Charmonium Decays into Light Hadrons at BESIII

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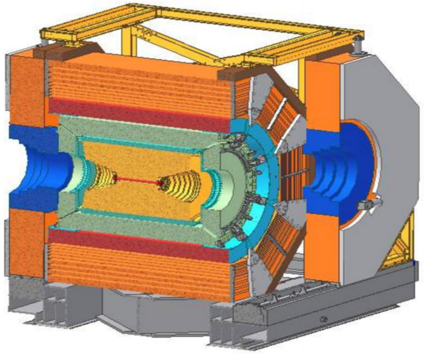
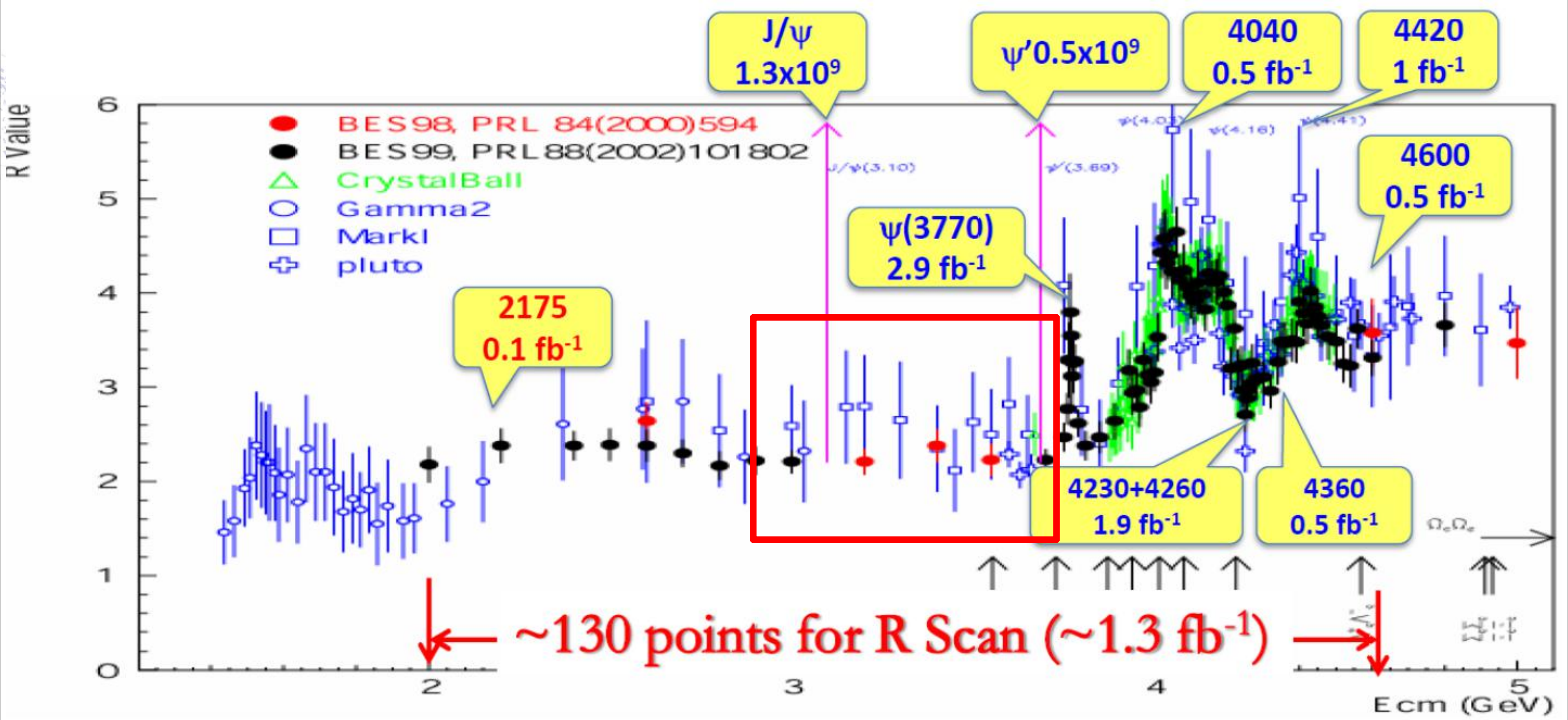
On behalf of BESIII Collaboration



Outline

- Data Set at BESIII
- Light Meson Spectroscopy
- $X(p\bar{p})$ and $X(1835)$
  - $J/\psi \to \gamma X \to \gamma K_S^0 K_S^0 \eta$
  - $J/\psi \to \gamma X \to \gamma \eta' \pi^+ \pi^-$
- Glueball Searches
  - $J/\psi \to \gamma \pi^0 \pi^0$
  - $J/\psi \to \gamma \phi\phi$
- $\chi_{c1} \to \eta \pi^+ \pi^-$
- Light Baryon Spectroscopy
  - $\psi(3686) \to (\gamma) K^{\mp} \Lambda \overline{\Xi}^{\pm}$
- Summary



3.1 fb^{-1} data at 4.18 GeV, 2016~2017

World largest J/ψ, ψ(3686), ψ(3770), … produced directly from e^+e^- collision: an ideal factory to study light meson spectroscopy

τ –charm physics

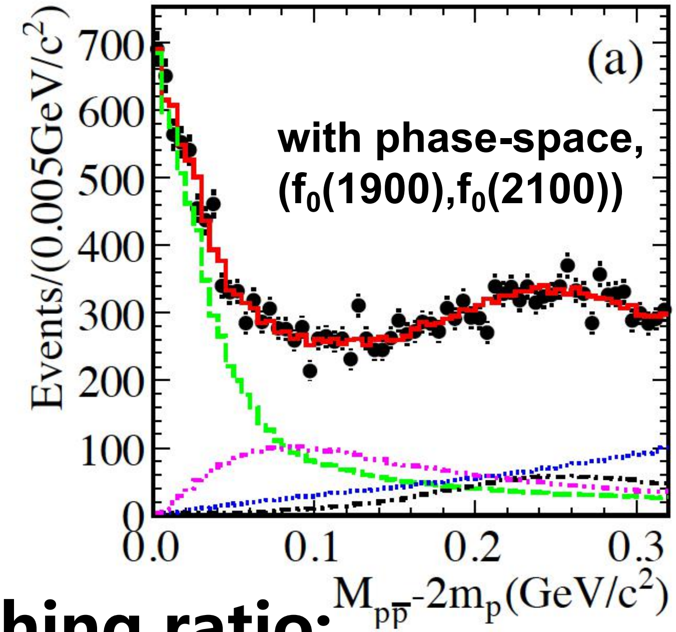
- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

Light Meson Spectroscopy

- **Light meson spectroscopy plays a crucial role in examining and understanding the QCD theory in non-perturbative energy region.**
- **J/ψ, χ_{c1} (the lowest 1^{--}, 1^{++} ccbar states) decays provide an ideal place to study the light meson spectroscopy.**

X(ppbar)

- **PWA of $J/\psi \to \gamma p\bar{p}$**
  - **The fit with a BW and S-wave FSI factor can well describe $p\bar{p}$ mass threshold structure.**
  - **It is much better than that without FSI effect (7.1σ).**
  - **It has model dependent uncertainty.**



- **Spin parity, mass, width and branching ratio:**
  - **$J^{pc}=0^{-+}$ (>6.8σ, better than other J^{pc} assignments)**

$$M = 1832^{+19}_{-5}(stat.)^{+18}_{-17}(sys.) \pm 19(model)\, MeV/c^2,$$

$$\Gamma = 13 \pm 39(stat.)^{+10}_{-13}(sys.) \pm 4(model)\, MeV/c^2, < 76\, MeV/c^2 (90\% CL),$$

$$B(J/\psi \to \gamma X) B(X \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(stat.)^{+1.5}_{-5.0}(sys.) \pm 2.3(model)) \times 10^{-5}$$

Phys. Rev. Lett. 108, 112003 (2012)

In J/ψ Hadronicdecays

BESIII, Phys. Rev. D87, 112004 (2013)

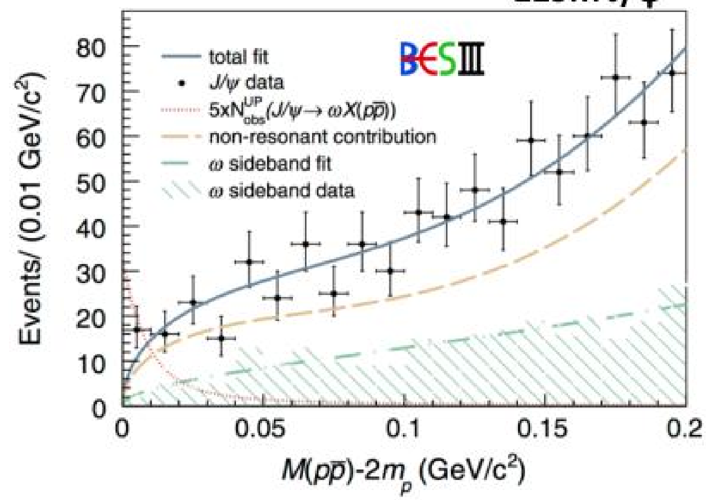
225M J/ψ

Study of J/ψ→ωp$\bar{p}$ and J/ψ→Φp$\bar{p}$ may shed further light on the nature of X(p$\bar{p}$)

$J/\psi \to \omega p\bar{p}$

B(J/ψ → ωX(p$\bar{p}$) → ωp$\bar{p}$) <3.7x10^{-6} (95% CL)

>10x suppressed compared to J/ψ →γX(p$\bar{p}$)→γp$\bar{p}$

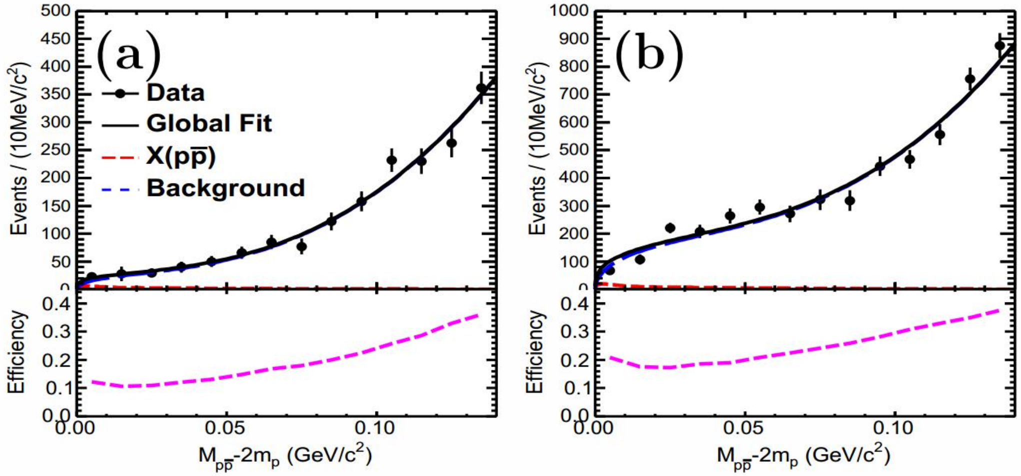


$J/\psi \to \phi p\bar{p}$

B(J/ψ→ΦX(p$\bar{p}$)→Φp$\bar{p}$) <2x10^{-7} (90% CL)

>100x suppressed compared to J/ψ → γX(p$\bar{p}$)→γp$\bar{p}$

$\psi(3686), B \to \gamma p\bar{p}$ *also* ×



Phys. Rev. D 93, 052010 (2016)

X(1835)

Phys. Rev. Lett. 95, 262001 (2005)

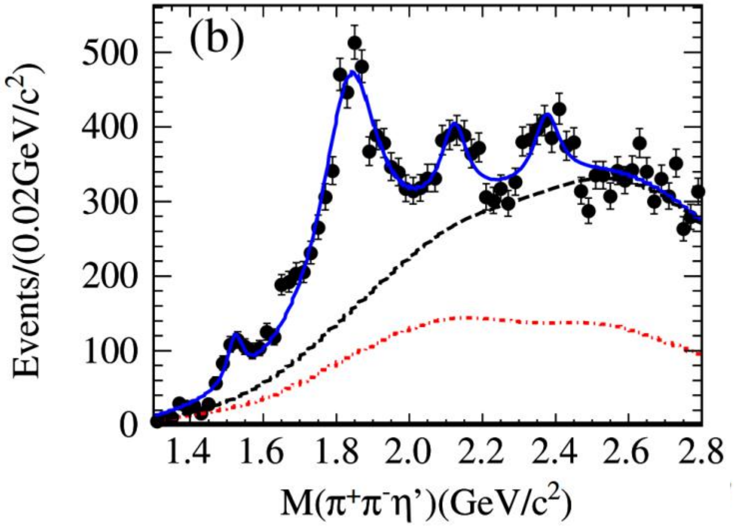
- **Discovered by BESII in $J/\psi \to \gamma\eta'\pi^+\pi^-$**
- **Confirmed by BESIII in $J/\psi \to \gamma\eta'\pi^+\pi^-$**

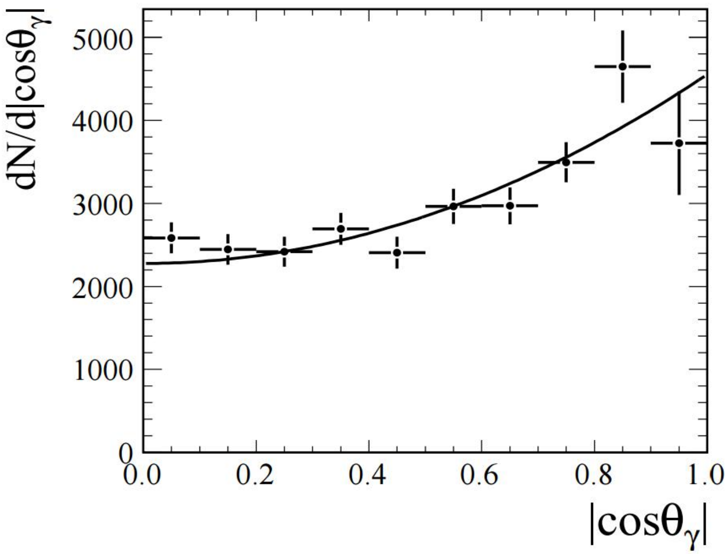
$$M = 1836.5 \pm 3.0^{+5.6}_{-2.1}\ MeV/c^2$$

$$\Gamma = 190 \pm 9^{+38}_{-36}\ MeV/c^2$$

Phys. Rev. Lett. 106, 072002 (2011)

Angular distribution is consistent with 0^-





$J/\psi \rightarrow \gamma K_S K_S \eta$

- **The structure around 1.85 GeV/c² in the $K_S K_S \eta$ mass spectrum is strongly correlated to $f_0(980)$**
- **Partial Wave Analysis for $M(K_S K_S) < 1.1$ GeV/c²**
  - **X(1835)→$K_S K_S \eta$ ($f_0(980)$ is dominant)**

    $J^{PC} = 0^{-+}, > 12.9\sigma$

    $M = 1844 \pm 9^{+16}_{-25}\ MeV/c^2, \Gamma = 192^{+20}_{-17}\ {}^{+38}_{-36} MeV/c^2$

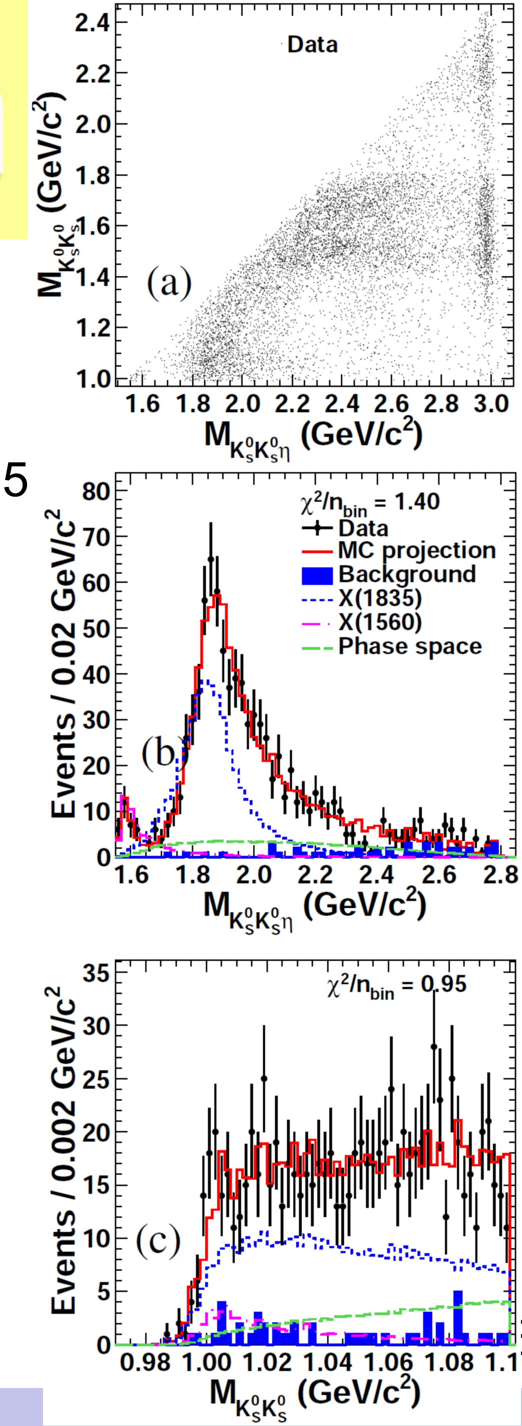
    $B(J/\psi \rightarrow \gamma X(1835)) B(X(1835) \rightarrow K_S K_S \eta)$

    $= (3.31^{+0.33}_{-0.30}\ {}^{+1.96}_{-1.29}) \times 10^{-5}$
  - **X(1560)→$f_0(980)\eta$**

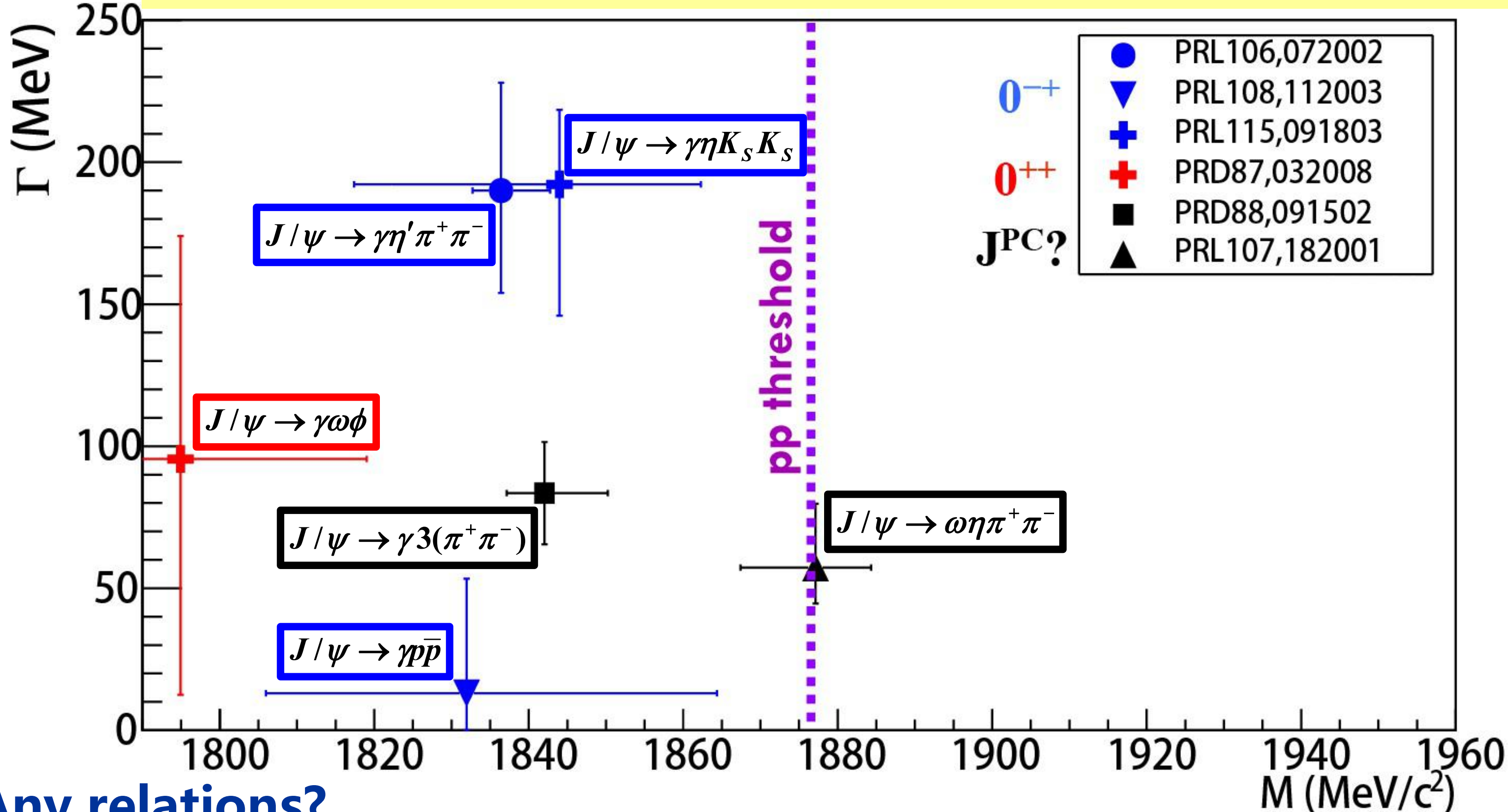
    $J^{PC} = 0^{-+}, > 8.9\sigma$

    $M = 1565 \pm 8^{+0}_{-63}\ MeV/c^2, \Gamma = 45^{+14}_{-13}\ {}^{+21}_{-28} MeV/c^2$

Phys.Rev.Lett. 115 091803(2015)

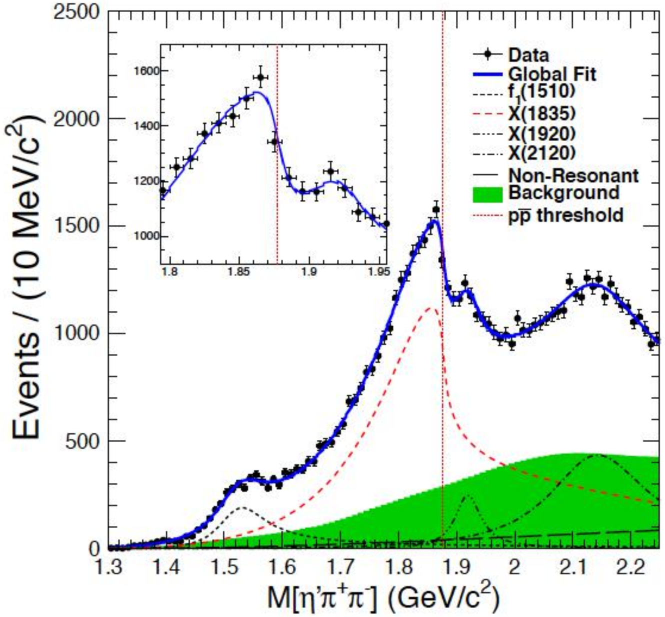


X(1835) and ppbar Threshold



- **Any relations?**
- **What is the role of the ppbar threshold?**
- **Patterns in the production and decay modes**

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



PRL 117, 042002 (2016)

The state around 1.85 GeV/c²	
$\mathcal{M}$ (MeV/c^2)	$1638.0\ ^{+121.9}_{-121.9}\ ^{+127.8}_{-254.3}$
g_0^2 ((GeV/c^2)^2)	$93.7\ ^{+35.4}_{-35.4}\ ^{+47.6}_{-43.9}$
$\mathbf{g^2_{p\bar{p}}/g^2_0}$	$\mathbf{2.31\ ^{+0.37}_{-0.37}\ ^{+0.83}_{-0.60}}$
M_{pole} (MeV/c^2) *	$1909.5\ ^{+15.9}_{-15.9}\ ^{+9.4}_{-27.5}$
Γ_{pole} (MeV/c^2) *	$273.5\ ^{+21.4}_{-21.4}\ ^{+6.1}_{-64.0}$
Branching Ratio	$(3.93\ ^{+0.38}_{-0.38}\ ^{+0.31}_{-0.84}) \times 10^{-4}$

* The pole nearest to the $p\bar{p}$ mass threshold

Model 1:

Flatte lineshape with strong coupling to $p\bar{p}$ and one additional, narrow Breit-Wigner at ~1920 MeV/c²

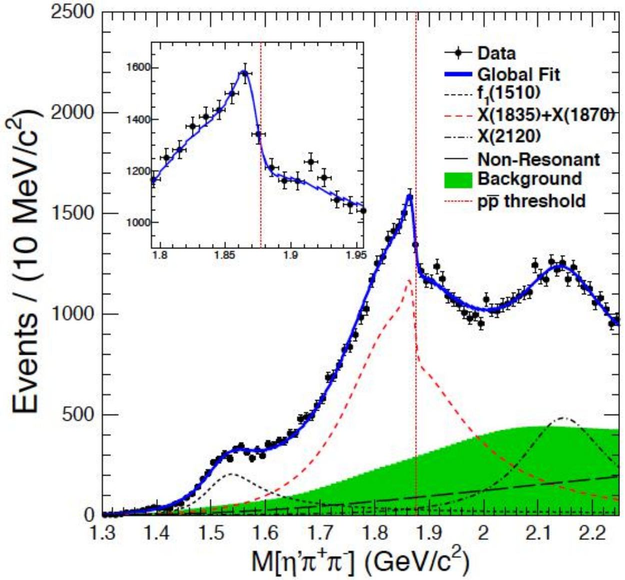
a $p\bar{p}$ molecule-like state?

Significance of $g^2_{p\bar{p}}/g^2_0$ being non-zero is larger than 7σ

X(1920) is needed with 5.7σ

$$T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k} \approx \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i g_0^2 \left(\rho_0 + \frac{g^2_{p\bar{p}}}{g_0^2}\rho_{p\bar{p}}\right)}$$

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



PRL 117, 042002 (2016)

X(1835)	
M (MeV/c^2)	$1825.3\ ^{+2.4}_{-2.4}\ ^{+17.3}_{-2.4}$
Γ (MeV/c^2)	$245.2\ ^{+14.2}_{-12.6}\ ^{+4.6}_{-9.6}$
B.R. (constructive interference)	$(3.01\ ^{+0.17}_{-0.17}\ ^{+0.26}_{-0.28}) \times 10^{-4}$
B.R. (destructive interference)	$(3.72\ ^{+0.21}_{-0.21}\ ^{+0.18}_{-0.35}) \times 10^{-4}$

X(1870)	
M (MeV/c^2)	$1870.2\ ^{+2.2}_{-2.3}\ ^{+2.3}_{-0.7}$
Γ (MeV/c^2)	$\mathbf{13.0\ ^{+7.1}_{-5.5}\ ^{+2.1}_{-3.8}}$
B.R. (constructive interference)	$(2.03\ ^{+0.12}_{-0.12}\ ^{+0.43}_{-0.70}) \times 10^{-7}$
B.R. (destructive interference)	$(1.57\ ^{+0.09}_{-0.09}\ ^{+0.49}_{-0.86}) \times 10^{-5}$

Model 2:
Coherent sum of X(1835) Breit-Wigner and one additional, narrow Breit-Wigner at ~1870 MeV/c^2

Significance of X(1870) is larger than 7σ

$$T = \left(\frac{\sqrt{\rho_{\rm out}}}{M_1^2 - s - iM_1\Gamma_1} + \frac{\beta e^{i\theta}\sqrt{\rho_{\rm out}}}{M_2^2 - s - iM_2\Gamma_2} \right)$$

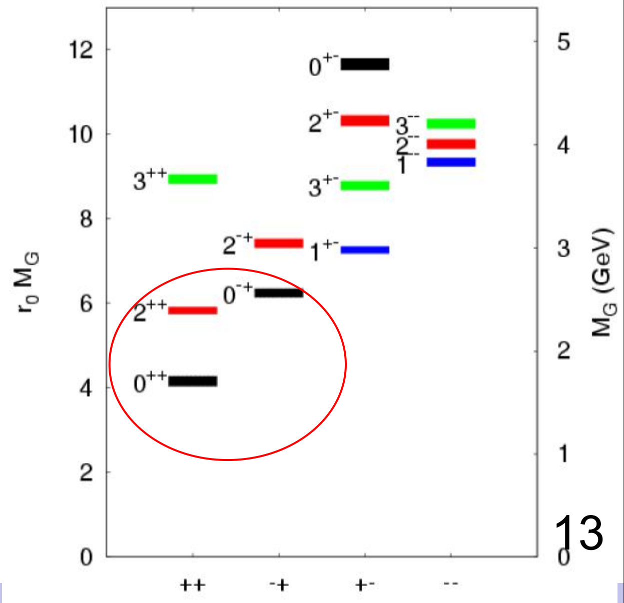
X(1920) is not significant

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

- **The anomalous line shape can be modeled by two models with equally good fit quality.**
  - **Suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold**
  - **Support the existence of a $p\bar{p}$ molecule-like state or bound state**
- **To elucidate further the nature of the state**
  - **more data or studying line shapes in other related decay channels**

Glueball Searches

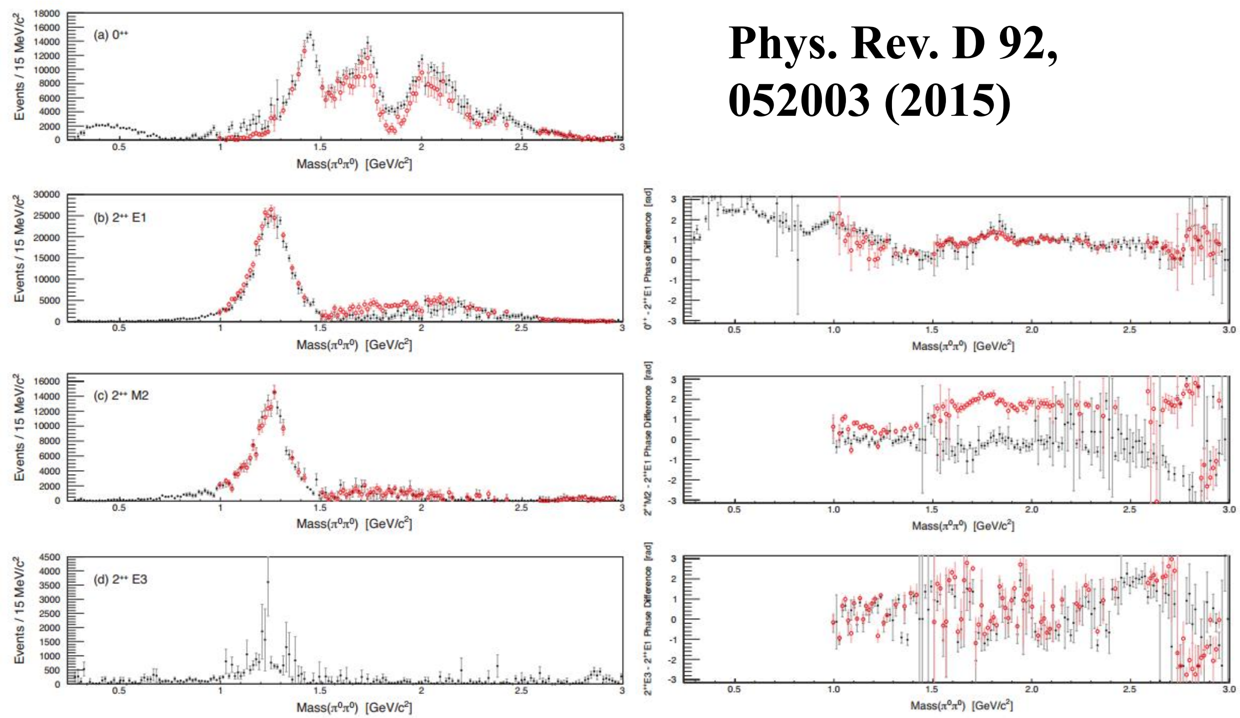
- Lattice QCD predictions:
  - Ground state of 2^{++} glueball in 2.3~2.4 GeV/c^2
  - Ground state of 0^{-+} glueball in 2.3~2.6 GeV/c^2
- Structures in $\phi\phi$ spectrum:
  - Pseudoscalar state η(2225) was observed in $J/\psi \to \gamma\phi\phi$ in DM2, MARKIII and BESII [PLB 241, 617 (1990); PRL 65, 1309 (1990);PLB 662, 330(2008)]
  - For higher 0^{-+}mass states above 2GeV/c^2, very little is known
  - Broad 2^{++} structures $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ were observed at BNL [PLB 165, 217 (1985); PLB 201, 568 (1988)]
- Tensor:
  - $f_2(2010)$, $f_2(2300)$, $f_2(2340)$: stated in $\pi^- p$ reaction
  - strong $f_2(2340)$ production
- Pseudoscalar:
  - η(2225): Dominant
  - η(2100) and X(2500)



Model Independent PWA
$J/\psi \to \gamma\pi^0\pi^0$

- **Extract amplitudes in each $M(\pi^0\pi^0)$ mass bin**
- **Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0GeV/c²**
- **Multi-solution problem in MIPWA is usually unavoidable**
- **Model dependent fit to the data is needed to extract model parameters**

Phys. Rev. D 92, 052003 (2015)



Extracted Intensity

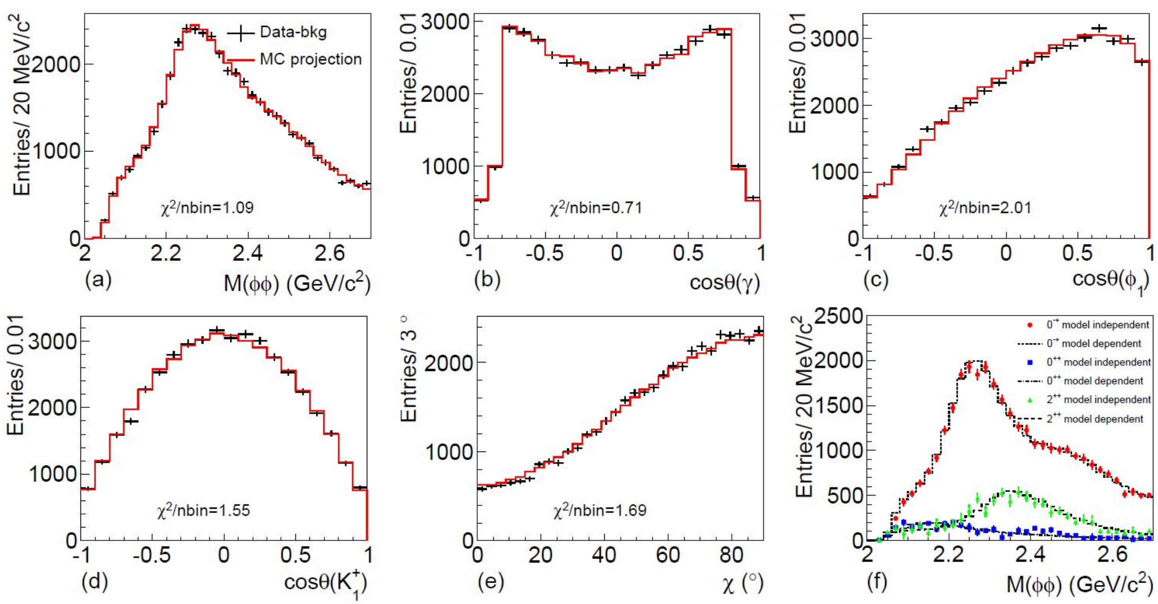
Relative Phase

Nominal Solution

Ambiguous Solution

PWA of $J/\psi \rightarrow \gamma\phi\phi$

- Besides $\eta(2225)$, very little was known in the sector of pseudoscalar above 2 GeV. The new experimental results are helpful for mapping out the pseudoscalarexcitations and searching for 0^{-+}glueball
- Dominant contribution from pseudoscalars
  - $\eta(2225)$ is confirmed;
  - $\eta(2100)$ and X(2500) are observed with large significance.
- The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in π^-N reactions (and ppar collisions) are also observed with a strong production of $f_2(2340)$.
- Model-dependent PWA results are well consistent with results from MIPWA



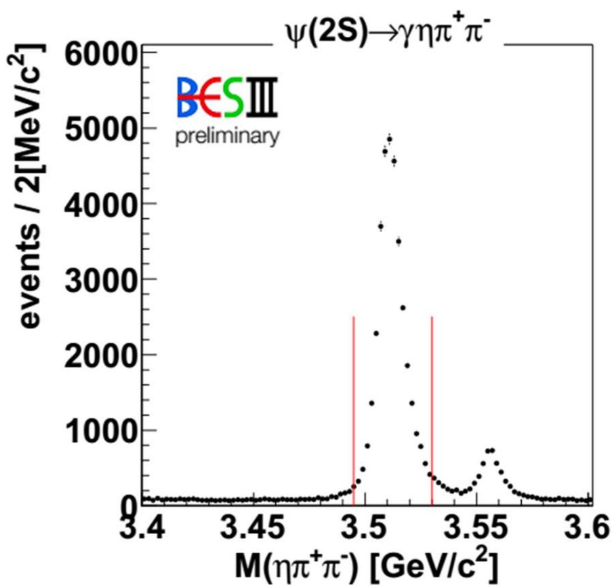
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	B.F.$(\times 10^{-4})$	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Phys. Rev. D 93 112011 (2016)

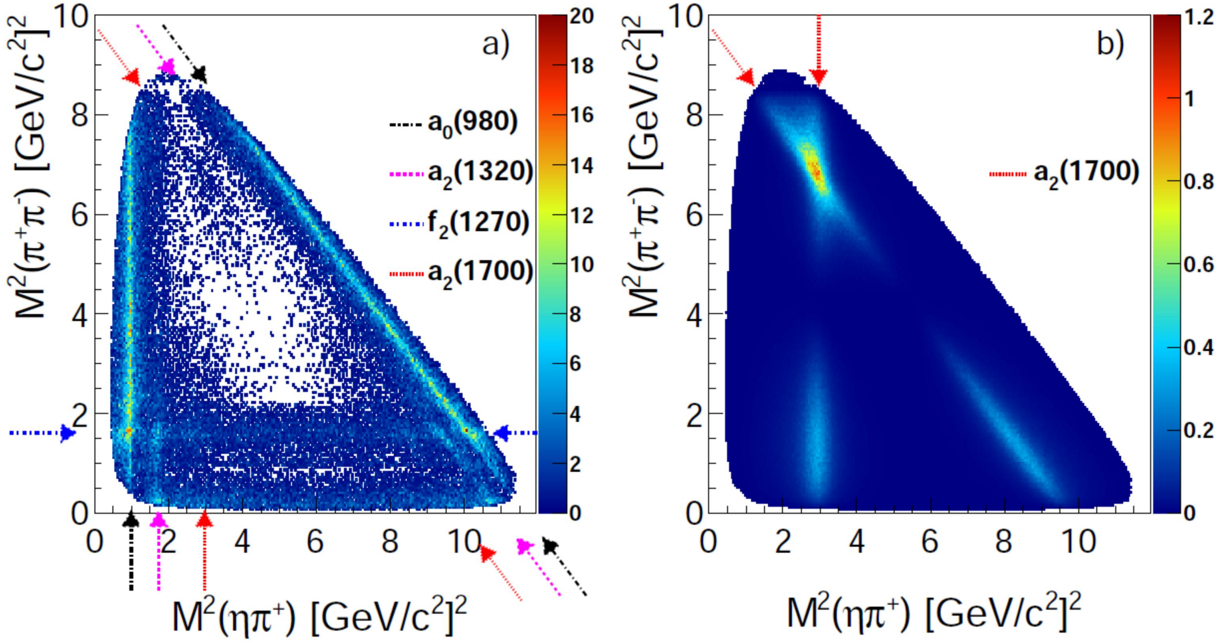
$\chi_{c1} \rightarrow \eta\pi^+\pi^-$

- χ_{c1} provides another suitable environment to look for 1^{-+}
- $\pi_1(1600)$ studied in χ_{c1} decays by CLEO-c
- only $\pi_1(1400)$ has been reported decays to $\eta\pi$
- Properties of a_2 and a_0 still need further studies

$N(\chi_{c1}) \sim 35000$

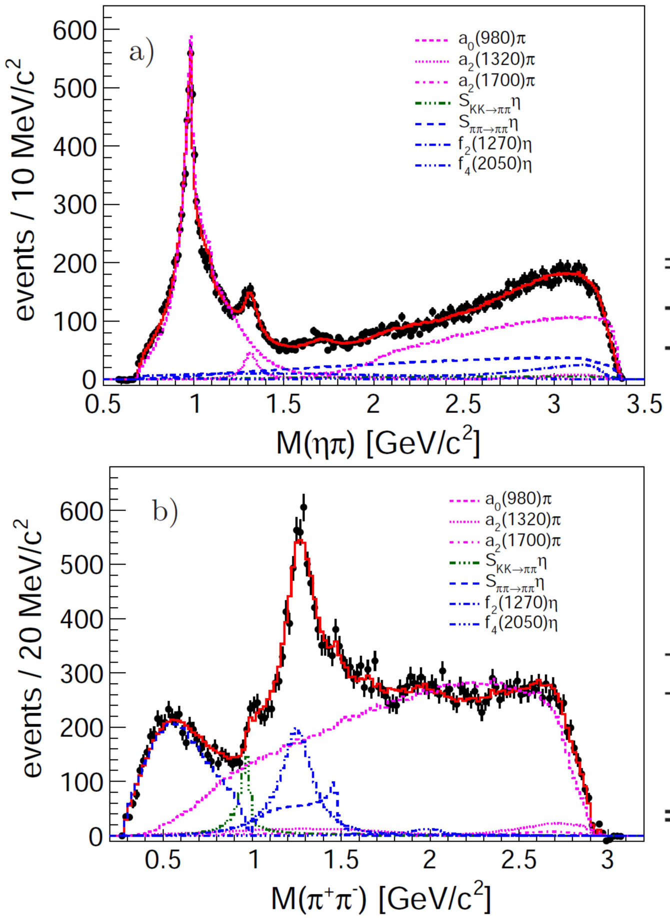


compatible with $a_2(1700)$ hypothesis



Phys. Rev. D 95, 032002 (2017)

$\chi_{c1} \rightarrow \eta\pi^+\pi^-$



$\pi\pi$ S-wave:
N/D by A.Szczepaniak
PRD84, 112009

$a_0(980)$:
dispersion integrals
PRD78,74023

Decay	$\mathcal{F}$ [%]	Significance [σ]	$\mathcal{B}(\chi_{c1} \to \eta\pi^+\pi^-)$ [10^{-3}]
$\eta\pi^+\pi^-$	...	...	$4.67 \pm 0.03 \pm 0.23 \pm 0.16$
$a_0(980)^+\pi^-$	$72.8 \pm 0.6 \pm 2.3$	> 100	$3.40 \pm 0.03 \pm 0.19 \pm 0.11$
$a_2(1320)^+\pi^-$	$3.8 \pm 0.2 \pm 0.3$	32	$0.18 \pm 0.01 \pm 0.02 \pm 0.01$
$a_2(1700)^+\pi^-$	$1.0 \pm 0.1 \pm 0.1$	20	$0.047 \pm 0.004 \pm 0.006 \pm 0.002$
$S_{K\bar{K}}\eta$	$2.5 \pm 0.2 \pm 0.3$	22	$0.119 \pm 0.007 \pm 0.015 \pm 0.004$
$S_{\pi\pi}\eta$	$16.4 \pm 0.5 \pm 0.7$	> 100	$0.76 \pm 0.02 \pm 0.05 \pm 0.03$
$(\pi^+\pi^-)_S\eta$	$17.8 \pm 0.5 \pm 0.6$	...	$0.83 \pm 0.02 \pm 0.05 \pm 0.03$
$f_2(1270)\eta$	$7.8 \pm 0.3 \pm 1.1$	> 100	$0.36 \pm 0.01 \pm 0.06 \pm 0.01$
$f_4(2050)\eta$	$0.6 \pm 0.1 \pm 0.2$	9.8	$0.026 \pm 0.004 \pm 0.008 \pm 0.001$
Exotic candidates			U.L. [90% C.L.]
$\pi_1(1400)^+\pi^-$	0.58 ± 0.20	3.5	< 0.046
$\pi_1(1600)^+\pi^-$	0.11 ± 0.10	1.3	< 0.015
$\pi_1(2015)^+\pi^-$	0.06 ± 0.03	2.6	< 0.008

- Clear evidence for $a_2(1700)$ in χ_{c1} decays.
- Measured upper limits for $\pi_1(1^{-+})$ in 1.4-2.0 GeV/c^2 region.

Phys. Rev. D 95, 032002 (2017)

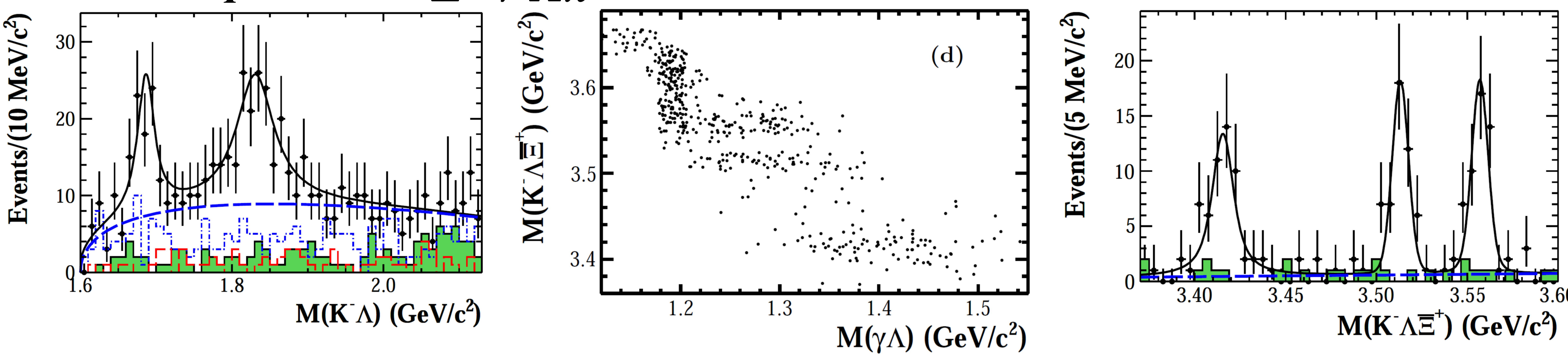
$\psi(3686) \to (\gamma) K^{\mp} \Lambda \overline{\Xi}^{\pm}$

- **Baryon spectroscopy is far from complete, since many of the states expected in the SU(3) multiplets are either undiscovered or not well established**
- **Small production cross sections(Ξ^{*})**

$\psi(3686) \to (\gamma) K^{\mp} \Lambda \overline{\Xi}^{\pm}$

$\Lambda \to p\pi \qquad \overline{\Xi} \to \overline{\Lambda}\pi$

Phys. Rev. D 91, 092006 (2015)



$\psi(3686) \to (\gamma) K^{\mp}\Lambda\bar{\Xi}^{\pm}$

- **Observe two hyperons, Ξ(1690) and Ξ(1820) in M(KΛ)**
  - **Both are well established states**
  - **Resonance parameters consist with PDG**
- **The measurements provide new information on charmonium decays to hyperons and on the resonance parameters of the hyperons**
- **It may help in the understanding of the charmonium decay mechanism**

Phys. Rev. D 91, 092006 (2015)

Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+,\ \Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+,\ \Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0},\ \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1},\ \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2},\ \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7\pm3.8\pm1.0$	$1826.7\pm5.5\pm1.6$
$\Gamma(\mathrm{MeV})$	$27.1\pm10.0\pm2.7$	$54.4\pm15.7\pm4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}$ (10^{-6})	$5.21\pm1.48\pm0.57$	$12.03\pm2.94\pm1.22$
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	<30	24^{+15}_{-10}

Summary

- **Highlights of latest results in light hadron spectroscopy from BESIII**
  - **Observation of X(1835) in $J/\psi \to \gamma K_S K_S \eta$**
    - New decay mode of X(1835) and its J^{PC} is determined: 0^{-+}
  - **Observation of anomalous $\eta'\pi^+\pi^-$ line shape near ppbar mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$**
    - Support the existence of a ppbar bound state or molecule-like state
  - **Model independent partial wave analysis of $J/\psi \to \gamma\pi^0\pi^0$**
    - Useful information for 0^{++}, 2^{++} components
  - **Partial wave analysis of $J/\psi \to \gamma\phi\phi$**
    - Resonance parameters for glueball search
  - **$\chi_{c1} \to \eta\pi^+\pi^-$**
    - $a_2(1700)$ in χ_{c1} decays and upper limits for π_1
  - $\psi(3686) \to (\gamma) K^{\mp}\Lambda\overline{\Xi}^{\pm}$
    - Observe two hyperons

Thanks for your attention!