News of h_c and $\eta_c(2S)$ from BESIII

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Introduction

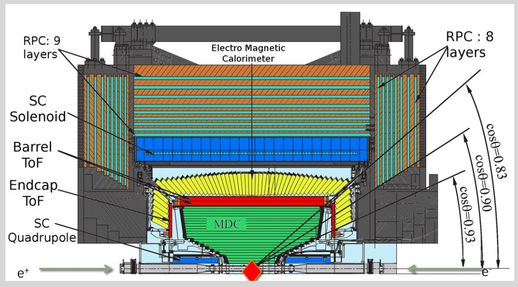
The study of charmonium states is crucial for a deeper understanding of the low-energy regime of quantum chromodynamics. All charmonium states below open-charm threshold have been observed experimentally and can be well described by potential models.

However, knowledge is still sparse on the S-wave spin-singlet, $\eta_c(2S)$, and the P-wave spin-singlet, h_c. So far, only a few hadronic decay modes of $\eta_c(2S)$ and h_c have been observed.

Searches for new hadronic decays of $\eta_c(2S)$ and h_c can provide useful information to constrain theoretical models in the charmonium region.

Beijing Spectrometer III (BESIII) at BEPCII

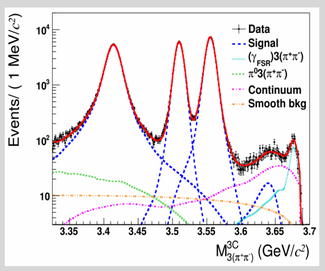
The BESIII detector records e^+e^- collisions provided by the BEPCII storage ring.

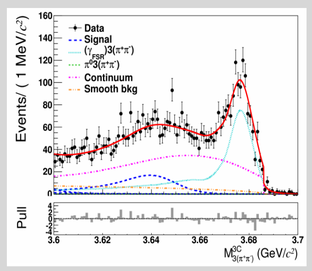


Beam energy: 1.0 – 2.47 GeV
Luminosity: 1 x 10^{33} $cm^{-2}s^{-1}$ at 3.773 GeV

Study of $\eta_c(2S) \to 3(\pi^+\pi^-)$ [1]

- **Data sample**: 448 million $\psi(2S)$ events
- **Reconstruction**: $\psi(2S) \to \gamma\eta_c(2S), \eta_c(2S) \to 3(\pi^+\pi^-)$





- First observation (9.3σ)
- **Mass** and **Width** of $\eta_c(2S)$:

$$M = (3643.4 \pm 2.3 \pm 4.4)\,\mathrm{MeV}/c^2$$
$$\Gamma = (19.8 \pm 3.9 \pm 3.1)\,\mathrm{MeV}$$

- **Branching fractions**:

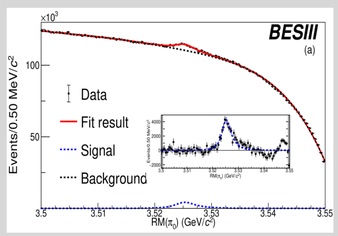
$$\mathcal{B}_{\eta_c(2S)\to 3(\pi^+\pi^-)} = (1.31 \pm 0.15 \pm 0.17^{+0.64}_{-0.47}) \times 10^{-2}$$
$$\mathcal{B}_{\chi_{c0}\to 3(\pi^+\pi^-)} = (2.080 \pm 0.006 \pm 0.068) \times 10^{-2}$$
$$\mathcal{B}_{\chi_{c1}\to 3(\pi^+\pi^-)} = (1.092 \pm 0.004 \pm 0.035) \times 10^{-2}$$
$$\mathcal{B}_{\chi_{c2}\to 3(\pi^+\pi^-)} = (1.565 \pm 0.005 \pm 0.048) \times 10^{-2}$$

Study of $\psi(2S) \to \pi^0 h_c$ [2]

- **Data sample:** 448 million $\psi(2S)$ events
- **Reconstruction:**

Inclusive: $\psi(2S) \to \pi^0 h_c, h_c \to$Anything
Tagged: $\psi(2S) \to \pi^0 h_c, h_c \to \gamma\eta_c, \eta_c \to$ Anything

Inclusive:



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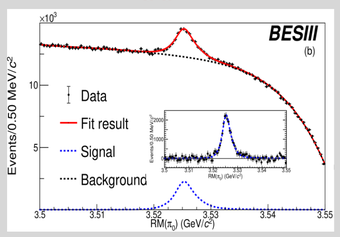


- **Mass and Width** of h_c:

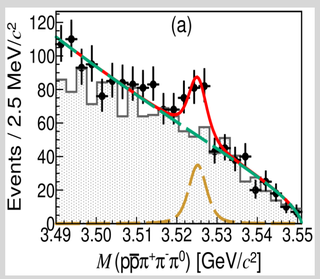
$$M = (3525.32 \pm 0.06 \pm 0.15)\,\mathrm{MeV}/c^2$$
$$\Gamma = \left(0.78^{+0.27}_{-0.24} \pm 0.12\right) MeV$$

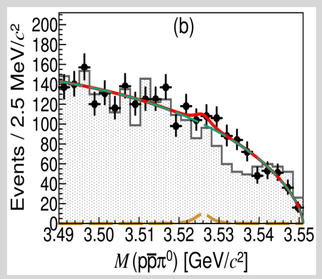
- **Branching fractions**:

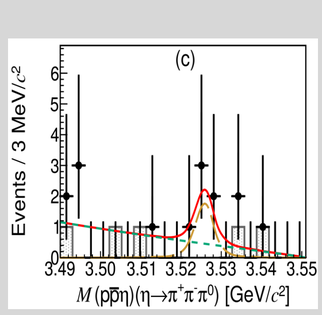
$$\mathcal{B}_{\psi(2S)\to\pi^0 h_c} \times \mathcal{B}_{h_c\to\gamma\eta_c} = (4.17^{+0.27}_{-0.25} \pm 0.19) \times 10^{-4}$$
$$\mathcal{B}_{\psi(2S)\to\pi^0 h_c} = (7.23 \pm 0.33 \pm 0.38) \times 10^{-4}$$
$$\mathcal{B}_{h_c\to\gamma\eta_c} = \left(57.66^{+3.62}_{-3.50} \pm 0.58\right) \times 10^{-2}$$

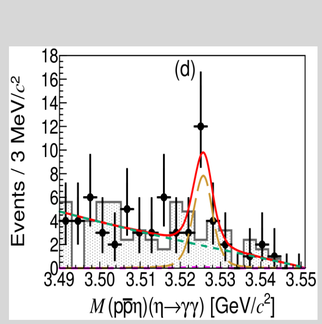
Search for $h_c \to p\bar{p}X$ [3]

- **Data sample:** 448 million $\psi(2S)$ events
- **Reconstruction:** $\psi(2S) \to \pi^0 h_c, h_c \to p\bar{p}\eta$, $p\bar{p}\pi^0$, $p\bar{p}\pi^+\pi^-\pi^0$









- First **observation** of $h_c \to p\bar{p}\eta$ (5.1σ)
- Strong **evidence** of $h_c \to p\bar{p}\pi^+\pi^-\pi^0$ (4.9σ)
- **No clear signal** of $h_c \to p\bar{p}\pi^0$ found

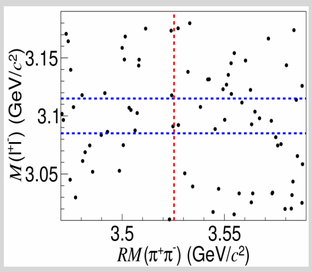
Mode	Branching Fraction ($\times 10^{-4}$)	Significance
$h_c \to p\bar{p}\eta$	$6.41 \pm 1.74 \pm 0.53 \pm 1.00$	5.1σ
$h_c \to p\bar{p}\pi^+\pi^-\pi^0$	$38.4 \pm 8.3 \pm 6.9 \pm 5.8$	4.9σ
$h_c \to p\bar{p}\pi^0$	< 6.59	--

Search for $h_c \to \pi^0 J/\psi$ [4]

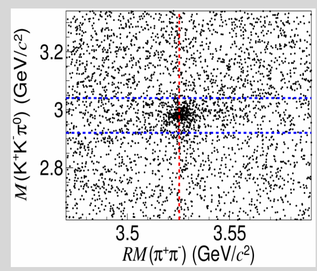
- **Data sample:** $\sqrt{s}$ = 4.189 - 4.437 GeV (11 fb^{-1})
- **Reconstruction:**

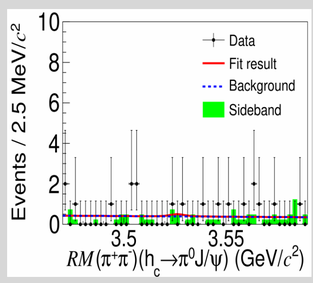
Signal: $e^+e^- \to \pi^+\pi^- h_c$, $h_c \to \pi^0 J/\psi$
Normalization: $h_c \to \gamma\eta_c$, $\eta_c \to K^+K^-\pi^0$

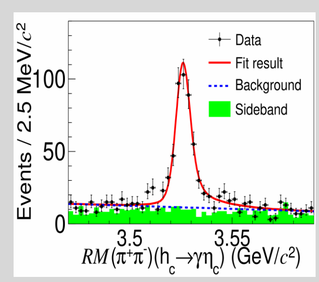
Signal:



Normalization:







- **No significant signal** observed for $h_c \to \pi^0 J/\psi$.
- **Upper limits** at 90% confidence level:

$$\frac{B_{h_c\to\pi^0 J/\psi}}{\mathcal{B}_{h_c\to\gamma\eta_c\to\gamma K^+K^-\pi^0}} < 7.5 \times 10^{-2}$$
$$B_{h_c\to\pi^0 J/\psi} < 4.7 \times 10^{-4}$$
$$\Gamma_{h_c\to\pi^0 J/\psi} < 0.52\ \mathrm{keV}$$

Summary

Based on the data sample collected by the BESIII detector, we study the hadronic decays of $\eta_c(2S)$ and h_c.

- The decays $\eta_c(2S) \to 3(\pi^+\pi^-)$ and $h_c \to p\bar{p}\eta$, $p\bar{p}\pi^+\pi^-\pi^0$ are seen for the first time. No signal is found for $h_c \to p\bar{p}\pi^0, \pi^0 J/\psi$.
- The masses and widths of $\eta_c(2S)$ and h_c are updated.
- The branching fractions of $\psi(2S) \to \pi^0 h_c$ and $h_c \to \gamma\eta_c$ are updated with improved precision.

References

1. M. Ablikim *et al.* (BESIII Collaboration), [arXiv:2206.08807]
2. M. Ablikim *et al.* (BESIII Collaboration), [arXiv:2204.09413]
3. M. Ablikim *et al.* (BESIII Collaboration), J. High Energ. Phys. **2022**, 108 (2022).
4. M. Ablikim *et al.* (BESIII Collaboration), J. High Energ. Phys. **2022**, 3 (2022).