Measurements of charmonia decays at BESIII

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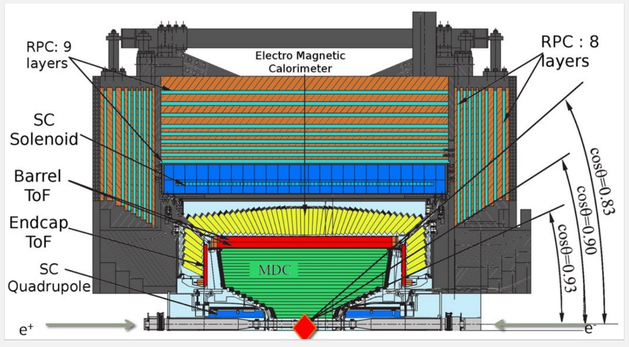
Introduction

The decays of charmonium states provide crucial information for a deeper understanding of non-perturbative behavior of Quantum Chromodynamics and test of various phenomenological models.
Large data samples collected at BESIII provide good opportunity for the study of decay dynamics of vector states, S-wave spin singlet states, and P-wave spin triplet states.

Beijing Spectrometer III(BESIII) at BEPCII

The BESIII detector records collisions provided by the BEPCII storage ring.



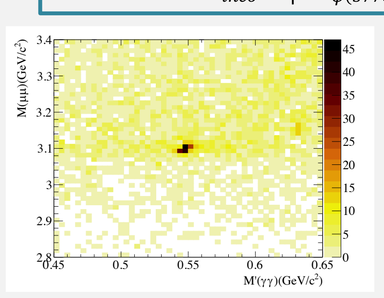
Beam energy:
1.0-2.47 GeV
Luminosity:
$1\times10^{33}\ \mathrm{cm^{-2}s^{-1}}$ at $\psi(3770)$ peak

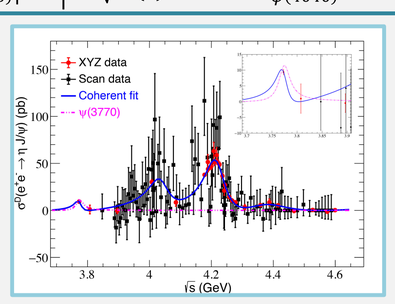
Observation of $\psi(3770)\to\eta J/\psi$[1]

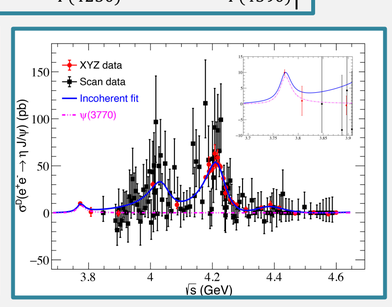
- The D-wave $c\bar{c}$ interpretation of $\psi(3770)$, cannot explain the measured large non-$D\overline{D}$ decay width of the state, the abnormal ratio of $\psi(3770)\to D^+D^-$ and $\psi(3770)\to D^0\overline{D}^0$
- Various theoretical models are developed to solve these puzzles, $\psi(3770)\to\eta J/\psi$ severs as an input in theoretical calculations
- **Data sample**: 2931.8 $\mathrm{pb^{-1}}$ $\psi(3770)$ sample + XYZ sample
- **Reconstruction**: $e^+e^-\to\eta J/\psi, J/\psi\to\mu^+\mu^-, \eta\to\gamma\gamma$
- **Fitting method:**

Coherent fit: $\sigma_{co}=\left|C\cdot\sqrt{\Phi(s)}+e^{i\phi_1}BW_{\psi(3770)}+e^{i\phi_2}BW_{\psi(4040)}+e^{i\phi_3}BW_{Y(4230)}+e^{i\phi_4}BW_{Y(4390)}\right|^2$

Incoherent fit: $\sigma_{inco}=\left|BW_{\psi(3770)}\right|^2+\left|C\cdot\sqrt{\Phi(s)}+e^{i\phi_2}BW_{\psi(4040)}+e^{i\phi_3}BW_{Y(4230)}+e^{i\phi_4}BW_{Y(4390)}\right|^2$







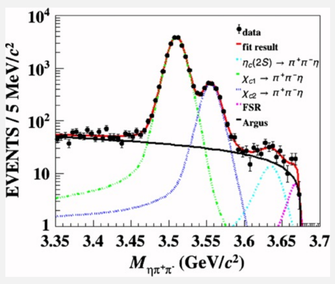
- **Born Cross section** at 3.773 GeV: $\sigma(\mathrm{e^+e^-}\to\eta\,\mathrm{J/\psi})=(8.88\pm0.87\pm0.42)\mathrm{pb}$
- **Branching fractions**:

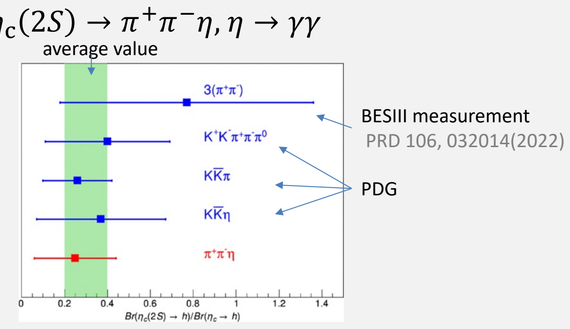
Parameters	Coherent fit				Incoherent fit
	Solution1	Solution2	Solution3	Solution4	
$\mathcal{B}r(\psi(3770)\to\eta J/\psi)\times10^{-4}$	11.3 ±5.9±1.1	11.6±6.0±1.1	11.2±5.8±1.1	11.5±6.0±1.1	8.7±1.0±0.8
ϕ(rad)	3.9±0.6±0.07	4.2±0.6±0.09	3.7±0.6±0.05	4.1±0.6±0.08	-

- First **observation** of $\psi(3770)\to\eta J/\psi$ (Coherent fit 7.9σ, Incoherent fit 8.3σ)
- There exists substantial interference effect, especially between $\psi(3770)$ and highly excited vector charmonium(-like) states

Evidence for the $\eta_c(2S)\to\pi^+\pi^-\eta$ decay[2]

- The knowledge about $\eta_c(2S)$ is limited in PDG.
- $\mathcal{B}r(\eta_c(2S)\to h)/\mathcal{B}r(\eta_c\to h)$ predicted to be 12%[PRD 44 1597 (1991)] or 100%[CTP 25 471 (1996)], need to be clarified
- **Data sample**: 448 million $\psi(2S)$ events
- **Reconstruction**: $\psi(2S)\to\gamma\eta_c(2S), \eta_c(2S)\to\pi^+\pi^-\eta, \eta\to\gamma\gamma$

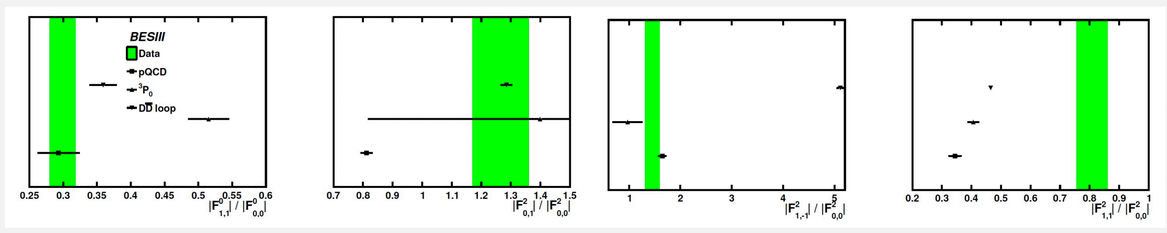




- First **evidence** of $\eta_c(2S)\to\pi^+\pi^-\eta$ (3.5σ)
- **Branching fractions**:
  $\mathcal{B}r\left(\psi(2S)\to\gamma\eta_c(2S)\right)\times\mathcal{B}r(\eta_c(2S)\to\pi^+\pi^-\eta)=(2.97\pm0.81\pm0.26)\times10^{-6}$
  $\mathcal{B}r(\eta_c(2S)\to\pi^+\pi^-\eta)=(42.4\pm11.6\pm3.8\pm30.0)\times10^{-4}$
- **The ratio of the branching fractions:**
  $\frac{\mathcal{B}r(\eta_c(2S)\to\pi^+\pi^-\eta)}{\mathcal{B}r(\eta_c\to\pi^+\pi^-\eta)}=0.25\pm0.20$

Helicity amplitude analysis of $\chi_{cJ}\to\phi\phi$[3]

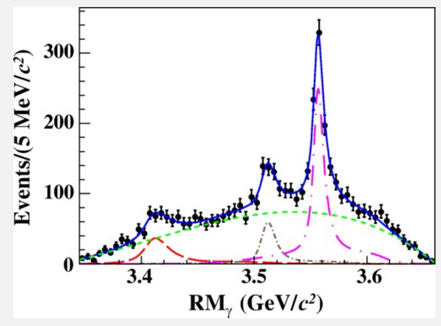
- Previously observed $\chi_{cJ}\to\phi\phi$ demonstrate that the decay mechanism of χ_{cJ} is not well understood
- The quark-pair creation model and charm-loop contributions have been proposed to interpret the experimental result of the rations of the helicity amplitudes are believed to be sensitive to different models
- **Data sample**: 448 million $\psi(2S)$ events
- **Reconstruction**: $\psi(2S)\to\gamma\chi_{cJ},\ \chi_{cJ}\to\phi\phi, \phi\to K^+K^-$
- **Amplitude analysis** is performed to extract helicity amplitudes
- **Branching fractions**:
  $\mathcal{B}r(\chi_{c0}\to\phi\phi)=(8.59\pm0.27\pm0.20)\times10^{-4}$
  $\mathcal{B}r(\chi_{c1}\to\phi\phi)=(4.26\pm0.13\pm0.15)\times10^{-4}$
  $\mathcal{B}r(\chi_{c2}\to\phi\phi)=(12.67\pm0.28\pm0.33)\times10^{-4}$
- **Amplitude ratios:**
  $\chi_{c0}\to\phi\phi$:
  $\left|\mathrm{F}^0_{1,1}\right|/\left|\mathrm{F}^0_{0,0}\right|=0.299\pm0.003\pm0.019$
  $\chi_{c2}\to\phi\phi$:
  $\left|\mathrm{F}^2_{0,1}\right|/\left|\mathrm{F}^2_{0,0}\right|=1.265\pm0.054\pm0.079$
  $\left|\mathrm{F}^2_{1,-1}\right|/\left|\mathrm{F}^2_{0,0}\right|=1.450\pm0.097\pm0.104$
  $\left|\mathrm{F}^2_{1,1}\right|/\left|\mathrm{F}^2_{0,0}\right|=0.808\pm0.051\pm0.009$



- **For the decay of χ_{c1},** no evidence of identical particle symmetry breaking
- **For the decay of χ_{c0},** consistent with the pQCD prediction
- **For the decay of χ_{c2},** the $D\overline{D}$ loop model[PRD 103 096006(2021)] ruled out due to the large deviation, while the pQCD model and the $^3\mathrm{P}_0$ cannot describe the measurements either

Observation of the decay $\chi_{cJ}\to\Omega^-\overline{\Omega}^+$ [4]

- Baryonic χ_{cJ} decays provide useful input to theoretical calculations involving the color-octet wave function
- **Data sample**: 2.708 billion $\psi(2S)$ events
- **Partial Reconstruction**:
  $\psi(2S)\to\gamma\chi_{cJ}$
  $\chi_{cJ}\to\Omega^-\overline{\Omega}^+$
  $\Omega^-(\overline{\Omega}^+)\to\Lambda K^-(\overline{\Lambda}K^+)$
  $\Lambda(\overline{\Lambda})\to p\pi^-(\bar{p}\pi^+)$
- First **observation** of $\chi_{c0,1,2}\to\Omega^-\overline{\Omega}^+$ ($5.6\sigma, 6.4\sigma, 18\sigma$)



- **Branching fractions**:
  $\mathcal{B}r(\chi_{c0}\to\Omega^-\overline{\Omega}^+)=(3.51\pm0.54\pm0.29)\times10^{-5}$
  $\mathcal{B}r(\chi_{c1}\to\Omega^-\overline{\Omega}^+)=(1.49\pm0.23\pm0.10)\times10^{-5}$
  $\mathcal{B}r(\chi_{c2}\to\Omega^-\overline{\Omega}^+)=(4.52\pm0.24\pm0.18)\times10^{-5}$
- Measured $\mathcal{B}r(\chi_{c0}\to\Omega^-\overline{\Omega}^+)$ is one order of magnitude smaller than those of χ_{c0} decaying to baryon antibaryon pairs with spin $1/2$ and $3/2$, which will be useful for theorists to investigate the helicity selection rule evading mechanism in χ_{c0} decays.

Outlook

BESIII has accumulated about 2.7 billion $\psi(2S)$ data and will have 20 $\mathrm{fb^{-1}}$ $\psi(3770)$ data in near future.

- Improved measurements of $\psi(3770)\to\pi^+\pi^-J/\psi,\ \pi^0J/\psi,\ \gamma\chi_{cJ}$,etc., in the future, as well as a finer scan around the $\psi(3770)$ are desirable to reveal the nature of this resonance.
- More searches on new decay modes and more precise measurements of the $\eta_c(2S)$ decays will shed light on decay mechanisms of the spin singlet charmonium states.
- The helicity amplitude analysis of $\chi_{cJ}\to\phi\phi$ can provide more constraints for further developing the models.
- The $\chi_{cJ}\to\Omega^-\overline{\Omega}^+$ decay can be used to probe the spin polarization of Ω^- baryon in the charmonium production at the future tau-charm factories.

References

1. M. Ablikim et al. (BESIII Collaboration), PRD 107, L091101 (2023).
2. M. Ablikim et al. (BESIII Collaboration), PRD 107, 052007 (2023).
3. M. Ablikim et al. (BESIII Collaboration), JHEP, 05(2023)069.
4. M. Ablikim et al. (BESIII Collaboration), PRD 107, 092004 (2023).

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