

# New states at BES

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# Outline

Light hadron spectroscopy

BES-III at BEPC-II

Threshold enhancement of  $p\bar{p}$  invariant mass in radiative  $J/\psi$  decays

Resonances in  $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$

Observation of  $X(1870)$  in  $J/\psi \rightarrow \omega\eta\pi^+\pi^-$

# Light hadron spectroscopy

Questions to constituent quark model:

Why so many states in meson spectrum?

- Too many isoscalar  $0^{++}$  states:  
 $f_0(600)$ ,  $f_0(980)$ ,  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_0(1710)$ ,  $f_0(1810)$
- Same for isoscalar  $1^{++}$  states:  
 $f_1(1285)$ ,  $f_1(1420)$ ,  $f_1(1510)$ , only 2 predicted
- Nature of  $a_0(980)$ ,  $f_0(980)$ ?

Do any of non- $q\bar{q}$  or non- $qqq$  states exist?

- multi-quark states, glueballs, hybrids . . .
- Allowed by QCD, but no candidates yet?

# Allowed hadronic states

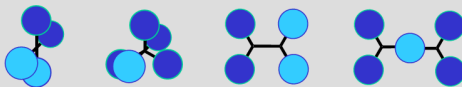
We know

mesons and baryons



QCD allows:

molecules/multi-quarks



hybrids



glueballs

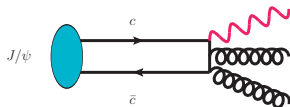


and more

## ... in charmonium decays

- Large production cross section:  
enormous statistics, favourable background conditions
- All quantum numbers accessible in  $J/\psi$  and  $\psi'$  decays
- Initial state well defined ( $J^{PC} = 1^{--}$ )
- Radiative decays: high probability  
provide access to  $C = +1$  states
- 3-gluon annihilation is flavour-blind  
nice source of excited strange and charmed baryons

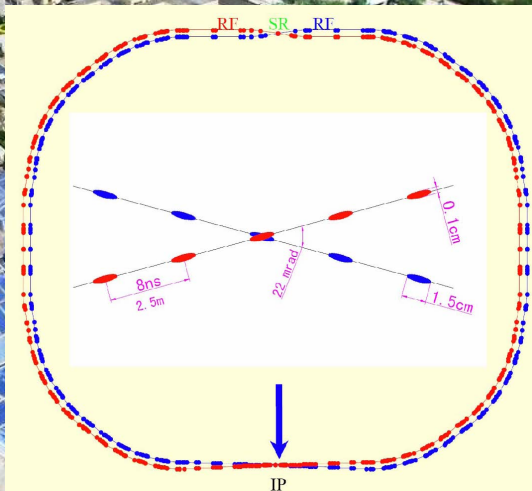
⇒ Need a copious source of charmonium and a good detector



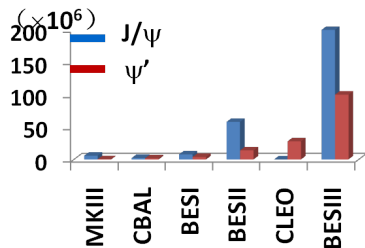
# BEPC-II and BES-III



# BEPC-II and BES-III



# BEPC-II: a $\tau$ -charm factory



## BEPC-II

Upgrade of BEPC (started 2004)

Beam energy 1 ... 2.3 GeV

Optimum energy 1.89 GeV

Design luminosity  $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Current record:  $6.5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

## Data samples

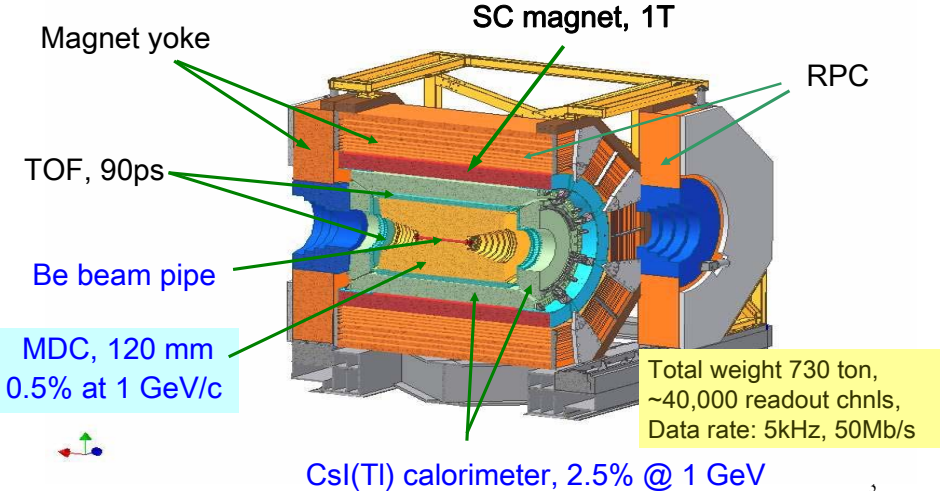
106 M  $\psi'$  (Apr. 2009)

225 M  $J/\psi$  (Jul. 2009)

$3 \text{ fb}^{-1} \psi(3770)$  (2010–2011)

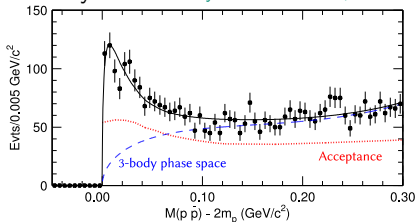


# BES-III detector



# $J/\psi \rightarrow \gamma p \bar{p}$ : threshold enhancement in $p \bar{p}$ mass

Seen by BES-II [Phys. Rev. Lett. 91, 022001](#)



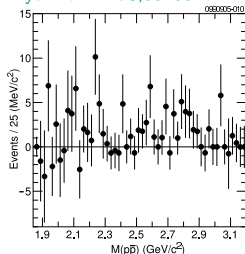
What could it be?

- FSI effect
- Baryonium (i.e.  $p \bar{p}$  bound state)
- something of both?
- ...

No similar structure observed in related channels:

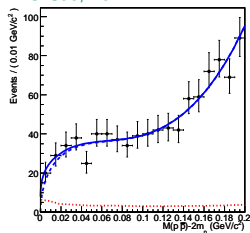
$\Upsilon(1S) \rightarrow \gamma p \bar{p}$  (CLEO)

[Phys. Rev. D 73,032001](#)



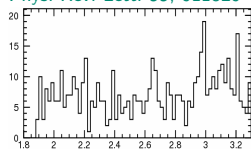
$J/\psi \rightarrow \omega p \bar{p}$  (BES-II)

[EPJ C53, 15](#)



$\psi' \rightarrow \gamma p \bar{p}$  (BES-II)

[Phys. Rev. Lett. 99, 011820](#)

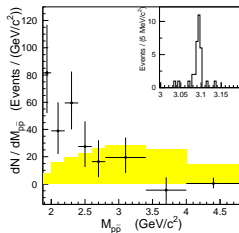


( $\sim 2\sigma$  significance for threshold enhancement)

# $p\bar{p}$ threshold enhancement in other reactions

BELLE,  $B^+ \rightarrow K^+ p\bar{p}$

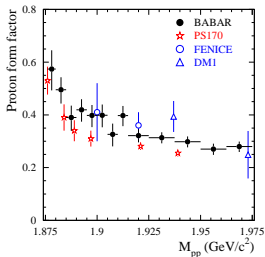
Phys. Rev. Lett. **88**,181803  
( $29.4 \text{ fb}^{-1}$ )



- Also seen in other  $B$  decays
- FSI? Sub-threshold resonance? ...
- Not enough statistics!

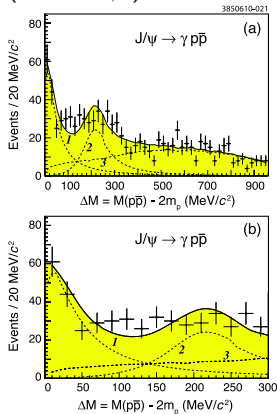
BABAR,  $e^+e^- \rightarrow \gamma p\bar{p}$

Phys. Rev. D **73**, 012005  
( $231 \text{ fb}^{-1}$ )

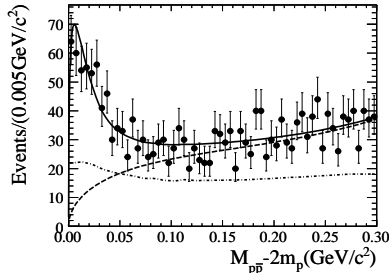
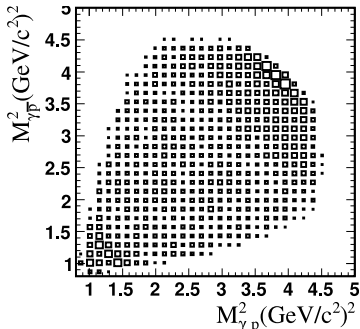
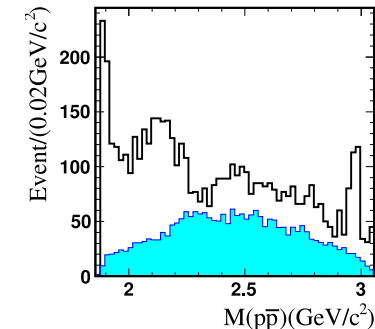


CLEO,  $\psi' \rightarrow \pi^+ \pi^- J/\psi$

Phys. Rev. D **82**,092002  
( $24.5 \text{ M } \psi'$ )



# BES-III: $\psi' \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$



BES-III [Chin. Phys. C, 34, 421](#)

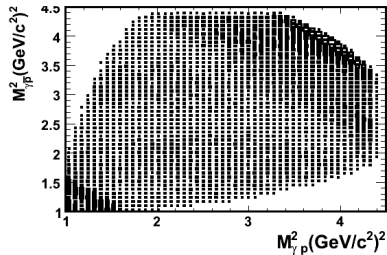
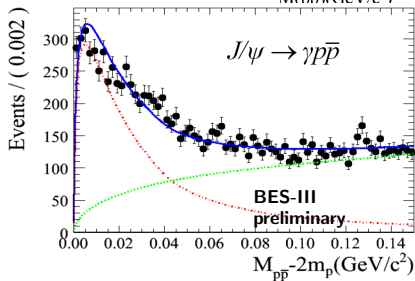
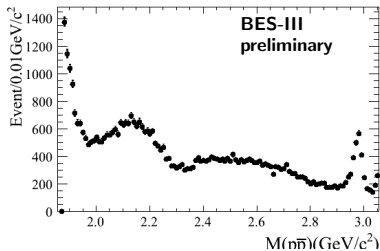
106 M  $\psi'$

Fit with  $S$ -wave Breit-Wigner:

$$\blacksquare m = 1861_{-13}^{+6}{}_{-26}^{+7} \text{ MeV}/c^2$$

$$\blacksquare \Gamma < 38 \text{ MeV}/c^2 \text{ at } 90\% \text{ C.L.}$$

# BES-III: $J/\psi \rightarrow \gamma p \bar{p}$

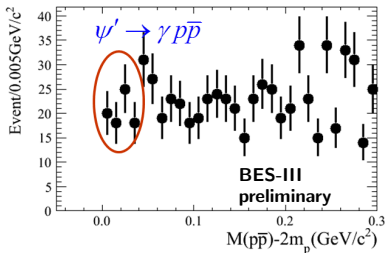


Fit with  $S$ -wave Breit-Wigner  
Preliminary:

- $m = 1861 \pm 0.8 \text{ MeV}/c^2$
- $\Gamma < 8 \text{ MeV}/c^2$  at 90% C.L.

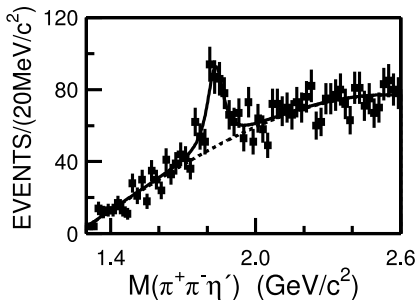
Compatible with BES-II results and  
with BES-III  $\psi'$  PWA ongoing

## BES-III: radiative decay $\psi' \rightarrow \gamma p \bar{p}$



- No evident or significant threshold enhancement observed in this decay channel
- Pure FSI effect to create narrow  $p \bar{p}$  threshold enhancement unlikely
- If there is indeed sub-threshold resonance  $X(1860)$ :  
should be visible in other (non- $p \bar{p}$ ) decay channels as well!

# $X(1835)$ in $J/\psi \rightarrow \gamma\eta'\pi\pi$



**BES-II**, *Phys. Rev. Lett.* **95**,262001

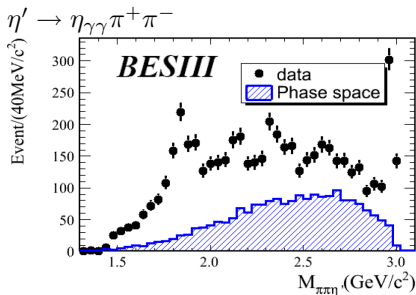
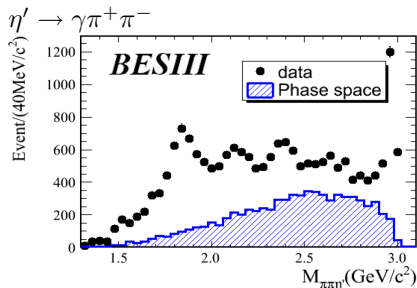
- Using 58 M  $J/\psi$
- $m = 1833.7 \pm 6.1 \pm 2.7 \text{ MeV}/c^2$
- $\Gamma = 67.7 \pm 20.3 \pm 7.7 \text{ MeV}/c^2$
- Significance  $\sim 7.7\sigma$

$p\bar{p}$  bound state? Pseudoscalar glueball? Radial excitation of  $\eta'$ ?

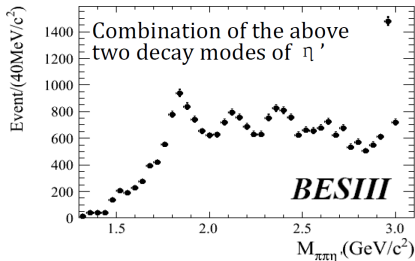
- $0^{-+}$  glueball expected to have similar decay properties of  $\eta_c$
- LQCD prediction for mass of  $0^{-+}$  glueball  $\sim 2.3 \text{ GeV}/c^2$

➡ Need higher statistics, measure quantum numbers of this  $X(1835)$

# BES-III: Mass spectrum of $\eta' \pi^+ \pi^-$

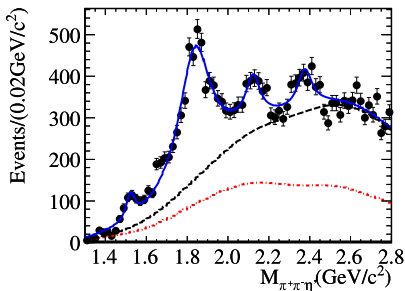


- 225 M  $J/\psi$  events
- $\eta_c$  and  $X(1835)$  visible
- More structure at  $\sim 2.1$  and  $2.3$   $\text{GeV}/c^2$
- Bump at  $1510$   $\text{MeV}/c^2$ :  $f_1(1510)$ ?





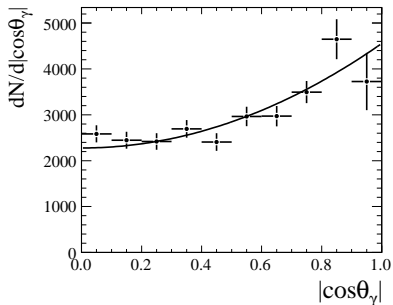
- Four resonances (rel. BW  $\otimes$  Gauss, acceptance weighted)
- Non-resonant  $\eta'\pi^+\pi^-$ : from MC, incoherent
- Background components:
  - ▶ non- $\eta'$  background estimated by  $\eta'$  sidebands
  - ▶ Mis-reconstructed  $J/\psi \rightarrow \pi^0\eta'\pi^+\pi^-$ : from data, reweight



Find three resonant structures in  $\eta'\pi^+\pi^-$  mass spectrum:

	$m$ [MeV/ $c^2$ ]	$\Gamma$ [MeV/ $c^2$ ]
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$

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

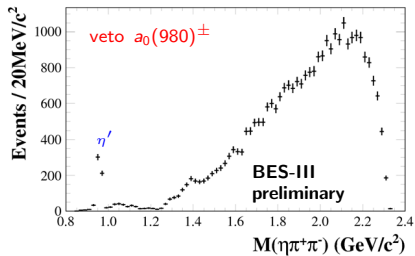
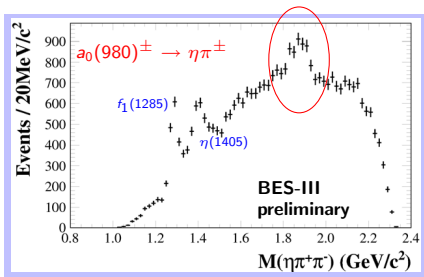
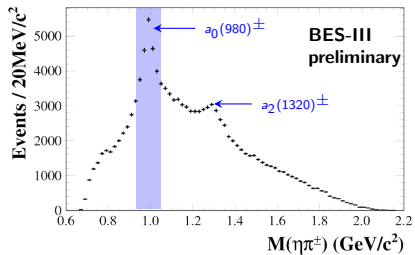


Angular distribution for events in  
 $X(1835)$  peak  $\propto 1 + \cos^2 \theta_\gamma$

⇒ supports  $J^{PC} = 0^{-+}$

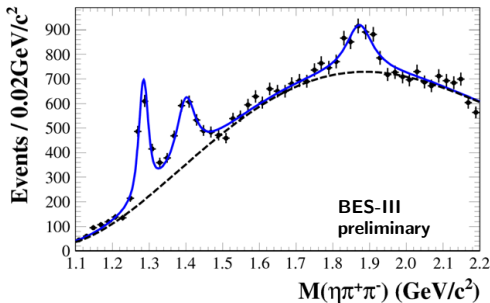
- $X(1835)$  mass consistent with BES-II msmt, width significantly larger
- Need PWA to determine spin-parity assignment will allow to take interference into account
- Need to look
  - ▶ with recoil particles  $(\omega, \phi, \dots)$  instead of  $\gamma$
  - ▶ in other related channels (e.g.  $\eta\pi\pi$ )

$$J/\psi \rightarrow \omega \eta \pi^+ \pi^-$$



# $\eta\pi^+\pi^-$ mass spectrum

- Require  $a_0(980)^\pm$



- Fit incoherent contributions of resonances (BW  $\otimes$  Gauss) and background
- $f_1(1285)$  and  $\eta(1405)$
- **X(1870)**

$$m = 1877.3 \pm 6.3 \text{ MeV}/c^2$$

$$\Gamma = 57 \pm 12 \text{ MeV}/c^2$$

(statistical errors only)  
decaying predominantly to  
 $a_0(980)^\pm\pi^\mp$

- Is X(1870) the X(1835) seen in the  $\eta'\pi^+\pi^-$  channel?  
Or the  $\eta_2(1870)$ ?
- Further careful study needed

# Summary and conclusions

- Light hadron spectroscopy still full of surprises
- BES-III confirms  $p\bar{p}$  mass threshold enhancement seen by BES-II ( $X(1860) \rightarrow p\bar{p}$ ?) with much higher statistics
- No obvious structure in corresponding  $\psi'$  decay
- $X(1835) \rightarrow \eta'\pi^+\pi^-$  confirmed with  $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$ .  
Two new states  $X(2120)$  and  $X(2370)$  seen!
- In  $J/\psi \rightarrow \omega\eta\pi^+\pi^-$ : observe  $X(1870) \rightarrow a_0(980)\pi$
  
- Nature of these states? Are they all the same state?
- BES-III will help to answer these questions:  
 $10^9 J/\psi$  in the next few years