# Femtoscopic study on $D^0 \overline{D^*}^0$ interaction

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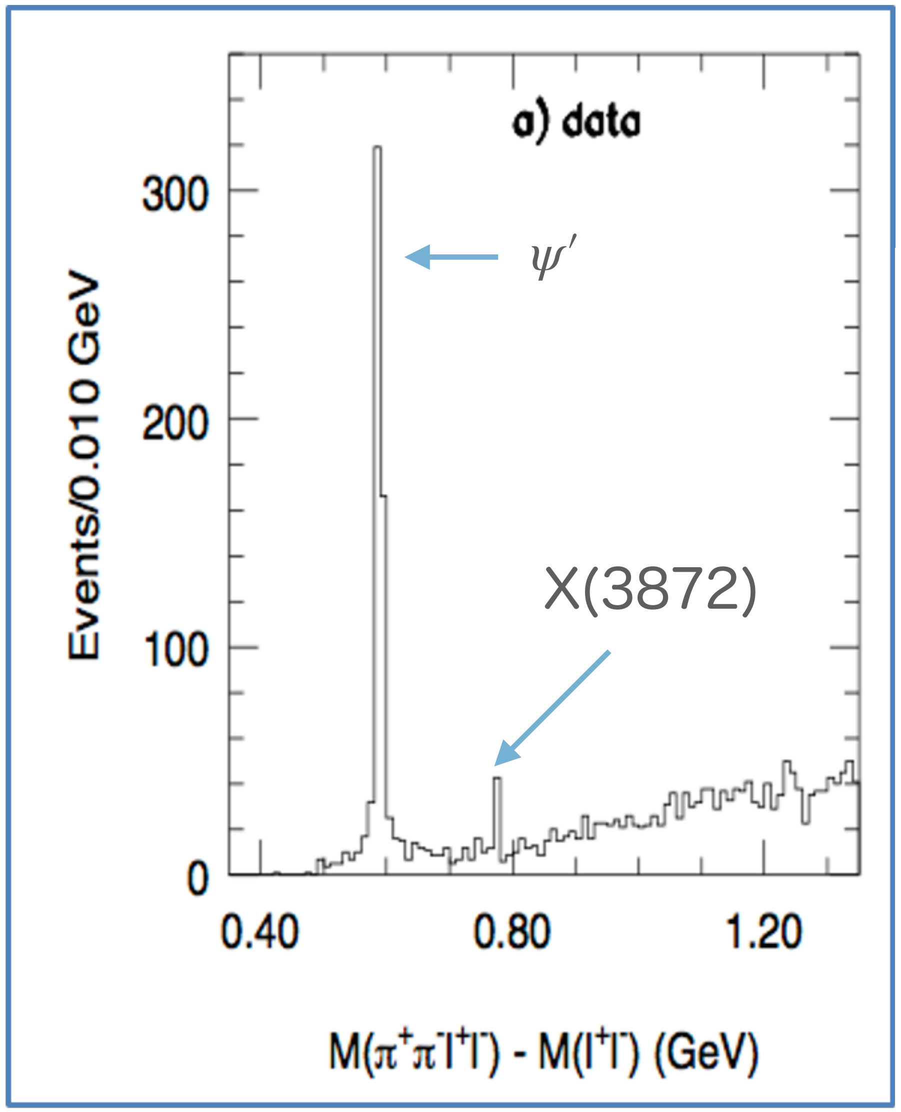
Baryons 2025, ICC Jeju, Korea, 2025/11/25

# Introduction

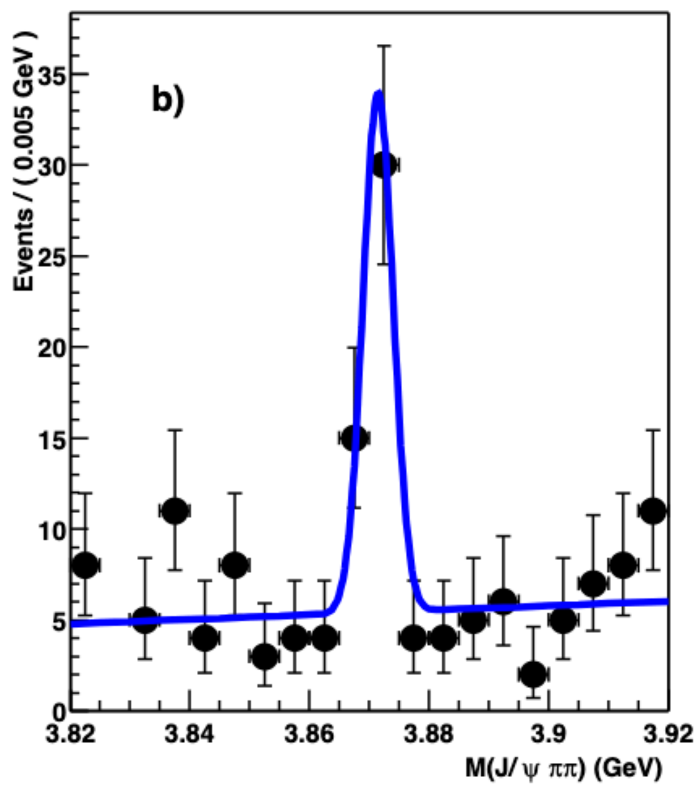
- In 2003, Belle Collaboration observed X(3872) in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays.

It was the beginning of the exotic hadron era!




Phys. Rev. Lett. 91 (2003) 262001

This paper's citation is more than 2800.



# Experimental fact of X(3872)

- LHCb measured the mass and the width of X(3872) precisely in $B^+ \to K^+\pi^+\pi^- J/\psi$ decays.

  (JHEP 08 (2020) 123)

  Mass: $3871.64 \pm 0.06 \pm 0.01$ MeV

  very close to $D^0\overline{D^{0*}} = 1864.84 + 2006.85 = 3871.69$ MeV threshold. Binding energy: ~ 0.05 MeV

- BESIII determined the T-matrix pole of X(3872) in $e^+e^- \to \gamma X(3872) \to \gamma[D^0\overline{D}^0\pi^0]$ (PRL 132 (2024)151903)

  $(3871.70 \pm 0.15^{+0.07}_{-0.08}) - i(0.19 \pm 0.08^{+0.14}_{-0.19})$ MeV

# Experimental fact of X(3872)

- Width: $1.19 \pm 0.21$ MeV

  Very small width

- $I^G = 1^+$, $J^{PC} = 1^{++}$

- We consider isospin symmetry is largely broken in X(3872) and it is the mixed state of $I = 0$ and $I = 1$.

# $D^0\overline{D}^{*0}$ correlation function

- Recently, femtoscopy techniques are developing.

- We will have a chance to observe $D^0\overline{D^*}^0$ correlation function.

- We study the relation between binding energy of X(3872) and $D^0\overline{D^*}^0$ correlation function.

- Experimentally observed $D^0\overline{D^*}^0$ channel is the mixing of X(3872) and Zc(3900) channels. We study $D^0\overline{D^*}^0$ correlation function in Zc(3900) channel too.

# Experimental fact of $Z_c(3900)^{\pm,0}$

- Mass: $3887.1 \pm 2.6$ MeV

  about 10 MeV above the $D\overline{D^*}$ threshold

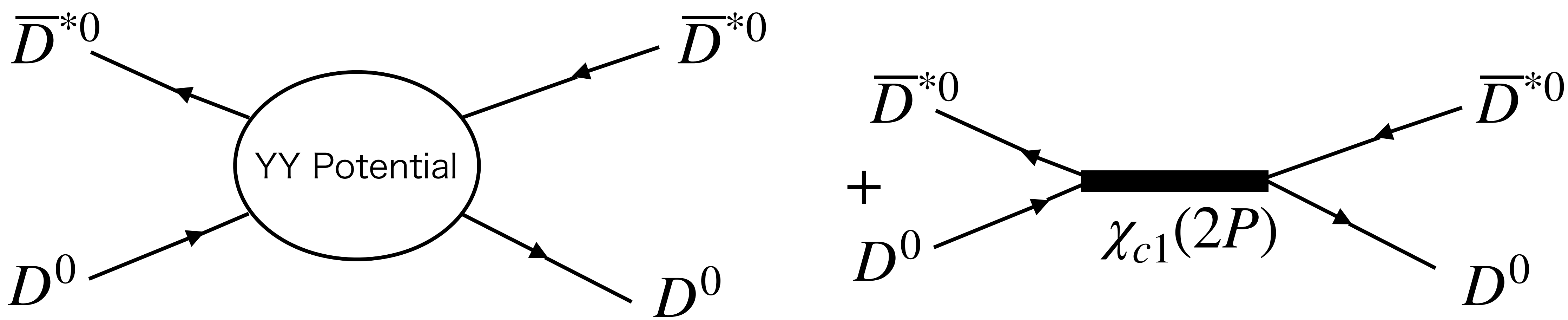
- Width: $28.4 \pm 2.6$ MeV

- $I^G = 1^+$, $J^{PC} = 1^{+-}$

- Minimal quark component of $Z_c(3900)^+$ is $c\bar{c}u\bar{d}$,

  namely, exotic state.

# Our model of X(3872)




- $D^0\overline{D}^{*0}$ molecule + $c\bar{c}$ core: $\chi_{c1}(2P)$
- To easily achieve effects similar to OPEP, we introduced Yamaguchi Separable Potential between $D^0$ and $\overline{D^*}^0$.
- We added the coupling between $c\bar{c}$ core and $D^0\overline{D^*}^0$ state with monopole form factor.

# Our model of X(3872)

- Effect of $c\bar{c}$ core: $\chi_{c1}(2P)$ coupling is just changing the YY Potential strength $\lambda \to \lambda + g^2/m_{c\bar{c}}$.

- Our model parameters are $\lambda$ and cutoff $\Lambda$.

- We fixed $\lambda$ so as to reproduce observed mass of X(3872):

- $\Lambda = 500$ MeV : typical hadron size

# Correlation function

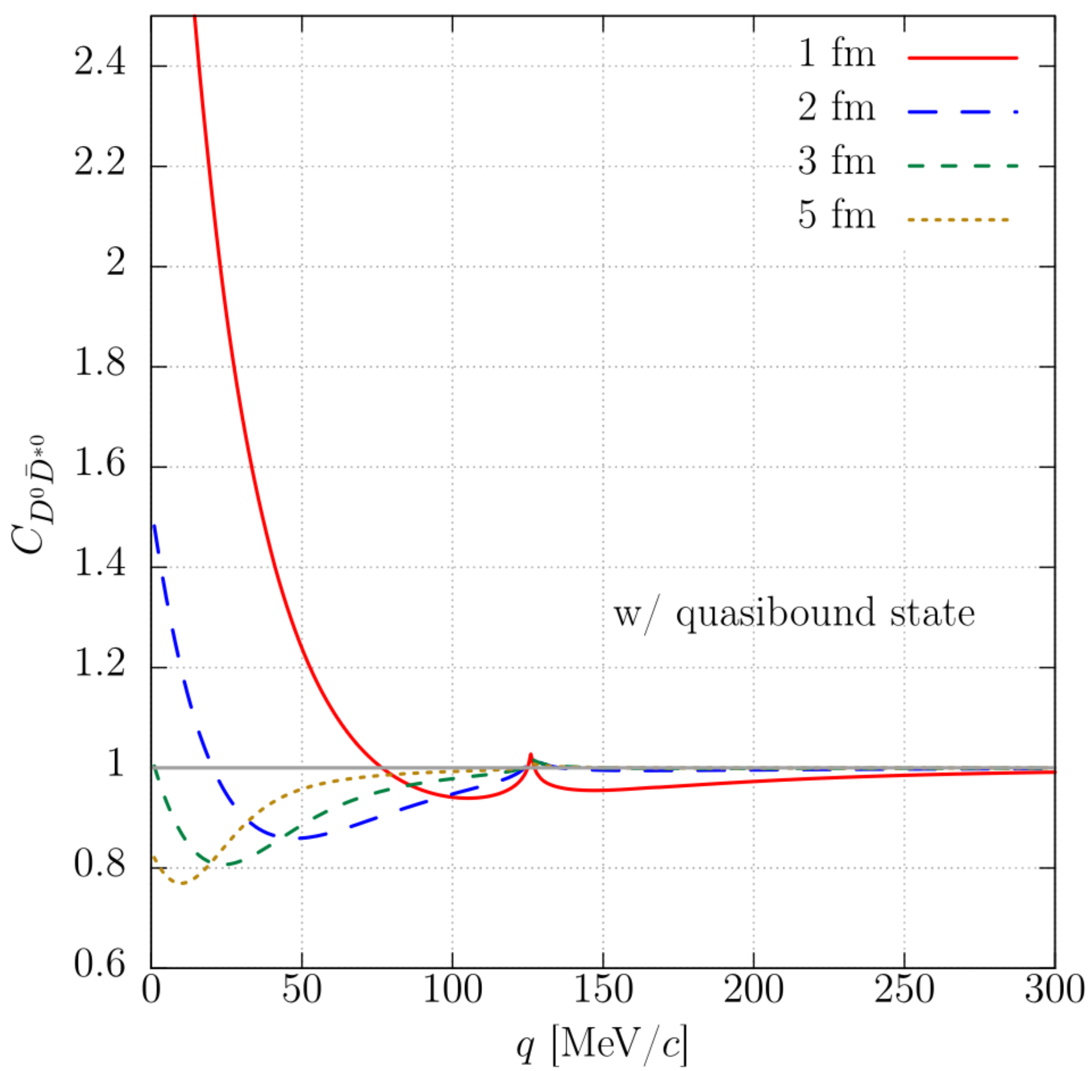
- We calculate correlation function $C(k)$ using the Koonin-Pratt formula given by

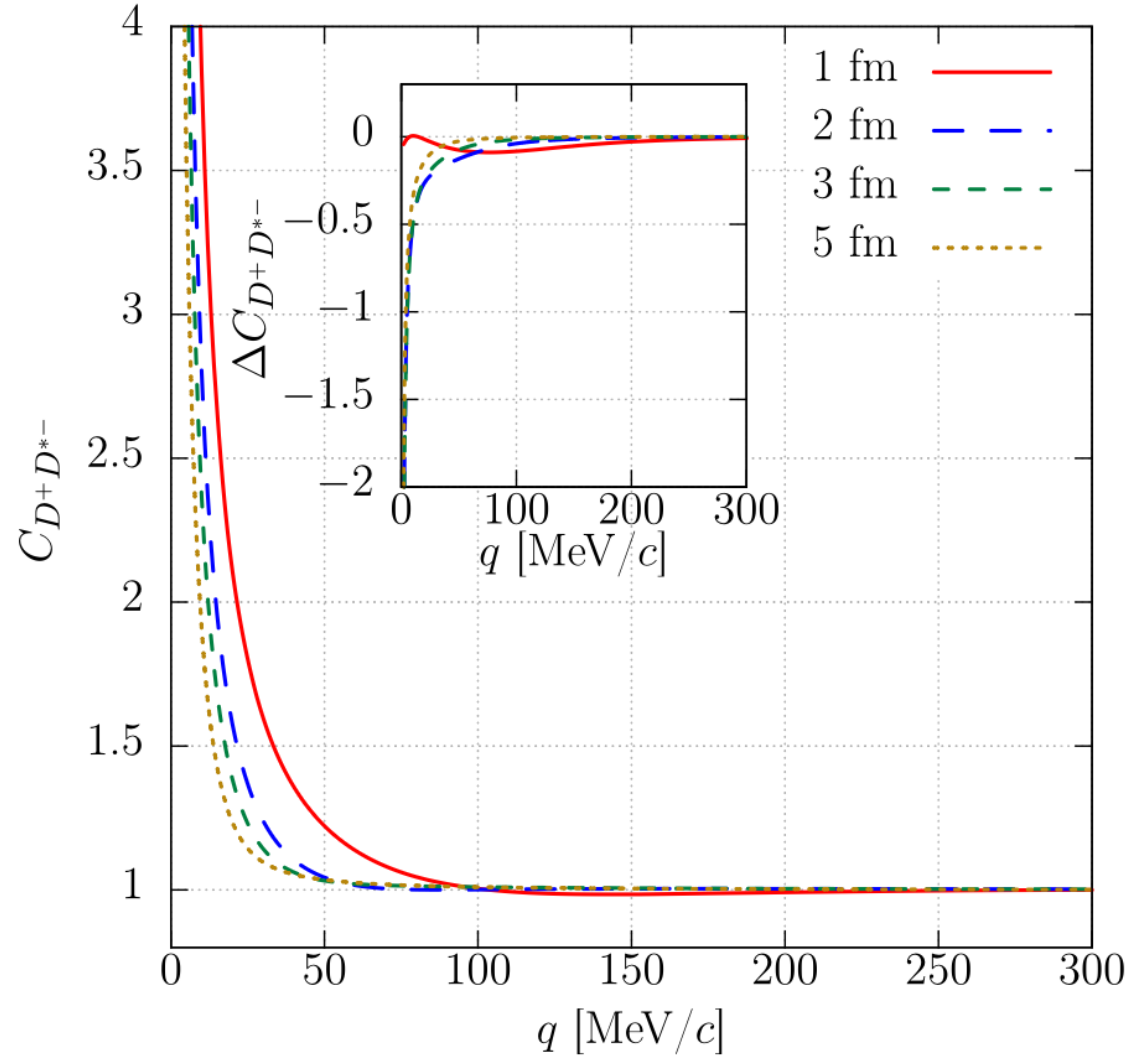
$$C_\beta(k_\beta) = \sum_\alpha \int d\mathbf{r} S(\mathbf{r}) \omega_\alpha |\Psi^{(-)}_{\beta\alpha}(\mathbf{r}, \mathbf{k}_\alpha)|^2 \ ,$$

$$S(\mathbf{r}) = \frac{1}{(2\sqrt{\pi}R)^3} \exp\left(-\frac{r^2}{4R^2}\right)$$: source function

# Outcomes of prior studies

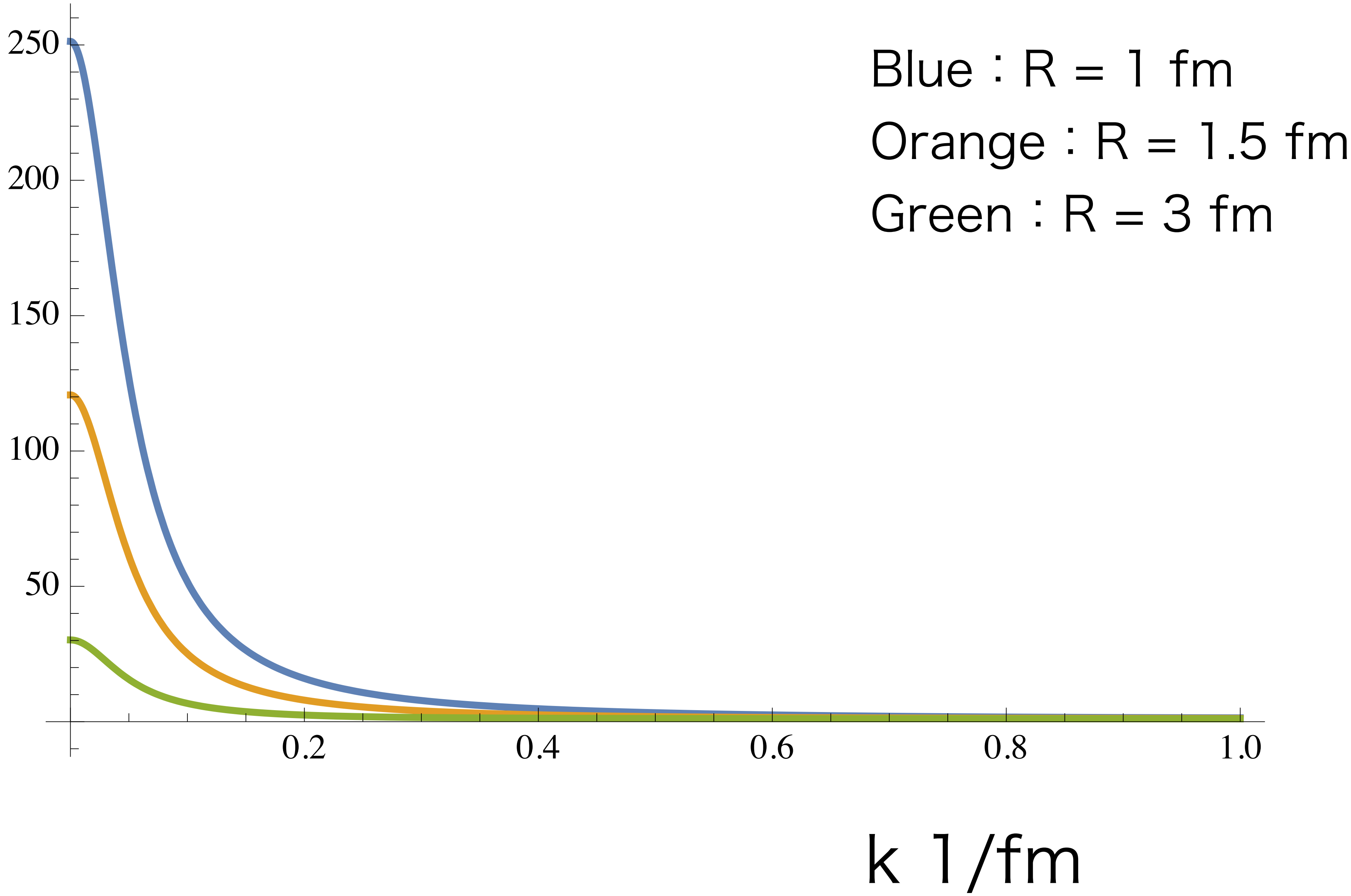
- Kamiya, Hyodo, Ohnishi, Eur. Phys. J. A58 (2022) 131



# Numerical results of $D^0\overline{D^*}^0$ $(J^{PC}=1^{++})$ correlation function

Binding energy of X(3872) = -0.05 MeV (exp. value)

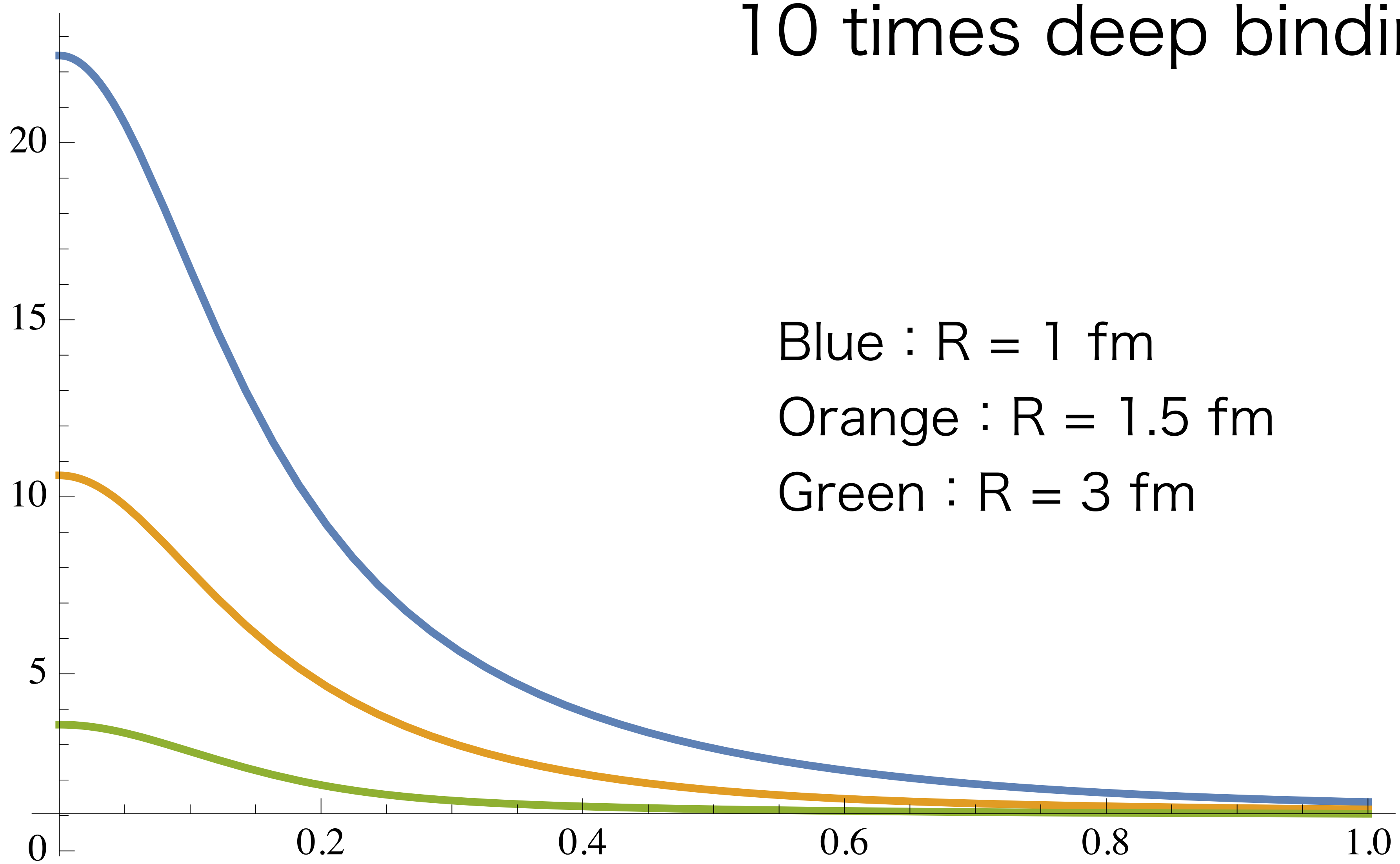



Correlation function becomes very large.

# Numerical results of $D^0 \overline{D^*}^0$ ($J^{PC} = 1^{++}$) correlation function

Binding energy of X(3872) = -0.5 MeV

10 times deep binding case




Blue : R = 1 fm

Orange : R = 1.5 fm

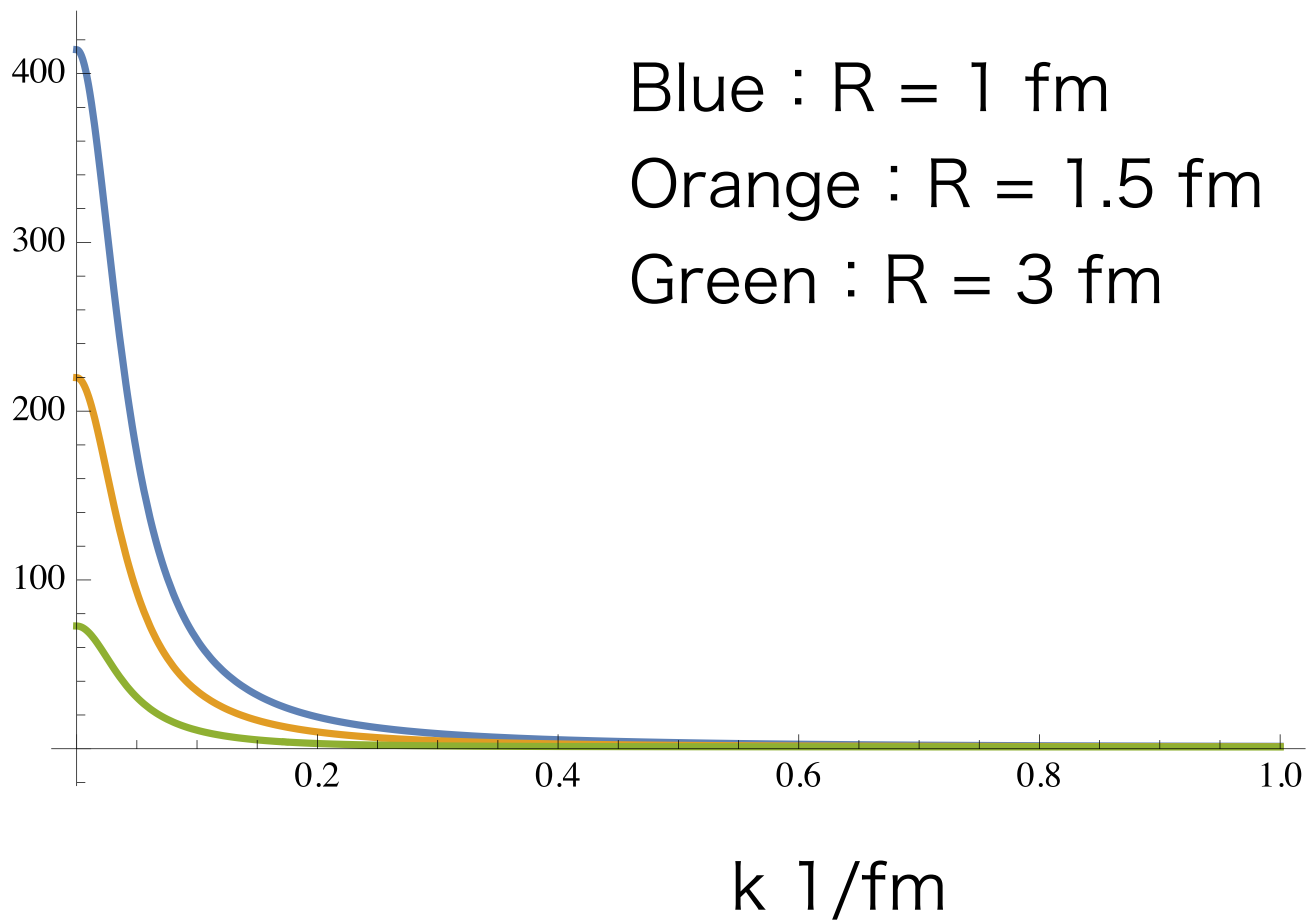
Green : R = 3 fm

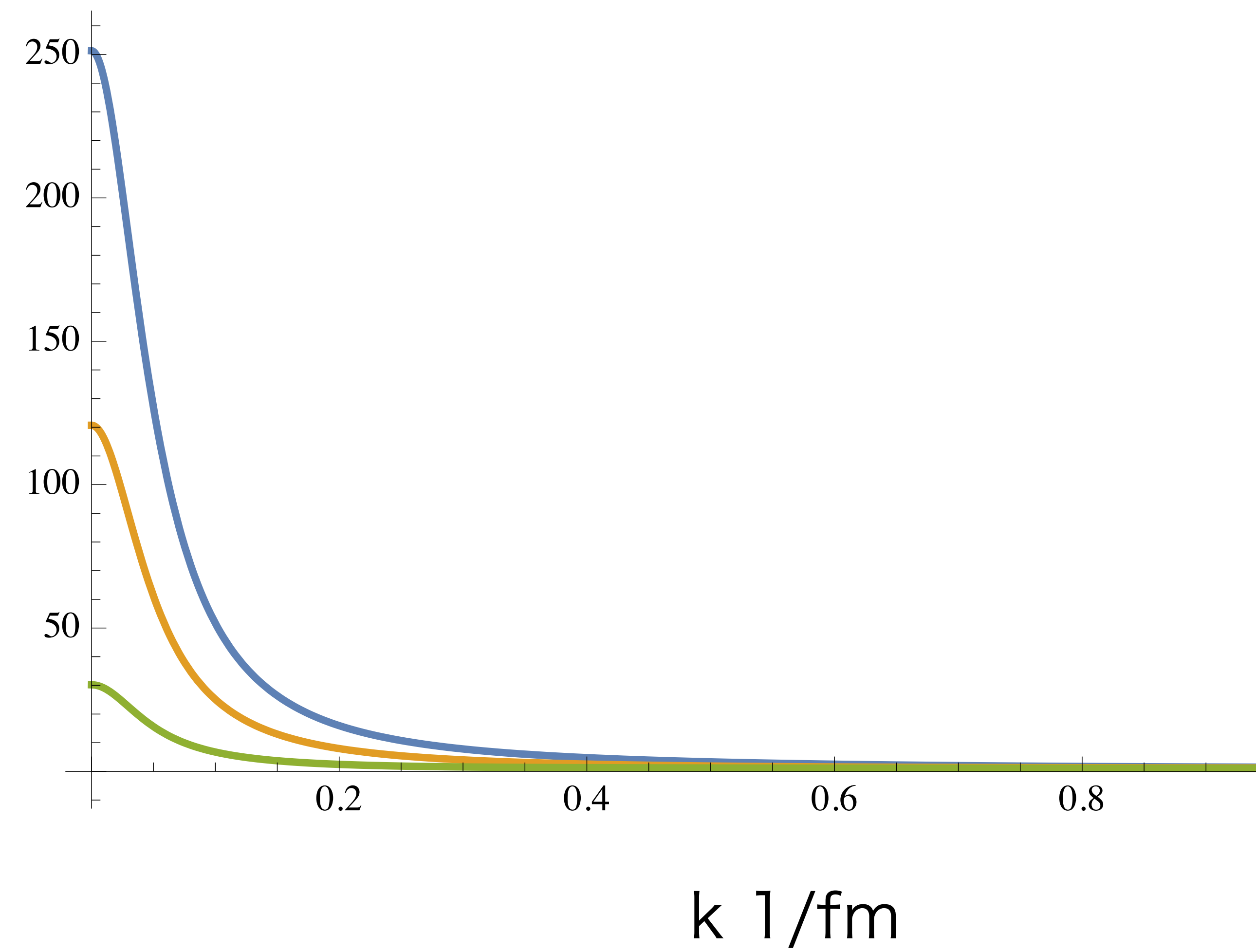
k 1/fm

# Numerical results of $D^0\overline{D^*}^0$ ($J^{PC} = 1^{++}$) correlation function

Virtual state: Pole position = -0.04 MeV from threshold in the second Riemann sheet

Bound state: Binding energy of X(3872) = -0.05 MeV (exp. value)



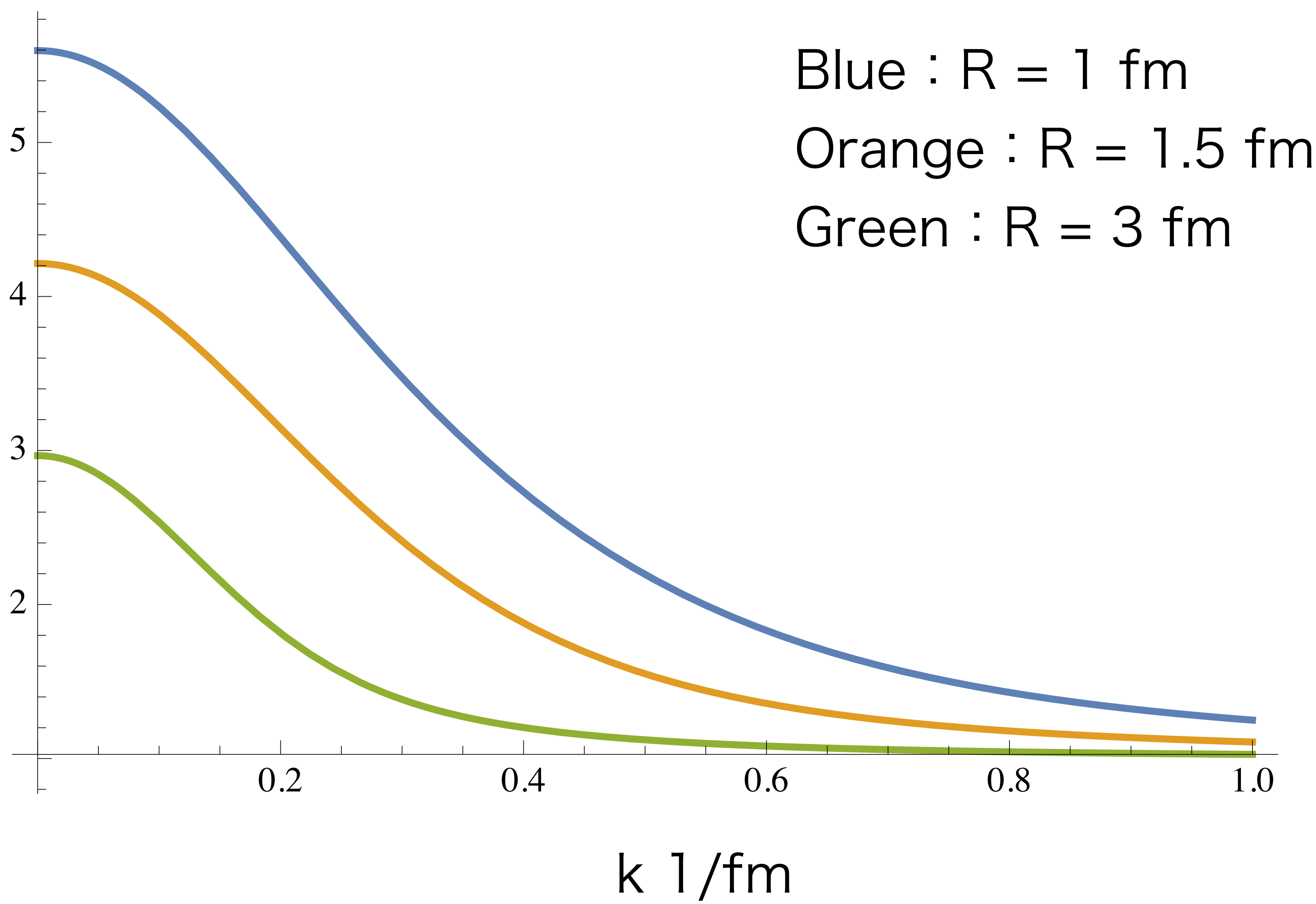




Correlation function for virtual state is similar to that for bound state. We cannot distinguish between these two.

# Numerical results of $B^+\overline{B}^{*0}$ ($J^{PC}=1^{+-}$) correlation function

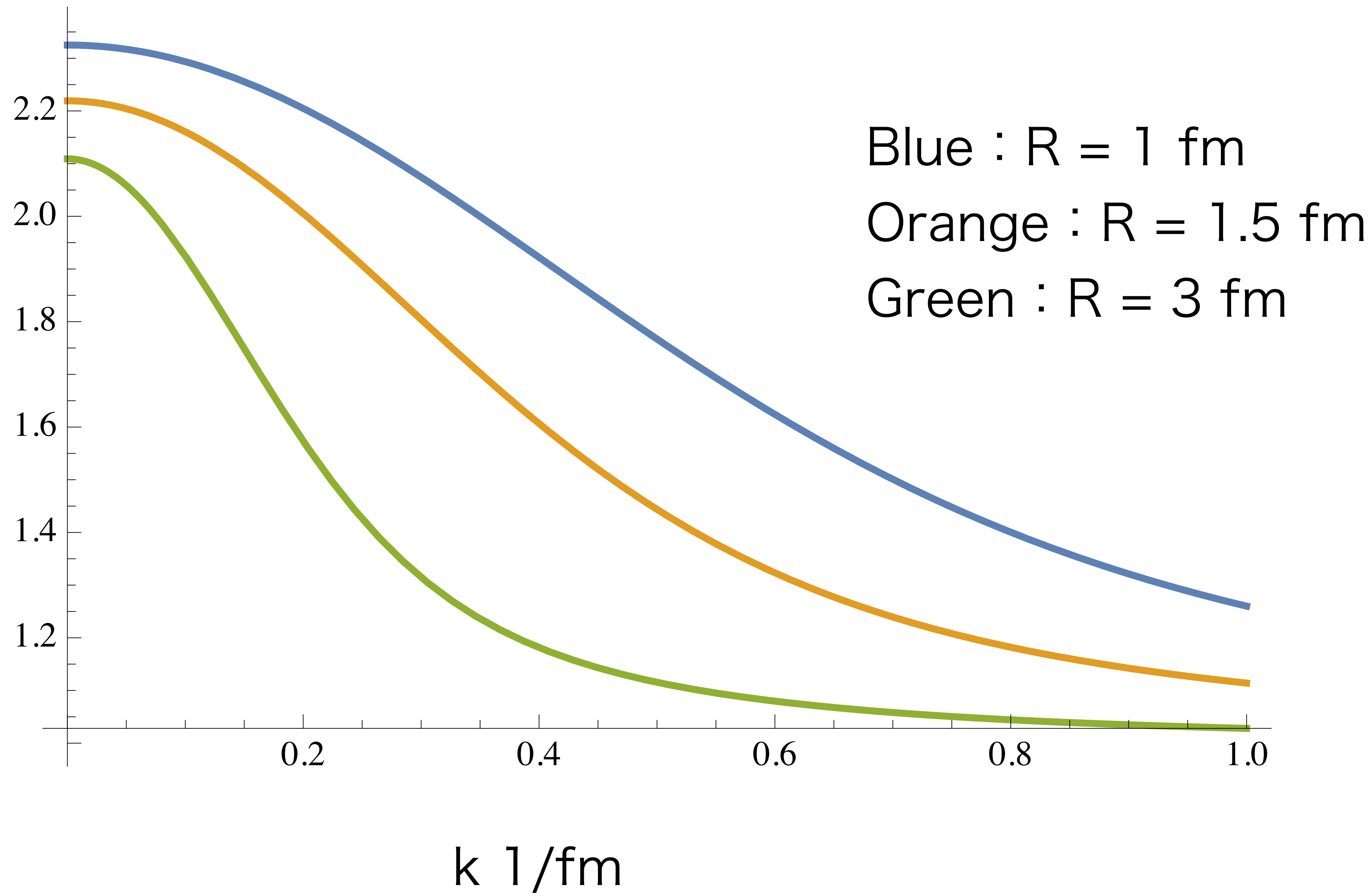
Zb(10610) Case：

Virtual state: Pole position = -1.0 MeV from threshold in the second Riemann sheet



# Numerical results of $D^0\overline{D^*}^0$ ($J^{PC}=1^{+-}$) correlation function

Potential is determined from Zb(10610). We apply this potential to Zc(3900): Virtual pole is -296 MeV from threshold



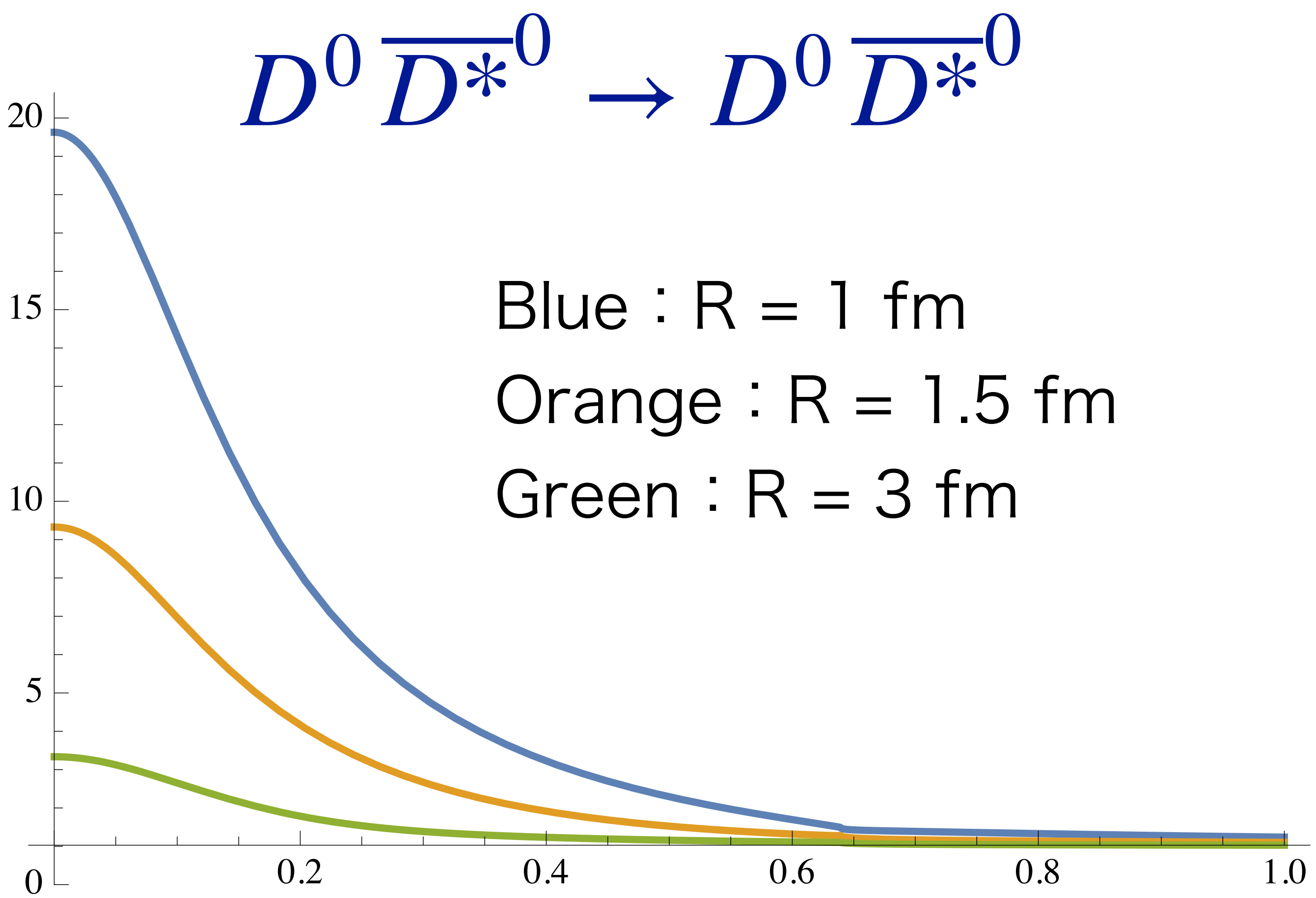

Correlation function in Zc(3900) channel is small.

# Numerical results of $D^0\overline{D^*}^0$ ($J^P = 1^+$) correlation function

$D^0\overline{D^*}^0 - D^+D^{*-}$ coupled channel case:

Binding energy of X(3872) = -0.5 MeV

Strength of $v_{12}$ is determined from $c\bar{c}$ core-$D\overline{D}^*$ coupling

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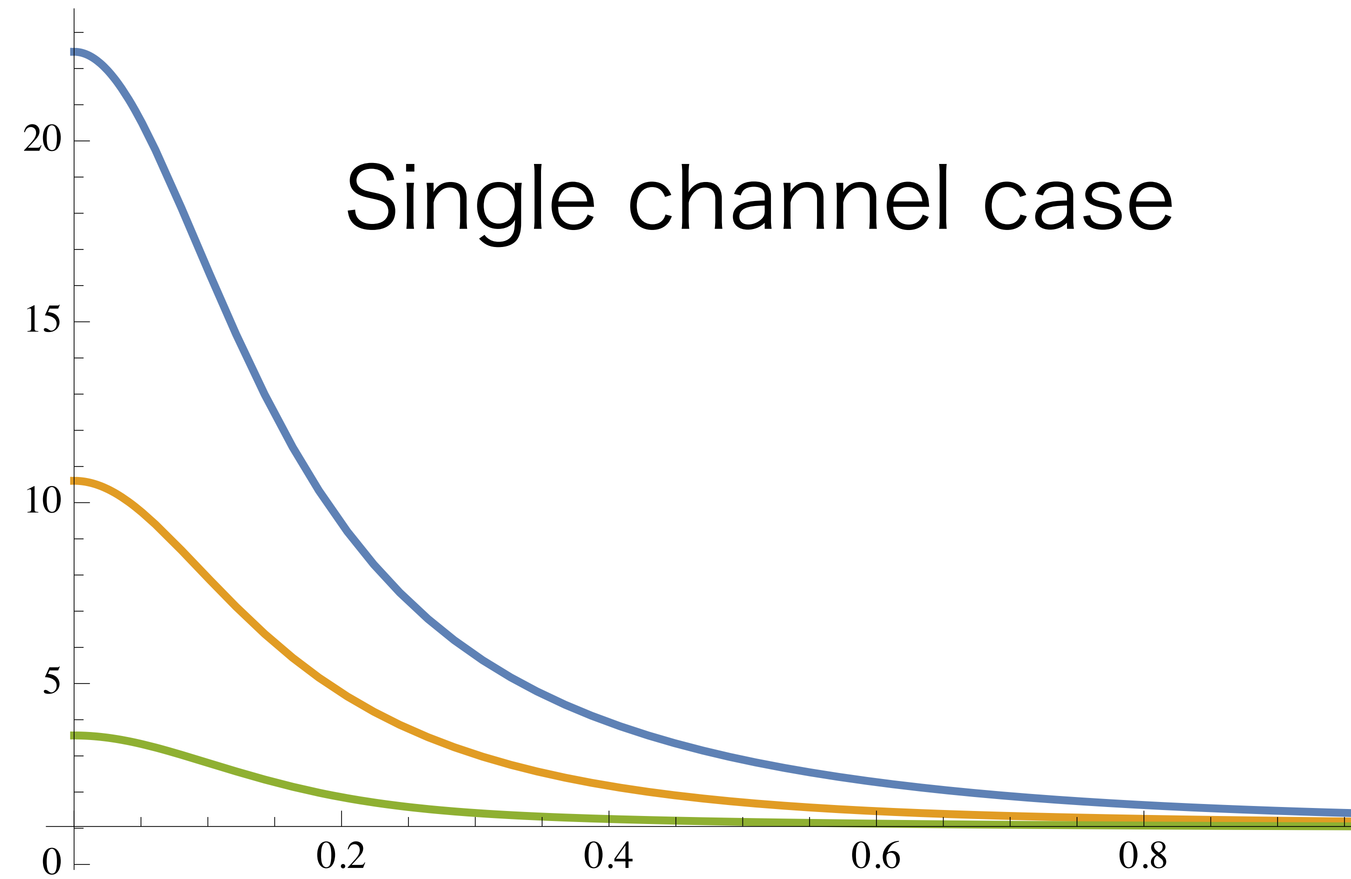


k 1/fm

Effect of the channel coupling is small.

# Numerical results of $D^0\overline{D}^{*0}$ correlation function

$D^0\overline{D}^{*0} - D^+D^{*-}$ coupled channel case:

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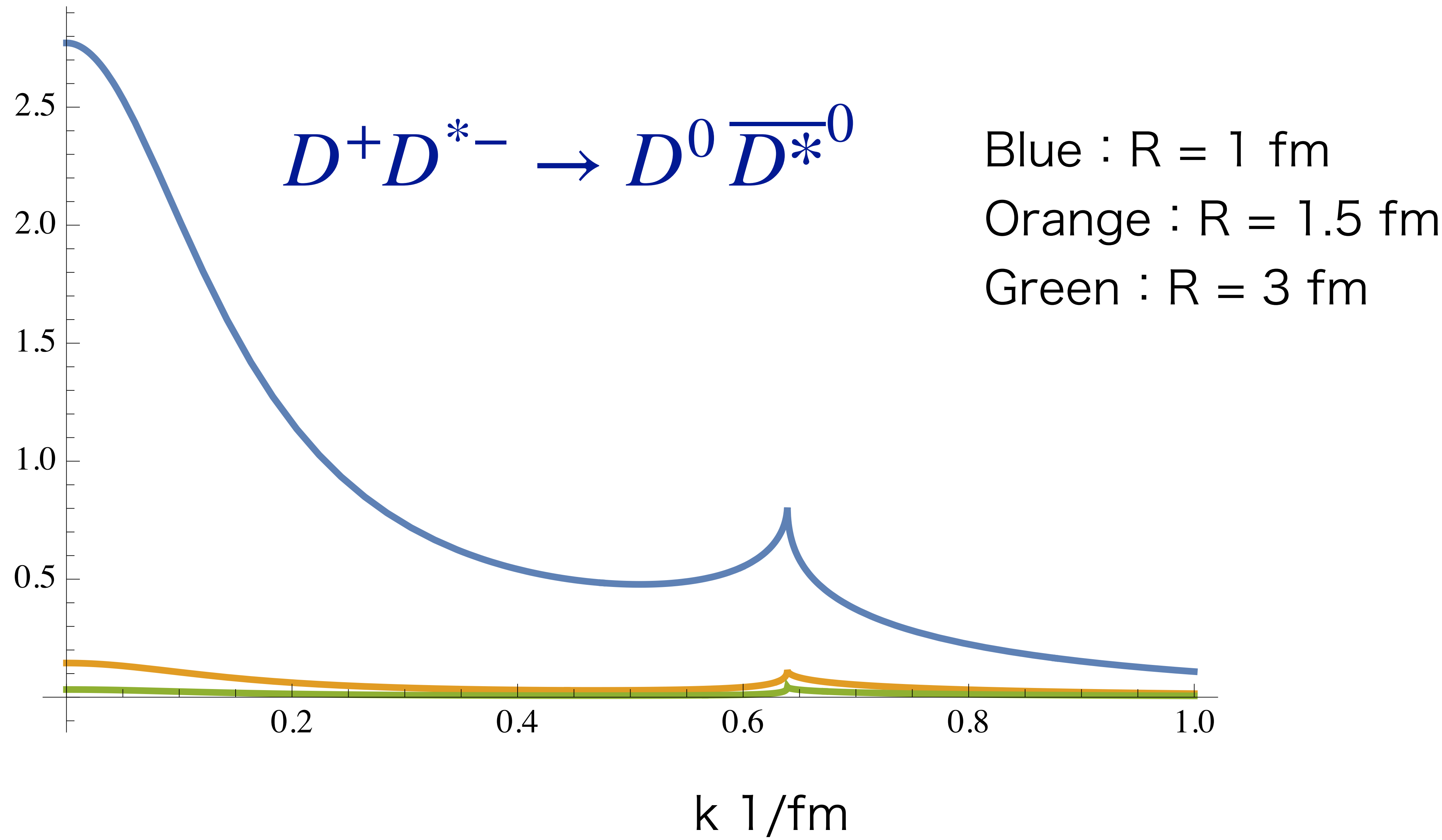

# Summary

- In order to understand the structure of X(3872), study of $D^0\overline{D^*}^0$ correlation function is important.

- If X(3872) pole position is very close to $D^0\overline{D^*}^0$ threshold, $D^0\overline{D^*}^0$ correlation function becomes very large O(100) at small momentum.

- $D^0\overline{D^*}^0$ correlation function cannot distinguish a bound state and a virtual state.

# Summary

- In Zc(3900) channel, $D^0\overline{D^*}^0$ correlation function is small.

- Experimentally observer $D^0\overline{D^*}^0$ correlation function is average of those in X(3872) and Zc(3900) channels. It gives the information of the pole position of X(3872).

- Coupled channel effects show the structure at the $D^+D^{*-}$ threshold.

# Back up

# Numerical results of $D^0\overline{D}^{*0}$ correlation function

$D^0\overline{D}^{*0} - D^+D^{*-}$ coupled channel case:

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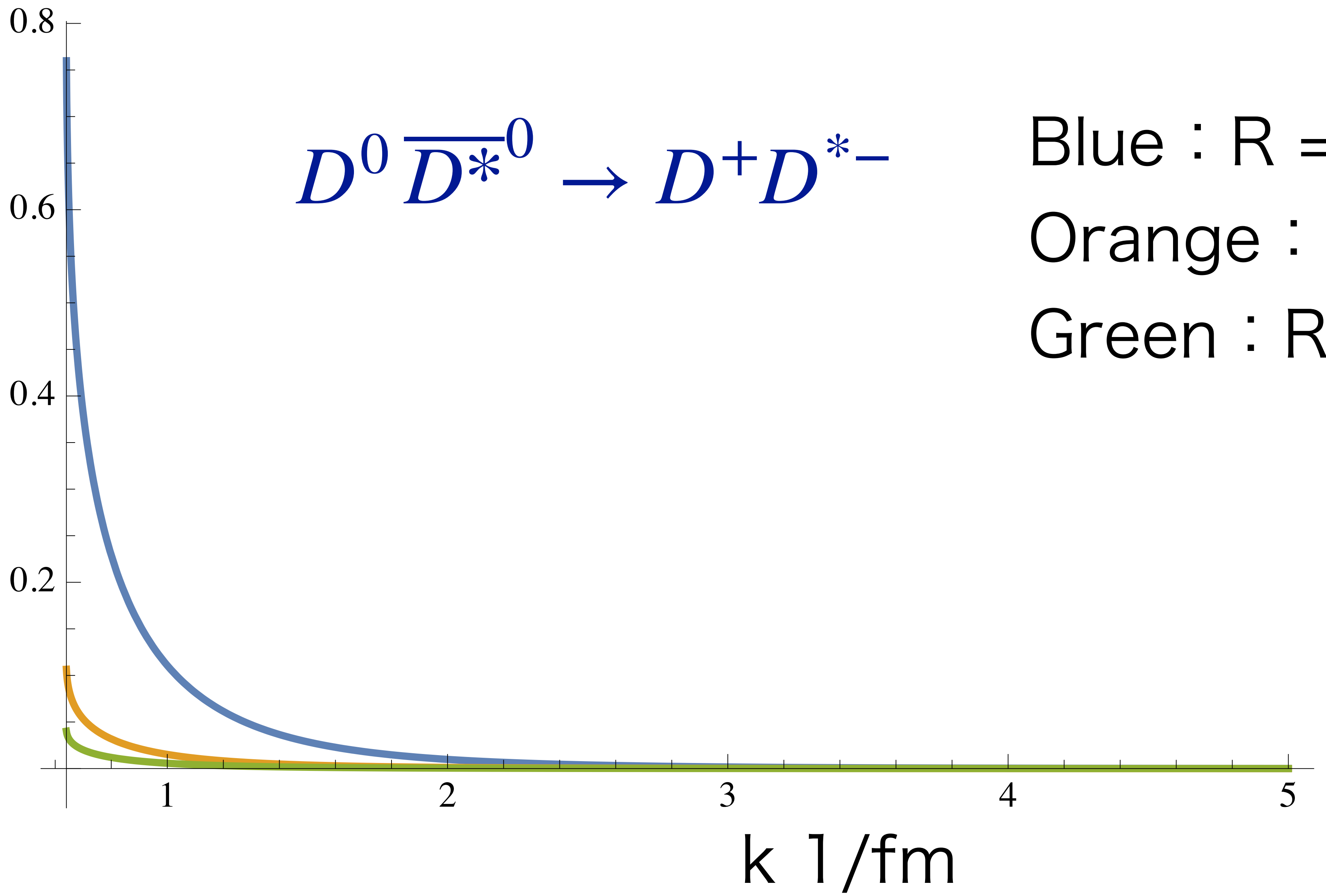


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# Numerical results of $D^0\overline{D}^{*0}$ correlation function

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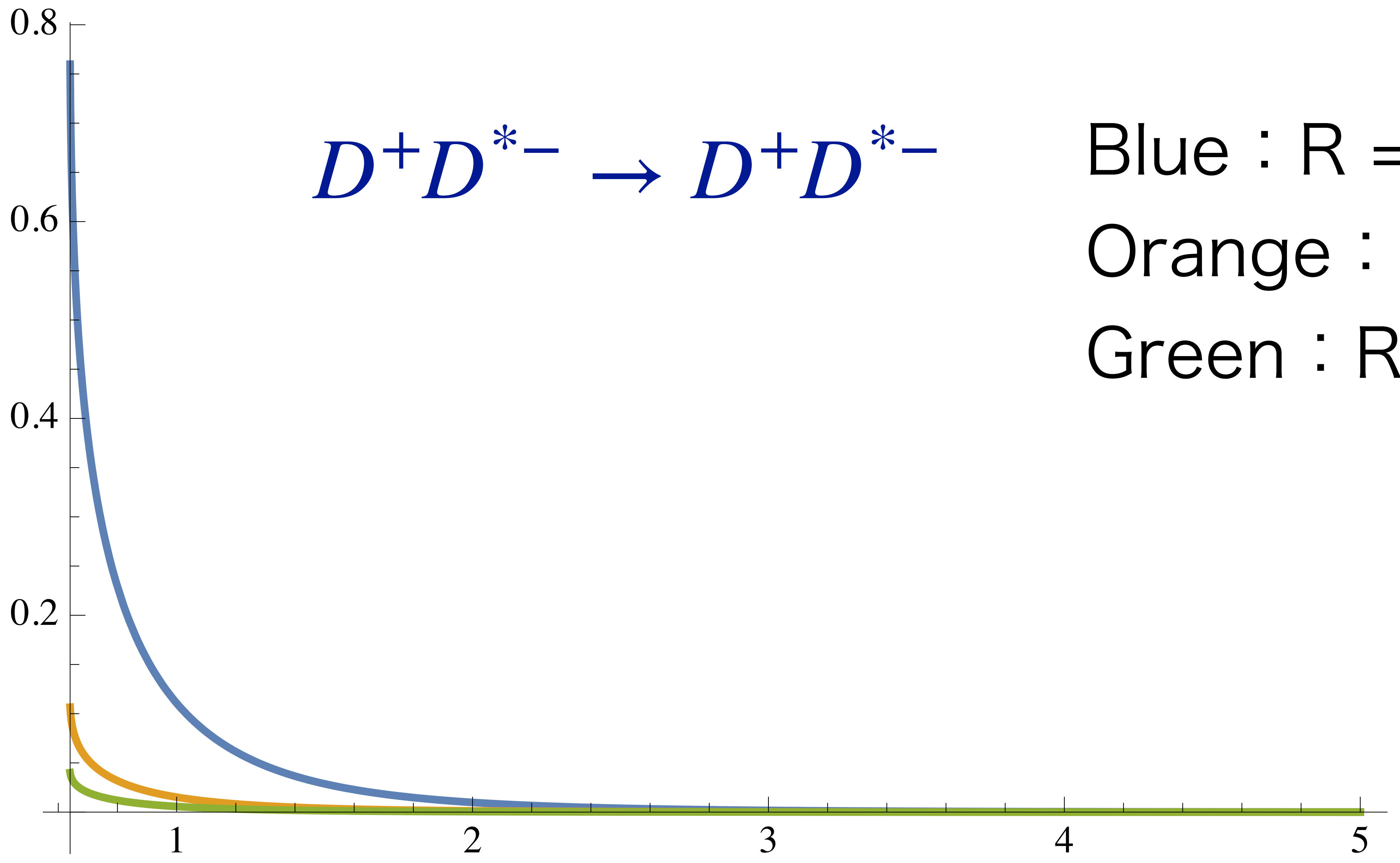


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