Charmonium Decays at BESIII

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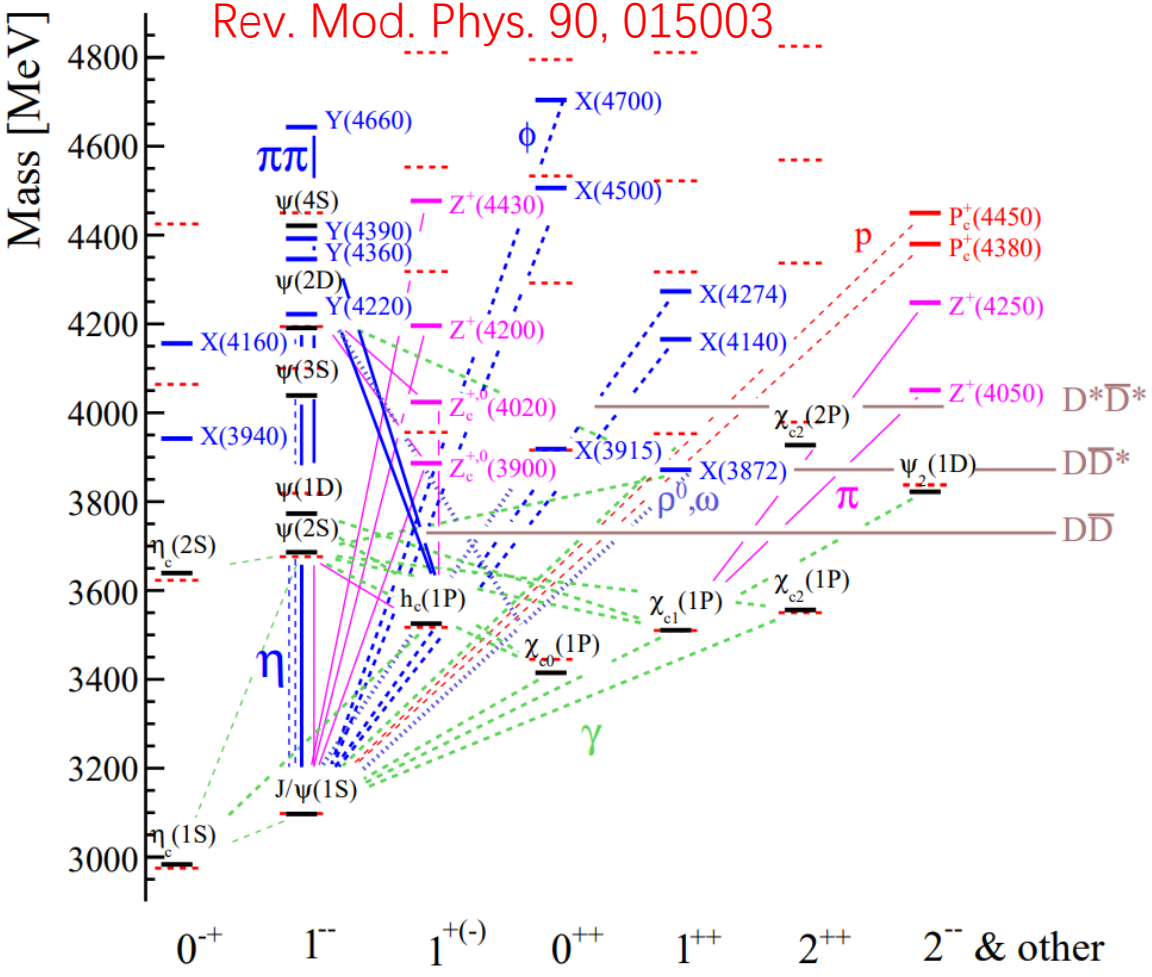
on behalf of BESIII Collaboration

(PANIC 2021)

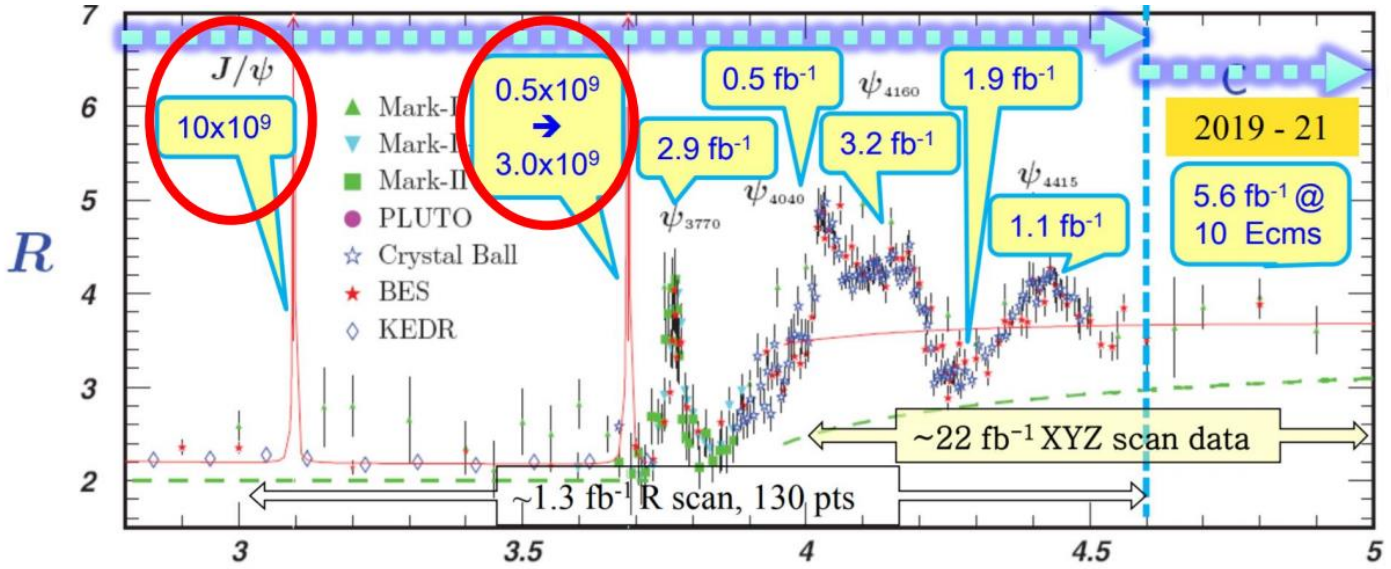
2021/9/8

Charmonium Spectroscopy



- Charmonium states locate in the transition region between perturbative QCD and nonperturbative QCD;
- The charmonium spectroscopy allows precision tests of QCD and inspired QCD models, providing a unique and important perspective on the dynamics of strong force physics;
- The spectrum of charmonium states with $M < 2m_D$ has been well-established for several decades;
- High mass region: Many excited states not found
  Many exotic states are observed;

Charmonium Spectroscopy at BESIII



- Data for charmonium spectroscopy: 10B-J/ψ, 448M-$\psi(3686)$→ 3B-$\psi(3686)$, ~22fb^{-1}XYZ above 3.8GeV, scan data around $\psi(3686)$;

- The goal of BESIII studies of charmonium states: investigate the spectroscopy, transitions, and find new decay channels ….. ;

- The light charmonium states are primarily studied using large and clean samples of $\psi(3686)$ or J/ψ decays, the excited charmonium states are produced using higher-energy collisions;

Recent results at BESIII

- Charmonium $\rightarrow B\bar{B}$ ...
  - $\psi(3686) \rightarrow \bar{\Sigma}^0\Lambda + c.c.$;
  - $\chi_{cJ}(J = 0,1,2) \rightarrow \Lambda\bar{\Lambda}$ / $nK_s^0\Lambda + c.c.$;
  - $\psi(3686), J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-$;

- Charmonium $\rightarrow Meson +$
  - $\psi(3686) \rightarrow K_s^0$ +anything;
  - $\eta_c \rightarrow \eta\eta\eta'$;

- Charmonium $\rightarrow X +$ Charmonium
  - $\psi(3823)$ decays: Several new decay modes are searched;
  - $\psi(4040)/\psi(4160)$ decays: Possible $\psi(4040)/\psi(4160) \rightarrow \gamma\chi_{c1,c2}$ in $e^+e^- \rightarrow \gamma\chi_{c0,c1,c2}$;

$\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$

PRD 103,112004(2021)

Data: 4.481×10^8 $\psi(3686)$

- The BF of isospin violating decay $\boldsymbol{\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.}$ is measured to be:

$$B(\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.) = 1.60 \pm 0.31 \pm 0.13 \pm 0.58 \times 10^{-6},$$

Interference between $\psi(3686)$ and continuum process

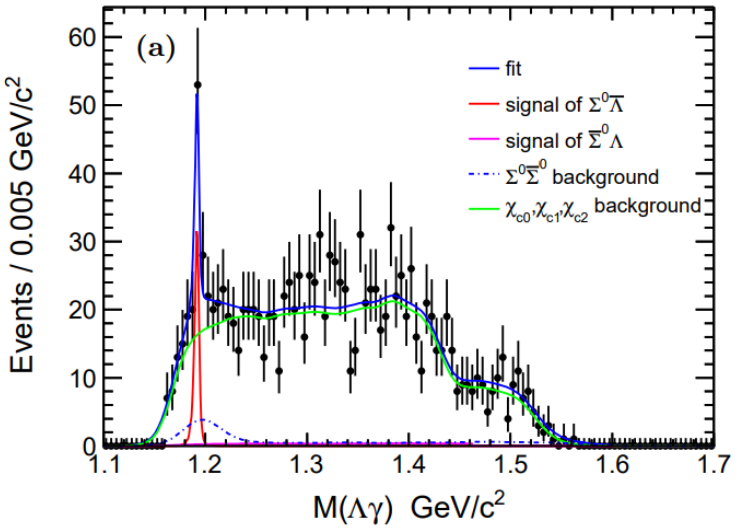
- CLEO-c: PRD 96, 092004 (2017)

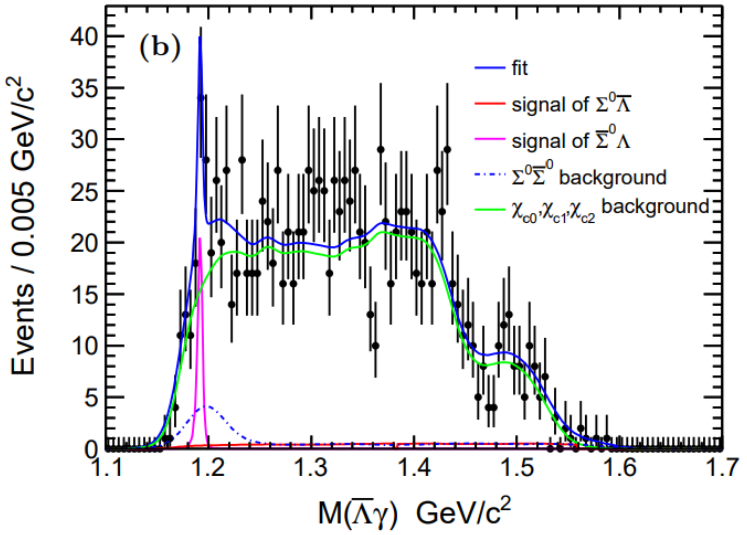
$$B(\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.) = 12.3 \pm 2.4 \times 10^{-6},$$

- Theoretical prediction: Int. J. Mod.Phys. A 30, 1550148

$$B(\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.) = 4.0 \pm 2.3 \times 10^{-6},$$

- Smaller than CLEO-c result, consistent with Theoretical prediction;



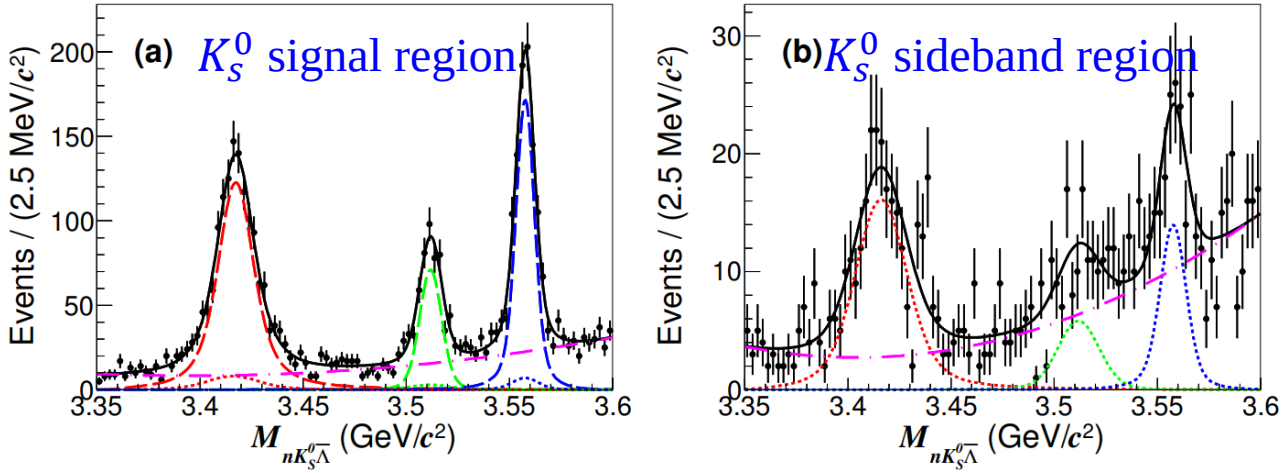


$\chi_{cJ} \to nK_S^0\Lambda + c.c$

arXiv:2106.13442

Data: 4.481×10^8 $\psi(3686)$

- The decay $\chi_{cJ} \to nK_S^0\Lambda + c.c$ are observed for the first time;



- The BFs of $\chi_{cJ} \to nK_S^0\Lambda + c.c$ are measured, the ratios $B(\chi_{cJ} \to pK^-\Lambda + c.c)/B(\chi_{cJ} \to nK_S^0\Lambda + c.c)$ are measured; No obvious isospin violation is observed

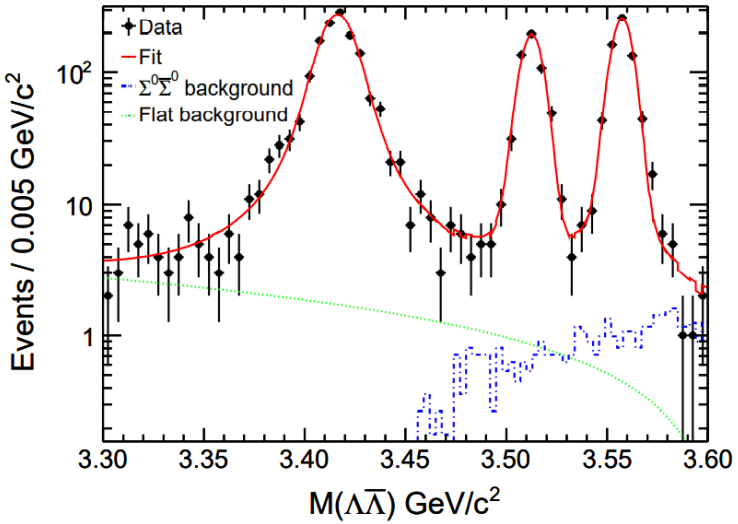
Mode	$N_{1,J}$	ϵ_J (%)	BF (10^{-4})	BF($pK^-\bar{\Lambda}$) / BF($nK_S^0\bar{\Lambda}$)
χ_{c0}	1288 ± 50	9.95	$6.67 \pm 0.26 \pm 0.41$	(1.98±0.09±0.14)
χ_{c1}	410 ± 30	12.44	$1.71 \pm 0.12 \pm 0.12$	(2.64±0.23±0.20)
χ_{c2}	900 ± 41	13.03	$3.66 \pm 0.17 \pm 0.23$	(2.29±0.13±0.16)

$\chi_{cJ} \to \Lambda\bar{\Lambda}$

PRD 103,112004(2021)

Data: 4.481×10^8 $\psi(3686)$

- The BF of decay $\boldsymbol{\chi_{cJ} \to \Lambda\bar{\Lambda}}$ via $\psi(3686) \to \gamma\chi_{cJ}$ are measured;
- The BFs are consistent with PDG values;
- Not consistent with the theoretical predictions, this should be understood further; Eur. Phys. J. A 23, 129, J. Phys. G 38, 035007, Eur. Phys. J. C 14, 643 (e.g. $\boldsymbol{\chi_{c0}}$ ~1.19~1.51× 10^{-4});



Uncertainties from $\psi(3686) \to \gamma\chi_{cJ}$

Mode	$N_{\chi_{cJ}}$	ϵ	$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) \times \mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda})\ (10^{-5})$	$\mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda})\ (\times 10^{-4})$	
				This work	PDG
χ_{c0}	1486 ± 42	22.80%	$3.56 \pm 0.10 \pm 0.10$	$3.64 \pm 0.10 \pm 0.10 \pm 0.07$	3.27 ± 0.24
χ_{c1}	528 ± 24	22.61%	$1.28 \pm 0.06 \pm 0.06$	$1.31 \pm 0.06 \pm 0.06 \pm 0.03$	1.14 ± 0.11
χ_{c2}	670 ± 27	20.16%	$1.82 \pm 0.08 \pm 0.17$	$1.91 \pm 0.08 \pm 0.17 \pm 0.04$	1.84 ± 0.15

$\psi(3686)$ and $J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-$

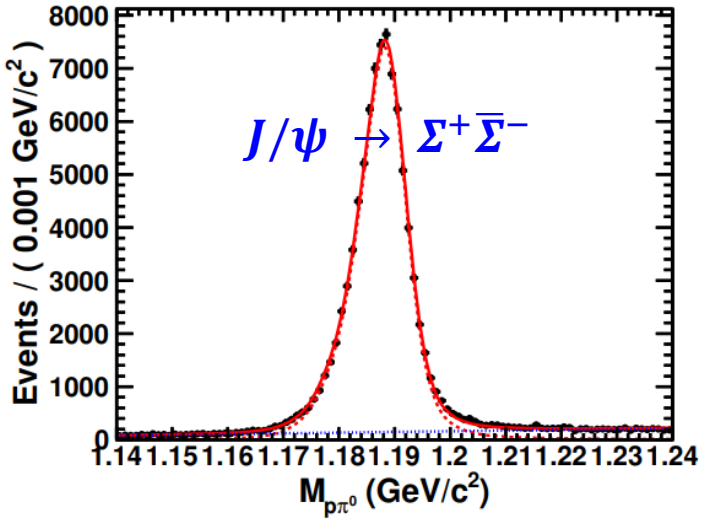
arXiv:2107.02977

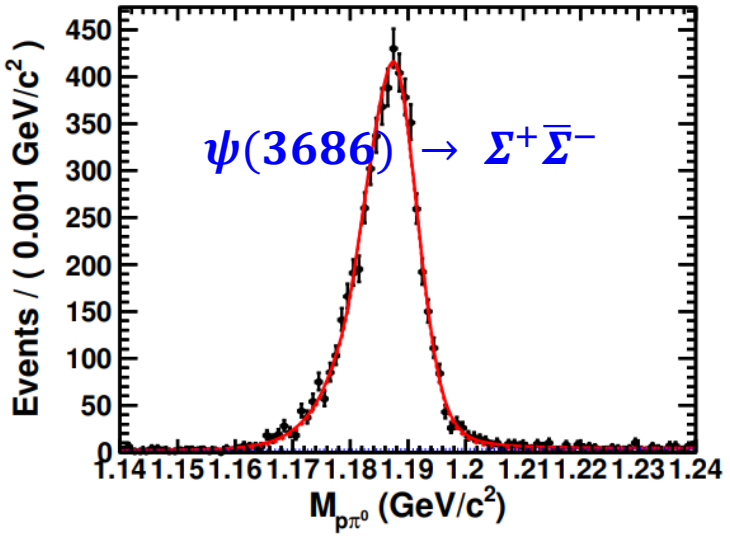
Data: 4.481×10^8 $\psi(3686)$ and 1.31×10^9 J/ψ

- The BF of decay $\psi(3686)$ and $J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-$ are measured to be:

Channel	Branching fraction(10^{-4})	BF($\psi(3686)$) / BF(J/ψ)
$\psi(3686) \longrightarrow \Sigma^+\bar{\Sigma}^-$	$2.52 \pm 0.04 \pm 0.10$	$(23.8 \pm 1.3)\%$
$J/\psi \longrightarrow \Sigma^+\bar{\Sigma}^-$	$10.61 \pm 0.04 \pm 0.38$	

violate the "12% rule"





- The BFs are in agreement with previous measurement (BES and CLEO), with improved precision; Phys. Rev. D 78, 092005, Phys. Rev. D 96, 092004

Recent results at BESIII

- Charmonium $\to B\bar{B}$ ...
  - $\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$;
  - $\chi_{cJ}(J = 0,1,2) \to \Lambda\bar{\Lambda}\,/\,nK_s^0\Lambda + c.c.$;
  - $\psi(3686), J/\psi \to \Sigma^+\bar{\Sigma}^-$;

- Charmonium $\to$ $Meson$ +
  - $\psi(3686) \to K_s^0$ +anything;
  - $\eta_c \to \eta\eta\eta'$;

- Charmonium $\to X$ + Charmonium
  - $\psi(3823)$ decays: Several new decay modes are searched;
  - $\psi(4040)/\psi(4160)$ decays: Possible $\psi(4040)/\psi(4160) \to \gamma\chi_{c1,c2}$ in $e^+e^- \to \gamma\chi_{c0,c1,c2}$;

$\psi(3686) \to K_S^0 +$ anything

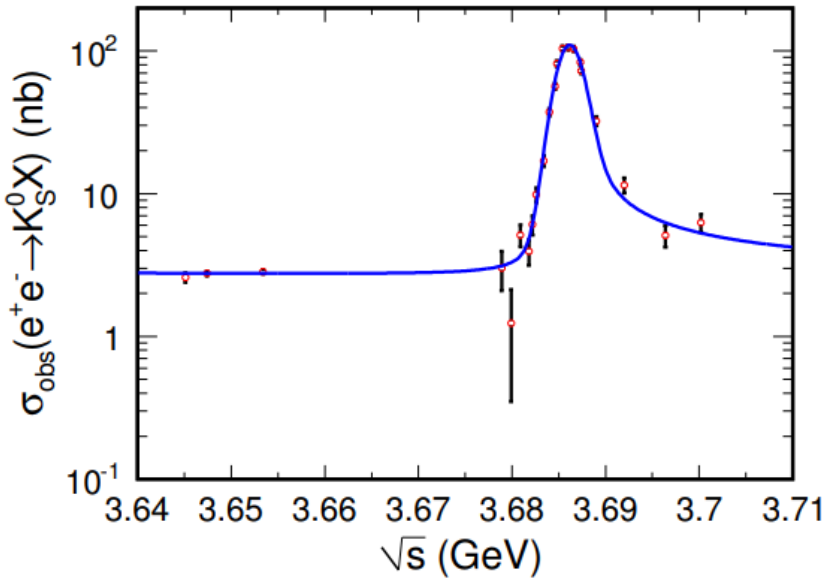
arXiv:2106.08766
Accepted by PLB

Data: $\mathcal{L} = 5.9 fb^{-1}$, $\sqrt{s} = 3.640 - 3.701$ GeV

- Measurements of the BFs of inclusive $\psi(3686)$ decays can guide the search for new exclusive decay modes.
- The BF of $\psi(3686) \to K_S^0 +$ anything is measured for the first time by fitting the observed inclusive K_S^0 cross sections around ψ(3686) energy region:

$$\mathcal{B}(\psi(3686) \to K_S^0 X) = (16.04 \pm 0.29 \pm 0.90)\%,$$

- The sum of all the BFs of ψ(3686) decays to exclusive K_S^0 final states is ~ 5.95% as reported in the PDG;(Much lower than the current measurement)
- This suggests that there are many undiscovered exclusive channels for ψ(3686) decay to final states containing K_S^0.



$\eta_c \to \eta\eta\eta'$

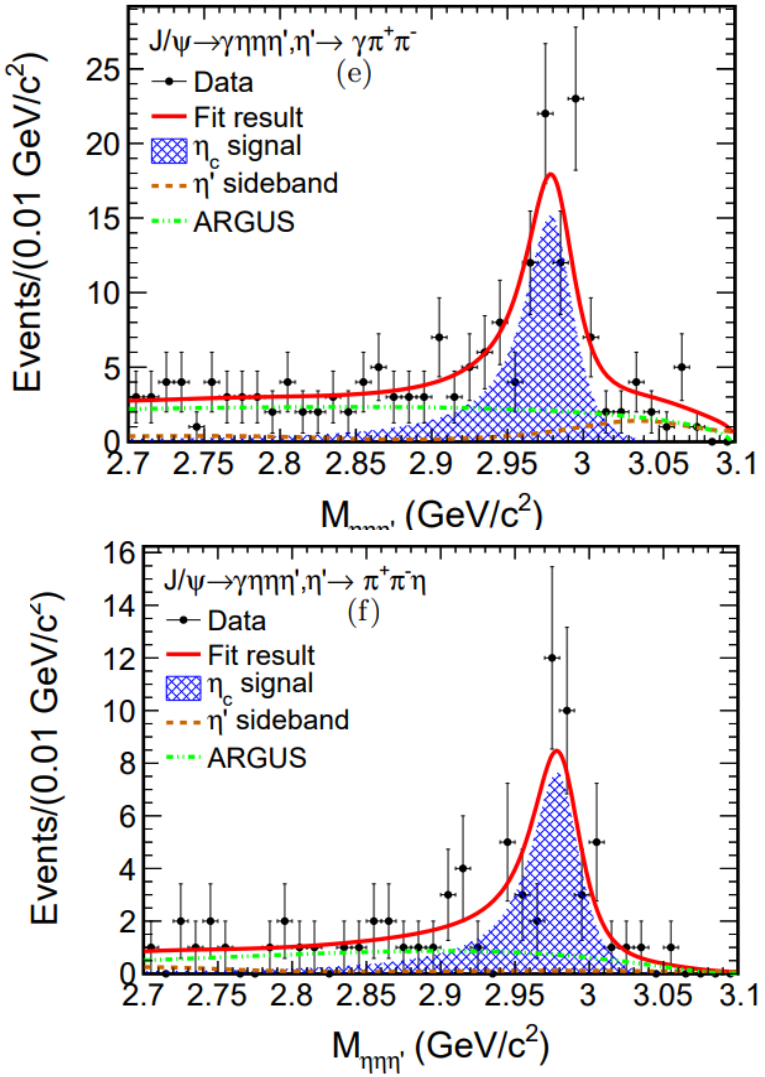
PRD 103,012009(2021)

Data: 1.31×10^9 J/ψ

- The decay $\eta_c \to \eta\eta\eta'$ are observed for the first time,

$$B(J/\psi \to \gamma\eta_c, \eta_c \to \eta\eta\eta') = 4.86 \pm 0.62 \pm 0.45 \times 10^{-5},$$

which is compatible with the theoretical prediction; Eur. Phys. J. A 54, 139 (2018)



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- Charmonium $\rightarrow X +$ Charmonium
  - $\psi(3823)$ decays: Several new decay modes are searched;
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Search for new decay modes of $\psi_2(3823)$

Data: $\mathcal{L} = 19fb^{-1}$, $\sqrt{s} = 4.1 - 4.7$ GeV

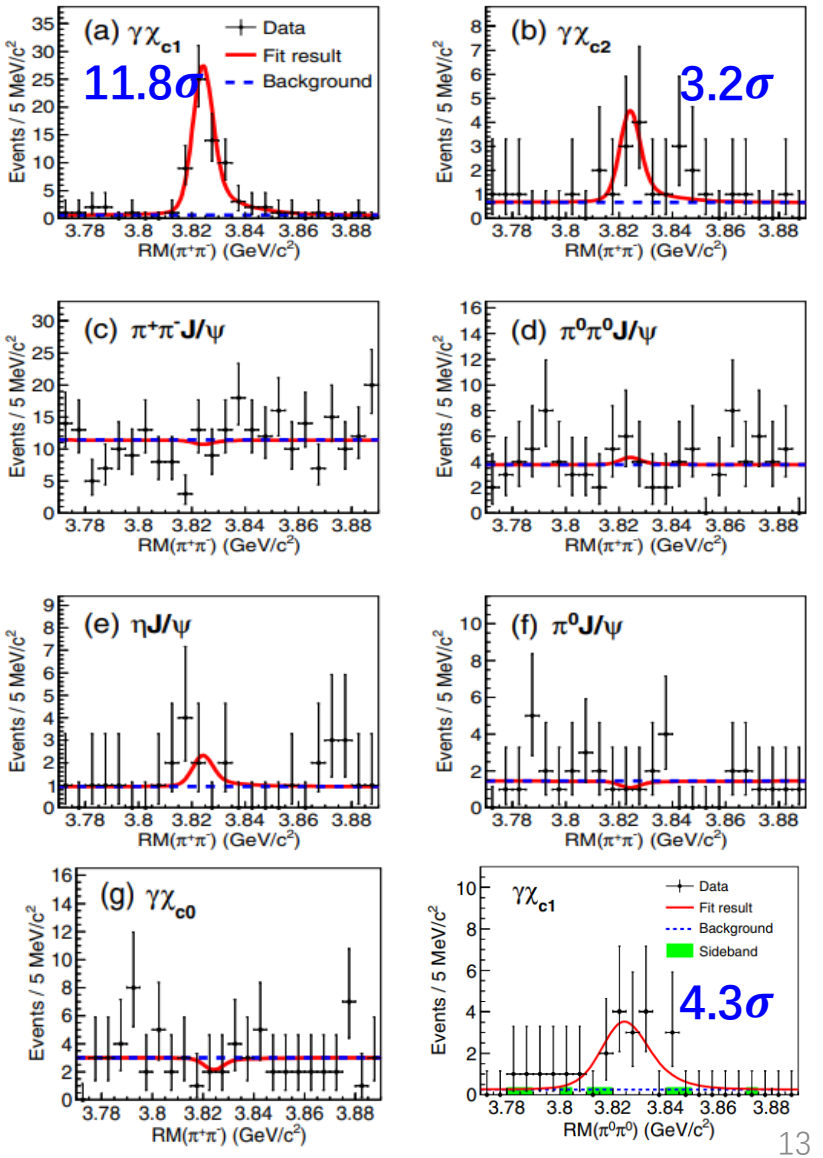
PRD103, L091102 (2021)

- The new decay modes of $\psi_2(3823)$ are searched;

Channel	$N^{\psi_2(3823)}$	$\frac{\mathcal{B}(\psi_2(3823)\to\cdots)}{\mathcal{B}(\psi_2(3823)\to\gamma\chi_{c1})}$
$\gamma\chi_{c1}$	63.1 ± 8.5	...
$\gamma\chi_{c2}$	$8.8^{+4.3}_{-3.4}$	$0.28^{+0.14}_{-0.11} \pm 0.02$
$\pi^+\pi^- J/\psi$	<21.0	<0.06
$\pi^0\pi^0 J/\psi$	<10.0	<0.11
$\eta J/\psi$	<9.8	<0.14
$\pi^0 J/\psi$	<5.6	<0.03
$\gamma\chi_{c0}$	<6.3	<0.24

consistent with theoretical predictions PRD 55, 4001 PRL89, 162002

lower than theoretical predictions



- $\psi_2(3823) \to \gamma\chi_{c1}$: confirm the previous observation at BESIII, with 11.8σ;
- No significant $\psi_2(3823)$ signals are observed for other channels;
- Evidence for $e^+e^- \to \pi^0\pi^0\,\psi_2(3823)$, 4.3σ;

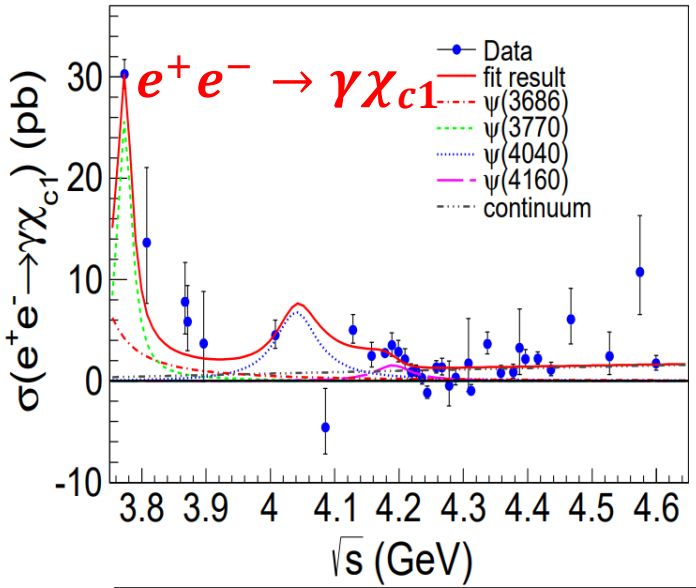
$e^+e^- \to \gamma\chi_{c0,c1,c2}$

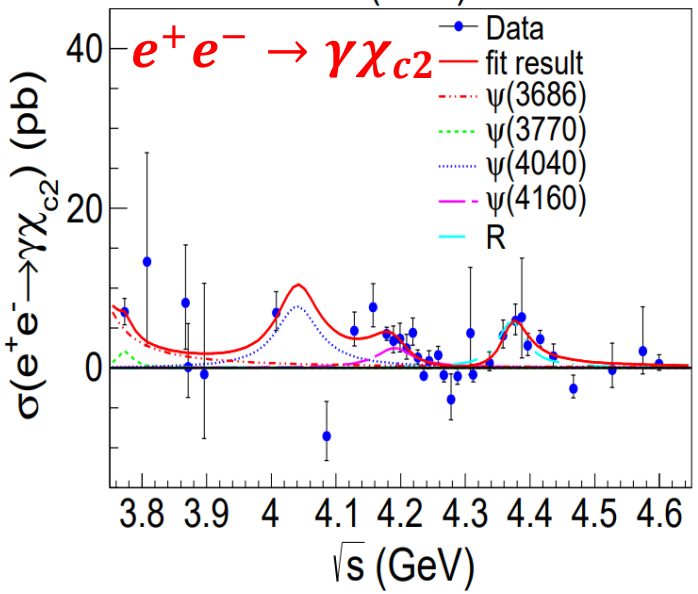
arXiv: 2107.03604

Data: $\mathcal{L} = 19.3fb^{-1}$, $\sqrt{s} = 3.77 - 4.6$ GeV

- The processes of $e^+e^- \to \gamma\chi_{c1,c2}$ are observed for the first time @ 4.178 GeV ($7.6\sigma$and 6.0σ) ;
- Components in the cross section fit:
  - $e^+e^- \to \gamma\chi_{c1}$: $\psi(3686)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ + continuum contribution;
    $\psi(4040)$ (3.3σ), $\psi(4160)$ (3.7σ), continuum (6.7σ);
  - $e^+e^- \to \gamma\chi_{c2}$: $\psi(3686)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ + Y(4360);
    $\psi(4040)$ (2.0σ), $\psi(4160)$ (4.6σ), Y(4360) (5.8σ);

- The measured cross section are consistent with potential model (3S/2D) predictions, except for B[$\psi(4160) \to \gamma\chi_{c2}$] (~$10^{-4}$) is much larger than potential model predictions(~10^{-7});



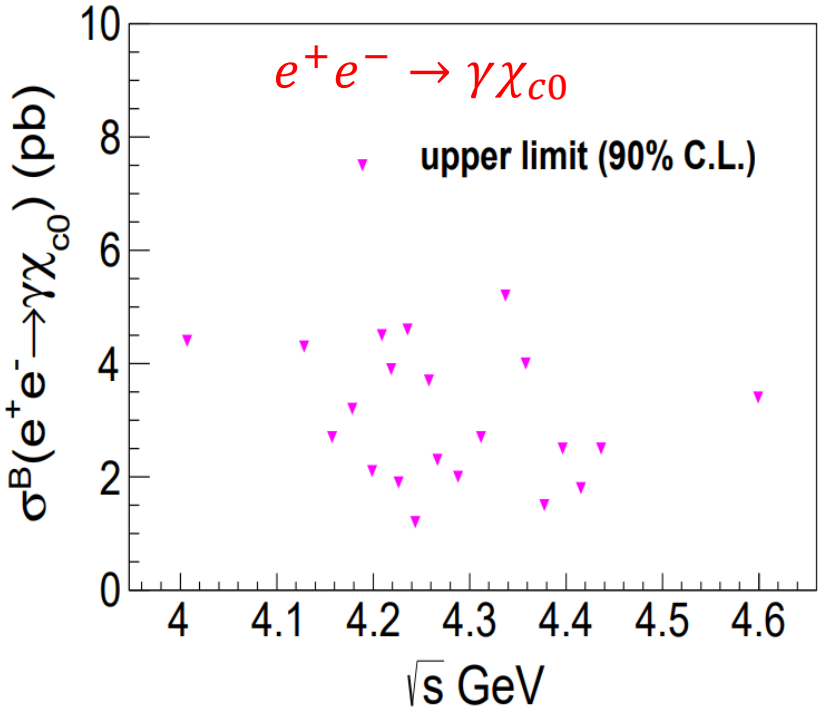


$e^+e^- \to \gamma\chi_{c0,c1,c2}$

arXiv: 2107.03604

Data: $\mathcal{L} = 15fb^{-1}$, $\sqrt{s} = 4.0 - 4.6$ GeV

- $\chi_{c0} \to K^+K^-\pi^+\pi^-/2(\pi^+\pi^-)/K^+K^-$;
- No obvious signal of $e^+e^- \to \gamma\chi_{c0}$;
- The UL is consistent with potential model expectations;



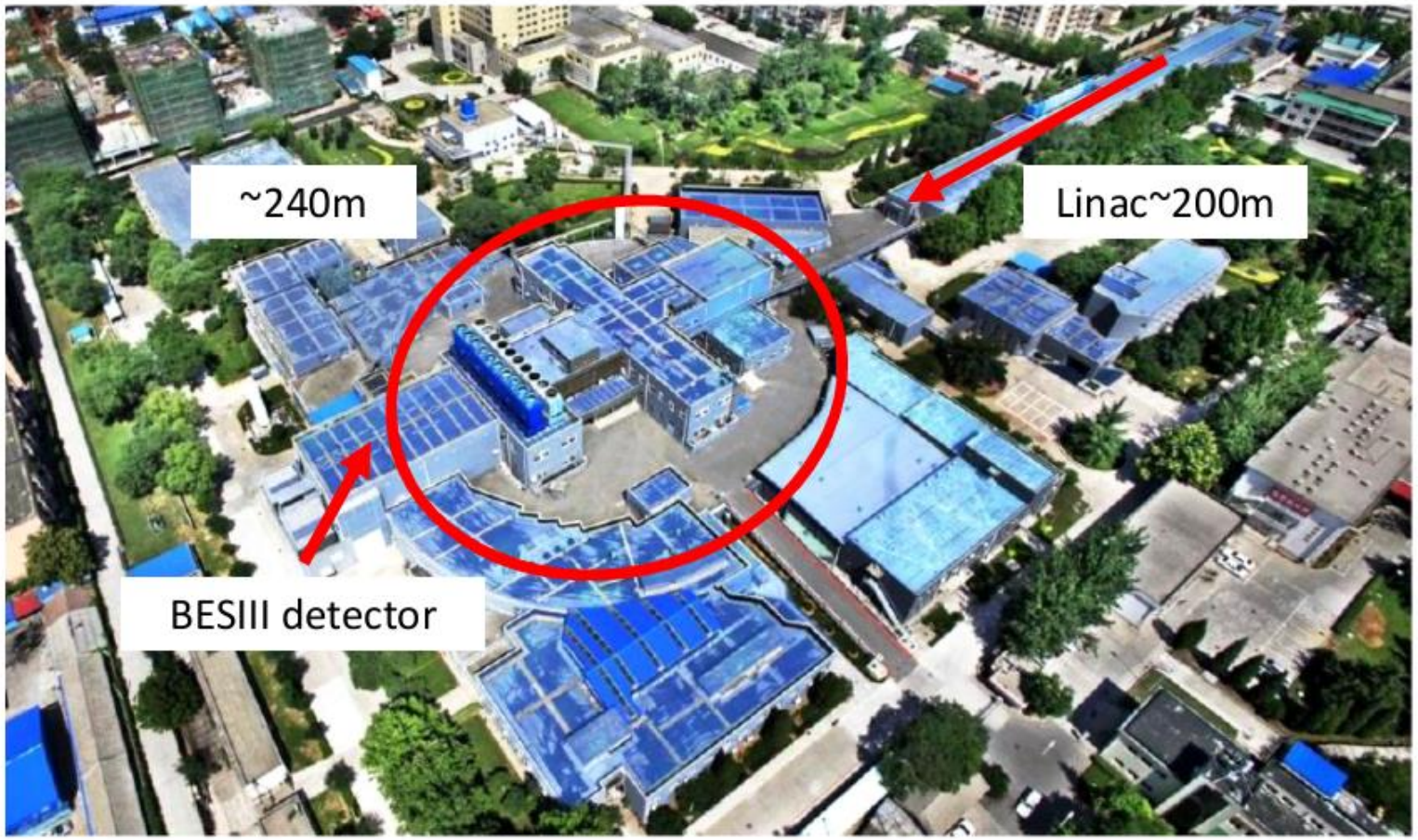
Summary

- Many progress in the study of charmonium decays in a recent year at BESIII;
- With 10 B J/ψ and 3B $\psi(3686)$, more precise measurements are coming!
- In this talk, we present the new decay channels or new measurements of (η_c, J/ψ, $\psi(3686)$, χ_{cJ}), and new transitions ($\psi_2(3823)$,$\psi(4040)$,$\psi(4160)$);

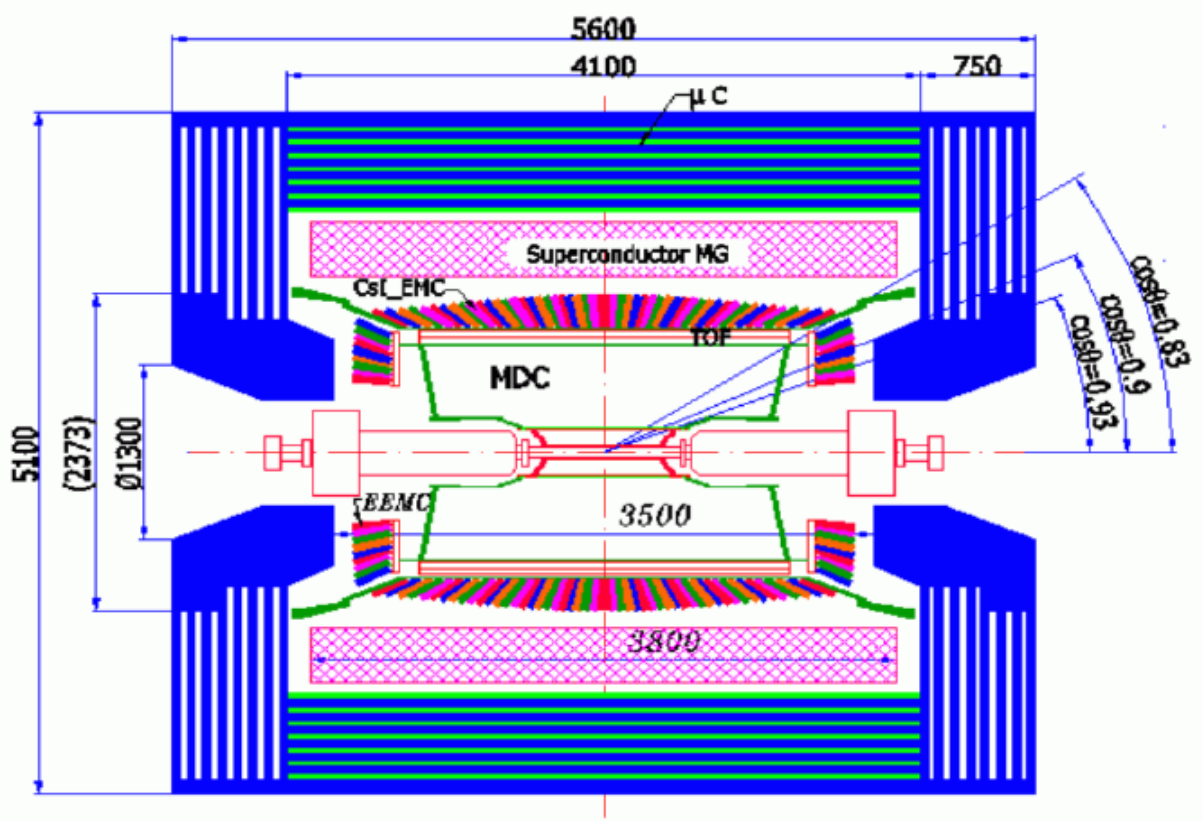
Thanks for your attention!!!

Back Up

BEPCII/BESIII



- Double rings;
- Ecm= 2.0-4.6 GeV (2.0-4.9 GeV since 2019);
- Energy spread: $\Delta E \approx 5 \times 10^{-4}$GeV;
- Design luminosity @Ecm= 3.77 GeV: ~1× $10^{33}\ cm^{-2}s^{-1}$ (reached 2016);
- 2009~ today: BESIII physics runs;



Chin.Phys.C 44 (2020) 4, 040001

Main Drift Chamber

σ_p/p <0.5% (@1GeV) (1T)

σ_{xy} ~120 μm

dE/dx~6%

Time Of Flight

$\sigma_t < 68ps$(barrel)

$\sigma_t < 70ps$(endcap MRPC)

Electromagnetic Calorimeter

σ_E/E <2.5% (@1GeV)

σ_{xy}~6mm （@1GeV）

Muon Counter

$\sigma_{\text{spatial}} < 2cm$