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

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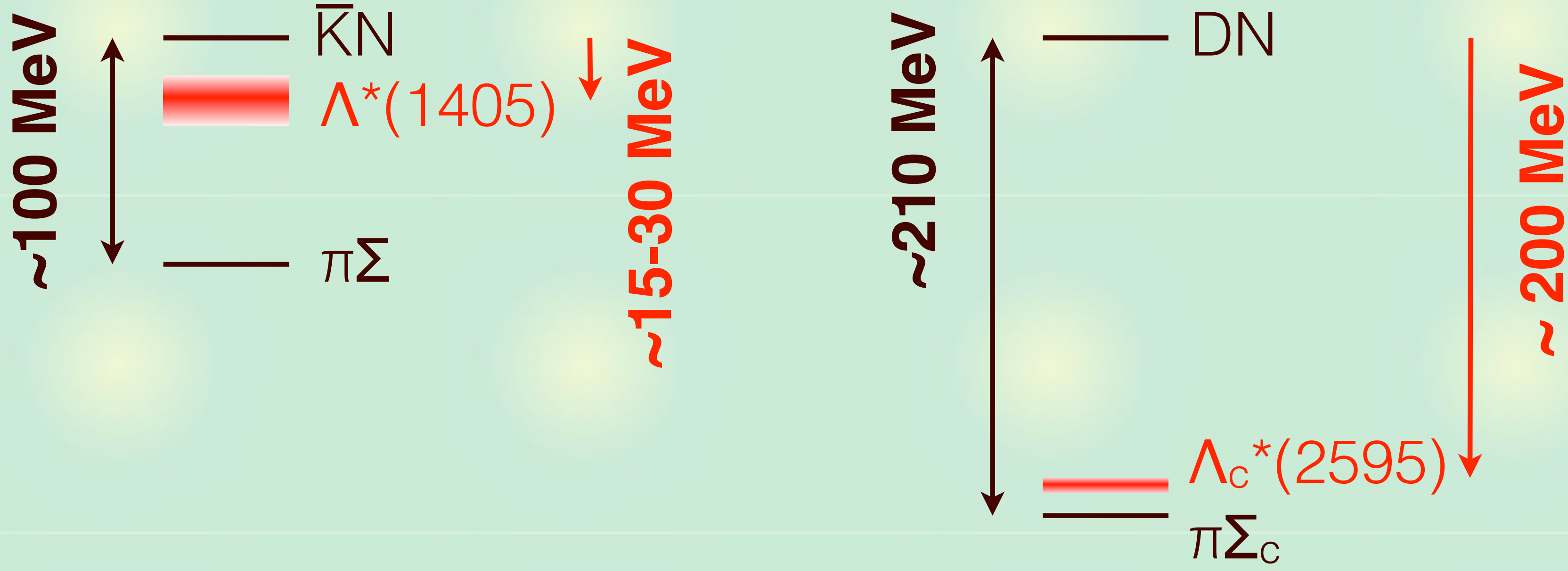
Contents

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.

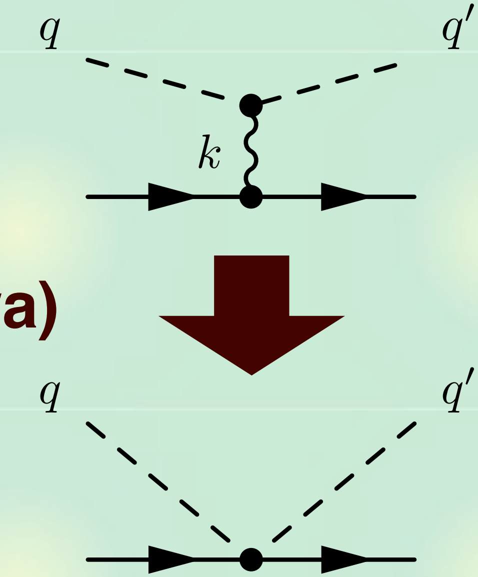
DN **system can generate a strongly bound state: Λ_c^*.**

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

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)

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

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

- strong DN interaction --> large binding energy

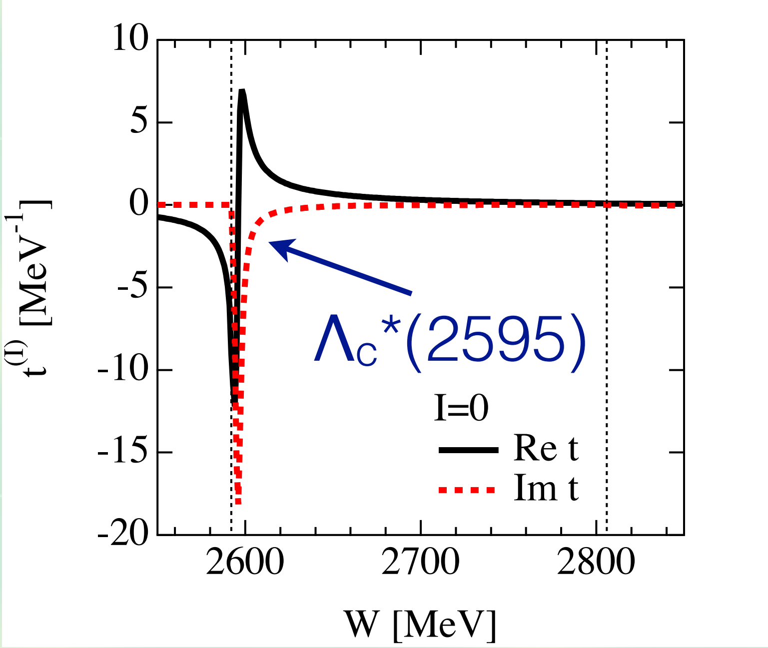
- suppressed off-diagonal coupling --> narrow width of Λ_c^*

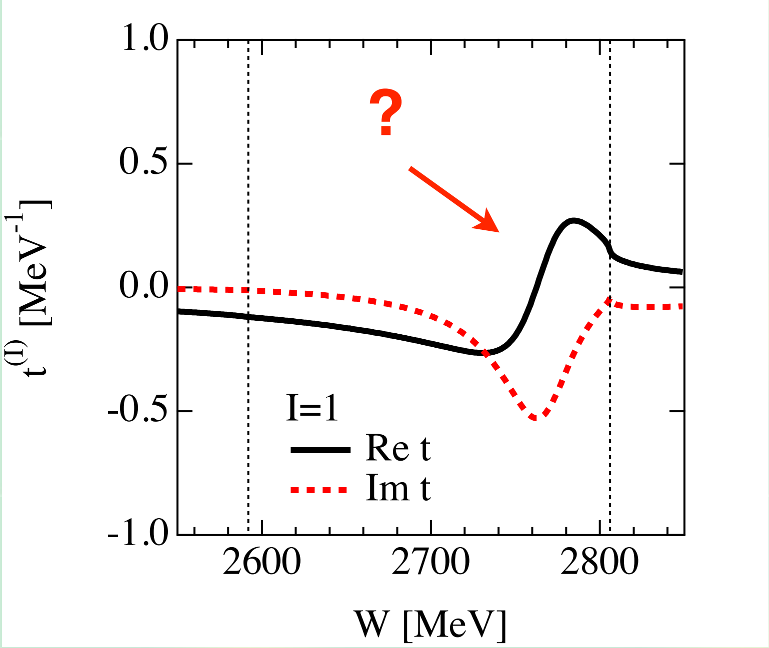
DN scattering amplitude

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** $\Sigma_c(2765)$ **??**

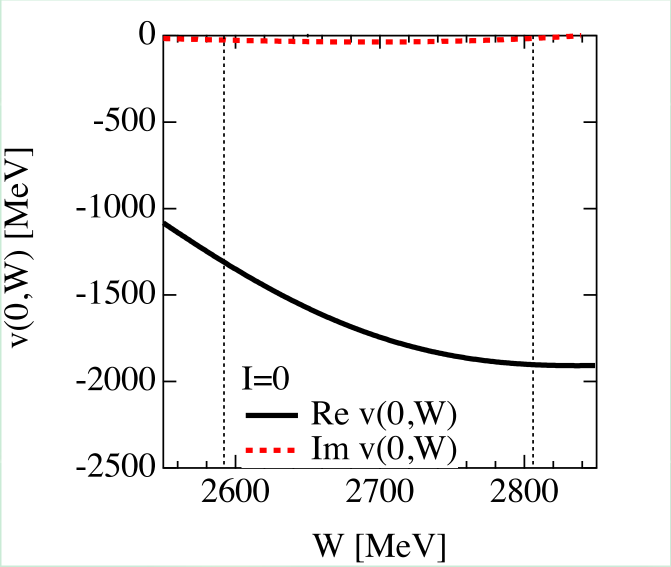
DN local potential

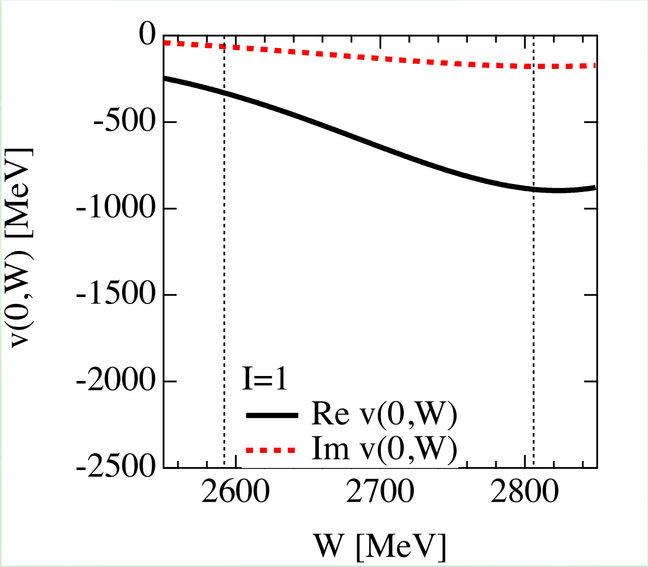
Equivalent single-channel local potential

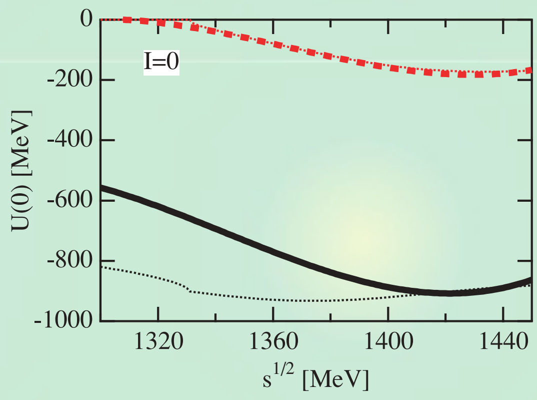
T. Hyodo, W. Weise, Phys. Rev. C77, 035204 (2008)

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

- reproduces the coupled channel amplitude







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

- This potential reproduces the DN amplitude in CC model.

- Larger (smaller) real (imaginary) part than $\bar{\mathrm{K}}$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.**

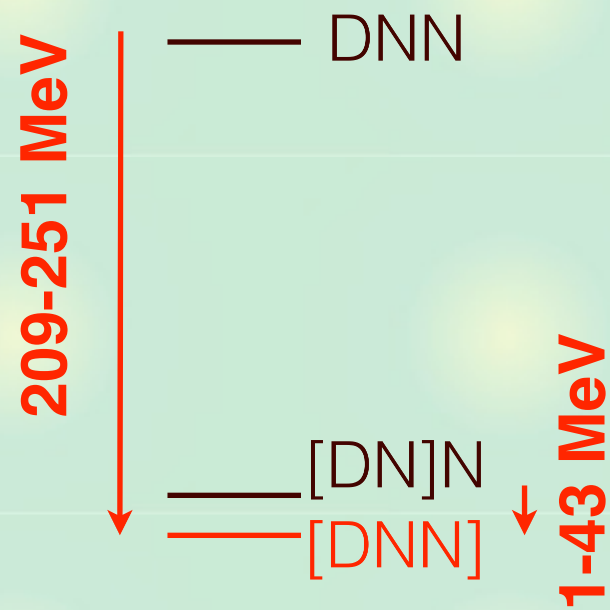
Coupled-channel ($\pi Y_c N$**) effect is partly included.**

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**

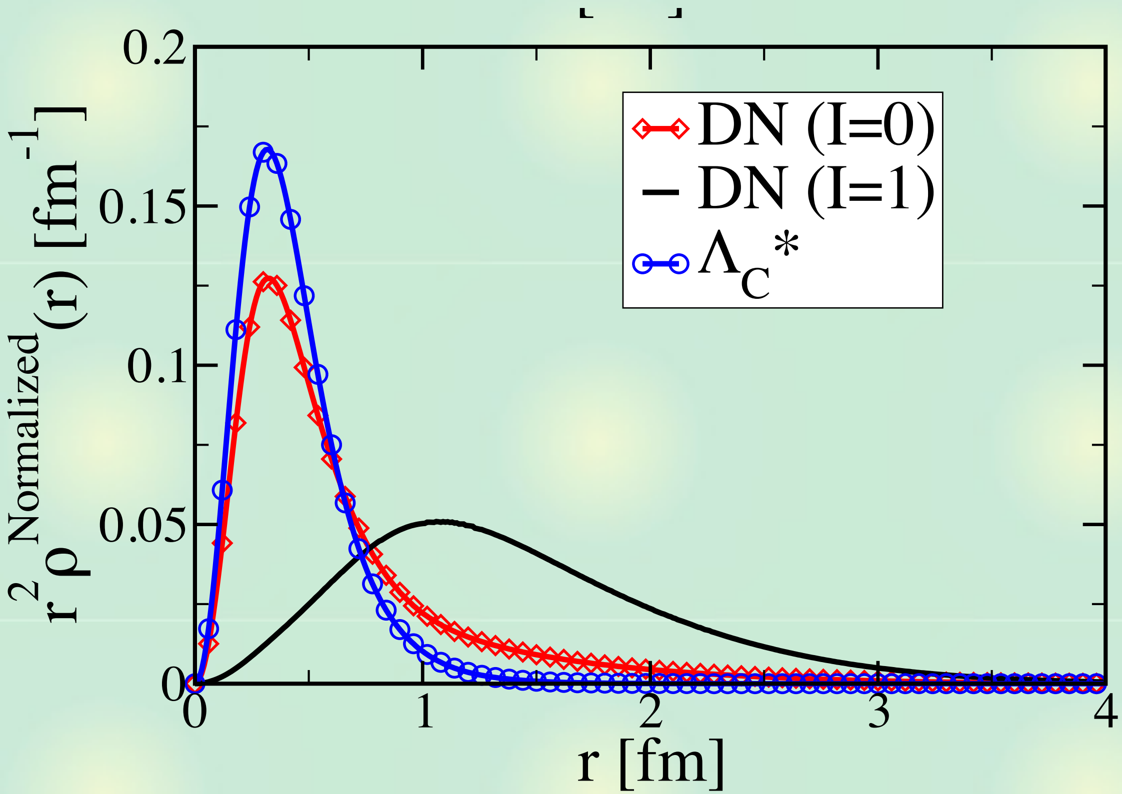
	HN1R		Minnesota	Av18
	$J=1$	$J=0$	$J=0$	$J=0$
	unbound	bound	bound	bound
B	208	225	251	209
M_B	3537	3520	3494	3536
$\Gamma_{\pi Y_c N}$	-	26	38	22
$E_{\rm kin}$	338	352	438	335
$V(NN)$	0	-2	19	-5
$V(DN)$	-546	-575	-708	-540
$T_{\rm nuc}$	113	126	162	117
E_{NN}	113	124	181	113
$P(\mathrm{Odd})$	75.0 %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

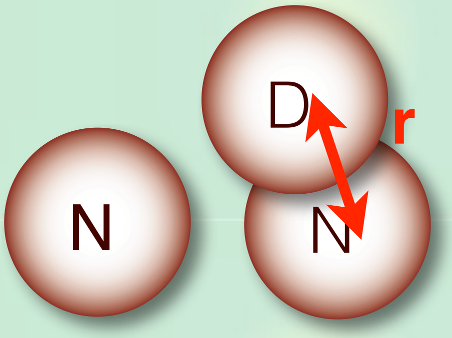


Variational calculation: DN correlation

Isospin decomposition of DN two-body correlation

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

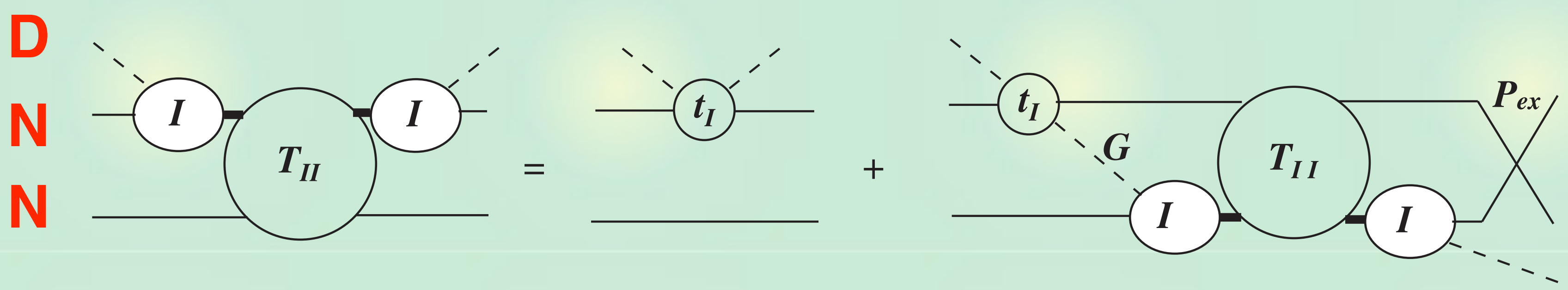




DN (I=0) correlation is similar to Λ_c^*

FCA calculation

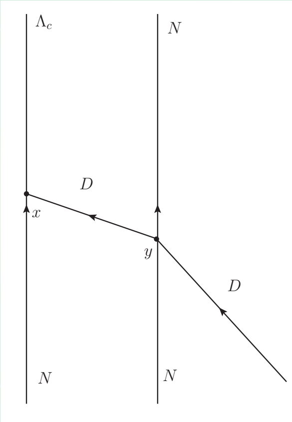
Fixed-center approximation to Faddeev equation

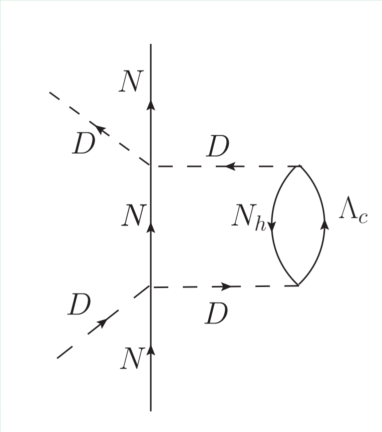


- **Complex** DN **amplitude**
- **all two-body pairs are in s-wave**
- NN **distribution is assumed**
  (checked with the variational calculation result)

FCA calculation: two-body absorption

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

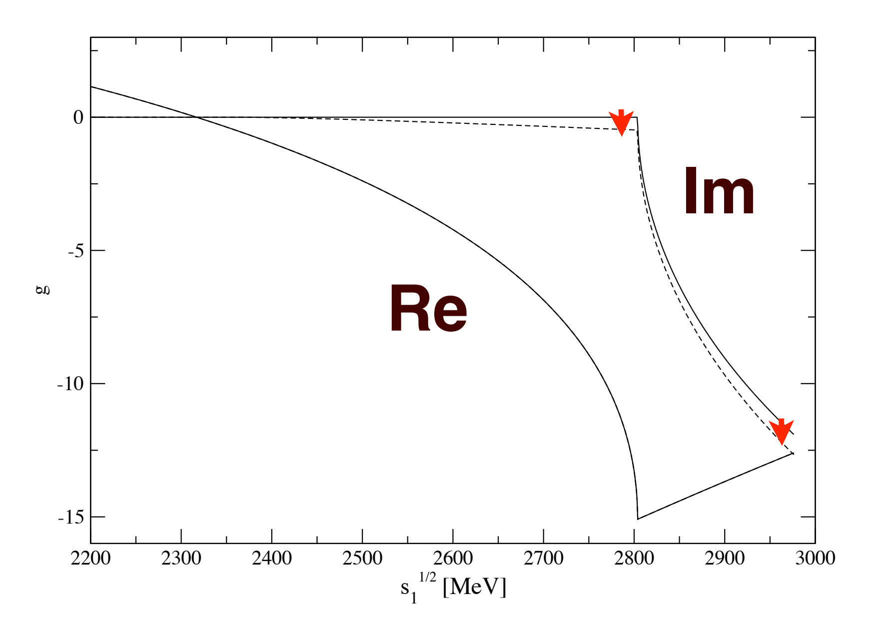




$$g_{DN} \to g_{DN} + i\,\boxed{\mathrm{Im}\ \delta\tilde{g}}$$

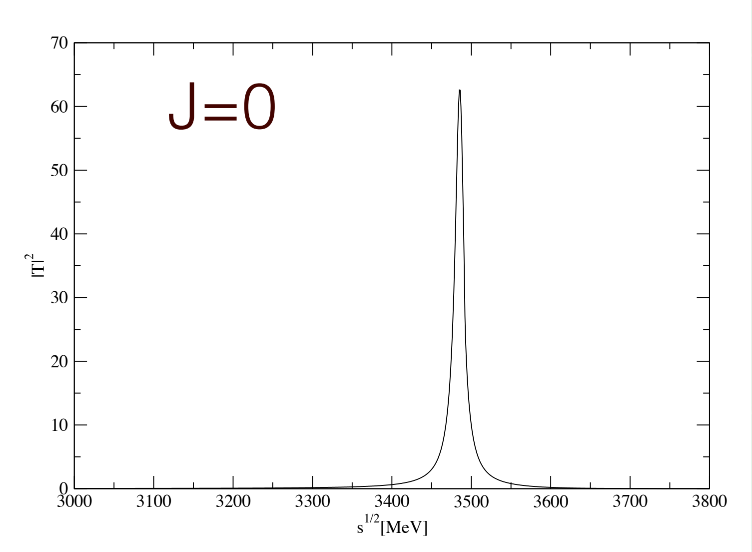
DN **loop**

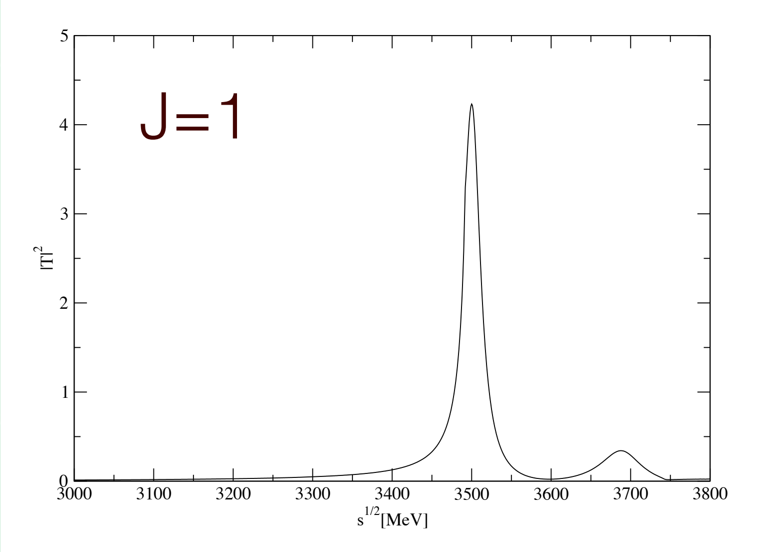
two-body absorption contribution



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)