

# Study of charmonium decays at BESIII

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# OUTLINE

- **BESIII/BEPCII status**
- **BESIII data sets**
- **BESIII selected results**
  - ✓ **Baryonic decays of particles above  $D\bar{D}$  threshold**
  - ✓ **Light hadron spectroscopy: charmonium radiative decays**
- **Summary**

# BEPCII/BESIII satellite view



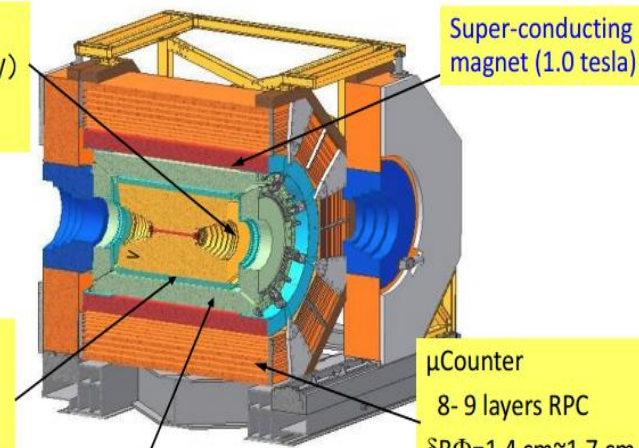
**E : 1.0-2.3 GeV**  
**dE/E = 5.16x10<sup>-4</sup>**

## The BESIII Detector

NIM A614, 345 (2010)

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

Time Of Flight (TOF)  
 $\sigma_T$ : 90 ps Barrel  
110 ps endcap



Super-conducting magnet (1.0 tesla)

$\mu$ Counter  
8-9 layers RPC  
 $\delta R\Phi = 1.4 \text{ cm} \sim 1.7 \text{ cm}$

EMC:  $\sigma_{E/VE} (\%) = 2.5\% (1\text{ GeV})$   
(Csl)  $\sigma_{z,\phi} (\text{cm}) = 0.5 - 0.7 \text{ cm/VE}$

**2004: BEPCII upgrade**  
**BESIII construction**

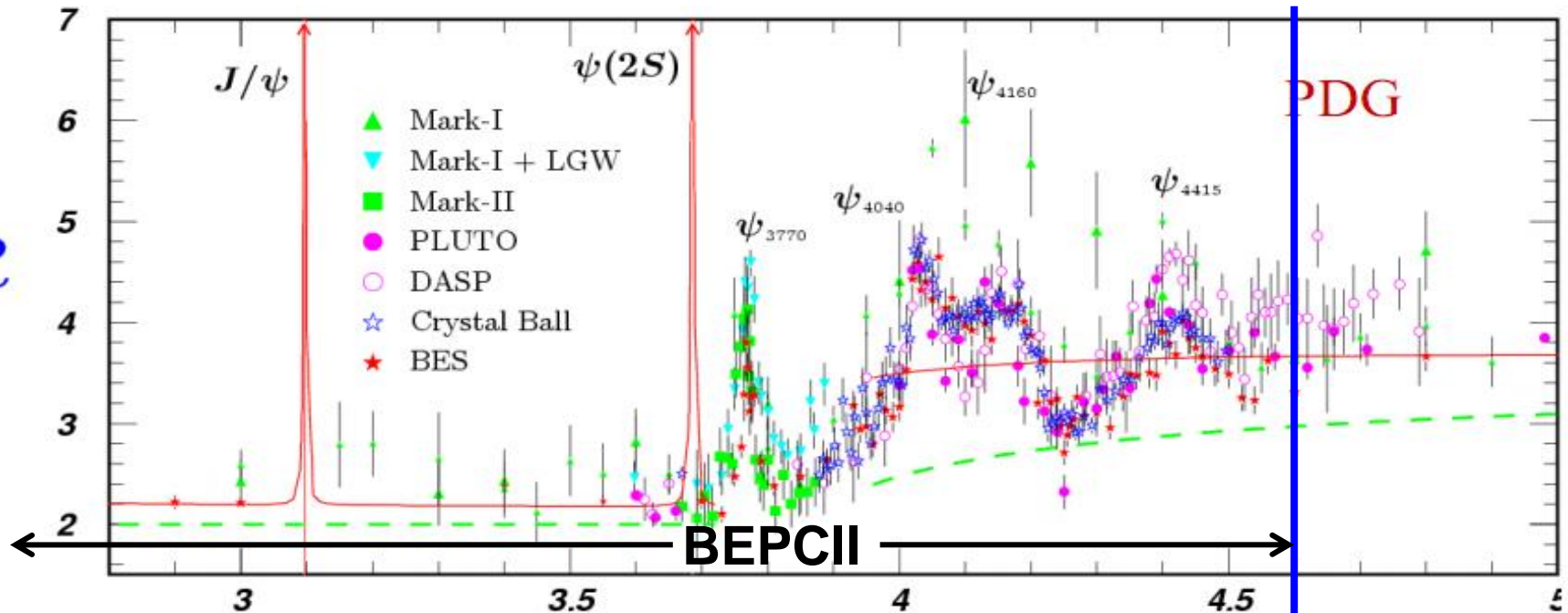
**2008: Test run**

**2009–now: BESIII physics run**



# BEPCII energy region

- **Resonances:** charmonia, charmed mesons,...
- **Threshold Characteristics:** pairs of  $\tau$ ,  $D$ ,  $D_s$ , ...
- **Transition Between:** smooth and resonances,  
perturbative and non-perturbative QCD
- **Energy Location:** glueball, hybrids and multi-quark states



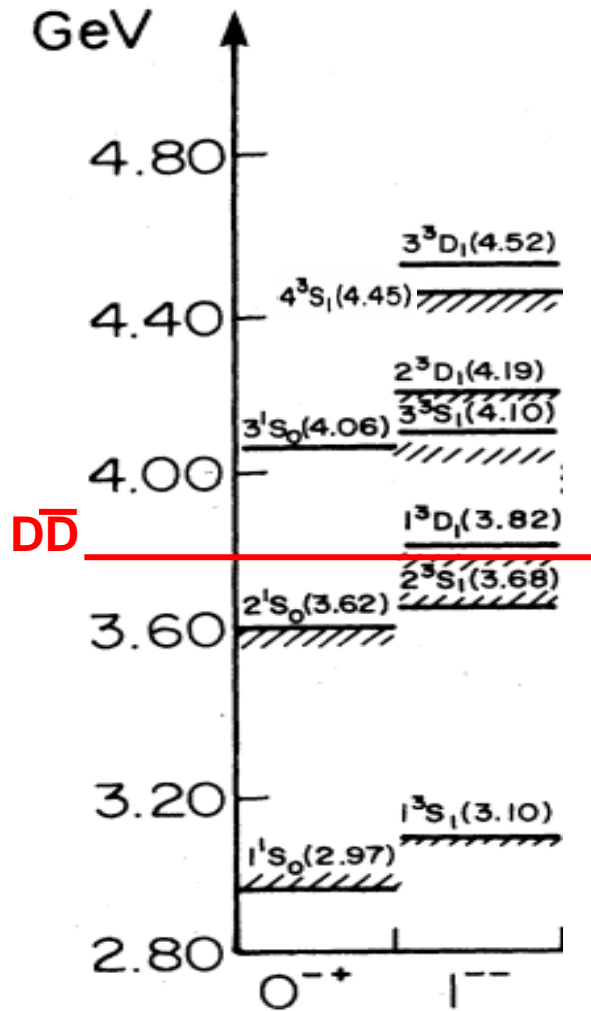
# BESIII data sets

	Previous Data	BESIII Present		Goal
J/ $\psi$	BESII: 58 M	1.2 B	20×BESII	10 B
$\psi(3686)$	CLEO: 28 M	0.5 B	20×CLEO-c	3 B
$\psi(3770)$	CLEO: 0.8 /fb	2.9 /fb	3.5×CLEO-c	20 /fb
$\psi(4040)$ & $\psi(4160)$ & $\psi(4260)$ & $\psi(4360)$	CLEO: 0.6 /fb @ $\psi(4160)$	2011: 0.5 /fb @ $\psi(4040)$ 2013: 2 /fb @ $\psi(4260)$ , 0.5 /fb @ $\psi(4360)$ data for lineshape		5-10 /fb
continuum& R scan& $\tau$ scan		2009: 44 /pb @3.65 GeV 2012: R @2.23, 2.4, 2.8, 3.4 GeV 25 /pb $\tau$ @3.542, 3.554, 3.561, 3.600 GeV		

# BESIII selected results

- ✓ Baryonic decays of particles above  $D\bar{D}$  threshold :
  - $\psi(3770)$  and  $\psi(4040)$  baryonic decays
- ✓ Light hadron spectroscopy: charmonium radiative decays
  - $X(p\bar{p})$  in  $J/\psi \rightarrow \gamma p\bar{p}$  decays

# $\psi(3770)$ and $\psi(4040)$ baryonic decays



Stephen Godfrey and  
Nathan Isgur  
PRD 32, 189(1985)

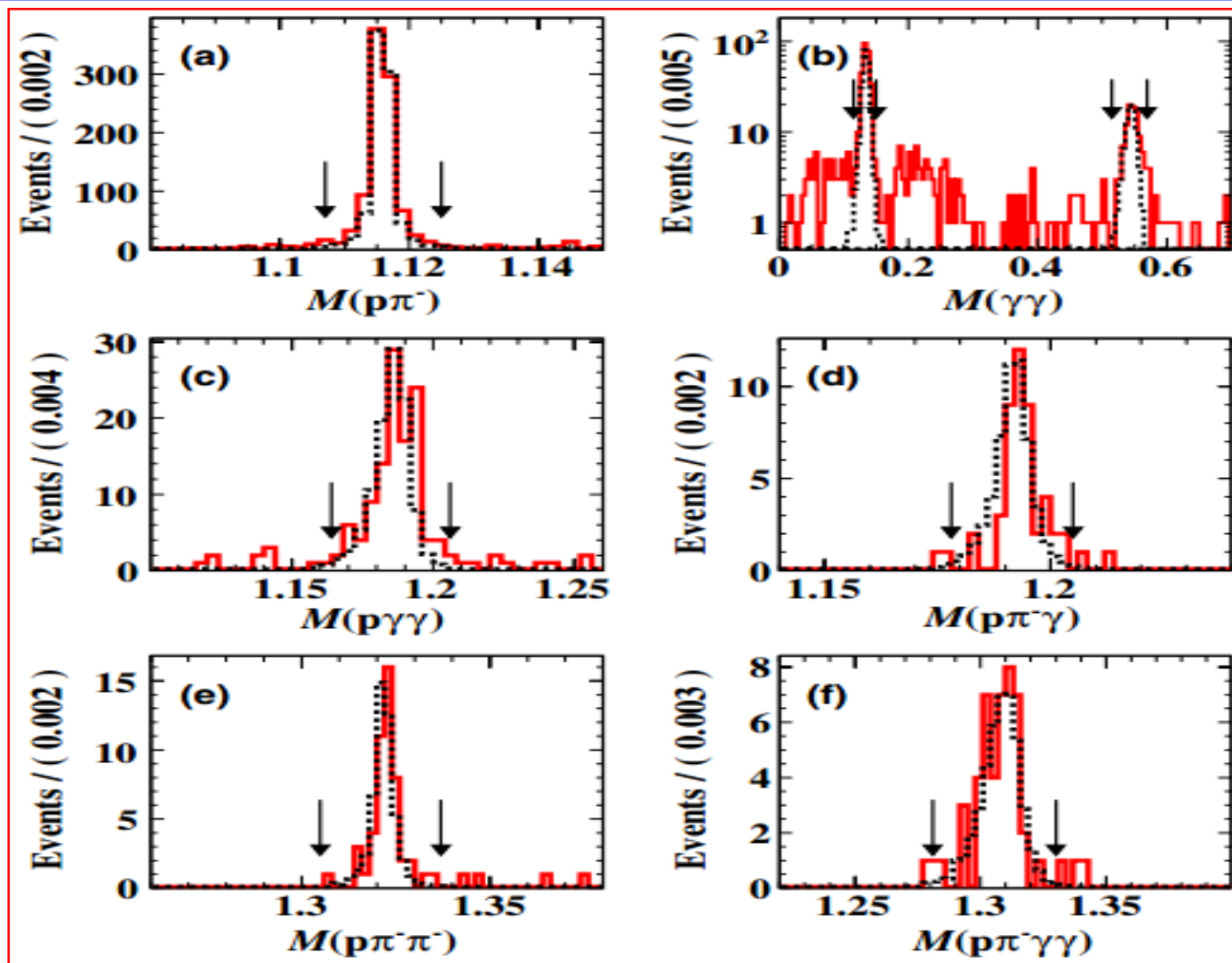
- Above  $D\bar{D}$  threshold, exist several broad  $1^{--}$  resonances:  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$ ,  $\psi(4415)$ .
- $\psi(3770)$  and  $\psi(4040)$  decay into open-charm, charmless decays supposed to be highly suppressed.

- BESII measured  $\psi(3770)$  decay to non- $D\bar{D}$  ( $15 \pm 5\%$ ), assuming only  $\psi(3770)$  exist in 3.70~3.87 GeV.
- BESII firstly observed a non- $D\bar{D}$  decay of  $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$ .

- BESIII firstly observed a non- $D\bar{D}$  decay of  $\psi(4040) \rightarrow \eta J/\psi$ .

- Fewer searches for baryonic decays of  $\psi(3770)$
- No searches for baryonic decays of  $\psi(4040)$

# $\psi(3770)$ and $\psi(4040)$ baryonic decays

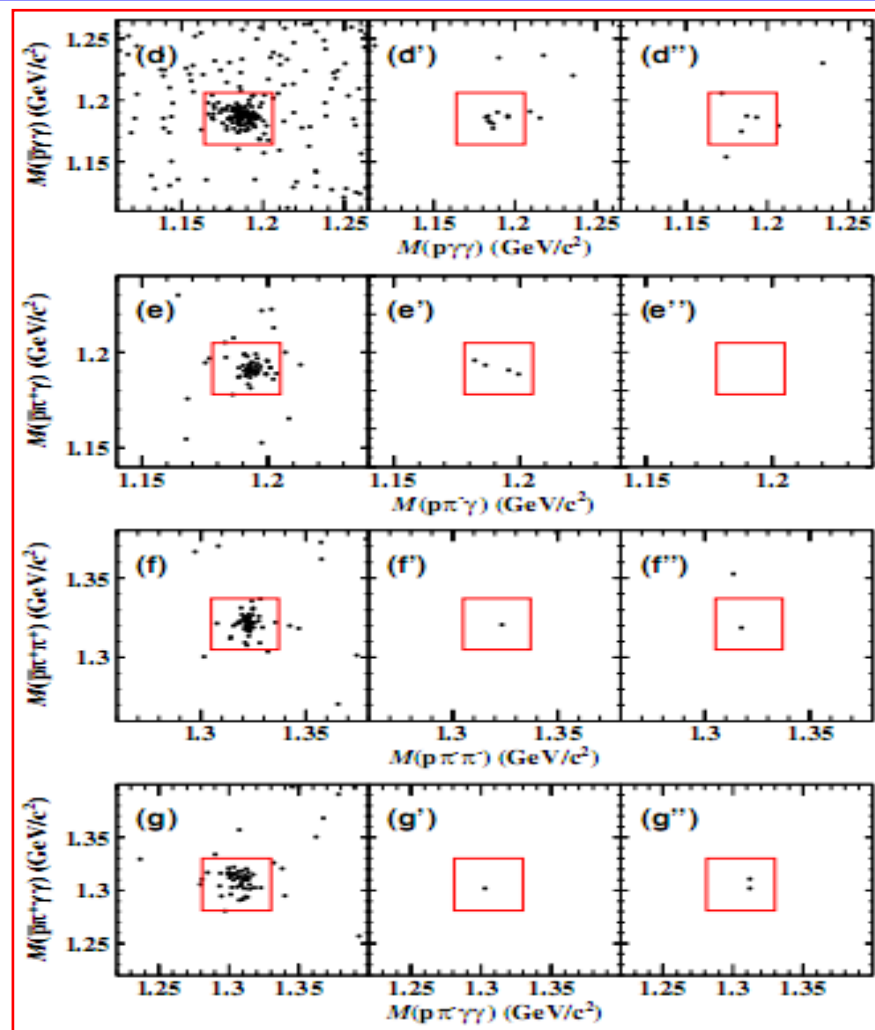
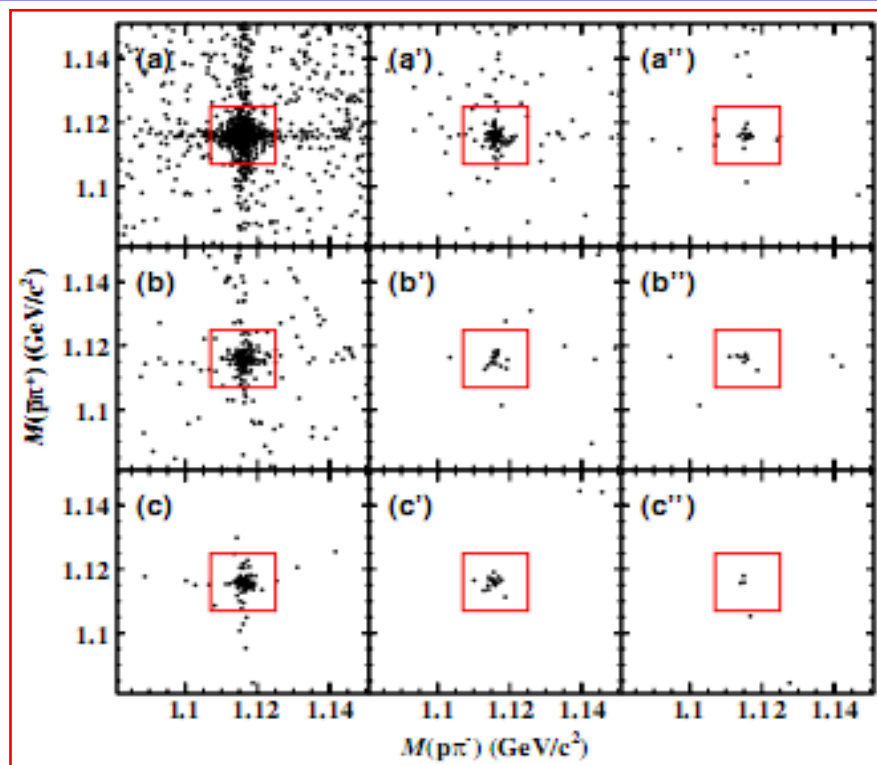


PRD 87, 112011(2013)

$\Lambda\bar{\Lambda}\pi^+\pi^-$ ,  $\Lambda\bar{\Lambda}\pi^0$ ,  $\Lambda\bar{\Lambda}\eta$ ,  $\Sigma^+\Sigma^-$ ,  $\Sigma^0\bar{\Sigma}^0$ ,  $\Xi^-\Xi^+$  and  $\Xi^0\Xi^0$  are studied



# $\psi(3770)$ and $\psi(4040)$ baryonic decays



- Assuming no interference between continuum and resonances
- Obtain events from  $\psi(3770)$  and  $\psi(4040)$  decays.

PRD 87, 112011(2013)

2-D scatter plots for (a-g)  $\psi(3770)$ , (a'-g')  $\psi(4040)$  and (a''-g'') continuum data.

# $\psi(3770)$ and $\psi(4040)$ baryonic decays

Mode $f$	$N_{\text{obs}}^f$ (3.773)	$N_{\text{B}}^f$ (3.773)	$N_{\text{obs}}^f$ (3.650)	$N_{\text{B}}^f$ (3.650)	$f_{\text{co}}^{3.773}$	$N_{\psi(3770) \rightarrow f}^S$	$N_{\psi(3770) \rightarrow f}^{\text{up}}$	$\epsilon$	$\Delta_{\text{sys}}$	$\mathcal{B}_{\psi(3770) \rightarrow f}$ [ $\times 10^{-4}$ ]	$\mathcal{B}^{\text{up}}$ [ $\times 10^{-4}$ ]
$\Lambda \bar{\Lambda} \pi^+ \pi^-$	$844.0 \pm 33.6$	5.2	$14.2^{+5.6}_{-4.2}$	0.1	45.27	$200.6^{+193.1}_{-255.7} \pm 42.0$	481.2	0.1321	8.0	$1.80^{+1.74}_{-2.30} \pm 0.40$	<4.7
$\Lambda \bar{\Lambda} \pi^0$	$124.9 \pm 14.4$	3.4	$7.1^{+5.0}_{-2.2}$	0.0	42.50	$-180.3^{+94.6}_{-213.0} \pm 16.2$	83.6	0.1694	8.0	$-1.28^{+0.67}_{-1.51} \pm 0.15$	<0.7
$\Lambda \bar{\Lambda} \eta$	$74.0 \pm 9.5$	0.9	$3.0^{+3.6}_{-1.6}$	0.0	44.76	$-61.2^{+72.2}_{-161.4} \pm 7.9$	87.7	0.1518	8.1	$-1.22^{+1.44}_{-3.21} \pm 0.19$	<1.9
$\Sigma^+ \bar{\Sigma}^-$	$100.5 \pm 11.9$	0.7	$3.3^{+4.3}_{-1.7}$	0.1	38.27	$-22.7^{+66.1}_{-165.0} \pm 5.1$	96.0	0.1975	8.0	$-0.21^{+0.63}_{-1.56} \pm 0.05$	<1.0
$\Sigma^0 \bar{\Sigma}^0$	$43.5 \pm 6.7$	0.0	$0.0^{+2.2}_{-0.0}$	0.0	38.69	$43.5^{+6.7}_{-85.4} \pm 5.8$	56.6	0.1752	8.0	$0.30^{+0.05}_{-0.58} \pm 0.05$	<0.4
$\Xi^- \bar{\Xi}^+$	$48.5 \pm 7.0$	0.0	$0.5^{+2.8}_{-1.4}$	0.0	41.74	$27.6^{+58.9}_{-117.1} \pm 3.7$	119.7	0.1060	8.1	$0.31^{+0.66}_{-1.32} \pm 0.05$	<1.5
$\Xi^0 \bar{\Xi}^0$	$43.5 \pm 6.6$	1.3	$2.0^{+3.2}_{-1.2}$	0.0	40.13	$-38.1^{+48.6}_{-128.6} \pm 5.6$	60.7	0.0581	8.2	$-0.80^{+1.03}_{-2.72} \pm 0.14$	<1.4

Mode $f$	$N_{\text{obs}}^f$ (4.009)	$N_{\text{B}}^f$ (4.009)	$N_{\text{obs}}^f$ (3.650)	$N_{\text{B}}^f$ (3.650)	$f_{\text{co}}^{4.009}$	$N_{\psi(4040) \rightarrow f}^S$	$N_{\psi(4040) \rightarrow f}^{\text{up}}$	$\epsilon$	$\Delta_{\text{sys}}$	$\mathcal{B}_{\psi(4040) \rightarrow f}$ [ $\times 10^{-4}$ ]	$\mathcal{B}^{\text{up}}$ [ $\times 10^{-4}$ ]
$\Lambda \bar{\Lambda} \pi^+ \pi^-$	$79.2 \pm 10.0$	20.0	$14.2^{+5.6}_{-4.2}$	0.1	7.69	$-49.2^{+33.8}_{-44.2} \pm 9.8$	35.6	0.1492	9.9	$-3.57^{+2.45}_{-3.21} \pm 0.79$	<2.9
$\Lambda \bar{\Lambda} \pi^0$	$14.5^{+4.1}_{-4.3}$	0.5	$7.1^{+5.0}_{-2.2}$	0.0	6.80	$-34.3^{+15.5}_{-34.3} \pm 3.0$	12.6	0.1753	9.9	$-2.14^{+0.97}_{-2.14} \pm 0.28$	<0.9
$\Lambda \bar{\Lambda} \eta$	$16.0^{+4.2}_{-4.3}$	3.6	$3.0^{+3.6}_{-1.6}$	0.0	7.38	$-9.8^{+12.5}_{-26.9} \pm 3.3$	16.2	0.1674	9.9	$-1.60^{+2.06}_{-4.43} \pm 0.57$	<3.0
$\Sigma^+ \bar{\Sigma}^-$	$8.5^{+3.0}_{-3.2}$	0.2	$3.3^{+4.3}_{-1.7}$	0.1	4.92	$-7.5^{+8.9}_{-21.4} \pm 1.5$	11.0	0.1704	9.9	$-0.74^{+0.89}_{-2.14} \pm 0.17$	<1.3
$\Sigma^0 \bar{\Sigma}^0$	$4.0^{+3.2}_{-1.9}$	0.0	$0.0^{+2.2}_{-0.0}$	0.0	5.03	$4.0^{+3.2}_{-11.2} \pm 0.5$	8.9	0.1537	9.9	$0.28^{+0.23}_{-0.79} \pm 0.04$	<0.7
$\Xi^- \bar{\Xi}^+$	$1.0^{+2.2}_{-0.8}$	0.0	$0.5^{+2.8}_{-1.4}$	0.0	5.61	$-1.8^{+8.2}_{-15.7} \pm 0.3$	12.5	0.0941	9.9	$-0.21^{+0.94}_{-1.81} \pm 0.04$	<1.6
$\Xi^0 \bar{\Xi}^0$	$1.0^{+2.2}_{-0.8}$	0.0	$2.0^{+3.2}_{-1.2}$	0.0	5.36	$-9.7^{+6.8}_{-17.2} \pm 1.3$	7.0	0.0490	10.0	$-2.22^{+1.55}_{-3.93} \pm 0.37$	<1.8

Since no statistically significant signal is observed, upper limits are set at 90% C.L.

# $\psi(3770)$ and $\psi(4040)$ baryonic decays

## ■ Continuum data limited:

- ✓ Statistical error large, central value  $\sim 1\sigma$  consistent with zero
- ✓ It doesn't mean there are no  $\psi(3770)$  and  $\psi(4040)$  baryonic decays

Dominant error, continuum subtraction

Phase difference not clear, resonance and continuum

## ■ Achieve the goals:

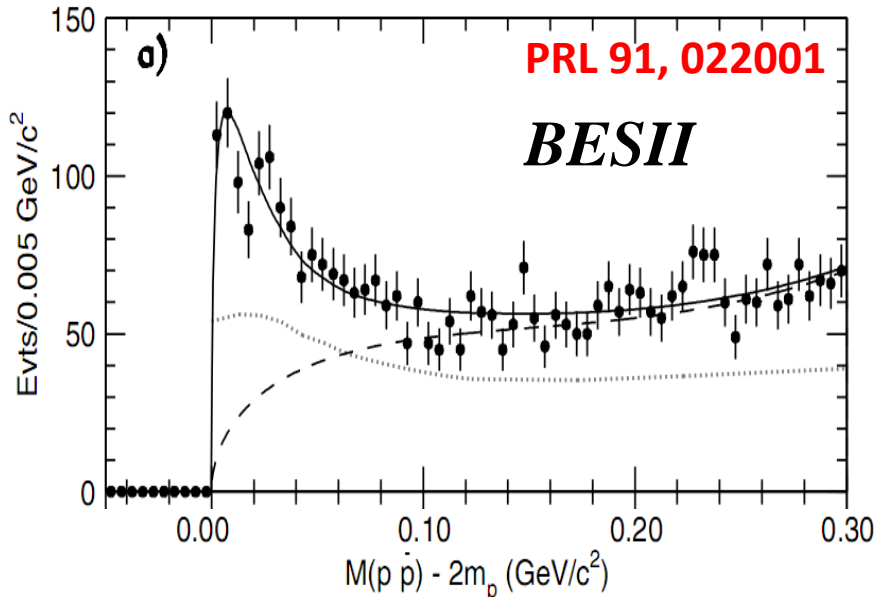
- ✓ More continuum data needed
- ✓ Fine energy scan helpful

Measure cross section, exclusive non-DDb processes

Determine branching fraction and phase difference

# Near-Threshold Enhancement in $M(p\bar{p})$

$J/\psi \rightarrow \gamma p\bar{p}$

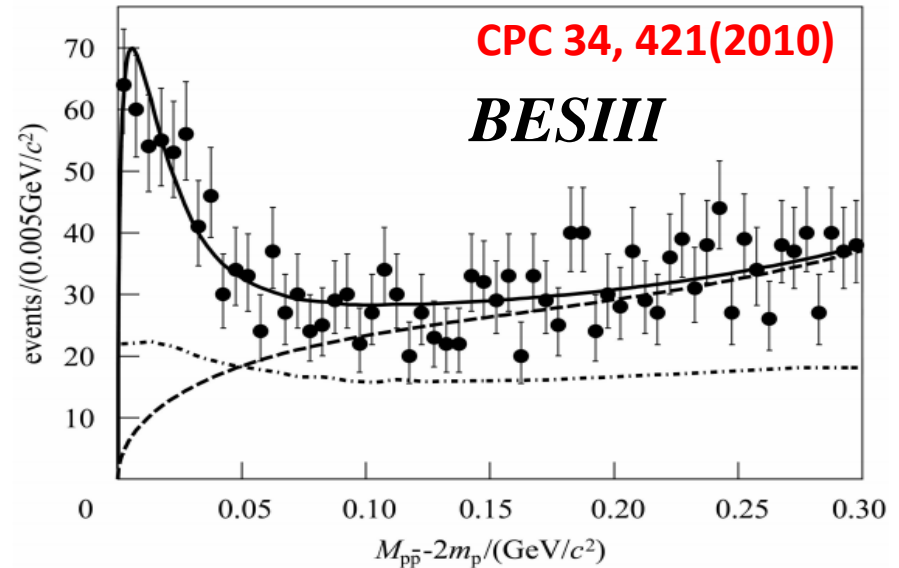


**Observed BESII 2003**

$$M = 1859_{-10}^{+3} \text{ (stat)}_{-25}^{+5} \text{ (syst)} \text{ MeV}/c^2$$

$$\Gamma < 30 \text{ MeV}/c^2 \text{ at 90\% C.L.}$$

$\psi(3686) \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$



**Confirmed BESIII 2010**

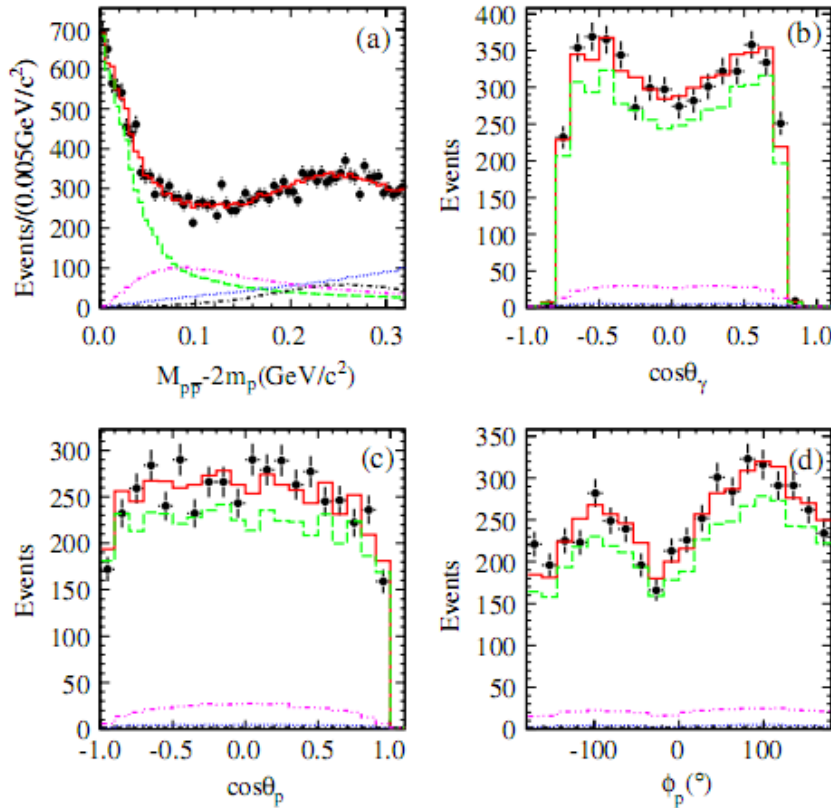
$$M = 1861_{-13}^{+6} \text{ (stat)}_{-26}^{+7} \text{ (syst)} \text{ MeV}/c^2$$

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

- Results consistent with each other
- Many possibilities: conventional meson,  $p\bar{p}$  bound state, multi-quark, glueball, final state interaction(FSI).....
- Spin-Parity analysis of  $p\bar{p}$  mass threshold structure in  $J/\psi$  radiative decays is necessary

# Partial Wave Analysis of $J/\psi \rightarrow \gamma p \bar{p}$

**BESIII** PRL 108, 112003(2012)



- The first PWA of  $p\bar{p}$  mass threshold structure via  $J/\psi \rightarrow \gamma p \bar{p}$  was performed
- The fit with a BW and S-wave FSI( $l=0$ ) factor can well describe  $p\bar{p}$  mass threshold structure
- $f_2(1910)$  and  $f_0(2100)$  are fixed at PDG
- **Stat. Sig. of  $X(p\bar{p}) \gg 30\sigma$**
- better than without FSI effect
- $\Delta 2\ln L = 51 (7.1\sigma)$

$J^{PC} = 0^{-+}$  **➡  $>6.8\sigma$  better than other  $J^{PC}$  assignments**

$$M = 1832_{-5}^{+19}(\text{stat})_{-17}^{+18}(\text{syst}) \pm 19(\text{model}) \text{ MeV}/c^2$$

$$\Gamma = 13 \pm 39(\text{stat})_{-13}^{+10}(\text{syst}) \pm 4(\text{model}) \text{ MeV}/c^2 (\Gamma < 76 \text{ MeV}/c^2 \text{ at } 90\% \text{ C.L.})$$

$$\text{BR}[J/\psi \rightarrow \gamma X(p\bar{p})] \text{BR}[X(p\bar{p}) \rightarrow p\bar{p}] = [9.0_{-1.1}^{+0.4}(\text{stat})_{-5.0}^{+1.5}(\text{syst}) \pm 2.3(\text{model})] \times 10^{-5}$$



# Summary

- BEPCII/BESIII is performing in very good shape
- Search for baryonic decays of  $\psi(3770)$  and  $\psi(4040)$  are studied at BESIII.
  - Although no obvious signal, it doesn't mean no such processes
  - More continuum data needed
  - Energy scan for exclusive processes
- $X(ppb)$  in  $J/\psi \rightarrow \gamma ppb$  decays has been extensively studied at BESIII
- More studies are on-going and new results are expected in the near future.
  - On non-DDb decays of particles above DDb threshold
  - Light hadron spectroscopy from charmonium radiative decays.

**Thanks for your attention!!**

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