遼寧師範大學
Liaoning Normal University

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

任旷洁

辽宁师范大学

(On behalf of the BESIII Collaboration)

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- BESIII Datasets
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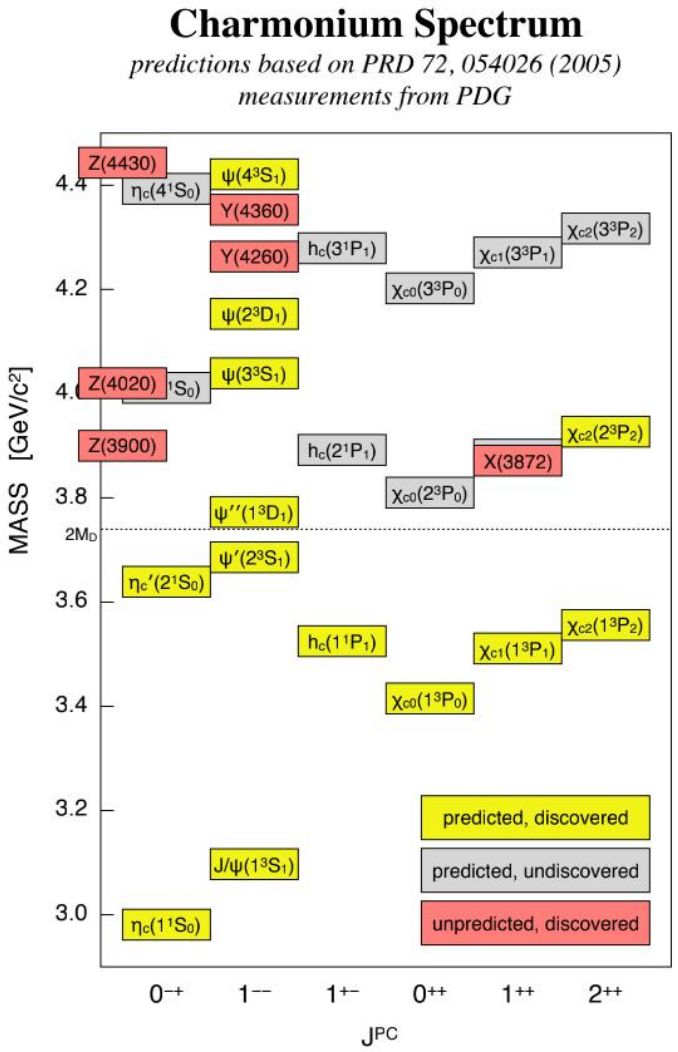
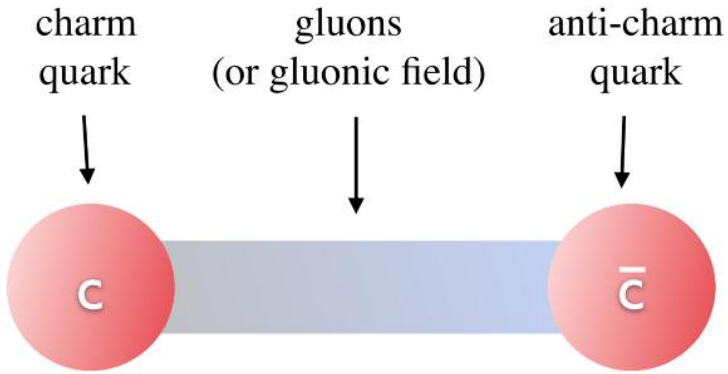
  - Study of the h_c meson via $\psi(2S) \to \pi^0 h_c$ decays
  - Observation of $h_c \to p\bar{p}\eta$
  - Search for the decay $h_c \to \pi^0 J/\psi$
- Summary

Charmonium spectrum





Experimentally accessible quantum numbers:

$$J^{PC}$$

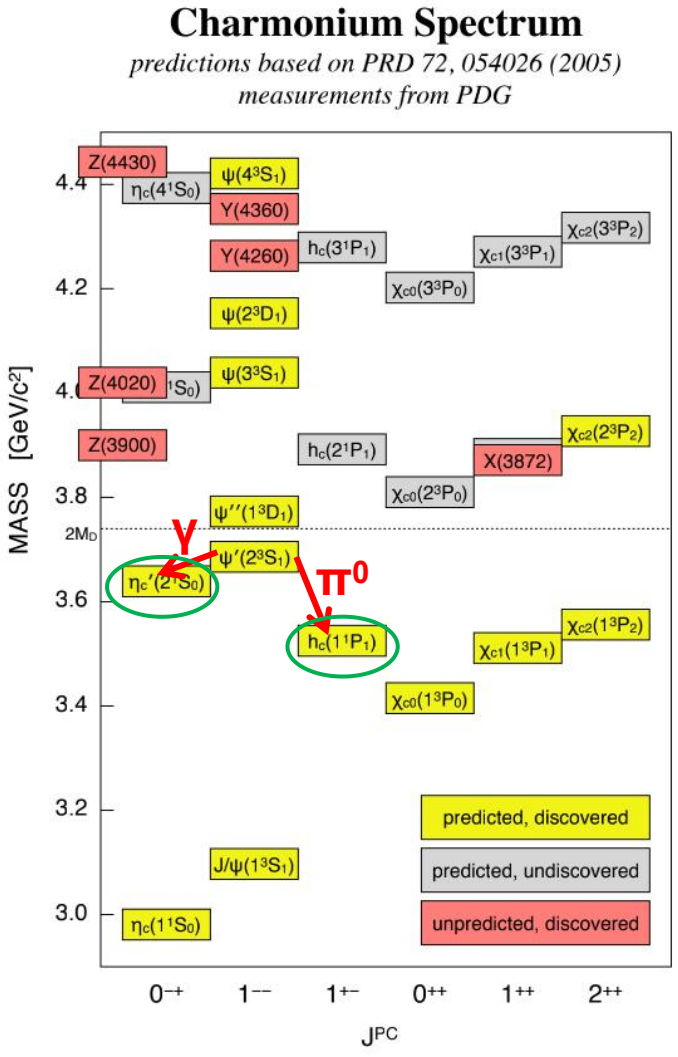
Derived quantum numbers:

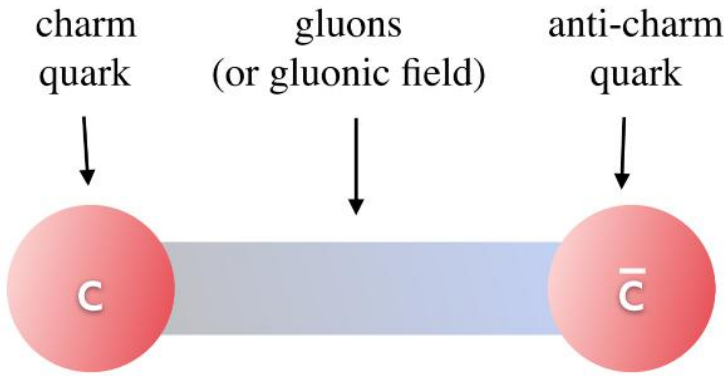
$$n^{2S+1}L_J$$

Relationships:

$$P = (-1)^{L+1} \qquad C = (-1)^{L+S}$$

Charmonium spectrum





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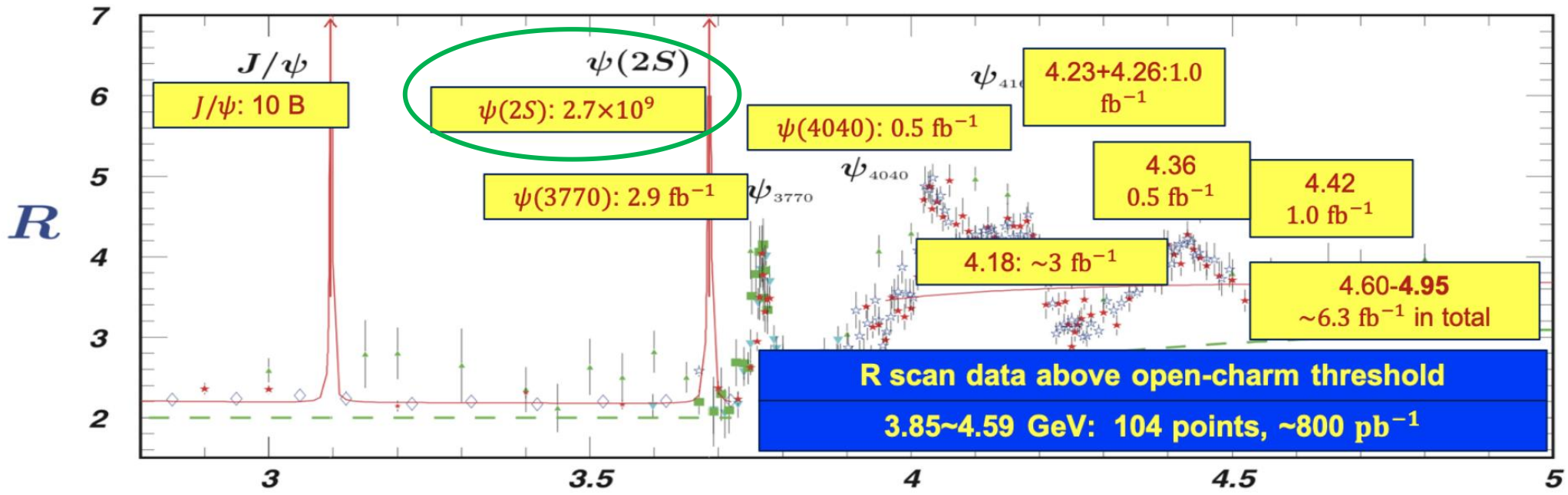
BESIII Datasets

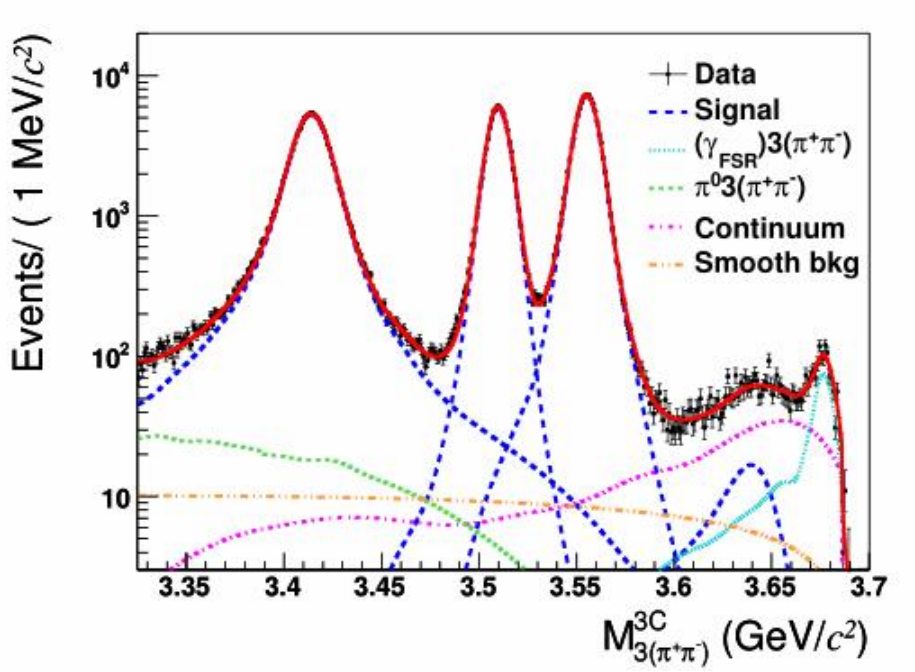


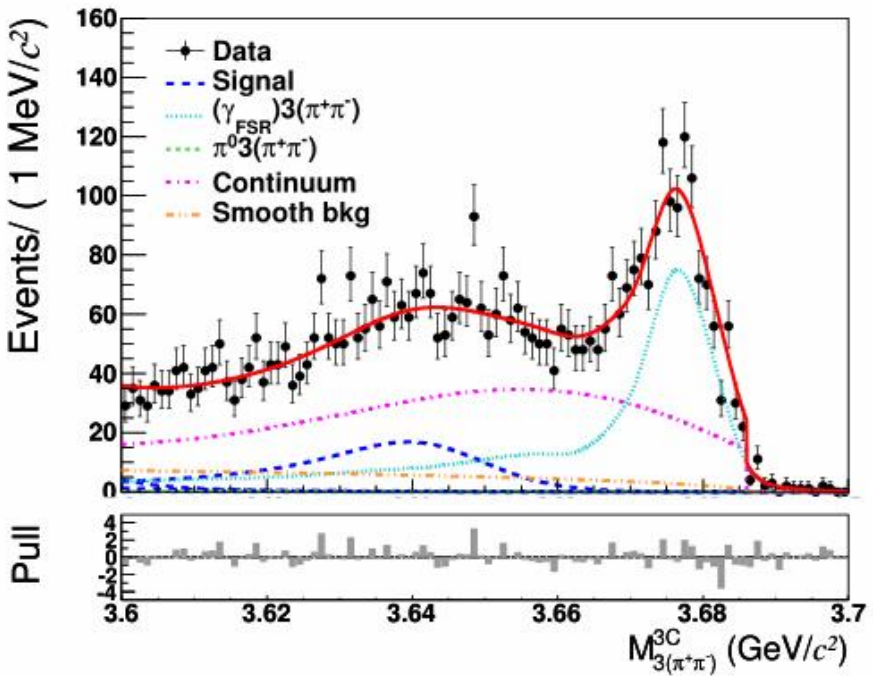
Observation of $\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$

Data: (448.1 ± 2.9) × 10^6 $\psi(2S)$

arXiv:2206.08807

- ✓ Looking for new decay modes of $\eta_c(2S)$ such as $3(\pi^+\pi^-)$ will provide more concrete avenues of approach of $\eta_c(2S)$ in experimental and theoretical research and better understand its properties.
- ✓ Observed $\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$ for the first time which significance is 9.3σ.





Observation of $\eta_c(2S) \to 3(\pi^+\pi^-)$

Data: $(448.1 \pm 2.9) \times 10^6$ $\psi(2S)$ ***arXiv:2206.08807***

✓ Mass and width of $\eta_c(2S)$ are measured which are consistent with the world average values within 2σ.

$M[\eta_c(2S)] = 3643.4 \pm 2.3 \pm 4.4$ MeV/c^2 $\quad \Gamma[\eta_c(2S)] = 19.8 \pm 3.9 \pm 3.1$ MeV

✓ Using $B[\psi(2S) \to \gamma\eta_c(2S)] = (7.0^{+3.4}_{-2.5}) \times 10^{-4}$ [13], we obtain $B[\eta_c(2S) \to 3(\pi^+\pi^-)]$ and update $B[\chi_{cJ} \to 3(\pi^+\pi^-)]$ at the same time.

Channel	$N^{\rm sig}_{\rm data}$	$\epsilon^{\rm corr}$ (%)	$\mathcal{B}_{\rm measured}$ $(\times 10^{-2})$	$\mathcal{B}_{\rm PDG}$ $(\times 10^{-2})$
$\eta_c(2S) \to 3(\pi^+\pi^-)$	568.8 ± 63.3	13.84 ± 0.01	$1.31 \pm 0.15 \pm 0.13^{+0.64}_{-0.47}$	-
$\chi_{c0} \to 3(\pi^+\pi^-)$	145300 ± 396	15.92 ± 0.01	$2.080 \pm 0.006 \pm 0.068$	1.20 ± 0.18
$\chi_{c1} \to 3(\pi^+\pi^-)$	84317 ± 299	17.67 ± 0.01	$1.092 \pm 0.004 \pm 0.035$	0.54 ± 0.14
$\chi_{c2} \to 3(\pi^+\pi^-)$	112510 ± 347	16.85 ± 0.01	$1.565 \pm 0.005 \pm 0.048$	0.84 ± 0.18

✓ Compared to the world average values, the measured values are almost twice as large. To validate our results, we perform a number of cross-checks and the results are consistent with each other and agree with the nominal results.

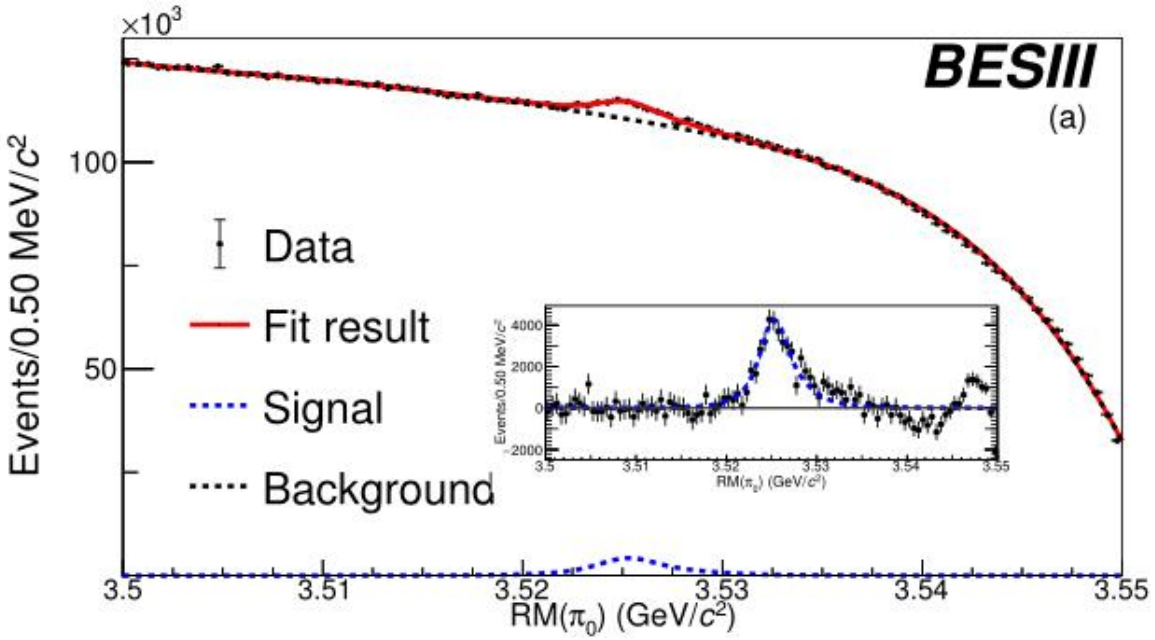
[13] Chin. Phys. C 46, 071001(2022).

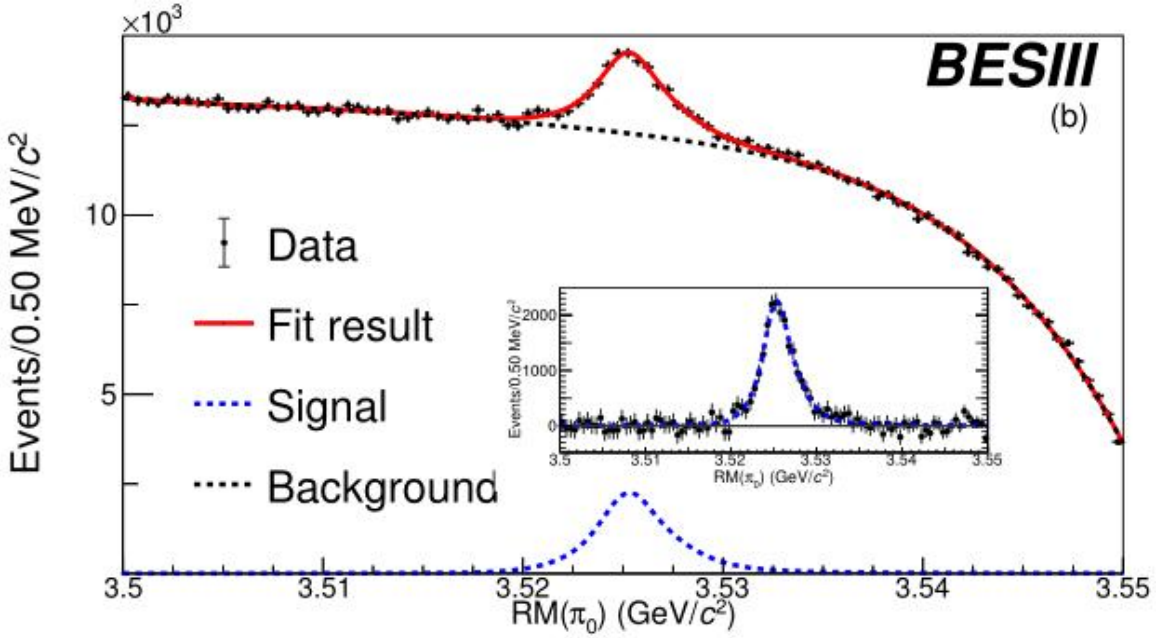
Study of the h_c meson via $\psi(2S)\to\pi^0 h_c$ decays

Data: (448.1 ± 2.9) × 10^6 ψ(2S)

arXiv:2204.09413

- ✓ The h_c resonance features are of particular importance inside the theoretical framework built to explain the $c\bar{c}$ spectrum.
- ✓ Using the π^0 recoil mass distribution to reconstruct the h_c mass, both inclusively ($\psi(2S) \to \pi^0 h_c$) and by tagging the decay via the electric dipole (E1) transition photon from $h_c \to \gamma\eta_c$.





Study of the h_c meson via $\psi(2S)\to\pi^0 h_c$ decays

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✓ The fit results are summarized in the table which shows the improved precision of this measurement with respect to the PDG values [5]and compatibility within 1σ.

Variable	Value	PDG Value [5]
$M(h_c)$ (MeV/c^2)	$3525.32 \pm 0.06 \pm 0.15$	3525.38 ± 0.11
$\Gamma(h_c)$ (MeV)	$0.78\ ^{+0.27}_{-0.24} \pm 0.12$	0.7 ± 0.4
$N_{\rm Tag}(h_c)$	$23118\ ^{+1500}_{-1398}$	—
$\mathcal{B}_{\rm Inc}\times\mathcal{B}_{\rm Tag}$ (10^{-4})	$4.17\ ^{+0.27}_{-0.25} \pm 0.19$	4.58 ± 0.64 (BESIII [11]) 4.16 ± 0.48 (CLEO [23])
$N_{\rm Inc}(h_c)$	46187 ± 2123	—
$\mathcal{B}_{\rm Inc}$ (10^{-4})	$7.23 \pm 0.33 \pm 0.38$	8.60 ± 1.30
$\mathcal{B}_{\rm Tag}$ (%)	$57.66^{+3.62}_{-3.50} \pm 0.58$	50 ± 9

- $\mathcal{B}_{\rm Inc}(\psi(2S)\to\pi^0 h_c)\times\mathcal{B}_{\rm Tag}(h_c\to\gamma\eta_c) = \frac{N_{\rm Tag}}{\epsilon_{\rm Tag}\times N(\psi(2S))}$;
- $\mathcal{B}_{\rm Inc}(\psi(2S)\to\pi^0 h_c) = \frac{N_{\rm Inc}}{\epsilon_{\rm Inc}\times N(\psi(2S))}$;
- $\mathcal{B}_{\rm Tag}(h_c\to\gamma\eta_c) = \frac{\mathcal{B}_{\rm Inc}(\psi(2S)\to\pi^0 h_c)\times\mathcal{B}_{\rm Tag}(h_c\to\gamma\eta_c)}{\mathcal{B}_{\rm Inc}(\psi(2S)\to\pi^0 h_c)} = \frac{N_{\rm Tag}\times\epsilon_{\rm Inc}}{N_{\rm Inc}\times\epsilon_{\rm Tag}}$.

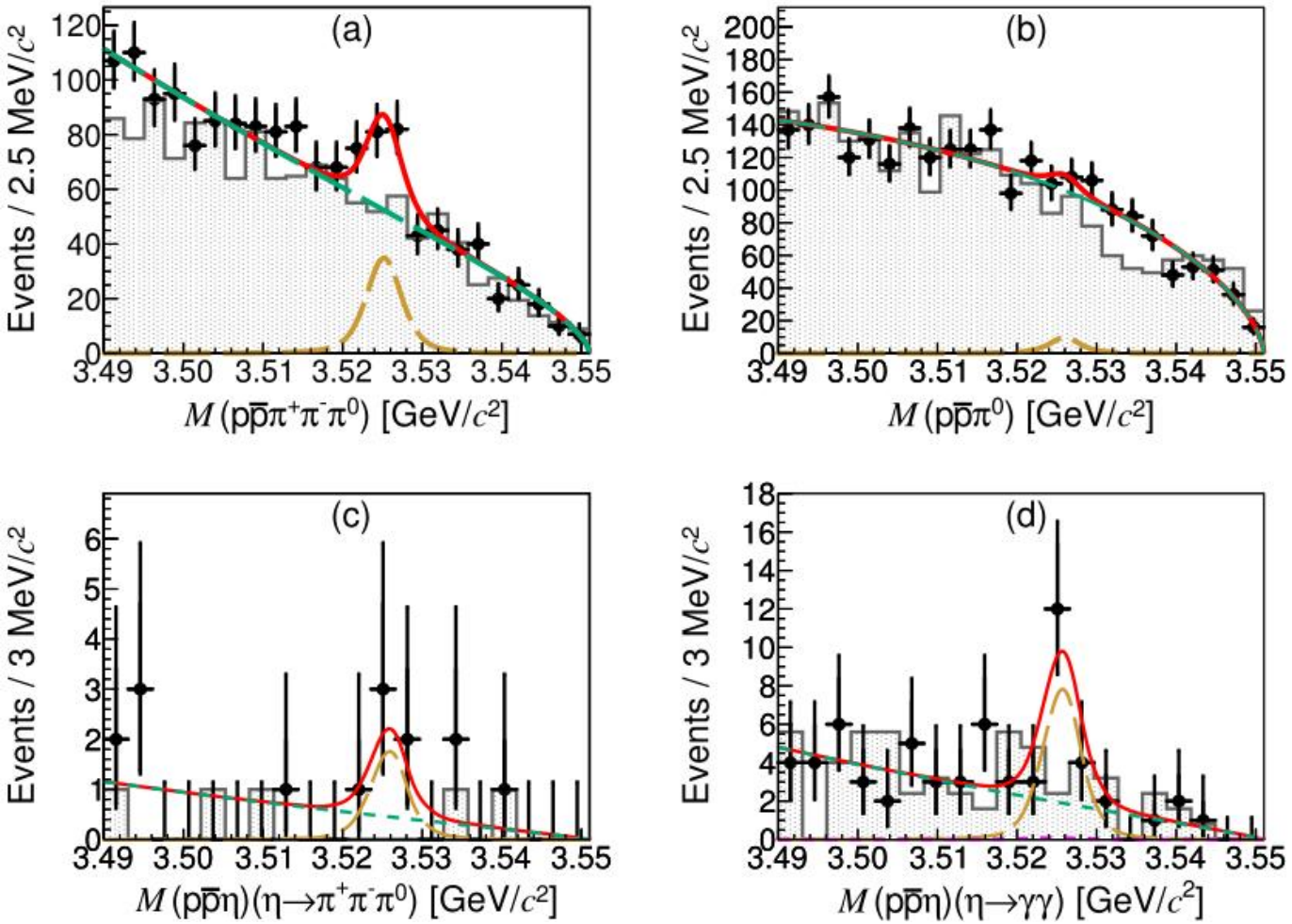
[5] PTEP 2020, 083C01(2020).
[11] Phys. Rev.Lett. 104, 132002 (2010).
[23] Phys. Rev.Lett.101,182003 (2008)

Observation of $h_c \to p\bar{p}\eta$

Data: (448.1 ± 2.9) × 10^6 ψ(2S)

JHEP05(2022)108

- ✓ First search for the $h_c \to p\bar{p}X$ ($X = \pi^+\pi^-\pi^0, \eta, \pi^0$) decays.
- ✓ The decay channel $h_c \to p\bar{p}\eta$ is observed for the first time with a 5.1σ statistical significance.
- ✓ Evidence for the decay $h_c \to p\bar{p}\pi^+\pi^-\pi^0$ is found with a statistical significance of 4.9σ.
- ✓ No obvious signal for $h_c \to p\bar{p}\pi^0$ is seen.



Observation of $h_c \to p\bar{p}\eta$

Data: (448.1 ± 2.9) × 10^6 ψ(2S)

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✓ The branching fractions of $h_c \to p\bar{p}X$ are determined by

$$\mathcal{B}(h_c \to p\bar{p}X) = \frac{N^{\rm sig}}{N_{\psi(3686)} \cdot \mathcal{B}(\psi(3686) \to \pi^0 h_c) \cdot \prod_i \mathcal{B}_i \cdot \varepsilon}.$$

Mode	I	III
$p\bar{p}X$	$p\bar{p}\pi^+\pi^-\pi^0$	$p\bar{p}\pi^0$
N_{h_c}	86.5 ± 18.7	< 57
$\mathcal{B}(h_c \to p\bar{p}X)$	$(3.84 \pm 0.83 \pm 0.69 \pm 0.58) \times 10^{-3}$	$< 6.59 \times 10^{-4}$
$\mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to p\bar{p}X)$	$(3.30 \pm 0.71 \pm 0.59) \times 10^{-6}$	$< 5.67 \times 10^{-7}$
Significance(σ)	4.9	–

Mode	II	
$p\bar{p}\eta$	$\eta \to \pi^+\pi^-\pi^0$	$\eta \to \gamma\gamma$
N_{h_c}	3.4 ± 0.9	18.1 ± 4.9
$\mathcal{B}(h_c \to p\bar{p}\eta)$	$(6.41 \pm 1.74 \pm 0.53 \pm 1.00) \times 10^{-4}$	
$\mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to p\bar{p}\eta)$	$(5.51 \pm 1.50 \pm 0.46) \times 10^{-7}$	
Significance(σ)	5.1	

[6]Phys. Rev. D 99, (2019) 072008
[7] Phys. Rev. D 102, (2020) 112007

✓ The branching fractions obtained in this analysis are at the level of ~10^{-3}, which is the same level as the previously observed decays of $h_c \to 2(\pi^+\pi^-)\pi^0$, $p\bar{p}\pi^+\pi^-$ [6] and $h_c \to K^+K^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\eta$, $K^0_S K^\pm\pi^\mp\pi^+\pi^-$ [7].

Search for the decay $h_c \to \pi^0 J/\psi$

Data: L = 11 fb^{-1}, $\sqrt{s}$ = 4.189 — 4.437 GeV

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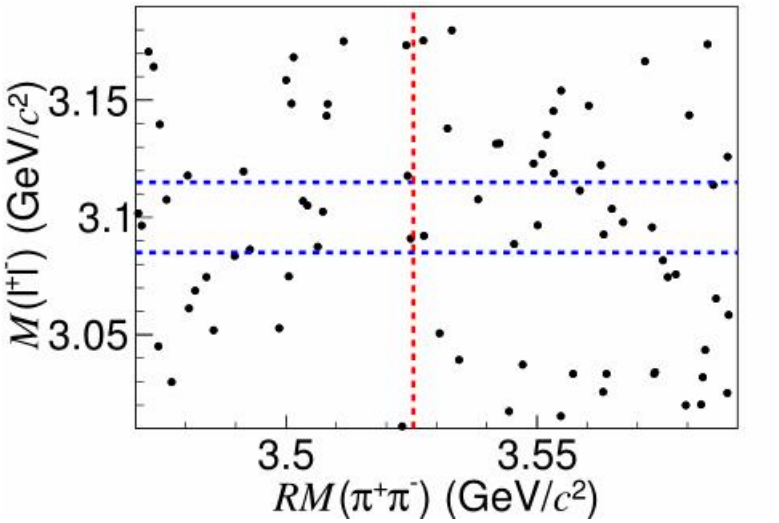
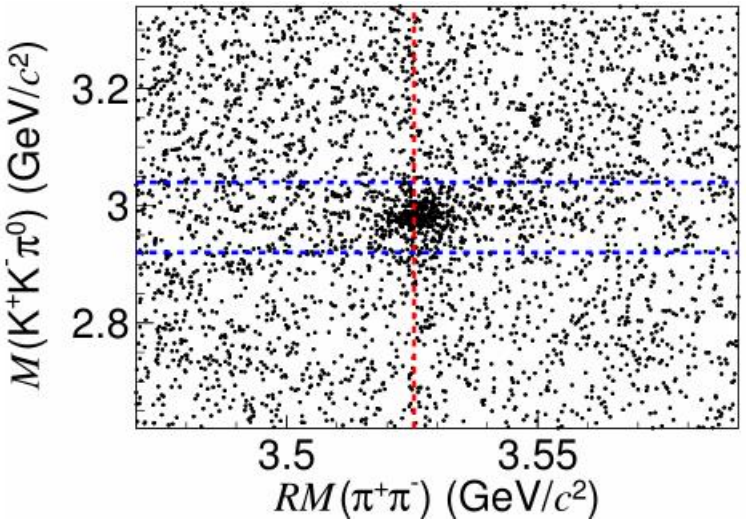
- ✓ In 1992, the E760 Collaboration reported an evidence of the h_c in the $\pi^0 J/\psi$ decay mode. Until now, there is no experimental result to confirm this.
- ✓ Search for $h_c \to \pi^0 J/\psi$ is reported using $e^+e^- \to \pi^+\pi^- h_c$ events from data samples at $\sqrt{s}$ = 4.189 — 4.437 GeV.
- ✓ Additionally, the decay $h_c \to \gamma\eta_c \to \gamma K^+K^-\pi^0$ is used as the normalization channel.



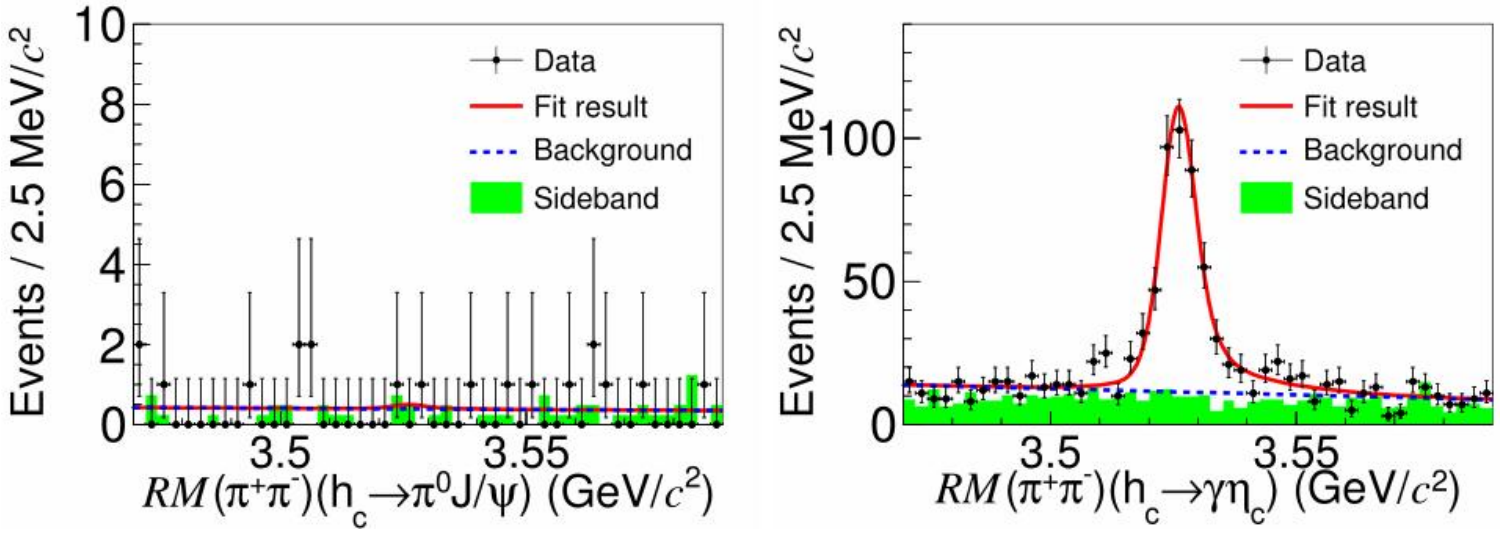


Search for the decay $h_c \to \pi^0 J/\psi$

Data: L = 11 fb^{-1} , $\sqrt{s}$ = 4.189 — 4.437 GeV

JHEP 05(2022)003

✓ No significant signal is seen for the $h_c \to \pi^0 J/\psi$ decay, while a clear peak is present for the $h_c \to \gamma\eta_c$ decay.



✓ The branching ratio $B(h_c \to \pi^0 J/\psi)/B(h_c \to \gamma\eta_c \to \gamma K^+K^-\pi^0)$ is calculated with

$$\frac{\mathcal{B}(h_c \to \pi^0 J/\psi)}{\mathcal{B}(h_c \to \gamma\eta_c \to \gamma K^+K^-\pi^0)} = \frac{N_{\pi^0 J/\psi}}{N_{\gamma\eta_c}} \frac{\sum_i \mathcal{L}_i\sigma_i(1+\delta_i)\epsilon_i^{\gamma\eta_c}}{\sum \mathcal{L}_i\sigma_i(1+\delta_i)\epsilon_i^{\pi^0 J/\psi}} \frac{1}{\mathcal{B}(J/\psi \to \ell^+\ell^-)}$$

$$\int_0^{N^{\rm up}_{\pi^0 J/\psi}} F(x)dx \Big/ \int_0^{\infty} F(x)dx = 0.90$$

Search for the decay $h_c \to \pi^0 J/\psi$

Data: L = 11 fb^{-1} , $\sqrt{s}$ = 4.189 — 4.437 GeV

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✓ $B(h_c \to \pi^0 J/\psi)/B(h_c \to \gamma\eta_c \to \gamma K^+K^-\pi^0) < 7.5 \times 10^{-2}$ at 90% C.L.

Upper limit on the branching fraction $B(h_c \to \pi^0 J/\psi)$ at 90% C.L. can be determined to be

$$B(h_c \to \pi^0 J/\psi) < 4.7 \times 10^{-4}.$$

This is the first upper limit measurement of $B(h_c \to \pi^0 J/\psi)$ which the results are not consistent with the measurements by the E760 Collaboration , while in agreement with the E835 Collaboration.

✓ The h_c total width is 0.7 ± 0.4 MeV from the PDG, and we take 1.1 MeV as the h_c total width conservatively. The upper limit on the partial width for $h_c \to \pi^0 J/\psi$ is conservatively determined to be

$$\Gamma(h_c \to \pi^0 J/\psi) < 0.52 \text{ keV},$$

which is one order-of-magnitude lower than the current theoretical predictions (several keV) .

Summary

✓ BESIII has collected large data samples at $\sqrt{s} = 2$ — 4.95GeV, which provide essential opportunity for the study of charmonium decay.

- Observation of $\eta_c(2S) \rightarrow 3(\pi^+\pi^-)$
- Study of the h_c meson via $\psi(2S) \rightarrow \pi^0 h_c$ decays
- Observation of $h_c \rightarrow p\bar{p}\eta$
- Search for the decay $h_c \rightarrow \pi^0 J/\psi$

✓ In the future, more data will be collected, more detailed studies will be done and more results will come out !

Thanks for your attention!