Study of Baryon Pair Production at BESIII

Xiongfei Wang *(王雄飞)*

(**On behalf of BESIII Collaboration**)

Lanzhou University

10th International Workshop on Charm Physics

June 1st, 2021

Outline

☐ **Introduction**

☐ **Recent results**

➢ **B$\overline{\text{B}}$ production in Charmonium decay**

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

➢ **B$\overline{\text{B}}$ production in e^+e^- annihilation**

- ✓ $e^+e^- \rightarrow N\overline{N}$
- ✓ $e^+e^- \rightarrow \Sigma^{\pm}\overline{\Sigma}^{\mp}$
- ✓ $e^+e^- \rightarrow \Xi^-\overline{\Xi}^+$
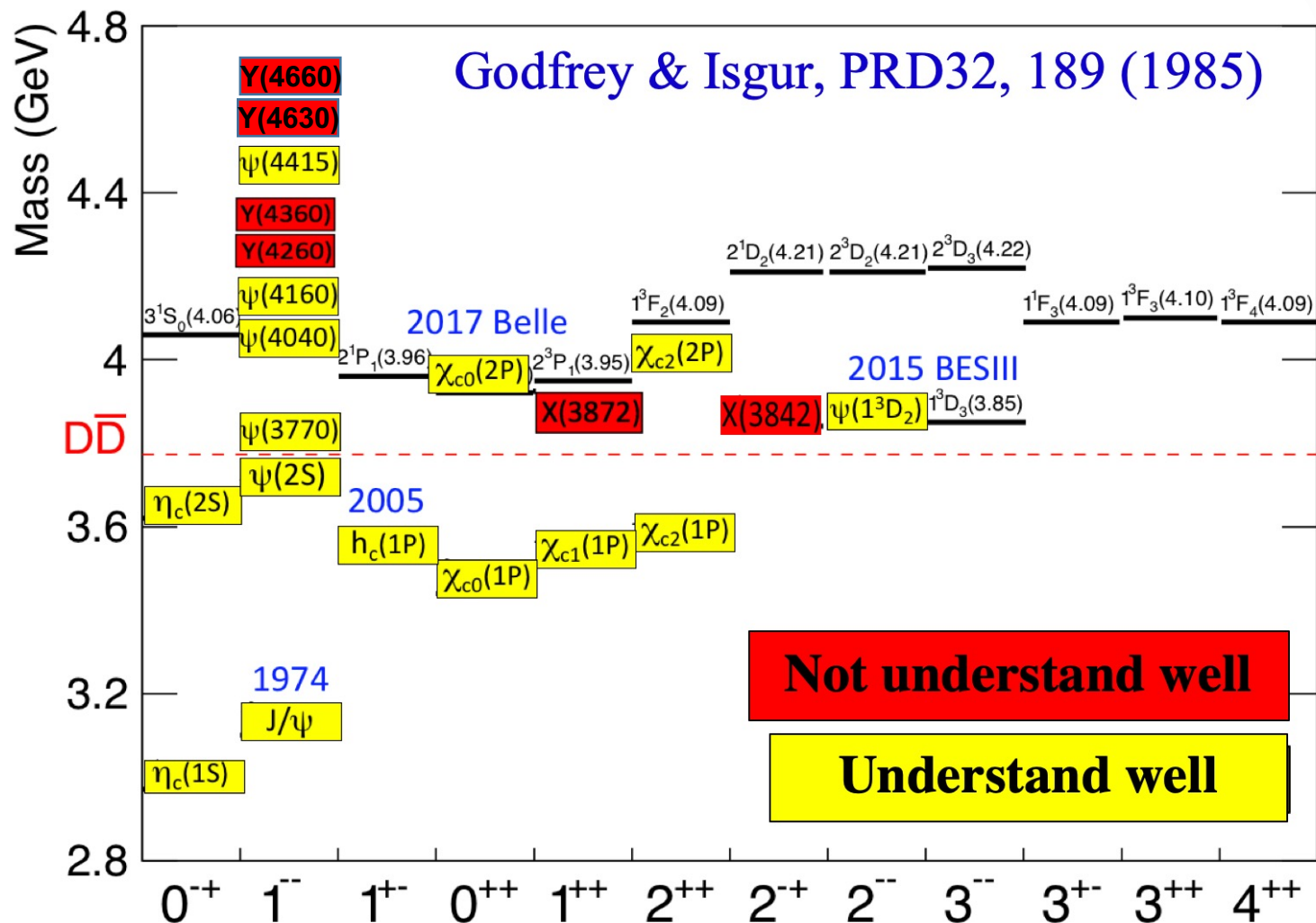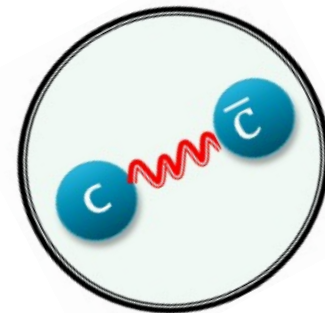
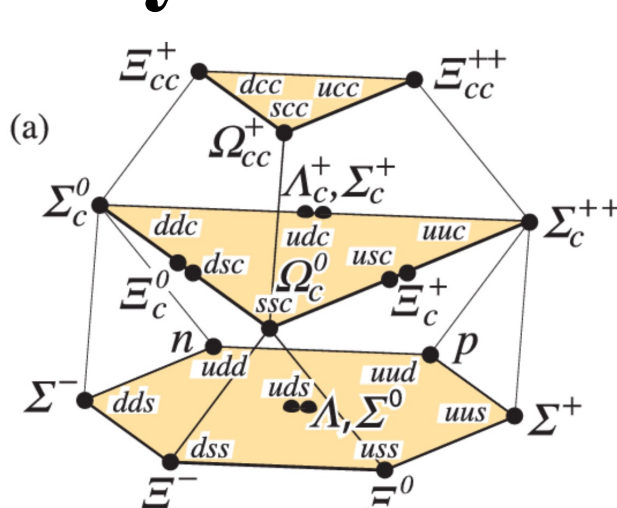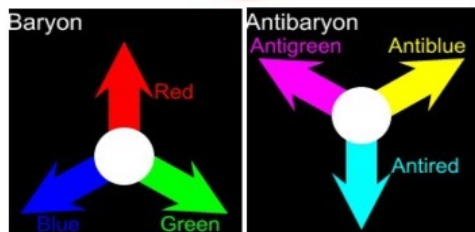☐ **Summary**

QQQ **Baryon (B)**

See Andrzej's talk for Hyperon polarization
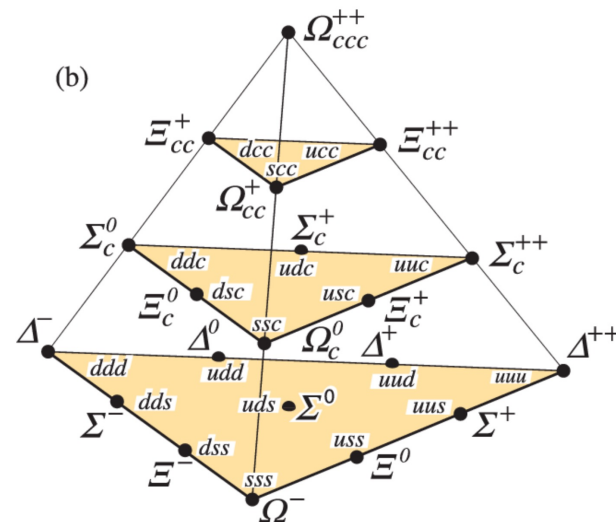
Charmonium (-like) states

■ **Nonrelativistic $c\bar{c}$ bound states**

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

Baryon States
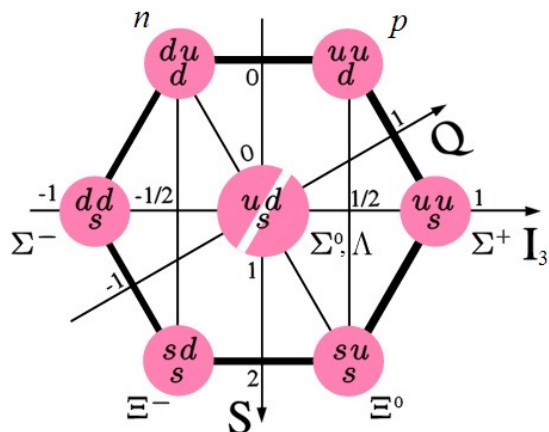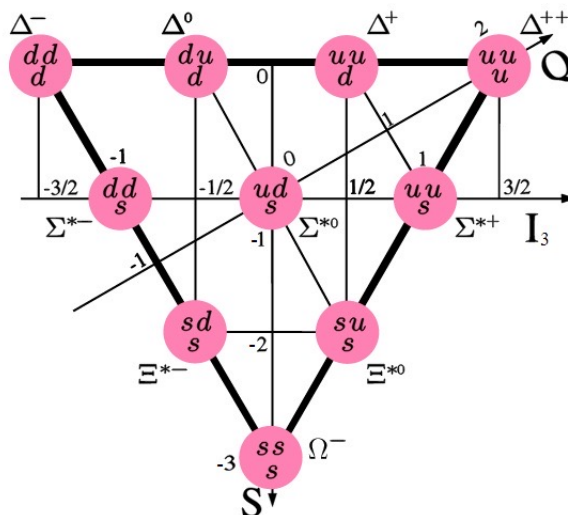

$(J^P = \frac{1}{2}^+)$

$(J^P = \frac{3}{2}^+)$

Baryon Octet (spin $\frac{1}{2}$)

Baryon Decuplet (spin $\frac{3}{2}$)

$$\Lambda_c^+$$

duc

M = 2286.46 $\pm$ 0.14 MeV

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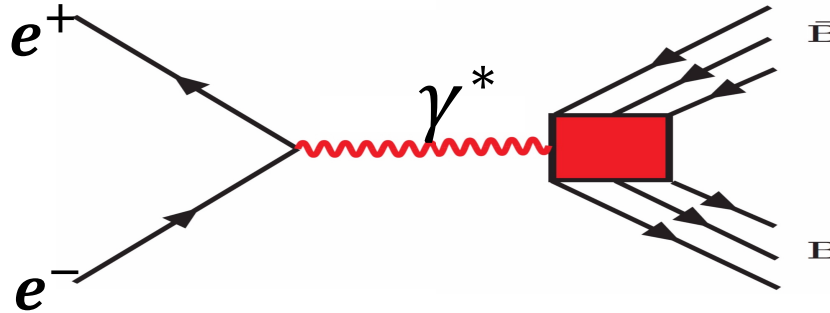# $B\bar{B}$ production in Charmonium (-like) decay

☐ **Main Feynman Diagrams**
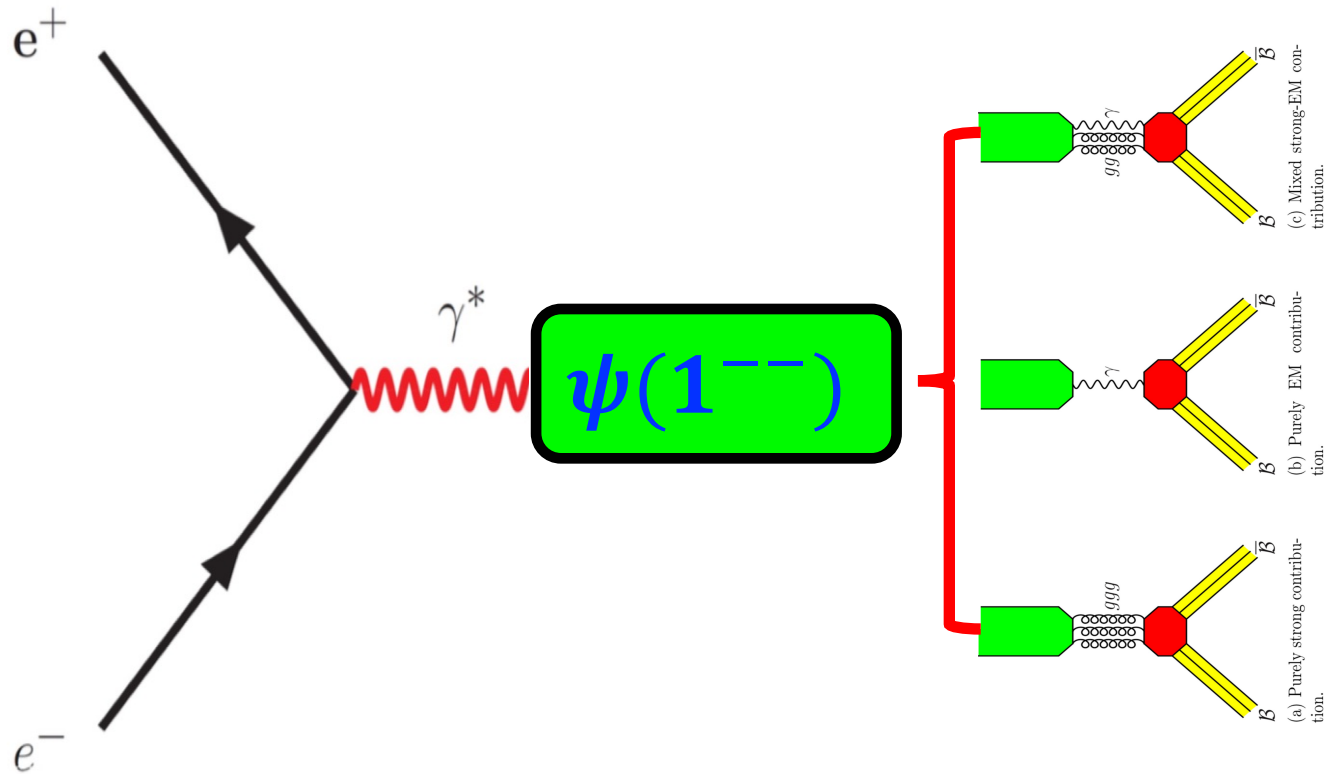
☐ **Provide a rich laboratory to prob both pQCD and non-pQCD.**

$B\bar{B}$ 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

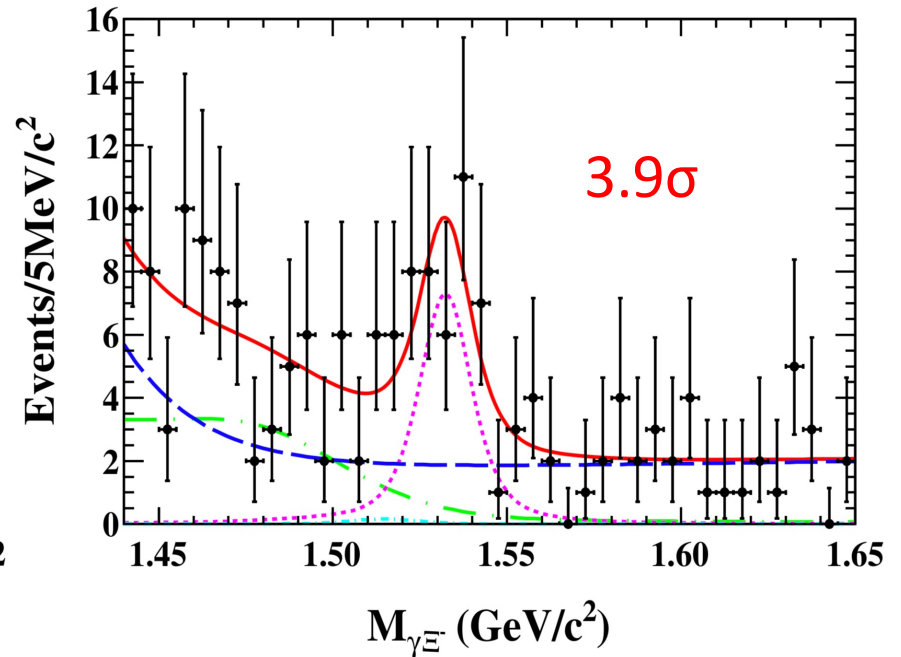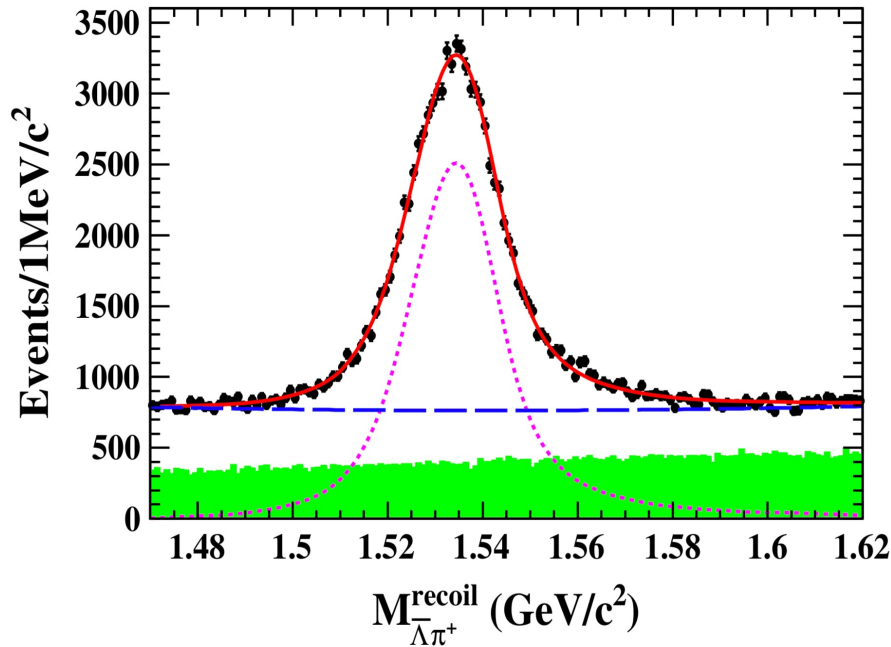**QQQ** **Baryon (B)**

Measurements of $J/\psi \to \Xi(1530)^-\bar{\Xi}^+ + c.c.$ **and** $\Xi(1530)^- \to \gamma\Xi^-$

Data Sample: 1310M J/ψ

PRD101, 012004 (2020)

3.9σ

(left plot x-axis) $M^{recoil}_{\bar{\Lambda}\pi^+}$ (GeV/c²)

(right plot x-axis) $M_{\gamma\Xi^-}$ (GeV/c²)
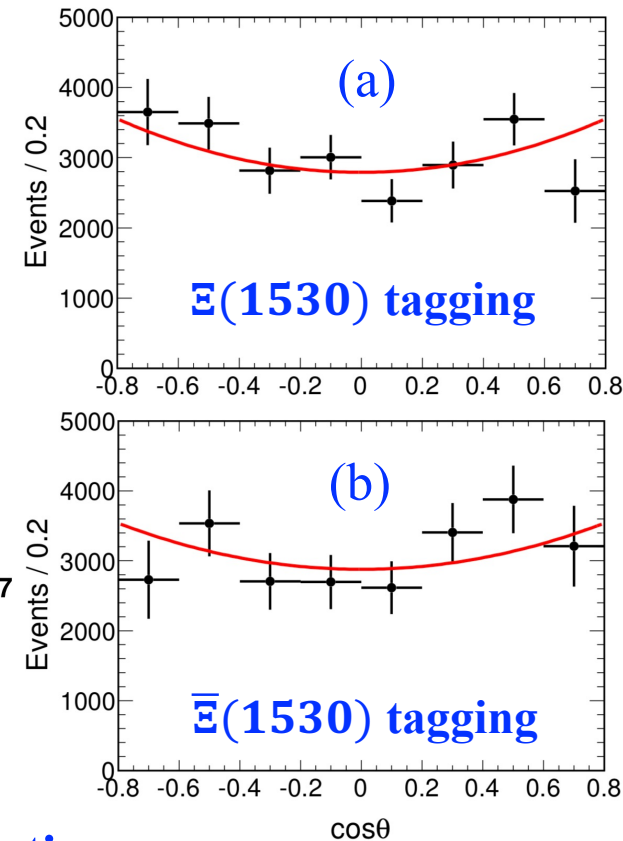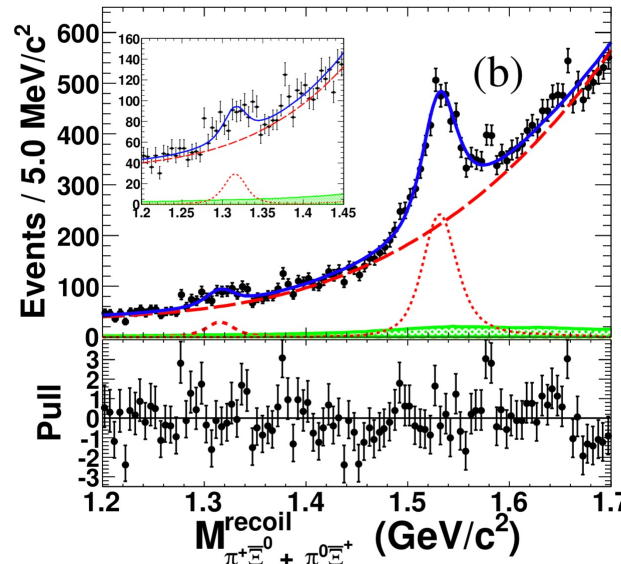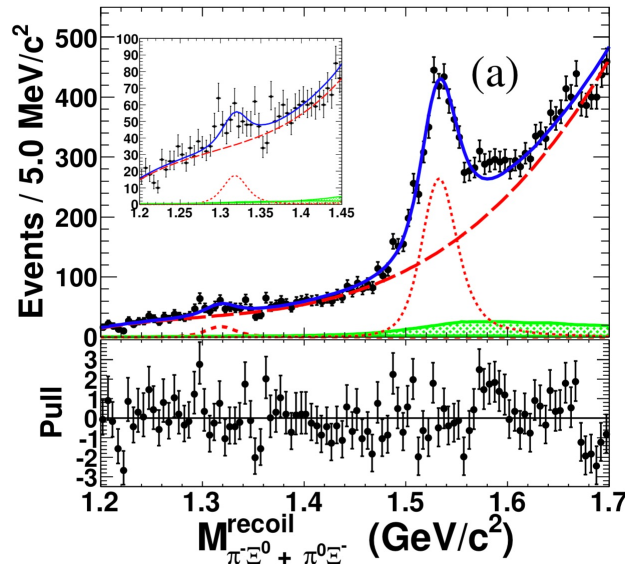
■ Precise measurement for $J/\psi \to \Xi(1530)^-\bar{\Xi}^+ + c.c.$

■ First evidence: $B[\Xi(1530)^- \to \gamma\Xi^-] < 3.7\%@90\%$ C.L.

■ Provide complementary experimental information for isolating both the octet-decuplet mixing mechanism.

Observations of $\psi(3686) \to \Xi(1530)^-\overline{\Xi}(1530)^+$ and $\Xi(1530)^-\overline{\Xi}^+$
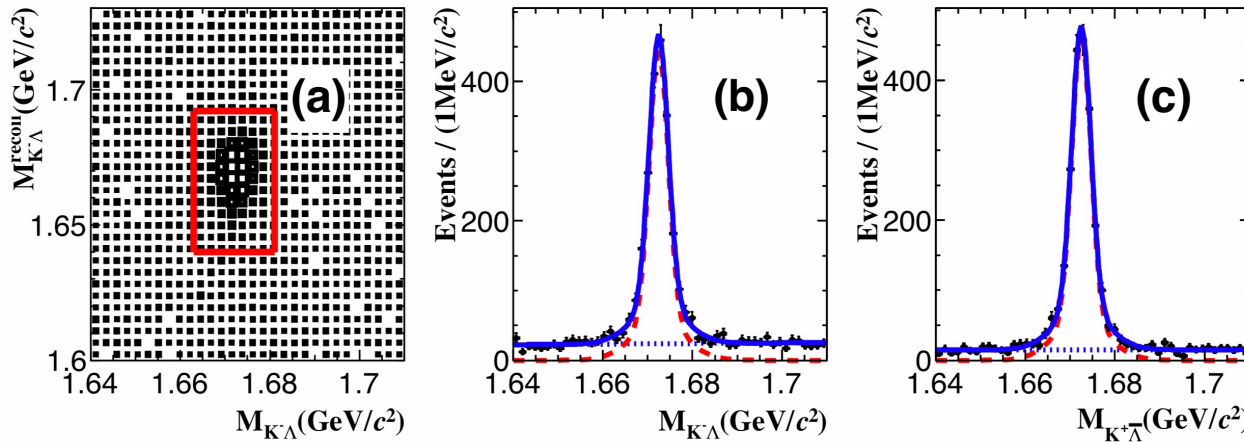
Data Sample: 448M $\psi(3686)$

- **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 $\psi(2S) \rightarrow \Omega^-\bar{\Omega}^+$

☐ Improve precision for branching fraction

This work:
$Br[\psi(2S) \rightarrow \Omega^-\bar{\Omega}^+]$
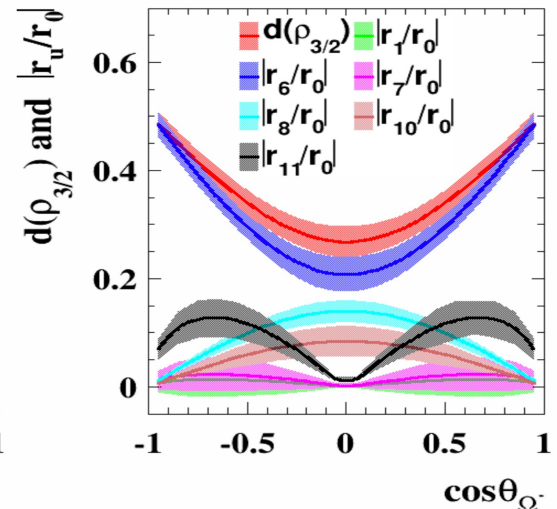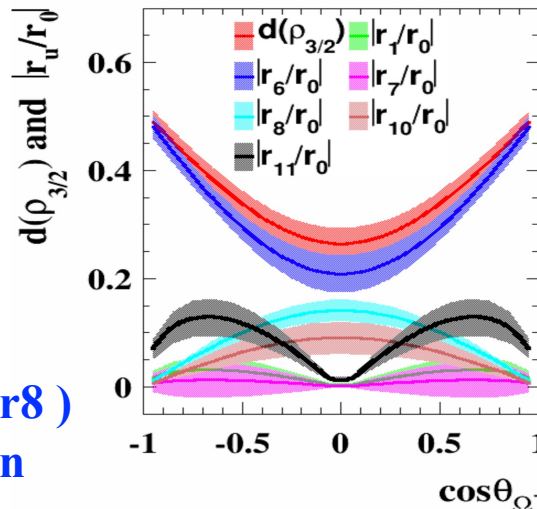$= (5.82 \pm 0.12 \pm 0.24)\times10^{-5}$
PDG value:
$Br[\psi(2S) \rightarrow \Omega^-\bar{\Omega}^+]$
$= (5.2 \pm 0.4)\times10^{-5}$

☐ The degree of polarization for Ω^- baryon 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 (r_1), quadrupole (r_6, r_7, r_8)
octupole (r_{10}, r_{11}) polarization

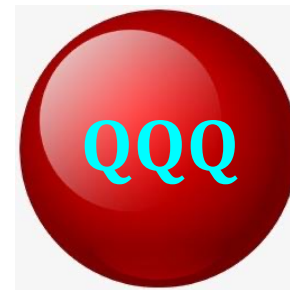# Outline

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   ➤ $B\overline{B}$ production in Charmonium decay
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   - ✓ $\psi(3686) \to \Xi(1530)^- \overline{\Xi}(1530)^+$
   - ✓ $\psi(3686) \to \Omega^-\overline{\Omega}^+$

   ➤ $B\overline{B}$ production in e^+e^- annihilation
   - ✓ $e^+e^- \to N\overline{N}$
   - ✓ $e^+e^- \to \Sigma^{\pm}\overline{\Sigma}^{\mp}$
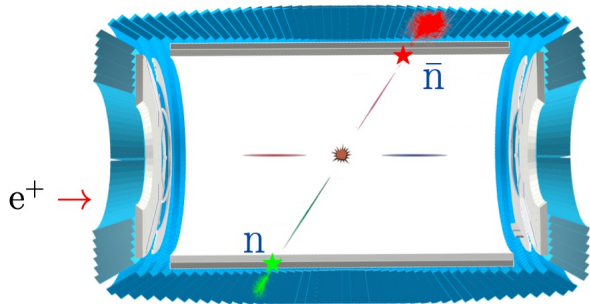   - ✓ $e^+e^- \to \Xi^-\overline{\Xi}^+$

☐ **Summary**

QQQ **Baryon (B)**

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

Data Sample: 650/pb, 18 points from 2.00 to 3.08 GeV

Typical response for signal process
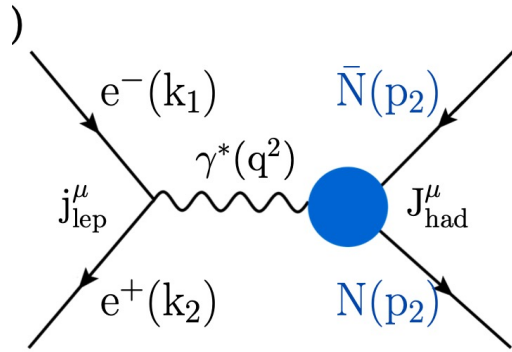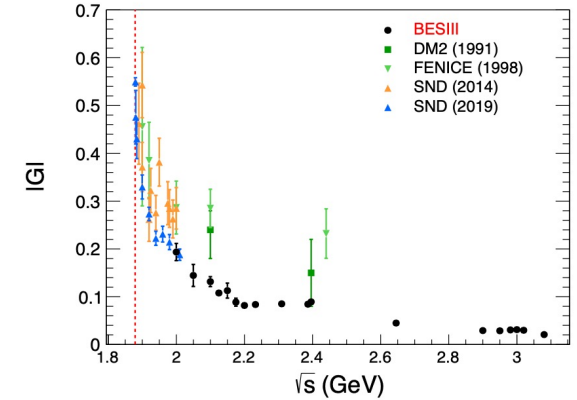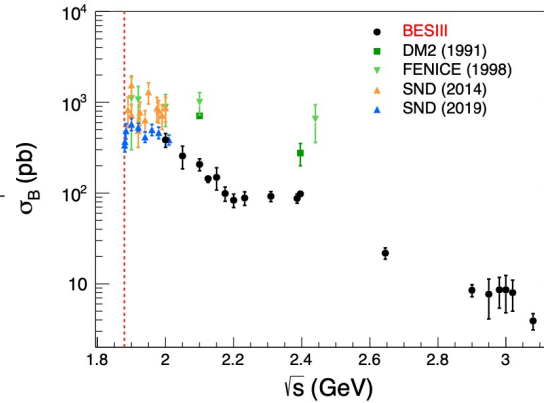
Lowest order Feynman diagram
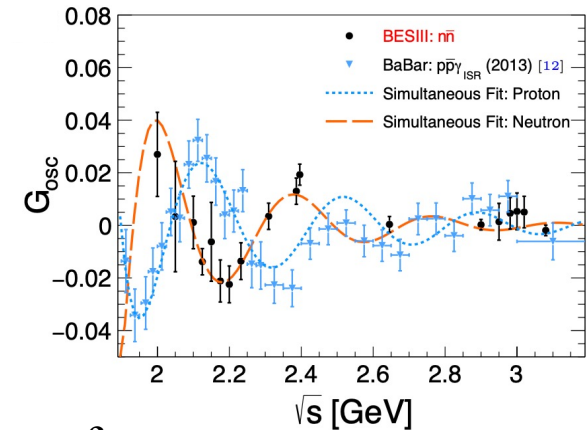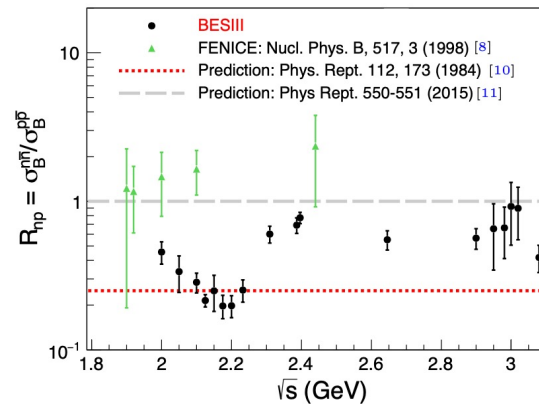
- Most accurate measurements for Born cross section and |G| form factor
- The ratio R_{np} is not consistent with FENICE results
- An oscillatory behavior of the effective form factor (observed for the proton) is discussed for the neutron

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Measurement of proton EFFs using ISR method
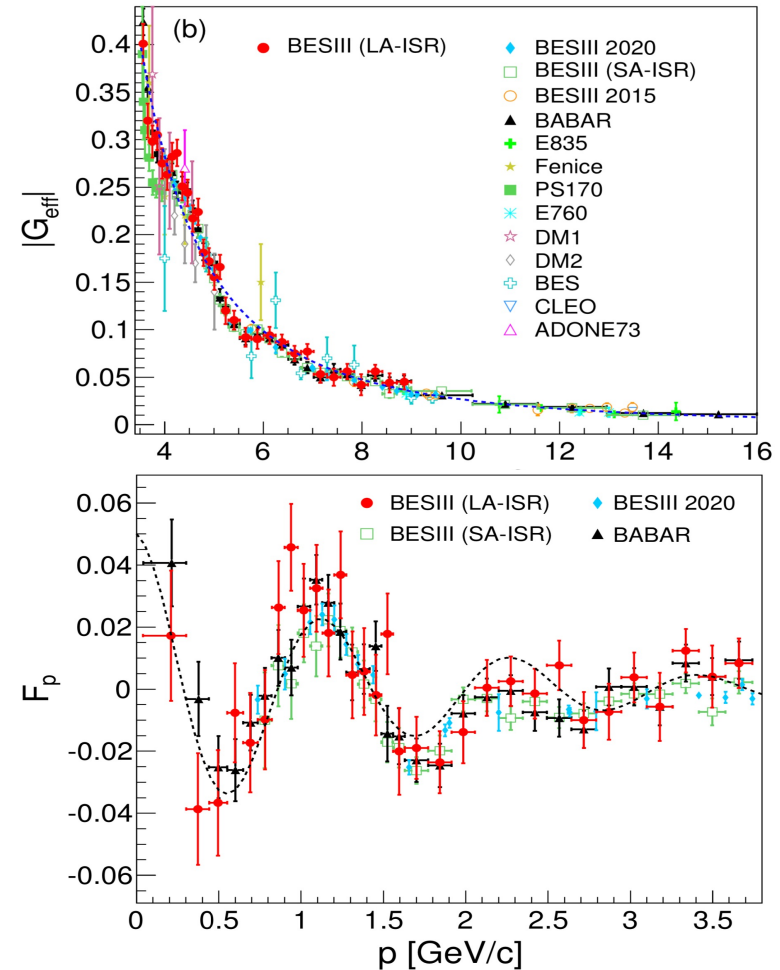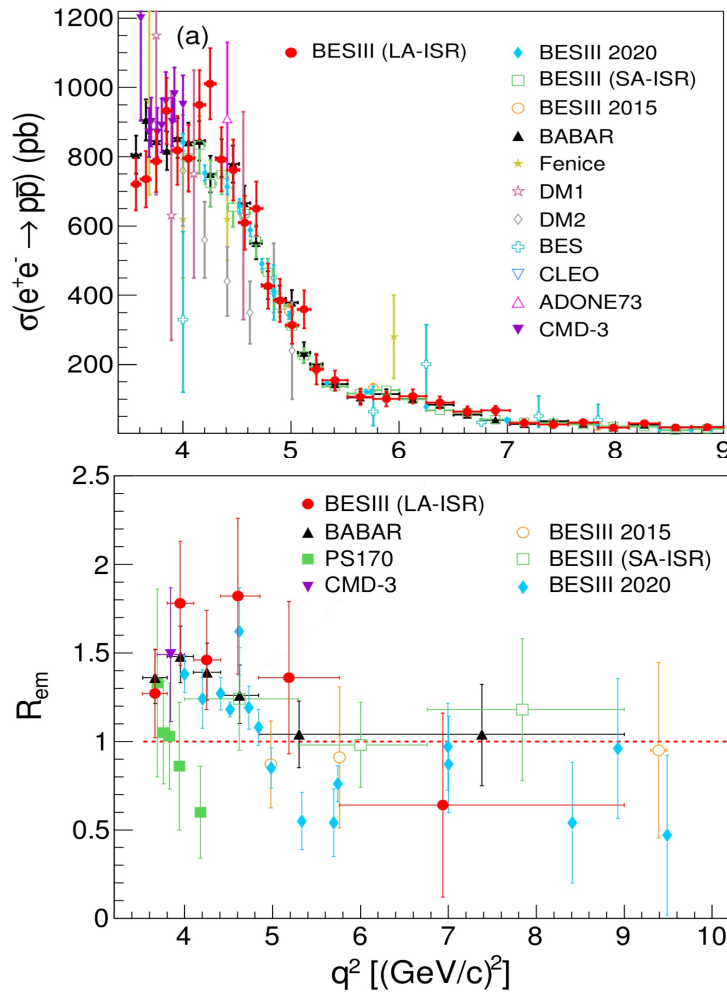
- **Oscillating structure:** a) Interference effect involving re-scattering processes in the final state; b) Independent resonant structures
- **Results are consistent with previous experiments and parameterization**

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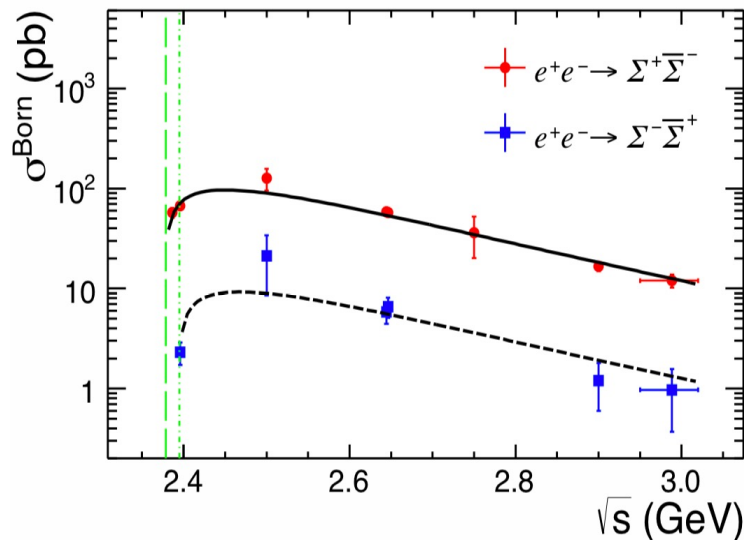
- **No obvious enhancement near threshold**
- **Nonzero cross sections near threshold**
- **The cross sections for $\Sigma^\pm\overline{\Sigma}^\mp$ baryon pairs disagree with each other within the sector of isospin conservation**
- **First measurements in the off-resonance region, provide precision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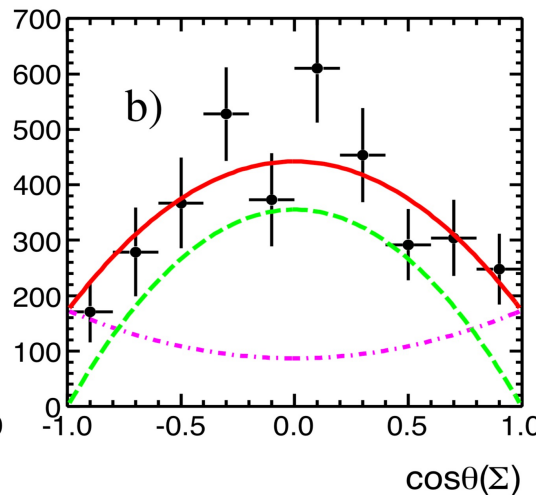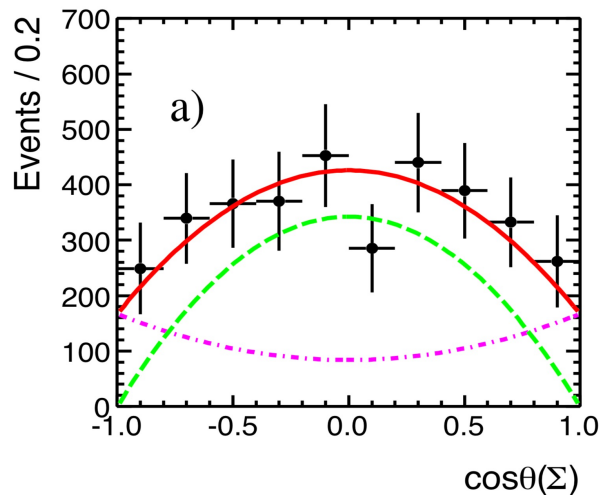
First measurement for the ratio of EM form factors at point $\sqrt{s} = 2.396\text{GeV}$ with a study of angular distribution

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

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

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

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

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

Effective form factor

$Y(4230) \to \Xi^-\bar{\Xi}^+$ ~2.7σ

$Y(4260) \to \Xi^-\bar{\Xi}^+$ ~2.7σ
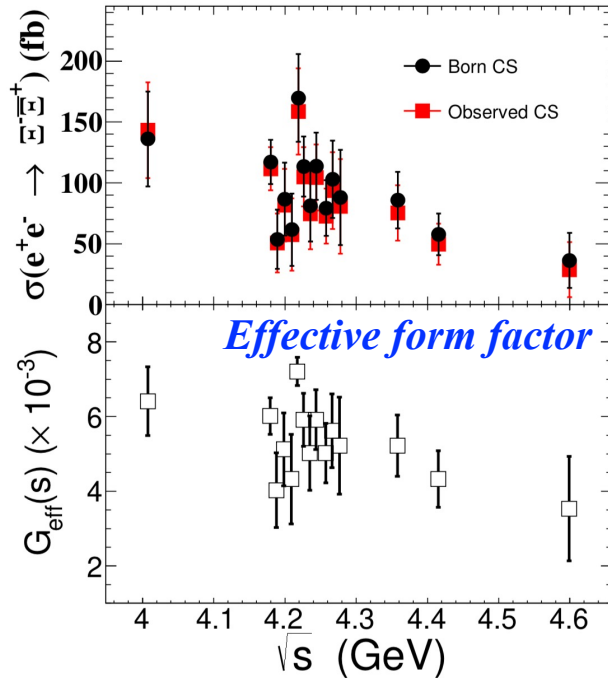
$e^+e^- \to \Xi^-\bar{\Xi}^+$

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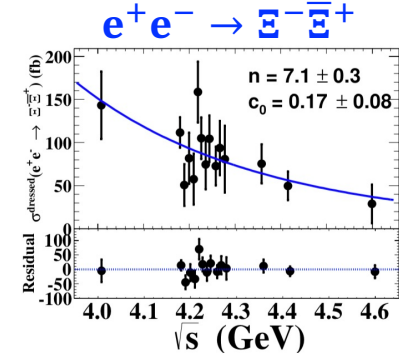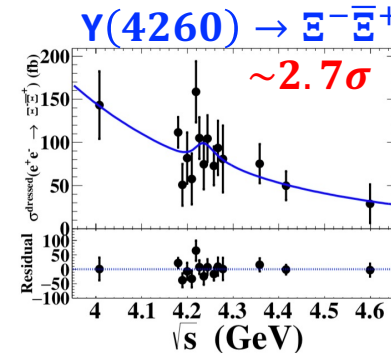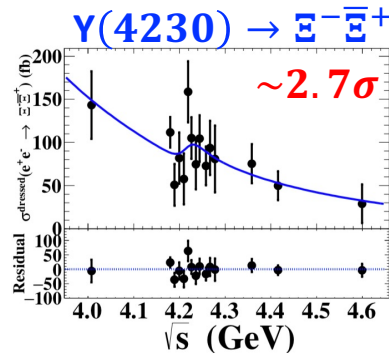
■ **No obvious significances for $\psi(4230/4260)$ are observed in the $\Xi^-\bar{\Xi}^+$ final states**

$$\Gamma_{ee}B[Y(4230) \to \Xi^-\bar{\Xi}^+] < 0.33 \times 10^{-3} eV$$
$$\Gamma_{ee}B[Y(4260) \to \Xi^-\bar{\Xi}^+] < 0.27 \times 10^{-3} eV$$

■ **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 $e^+e^- \to \Xi^-\overline{\Xi}^+$ above open charm

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

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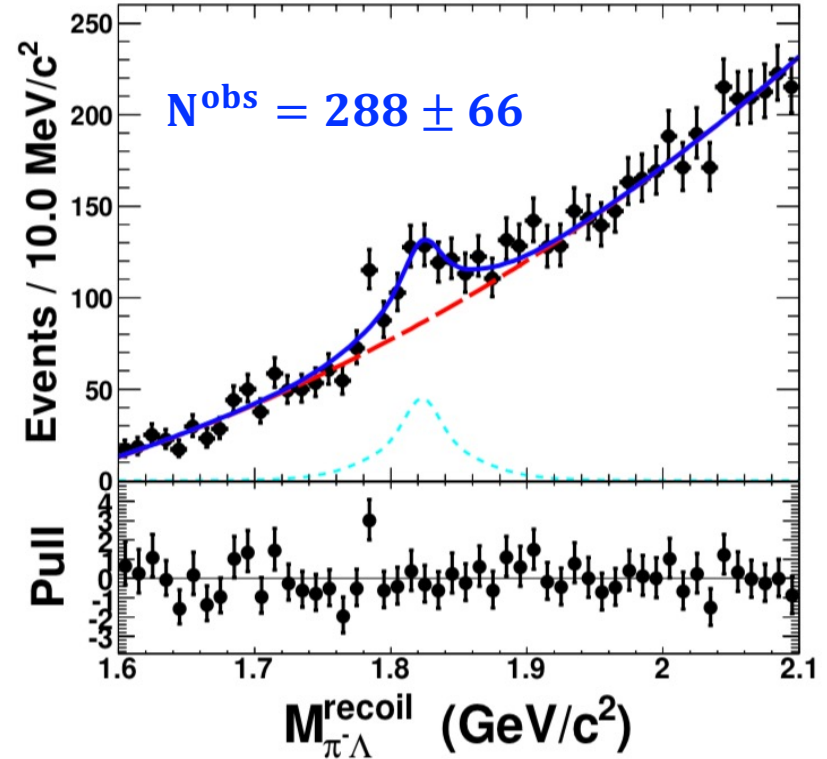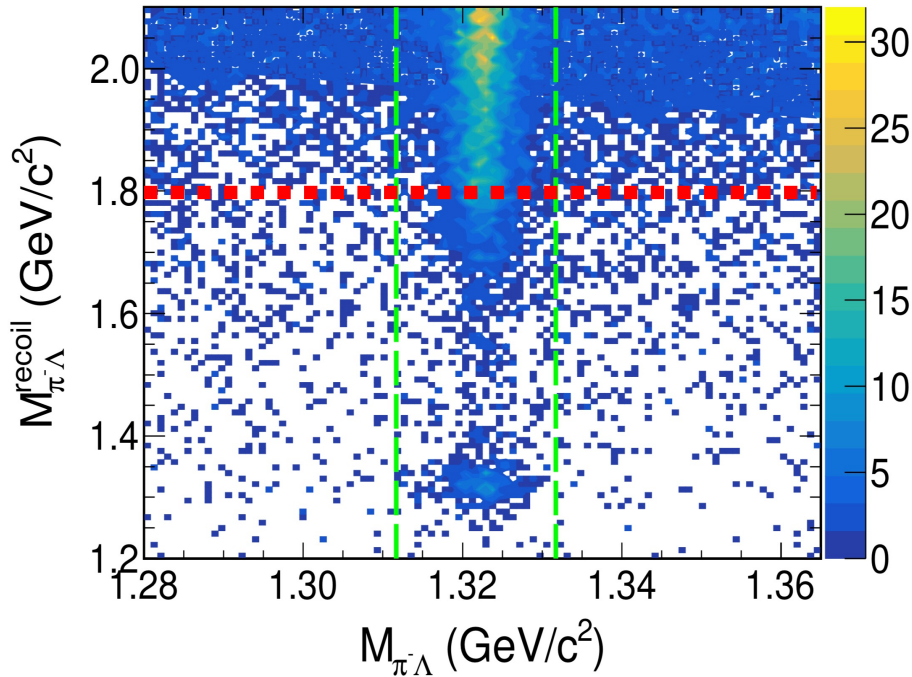
□ **Observed $e^+e^- \to \Xi^{\mp}X(1820)$ with 6.2σ significance**

$$M = (1825.5 \pm 4.7 \pm 4.7)\text{GeV}$$

$$\Gamma = (17.0 \pm 15.0 \pm 7.9)\text{MeV}$$

□ **Consistent with the mass and width of Ξ(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**
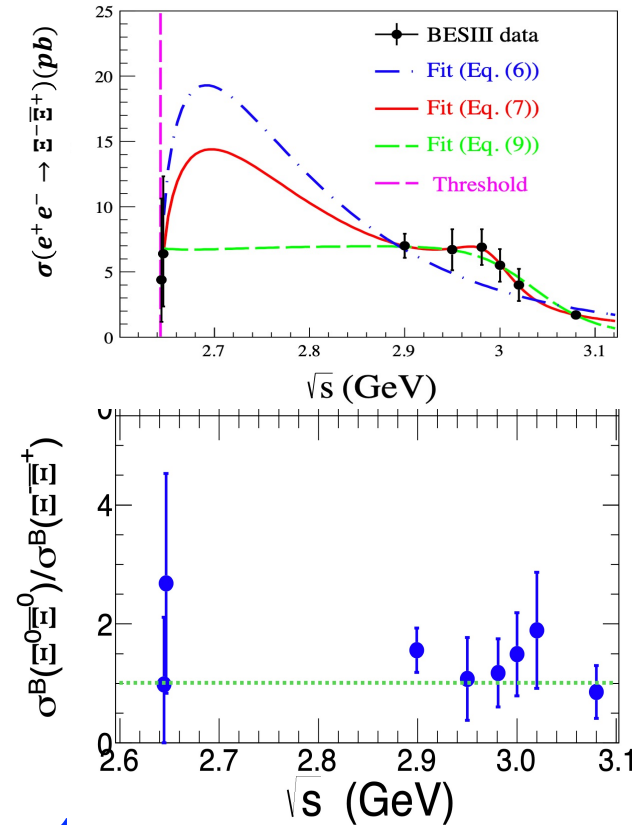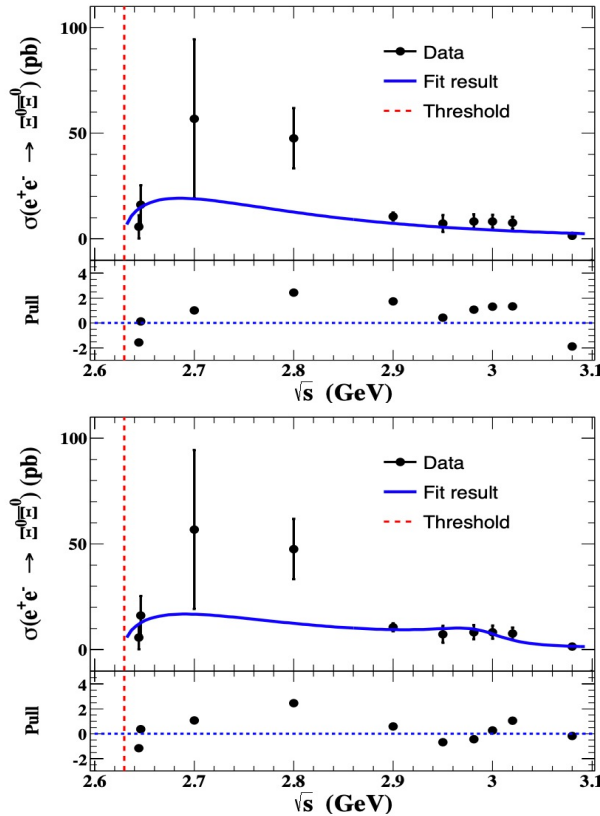
■ **No obvious $\Xi\bar{\Xi}$ threshold enhancement**
■ **The ratio of Born cross sections for both modes agrees with the expectation of isospin symmetry.**

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 $B\bar{B}$ production in Charmonium decay and in e^+e^- annihilation achieved:**
  - ✓ More new observation for $B\bar{B}$ production in Charmonium decay
  - ✓ Hyperon polarization observation
  - ✓ Most accurate measurement for neutron and proton form factor
  - ✓ More new/precise study for baryon pair production near threshold
  - ✓ Still need more experimental/theoretical efforts
- **More new results for $B\bar{B}$ pair production in Charmonioum decay and in e^+e^- annihilation are on the way!**
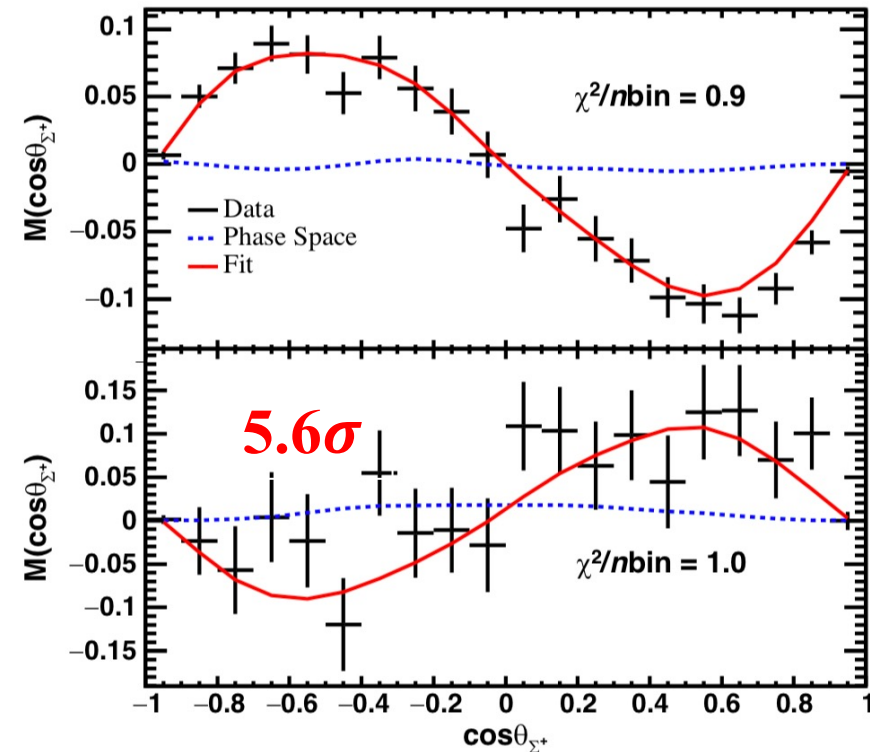
谢谢

积石堂

Backup

Observation of Σ^+ hyperon spin polarization in $\psi \to \Sigma^+\overline{\Sigma}^-$

Data Sample: 1310M J/ψ & 448M ψ(3686)

Phys. Rev. Lett. 125, 052004 (2020)

Moment: $M(\cos\theta) = \frac{m}{N}\sum_i^{N(\theta_\Sigma)}(\sin\theta_p^i \sin\phi_p^i - \sin\theta_{\bar{p}}^i \sin\phi_{\bar{p}}^i)$

Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

Test of CP violation:

$$A_{CP} = \frac{\alpha_0 + \bar{\alpha}_0}{\alpha_0 - \bar{\alpha}_0} = -0.015 \pm 0.037 \pm 0.008 \approx 0?$$

Observation of Λ hyperon spin polarization in J/ψ → ΛΛ̄

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

- **Moment corresponds to the polarization calculated for 50 bins in $cos\theta$.**
- **A clear polarization signal, strongly dependent on the Λ direction $cos\theta$ is observed for Λ and Λ̄.**

Highlights!

Observation of Λ hyperon spin polarization in J/ψ → ΛΛ̄

Data Sample: 1310M J/ψ

Nature Physics **15**, 631 (2019)

First observation of a transverse polarization.

>5σ difference (17% higher than) to PDG

Test of CP violation:
$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$$

Table 1 | Summary of the results

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 (ref. [14])
$\Delta\Phi$	$42.4 \pm 0.6 \pm 0.5°$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 (ref. [6])
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 (ref. [6])
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 (ref. [6])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

- ■ **Most sensitive test of CP violation for Λ baryons with precision over previous measurements.**
- ■ **BESIII has collected 10B J/ψ data sample, test of CP violation in baryon decays are hopeful to reach sensitivities $\left(A_{CP}^{SM} \approx 10^{-4}\right)$.**