Latest results on light hadron spectroscopy at BESIII

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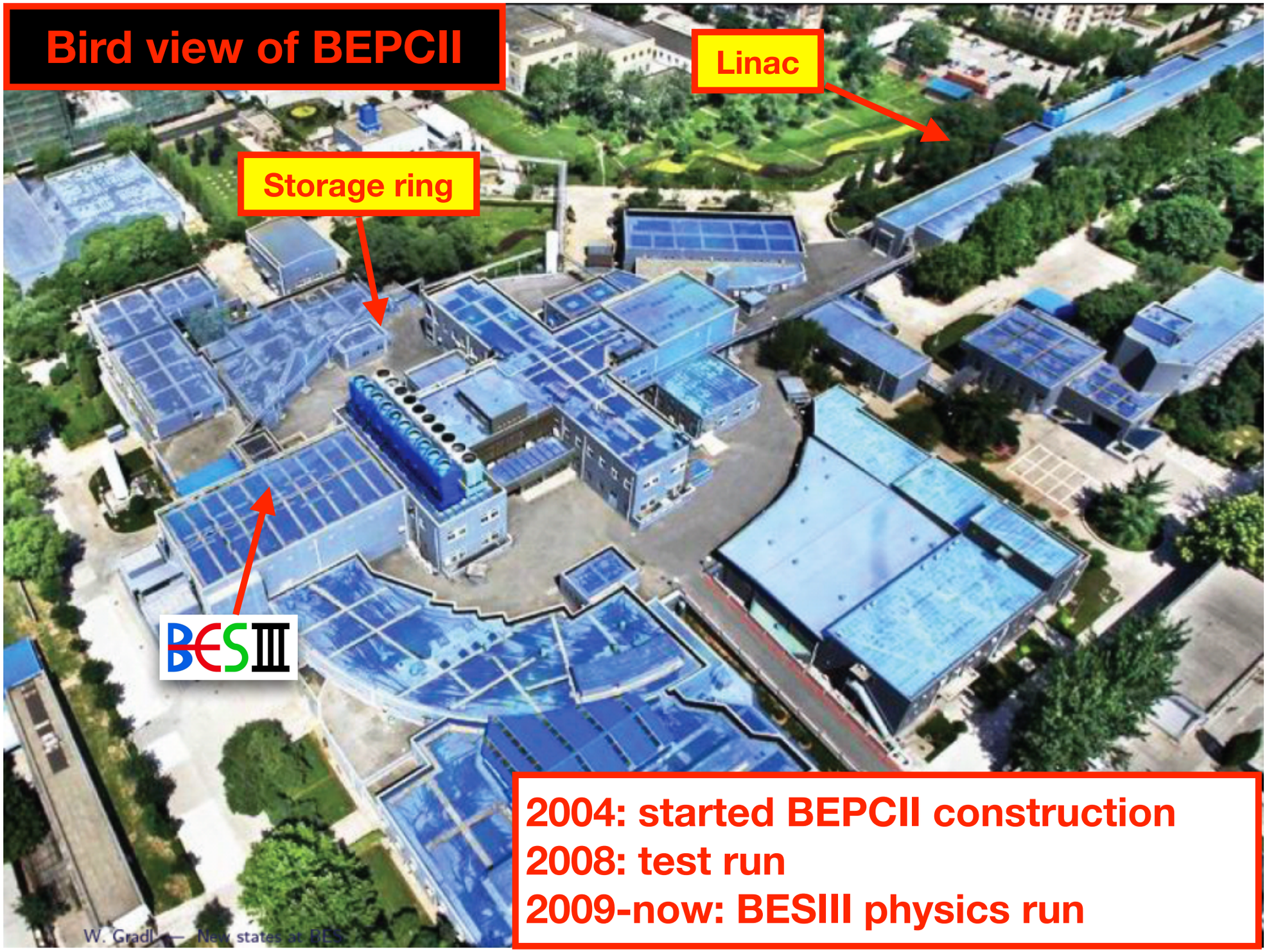
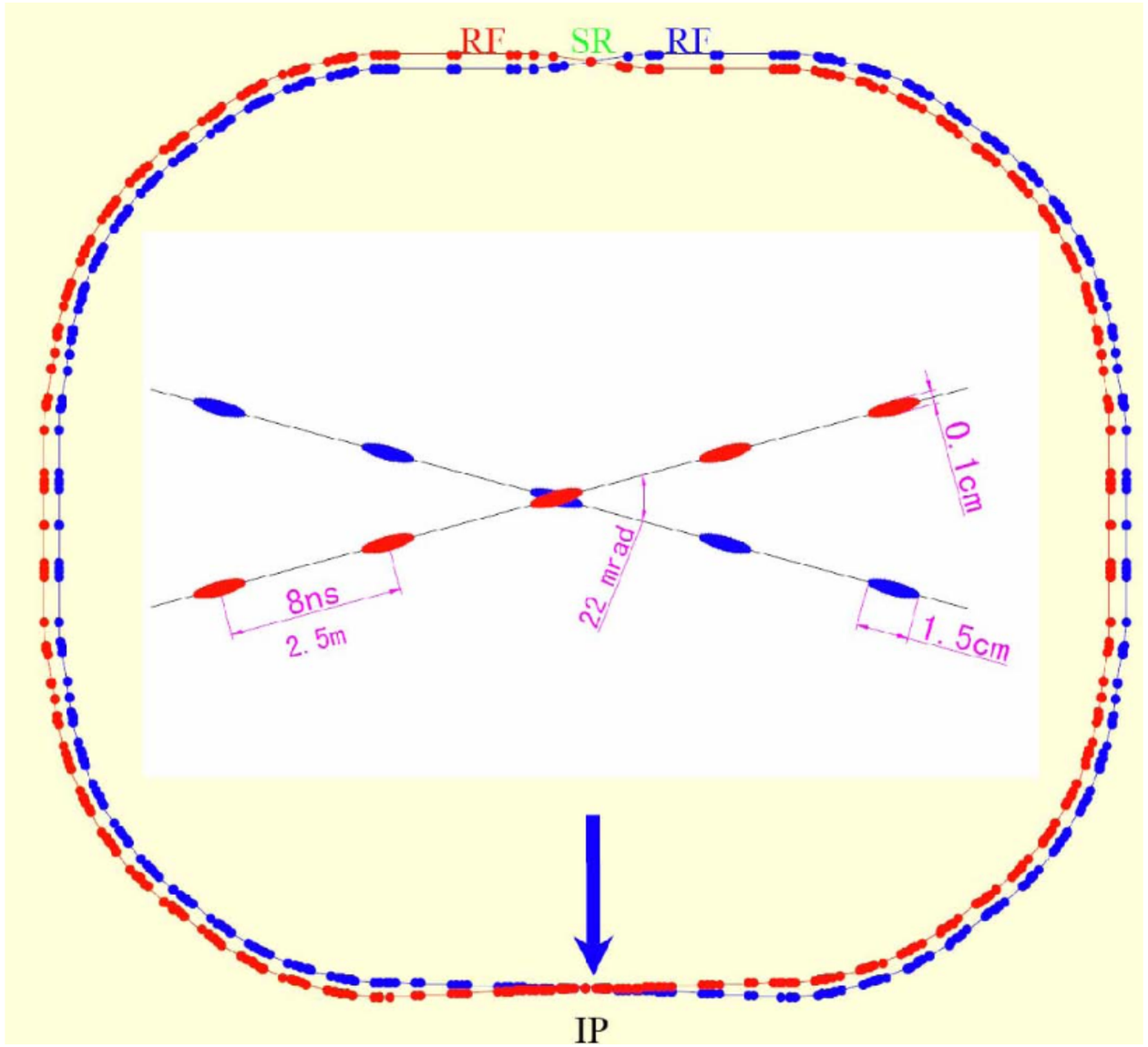
Outline

- Introduction
- Selections of latest results
  - X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$
  - Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$
  - Observation of the electromagnetic doubly OZI-suppressed decay $J/\psi \to \phi\pi^0$
  - Measurement of $\psi(3686) \to K^-\Lambda\bar{\Xi}^+ + c.c.$ and $\psi(3686) \to \gamma K^-\Lambda\bar{\Xi}^+ + c.c.$
- Summary

BEPCII&BESIII at IHEP （Beijing）



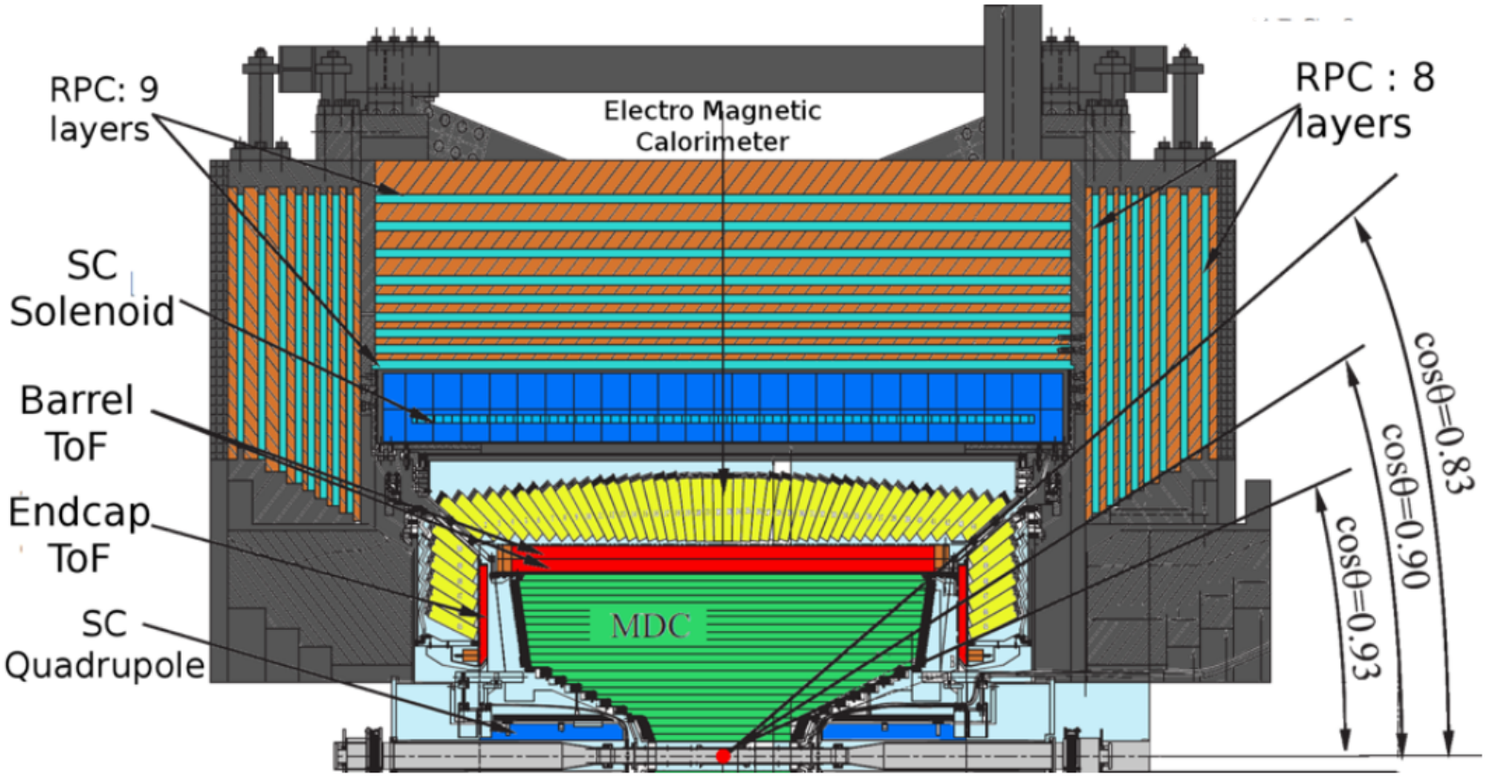
The BEPCII Collider



- ✓ **Beam energy: 1.0-2.3GeV**
- ✓ **Design Luminosity: 1×10^{33} $cm^{-2}s^{-1}$ @ ψ(3770)**
- ✓ **Achieved Luminosity: ~0.85×10^{33} $cm^{-2}s^{-1}$**
- ✓ **Optimum energy: 1.89 GeV**
- ✓ **Energy spread: 5.16×10^{-4}**
- ✓ **No. of bunches: 93**
- ✓ **Bunch length: 1.5 cm**
- ✓ **Total current: 0.91 A**
- ✓ **Circumference: 237m**

BESIII detector

Nucl. Instr. Meth. A 614, 345 (2010)



Sub-system			BESIII
MDC	Single wire $\sigma_{r\phi}$ (μm)		130
	σ_p/p (1 GeV/c)		0.5%
	σ (dE/dx)		6 %
EMC	σ_E/E (1GeV)		2.5%
	Position resolution (1 GeV)		0.6 cm
TOF	σ_T (ps)	Barrel	100
		End cap	110
Muon	No. of layers (barrel/end cap)		9/8
	cut-off momentum (MeV/c)		0.4
Solenoid magnet Field (T)			1.0
$\Delta\Omega/4\pi$			93%

Excellent performance detector

Physics goals cover a diverse range:

- **Charmonium physics: XYZ spectroscopy, decays to study QCD**
- **Open Charm physics: D0-$\bar{D}$0 mixing, (semi)leptonic+hadronic decays, …**
- **Light hadron: meson & baryon spectroscopy, Time-like e.m. form factors, …**
- **τ physics: most precise mass measurement**
- **and many more**

BESIII Collaboration

Data samples of BESIII(Till June, 2015)

Taking data	Total Num./Lum.	Taking time
J/ψ	225+1086 M	2009+2012
ψ(2S)	106+350 M	2009+2012
ψ(3770)	2916 pb^{-1}	2010~2011
τ scan	24 pb^{-1}	2011
Y(4260)/Y(4230)/Y(4360)/scan	806/1054/523/488 pb^{-1}	2012~2013
4600/4470/4530/4575/4420	506/100/100/42/993 pb^{-1}	2014
J/ψ line shape scan	100 pb^{-1}	2012
R scan (2.23, 3.40) GeV	12 pb^{-1}	2012
R scan (3.85, 4.59) GeV	795 pb^{-1}	2013~2014
R scan (2.0, 3.08) GeV	~525 pb^{-1}	2014~2015
Y(2175)	~100 pb^{-1}	2015

Introduction

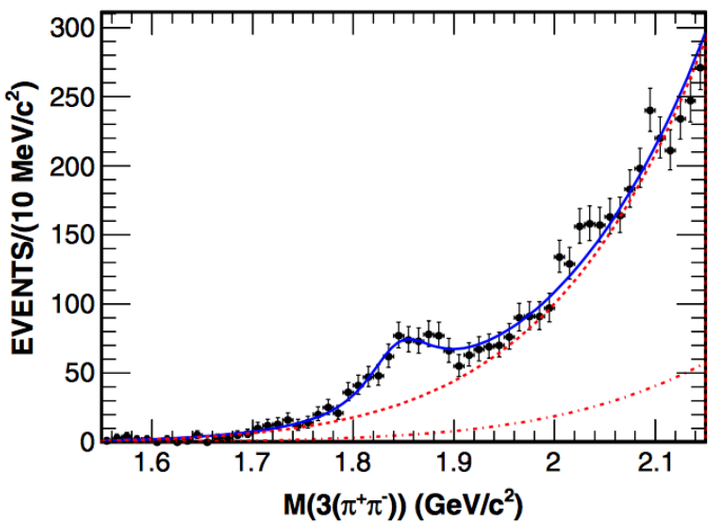
- Constituent Quark Model(CQM) has two types of hadrons:
  - Mesons: $q\bar{q}$
  - Baryons: qqq
- QCD allows hadrons of other types:
  - Multi-quark states: more than 3 quarks
  - Hybirds: $q\bar{q}g$
  - Glueballs: gg,ggg,…
  - …
- BESIII has collected the largest J/ψ and ψ(2S) data samples in the world
  - 1.3 billion J/ψ events taken in 2009 and 2012
  - 0.5 billion ψ(2S) events taken in 2009 and 2012
- Over the past few years, many new particles have been found or confirmed at BESIII
  - $X(p\bar{p})$, X(1835), X(1870), X(1810), X(1840), X(2120), X(2370), …

X(1840) in J/ψ to γ3($\pi^+\pi^-$)

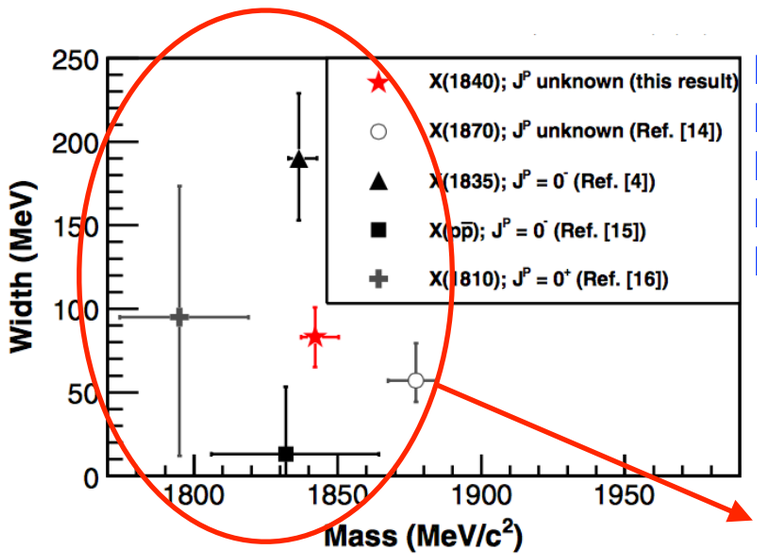
Phys. Rev. D 88, 091502(2013)

Based on 225M J/ψ events

- X(1835) is likely to have similar properties as η_c
  - 3($\pi^+\pi^-$) is a relatively large decay mode of η_c, also for X(1835)?
- A distinct enhancement can be clearly seen on mass spectrum of 3(π+π-)around 1.84 GeV/c^2
- Mass is consistent with that of X(1835), but the width is much smaller
  - M=$1842\pm4.2^{+7.1}_{-2.6}$MeV/c^2, Γ=$83\pm14\pm11$MeV/c^2
  - Br(J/ψ→γX(1840)).Br(X(1840)→3($\pi^+\pi^-$))=$(2.44\pm0.36^{+0.60}_{-0.74})\times10^{-5}$



Phys. Rev. D 88, 091502(2013)



Phys. Rev. D 88, 091502(2013)
Phys. Rev. Lett. 107, 182001(2001)
Phys. Rev. Lett. 106, 072002(2001)
Phys. Rev. Lett. 108, 112003(2012)
Phys. Rev. D 87, 032008(2013)

Need more study: more data, PWA, …

Observation and Spin-Parity Determination of the X(1835) in $J/\psi\to\gamma K_sK_s\eta$

arXiv:1506.04807

Based on 1.3B J/ψ events

- X(1835) was first observed by BESII and then confirmed by BESIII in its decay to $\pi^+\pi^-\eta'$ in $J/\psi\to\gamma\pi^+\pi^-\eta'$

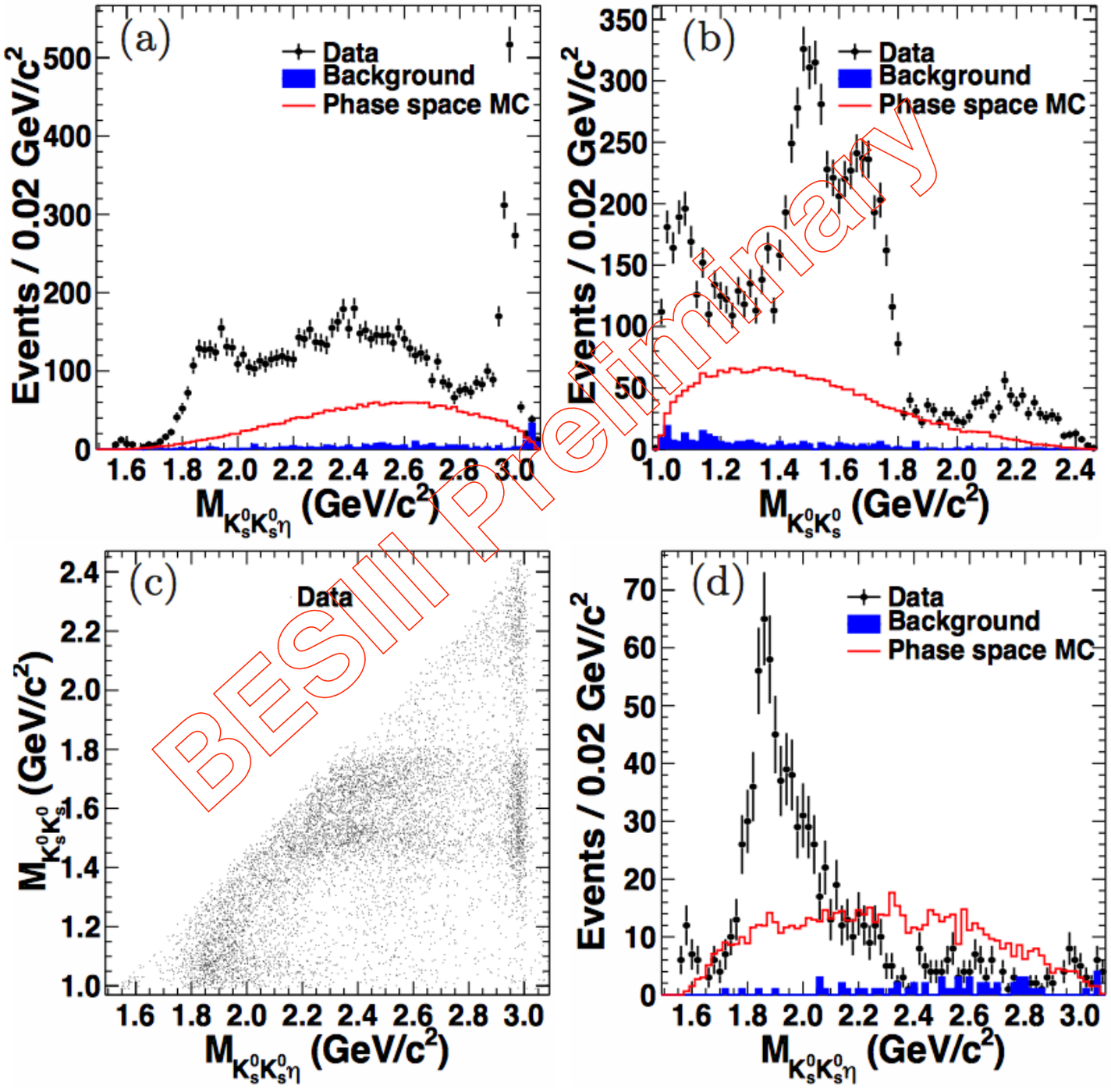
- The discovery of X(1835) has stimulated theoretical speculations concerning its nature: $p\bar{p}$ bound state, second radial excitation of the η′, pseudo-scalar glueball.

- It is crucial to measure the J^{PC} of X(1835) and to search for its new decay modes.

- $J/\psi\to\gamma K\bar{K}\eta$ is a favorable channel to search for $X(1835)\to K\bar{K}\eta$. Contrary to $J/\psi\to\gamma K^+K^-\eta$, there is no background contamination for from $J/\psi\to\gamma K_sK_s\eta$ and $J/\psi\to K_sK_s\eta\pi^0$, which are forbidden by exchange symmetry and CP conservation.

Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$

arXiv:1506.04807



- ✓ **The structure around 1.85 GeV/c^2 in the $K_SK_S\eta$ mass spectrum is strongly correlated to $f_0(980)$**

- ✓ **To reduce complexities, we perform PWA by requiring $M(K_SK_S)$<1.1 GeV/c^2**

- ✓ **PWA method**
- **Unbinned maximum likelihood fit**
- **Amplitudes: covariant tensor formalism**
  Eur.Phys.J.A16,537(2003)

Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$

PWA Solution

- **Three components:**

$J/\psi \to \gamma$ X(1835), X(1835)$\to K_S K_S \eta$ (the $K_S K_S$ system is dominantly produced through the $f_0(980)$)
$J/\psi \to \gamma$ X(1560), X(1560)$\to f_0(980)\eta$
$J/\psi \to \gamma$ + 0^{-+} non-resonance, 0^{-+} non-resonance$\to f_0(1500)\eta$

- **Measured parameters:**

X(1835):

$J^{PC}=0^{-+}$, $M=1844 \pm 9(\text{stat})^{+16}_{-25}(\text{syst})$ MeV/c^2, $\Gamma=192^{+20}_{-17}(\text{stat})^{+62}_{-43}(\text{syst})$ MeV,

$Br(J/\psi \to \gamma X(1835) * Br(X(1835) \to K_s K_s \eta) = (3.31^{+0.33}_{-0.30}{}^{+1.96}_{-1.29}) * 10^{-5}$, significance > 12.9 σ

X(1560):

$J^{PC}=0^{-+}$, $M=1565 \pm 8(\text{stat})^{+0}_{-63}(\text{syst})$ MeV/c^2, $\Gamma=45^{+14}_{-13}(\text{stat})^{+21}_{-28}(\text{syst})$ MeV, significance > 8.9 σ

Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$

Systematic errors & Various checks

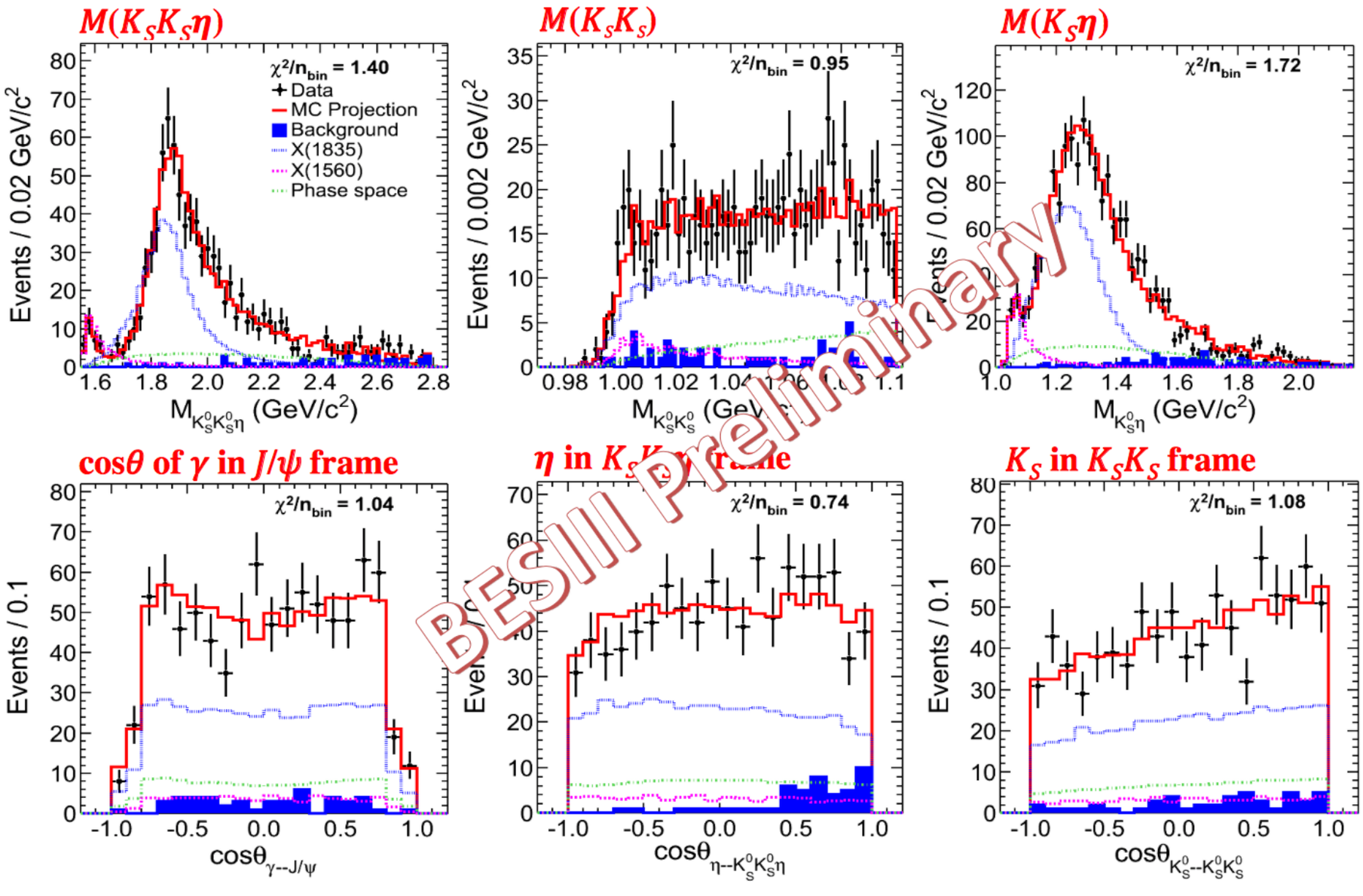
- ✓ **The systematic errors are carefully considered, including checking the components in the nominal solution, changing the $K_S K_S$ mass range, background study etc.**

- ✓ **The X(1835) 0^{-+} hypothesis is significantly better than the 1^{++} or 2^{-+} hypotheses, with the negative log-likelihood (NLL) value improving by at least 41.6 units**

- ✓ **The statistics can not distinguish the decay mode of the X(1560) between $f_0(980)\eta$ and $(K_S K_S)_S \eta$. The mass and width of the X(1560) are consistent with those of the $\eta(1405)$ and $\eta(1475)$ within 2.0 σ and 1.4 σ, respectively**

Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$

Projections



Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$

Summary

- The PWA fit requires a contribution from X(1835)$\to K_S K_S \eta$ with a statistical significance greater than 12.9 σ, where the $K_S K_S$ system is dominantly produced through the $f_0(980)$
- The spin-parity of the X(1835) is determined to be 0^{-+}
- The measured mass and width of the X(1835) are consistent with values obtained from the decay $J/\psi \to \gamma\pi\pi\eta'$ by BESIII
- These results are all first-time measurements and can provide important information to further understand the nature of the X(1835)

State	J^{pc}	Decay Mode	Mass (MeV/c^2)	Width (MeV)	Product Branching Ratio	Significance
X(1835)*	0^{-+}	$K_S K_S \eta$	$1844 \pm 9^{+16}_{-25}$	$192^{+20\ +62}_{-17\ -43}$	$(3.31^{+0.33\ +1.96}_{-0.30\ -1.29})*10^{-5}$	> 12.9 σ
X(1835)**	---	$\pi^+\pi^-\eta'$	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$	$(2.87 \pm 0.09^{+0.49}_{-0.52})*10^{-4}$	> 20 σ
X($p\bar{p}$)***	0^{-+}	$p\bar{p}$	$1832^{+19\ +18}_{-5\ \ -17} \pm 19$	<76@90%C.L.	$(9.0^{+0.4\ +1.5}_{-1.1\ -5.0} \pm 2.3)*10^{-5}$	> 30 σ

*This result ** PRL 106, 072002 (2011), the angular distribution consists with 0^{-+} hypothesis *** PRL 108, 112003 (2012)

Observation of the electromagnetic doubly OZI-suppressed decay J/ψ→ϕπ

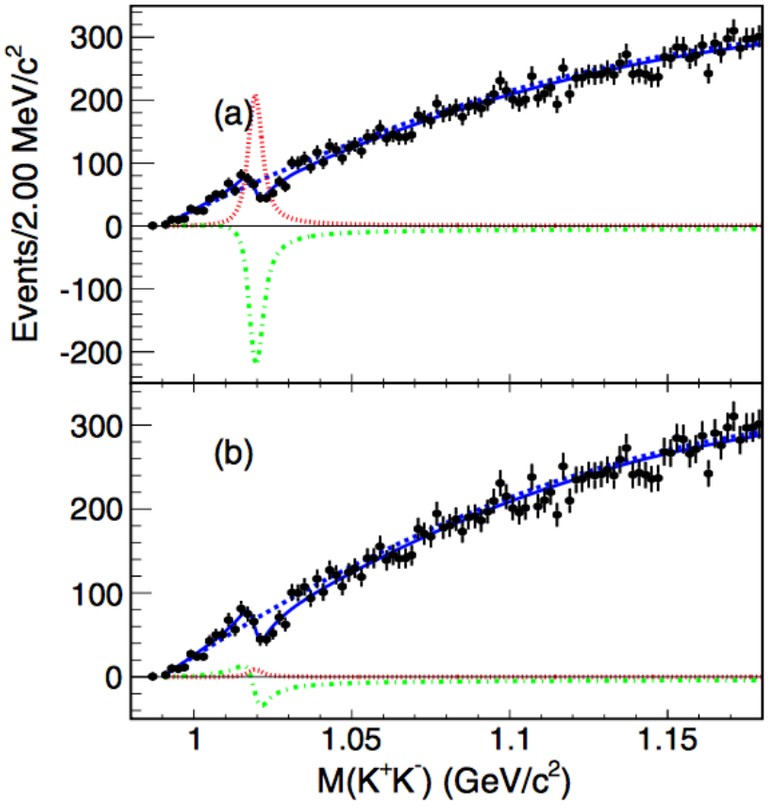
Phys. Rev. D 91, 112001(2015)

Based on 1.3B J/ψ events

- First evidence for a DOZI suppressed electromagnetic J/ψ decay.
- A clear structure is observed in the K^+K^- mass spectrum around 1.02GeV/c^2, which can be attributed to interference between $J/\psi\to\phi\pi^0$ and $J/\psi\to K^+K^-\pi^0$
- Two possible solutions with two different phase angles between the ϕ resonance and the non-ϕ contributions are found :

- Br($J/\psi\to\phi\pi^0$)=$(2.94\pm0.16\pm0.16)\times10^{-6}$(solution I)
- Br($J/\psi\to\phi\pi^0$)=$(1.24\pm0.33\pm0.30)\times10^{-6}$(solution II)

Solution	N^{sig}	δ	$2\Delta\log\mathcal{L}/N_f$	Z
I	838.5 ± 45.8	$-95.9°\pm1.5°$	45.8/2	6.4σ
II	35.3 ± 9.3	$-152.1°\pm7.7°$	45.8/2	6.4σ



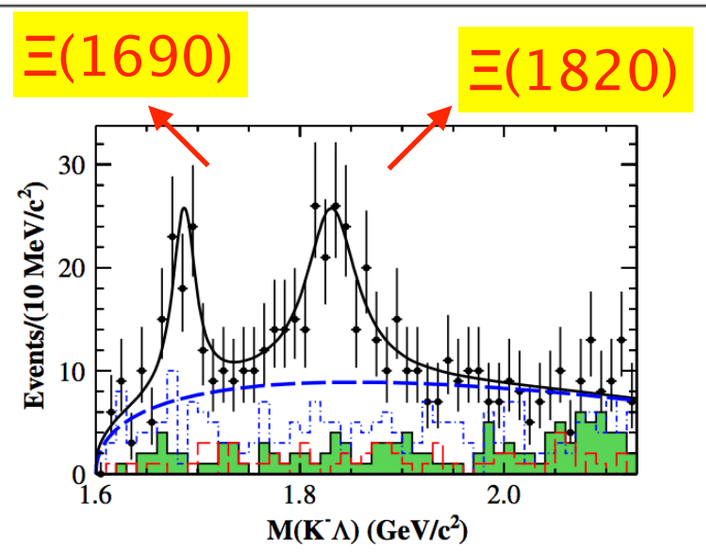
Measurement of $\psi(3686)\to K^-\Lambda\bar{\Xi}^+ + c.c.$ and $\psi(3686)\to\gamma K^-\Lambda\bar{\Xi}^+ + c.c.$

Phys. Rev. D 91, 092006(2015)

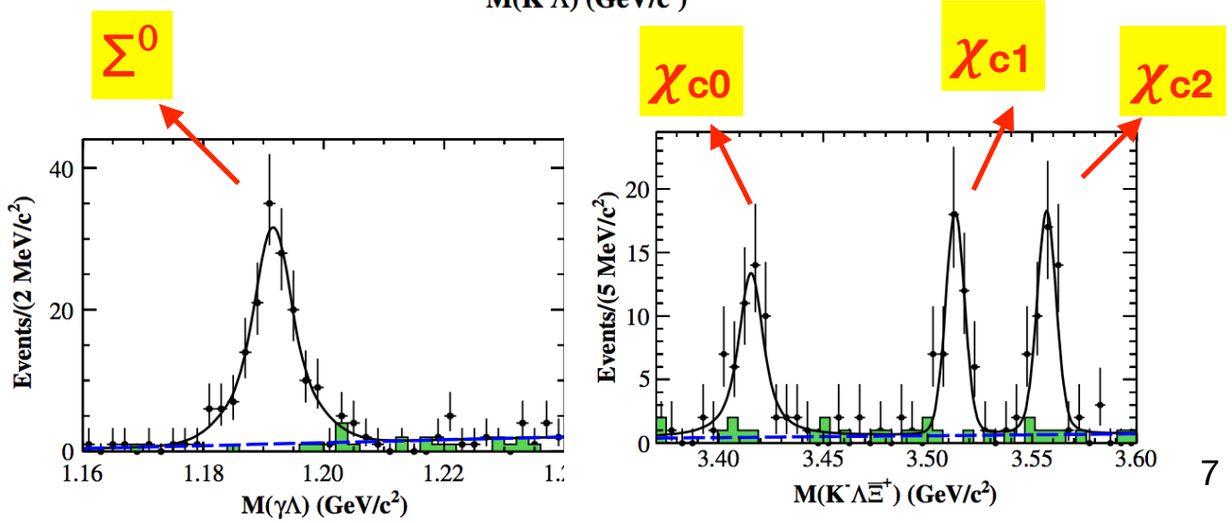
Based on 106M ψ(2S) events

- $\Xi(1690)^-$ and $\Xi(1820)^-$ are observed in the $K^-\Lambda$ invariant mass distribution in the decay $\psi(3686)\to K^-\Lambda\bar{\Xi}^+ + c.c.$ with significances of 4.9σ and 6.2σ, respectively.
- Many branching fractions are measured for the first time.

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\mathrm{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}(10^{-6})$	$5.21 \pm 1.48 \pm 0.57$	$12.03 \pm 2.94 \pm 1.22$
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	< 30	24^{+15}_{-10}



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



Summary

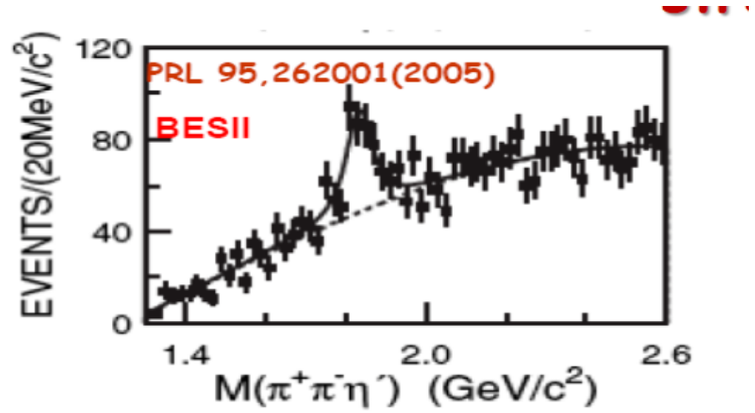
- By using huge data samples collected for charmonium decays at BESIII, a lot of results have been obtained :
  - X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$
  - Observation and Spin-Parity Determination of the X(1835) in $J/\psi \to \gamma K_S K_S \eta$
  - Observation of the electromagnetic doubly OZI-suppressed decay $J/\psi \to \phi\pi^0$
  - Measurement of $\psi(3686) \to K^-\Lambda\bar{\Xi}^+ + c.c.$ and $\psi(3686) \to \gamma K^-\Lambda\bar{\Xi}^+ + c.c.$
- Expect more results with 1.3B J/ψ and 0.5B ψ(2S).

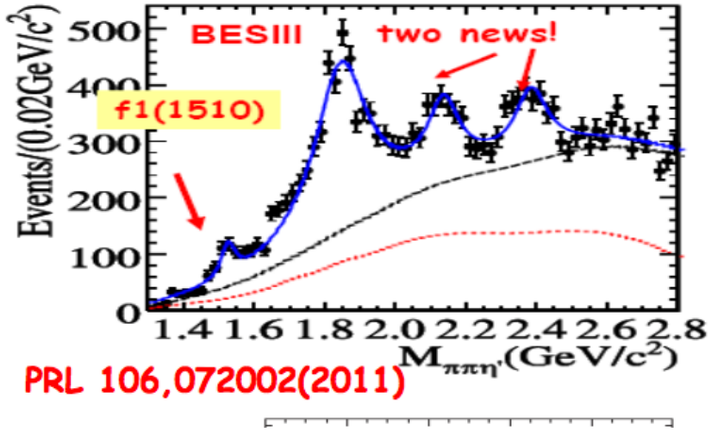
Thank you for your attention!

Back up

Review of X(18??) at BESIII

- X(1835)
  - First observed in $J/\psi \to \gamma\pi^+\pi^+\eta'$ by BESII, then confirmed by BESIII
  - Possible interpretations: pp bound state, a second radial excitation of η' , a pseudo-scalar glueball?

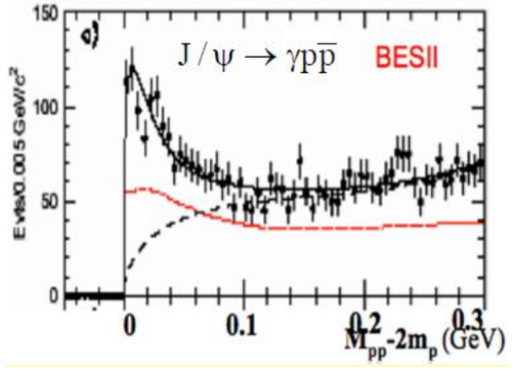




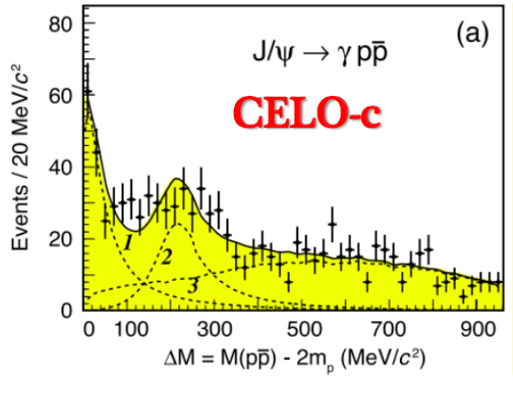
Review of X(18??) at BESIII

- X(pp)
  - First observed by BESII and confirmed by BESIII and CLEO

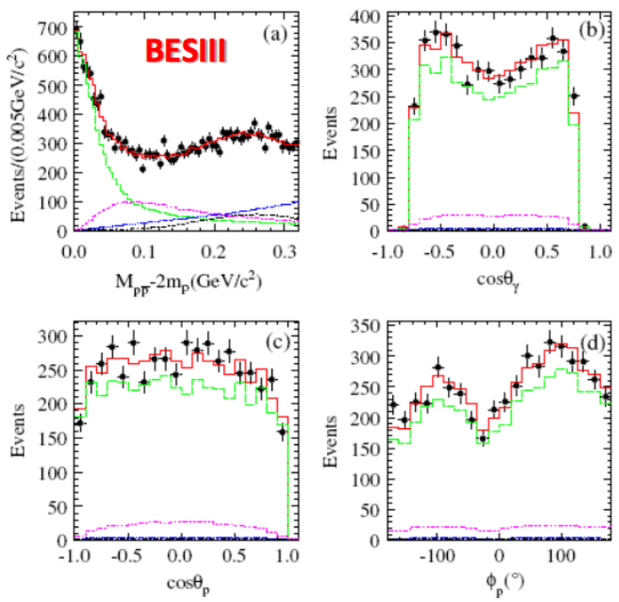
PRL 91, 022001 (2003)



PRD 82, 092002 (2010)



- A spin-parity analysis of J/ψ→γpp was performed by BESIII and the J^{PC} of X(pp) was determined to be 0^{-+}



PRL 108, 112003 (2012)

CPC 34, 421 (2010)