Observation of New Charmonium Decays

Guangrui Liao (廖广睿)
(On behalf of the BESIII Collaboration)
Guangxi Normal University

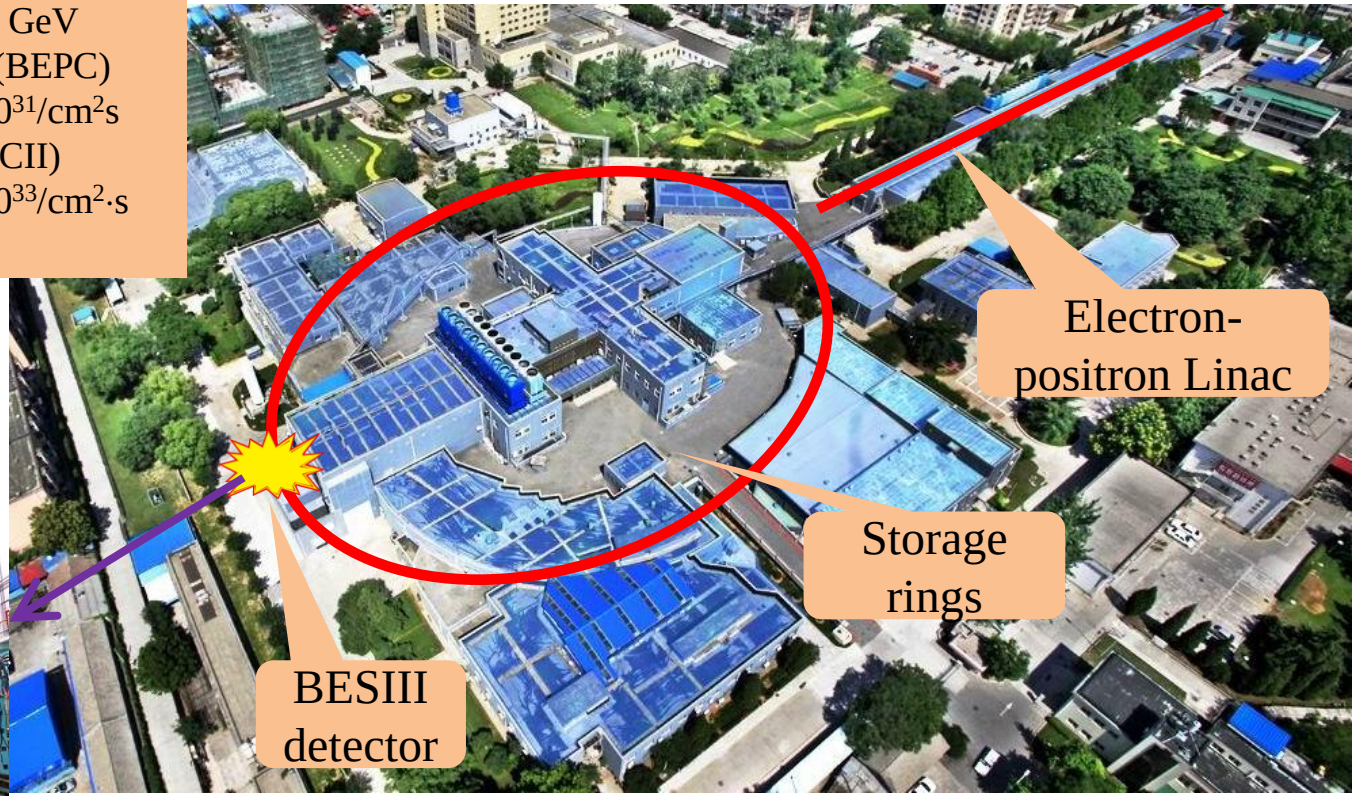
The 18th International Conference on Hadron Spectroscopy and Structure
Guilin, China, August 2019

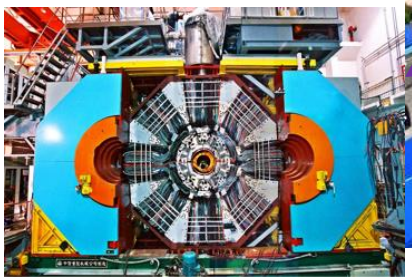
Outline

- BEPCII/BESIII
- Data set at BESIII
- Physics results
  - $\psi(3686)\to\Xi^{-}(1530)\bar{\Xi}^{+}(1530)$ and $p\bar{p}\eta'$
  - $h_c \to$ hadrons
  - $\chi_{cJ}\to\mu^{+}\mu^{-}$J/$\psi$, $\omega\phi$ and $4K_s^0$
  - $\eta_c\to\omega\omega$, $K^{+}K^{-}\pi^0$, $K_s^0K^{\pm}\pi^{-/+}$, $2(\pi^{+}\pi^{-}\pi^0)$ and $p\bar{p}$
- Summary

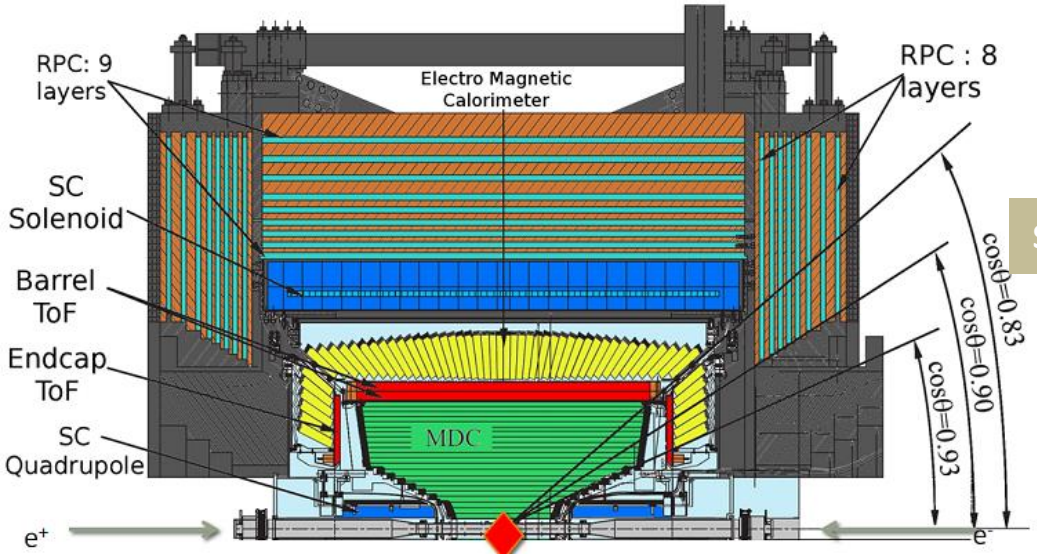
BEPCII/BESIII

- ECM:2-4.6 GeV
- 1988-2005(BEPC)
  $L_{peak}=1.0\times10^{31}/cm^2s$
- 2008-(BEPCII)
  $L_{peak}=1.0\times10^{33}/cm^2\cdot s$
  (5/4/2016)





BEPCII/BESIII



SC Magnet 1.0T

Main Drift Chamber
Small cell, 43 layer
σ_{xy}=130 μm, dE/dx~6%
σ_p/p = 0.5% at 1 GeV

Time Of Flight
Plastic scintillator
σ_T(barrel): 80 ps
σ_T(endcap): 110 ps
(endcap update with MRPC σ_T:65 ps)

Electromagnetic Calorimeter
CsI(Tl): L=28 cm (15X_0)
Energy range: 0.02-2GeV
Barrel σ_E 2.5%, σ_l 6mm
Endcap σ_E 5.0%, σ_l 9mm

Muon Counter
Resistive plate chamber
Barrel: 9 layers
Endcaps: 8 layers
$\sigma_{spatial}$: 1.48 cm

BESIII data set

2009: **107 M ψ(2S)** and **225 M J/ψ**

2010: 975pb^{-1} @ ψ(3770)

2011: 2.9 fb^{-1} @ ψ(3770) and 482 pb^{-1} @ 4.01 GeV

2012: **341 M ψ(2S)** and **1.09 B J/ ψ**

2013: 1092 pb^{-1} @ 4.23 GeV 826 pb^{-1} @ 4.26 GeV

540 pb^{-1} @ 4.36 GeV ~50 pb^{-1} 3.81 to 4.42 GeV

0.8 fb^{-1} R-scan from 3.85 to 4.59 GeV

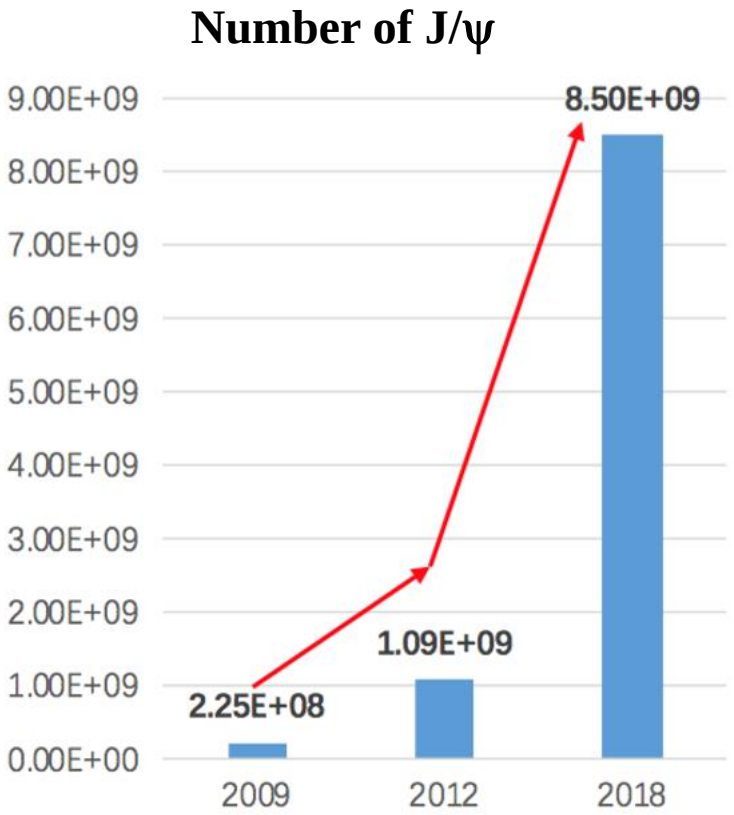
2015: R-scan from 2-3 GeV + 2.175 GeV

2016: ~3 fb^{-1} @ 4.18 GeV (for Ds)

2017: 7×500 pb^{-1} between 4.19 and 4.27 GeV

2018: J/ ψ (and tuning new RF cavity)

2019: 10 B J/ ψ**;** more data in the XYZ region



Observation of $\psi(3686)\to\Xi(1530)^-\bar{\Xi}(1530)^+$ and $\Xi(1530)^-\bar{\Xi}^+$

Int. J. Mod. Phys. A 24, S1

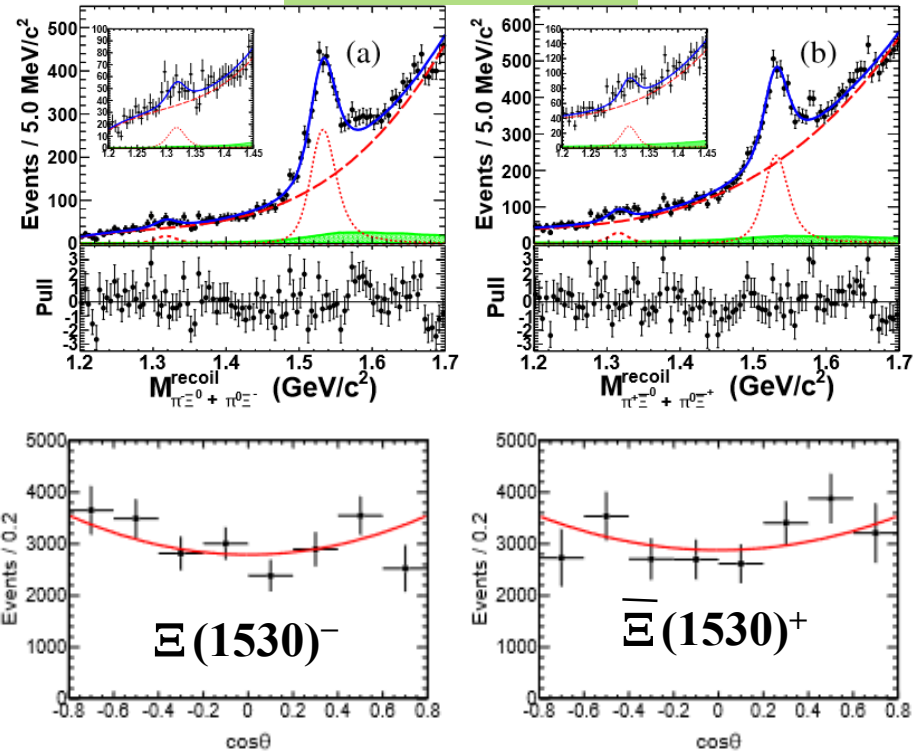
- The decays of charmonium into octet-decuplet baryonic pairs are forbidden. *PRD14, 852*
- J/ψ into octet-decuplet baryonic pairs has been observed by DM2 and BESIII, but there is no observation in $\psi(3686)$. *Nucl. Phys. B 292, 670* *PRD 87, 052007*
- Study the angular distributions of the final states

$$dN/d(\cos\theta)\propto 1+\alpha\cos^2\theta$$

- Theory: $0 < \alpha < 1$ *Int. J. Mod. Phys. A2,249* *PRD25, 1345*
- Experiment: $\alpha < 0$ in $J/\psi\to\Sigma^0\bar{\Sigma}^0$ and $J/\psi\to\Sigma(1385)\bar{\Sigma}(1385)$ *PLB 770, 217* *PLB 632, 181*

Observation of $\psi(3686)\to\Xi(1530)^-\bar{\Xi}(1530)^+$ and $\Xi(1530)^-\bar{\Xi}^+$

arXiv:1907.13041



- **Branching fractions:**

1) $\psi(3686)\to\Xi(1530)^-\bar{\Xi}(1530)^+$:

$BF=(11.45\pm0.40\pm0.59)\times10^{-5}$

2) $\psi(3686)\to\Xi(1530)^-\bar{\Xi}^+$:

$BF=(0.70\pm0.11\pm0.04)\times10^{-5}$

SU(3) flavor symmetry is broken in $\psi(3686)$

- **α= 0.40±0.24±0.06**

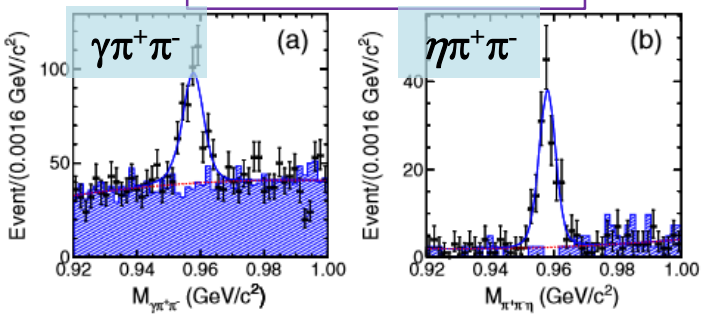
Consistent with theoretical prediction: 0.31

PRD 25,1345

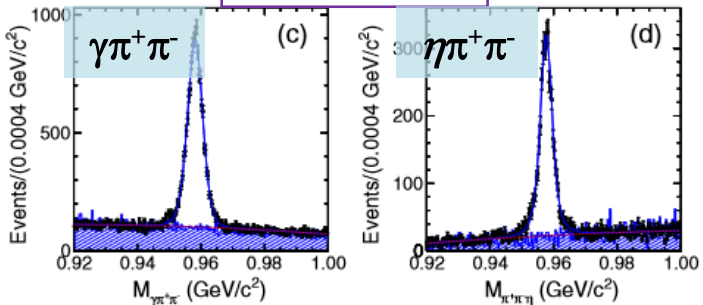
Observation of $\psi(3686) \to p\bar{p}\eta'$ and improved measurement of $J/\psi \to p\bar{p}\eta'$

PRD 99, 032006 (2019)

$\psi(3686) \to p\bar{p}\eta'$



$J/\psi \to p\bar{p}\eta'$



- Signal yields extracted from a simultaneous fit to the $\gamma\pi^+\pi^-$ and $\eta\pi^+\pi^-$ invariant mass spectra

$$\mathcal{B}(\psi(3686) \to p\bar{p}\eta') = (1.10 \pm 0.10 \pm 0.08) \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to p\bar{p}\eta') = (1.26 \pm 0.02 \pm 0.07) \times 10^{-4}$$

- η-η' mixing angle

$$\psi(3686) \to p\bar{p}\eta/p\bar{p}\eta' : \theta_{\eta\text{-}\eta'} = -24° \pm 11°$$

$$J/\psi \to p\bar{p}\eta/p\bar{p}\eta' : \theta_{\eta\text{-}\eta'} = -24° \pm 9°$$

QCD-inspired calculations of –(17°~10°)

PRD30,2333

$h_c \rightarrow$ hadrons

- Knowledge on decay behavious of h_c still sparse since discovery in 2005.
- Only few decay modes have been observed.
- More h_c hadronic decay modes are needed to shed light on the h_c decay mechanism.

$J/\psi(1S)\pi\pi$	not seen
$p\bar{p}$	$< 1.5 \times 10^{-4}$
$\pi^+\pi^-\pi^0$	$< 2.2 \times 10^{-3}$
$2\pi^+2\pi^-\pi^0$	$(2.2^{+0.8}_{-0.7})\%$
$3\pi^+3\pi^-\pi^0$	< 2.9 %
Radiative decays	
$\gamma\eta$	$(4.7\pm2.1)\times10^{-4}$
$\gamma\eta'(958)$	$(1.5\pm0.4)\times10^{-3}$
$\gamma\eta_c(1S)$	$(51 \pm 6)\%$

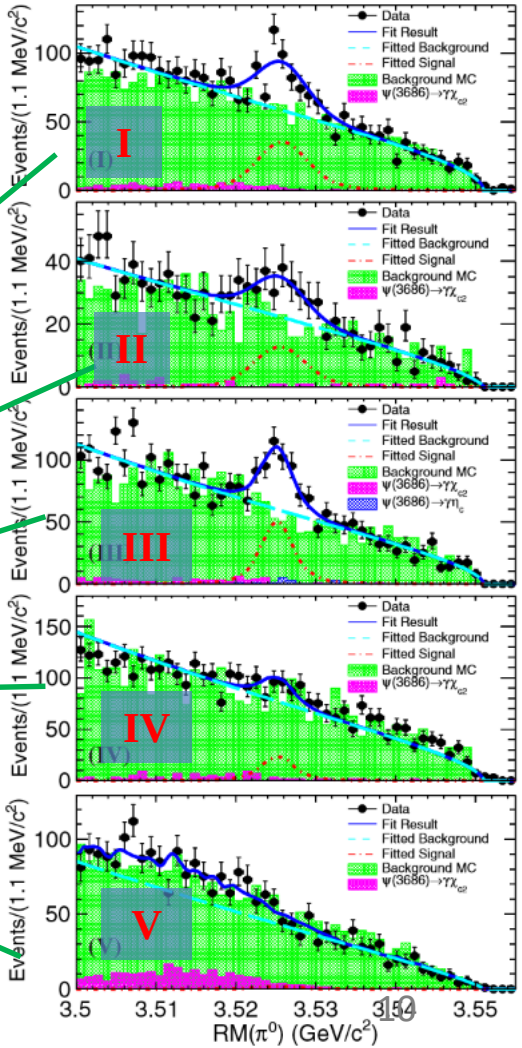
PDG2018

$h_c \rightarrow$ hadrons

- Five h_c hadronic decays have been studied at BESIII with 448 M ψ(3686) events, .

PRD **99**, 072008 (2019)

Mode		$\mathcal{B}_{h_c}(10^{-3})$	S.S.	$\mathcal{B}^{\rm PDG}_{h_c}(10^{-3})$
I	$h_c \to p\bar{p}\pi^+\pi^-$	$2.89 \pm 0.32 \pm 0.55$	7.4σ	...
II	$h_c \to \pi^+\pi^-\pi^0$	$1.60 \pm 0.40 \pm 0.32$	4.6σ	<2.2
III	$h_c \to 2(\pi^+\pi^-)\pi^0$	$7.44 \pm 0.94 \pm 1.52$	9.1σ	22^{+8}_{-7}
IV	$h_c \to 3(\pi^+\pi^-)\pi^0$	$4.65 \pm 2.17 \pm 1.08$	2.1σ	<29
		<8.7	...	
V	$h_c \to K^+K^-\pi^+\pi^-$	<0.6	...	...

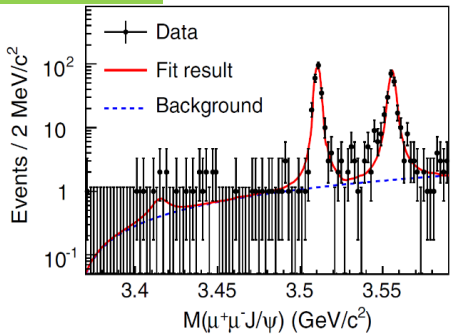


Study of electromagnetic Dalitz decays

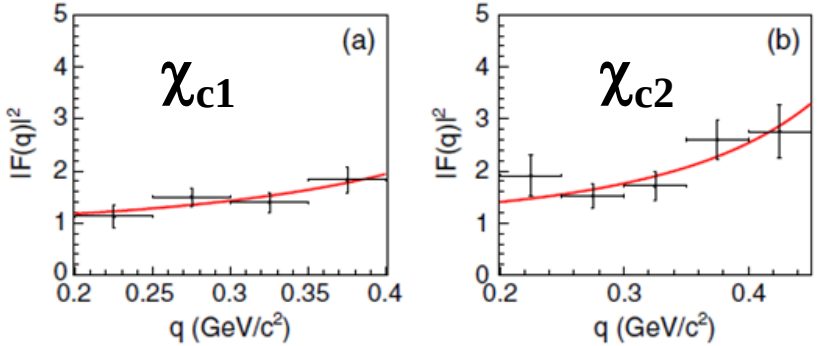
$\chi_{cJ} \to \mu^+\mu^- J/\psi$

- Understand the intrinsic structure of hadrons, test to theoretical models.
- Measurement of the branching fractions of $\chi_{cJ} \to \mu^+\mu^- J/\psi$ are related to the TFF.

PRD99, 051101 (2019)



Decay mode	Yields	Branching fraction
$\chi_{c0} \to \mu^+\mu^- J/\psi$	<9.5	$< 2.0 \times 10^{-5}$
$\chi_{c1} \to \mu^+\mu^- J/\psi$	221.9 ± 15.3	$(2.51 \pm 0.18 \pm 0.20) \times 10^{-4}$
$\chi_{c2} \to \mu^+\mu^- J/\psi$	218.9 ± 16.1	$(2.33 \pm 0.18 \pm 0.29) \times 10^{-4}$



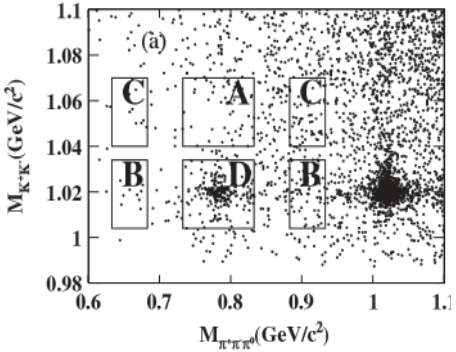
$$F(q) = \frac{1}{1 - q^2/\Lambda^2} \begin{cases} \Lambda_{\chi_{c1}} = 0.76 \pm 0.18\ \mathrm{GeV}/c^2 \\ \Lambda_{\chi_{c2}} = 0.71 \pm 0.10\ \mathrm{GeV}/c^2 \end{cases}$$

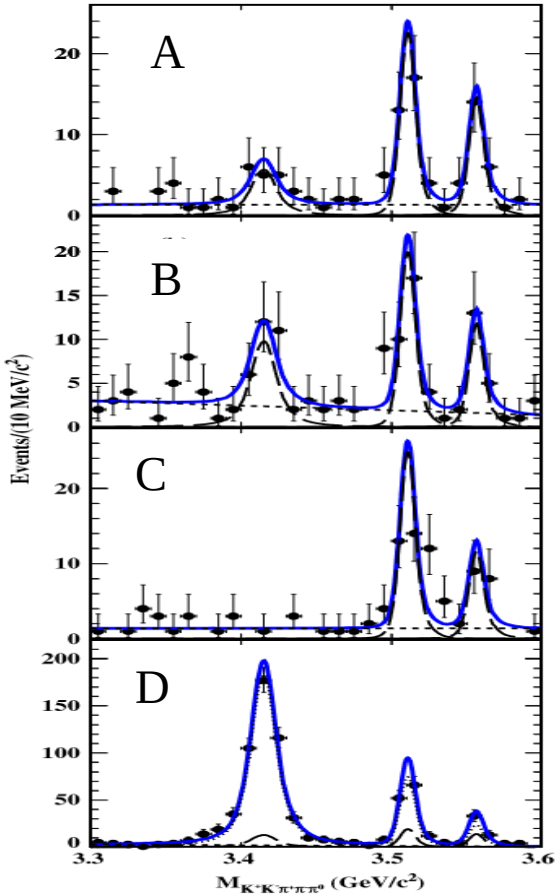
Observation of OZI-suppressed decays $\chi_{cJ} \rightarrow \omega\phi$

- The hadronic χ_{cJ} decays provide a prospective laboratory to limit theoretical parameters and test various phenomenological models.
- $\chi_{cJ} \rightarrow$VV decays are ideal objects to exploit the glueball-qqbar mixing and quark-gluon coupling of strong interaction in the low energy region.
- $\chi_{cJ} \rightarrow \omega\phi$ decay modes are doubly OZI suppressed.

Observation of OZI-suppressed decays $\chi_{cJ} \to \omega\phi$

PRD 99, 012015 (2019)





Mode	$\mathcal{B}(\chi_{cJ} \to \omega\phi)$
$\chi_{c0} \to \omega\phi$	$(13.84 \pm 0.70 \pm 1.08) \times 10^{-5}$
$\chi_{c1} \to \omega\phi$	$(2.80 \pm 0.32 \pm 0.30) \times 10^{-5}$
$\chi_{c2} \to \omega\phi$	$(1.00 \pm 0.25 \pm 0.14) \times 10^{-5}$

PRL107, 092001

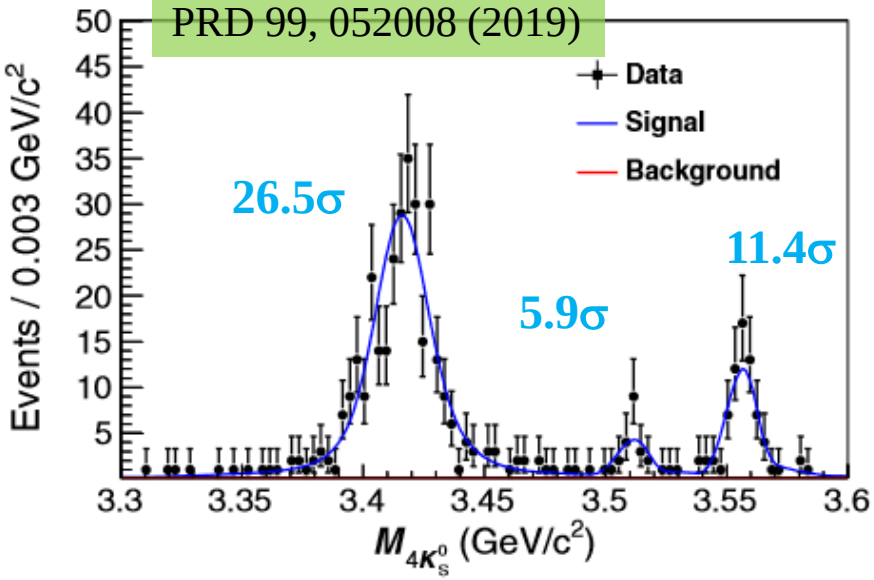
- $\chi_{c0} \to \omega\phi$: improved precisions
- $\chi_{c1} \to \omega\phi$: **observed for the first time with a 12.3σ**
- $\chi_{c2} \to \omega\phi$: strong evidence with a 4.8σ
- The ratios are one order of magnitude larger than theoretical predictions *PRD81,074006*

$$\begin{cases} \dfrac{\mathcal{B}(\chi_{c1} \to \omega\phi)}{\mathcal{B}(\chi_{c1} \to \omega\omega)} = (4.67 \pm 0.78) \times 10^{-2} \\ \dfrac{\mathcal{B}(\chi_{c1} \to \omega\phi)}{\mathcal{B}(\chi_{c1} \to \phi\phi)} = (5.60 \pm 1.01) \times 10^{-2} \end{cases}$$

Observation of $\chi_{cJ} \to 4K_s^0$

- χ_{c0} and χ_{c2} are expected to decay via two-gluon processes ⇒ investigation of glueball dynamics
- shed light on the understanding of isospin invariance.

PRD 99, 052008 (2019)



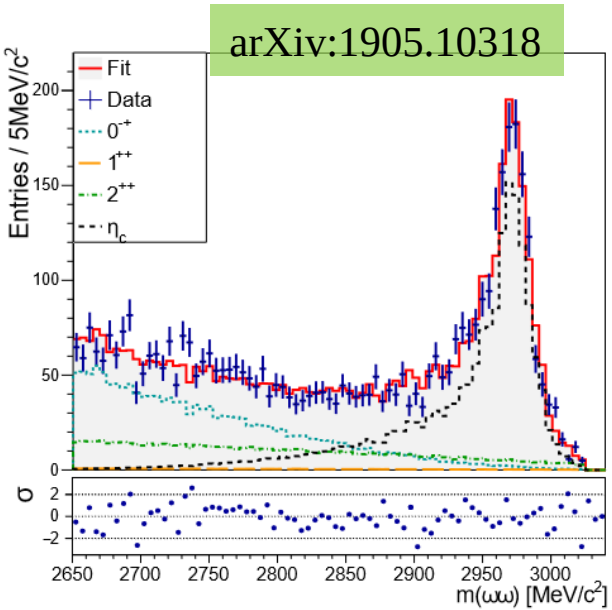
$$\mathcal{B}_{\chi_{c0}\to 4K_S^0} = (5.76 \pm 0.34 \pm 0.38) \times 10^{-4}$$
$$\mathcal{B}_{\chi_{c1}\to 4K_S^0} = (0.35 \pm 0.09 \pm 0.03) \times 10^{-4}$$
$$\mathcal{B}_{\chi_{c2}\to 4K_S^0} = (1.14 \pm 0.15 \pm 0.08) \times 10^{-4}$$

First observation

Observation of $\eta_c \to \omega\omega$ in $J/\psi \to \gamma\omega\omega$

- Properties of η_c are not fully understood yet, the observed branching fractions sum up to only about 57%.
- The predictions for the branching fraction of the $\eta_c \to \omega\omega$ process range from 9.1×10^{-5} to 1.3×10^{-4}, while the best experimental determination yielded an upper limit of $< 3.1 \times 10^{-3}$ at the 90% confidence level.

Observation of $\eta_c \to \omega\omega$ in $J/\psi \to \gamma\omega\omega$



- The decay $\eta_c \to \omega\omega$ in the process $J/\psi \to \gamma\omega\omega$ is measured for the first time at BESIII.

$$\mathcal{B}(J/\psi \to \gamma\eta_c) \cdot \mathcal{B}(\eta_c \to \omega\omega) = (4.90 \pm 0.17_{\text{stat.}} \pm 0.77_{\text{syst.}}) \times 10^{-5}$$

$$\mathcal{B}(\eta_c \to \omega\omega) = (2.88 \pm 0.10_{\text{stat.}} \pm 0.46_{\text{syst.}} \pm 0.68_{\text{ext.}}) \times 10^{-3}$$

about one order of magnitude larger than prediction Next-to-Leading order pQCD calculations

- The mass and decay width of η_c

$$M(\eta_c) = (2985.9 \pm 0.7_{\text{stat.}} \pm 2.1_{\text{syst}})\,\text{MeV}/c^2$$

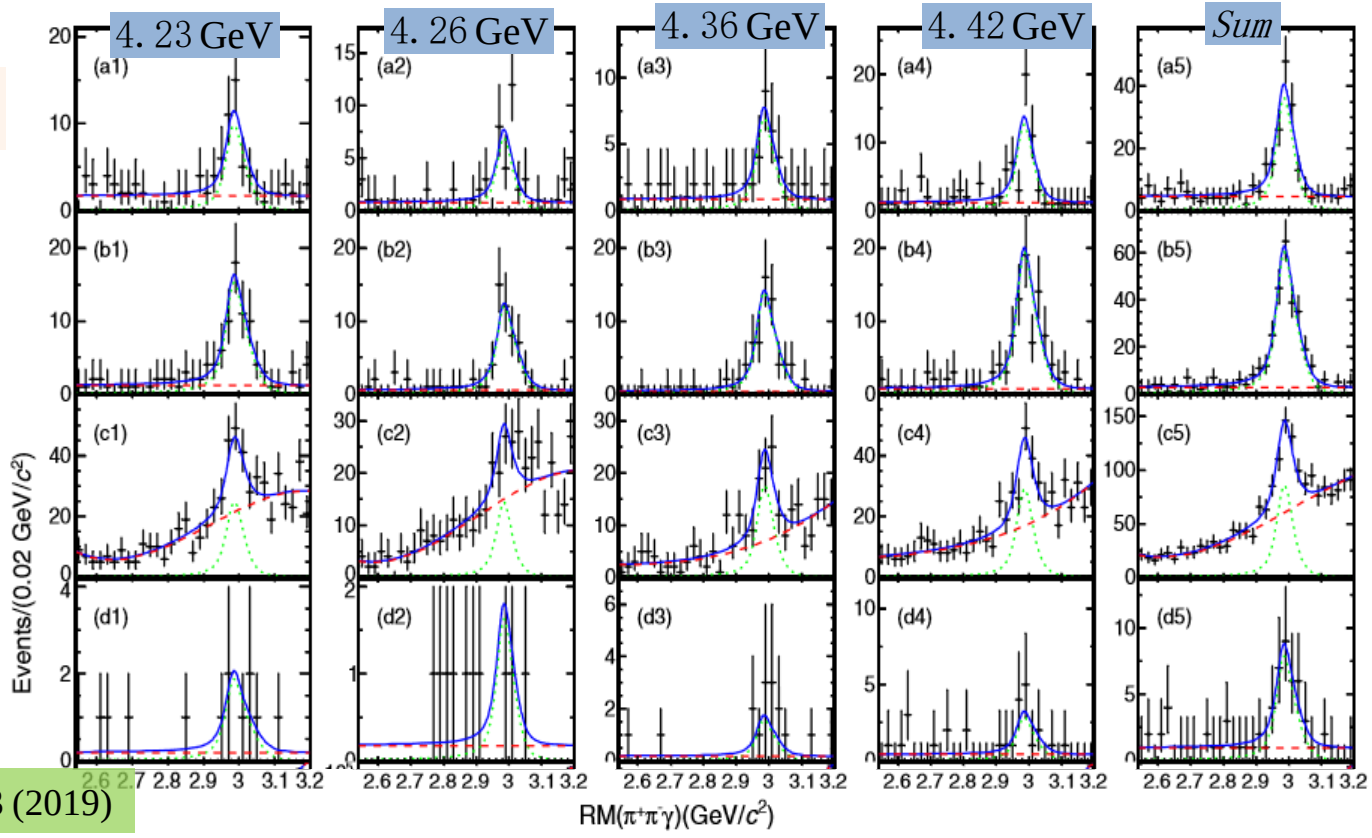
$$\Gamma(\eta_c) = (33.8 \pm 1.6_{\text{stat.}} \pm 4.1_{\text{syst.}})\,\text{MeV}$$

in good agreement with the world average values.

Measurements of the branching fractions of $\eta_c \to K^+K^-\pi^0$, $K_s^0K^\pm\pi^{-/+}$, $2(\pi^+\pi^-\pi^0)$ and $p\bar{p}$

- $h_c \to \gamma\eta_c$ was found to be a perfect process to measure both η_c resonant parameters and its decay branching fractions.
- A large production rate of $e^+e^- \to \pi^+\pi^- h_c$ has been found at BESIII.
- The chain $e^+e^- \to \pi^+\pi^- h_c$, $h_c \to \gamma\eta_c$ has been used to analyze these channels.

Measurements of the branching fractions of $\eta_c \to K^+K^-\pi^0$, $K_s^0K^\pm\pi^{-/+}$, $2(\pi^+\pi^-\pi^0)$ and $p\bar{p}$



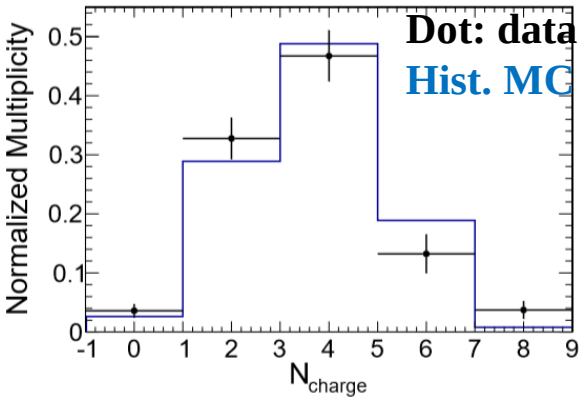
PRD 100, 012003 (2019)

Measurements of the branching fractions of $\eta_c \to K^+K^-\pi^0$, $K_s^0K^\pm\pi^{-/+}$, $2(\pi^+\pi^-\pi^0)$ and $p\bar{p}$

PRD 100, 012003 (2019)

Measurements of η_c decay channel

Final states	BF (%)	BF (%) **(PRD 86, 092009)**
$K^+K^-\pi^0$	$1.15 \pm 0.12 \pm 0.10$	$1.04 \pm 0.17 \pm 0.11 \pm 0.10$
$K_S^0K^\pm\pi^\mp$	$2.60 \pm 0.21 \pm 0.20$	$2.60 \pm 0.29 \pm 0.34 \pm 0.25$
$2(\pi^+\pi^-\pi^0)$	$15.3 \pm 1.8 \pm 1.8$	$17.23 \pm 1.70 \pm 2.29 \pm 1.66$
$p\bar{p}$	$0.120 \pm 0.026 \pm 0.015$	$0.15 \pm 0.04 \pm 0.02 \pm 0.01$



- The measurements are consistent with previous results with improved accuracy.
- The good consistency between data and MC simulation for the multiplicity indicates that the current MC simulation works generally well.

Summary

- Lots of new results on charmonium decays have been obtained, a few of them are presented:
  - $\psi(3686)\to\Xi^-(1530)\bar{\Xi}^+(1530)$ and $p\bar{p}\eta'$
  - $h_c \to$ hadrons
  - $\chi_{cJ}\to\mu^+\mu^-$J/ψ, $\omega\phi$ and $4K_s^0$
  - $\eta_c\to\omega\omega$, $K^+K^-\pi^0$, $K_s^0K^{\pm}\pi^{-/+}$, $2(\pi^+\pi^-\pi^0)$ and $p\bar{p}$
- 10 B J/ψ data sample has been collected at BESIII, which will offer unique possibilities to study rare processes and to improve statistical accuracy.

Thanks for your attention!