

The isospin mixing in the $X(3872)$ decay spectrum

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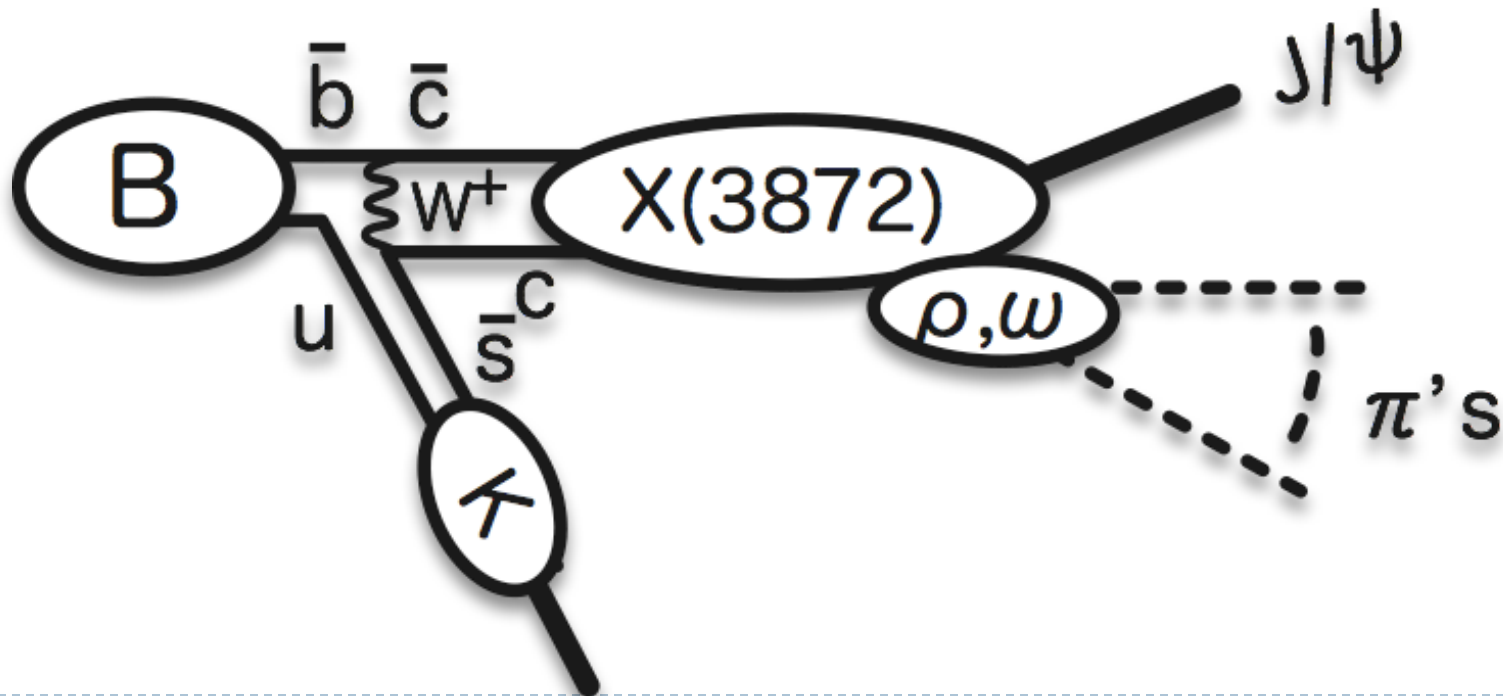
Kiyotaka Shimizu (Sophia U)

$$B^+ \rightarrow K^+ + J/\psi + \pi \pi (\pi)$$

► $B^+ \rightarrow \underline{X(3872)} + K^+$

→ J/ψ + vector meson → π 's

→ $D + D^*$



X(3872) facts

- ▶ $M = 3871.68 \pm 0.17 \text{ MeV}$, $J^{PC} = 1^{++}$ [PDG]
- ▶ X(3872) ($uc\bar{u}c\bar{c}$, $d\bar{c}d\bar{c}$) thresholds

- ▶ $D^\pm D^{*\mp}$ 3879.79 MeV
- ▶ $J/\psi \omega$ 3879.57 MeV
- ▶ $J/\psi \rho$ 3872.41 MeV
- ▶ $D^0 D^{*0\bar{c}}$ 3871.73 MeV

X is almost 'on'
the threshold!

- ▶ $\Gamma < 1.2 \text{ MeV}$

X has a very small width!

- ▶ production rate from $pp^{\bar{c}}$ collision:

- ▶ $X(3872) / J/\psi \sim 0.05$

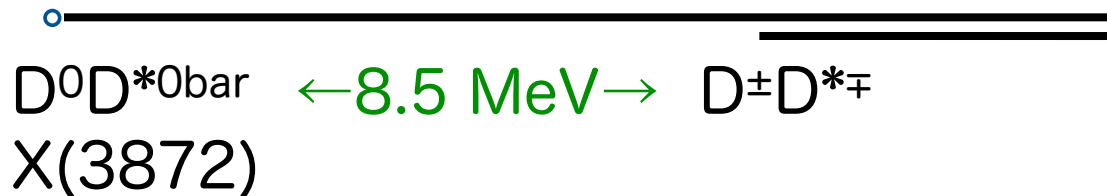
X production rate is about 1/20 of
that of J/ψ ... $cc^{\bar{c}}$ component?

Isospin sym breaking

- ▶ $c\bar{c}$ ($I=0$) $\rightarrow X \rightarrow J/\psi \omega \rightarrow J/\psi \pi^3$ ($I=0$)
 - ▶ $\rightarrow J/\psi \rho \rightarrow J/\psi \pi^2$ ($I=1$)
- } Experimentally,
Comparable

▶ Qualitatively speaking,

▷ Origin of Isospin sym breaking : thresholds



▷ $V_{(I=0)} \sim V_{(I=1)}$ if from OGE, or σ exch. π exch is small

▷ $I=1$ enhancement : ρ width \gg ω width

149.1 MeV 8.5 MeV

I. V. Danilkin and Y. A. Simonov, 2010

S. Coito, G. Rupp, and E. van Beveren 2011

R. D. Matheus, et al 2009

Isospin sym breaking

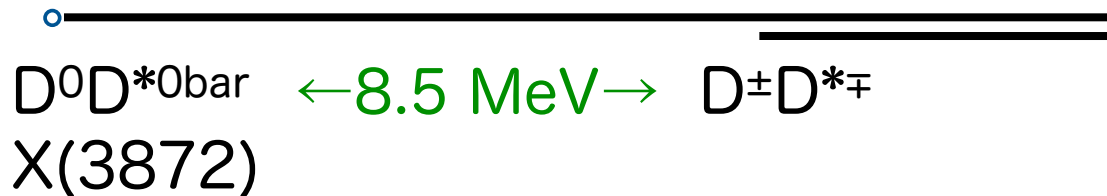
▶ $c\bar{c}$ ($I=0$)

$$\frac{Br(X \rightarrow \pi^+ \pi^- \pi^0 J/\psi)}{Br(X \rightarrow \pi^+ \pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3 \quad (\text{Belle})$$

$$= 0.8 \pm 0.3 \quad (\text{BABAR}).$$

▶ Qualitatively speaking,

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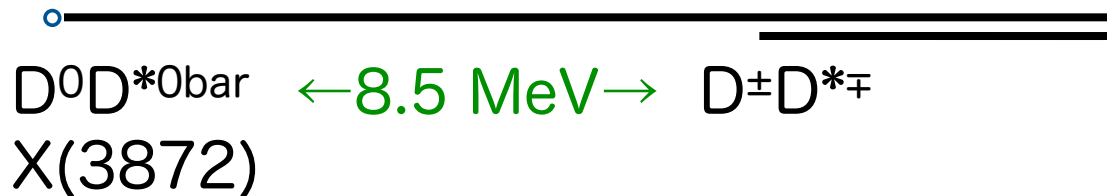
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Isospin sym breaking

- ▶ $cc^{\text{bar}} (I=0) \rightarrow X \rightarrow J/\psi \omega \rightarrow J/\psi \pi^3 (I=0)$
 - ▶ $\rightarrow J/\psi \rho \rightarrow J/\psi \pi^2 (I=1)$
- } Experimentally,
Comparable

▶ Qualitatively speaking,

▷ Origin of Isospin sym breaking : thresholds



▷ $V_{(I=0)} \sim V_{(I=1)}$ if from OGE, or σ exch. π exch is small

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R. D. Matheus, et al 2009

Quantitatively speaking?

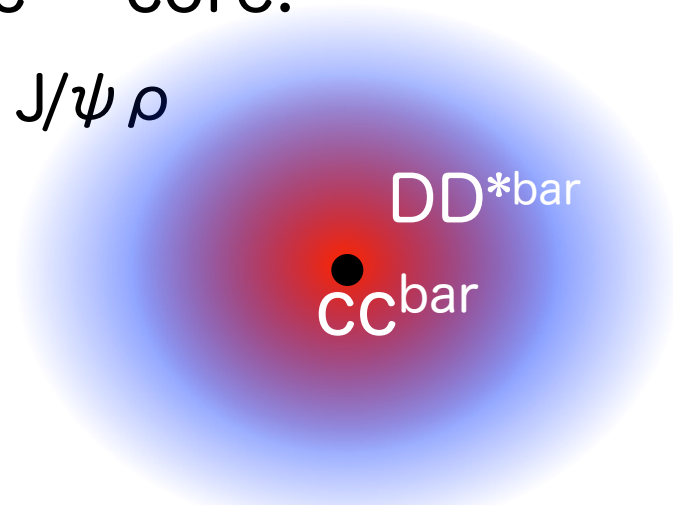
What we'd like to discuss today

- ▶ There is a mechanism to have such narrow peaks of $J/\psi \rho, \omega$ that appears on the threshold.
 - ▷ peak by $J/\psi n\pi$ is little lighter than peak by $DD^{\text{bar}*}$
 - ▷ $J/\psi - n\pi$ width is very small ($1.4 \pm 0.7, 1.1 \pm 1.5 \pm 0.2$ MeV) v.s. $DD^{\text{bar}*}$ width is larger ($3.5 + 1.6 - 1.0$ MeV)
 - ▷ This occurs as far as large strength of DD exists just above threshold.
- ▶ A large Isospin breaking can be realized.
 - ▷ a small breaking is enhanced by the large width of ρ meson

Our picture of $X(3872)$

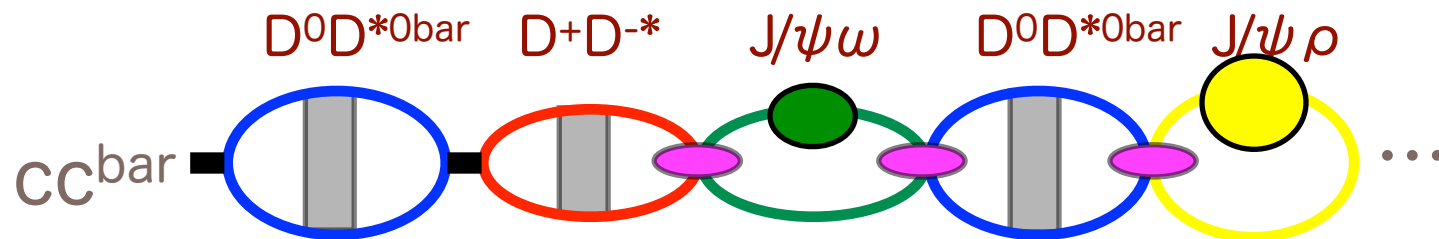
▶ Two-meson molecule with a cc^{bar} core:

▷ $cc^{\text{bar}} - D^0 D^{*0\text{bar}} - D^+ D^{*-} - J/\psi \omega - J/\psi \rho$



▷ ω and ρ have width.

▷ $J/\psi \omega$ and $J/\psi \rho$ couple to cc^{bar} only via DD^{*bar} channels (OZI).



M. Takizawa and S. Takeuchi, Prog. Theor. Exp. Phys.

2013, 0903D01

Hamiltonian

► $H = H_0 + V$

$$H_0 = \begin{pmatrix} H_0^{(P)} & 0 \\ 0 & E_0^{(Q)} \end{pmatrix} \quad H_0^{(P)} = \sum_i \left(M_i + m_i + \frac{k_i^2}{2\mu_i} \right)$$

$$V = \begin{pmatrix} V_{PP} & V_{PQ} \\ V_{QP} & 0 \end{pmatrix}$$

$P : D^0 D^{*0\text{bar}} - D^+ D^{*-} - J/\psi \omega - J/\psi \rho$, $Q : c c^{\text{bar}}$

V_{PP} : potential between the two mesons

► RGM for a quark model $\rightarrow V_{PP} = N^{-1/2} H N^{-1/2} - H_0$

V_{PQ} : coupling between the two mesons and $c c^{\text{bar}}$

Potentials

► Isospin invariant

in this calculation, we take $\Lambda = 500\text{MeV}$

► separable Lorentzian for D and $D^{\text{bar}*}$ interaction

$$\frac{-\lambda}{\Lambda^2} \left(\frac{\Lambda^2}{q^2 + \Lambda^2} \right) \left(\frac{\Lambda^2}{p^2 + \Lambda^2} \right)$$

► Lorentzian for $DD\text{-}c\bar{c}$ coupling

$$\frac{g}{\sqrt{\Lambda}} \left(\frac{\Lambda^2}{q^2 + \Lambda^2} \right)$$

	D^0D^{0*}	D^+D^{-*}	$J/\psi \rho$	$J/\psi \omega$	$c\bar{c}$
D^0D^{0*}	$-\lambda$	0	u	u	g
D^+D^{-*}		$-\lambda$	-u	u	g
$J/\psi \rho$			0	0	0
$J/\psi \omega$				0	0

$V(DD\text{-}DD)$ is the same for $l=0$ and 1

$V(J/\psi V\text{-}c\bar{c}) = 0 \leftarrow \text{OZI}$

$V(J/\psi V\text{-}J/\psi V) = 0 \leftarrow \text{no int btw light quarks}$

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D^0D^{0*}	$-\lambda$	0	u	u	g
D^+D^{-*}		$-\lambda$	$-u$	u	g
$J/\psi \rho$			0	0	0
$J/\psi \omega$				0	0

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in this calculation, we take $\Lambda = 500\text{MeV}$

► separable Lorentzian for DD-DD interaction

$$\frac{-\lambda}{\Lambda^2} \left(\frac{\Lambda^2}{q^2 + \Lambda^2} \right) \left(\frac{\Lambda^2}{p^2 + \Lambda^2} \right)$$

► Lorentzian for DD- $c\bar{c}$ coupling

$$\frac{g}{\sqrt{\Lambda}} \left(\frac{\Lambda^2}{q^2 + \Lambda^2} \right)$$

	$D^0\bar{D}^{0*}$	D^+D^{*-}	$J/\psi \rho$	$J/\psi \omega$	$c\bar{c}$
$D^0\bar{D}^{0*}$	$-\lambda$	0	u	u	g
D^+D^{*-}		$-\lambda$	-u	u	g
$J/\psi \rho$			0	0	0
$J/\psi \omega$				0	0

$V(\text{DD-DD})$ is the same for $l=0$ and 1

$V(J/\psi V-c\bar{c}) = 0 \leftarrow \text{OZI}$

$V(J/\psi V-J/\psi V) = 0 \leftarrow$ no int btw light quarks

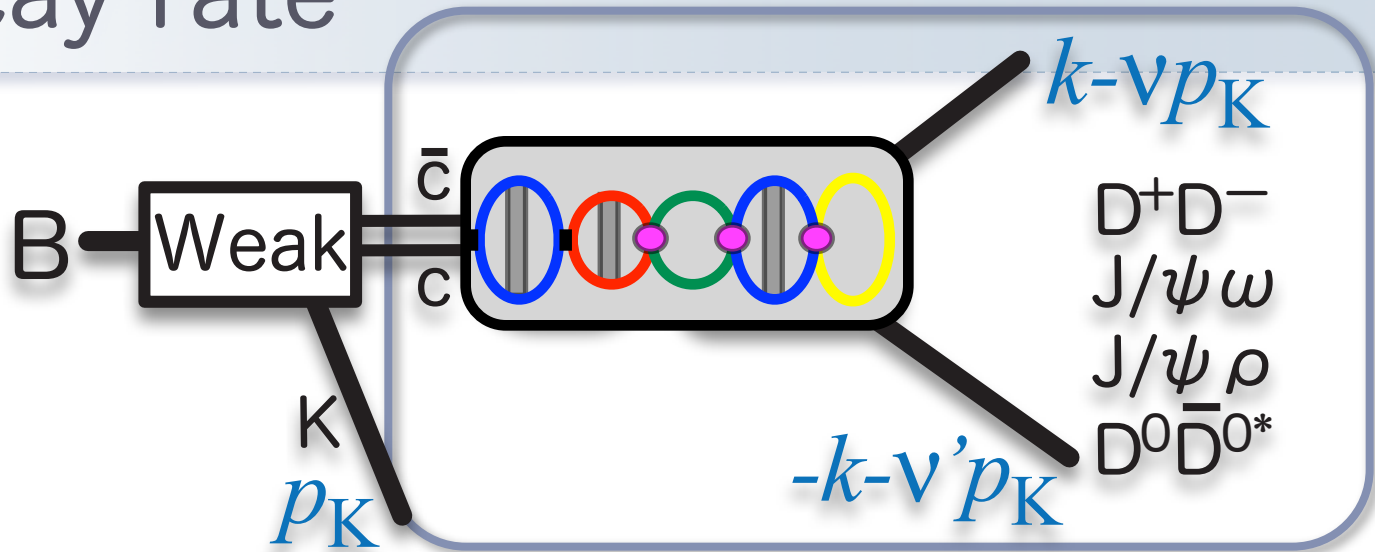
Potentials

	$D^0 D^{0*}$	$D^+ D^{-*}$	$J/\psi \rho$	$J/\psi \omega$	$c\bar{c}$
$D^0 D^{0*}$	$-\lambda$	0	u	u	g
$D^+ D^{-*}$		$-\lambda$	-u	u	g
$J/\psi \rho$			0	0	0
$J/\psi \omega$				0	0

► Interaction strengths are determined by

- ▶ D - $D^{\text{bar}*}$ coupling λ : we assume it is the same as the strength between B - B^* , and B - B^* interaction is taken so that it has a zero-energy resonance, like Z_b (10610) or $Z_b(10650)$. (similar to quark model)
- ▶ $DD^{\text{bar}*}$ - $J/\psi \omega$ coupling u : we assume the quark model with Godfrey-Isgur qq^{bar} interaction to obtain this transfer strength.
 - ▶ RGM for a quark model $\rightarrow V_{PP} = N^{-1/2} H N^{-1/2} - H_0$
- ▶ $DD^{\text{bar}*}$ - $c\bar{c}$ coupling g : we use this strength as a free parameter to give the $X(3872)$ mass.

Decay rate



- Decay rate $\propto c\bar{c}$ full propagator

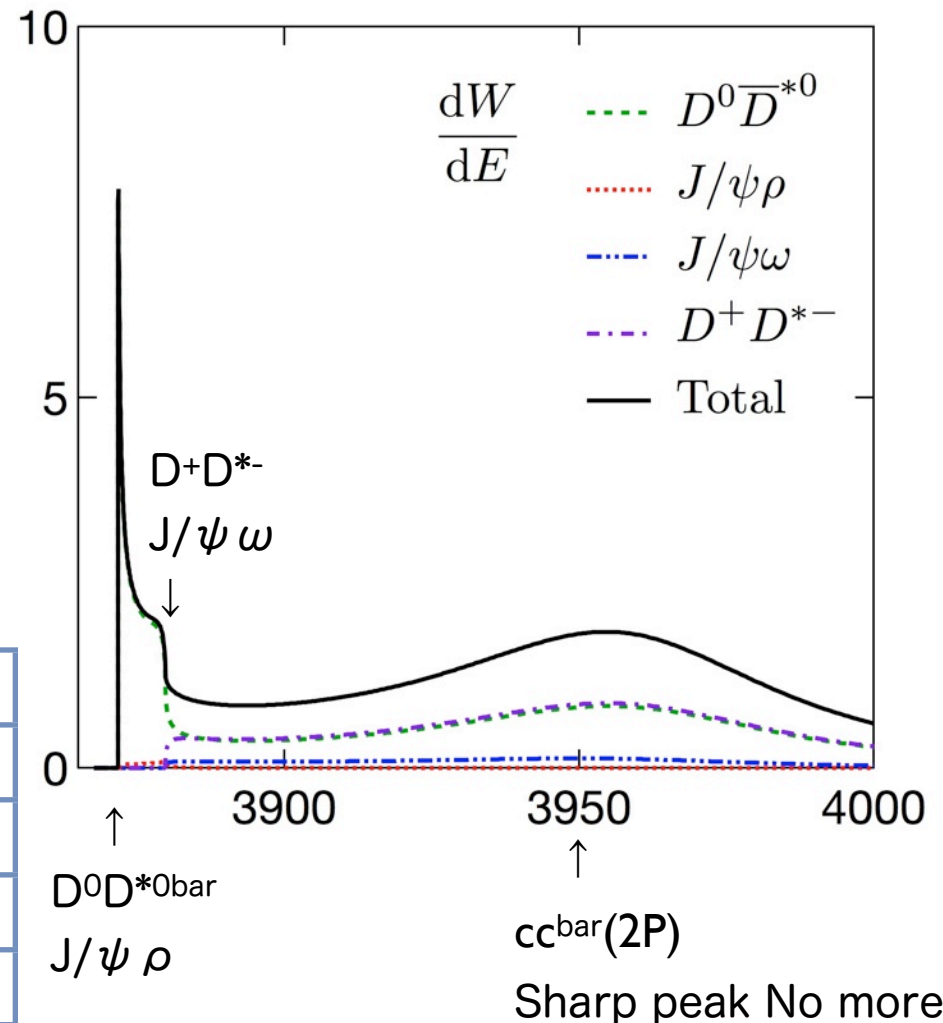
$$\frac{dW}{dE} = -\frac{1}{\pi} \text{Im} \langle c\bar{c} | G_Q(E) | c\bar{c} \rangle \quad \int_{E_{\text{threshold}}}^{\infty} \frac{dW}{dE} dE = 1$$

$$\frac{dW(c\bar{c} \rightarrow f)}{dE} = \pi \mu_f k_f \left| \langle f; k_f | (1 + V_{PP}G^{(P)}) V_{PQ}G_Q | c\bar{c} \rangle \right|^2$$

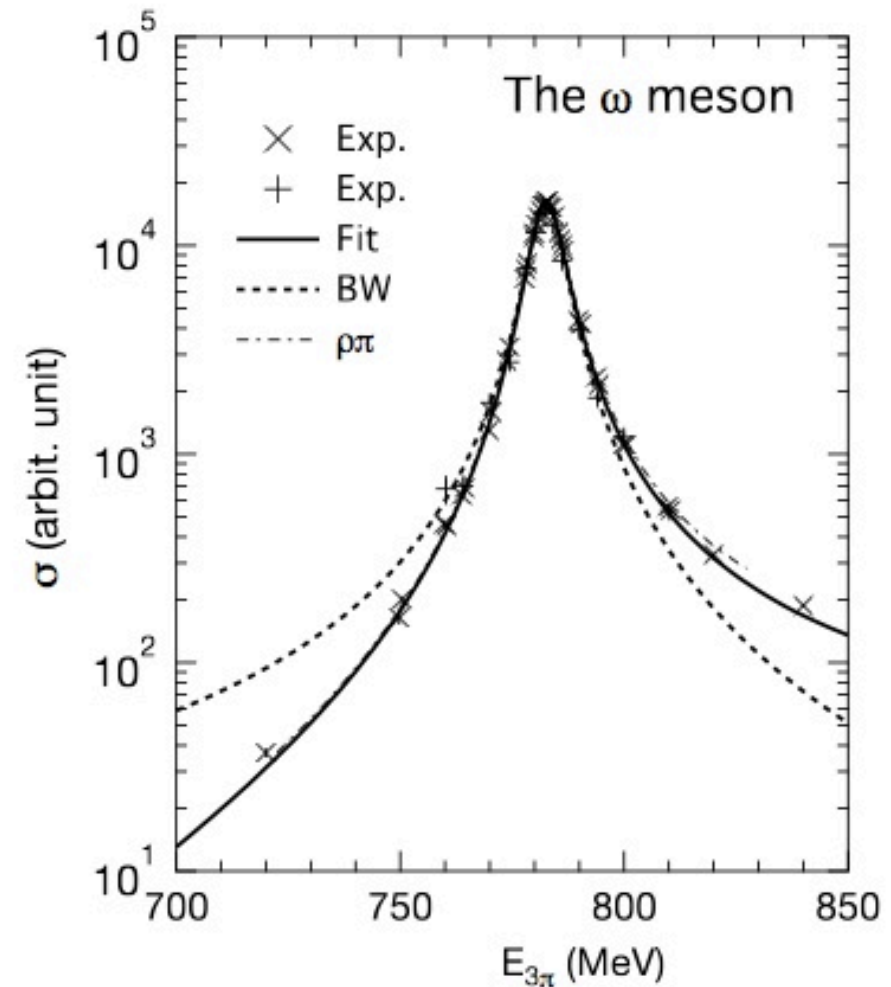
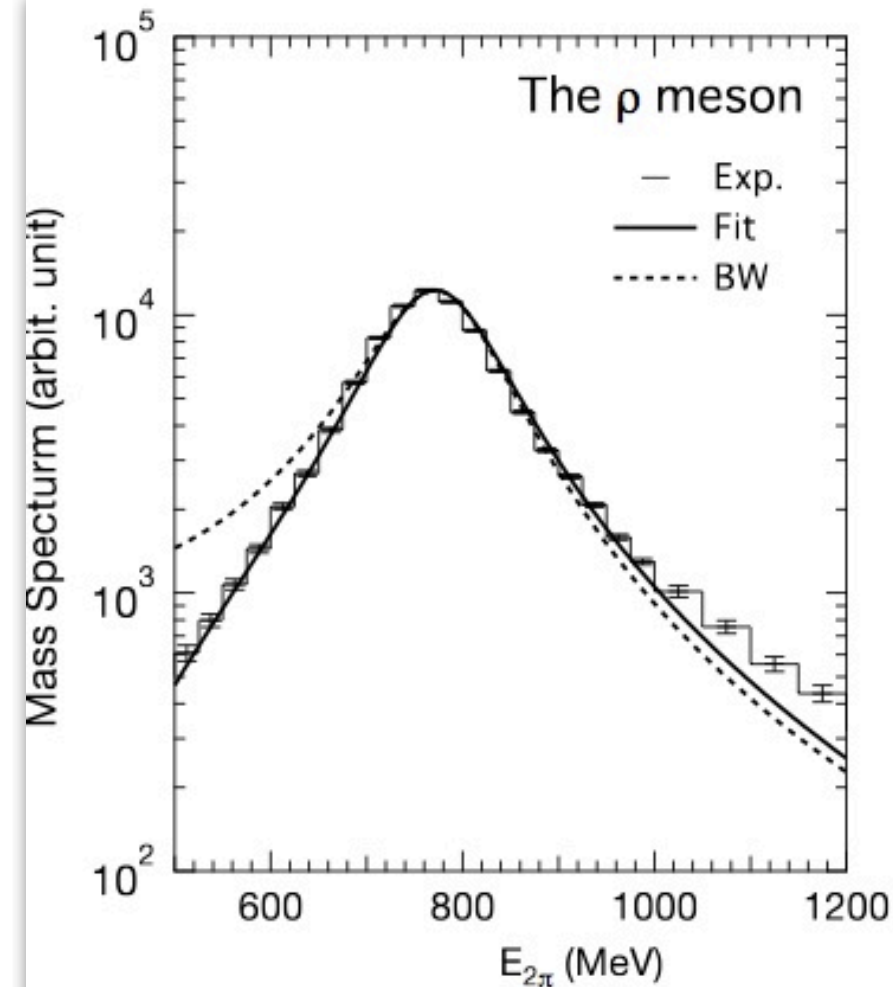
$c\bar{c}$ → mesons - for resonance X(3872)

- ▶ no width for $\rho \omega$.
- ▷ $D^0\bar{D}^{0*}$ peak appears
- ▷ Almost no $J/\psi \rho$ strength.
- ▷ X(3872) is a bound state, $c\bar{c} \rightarrow X$ prob 0.024

V_0, W_0	$D^0\bar{D}^{0*b}$	D^+D^{*-}	$J/\psi \rho$	$J/\psi \omega$	$c\bar{c}$
$D^0\bar{D}^{0*b}$	-9.6	0	-9.8	-9.8	3.85
D^+D^{*-}		-9.6	-9.8	9.8	3.85
$J/\psi \rho$			0	0	0
$J/\psi \omega$				0	0

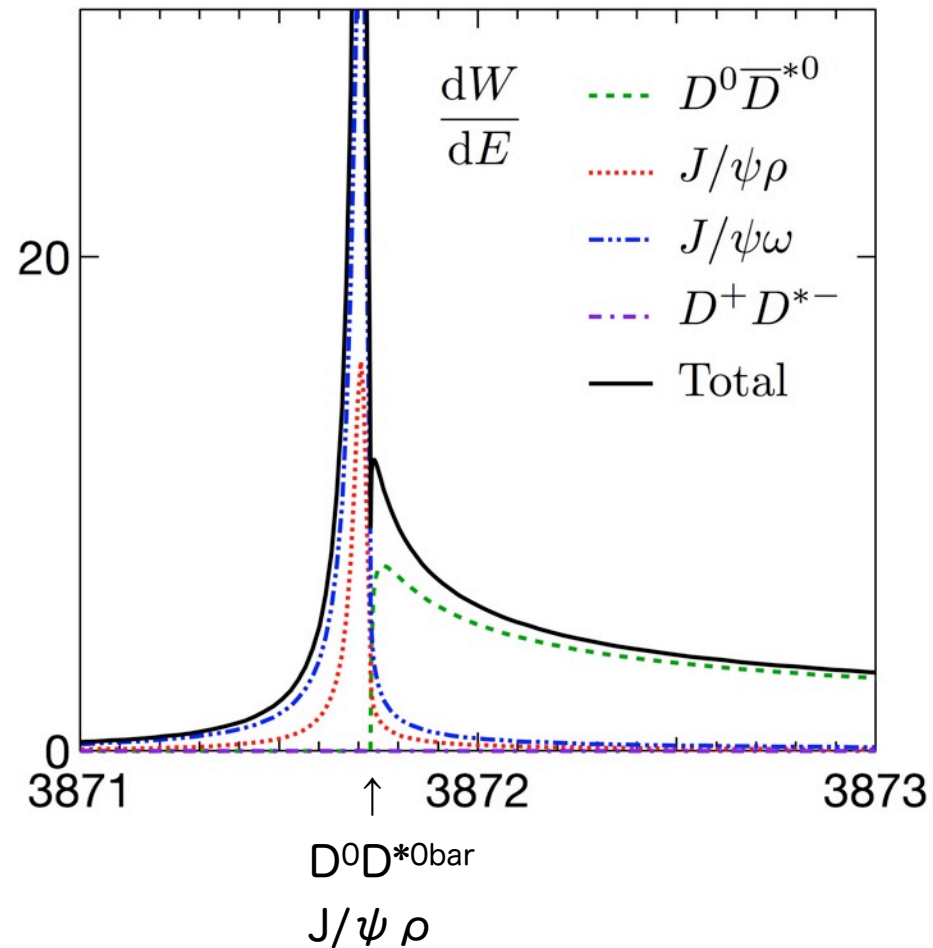


Energy dep't vector meson width



$c\bar{c} \rightarrow \text{mesons} - \text{for resonance } X(3872)$

- ▶ inc width for $\rho \omega$.
- ▶ J/ψ -Vector meson peak appears at the threshold.
- ▶ $J/\psi \omega$ and $J/\psi \rho$ are comparable.
- ▶ Calculated 'width' is within the observed width, $< 1.2 \text{ MeV}$



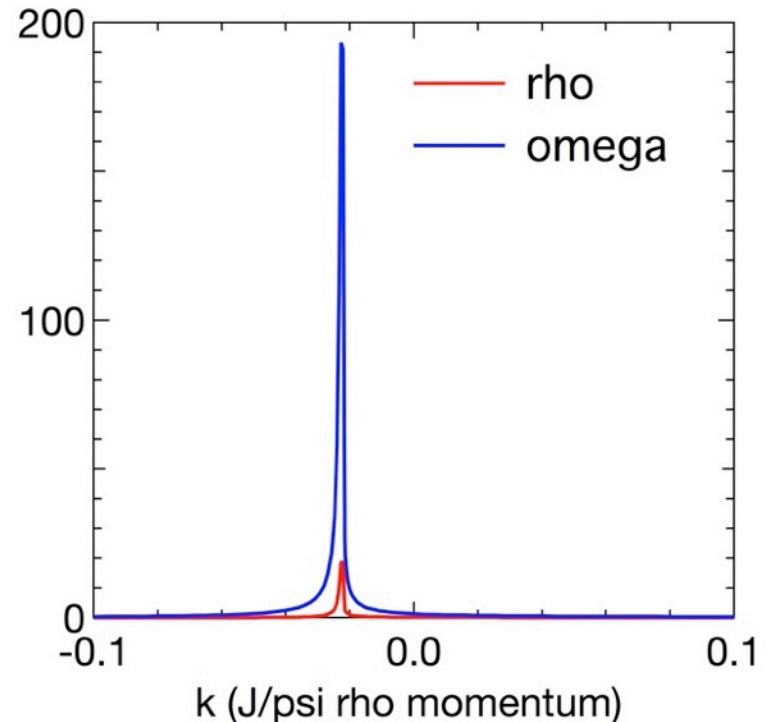
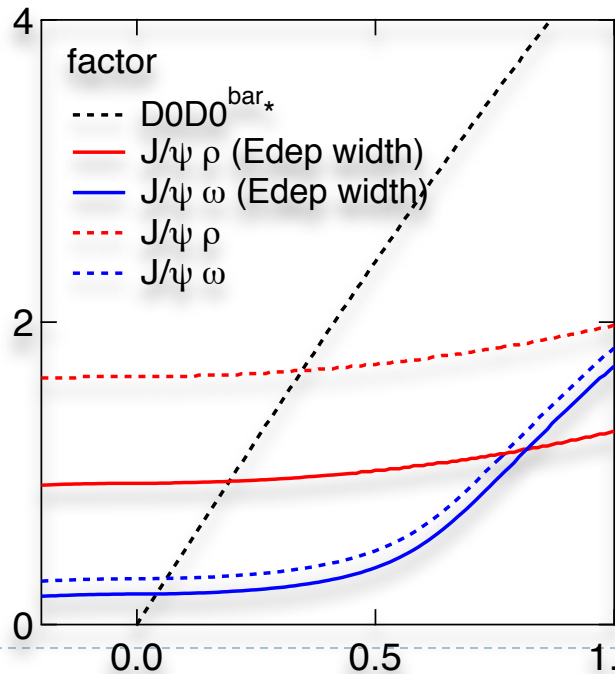
$c\bar{c}$ → mesons - for resonance X(3872)

$$\frac{dW(c\bar{c} \rightarrow f)}{dk} = \frac{2}{\pi} \mu_f \times \left(\frac{\Lambda^2}{k^2 + \Lambda} \right)^2 / \left(\frac{\Lambda^2}{k^2 + \Lambda} \right)^2$$

$$\times \int \frac{k^2 dk \mu_f \Gamma_V(s(k))}{(k_f^2 - k^2)^2 + (\mu_f \Gamma_V(s(k)))^2} \left| \langle f; k | (1 + V_{PP} G^{(P)}) V_{PQ} G_Q | c\bar{c} \rangle \right|^2$$

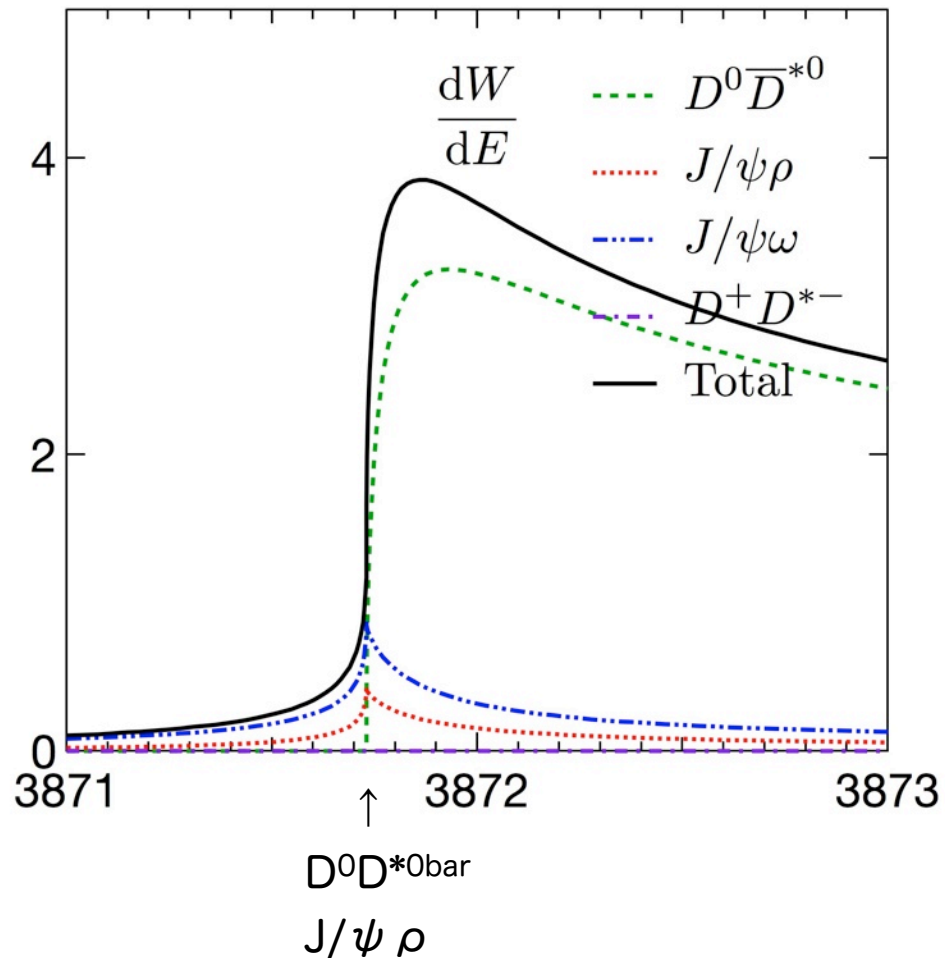
J/ψ ρ (I=1) is enhanced

small Isospin sym breaking



$c\bar{c} \rightarrow \text{mesons} - \text{for resonance } X(3872)$

- ▶ inc width for $\rho \omega$.
- ▶ DD- $c\bar{c}$ coupling x 0.94
 - ▷ Not so much difference as far as J/ψ -Vector meson peaks concerned.
 - ▷ ratio J/ψ -V/DD \bar{c}^* becomes much smaller.



$(X \rightarrow J/\psi \omega) / (X \rightarrow J/\psi \rho)$ ratio

▶ Integrating for $(M_X - 1.2 \text{ MeV}, M_X + 1.2 \text{ MeV})$,
we get

▷ $(X \rightarrow J/\psi \omega) / (X \rightarrow J/\psi \rho) = 2.5$

▶ Ambiguities:

▷ origin of the attraction, $c\bar{c} - D\bar{D}$ or $D - D^{\text{bar}}$ int?

▷ size of J/ψ -V interaction

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$$\frac{\text{Br}(X \rightarrow \pi^+ \pi^- \pi^0 J/\psi)}{\text{Br}(X \rightarrow \pi^+ \pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3 \quad (\text{Belle})$$
$$= 0.8 \pm 0.3 \quad (\text{BABAR}).$$

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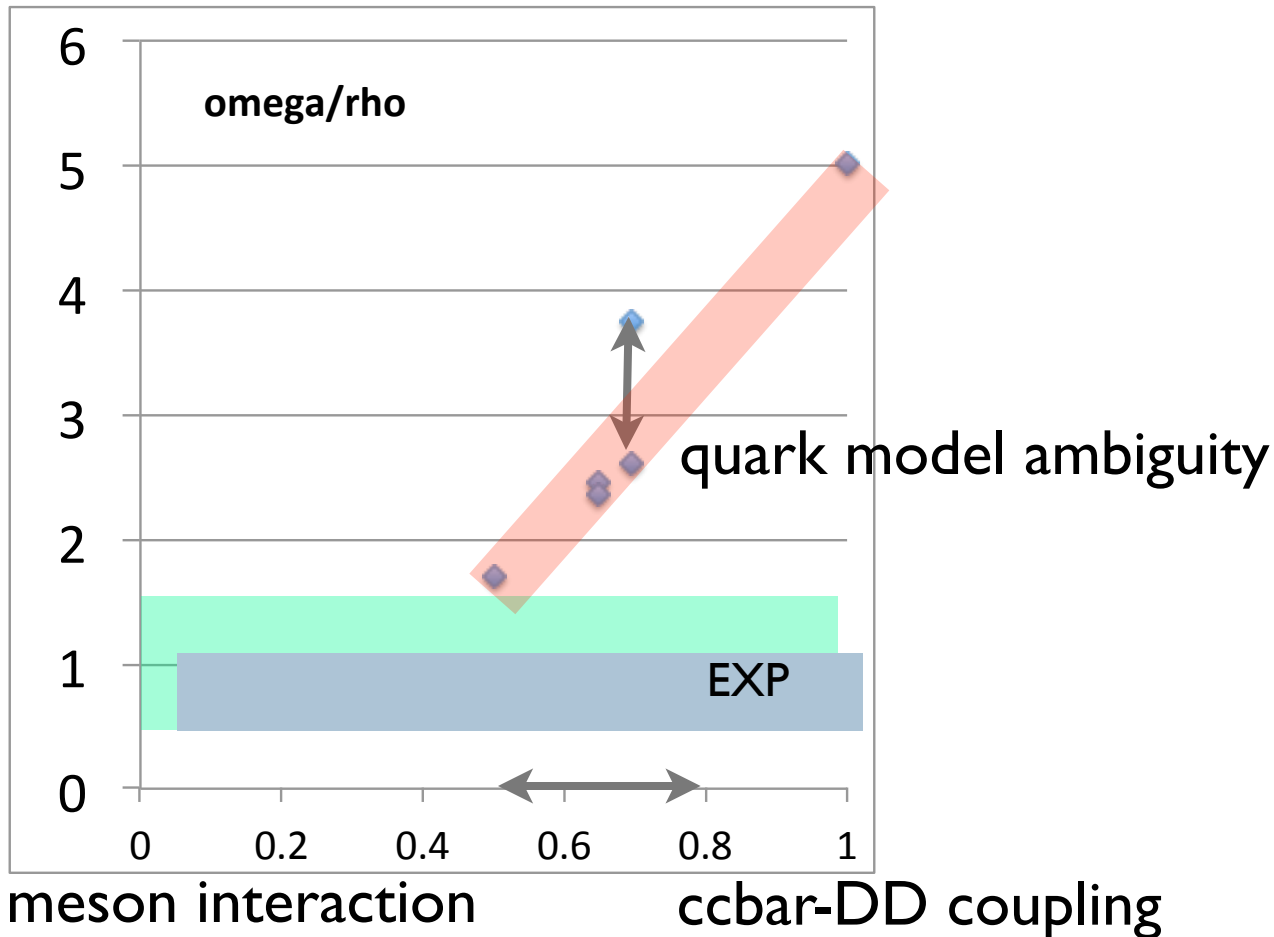
▶ Ambiguities:

▷ origin of the attraction, $c\bar{c} - D\bar{D}$ or $D - D^{\text{bar}}$ int?

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$(X \rightarrow J/\psi \omega) / (X \rightarrow J/\psi \rho)$ ratio

- Ambiguities: origin of the attraction,



Summary

- ▶ $c\bar{c}$ → $J/\psi \omega$, $J/\psi \rho$ spectrum is calculated by
 - ▷ $c\bar{c} - D^0 \bar{D}^{*0} - D^+ D^{*-} - J/\psi \omega - J/\psi \rho$
- ▶ X(3872) is a two-meson molecule with a $c\bar{c}$ core.
- ▶ There is a mechanism to have such narrow peaks of $J/\psi \rho, \omega$ that appears on the threshold.
 - ▷ This occurs as far as large strength of DD exists just above threshold. Not so accidental.
- ▶ A large Isospin breaking can be realized.
 - ▷ a small breaking is enhanced by the large width of ρ meson

Summary

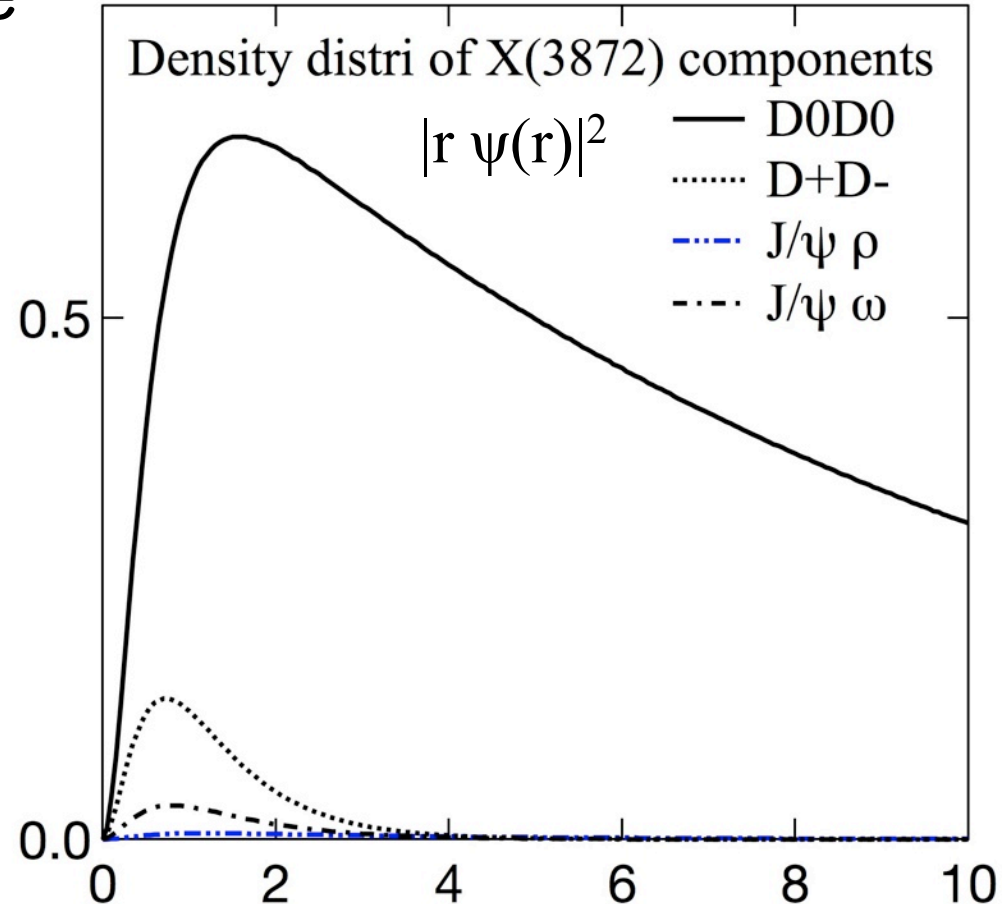
- ▶ This $c\bar{c}-D\bar{D}^*-J/\psi V$ picture is promising to satisfy the constraints from the experiments.
 - ▷ X(3872) mass & width
 - ▷ No extra $c\bar{c}$ peak
 - ▷ Size of Isospin breaking
 - ▷ Production rate, γ decay

Thank you !

Back up

Isospin density at the resonance

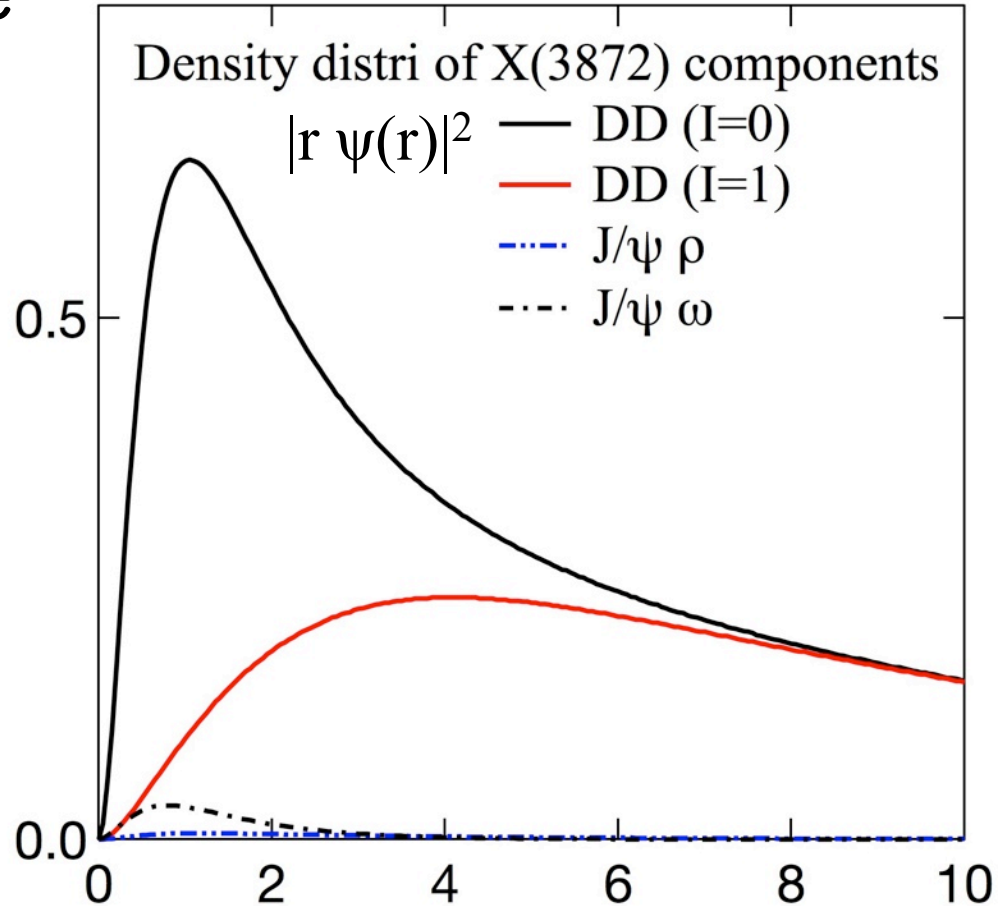
- ▶ Density from the wave function at the resonance energy (no vector width) shows
 - ▷ At the short range, density ($l=0$) \gg ($l=1$).
 - ▷ At $r \rightarrow \infty$, density ($l=0$) = ($l=1$).
 - ▷ ρ ω components are small.



Isospin density at the resonance

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X(3872) components

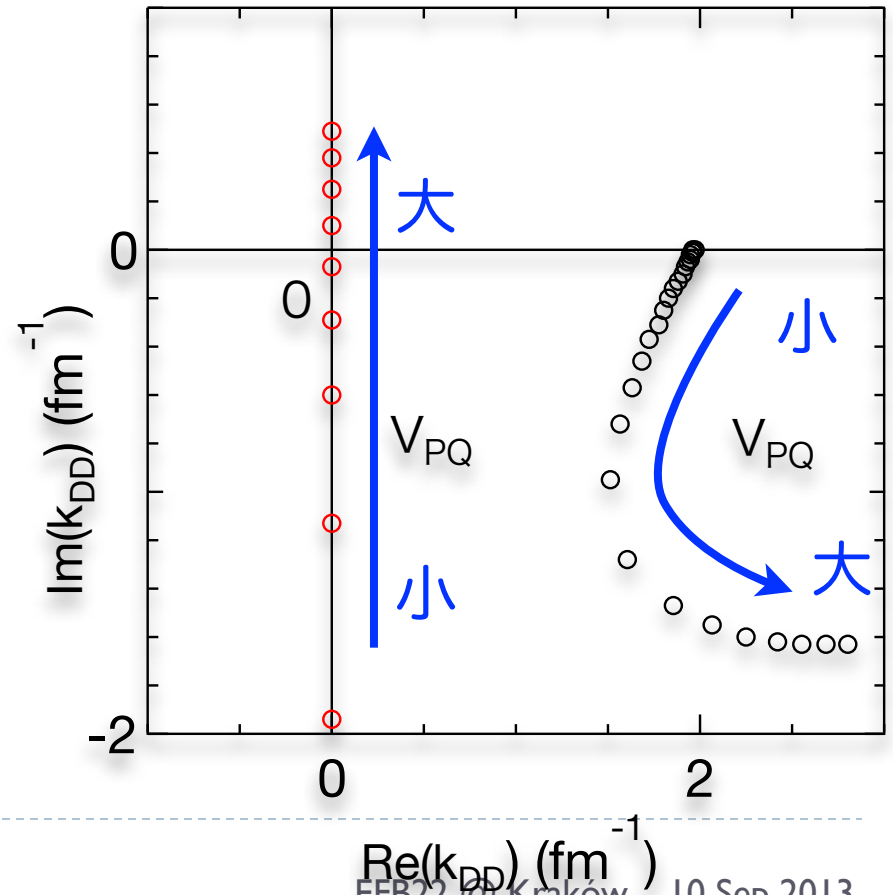
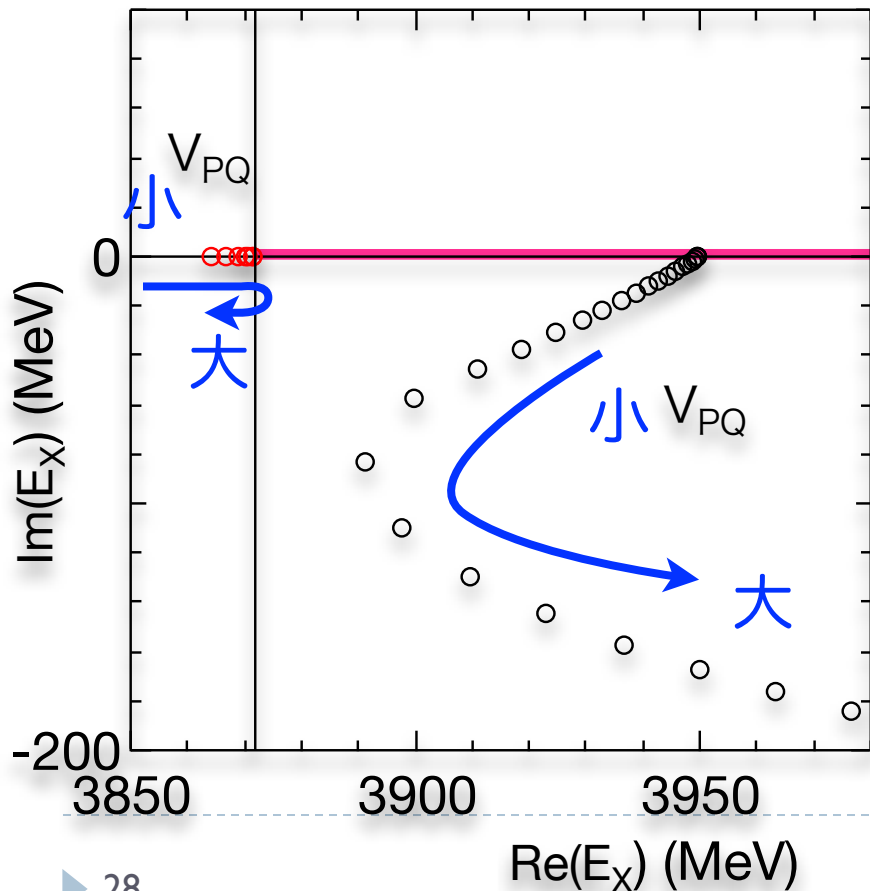
- ▶ Almost all is $D^0\bar{D}^{*0}$, however, there is a $J/\psi V$ components.
- ▶ $J/\psi \omega / J/\psi \rho$ ratio is 1.9

$D^0\bar{D}^{*0}$	0.9422
$J/\psi \rho$	0.0037
$J/\psi \omega$	0.0070
$D^+\bar{D}^{*-}$	0.0260
$c\bar{c}$	0.0245

Peak が threshold 上にあるのは偶然？

▶ G_Q の pole の動き (1 channel)

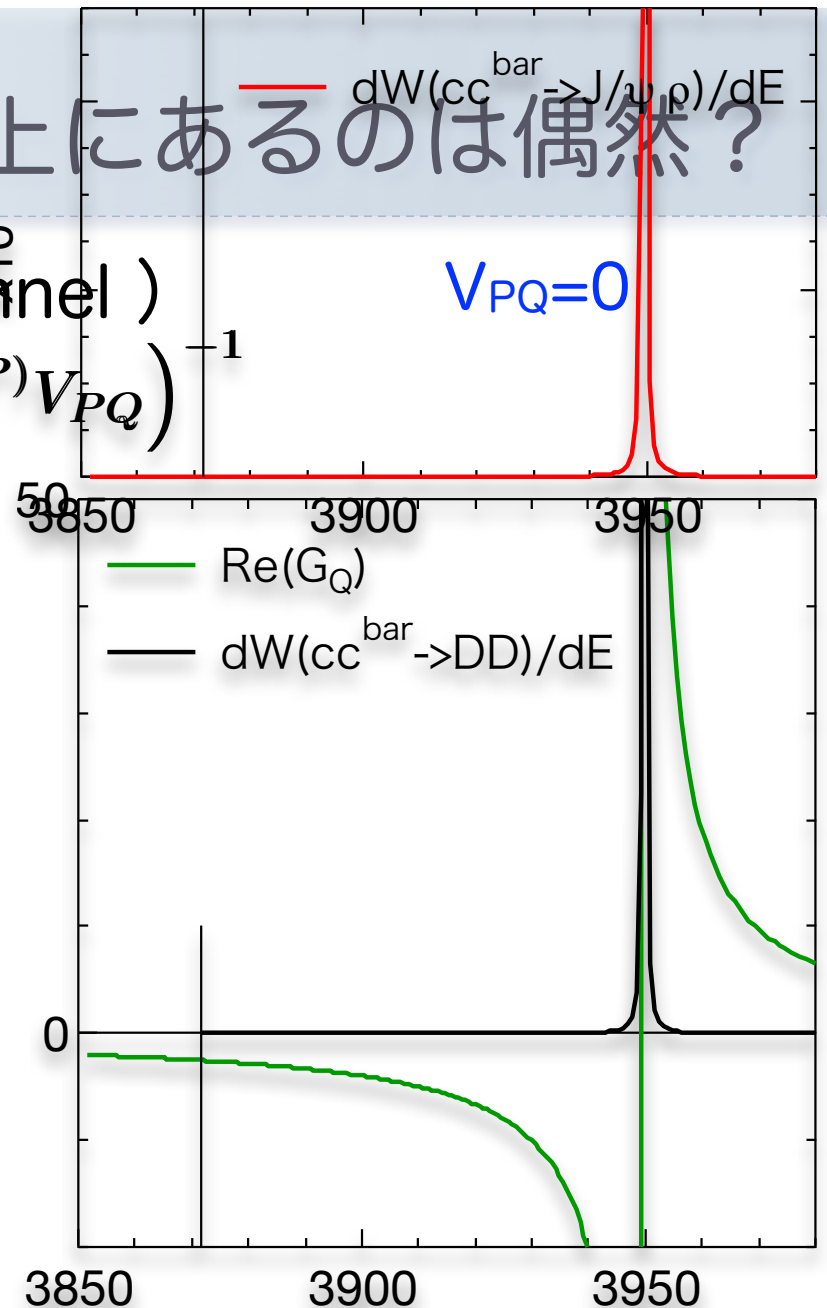
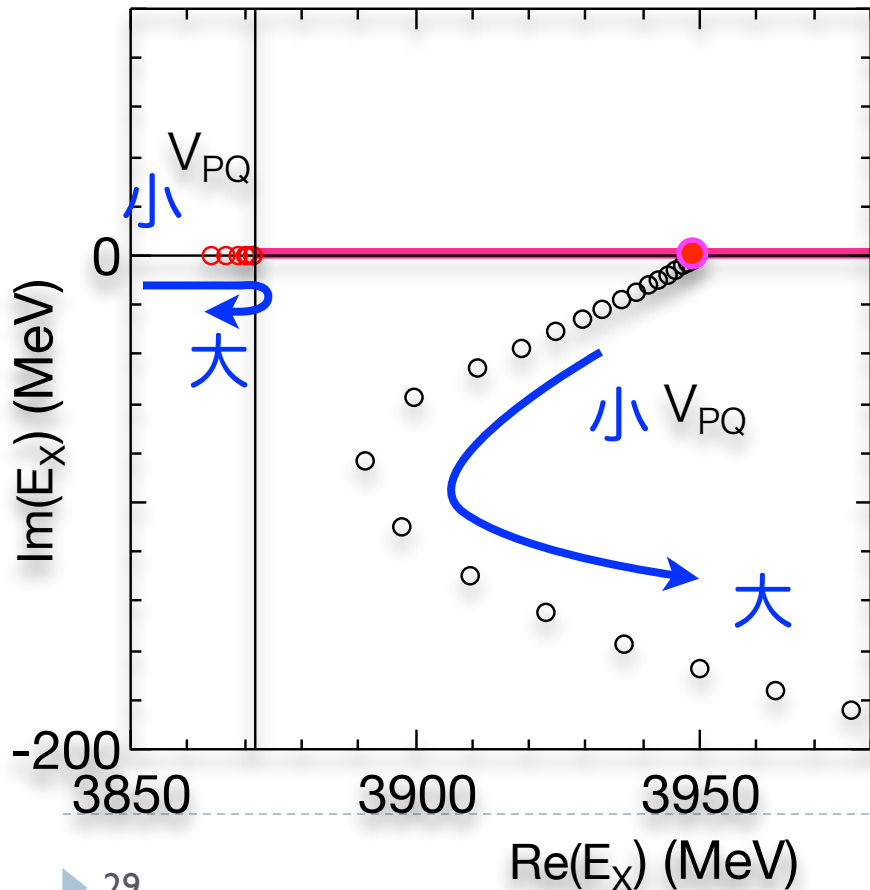
$$G_Q = \left(H - E_0^{(Q)} - V_{QP} G^{(P)} V_{PQ} \right)^{-1}$$



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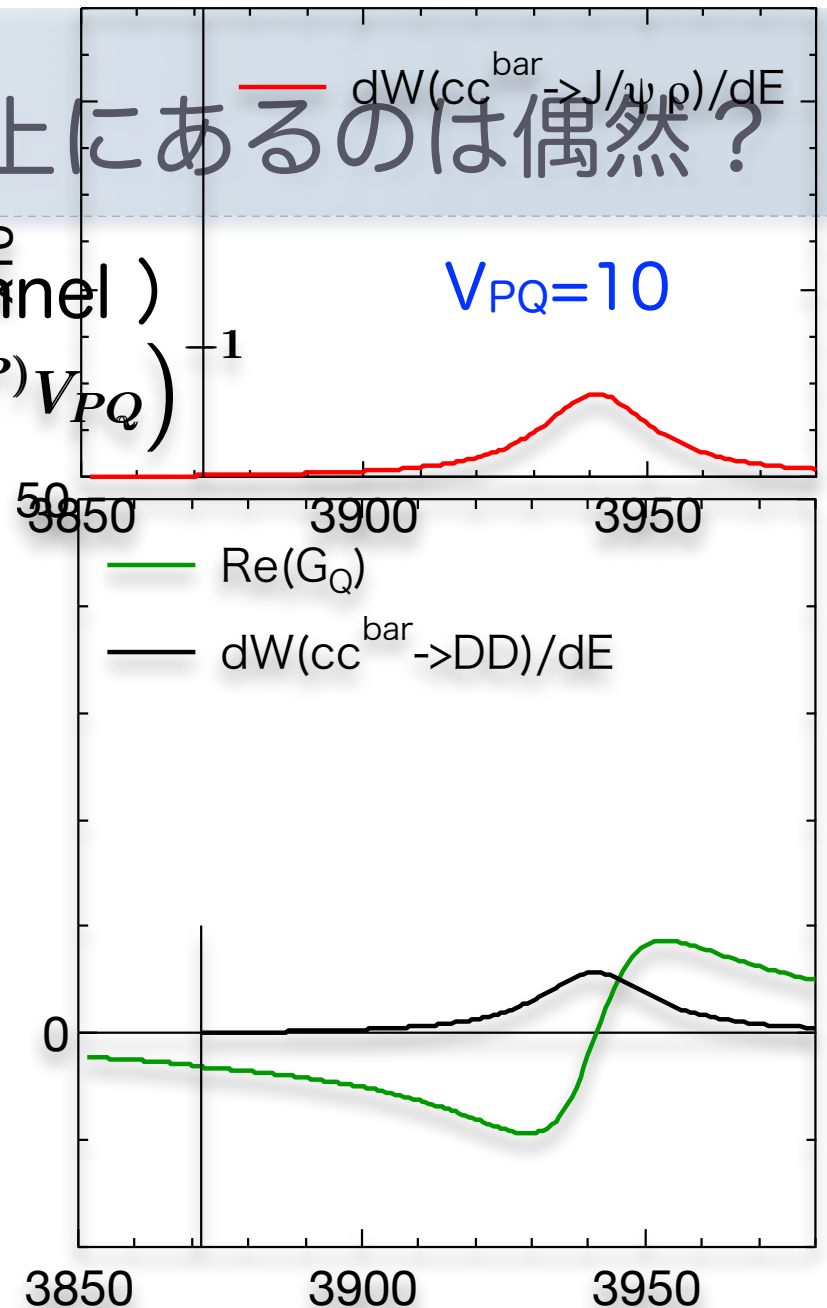
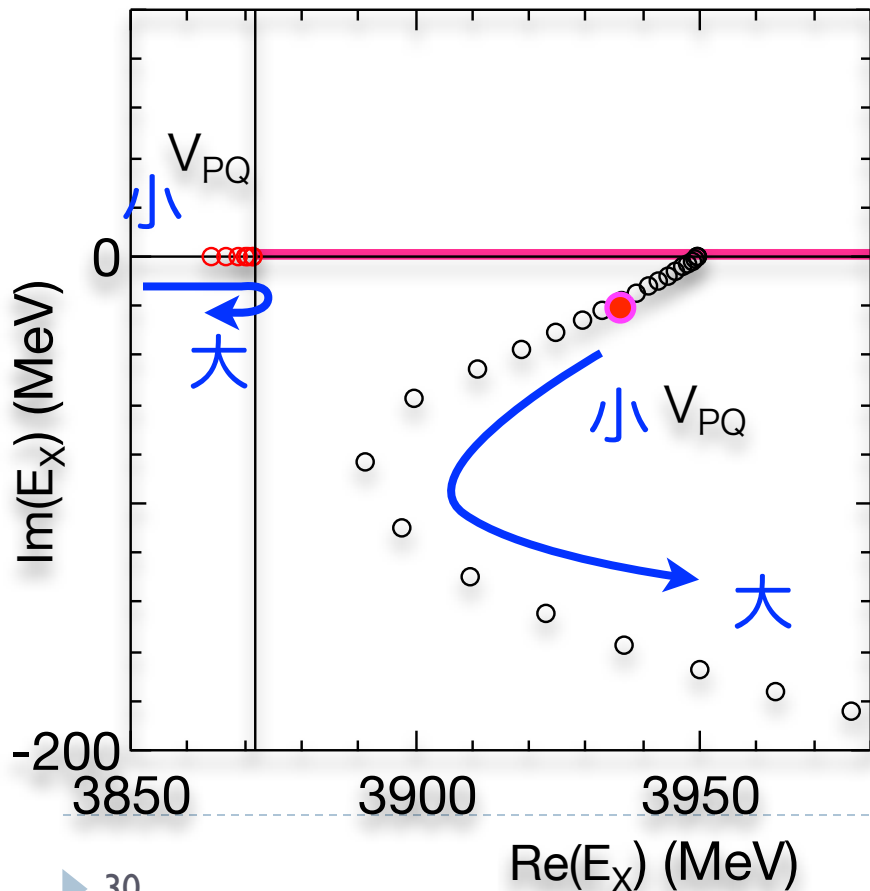
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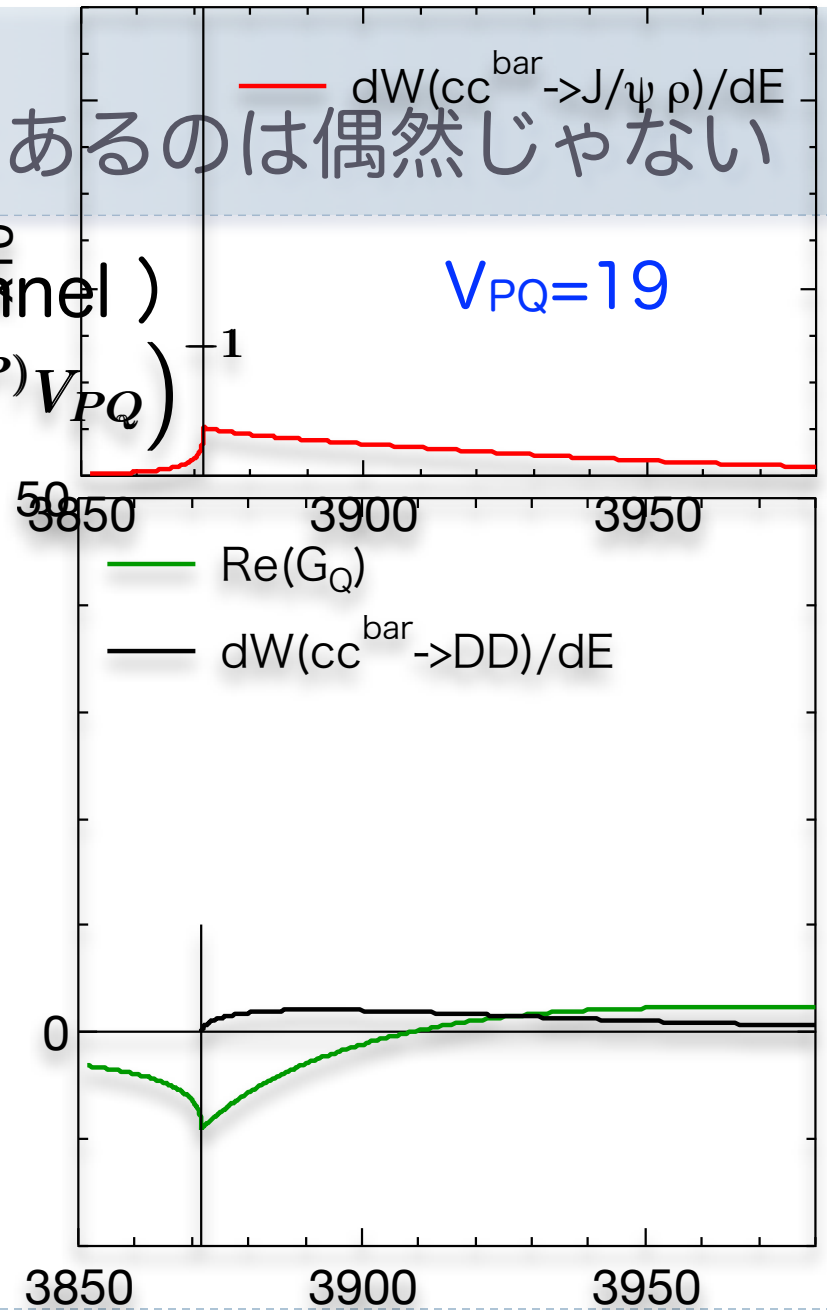
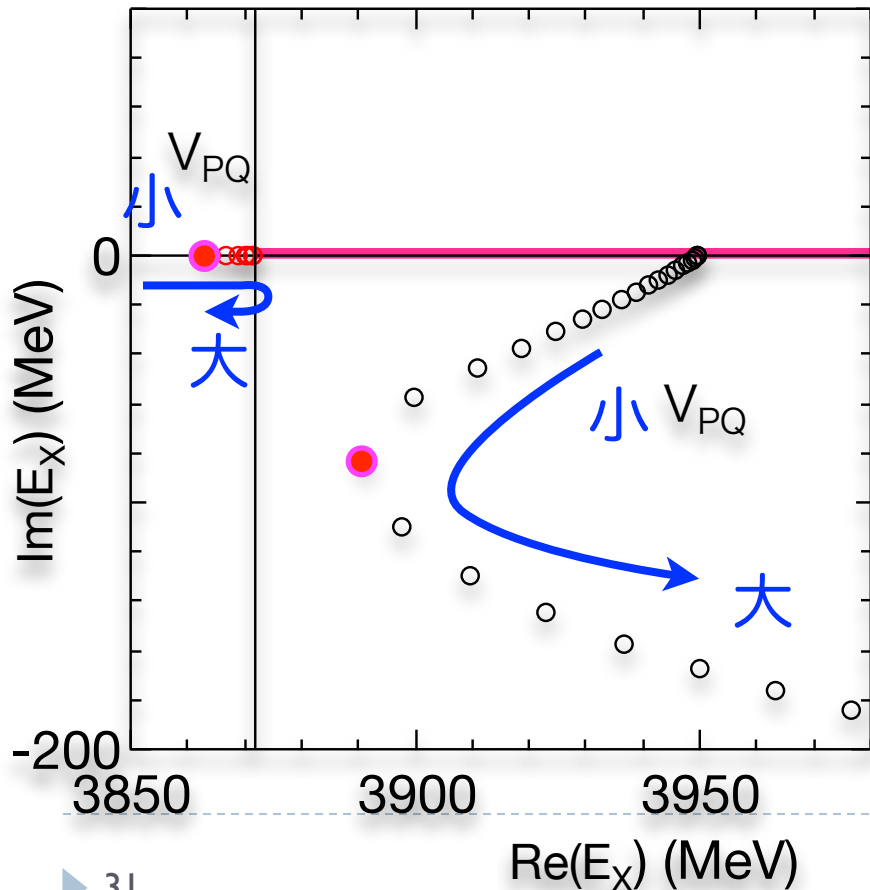
$$G_Q = \left(H - E_0^{(Q)} - V_{QP} G^{(P)} V_{PQ} \right)^{-1}$$



Peak が threshold 上にあるのは偶然じゃない

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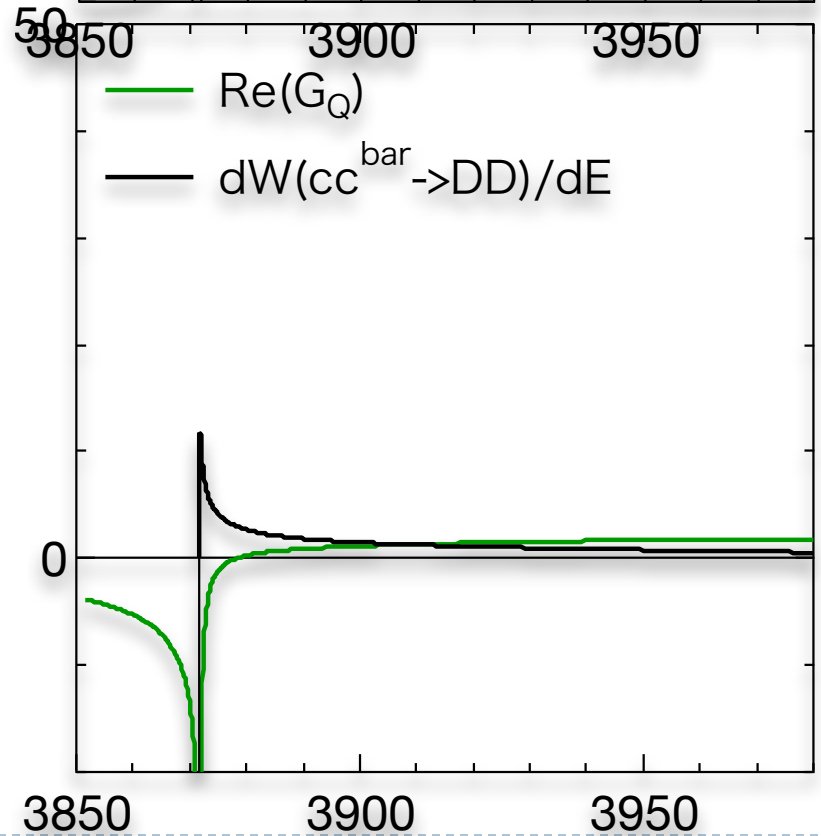
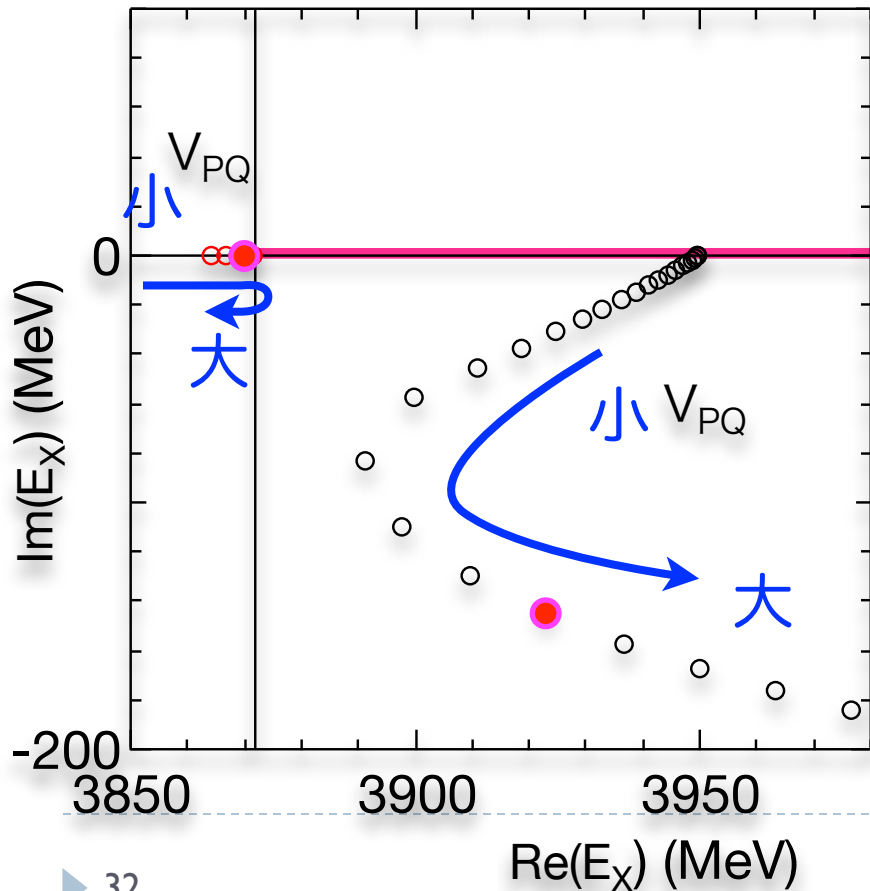
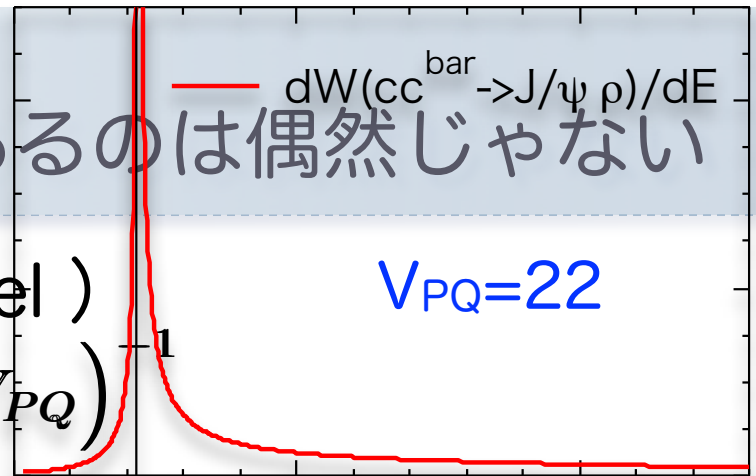
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