中国科学院高能物理研究所
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Overview of the $J^{PC} = 1^{--}$ charmonium (-like) states decaying in $B\bar{B}$ @ BESIII

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IHEP, CAS

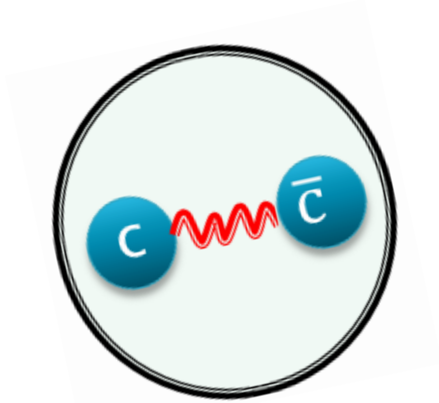
Mini-workshop on Baryonic spectroscopy at e+e- colliders

April 19, 2018, IHEP

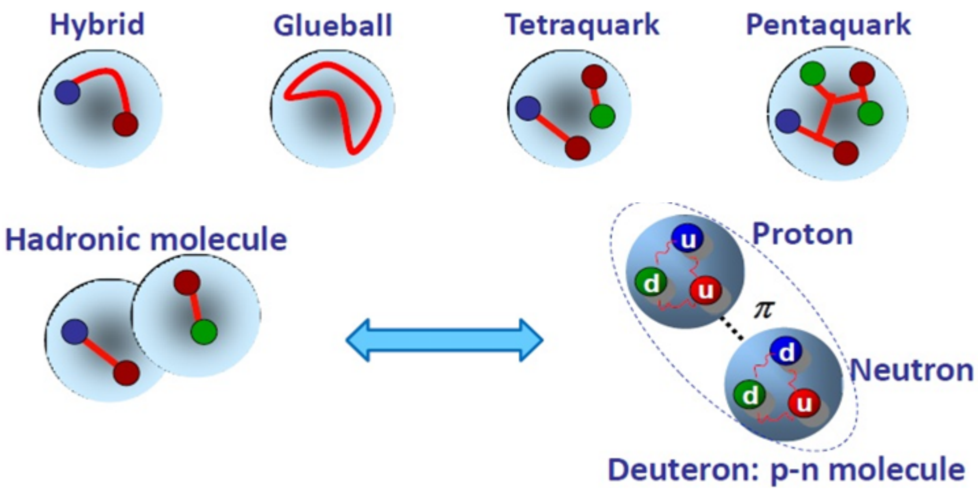
Outline

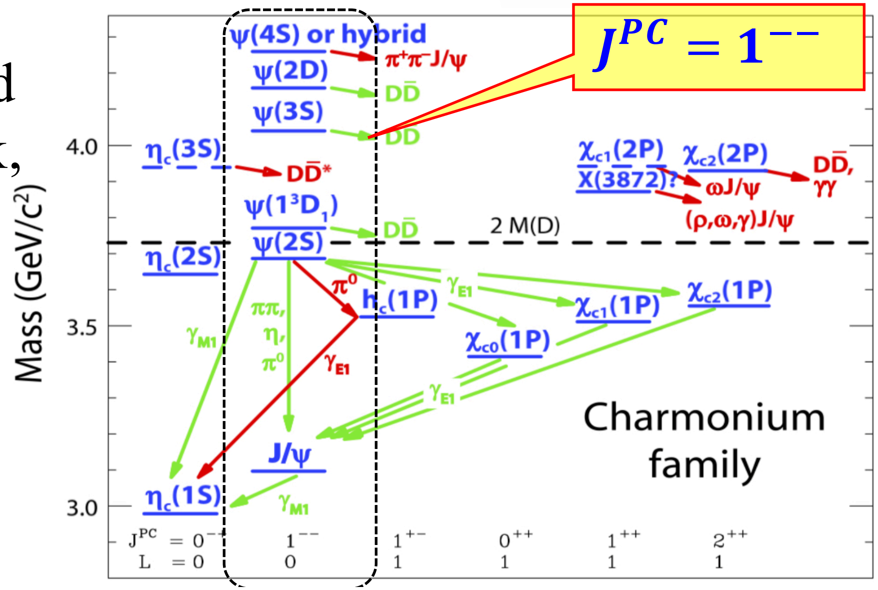
- Introduction
- Recent results
  - Study of $J/\psi, \psi(3686) \to B\bar{B}$ (baryon anti-baryon)
    1. $J/\psi, \psi(3686) \to \Xi^-\bar{\Xi}^+, \Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$
    2. $J/\psi, \psi(3686) \to \Xi^0\bar{\Xi}^0, \Sigma(1385)^0\bar{\Sigma}(1385)^0$
    3. $J/\psi, \psi(3686) \to \Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0$
    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 $\boldsymbol{c\bar{c}}$ bound states, $J/\psi\ (1^3S_1)$ is the first member with $\boldsymbol{J^{PC}=1^{--}}$, 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 and L-QCD, very successful in describing spectra & onium properties!**

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)

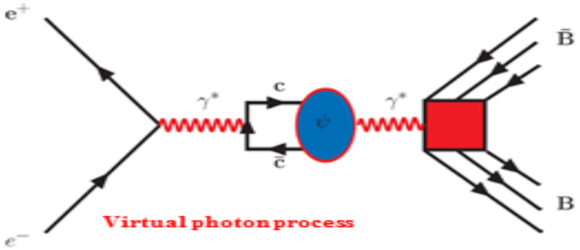
$$V_{\text{spin-dep}} = \frac{1}{m_c^2}\left[\left(\frac{2\alpha_s}{r^3}-\frac{b}{2r}\right)\vec{L}\cdot\vec{S} + \frac{4\alpha_s}{r^3}T\right]$$

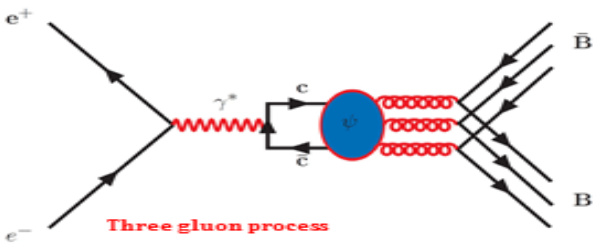
(Spin-Orbit + Tensor)

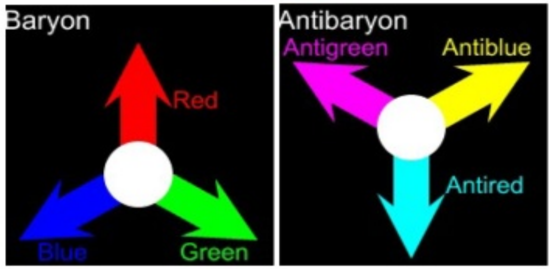
PRD72, 054026 (2005)

Baryon spectroscopy/production

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

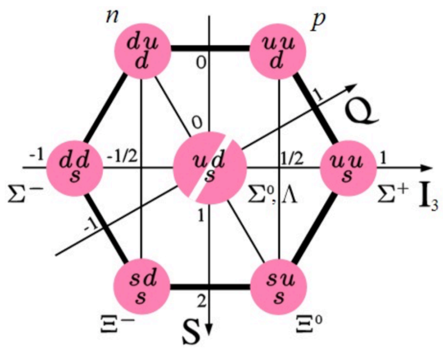


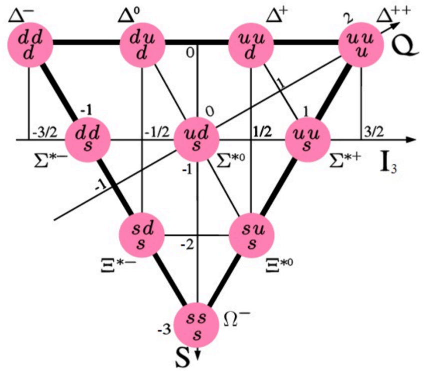




- **Provide a favorable test of pQCD and baryonic properties**
  - ✓ Test "12%" rule: $Q_h = \frac{Br(\psi(2S)\to X_h)}{Br(J/\psi\to X_h)} = 12\%$ (QCD prediction).
  - ✓ Test SU(3)-flavor symmetry
    - -- Allowed for $\psi \to B_8\overline{B}_8, B_{10}\overline{B}_{10}$, forbidden for $\psi \to B_8\overline{B}_{10}$.
  - ✓ Angular distribution study ($\frac{dN}{d(cos\theta)} \propto 1 + \alpha cos^2\theta$):
    - -- Quark mass effect, electromagnetic effect, etc.: $0 < \alpha < 1$.
  - ✓ $B\overline{B}$ threshold effect
    - -- $B\overline{B}$ 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 $B\overline{B}$ final states above open charm threshold.

Octet / decuplet





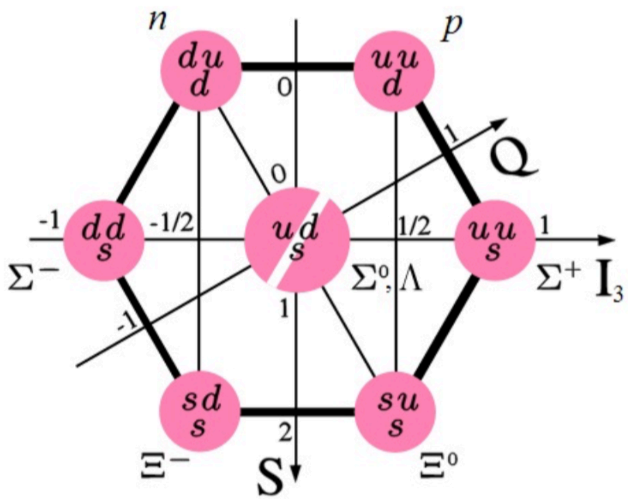
Outline

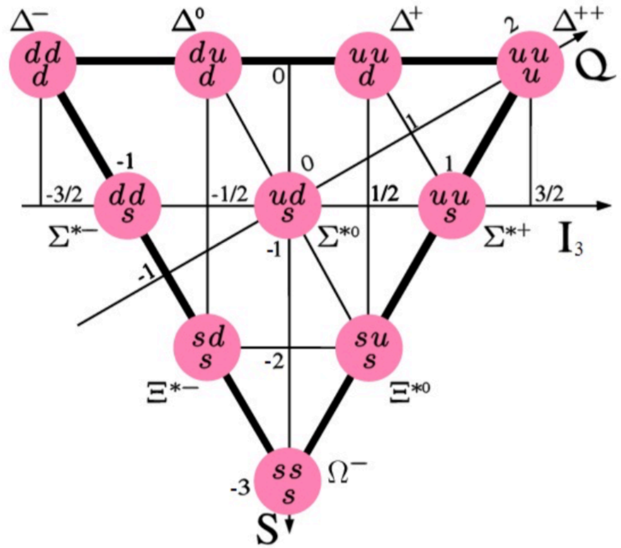
□Introduction

□Recent results

- ➢**Study of J/ψ, ψ(3686) → $B\bar{B}$ (B: 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. $J/\psi, \psi(3686) \to N\bar{N}(p\bar{p}, n\bar{n})$
  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





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

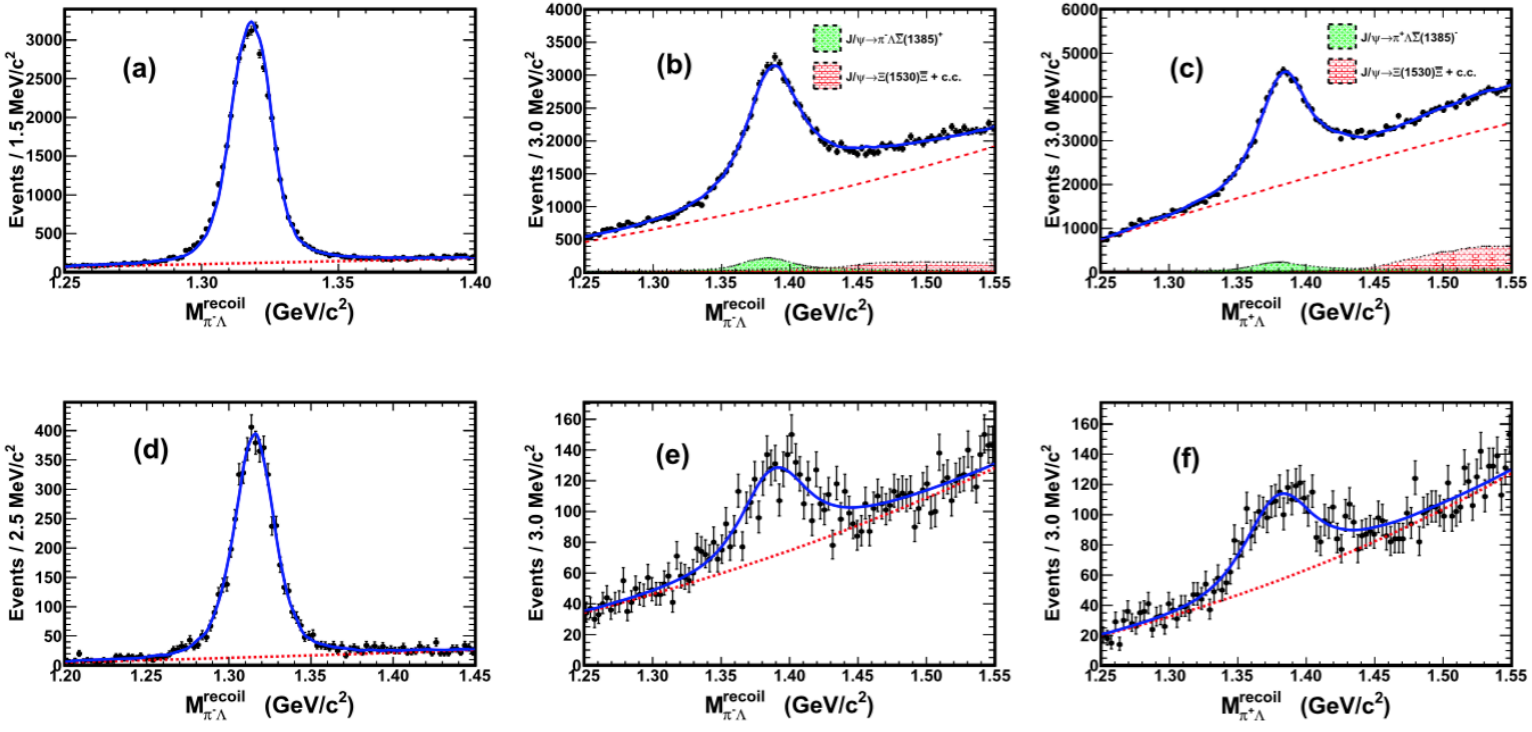
$J/\psi(\psi(2S)) \rightarrow \Xi^-\bar{\Xi}^+, \Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

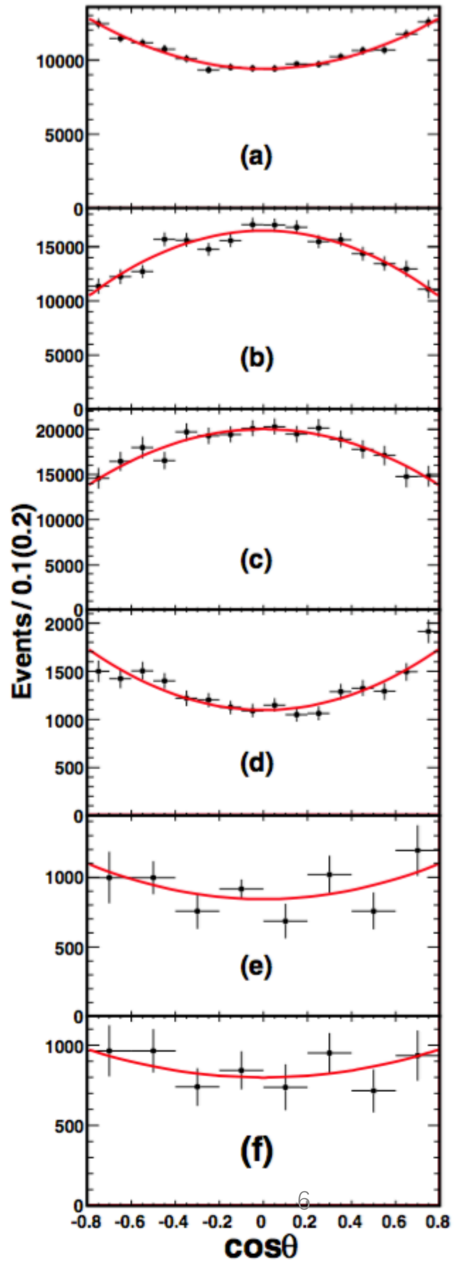
$\rightarrow \pi^{\pm}\Lambda \rightarrow p\pi^{\pm}$

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

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	$J/\psi \to$ $\Xi^-\bar{\Xi}^+$	$J/\psi \to$ $\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$J/\psi \to$ $\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\psi(3686) \to$ $\Xi^-\bar{\Xi}^+$	$\psi(3686) \to$ $\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\psi(3686) \to$ $\Sigma(1385)^+\bar{\Sigma}(1385)^-$
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	$J/\psi \to$ $\Xi^-\bar{\Xi}^+$	$J/\psi \to$ $\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$J/\psi \to$ $\Sigma(1385)^+\bar{\Sigma}(1385)^-$	$\psi(3686) \to$ $\Xi^-\bar{\Xi}^+$	$\psi(3686) \to$ $\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\psi(3686) \to$ $\Sigma(1385)^+\bar{\Sigma}(1385)^-$
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 ($\frac{Br(\psi(3686)\to X_h)}{Br(J/\psi\to X_h)}$)

$\Xi^-\bar{\Xi}^+$	$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	$\Sigma(1385)^+\bar{\Sigma}(1385)^-$
$(26.73\pm0.50\pm2.30)\%$	$(7.76\pm0.55\pm0.68)\%$	$(6.68\pm0.40\pm0.50)\%$

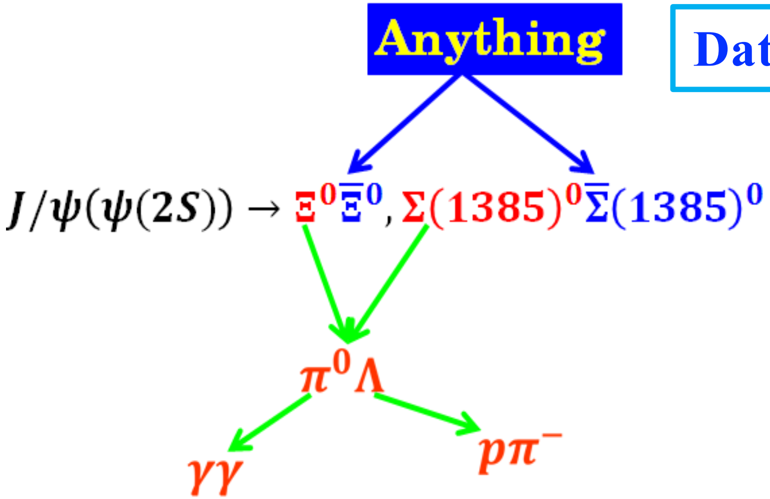
Deviated from 12% !

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

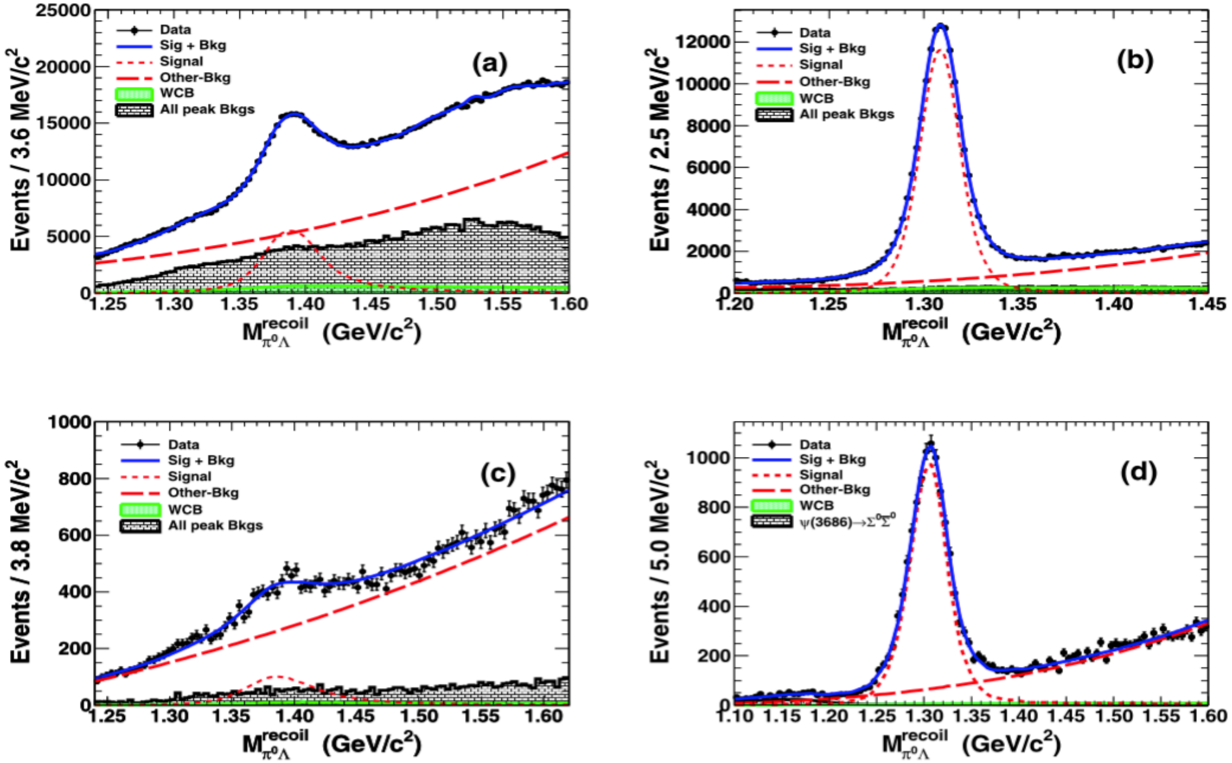
Physics Letters **B** 770 (2017) 217-225

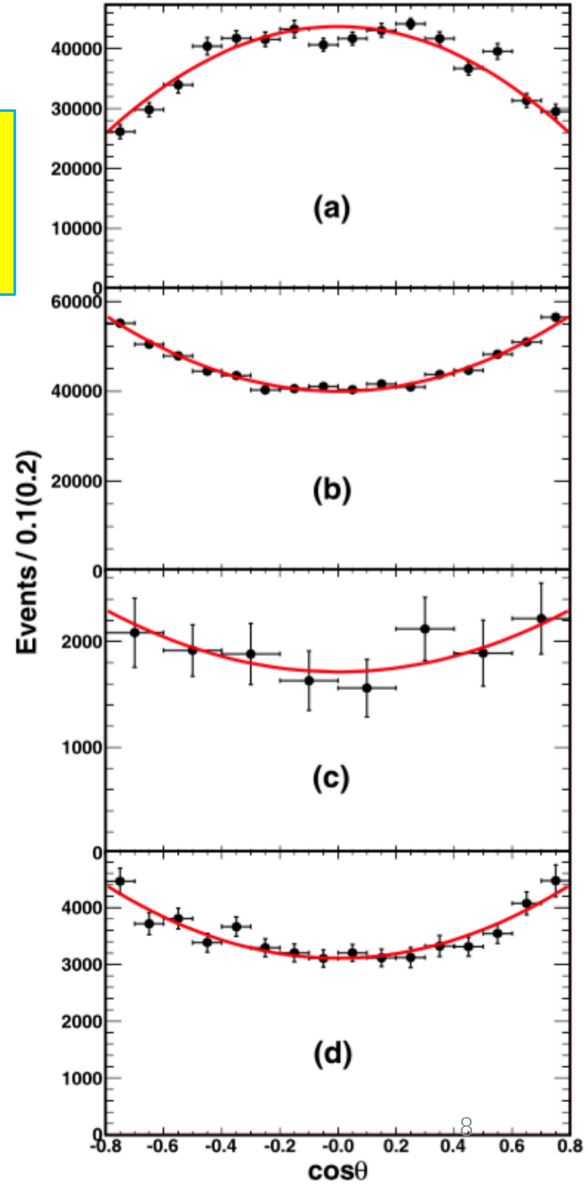
Study of J/ψ and $\psi(3686) \rightarrow \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$

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

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

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

Deviated from 12%

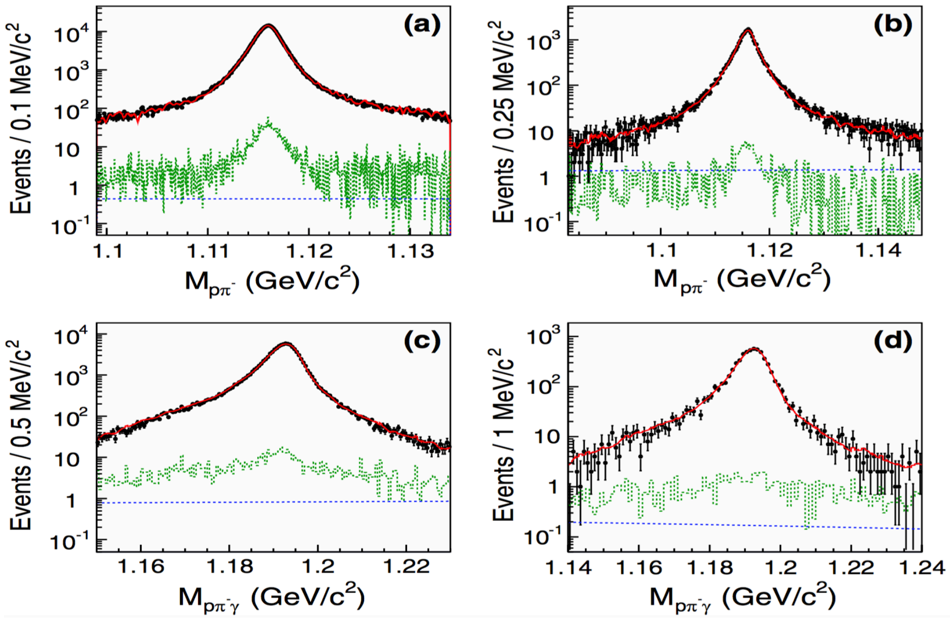
Physical Review D 95, 052003 (2017)

Study of J/ψ and ψ(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

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



■ Numerical results (*α* values and *Br*)

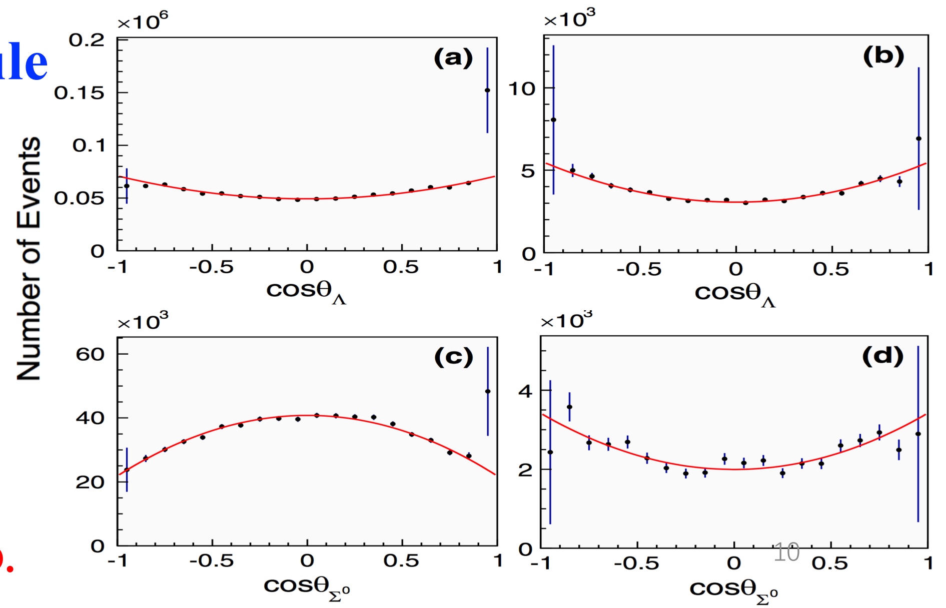
	Channel	α	$\mathcal{B}$ ($\times10^{-4}$)
(a)	$J/\psi \to \Lambda\bar{\Lambda}$	$0.469 \pm 0.026 \pm 0.008$	$19.43 \pm 0.03 \pm 0.33$
(c)	$J/\psi \to \Sigma^0\bar{\Sigma}^0$	$-0.449 \pm 0.020 \pm 0.008$	$11.64 \pm 0.04 \pm 0.23$
(b)	$\psi(3686) \to \Lambda\bar{\Lambda}$	$0.82 \pm 0.08 \pm 0.02$	$3.97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

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

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

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

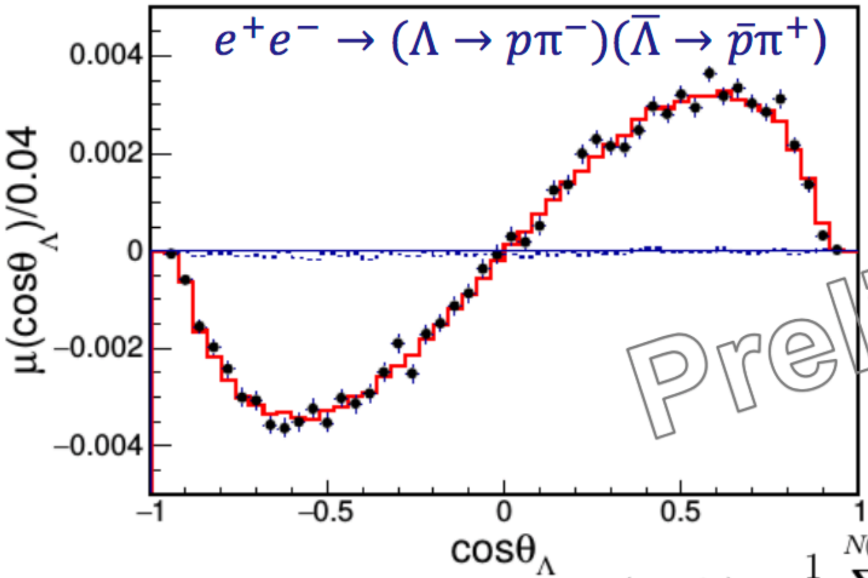
- ✓ The branching fractions are measured consistently and with high precision compared with the previous experiments .
- ✓ The α values are measured with high precision for J/ψ decay, and first measurement for $\psi(2S)$ decay.
- ✓ The Q value is still different with the expectation of pQCD.

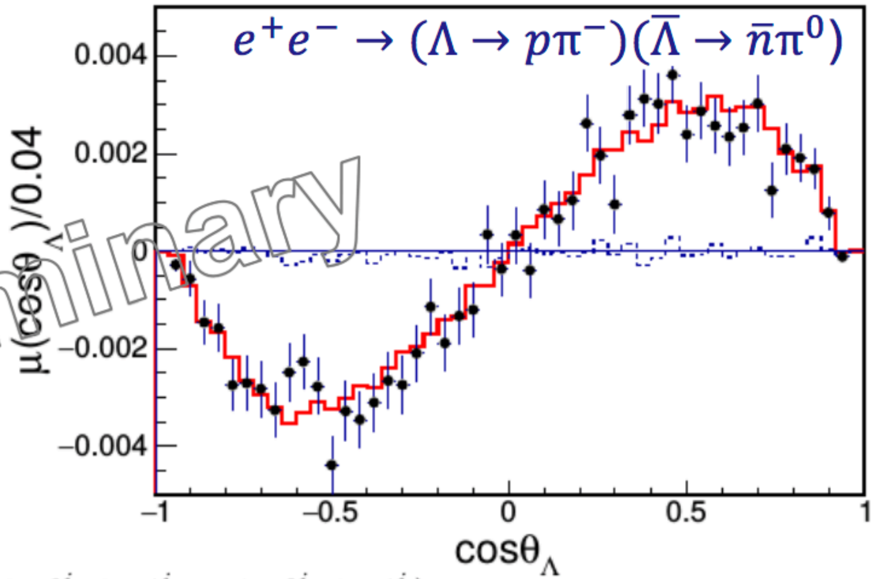


Observation of spin polarization in $J/\psi \to \Lambda\bar{\Lambda}$

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

$\Delta\Phi$=42.3°±0.6°±0.5°





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

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

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

■ Numerical results (α values and Br)

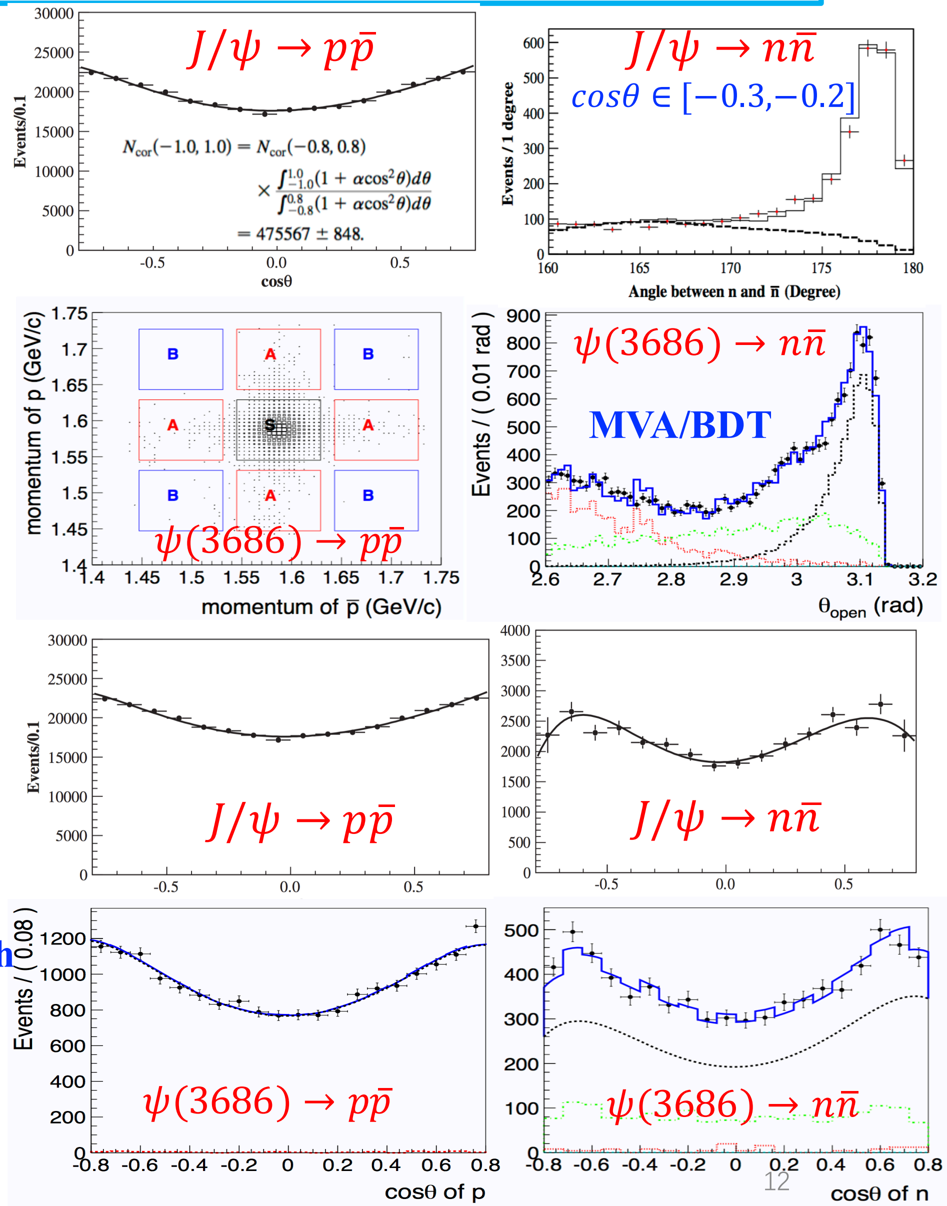
Channel	α	$Br\times10^{-4}$
$J/\psi\to p\bar{p}$	$0.60\pm0.01\pm0.02$	$21.12\pm0.04\pm0.31$
$J/\psi\to n\bar{n}$	$0.50\pm0.04\pm0.21$	$20.70\pm0.10\pm1.70$
$\psi(3686)\to p\bar{p}$	$1.03\pm0.06\pm0.03$	$3.05\pm0.02\pm0.12$
$\psi(3686)\to n\bar{n}$	$0.68\pm0.12\pm0.11$	$3.06\pm0.06\pm0.14$

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

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

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

- ✓ 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%.

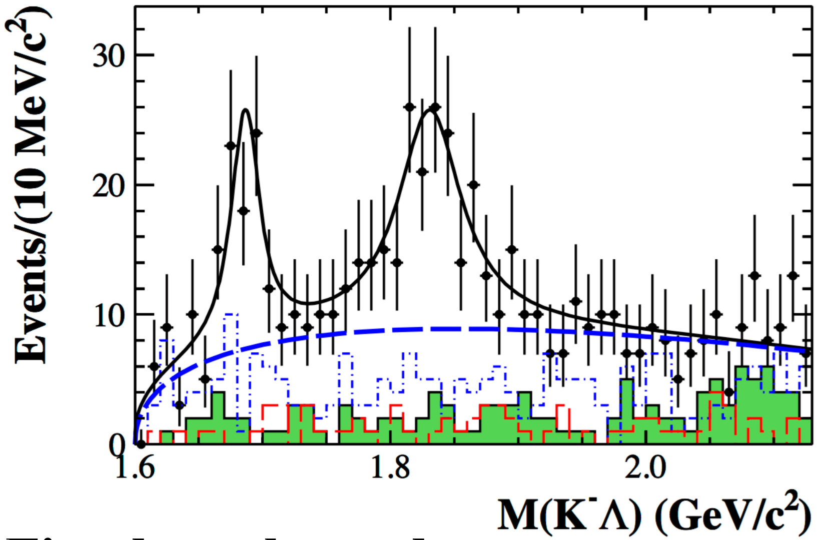


Physical Review D 86, 032014 (2012)

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

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

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



■ **PDF:** Breit-Wigner ⊗ Gaussian

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

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(MeV/c^2)	1687.7±3.8±1.0	1826.7±5.5±1.6
Γ(MeV)	27.1±10.0±2.7	54.4±15.7±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±1.48±0.57	12.03±2.94±1.22
$M_{\rm PDG}$(MeV/c^2)	1690±10	1823±5
$\Gamma_{\rm PDG}$(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
- Recent results
  - Study of $J/\psi, \psi(3686) \to B\bar{B}$ (B: 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

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
- $\beta = \sqrt{1-\frac{4m_B^2}{s}}$: velocity
- $\alpha = \frac{1}{137}$: 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

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

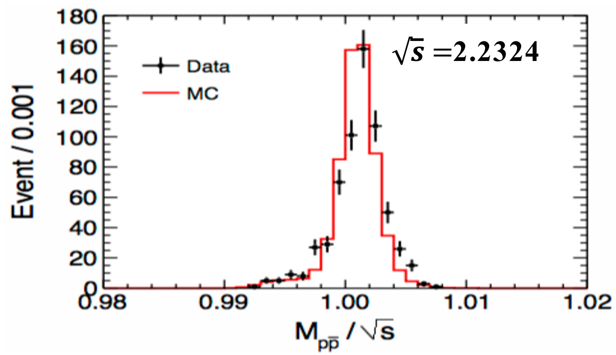
- **The electric and magnetic form factor G_E, G_M can be expressed by the following**

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

Physical Review D 91, 112004(2015)

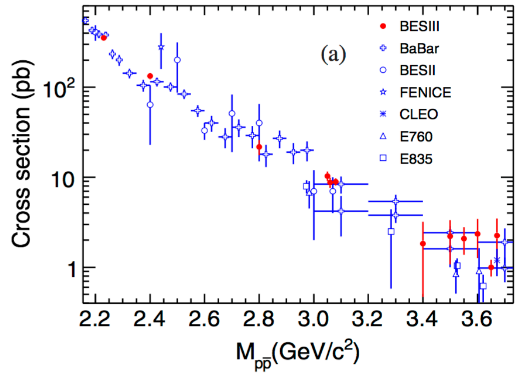
Measurement of the proton form factor in $e^+e^- \to p\bar{p}$

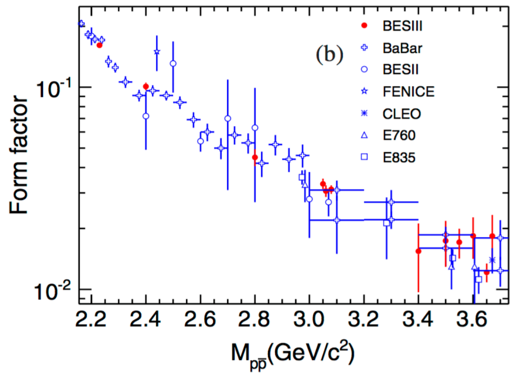
- Full reconstruction method
- Signal yields extraction by counting number of events



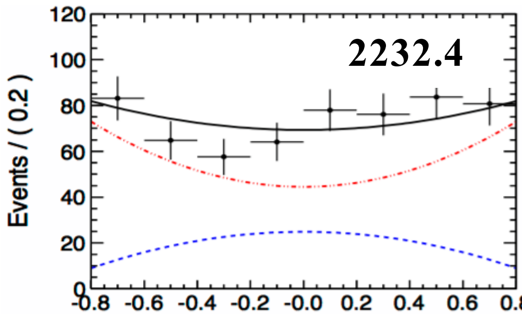
Data samples: $\sqrt{s} = 2.2324\ to\ 3.671\ GeV$

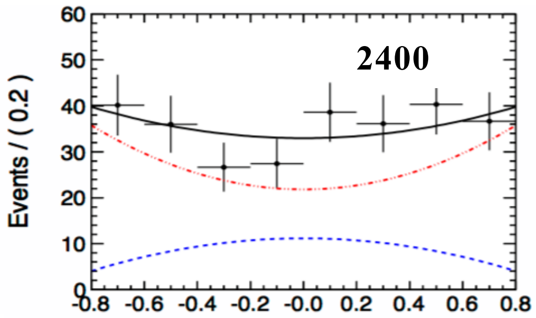
- Born cross section and effective FFs

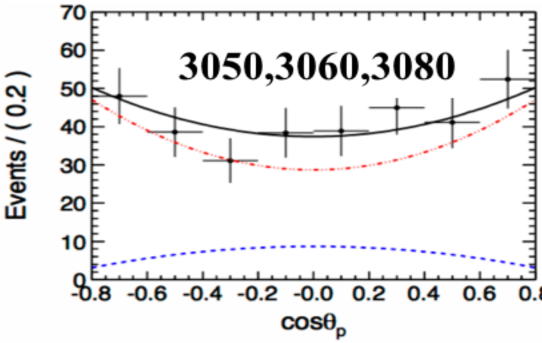




- Electromagnetic G_E/G_M ratio extraction



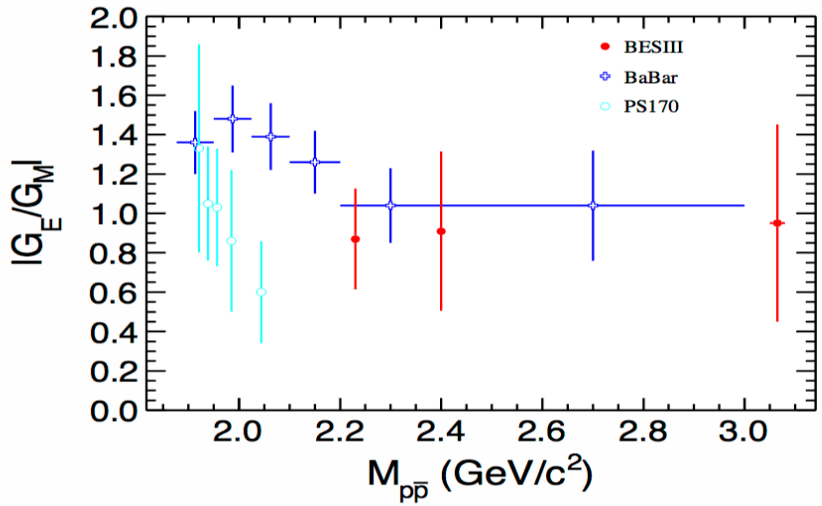




$$\frac{d\sigma^B(s)}{d\cos\theta} \propto 1 + \eta\cos^2\theta$$

$$R = \sqrt{\frac{\tau(1-\eta)}{1+\eta}}$$

$$R = \left|\frac{G_E(s)}{G_M(s)}\right|$$



Provide more experimental evidences about nucleon internal structure and dynamics!

Physical Review D 97, 032013 (2018)

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

■ Reconstruction

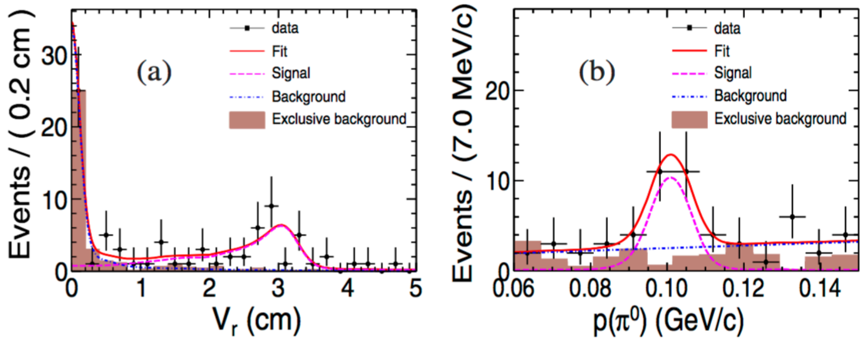
1. $e^+e^- \to \Lambda\bar{\Lambda} \to \bar{p}\pi^+\pi^-, \bar{n}\pi^0 X$ @2.2324
2. $e^+e^- \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$ @others

Data samples

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

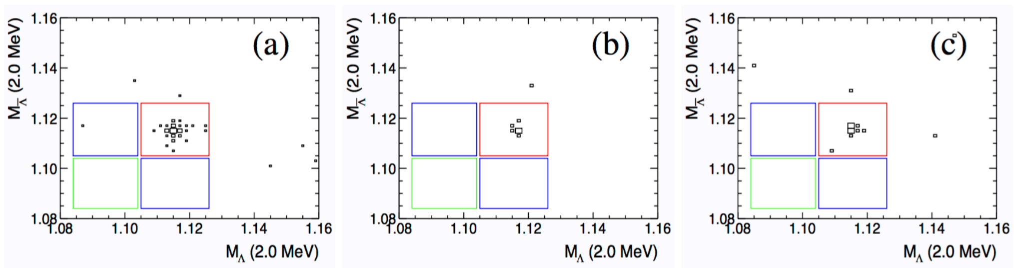
■ Signal yields extraction @2.2324

- ✓ 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

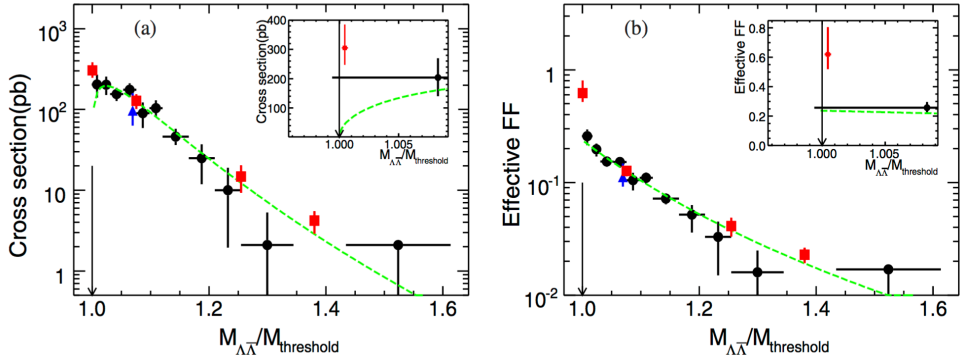


■ Signal yields extraction @others

- ✓ 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

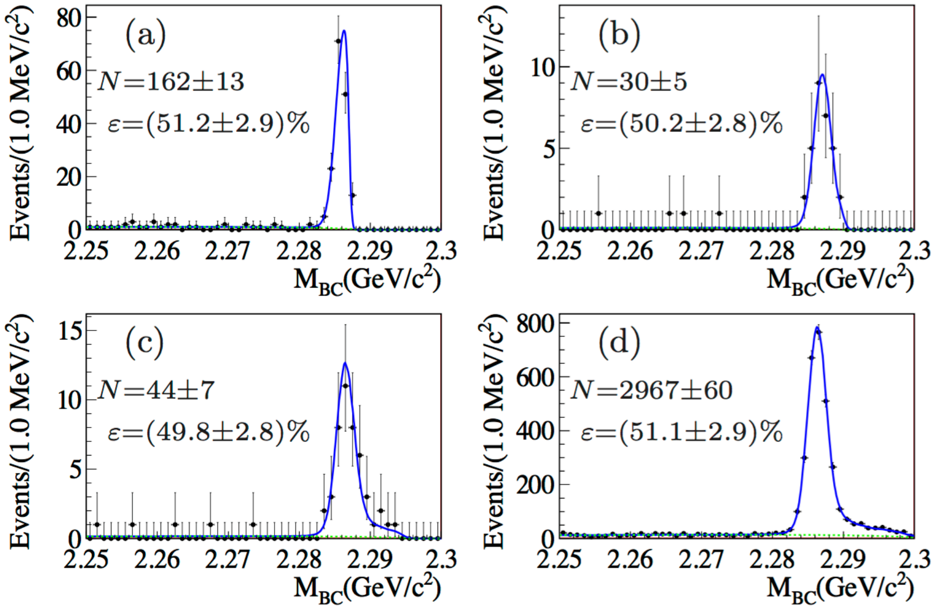
Precision measurement of the $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ cross section near threshold

Data samples

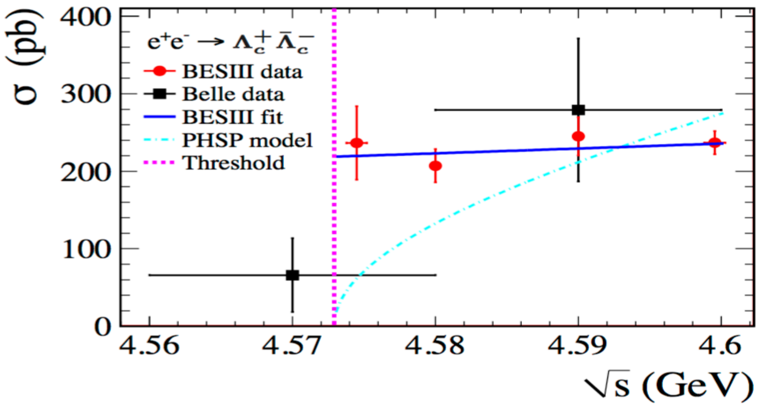
$\sqrt{s}$ (GeV)	$\mathcal{L}_{int}$ (pb^{-1})
4.5745	47.67
4.580	8.545
4.590	8.162
4.5995	566.9

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

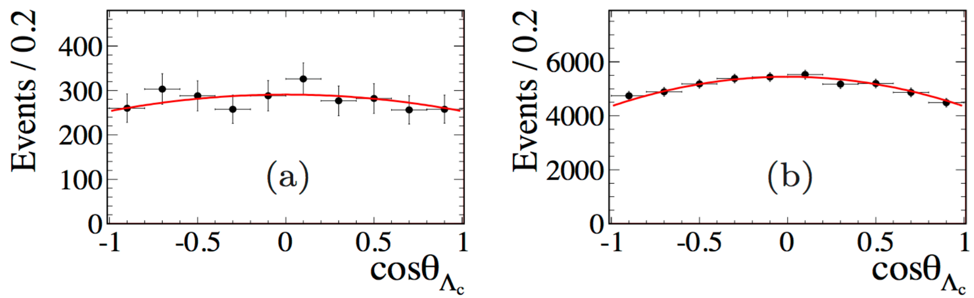
- ➢ **10 Cabibbo-favored hadronic modes:**
  $pK^-\pi^+, pK_S^0, \Lambda\pi^+, pK^-\pi^+\pi^0, pK_S^0\pi^0, \Lambda\pi^+\pi^0, pK_S^0\pi^+\pi^-, \Lambda\pi^+\pi^+\pi^-, \Sigma^0\pi^+, \Sigma^+\pi^+\pi^-$
- ➢ **c.c. mode is included by default**



■ 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!**

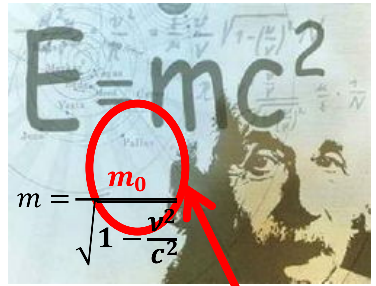
Thanks for your attention !

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?"***

Gauguin's monumental classic



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