

Ψ

Spectroscopy of charmonium(-like) states at BESIII

Nils Hüsken on behalf of the BESIII collaboration

14th Conference on the Intersections of Particle and Nuclear Physics
September 3rd, 2022

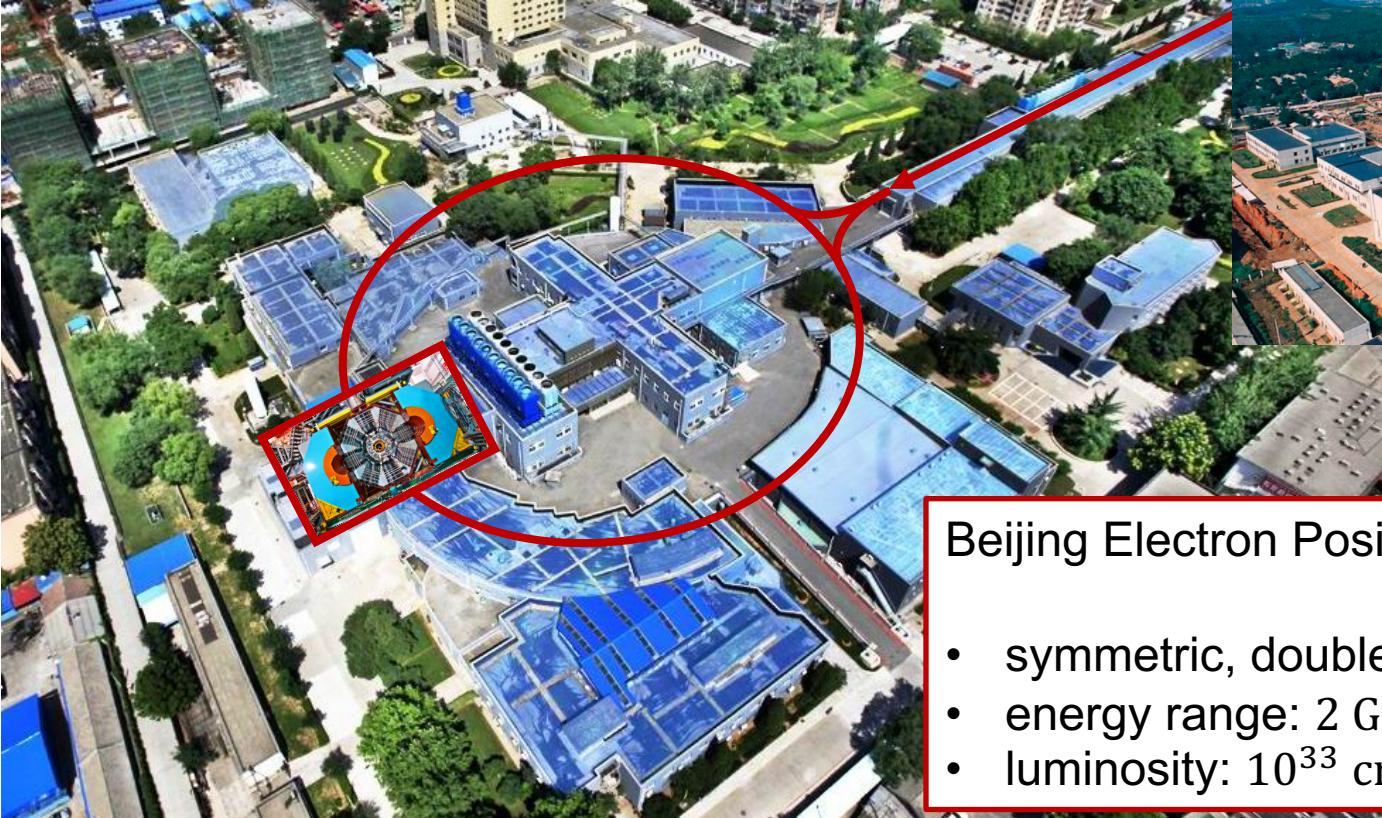
INDIANA UNIVERSITY BLOOMINGTON



The BESIII Experiment



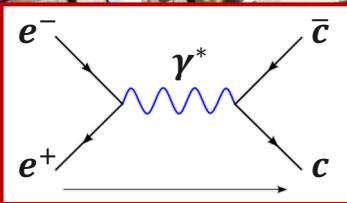
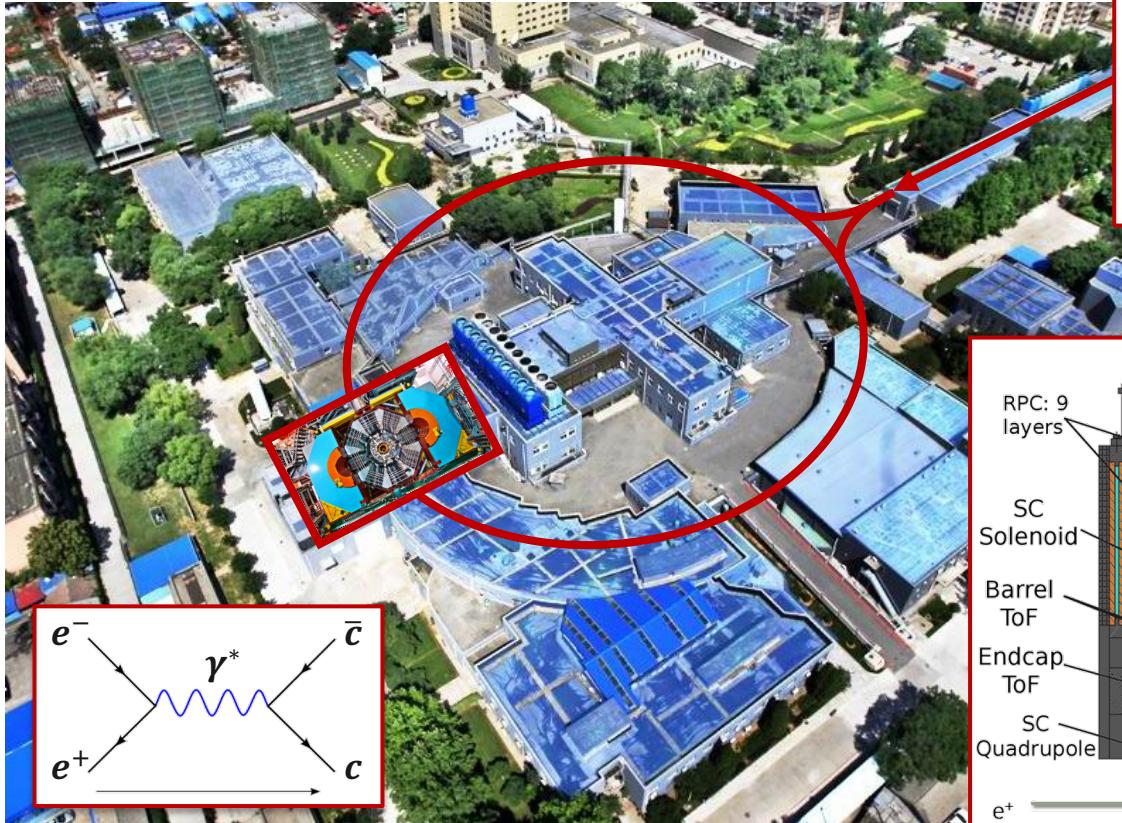
BESIII



Beijing Electron Positron Collider:

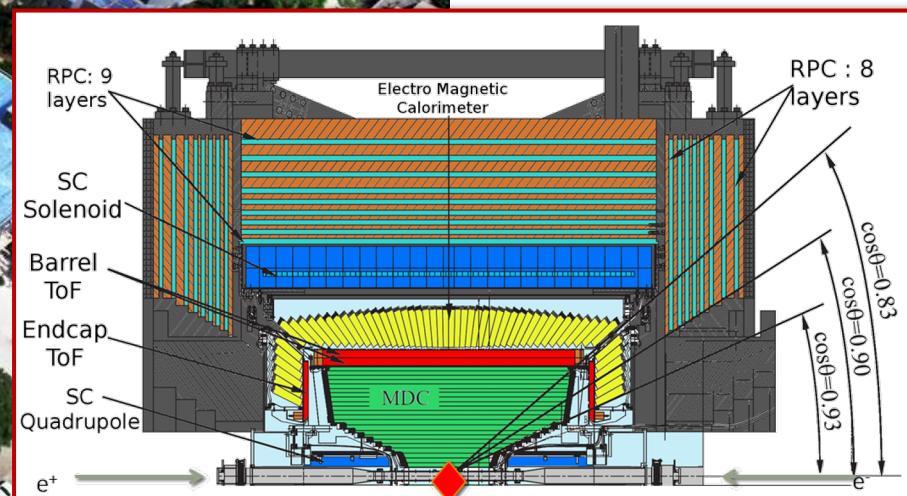
- symmetric, double-ring e^+e^- collider
- energy range: $2 \text{ GeV} < \sqrt{s} < 4.94 \text{ GeV}$
- luminosity: $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (at $\psi(3770)$)

BESIII



Beijing Spectrometer BESIII:

- drift chamber in 1 T magnetic field
- time-of-flight detector
- electromagnetic calorimeter
- muon counter



BESIII

- light hadron spectroscopy
- η & η' decays
- charmonium transitions
- hyperon physics
- ...

+ another $\sim 715 \text{ pb}^{-1}$ for $2.0 \text{ GeV} \leq \sqrt{s} \leq 3.08 \text{ GeV}$

- excited ρ, ω, ϕ
- ...

$10^{10} J/\psi$

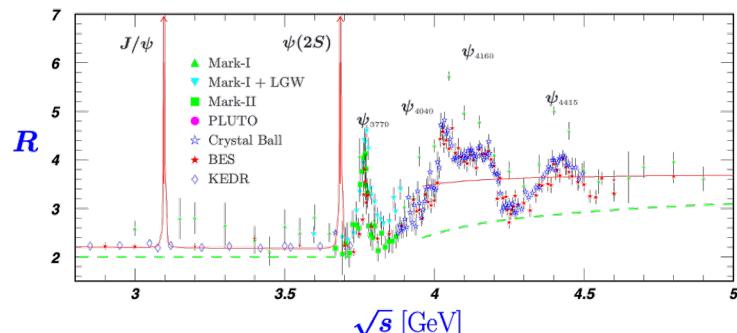
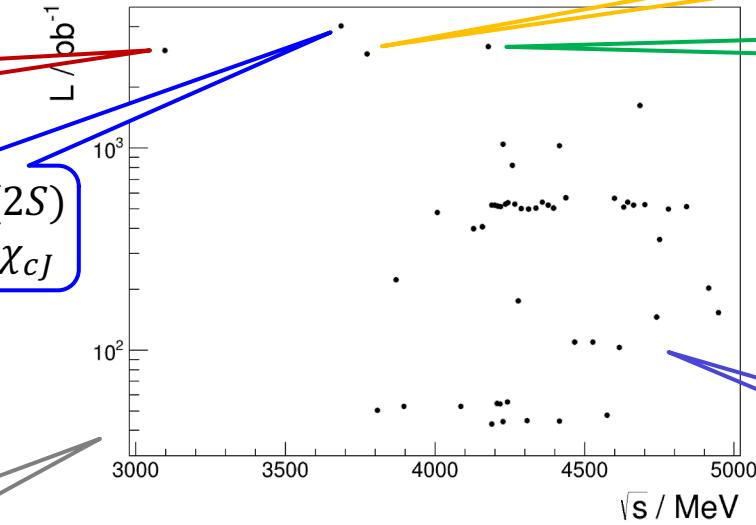
$2.7 \times 10^9 \psi(2S)$
 $\sim 260 \times 10^6 \chi_{cJ}$

$\sim 2.9 \text{ fb}^{-1}$ at $\psi(3770)$

$\sim 3.2 \text{ fb}^{-1}$ at 4.178 GeV

- $D_{(s)}$ meson decays
- $D^0 \bar{D}^0$ pairs
- ISR processes
- $\gamma\gamma$ physics
- ...

$\sim 22 \text{ fb}^{-1}$ in XYZ region



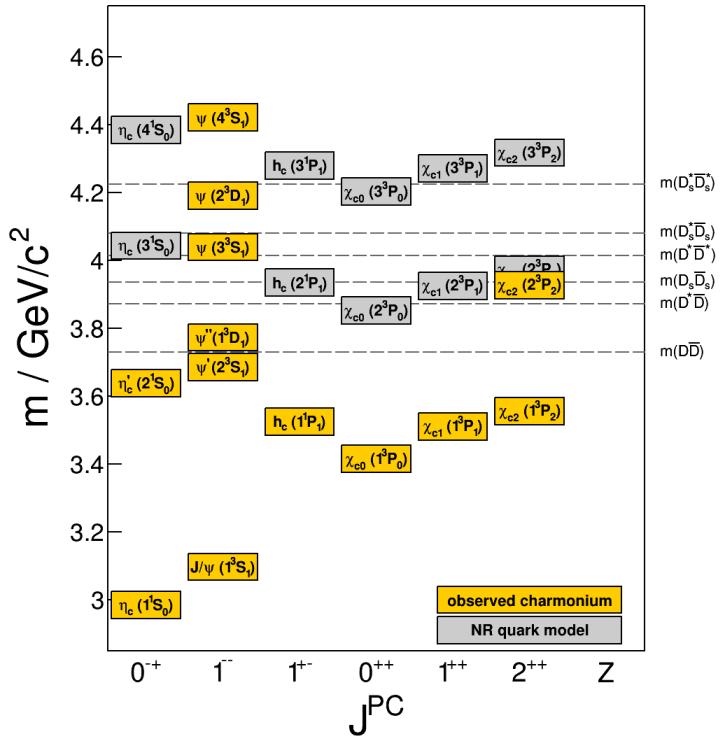
- XYZ spectroscopy
- XYZ decays
- open-charm production
- charmed baryons
- ...



Charmonium(-like) states



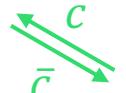
Charmonium



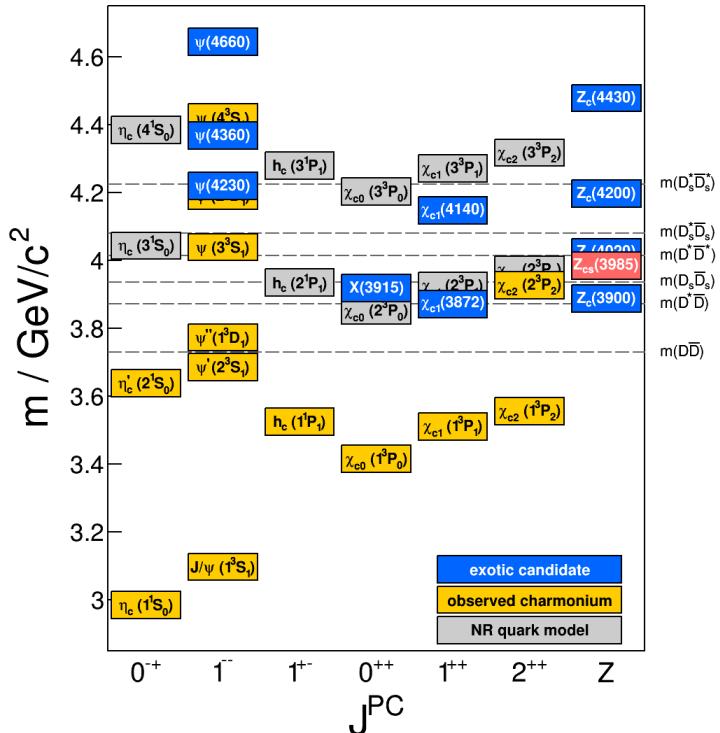
- conventional charmonia ($c\bar{c}$) fit well with potential model calculations

$$V_{c\bar{c}} = -\frac{4}{3} \cdot \frac{\alpha_s(r)}{r} + k \cdot r$$

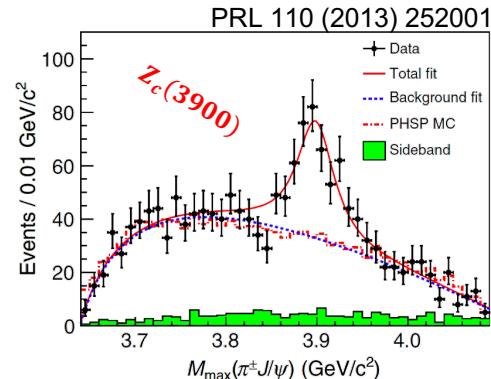
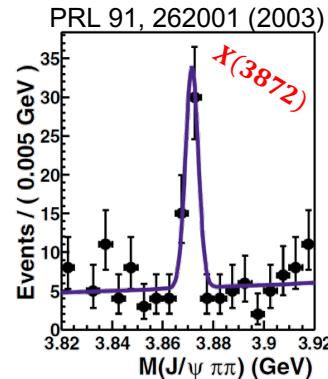
+ spin-dependent terms



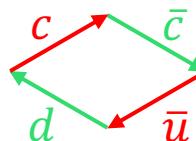
Charmonium-like states



- several unexpected states observed



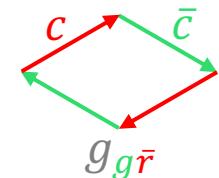
- their nature is still unclear



tetraquark

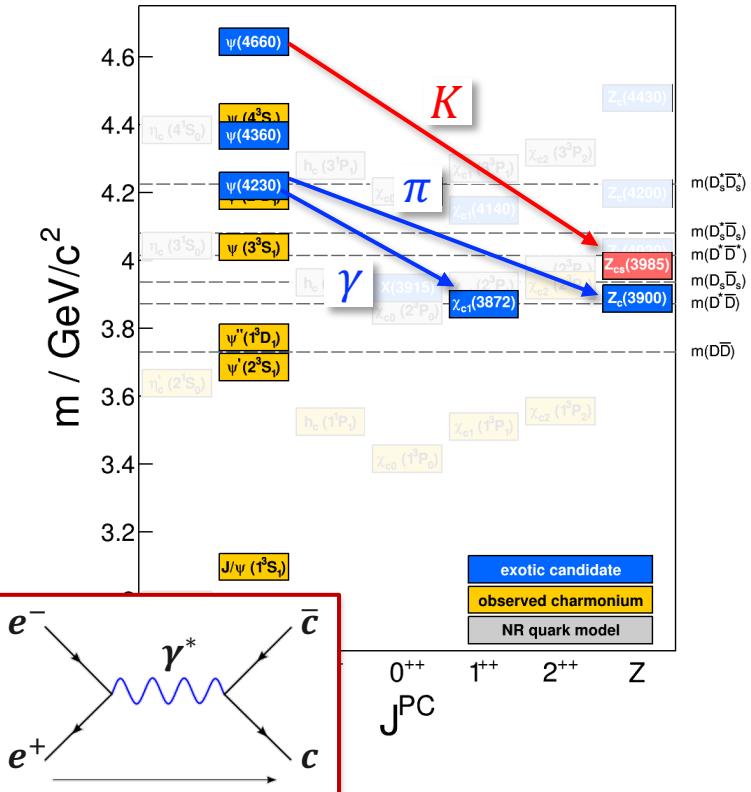


molecular state

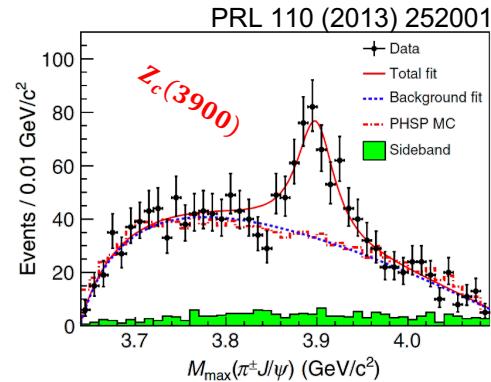
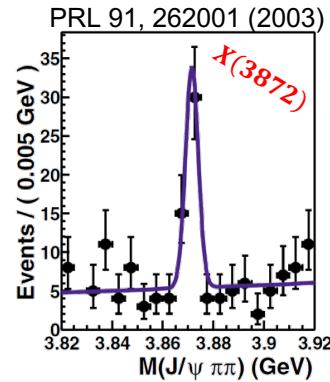


hybrid meson

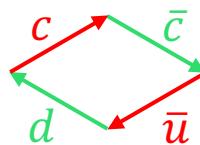
Charmonium-like states



- several unexpected states observed



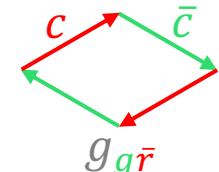
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tetraquark



molecular state



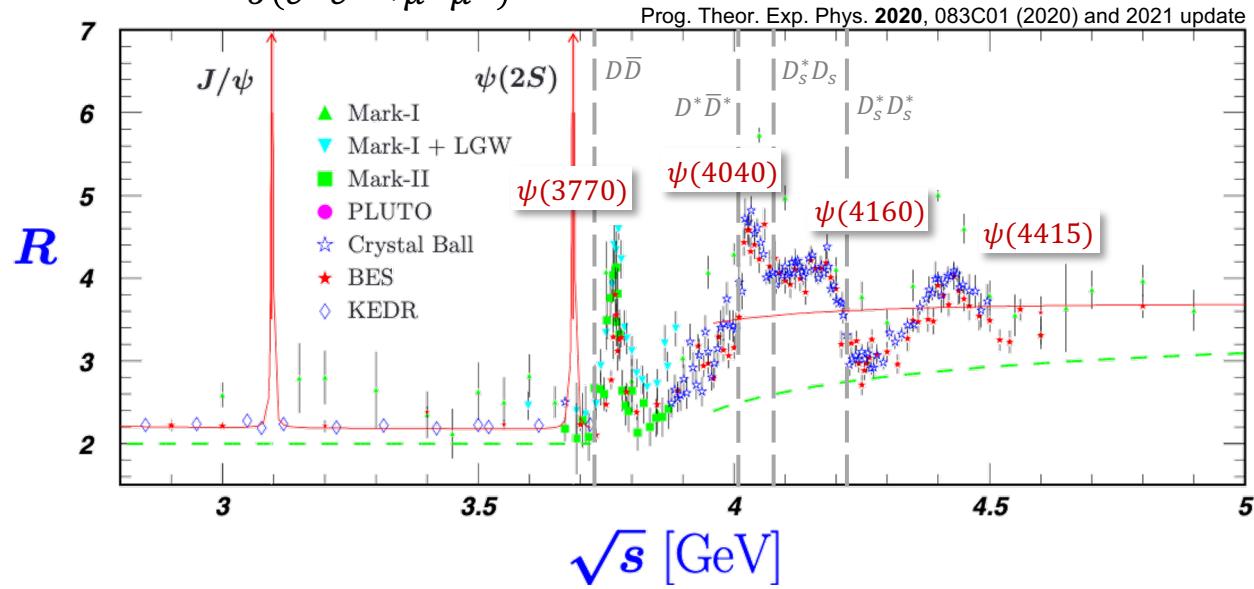
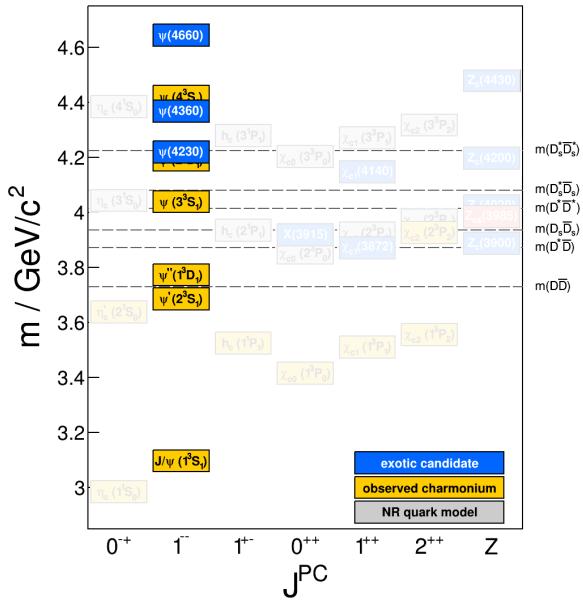
hybrid meson

Vector states



Vector states

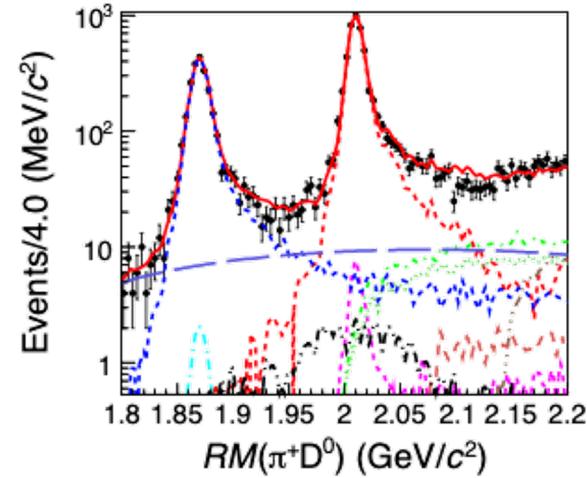
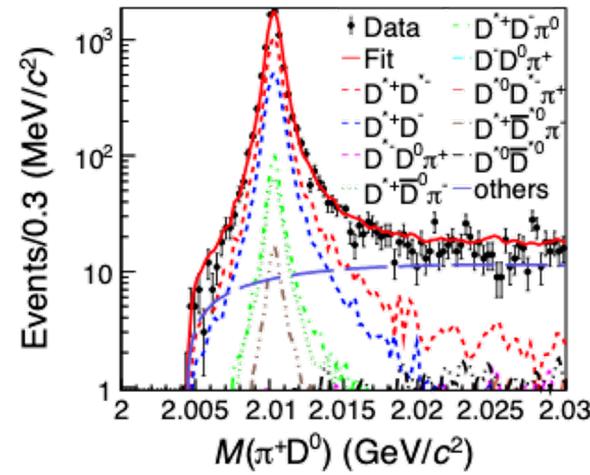
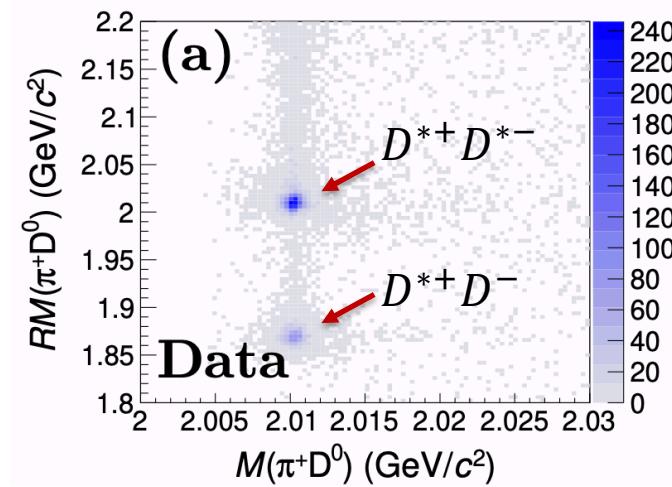
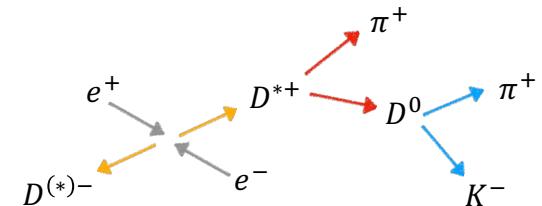
$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$



- 4 conventional $c\bar{c}$ -states above $D\bar{D}$ threshold: $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$
- almost all information on them is from inclusive $e^+e^- \rightarrow \text{hadrons}$

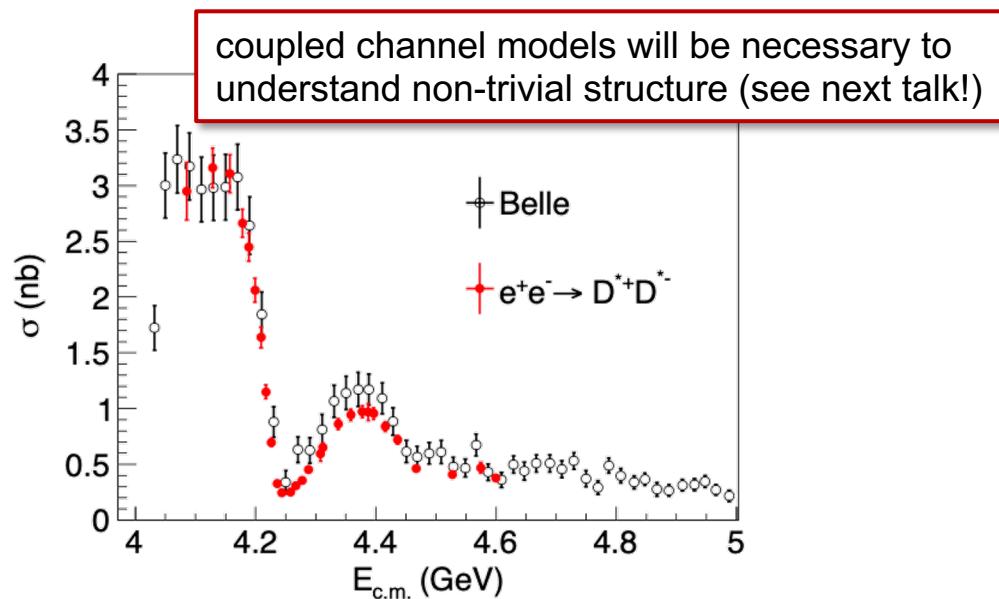
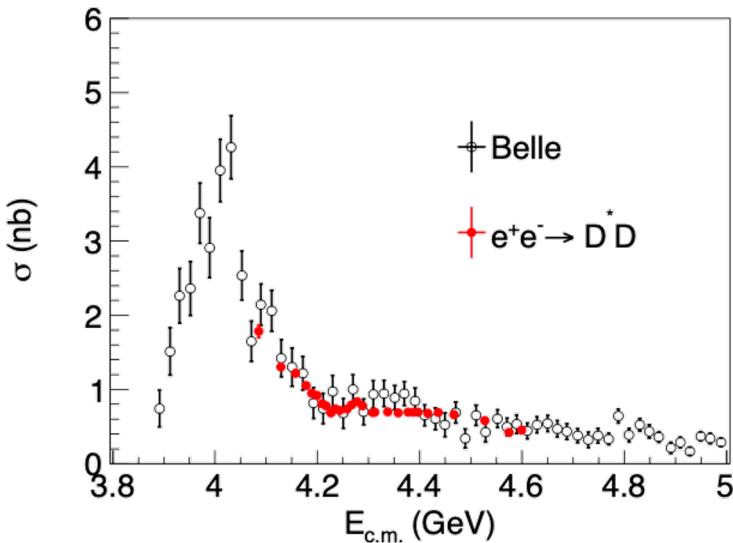
Vector states: Open-charm production

- measurement of $e^+e^- \rightarrow D^{*+}D^-$ and $D^{*+}D^{*-}$
- reconstruct $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$, identify missing $D^{(*)-}$

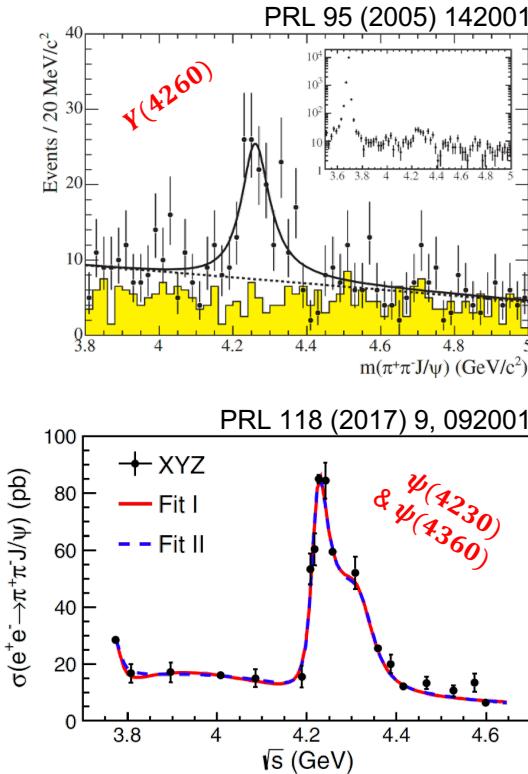


Vector states: Open-charm production

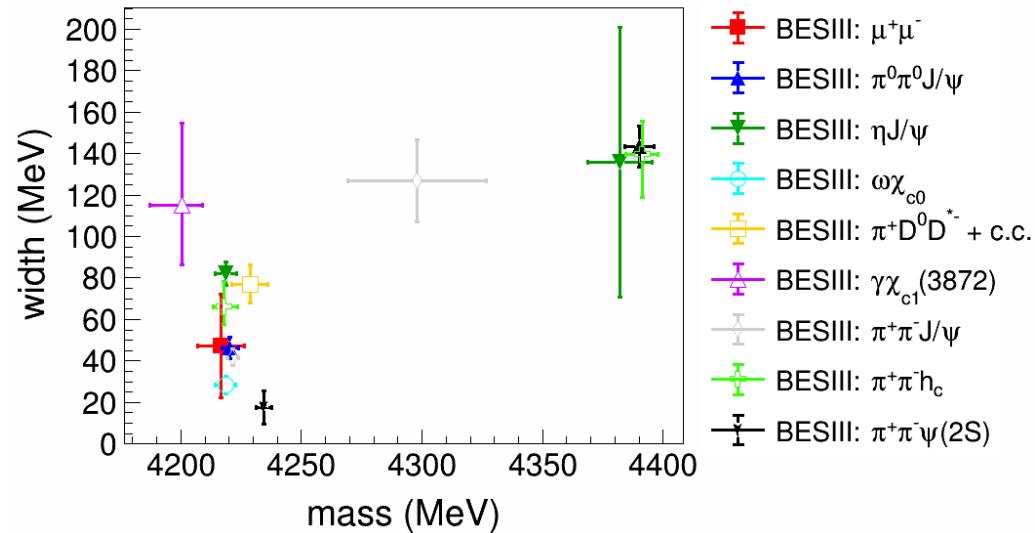
- measurement of $e^+e^- \rightarrow D^{*+}D^-$ and $D^{*+}D^{*-}$
- reconstruct $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$, identify missing $D^{(*)-}$



Vector states: Hidden-charm production



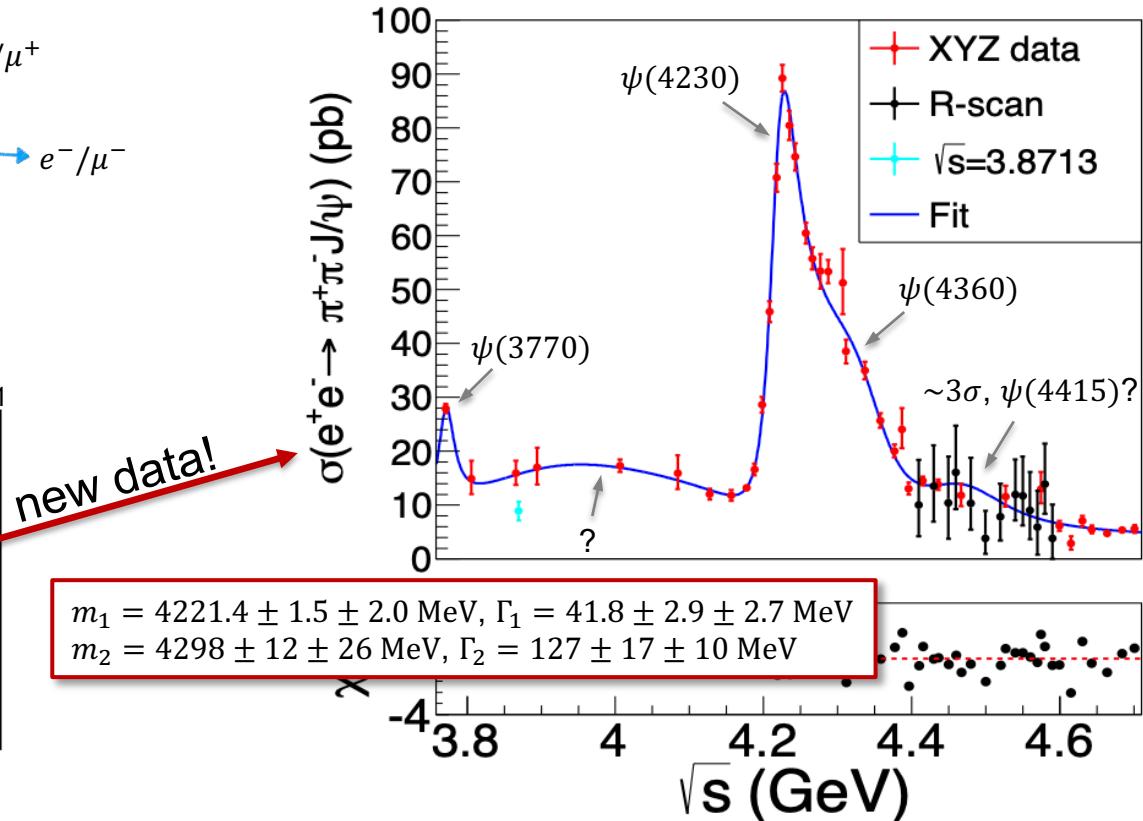
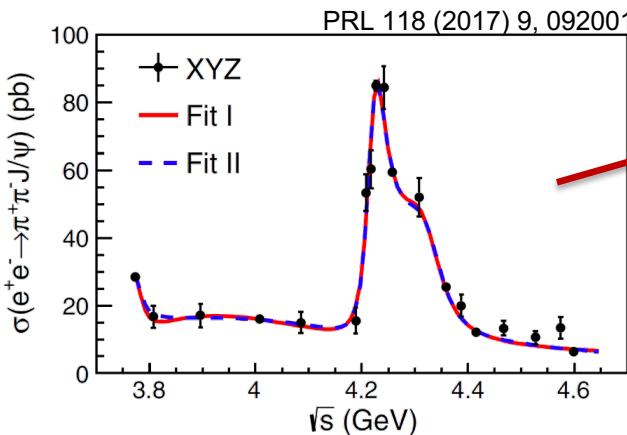
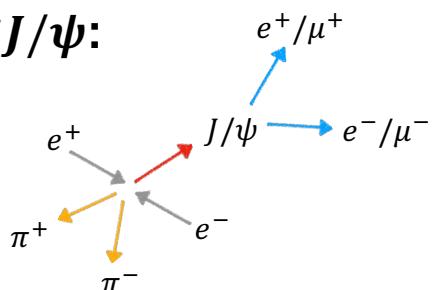
- $\gamma(4260)$ first observed by BaBar in $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-J/\psi$
- we find two structures $\psi(4230)$ & $\psi(4360)$



- different channels show (slightly) different masses and widths

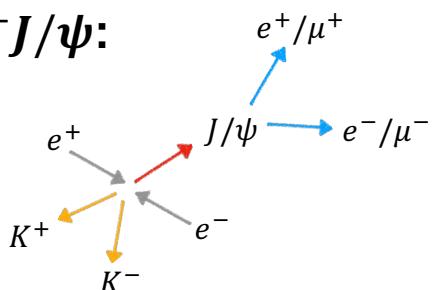
Vector states: Hidden-charm production

- $e^+e^- \rightarrow \pi^+\pi^-J/\psi$:

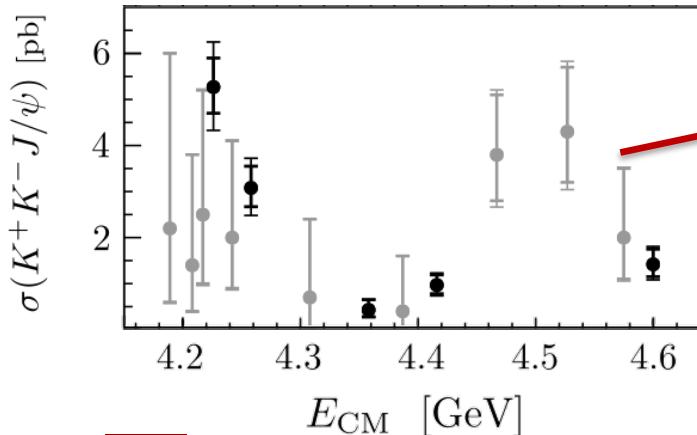


Vector states: Hidden-charm production

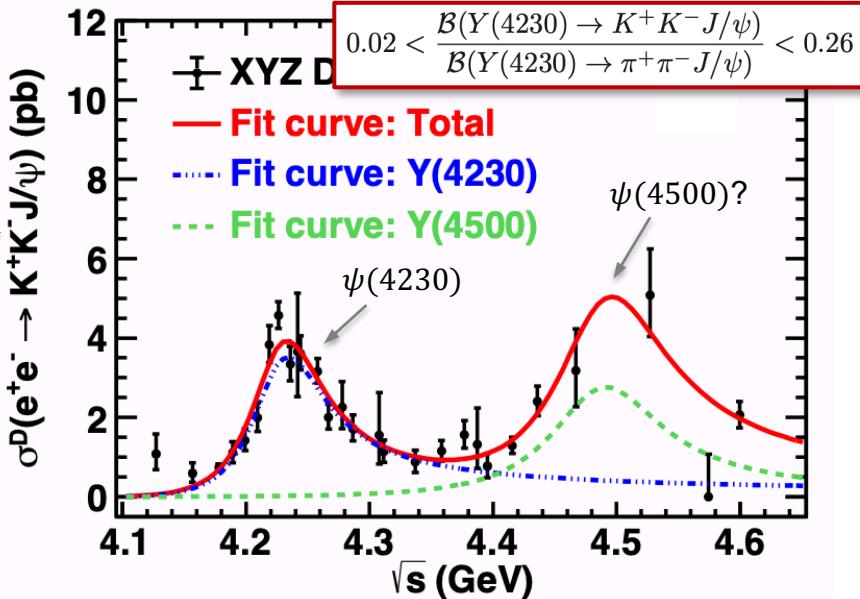
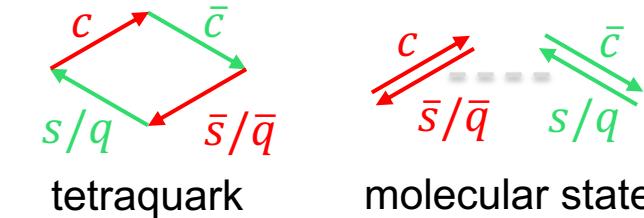
- $e^+ e^- \rightarrow K^+ K^- J/\psi:$



reconstruct $J/\psi \rightarrow l^+ l^-$ and at least one kaon

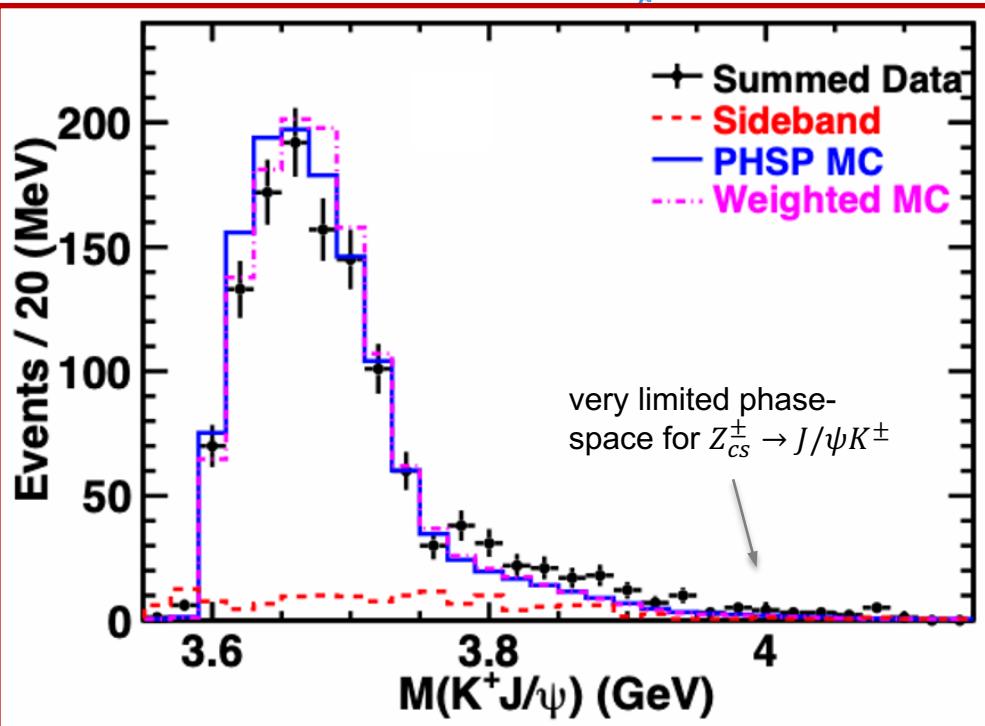


new data!
improved ϵ

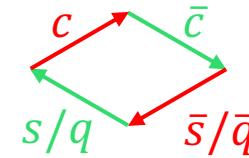
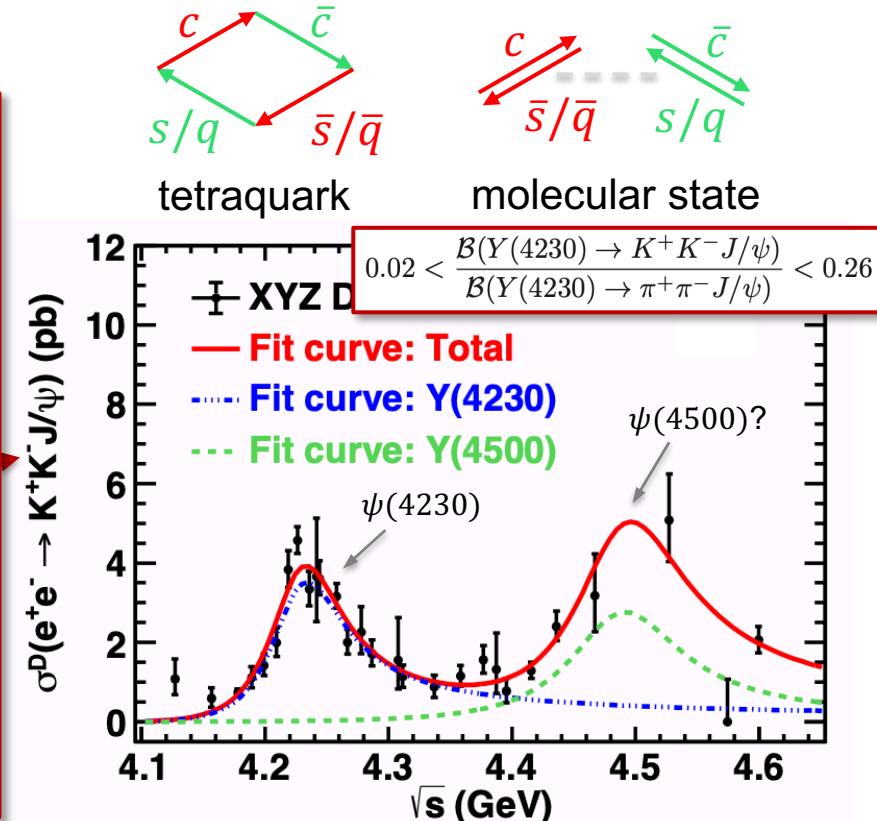


Vector states: Hidden-charm production

- $e^+ e^- \rightarrow K^+ K^- J/\psi:$

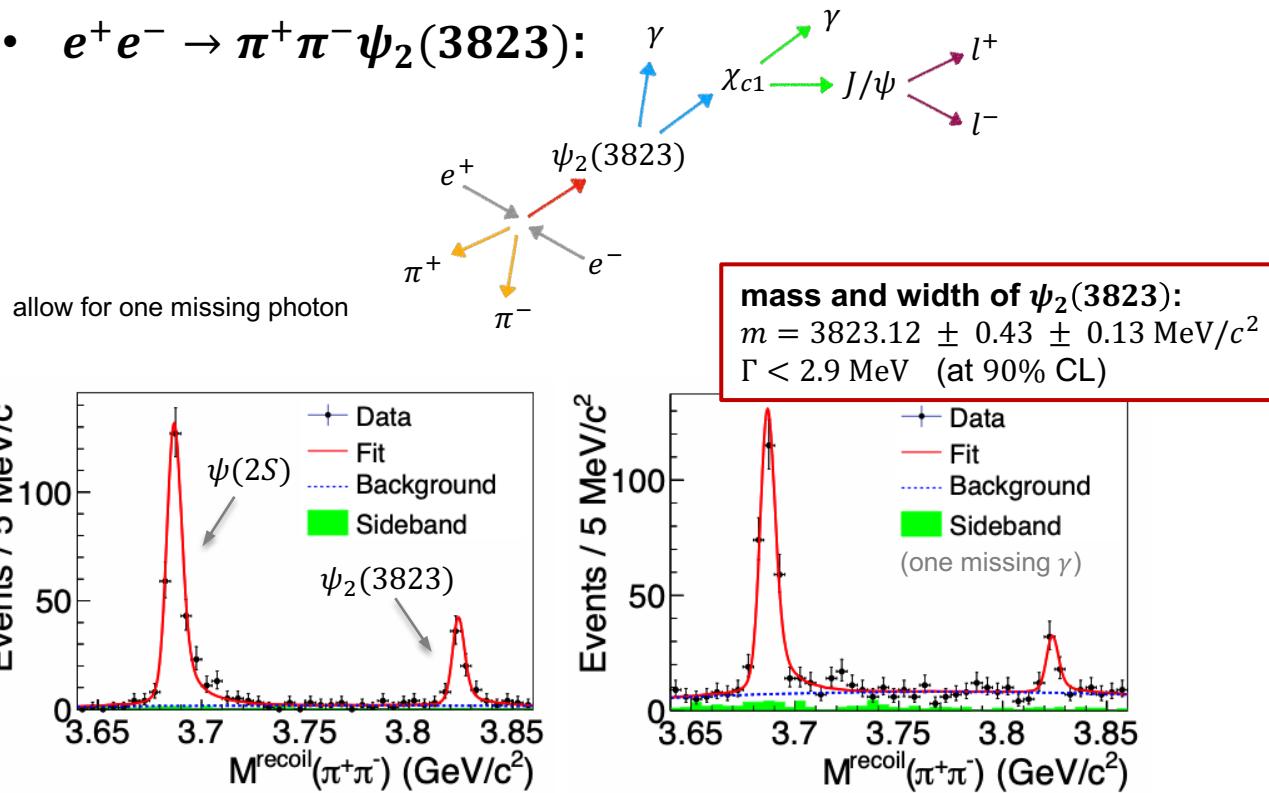


e^+/μ^+



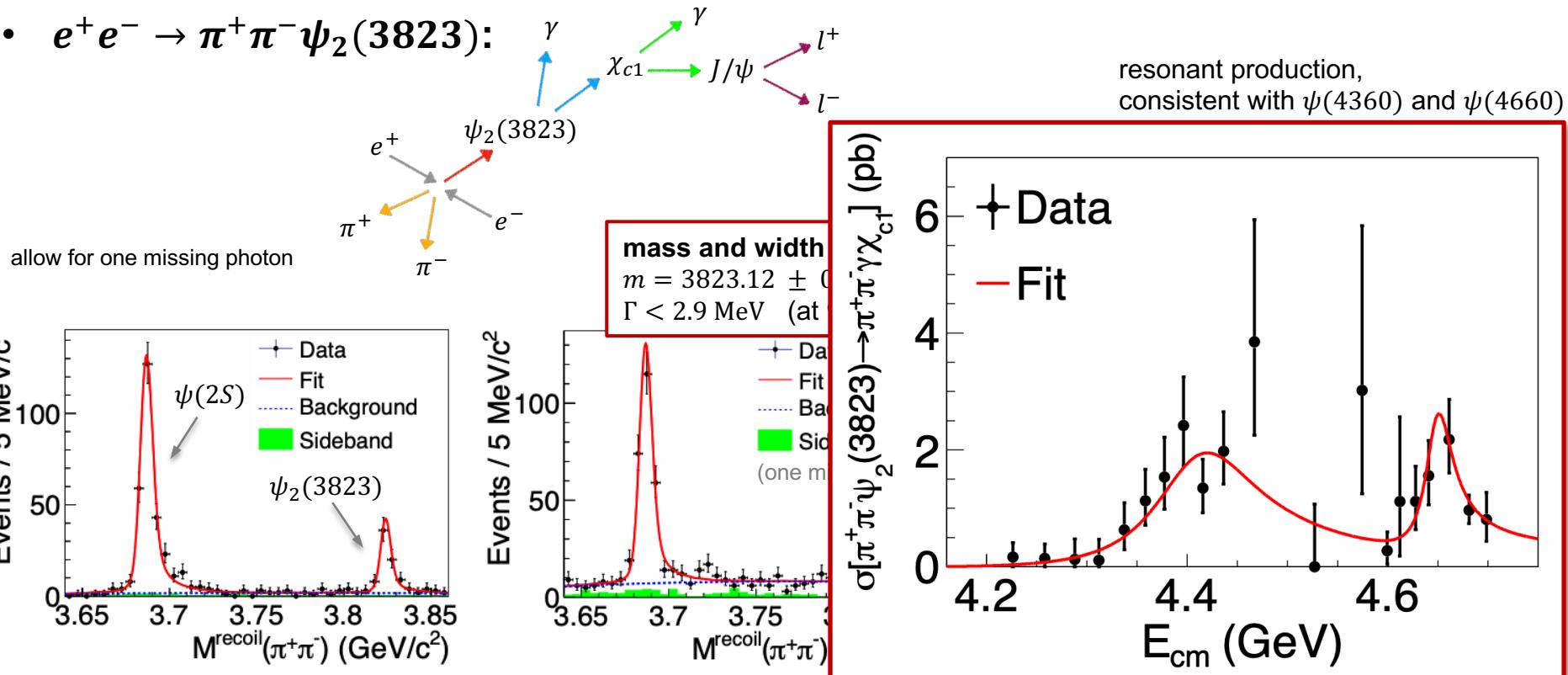
Vector states: Hidden-charm production

- $e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$:



Vector states: Hidden-charm production

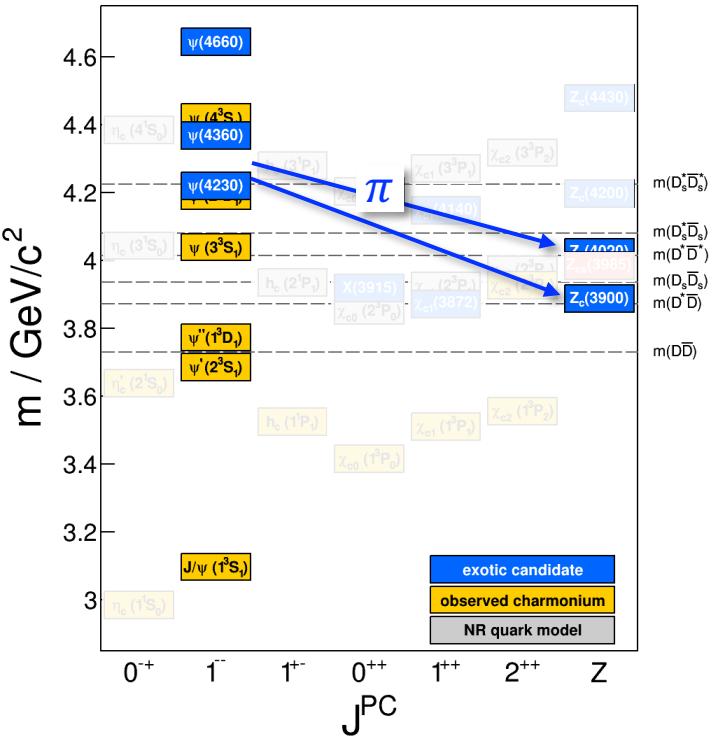
- $e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$:



Charged charmonium-like states

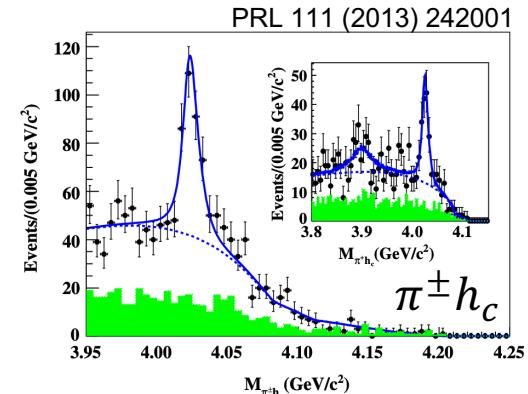
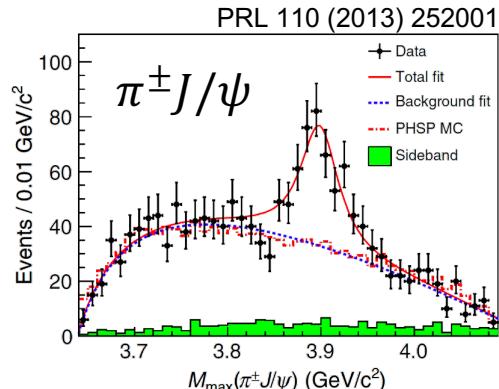


Charged charmonium-like states



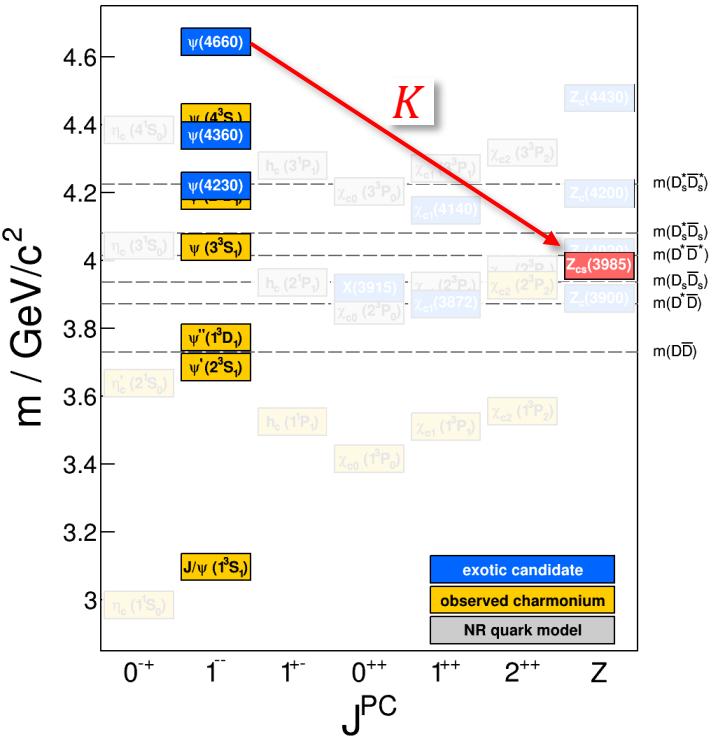
- openly exotic with $I \neq 0$ ($q \neq 0$)

- nature still unclear (tetraquark, molecule, ...)

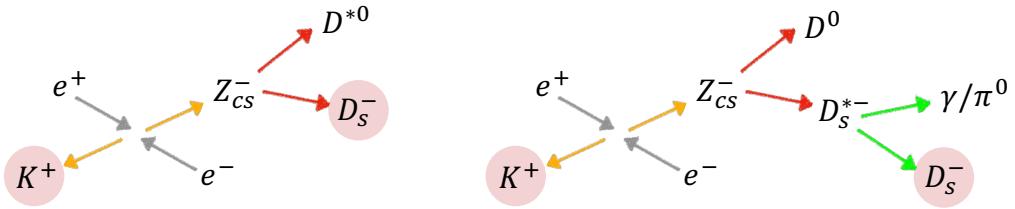


- if genuine resonance, minimal quark content of $c\bar{c}q\bar{q}$
- intriguing connection to $\psi(4230)$

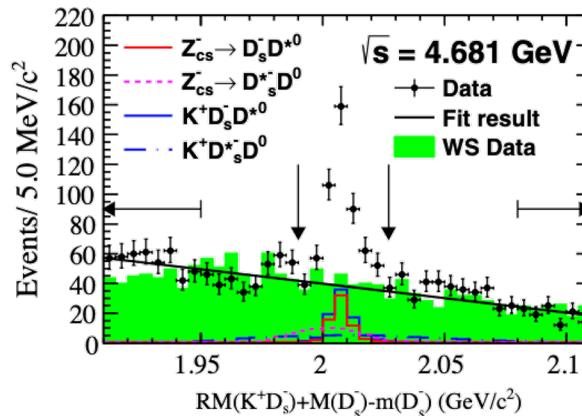
Charged charmonium-like states



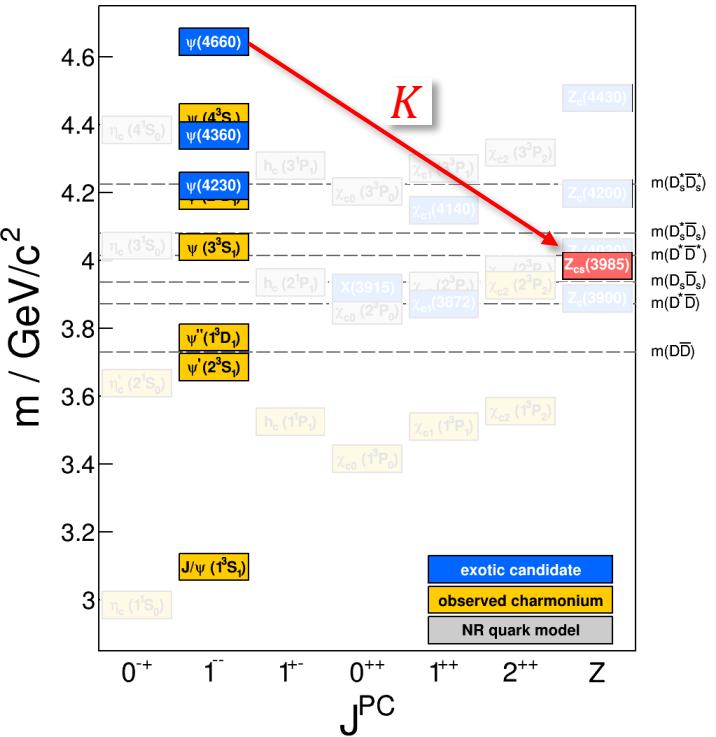
- search for an open-strange $c\bar{c}s\bar{q}$ partner Z_{cs}



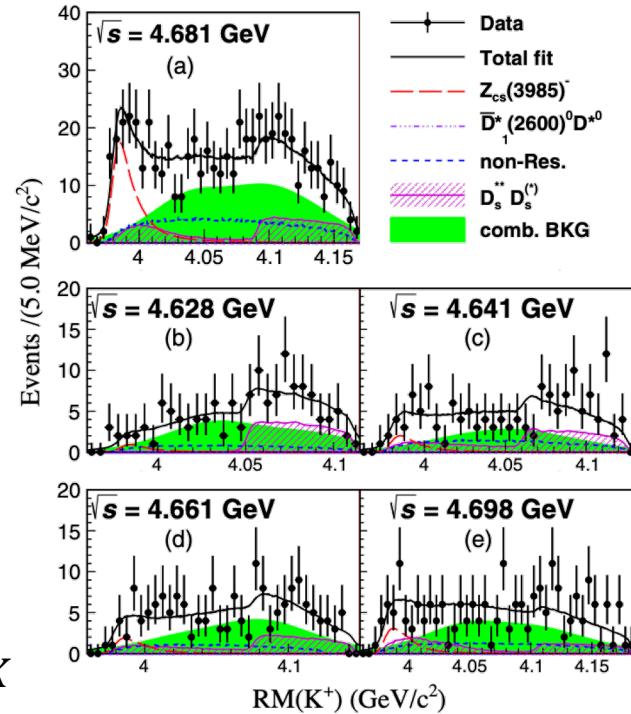
partial reconstruction method: K^+, D_s^-



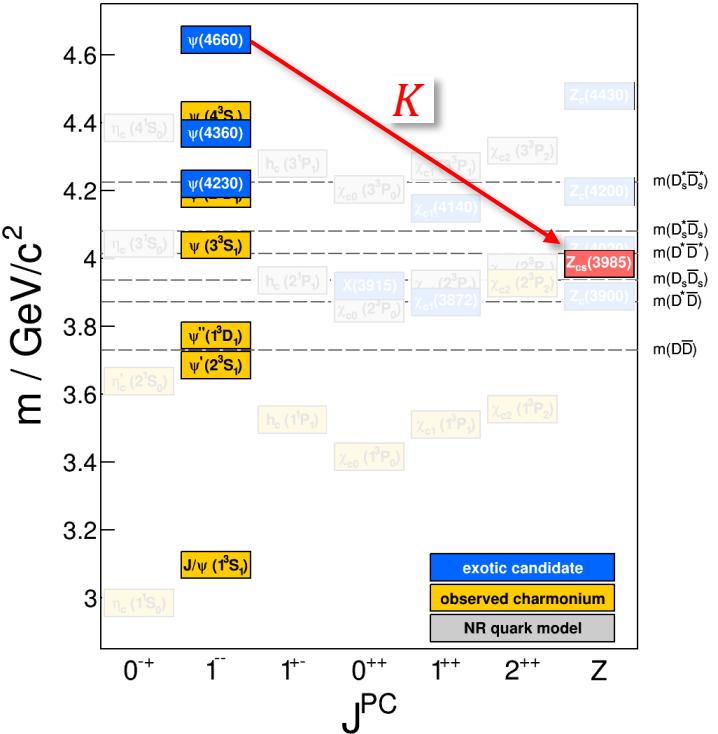
Charged charmonium-like states



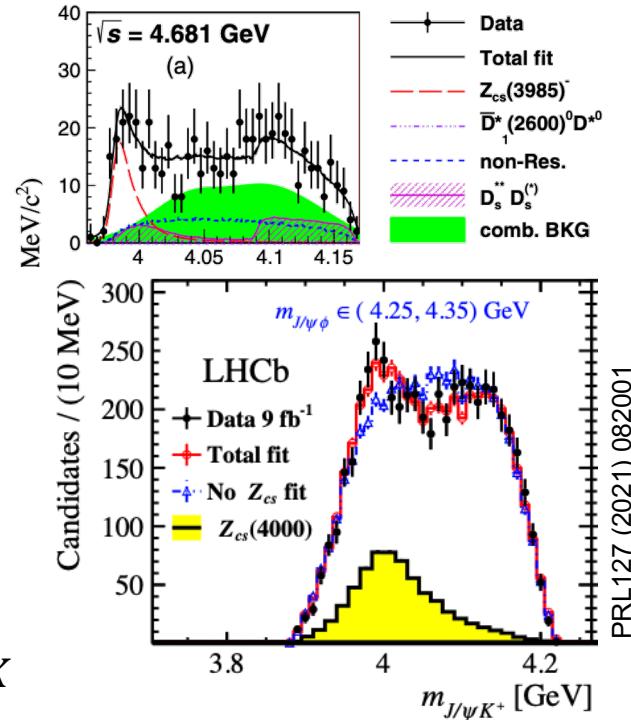
- search for an open-strange $c\bar{c}s\bar{q}$ partner Z_{cs}
- 5.3 σ excess close to threshold for data at $\sqrt{s} = 4.681 \text{ GeV}$
- not explained by $D_S^{**} D_S^{(*)}$ contributions
- coupling to at least one of $D_s^- D^{*0}$ and $D_S^{*-} D^0$
- LHCb sees a much wider structure in $J/\psi K$



Charged charmonium-like states

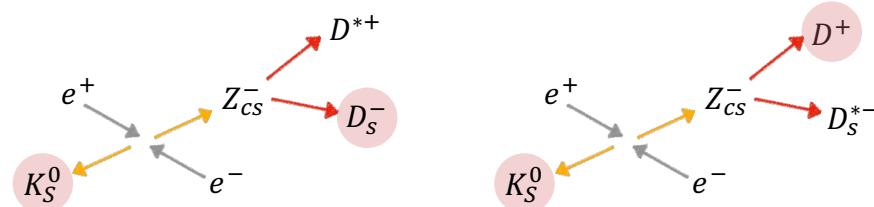


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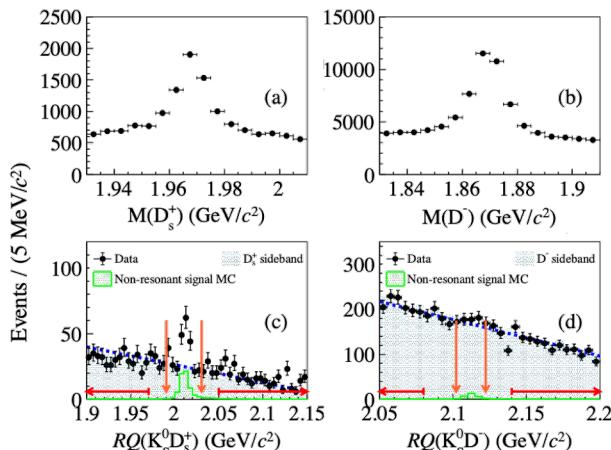


Charged charmonium-like states

- search for Z_{cs}^0 in $e^+e^- \rightarrow K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$

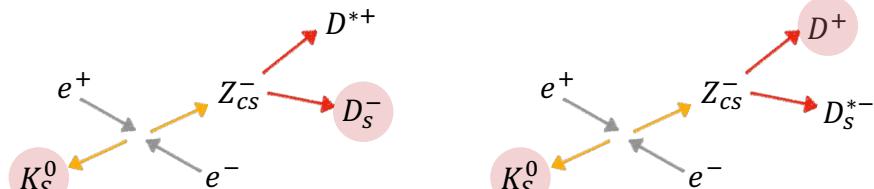


partial reconstruction method: K_S^0 , ground state D_s^-/D^+



Charged charmonium-like states

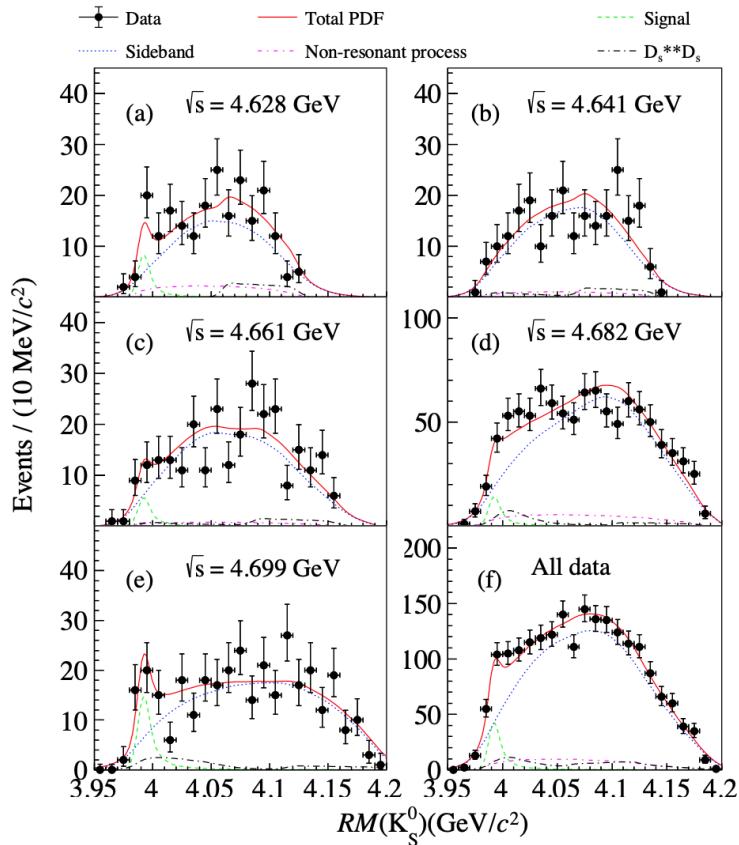
- search for Z_{cs}^0 in $e^+e^- \rightarrow K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$



partial reconstruction method: K_S^0 , ground state D_s^-/D^+

- signal significance of 4.6σ
- mass and width consistent with charged Z_{cs}^\pm , potential isospin-partner

	Mass (MeV/c^2)	Width (MeV)
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$

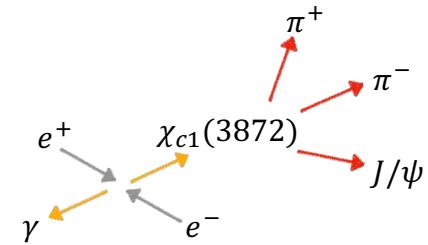
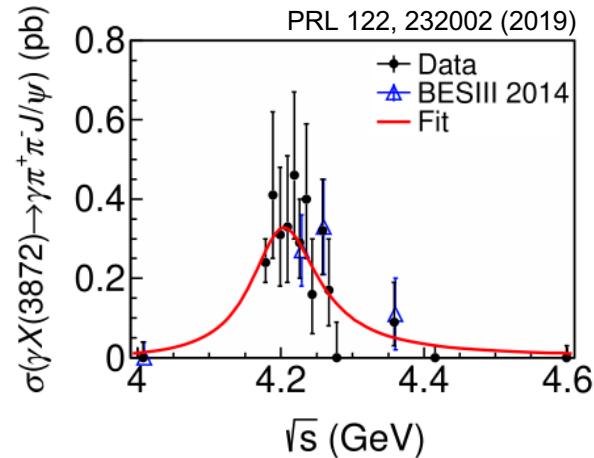
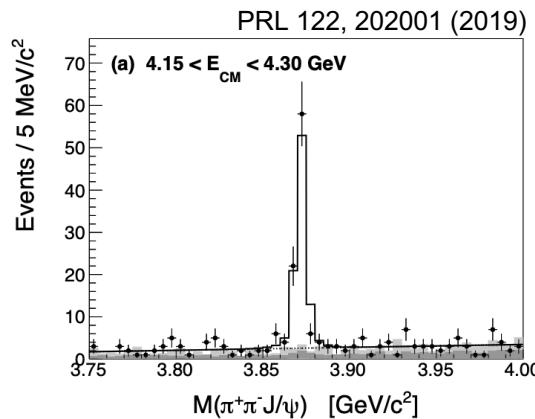


On $\chi_{c1}(3872)$



Production in $e^+e^- \rightarrow \gamma\chi_{c1}(3872)$

- production process established using well known decay $\pi^+\pi^-J/\psi$



- indication of resonant production through $\psi(4230)$
- we can use this clean production to look for new decay modes

Search for $\chi_{c1}(3872) \rightarrow \pi^0 \chi_{c0}$

What is known about $\chi_{c1}(3872)$:

- very close to $D^{*0}\bar{D}^0$ threshold: $m_{D^{*0}D} - m_{\chi_{c1}(3872)} = 0.07 \pm 0.12$ MeV
- very narrow: $\Gamma_{\chi_{c1}(3872)} = 0.96^{+0.19}_{-0.18} \pm 0.21$ MeV LHCb: JHEP08 (2020) 123
- $J^{PC} = 1^{++}$
- large isospin violation ($\chi_{c1}(3872) \rightarrow \rho J/\psi, \omega J/\psi, \pi^0 \chi_{c1}$)
- production in B -decays, hadron collisions and $\psi(4230) \rightarrow \gamma \chi_{c1}(3872)$

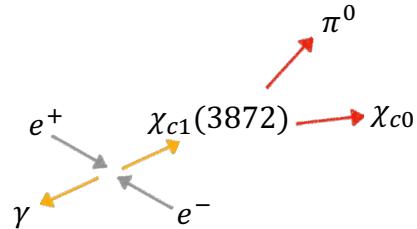
but what is its nature?

→ search for decay modes that are sensitive to internal structure of $\chi_{c1}(3872)$

Ref.	Technique	Interpretation	$\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}$	$\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c1})}$
PRD 77 (2008) 014013	Multipole expansion	Four-quark/molecule	...	2.97
	Multipole expansion	$\chi_{c1}(2P)$	0.0	0.0
PRD 78 (2008) 094019	Effective field theory	$D^0 \bar{D}^{0*}$...	2.84–2.98
	Effective field theory	$D^0 \bar{D}^{0*} + D^+ D^{-*}$	1.3–2.07	1.65–1.77
PRD 79 (2009) 094013	Effective field theory	$D^0 \bar{D}^{0*} + D^+ D^{-*}$...	3.72
PRD 100 (2019) 094025	Effective field theory	$D^0 \bar{D}^{0*} + D^+ D^{-*} + \chi_{c1}(2P)$	0.094	1.15



Search for $\chi_{c1}(3872) \rightarrow \pi^0 \chi_{c0}$



- no signal found, limits currently not conclusive

Ratio	90% C.L. upper limit
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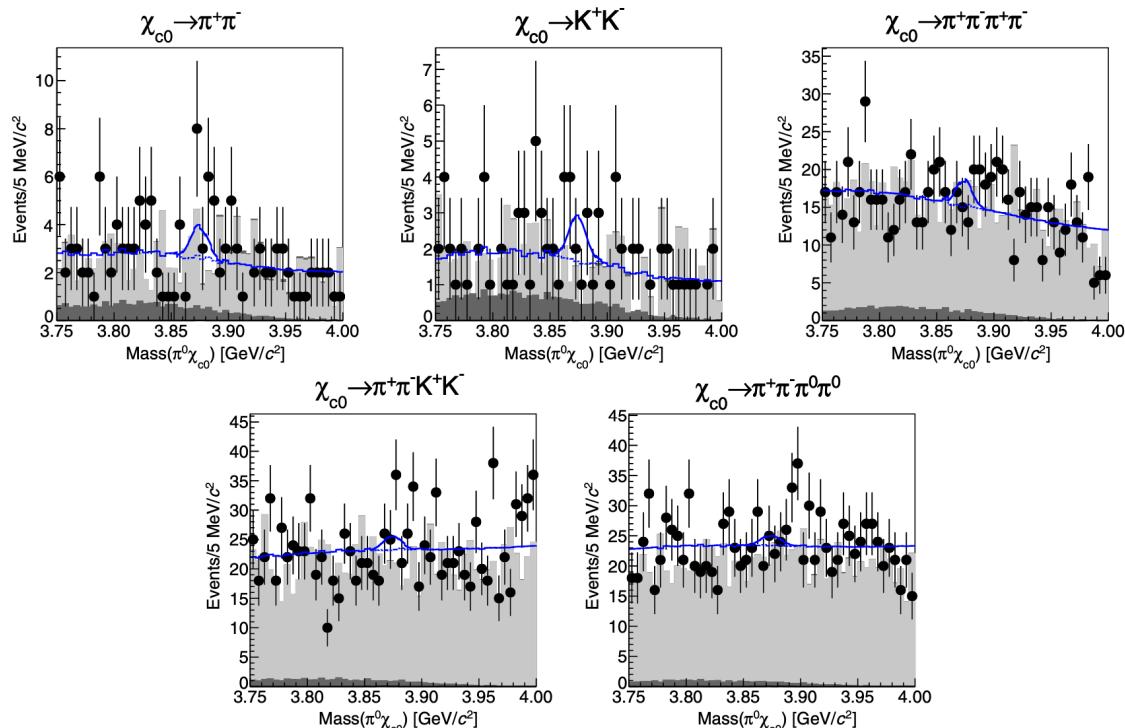
$\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}$	3.6
$\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c1})}$	4.5

- larger datasets in the future
(upgrade to BEPCII)



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PRD 105 (2022) 072009



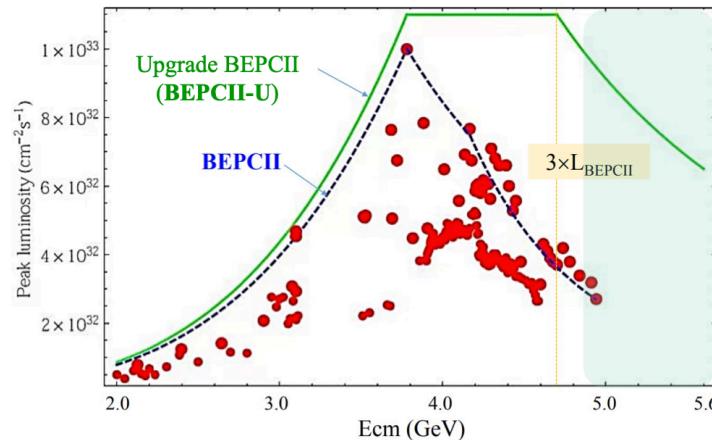
Summary and Outlook

- BESIII is taking data since 2008
- broad physics reach
 - light hadron spectroscopy & decays
 - open charm physics
 - (exotic) charmonia
 - precision measurements (R , TFF, ...)
 - ...
- several new data sets currently being analyzed
 - first exciting results from new J/ψ and XYZ data
 - many analyses in progress, plenty of results to come
- data taking is ongoing
 - new: $2.7 \cdot 10^9 \psi(2S)$, soon: 20 fb^{-1} at the $\psi(3770)$



Summary and Outlook

- BESIII is taking data since 2008
- broad physics reach
 - light hadron spectroscopy & decays
 - open charm physics
 - (exotic) charmonia
 - precision measurements (R , TFF, ...)
 - ...
- several new data sets currently being analyzed
 - first exciting results from new J/ψ and XYZ data
 - many analyses in progress, plenty of results to come
- data taking is ongoing
 - new: $2.7 \cdot 10^9 \psi(2S)$, soon: 20 fb^{-1} at the $\psi(3770)$
- first data at higher c.m. energies
 $4.7 \text{ GeV} < \sqrt{s} < 4.94 \text{ GeV}$ is available
- further upgrade in energy (5.6 GeV) and luminosity (BEPCII-U) coming





Thank you for
your attention!



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