Improved measurements of χ_{cj} -> $\Sigma^{+}\Sigma^{-}$bar and $\Sigma^{0}\Sigma^{0}$bar decays

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Event Selection

- χ_{cj} -> $\Sigma^+\Sigma^-$bar
  - In the decay chain $\Psi(3686)$ -> $\gamma\chi_{CJ}$, χ_{cj} -> $\Sigma^+\Sigma^-$bar, the $\Sigma^+(\Sigma^-$bar) particle is reconstructed in the decay channel $p\pi^0(\text{pbar}\pi^0)$, π^0->$\gamma\gamma$
    - at least 5 photons and 2 charged tracks with 0 net charge are required
    - |costheta| < 0.93
    - Vz < 15cm, Vr < 2cm (normal: Vz < 10cm, Vr < 1cm) due to the decay length of Σ+(Σ-)
    - dE/dx information obtained from the MDC and time information from the TOF system is combined in a global likelihood to identify protons and anti-proton
    - |costheta| < 0.8, E > 25MeV
    - 0.86 < |costheta| < 0.92, E > 50MeV
    - timing of good photon candidate within 700ns
      - reduce contributions from electronics noise
      - reduce beam-related background
    - χ_{4c}^2 < 50

Event Selection

- χ_{cj} -> $\Sigma^0\Sigma^0$
  - In the decay chain $\Psi(3686)$ -> $\gamma\chi_{CJ}$, χ_{cj} -> $\Sigma^0\Sigma^0$bar, the $\Sigma^0(\Sigma^0$bar) particle is reconstructed in the decay channel $\gamma\Lambda(\gamma\Lambda$bar), Λ->$p\pi^-(\Lambda$bar->$\bar{p}\pi^+$)
    - at least 3 photons and 4 charged tracks with 0 net charge are required
    - |costheta| < 0.93
    - no requirements are placed on the point of closest approach for the tracks since the Λ baryon has a large decay length of $c\tau$=7.9 cm
    - decay length of Λ and Λbar are required to be greater than 0
    - reonstructed invariant masses of the Λ and Λbar candidates are required to be within ±7 MeV/c2 of the nominal mass
    - reconstructed Σ0 and Σ0bar mass is required to lie in a window of ±15 MeV/c2 around the nominal mass
    - χ_{4C}^2 < 30

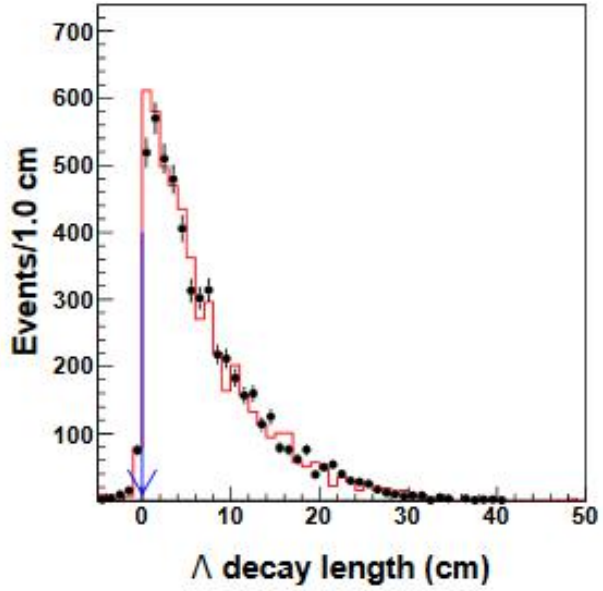

Fig. 2: The distribution of the Λ decay length for data (points) and MC (histogram).

Background Study

- $\chi_{cj} \rightarrow \Sigma^{+}\Sigma^{-}$

- $\chi_{cj} \rightarrow \Sigma^{0}\Sigma^{0}$

Background from continuum quantum electrodynamics (QED) processes, cosmic rays, beam-gas and beamwall interactions is estimated using the data collected outside of the ψ(3686) peak.
Peaking background:
χ_{cj} ->ppbarπ0π0

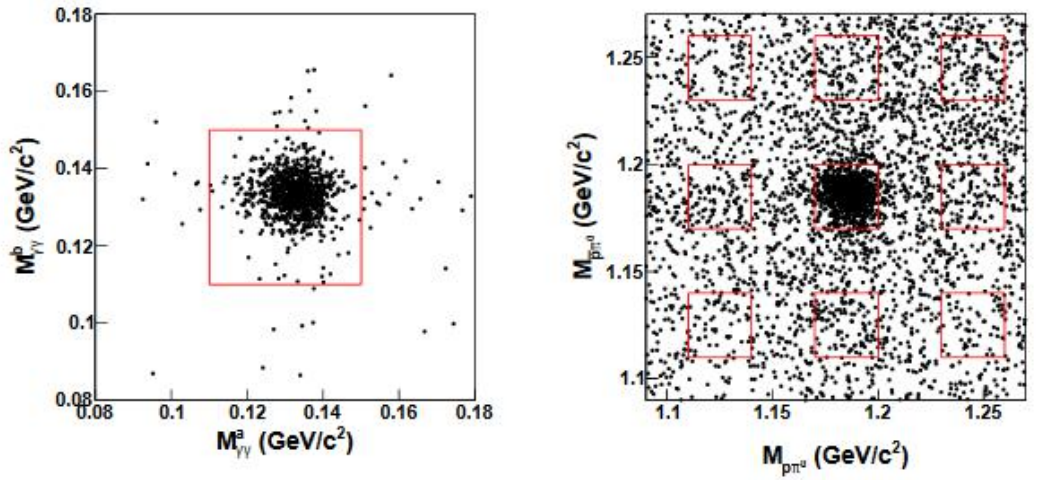

Fig. 1: Distribution of $M^a_{\gamma\gamma}$ versus $M^b_{\gamma\gamma}$ (left) and distribution of $M_{p\pi^0}$ versus $M_{\bar{p}\pi^0}$ (right) for $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$. The central (surrounding) boxes indicate the signal (sideband) regions.

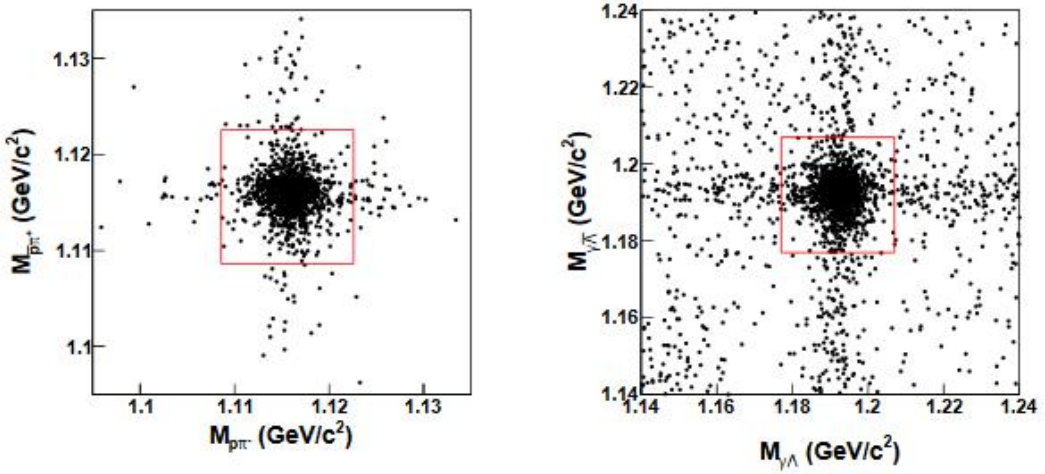

Fig. 3: Distribution of $M_{p\pi^-}$ versus $M_{\bar{p}\pi^+}$ (left) and distribution of $M_{\gamma\Lambda}$ versus $M_{\gamma\bar{\Lambda}}$ (right) for $\chi_{cJ} \to \Sigma^0\bar{\Sigma}^0$. The solid boxes indicate the signal regions.

Determination of the χ_{cj} signals

To determine the number of χcJ→Σ+ Σ−bar events, an extended unbinned maximum-likelihood fit is performed to the Σ+ Σ−bar invariant mass distribution between 3.3 and 3.6 GeV/c2.
In the fit, the signal yields and the masses of all three χcJ signals as well as the width of the χc0 signal are left free, while the detection resolution and the width of the χc1 and χc2 resonances are fixed.

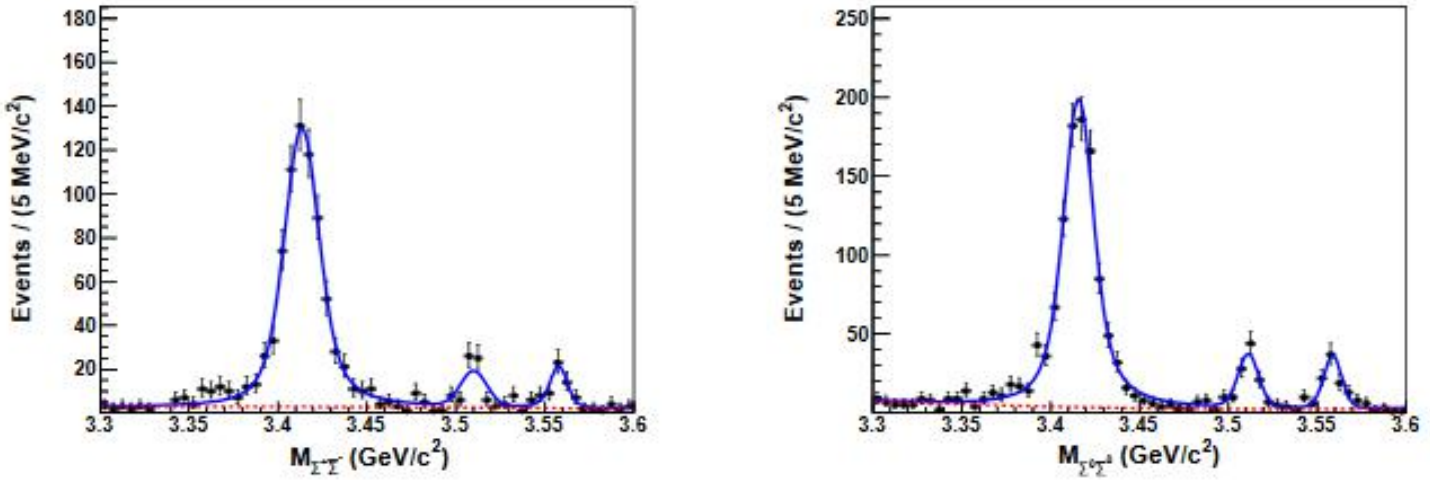

Fig. 4: Fit results to the invariant mass spectra of $\Sigma^+\bar{\Sigma}^-$ (left) and $\Sigma^0\bar{\Sigma}^0$ (right). The dots with error bars represent the data, the solid line represents the fit results and the dashed line represents the smooth background.

The statistical significances of the χc1,2→Σ+Σ−bar signal are 8.7σ and 7.1σ, respectively.
The statistical significances of the χc1,2→Σ0Σ0bar signal are 11.8σ and 10.9σ, respectively.
(previous result on the 2 channels from BESIII had a statistical significances of less than 5σ)

Determination of the χ_{cj} signals

TABLE II: The BF results for the measurement of $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ (second column), together with values from PDG world average [20], previous measurement from BESIII publications [6], CLEO [5] and theoretical predictions [2–4] for comparison. To make an objective comparison, the BF of $\chi_{cJ} \to \Sigma\bar{\Sigma}$ decays from previous BESIII are corrected with the newest BF of $\psi(3686) \to \gamma\chi_{cJ}$ from Ref. [20]. To be independent from the BF of $\psi(3686) \to \gamma\chi_{cJ}$, the product BF ($\mathcal{B}_{\rm prod}$) of $\psi(3686) \to \gamma\chi_{cJ}$ and $\chi_{cJ} \to \Sigma\bar{\Sigma}$ are also listed (last column). The first uncertainty is statistical and the second systematic. The unit is 10^{-5}.

Channel	This work	PDG [20]	Previous BESIII [6]	CLEO [5]	Theory	$\mathcal{B}_{\rm prod}$
$\chi_{c0} \to \Sigma^+\bar{\Sigma}^-$	$50.4 \pm 2.5 \pm 2.7$	39 ± 7	$43.7 \pm 4.0 \pm 2.8$	$32.5 \pm 5.7 \pm 4.3$	5.5-6.9 [3]	$4.99 \pm 0.24 \pm 0.24$
$\chi_{c1} \to \Sigma^+\bar{\Sigma}^-$	$3.7 \pm 0.6 \pm 0.2$	< 6	$5.2 \pm 1.3 \pm 0.5 (< 8.3)$	< 6.5	3.3 [4]	$0.35 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \Sigma^+\bar{\Sigma}^-$	$3.5 \pm 0.7 \pm 0.3$	< 7	$4.7 \pm 1.8 \pm 0.7 (< 8.4)$	< 6.7	5.0 [4]	$0.32 \pm 0.06 \pm 0.03$
$\chi_{c0} \to \Sigma^0\bar{\Sigma}^0$	$47.7 \pm 1.8 \pm 3.5$	44 ± 4	$46.0 \pm 3.3 \pm 3.7$	$44.1 \pm 5.6 \pm 4.7$	$(25.1 \pm 3.4, 18.7 \pm 4.5)$ [2]	$4.72 \pm 0.18 \pm 0.28$
$\chi_{c1} \to \Sigma^0\bar{\Sigma}^0$	$4.3 \pm 0.5 \pm 0.3$	< 4	$3.7 \pm 1.0 \pm 0.5 (< 6.0)$	< 4.4	3.3 [4]	$0.41 \pm 0.05 \pm 0.03$
$\chi_{c2} \to \Sigma^0\bar{\Sigma}^0$	$3.9 \pm 0.5 \pm 0.3$	< 6	$3.8 \pm 1.0 \pm 0.5 (< 6.2)$	< 7.5	5.0 [4]	$0.35 \pm 0.05 \pm 0.02$

Systematic Uncertainties

by counting inclusive hadronic events from ψ(3686) decays with an uncertainty of 0.6%

control sample

uncertainties quoted in the PDG

changed from a second order Chebyshev polynomial to a first or third order one

changing the damping factor

changing the boundary of the sideband, the fit range, the shape of the background and signal in the sideband data similarly as described above as well as the scale factor

TABLE IV: Summary of relative systematic uncertainties for the measurement of $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ (%) .

Sources	$\chi_{c0} \to \Sigma^+\bar{\Sigma}^-$	$\chi_{c1} \to \Sigma^+\bar{\Sigma}^-$	$\chi_{c2} \to \Sigma^+\bar{\Sigma}^-$	$\chi_{c0} \to \Sigma^0\bar{\Sigma}^0$	$\chi_{c1} \to \Sigma^0\bar{\Sigma}^0$	$\chi_{c2} \to \Sigma^0\bar{\Sigma}^0$
Number of $\psi(3686)$	0.6	0.6	0.6	0.6	0.6	0.6
Photon selection	0.6	0.6	0.6	1.8	1.8	1.8
Tracking and PID	2.7	2.7	2.7	—	—	—
Λ and $\bar{\Lambda}$ reconstruction	—	—	—	4.5	4.5	4.5
π^0 reconstruction	2.4	2.4	2.4	—	—	—
Σ mass window	0.3	0.3	0.3	0.6	0.6	0.6
4C kinematic fit	0.8	0.8	0.8	3.1	3.1	3.1
$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ})$	2.7	3.2	3.4	2.7	3.2	3.4
$\mathcal{B}(\Sigma^+ \to p\pi^0) + \text{c.c.}$	1.2	1.2	1.2	—	—	—
$\mathcal{B}(\Lambda \to p\pi^-) + \text{c.c.}$	—	—	—	1.6	1.6	1.6
Fit range	0.8	0.9	1.9	1.1	1.2	2.3
$\chi_{c1,2}$ width	—	0.1	0.3	—	0.1	0.3
Background shape	1.4	1.6	4.1	1.7	3.1	1.2
Signal shape	1.5	2.3	3.7	1.7	0.9	1.5
Peaking background	0.9	3.1	5.0	—	—	—
Generator	0.1	1.1	1.5	2.0	2.3	2.5
Total	5.4	6.8	9.4	7.4	8.0	8.0

Summary

In summary, using the world's largest ψ(3686) sample at on-resonance production taken with the BESIII detector, we have measured the BF of $\chi_{cj} \to \Sigma^+\Sigma^-$ and $\chi_{cj} \to \Sigma^0\Sigma^0$. The decays $\chi_{cj} \to \Sigma^+\Sigma^-$ and $\chi_{cj} \to \Sigma^0\Sigma^0$ are observed with more than 5σ significance for the first time.

The results are consistent with and improve on the precision compared to the world average values. The current results on $\chi_{cj} \to \Sigma^+\Sigma^-$ and $\chi_{cj} \to \Sigma^0\Sigma^0$ are in good agreement with theoretical predictions based on the color octet contribution model. The ratio between charged and neutral decay modes is consistent with the expectation from isospin symmetry.