Studies of XYZ resonances with open-charm

Tong Liu
(On behalf of BESIII Collaboration)

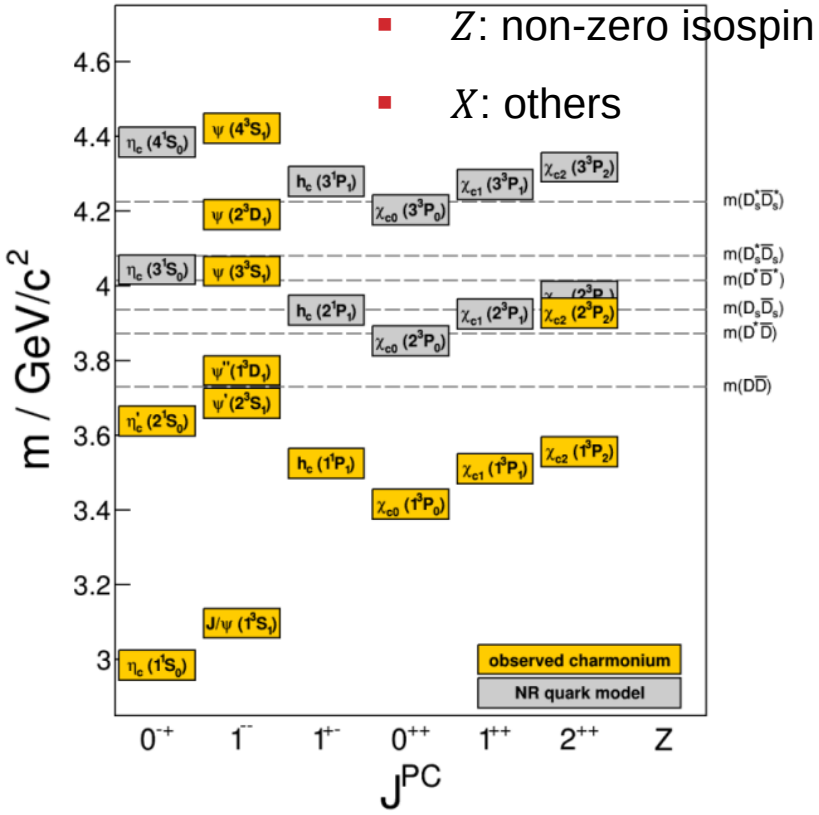
The 13th International Workshop on e+e- collisions from Phi to Psi

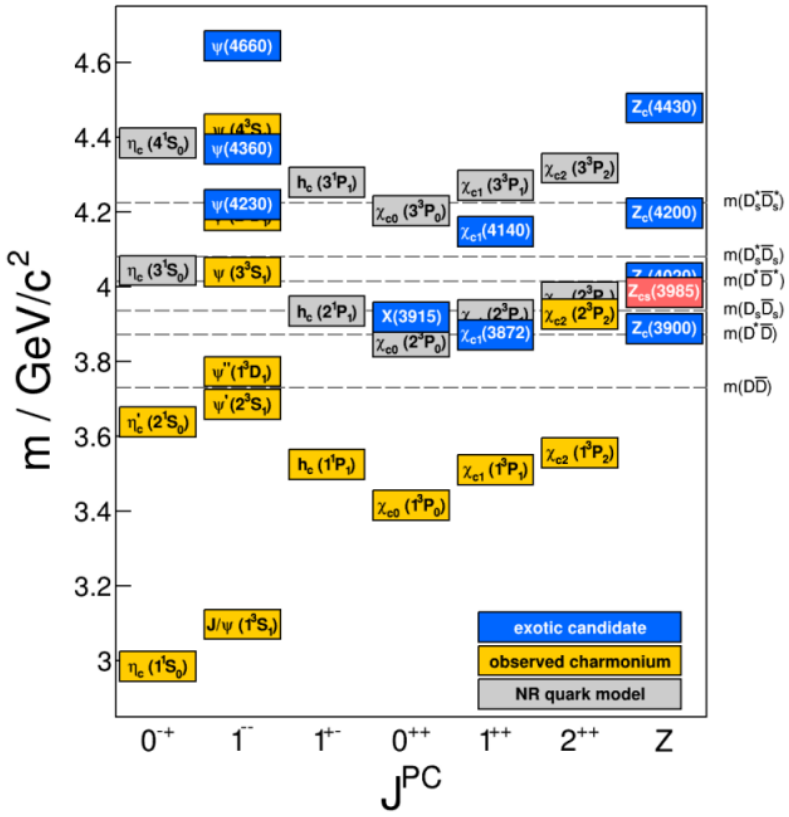
Outline

- XYZ physics
- BEPCII & BESIII
- Z: $e^+e^- \to K_S^0(D_s^-D^{*+} + D_s^{*-}D^+)$ and $Z_{cs}(3985)^0$
- Y: $e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^- + c.c.$
- X&Y: $e^+e^- \to \pi^+\pi^-D^+D^-$
- Summary

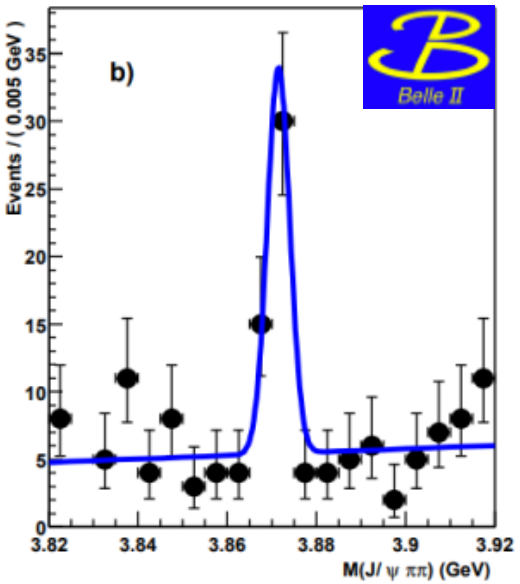
XYZ physics

- Potential model works well
- Until 2003, the observation of $X(3872)$, non-standard hadrons?
  - Y: $J^{PC} = 1^{--}$
  - Z: non-zero isospin
  - X: others

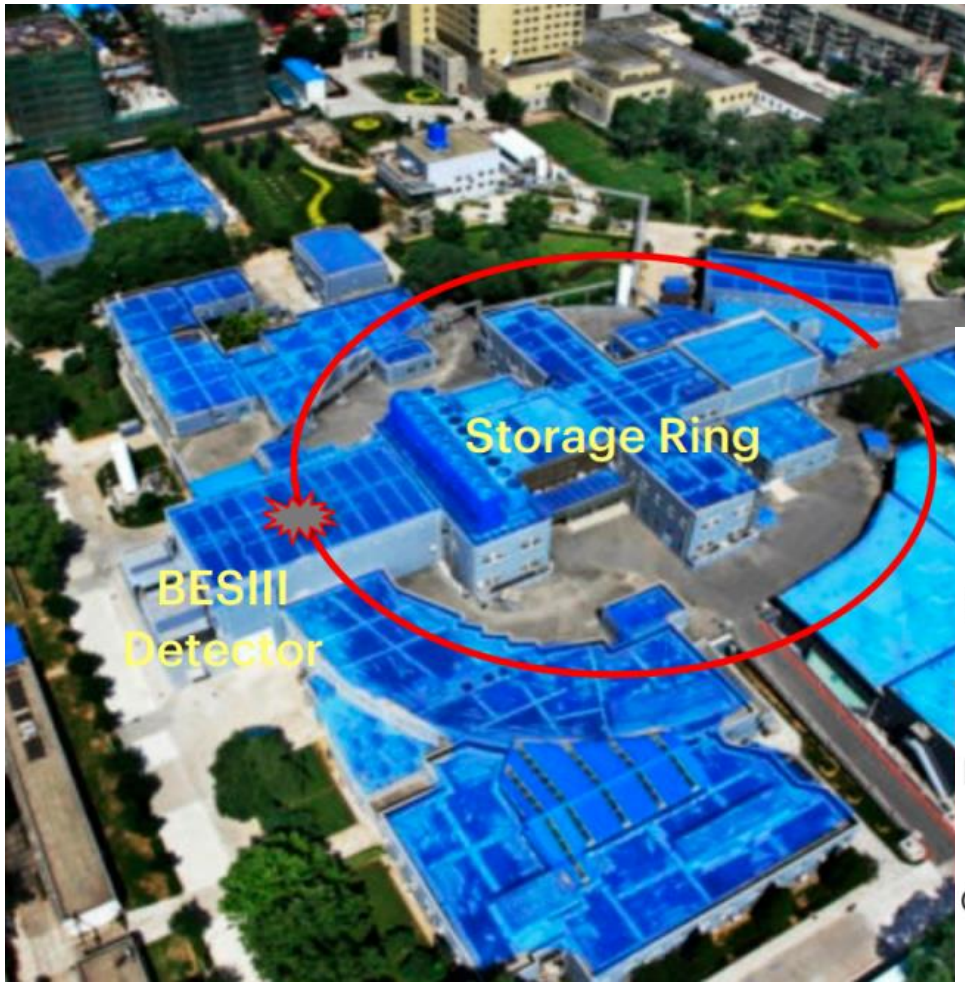




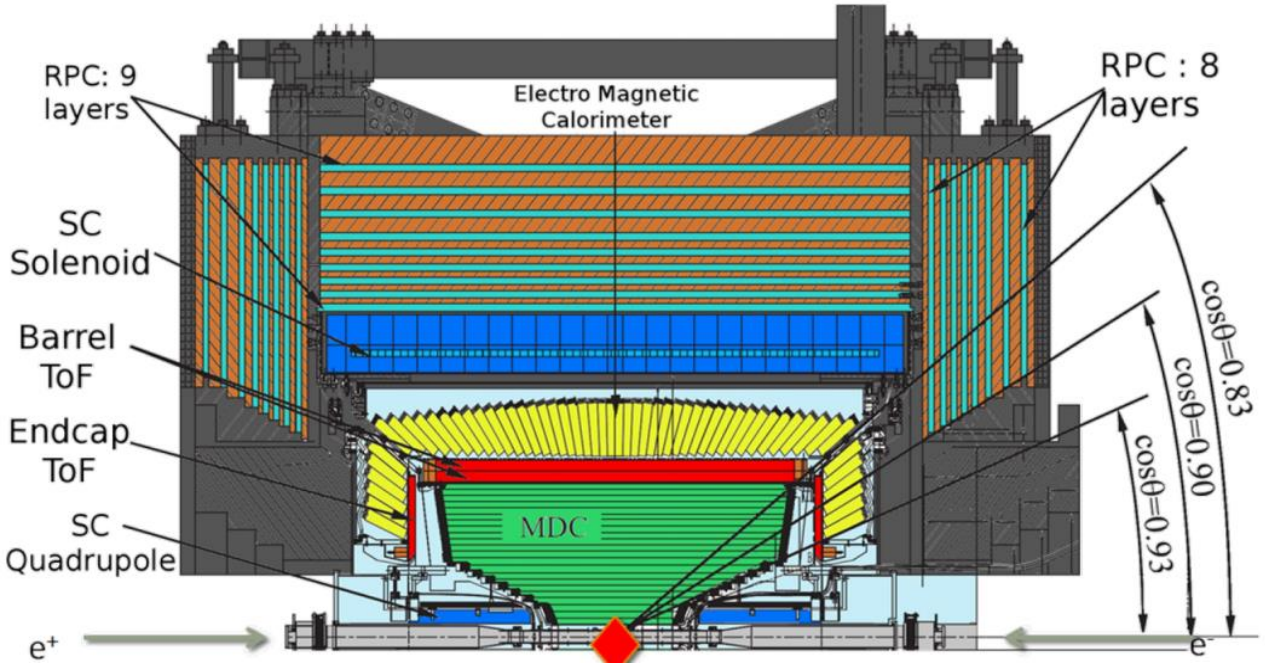
PRL **91**, 262001 (2003)



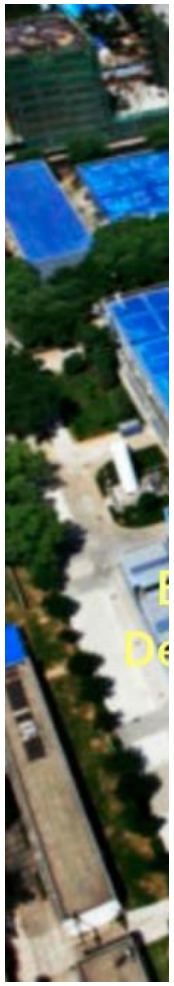
BEPCII & BESIII

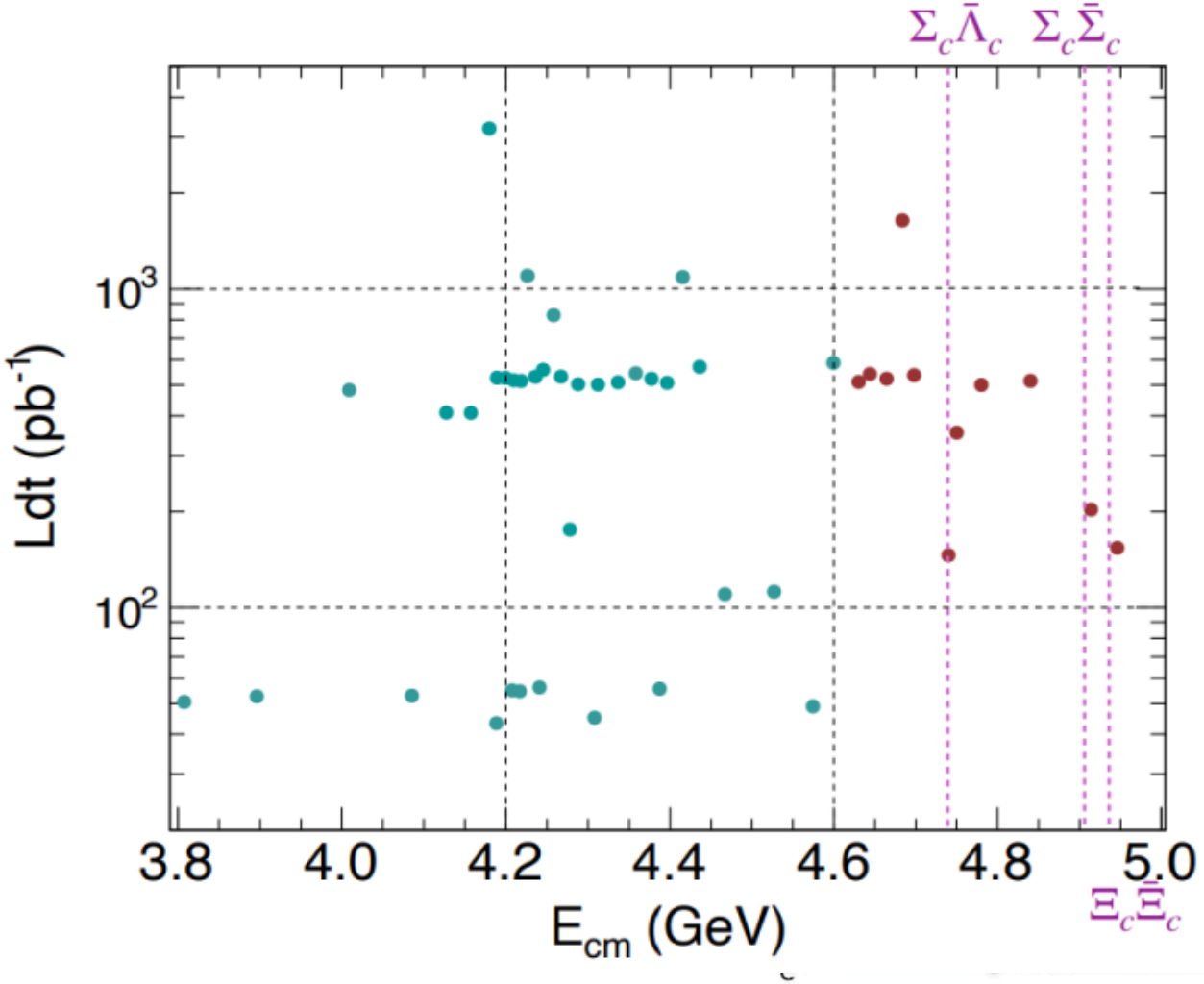


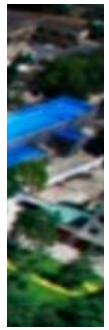
- ✓ $2 < \sqrt{s} < 5$ GeV
- ✓ $L_{max}=10^{33}$ / cm^2s (at $\psi(3770)$)



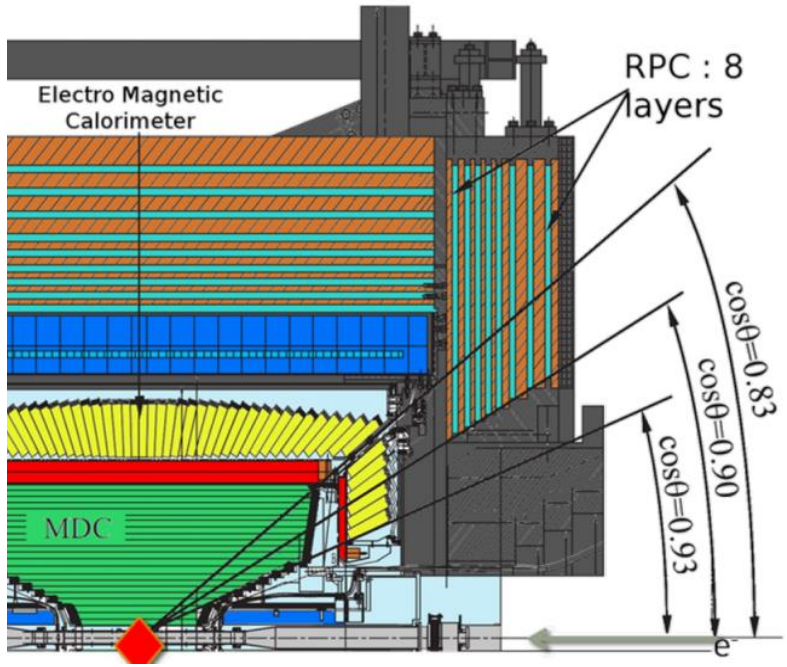
BEPCII & BESIII







- ✓ The biggest scan sample in the charmonium(-like) region

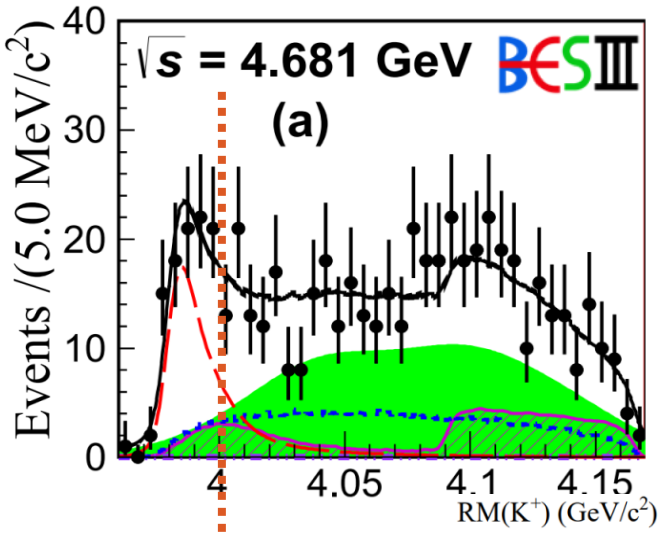


$Z_{cs}(3985)^+$

- The first state contains four quarks: $Z_c(3900)$
- With SU(3) flavor symmetry, the strange partner Z_{cs}
  - BESIII: $M = (3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV/c², $\Gamma = \left(12.8^{+5.3}_{-4.4} \pm 3.0\right)$ MeV
  - LHCb (PWA): $M = (4003 \pm 6^{+4}_{-14})$ MeV/c², $\Gamma = (131 \pm 15 \pm 25)$ MeV

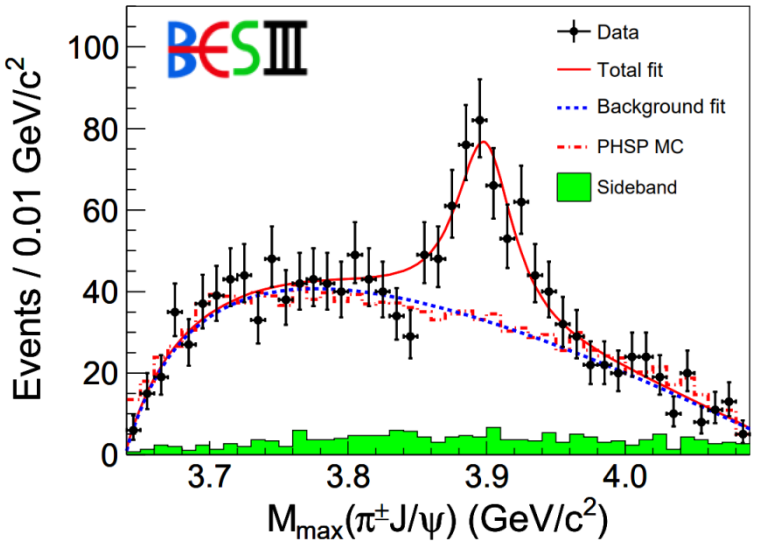
PRL **127**, 082001 (2021)

$e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$



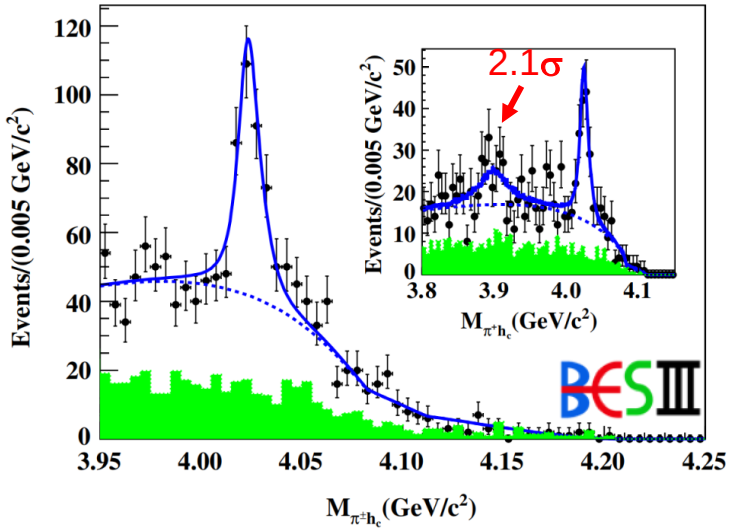
PRL **110**, 252001 (2013)

$e^+e^- \to \pi^+\pi^- J/\psi$



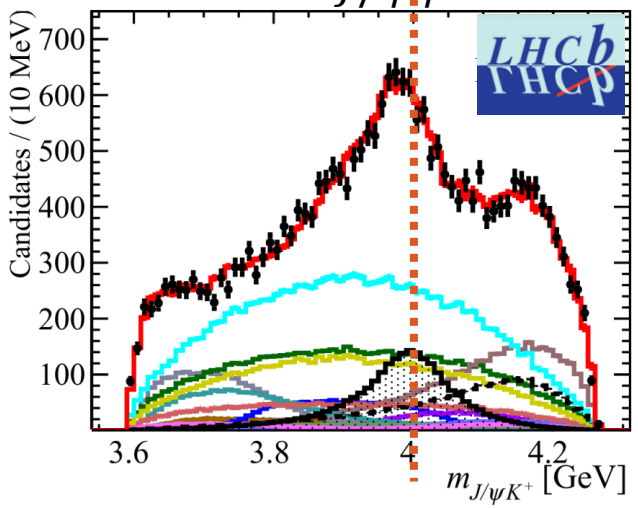
PRL **111**, 242001 (2013)

$e^+e^- \to \pi^+\pi^- h_c$



PRL **126**, 102001 (2021)

$B^+ \to J/\psi\phi K^+$

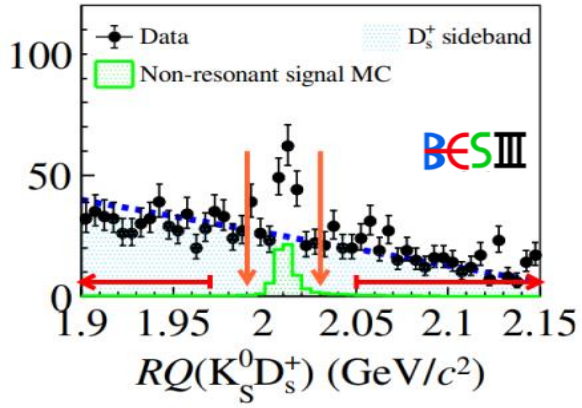


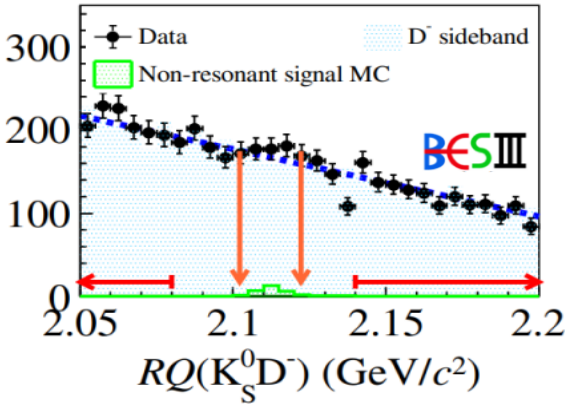
$Z_{cs}(3985)^0$

$$R = \left| \frac{1}{M^2 - m_0^2 + im_0(f \cdot \Gamma_1(M) + (1-f) \cdot \Gamma_2(M))} \right|^2$$

$$R_1 = R \cdot q \cdot p_1,$$
$$R_2 = R \cdot q \cdot p_2,$$
$$\Gamma_1(M) = \Gamma_0 \cdot \frac{p_1}{p_1^*} \cdot \frac{m_0}{M},$$
$$\Gamma_2(M) = \Gamma_0 \cdot \frac{p_2}{p_2^*} \cdot \frac{m_0}{M},$$

- Theory expect heavier mass: Nucl. Phys. B **968**, 115450 543 (2021)
  - Molecular: (0.05 ± 0.21) GeV/c²
  - Tetraquark: (0.06 ± 0.12) GeV/c²
- If product through an isospin=0 state, one have:
  - $\pi^+ Z_c^- : \pi^- Z_c^+ : \pi^0 Z_c^0 = \frac{1}{3} : \frac{1}{3} : \frac{1}{3}$
  - $\mathrm{K}^+ Z_{cs}^- : K^- Z_{cs}^+ : K^0 \bar{Z}_{cs}^0 : \bar{K}^0 Z_{cs}^0 = \frac{1}{4} : \frac{1}{4} : \frac{1}{4} : \frac{1}{4}$
- Partial reconstruction: K_S^0 + ground-state D ($K_S^0 D_S^\pm$ / $K_S^0 D^\pm$)
  - $D_S^+ \to K^+K^-\pi^+, K_S^0K^+, K^+K^-\pi^+\pi^0, K_S^0K^+\pi^+\pi^-$
  - $D^- \to K^+\pi^-\pi^-, K_S^0\pi^-, K_S^0\pi^+\pi^-\pi^-$
- Fit to $RM(K_S^0)$
  - Two S-wave BW ($\otimes$ Gaus.) for signal, f is the ratio of two channels
  - BG1: the non-resonant process, MC shape, N_{BG1} float
  - BG2: $D_S^* D_S^{**}$, MC shape, N_{BG2} fixed
  - BG3: the combinatorial backgrounds, sideband, N_{BG3} fixed





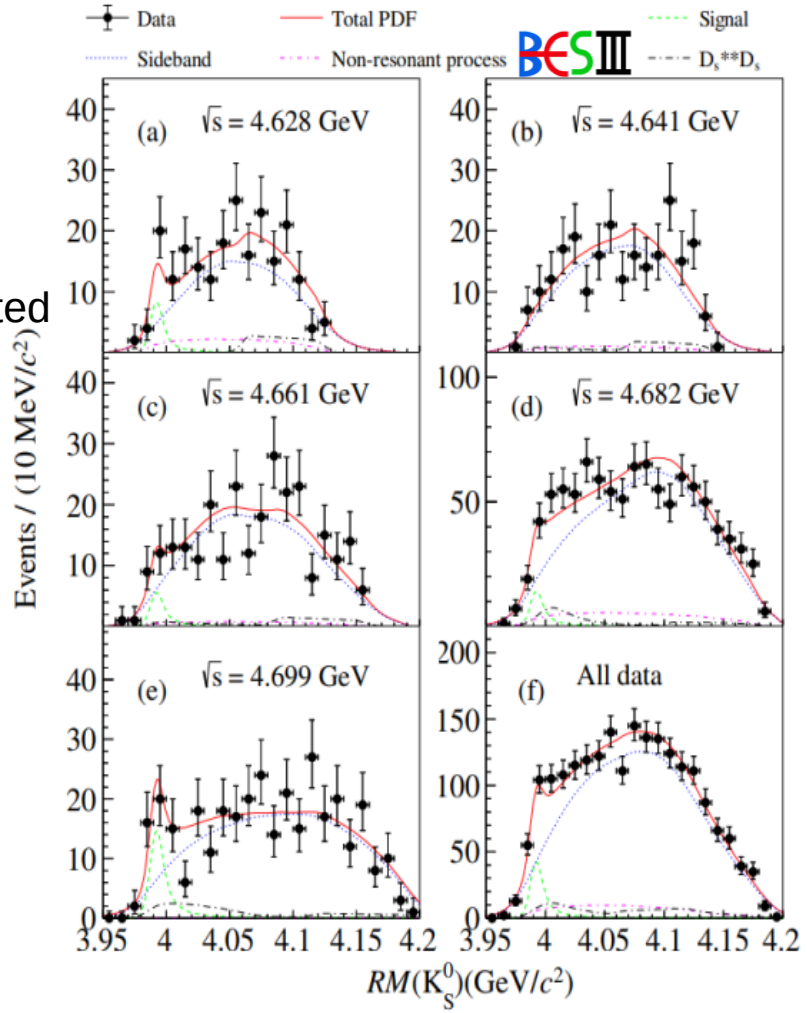
The fits to the D sideband regions

$Z_{cs}(3985)^0$

- $Z_{cs}(3985)^0$ with significance as 5.0σ
  - 4.6σ including systematic uncertainty
  - $M = (3992.2 \pm 1.7 \pm 1.6)$ MeV/c², $\Gamma = (7.7^{+4.1}_{-3.8} \pm 4.3)$ MeV
  - Contain $c\bar{c}\bar{s}d$
  - $\sigma^{born}(\bar{K}^0 Z_{cs}^0) = \sigma^{born}(K^- Z_{cs}^+)$, as isospin symmetry expected

Accepted by PRL: arXiv:2204.13703

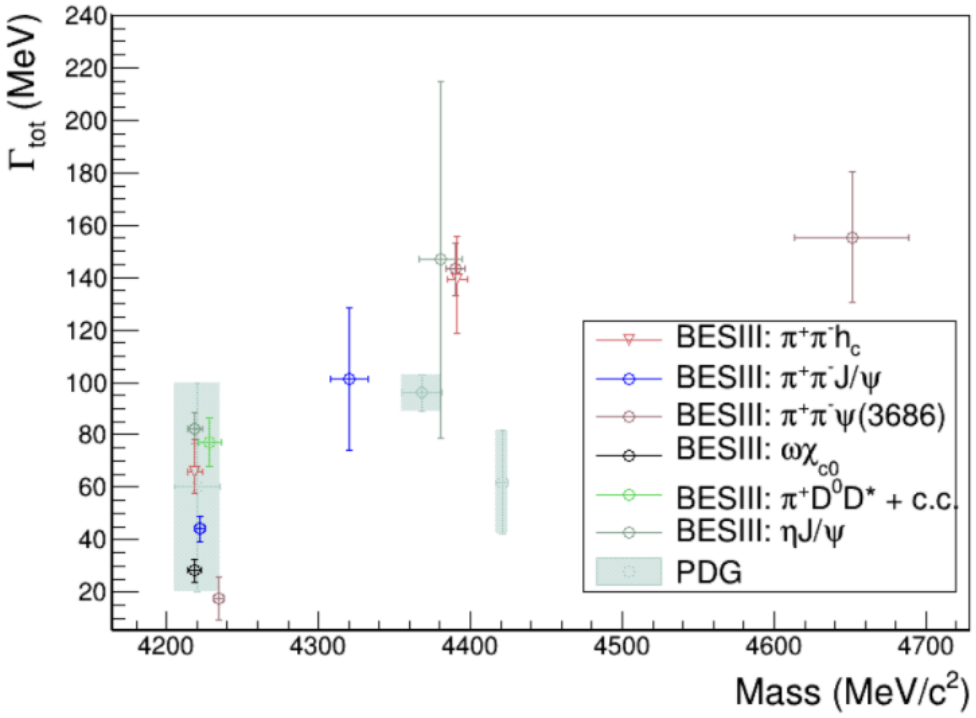
$\sqrt{s}$ (MeV)	$\sigma^{\rm Born} \times \mathcal{B}$ (pb) $\bar{K}^0 Z_{cs}(3985)^0$	$K^- Z_{cs}(3985)^+$	χ^2	$\chi^2_{\rm total}$/ndf
4628	$4.4^{+2.6}_{-2.2} \pm 2.0$	$0.8^{+1.2}_{-0.8} \pm 0.6$	1.2	
4641	$0.0^{+1.6}_{-0.0} \pm 0.2$	$1.6^{+1.2}_{-1.1} \pm 1.3$	0.5	
4661	$2.8^{+1.8}_{-1.6} \pm 0.6$	$1.6^{+1.3}_{-1.1} \pm 0.8$	0.3	5.1/5
4682	$2.2^{+1.2}_{-1.0} \pm 0.8$	$4.4^{+0.9}_{-0.8} \pm 1.4$	1.0	
4699	$7.0^{+2.2}_{-2.0} \pm 1.8$	$2.4^{+1.1}_{-1.0} \pm 1.2$	2.1	

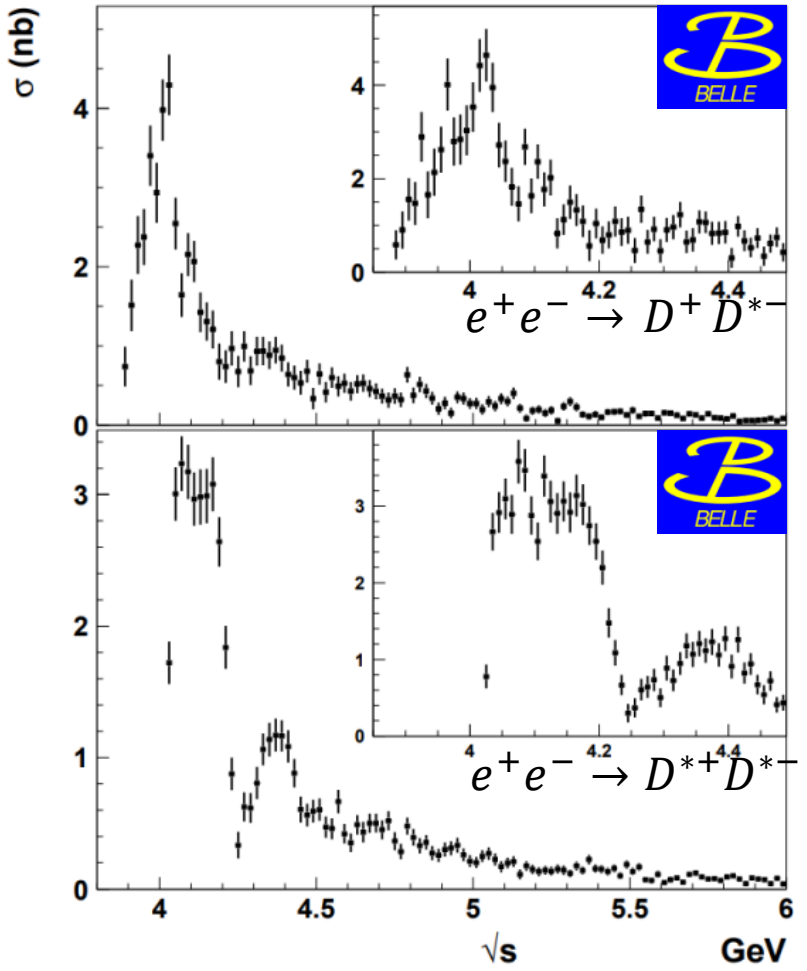


$e^+e^- \to D^{*+}D^{*-}, D^{*+}D^- + c.c.$

- Y states are vector, strongly couple to hidden-charm
- How many Y states in the region?
- Belle's result via ISR method
  - Coupled channel models will be necessary

PRD **97**, 012002 (2018)

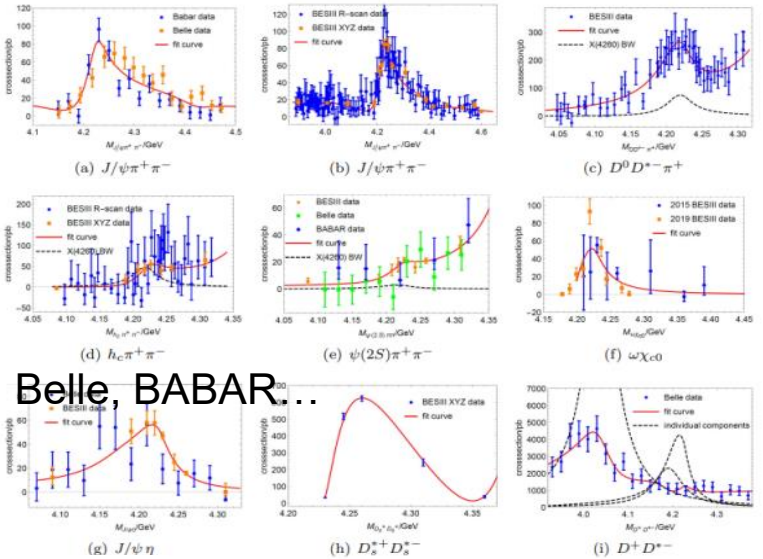




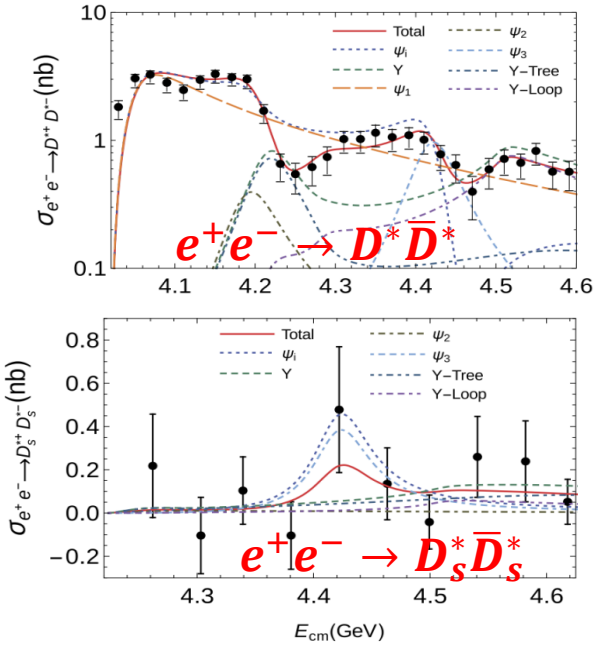
$e^+e^- \to D^{*+}D^{*-}, D^{*+}D^- + c.c.$

- How many Y states in the region? What is $Y(4260)$
  - 1) $\psi(4040)$, $\psi(4160)$, $\psi(4415)$, and $Y(4260)$ treating $Y(4260)$ as mainly a $\bar{D}D_1(2420) + c.c$ molecule
  - 2) $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$
  - 3) include more (hidden/open charm) channels from BESIII, Belle, BABAR…
  - **more precise data for a stronger conclusion**

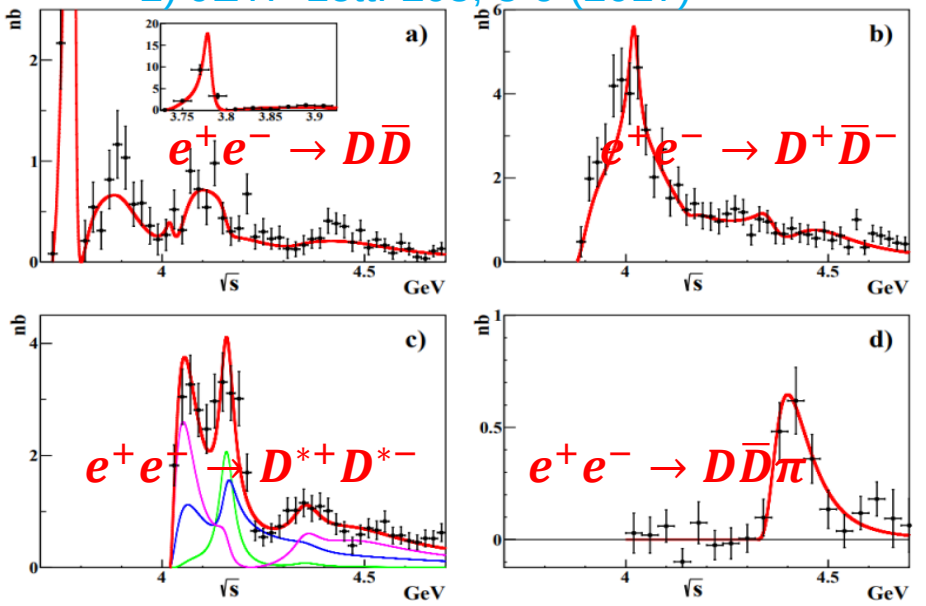
3) EPJC **81**, 83 (2021)



1) PLB **779,** 402 (2018)



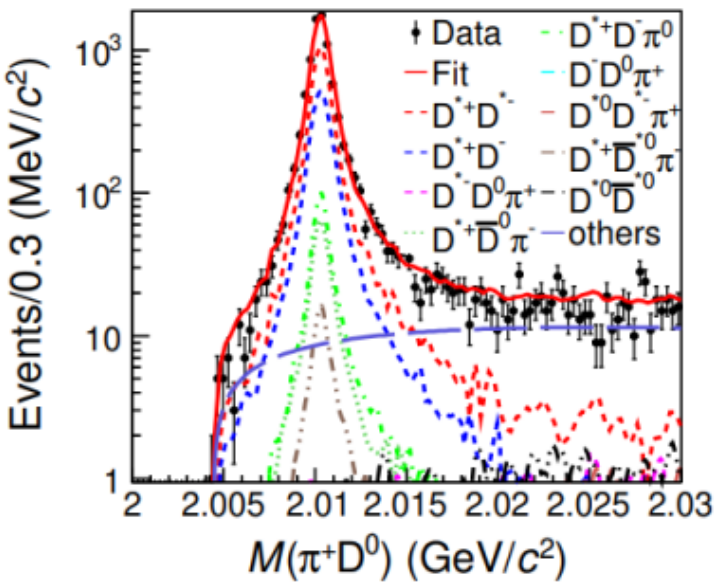
2) JETP Lett. **105**, 3-9 (2017)

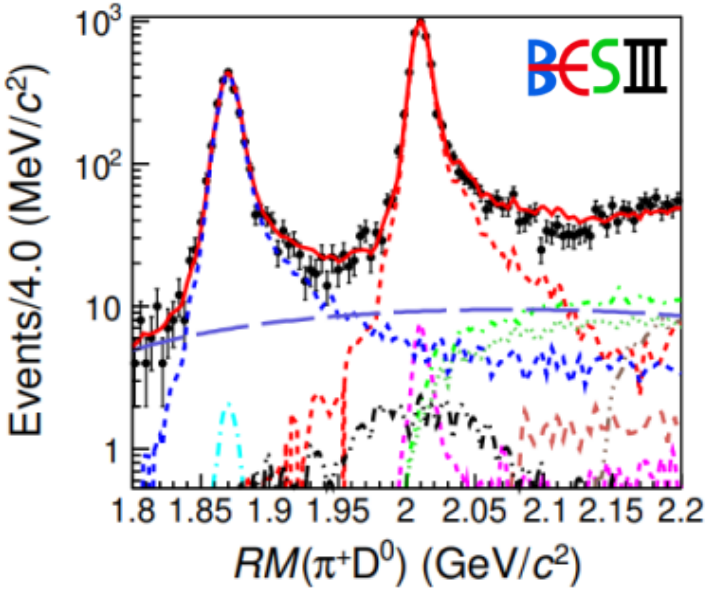


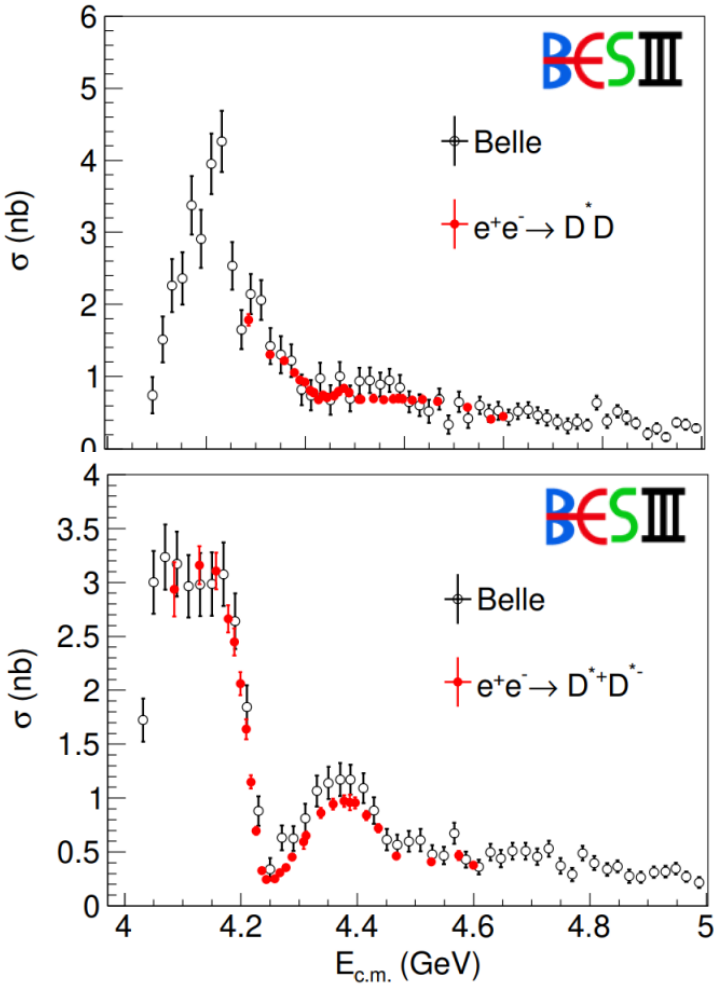
$e^+e^- \to D^{*+}D^{*-}, D^{*+}D^- + c.c.$

- Partial reconstruction: $D^{*+} \to \pi^+ D^0,\ D^0 \to K^-\pi^+$
- A 2D fit method
- Consistent with earlier result with better precision

Published: JHEP **05**, 155 (2022)



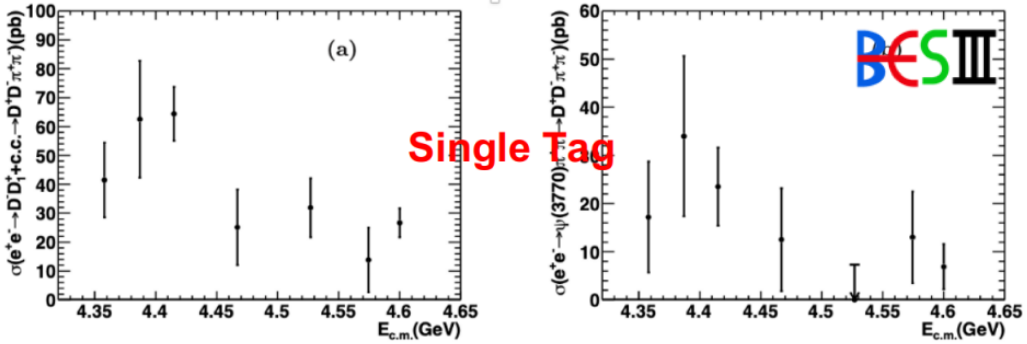




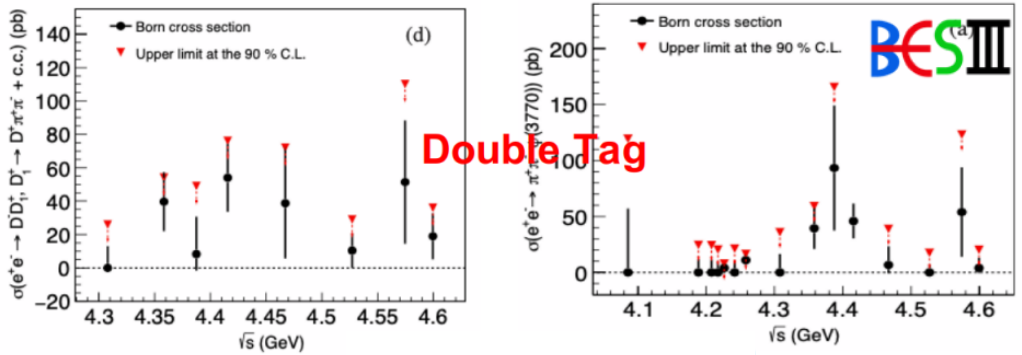
$e^+e^- \to \pi^+\pi^- D^+D^-$

- The production of intermediate states $\sigma(e^+e^- \to D_1(2420)\bar{D} + c.c.)$ and $\sigma(e^+e^- \to \pi^+\pi^-\psi(3770))$ have been reported with partial/full reconstruction
  - The total four-body final state?
- Search as well for $e^+e^- \to \pi^+\pi^-\psi_3(3842)$

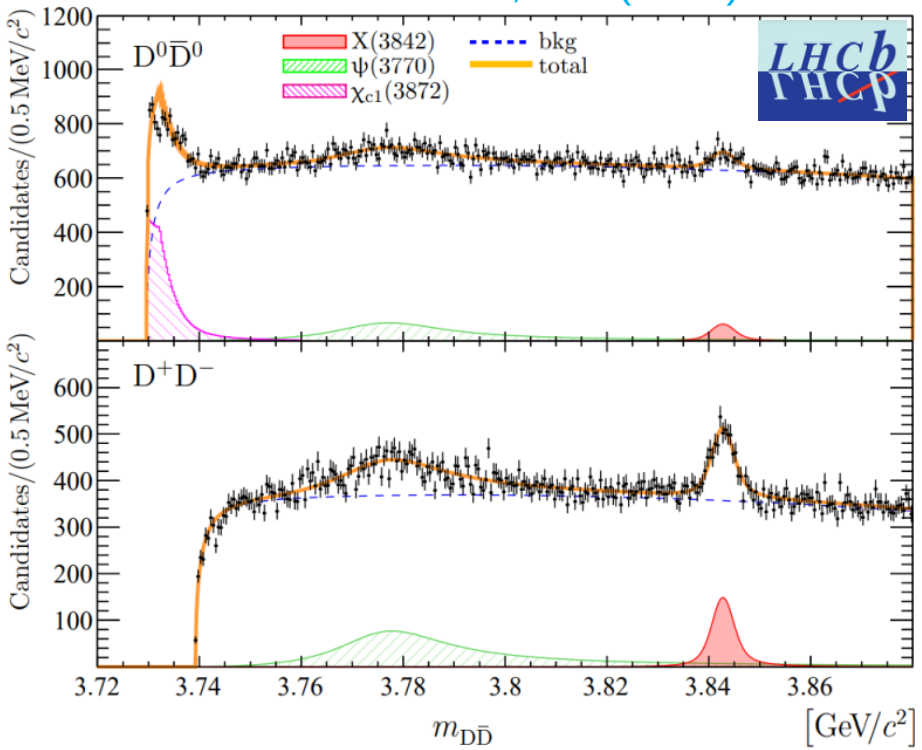
PLB **804**, 135395 (2020)



PRD **100**, 032005 (2019)

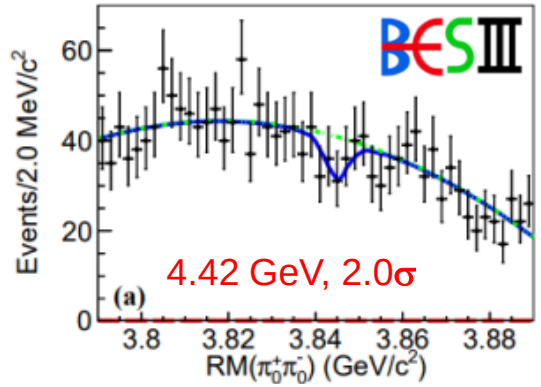


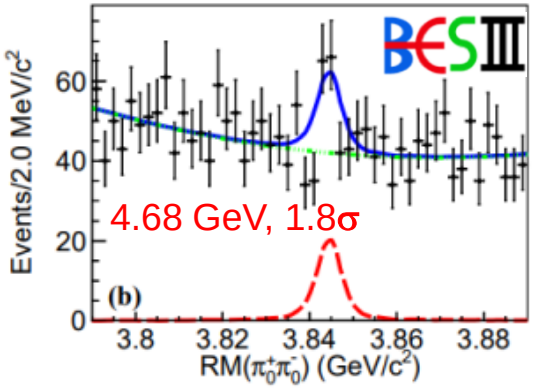
JHEP **1907**, 035 (2019)

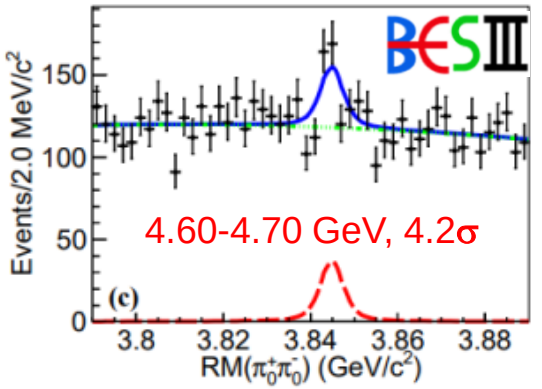


$e^+e^- \to \pi^+\pi^- D^+ D^-$

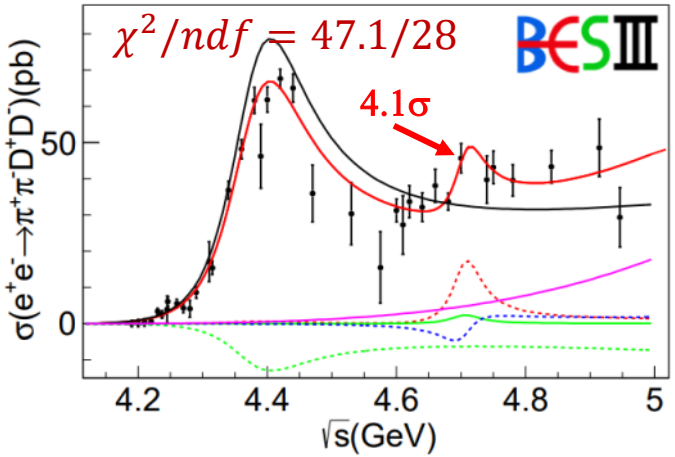
- Partial reconstruction: $\pi^+\pi^- D^+$, $D^+ \to K^-\pi^+\pi^+$
- Test 2BW+PHSP and 2BW models
  - 2BW+PHSP: $M = (4706 \pm 11 \pm 4)$ MeV/c², $\Gamma = (45 \pm 28 \pm 9)$ MeV
  - 2BW: $M = (4605 \pm 90)$ MeV/c², $\Gamma = (245 \pm 67)$ MeV
- $e^+e^- \to \pi^+\pi^-\psi_3(3842)$ may peaks at around 4.60-4.70 GeV

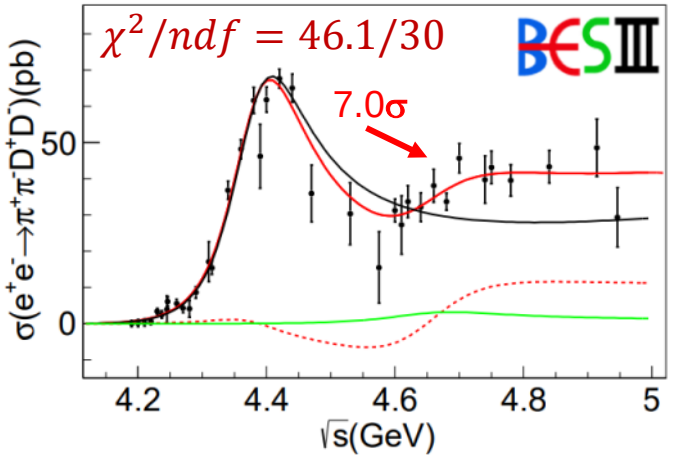






Submitted: arXiv:2208.00099





Fit to the cross section with 2BW+PHSP and 2BW

Summary

- XYZ physics is one of the hot point of current particle physics
- Recently at BESIII, we:
  - Find a strong evidence of $Z_{cs}(3985)$'s isospin partner $Z_{cs}(3985)^0$
  - Measure the cross section of $e^+e^- \to D^{*+}D^{*-}$, $D^{*+}D^- + c.c.$
  - Measure the cross section of $e^+e^- \to \pi^+\pi^- D^+D^-$, search for $e^+e^- \to \pi^+\pi^-\psi_3(3842)$
- More results will be released in the near future

Thank you for your attention!