Light hadron spectroscopy at BESIII

Nils Hüsken on behalf of the BESIII collaboration

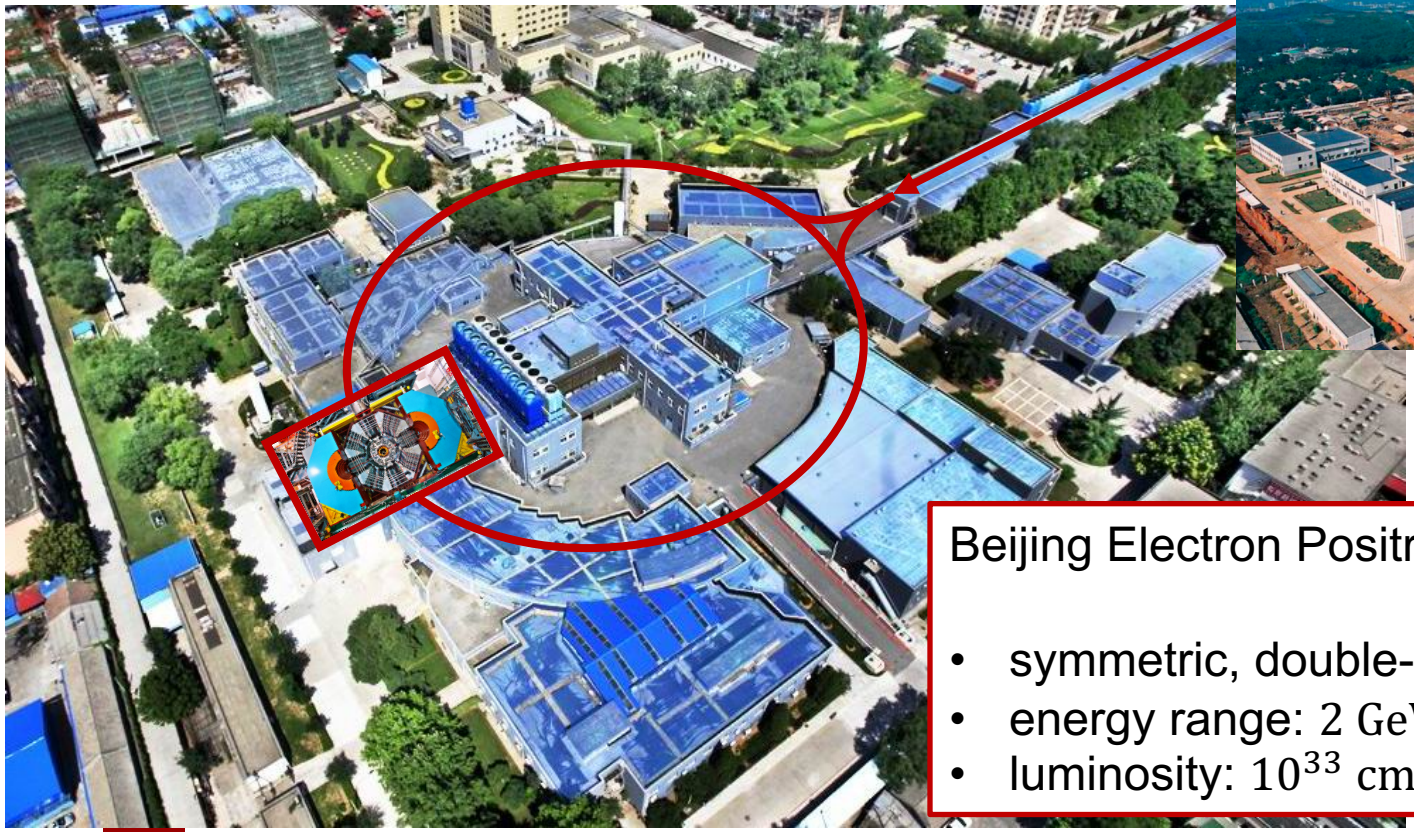
9th International Conference on Quarks and Nuclear Physics
September 5th, 2022

INDIANA UNIVERSITY BLOOMINGTON

MARIE CURIE ACTIONS

The BESIII Experiment

BESIII



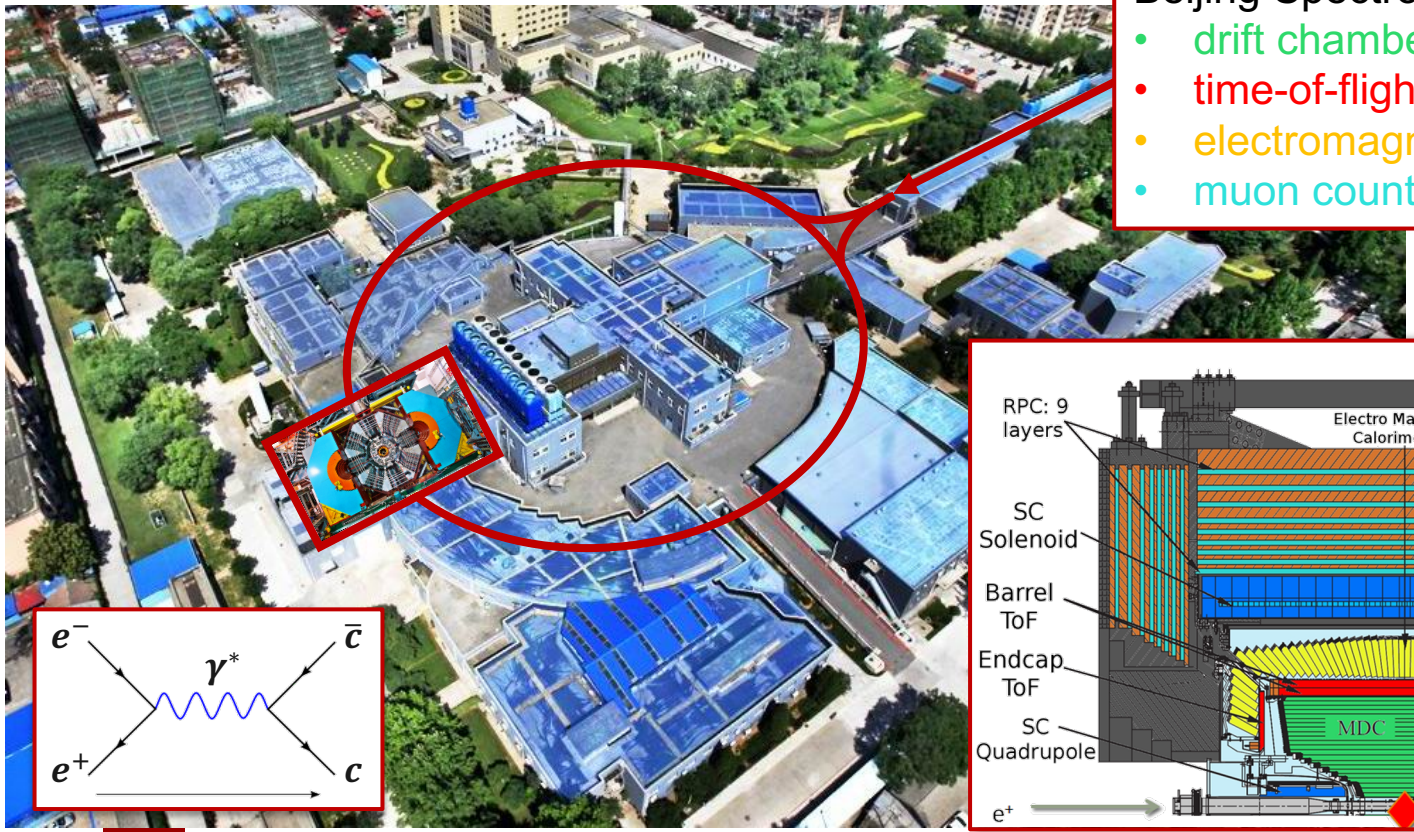
Beijing Electron Positron Collider:

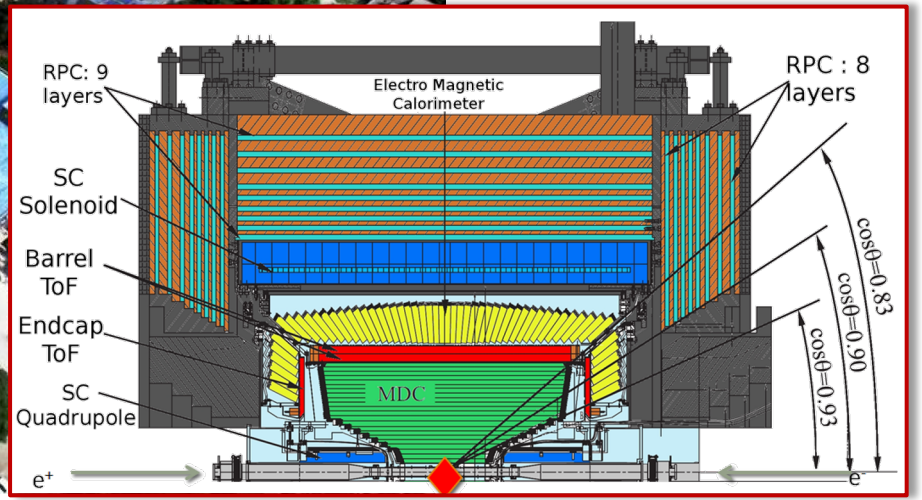
- symmetric, double-ring e^+e^- collider
- energy range: $2\ \mathrm{GeV} < \sqrt{s} < 4.94\ \mathrm{GeV}$
- luminosity: $10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (at $\psi(3770)$)

BESIII

Beijing Spectrometer BESIII:

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





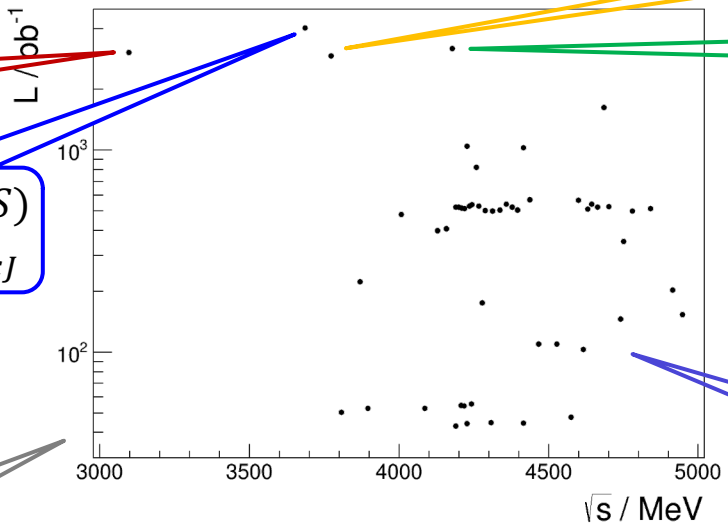
BESIII

$10^{10}\ J/\psi$

$2.7\times10^{9}\ \psi(2S)$
$\sim260\times10^{6}\ \chi_{cJ}$

$\sim2.9\ \mathrm{fb}^{-1}$ at $\psi(3770)$

$\sim3.2\ \mathrm{fb}^{-1}$ at $4.178\ \mathrm{GeV}$



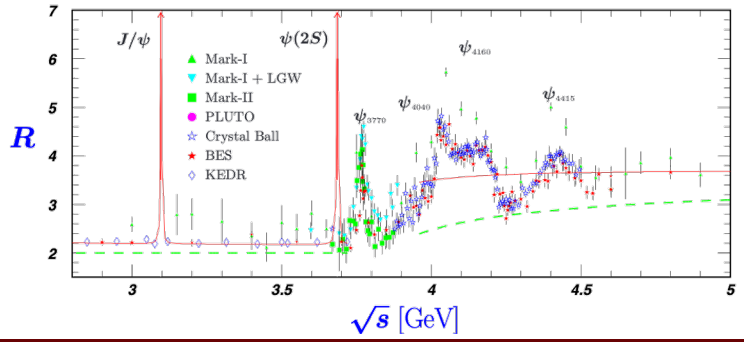
- light hadron spectroscopy
- η & η' decays
- charmonium transitions
- hyperon physics
- …

+ another $\sim715\ \mathrm{pb}^{-1}$ for $2.0\ \mathrm{GeV} \leq \sqrt{s} \leq 3.08\ \mathrm{GeV}$

- excited ρ, ω, ϕ
- …

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

$\sim22\ \mathrm{fb}^{-1}$ in XYZ region



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

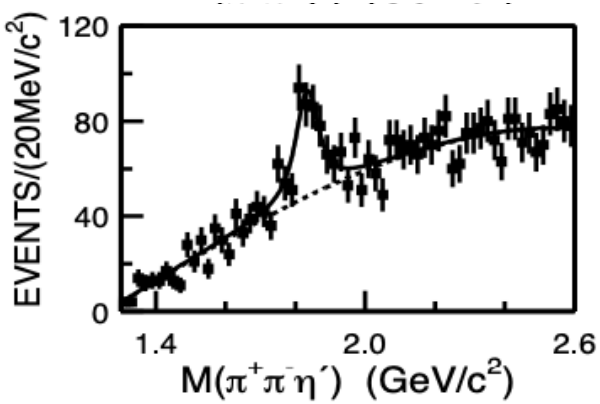
Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update

On $X(1835)$ and company

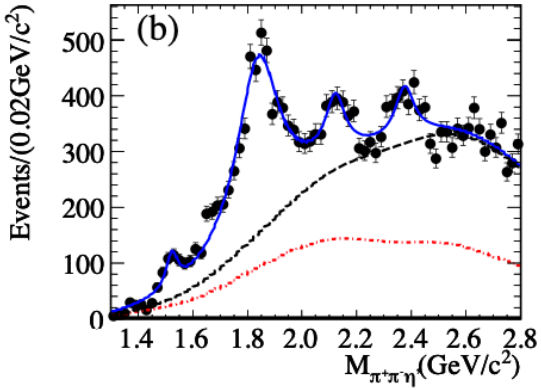
On $X(1835)$, $X(2120)$, $X(2370)$, …

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

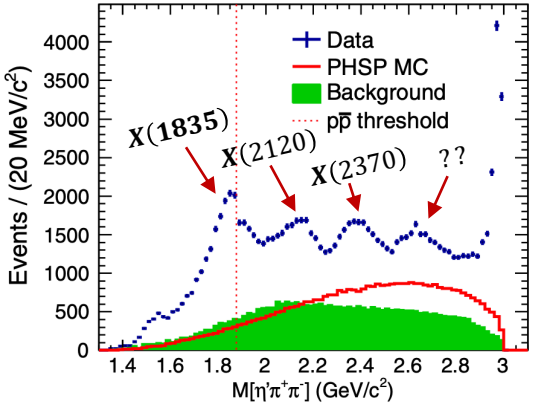
PRL 95 (2005) 262001



PRL 106 (2011) 072002



PRL 117 (2016) 4, 042002

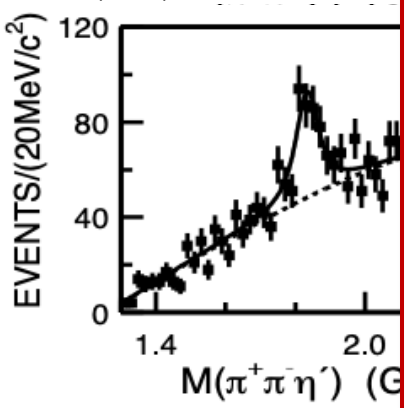


$58 \cdot 10^6\ J/\psi$ → $225 \cdot 10^6\ J/\psi$ → $1.3 \cdot 10^9\ J/\psi$

On $X(1835)$, $X(2120)$, $X(2370)$, …

- structures in J/ψ –

PRL 95 (2005) 262001



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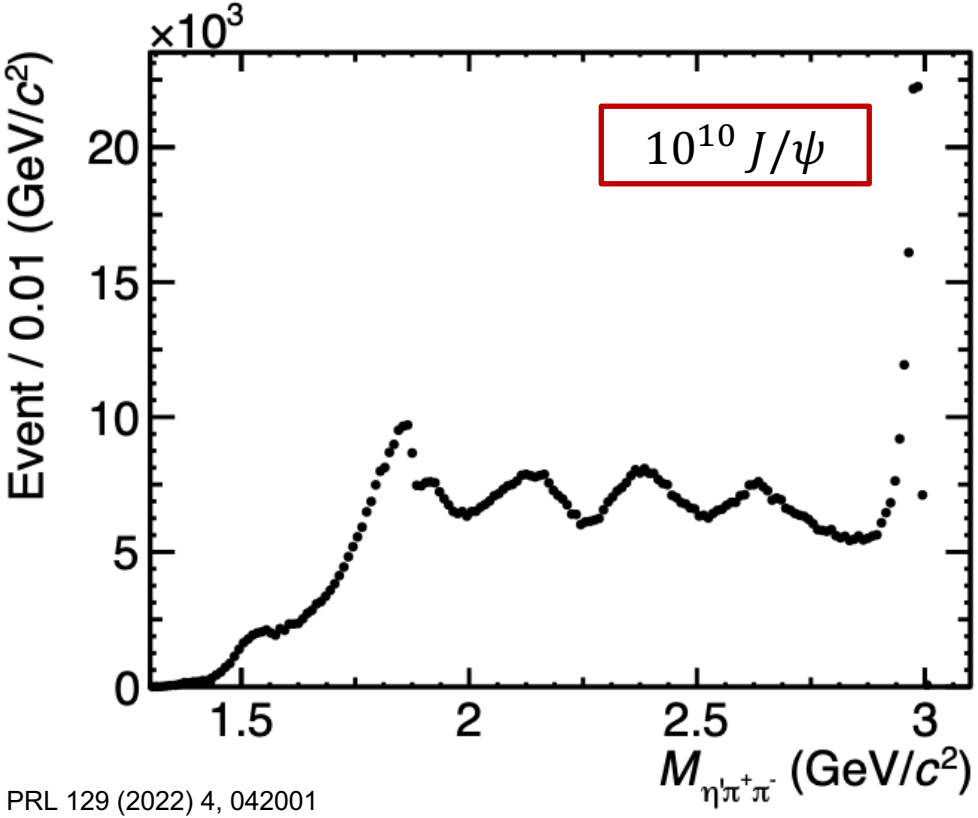
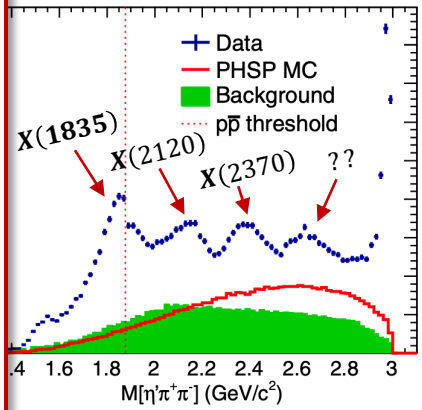


$10^{10}\ J/\psi$

PRL 129 (2022) 4, 042001

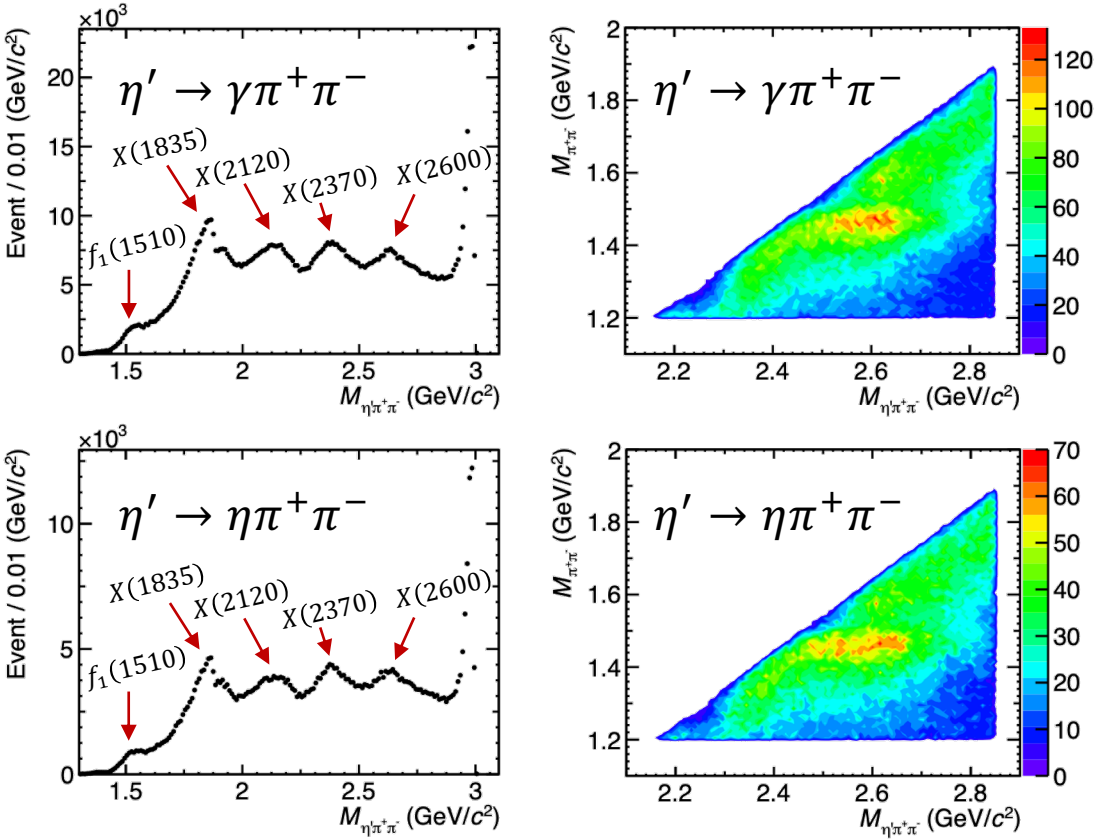
2016) 4, 042002



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

On $X(1835)$, $X(2120)$, $X(2370)$, …

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



PRL 129 (2022) 4, 042001

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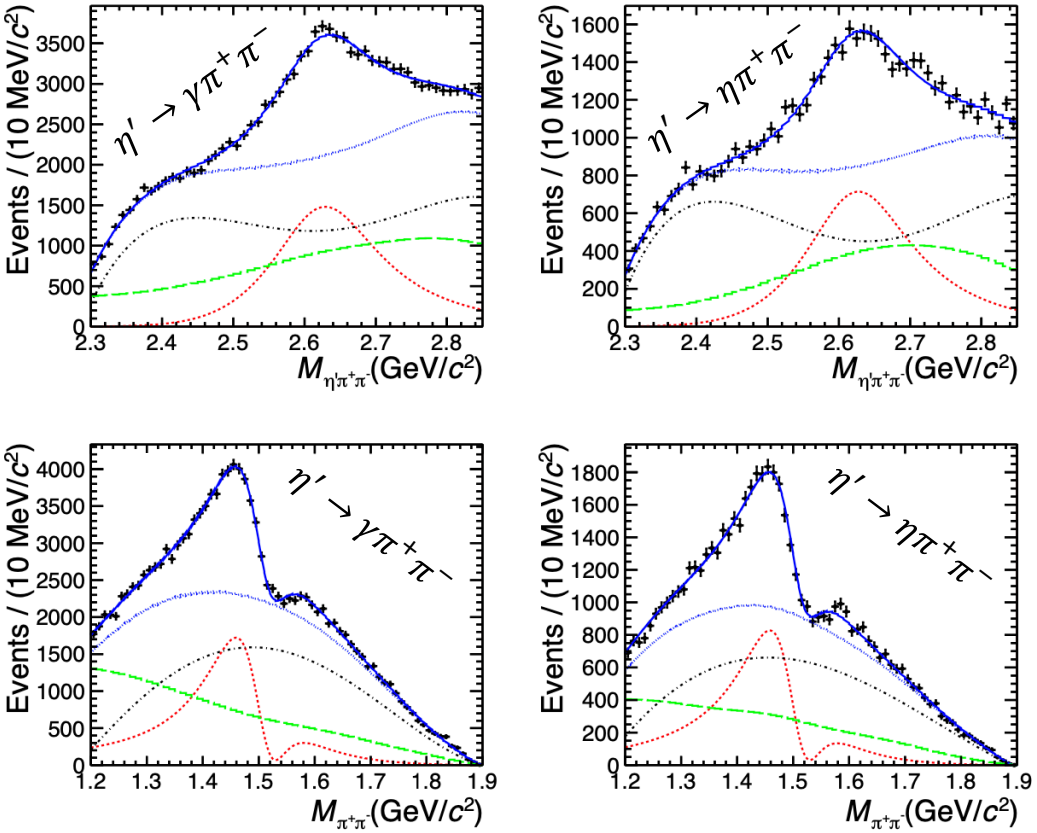
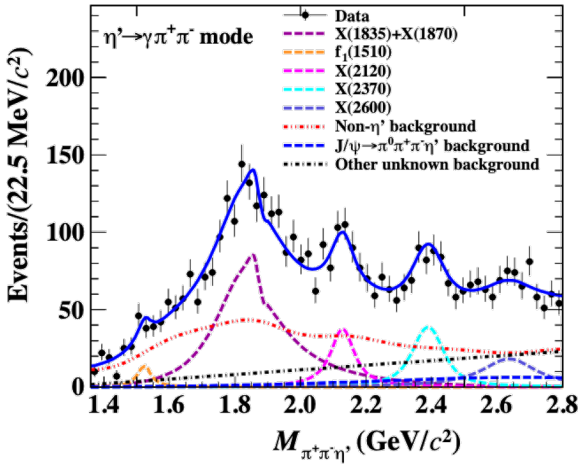
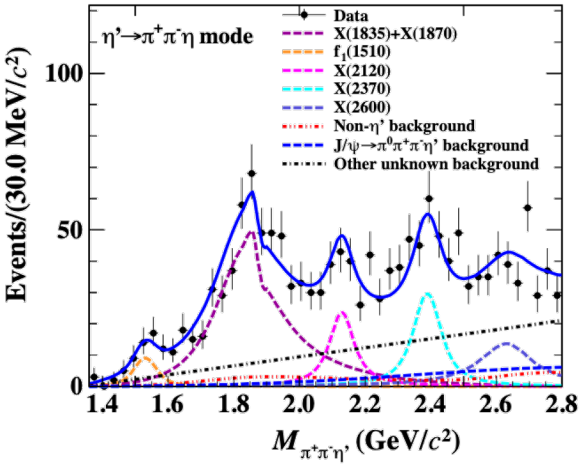


PRL 129 (2022) 4, 042001

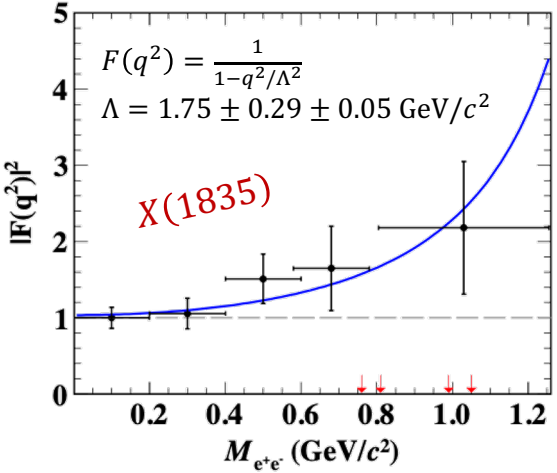
On $X(1835)$, $X(2120)$, $X(2370)$, …

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





$$\frac{d\Gamma(J/\psi \to e^+e^-X(1835)}{dq^2\Gamma(J/\psi \to \gamma X(1835))} = |F(q^2)|^2 \cdot [\mathrm{QED}(q^2)]$$

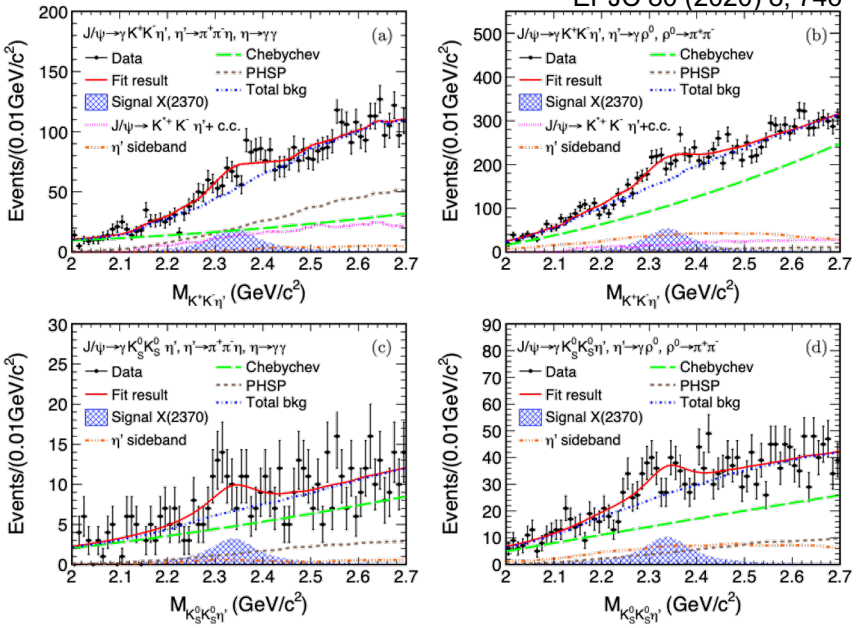


- additional input to model calculations regarding nature of these states

On $X(1835)$, $X(2120)$, $X(2370)$, …

$J/\psi \to \gamma\eta' K\bar{K}$:

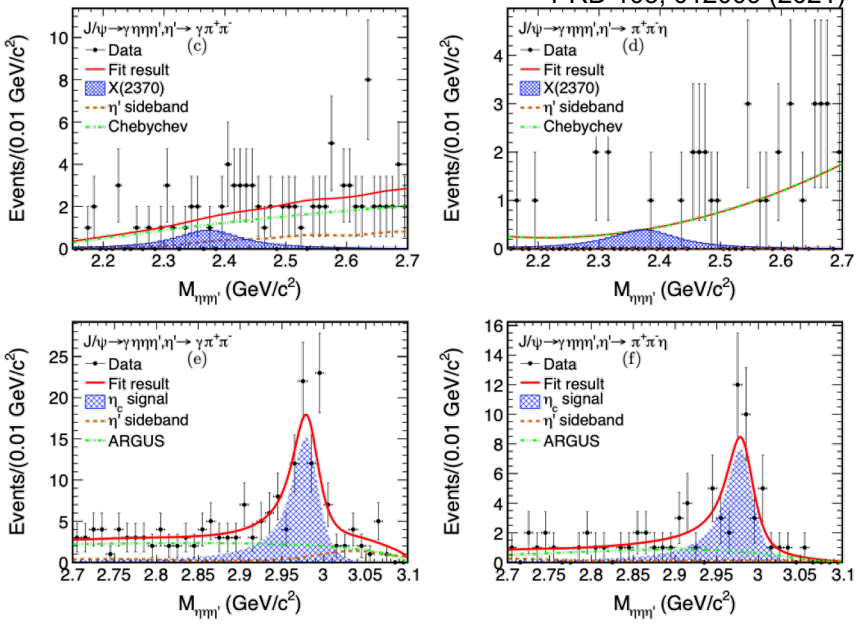
EPJC 80 (2020) 8, 746



- 8.3σ observation of $X(2370) \to \eta' K\bar{K}$

$J/\psi \to \gamma\eta'\eta\eta$:

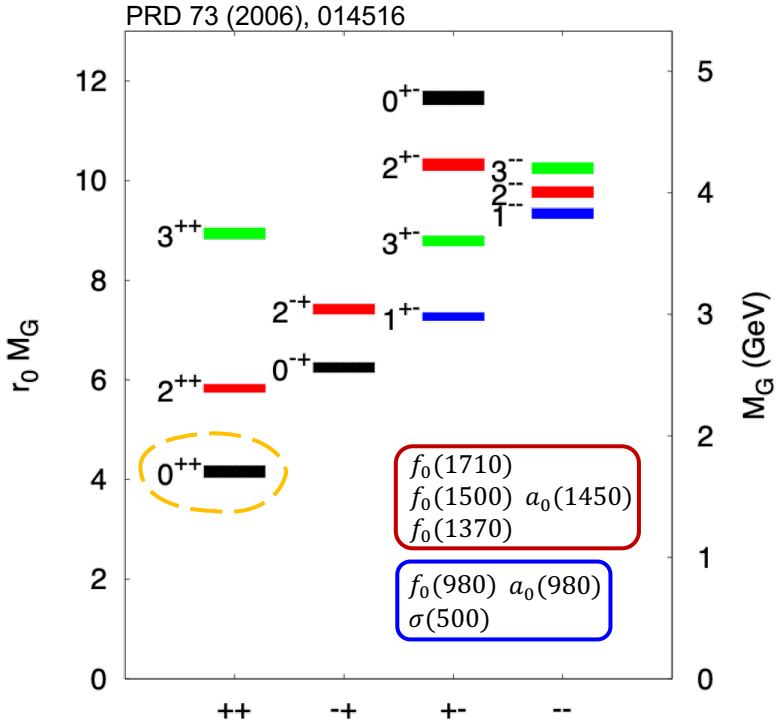
PRD 103, 012009 (2021)



- no indication for $X \to \eta'\eta\eta$ decays
- first observation of $\eta_c \to \eta'\eta\eta$

An isovector $a_0(1710)$?

Light scalar mesons

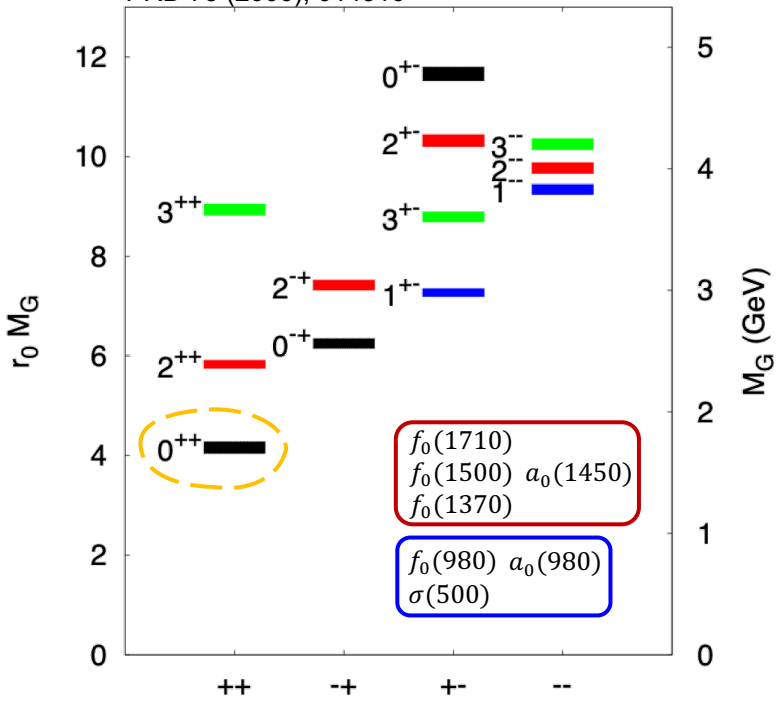


- lightest glueball predicted to be a scalar
- five well-established isoscalar scalar mesons:

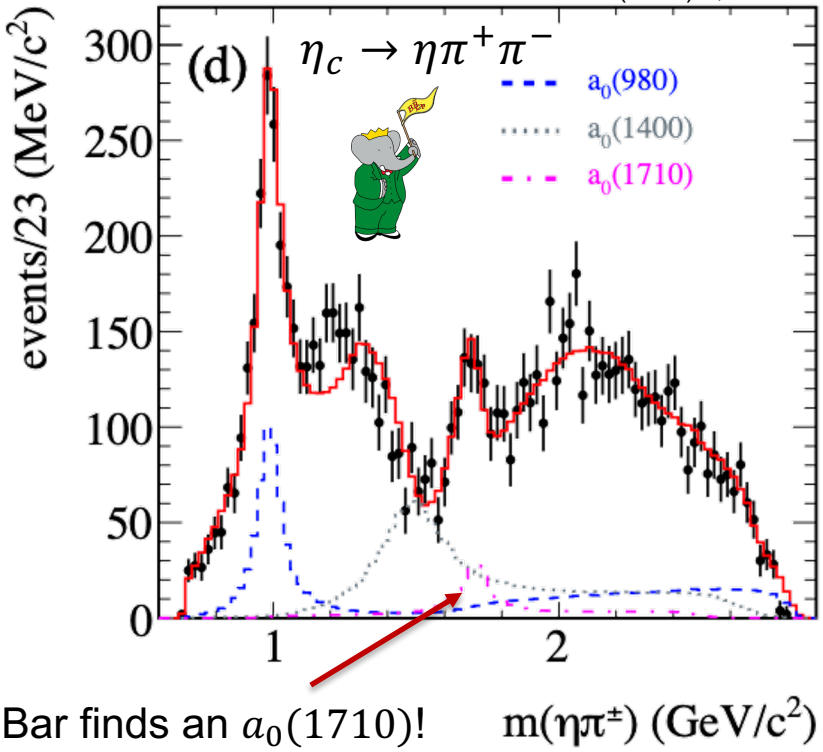
  $\sigma(500)$, $f_0(980)$,
  $f_0(1370)$, $f_0(1500)$, $f_0(1710)$
- seemingly an overpopulation…

Light scalar mesons

PRD 73 (2006), 014516



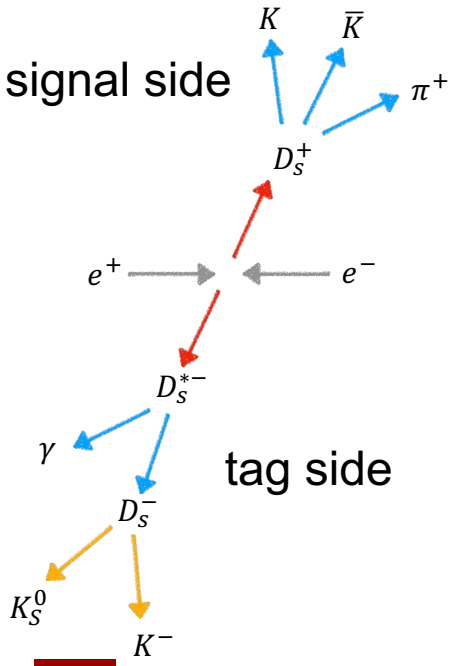
PRD 104 (2021) 7, 072002

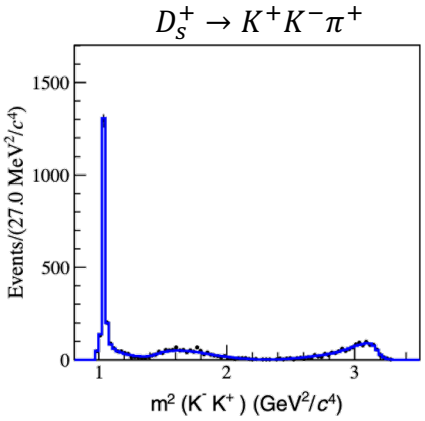


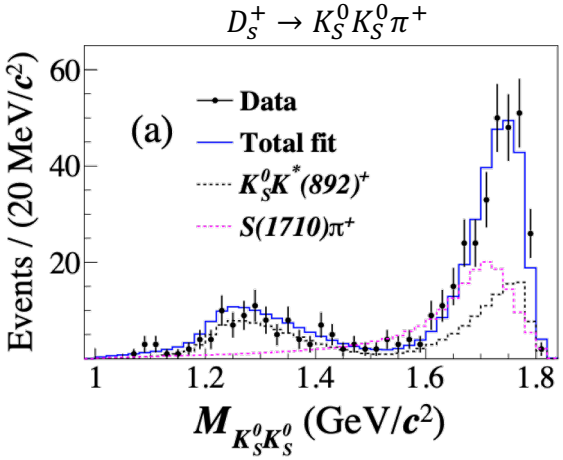
BaBar finds an $a_0(1710)$!

Isovector $a_0(1710)$ in D_s decays

- study of light scalar mesons in $D_s^+ \to K^+K^-\pi^+$ and $K_S^0K_S^0\pi^+$







$BF(D_s^+ \to S(980)\pi^+) = 1.05 \pm 0.04 \pm 0.06\ \%$
$BF(D_s^+ \to S(1710)\pi^+) = 0.10 \pm 0.02 \pm 0.03\ \%$

$BF(D_s^+ \to S(980)\pi^+)$ → decay not found
$BF(D_s^+ \to S(1710)\pi^+) = 0.31 \pm 0.03 \pm 0.01\ \%$

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

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

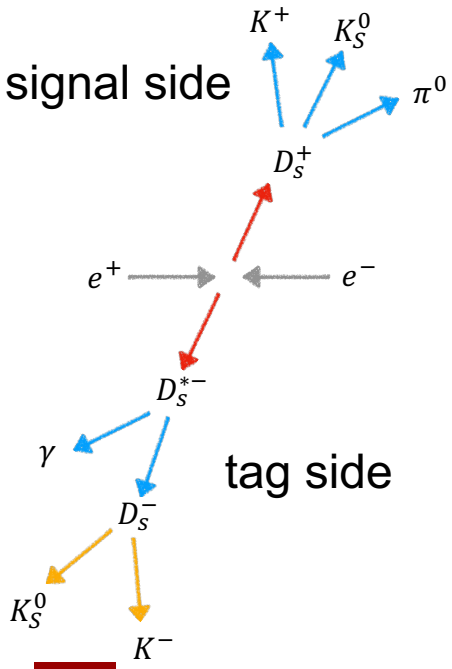
S. U. Chung, BNL-QGS-13-0901

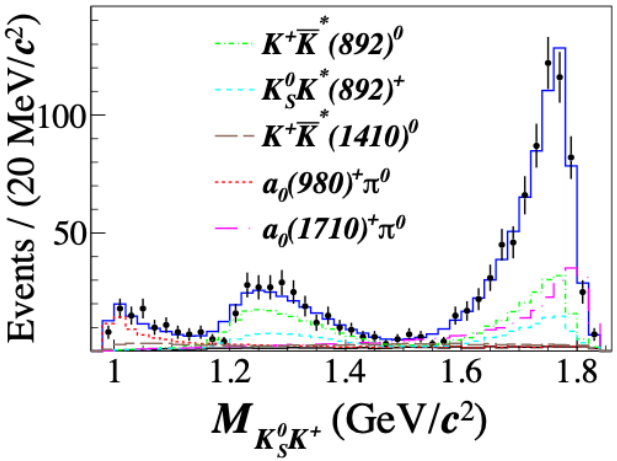
→ $a_0(980)$-$f_0(980)$ interference
→ $a_0(1710)$-$f_0(1710)$ interference → $a_0(1710)$ needed!

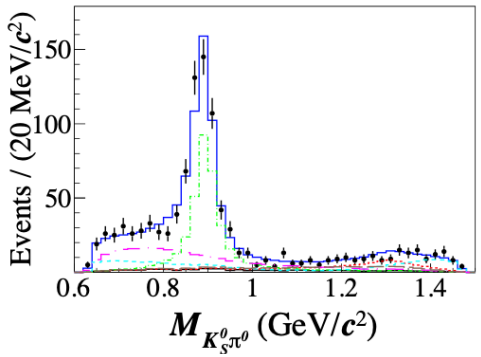
PRD 104 (2021), 012016 PRD 105 (2022) 5, L051103

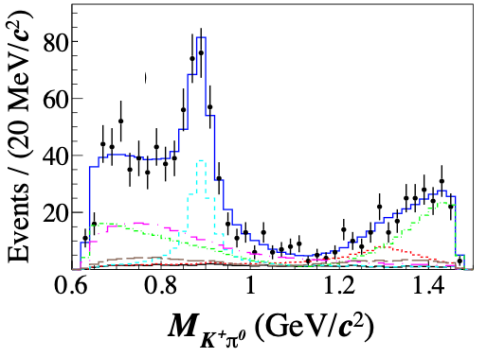
Isovector $a_0(1710)$ in D_s decays

- only isovector resonances in $K\bar{K}$ for $D_s^+ \to K^+ K_S^0 \pi^0$







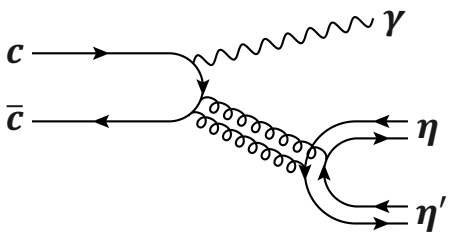


- confirmation of an $I = 1$ state $a_0(1710)$ in the charged channel
- existence suggested in [1] PRD 79, 074009 (2009) [2] EPJC 82, 225 (2022) [3] PLB 820, 136512 (2021)
- $BR(D_s \to a_0(1710)\pi)$ consistent with [2]

$J/\psi \to \gamma\eta'\eta^{(\prime)}$ decays

Spin-exotic $\eta_1(1855)$

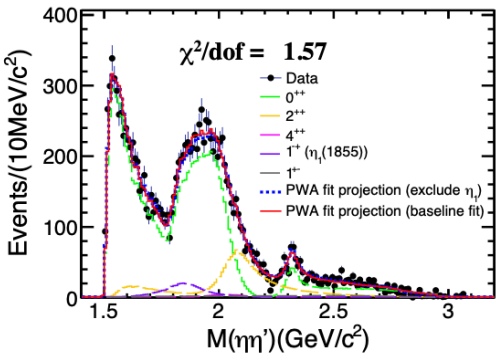
- PWA of $J/\psi \to \gamma\eta\eta'$

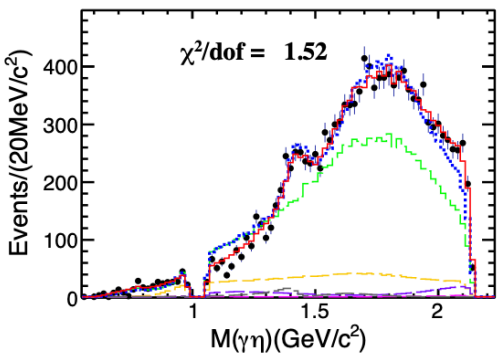


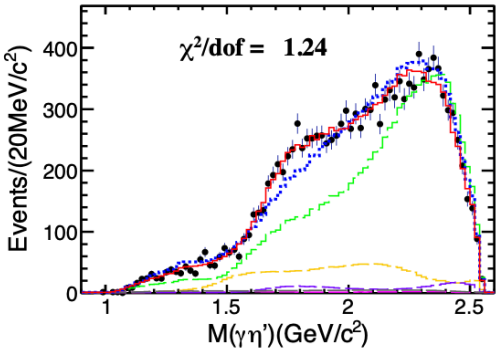
- iso-scalar spin-exotic $\eta_1(1855)$

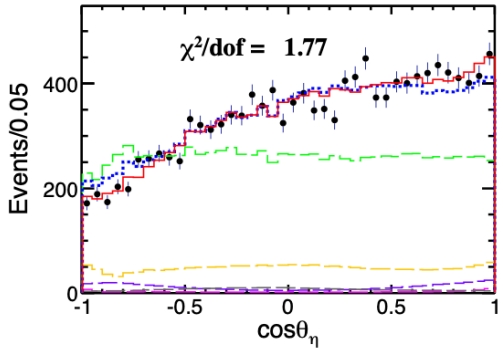
$$m = 1855 \pm 9^{+6}_{-1}\ \text{MeV}$$
$$\Gamma = 188 \pm 18^{+3}_{-8}\ \text{MeV}$$

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





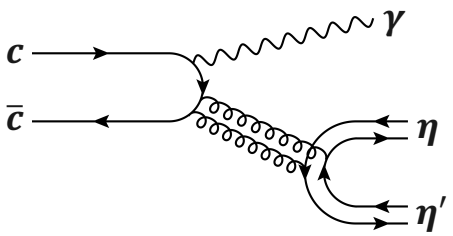




arXiv:2202.00621
arXiv:2202.00623

Spin-exotic $\eta_1(1855)$

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



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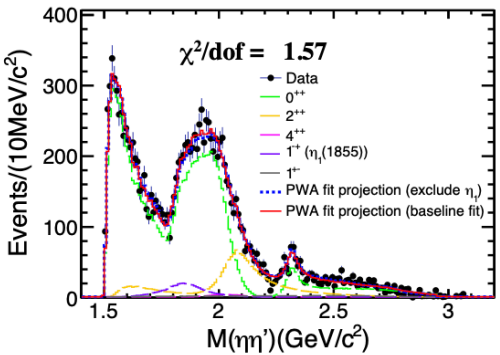
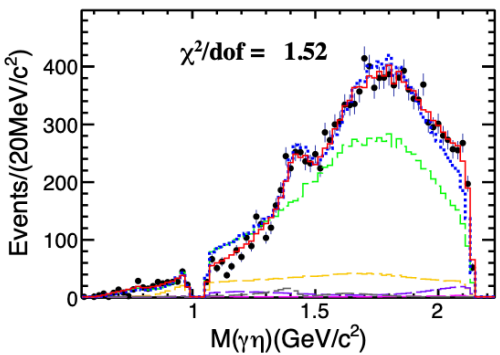
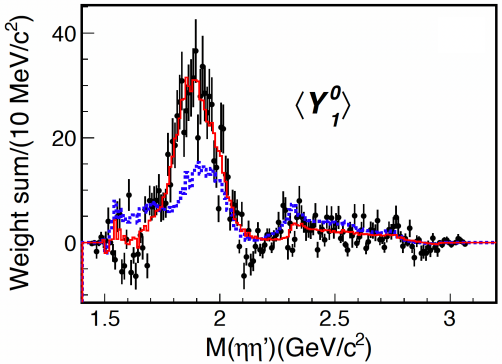
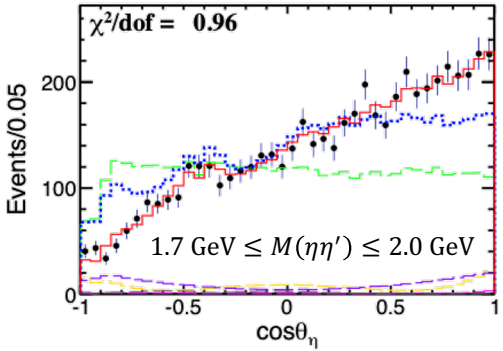








arXiv:2202.00621
arXiv:2202.00623

On $f_0(1500)$ and $f_0(1710)$

- scalar glueball decays to $\eta\eta'$ expected to be suppressed $\frac{B(G\to\eta\eta')}{B(G\to\pi\pi)} < 0.04$

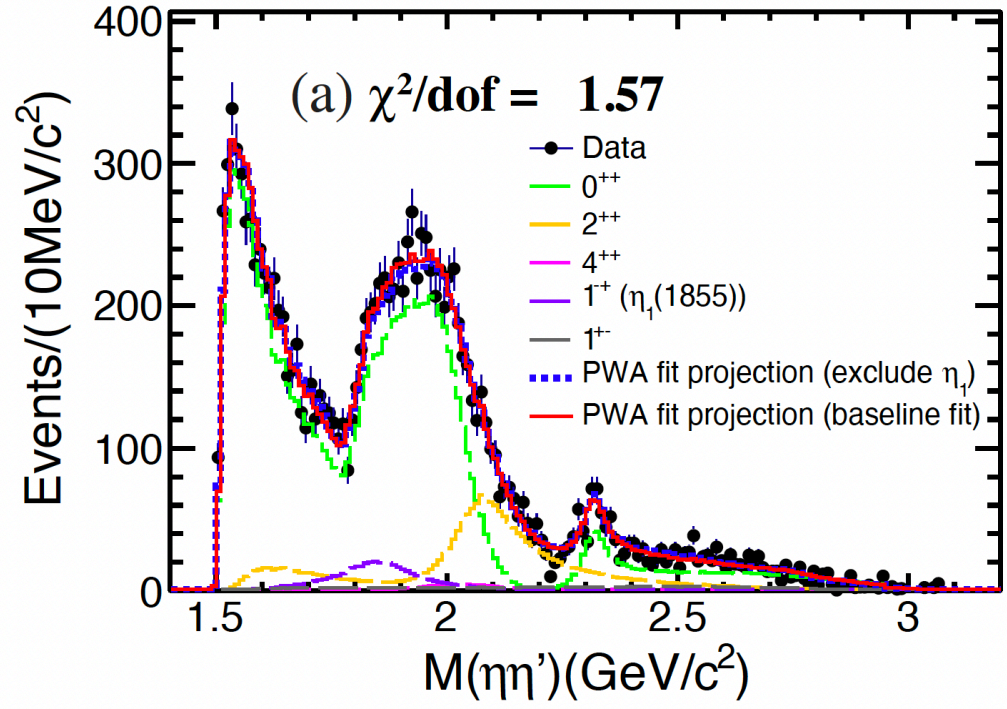
  PRD 92, 121902 (2015)

- significant $f_0(1500)$ contribution, but no $f_0(1710)$ (there is a small $f_0(1810)$ in the fit)

$$\frac{B(f_0(1500)\to\eta\eta')}{B(f_0(1500)\to\pi\pi)} = \left(8.96^{+2.95}_{-2.87}\right)\times10^{-2},$$

$$\frac{B(f_0(1710)\to\eta\eta')}{B(f_0(1710)\to\pi\pi)} < 1.61\times10^{-3} \text{ (90\% CL)}$$

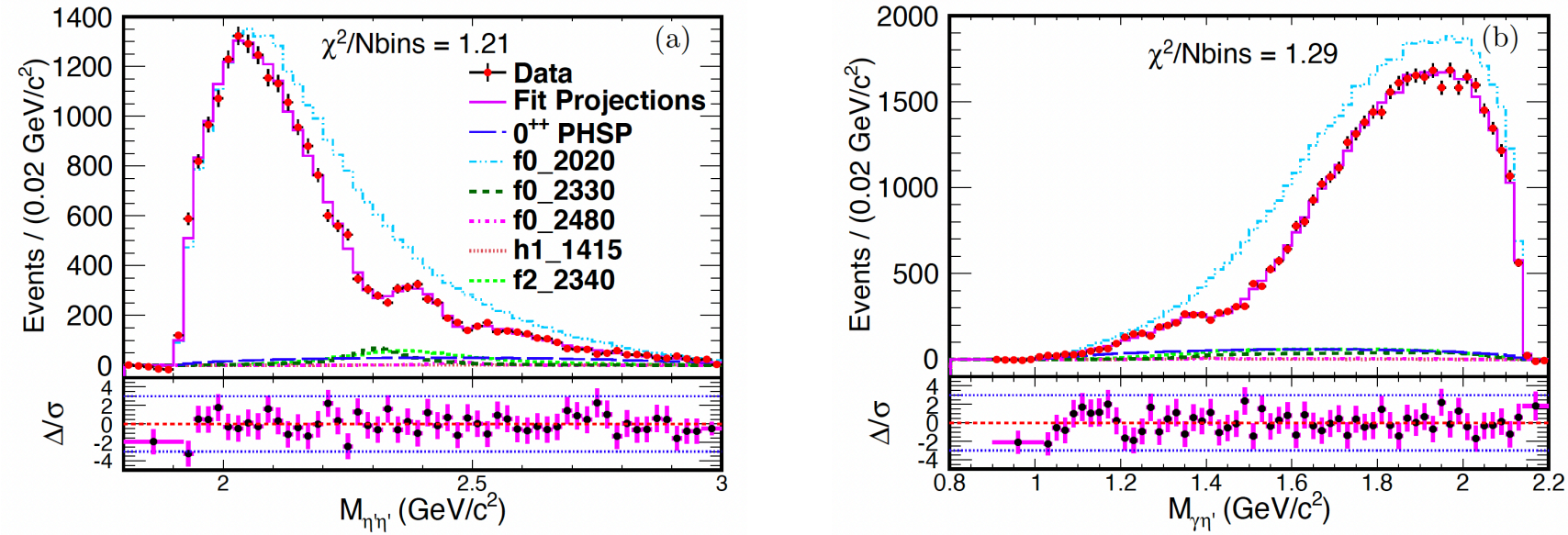
$$\frac{B(f_0(1810)\to\eta\eta')}{B(f_0(1710)\to\pi\pi)} = \left(1.39^{+0.62}_{-0.52}\right)\times10^{-2}$$



arXiv:2202.00621
arXiv:2202.00623

PWA of $J/\psi \to \gamma\eta'\eta'$

- similar analysis for $J/\psi \to \gamma\eta'\eta'$



- dominant contribution from $f_0(2020)$, in addition $f_0(2330)$, $f_0(2480)$, $f_2(2340)$ and $h_1(1415)$
- $f_0(2020)$ relative decay widths to $\eta\eta'$ and $\eta'\eta'$ consistent with expectation for singlet state

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, …)
  - …

see other talks:
XYZ States, Tue 1:45, J. Jackson
Nucleon Time-like Form Factors, Tue 1:45, X. Zhou
Hyperon Form Factors, Tue 3:00, V. Thoren
Baryons in $c\bar{c}$ Decays, Tue 3:15, R.G. Ping
Light Meson Decays, Wed 1:25, S. Fang
Hyperon Decays and Production, Wed 3:25, H. Li
Recent Results from BESIII, Fr 11:00, I. Garzia

- several new data sets currently being analyzed
  - first exciting results from **new J/ψ** and XYZ data
  - **new 2.7×10^9 $\psi(2S)$ dataset:** baryon spectroscopy, exotics in χ_{cJ} decays, …
  - many analyses in progress, plenty of results to come

BESIII White paper: arXiv:1912.05983
Chin. Phys. C 44, 040001 (2020)

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