Baryon Spectroscopy at BESIII

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(on the behalf of BESIII collaboration)

Tsinghua University

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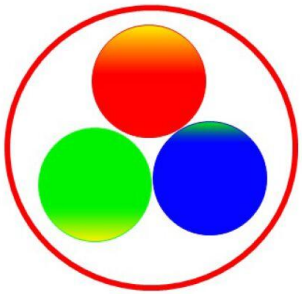
Outline

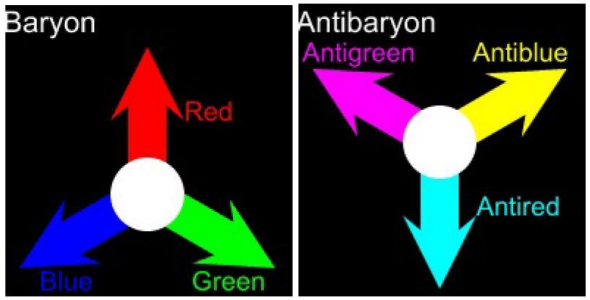
- **Introduction**
- **Recent results on baryon spectroscopy**
  - Measurement of $\chi_{cJ} \to B\bar{B}$
  - Observation of $\eta_c \to B\bar{B}$
  - Observation of $\Lambda^*/\Sigma^*/\mathrm{N}^*$
  - Observation of $\Xi(1690)^-/\Xi(1820)^-$
  - Study of Λ_c^+ decays
  - Study of the decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$

  } **Preliminary**
- **Summary**

Introduction

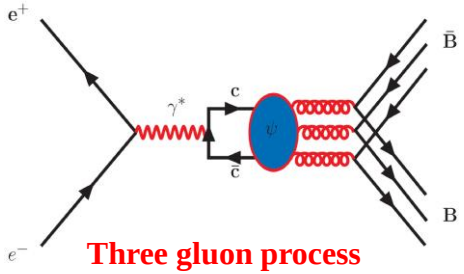
- **The established baryons are described by 3-quark configuration with the zero total color charge.**
- **An important field for understanding the structure of hadron.**
- **NR quark model:**
  - ✓ Successfully interpreted the excited baryons
  - ✓ Provided an explicit classification for light baryon in terms of group symmetry
  - ✓ Predicted more excited baryon states



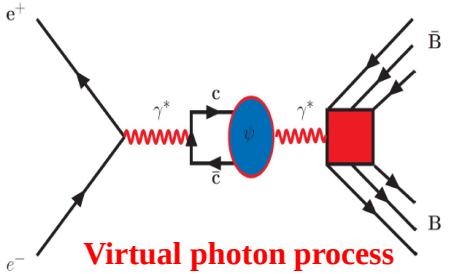


- **The baryon decays of charmonium can provide a favorable test of pQCD and baryonic properties.**

Main decay diagrams for $\psi \to B\bar{B}$ in e^+e^- annihilation



Three gluon process

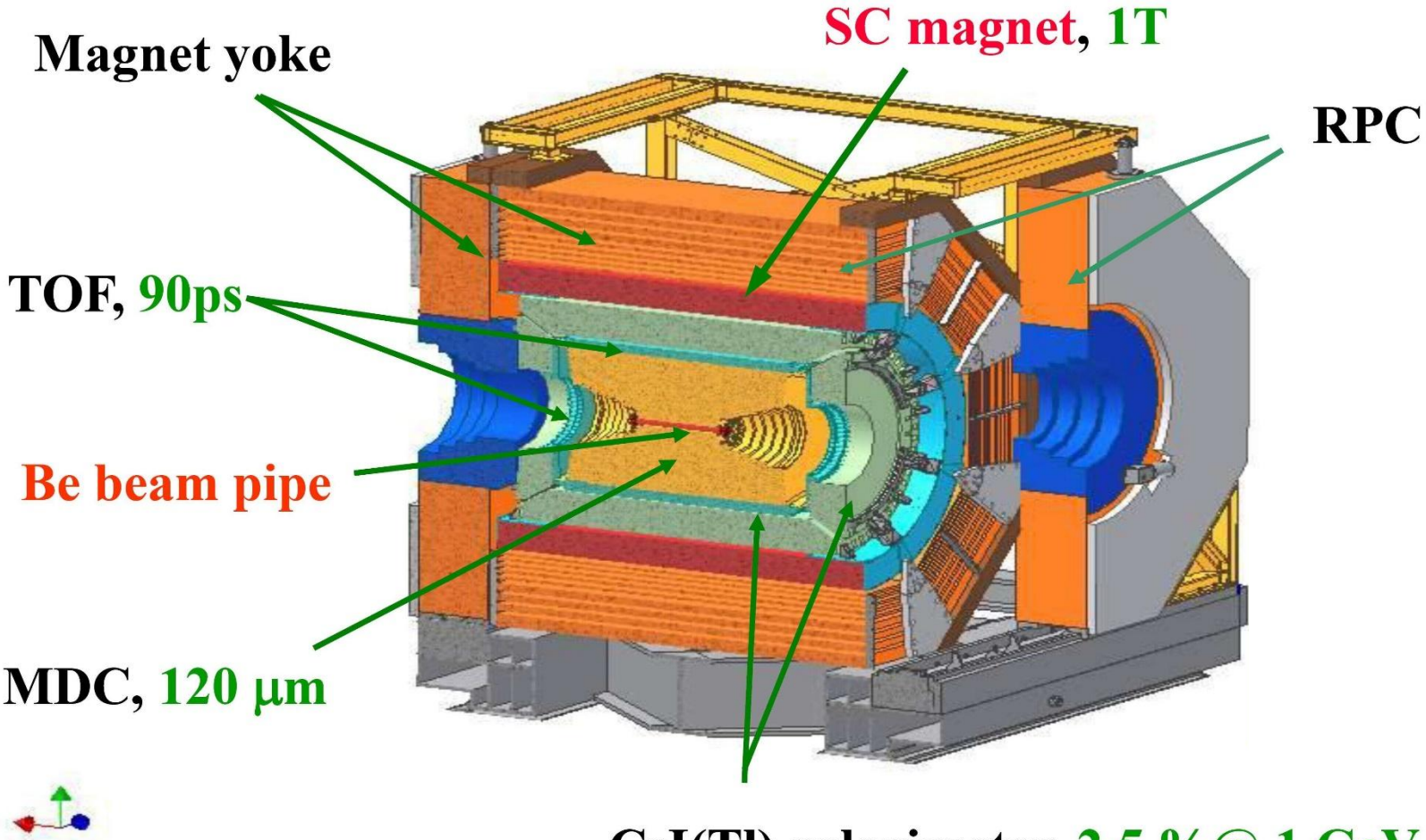


Virtual photon process

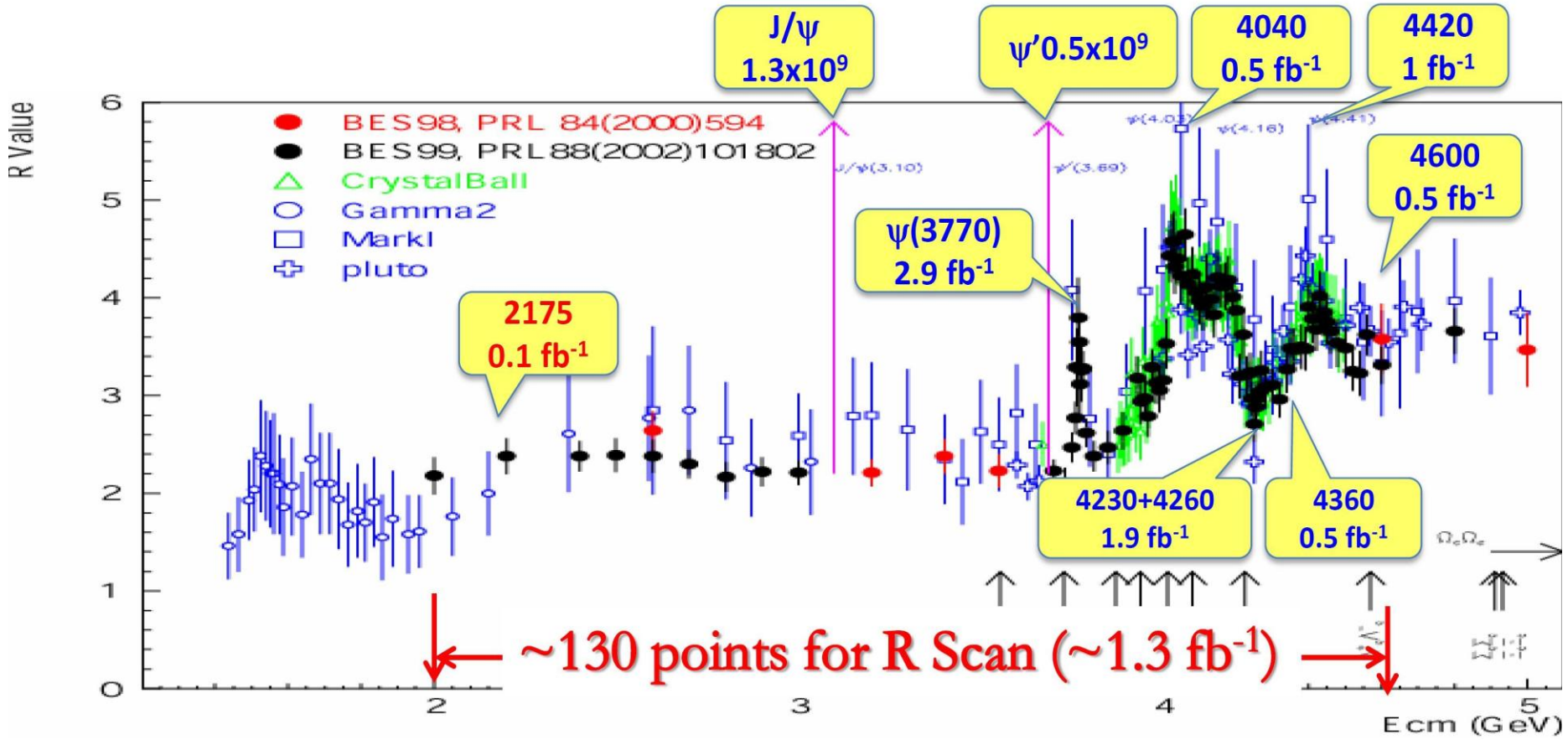
Beijing Electron Positron Collider-II

Reached peaking luminosity: $0.85 \times 10^{33}\ cm^{-2}s^{-1}$

Beijing Spectrometer-III Detector



BESIII Data Samples



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

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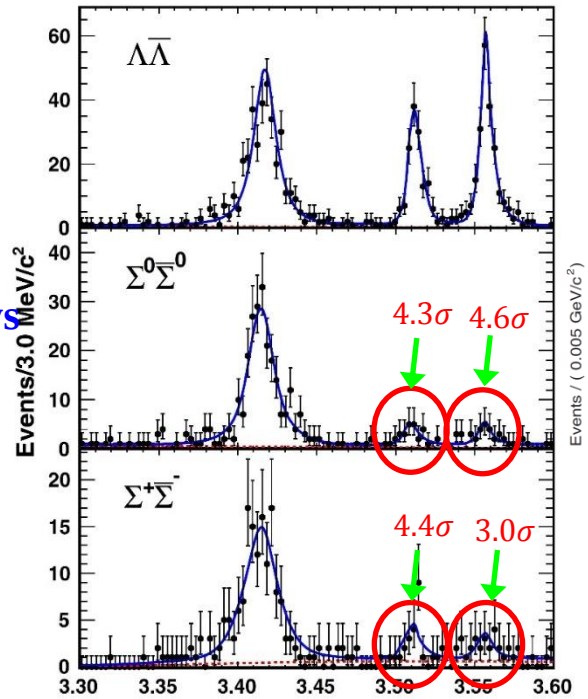
Measurement of $\chi_{cJ} \to B\bar{B}$

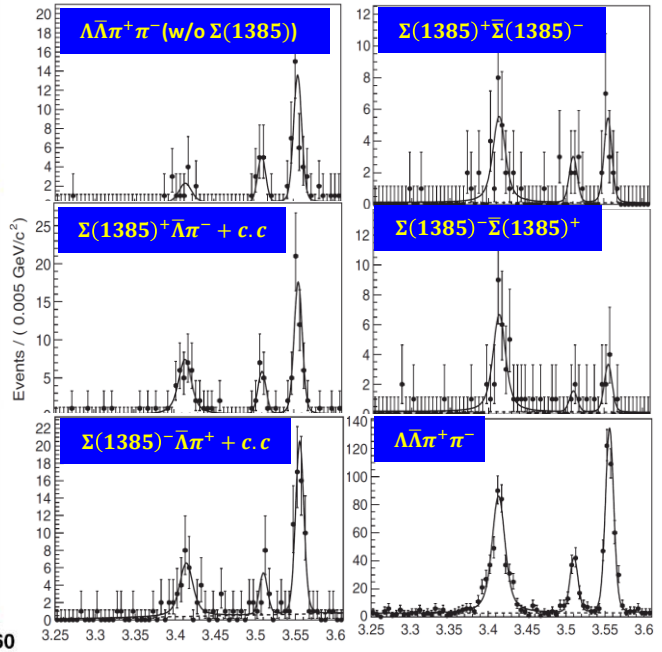
Phys. Rev. D **87** 032007 (2013)

Phys. Rev. D **86** 052004 (2012)

Data sample: $106 \times 10^6\ \psi(2S)$

- **Test the pQCD:**
  - ✓ Test COM model
  - ✓ Test helicity selection rule
  - ✓ Enrich the experimental evidences of baryonic decays
  - ✓ Study the χ_{cJ} meson properties
- **Branching fractions are consistent with the previous published results**





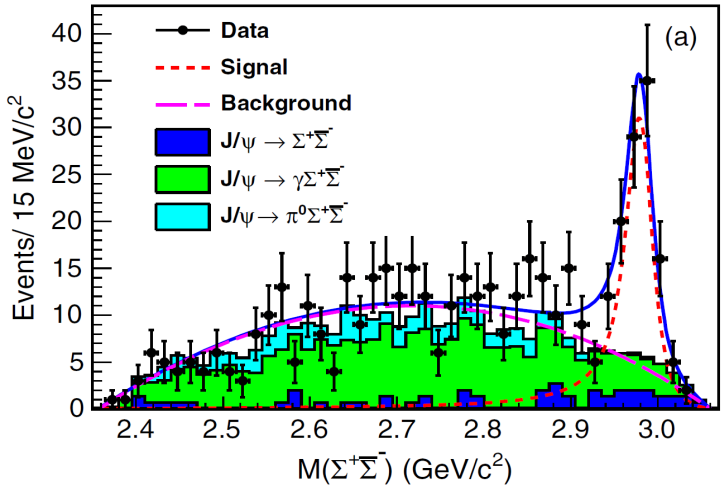
$Br(\chi_{c0} \to \Lambda\bar{\Lambda}) = 33.2 \pm 2.0 \pm 2.6$
$Br(\chi_{c1} \to \Lambda\bar{\Lambda}) = 12.2 \pm 1.1 \pm 1.1$
$Br(\chi_{c2} \to \Lambda\bar{\Lambda}) = 20.8 \pm 1.6 \pm 2.3$
$Br(\chi_{c0} \to \Sigma^0\bar{\Sigma}^0) = 47.8 \pm 3.4 \pm 3.9$
$Br(\chi_{c1} \to \Sigma^0\bar{\Sigma}^0) = 3.8 \pm 1.0 \pm 0.5 (< 6.2)$
$Br(\chi_{c2} \to \Sigma^0\bar{\Sigma}^0) = 4.0 \pm 1.1 \pm 0.5 (< 6.5)$
$Br(\chi_{c0} \to \Sigma^+\bar{\Sigma}^-) = 47.8 \pm 3.4 \pm 3.9$
$Br(\chi_{c1} \to \Sigma^+\bar{\Sigma}^-) = 3.8 \pm 1.0 \pm 0.5 (< 8.7)$
$Br(\chi_{c2} \to \Sigma^+\bar{\Sigma}^-) = 4.0 \pm 1.1 \pm 0.5 (< 8.8)$

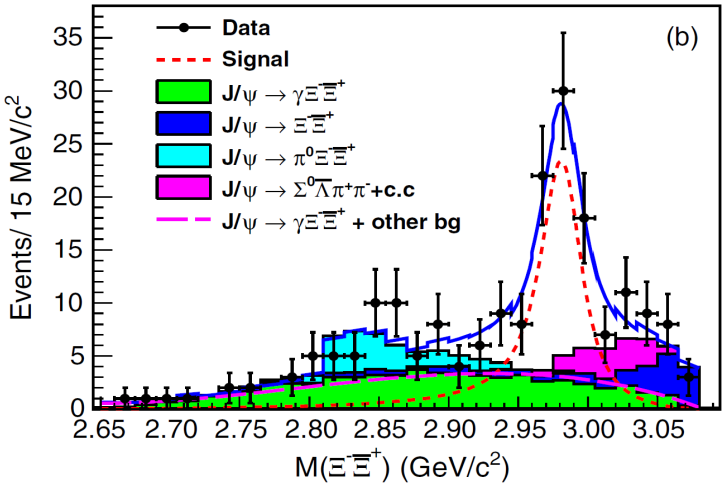
χ_{cJ} decay mode	χ_{c0}			χ_{c1}			χ_{c2}		
	$\mathcal{B}$	UL	S	$\mathcal{B}$	UL	S	$\mathcal{B}$	UL	S
$\Lambda\bar{\Lambda}\pi^+\pi^-$(w/oΣ(1385))	28.6 ± 12.6 ± 2.7	<54	2.2	26.2 ± 5.5 ± 3.3		4.8	71.8 ± 14.5 ± 8.2		6.4
$\Sigma(1385)^+\bar{\Lambda}\pi^-$ + c.c.	34.8 ± 13.2 ± 3.4	<55	2.2		<14	0.3	23.6 ± 11.8 ± 2.7	<42	1.7
$\Sigma(1385)^-\bar{\Lambda}\pi^+$ + c.c.	24.6 ± 12.7 ± 2.4	<50	1.6		<14	0.0	37.8 ± 11.8 ± 4.4	<61	2.6
$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	16.4 ± 5.7 ± 1.6		3.1	4.4 ± 2.5 ± 0.6	<10	1.9	7.9 ± 4.0 ± 0.9	<17	2.0
$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	23.5 ± 6.2 ± 2.3		4.3		<5.7	0.9		<8.5	0.0
$\Lambda\bar{\Lambda}\pi^+\pi^-$ (total)	119.0 ± 6.4 ± 11.4		>10	31.1 ± 3.4 ± 3.9		>10	137.0 ± 7.6 ± 15.7		>10

Observation of $\eta_c \to B\bar{B}$

Data sample: 225.3× 10^6 J/ψ

Phys. Rev. D **87** 012003 (2013)





$$\mathcal{B}(J/\psi \to \gamma\eta_c \to \gamma\Sigma^+\bar{\Sigma}^-) = (3.60 \pm 0.48 \pm 0.31) \times 10^{-5},$$

$$\mathcal{B}(J/\psi \to \gamma\eta_c \to \gamma\Xi^-\bar{\Xi}^+) = (1.51 \pm 0.27 \pm 0.14) \times 10^{-5}.$$

$$F(m) = \sigma_{\text{res}} \otimes (\varepsilon(m) \times E_\gamma^3 \times \text{damping}(E_\gamma) \times \text{BW}(m)) + \text{BKG}(m),$$

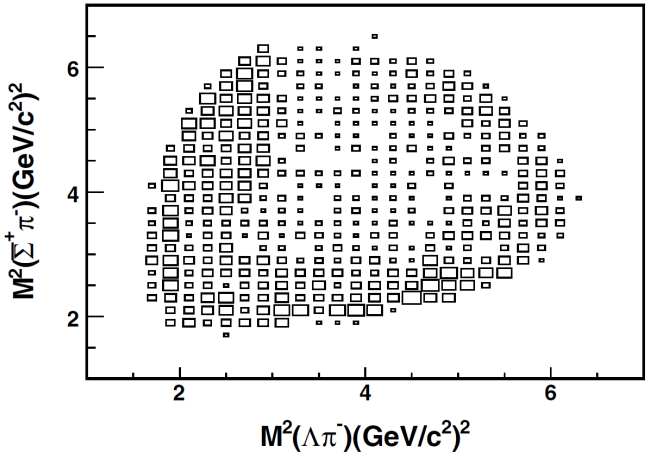
$$\mathcal{B}(\eta_c \to \Sigma^+\bar{\Sigma}^-) = (2.11 \pm 0.28 \pm 0.18 \pm 0.50) \times 10^{-3}$$

$$\mathcal{B}(\eta_c \to \Xi^-\bar{\Xi}^+) = (0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}$$

The measurements provide more experimental information on the study of the η_c decay!

Observation of Λ^* and Σ^* in $\psi(2S) \to \Lambda\bar{\Sigma}^+\pi^-$

Data sample:106×10^6 $\psi(2S)$

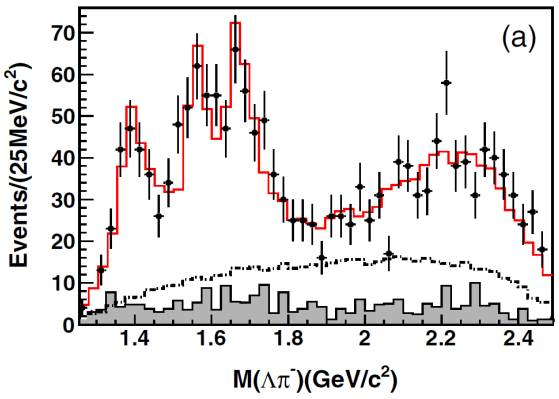


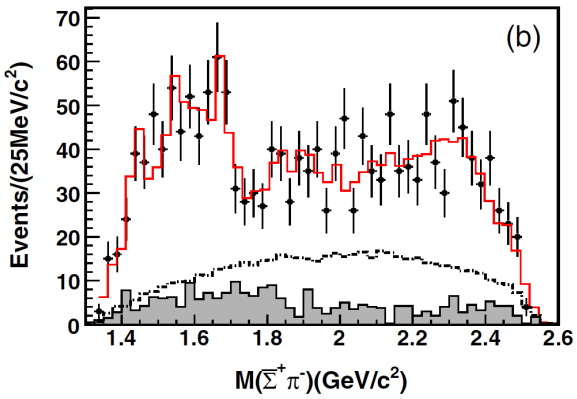
Phys. Rev. D **88**, 112007 (2013)

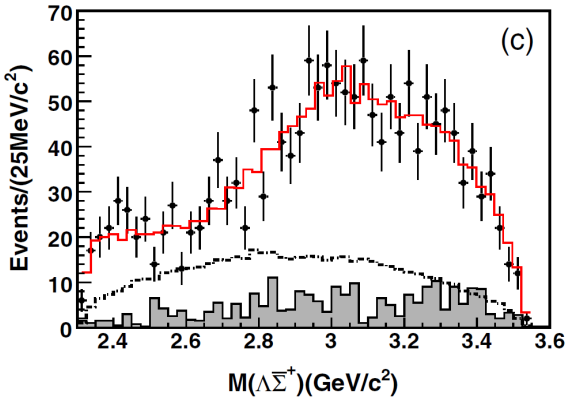
- **Branching fractions are measured for the first time.**

$$\mathcal{B}(\psi(3686) \to \Lambda\bar{\Sigma}^+\pi^- + \text{c.c.}) = (1.40 \pm 0.03 \pm 0.13) \times 10^{-4},$$

$$\mathcal{B}(\psi(3686) \to \Lambda\bar{\Sigma}^-\pi^+ + \text{c.c.}) = (1.54 \pm 0.04 \pm 0.13) \times 10^{-4},$$





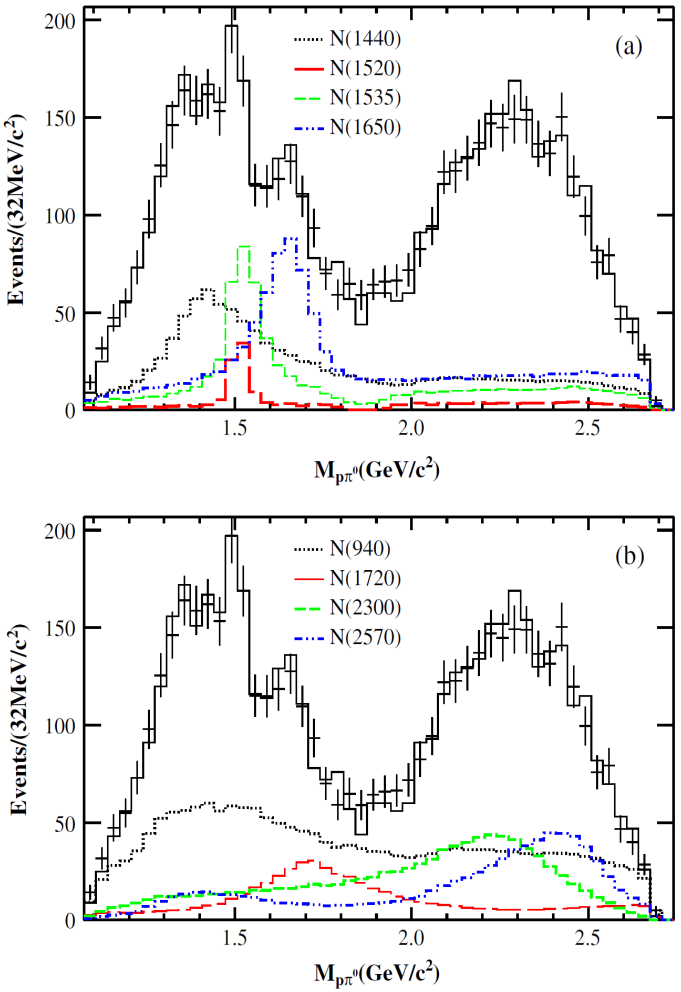


Excited strange baryons around 1.5 to 1.7 GeV/c^2 are observed.

PWA of $\psi(2S) \to p\bar{p}\,\pi^0$

Data sample:106×10^6 $\psi(2S)$

Phys. Rev. Lett. **110**, 022001 (2013)



- **2-body decay:**
  - ✓ $\psi(2S) \to X\pi^0, X \to p\bar{p}$,
  - ✓ $\psi(2S) \to pN^*, \quad N^* \to \bar{p}\pi^0 + c.c.$.
- **Isospin conservation:**
  - ✓ Suppress Δ resonance

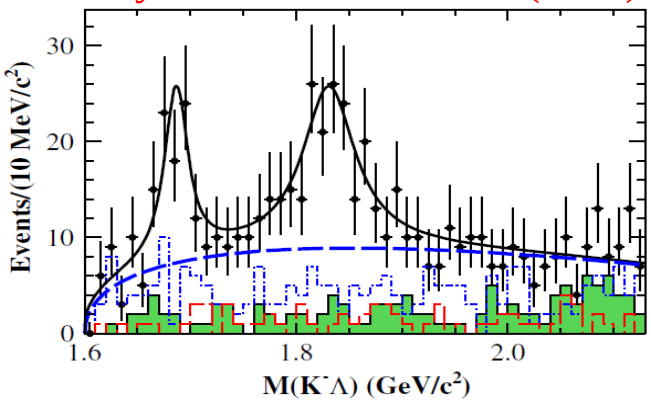
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$

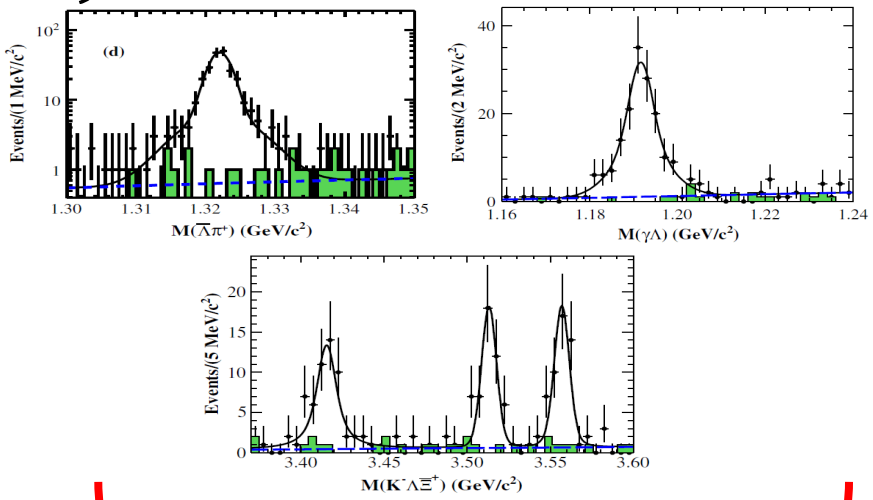
- **2 new N^*s are significant ($J^P = \frac{1}{2}^+, \frac{5}{2}^-$)**
- **First 5 well-known are also measured with higher precision.**

Observation of $\Xi(1690)^-/\Xi(1820)^-$ in $\psi(2S) \to K\Lambda\Xi$

Data sample:106×10^6 $\psi(2S)$

Phys. Rev. D **91**, 092006 (2015)





- Two hyperons $\Xi(1690)/\Xi(1820)$ are observed with significances of **4.9σ** and **6.2σ** in $\psi(2S) \to K^-\Lambda\bar{\Xi}^+ + c.c.$
- Resonance parameters consist with PDG

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\mathrm{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}(10^{-6})$	$5.21 \pm 1.48 \pm 0.57$	$12.03 \pm 2.94 \pm 1.22$
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	< 30	24^{+15}_{-10}

- **The branching fractions are measured for the first time!**

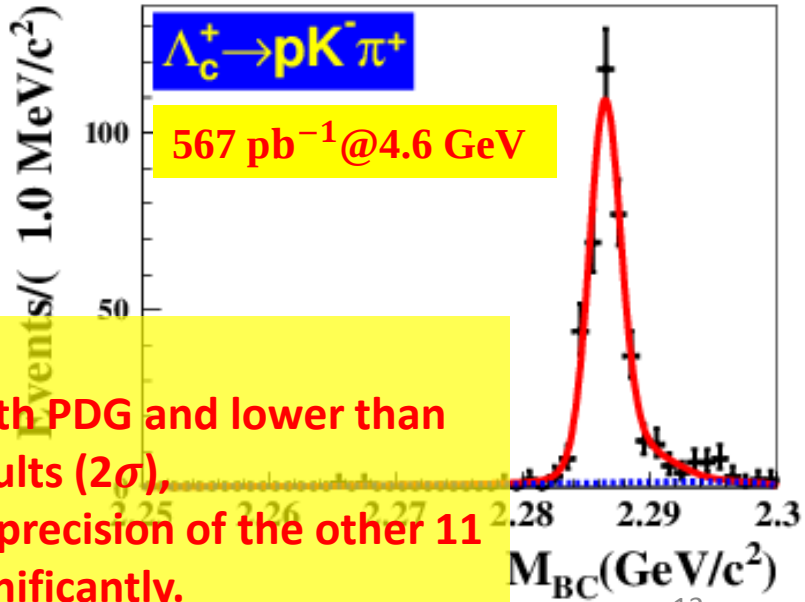
Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+$, $\Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+$, $\Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0}, \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1}, \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2}, \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$

Measurement of absolute BF for charmed baryon (Λ_c^+) decay

- **Absolute BFs of Λ_c^+ decays suffer from large uncertainties since its discovery 30 years ago**
- **Provide crucial information:**
  - **Important input to Λ_b physics**
  - **Open a window into the study of final state (strong) interactions**
  - **Constrain fragmentation functions of charm and bottom quarks**

Mode	This work(%)	PDG(%)	Belle(%)
pK_S^0	$1.47 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.64 \pm 0.27 \pm 0.22$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.75 \pm 0.12 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.46 \pm 0.10 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.22 \pm 0.23 \pm 0.28$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.19 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$6.67 \pm 0.35 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.66 \pm 0.23 \pm 0.17$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.21 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.13 \pm 0.09 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.05 \pm 0.23 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.50 \pm 0.20 \pm 0.09$	2.7 ± 1.0	

BESIII preliminary



$Br(pK^-\pi^+)$:
- ✓ Consist with PDG and lower than Belle's results (2σ),
- ✓ Improved precision of the other 11 modes significantly.

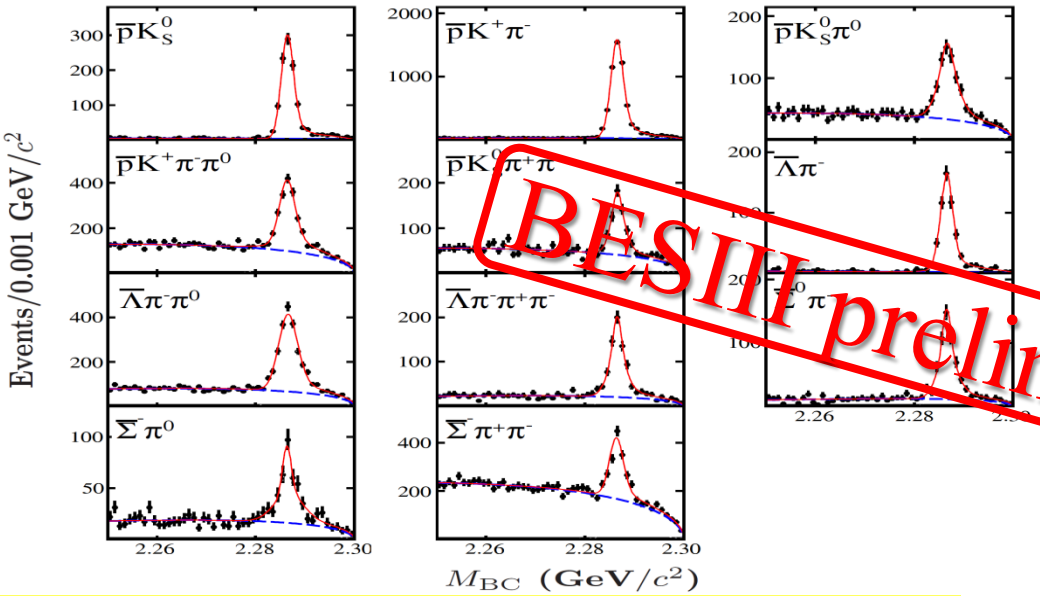
Measurement of absolute BF for semi-leptonic decay of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

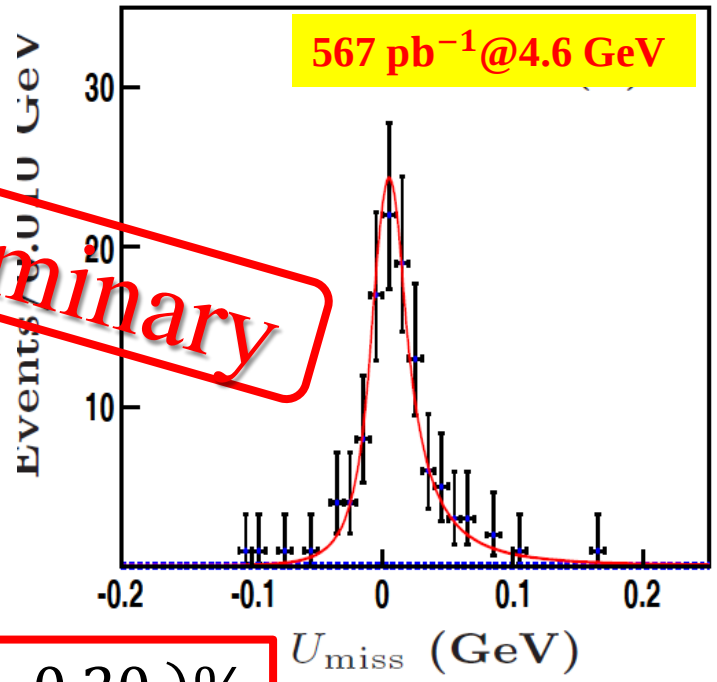
- Test the theoretical model
- Calibrate the LQCD calculations
- Determine additionally CKM elements

$$U_{miss} = E_{miss} - c|\vec{p}_{miss}|$$

$$E_{miss} = E_{beam} - E_{\Lambda} - E_{e^+}$$
$$\vec{p}_{miss} = \vec{p}_{\Lambda_c^+} - \vec{p}_{\Lambda} - \vec{p}_{e^+}$$

$$\vec{p}_{\Lambda_c^+} = -\hat{p}_{\rm tag}\sqrt{E^2_{\rm beam} - m^2_{\bar{\Lambda}_c^-}}$$





BESIII preliminary

11 ST for $\bar{\Lambda}_c^-$ reconstruction: $M_{BC} = \sqrt{E^2_{beam} - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$

$$Br(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

Summary

- **BESIII has collected the world largest data samples at J/ψ , $\psi(2S)$, etc. .**
- **Many baryonic results are presented in charmonium decays.**
- **Precise BR measurements of charmed baryon (Λ_c^+) decays are presented with the data sample at Λ_c^+-pair threshold (4.6 GeV).**
- **More results of baryon spectroscopies are on the way!**
- **…**

Thanks for your attention!

Backup

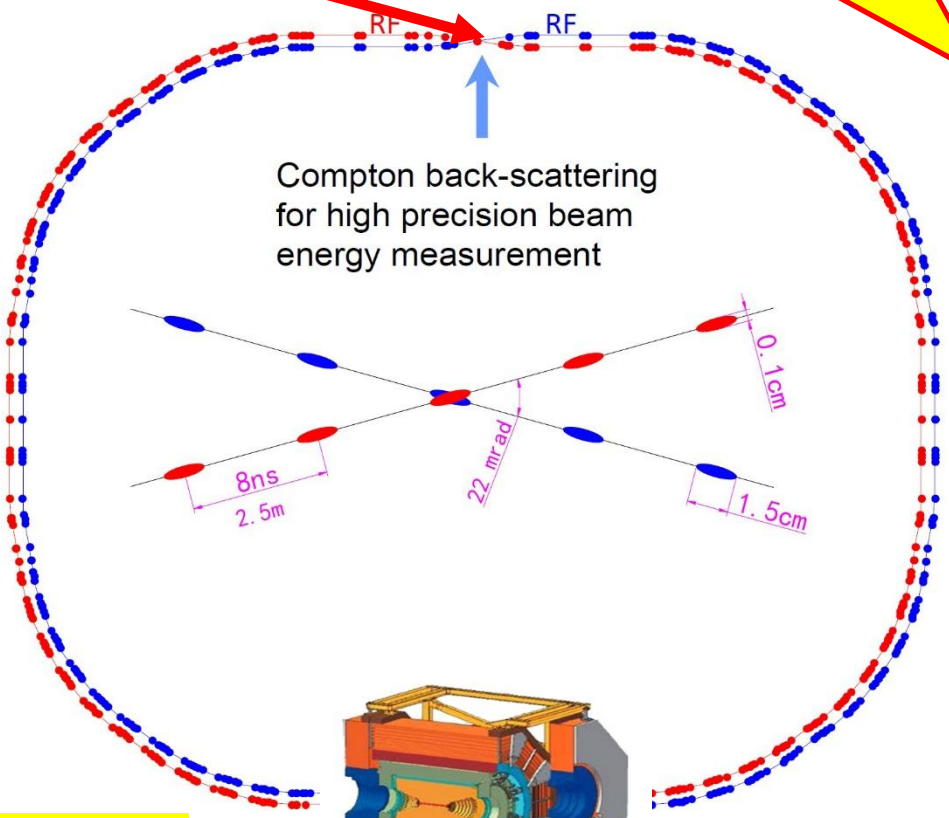
BESIII Collaboration

Beijing Electron Positron Collider-II

BEMS (beam energy measurement system): based on Compton backscattering

$L_{Peak}^{Reached}$: $0.85 \times 10^{33}\ cm^{-2}s^{-1}$

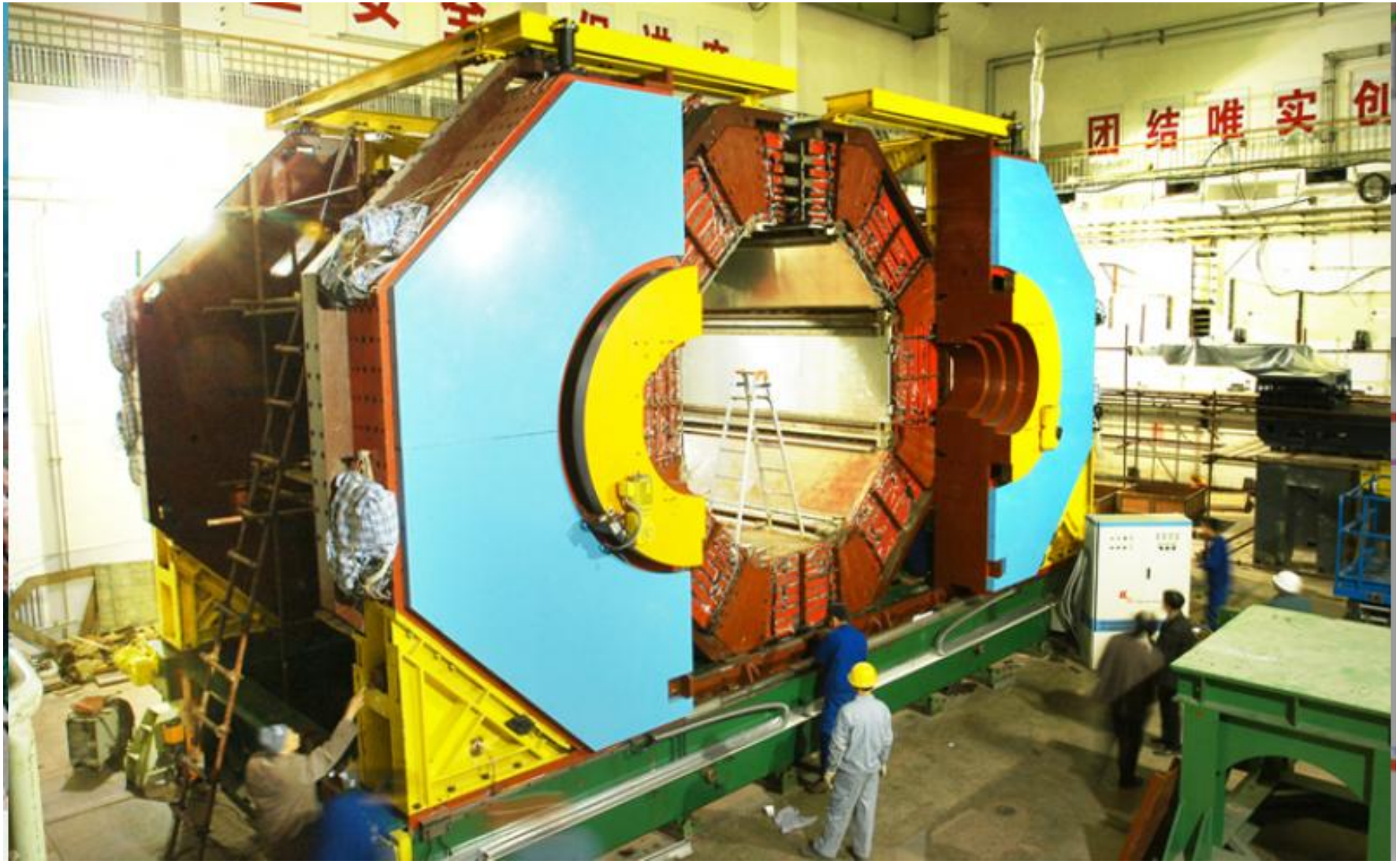
Double-ring collider



BESIII

Physics data taking in 2009 !

Beam energy:
1-2.3 GeV
Crossing angle:
22 mrad
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV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