

# Heavy Quark Physics at B-Factories

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*Kobayashi-Maskawa Institute*

*Nagoya University*

*2015 Erice School*

*September 18, 2015*



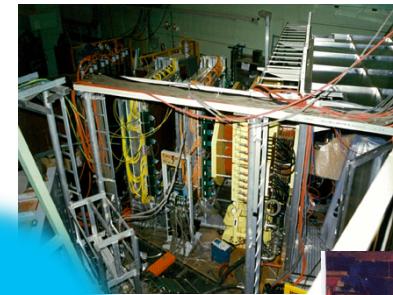
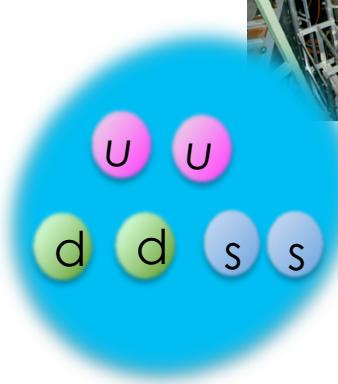
Kobayashi-Maskawa Institute  
for the Origin of Particles and the Universe



# About Me

1987-1994: Kyoto University

- **H dibaryon search**
  - KEK-E176
  - A-dependence of ( $K^-$ ,  $K^+$ )
  - BNL-E813/E836



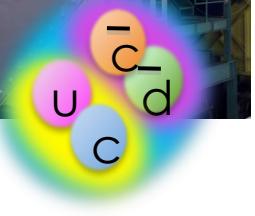
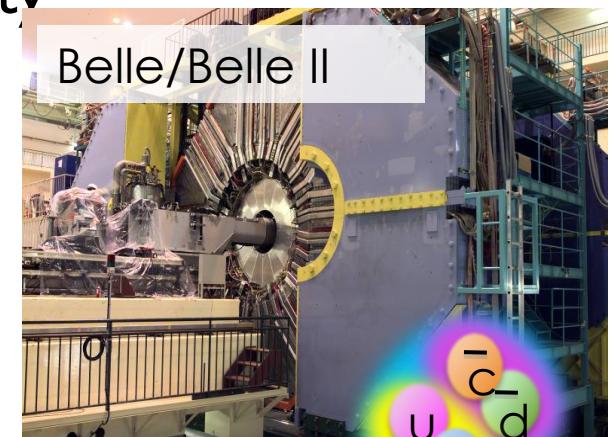
KEK-E176/E224



BNL-E813/E836

1994-2002: KEK, 2002-now: Nagoya University

- **B factory  $\rightarrow$  Super B factory**
  - Particle ID (Cherenkov detectors)
  - CP violation
  - Rare decays
  - Hadron physics



Hadron physics is one of my favorite subjects

# Outline

- Introduction
- XYZ spectroscopy at  $e^+e^-$  colliders
  - Charmonium-like states
  - Bottomonium-like states
- Future Prospect
- Summary

There are more topics in “Heavy Quark Physics”

- Spectroscopy of conventional quarkonium
- Double charmonium production
- Open charm meson ( $D_{SJ}$ ,  $D^{**}$ , ...)
- Charmed baryon
- ...

*Apology:*

*I cannot cover these topics in this talk*

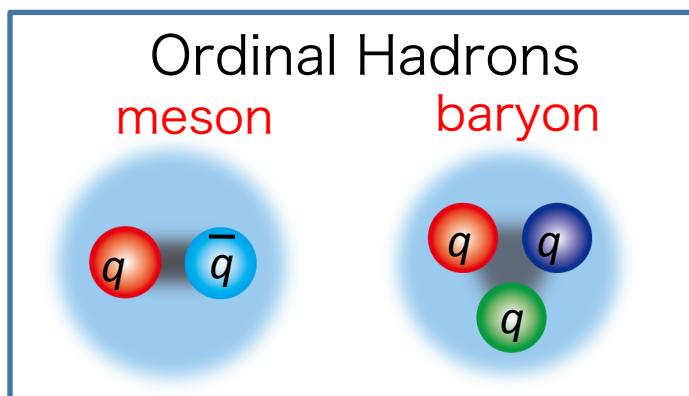
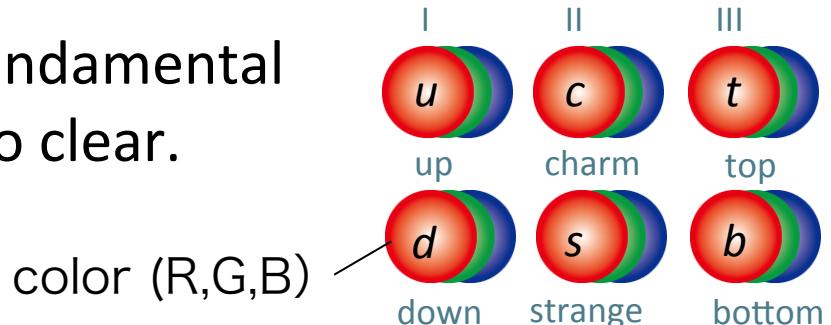


See also other talks (Yubing Dong, Fulvio Piccinini, ...) for interpretation

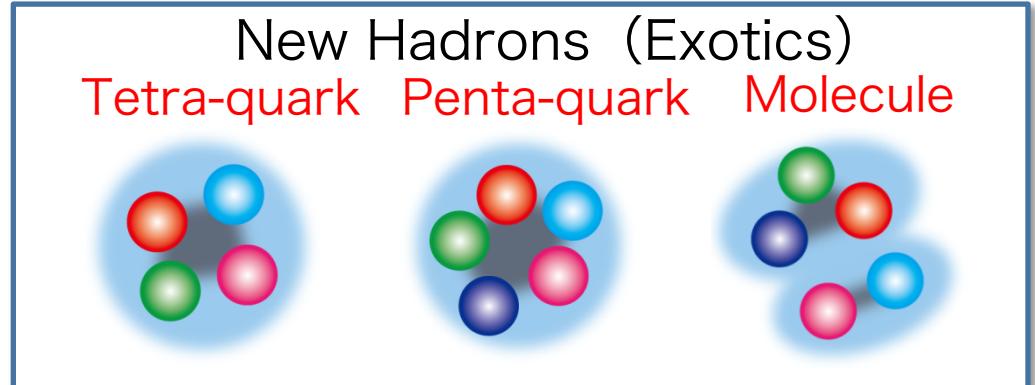
# Quest in low-energy QCD

- The Quark Model (QM) is an effective model, which works very well to explain spectra and properties of observed hadrons.
- However the link between QCD (fundamental equation) and QM (model) is not so clear.

Gell-Mann



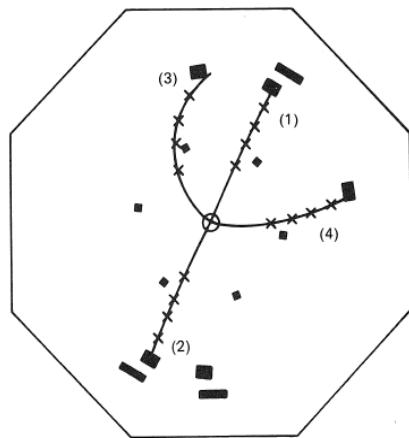
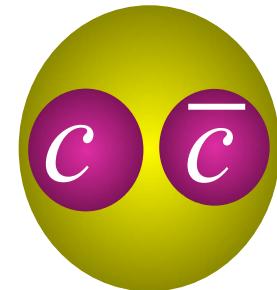
"Constituent quark"



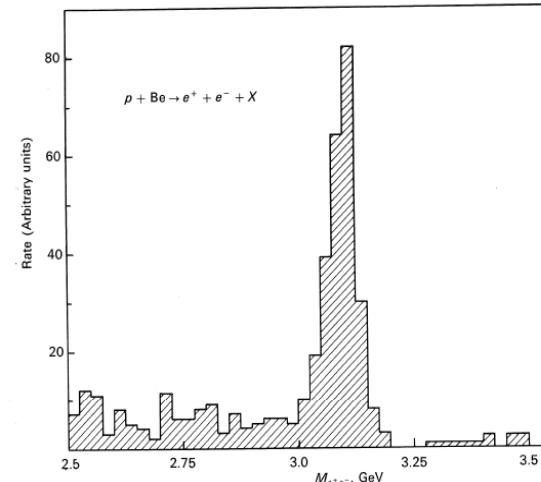
QCD just require hadrons to be colorless, and allow exotics.  
Such exotic states exist ?

# Discoveries in 1974

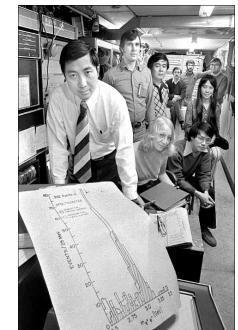
- Discovery of J/ $\psi$ 
  - SLAC, Burton Richter et al.
  - BNL, Samuel Ting et al.



**Figure 5.12** Example of the decay  $\psi(3.7) \rightarrow \psi(3.1) + \pi^+ + \pi^-$  observed in a spark chamber detector. The  $\psi(3.1)$  decays to  $e^+ + e^-$ . Tracks (3) and (4) are due to the relatively low-energy (150-MeV) pions, and (1) and (2) to the 1.5-GeV electrons. The magnetic field and the SPEAR beam pipe are normal to the plane of the figure. The trajectory shown for each particle is the best fit through the sparks, indicated by crosses. [From G. S. Abrams *et al.*, *Phys. Rev. Letters* 34, 1181 (1975).]



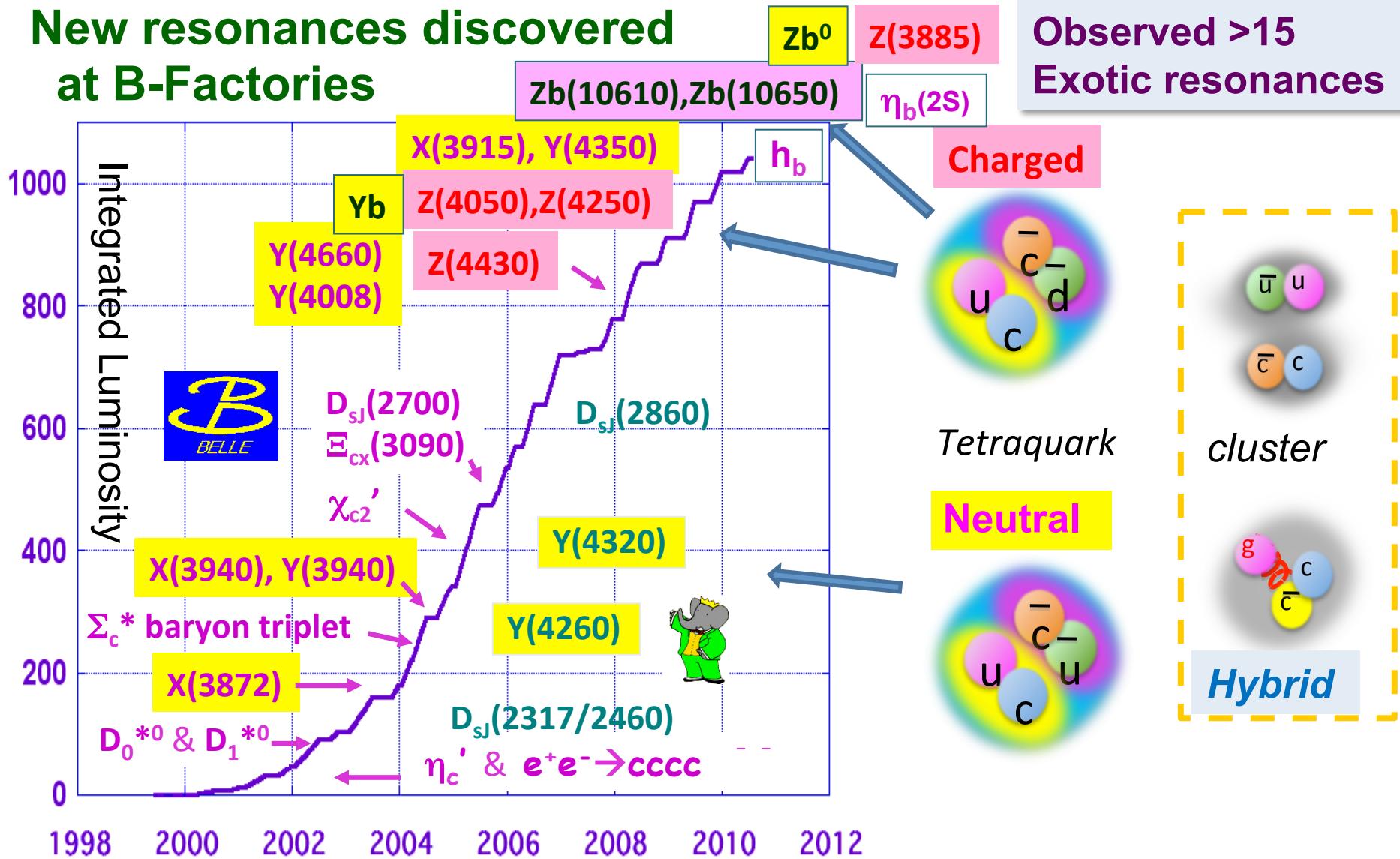
**Figure 5.10** Results of Aubert *et al.* (1974) indicating the narrow resonance  $\psi/J$  in the invariant-mass distribution of  $e^+e^-$  pairs produced in inclusive reactions of protons with a beryllium target. The experiment was carried out with the 28-GeV AGS at Brookhaven National Laboratory.



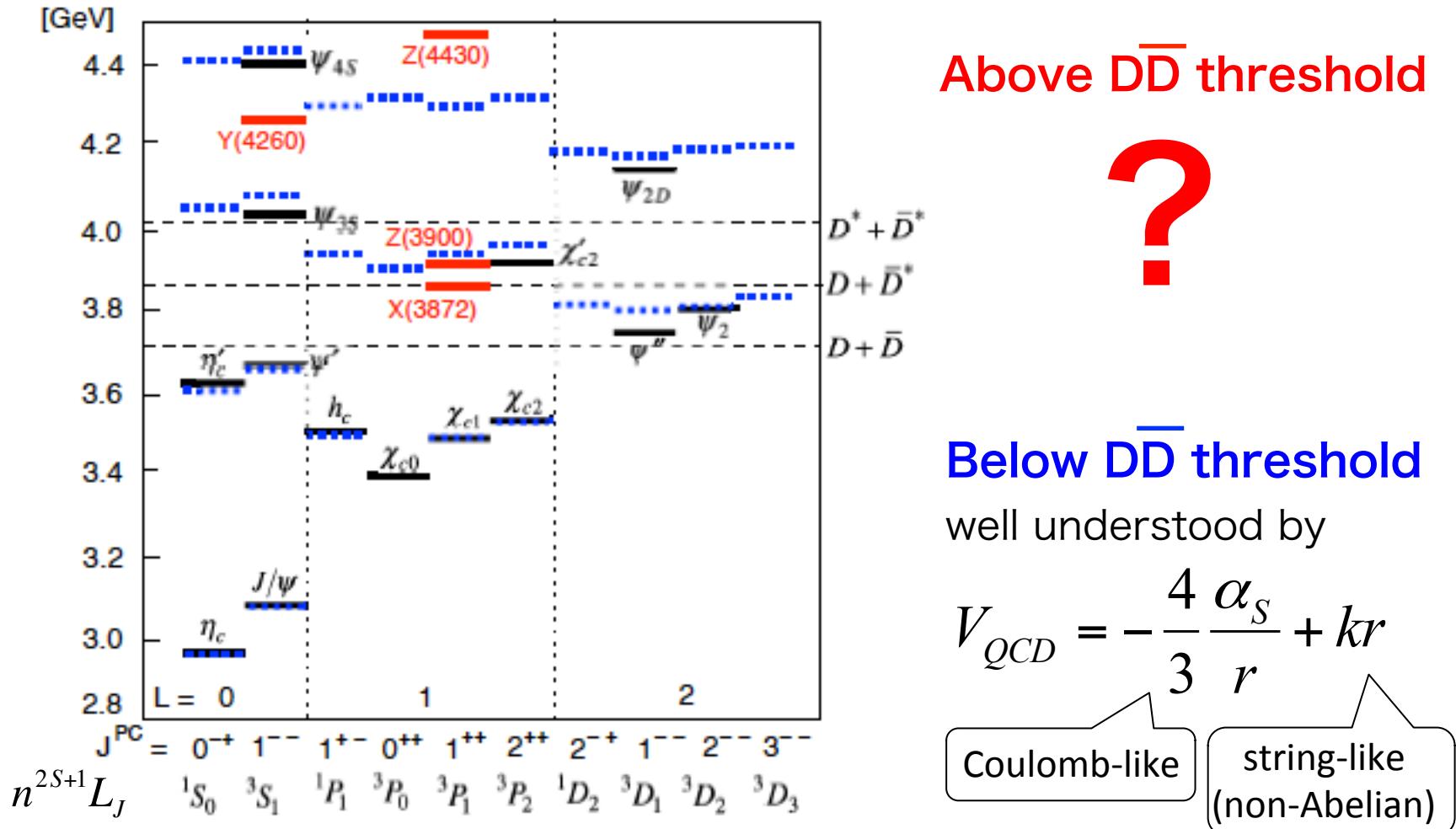
And following quarkonium spectroscopy established physical existence of quarks and  $q\bar{q}$  picture of mesons.

# Discoveries at B-factories

## New resonances discovered at B-Factories



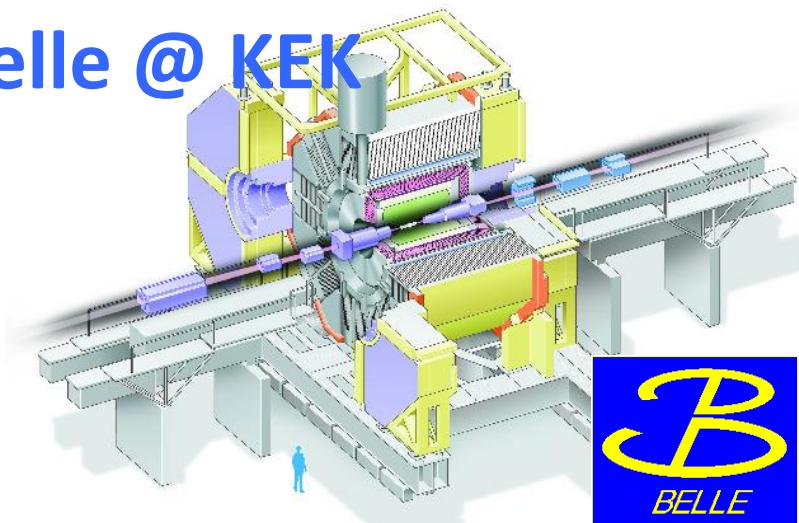
# Charmonium (-like) Spectroscopy



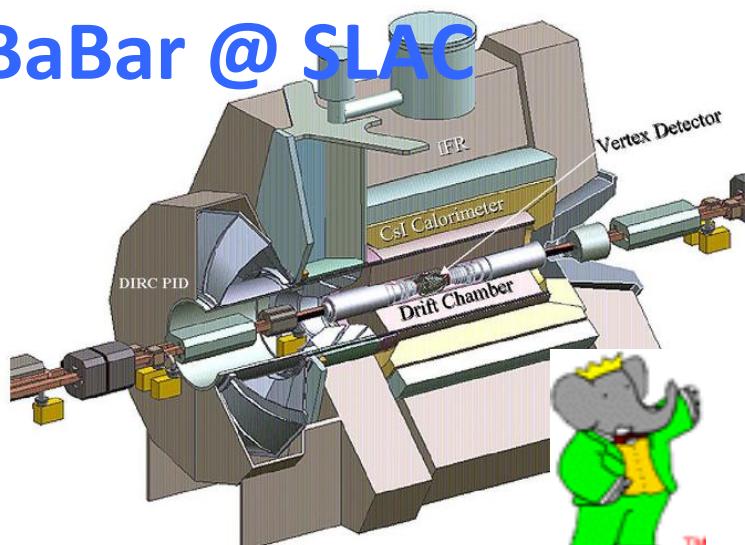
Conventional quark model describes only part of hadronic states.

# $e^+e^-$ Experiments for Heavy Quark Physics

Belle @ KEK



BaBar @ SLAC

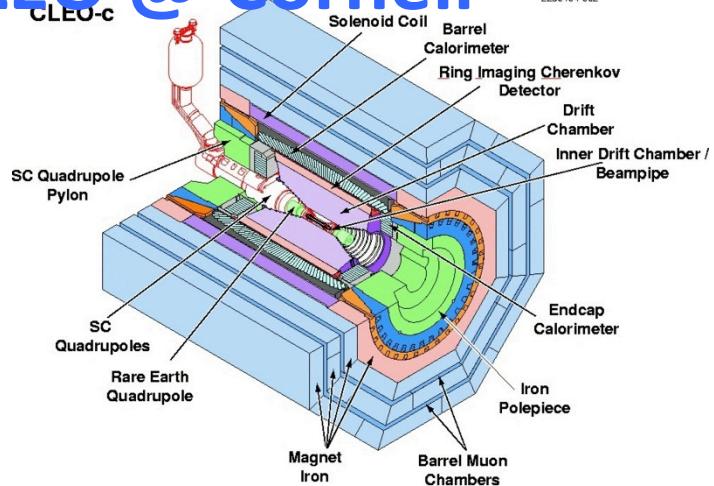


BES III @ IHEP (Beijing)



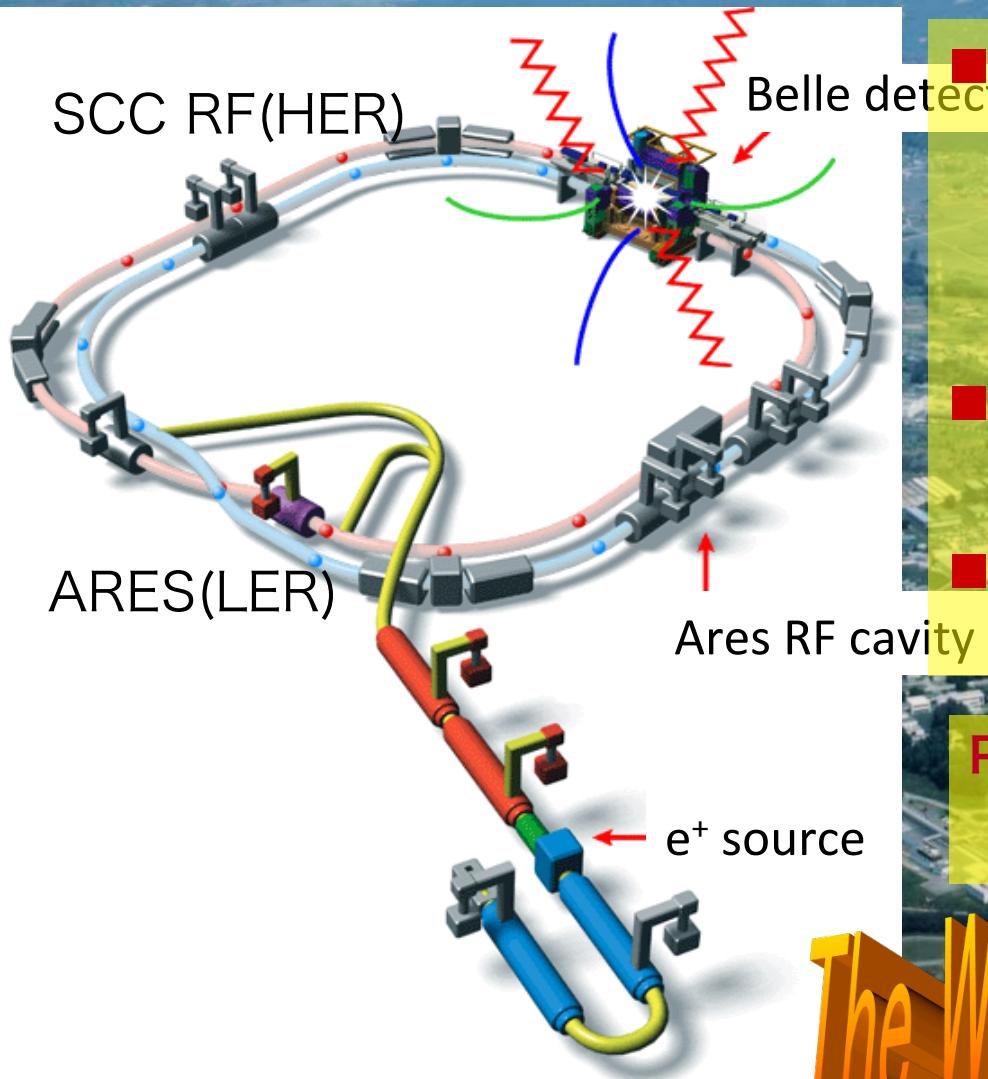
CLEO @ Cornell

CLEO-C



Talk by Ulrich Uwer for results from LHCb.

# The KEKB Collider

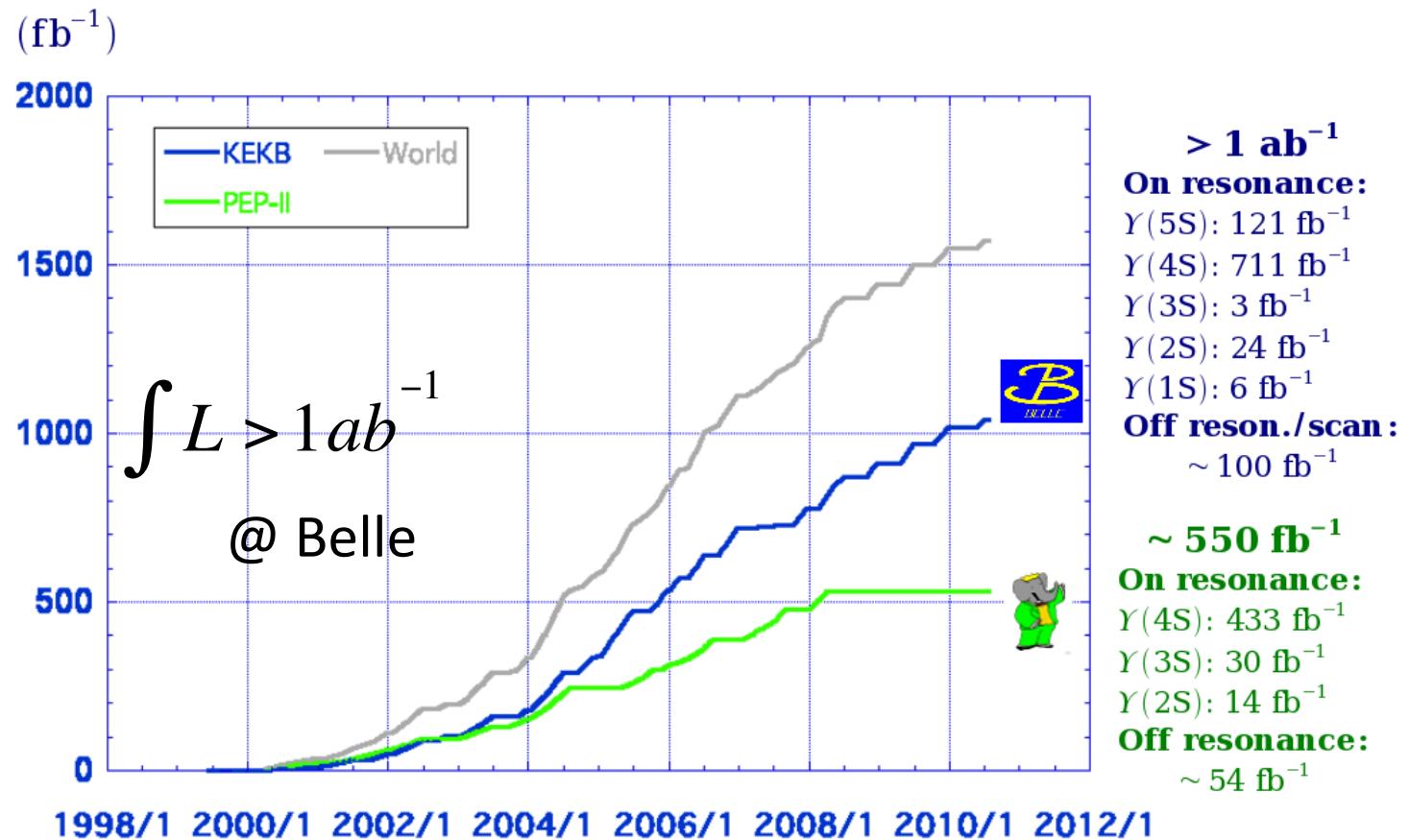


- $e^- (8.0\text{GeV}) \times e^+ (3.5\text{GeV})$   
 $\Rightarrow Y(4S) \rightarrow B\bar{B}$
- Lorentz boost:  
 $\beta\gamma = 0.425$
- Finite crossing angle  
- 11 mrad  $\times 2$
- Operated 1999-2010

Peak luminosity  
 $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

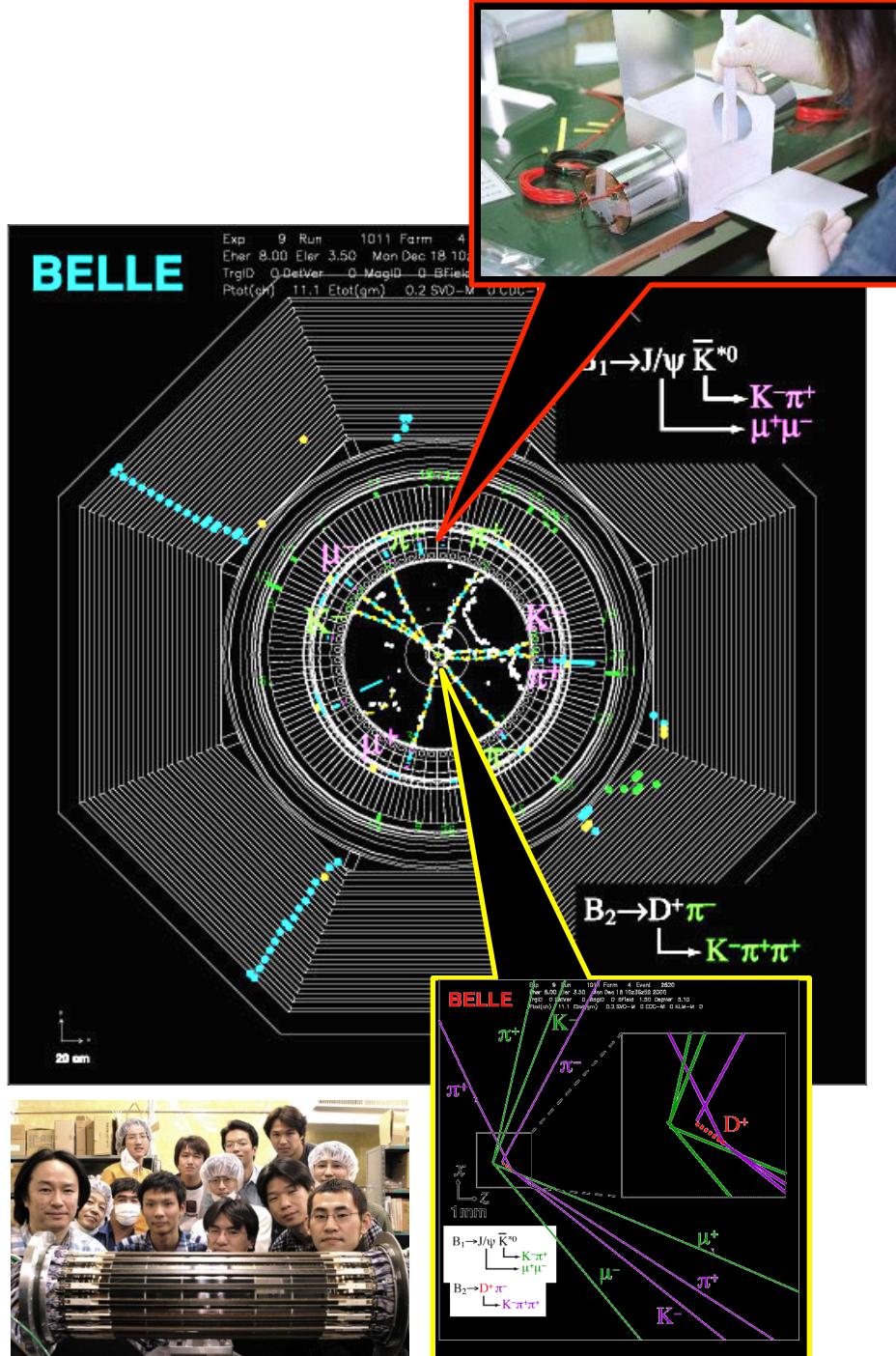
The World Highest Luminosity

# Luminosity at B Factories



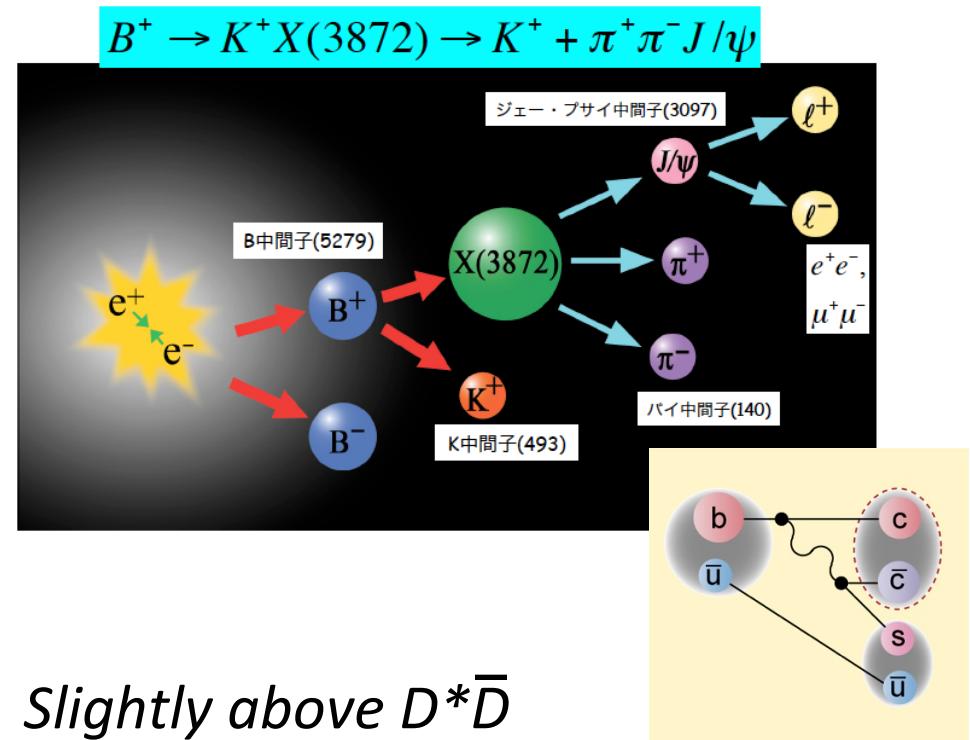
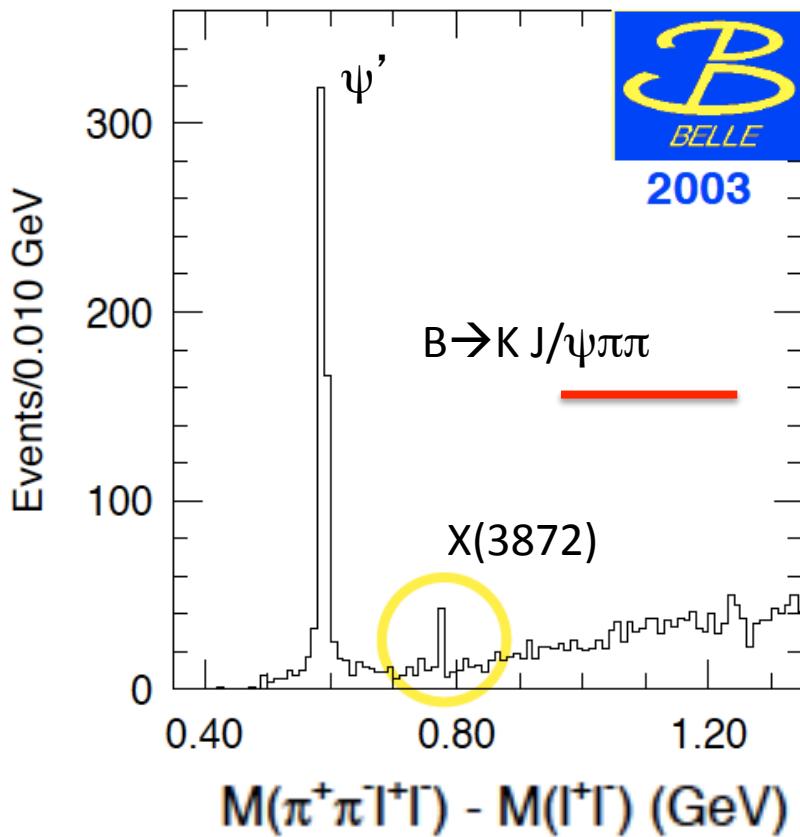
# Belle Detector

- Acceptance:  $0.9 \times 4\pi$
- Vertex resolution  
 $s(J/\psi \rightarrow ll) \sim 75\mu\text{m}$
- Momentum resolution  
 $\sigma(Pt) = 0.19 \cdot Pt + 0.34/\beta \%$
- Energy resolution  
 $\sigma(E\gamma)/E\gamma = 1.8\% @ 1\text{GeV}$
- Particle ID  
 $e, \mu, \pi, K, p$
- Minimum bias trigger  
 $E_{\text{vis}} \geq 1\text{GeV} \& N_{\text{trk}} \geq 2$   
 $\& N_{\text{cluster}} \geq 4$   
→ essentially no loss for  $B\bar{B}$ .



# Discovery of X(3872)

- 2003, by Belle

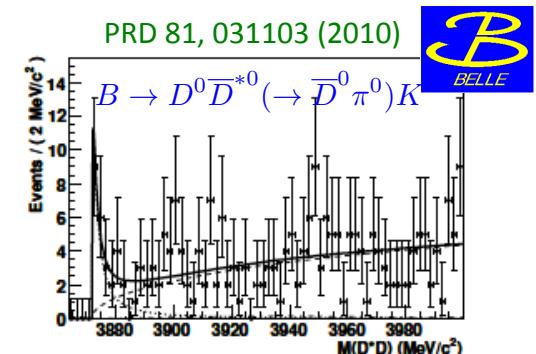
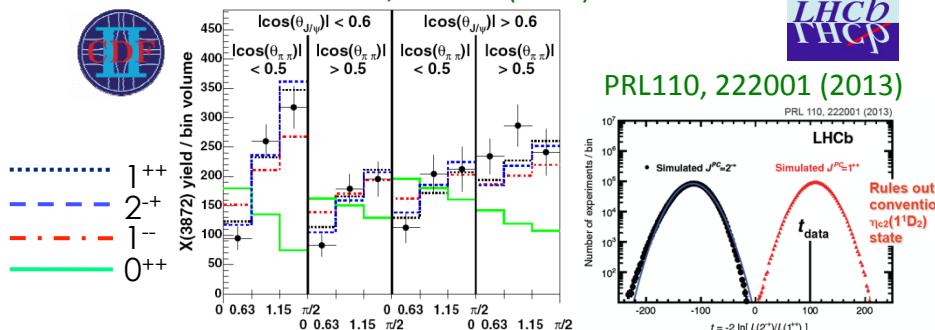
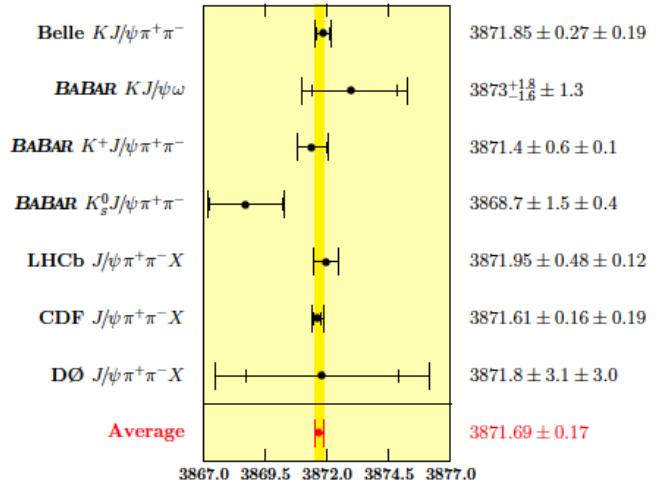


*Slightly above  $D^*\bar{D}$   
Surprisingly narrow !  
Mass unexpected for  $c\bar{c}$*

- Observed also by D0, CDF, BaBar, LHCb, CMS

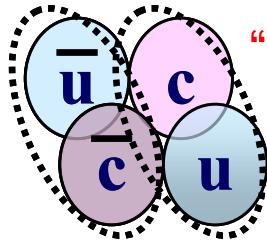
# Properties of X(3872)

- Mass  $M = 3871.69 \pm 0.17$  MeV (PDG2014)
  - Very close to  $M(D^0) + M(D^{*0}) = 3871.80$  MeV
- Width  $\Gamma < 1.2$  MeV (90% C.L.)
- Di-pion mass dist. consistent with  $\rho^0$  ( $\rightarrow l = 1$ )
  - Isospin violation if  $X = (c\bar{c})$
  - Charged partner not found yet
- Quantum numbers:  $J^{PC} = 1^{++}$ 
  - $X(3872) \rightarrow J/\psi \gamma$  seen  $C = +1$
  - Angular distribution analysis  $J^P = 1^+$
- Decay modes
  - $J/\psi \pi^+ \pi^-$
  - $J/\psi \omega$  (Belle)
  - $D^0 D^{*0}$  (Belle)
  - $J/\psi \gamma$  (Belle)
  - $\psi(2S) \gamma$  (BaBar, LHCb)

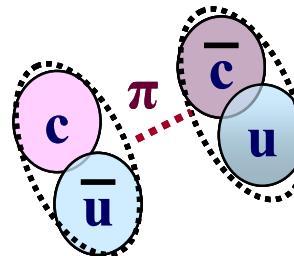


# Interpretation of X(3872)

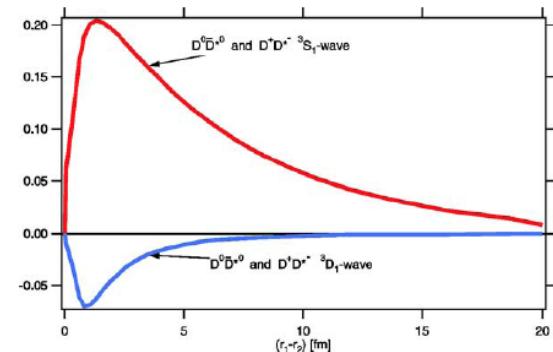
Tetraquark



$D^{(*)}\bar{D}^{(*)}$  Molecule

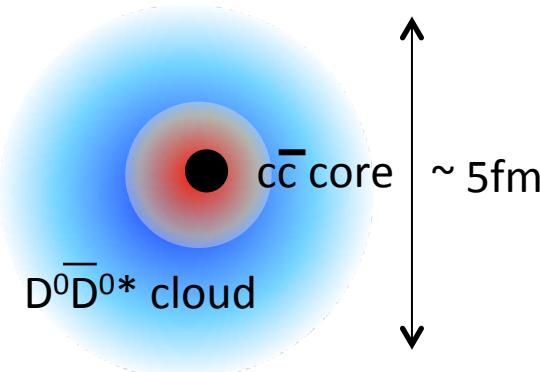


N. A. Tornqvist,  
PLB590.209 (2004)



- Molecule interpretation is popular.
  - Closeness to the  $D^*\bar{D}$  threshold.
  - Decay into  $D^*\bar{D}$  is seen (Belle).
  - If so, very large object ( $R > 5$  fm !)
- But, how such a state could be produced in  $pp$  ( $p\bar{p}$ ) collision (CDF, CMS, ...) ?
- Mixture of molecule +  $c\bar{c}$ , and/or tetra-quark ?

e.g. ; M. Takizawa and S. Takeuchi,  
PTEP, 2013(9), 0903D01 (2013)



# $\Upsilon(4260)$

- Found by BaBar in  $e^+e^- \rightarrow (J/\psi \pi^+\pi^-) \gamma_{ISR}$ 
  - Confirmed by Belle and CLEO
- $J^{PC} = 1^{--}$  (same as  $\gamma^*$ )
- $M = 4251 \pm 9$  (MeV/c<sup>2</sup>)
- $\Gamma = 120 \pm 12$  (MeV/c<sup>2</sup>)
- Other similar states with  $\psi(2S) \pi^+\pi^-$

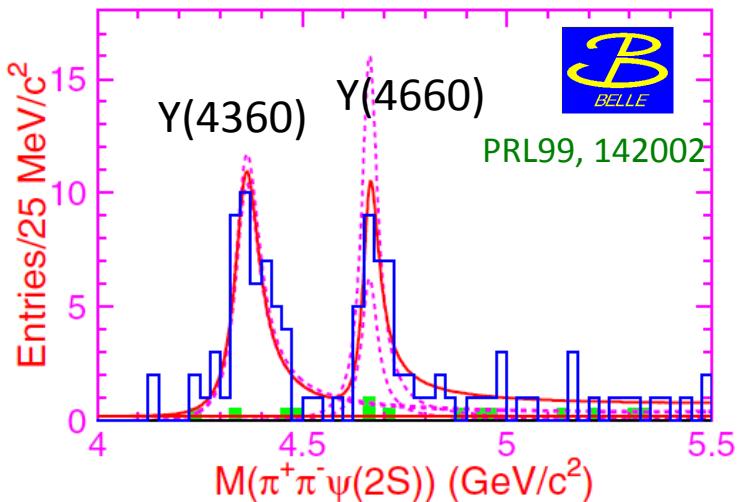
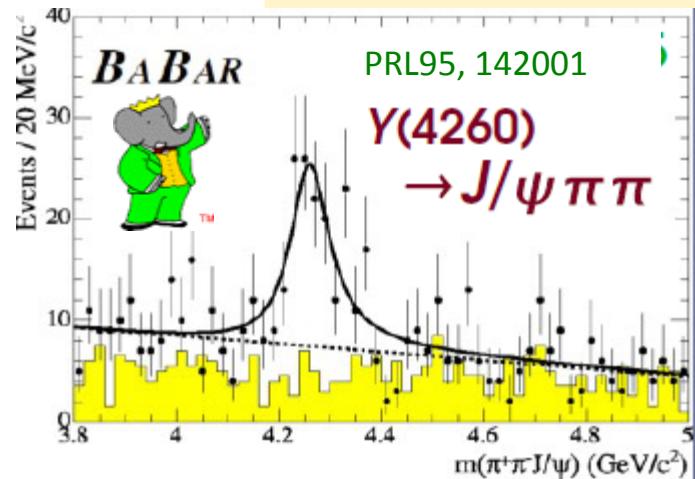
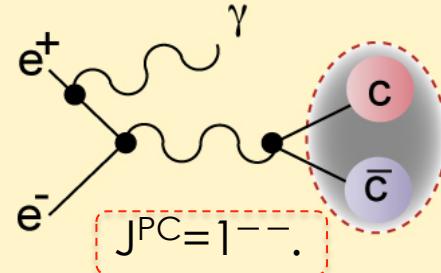
state	$M$ (MeV/c <sup>2</sup> )	$\Gamma$ (MeV/c <sup>2</sup> )
$\Upsilon(4360)$	$4362 \pm 13$	$74 \pm 18$
$\Upsilon(4660)$	$4664 \pm 12$	$48 \pm 15$

- No evidence for decays to  $D\bar{D}$

– e.g. 
$$\frac{\mathcal{B}(Y(4260) \rightarrow D\bar{D})}{\mathcal{B}(Y(4260) \rightarrow J/\psi\pi^+\pi^-)} < 1.0$$
 (BaBar)

$$\frac{\mathcal{B}(Y(4260) \rightarrow D^0 D^{*-}\pi^+)}{\mathcal{B}(Y(4260) \rightarrow J/\psi\pi^+\pi^-)} < 9 \text{ (Belle)}$$

$$\leftrightarrow \frac{\mathcal{B}(\psi(3770) \rightarrow D^0 \bar{D})}{\mathcal{B}(\psi(3770) \rightarrow J/\psi\pi^+\pi^-)} \geq 480$$



# $Z_c(4430)^+$

## Unambiguous evidence of 4-quark states

$c\bar{c}ud\bar{d}$

- Belle found  $Z(4430)^+$  in  $B \rightarrow K \pi^+ \psi'$  decays.
  - One-dimensional fit on  $\psi' \pi^+$  distribution after  $K^*(890) / K^*(1430)$  vetos.
 

PRL 100, 142001(2008)

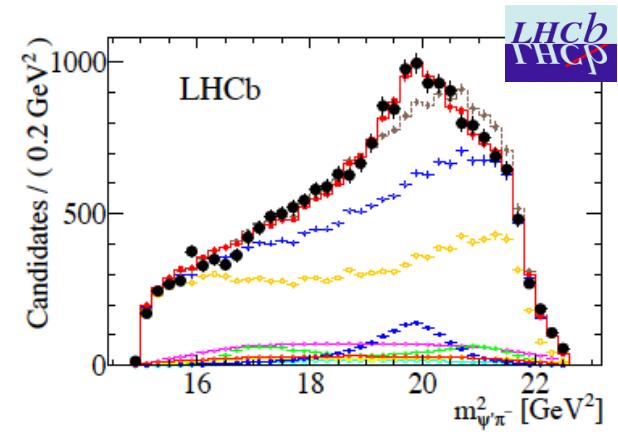
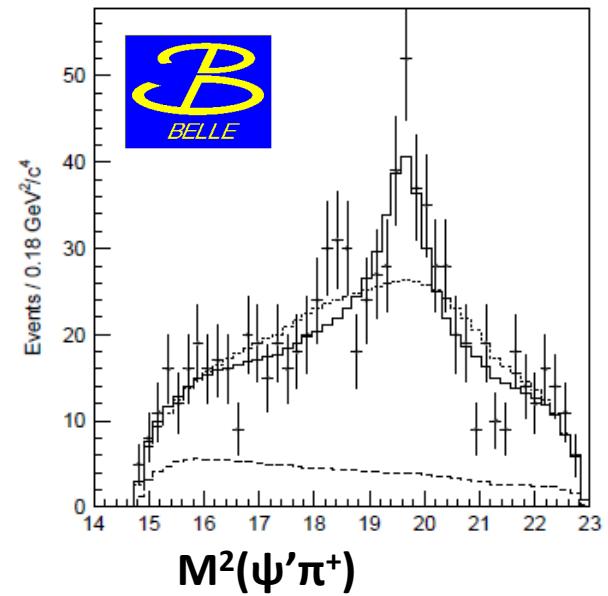
    - BaBar found only  $1.9 \sigma$  excess (does not contradict with the Belle result statistically)

PRD 79, 112001(2009)
- Confirmed by analysis with a full Dalitz plot.
- $M = (4443^{+15}_{-12} {}^{+19}_{-13}) \text{ MeV}/c^2$ 

PRD 80, 031104(2009)
- $\Gamma = (107^{+86}_{-43} {}^{+74}_{-56}) \text{ MeV}$
- LHCb confirmed the Belle result and  $J^P = 1^+$ 

$M = (4478 \pm 17) \text{ MeV}/c^2, \Gamma = (180 \pm 21) \text{ MeV}$
- Recent Belle analysis found
  - Hint of  $Z_c(4430)^+ \rightarrow J/\psi \pi^+$  in  $B \rightarrow J/\psi \pi^+ K^-$

PRD 90, 112009 (2014)



# $Z_c(3900)^+$

- BES III and Belle claimed  $Z_c(3900)^+$  in  $\Upsilon(4260) \rightarrow (J/\psi \pi^+) \pi^-$ 
  - BES III took data on the  $\Upsilon(4260)$  pole
  - Belle analyzed  $e^+e^- \rightarrow \Upsilon(4260) \gamma_{\text{ISR}}$
  - PDG2014:

$$M = (3888.7 \pm 3.4) \text{ MeV}/c^2, \Gamma = (35 \pm 7) \text{ MeV}$$

- BES III has seen also  $Z_c(3900)^+ \rightarrow (D\bar{D}^*)^+$

$$\frac{\Gamma(Z_c(3900) \rightarrow D\bar{D}^*)}{\Gamma(Z_c(3900) \rightarrow J/\psi \pi^+)} = 6.2 \pm 1.1 \pm 2.7$$

PRL 112, 02201 (2014)

- BES III has observed the neutral partner  $Z_c(3900)^0 \rightarrow Z_c(3900)^0 \pi^0 \rightarrow (J/\psi \pi^0) \pi^0$

$$M = (3894.8 \pm 2.3 \pm 3.2) \text{ MeV}/c^2, \Gamma = (29.6 \pm 8.2 \pm 8.2) \text{ MeV}$$

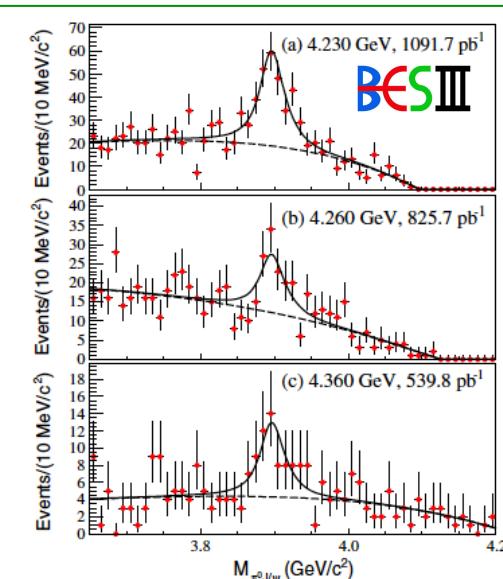
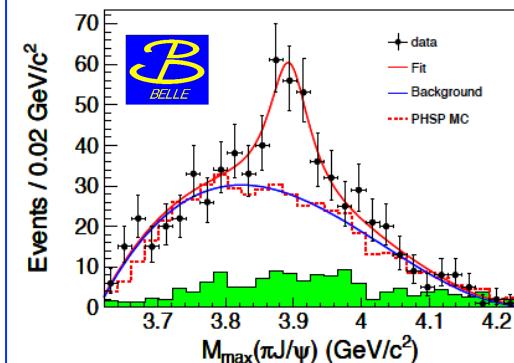
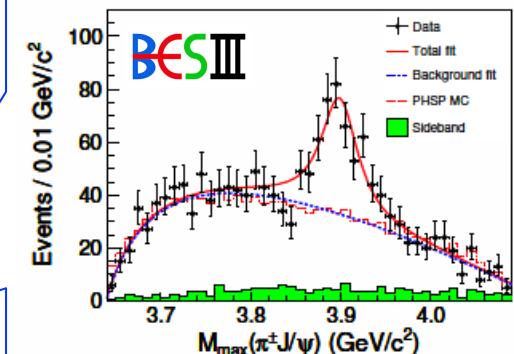
PRL 115, 112003 (2015)

T. Xiao et al. also claimed  $Z_c(3900)^+$  and  $Z_c(3900)^0$  using CLEO-c data.

Phys. Lett. B727, 366 (2013)

$$\psi(4160) \rightarrow J/\psi \pi^+ \pi^-$$

$$\psi(4160) \rightarrow J/\psi \pi^0 \pi^0$$



# Other $Z_c^+$ states

- $Z_c(4050)^+$  and  $Z_c(4250)^+$  in  $B \rightarrow K \pi^+ \chi_{c1}$  decays (Belle). PRD 78, 072004 (2008)

$$M_1 = (4051 \pm 14^{+20}_{-41}) \text{ MeV}/c^2$$

$$\Gamma_1 = (82^{+21}_{-17} {}^{+47}_{-22}) \text{ MeV}$$

$$M_2 = (4248^{+44}_{-29} {}^{+180}_{-35}) \text{ MeV}/c^2$$

$$\Gamma_2 = (177^{+54}_{-39} {}^{+316}_{-61}) \text{ MeV}$$

- $Z_c(4200)^+$  in  $B \rightarrow J/\psi \pi^+ K^-$  (Belle) PRD 90, 112009 (2014)

$$M = (4196^{+31}_{-29} {}^{+17}_{-13}) \text{ MeV}/c^2, \quad \Gamma = (370^{+70}_{-70} {}^{+70}_{-132}) \text{ MeV}/c^2$$

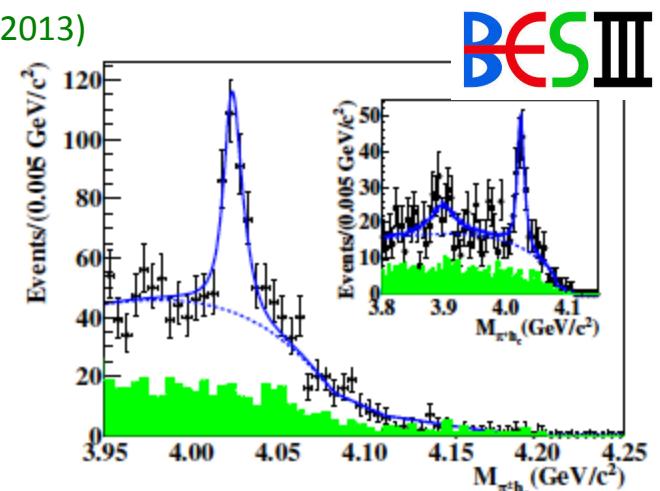
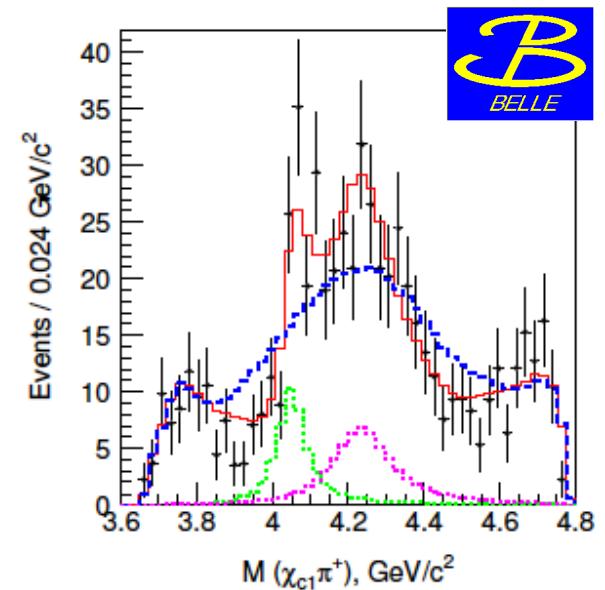
- $Z_c(4020)^+$  in  $e^+e^- \rightarrow (D^*\bar{D}^*)^+\pi^-$  and  $(h_c\pi^+)\pi^-$  (BES III) PRL 112, 132001 (2014) PRL 111, 242001 (2013)

$$M = (4023.9 \pm 2.4) \text{ MeV}/c^2, \quad \Gamma = (10 \pm 6) \text{ MeV}/c^2 \quad (\text{PDG})$$

- The mass is slightly above  $D^*\bar{D}^*$
- Also evidence for the neutral isospin partner  $Z_c(4020)^0$  PRL 113, 212002 (2014)

$$M = (4023.9 \pm 2.2 \pm 3.89) \text{ MeV}/c^2$$

(Width fixed to that of  $Z_c(4020)^+$ )

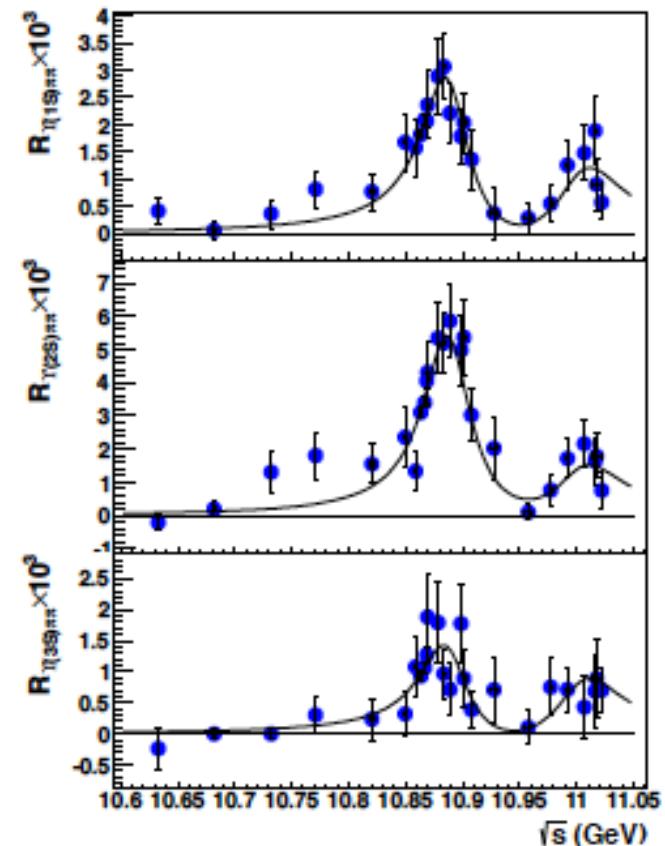
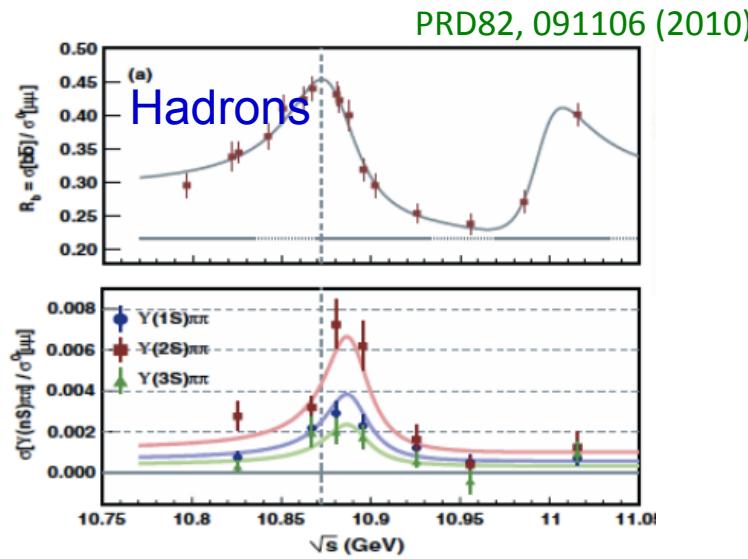


# $\Upsilon_b$ : $\Upsilon_c(4260)$ counter part

Large rate of  $\Upsilon(4260) \rightarrow J/\psi \pi^+ \pi^-$

Anomalously large rates of  $\Upsilon(5S) \rightarrow \Upsilon(nS) \pi^+ \pi^-$   
~100 times larger than  $\Upsilon(1-4S) \rightarrow \Upsilon(nS) \pi^+ \pi^-$

arXiv: 1501.01137



$$M_{10860} = (10891.1 \pm 3.2^{+0.6}_{-1.5}) \text{ MeV}/c^2$$

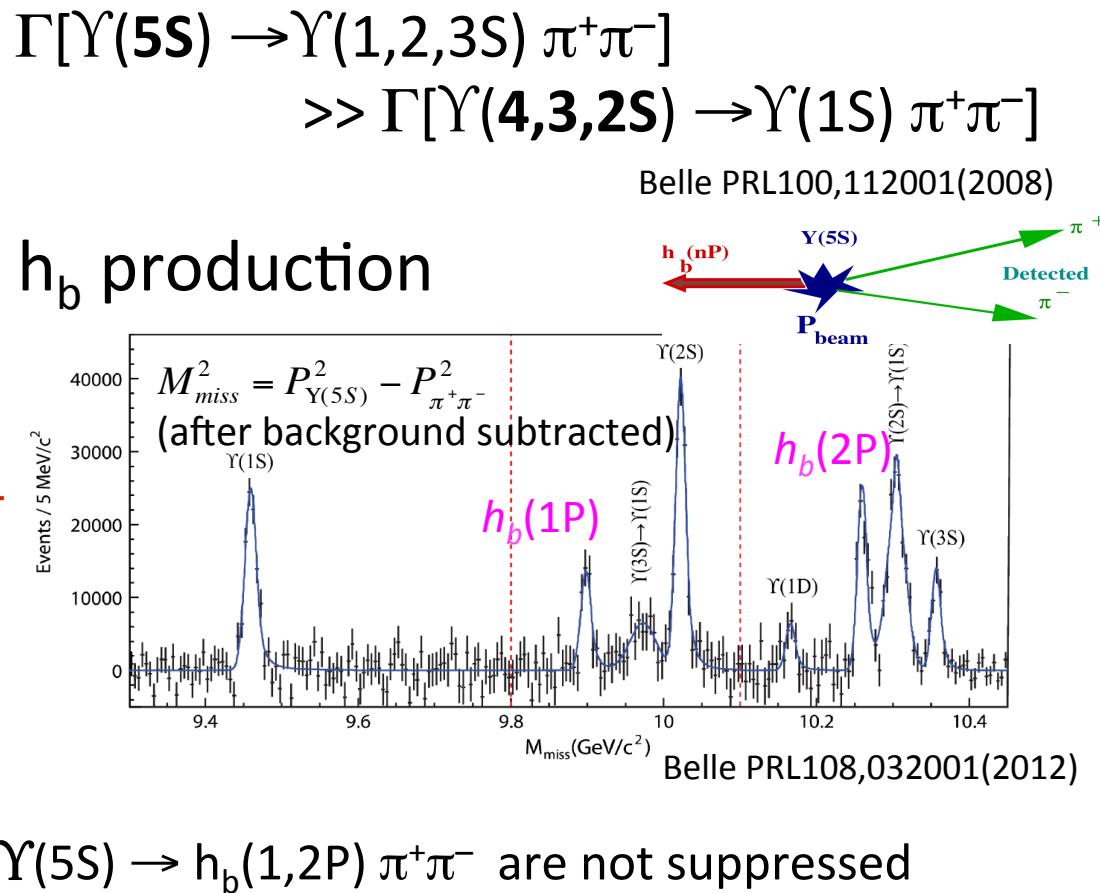
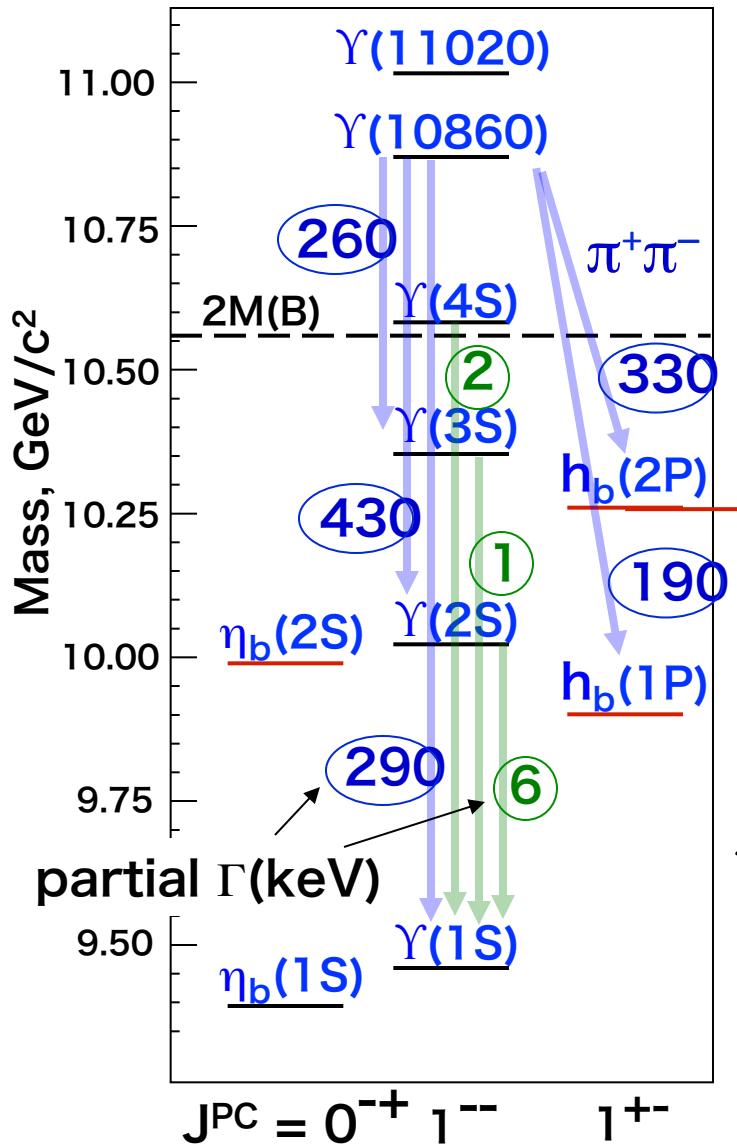
$$\Gamma_{10860} = (53.7^{+7.1}_{-5.6}{}^{+0.9}_{-5.4}) \text{ MeV}$$

$$M_{11020} = (10987.5^{+6.4}_{-2.5}{}^{+9.0}_{-2.1}) \text{ MeV}/c^2$$

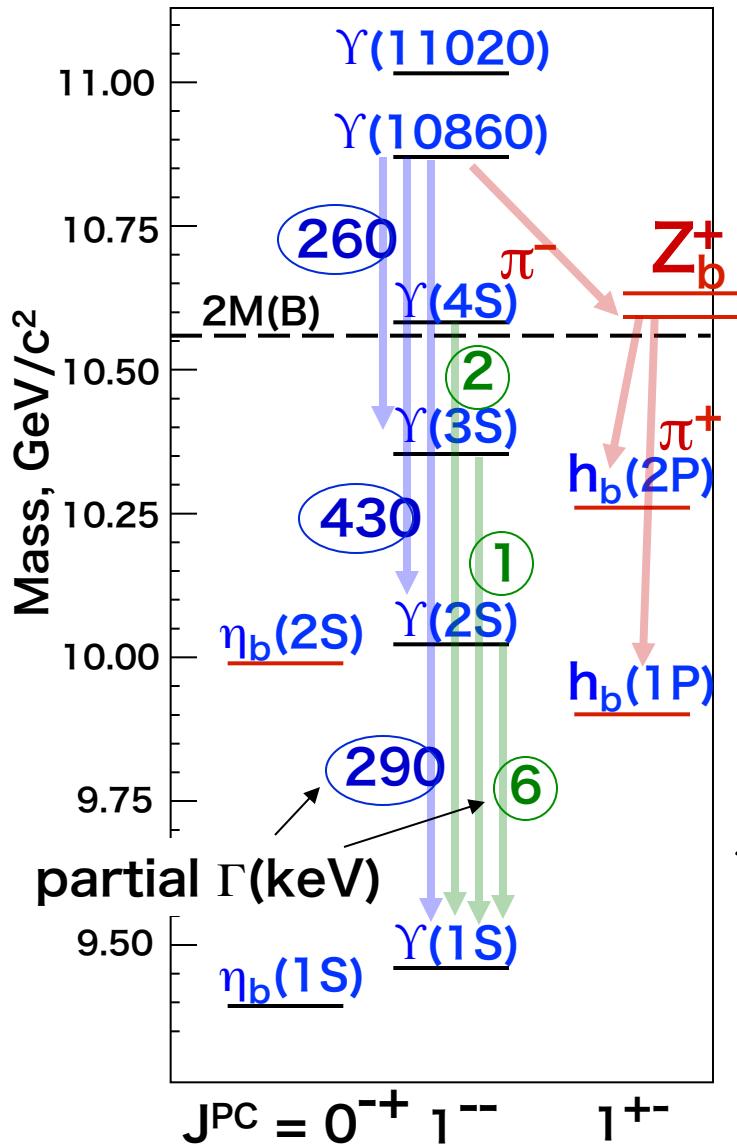
$$\Gamma_{11020} = (61^{+9}_{-19}{}^{+2}_{-20}) \text{ MeV}$$

$$\phi_{11020} - \phi_{10860} = (-1.0 \pm 0.4^{+1.0}_{-0.1}) \text{ rad}$$

# Anomalies in $\Upsilon(5S)$ decay



# Anomalies in $\Upsilon(5S)$ decay



**$h_b$  production**  
 $\Rightarrow$  via intermediate charged states  $Z_b$

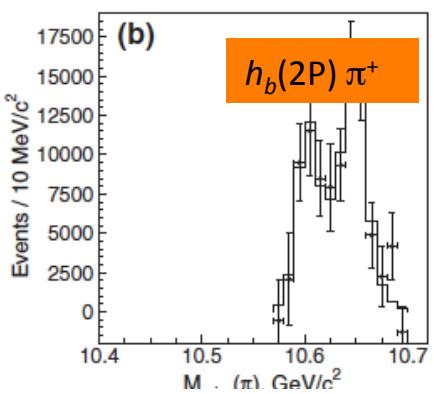
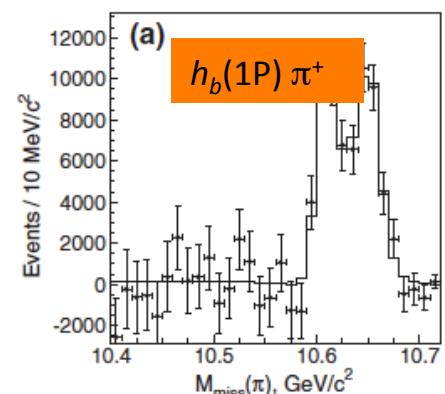
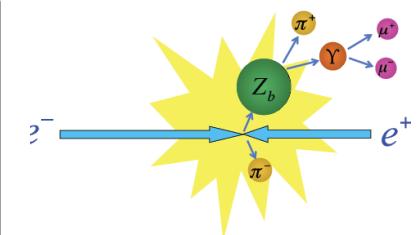
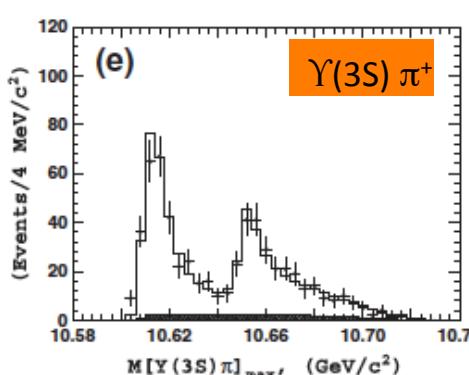
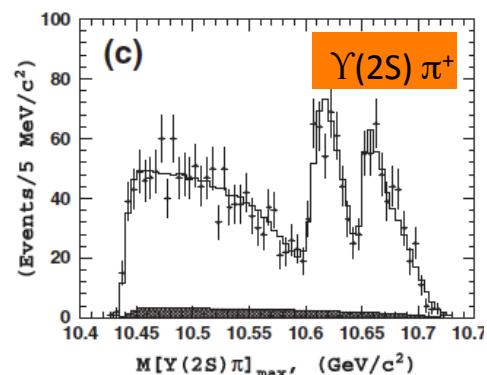
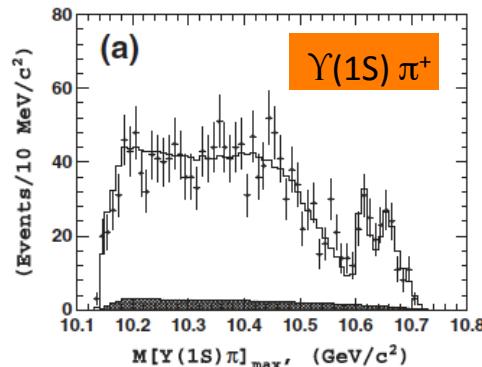
$\Upsilon(5S) \rightarrow h_b(1,2P) \pi^+ \pi^-$  are not suppressed



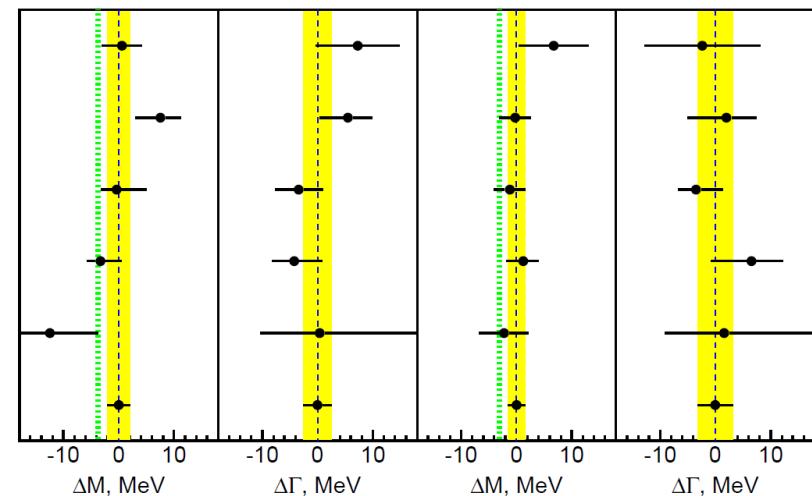
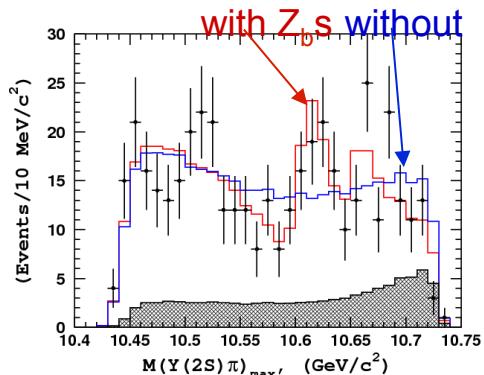
Expect suppression  $\sim \Lambda_{\text{QCD}}/m_b$   
 Heavy Quark Symmetry Violation



# $Z_b(10610)^+$ and $Z_b(10650)^+$



$Z_b(10610)^0$  signal  
seen in  $\Upsilon(2S)\pi^0\pi^0$



$$M = 10608.4 \pm 2.0 \text{ MeV}$$

$$\Gamma = 15.6 \pm 2.5 \text{ MeV}$$

$$M = 10653.2 \pm 1.5 \text{ MeV}$$

$$\Gamma = 14.4 \pm 3.2 \text{ MeV}$$

$J^P = 1^+$  from amplitude analysis

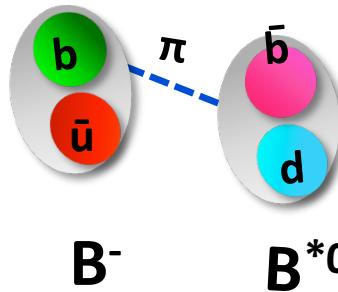
PRD 91, 072003 (2015)

# Molecule Explanation of $Z_b^+$

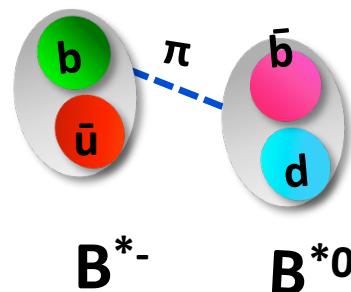
Bondar et al, PRD84,054010(2011)

**Proximity to thresholds favors molecule picture**

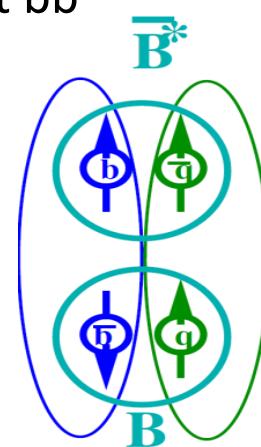
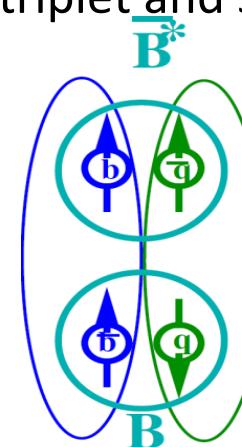
$Z_b^+(10610)$



$Z_b^+(10650)$



Each of them is mixture of spin triplet and singlet  $b\bar{b}$



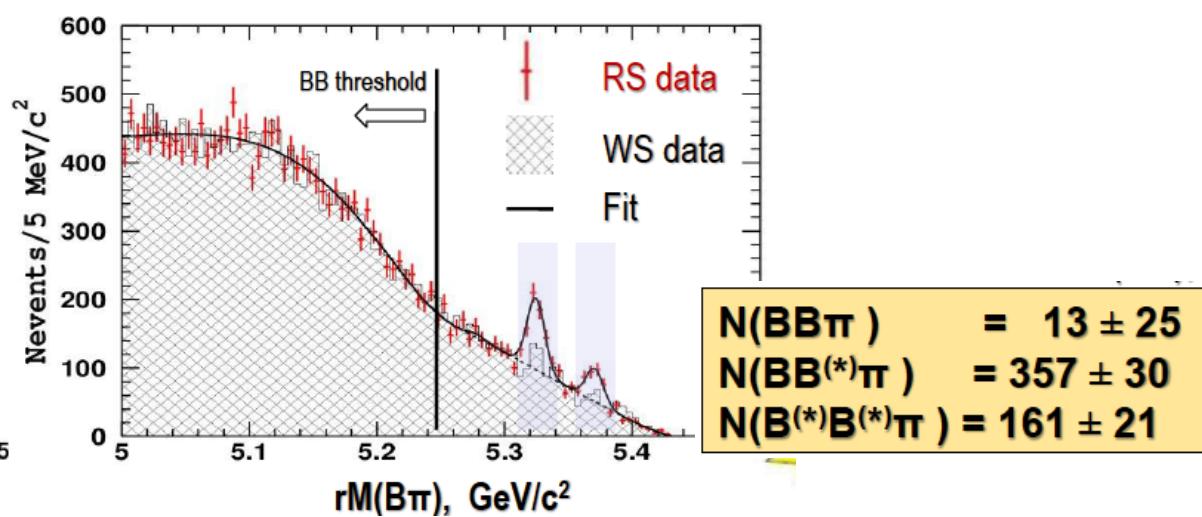
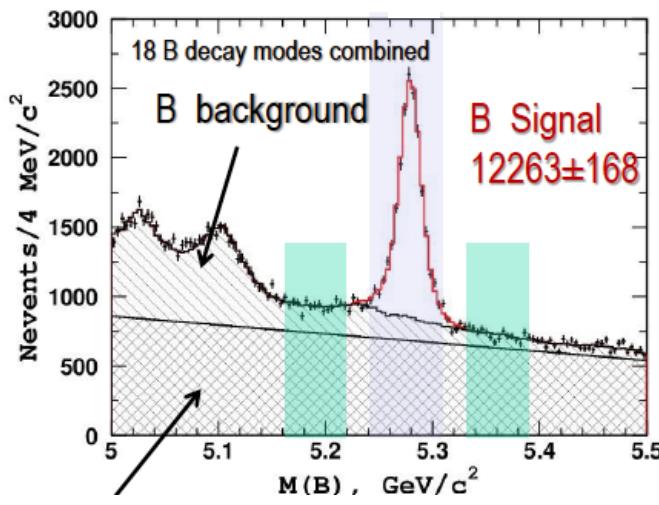
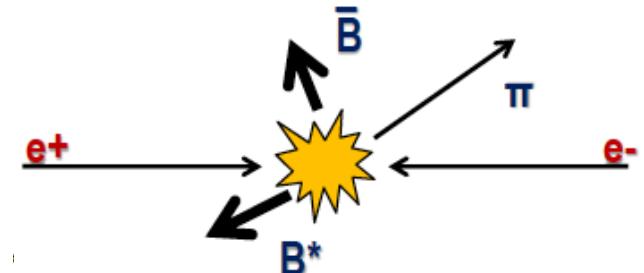
This model explains

- Why  $h_b \pi\pi$  is unsuppressed relative to  $\gamma \pi\pi$
- Relative phase  $\sim 0$  for  $\gamma$  and  $\sim 180^\circ$  for  $h_b$
- Production rates of  $Z_b(10610)$  and  $Z_b(10650)$  are similar widths

If  $Z_b^+$  is  $B^*B^{(*)}$  molecule, it should decay into  $B^*B^{(*)}...$

# Study of $Z_b^+ \rightarrow B^*\bar{B}^{(*)}$

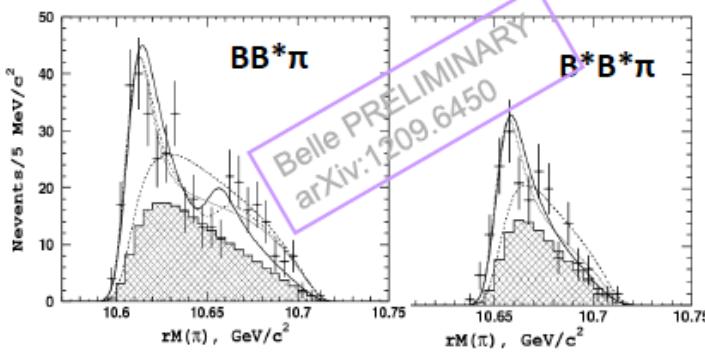
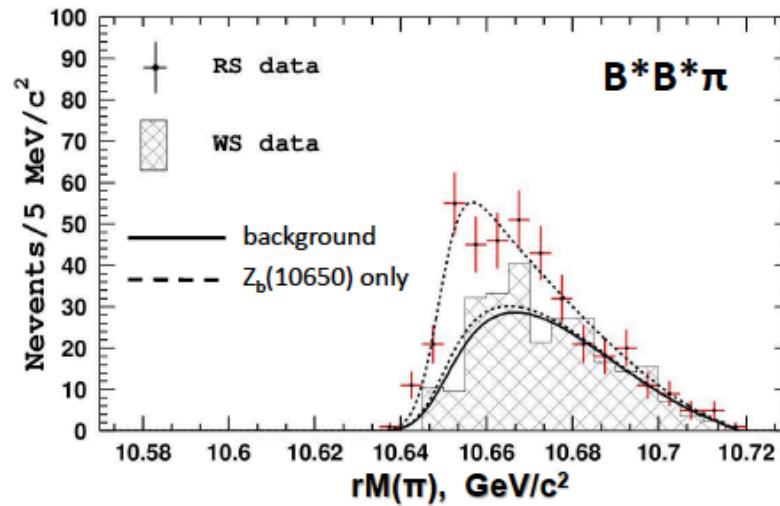
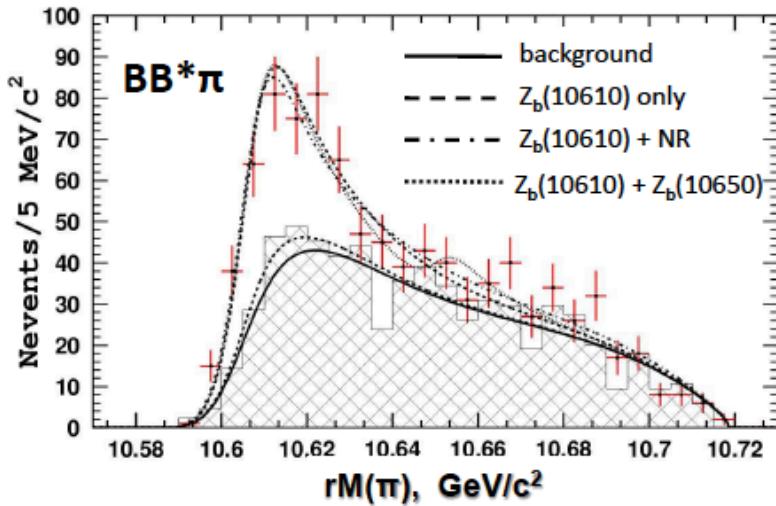
- Since masses of  $Z_b(10610)^+$  and  $Z_b(10650)^+$  are close to  $\bar{B}B^*$  and  $B^*\bar{B}^*$ , respectively, branching fractions of  $Z_b^+ \rightarrow B^*\bar{B}^{(*)}$  may be large.
- Analysis strategy: for  $e^+e^- \rightarrow B^{(*)}\bar{B}^{(*)}\pi^\pm$ 
  - Fully reconstruct one of B meson ( $B_{\text{rec}}$ ).
  - Combine the  $B_{\text{rec}}$  with  $\pi$  in the rest of the event, and look at the recoil mass to distinguish  $\bar{B}B\pi$ ,  $\bar{B}B^*\pi$ ,  $B^*\bar{B}^*\pi$
  - Then, look at the recoil mass against the pion.



$q\bar{q}$  background

See talk by A. Bondar at LP2015

- For events in the 3-body signal regions, look at the recoil mass against the primary pion.



- $\overline{B}B^*\pi$  and  $B^*\overline{B}^*\pi$  data fit well to just  $Z_b(10610)$  and  $Z_b(10650)$  signals, respectively.
- Assuming  $Z_b$  decays are saturated by already observed decay channels,  $B^{(*)}\overline{B}^*$  channels dominate the  $Z_b$  decays.

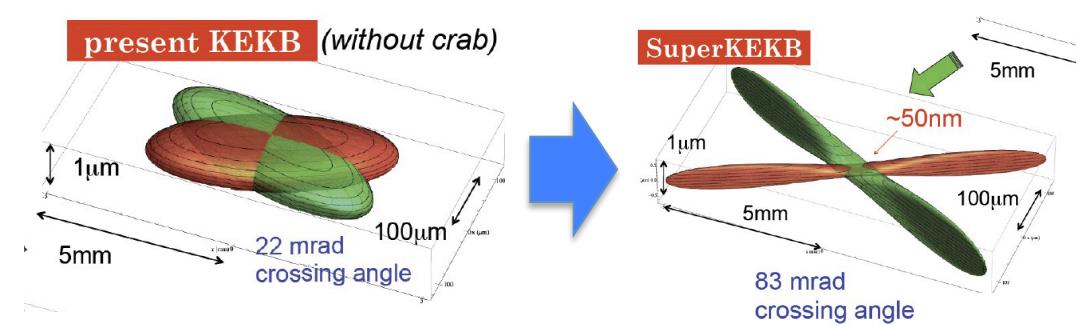
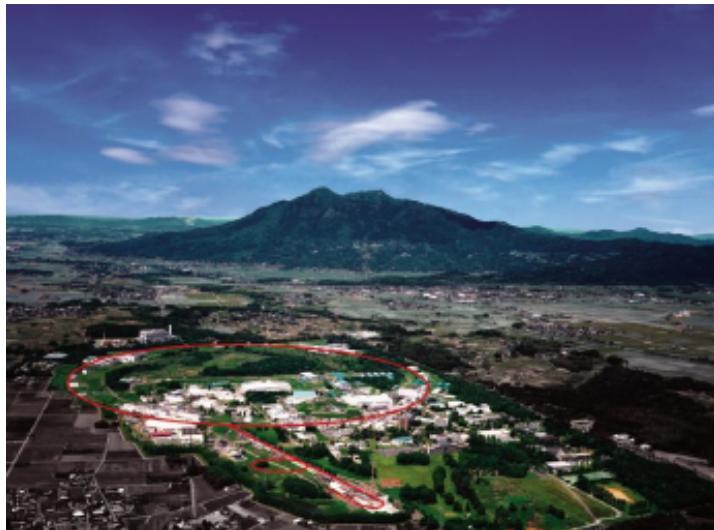
# Summary of Experimental Results

>20 exotic states !

State	$m$ (MeV)	$\Gamma$ (MeV)	$J^{PC}$	Process (mode)	References
$X(3872)$	$3871.69 \pm 0.17$	$<1.2$	$1^{++}$	$B \rightarrow K(\pi^+ \pi^- J/\psi)$	Belle [10, 28], BaBar [32], LHCb [30, 65]
				$p\bar{p} \rightarrow (\pi^+ \pi^- J/\psi) + \dots$	CDF [27, 66, 67], D0 [68]
				$e^+ e^- \rightarrow \gamma(\pi^+ \pi^- J/\psi)$	BES III [69]
				$B \rightarrow K(\omega J/\psi)$	Belle [70], BaBar [29]
				$B \rightarrow K(D^{*0} D^0)$	Belle [35, 71], BaBar [34]
				$B \rightarrow K(\gamma J/\psi)$ and $B \rightarrow K(\gamma\psi(2S))$	Belle [25], BaBar [26], LHCb [37]
$Z_c(3900)^+$	$3888.7 \pm 3.4$	$35 \pm 7$	$1^+$	$e^+ e^- \rightarrow (J/\psi \pi^+) \pi^-$	Belle [40], BES III [51]
				$e^+ e^- \rightarrow (D\bar{D}^*)^+ \pi^-$	BES III [72]
$X(3915)$	$3915.6 \pm 3.1$	$28 \pm 10$	$0/2^{?+}$	$B \rightarrow K(\omega J/\psi)$	Belle [73], BaBar [29]
				$e^+ e^- \rightarrow e^+ e^- (\omega J/\psi)$	Belle [74], BaBar [75]
$X(3940)$	$3942^{+9}_{-8}$	$37^{+27}_{-17}$	$?^+$	$e^+ e^- \rightarrow J/\psi(DD^*)$	Belle [76]
				$e^+ e^- \rightarrow J/\psi (\dots)$	Belle [77]
$Y(4008)$	$3891 \pm 42$	$255 \pm 42$	$1^{--}$	$e^+ e^- \rightarrow \gamma(\pi^+ \pi^- J/\psi)$	Belle [39, 40]
$Z_c(4050)^+$	$4051^{+24}_{-43}$	$82^{+51}_{-55}$	$?$	$B \rightarrow K(\pi^+ \chi_{c1}(1P))$	Belle [78], BaBar [79]
$X(4050)^+$	$4054 \pm 3$	$45$	$?$	$e^+ e^- \rightarrow (\pi^+ \psi(2S)) \pi^-$	Belle [80]
$Y(4140)$	$4143.4 \pm 3.0$	$15^{+11}_{-7}$	$?^+$	$B \rightarrow K(\phi J/\psi)$	CDF [64], D0 [81]
$X(4160)$	$4156^{+29}_{-25}$	$139^{+113}_{-65}$	$?^+$	$e^+ e^- \rightarrow J/\psi(DD^*)$	Belle [76]
$Z_c(4200)^+$	$4196^{+35}_{-32}$	$370^{+99}_{-149}$	$?$	$B \rightarrow K(\pi^+ J/\psi)$	Belle [50]
$Z_c(4250)^+$	$4248^{+185}_{-45}$	$177^{+321}_{-72}$	$?$	$B \rightarrow K(\pi^+ \chi_{c1}(1P))$	Belle [78], BaBar [79]
$Y(4260)$	$4263 \pm 5$	$108 \pm 14$	$1^{--}$	$e^+ e^- \rightarrow \gamma(\pi^+ \pi^- J/\psi)$	BaBar [38, 82], CLEO [83], Belle [39, 40]
				$e^+ e^- \rightarrow (\pi^+ \pi^- J/\psi)$	CLEO [44], BES III [72]
				$e^+ e^- \rightarrow (\pi^0 \pi^0 J/\psi)$	CLEO [44]
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$?^+$	$e^+ e^- \rightarrow e^+ e^- (\phi J/\psi)$	Belle [84]
$Y(4360)$	$4361 \pm 13$	$74 \pm 18$	$1^{--}$	$e^+ e^- \rightarrow \gamma(\pi^+ \pi^- \psi(2S))$	BaBar [41], Belle [42, 80]
$Z_c(4430)^+$	$4485^{+36}_{-25}$	$200^{+49}_{-58}$	$1^+$	$B \rightarrow K(\pi^+ \psi(2S))$	Belle [46, 48, 49], BaBar [47], LHCb [18]
				$B \rightarrow K(\pi^+ J/\psi)$	Belle [50], BaBar [47]
$X(4630)$	$4634^{+9}_{-11}$	$92^{+41}_{-32}$	$1^{--}$	$e^+ e^- \rightarrow \gamma(\Lambda_c^+ \Lambda_c^-)$	Belle [85]
$Y(4660)$	$4664 \pm 12$	$48 \pm 15$	$1^{--}$	$e^+ e^- \rightarrow \gamma(\pi^+ \pi^- \psi(2S))$	Belle [42]
$Z_b(10610)^+$	$10607.2 \pm 2.0$	$18.4 \pm 2.4$	$1^+$	$e^+ e^- \rightarrow (b\bar{b} \pi^+) \pi^-$	Belle [17]
$Z_b(10610)^0$	$10609 \pm 4 \pm 4$	N.A.	$1^{?1}$	$e^+ e^- \rightarrow (\Upsilon(2,3S)\pi^0) \pi^0$	Belle [19]
$Z_b(10650)^+$	$10652.2 \pm 1.5$	$11.5 \pm 2.2$	$1^+$	$e^+ e^- \rightarrow (b\bar{b} \pi^+) \pi^-$	Belle [17]
$Y_b(10888)$	$10888.4 \pm 3.0$	$30.7^{+8.9}_{-7.7}$	$1^{--}$	$e^+ e^- \rightarrow (\pi^+ \pi^- \Upsilon(nS))$	Belle [53, 55]

# Future: SuperKEKB / Belle II

- New intensity frontier facility
- Target luminosity ;  $L_{\text{peak}} = 8 \times 10^{35} \text{ cm}^{-2} \text{s}^{-1}$   
 $L_{\text{int}} > 50 \text{ ab}^{-1}$  by early 2020's.  
 $\Rightarrow \sim 10^{10}$  BB,  $\tau+\tau-$  and charms per year !

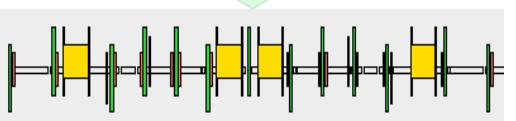
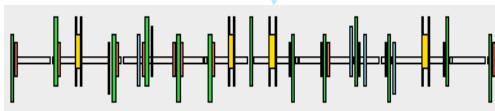


“nano-beam scheme”  
+ doubling the beam currents

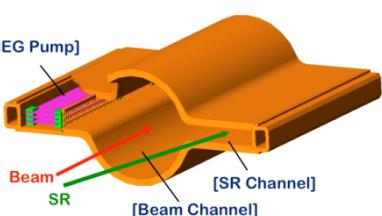
x50 data to find more exotic states (XYZ, (double-) charm hadrons, ...), study properties of observed hadrons.



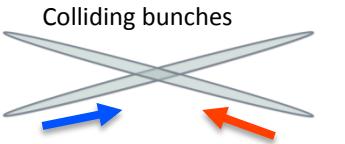
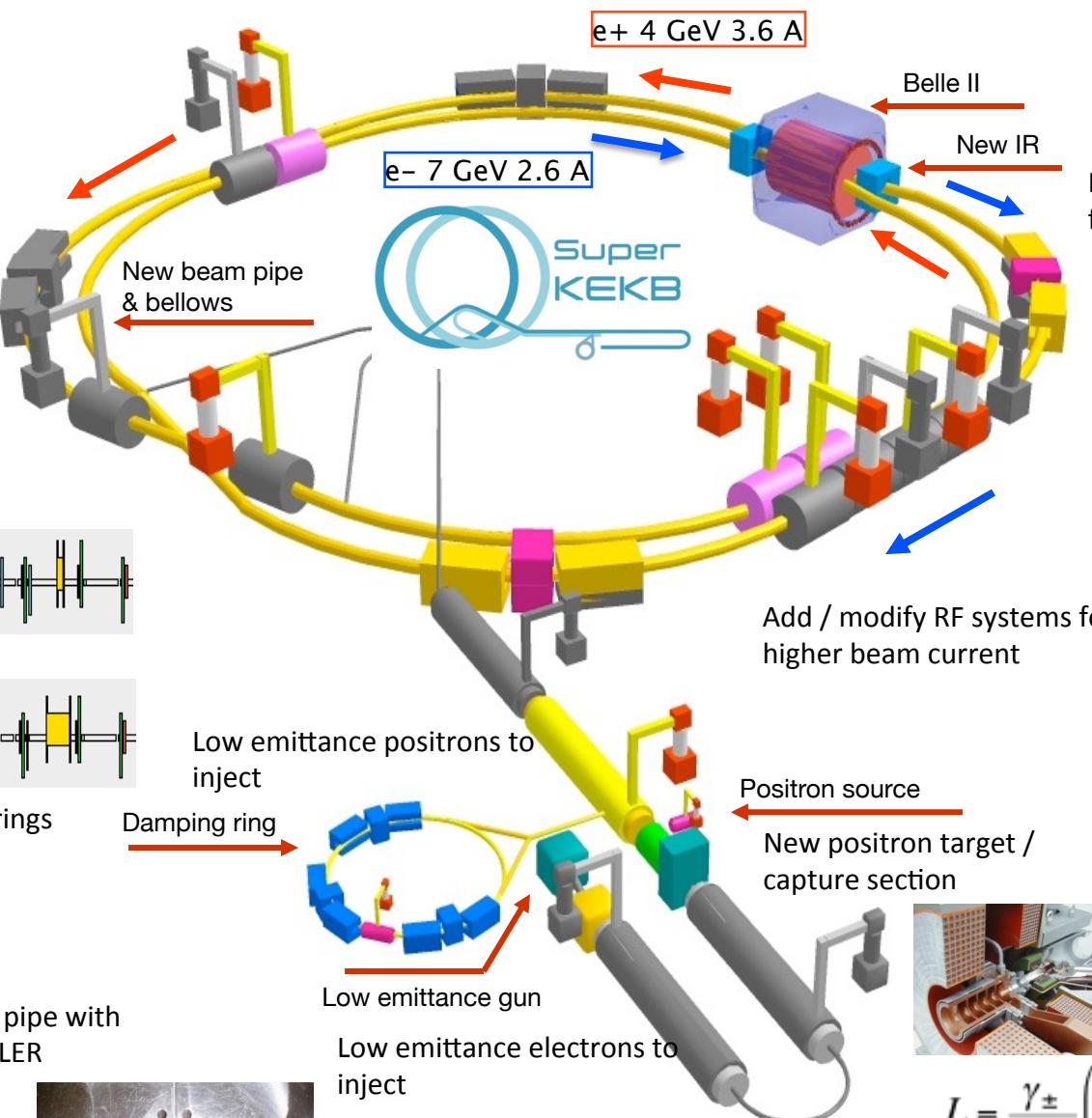
Replace short dipoles with longer ones (LER)



Redesign the lattices of both rings to reduce the emittance



TiN-coated beam pipe with antechambers in LER



New superconducting final focusing quads near the IP



$$L = \frac{\gamma_{\pm}}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \frac{I_{\pm} \xi_{\pm y}}{\beta_v^*} \left( \frac{R_L}{R_y} \right)$$

x 40 Gain in Luminosity

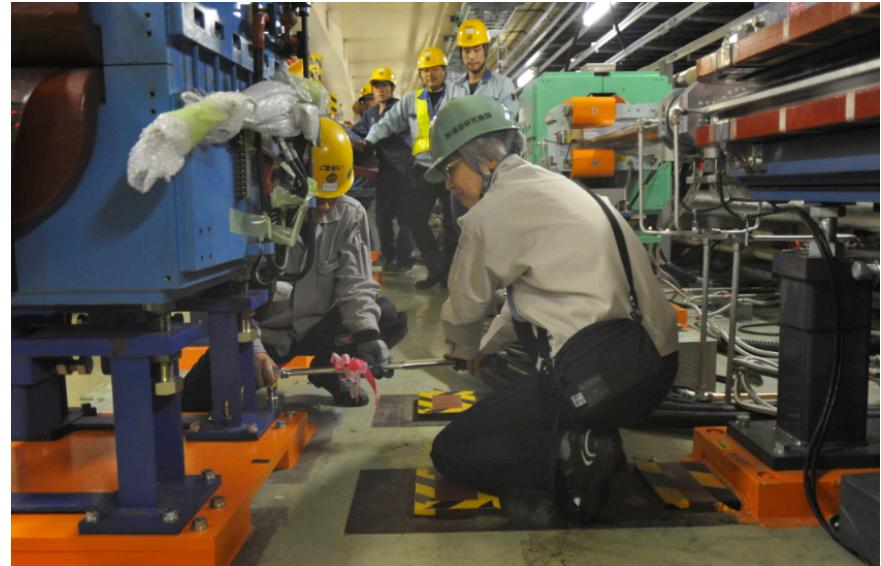
## Newly installed beam pipes



## Installation of magnets

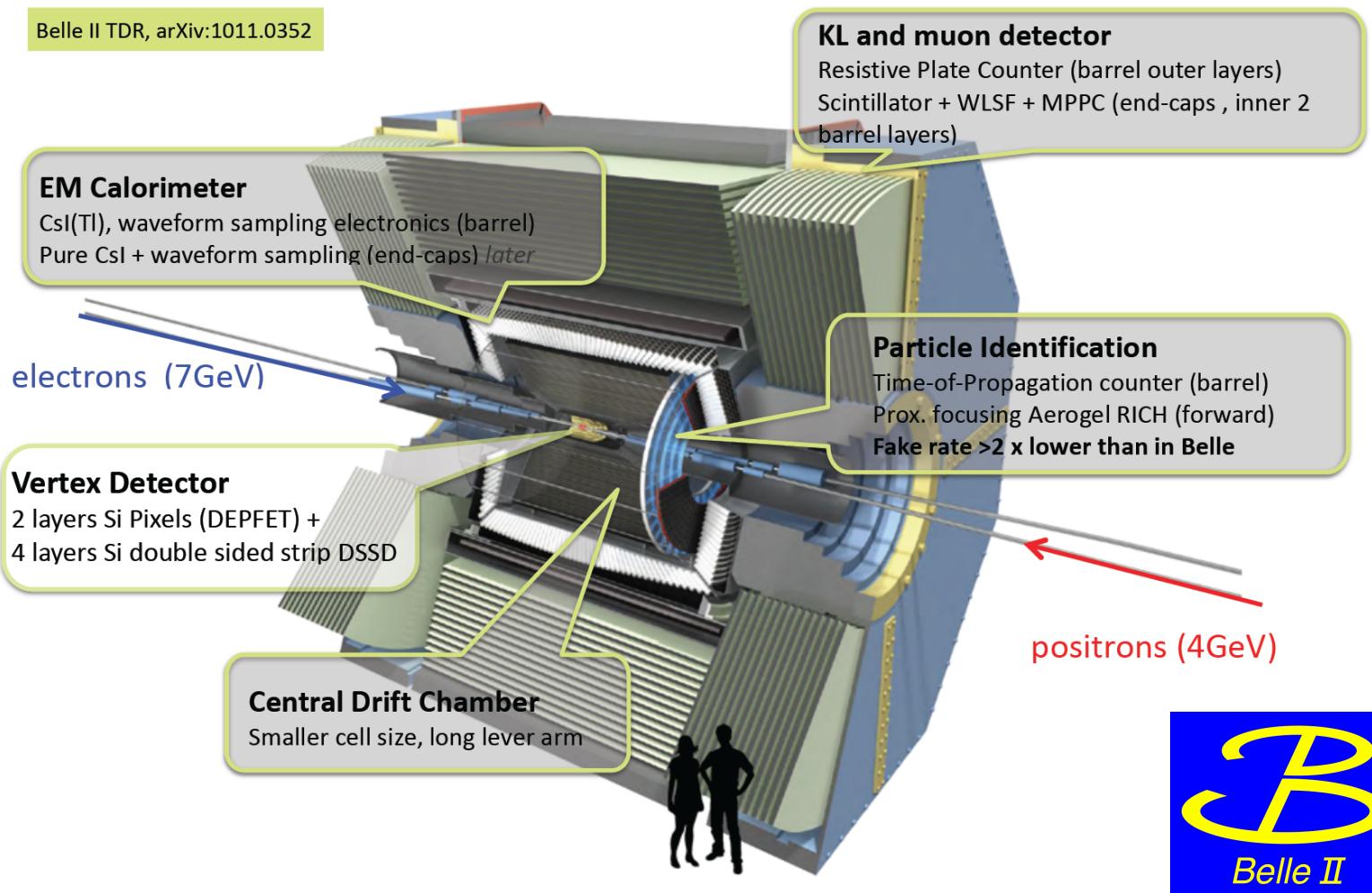


## Completion of magnet installation

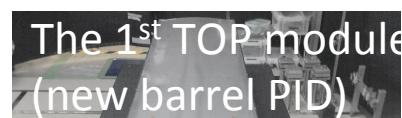
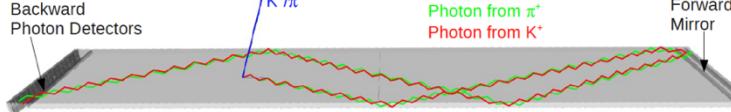
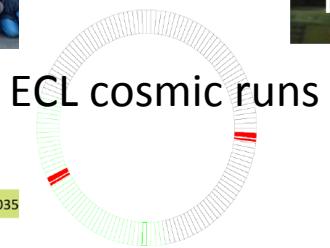
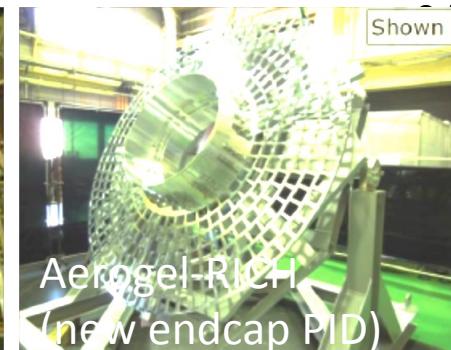


# Belle II Detector

- Deal with higher background (10-20×), radiation damage, higher occupancy, higher event rates (L1 trigg. 0.5→30 kHz)
- Improved performance and hermeticity



# Belle II collaboration ( >600 from 99 institutes)



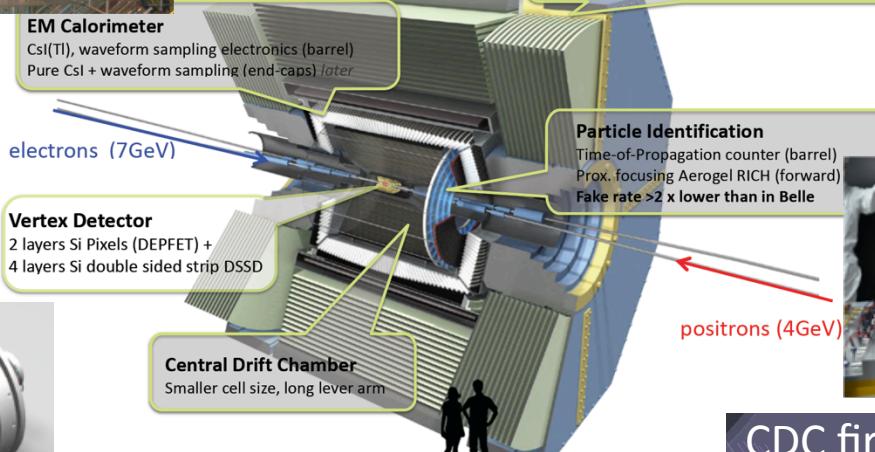
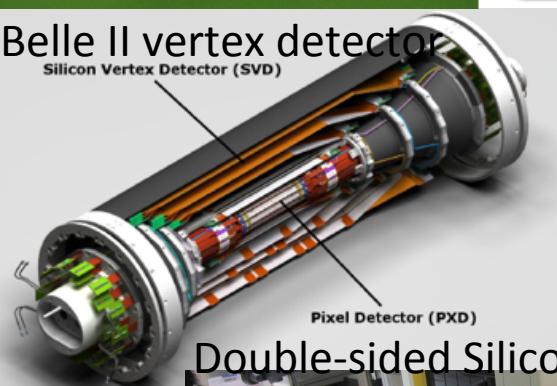
## Pixel Detector

Mechanical Mock-up

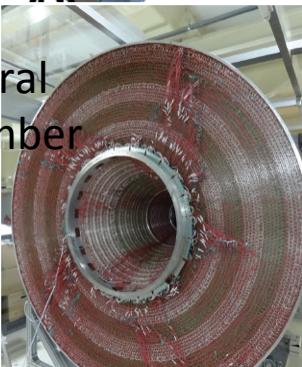


## Belle II vertex detector

Silicon Vertex Detector (SVD)



## New Central Drift Chamber



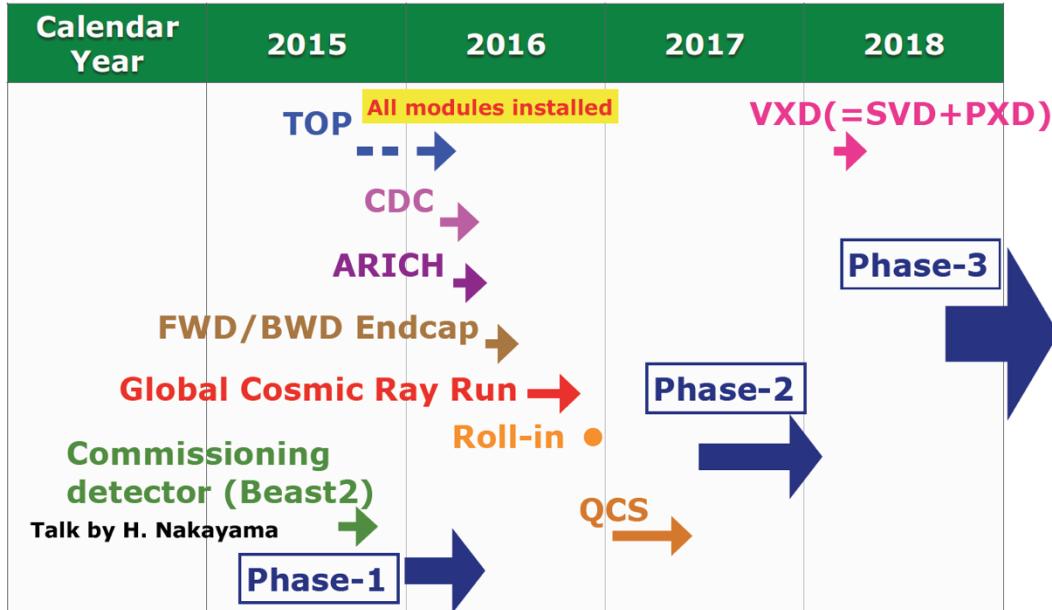
## CDC first cosmic ray event



CDC cosmic – 2015 April 14

# Schedule

- Accelerator commissioning starts in Jan. 2016.



BEAST phase 1 2016

BEAST phase 2 Mid 2017- Early 2018

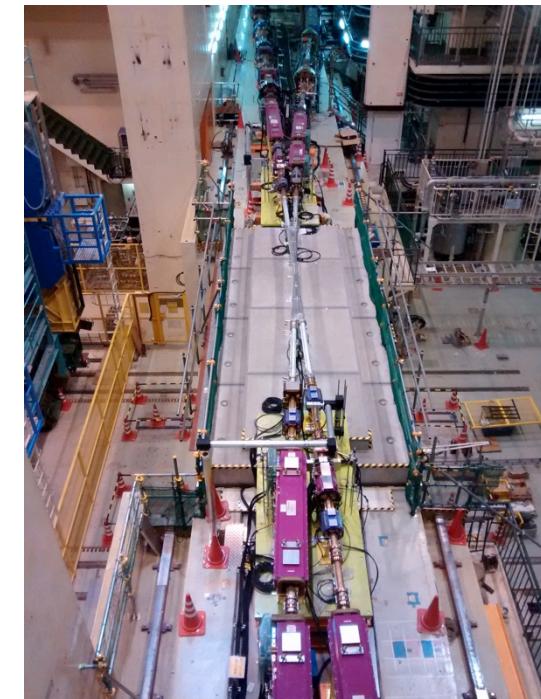
Full physics Oct 2018-

BEAST/SuperKEKB & cosmics

BEAST with Partial Belle II

Full detector

Phase 1 IP beam pipe already connected,  
and ready for beam.



**Stay Tuned !**

**We welcome new collaborators !**

# Summary

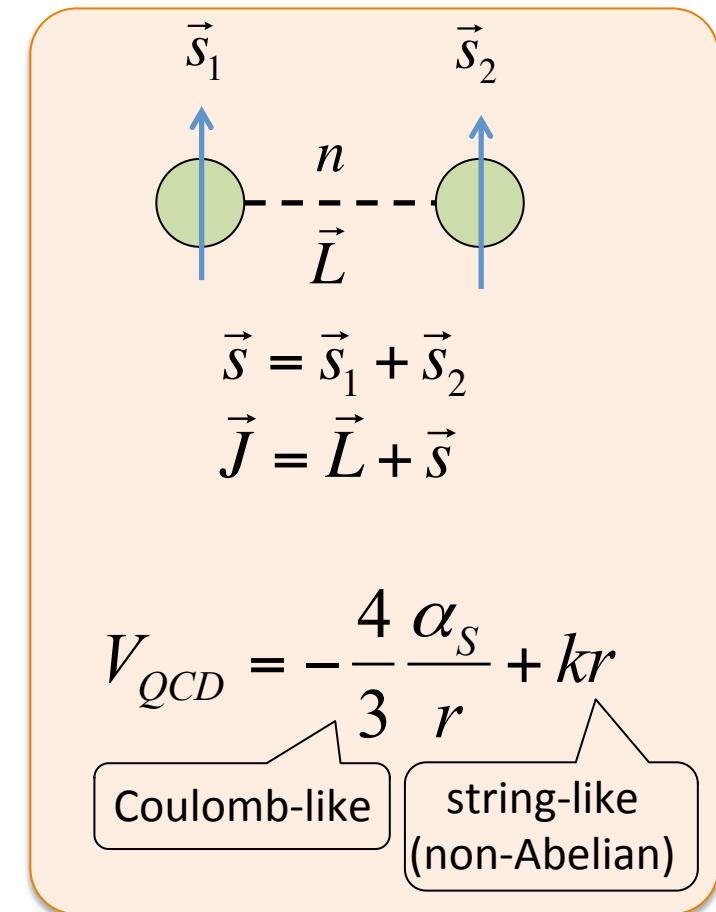
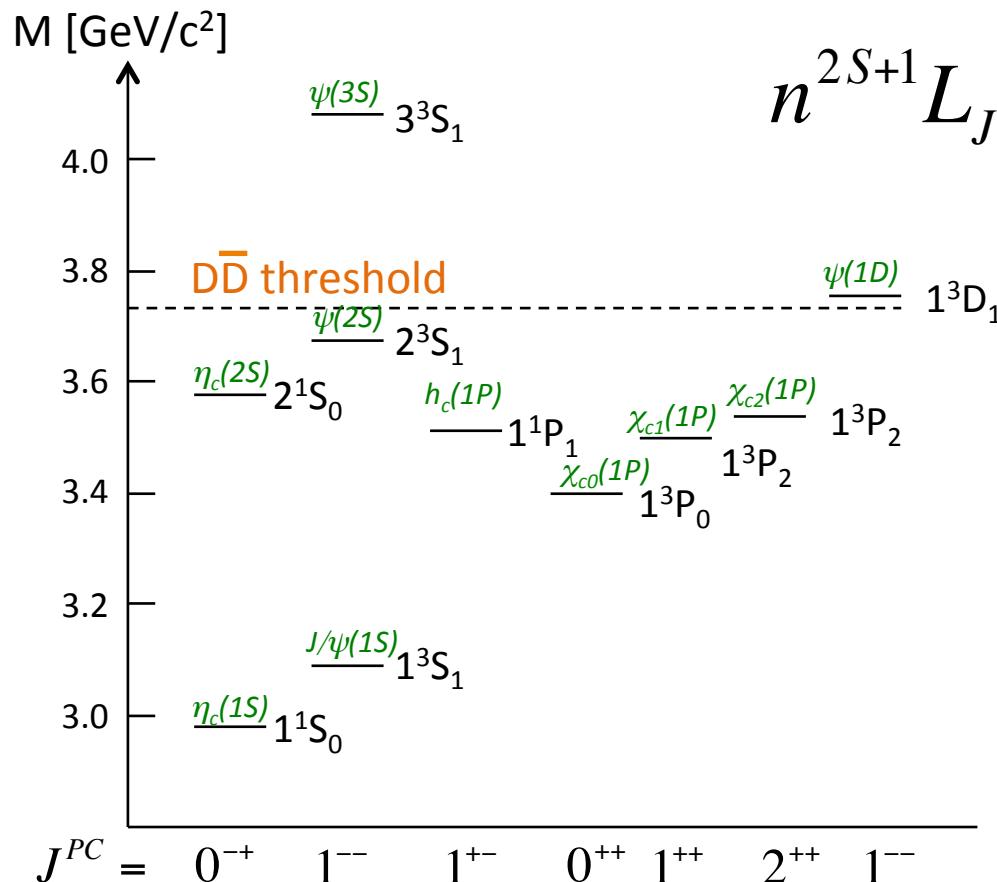
- B (+  $\tau$ -c)-Factories provides rich research opportunities for heavy quark physics, especially the charmonium-like and bottomonium-like exotics.
- Conventional quark model does not work for excited states. **d.o.f. = “consti. quark”**
- We need far more studies (both experimental and theoretical) for understanding the observed phenomena and building “new picture”. **What is the good d.o.f. ?**
- More opportunities in future
  - Belle II,  $\tau$ -c factory, LHC, heavy-ion, ...
  - Need more people, and “**fusion**” between particle and nuclear communities.

***Let's work together !***

**Thank you !**

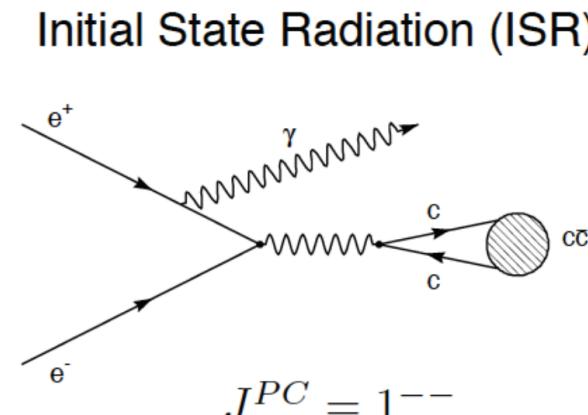
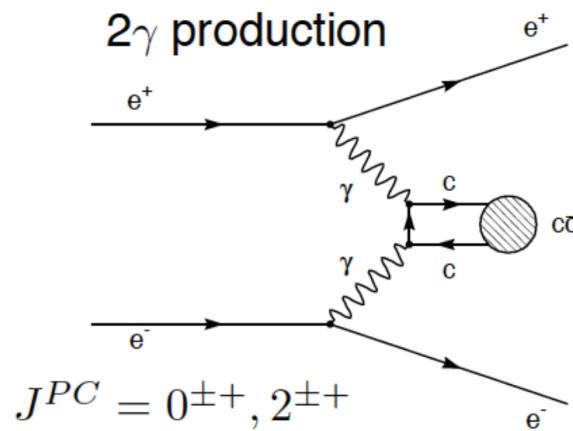
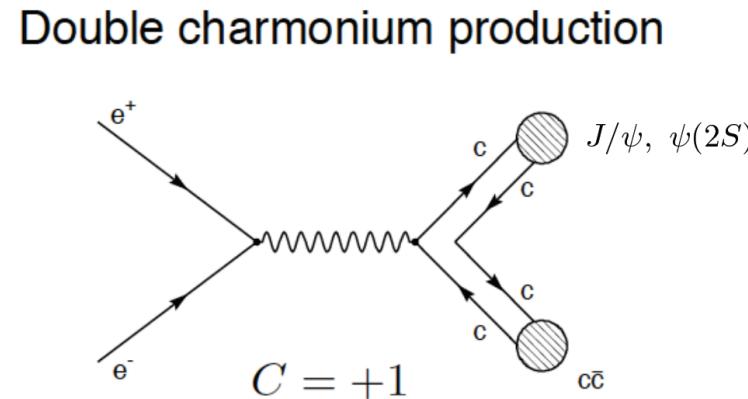
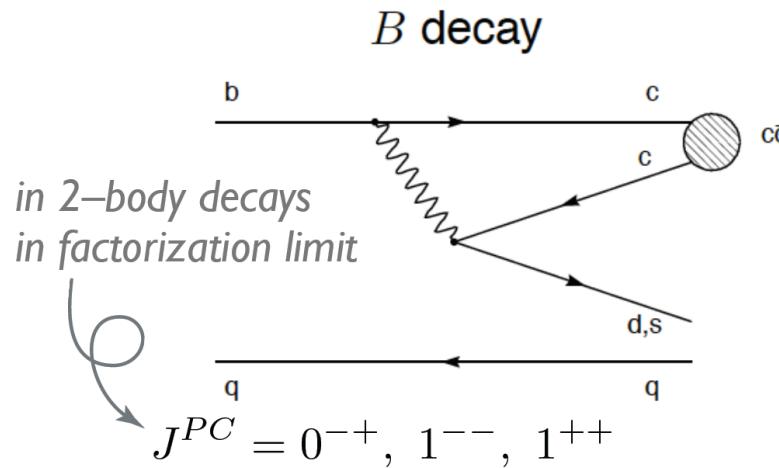
# Charmonium

- Observed spectra can be understood by  $c\bar{c}$  picture with the QCD potential.
- Bottomonium also can be described in the similar way.



# Production of $c\bar{c}$ in $b, c$ factories

$b, c$  factories can produce charmonium (-like) states in...



+ energy scan, as well