



# Recent results from BESIII

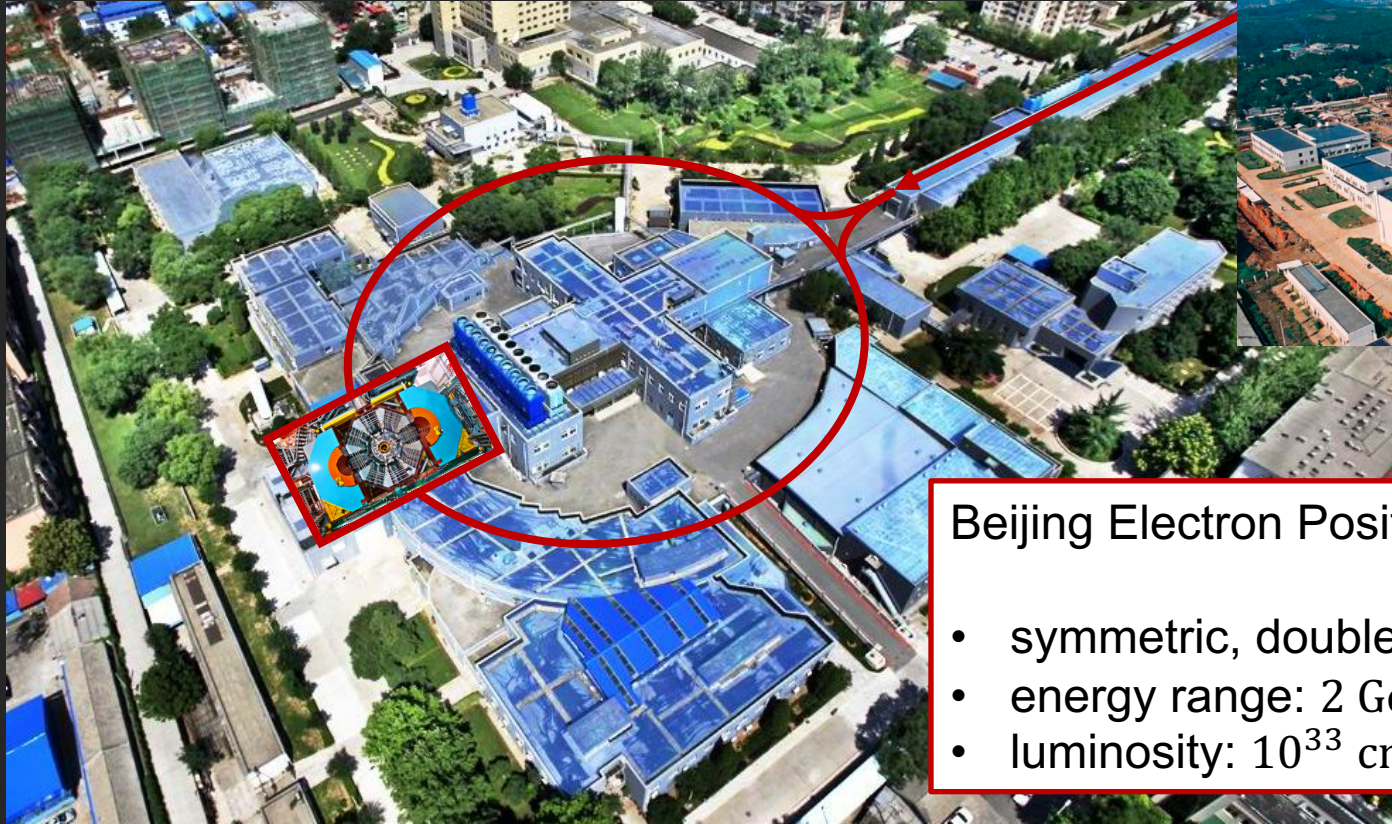
Nils Hüsken  
on behalf of the BESIII Collaboration

19th International Conference on Hadron Spectroscopy and Structure

INDIANA UNIVERSITY BLOOMINGTON



# BEPCII



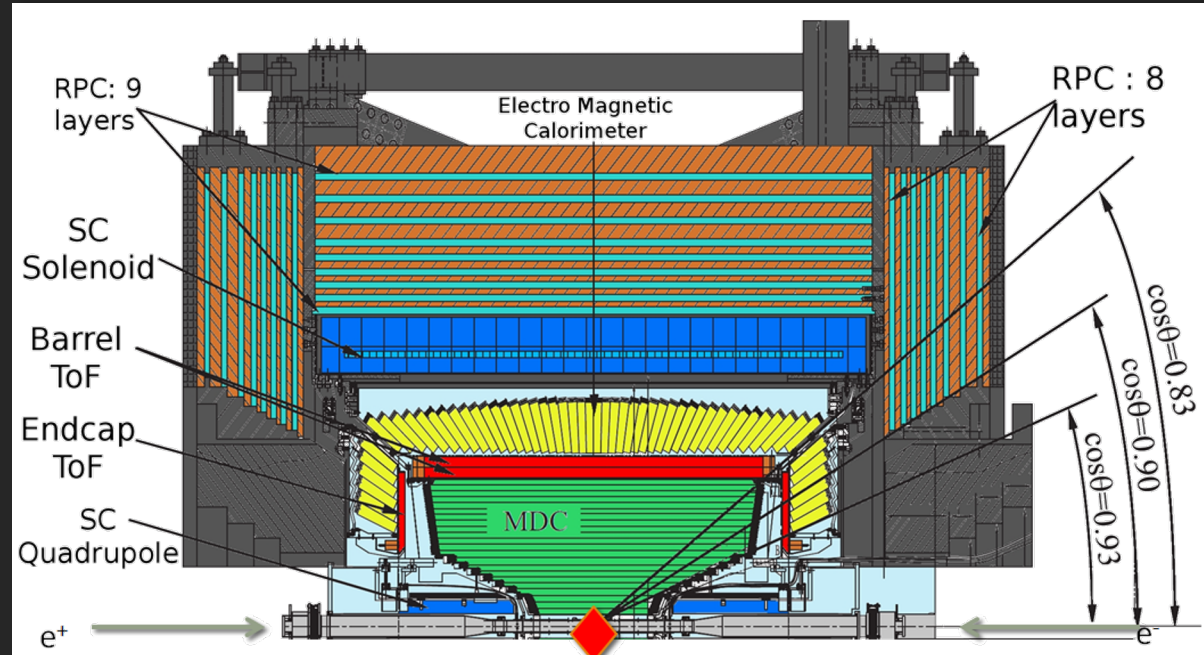
## Beijing Electron Positron Collider:

- symmetric, double-ring  $e^+e^-$  collider
- energy range:  $2 \text{ GeV} < \sqrt{s} < 4.94 \text{ GeV}$
- luminosity:  $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  (at  $\psi(3770)$ )



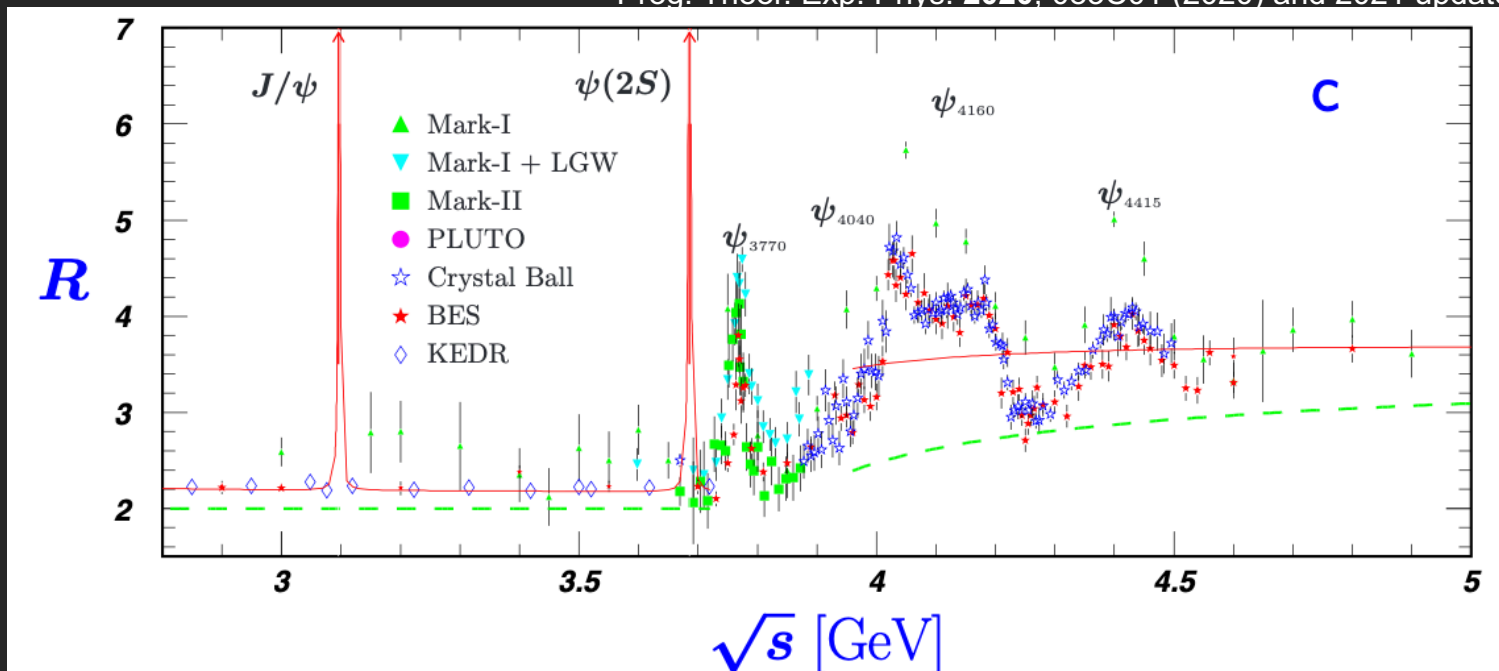
# BESIII

- MDC: drift chamber in 1 T magnetic field
- TOF: plastic scintillator / MRPC based time-of-flight system
- EMC: electromagnetic calorimeter
- RPC: resistive plate chambers for muon ID



# BESIII datasets

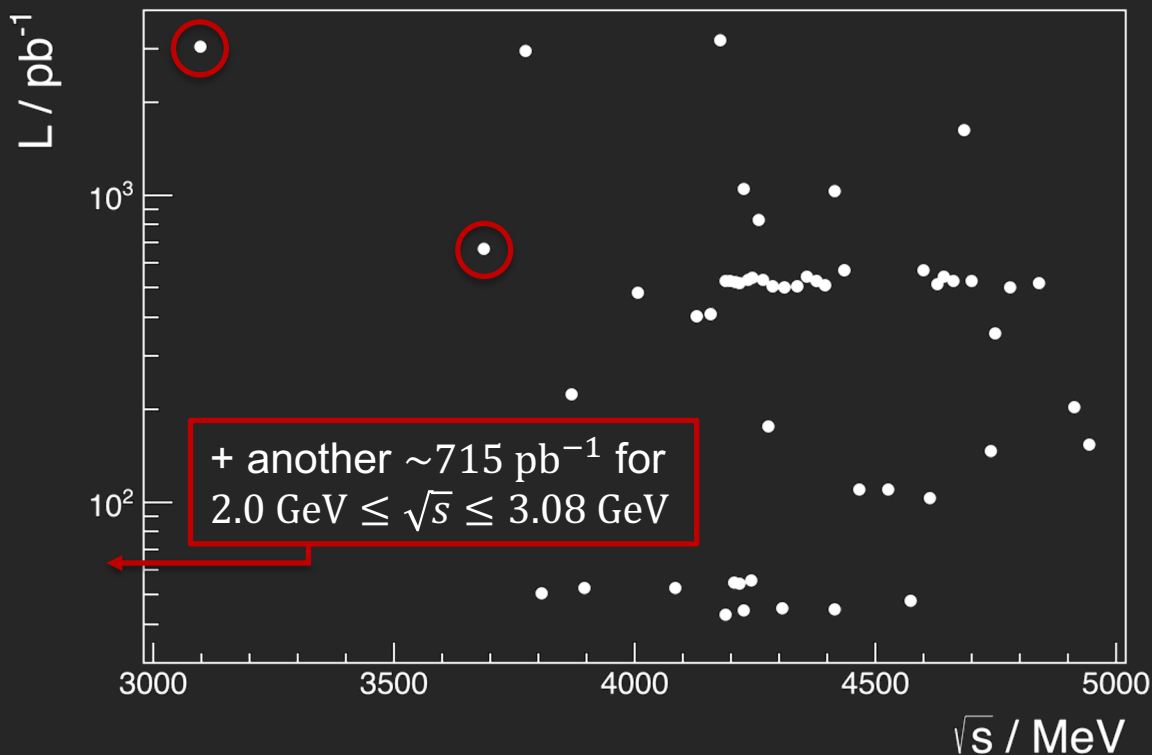
Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update



energy range:  $2 \text{ GeV} < \sqrt{s} < 4.94 \text{ GeV}$



# BESIII datasets



- $10^{10} J/\psi$  decays
  - $448 \cdot 10^6 \psi(2S)$  decays (with another  $2.3 \cdot 10^9$  recently finished)
- light hadron spectroscopy & decays, charmonium decays, hyperon physics, ...

see other talks:

07/26 11:15, 11:40

07/27 11:40

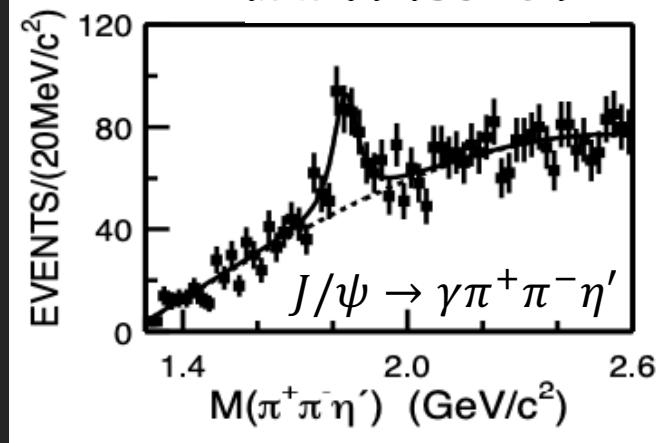
07/28 07:25, 09:45

07/30 09:45, 10:05, 11:15



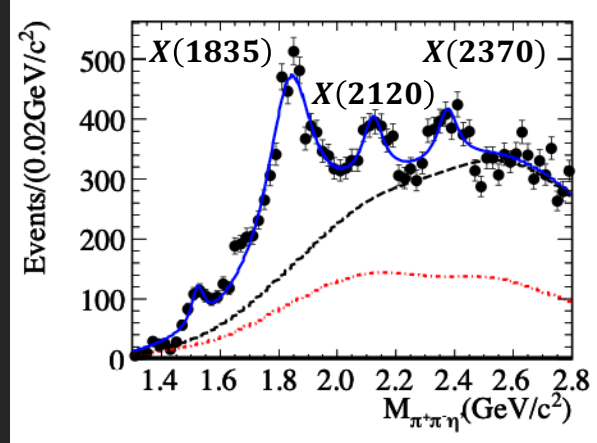
# On $X(1835)$ , $X(2120)$ , $X(2370)$

PRL 95 (2005) 262001



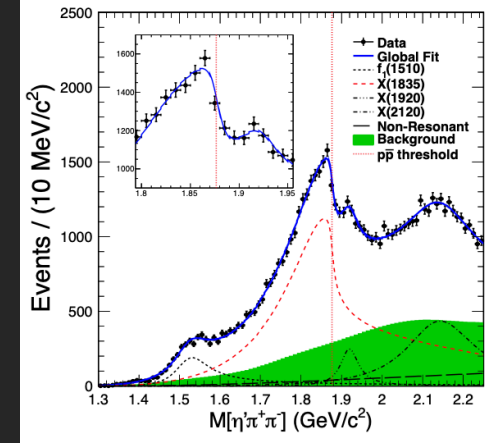
$58 \cdot 10^6 J/\psi$

PRL 106 (2011) 072002



$225 \cdot 10^6 J/\psi$

PRL 117 (2016) 4, 042002



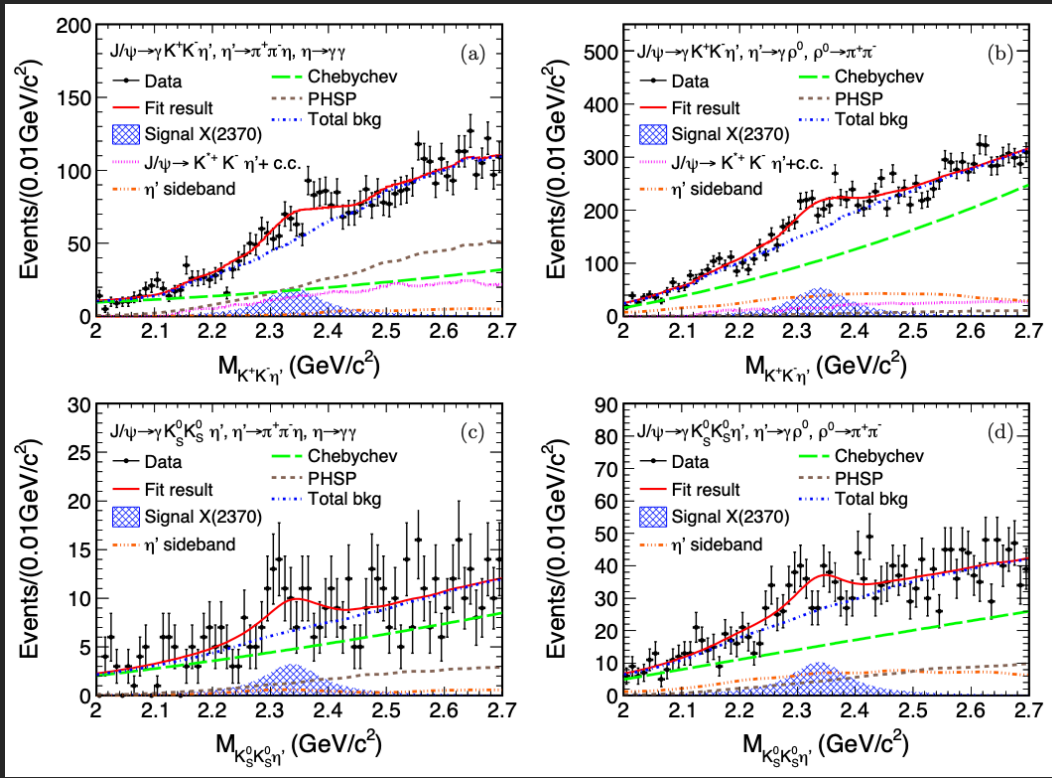
$1.3 \cdot 10^9 J/\psi$

- $X(1835)$ : seen in  $\gamma \eta' \pi^+ \pi^-$ ,  $\gamma \eta K_S^0 K_S^0$ ,  $\gamma \gamma \phi$ ,  $\gamma \omega \phi$
  - similar state in:  $\gamma p \bar{p}$ ,  $\gamma 3(\pi^+ \pi^-)$ ,  $\omega \eta \pi^+ \pi^-$  (recoiling off an  $\omega$ )
  - what about the other peaks?
- } close to  $p\bar{p}$  threshold

→ factor of 8 increase in statistics upcoming!



# On $X(1835)$ , $X(2120)$ , $X(2370)$



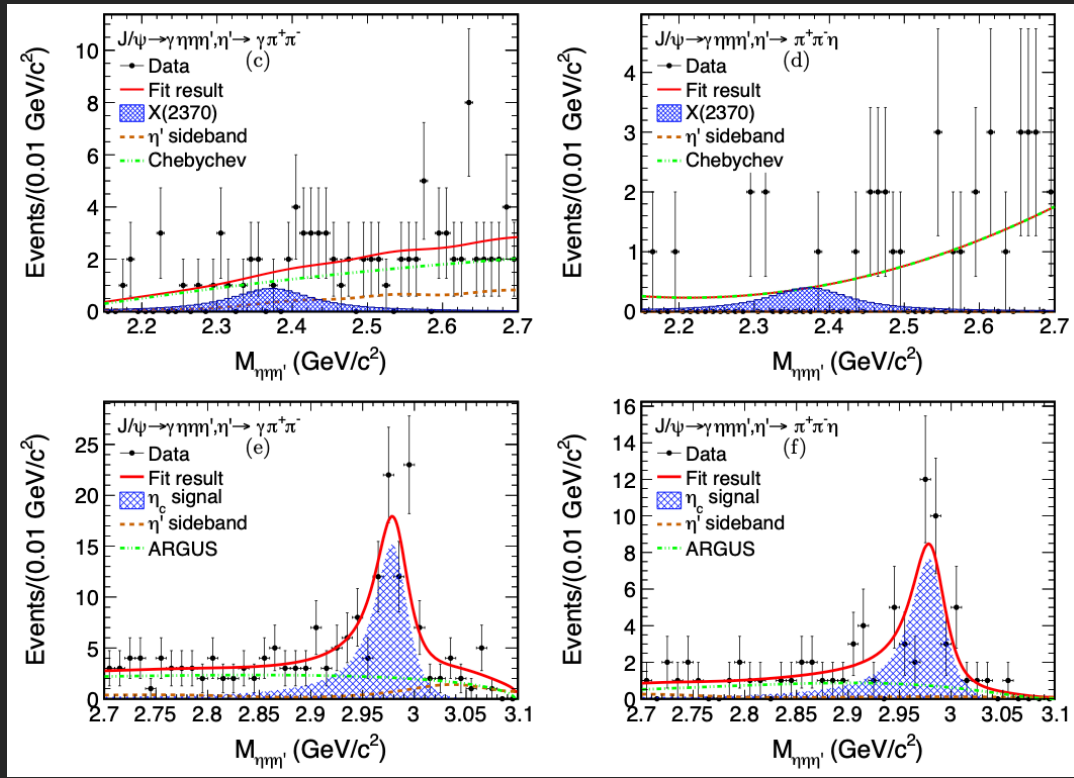
$J/\psi \rightarrow \gamma K \bar{K} \eta'$ :

- based on  $1.3 \cdot 10^9 J/\psi$
- simultaneous fit to  $\eta' \rightarrow \eta \pi^+ \pi^-$  and  $\eta' \rightarrow \gamma \pi^+ \pi^-$ , and  $J/\psi \rightarrow \gamma K^+ K^- \eta'$  and  $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$
- $8.3\sigma$  for  $X(2370) \rightarrow K \bar{K} \eta'$
- no indication for  $X(2120) \rightarrow K \bar{K} \eta$

Eur.Phys.J.C 80 (2020) 8, 746



# On $X(1835)$ , $X(2120)$ , $X(2370)$



$J/\psi \rightarrow \gamma \eta \eta' \eta'$ :

- based on  $1.3 \cdot 10^9 J/\psi$
- simultaneous fit to  $\eta' \rightarrow \eta \pi^+ \pi^-$  and  $\eta' \rightarrow \gamma \pi^+ \pi^-$
- no signal of  $X(2370) \rightarrow \eta \eta' \eta'$
- first observation of  $\eta_c \rightarrow \eta \eta' \eta'$

more light meson spectroscopy:  
Shuangshi Fang, 07/26 11:15





# Light meson decays

- radiative  $J/\psi$  decays provide a clean source of  $\eta, \eta'$  mesons

$$BR(J/\psi \rightarrow \gamma\eta) = (1.108 \pm 0.027) \cdot 10^{-3}$$

$$BR(J/\psi \rightarrow \gamma\eta') = (5.25 \pm 0.07) \cdot 10^{-3}$$

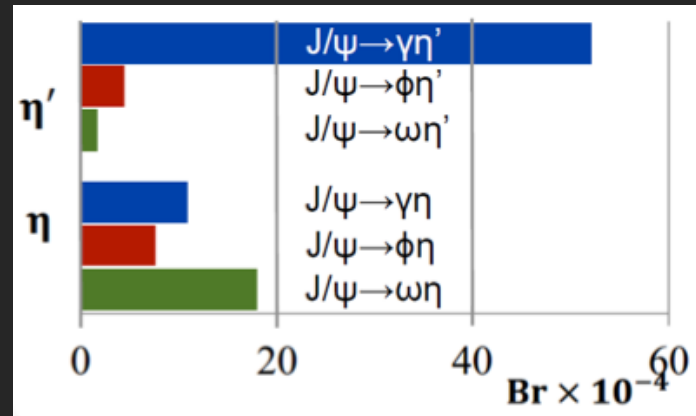
$$\xrightarrow[\text{(}10^{10} J/\psi\text{)}]{1.3 \cdot 10^9 J/\psi} \quad 1.4 \cdot 10^6 \eta \quad (1.1 \cdot 10^7 \eta)$$

$$\quad \quad \quad 6.8 \cdot 10^6 \eta' \quad (5.3 \cdot 10^7 \eta')$$

- ideal testbed to study:

- low energy QCD
- $\chi$ PT predictions
- symmetry violations
- ...

→ see yesterday's talk by Rongsheng Shi



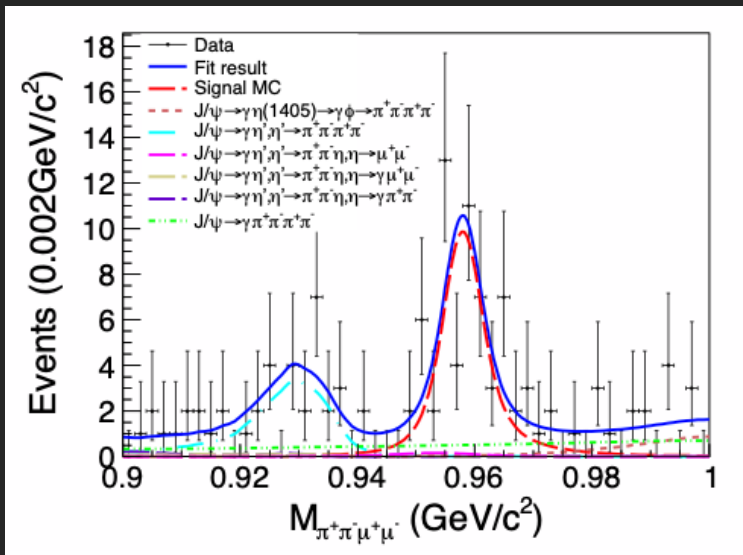
# Light meson decays: $\eta' \rightarrow \pi^+ \pi^- l^+ l^-$

$$\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-:$$

$$BR = (1.93 \pm 0.33 \pm 0.18) \cdot 10^{-5}$$

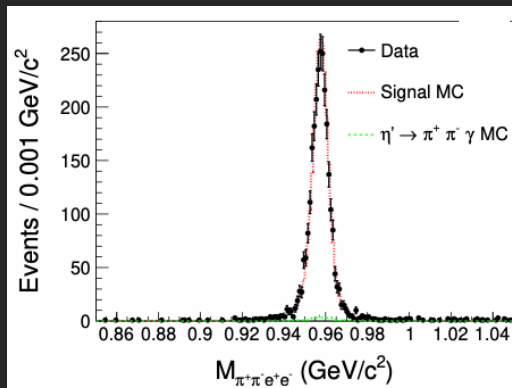
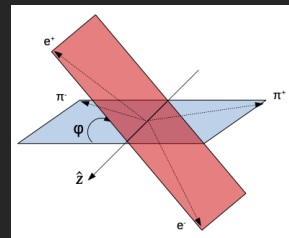
$$\eta' \rightarrow \pi^+ \pi^- e^+ e^-:$$

$$BR = (2.42 \pm 0.05 \pm 0.08) \cdot 10^{-3}$$

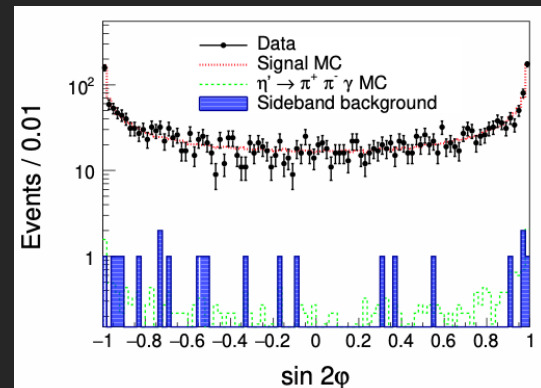


Phys. Rev. D 103, 072006 (2021)

- interference between CP-allowed M1 transition and CP-violating transition would produce asymmetry  $A_\phi$
- $A_\phi = (2.9 \pm 3.7 \pm 1.1)\%$

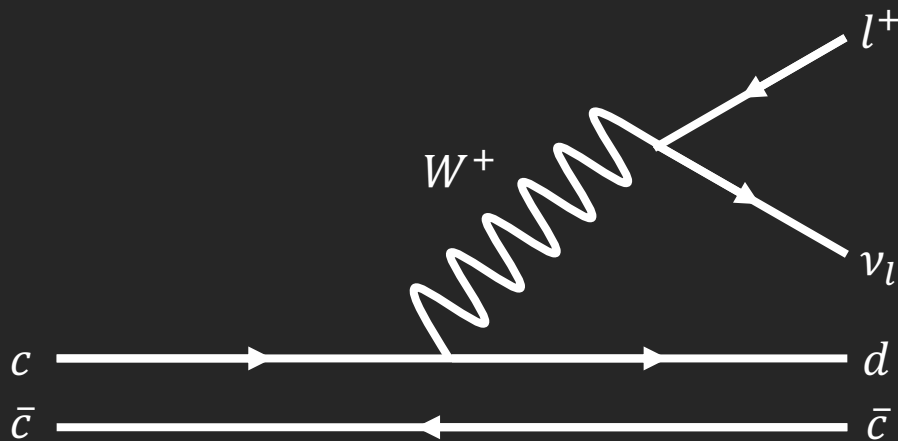


Phys. Rev. D 103, 092005 (2021)

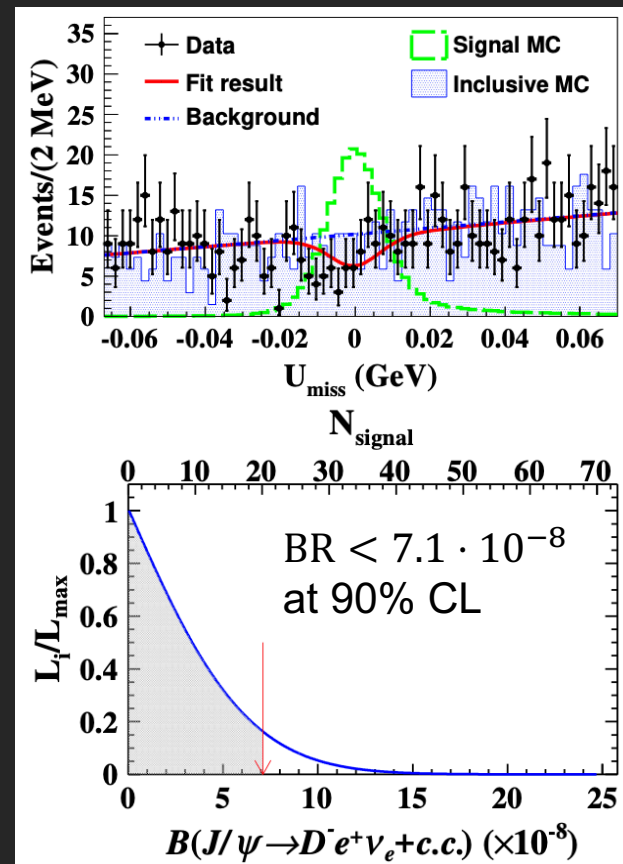


# Search for $J/\psi$ weak decays

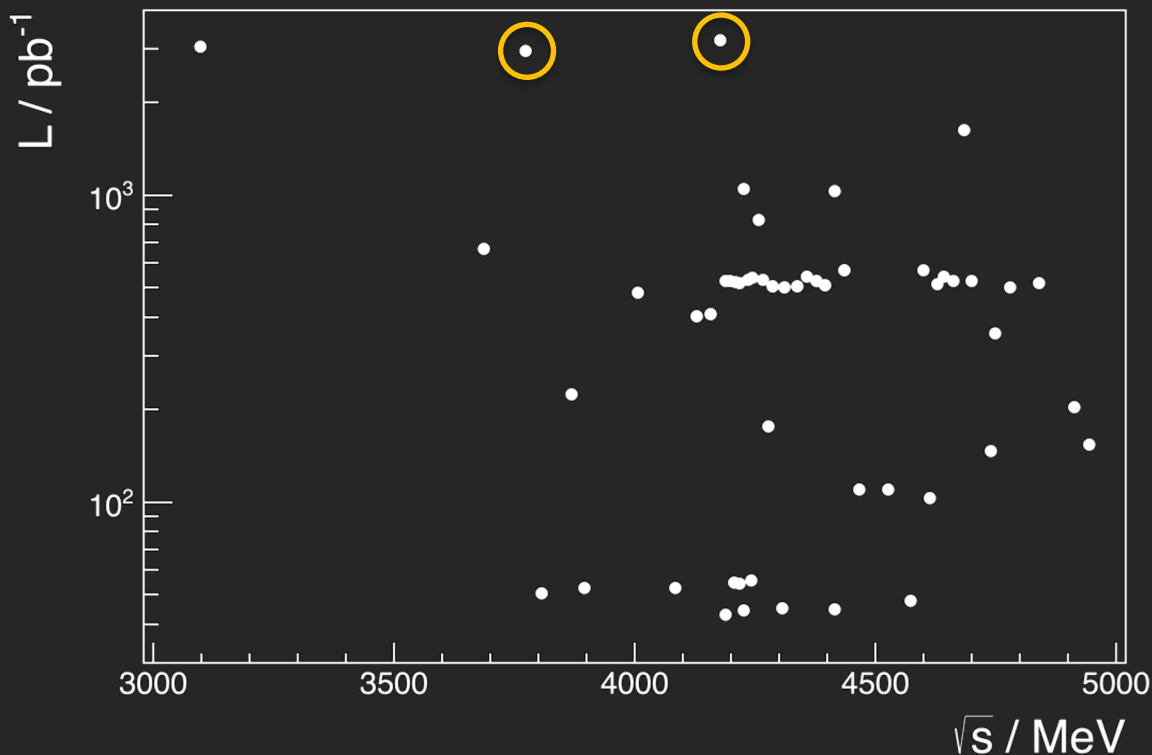
JHEP 06 (2021) 157



- standard model prediction:  $BR \sim 10^{-11}$
- several BSM: predict larger BR up to  $\sim 10^{-5}$
- one of the first published results using  $10^{10}$   $J/\psi$  events



# BESIII datasets

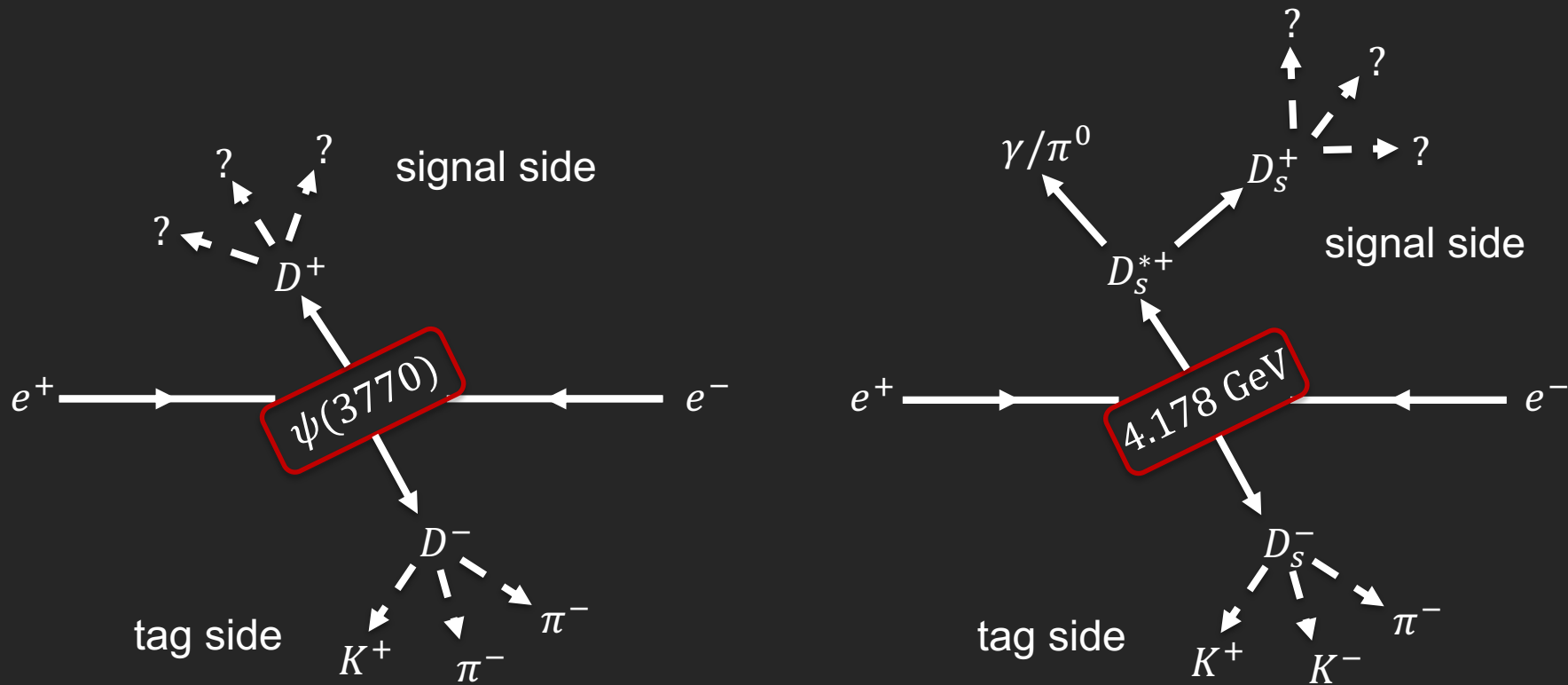


- $\sim 2.9 \text{ fb}^{-1}$  at  $\psi(3770)$   
(to be upgraded to  $\sim 20 \text{ fb}^{-1}$  in the near future)
  - $\sim 3.2 \text{ fb}^{-1}$  at  $\sqrt{s} = 4.178 \text{ GeV}$
- $D_{(s)}$  meson decays,  
quantum-correlated  
 $D^0 \bar{D}^0$  pairs, ISR and  
 $\gamma\gamma$  processes, ...

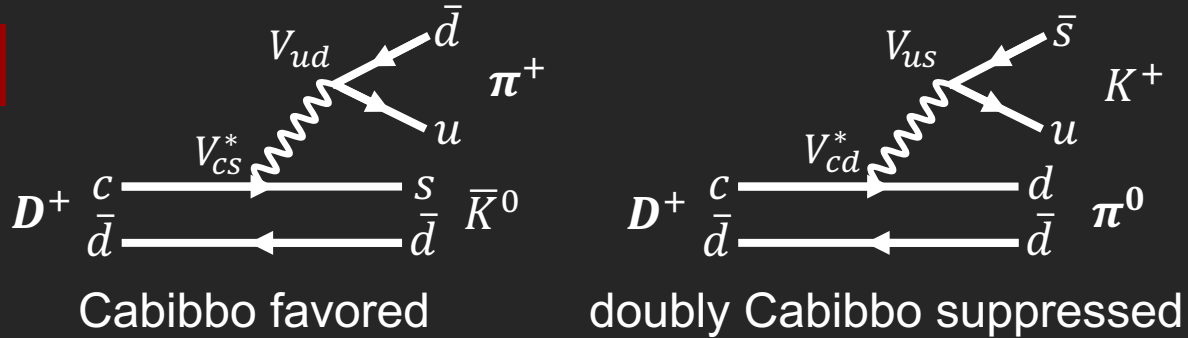
see other talks:  
07/28 07:00, 07:25



# Open charm production



$$D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$$



- expectation:  $\frac{Br(DCS)}{Br(CF)} \sim \tan^4 \theta_c \sim 0.29\%$

- $Br(D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0) = (1.13 \pm 0.08 \pm 0.03) \cdot 10^{-3}$

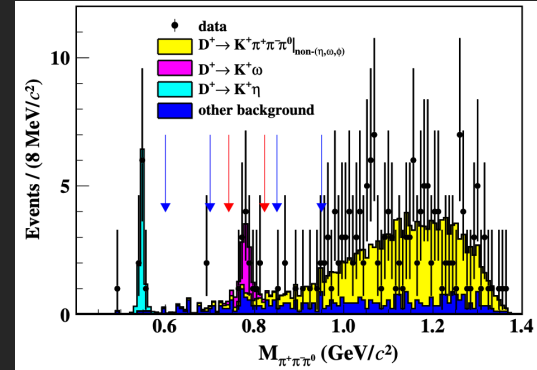
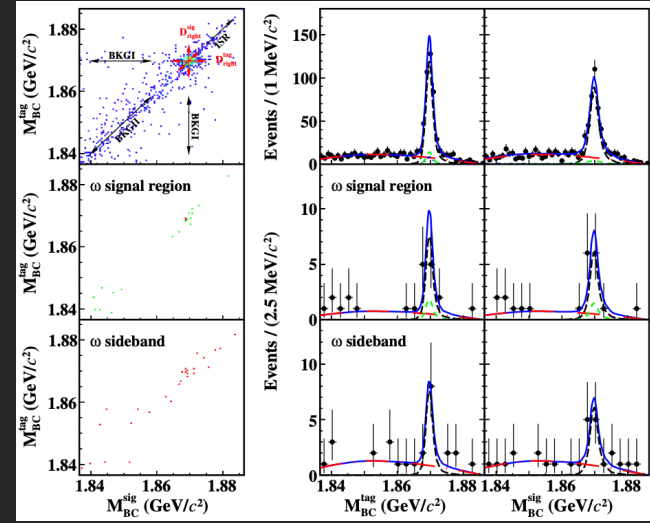
$$\rightarrow \frac{Br(D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0)}{Br(D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0)} = (1.81 \pm 0.15)\%$$

Tags:

$$D^- \rightarrow K^+ \pi^- \pi^-$$

$$D^- \rightarrow K_S^0 \pi^-$$

$$D^- \rightarrow K^+ \pi^- \pi^- \pi^0$$



PRL 125, 141802 (2020)



$$D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$$

- new measurement using semi-leptonic instead of hadronic tags
- $\text{Br}(D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0) = (1.03 \pm 0.12 \pm 0.06) \cdot 10^{-3}$

$$\rightarrow \frac{\text{Br}(D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0)}{\text{Br}(D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0)} = (1.65 \pm 0.21)\%$$

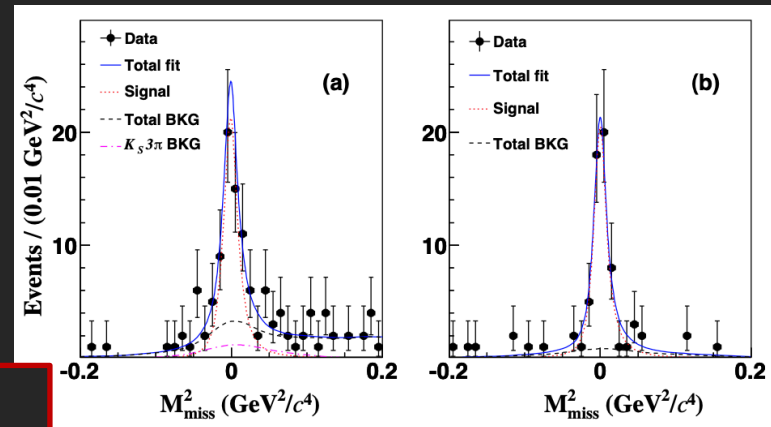
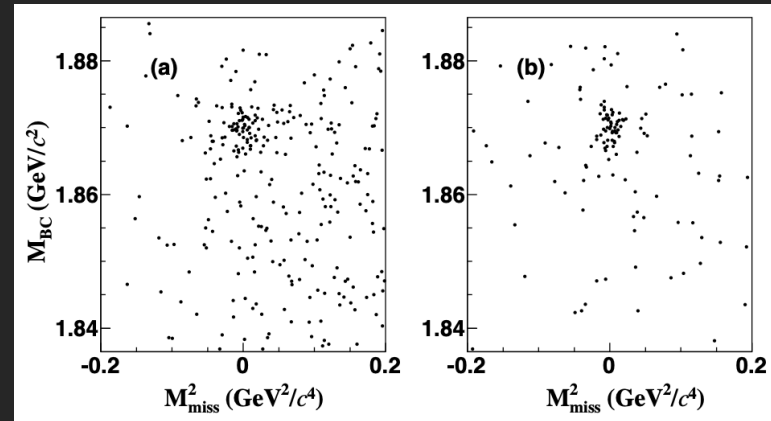
→ confirms unexpectedly large branching ratio

→ first demonstration of semi-leptonic tag, useful for  $D^0$  decays in the future

Tags:

$$D^- \rightarrow K^0 e^- \bar{\nu}_e$$

$$D^- \rightarrow K^+ \pi^- e^- \bar{\nu}_e$$

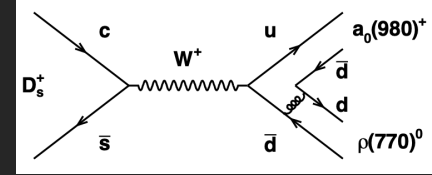


arXiv:2105.14310

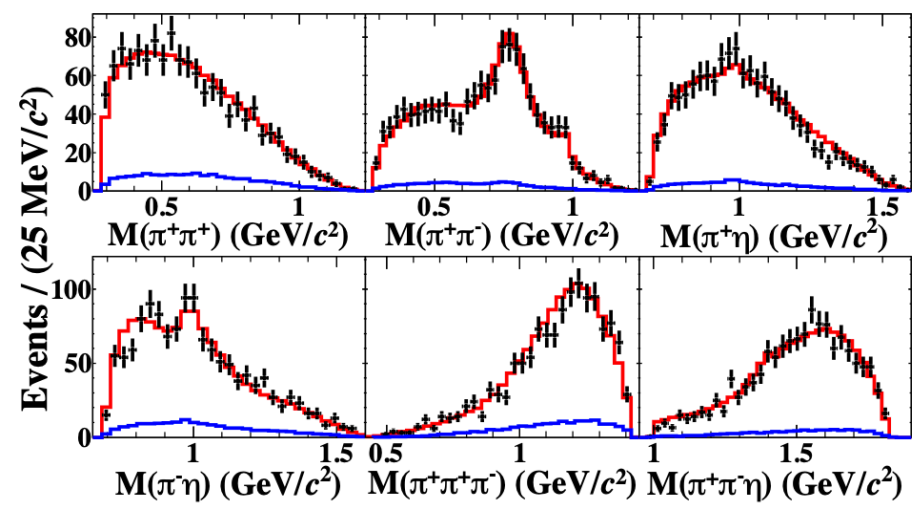


$$D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \eta$$

- first measurement of  $Br(D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \eta) = (3.12 \pm 0.13 \pm 0.09)\%$
- amplitude analysis reveals dominant  $a_1(1260)^+ \eta$  contribution
- observation of weak annihilation  $D_s^+ \rightarrow a_0(980)^+ \rho(770)^0$



Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0 \pi^+) \eta$	0.0(fixed)	$55.4 \pm 3.9 \pm 2.0$
$a_1(1260)^+(f_0(500) \pi^+) \eta$	$5.0 \pm 0.1 \pm 0.1$	$8.1 \pm 1.9 \pm 2.1$
$a_0(980)^+ \rho(770)^0$	$2.5 \pm 0.1 \pm 0.1$	$6.7 \pm 2.5 \pm 1.5$
$\eta(1405)(a_0(980)^- \pi^+) \pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$\eta(1405)(a_0(980)^+ \pi^-) \pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$f_1(1420)(a_0(980)^- \pi^+) \pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.9 \pm 0.5 \pm 0.3$
$f_1(1420)(a_0(980)^+ \pi^-) \pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.7 \pm 0.5 \pm 0.3$
$[a_0(980)^- \pi^+]_S \pi^+$	$0.1 \pm 0.2 \pm 0.2$	$5.1 \pm 1.2 \pm 0.9$
$[a_0(980)^+ \pi^-]_S \pi^+$	$0.1 \pm 0.2 \pm 0.2$	$3.4 \pm 0.8 \pm 0.6$
$[f_0(980) \eta]_S \pi^+$	$1.4 \pm 0.2 \pm 0.3$	$6.2 \pm 1.7 \pm 0.9$
$[f_0(500) \eta]_S \pi^+$	$2.5 \pm 0.2 \pm 0.3$	$12.7 \pm 2.6 \pm 2.0$

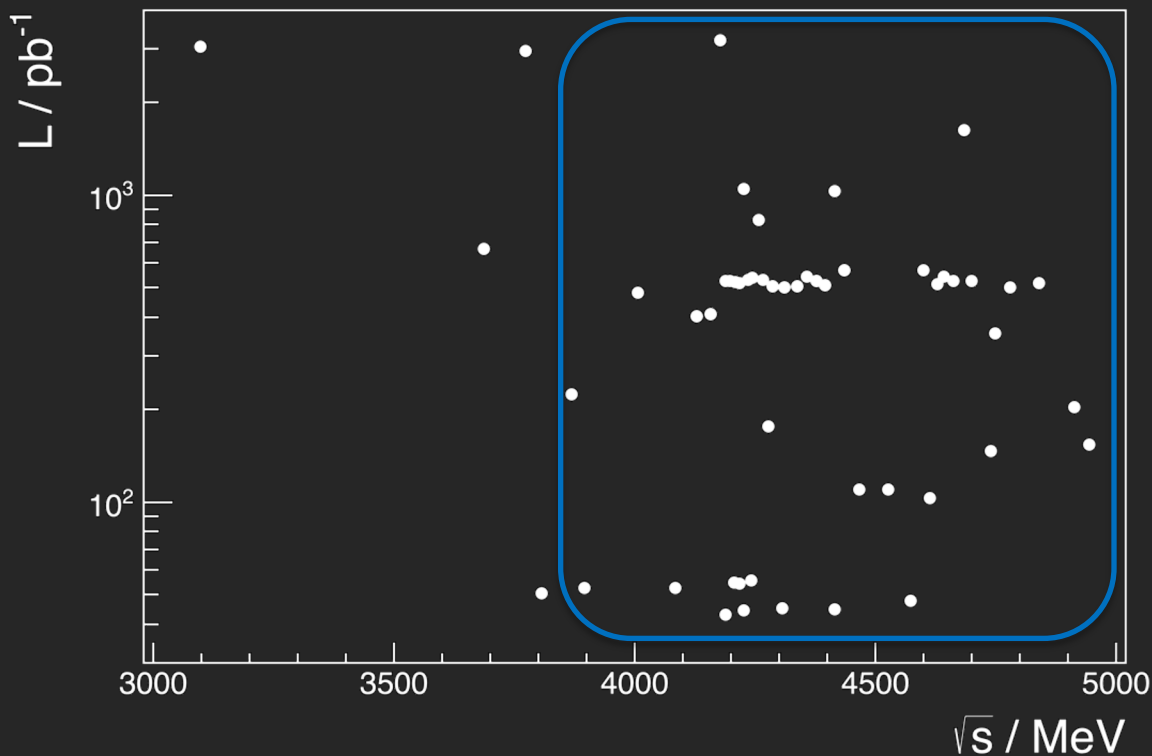


arXiv:2106.13536





# BESIII datasets



- $\sim 22 \text{ fb}^{-1}$  at various  $\sqrt{s}$  in the XYZ region

→ spectroscopy of XYZ-states,  
XYZ-decays,  
open-charm production,  
charmed baryons, ...

see other talks:

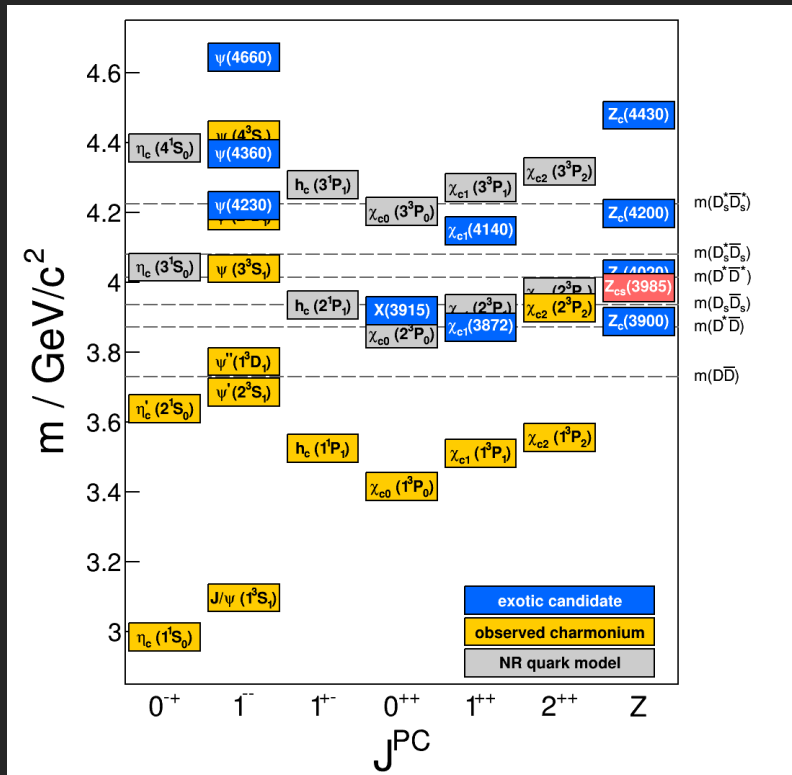
07/28 09:25

07/29 09:25, 11:15

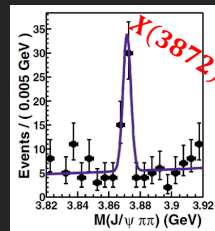
07/30 09:45



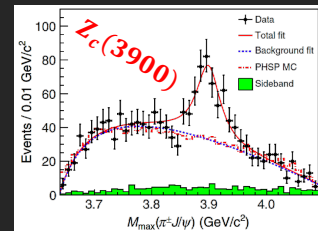
# Charmonium-like exotic states



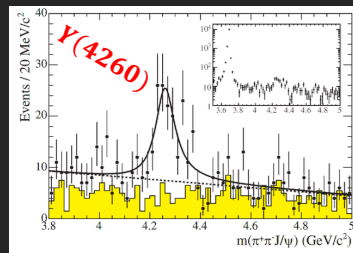
- conventional charmonia ( $c\bar{c}$ ) fit well with potential model calculations
- several unexpected states observed



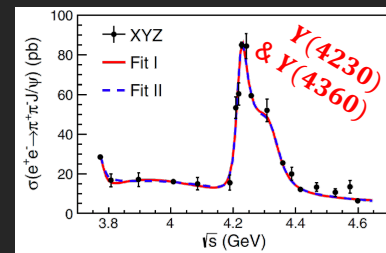
PRL 91, 262001 (2003)



PRL 110 (2013) 252001



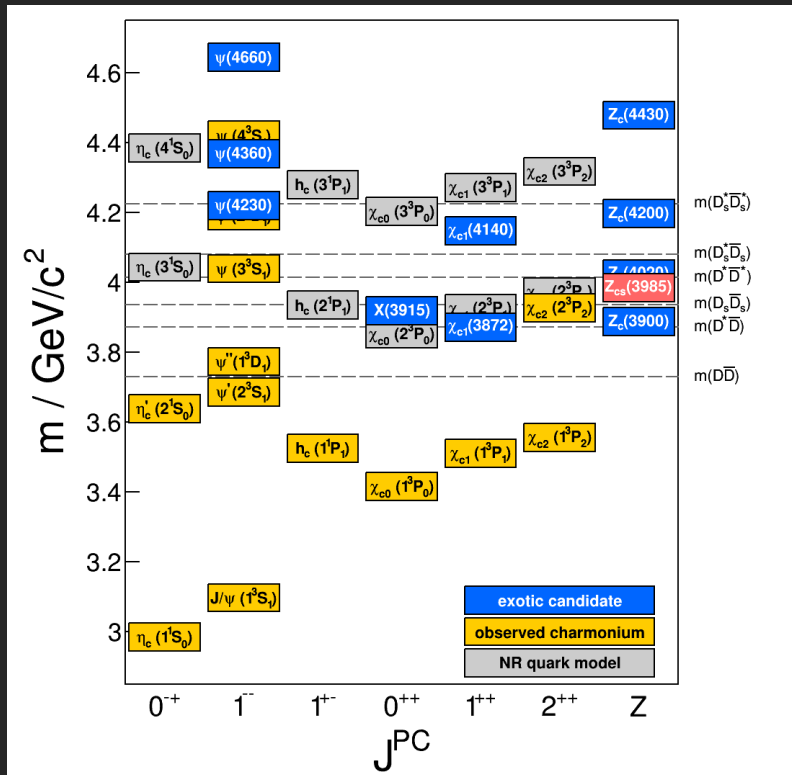
PRL 95 (2005) 142001



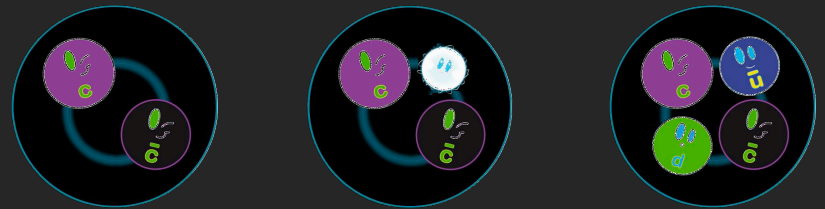
PRL 118 (2017) 9, 092001



# Charmonium-like exotic states



- charmonium-like states:
  - supernumerary
  - do not fit into spectrum
  - strong couplings to hidden charm channels
  - *exotic* decays (e.g.  $Z_c^\pm \rightarrow J/\psi \pi^\pm$ )
- nature of these states is still unclear

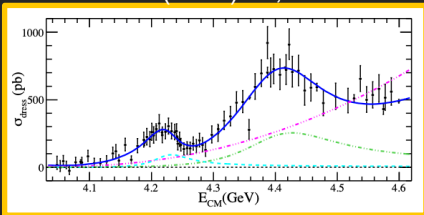


<https://physicsmore.blogspot.com>

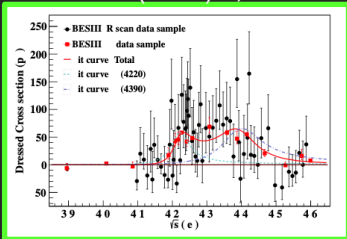


# The $\Upsilon$ - (or $\psi$ -) states

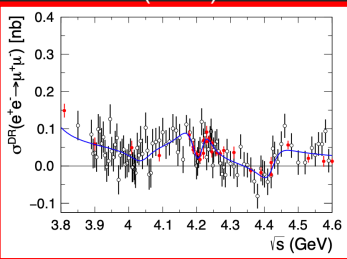
PRL 122 (2019) 10, 102002



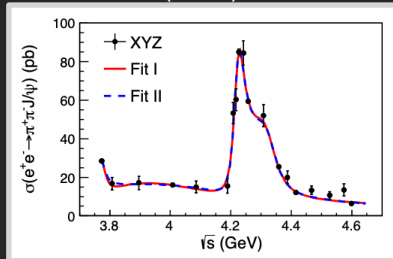
PRL 118 (2017) 9, 092002



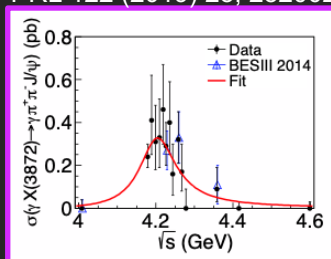
PRD 102 (2020) 11, 2009



PRL118 (2017) 9, 092001

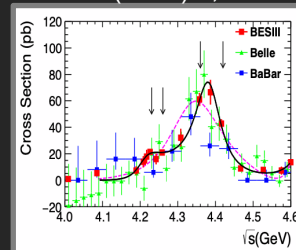


PRL 122 (2019) 23, 232002

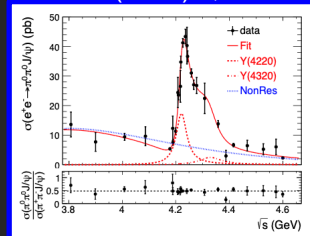


PRD 96 (2017) 3, 032004

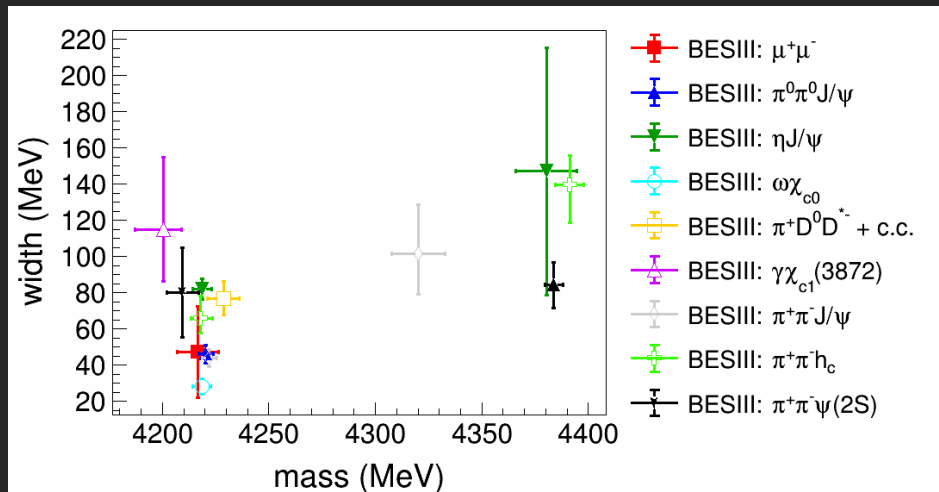
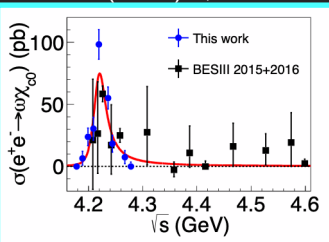
PRD 99 (2019) 1, 019903



PRD 102 (2020) 1, 012009



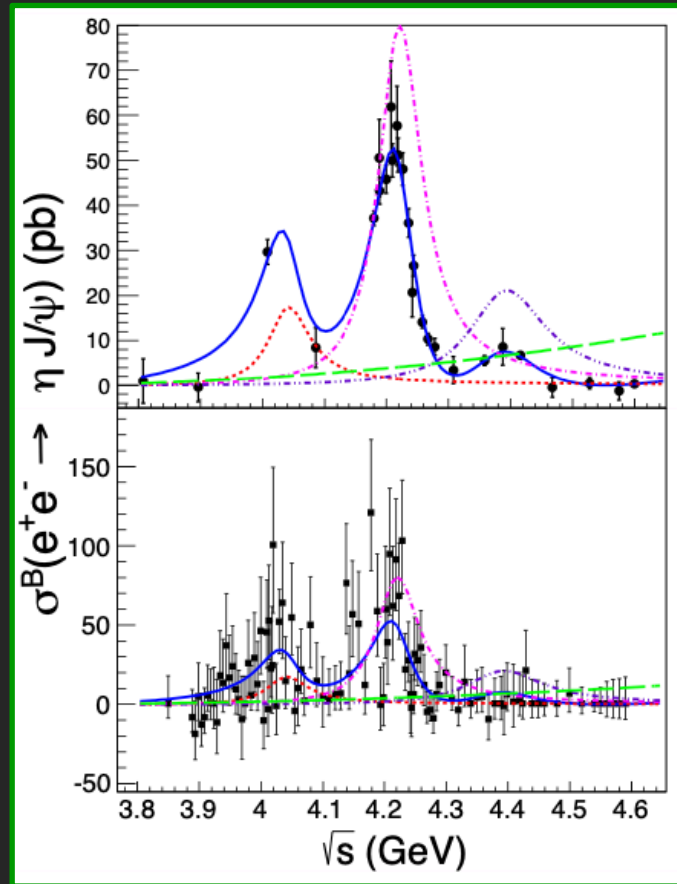
PRD 99 (2019) 9, 091103



# The $Y$ - (or $\psi$ -) states

$$e^+e^- \rightarrow \eta J/\psi:$$

- updated measurement using  $13.1 \text{ fb}^{-1}$  of data in the range  $3.8 \text{ GeV} \leq \sqrt{s} \leq 4.6 \text{ GeV}$
- $\eta$  reconstructed in  $\gamma\gamma, \pi^+\pi^-\pi^0$
- fit with three resonances:
  - $\psi(4040)$ , fixed to world-average
  - two additional, found compatible with  $\psi(4230)$  and  $\psi(4360)$



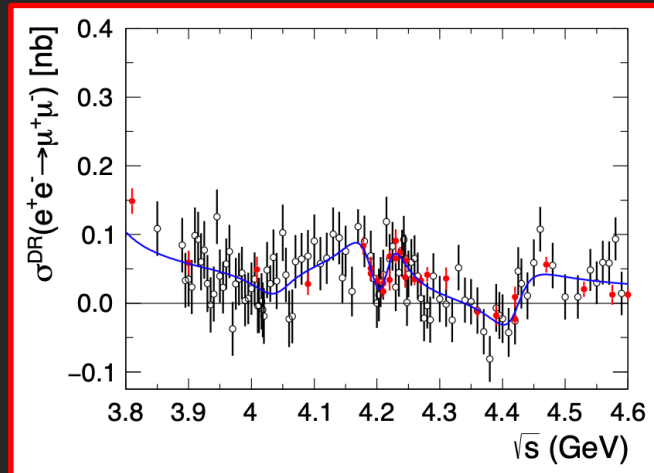
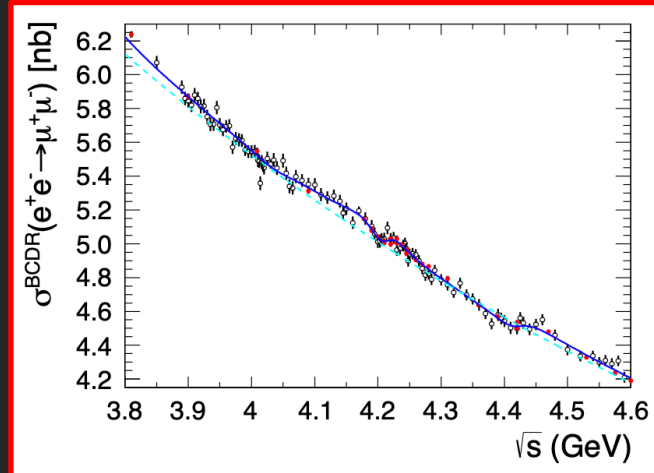
PRD 102 (2020) 3, 031101



# The $Y$ - (or $\psi$ -) states

$$e^+e^- \rightarrow \mu^+\mu^-:$$

- using 133 data samples in the range  $3.8 \text{ GeV} \leq \sqrt{s} \leq 4.6 \text{ GeV}$  with  $L_{int} = 13.2 \text{ fb}^{-1}$
- measurement of  $\Gamma_{\mu\mu}$  for  $\psi(4040)$ ,  $\psi(4160)$  and  $\psi(4415)$
- observation of an additional state with  
 $m = (4216.7 \pm 8.9 \pm 4.1) \text{ MeV}$   
 $\Gamma = (47.2 \pm 22.8 \pm 10.5) \text{ MeV}$   
 $\Gamma_{\mu\mu} = (1.53 \pm 1.26 \pm 0.54) \text{ keV}$   
(1 of 8 ambiguous solutions)

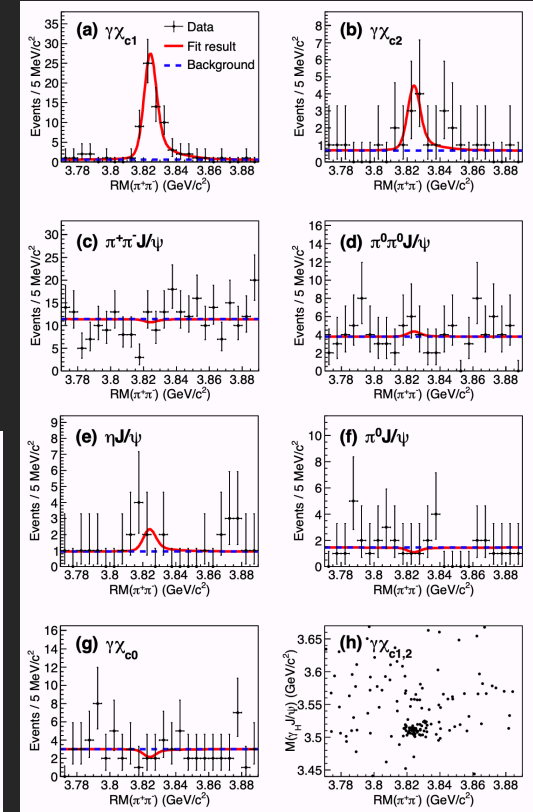
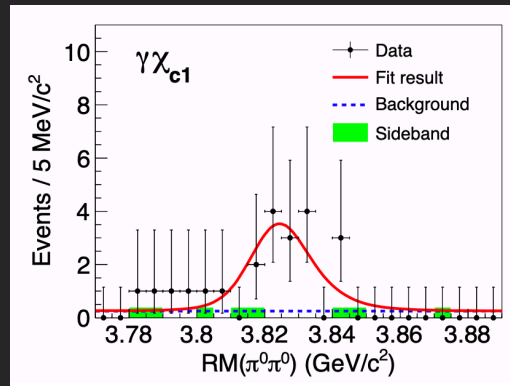


# $\psi_2(3823)$ – the $\psi(1^3D_2)$ state?

PRD 103, L091102 (2021)

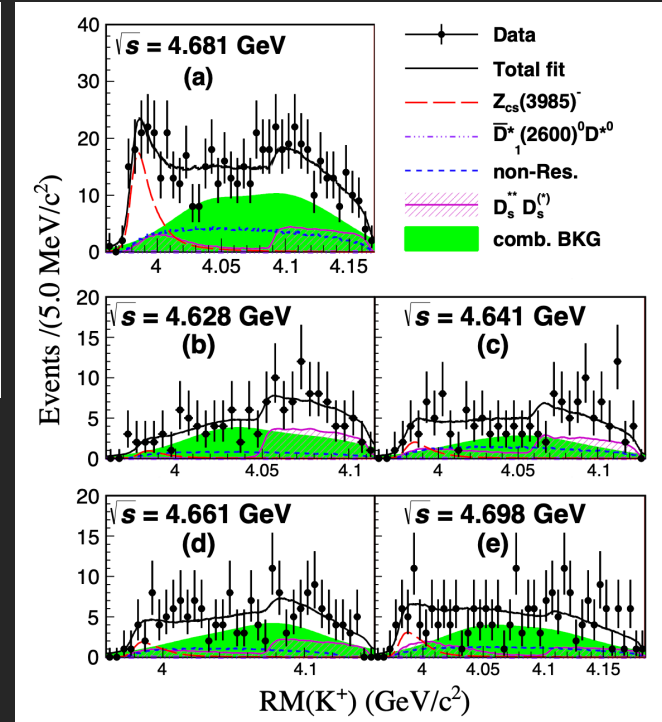
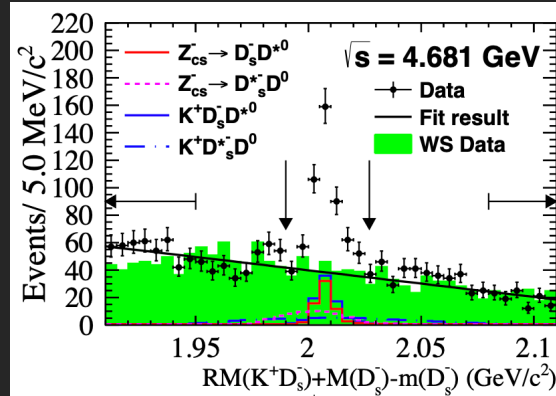
$$e^+e^- \rightarrow \pi\pi\psi_2(3823):$$

- search for various (new) decay modes of the  $\psi_2(3823)$
- first evidence for  $\psi_2(3823) \rightarrow \gamma\chi_{c2}$
- first evidence for  $e^+e^- \rightarrow \pi^0\pi^0\psi_2(3823)$  with  $\psi_2(3823) \rightarrow \gamma\chi_{c1}$



# The $Z_{cs}(3985)$ in $e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$

- partial reconstruction method:  $K^+, D_s^-$
- using 5 new datasets above 4.6 GeV
- $5.3\sigma$  excess close to threshold for data at  $\sqrt{s} = 4.681$  GeV
- coupling to at least one of  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$  suggests minimal quark-content of  $c\bar{c}s\bar{u}$



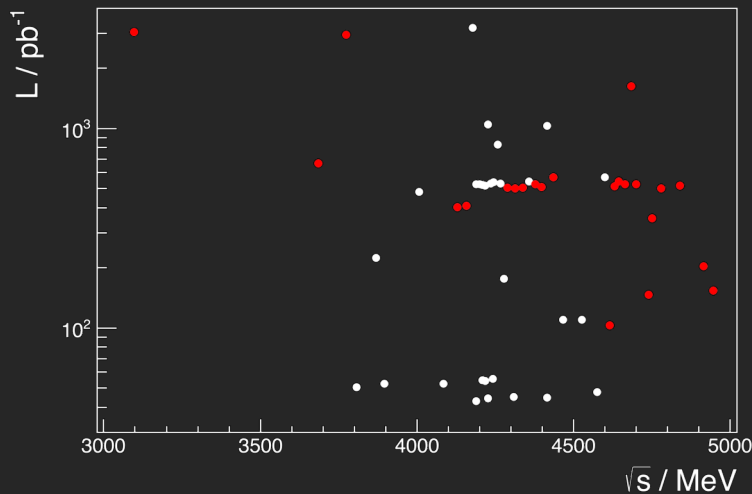
PRL 126, 102001 (2021)

→ see talk by Ronggang Ping 07/29 11:15





# Future perspectives

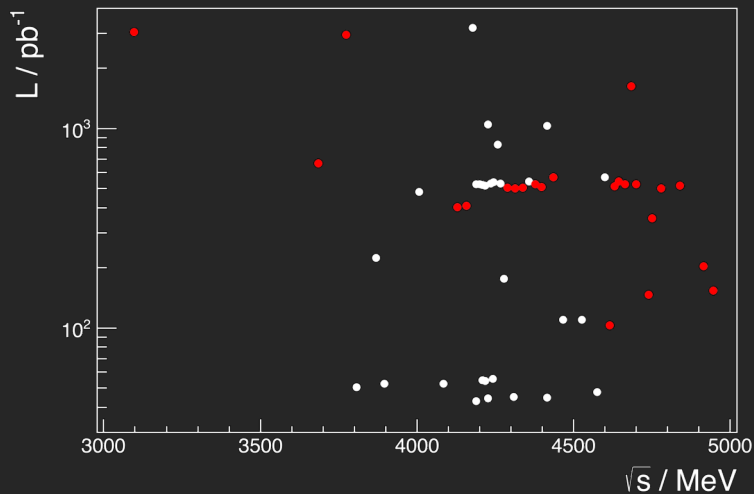


$10^{10} J/\psi$  and  $2.7 \cdot 10^9 \psi(2S)$ :

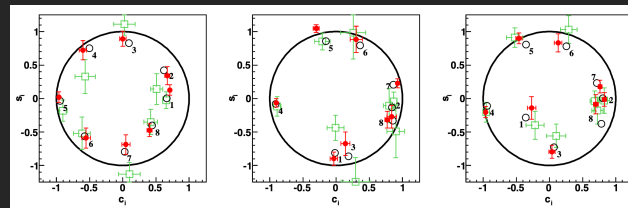
- detailed studies of scalar and pseudo-scalar glueball candidates  
(see also talks by A. Rodas, A. Sarantsev, E. Klempt)
- search for hybrid mesons, e.g. in  $\chi_{c1}$  decays
- many more opportunities:
  - baryon spectroscopy
  - hyperon physics    see talks by Liang Yan, 07/27 11:15  
Xiongfei Wang 07/30 11:15
  - $\eta_c$  and  $\chi_{cJ}$  decays
  - ...

# Future perspectives

20 fb<sup>-1</sup> at the  $\psi(3770)$ :



- precise charm and flavour physics
- quantum correlated  $D^0\bar{D}^0$  pairs
  - strong phase measurement as important input to study CKM angle  $\gamma$  in  $B \rightarrow DK$

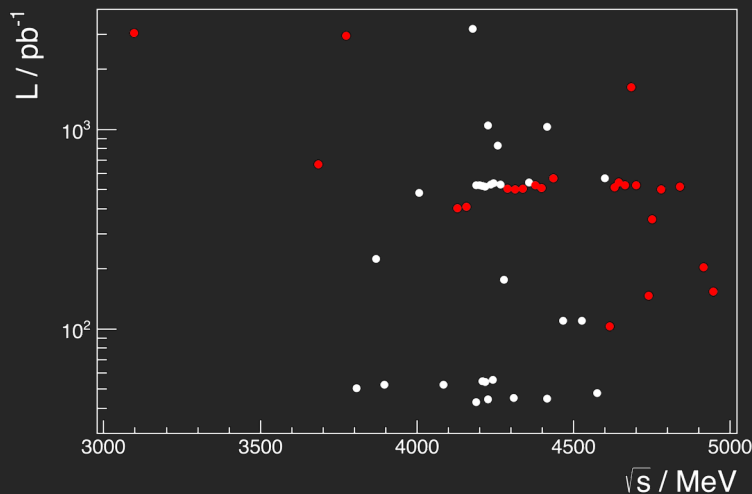


PRD 101, 112002 (2020)  
 PRL 124, 241802 (2020)  
 PRD 102, 052008 (2020)

- source of ISR and  $\gamma^{(*)}\gamma^{(*)}$  events
  - exclusive cross sections
  - transition form factors

$$\left. \begin{array}{l} \text{– exclusive cross sections} \\ \text{– transition form factors} \end{array} \right\} g_\mu - 2$$

# Future perspectives

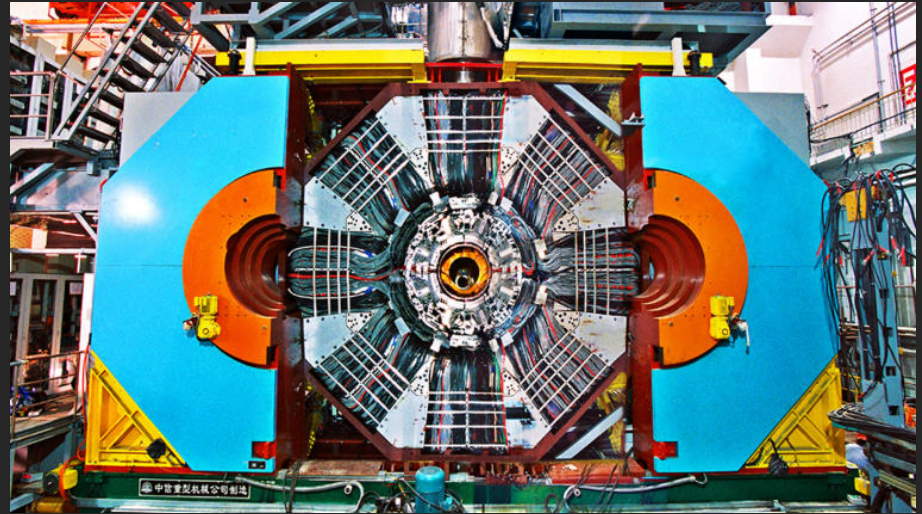


new data above 4 GeV:

- filled up some blank spaces in the  $\psi(4230)$ ,  $\psi(4360)$  region
- new data between 4.6 GeV and 4.95 GeV  
→  $Z_{CS}(3985)$  as first result
- production of charmed baryons  
 $\Lambda_c \bar{\Lambda}_c, \Sigma_c \bar{\Sigma}_c, \Xi_c \bar{\Xi}_c$
- more surprises to come in the XYZ region?

# Summary

- BESIII is taking data since 2008
- broad physics reach
  - light hadron spectroscopy & decays
  - open charm physics
  - (exotic) charmonia
  - precision measurements ( $R$ , TFF, ...)
  - ...
- several new data sets currently being analyzed
  - first exciting results from new  $J/\psi$  and  $XYZ$  data
  - many analyses in progress, plenty of results to come
- data taking is ongoing
  - new:  $2.3 \cdot 10^9 \psi(2S)$ , soon:  $20 \text{ fb}^{-1}$  at the  $\psi(3770)$



BESIII White paper:  
arXiv:1912.05983  
Chin. Phys. C 44, 040001 (2020)



# Thank you for your attention – questions?

THE BESIII COLLABORATION MEETING IN SUMMER OF 2021  
2021年 北京谱仪III国际合作组夏季会议合影 2021.6.28 甘肃·兰州



BESIII Collaboration Meeting in Summer 2021, Jun.28-Jul.2, 2021.

