Recent Progresses on Baryon Pair Production at BESIII

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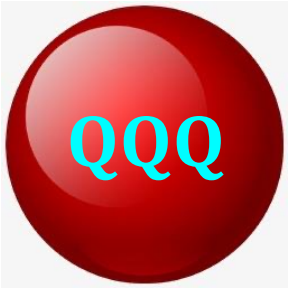
July 14th, 2021

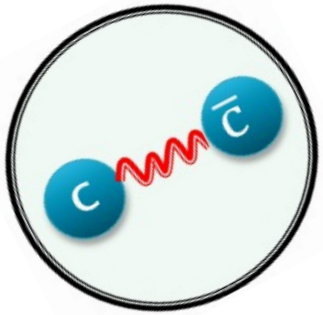
Outline

- **Introduction**
- **Recent results**
  - **$B\bar{B}$ production in Charmonium decay**
    - ✓ $J/\psi \to \Lambda\bar{\Lambda}$
    - ✓ $J/\psi, \psi(3686) \to \Sigma^+\bar{\Sigma}^-$
    - ✓ $J/\psi \to \Xi^-\bar{\Xi}^+$
    - ✓ $\psi(3686) \to \Xi(1530)^-\,\bar{\Xi}(1530)^+$
    - ✓ $\psi(3686) \to \Omega^-\bar{\Omega}^+$
  - **$B\bar{B}$ production in e^+e^- annihilation**
    - ✓ $e^+e^- \to N\bar{N}$
    - ✓ $e^+e^- \to \Lambda\bar{\Lambda}$
    - ✓ $e^+e^- \to \Sigma^{\pm}\bar{\Sigma}^{\mp}$
    - ✓ $e^+e^- \to \Xi^0\bar{\Xi}^0, \Xi^-\bar{\Xi}^+$
- **Summary**

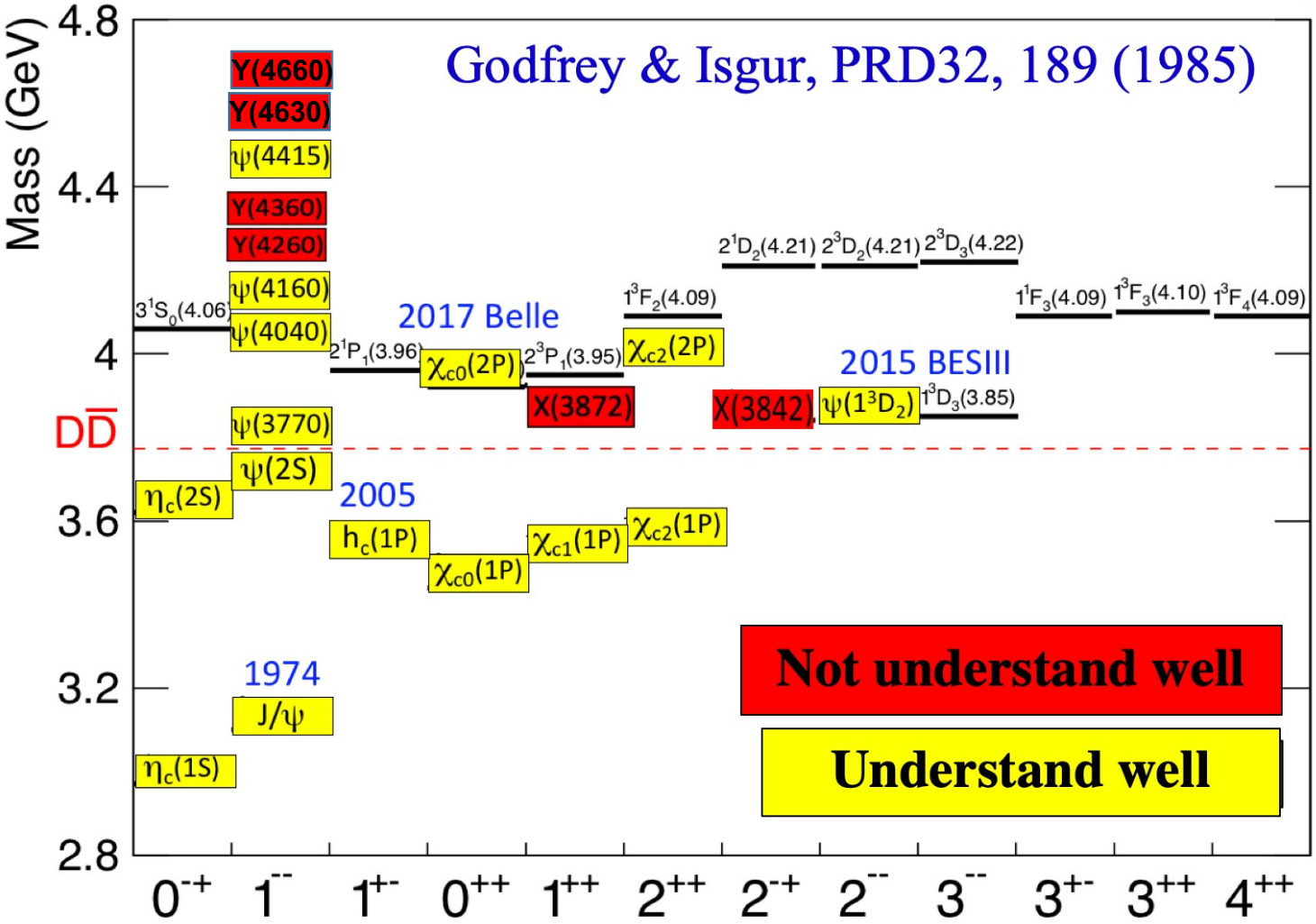


Baryon (B)

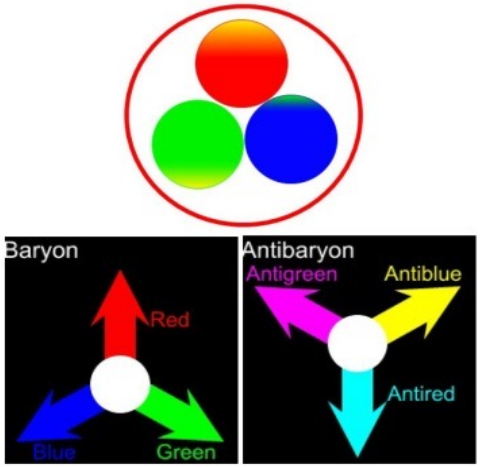
Charmonium (-like) states

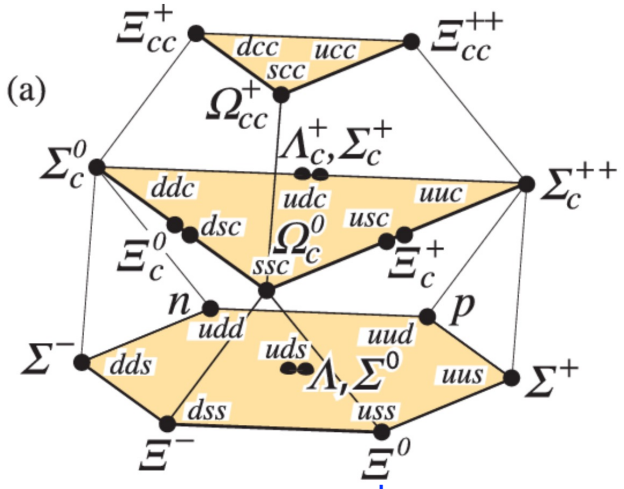


- **Nonrelativistic $c\bar{c}$ bound states**
  - $J/\psi\ (1^3S_1)$, first member with $J^{PC} = 1^{--}$(1974)

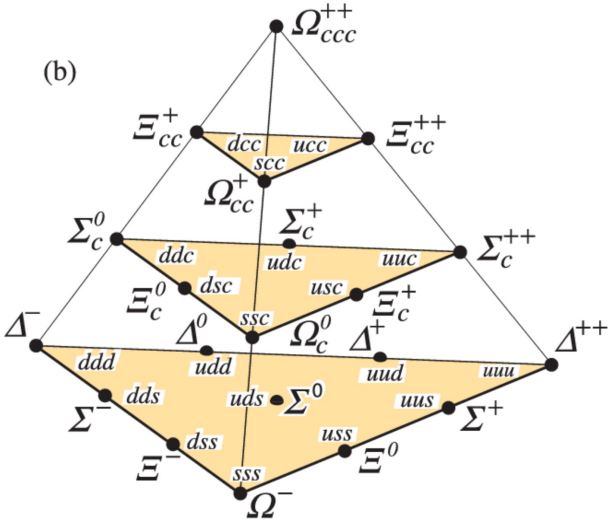


Baryon States

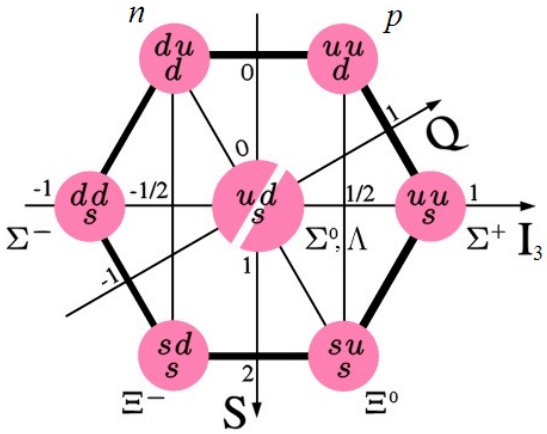




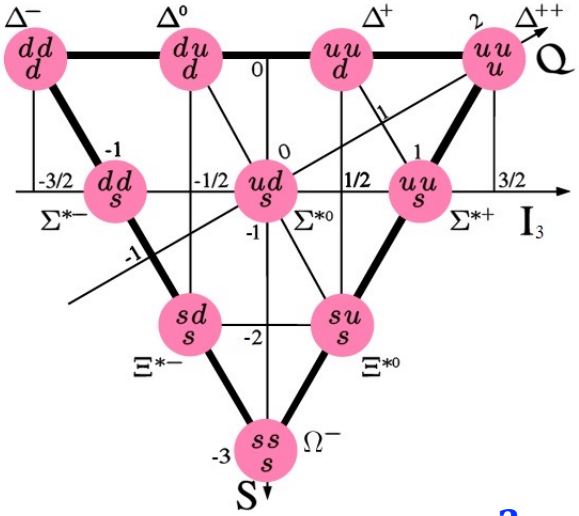
$(J^P = \frac{1^+}{2})$



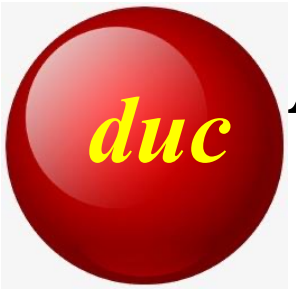
$(J^P = \frac{3^+}{2})$



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



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

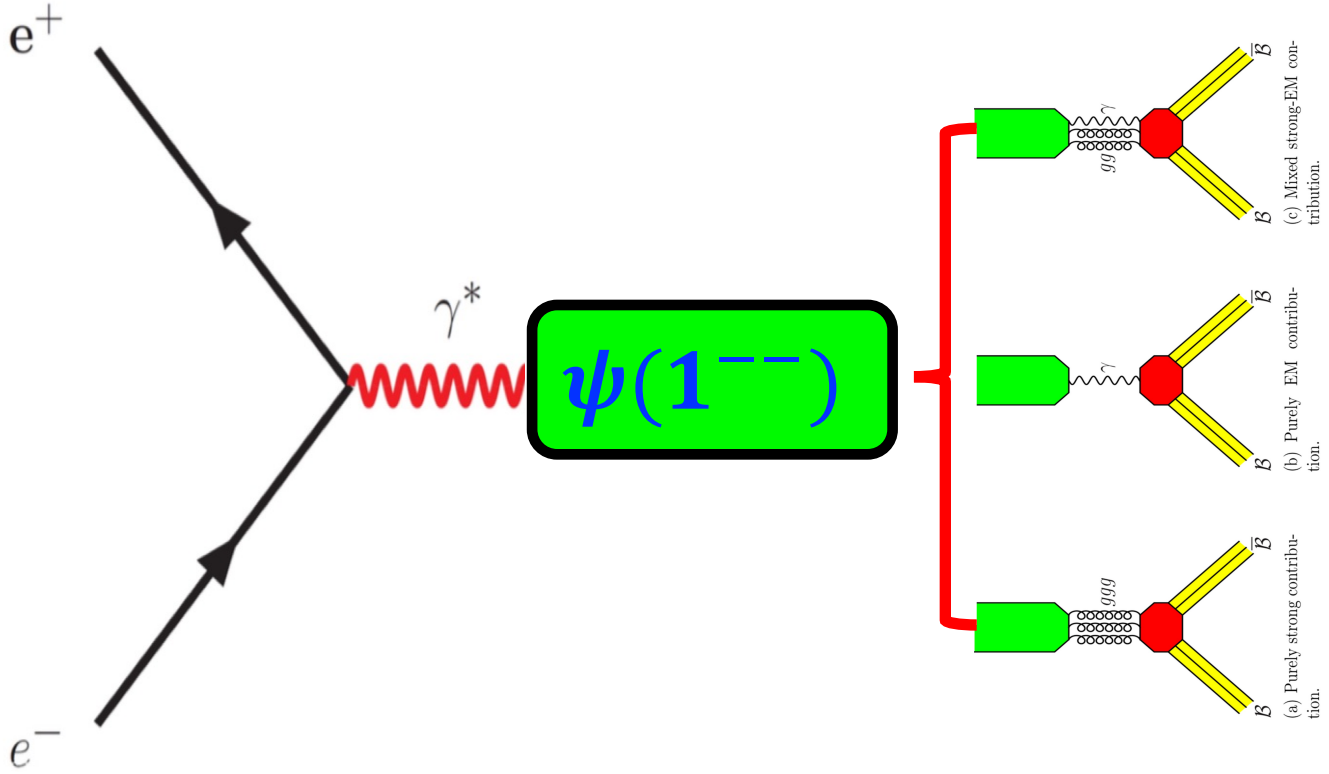


Λ_c^+

M = 2286.46 ± 0.14 MeV

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

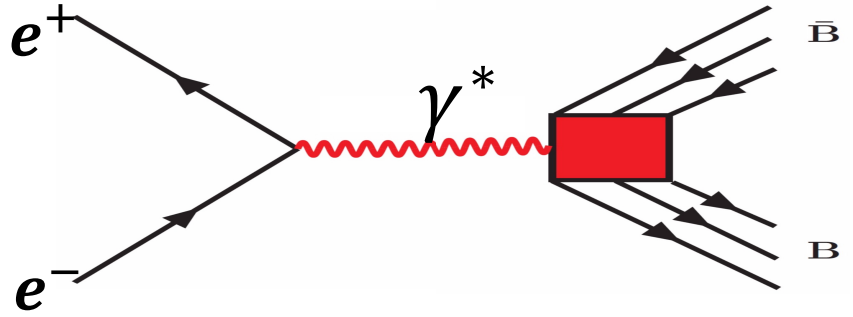
- Main Feynman Diagrams



- Provide a rich laboratory to prob both pQCD and non-pQCD, the hyperon properties

$B\bar{B}$ 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, $G_{E/G}$)**

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

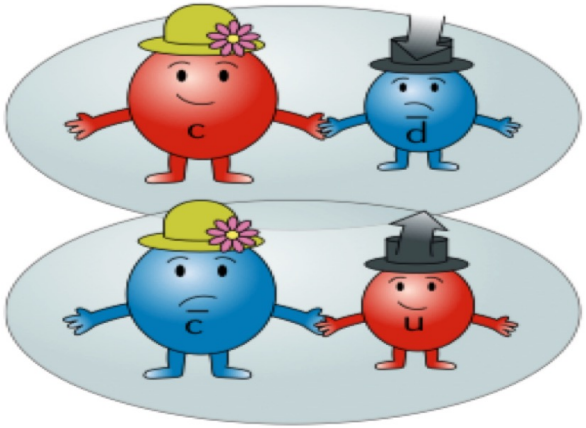
$$R = |\frac{G_E(s)}{G_M(s)}| = \sqrt{\frac{\tau(1-\eta)}{1+\eta}} \quad \left(\frac{d\sigma^B(s)}{d\cos\theta} \propto 1+\eta\cos^2\theta\right)$$

Understand the internal structure of hadron

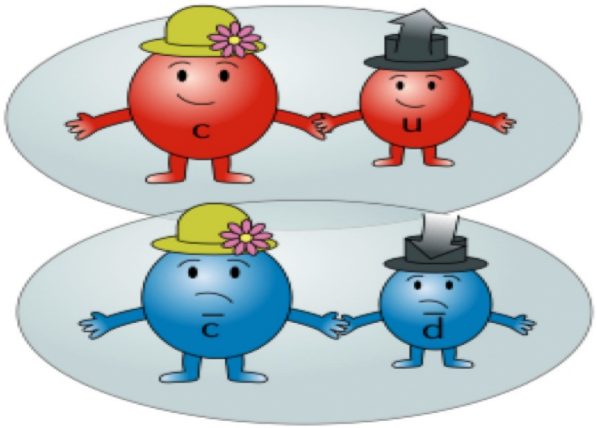
Provide extra insights for Charmonium(-like) states

Non-standard hadron model

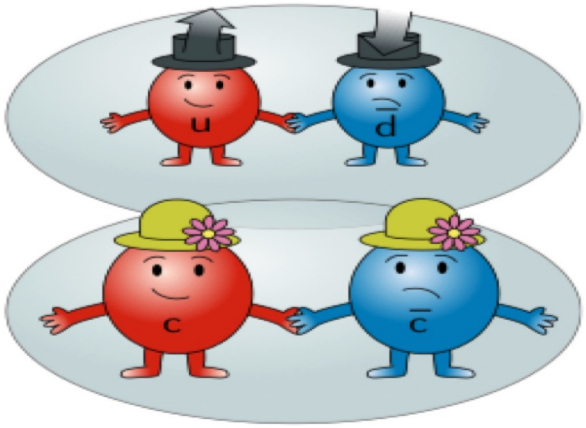
C. Z. Yuan S. L. Olsen, Nature Rev. Phys. 1 (2019) no.8, 480-494



Molecule

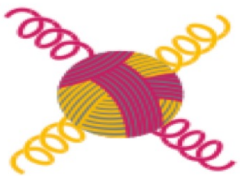


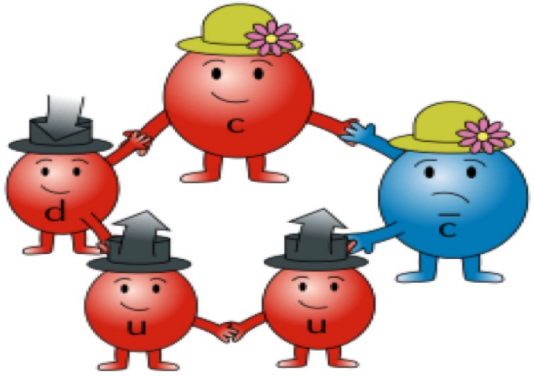
Tetraquark



Hadro-quarkonium

Hybrid


Glueball



Pentaquark

- **Which one is the winner?**

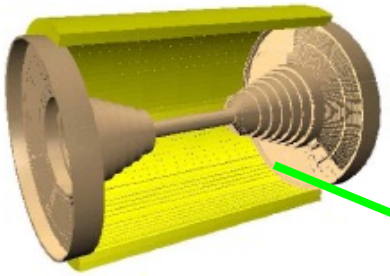
Beijing Electron Positron Collider-II

Beam energy: 1-2.5 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: $1.0\times10^{33}\ cm^{-2}s^{-1}$

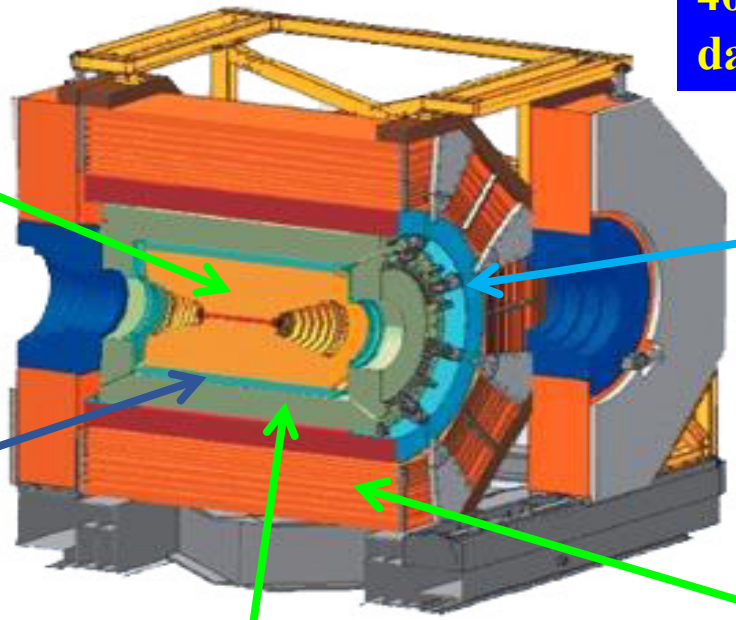
Beijing Spectrometer-III detector

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

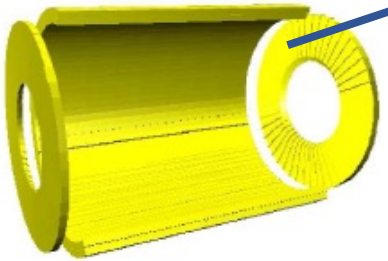


(Main Drift Chamber)

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

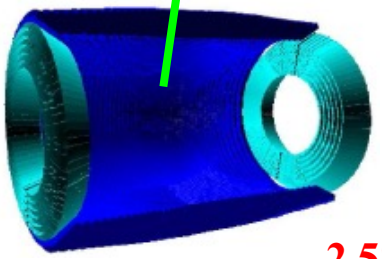


Super-conducting magnet (1.0 tesla)



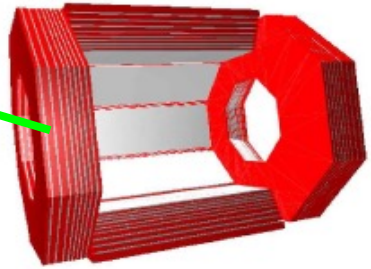
(Time-Of-Flight System)

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



2.5%@1GeV

(Electromagnetic Calorimeter)



(Muon counter)

(made of 9 RPCs)

BESIII Collaboration

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

~500 members

From 80 institutions in 17 countries

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    - ✓ $J/\psi \to \Lambda\bar{\Lambda}$
    - ✓ $J/\psi, \psi(3686) \to \Sigma^+\bar{\Sigma}^-$
    - ✓ $J/\psi \to \Xi^-\bar{\Xi}^+$
    - ✓ $\psi(3686) \to \Xi(1530)^-\,\bar{\Xi}(1530)^+$
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  - $B\bar{B}$ production in e^+e^- annihilation
    - ✓ $e^+e^- \to N\bar{N}$
    - ✓ $e^+e^- \to \Lambda\bar{\Lambda}$
    - ✓ $e^+e^- \to \Sigma^{\pm}\bar{\Sigma}^{\mp}$
    - ✓ $e^+e^- \to \Xi^0\bar{\Xi}^0, \Xi^-\bar{\Xi}^+$
- Summary

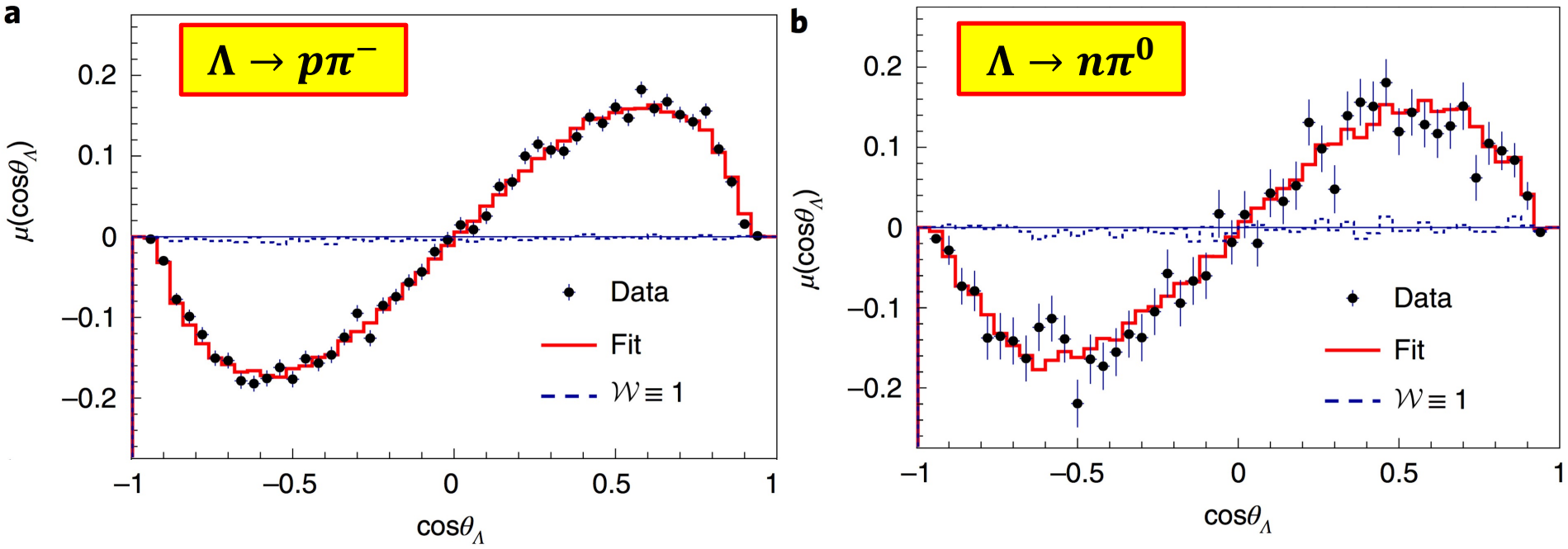
Baryon (B)

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

Data Sample: 1310M J/ψ

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

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 $\bar{\Lambda}$.

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

Data Sample: 1310M J/ψ

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

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])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	-

First observation of a transverse polarization.

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

Test of CP violation:

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

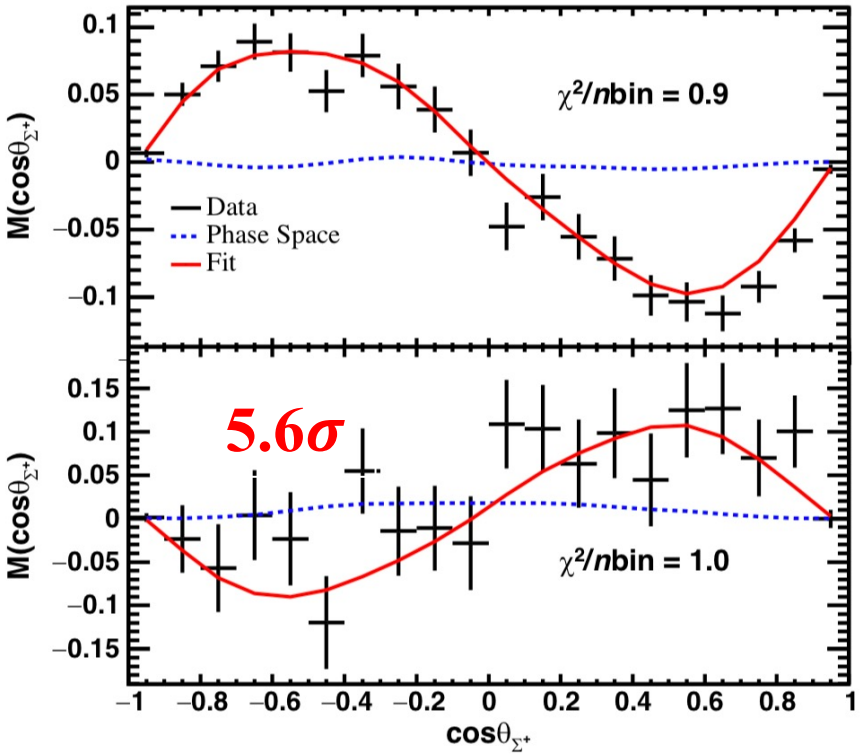
- **Most sensitive test of CP violation for Λ baryons with precision over previous measurements.**
- **BESIII has collected 10B J/ψ data sample, test of CP violation in baryon decays are hopeful to reach sensitivities $\left(A_{CP}^{SM} \approx 10^{-4}\right)$.**

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

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:

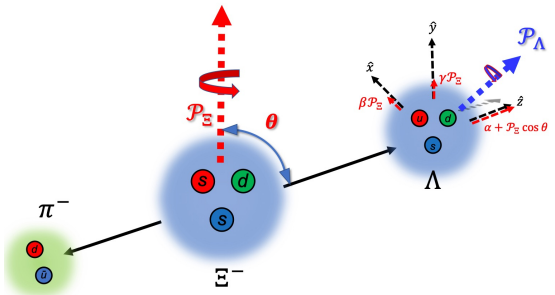
$$A_{CP} = \frac{\alpha_0 + \bar{\alpha}_0}{\alpha_0 - \bar{\alpha}_0} = -0.015 \pm 0.037 \pm 0.008 \approx 0?$$

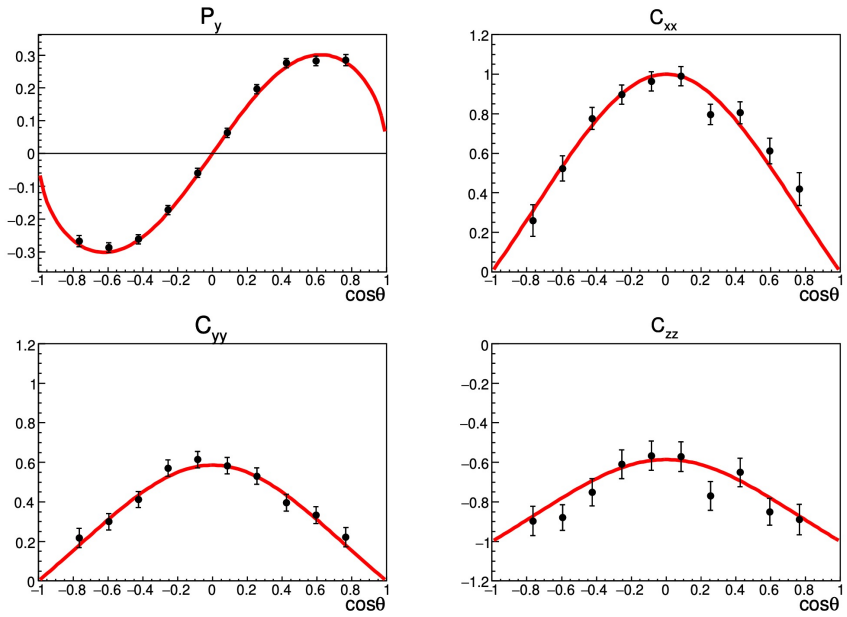
Observation of Ξ^- hyperon spin polarization in $J/\psi \to \Xi^-\bar{\Xi}^+$

Data Sample: 1310M J/ψ

Submitted to Nature

arXiv:2105.11155





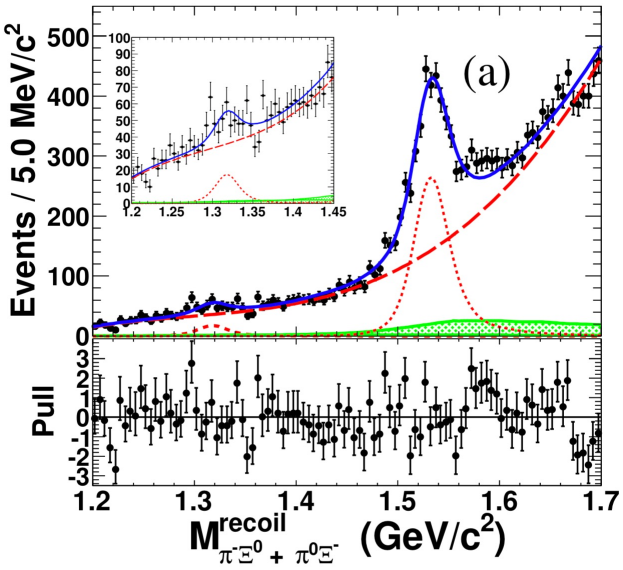
Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	[39]
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	[21]
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad	-0.037 ± 0.014 rad	[21]
$\bar{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	–	
$\bar{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ 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		

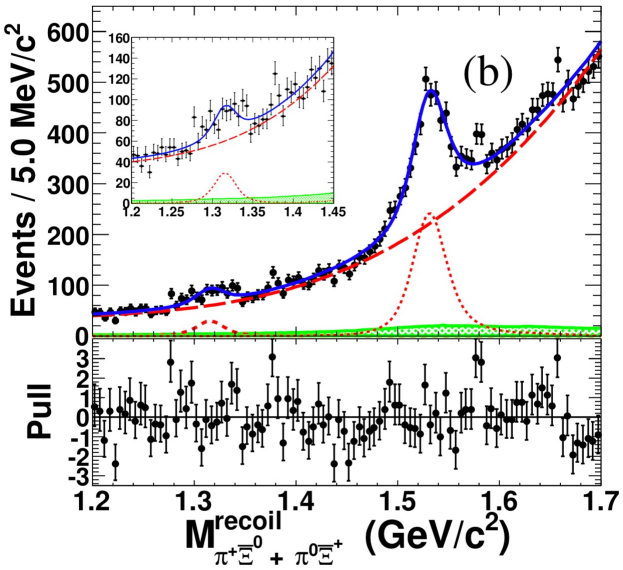
- **Observation of Ξ^- spin polariztion, non-zero weak phase difference**
- **The most precise test for CPV on strange baryon decay**

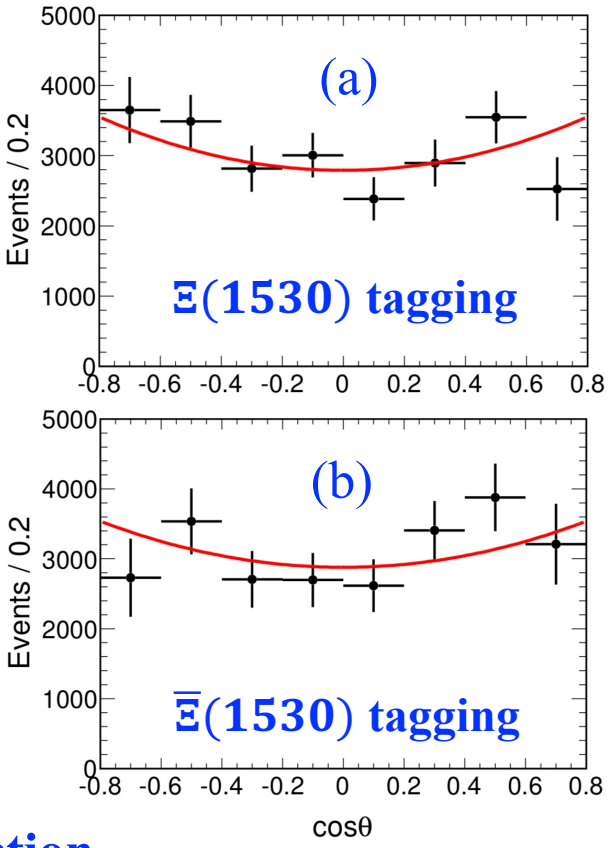
Observations of $\psi(3686) \to \Xi(1530)^-\bar{\Xi}(1530)^+$ and $\Xi(1530)^-\bar{\Xi}^+$

Data Sample: 448M ψ(3686)

PRD100, 051101(RC) (2019)







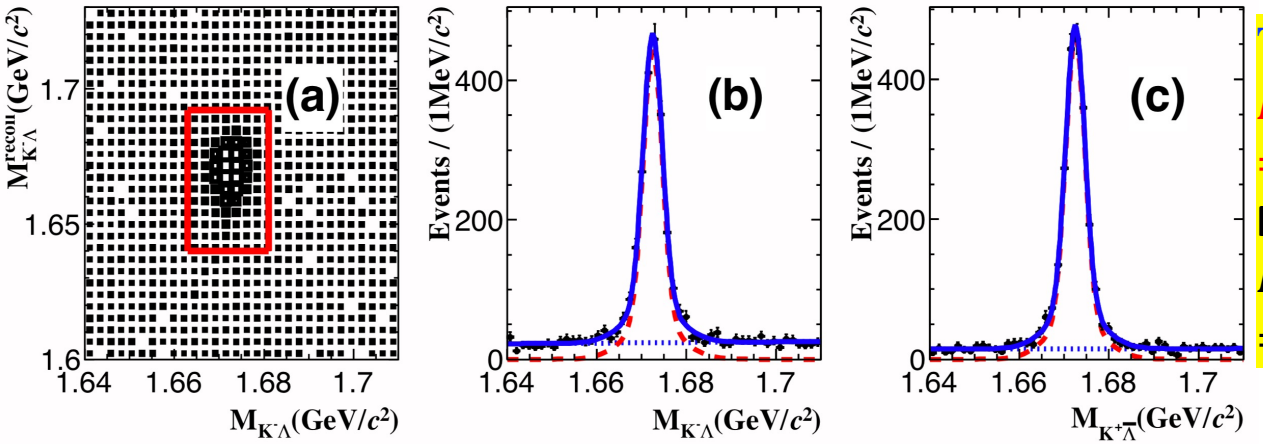
- **Observation for SU(3) broken process**
- **The measured α value favors the theoretical prediction**
  - **Quark mass effect, SU(3) violated effect, Electro-magnetic effect, etc.**
- **Provide new input to test pQCD.**

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:

$Br[\psi(2S) \to \Omega^-\bar{\Omega}^+] = (5.82 \pm 0.12 \pm 0.24)\times 10^{-5}$

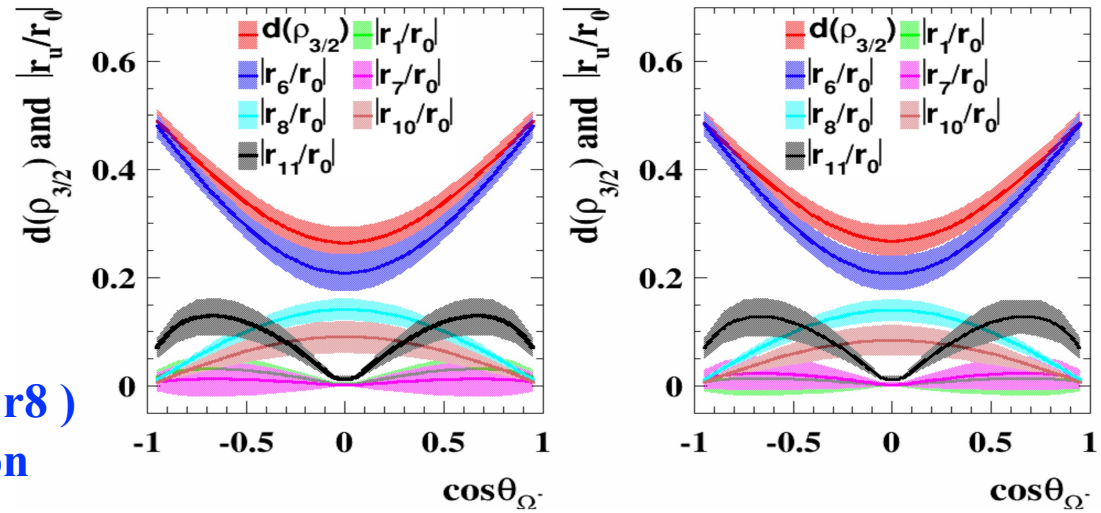
PDG value:

$Br[\psi(2S) \to \Omega^-\bar{\Omega}^+] = (5.2 \pm 0.4)\times 10^{-5}$

The degree of polarization for Ω^- baryon is determined (Two solutions)

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

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



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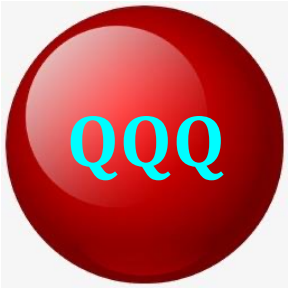
    - ✓ $e^+e^- \to \Xi^0\bar{\Xi}^0, \Xi^-\bar{\Xi}^+$
- **Summary**



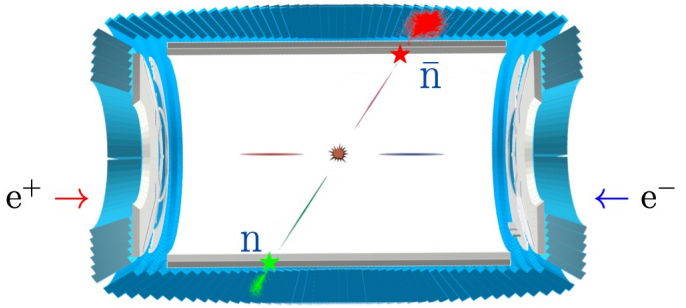
Baryon (B)

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

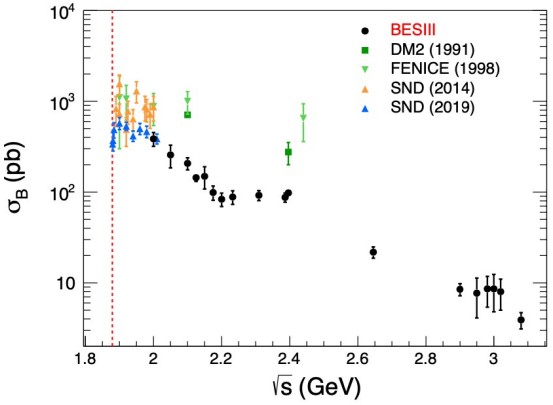
Data Sample: 650/pb, 18 points from 2.00 to 3.08 GeV

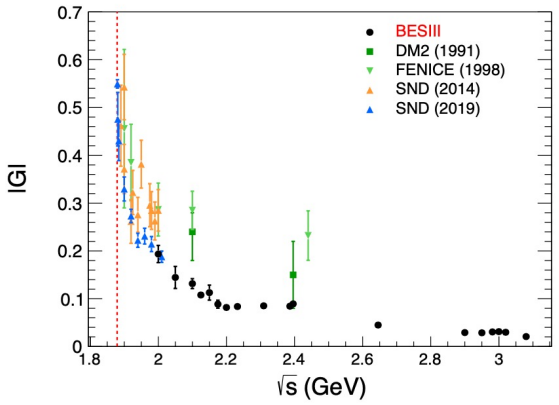
Accepted by Nature Physics

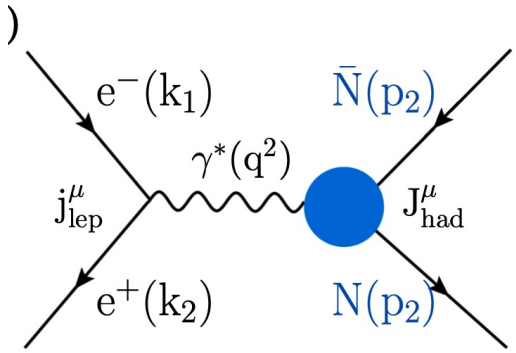
arXiv:2103.12486



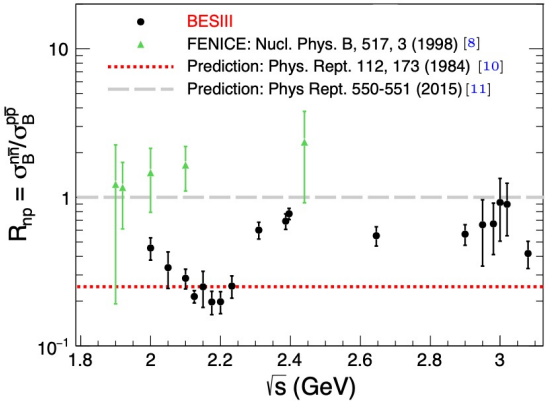
Typical response for signal process

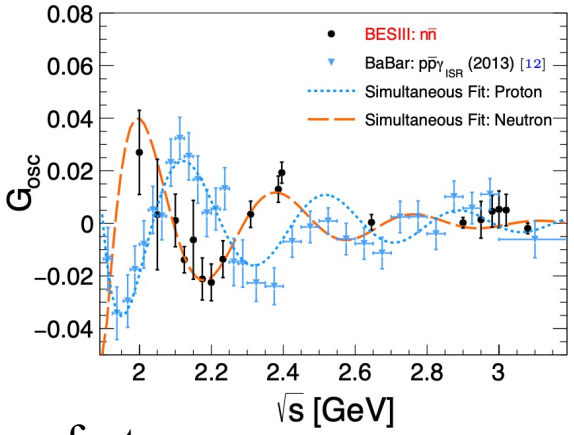






Lowest order Feynman diagram



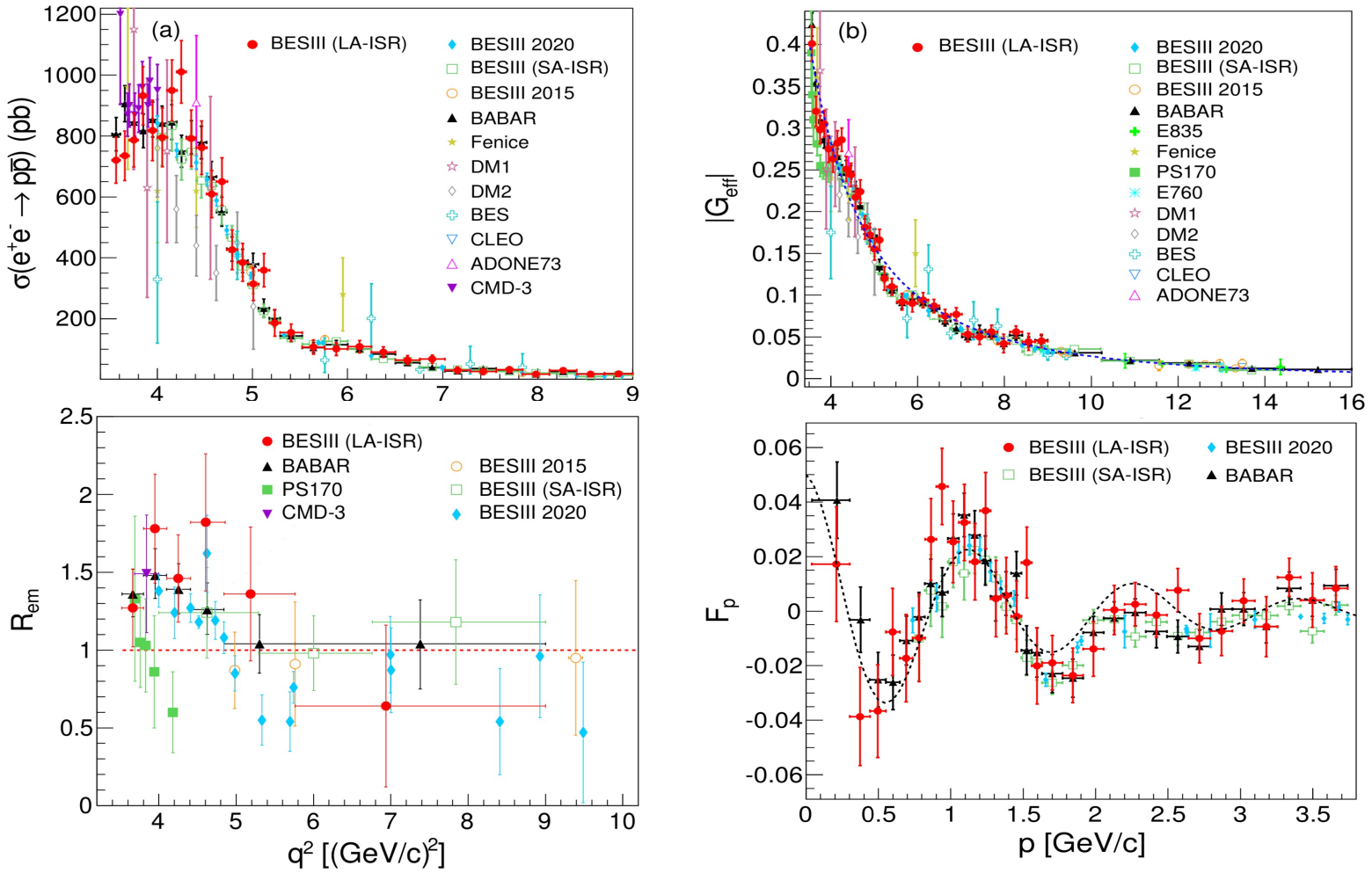


- Most accurate measurements for Born cross section and |G| form factor
- The ratio R_{np} is not consistent with FENICE results
- An oscillatory behavior of the effective form factor (observed for the proton) is discussed for the neutron

Measurement of proton EFFs using ISR method

Data Sample: 7.4/pb @ $\sqrt{s}$ = 3.773 to 4.6 GeV

Phy. Lett. B 817 (2021) 136328

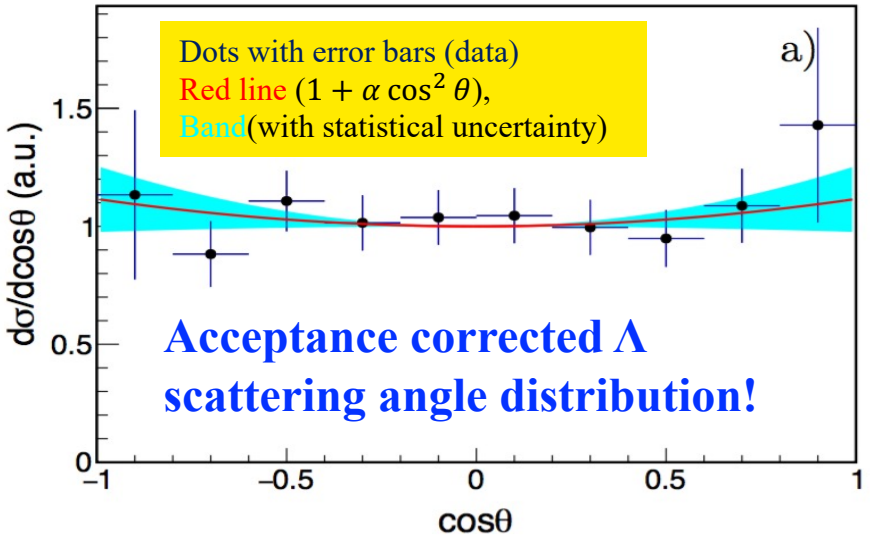


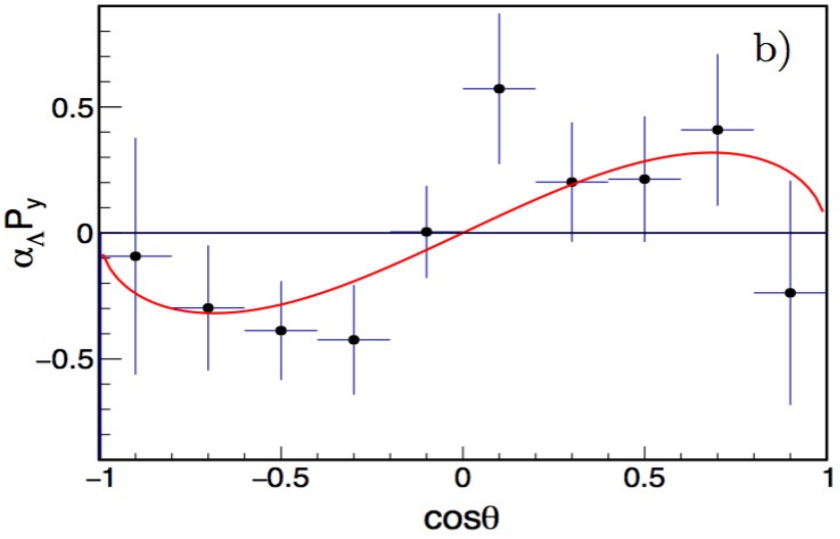
- **Oscillating structure**：a) Interference effect involving re-scattering processes in the final state；b) Independent resonant structures
- **Results are consistent with previous experiments and parameterization**

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

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

PRL 123,122003 (2019)





Numerical Results

$$\sigma = 118.7 \pm 5.3 \pm 5.1$$

$$|G_{eff.}| = 0.123 \pm 0.003 \pm 0.003$$

$$R = \left|\frac{G_E}{G_M}\right| = 0.96 \pm 0.14 \pm 0.02$$

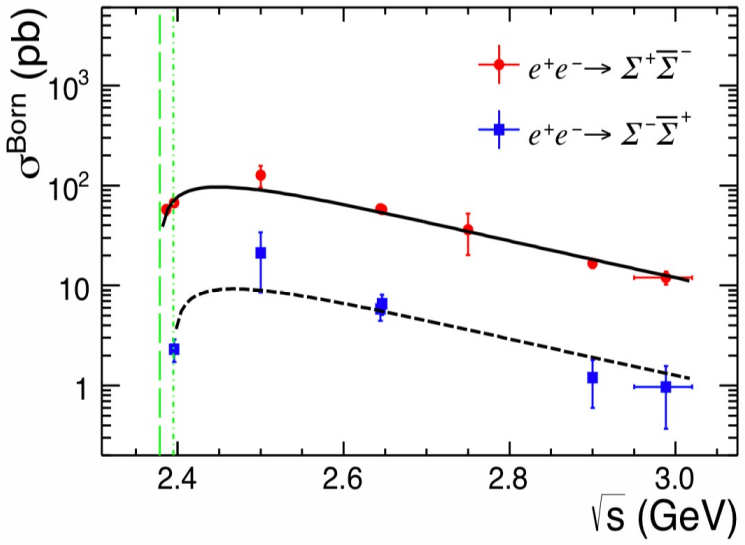
$$\Delta\Phi = \Phi_E - \Phi_M = 37^o \pm 12^o \pm 6^o$$

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

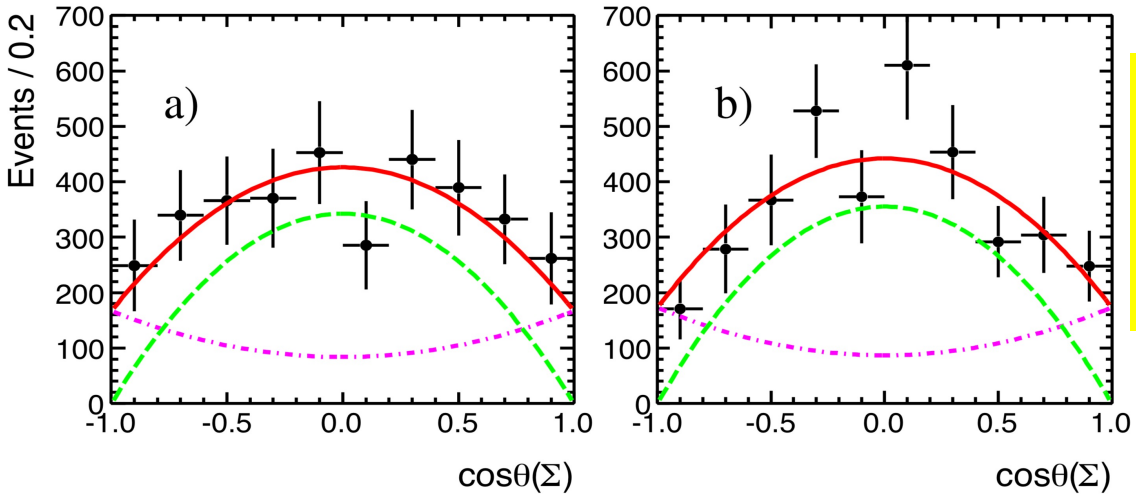
Measurement of $\sigma^B(e^+e^- \to \Sigma^{\pm}\overline{\Sigma}^{\mp})$ near threshold

Data Sample: ~400/pb (6 points: 2.3864 to 3.0200 GeV)

PLB 814,136059 (2021)



- 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



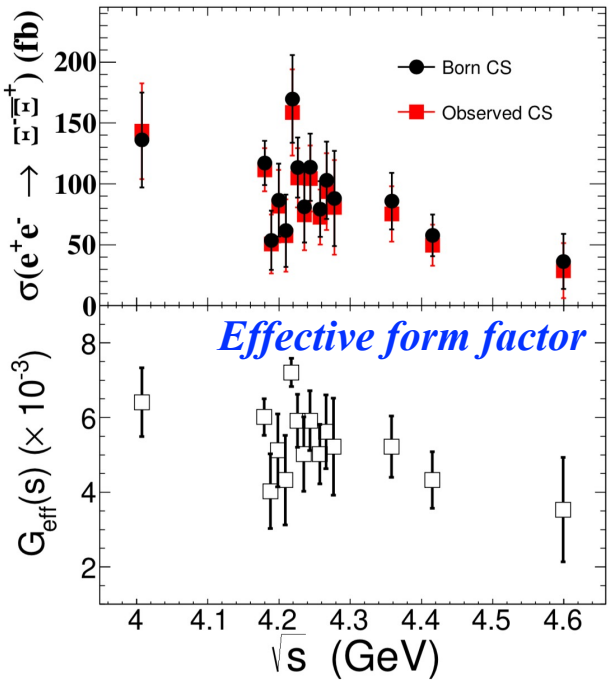
First measurement for the ratio of EM form factors at point $\sqrt{s}$ = 2.396GeV with a study of angular distribution

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

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

Phys.Rev.Lett. 124, 032002, (2020)

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

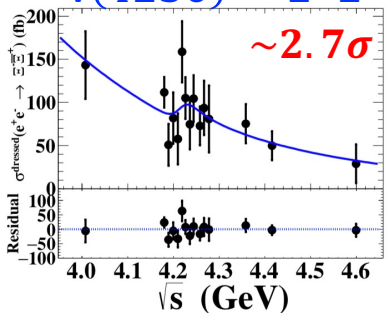


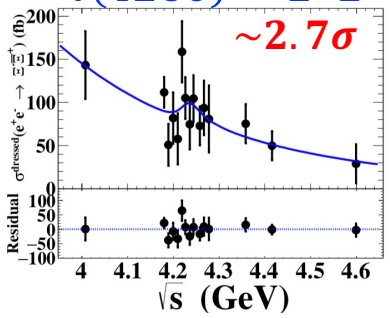
- **A maximum likelihood fit to cross section:**

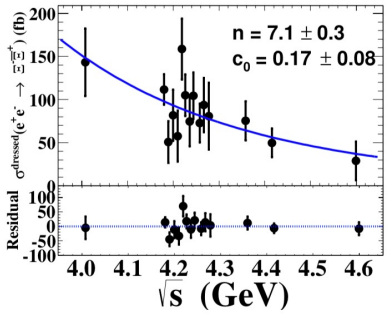
$$\sigma^{\text{dressed}}(\sqrt{s}) = |c_0 \frac{\sqrt{P(\sqrt{s})}}{s^n} + e^{i\phi} BW(\sqrt{s}) \sqrt{\frac{P(\sqrt{s})}{P(M)}}|^2$$

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

$\Upsilon(4230) \to \Xi^-\bar{\Xi}^+$ $\Upsilon(4260) \to \Xi^-\bar{\Xi}^+$ $e^+e^- \to \Xi^-\bar{\Xi}^+$







- **No obvious significances for ψ(4230/4260) are observed in the $\Xi^-\bar{\Xi}^+$ final states**

$$\Gamma_{ee}B[Y(4230) \to \Xi^-\bar{\Xi}^+] < 0.33\times10^{-3}eV$$

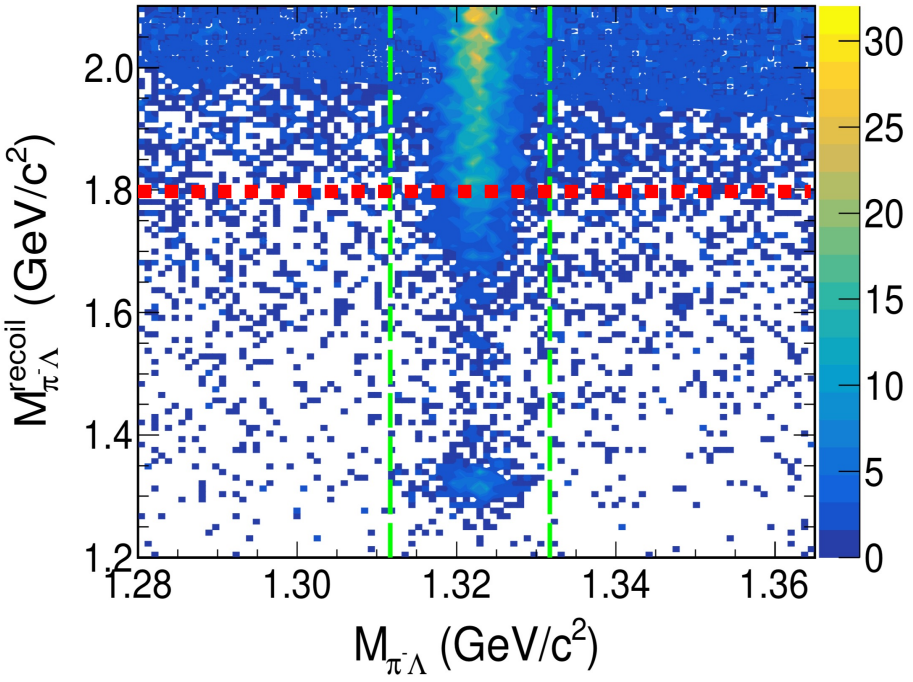
$$\Gamma_{ee}B[Y(4260) \to \Xi^-\bar{\Xi}^+] < 0.27\times10^{-3}eV$$

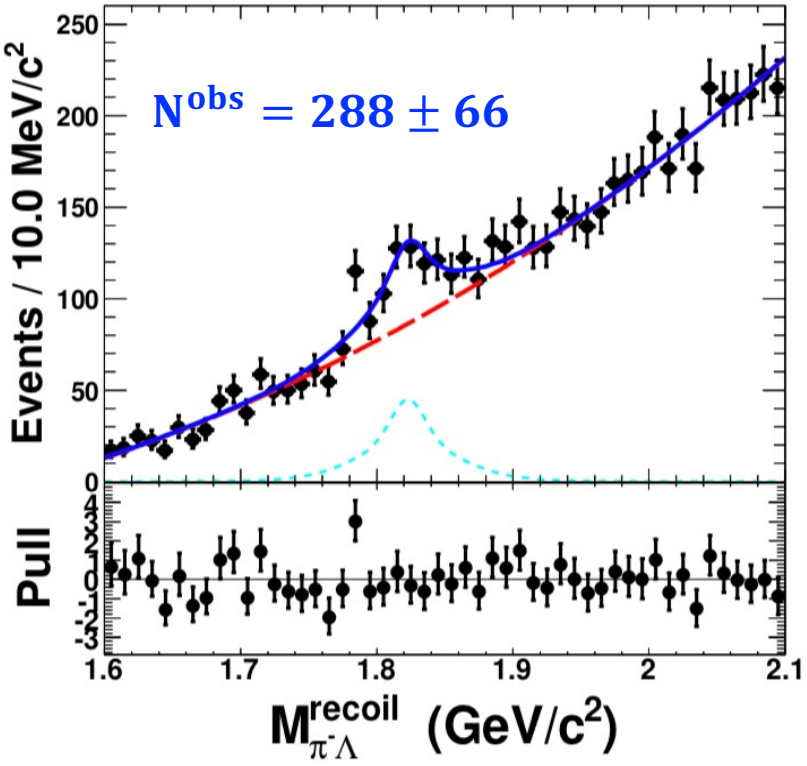
- **Provide more experimental information to understand the nature of Y (4260)**
- **Charmless decays of the Y (4260) are expected by the hybrid model (F. E. Close and P. R. Page, PLB628,215(2005))**

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

Phys.Rev.Lett. 124, 032002, (2020)

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





- **Observed $e^+e^- \to \Xi^{\mp}X(1820)$ with 6.2σ significance**

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

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

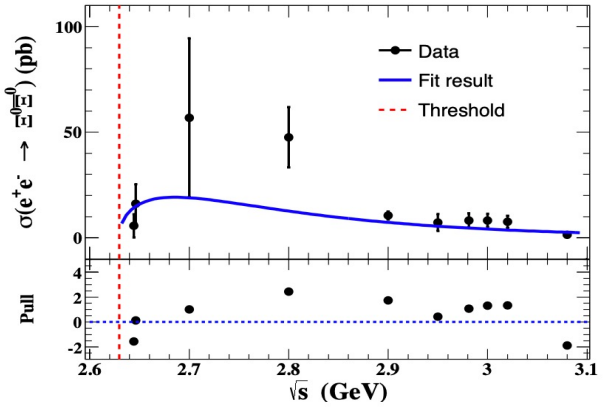
- **Consistent with the mass and width of Ξ(1820) from PDG within the 1σ uncertainty**
- **JPC has not determined due to limited statistics**

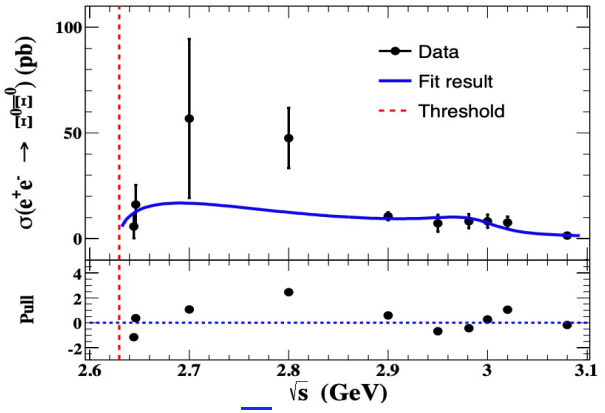
Measurement of $\sigma^B(e^+e^- \to \Xi\bar{\Xi})$ near threshold

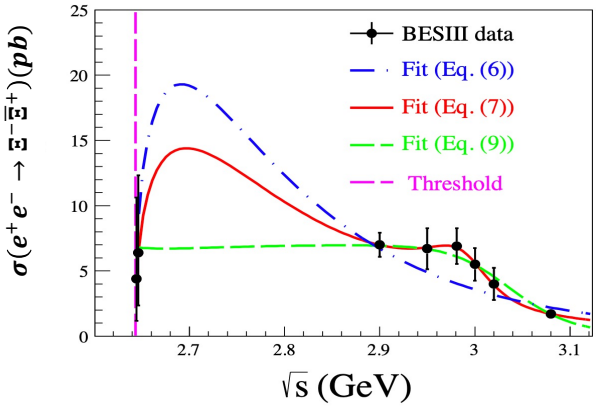
Data Sample: ~360/pb (8 points: 2.644 to 3.080 GeV)

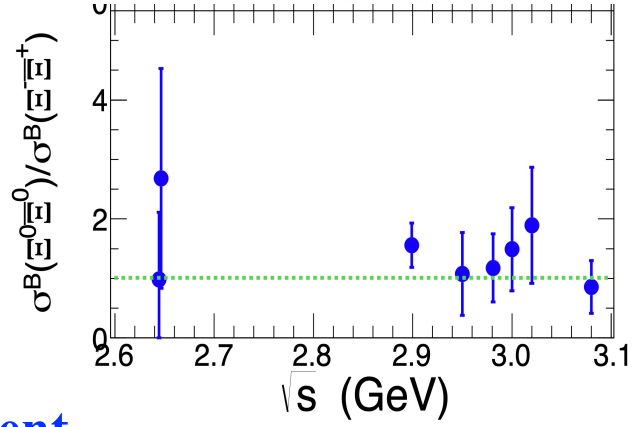
PRD103, 012005(2021), arXiv: 2105.14657

- **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.**

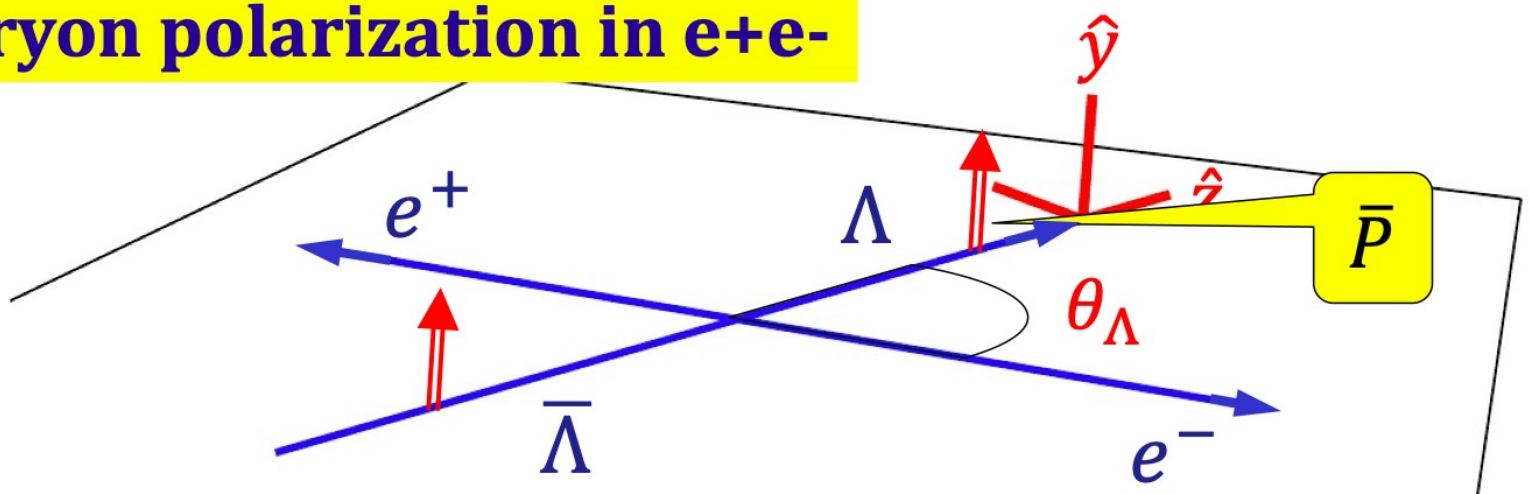
Summary

- **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!**


Thanks

Backup

Baryon polarization in e+e-



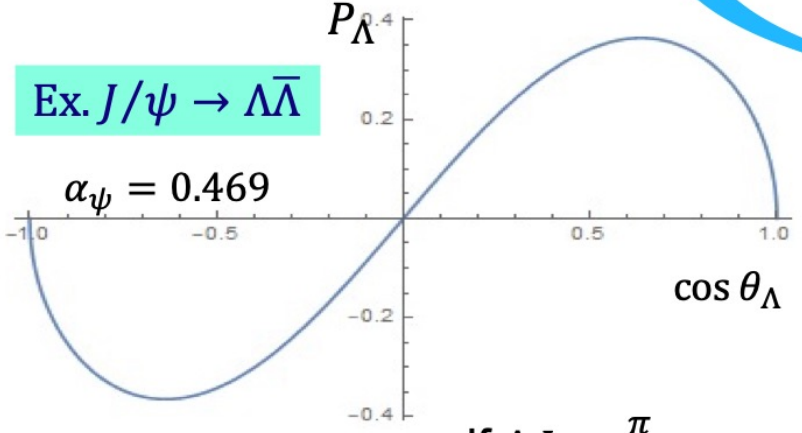
Unpolarized e+e- beams ⇨ transverse polarization:

$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi{}^2}\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi \cos^2\theta_\Lambda} \sin(\Delta\Phi)$$

$\Delta\Phi \neq 0$

Ex. $J/\psi \to \Lambda\bar{\Lambda}$

$\alpha_\psi = 0.469$



if $\Delta\Phi = \frac{\pi}{2}$

Baryon-antibaryon spin density matrix

$$e^+e^- \to B_1\bar{B}_2$$

General two spin ½ particle state:

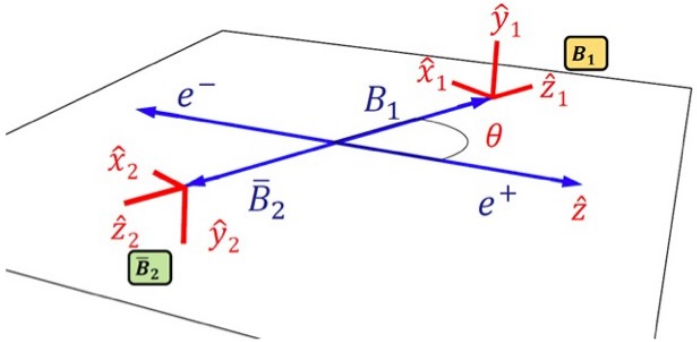
$$\rho_{1/2,\overline{1/2}} = \frac{1}{4}\sum_{\mu\bar{\nu}} C_{\mu\bar{\nu}}\, \sigma_\mu^{B_1} \otimes \sigma_{\bar{\nu}}^{\bar{B}_2}$$

$(\sigma_0 = \mathbf{1}_2, \sigma_1 = \sigma_x, \sigma_2 = \sigma_y, \sigma_3 = \sigma_z)$

P_y

$$C_{\mu\bar{\nu}} = \begin{pmatrix} 1+\alpha_\psi\cos^2\theta & 0 & \beta_\psi\sin\theta\cos\theta & 0 \\ 0 & \sin^2\theta & 0 & \gamma_\psi\sin\theta\cos\theta \\ -\beta_\psi\sin\theta\cos\theta & 0 & \alpha_\psi\sin^2\theta & 0 \\ 0 & -\gamma_\psi\sin\theta\cos\theta & 0 & -\alpha_\psi-\cos^2\theta \end{pmatrix}$$

$$\beta_\psi = \sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi) \qquad \gamma_\psi = \sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)$$



Angular distribution:

$$\frac{d\Gamma}{d\Omega} \propto 1+\alpha_\psi\cos^2\theta \qquad -1 \le \alpha_\psi \le 1$$

Decay amplitudes in hyperon decays

$\Lambda \to p\pi^-$
$\Xi^- \to \Lambda\pi^-$
$\Sigma \to N\pi$

P and S transitions

P and D

$\bar{\Omega}^- \to \Lambda K^-$

$$\mathcal{A}(\Xi^- \to \Lambda\pi^-) = S + P\boldsymbol{\sigma}\cdot\hat{\mathbf{n}}$$

weak CP-odd phases

$$S = |S|\exp(i\xi_S)\exp(i\delta_S)$$
$$P = |P|\exp(i\xi_P)\exp(i\delta_P)$$

strong phases

$|\Delta I| = 1/2$

For $\Lambda \to p\pi^-$ admixture of $|\Delta I| = 3/2$ (~1/22)

Measurable: BF and two decay parameters

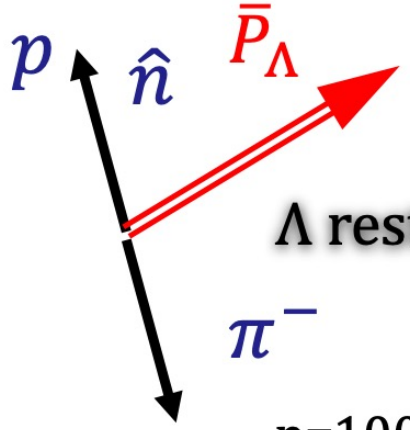
$$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2 + |P|^2}$$

$$\beta = \frac{2\mathrm{Im}(S^*P)}{|P|^2 + |S|^2}$$

$$\beta = \sqrt{1-\alpha^2}\sin\phi$$

$$\gamma = \sqrt{1-\alpha^2}\cos\phi$$

Measuring hyperon decay parameters

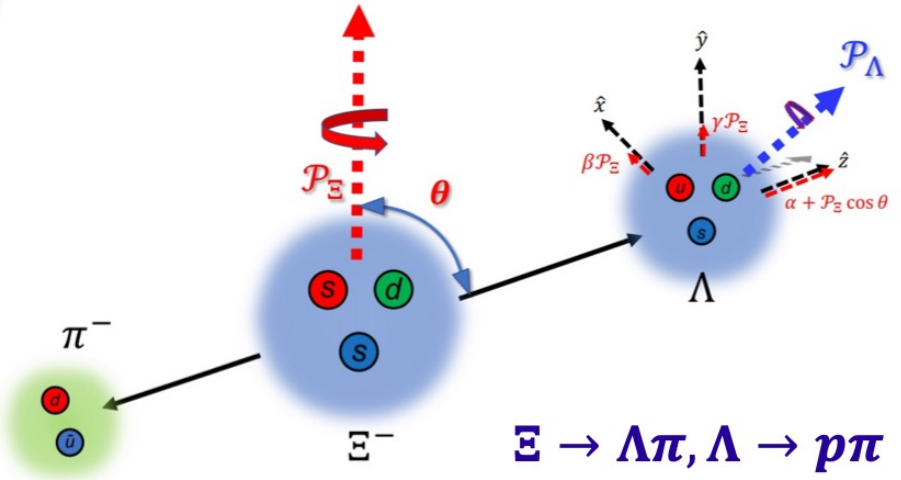


Λ rest frame

p=100 MeV/c

$\Lambda \rightarrow p\pi^-$

$$\frac{d\Gamma}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_\Lambda \hat{n}\, \bar{P}_\Lambda)$$



$\Xi \rightarrow \Lambda\pi, \Lambda \rightarrow p\pi$

$\alpha_\Lambda = 0.750 \pm 0.010$ $\quad \beta_\Lambda = -0.075 \pm 0.040$

$\alpha_\Xi = -0.392 \pm 0.008$ $\quad \beta_\Xi = -0.034 \pm 0.013$

Accesible if daughter baryon polarization measured eg in decay sequence:
$\Xi \rightarrow \Lambda\pi, \Lambda \rightarrow p\pi$

Testing CP violation in hyperon decays

Compare the two decay parameters for c.c. decay modes:

$$A_{\rm CP} = \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}}, \quad B_{\rm CP} = \frac{\phi + \overline{\phi}}{2}$$

In the leading order:

$$A_{\rm CP} = -\sin\phi \tan(\xi_P - \xi_S) \frac{\sqrt{1-\alpha^2}}{\alpha}$$

$$B_{\rm CP} = \cos\phi \tan(\xi_P - \xi_S) \frac{\alpha}{\sqrt{1-\alpha^2}}$$

weak *P-S* phase diff.

	ξ_S $(\eta\lambda^5 A^2)$	ξ_P $(\eta\lambda^5 A^2)$	C_B	C'_B
	SM Ref. [13]		BSM Ref. [21]	
$\Lambda \to p\pi^-$	1.0 ± 1.0	1.2 ± 0.6	1.1 ± 2.2	0.4 ± 0.8
$\Xi^- \to \Lambda\pi^-$	0.9 ± 0.9	-0.5 ± 0.3	-0.5 ± 1.0	0.4 ± 0.7

$-3 \times 10^{-5} \le A_\Lambda \le 4 \times 10^{-5}$
$-2 \times 10^{-5} \le A_\Xi \le 1 \times 10^{-5}$

SM

Tandean, Valencia PRD67 (2003) 056001

$$(\xi_P - \xi_S)_{BSM} = \frac{C'_B}{B_G}\left(\frac{\epsilon'}{\epsilon}\right)_{BSM} + \frac{C_B}{\kappa}\epsilon_{BSM}$$