Narrow quasi-bound states of DNN system

1. Introduction
2. Setup for the variational calculation
   I. DN potential
   II. NN potential
3. Result
   I. Variational calculation
      - DNN bound state with S_{NN}=0
      - DNN state with S_{NN}=1
   II. Faddeev-FCA calculation
4. Comparison with strangeness sector
5. Summary

Variational part:
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Phys. Rev. C86, 044004 (2012)

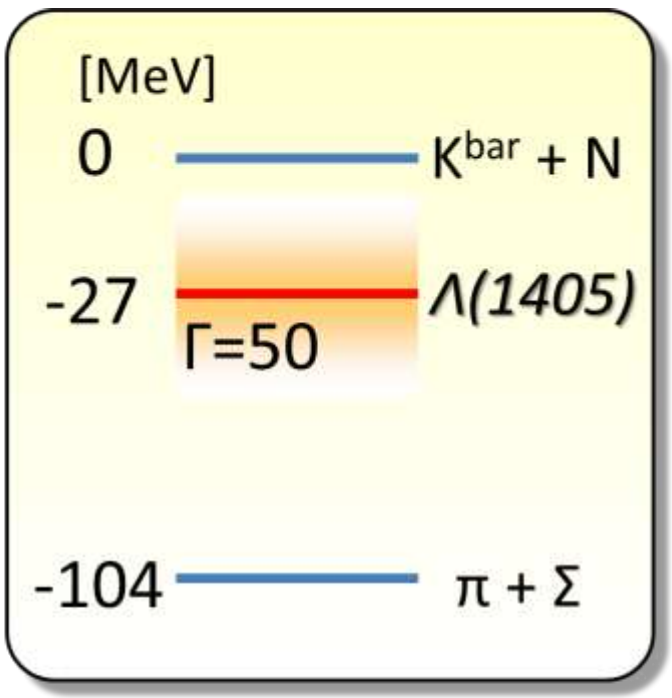
1. Introduction

D mesic nuclei
= Charm analog system of K^{bar} nuclei?

Strangeness

$K^{bar} = s\ q^{bar}$

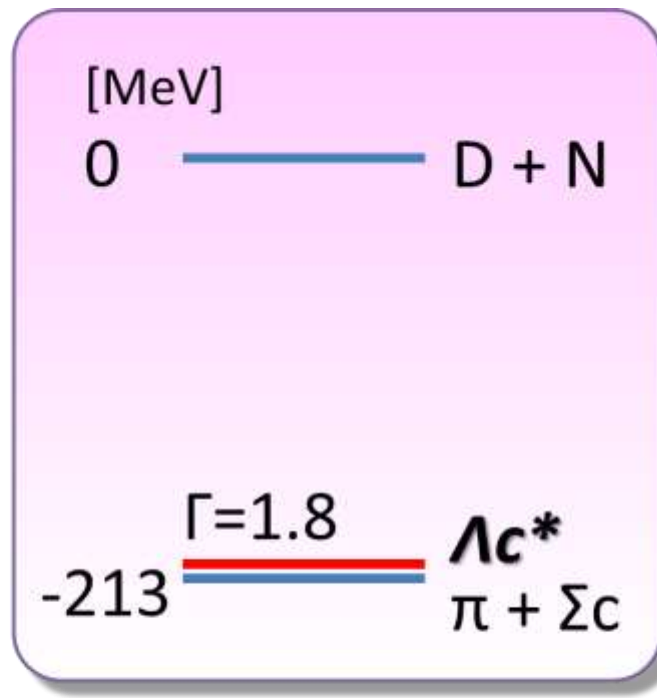
$\Lambda(1405) = K^{bar}N$ Q.B.S.



Charm

$D = c\ q^{bar}$

$\Lambda_c(2595) = DN$ Q.B.S ?



D mesic nuclei
= Charm analog system of K^{bar} nuclei?

If $\Lambda_c(2595)$ is a quasi-bound state of *I=0 DN* system, …

- *D nuclei may be a narrow state.*

  $$\Gamma(\Lambda_c^*) = 1.8\ MeV \ll \Gamma(\Lambda^*) = 50\ MeV$$

- *Non-rela. treatment is justified.*

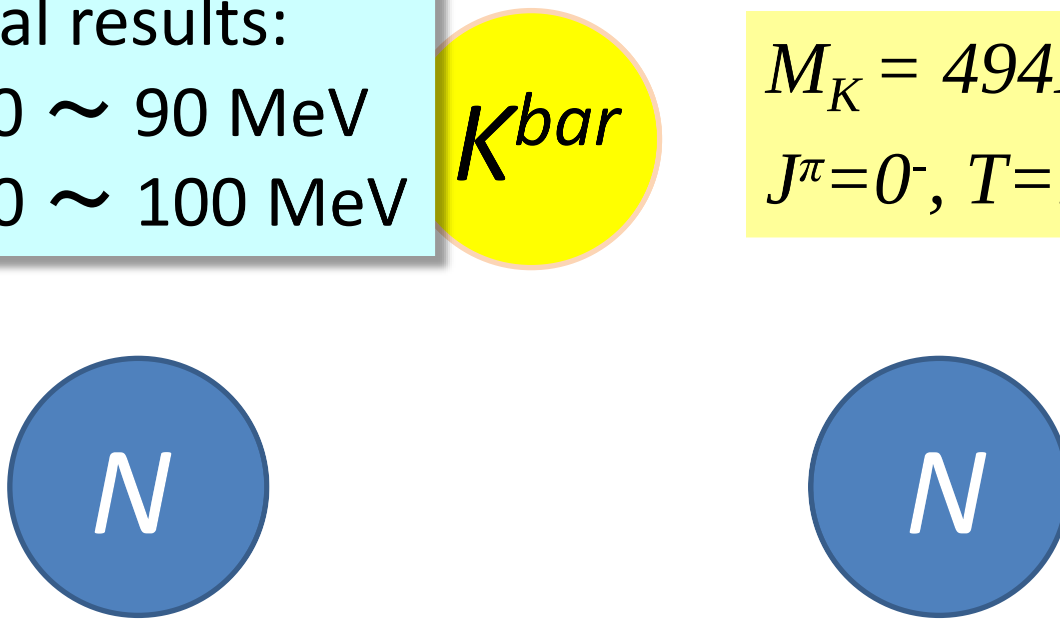
  $$M_D = 1867\ MeV \gg M_K = 494\ MeV$$

Physics of D mesic nuclei is more clear than that of K^{bar} nuclei.
D nuclei may help the study of K^{bar} nuclei.

Essential D mesic nucleus = DNN

$K^{-}pp \sim K^{bar}NN\text{-}\pi YN$

Theoretical results:
B.E. = 20 ∼ 90 MeV
Γ = 50 ∼ 100 MeV

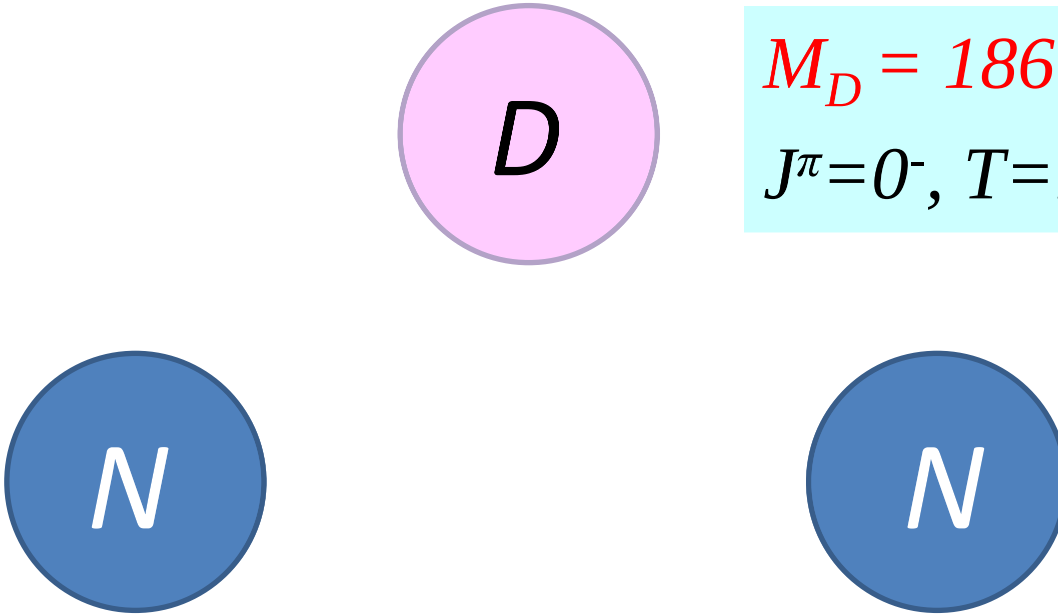


$M_K = 494MeV$
$J^{\pi}=0^{-}$, $T=1/2$

- $J^{\pi}=0^{-}$ ($S_{NN}=0$, $L=0$), $T=1/2$

Essential D mesic nucleus = DNN

$DNN\text{-}\pi Y_c N$



$M_D = 1867 MeV$

$J^\pi = 0^-$, $T = 1/2$

- $J^\pi = 0^-$ ($S_{NN} = 0$, $L = 0$), $T = 1/2$
- $J^\pi = 1^-$ ($S_{NN} = 1$, $L = 0$), $T = 1/2$

2. Set up

2. Set up … same as K^-pp study

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

- Effective DN potential

  Vector meson exchange picture potential

  … Coupled-channel potential (DN, $\pi\Sigma_c$, $\pi\Lambda_c$, …)

  Generate dynamically the I=0 resonance $\Lambda_c(2595)$

DN single-channel potential … equivalent as for DN scattering amplitude

DN potential

Based on Mizutani-Ramos study†

Coupled-channel calculation in *DN*, $\pi\Sigma_c$, $\pi\Lambda_c$, … etc
with WT-type interaction

- *κ=1/4 for charm exchange process*
  … DN <---> πY_c
- *κ=1 for other cases*

$$\boxed{v_{ij}^{(I)}(W) = -\frac{\kappa C_{ij}^{(I)}}{4f^2}(2W-M_i-M_j)\sqrt{\frac{M_i+E_i}{2M_i}}\sqrt{\frac{M_j+E_j}{2M_j}}}$$

➢ WT interaction ≈ Vector meson exchange potential
Due to KSRF relation

➡ Effective *DN* potential

Similar way to the $K^{bar}N$ study††

- ✓ *Eliminate other channels than DN.*
- ✓ *Reproduce the original DN scattering amplitude.*
- ✓ *Single-range Gaussian form*

† *T. Mizutani and A. Ramos, PRC74, 065201 (2006)*
†† *T. Hyodo and W. Weise, PRC77, 035204 (2007)*

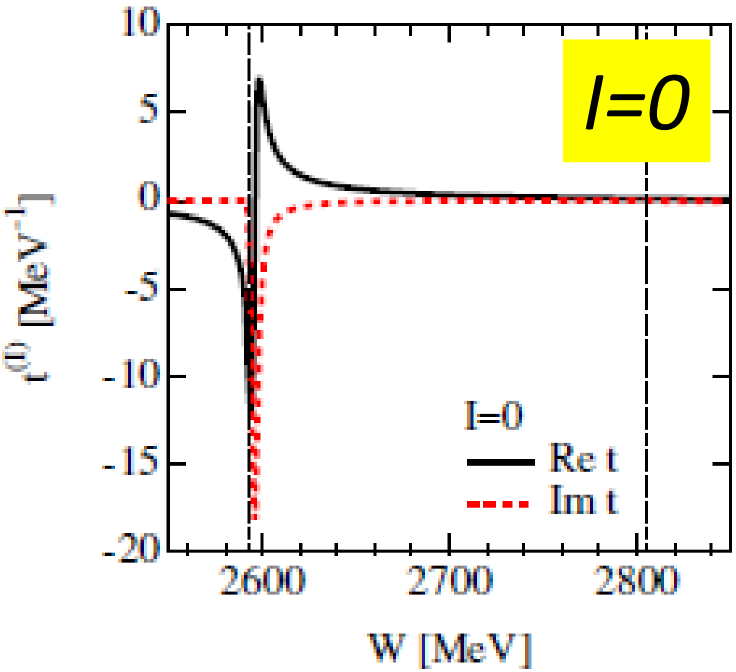
DN potential

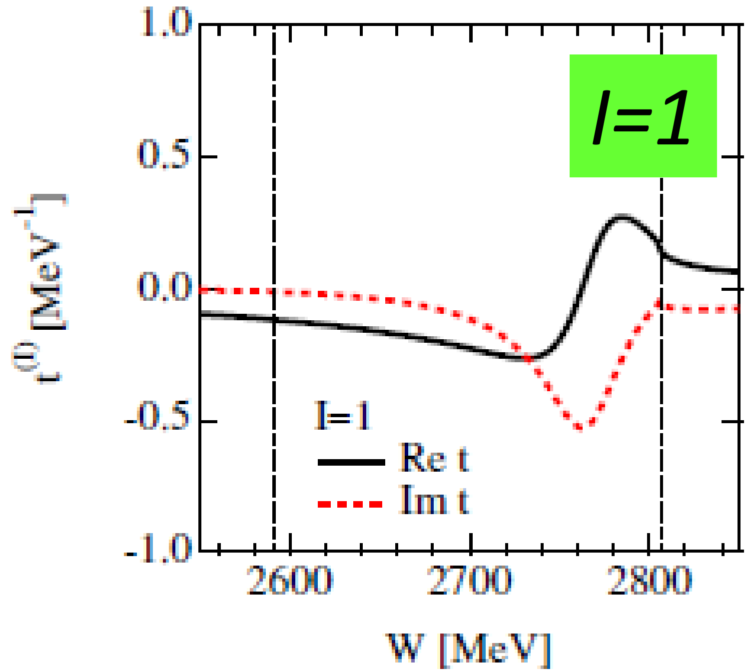
$$v_{DN}(r;W) = \frac{M_N}{2\pi^{3/2} a_s^3 \tilde{\omega}(W)} \times [v^{\mathrm{eff}}(W) + \Delta v(W)] \exp[-(r/a_s)^2]$$

Energy-dependent pot.

a_s = 0.40fm

- *DN* scattering amplitude





Λ_c(2595) dynamically generated

Resonance @ 2766 MeV

2. Set up … same as $K^- pp$ study

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

- <u>Effective *DN* potential</u>

  Vector meson exchange picture potential

  … Coupled-channel potential (*DN*, $\pi\Sigma_c$, $\pi\Lambda_c$, …)

  Generate dynamically the I=0 resonance $\Lambda_c(2595)$

DN single-channel potential … equivalent as for DN scattering amplitude

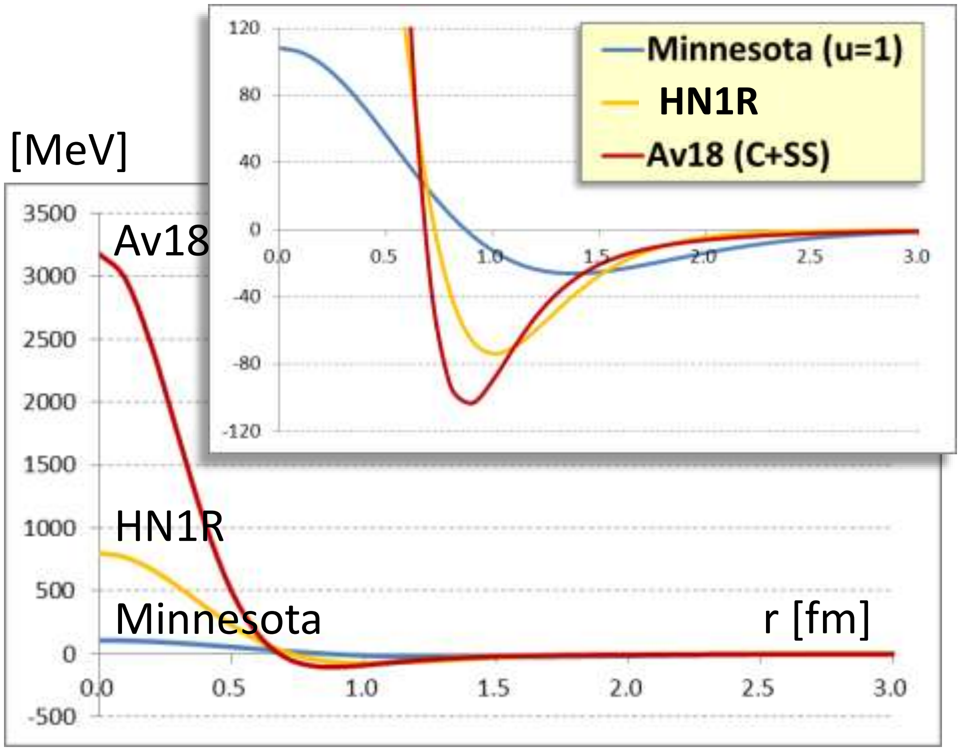
- <u>*NN* potential</u> … *NN* phase shift respected

• Av18[1)]	Repulsive core	~ 3 GeV
• Hasegawa-Nagata No.1[2)] Revised		~ 1 GeV
• Minnesota[3)]		~ 0.1 GeV

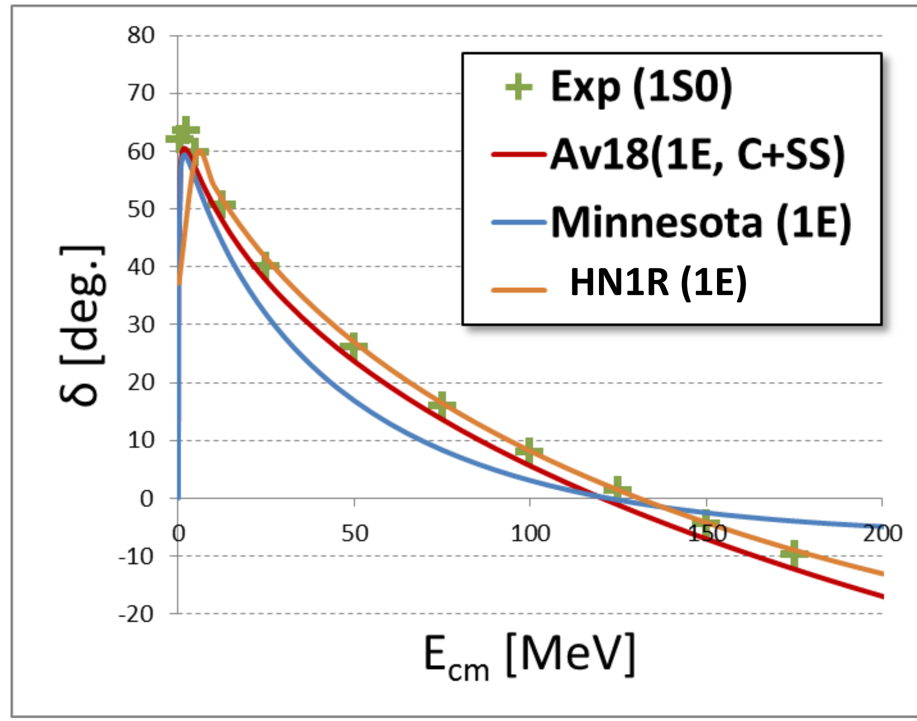
1) R. B. Wiringa, V. G. J. Stoks and R. Schiavilla, PRC51, 38 (1995)
2) A. Hasegawa and S. Nagata, PTP45, 1786 (1971)
3) D. R. Thompson, M. Lemere and Y. C. Tang, NPA286, 53 (1977)

NN potentials = Minnesota, HN1R, Av18

Potential (^{1}E channel)



Phase shift ($^{1}S_{0}$)



**** HN1R = slightly modified Hasegawa-Nagata No.1***

- ^{3}E channel: Reproduce B. E. of deuteron
- ^{1}E channel: No bound state in $^{1}S_{0}$ channel

$$\color{red}{0.25}\color{black}{\times V_1 +} \color{red}{0.95}\color{black}{\times V_2 + 1.00 \times V_3}$$

Long -range	Middle -range	Short -range

2. Set up … same as $K^{-}pp$ study

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

- Effective *DN* potential = *Complex potential*

  Vector meson exchange picture potential

  … Coupled-channel potential (*DN*, $\pi\Sigma_c$, $\pi\Lambda_c$, …)

  Generate dynamically the I=0 resonance $\Lambda_c(2595)$

  DN single-channel potential … equivalent as for DN scattering amplitude

- *NN* potential … *NN* phase shift respected
  - Av18 — Repulsive core ~ 3 GeV
  - Hasegawa-Nagata No.1 Revised — ~ 1 GeV
  - Minnesota — ~ 0.1 GeV

- Variational calculation
  - Use the *real part* of the effective *DN* potential
  - Expand the trial wave function with Gaussian base

3. Result

DNN bound state with $S_{NN}=0$

L=0

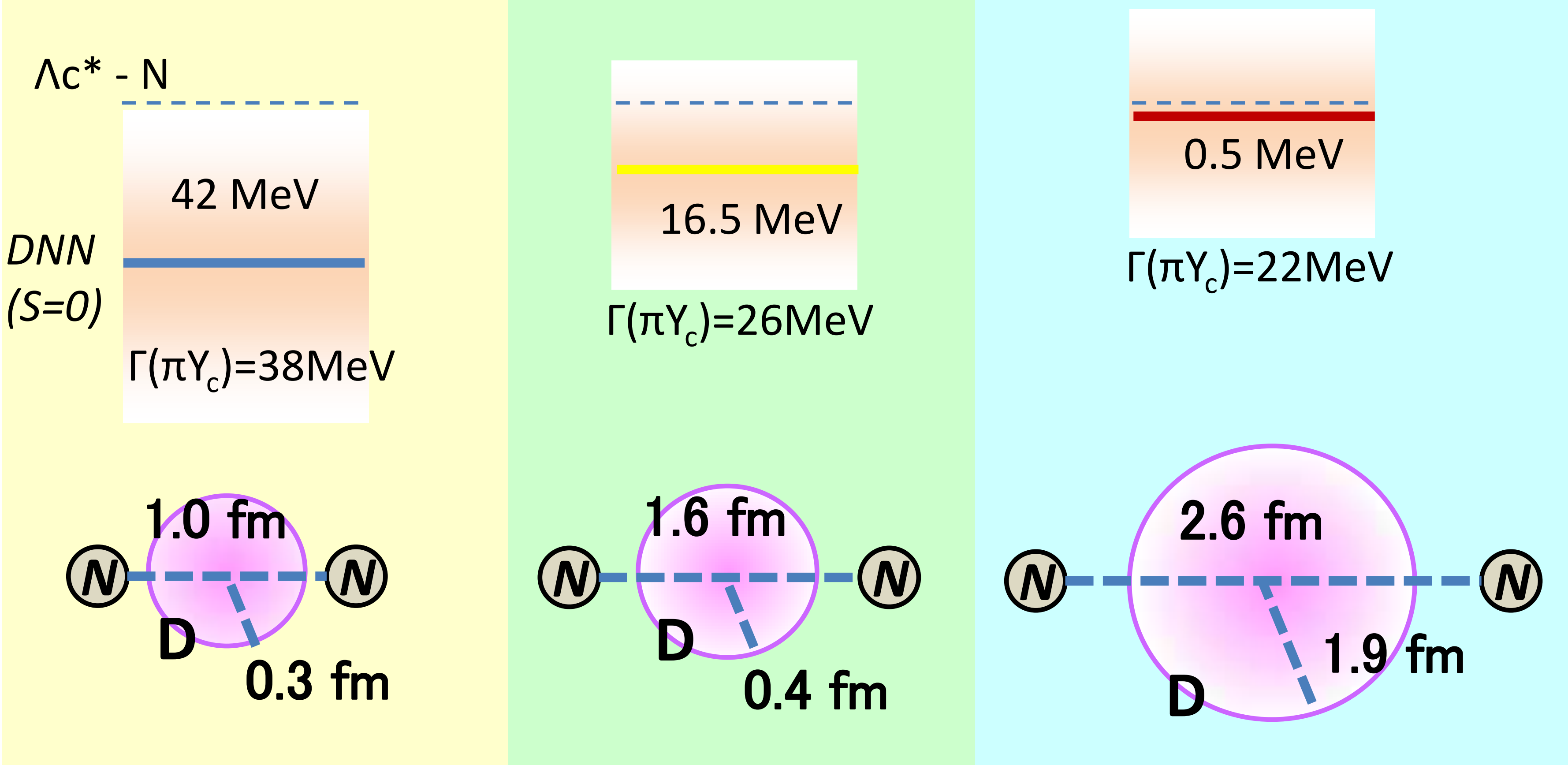
$J^{\pi}=0^{-}$, $T=1/2$

DNN(S=0) : Minnesota, HN1R, Av18

DN pot. :
b=0.40fm,
B(D)=208.9MeV

B. E. and size of *DNN (S=0)*

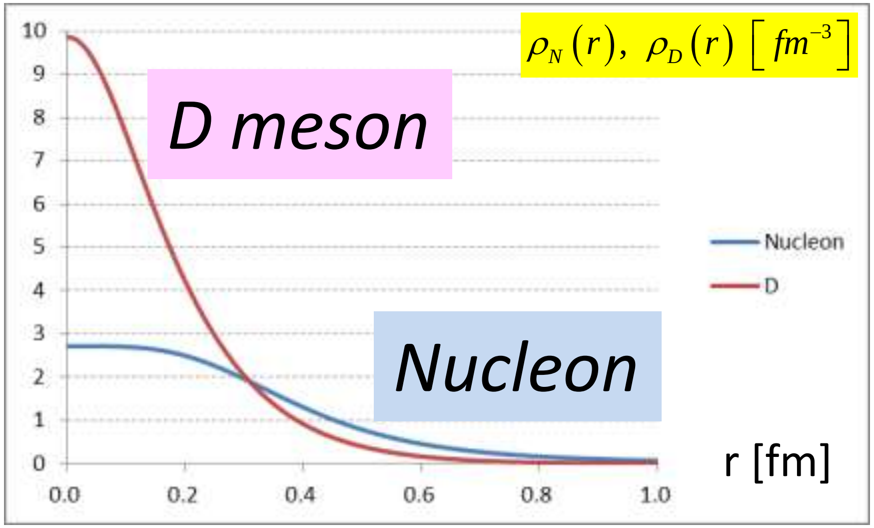
NN	Minnesota	HN1R	Av18 (C+SS)
B. E.	250.9 MeV	225.4 MeV	209.4 MeV
R_{rms}	0.5 fm	0.75 fm	1.26 fm

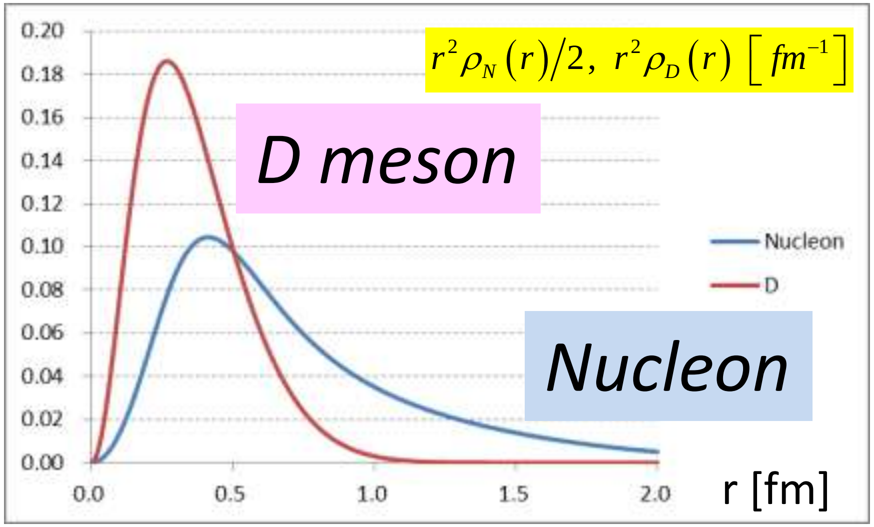


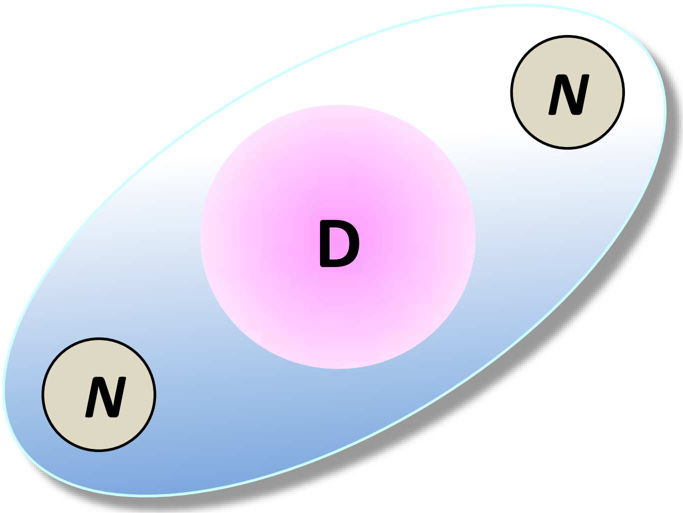
Structure of DNN (S=0)

NN pot: HN1R
DN pot. : b=0.40fm, B(D)=208.9MeV

One-body density







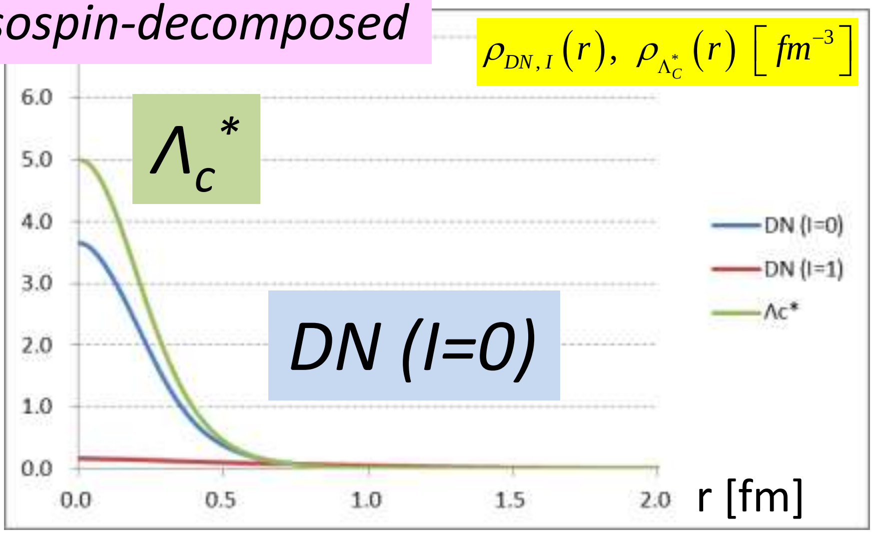
D meson distributes compactly inside of the system.

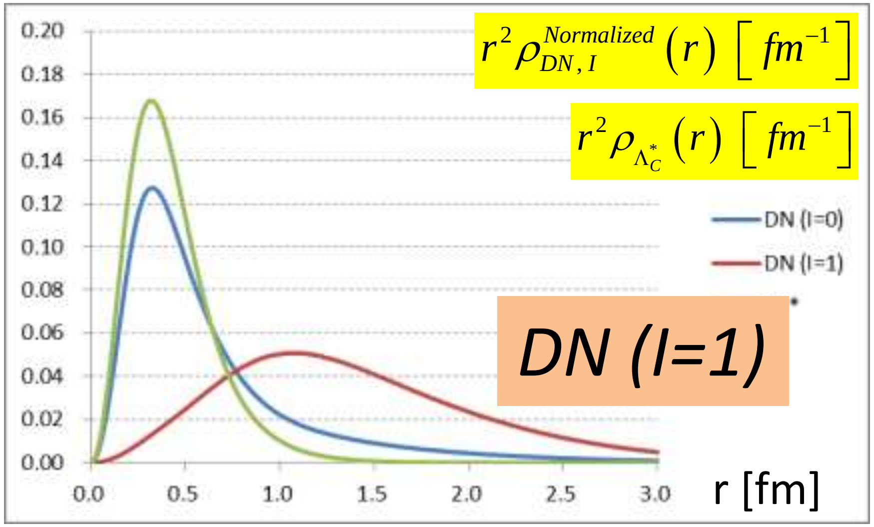
Structure of DNN (S=0)

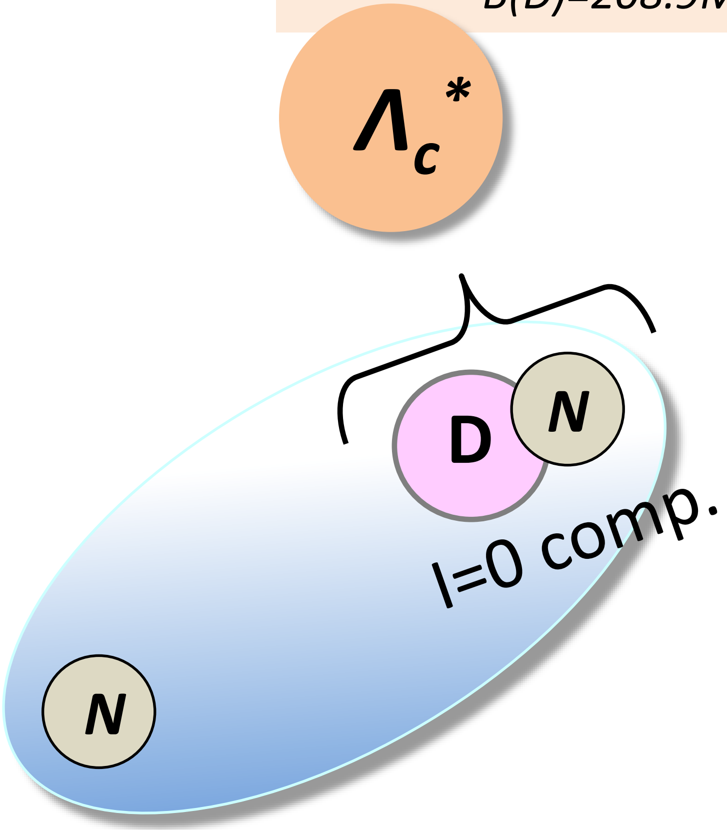
NN pot: HN1R
DN pot. : b=0.40fm, B(D)=208.9MeV

DN correlation density

Isospin-decomposed







- The distribution of the I=0 DN component in DNN (S=0) system is similar to that of **the DN forms Λc***. (Similar to K^{bar}NN case)

3. Result

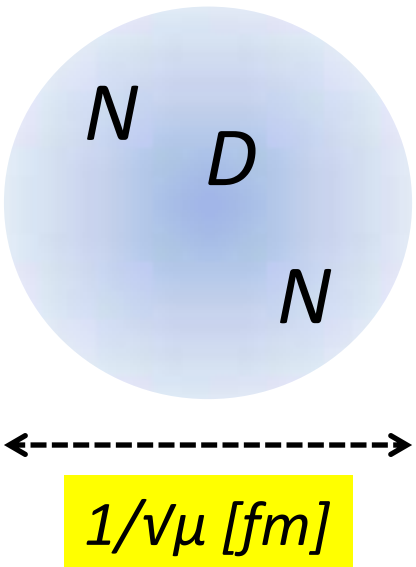
DNN bound state with S_{NN}=1

L=0

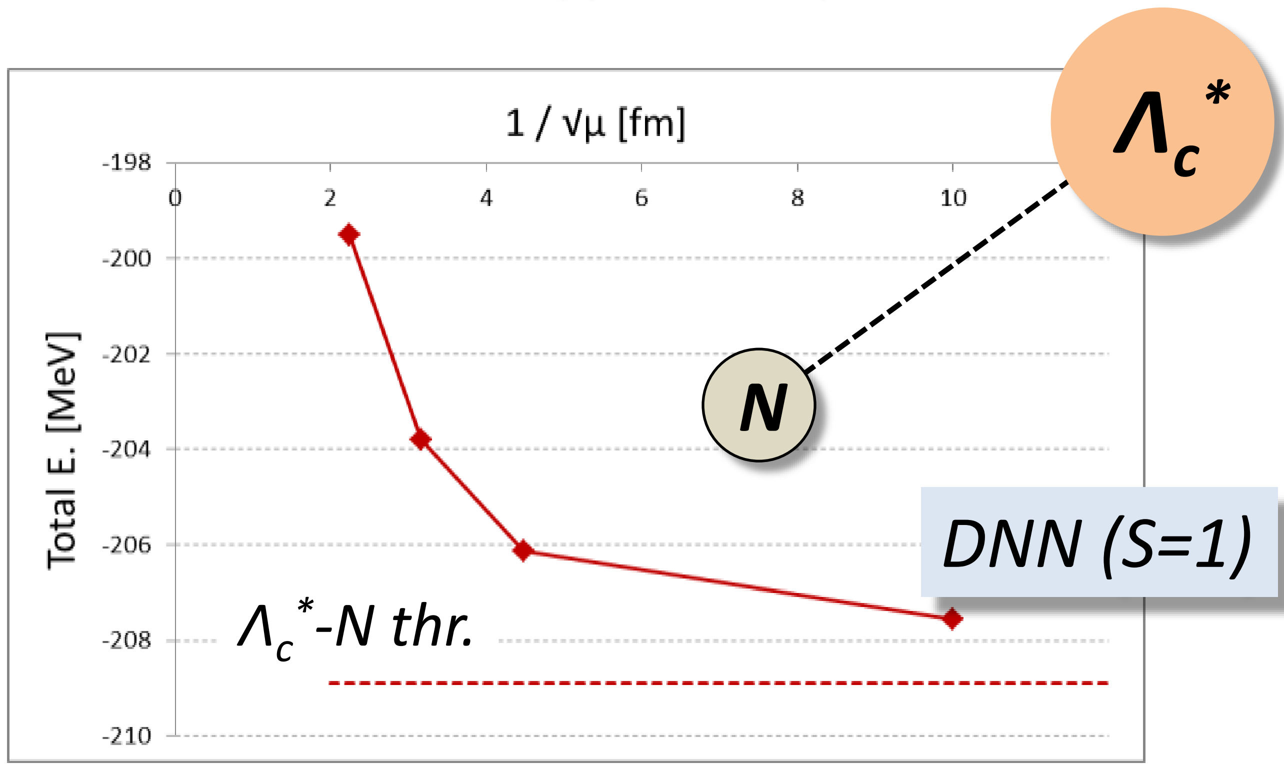
$J^{\pi}=1^{-}$, $T=1/2$

S=1 state of DNN

NN pot: HN1R
DN pot. : b=0.40fm,
B(D)=208.9MeV



Total energy vs 1/√μ



- Increase 1/√μ
  ⇒ *DNN (S=1)* energy → Λ_c^*-*N* threshold energy

➡ ***Λ_c^*-N scattering state !***

3. Result

Faddeev calculation
with Fixed Center Approximation

$J^{\pi}=0^{-}, T=1/2$

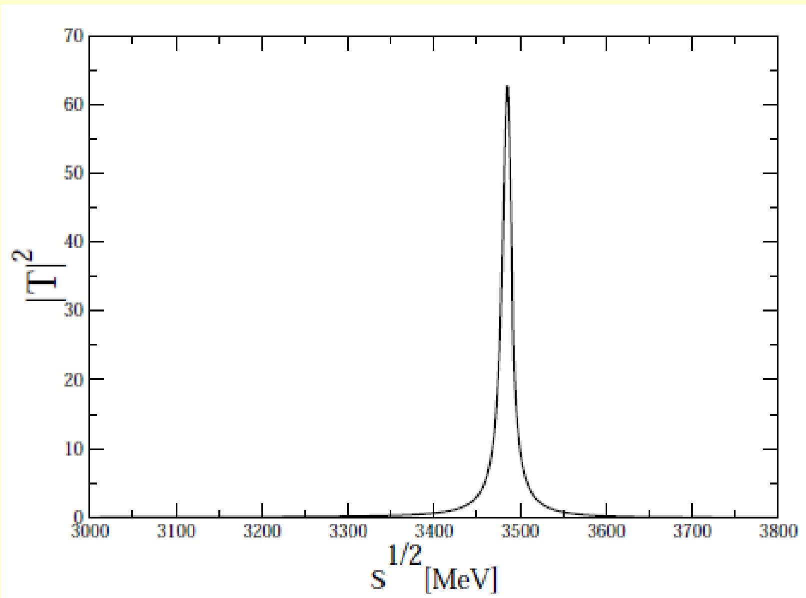
$J^{\pi}=1^{-}, T=1/2$

DNN with Faddeev-FCA calculation

Result (with 2N absorption)

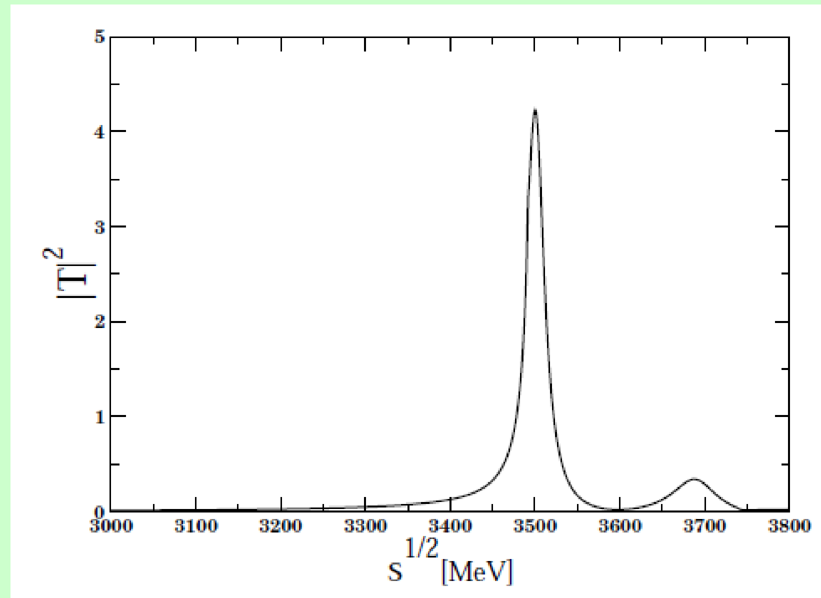
$J^{\pi}=0^{-}$, $T=1/2$

Total mass ~ 3490 MeV



$J^{\pi}=1^{-}$, $T=1/2$

Total mass ~ 3500 MeV



- ~ 250MeV below DNN threshold
  … both states are below $\Lambda_c^{*}N$ threshold
- Full decay width ~ 20-25 MeV

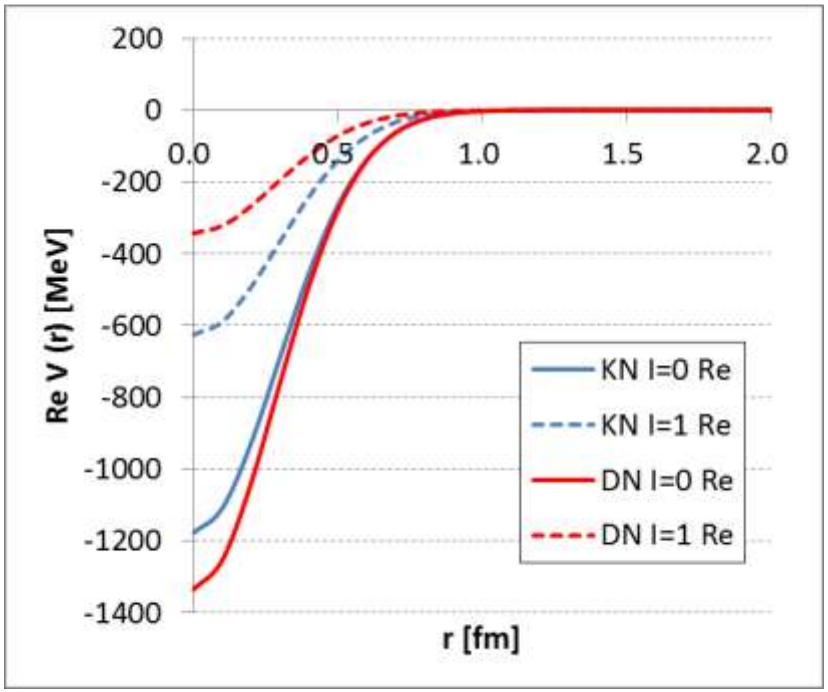
4. Comparison with strangeness sector

DNN vs K^{bar}NN

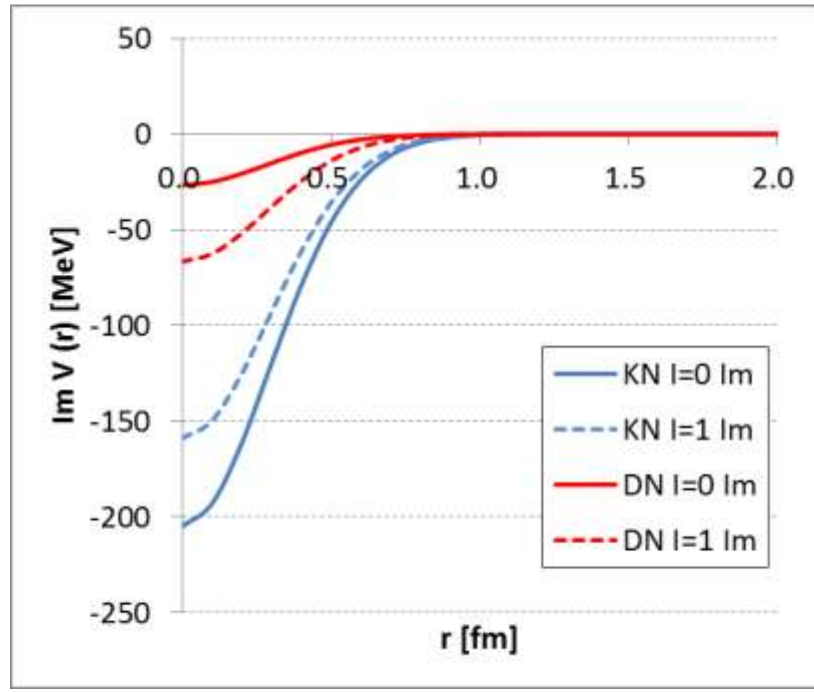
Potential at I=0 resonance

$K^{bar}N$ pot. (b=0.41fm) @ B_K=13.3MeV … Λ^* *$R(K^{bar}N)$ = 1.72 fm*
DN pot. (b=0.40fm) @ B_D=208.9MeV … Λ_c^* *R(DN) = 0.49 fm*

Real



Imaginary



In I=0 channel,
$K^{bar}N$ pot. ≒ DN pot.

Imaginary potential,
$K^{bar}N$ pot. >> DN pot.

DNN vs $K^{bar}NN$

NN pot.: HN1R

	$K^{bar}N$ potential	DN potential
M_K	***$K^{bar}NN$*** *Total B.E. = 28 MeV* *Γ = 67 MeV*	
M_D		***DNN*** *Total B.E. = 225 MeV* *Γ = 26 MeV*

DNN vs $K^{bar}NN$

NN pot.: HN1R

	$K^{bar}N$ potential	DN potential
M_K	**$K^{bar}NN$** Total B.E. = 28 MeV Γ = 67 MeV	Total B.E. = 40 MeV Γ = 11 MeV
M_D		**DNN** Total B.E. = 225 MeV Γ = 26 MeV

B.E. not so increase.

Γ decreases,
due to small Im V_{DN}

DNN vs *K^bar^NN*

NN pot.: HN1R

	$K^{bar}N$ potential	DN potential
M_K	**$K^{bar}NN$** Total B.E. = 28 MeV Γ = 67 MeV	Total B.E. = 40 MeV Γ = 11 MeV
M_D	Total B.E. = 187 MeV Γ = 180 MeV	**DNN** Total B.E. = 225 MeV Γ = 26 MeV

B.E. drastically increases.

Suppression of kinetic energy of D meson

DNN vs *K^bar^NN*

NN pot.: HN1R

	$K^{bar}N$ potential	DN potential
M_K	***K^bar^NN*** *Total B.E. = 28 MeV* *Γ = 67 MeV*	*Total B.E. = 40 MeV* *Γ = 11 MeV*
M_D	*Total B.E. = 187 MeV* *Γ = 180 MeV*	***DNN*** *Total B.E. = 225 MeV* *Γ = 26 MeV*

Kin. E. 352 → 681 MeV if $m_D \rightarrow m_K$.

Suppression of kinetic energy of D meson

5. Summary

5. Summary

The DNN system studied with two approaches: Variational and Faddeec-FCA approaches

- Charm analog state of $K^{bar}NN$
- $J^{\pi}=0^{-}$ $(S_{NN}=0)$ and 1^{-} $(S_{NN}=1)$, $T=1/2$

DN potential

- Based on *vector-meson exchange picture*
- $\Lambda_c(2595)$ … described as *a DN resonance of I=0*
- *[Variational] Effective DN potential* reproducing *I=0* scattering amplitude with single Gaussian form

NN potentials [Variational]

- Minnesota … Soft core (0.1GeV)
- Hasegawa Nagata No.1 (R) … Mild core (1GeV)
- Av18 (Gaussian fitted) … Hard core (3GeV)

5. Summary

As a result of variational calculation, …

DNN ($J^\pi=0^-$) … bound below $\Lambda_c(2595)$-N threshold

- Total B. E. ~ 225 MeV

  (~15MeV below $\Lambda_c(2595)$-N threshold
  Total mass ~ 3520MeV)

- Decay width (πY_c) ~ 25MeV

  … *narrow* compared with total B.E.

D meson stays at center of the system, I=0 DN component ≒ $\Lambda_c(2595)$

DNN ($J^\pi=1^-$) … scattering state of $\Lambda_c(2595)$-N

Faddeev-FCA calculation supports the result of variatoinal calculation.

"*Mass effect*" = Suppression of kinetic energy of D meson
due to its heavy mass

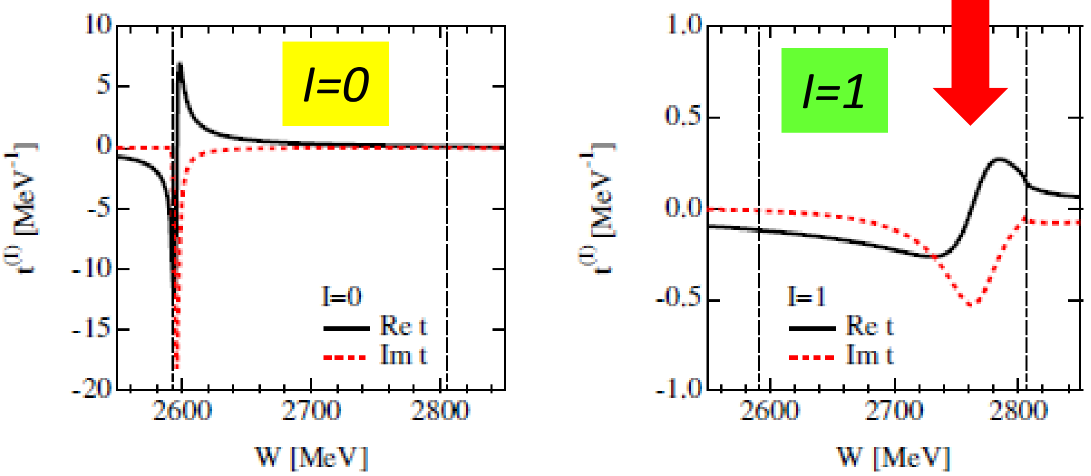

Dora-cat in KEK
Thank you
for
your attention!
D
N
N

与太話

- DNN (T=3/2)は？… DN(I=1)がdominate

DN scattering amplitude

Σ$_c^*$ (?)



共鳴状態が出来るほど、
DN I=1 チャネルも引力が強い。

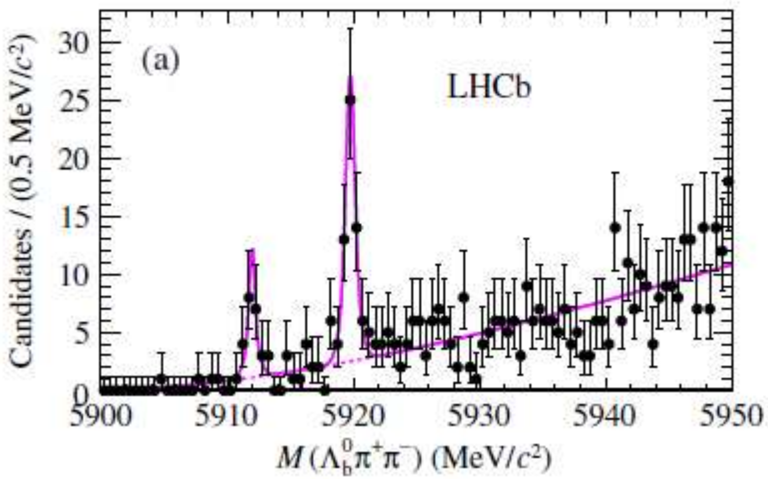
W ~ 2766 MeV
(B(DN) ~ 40 MeV)

Σ$_c^*$ Nより束縛するか？

与太話

- Bottom sectorは？

LHCbで見つかった二つのΛ_b^*



$\Lambda_b^*(5912)$, $\Lambda_b^*(5920)$

$\Gamma < 0.66$, 0.63 MeV

R. Aaij, et al., PRL109, 172003 (2012)

BN	6218	(0)
$\pi\Sigma_b$	5949	(-269)
$\Lambda_b^*(5920)$	5920	(-298)
$\Lambda_b^*(5912)$	5912	(-306)
$\pi\pi\Lambda_b$	5895	(-323)
Σ_b	5811	(-407)
$\pi\Lambda_b$	5757	(-461)
Λ_b	5619	(-599)

$B^{\pm}$ (5279), B^0 (5280)