XYZ Particles at BESIII

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On behalf of **The BESIII Collaboration**

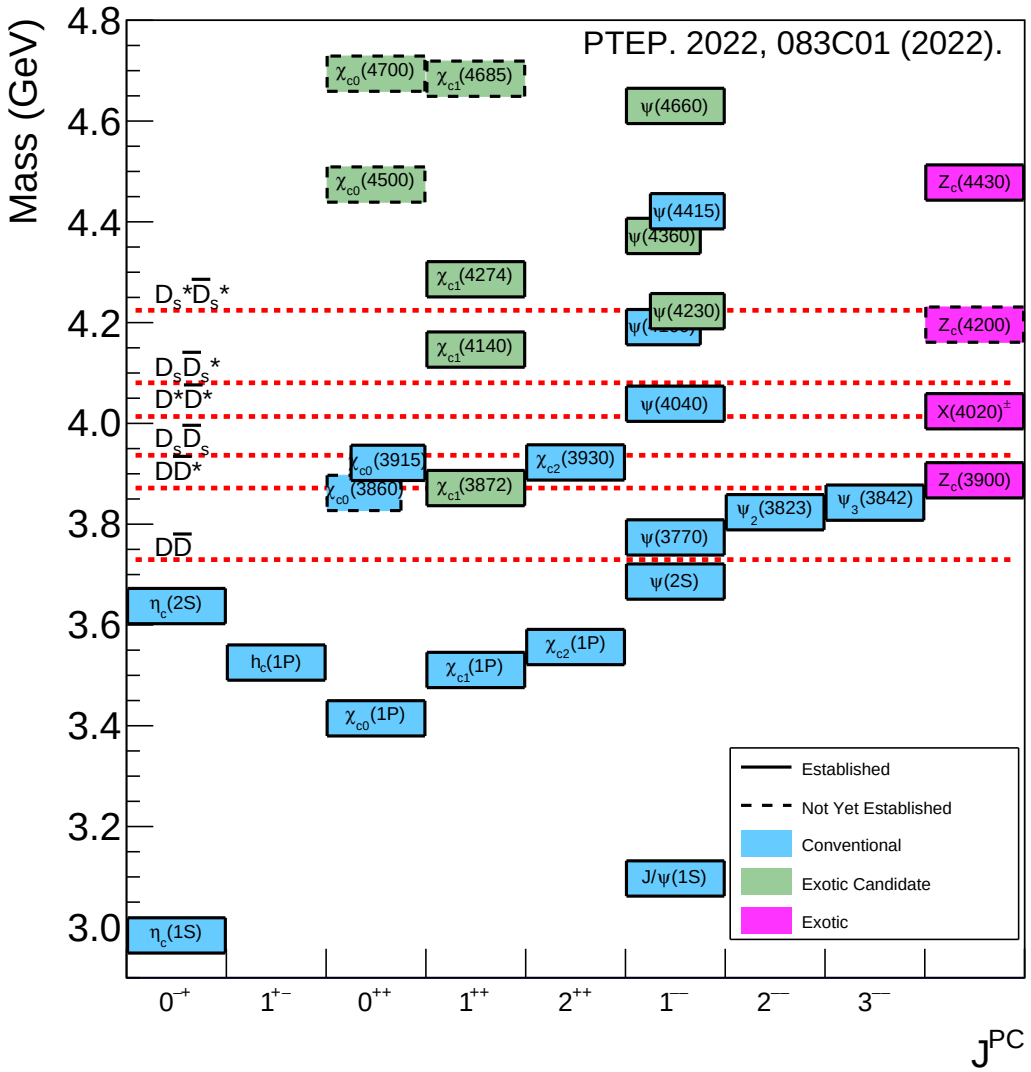
The 9th International Conference on Quarks and Nuclear Physics

Outline

- Overview of charmonium spectrum
- BESIII and XYZ physics
- Recent results of note:
  - $e^+e^- \to K^+K^- J/\psi$
  - $e^+e^- \to \pi^+\pi^- \psi_2(3823)$
  - $e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^-$
  - $X(3872) \to \pi^0 \chi_{c0}$ and $X(3872) \to \pi\pi\chi_{c0}$
- XYZ outlook at BESIII

The Charmonium System

List of Charmonium States



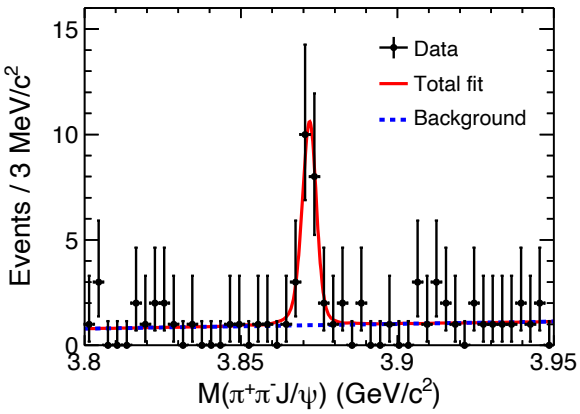
- Conventional charmonium ($c\bar{c}$) well-described by Cornell potential
- Some observed states have strange properties
- Others have properties totally incompatible with $c\bar{c}$ interpretation
- Exotic candidates occur near open charm thresholds

The BESIII Experiment

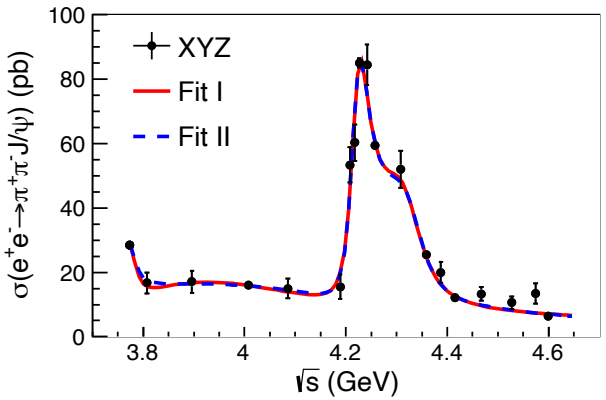
arXiv:2204.08943

- BESIII runs at BEPCII accelerator in Beijing
- BEPCII is symmetric e^+e^- collider
- Data taken over wide range of energies include:
  - 10 billion J/ψ events for light hadron physics
  - 2.7 billion $\psi(2S)$ events for charmonium physics
  - 3 fb^{-1} of $\psi(3770)$ data for charm physics
- 23 fb^{-1} of targeted samples above 4 GeV for XYZ physics
  - Can produce the $Y(4230)$ directly
  - States produced nearly at rest with low backgrounds
  - Data at wide array of $\sqrt{s}$ allows cross section measurement

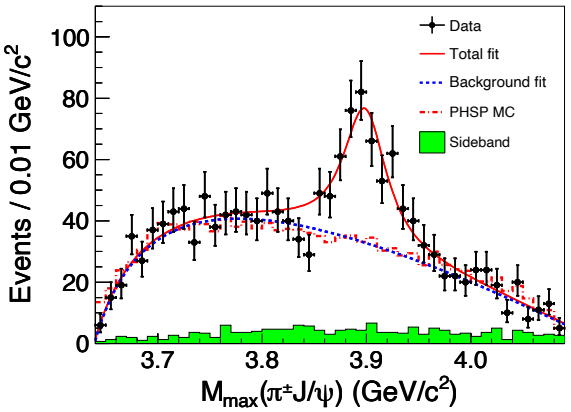
History of XYZ Physics at BESIII



$e^+e^- \to \gamma \boldsymbol{X(3872)}$
where
$X(3872) \to \pi^+\pi^- J/\psi$
PRL 112, 092001



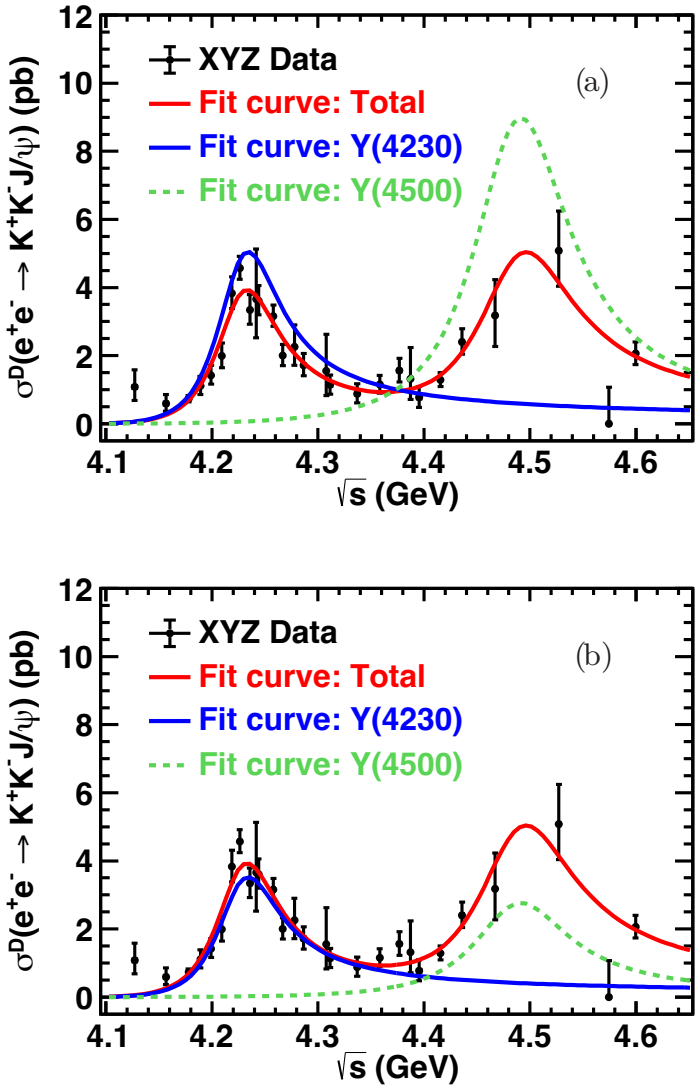
$e^+e^- \to \pi^+\pi^- J/\psi$
resolved into
$\boldsymbol{Y(4230)}$ **and** $\boldsymbol{Y(4360)}$
PRL 118, 092001



$e^+e^- \to \pi^\pm \boldsymbol{Z_c(3900)}^\mp$
where
$Z_c(3900)^\mp \to \pi^\mp J/\psi$
PRL 110, 252001

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

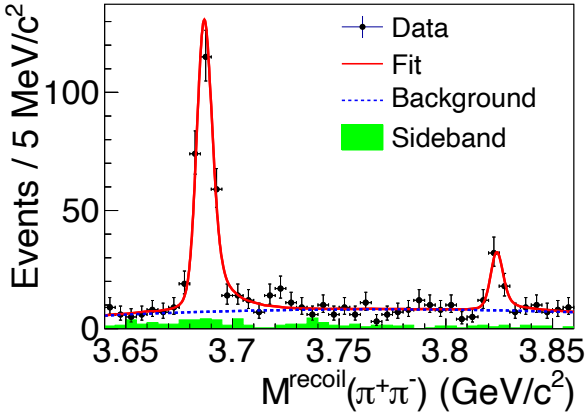
arXiv:2204.07800



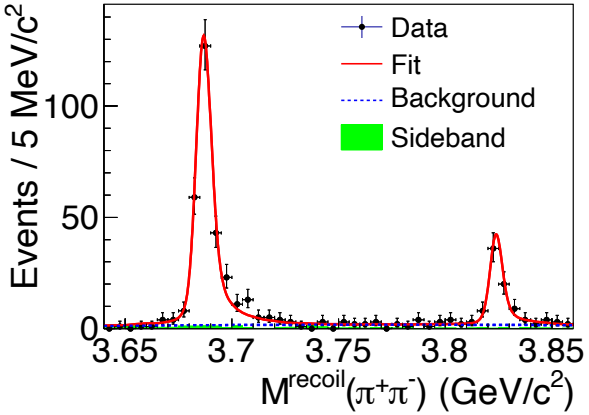
- Refined measurement of $Y(4230) \to K^+K^-J/\psi$ may indicate strange quark content of $Y(4230)$
- First observation of $Y(4230) \to K^+K^-J/\psi$
- First observation of resonance-like structure $Y(4500)$ at 8σ
  - Conventional $c\bar{c}$ predicted in 4489–4529 MeV
  - Heavy-antiheavy hadronic molecule predicted in 4483–4503 MeV
  - Exotic $c\bar{c}s\bar{s}$ predicted in 4350–4550 MeV

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

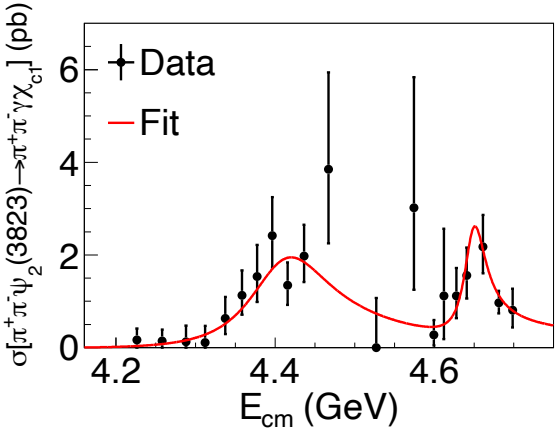
arXiv:2203.05815



(a) Single-photon yield



(b) Multi-photon yield



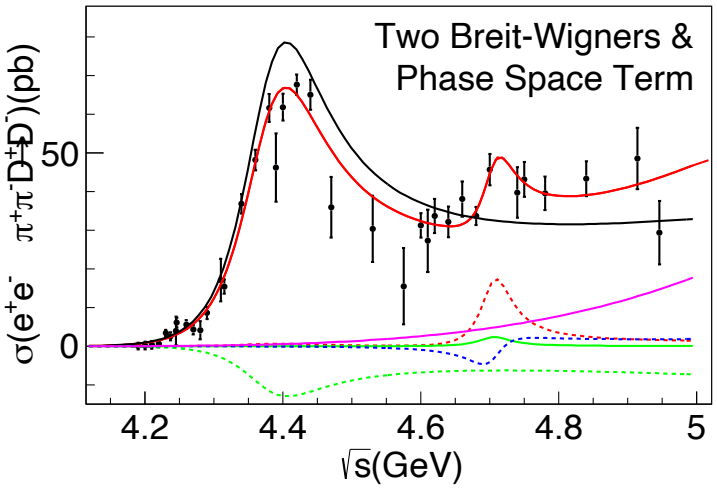
(c) Cross section

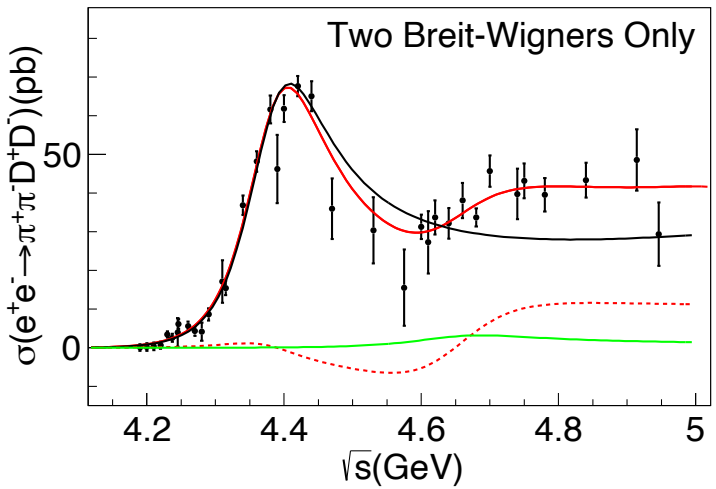
- $\psi_2(3823)$ coupling to Y states may indicate internal structure
- First significant observation of resonance structures in lineshape
  - May correspond to $Y(4360)$ and $Y(4660)$

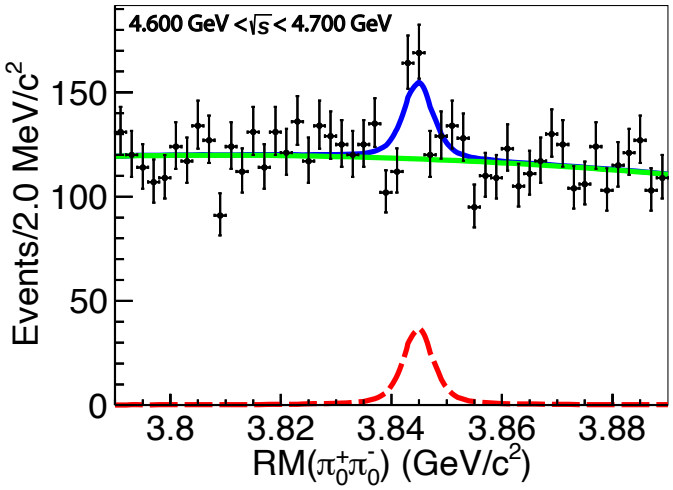
$M[\psi_2(3823)]$	$3823.12 \pm 0.43 \pm 0.13$ MeV$/c^2$	13σ
$\Gamma[\psi_2(3823)]$	< 2.9 MeV	90% CL
$\frac{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c2}]}{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c1}]}$	< 0.51	90% CL

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

arXiv:2208.00099

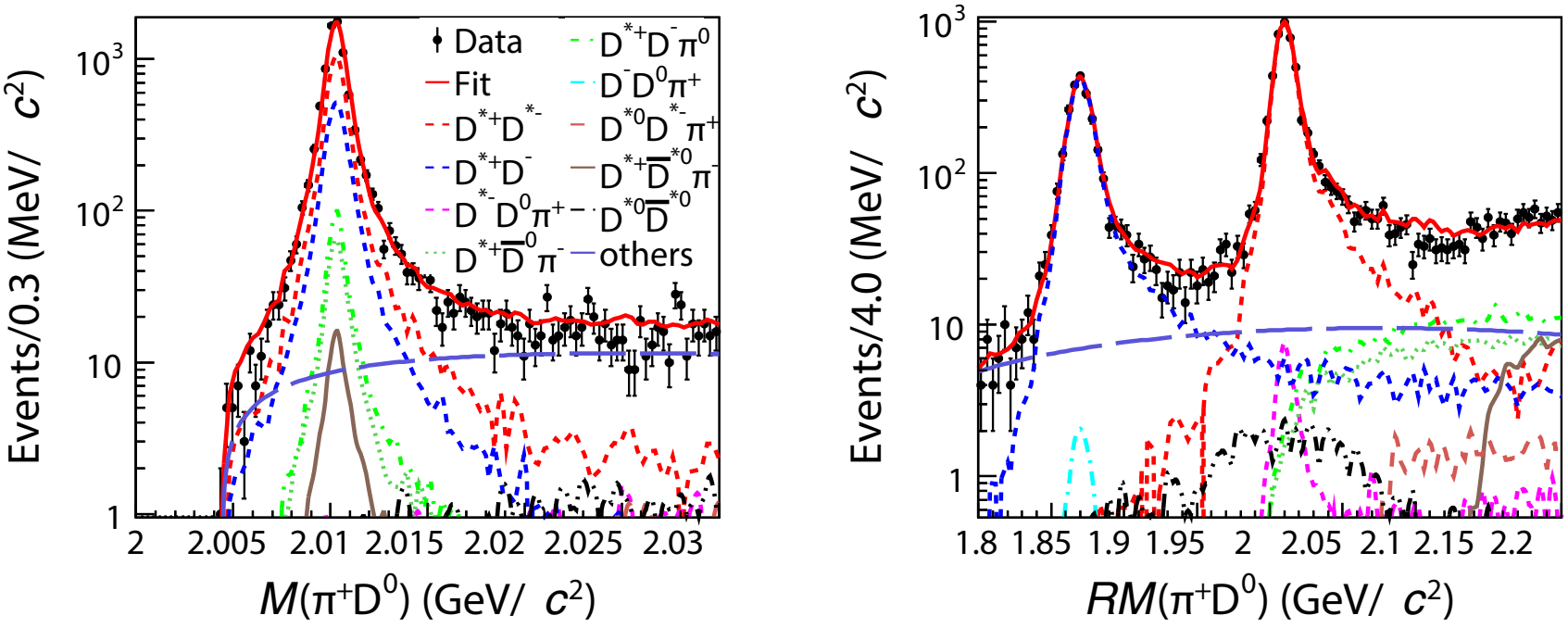






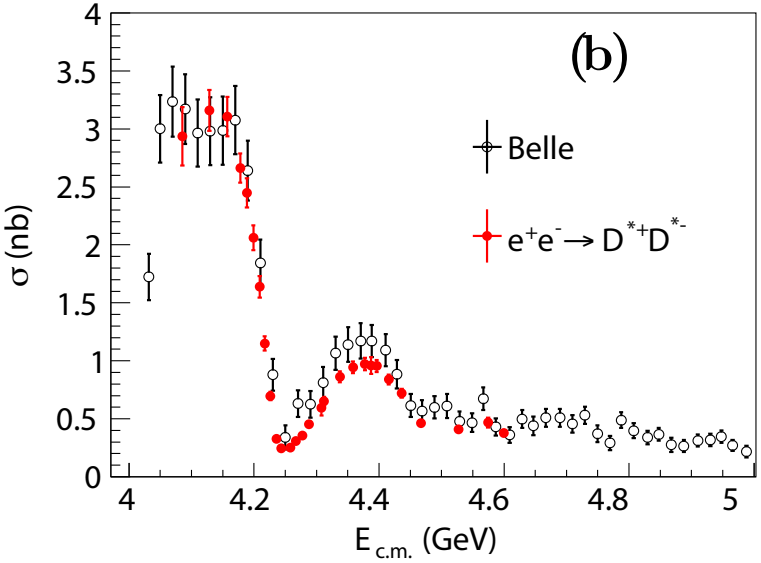
- Measured cross section for $\sqrt{s}$ in 4.190 to 4.946 GeV
- Observed resonant structure consistent with $Y(4390)$
- Evidence at 4.2σ for $X(3842)$ in recoil mass of $\pi^+\pi^-$
  - $X(3842)$, or $\psi_3(3842)$, is spin-3 D-wave charmonium state

$e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^-$ 10.1007/JHEP05(2022)155

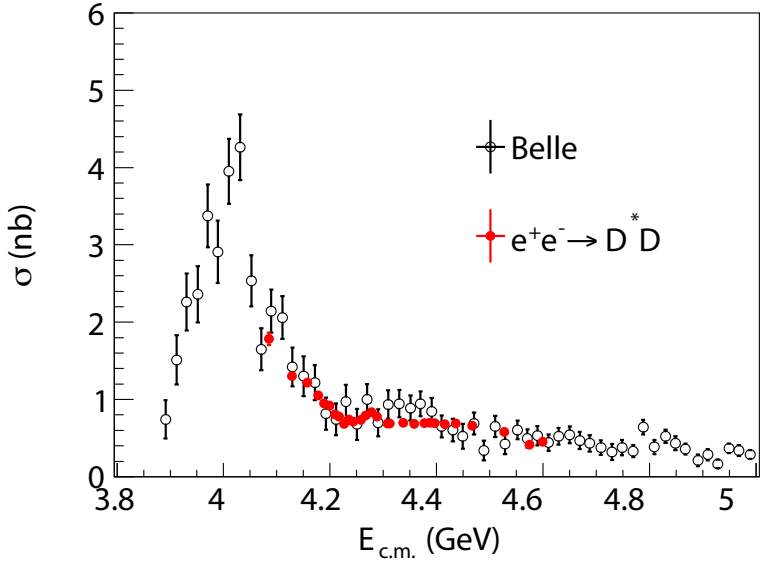


- Goal: measure cross sections for $\sqrt{s}$ between 4.085 and 4.600 GeV
- Yields determined by 2D fit to $M(\pi^+D)$ vs. $M_{\text{recoil}}(\pi^+D)$
- Projections above given for $\sqrt{s} = 4.416\,\text{GeV}$

$e^+e^- \to D^{*+}D^{*-}$ and $e^+e^- \to D^{*+}D^-$ 10.1007/JHEP05(2022)155



(a) $e^+e^- \to D^{*+}D^{*-}$

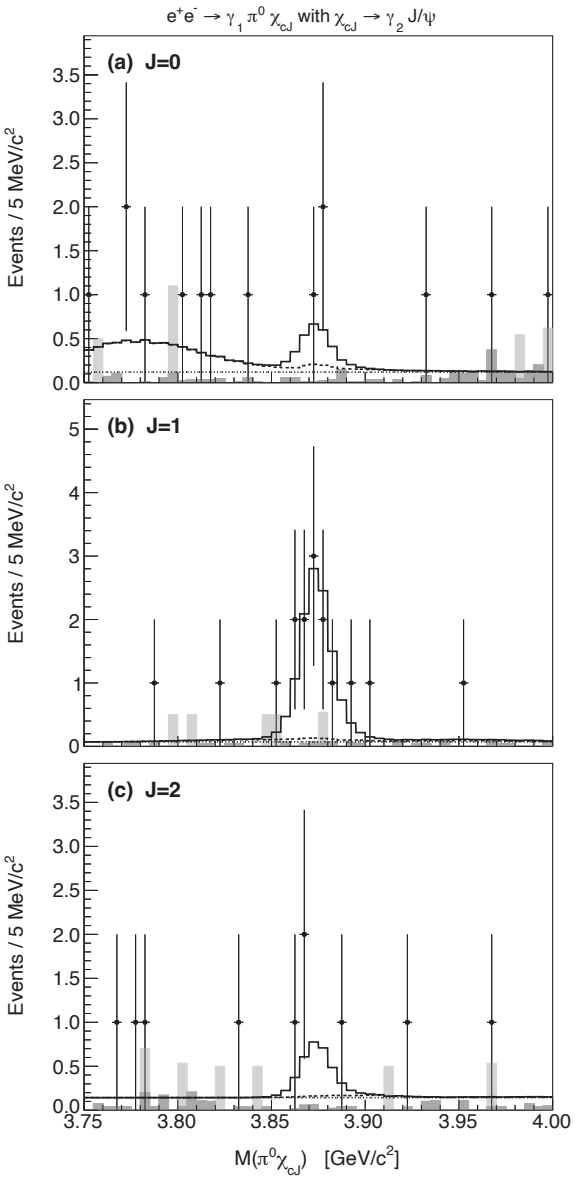


(b) $e^+e^- \to D^{*+}D^-$

- Results consistent with but more precise than Belle, BaBar, CLEO
- Useful for future coupled channel analyses
  - Could suggest interpretation for $Y(4230)$

$X(3872) \to \pi^0 \chi_{cJ}$

10.1103/PhysRevLett.122.202001



- In 2019, first observation of $X(3872) \to \pi^0 \chi_{c1}$ at 5.2σ
- Not sensitive to χ_{c0}, χ_{c2}; upper limits placed
- Isospin violating decay not expected in conventional $c\bar{c}$
- Measurement supports four-quark hypothesis

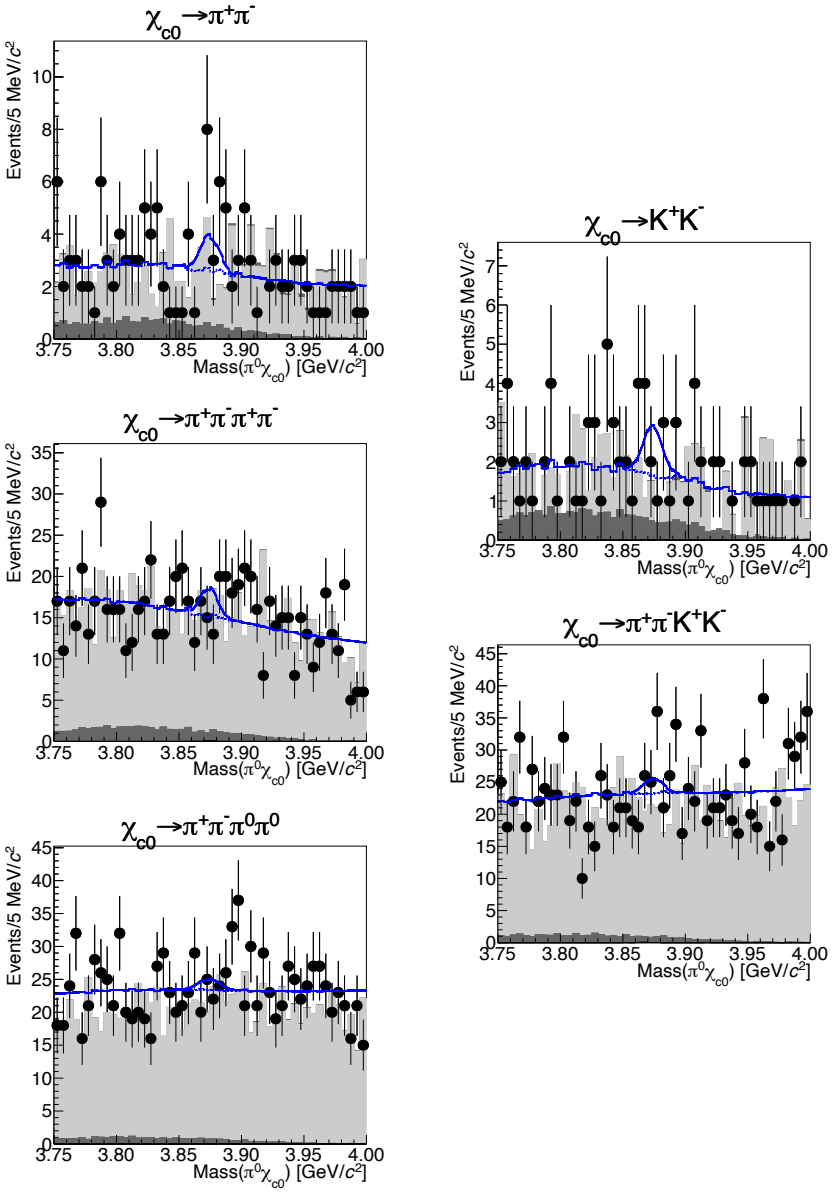
$$\frac{\mathcal{B}[X(3872) \to \pi^0 \chi_{c0}]}{\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]} < 19$$

$$\frac{\mathcal{B}[X(3872) \to \pi^0 \chi_{c1}]}{\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]} = 0.88^{+0.33}_{-0.27} \pm 0.10$$

$$\frac{\mathcal{B}[X(3872) \to \pi^0 \chi_{c2}]}{\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]} < 1.1$$

$X(3872) \to \pi^0\chi_{c0}$ and $X(3872) \to \pi\pi\chi_{c0}$

10.1103/PhysRevD.105.072009

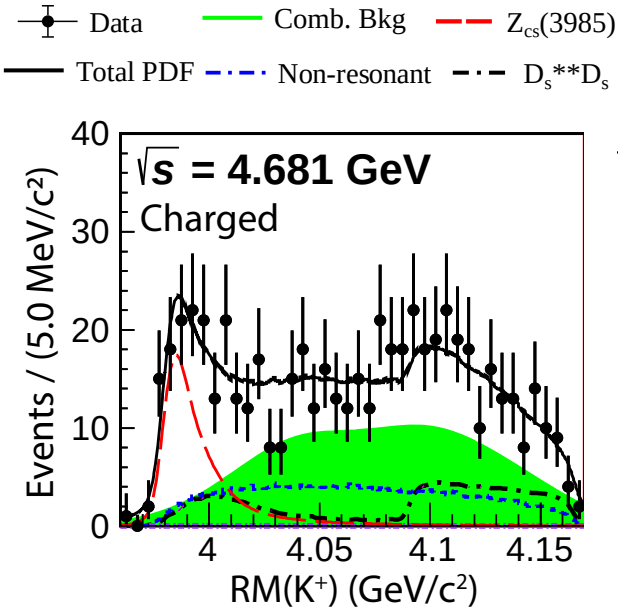


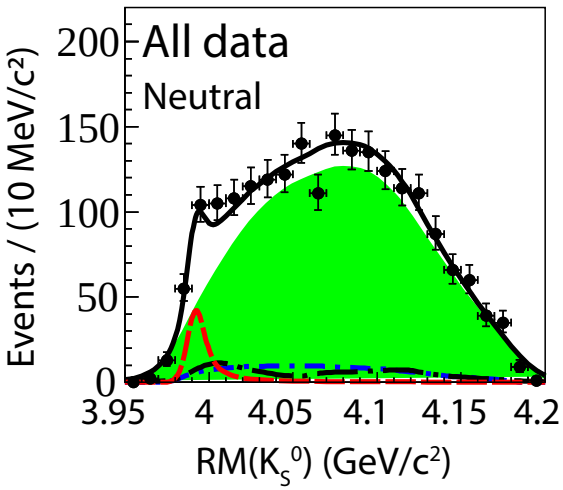
	90% CL UL
$\mathbf{\frac{\mathcal{B}[X(3872)\to\pi^0\chi_{c0}]}{\mathcal{B}[X(3872)\to\pi^0\chi_{c1}]}}$	**4.5**
$\frac{\mathcal{B}[X(3872)\to\pi^0\chi_{c0}]}{\mathcal{B}[X(3872)\to\pi^+\pi^-J/\psi]}$	3.6
$\frac{\mathcal{B}[X(3872)\to\pi^0\pi^0\chi_{c0}]}{\mathcal{B}[X(3872)\to\pi^+\pi^-J/\psi]}$	1.7
$\frac{\mathcal{B}[X(3872)\to\pi^+\pi^-\chi_{c0}]}{\mathcal{B}[X(3872)\to\pi^+\pi^-J/\psi]}$	0.56

- Only expect $X(3872) \to \pi^0\chi_{c0}$ if $X(3872)$ has four-quark component
- Upper limits placed on $X(3872) \to \pi(\pi)\chi_{c0}$
- Upper limits consistent with conventional, four quark, and superposition state

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

arXiv:2204.13703





- Charged structure $Z_{cs}(3985)^+$ first observed in 10.1103/PhysRevLett.126.102001
- Evidence for neutral isospin partner $Z_{cs}(3985)^0$ found at 4.6σ
- Z_{cs} states predicted as $c\bar{c}s\bar{q}$

	Mass (MeV/c^2)	Width (MeV)
$Z_{cs}(3985)^+$	$3982.5\,^{+1.8}_{-2.6} \pm 2.1$	$12.8\,^{+5.3}_{-4.4} \pm 3.0$
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7\,^{+4.1}_{-3.8} \pm 4.3$

Summary and Outlook

- Several significant contributions to XYZ physics
- Many new vector results including observation of $Y(4500)$
- Search for new decay modes of $X(3872)$ through χ_{c0}
- BESIII plans to operate for up to 10 more years
- Upgrades planned for 2024
  - Increase center of mass energy up to 5.6 GeV $\rightarrow$ access new thresholds!
  - Increase luminosity by a factor of 3 $\rightarrow$ better statistics!
- Many more analyses in the works