

Production of X(3872) and a Photon in e^+e^- Annihilation

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Outline

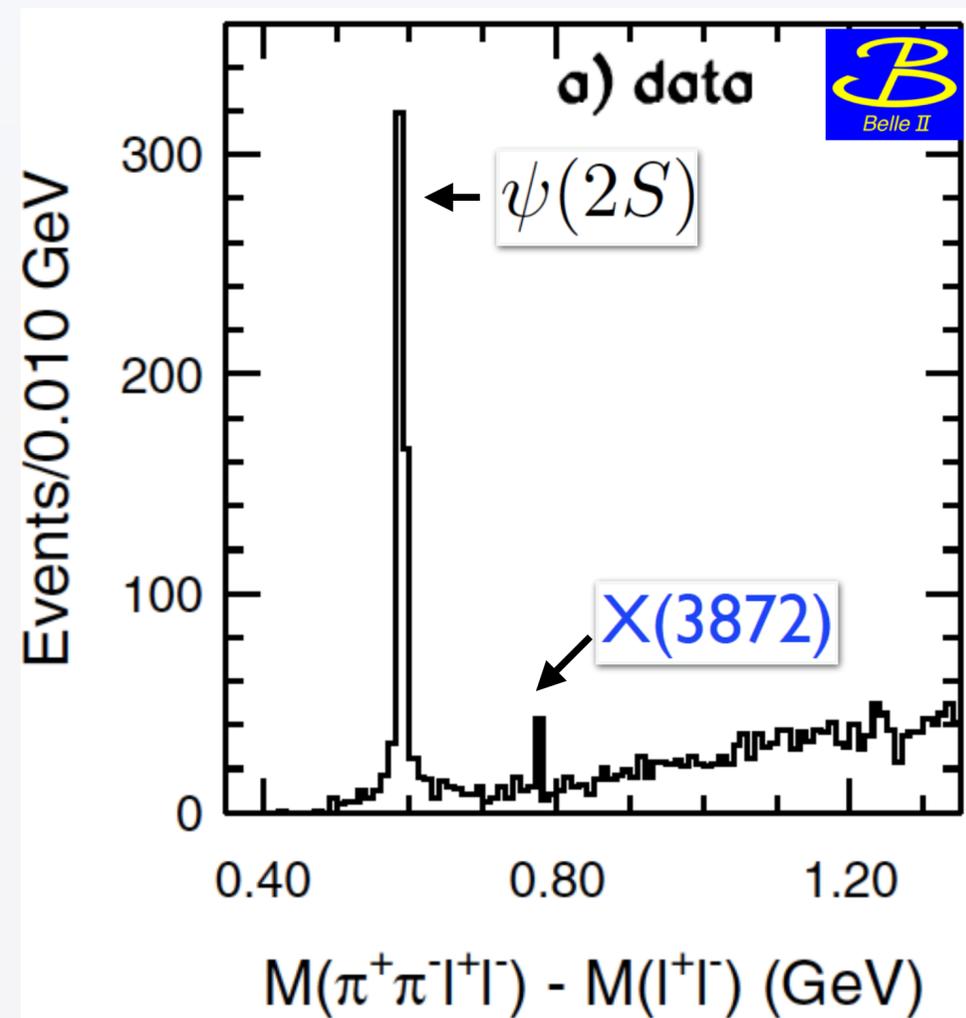
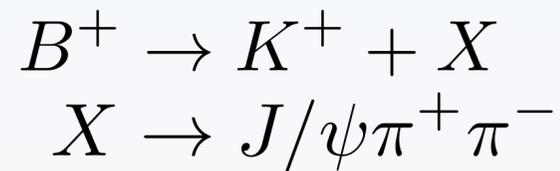
- * Introduction to the X(3872) state [X for later use]
- * Universal properties of near-threshold S-wave resonance
- Production of X accompanied by a photon (γ) in e^+e^- annihilation
[arXiv: 1904.12915]
- * Summary

Introduction to the $X(3872)$

* Discovery

❖ Belle Collaboration (2003)

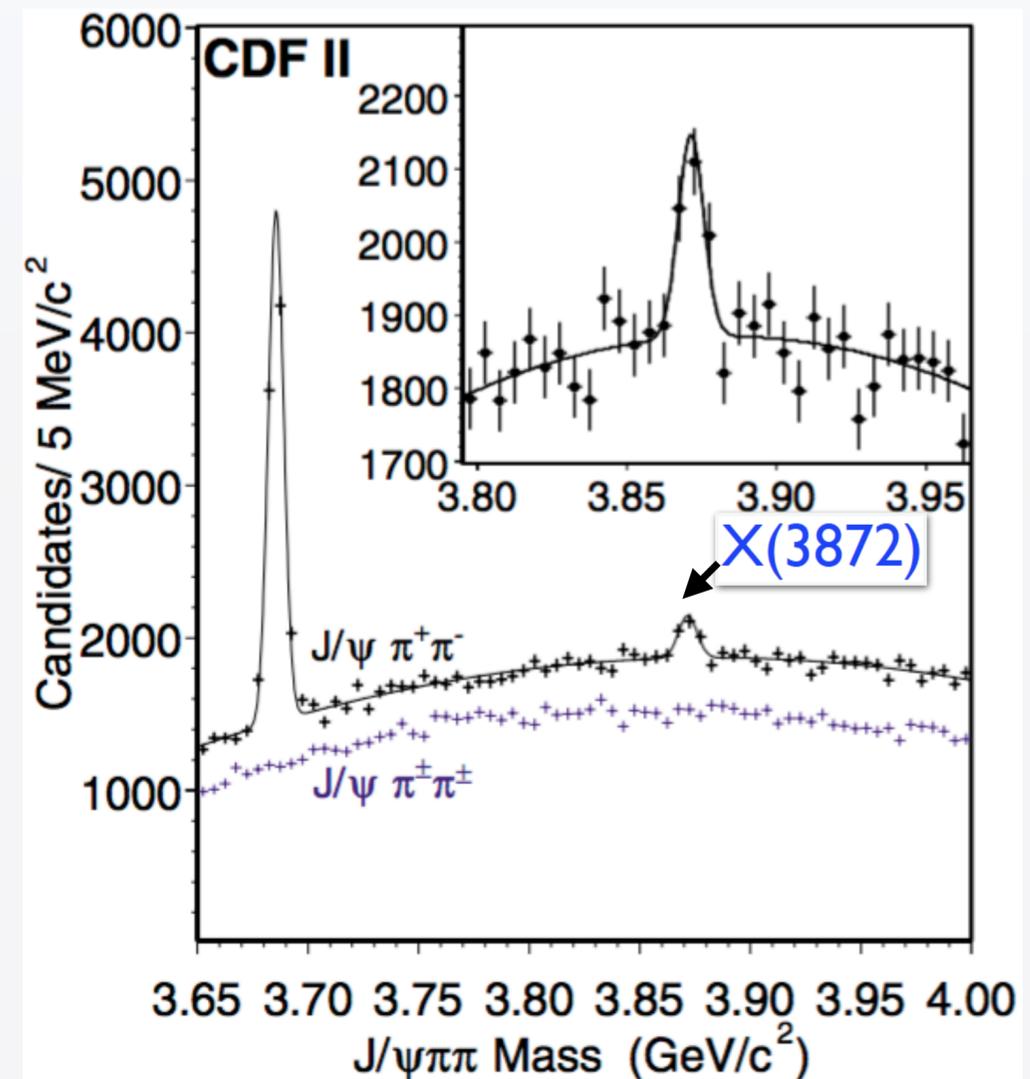
PRL 91,262001(2003)



* Confirmation

❖ CDF Collaboration

PRL 91,262001(2004)



Introduction to the $X(3872)$

- * Observed decay modes:

$J/\psi \pi^+ \pi^-$, $J/\psi \pi^+ \pi^- \pi^0$, $J/\psi \gamma$, $\psi(2S)\gamma$, $DD\pi^0$, $DD\gamma$, $\chi_{c1}\pi^0$

- * Mass: very close to $D^{*0}D^0$ threshold

$$E_X = M_X - (M_{D^{*0}} + M_{D^0}) = (0.01 \pm 0.18) \text{ MeV [PDG 2018]}$$

- * J^{PC} Quantum numbers:

$$J^{PC} = 1^{++} \text{ [LHCb, PRL, 110, 222001(2013)]}$$

- * Width: very narrow

$< 1.2 \text{ MeV at 90\% C.L.}$

[Belle, PRD 84, 052004 (2011)]

- * What is the $X(3872)$?

Charmonium? \times

isospin violation

Introduction to the $X(3872)$

- * Observed decay modes:

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resonant coupling

- * J^{PC} Quantum numbers:

$$J^{PC} = 1^{++} \text{ [LHCb, PRL, 110, 222001(2013)]}$$



S-wave coupling to $D^{*0}\bar{D}^0/\bar{D}^{*0}D^0$

- * Width: very narrow

$< 1.2 \text{ MeV at 90\% C.L.}$

[Belle, PRD 84, 052004 (2011)]

- * What is the $X(3872)$?

$X(3872)$: charm meson molecule:

$$|X(3872)\rangle = \frac{1}{\sqrt{2}} (|D^{*0}\bar{D}^0\rangle + |D^0\bar{D}^{*0}\rangle)$$

[short-distance wave function may have $\chi_{c1}(2P)$ component]

Universal properties near threshold

* nonrelativistic Quantum Mechanics:

- Short-range interactions
- S-wave resonance close enough to **threshold**

 * large scattering length $|a| \gg \text{range}$

* universal features depend only on a (or $\gamma = 1/a$)

* universal wave function at $r \gg \text{range}$: $\psi(r) = \frac{e^{-\gamma r}}{r}$

* scattering amplitude at $k \ll 1/\text{range}$: $f(k) = \frac{1}{-\gamma - ik}$

* X(3872) close to $D^*0\bar{D}^0$ threshold:

 * universal features depend only on inverse scattering length γ_X for $D^*0\bar{D}^0/\bar{D}^*0D^0$

e^+e^- : production of $X(3872)$ and a photon near $D^{*0}D^{*0}$ threshold

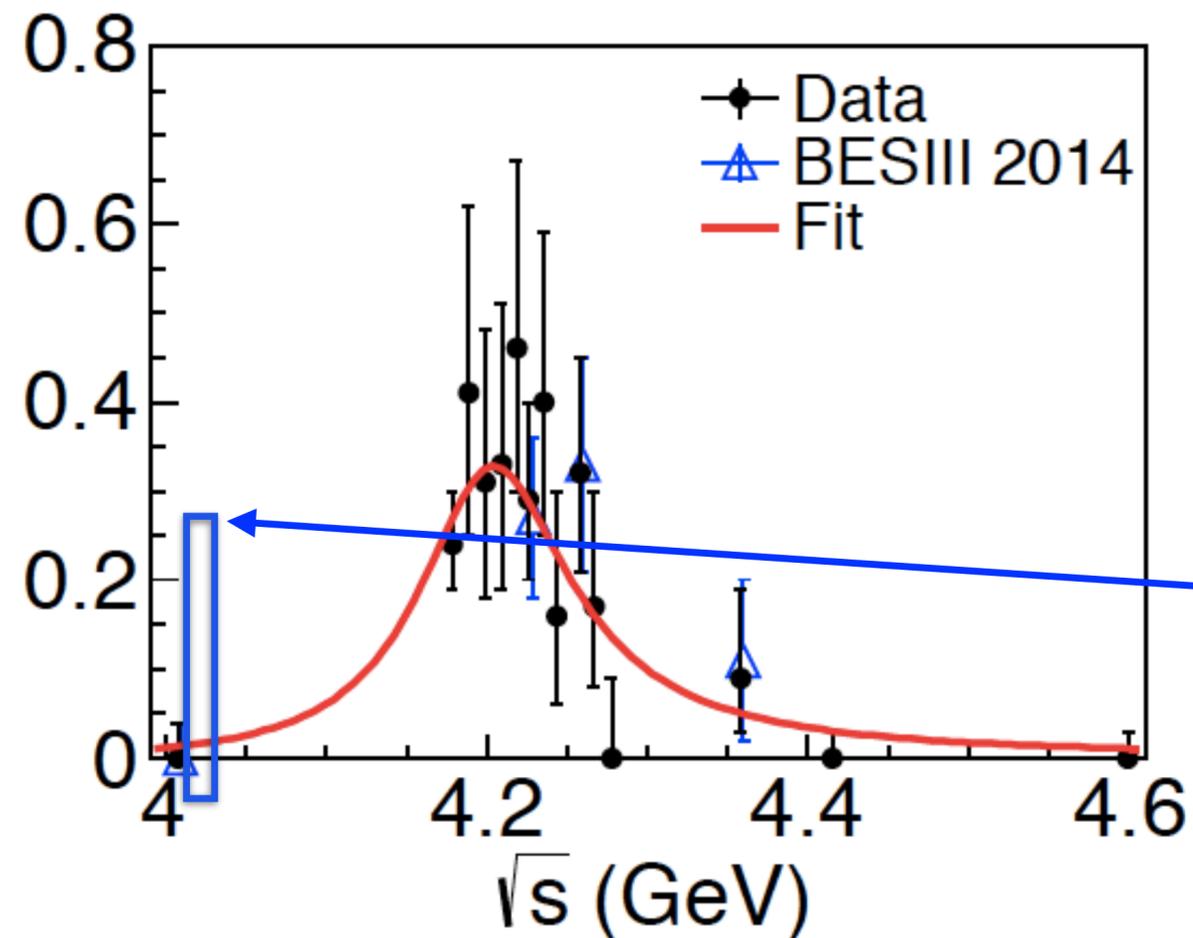
* Experimental observation

BESIII: $e^+e^- \rightarrow X\gamma$ [PRL 112, 092001(2014), arXiv: 1903.04695]

* Dubynskiy and Voloshin

[PRD 74, 094017 (2006)]

$\sigma(\gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi)$ (pb)



absorptive contribution
(imaginary part of amplitude):

$e^+e^- \rightarrow D^{*0}\bar{D}^{*0} \rightarrow X\gamma$

on mass shells

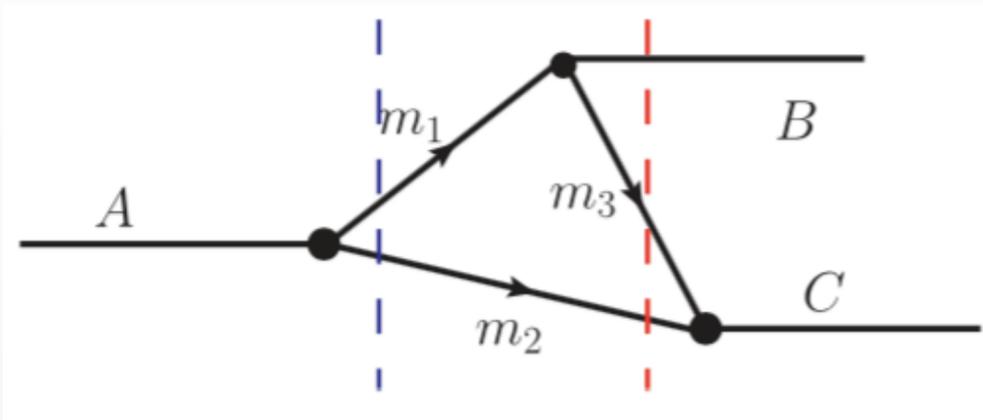
❖ Line shape of $X\gamma$:

◇ peak at a few MeV above $D^{*0}D^{*0}$ threshold

◇ depends on binding energy

e^+e^- : production of $X(3872)$ and a photon near $D^{*0}D^{*0}$ threshold

* Triangle singularity



three virtual particles

- ❖ on shell simultaneously
- ❖ 4-momentum conservation at each vertex.
- ❖ zero decay width, zero binding energy



kinematic singularity

- ❖ nonzero decay width and binding energy



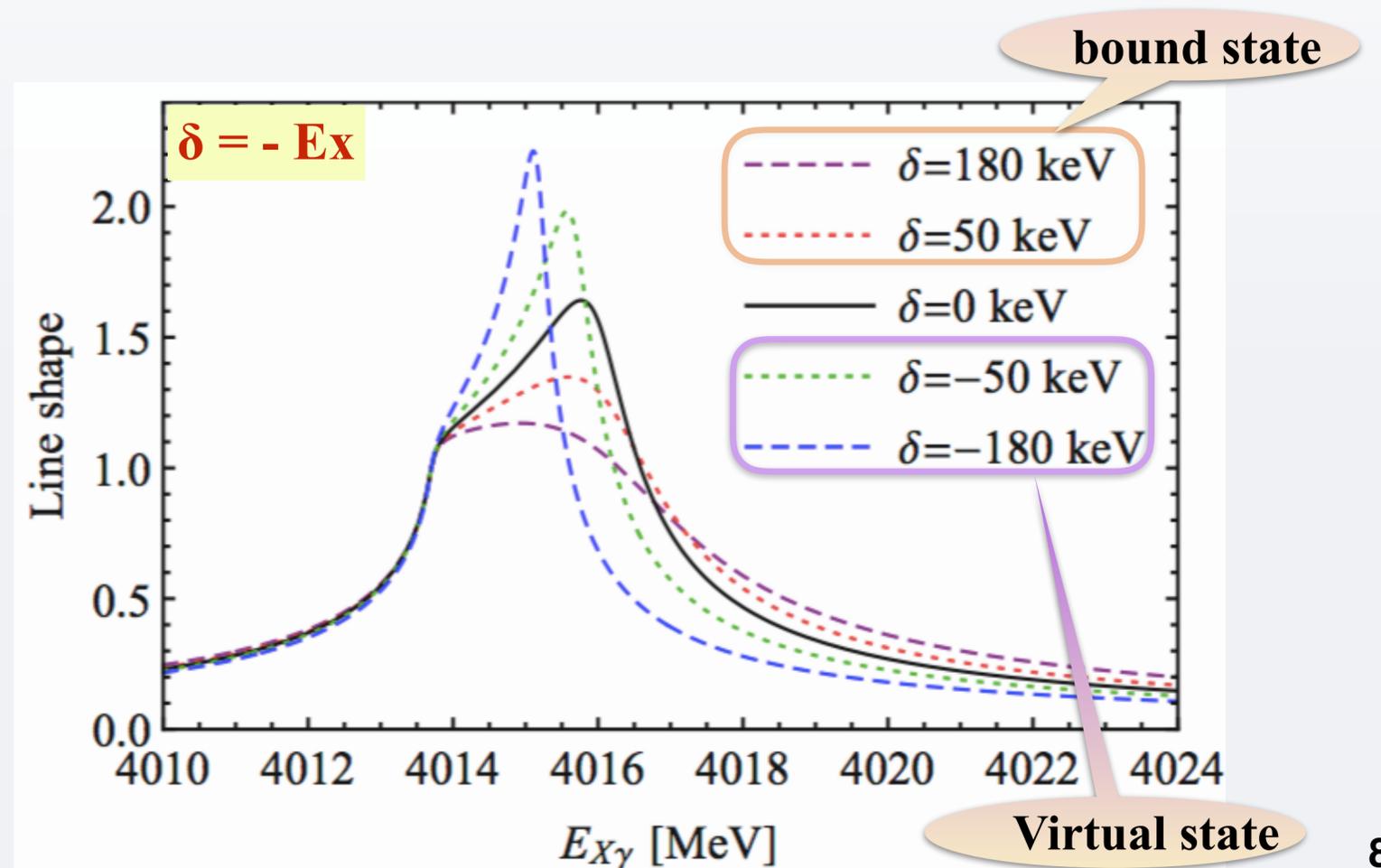
narrow peak in reaction rate

* Guo [arXiv: 1903.11221]

$$e^+e^- \rightarrow D^{*0}\bar{D}^{*0} + \pi \rightarrow (X\gamma) + \pi$$

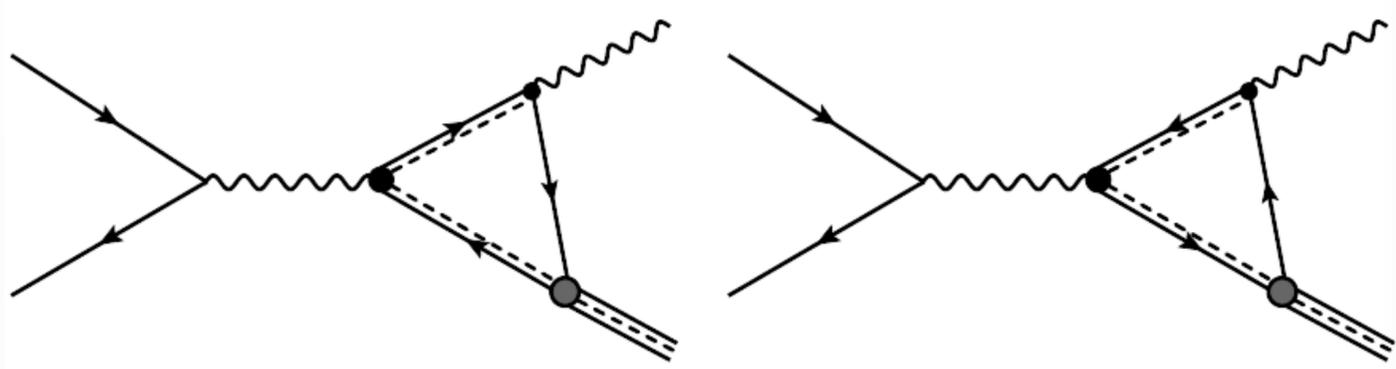
Line shape in $X\gamma$:

- ❖ sensitive to E_x (can be used to measure E_x)
- ❖ peak at ~ 2 MeV above $D^{*0}D^{*0}$ threshold (bound state)



e^+e^- : production of $X(3872)$ and a photon near $D^{*0}D^{*0}$ threshold

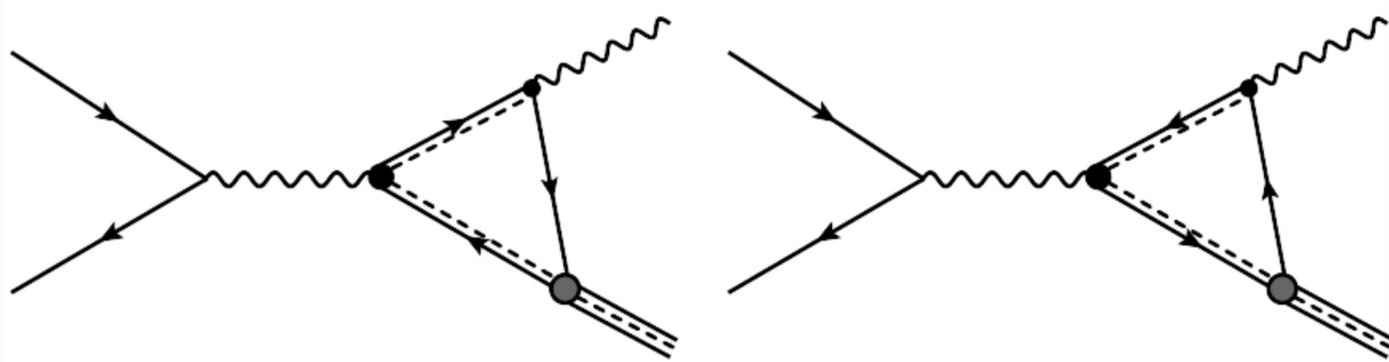
* $e^+e^- \rightarrow D^{*0}\bar{D}^{*0}(\text{P-wave}) \rightarrow X(3872)\gamma$ [Braaten, He, Ingles, arXiv: 1904.12915]



- ❖ $\text{Re}[M]$ as well as $\text{Im}[M]$ (absorptive part)
- ❖ Decay width of D^{*0}

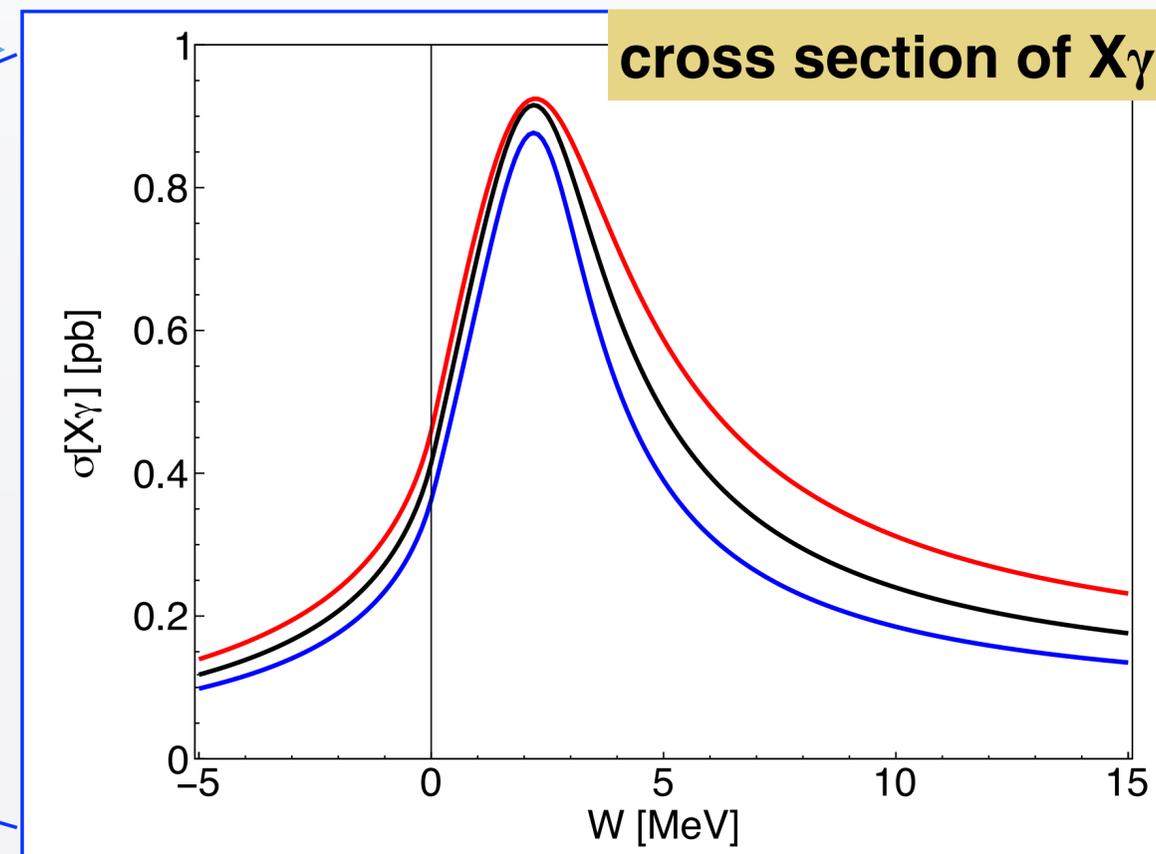
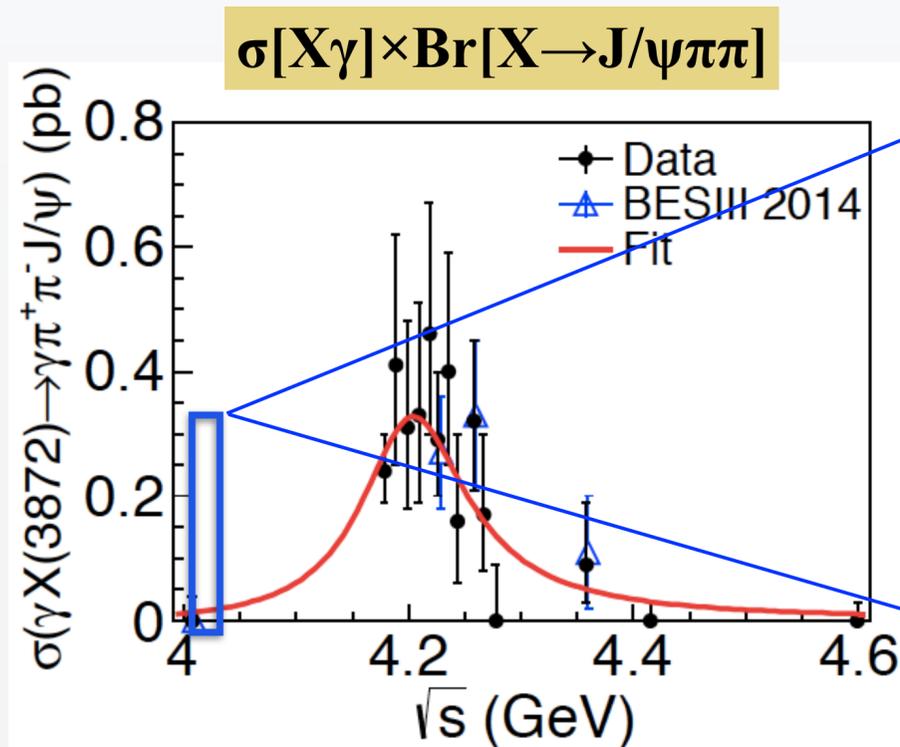
e^+e^- : production of $X(3872)$ and a photon near $D^{*0}\bar{D}^{*0}$ threshold

* $e^+e^- \rightarrow D^{*0}\bar{D}^{*0}(\text{P-wave}) \rightarrow X(3872) \gamma$ [Braaten, He, Ingles, arXiv: 1904.12915]



Triangle singularity:
narrow peak ~ 2 MeV above $D^{*0}\bar{D}^{*0}$ threshold

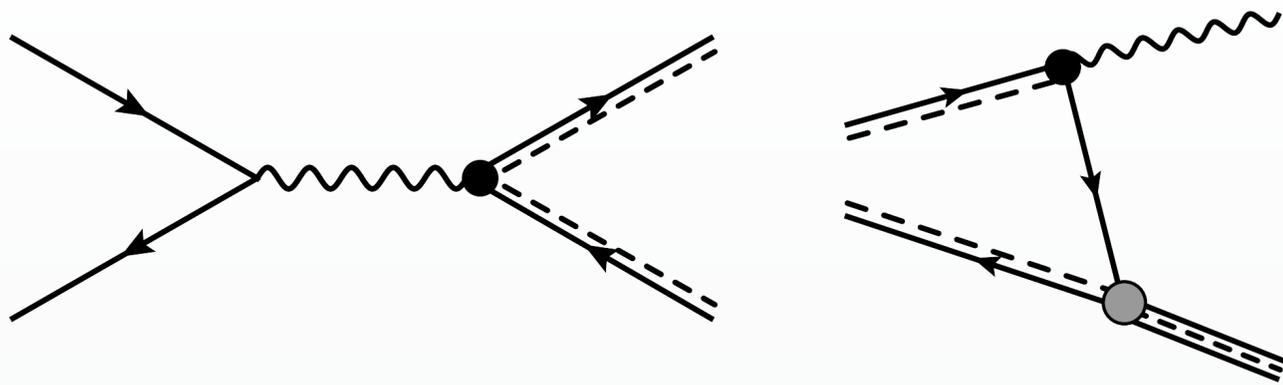
- ❖ $\text{Re}[M]$ as well as $\text{Im}[M]$ (absorptive part)
- ❖ Decay width of D^{*0}
- ❖ Peak insensitive to binding energy (unless $E_X \sim 0$ or $|E_X| >$ a few MeV)
- ❖ Normalized cross section using $\sigma[D^{*+}D^{*-}]$ [Uglov *et al.* (JETP Lett. 105,1 (2017))]
- ❖ Could be observable at BESIII!



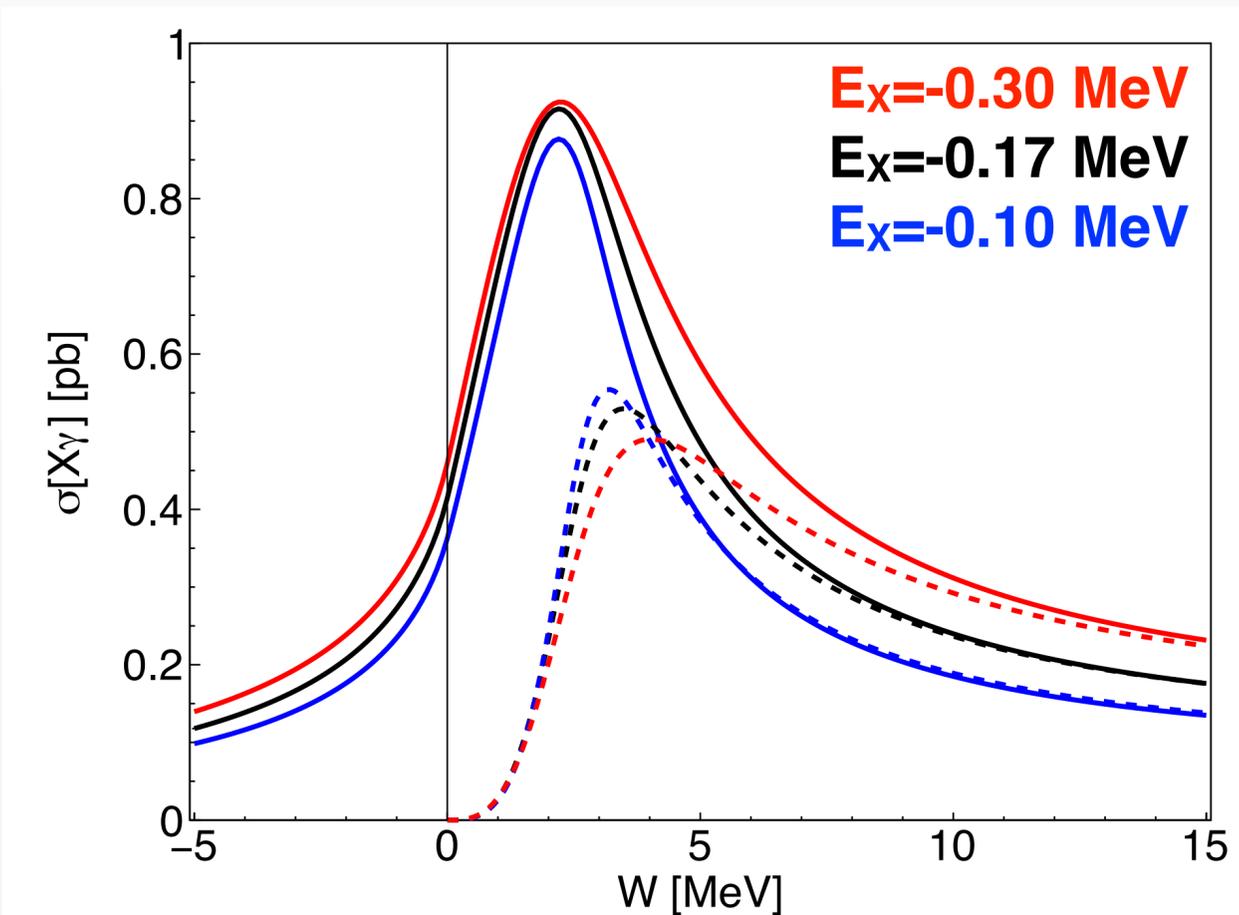
$E_X = -0.30$ MeV
 $E_X = -0.17$ MeV
 $E_X = -0.10$ MeV

e^+e^- : production of X(3872) and a photon near $D^{*0}D^{*0}$ threshold

* $e^+e^- \rightarrow D^{*0}D^{*0}(\text{P-wave}) \rightarrow X(3872) \gamma$ [Braaten, He, Ingles, arXiv: 1904.12915]



absorptive contribution (dashed lines):



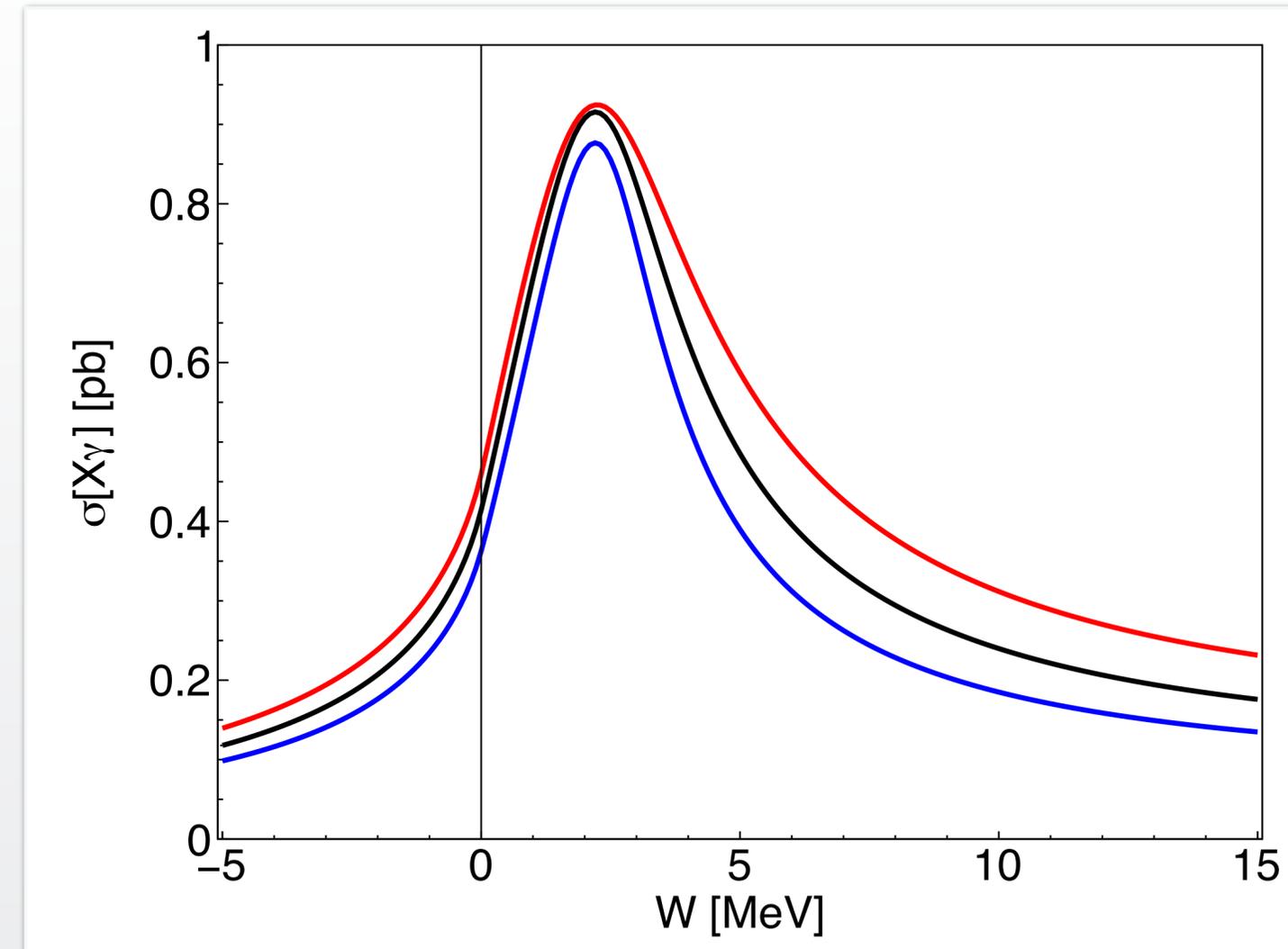
- ❖ Zero below threshold
- ❖ Peak position depends on binding energy

Absorptive contribution to the cross section is not a good approximation

Summery

$e^+e^- \rightarrow X(3872)\gamma$ near $D^{*0}\bar{D}^{*0}$ threshold

- * **Narrow peak in the cross section of $X\gamma$**
- * **Could be observable at BESIII!**



Thank you!