Hyperon Pair Production at BESIII

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(On behalf of BESIII Collaboration)

Lanzhou University

19th International Conference on Hadron Spectroscopy and Structure in memoriam Simon Eidelman

July 30, 2021

Outline

☐ **Introduction**

☐ **Recent results**

➤ *$H\bar{H}$* **production in Charmonium decay**

  ✓ $J/\psi \rightarrow \Xi^-\bar{\Xi}^+$
  ✓ $\psi(3686) \rightarrow \Xi(1530)^- \bar{\Xi}(1530)^+，\Xi(1530)^- \bar{\Xi}^+$
  ✓ $\psi(3686) \rightarrow \Omega^-\bar{\Omega}^+$

➤ *$H\bar{H}$* **production in e^+e^- annihilation**

  ✓ $e^+e^- \rightarrow \Lambda\bar{\Lambda}$
  ✓ $e^+e^- \rightarrow \Sigma^{\pm}\bar{\Sigma}^{\mp}$
  ✓ $e^+e^- \rightarrow \Xi^-\bar{\Xi}^+, \Xi^0\bar{\Xi}^0$

☐ **Summary**
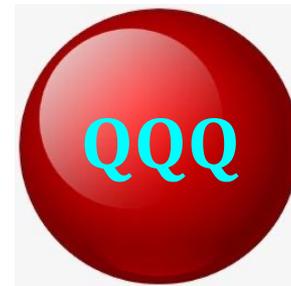
QQQ **Hyperon (H)**

Charmonium (-like) state
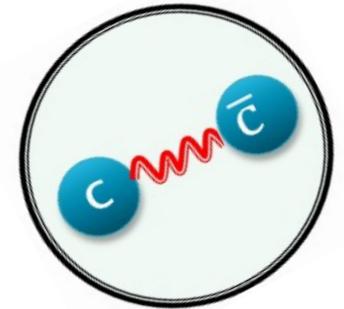
■ **Nonrelativistic $c\bar{c}$ bound state**

➤ J/ψ (1^3S_1), **first member with** $J^{PC} = 1^{--}$ **(1974)**

Godfrey & Isgur, PRD32, 189 (1985)

Not understand well

Understand well
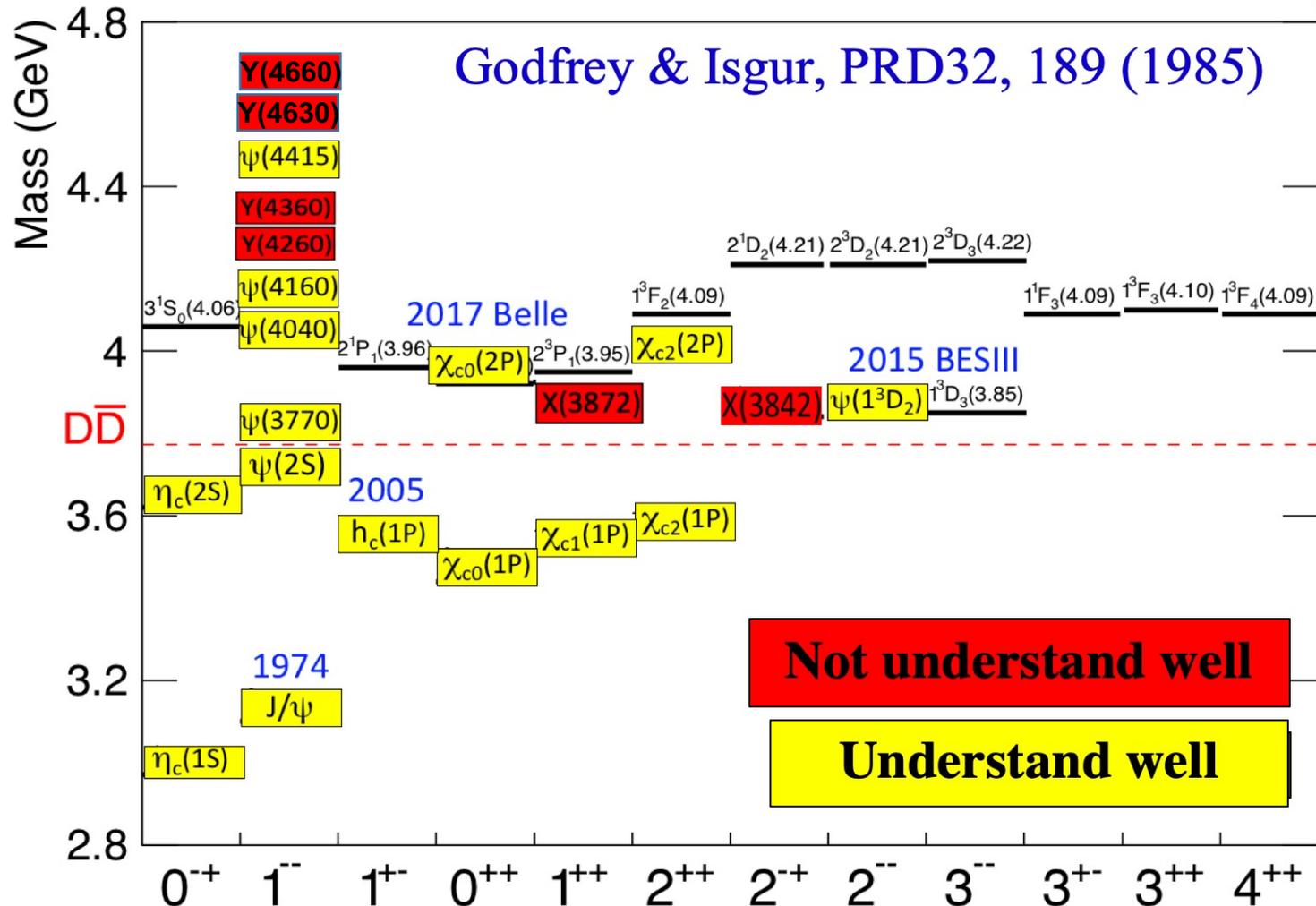
Baryon/hyperon States
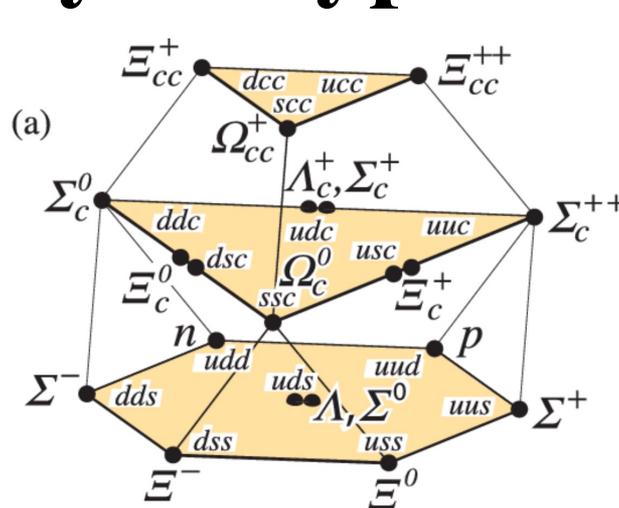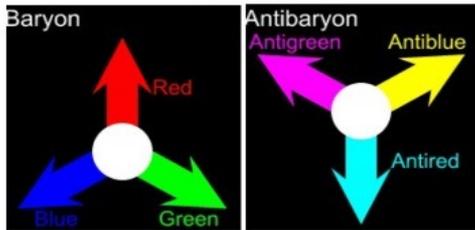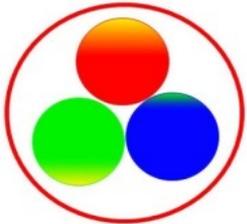
$(J^P = \frac{1}{2}^+)$
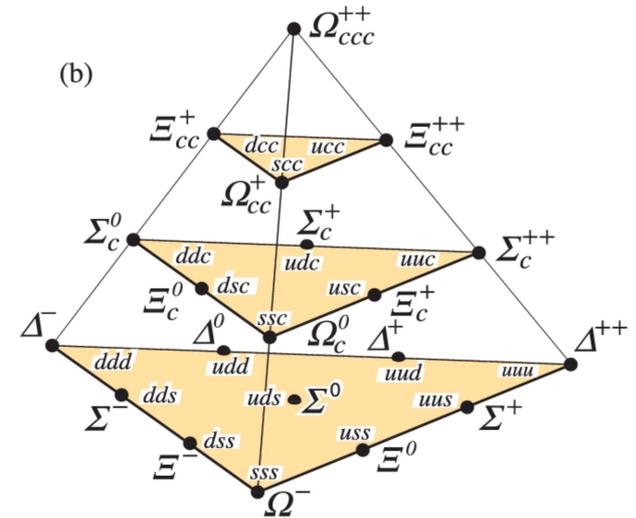
$(J^P = \frac{3}{2}^+)$
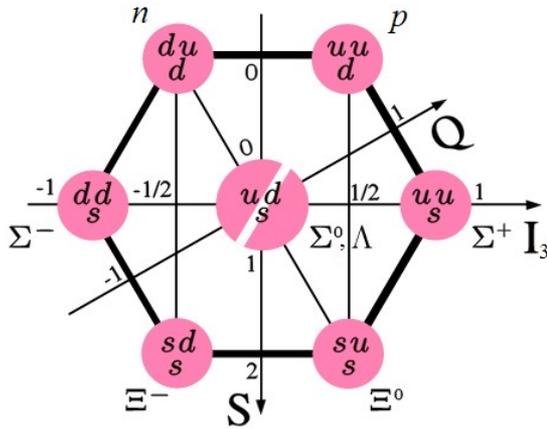
Baryon Octet (spin $\frac{1}{2}$)
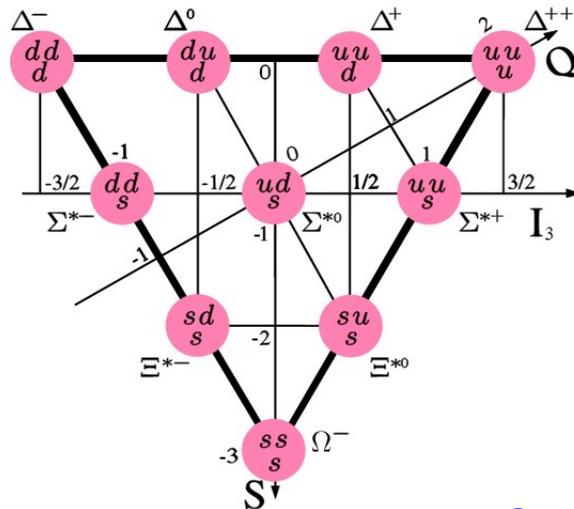
Baryon Decuplet (spin $\frac{3}{2}$)

duc Λ_c^+
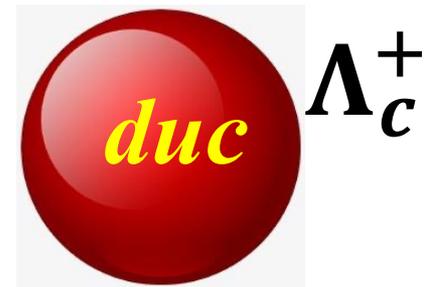
M = 2286.46 $\pm$ 0.14 MeV

$H\overline{H}$ production in Charmonium (-like) decay

□ **Main Feynman Diagrams**
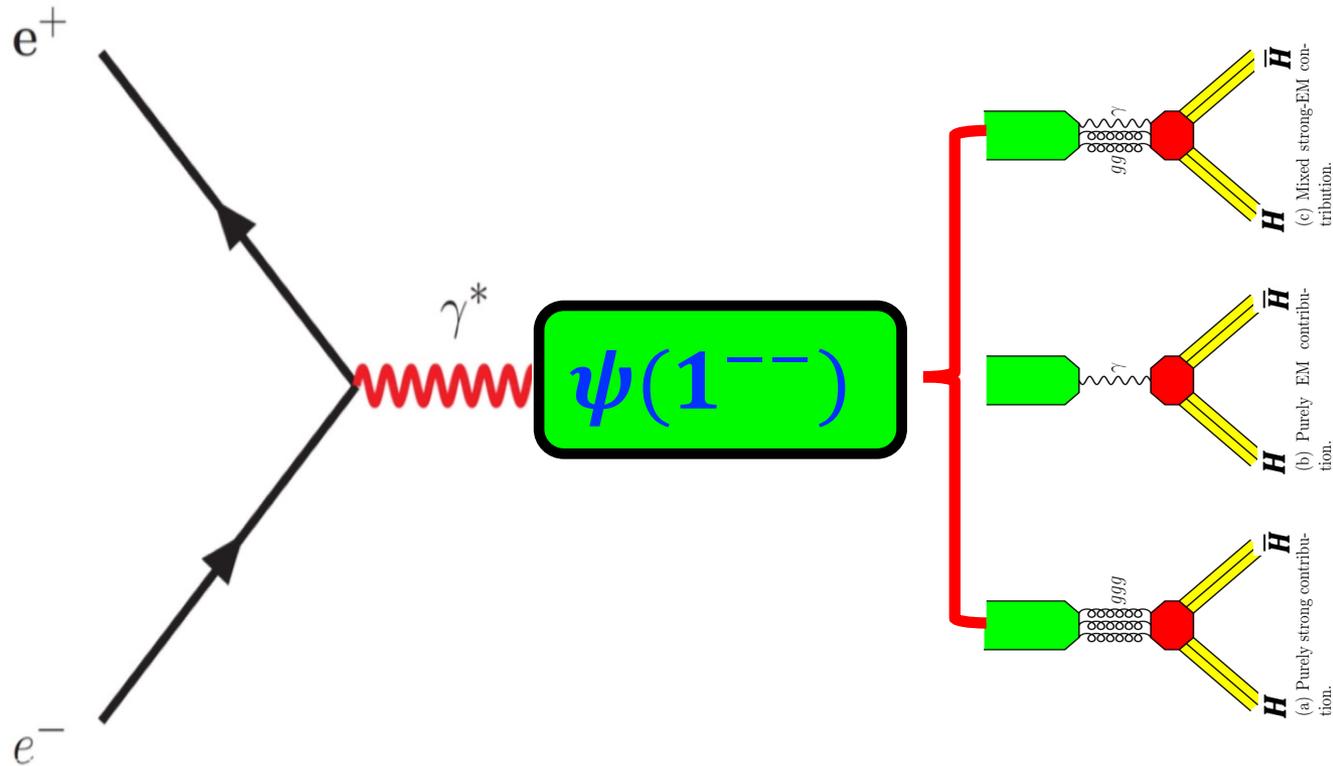
□ **Provide a rich laboratory to prob both pQCD and non-pQCD, the hyperon properties.**

$H\bar{H}$ production in e^+e^- annihilation

☐ **One Photon Exchange**
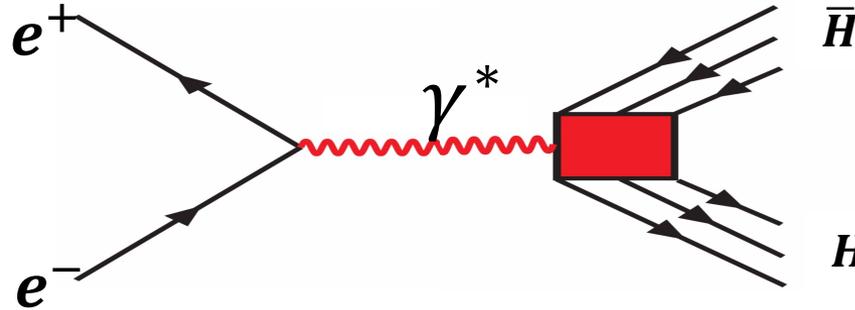
● **Differential cross section with combination of $G_{E/G}$**

$$\frac{d\sigma^B(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}[|G_M(s)|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E(s)|^2\sin^2\theta]$$

● **Form factor (Effective, $G_{E/G}$)**

$$|G_{\text{eff}}(s)| = \sqrt{\frac{2\tau|G_M(s)|^2 + |G_E(s)|^2}{2\tau+1}} = \sqrt{\frac{\sigma^B(s)}{(1+\frac{1}{2\tau})\cdot(\frac{4\pi\alpha^2\beta}{3s})}}$$

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

☐ **Understand the internal structure of hadron**
☐ **Provide extra insights for Charmonium(-like) states**

Outline

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☐ **Recent results**

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  - ✓ $\mathbf{J/\psi \rightarrow \Xi^-\overline{\Xi}^+}$
  - ✓ $\mathbf{\psi(3686) \rightarrow \Xi(1530)^-\,\overline{\Xi}(1530)^+,\ \Xi(1530)^-\,\overline{\Xi}^+}$
  - ✓ $\mathbf{\psi(3686) \rightarrow \Omega^-\overline{\Omega}^+}$

  ➢ $H\overline{H}$ production in e^+e^- annihilation
  - ✓ $\mathbf{e^+e^- \rightarrow \Lambda\overline{\Lambda}}$
  - ✓ $\mathbf{e^+e^- \rightarrow \Sigma^\pm\overline{\Sigma}^\mp}$
  - ✓ $\mathbf{e^+e^- \rightarrow \Xi^-\overline{\Xi}^+, \Xi^0\overline{\Xi}^0}$

☐ **Summary**
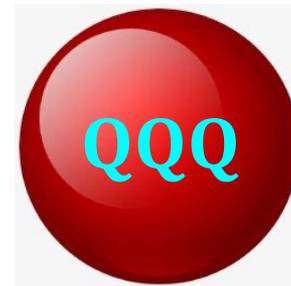
QQQ **Hyperon (H)**

Observation of Ξ^- hyperon spin polarization in $J/\psi \to \Xi^-\bar{\Xi}^+$

Data Sample: 1310M J/ψ
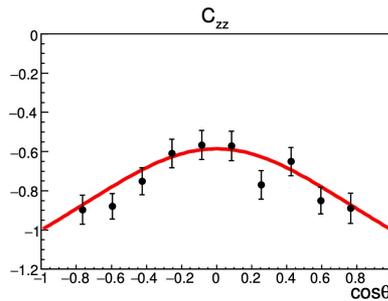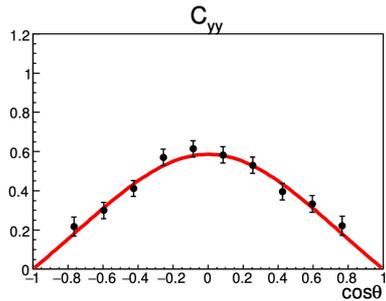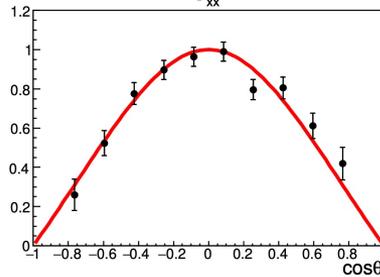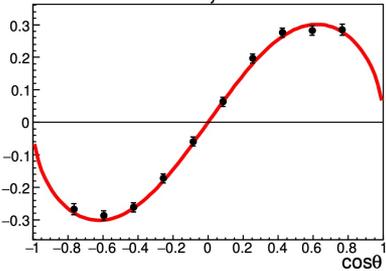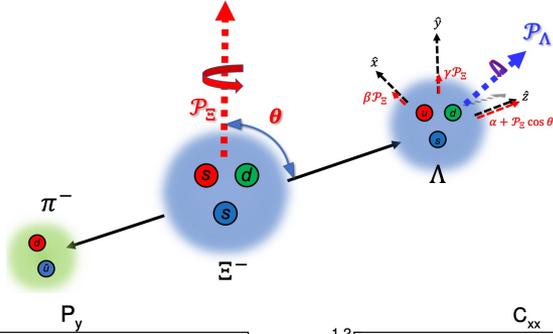
Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	[39]
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	[21]
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad	-0.037 ± 0.014 rad	[21]
$\bar{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	–	
$\bar{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ rad	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$	[14]
$\bar{\alpha}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$	[14]
$\xi_P - \xi_S$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad	–	
$\delta_P - \delta_S$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2}$ rad	$(10.2 \pm 3.9) \times 10^{-2}$ rad	[17]
A_{CP}^Ξ	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$	–	
$\Delta\phi_{CP}^\Xi$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad	–	
A_{CP}^Λ	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	[14]
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad		

☐ **Observation of Ξ^- spin polariztion, non-zero weak phase difference**
☐ **The most precise test for CPV on strange hyperon decay**

Observations of $\psi(3686) \to \Xi(1530)^-\overline{\Xi}(1530)^+$ and $\Xi(1530)^-\overline{\Xi}^+$

Data Sample: 448M ψ(3686)
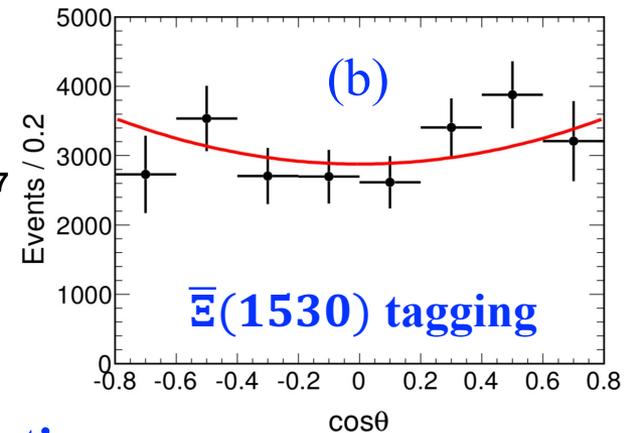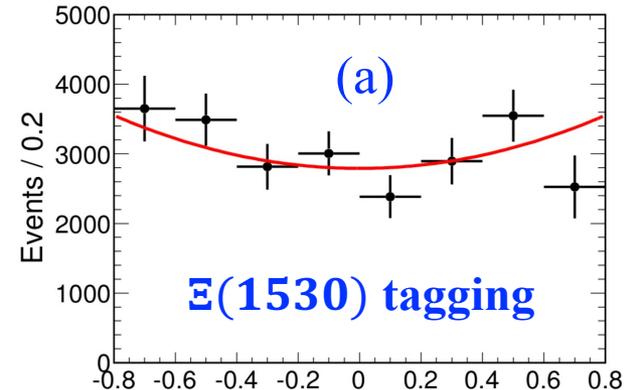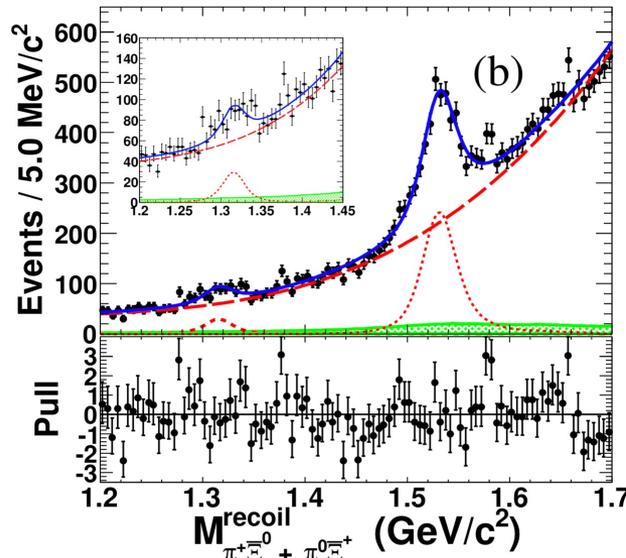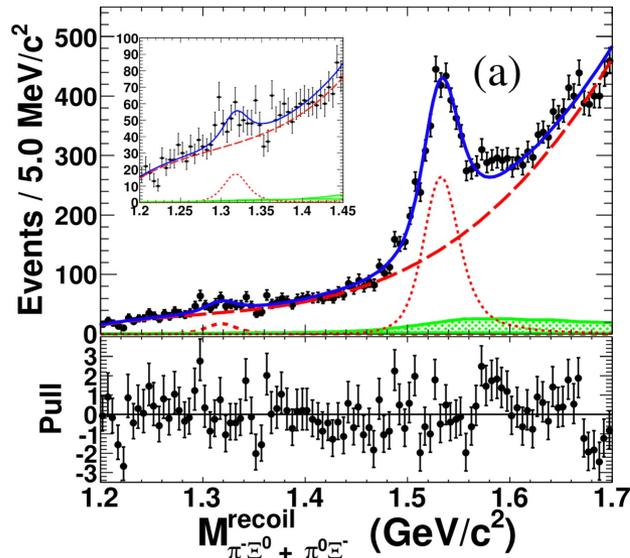
- **Observation for SU(3) broken process**
- **The measured α value favors the theoretical prediction**
  - ➤ **Quark mass effect, SU(3) violated effect, Electro-magnetic effect, etc.**
- **Provide new input to test pQCD.**

Helicity Amplitude Analysis of $\psi(2S) \to \Omega^-\bar{\Omega}^+$

Data Sample: 448M ψ(3686)

Phys. Rev. Lett. 126, 092002 (2021)

☐ **Improve precision for branching fraction**
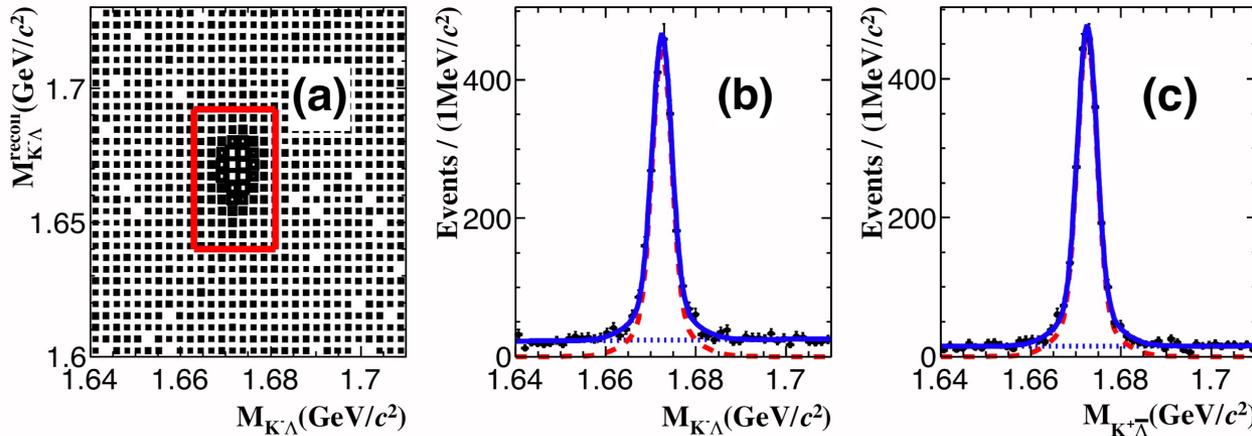
This work:
$Br[\psi(2S) \to \Omega^-\bar{\Omega}^+]$
$= (5.82 \pm 0.12 \pm 0.24) \times 10^{-5}$
PDG value:
$Br[\psi(2S) \to \Omega^-\bar{\Omega}^+]$
$= (5.2 \pm 0.4) \times 10^{-5}$

☐ **The degree of polarization for Ω^- hyperon is determined (Two solutions)**

$$d_{\left(\rho_{\frac{3}{2}}\right)} = \sqrt{\sum_{\mu=1}^{15} \left(\frac{r_\mu}{r_0}\right)^2}$$

vector (r1), quadrupole (r6 , r7 , r8)
octupole (r10 , r11) polarization
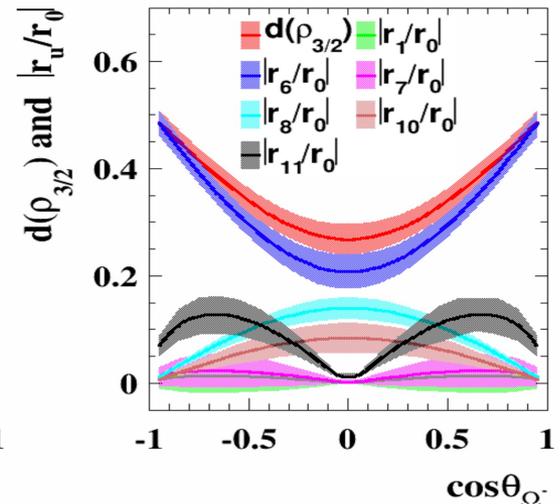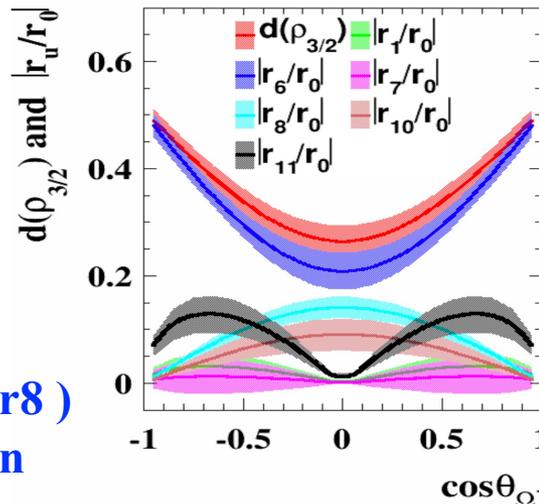
Outline

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☐ **Summary**
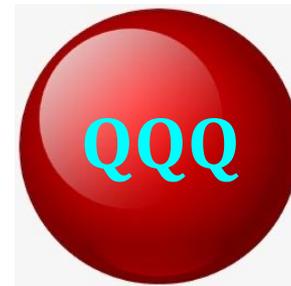
QQQ **Hyperon (H)**

IV. Measurement of Λ hyperon polarization in $e^+e^- \to \Lambda\bar{\Lambda}$

Data Sample: 66.9 pb^{-1} @ $\sqrt{s}$=2.396GeV

Dots with error bars (data)
Red line $(1 + \alpha \cos^2 \theta)$,
Band(with statistical uncertainty)

Acceptance corrected Λ scattering angle distribution!
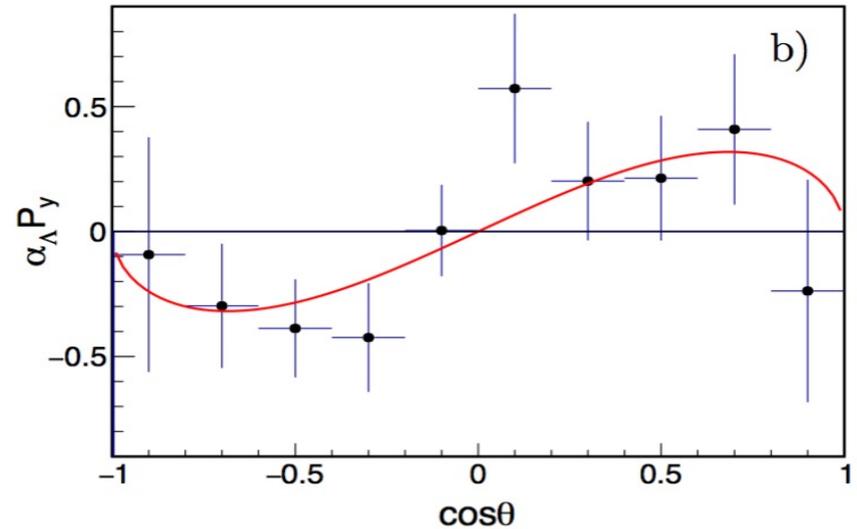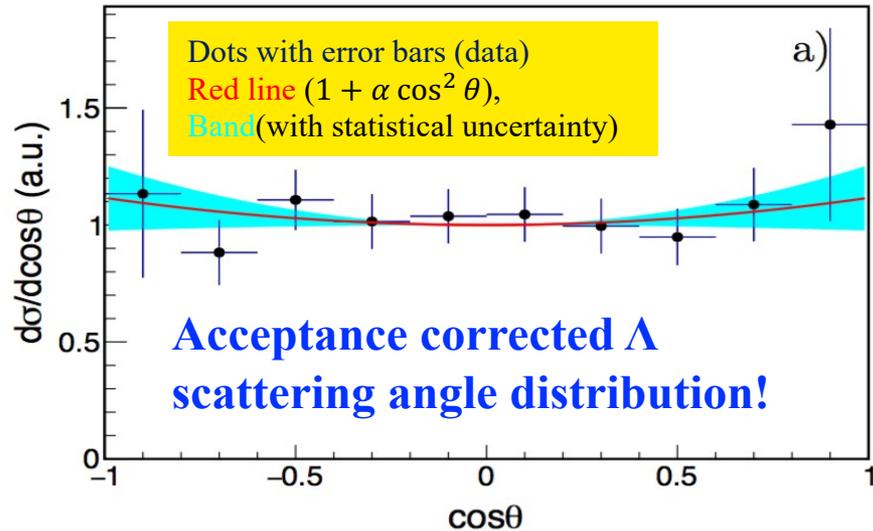
Numerical Results

$\sigma = 118.7 \pm 5.3 \pm 5.1$ pb
$|G_{eff.}| = 0.123 \pm 0.003 \pm 0.003$
$R = \left|\dfrac{G_E}{G_M}\right| = 0.96 \pm 0.14 \pm 0.02$
$\Delta\Phi = \Phi_E - \Phi_M = 37^o \pm 12^o \pm 6^o$

- **First complete determination of baryon time-like EMFFs**
- **Confirm Λ hyperon polarization observed in J/ψ decay**
- **More information for understanding $\Lambda\bar{\Lambda}$ production near threshold**

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Measurement of $\sigma^B(e^+e^- \to \Sigma^{\pm}\overline{\Sigma}^{\mp})$ near threshold

Data Sample: ~400/pb (6 points: 2.3864 to 3.0200 GeV)
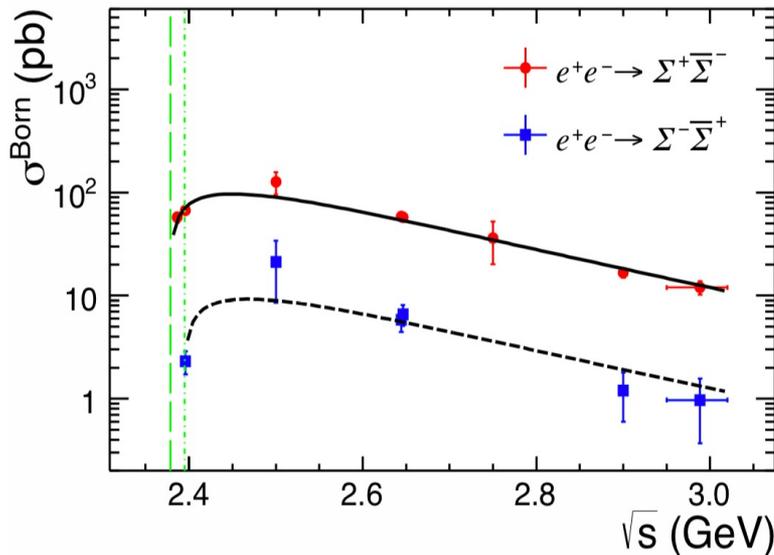
- **No obvious enhancement near threshold**
- **Nonzero cross sections near threshold**
- **The cross sections for $\Sigma^{\pm}\overline{\Sigma}^{\mp}$ baryon pairs disagree with each other within the sector of isospin conservation**
- **First measurements in the off-resonance region, provide precision experimental input for understanding baryonic structure**
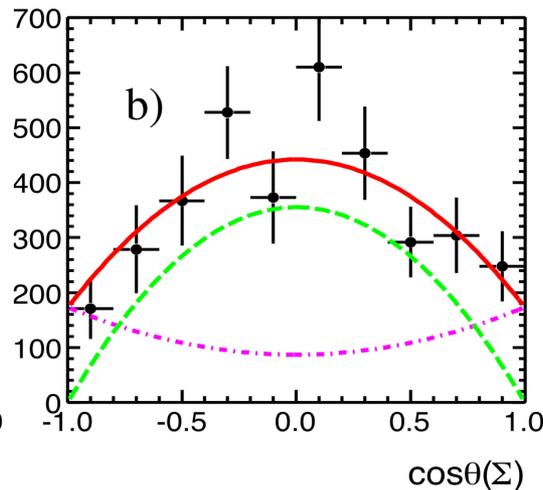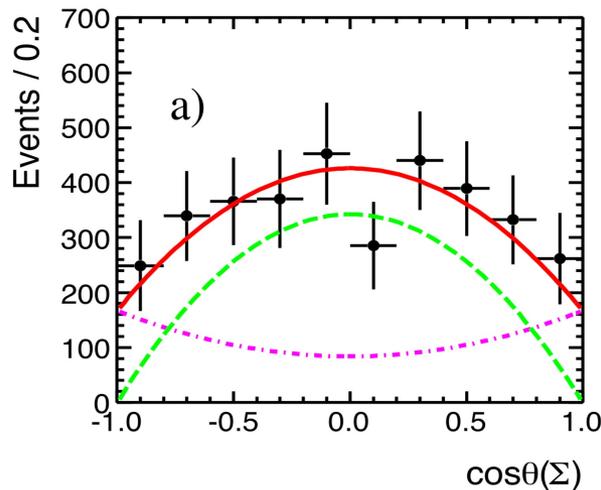
First measurement for the ratio of EM form factors at point $\sqrt{s} = 2.396$GeV with a study of angular distribution

Study of $e^+e^- \to \Xi^-\bar{\Xi}^+$ above open charm

Data Sample: 11.0 fb^{-1} @ $\sqrt{s}$=4.009-4.6GeV

- **First study of $e^+e^- \to \Xi^-\bar{\Xi}^+$ above open charm threshold**

Effective form factor

- **A maximum likelihood fit to cross section:**

$$\sigma^{\text{dressed}}(\sqrt{s}) = |c_0 \frac{\sqrt{P(\sqrt{s})}}{s^n} + e^{i\phi} BW(\sqrt{s}) \sqrt{\frac{P(\sqrt{s})}{P(M)}}|^2$$

$$BW(\sqrt{s}) = \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}\Gamma}}{s - M^2 + iM\Gamma}$$

$Y(4230) \to \Xi^-\bar{\Xi}^+$ ~2.7σ

$Y(4260) \to \Xi^-\bar{\Xi}^+$ ~2.7σ

$e^+e^- \to \Xi^-\bar{\Xi}^+$ $n = 7.1 \pm 0.3$ $c_0 = 0.17 \pm 0.08$
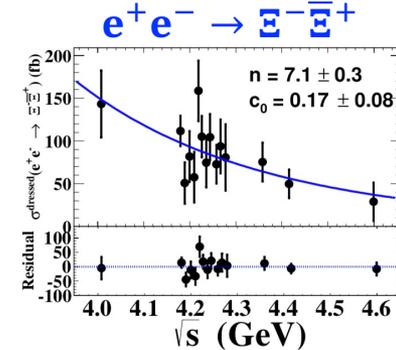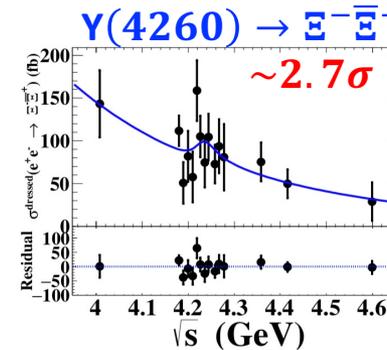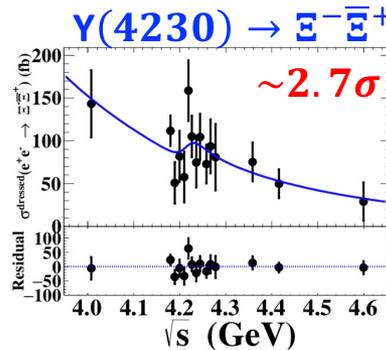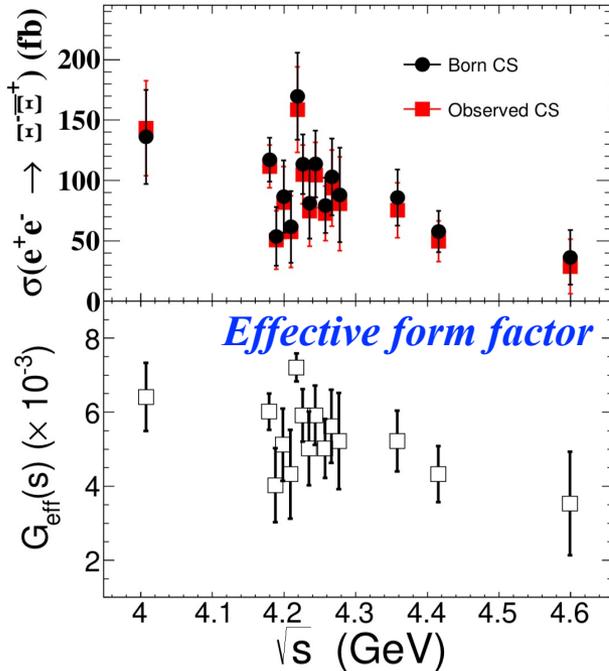
- **No obvious significances for ψ(4230/4260) are observed in the $\Xi^-\bar{\Xi}^+$ final states**

$$\Gamma_{ee}Br[Y(4230) \to \Xi^-\bar{\Xi}^+] < 0.33 \times 10^{-3} eV$$

$$\Gamma_{ee}Br[Y(4260) \to \Xi^-\bar{\Xi}^+] < 0.27 \times 10^{-3} eV$$

- **Provide more experimental information to understand the nature of Y (4260)**
- **Charmless decays of the Y (4260) are expected by the hybrid model (F. E. Close and P. R. Page, PLB628,215(2005))**

Study of $e^+e^- \to \Xi^-\bar{\Xi}^+$ above open charm

■**Observed an excited Ξ state by combining all energy points**

$N^{obs} = 288 \pm 66$
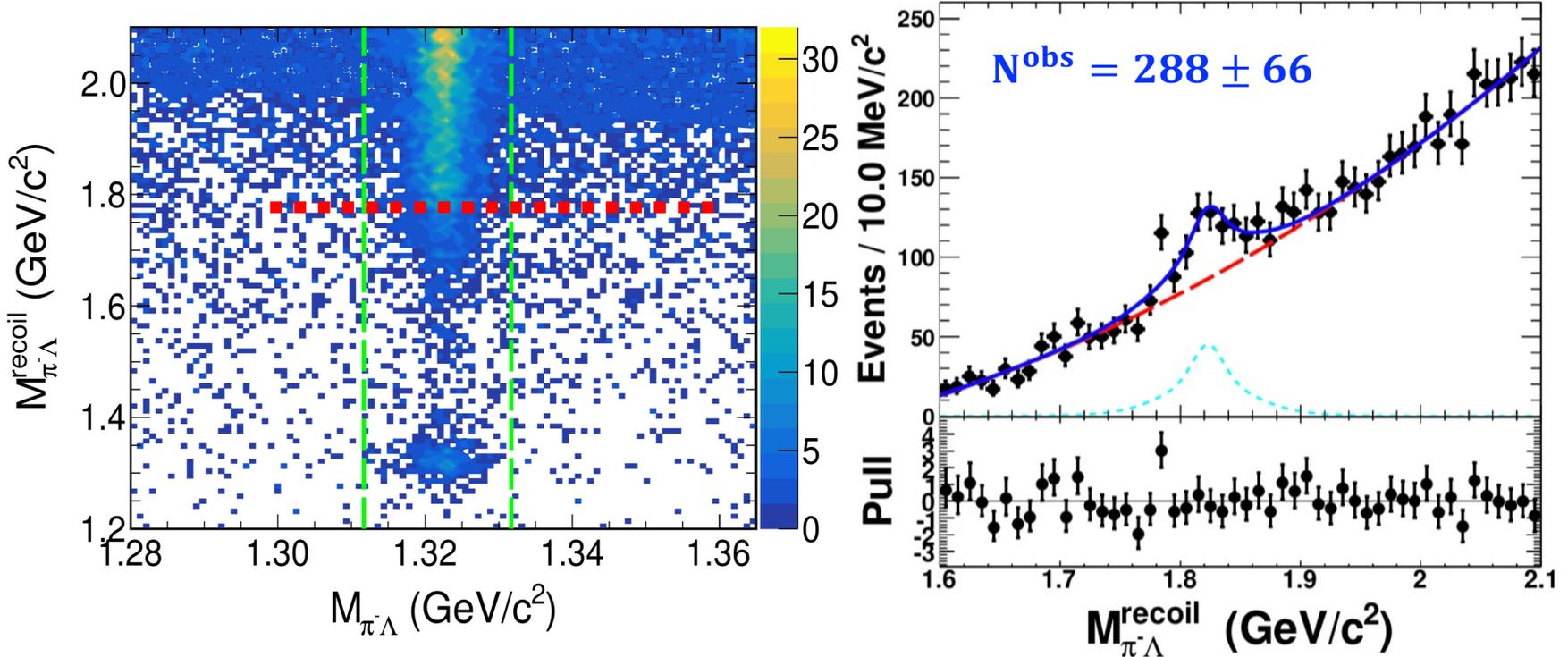
□**Observed $e^+e^- \to \Xi^{\mp}X(1820)$ with 6.2σ significance**

$$M = (1825.5 \pm 4.7 \pm 4.7)\text{GeV}$$
$$\Gamma = (17.0 \pm 15.0 \pm 7.9)\text{MeV}$$

□**Consistent with the mass and width of $\Xi(1820)$ from PDG within the 1σ uncertainty**

□**JPC has not determined due to limited statistics**

Measurement of $\sigma^B(e^+e^- \to \Xi\bar{\Xi})$ near threshold

Data Sample: ~360/pb (8 points: 2.644 to 3.080 GeV)

■ **First study for $\Xi\bar{\Xi}$ production near threshold**
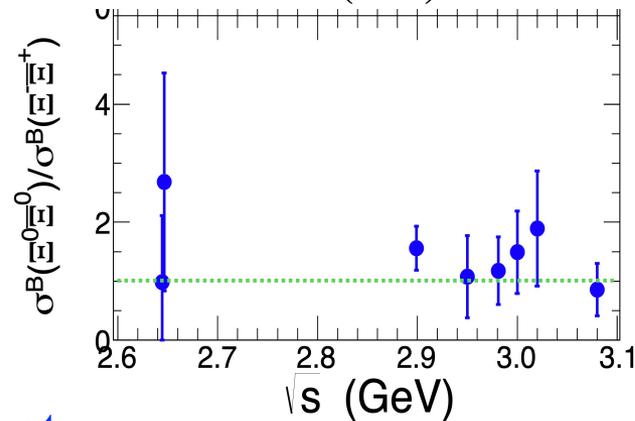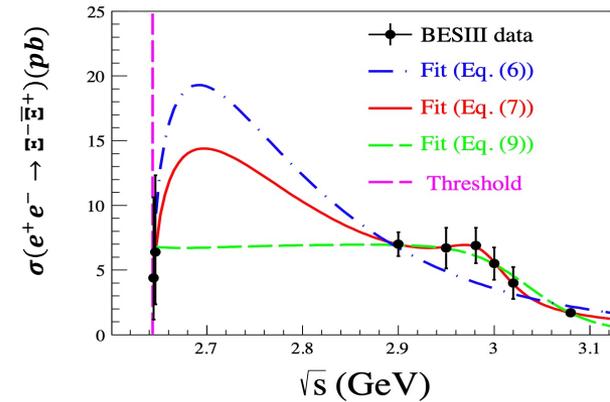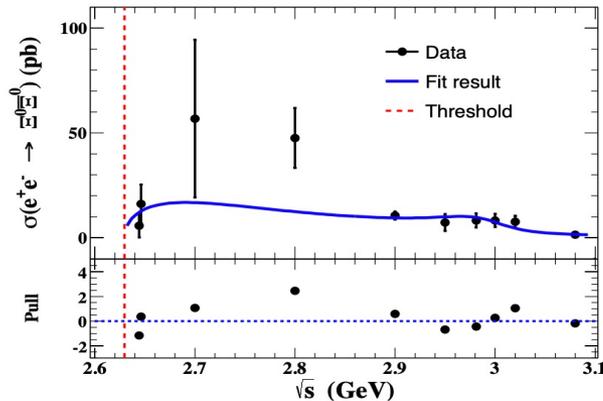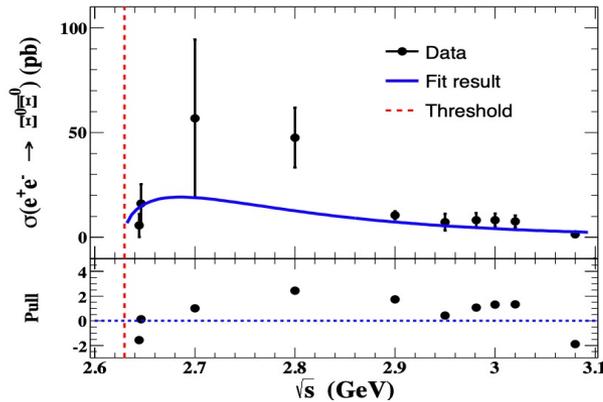
■ **No obvious $\Xi\bar{\Xi}$ threshold enhancement**
■ **The ratio of Born cross sections for both modes agrees with the expectation of isospin symmetry.**

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Summary

■**BESIII is successfully operating since 2008.**

- ✓ **Collected large data samples in the τ-charm physics region**
- ✓ **Continues to take data in coming 5 years (at least)**

■**Many studies for $H\bar{H}$ production in Charmonium decay and in e^+e^- annihilation achieved:**

- ✓ **More new observation for $H\bar{H}$ production in Charmonium decay**
- ✓ **Hyperon polarization observation**
- ✓ **More new/precise study for hyperon pair production near threshold**
- ✓ **Still need more experimental/theoretical efforts**

■**More new results are on the way!**

Thanks for your attention !

Backup

Beijing Electron Positron Collider-II

Double-Storage-ring

Linac

BESIII

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

Super-conducting magnet (1.0 tesla)
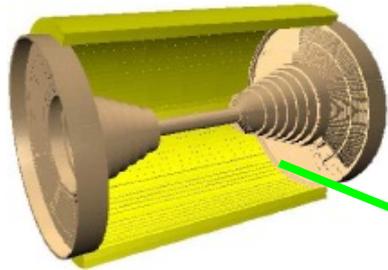
(Main Drift Chamber)

$\sigma_{sigle-wire} = 120\mu m$
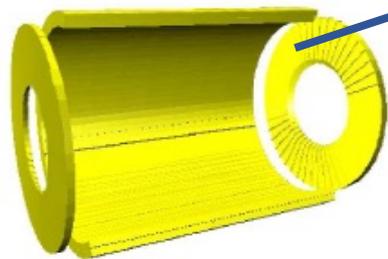
(Time-Of-Flight System)

$\sigma_{barrel} = 68\mathrm{p}s$
$\sigma_{endcap} = 65\mathrm{p}s$

2.5%@1GeV
(Electromagnetic Calorimeter)
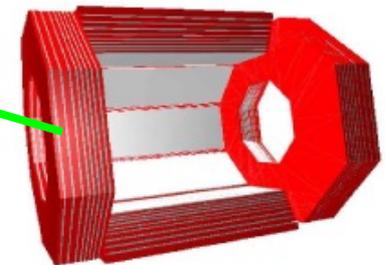
(Muon counter)

(made of 9 RPCs)

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BESIII Collaboration

Political Map of the World, November 2011

Europe (17)
Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster
Italy(3): Ferrara University, INFN, University of Turin,
Netherlands(1): KVI/University of Groningen
Russia(2): Budker Institute of Nuclear Physics, Dubna JINR
Sweden(1): Uppsala University
Turkey (1): Turkish Accelerator Center Particle Factory Group
UK(2): University of Manchester, University of Oxford
Poland(1): National Centre for Nuclear Research

Mongolia(1)
Institute of Physics and Technology

Korea(2)
Seoul National University
Chung-Ang University

Japan(1)
Tokyo University

USA(5)
Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota
University of Rochester

Pakistan(3)
COMSATS Institute of Information Technology
University of the Punjab,
University of Lahore

Thailand(1)
Suranaree University of Technology

India(1)
Indian Institute of Technology madras

Chile(1)
University of Tarapaca

China (48)
Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, YunNan University , Zhejiang University, Zhengzhou University

BES Ⅲ

**~500 members
From 80 institutions in 17 countries**

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