Study χ_{cJ} decays @ BESIII

Zhi-yong Wang (王至勇)
(On behalf of BESIII Collaboration)
IHEP,CAS, Beijing, China
Sep. 26-30, 2022, GSI Darmstadt (*Online*)

Outline

➢ **Introduction**

    ✓ Physics motivation
    ✓ BESIII experiment

➢ **Recent Physics Highlights**
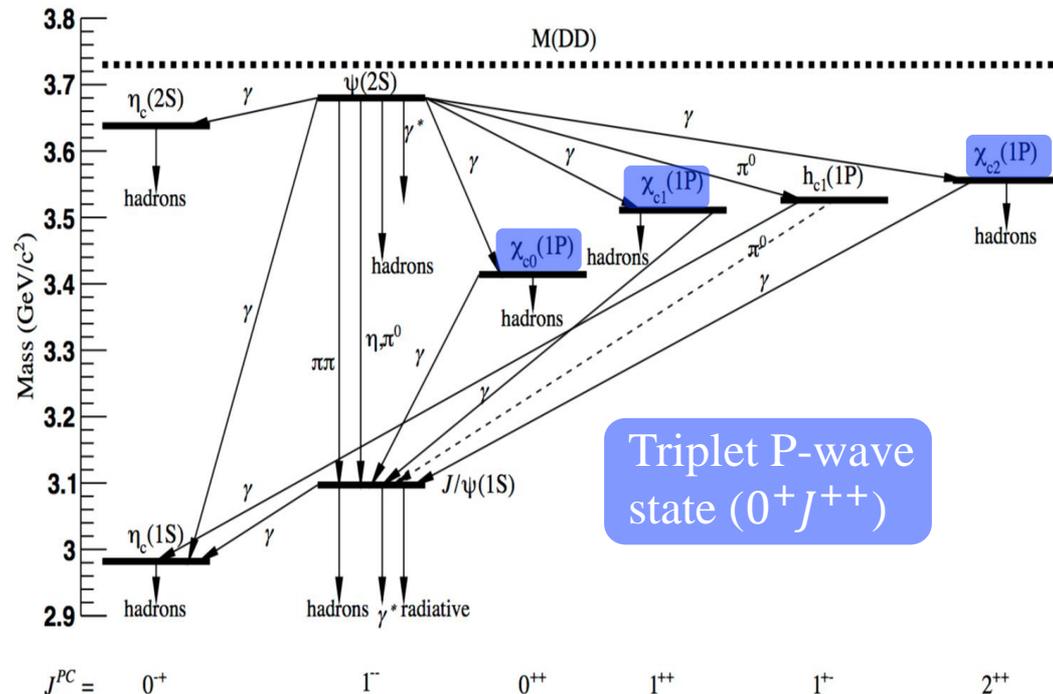
- Improved measurement of $B(\chi_{cJ} \to \Lambda\bar{\Lambda})$
- Study of the process $\chi_{cJ} \to \Xi^-\bar{\Xi}^+$ and $\chi_{cJ} \to \Xi^0\bar{\Xi}^0$
- Observation of the decays of $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$
- Measurement of $B(\chi_{cJ} \to 3(\pi^+\pi^-))$
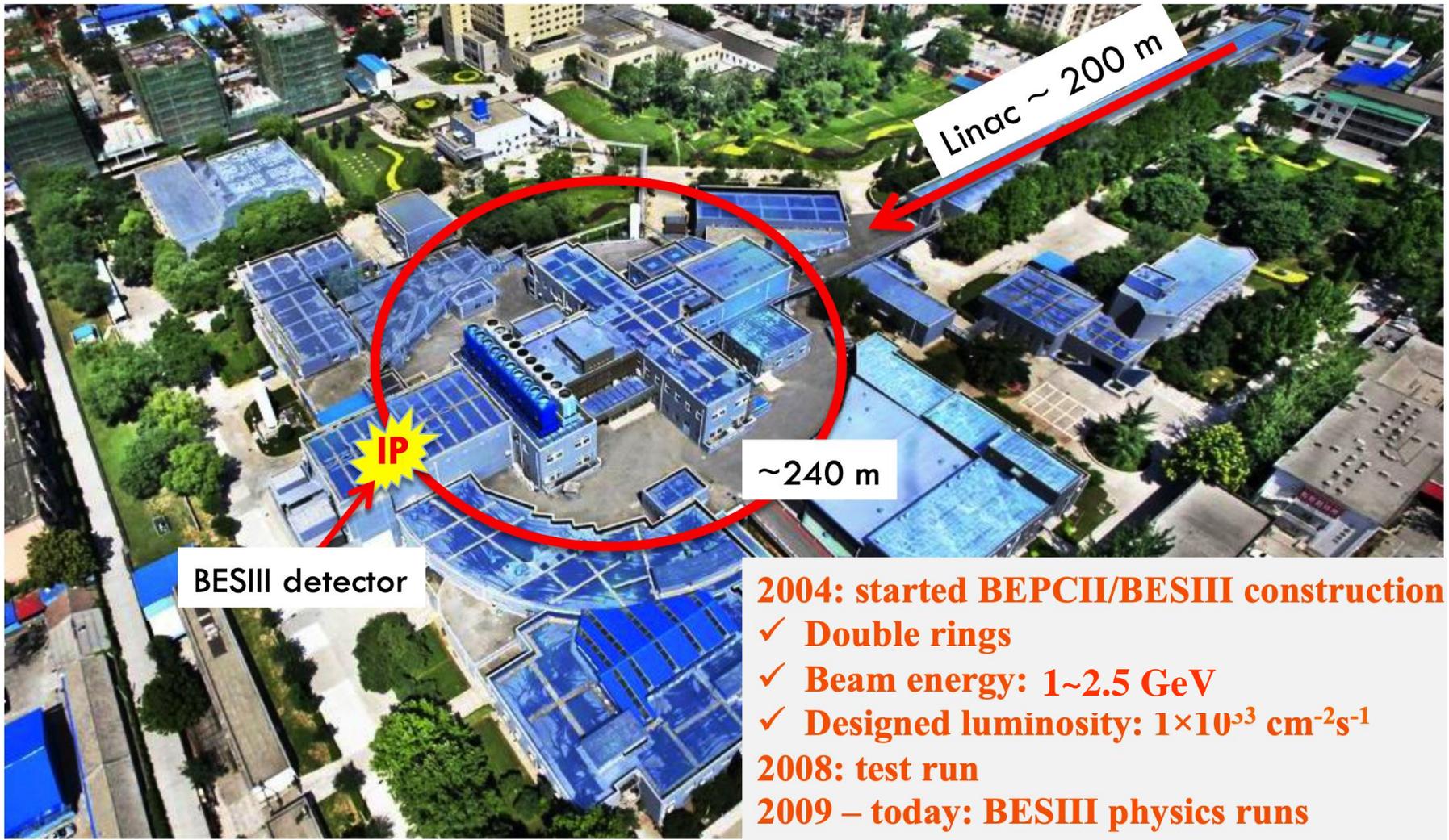- Observation of the decays of $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

➢ **Summary**

Physics Motivation
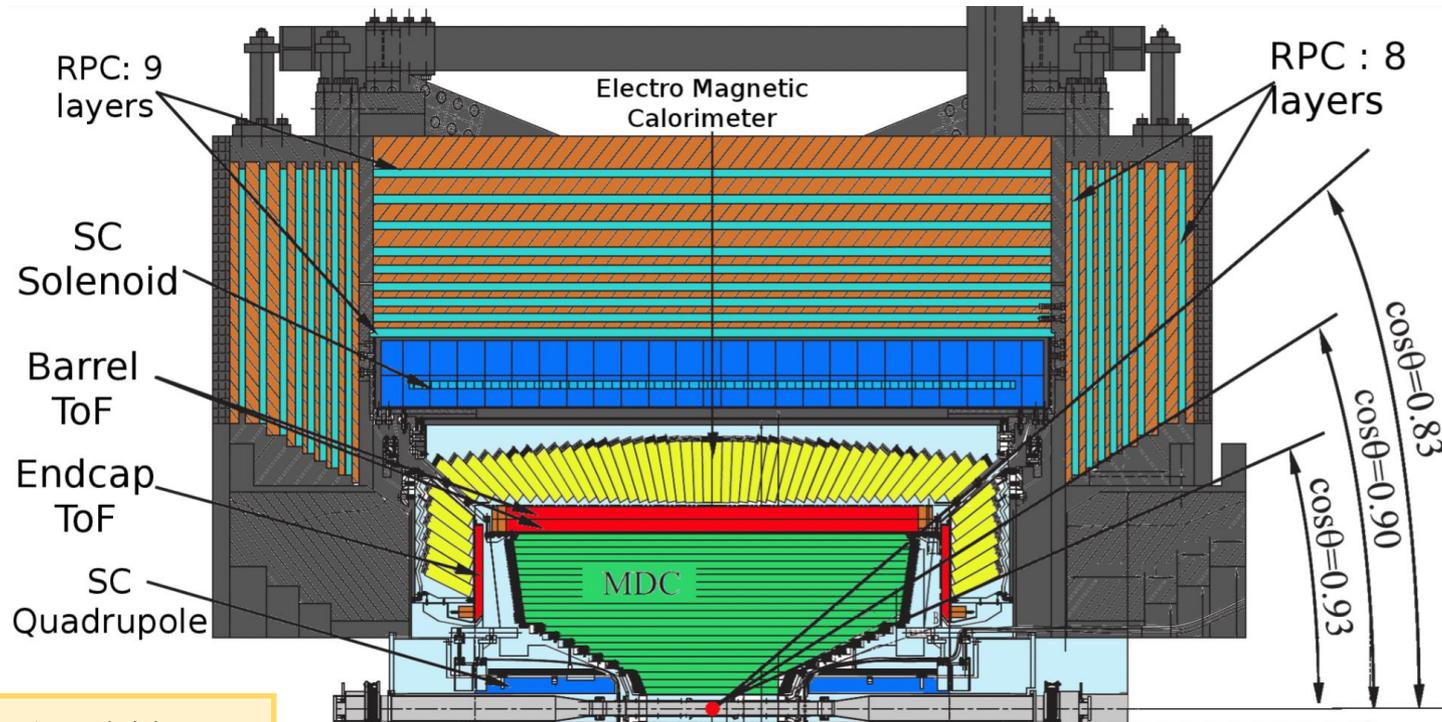

Non-pQCD   Charmonium   pQCD

❖ The multi-hadron decay modes of χ_{cJ} are expected to be an important source of exotic states and excited hadrons.

❖ The baryon pair decays of charmonium are essential to test pQCD, e.g. helicity selection rule (HSR) . In addition, it is used to test color-octet mechanism (COM).

Triplet P-wave state ($0^{+}J^{++}$)

Kind reminder: $\psi(3686) \equiv \psi(2S) \equiv \psi'$

BEPCII

Linac ~ 200 m

~240 m

IP

BESIII detector

2004: started BEPCII/BESIII construction
- ✓ **Double rings**
- ✓ **Beam energy: 1~2.5 GeV**
- ✓ **Designed luminosity: 1×10^{33} cm^{-2}s^{-1}**

2008: test run
2009 – today: BESIII physics runs

BESIII Detector

RPC: 9 layers

Electro Magnetic Calorimeter

RPC : 8 layers

SC Solenoid

Barrel ToF

Endcap ToF

SC Quadrupole

MDC

$\cos\theta=0.83$

$\cos\theta=0.90$

$\cos\theta=0.93$
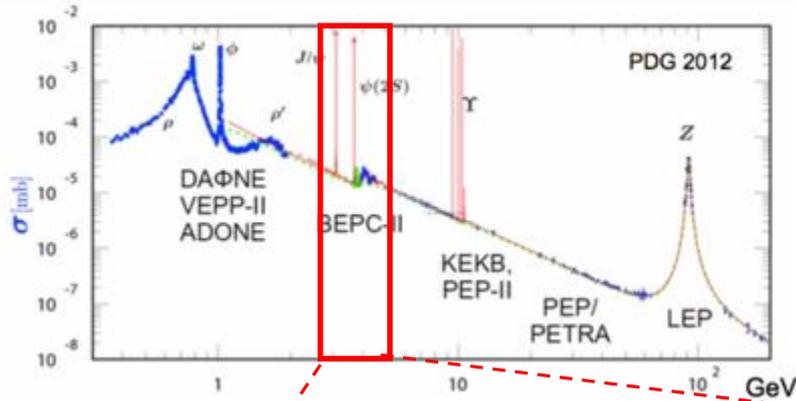
Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Drift Chamber
$\sigma_{r\varphi}$ ~ 130 μm (single wire)
σ_{pt}/p_t ~ 0.5 % @ 1 GeV

Electromagnetic CsI(Tl) Calorimeter
$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)
$\sigma_E/E < 5\%$ @ 1 GeV (end caps)
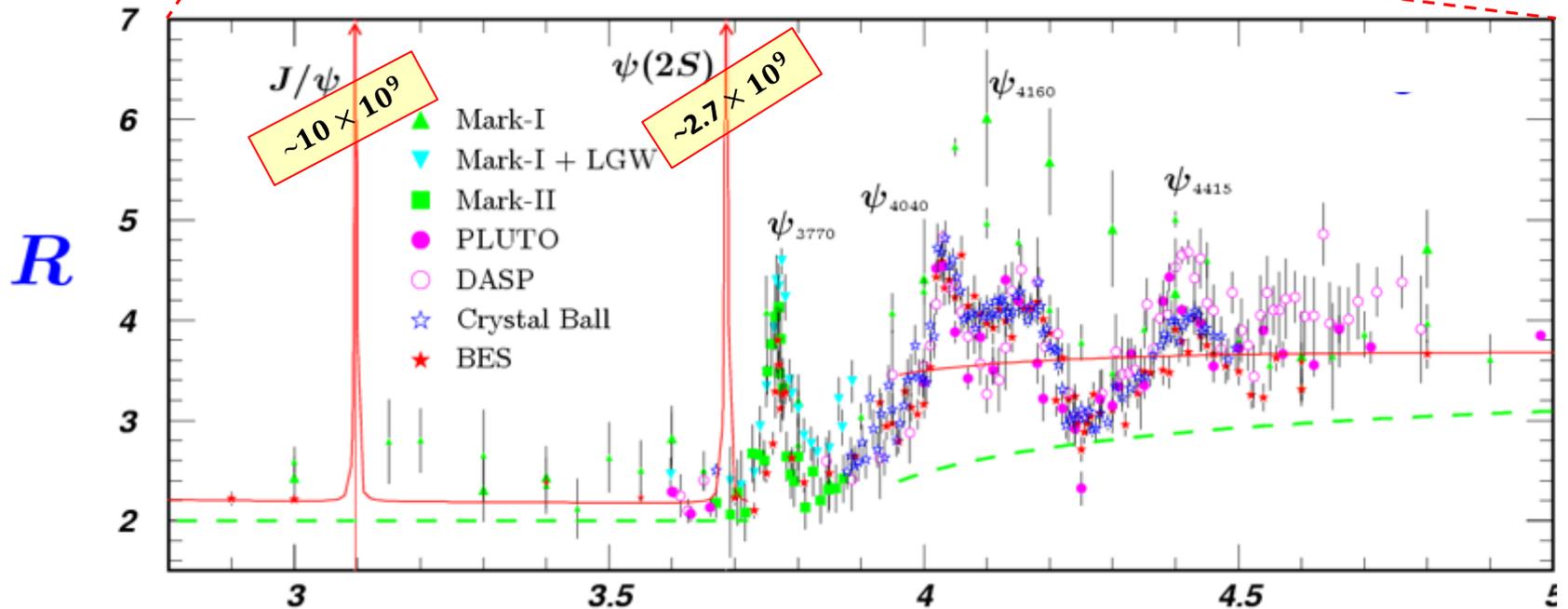σ_{xy} ~ (6 mm)/$E_{1/2}$ @ 1 GeV

ToF
σ_t ~ 90 ps (barrel)
σ_t ~ 60-120 ps (end caps)

RPC Muon Counter
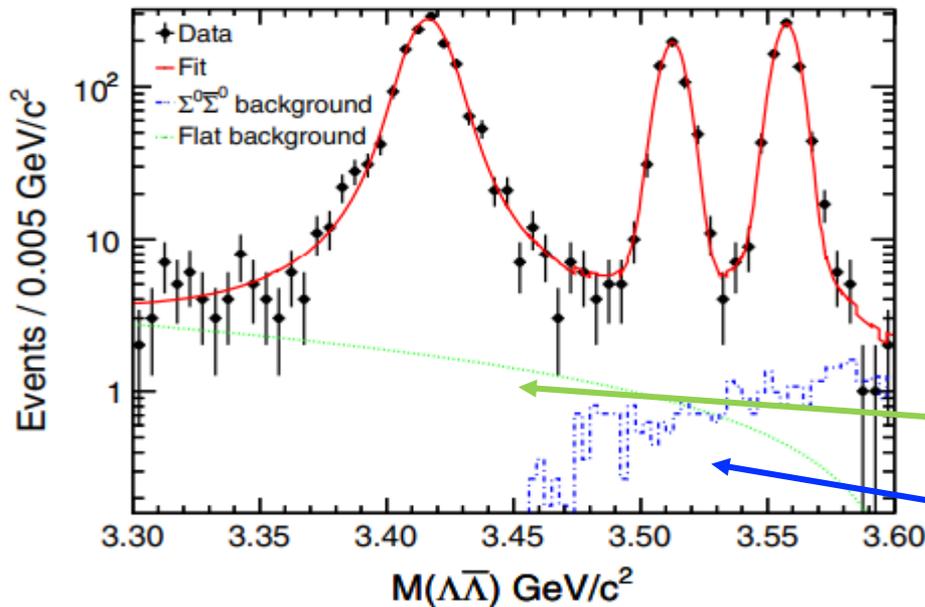$\Delta\Omega/4\pi$=93%

BESIII Data Collections

- ✓ BESIII detector has collected the largest data samples of the $\psi(3686)$ in the world.

- ✓ ~30% of $\psi(3686)$ produces χ_{cJ} in its EM radiative transition decay.

- Improved measurement of $B(\chi_{cJ} \to \Lambda\bar{\Lambda})$

- Study of the process $\chi_{cJ} \to \Xi^-\bar{\Xi}^+$ and $\chi_{cJ} \to \Xi^0\bar{\Xi}^0$

- Observation of the decays of $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$

- Measurement of $B(\chi_{cJ} \to 3(\pi^+\pi^-))$

- Observation of the decays of $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

Improved measurement of $B(\chi_{cJ} \rightarrow \Lambda\bar{\Lambda})$

➢ The measurement precisions for $B(\chi_{cJ} \rightarrow B\bar{B})$ (B=baryon) are not high.

$$\mathcal{B}(\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}) \cdot \mathcal{B}(\psi(3686) \rightarrow \gamma\chi_{cJ})$$

$$= \frac{N_{\chi_{cJ}}}{N_{\psi(3686)} \cdot \epsilon \cdot \mathcal{B}(\Lambda \rightarrow p\pi^-) \cdot \mathcal{B}(\bar{\Lambda} \rightarrow \bar{p}\pi^+)},$$

The blue dashed-line denotes the background from $\psi(3686) \rightarrow \Sigma^0\bar{\Sigma}^0$, while green line is the other background.

Mode	$N_{\chi_{cJ}}$	ϵ	$\mathcal{B}(\psi(3686) \rightarrow \gamma\chi_{cJ})$ $\times\mathcal{B}(\chi_{cJ} \rightarrow \Lambda\bar{\Lambda})(10^{-5})$	$\mathcal{B}(\chi_{cJ} \rightarrow \Lambda\bar{\Lambda})(\times 10^{-4})$ This work	PDG
χ_{c0}	1486 ± 42	22.80%	$3.56 \pm 0.10 \pm 0.10$	$3.64 \pm 0.10 \pm 0.10 \pm 0.07$	3.27 ± 0.24
χ_{c1}	528 ± 24	22.61%	$1.28 \pm 0.06 \pm 0.06$	$1.31 \pm 0.06 \pm 0.06 \pm 0.03$	1.14 ± 0.11
χ_{c2}	670 ± 27	20.16%	$1.82 \pm 0.08 \pm 0.17$	$1.91 \pm 0.08 \pm 0.17 \pm 0.04$	1.84 ± 0.15

> Single-baryon-tagged technique is applied in the analysis. The $\bar{B}$ is reconstructed by $M_{\gamma B}^{recoil}$

JHEP06, (2022) 074
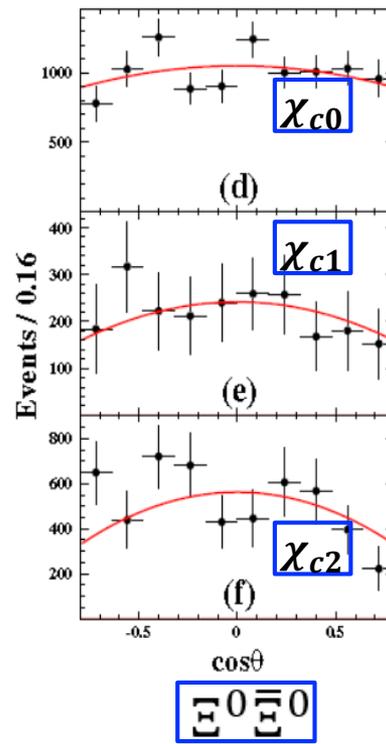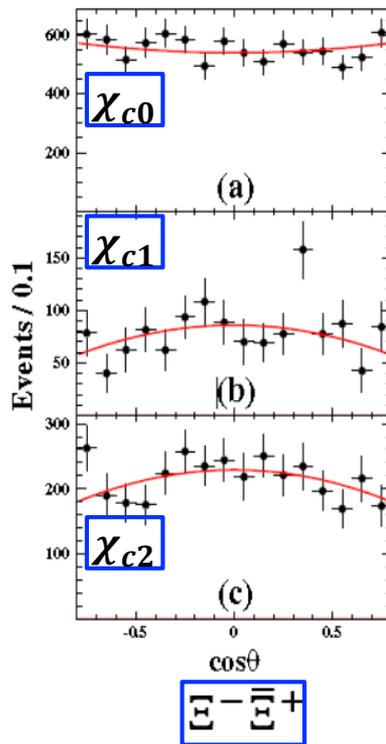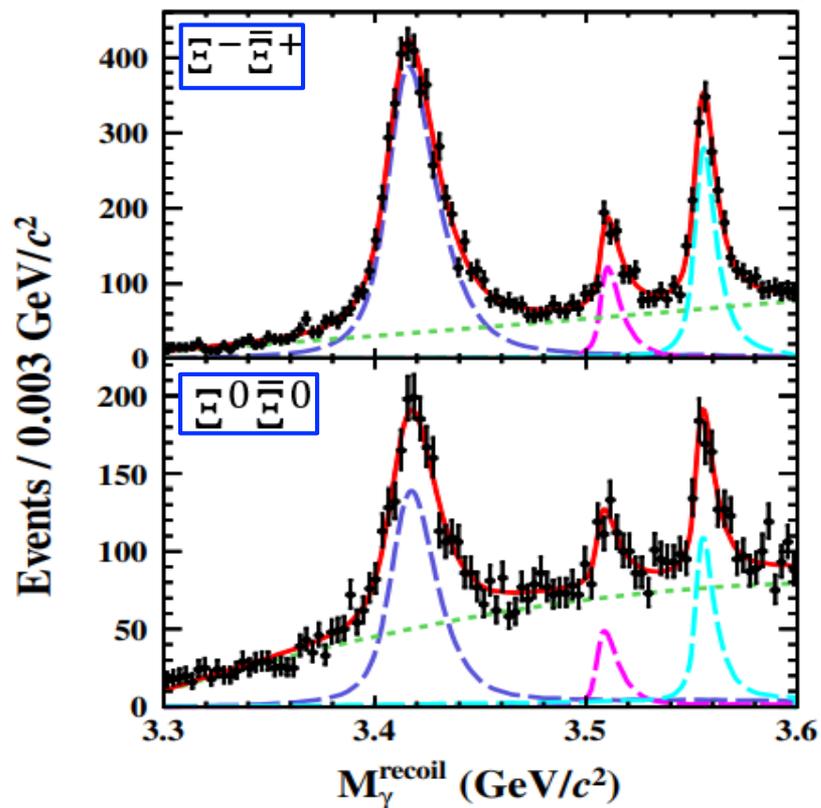
Signal yields (N_{obs}), detection efficiencies(ε), decay parameter (α), and the branching fractions ($\mathcal{B}$)

Channel		N_{obs}	ϵ (%)	α	$\mathcal{B}$ ($\times 10^{-4}$)
$\chi_{c0} \to$	$\Xi^- \bar{\Xi}^+$	4932 ± 92	25.4	$0.09 \pm 0.11 \pm 0.17$	$4.43 \pm 0.08 \pm 0.18$
	$\Xi^0 \bar{\Xi}^0$	1741 ± 71	8.5	$-0.23 \pm 0.19 \pm 0.36$	$4.67 \pm 0.19 \pm 0.26$
$\chi_{c1} \to$	$\Xi^- \bar{\Xi}^+$	692 ± 44	27.3	$-0.52 \pm 0.29 \pm 0.48$	$0.58 \pm 0.04 \pm 0.05$
	$\Xi^0 \bar{\Xi}^0$	325 ± 49	9.9	$-0.54 \pm 0.52 \pm 0.43$	$0.75 \pm 0.11 \pm 0.06$
$\chi_{c2} \to$	$\Xi^- \bar{\Xi}^+$	1691 ± 66	27.6	$-0.34 \pm 0.18 \pm 0.30$	$1.44 \pm 0.06 \pm 0.11$
	$\Xi^0 \bar{\Xi}^0$	804 ± 67	10.3	$-0.65 \pm 0.31 \pm 0.22$	$1.83 \pm 0.15 \pm 0.16$

	χ_{c0}	χ_{c1}	χ_{c2}
Ratio	$0.95 \pm 0.04 \pm 0.06$	$0.77 \pm 0.12 \pm 0.08$	$0.79 \pm 0.07 \pm 0.09$

➢ $\chi_{c1} \to \Xi^0 \bar{\Xi}^0$ and $\chi_{c2} \to \Xi^0 \bar{\Xi}^0$ are observed for the first time.

➢ The measurement precisions for B($\chi_{cJ} \to \Xi\bar{\Xi}$) are significantly improved.

➢ No obvious isospin violation are found for $\chi_{cJ} \to \Xi\bar{\Xi}$ decay mode.

$\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$

➢ Search for the potential enhancement around $B\bar{B}$ threshold and excited baryon candidates in $BP(\bar{B}P)$ invariant mass spectrum.

$\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$

Signal yields (Nobs), detection efficiencies(ϵ), and the branching fractions (B)

	χ_{c0}	χ_{c1}	χ_{c2}
N_{obs}^J	66.9 ± 8.8	21.3 ± 5.0	31.6 ± 6.2
$\epsilon(\chi_{cJ} \to \Lambda\bar{\Lambda}\eta)$	$(4.11 \pm 0.03)\%$	$(5.17 \pm 0.03)\%$	$(4.37 \pm 0.03)\%$
$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) \cdot \mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda}\eta)$	$(2.26 \pm 0.30 \pm 0.20) \times 10^{-5}$	$(5.71 \pm 1.34 \pm 0.66) \times 10^{-6}$	$(1.00 \pm 0.20 \pm 0.15) \times 10^{-5}$
$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ})$ [7]	$(9.79 \pm 0.20)\%$	$(9.75 \pm 0.24)\%$	$(9.52 \pm 0.20)\%$
$\mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda}\eta)$	$(2.31 \pm 0.30 \pm 0.21) \times 10^{-4}$	$(5.86 \pm 1.38 \pm 0.68) \times 10^{-5}$	$(1.05 \pm 0.21 \pm 0.15) \times 10^{-4}$

✓ $\chi_{cJ} \to \Lambda\bar{\Lambda}\eta$ are observed for the first time

✓ No obvious enhancement near $\Lambda\bar{\Lambda}$ threshold and excited Λ state is found

❖ Improve the previous measurement precision.
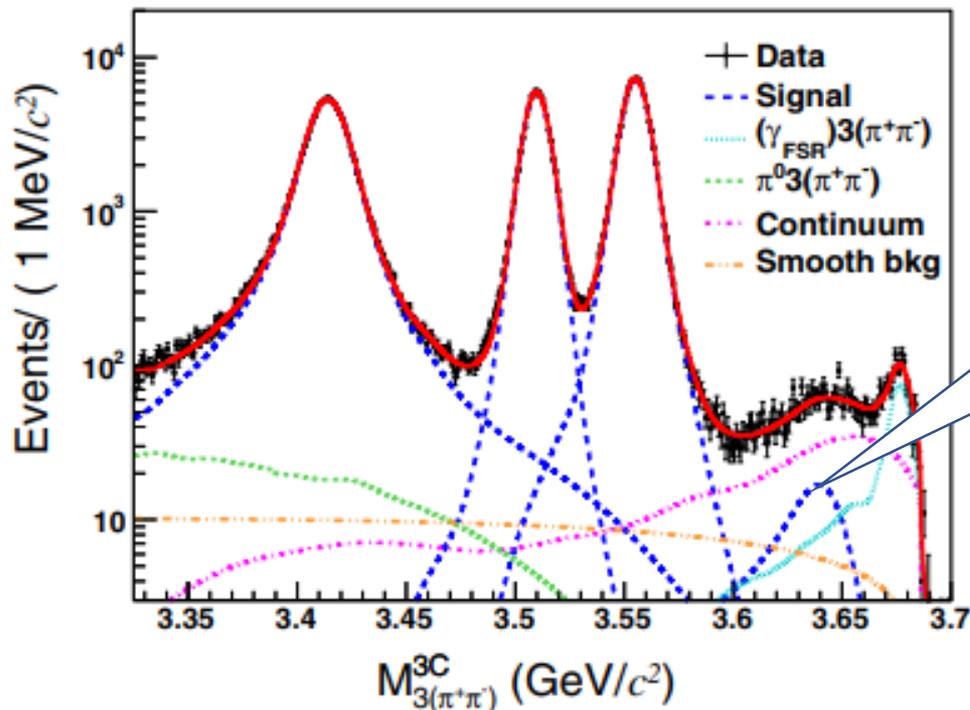

η(2S) signal, see Jielei's talk.

Channel	$N_{\text{data}}^{\text{sig}}$	ϵ^{corr} (%)	$\mathcal{B}_{\text{measured}}$ ($\times 10^{-2}$)	$\mathcal{B}_{\text{PDG}}$ ($\times 10^{-2}$)
$\chi_{c0} \to 3(\pi^+\pi^-)$	145300 ± 396	15.92 ± 0.01	$2.080 \pm 0.006 \pm 0.068$	1.20 ± 0.18
$\chi_{c1} \to 3(\pi^+\pi^-)$	84317 ± 299	17.67 ± 0.01	$1.092 \pm 0.004 \pm 0.035$	0.54 ± 0.14
$\chi_{c2} \to 3(\pi^+\pi^-)$	112510 ± 347	16.85 ± 0.01	$1.565 \pm 0.005 \pm 0.048$	0.84 ± 0.18

Observation of the decay of $\chi_{cJ} \to nK_S^0\overline{\Lambda} + c.c.$

❖ Search for the potential anomalous enhancements near the threshold of nK_S^0, and test if the isospin symmetry is conserved in χ_{cJ} 3-body decay

Observation of the decay of $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

$M_{n\bar{\Lambda}}$

$M_{nK_S^0}$

$M_{K_S^0\bar{\Lambda}}$

χ_{c0} χ_{c1} χ_{c2}
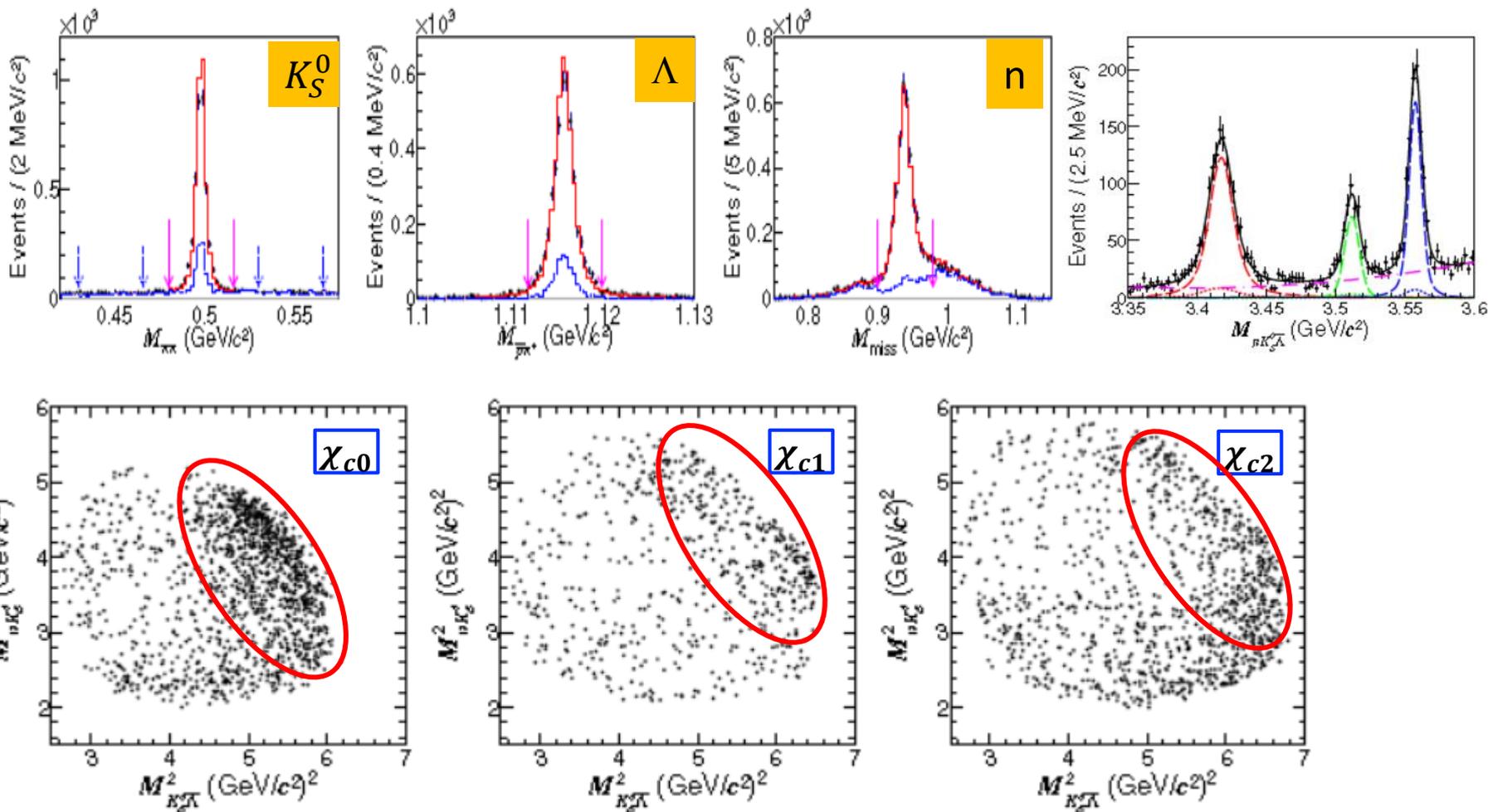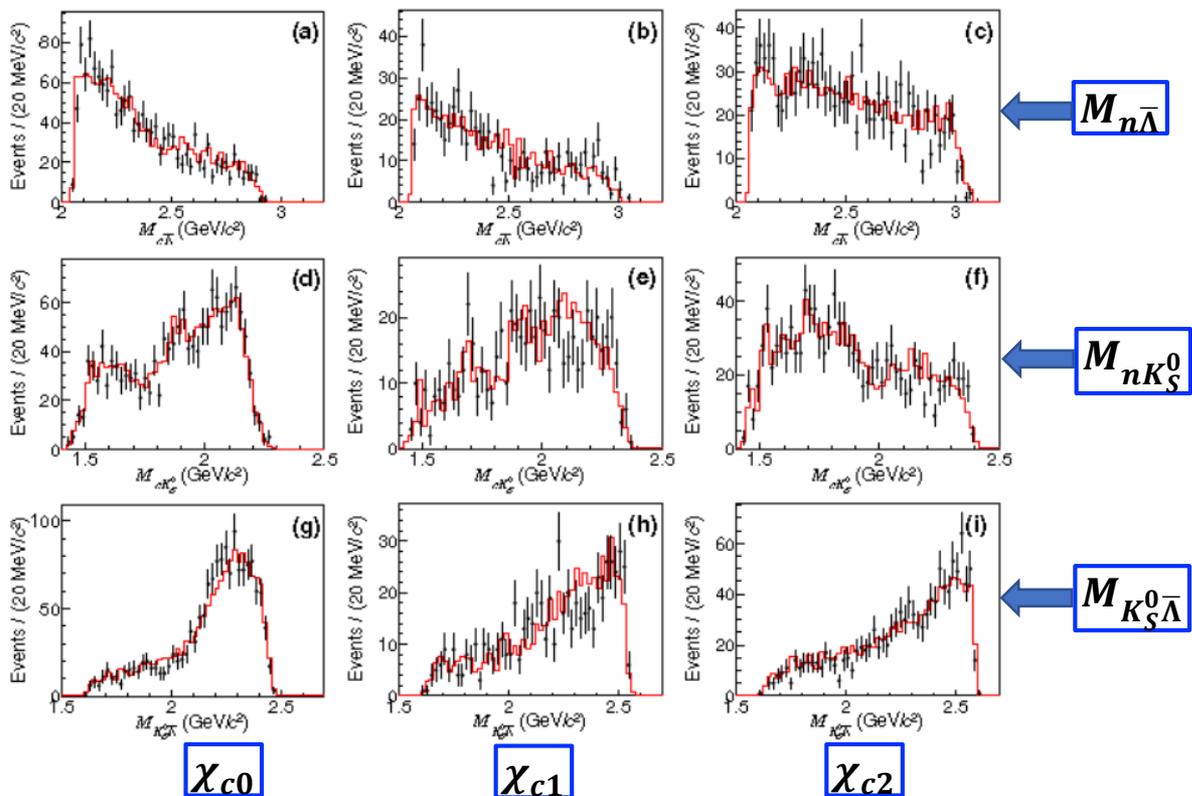
- $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$ are observed for the first time.
- No isospin violation is found in $\chi_{cJ} \to n(p)K\Lambda$ system.
- Enhancements are observed in the Dalitz plots and the mass distributions of two-body $n\bar{\Lambda}$ subsystems

Signal yields (Nobs), detection efficiencies(ε), and the branching fractions (BF)

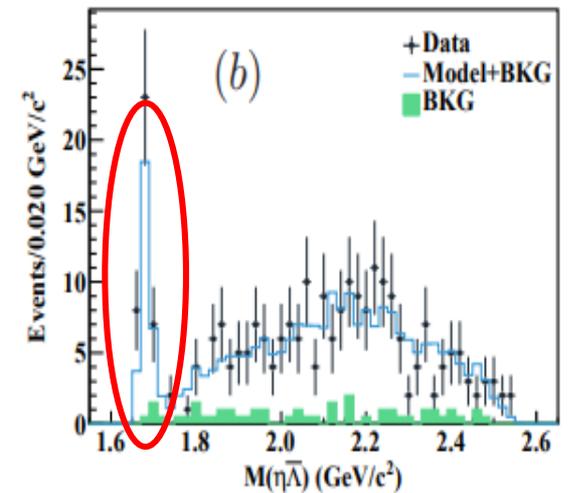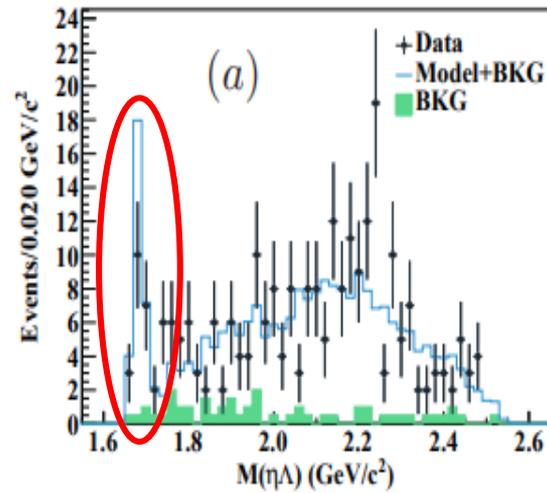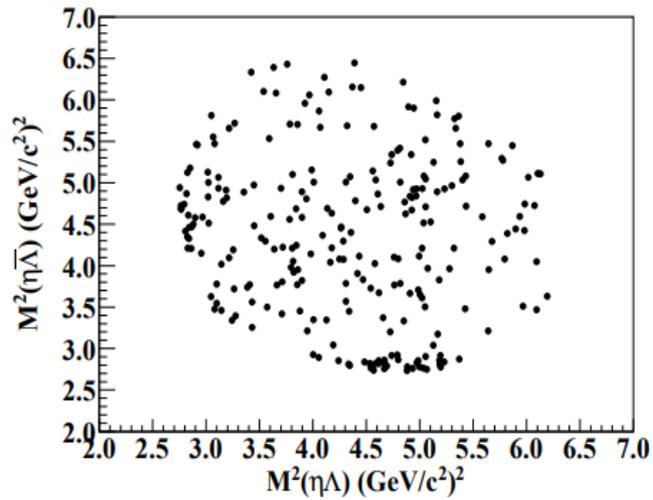| Mode	$N_{1,J}$	ϵ_J (%)	BF (10^{-4})
χ_{c0}	1284 ± 50	9.95	$6.65 \pm 0.26 \pm 0.41$
χ_{c1}	399 ± 30	12.44	$1.66 \pm 0.12 \pm 0.12$
χ_{c2}	879 ± 40	13.03	$3.58 \pm 0.16 \pm 0.23$

Summary

❖ BESIII is successfully operating since 2008, and continues to take data.

• $\psi(3686)$: 0.448×10^9 (1st, 2nd rounds)
             $\sim 4 \times (1^{st} + 2^{nd})$ (3rd round)

❖ Many interesting physics topics around χ_{cJ} decays into hadronic final states have been done.

❖ Some analysis techniques are improved.

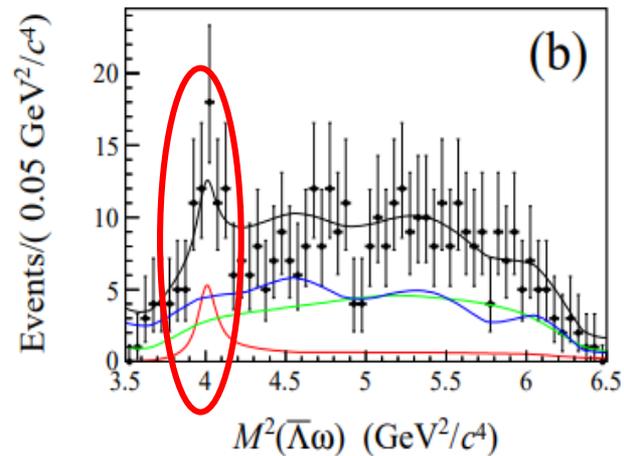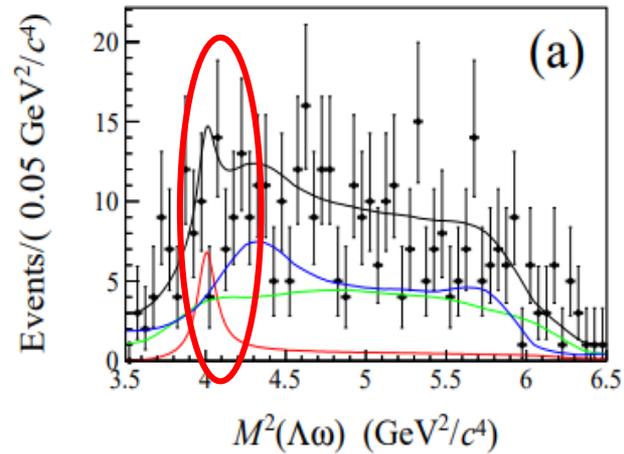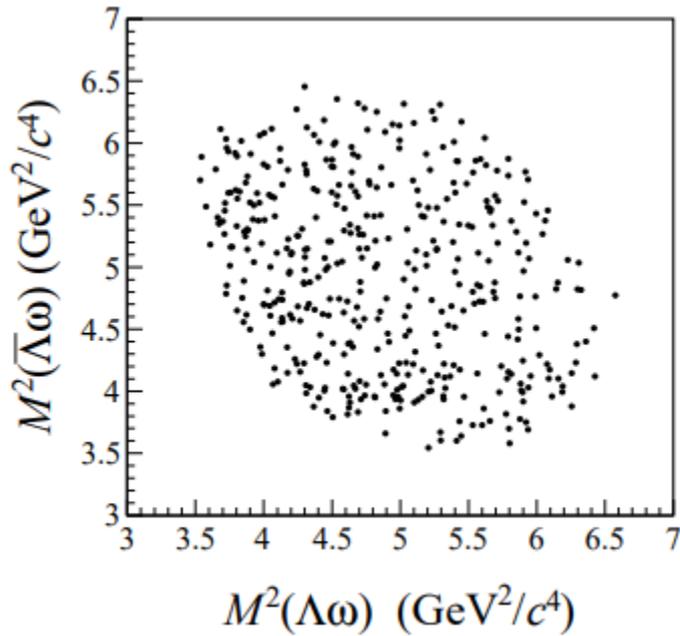❖ Much more results will be presented in the future.

Thank you!

Backup

$\psi(3686) \rightarrow \Lambda\bar{\Lambda}\eta$

Accepted by PRD

$\psi(3686) \rightarrow \Lambda\bar{\Lambda}\omega$

$e^+e^- \to \phi\Lambda\bar{\Lambda}$