Observation of new charmonium decays at BESIII

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Introduction

- Since its discovery in 1974, the charmonium system is always considered an ideal place for testing the non-perturbative regime of the QCD theory [1].
- Based on a 448 million $\psi(2S)$ sample, several decay channels of charmonium states have been searched for at BESIII recently. The decays of $\psi(2S) \to \Xi(1530)^0\bar{\Xi}(1530)^0$, $\psi(2S) \to \Xi(1530)^0\bar{\Xi}^0$, $\chi_{c1} \to \Xi^0\bar{\Xi}^0$ and $\chi_{c2} \to \Xi^0\bar{\Xi}^0$ have been observed for the first time.
- Using data sample above 4.0 GeV, the new decay modes of $h_c \to \pi^0 J/\psi$, $\psi_2(3823) \to \gamma\chi_{c0}$, $\gamma\chi_{c2}$, $\pi\pi J/\psi$, $\eta J/\psi$ and $\pi^0 J/\psi$ have been searched for.

The BESIII is unique for studying charmonium decays!

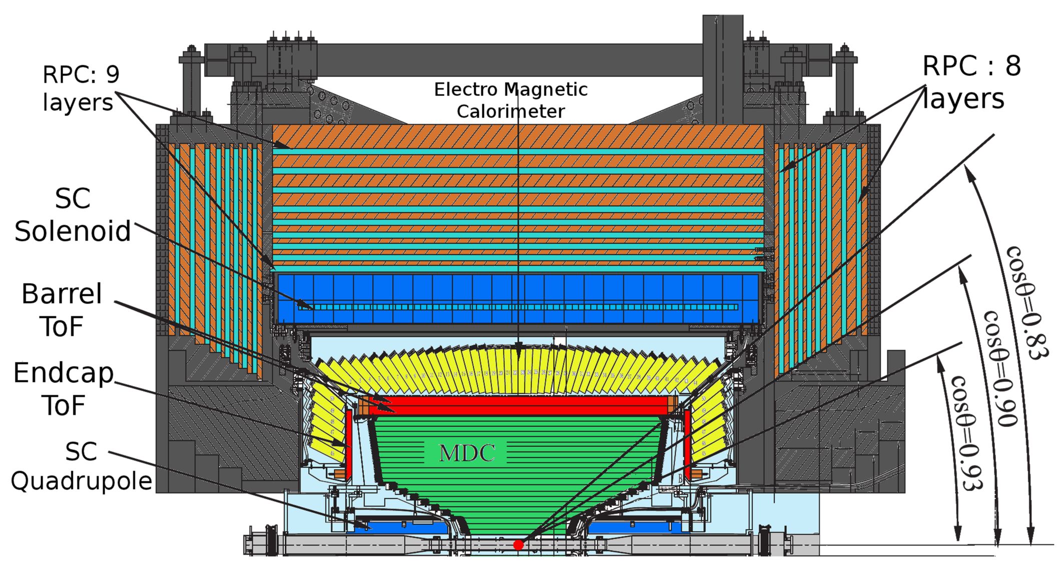

Figure 1:The BESIII detector

- Beam energy: $1.0 - 2.47$ GeV
- Luminosity: 1×10^{33} cm^{-2}s^{-1} at 3.773 GeV
- Charmonium physics:
  - Study of the $\psi(2S)$ decays: a 448 million $\psi(2S)$ sample!
  - Study of the χ_{cJ} decays: $\mathcal{B}[\psi(2S) \to \gamma\chi_{cJ}] \approx 10\%$
  - Study of the excited charmonium decays: a 21.3 fb^{-1} data sample at $4 - 4.95$ GeV.

Observation of $\psi(2S) \to \Xi(1530)^0\bar{\Xi}(1530)^0$ and $\Xi(1530)^0\bar{\Xi}^0$ decays [2]

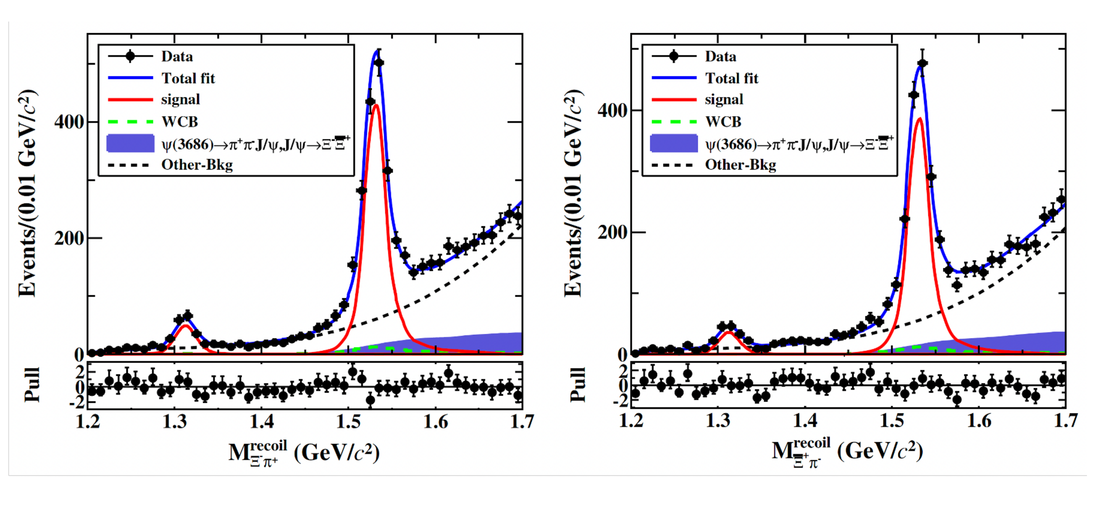

Figure 2:Simultaneous fits to the $M^{\rm recoil}_{\Xi^-\pi^+}$ (left) and $M^{\rm recoil}_{\bar{\Xi}^+\pi^-}$ (right) spectra for $\psi(2S) \to \Xi(1530)^0\bar{\Xi}(1530)^0$ and $\Xi(1530)^0\bar{\Xi}^0$ decays, respectively.

- The first observation! (Statistical significances $> 10\sigma$)
- Branching fractions:
  $\mathcal{B}\left[\psi(2S) \to \Xi(1530)^0\bar{\Xi}(1530)^0\right] = (6.77 \pm 0.14 \pm 0.39) \times 10^{-5}$
  $\mathcal{B}\left[\psi(2S) \to \Xi(1530)^0\bar{\Xi}^0\right] = (0.53 \pm 0.04 \pm 0.03) \times 10^{-5}$
- The "12% rule", $\frac{\mathcal{B}[\psi(2S)\to \text{hadrons}]}{\mathcal{B}[J/\psi \to \text{hadrons}]} \approx 12\%$, is tested in the decay $\psi \to \Xi(1530)\bar{\Xi}$ and found to be highly violated.

Observation of $\psi(2S) \to \omega K^0_S K^0_S$ decay [3]

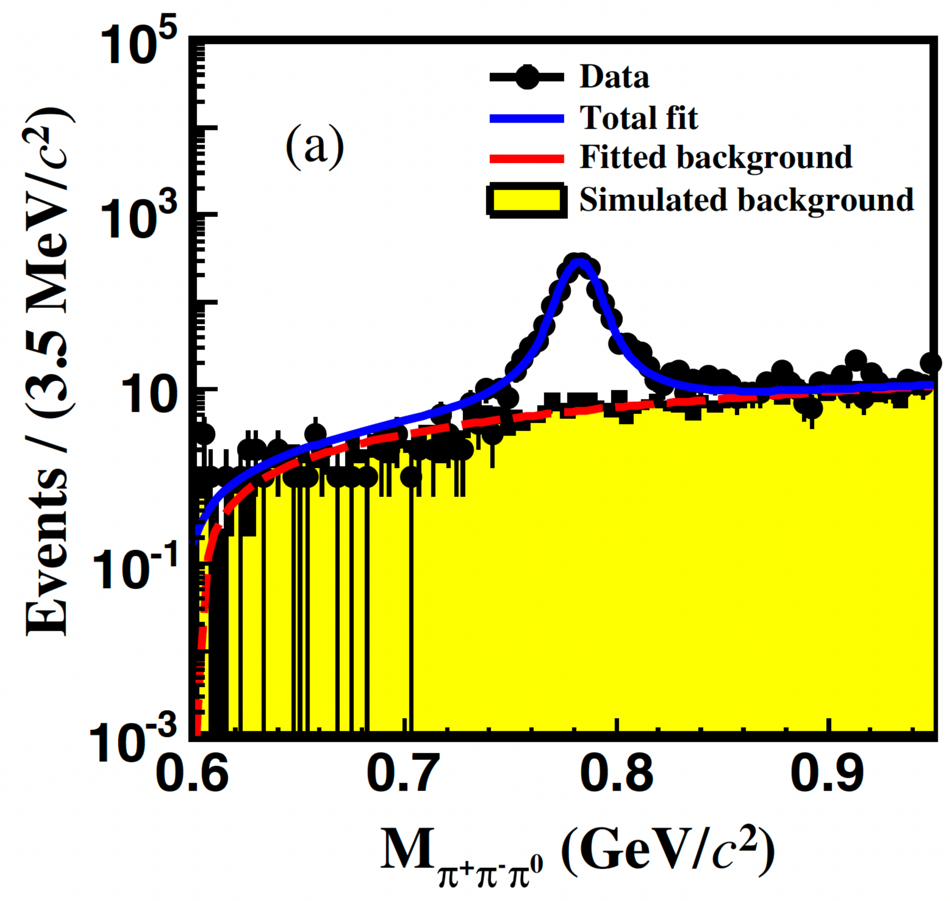

Figure 3:Fit to the $M_{\pi^+\pi^-\pi^0}$ distributions of the accepted candidates in the 2D signal region for the $\psi(2S)$ data.

- The first observation! (Statistical significance $> 5\sigma$)
- Branching fraction:
  $\mathcal{B}[\psi(2S) \to \omega K^0_S K^0_S] = (7.04 \pm 0.39 \pm 0.36) \times 10^{-5}$
- The ratio $\frac{\mathcal{B}[\psi(2S)\to\omega K^0_S K^0_S]}{\mathcal{B}[J/\psi\to\omega K^0_S K^0_S]} = (14.8 \pm 3.2)\%$ shows consistency with the "12% rule" within uncertainty.

Observation of $\chi_{c1} \to \Xi^0\bar{\Xi}^0$ and $\chi_{c2} \to \Xi^0\bar{\Xi}^0$ decays [4]

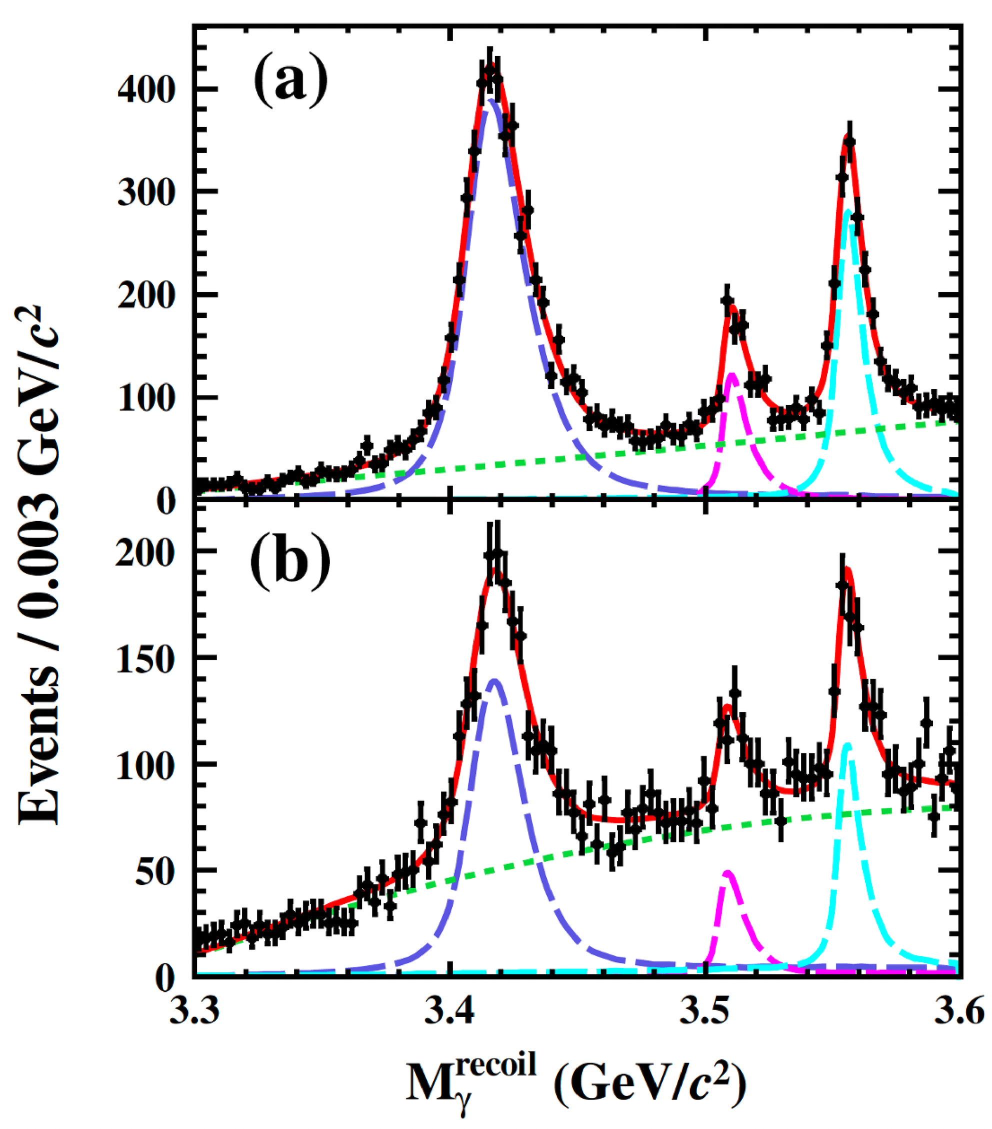

Figure 4:Fits to the $M^{\rm recoil}_{\gamma}$ distributions for the (a) $\chi_{cJ} \to \Xi^-\bar{\Xi}^+$ and (b) $\chi_{cJ} \to \Xi^0\bar{\Xi}^0$ processes.

- The first observation! (Statistical significances of 7σ for $\chi_{c1} \to \Xi^0\bar{\Xi}^0$ and 15σ for $\chi_{c2} \to \Xi^0\bar{\Xi}^0$)
- Branching fractions:
  $\mathcal{B}(\chi_{c0} \to \Xi^-\bar{\Xi}^+) = (4.43 \pm 0.08 \pm 0.18) \times 10^{-4}$
  $\mathcal{B}(\chi_{c0} \to \Xi^0\bar{\Xi}^0) = (4.67 \pm 0.19 \pm 0.26) \times 10^{-4}$
  $\mathcal{B}(\chi_{c1} \to \Xi^-\bar{\Xi}^+) = (0.58 \pm 0.04 \pm 0.05) \times 10^{-4}$
  $\mathcal{B}(\chi_{c1} \to \Xi^0\bar{\Xi}^0) = (0.75 \pm 0.11 \pm 0.06) \times 10^{-4}$
  $\mathcal{B}(\chi_{c2} \to \Xi^-\bar{\Xi}^+) = (1.44 \pm 0.06 \pm 0.11) \times 10^{-4}$
  $\mathcal{B}(\chi_{c2} \to \Xi^0\bar{\Xi}^0) = (1.83 \pm 0.15 \pm 0.16) \times 10^{-4}$
- Significantly improved precision for the branching fractions and parameters of the angular distributions!

Search for new decay modes of the h_c and the $\psi_2(3823)$

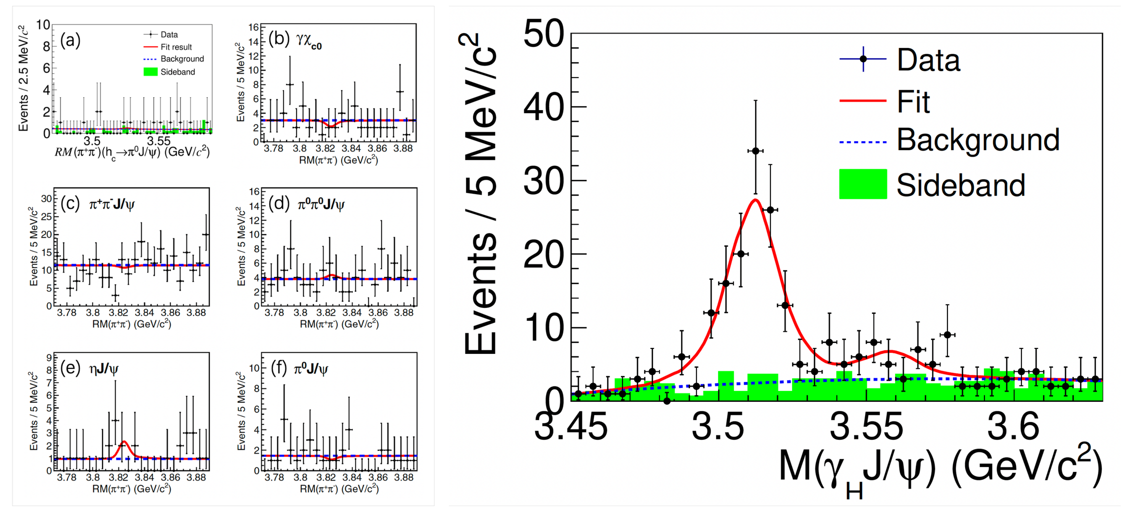

Figure 5:The $RM(\pi^+\pi^-)$ distribution from the study of $e^+e^- \to \pi^+\pi^- h_c \to \pi^+\pi^-\pi^0 J/\psi$ (left a) [5].
The $RM(\pi^+\pi^-)$ distributions from the $e^+e^- \to \pi^+\pi^-\psi_2(3823)$ process for the corresponding decays of $\psi_2(3823)$ (left b-f) [6]
The $M(\gamma_H J/\psi)$ distribution with the events in the $\psi_2(3823)$ signal region for the study of $\psi_2(3823) \to \gamma\chi_{c1,c2}$ (right), where γ_H is the one with higher energy of the two signal photons [7].

- Using the data sample above 4.0 GeV, the new decay modes of the h_c and $\psi_2(3823)$ have been searched for.
- Branching fractions (upper limits at 90% C.L.):
  $\mathcal{B}(h_c \to \pi^0 J/\psi)/\mathcal{B}(h_c \to \gamma\eta_c \to \gamma K^+K^-\pi^0) < 7.5 \times 10^{-2}$
  $\mathcal{B}(h_c \to \pi^0 J/\psi) < 4.7 \times 10^{-4}$
  $\mathcal{B}[\psi_2(3823) \to \pi^+\pi^- J/\psi]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] < 0.06$
  $\mathcal{B}[\psi_2(3823) \to \pi^0\pi^0 J/\psi]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] < 0.11$
  $\mathcal{B}[\psi_2(3823) \to \eta J/\psi]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] < 0.14$
  $\mathcal{B}[\psi_2(3823) \to \pi^0 J/\psi]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] < 0.03$
  $\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c0}]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] < 0.24$
  $\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c2}]/\mathcal{B}[\psi_2(3823) \to \gamma\chi_{c1}] = 0.33 \pm 0.12$ (or < 0.51 at 90% C.L.)

Study of the $\psi_2(3823)$:

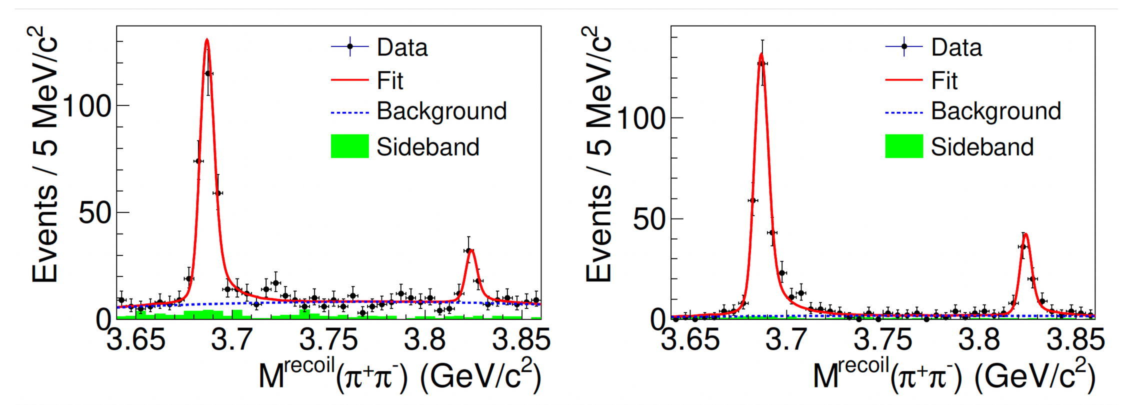

Figure 6:The $M^{\rm recoil}(\pi^+\pi^-)$ distributions for one-photon events (left) and multi-photon events (right) from the $e^+e^- \to \pi^+\pi^-\psi_2(3823)$ process [7].

- A statistical significance of 13.4σ for the $\psi_2(3823)$ signal!
- The most precise measurement of the $\psi_2(3823)$ mass and the most stringent constraint on its width to date!
  - $M[\psi_2(3823)] = 3823.12 \pm 0.43 \pm 0.13$ MeV/c^2
  - $\Gamma[\psi_2(3823)] < 2.9$ MeV at 90% C.L.
- This will help refine the parameters of potential models and significantly reduce the uncertainties (ca. ± 50 MeV) of the D-wave states predicted by the potential model [8].

References

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