Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

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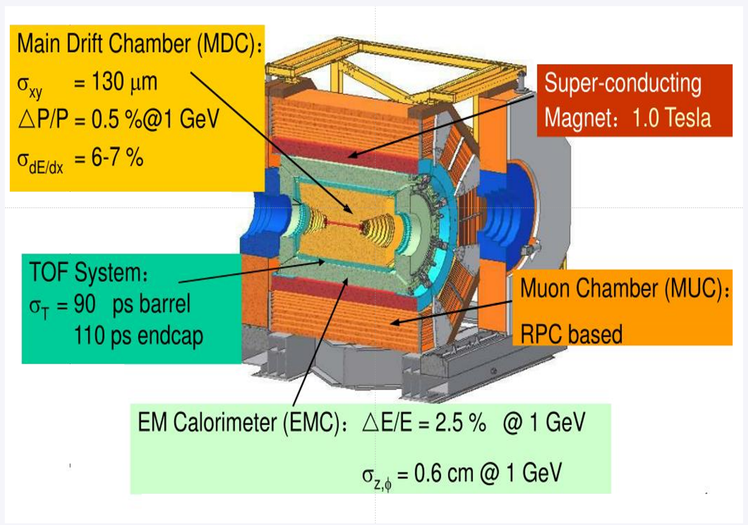
MOTIVATION

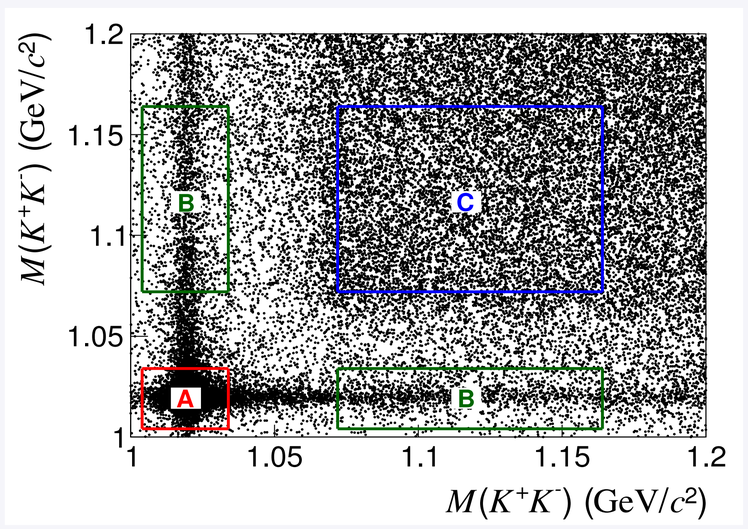
- Helicity selection rule (HSR) [1] requires $\lambda_1 + \lambda_2 = 0$. For charmonium decays to light hadrons $h_1(\lambda_1)h_2(\lambda_2)$, violating HSR exhibit suppressed branching fractions, as demonstrated in $\chi_{c1} \to \phi\phi$.
- However, BESIII observed comparable $\chi_{cJ} \to \phi\phi$ branching fractions for $J = 0, 1, 2$ [2], contradicting HSR expectations.
- Various models, including perturbative QCD (pQCD) [3], the quark-pair creation ($^3P_0$) model [4], and charm-loop ($D\bar{D}$) contributions [5], have been proposed to explain this anomaly. **Helicity amplitude ratios** provide key discriminators among these mechanisms.
- Measurements in this analysis: (I) $\left|F^0_{1,1}/F^0_{0,0}\right|$ in $\chi_{c0} \to \phi\phi$; (II) $\left|F^2_{0,1}/F^2_{0,0}\right|$, $\left|F^2_{1,-1}/F^2_{0,0}\right|$, $\left|F^2_{1,1}/F^2_{0,0}\right|$ in $\chi_{c2} \to \phi\phi$; (III) $\chi_{cJ} \to \phi\phi$ branching fraction, where $F^{J=0,2}_{\lambda_1,\lambda_2}$ are the helicity amplitudes.

BESIII DETECTORS



- Stable and reliable operation since **2008**
- Large acceptance
- Good particle identification
- High energy and momentum resolution

SIGNAL(BACKGROUND)



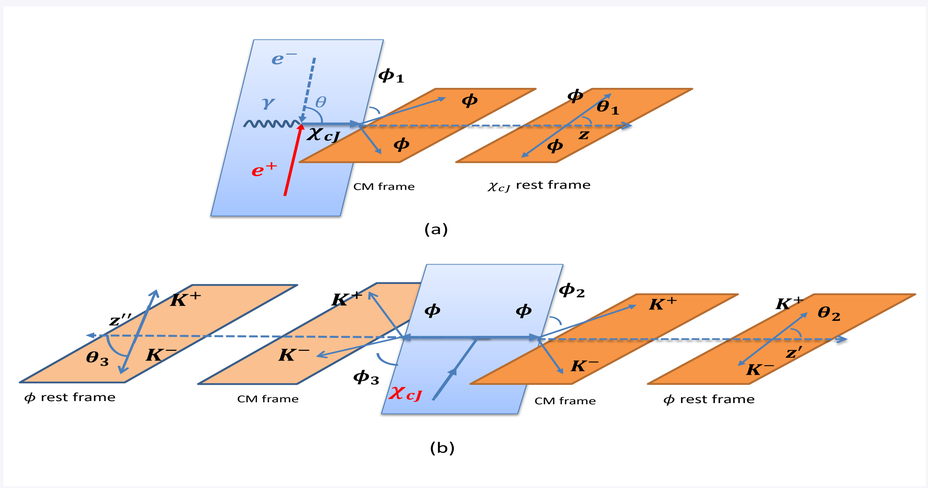
- **Signal**: $\chi_{cJ} \to \phi\phi$, area A
- **Background**:
  - $\chi_{cJ} \to \phi K^+K^-$, area B
  - $\chi_{cJ} \to K^+K^-K^+K^-$, area C

REFERENCES

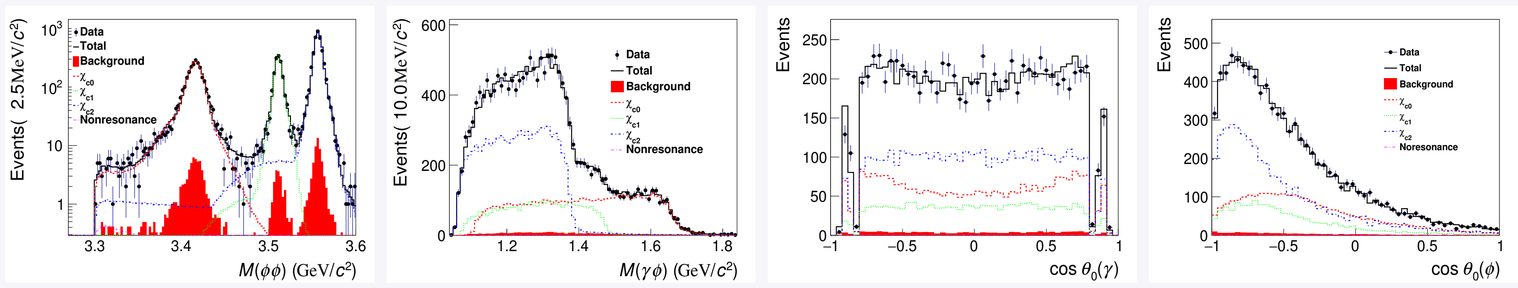
[1] S.J. Brodsky, G.P. Lepage, *Helicity selection rules and tests of gluon spin in exclusive quantum-chromodynamic processes*, *Phys. Rev. D* **24** (1981) 2848.
[2] M. Ablikim *et al.*, [BESIII Collaboration], *Observation of χ_{c1} Decays into Vector Meson Pairs $\phi\phi, \omega\omega,$ and $\omega\phi$*, *Phys. Rev. Lett.* **107** (2011) 092001.
[3] V. L. Chernyak and A. R. Zhitnitsky, *Exclusive decays of heavy mesons*, *Nucl. Phys. B* **201** (1982) 492.
[4] H. Chen and R. G. Ping, *Polarization in $\chi_{cJ} \to \phi\phi$ decays*, *Phys. Rev. D* **88** (2013) 034025.
[5] Q. Huang, J. Z. Wang, R. G. Ping and X. Liu, *Detecting the polarization in $\chi_{cJ} \to \phi\phi$ decays to probe hadronic loop effect*, *Phys. Rev. D* **103** (2021) 096006.
[6] S. U. Chung, *A General formulation of covariant helicity-coupling amplitudes*, *Phys. Rev. D* **57** (1998) 431-442.

AMPLITUDE ANALYSIS

- **Dataset and Methodology**:
  - BESIII 448.1×10^6 $\psi(3686)$ events
  - Covariant tensor expansion for helicity amplitudes [6]
  - Full angular distribution for $e^+e^- \to \psi(3686) \to \gamma\chi_{cJ} \to \gamma\phi\phi \to \gamma K^+K^-K^+K^-$

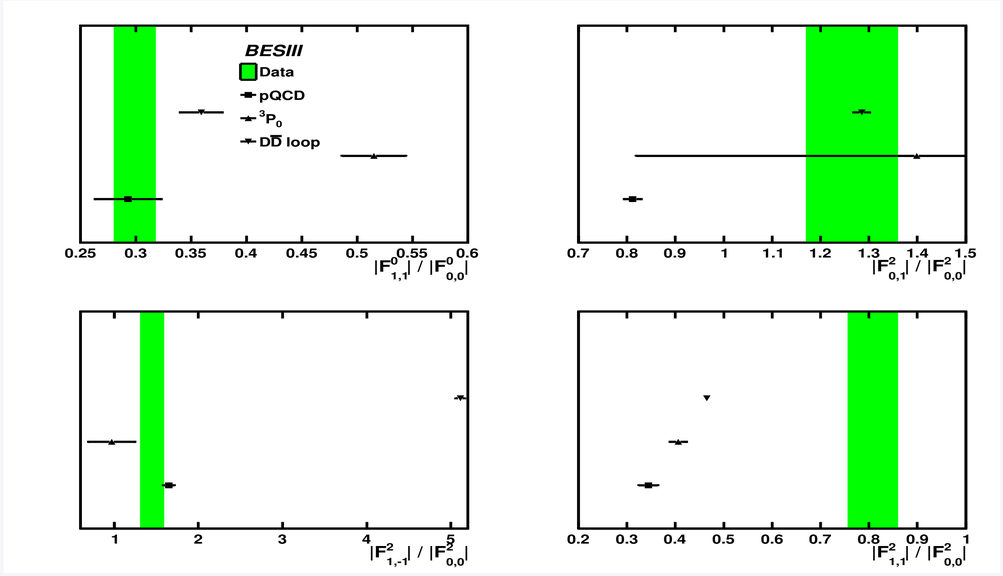


- **Fit Model**:
  - Resonance: Relativistic Breit-Wigner with damping factors (mass resolution included)
  - Non-resonant: Pure $J^P = 0^+$ component
  - Background: Sideband subtraction in likelihood fit
- **Fit results**: From left to right: invariant mass distributions (I) $m_{\phi\phi}$; (II) $m_{\gamma\phi}$; helicity angular distributions for (III) the photon; (IV) the ϕ meson.



SUMMARY AND OUTLOOK

- Helicity amplitude ratios exclude $D\bar{D}$ loop model; other theories show deviations.



Measured $\chi_{cJ} \to \phi\phi$ branching fractions ($\times 10^{-4}$)

Decay Mode	2011 BESIII [2]	This work	PDG
$\chi_{c0} \to \phi\phi$	$7.8 \pm 0.4 \pm 0.8$	$8.59 \pm 0.27 \pm 0.20$	8.0 ± 0.7
$\chi_{c1} \to \phi\phi$	$4.1 \pm 0.3 \pm 0.5$	$4.26 \pm 0.13 \pm 0.15$	4.2 ± 0.5
$\chi_{c2} \to \phi\phi$	$10.7 \pm 0.4 \pm 1.2$	$12.67 \pm 0.28 \pm 0.33$	10.6 ± 0.9

- **Key results**: First amplitude analysis and most precise $\chi_{cJ} \to \phi\phi$ BF measurements
- **Future**: 2.7B $\psi(3686)$ events for further analysis