Recent Results on J/ψ Radiative Decays at BESIII

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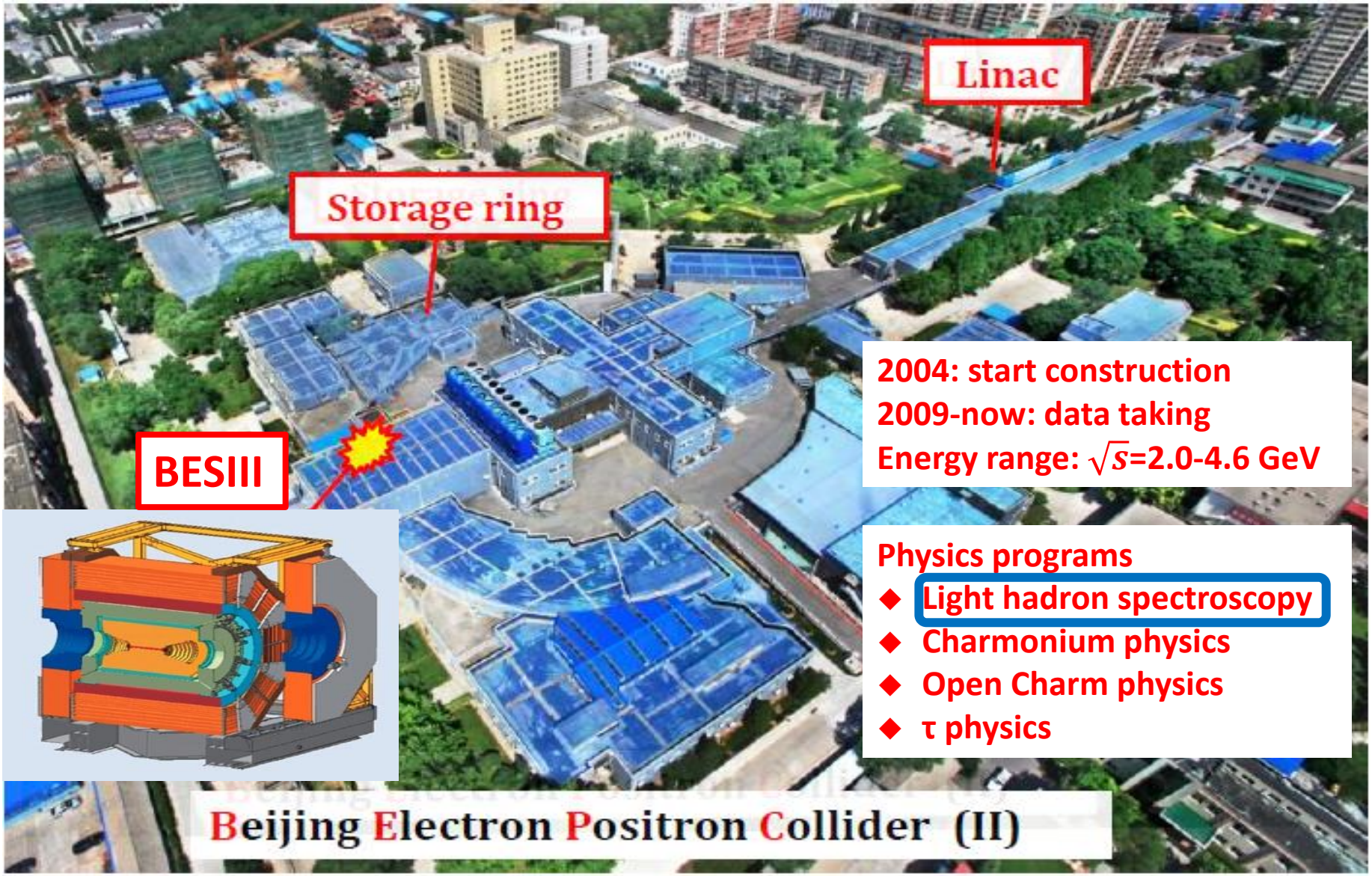
Outline

- **Introduction**
- **Selected results on J/ψ radiative decays**
  - ✓ Observation of X(1835) in $J/\psi \to \gamma K_s K_s \eta$
  - ✓ Model independent PWA of $J/\psi \to \gamma \pi^0 \pi^0$
  - ✓ PWA of $J/\psi \to \gamma \phi \phi$
- **Summary**

BEPCII and BESIII



2004: start construction
2009-now: data taking
Energy range: $\sqrt{s}$=2.0-4.6 GeV

Physics programs
- Light hadron spectroscopy
- Charmonium physics
- Open Charm physics
- τ physics

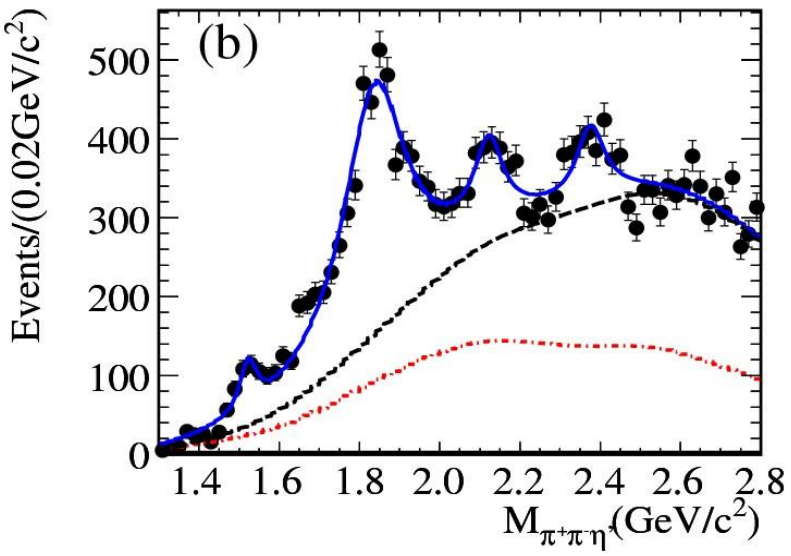
Introduction

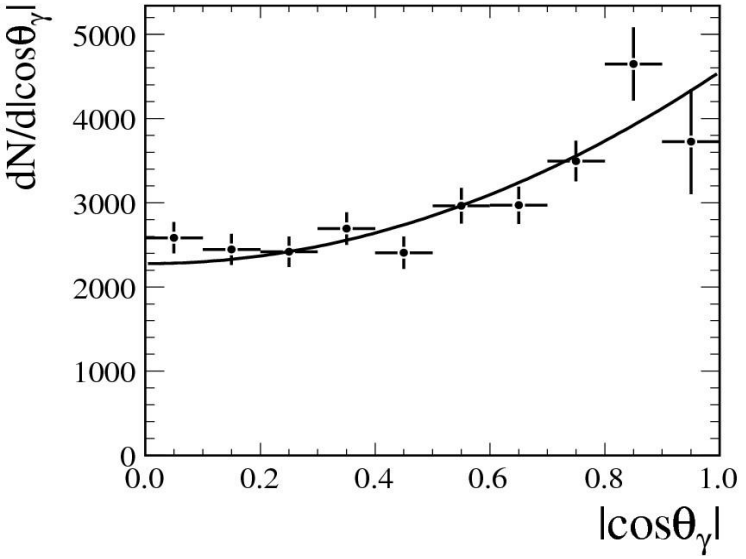
- QCD allows hadrons beyond conventional meson and baryon
  - Multiquark state: more than 3 quarks
  - Hybrid state: $q\bar{q}g$
  - Glueball: gg, ggg, …
- Radiative J/ψ decays provide ideal laboratory to search for glueballs and hybrids
- Many new hadrons have been observed at BESIII, but unclear nature
  - X($p\bar{p}$), X(1810), X(1835), X(1840), X(1870), X(2120), X(2370), …
- BESIII has collected the largest J/ψ data sample in the world
  - **1.3 billion J/ψ** events taken in 2009 and 2012

X(1835) review

- Observed in **$J/\psi \to \gamma\eta'\pi^+\pi^-$** at BESII in 2005
- Nature unclear, interpretations include $p\bar{p}$ bound state, excited η', glueball
- Confirmed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESIII
- Angular distribution consists with pseudoscalar, but other spin-parity assignments not excluded

225 million J/ψ events **PRL 106, 072002 (2011)**



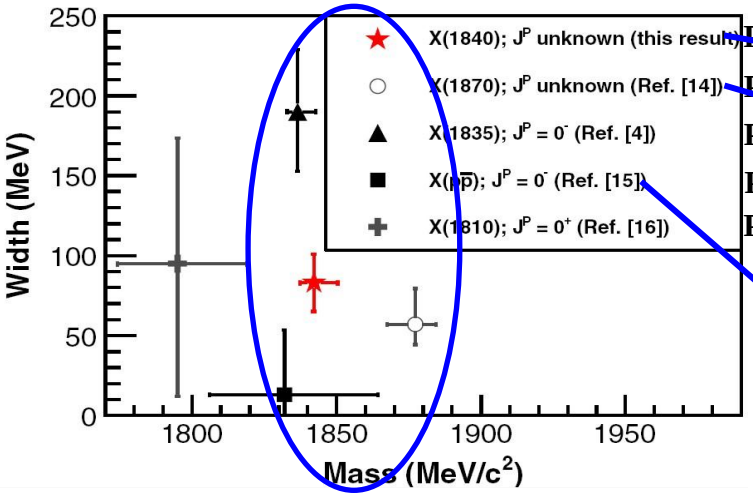


X(1835) review

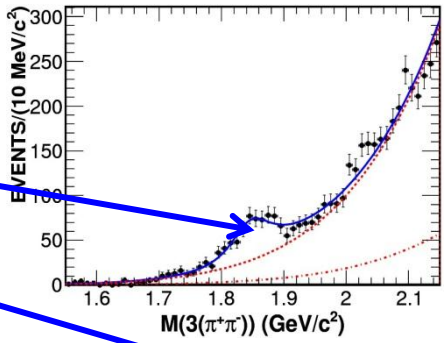
- Simulated by $p\bar{p}$ threshold enhancement X($p\bar{p}$) in $J/\psi \rightarrow \gamma p\bar{p}$
- Results in the observations of X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$ and X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$

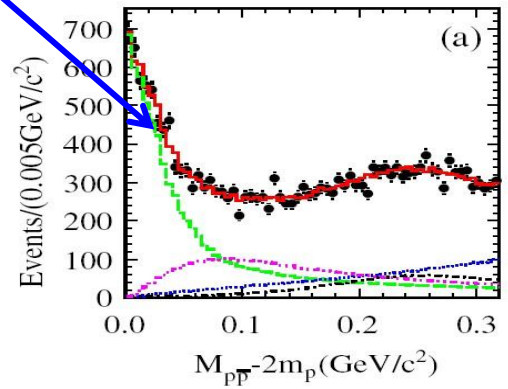
- Are these states observed around 1.8 GeV/c^2 from the same origin?
- Further investigations on different production and decay mechanisms, precise physical parameters measurement are necessary

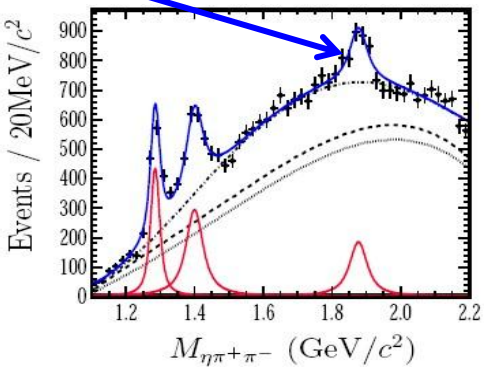
Possible channels: $J/\psi \rightarrow \gamma$ / ω / ϕ + $\eta^{(')}\pi\pi$ / $K\bar{K}\eta$ / $K\bar{K}\pi$



PRD 88, 091502 (2013)
PRL 107, 182001 (2011)
PRL 106, 072002 (2011)
PRL 108, 112003 (2012)
PRD 87, 032008 (2013)



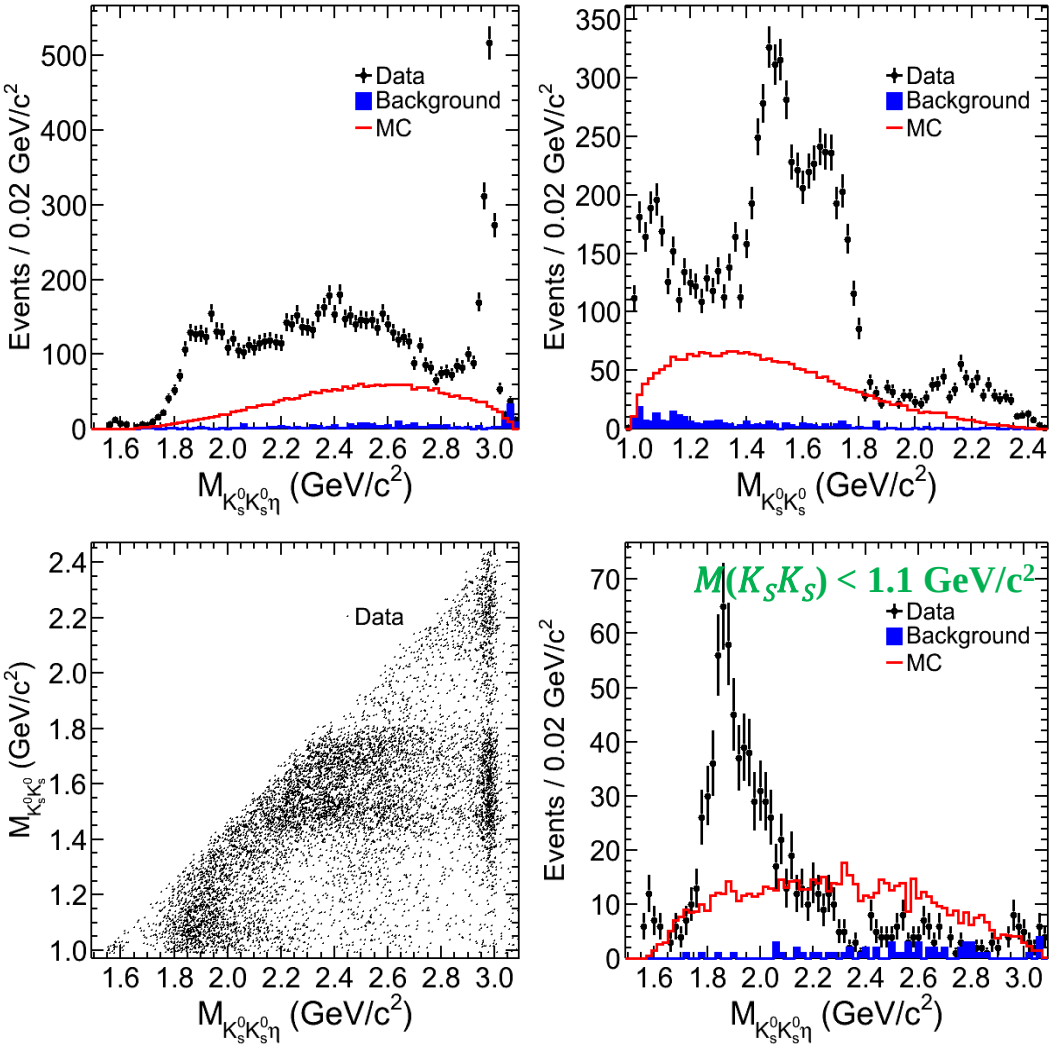




Observation of X(1835) in $J/\psi \to \gamma K_s K_s \eta$

1.3 billion J/ψ events **PRL 115, 091803 (2015)**

- Why this channel?
  - Unlike $J/\psi \to \gamma K^+ K^- \eta$, no background from two potential but forbidden channels of $J/\psi \to K_S K_S \eta$ and $J/\psi \to K_S K_S \eta \pi^0$
- Clear structure on mass spectrum of $K_s K_s \eta$ around 1.85 GeV/c^2
- Strong correlation with the enhancement near $K_s K_s$ mass threshold (interpreted as $f_0(980)$)
- Structure is enhanced for $M(K_S K_S) < 1.1$ GeV/c^2



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

- PWA for $M(K_S K_S) < 1.1$ GeV/c^2

- Two resonant pseudoscalar components are required in nominal solution

  $X(1835) \to K_S K_S \eta$ (> 12.9 σ)
  dominated by $f_0(980)$ production

  $m = 1844 \pm 9^{+16}_{-25}$ MeV/c^2

  $\Gamma = 192^{+20+62}_{-17-43}$ MeV

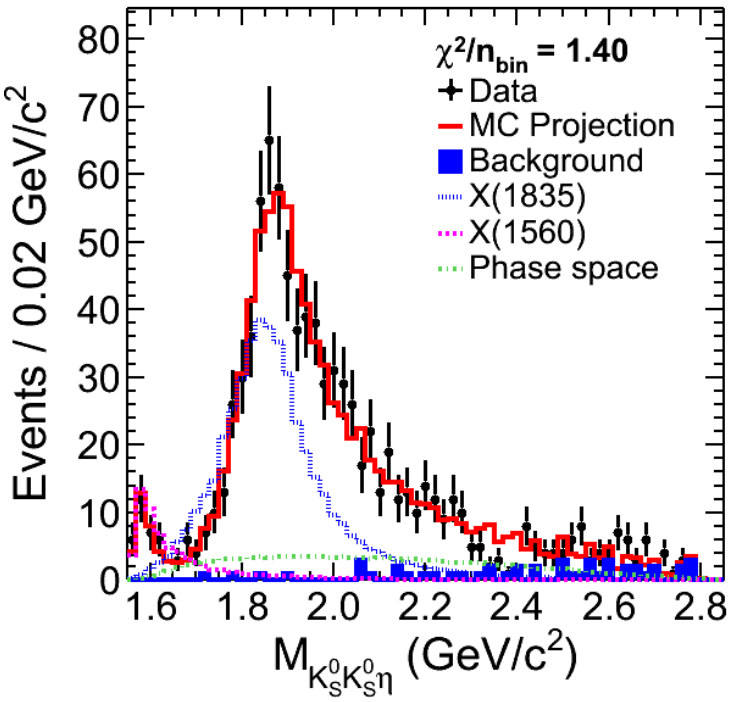
  $\mathcal{B}(J/\psi \to \gamma X(1835)) * \mathcal{B}(X(1835) \to K_S K_S \eta)$
  $= (3.31^{+0.33\ +1.96}_{-0.30\ -1.29}) * 10^{-5}$

  $X(1560) \to f_0(980)\eta$ (> 8.9 σ)

  $m = 1565 \pm 8^{+0}_{-63}$ MeV/c^2

  $\Gamma = 45^{+14+21}_{-13-28}$ MeV

PRL 115, 091803 (2015)



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

- The X(1835) 0^{-+} hypothesis is significantly better than the 1^{++} or 2^{-+} hypotheses
- Compared with previous measurements:
  - ✓ Consistent with the values obtained from **$J/\psi\to\gamma\eta'\pi^+\pi^-$**
  - ✓ The mass of X(1835) consists with the X(p$\bar{p}$) mass, while the width of X(p$\bar{p}$) is significantly narrower
  - ✓ **Both X(p$\bar{p}$) and X(1835) are pseudoscalars**

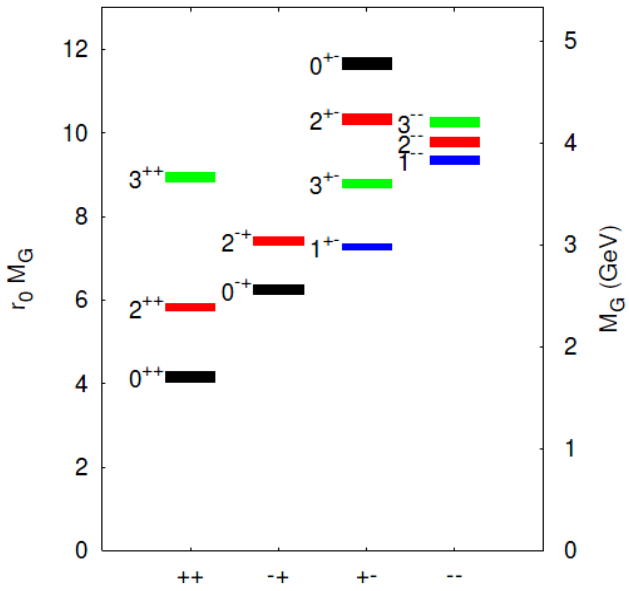
State	J^{PC}	Decay Mode	Mass (MeV/c^2)	Width (MeV)	Product Branching Ratio	Significance
X(1835)	0^{-+}	$K_SK_S\eta$	$1844\pm9^{+16}_{-25}$	$192^{+20\ +62}_{-17\ -43}$	$(3.31^{+0.33\ +1.96}_{-0.30\ -1.29})*10^{-5}$	> 12.9 σ
X(1835)	---	$\pi^+\pi^-\eta'$	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190\pm9^{+38}_{-36}$	$(2.87\pm0.09^{+0.49}_{-0.52})*10^{-4}$	> 20 σ
X(p$\bar{p}$)	0^{-+}	p$\bar{p}$	$1832^{+19\ +18}_{-5\ -17}\pm19$	<76@90%C.L.	$(9.0^{+0.4\ +1.5}_{-1.1\ -5.0}\pm2.3)*10^{-5}$	> 30 σ

red: PRL 115, 091803 (2015) blue: PRL 106, 072002 (2011) black: PRL 108, 112003 (2012)

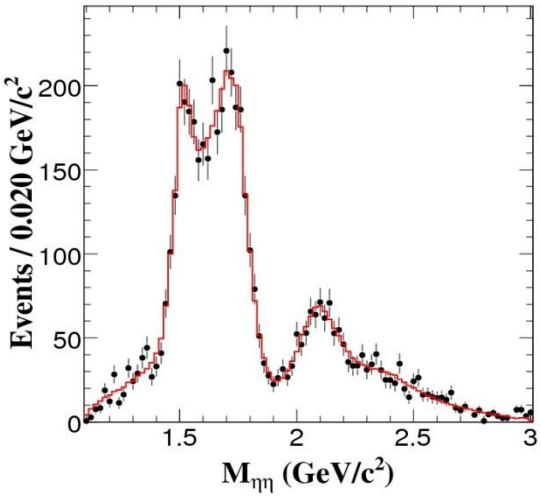
- The mass and width of the X(1560) are consistent with those of $\eta(1405)$ / $\eta(1475)$ within 2.0 σ
- More statistics in this channel and an amplitude analysis of $J/\psi\to\gamma\eta\pi^0\pi^0$ and $J/\psi\to\gamma K_sK_s\pi^0$ processes may help to understand the nature of the X(1560)

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

- The lowest glueball predicted by LQCD should be a scalar state lying at 1.5-1.7 GeV/c^2
- J/ψ radiative decays into two pseudoscalar mesons ($\eta\eta$, $\pi\pi$, $\eta\eta'$) offers a clean environment to search for scalar and tensor glueballs
- BESIII has analyzed the $J/\psi \to \gamma\eta\eta$ channel using model-dependent PWA
  - ✓ $f_0(1710)$ and $f_0(2100)$ are dominant scalars, $f_0(1500)$ exists
  - ✓ $f_2'(1525)$ is the dominant tensor, $f_2(1810)$ and $f_2(2340)$ exist
  - ✓ Production rate of $f_0(1710)$ is compatible with LQCD's prediction on scalar glueball



PRD 87, 092009 (2013)



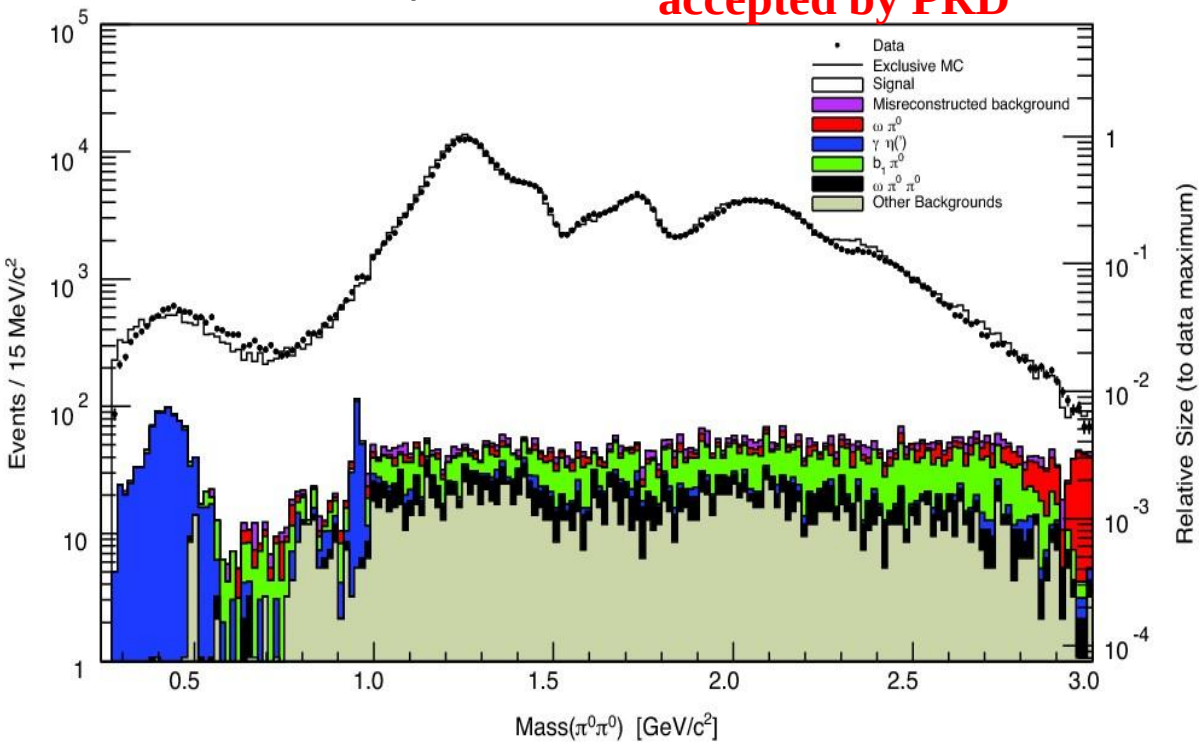
Model independent PWA of $J/\psi \to \gamma\pi^0\pi^0$

- $\pi^0\pi^0$ system: **only significant 0^{++} and 2^{++} contributions**
  - Very **clean** channel, while $J/\psi \to \gamma\pi^+\pi^-$ suffers from large ratio of $\rho\pi$ background
  - Compared with $\eta\eta$ system, larger statistics and more open channels
  - Many broad and overlapping resonances (parameterization challenging)
  - **Model independent PWA**

1.3 billion J/ψ events

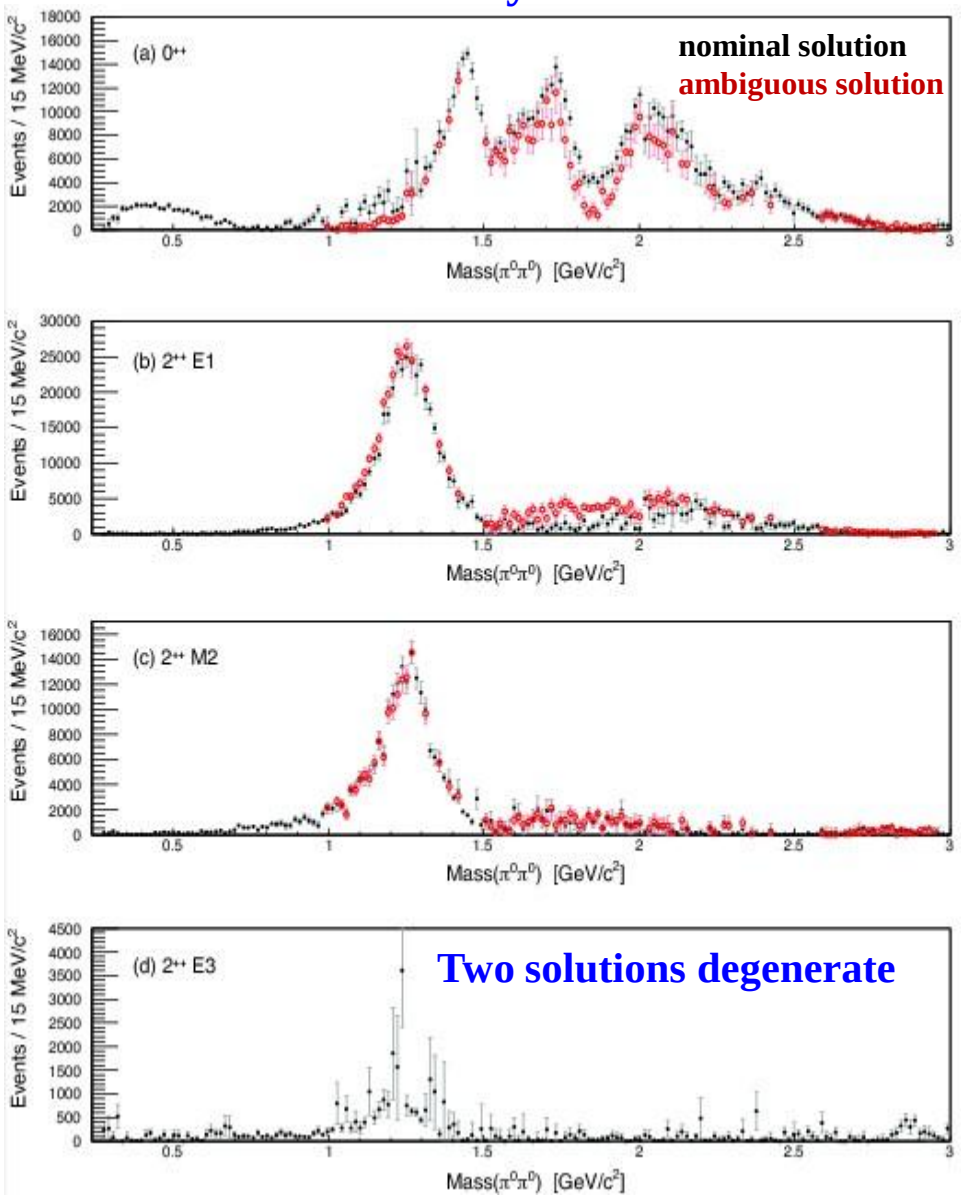
arXiv: 1506.00546
accepted by PRD

> 440k reconstructed events at a background level of 1.8%

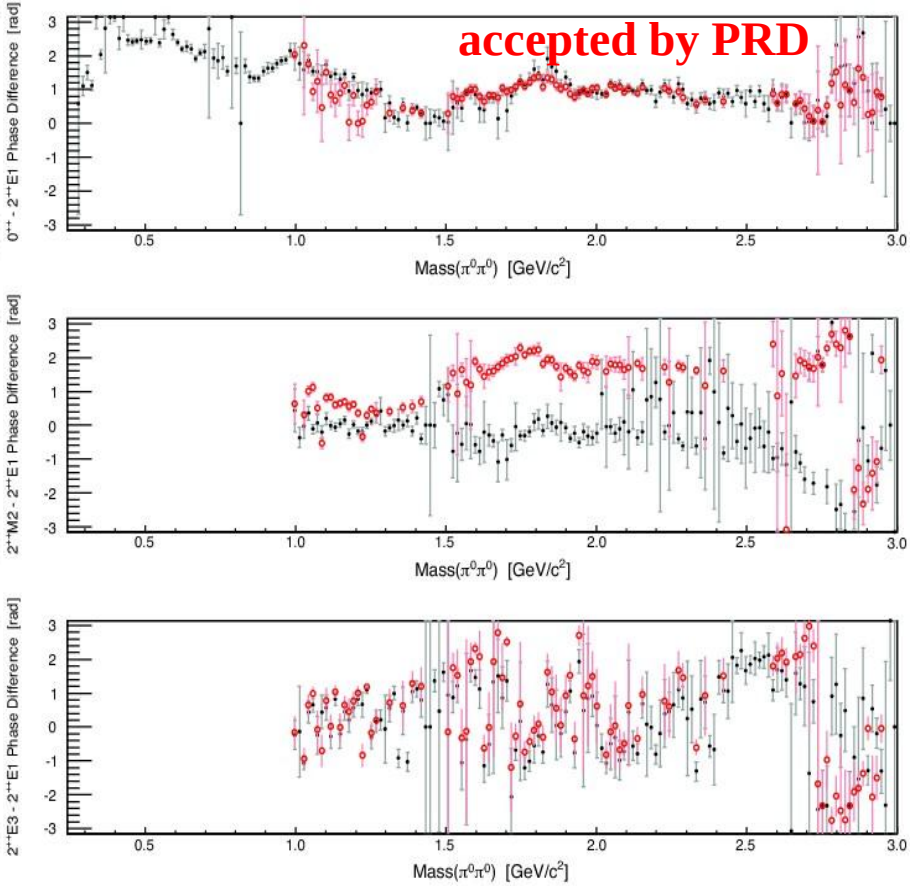


Model independent PWA of $J/\psi \to \gamma\pi^0\pi^0$

Extracted Intensity



Relative Phase



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1. A piecewise function that describes the dynamics of the $\pi^0\pi^0$ system is determined as a function of $M(\pi^0\pi^0)$
2. Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/c^2
3. Ambiguities present above $K\bar{K}$ threshold

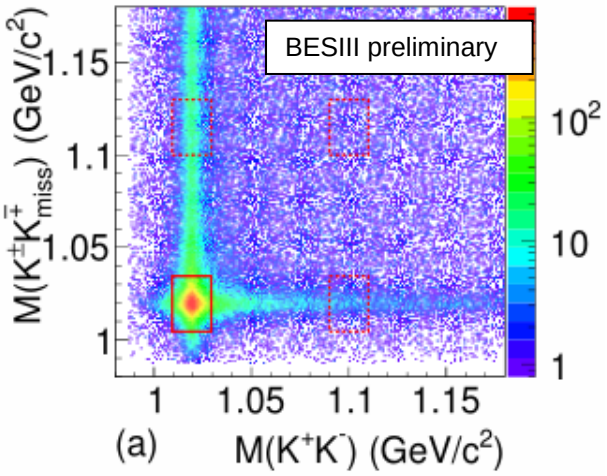
PWA of J/ψ→γϕϕ

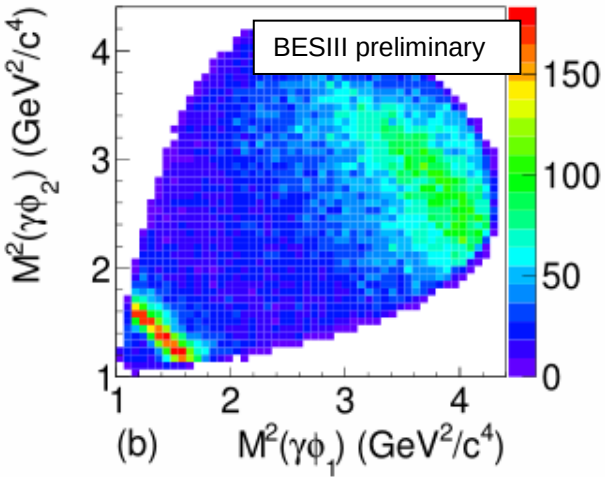
- Ground-state glueball mass prediction by LQCD
  - 0^{-+}: 2.3~2.6 GeV/c^2
  - 2^{++}: 2.3 ~2.4 GeV/c^2
- ϕϕ system observations
  - 0^{-+}: η(2225) was observed in J/ψ→γϕϕ, very little knowledge for those above 2 GeV/c^2
  - 2^{++}: broad structures around 2.3 GeV/c^2 in π^-N reactions and $p\bar{p}$ central collisions

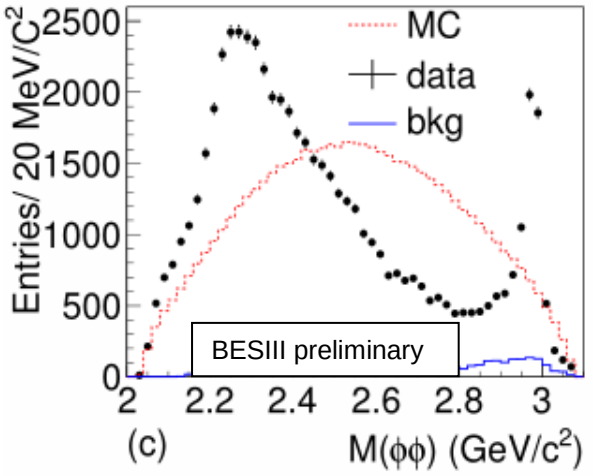
- **J/ψ→γϕϕ @ BESIII**

  both ϕ are reconstructed from K^+K^- (one Kaon is missing)

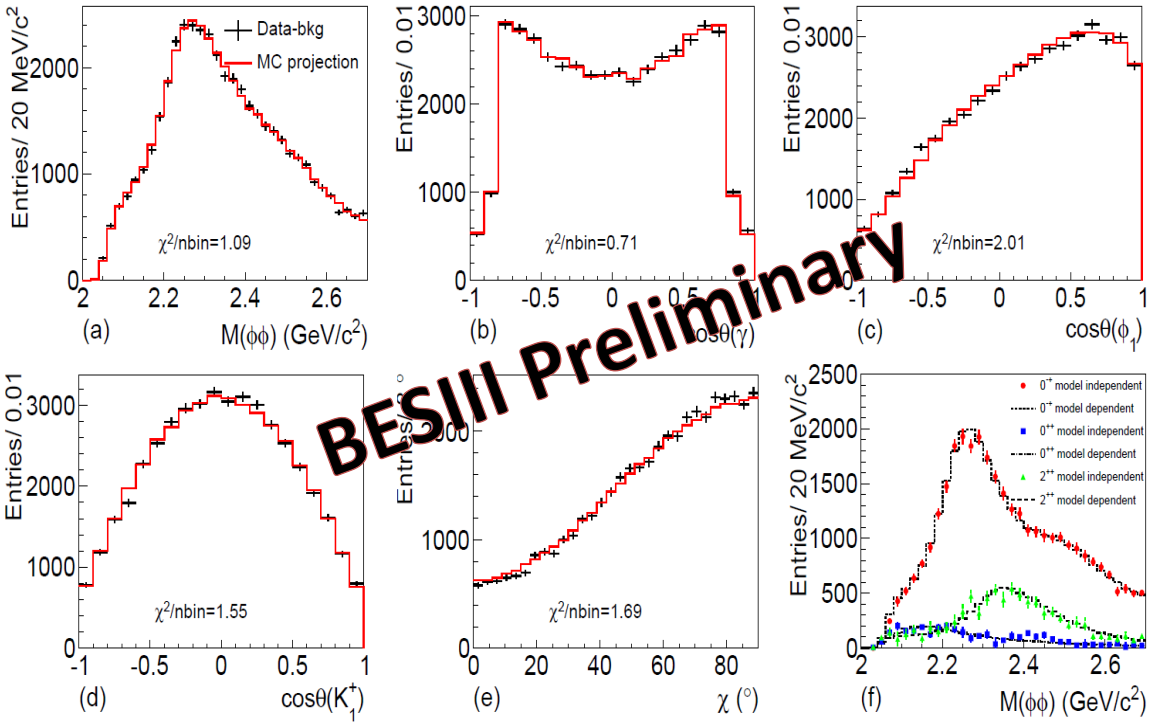
1.3 billion J/ψ events







PWA of J/ψ→γϕϕ



Resonance	M(MeV/c^2)	Γ(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

- Dominant 0^{-+} contribution
  - **η(2225) is confirmed**
  - **η(2100) and X(2500) are observed**
- The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in π^-p reactions are also observed with a strong production of $f_2(2340)$
- Model dependent PWA results are well consistent with the results from model independent PWA

The new experimental results are helpful for mapping out the pseudoscalar excitations and searching for a 0^{-+} glueball

Summary

- BESIII is successfully operating since 2008
  - World's largest data sample at the J/ψ resonance recorded
  - Clean and rich source for light hadrons
- Systematic studies to understand X(1835) and other structures observed near $p\bar{p}$ threshold
  - Nature unclear: $p\bar{p}$ bound state, glueball, excited η meson?
- Sophisticated model-independent analysis of $J/\psi \to \gamma\pi^0\pi^0$
  - Improve our understanding of the rich structures in ππ system
- φφ system investigation to search for glueballs
- More results are expected to come soon!

Thank you!