Quasi-bound states of a DNN system

1. Introduction
2. Setup for the variational calculation
   1. DN potential
   2. NN potential
3. Result of DNN states
   - $J^{\pi}=0^{-}$ ($S_{NN}=0$) with $T=1/2$
   - $J^{\pi}=1^{-}$ ($S_{NN}=1$) with $T=1/2$
   - $J^{\pi}=0^{-}$ ($S_{NN}=0$) with $T=3/2$
4. Comparison with strangeness sector
5. Summary

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

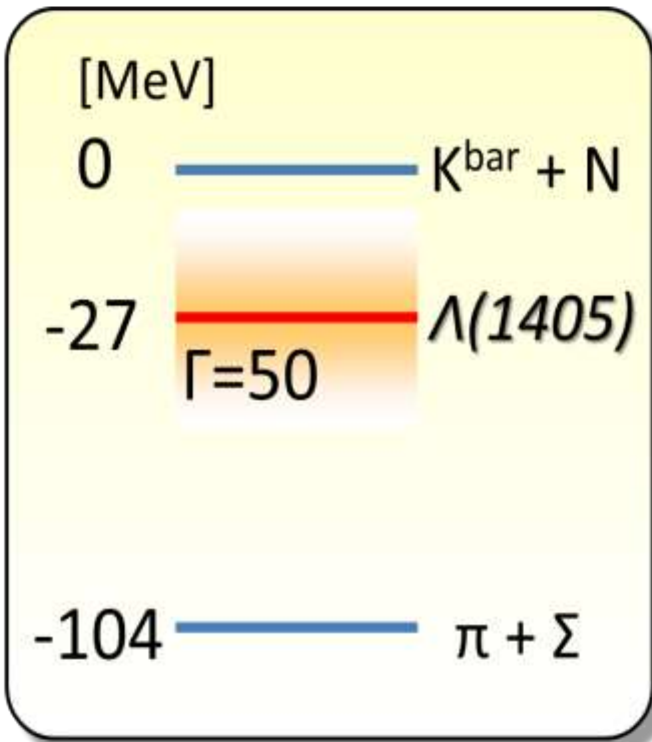
1. Introduction

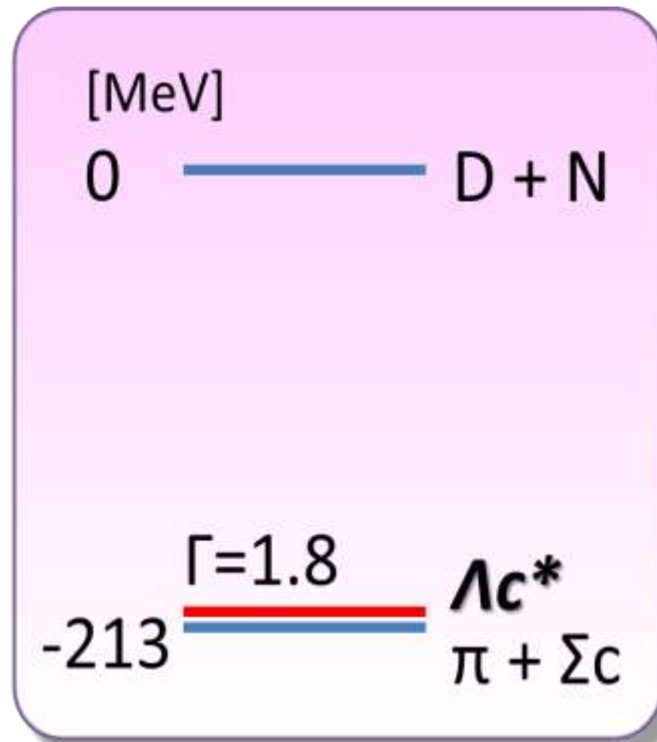
Analogy of strangeness and charm?

- *P-wave baryon (J^p=1/2$^-$, I=0)*

  Strangeness: Λ(1405) … K^{bar}N quasi-bound state

  Charm: Λ_c^+(2595) … DN quasi-bound state?





Analogy of strangeness and charm?

- *P-wave baryon (J^p=1/2$^-$, I=0)*

  Strangeness: Λ(1405) … $K^{bar}N$ quasi-bound state

  Charm: Λ_c^+(2595) … DN quasi-bound state?

- *Nucleus with D meson (D nucleus)*

  … *Charm-analog state of kaonic nuclei (K^{bar} nuclei)*

  Narrow resonance states? $\Gamma(\Lambda_c^*) = 1.8$ MeV << $\Gamma(\Lambda^*) = 50$ MeV

  Non-relativistic treatment! $M_D = 1867$ MeV >> $M_K = 494$ MeV

  → ***Theoretically and experimentally, clearer than kaonic nuclei***

- *Most essential three-body system*

  Strangeness: "K^-pp" (a prototype of kaonic nuclei)

  B. E. = 20 ~ 90 MeV, Γ = 50 ~ 100 MeV (Theor.)

  → ***Consider DNN in charm sector.***

2. Set up

K^{bar} *NN* → *D NN*

494 MeV

1867 MeV

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*

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

➢ 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

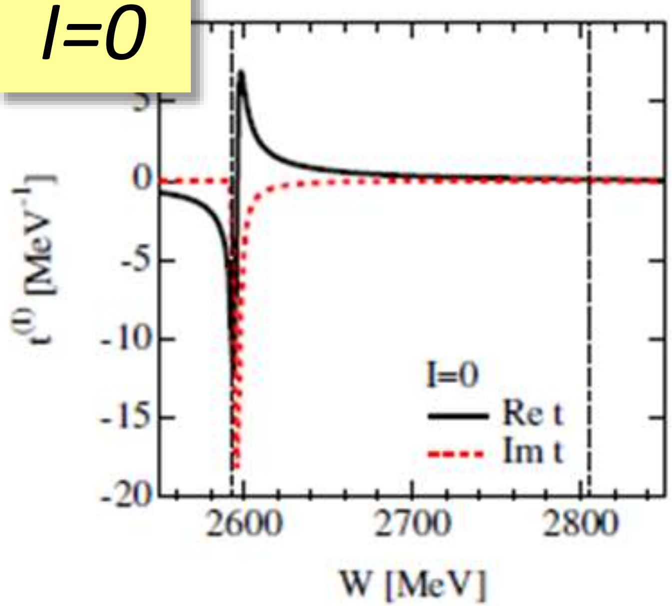
$$v_{DN}(r;W) = \frac{M_N}{2\pi^{3/2}a_s^3\tilde{\omega}(W)} \times [v^{\text{eff}}(W) + \Delta v(W)]\exp[-(r/a_s)^2]$$

Energy-dependent pot.

a_s = 0.40fm

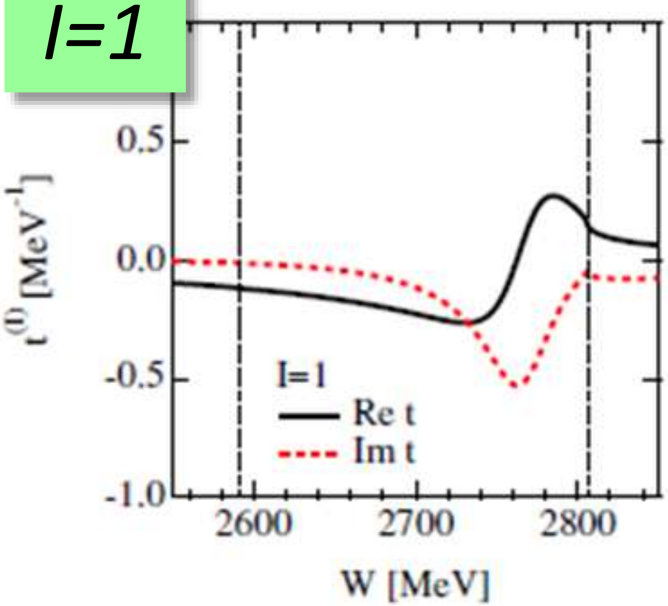
- ***DN scattering amplitude***

I=0



Λ_c(2595) dynamically generated

I=1



Resonance @ 2766 MeV

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

- *NN* potential … *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)

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

Energy and width

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

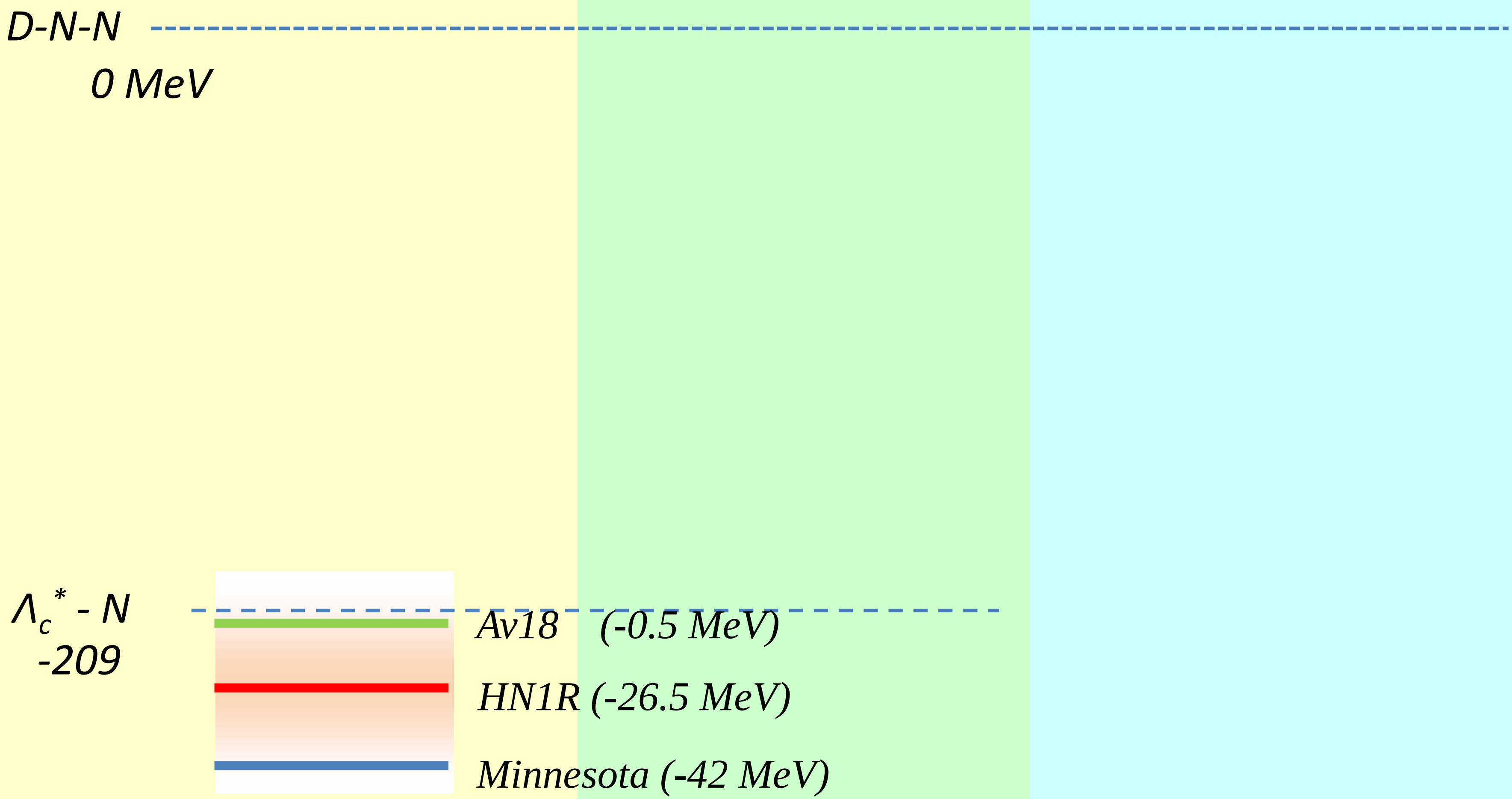
$J^{\pi}=1^{-}, T=1/2$

$J^{\pi}=0^{-}, T=3/2$

Binding energy and decay width

DN pot. : b=0.40fm,
B(D)=208.9MeV (T=1/2)
B(D)= 39.9MeV (T=3/2)

$J^p=0^-$, T=1/2	$J^p=1^-$, T=1/2	$J^p=0^-$, T=3/2

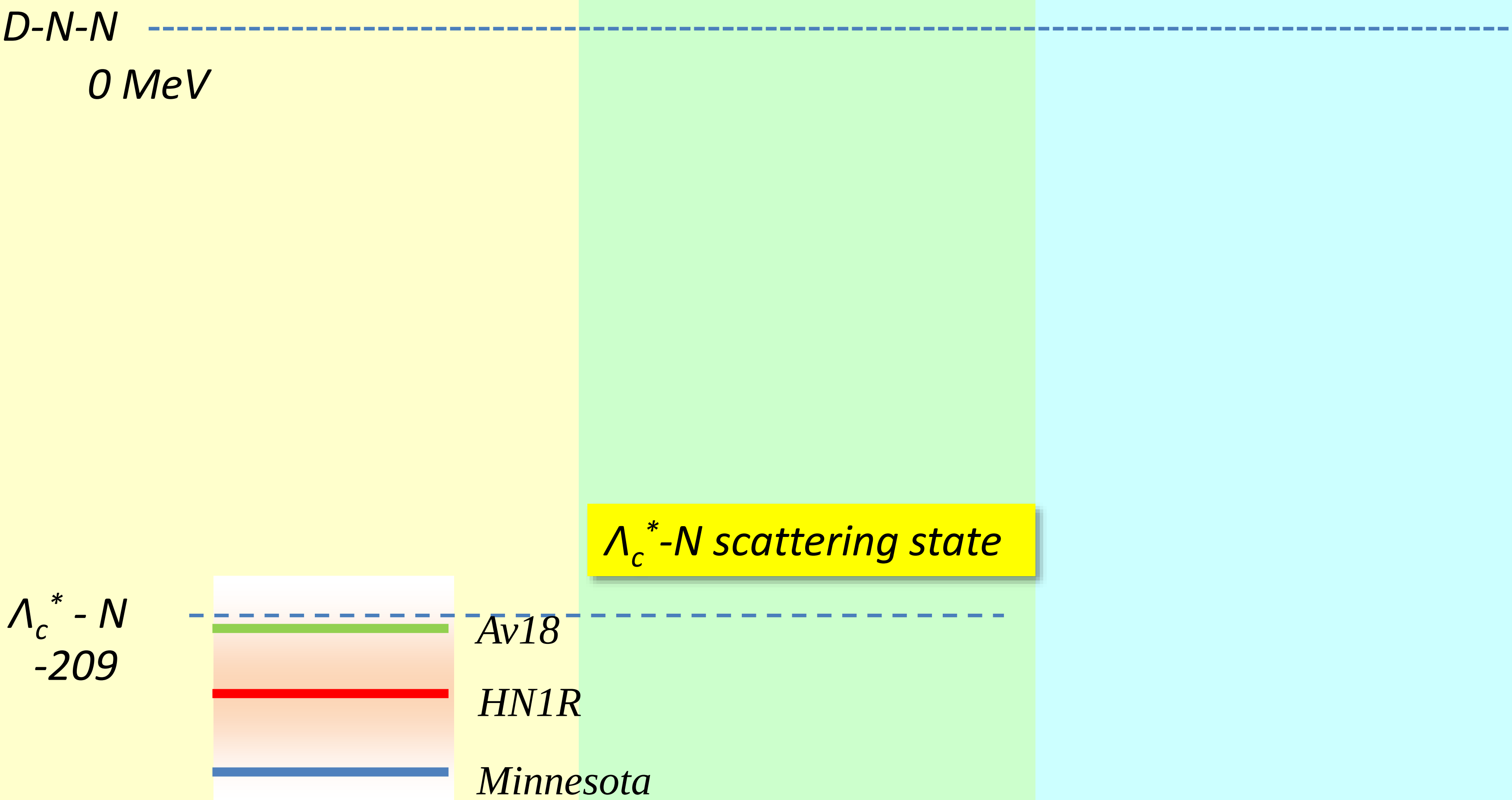


B. E. (Λ_c^*-N) = 42 ~ 0.5 MeV
$\Gamma(\pi Y_c)$ = 38 ~ 22 MeV

Binding energy and decay width

DN pot. : b=0.40fm,
B(D)=208.9MeV (T=1/2)
B(D)= 39.9MeV (T=3/2)

$J^p=0^-$, $T=1/2$	$J^p=1^-$, $T=1/2$	$J^p=0^-$, $T=3/2$



B. E. (Λ_c^*-N) = 42 ~ 0.5 MeV
$\Gamma(\pi Y_c)$ = 38 ~ 22 MeV

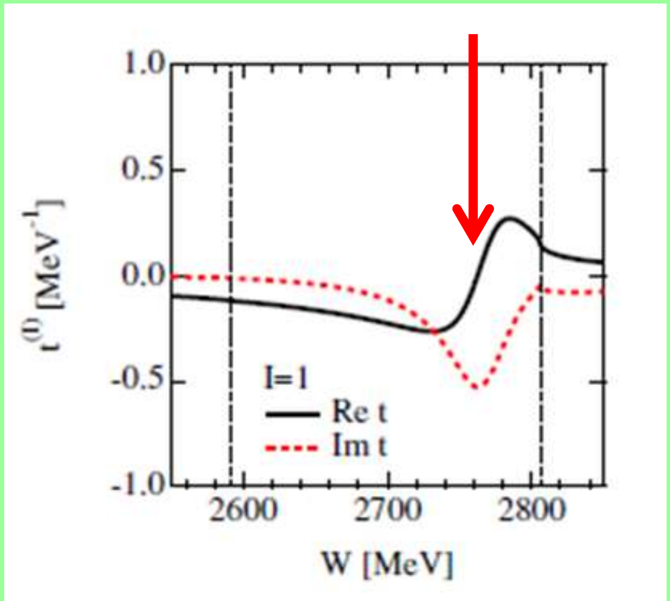
DNN ($J^{\pi}=0^{-}$, $T=3/2$)

According to the vector-meson exchange picture potential…

I=0 DN potential:
Strongly attractive to generate $\Lambda_c(2595)$

I=1 DN potential:
Mildly attractive to generate a resonance at 2766 MeV
"Σ_c^*" (?)

Assume Iso-symmetric cutoff



→

DNN ($S_{NN}=0$, $T=3/2$)

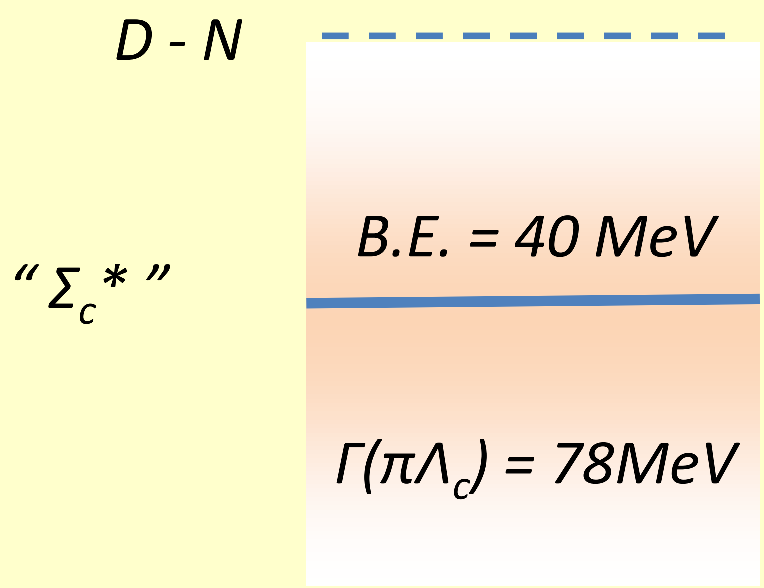
$$V_{DN} = v_{DN}(I=1)$$

Interesting state?
D^0nn or D^+pp

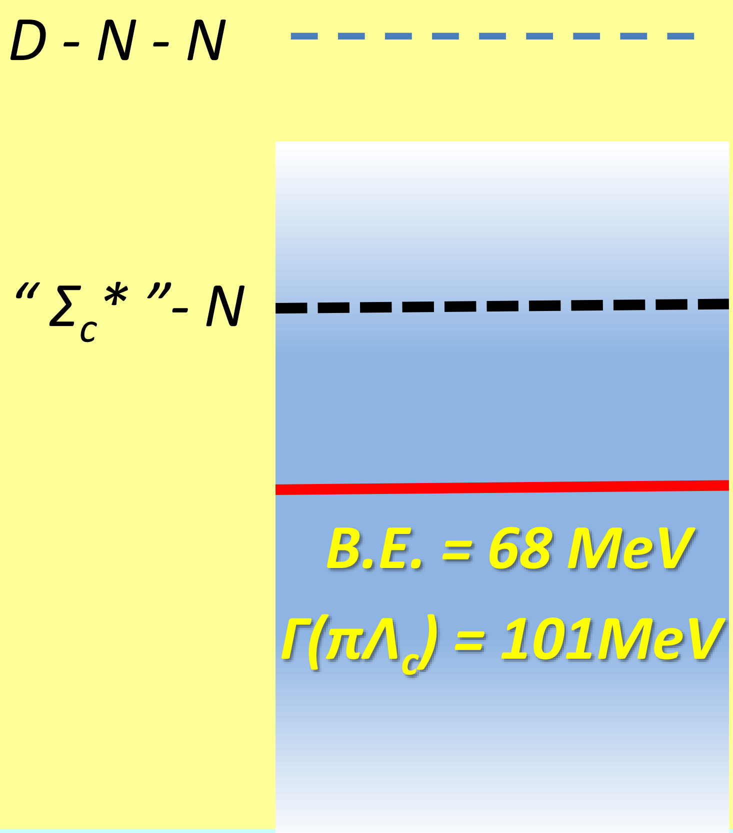
DNN ($J^{\pi}=0^{-}$, $T=3/2$)

NN pot: HN1R
DN pot. : b=0.40fm,
B(D)= 39.9MeV

"$\Sigma_c(2766)$" … DN (I=1)



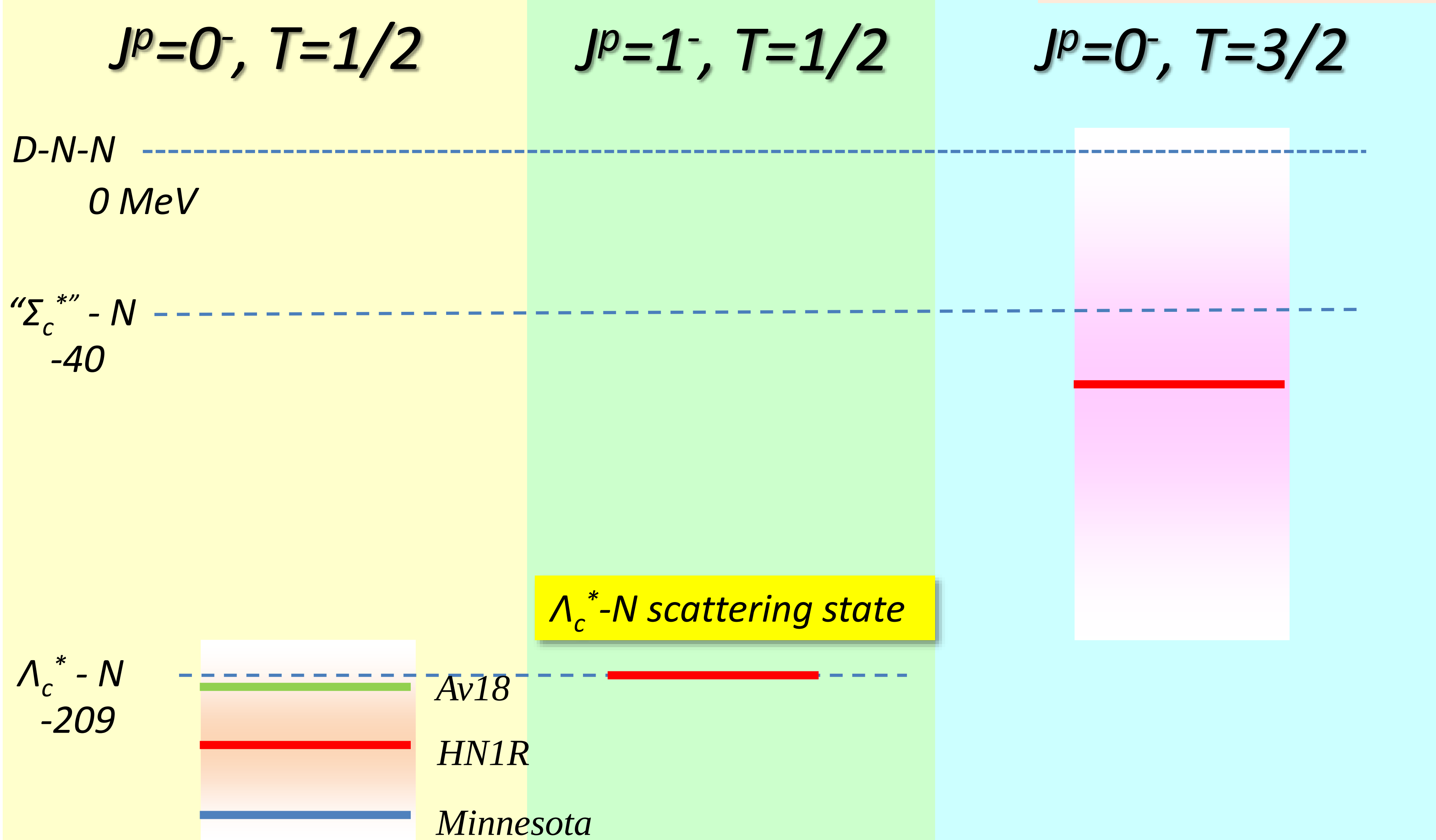
DNN ($S_{NN}=0$, $T=3/2$)



- Bound below "Σ_c*"- N threshold by ~30MeV
- Large decay width

Binding energy and decay width

DN pot. : b=0.40fm,
B(D)=208.9MeV (T=1/2)
B(D)= 39.9MeV (T=3/2)

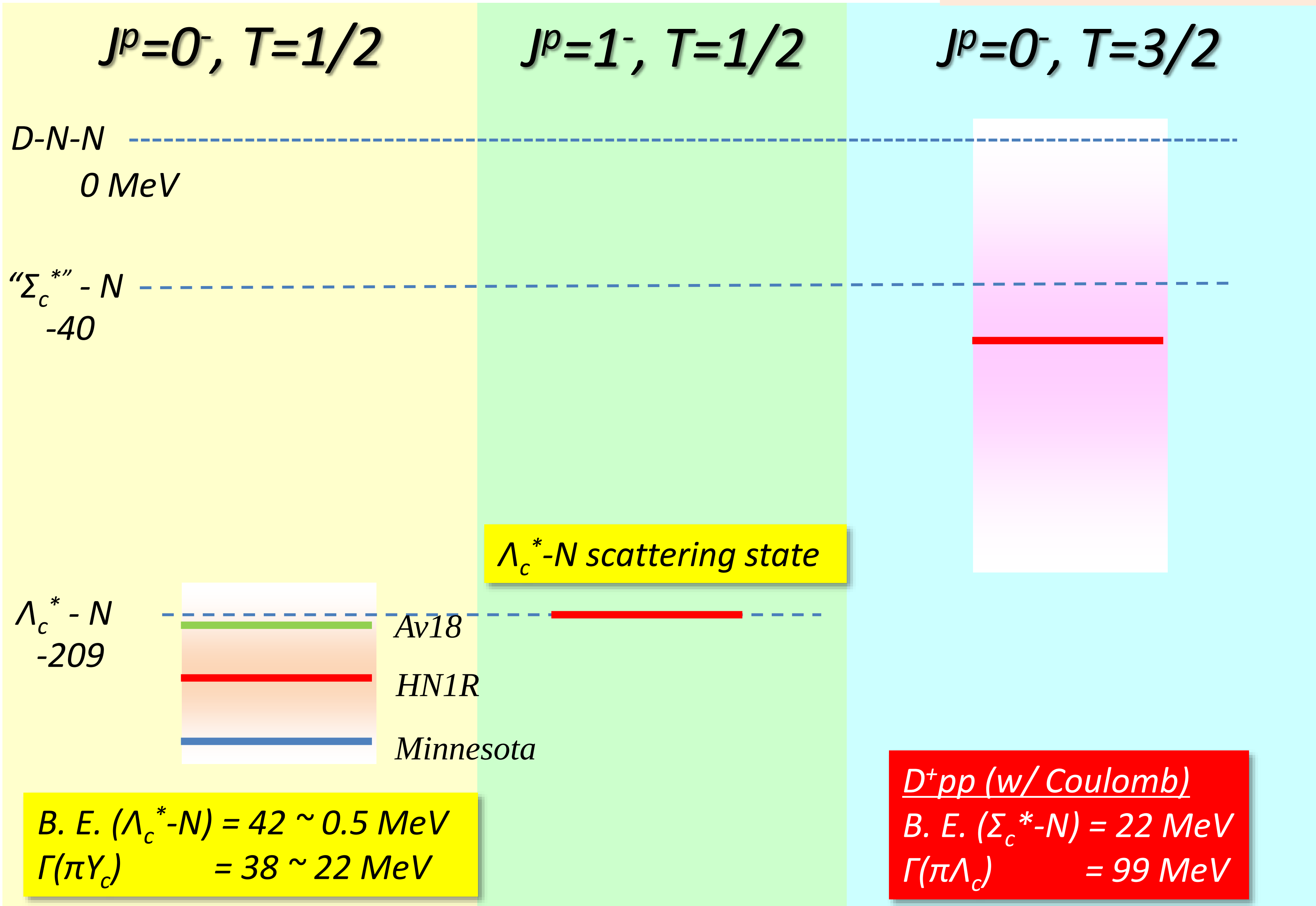


B. E. (Λ_c^*-N) = 42 ~ 0.5 MeV
$\Gamma(\pi Y_c)$ = 38 ~ 22 MeV

B. E. (Σ_c^*-N) = 28 MeV
$\Gamma(\pi \Lambda_c)$ = 101 MeV

Binding energy and decay width

DN pot. : b=0.40fm,
B(D)=208.9MeV (T=1/2)
B(D)= 39.9MeV (T=3/2)



3. Result

Structure of DNN

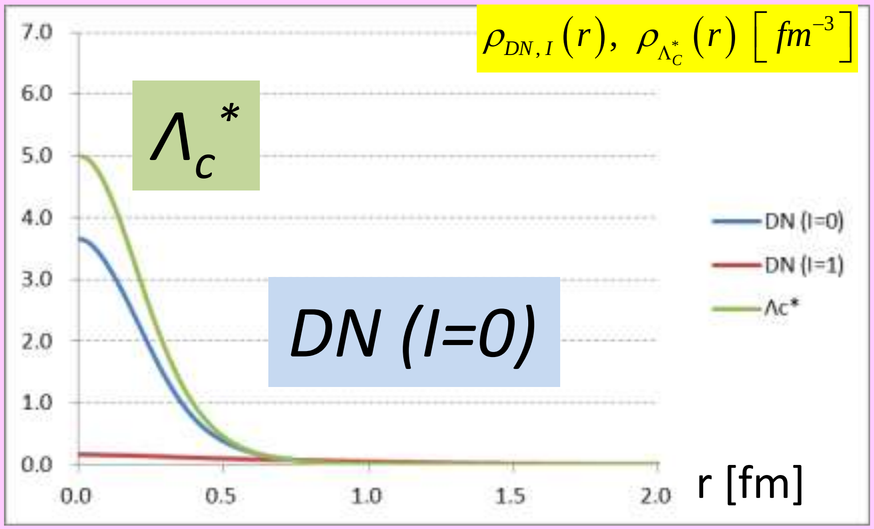
$J^{\pi}=0^{-}$, $T=1/2$

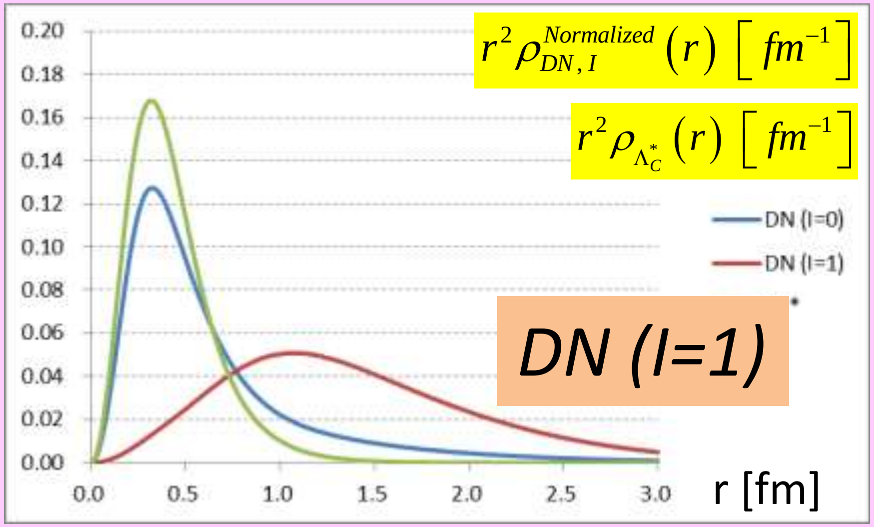
Structure of DNN (S=0)

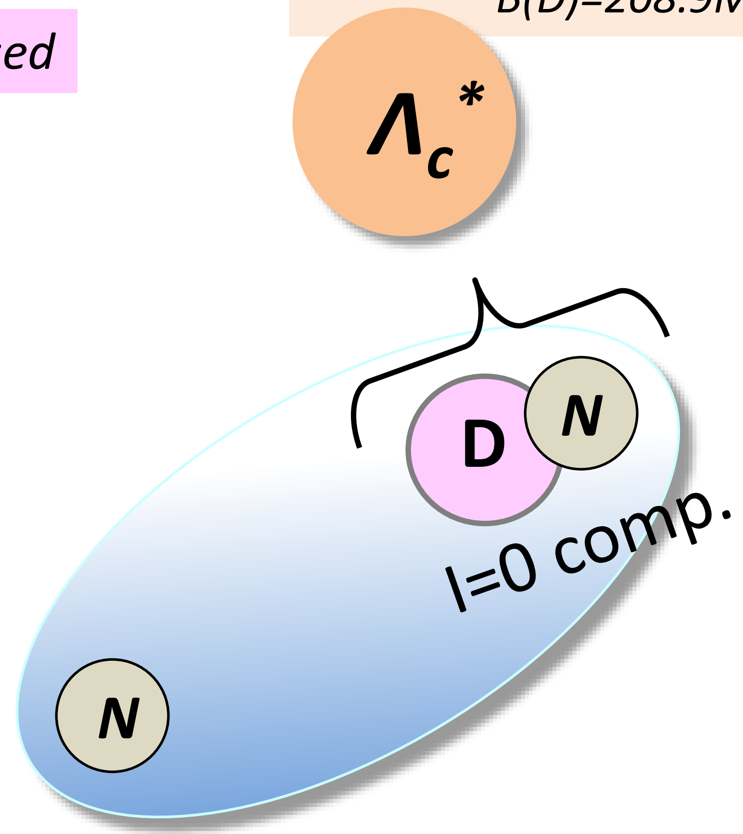
NN pot: HN1R
DN pot. : b=0.40fm, B(D)=208.9MeV

DN correlation density

Isospin-decomposed





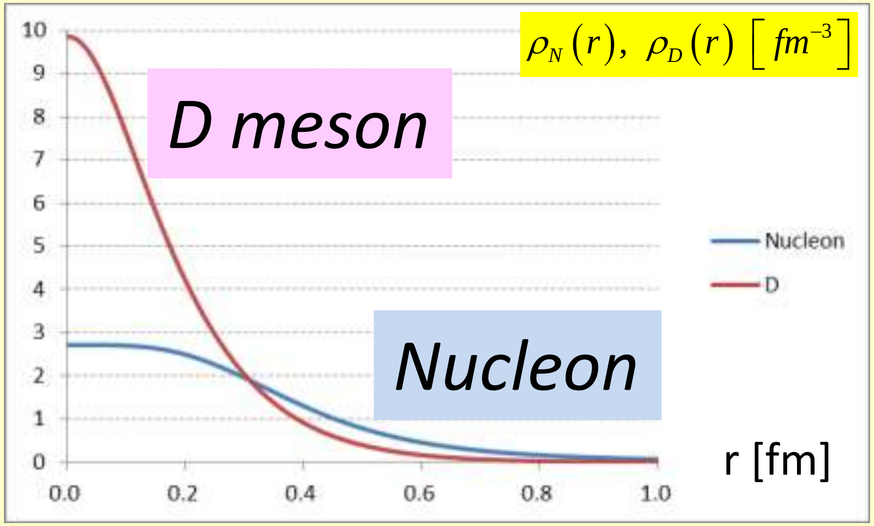


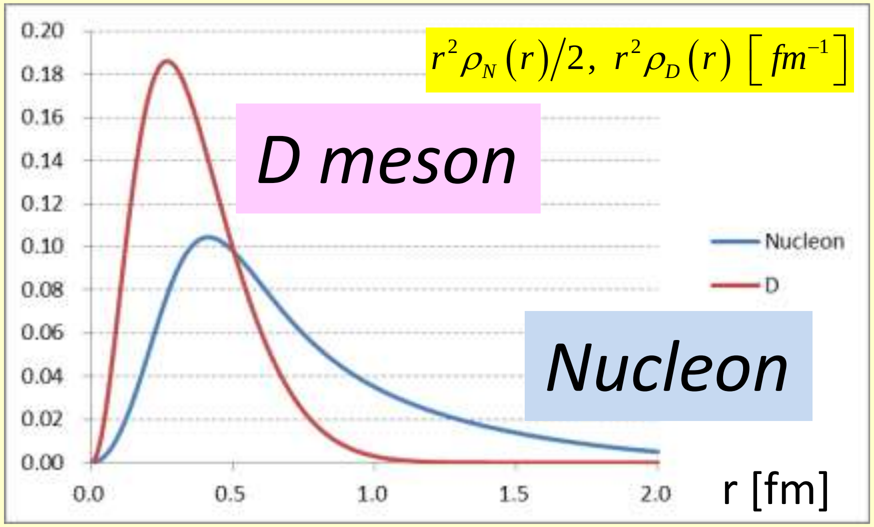
- The distribution of the I=0 DN component in DNN (S=0) system is similar to that of **the DN forms Λc***. (Similar to K^{bar}NN case)

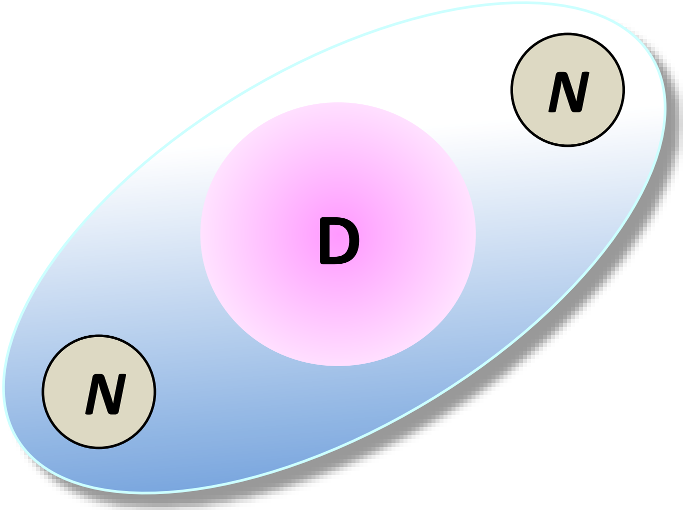
Structure of DNN (S=0)

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

One-body density







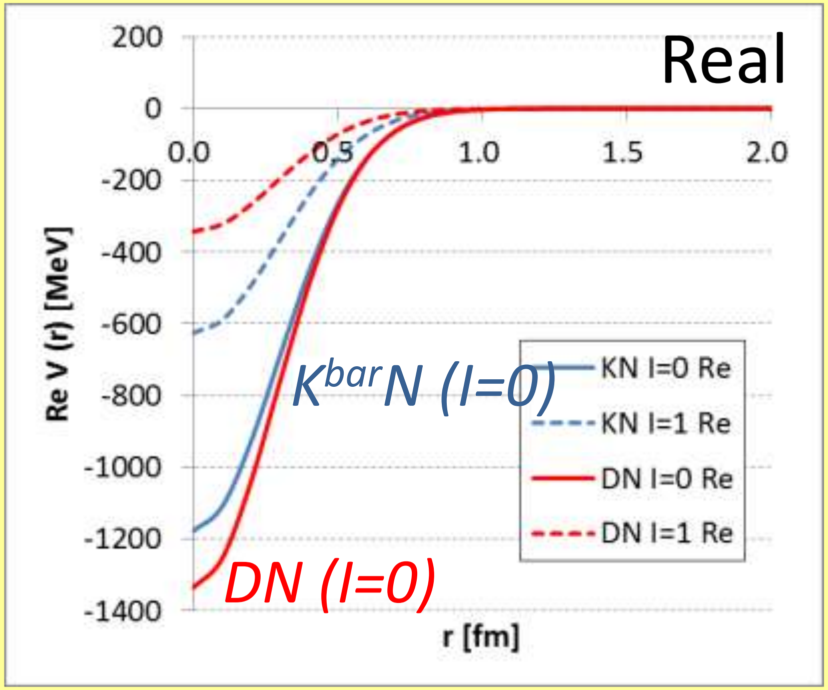
D meson distributes compactly inside of the system.

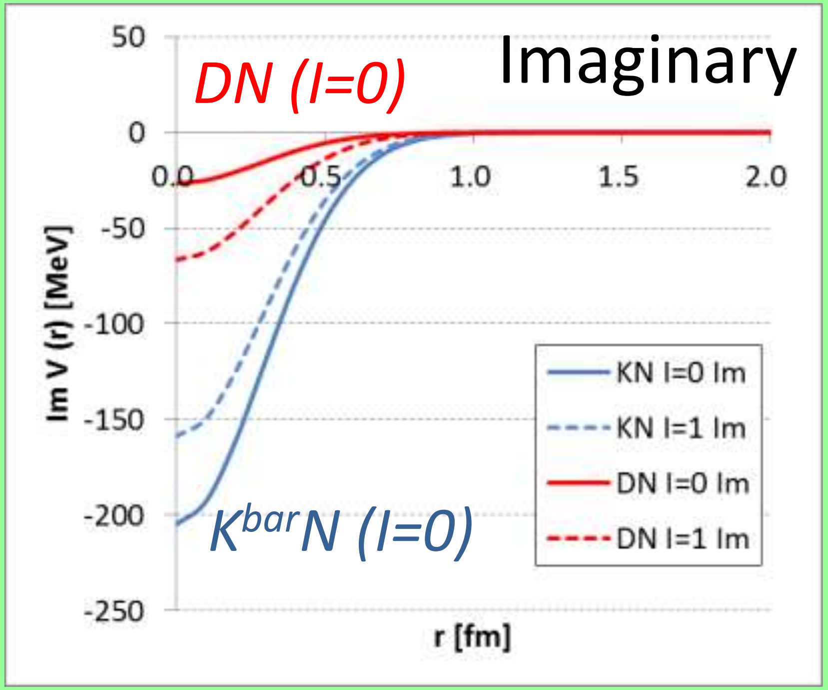
4. Comparison with strangeness sector

DNN vs $K^{bar}NN$

Potential at I=0 resonance

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





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*	*B.E. not so increase.* *Total B.E. = 40 MeV* *Γ = 11 MeV* *Γ decreases.*
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	*Total B.E. = 187 MeV* *Γ = 180*	***DNN*** *Total B.E. = 225 MeV*

B.E. drastically increases.

Suppression of kinetic energy due to large mass of D meson

5. Summary and Future plan

5. Summary

DNN system studied with a variational approach

DN pot.: Vector-meson exchange picture potential, $\Lambda_c(2595)$ = DN q.b.s
NN pot.: Av18, Hasegawa-Nagata No.1 (R), Minnesota

DNN ($J^\pi=0^-$, T=1/2) … bound below $\Lambda_c(2595)$-N threshold

- *Total B. E. ~ 225 MeV (~15MeV below $\Lambda_c(2595)$-N threshold)*
- *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 ($J^\pi=1^-$, T=1/2) … scattering state of $\Lambda_c(2595)$-N

DNN ($J^\pi=0^-$, T=3/2) … bound below "Σ_c"-N threshold*

- *Total B. E. ~ 70 MeV (60 MeV w/ Coulomb)*
- *Decay width ($\pi\Lambda_c$) ~ 100 MeV*

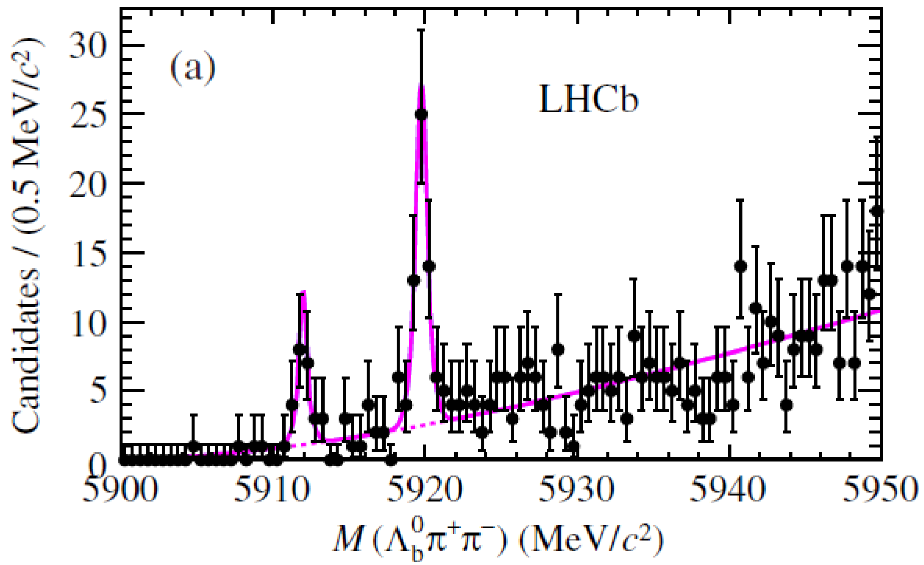
but large width

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

5. Future plan

How is the bottom sector?

LHCb reported excited Λ_b's.



$$M_{\Lambda_b^{*0}(5912)} = 5911.97 \pm 0.12 \pm 0.02 \pm 0.66\ \mathrm{MeV}/c^2,$$
$$M_{\Lambda_b^{*0}(5920)} = 5919.77 \pm 0.08 \pm 0.02 \pm 0.66\ \mathrm{MeV}/c^2,$$

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

$\Lambda_b^0(5912)$ ~ $B^{bar}N$ q.b.s?

→ *How is $B^{bar}NN$??*

Need more information of excited charmed baryons!

Isospin?
Spin??
Parity???

Belle! J-PARC !?
Lattice QCD ??

Thank you for your attention!