 801 (1998)

Express the $G_Q(E)$ with **Gaussian base** using ECR

$$U_P^{Eff}(E) = v_P + V_{PQ} \underbrace{U^{-1}(\theta) G_Q^{\theta}(E) U(\theta)}_{G_Q(E)} V_{QP}$$

$$G_Q^{\theta}(E) \approx \sum_n \left| \chi_n^{\theta} \right\rangle \frac{1}{E - \varepsilon_n^{\theta}} \left\langle \chi_n^{\theta} \right|$$

$\left\{ \left| \chi_n^{\theta} \right\rangle \right\}$: expanded with Gaussian base.

Apply ccCSM + Feshbach method to K^-pp

"K^-pp" … $K^{bar}NN$ - $\pi\Sigma N$ - $\pi\Lambda N$ ($J^\pi=0^-$, $T=1/2$)

In the two-body system, $P = K^{bar}N$, $Q = \pi Y$

$$V\left(K^{bar}N-\pi Y; I=0,1\right)$$
$$V\left(\pi Y-\pi Y' \quad ; I=0,1\right)$$

Feshbach + ccCSM →

$$U^{Eff}_{K^{bar}N(I=0,1)}\left(E\right)$$

- Schrödinger eq. for $K^{bar}NN$ channel :

$$\left(T_{K^{bar}NN}+V_{NN}+\sum_{i=1,2}U^{Eff}_{K^{bar}N_i(I)}\left(E_{K^{bar}N}\right)\right)\Phi_{K^{bar}NN} = E\,\Phi_{K^{bar}NN}$$

- Trial wave function

$$\left|"K^- pp"\right\rangle = \sum_a C_a^{(KNN,1)}\left\{G_a^{(KNN,1)}\left(\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)+G_a^{(KNN,1)}\left(-\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)\right\}\left|S_{NN}=0\right\rangle\left|\left[K\left[NN\right]_1\right]_{T=1/2}\right\rangle$$

Ch. 1: $K^{bar}NN$, NN: ^1E

$$+\sum_a C_a^{(KNN,2)}\left\{G_a^{(KNN,2)}\left(\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)-G_a^{(KNN,2)}\left(-\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)\right\}\left|S_{NN}=0\right\rangle\left|\left[K\left[NN\right]_0\right]_{T=1/2}\right\rangle$$

Ch. 2: $K^{bar}NN$, NN: ^1O

- Basis function = Correlated Gaussian
  …including 3-types Jacobi-coordinates

$$G_a^{(KNN,i)}\left(\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)=N_a^{(KNN,i)}\exp\left[-\left(\mathbf{x}_1^{(3)},\mathbf{x}_2^{(3)}\right)A_a^{(KNN,i)}\begin{pmatrix}\mathbf{x}_1^{(3)}\\ \mathbf{x}_2^{(3)}\end{pmatrix}\right]$$

Apply ccCSM + Feshbach method to $K^{-}pp$

"$K^{-}pp$" … $K^{bar}NN$ - $\pi\Sigma N$ - $\pi\Lambda N$ ($J^{\pi}=0^{-}$, $T=1/2$)

Chiral SU(3)-based potential

A. D., T. Inoue, T. Myo, Nucl. Phys. A 912, 66 (2013)

$$V_{ij}^{(I=0,1)}(r) = -\frac{C_{ij}^{(I=0,1)}}{8 f_\pi^2}\left(\omega_i + \omega_j\right)\sqrt{\frac{M_i M_j}{s\,\omega_i \omega_j}}\, g_{ij}(r) \qquad g_{ij}(r) = \frac{1}{\pi^{3/2} d_{ij}^3} \exp\left[-\left(r/d_{ij}\right)^2\right]$$

- Flux factor ansatz to make a potential from an interaction kernel

N. Kaiser, P. B. Siegel and W. Weise, NPA 594, 325 (1995)

- Based on Chiral SU(3) theory → **Energy dependence**
- WT term, Gaussian form in r-space
- Constrained by $K^{bar}N$ scattering length

$a_{KN(I=0)} = -1.70 + i0.67$ fm, $a_{KN(I=1)} = 0.37 + i0.60$ fm (A.D.Martin, NPB179, 33(1979))

Self-consistency for complex $K^{bar}N$ energy

A. D., T. Hyodo, W. Weise, PRC79, 014003(2009)

… Similarly to the DHW study

1. Kaon's binding energy: $B(K) \equiv -\left\{ \langle H \rangle - \langle H_{Nucl} \rangle \right\}$ H_{Nucl} : Hamiltonian of nuclear part

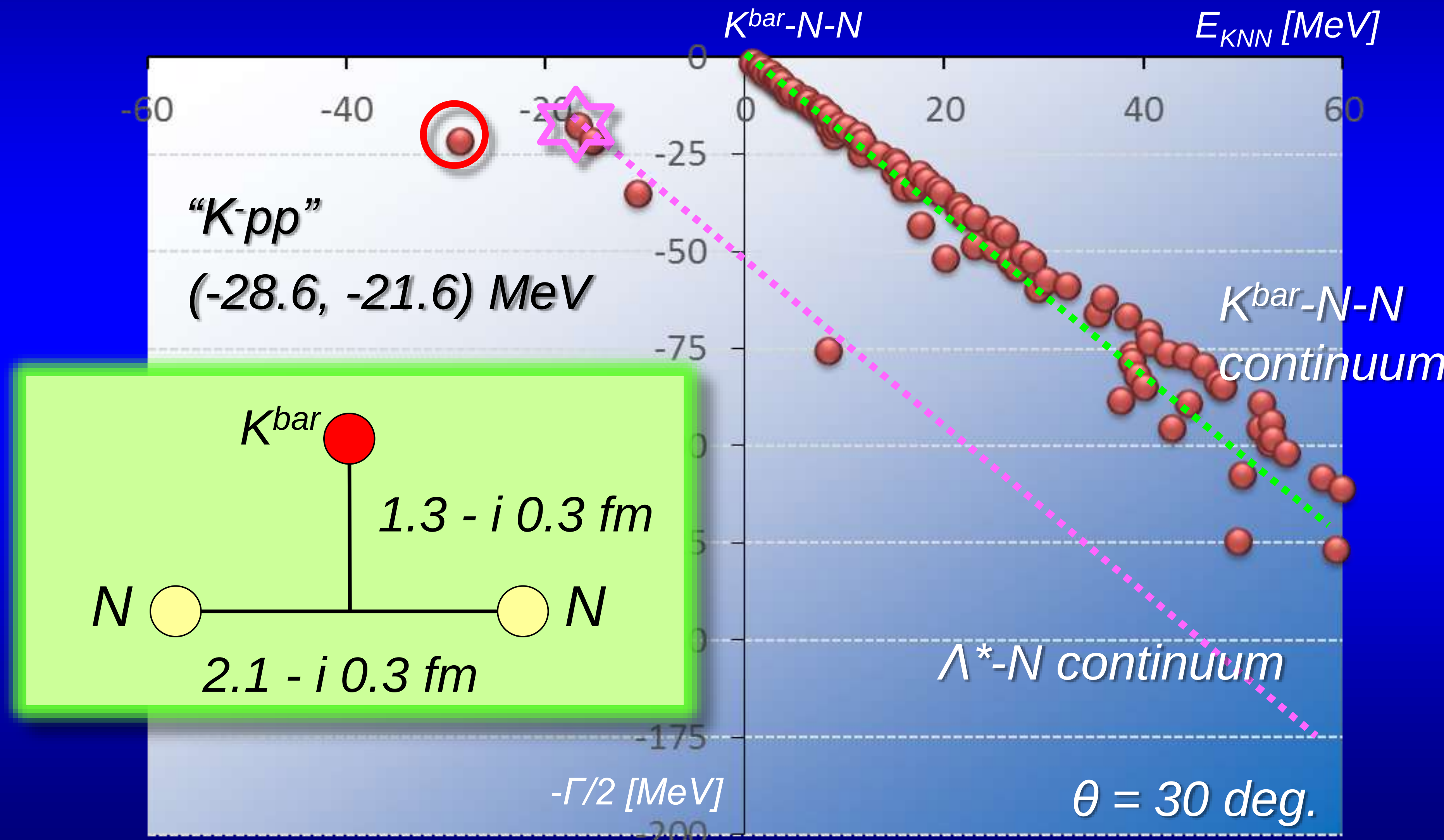
2. Define $K^{bar}N$ energy in two ways

$$E_{KN} = M_N + \omega = \begin{cases} M_N + m_K - B(K) & \text{: Field picture} \\ M_N + m_K - B(K)/2 & \text{: Particle picture} \end{cases}$$

Result: KSW-NRv2 potential (f_{π}=110MeV)

NN potential : Av18 (Central + spin-spin)

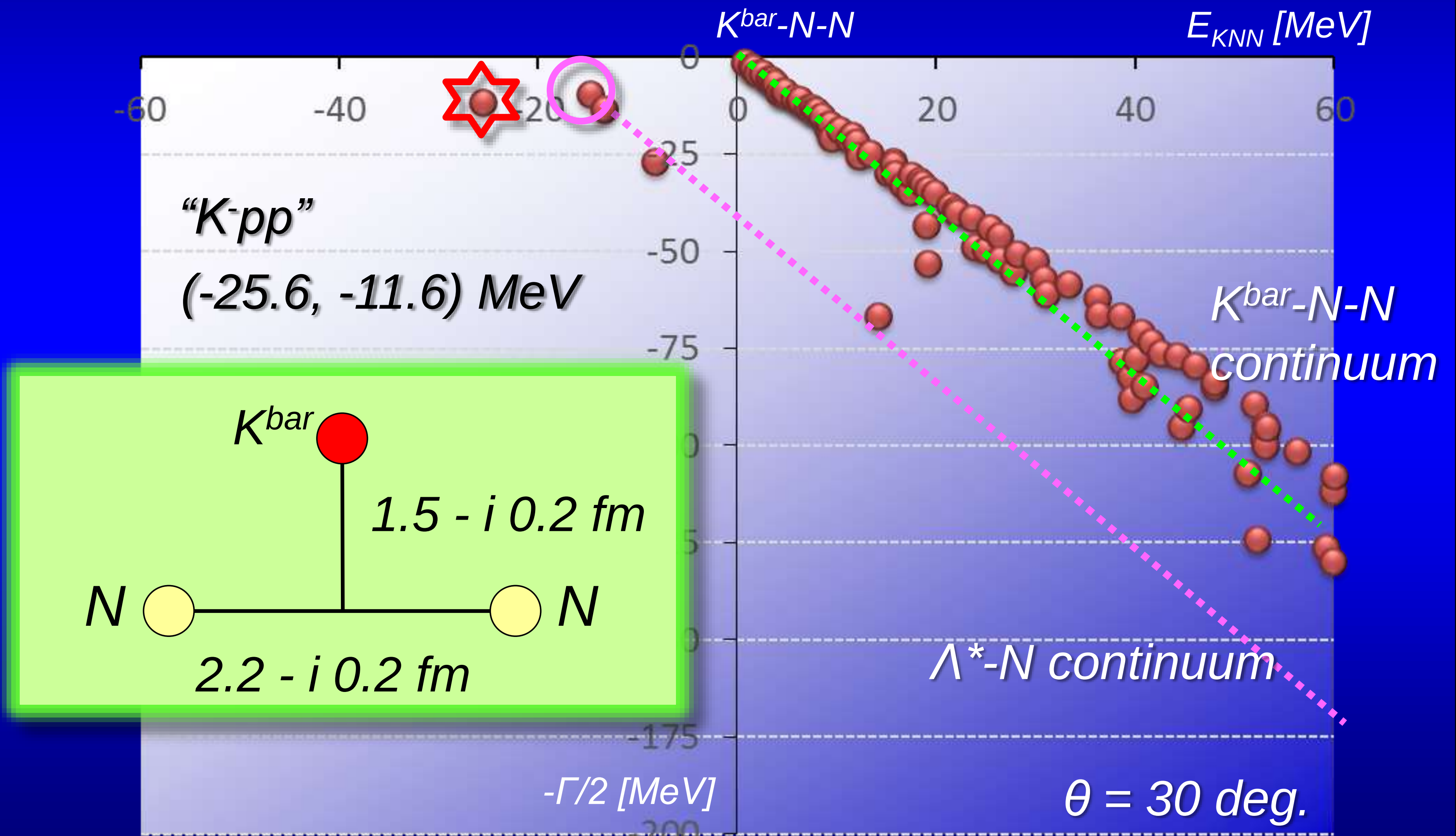
$K^{bar}N$ energy is fixed at Λ*. (self-consistent at Λ*)



Result: KSW-NRv2 potential (f_π=110MeV)

NN potential : Av18 (Central + spin-spin)

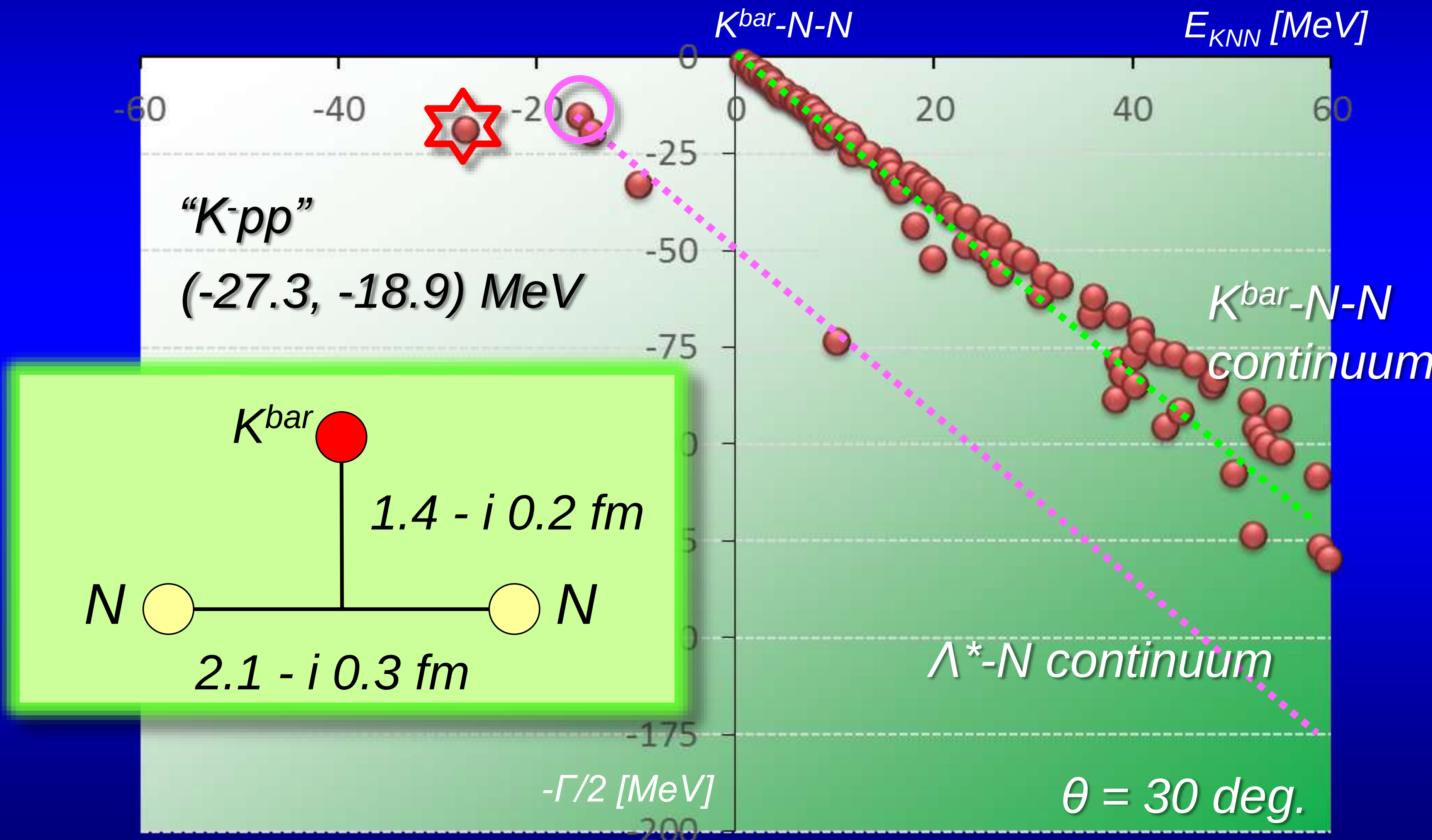
$K^{bar}N$ energy is self-consistent at K^-pp. (Ansatz 1)



Result: KSW-NRv2 potential (f_{π}=110MeV)

NN potential : Av18 (Central + spin-spin)

$K^{bar}N$ energy is self-consistent at $K^{-}pp$. (Ansatz 2)



4. Issues on kaonic nuclei

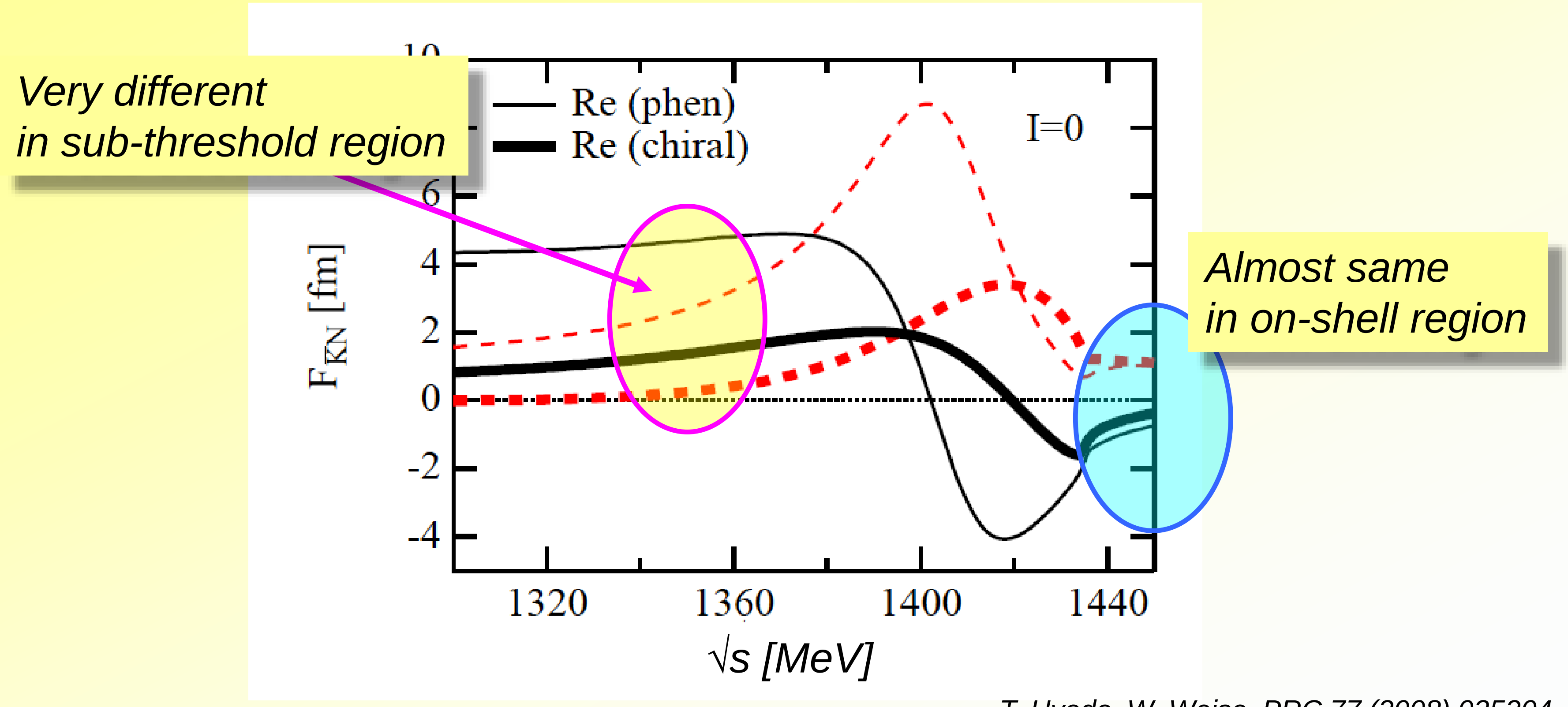
i) $K^{bar}N$ interaction, Λ(1405)

"$K^{bar}N$ potential is shallow or deep?"

Phenomenological potential = Deep
(Akaishi-Yamazaki, E-indep.)

Chiral SU(3)-based potential = Shallow
(chiral unitary model, E-dep.)

I=0 $K^{bar}N$ full scattering amplitude



T. Hyodo, W. Weise, PRC 77 (2008) 035204.

i) $K^{bar}N$ interaction, Λ(1405)

"$K^{bar}N$ potential is shallow or deep?"

Phenomenological potential = Deep
(Akaishi-Yamazaki, E-indep.)

Chiral SU(3)-based potential = Shallow
(chiral unitary model, E-dep.)

- *$K^{bar}N$ scattering amplitude*
  - *Almost the same, above $K^{bar}N$ threshold*
  - *Resonance structure … AY: 1405 MeV, Chiral: 1420 MeV*
  - *AY pot. is ~4 times more attractive than Chiral pot. far below the resonance.*

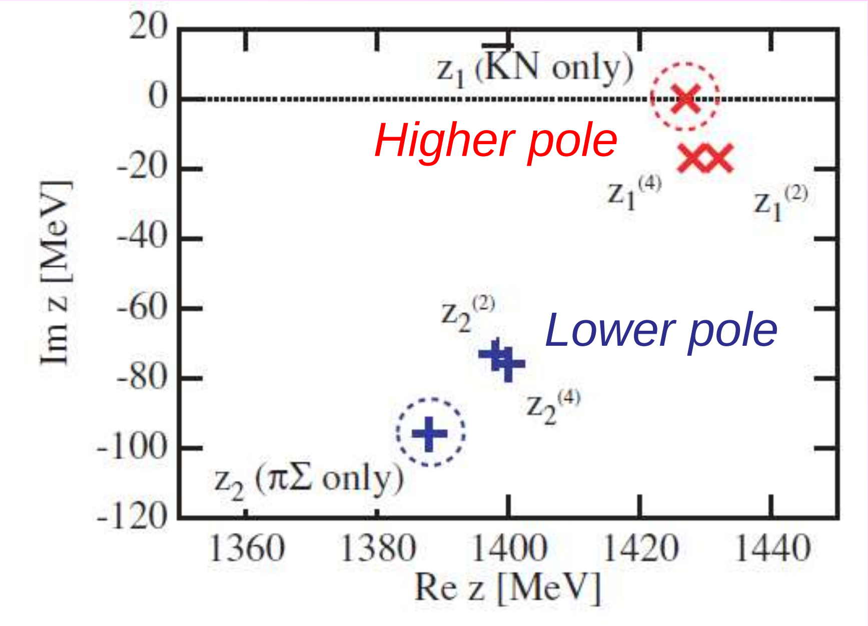
i) $K^{bar}N$ in

"$K^{bar}N$ poten

Phenomenolog ... = Shallow
(Akaishi-Yamaza

- $K^{bar}N$ scatterin
  - ➢ *Almost*
  - ➢ *Resona*
  - ➢ *AY pot.* ... *nce.*

Pole positions of I=0 channel



T. Hyodo, W. Weise, PRC 77 (2008) 035204.

- $\Lambda(1405)$ = $K^{bar}N$ quasi-bound state, *"Building block of K^{bar} nuclei"*

Double-pole nature of chiral potential

D. Jido, J.A. Oller, E. Oset, A. Ramos, U.-G. Meißner, Nucl. Phys. A 725 (2003) 181.
T. Hyodo, W. Weise, Phys. Rev. C 77 (2008) 035204.

	B and Γ	Coupling to	
Higher pole	Shallow and narrow	$K^{bar}N$	Close to $K^{bar}N$ threshold
Lower pole	Deep and broad	πΣ	*Generated by energy dependence*

i) $K^{bar}N$ interaction, Λ(1405)

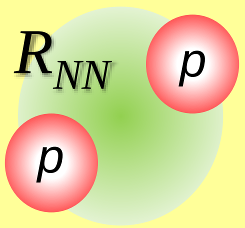
"K^{bar}N potential is shallow or deep?"

Phenomenological potential = Deep
(Akaishi-Yamazaki, E-indep.)

Chiral SU(3)-based potential = Shallow
(chiral unitary model, E-dep.)

- *Difference in K^-pp*

	B. E. [MeV]	Γ [MeV]	R_{NN} [fm]	"Density"
AY	49	60	1.8	$\sim 2\rho_0$
Chiral	17	47	2.2	ρ_0



A. D., T. Hyodo, W. Weise, PRC 79 (2009) 014003.

AY case may be a doorway to dense matter.

i) $K^{bar}N$ interaction, Λ(1405)

"$K^{bar}N$ potential is shallow or deep?"

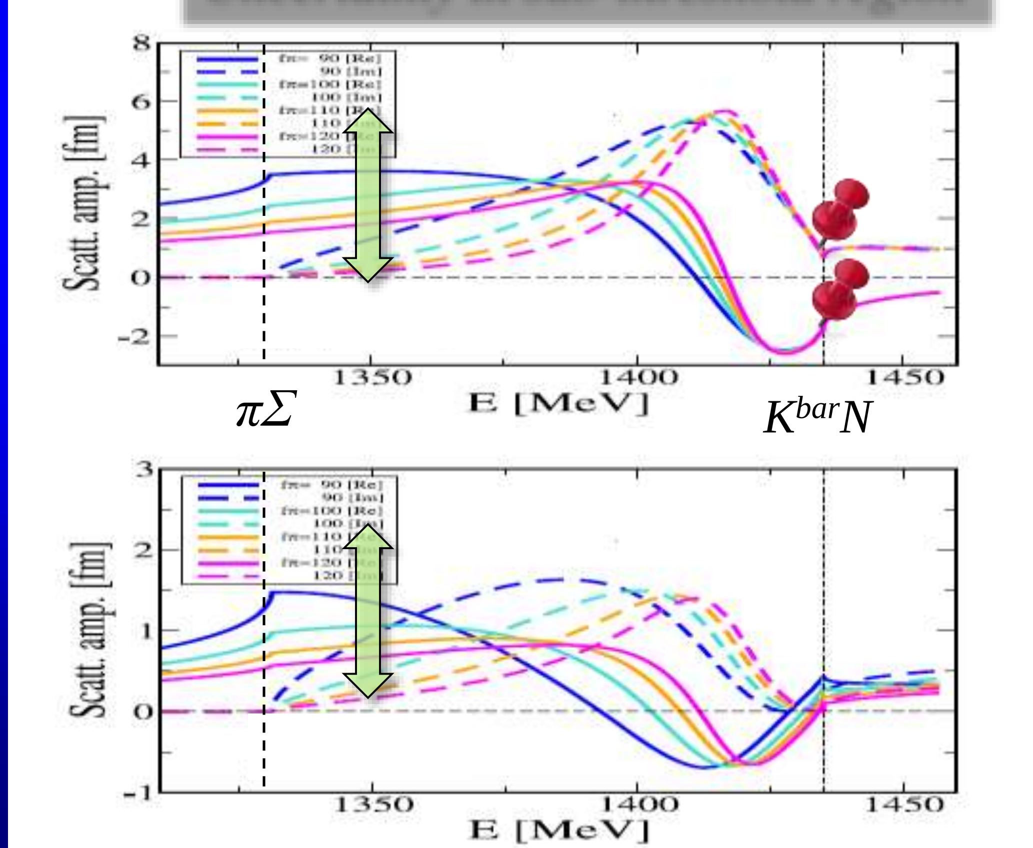
Phenomenological potential = Deep
(Akaishi-Yamazaki, E-indep.)

Chiral SU(3)-based potential = Shallow
(chiral unitary model, E-dep.)

Uncertainty in sub-threshold region

$K^{bar}N$

$\pi\Sigma$



A. D., T. Inoue, T. Myo,
Nucl. Phys. A 912, 66 (2013)

i) $K^{bar}N$ interaction, Λ(1405)

"$K^{bar}N$ potential is shallow or deep?"

Phenomenological potential = Deep
(Akaishi-Yamazaki, E-indep.)

Precise measurement of Kaonic atoms

- Kaonic Hydrogen: KpX, DEAR, SIDDHATA
- Kaonic ^{4}He: KEK (E570), J-PARC (E17)
- Kaonic Deuteron, ^{3}He: SIDDHATA2

To fix uncertainty in sub-threshold region…

$K^{bar}N$

???

Λ(1405) study with d(K^-, n)

J-PARC (E31) will be done

Scattering data

$\sqrt{s}$

$K^{bar}N$ threshold

πΣ scattering length from Λ_c decay

T. Hyodo, M. Oka, PRC84, 035201 (2011)

πΣ mass spectrum
$\pi^-\Sigma^+$, $\pi^+\Sigma^-$, π

Precise πΣ line shape

CLAS/Jlab, LEPS/SPring8

$\sqrt{s}$

πΣ threshold

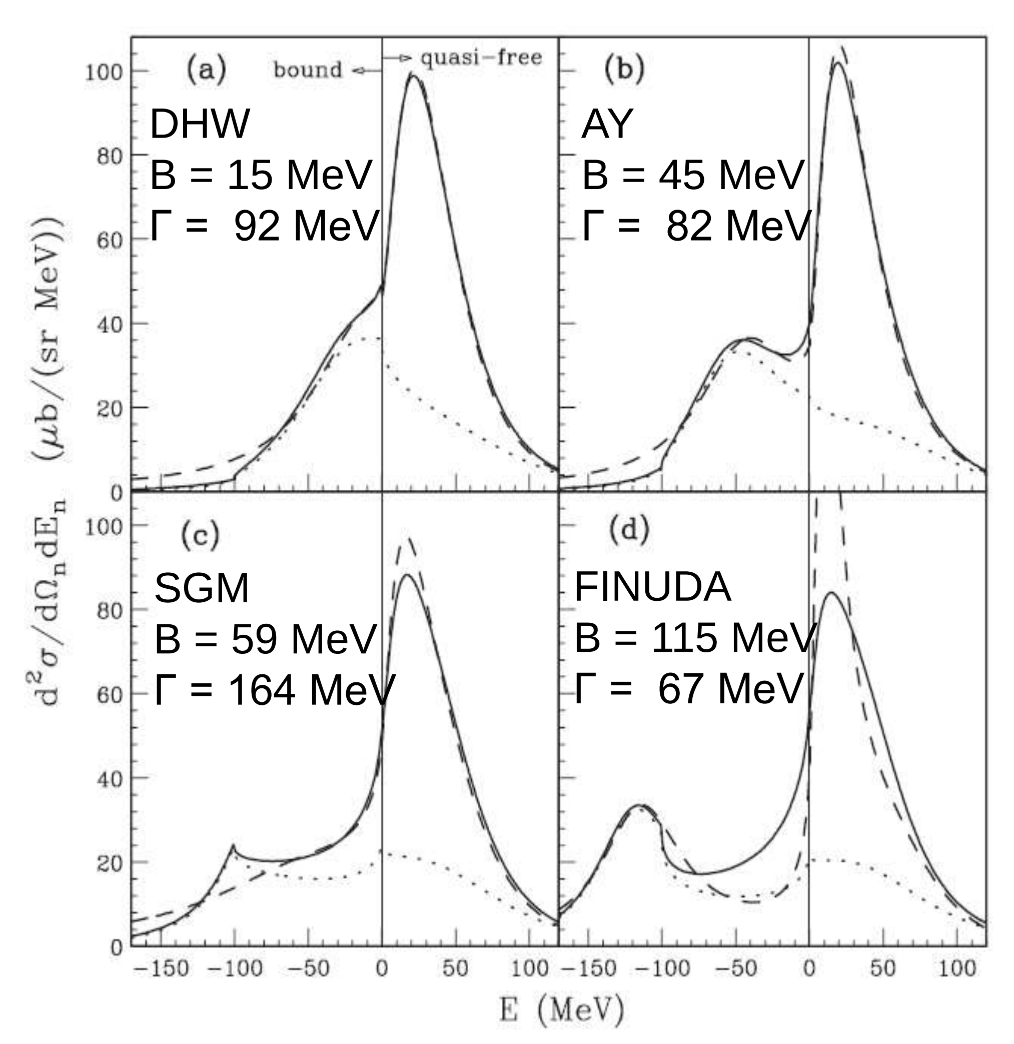
ii) Comparison between theory and experiment

Peak structure observed in exp.

- *Large decay width*
- *$\pi\Sigma N$ threshold*

Pole position calculated in theor.

Inclusive spectra of ^{3}He(K$^-$, inflight n)



T. Koike and T. Harada, PRC80, 055208 (2009)

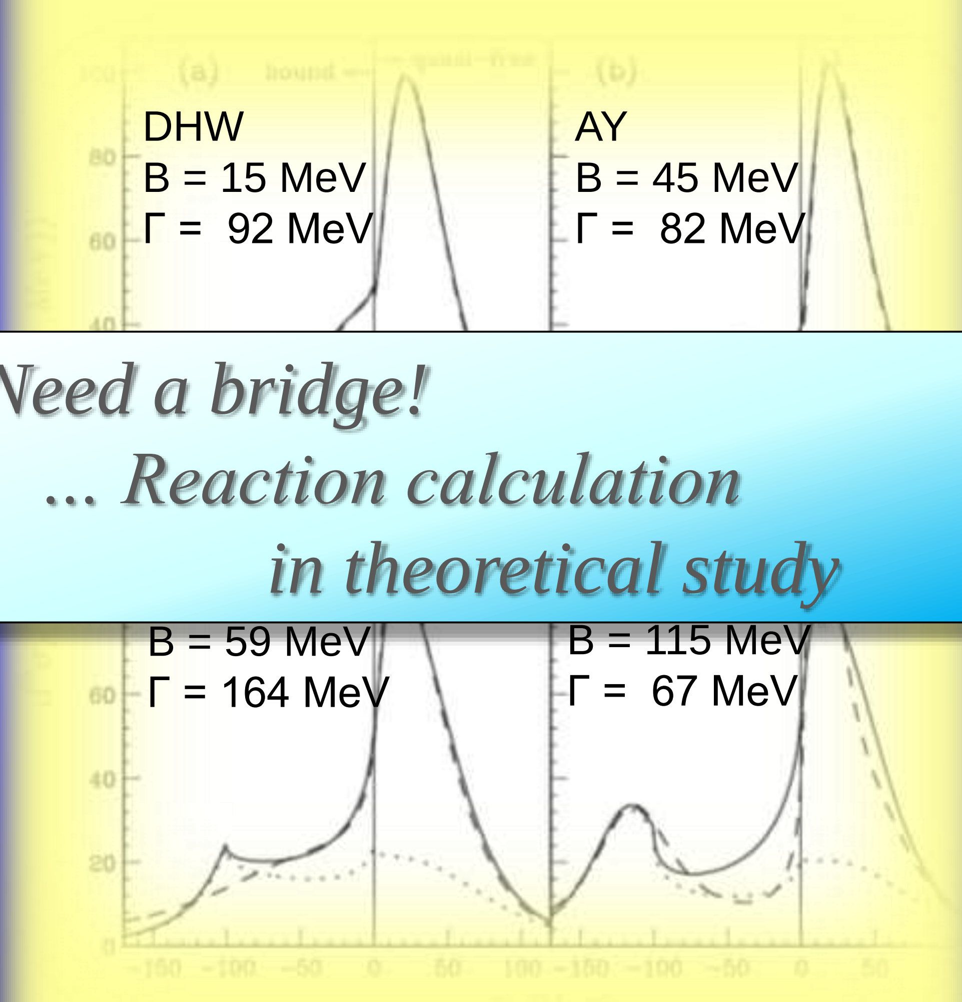
ii) Comparison between theory and experiment

Peak structure observed in exp.

- *Large decay width*
- *πΣN threshold*

Pole position calculated in theor.

Inclusive spectra of $^{3}He(K^{-}$, inflight n)



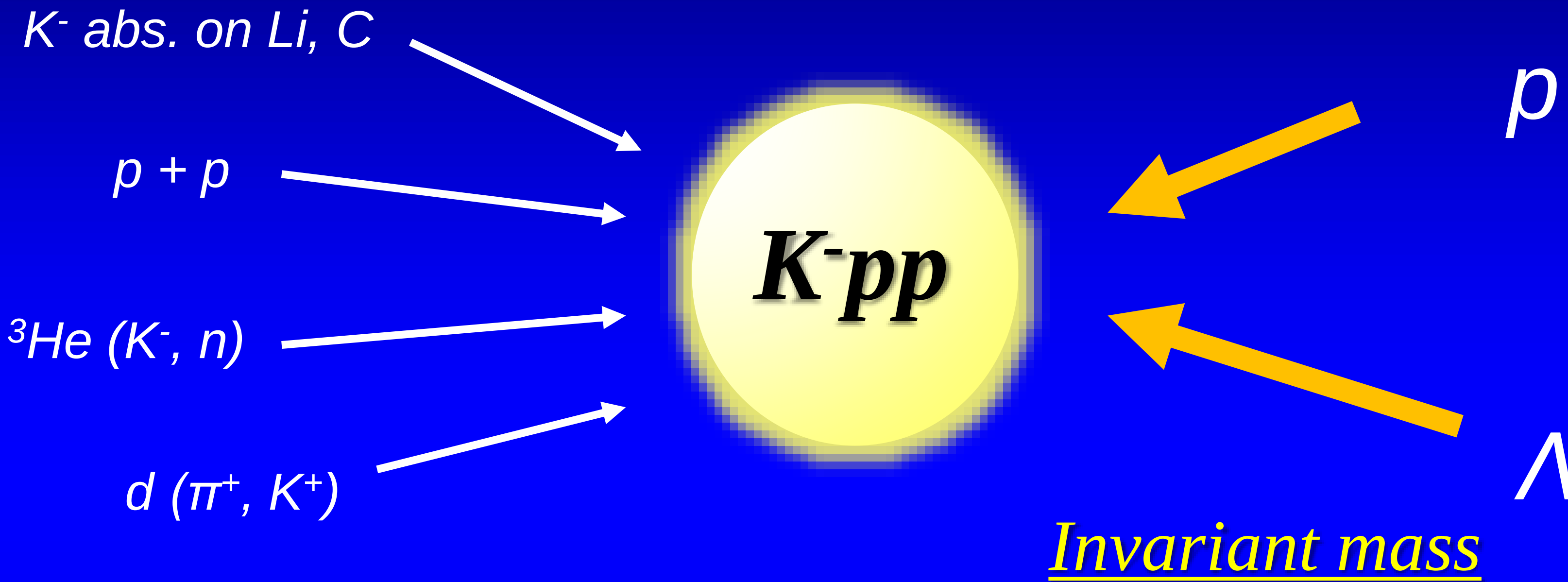
Need a bridge!

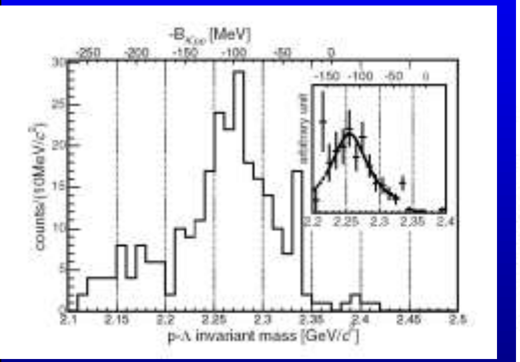
… Reaction calculation

in theoretical study

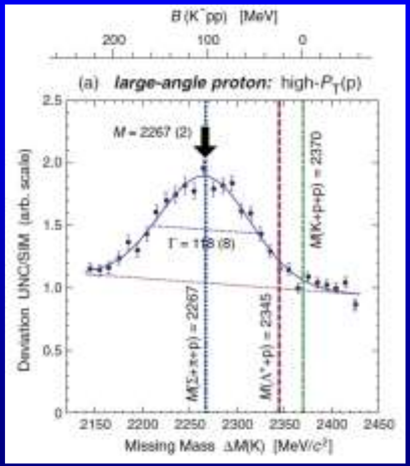
T. Koike and T. Harada, PRC80, 055208 (2009)

iii) Relevant degree of freedom

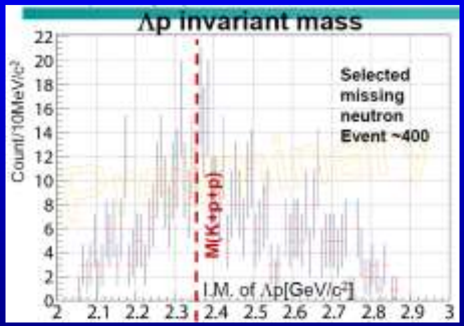




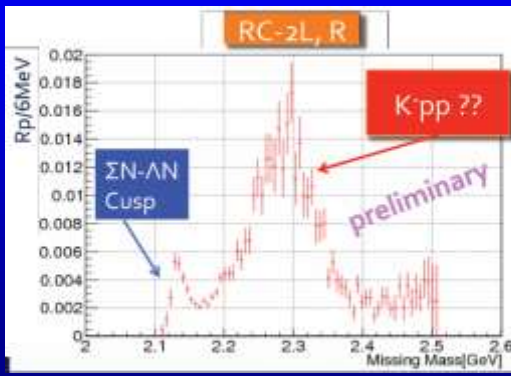
FINUDA



DISTO

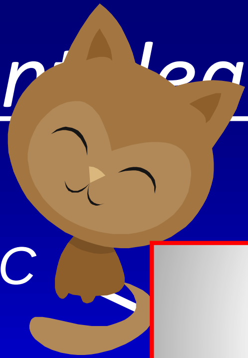


J-PARC E15



J-PARC E27

iii) Relevant degree of freedom



K⁻ abs. on Li, C

p + p

^{3}He (K⁻, n)

d (π⁺, K⁺)

Something with B=2, S=-1, charge +1

p

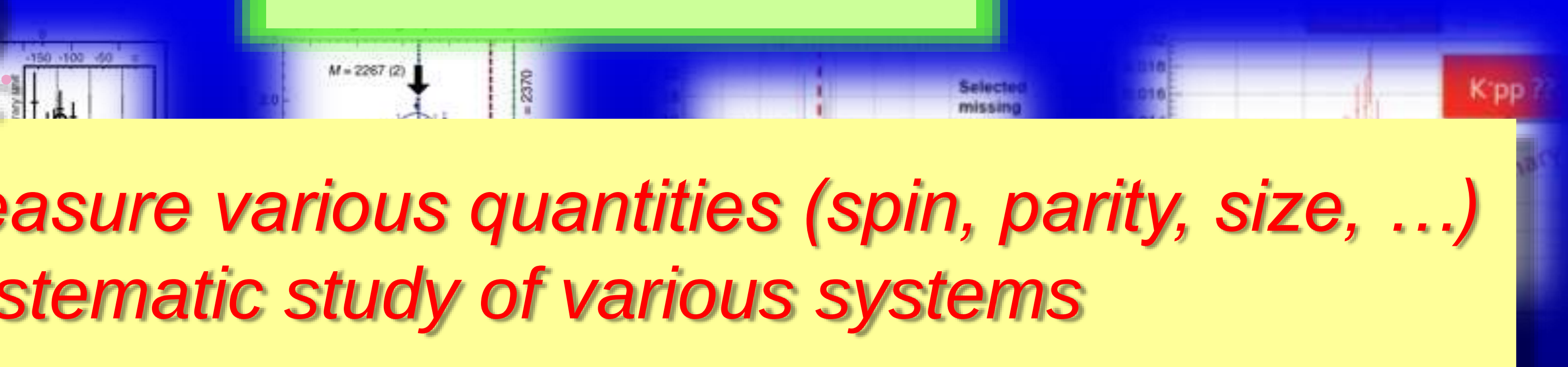
Λ

K⁻pp? πΣN?

Λ*N?? Σ*N??

qqq-qqq-q^{bar} s ???

iant mass



- *Measure various quantities (spin, parity, size, …)*
- *Systematic study of various systems*

FINUDA

DISTO

J-PARC E15

J-PARC E27

5. Summary

5. Summary

Kaonic nuclei (nuclear system with anti-kaon)

… *Exotic system due to strong $K^{bar}N$ attraction?* *Doorway to dense matter?*

$K^{-}pp$ = "Prototype of K^{bar} nuclei"

Lots of theoretical studies predict *$K^{-}pp$ can be bound below K^{bar} + 2N threshold.*

Variational calc.	×	Chiral pot.
Faddeev-AGS		Phen. pot.

⇒ *$K^{-}pp$ exists as a **resonance** between $K^{bar}NN$ and $\pi\Sigma N$ thresholds.*
Binding energy < 100 MeV, Large decay width (>40MeV)

$K^{-}pp$ studied with ccCSM+Feshbch method

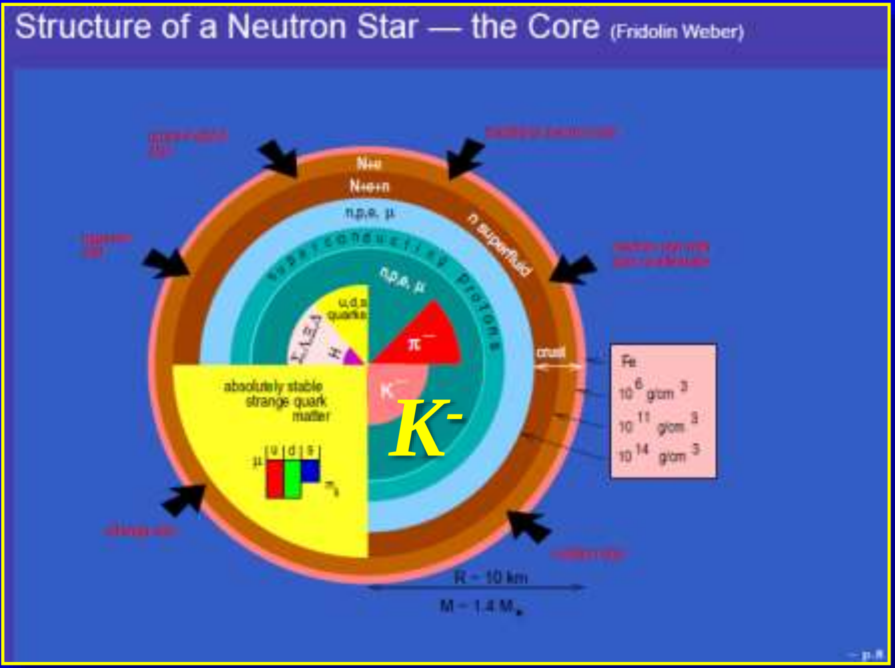
Effective single-channel potential derived in ccCSM
Chiral SU(3)-based pot. (Gauss-type)
*Self-consistency for kaon's **complex** energy*

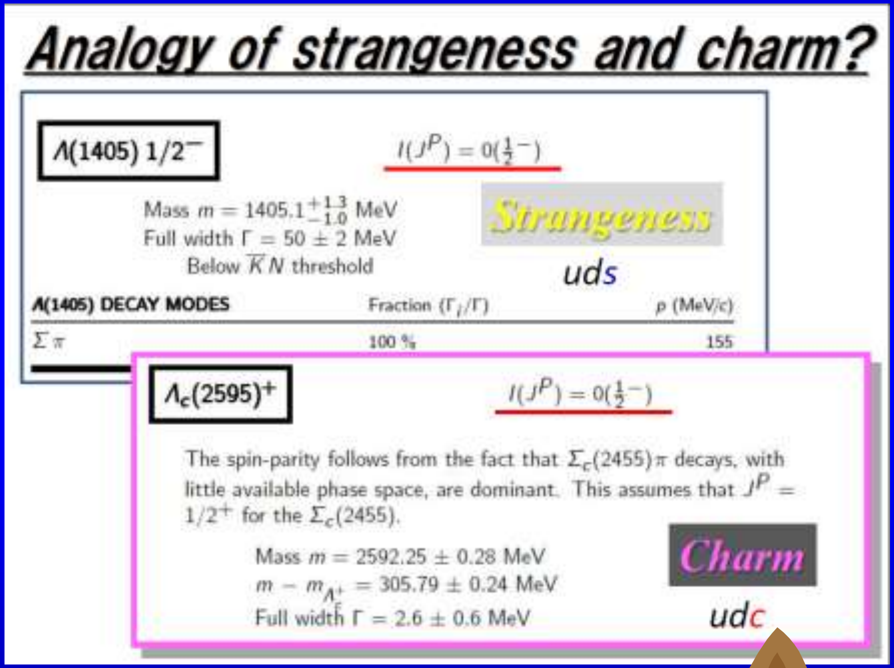
⇒ *$(B, \Gamma/2)$ = (26, 12) MeV : Ansatz 1*
(27, 19) MeV : Ansatz 2
Mean NN distance ~ 2.2 fm

Issues on kaonic nuclei

- $K^{bar}N$ interaction *"Deep or shallow?", "Double pole of Λ(1405)"* by chiral potential
  … Solve uncertainty in $K^{bar}N$ sub-threshold region
- Observed spectra and calculated pole position
  … *Large decay width, threshold effect* ⇒ Help theoretical analysis of reaction study
- What is observed in invariant-mass measurement? $K^{-}pp$? $\pi\Sigma N$? $\Lambda^{*}N$?? $\Sigma^{*}N$?? 7q-q^{bar} s
  ⇒ Measurement of various quantities (spin-parity, size …), Systematic study

- *What's the role of anti-kaon in neutron star?*
- *Compare with charm sector…*





Thank you for your attention!