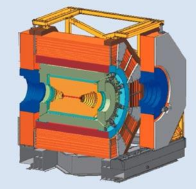
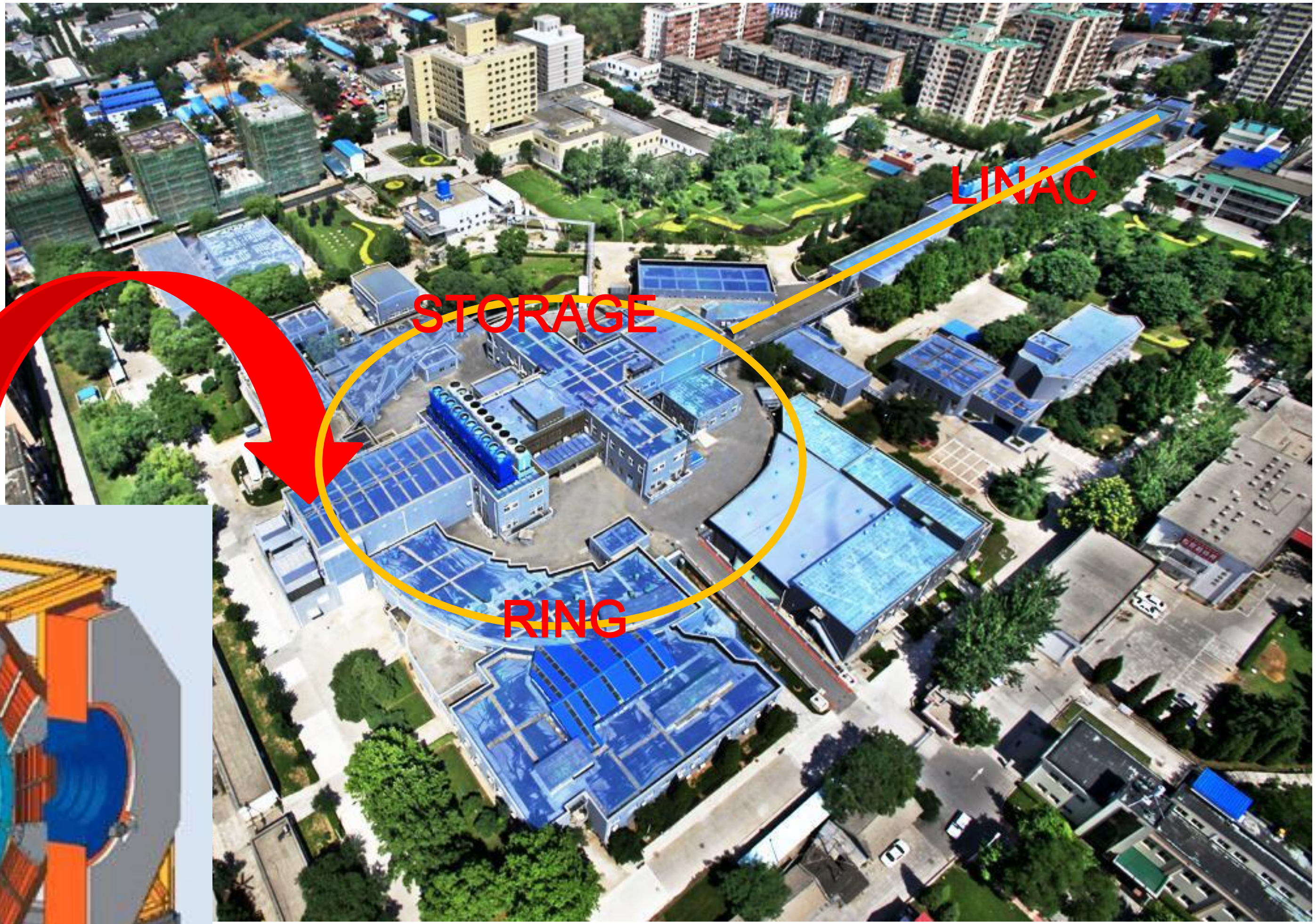
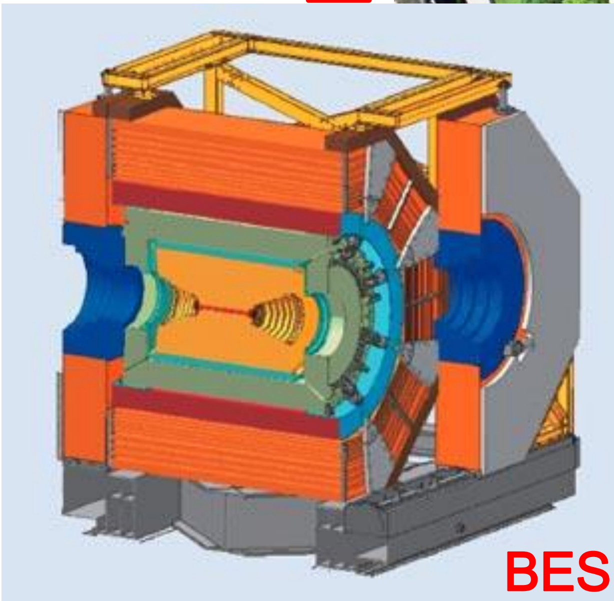


Light meson spectroscopy at BESIII

Zhenxing CHEN
(Peking University & Institute of High Energy Physics, CAS)
On behalf of BESIII Collaboration

BEPCII and BESIII



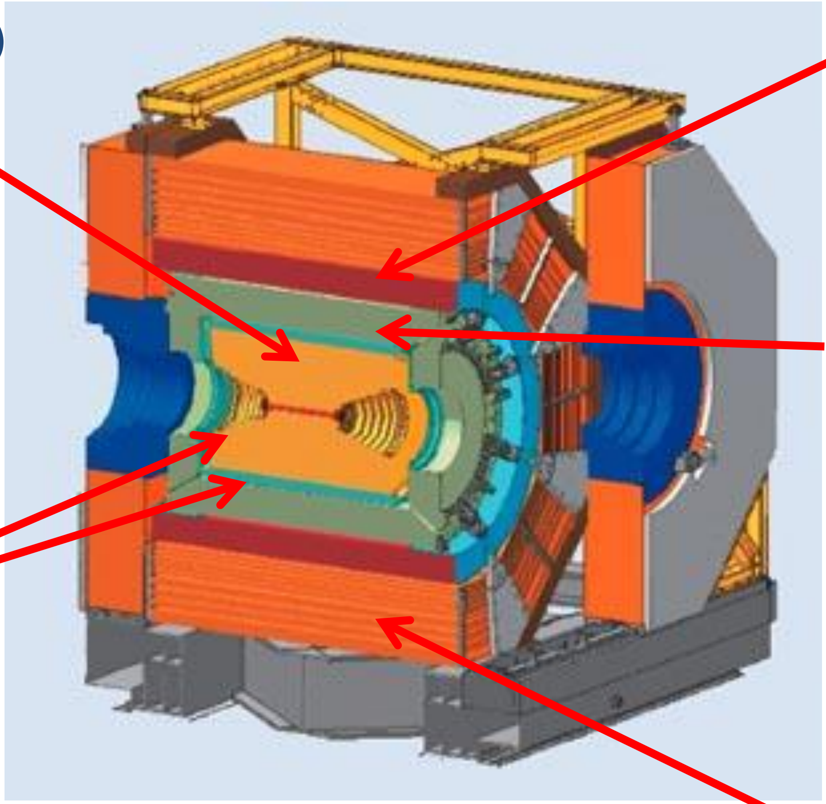


Beam energy: 1.0 ~ 2.3 GeV
Luminosity: 1.0 x 10^{33} $cm^{-2}s^{-1}$
(reached in April 5^{th}, 2016)

BESIII Detector

Super-Conducting Magnet
1.0 T (2009) 0.9 T (2012)

Main Drift Chamber (MDC)
σ_P/P = 0.5% @ 1 GeV
$\sigma_{dE/dx}$ = 6%

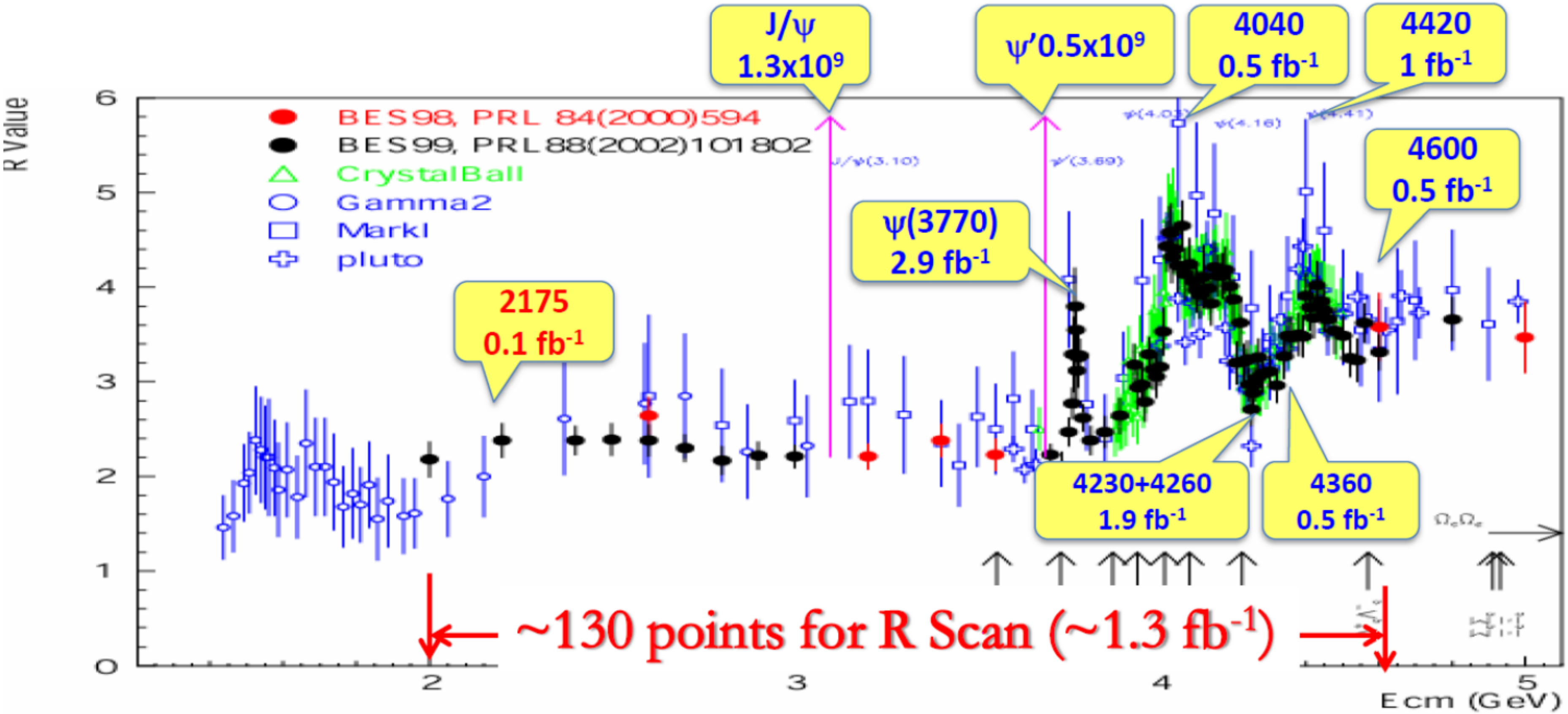


Electromagnetic Calorimeter (EMC)
$\sigma_E/\sqrt{E}$ = 2.5% @ 1 GeV
$\sigma_{Z,\varphi}$ = 0.5 – 0.7 cm/$\sqrt{E}$

Time of Flight (TOF)
σ_T: 90 ps (barrel)
110 ps (endcap)

μ Counter (MUC)
$\delta_{R,\varphi}$ = 1.4 – 1.7 cm

Data set



World largest J/ψ, ψ(3686), ψ(3770), … produced directly from e^+e^- collision :

an ideal factory to study light meson spectroscopy

Highlights of recent progress at BESIII

☐ X($p\bar{p}$) and X(1835)

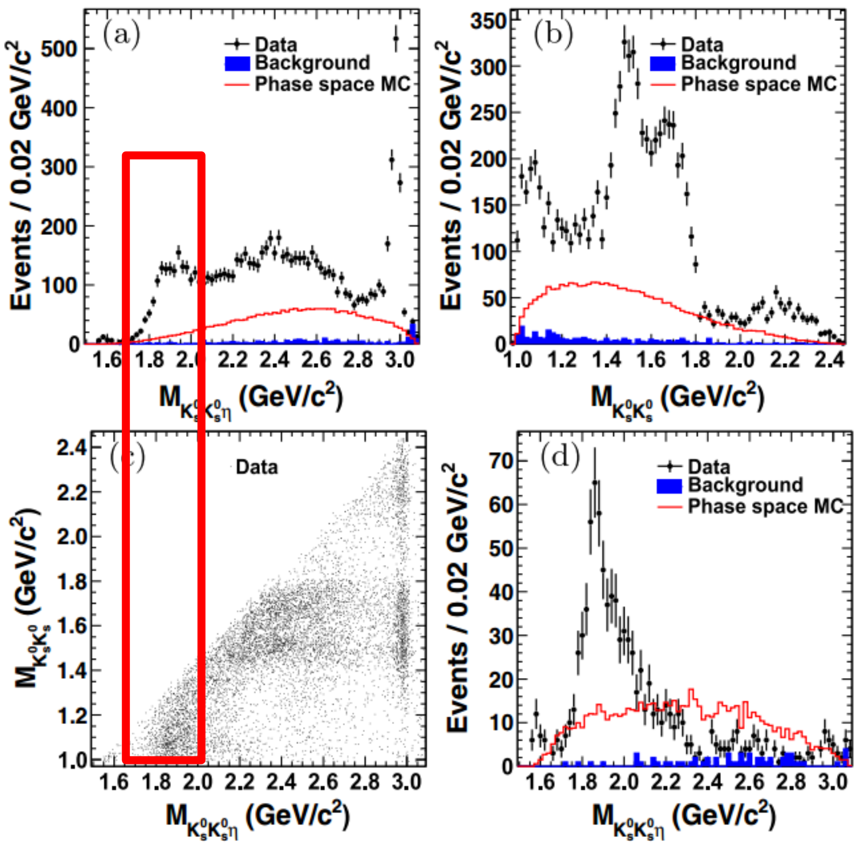
- ✓ A new decay mode of X(1835) ($\rightarrow K_S K_S \eta$) observed and its J^{PC} determined
- ✓ Anomalous $\eta' \pi^+ \pi^-$ mass line shape near $p\bar{p}$ mass threshold is observed

☐ Glueball Searches

- ✓ Model independent partial wave analysis of $J/\psi \rightarrow \gamma \pi^0 \pi^0$
- ✓ Partial wave analysis of $J/\psi \rightarrow \gamma \phi \phi$

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

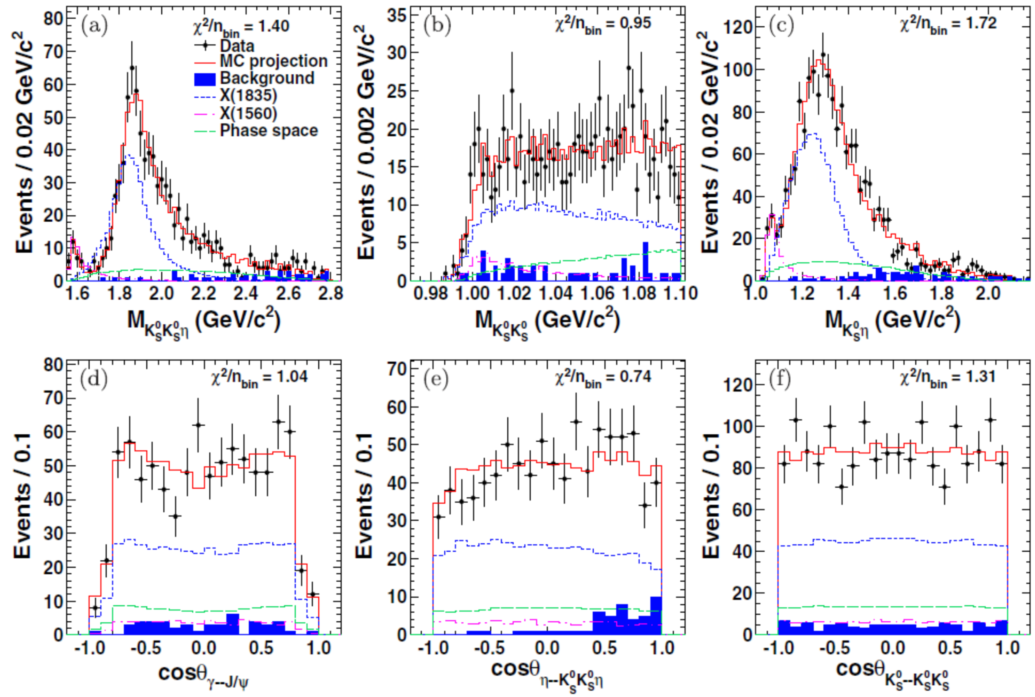
- Based on 1.3×10^9 J/ψ events collected in 2009 and 2012
- Clear structure on mass spectrum of $K_S K_S \eta$ around 1.85 GeV/c^2
- Strongly correlated to $f_0(980)$
- PWA for $M(K_S K_S) < 1.1$ GeV/c^2



PRL 115, 091803 (2015)

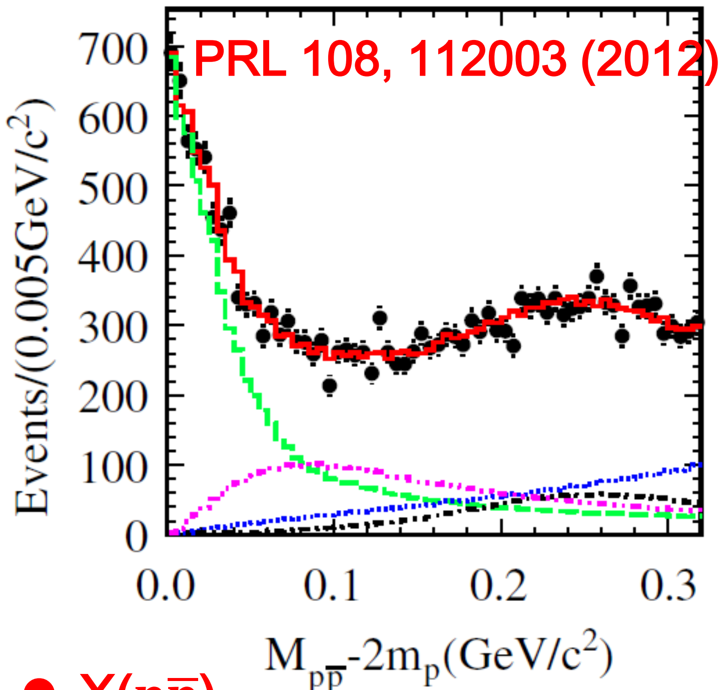
PWA of $J/\psi \to \gamma K_S K_S \eta$

- Nonresonant $f_0(1500)\eta$
- X(1560)
  - ✓ $J^{PC}=0^{-+}$
  - ✓ $X(1560) \to K_S K_S \eta$ (> 8.9σ)
  - ✓ $M = 1565 \pm 8^{+0}_{-63}\ \mathrm{MeV}/c^2$
  - ✓ $\Gamma = 45^{+14}_{-13}{}^{+21}_{-28}\ \mathrm{MeV}/c^2$
  - ✓ Consistent with η(1405)/η(1475) within 2.0σ

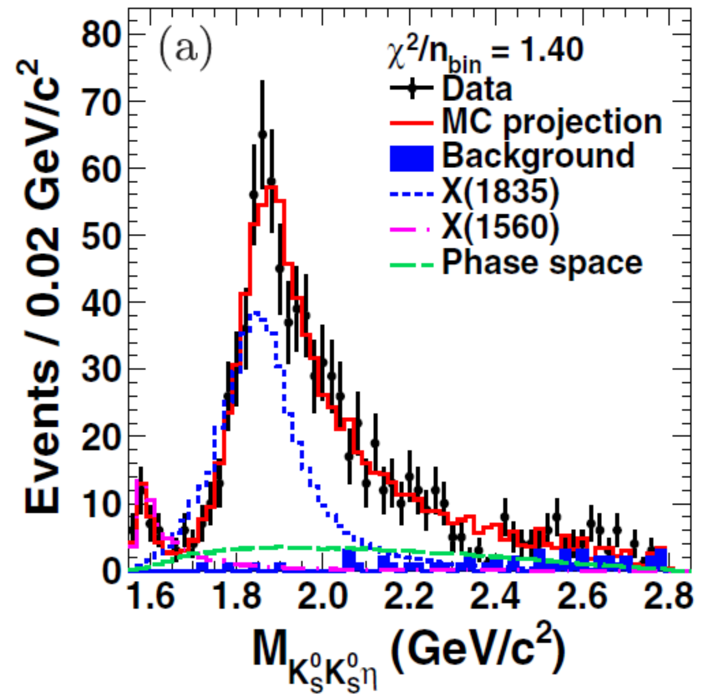


- X(1835)
  - ✓ **J^{PC} determined to be 0^{-+}**
  - ✓ $X(1835) \to K_S K_S \eta$ (> 12.9σ), dominated via $f_0(980)$
  - ✓ $M = 1844 \pm 9^{+16}_{-25}\ \mathrm{MeV}/c^2$
  - ✓ $\Gamma = 192^{+20}_{-17}{}^{+62}_{-43}\ \mathrm{MeV}/c^2$
  - ✓ **Consistent with the values obtained from $J/\psi \to \gamma \eta' \pi^+ \pi^-$**
  - ✓ $\mathfrak{B}(J/\psi \to \gamma X(1835)) \cdot \mathfrak{B}(X(1835) \to K_S K_S \eta) = (3.31^{+0.33}_{-0.30}{}^{+1.96}_{-1.29}) \times 10^{-5}$

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



The same state?



● X($p\bar{p}$)

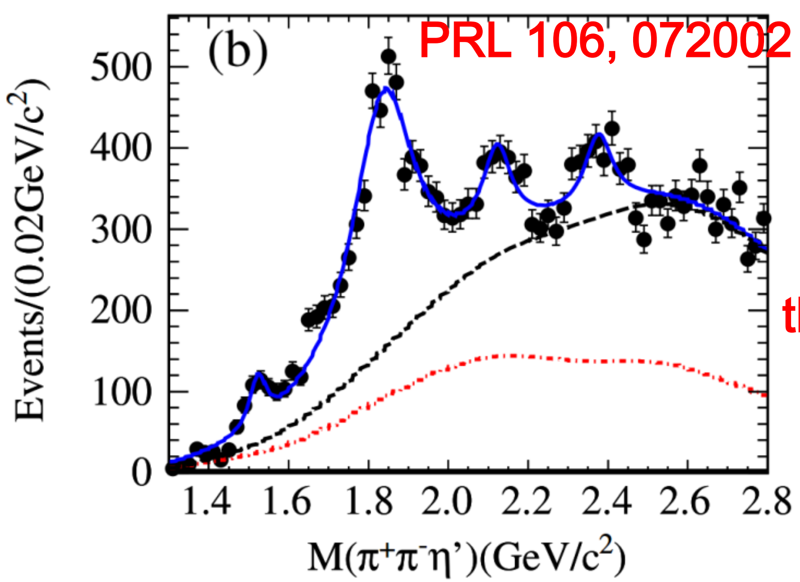
- Discovered by BESII in $J/\psi \to \gamma p\bar{p}$
  PRL 91, 022001 (2003)
- Confirmed by BESIII in $J/\psi \to \gamma p\bar{p}$ with data collected in 2009
- PWA for $M(p\bar{p}) < 2.2$ GeV/c^2
  - ✓ $J^{PC}=0^{-+}$
  - ✓ $M = 1832 \pm 19^{+19}_{-5}{}^{+18}_{-17}$ MeV/c^2
  - ✓ $\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c^2 @ 90% C. L.)

● X(1835)

- Discovered by BESII in $J/\psi \to \gamma \eta' \pi^+\pi^-$
  PRL 95, 062001 (2005)
- Confirmed by BESIII in $J/\psi \to \gamma \eta' \pi^+\pi^-$ with data collected in 2009
- Confirmed by BESIII in $J/\psi \to \gamma K_S K_S \eta$ with data collected in 2009 and 2012
- PWA for $M(K_S K_S) < 1.1$ GeV/c^2
  - ✓ $J^{PC}=0^{-+}$
  - ✓ $M = 1844 \pm 9^{+16}_{-25}$ MeV/c^2
  - ✓ $\Gamma = 192^{+20}_{-17}{}^{+62}_{-43}$ MeV/c^2

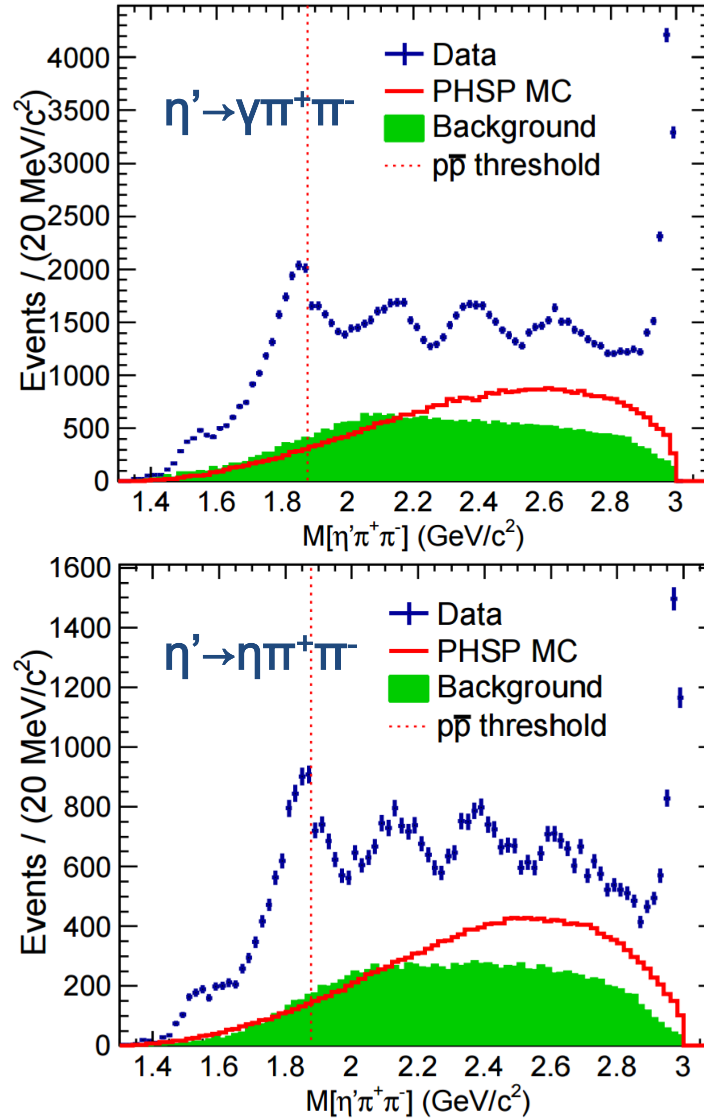
Anomalous line shape of η’π⁺π⁻ near the $p\bar{p}$ mass threshold in J/ψ→γη’π⁺π⁻

- Based on 1.09×10^9 J/ψ events collected by BESIII in 2012
- Two decay modes of η′
  - ✓ $\eta'\to\gamma\pi^+\pi^-$
  - ✓ $\eta'\to\eta\pi^+\pi^-$, $\eta\to\gamma\gamma$
- X(2120) and X(2370) confirmed, a structure near 2.6 GeV/c² observed
- A significant distortion of the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold



PRL 106, 072002 (2011)

three BWs



PRL 117, 042002 (2016)

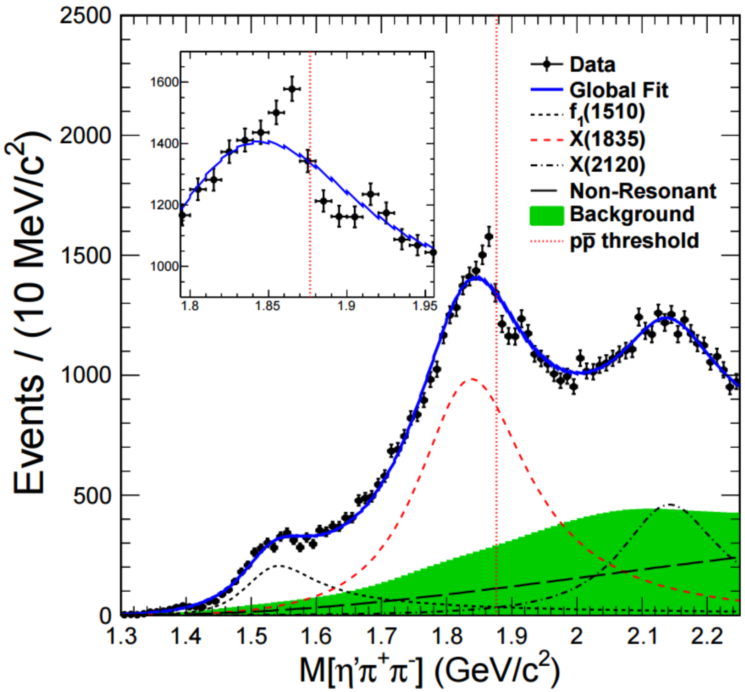
Anomalous line shape of $\eta'\pi^+\pi^-$ near the $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

- Simultaneous fits to two η' decay modes

- Simple Breit-Wigner function fails in describing the $\eta'\pi^+\pi^-$ 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 the 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

PRL 117, 042002 (2016)



$\log\mathcal{L} = 630503.3$

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

- Use the Flatté formula for the line shape

$$T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}$$

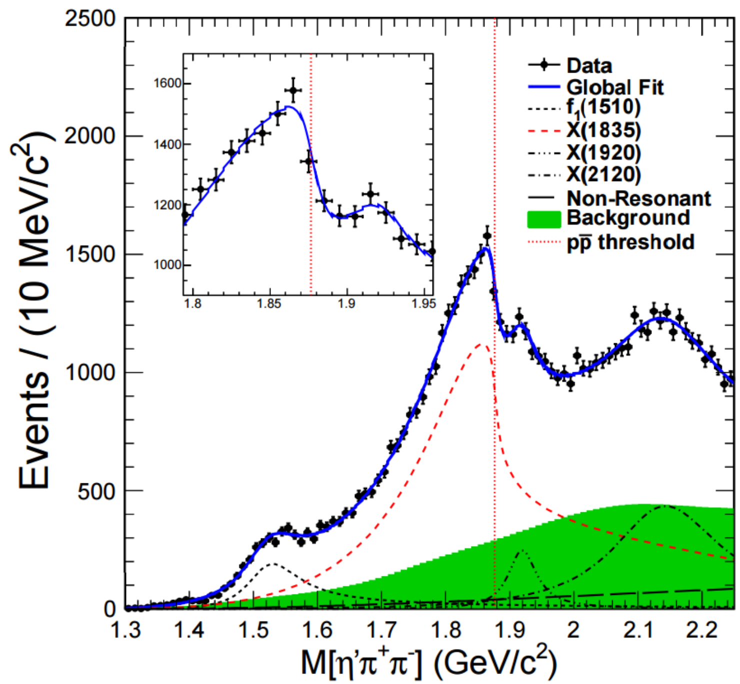
  - $\sum_k g_k^2 \rho_k \simeq g_0^2 (\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2} \rho_{p\bar{p}})$
  - $g_{p\bar{p}}^2 / g_0^2$ is the ratio between the coupling strength to the $p\bar{p}$ channel and the summation of all other channels

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

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

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

PRL 117, 042002 (2016)



$\log\mathcal{L} = 630549.5$

Significance of $g_{p\bar{p}}^2/g_0^2$ being non-zero is larger than 7σ

X(1920) is needed with 5.7σ

Anomalous line shape of $\eta'\pi^+\pi^-$ near the $p\bar{p}$ mass threshold in $J/\psi\to\gamma\eta'\pi^+\pi^-$

- Use coherent sum of two Breit-Wigner amplitudes

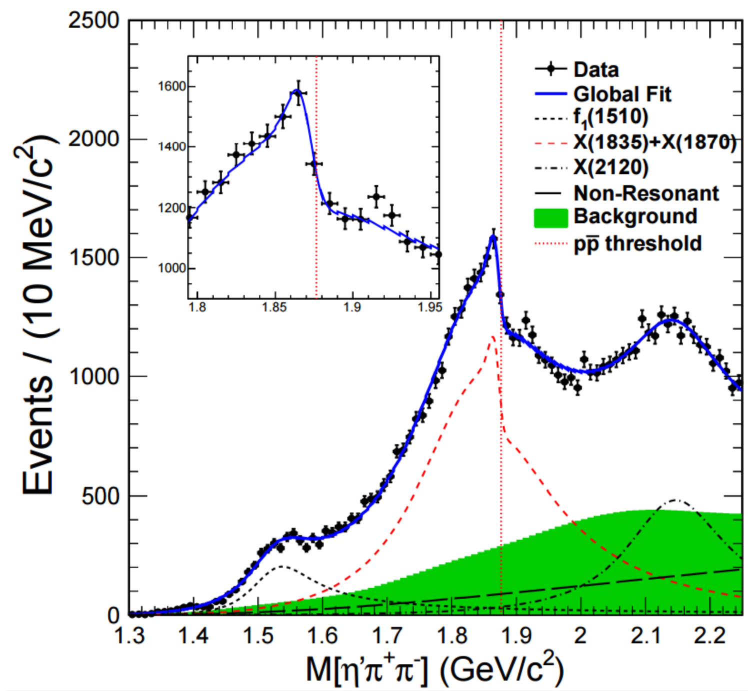
$$T = \frac{\sqrt{\rho_{out}}}{M_1^2 - s - iM_1\Gamma_1} + \frac{\beta \cdot e^{i\theta} \cdot \sqrt{\rho_{out}}}{M_2^2 - s - iM_2\Gamma_2}$$

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

a $p\bar{p}$ bound state?

PRL 117, 042002 (2016)



$\log\mathcal{L} = 630540.3$

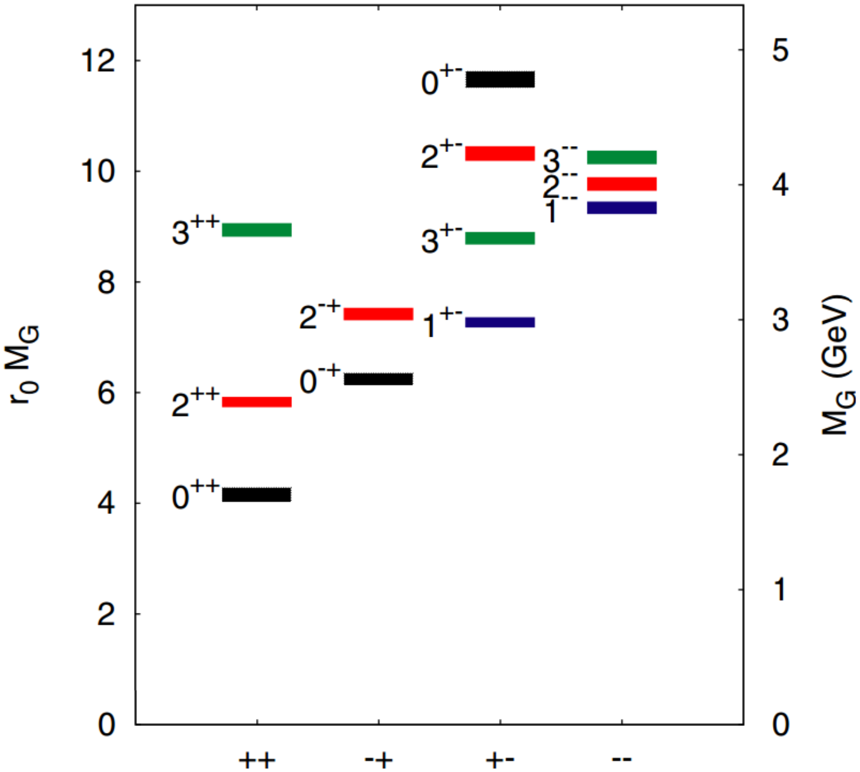
Significance of X(1870) is larger than 7σ

X(1920) is not significant

Anomalous line shape of $\eta'\pi^+\pi^-$ near the $p\bar{p}$ mass threshold in $J/\psi\to\gamma\eta'\pi^+\pi^-$

- Both models fit the data well with almost equally good quality
  - ✓ Cannot distinguish them with current statistics
  - ✓ 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
  - ✓ More J/ψ data
  - ✓ Study line shapes in other decay modes
    - ➢ $J/\psi\to\gamma p\bar{p}$
    - ➢ $J/\psi\to\gamma K_S K_S \eta$
    - ➢ …

Glueballs



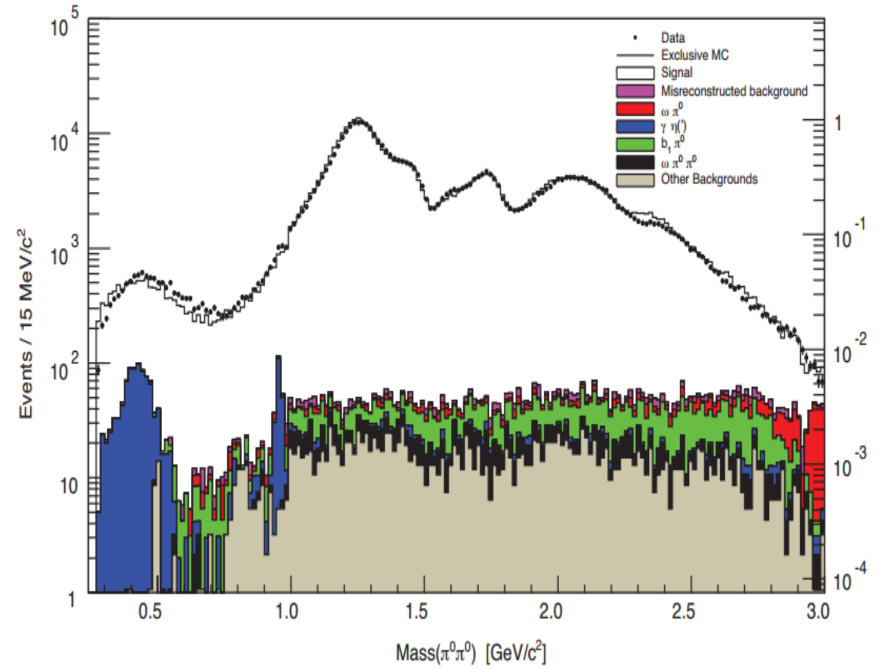
- Predicted by QCD
- Not established in experiment
- LQCD prediction
  - 0^{++} ground state: 1~2 GeV/c^2
  - 2^{++} ground state: 2.3~2.4 GeV/c^2
  - 0^{-+} ground state: 2.3~2.6 GeV/c^2

- J/ψ radiative decays are believed to be an ideal place to search for glueballs

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

PRD 92, 052003 (2015)

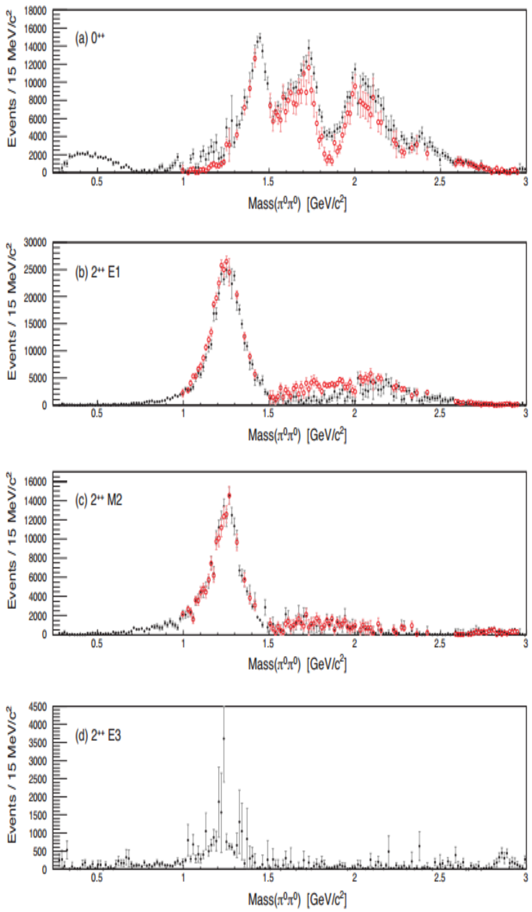
- Based on 1.3×10^9 J/ψ events collected by BESIII in 2009 and 2012
- $\pi^0\pi^0$ system
  - ✓ Very clean
  - ✓ Large statistics
  - ✓ Many broad and overlapping resonances (parameterization challenging)
  - ✓ Model independent PWA (MIPWA)



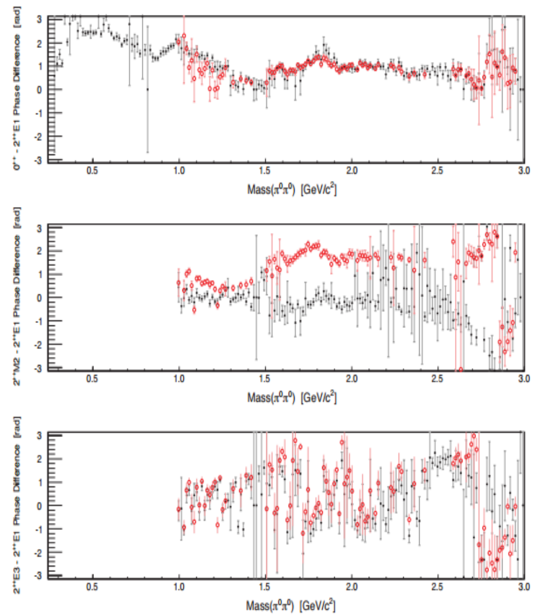
✓ More than 440k reconstructed events
✓ Background level ~ 1.8%

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

Extracted Intensity



Relative Phase



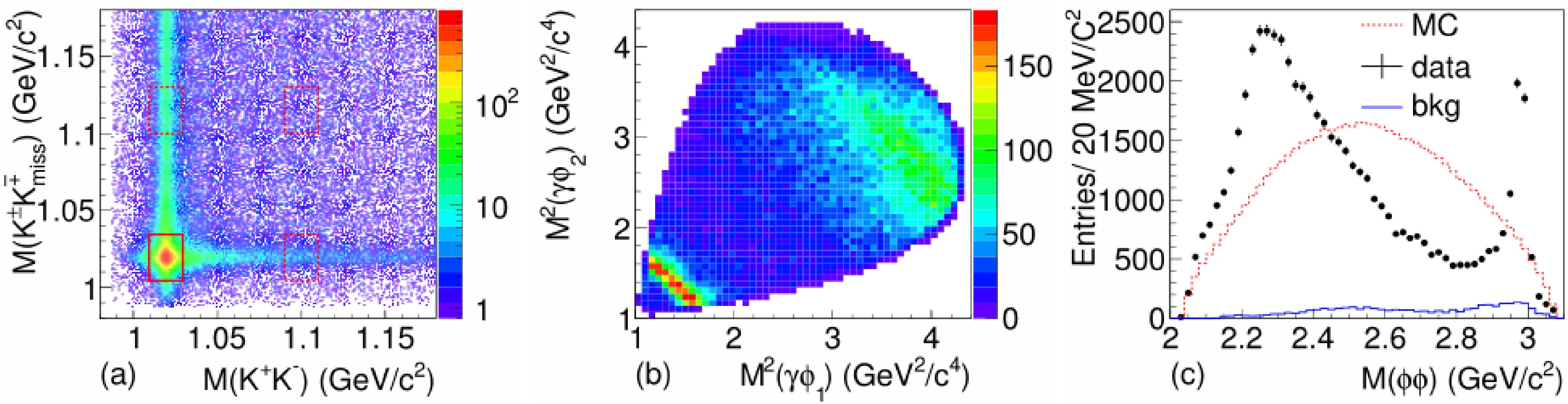
- Solution 1
- Solution 2

- ✓ A piecewise function that describes the dynamics of the $\pi^0\pi^0$ system is determined as a function of $M(\pi^0\pi^0)$
- ✓ Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/c^2
- Multi-solution problem in MIPWA
- MIPWA can not measure resonance parameters

PRD 92, 052003 (2015)

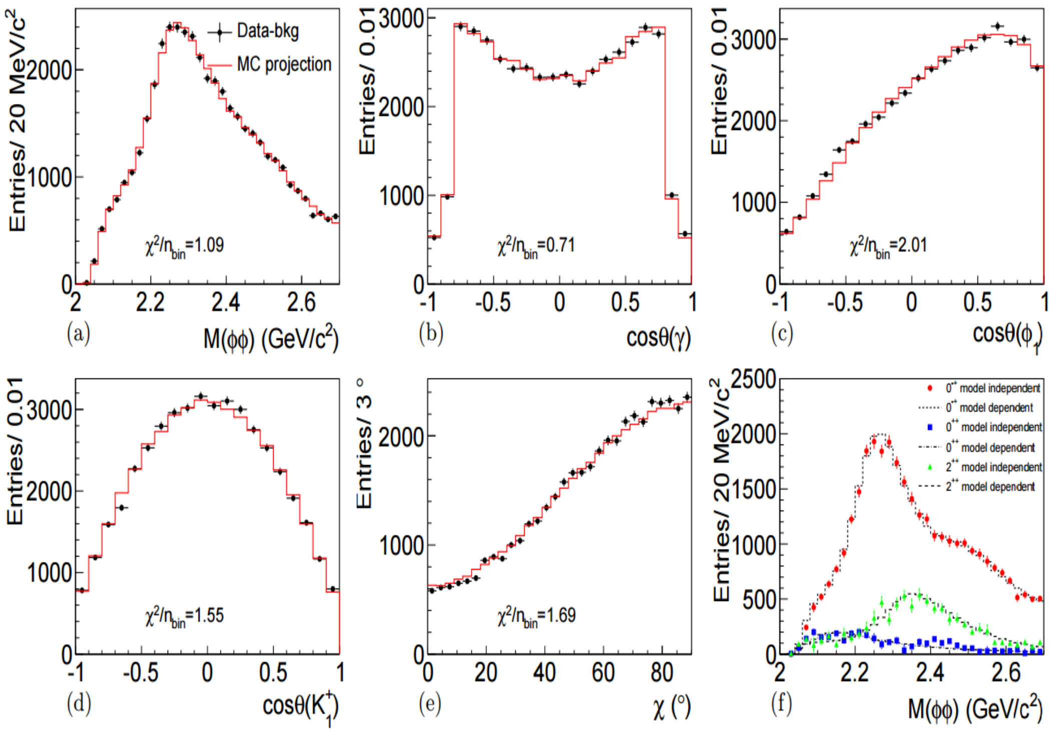
PWA of J/ψ→γφφ

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



PRD 93, 112011 (2016)

PWA of J/ψ→γφφ



Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.(×10^{-4})	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40\pm0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30\pm0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17\pm0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43\pm0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35\pm0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44\pm0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91\pm0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74\pm0.15^{+0.16}_{-1.48})$	6.8σ

PRD 93, 112011 (2016)

Pesudoscalar:
η(2225) confirmed
η(2100) and X(2500)

Tensor:
$f_2(2010)$, $f_2(2300)$, $f_2(2340)$:
strong $f_2(2340)$ production.

✓ **Well consistent with the results from Model-independent PWA**

Summary

- Highlights of latest results in light meson 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 $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$
    - ✓ **Support the existence of a $p\bar{p}$ 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**

- More results are expected in the future!

Thanks for your attention!