Helicity amplitudes and branching fractions measurements of $\chi_{cJ} \to \Lambda\bar{\Lambda}$ at BESIII

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Helicity Selection Rule

For a charmonium states decay to baryon anti-baryon pair, there are two helicity amplitudes:

- H_{++} for same helicity;
- H_{+-} for opposite helicity;

In the massless QCD, the $q\bar{q}g$ vertex $V^{\mu} = \bar{u}^{(\lambda_1)}(p_1)\gamma^{\mu}v^{(\lambda_2)}(p_2)$ vanishes unless $\lambda_1 = -\lambda_2$. This leads to the *helicity selection rule* (HSR): H_{++} is forbidden, while H_{+-} is allowed. Furthermore, the perturbative QCD (pQCD) predicts the branching ratio of $J_{c\bar{c}} \to h_1 h_2$ decays as:

$$BR_{J_{c\bar{c}}(\lambda)\to h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2},$$

The leading term is $\lambda_1 + \lambda_2 = 0$, while other configurations are suppressed by Λ^2_{QCD}/m_c^2.

This Work

For $\chi_{cJ} \to \Lambda\bar{\Lambda}$ $(J = 0, 1, 2)$:

- χ_{c0}: only H_{++} exists duo to angular momentum conservation $\to$ HSR suppressed.
- χ_{c1}: only H_{+-} exists due to CP conservation $\to$ HSR allowed.
- χ_{c2}: both H_{++} and H_{+-} exist.

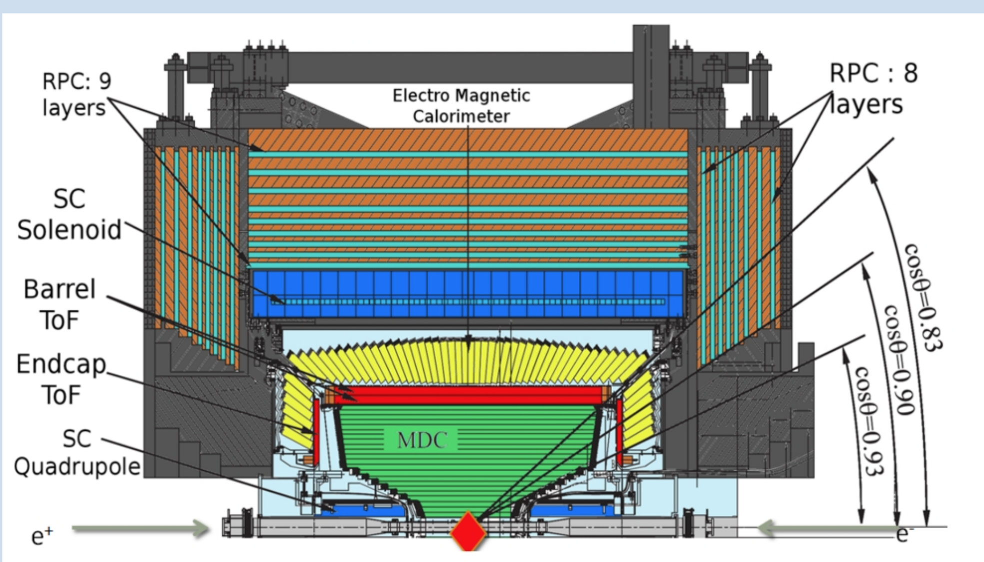
This work : measure the ratio between the HSR-suppressed amplitude H_{++} and the HSR-allowed amplitude H_{+-} in the χ_{c2} decay.

BESIII Detector

BESIII operates at BEPCII e^+e^- collider ($\sqrt{s}$ = 1.84 − 4.95 GeV). Peak luminosity: 1.1×10^{33} cm^{-2}s^{-1} at $\sqrt{s} = 3.773$ GeV.
Detector components (93% solid angle coverage):

- **MDC**: Helium-based drift chamber, momentum resolution 0.5% at 1 GeV/c
- **TOF**: Plastic scintillator, time resolution 68 ps (barrel), 60 ps (end cap)
- **EMC**: CsI(Tl) calorimeter, energy resolution 2.5%/5% at 1 GeV (barrel/end cap)
- **Magnet**: 1.0 T superconducting solenoid

Dataset: 2712.4 ± 14.3 million $\psi(3686)$ events.



Event Selection

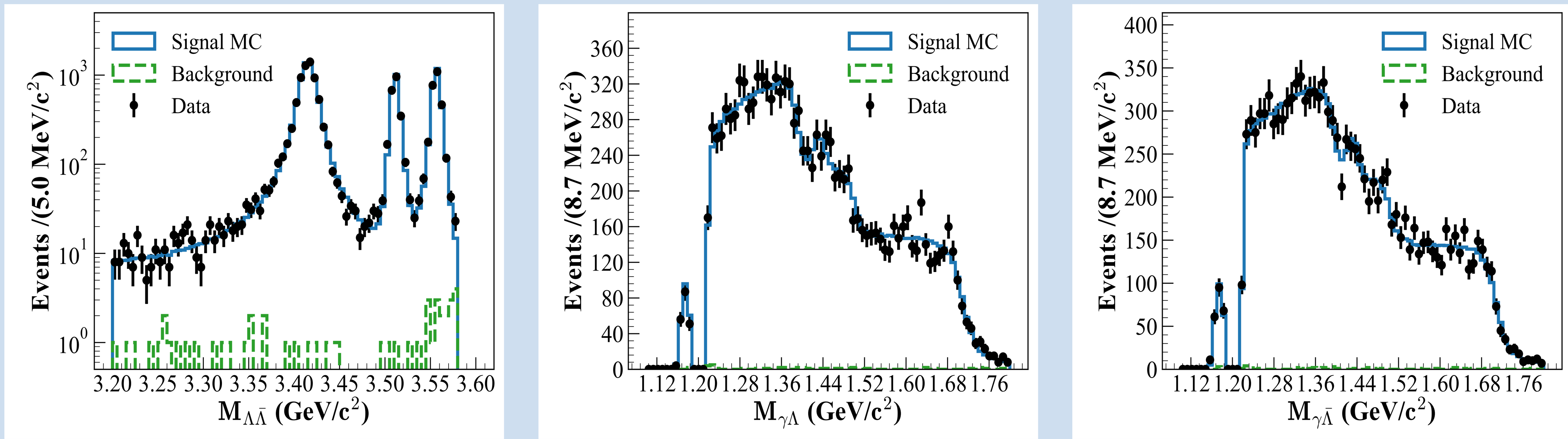
Charged tracks: Standard quality cuts and particle identification applied.
$\Lambda/\bar{\Lambda}$ reconstruction:

- Minimizing $(M_{p\pi^-} - m_{\Lambda})^2 + (M_{\bar{p}\pi^+} - m_{\bar{\Lambda}})^2$
- Vertex fit / decay length cut / mass window

Σ^0 veto : to suppress $J/\psi \to \Sigma^0\bar{\Sigma}^0$
Photon selection: the one with smallest χ^2 of four-constraint kinematic fit (constraint the total momentum of final states to the initial state.)

Mass Projections

After event selection, clean χ_{cJ} signals are obtained. The invariant mass distributions show excellent signal-to-background ratios, making the sample well-suited for partial wave analysis. The background is estimated using the inclusive Monte Carlo sample.



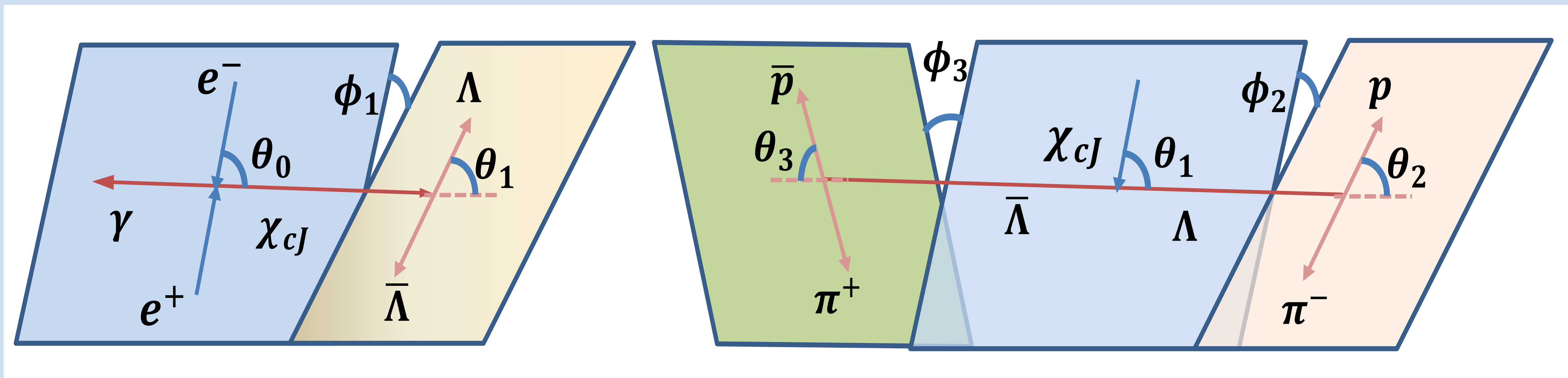
Left: χ_{cJ} mass spectrum. **Center & Right:** $\gamma\Lambda$ and $\gamma\bar{\Lambda}$ mass distributions.

Partial Wave Analysis

Isobar model: cascade decay $\to$ sequential two-body decays.
Helicity amplitude for a decay process $0 \to 1 + 2$:

$$A^{0\to 1+2}_{\lambda_0,\lambda_1\lambda_2} = H^{0\to 1+2}_{\lambda_1\lambda_2} D^{J_0^*}_{\lambda_0,\lambda_1-\lambda_2}(\phi,\theta,0)$$

$H^{0\to 1+2}_{\lambda_1,\lambda_2}$ is the helicity amplitude strength; $D^{J_0}_{\lambda_0,\lambda_1-\lambda_2}(\phi,\theta,0)$ is Wigner D-function; J_0 represents spin of partial 0 and θ, ϕ are the helicity angles.



Decay topology and helicity angle definitions.

Automatic amplitude construction and parameter estimation are implemented in TF-PWA, an open source software for partial wave analysis developed by Yi Jiang.

Main Results

$\chi_{c2} \to \Lambda\bar{\Lambda}$ helicity amplitudes ratio and relative phase:

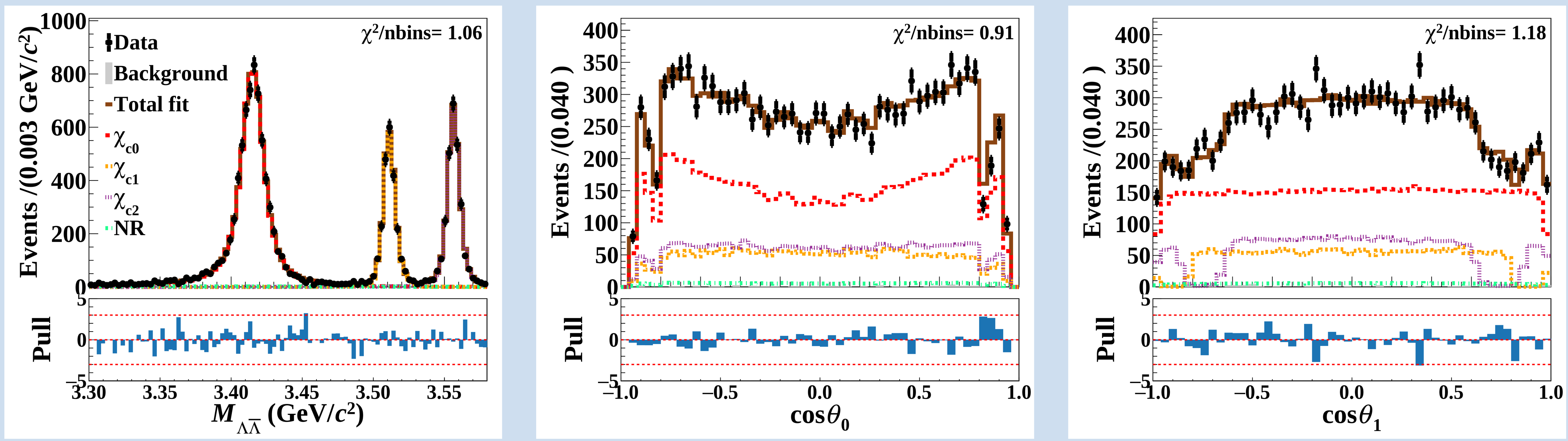
$$R_{\chi_{c2}} = 0.575 \pm 0.048 \pm 0.018\ ,$$
$$\Delta\Phi_{\chi_{c2}} = 0.37 \pm 0.15 \pm 0.05 \text{ rad}$$

χ_{c0} width:

$$\Gamma_{\chi_{c0}} = 12.31 \pm 0.26 \pm 0.12 \text{ MeV}$$

Branching fractions for $\chi_{cJ} \to \Lambda\bar{\Lambda}$:

$$\mathcal{B}(\chi_{c0} \to \Lambda\bar{\Lambda}) = (3.662 \pm 0.048 \pm 0.111) \times 10^{-4}$$
$$\mathcal{B}(\chi_{c1} \to \Lambda\bar{\Lambda}) = (1.182 \pm 0.026 \pm 0.042) \times 10^{-4}$$
$$\mathcal{B}(\chi_{c2} \to \Lambda\bar{\Lambda}) = (1.704 \pm 0.035 \pm 0.057) \times 10^{-4}$$



Summary

Utilizing the world's largest χ_{cJ} sample collected at BESIII, we measured the helicity amplitudes ratio of $\chi_{c2} \to \Lambda\bar{\Lambda}$. The large value of this ratio ($R_{\chi_{c2}} = 0.575 \pm 0.048 \pm 0.018$) indicates significant HSR violation in χ_{c2} decay. This provides us with more information about the non-perturbative nature of QCD. We also measured the width of χ_{c0} and the branching fractions of $\chi_{cJ} \to \Lambda\bar{\Lambda}$ with improved precision.