Charmonium decays at BESIII

Marco Scodeggio

on behalf of the BESIII Collaboration

Dipartimento
di Fisica
e Scienze della Terra

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Istituto Nazionale di Fisica Nucleare

BESIII Experiment

BESIII (BEijing Spectrometer III) is an experiment located at the BEPCII (Beijing Electron Positron Collider II) at IHEP (Institute of High Energy Physics)

Being **BEPCII** an **e^+e^- collider**, BESIII can profit from **direct production** of **vector states** ($J^{PC} = 1^{--}$)
The **statistics of the ψ(nS)** decays allows to probe and study with **high precision** also the non vector states
BESIII has also **unique opportunities** with datasets **above 3.8 GeV**

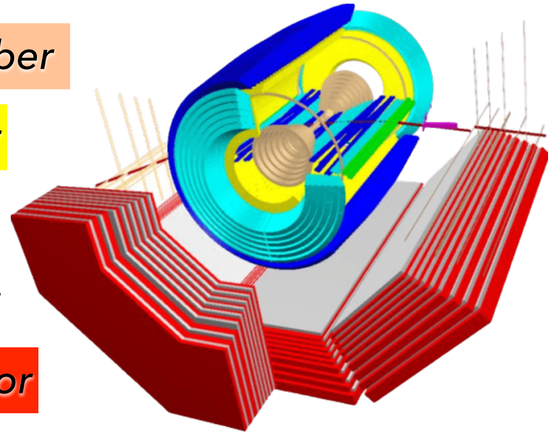
Multi-layer Drift Chamber

Time of Flight Detector

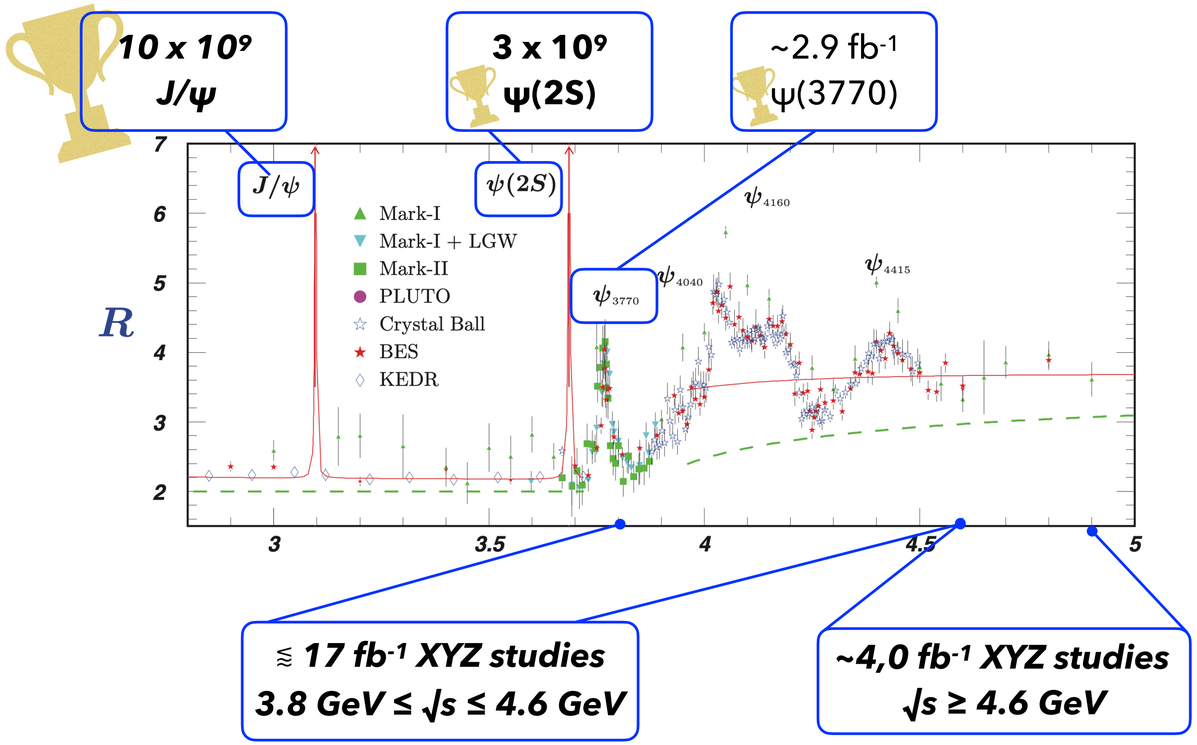
EM Calorimeter

1T Solenoidal Magnet

Muon Detector



τ-charm factory 2.0 GeV ≤ √s ≤ 4.9 GeV
with a 10^{33} $cm^{-2}s^{-1}$ designed luminosity
@ √s = 3.77 GeV



Preamble

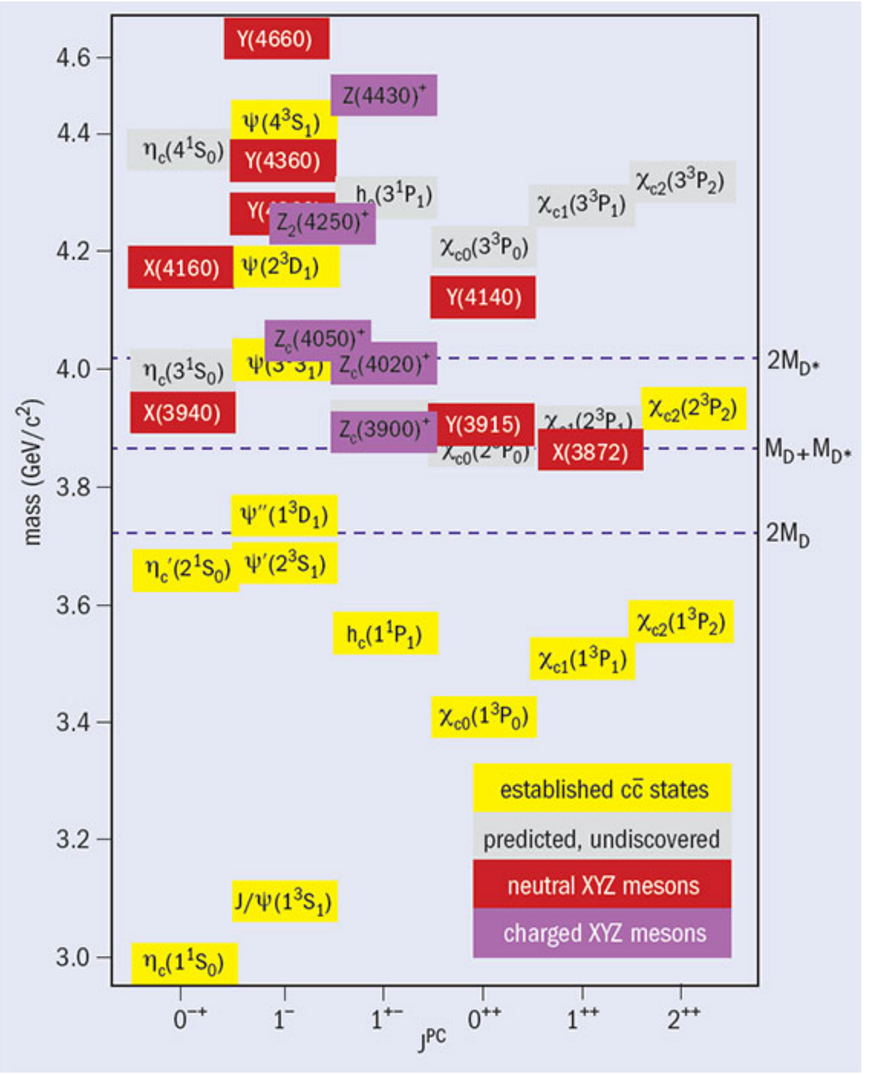
Charmonium resonances are located in the transition region of perturbative and non-perturbative QCD

Non vector states still mostly unknown

Vector states can be used either to reach non-1^{--} ones or as a way to test pQCD predictions (e.g., 12% rule, $\not{A}$(EM - strong), …), especially above $D\bar{D}$ threshold

Gateway to the XYZ exotic states

Another way to probe the SM (via weak decays)



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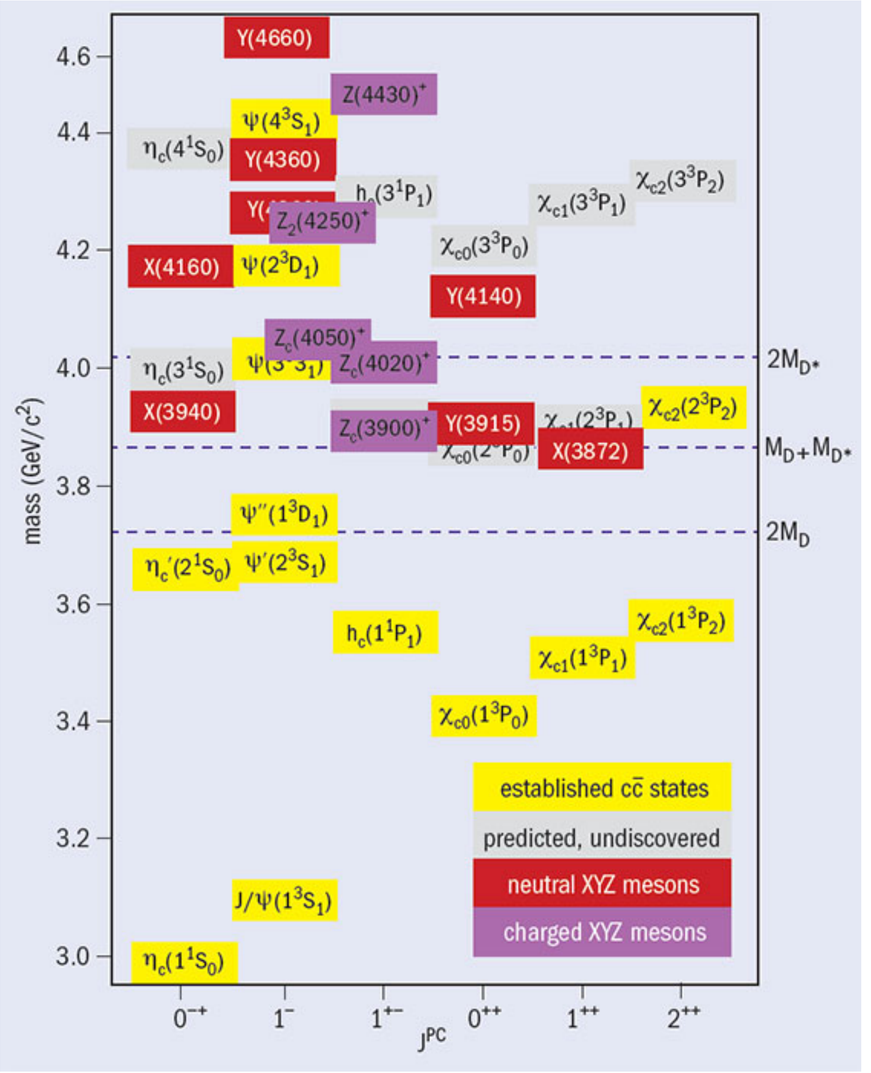

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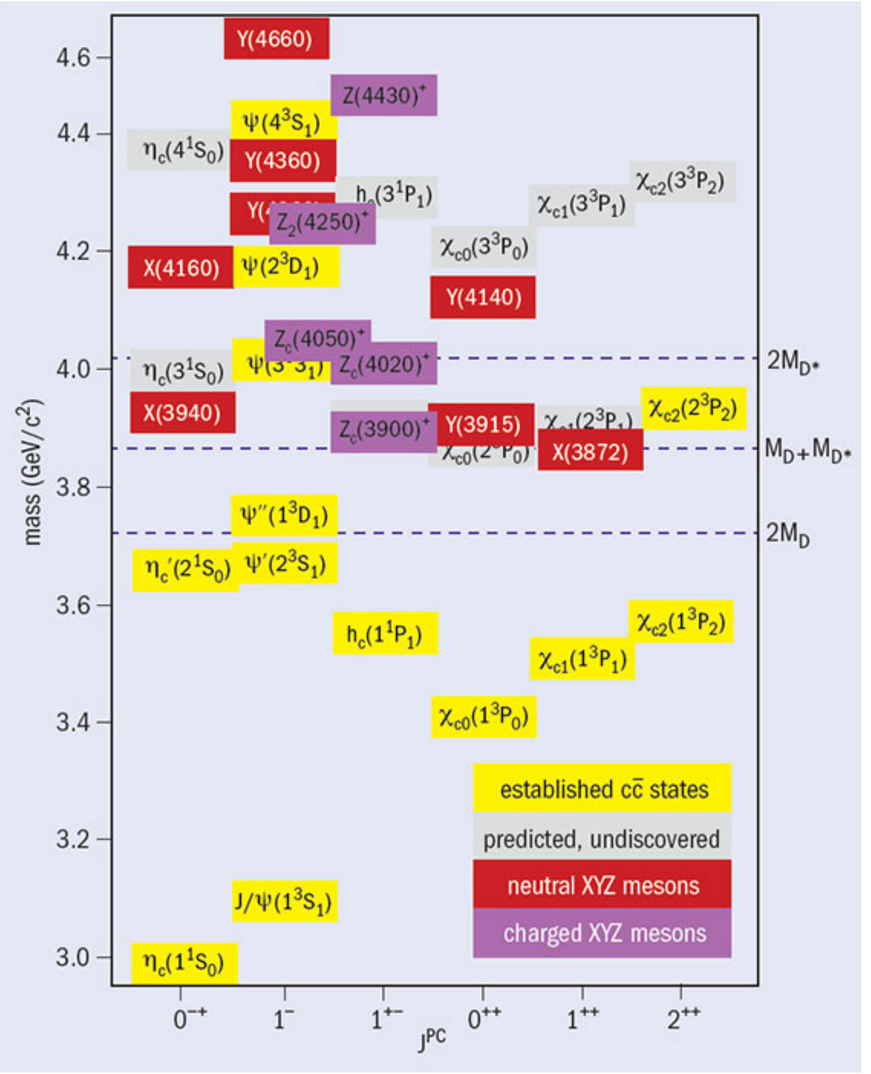

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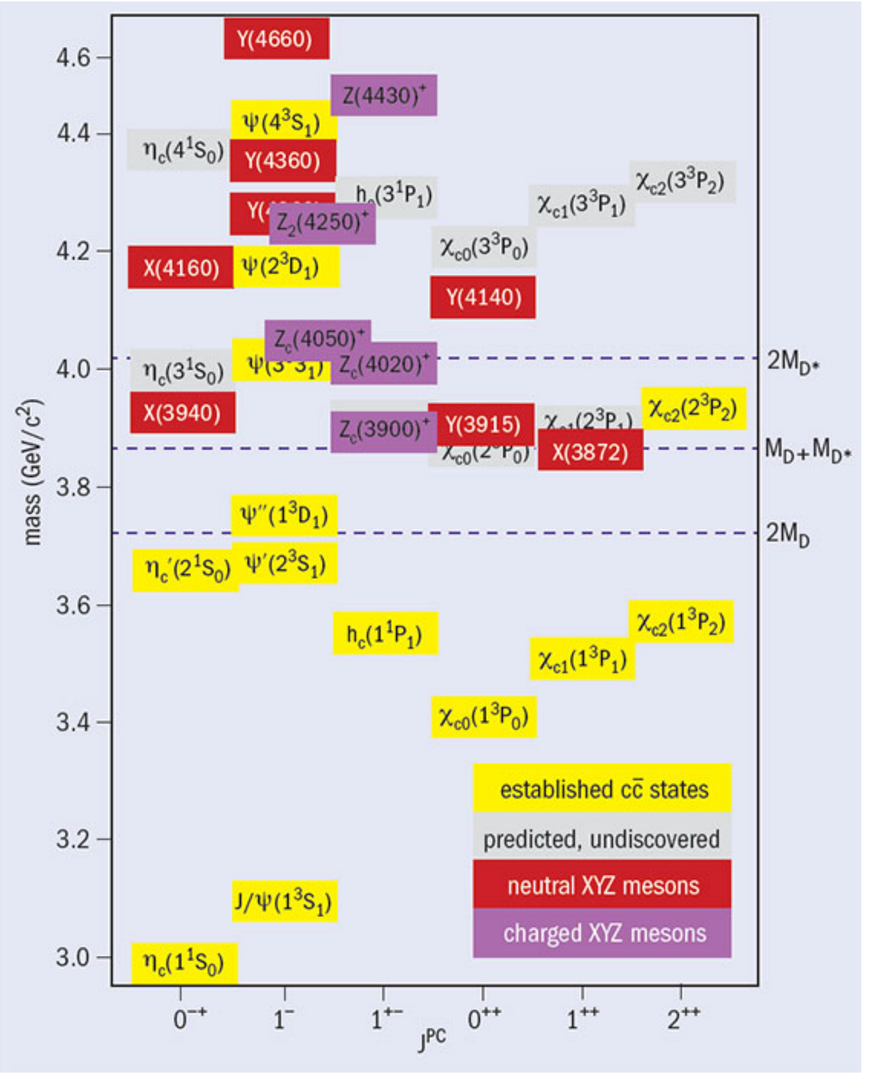

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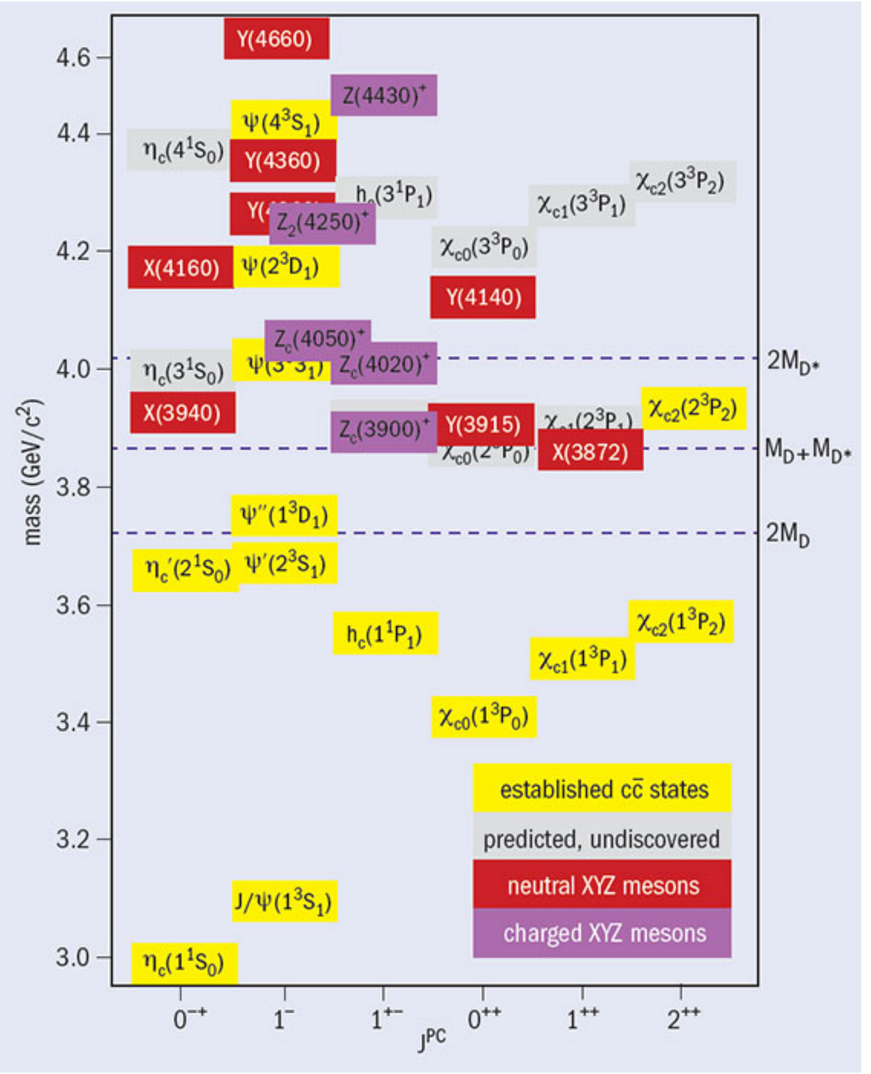

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Another way to probe the SM (via weak decays)

BESIII has the capability to perform such studies and many charmonium analyses could be discussed:

1. Measurement of the inclusive branching fraction for $\psi(3686) \to K_S^0$ + anything
2. ***Measurement of Branching Fractions of J/ψ and ψ(3686) decays to Σ⁺ and Σ***
3. ***Measurements of the branching fractions of $\psi(3686) \to \Sigma^0 \Lambda$ + c.c.***
4. *Search for New Hadronic Decays of h_c and Observation of $h_c \to K^+K^-\pi^+\pi^-\pi^0$*
5. ***Measurement of $e^+e^- \to \gamma\chi_{cJ}$ cross sections at center-of-mass energies between 3.77 and 4.60 GeV***
6. *Observation of the decays $\chi_{cJ} \to nK^0\Lambda$ + c.c.*
7. Search for the X(2370) and observation of $\eta_c \to \eta\eta\eta'$ in $J/\psi \to \gamma\eta\eta\eta'$
8. Search for the rare semi-leptonic decay $J/\psi \to D^-e^+\nu_e$ + c.c.
9. ***Search for new decay modes of the $\psi_2(3823)$ and the process $e^+e^- \to \pi^0\pi^0\psi_2(3823)$***
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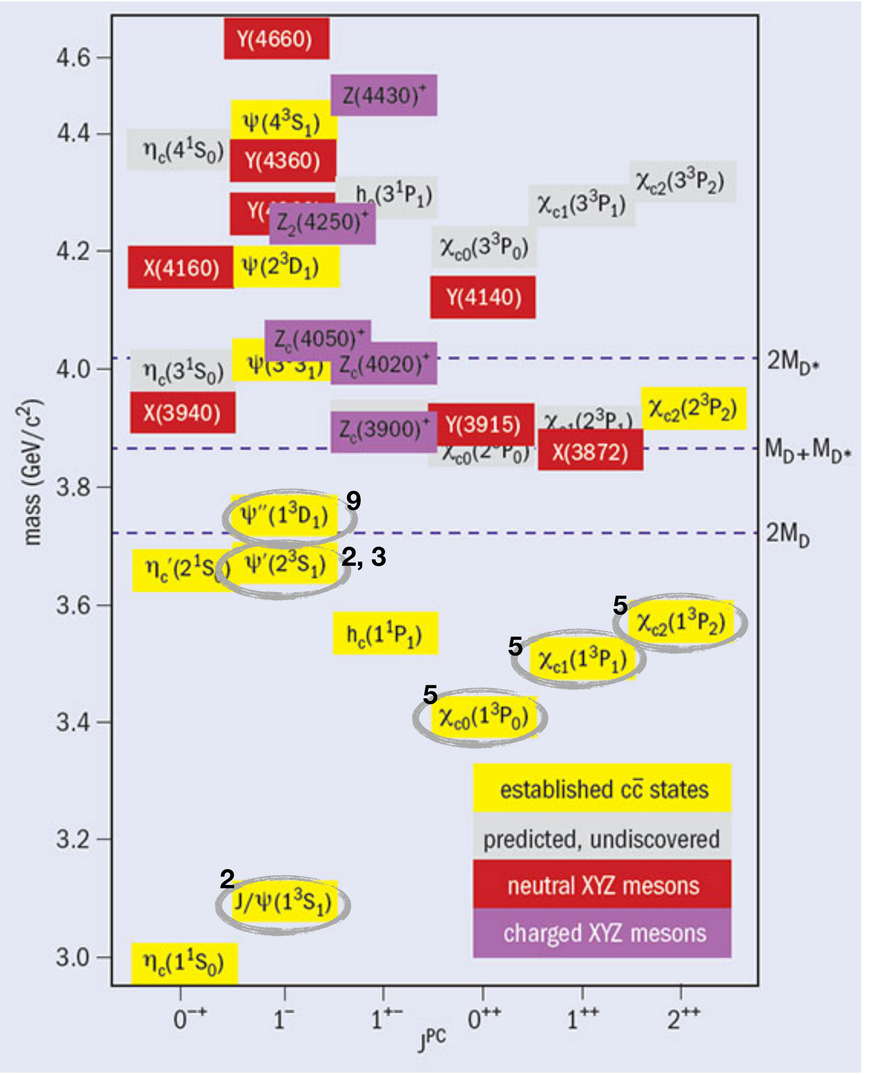

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→ **Recent study about XYZ particles at BESIII by J. Bloms**

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→ **Light meson spectroscopy at BESIII by Jinfei Wu**

8. Search for the rare semi-leptonic decay $J/\psi \to D^-e^+\nu_e$ + c.c.

→ **Results of J/ψ Weak Decay Searching at BESIII by Chuang-xin Lin**

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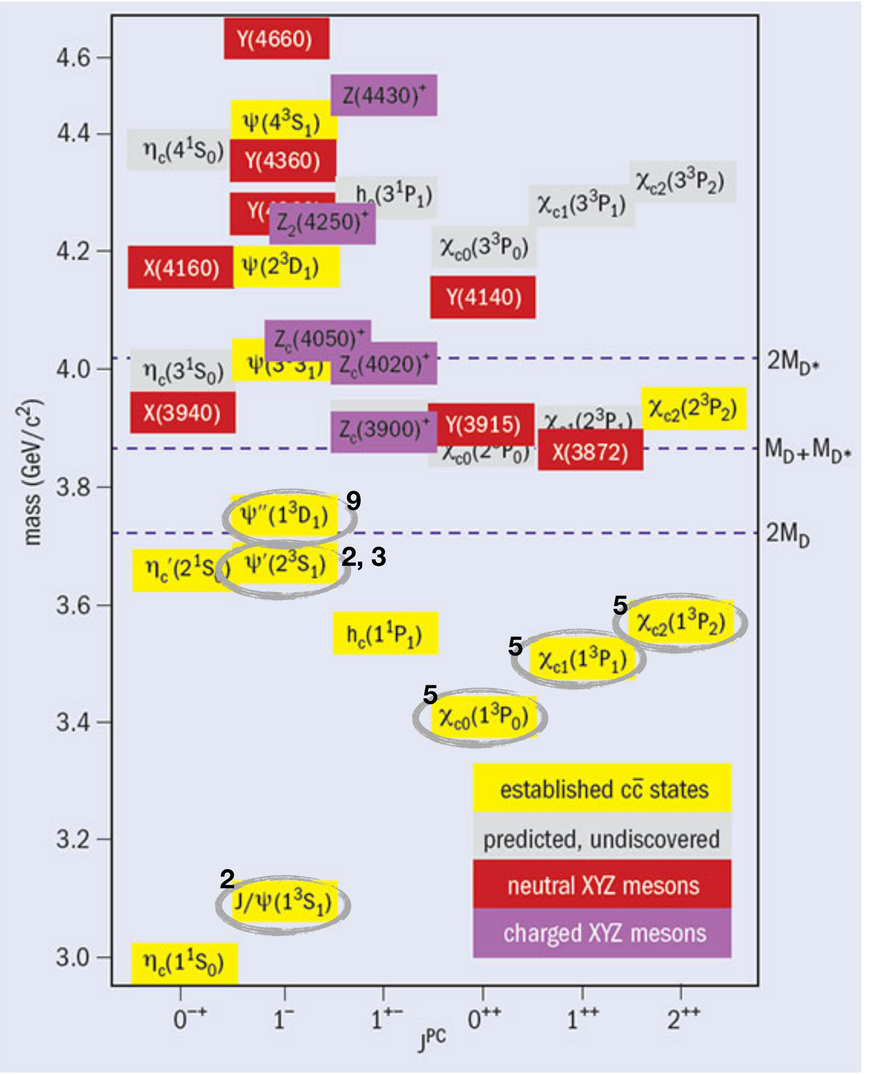

Measurement of Branching Fractions of J/ψ and ψ(3686) decays to Σ^+ and $\overline{\Sigma}^-$

arXiv:2107.02977
Submitted to JHEP

Data sets ('09 - '12):

J/ψ - 1.31×10^9

ψ(3686) - 0.45×10^9

Channel selection:

$\psi \rightarrow \Sigma^+\overline{\Sigma}^- \rightarrow (p\pi^0)(\overline{p}\pi^0)$

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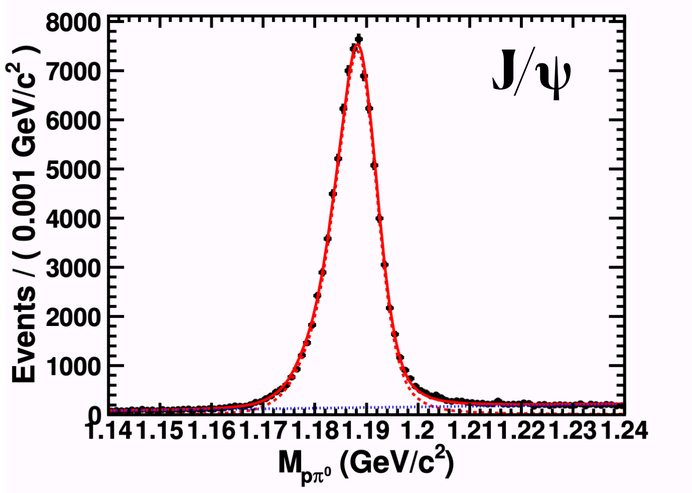
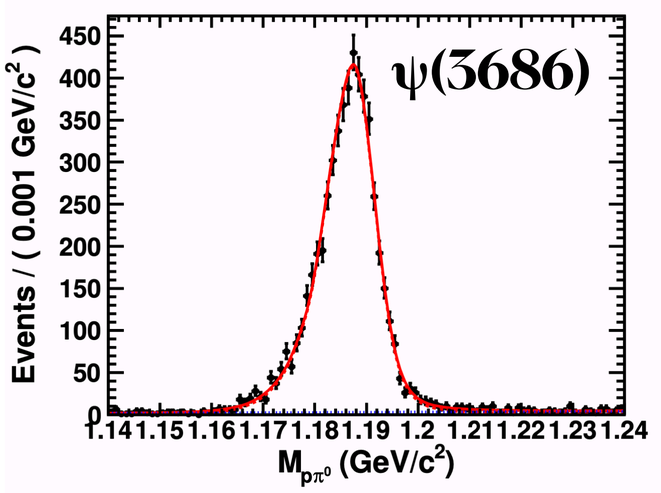
Channel	N_{sig}	Branching fraction (10^{-4})
$J/\psi \rightarrow \Sigma^+\overline{\Sigma}^-$	86976 ± 314	$10.61 \pm 0.04 \pm 0.38$
$\psi(3686) \rightarrow \Sigma^+\overline{\Sigma}^-$	5447 ± 76	$2.52 \pm 0.04 \pm 0.10$

$$\frac{\mathcal{B}_{\psi(3686)\rightarrow h}}{\mathcal{B}_{J/\psi\rightarrow h}} = (23.8 \pm 1.3)\ \%$$

Number of signal events are counted
by fitting the $M_{p\pi}$ distribution requiring $M_{\bar{p}\pi}$ to be within the signal region ($1.17 < SR < 1.20$ GeV/c^2)





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Violation of the "12% rule" in accordance with the previous measurement in the $\Sigma^0\overline{\Sigma}^0$ final states by BESIII [PRD 95, 052003 (2017)]

Measurements of the branching fractions of $\psi(3686) \to \bar{\Sigma}^0 \Lambda + c.c.$ and $\chi_{cJ(J=0,1,2)} \to \Lambda\bar{\Lambda}$

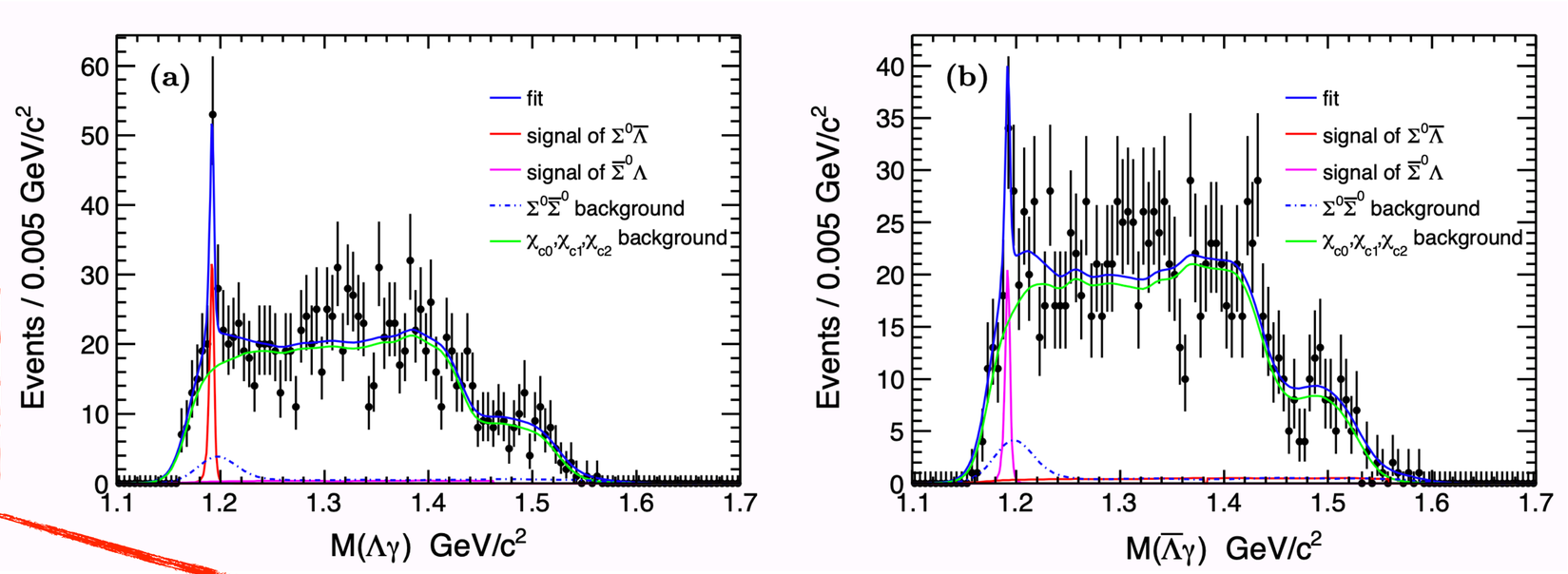
Data sets ('09 - '12):
$\psi(3686)$ - 0.45 $\times 10^9$

Phys. Rev. D **103**, 112004

Isospin symmetry breaking decay

Channel selection:
$\psi(2S) \to \bar{\Sigma}^0\Lambda \to (\gamma\bar{\Lambda})(p\pi^-)$

$\mathcal{BR}(\psi(3686) \to \bar{\Sigma}^0 \Lambda + c.c.)$
$(1.60 \pm 0.31^{stat} \pm 0.13^{syst} \pm 0.58) \times 10^{-6}$



Coming from the $\psi(3686)$-continuum interference, where the prior of the mixing angle is assumed uniform

Tension with CLEO-c result [1] of $(12.30 \pm 2.4) \times 10^{-6}$
Consistent within $1\sigma/2\sigma$ (depending on the $\psi(3686)$-continuum interference) wrt **theoretical prediction** [2]

[1] Phys. Rev. D **96**, 092004
[2] Int. J. Mod. Phys. A **30**, 1550148

Measurements of the branching fractions of $\psi(3686) \to \bar{\Sigma}^0 \Lambda + c.c.$ and $\chi_{cJ(J=0,1,2)} \to \Lambda\bar{\Lambda}$

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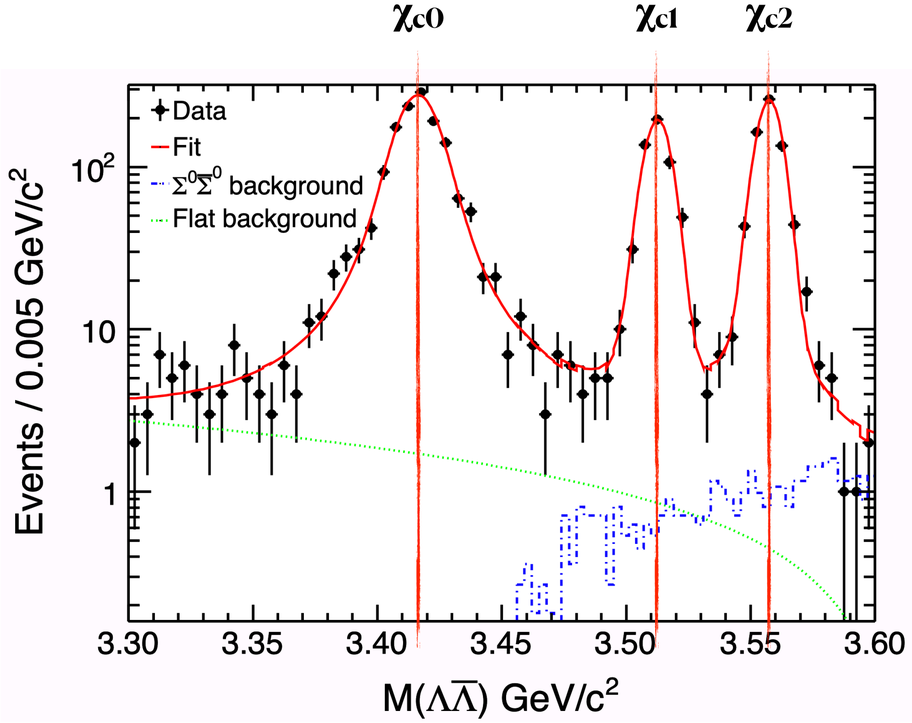
Phys. Rev. D **103**, 112004

Same channel selection:
$\Lambda\,(\bar{\Lambda}) \to p\pi^-\,(\bar{p}\pi^+)$

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

Due to the uncertainty on the
$\mathcal{BR}(\psi(3686) \to \gamma\chi_{cJ})$



Improvements on the $\mathcal{BR}$ knowledge for the J = 0,1 states
Results keep not being consistent with theoretical predictions (e.g., 1.19 ~ 1.51 $\times 10^{-4}$ for χ_{c0}) [3]

[3] J. Phys. G 38, 035007

Measurement of $e^+e^- \to \gamma\chi_{cJ}$ cross sections at center-of-mass energies between 3.77 and 4.60 GeV

arXiv:2107.03604
Submitted to PRD

Data set:

19.3 fb^{-1}

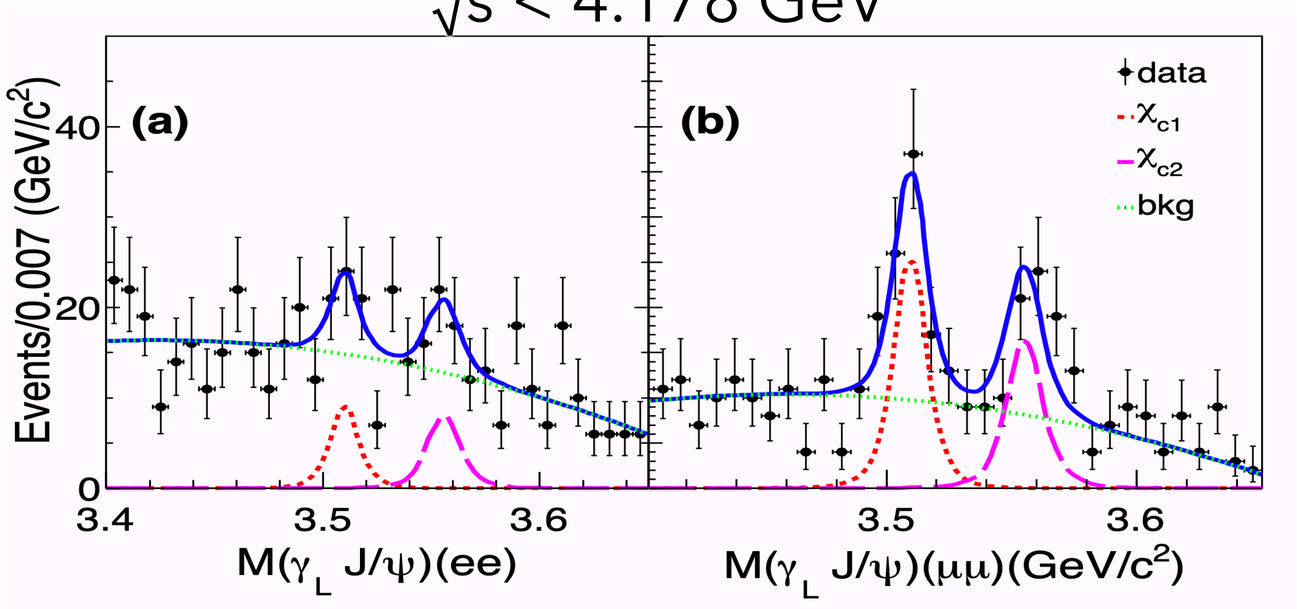
@3.773 < $\sqrt{s}$ < 4.600 GeV

Channel selection:

$e^+e^- \to \gamma\chi_{c(1,2)} \to \gamma\gamma J/\psi$

22 out 34 energy points have $\mathcal{L}_{int} > 400$ pb^{-1},
number of **signal events from** fitting
$M(\gamma_H J/\psi)$ (@ $\sqrt{s}$ < 4.009 GeV) **or $M(\gamma_L J/\psi)$** (@ $\sqrt{s}$ > 4.009 GeV)*

$\sqrt{s}$ < 4.178 GeV



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First observation of the

$e^+e^- \to \gamma\chi_{c(1,2)}$ process between 4-5 GeV

$e^+e^- \to \gamma\chi_{c1}$ @7.6σ

$e^+e^- \to \gamma\chi_{c2}$ @6.0σ

22 out 34 energy points have $\mathcal{L}_{int}$ > 400 pb^{-1},
number of **signal events from** fitting
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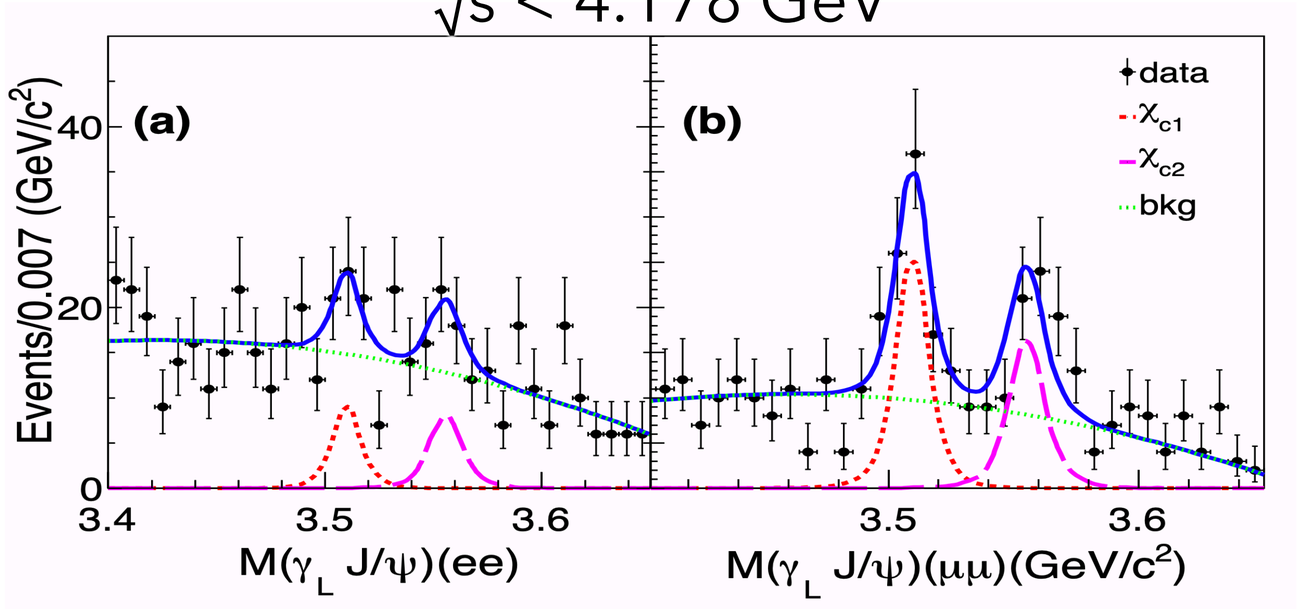
$\sqrt{s}$ < 4.178 GeV



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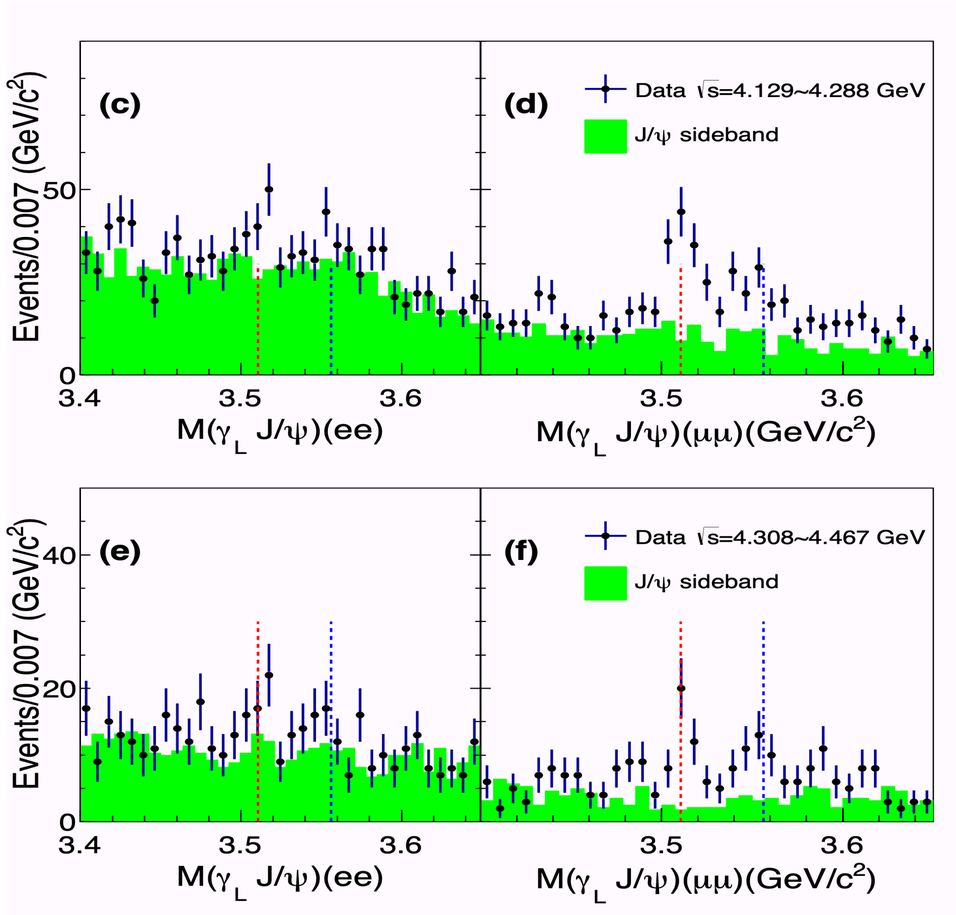
For energy points with $\mathcal{L}_{int}$ < 200 pb^{-1},
number of **signal events by** counting the **events in the signal** region (SR) **subtracted by** the **events in** the **sideband** regions (SBR)

	SR [GeV]	SBR [GeV]
χ_{c1}	3.49 < $M(\gamma_L J/\psi)$ < 3.53	3.42 < $M(\gamma_L J/\psi)$ < 3.46
χ_{c2}	3.54 < $M(\gamma_L J/\psi)$ < 3.58	3.60 < $M(\gamma_L J/\psi)$ < 3.64



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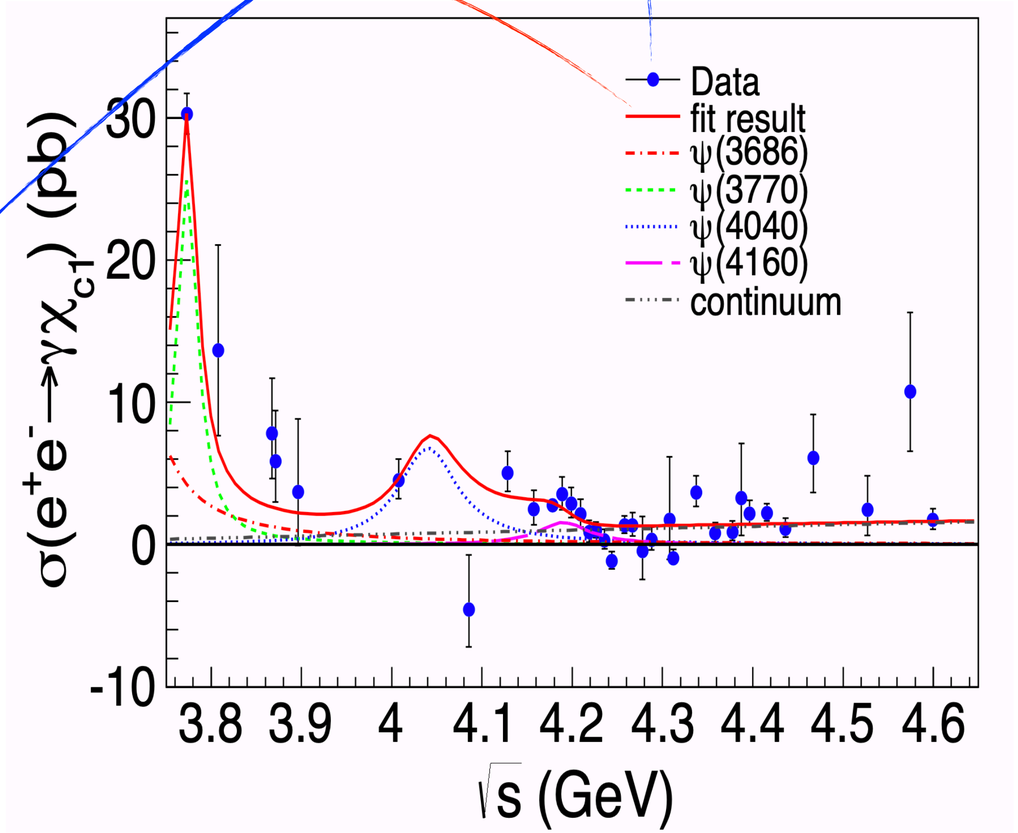
$$\sigma_{e^+e^-\to\gamma\chi_{c1}}(\sqrt{s}) = |A_{cont}|^2 + |BW_{\psi(3686)}(\sqrt{s})|^2 + |BW_{\psi(3770)}(\sqrt{s})|^2 + |BW_{\psi(4040)}(\sqrt{s}) + BW_{\psi(4160)}(\sqrt{s})e^{i\phi_1}|^2$$

$$\sigma(\sqrt{s}) = \frac{N^{\text{signal}}}{\mathcal{L}_{\text{int}}(1+\delta)\epsilon\mathcal{B}}$$



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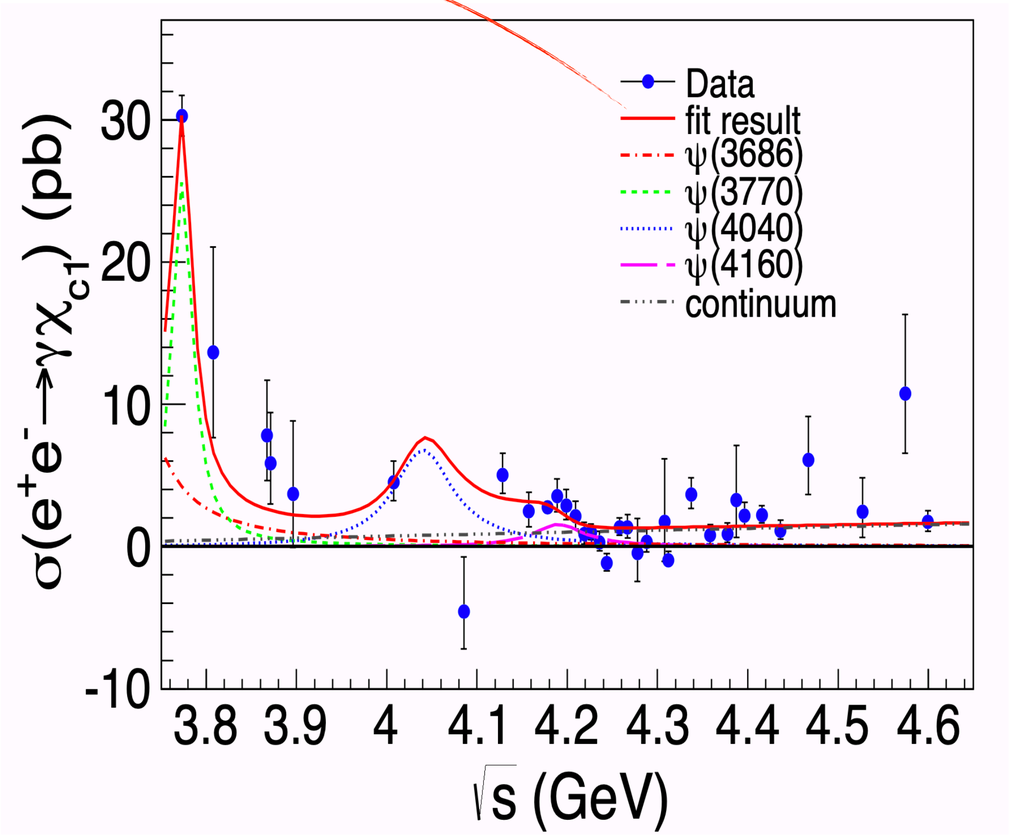
Interference between continuum and other components was found to be small



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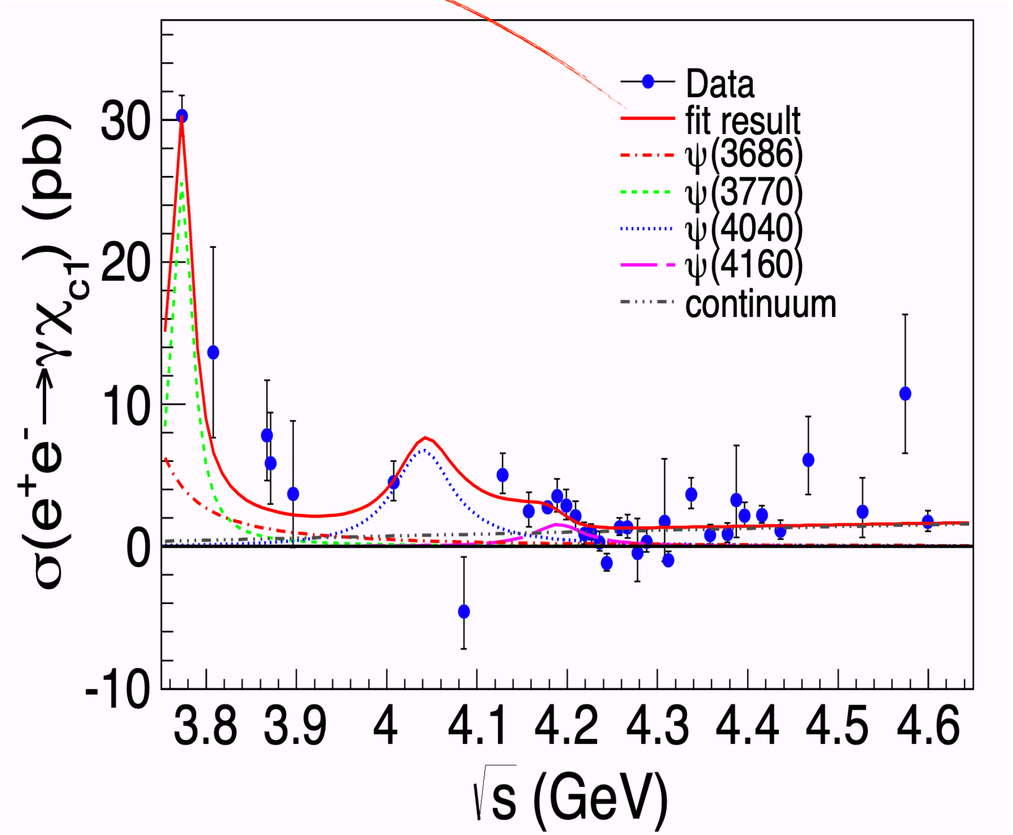
Incoherent sum of ψ(2S) and ψ(3770) because their contribution is small



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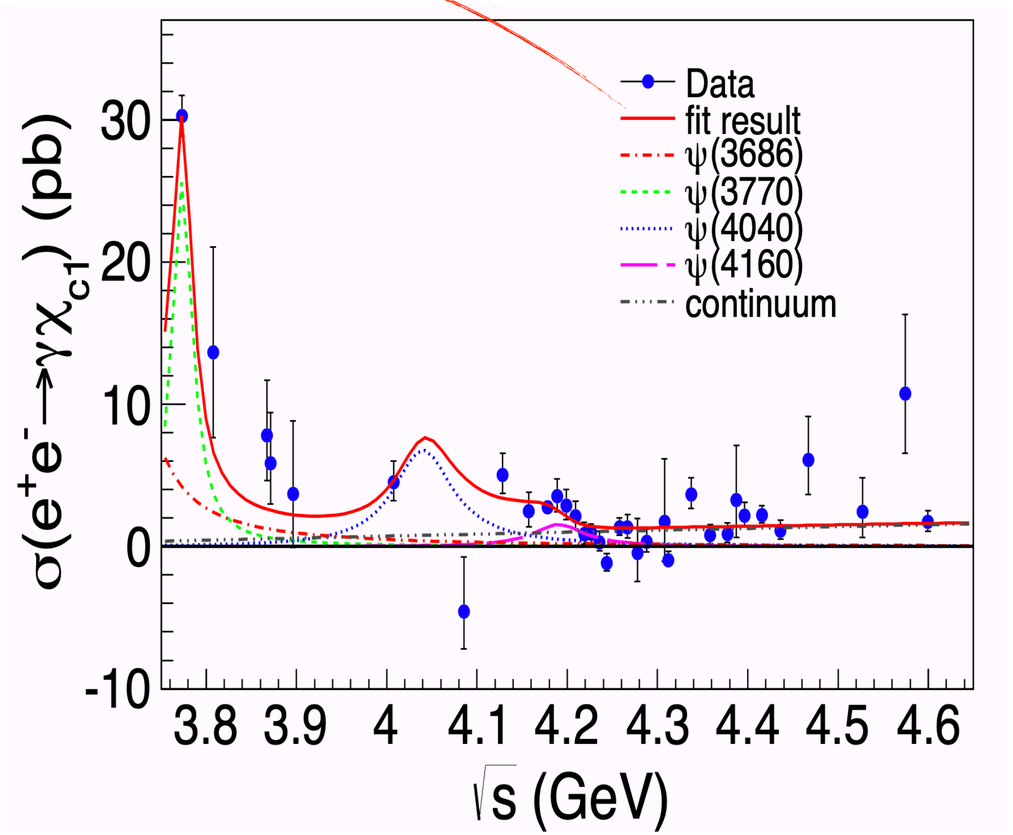
$$\sigma_{e^+e^-\to\gamma\chi_{c1}}(\sqrt{s}) = |A_{cont}|^2 + |BW_{\psi(3686)}(\sqrt{s})|^2 + |BW_{\psi(3770)}(\sqrt{s})|^2 + |BW_{\psi(4040)}(\sqrt{s}) + BW_{\psi(4160)}(\sqrt{s})e^{i\phi_1}|^2$$

Significances for ψ(4040) and ψ(4160) are estimated to be 3.7σ and 3.3σ



NB Negative is due to the subtraction in the number of signal events estimation

Measurement of $e^+e^- \to \gamma\chi_{cJ}$ cross sections at center-of-mass energies between 3.77 and 4.60 GeV

Data set:

19.3 fb^{-1}

@3.773 < $\sqrt{s}$ < 4.600 GeV

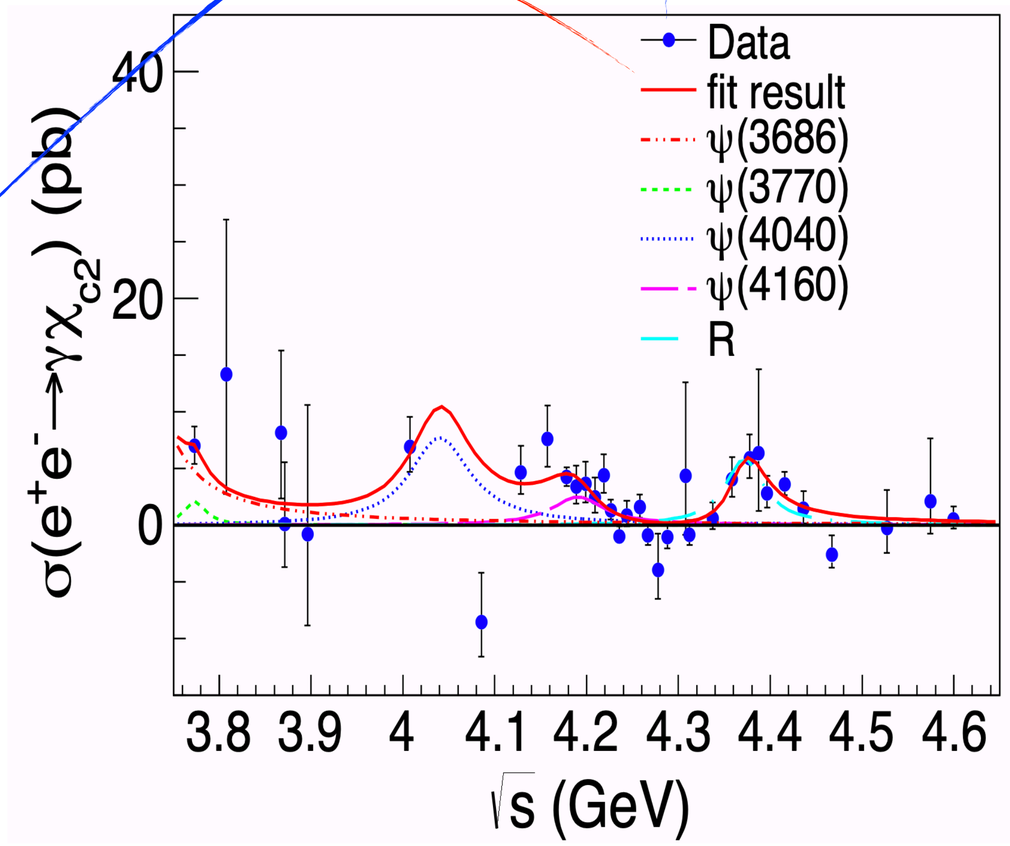
Channel selection:

$e^+e^- \to \gamma\chi_{c2} \to \gamma\gamma J/\psi$

$$\sigma_{e^+e^-\to\gamma\chi_{c2}}(\sqrt{s}) = |BW_{\psi(3686)}(\sqrt{s})|^2 + |BW_{\psi(3770)}(\sqrt{s})|^2 + |BW_{\psi(4040)}(\sqrt{s}) + BW_{\psi(4160)}(\sqrt{s})e^{i\phi_1} + BW_{\mathcal{R}}(\sqrt{s})e^{i\phi_2}|^2$$

$$\sigma(\sqrt{s}) = \frac{N^{\text{signal}}}{\mathcal{L}_{\text{int}}(1+\delta)\epsilon\mathcal{B}}$$

arXiv:2107.03604
Submitted to PRD



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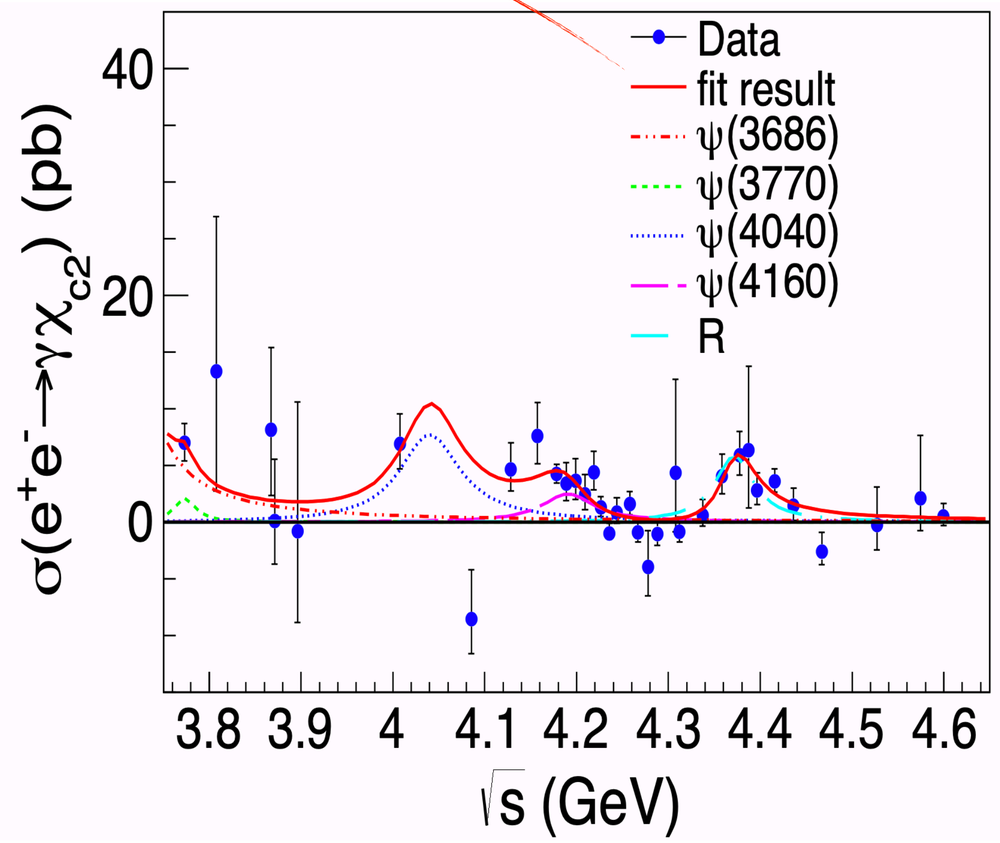
Significances for ψ(4040) and ψ(4160) are estimated to be 2.0σ and 4.6σ

Resonance @4.39 has a significance of 5.8σ



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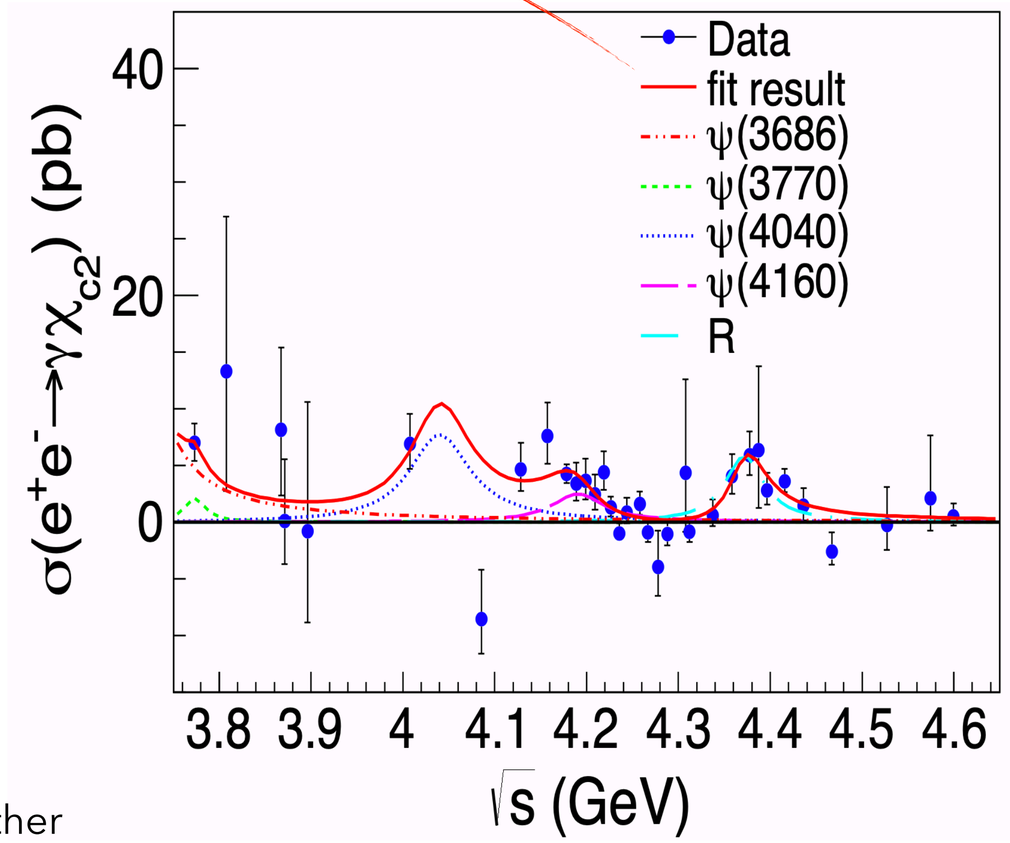


Significances for ψ(4040) and ψ(4160) are estimated to be 2.0σ and 4.6σ

Resonance @4.39 has a significance of 5.8σ

M = 4371.7 ± 7.5 ± 1.8 MeV/c^2 → Consistent with either Y (4360) or Y (4390) resonance

Γ_{tot} = 51.1 ± 17.6 ± 1.9 MeV

NB Negative is due to the subtraction in the number of signal events estimation

Measurement of $e^+e^- \to \gamma\chi_{cJ}$ cross sections at center-of-mass energies between 3.77 and 4.60 GeV

arXiv:2107.03604
Submitted to PRD

Data set:

16 fb^{-1}

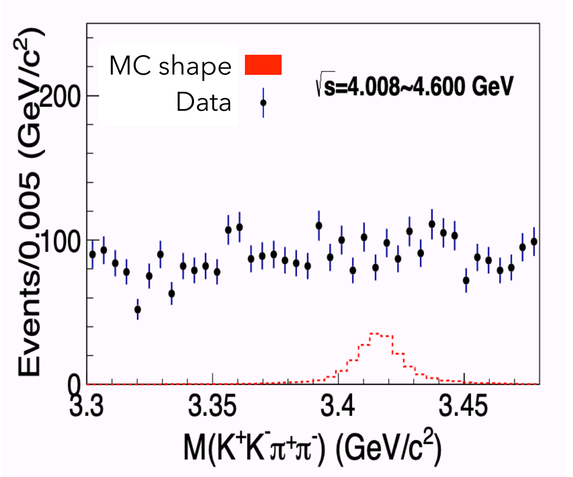
@ $4.008 < \sqrt{s} < 4.600$ GeV

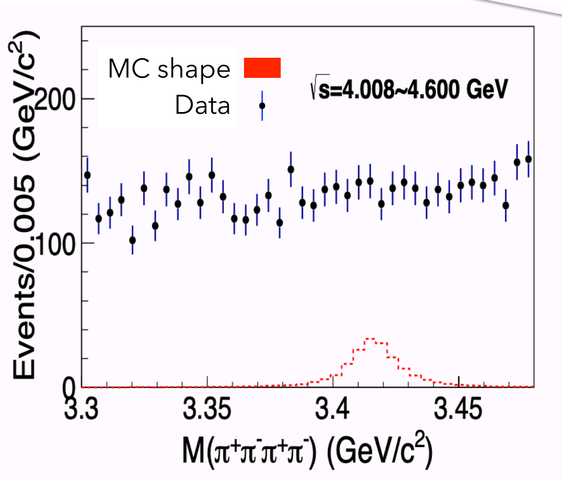
Only the energy points with $\mathcal{L}_{int} > 400$ pb^{-1}

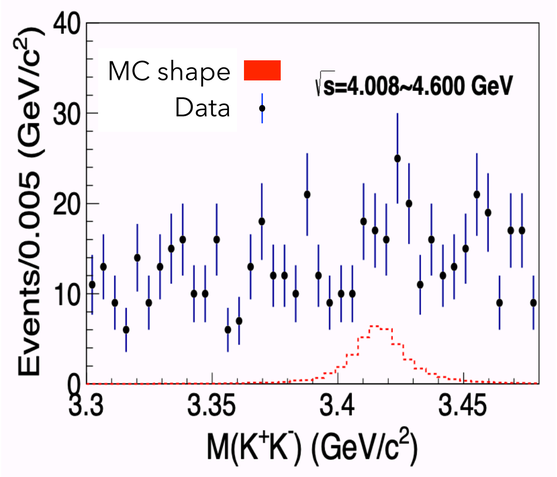
Channel selection:

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

$\gamma[(K^+K^-\pi^+\pi^-)/(K^+K^-)/2(\pi^+\pi^-)]$







Number of signal events by fitting simultaneously 3 invariant mass distributions

Significance was estimated to be $< 2\sigma$ $\forall$ energy point

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Channel selection:

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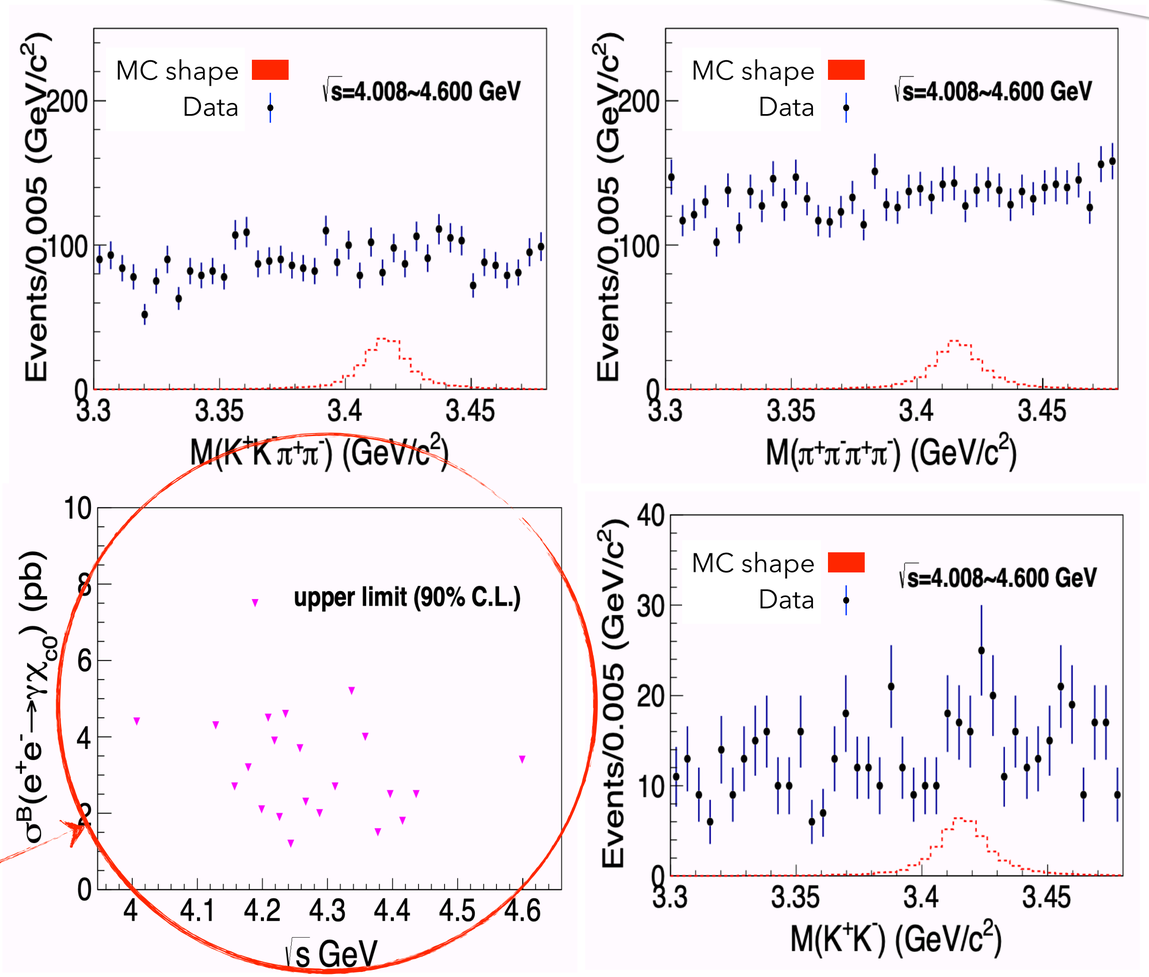
Significance was estimated to be $< 2\sigma$ $\forall$ energy point

Hence, UL were estimated



Search for new decay modes of the $\psi_2(3823)$ and the process $e^+e^- \to \pi^0\pi^0\psi_2(3823)$

Data set:

19 fb^{-1} @4.1 < $\sqrt{s}$ < 4.7 GeV

Above D$\bar{\text{D}}$ threshold

Phys. Rev. D **103**, L091102

Reaction:

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

7 decay modes studied

- $\gamma\chi_{c1}$, $\gamma\chi_{c2}$ } $\chi_{c(1,2)} \to \gamma J/\psi$
- $\pi^+\pi^- J/\psi$
- $\pi^0\pi^0 J/\psi$
- $\eta J/\psi$
- $\pi^0 J/\psi$
- $\gamma\chi_{c0} \to \gamma\chi_{c0} \to \gamma[(K^+K^-)/(\pi^+\pi^-)]$

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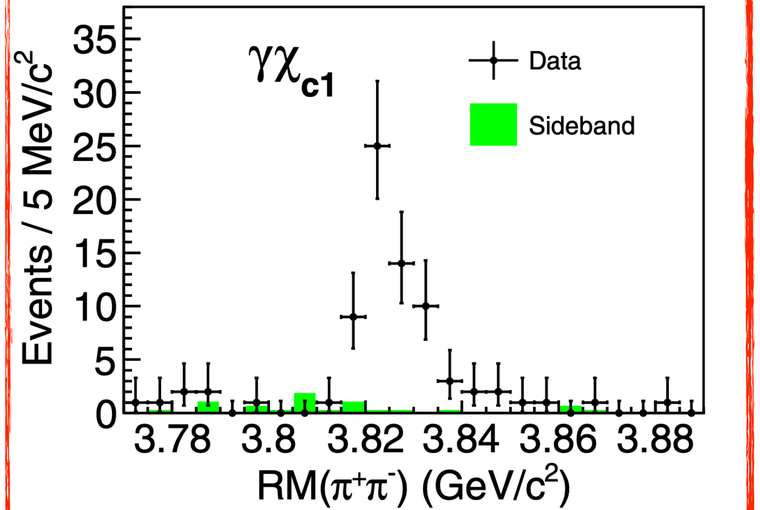
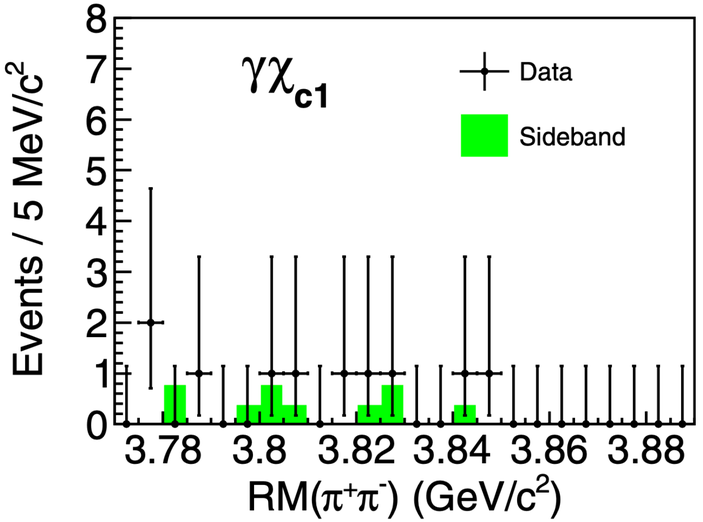
4.3 < $\sqrt{s}$ < 4.7 GeV



4.1 < $\sqrt{s}$ < 4.3 GeV



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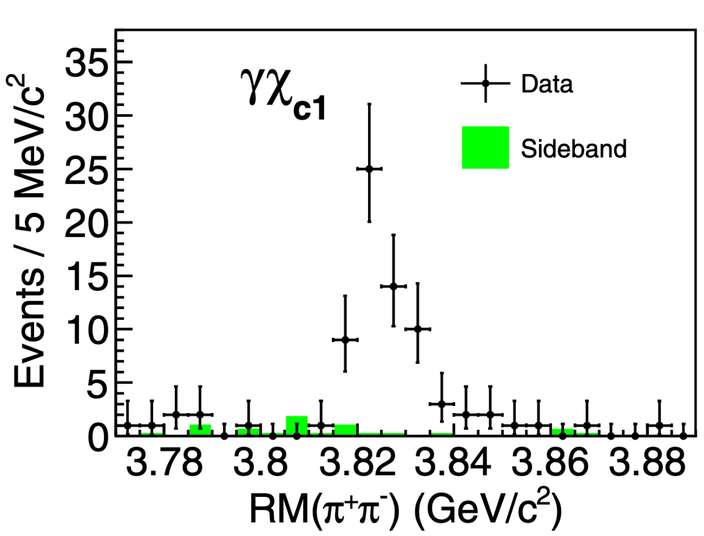
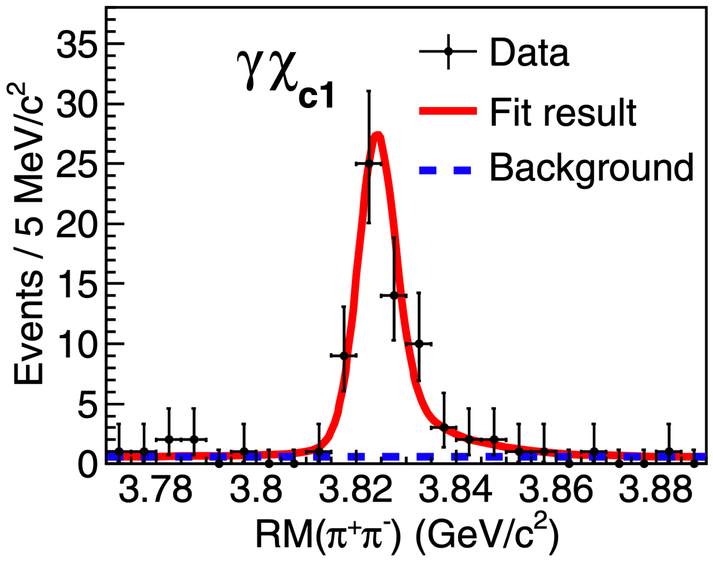
- $\gamma\chi_{c0} \to \gamma\chi_{c0} \to \gamma[(K^+K^-)/(\pi^+\pi^-)]$

Observed

$\psi_2(3823) \to \gamma\chi_{c1}$ @11.8σ

4.3 < $\sqrt{s}$ < 4.7 GeV





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Data set:

9 fb^{-1} @4.3 < $\sqrt{s}$ < 4.7 GeV

Above D$\bar{\text{D}}$ threshold

Phys. Rev. D **103**, L091102

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- $\gamma\chi_{c1}$, $\gamma\chi_{c2}$ } $\chi_{c(1,2)} \to \gamma J/\psi$
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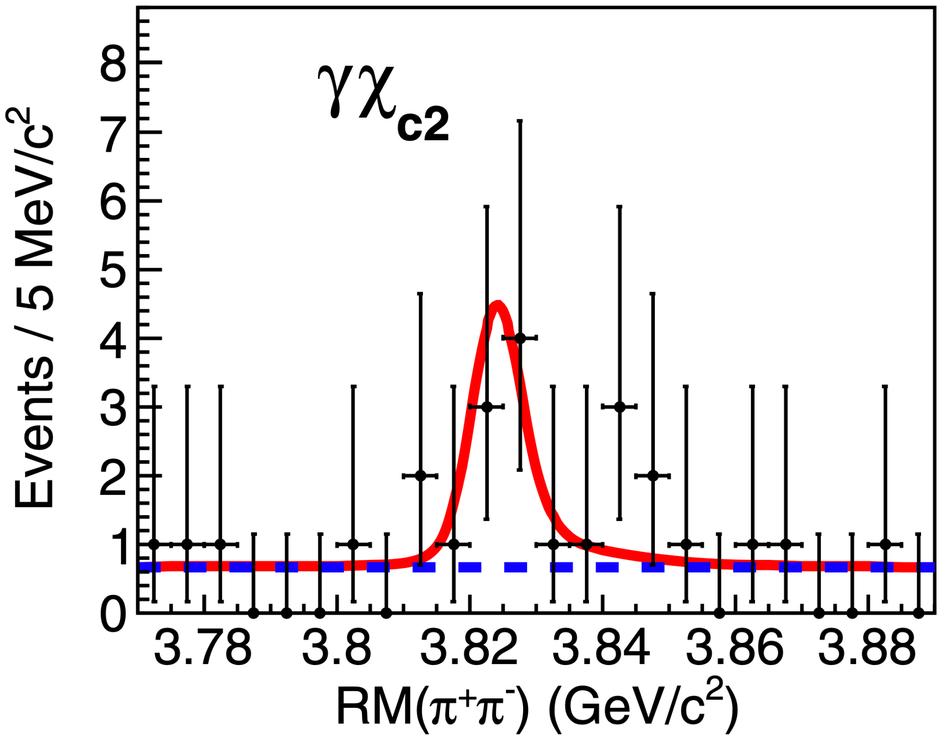
- $\gamma\chi_{c0} \to \gamma\chi_{c0} \to \gamma[(K^+K^-)/(\pi^+\pi^-)]$

First time evidence for $\psi_2(3823) \to \gamma\chi_{c2}$ @3.2σ



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Above D$\bar{\text{D}}$ threshold

Reaction:

$e^+e^- \to \pi^+\pi^-\psi_2(3823)$

Phys. Rev. D **103**, L091102

7 decay modes studied	$N^{\psi_2(3823)}$	$\frac{\mathcal{B}(\psi_2(3823)\to\cdots)}{\mathcal{B}(\psi_2(3823)\to\gamma\chi_{c1})}$
$\gamma\chi_{c1}$	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 within 1σ wrt **theoretical prediction** (0.317 - 0.324) [4] of

$$\frac{\mathcal{B}(\psi(1^3D_2)\to\gamma\chi_{c2})}{\mathcal{B}(\psi(1^3D_2)\to\gamma\chi_{c1})}$$

[4] Phys. Rev. D **95**, 034026

Search for new decay modes of the $\psi_2(3823)$ and the process $e^+e^- \to \pi^0\pi^0\psi_2(3823)$

Above $D\bar{D}$ threshold

Phys. Rev. D **103**, L091102

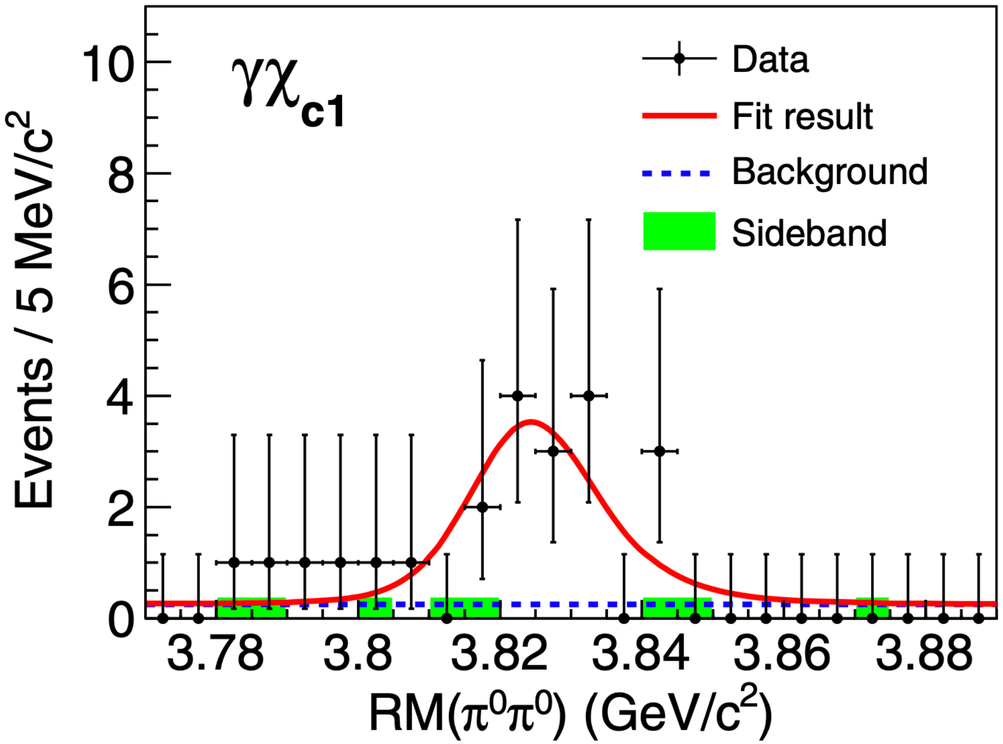
Data set:

9 fb^{-1} @4.3 < $\sqrt{s}$ < 4.7 GeV

Reaction:

$e^+e^- \to \pi^0\pi^0\psi_2(3823) \to \gamma\chi_{c1}$

With $15.9^{+5.1}_{-4.4}$ number of signal events…



Search for new decay modes of the $\psi_2(3823)$ and the process $e^+e^- \to \pi^0\pi^0\psi_2(3823)$

Above $D\bar{D}$ threshold

Phys. Rev. D **103**, L091102

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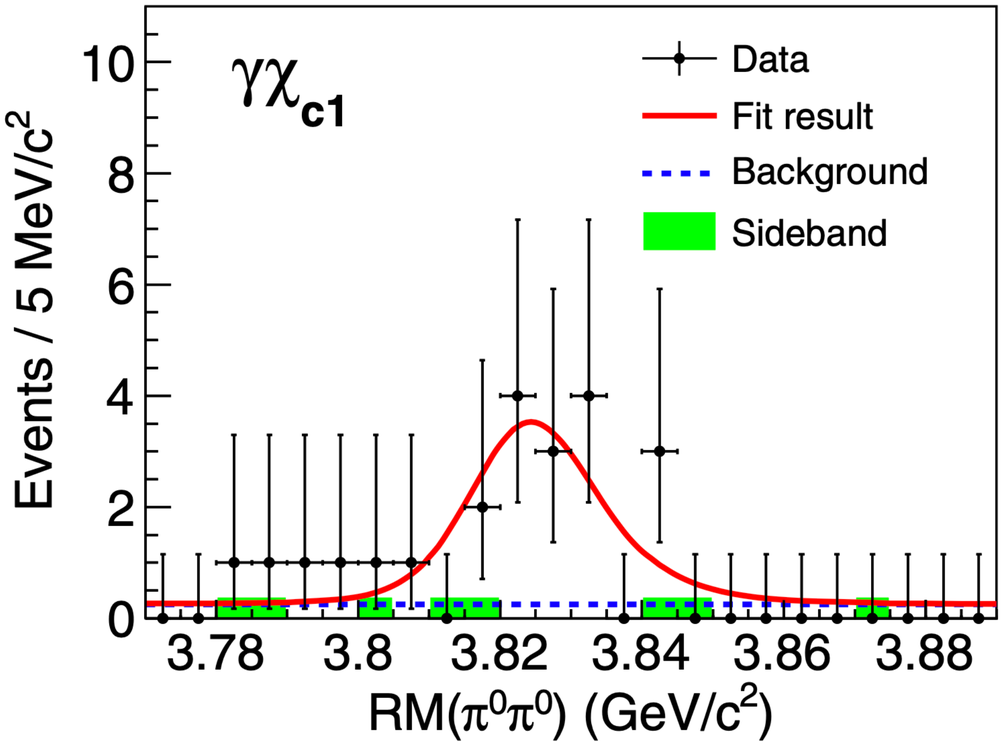
$e^+e^- \to \pi^0\pi^0\psi_2(3823) \to \gamma\chi_{c1}$

With $15.9^{+5.1}_{-4.4}$ number of signal events, evidence for $e^+e^- \to \pi^0\pi^0\psi_2(3823)$ @4.3σ



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Phys. Rev. D **103**, L091102

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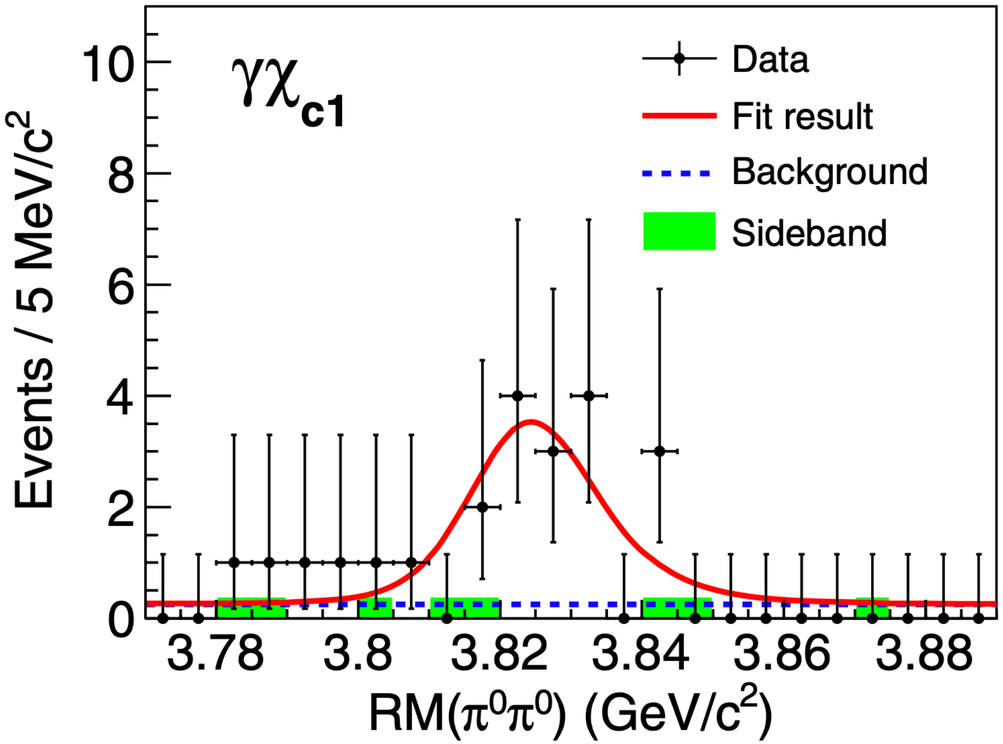
With $15.9^{+5.1}_{-4.4}$ number of signal events, evidence for $e^+e^- \to \pi^0\pi^0\psi_2(3823)$ @4.3σ

$$\frac{\sigma(e^+e^- \to \pi^0\pi^0\psi_2(3823))}{\sigma(e^+e^- \to \pi^+\pi^-\psi_2(3823))} = 0.63^{+0.22}_{-0.20} \pm 0.05$$

Isospin conservation is confirmed within the uncertainty



Summary

The **largest datasets** of **$c\bar{c}$ vector** states collected by BESIII provide the power to **investigate** not only **rare vector decays**, but also to **study** the h_c, **χ_{cJ}** and $\eta_c(2S)$ states, decays of which are mostly unknown

As shown throughout this talk, also **datasets above** the **$D\bar{D}$ threshold** can shed new light on charmonium decays and hint at possible **connections** between **XYZ states and** conventional **charmonia**

4 analyses are **discussed** in this talk:

Measurement of Branching Fractions of J/ψ and ψ(3686) decays to Σ^+ and Σ^-

arXiv:2107.02977 Submitted to JHEP

Measurements of the branching fractions of $\psi(3686) \to \Sigma^0 \Lambda$ + c.c. and $\chi_{cJ(J = 0, 1, 2)} \to \Lambda\Lambda$

Phys. Rev. D **103**, 112004

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More interesting **results** are expected **with** the **full** J/ψ and ψ(3686) **data samples**

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Thank you for the attention!

Back-up Slides

Search for New Hadronic Decays of h_c and Observation of $h_c \to K^+K^-\pi^+\pi^-\pi^0$

Data sets ('09 - '12):
ψ(3686) - 0.45 ×10⁹

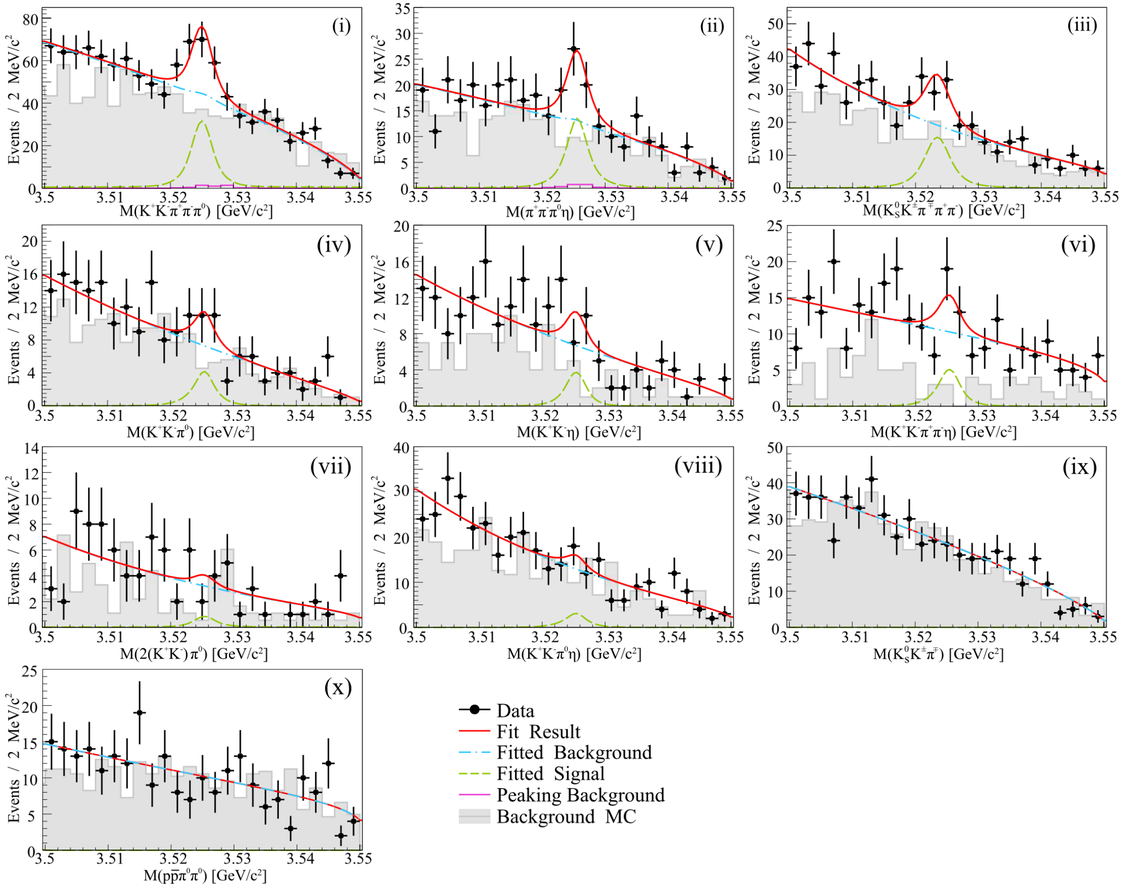
Phys. Rev. D **102**, 112007

First observation of the **h_c decaying to** mesons carrying **strangeness**

Predictions of the decay process
$h_c \to$ *light hadrons* 14 – 48% [I]

Best-measured decay mode is the radiative transition (51%) $h_c \to \gamma\eta_c$

Sum of all other known $\mathcal{BR} < 3\%$



[I] Phys. Rev. D **37**, 1210

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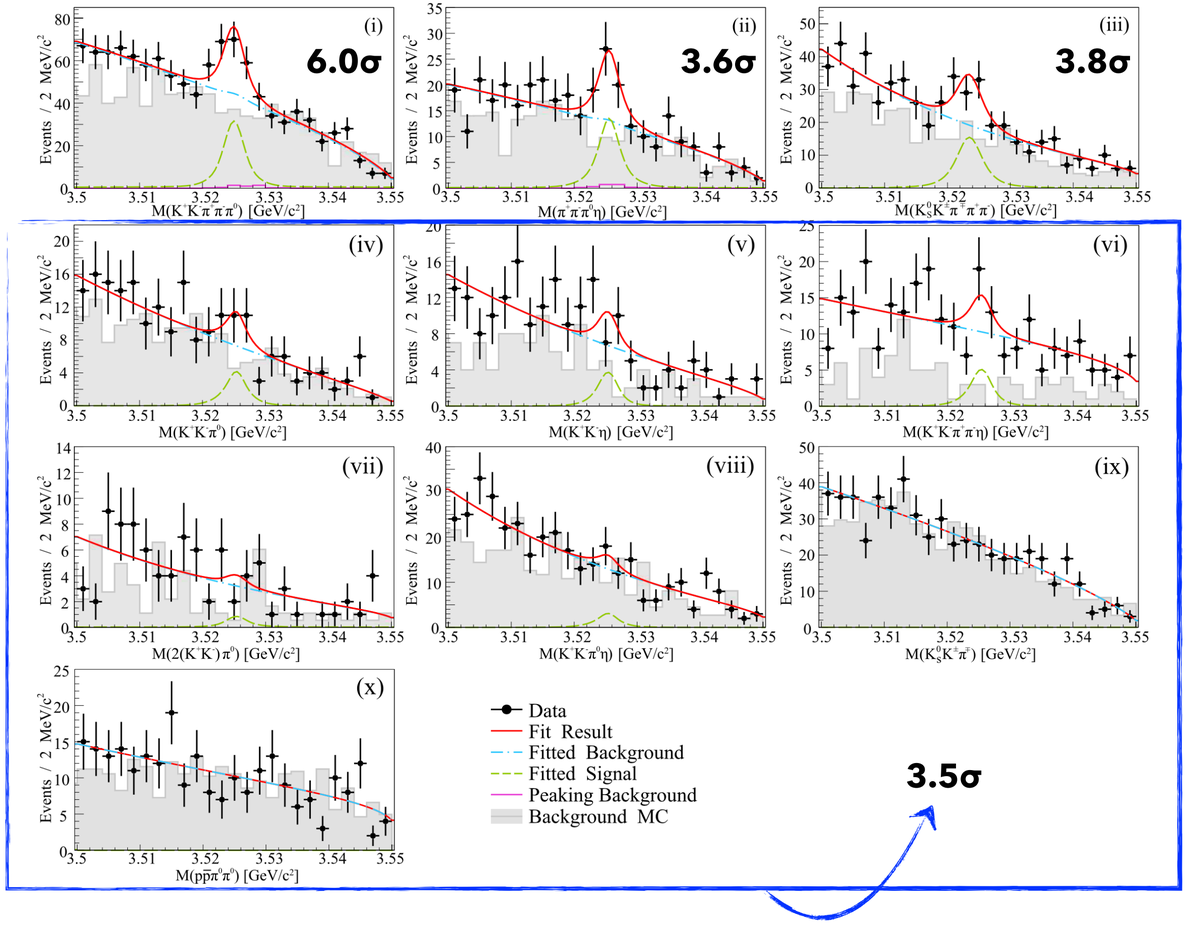
Phys. Rev. D **102**, 112007

First observation of the **h_c decaying to** mesons carrying **strangeness**

10 decay modes studied	
(i)	$K^+K^-\pi^+\pi^-\pi^0$
(ii)	$\pi^+\pi^-\pi^0\eta$
(iii)	$K^0_S K^\pm\pi^\mp\pi^+\pi^-$
(iv)	$K^+K^-\pi^0$
(v)	$K^+K^-\eta$
(vi)	$K^+K^-\pi^+\pi^-\eta$
(vii)	$2(K^+K^-)\pi^0$
(viii)	$K^+K^-\pi^0\eta$
(ix)	$K^0_S K^\pm\pi^\mp$
(x)	$p\bar{p}\pi^0\pi^0$



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Phys. Rev. D **102**, 112007

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

	10 decay modes studied	N_{h_c}	$\mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to X)$	$\mathcal{B}(h_c \to X)$
6.0σ (i)	$K^+K^-\pi^+\pi^-\pi^0$	80 ± 15	$(2.8 \pm 0.5 \pm 0.3) \times 10^{-6}$	$(3.3 \pm 0.6 \pm 0.6) \times 10^{-3}$
3.6σ (ii)	$\pi^+\pi^-\pi^0\eta$	35 ± 9	$(6.2 \pm 1.6 \pm 0.7) \times 10^{-6}$	$(7.2 \pm 1.8 \pm 1.3) \times 10^{-3}$
		< 50.0	$< 1.5 \times 10^{-5}$	$< 1.8 \times 10^{-2}$
3.8σ (iii)	$K^0_S K^\pm \pi^\mp \pi^+ \pi^-$	41 ± 13	$(2.4 \pm 0.7 \pm 0.3) \times 10^{-6}$	$(2.8 \pm 0.9 \pm 0.5) \times 10^{-3}$
		< 65.3	$< 3.9 \times 10^{-6}$	$< 4.7 \times 10^{-3}$
(iv)	$K^+K^-\pi^0$	< 20.1	$< 4.8 \times 10^{-7}$	$< 5.8 \times 10^{-4}$
(v)	$K^+K^-\eta$	< 18.5	$< 7.5 \times 10^{-7}$	$< 9.1 \times 10^{-4}$
(vi)	$K^+K^-\pi^+\pi^-\eta$	< 24.1	$< 2.0 \times 10^{-6}$	$< 2.5 \times 10^{-3}$
(vii)	$2(K^+K^-)\pi^0$	< 11.7	$< 2.1 \times 10^{-7}$	$< 2.5 \times 10^{-4}$
(viii)	$K^+K^-\pi^0\eta$	< 20.2	$< 1.8 \times 10^{-6}$	$< 2.2 \times 10^{-3}$
(ix)	$K^0_S K^\pm \pi^\mp$	< 17.4	$< 4.8 \times 10^{-7}$	$< 5.7 \times 10^{-4}$
(x)	$p\bar{p}\pi^0\pi^0$	< 11.8	$< 4.4 \times 10^{-7}$	$< 5.2 \times 10^{-4}$

Summing up the $\mathcal{BR}$ of these decays, one gets ~1.3% to all h_c decays

More studied are needed to establish if hadronic decays of the h_c are same order as the radiative ones [II]

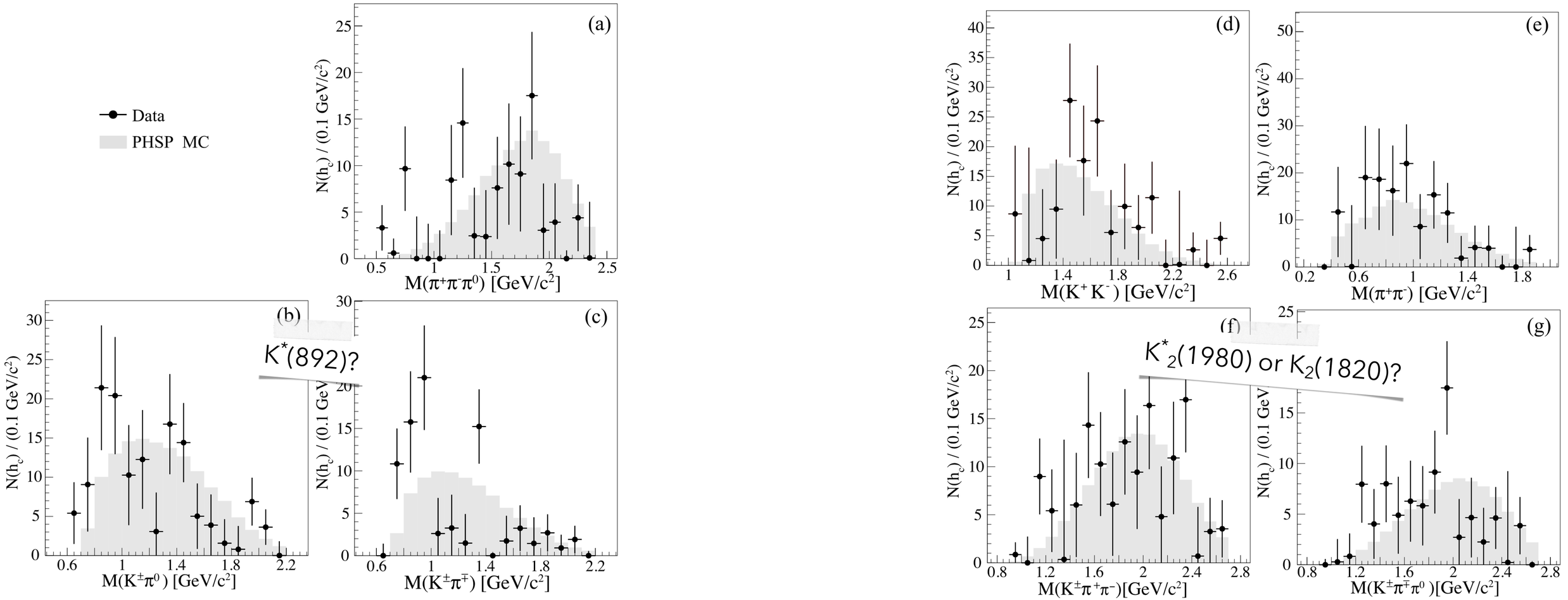
[II] Phys. Rev. D **46**, R1914

Search for New Hadronic Decays of h_c and Observation of $h_c \to K^+K^-\pi^+\pi^-\pi^0$

Data sets ('09 - '12):
ψ(3686) - 0.45 ×10⁹

Phys. Rev. D **102**, 112007

For $h_c \to K^+K^-\pi^+\pi^-\pi^0$ in the h_c decay, a search for intermediate resonances was performed



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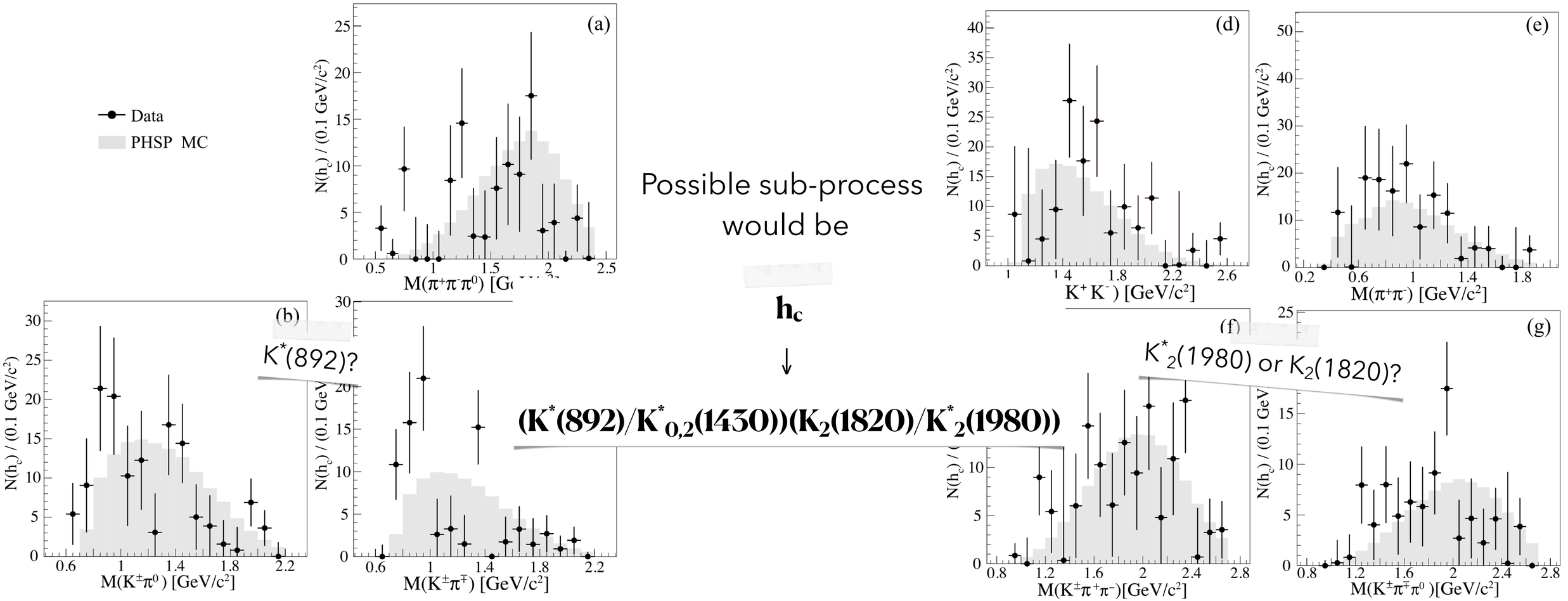


Possible sub-process would be

h_c

↓

$(K^*(892)/K^*_{0,2}(1430))(K_2(1820)/K^*_2(1980))$

$K^*(892)$?

$K^*_2(1980)$ or $K_2(1820)$?

Search for New Hadronic Decays of h_c and Observation of $h_c \to K^+K^-\pi^+\pi^-\pi^0$

UL determination procedure

Phys. Rev. D **102**, 112007

Bayesian approach

1) Signal yield is scanned using the fit function

Sig: Breit-Wigner (mass and width of h_c fixed to PDG values) convoluted with detector resolution

BKG: ARGUS function with kinematical threshold of 3551 MeV/c^2

2) Systematic uncertainties are introduced by smearing the likelihood function with a Gaussian one (width of which is set to the systematic uncertainty of the corresponding decay mode)

3)

$$0.9 = \frac{\int_0^{N_{h_c}^{up}} dN\mathcal{L}(N)}{\int_0^{\infty} dN\mathcal{L}(N)}$$

Number of h_c events to define the UL

90% C.L.

Search for the rare semi-leptonic decay $J/\psi \to D^- e^+ \nu_e + c.c.$

Charmonium decays can also probe the SM

arXiv:2104.06628
Submitted to JHEP

Data set:

J/ψ - 10.1×10^9

Channel selection:

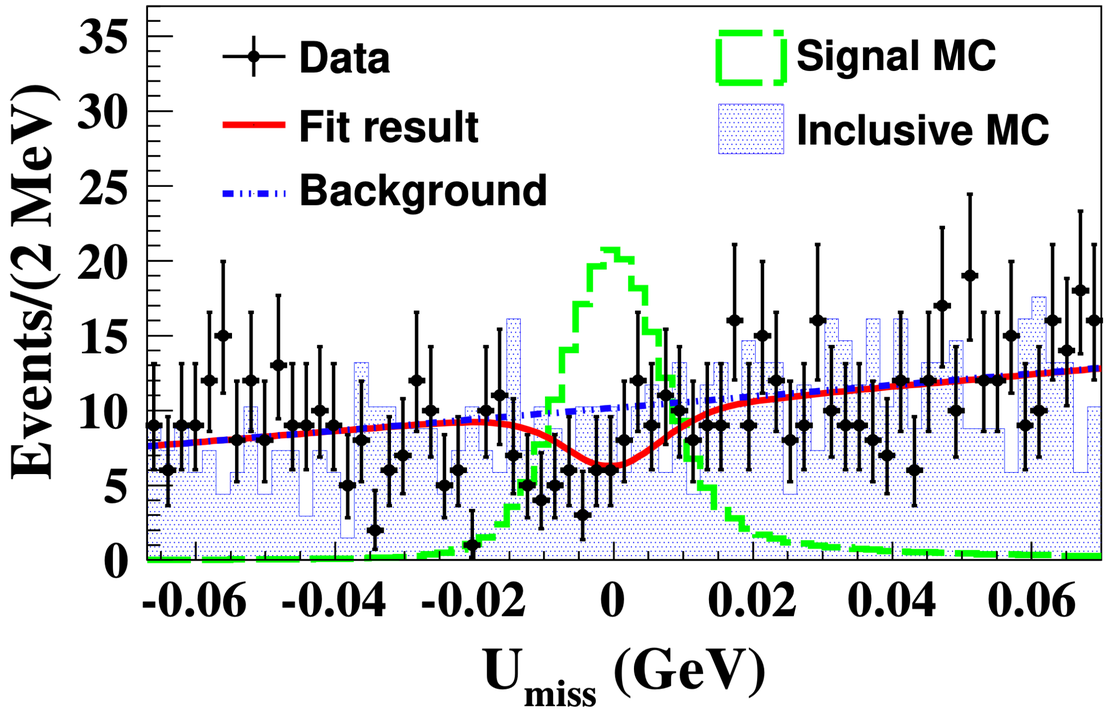
$J/\psi \to D^- e^+ \nu_e \to (K^+ \pi^- \pi^-) e^+ \nu_e$

Missing quantity $U_{Miss} = E_{Miss} - p_{miss}$
($\#_{Miss} = \#_{J/\psi} - \#_D - \#_e$)
used to count events

No signal (negative number of events is interpreted as such) is found, hence an upper limit is set

The $\mathcal{BR}(J/\psi \to D^- e^+ \nu_e) < 7.1 \times 10^{-8}$ @90% C.L. (systematics are included) improves the superseded results by ~170 times [III]

The $\mathcal{BR}(J/\psi \to D^- e^+ \nu_e)$ is also compatible with SM predictions of $\sim 10^{-11}$ [IV]



[III] Phys. Lett. B 639, 418

[IV] Phys. Rev. D 92, 074030

Search for the rare semi-leptonic decay $J/\psi \to D^- e^+ \nu_e + c.c.$

UL determination procedure

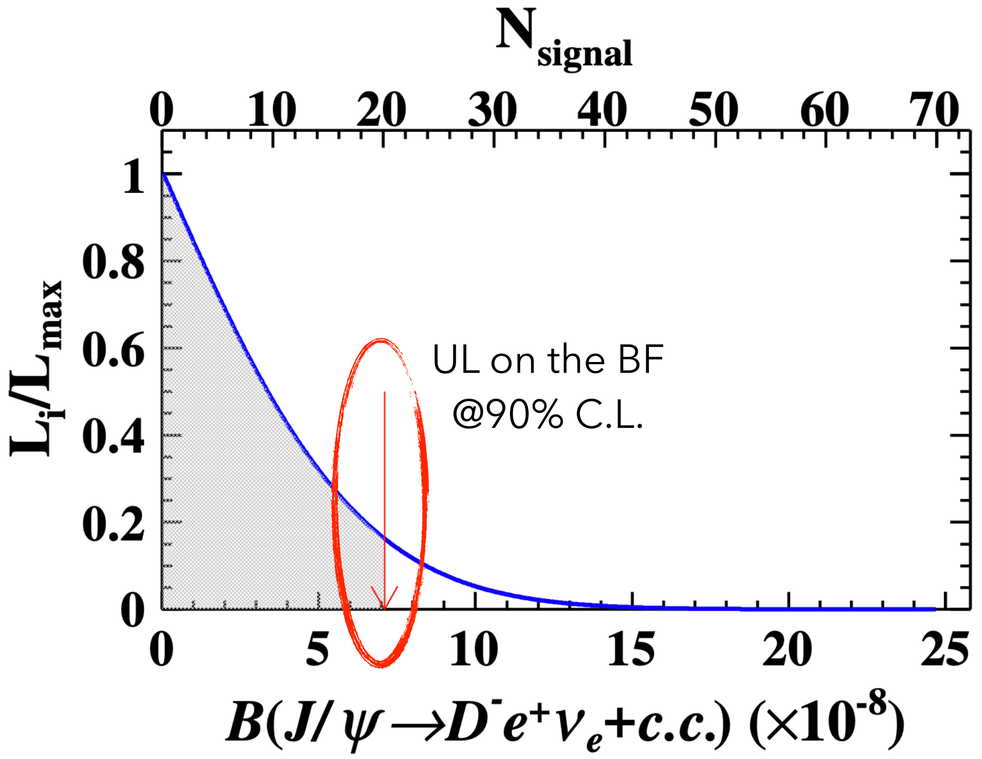
arXiv:2104.06628
Submitted to JHEP

Bayesian approach

Likelihood scan, with N_{signal} ranging from -70 to 70 (with steps of 0.1)

Uncertainties from the fit range and the background shape of the U_{miss} are included in the fit and the largest likelihood value is retained as the most conservative result

Other systematic uncertainties are implemented as prescribed in Ref. [V]



Distribution of the normalised smeared likelihood
Grey area corresponds to the 90% CL

[V] Chin. Phys. C 39, 103001

Observation of the decays $\chi_{cJ} \to n K^0 \bar{\Lambda} + c.c.$

Data sets ('09 - '12):

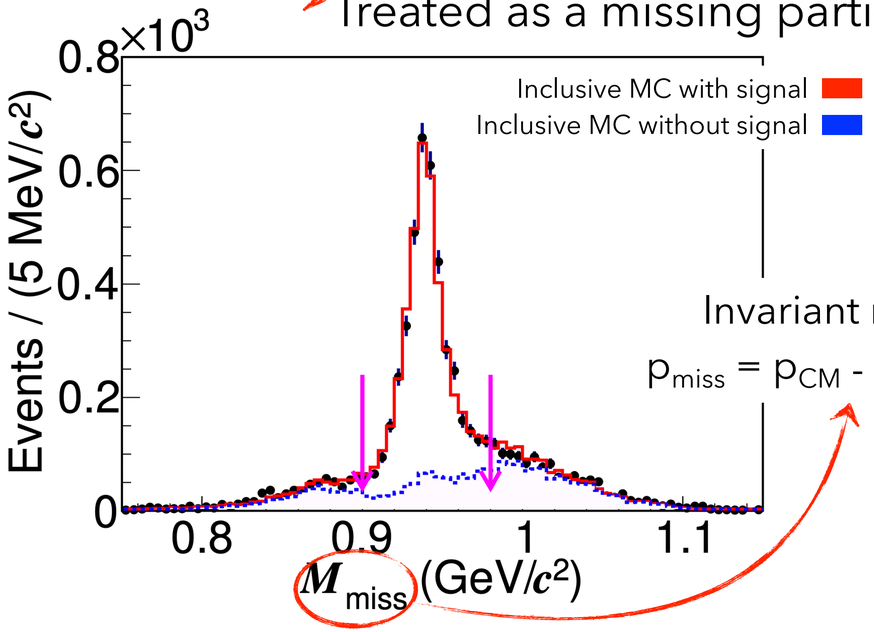
$\psi(3686)$ - 0.45 $\times 10^9$

Channel selection:

$\psi(2S) \to \gamma \chi_{cJ} \to \gamma n K^0 \bar{\Lambda}$

$\to \gamma n(\pi^+\pi^-)(\bar{p}\pi^+)$

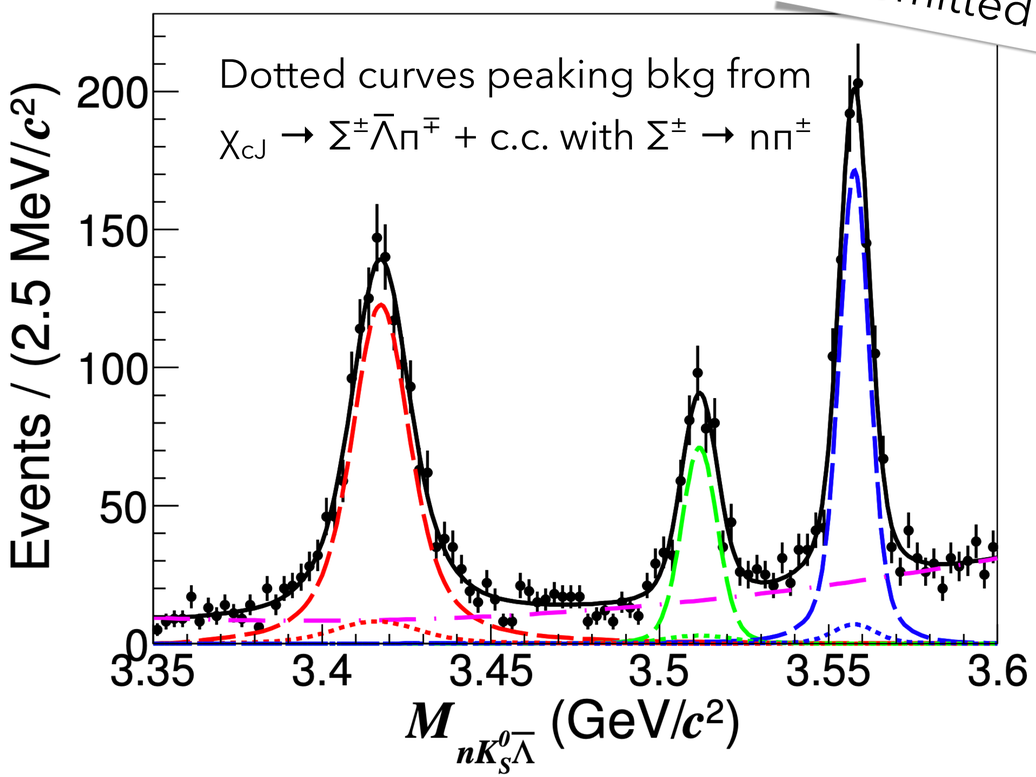
Treated as a missing particle



Invariant mass of

$p_{miss} = p_{CM} - p_\gamma - p_K - p_\Lambda$

arXiv:2106.13442
Submitted to JHEP



Dashed line shapes

BW ($M_{nK\Lambda}$) × E^3_γ × $D(E_\gamma)$,

where $D(E_\gamma)$ is a damping factor to suppress the E^3_γ tail

Observation of the decays $\chi_{cJ} \to n K^0 \bar{\Lambda} + c.c.$

arXiv:2106.13442
Submitted to JHEP

Mode	$N_{1,J}$	BF (10^{-4})
χ_{c0}	1288 ± 50	$6.67 \pm 0.26 \pm 0.41$
χ_{c1}	410 ± 30	$1.71 \pm 0.12 \pm 0.12$
χ_{c2}	900 ± 41	$3.66 \pm 0.17 \pm 0.23$

$\chi_{cJ} \to n K^0 \Lambda$ + c.c. decay observed for the first time

Observation of the decays $\chi_{cJ} \to n K^0 \bar{\Lambda} + c.c.$

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

$\chi_{cJ} \to nK^0\Lambda + c.c.$ decay observed for the first time

arXiv:2106.13442
Submitted to JHEP

$\mathcal{BR}$ checked with isospin conjugate $\chi_{cJ} \to pK^-\Lambda + c.c.$ [VI] and no isospin violation is found within the uncertainty

[VI] Phys. Rev. D 87, 012007

Observation of the decays $\chi_{cJ} \to n K^0 \bar{\Lambda} + c.c.$

Mode	$N_{1,J}$	BF (10^{-4})	$\mathcal{BR}(pK^-\Lambda)/\mathcal{BR}(nK^0\Lambda)$
χ_{c0}	1288 ± 50	$6.67 \pm 0.26 \pm 0.41$	1.98 ± 0.09 ± 0.14
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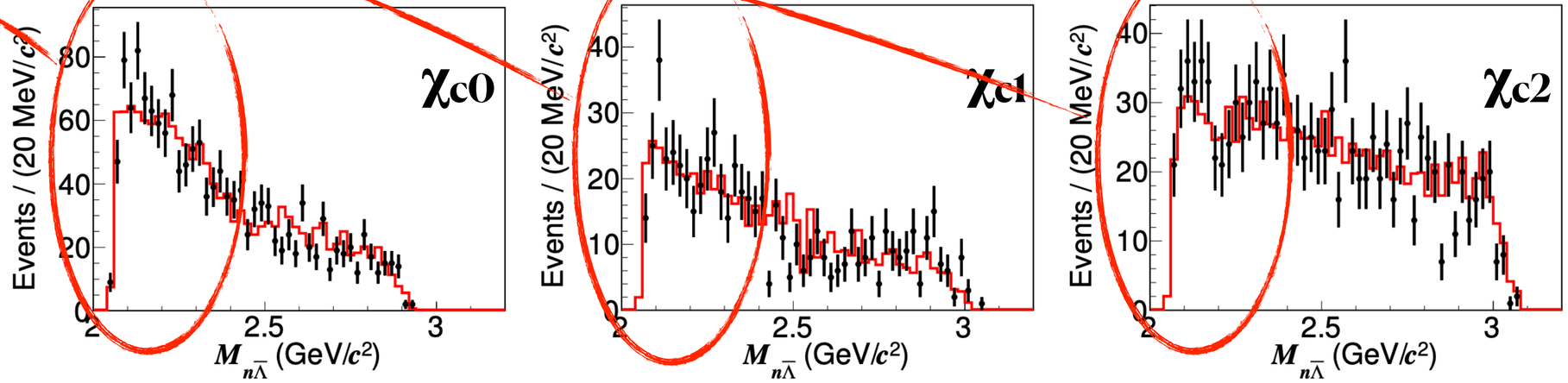
$\chi_{cJ} \to nK^0\Lambda + c.c.$ decay observed for the first time

$\mathcal{BR}$ checked with isospin conjugate $\chi_{cJ} \to pK^-\Lambda + c.c.$ [VI] and no isospin violation is found within the uncertainty

Observed near threshold enhancements



[VI] Phys. Rev. D 87, 012007