Light quark physics at BESIII

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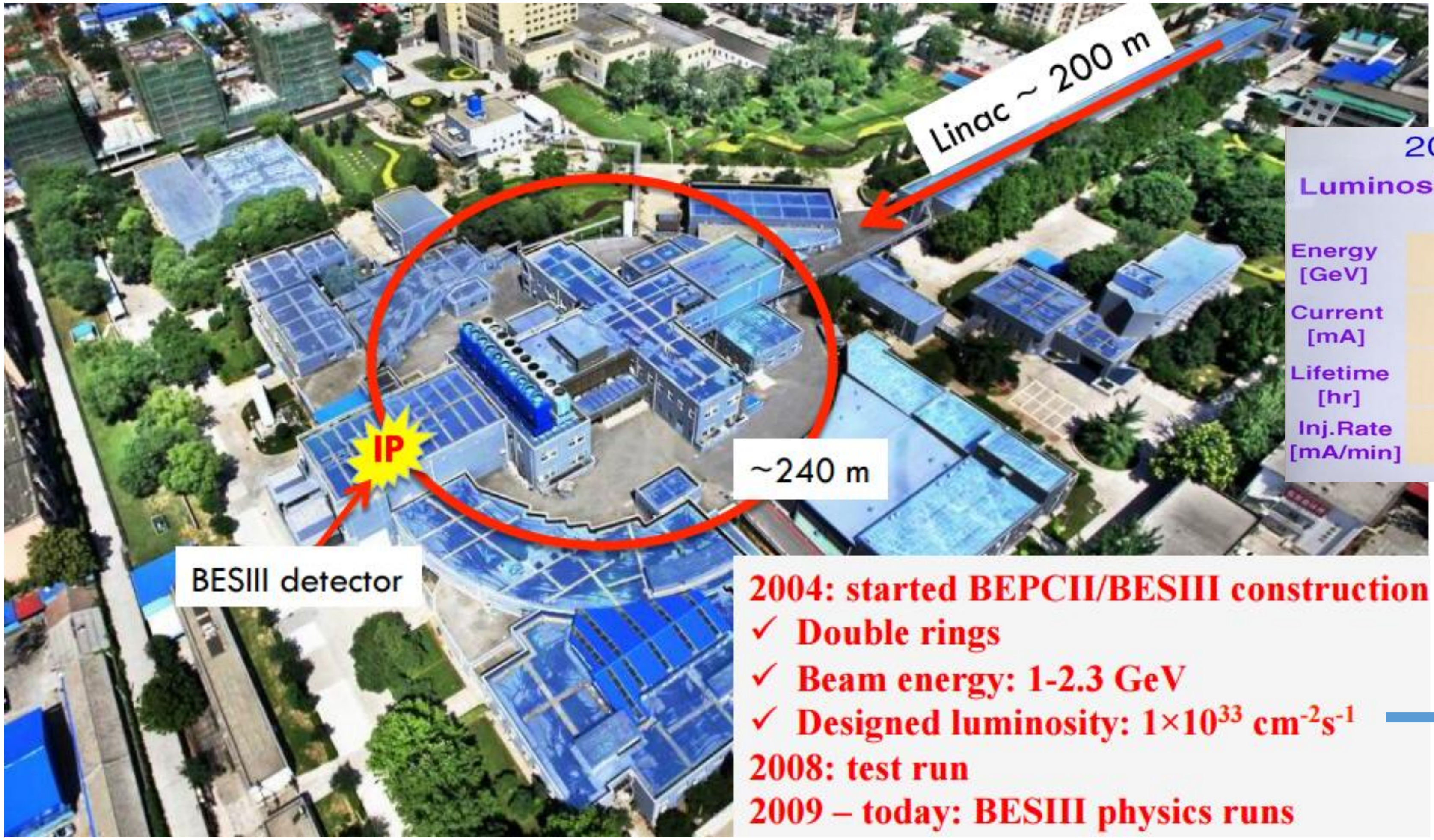
Out line

- BEPCII and BESIII
- Recent highlights from BESIII on Light Hadrons
  - Research on Helicity-selection-rule suppressed decays
  - Research on η(1405)/η(1475)
  - Research on X(1835) and X($p\bar{p}$)
  - Research on glueballs
- Summary and Conclusions

BEPCII and BESIII

Beijing Electron Positron Collider II



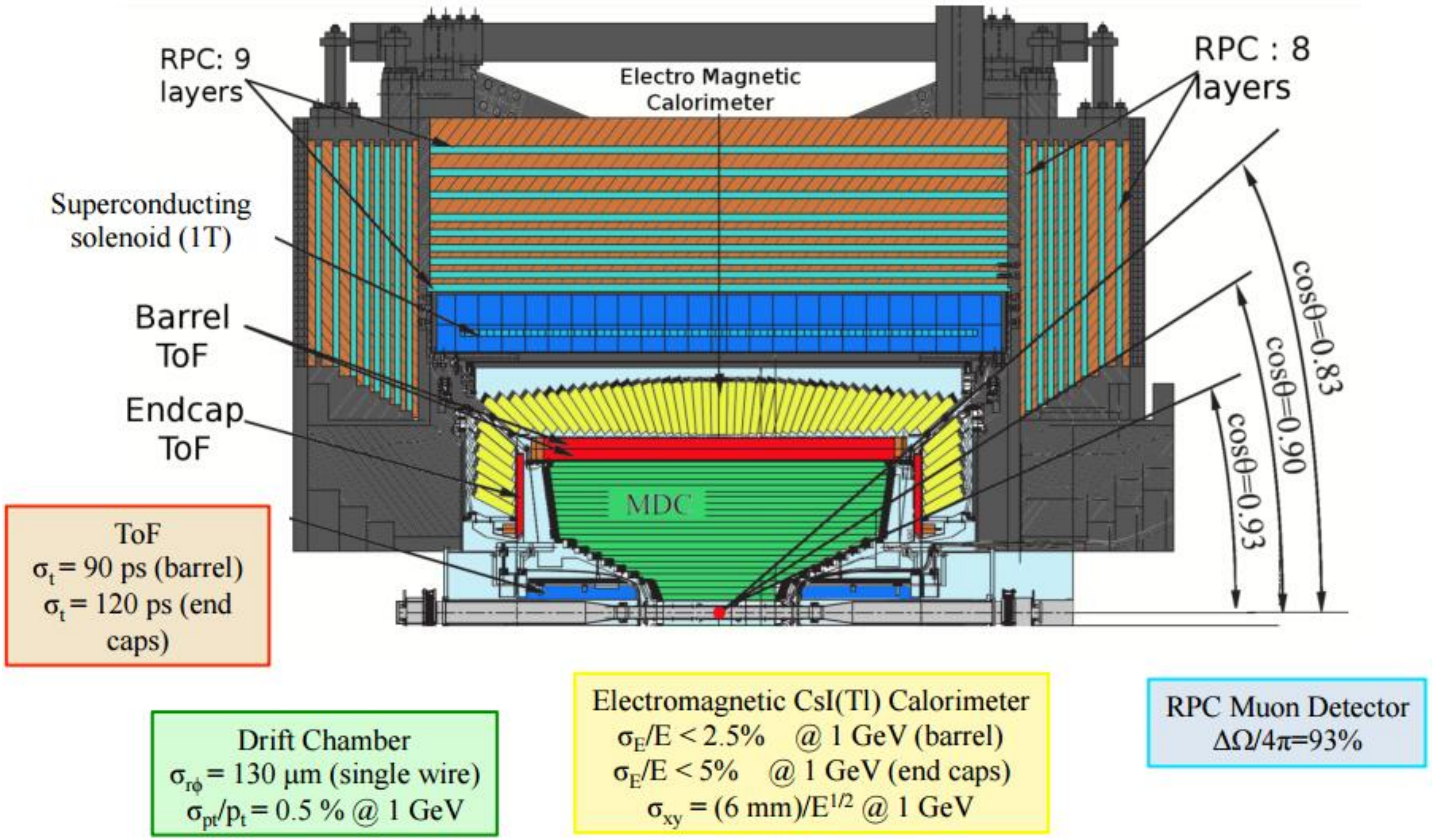
2016/04/05 22:29:41

Luminosity 10.00 E32/cm^2/s

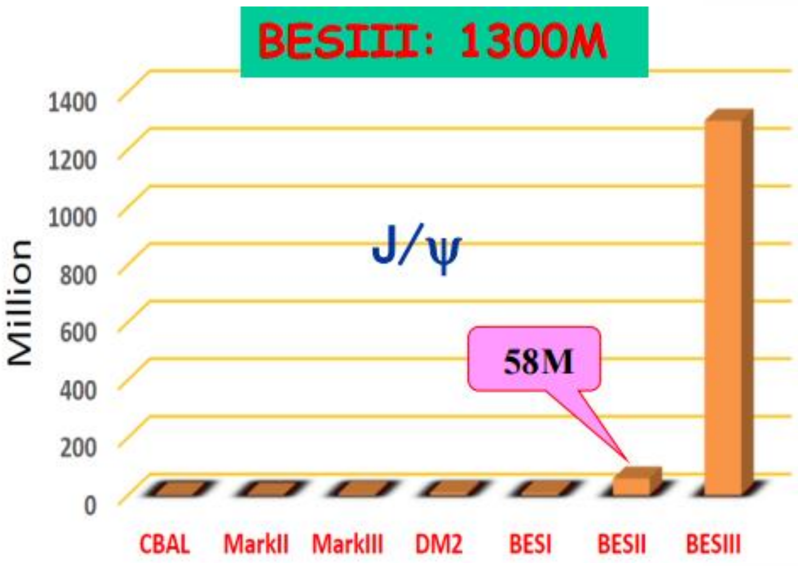
	e+	e−
Energy [GeV]	1.8833	1.8830
Current [mA]	849.97	852.83
Lifetime [hr]	1.52	2.27
Inj.Rate [mA/min]	0.00	0.00

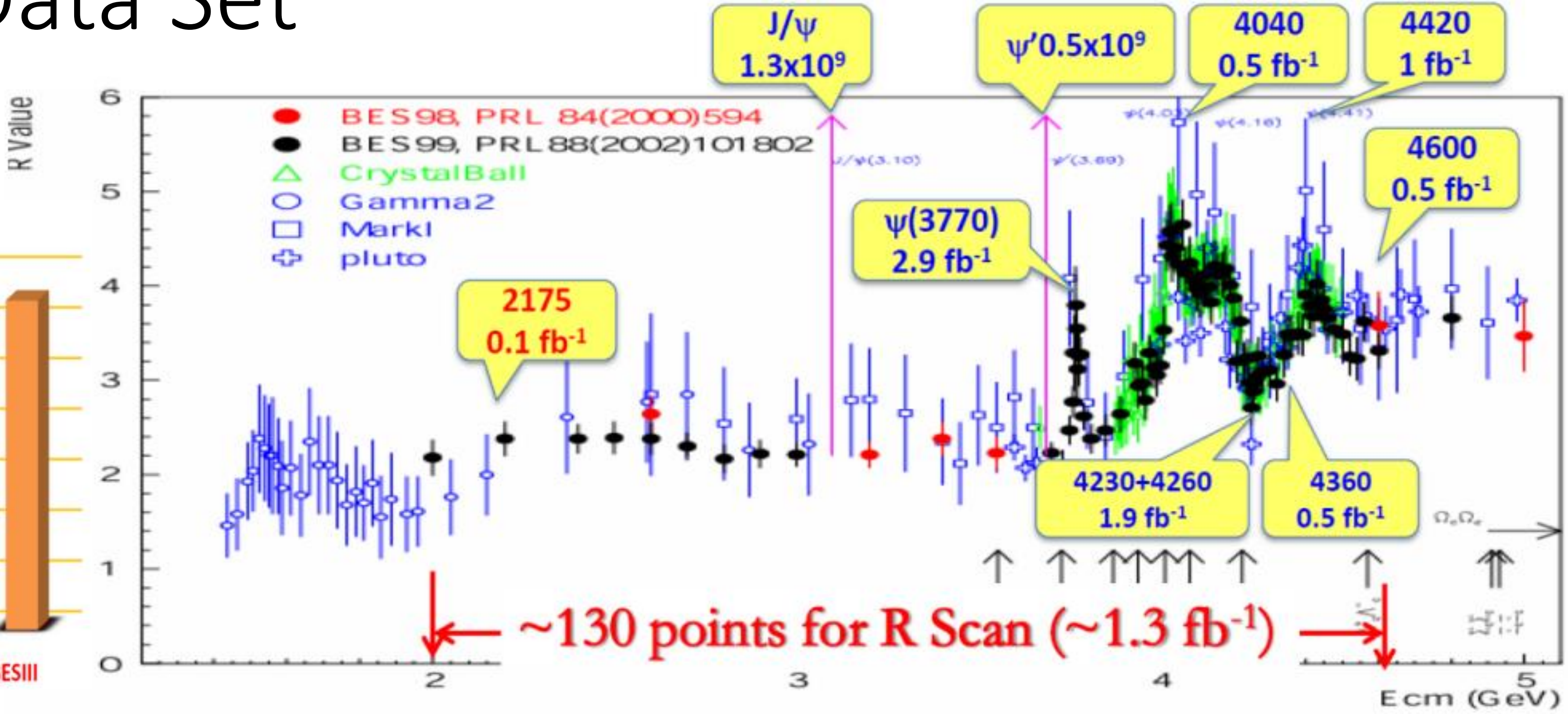
(Reached in April 5th, 2016)

The BESIII Detector



The BESIII Data Set





World **largest** J/ψ, ψ(3686), ψ(3770), ...

Produced directly from e^+e^- annihilation: an ideal factory to study hadron spectroscopy

Light Hadrons

Helicity-selection-rule suppressed decay

Helicity-selection-rule suppressed decay

- $\chi_{c2} \rightarrow$ VP suffers not only from the **suppression** of the helicity selection rule, but also from the approximate G-parity or isospin (U-spin for strange mesons) conservation
- Because of the relatively large mass difference between the u/d quark and s quark, the intermediate meson loops may still bring in sizeable branching ratios for $\chi_{c2} \rightarrow$ K*K + c.c.
- **No experimental results available**

Xiao-Hai Liu, Qiang Zhao

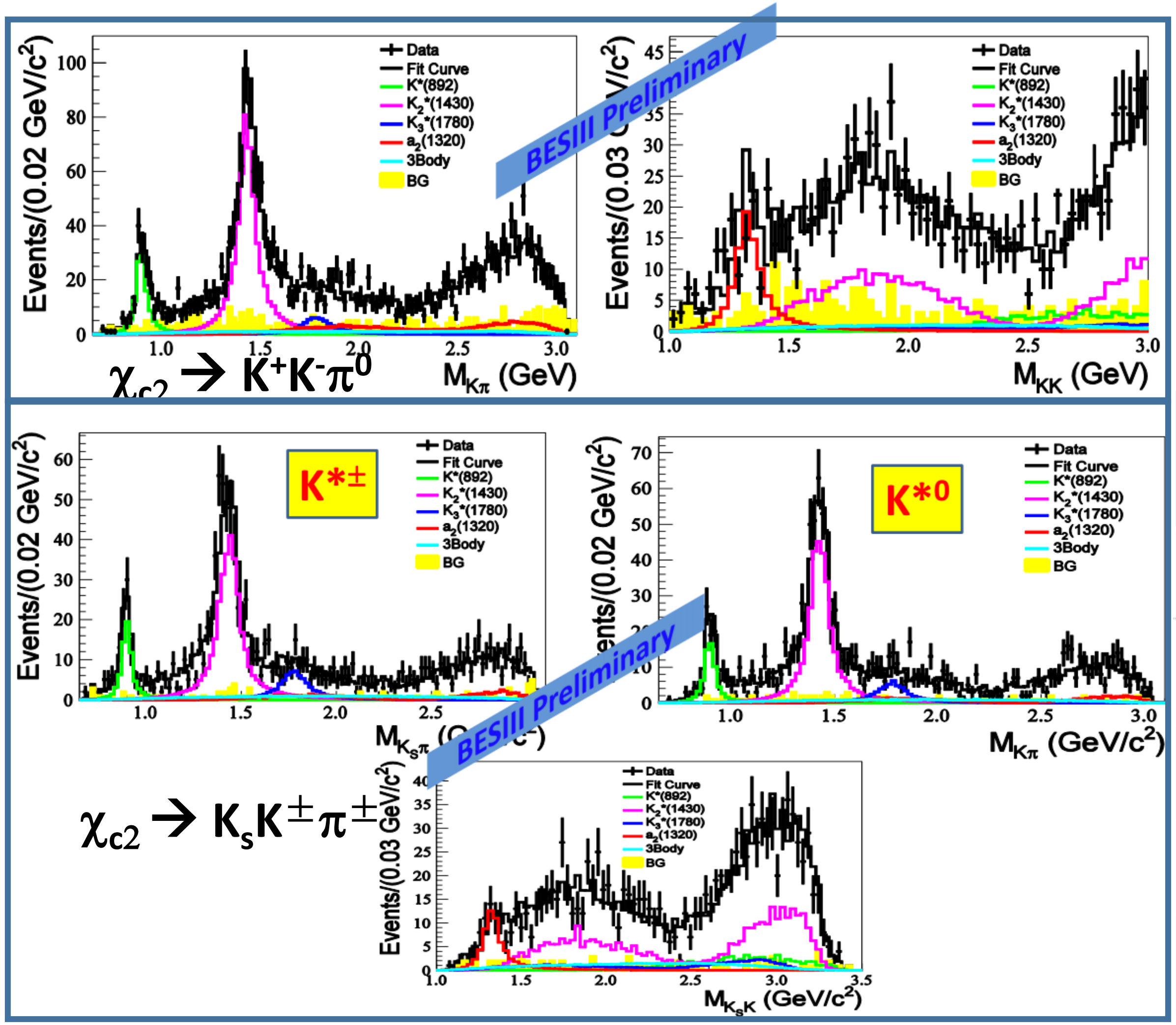
Phys. Rev. D81(2010)014017

PWA: $\chi_{c2} \rightarrow K^+K^-\pi^0$

$\chi_{c2} \rightarrow K_sK^{\pm}\pi^{\pm}$

Br ($\times 10^{-5}$)	$K^{*0}K^0$+c.c.	$K^{*+}K^-$+c.c.
Meson Loop	4.0~6.7	4.0~6.7

Helicity-selection-rule suppressed decay



Relativistic Breit-Wigner has been used for resonances. The mass and width for Breit-Wigner are fixed with PDG.

$Br(\chi_{c2}\to K^*K, K^*\to K\pi$ +c.c.) [or $Br(\chi_{c2}\to a_2\pi, a_2\to KK$ +c.c.] ($\times 10^{-4}$)	Charged	Neutral
$K^*(892)$	1.6±0.1±0.2	1.3±0.2±0.2
$K^*_2(1430)$	8.0±0.3±0.6	6.5±0.5±0.9
$K^*_3(1780)$	1.0±0.1±0.1	1.1±0.3±0.3
$a_2(1320)$	0.9±0.16±0.23	0.66±0.08±0.12

BESIII Preliminary

$\eta(1405)/\eta(1475)$

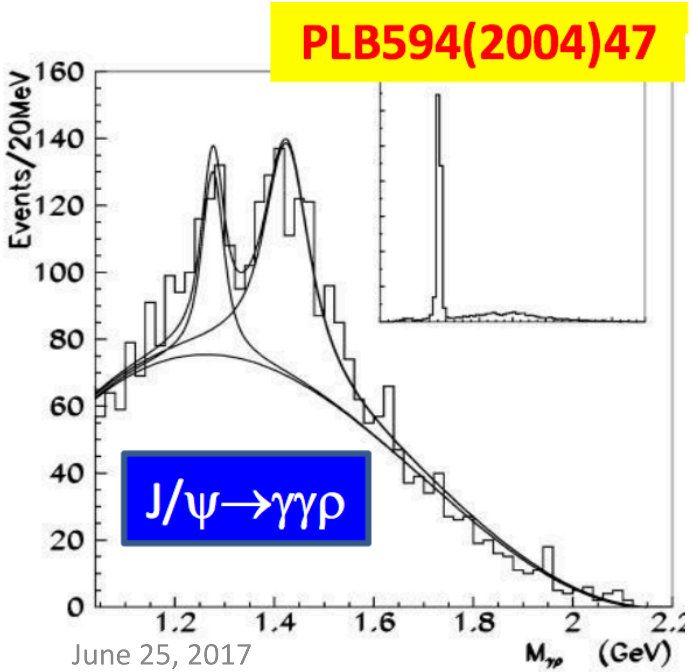
Pseudoscalar (0^{-+})--η(1440)

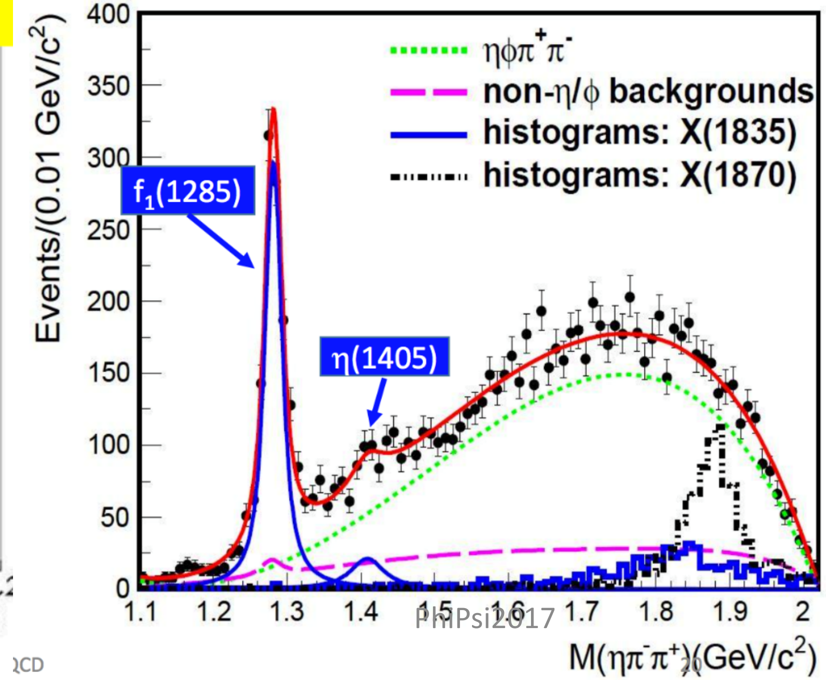
The Structure of η(1440)

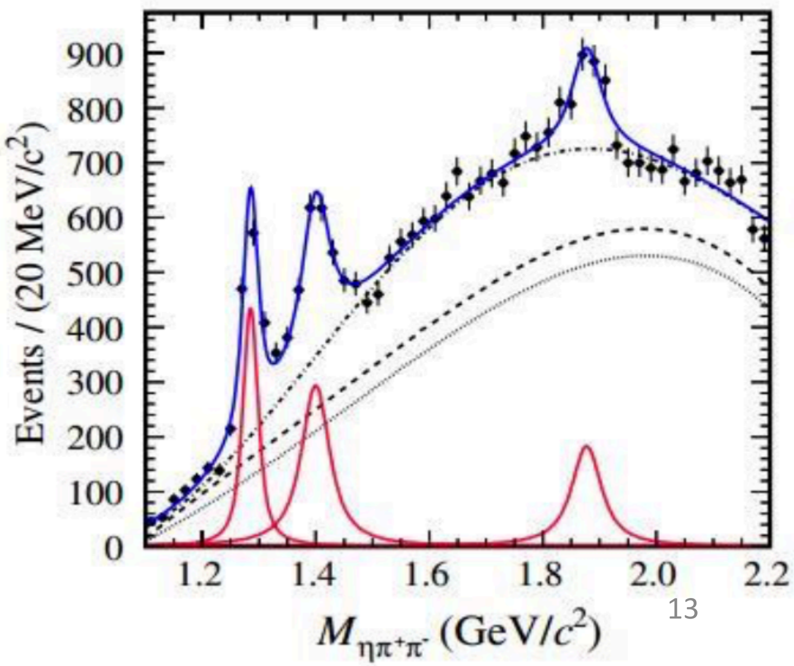
- **Experiment**
  - ✓η(1440) split to η(1405) and η(1475) (from PDG04)
  - ✓$\eta(1405)\rightarrow\eta\pi\pi$, or through $a_0(980)\pi$ (or direct) to KKπ
  - ✓$\eta(1475)\rightarrow K^*(892)K$
- **Quark-model**
  - η(1475): the first radial excitation of the η'
  - **η(1405) ?**
- **Phys. Rev. D87, 014023(2013)**
  - η(1405) and η(1475) are the same state with a mass shift in different modes

Pseudoscalar (0^{-+})--η(1440)

1. J/ψ → γγρ [**Phys. Lett. B594, 47(2004)**]
2. J/ψ → φηππ [**Phys. Rev. D91, 052017(2011)**]
3. J/ψ → ωηππ [**Phys. Rev. Lett. 107, 182001(2011)**]
4. J/ψ → γπππ [**Phys. Rev. Lett. 108, 182001 (2012)**]

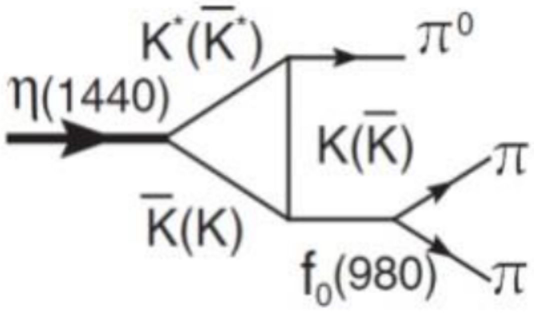






Pseudoscalar (0^{-+})--η(1440)

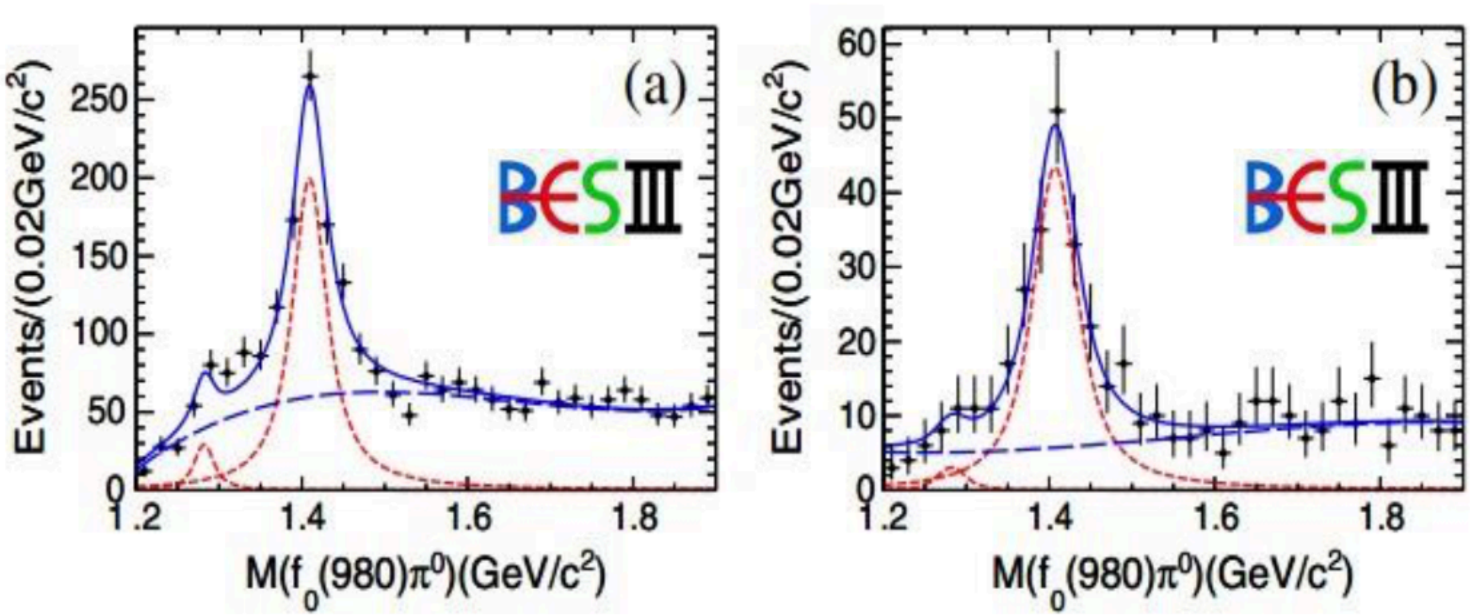
J/ψ → γπππ



Triangle Singularity (TS)
One η(1440) is enough to describe the experimental data

J. J. Wu et al. , Phys. Rev. Lett. 108, 081803

Phys. Rev. Lett. 108, 182001 (2012)

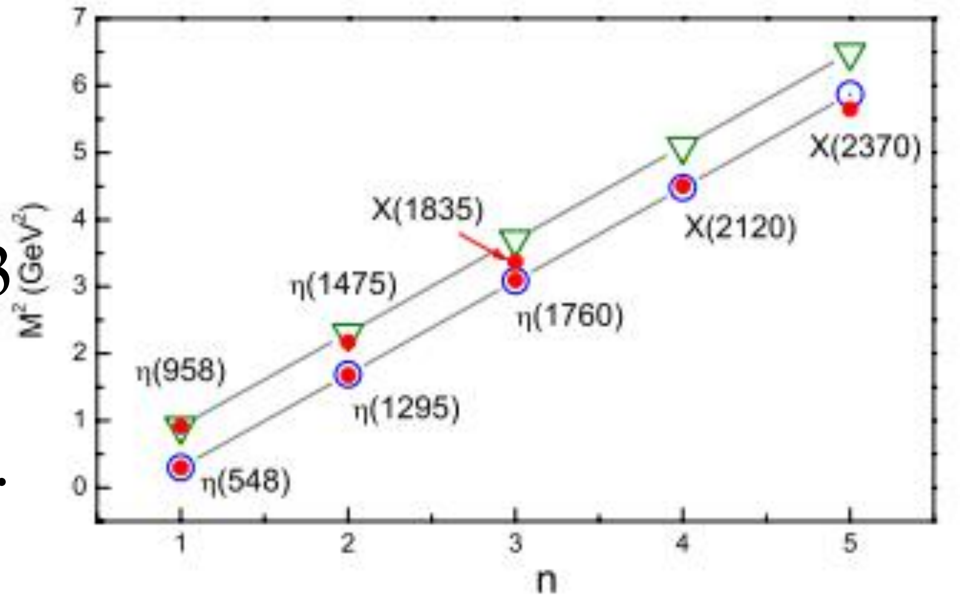


The isospin violated decay η(1405) → $f_0(980)\pi^0$ is observed for the first time with a significance >10σ.

X(1835) and X($p\bar{p}$)

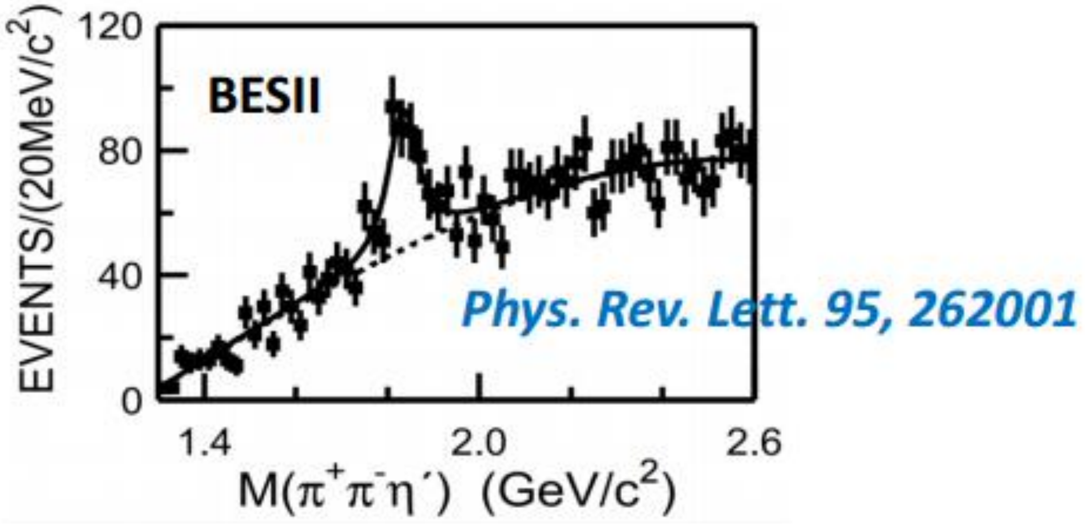
X(1835)

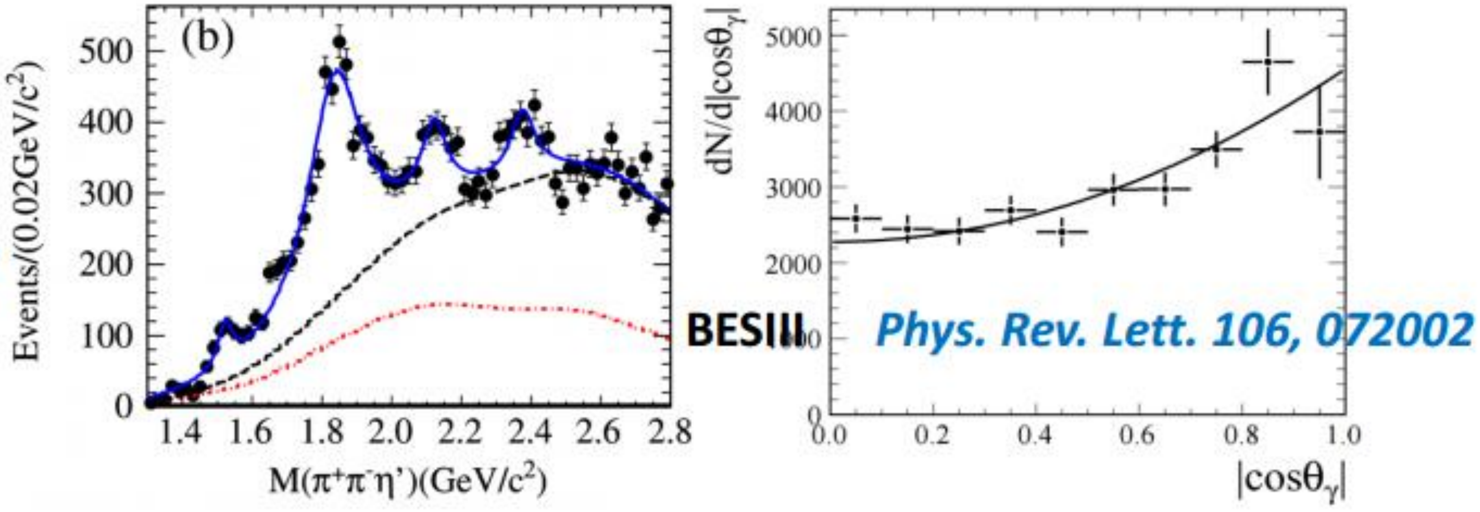
- The second radial excitation of η'[Phys. Rev. D83. 114007(2011)]
- The NN bound state [Phys. Rev. D91. 074003 (2015)]
- The pseudo-scalar glueball [Phys. Lett. B633. 283 (2006)]
- …



X(1835)

- Discovered by BESII in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$
- Confirmed by BESIII in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$
  - $M = 1836.5 \pm \mathbf{3.0^{+5.6}_{-2.1}}$ MeV/c^2
  - $\Gamma = 190 \pm \mathbf{9^{+38}_{-36}}$ MeV/c^2
  - Angular distribution is consistent with 0^-

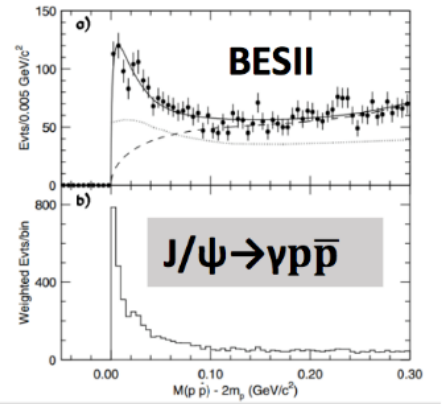




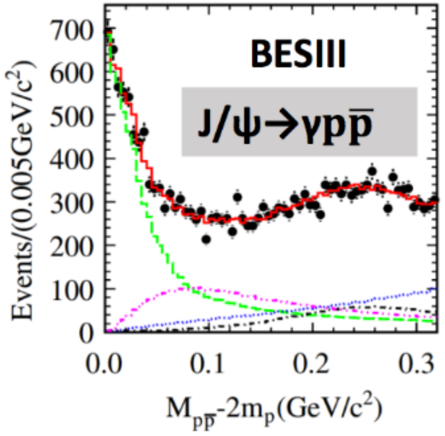
X($p\bar{p}$)

- Discovered by BESII in J/ψ → $\gamma p\bar{p}$
- Confirmed by BESIII and CLEO-c in ψ (3686) → $\pi^+\pi^-$ J/ψ, J/ψ → $\gamma p\bar{p}$
- Confirmed by BESIII in J/ψ → $\gamma p\bar{p}$ and its J^{PC} determined by PWA
  - ➢ 0^{-+}
  - ➢ $M = \mathbf{1832^{+19}_{-5}}\,{}^{+18}_{-17} \pm 19$ MeV/c²
  - ➢ $\Gamma = 13 \pm 19$ MeV/c² (<76 MeV/c² @ 90% C.L.)

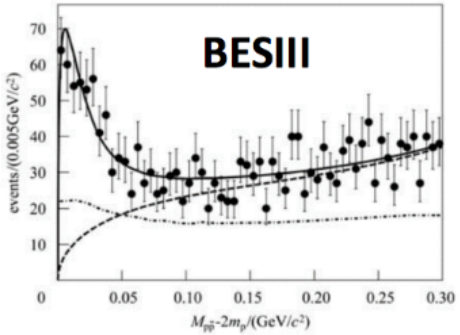
Phys. Rev. Lett. 91, 022001



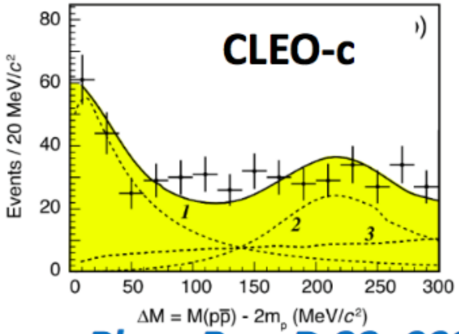
Phys. Rev. Lett. 106, 072002



ψ(3686)→π⁺π⁻J/ψ, J/ψ→γpp̄



Chin. Phys. C 34, 421

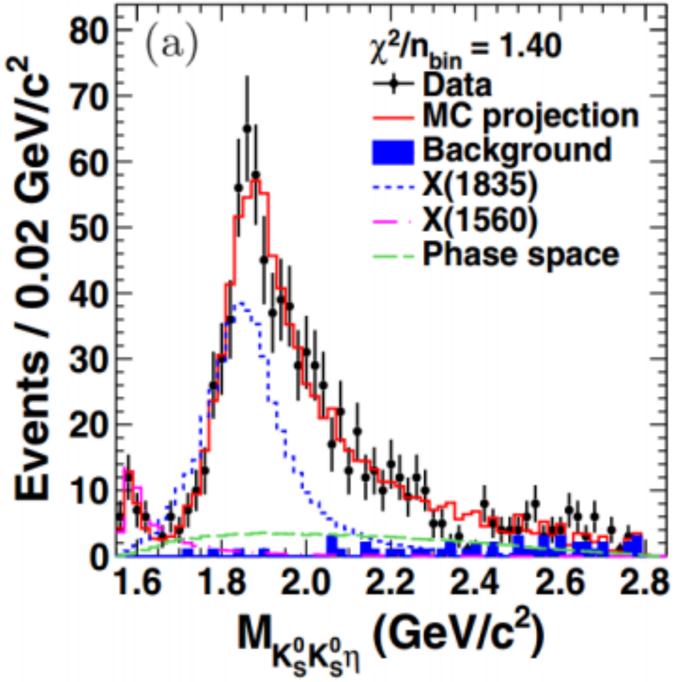


Phys. Rev. D 82, 092002

Observation of X(1835) in $J/\psi \to \gamma K_S K_S \eta$

- X(1560)
  - $J^{PC} = 0^{-+}$; X(1560) → $K_S K_S \eta$ (>8.9σ)
  - $M = 1566 \pm 8 {}^{+0}_{-63}$ MeV/c^2
  - $\Gamma = 45 {}^{+14}_{-13} {}^{+21}_{-28}$ MeV/c^2
  - Consistent with η(1405)/η(1475)(from its tail) within 2.0σ
- X(1835)
  - J^{PC} determined to be 0^{-+}
  - X(1835) → $K_S K_S \eta$ (>12.9σ), dominated by $f_0(980)$ production
  - $M = 1844 \pm \mathbf{9}^{+16}_{-25}$ MeV/c^2
  - $\Gamma = 192^{+20}_{-17} {}^{+62}_{-43}$ MeV/c^2
  - Consistent with X(1835) parameters obtained from $J/\psi \to \gamma \eta' \pi\pi$

Phys. Rev. Lett. 115, 091803



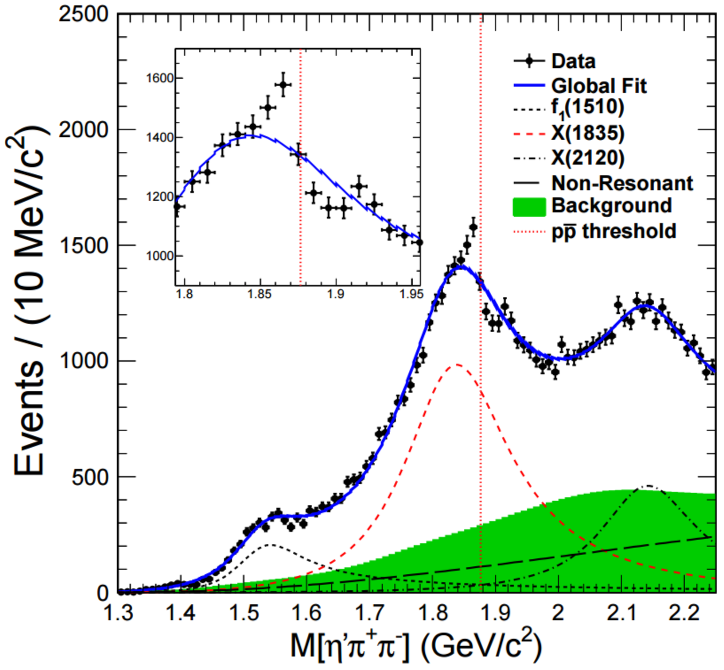
X(1835) && X($p\bar{p}$)

X($p\bar{p}$)	X(1835)
0^{-+}	0^{-+}
$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/c^2	$M = 1836.5 \pm 3.0^{+5.6}_{-2.1}$ MeV/c^2
$\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c^2 @ 90% C.L.)	$\Gamma = 190 \pm 9^{+38}_{-36}$ MeV/c^2
$p\bar{p}$ bound state? ...	$p\bar{p}$ bound state? η' excitation? glueball? ...
The SAME state?	

Anomalous line shape of η’ππ near the $p\bar{p}$ mass threshold in J/ψ → γη’ππ

Phys. Rev. Lett. 117, 042002

- Simultaneous fits to two η’ decay modes
- Simple Breit-Wigner function fails in describing the η’ππ line shape near the $p\bar{p}$ mass threshold
- Two typical circumstances where an abrupt distortion of a resonance’s line shape shows up
  - **Threshold structure caused by the opening of an additional $p\bar{p}$ decay mode**
    - **Use Flatté formula for the line shape**
  - **Interference between two resonances with one very narrow close to threshold**
    - **Use coherent sum of two Breit-Wigner amplitudes for the line shape**



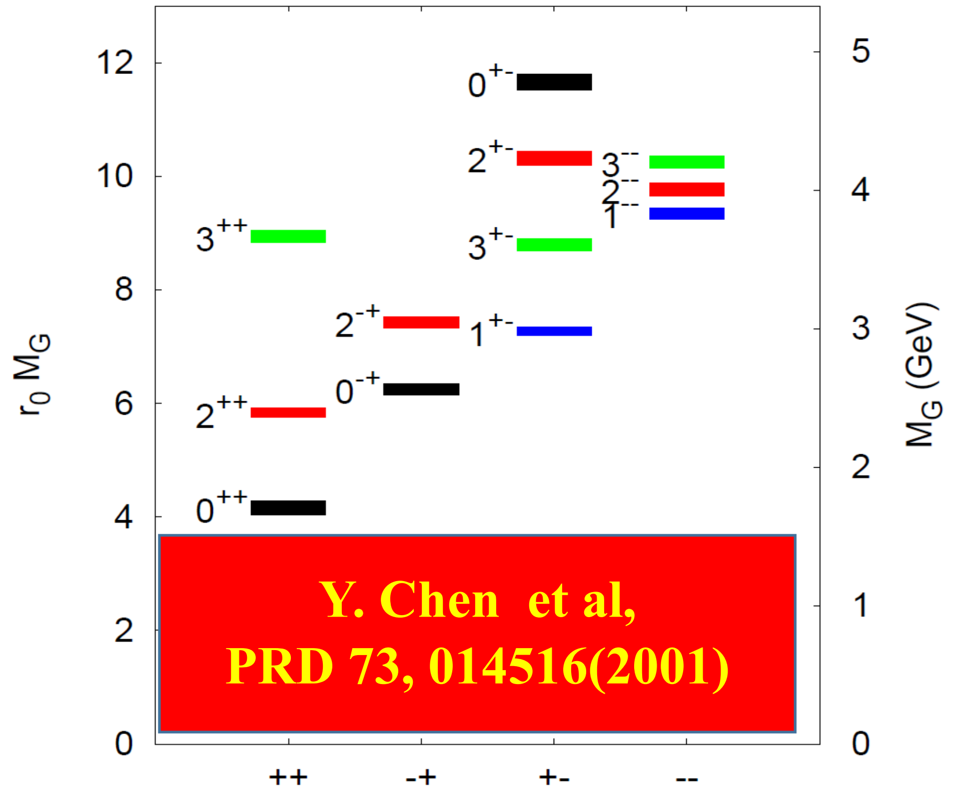
$\log\mathcal{L} = 630503.3$

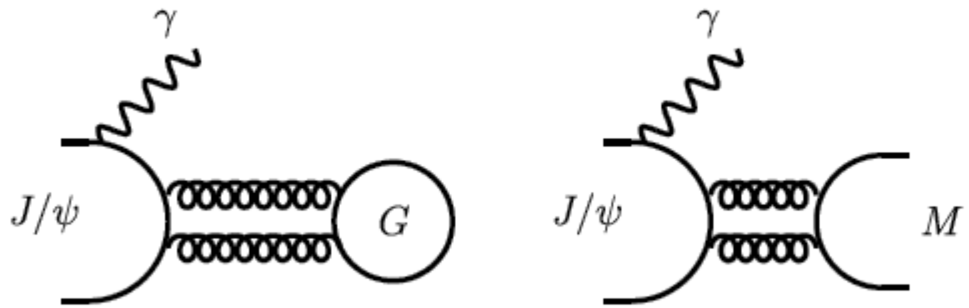
Both models fit the data well with almost equally good quality

Glueballs

Glueballs

- Formed by gluon-gluon interaction
  - Predicted by QCD
  - Not established in experiment
- LQCD prediction
- 0^{++} ground state: 1~2 GeV/c^2
- 2^{++} ground state: 2.3~2.4 GeV/c^2
- 0^{-+} ground state: 2.3~2.6 GeV/c^2
- Radiative J/ψ decays are believed to be an ideal place to search for glueballs



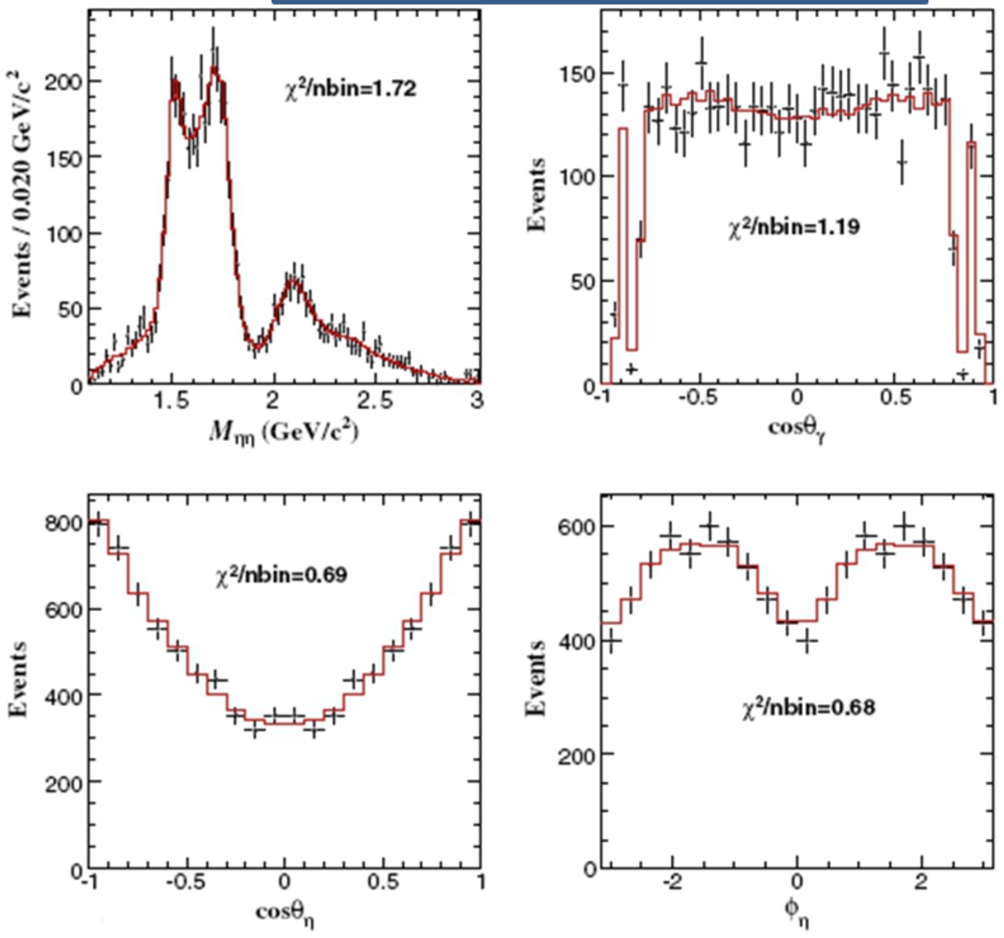


PWA of J/ψ → γηη, η → γγ

PRD 87,092009

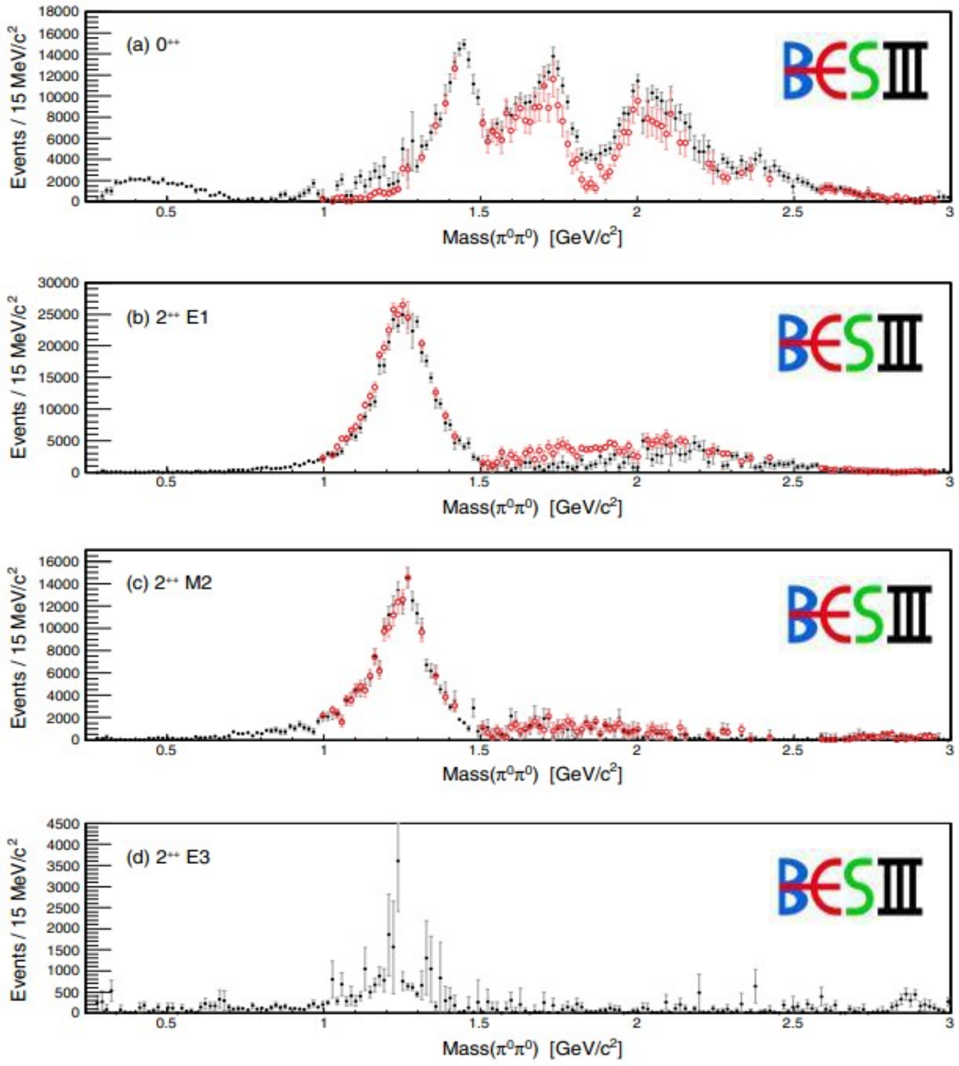
- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- $f_2'(1525)$ is the dominant tensor
- $f_2(1810)$ and $f_2(2340)$ exist (6.4 and 7.6σ)
- No evidence for $f_J(2220)$

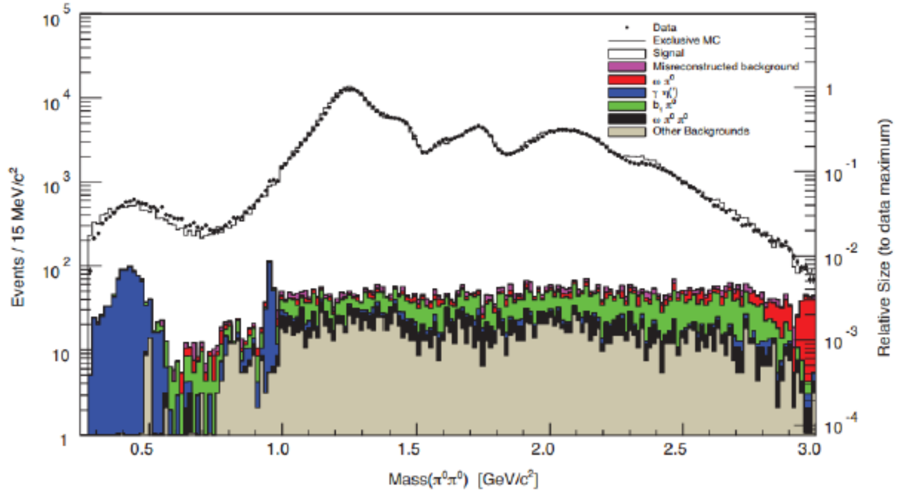
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513\pm5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ



PWA of $J/\psi \to \gamma\pi^0\pi^0$

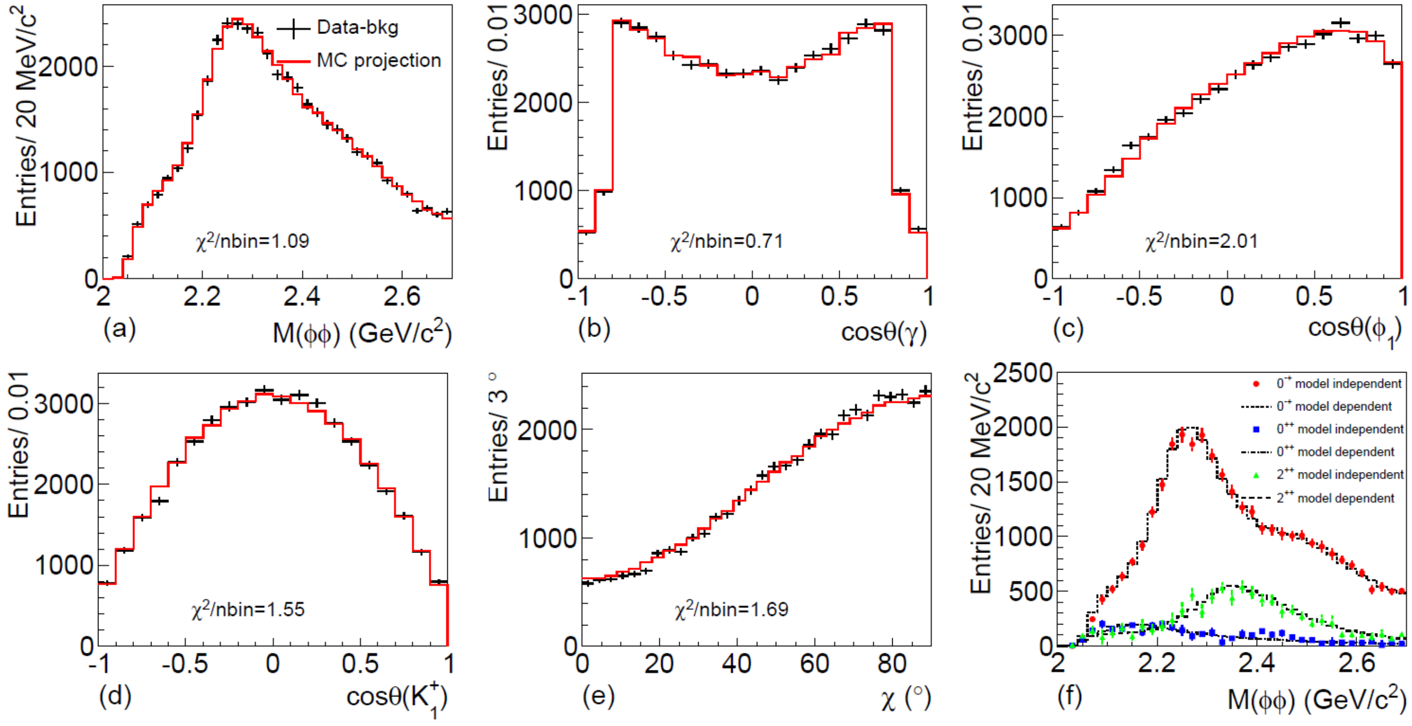
PRD 92, 052003(2015)





- Model-independent PWA;
- Provide a description of the scalar and tensor components of the $\pi^0\pi^0$ system;
- Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/c^2
- Only Model Dependent PWA of global PWA fit can rigerously extract resonance parameters, but cross-check between MDPWA and MIPWA is helpful.

PWA : J/ψ → γϕϕ



Resonance	M (MeV/c^2)	Γ (MeV/c^2)	B.F. ($\times 10^{-4}$)	Sig.
$\eta(2225)$	2216^{+4+21}_{-5-11}	185^{+12+43}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28σ
$\eta(2100)$	2050^{+30+75}_{-24-26}	$250^{+36+181}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	22σ
$X(2500)$	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2101	224	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24σ
$f_2(2010)$	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	$(1.91 \pm 0.14^{+0.72}_{-0.73})$	11σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Well consistent with the results from Model-independent PWA

f_2 (2340): tensor glueball?

Decay rate of pure glueball from LQCD

- **Pure scalar-glueball rate in J/ψ radiative decays**
  - **$BR(J/\psi \to \gamma G(0^{++}))=3.8(9)\times10^{-3}$**
  - **$BR(J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K})=(8.5^{+1.2}_{-0.9})\times10^{-4}$**
  - **$BR(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi)=(4.0\pm1.0)\times10^{-4}$**
  - **$BR(J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega)=(3.1\pm1.0)\times10^{-4}$**
  - **$BR(J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta)=(2.35^{+0.13+1.24}_{-0.11-0.74})\times10^{-4}$**

Long-Cheng Gui et al.
PRL 110 (2013) 021601

Exp.

BESIII results

- **Pure Tensor-glueball rate in J/ψ radiative decays**
  - **$BR(J/\psi \to \gamma G(2^{++}))=1.1(2)\times10^{-2}$**
  - **$BR(J/\psi \to \gamma f_2(2340) \to \gamma\phi\phi)=(1.91\pm0.14^{+0.72}_{-0.73})\times10^{-4}$**
  - **$BR(J/\psi \to \gamma f_2(2340) \to \gamma\eta\eta)=(5.60^{+0.62}_{-0.65}{}^{+2.37}_{-2.07})\times10^{-5}$**

Yi-Bo Yang et al.
PRL 111, 091601

Summary

BESIII started data taking for physics since 2009

- World largest data samples at J/ψ, ψ′,ψ(3770), ψ(4040), Y(4260) already collected, more data in future coming soon
- BESIII is in her golden age, more results will appear: charm meson, form factors, tau physics, two-photon, rare processes …
- BESIII is playing leading role on hadron spectroscopy
- Expect more results from BESIII in the future !

Thanks for your attention!

Backup

$\chi_{cJ} \to VV, VP$

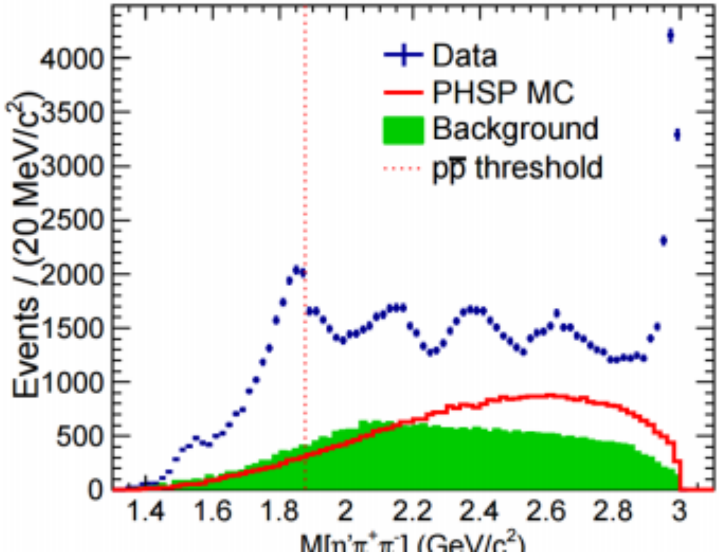
- Helicity Selection Rule (HSR): $\sigma^{initial} = \sigma_1 \cdot \sigma_2$ $(,\sigma = P\cdot(-1)^J)$

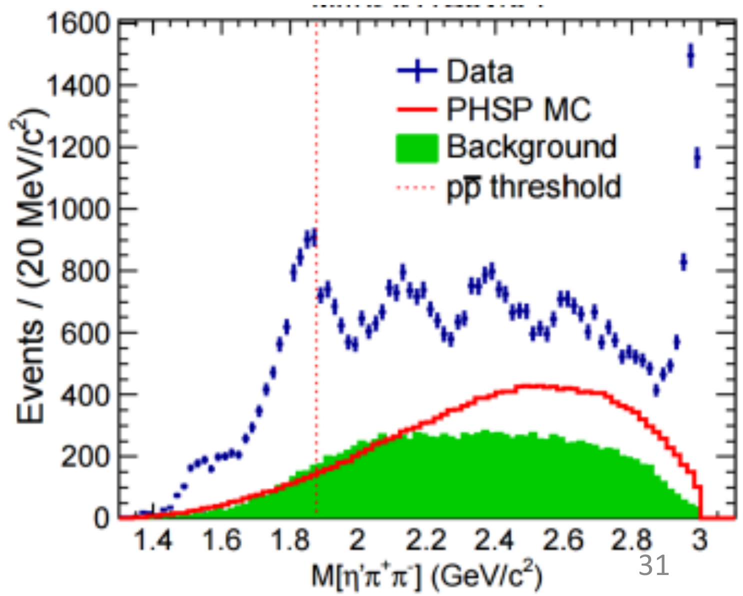
	V V	V P
χ_{c0}	√	Suppressed
χ_{c1}	Suppressed	√
χ_{c2}	√	Suppressed

Anomalous line shape of η'ππ near the $P\bar{P}$ mass threshold in J/ψ → η'ππ

Phys. Rev. Lett. 117, 042002

- Use 1.3×10^9 J/ψ events collected by BESIII in 2009 and 2012
- η' decay modes:
  - η'→ γππ
  - η'→ ηππ; η→γγ
- Clear peaks of X(1835), X(2120), X(2370), η_c, and a structure near 2.6 GeV/c^2
- A significant distortion of the η'ππ line shape near the $p\bar{p}$ mass threshold





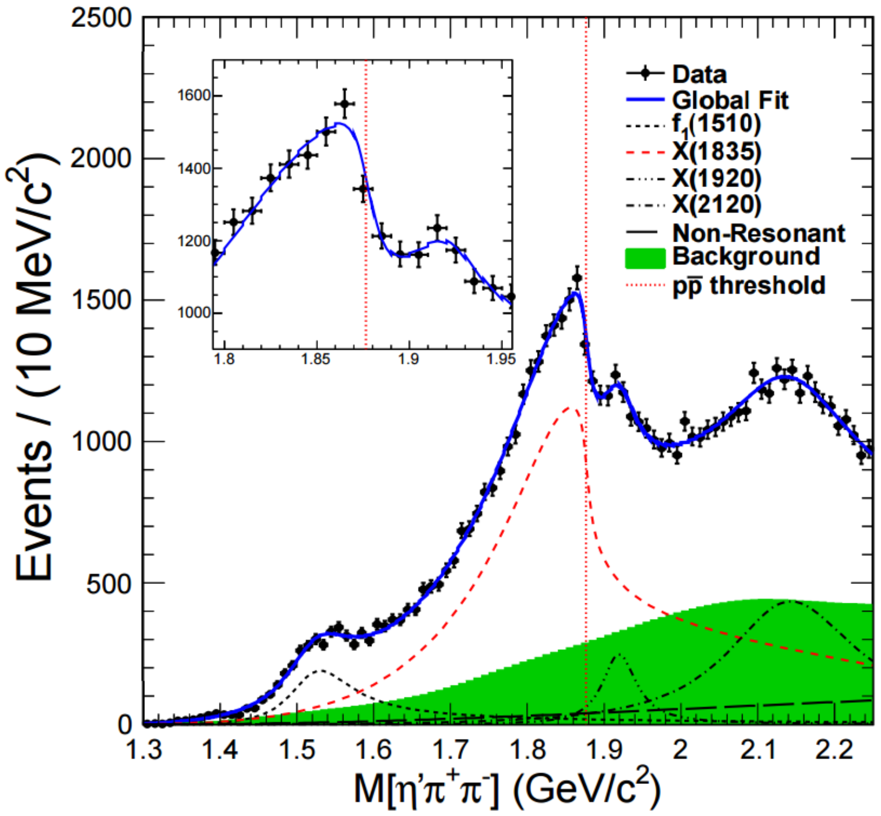
Anomalous line shape of η'ππ near the $P\bar{P}$ mass threshold in J/ψ → η'ππ – Model I

- Use the Flatté formula for the line shape
  - $T = \dfrac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}$
    - $\sum_k g_k^2\, \rho_k \simeq g_0^2 \left(\rho_0 + \dfrac{g_{P\bar{P}}^2}{g_0^2}\, \rho_{P\bar{P}}\right)$
    - $g_{P\bar{P}}^2 / g_0^2$ is the ratio between the coupling strength to the pp channel and the summation of all other channels

The state around 1.85 GeV/c^2	
$\mathcal{M}$ (MeV/c^2)	$1638.0\ ^{+121.9}_{-121.9}\ ^{+127.8}_{-254.3}$
g_0^2 ((GeV/c^2)^2)	$93.7\ ^{+35.4}_{-35.4}\ ^{+47.6}_{-43.9}$
$g_{p\bar{p}}^2 / g_0^2$	$2.31\ ^{+0.37}_{-0.37}\ ^{+0.83}_{-0.60}$
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

Phys. Rev. Lett. 117, 042002



$\log\mathcal{L} = 630549.5$

Anomalous line shape of η'ππ near the $P\bar{P}$ mass threshold in J/ψ → η'ππ – Model II

- **Use coherent sum of two Breit-Wigner amplitudes**
  - $T = \frac{\sqrt{\rho_{out}}}{M_1^2 - s - iM_1 \Gamma_1} + \frac{\beta e^{i\theta}\sqrt{\rho_{out}}}{M_2^2 - s - iM_2 \Gamma_2}$

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)	$13.0\ ^{+7.1}_{-5.5}\ ^{+2.1}_{-3.8}$
B.R. (constructive interference)	$(2.03\ ^{+0.12}_{-0.12}\ ^{+0.43}_{-0.70}) \times 10^{-7}$
B.R. (destructive interference)	$(1.57\ ^{+0.09}_{-0.09}\ ^{+0.49}_{-0.86}) \times 10^{-5}$

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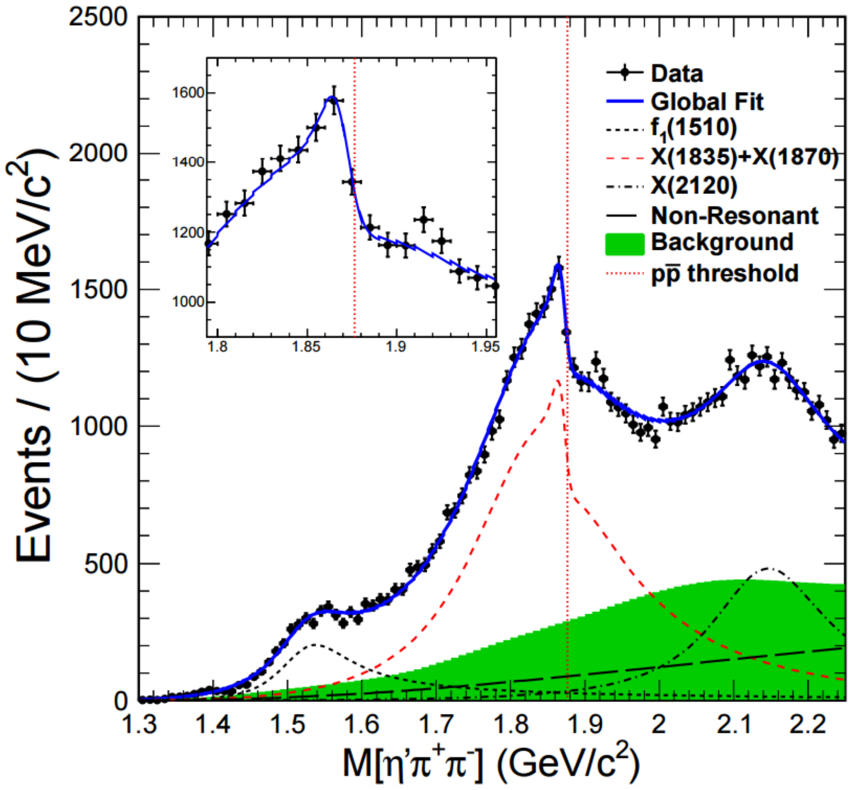


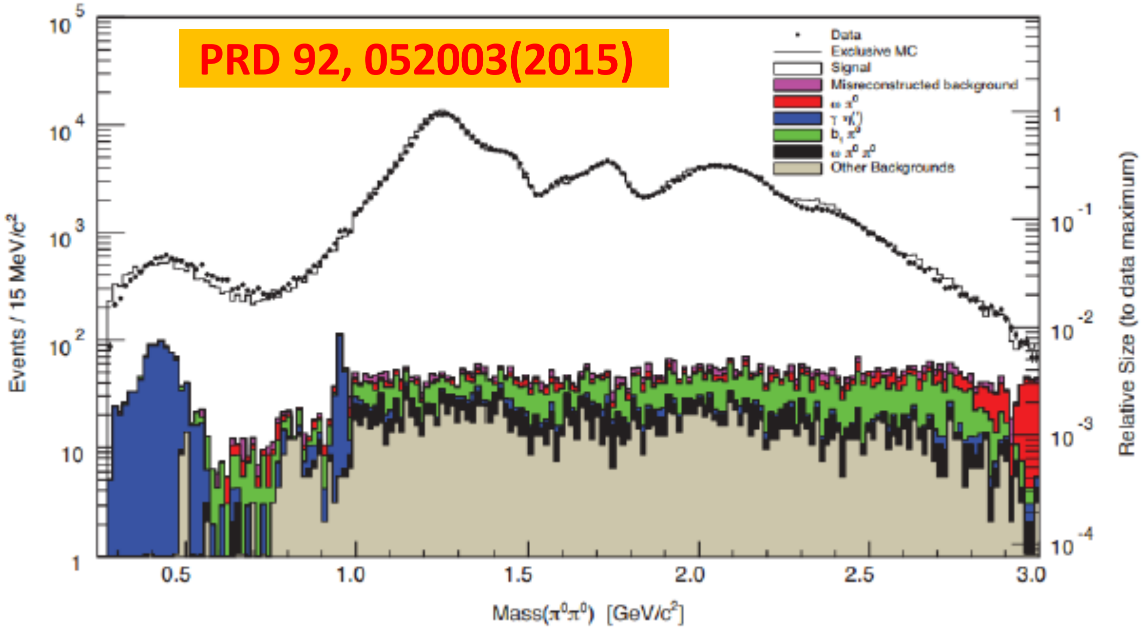
$\log\mathcal{L} = 630540.3$

Anomalous line shape of η'ππ near the $P\bar{P}$ mass threshold connection between X(1835) and X($P\bar{P}$)

- Both models fit the data well with almost equally good quality
  - Cannot distinguish them with current data
  - 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 understand the nature of the state(s)
  - More J/ψ data to distinguish two models
  - Study line shapes in other decay modes
    - J/ψ → $\gamma P\bar{P}$
    - J/ψ → $\gamma K_s K_s \eta$
    - …

PWA of $J/\psi \rightarrow \gamma\pi^0\pi^0$

- Use 1.3×10^9 J/ψ events collected by BESIII in 2009 and 2012
- The $\pi^0\pi^0$ system
  - Very clean
  - Large statistics and many open channels
  - Many broad and overlapping resonances
  - Model independent PWA



➢ More than 440,000 reconstructed events
➢ Background level ~ 1.8%

PWA : J/ψ → γφφ

- Use 1.3×10^9 J/ψ events collected by BESIII in 2009 and 2012
- PWA procedure
  - Covariant tensor formalism
  - Data-driven background subtraction
  - Resonances are parameterized by relativistic Breit-Wigner with constant width
  - Resonances with significance > 5 σ are selected as components in solution

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