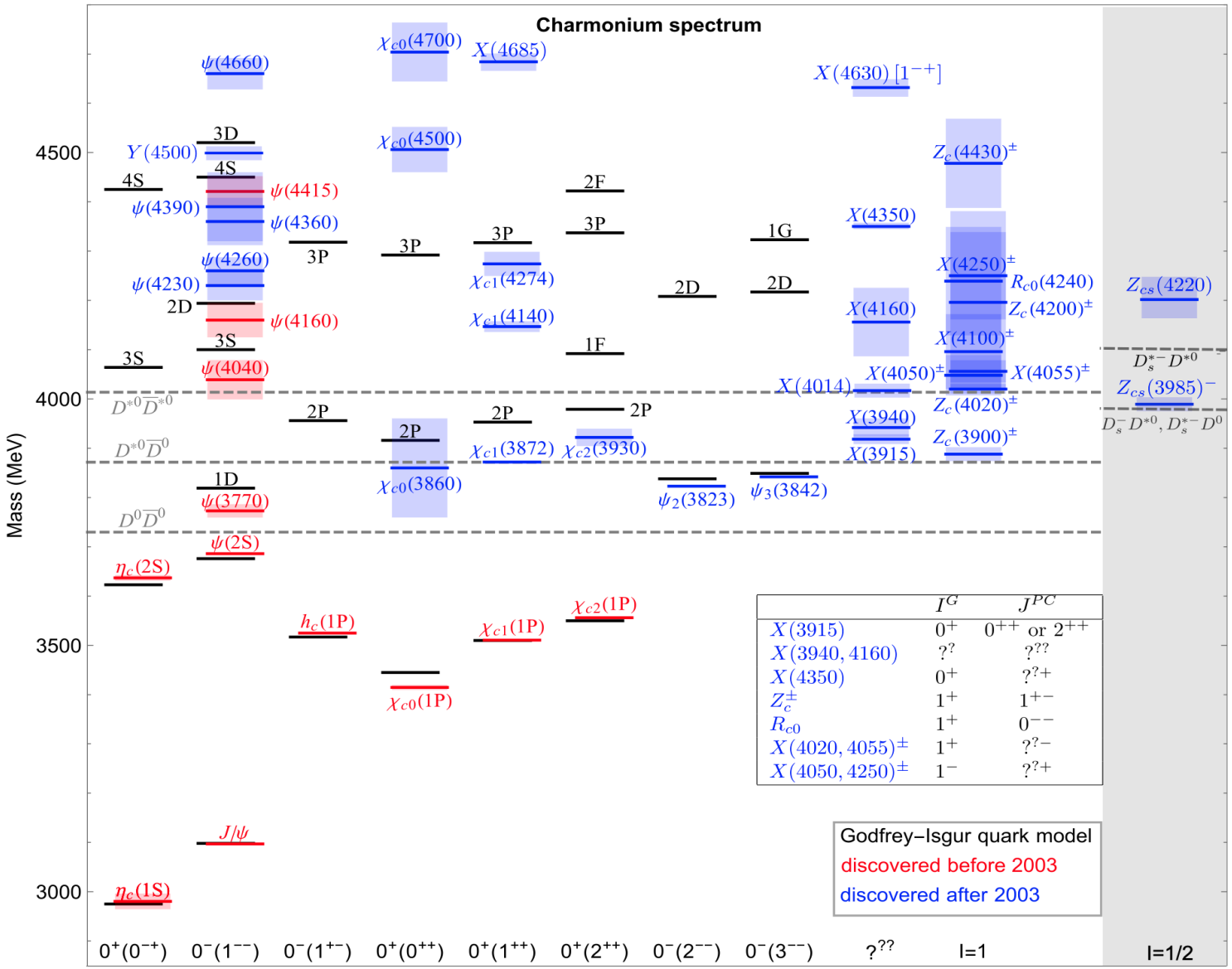
Recent results on spectroscopy of X, Y and Z states in BESIII

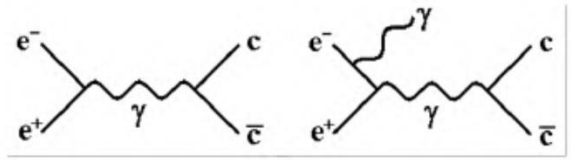
(For BESIII Collaboration)
Institute of High Energy Physics, CAS

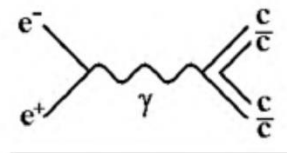
BEAUTY 2023 - The 21st International Conference on B-Physics at Frontier Machines

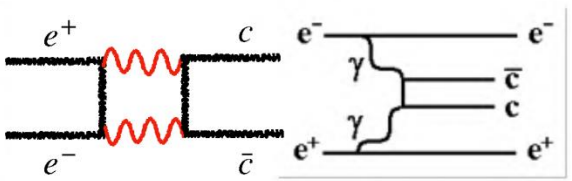
Clermont-Ferrand, France, from the 3rd to the7th July 2023

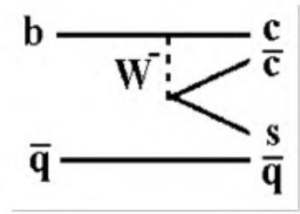
Charmonium like states

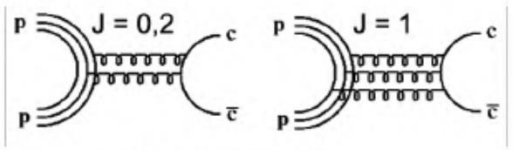






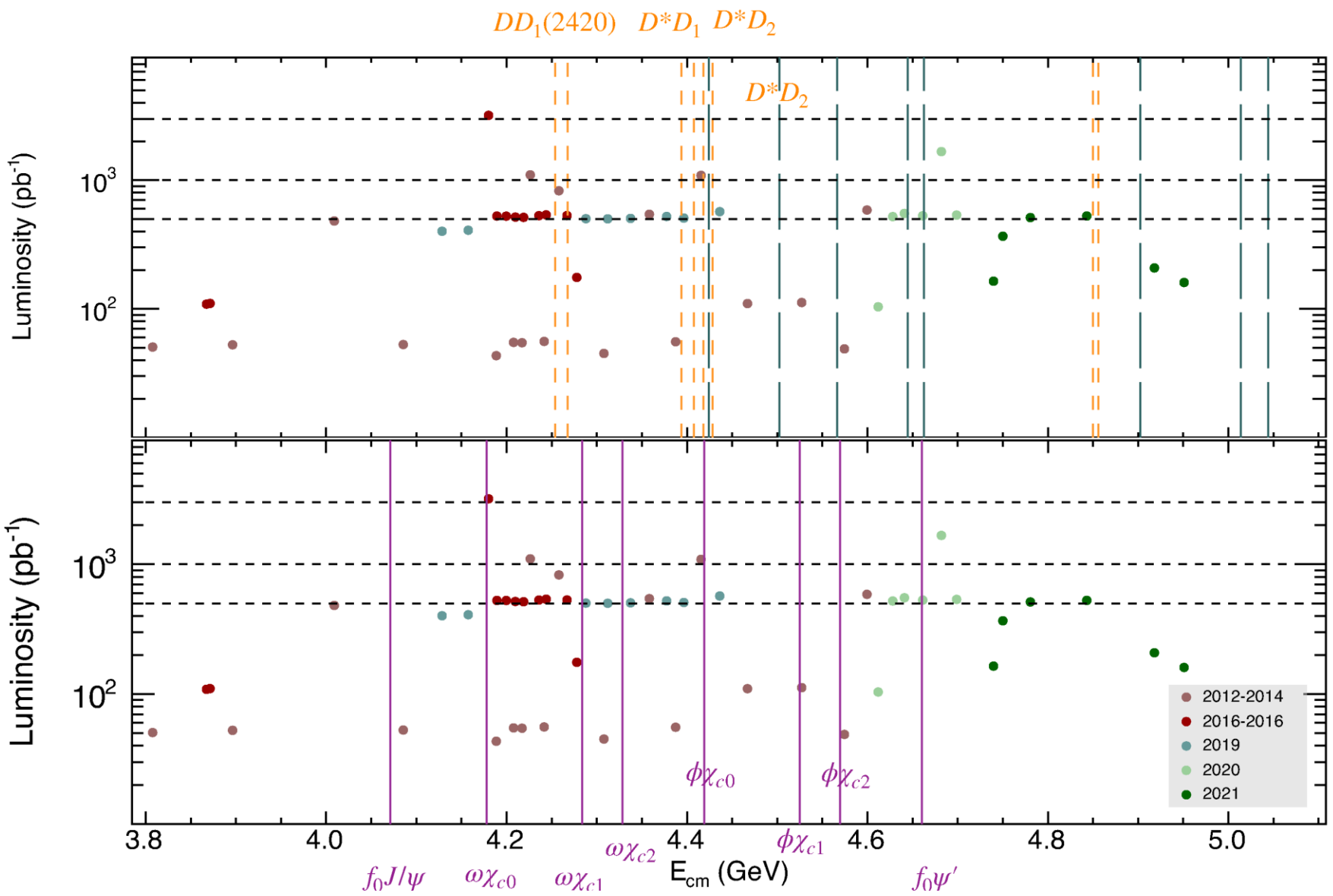






All quantum numbers

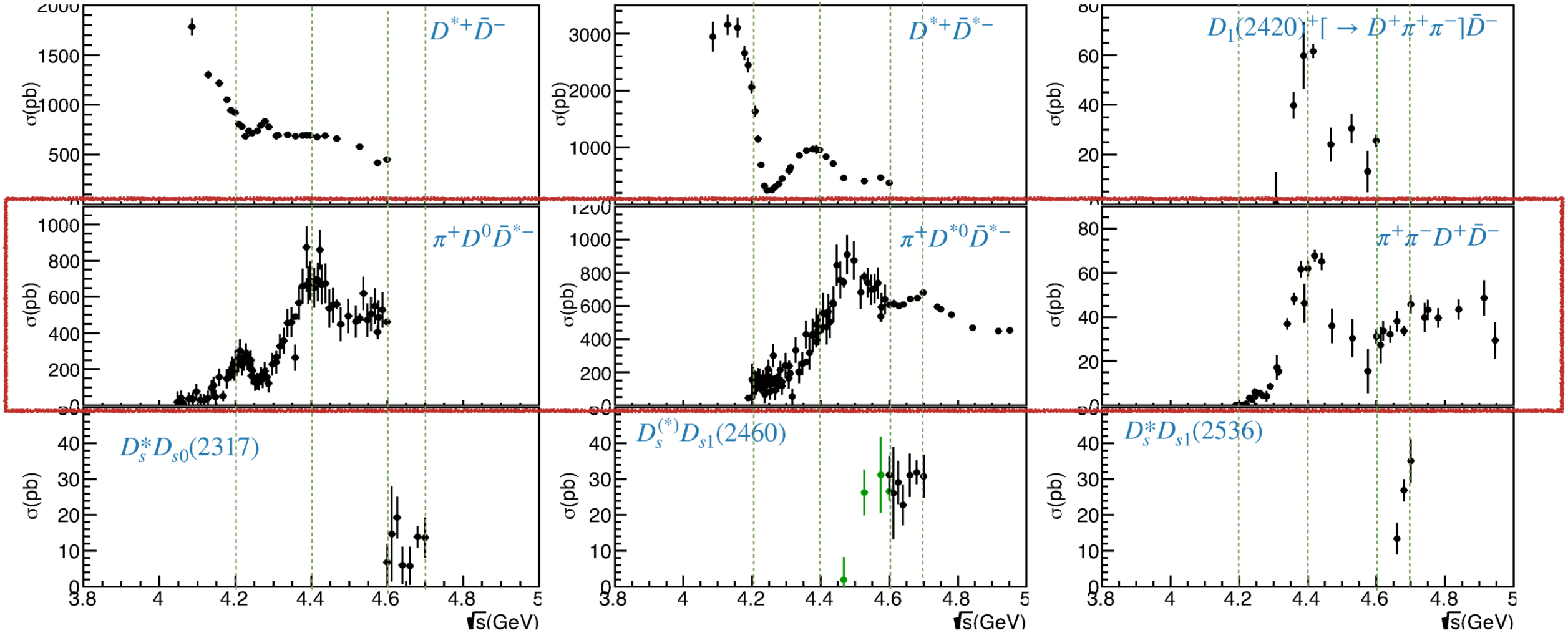
BESIII data samples



- 46 samples
  ~22 fb^{-1}
- small scan samples
  ~2.5 fb^{-1}

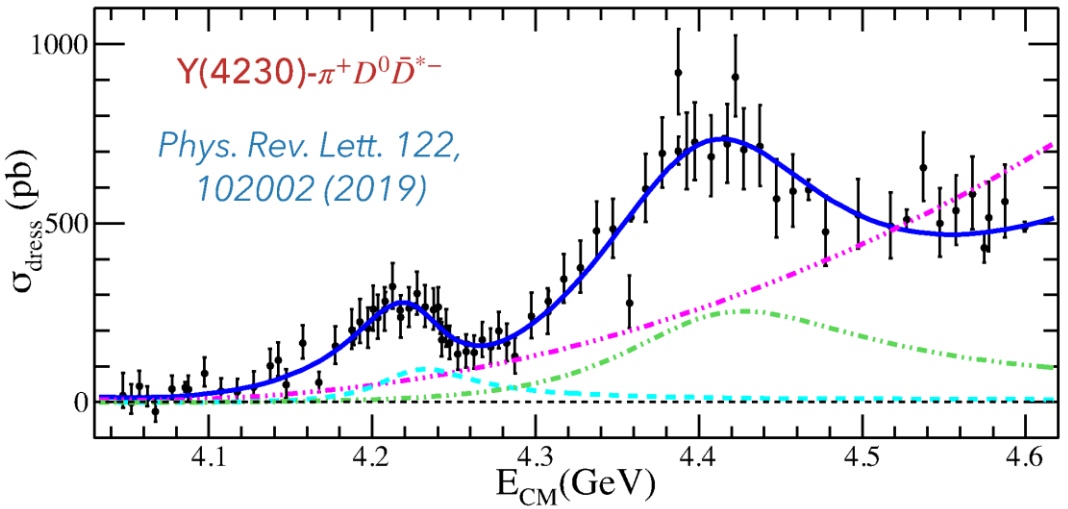
1^{--} states in open charm processes

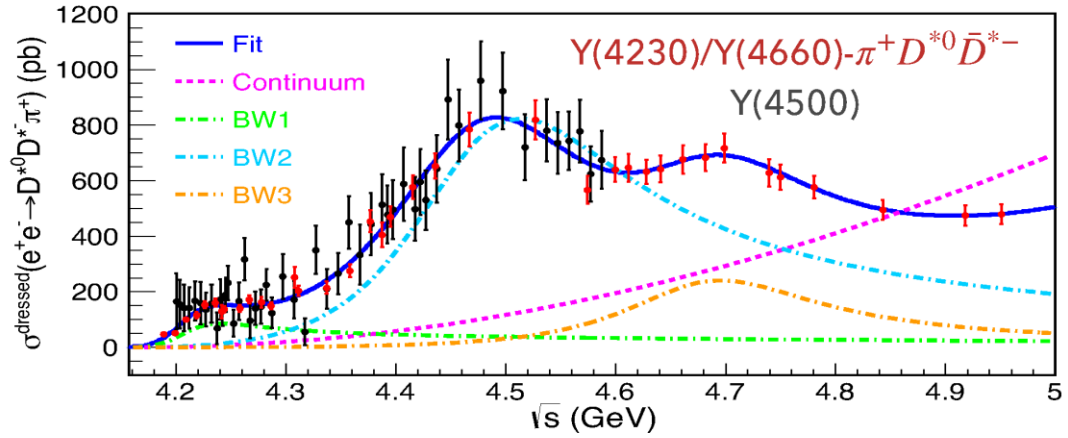
- Investigated by measuring the cross section as a function of c.m.s $\sigma(\sqrt{s})$



1^{--} states in open charm processes (cont.)

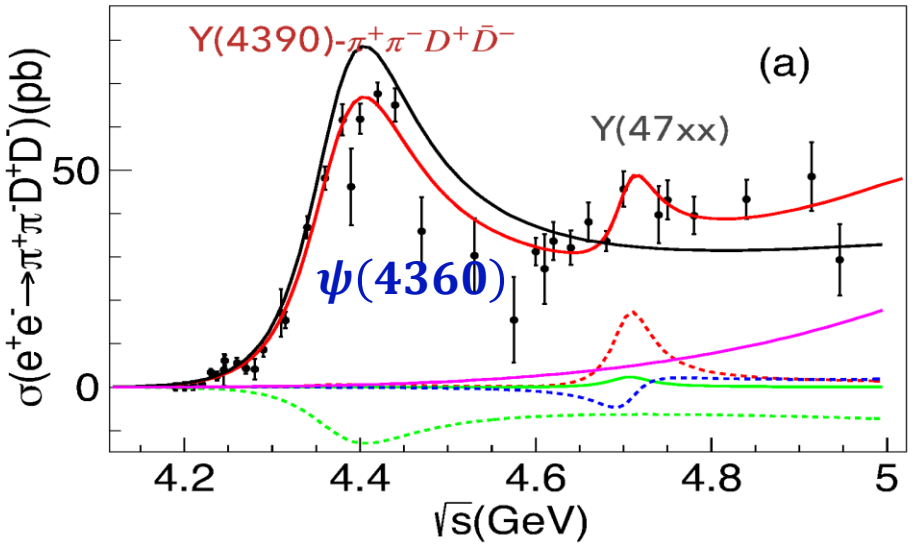
- Investigated by measuring the cross section as a function of c.m.s $\sigma(\sqrt{s})$

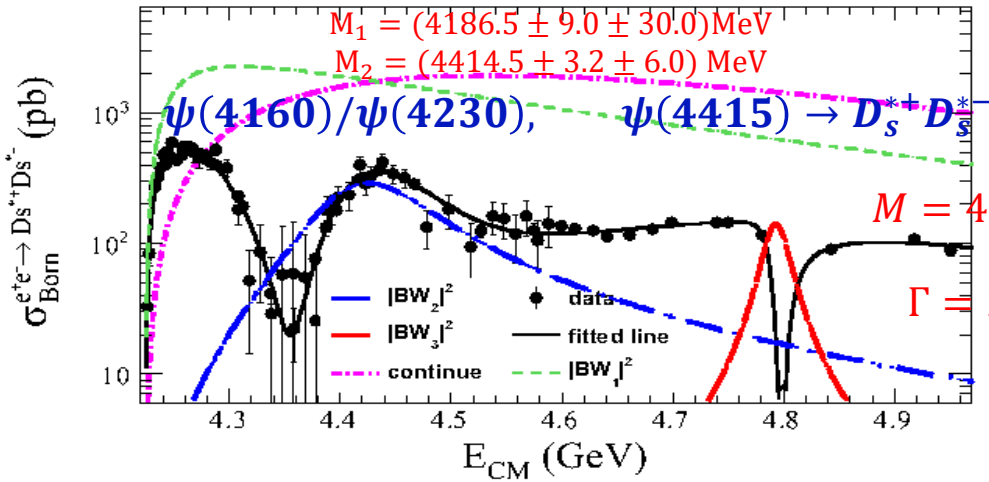




Phys. Rev. Lett., 130, 121901 (2023)

Phys. Rev., D 106, 052012 (2022)





$M = 4793.3 \pm 3.3$ MeV

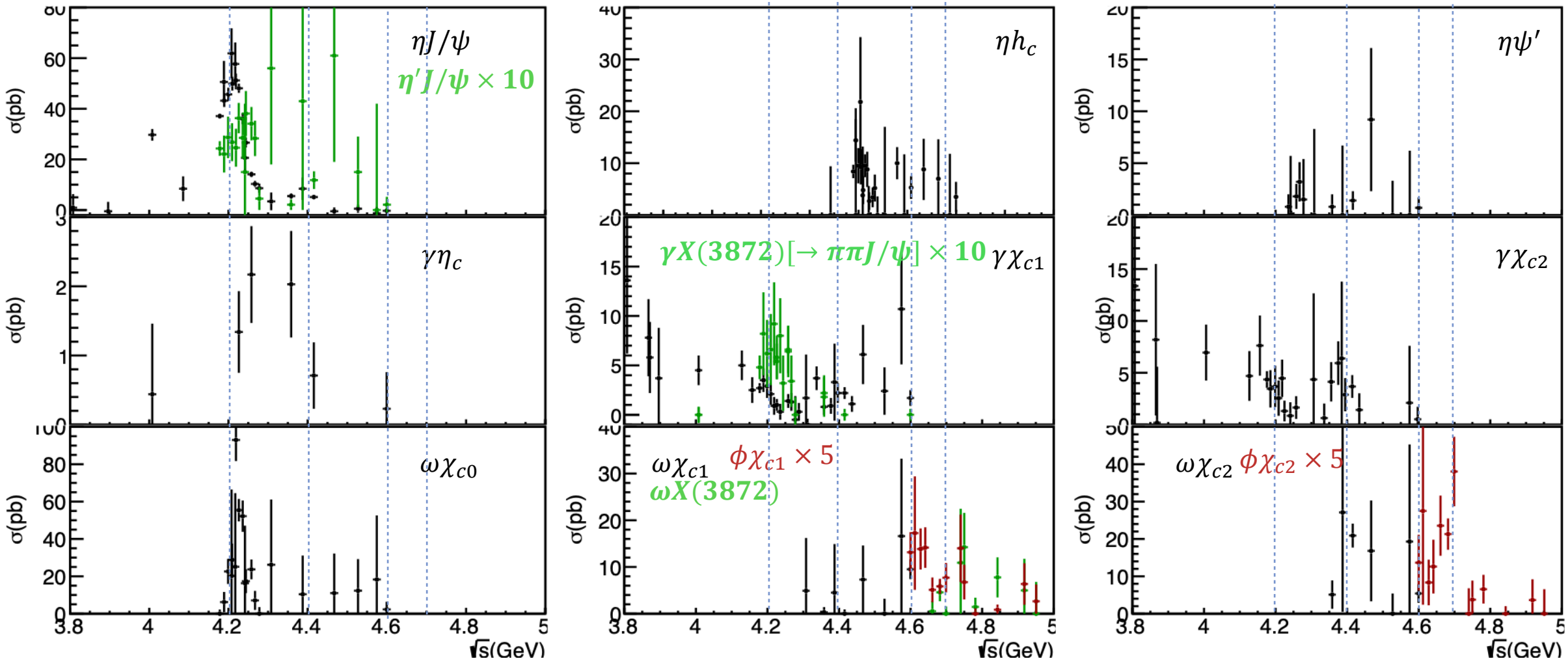
$\Gamma = 27.1 \pm 7.0$ MeV

6.1σ

arXiv: 2305.10789, submitted to PRL

1^{--} states in hidden charm processes (cont.)

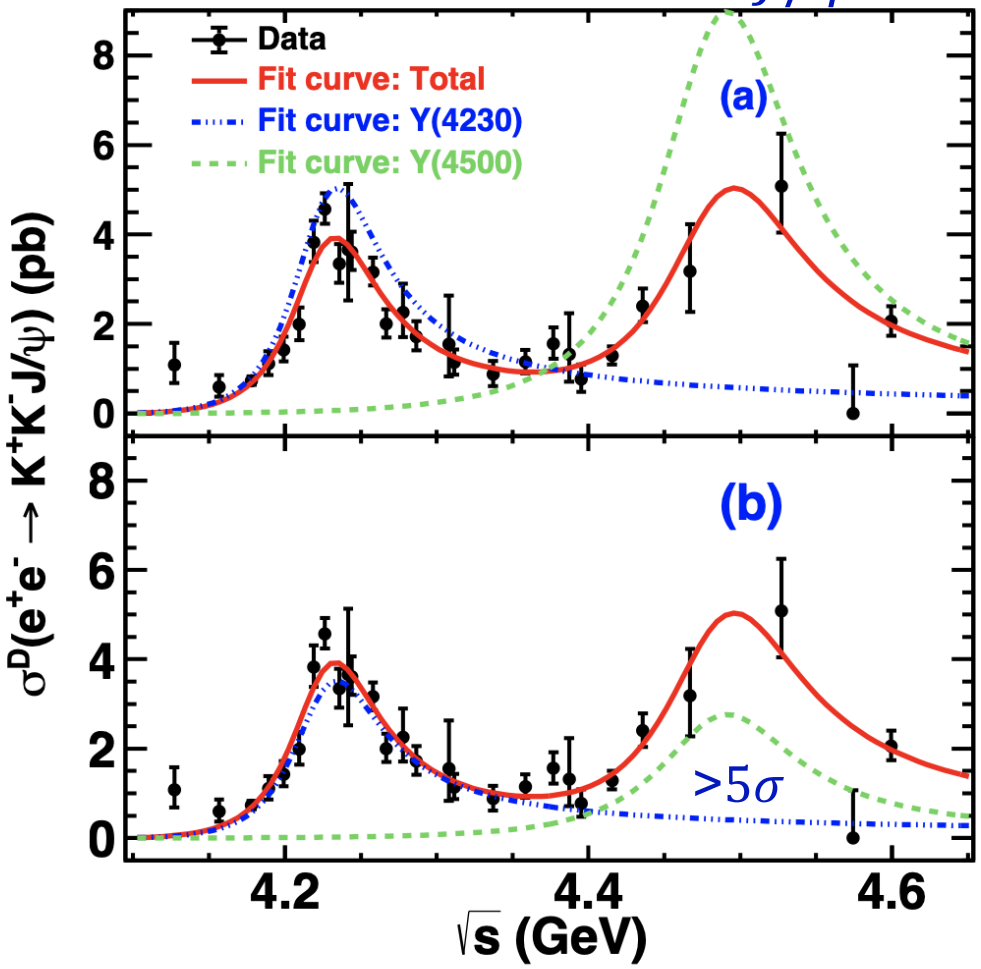
- Investigated by measuring the cross section as a function of c.m.s $\sigma(\sqrt{s})$ [24 published]



1^{--} states in hidden charm processes (cont.)

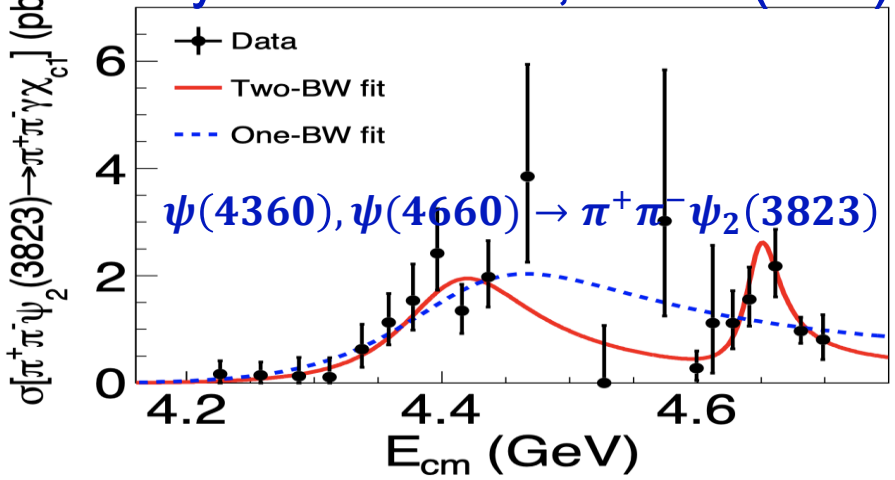
- Investigated by measuring the cross section as a function of c.m.s $\sigma(\sqrt{s})$ [24 published]

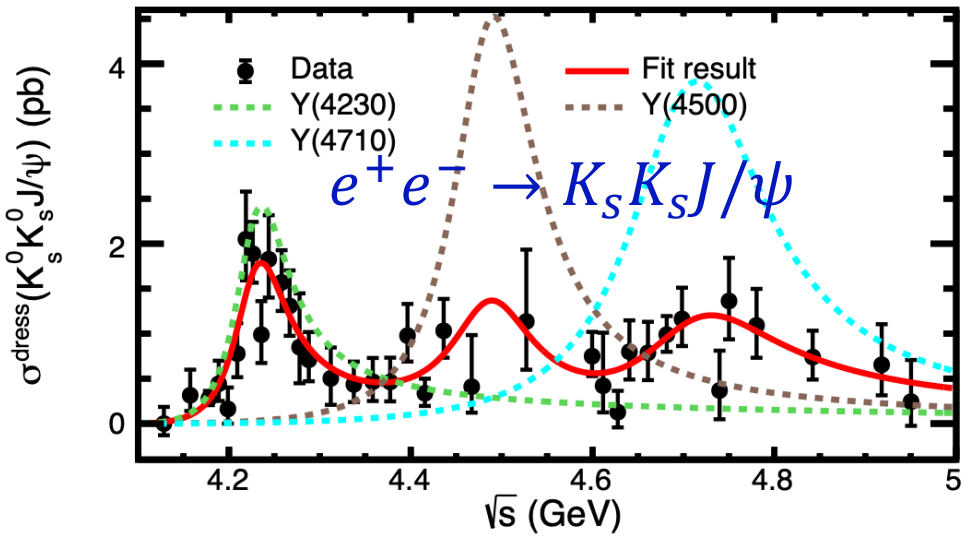
$e^+e^- \to K^+K^-J/\psi$



Chinese Phys. C 46 111002 (2022)

Phys. Rev. Lett. 129, 102003 (2022)





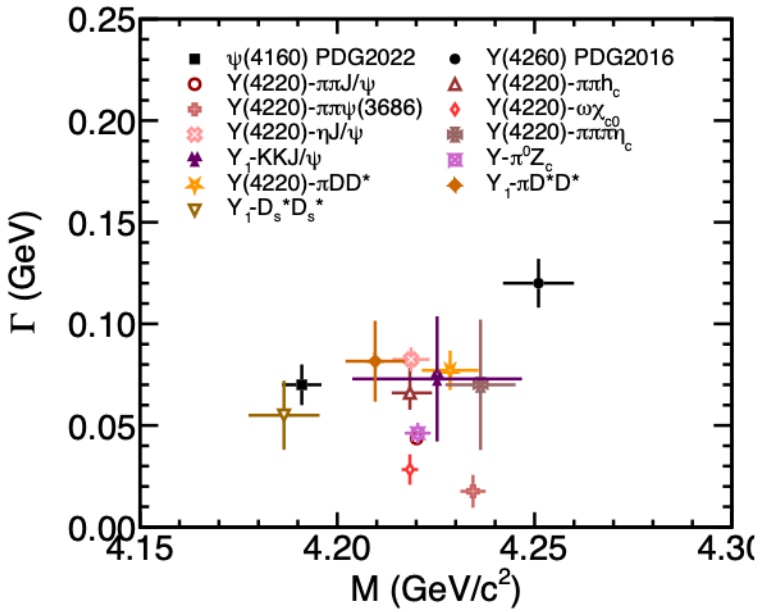
4.2σ

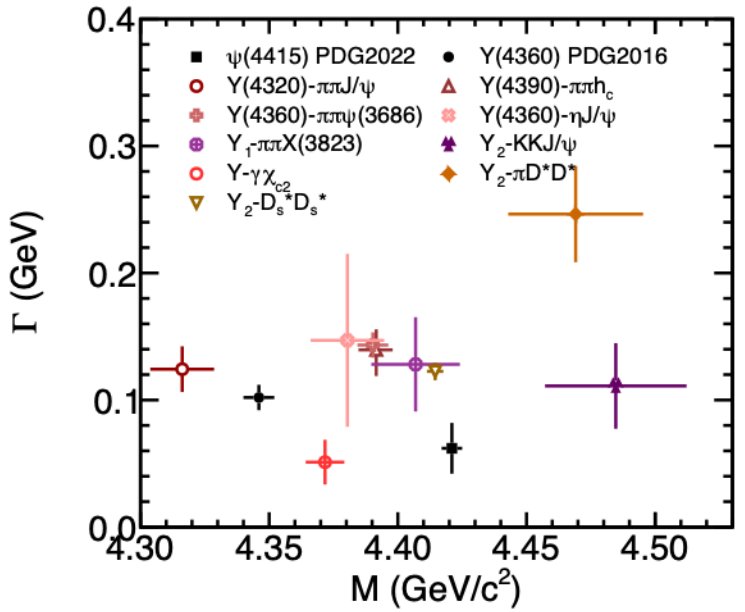
Phys. Rev. D 107, 092005 (2023)

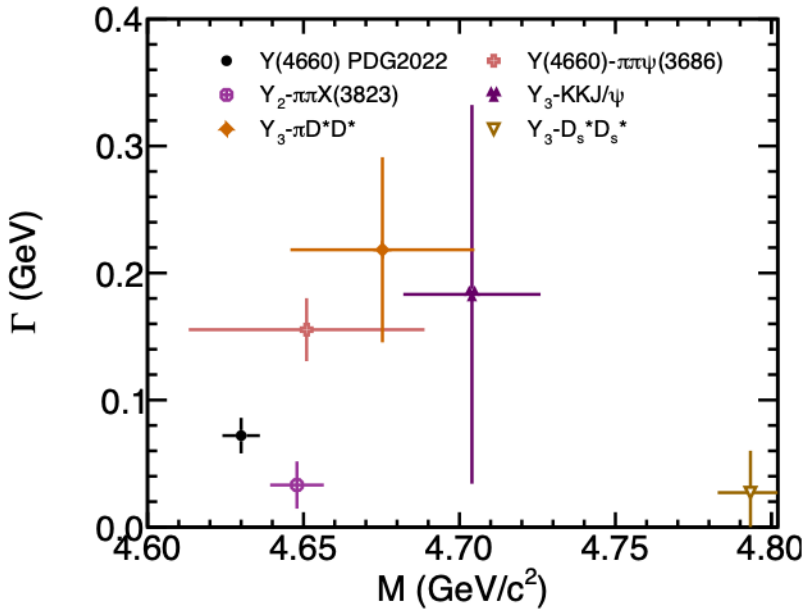
1^{--} states in hidden charm processes (cont.)

- $e^+e^- \to \pi^+\pi^-\eta_c$, $\gamma\pi^0\eta_c, \pi^+\pi^-\eta\eta_c$ [4.18, 4.23, 4.26, 4.36, 4.42, 4.60, upper limit]
- $e^+e^- \to \pi^+\pi^-\chi_{cJ}$, [4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.245, 4.26, 4.27, 4.28, 4.36, 4.40, 4.53, 4.60, upper limit]
- $e^+e^- \to \pi^+\pi^-\pi^0\eta_c$ [4.009, 4.23, 4.26, 4.42, 4.60, upper limit]
- $e^+e^- \to \rho X_2(4013) \to \rho D\bar{D}$ [4.36, 4.42, 4.60, upper limit]

Need:
Proper parameterization
couple channel analysis

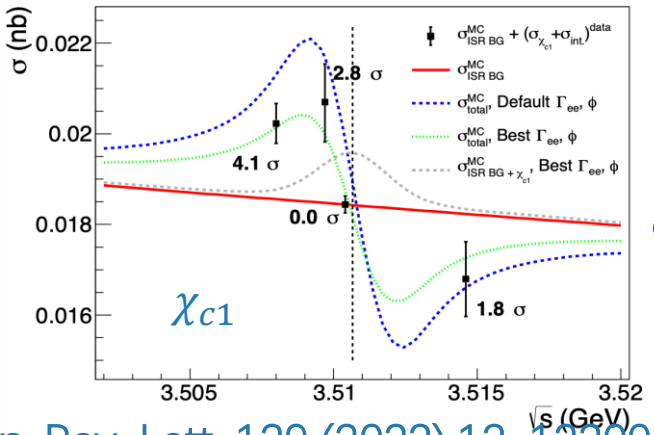






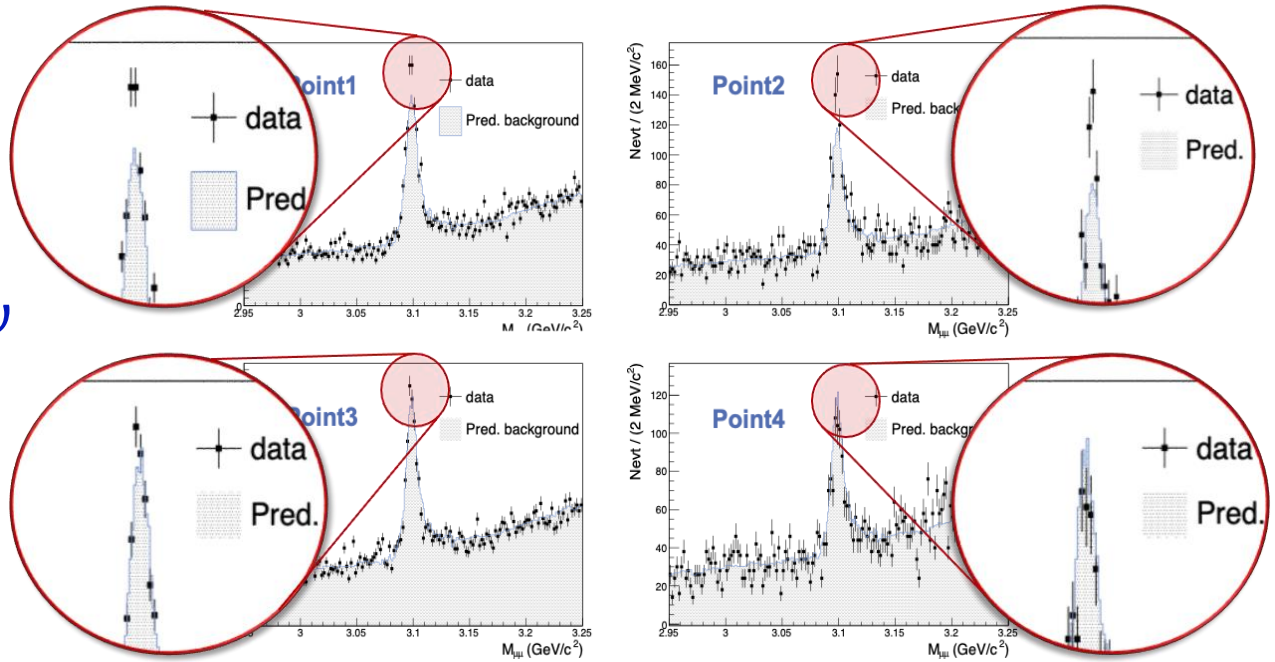
C-even states direct production from e^+e^- annihilation

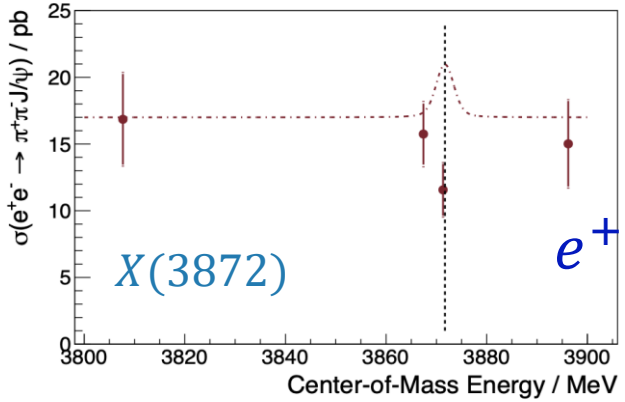
- **Dedicated scan sample around the resonance**
- **Careful study of background process and interference effect!**



Phys. Rev. Lett. 129 (2022) 12, 122001

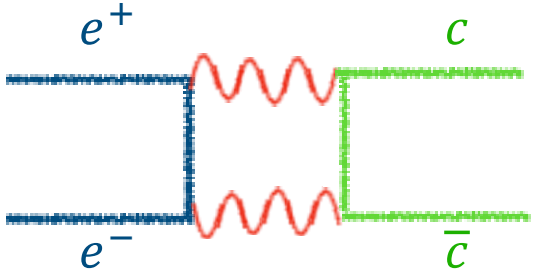
$e^+e^- \to \chi_{c1}$
$\to \gamma J/\psi$





Phys. Rev. , D107 (2023) , 032007

$e^+e^- \to X(3872)$
$\to \pi^+\pi^- J/\psi$

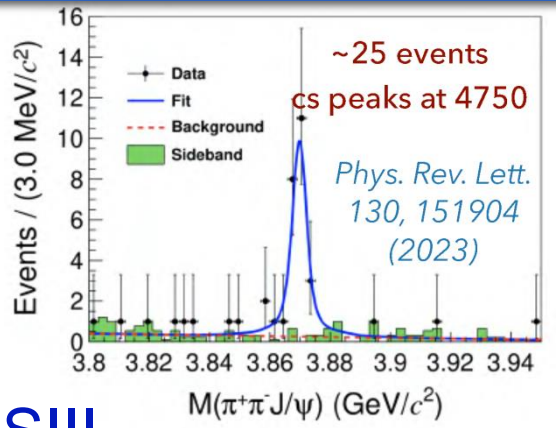


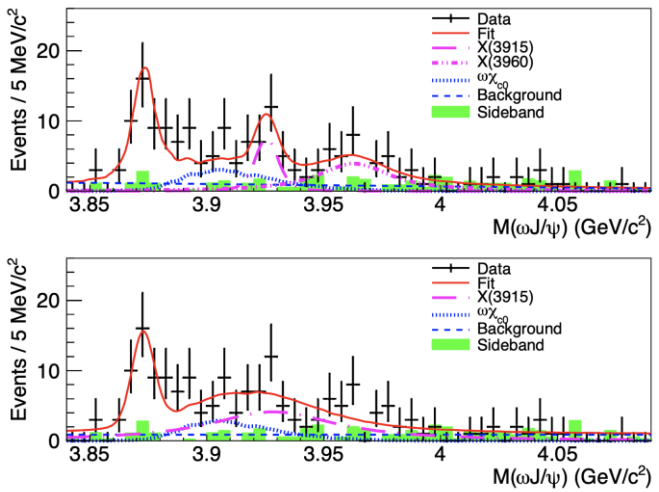
$J^{PC} = 1^{++}, 2^{++}$

- Bkgs.:
- $e^+e^- \to \gamma_{ISR} J/\psi$
- $e^+e^- \to \gamma\mu^+\mu^-$

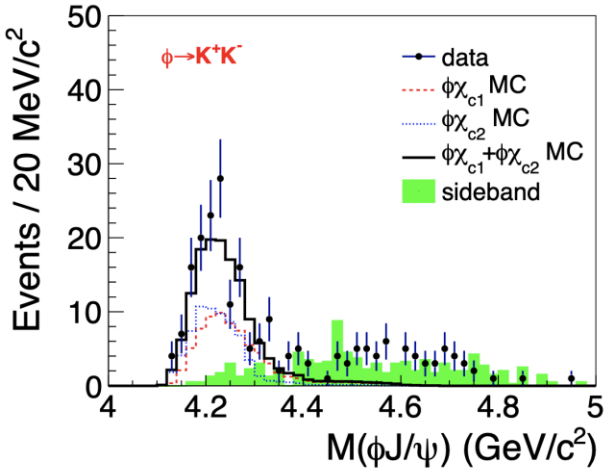
C-even states-radiative/hadronic transition

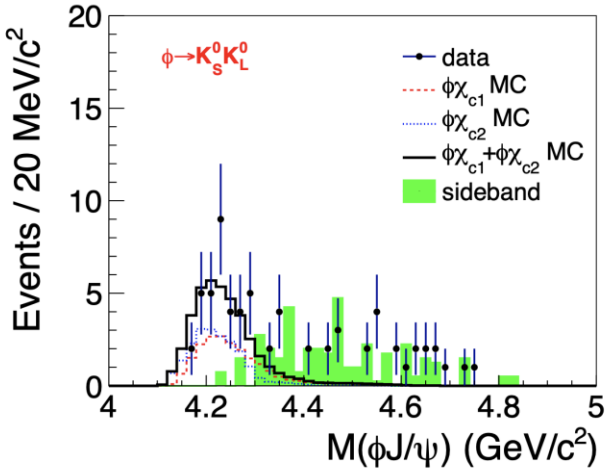
- Small production rate in radiative transition process
- Low detection efficiency [full reconstruction] or high bkg. [partial reconstruction] in open charm final state
  - ➢ Need novel approach to increase statistics or suppress bkg.
- Radiative and hadronic transitions to $X(3872)$ are observed at BESIII
- Found evidence of $X(3915)/X(3960)$ [$\omega J/\psi$ mode] , no obvious signal for $X(4140), X(4274), X(4500)$ [$\phi J/\psi$ mode], no evidence of $X2(4013)$ [$D\bar{D}$ mode]





Phys. Rev. Lett. 122, 232002 (2019)

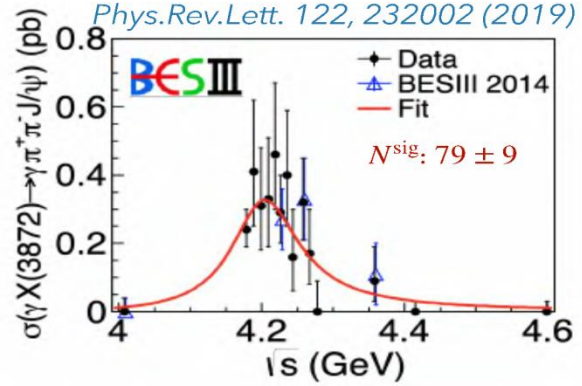




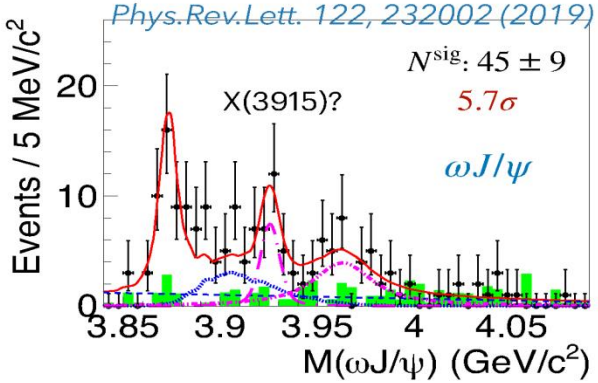
JHEP 01, 132 (2023)

$X(3872)$ decays

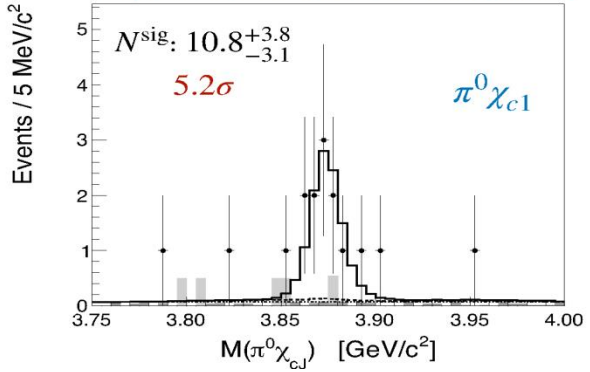
Phys.Rev.Lett. 122, 232002 (2019)



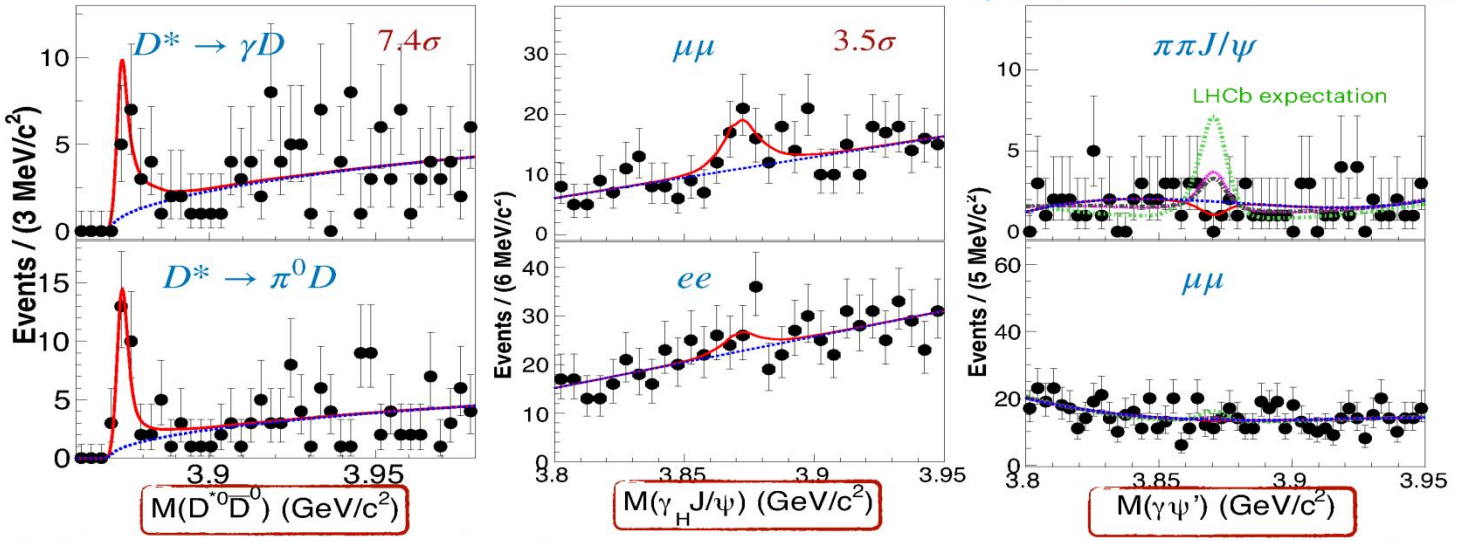
Phys.Rev.Lett. 122, 232002 (2019)



Phys.Rev.Lett. 122, 202001 (2019)



Phys.Rev.Lett. 124, 242001 (2020)



mode	ratio	UL
$\gamma J/\psi$	0.79 ± 0.28	-
$\gamma\psi'$ 2.8σ lower	-0.03 ± 0.22	< 0.42
$\gamma D^0\bar{D}^0$	0.54 ± 0.48	< 1.58
$\pi^0 D^0\bar{D}^0$	-0.13 ± 0.47	< 1.16

mode	ratio	UL
$D^{*0}\bar{D}^0 + c.c.$	11.77 ± 3.09	-
$\gamma D^+ D^-$	$0.00^{+0.48}_{-0.00}$	< 0.99
$\omega J/\psi$	$1.6^{+0.4}_{-0.3} \pm 0.2$ [18]	-
$\pi^0\chi_{c1}$	$0.88^{+0.33}_{-0.27} \pm 0.10$ [31]	-

Ratio	90% C.L Upper Limit
$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	3.6
$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^0\chi_{c1})}$	4.5
$\frac{\mathcal{B}(X(3872)\to\pi^+\pi^-\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	0.56
$\frac{\mathcal{B}(X(3872)\to\pi^0\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	1.7

Phys. Rev. D 105, 072009 (2022)

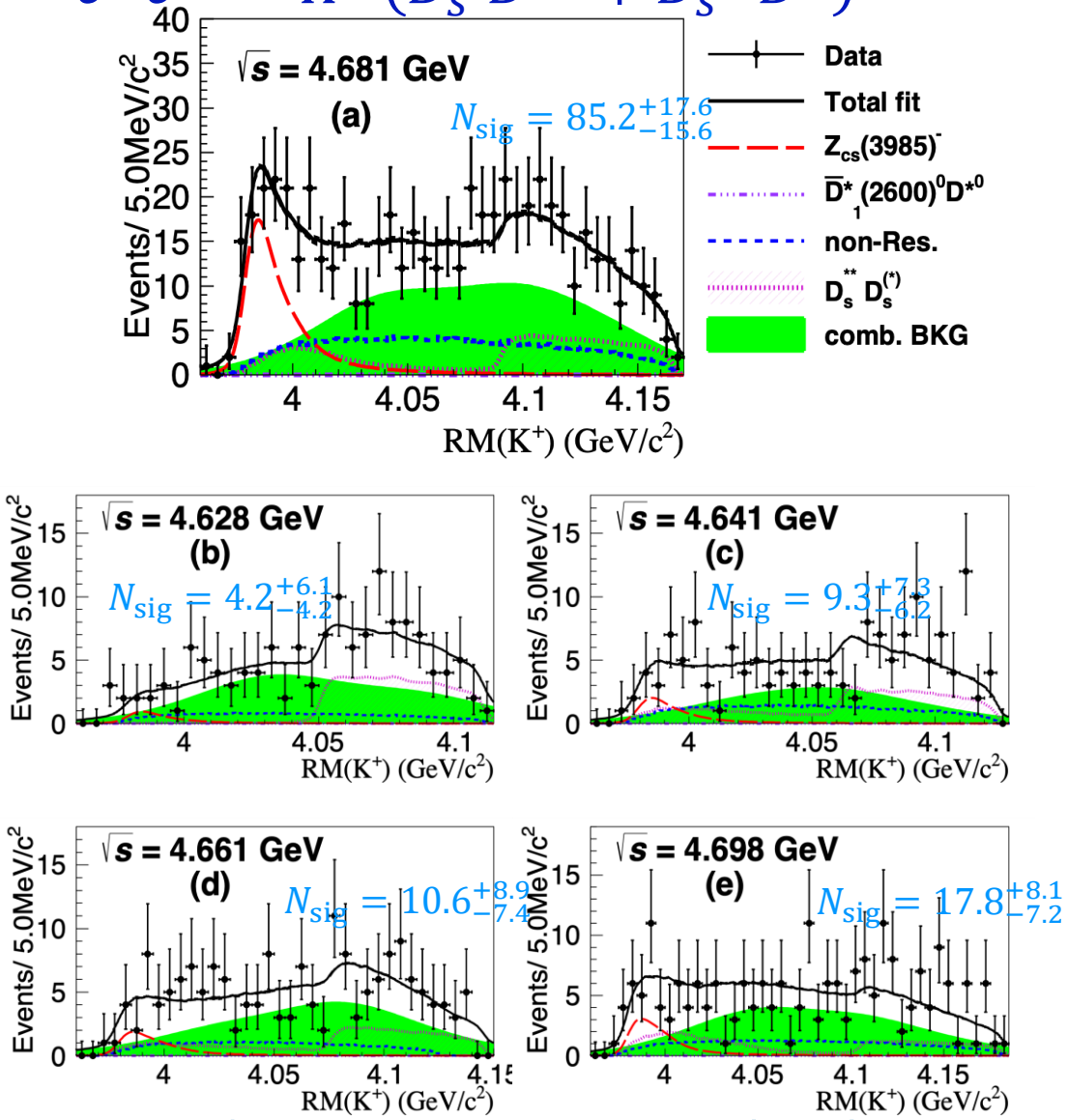
$Z_{c(s)}$ states

State	M (MeV/c^2)	Γ (MeV)	J^{PC}	Process	Experiment
$Z_c(3900)^{(\pm,0)}$	3888.4 ± 2.5	28.3 ± 2.5	1^{+-}	$e^+e^- \to \pi^{(+,0)}(\pi^{(-,0)}J/\psi)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D\bar{D}^*)^{(-,0)}$	BESIII
				$H_b \to X\pi^+(\pi^- J/\psi)$	D0
				$e^+e^- \to \pi^+(\eta_c\rho^-)$	BESIII
$Z_c(4020)^{(\pm,0)}$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e^- \to \pi^{(+,0)}(\pi^{(-,0)}h_c)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D^*\bar{D}^*)^{(-,0)}$	BESIII
$Z(4050)^{\pm}$	4051^{+24}_{-40}	82^{+50}_{-28}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
				$e^+e^- \to \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	BESIII Not Seen!
$Z(4055)^{\pm}$ 3.5σ	4054 ± 3.2	45 ± 13	$?^{?-}$	$e^+e^- \to \pi^+(\pi^-\psi(2S))$	Belle
$Z(4100)^{\pm}$ 3.4σ	4096 ± 28	152^{+80}_{-70}	$?^{??}$	$B^0 \to K^+(\pi^-\eta_c)$	LHCb
				$e^+e^- \to \pi^{(+,-)}\pi^0(\pi^{(-,+)}\eta_c)$	BESIII Not Seen!
				$e^+e^- \to \pi^{(+,-)}\eta(\pi^{(-,+)}\eta_c)$	BESIII Not Seen!
$Z(4200)^{\pm}$	4196^{+35}_{-32}	370^{+100}_{-150}	1^{+-}	$\bar{B}^0 \to K^-(\pi^+J/\psi)$	Belle, LHCb
$Z(4250)^{\pm}$	4248^{+190}_{-50}	177^{+320}_{-70}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
				$e^+e^- \to \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	BESIII Not Seen!
$Z(4430)^{\pm}$ first/2008	4478^{+15}_{-18}	181 ± 31	1^{+-}	$B^0 \to K^+(\pi^-\psi(2S))$	Belle, LHCb
				$\bar{B}^0 \to K^-(\pi^+J/\psi)$	Belle
$R_{c0}(4240)$	4239^{+50}_{-21}	220^{+120}_{-90}	0^{--}	$B^0 \to K^+\pi^-\psi(2S)$	LHCb
$Z_{cs}(3985)^{\pm,0}$ 4.6σ-neutral	$3982.5^{+2.8}_{-3.4}$	$12.8^{+6.1}_{-5.3}$	?	$e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$	BESIII
				$e^+e^- \to K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$	BESIII
$Z_{cs}(4000)^{\pm}$	4003^{+7}_{-15}	131 ± 30	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb
$Z_{cs}(4220)^{\pm}$	4216^{+49}_{-38}	233^{+110}_{-90}	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb

- Produced in e^+e^- annihilation or b-flavor hadron decays
- Typically in h+ charmonium final states
- Intrinsic nature unclear, exotic states? kinematic effects?

$Z_{cs}^{\pm}$ and Z_{cs}^{0} states

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



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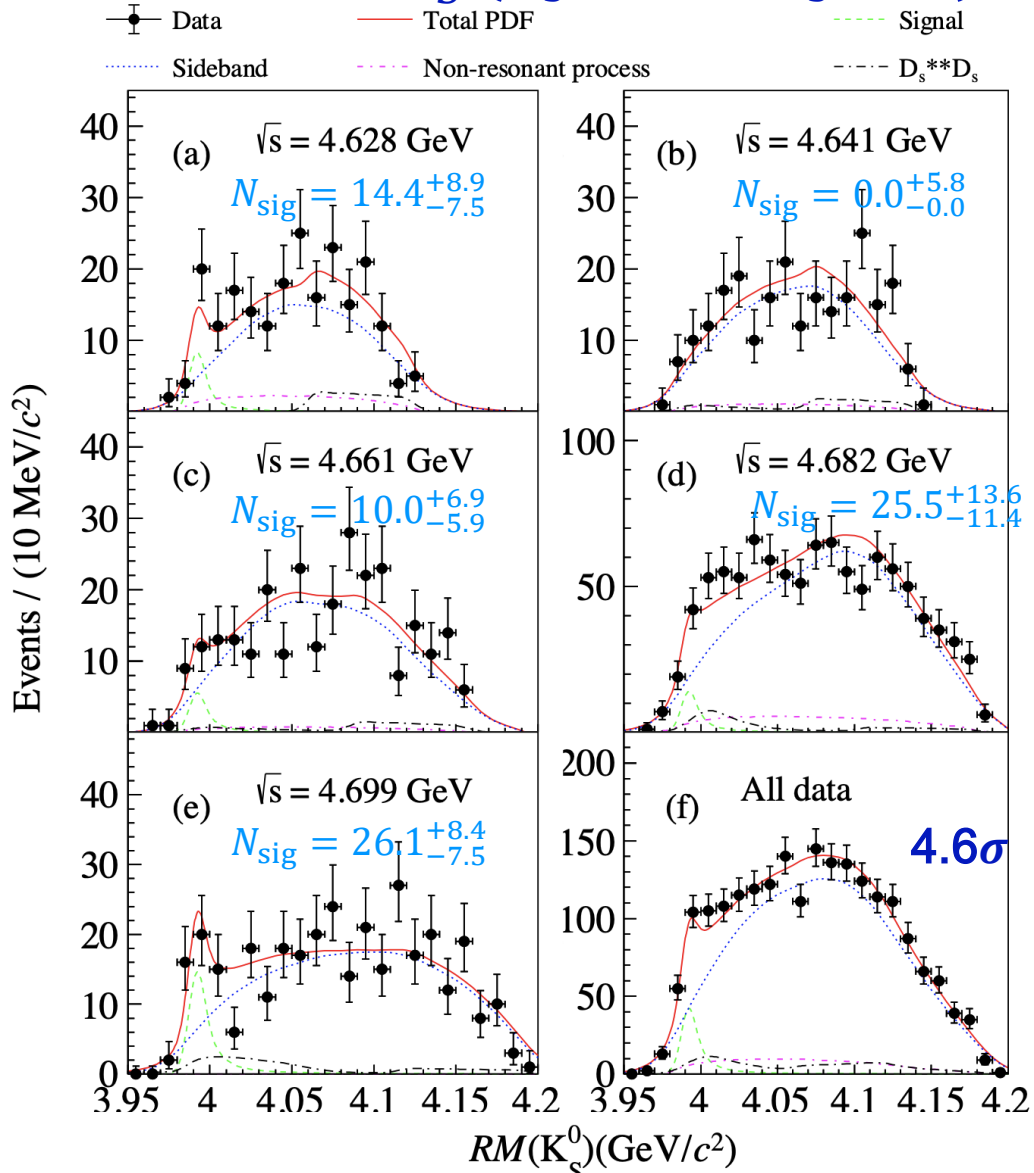
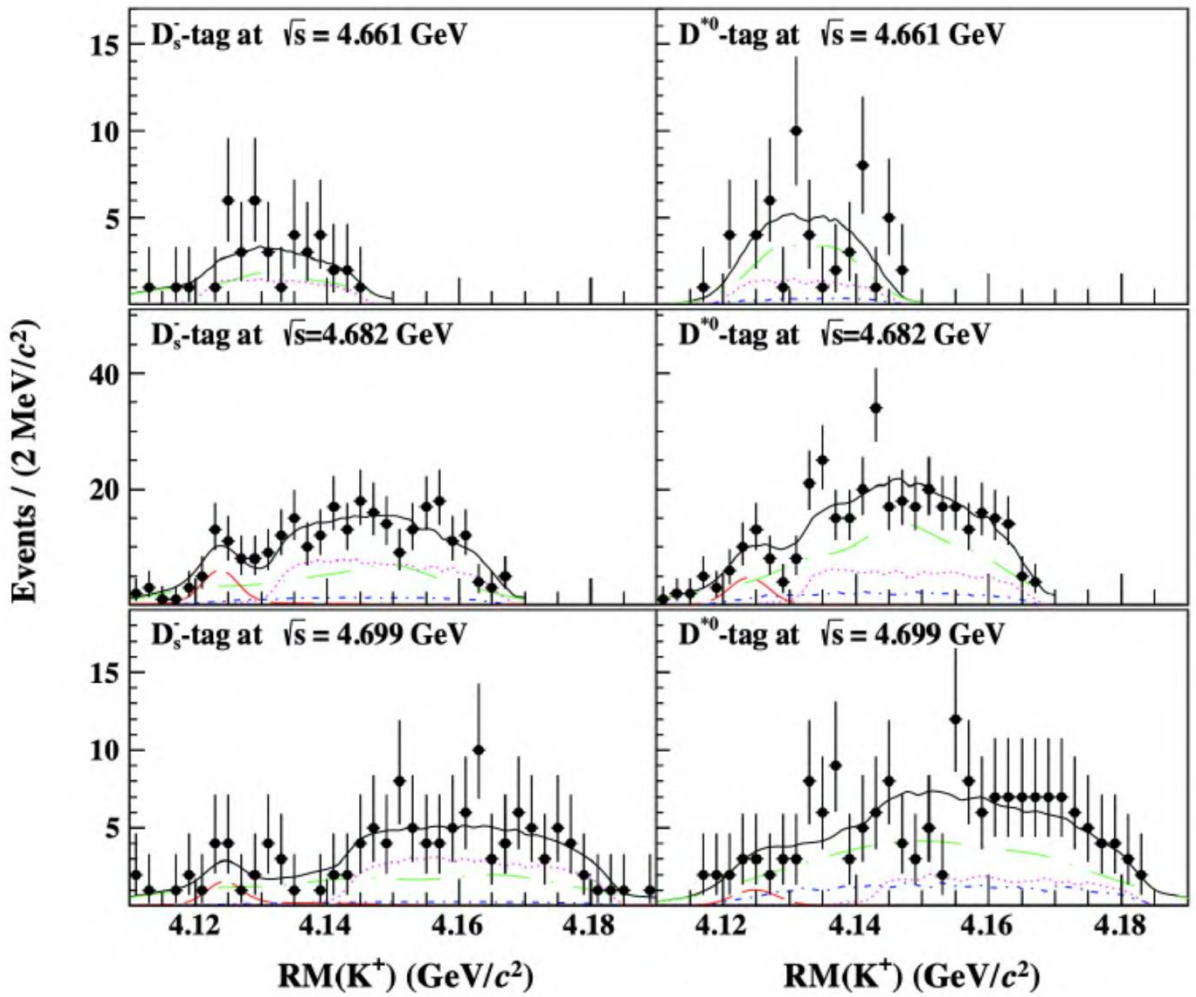
- $e^+e^- \to K_S^0(D_s^+ D^{*-} + D_s^{*+} D^-)$



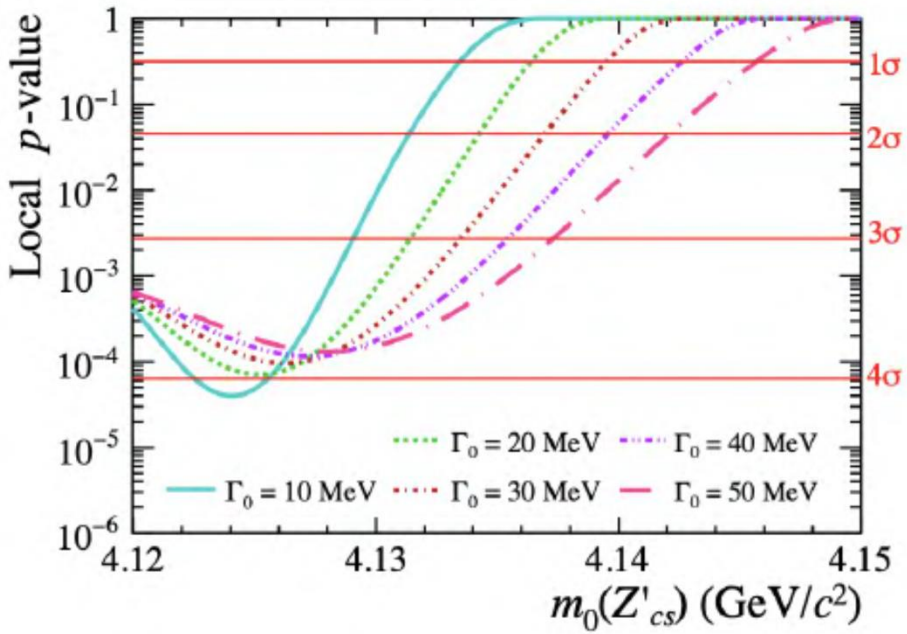
Phys. Rev. Lett. 129, 112003 (2022)

Z'_{cs} in $e^+e^- \to K^+D^{*0}D_s^{*-}$



- Signal: $\left|\frac{|\sqrt{p.q}|}{M^2-m_0^2+im_0\Gamma(M)}\right|^2$

- $e^+e^- \to K^+D^{*0}D_s^{*-}$
- Chin. Phys. C47, 033001(2023)

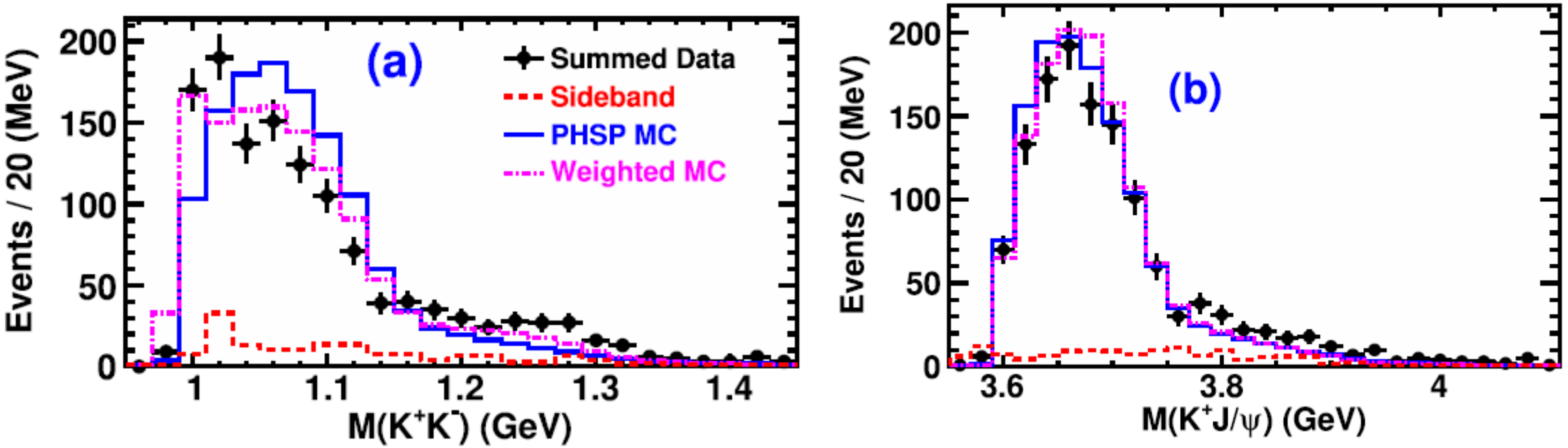


- $m = 4123.5 \pm 0.7 \pm 4.7$ MeV / c^2
- significance 2.1σ (w. sys.)

Z_{cs} in $K^+K^-(c\bar{c})$

- Small cross section of $e^+e^- \to K\bar{K} + c\bar{c}$ [$J/\psi, h_c, \psi'$ at similar level], will be difficult to get solid conclusion without larger statistics.

Chinese Phys. C 46 111002 (2022)

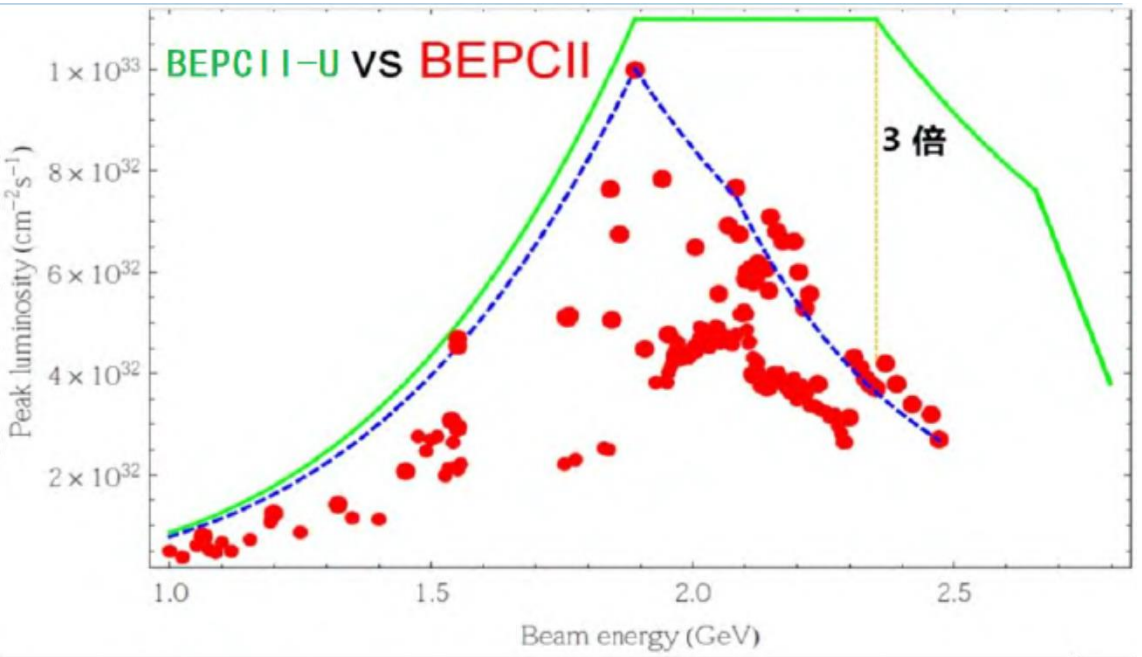


- $\sqrt{s} = 4.127 \sim 4.6\ \mathrm{GeV}\ , \mathcal{L} = 15.6\ fb^{-1}$
- $e^+e^- \to K\bar{K}J/\psi$

Future data samples

Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019. ... most column shows the number of required data taking days with the ... implementation and beam current increase.

Energy	Physics motivations			
1.8 - 2.0 GeV	R values Nucleon cross-sections			
2.0 - 3.1 GeV	R values Cross-sections			
J/ψ peak	Light hadron & Glueball J/ψ decays			
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays			
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays			
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days



- Pentaquark : 4.96 GeV - $p\bar{p}\eta_c$ threshold ; 4.97 GeV - $p\bar{p}\,J/\psi$ threshold

Summary

- Properties of vector charmonium like states have been investigated using various processes, including open charm, hidden charm, and light hadronic final states.
  - Rich structures in the cross section line shapes
  - Hard to get a unified picture with current used strategy [use simply formula to fit cross section], require joint effort/better modeling
- C-even states
  - Direct electron-positron annihilation process: dedicated data sample, special attention to be paid to signal MC modeling with interference effect taken into account
  - Radiative transition: small production rate; Hadronic transition: high energy data sample
- Z_c and P_c states
  - Precise measurement of the properties, build connections with other states ⇒Larger data sample for heavier states

Thank you