Experimental review of Z_c states

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Ping Ronggang

Institute of High Energy Physics, CAS
pingrg@ihep.ac.cn

第五届 XYZ 粒子学术研讨会 , **2018年10月19至24日, 郑州， 郑州大学**

Z_c calendar

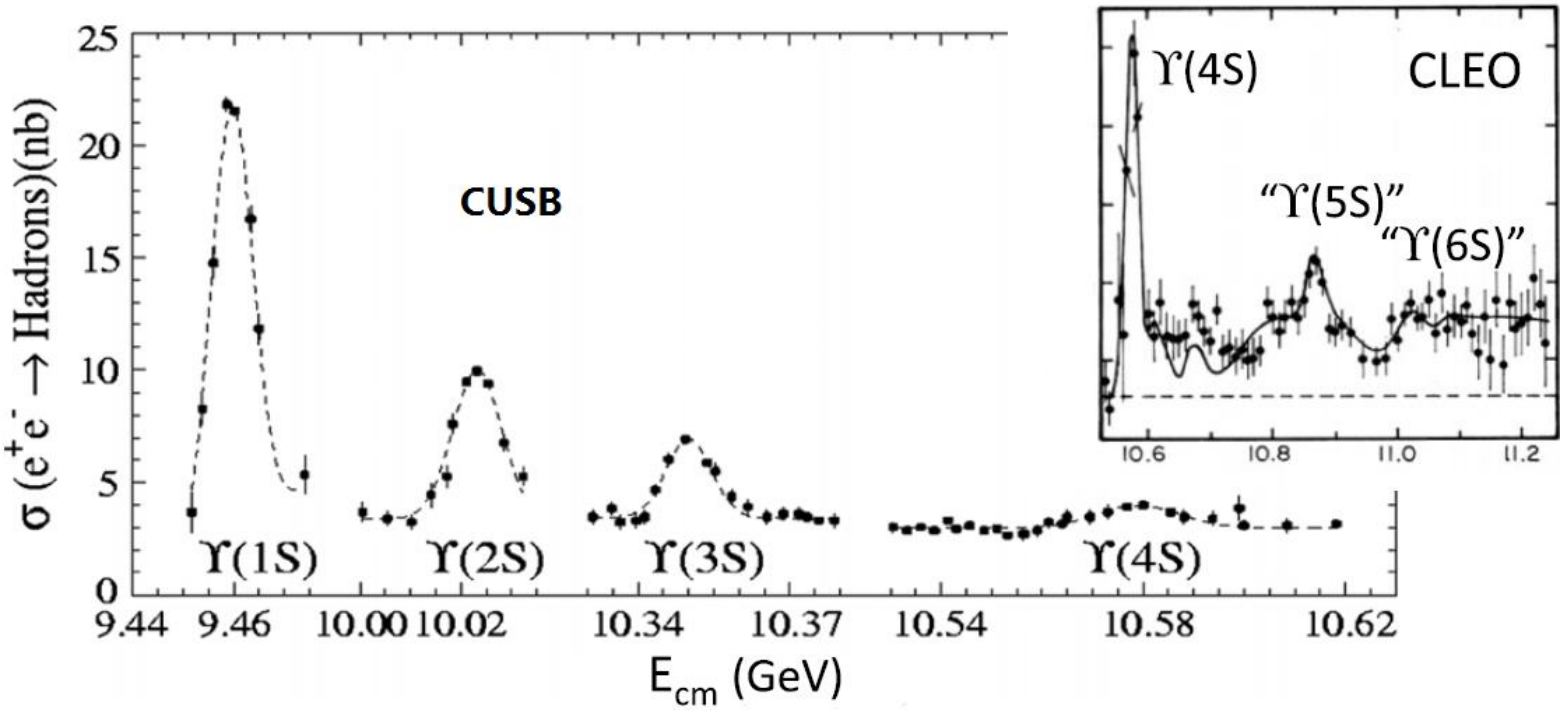
Year	State	M (MeV)	Γ (MeV)	Process	Exp.
2008	$Z_c(4430)^+$	4458 ± 15	166^{+37}_{-38}	$\overline{B_0} \to K^-(\psi(2S)\pi^+)$, $\overline{B_0} \to K^-(J/\psi\pi^+)$	Belle, LHCb
2008	$Z_c(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	$\overline{B_0} \to K^-(\chi_{c1}\pi^+)$	Belle
2008	$Z_c(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	$\overline{B_0} \to K^-(\chi_{c1}\pi^+)$	Belle
2013	$Z_c(3900)^\pm$	3891.2 ± 3.3	40 ± 8	$Y(4260) \to \pi^\pm(J/\psi\pi^\mp)$	BESIII
2013	$Z_c(4020)^\pm$	4022.9 ± 2.8	7.9 ± 3.7	$Y(4260,4360) \to \pi^\pm(h_c\pi^\mp)$	BESIII
2014	$Z_c(4200)^+$	4196^{+35}_{-38}	370^{+99}_{-110}	$\overline{B_0} \to K^-(J/\psi\pi^+)$	Belle
2014	$Z_c(4025)^\pm$	4026.3 ± 4.5	24.8 ± 9.5	$Y(4260) \to \pi^-(\overline{D}^{*-}D^{*+})$	BESIII
2014	$Z_c(4020)^0$	4023.9 ± 4.3	7.9 ± 3.7	$Y(4260,4360) \to \pi^0(h_c\pi^0)$	BESIII
2014	$Z_c(3885)^\pm$	3883.9 ± 4.5	25 ± 12	$Y(4260) \to \pi^-(\overline{D}^{*-}D^+)$	BESIII

Z_c calendar

Year	State	M (MeV)	Γ (MeV)	Process	Exp.
2015	$Z_c(4055)^{\pm}$	4032.1 ± 2.4	26.1 ± 5.3	$Y(4360) \rightarrow \pi^{\pm}(\psi(2S)\pi^{\mp})$	Belle
2015	$Z_c(4025)^0$	4025.5 ± 4.6	23.0 ± 6.1	$e^+e^- \rightarrow \pi^0(\bar{D}^*D^*)^0$	BESIII
2015	$Z_c(3885)^0$	3885.7 ± 9.8	35 ± 19	$e^+e^- \rightarrow \pi^0(\bar{D}^*D)^0$	BESIII
2018	$Z_c(4100)^-$	$4096 \pm 20^{+18}_{-22}$	$152 \pm 58^{+60}_{-35}$	$B^0 \rightarrow \eta_c K^+\pi^-$	LHCb

Heavy flavor experiments

- Babar and Belle experiments

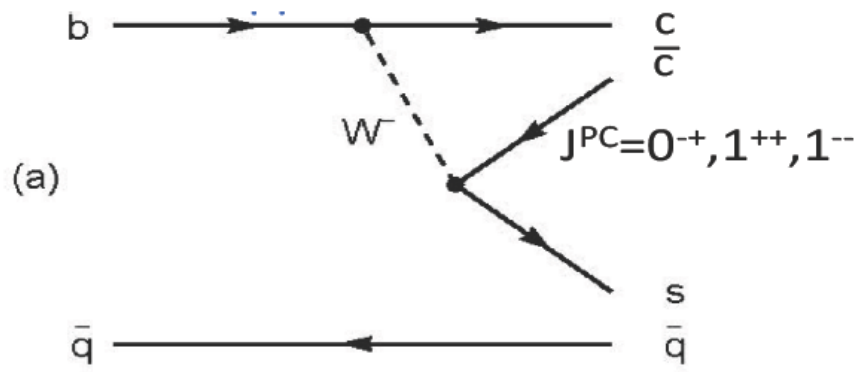


- *B*-factory at 10.58 GeV

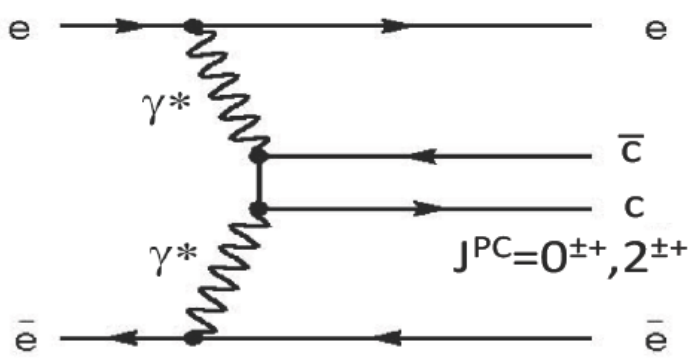
  $\Upsilon(4S)$: 10.58 GeV > 2 M_B

Charm quark production at *B*-flavor

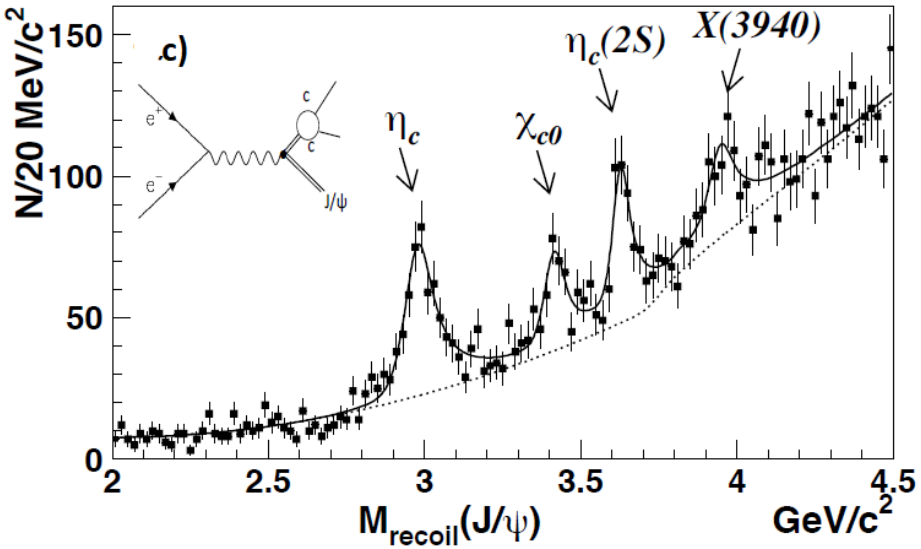
Color-suppressed B-meson decays



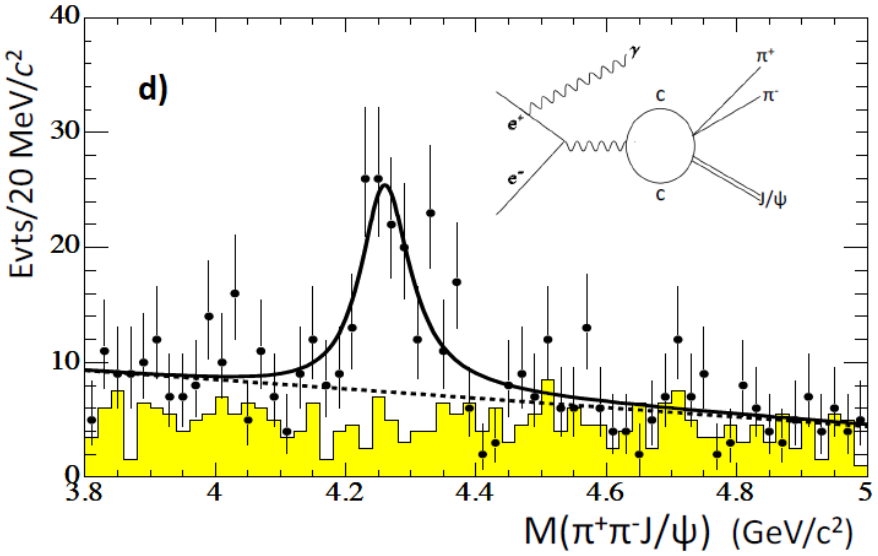
Two-photon fusion processes



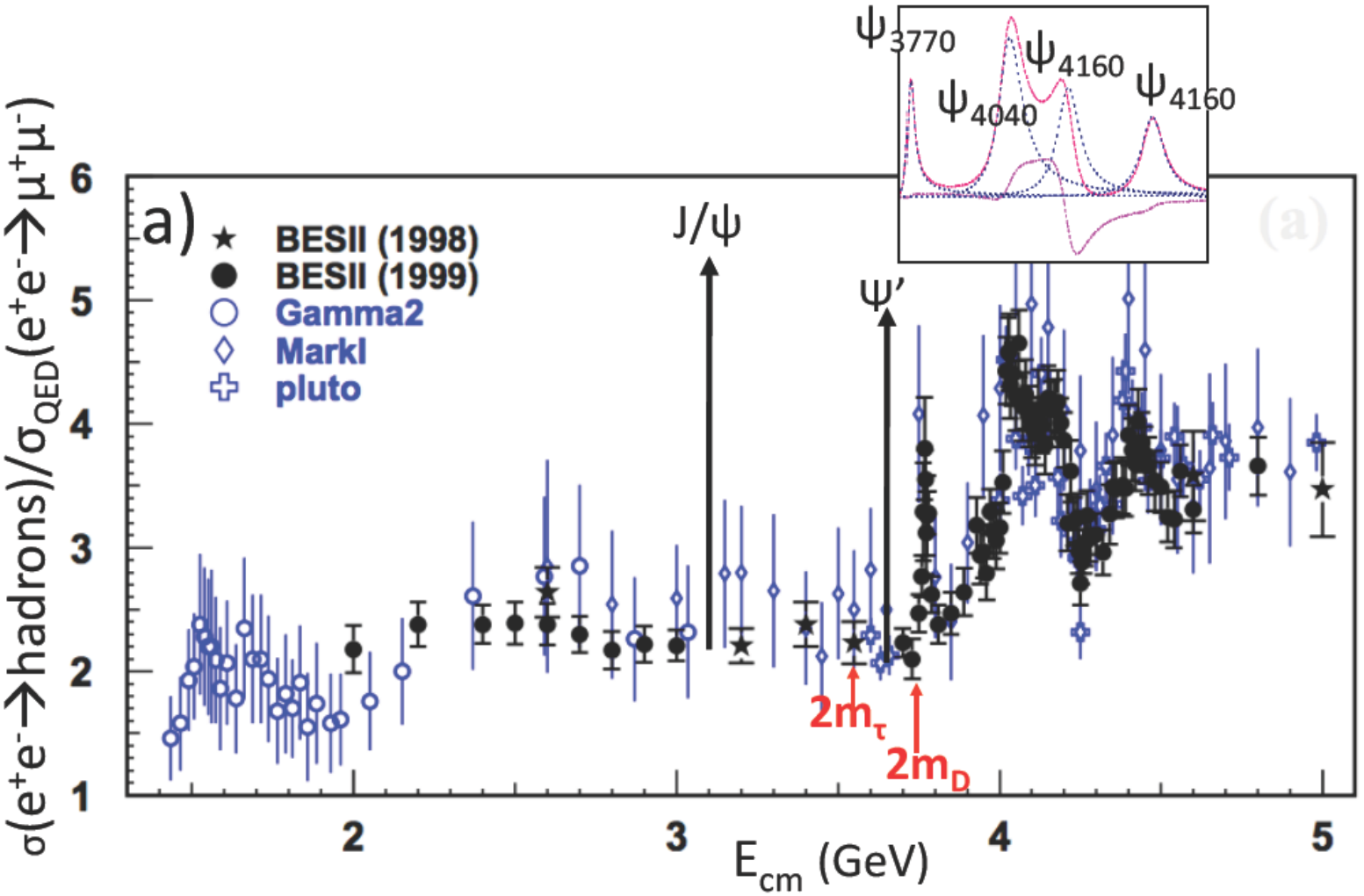
double charmonium production



Initial state radiation (ISR)

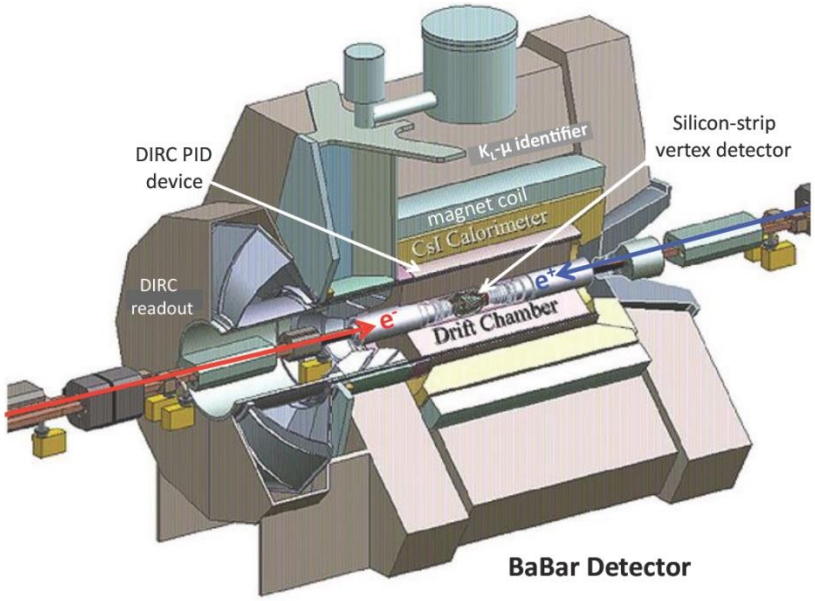


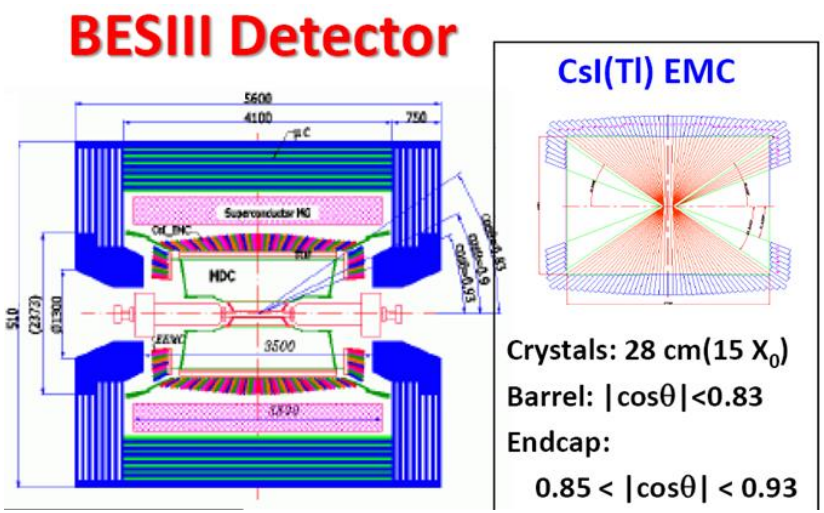
BESIII as tau-charm factory



- Vector charmonium directly produced
- No ISR luminosity penalty, and clean background

Detector



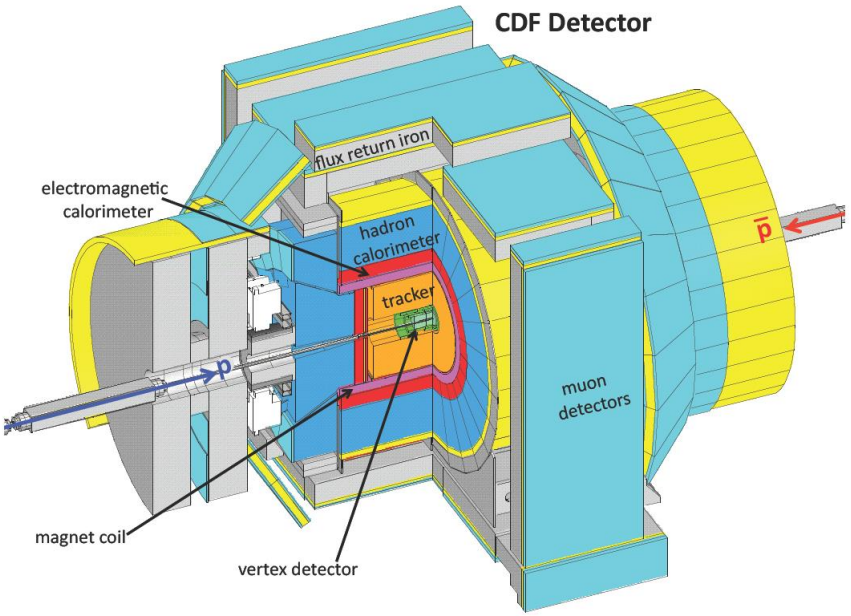


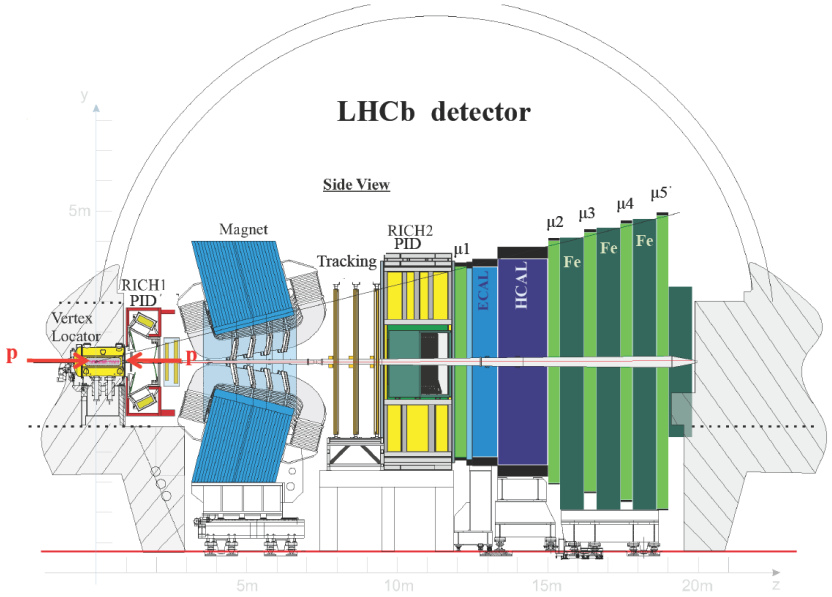
Common structure:

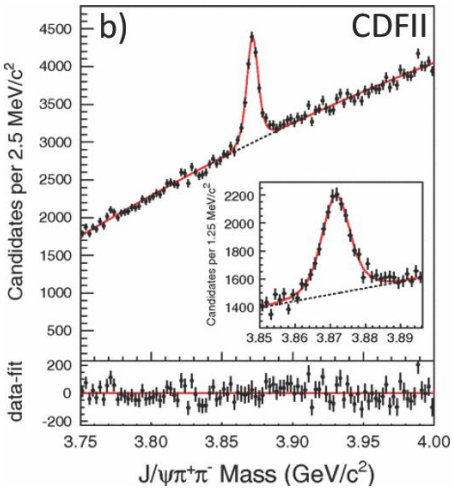
- Vertex measuring system
- Gas-filled drift chamber: charged particle trajectory
- Particle identification device
- Electromagnetic calorimeter: CsI crystals measure photon

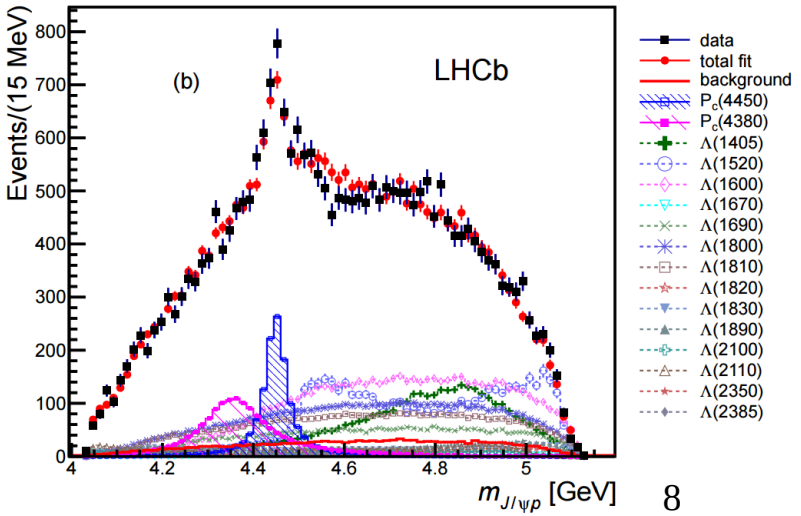
Differs in many details, esp. PID

High p_T detector at high-energy hadron collider





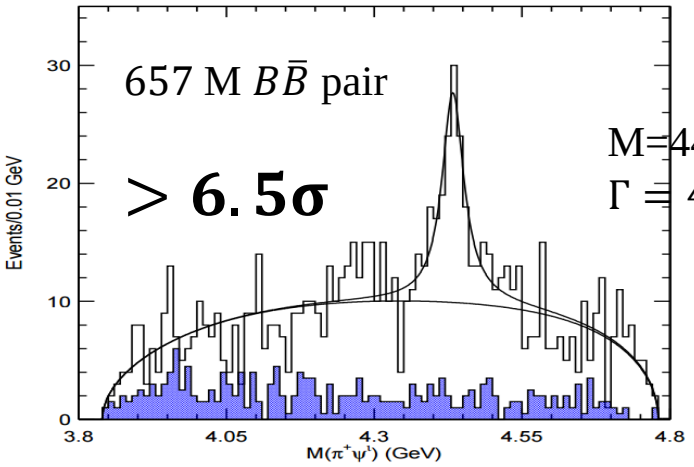




$Z(4430)^+$

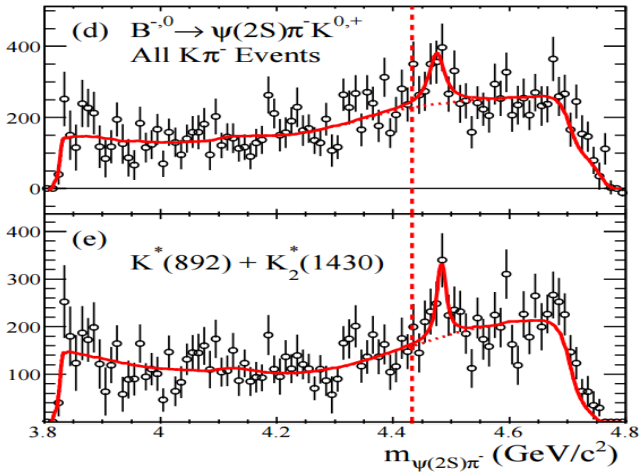
- $Z(4430)^+$ observed by Belle in $B \to \psi' \pi^+ K$, but not confirmed by Babar

Belle, PRLett. 100 (2008) 142001



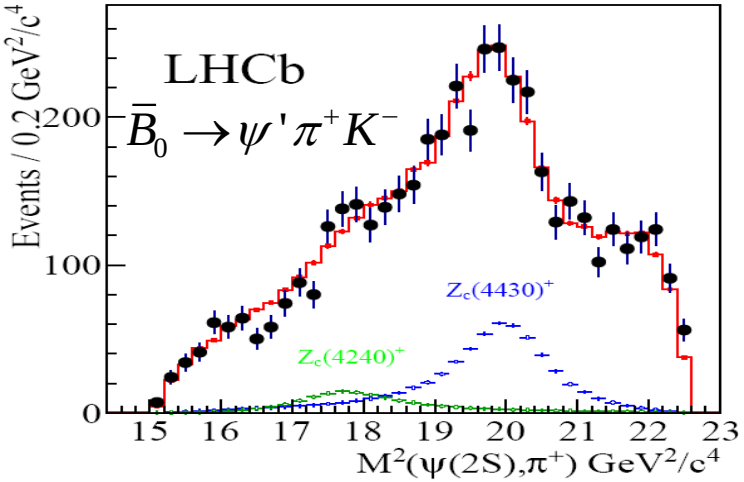
M=4433± 4 MeV
$\Gamma = 45^{+18}_{-23}$MeV

Babar, PRD79 (2009) 112001

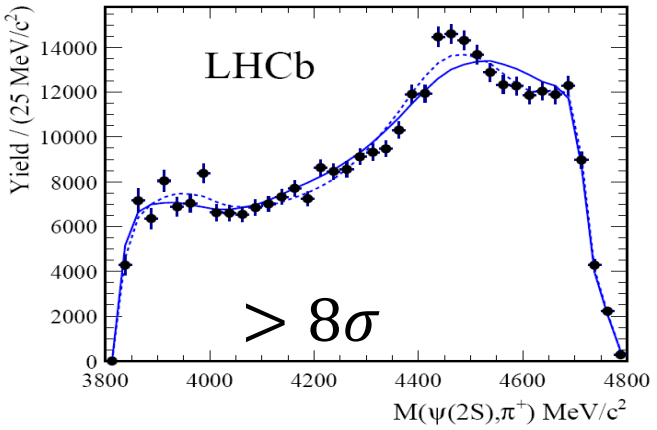


448 M $B\bar{B}$

- LHCb independently confirm $Z(4420)^+$ at 13.9σ C.L.



~20,000 evts



LHCb, PRL112 (2014), 222002

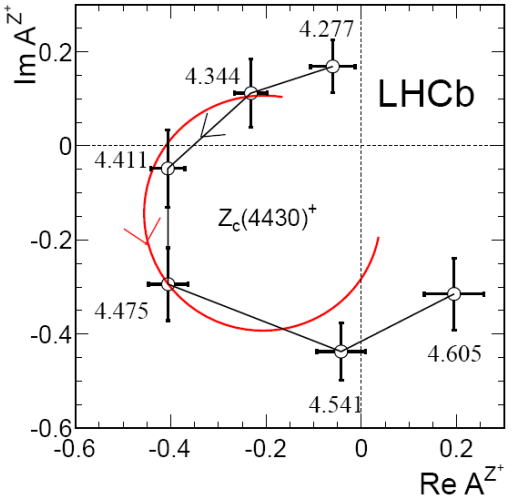
LHCb, Phys. Rev. D92 (2015) 112009

$Z(4430)^+$ continued

- LHCb measurements

$J^P=1^+$. Average over Belle and LHCb:

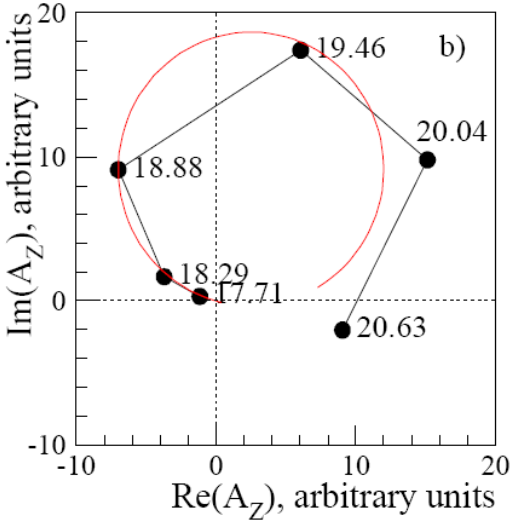
$$M(Z(4430)) = 4478^{+15}_{-81}\ \text{MeV}$$
$$\Gamma(Z(4430)) = 181 \pm 31\ \text{MeV}.$$



- Argand plot rule out the rescattering mechanisms

Phys. Lett. B748 (2015) 183

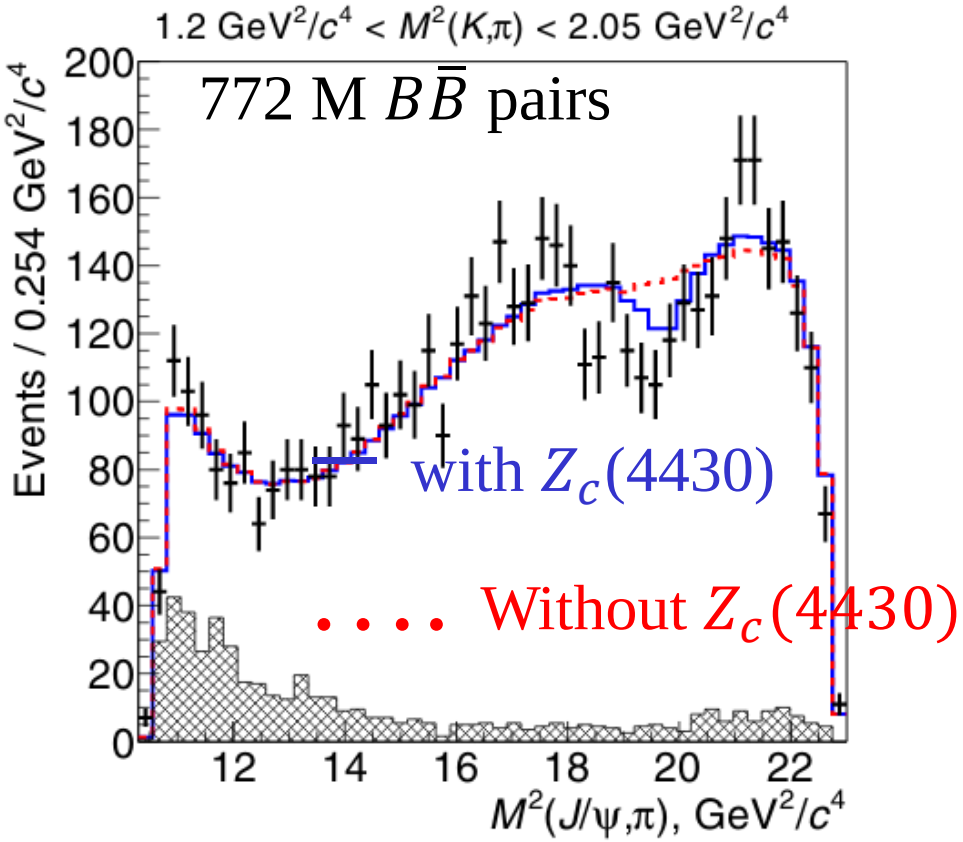
Counter-clockwise phase motion in data, but predicted the clockwise motion

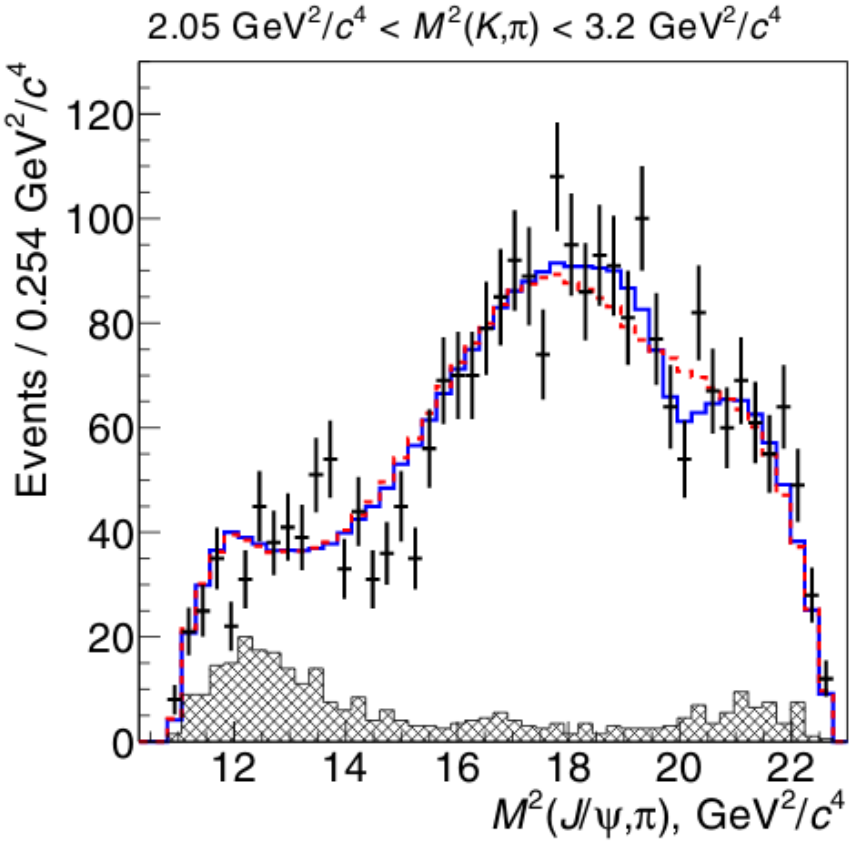


$Z(4430)^+$ continued

- $Z(4430)^+$ evidence in $\bar{B}^0 \to J/\psi K^- \pi^+$ from BELLE (2014)

Belle, PRD 90, 112009 (2014)





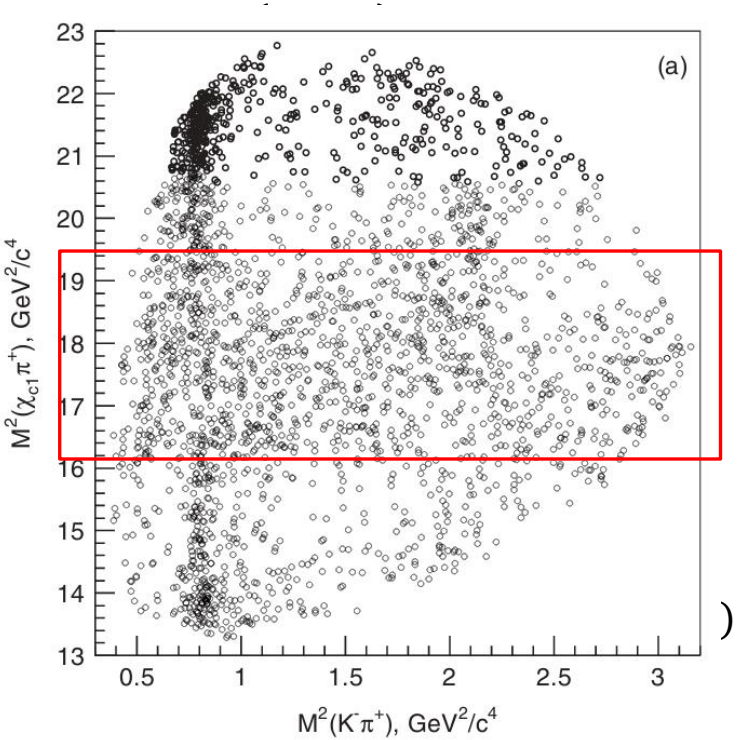
Significance: 4.0 σ

Destructive interference

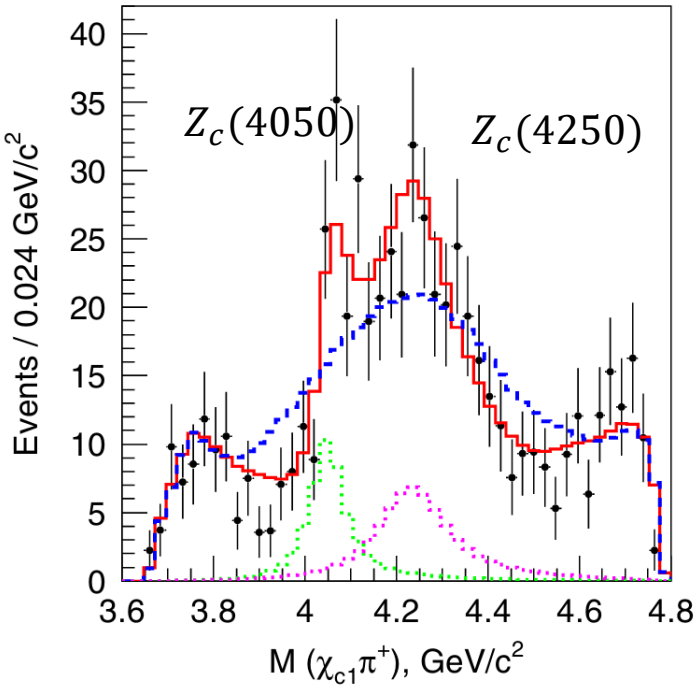
$Z(4050, 4250)^+ \rightarrow \chi_{c1}\pi^+$ in $\bar{B}^0 \rightarrow K^-\pi^+\chi_{c1}$

- $Z(4050, 4250)^+$ in $\bar{B}^0 \rightarrow K^-\pi^+\chi_{c1}$ from BELLE (2008)

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



Belle, PRD78, 072004 (2008)



1.0 GeV^2 $< M^2(K^-\pi^+) <$ 1.75 GeV^2

Significance for each Z exceeds 5σ, both assumed $J^P = 0^+$

$$M_1 = (4051 \pm 14^{+20}_{-41})\ \text{MeV}/c^2, \qquad M_2 = (4248^{+44+180}_{-29-35})\ \text{MeV}/c^2,$$

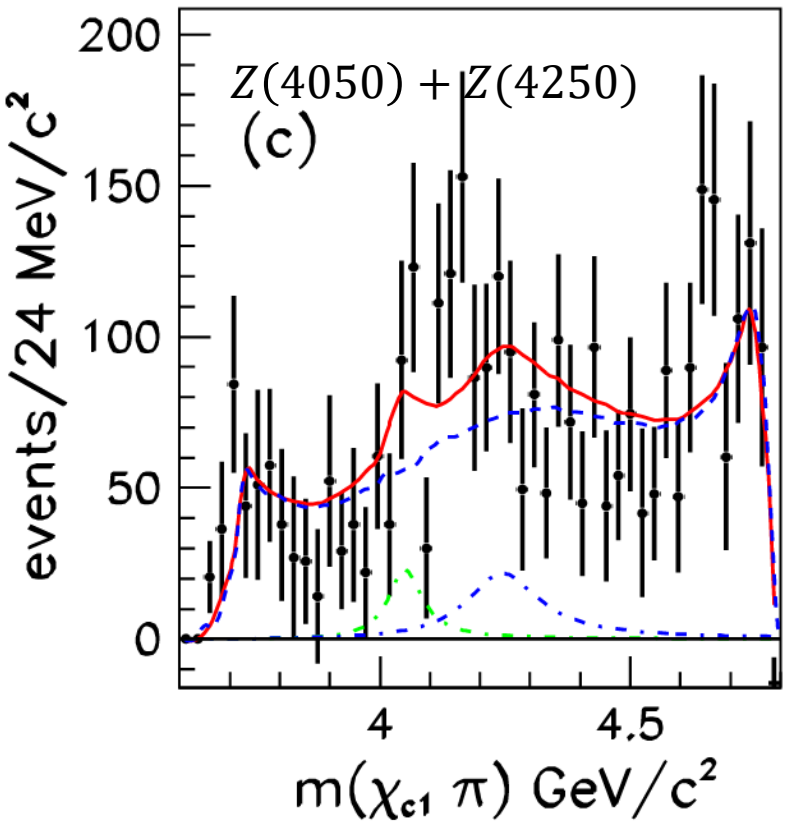
$$\Gamma_1 = (82^{+21+47}_{-17-22})\ \text{MeV}, \qquad \Gamma_2 = (177^{+54+316}_{-39-61})\ \text{MeV},$$

$Z(4050, 4250)^+ \rightarrow \chi_{c1}\pi^+$ in $\bar{B}^0 \rightarrow K^-\pi^+\chi_{c1}$

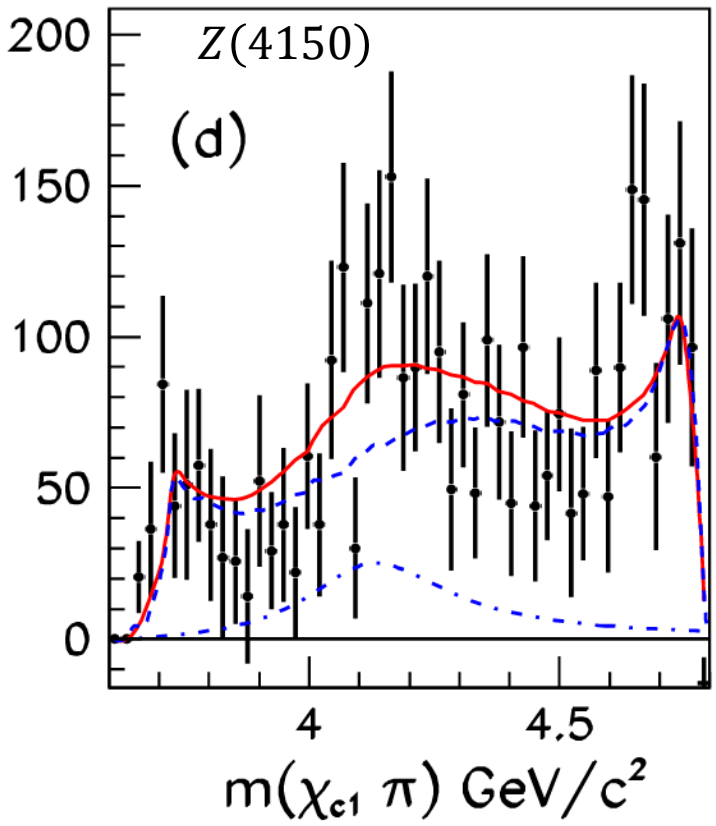
- $Z(4050, 4250)^+$ in $\bar{B}^0 \rightarrow \chi_{c1}K^-\pi^+, \bar{B}^+ \rightarrow \chi_{c1}K_S^0\pi^+$ from Babar

Babar, PRD85, 052003 (2012)

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



$1.0\ \text{GeV}^2 < M^2(K^-\pi^+) < 1.75\ \text{GeV}^2$



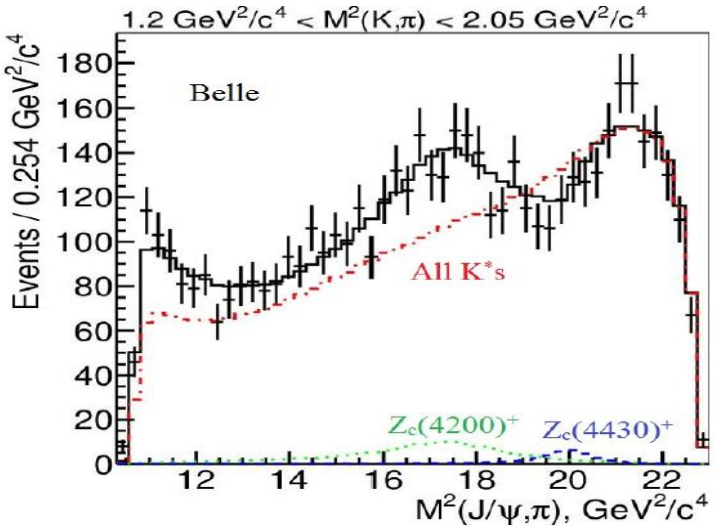
Significance $< 2.0\ \sigma$

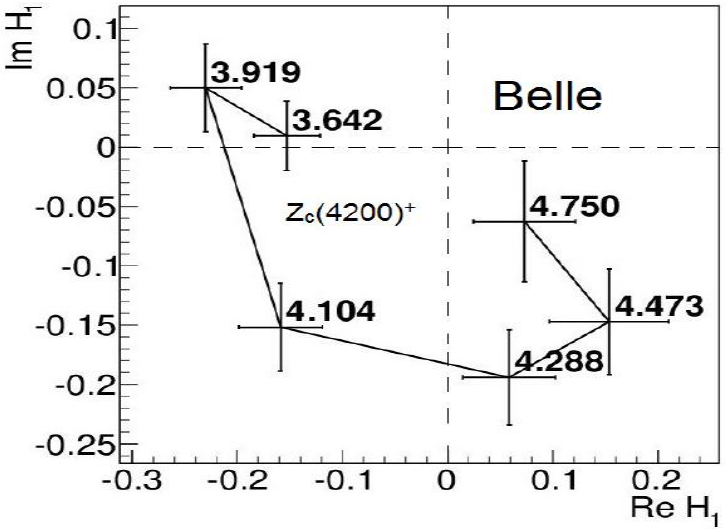
Signal yields consistent with zero

$Z(4200)^+ \rightarrow J/\psi\pi^+$ in $\underline{B}^0 \rightarrow J/\psi\pi^+K^-$

- Belle amplitude analysis

Belle, Phys. Rev. D90 (2014) 112009





1^+ $Z(4200)^+$, 6.2σ

0^- or 1^+, $Z(4300)^+$, 5.1σ

$$\text{mass } 4196\,^{+31}_{-29}\,^{+17}_{-13}\ \text{MeV}$$

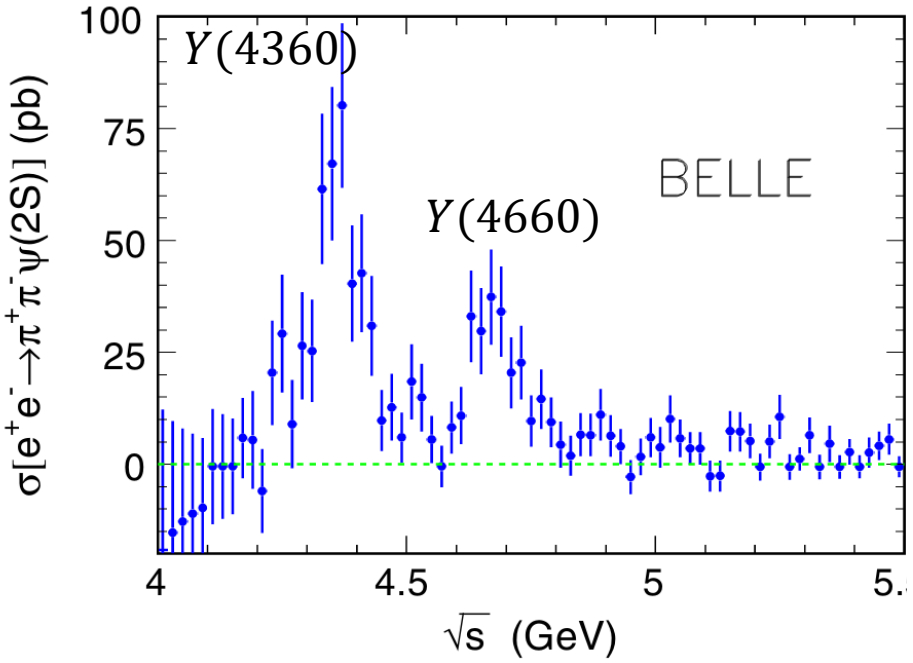
$$\Gamma = 370 \pm 70^{+70}_{-132}\ \text{MeV}$$

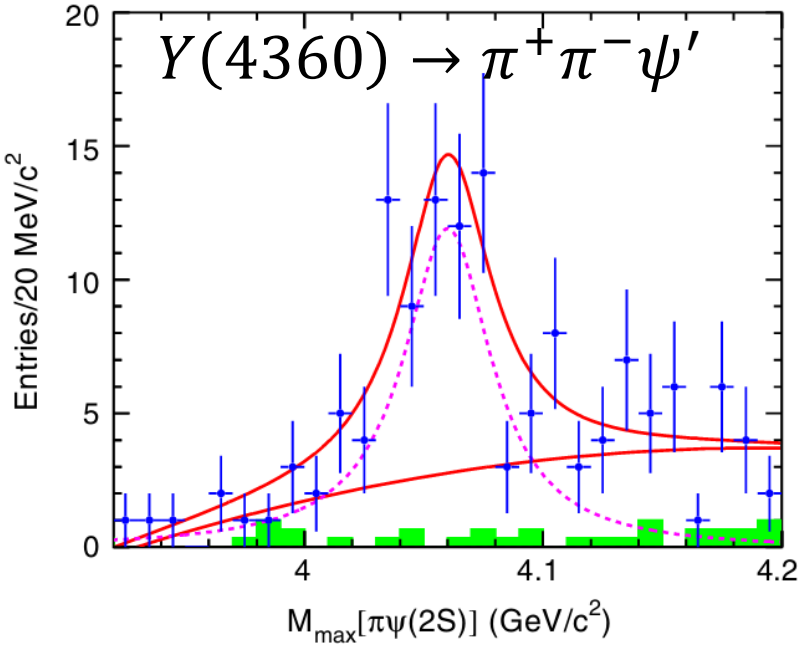
Strong destructive interference between them.
Need to confirmation of $Z(4200)$

Waiting for LHCb?

Evidence $Z(4055)^{\pm} \to \psi'\pi^{\pm}$ in $e^+e^- \to \gamma_{ISR}\,\pi^+\pi^-\psi'$

BELLE, PRD 91, 112007 (2015)



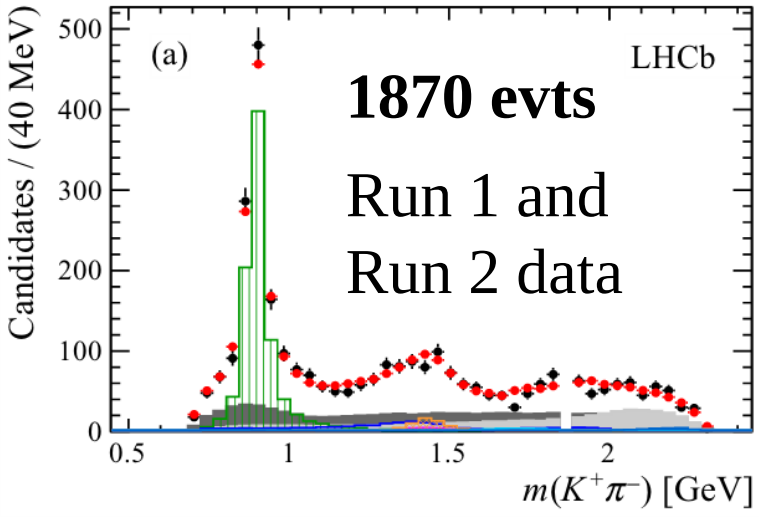


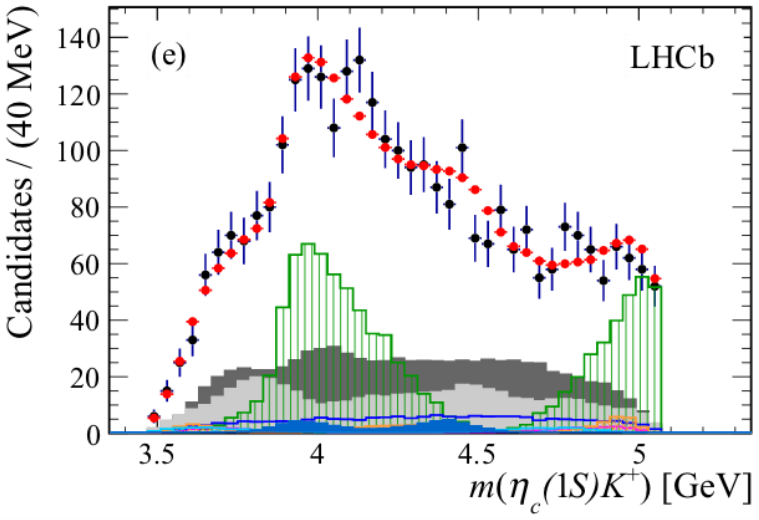
Significance: $\sim 3.5\sigma$

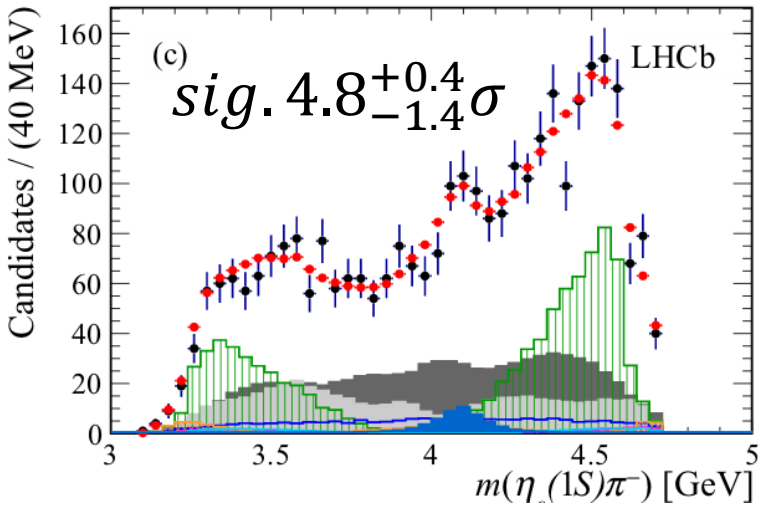
$M = 4060 \pm 3_{stat.}$ MeV,
$\Gamma = 40.8 \pm 2.2_{stat}$ MeV

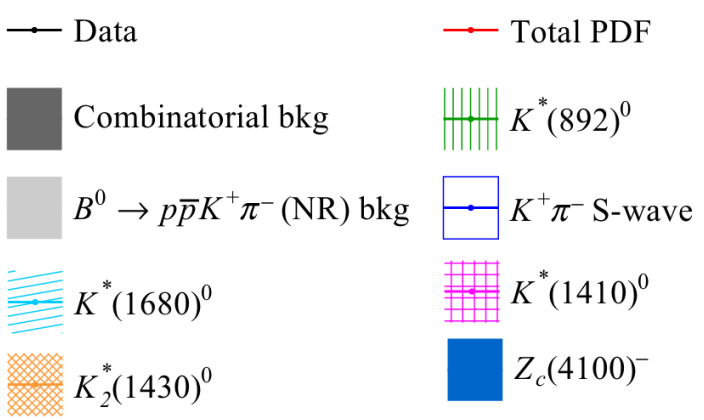
Evidence for $Z(4100)^- \to \eta_c \pi^-$ in $B^0 \to \eta_c(1S) K^- \pi^-$

arXiv: 0809.07416







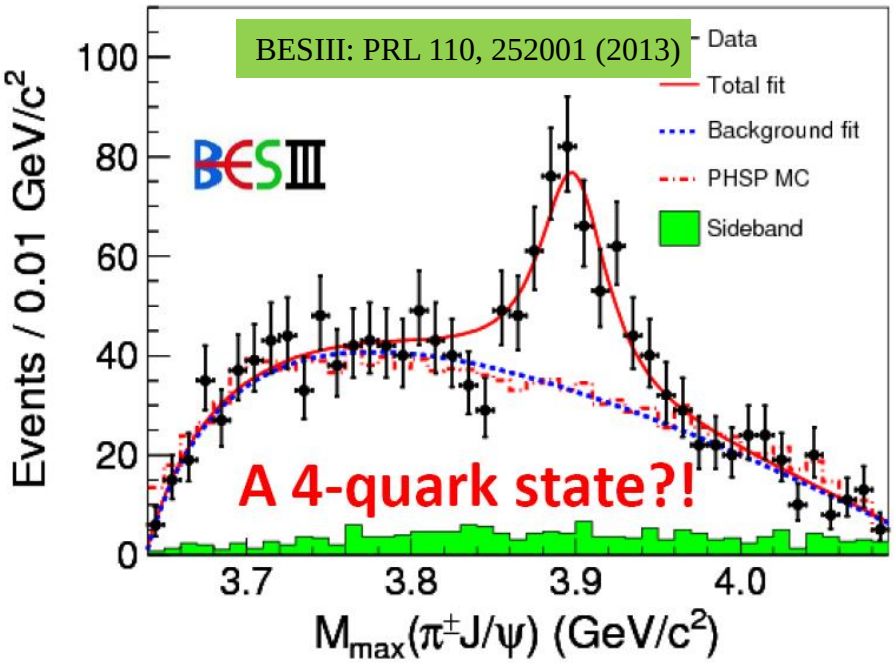


$Z_c(4100)$: $M = 4096 \pm 20^{+18}_{-22}$ MeV

$\Gamma = 152 \pm 58^{+60}_{-35}$ MeV

$J^P = 0^+ \ or \ 1^-$

Observation of Zc(3900)



$Z_c(3900)^+$: $J^P=1^+$

$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$

$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$

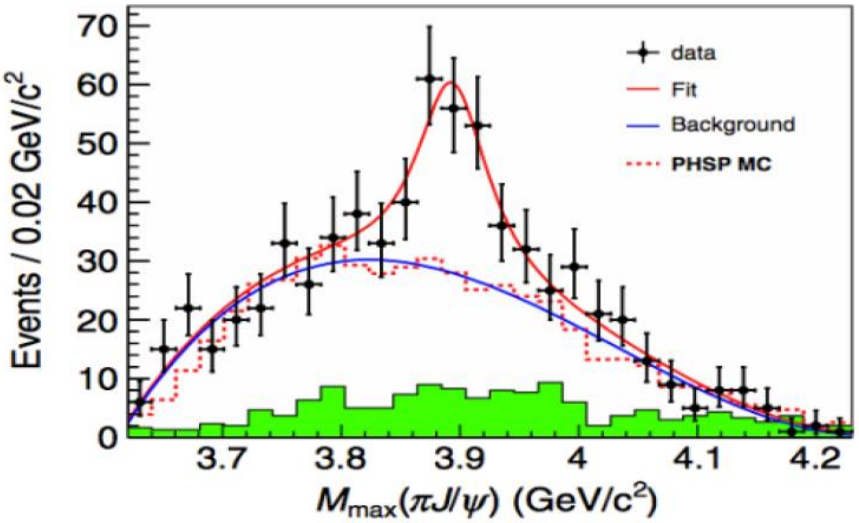
Mass close to $D\bar{D}^*$ threshold

Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$

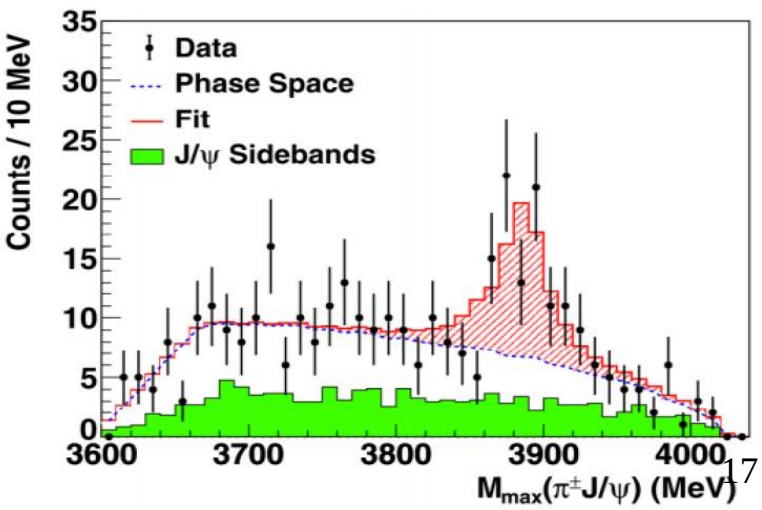
$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7$ pb at 4.26 GeV

$\frac{\sigma[e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%$ at 4.26 GeV

Belle with ISR data (PRL110,252002)

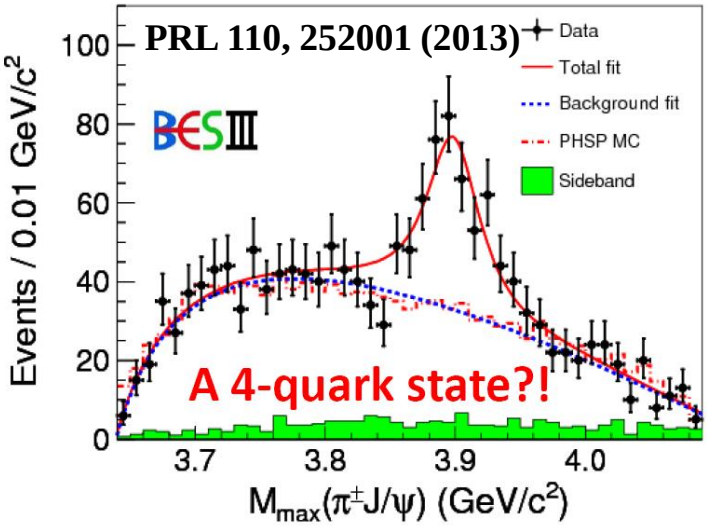


CLEOc data at 4.17 GeV (PLB 727,366)

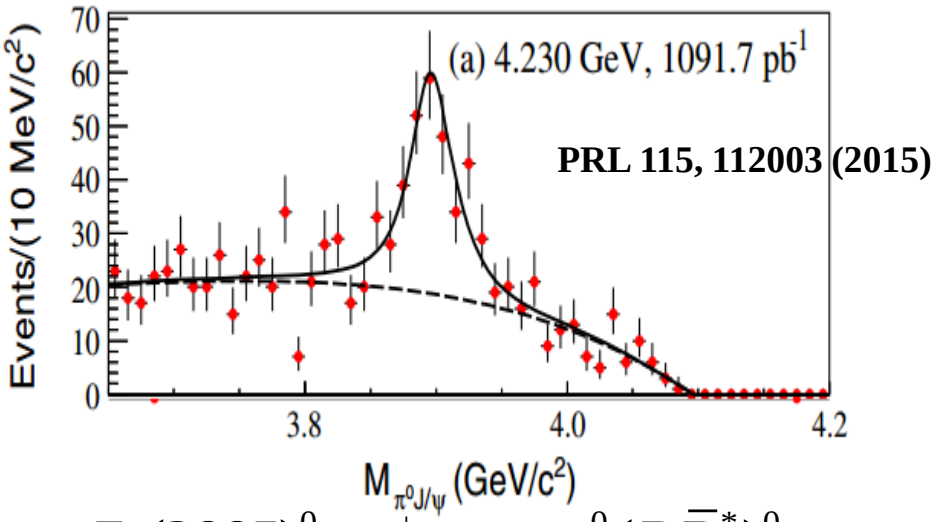


Overview Zc states from BESIII

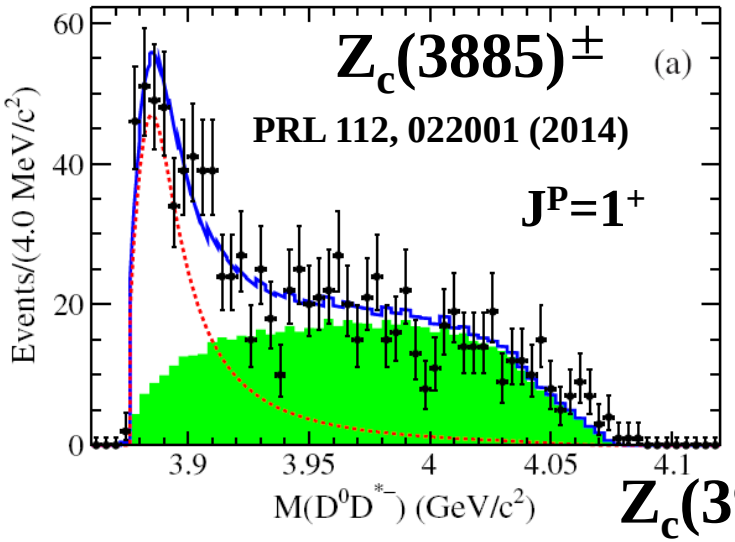
$Z_c(3900)^{\pm} : e^+e^- \to \pi^+\pi^- J/\psi$



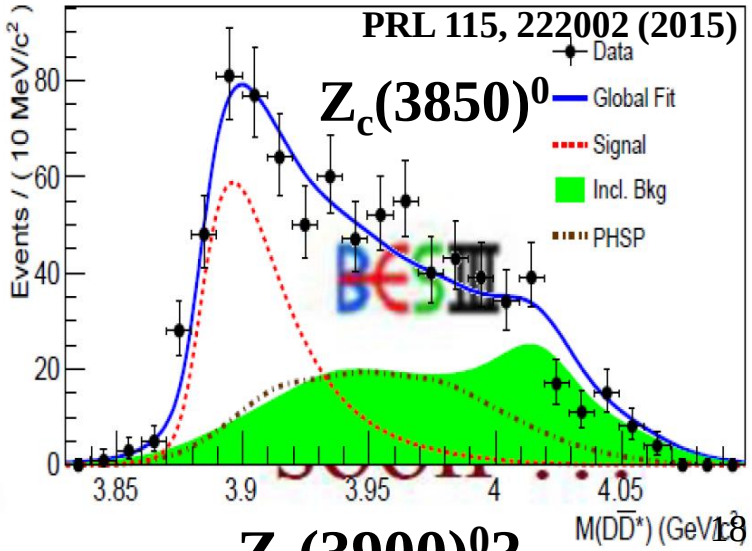
$Z_c(3900)^0 : e^+e^- \to \pi^0\pi^0 J/\psi$



$Z_c(3885)^{\pm} : e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$



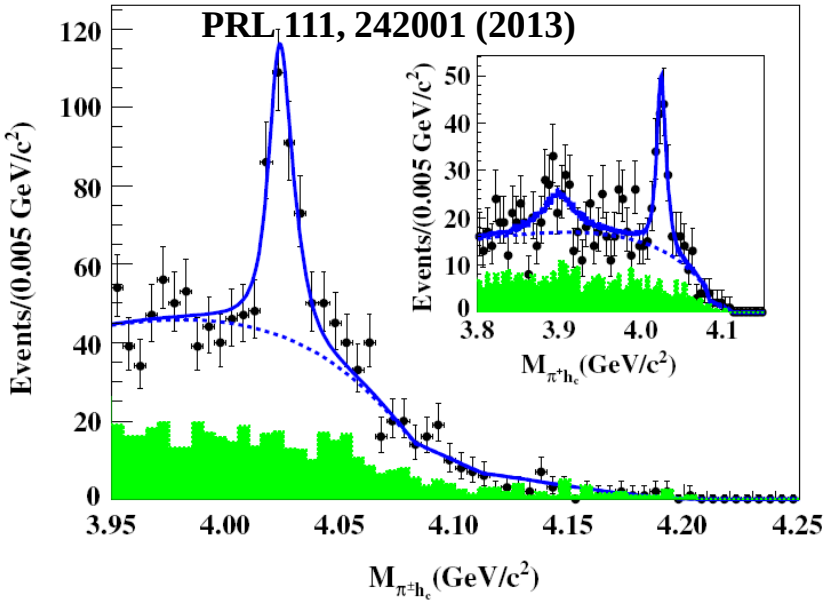
$Z_c(3885)^0 : e^+e^- \to \pi^0(D\bar{D}^*)^0$



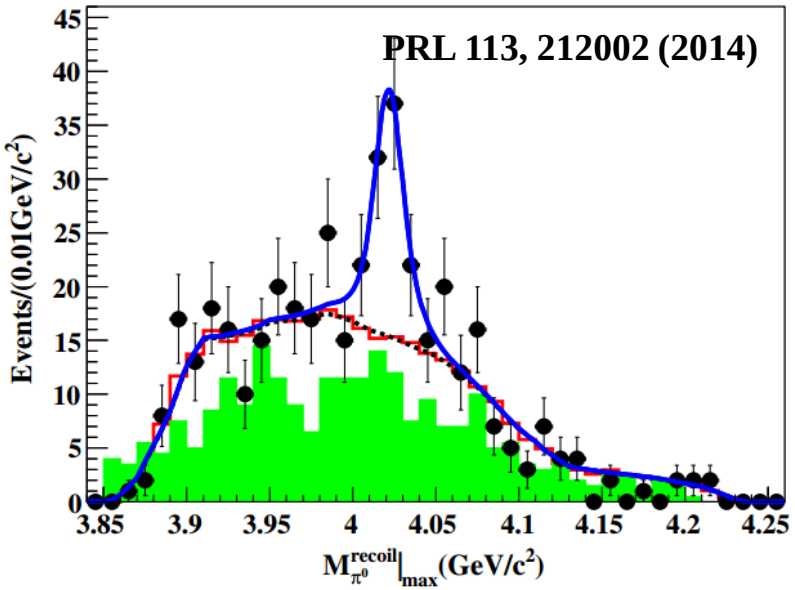
$Z_c(3900)^{\pm}$?

$Z_c(3900)^0$?

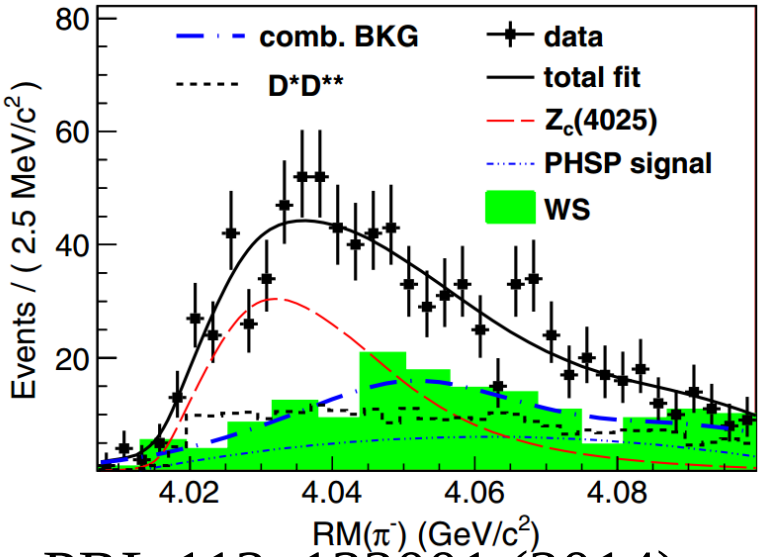
$Z_c(4020)^{\pm} : e^+e^- \to \pi^+\pi^- h_c$



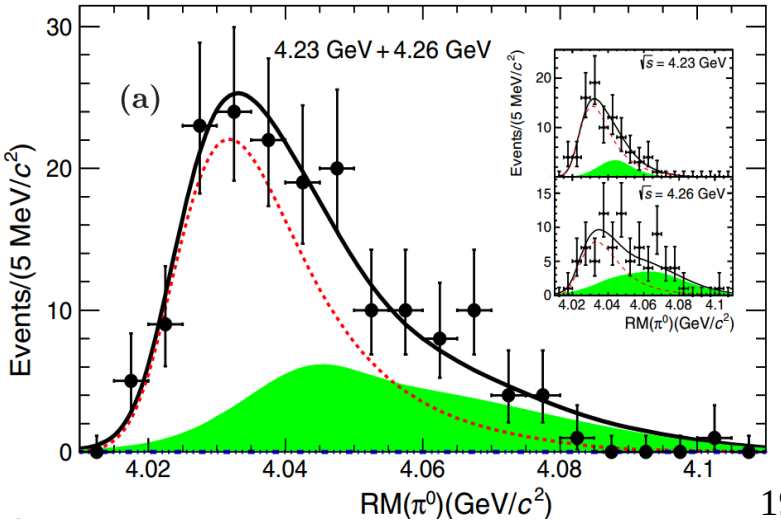
$Z_c(4020)^{0} : e^+e^- \to \pi^0\pi^0 h_c$



$Z_c(4025)^{\pm} : e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}$



$Z_c(4025)^{0} : e^+e^- \to \pi^0(D^*\bar{D}^*)^0$



PRL 112, 132001 (2014)

PRL 115, 182002 (2015)

Mass and width in Breit-Wigner parametrization

Zc 态	M(MeV)	Γ(MeV)	过程	实验
$Z_c^{\pm}(3900)$	3899.0 ± 6.1	46 ± 22	$Y(4260)\to\pi^{\pm}(\pi^{\mp}J/\psi)$	BESIII
	3894.5 ± 8.0	63.0 ± 35.4	$e^+e^-\to\gamma_{ISR}\pi^{\pm}(\pi^{\mp}J/\psi)$	Belle
	3897.6 ± 1.2	43.5 ± 1.5	$Y(4230),Y(4260)\to\pi^{\pm}(\pi^{\mp}J/\psi)$	BESIII
$Z_c^{\pm}(3885)$	3890.5 ± 1.8	28.0 ± 4.0	$Y(4260)\to\pi^{\pm}(D^0\bar{D}^*)^{\mp}$	BESIII

Zc 态	M(MeV)	Γ(MeV)	过程	实验
$Z_c^{\pm}(4020)$	4022.9 ± 2.8	7.9 ± 3.7	$e^+e^-\to\pi^{\pm}(\pi^{\mp}h_c)$	BESIII
$Z_c^{\pm}(4025)$	4026.3 ± 4.5	24.5 ± 9.5	$Y(4260)\to\pi^{\pm}(D^*\bar{D}^*)^{\mp}$	BESIII

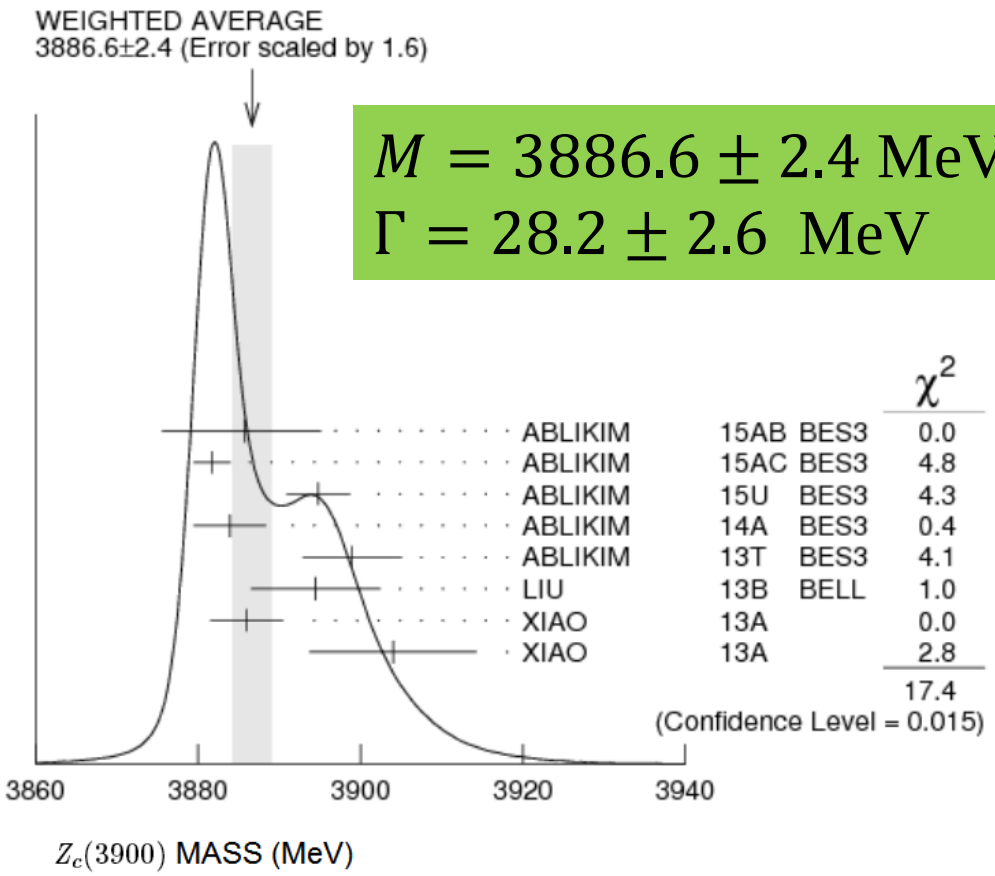
$$\Gamma_{Z_c(3885)}\sim\frac{1}{2}\Gamma_{Z_c(3900)}$$

$$\Gamma_{Z_c(4020)}\sim\frac{1}{3}\Gamma_{Z_c(4025)}$$

- 2σ difference in masses, and width of Zc(3885) is about half of that $Z_c(3900)$. The two have $J^P=1^+$

$Z_c(3900)$ in 2018 PDG

$Z_c(3900)$ $I^G(J^{PC}) = 1^+(1^{+-})$



$M = 3886.6 \pm 2.4$ MeV

$\Gamma = 28.2 \pm 2.6$ MeV

$e^+ e^- \to \pi^0 (D\overline{D}^*)^0$

$e^+ e^- \to \pi^\pm (D\overline{D}^*)^{-+}$

$e^+ e^- \to \pi^0\pi^0 J/\psi$

$e^+ e^- \to \pi^\pm (D\overline{D}^*)^{-+}$

$e^+ e^- \to \pi^+\pi^- J/\psi$

$e^+ e^- \to \gamma\pi^+\pi^- J/\psi$

4.17 $e^+ e^- \to \pi^+\pi^- J/\psi$

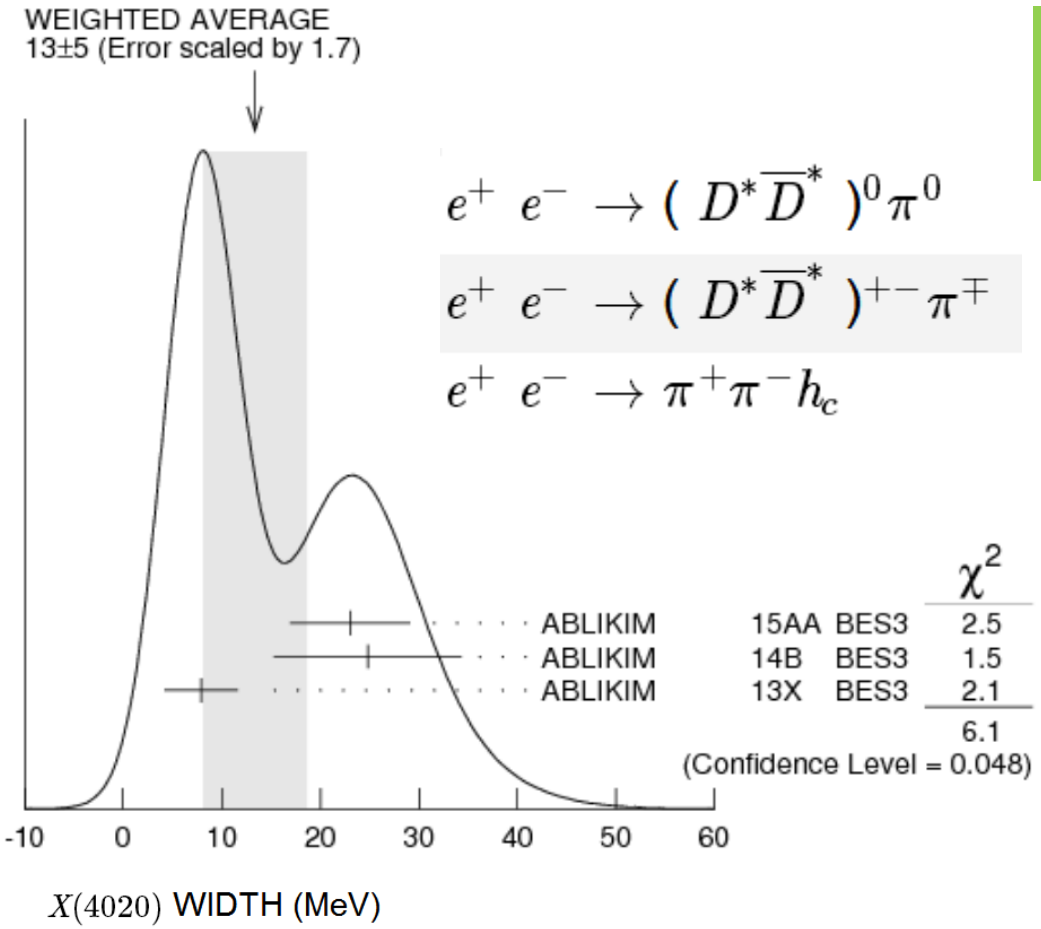
4.17 $e^+ e^- \to \pi^0\pi^0 J/\psi$

Comments:

- Inconsistent width definition, e.g. pole width, BW width
- No interference effect considered

$Z_c(4020)$ in 2018 PDG

$$Z_c(4020): I^G(J^{PC}) = 1^+(?^?)$$



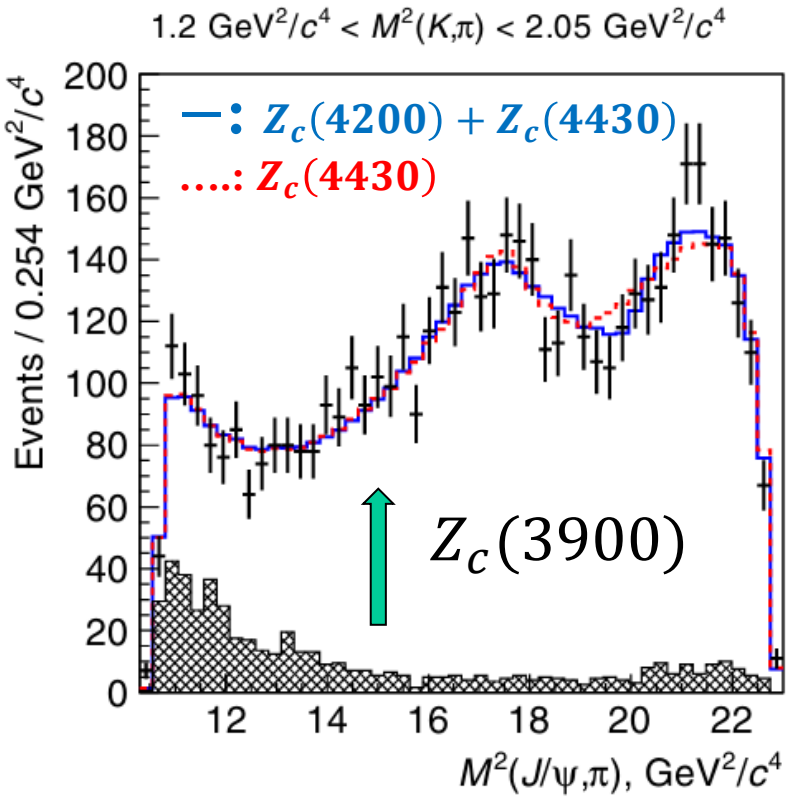
$M = 4024.1 \pm 1.9$ MeV
$\Gamma = 13.5 \pm 1.5$ MeV

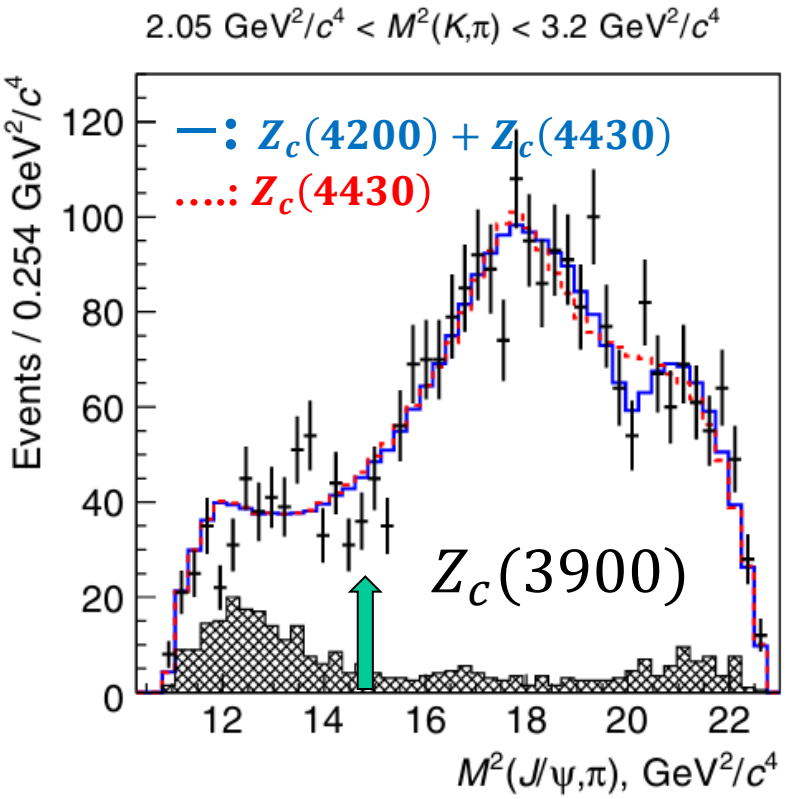
- No interferences effects with non resonance
- 1^+ assumed in $\pi\pi h_c$ mode

Search for $Z_c(3900)$ in B decays

- No significant signals in $\bar{B}^0 \to J/\psi K^- \pi^+$ from Belle exp.

Belle, PRD90, 112009 (2014)



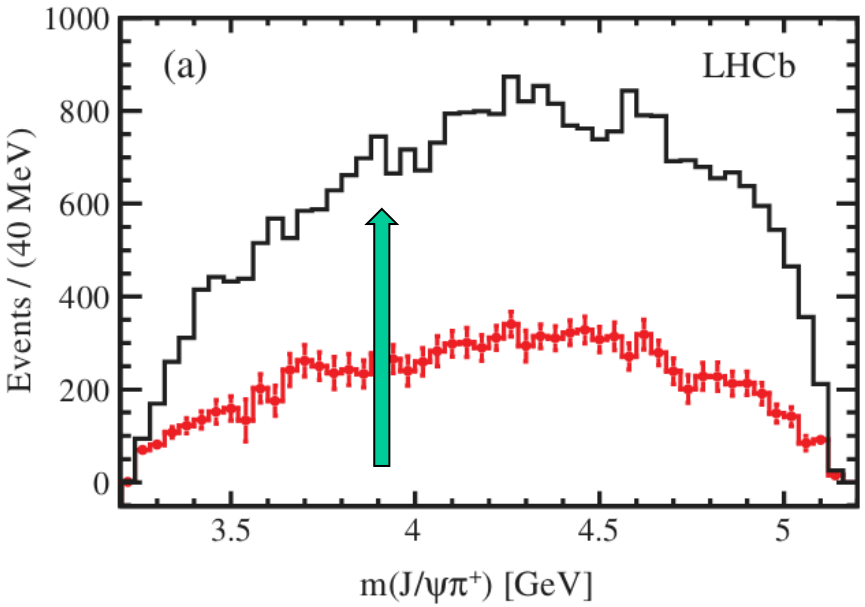


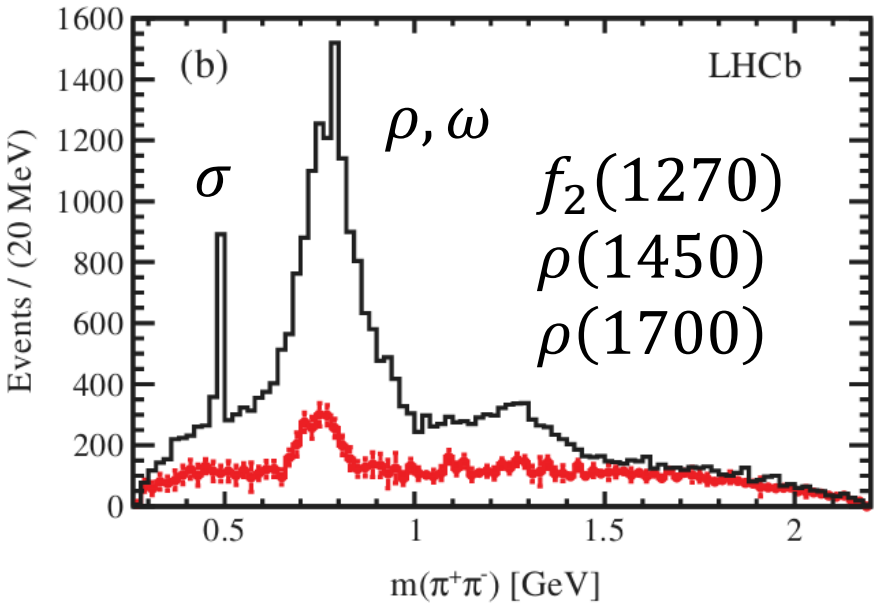
If $Z_c(3900)$ as 1^+, $S = 0.1\sigma$

Search for $Z_c(3900)$ in B decays

- No significant signals in $\bar{B}^0 \to J/\psi\pi^+\pi^-$ from LHCb exp.

LHCb, PRD90, 012003 (2014)



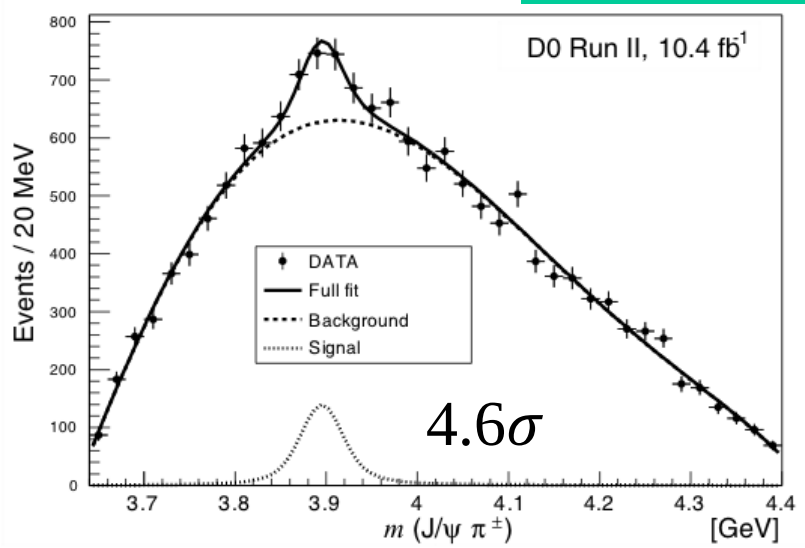


No signal of $Z_c(3900)$

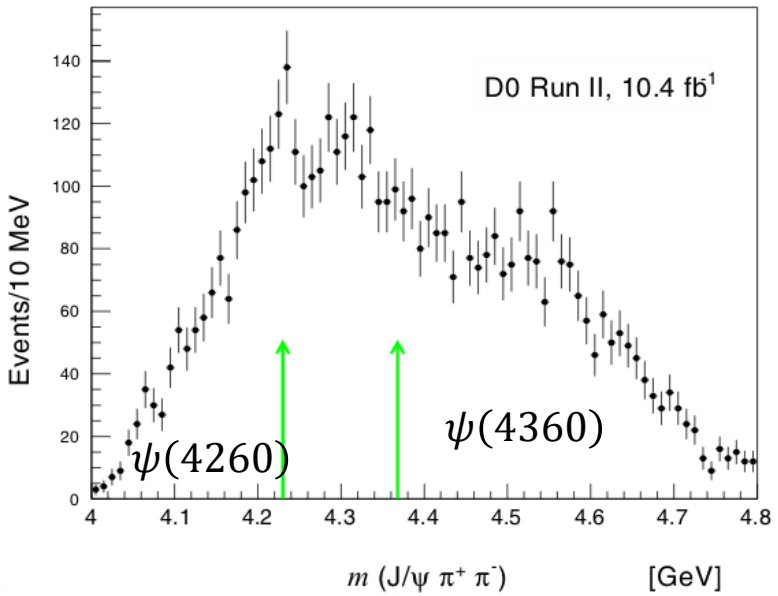
Evidence for $Z_c(3900)^{\pm}$ in semi-inclusive decays of b-flavor hadrons

- D0 experiment: b-quark hadron→ $Y(4260)$+ anything, $Y(4260) \to Z_c(3900)^{\pm}\pi^{\mp}, Z_c(3900)^{\pm} \to J/\psi\pi^{\pm}$

D0, arXiv: 1807.00183



$4.2 < m(J/\psi\pi^+\pi^-) < 4.7$ GeV



$3.83 < m(J/\psi\pi) < 3.95$ GeV

Mass: $M = 3895.0 \pm 5.2^{+4.0}_{-2.7}$ MeV, width fixed to PDG value

Open issues for Z_c states

- Lineshape parameterization
  - Breit-Wigner or Flatte-like formula in experiments
  - Unitarized for coupled channel analysis

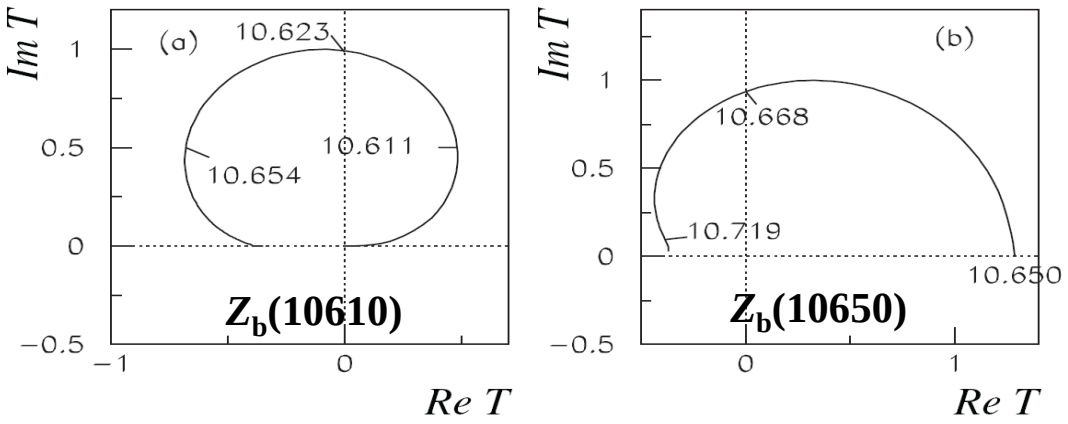
W. Qin, S.R. Xie, and Q.Zhao, PRD94, 054035 (2016)
M. Cleven, Q. Wang, F.K. Guo, C. Hanhart, U-G. Meibner, Q.Zhao, PRD90, 074039 (2014)
Q.R. Gong, Z.H. Guo, C. Meng, G.Y. Tang, Y.F. Wang and H.Q. Zheng, PRD94, 114019(2016)

- Phase shift model independent measurement
  - Lattice QCD predictions

CLQCD, PRD92 054507 (2015)
CLQCD, PRD89 094506 (2014)

- Argand plot due to cusp

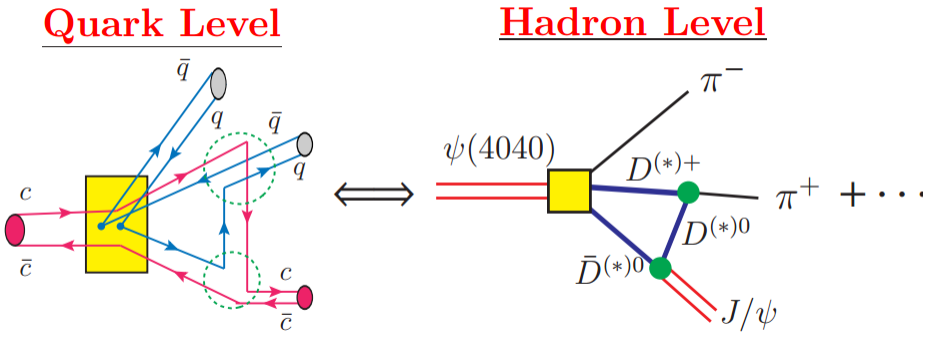
D.V.Bugg, EPL96 (2011) , 11002



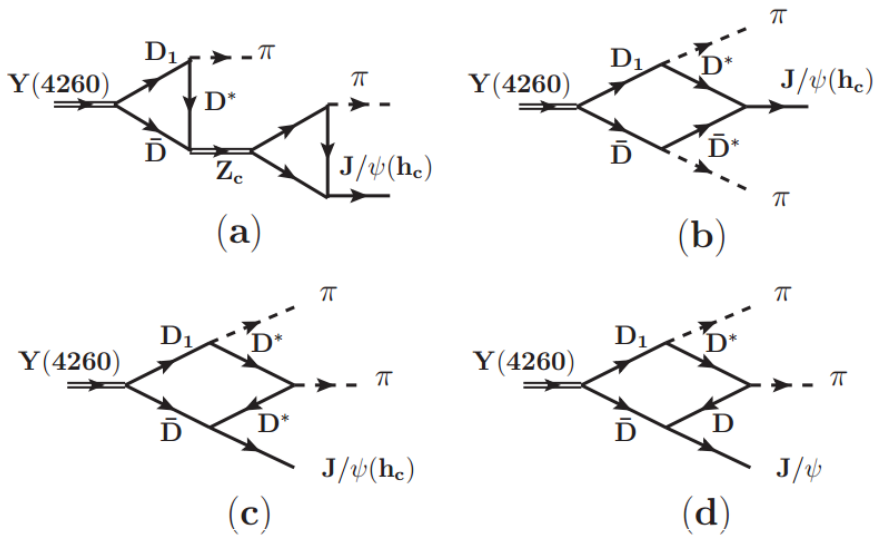
Open issues for Z_c states

- Production model test

D.Y. Chen, X. Liu, PRD**84 (2011) 034032**



Q.Wang, C. Hanhart, Q.Zhao, PRL111 (2013),132003



- Continuum production or resonance decays

BESIII *XYZ* scan data, 500 pb^{-1}, with step of 10 MeV

Measurement of Z_c production cross section above 4.0 Gev

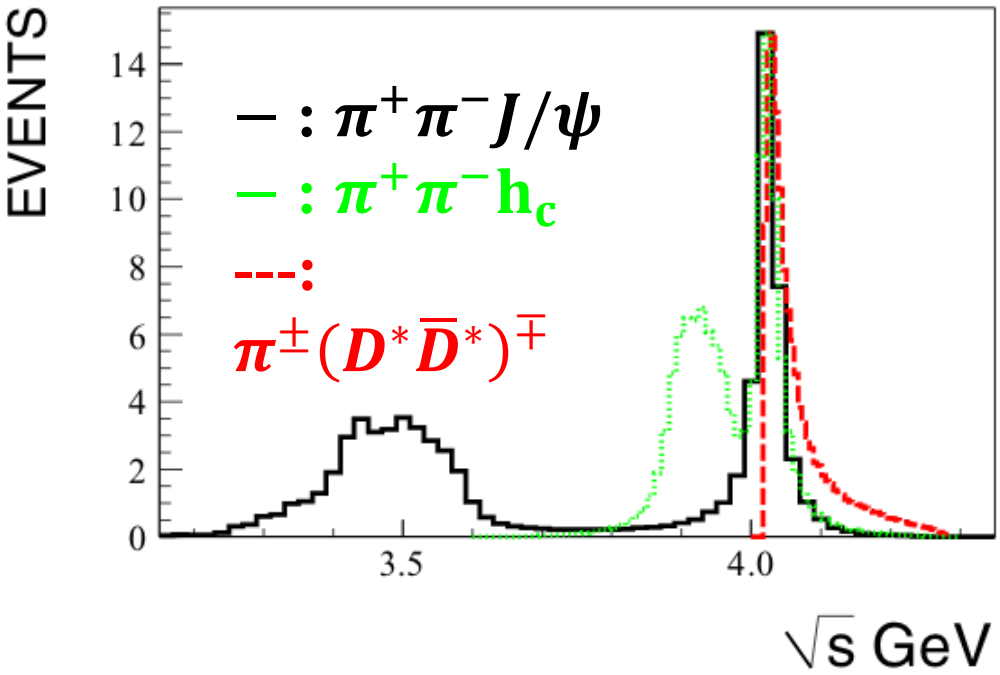
Open issues for Z_c states

- Coupled channel analysis in experiment

$$Zc(3900/3885)^{\pm}: \; e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}, \pi^+\pi^- J/\psi, \pi^+\pi^- h_c$$

$$Zc(4020/4025)^{\pm}: \; e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}, \pi^+\pi^- J/\psi, \pi^+\pi^- h_c$$

How to define the branching fraction?



$Z_c(4020)$ lineshape
Using $\sqrt{s}$=4420 MeV data

Summary

From 2003, a huge number of exotic charmonium like states were observed tau-charm and B-factory and LHC experiment, and they are characterized by

- $Z_c(4430)$, $Z_c(3900)$ established as $I^G(J^{PC}) = 1^+(1^{+-})$ but their decay branching fractions are unmeasured

- Other Z_c states need confirmation from BELLEII, LHCb, BESIII