Structure and formation spectra of Dbar meson-nucleus systems

Junko Yamagata-Sekihara
(Nara Women's Univ.)

Collaborator :
L. Tolos (Barcelona Univ.)
J. Nieves (IFIC, Valencia Univ.)
C. Garcia-Recio (Granada Univ.)

Contents

Introduction

- **Meson-Nucleus systems** are very important and useful objects to extract the meson properties at finite density.

⇨ Pionic atoms, Kaonic atoms/Kaonic nuclei, Eta mesic nuclei, Eta' mesic nuclei, Phi mesic nuclei …

⇨ Recently, heavy meson-nucleus systems are studied by many theorists. One of the most interesting meson is $D/\bar{D}$ meson, which has a charm quark.

Introduction

- **Theoretical Works**

  - Tsushima, Lu, Thomas, Saito, Landau, PRC59(99)2824
    Quark-meson coupling model, Dbar in ^{208}Pb.
  - Yasui, Sudoh, PRD80(09)034008
  - Yamaguchi, Yasui, Hosaka, NPA927(14)110
    Heavy Quark Symmetry. One pion exchange interaction.
    DbarN bound state, DbarNN bound state
  - Garcia-Recio, Nieves, Tolos, PLB690(10)369
    D^0 in ^{12}C up to ^{208}Pb, D^+ in ^{12}C
  - Garcia-Recio, Nieves, Salcedo, Tolos, PRC85(12)025203
    D^- in ^{12}C up to ^{208}Pb
  - Ikeno, Nagahiro, Hirenzaki, JPS Meeting 2010
    Formation spectrum of D^0 in ^{12}C by Effective number approach
  - Nagahiro at KEK workshop, Formation spectrum of D^- in ^{12}C

  etc …

- **Experiments**

  - New Facility FAIR @ GSI
    High intensity pbar beam up to 15 GeV/c.
  - J-PARC

Introduction

- **Our motivation**

  - We'd like to know the possibility of the observation for $D/\bar{D}$ bound states by ^{12}C(pbar, $\bar{D}/D$) reaction at the incident $\overline{\mathrm{p}}$ beam = 8GeV/c.

  - We'd like to focus on the structure of the formation spectrum.

  " The peak structure corresponding to bound states appear or not"

  - This is the first calculation for the formation spectra for $D/\bar{D}$ mesic nuclear states with energy dependent optical potential with the Green's function method .

$\bar{D}$ mesic Nucleus

- $\bar{D}$ ($\bar{c}$q)meson-nucleus Interaction

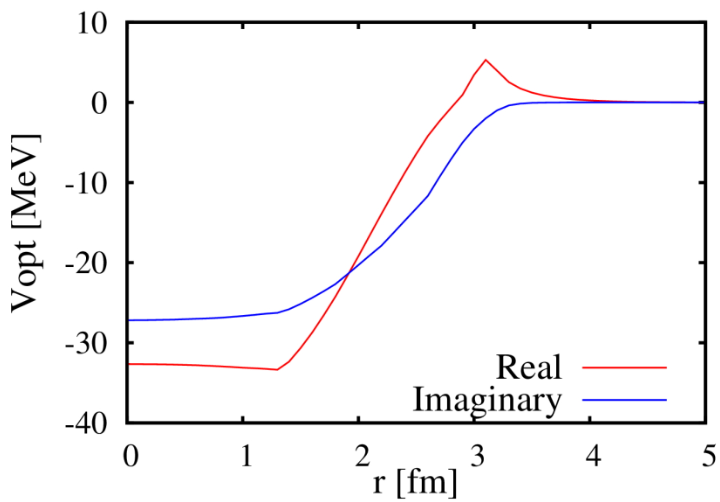
Garcia-Recio, Nieves, Salcedo, Tolos, PRC85(12)05203.

- Unitarized coupled-channel theory

I=0	J=1/2	$\bar{D}N, \bar{D}^*N$
I=1	J=1/2	$\bar{D}N, \bar{D}^*N, \bar{D}^*\Delta$

- Medium effect

- Optical potential with ^{11}B at E=0



$\bar{D}$ mesic Nucleus

- Klein-Gordon equation

$$[-\nabla^2 + \mu^2 + 2\mu V_{\rm opt}(r,E)]\phi(r) = (E - V_{\rm coul}(r))^2\phi(r)$$

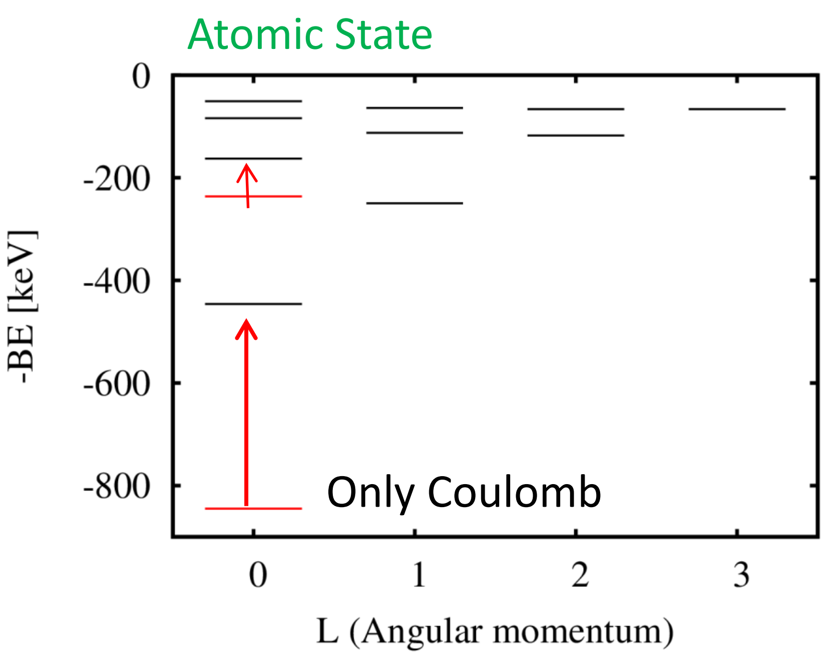
- Intro.
- **Dbar Nucleus**
  - -Interaction
  - **-Bound Systems**
  - -Formation Spectrum
- D0 Nucleus
  - -Interaction
  - -Bound systems
  - -Formation Spectrum
- Summary

$\bar{D}$ mesic Nucleus

- Klein-Gordon equation

$$[-\nabla^2 + \mu^2 + 2\mu V_{\rm opt}(r, E)]\phi(r) = (E - V_{\rm coul}(r))^2\phi(r)$$

- Bound state for ^{11}B



Nuclear Sate : BE (Width) [MeV]

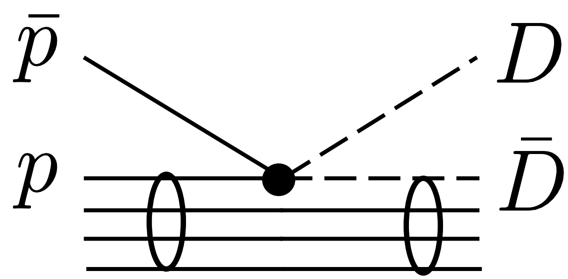
1s : 21.662 (0.458)
2p: 14.451(2.359)

Deeply bound Dbar mesic nuclear states exist with narrow width !!

How can we observe these states ?

$\bar{D}$ mesic Nucleus

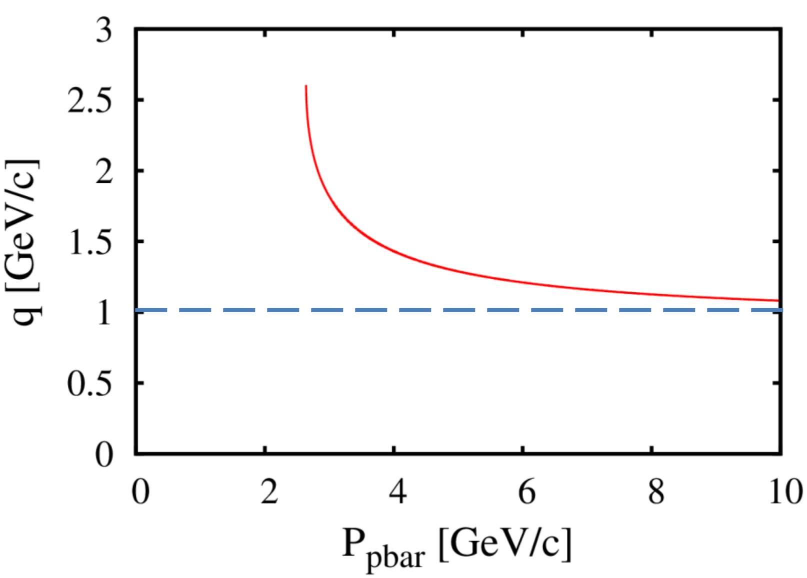
- Formation reaction



Target Nucleus : ^{12}C

$$^{12}\mathrm{C}(\bar{p}, D)^{11}\mathrm{B}\text{-}D^{-}$$

- Momentum transfer



We consider the incident pbar beam as 8 GeV/c. This energy will be achieved in PANDA experiments at the future FAIR facility.

$$\sim 1 \quad [\mathrm{GeV/c}]$$

$\bar{D}$ mesic Nucleus

- Formulation : Green's function method

$$\frac{d^2\sigma}{dEd\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\bar{p}p\to D\bar{D}} \sum_{\alpha} -\frac{1}{\pi}\mathrm{Im}\int d\vec{r}d\vec{r}' f_{\alpha}^{*}(\vec{r}\,')G(E;\vec{r}\,',\vec{r})f_{\alpha}(\vec{r})$$

In this calculation, we doesn't include the elementary cross section.
So, the calculated formation spectra has arbitrary unit.

This is very simple calculation of the formation spectra.
We'd like to know if the signals of bound states could appear in that spectra or not.

$\bar{D}$ mesic Nucleus

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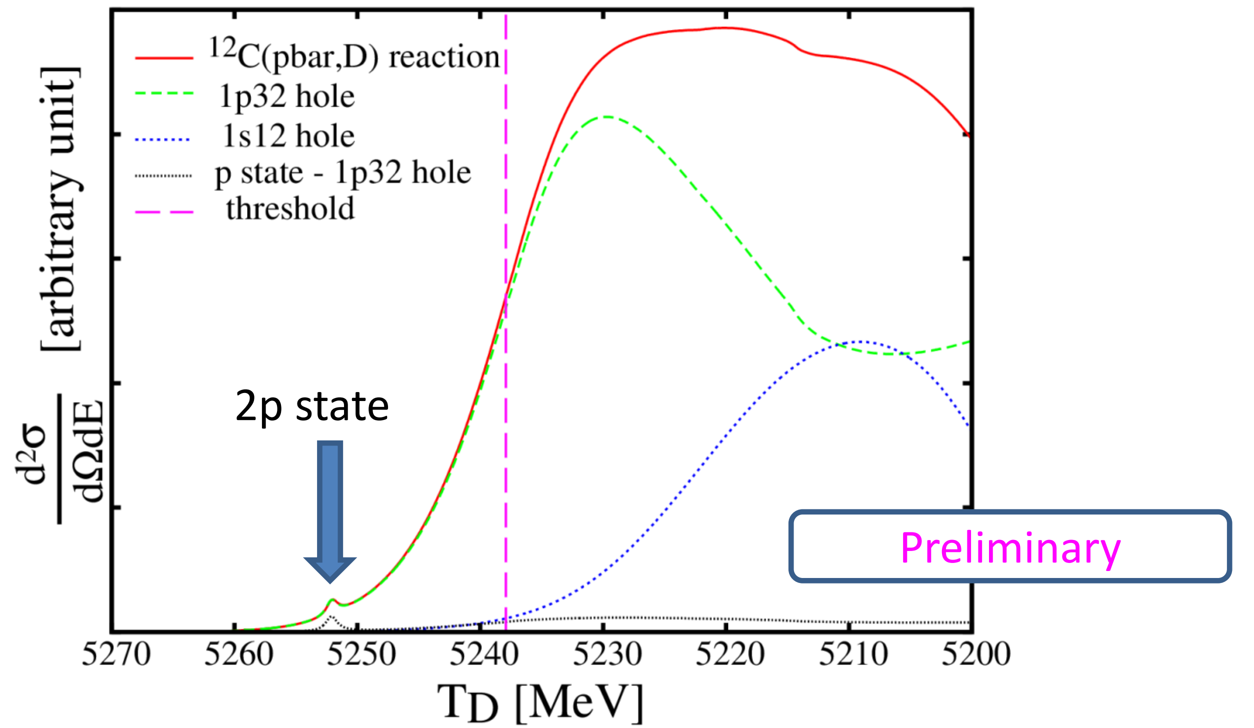
$\bar{D}$ mesic Nucleus

- Results : formation spectra



Nuclear Sate :
1s : 21.662 (0.458)
2p: 14.451(2.359)

The peak corresponding to the 2p state might appear, and very small.
One of the reason of that is the momentum transfer is very large.
In this calculation, we consider Dbar state up to L=15.

➔ Different formation reaction is needed to get clearer peak structure.

D^0 mesic Nucleus

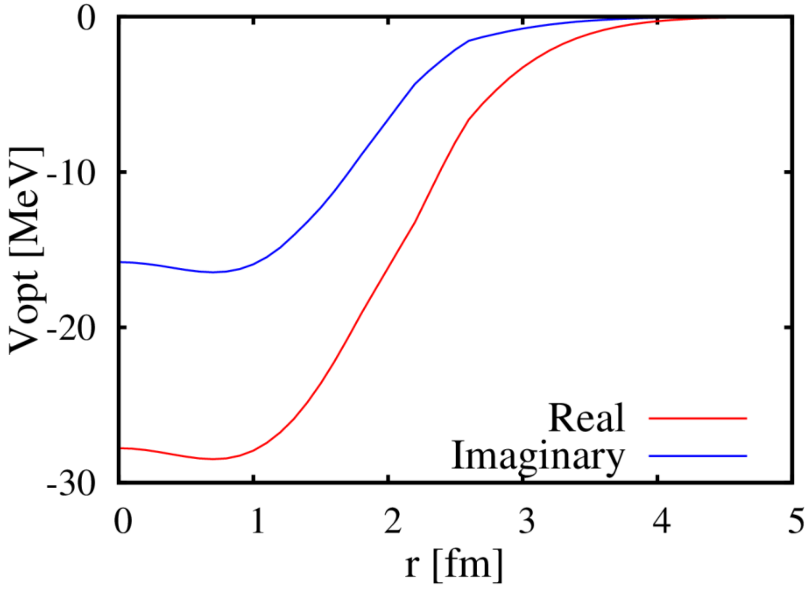
- D^0 meson-nucleus Interaction

Tolos, Garcia-Recio, Nieves, PRC80(09)065202.

Garcia-Recio, Nieves, Tolos, PLB690(10)369.

- Unitarized coupled-channel theory
- Medium effect

- Optical potential with ^{11}B at E=0



D^0 mesic Nucleus

- Klein-Gordon equation

$$[-\nabla^2 + \mu^2 + 2\mu V_{\rm opt}(r, E)]\phi(r) = E^2\phi(r)$$

- Bound state for ^{11}B

Nuclear Sate : BE (Width) [MeV]

1s : 6.525(10.78)

Deeply bound D0 mesic nuclear states exist !!
This result is consistent with Ikeno's calculation.

Does this state appear in the spectrum by (pbar,Dbar) reaction ?

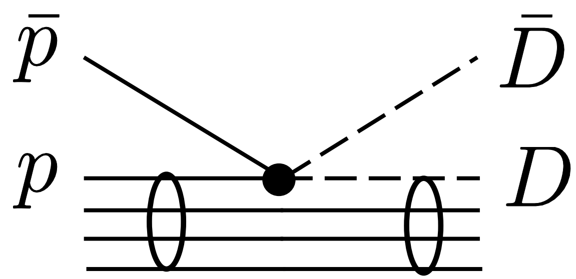
- D^0- nucleus bound states

State	^{11}B (BE, $\Gamma/2$) [MeV]
1s	(6.6, 5.2)

From Ikeno's slide @ JPS Meeting 2010

D^0 mesic Nucleus

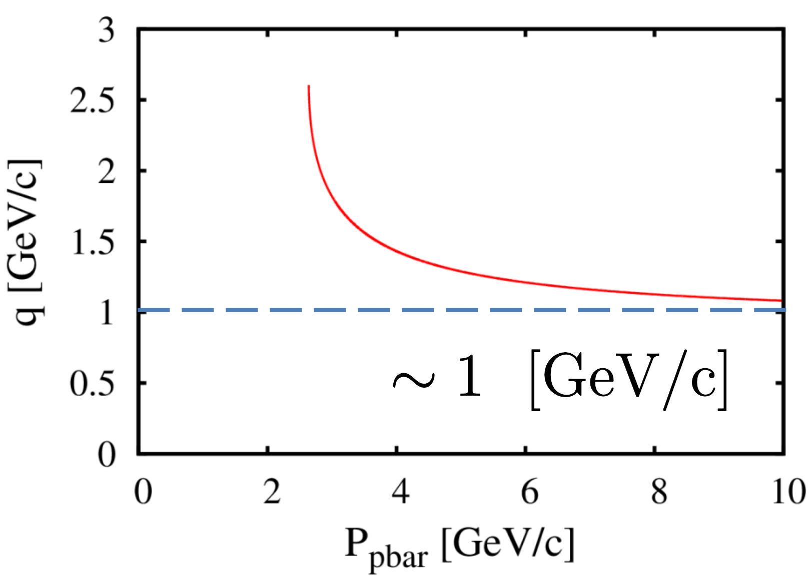
- Formation reaction



Target Nucleus : ^{12}C

The difference of D0 and Dbar production is just the emitted particle.
In this case, the emitted particle is Dbar meson.

- Momentum transfer



As same as Dbar mesic nucleus, we consider the incident pbar beam as 8 GeV/c.
This energy will be achieved in PANDA experiments at the future FAIR facility.

Momentum transfer is almost same as Dbar production.

D^0 mesic Nucleus

- Formulation : Green's function method

$$\frac{d^2\sigma}{dEd\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\bar{p}p\to D\bar{D}} \sum_{\alpha} -\frac{1}{\pi}\mathrm{Im}\int d\vec{r}d\vec{r}' f_\alpha^*(\vec{r}\,')G(E;\vec{r}\,',\vec{r})f_\alpha(\vec{r})$$

Elementary Cross section (Theory)

0.05 μb

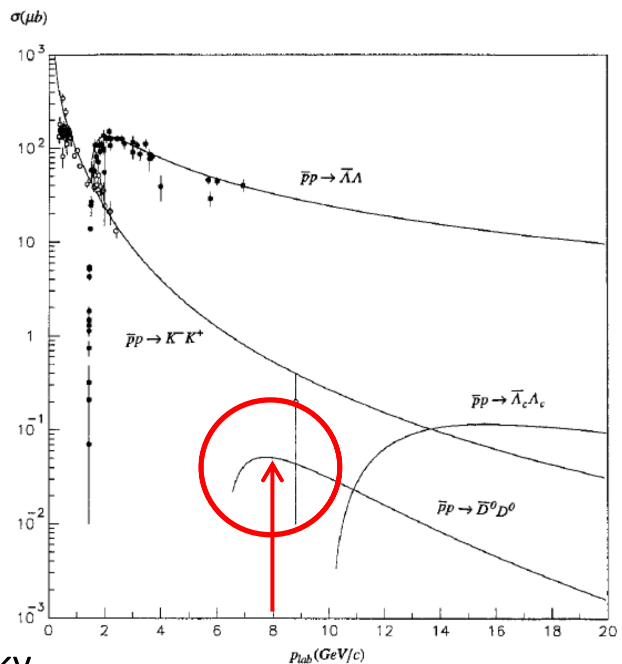


Fig. 2. Description of $\bar{p}p\to\bar{\Lambda}\Lambda$ and $\bar{p}p\to K^-K^+$ cross-sections and predictions for $\bar{p}p\to\bar{\Lambda}_c\Lambda_c$ and $\bar{p}p\to\bar{D}^0D^0$ cross-sections

Kaidalov, Volkovitsky, ZPC63(94)517

$$\sigma_{p\bar{p}\to D^0\bar{D}^0} = 0.05\ [\mu b]$$

Assumption :
a flat angular distribution in CM.

$$\left(\frac{d\sigma}{d\Omega}\right)^{\mathrm{CM}}_{p\bar{p}\to D^0\bar{D}^0} = 3.98\ [nb/sr]$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{\mathrm{Lab}}_{p\bar{p}\to D^0\bar{D}^0} = 190\ [nb/sr]$$

D^0 mesic Nucleus

- Formulation : Green's function method

$$\frac{d^2\sigma}{dEd\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\bar{p}p\to D\bar{D}} \sum_\alpha -\frac{1}{\pi}\mathrm{Im}\int d\vec{r}d\vec{r}' f^*_\alpha(\vec{r}\,')G(E;\vec{r}\,',\vec{r})f_\alpha(\vec{r})$$

- Distortion factor F(r)

$$f_\alpha(\vec{r}) = \exp(i\vec{q}\cdot\vec{r})F(\vec{r}) < \alpha|\psi_p(\vec{r})|i >$$

$$F(\vec{r}) = \exp\left(-\frac{1}{2}\bar{\sigma}\int\bar{\rho}(z',b)dz'\right)$$

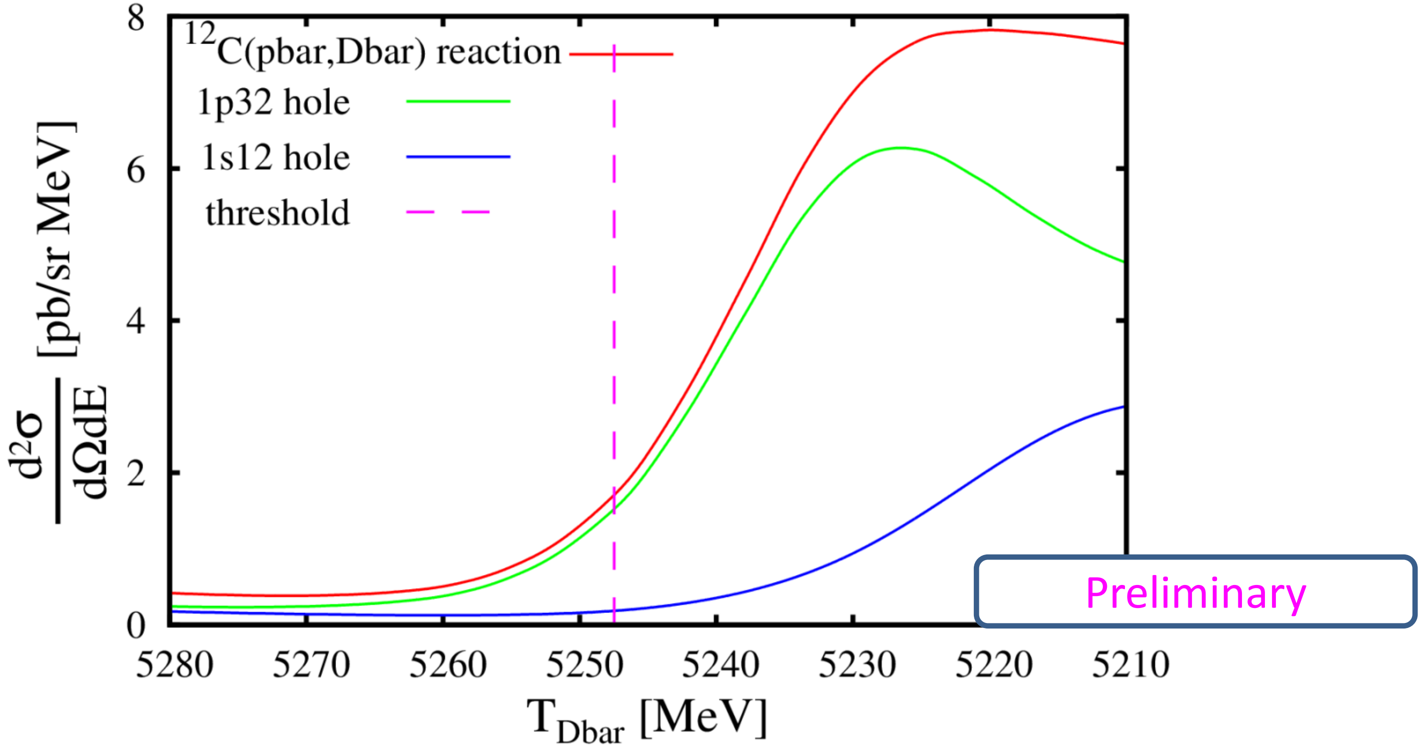
$$\bar{\sigma} = \frac{\sigma_{\bar{p}N} + \sigma_{\bar{D}^0N}}{2}$$

Theory : $\sigma_{\bar{D}^0N} = 10$ mb

J. Haidenbauer et al., EPJA37(08)55

D^0 mesic Nucleus

- Results : formation spectra



Nuclear Sate :
1s : 6.525(10.78)

The peak corresponding to the 1s state doesn't appear.
The momentum transfer is very large.

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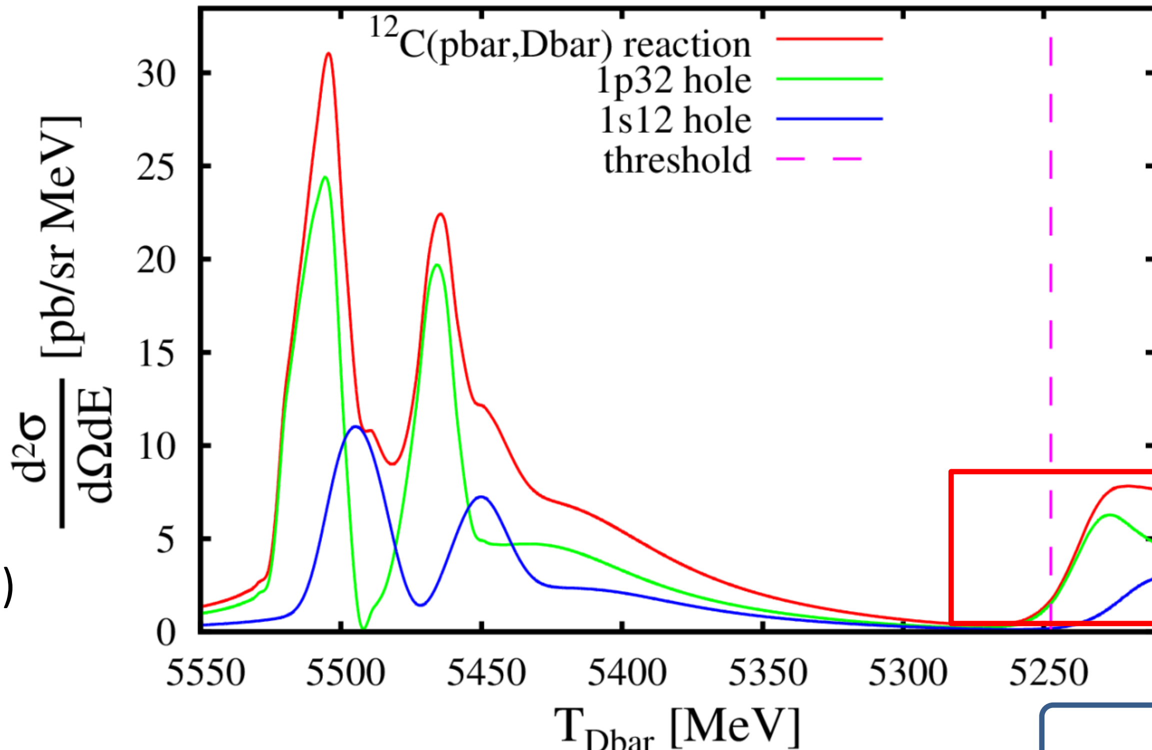
D^0 mesic Nucleus

- Results : formation spectra



Nuclear Sate :
1s : 6.525(10.78)

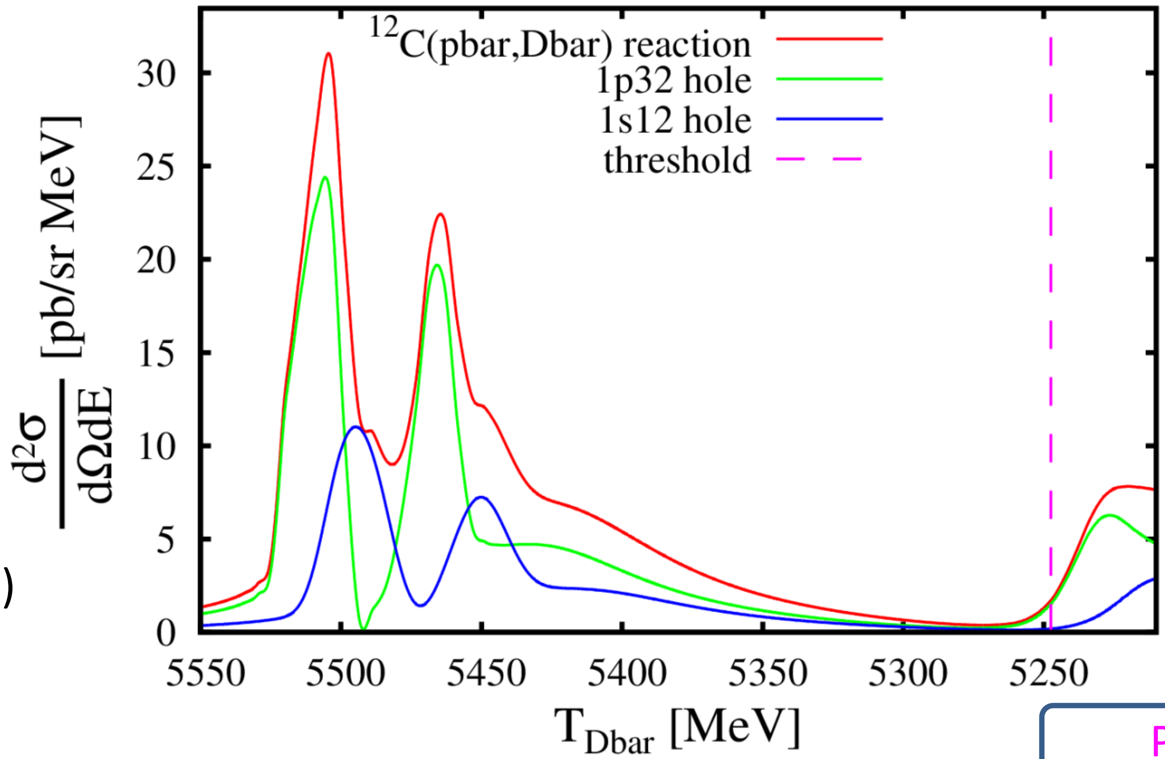
Preliminary

There are two peaks in the spectrum.
However, we don't have an eigen state around this energy.

What are these peaks ?

D^0 mesic Nucleus

- Results : formation spectra



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D^0 mesic Nucleus

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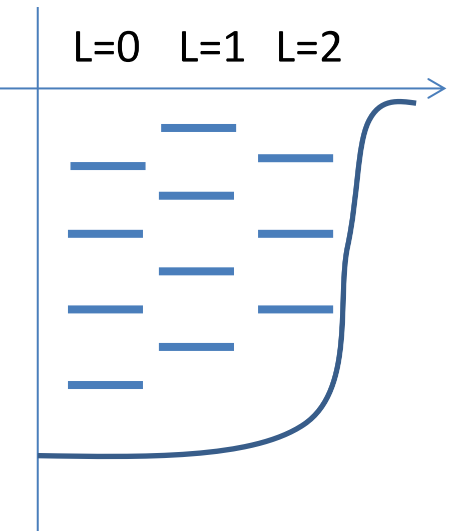
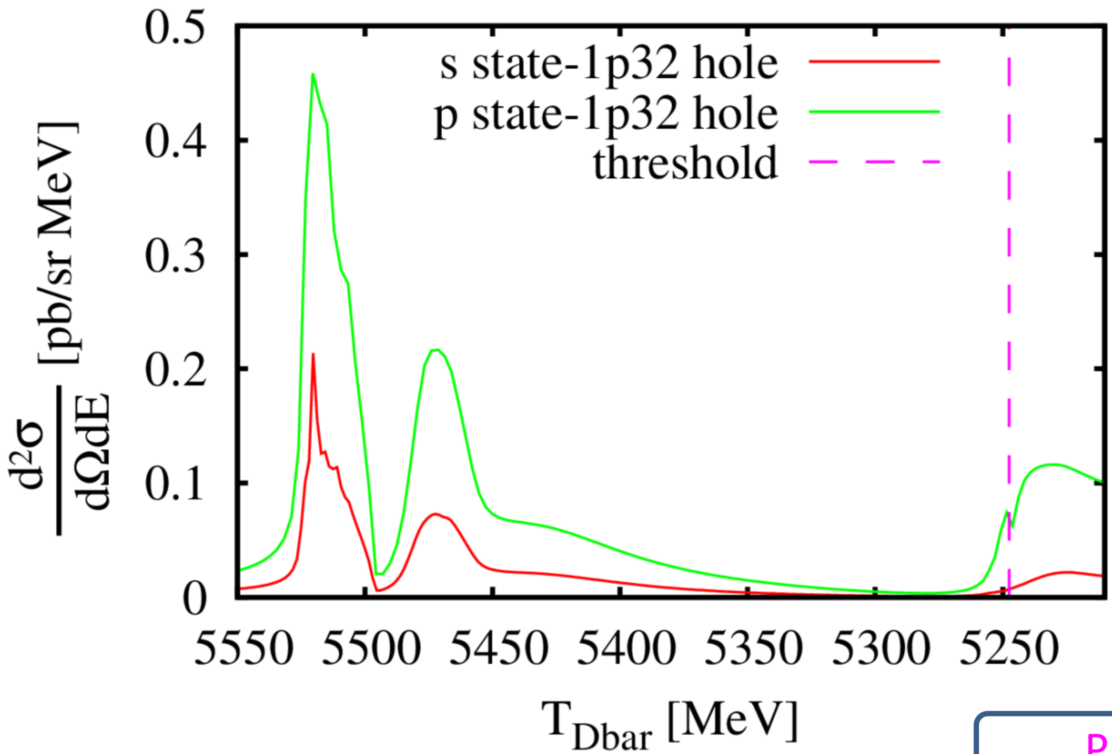
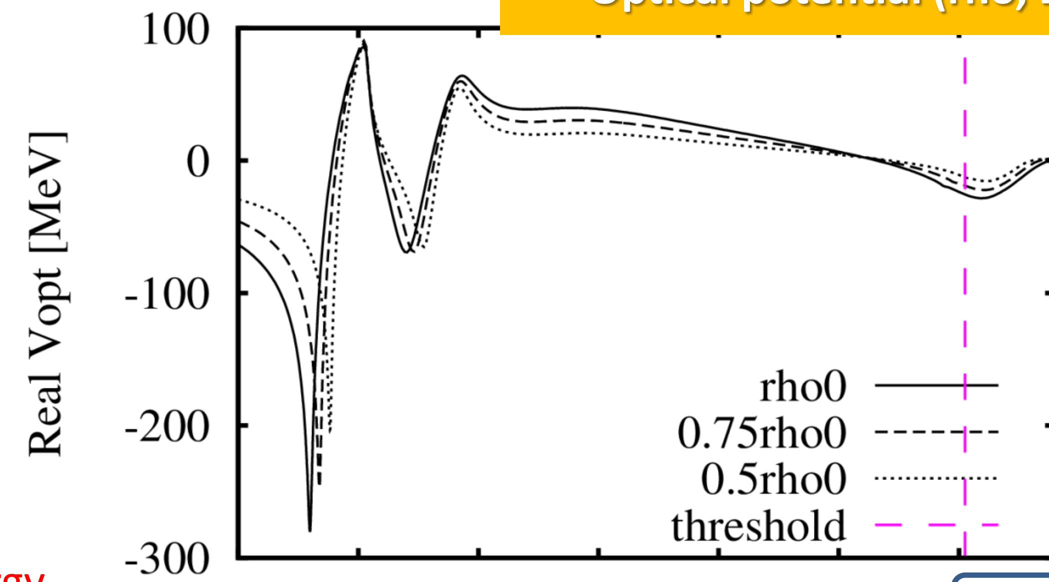




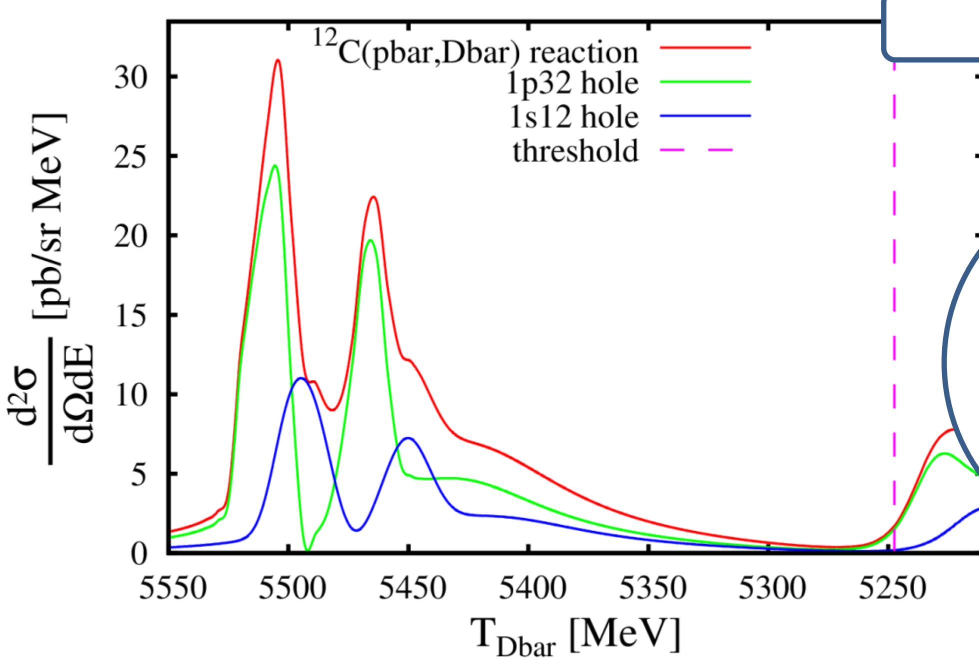
Preliminary

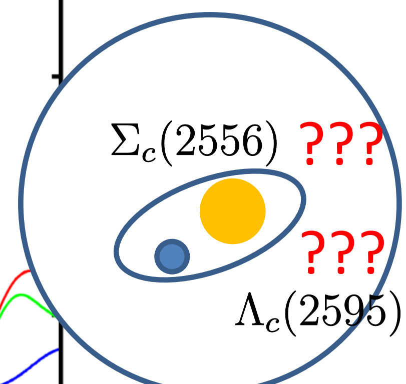
Two peaks appear in each angular momentum of D0 meson at similar energy. According to the shell model structure, it is strange that L=0 and L=1 have bound states at similar energy.

Optical potential (rho, E)



Preliminary





These structures may appear from the energy dependence of the strength of the optical potential.

This origin is from the $\Sigma_c(2556)$ and $\Lambda_c(2595)$ states as meson-baryon bound state..

Tolos, Garcia-Recio, Nieve PRC80(09)065202.

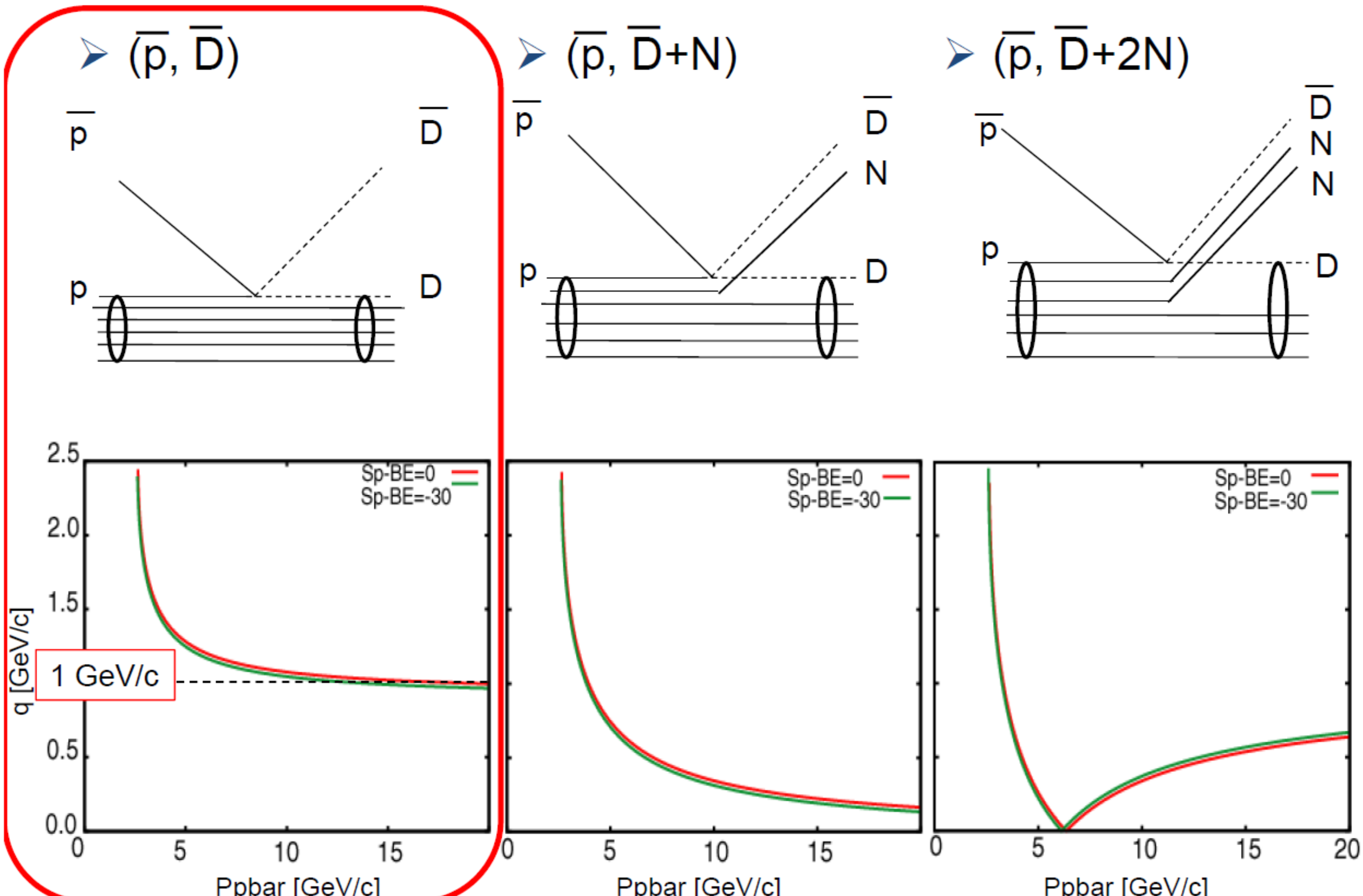
Summary

- We calculated the formation spectra of $D/\bar{D}$ mesic nuclear states via pbar beam.
- $D/\bar{D}$ mesic nuclear states exist as same as other theoretical works.
- We consider the (pbar, $\bar{D}/D$) reaction at $P_{\bar{p}}$ = 8 GeV/c.
- The momentum transfer is large.
- For $\bar{D}$ meson, 2p bound state may appear as small peak.
- For D meson, the bound state doesn't appear in the spectrum, but large peaks appear at deep energy region in this work.
- We should consider different production reaction with small momentum transfer.

Ikeno's slide @ JPS Meeting 2010

2. Formulation - reaction

(Momentum transfer)



Summary

Future Work

- We do more realistic calculation for both meson.
  (Elementary cross section, Distortion factor
  Different reaction …)

Dbar meson nucleus potential

Garcia-Recio, Nieves, Salcedo, Tolos, PRC85(12)05203.

I=0	**J=1/2**	$\bar{D}N, \bar{D}^{*}N$
I=1	**J=1/2**	$\bar{D}N, \bar{D}^{*}N, \bar{D}^{*}\Delta$

- SU(8) spin-flavor symmetry
- The optical potential is obtained by Tρ approximation.

Amplitude T has a pole X(2805) state : I=0, J=1/2

- Decay mode :

For atomic states, a bound Dbar meson may falls to lower level.

For nuclear states, the decay width comes from the existence of X(2805) state, which appears around threshold energy.

D meson nucleus potential

Tolos, Garcia-Recio, Nieves, PRC80(09)065202.

Garcia-Recio, Nieves, Tolos, PLB690(10)369

$I = 0,\ J = 1/2$

$\Sigma_c \pi$	ND	$\Lambda_c \eta$	ND^*	$\Xi_c K$	$\Lambda_c \omega$	$\Xi'_c K$	ΛD_s
2591.6	2806.15	2833.97	2947.54	2965.11	3069.11	3072.51	3084.18
ΛD_s^*	$\Sigma_c \rho$	$\Lambda_c \eta'$	$\Sigma_c^* \rho$	$\Lambda_c \phi$	$\Xi_c K^*$	$\Xi'_c K^*$	$\Xi_c^* K^*$
3227.98	3229.05	3244.24	3293.46	3305.92	3361.11	3468.51	3538.01

$I = 1,\ J = 1/2$

$\Lambda_c \pi$	$\Sigma_c \pi$	ND	ND^*	$\Xi_c K$	$\Sigma_c \eta$	$\Lambda_c \rho$	$\Xi'_c K$	ΣD_s	$\Sigma_c \rho$	$\Sigma_c \omega$
2424.5	2591.6	2806.15	2947.54	2965.12	3001.07	3061.95	3072.52	3161.64	3229.05	3236.21
ΔD^*	$\Sigma_c^* \rho$	$\Sigma_c^* \omega$	ΣD_s^*	$\Xi_c K^*$	$\Sigma_c \eta'$	$\Xi'_c K^*$	$\Sigma_c \phi$	$\Sigma^* D_s^*$	$\Sigma_c^* \phi$	$\Xi_c^* K^*$
3240.62	3293.46	3300.62	3305.45	3361.11	3411.34	3468.51	3473.01	3496.87	3537.42	3538.01

- SU(8) spin-flavor symmetry
- Optical potential is obtained by T ρ approximation.
- Amplitude T has a pole of Σc(2556) state (I=1, J=1/2) and Λc(2595) state (I=0, J=1/2).