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Hadron Spectroscopy at BESIII

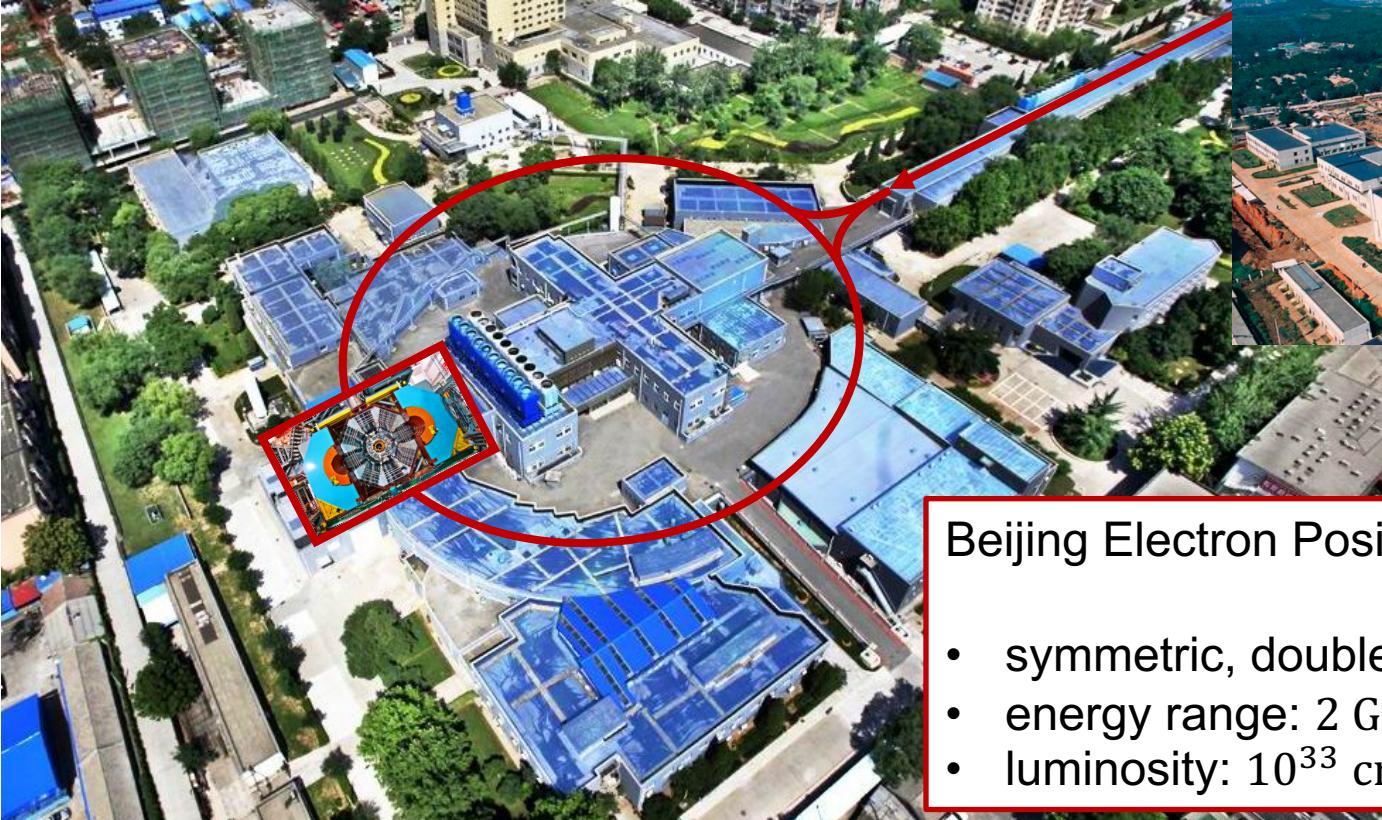
Nils Hüsken on behalf of the BESIII collaboration

MITP Workshop - Hadron Spectroscopy: The Next Big Steps
March 15th, 2022

INDIANA UNIVERSITY BLOOMINGTON



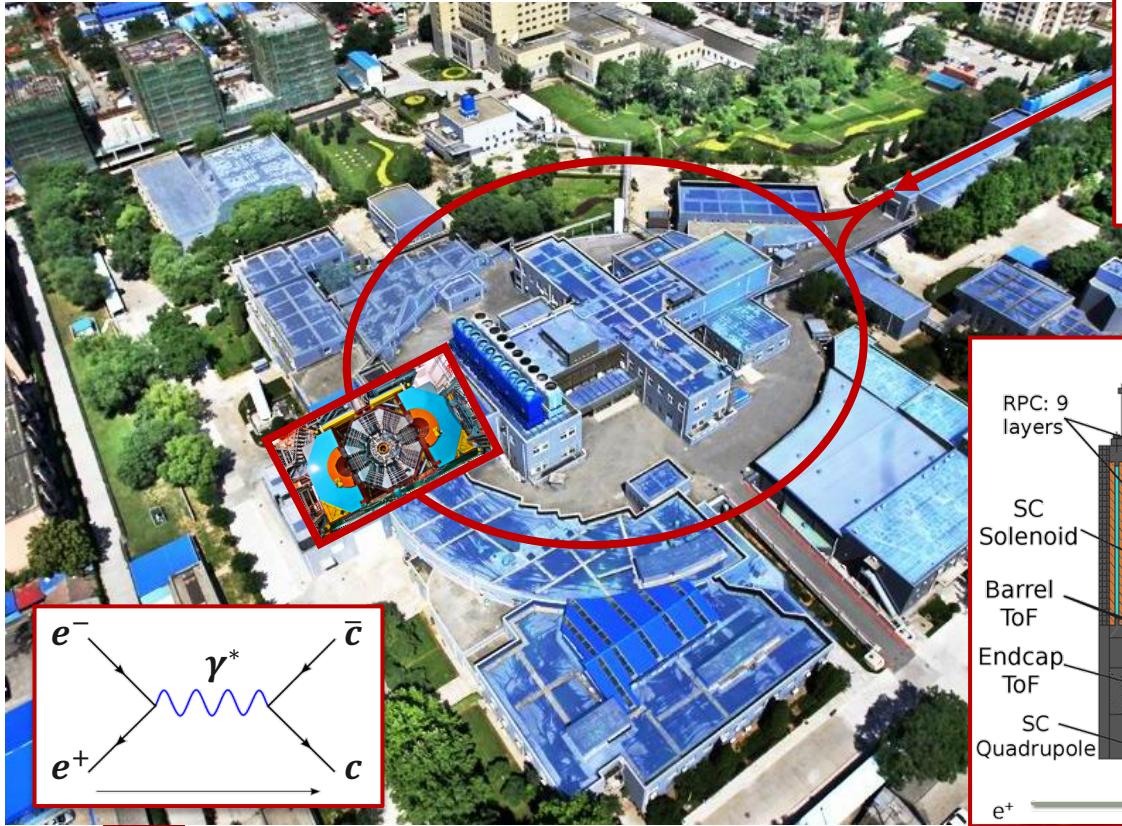
BESIII



Beijing Electron Positron Collider:

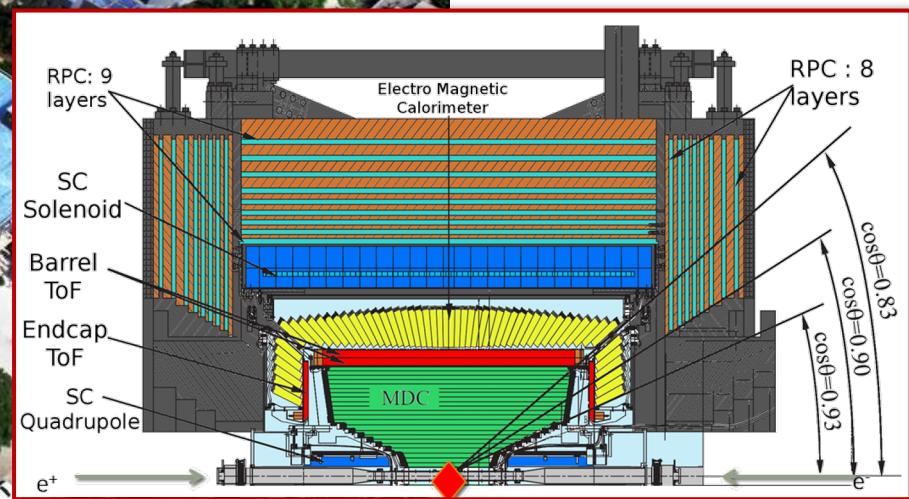
- symmetric, double-ring e^+e^- collider
- energy range: $2 \text{ GeV} < \sqrt{s} < 4.94 \text{ GeV}$
- luminosity: $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (at $\psi(3770)$)

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
- ...

$10^{10} J/\psi$

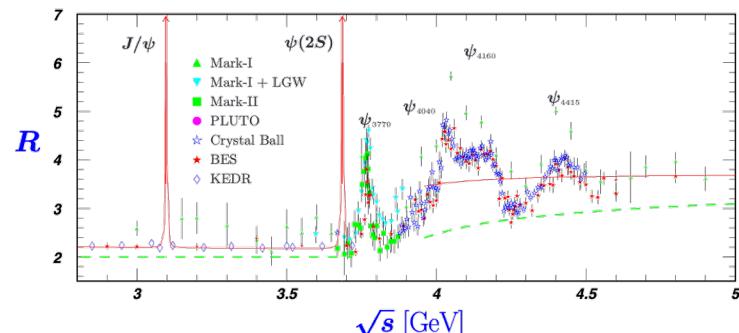
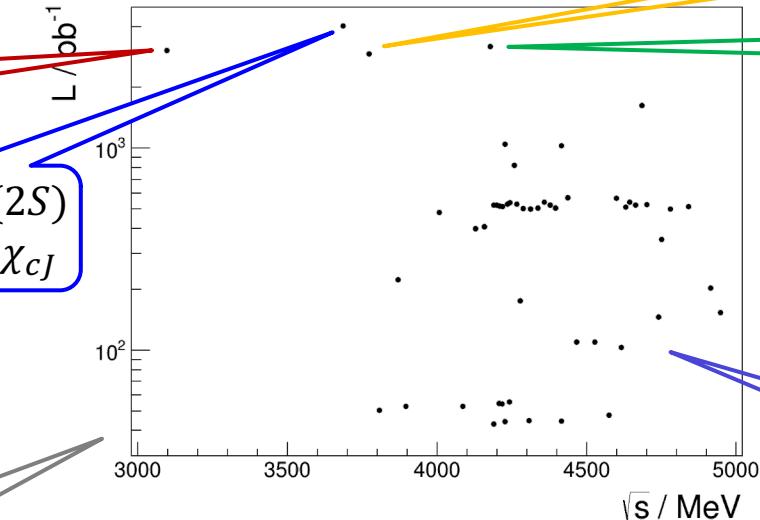
$2.7 \times 10^9 \psi(2S)$
 $\sim 260 \times 10^6 \chi_{cJ}$

$\sim 2.9 \text{ fb}^{-1}$ 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



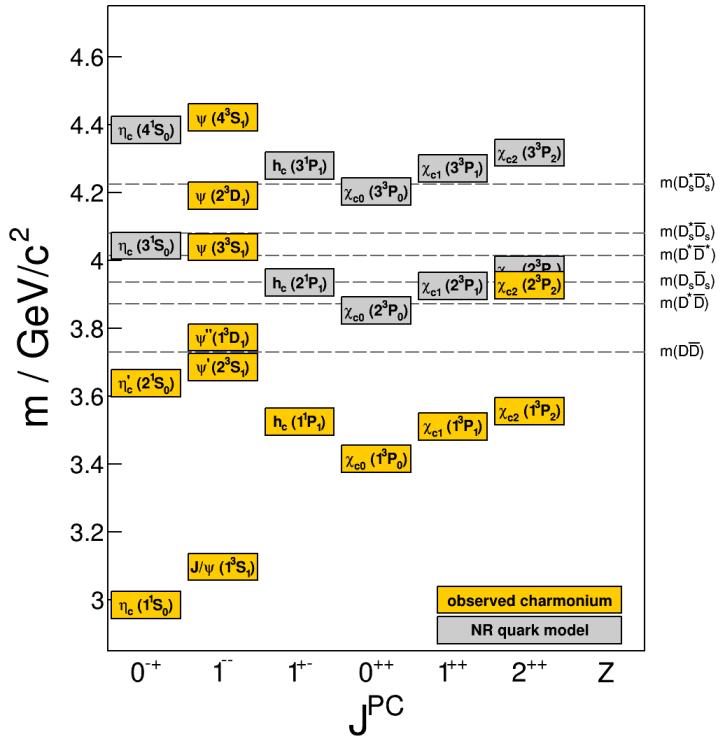
- XYZ spectroscopy
- XYZ decays
- open-charm production
- charmed baryons
- ...



Charmonium(-like) Spectroscopy



Charmonium

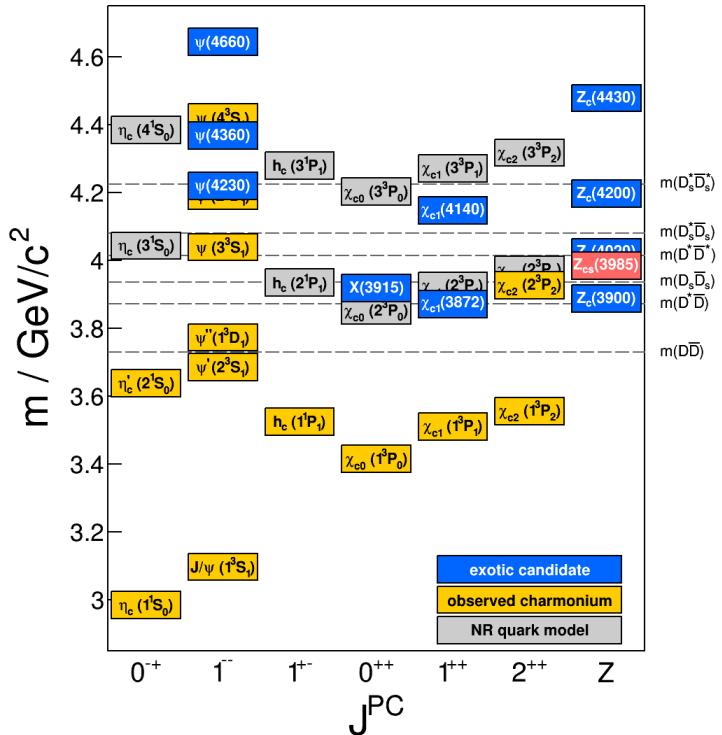


- conventional charmonia ($c\bar{c}$) fit well with potential model calculations

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

+ spin-dependent terms

Charmonium-like states

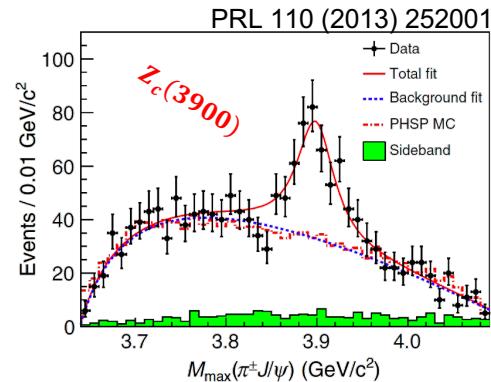
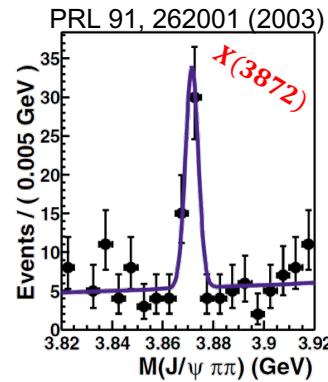


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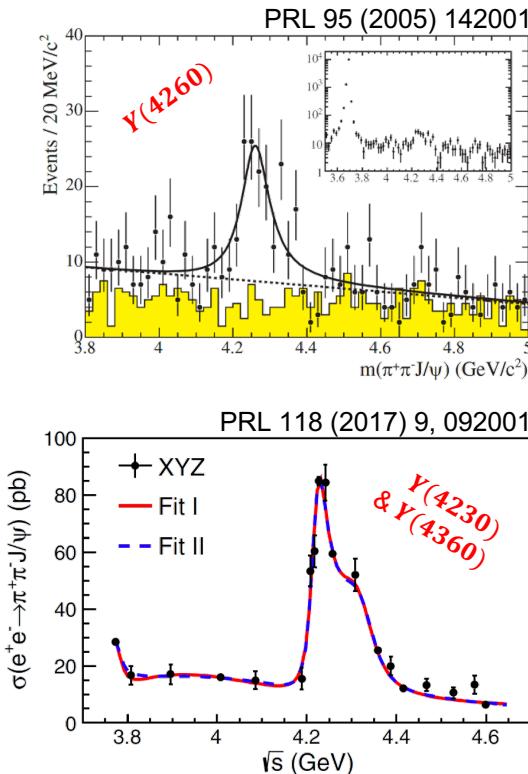
$$V_{c\bar{c}} = -\frac{4}{3} \cdot \frac{\alpha_s(r)}{r} + k \cdot r$$

+ spin-dependent terms

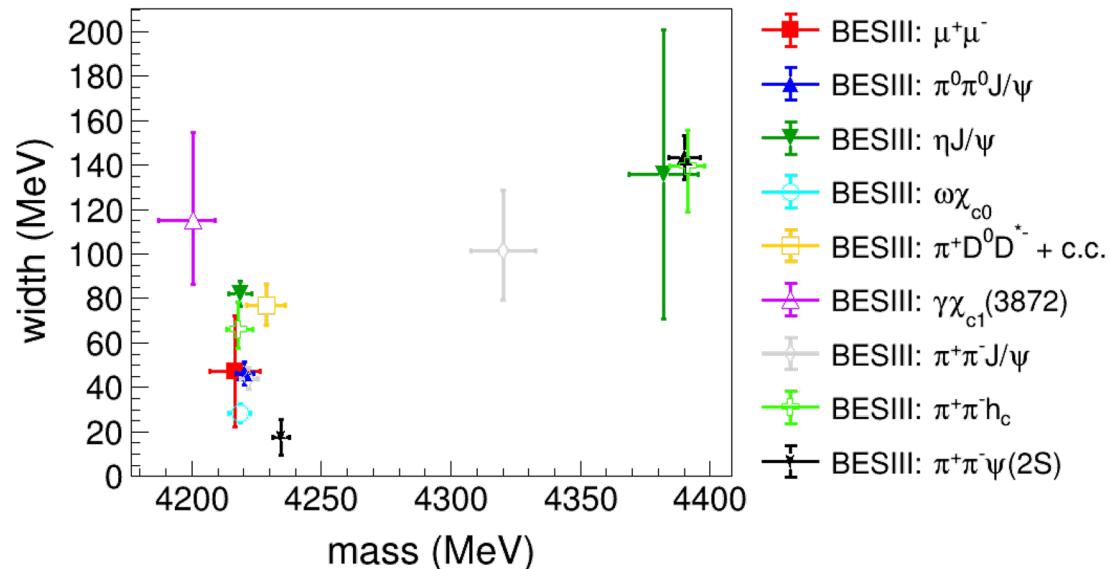
- several unexpected states observed



Vector states: $\psi(4230)$ & $\psi(4360)$

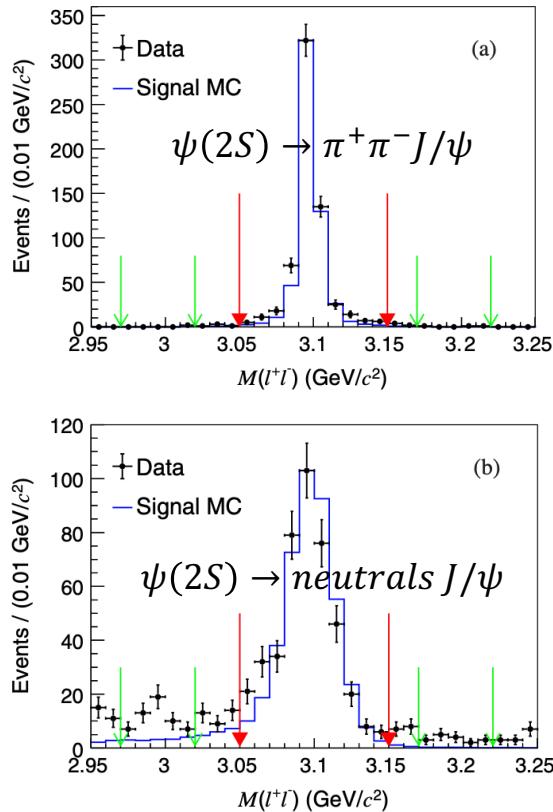


- $\gamma(4260)$ first observed by BaBar, we find two states $\psi(4230)$ & $\psi(4360)$

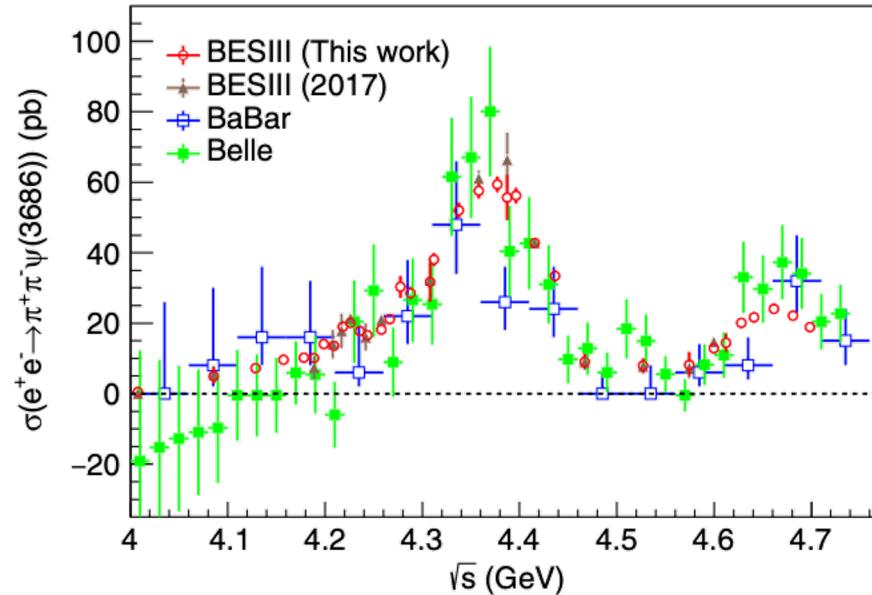


- different channels show (slightly) different masses and widths

Vector states: $\psi(4230)$ & $\psi(4360)$



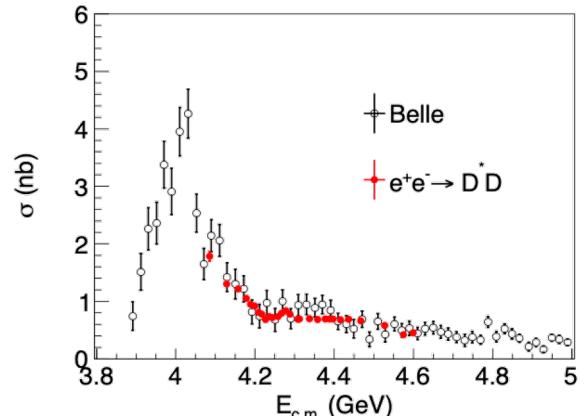
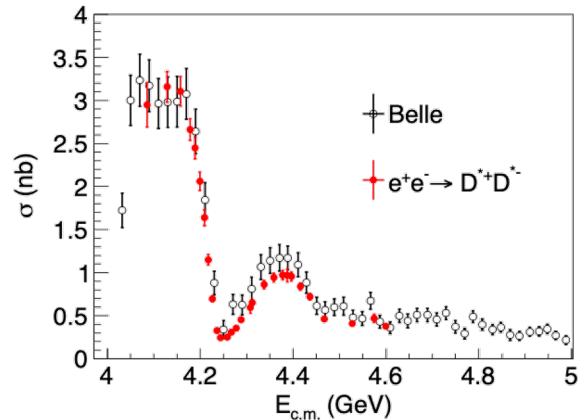
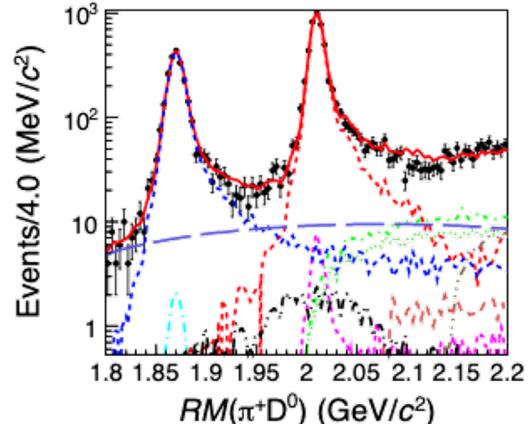
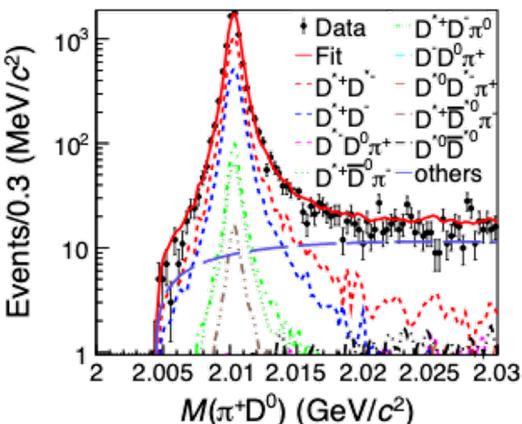
- recent update of $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$ with improved precision



- first observation of $\psi(4660)$ at BESIII using new data above 4.6 GeV

Open-charm production

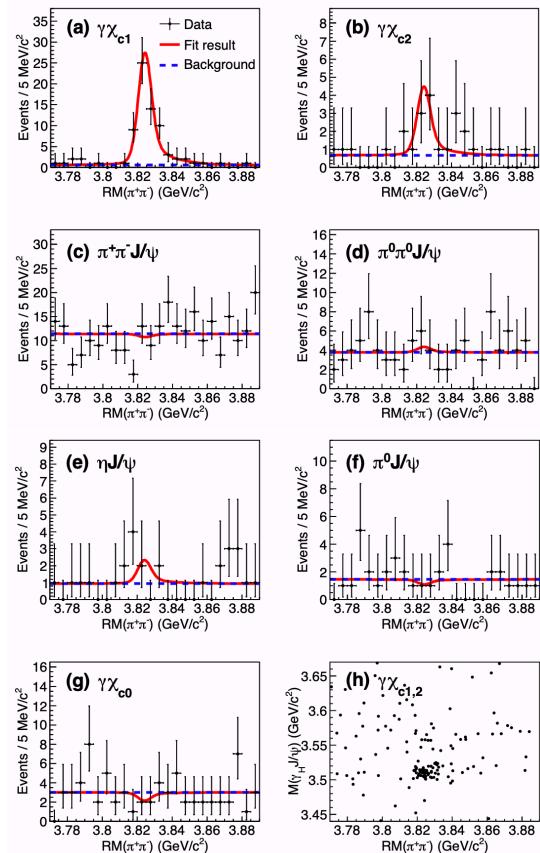
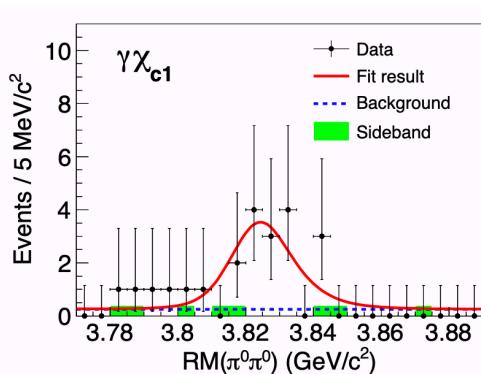
- measurement of $e^+e^- \rightarrow D^{*+}D^-$ and $D^{*+}D^{*-}$
- consistent with earlier measurements by Belle, BaBar and CLEO at improved precision
- sophisticated (coupled channel) models will be necessary to understand non-trivial structure



$\psi_2(3823)$ – the $\psi(1^3D_2)$ state?

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

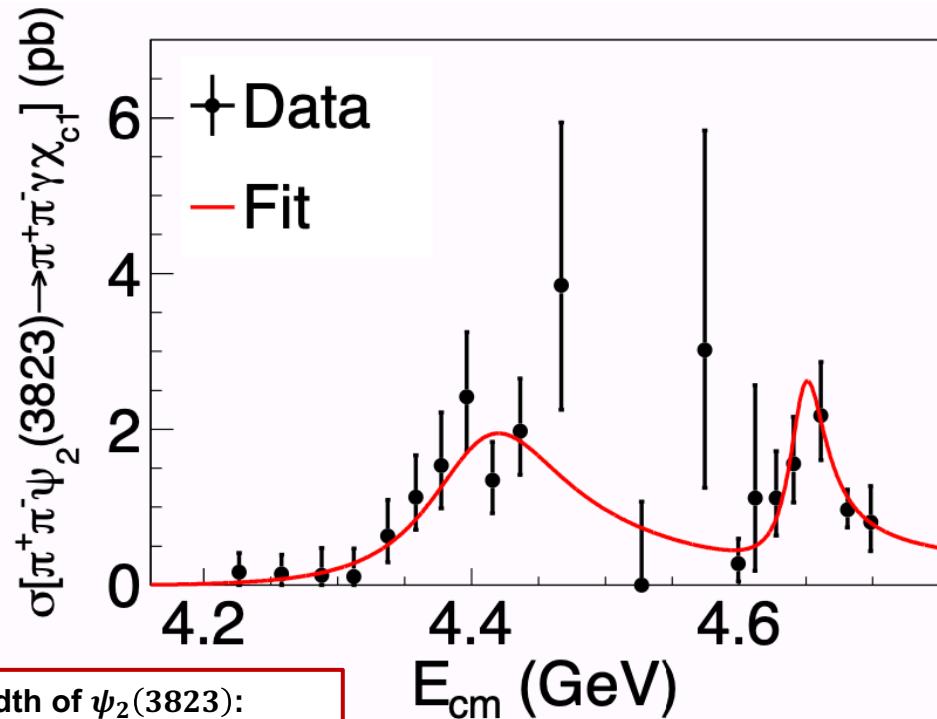
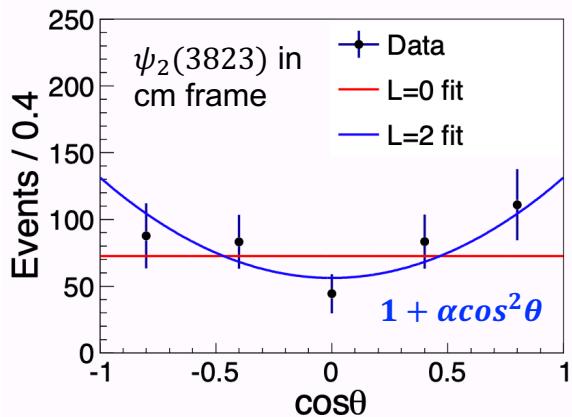
- search for various (new) decay modes of the $\psi_2(3823)$
- first evidence for $\psi_2(3823) \rightarrow \gamma\chi_{c2}$
- first evidence for $e^+e^- \rightarrow \pi^0\pi^0\psi_2(3823)$ with $\psi_2(3823) \rightarrow \gamma\chi_{c1}$



$\psi_2(3823)$ – the $\psi(1^3D_2)$ state?

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

- updated study using $\psi_2(3823) \rightarrow \gamma\chi_{c1}$ allowing missing photon
- cross section indicates resonant production
- $L = 2$ slightly favored over $L = 0$

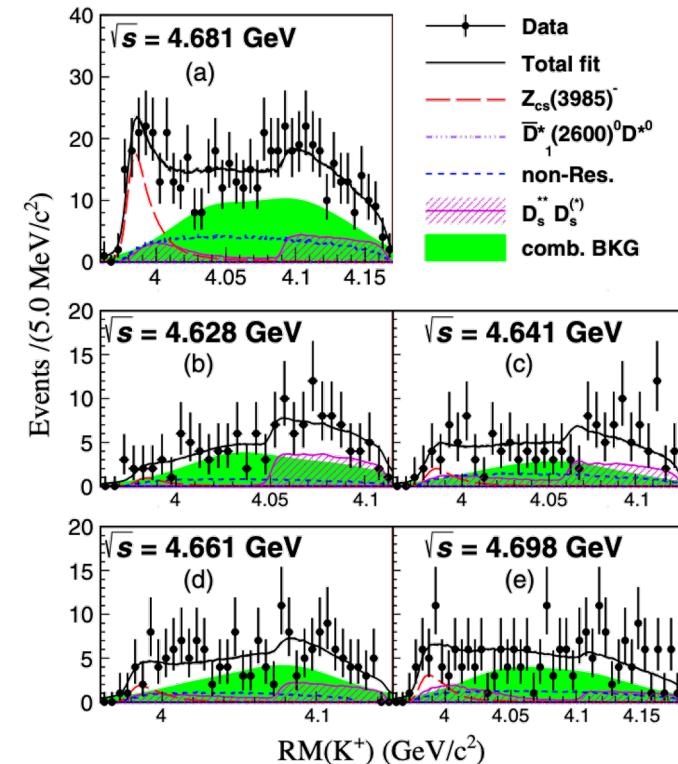
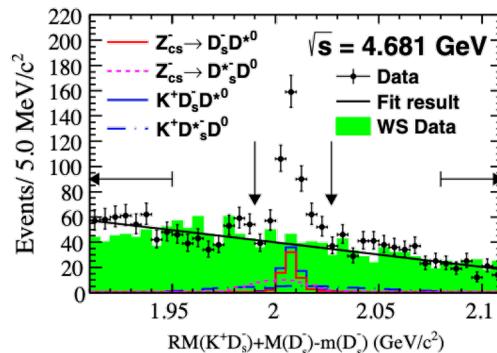


mass and width of $\psi_2(3823)$:
 $m = 3823.12 \pm 0.43 \pm 0.13 \text{ MeV}/c^2$
 $\Gamma < 2.9 \text{ MeV}$ (at 90% CL)

The $Z_{cs}(3985)$

- partial reconstruction method: K^+, D_s^-
- using 5 new datasets above 4.6 GeV
- 5.3σ excess close to threshold for data at $\sqrt{s} = 4.681$ GeV
- coupling to at least one of $D_s^- D^{*0}$ and $D_s^{*-} D^0$ suggests minimal quark-content of $c\bar{c}s\bar{u}$

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



see more: Y. Guo, Thursday 17/03, 12:20



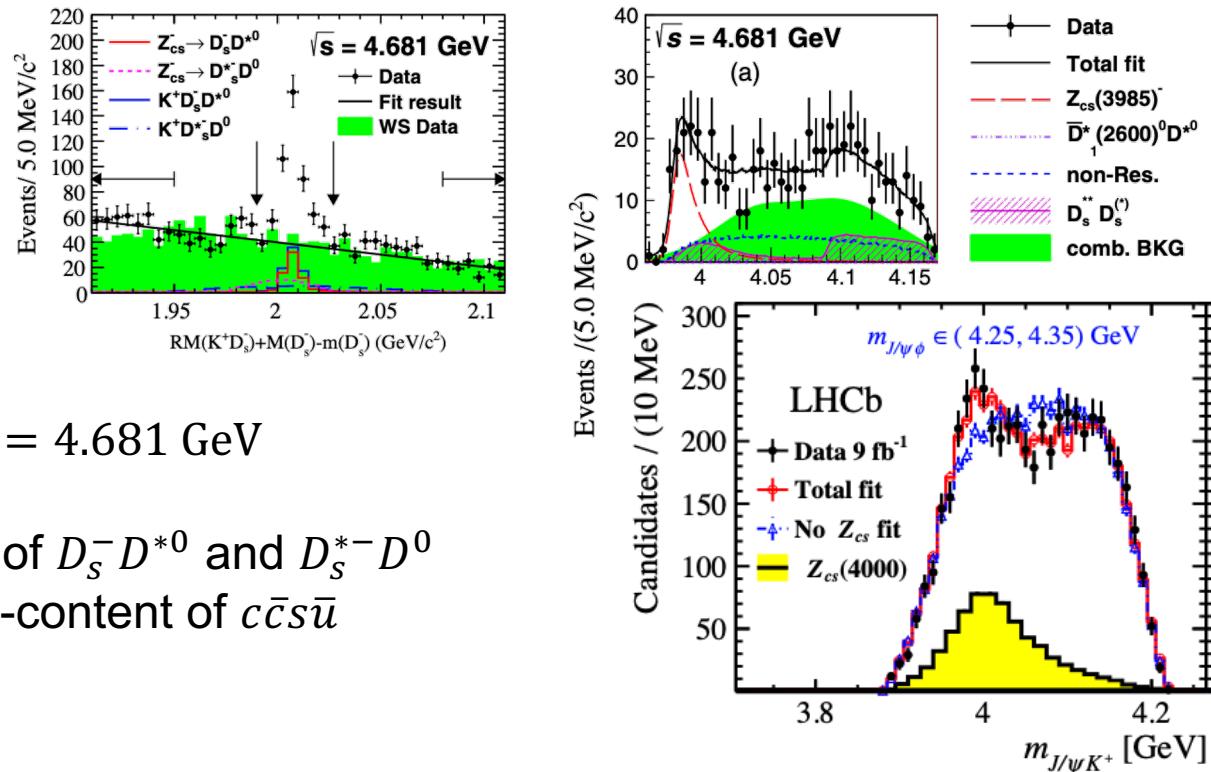
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PRL 126 (2021) 10, 102001

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LHCb: PRL 127, 082001 (2021)

PRL 126 (2021) 10, 102001

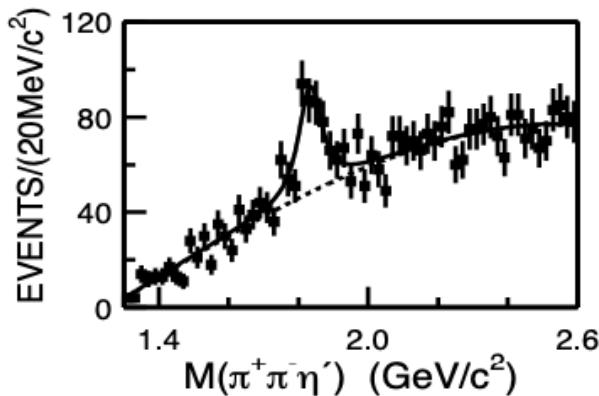
Light Hadron Spectroscopy



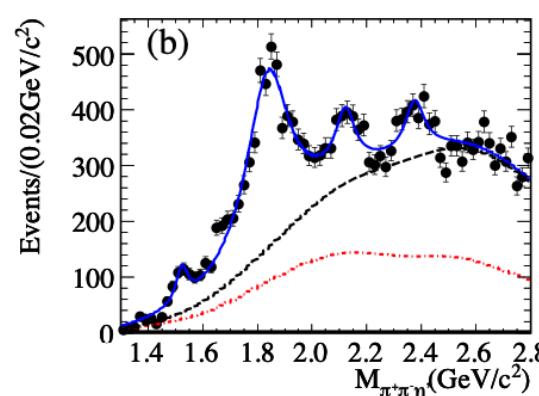
On $X(1835)$, $X(2120)$, $X(2370)$, ...

- structures in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$

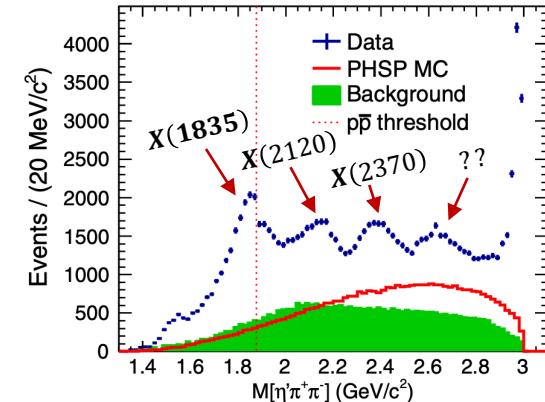
PRL 95 (2005) 262001



PRL 106 (2011) 072002



PRL 117 (2016) 4, 042002



$$58 \cdot 10^6 J/\psi$$



$$225 \cdot 10^6 J/\psi$$



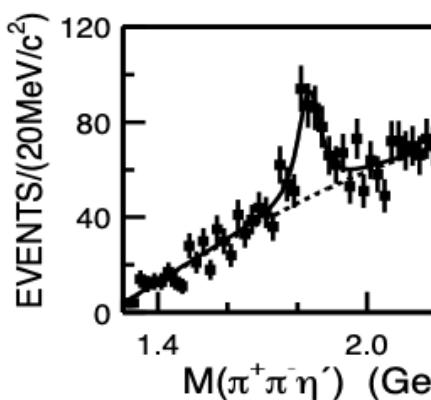
$$1.3 \cdot 10^9 J/\psi$$



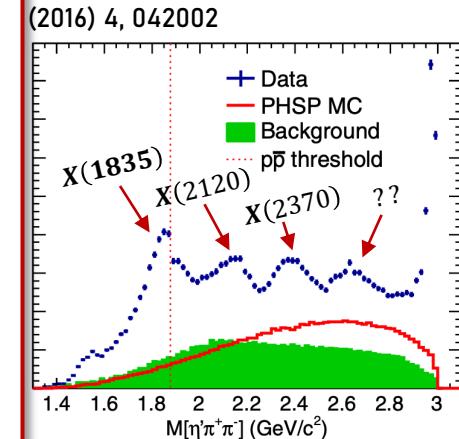
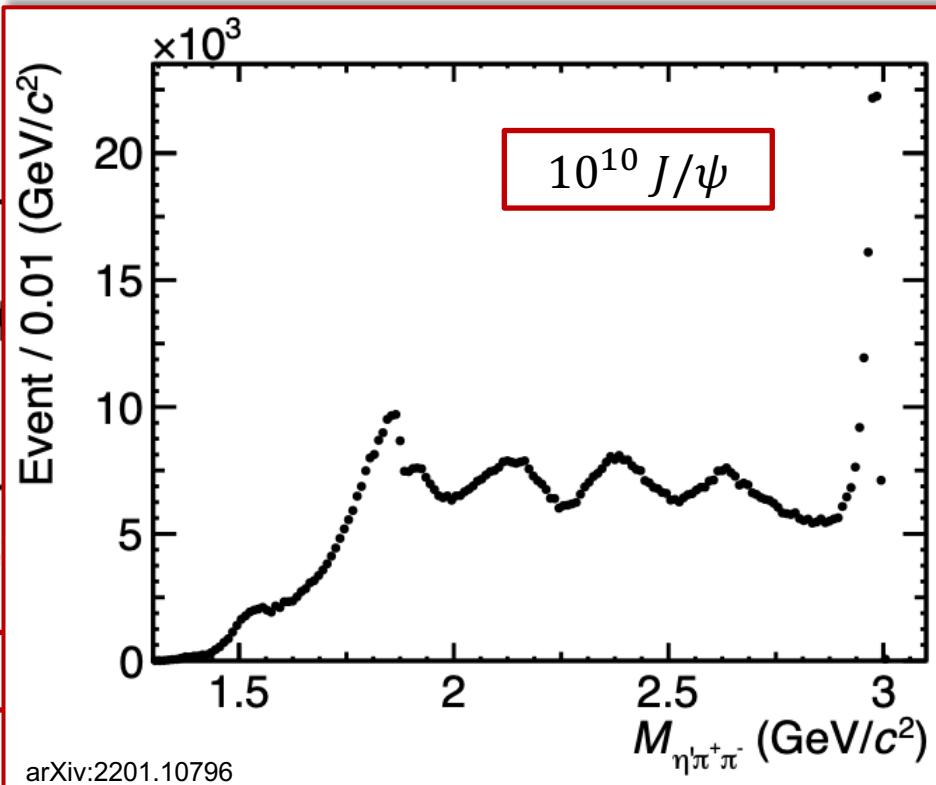
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PRL 95 (2005) 262001



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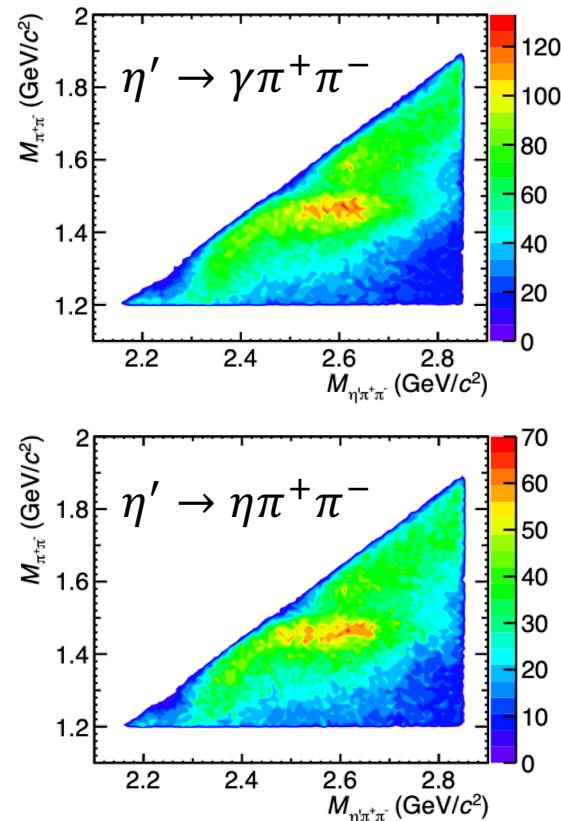
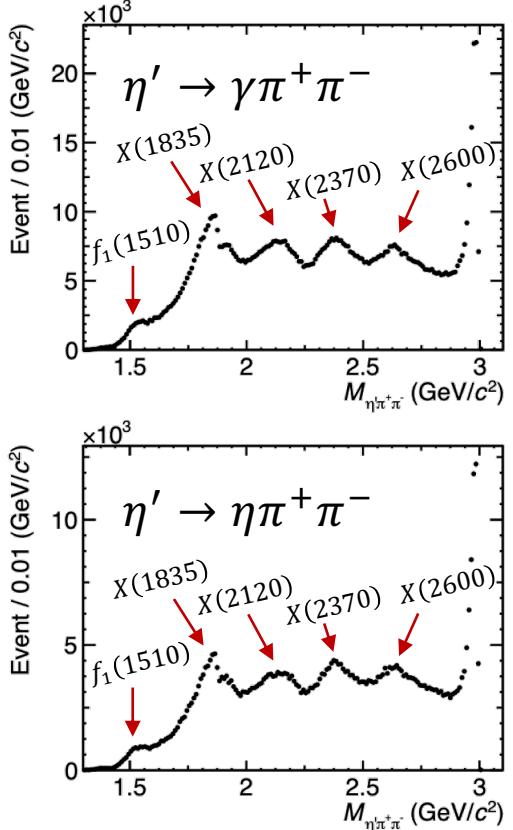


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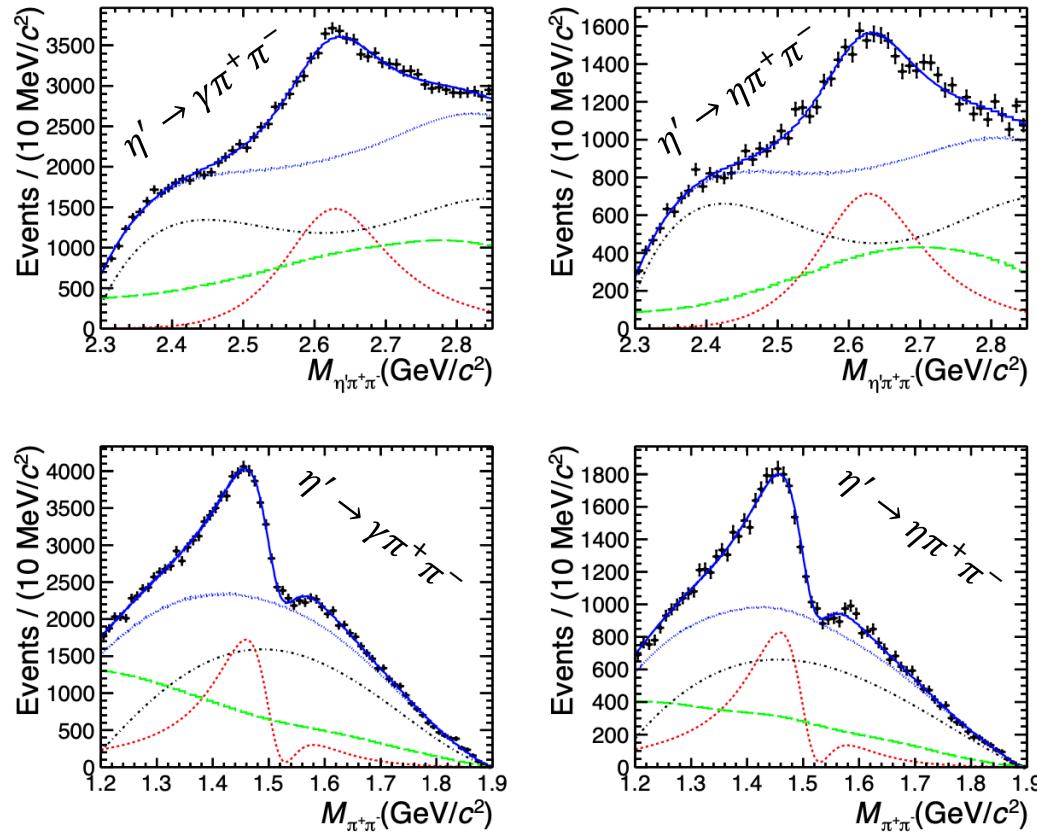
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- structures in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$
- confirmation of $X(1835)$, $X(2120)$ and $X(2370)$
- new structure $X(2600)$
- correlation with $M_{\pi^+\pi^-} \approx 1.5$ GeV
- complicated pattern in $M_{\pi^+\pi^-}$
- more studies (including J^{PC} determination!) necessary



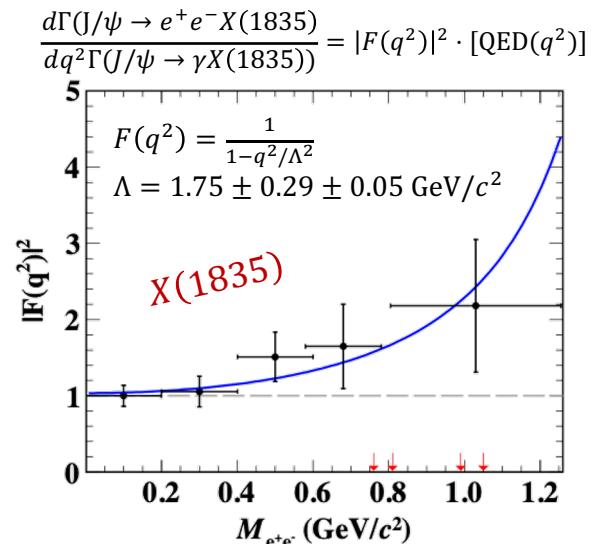
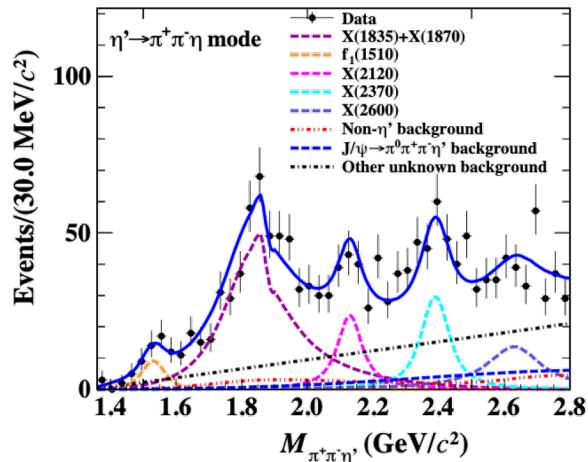
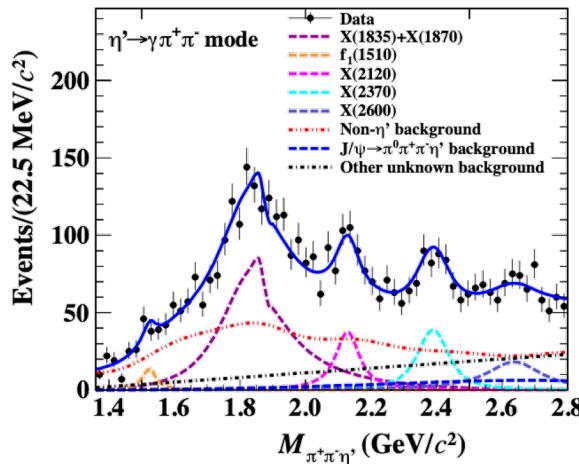
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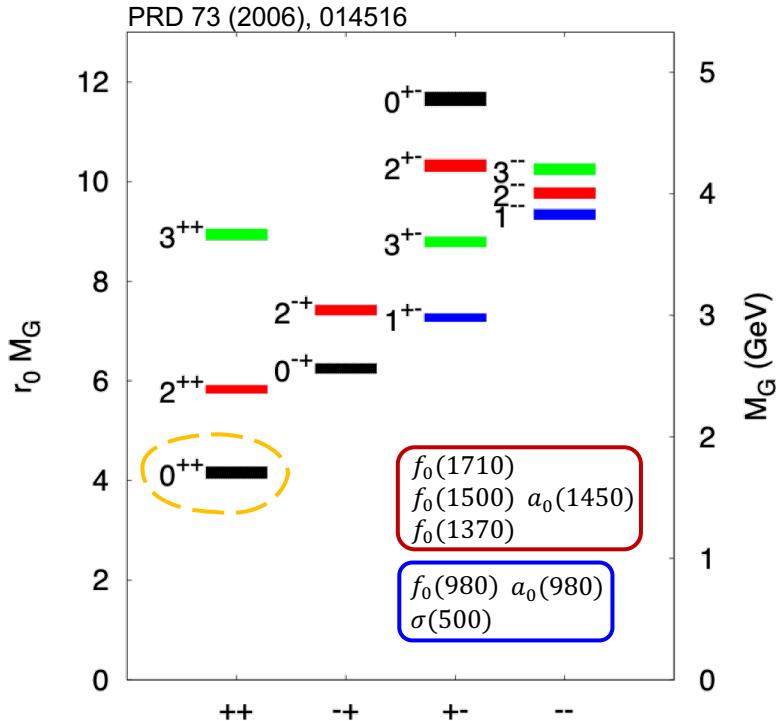
On $X(1835)$, $X(2120)$, $X(2370)$, ...

- same structures in EM Dalitz decay $J/\psi \rightarrow e^+e^-\eta'\pi^+\pi^-$



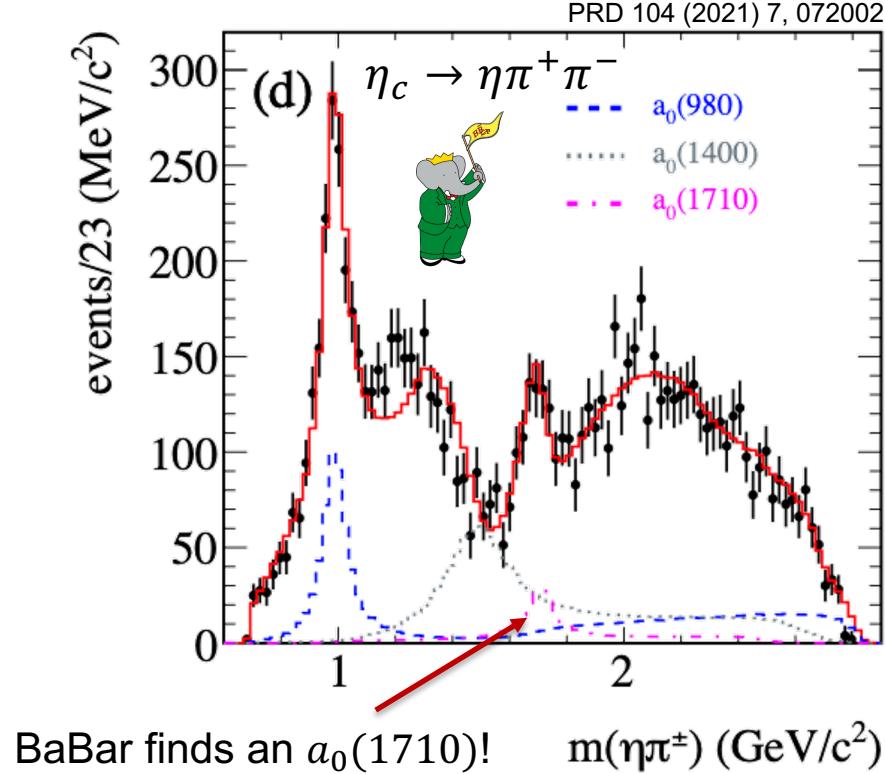
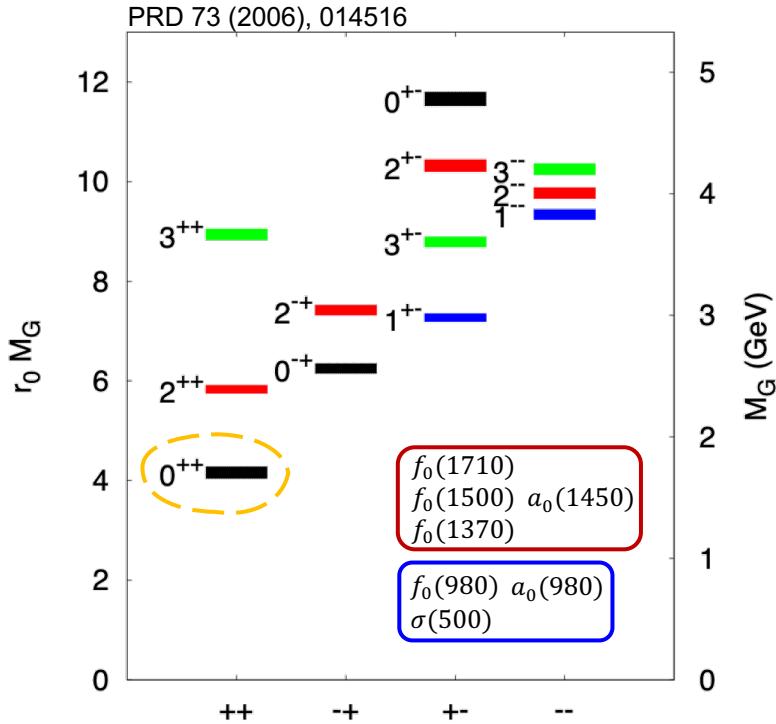
- additional input to model calculations regarding nature of these states

Light scalar mesons

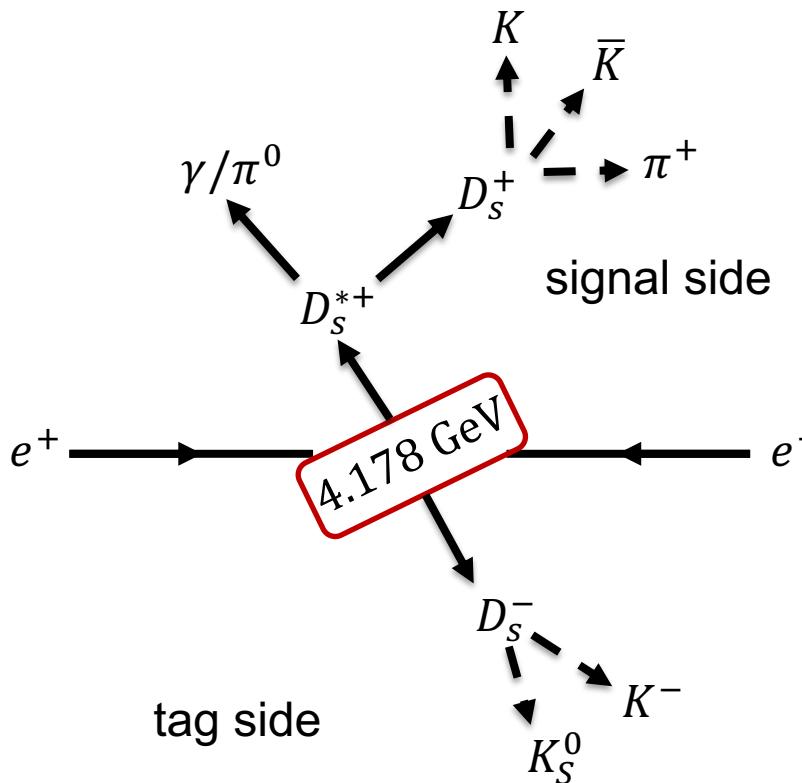


- lightest glueball predicted to be a scalar
- five well-established isoscalar scalar mesons:
 $\sigma(500)$, $f_0(980)$,
 $f_0(1370)$, $f_0(1500)$, $f_0(1710)$
- seemingly an overpopulation...

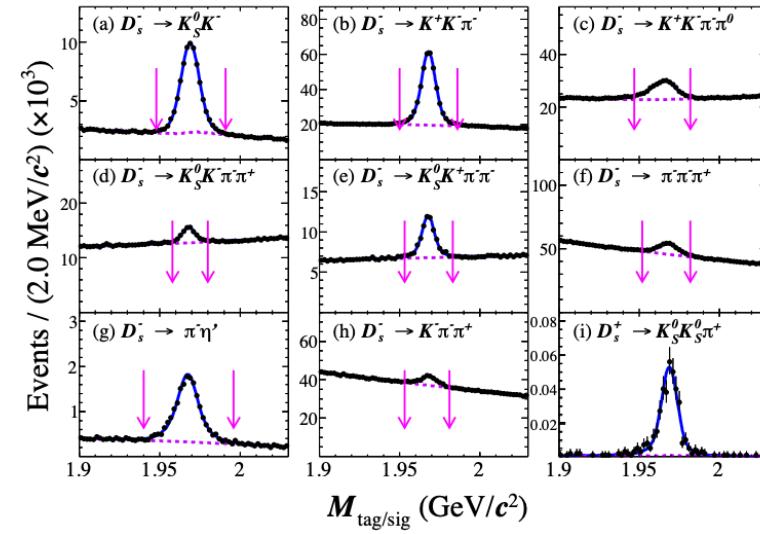
Light scalar mesons



Light scalar mesons



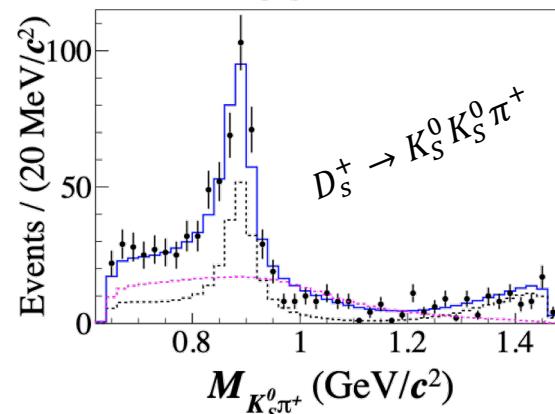
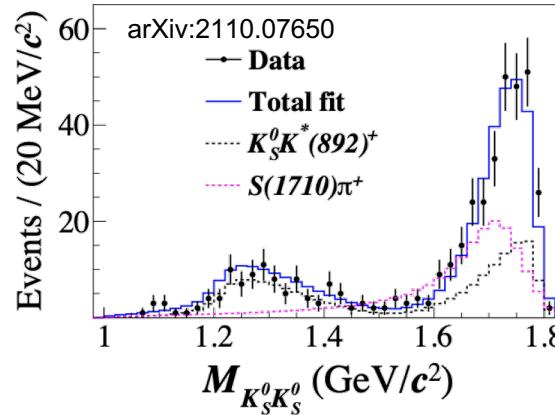
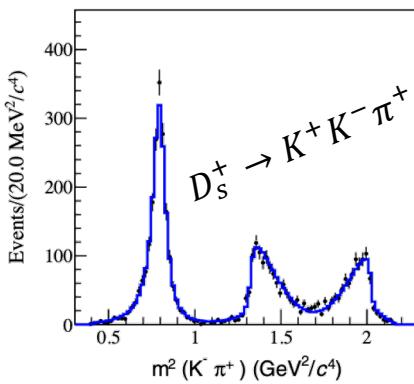
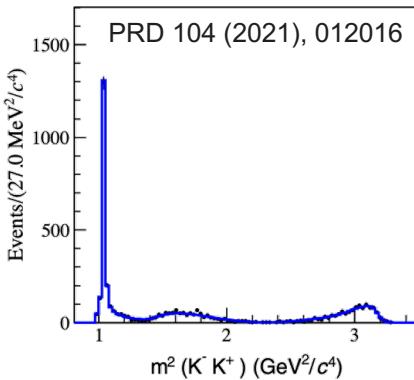
- study of light scalar mesons in $D_s^+ \rightarrow K^+ K^- \pi^+$ and $K_S^0 K_S^0 \pi^+$
- using double-tag technique



arXiv:2110.07650



Light scalar mesons



$D_s^+ \rightarrow K^+ K^- \pi^+$:

- strong $S_0(980)$ contribution
- small $S_0(1710)$ contribution

$D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$:

- vanishing $S_0(980)$ contribution
- large $S_0(1710)$ contribution

opposing interference pattern:

$$|I = 1\rangle \sim |K^+ K^-\rangle + |K^- K^+\rangle + |K^0 \bar{K}^0\rangle + |\bar{K}^0 K^0\rangle$$

$$|I = 0\rangle \sim |K^+ K^-\rangle + |K^- K^+\rangle - |K^0 \bar{K}^0\rangle - |\bar{K}^0 K^0\rangle$$

$\rightarrow a_0(980)-f_0(980)$ interference

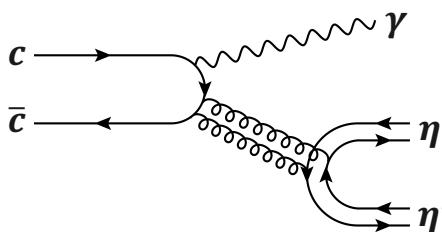
$\rightarrow a_0(1710)-f_0(1710)$ interference

➤ $a_0(1710)$ needed!



Spin-exotic $\eta_1(1855)$

- PWA of $J/\psi \rightarrow \gamma\eta\eta'$



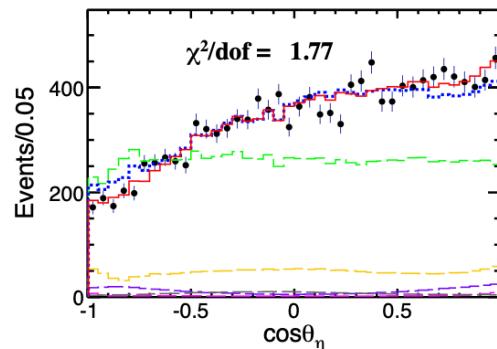
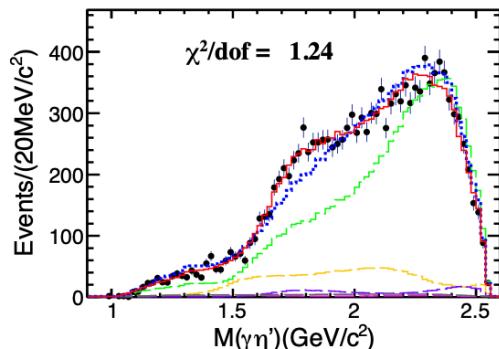
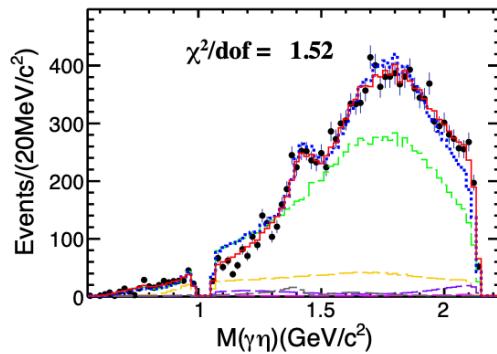
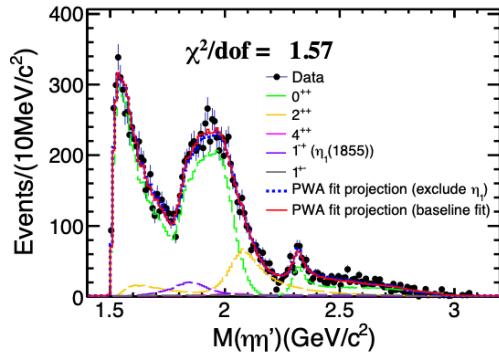
- iso-scalar spin-exotic $\eta_1(1855)$

$$m = 1855 \pm 9^{+6}_{-1} \text{ MeV}$$

$$\Gamma = 188 \pm 18^{+3}_{-8} \text{ MeV}$$

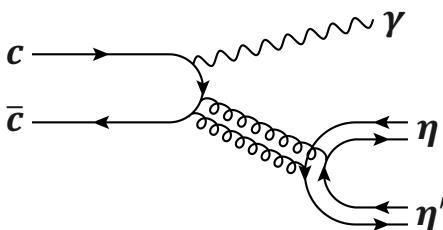
- study of other production & decays necessary to understand nature of this state

see more: B. Liu, Monday 21/03, 11:00



Spin-exotic $\eta_1(1855)$

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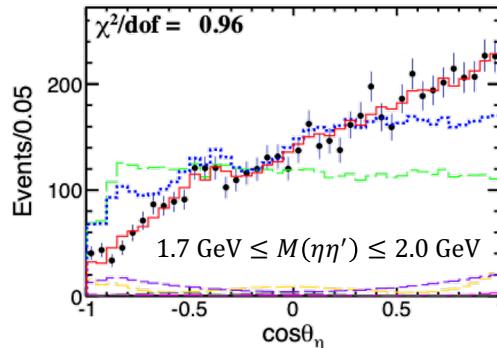
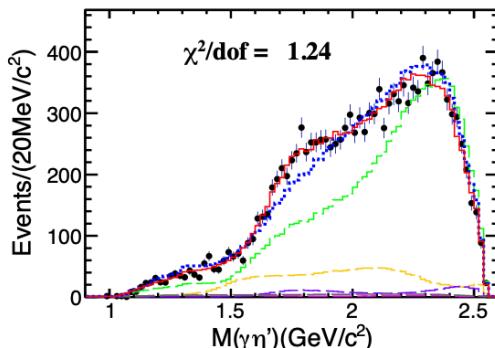
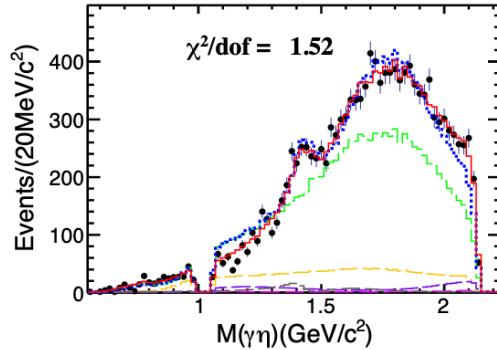
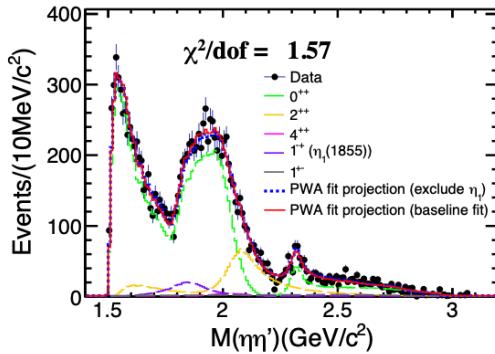
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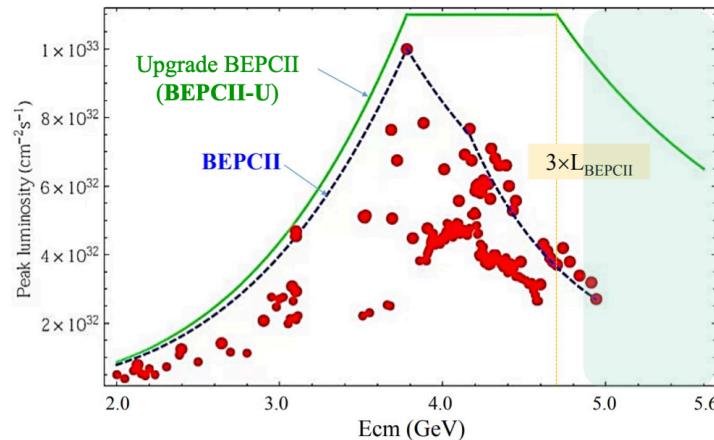
Summary and Outlook

- 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 $\psi(3770)$



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 - 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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