Study of Vector Charmonium(-like) States in Open Charm States

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Outline

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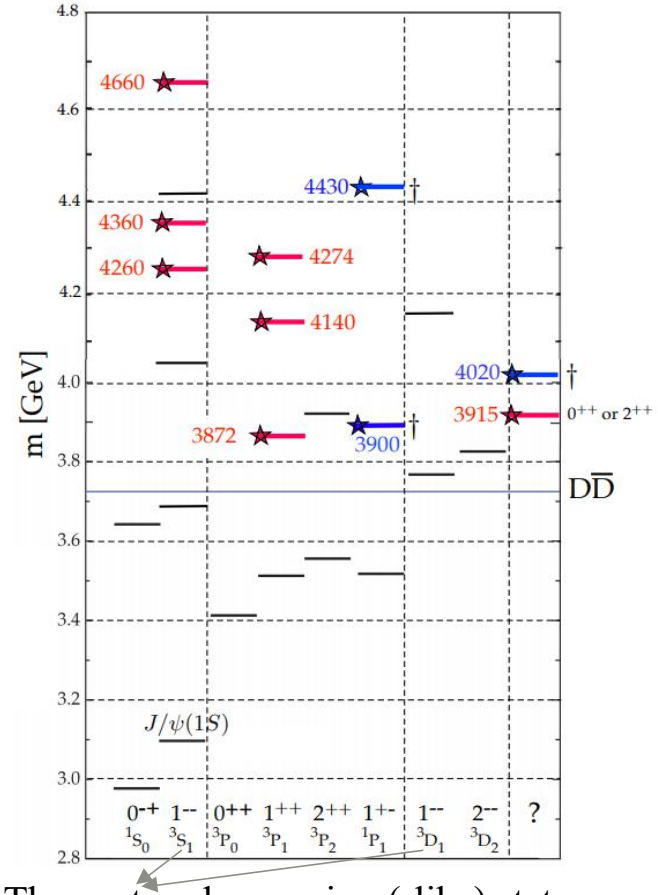
- BESIII data sets
- Study of vector charmonium(-like) states in open charm states at BESIII (in recent two years)
  - $e^+e^- \to \pi^+ D^0 D^{*-}$
  - $e^+e^- \to \pi^+\pi^- D^0 \bar{D}^0$, $\pi^+\pi^- D^+ D^-$
  - $e^+e^- \to D_s^+ D_{s1}(2460)^-$, $D_s^{*+} D_{s1}(2460)^-$
- Summary

Introduction

Charmonium spectrum from PDG 2020



The vector charmonium(-like) states can be produced directly in e^+e^- annihilation.

- The first vector charmonium state, J/ψ, was discovered in 1974. Since then, a series of excited ψ states (ψ(2S), ψ(3770)…) were found.
- There are exotics states that cannot be explained within the framework of the quark model (Y(4230), Y(4260), Y(4660)…).
- According to the OZI rule, the charmonium states above the open charm threshold would most probably decay to open charm final states.
- Studying the open charm final states in the e^+e^- annihilation would help us to understand the nature of the charmonium(-like) states.

BESIII Data Sets

- **BEPCII Collider:**
  - Double ring e^+e^- collider;
  - 2.0 GeV < $\sqrt{s}$ < 4.9 GeV;
  - The peak luminosity is 10^{33} $cm^{-2}s^{-1}$ at $\sqrt{s}$ = 3.78 GeV.
- **BESIII Detector:**
  - Helium-based multilayer drift chamber (MDC),
  - Plastic scintillator time-of-flight system (TOF),
  - CsI(Tl) electromagnetic calorimeter (EMC),
  - Superconducting solenoidal magnet providing a 1.0 T magnetic field.
  - Octagonal flux-return yoke with resistive plate counter muon identifier modules interleaved with steel.
- **The BESIII Collaboration has about 500 members from 72 institutions in 15 countries.**

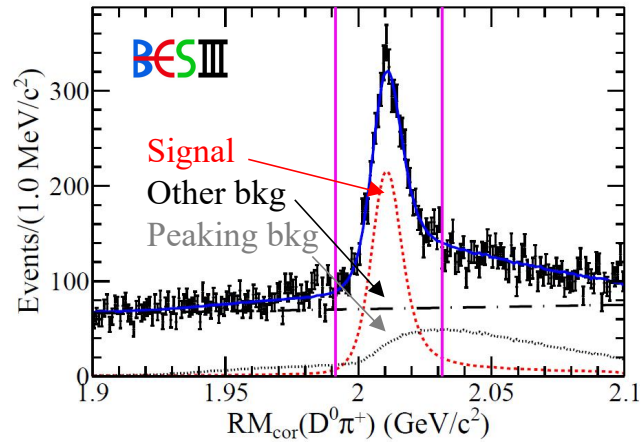
- **XYZ data:**
  - ~ 20 fb^{-1} data event in open charm region 3.8-4.7GeV.
  - Larger data sets at some special energy points: 4.18 GeV, 4.23 GeV, 4.26 GeV, 4.42 GeV, 4.68 GeV.
- **R-scan data in open charm region:**
  - Energy points with luminosity less than 20 pb^{-1}.
  - Initially taken for R study, can also help the XYZ study.

Details of BEPCII, BESIII, and data sets could be found from previous talks.

$e^+e^- \to \pi^+ D^0 D^{*-}$

- The process $e^+e^- \to \pi^+ D^0 D^{*-}$ from 4.05 to 4.60 GeV has been studied.
  - The bachelor π^+ and the D^0 (through $D^0 \to K^-\pi^+$) are reconstructed.
  - The D^{*-} is inferred from energy-momentum conservation.
- The $e^+e^- \to D^*\overline{D}^*$ background events are rejected by vetoing any $D^0\pi^+$ candidates satisfying $M(D^0\pi^+)<2.03$ GeV/c^2.

$$RM_{\rm cor}(D^0\pi^+) = RM(D^0\pi^+) + M(K^-\pi^+) - m(D^0)$$



- The only peaking background is from the isospin partner process $e^+e^- \to \pi^+ D^- D^{*0}$. The other backgrounds are described by a first order polynomial function.
- The dressed cross sections are calculated.

$$\sigma_{\rm dress} = \frac{N^{\rm obs}}{\mathcal{L}\cdot(1+\delta)\cdot\mathcal{B}(D^0\to K^-\pi^+)\cdot\epsilon}$$

$\Rightarrow$

$N^{\rm obs}$ is the signal yield;
L is the integrated luminosity;
$(1+\delta)$ is the ISR correction factor;
$B(D^0 \to K^-\pi^+) = (3.93 \pm 0.04)\%$;
ε is the detection efficiency.

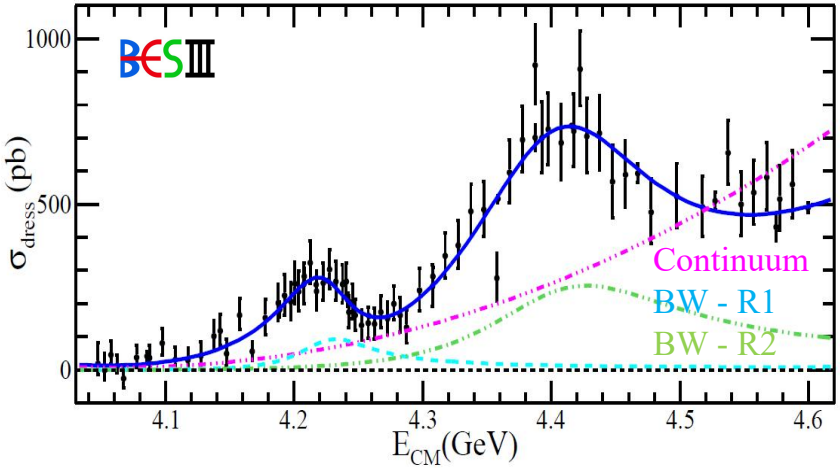
Phys. Rev. Lett. 122, 102002 (2019)

$e^+e^- \to \pi^+ D^0 D^{*-}$

- A fit was applied to the dressed cross sections.

$$\sigma_{\rm dress}(m) = \left| c \cdot \sqrt{P(m)} + e^{i\phi_1} B_1(m) \sqrt{P(m)/P(M_1)} + e^{i\phi_2} B_2(m) \sqrt{P(m)/P(M_2)} \right|^2$$

⇨ P(m) is the three-body phase-space factor; B(m) is the Breit-Wigner (BW) function.



Parameter	Solution I	Solution II	Solution III	Solution IV
c (MeV$^{-3/2}$)		$(6.2 \pm 0.5) \times 10^{-4}$		
M_1 (MeV/c^2)	Parameters of the 1st BW	4228.6 ± 4.1		
Γ_1 (MeV)		77.0 ± 6.8		
M_2 (MeV/c^2)	Parameters of the 2nd BW	4404.7 ± 7.4		
Γ_2 (MeV)		191.9 ± 13.0		
$\Gamma_1^{\rm el}$ (eV)	77.4 ± 10.1	8.6 ± 1.6	99.5 ± 14.6	11.1 ± 2.3
$\Gamma_2^{\rm el}$ (eV)	100.4 ± 13.3	64.2 ± 8.0	664.2 ± 80.0	423.0 ± 47.0
ϕ_1 (rad)	-2.0 ± 0.1	3.0 ± 0.2	-0.9 ± 0.1	-2.2 ± 0.1
ϕ_2 (rad)	2.1 ± 0.2	2.5 ± 0.2	-2.3 ± 0.1	-1.9 ± 0.1

- Fixing the parameters of the second peak to (or include one additional resonance of) Y(4260), Y(4320), Y(4360), or ψ(4415) would yield wildly varying parameters for R_2.
- The mass and width of the R_1 are stable: $M_1 = (4228.6 \pm 4.1 \pm 6.3)$ MeV/c^2

  $\Gamma_1 = (77.0 \pm 6.8 \pm 6.3)$ MeV
- The statistical significance of the two-resonance model over a one-resonance model is 10.5σ.

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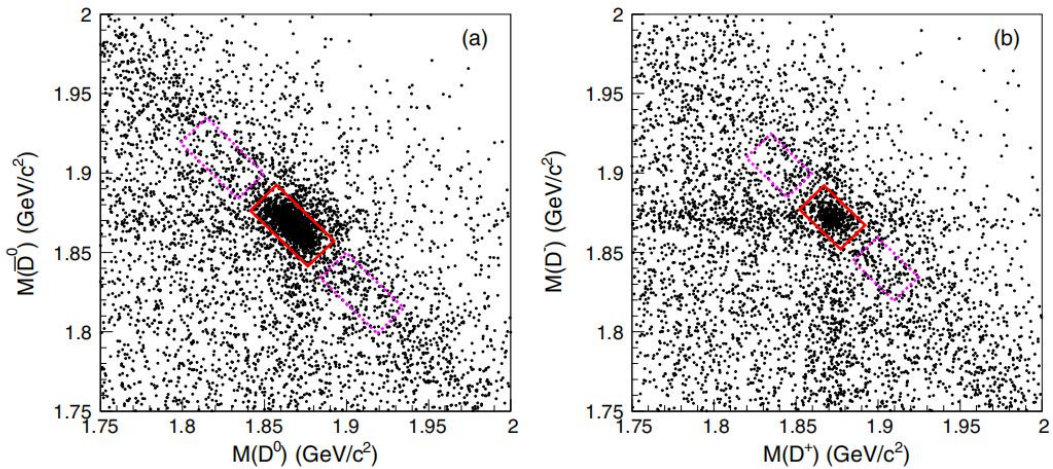
$e^+e^- \to \pi^+\pi^- D^0 D^0$, $\pi^+\pi^- D^+ D^-$

- Several intermediate states of the reaction channels $e^+e^- \to \pi^+\pi^- D^0\overline{D}^0$, $\pi^+\pi^- D^+D^-$ from 4.08 to 4.60 GeV are studied.
  - $e^+e^- \to \pi^+\pi^-\psi(3770)$
  - $e^+e^- \to \rho^0 X_2(4013)$
  - $e^+e^- \to D_1(2420)\overline{D}$
- The D^0 mesons are reconstructed in four decay modes: $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, and $K^-\pi^+\pi^+\pi^-\pi^0$.
- The D^+ mesons are reconstructed in five decay modes: $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K_S^0\pi^+$, $K_S^0\pi^+\pi^0$, and $K_S^0\pi^+\pi^-\pi^+$.

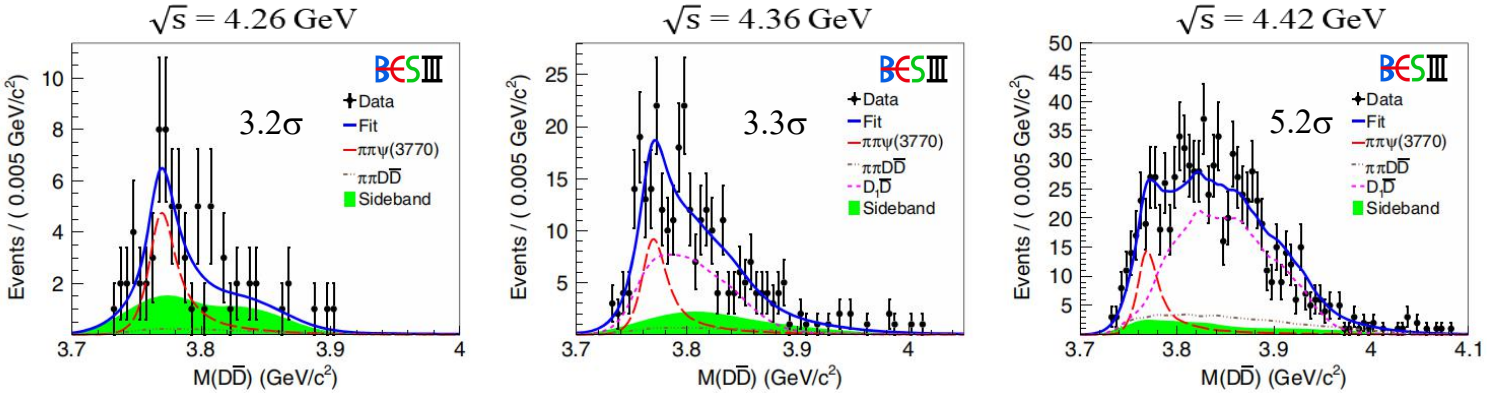


$\sqrt{s} = 4.42$ GeV

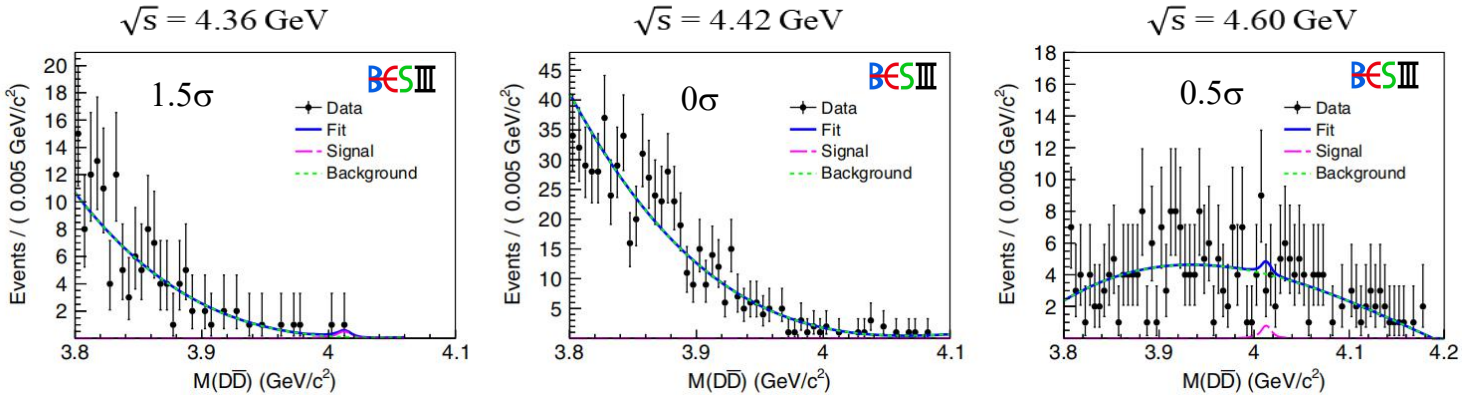
Phys. Rev. D 100, 032005 (2019)

$e^+e^- \to \pi^+\pi^- D^0\bar{D}^0$, $\pi^+\pi^- D^+D^-$

- The signal of ψ(3770) could be found from the invariant mass $M(D\bar{D})$.



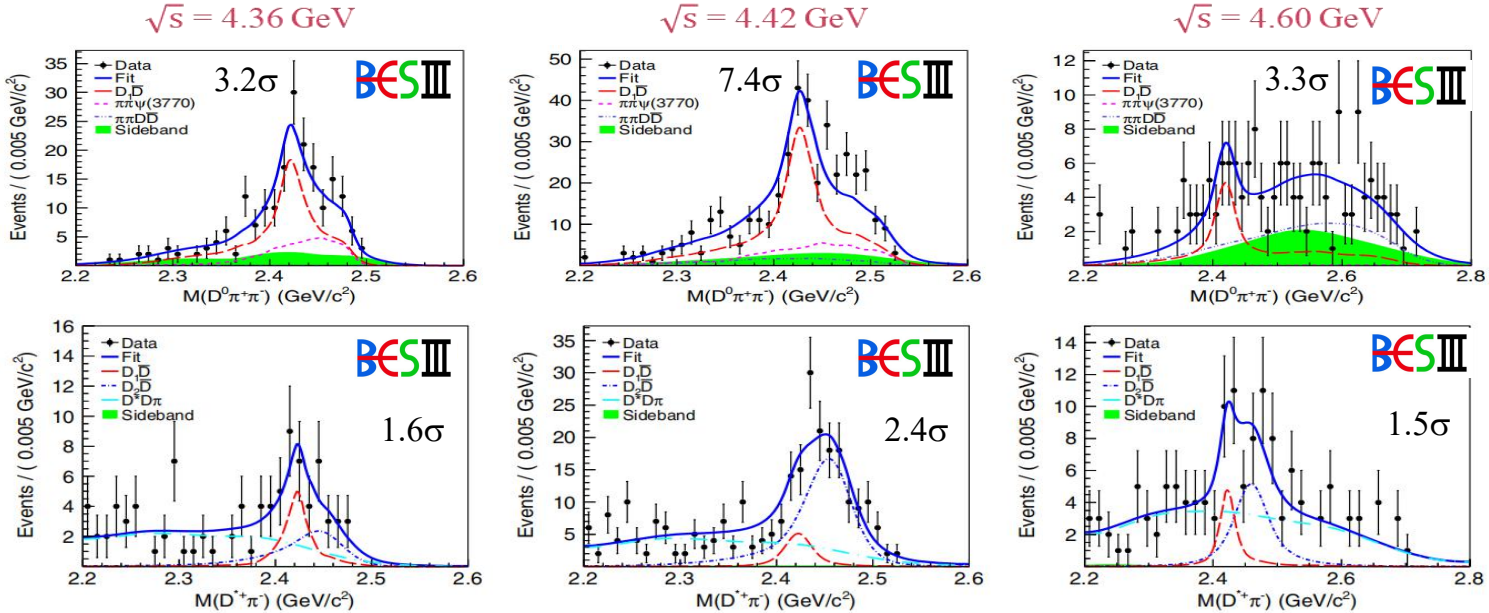
- No obvious $X_2(4013)$ is found.



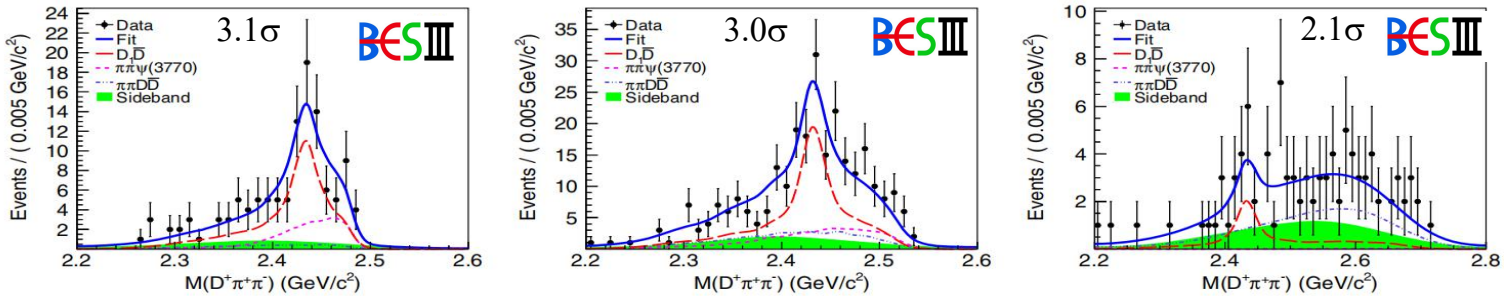
Phys. Rev. D 100, 032005 (2019)

$e^+e^- \to \pi^+\pi^- D^0\bar{D}^0$, $\pi^+\pi^- D^+D^-$

- The signal of $D_1(2420)^0$ could be found from the invariant mass $M(D^0\pi^+\pi^-)$ and $M(D^{*+}\pi^-)$.



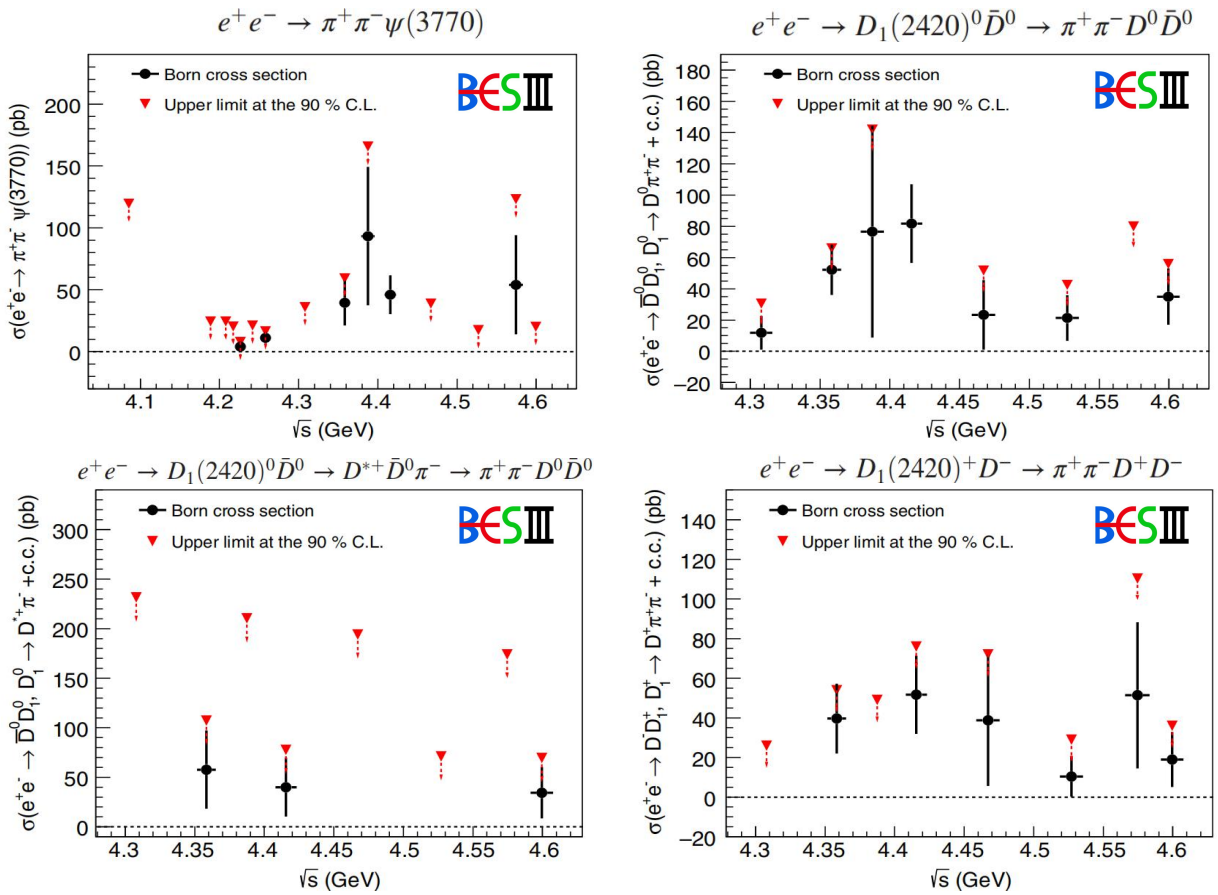
- The signal of $D_1(2420)^+$ could be found from the invariant mass $M(D^+\pi^+\pi^-)$.



Phys. Rev. D 100, 032005 (2019)

$e^+e^- \to \pi^+\pi^- D^0\bar{D}^0$, $\pi^+\pi^- D^+D^-$

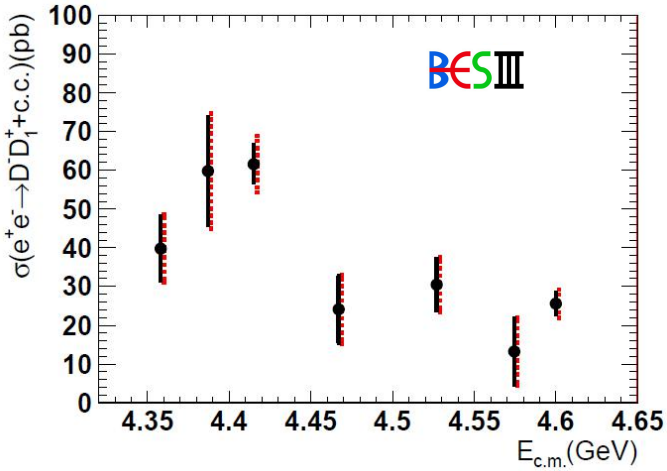
- Cross sections are calculated.

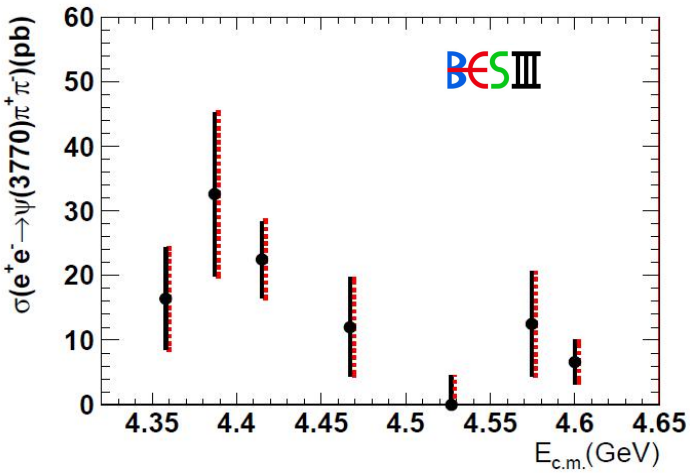


Phys. Rev. D 100, 032005 (2019)

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

- The process $e^+e^- \rightarrow \pi^+\pi^- D^+D^-$ from 4.36 to 4.60 GeV has been studied through partial reconstruction method, too.
- The bachelor $\pi^+\pi^-$ and the D^+ (through $D^+ \rightarrow K^-\pi^+\pi^+$) are reconstructed. The missing D^- is found from the recoil-mass distribution.
- The measured cross sections are consistent with the full reconstruction method.



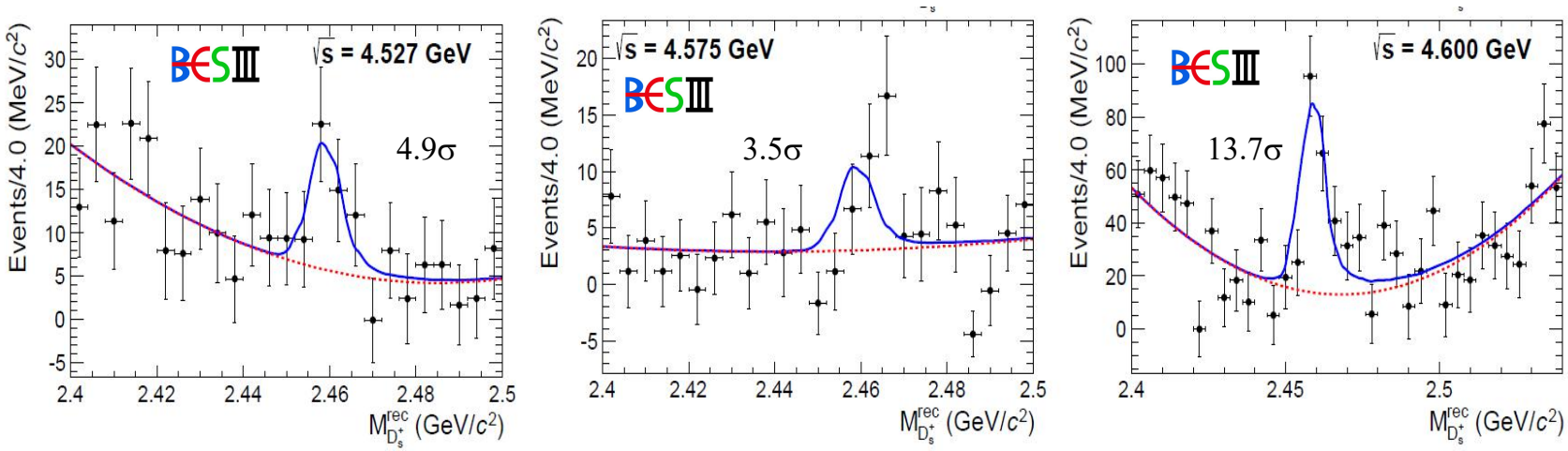


The (black) solid lines are the sum of statistical uncertainties and independent systematic uncertainties in quadrature, the (red) dot lines are total uncertainties.

Phys. Lett. B 804, 135395 (2020)

$e^+e^- \to D_s^+ D_{s1}(2460)^-$, $D_s^{*+} D_{s1}(2460)^-$

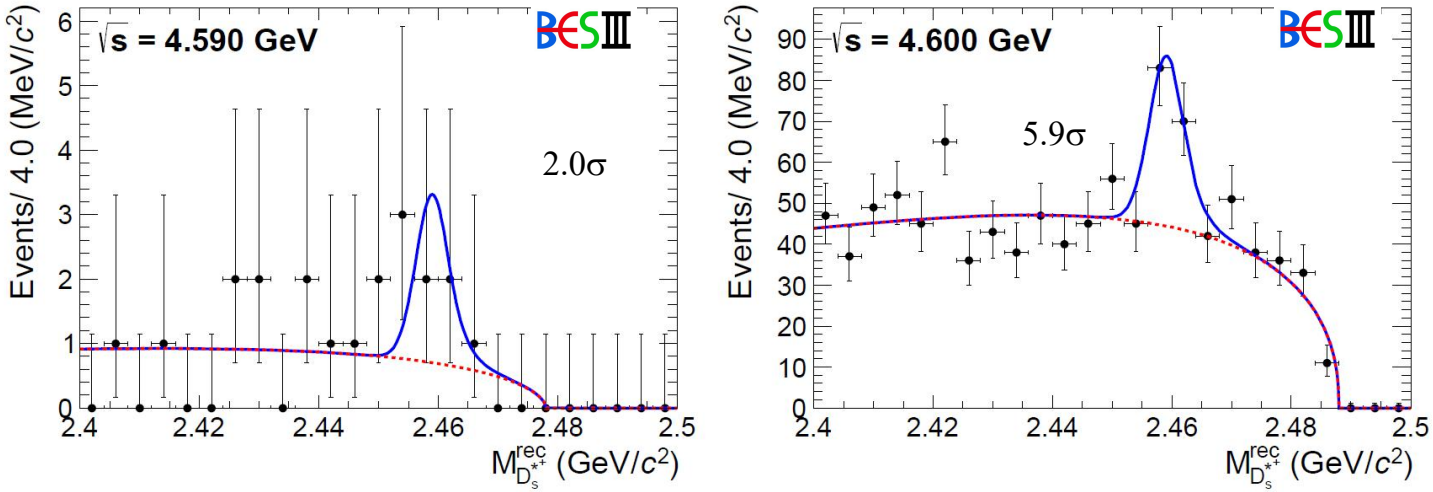
- The process $e^+e^- \to D_s^+ D_{s1}(2460)^-$ from 4.467 to 4.600 GeV has been studied.
  - The D_s^+ candidates are reconstructed via $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$ and $D_s^+ \to \bar{K}^{*0}K^+$, $\bar{K}^{*0} \to K^-\pi^+$.
  - The missing $D_{s1}(2460)^-$ is found from the recoil-mass distribution.
  - The dominant backgrounds are e+e-→$D_s^{*+}D_s^{*-}$ (lower mass region), and $D_s^+\bar{D}^{(*)0}K^-$, $D_s^+D^{(*)-}\bar{K}^0$ (higher mass region).



Phys. Rev. D 101, 112008 (2020)

$e^+e^- \to D_s^+ D_{s1}(2460)^-$, $D_s^{*+} D_{s1}(2460)^-$

- The process $e^+e^- \to D_s^{*+} D_{s1}(2460)^-$ at 4.590 GeV and 4.600 GeV has been studied.
  - The D_s^{*+} is reconstructed through $D_s^{*+} \to \gamma D_s^+$.
  - The D_s^+ candidates are reconstructed via $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$ and $D_s^+ \to \bar{K}^{*0}K^+$, $\bar{K}^{*0} \to K^-\pi^+$.
  - The missing $D_{s1}(2460)^-$ is found from the recoil-mass distribution.

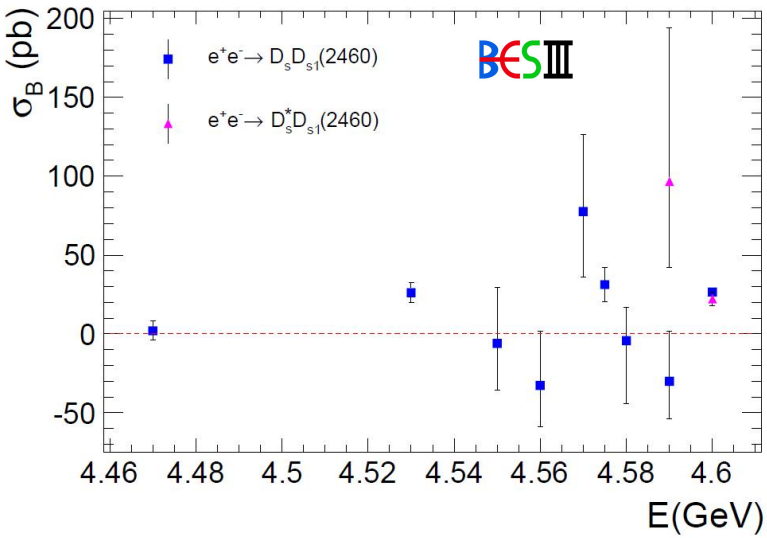


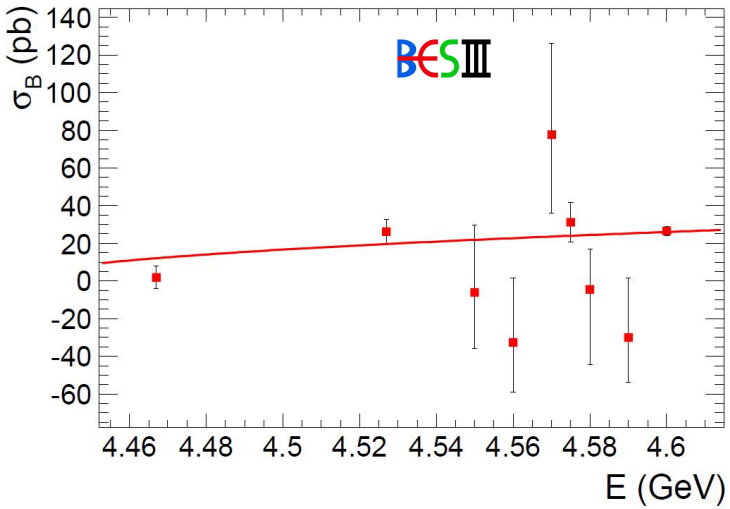
Phys. Rev. D 101, 112008 (2020)

$e^+e^- \to D_s^+ D_{s1}(2460)^-$, $D_s^{*+} D_{s1}(2460)^-$

- No obvious charmonium or charmonium-like structure is seen in the measured cross sections.
- Within the statistical uncertainty of the measurement, the cross section of $e^+e^- \to D_s^+ D_{s1}(2460)^-$ could be described by the theoretical prediction.

$$\sigma[e^+e^- \to D_s D_{s1}(2460)] \propto \sqrt{E_{cm} - E_0}$$





Phys. Rev. D 101, 112008 (2020)

Summary

- With data samples collected by the BESIII detector, we studied vector charmonium(-like) states in some open charm states.
  - $e^+e^- \to \pi^+ D^0 D^{*-}$

    A structure is observed: $M_1 = (4228.6 \pm 4.1 \pm 6.3)$ MeV/c^2, $\Gamma_1 = (77.0 \pm 6.8 \pm 6.3)$ MeV.
  - $e^+e^- \to \pi^+\pi^- D^0 \overline{D}^0$, $\pi^+\pi^- D^+ D^-$

    There are enhancements between 4.36 and 4.42 GeV.
  - $e^+e^- \to D_s^+ D_{s1}(2460)^-$, $D_s^{*+} D_{s1}(2460)^-$

    No obvious structure is seen.
- More results from open charm final states study are coming soon.

Thank you !