Cross Section Measurement of Charm Hadron Pair at BESIII

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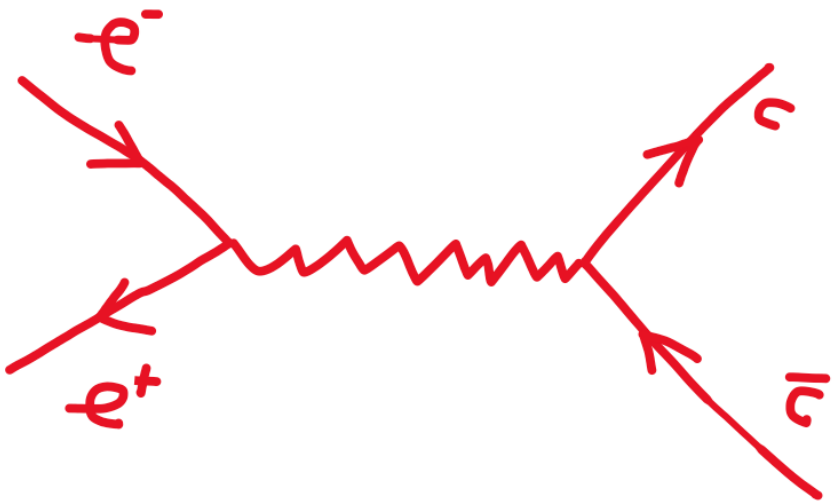
2025年BESIII粲强子物理研讨会，兰州，8月5-8日

Outline

- Introduction
- Cross section for open charm final states
  - $e^+e^- \to D_s^{*+}D_s^{*-}$ (PRL 131, 151903 (2023))
  - $e^+e^- \to D_s^{+}D_s^{-}$ (PRL 133, 261902 (2024))
  - $e^+e^- \to D^+D^-/D^0\bar{D}^0$ (PRL 133, 081901 (2024))
  - $e^+e^- \to D_s^+D_{s1}(2536)^-, D_s^+D^*_{s2}(2573)^-$ (PRL 133, 171903 (2024))
  - Charmed baryon (PRL 131, 191901 (2023), PRD 109, L071104 (2024))
- Summary

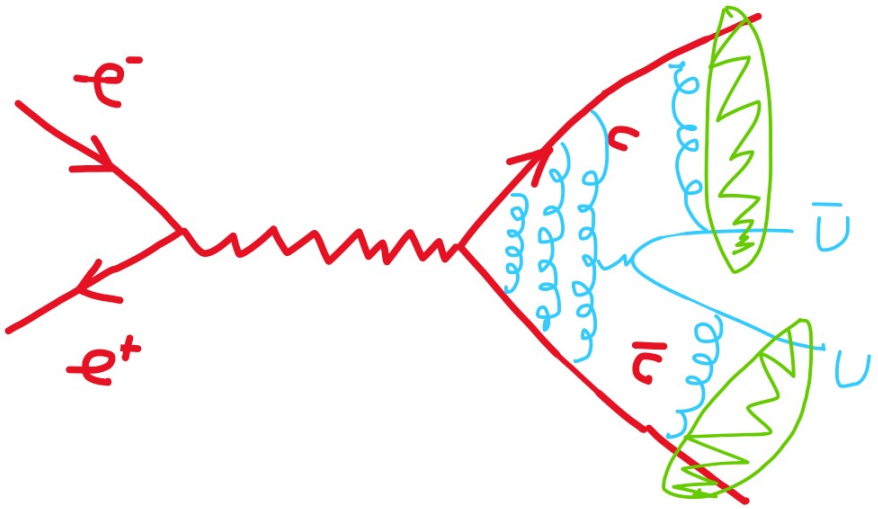
Introduction

Charm Quark Production Is Simple



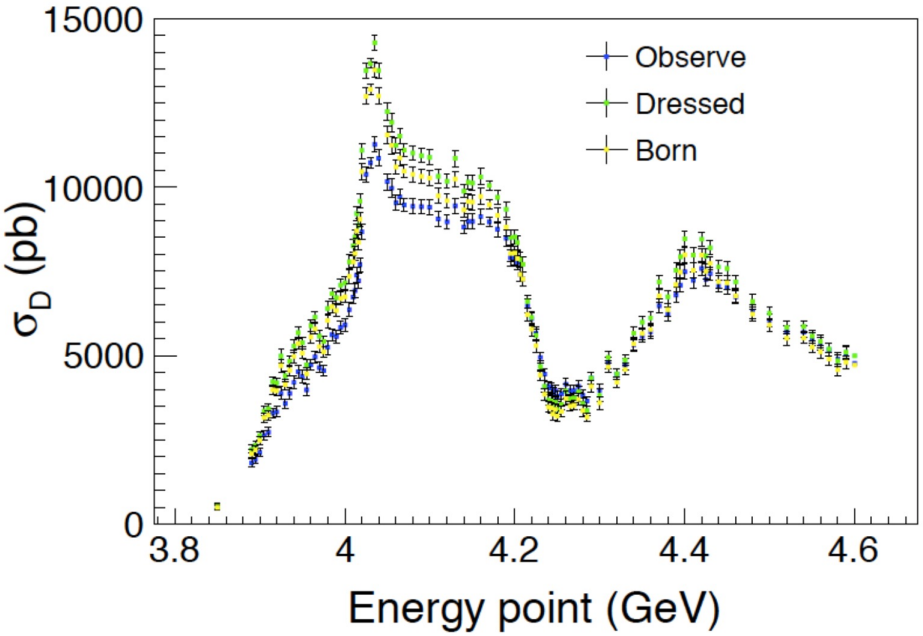
- **QED is for the quark pair production.**
- **However, quark is confined into hadron based on QCD, which is very complicated.**
- **There are a lot of resonances in this energy regime which makes things more complicated.**

Charmed Hadron Production is NOT Simple

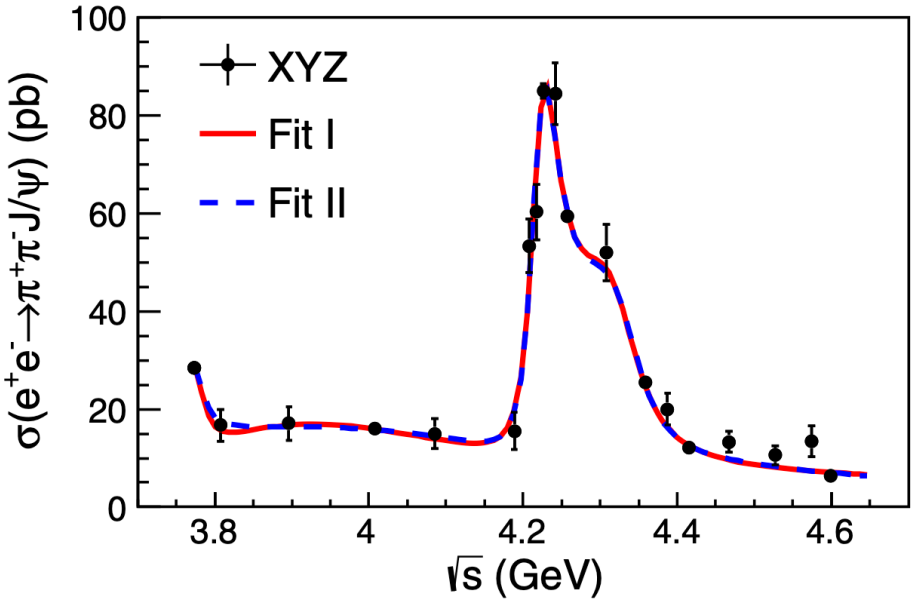


- QED is for the quark pair production.
- **However, quark is confined into hadron based on QCD, which is very complicated.**
- **There are a lot of resonances in this energy regime which makes things more complicated.**

Open Charm Process Dominates at 4-5 GeV

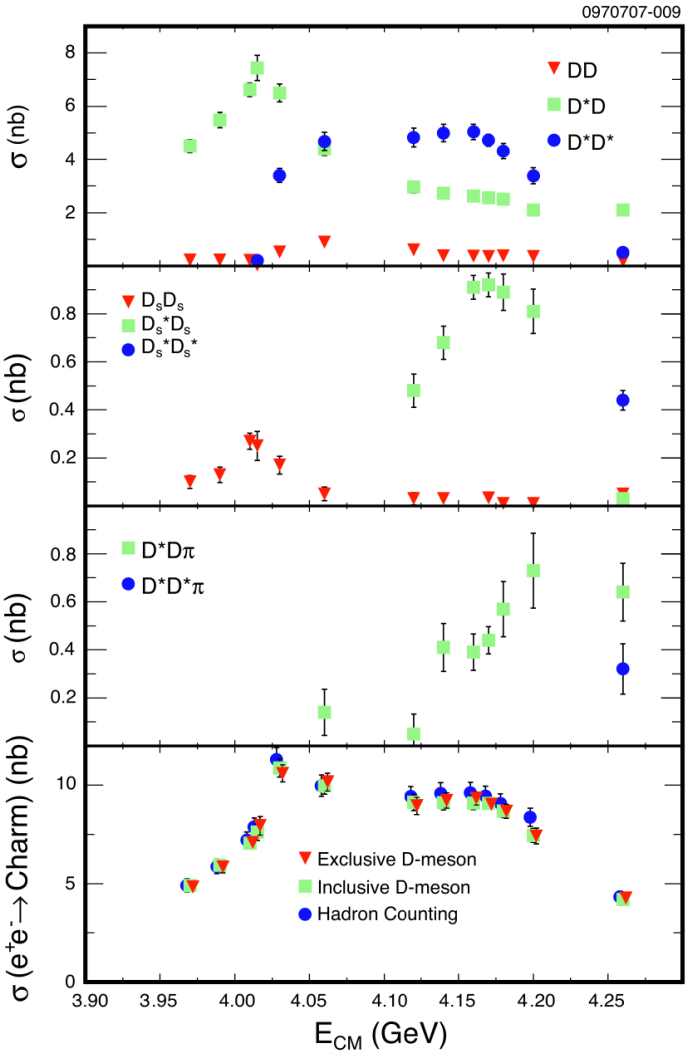


Weimin Song, PhD thesis

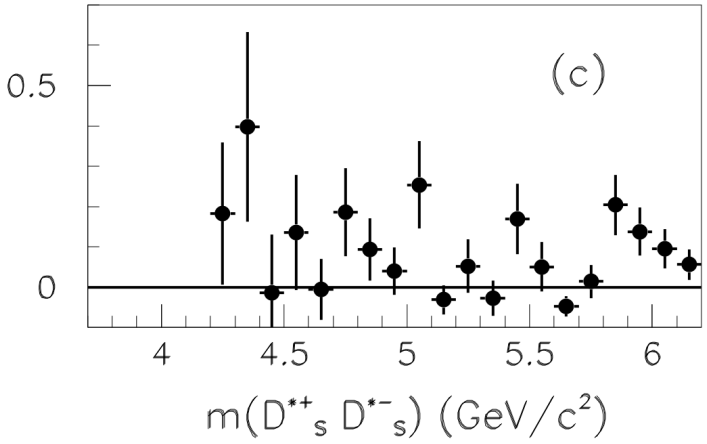


Phys. Rev. Lett. **118**, 092001 (2017)

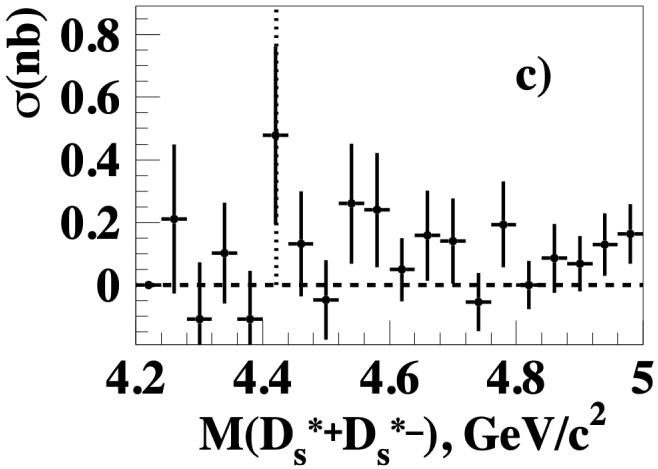
How about Previous Results?



Phys. Rev. D 80, 072001 (2009)

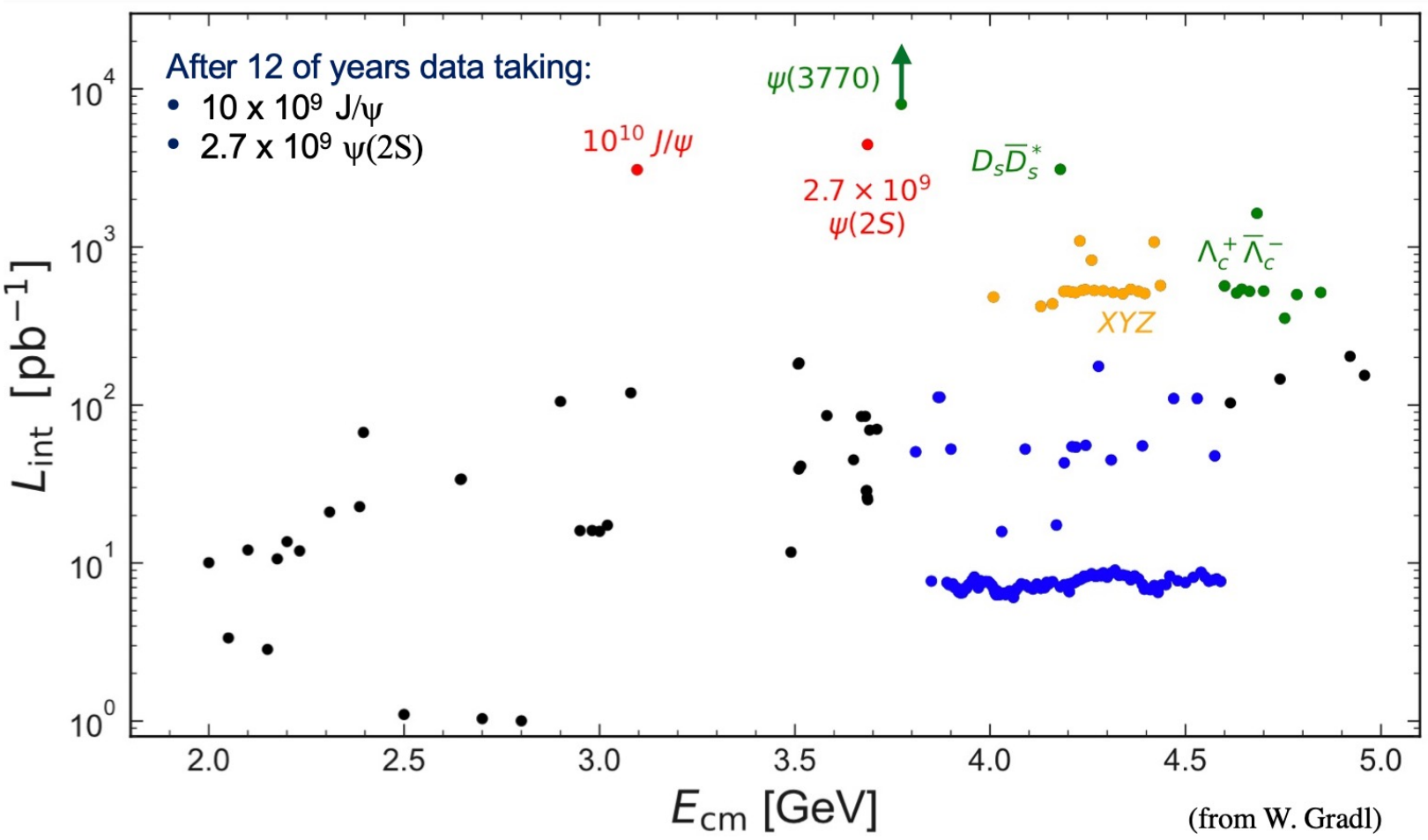


Phys. Rev. D 82, 052004 (2010)



Phys. Rev. D 83, 011101(R) (2011)

Huge Data Sample at BESIII

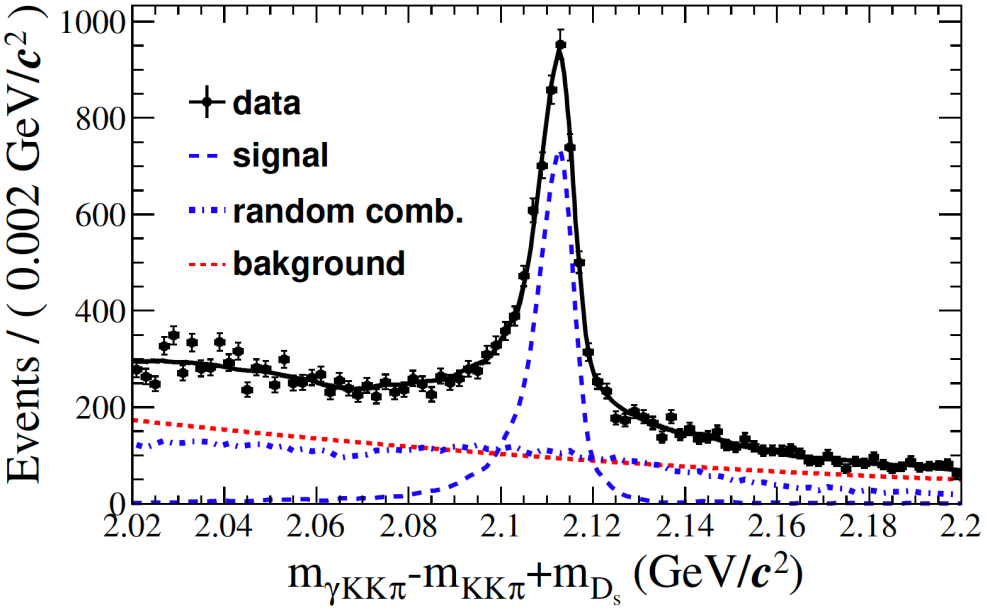


$e^+e^- \rightarrow D_s^{*+}D_s^{*-}$

PRL 131, 151903 (2023)

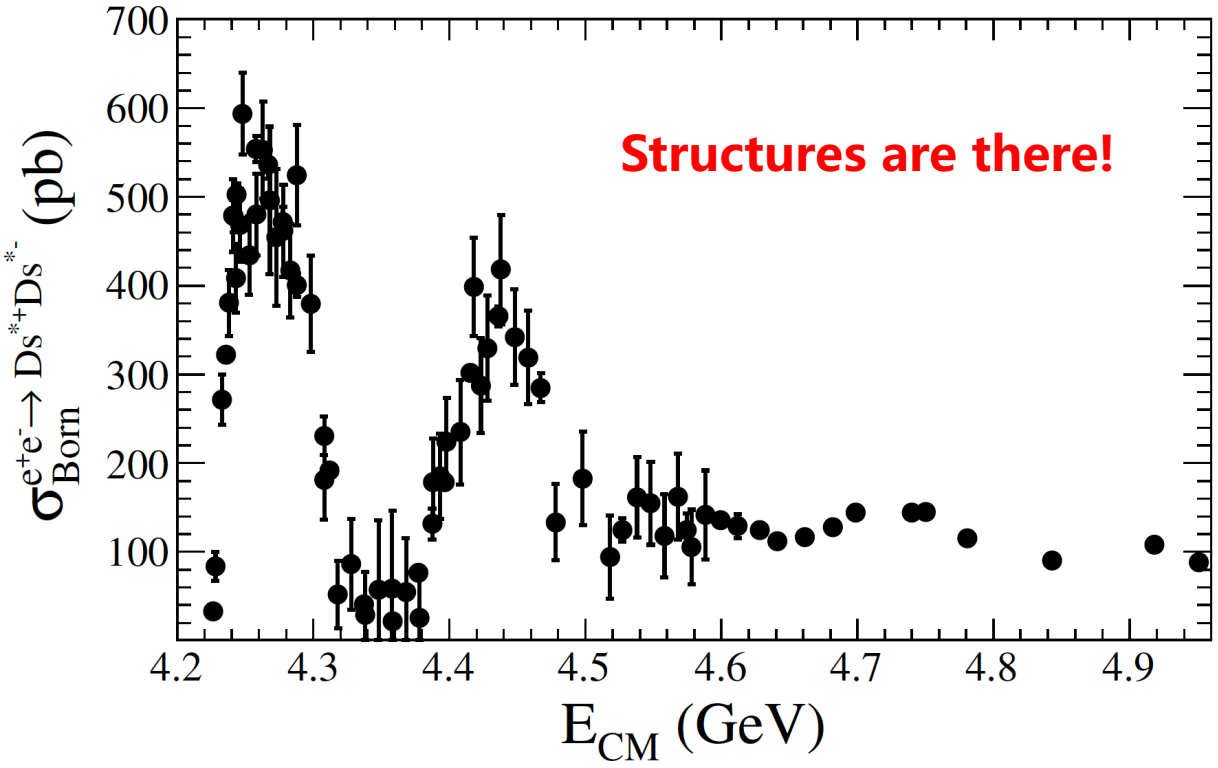
Event Selection and Background Estimation

- **Process:** $e^+e^- \to D_s^{*+}D_s^{*-}$
- **Reconstruct Ds* by Ds+photon**
- **Cutting on the recoil mass of Ds* and fitting the "modified" mass of Ds***
- **Background: peaking one from $e^+e^- \to D_s^{*+}D_s^-$ is estimated by its measured cross section; random combination from $e^+e^- \to D_s^{*+}D_s^{*-}$ is controlled by signal MC; others by flat function**



Fit example for data at 4.29 GeV

Born Cross Section

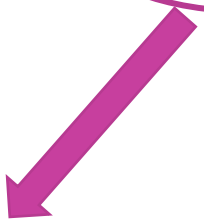


$$\sigma_{\rm Born} = \sigma_{\rm dressed}|1+\Pi|^2$$

$$= \frac{N^{\rm fit}_{D_s^*} - N_{D_s^\pm D_s^{*\mp}}}{2\mathcal{B}(D_s^\pm \to K^+K^-\pi^\pm)\epsilon(1+\delta)\frac{1}{|1+\Pi|^2}\mathcal{L}_{\rm int}}$$

Systematic Uncertainty on Cross Section

Sources	Systematic uncertainties (%)								
Common	4.0								
Energy (interval) (GeV)	4.226	4.228	4.233	4.233∼4.24	4.24∼4.3	4.3∼4.4	4.4∼4.82	4.843	4.86∼4.95
Signal yields fitting with fixed parameters	2.0					5.0	2.0		
Signal yields fitting range	4.0					5.0	4.0		
Cross section line shape description	5.0				2.0	5.0	2.0	5.0	2.0
$E_{\rm CM}$ uncertainty	24.5	20.0	9.4	0.8					
Total	25.7	21.5	12.2	7.9	6.4	9.6	6.4	7.9	6.4



The ISR correction factor is extremely sensitive to the Ecm when it is too close to the threshold.

Fit the Cross Section with Breit-Wigner Function

PHSP term for the continuum production

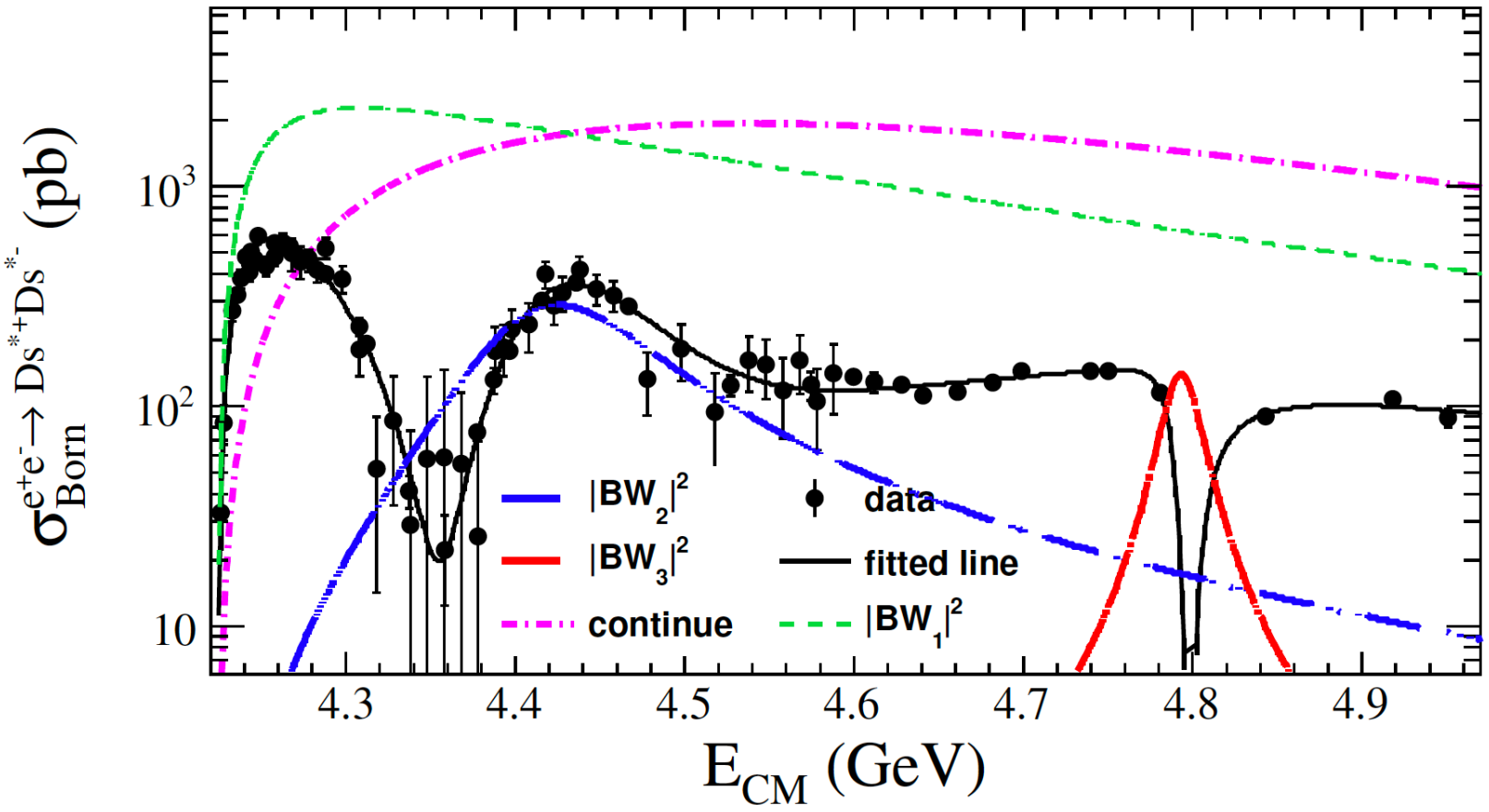
$$\left| \sum_{j=1}^{3} a_j \cdot e^{i\phi_j} \cdot BW_j(E_{\mathrm{CM}}) + \frac{a_0}{E_{\mathrm{CM}}^n} \right|^2 \beta^3(E_{\mathrm{CM}})$$

Fixed width BW function with P wave Blatt-Weisskopf barrier factor

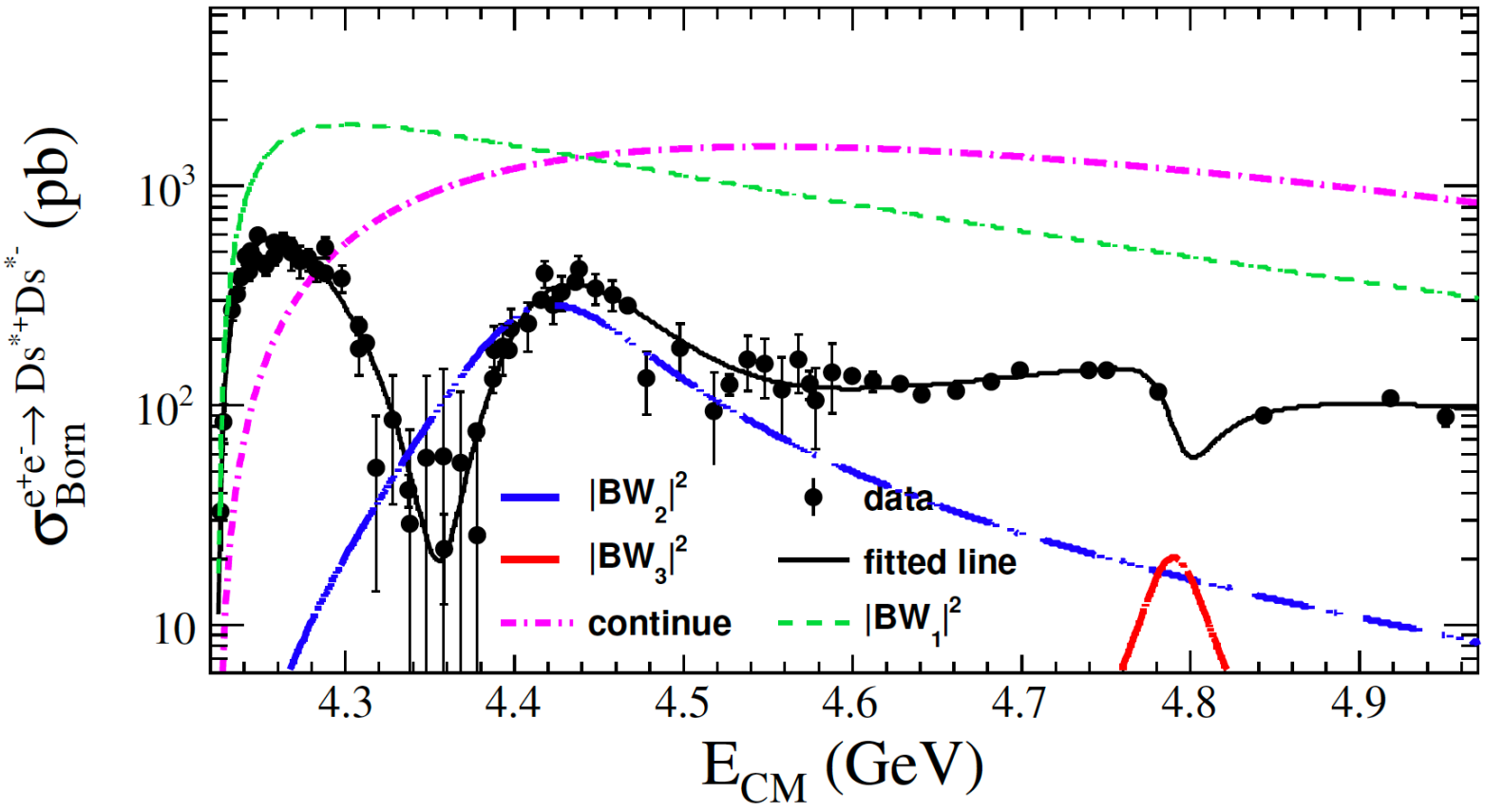
P wave assumption

We are aware that it is imperfect to fit with BW functions!

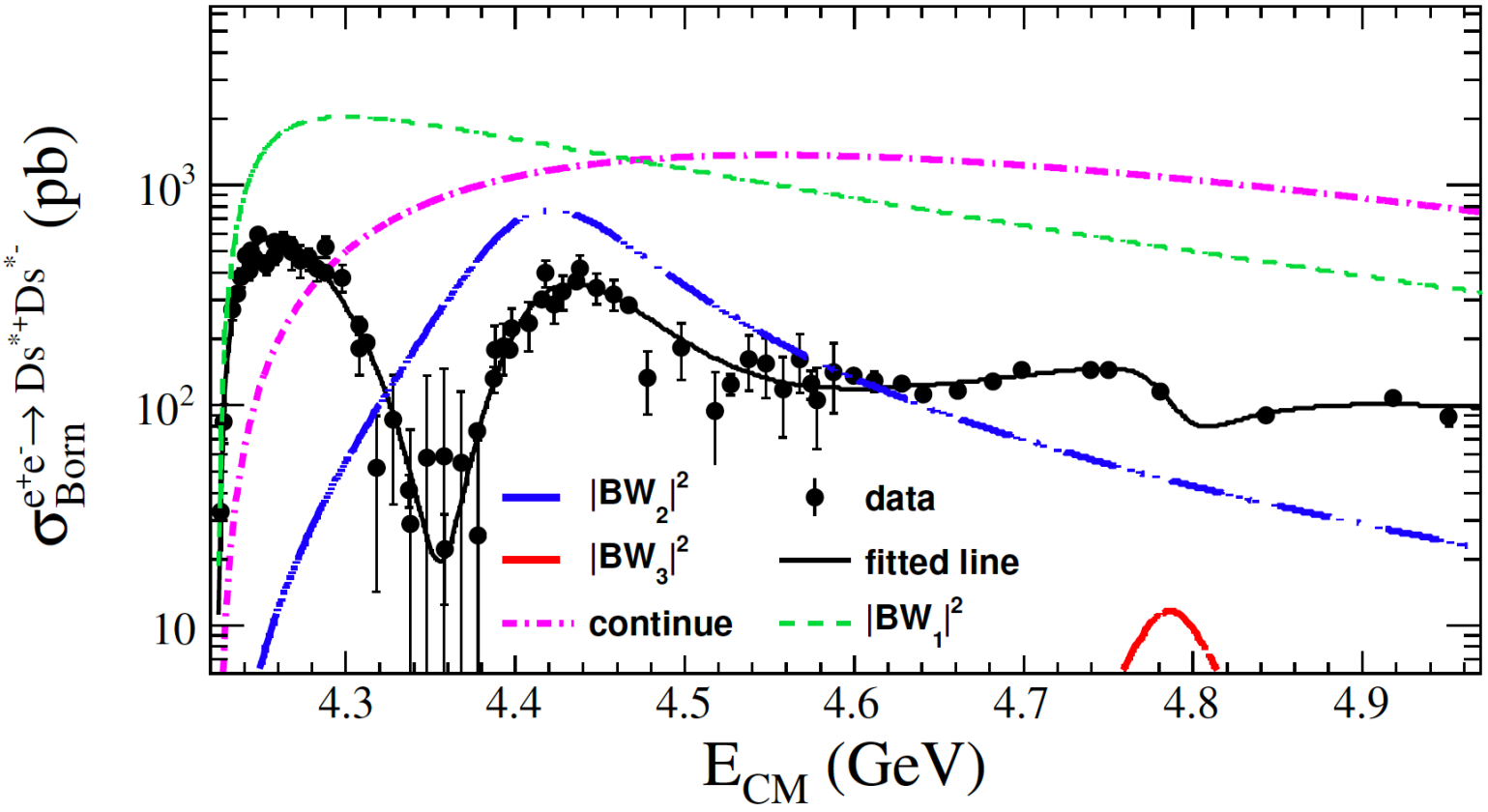
Fit Result 1


$\sigma^{e^+e^-\to Ds^{*+}Ds^{*-}}_{Born}$ (pb)
10^3
10^2
10
4.3
4.4
4.5
4.6
4.7
4.8
4.9
E_{CM} (GeV)
$|BW_2|^2$
$|BW_3|^2$
continue
data
fitted line
$|BW_1|^2$

Fit Result 2


$\sigma^{e^+e^-\to Ds^{*+}Ds^{*-}}_{Born}$ (pb)
10^3
10^2
10
4.3
4.4
4.5
4.6
4.7
4.8
4.9
E_{CM} (GeV)
$|BW_2|^2$
$|BW_3|^2$
continue
data
fitted line
$|BW_1|^2$

Fit Result 3


$\sigma^{e^+e^-\to Ds^{*+}Ds^{*-}}_{Born}$ (pb)
10^3
10^2
10
4.3
4.4
4.5
4.6
4.7
4.8
4.9
E_{CM} (GeV)
$|BW_2|^2$
$|BW_3|^2$
continue
data
fitted line
$|BW_1|^2$

Summary of the Fit

- **The significance of the third structure is larger than 6σ for all the three results**
- **The mass and width of the first structure vary among the three results, mainly due to mass is too close to the threshold; they vary for the third structure also, mainly due to lack of data around 4.7 GeV; stable for the second structure**
- **The width of the third structure is not large**

	Result 1	Result 2	Result 3
M_1 (MeV/c^2)	4186.5±9.0	4193.8±7.5	4195.3±7.5
Γ_1 (MeV)	55±17	61.2±9.0	61.8±9.0
M_2 (MeV/c^2)	4414.5±3.2	4412.8±3.2	4411.0±3.2
Γ_2 (MeV)	122.6±7.0	120.3±7.0	120.0±7.0
M_3 (MeV/c^2)	4793.3±7.5	4789.8±9.0	4786±10
Γ_3 (MeV)	27.1±7.0	41±39	60±35

Sources	Fitting	R	$E_{\rm CM}$	$\sigma_{\rm Born}$	Total
M_1 (MeV/c^2)	8.8	2.6	28.6	4.8	30
Γ_1 (MeV)	6.8	1.9	51	11.8	53
M_2 (MeV/c^2)	3.5	0.7	3.9	2.9	6.0
Γ_2 (MeV)	2.6	0.3	7.7	0.9	8.2
M_3 (MeV/c^2)	7.3	1.0	2.4	5.1	9.3
Γ_3 (MeV)	32.9	1.1	5.3	3.4	34

Systematic uncertainties

Discusstion on the Fit

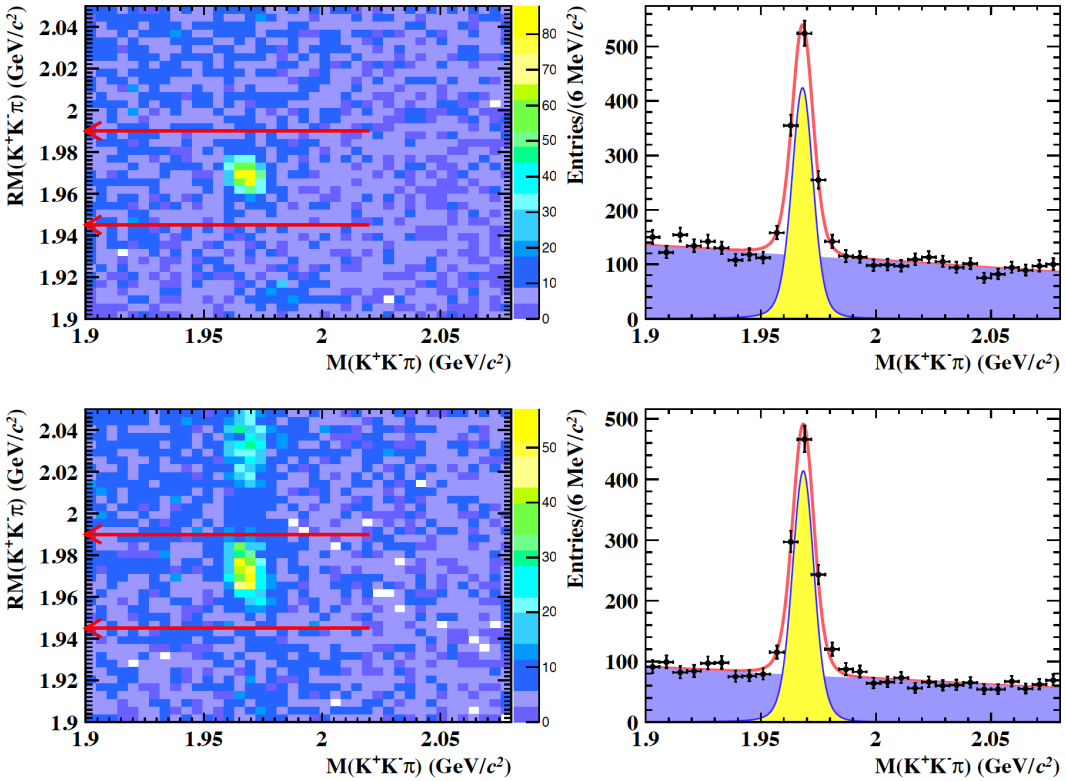
- **The first structure is both consistent with ψ(4160) and Y(4230); in the second case, the coupling between Y(4230) and Ds*Ds* is MUCH larger than for $\pi\pi$J/ψ, even larger than that for πDD***
- **The second structure is consistent with ψ(4415); if they are same state, it is the first time ψ(4415) is observed in Ds*Ds* final state**
- **Once more channels are measured, K-matrix based analysis will be performed in the similar way as that in bottomonia sector:** N. Husken, R. E. Mitchell, and E. S. Swanson, Phys. Rev. D 106, 094013 (2022)

$e^+e^- \rightarrow D_s^+D_s^-$

PRL 133, 261902 (2024)

Event Selection and Background Estimation

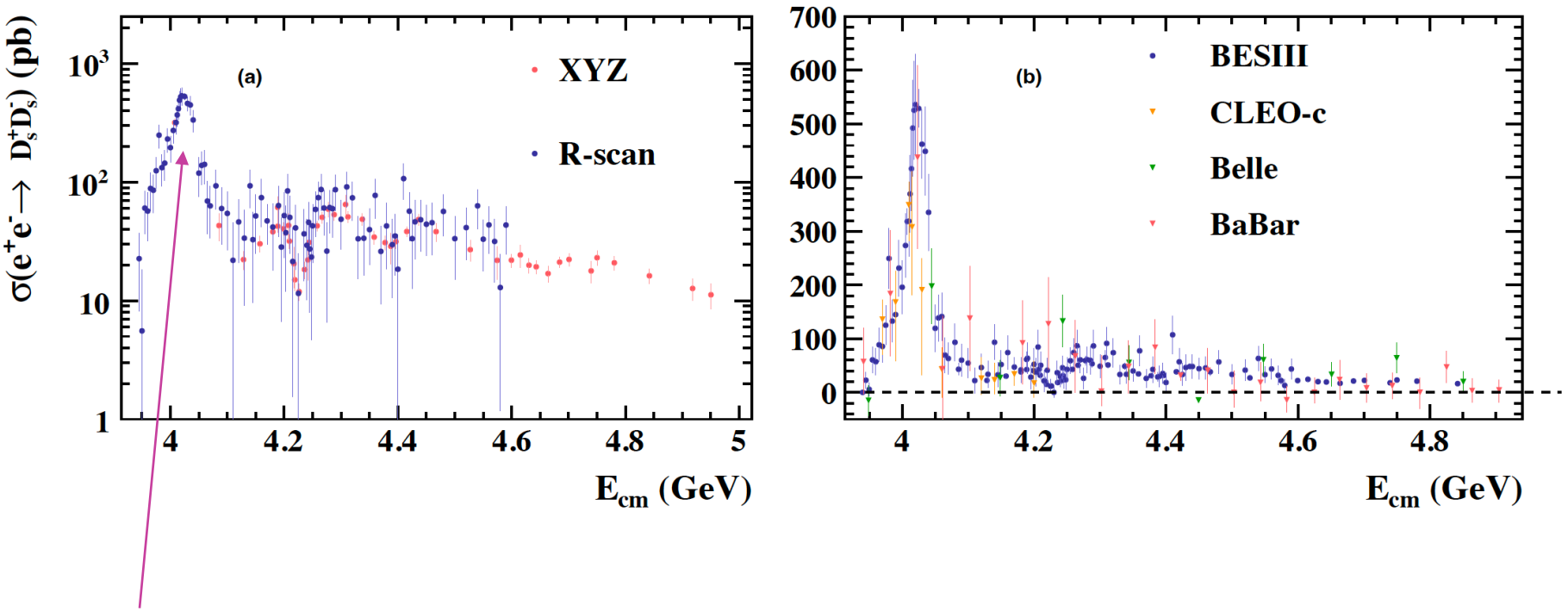
- Cutting on the recoil mass of Ds and fitting the "modified" mass of Ds
- Background: peaking one from $e^+e^- \to D_s^{*+}D_s^-$ is estimated by its measured cross section



$$\sigma_{\rm Born} = \frac{N^{\rm fit}_{D_s} - N_{D_s^\pm D_s^{\mp *}}}{2\mathcal{B}(D_s^\pm \to K^+K^-\pi^\pm)\epsilon(1+\delta)\frac{1}{|1-\Pi|^2}\mathcal{L}}$$

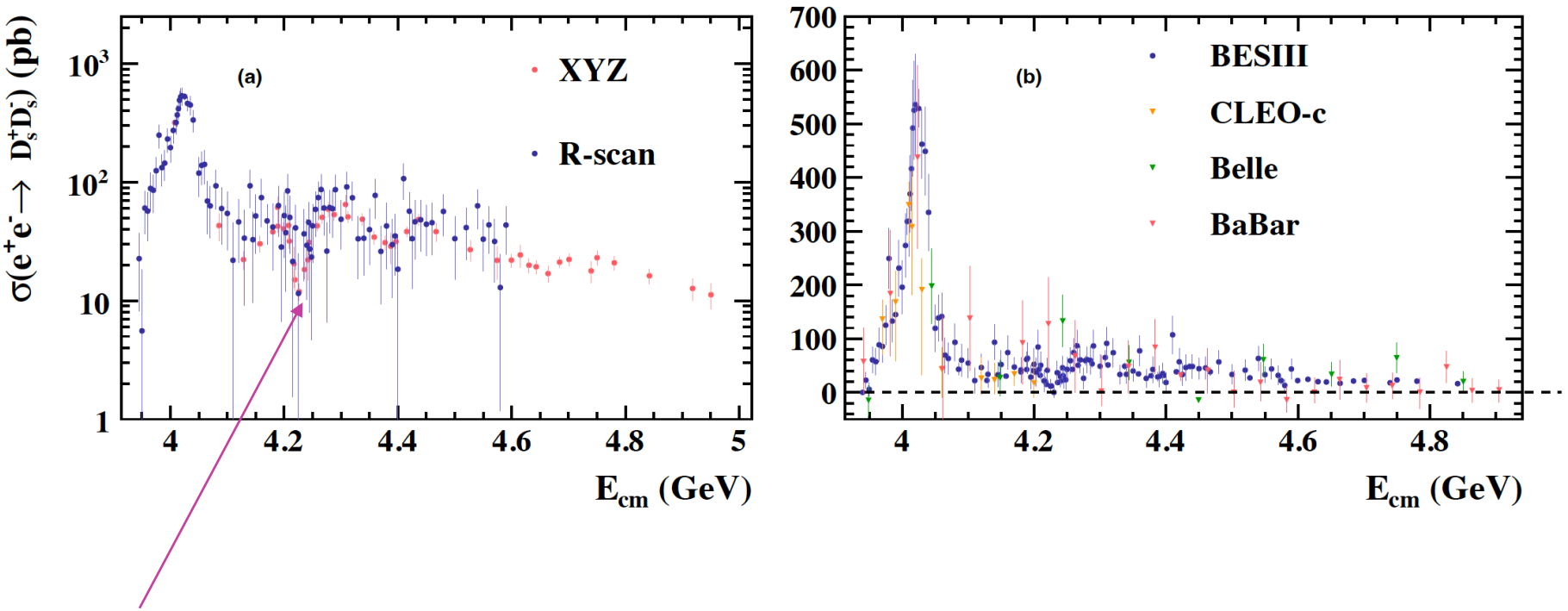
4.26 GeV (top), 4.68 GeV (bottom)

Born Cross Section



Feature 1: the first peak is around $\psi(4040)$; if we fit the peak with BW function, the width is about 40 ± 4 MeV, which is much narrower than 80 ± 10 MeV (the width of $\psi(4040)$ on PDG). This implies couple channel effect changes the line shape a lot.

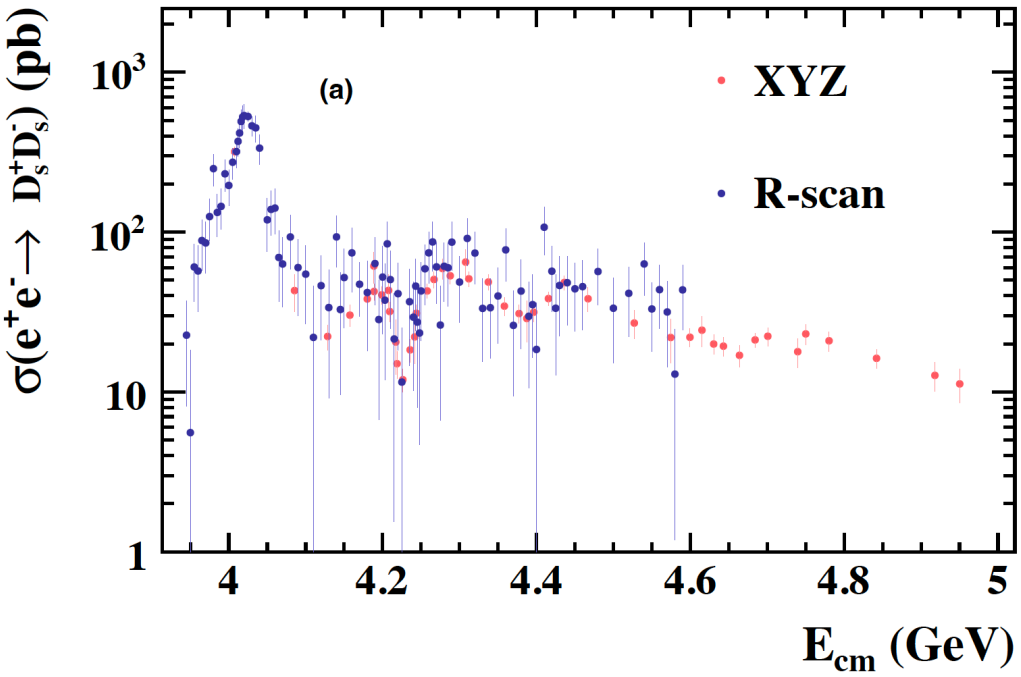
Born Cross Section

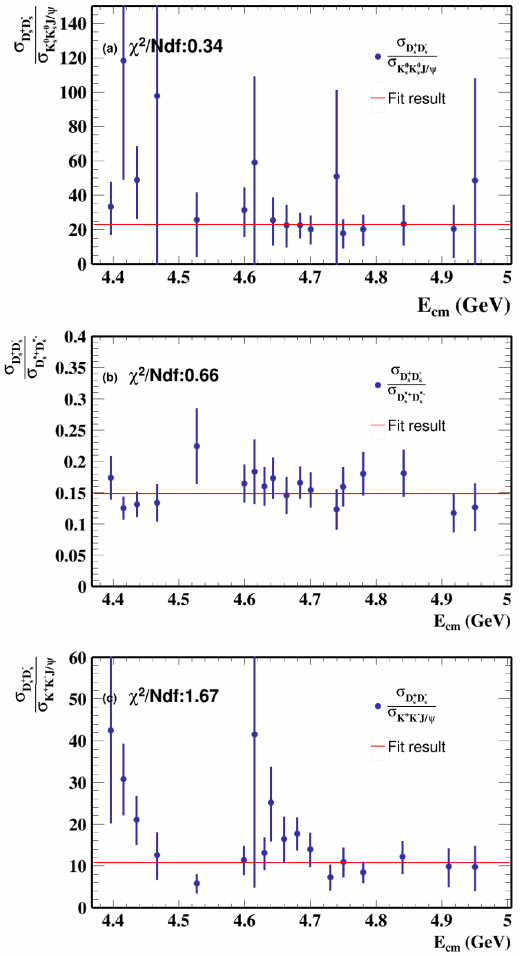


Feature 2: a significant dip is observed which is around the threshold of Ds*Ds*, and peak of $\psi(4230)$. This reflects the open channel effect from Ds*Ds* on the DsDs cross section; the decay width of $\psi(4230) \to f_0(980)J/\psi$ is not small, and $f_0(980)$ contains a significant ssbar component. Any correlations?

If we disregars the dip, a borad structure spanning from 4.4 to 4.4 GeV is there.

Born Cross Section





Feature 3: from 4.4 GeV the cross section ratio between this process to KK J/ψ and Ds*Ds* is consistent with constant; structures around 4.5 and 4.7 GeV are observed on KK J/ψ cross section, and structure around 4.79 GeV is observed on Ds*Ds* cross section.

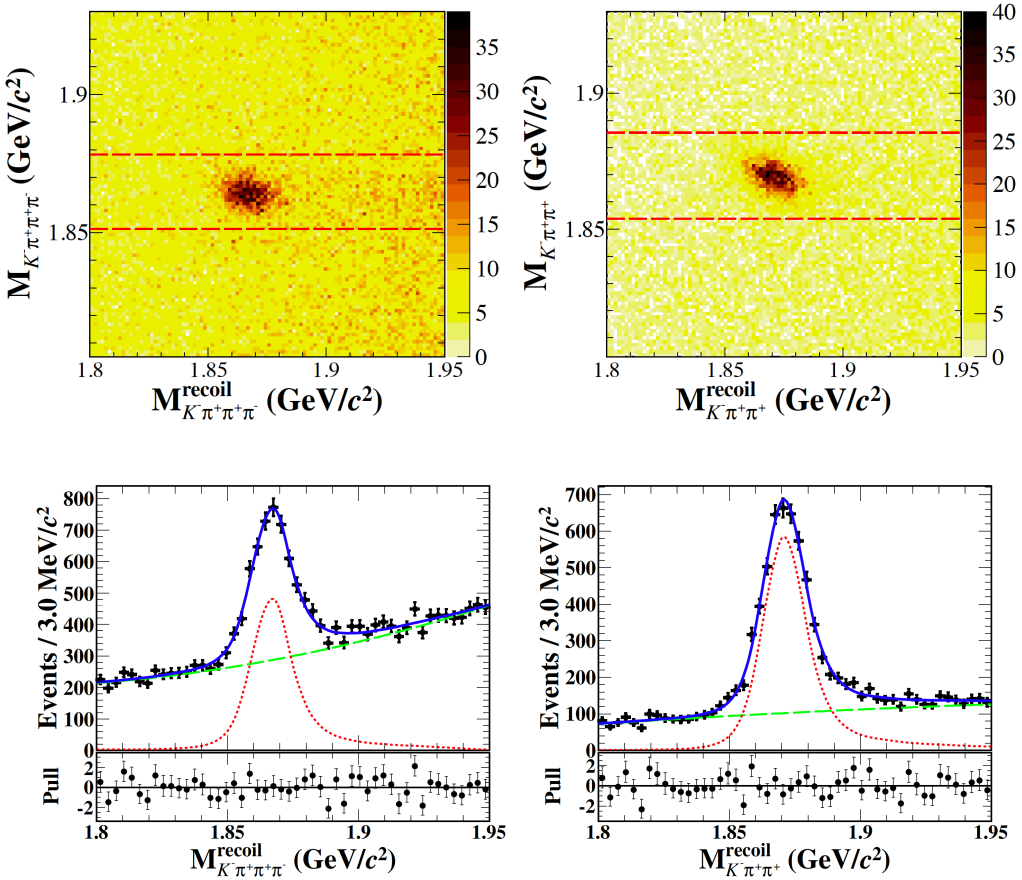
$e^+e^- \rightarrow D^+D^-/D^0\bar{D}^0$

PRL 133, 081901 (2024)

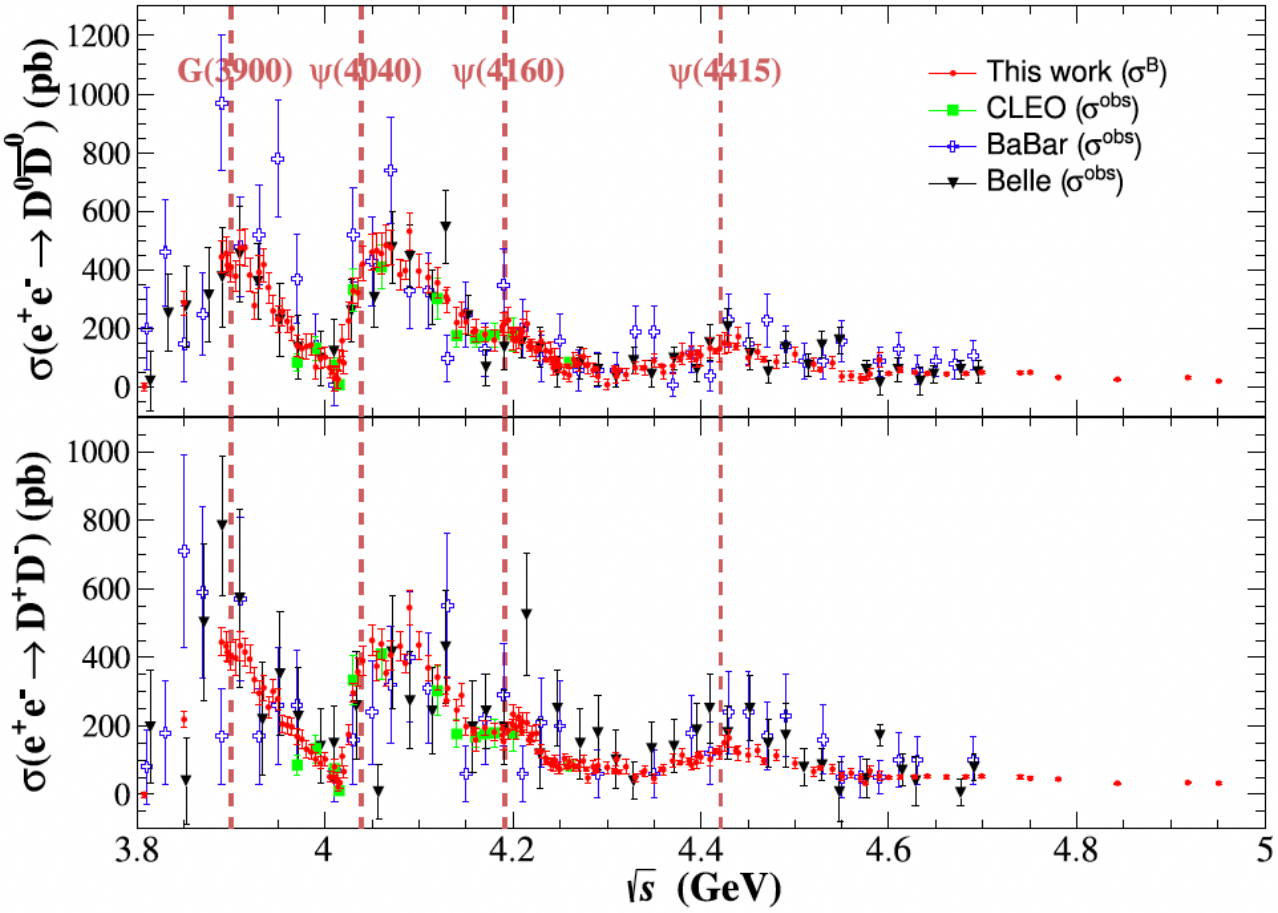
Event Selection and Background Estimation

- Cutting on the mass of D and fitting the "modified" recoil mass of D
- $D^+ \to K^-\pi^+\pi^+$; $D^0 \to K^-\pi^-\pi^+\pi^+$

$$\sigma^B(s) = \frac{N_{\rm obs}}{2\mathcal{L}(1+\delta)\frac{1}{|1-\prod|^2}\epsilon\mathcal{B}}$$



Born Cross Section

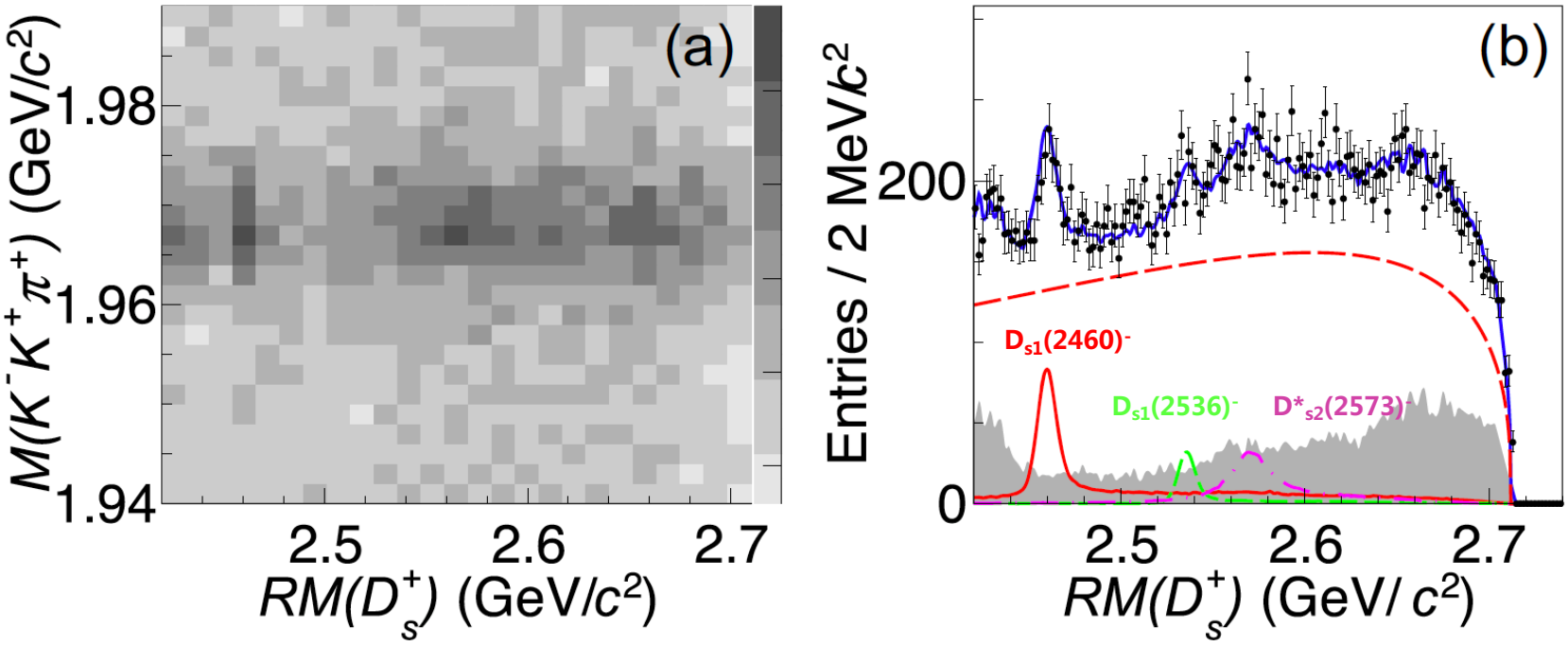


Clear peaks around mass range of G(3900), $\psi(4040)$, $\psi(4160)$, $\psi(4260)$ and $\psi(4415)$.

$e^+e^- \rightarrow D_s^+ D_{s1}(2536)^-, D_s^+ D^*_{s2}(2573)^-$

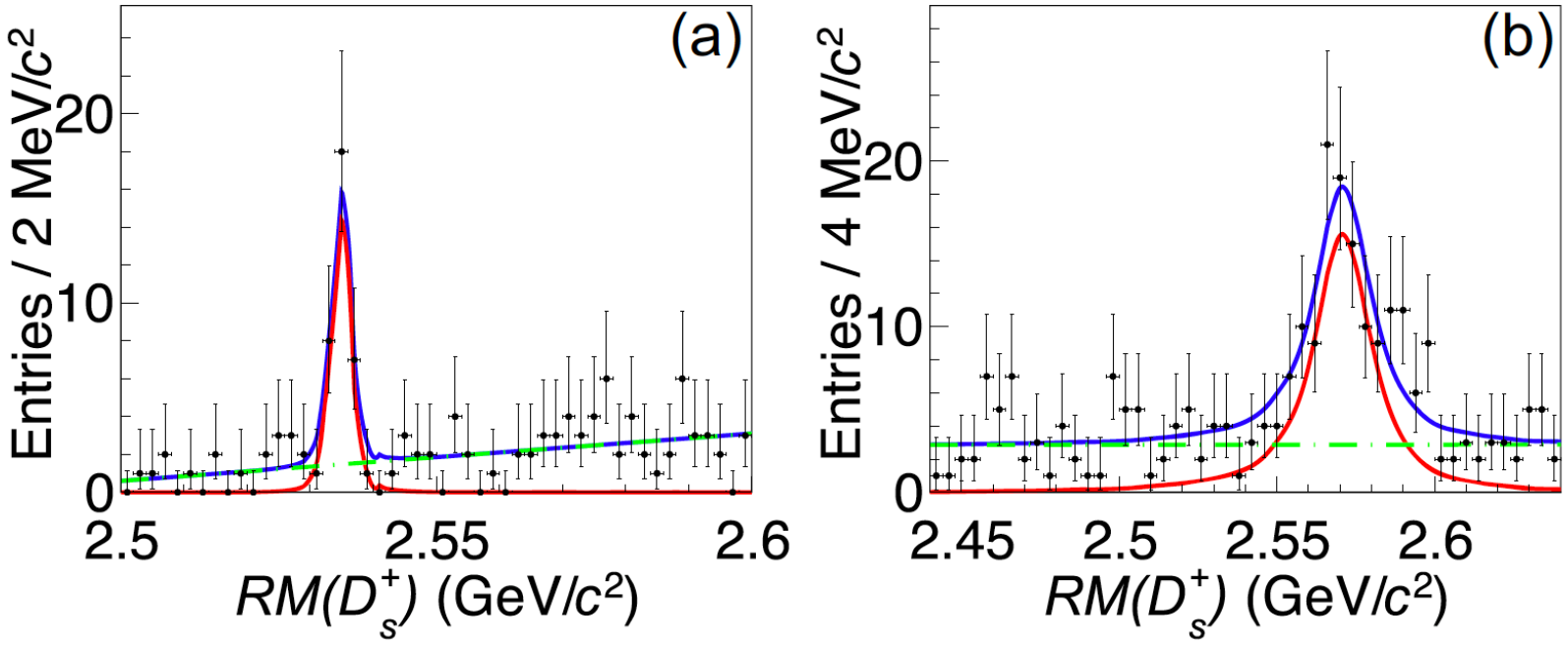
PRL 133, 171903 (2024)

Inclusive reconstruction



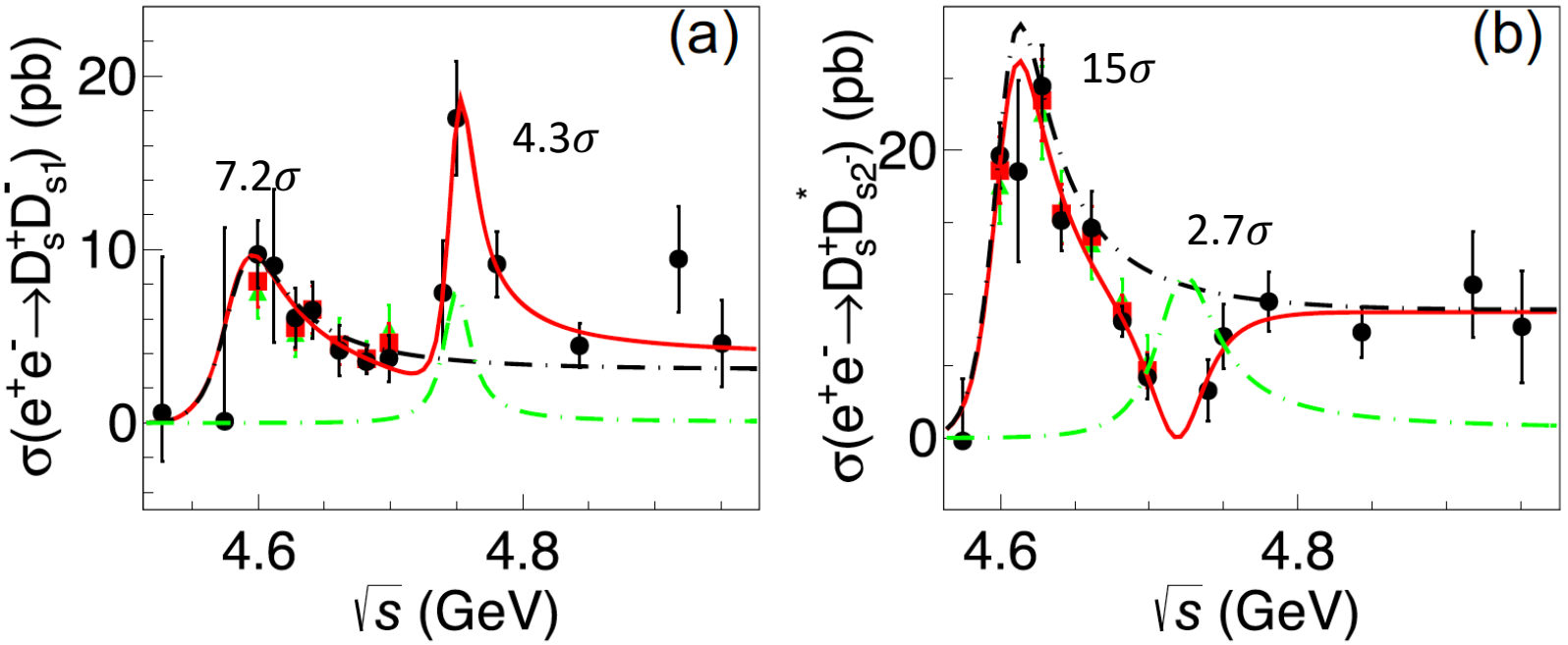
Reconstruction one Ds, and 2D fit on the reconstruction and recoil mass spectrum

Exclusive reconstruction



In addition to the reconstructed Ds, **$D^*_{s2}(2573)$ -> DK** and **$D_{s1}(2536)$ -> D*K** are used for exclusive reconstruction

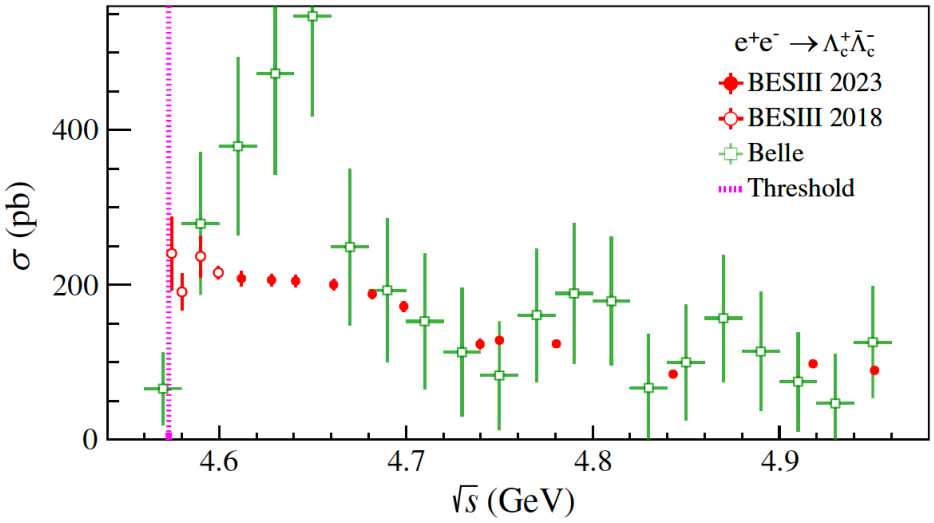
Born Cross Section



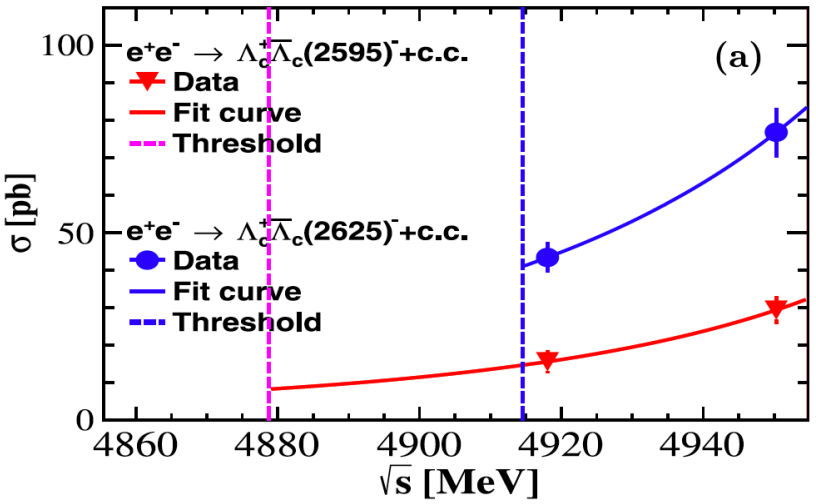
Clear structure around 4.6 GeV is observed, consistent with Y(4620)/Y(4626) from Belle; Evidence for structure around 4.75 GeV, consistent with Y(4710)/Y(4790) from BESIII

Charmed baryon

PRL 131, 191901 (2023)



PRD 109, L071104 (2024)



Production cross section are studied for both charmed baryon and its exited states

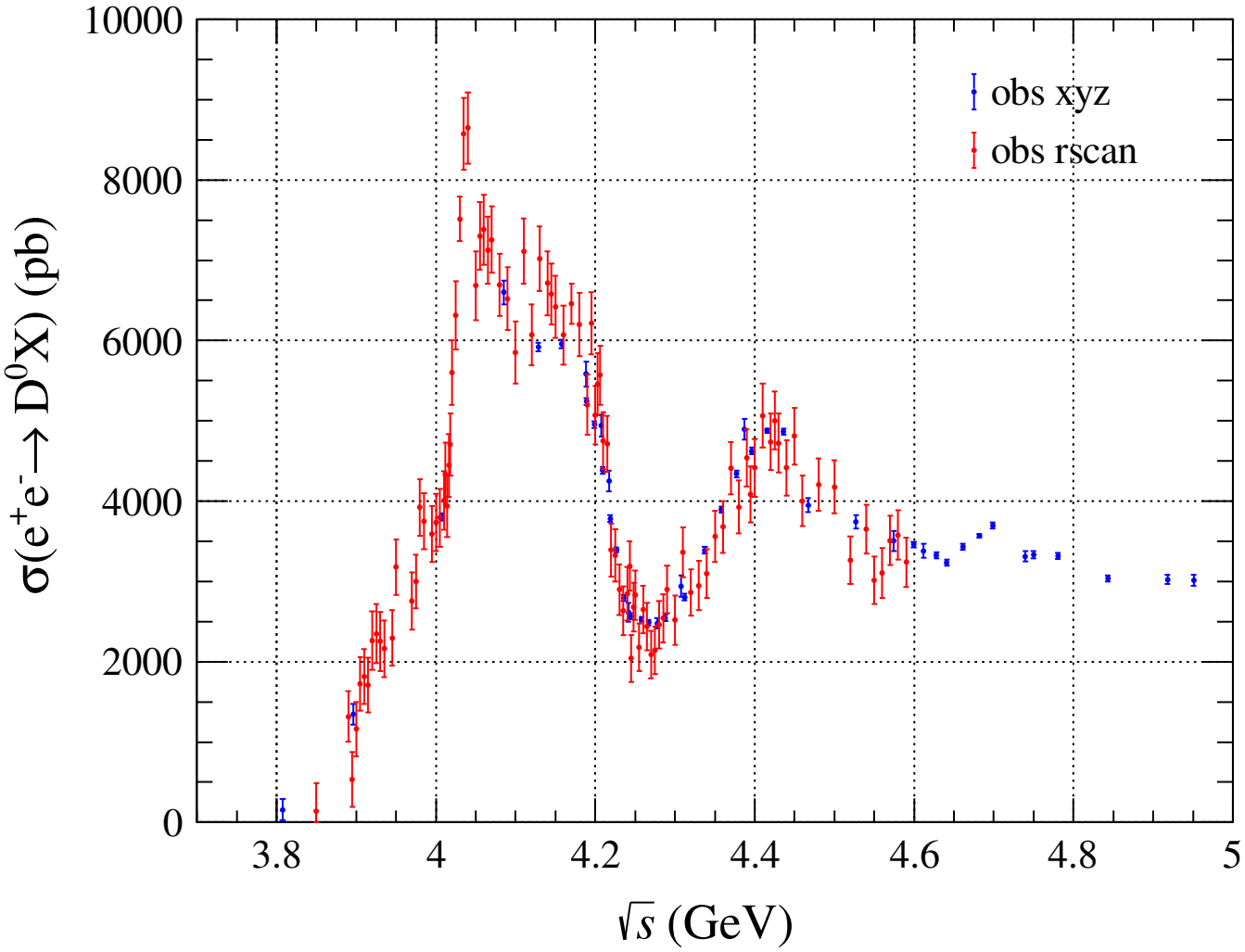
Summary and Outlook

- **The cross sections of charm meson pair are measured with high precision at BESIII**
- **Many intersteing features are observed, and need more theoretical interpretations**
- **The results from other channles are still on the way**

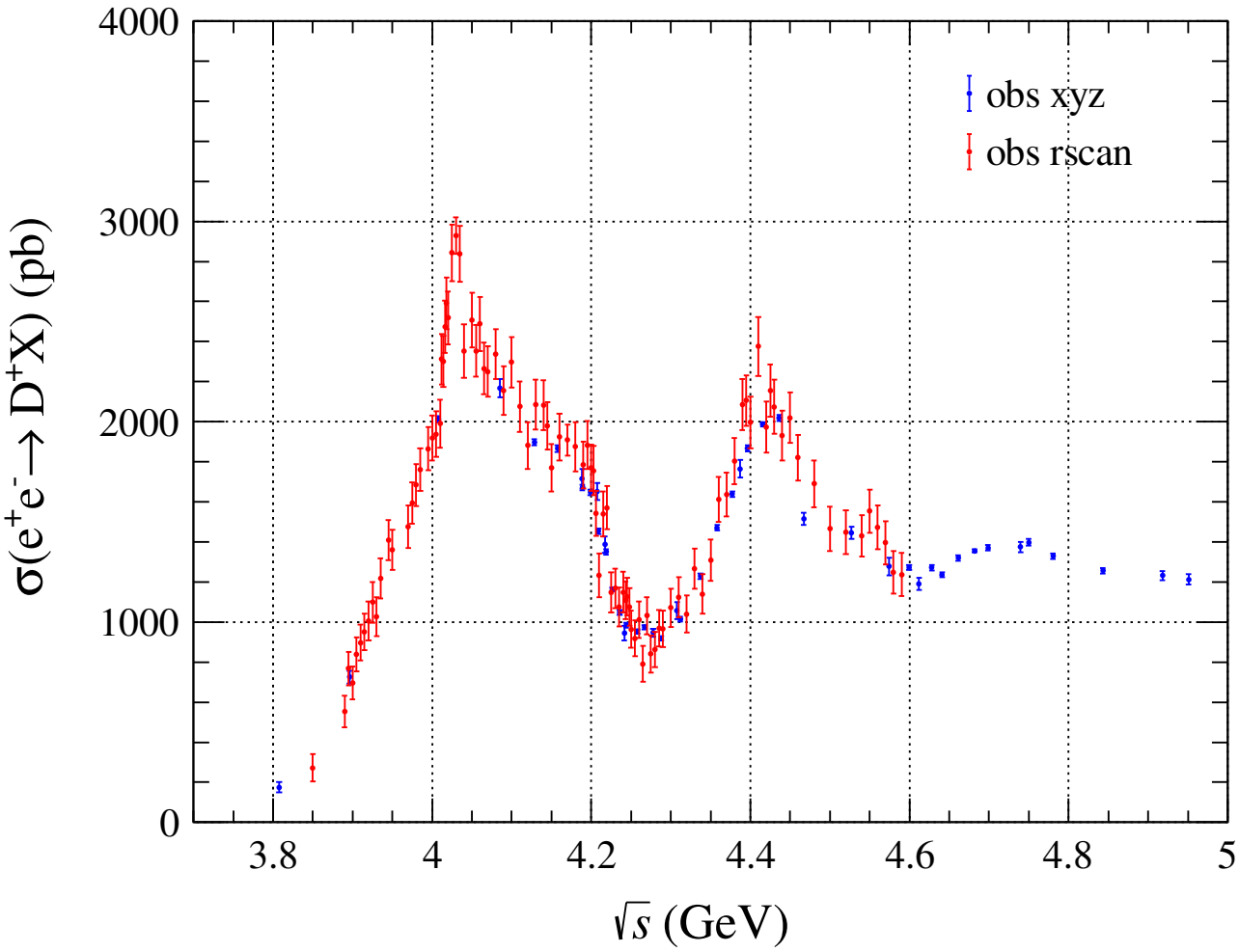
Thanks very much!

BACK UP

Observed cross section



Observed cross section



Observed cross section