Charmonium (Charm) Spectroscopy and Decay

Yuping Guo(郭玉萍)

on behalf of BESIII Collaboration

(results from BESIII, Belle, and LHCb experiments)

Conference on Flavor Physics and CP Violation

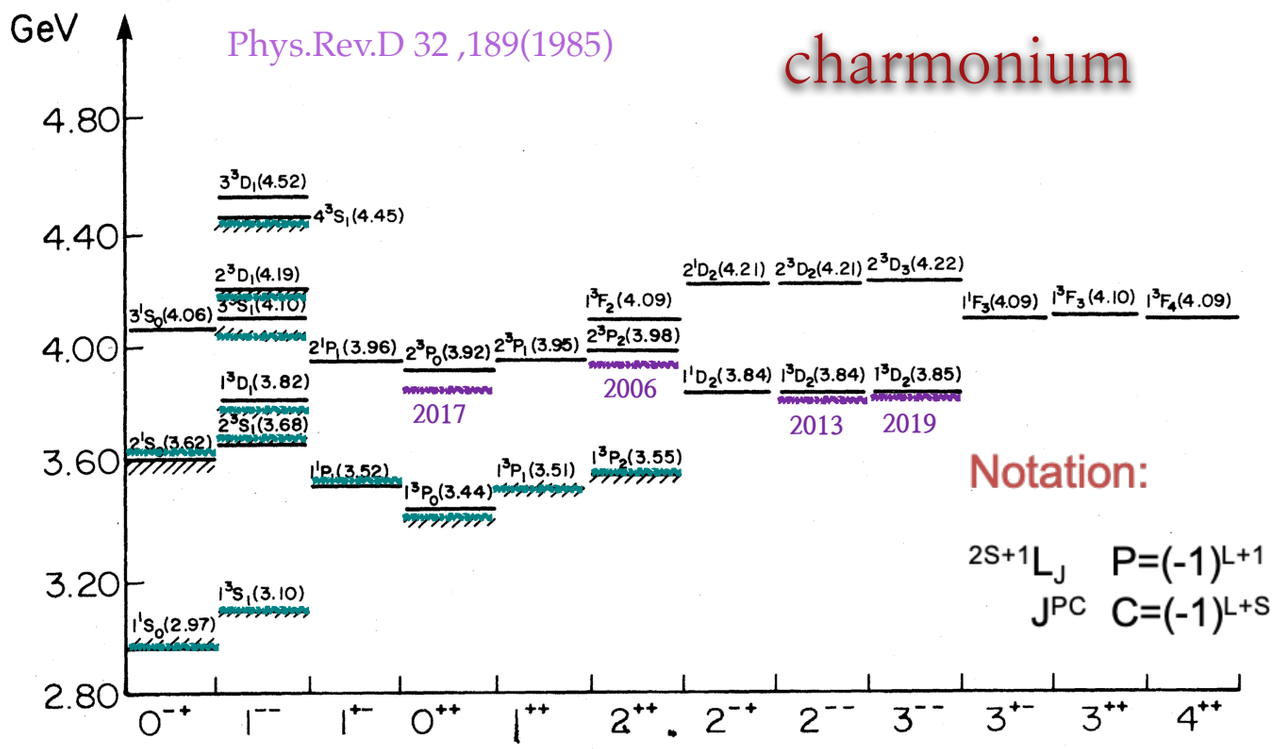
FPCP2021

Fudan University, Shanghai, China, 7–11 June, 2021

Charmonium/Charm Spectroscopy

- "confinement" of strong interaction
- Charmonium/Charm states located in the transition region, provide good opportunities to test QCD
  - Various theoretical models make predictions for the properties of charmonium/charm states
  - New states and new decays provide inputs for theory
  - Many new states observed can not fit into conventional hadron picture

Charmonium/Charm Spectroscopy

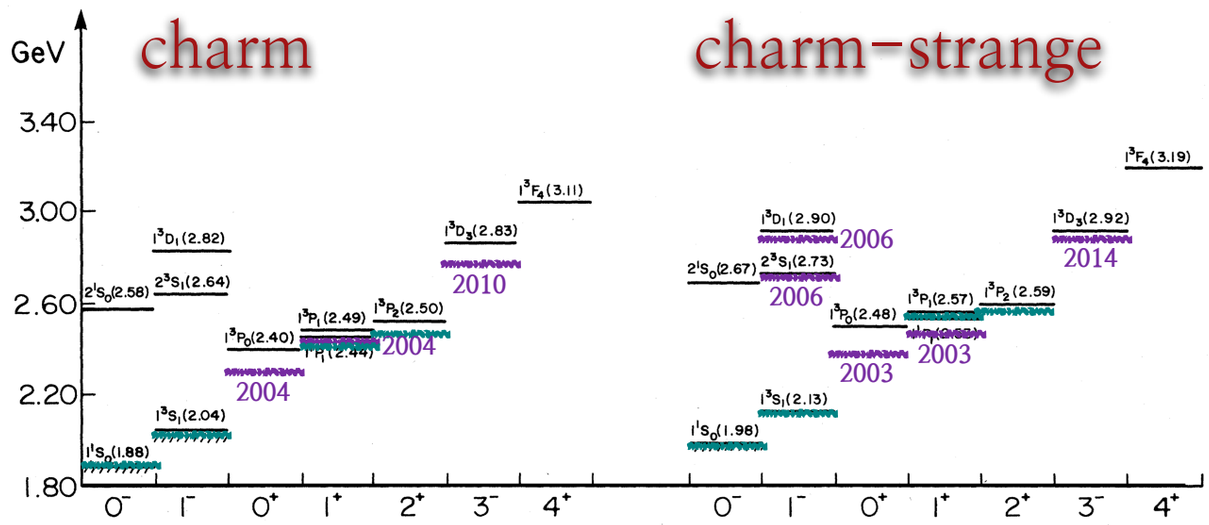


Phys.Rev.D 32 ,189(1985)

charmonium

Charmonium Spectroscopy

- Well established below $2m_D$
- Many excited states not found yet
- Many exotic candidates observed

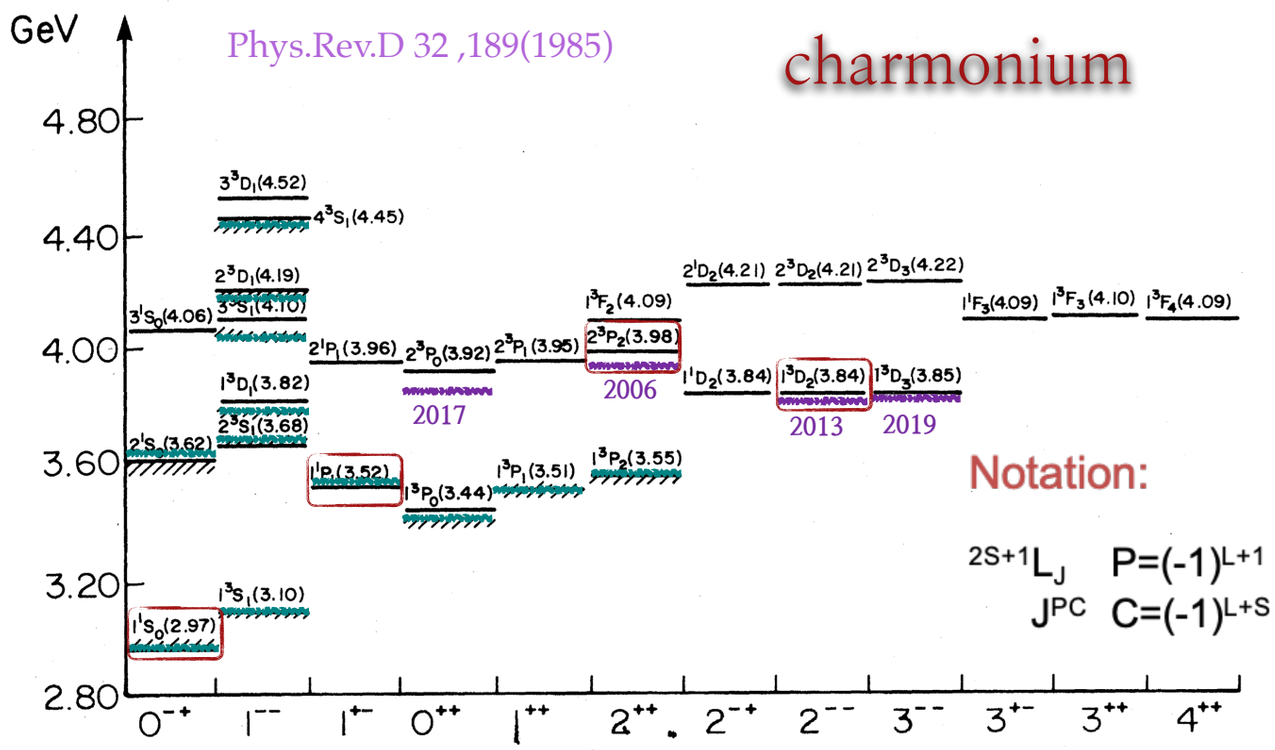


Charm Spectroscopy

- Excited states from inclusive reaction or B decays
- Much more states from updated theoretical calculation

Phys.Rev.D 93, 034035(2016)

Spectroscopy and Decay



Selected results in this talk

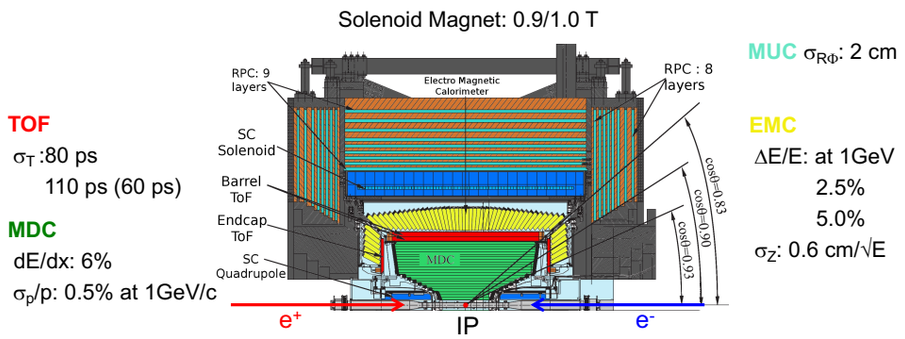
- New decay modes of η_c, h_c, and $\psi_2(3823)$
- Study of $\psi_2(3823)$ in $B^+ \to (J/\psi\pi^+\pi^-)K^+$ decays
- Study of $\chi_{c0,2}(2P)$ in $\gamma\gamma \to \gamma\psi(2S)$
- Charmonium/charm meson in $B^+ \to D^+D^-K^+$ decays
- Observation of $D_{s0}(2590)^+$ in $B \to D^-(D^+K^+\pi^-)$ decays
- Absolute Br. measurement of D_{sJ}

Experiments

BESIII at BEPCII

e^+e^- collision, $\sqrt{s}$ =2–5.0 GeV, $L_{peak} = 1 \times 10^{33}cm^{-2}s^{-1}$

Data Taking from 2009, $\psi(1,2S)/\psi(3770)$ peak; 2.0 – 5.0 GeV scan



BELLE at KEK

e^+e^- collision

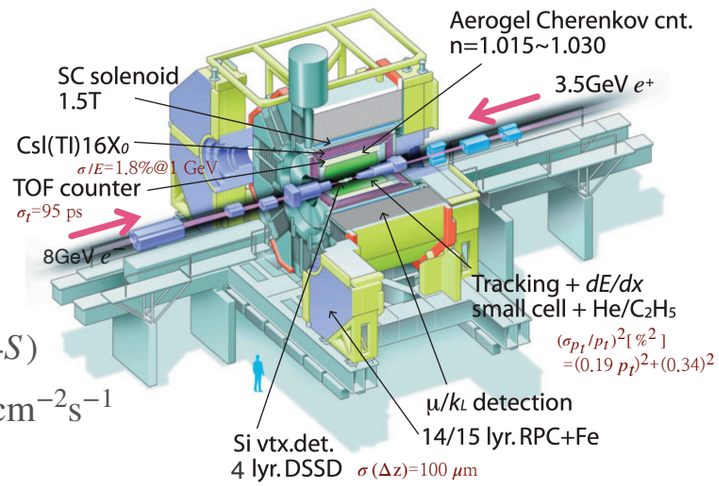
$\Upsilon(nS)$ peak/off peak

Data Taking 1999–2010

L_{int}: 980 fb^{-1}

772M $B\bar{B}$ @ $\Upsilon(4S)$

L_{peak} : $2 \times 10^{34}cm^{-2}s^{-1}$



LHCb at LHC

Forward single arm detector

pp collision

L_{int} : 3 fb^{-1} at $\sqrt{s}$ = 7,8 TeV

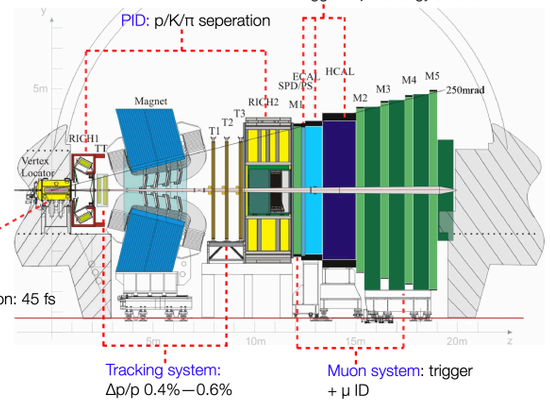
L_{int} : 6 fb^{-1} at $\sqrt{s}$ = 13 TeV

Run2:

$\sigma(pp \to b\bar{b}) \simeq 144\ \mu b$

$L_{peak} \simeq 4.4 \times 10^{32}$ $cm^{-2}s^{-1}$

pPb collision



CLEO-c

BABAR Collaboration Home Page

CMS

CDF II

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ATLAS EXPERIMENT

COMPASS

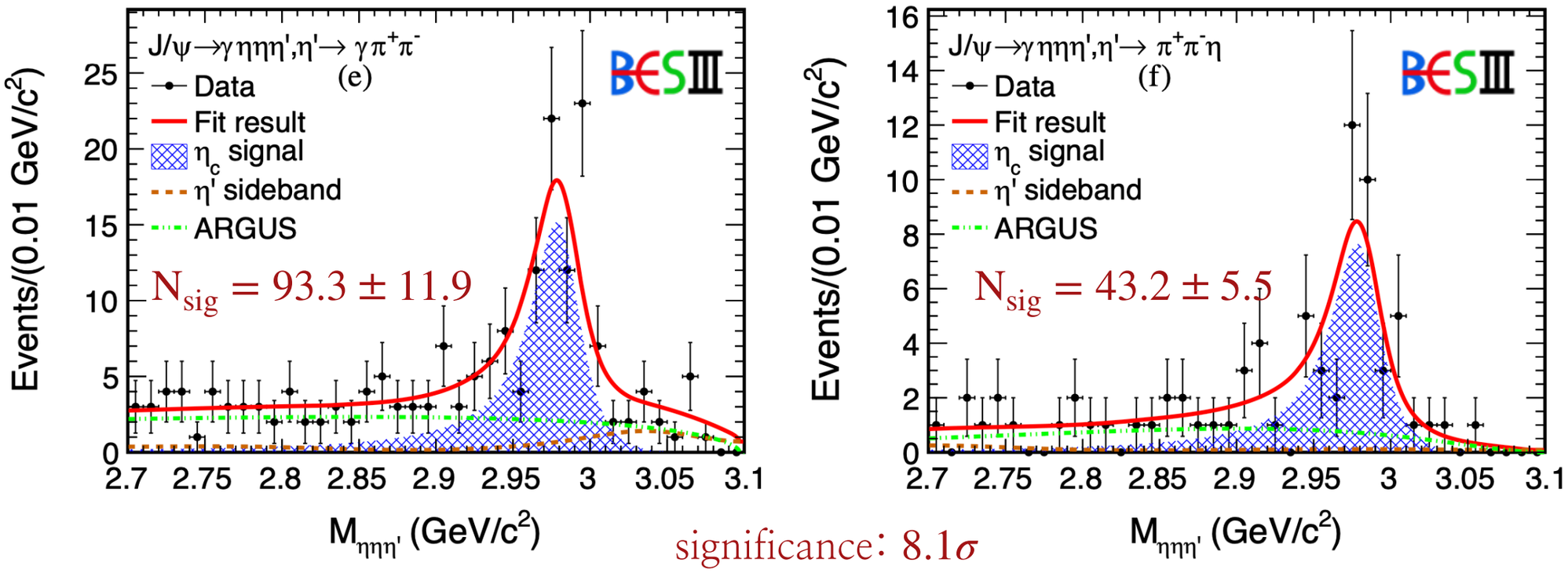
...

Observation of $\eta_c \to \eta'\eta\eta$

1^1S_0

- 1.31×10^9 J/ψ events, $J/\psi \to \gamma\eta'\eta\eta$
- Full reconstruction, $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \eta\pi^+\pi^-$ with $\eta \to \gamma\gamma$
- Interference with non−resonant contribution ignored
- $B[J/\psi \to \gamma\eta_c, \eta_c \to \eta'\eta\eta] = (4.86 \pm 0.62 \pm 0.45) \times 10^{-5}$, compatible to theoretical prediction (2.6×10^{-5}) Eur. Phys. J. A 54, 139 (2018)

Phys.Rev.D 103 ,012009(2021)



significance: 8.1σ

New Hadronic Decays of h_c 1^1P_1

- 4.48×10^8 $\psi(3686)$ events, h_c from $\psi(3686) \to \pi^0 h_c$ [$B = 8.6 \times 10^{-4}$], 3.85×10^5 h_c can be produced
- Systematic study of ten hadronic final states of h_c, mostly with kaons

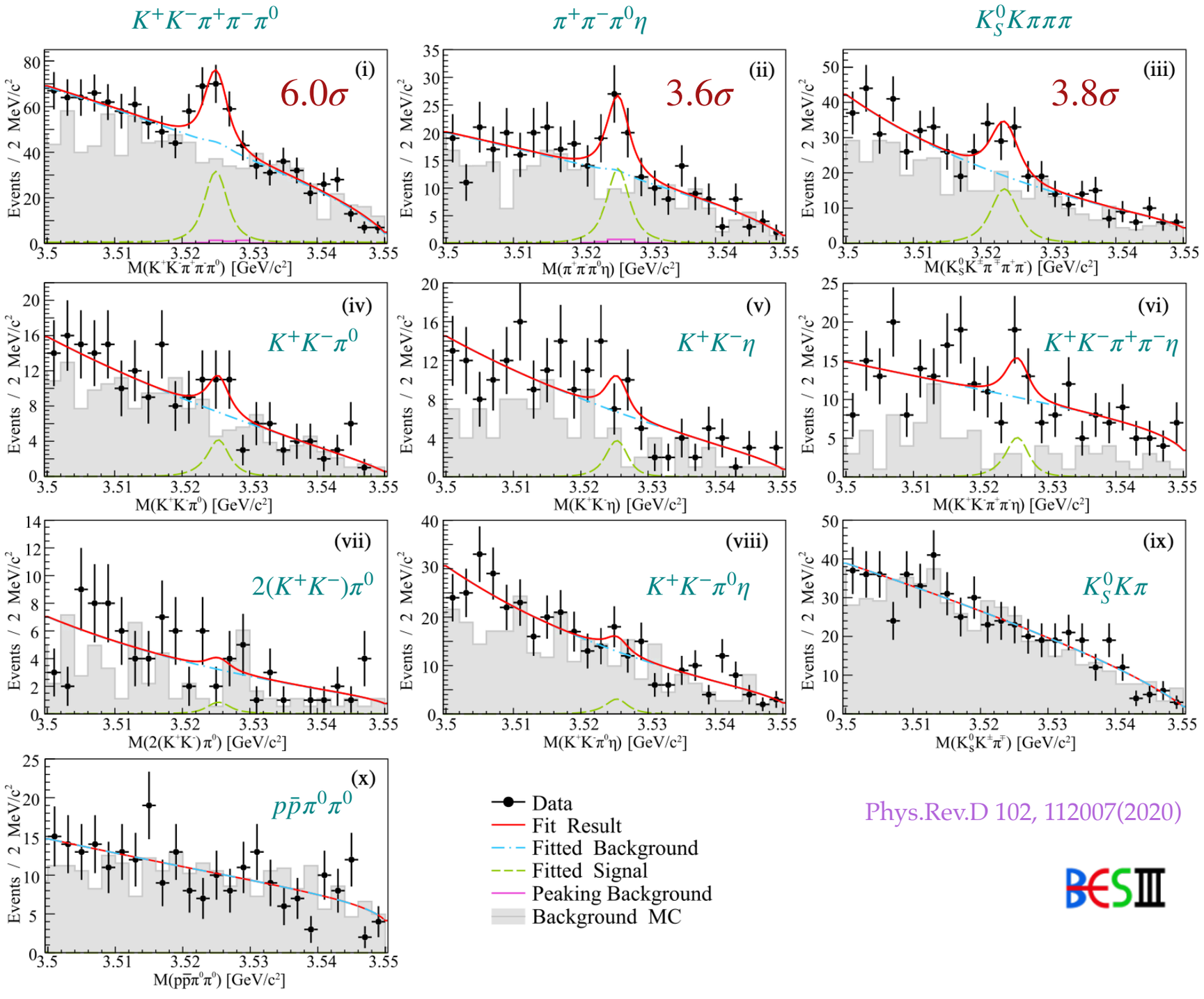
Phys.Rev.D 102, 112007(2020)

Mode	X	N_{h_c}	$\varepsilon(\%)$	$\mathcal{B}(\psi(3686) \to \pi^0 h_c) \times \mathcal{B}(h_c \to X)$	$\mathcal{B}(h_c \to X)$
(i)	$K^+K^-\pi^+\pi^-\pi^0$	80 ± 15	6.5	$(2.8 \pm 0.5 \pm 0.3) \times 10^{-6}$	$(3.3 \pm 0.6 \pm 0.6) \times 10^{-3}$
(ii)	$\pi^+\pi^-\pi^0\eta$	35 ± 9	3.3	$(6.2 \pm 1.6 \pm 0.7) \times 10^{-6}$	$(7.2 \pm 1.8 \pm 1.3) \times 10^{-3}$
		<50.0		$<1.5 \times 10^{-5}$	$<1.8 \times 10^{-2}$
(iii)	$K^0_S K^\pm \pi^\mp \pi^+ \pi^-$	41 ± 13	5.5	$(2.4 \pm 0.7 \pm 0.3) \times 10^{-6}$	$(2.8 \pm 0.9 \pm 0.5) \times 10^{-3}$
		<65.3		$<3.9 \times 10^{-6}$	$<4.7 \times 10^{-3}$
(iv)	$K^+K^-\pi^0$	<20.1	9.8	$<4.8 \times 10^{-7}$	$<5.8 \times 10^{-4}$
(v)	$K^+K^-\eta$	<18.5	14.3	$<7.5 \times 10^{-7}$	$<9.1 \times 10^{-4}$
(vi)	$K^+K^-\pi^+\pi^-\eta$	<24.1	6.9	$<2.0 \times 10^{-6}$	$<2.5 \times 10^{-3}$
(vii)	$2(K^+K^-)\pi^0$	<11.7	6.7	$<2.1 \times 10^{-7}$	$<2.5 \times 10^{-4}$
(viii)	$K^+K^-\pi^0\eta$	<20.2	6.3	$<1.8 \times 10^{-6}$	$<2.2 \times 10^{-3}$
(ix)	$K^0_S K^\pm \pi^\mp$	<17.4	14.4	$<4.8 \times 10^{-7}$	$<5.7 \times 10^{-4}$
(x)	$p\bar{p}\pi^0\pi^0$	<11.8	8.7	$<4.4 \times 10^{-7}$	$<5.2 \times 10^{-4}$

observation

BESIII

New Hadronic Decays of h_c



Phys.Rev.D 102, 112007(2020)

BESIII

$\psi_2(3823)$

1^3D_2

- Evidence of $\psi_2(3823)$ from Belle experiment in $B \to (\psi_2(3823) \to \gamma\chi_{c1})K$
  - $772 \times 10^6\ B\bar{B}$ events, 3.8σ
  - $M = 3823.1 \pm 1.8 \pm 0.7$ MeV, $\Gamma_{\text{tot}} < 24$ MeV

Phys.Rev.Lett. 111, 032001(2013)

- Observed by BESIII experiment in $e^+e^- \to \pi^+\pi^-\psi_2(3823), \psi_2(3823) \to \gamma\chi_{c1}$
  - Scan data sample at $\sqrt{s} = 4.23, 4.26, 4.36, 4.42, 4.60$ GeV, 6.2σ
  - $M = 3821.7 \pm 1.3 \pm 0.7$ MeV, $\Gamma_{\text{tot}} < 16$ MeV

Phys.Rev.Lett. 115, 011803(2015)

- Decays of $\psi_2(3823)$ to $\gamma\chi_{c2}$, $\pi^+\pi^- J/\psi$, ggg, γgg have been predicted by various theoretical work
  - $\Gamma_{\psi_2(3823)\to\gamma\chi_{c1}} \sim 200 - 350$ keV, $\Gamma_{\psi_2(3823)\to\gamma\chi_{c2}} \sim 40 - 90$ keV

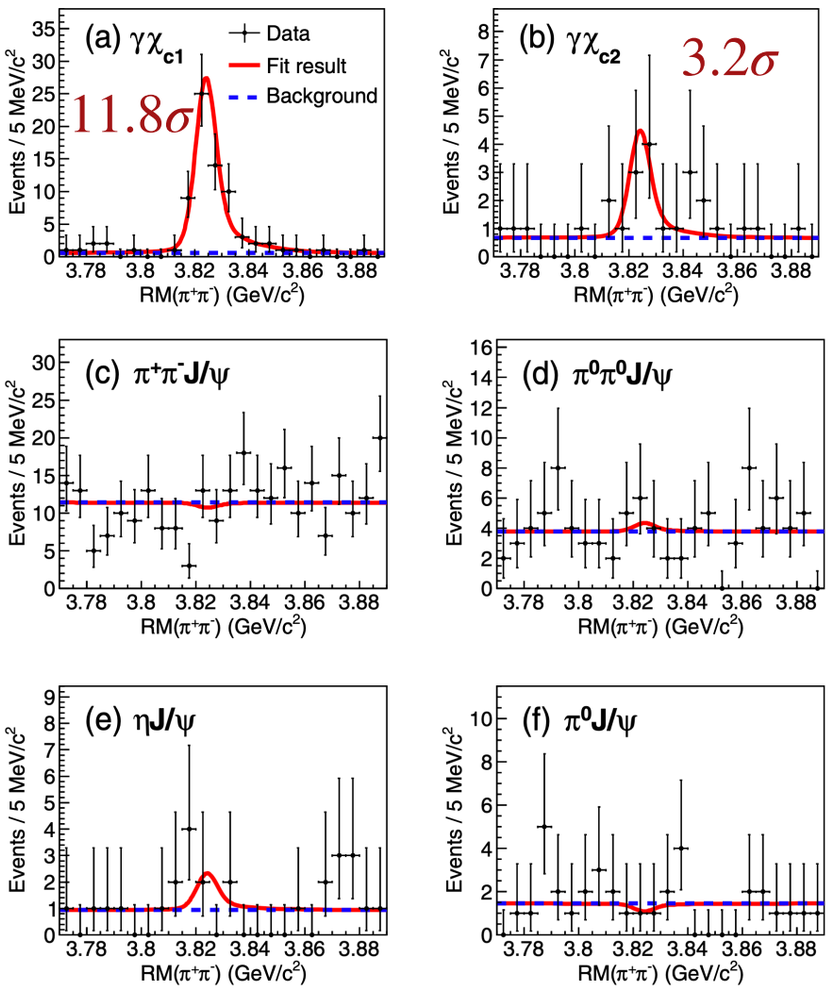
    $\Gamma_{\psi_2(3823)\to\gamma\chi_{c2}}/\Gamma_{\psi_2(3823)\to\gamma\chi_{c1}} \sim 0.19 - 0.32$
  - $\Gamma_{\psi_2(3823)\to\pi\pi J/\psi} \sim 45 - 200$ keV

    $\Gamma_{\psi_2(3823)\to\pi^+\pi^- J/\psi}/\Gamma_{\psi_2(3823)\to\gamma\chi_{c1}} \sim 0.12 - 0.39$

Phys.Rev.D 55, 4001(1997)
Phys.Rev.Lett. 89, 162002(2002)
Phys.Rev.D 67, 014027(2003)
Phys.Rev.D 69, 054008(2004)
Phys.Rev.D 72, 054026(2005)
Phys.Rev.D 79, 094004(2009)
Phys.Rev.D 94, 034005(2016)
Front.Phys. 11, 111402 (2016)
arXiv:1501.08269

New Decay Modes of $\psi_2(3823)$

- 9 fb^{-1} scan data sample between $\sqrt{s}$ = 4.3 and 4.7 GeV at BESIII experiment
  - $e^+e^- \to \pi^+\pi^-\psi_2(3823)$, study of the decays of $\psi_2(3823) \to \gamma\chi_{c0,1,2}$, $\pi^{+,0}\pi^{-,0}J/\psi$, $\eta J/\psi$, $\pi^0 J/\psi$



Phys.Rev.D 103, L091102(2021)

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

BESIII

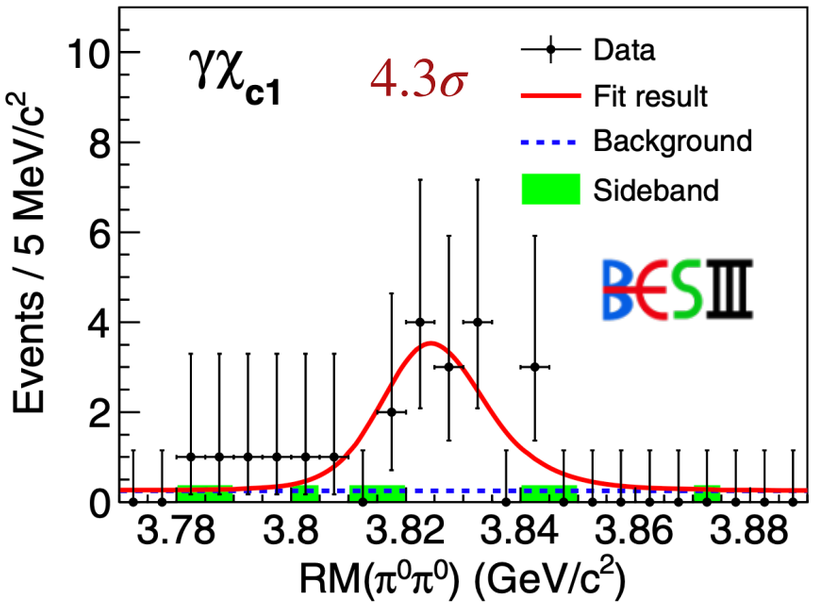
Lower then prediction

consistent with theoretical prediction

New Decay Modes of $\psi_2(3823)$

- 9 fb^{-1} scan data sample between $\sqrt{s} = 4.3$ and 4.7 GeV at BESIII experiment
  - Search for $e^+e^- \to \pi^0\pi^0\psi_2(3823)$ with $\psi_2(3823) \to \gamma\chi_{c1}$
  - $$\frac{\sigma[e^+e^- \to \pi^0\pi^0\psi_2(3823)]}{\sigma[e^+e^- \to \pi^+\pi^-\psi_2(3823)]} = 0.64^{+0.22}_{-0.20} \pm 0.05$$

Phys.Rev.D 103, L091102(2021)



$N_{\rm sig} = 15.9^{+5.1}_{-4.4}$

$\psi_3(1^3D_3)$ candidate

Found by LHCb in 2019

- Search for $e^+e^- \to \pi^+\pi^-\psi_3(3842)$
- Not found in any decay modes

$\psi_2(3823)$ from $B \to \psi_2(3823)K$

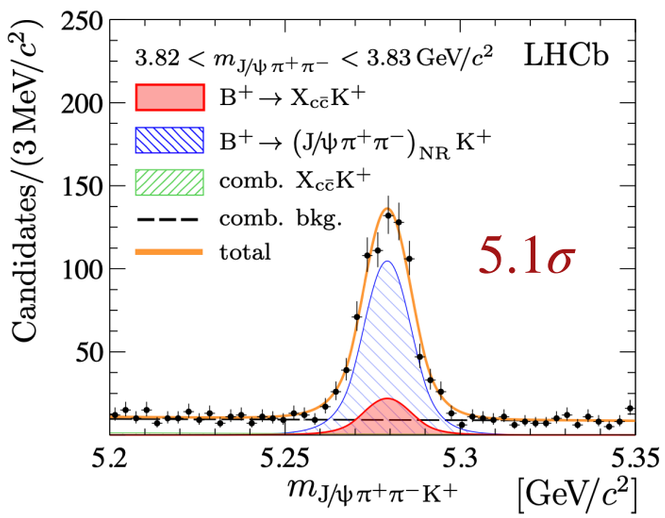
- 9 fb^{-1} pp collision data, $B^+ \to J/\psi\pi^+\pi^-K^+$ with $J/\psi \to \mu^+\mu^-$ JHEP 08 (2020) 123
  - Study $\psi(2S)$, $\psi_2(3823)$, and $\chi_{c1}(3872)$ at the same time
  - 2D fit to $m_{J/\psi\pi^+\pi^-K^+}$ and $m_{J/\psi\pi^+\pi^-}$
  - $M = 3824.08 \pm 0.53 \pm 0.14 \pm 0.01$ MeV, $\Gamma_{\rm tot} < 5.2$ MeV
  - $B[B^+ \to \psi_2(3823)K^+] \times B[\psi_2(3823) \to J/\psi\pi^+\pi^-] = (2.82 \pm 0.54 \pm 0.09 \pm 0.10) \times 10^{-7}$
  - Taking $B[B^+ \to \psi_2(3823)K^+] \times B[\psi_2(3823) \to \gamma\chi_{c1}] = (9.7 \pm 2.8 \pm 1.1) \times 10^{-6}$ from Belle experiment Phys.Rev.Lett. 111, 032001(2013)

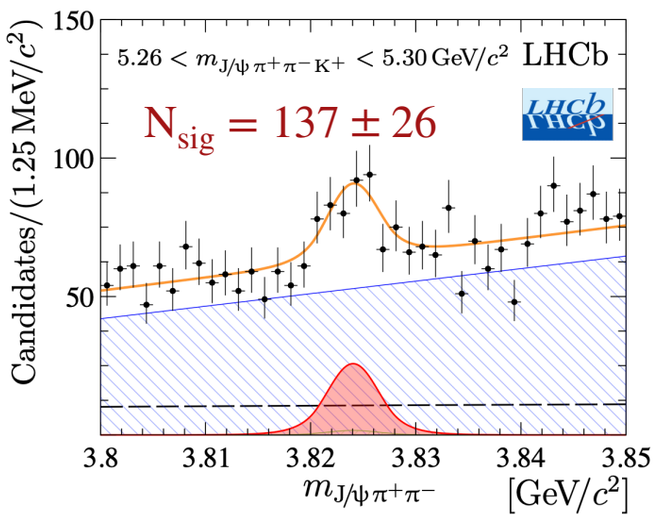
$$\frac{B[\psi_2(3823) \to \pi^+\pi^- J/\psi]}{B[\psi_2(3823) \to \gamma\chi_{c1}]} = 0.029$$

$$B[B^+ \to \psi_2(3823)K^+] = (1.24 \pm 0.25) \times 10^{-6}$$

Input/constrain for theoretical estimation of $D_s^{(*)+}\bar{D}^{(*)0}$ rescattering effect in $B \to c\bar{c}K$!

Phys.Rev.D 94, 034005(2016)





Study of $\gamma\gamma \to \gamma\psi(2S)$

$2^3P_{0,2}$

- P wave charmonium triplet states around 3.9 GeV
  - $\chi_{c0}(2P)$ candidate: $\chi_{c0}(3860)$ observed in $e^+e^- \to J/\psi D\bar{D}$
  - $\chi_{c2}(2P)$ candidate: $\chi_{c2}(3930)$ observed in $\gamma\gamma \to D\bar{D}$ Prog.Theor.Exp.Phys. 2020, 083C01 (2020)
  - $X(3915)$ observed in $\gamma\gamma \to \omega J/\psi$ and $B \to K\omega J/\psi$ $(0^{++}$ or $2^{++})$
  - $\chi_{c0}(3930)$ and $\chi_{c2}(3930)$ needed in LHCb's amplitude analysis of $B^+ \to D^+D^-K^+$

Phys.Rev.Lett. 102, 112003(2020)

  - Partial width of $\chi_{c0}(2P) \to \gamma\psi(2S) \approx 135$ keV, $\chi_{c2}(2P) \to \gamma\psi(2S) \approx 207$ keV

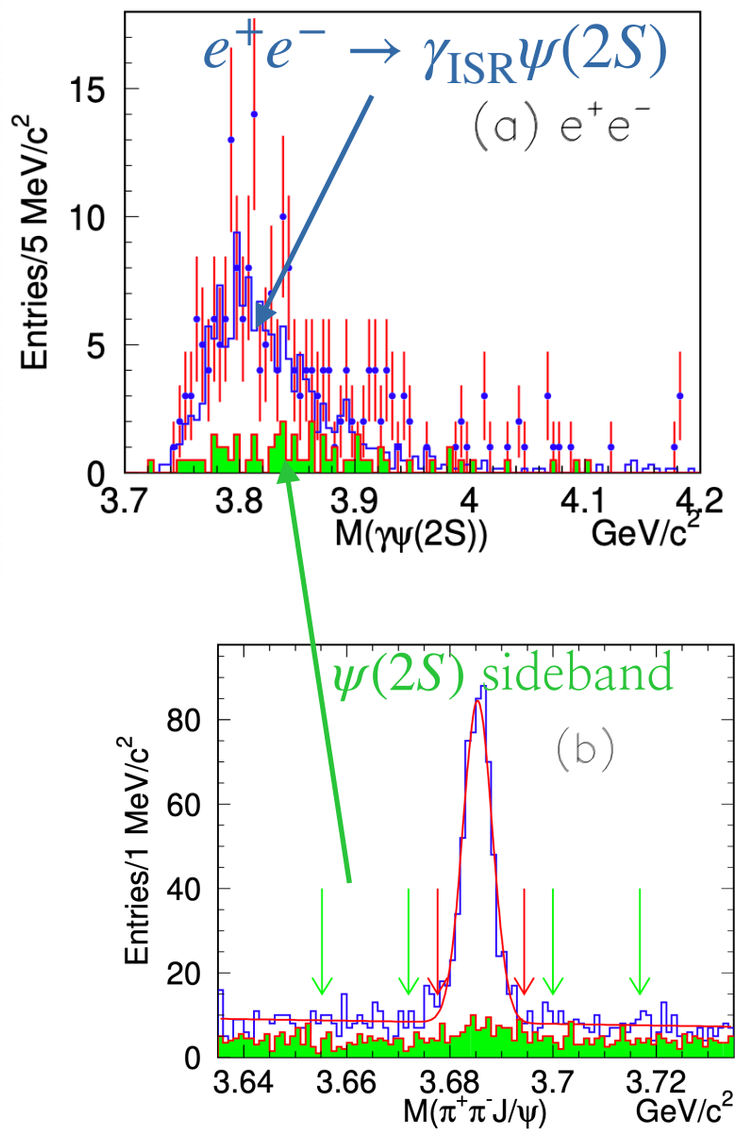
Phys.Rev.D 72, 054026(2005)

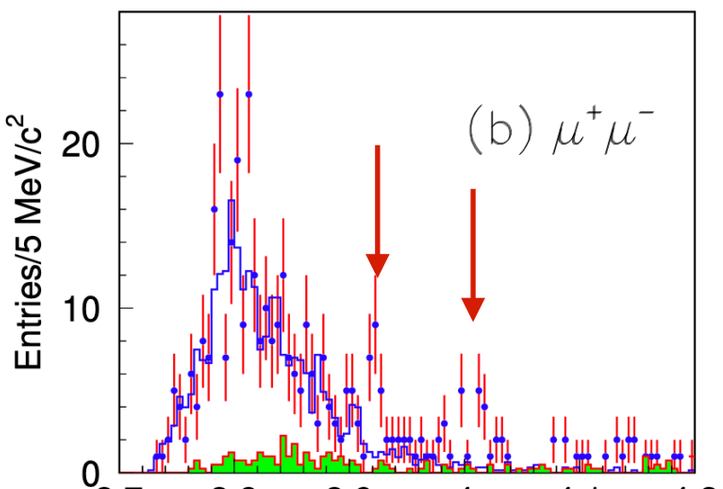
- 980 fb^{-1} data sample on the $\Upsilon(nS)$ resonance at Belle experiment, using $\gamma\gamma \to \gamma\psi(2S)$ decay with $\psi(2S) \to \pi^+\pi^- J/\psi$ and $J/\psi \to l^+l^-$

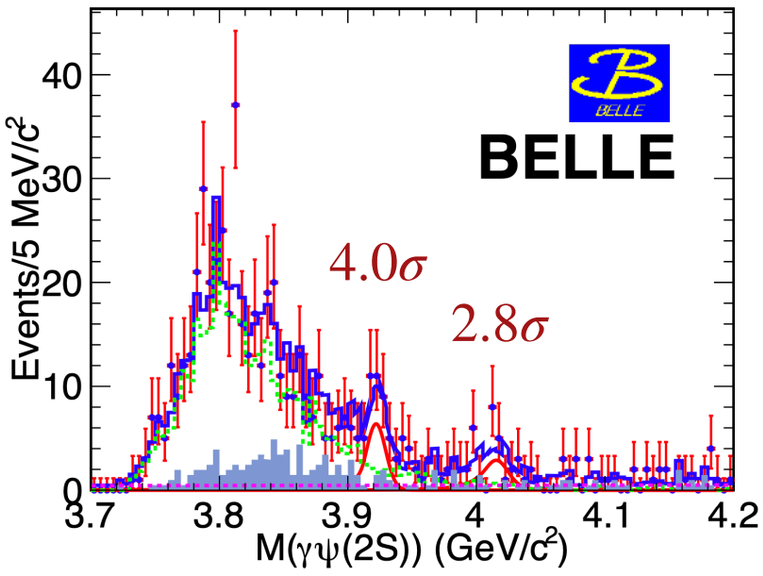
arXiv:2105.06605[hep-ex]

Study of $\gamma\gamma \to \gamma\psi(2S)$

arXiv:2105.06605[hep-ex]







- $M_1 = 3921.3 \pm 2.4 \pm 1.6$ MeV, $\Gamma_1 = 0.0 \pm 5.3 \pm 2.0$ (< 11.5) MeV, $N_1 = 30.3 \pm 8.6$, cannot distinguish between $\chi_{c2}(3930)$, $X(3915)$, or combination of two
- $M_2 = 4014.4 \pm 4.1 \pm 0.5$ MeV, $\Gamma_2 = 6 \pm 16 \pm 6$ (< 39.3) MeV, $N_2 = 18.2 \pm 9.3$
  close to $D^*\bar{D}^*$ threshold, $X_2(4013)$?
  mass close to $\chi_{c2}(2P)$ predicted by potential model (GI)

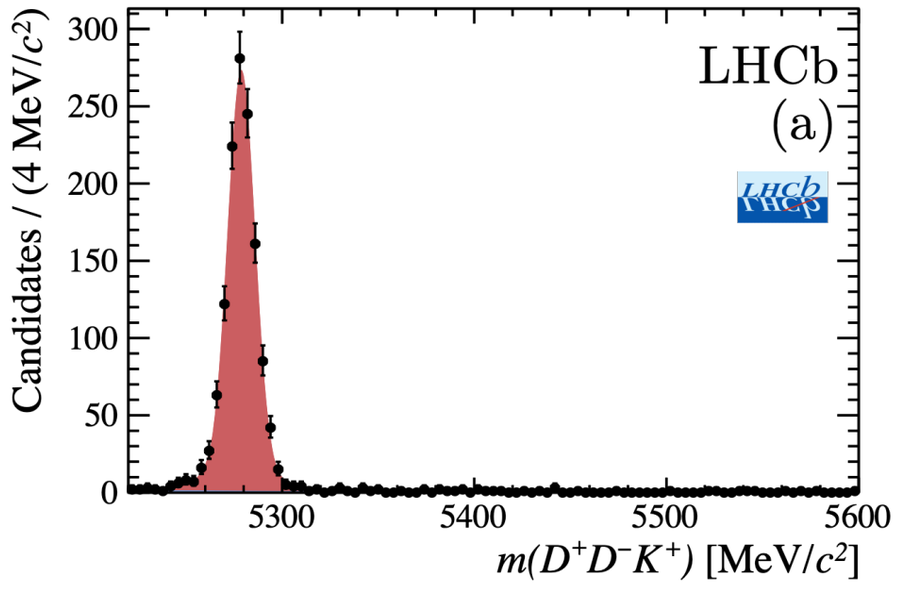
Phys.Rev.D 72, 054026(2005)

Charmonium/Charm Meson in $B^+ \to D^+D^-K^+$ Decays

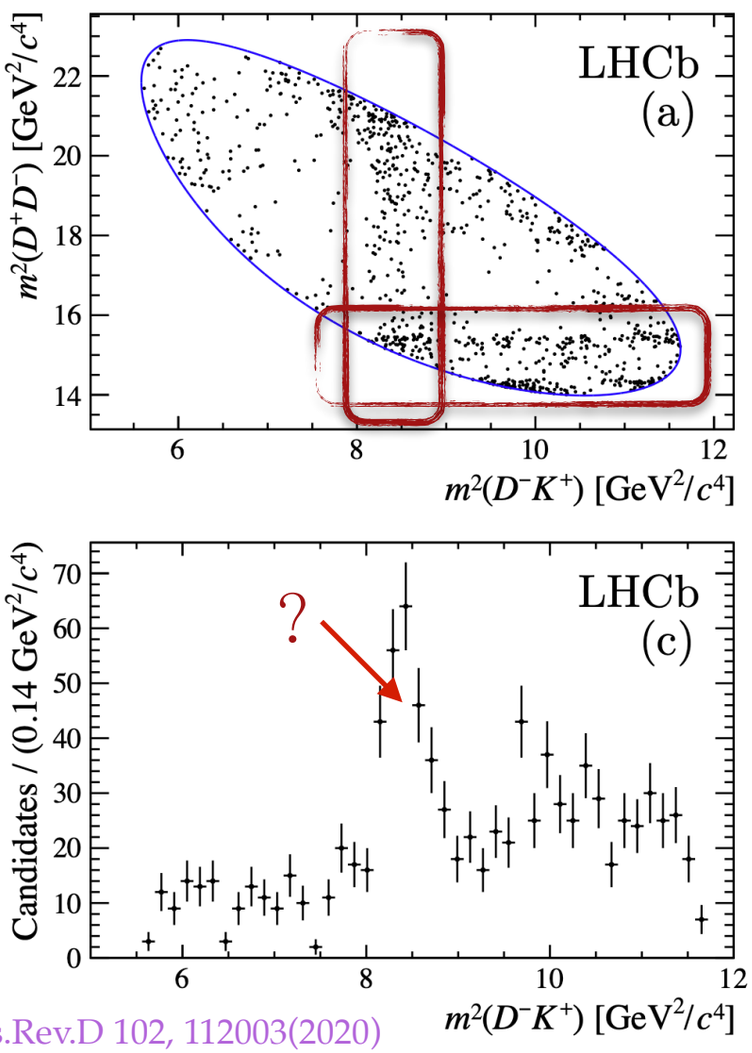
- $B^+ \to D^{(*)+}D^{(*)-}K^+$ decays offers unique opportunities to study charmonium states
  - Constrained environment of B meson decays
  - Low background level
  - Exotic hadrons in intermediate states, many in $c\bar{c}$, none in $c\bar{q}$ yet
- Could be used to aid characterization of the $c\bar{c}$ contribution in $B^+ \to K^+\mu^+\mu^-$ decays
- 9 fb^{-1} pp collision data, with $D^+ \to K^-\pi^+\pi^+$
  - 1374 candidates, 1260 have a value of $|m(D^+D^-K^+) - M_{B^+}| < 20$ MeV
  - Purity > 99.5 %

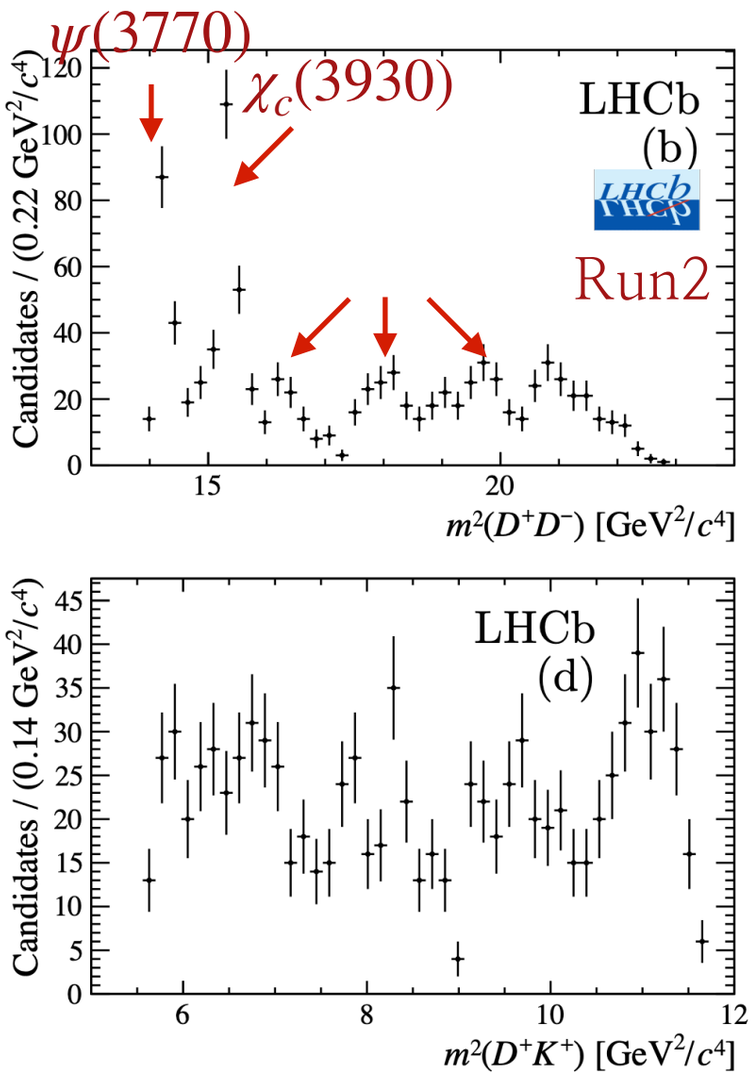
Phys.Rev.D 102, 112003(2020)

Phys.Rev.Lett. 125, 242001(2020)



Charmonium/charm Meson in $B^+ \to D^+D^-K^+$ Decays





Phys.Rev.D 102, 112003(2020)

Rich structures in $D\bar{D}$

0^{++}: $\chi_{c0}(3860)$

$X(3915)$ [could be 2^{++}]

1^{--}: $\psi(3770)$, $\psi(4040)$

$\psi(4160)$, $\psi(4415)$

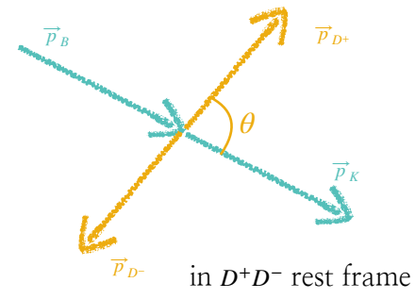
$\psi(4220)$, ...

2^{++}: $\chi_{c2}(3930)$

3^{--}: $X(3842)$

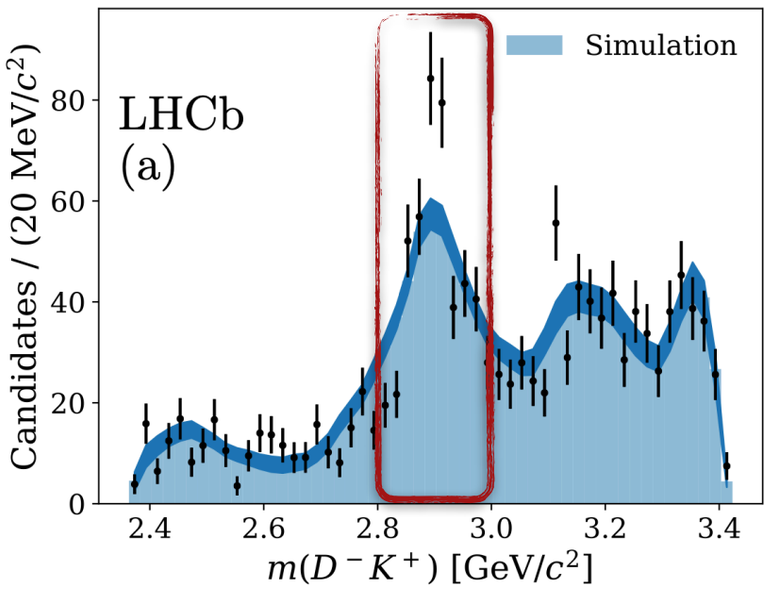
Model-independent Study

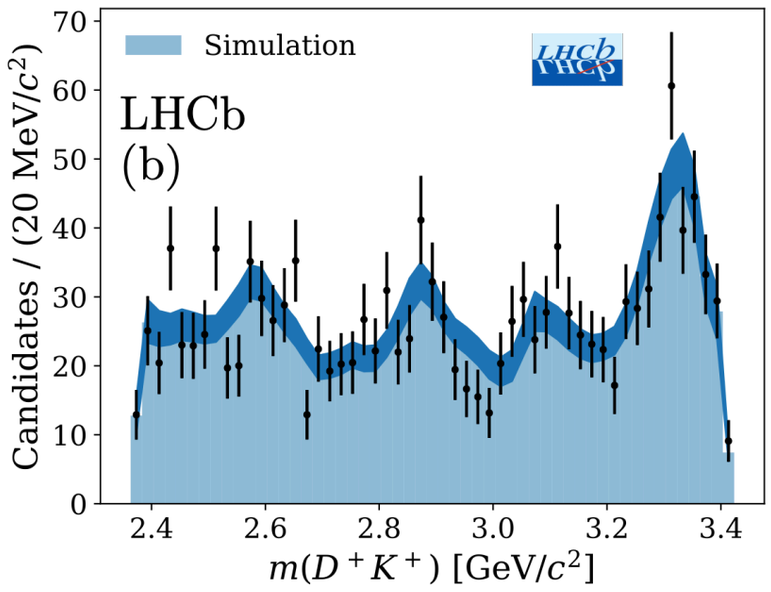
- In slides of the D^+D^- invariant mass, decomposing the $h(D^+D^-)$ in terms of Legendre polynomials [$h(D^+D^-)$: cosine of the D^+D^- helicity angle ($\cos\theta$)]
  - Construct full probability distribution, test significance of deviation between the truncated Legendre polynomial description and the date [Project in $m(DK)$]
- Moments up to order 4 (D^+D^- resonances up to spin-2), 3.9σ
- Moments up to 6, 3.7σ



- Structures in D^-K^+ around 2.9 GeV cannot be explained by D^+D^- reflection

Phys.Rev.Lett. 125, 242001(2020)

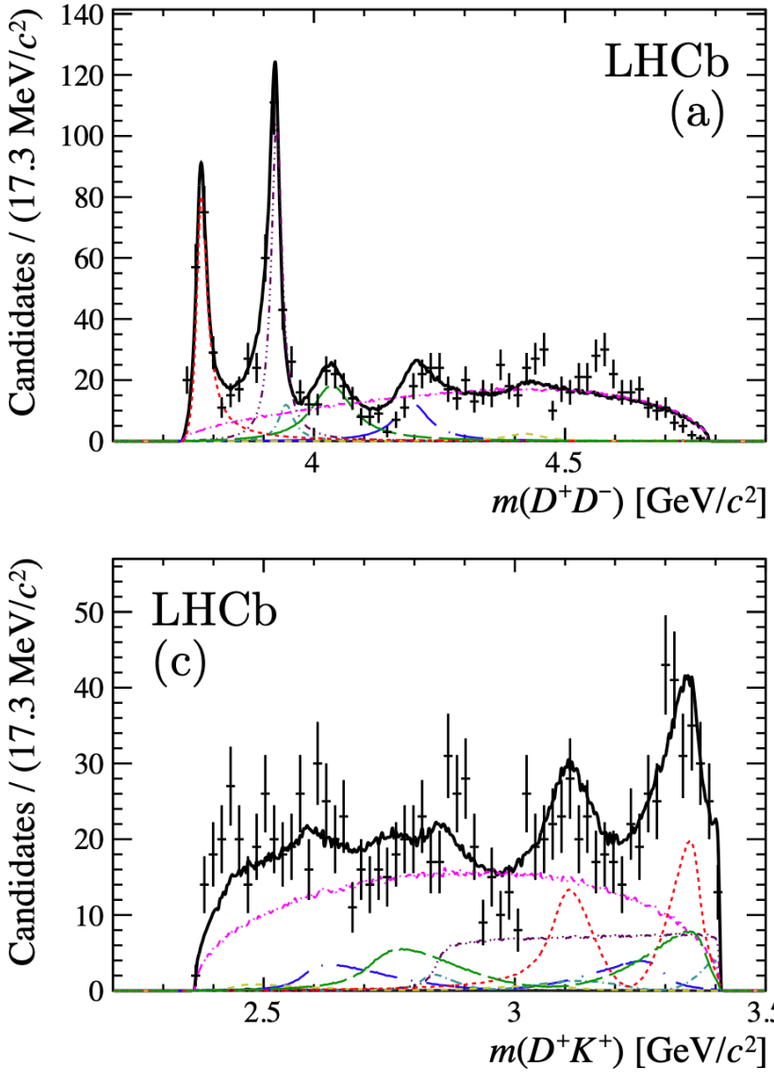


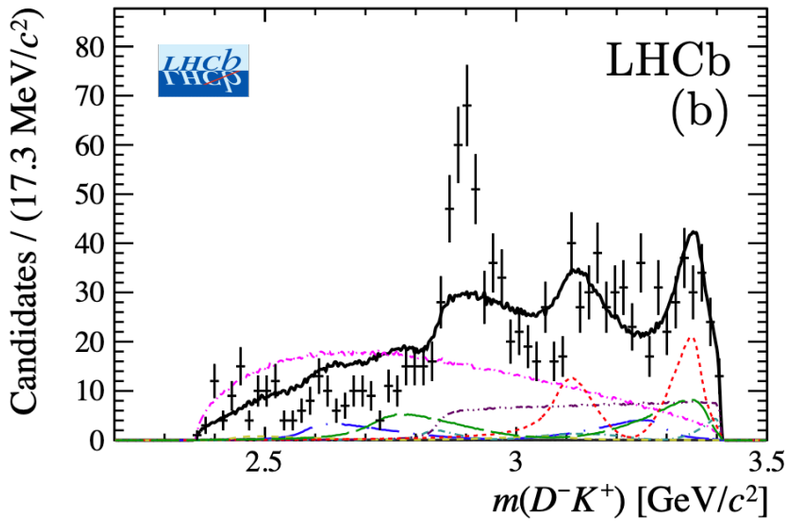


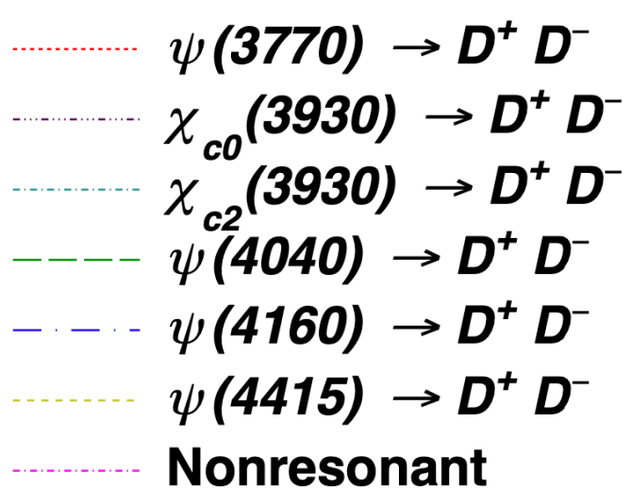
Amplitude Analysis

- Fit with only D^+D^- resonances, significant discrepancy in D^-K^+ around 2.9 GeV

Phys.Rev.D 102, 112003(2020)







Amplitude Analysis

Phys.Rev.D 102, 112003(2020)

- $X_0(2900)$:

  $M = 2866 \pm 7 \pm 2$ MeV

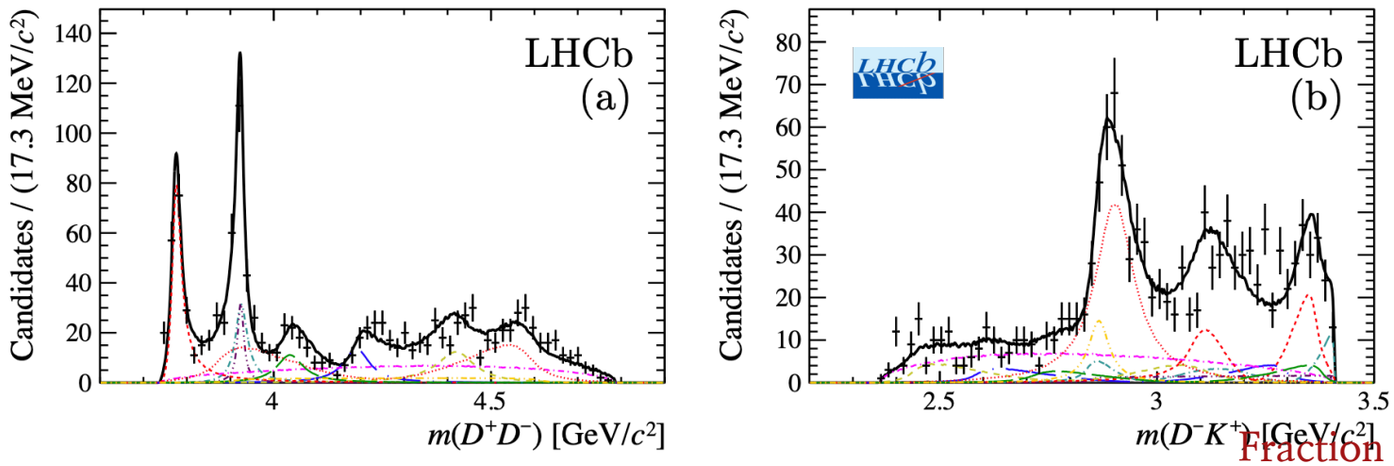
  $\Gamma = 57 \pm 12 \pm 4$ MeV

- $X_1(2900)$:

  $M = 2904 \pm 5 \pm 1$ MeV

  $\Gamma = 110 \pm 11 \pm 4$ MeV

- Other models are tested:
  one resonance (spin−0,1,2)
  two resonances (spin−1+2)



- Other hadronic effects (e.g. rescattering effect) cannot be ruled out
- If explained as resonance, exotic hadrons, more investigation needed!

Amplitude Analysis

$2^3P_{0,2}$

- $\chi_{c0}(3930)$:

  $M_0 = 3923.8 \pm 1.5 \pm 0.4$ MeV, $\Gamma_0 = 17.4 \pm 5.1 \pm 0.8$ MeV

- $\chi_{c2}(3930)$:

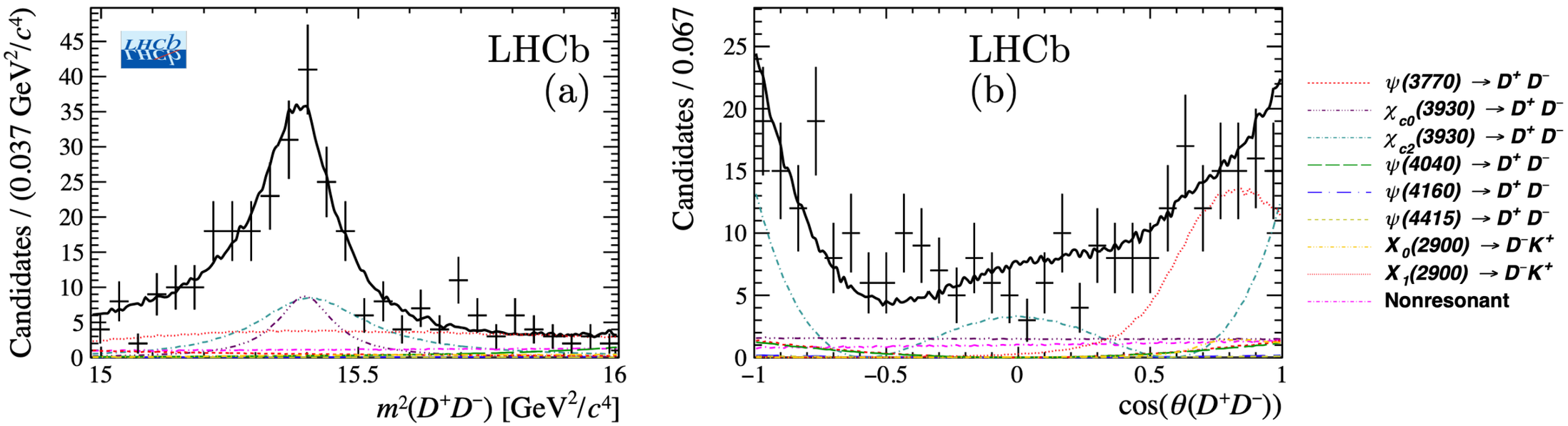
  $M_2 = 3926.8 \pm 2.4 \pm 0.8$ MeV, $\Gamma_0 = 34.2 \pm 6.6 \pm 1.1$ MeV

- No evidence of $\chi_{c0}(3860)$

$X(3915)$:
$M = 3921.7 \pm 1.8$ MeV
$\Gamma = 18.8 \pm 3.5$ MeV

$\chi_{c2}(3930)$:
$M = 3922.5 \pm 1.0$ MeV
$\Gamma = 35.2 \pm 2.2$ MeV

Phys.Rev.D 102, 112003(2020)

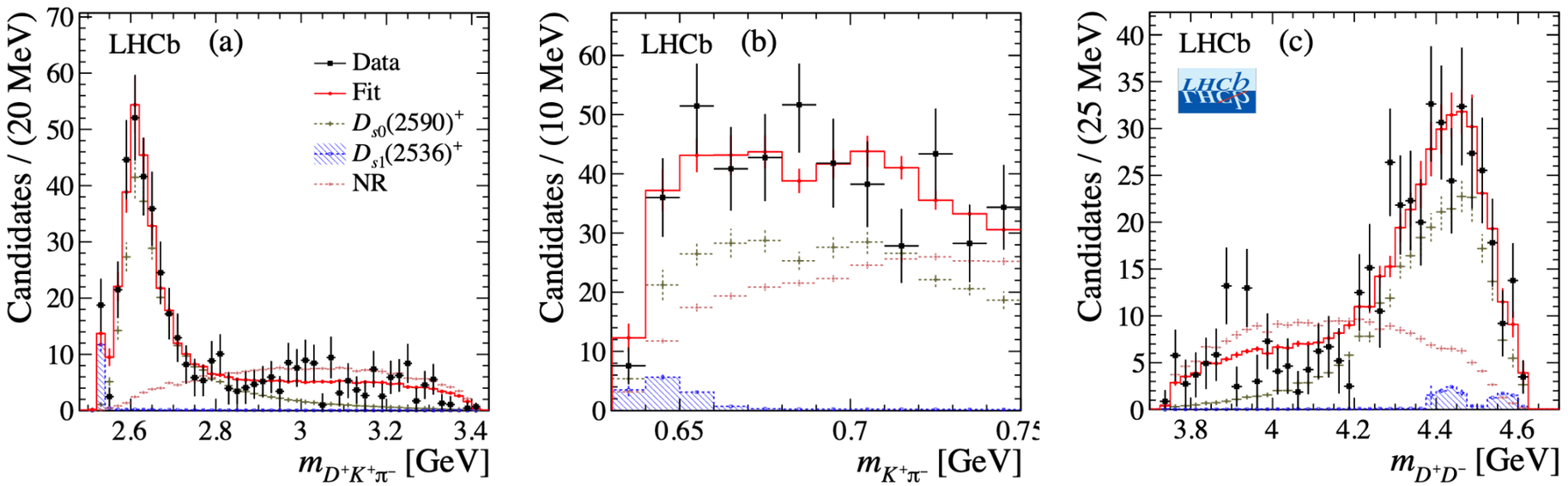


worse fit quality if include only one

Observation of $D_{s0}(2590)^+$ 2^1S_0

- Limited experiment information for radial excited charm−strange meson
- 2^1S_0 state is expected to be lightest, mass around 2.6 GeV
- D_s resonance decaying to $DK\pi$ final state has not been explored
- 5.4 fb^{-1} pp collision at $\sqrt{s} = 13$ TeV, using $B^0 \to D^-D^+K^+\pi^-$ decays with $D^\pm \to K^\mp\pi^\pm\pi^\pm$ final state, $K^+\pi^-$ restrict to be < 0.75 GeV

Phys.Rev.Lett. 126, 122002(2021)

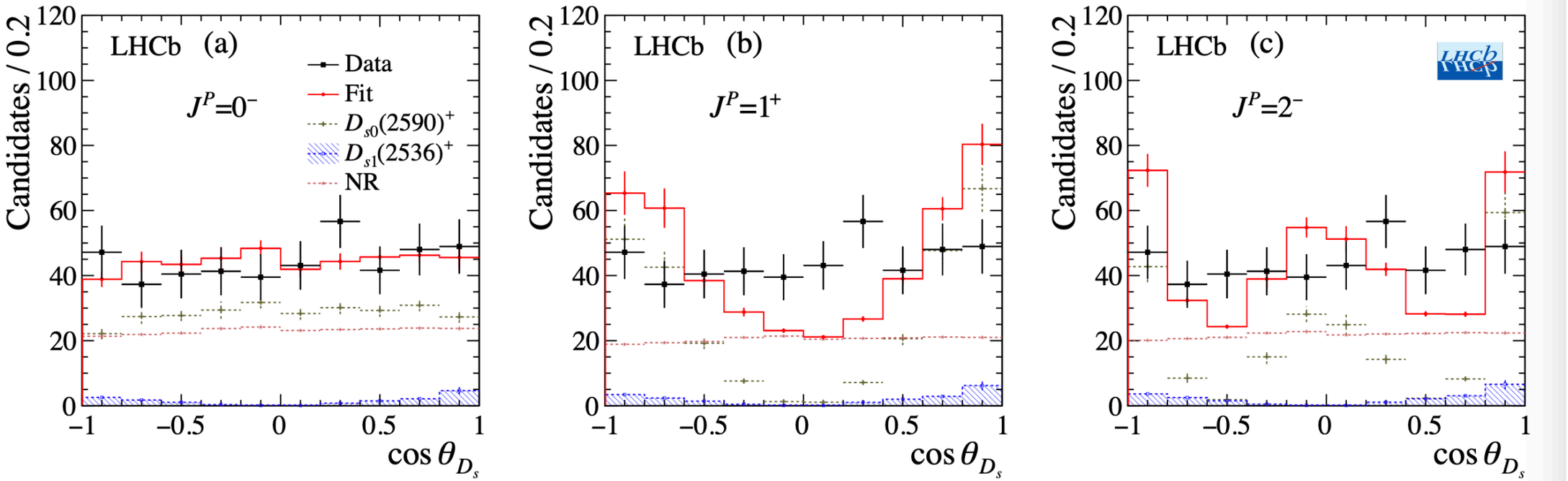


- $M = 2591 \pm 6 \pm 7$ MeV, $\Gamma = 89 \pm 16 \pm 12$ MeV (pole mass)

Observation of $D_{s0}(2590)^+$ 2^1S_0

- $J^P = 0^-$, strong candidate for $D_s(2^1S_0)^+$ state
- 1^+ and 2^- rejected with more than 10 standard deviations

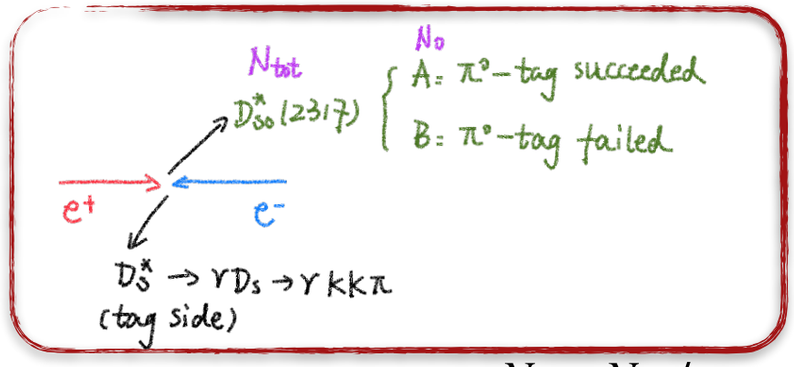
Phys.Rev.Lett. 126, 122002(2021)



Absolute Br. Measurement of $D_{s0}^*(2317)$

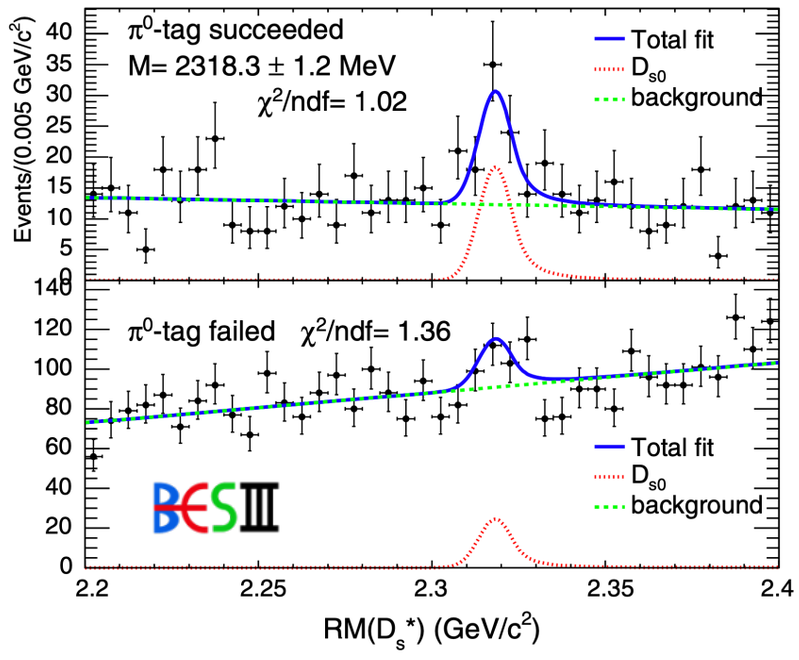
- $D_{s0}^*(2317)$ observed by BaBar experiment via its decay to $\pi^0 D_s^-$, $J^P = 0^+$

  Phys.Rev.Lett. 90, 242001 (2003)
- A $\bar{c}s$ meson, DK molecule, $\bar{c}sq\bar{q}$ tetra quark, or mixture
- Partial decay width is a key quantity to identify its nature
  - Pure $\bar{c}s$ meson: few to few tens keV; Molecule: hundred keV or larger
- 567 pb^{-1} data at $\sqrt{s} = 4.6$ GeV, using $e^+e^- \to D_s^* D_{s0}^0(2317)$ process with $D_s^* \to \gamma D_s$, $D_s \to KK\pi$



- $N_0 = \dfrac{N_{\rm tot}}{\epsilon_{\rm tot}} \cdot B \cdot \epsilon_{\rm sig} + \dfrac{N_{\rm tot}}{\epsilon_{\rm tot}} \cdot (1-B) \cdot \epsilon_{\rm bkg}$, $B = \dfrac{N_0 - N_{\rm tot}/\epsilon_{\rm tot} \cdot \epsilon_{\rm bkg}}{N_{\rm tot}/\epsilon_{\rm tot} \cdot (\epsilon_{\rm sig} - \epsilon_{\rm bkg})}$
- $N_{\rm tot} = 115 \pm 21$, $N_0 = 46.8 \pm 9.4(49.3)$, $B = 1.00^{+0.00+0.00}_{-0.14-0.14}$
- $M = 2318.3 \pm 1.2 \pm 1.2$ MeV

Phys.Rev.D 97, 051103(R) (2018)



- Similar method can be used for $D_{s1}(2536)$, $D_{s2}^*(2573)$, with data sample above 4.6 GeV

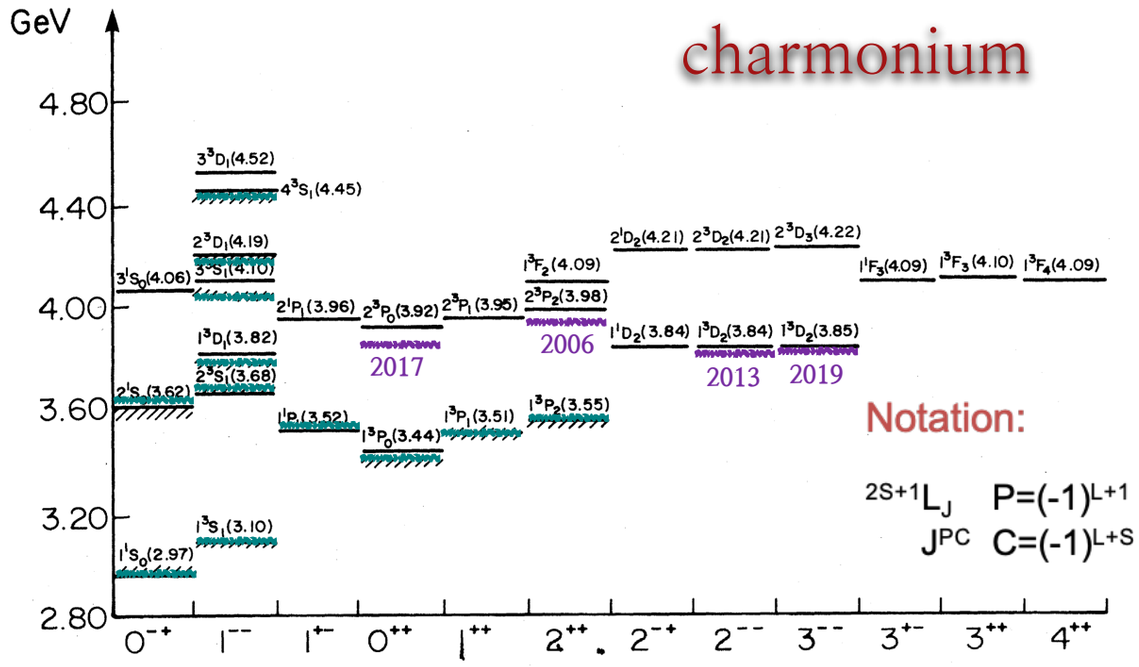
Summary and Perspectives

- Knowledge of charmonium and charm spectroscopy is improving, selected results from 2020–2021 are presented
- Charmonium states below open-charm threshold well established, while knowledge of their decay behavior need further improvement
- Excited states largely unknown
  - Precise measurement from experiment, need large data sample
    - BESIII: 10 billion J/ψ, 3 billion $\psi(2S)$ [on going], 20 fb^{-1} $\psi(3770)$ [on plan], $>$ 20 fb^{-1} from 3.8 to 5.0 GeV; An upgrade of BEPCII under discussion
    - Belle II: smooth data taking, $>$ 170 fb^{-1} accumulated, aim is 50 ab^{-1}
    - LHCb: Run3 from next year, 7x more data by 2029, half of these by 2023
  - Better description of data, development of theoretical models
- Looking forward to new excited results!

Thank you for your attention!

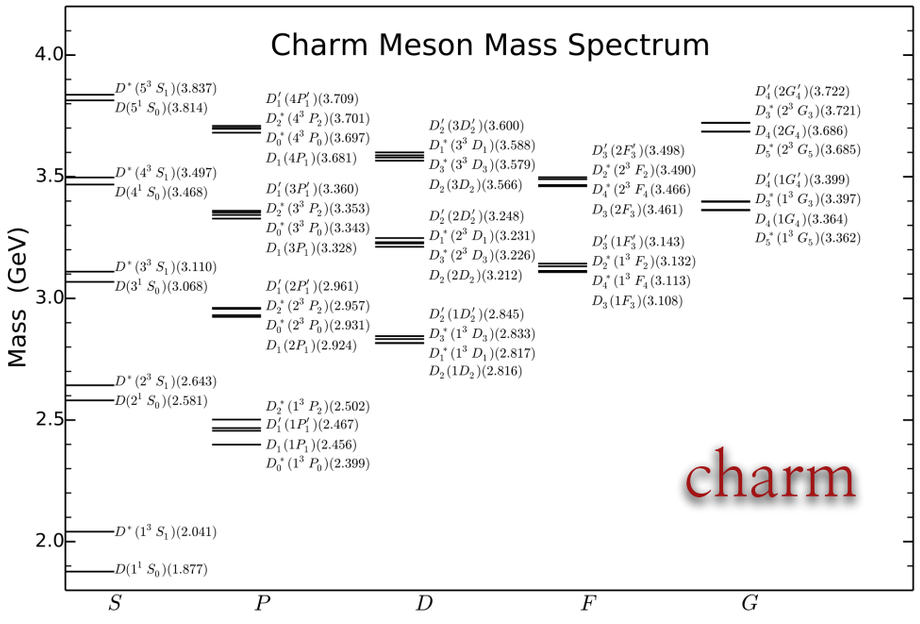
Charmonium/Charm Spectroscopy

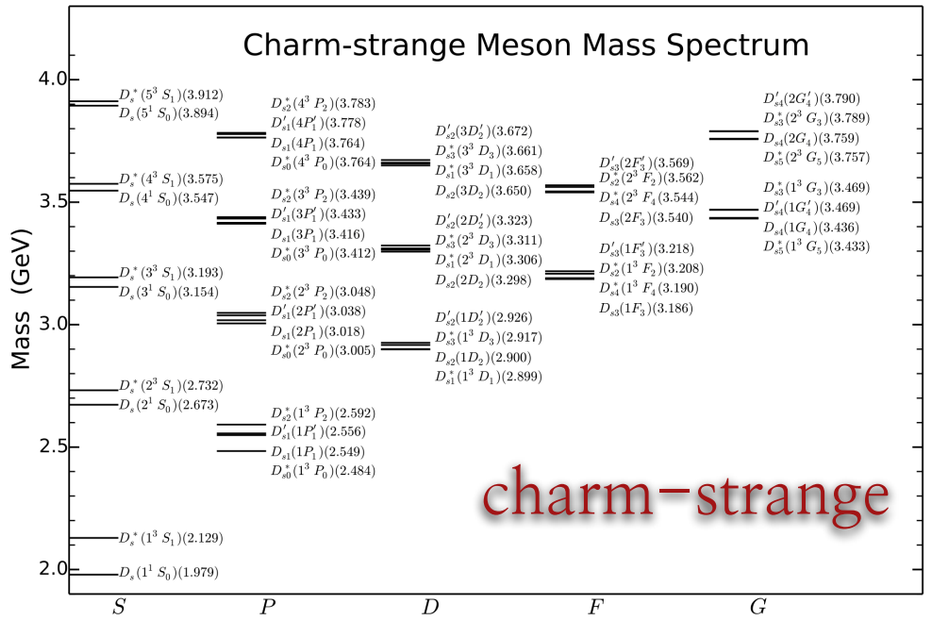
Phys.Rev.D 32 ,189(1985)



- Charmonium Spectroscopy
  - Well established below $2m_D$
  - Many excited states not found yet
  - Many exotic candidates observed

Phys.Rev.D 93, 034035(2016)





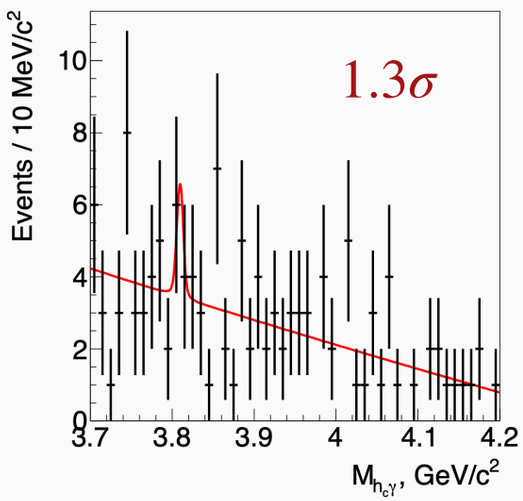
Search for $\eta_{c2}(1D)$ in B Decays

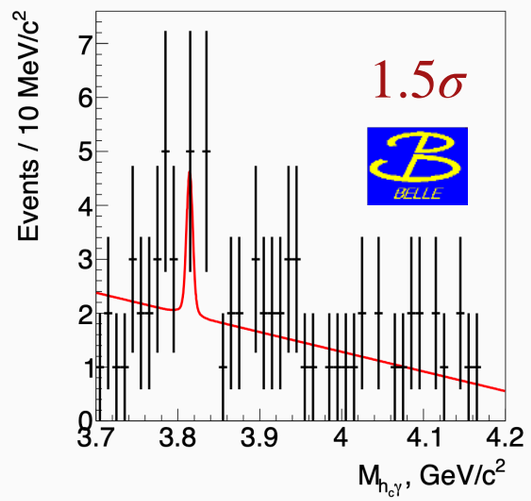
- $\eta_{c2}(1D)$ not observed yet, theoretical prediction of its properties
  - The mass very close to $\psi_2(1D)$ (~3823 MeV) arXiv:hep-ph/0412158
  - $M_{\eta_{c2}(1D)}$ calculated from hyperfine splitting:
    $\approx (3M_{\psi(3770)} + 5M_{\psi_2(1D)} + 7M_{\psi_3(1D)})/15 \approx 3822$ MeV
  - Cannot decay to $D\bar{D}^{(*)}$, expected to be narrow
  - Decay dominantly via an E1 transition to γh_c (~50%) Phys.Rev.Lett. 89, 162002(2002) Phys.Rev.D 80, 014001(2009)
- 711 fb^{-1} data sample on the $\Upsilon(4S)$ resonance at Belle experiment, using $B^{+,0} \to \eta_{c2}(1D)K^{+,0}$, $B^{+,0} \to \eta_{c2}(1D)\pi^{+,-}K^{0,+}$ decays with $\eta_{c2}(1D) \to \gamma h_c$ JHEP 05 (2020) 034
  - Ten decay modes of $h_c \to \gamma\eta_c$, $\eta_c \to X_i$
  - $\eta_{c2}(1D)$ signal searched in range between 3795 and 3845 MeV

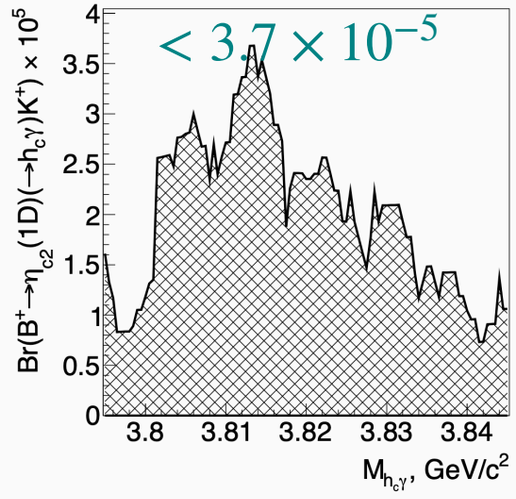
Search for $\eta_{c2}(1D)$ in B Decays

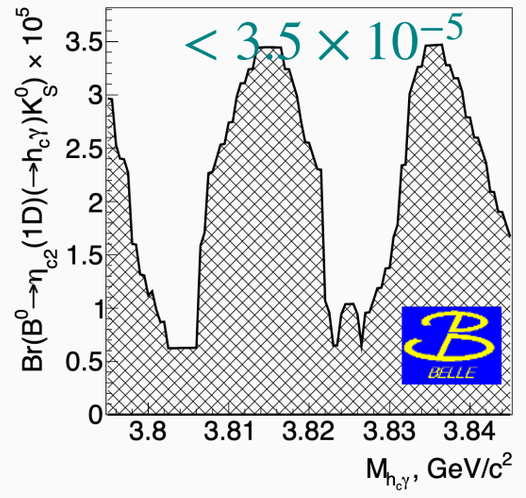
JHEP 05 (2020) 034

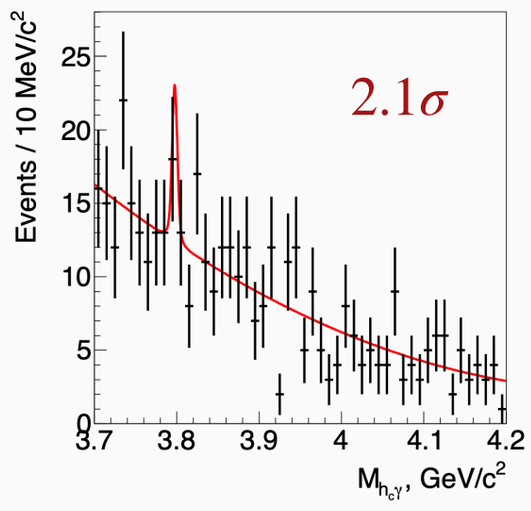
consistent with theoretical prediction
$(1.72 \pm 0.42) \times 10^{-5}$
can be observed with 10 ab^{-1} data

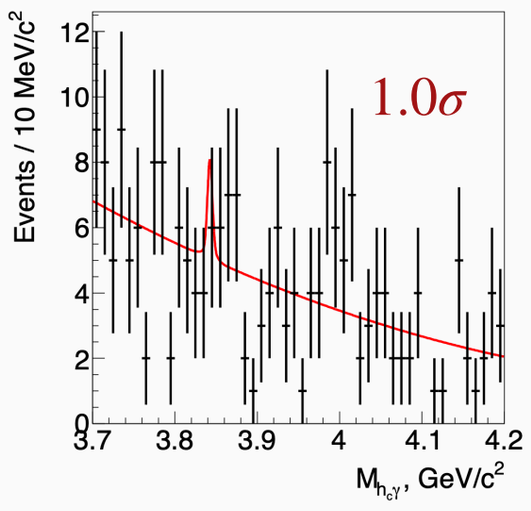


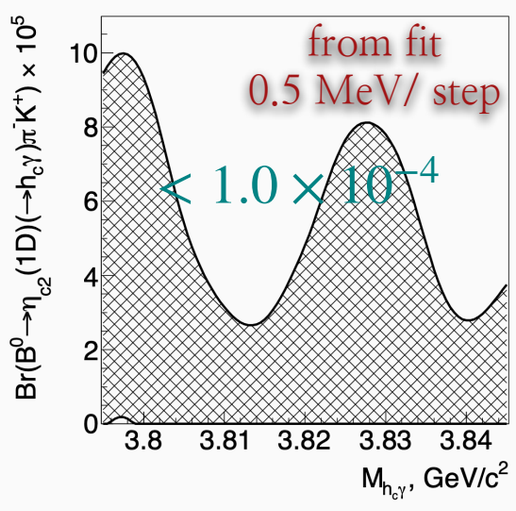


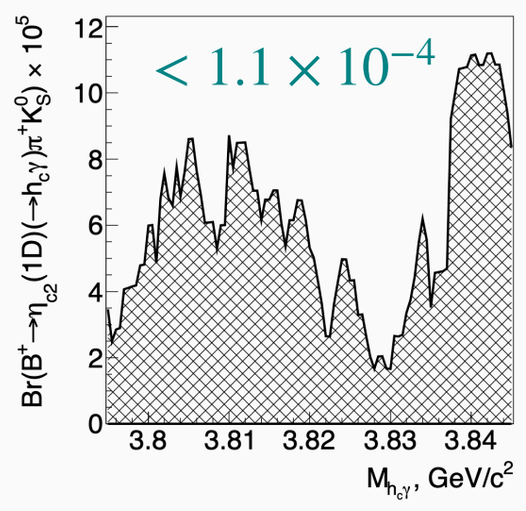








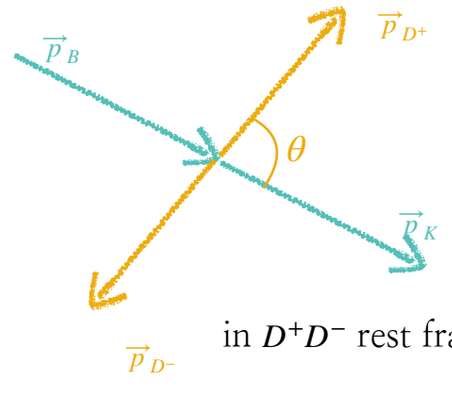




Model-independent Study

- In slides of the D^+D^- invariant mass, decomposing the $h(D^+D^-)$ in terms of Legendre polynomials
  - $h(D^+D^-)$: cosine of the D^+D^- helicity angle ($\cos\theta$)
  - For each D^+D^- bin, the k-th unnormalised momentum

$$< Y_k^j > = \sum_{l=1}^{N_j^{data}} w_l P_k(h_l(D^+D^-))$$



in D^+D^- rest frame

w_l: weight for background subtraction and detection efficiency

$k_{\max} = 2J_{\max}$

- Construct full probability distribution, test significance of deviation between the truncated Legendre polynomial description and the date [Project in $m(DK)$]

Phys.Rev.Lett. 125, 242001(2020)