Hadron Spectroscopy at BESIII

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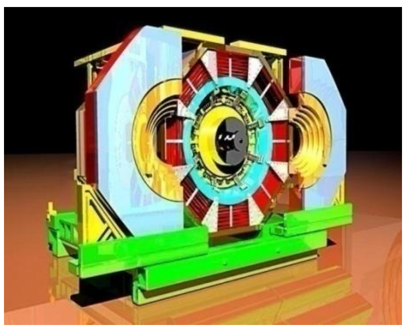
on behalf of the BESIII Collaboration



QCD@Work 2016

International Workshop on QCD Theory and Experiment

Martina Franca, Italy

June 27-30, 2016

Overview

- Introduction

BEPCII and the BESIII experiment

BESIII dataset

- Physics highlights

Meson spectroscopy

Charmonium-like states: XYZ states

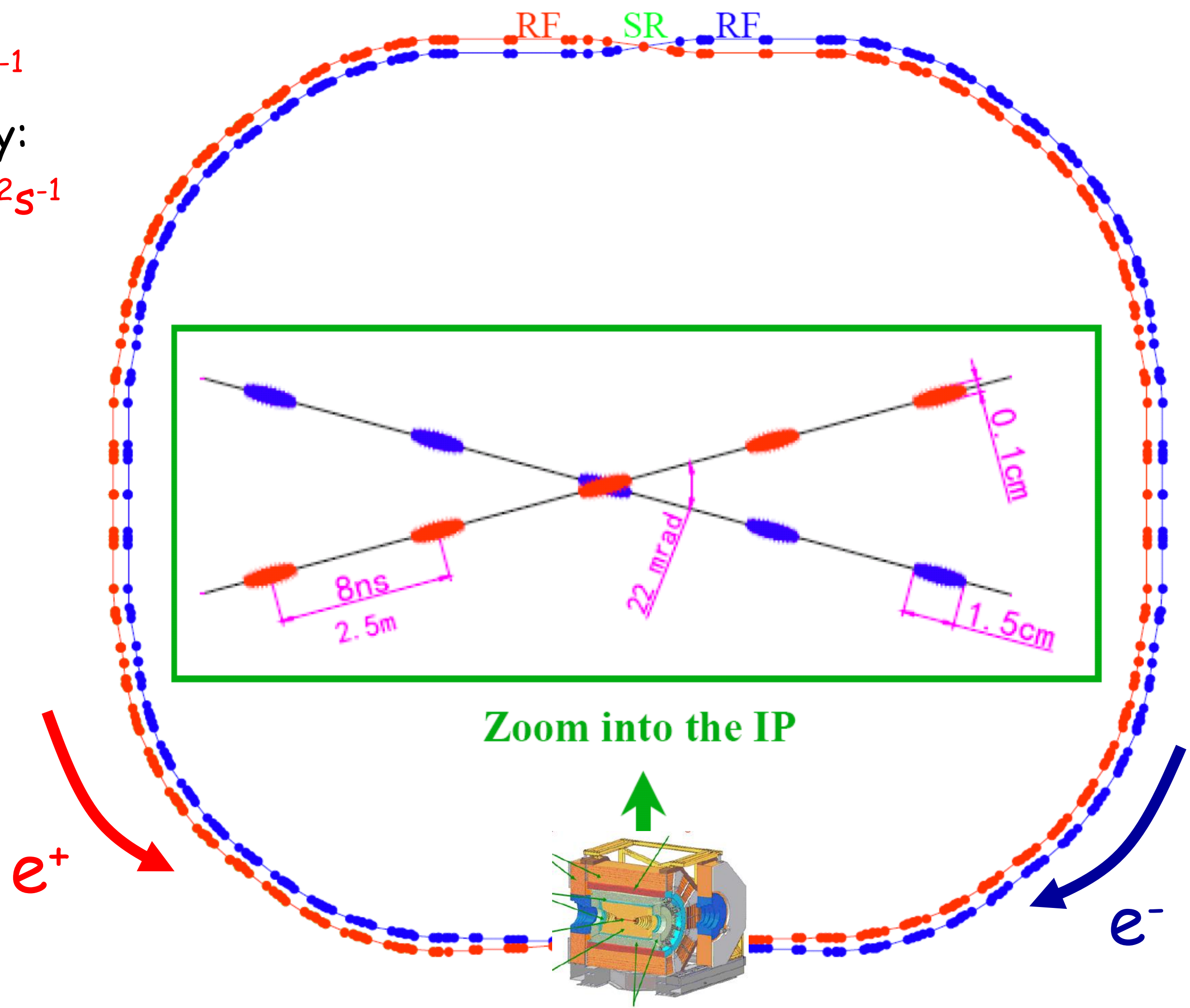
Baryon spectroscopy

- Summary

BEPCII Storage Rings

- Beam energy:
  1.0-2.3 GeV
- Design Luminosity:
  $1 \times 10^{33}\ cm^{-2}s^{-1}$
- Achieved Luminosity:
  $\sim 1 \times 10^{33}\ cm^{-2}s^{-1}$
- 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

Beijing Electron-Positron Collider II

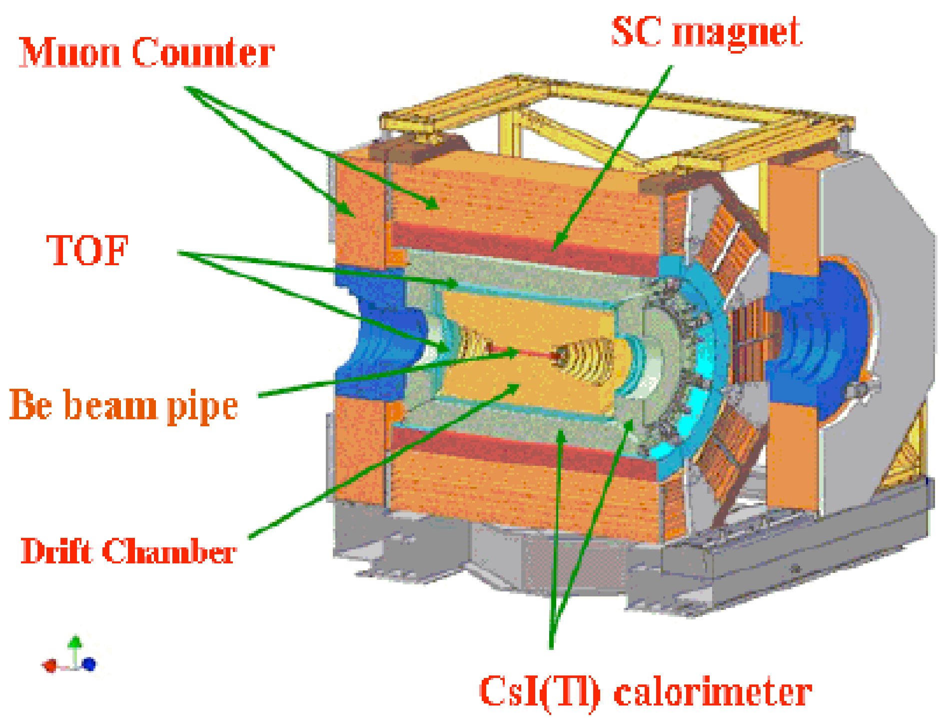


The BESIII Spectrometer @ IHEP

BEijing Spectrometer III

e^+e^- collisions

$\sqrt{S}$ tuned depending on energy

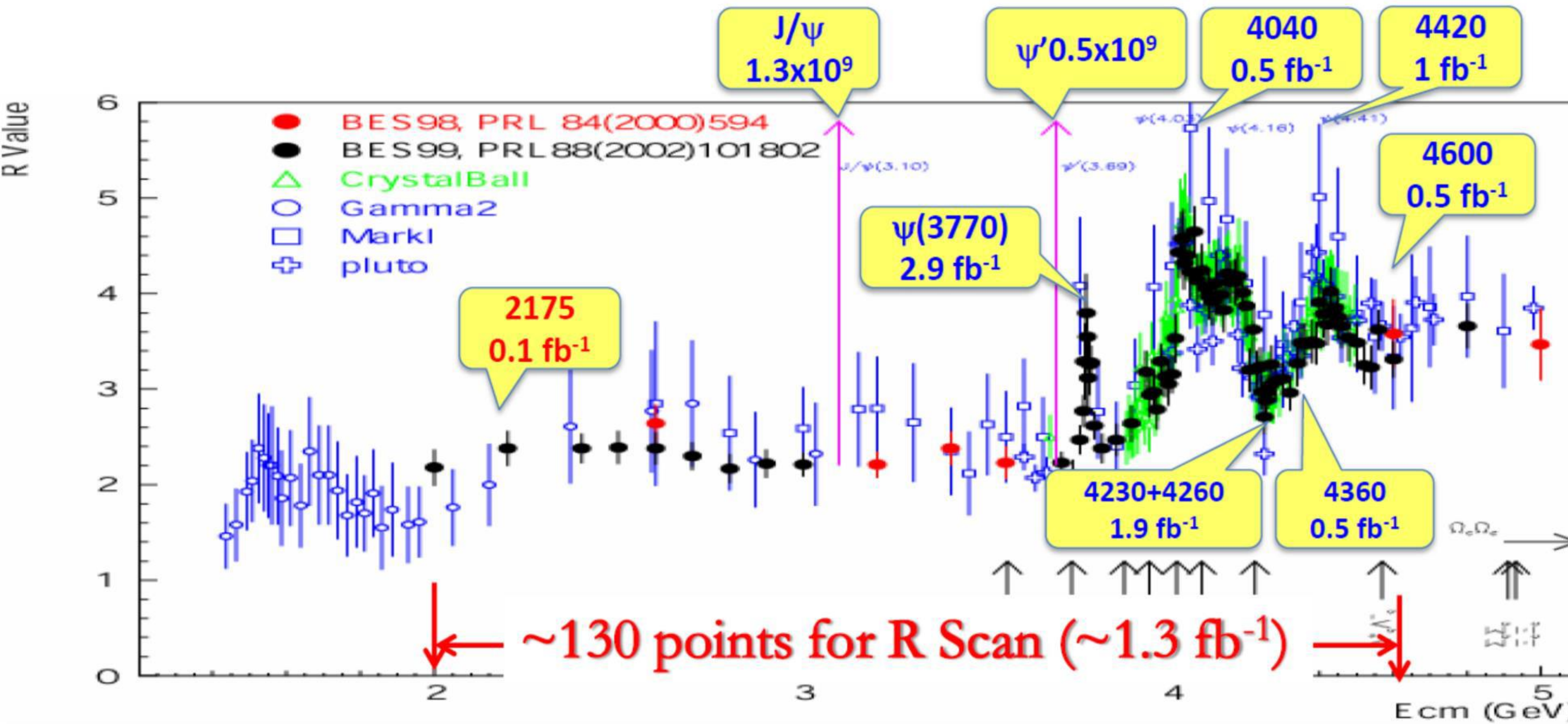


Physics program

- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- τ-Physics
- ...

D.M. Asner et al, Physics at BES-III, arXiv:0809.1869v1 [hep-ex] (2008)

BESIII Dataset

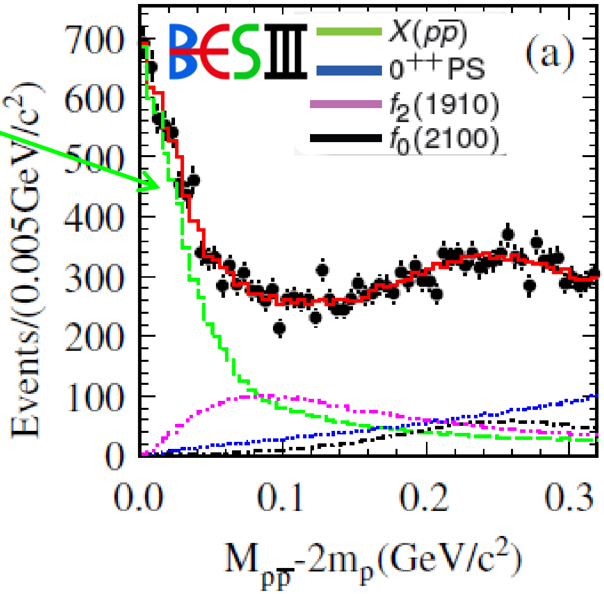


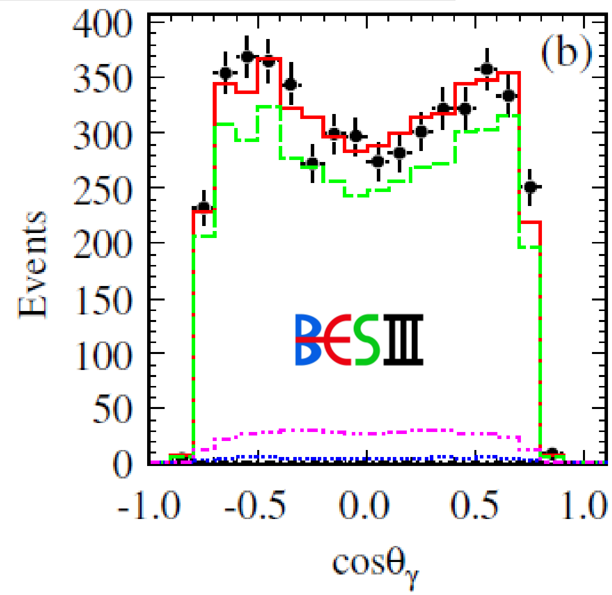
- World largest data sample on J/ψ, ψ(2S), ψ(3770), Y(4260)… in e^+e^- collisions
- From light meson spectroscopy to $\Lambda_c\bar{\Lambda}_c$
- Fine and coarse scan of the accessible energy region

$p\bar{p}$ Near Threshold Enhancement: $J/\psi \to \gamma p\bar{p}$

PRL 108, 112003 (2012)

Unclear nature: normal meson, ppbound state, multiquark, glueball,…





PWA fit features:

- Mass structure can be described by BW and FSI corrections (PRD 71, 054010 (2005))
- FSI corrections notably improve description
- Different FSI → model systematic

Fit components: X($p\bar{p}$), f2(1920), f0(2100), 0++ PHSP

Fit results:

$$J^{PC} = 0^{+-} \text{ are preferable(by} > 6.8\sigma \text{ better than other assignments)}$$

$$M = 1832^{+19}_{-5}(stat)^{+18}_{-17}(syst) \pm 19(model)MeV$$

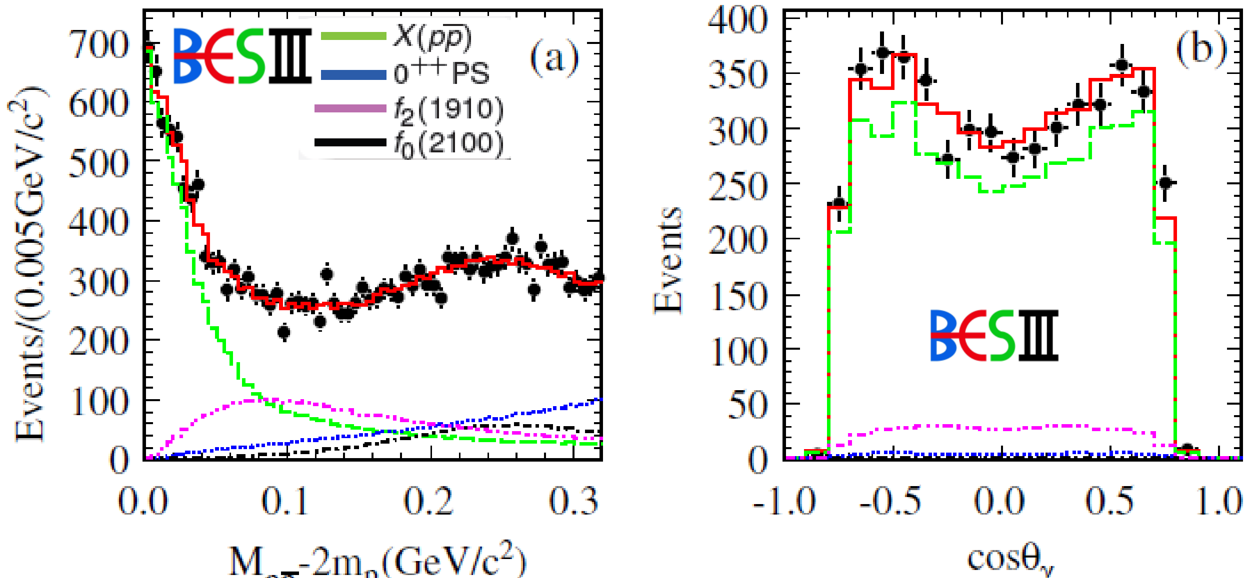
$$\Gamma < 76\ MeV\ @90\%\ C.L.$$

$$Br(J/\psi \to \gamma X)Br(X \to p\bar{p}) = 9.0^{+0.4}_{-1.1}(stat)^{+1.5}_{-5.0}(syst) \pm 2.3(mod)x10^{-5}$$

$p\bar{p}$ Near Threshold Enhancement: $J/\psi \to \gamma p\bar{p}$

PRL 108, 112003 (2012)

Unclear nature: normal meson, ppbound state, multiquark, glueball,…

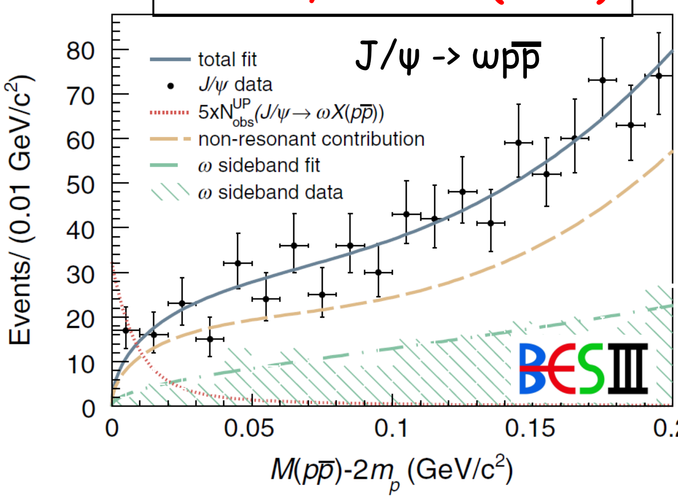


PWA fit features:

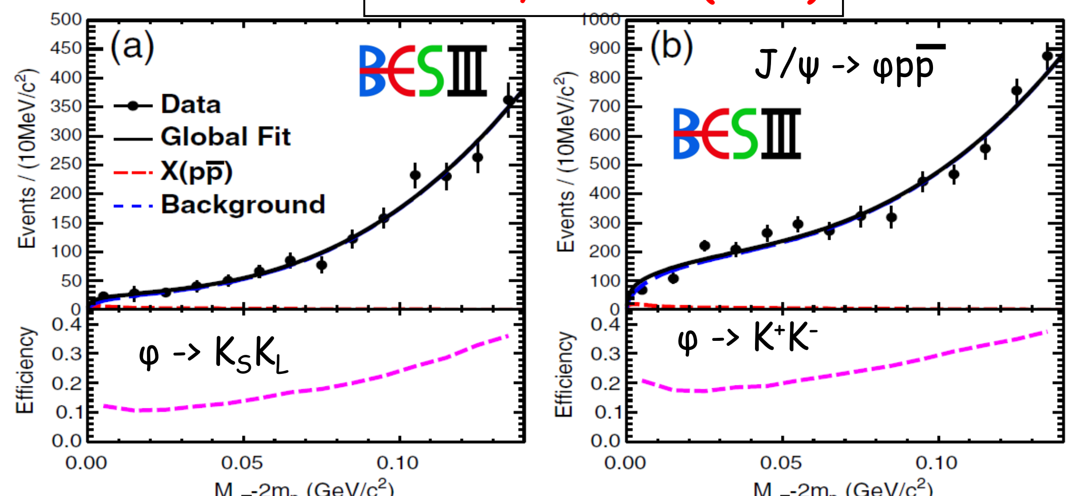
- Mass structure can be described by BW and FSI corrections (PRD 71, 054010 (2005))
- FSI corrections notably improve description
- Different FSI → model systematic

No similar structure was observed in $J/\psi \to \omega p\bar{p}$ or $J/\psi \to \phi p\bar{p}$

PRD 87, 112004 (2013)



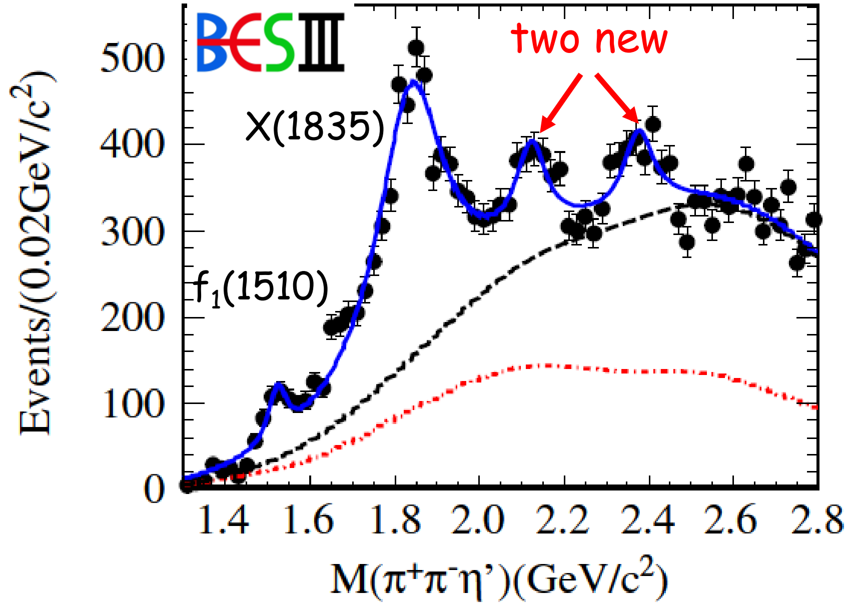
PRD 93, 052010 (2016)

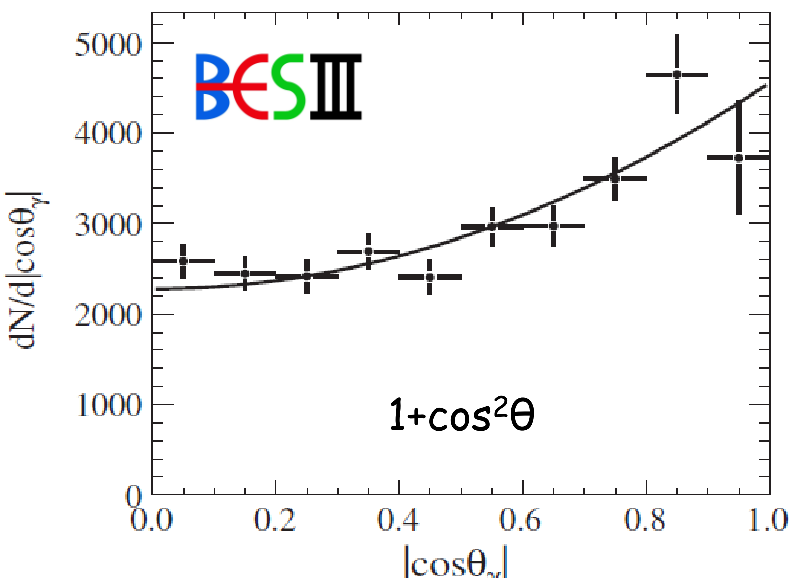


Confirmation of X(1835) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

PRL 106, 072002 (2011)

- X(1835) was first observed at BES, and then confirmed at BESII [PRL95,262001(2005)]
- The angular distribution of the radiative photon is consistent with expectations for pseudoscalar
- Two additional structures observed at BESIII
- Nature of X(2120)/X(2370): pseudoscalar glueball? η/η′ excited states?

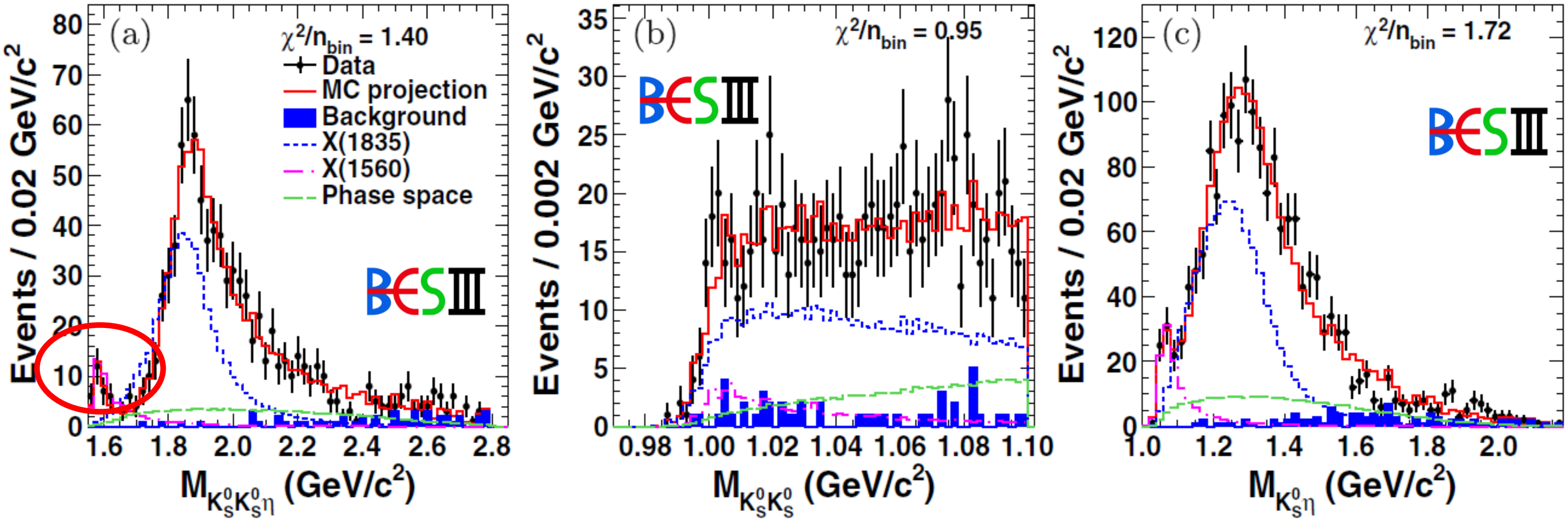




Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	N_{event}	
$f_1(1510)$	1522.7 ± 5.0	48 ± 11	230 ± 37	>5.7σ
$X(1835)$	1836.5 ± 3.0	190.1 ± 9.0	4265 ± 131	>20σ
$X(2120)$	2122.4 ± 6.7	83 ± 16	647 ± 103	>7.2σ
$X(2370)$	2376.3 ± 8.7	83 ± 17	565 ± 105	>6.4σ

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

PRL 115, 091803 (2015)



- PWA of events with $M(K_SK_S) < 1.1$GeV/c2 and $M(K_SK_S\eta) < 2.8$GeV/c2
- Final fit results:
  - the data can be best described with three components: $X(1835) \to f_0(980)\eta$, $X(1560) \to f_0(980)\eta$, and a non-resonant $f_0(980)\eta$ component
  - J^{PC} of X(1835), X(1560), and non-resonant component are all found to be 0^{-+}

$$M = 1844 \pm 19\,(\text{stat})\,^{+16}_{-25}(\text{syst})\ \text{MeV}/c^2 \quad \Gamma = 192\,^{+20}_{-17}(\text{stat})\,^{+62}_{-43}(\text{syst})\ \text{MeV} \quad (>12.9\sigma)$$

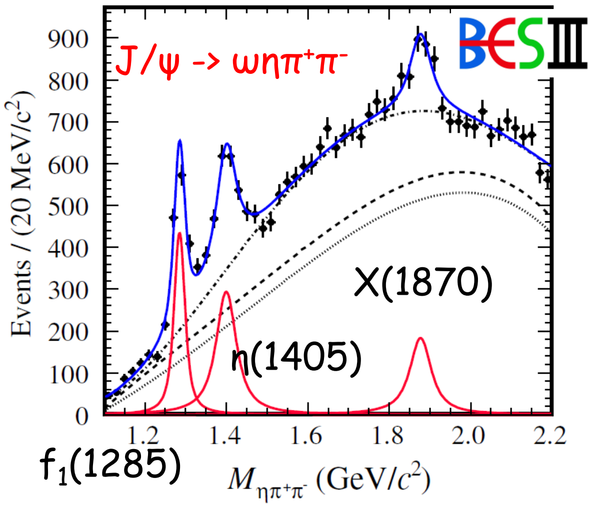
$$BR = (3.31\,^{+0.33}_{-0.30}(\text{stat})\,^{+1.96}_{-1.29}(\text{syst})) \times 10^{-5}$$

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

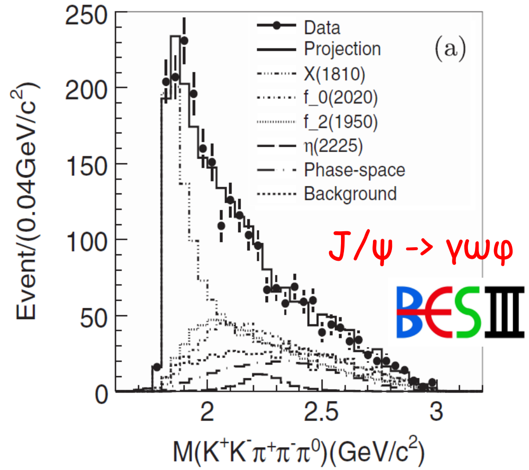
  - $J^{PC} = 1^{++}$ for non-resonant component cannot be excluded
  - Consistent with the X(1835) observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$

Other BESIII Observations

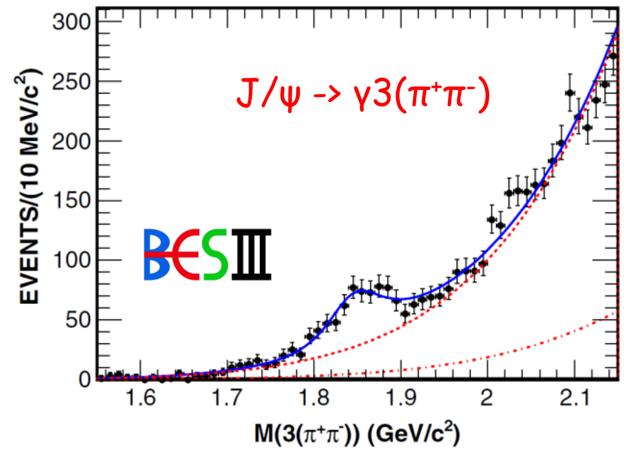
PRL 107, 182001 (2011)

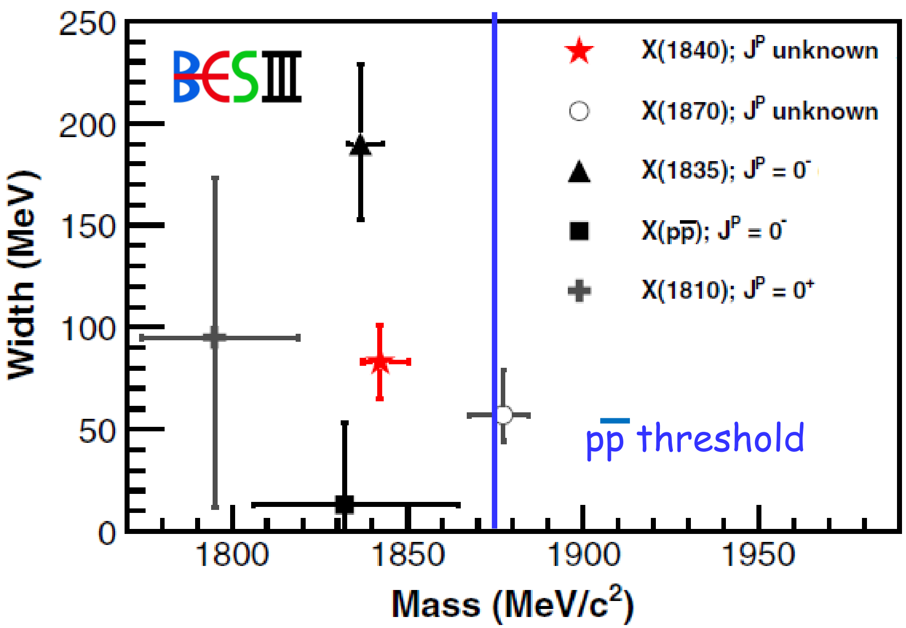


PRD 87, 032008 (2013)



PRD 88, 091502 (2013)





- ★ X(1840): $J/\psi \to \gamma 3(\pi^+\pi^-)$ [PRD88, 091502]
- ○ X(1870): $J/\psi \to \omega\eta\pi^+\pi^-$ [PRL107, 182001]
- ▲ X(1835): $J/\psi \to \gamma(\eta\pi^+\pi^-)$ [PRL106, 072002]
- ■ X(1840): $J/\psi \to \gamma(p\bar{p})$ [PRL108, 112003]
- ✚ X(1840): $J/\psi \to \gamma(\omega\phi)$ [PRD87, 032008]

X(18??) near proton-antiproton threshold:

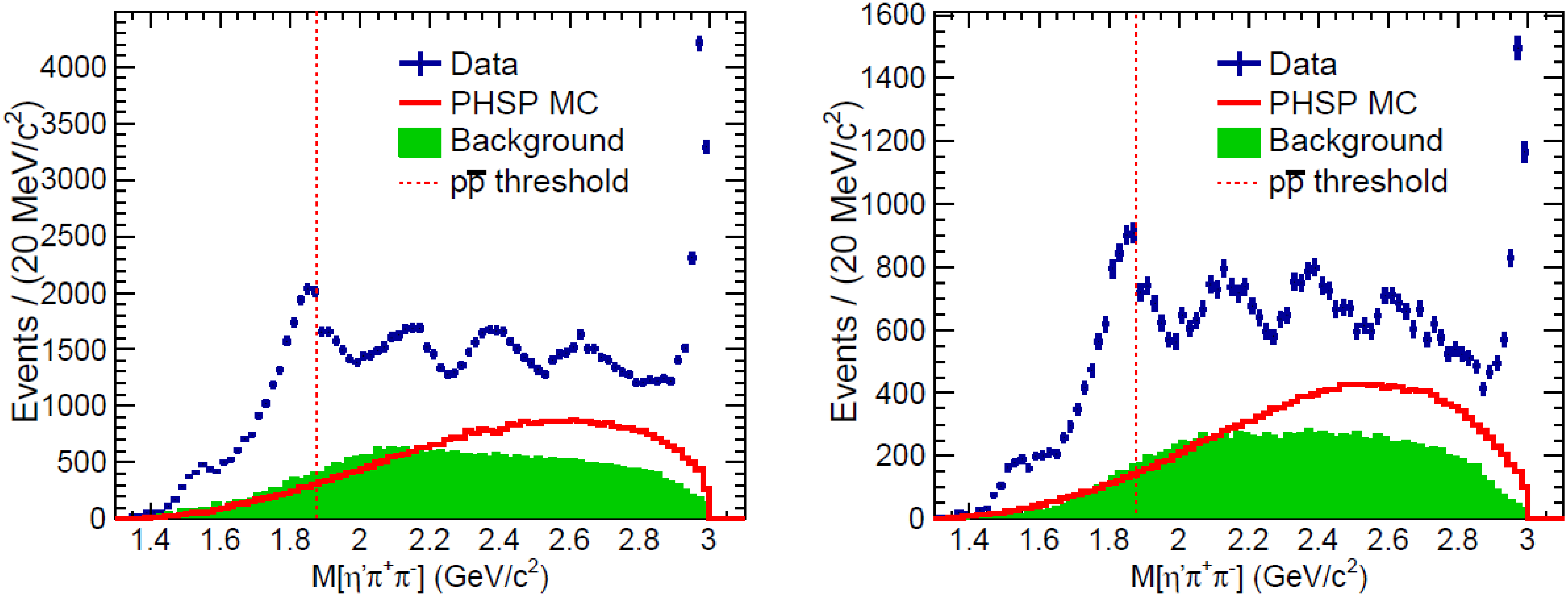
- X(1840) is in agreement with X(1835) and X($p\bar{p}$), while its width is significantly different
- Are they the same particles?

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

arXiv:1603.09653

If the X(1835) is a $p\bar{p}$ bound state, the $\eta'\pi^-\pi^+$ line shape at the $p\bar{p}$ threshold would be affected by the opening of the X(1835) $\to p\bar{p}$ decay mode

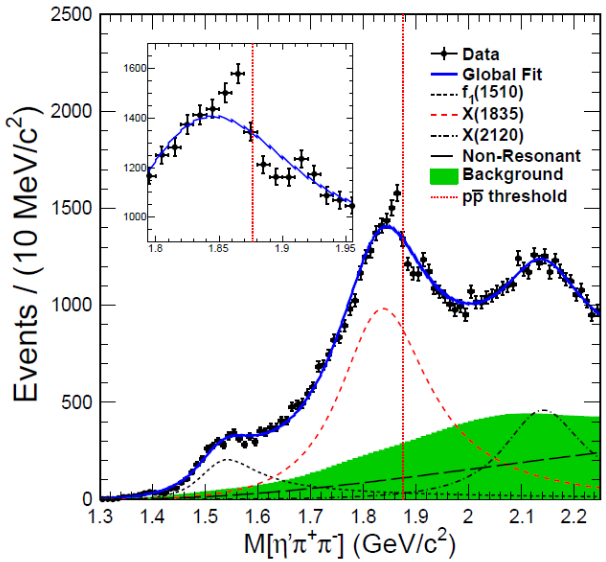
- 1.09×10^9 J/ψ events collected in 2012
- $\eta' \to \gamma\pi^-\pi^+$ and $\eta' \to \eta\,\gamma\gamma\pi^-\pi^+$
- Clear peaks of X(1835), X(2120), X(2370), η_c, and a structure near 2.6 GeV/c^2

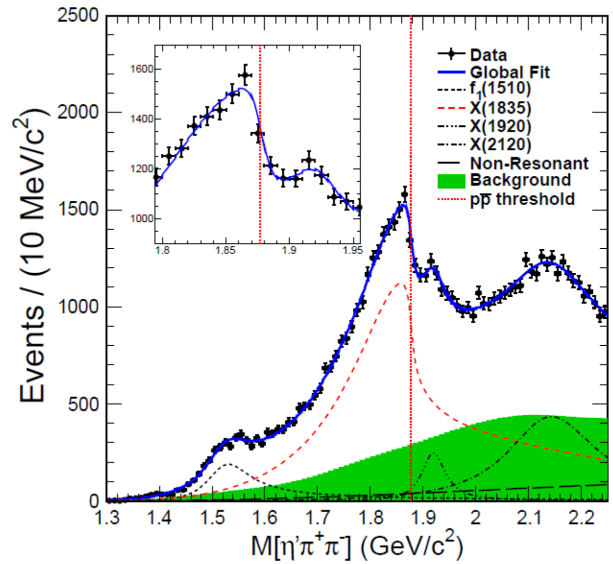


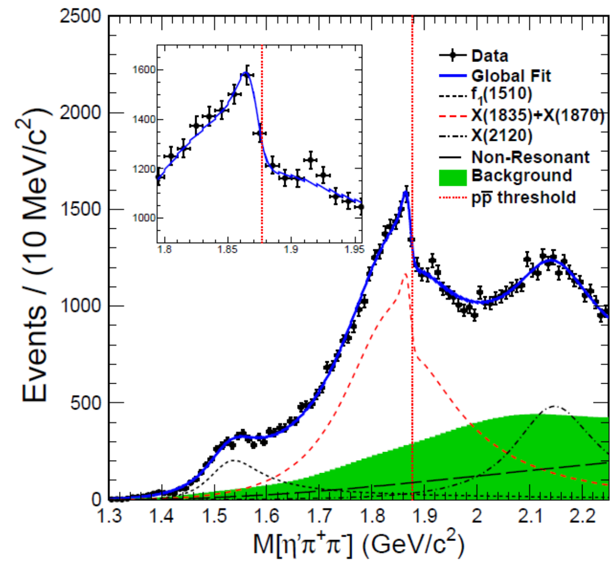
Significant distortion of the $\eta'\pi^-\pi^+$ line shape near the $p\bar{p}$ mass threshold

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

arXiv:1603.09653







- Three efficiency-corrected Breit-Wigner functions
- Simple BW function fails in describing the $\eta'\pi^-\pi^+$ line shape near the threshold

MODEL 1

Threshold structure caused by the opening of additional decay mode

- Flatté formula for the shape (Phys.Lett.B**63**, 224)
- An additional BW resonance (X(1920)) is needed (5.7σ)

MODEL 2

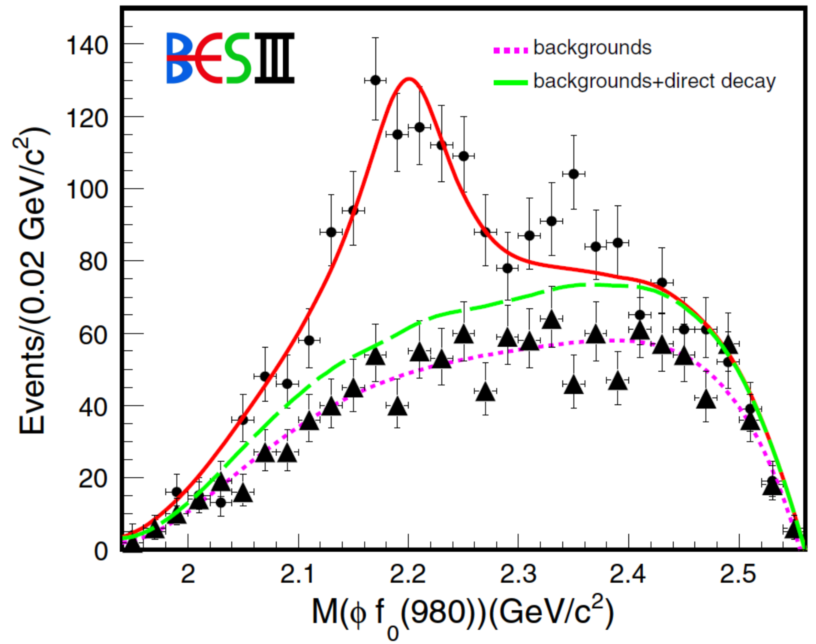
Interference between two resonances

- Use coherent sum of two BW amplitudes for the line shape: X(1835) and a narrow resonance called X(1870)
- X(1920) not significant

- Both fits support the existence of one of
  - Broad state with strong coupling to $p\bar{p}$
  - Narrow state just below the $p\bar{p}$ mass threshold

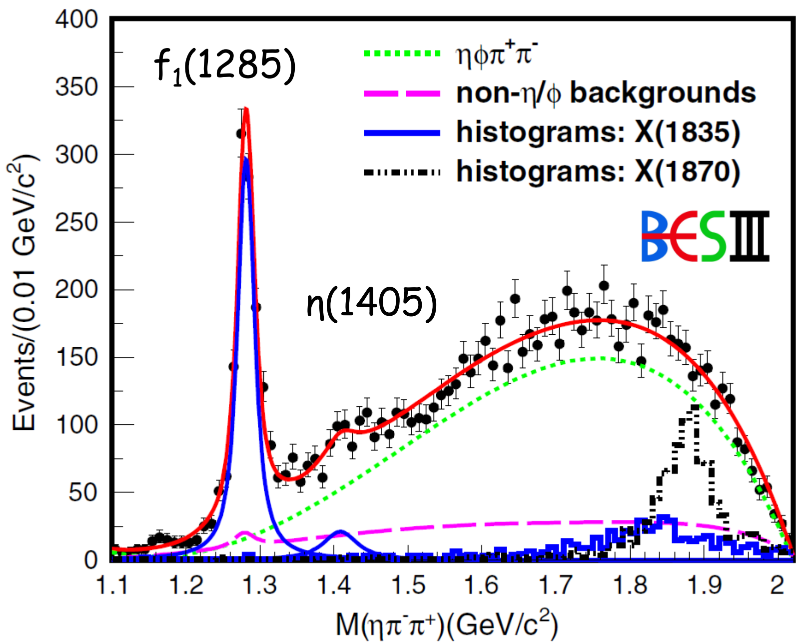
$J/\psi \to \eta\phi\pi^+\pi^-$

PRD 91, 052017 (2015)



- Study based on 2.25×10^8 J/ψ events
- Unbinned maximum likelihood fit is performed to the $\phi f_0(980)$ invariant mass distribution
- Y(2175) resonance observed with a significance greater than **10σ**

M=2200 ± 6 ± 5 MeV/c2, Γ=104 ± 15 ± 15 MeV



$\eta\pi\pi$ mass spectrum recoiling against the ϕ:

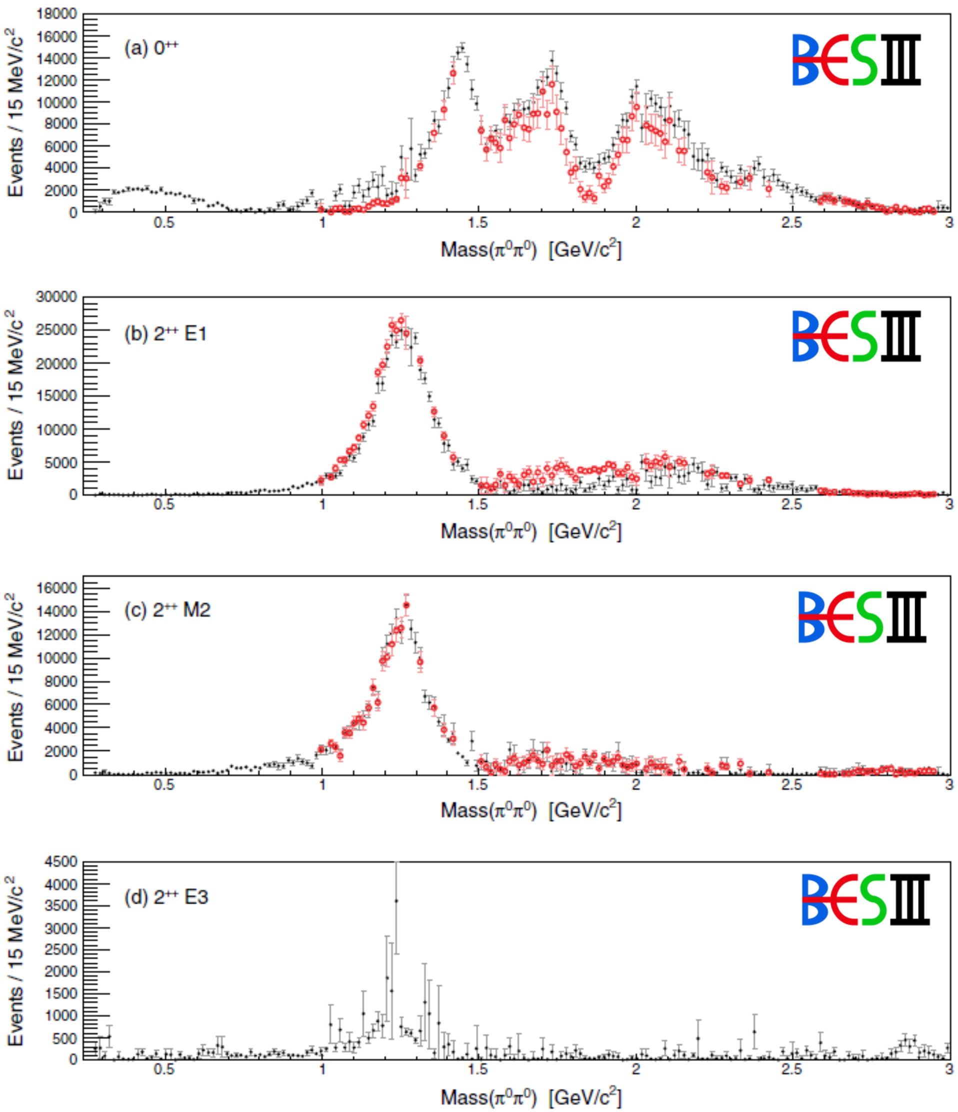
- Fit includes contributions from the $f_1(1285)$ and $\eta(1405)$ signals, the $J/\psi\to\eta\phi\pi\pi$ decay, and backgrounds from non-η and non-φ processes
- No evidence of X(1835) and X(1870) states

$B(J/\psi\to\phi f_1\to\phi\eta\pi\pi) = (1.20\pm0.06\pm0.14)\times10^{-4}$

$B(J/\psi\to\phi\eta(1405)\to\phi\eta\pi\pi) = (2.01\pm0.58\pm0.82)\times10^{-5}$

f_0^* and f_2^* in $J/\psi \to \gamma\pi^0\pi^0$

PRD 92, 052003 (2015)



- Model independent PWA
- Provide a description of the scalar and tensor components of the $\pi^0\pi^0$ system
- 0++:
  $f_0(500)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, and $f_0(2020)$
- 2++:
  dominated by $f_2(1270)$

XYZ States

Below $D\bar{D}$ threshold: all the states have been observed and described by the cc potential model

Above the threshold: more complex situation

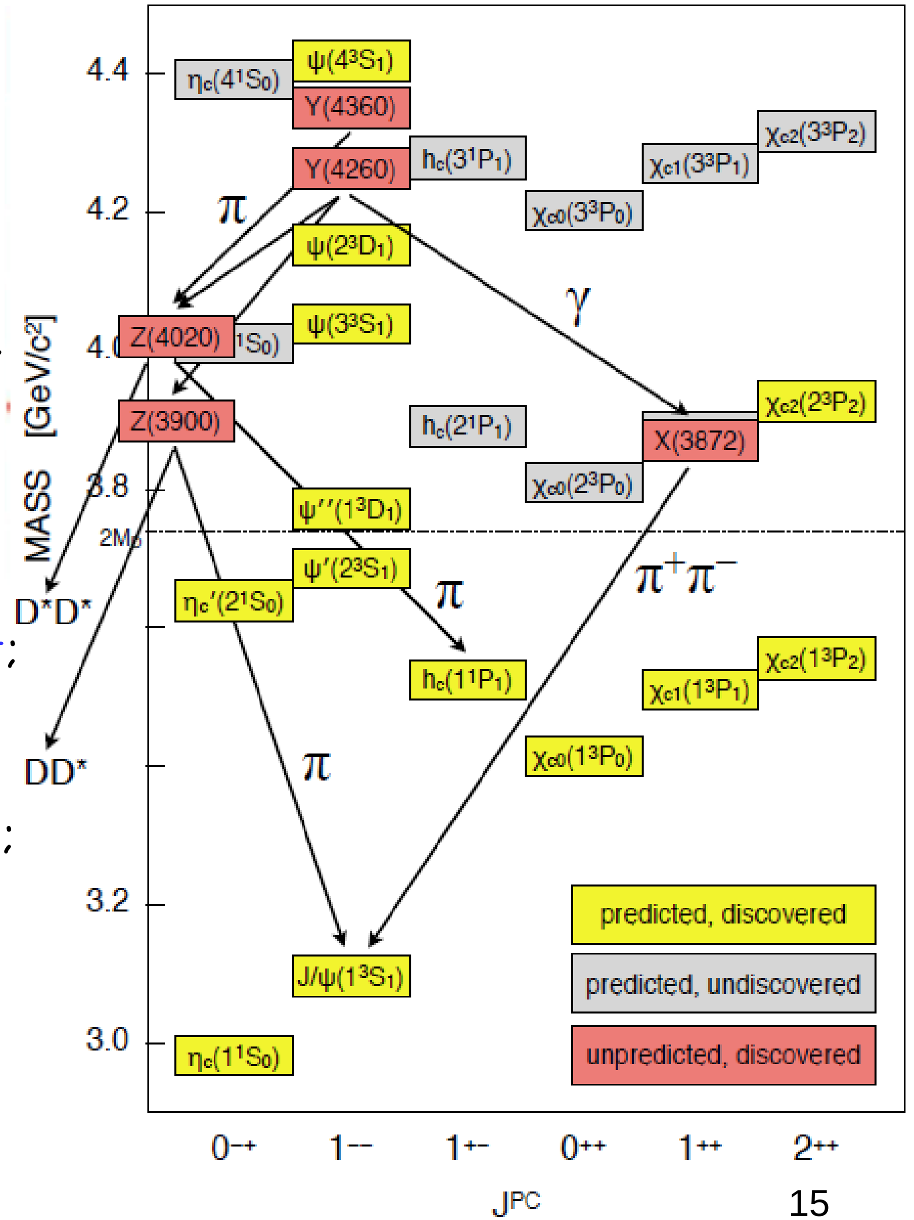
• only a few of the predicted states above the threshold have been found

• Many new states have been observed with properties that are not consistent with the expectation for charmonium: X, Y, Z

X states: charmonium-like states with $J^{PC} \neq 1^{--}$; observed in B decays, proton-proton, and proton-antiproton collisions.

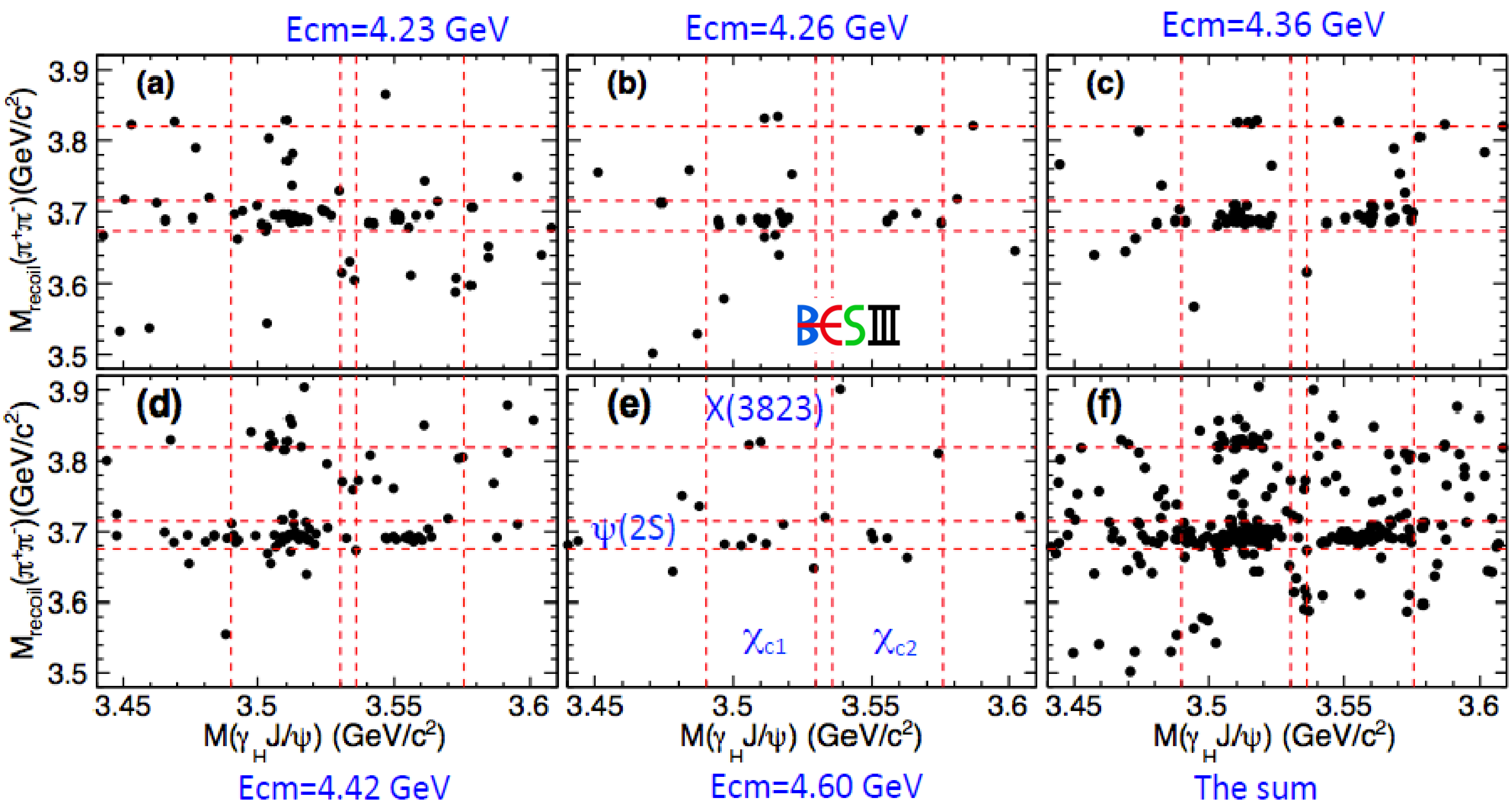
Y states: charmonium-like states with $J^{PC}=1^{--}$; Observed in direct e+e- annihilation or initial state radiation (ISR).

Z states: charmonium-like states **carrying electric charge**; must contain at least cc and a light $q\bar{q}$ pair



$e^+e^- \to \pi^+\pi^- X(3823) \to \gamma\chi_{c1,2}$ @ 4.19-4.60 GeV

PRL 115, 011803 (2015)



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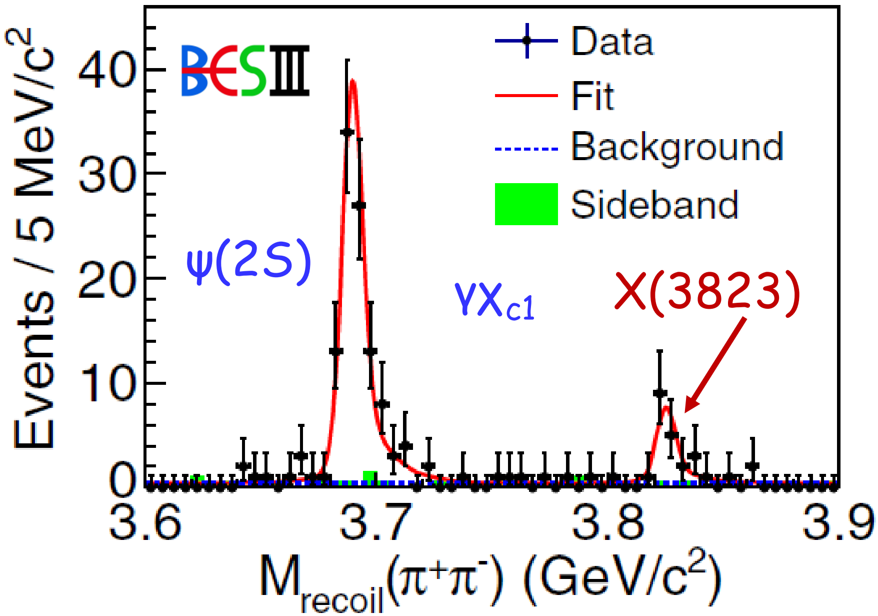
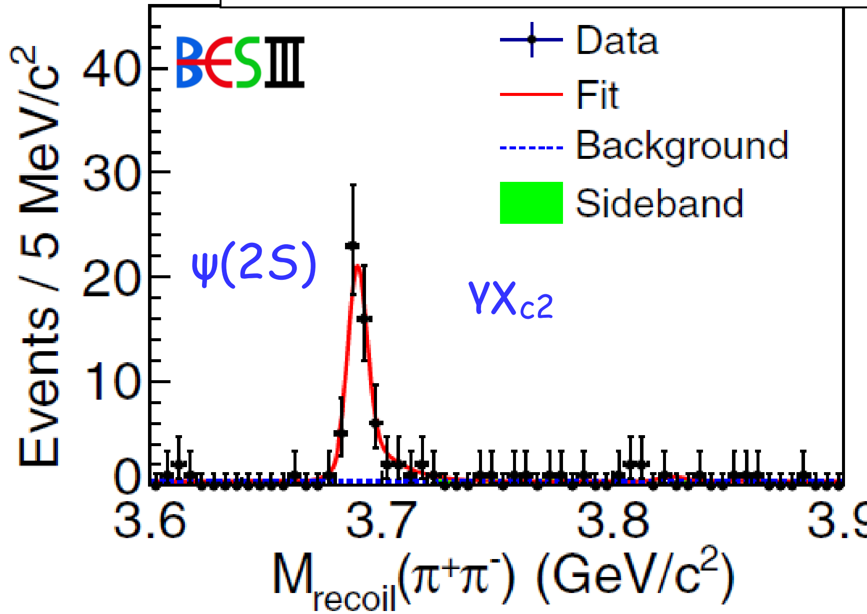
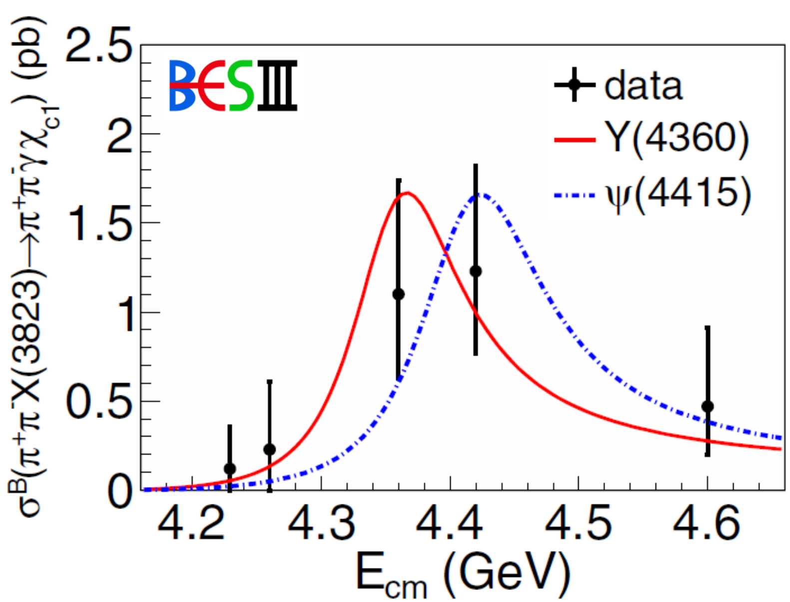






- Simultaneous fit: 4.36, 4.42, and 4.60 GeV
- Signal: MC simulated shape
- Background: linear
- $M = 3821.7 \pm 1.3 \pm 0.7$ MeV
- Significance: 6.7σ

- Both Y(4360) and ψ(4415) give reasonable description

Y States Investigation

- The observed charmonium-like states Y(4260), Y(4360), and Y(4660) can not interpreted as conventional charmoniums.
- New decay modes searching and the line shape measurement is useful for understanding the nature of these Y-states.
- Hadronic transitions (by an η or π^0) to lower charmonia like J/ψ are regarded as sensitive probes to study the properties of these Y-states.
- Nature of these Y-states:

  hybrids ?

  tetraquarks?

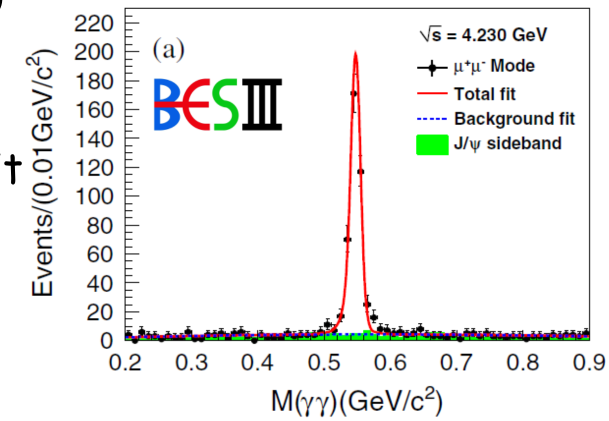
  hadro-charmonium?

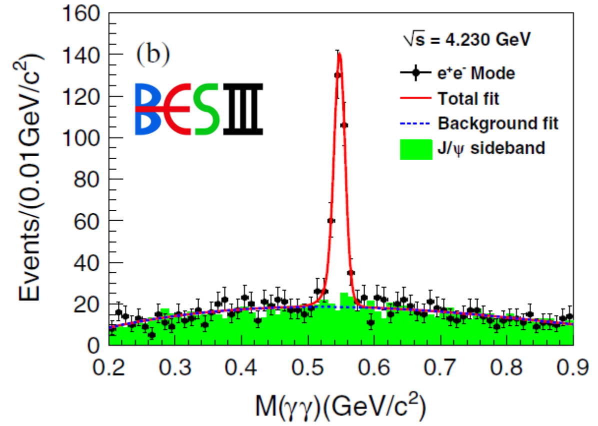
  hadronic molecule?

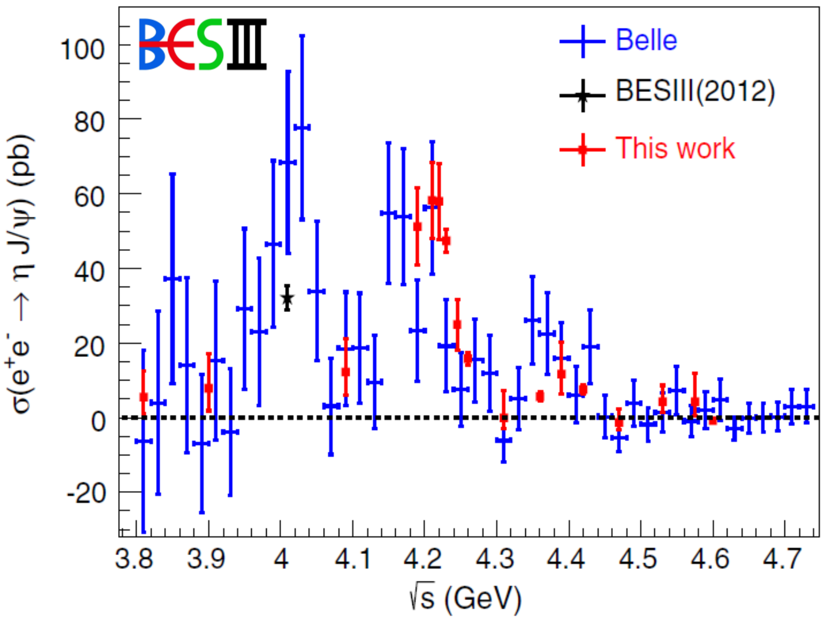
Y States: $e^+e^- \to \eta J/\psi$

PRD 91, 112005 (2015)

- The study of hadronic transitions to J/ψ allows to probe their properties
- BESIII analysis: $e^+e^- \to \eta(\pi^0)J/\psi$ from 3.81 to 4.60 GeV (17 c.m. points)
- Unbinned maximum likelihood fit
- Signal: signal MC shape $\otimes$ Gaussian function
- BKG: 2th-order Chebishev





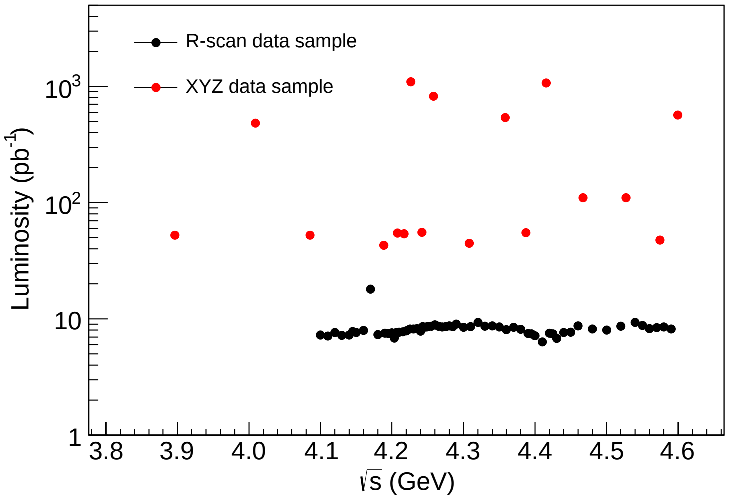


- Cross section peaks around 4.2 GeV
- Different shape if compared to Belle $\pi^+\pi^-J/\psi$ data
- Different dynamic at work in $e^+e^- \to \eta J/\psi$ and $e^+e^- \to \pi^+\pi^-J/\psi$

Belle: PRL99, 182004
BESIII(2012): PRD86, 071101

Y States: $e^+e^- \to \pi^+\pi^-h_c$

Data samples



- Data samples:
  - XYZ sample:
    - 17 energy points from 3896 MeV to 4600 MeV
    - total luminosity: 5.26 fb^{-1}
  - R-scan data sample:
    - 62 energy points from 4097 MeV to 4587 MeV
    - total luminosity: 0.51 fb^{-1}

PRELIMINARY

- Decay channel: $e^+e^-\to\pi^+\pi^-h_c$, $h_c\to\gamma\eta_c$, $\eta_c\to X_i$

  X_i={pp-bar, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-$pp-bar, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$ +c.c., $K_S^0K^+\pi^-\pi^+\pi^-$ +c.c., $K^+K^-\pi^0$, pp-barπ^0, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$ }

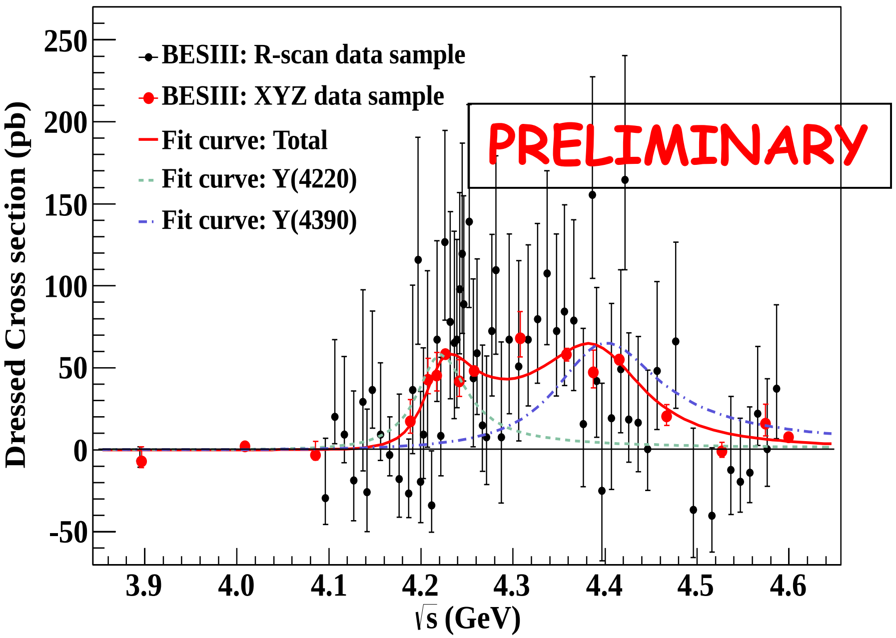
Y States: e+e- -> $\pi^+\pi^- h_c$

fit to the cross section

$$\sigma(m) = \left| B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}} \right|^2$$

$B_i(m)$: constant width Breit-Wigner function
$P(m)$: 3-body phase space factor
ϕ: relative phase between two resonances

significance of two structures assumption over one structure > 10 σ



	M (MeV)	Γ_{tot} (MeV)	Γ_{ee}•Br (eV)	ϕ (rad)
Y(4220)	4218.4±4.0±0.9	66.0±9.0±0.4	4.6±4.1±0.8	--
Y(4390)	4391.6±6.3±1.0	139.5±16.1±0.6	11.8±9.7±1.9	3.1±1.5±0.2

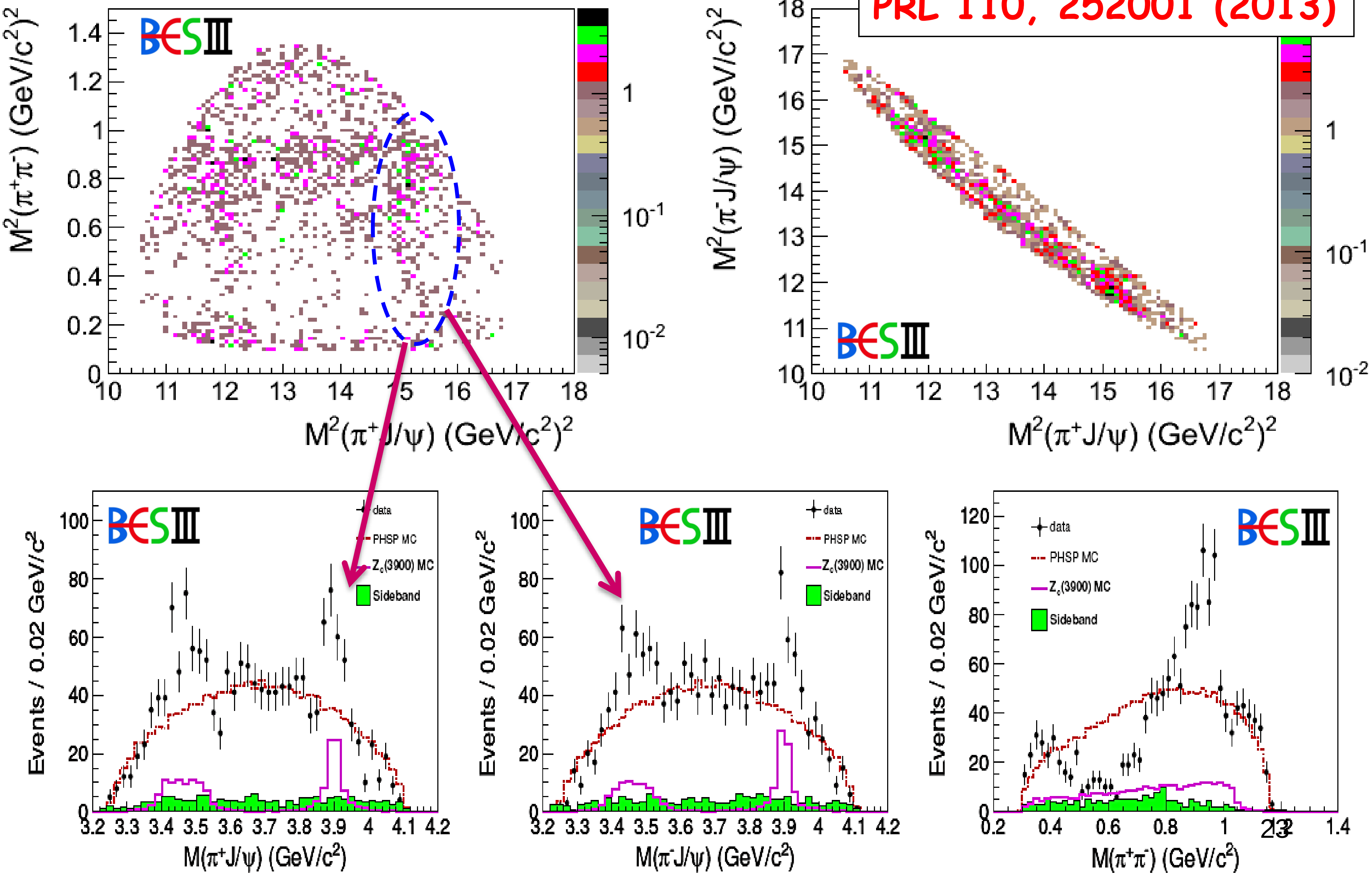
Observation of a charmonium like structure: $Z_c(3900)^{\pm}$

PRL 110, 252001 (2013)

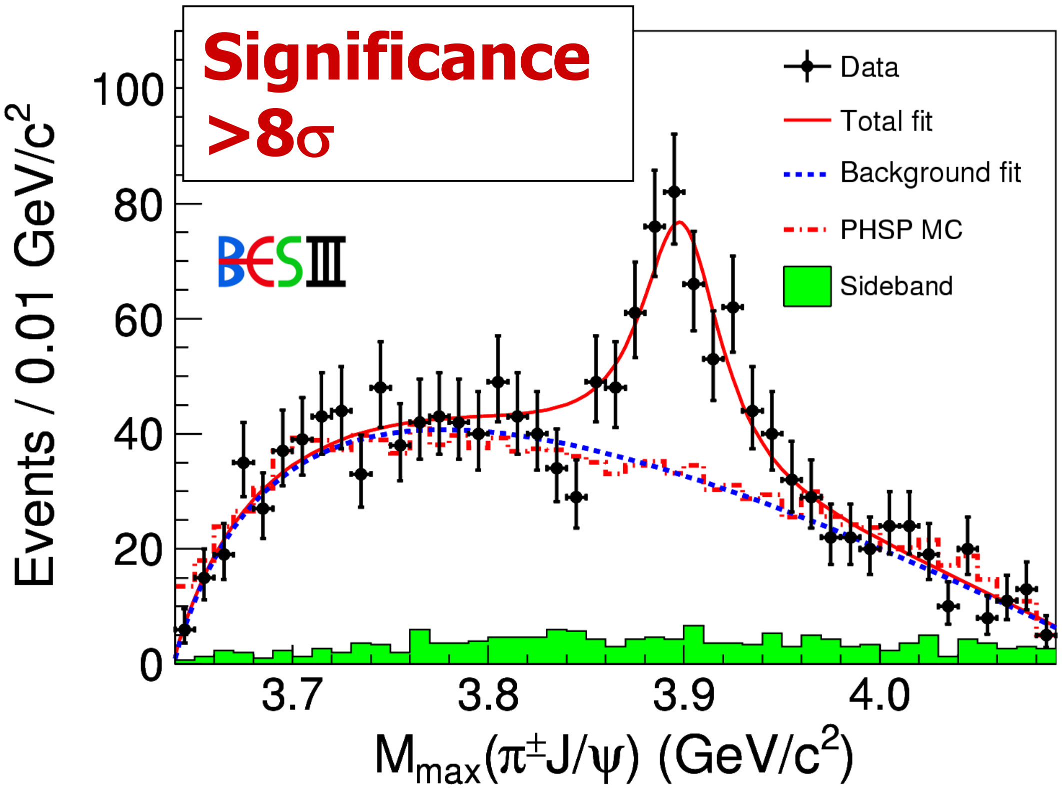
- 2013: 515 pb^{-1} @ 4260 MeV
- $e^+e^- \rightarrow \pi^+\pi^- J/\psi$
- Dominant background $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV
- Structure seen: $Z_c(3900)^{\pm}$ -> $\pi^{\pm}$ J/ψ

Dalitz Plots and 1D Projections

PRL 110, 252001 (2013)

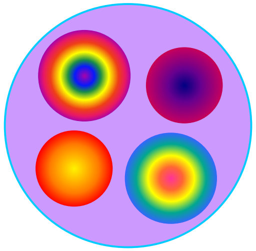


The $Z_c(3900)$ signal



PRL 110, 252001 (2013)

- Couples to $c\bar{c}$
- Has electric charge
- At least 4-quarks
- What is its nature?

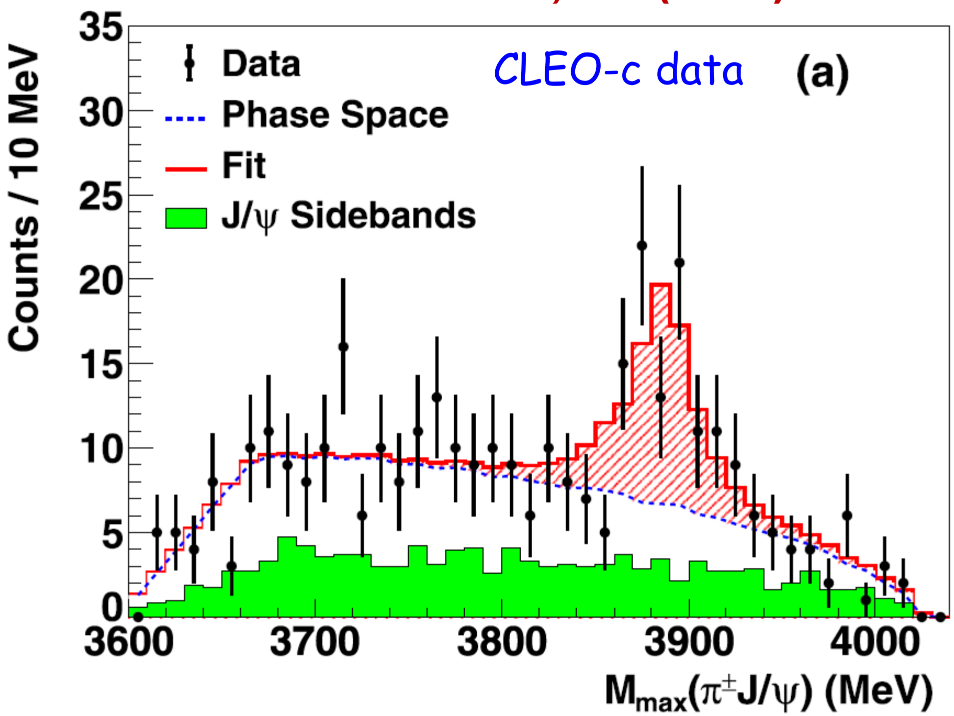


- S-wave Breit-Wigner with efficiency correction
- Mass = (3899.0±3.6±4.9) MeV
- Width = (46±10±20) MeV
- Fraction = (21.5±3.3±7.5)%

BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.26 GeV

K. Seth & co. @ 4.170 GeV

PLB 727, 366 (2013)

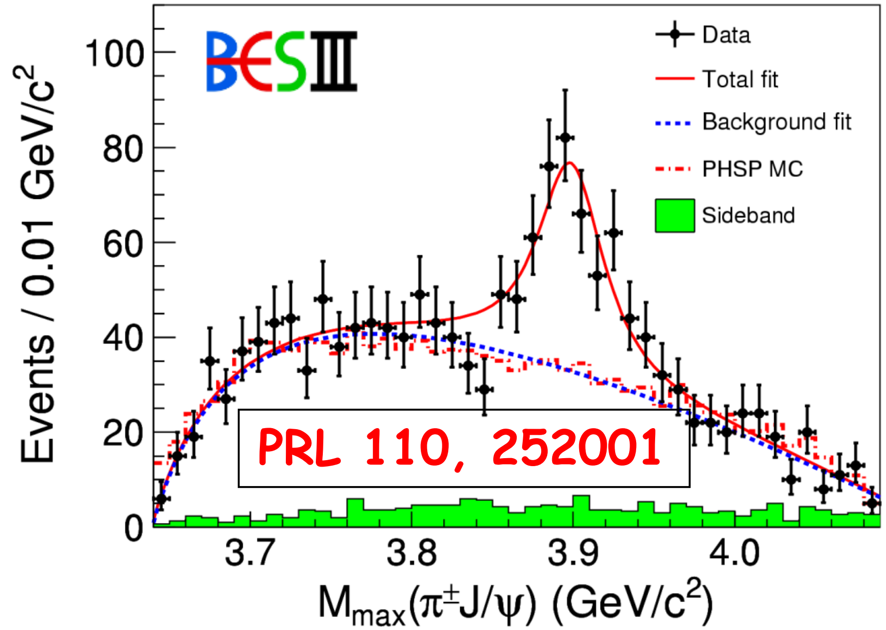


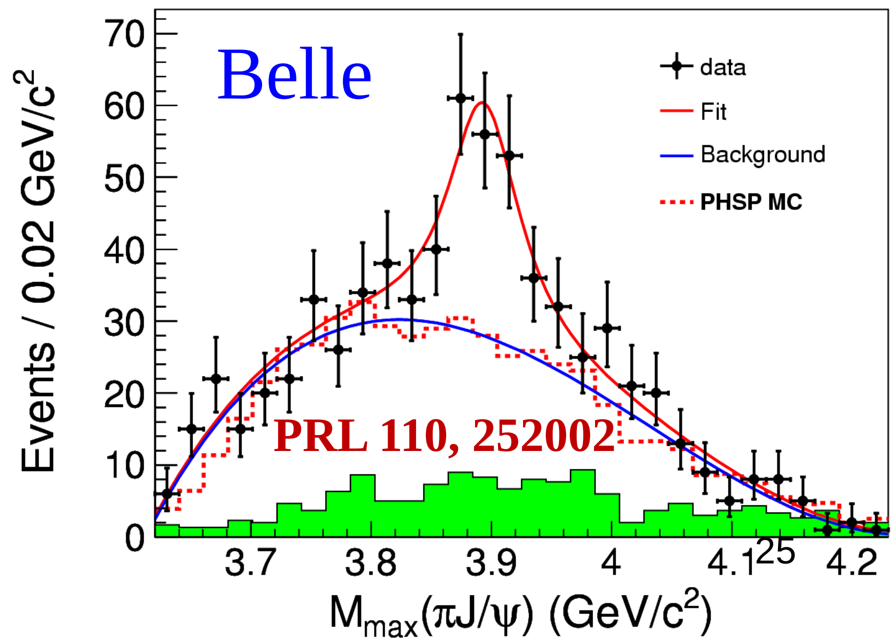
M = $(3885\pm5\pm1)$ MeV/c^2

Γ = $(34\pm12\pm4)$ MeV/c^2

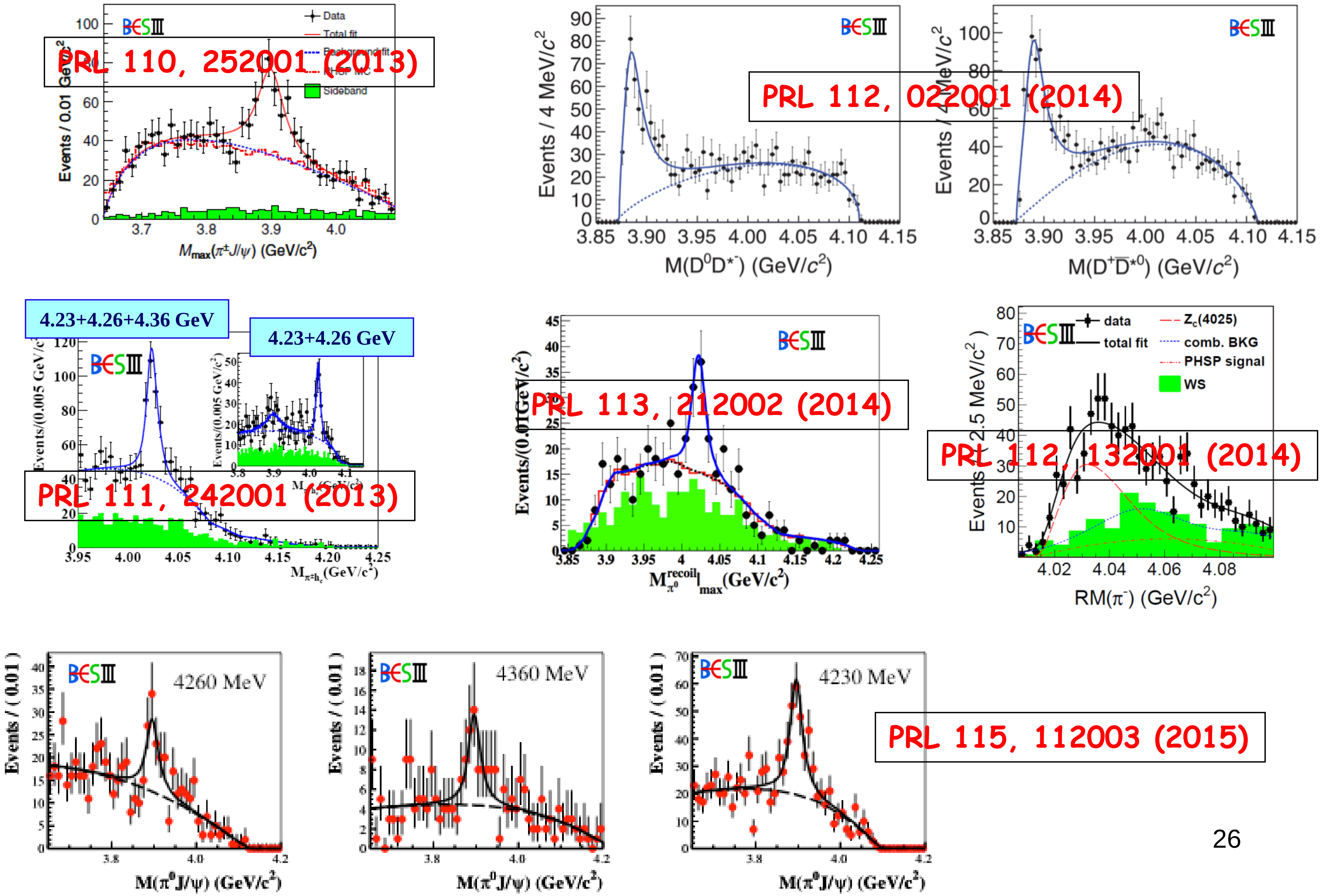
81 ± 20 events

6.1σ





BESIII: Z_c Results



Baryonic States

- All ground baryonic states are well estabilished
  - ➢ Good agreement between experimental data and quark model
- The excited spectrum is much less clear
  - ➢ Many more states predicted than observed
- Insight to hadron structure

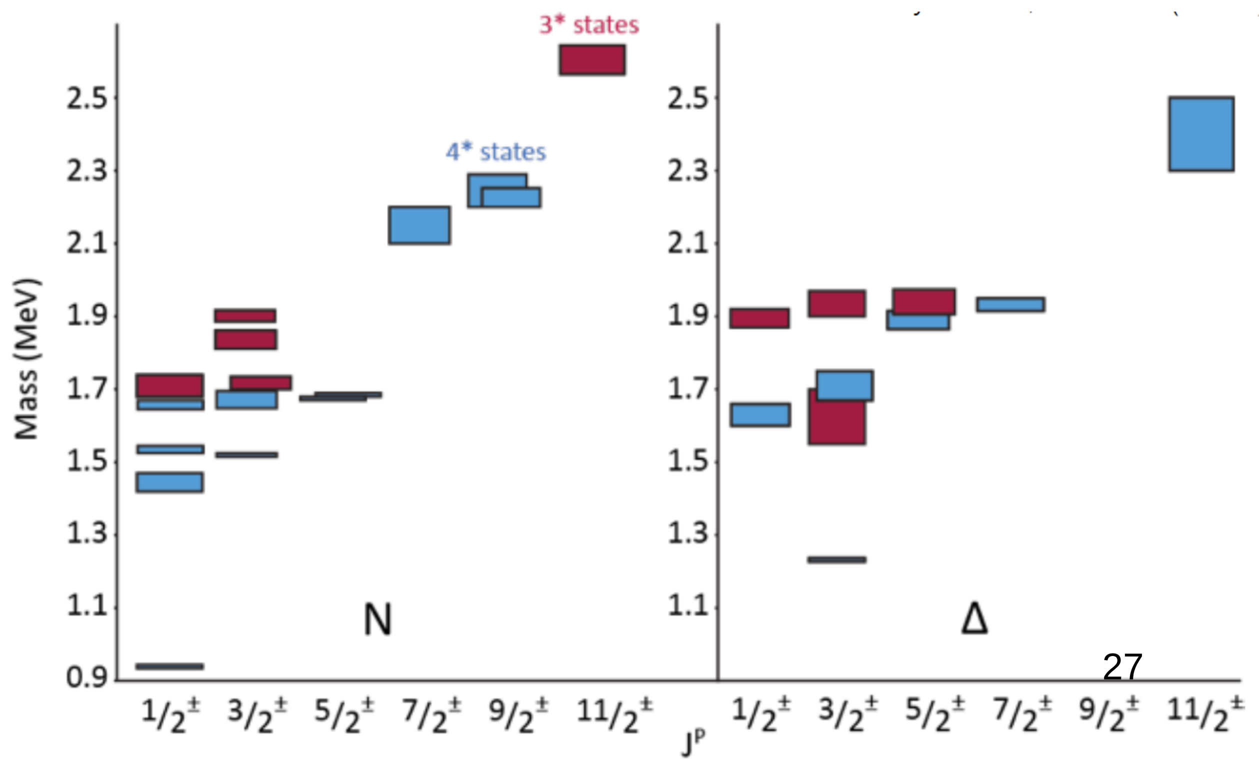
Chin. Phys. C 38 090001 (2014)

Up to 2.5 GEV:

45 N states predicted

15 estabilished

10 tentative



Missing Resonances

- Many of the predicted resonances were not observed experimentally
- Experimental and theoretical efforts

- **Experimentally**:

  baryon resonances may couple very weakly to single pions
- **Theoretically**:

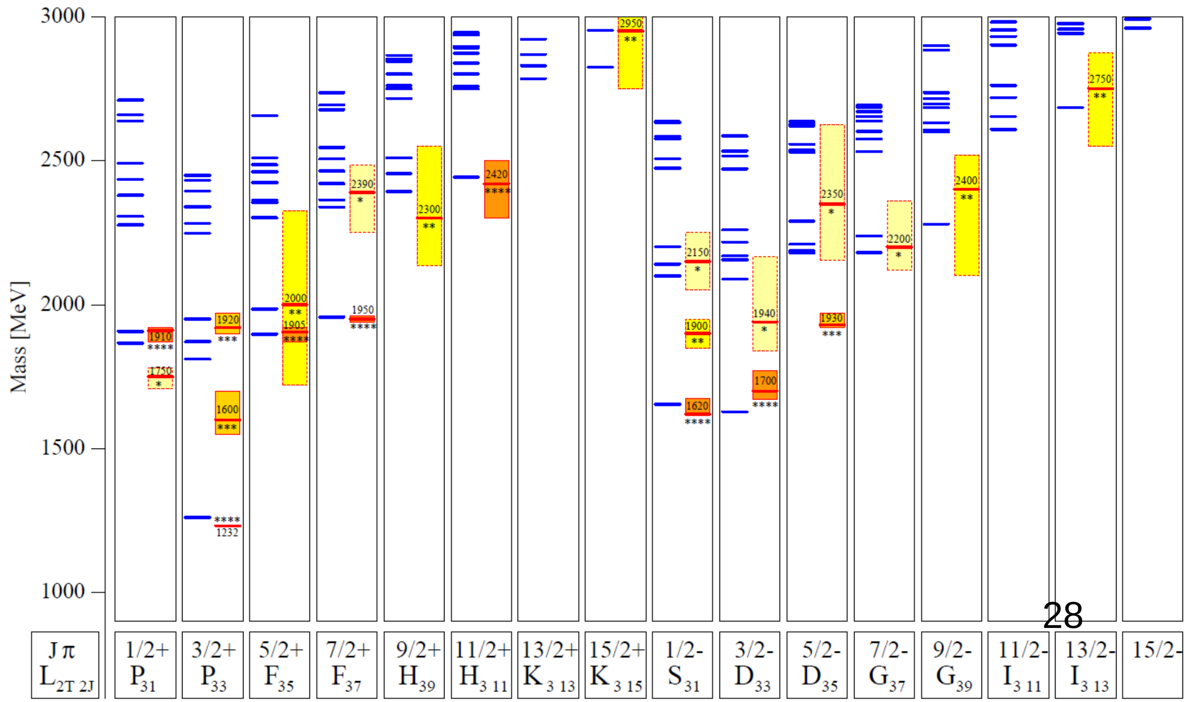
  the baryon spectrum can be modeled with *fewer effective degrees of freedom* (quark-diquark or Y/Δ-type models)

Relativistic quark model

Δ-resonance spectrum

Potential model: A

EPJ A10, 395-446 (2001)



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  baryon resonances may couple very weakly to single pions
- **Theoretically**:

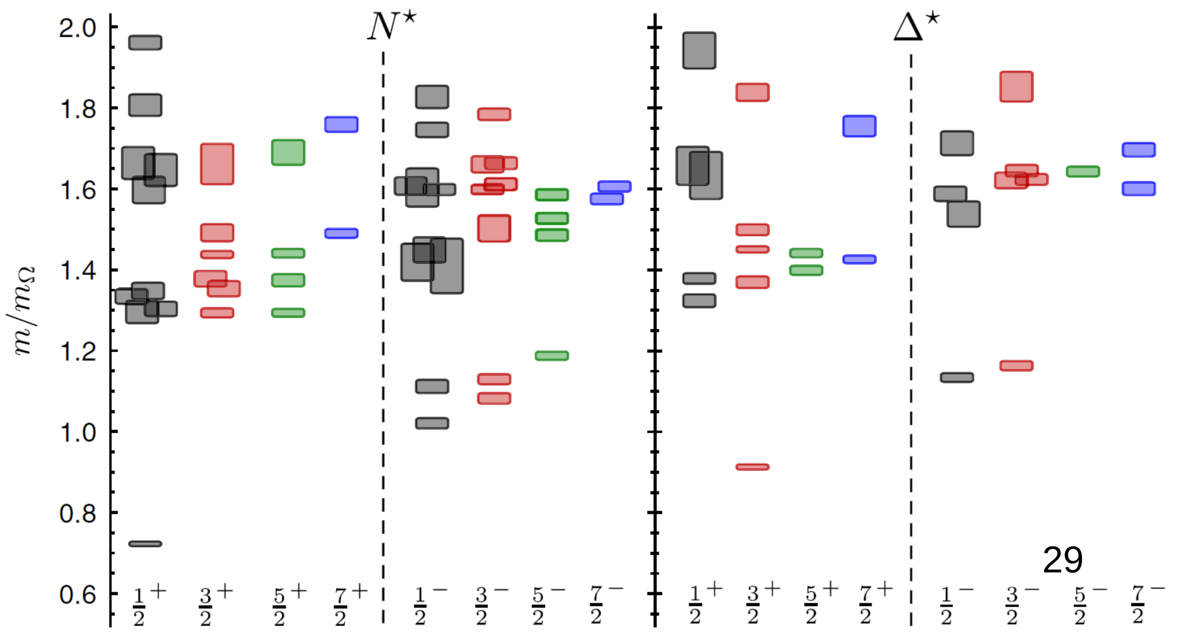
  the baryon spectrum can be modeled with *fewer effective degrees of freedom* (quark-diquark or Y/Δ-type models)

Lattice QCD

Δ and *N* spectrum

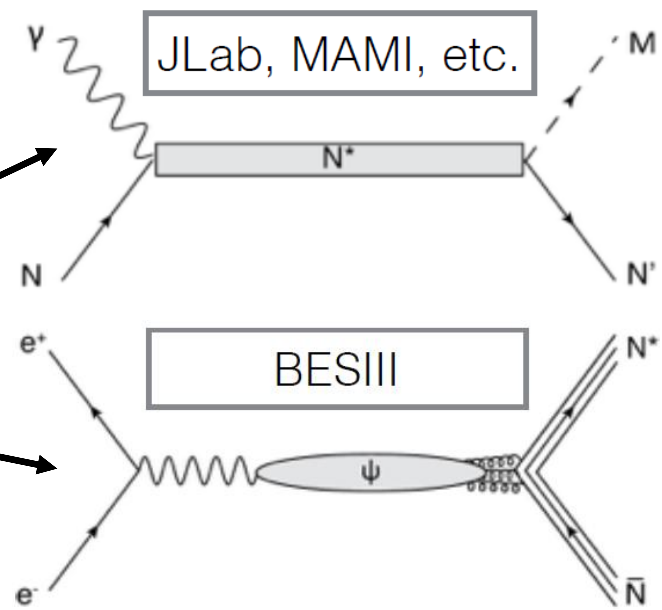
m_π = 396 MeV

Phys Rev D84, 074508 (2011)



BESIII: Baryon Production

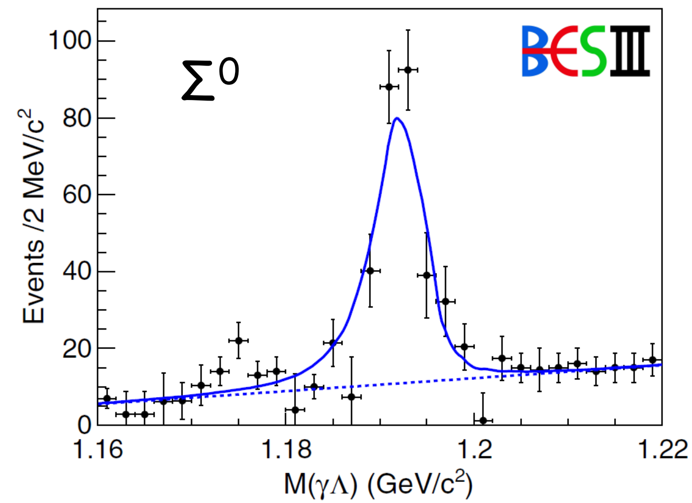
- Charmonium decays offer complementary information to existing data
  - Coupling of unobserved states through conventional production channels could be small, but coupling may be large to gggN: $\psi \longrightarrow N\bar{N}\ (\pi/\eta/\eta'/\omega/\phi)$, $\bar{p}\Sigma\pi$, $\bar{p}\Lambda K$
  - High statistics available at BESIII

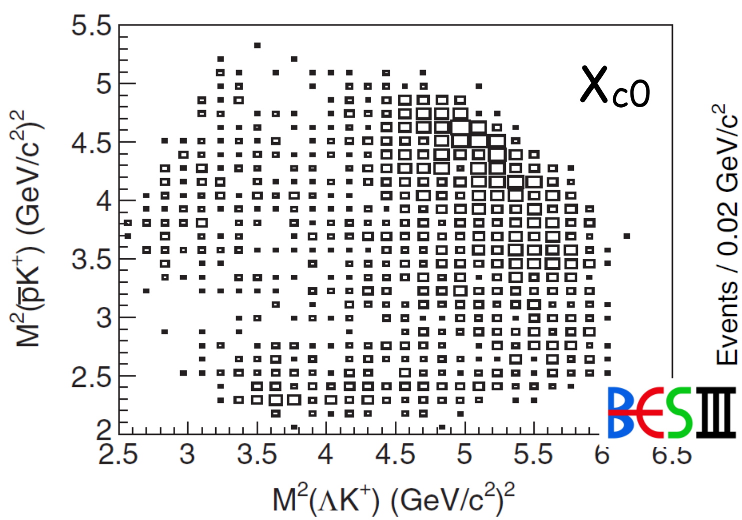


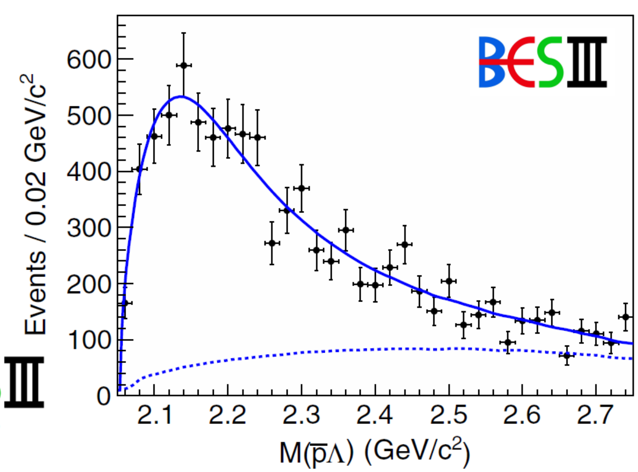
$\psi(3686) \to \bar{p}K^+\Sigma^0$ and $\chi_{cJ} \to \bar{p}K^+\Lambda$

PRD 87, 012007 (2013)

- $\psi(3686) \to \bar{p}K^+\Sigma^0$: first measurement
- $\chi_{cJ} \to \bar{p}K^+\Lambda$: BR improvement
- $\chi_{c0} \to \bar{p}K^+\Lambda$: anomalous enhancement close to threshold
- Possible reasons:
  - quasi bound dibaryon state
  - final state interactions
  - interference of high mass N* and Λ* states







Channel	$\psi' \to \bar{p}K^+\Sigma^0$ + c.c.	$\chi_{c0} \to \bar{p}K^+\Lambda$ + c.c.	$\chi_{c1} \to \bar{p}K^+\Lambda$ + c.c.	$\chi_{c2} \to \bar{p}K^+\Lambda$ + c.c.
$\mathcal{B}$(BESIII)	$(1.67 \pm 0.13 \pm 0.12) \times 10^{-5}$	$(13.2 \pm 0.3 \pm 1.0) \times 10^{-4}$	$(4.5 \pm 0.2 \pm 0.4) \times 10^{-4}$	$(8.4 \pm 0.3 \pm 0.6) \times 10^{-4}$
PDG		$(10.2 \pm 1.9) \times 10^{-4}$	$(3.2 \pm 1.0) \times 10^{-4}$	$(9.1 \pm 1.8) \times 10^{-4}$

$\psi(3686) \to \Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$

PRD 88, 112007 (2013)

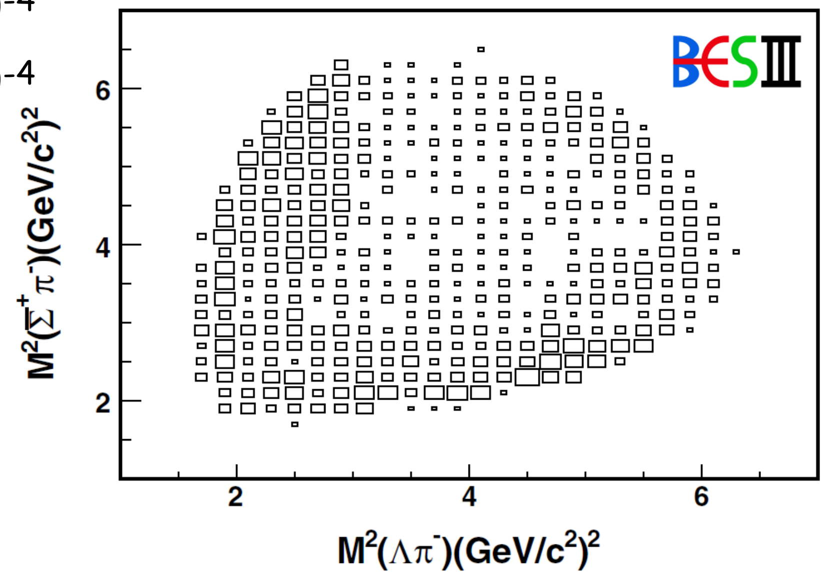
- BR first measurements:

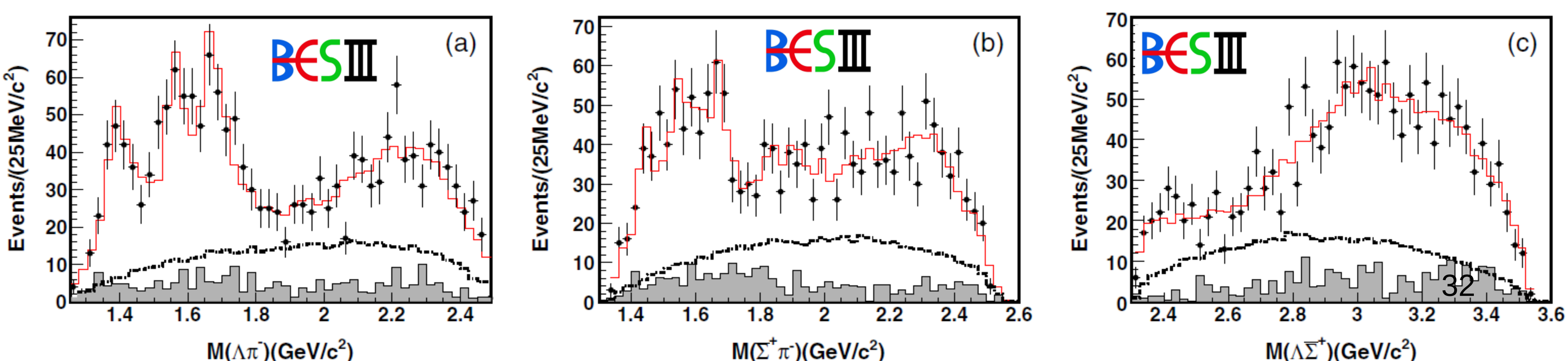
  $B(\psi(3686)\to\Lambda\bar{\Sigma}^{+}\pi^{-}+cc) = (1.40\pm0.03\pm0.13)\times10^{-4}$

  $B(\psi(3686)\to\Lambda\bar{\Sigma}^{-}\pi^{+}+cc) = (1.54\pm0.04\pm0.13)\times10^{-4}$

$$Q_{\Lambda\bar{\Sigma}^-\pi^+} = \frac{\mathcal{B}(\psi(3686)\to\Lambda\bar{\Sigma}^-\pi^+)}{\mathcal{B}(J/\psi\to\Lambda\bar{\Sigma}^-\pi^+)} = (9.3\pm1.2)\%$$

- PWA used to determine detection efficiency
  - Includes 16 possible intermediate excited states with at least two stars according to the PDG, with parameters fixed to world averages

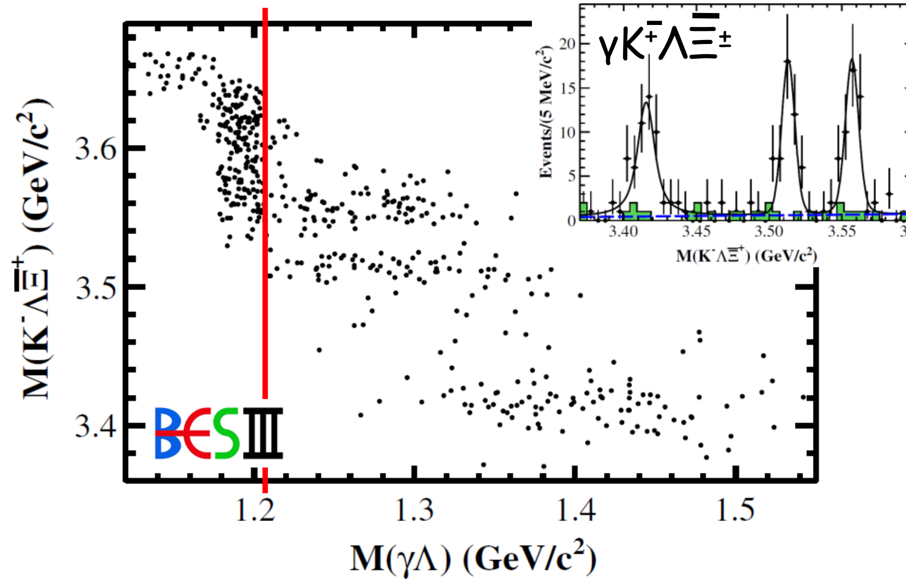


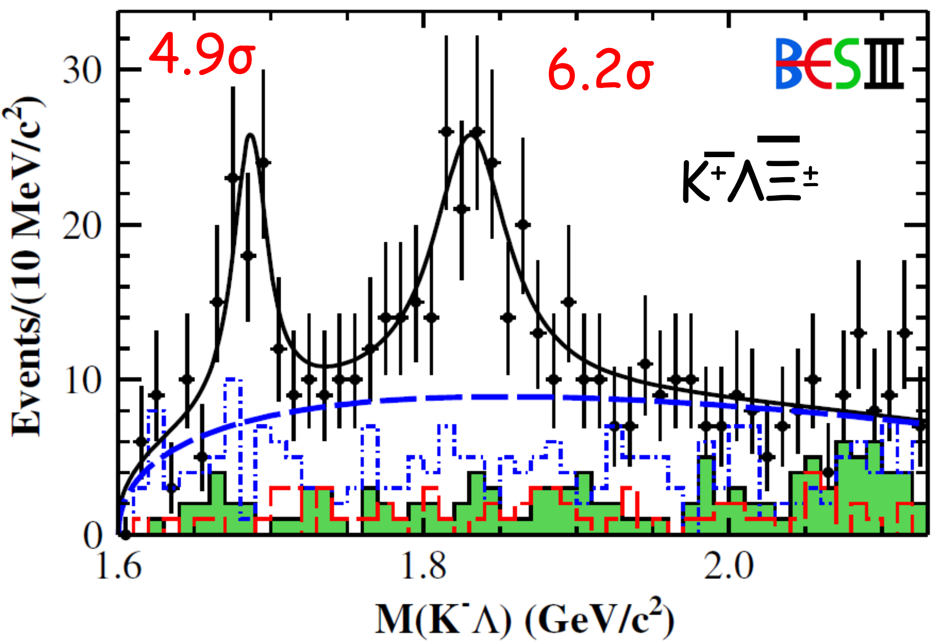


$\psi(3686) \to (\gamma)K^{\mp}\Lambda\bar{\Xi}^{\pm}$

PRD 91, 092006 (2015)

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





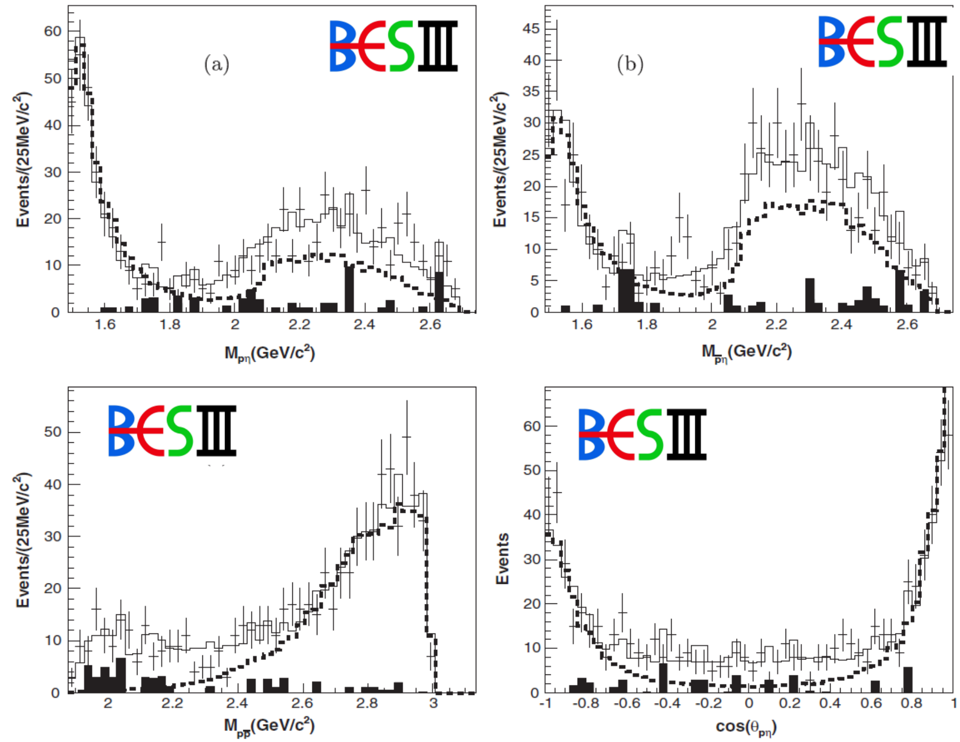
- $\Xi(1690)$ and $\Xi(1820)$ observed in $M(K\Lambda)$
- Both are well established states
- Resonance parameters consistent with PDG

	$\Xi(1690)^-$	$\Xi(1820)^-$
M(MeV$/c^2$)	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
Γ(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_{PDG}(MeV$/c^2$)	1690 ± 10	1823 ± 5
Γ_{PDG}(MeV)	< 30	24^{+15}_{-10}

ψ(3686) -> $p\bar{p}\eta$

PRD 88, 032010 (2013)

- Intermediate state N(1535) -> pη is dominant
- No evidence for a $p\bar{p}$ resonance, indicating that the threshold enhancement in previous results may be explained by interference between the N(1535) and phase space



Mass and width of N(1535)

- $M = 1524 \pm 5^{+10}_{-4}$ MeV$/c^2$
- $\Gamma = 130^{+27+57}_{-24-10}$ MeV$/c^2$

PDG value:

- $M = 1525$ to 1545 MeV$/c^2$
- $\Gamma = 125$ to 175 MeV$/c^2$

$$Q_{p\bar{p}\eta} = \frac{B(\psi(2S) \to p\bar{p}\eta)}{B(J/\psi \to p\bar{p}\eta)} = (3.2 \pm 0.4)\%$$

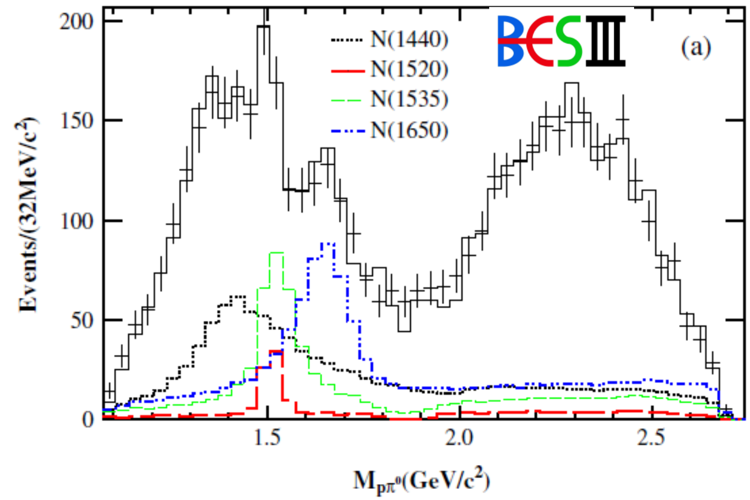
$$B(\psi(2S) \to N(1535)\bar{p}) \times B(N(1535) \to p\eta)$$
$$= \frac{N_{\text{obs}}}{\varepsilon \cdot N_{\psi(2S)} \cdot B(\eta \to \gamma\gamma)} = (5.2 \pm 0.3^{+3.2}_{-1.2}) \times 10^{-5}$$

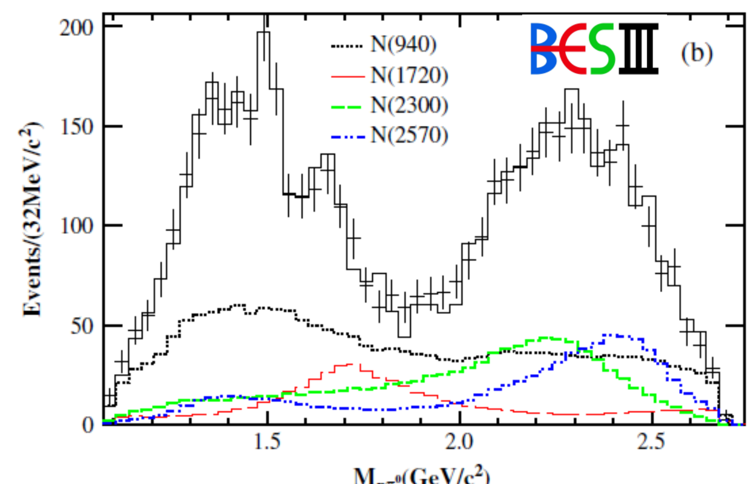
$\psi(3686)$ -> $p\bar{p}\pi^0$

PRL 110, 022001 (2013)

- In photon or meson beam studies, isospin 1/2 and 3/2 resonances are excited, complicating the analysis
- Δ resonances suppressed in charmonium decays to $p\bar{p}\pi^0$, giving a cleaner spectrum
  - Thought to be dominated by two body decays involving N* intermediate states
  - Also consider $p\bar{p}$ resonances ($\psi(3686) \to R\pi^0$)
- Seven N* states observed in partial wave analysis
  - Two new resonances, N(2300) with $J^P = 1/2^+$ and N(2570) with $J^P = 5/2^-$
  - Other five consistent with previous results

Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$





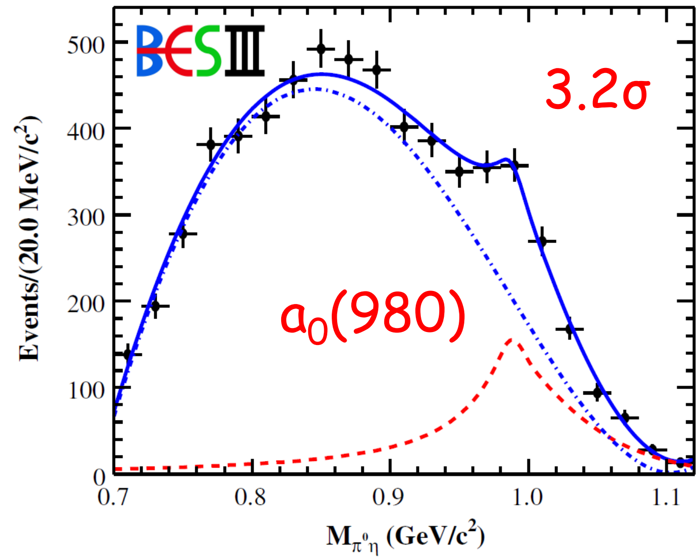
$\psi(3686) \to p\bar{p}a_0(980)$

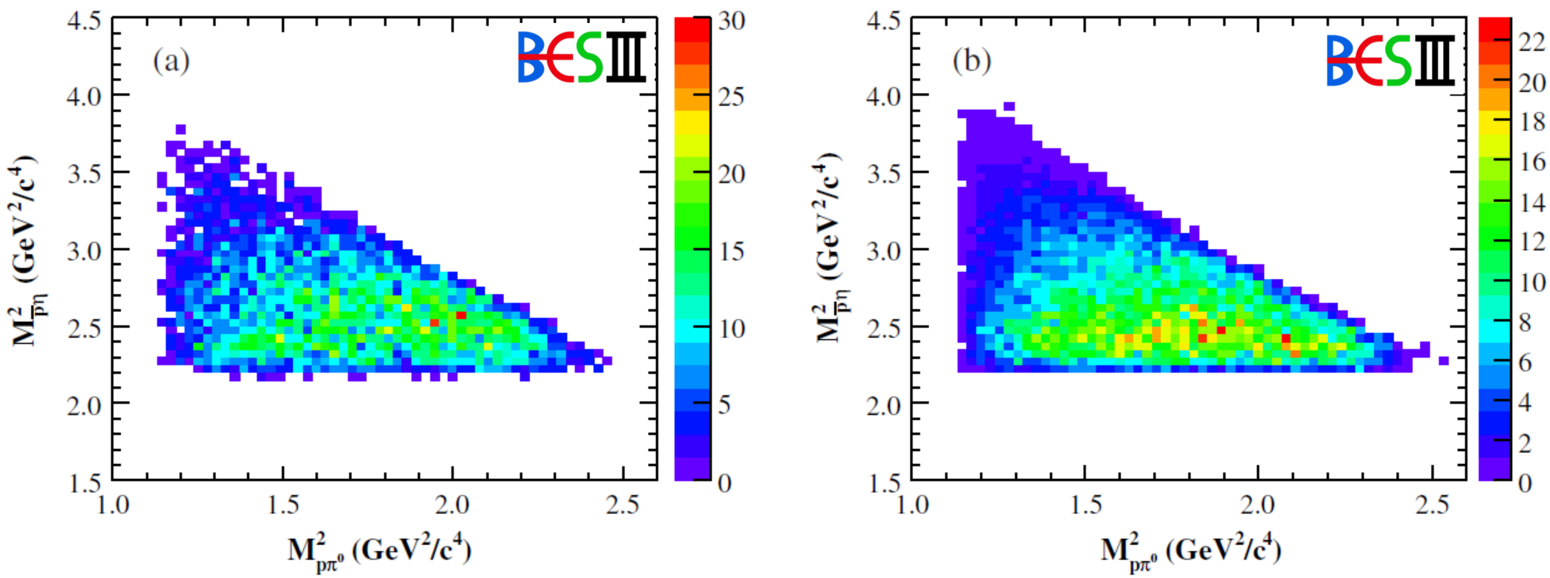
PRD 90, 052009 (2014)

- First observation of $J/\psi \to p\bar{p}a_0(980)$, $a_0(980) \to \pi^0\eta$
- Applies a chiral unitary coupled channel approach
  - Four-body decays $J/\psi \to N\bar{N}MM$
  - $a_0(980)$ generated through Final State Interactions
  - Provides useful information on dynamics of four-body FSI processes

$$\mathrm{Br}(J/\psi \to p\bar{p}a_0(980) \to p\bar{p}\pi^0\eta)$$

$$= (6.8 \pm 1.2 \pm 1.3) \times 10^{-5}$$





$J/\psi(\psi(3686)) \to \Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

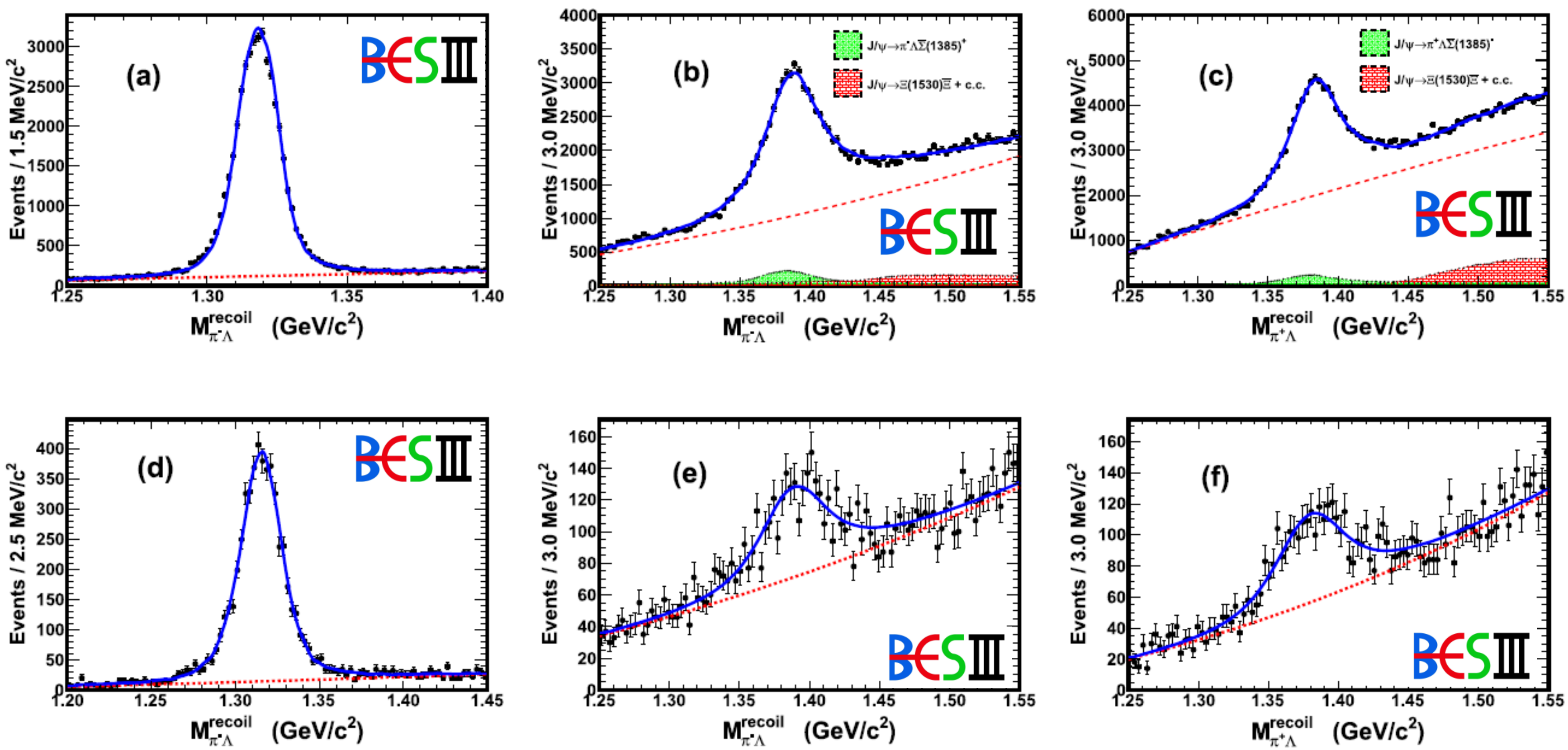
PRD 93, 072003 (2016)

- First observation of $\psi(3686)$ into $\Sigma(1835)$ states
- Single tag method
- BR and angular distribution investigations
- Most precise measurements available

$\Xi^-\bar{\Xi}^+$ | $\Sigma(1385)^-\bar{\Sigma}(1385)^+$ | $\Sigma(1385)^+\bar{\Sigma}(1385)^-$

J/ψ

ψ'



$J/\psi(\psi(3686)) \to \Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

PRD 93, 072003 (2016)

12% rule

$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
26.73%	7.76%	6.68%

Branching Ratios

Mode	$J/\psi \to$			$\psi(3686) \to$		
	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
This work	$10.40 \pm 0.06 \pm 0.74$	$10.96 \pm 0.12 \pm 0.71$	$12.58 \pm 0.14 \pm 0.78$	$2.78 \pm 0.05 \pm 0.14$	$0.85 \pm 0.06 \pm 0.06$	$0.84 \pm 0.05 \pm 0.05$
MarkI [5]	14.00 ± 5.00	...	...	< 2.0	...	...
MarkII [6]	$11.40 \pm 0.80 \pm 2.00$	$8.60 \pm 1.80 \pm 2.20$	$10.3 \pm 2.4 \pm 2.5$	...	...	...
DM2 [7]	$7.00 \pm 0.60 \pm 1.20$	$10.00 \pm 0.40 \pm 2.10$	$11.9 \pm 0.4 \pm 2.5$	...	...	...
BESII [8,12]	$9.00 \pm 0.30 \pm 1.80$	$12.30 \pm 0.70 \pm 3.00$	$15.0 \pm 0.8 \pm 3.8$	$3.03 \pm 0.40 \pm 0.32$	...	...
CLEO [9]	...	...	...	$2.40 \pm 0.30 \pm 0.20$	...	...
BESI [26]	...	...	...	$0.94 \pm 0.27 \pm 0.15$	...	...
PDG [3]	8.50 ± 1.60	10.30 ± 1.30	10.30 ± 1.30	1.80 ± 0.60	...	...

Angular distributions

Mode	$J/\psi \to$			$\psi(3686) \to$		
	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
This work	$0.58 \pm 0.04 \pm 0.08$	$-0.58 \pm 0.05 \pm 0.09$	$-0.49 \pm 0.06 \pm 0.08$	$0.91 \pm 0.13 \pm 0.14$	$0.64 \pm 0.40 \pm 0.27$	$0.35 \pm 0.37 \pm 0.10$
BESII [8]	$0.35 \pm 0.29 \pm 0.06$	$-0.54 \pm 0.22 \pm 0.10$	$-0.35 \pm 0.25 \pm 0.06$	...	...	...
MarkIII [6]	0.13 ± 0.55	...	...	...	...	...
Claudson *et al.* [10]	0.16	0.11	0.11	0.32	0.29	0.29
Carimalo [11]	0.27	0.20	0.20	0.52	0.50	0.50

Summary

- Huge statistics

  J/ψ, $\psi(2S)$, $\psi(3770)$

  XYZ studies

  R scans

- Near future

  collect data at higher energies to complete scans

  higher luminosity expected from BEPCII

  analyse the full data sample

  many PWA to be completed

- Stay tuned for new results!!

Backup Slides

BESIII Detector

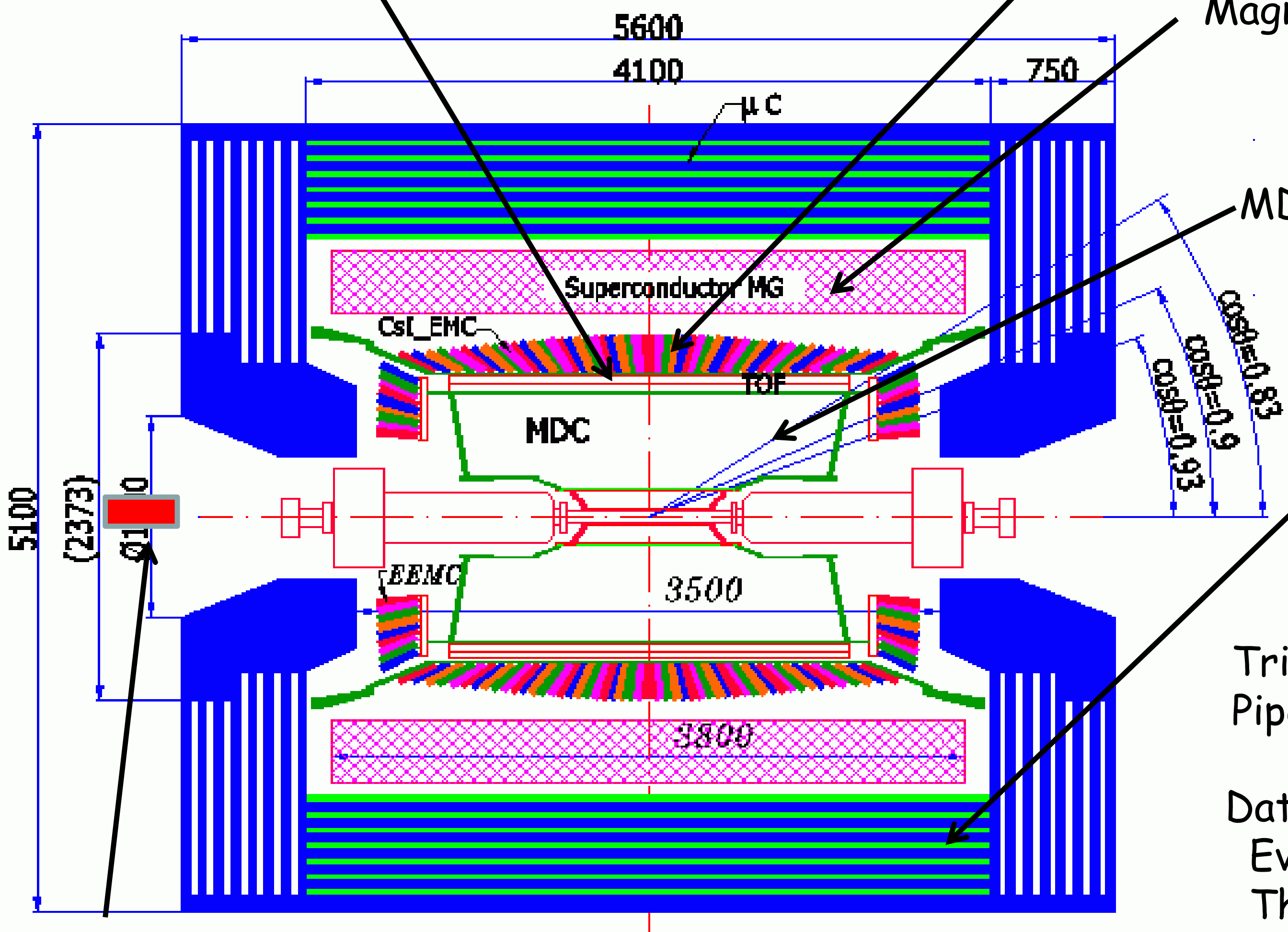
TOF:
σ_T = 80 ps Barrel
110 ps Endcap

EMC: CsI crystals, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
σ_z = 0.6 cm/$\sqrt{E}$

Magnet: 1T Superconducting

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Muon: 9 layer RPC

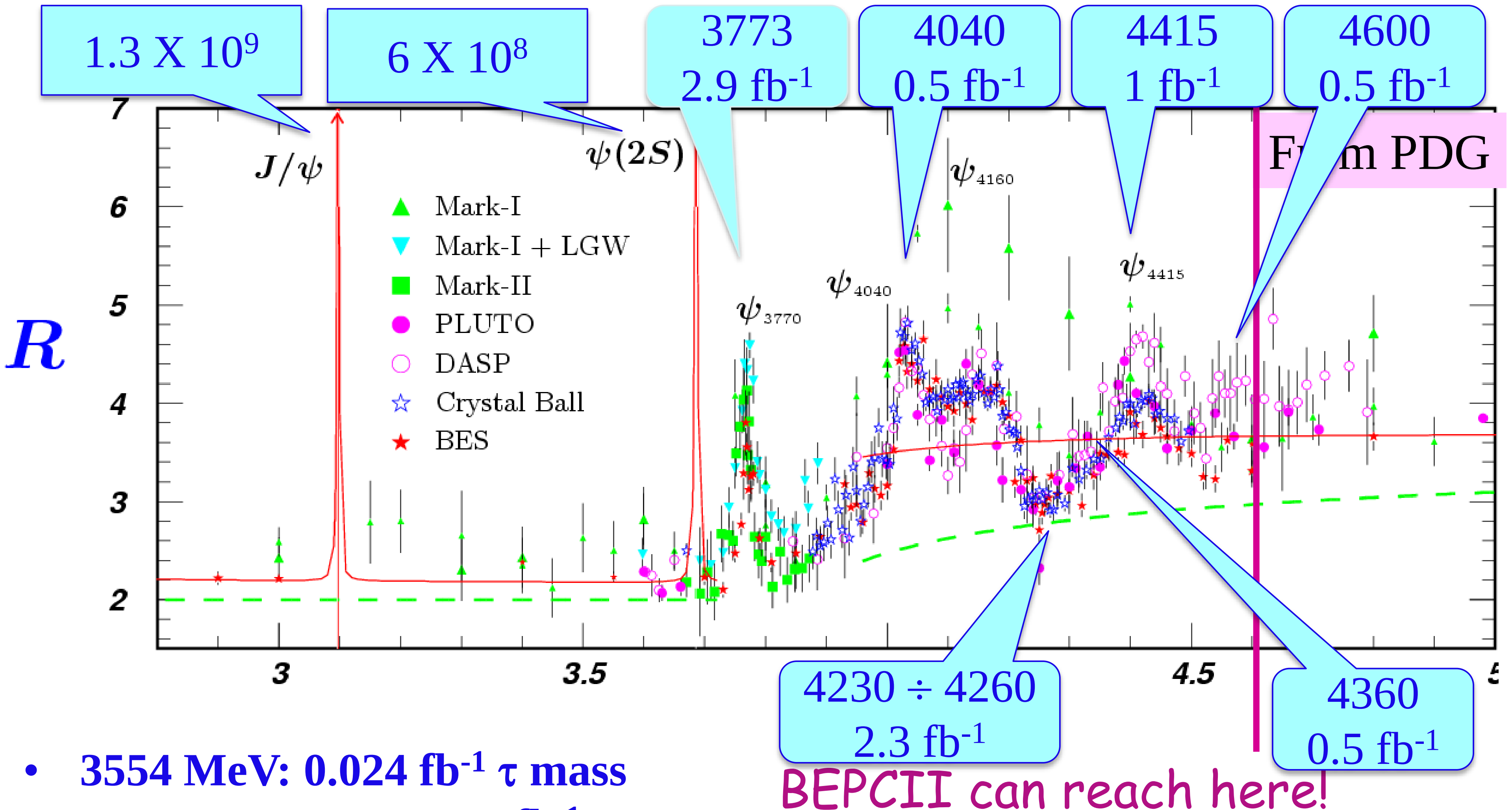


Zero Degree Detector (ISR)

Trigger: Tracks & Showers
Pipelined; Latency = 2.4 ms

Data Acquisition:
Event rate = 3 kHz
Thruput ~ 50 MB/s

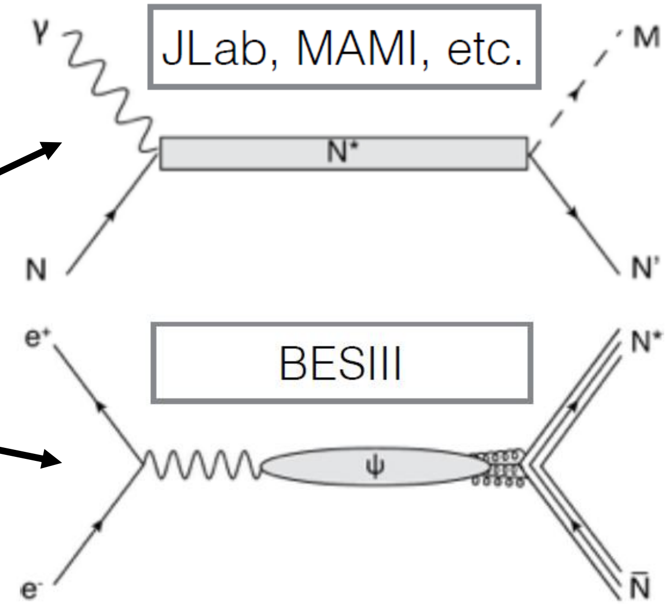
BESIII Production of Charmonium(like) states

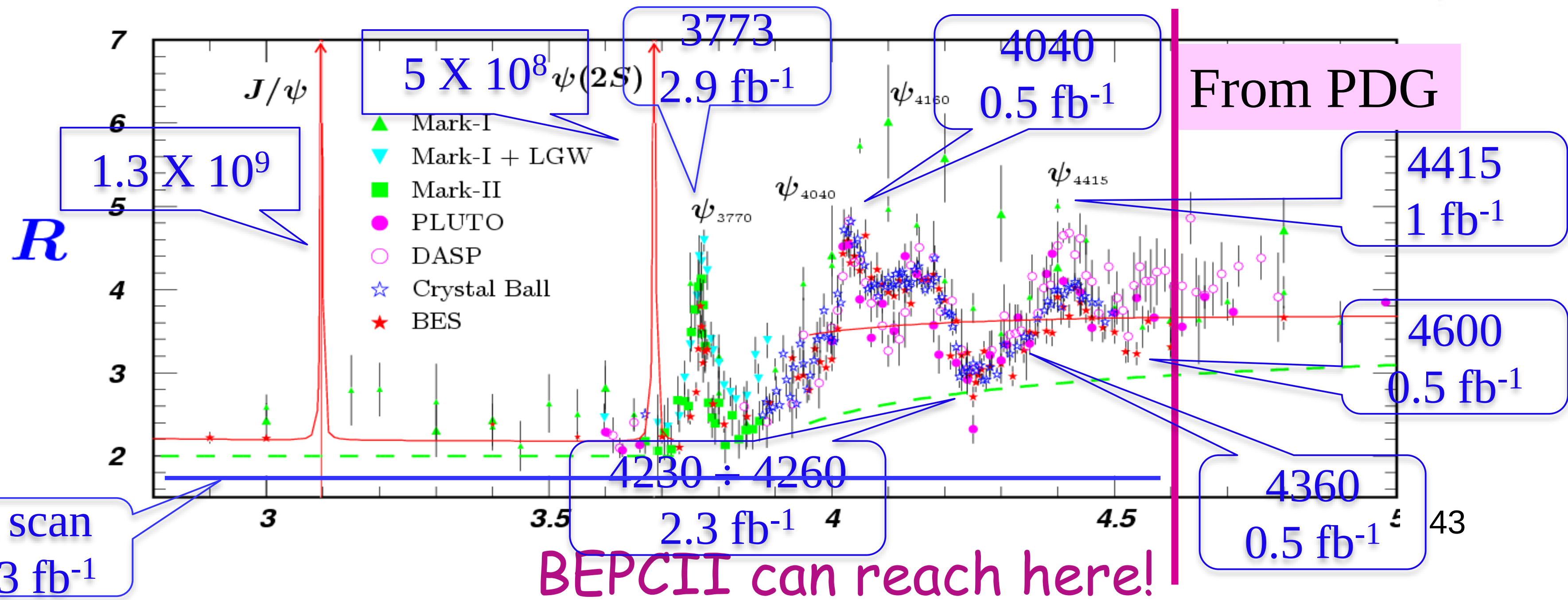


- **3554 MeV: 0.024 fb^{-1} τ mass**
- **4100 ÷ 4400 MeV: 0.5 fb^{-1} coarse scan**
- **3850 ÷ 4590 MeV: 0.5 fb^{-1} fine scan**

BESIII: Baryon Production

- Charmonium decays offer complementary information to existing data
  - Coupling of unobserved states through conventional production channels could be small, but coupling may be large to gggN:
    $\psi \longrightarrow N\bar{N}(\pi/\eta/\eta'/\omega/\varphi), \bar{p}\Sigma\pi, \bar{p}\Lambda K$
  - High statistics available at BESIII





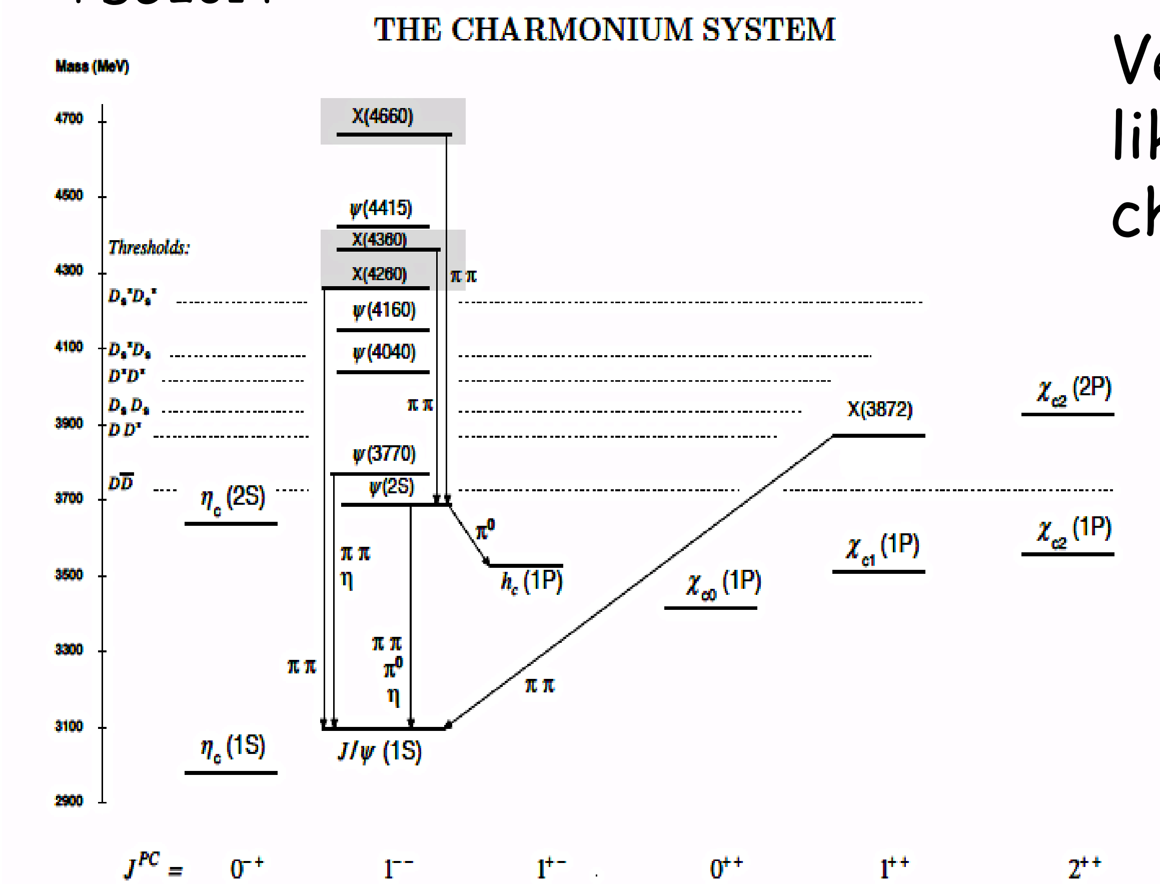
Observation of two structures in

$e^+e^- \to \pi^+\pi^- h_c$

Preliminary result for conference

introduction

PDG2014

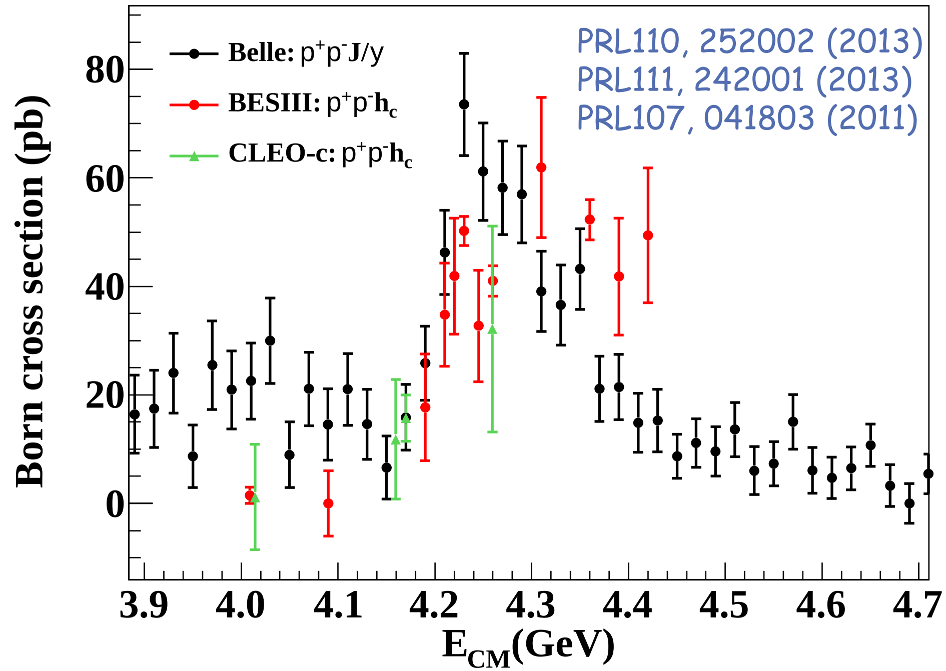


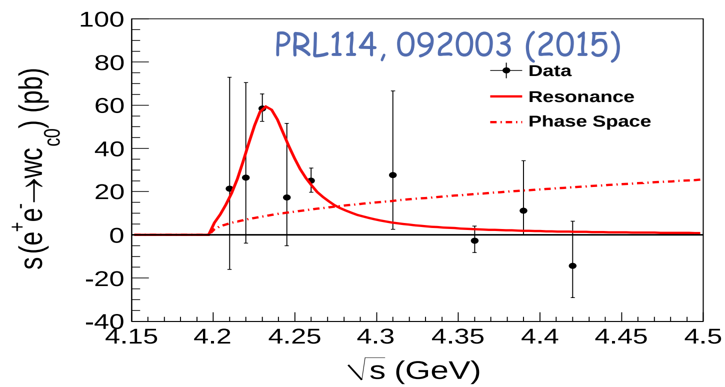
Vector charmonium like state (Ys) above charm threshold:

- relatively narrow
- large coupling to hadronic transition process
- small coupling to open charm process

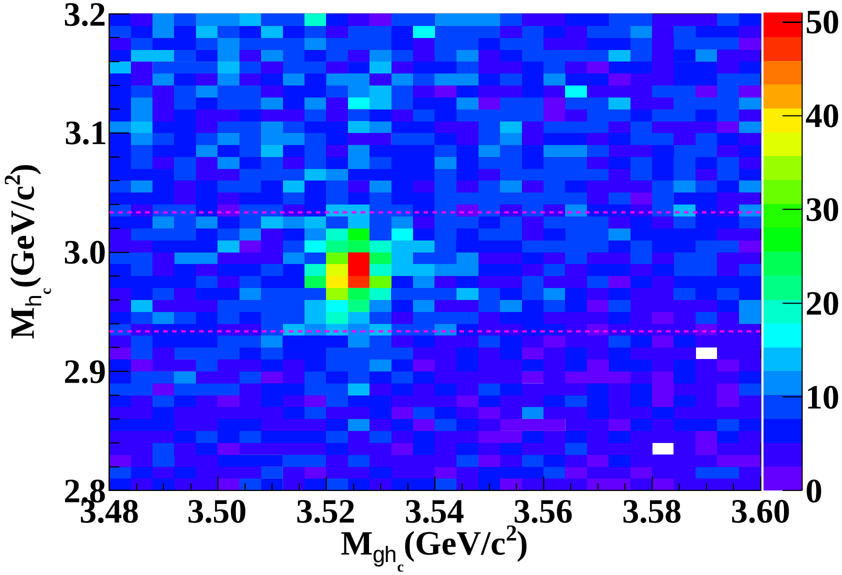
Introduction

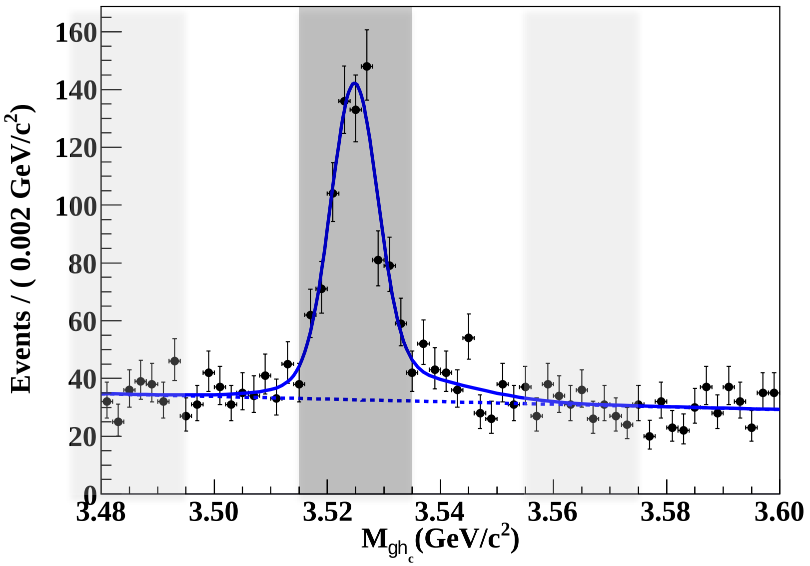
- $\pi^+\pi^- h_c$ first observed at CLEO-c at 4170 MeV
- Previous measurement up to 4420 MeV shows different line shape of $\pi^+\pi^- h_c$ cross section comparing to that of $\pi^+\pi^- J/\psi$
- Resonance around 4230 MeV in $e^+e^-\to\omega\chi_{c0}$ cross section at BESIII





Signals in data (4415 MeV as example)



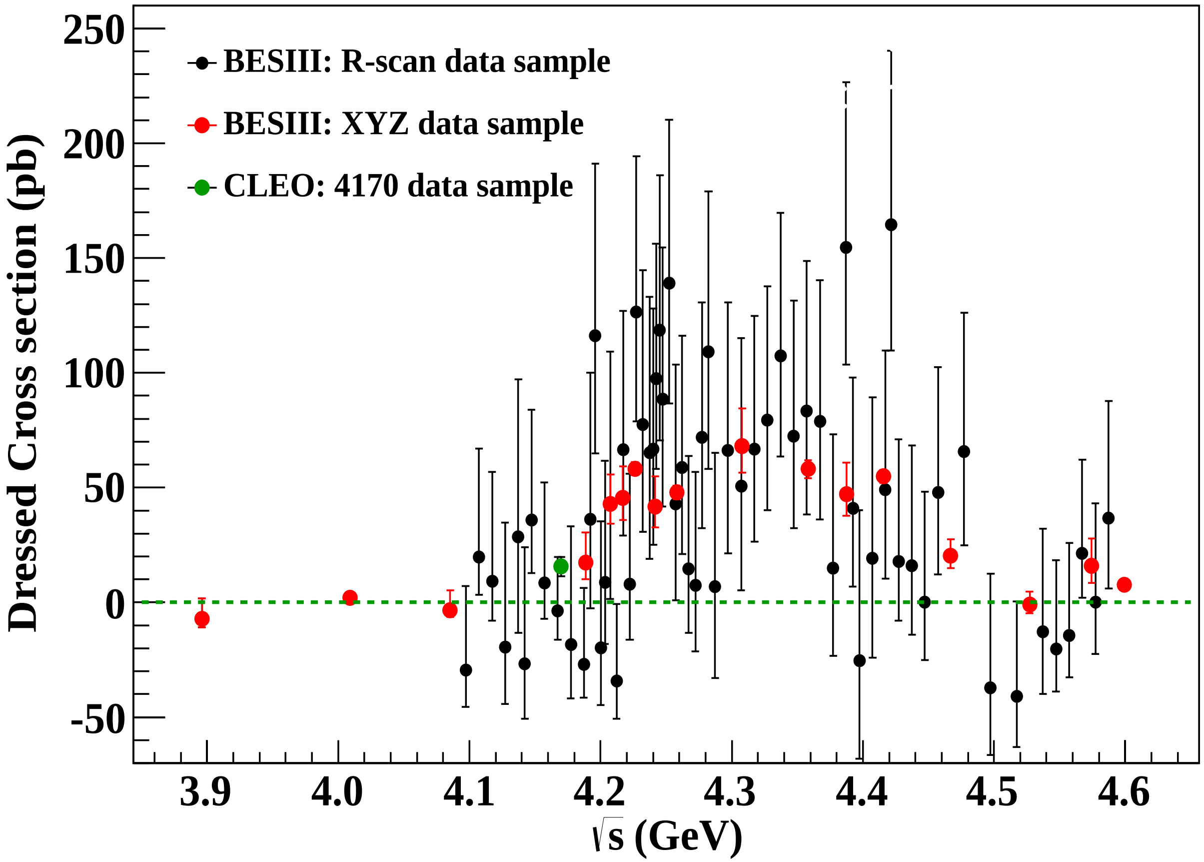


Number of signal events extracted from $\pi^+\pi^-$ recoil mass spectrum:

- XYZ sample: fit to the mass spectrum
- R-scan sample: calculate by counting the entries in h_c signal region and the entries in

cross section

$$\sigma^{\text{dressed}} = \frac{N^{\text{obs}}}{\mathcal{L}(1+\delta)\sum_{i=1}^{16}\epsilon_i\mathcal{B}(\eta_c \to X_i)\mathcal{B}(h_c \to \gamma\eta_c)}$$



Systematic uncertainty

Cross section measurement

Total: 15.2%-18.0% depending on CM energies

- Luminosity:
- Branching fraction of $h_c \to \gamma\eta_c$:11.8%
- Detection efficiency and branching fraction of η_c: 6.4%-9.1%
  - efficiency: 5.5%-10.8%, depend on the η_c decay modes and CM energies
- ISR correction factor: 0.1%-2.0%
- Number of signal events extraction: 2.0%-10.0%

Systematic uncertainty

Parameters of the structures

Sources	$Y(4220)$ M (MeV/c^2)	$Y(4220)$ Γ (MeV)	$Y(4220)$ Γ^{el} (eV)	$Y(4390)$ M (MeV/c^2)	$Y(4390)$ Γ (MeV)	$Y(4390)$ Γ^{el} (eV)	ϕ (rad)
CM energy$^{1(2)}$	0.8(0.1)	−(0.1)	−(0.2)	0.8(0.1)	−(0.2)	−(0.3)	−(0.1)
CM energy spread	0.1	0.3	0.3	0.1	0.1	0.7	0.1
Cross section$^{1(2)}$	0.1(−)	−(−)	0.2(0.7)	0.6(−)	0.5(−)	0.4(1.7)	0.1(−)
Total	0.9	0.4	0.8	1.0	0.6	1.9	0.2

- CM energy^1: systematic uncertainty of center-of-mass energy measurement
- CM energy^2: assumptions made in the center-of-mass energy measurement for R-scan data sample
- Cross section^1: systematic uncertainties of the cross section measurement which are different in each energy point
- Cross section^2: systematic uncertainties of the cross section measurement which are common in each energy point

summary

- Cross section of $e^+e^-\to\pi^+\pi^-h_c$ has been measured at 79 energy points from 3896 MeV to 4600 MeV
  - The cross section drops in high energy region, likely two resonant structures
  - The significance of the two resonant structures assumption over one structure is larger than 10σ
  - Parameters of the two resonances are different from those of Y(4260), Y(4360), and the ψ(4415)