Belle II experiment

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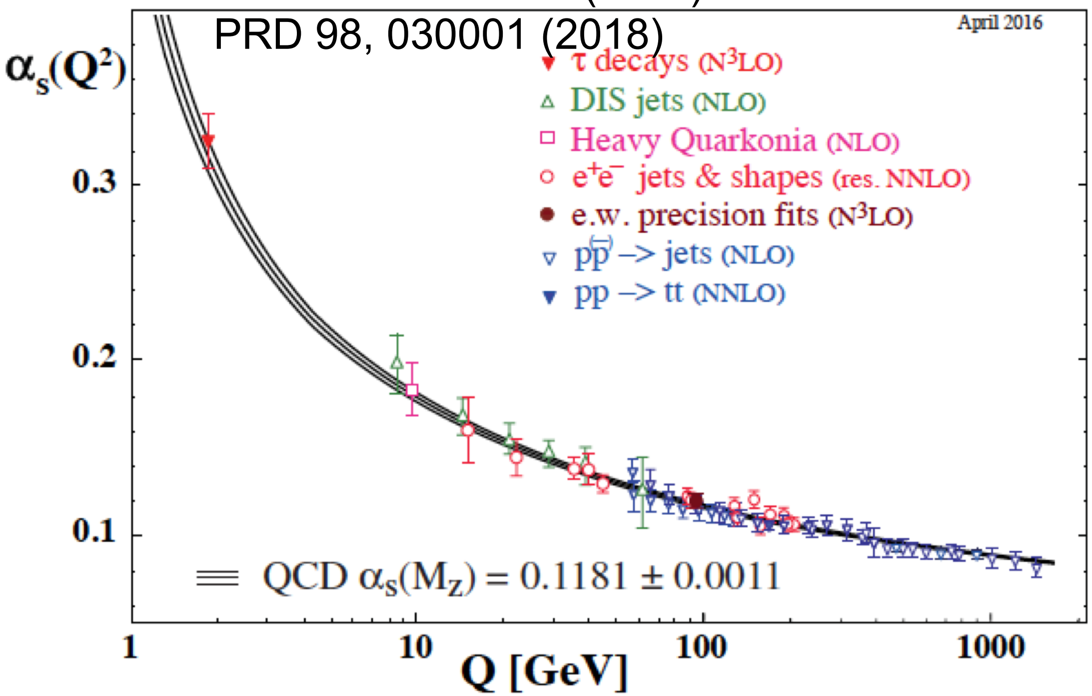
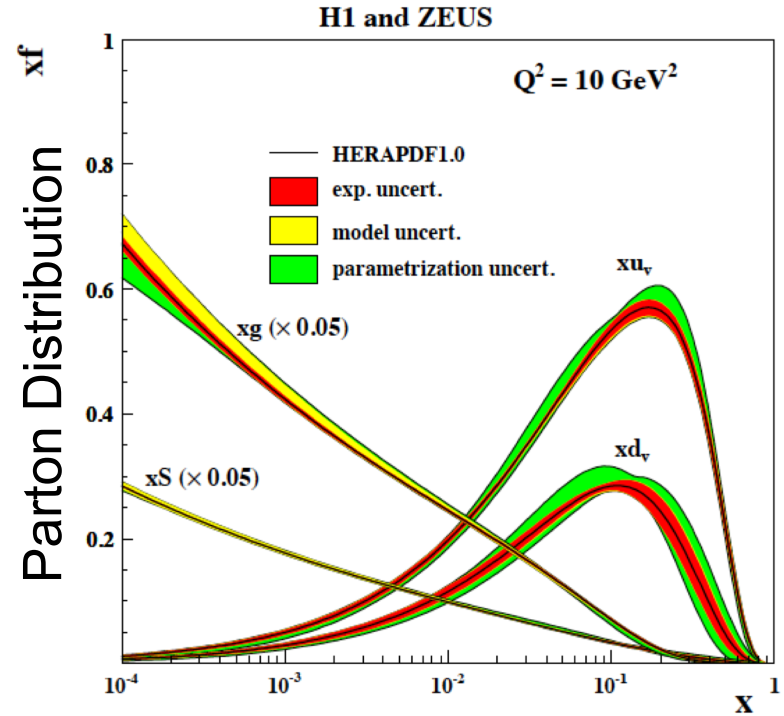
8th International Conference on
Quarks and Nuclear Physics
2018 Nov. 17th

For QCD, LEP, HERA, .. gave

M. Tanabashi et al. (PDG)
PRD 98, 030001 (2018)





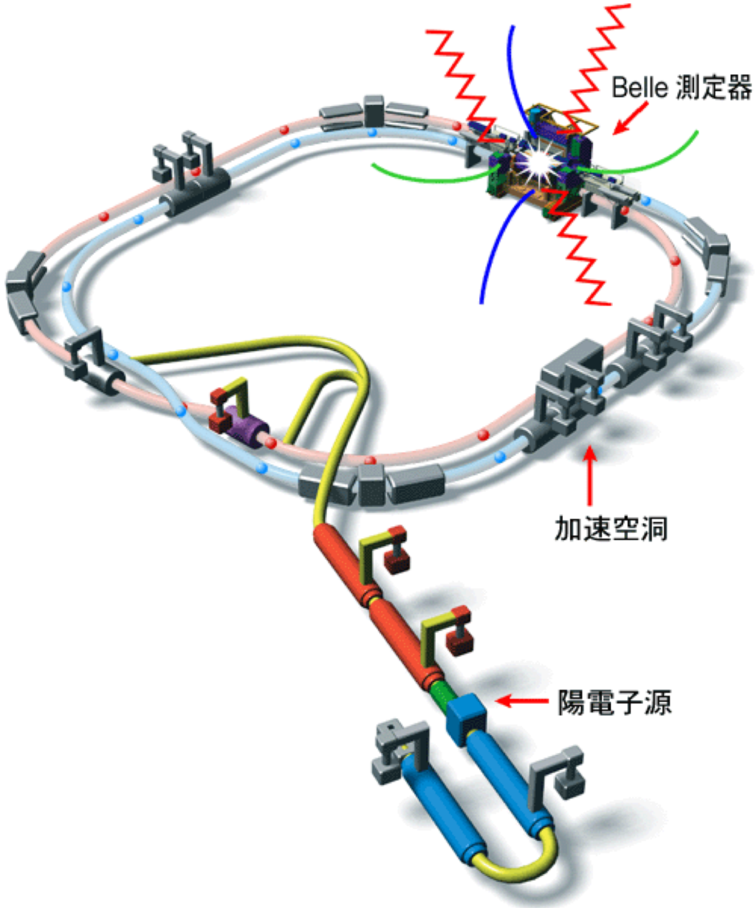
Running of α_S and Parton Distribution established, i.e. we have good knowledge about the region of perturbative treatment.
Still unrevealed aspects in non-perturbative region.

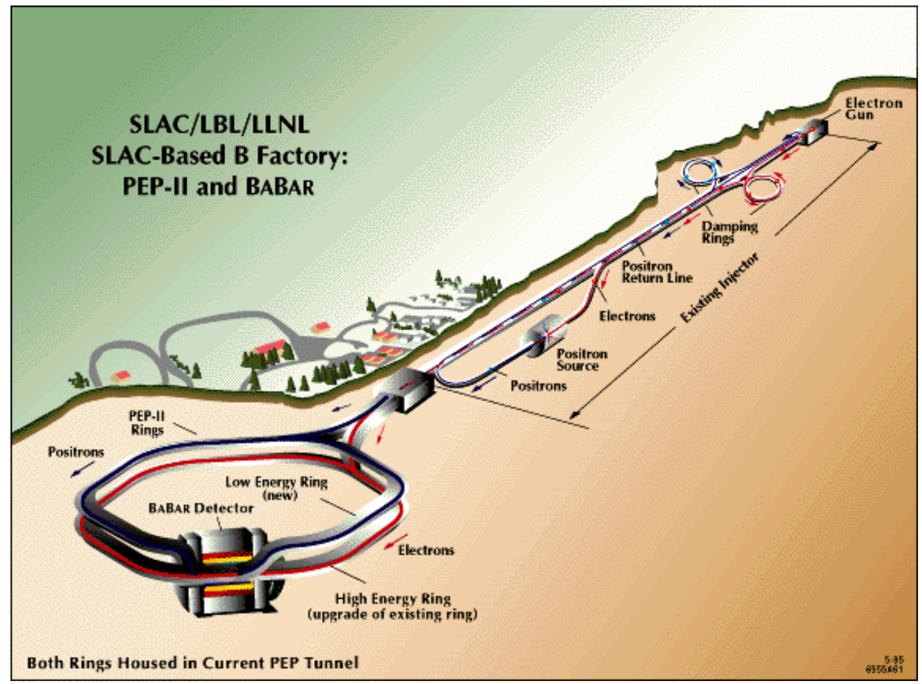
Outline

- Legacy of B-factories
- Missions/possibilities at a higher luminosity e^+e^- colliding beam experiment
  - Challenges in non-perturbative region QCD
- SuperKEKB accelerator / Belle II detector
  - Design
  - Status and plans
- Summary

Legacy of B-factories

High luminosity, asymmetric-energy e^+e^- colliding beam experiments were desired to study CP violation.

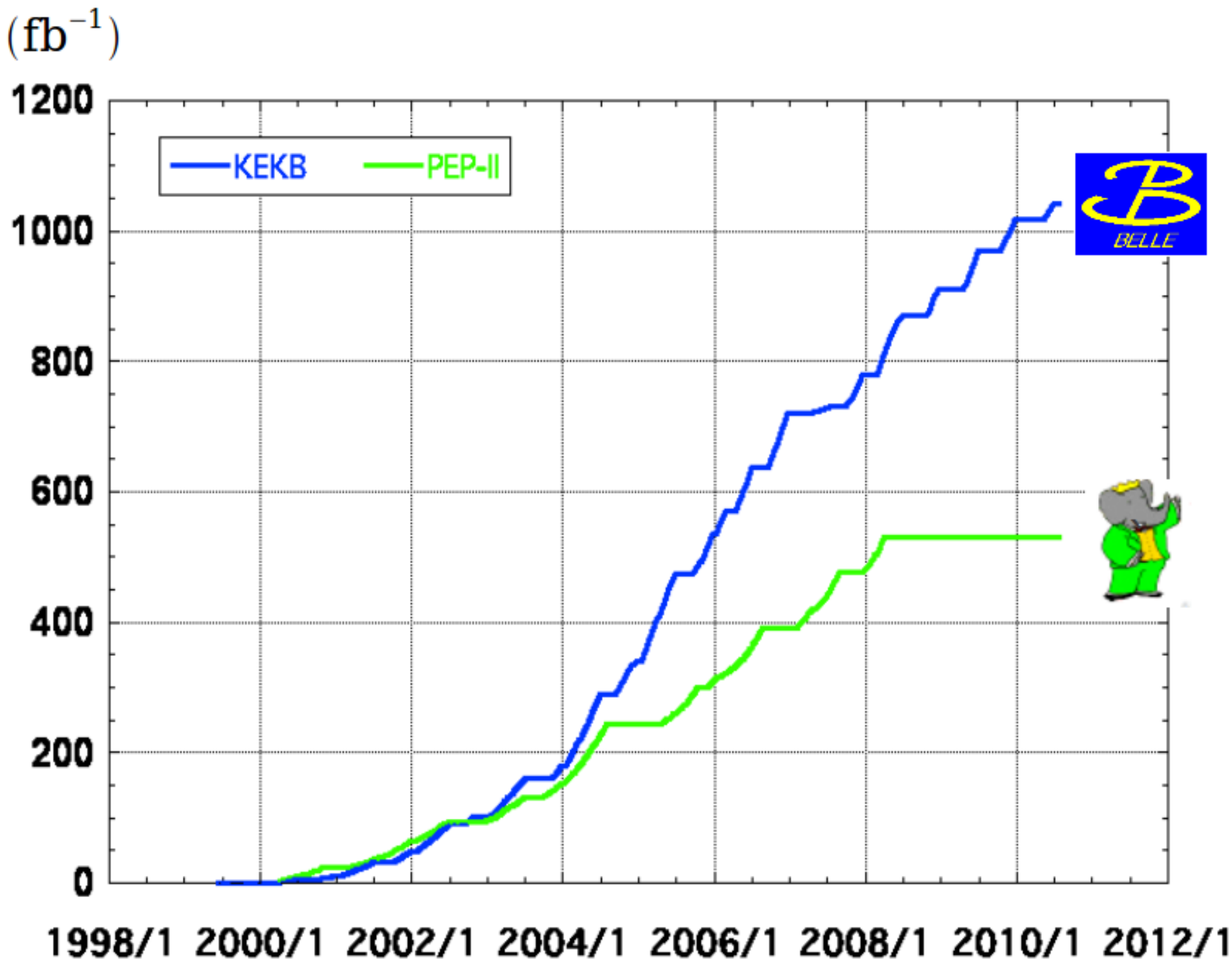




KEKB&Belle 8 GeV × 3.5 GeV (Run 1999-2010)

PEP II&BaBar 9 GeV × 3.1 GeV (Run 1999-2008)

Integrated luminosity of B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1} 772M $B\bar{B}$

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1} 470M $B\bar{B}$

$\Upsilon(3S)$: 30 fb^{-1}

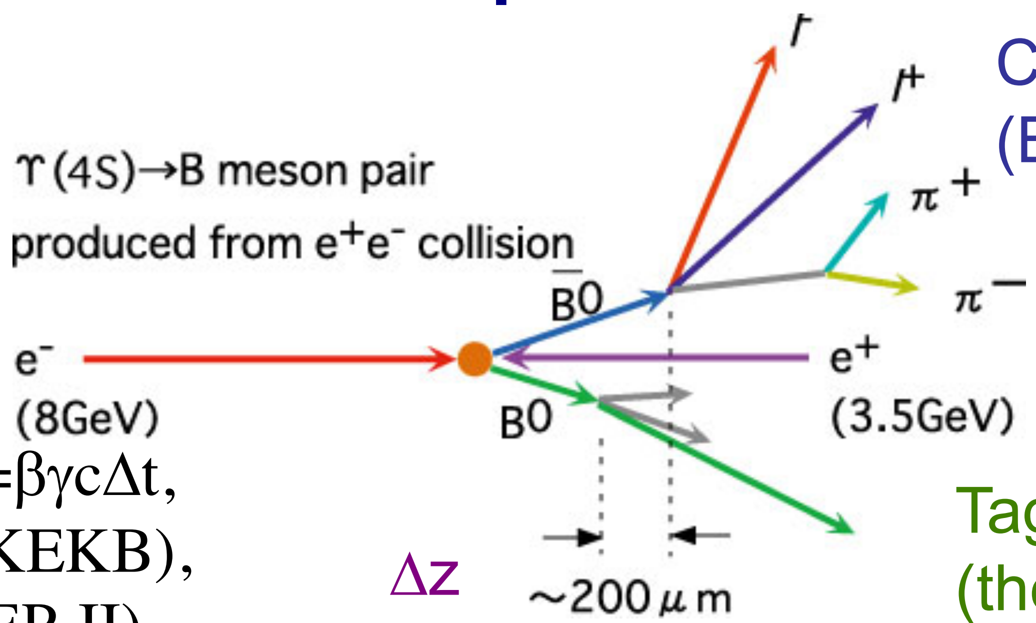
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~ 54 fb^{-1}

In total, more than 1.5 ab^{-1} including 1G $B\bar{B}$ pairs are recorded at B-factories

Originally in order for time-dependent CPV



CP side
(B to f_{CP})

Tag side
(the other B)

Δz measurement

$\Delta z = \beta\gamma c \Delta t$,
$\beta\gamma = 0.425$(KEKB),
0.56(PEP-II)

$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})} = S_{f_{CP}} \sin(\Delta m \Delta t) + A_{f_{CP}} \cos(\Delta m \Delta t)$$

This is very demanding measurement, requires sophisticated detector and analysis methodology!

All these are great benefit

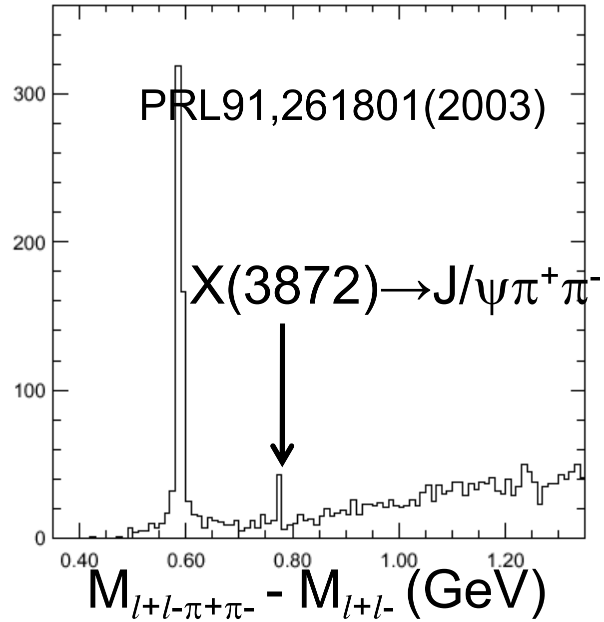
4π general purpose spectrometer with

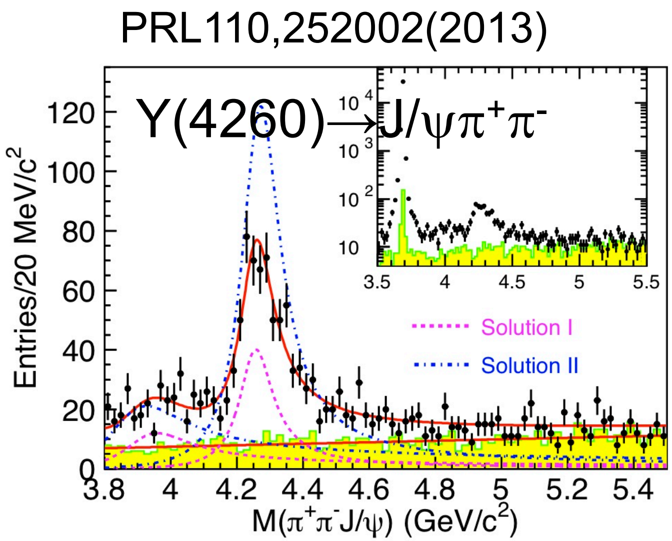
- High momentum resolution, σ_p/p = 0.3%@1GeV/c.
- Ability to detect γ down to 30 MeV.
- Good γ energy resolution, σ_M =5 MeV for $\pi^0 \rightarrow \gamma\gamma$.
- Lepton identification capability, ε>0.9, fake<0.01.
- K/π/p separation capability, ε~0.9, fake<0.1.
- Excellent B decay vertex reconstruction, $\sigma_{\Delta z}$ =80 μm.

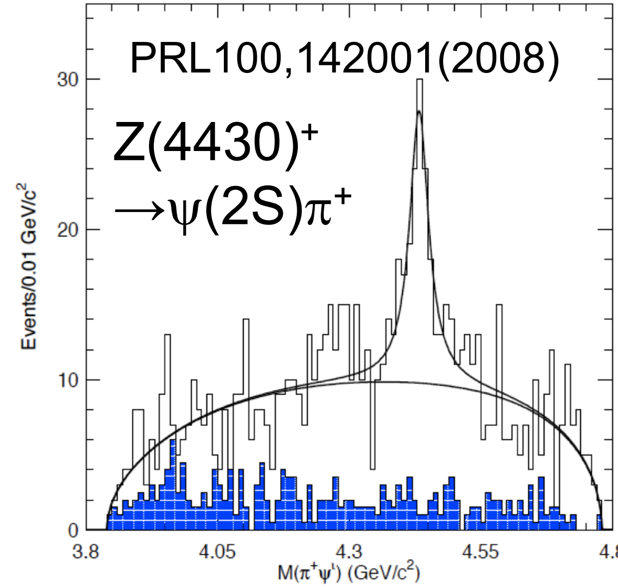
+

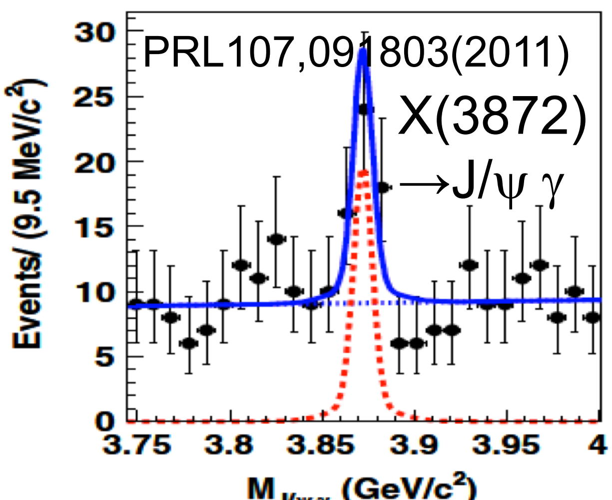
- World highest luminosity

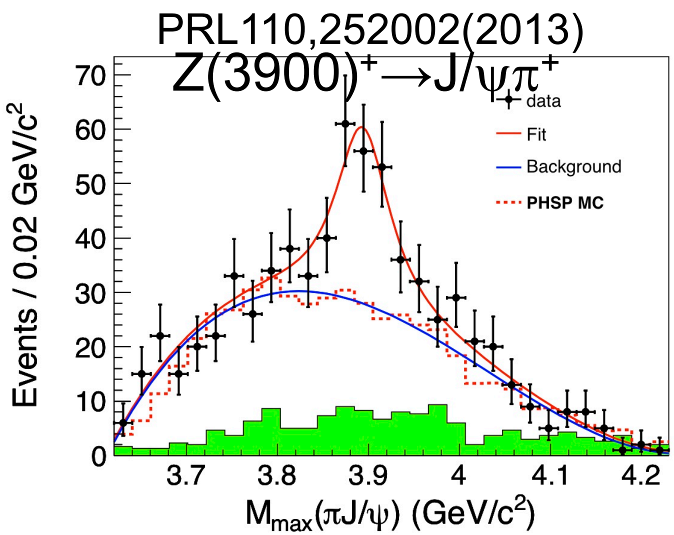
"XYZ" sensations at Belle

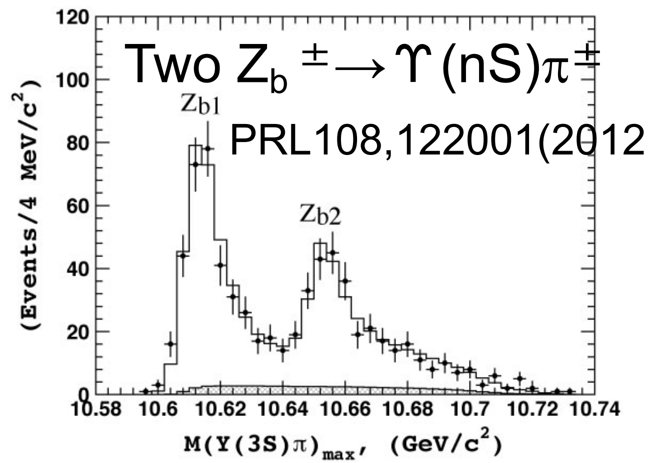












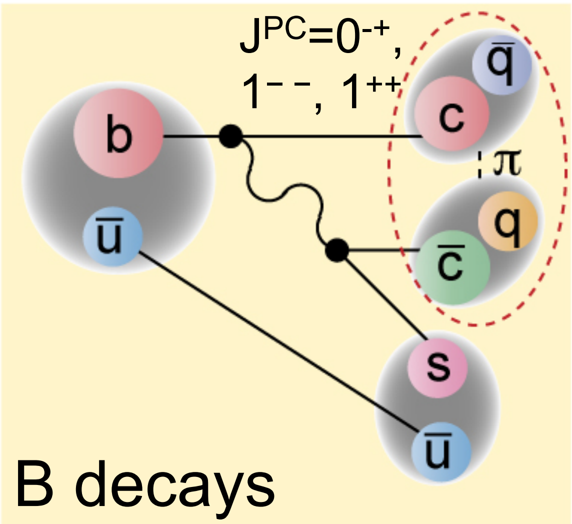
What made it possible?

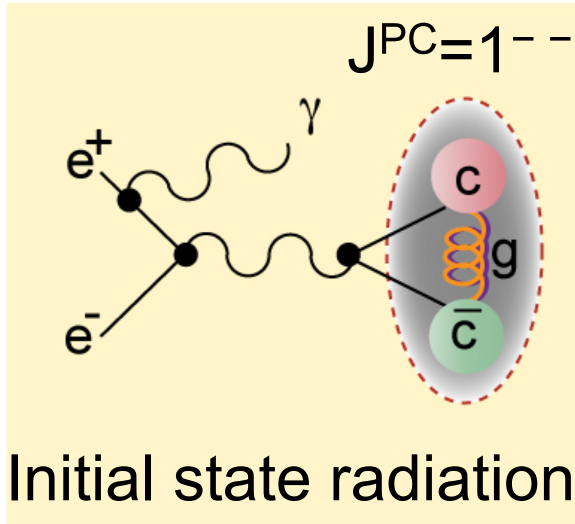
From the experience of “XYZ” states,

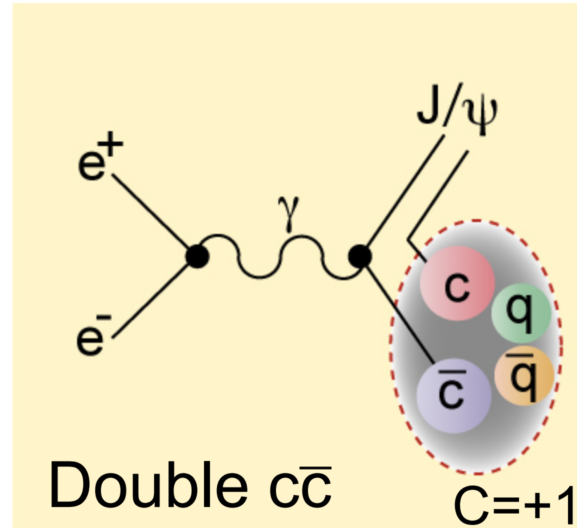
We need to have possibilities to access;

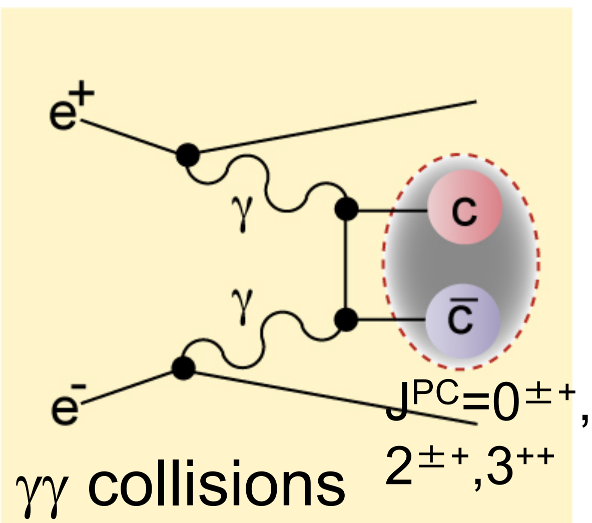
- Various production mechanisms
  - Each physics process has preferable states.
  - Interplay among several approaches is effective.
- Various decay modes
  - Each hypothesis; other decay modes, partner states.
  - Partner states have specific decay modes.

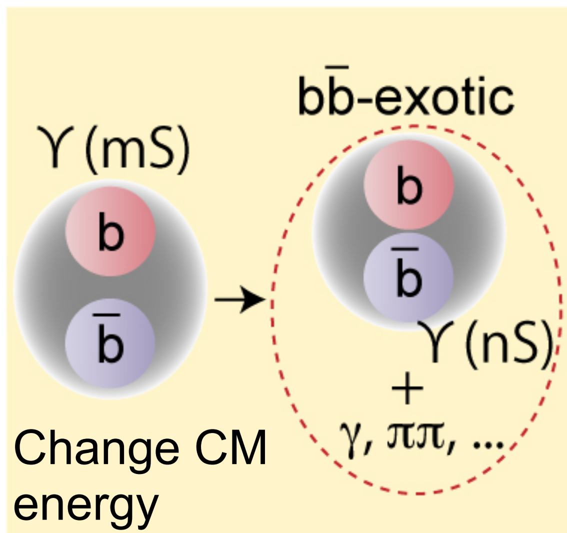
Variety of recorded reactions









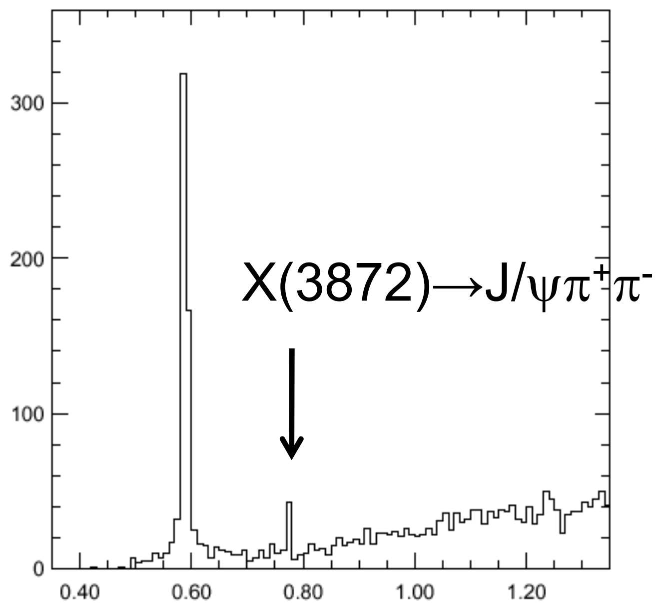


Allowed/favored quantum numbers are different depending on production processes.

X(3872) 1530 citations as of Nov. 10th

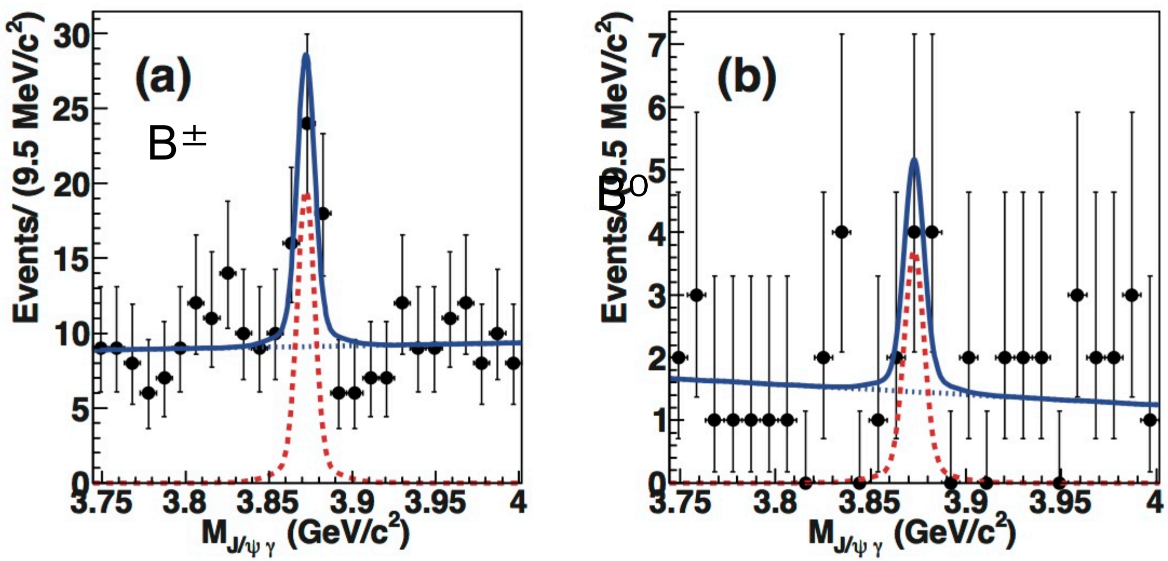
Belle's the most famous discovery

Belle PRL91,261801(2003)



$M_{l+l-\pi+\pi-}$ - M_{l+l-} (GeV)

X(3872)→J/ψ γ; C=+1



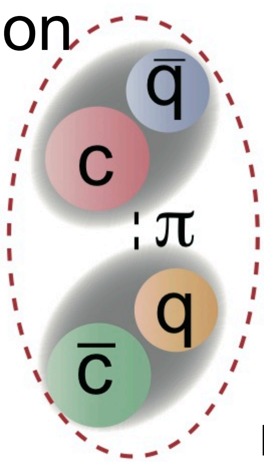
Belle PRL07,091803(2011)

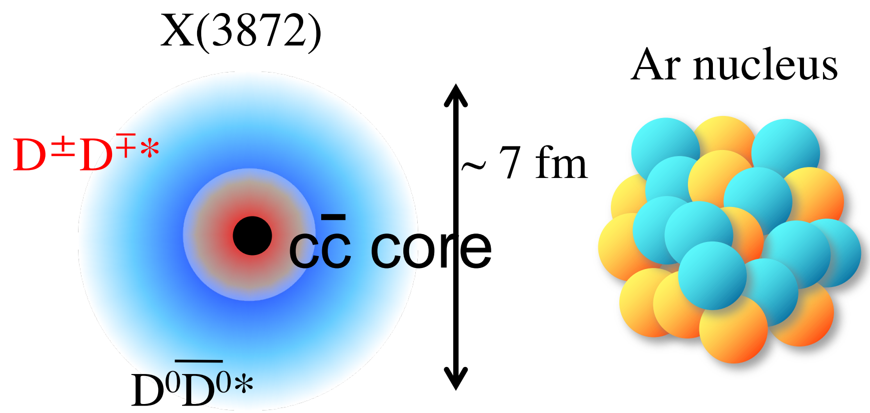
$J^{PC}=1^{++}$ (Belle, BaBar, CDF, LHCb) from J/ψ $\pi^+\pi^-$ angular distribution. (PRL110, 222001(2013) and cited papers)

Br(X(3872)→D^0D^{*0}) is about Br(X(3872)→J/ψ $\pi^+\pi^-$) × 10.

Admixture : most plausible interpretation for X(3872)

Meson-meson molecule





E. J. Eichiten et al. Phys. Rev. D 73, 014014 (2006);
A. M. Badalin et al. Phys. Rev.D 85, 031103 (2012);
S. Takeuchi, K. Shimizu and M.Takizawa PTEP2014, 123D01(2014).

$D\overline{D}^*$ component is coupled with the same J^{PC} $c\bar{c}$, χ_{c1}(2P) (unseen).

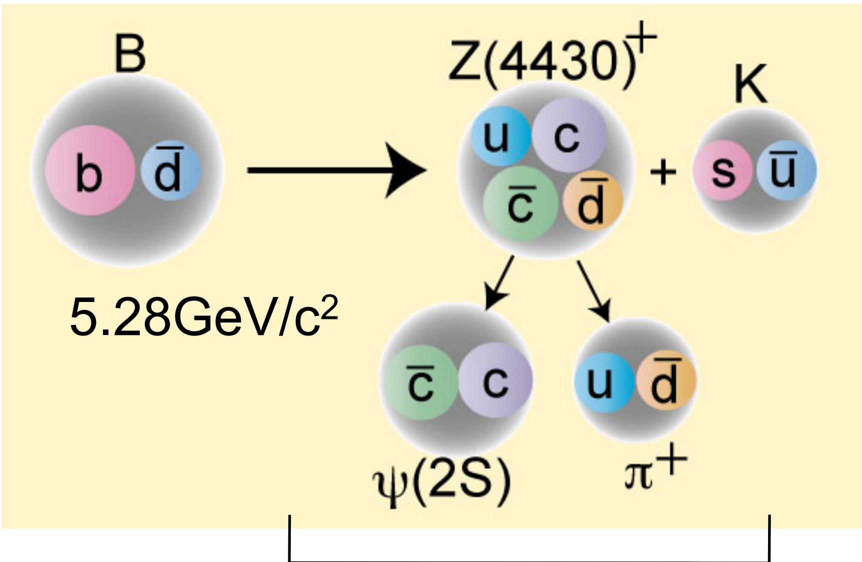
→can explain Br($X \rightarrow D^0\overline{D}^{*0}$)/Br($X \rightarrow J/\psi\ \pi^+\pi^-$) is about 10.

→D^+D^{*-} component can explain $J/\psi\ \pi^+\pi^-$ and $J/\psi\ \pi^+\pi^-\pi^0$ coexitst.

→pure molecule; too fragile to have prompt produced in Tevatron/LHC.

→another χ_{c1}(2P) dominant state would become broad.

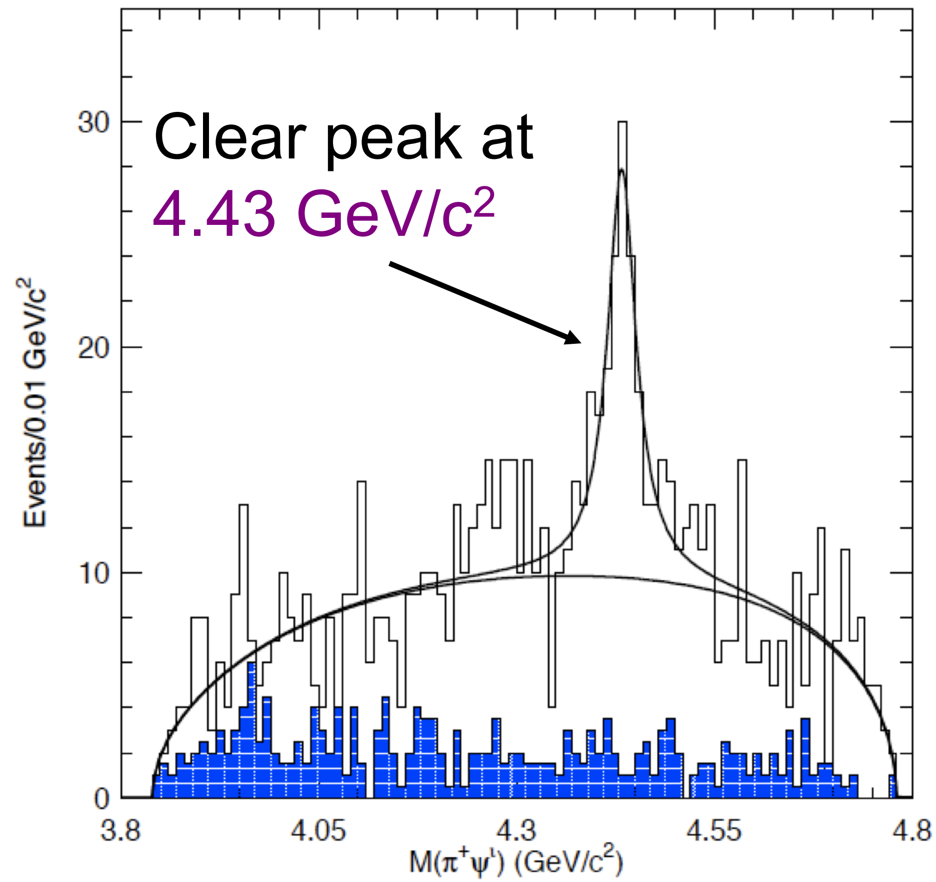
$Z(4430)^+$ in $\psi(2S)\pi^\pm$ final state



Reconstructing $B \to \psi(2S)\, \pi^\pm$ K, $M(\psi(2S)\, \pi^\pm)$ is looked back.

Confirmed by LHCb

PRL112, 222002(2014)

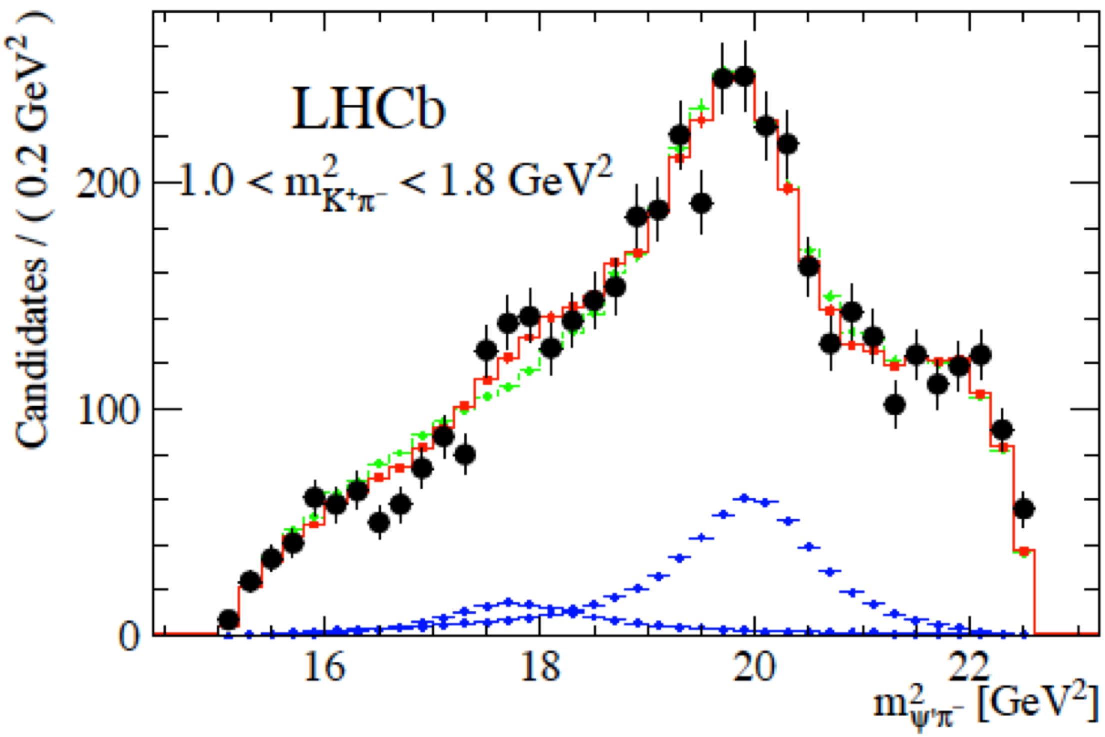


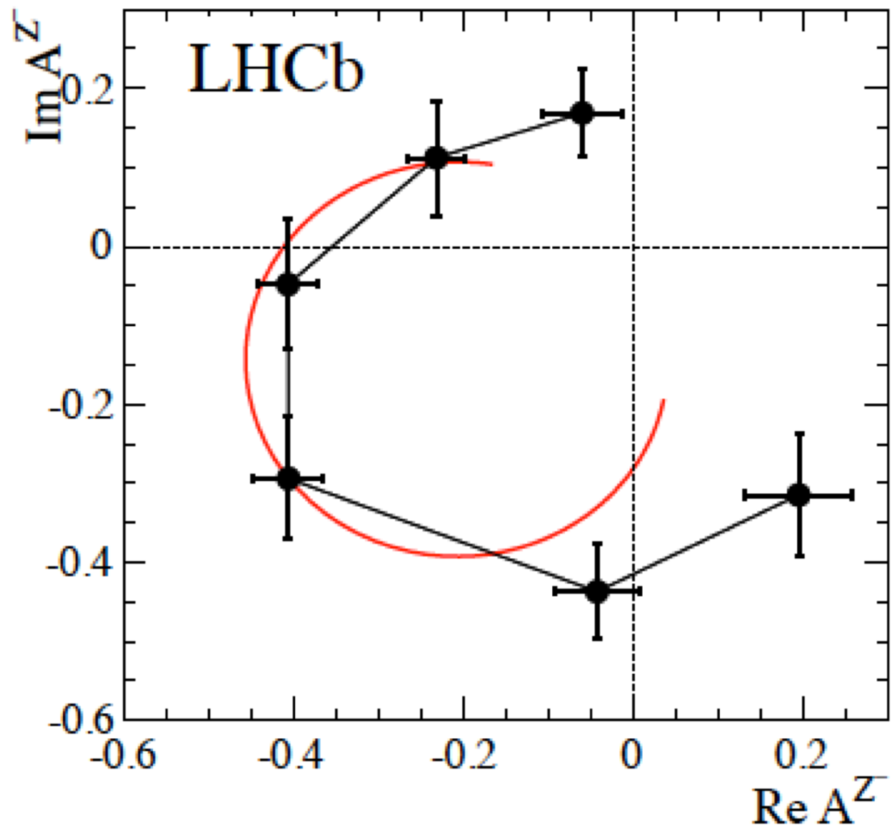
PRL100,142001(2008)

PRD 80, 031104(2009)

PRD 88, 074026(2013)

Confirmation by LHCb



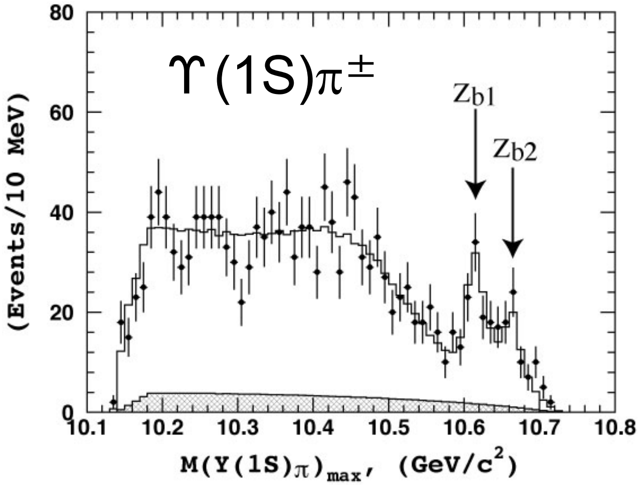


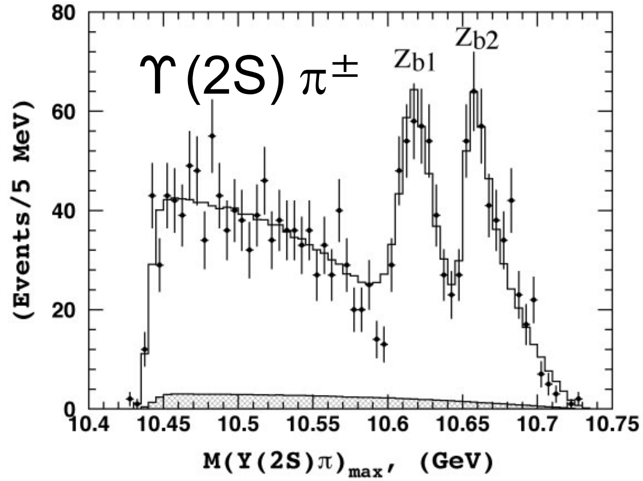
4D fit(M(ψ(2S)$\pi^{\pm}$), M(Kπ), cos$\theta_{\psi(2S)}$, ϕ), PRL112, 222002(2014)

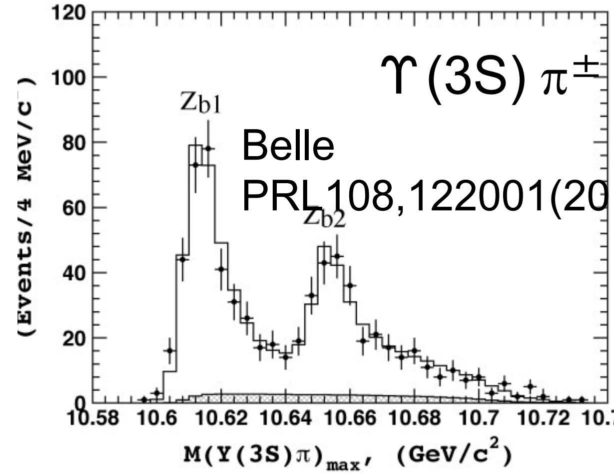
Argand diagram (phase change as a func .of mass) gives a proof of resonance.

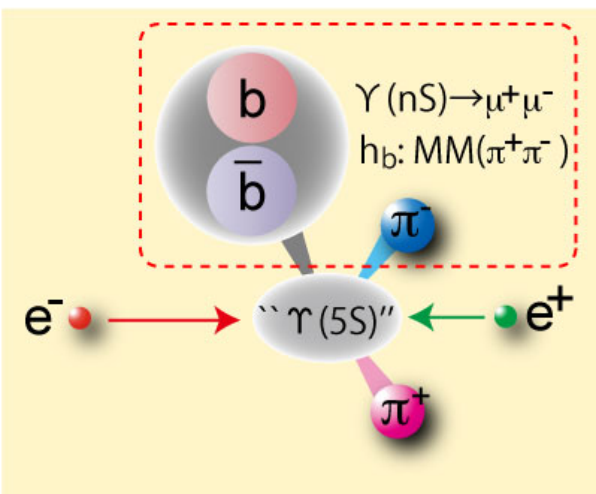
Such approach will be possible to study other states with Belle II statistics only.

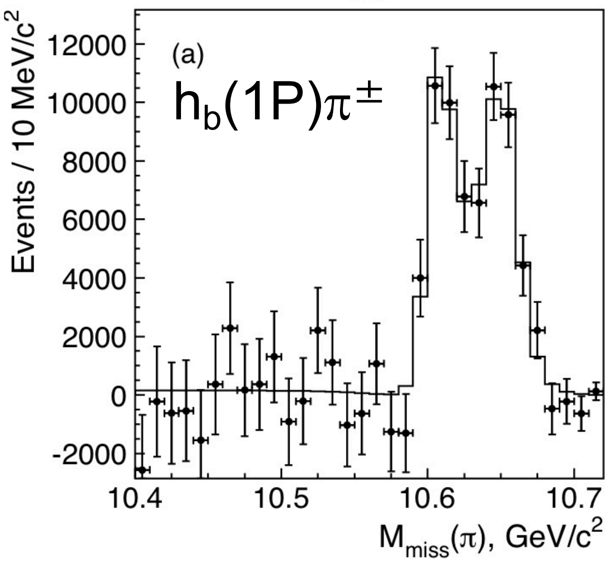
$b\bar{b}\,\pi^{\pm}$ system at $\Upsilon(10860)$

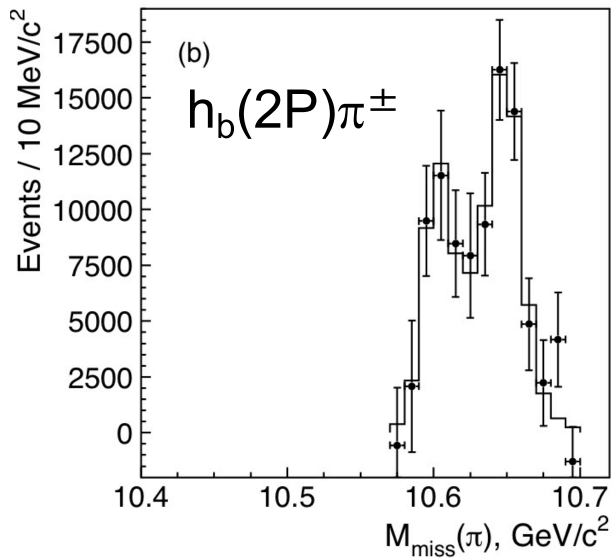










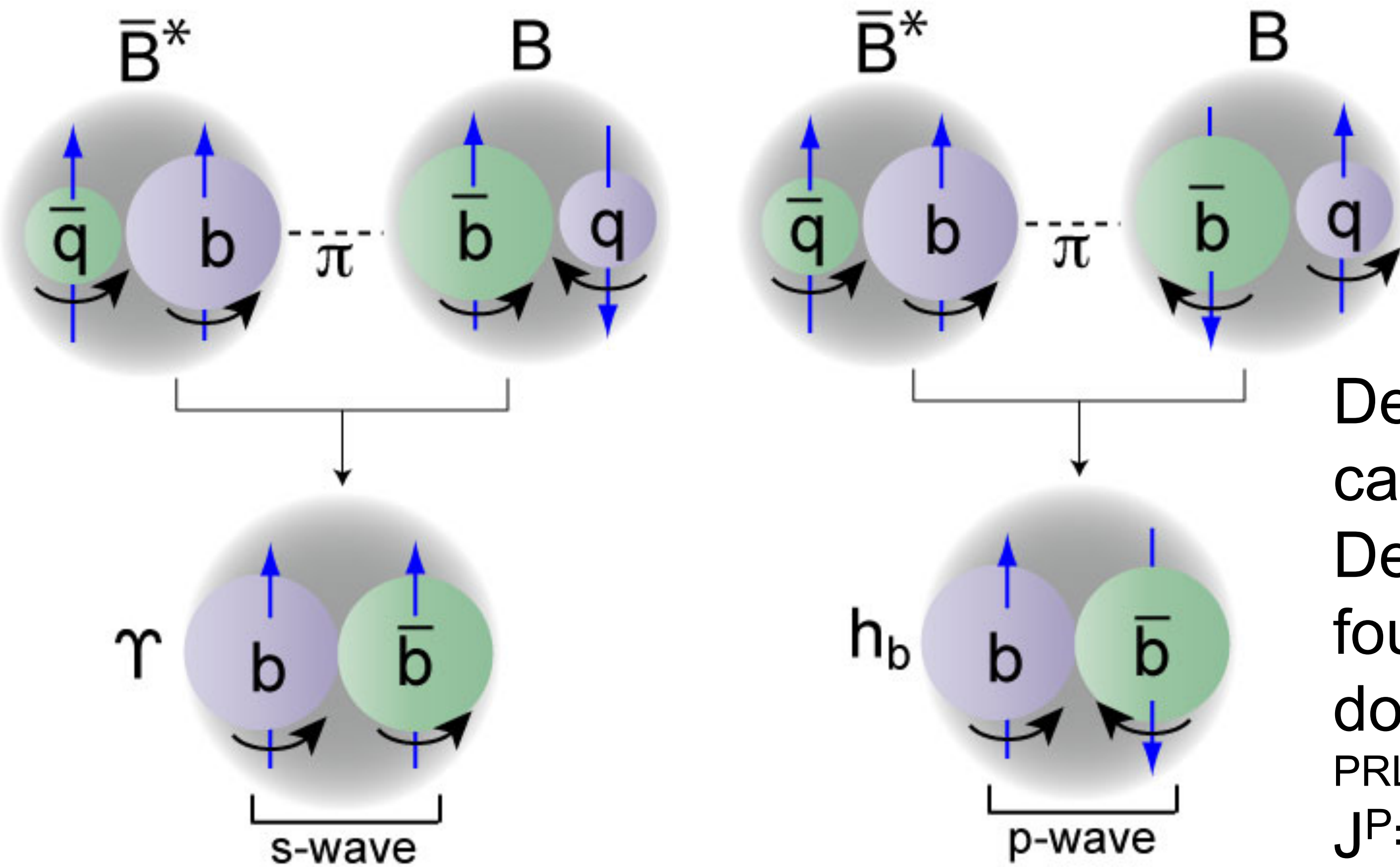


10610 MeV~M($B\bar{B}^*$)
10650 MeV~M($B^*\bar{B}^*$)

Z_bs' decay to $B^{(*)}B^*$ found to be dominant.

Belle PRL116,212001(2016)

Molecular picture works



A.E.Bondar et al., PRD84,054010(2011)

Decays to ϒ and h_b can co-exist.

Decay into $B^*\bar{B}^{(*)}$ found to be dominant.

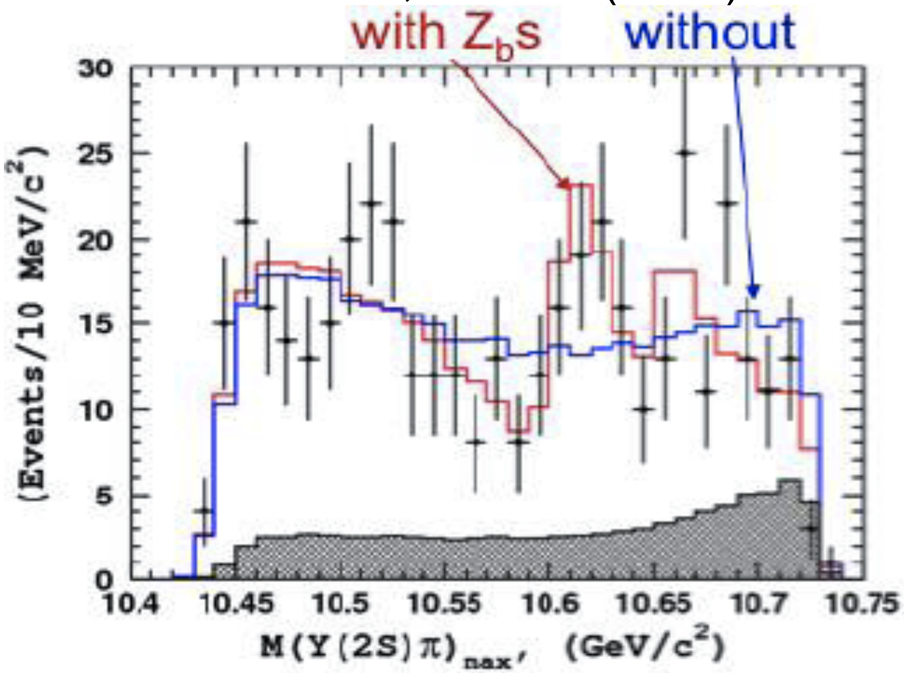
PRL116,212001(2016)

$J^P=1^+$ is supported by Dalitz analysis.

PRD91,072003(2015).

Partner states of Z_b

PRD88, 052016 (2013)



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

6.5σ stat. significance

$I^G=1^+$, first isospin partner among "XYZ".

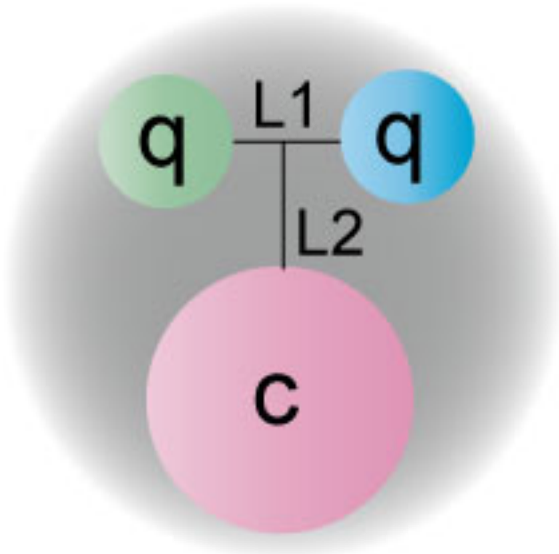
- Partners may decay into χ_{bJ} (PRD86,014004(2012)).
  - $Z_b \to \chi_{bJ}\,\pi$, $Z_{b0} \to \chi_{bJ}\,\gamma$
- Br($\chi_{bJ} \to \Upsilon(1,2,3S)\gamma$) and γ efficiency are multiplied, signal yield may be lower one order of magnitude.

↓

Higher statistics needed.

Various partner searches at Belle II are awaited.

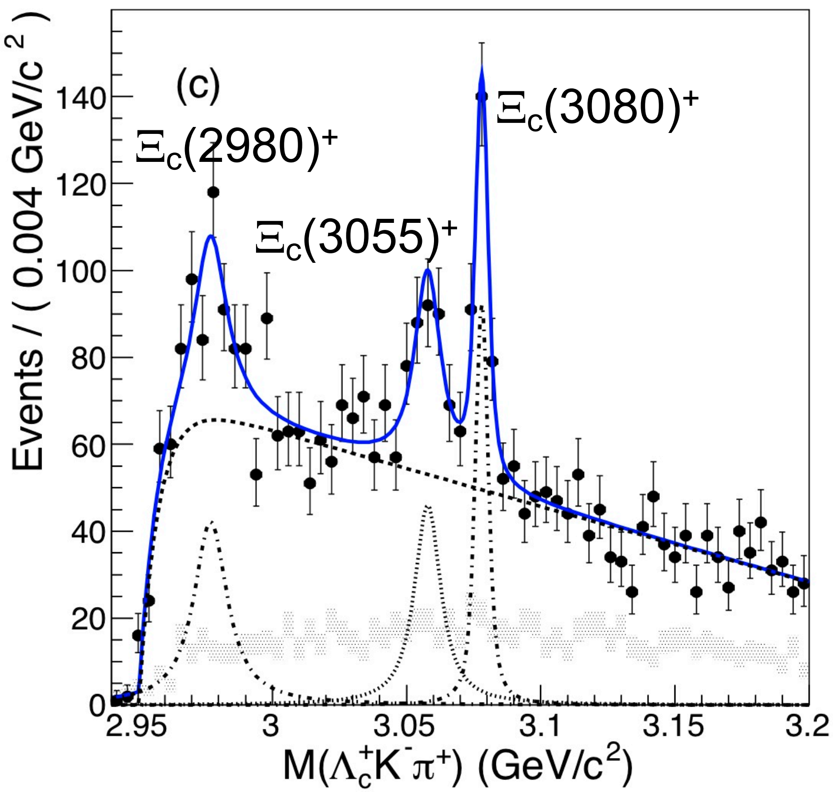
Charm baryon to check "di-quark"



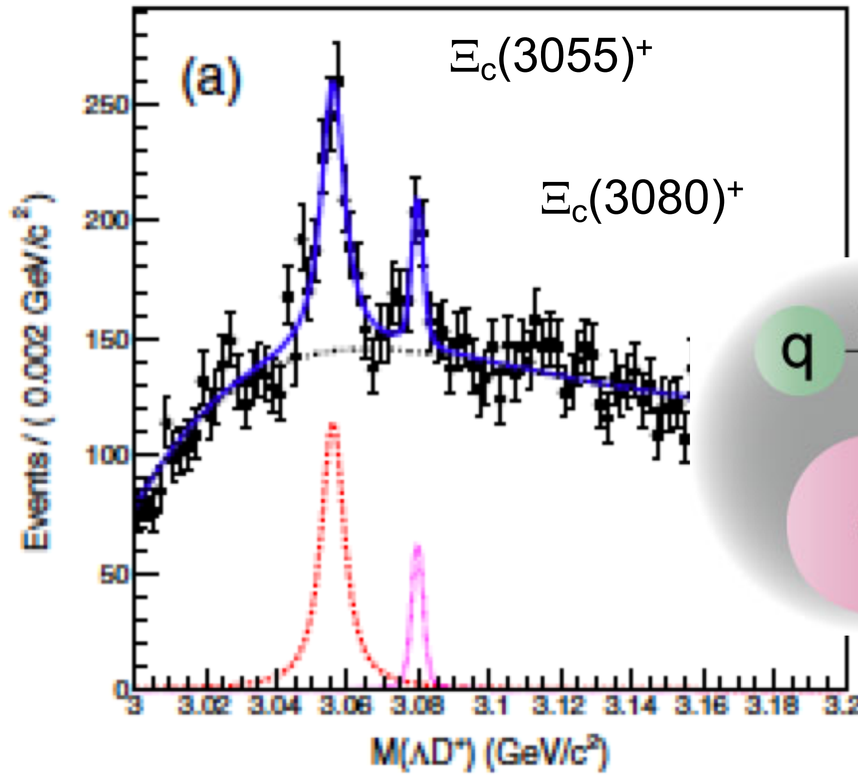
- Thought to be a good place to check if "di-quarks" is behaving as a good degree of freedom to form hadrons.
- One of the constituent quark is heavy, correlation between the remaining light quarks would become clear.
- L_1 : ρ mode, L_2 : λ mode.

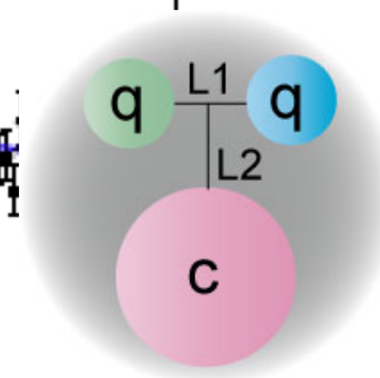
To which mode, how much br.?

PRD89,052003(2014)



PRD94,032002(2016)



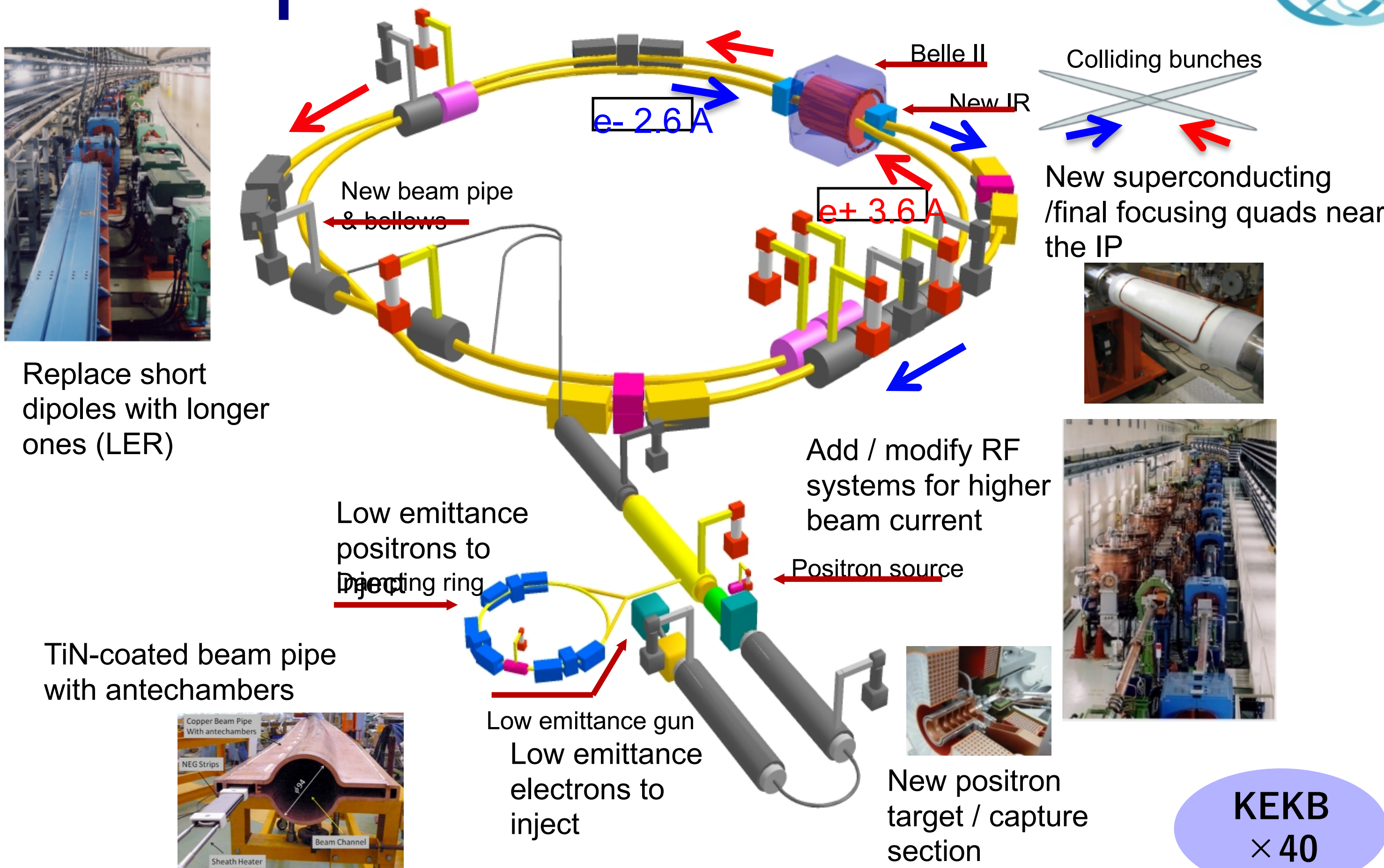


"charm baryon + light hadron" or "charm meson + baryon" ?

Very important info., just started to be got in our hand.

For J^P determination, higher statistics needed.

SuperKEKB collider



KEKB ×40

- Nano-beam
- Increase currents

➡ Peak luminosity : $2.1 \times 10^{34}\ cm^{-2}s^{-1}$ => **$8.0 \times 10^{35}\ cm^{-2}s^{-1}$**

Beam energy : 3.5 / 8.0 GeV => **4.0 / 7.0 GeV**

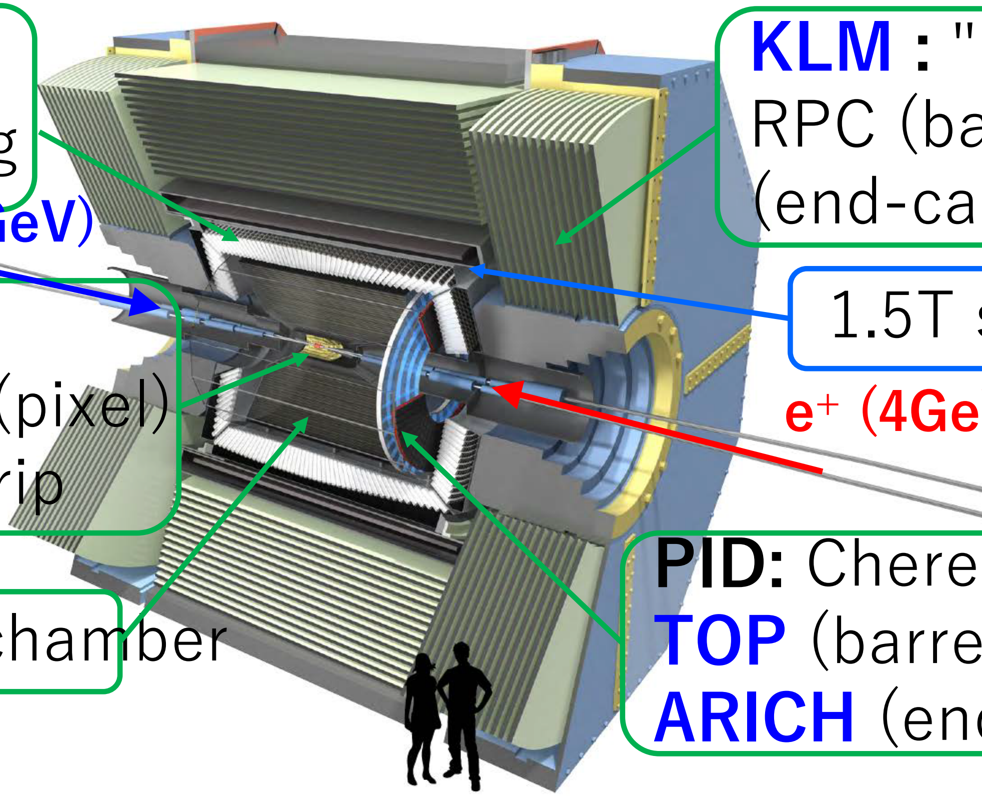
Boost factor ~2/3

20

Belle II detector

ECL : CsI (Tl),
waveform sampling

KLM : "KL and muon"
RPC (barrel) + SiPM
(end-cap, inner barrel)



VXD :
PXD : DEPFET (pixel)
SVD : Silicon strip

CDC : drift chamber

PID: Cherenkov ring image
TOP (barrel): Quarts
ARICH (endcap): Aerogel

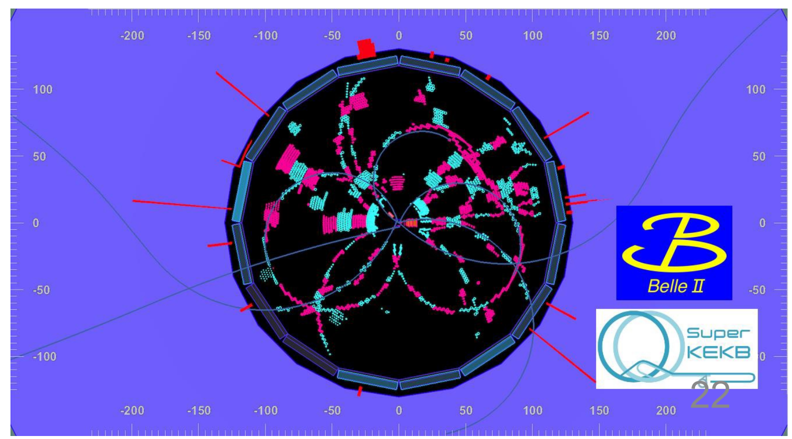
Issues to overcome
- Beam background
- High rate capability
- Boost ~ 2/3

➡

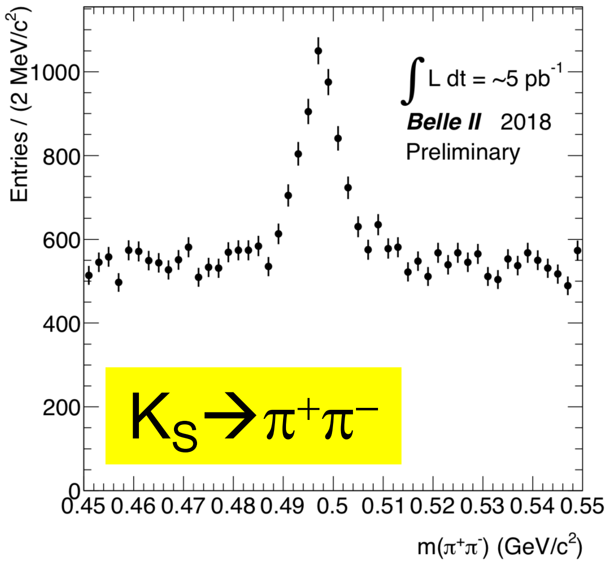
Technical choice
- Finer segmentation, waveform sampling.
- Material change
- Larger angular coverage (CDC, SVD)
- Closer to the IP (PXD) 3 -> 2cm
- Particle ID improve (K/π)(TOP, ARICH)

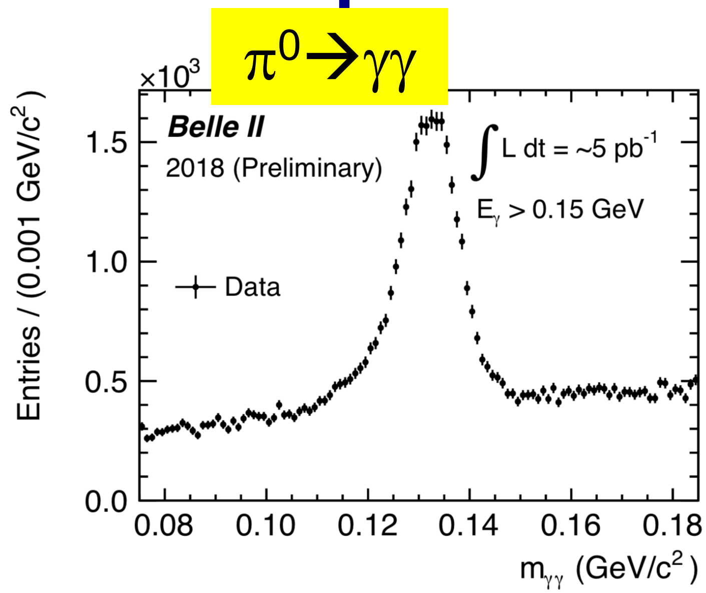
First e^+e^- collision
2018 April 26th 0:38 JST


- Not only accelerator and detector control rooms but also made remotely accessible.
- Not only Bhabha, continuum but also the first B-meson pair production candidate event was gotten.

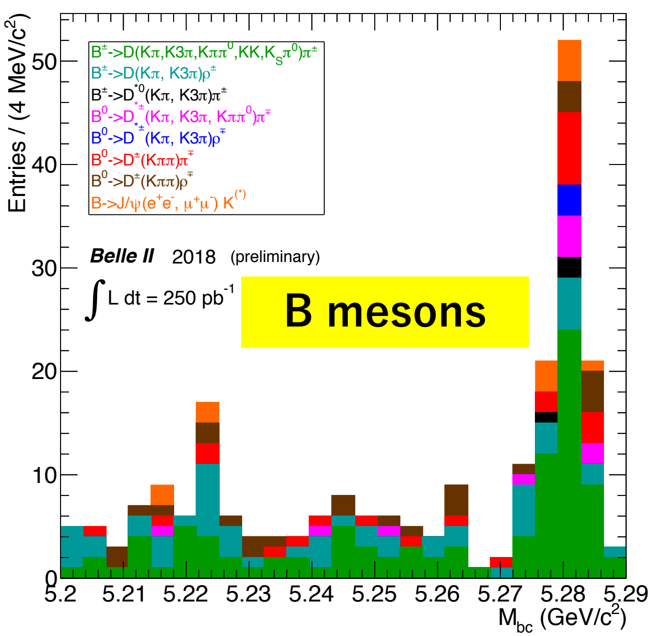


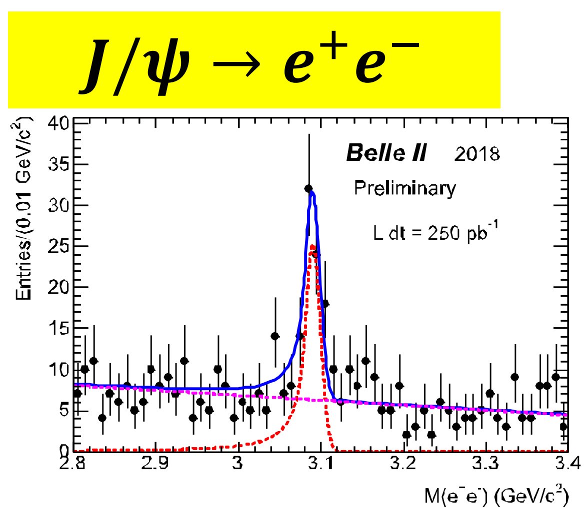
Rediscoveries in phase-2 operation

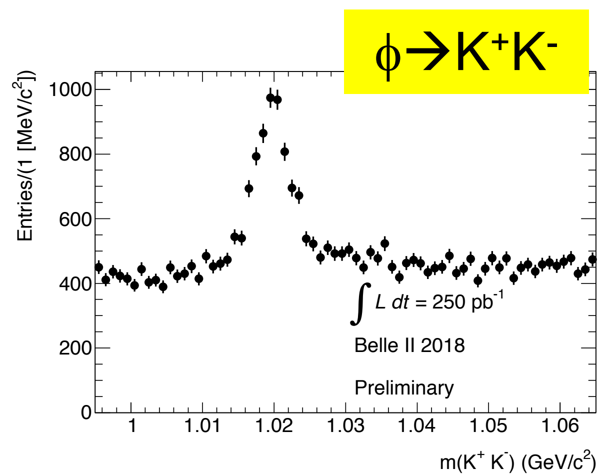




K_S, π^0 are confirmed by the early 5/pb.
Fully reconstructed B mesons are seen with 250/pb.
In total, 500/pb got.



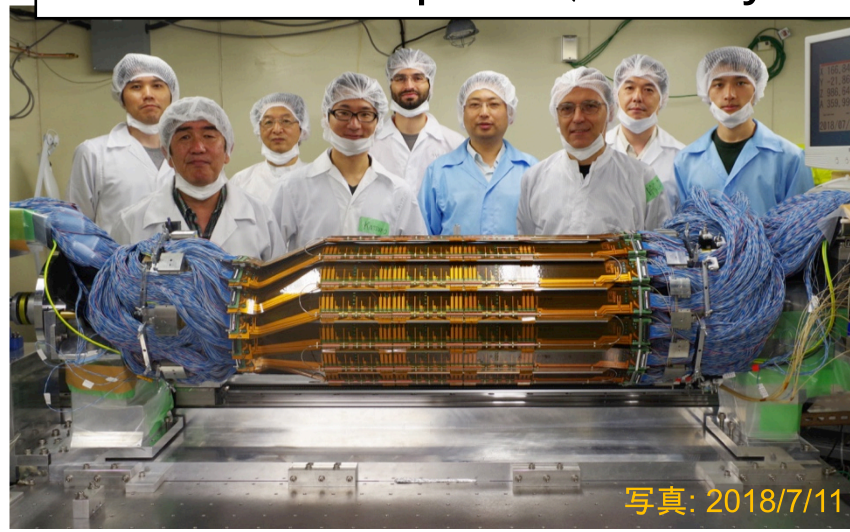


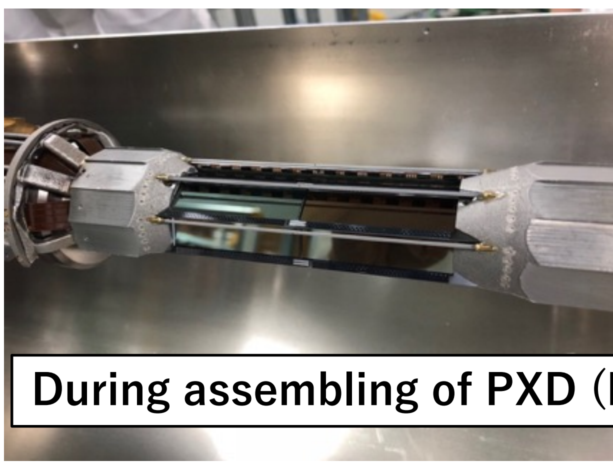


Vertex detector

1st half-SVD completed（2018 Feb. 1st）

2nd half-SVD completed（2018 July 17th）





During assembling of PXD（L1）

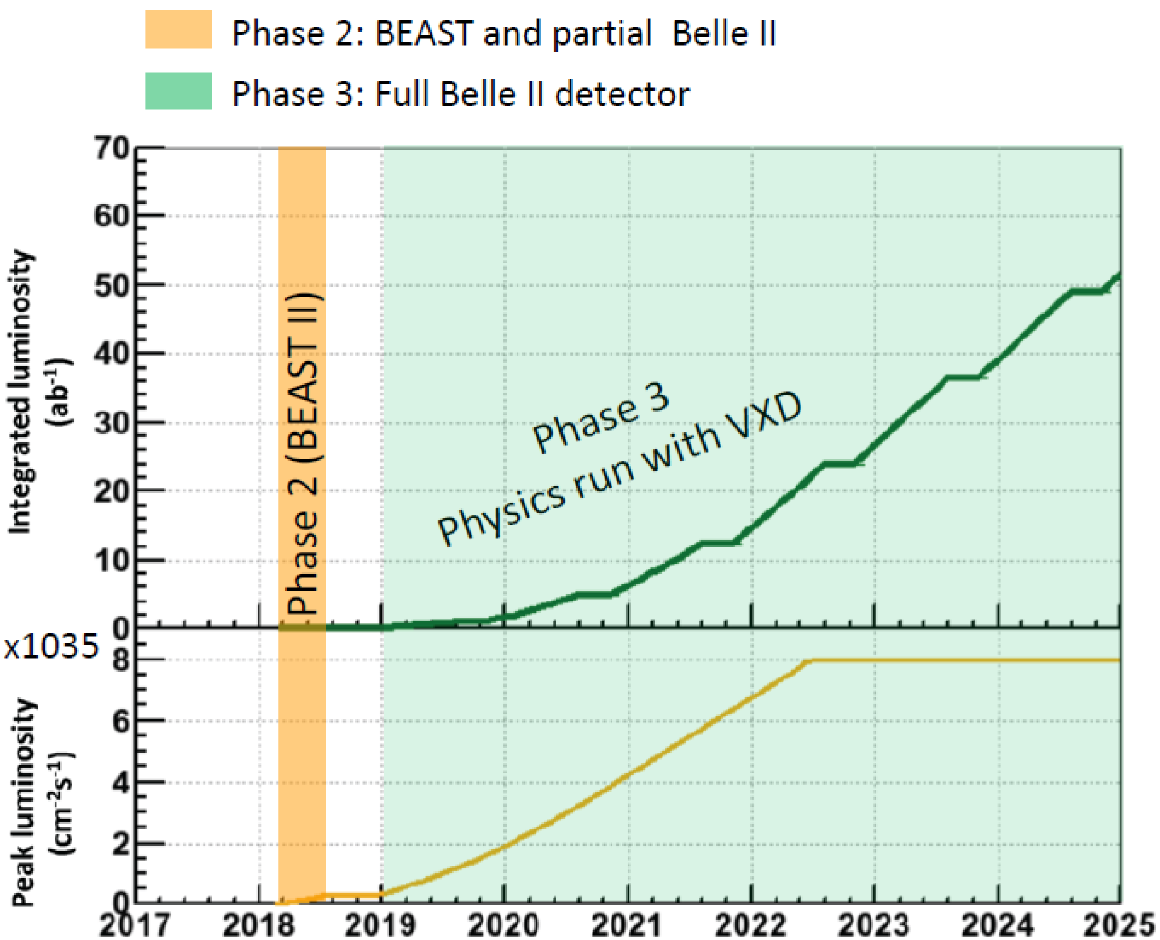
SVD：All the sensor ladder completed

- L3: 7+2, L4: 10+2, L5: 12+3, L6: 16+4
- Assembling half-SVD x2 completed.

PXD : only L1 to be installed.

- Combined with SVD.
- Cosmic test is being carried out.

Next runs and prospects



- Phase 2: without fully equipped vertex detector, data taking with e^+e^- collision, studying beam background.
- Phase 3: fully equipped detector, tuning up operation parameters toward the design luminosity $8 \times 10^{35} cm^{-2}s^{-1}$.

Closing remarks

- For quarkonium(-like) XYZ states
  - Other decay modes and Partner searches need more data.
  - Argand diagram only possible with Belle II statistics.
- Charmed baryons to test “di-quark” picture.
  - J^P determination need more data.
- Variety of recorded reactions and accessible decay modes continue to be exploited.
- All attempts with higher statistics data to give convincing and comprehensive understanding is a Belle II mission in hadron physics.
- Accelerator and detector commissioning is going on.