Energy and width of a narrow I=1/2 DNN quasibound state


Tetsuo Hyodo

Tokyo Institute of Technology

with M. Bayar, C.W. Xiao, A. Dote, M. Oka, E. Oset

supported by Global Center of Excellence Program
"Nanoscience and Quantum Physics"

2012, Dec. 17th

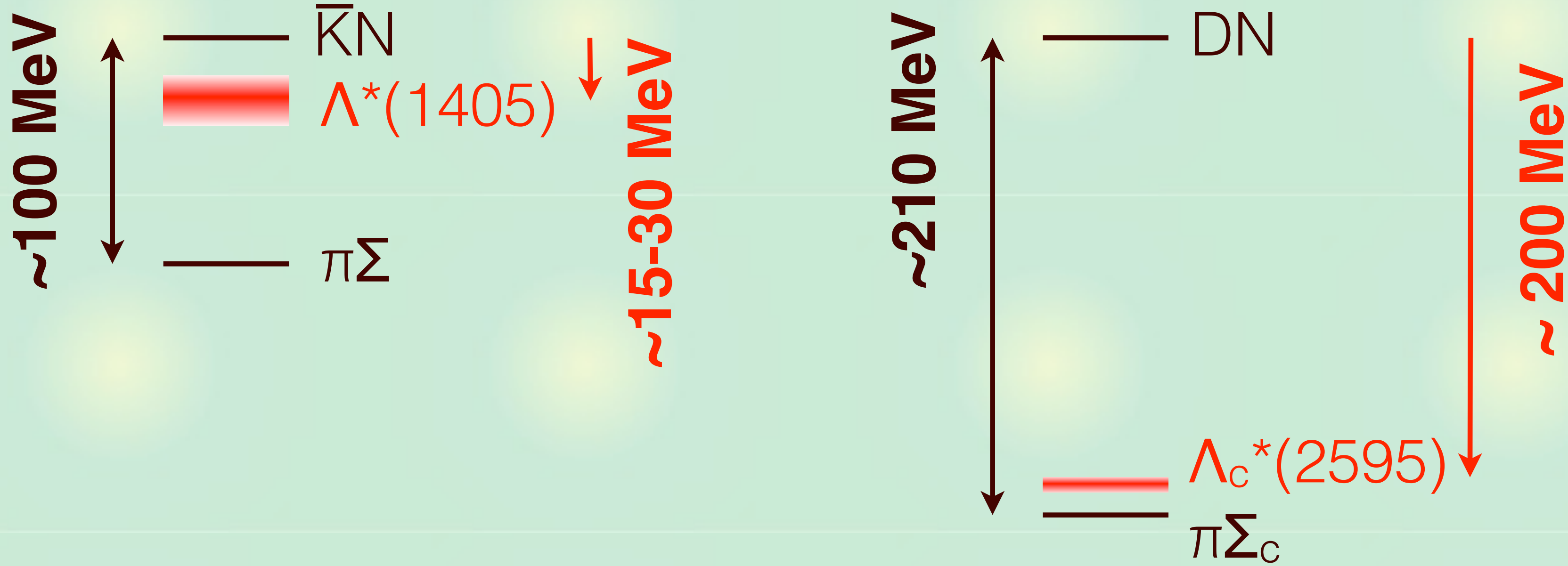
Contents

Why DN **and** DNN**?**

$\bar{K}$ **nuclei <-- Λ^*: a $\bar{K}N$ bound state in the $\pi\Sigma$ continuum**

D **nuclei? <-- Λ_c^*: a DN bound state in the $\pi\Sigma_c$ continuum**

Comparison with $\bar{K}N$ system in I=0 channel



- narrow negative parity Λ_c^*, analogous to $\Lambda(1405)$?

(conventional view : Λ_c^* ~ 3-quark state
200 MeV binding : too large?)

DN bound state picture ?

Can Λ_c^* (with large binding) be a DN quasi-bound state?

- **Vector meson exchange picture leads to a stronger DN interaction than $\bar{K}N$ (at threshold)**

$$\frac{V_D}{V_K} = \frac{m_D}{m_K} \sim 3.8$$

(next slide)

- **D (1867 MeV) is heavier than $\bar{K}$ (496 MeV).**
  Kinetic energy is suppressed.
  If the DN interaction were the same with $\bar{K}N$, system would develop a deeper quasi-bound state.

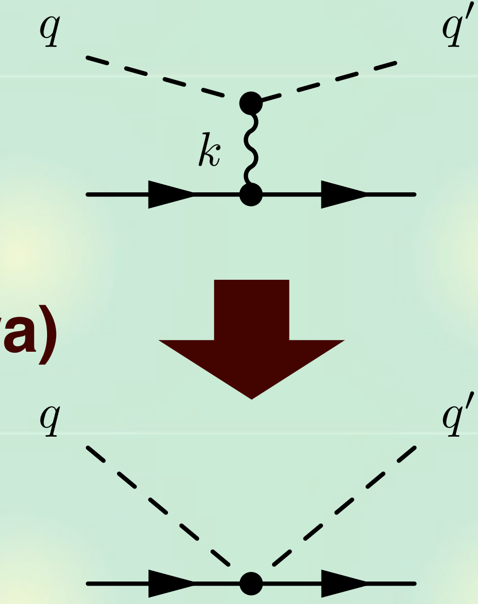
DN **system can generate a strongly bound state: Λ_c^*.**

$$B_{DN} > B_{\bar{K}N} = 15\text{-}30 \text{ MeV}$$

Vector meson exchange for DN

DN ($\bar{K}$N) interaction in vector meson exchange (low energy)

$$V \sim g\bar{u}\gamma^{\mu}u \times \frac{1}{k^2 - m_v^2}\left[g_{\mu\nu} - \frac{k_\mu k_\nu}{m_v^2}\right] \times g(q+q')^{\nu}$$



- k << m_v + KSRF relation

$$\rightarrow -\frac{1}{2f^2}(q^0 + q^{0\prime})$$ **(Weinberg-Tomozawa)**

- at threshold

$$\rightarrow -\frac{m}{f^2} \quad \text{(at threshold)}$$

Interaction in DN-$\pi\Sigma_c$ system (J/Ψ exchange ignored)

$$V \sim \begin{pmatrix} -3m_D & \sqrt{\frac{3}{2}}\kappa_c \frac{m_D+m_\pi}{2} \\ \sqrt{\frac{3}{2}}\kappa_c \frac{m_D+m_\pi}{2} & -4m_\pi \end{pmatrix}$$

$$\kappa_c \sim \frac{m_{K^*}^2}{m_{D^*}^2} \sim \frac{1}{4}$$

- strong DN interaction --> large binding energy

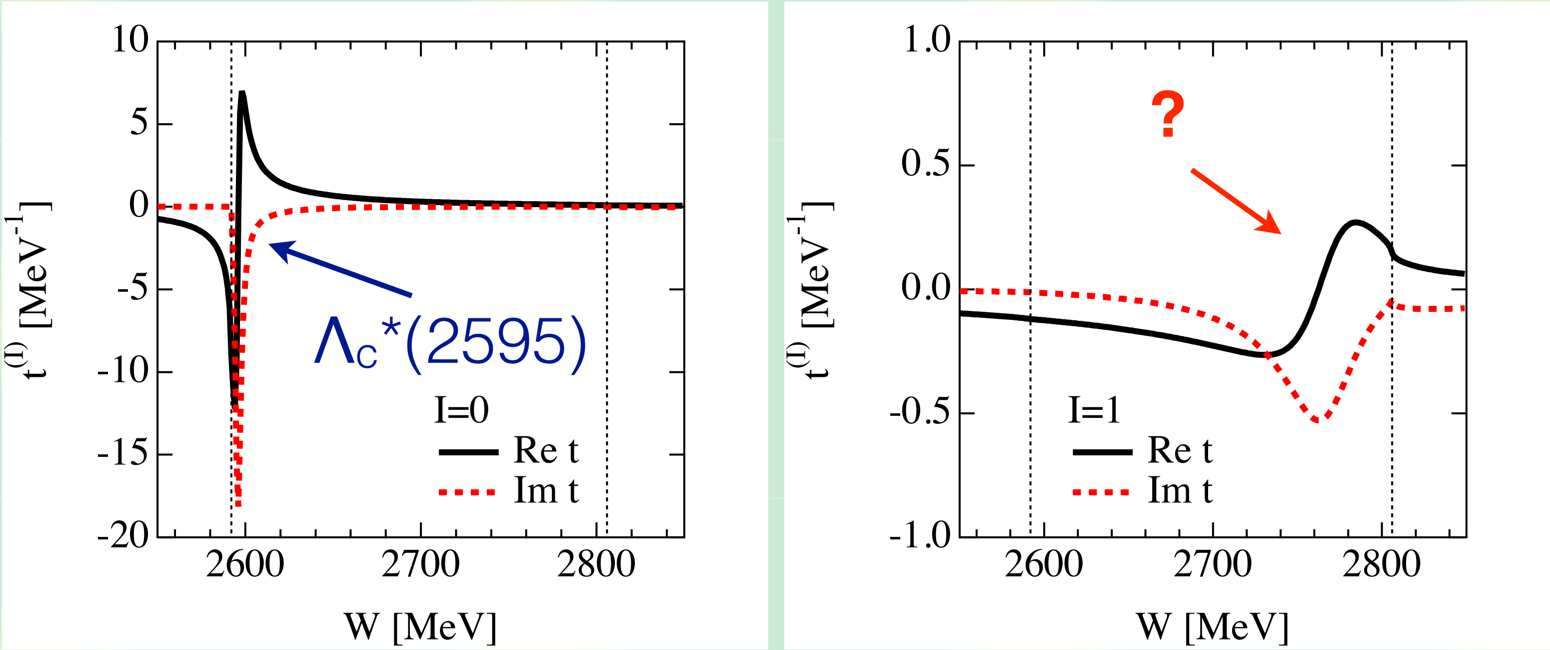
- suppressed off-diagonal coupling --> narrow width of Λ_c^*

DN scattering amplitude

Coupled-channel DN ($\pi\Sigma_c$, $\eta\Lambda_c$, $K\Xi_c$, $K\Xi_c'$, $D_s\Lambda$, $\eta'\Lambda_c$) **scattering**

see T. Mizutani, A. Ramos, Phys. Rev. C74, 065201 (2006)

Subtraction constants (cutoff parameters) are chosen to reproduce Λ_c^* in I=0. Apply the same constants to I=1.



A resonance at ~ 2760 MeV is generated in I=1 channel.

c.f. PDG 1*: $\Lambda_c(2765)$ or $\Sigma_c(2765)$??

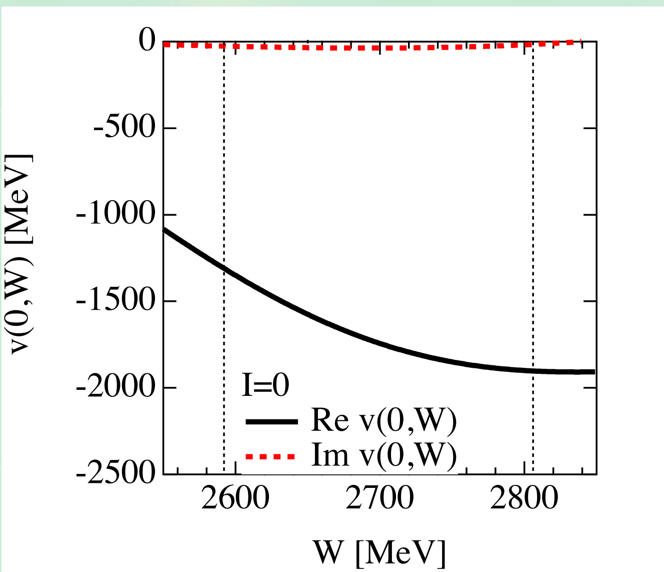
DN **local potential**

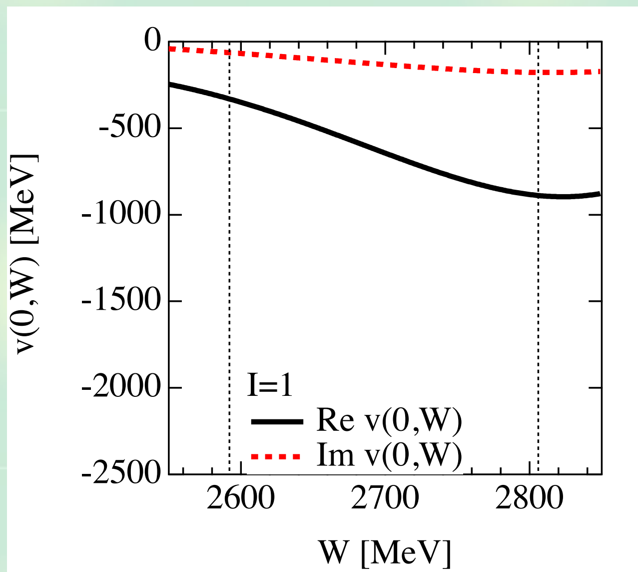
Equivalent single-channel local potential

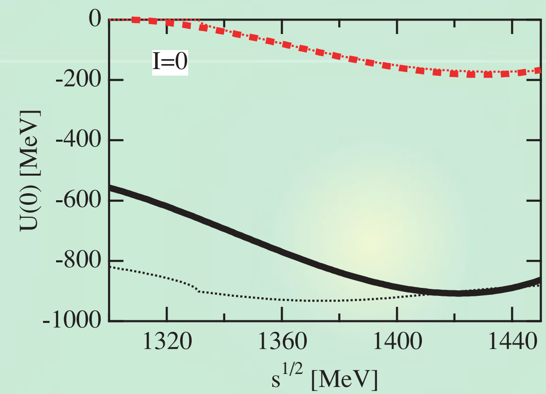
T. Hyodo, W. Weise, Phys. Rev. C77, 035204 (2008)

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

- reproduces the coupled channel amplitude







c.f. $\bar{K}$N case

- This potential reproduces the DN **amplitude in CC model.**

- Larger (smaller) real (imaginary) part than $\bar{K}$N

Strategy for DNN bound state

Coupled-channel model
DN **amplitude,** $\Lambda_c(2595)$

DN **single-channel potential**

real part

Three-body variational calculation

- **Structure from wave function**
- NN **dynamics is dynamically solved.**

Assume NN **distribution**

Fixed-center approximation to Faddeev equation

- **Two-body absorption**
- **Imaginary part of the amplitude is treated.**

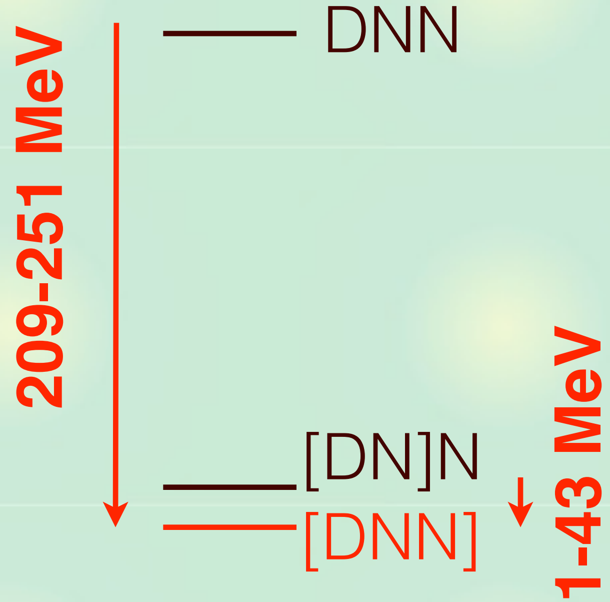
Coupled-channel ($\pi Y_c N$**) effect is partly included.**

Variational calculation: results

Results of the DNN system

- J=0 **bound,** J=1 **unbound w.r.t.** [DN]N
- **mesonic decay width is small**
- **softer the core, larger the binding**

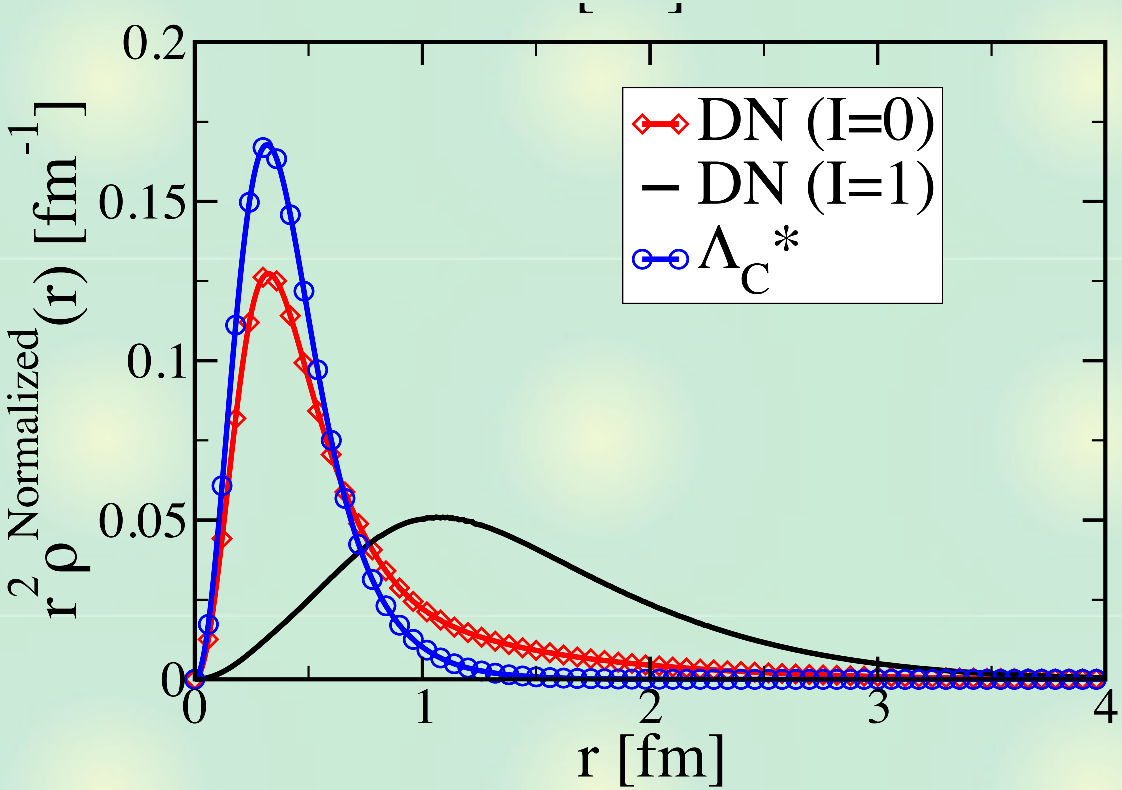
	HN1R		Minnesota	Av18
	$J=1$	$J=0$	$J=0$	$J=0$
	unbound	bound	bound	bound
B	208	225	251	209
M_B	3537	3520	3494	3536
$\Gamma_{\pi Y_c N}$	-	26	38	22
$E_{\rm kin}$	338	352	438	335
$V(NN)$	0	-2	19	-5
$V(DN)$	-546	-575	-708	-540
$T_{\rm nuc}$	113	126	162	117
E_{NN}	113	124	181	113
P(Odd)	75.0 %	14.4 %	7.4 %	18.9 %

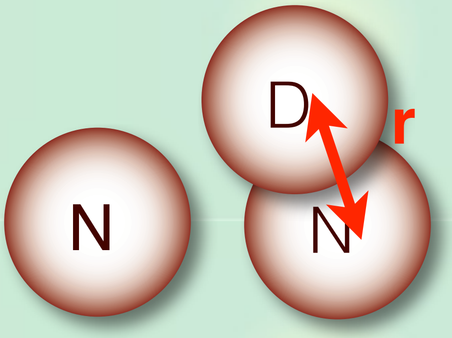


Variational calculation: DN correlation

Isospin decomposition of DN two-body correlation

$$\rho_{DN}(r) = \langle\Psi|\sum_{i=1,2}\delta^3(|\boldsymbol{r}_D - \boldsymbol{r}_i| - r)|\Psi\rangle$$

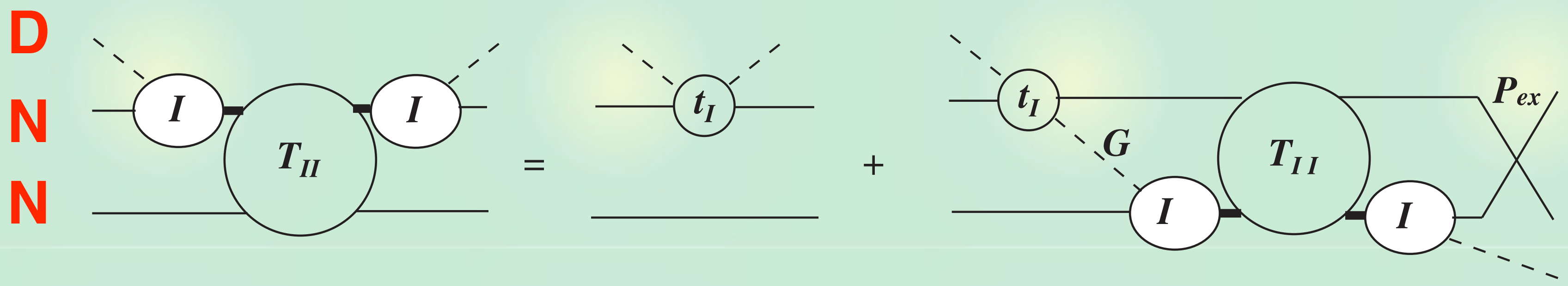




DN (I=0) **correlation is similar to** Λ_c*

FCA calculation

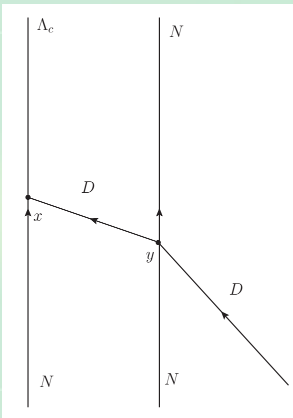
Fixed-center approximation to Faddeev equation

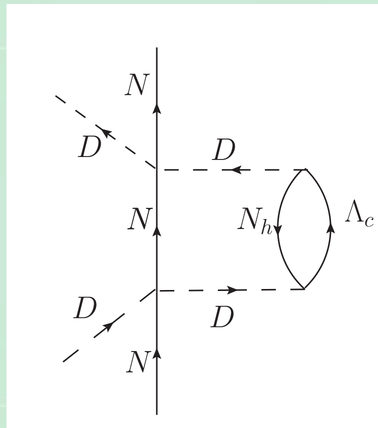


- **Complex** DN **amplitude**
- **all two-body pairs are in s-wave**
- NN **distribution is assumed**
  (checked with the variational calculation result)

FCA calculation: two-body absorption

Two-body absorption --> imaginary part of DN amplitude

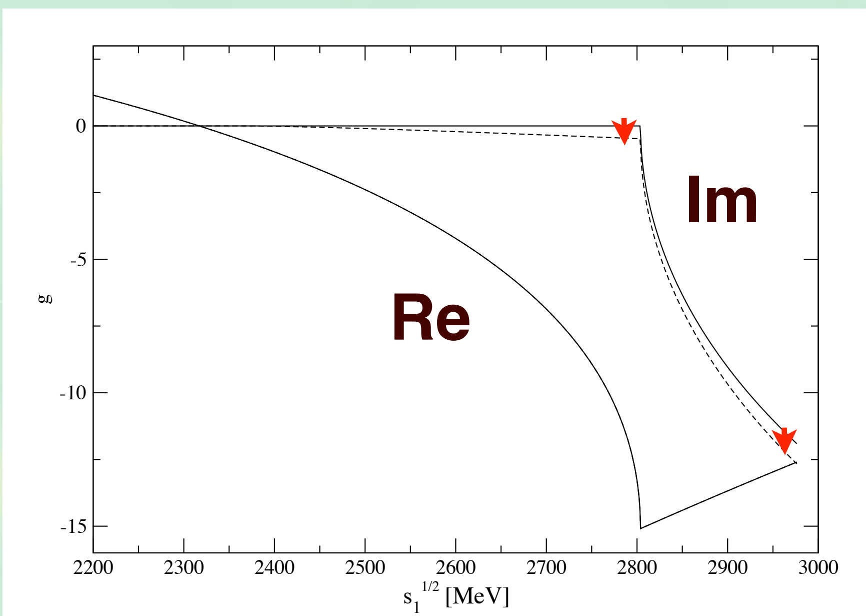




$$g_{DN} \rightarrow g_{DN} + i \, \boxed{\mathrm{Im} \; \delta\tilde{g}}$$

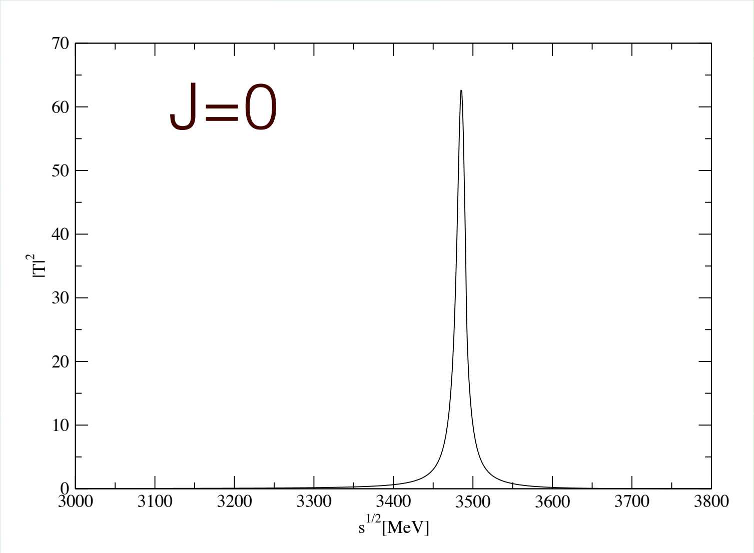
DN **loop**

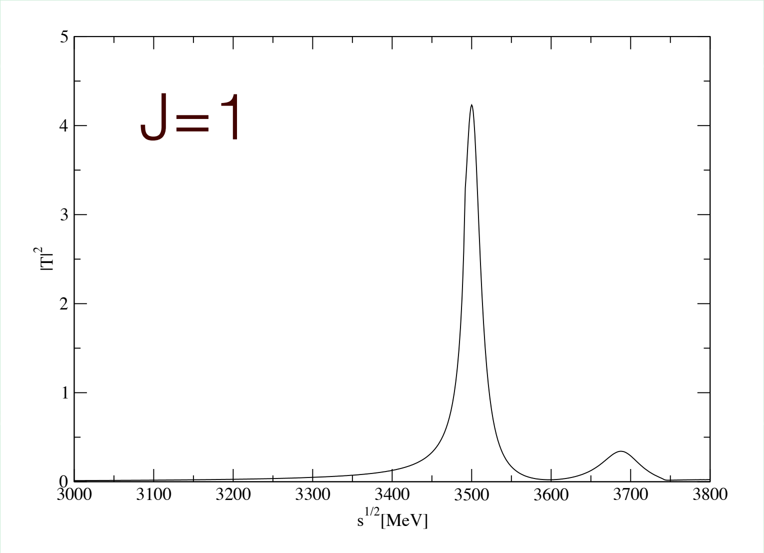
two-body absorption contribution



FCA calculation: result

Magnitude of the three-body amplitude square





J=0 **channel: M ~ 3500 MeV**

- strong signal, consistent with the variational calculation

J=1 **channel: M ~ 3500 MeV and M ~ 3700 MeV?**

- week signal, not found in the variational calculation??

- I=1 DN **interaction is important for this channel.**

Possible experiments

Antiproton beam

$$\bar{p} + {}^3\,\mathrm{He} \to \bar{D}^0 D^0 np \to \bar{D}^0 [DNN]^+$$

- PANDA?

Pion beam

$$\pi^- + d \to D^- D^+ np \to D^- [DNN]^+$$

$$\pi^- + d \to D^- \Lambda_c^{*+} n \to D^- [DNN]^+$$

- J-PARC high momentum beamline?

Heavy Ion collision

Coalescence DNN **(large binding),** Λ_c*N **(small binding)**

- RHIC, LHC,...

S. Cho, *et al*, Phys. Rev. Lett. 106, 212001 (2011); Phys. Rev. C 84, 064910 (2011)

Summary

We study DN interaction and DNN system

- DN **interaction is constructed by regarding** Λ_c^* **as "**DN **quasi-bound state".**

- **A narrow** DNN **quasi-bound state in spin** J=0 **and isospin** I=1/2 **channel.**

  B_{DNN} **~ 250 MeV,** $B_{\Lambda_c^* N}$ **~ 40 MeV**

  Γ **~ 20-40 MeV**

- DN **forms a compact cluster, but** Λ_c^*N **bounds loosely.**

M. Bayar *et al.*, Phys. Rev. C 86, 044004 (2012)