New developments in the cross sections measurements of
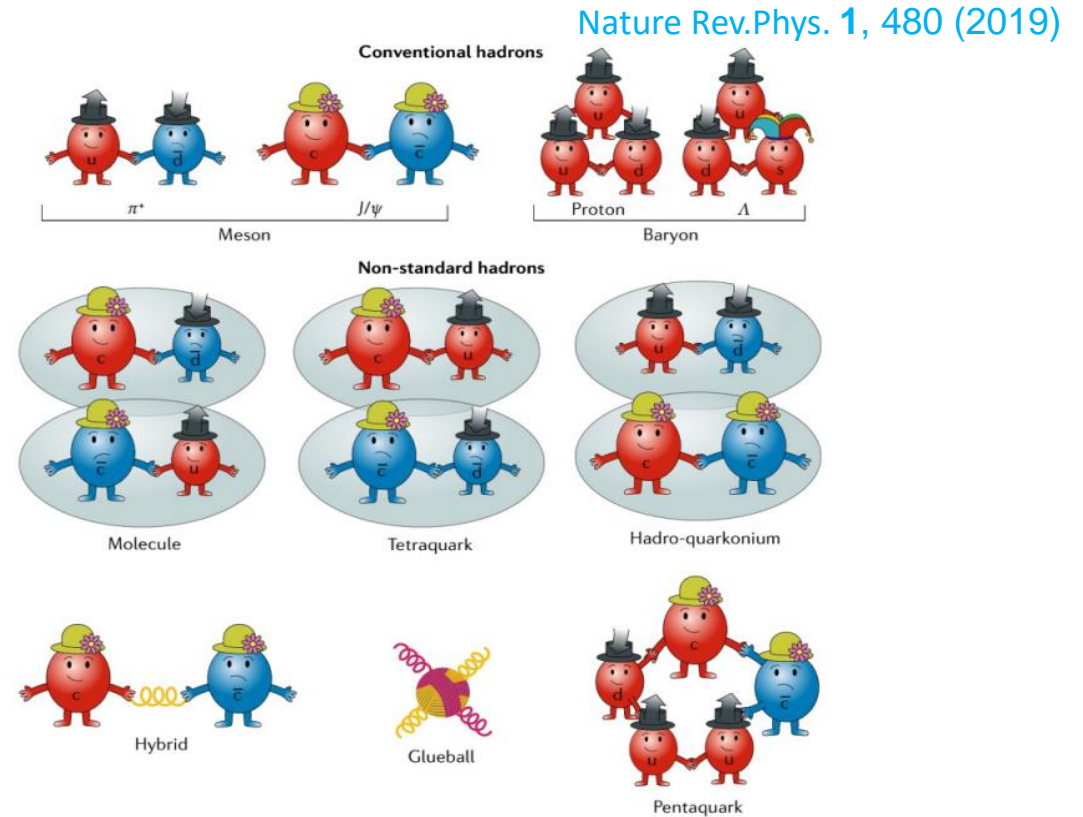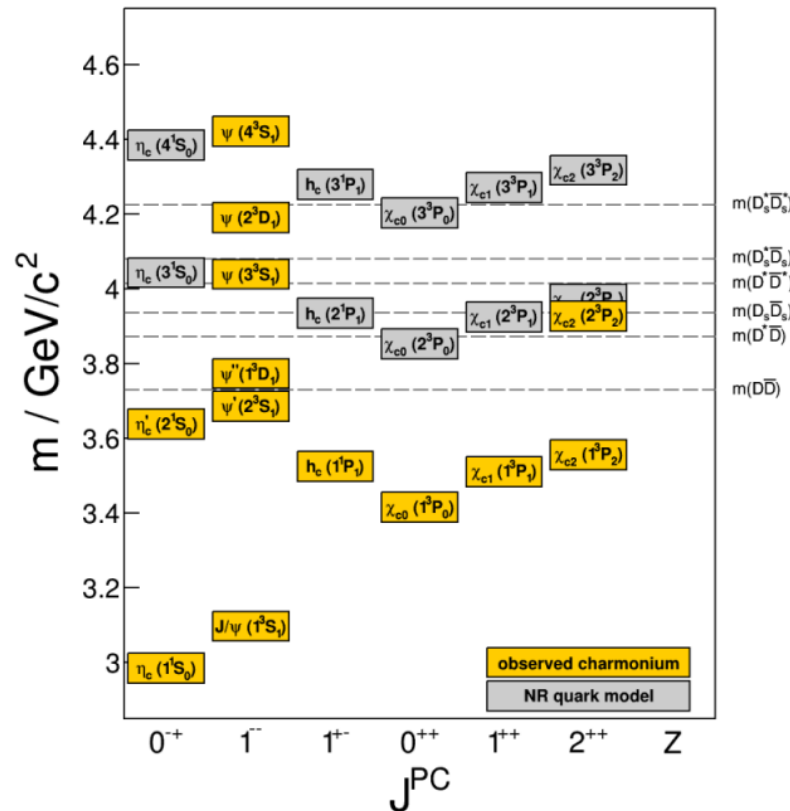$$e^+e^- \rightarrow \text{open} - \text{charm}$$

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Outline

- Introduction

- Recent (2023+2024) result from BESIII: cross section of open charm final states

  - $e^+e^- \to \pi^+\pi^- D^+D^-$ [PRD 106, 052012 (2022)]

  - $e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^-$ [JHEP 05, 155, (2022)]

  - $e^+e^- \to D_s^{*+}D_s^{*-}$ [PRL 131, 151903 (2023)]

  - $e^+e^- \to D^{*0}D^{*-}\pi^+ + c.c.$ [PRL 130, 121901 (2023)]

  - $e^+e^- \to D_s^{*+}D_{s1}(2536)^-$ and $e^+e^- \to D_s^{*+}D_{s2}^*(2573)^-$ [arXiv:2407.07651]

  - $e^+e^- \to D_s^+D_s^-$ [arXiv:2403.14998]

  - $e^+e^- \to D\bar{D}$ [arXiv:2402.03829]
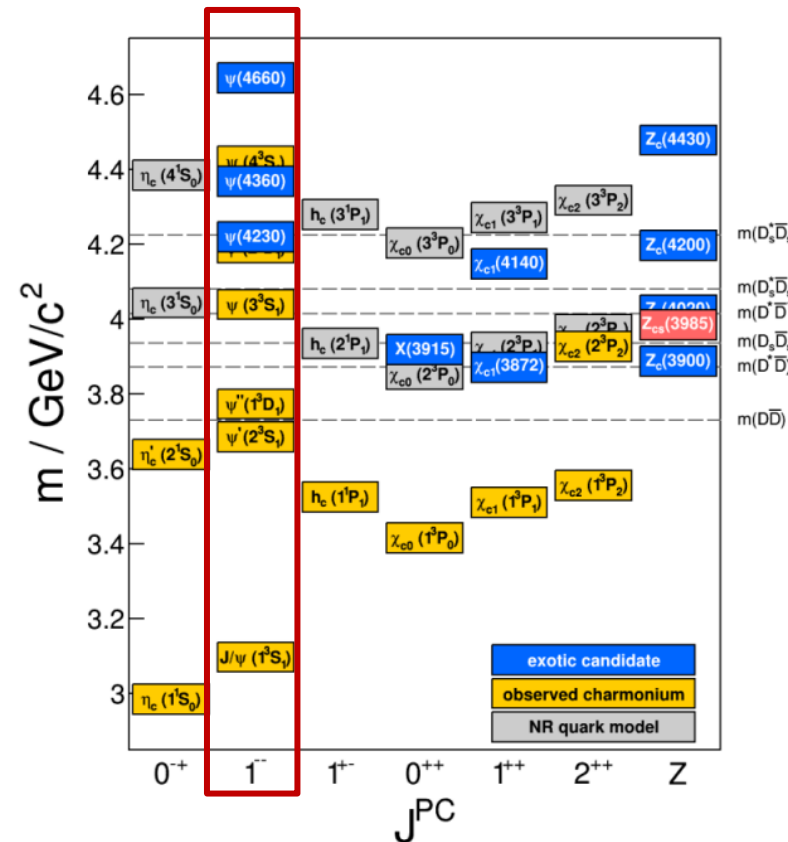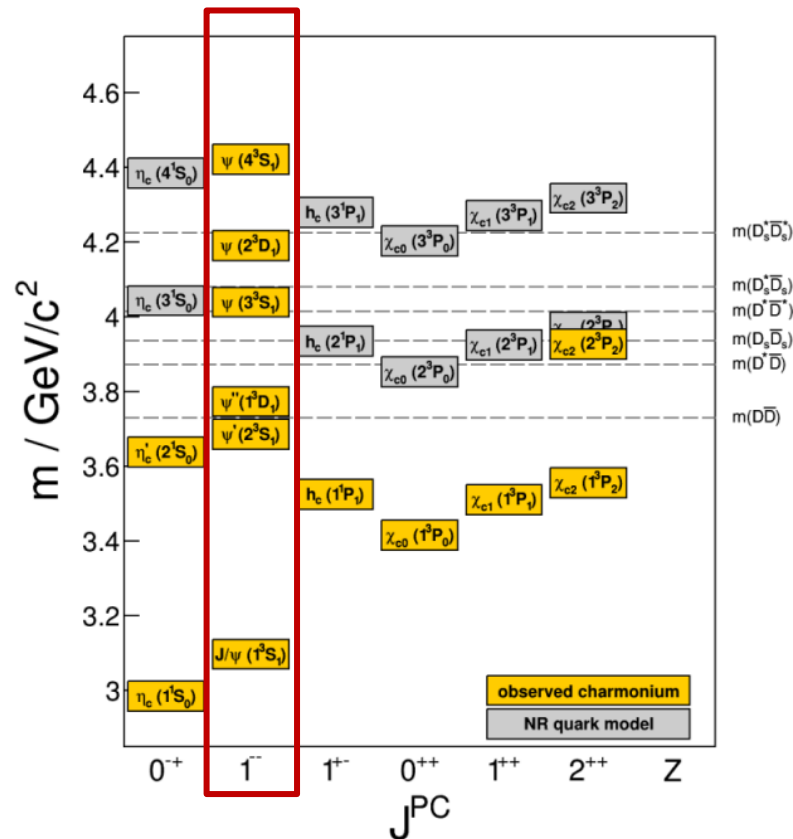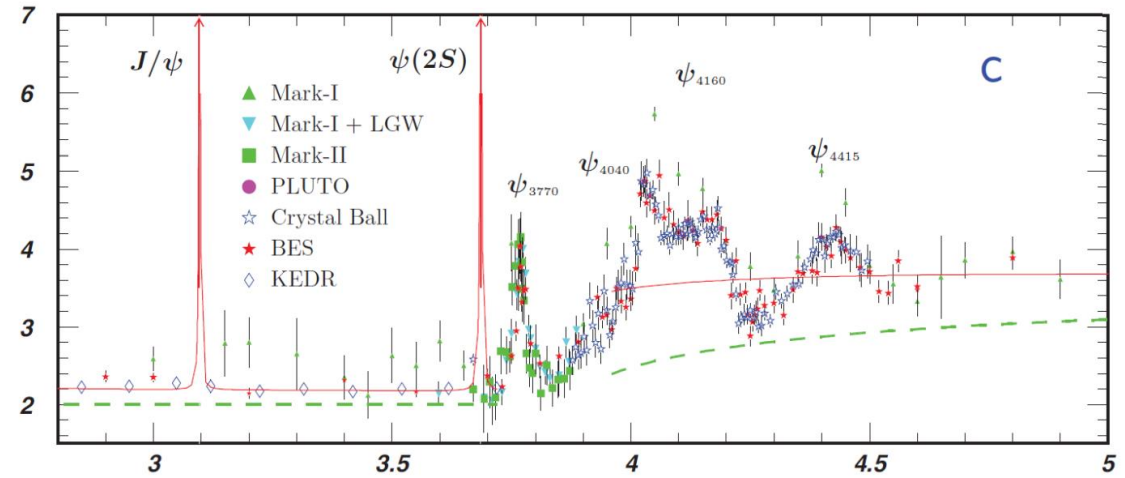
- Summary & outlook

Introduction

- Charmonium below $D\overline{D}$ threshold are well understood

  - While there are undiscovered states above the threshold

- Besides conventional hadrons (mesons, baryons), QCD allow non-standard (exotic) hadrons
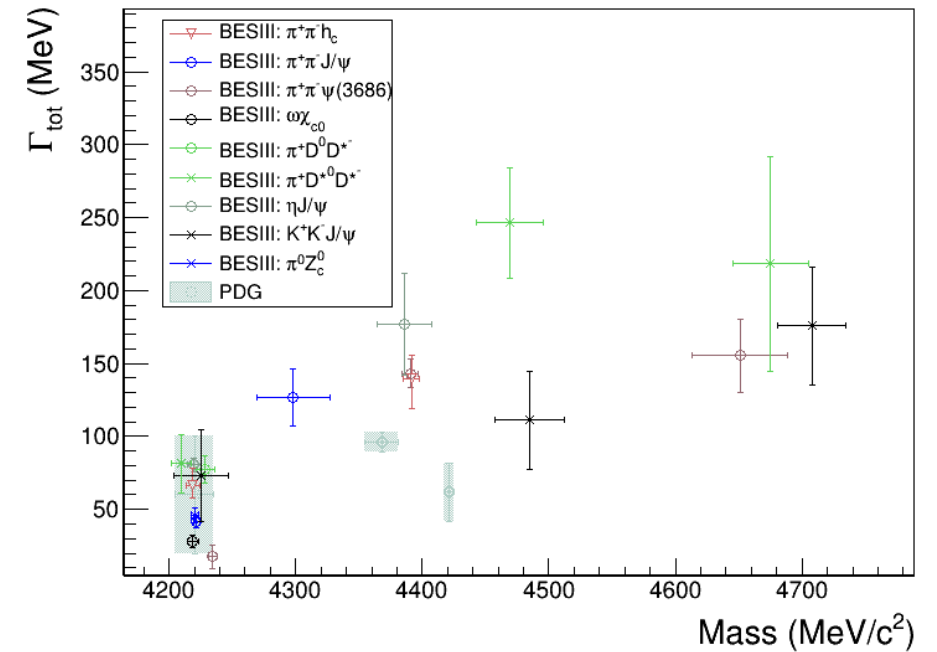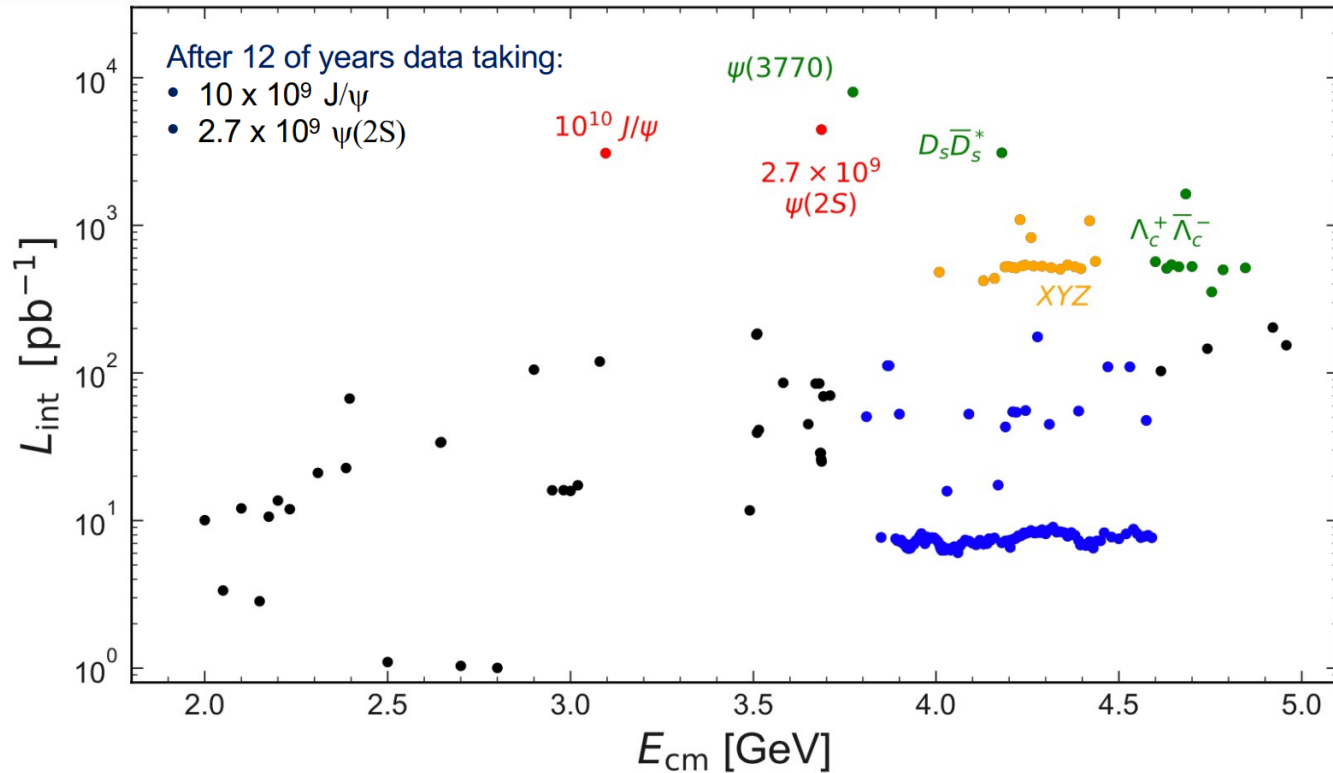
Nature Rev.Phys. **1**, 480 (2019)

Introduction

- By now the vector states (Y) are over crowded
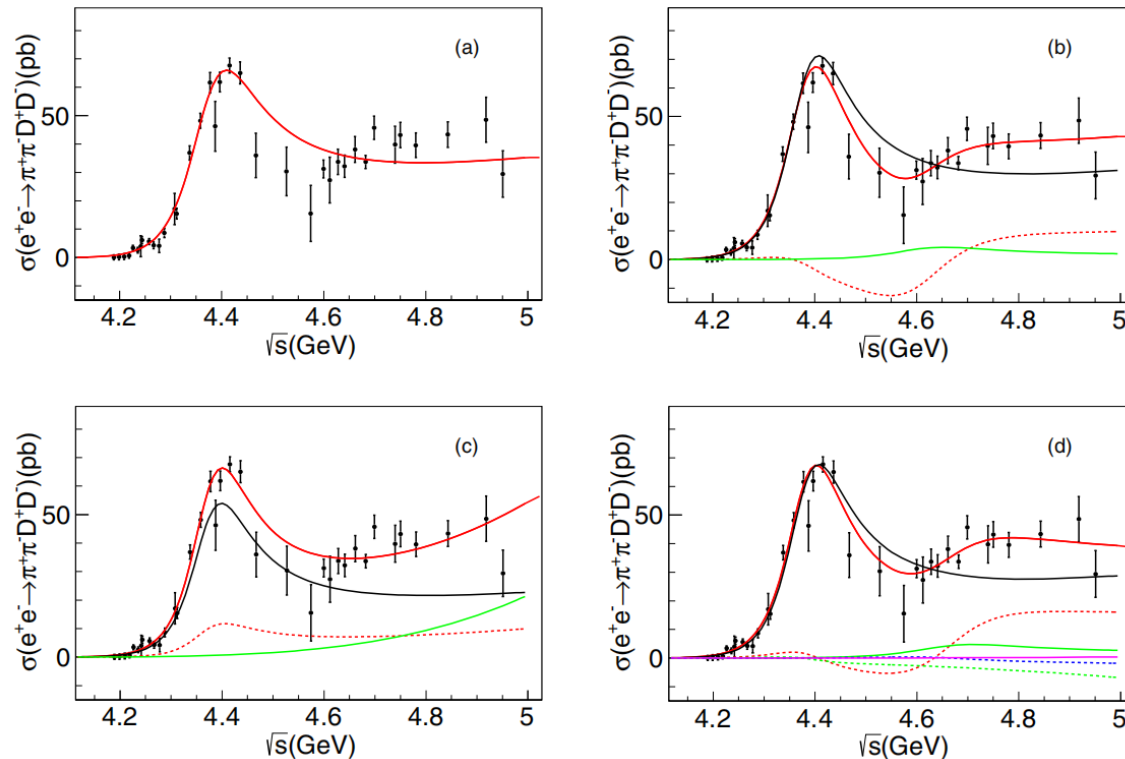
- Missing in R measurement

Introduction

- BESIII has

    - World largest $e^+e^- \rightarrow J/\psi(\psi', \psi'')$ sample

    - **Large scan sample above $D\bar{D}$ sample: a series of results for Y**
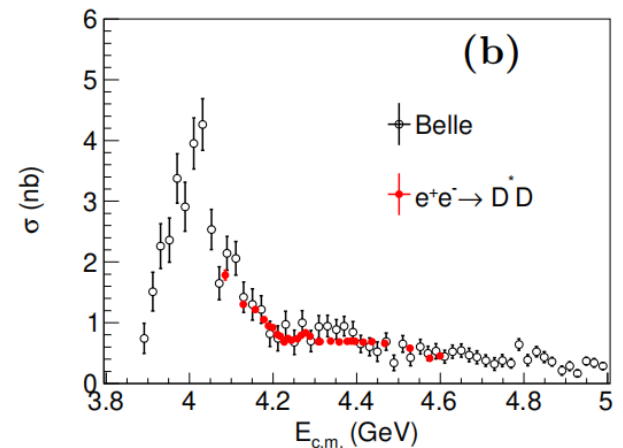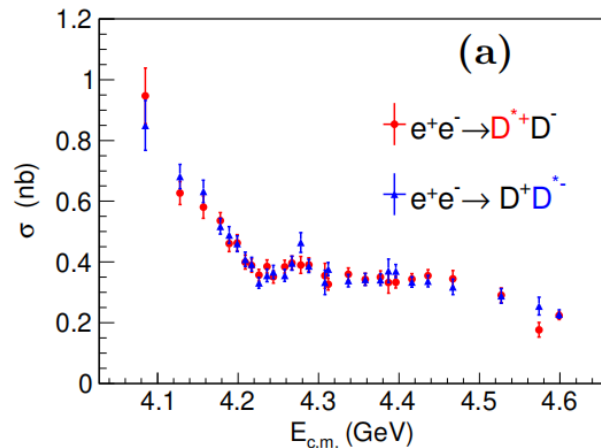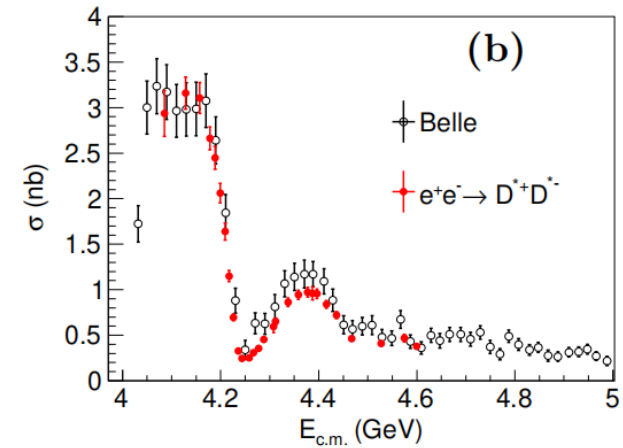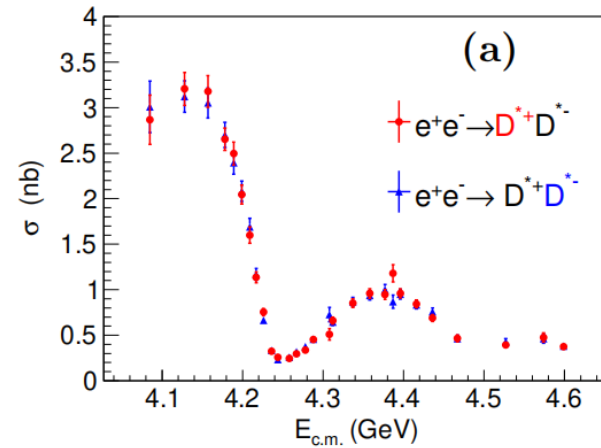
    - R-scan points

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

- The full $e^+e^- \to \pi^+\pi^- D^+ D^-$: include $\pi^+\pi^-\psi(3773), D_1^\pm(2420)D^\mp, \pi^+\pi^- D^+ D^-$

- Fit with **one BW**, or add a BW, a PHSP, or both

- The nominal fit gives $M = (4371.6 \pm 2.5 \pm 9.2)\mathrm{MeV}/c^2, \Gamma_{tot} = (167 \pm 4 \pm 29)$ MeV

- Uncertainties dominated by the choice of fit model

Sources	m_0 (MeV/c^2)	Γ_0^{tot} (MeV)	$\Gamma_0^{e^+e^-}\mathcal{B}_0$ (eV)
$\sqrt{s}$ measurement	0.8	$\cdots$	$\cdots$
$\sqrt{s}$ shift	1.9	1	0.1
$\sqrt{s}$ spread	0.0	0	1.4
Cross section$_a$	0.1	2	0.1
Cross section$_b$	$\cdots$	$\cdots$	1.0
R_1	6.4	14	+21.0
Φ_4	0.5	19	-3.7
$R_1 + \Phi_4$	6.3	16	+13.1
Overall	9.2	29	$+21.1$ -4.4

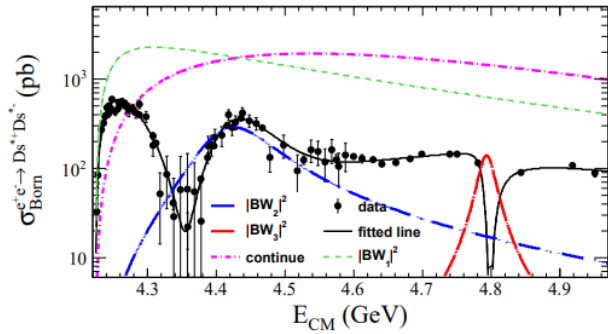# $e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^-$

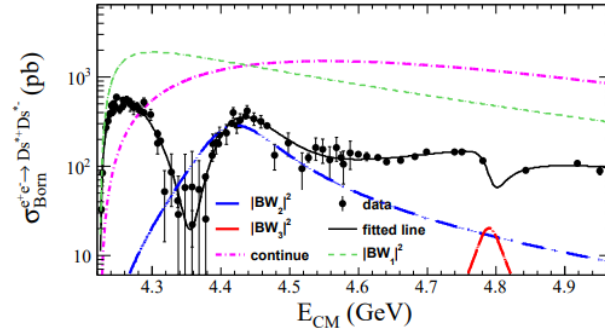- Tag D^{*+} or D^{*-}

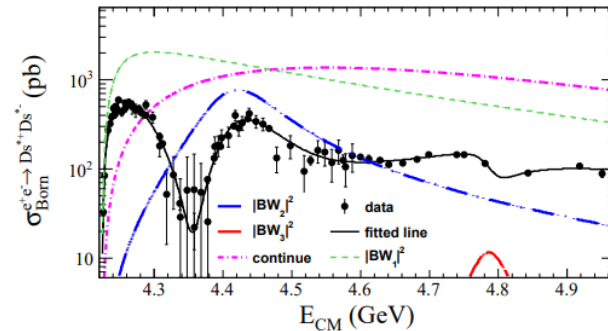- Basically in agreement with Belle's result

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

- Three results with similar fit quality

- Non-trivial cross section line shape at around 4.79 GeV (6.1σ), $Y(4710)$ in $e^+e^- \to KKJ/\psi$?
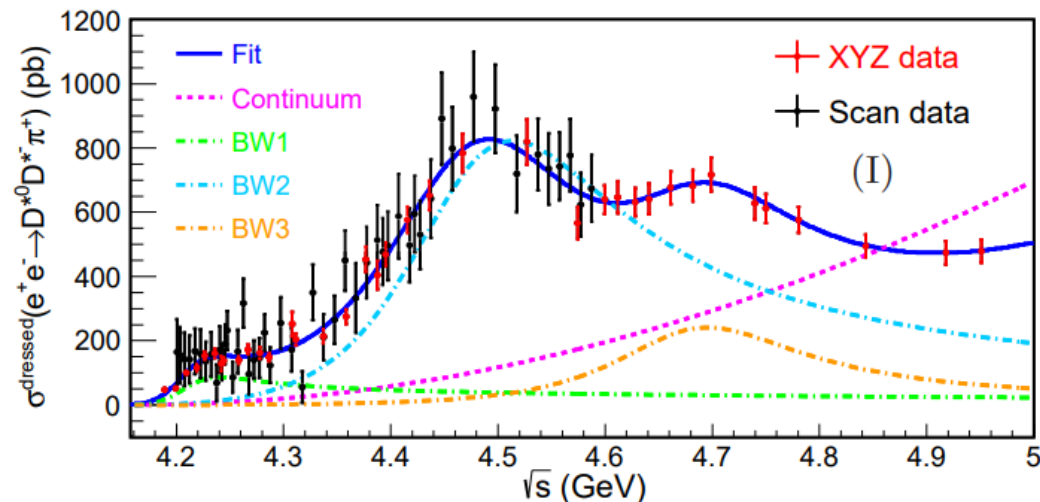

(a) Result 1

(b) Result 2

(c) Result 3

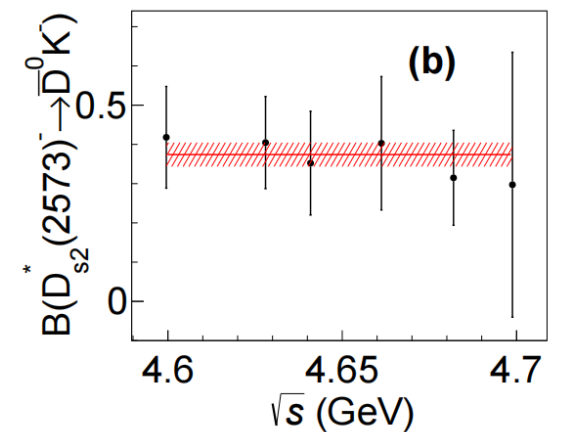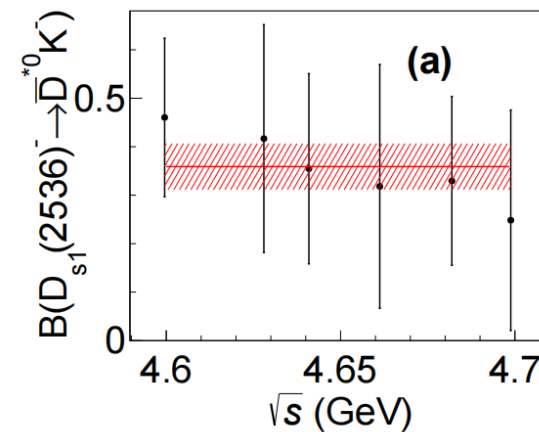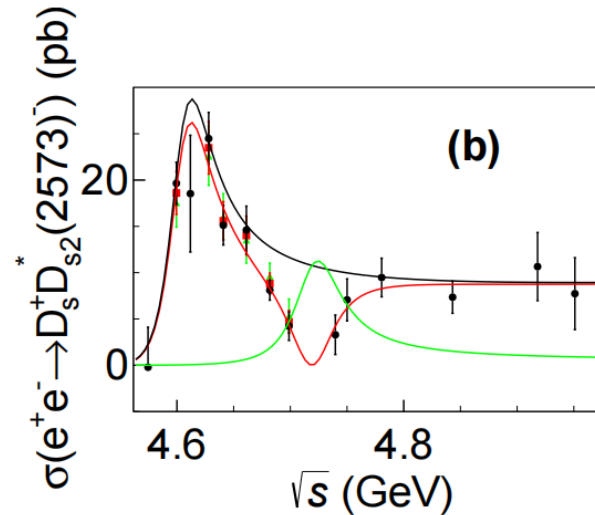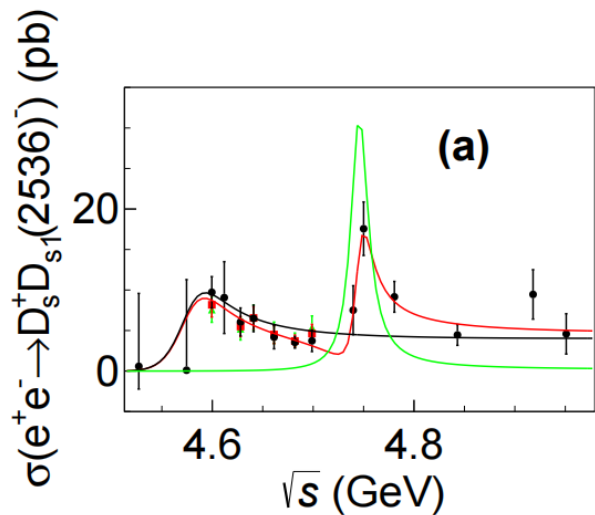|	Result 1	Result 2	Result 3
M_1 (MeV/c^2)	4186.5±9.0	4193.8±7.5	4195.3±7.5
Γ_1 (MeV)	55±17	61.2±9.0	61.8±9.0
M_2 (MeV/c^2)	4414.5±3.2	4412.8±3.2	4411.0±3.2
Γ_2 (MeV)	122.6±7.0	120.3±7.0	120.0±7.0
M_3 (MeV/c^2)	4793.3±7.5	4789.8±9.0	4786±10
Γ_3 (MeV)	27.1±7.0	41±39	60±35

8

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

- $e^+e^- \rightarrow D^{*0}D^{*-}\pi^+$, structures with parameters consistent with $Y(4230), Y(4500)$ and $Y(4660)$:

  - $M(R1) = (4209.6 \pm 4.7 \pm 5.9)\ \text{MeV/c}^2$, $\Gamma(R1) = (81.6 \pm 17.8 \pm 9.0)\ \text{MeV}$

  - $M(R2) = (4469.1 \pm 26.2 \pm 3.6)\ \text{MeV/c}^2$, $\Gamma(R2) = (246.3 \pm 36.7 \pm 9.4)\ \text{MeV}$

  - $M(R3) = (4675.3 \pm 29.5 \pm 3.5)\ \text{MeV/c}^2$, $\Gamma(R3) = (218.3 \pm 72.9 \pm 9.3)\ \text{MeV}$

- Cannot see $Y(4360)$, $\psi(4415)$ and $Y(4710)$

- Confirm $Y(4500)$

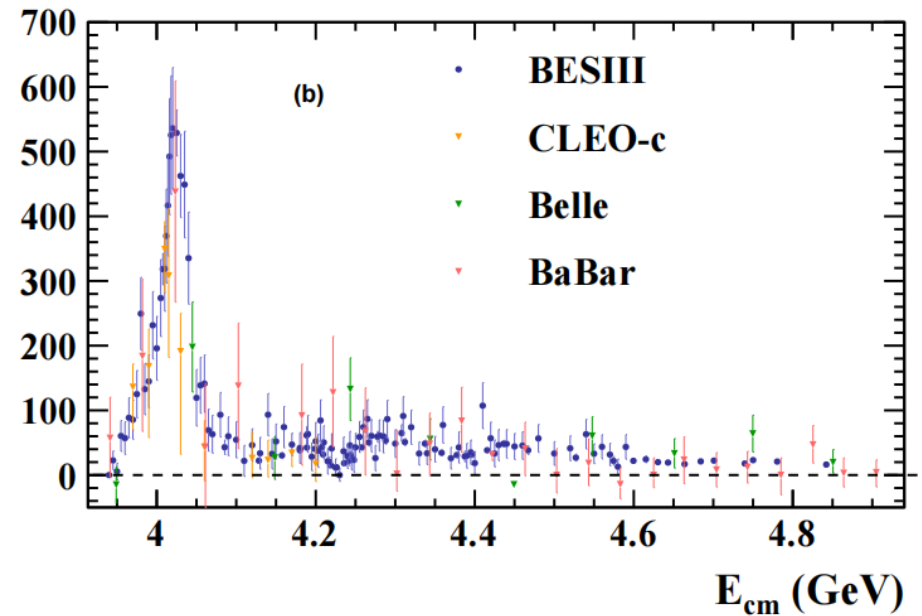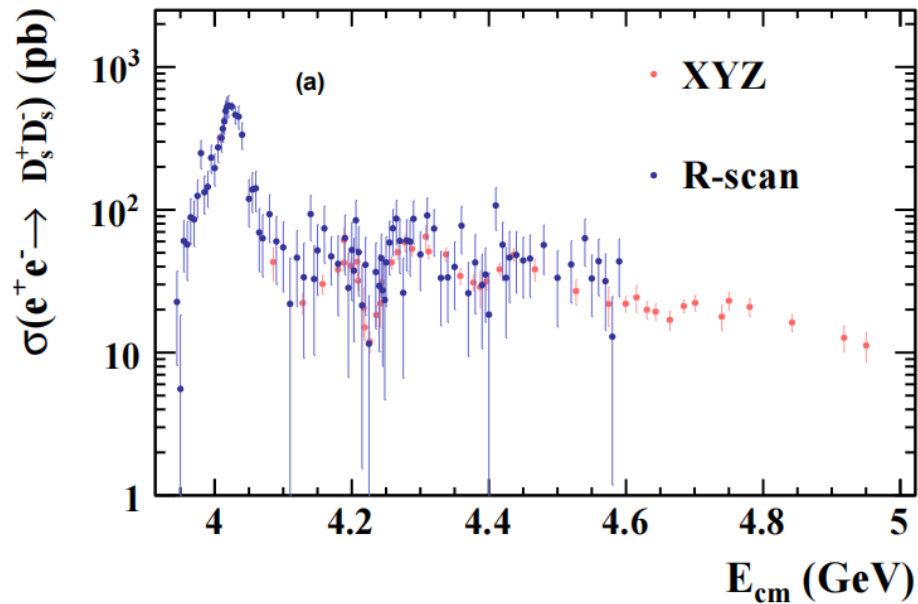- See $Y(4660)$ in open-charm final states for the first time

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

- Clear enhancement at 4.6 GeV

- Evidence of a structure at 4.75 GeV

- The absolute branching ratios are determined, indicate a $\mathrm{non}-c\bar{s}$ contribution

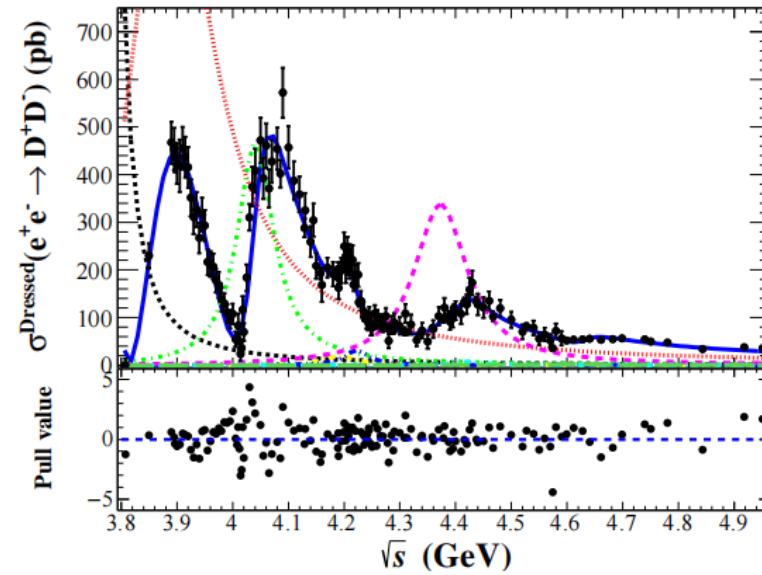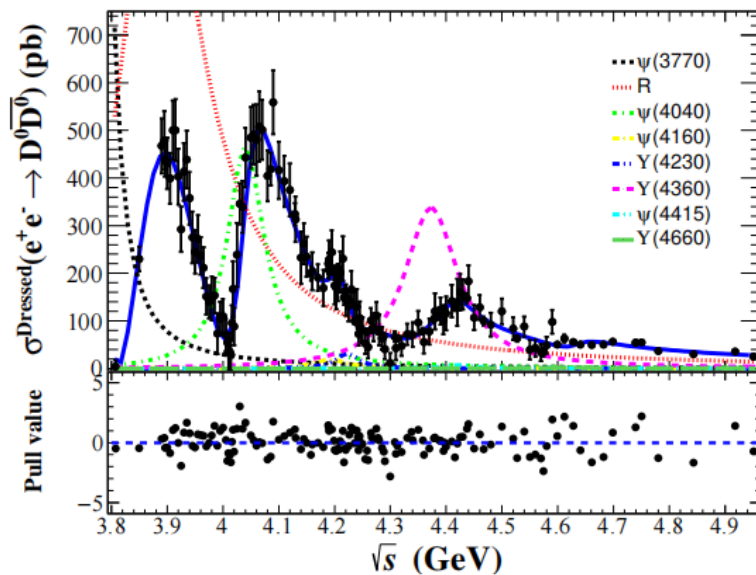$$e^+e^- \rightarrow D_s^+ D_s^-$$

- The structure at 4.02 is narrower than $\psi(4020)$, may indicate a strong couple channel effect

- A narrow dip at 4.23 GeV ($\sim D_s^{*+} D_s^{*-}$)

$e^+e^- \to D\bar{D}$

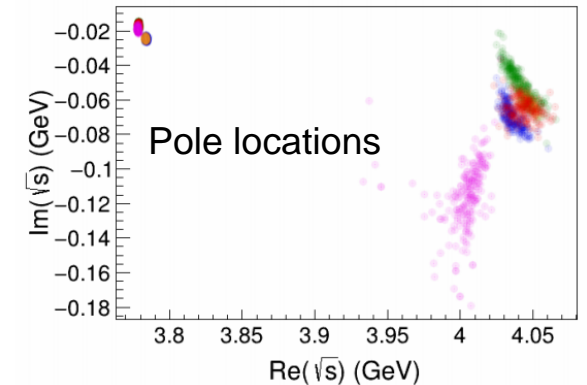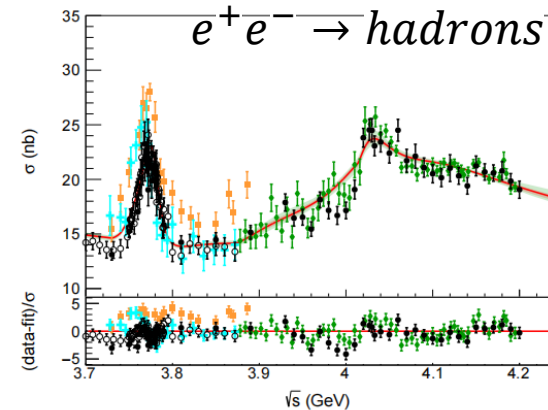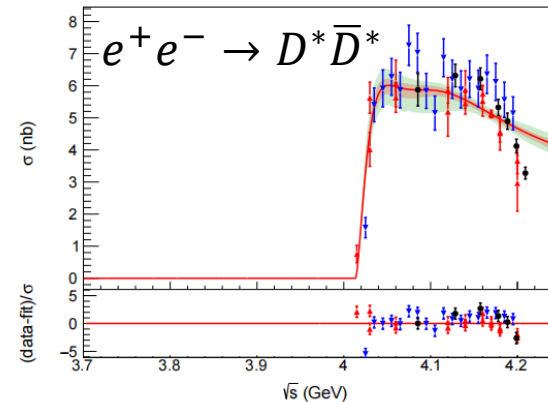- A simultaneous fit to $e^+e^- \to D^0\bar{D}^0$ and $e^+e^- \to D^+\bar{D}^-$ suggests a new structure at 3.9 GeV

				$e^+e^- \to D\bar{D}$				
Resonance	$\psi(3770)$	R	$\psi(4040)$	$\psi(4160)$	$Y(4230)$	$Y(4360)$	$\psi(4415)$	$Y(4660)$
Mass (MeV/c^2)	3773.7 (fixed)	3872.5±14.2±3.0	4039 (fixed)	4191 (fixed)	4222.5 (fixed)	4374 (fixed)	4421 (fixed)	4630 (fixed)
Width (MeV/c^2)	87.6 (fixed)	179.7±14.1±7.0	80 (fixed)	70 (fixed)	48 (fixed)	118 (fixed)	62 (fixed)	72 (fixed)
$\Gamma_{ee}\mathcal{B}$ (eV)	95-106	202-292	41-44	1-2	1-2	50-144	0-2	0-1
$S(\sigma)$	10	> 20	13	7	11	11	4	8
χ^2/d.o.f $= 346/275$				p-value = 0.002				

12

$e^+e^- \to D\bar{D}$, **a combined fit**

- A coupled-channel K-matrix fit to $D^0\bar{D}^0$, $D^+\bar{D}^-$, $D^*\bar{D} + c.c.$, $D^*\bar{D}^*$, and inclusive hidden-charm

- $\Gamma_{ee}^{\psi(4040)} < \Gamma_{ee,\text{PDG}}^{\psi(4040)}$

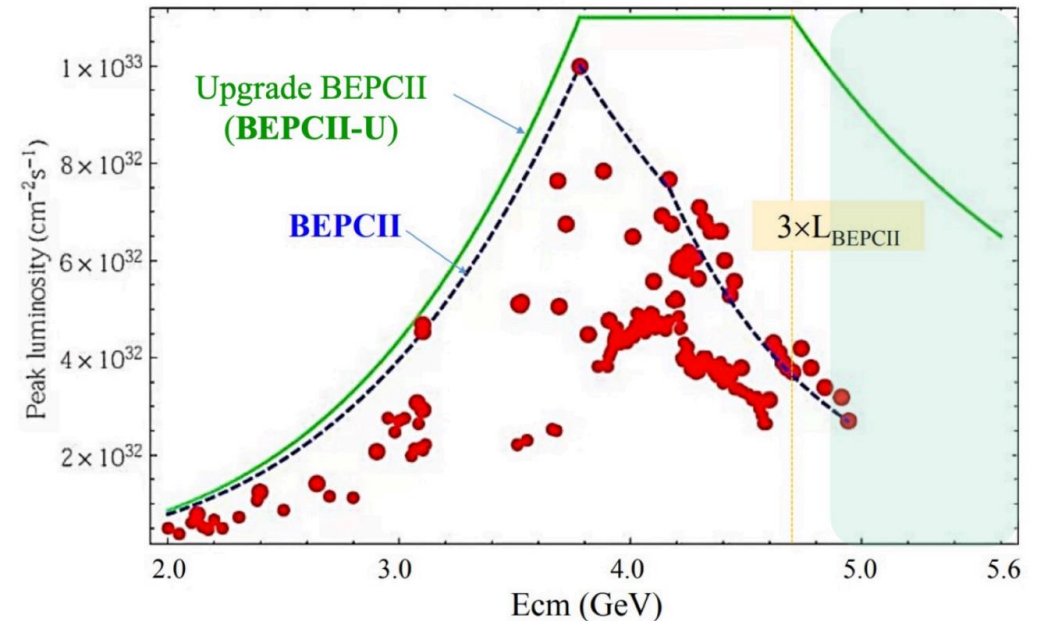| Model	Mass (MeV)	Γ (MeV)	Γ_{ee} (eV)	χ^2/ndf
1	3778.7(7)	34(4)	205(25)	2.20
2	3784.2(7)	49(4)	3000(1500)	2.48
3	3778.9(6)	33(4)	210(20)	2.39
4	3783.7(6)	49(4)	270(25)	2.45
5	3778.3(6)	38(5)	200(400)	1.88
fit summary	3778.7(7)(50)	34(4)(15)	205(25)(70)	
PDG	3773.7(4)	27.2(1)	261(21)	
1	4044.0(15)	130(30)	180(100)	
2	4036.0(10)	135(35)	15000(8000)	
3	4040.0(10)	95(30)	80(80)	
4	4046.0(10)	120(20)	10(50)	
5	4008.0(10)	220(80)	50000(40000)	
fit summary	4044(15)(36)	130(30)(125)	180(100)(170)	
PDG	4039(1)	80(10)	856(162)	

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

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

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

$e^+e^- \to D^*\bar{D}^*$

$e^+e^- \to hadrons$

Pole locations

13

Summary

- Several new $e^+e^- \to \mathrm{open-charm}$ results

- BEPCII upgrades in 2024:

  - higher luminosity in the XYZ region

  - c.m. energy up to 5.6 GeV

- More results will be released in the near future

Thank you for your attention!