中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Overview of the $J^{PC} = 1^{--}$ charmonium (-like) states decaying in $B\bar{B}$ @ BESIII

Xiongfei Wang(王雄飞), Xinchou Lou

(on behalf of BESIII collaboration)

IHEP

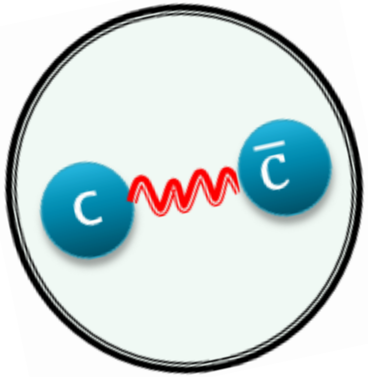
甘肃，兰州大学

April 1, 2018

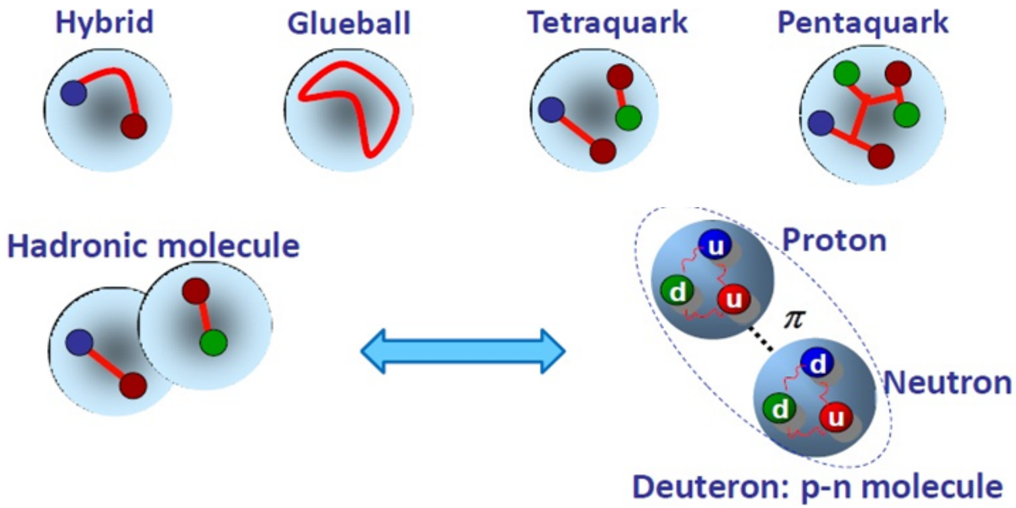
Outline

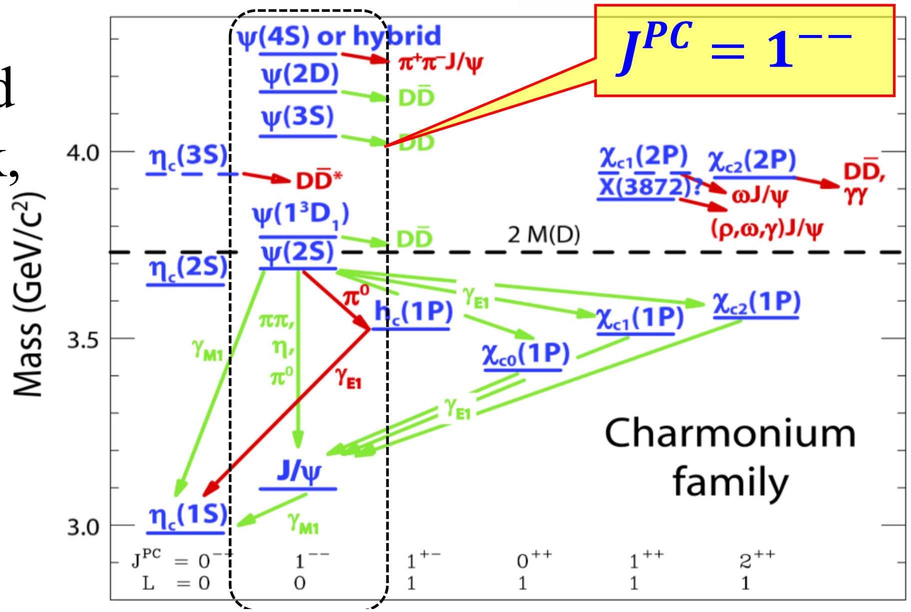
- **Introduction**
- **Experimental apparatus**
  - BEPCII
  - BESIII detector
- **Recent results**
  - Study of $J/\psi, \psi(3686) \to B\bar{B}$ (baryon anti-baryon)
    1. $J/\psi, \psi(3686) \to \Xi^-\bar{\Xi}^+, \Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$
    2. $J/\psi, \psi(3686) \to \Xi^0\bar{\Xi}^0, \Sigma(1385)^0\bar{\Sigma}(1385)^0$
    3. $J/\psi, \psi(3686) \to \Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0$
    4. $J/\psi, \psi(3686) \to NN(p\bar{p}, n\bar{n})$
    5. $\psi(3686) \to \Xi(1690/1820)\Xi$
  - Measurement of cross section of $e^+e^- \to B\bar{B}$
    1. $e^+e^- \to p\bar{p}$
    2. $e^+e^- \to \Lambda\bar{\Lambda}$
    3. $e^+e^- \to \Lambda_c\bar{\Lambda}_c$
- **Summary**

Charmonium(-like) states



- Nonrelativistic $c\bar{c}$ bound states, J/ψ (1^3S_1) is the first member with $J^{PC} = 1^{--}$, other *below charm threshold* like $\psi(2S)$, *etc.*.
- Chamonium (-like) states *above charm threshold* like Y(4260), Y(4360),etc., proposed more exotic explanations as hybrids, tetraquark, hadronic molecule, glueball, etc..





Potential models:

Example from Barnes, Godfrey, Swanson:

$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c\cdot\vec{S}_{\bar{c}}$$

(Coulomb + Confinement + Contact)

$$V_{\text{spin-dep}} = \frac{1}{m_c^2}\left[\left(\frac{2\alpha_s}{r^3} - \frac{b}{2r}\right)\vec{L}\cdot\vec{S} + \frac{4\alpha_s}{r^3}T\right]$$

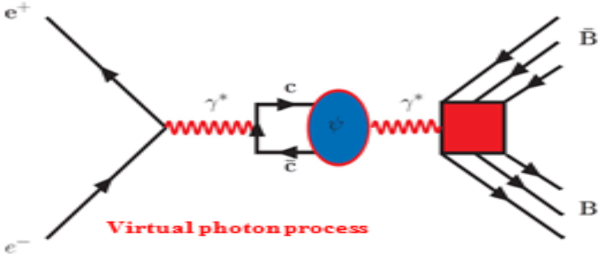
(Spin-Orbit + Tensor)

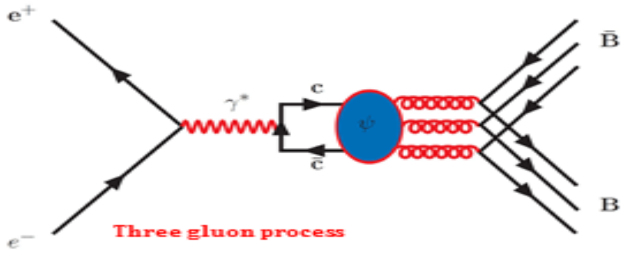
PRD72, 054026 (2005)

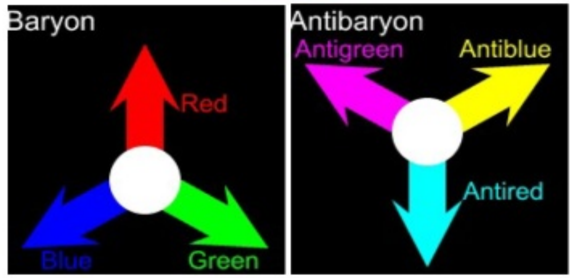
- **Potential models and L-QCD, very successful in describing spectra & onium properties!**

Baryon spectroscopy/production

- **Established baryons described by 3-quark configuration with the zero total color charge.**
- **Production of $B\bar{B}$ in e^+e^- annihilation:**

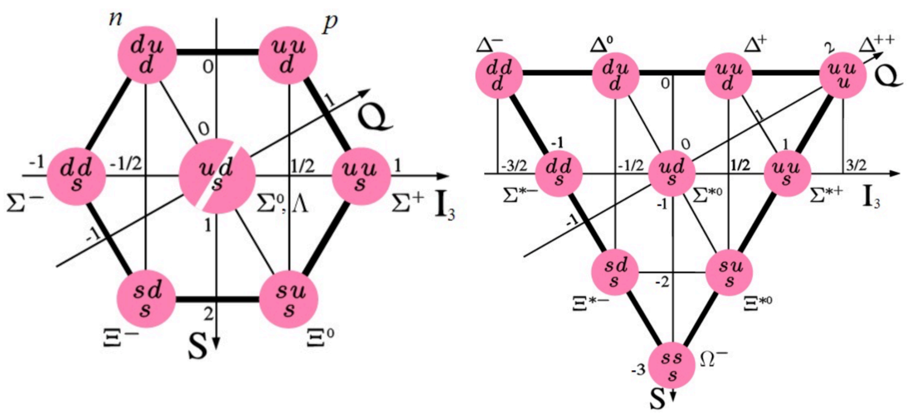






- **Provide a favorable test of pQCD and baryonic properties**
  - ✓ Test "12%" rule: $Q_h = \frac{Br(\psi(2S)\to X_h)}{Br(J/\psi\to X_h)} = 12\%$ (QCD prediction).
  - ✓ Test SU(3)-flavor symmetry
    - -- Allowed for $\psi \to B_8\bar{B}_8, B_{10}\bar{B}_{10}$, forbidden for $\psi \to B_8\bar{B}_{10}$.
  - ✓ Angular distribution study ($\frac{dN}{d(cos\theta)} \propto 1 + \alpha cos^2\theta$):
    - -- Quark mass effect, electromagnetic effect, etc.: $0 < \alpha < 1$.
  - ✓ $B\bar{B}$ threshold effect
    - -- $B\bar{B}$ bound states or unobserved meson resonances
  - ✓ Electromagnetic form factor (EMFFs)
    - -- Further understand the strong interaction
    - -- Measure time-like EMFFs
  - ✓ Search for 1^{--} Y states in $B\bar{B}$ final states above open charm threshold.

Octet / decuplet



Outline

- Introduction
- **Experimental apparatus**
  - BEPCII
  - BESIII detector
- Recent results
  - Study of $J/\psi, \psi(3686) \to B\overline{B}$ (B: baryon)
    1. $J/\psi, \psi(3686) \to \Xi^-\overline{\Xi}^+, \Sigma(1385)^{\mp}\overline{\Sigma}(1385)^{\pm}$
    2. $J/\psi, \psi(3686) \to \Xi^0\overline{\Xi}^0, \Sigma(1385)^0\overline{\Sigma}(1385)^0$
    3. $J/\psi, \psi(3686) \to \Lambda\overline{\Lambda}, \Sigma^0\overline{\Sigma}^0$
    4. $J/\psi, \psi(3686) \to NN(p\overline{p}, n\overline{n})$
    5. $\psi(3686) \to \Xi(1690/1820)\Xi$
  - Measurement of cross section of $e^+e^- \to B\overline{B}$
    1. $e^+e^- \to p\overline{p}$
    2. $e^+e^- \to \Lambda\overline{\Lambda}$
    3. $e^+e^- \to \Lambda_c\overline{\Lambda}_c$
- Summary

Beijing Electron Positron Collider-II

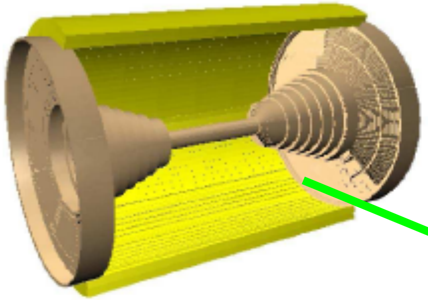
Physics data taking was started in 2009 !

Beam energy:
1-2.3 GeV
Design Lum:
1×10^{33} cm^{-2}s^{-1}
Opt. energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
Bunches No.:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

Reached peaking luminosity: $1.0 \times 10^{33}\ cm^{-2}s^{-1}$

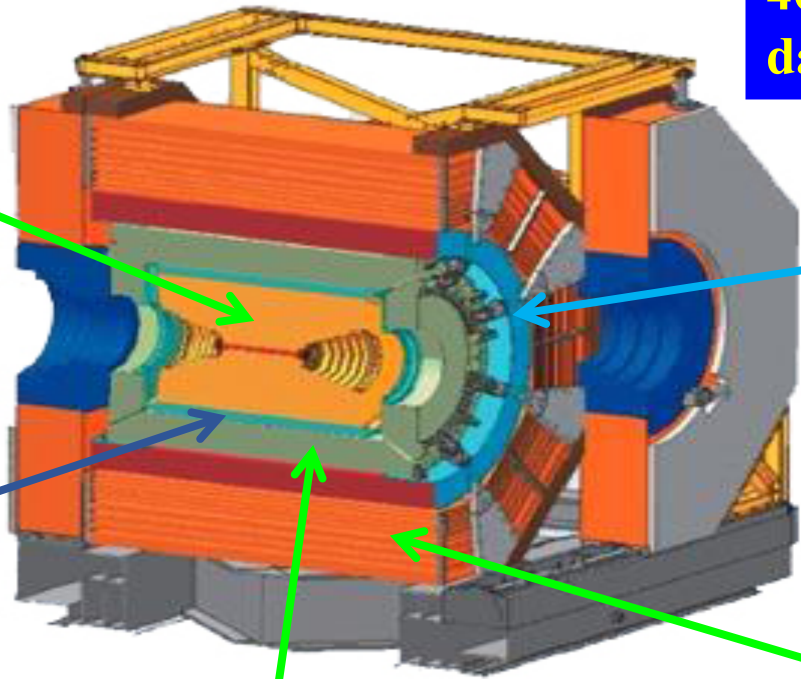
Beijing Spectrometer-III detector

A total weight of over 785t,
40,000 readout channels,
data rate 6,000Hz,~50Mb/s

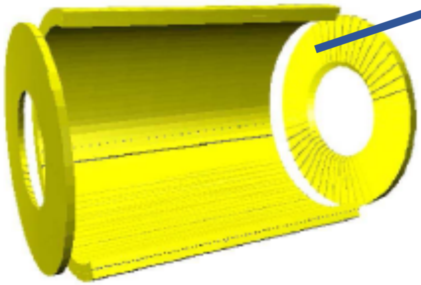


(Main Drift Chamber)

$\sigma_{sigle-wire} = 120\mu m$

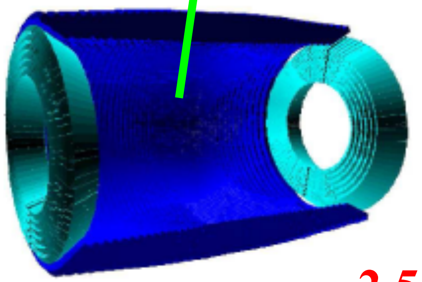


Super-conducting magnet (1.0 tesla)

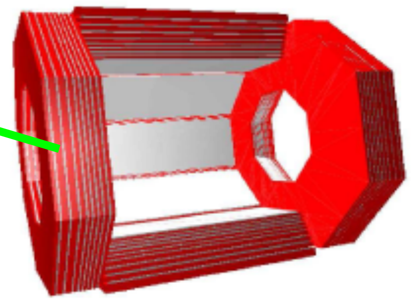


(Time-Of-Flight System)

$\sigma_{barrel} = 68\text{ps}$
$\sigma_{endcap} = 65\text{ps}$

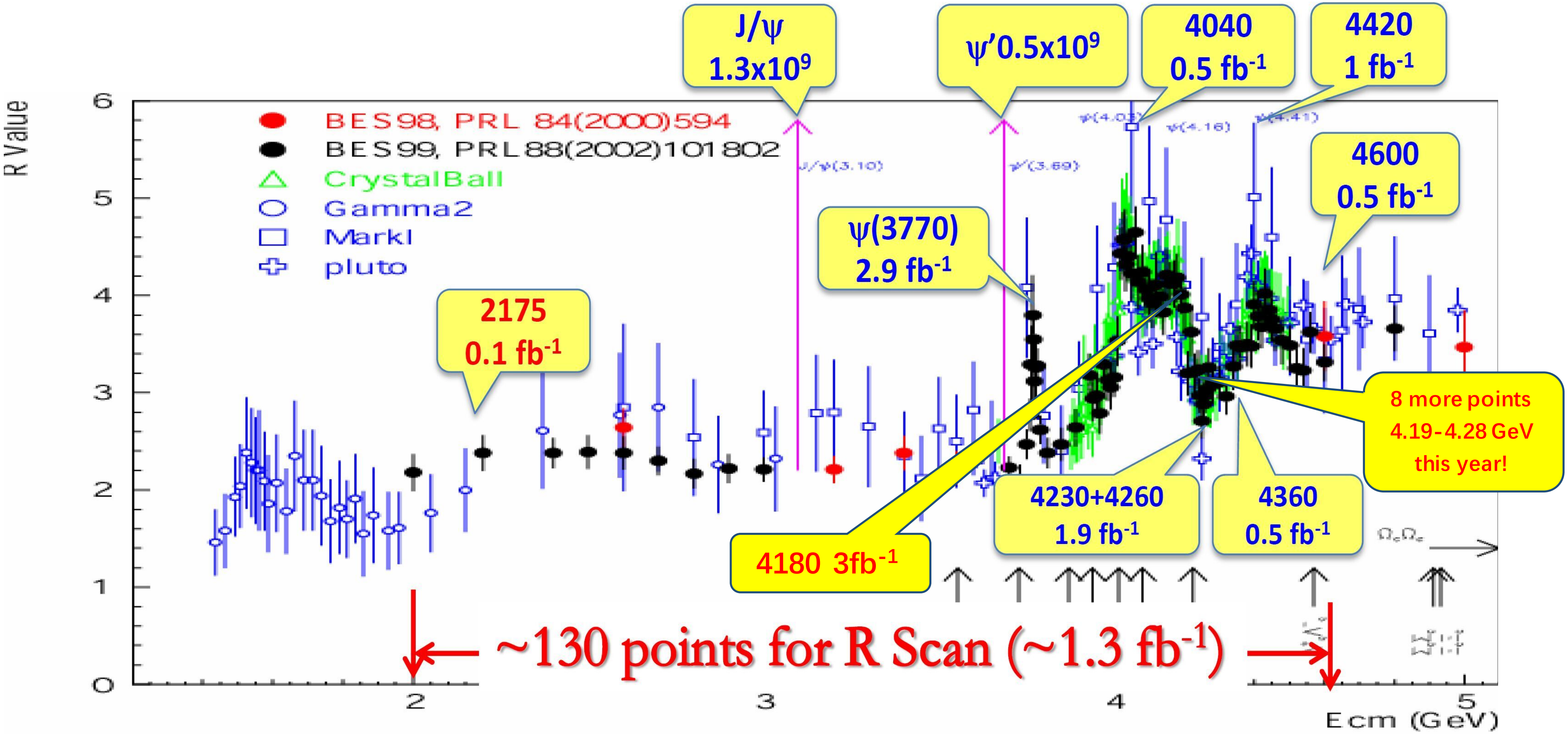


2.5%@1GeV
(Electromagnetic Calorimeter)



(Muon counter)
(made of 9 RPCs)

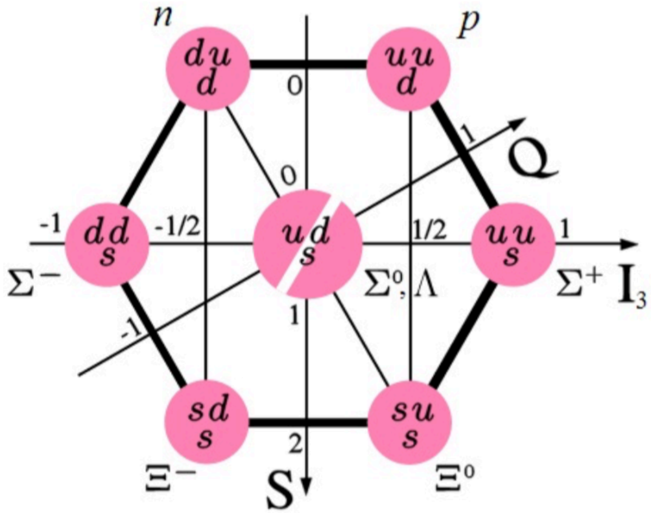
BESIII Data Samples

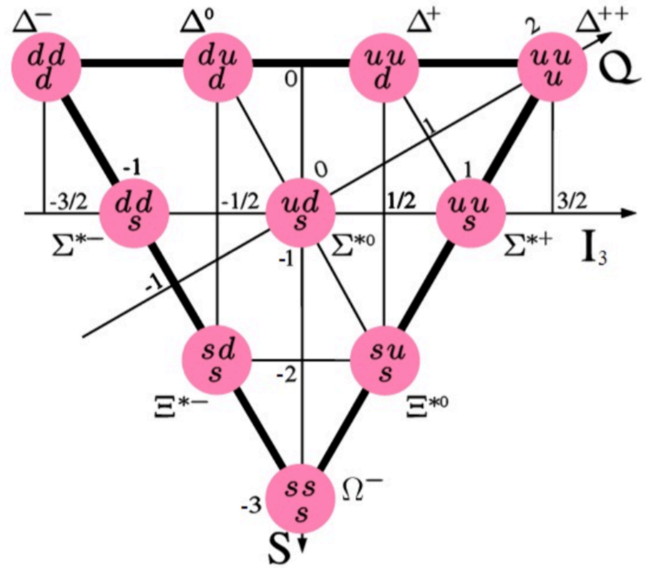


World largest data samples of J/ψ, $\psi(2S)$, $\psi(3770)$, etc., produced directly from e^+e^- collision.

Outline

- ☐ Introduction
- ☐ Experimental apparatus
  - ➢ BEPCII
  - ➢ BESIII detector
- ☐ **Recent results**
  - ➢ **Study of J/ψ, ψ(3686) → $B\bar{B}$ (B: baryon)**
    1. J/ψ, ψ(3686) → $\Xi^-\bar{\Xi}^+$, $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$
    2. J/ψ, ψ(3686) → $\Xi^0\bar{\Xi}^0$, $\Sigma(1385)^0\bar{\Sigma}(1385)^0$
    3. J/ψ, ψ(3686) → $\Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$
    4. J/ψ, ψ(3686) → NN($p\bar{p}$, $n\bar{n}$)
    5. ψ(3686) → Ξ(1690/1820)Ξ
  - ➢ Measurement of cross section of $e^+e^- \to B\bar{B}$
    1. $e^+e^- \to p\bar{p}$
    2. $e^+e^- \to \Lambda\bar{\Lambda}$
    3. $e^+e^- \to \Lambda_c\bar{\Lambda}_c$
- ☐ Summary





PHYSICAL REVIEW **D** 93, 0732003 (2016)

Study of ψ decays to the $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$ final states

DIRECTLY accepted for first one at BESIII!

Anything

$J/\psi(\psi(2S)) \rightarrow \Xi^-\bar{\Xi}^+, \Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

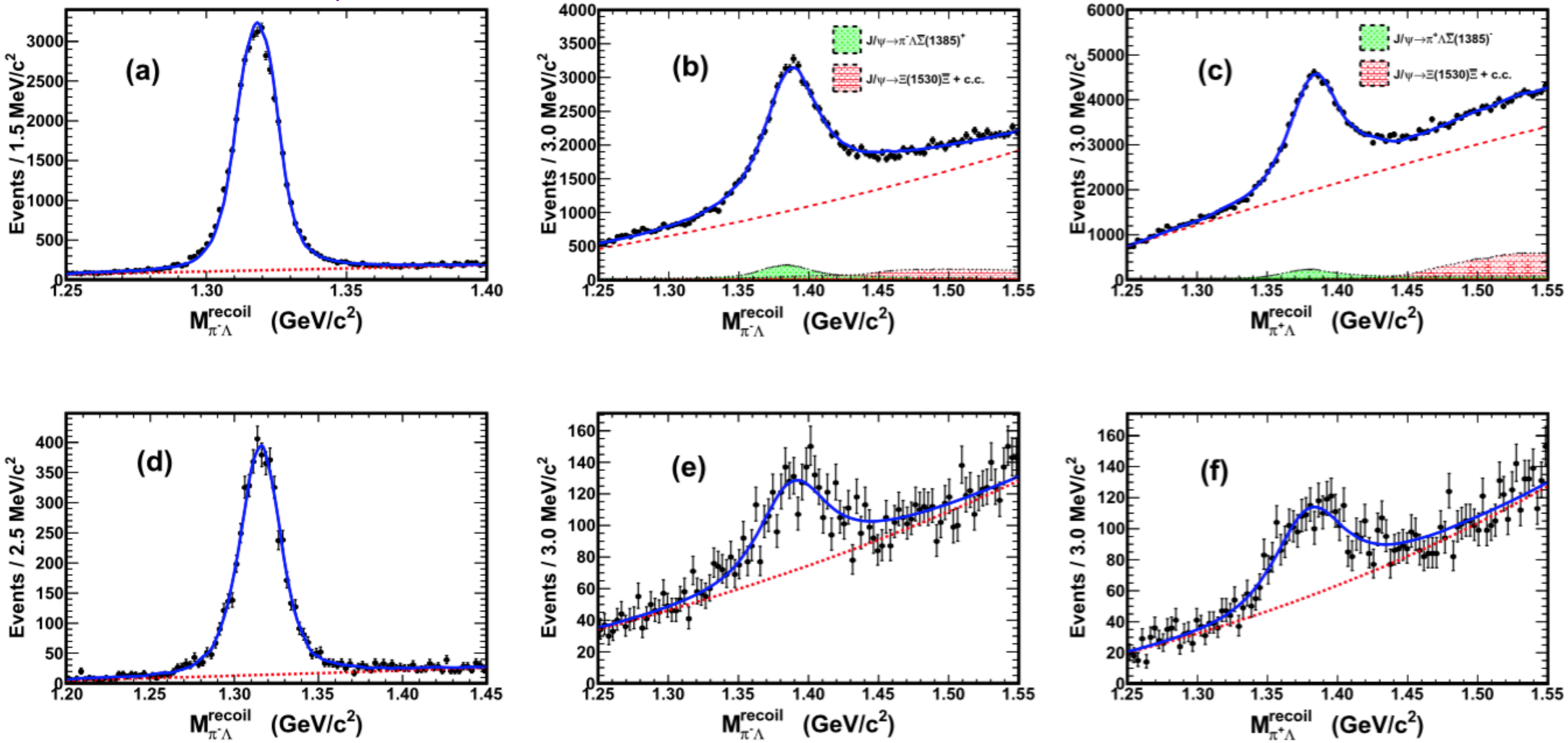
$\pi^{\pm}\Lambda$

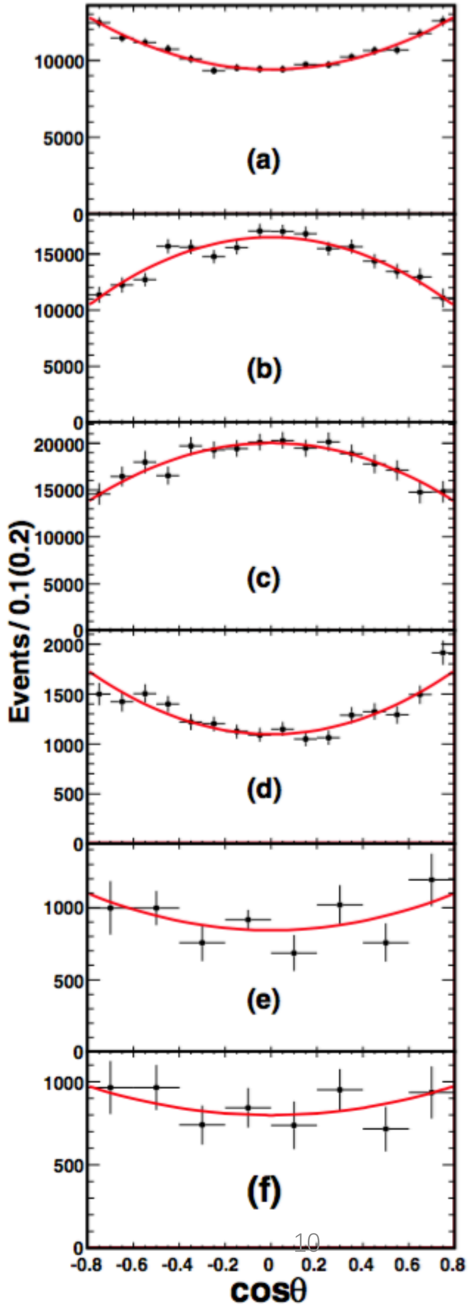
$p\pi^{\pm}$

$$M_{\pi\Lambda}^{recoil} = \sqrt{(E_{c.m.} - E_{\pi\Lambda})^2 - \vec{p}^2}$$

Data samples: $225\times10^6 J/\psi$ and $106\times10^6 \psi(3686)$

(a) $J/\psi \rightarrow \Xi^-\bar{\Xi}^+$
(b) $J/\psi \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$
(c) $J/\psi \rightarrow \Sigma(1385)^+\bar{\Sigma}(1385)^-$
(d) $\psi(3686) \rightarrow \Xi^-\bar{\Xi}^+$
(e) $\psi(3686) \rightarrow \Sigma(1385)^-\bar{\Sigma}(1385)^+$
(f) $\psi(3686) \rightarrow \Sigma(1385)^+\bar{\Sigma}(1385)^-$





PHYSICAL REVIEW **D** 93, 0732003 (2016)

Study of ψ decays to the $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$ final states

■ Numerical results ($Br(N_{obs}/N_{\psi}\cdot\epsilon)$ and α values)

Br ($\times 10^{-4}$)

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	...	...

α

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

Negative!

➢ Provide more new and precise measurements and experimental evidences, But for the predictions of α values without the consideration of the higher order correction, it is deviated from the measured values.

■ Ratio of branching fractions ($\frac{Br(\psi(3686)\to X_h)}{Br(J/\psi\to X_h)}$)

$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
(26.73±0.50±2.30)%	(7.76±0.55±0.68)%	(6.68±0.40±0.50)%

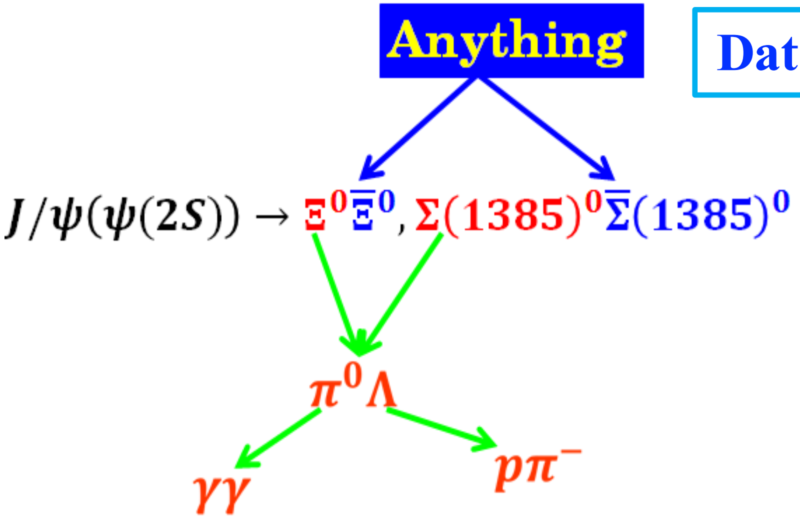
Deviated from 12% !

➢ Theoretical models are expected to be improved to understand the difference.

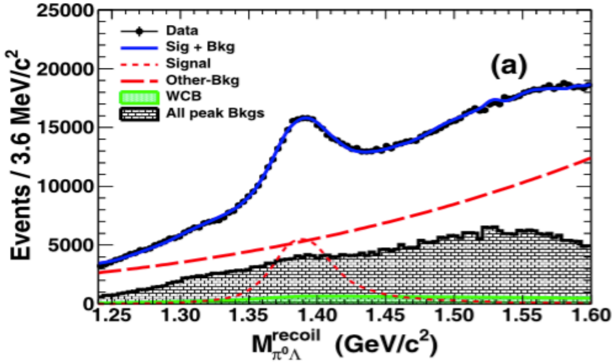
Physics Letters B 770 (2017) 217-225

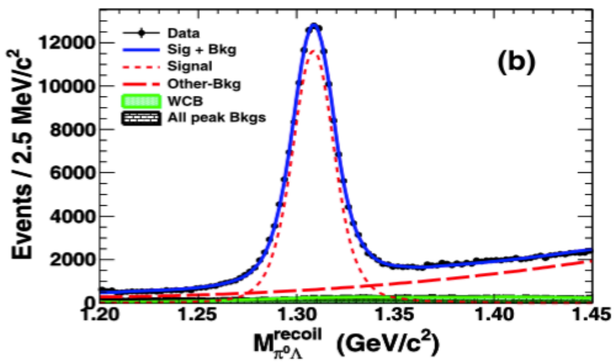
Study of J/ψ and $\psi(3686) \rightarrow \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$

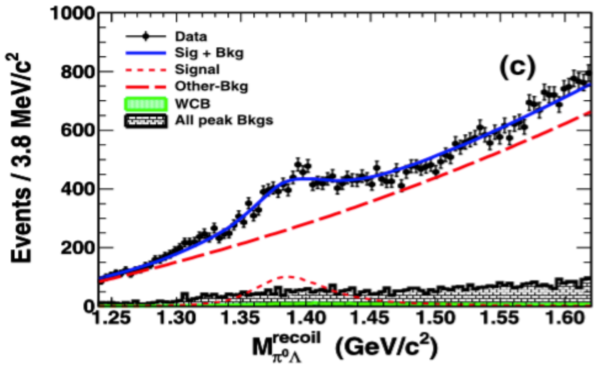
Data samples: $1310\times10^6 J/\psi$ and $448\times10^6 \psi(3686)$

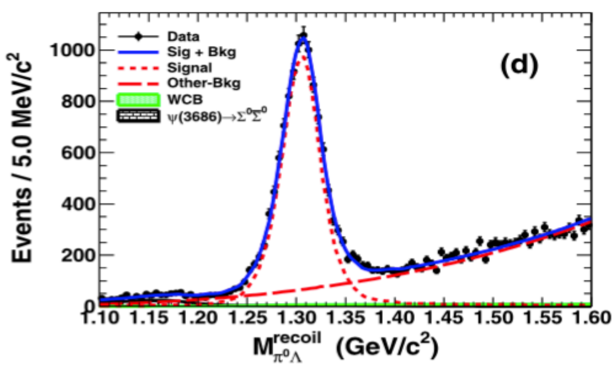


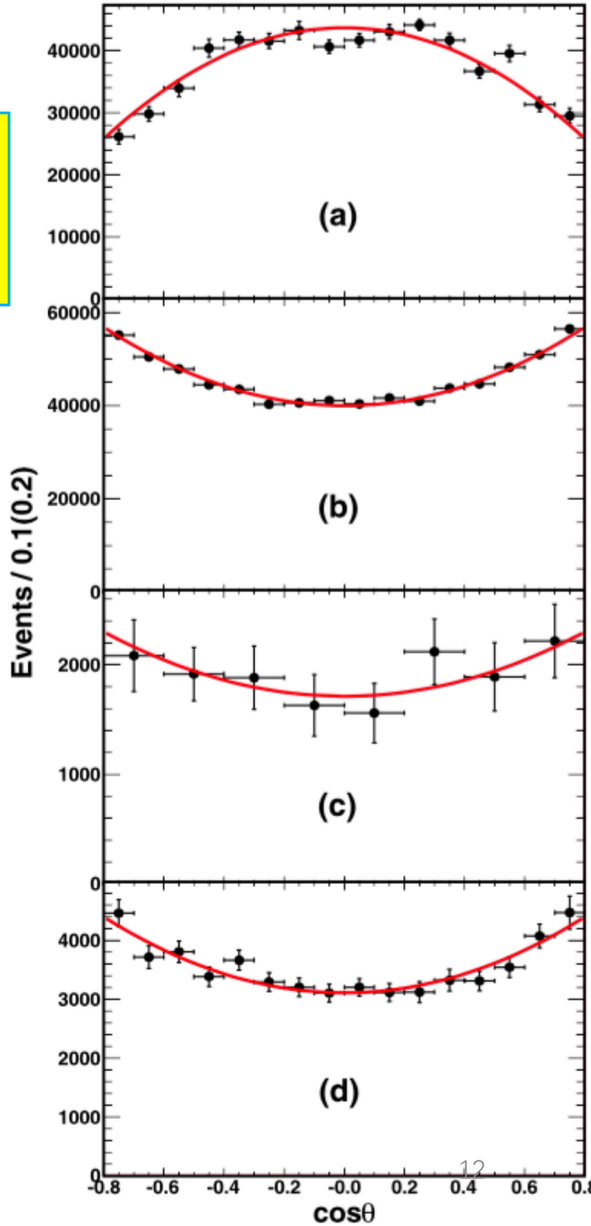
(a) $J/\psi \rightarrow \Sigma(1385)^0\bar{\Sigma}(1385)^0$
(b) $J/\psi \rightarrow \Xi^0\bar{\Xi}^0$
(c) $\psi(3686) \rightarrow \Sigma(1385)^0\bar{\Sigma}(1385)^0$
(d) $\psi(3686) \rightarrow \Xi^0\bar{\Xi}^0$











Physics Letters **B** 770 (2017) 217-225

Study of J/ψ and $\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$

Numerical results (*Br* and α values)

Br ($\times 10^{-4}$)

Mode	$J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$J/\psi \to \Xi^0\bar{\Xi}^0$	$\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$\psi(3686) \to \Xi^0\bar{\Xi}^0$
This work	$10.71 \pm 0.09 \pm 0.82$	$11.65 \pm 0.04 \pm 0.43$	$0.69 \pm 0.05 \pm 0.05$	$2.73 \pm 0.03 \pm 0.13$
BESII [23]	–	$12.0 \pm 1.2 \pm 2.1$	–	–
CLEO [24]	–	–	–	$2.75 \pm 0.64 \pm 0.61$
Dobbs et al. [25]	–	–	–	$2.02 \pm 0.19 \pm 0.15$
PDG [4]	–	12.0 ± 2.4	–	2.07 ± 0.23

α

Mode	$J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$J/\psi \to \Xi^0\bar{\Xi}^0$	$\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$\psi(3686) \to \Xi^0\bar{\Xi}^0$
This work	$-0.64 \pm 0.03 \pm 0.10$	$0.66 \pm 0.03 \pm 0.05$	$0.59 \pm 0.25 \pm 0.25$	$0.65 \pm 0.09 \pm 0.14$
Carimalo et al. [6]	0.11	0.16	0.28	0.33
Claudson [7]	0.19	0.28	0.46	0.53

Negative!

- Provide more new and precise measurements and experimental evidences, but for the predictions of α values without the consideration of the higher order correction, it is basically deviated from the measured values.

Test of isospin conservation

Mode	$\frac{\mathcal{B}(\psi\to\Xi^0\bar{\Xi}^0)}{\mathcal{B}(\psi\to\Xi^-\bar{\Xi}^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^-\bar{\Sigma}(1385)^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^+\bar{\Sigma}(1385)^-)}$
J/ψ	$1.12 \pm 0.01 \pm 0.07$	$0.98 \pm 0.01 \pm 0.08$	$0.85 \pm 0.02 \pm 0.09$
$\psi(3686)$	$0.98 \pm 0.02 \pm 0.07$	$0.81 \pm 0.12 \pm 0.12$	$0.82 \pm 0.11 \pm 0.11$

Within 1σ of expectation of isospin symmetry!

Ratio ($\frac{Br(\psi(3686)\to X_h)}{Br(J/\psi\to X_h)}$) for testing 12% rule

Deviated from 12%

$$\frac{Br(\psi(2S) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0)}{Br(J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0)} = (7.28 \pm 0.56 \pm 0.75)\%, \quad \frac{Br(\psi(2S) \to \Xi^0\bar{\Xi}^0)}{Br(J/\psi \to \Xi^0\bar{\Xi}^0)} = (23.43 \pm 0.27 \pm 1.28)\%,$$

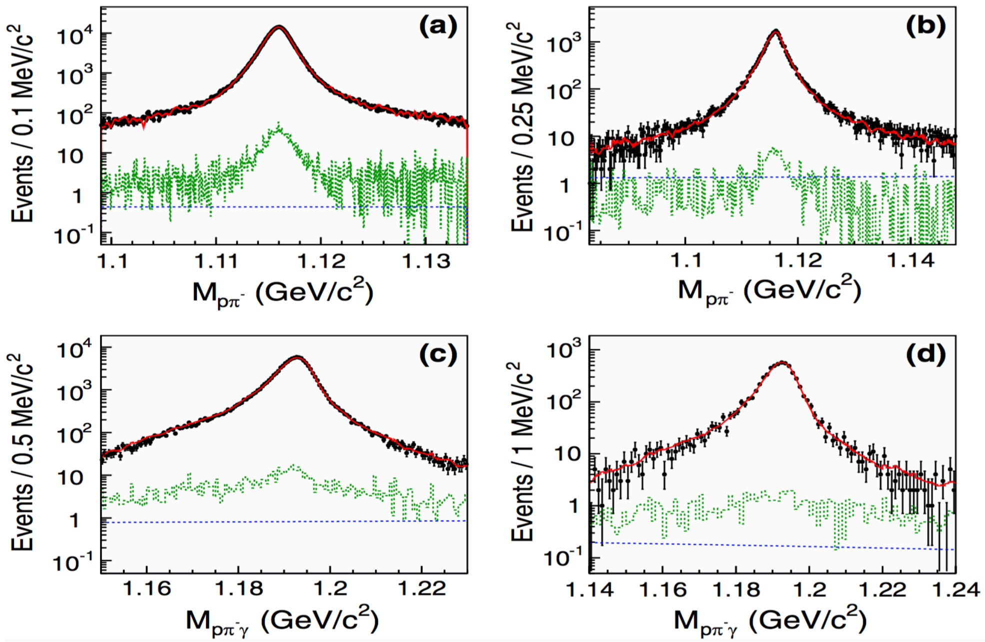
Physical Review D 95, 052003 (2017)

Study of J/ψ and $\psi(3686)$ decay to $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ final states

Data samples: $1310\times10^6 J/\psi$ and $448\times10^6\psi(3686)$

■ Full reconstruction

$$J/\psi, \psi(3686) \rightarrow \Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0 \rightarrow \Lambda\bar{\Lambda}, \gamma\gamma\Lambda\bar{\Lambda}$$
$$\rightarrow p\bar{p}\pi^+\pi^-, \gamma\gamma p\bar{p}\pi^+\pi^-$$



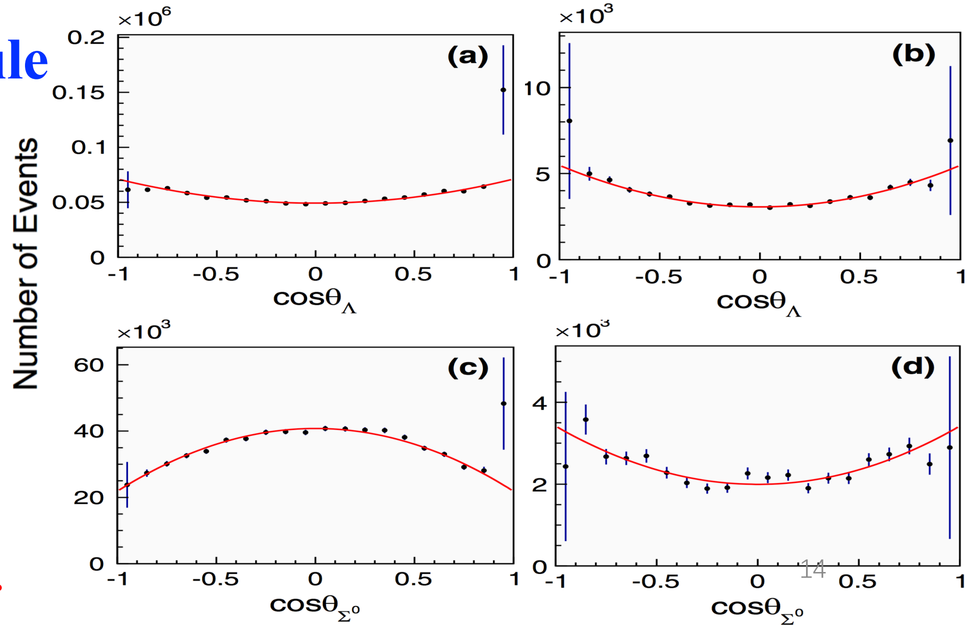
■ Numerical results (α values and Br)

	Channel	α	$\mathcal{B}$ ($\times10^{-4}$)
(a)	$J/\psi \rightarrow \Lambda\bar{\Lambda}$	$0.469 \pm 0.026 \pm 0.008$	$19.43 \pm 0.03 \pm 0.33$
(c)	$J/\psi \rightarrow \Sigma^0\bar{\Sigma}^0$	$-0.449 \pm 0.020 \pm 0.008$	$11.64 \pm 0.04 \pm 0.23$
(b)	$\psi(3686) \rightarrow \Lambda\bar{\Lambda}$	$0.82 \pm 0.08 \pm 0.02$	$3.97 \pm 0.02 \pm 0.12$
(d)	$\psi(3686) \rightarrow \Sigma^0\bar{\Sigma}^0$	$0.71 \pm 0.11 \pm 0.04$	$2.44 \pm 0.03 \pm 0.11$

■ Ratio ($\frac{Br(\psi(3686)\rightarrow X_h)}{Br(J/\psi\rightarrow X_h)}$) for testing 12% rule

$$\frac{\mathcal{B}(\psi(3686)\rightarrow\Lambda\bar{\Lambda})}{\mathcal{B}(J/\psi\rightarrow\Lambda\bar{\Lambda})} = (20.43\pm0.11\pm0.58)\%$$

$$\frac{\mathcal{B}(\psi(3686)\rightarrow\Sigma^0\bar{\Sigma}^0)}{\mathcal{B}(J/\psi\rightarrow\Sigma^0\bar{\Sigma}^0)} = (20.96\pm0.27\pm0.92)\%$$

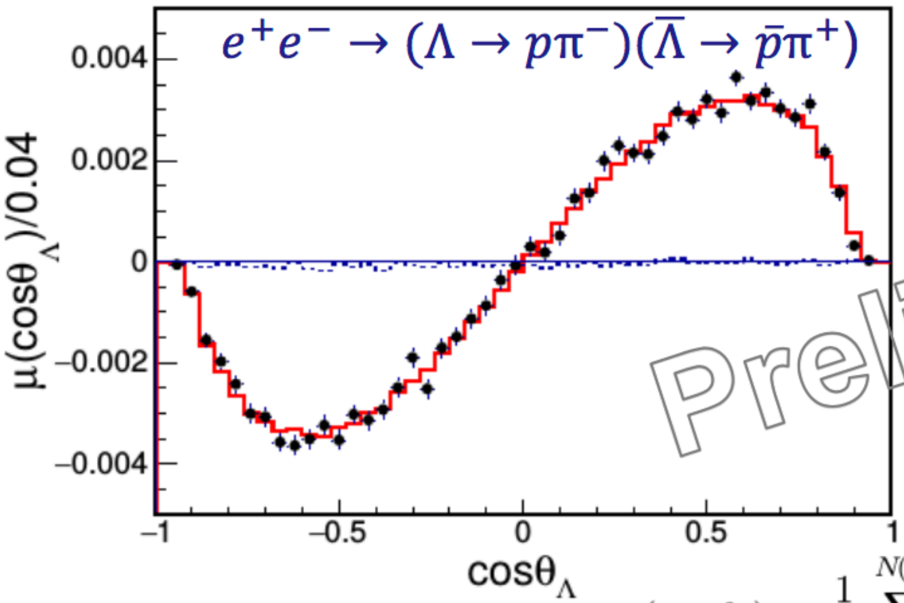


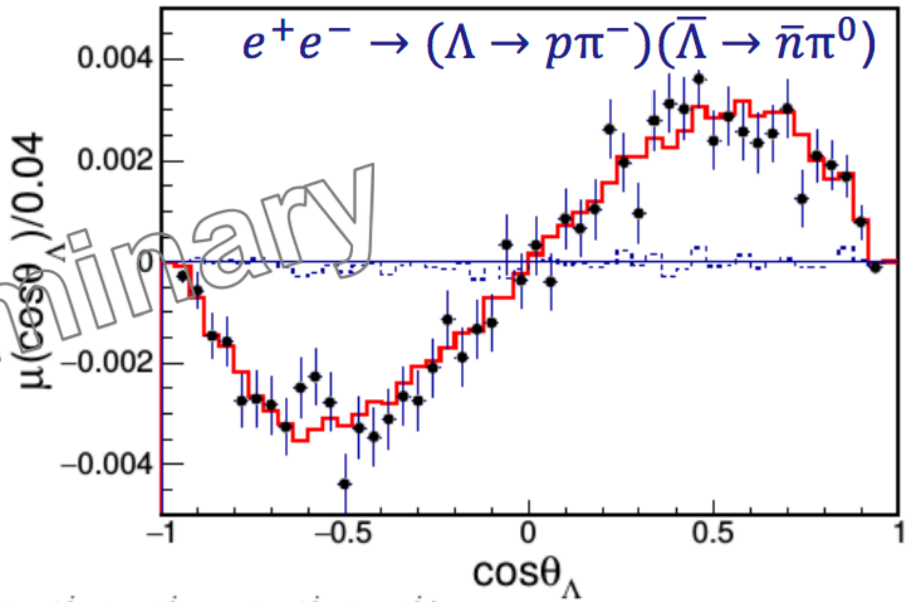
- ✓ The branching fractions are measured consistently and with high precision compared with the previous experiments .
- ✓ The α values are measured with high precision for J/ψ decay, and first measurement for $\psi(2S)$ decay.
- ✓ The Q value is still different with the expectation of pQCD.

Observation of spin polarization in $J/\psi \to \Lambda\bar{\Lambda}$

Data: $1310\times10^{6} J/\psi$

$\Delta\Phi = 42.3^{o} \pm 0.6^{o} \pm 0.5^{o}$





$$\mu(\cos\theta_\Lambda) = \frac{1}{N}\sum_{i}^{N(\theta_\Lambda)} (\sin\theta_1^i \sin\phi_1^i - \sin\theta_2^i \sin\phi_2^i)$$

Parameters	This work	Previous results	
α_ψ	$\mathbf{0.461 \pm 0.006 \pm 0.007}$	0.469 ± 0.027	BESIII
$\Delta\Phi$ (rad)	$\mathbf{0.740 \pm 0.010 \pm 0.008}$	–	
α_-	$\mathbf{0.750 \pm 0.009 \pm 0.004}$	0.642 ± 0.013	PDG
α_+	$\mathbf{-0.758 \pm 0.010 \pm 0.007}$	-0.71 ± 0.08	PDG
$\bar{\alpha}_0$	$\mathbf{-0.692 \pm 0.016 \pm 0.006}$	–	
A_{CP}	$\mathbf{-0.006 \pm 0.012 \pm 0.007}$	0.006 ± 0.021	PDG
$\bar{\alpha}_0/\alpha_+$	$\mathbf{0.913 \pm 0.028 \pm 0.012}$	–	

Preliminary

CP asymmetry:

$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$$

Physical Review D 86, 032014 (2012) , arXiv:1803.02039

Study of J/ψ and ψ(3686) → $N\bar{N}$ final states

Data samples: $225\times10^6 J/\psi$ and $448\times10^6 \psi(3686)$

■ Full reconstruction

$J/\psi, \psi(3686) \rightarrow N\bar{N}$ ($p\bar{p}, n\bar{n}$)

■ Numerical results (α values and Br)

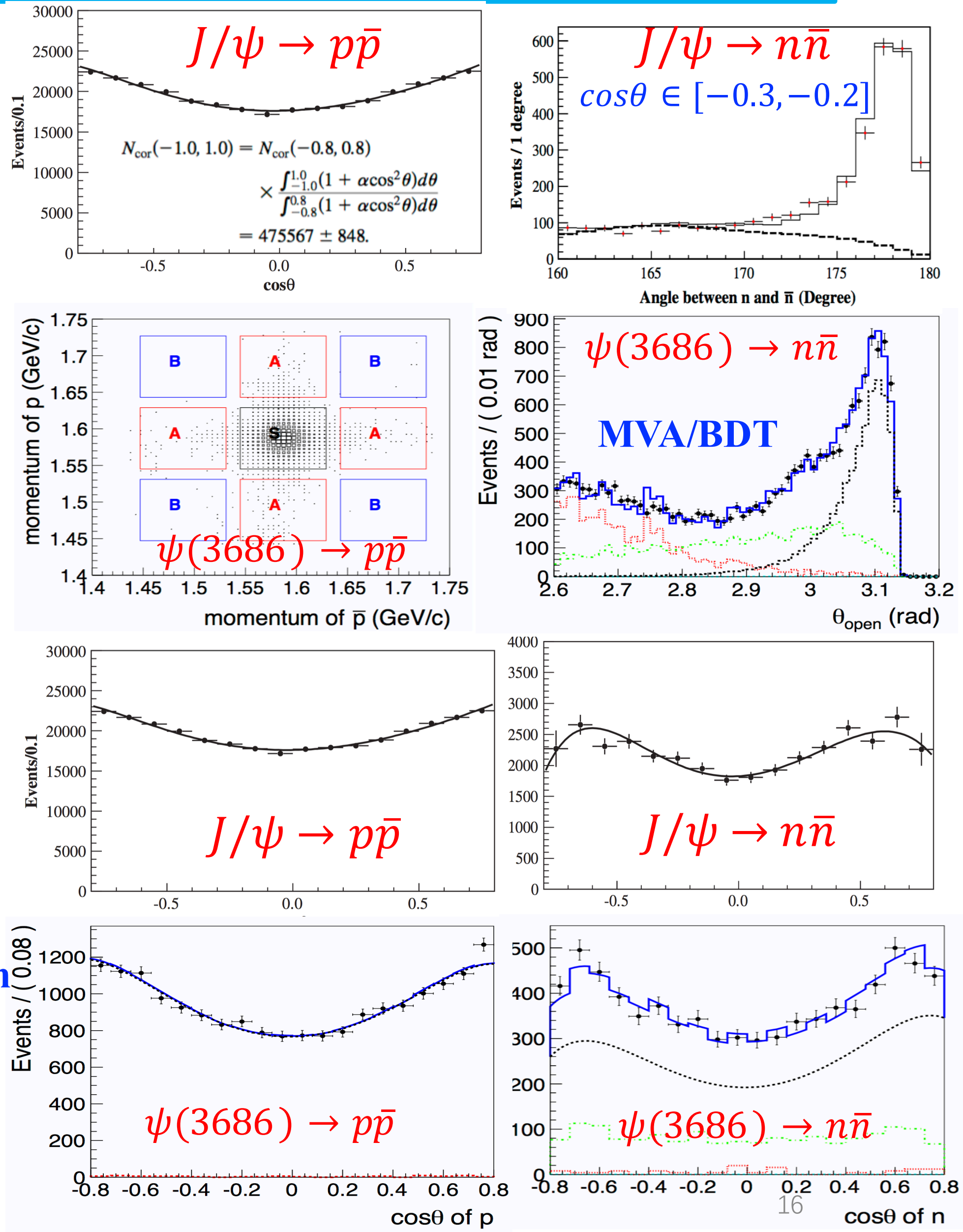
Channel	α	$Br\times10^{-4}$
$J/\psi\rightarrow p\bar{p}$	$0.60\pm0.01\pm0.02$	$21.12\pm0.04\pm0.31$
$J/\psi\rightarrow n\bar{n}$	$0.50\pm0.04\pm0.21$	$20.70\pm0.10\pm1.70$
$\psi(3686)\rightarrow p\bar{p}$	$1.03\pm0.06\pm0.03$	$3.05\pm0.02\pm0.12$
$\psi(3686)\rightarrow n\bar{n}$	$0.68\pm0.12\pm0.11$	$3.06\pm0.06\pm0.14$

■ Ratio ($\frac{Br(\psi(3686)\rightarrow X_h)}{Br(J/\psi\rightarrow X_h)}$) for testing 12% rule

$$\frac{\mathcal{B}(\psi(3686)\rightarrow p\bar{p})}{\mathcal{B}(J/\psi\rightarrow p\bar{p})}=(14.4\pm0.6)\%$$

$$\frac{\mathcal{B}(\psi(3686)\rightarrow n\bar{n})}{\mathcal{B}(J/\psi\rightarrow n\bar{n})}=(14.8\pm1.2)\%$$

- ✓ The branching fractions are measured consistently and with high precision compared with the previous experiments .
- ✓ The α values are measured with high precision for J/ψ decay, and first measurement for $\psi(2S)$ decay.
- ✓ The Q value is consistent with the expectation of pQCD 12%.

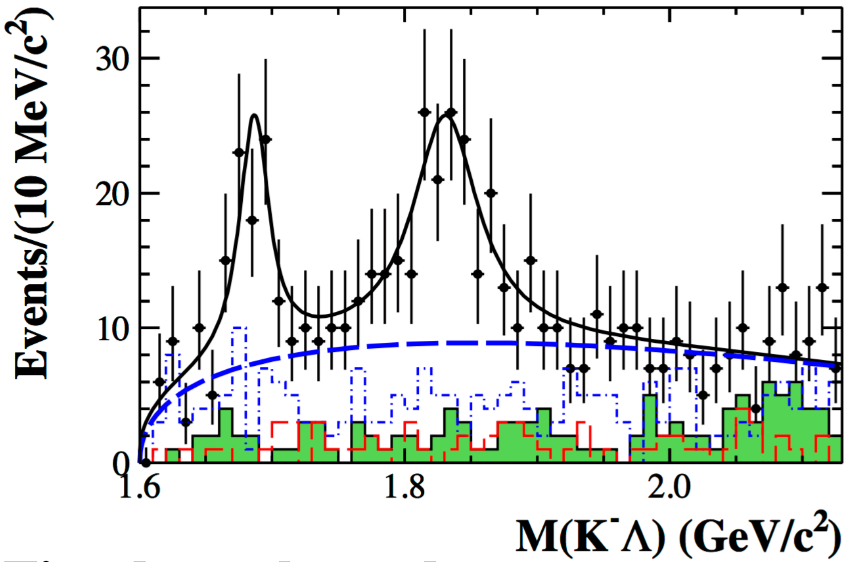


Physical Review D 86, 032014 (2012)

Observation of $\psi(3686) \rightarrow \Xi(1690/1820)\bar{\Xi}^{+}$ + c. c.

Data samples:
$106\times10^{6}\psi(3686)$

■ Two resonances are observed in $\psi(3686) \rightarrow K^{-}\Lambda\bar{\Xi}^{+}$ process



■ **PDF:** Breit-Wigner ⊗ Gaussian

$$A(m) = \frac{p_\Lambda(m)^{(L_{(K-\Lambda)}+1/2)} p_{\Xi^+}(m)^{(L_{(\Xi^*-\Xi^+)}+1/2)}}{m - M + i\frac{\Gamma}{2}} \cdot \left(\frac{B_{L_{(K-\Lambda)}}(p_\Lambda(m))}{B_{L_{(K-\Lambda)}}(p'_\Lambda)}\right)\left(\frac{B_{L_{(\Xi^*-\Xi^+)}}(p_{\Xi^+}(m))}{B_{L_{(\Xi^*-\Xi^+)}}(p'_{\Xi^+})}\right)$$

Mass and width (M,Γ); $p_{\Lambda/\Xi}$ momentum; L is orbital angular distribution; $B_L(p)$ Blatt-Weisskopf form factor[1].

■ Fitted results and resonance parameters

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7\pm3.8\pm1.0$	$1826.7\pm5.5\pm1.6$
$\Gamma(\mathrm{MeV})$	$27.1\pm10.0\pm2.7$	$54.4\pm15.7\pm4.2$
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})	$5.21\pm1.48\pm0.57$	$12.03\pm2.94\pm1.22$
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	<30	24^{+15}_{-10}

The spin-parities for both resonances have not determined due to the limited statistics.

In the fit, the spin- parities for both resonances assumed to be JP = 1/2− ,3/2− with previous experimental results[2,3], the $\Xi^*\bar{\Xi}$ angular momenta L($\Xi^*\bar{\Xi}$) are set to be 0 for both resonances, while the $K^-\Lambda$ angular momenta L($K^-\Lambda$) are 0 and 2.

[1] B. S. Zou and D. V. Bugg, Eur. Phys. J. A 16, 537 (2003).
[2] B. Aubert et al., (BABAR Collaboration), Phys. Rev. D604 78, 034008 (2008).
[3] J. B. Gay et al., Phys. Lett. B 62, 477 (1976).

Outline

- Introduction
- Experimental apparatus
  - BEPCII
  - BESIII detector
- Recent results
  - Study of $J/\psi, \psi(3686) \rightarrow B\overline{B}$ (B: baryon)
    1. $J/\psi, \psi(3686) \rightarrow \Xi^-\overline{\Xi}^+, \Sigma(1385)^{\mp}\overline{\Sigma}(1385)^{\pm}$
    2. $J/\psi, \psi(3686) \rightarrow \Xi^0\overline{\Xi}^0, \Sigma(1385)^0\overline{\Sigma}(1385)^0$
    3. $J/\psi, \psi(3686) \rightarrow \Lambda\overline{\Lambda}, \Sigma^0\overline{\Sigma}^0$
    4. $J/\psi, \psi(3686) \rightarrow NN(p\overline{p}, n\overline{n})$
    5. $\psi(3686) \rightarrow \Xi(1690/1820)\Xi$
  - **Measurement of cross section of $e^+e^- \rightarrow B\overline{B}$**
    1. $e^+e^- \rightarrow p\overline{p}$
    2. $e^+e^- \rightarrow \Lambda\overline{\Lambda}$
    3. $e^+e^- \rightarrow \Lambda_c\overline{\Lambda}_c$
- Summary

Calculation of Born cross sections and FFs

- **Experimentally**, Born cross sections of $e^+e^- \to B\bar{B}$ are calculated by:

$$\sigma^B = \frac{N_{obs}}{2\,\mathcal{L}(1+\delta)(1+\Pi)\epsilon \mathcal{B}r(B\to \text{hadrons})},$$

where N_{obs} number of observed events, $\mathcal{L}$ luminosity, $1+\sigma$ ISR factor, $1+\Pi$ vacuum polarization factor, $\mathcal{B}r$ the branching fraction.

- **Theoretically**, Born cross section can be expressed as:

$$\sigma^B = \frac{4\pi\alpha^2 C\beta}{3s}\left[|G_M|^2 + \frac{2m_B^2}{s}|G_E|^2\right].$$

- $G_{M/E}$: electric/magnetic FF
- $\beta = \sqrt{1-\frac{4m_B^2}{s}}$: velosity
- $\alpha = \frac{1}{137}$: fine structure constant
- s: the square of CM energy

The effective form factor defined by

$$|G_{eff}(s)| = \sqrt{\frac{|G_M|^2+\left(\frac{2m_B^2}{s}\right)|G_E|^2}{1+2m_B^2/s}}$$

Coulomb factor C

- For neutral B: C =1,
- For charged B: C $=\varepsilon F$ with $\varepsilon = \frac{\pi\alpha}{\beta}$ and F= $\frac{\sqrt{1-\beta^2}}{1-e^{-\varepsilon}}$

for a non-zero cross section at threshold

is proportional to the square root of the baryon pair born cross section

$$|G_{eff}(s)| = \sqrt{\frac{3s\sigma^B}{4\pi\alpha^2 C\beta(1+\frac{2m_B^2}{s})}}.$$

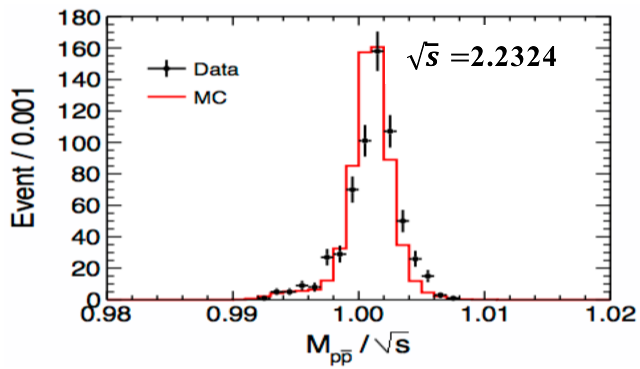
- The electric and magnetic form factor G_E, G_M can be expressed by the following

$$\frac{d\sigma^B(s)}{d\cos\theta} \propto 1+\eta\cos^2\theta \qquad R = \sqrt{\frac{\tau(1-\eta)}{1+\eta}} \qquad R = \left|\frac{G_E(s)}{G_M(s)}\right|$$

Physical Review D 91, 112004(2015)

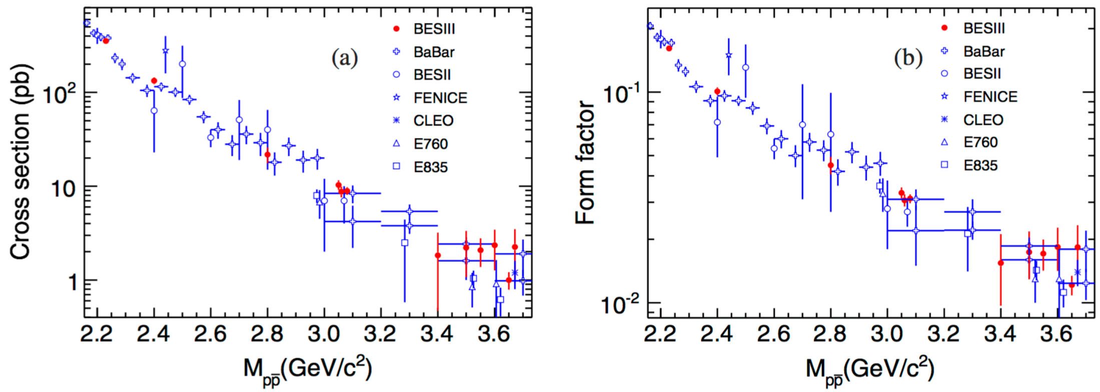
Measurement of the proton form factor in $e^+e^- \to p\bar{p}$

- **Full reconstruction method**
- **Signal yields extraction by counting number of events**

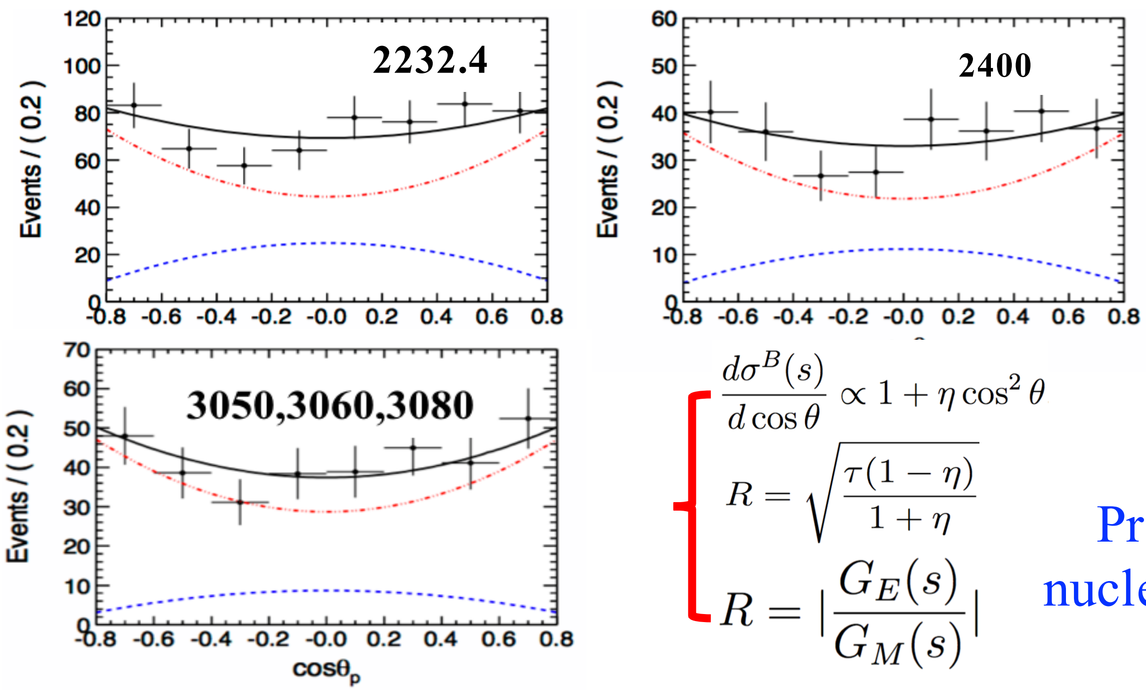


Data samples: $\sqrt{s} = 2.2324$ to 3.671 GeV

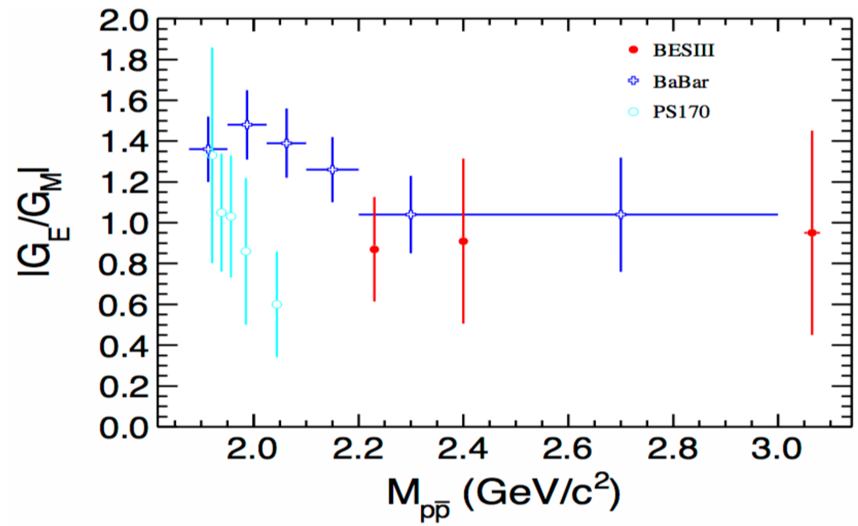
- **Born cross section and effective FFs**



- **Electromagnetic G_E/G_M ratio extraction**



$$\left\{\begin{array}{l} \frac{d\sigma^B(s)}{d\cos\theta} \propto 1 + \eta\cos^2\theta \\ R = \sqrt{\frac{\tau(1-\eta)}{1+\eta}} \\ R = \left|\frac{G_E(s)}{G_M(s)}\right| \end{array}\right.$$



Provide more experimental evidences about nucleon internal structure and dynamics!

Physical Review D 97, 032013 (2018)

Measurement of cross section near mass threshold for $e^+e^- \to \Lambda\bar{\Lambda}$

Data samples

$\sqrt{s}$ GeV	Lumi. (pb^{-1})
2.2324	2.63
2.40	3.42
2.80	3.75
3.08	30.73

■ Reconstruction

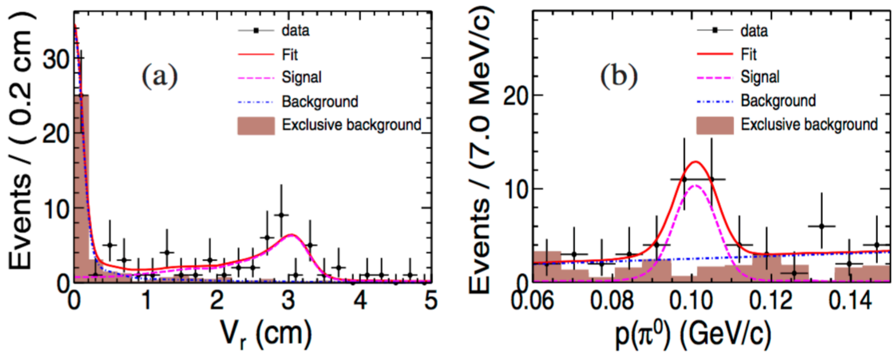
1. $e^+e^- \to \Lambda\bar{\Lambda} \to \bar{p}\pi^+\pi^-, \bar{n}\pi^0 X$ @2.2324
2. $e^+e^- \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$ @others

■ Signal yields extraction @2.2324

✓ Fit to the distance from IP to the beam pipe

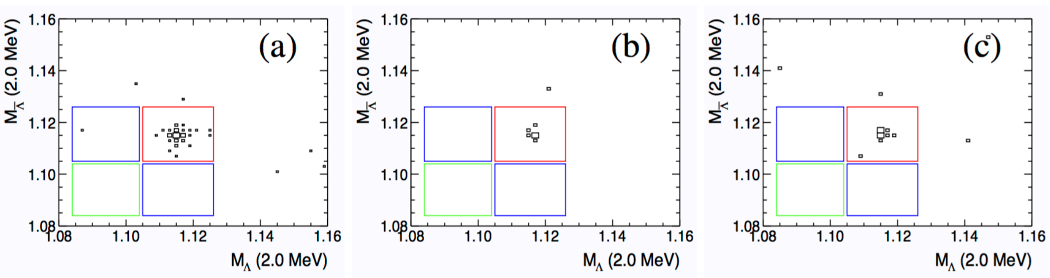
✓ Fit to π^0 momentum for $\bar{n}\pi^0$X

✓ A boosted decision tree (BDT) technique are used to distinguish between $\bar{n}$ and γ

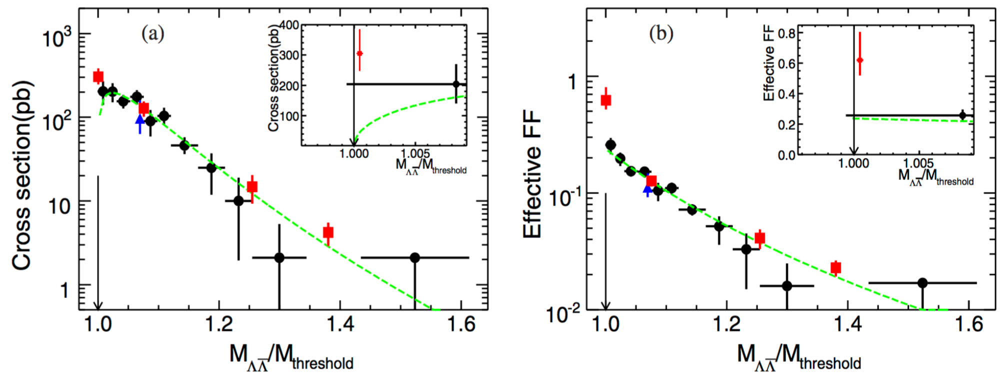


■ Signal yields extraction @others

✓ Counting



■ Born cross section and effective FFs



- The result is larger than the traditional theory expectation for neutral baryon pairs, which predicts a vanishing cross section at threshold.
- The results may help to understand the mechanism of baryon production and test the theory hypotheses based on the threshold enhancement effect.

Accepted by PRL/arXiv:1710.00150

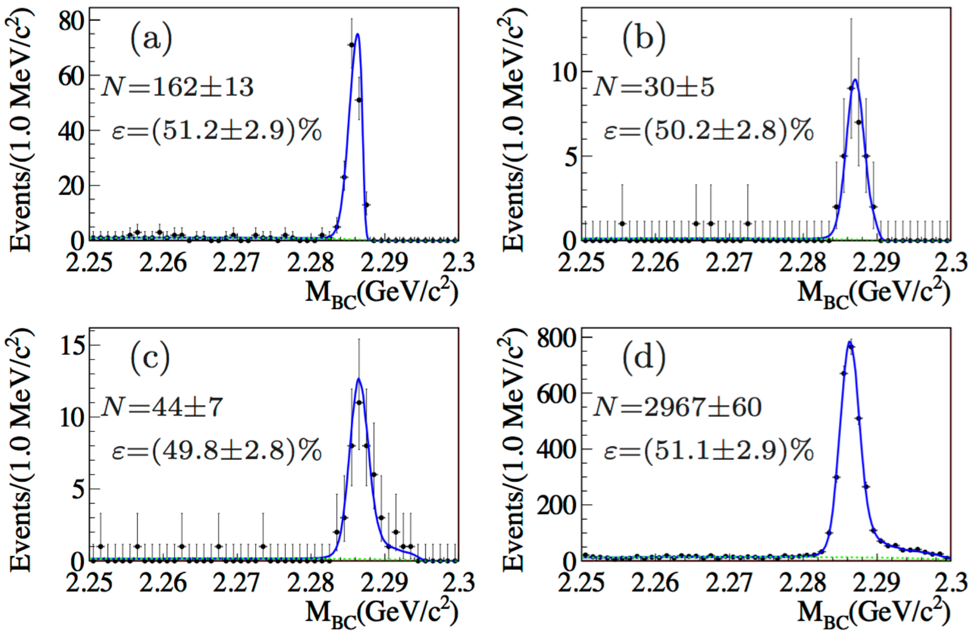
Precision measurement of the $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ cross section near threshold

Data samples

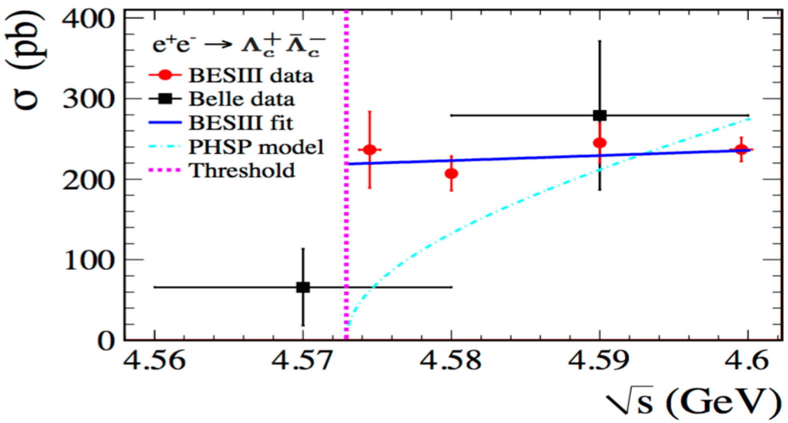
$\sqrt{s}$ (GeV)	$\mathcal{L}_{int}$ (pb^{-1})
4.5745	47.67
4.580	8.545
4.590	8.162
4.5995	566.9

■ Reconstruction method $M_{BC}c^2 \equiv \sqrt{E^2_{beam} - p^2c^2}$

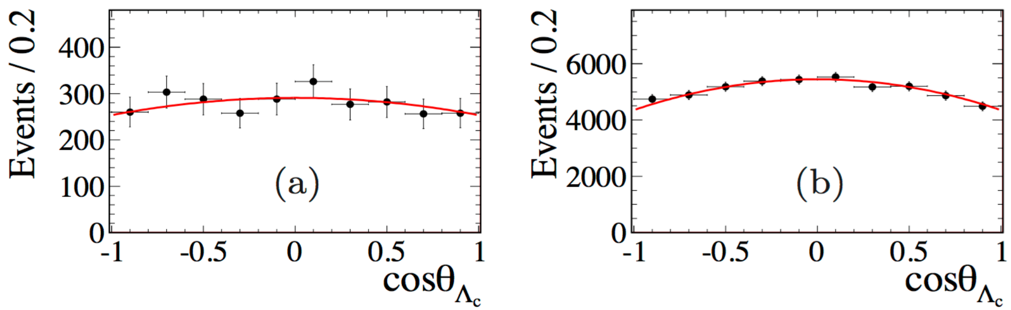
- ➢ **10 Cabibbo-favored hadronic modes:** $pK^-\pi^+, pK^0_S, \Lambda\pi^+, pK^-\pi^+\pi^0, pK^0_S\pi^0, \Lambda\pi^+\pi^0, pK^0_S\pi^+\pi^-, \Lambda\pi^+\pi^+\pi^-, \Sigma^0\pi^+, \Sigma^+\pi^+\pi^-$
- ➢ **c.c. mode is included by default**



■ Comparison of Born cross section



■ Measurements of α and G_M/G_E ratio



$\sqrt{s}$ (MeV)	α_{Λ_c}	$\lvert G_E/G_M \rvert$
4574.5	$-0.13 \pm 0.12 \pm 0.08$	$1.14 \pm 0.14 \pm 0.07$
4599.5	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

These results provide important insights into the production mechanism and structure of the Λ_c baryons.

Summary

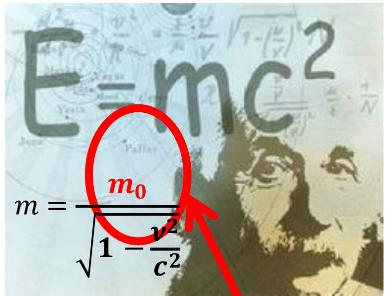
- **BESIII is successfully operating since 2008.**
  - ✓ Collected large data samples in the τ-charm threshold region
  - ✓ Continues to take data until 2022 at least
- **Many results for $B\bar{B}$ in 1^{--} state decay have been obtained:**
  - ✓ Precise measurement of Br/α for $J/\psi, \psi(2S) \to B\bar{B}$
  - ✓ New observation/measurement of $J/\psi, \psi(2S) \to B\bar{B}$
  - ✓ Born cross section of $e^+e^- \to B\bar{B}$ near threshold measured.
  - ✓ "12% rule" is violated compared with the expectation of pQCD **with exception of $\psi \to N\bar{N}$.**
  - ✓ The threshold effect of production cross section observed.
  - ✓ Need theoretical model further explain above difference
- **More new results for $B\bar{B}$ in 1^{--} state decay are on the way!**

Thanks for your attention !

Backup

Standard Model of Particle Physics

- Since time immemorial, human has begun to explore the world around us, “*Where Do We Come From? What Are We? Where Are We Going?*”



SM of Particle Physics:

Fundamental Interactions

	Strong	Electromagnetic	Weak
Source	Color charge	Charge	Flavor
Object	Quarks, Gluons	Charged particles, Photon	Quarks, Leptons
Mediator	Gluons (g)	Photons (γ)	$W^{\pm}$, Z^0
Force range (m)	10^{-15}	∞	10^{-18}
Strength	10^{38}	10^{36}	10^{25}
Lifetime (s)	10^{-23}	10^{-20}	10^{-10}
Cross section	mb	μb	pb
Current theory	QCD	QED	EW

Fundamental particles