Hadron Spectroscopy with a variety of flavors

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December 15, 2012

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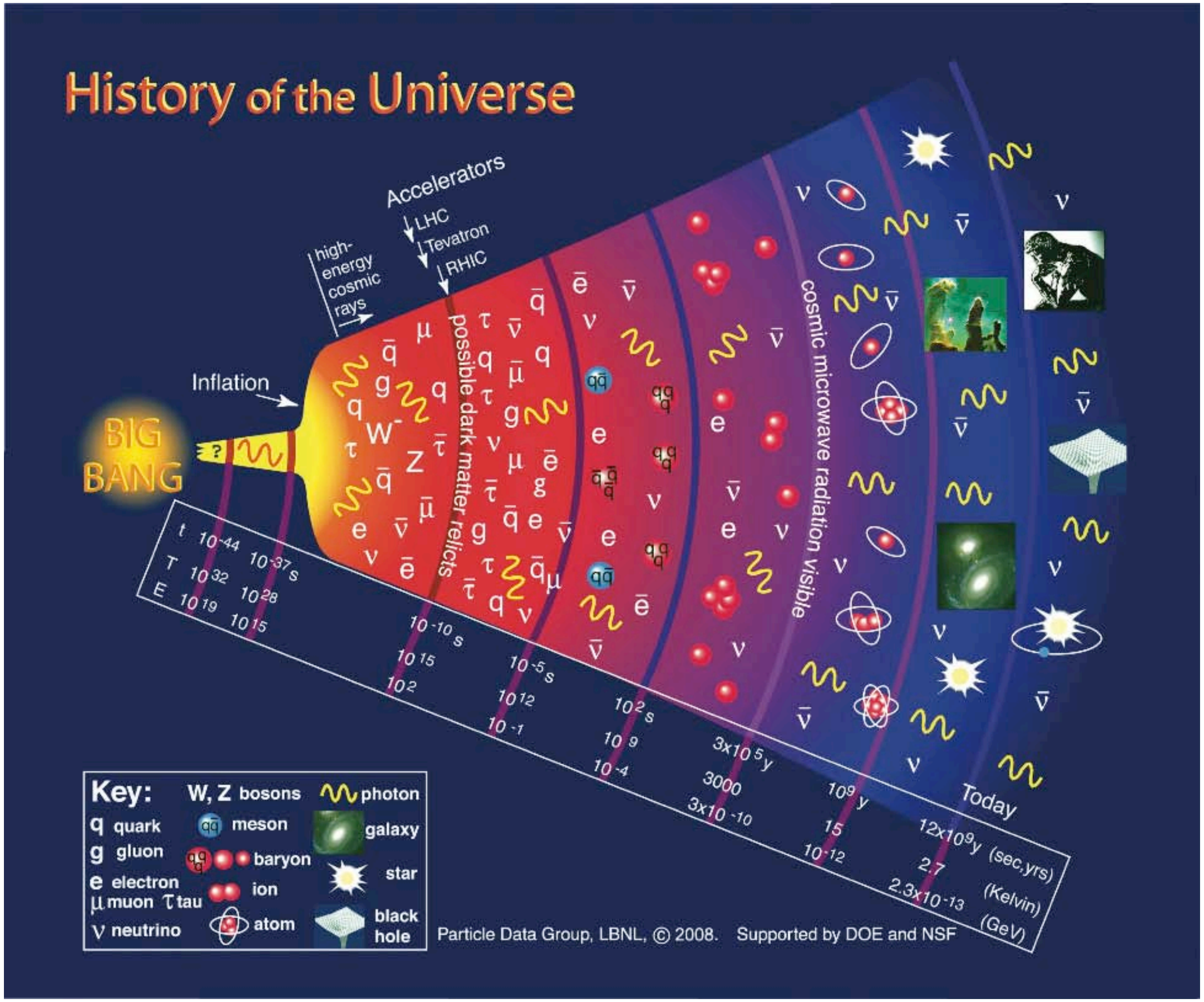
BELLE

Quarks to Universe



How quarks acquire their mass and form hadrons ?

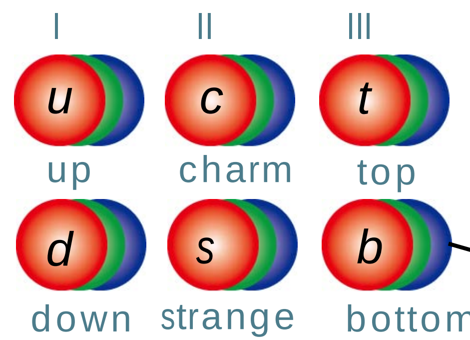
Quest in low-energy QCD

Are there exotics beyond meson($q\bar{q}$) /baryon (qqq) ?

Sakata Model
(p, n, Λ)

Gell-Mann
(u,d,s)

6 quark model



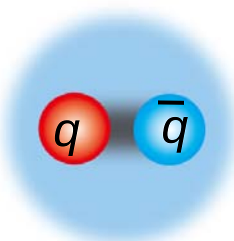
q=u, d, s, c, b, t

flavor

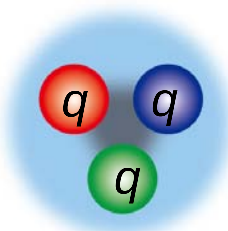
color (R,G,B)

Ordinal Hadrons

meson

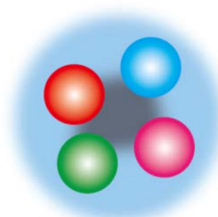


baryon

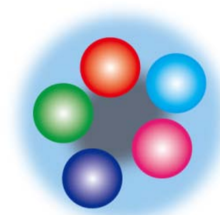


New Hadrons (Exotics)

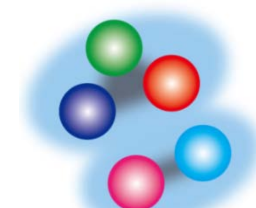
Tetra-quark



Penta-quark



Molecule



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

Gell-Mann 1964

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (q q q), (q q q q $\bar{q}$), etc., while mesons are made out of (q $\bar{q}$), (q q $\bar{q}$ $\bar{q}$), etc. It is assuming that the lowest baryon configuration (q q q) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration (q $\bar{q}$) similarly gives just **1** and **8**.

A formal mathematical model based on field theory can be built up for the quarks exactly as for p, n, Λ in the old Sakata model, for example 3) with all strong interactions ascribed to a neutral vector meson field interacting symmetrically with the three particles. Within such a framework, the

Existence of such exotics have long been discussed since the birth of the quark model.

Discoveries in 1974

- Discovery of J/ψ
  - SLAC, Burton Richter et al.
  - BNL, Samuel Ting et al.

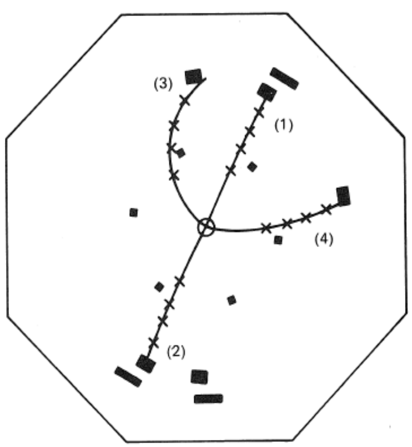


Figure 5.12 Example of the decay $\psi'(3.7) \rightarrow \psi(3.1) + \pi^+ + \pi^-$ observed in a spark chamber detector. The $\psi(3.1)$ decays to $e^+ + e^-$. Tracks (3) and (4) are due to the relatively low-energy (150-MeV) pions, and (1) and (2) to the 1.5-GeV electrons. The magnetic field and the 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).]

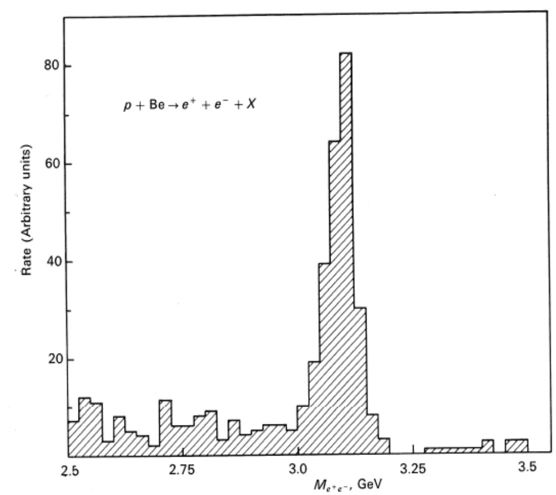
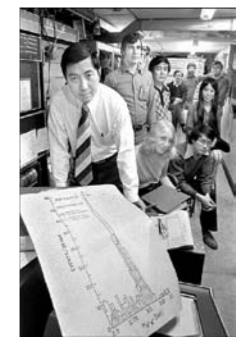


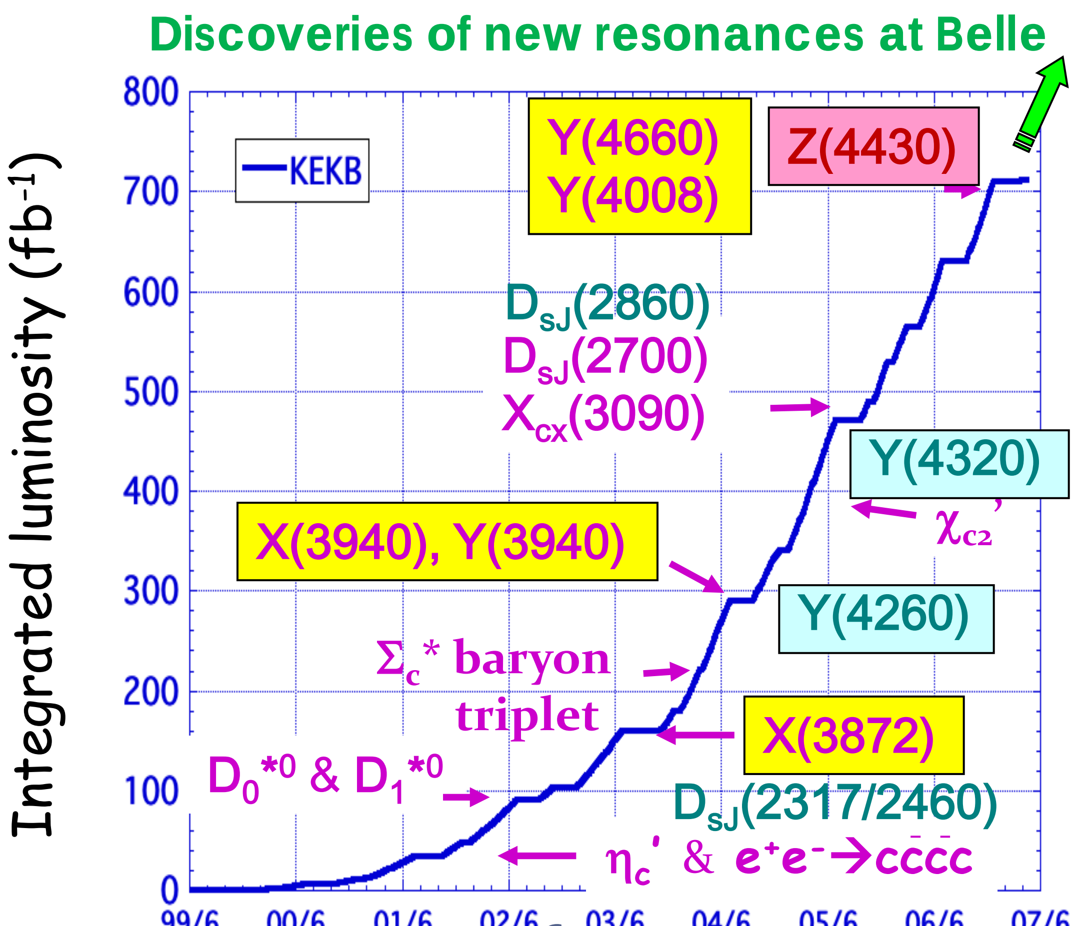
Figure 5.10 Results of Aubert *et al.* (1974) indicating the narrow resonance ψ/J in the invariant-mass distribution of e^+e^- pairs produced in inclusive reactions of protons with a beryllium target. The experiment was carried out with the 28-GeV AGS at Brookhaven National Laboratory.

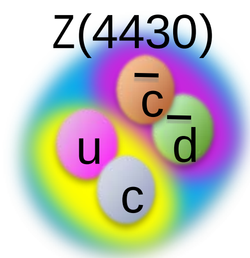


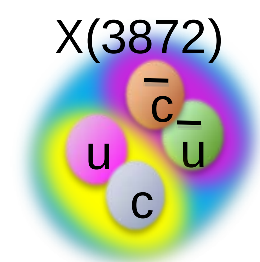
And following qurkonium spectroscopy established physical existence of quarks and qq picture of mesons.

Discoveries at B-factories

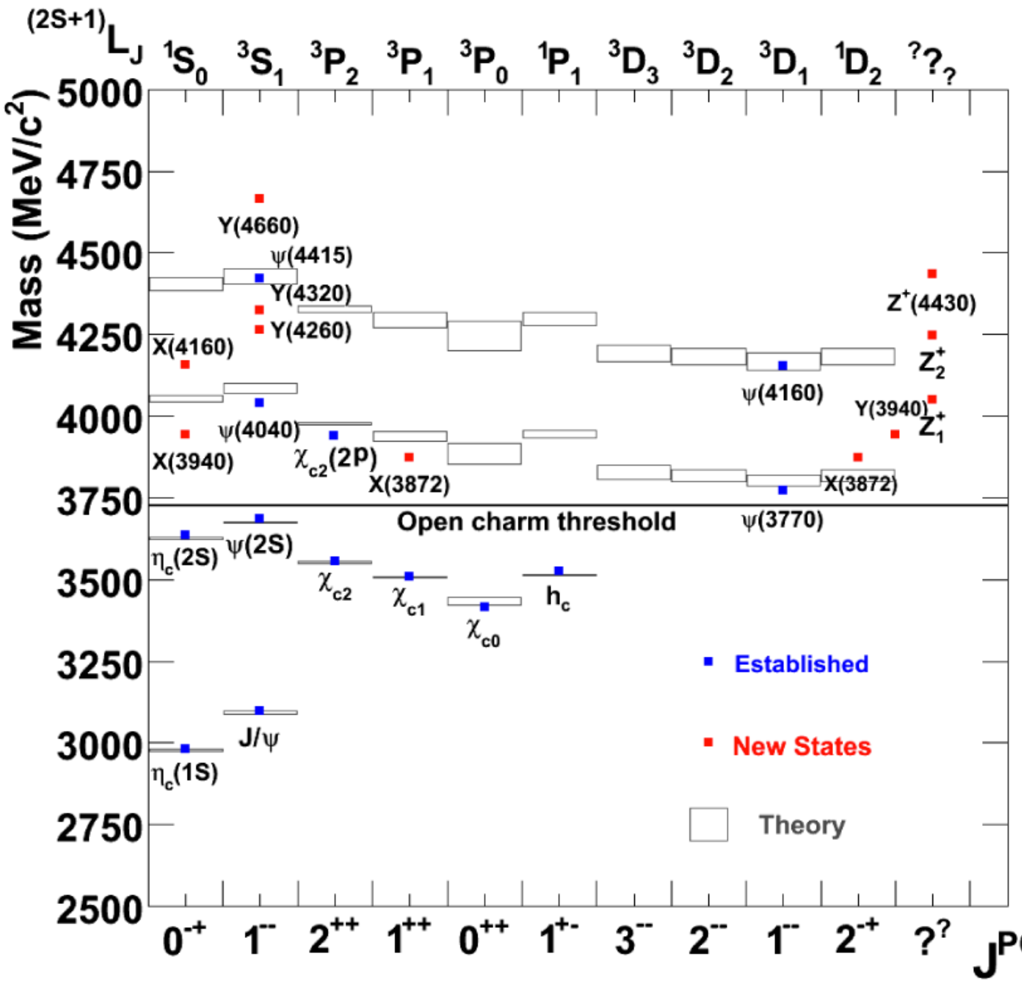
- Discovery of X(3872) and other many XYZ states etc.
- Unexpected bonus of the B-factories







Charmonium-like Spectroscopy



Above DD threshold

?

Below DD threshold

well understood by

$$V_{QCD} = -\frac{4}{3}\frac{\alpha_S}{r} + kr$$

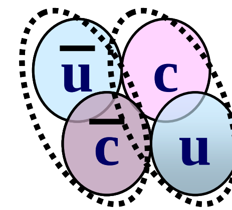
We do not understood yet how hadrons are formed from QCD.

XYZ at B Factories

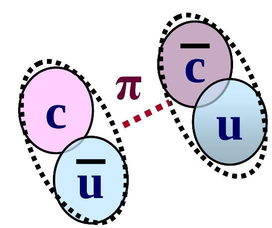
State	Mass (MeV)	Width (MeV)	Decay	Production
Ys(2175)	2175±8	58±26	ϕf_0	ISR
X(3872)	3871.84±0.33	<0.95	$J/\psi\pi\pi$, $J/\psi\gamma$	B decay
X(3872)	3872.8 +0.7/-0.6	3.9 +2.8/-1.8	$D^{*0}D^0$, $J/\psi\omega$	B decay
Y(3915)	3915±4	17±10	$J/\psi\omega$	$\gamma\gamma$
Z(3940)	3929±5	29±10	DD	$\gamma\gamma$
X(3940)	3942±9	37±17	DD*	Double-charm
Y(3940)	3942±17	87±34	$J/\psi\omega$	B decay
Y(4008)	4008 +82/-49	226 +97/-80	$J/\psi\pi\pi$	ISR
$Z(4051)^+$	4051 +24/-43	82 +51/-28	$\pi\chi_{c1}$	B decay
X(4160)	4156±29	139 +113/-65	D*D*	Double-charm
$Z(4248)^+$	4248 +185/-45	177 +320/-72	$\pi\chi_{c1}$	B decay
Y(4260)	4264±12	83±22	$J/\psi\pi\pi$	ISR
X(4350)	4350 +4.7/-5.1	13 +18/-14	$J/\psi\phi$	$\gamma\gamma$
Y(4350)	4361±13	74±18	$\psi'\pi\pi$	ISR
$Z(4430)^+$	4433±5	45 +35/-18	$\psi'\pi$	B decay
Y(4660)	4664±12	48±15	$\psi'\pi\pi$	ISR
$Y_b(10890)$	10889.6±2.3	54.7 +8.9/-7.6	$\pi\pi Y(nS)$	e^+e^- annihilation
$Z_b(10610)$	10608.4±2.0	15.6±2.5	(Y(nS) or h_b) π	Y(5S) /Y_b decay
$Z_b(10650)$	10653.2±1.5	14.4±3.2	(Y(nS) or h_b) π	Y(5S) /Y_b decay

Tetraquark

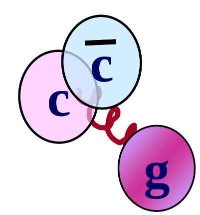
"Di-quark"



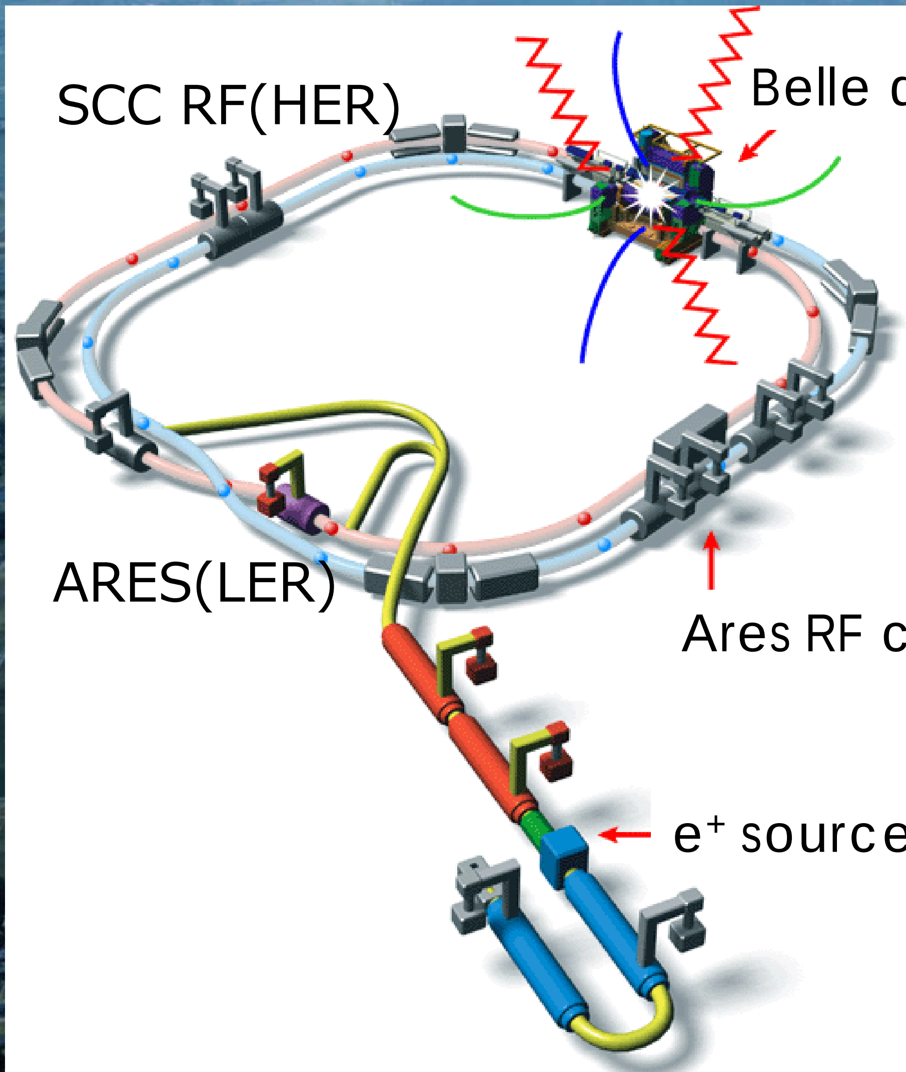
$D^{(*)}D^{(*)}$ Molecule



Hybrid



The KEKB Collider



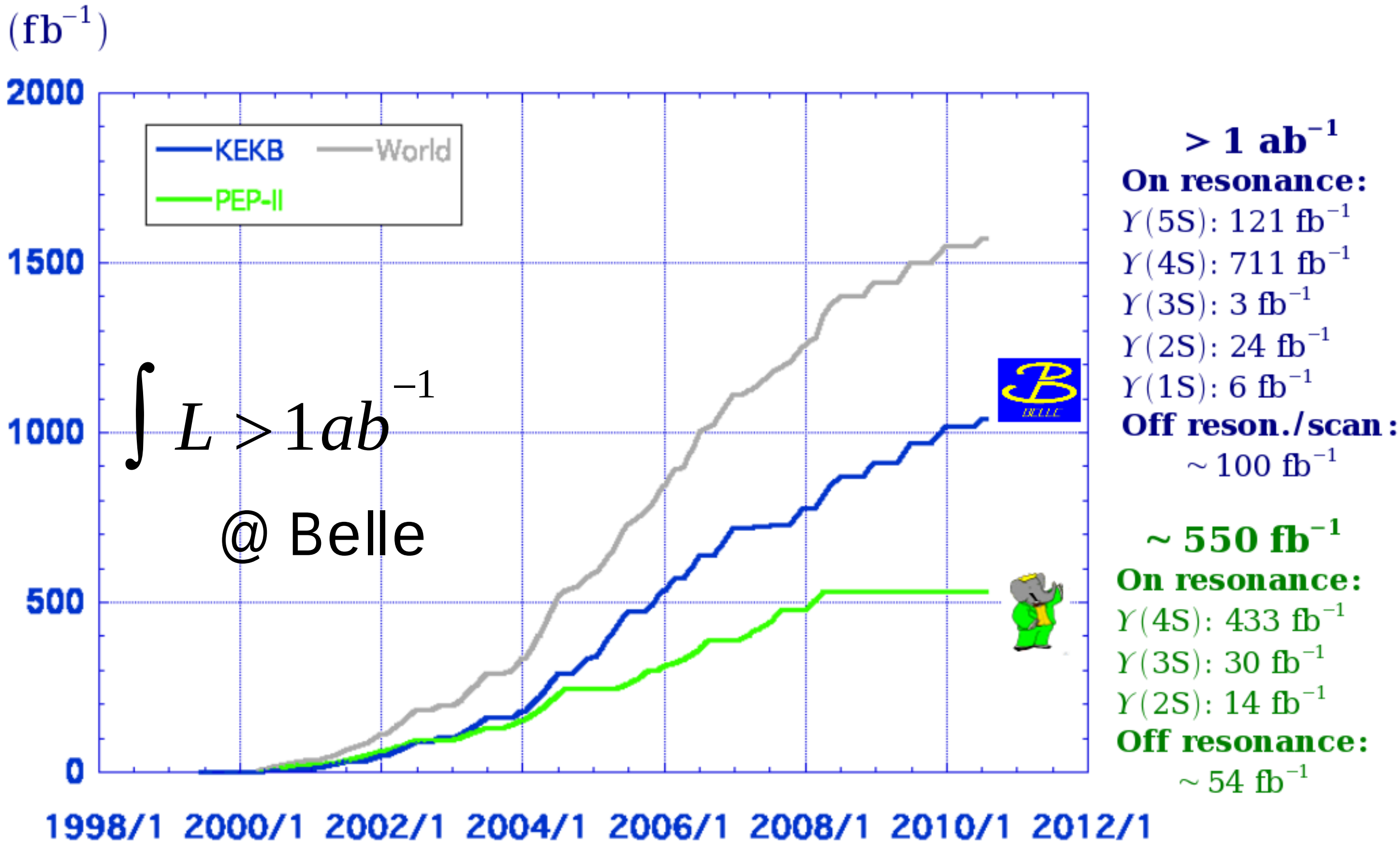
- e^- (8.0GeV) × e^+ (3.5GeV)
  - ⇒ $\Upsilon(4S) \to B\bar{B}$
  - ⇒ Lorentz boost:
  - $\beta\gamma = 0.425$
- Finite crossing angle
  - 11mrad ×2
- Operated 1999-2010

Peak luminosity

$2.1 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$!

The World Highest Luminosity

Luminosity at B Factories



Belle Detector

- Acceptance: 0.9 ×4π
- Vertex resolution

  s(J/ψ →ll) ~75nm
- Momentum resolution

  $\sigma(Pt) = 0.19 \cdot Pt \oplus 0.34/\beta$ %
- Energy resolution

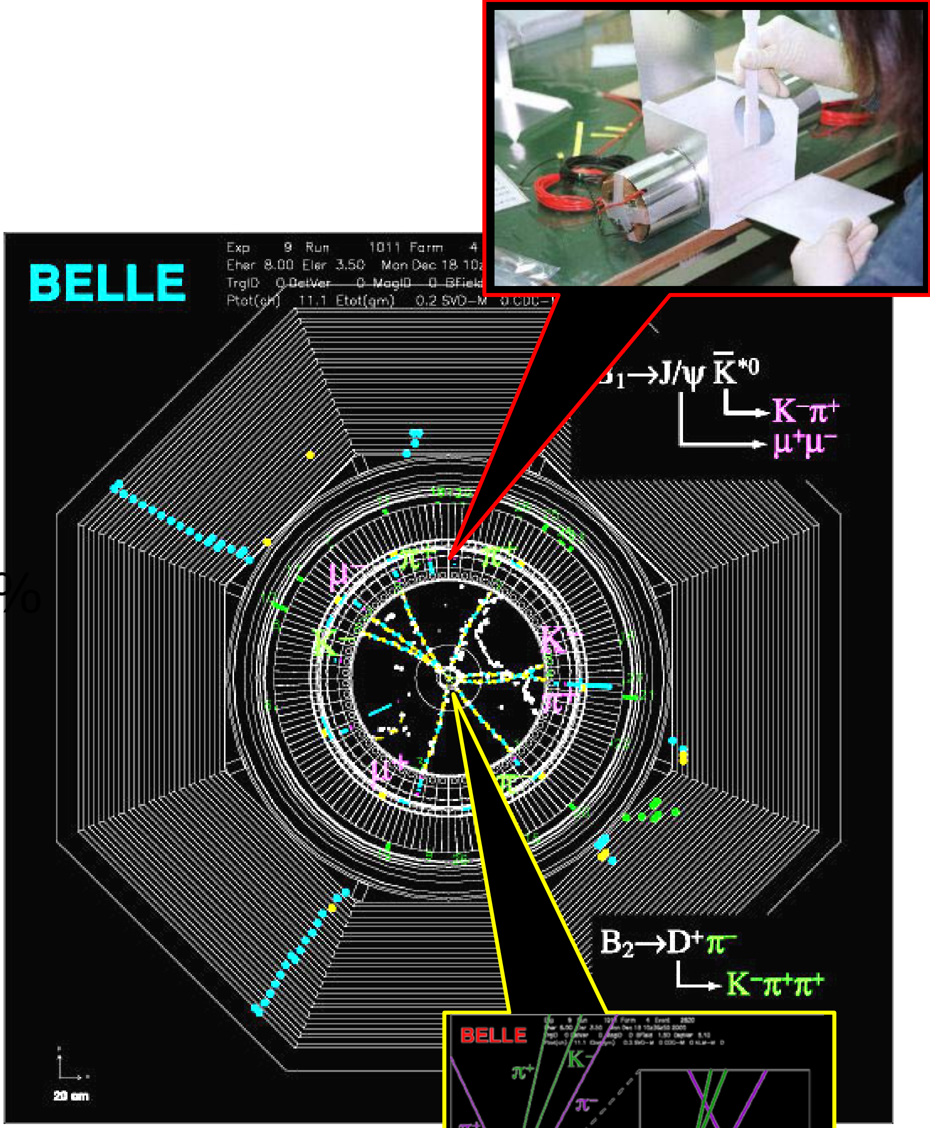
  $\sigma(E\gamma)/E\gamma = 1.8\%$ @ 1GeV
- Particle ID

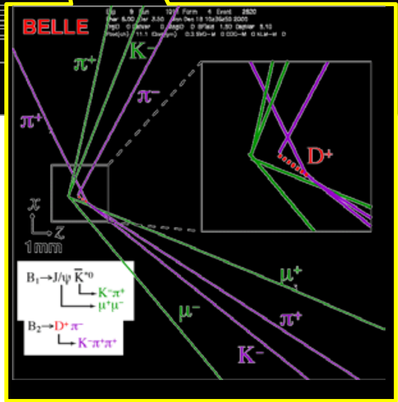
  e, μ, π, K, p
- Minimum bias trigger

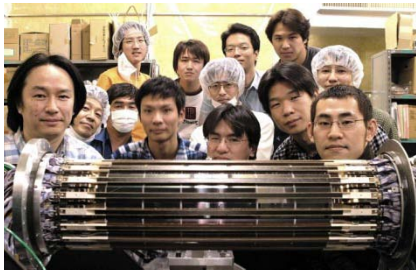
  Evis >= 1GeV & Ntrk >= 2

  & Ncluster >= 4

→ essentially no loss for $B\bar{B}$.

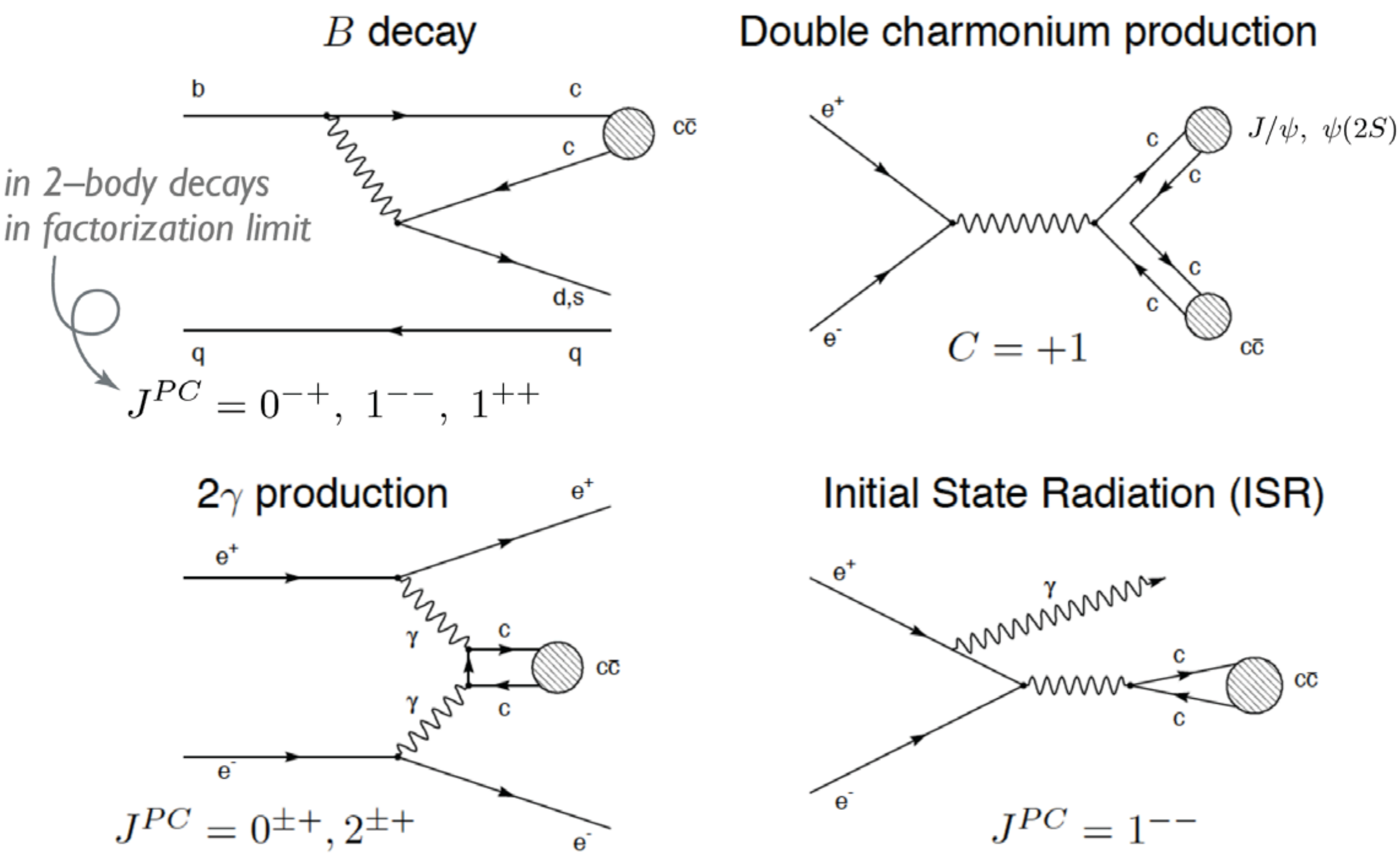






Production of $c\bar{c}$ in B Factories

B factories can produce charmonium (-like) states in four ways.



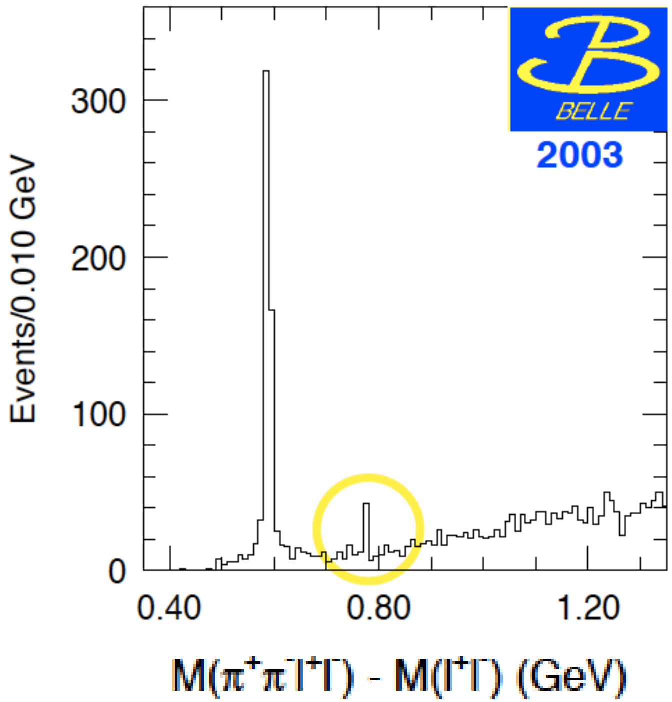
World-wide Activity

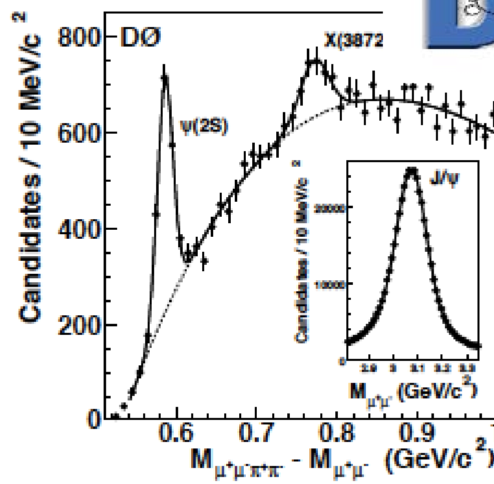
Results are mainly from Belle for this talk

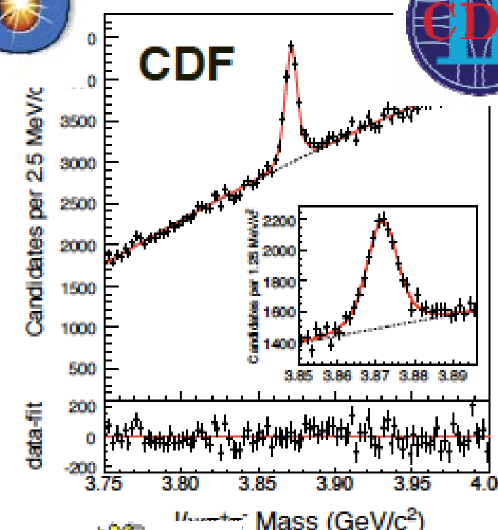
Chamonium-like Exotics

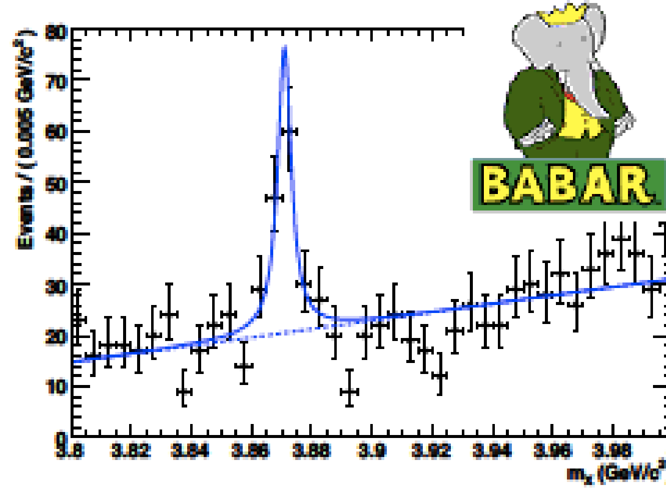
X (3872)

Discovery by Belle in 2003, followed by D0, CDF, BaBar.









World Average

$$M(X(3872)) = 3871.67 \pm 0.17 \text{ MeV}$$

$$\Gamma(X(3872)) < 1.2 \text{ MeV} \quad (90\%\text{CL})$$

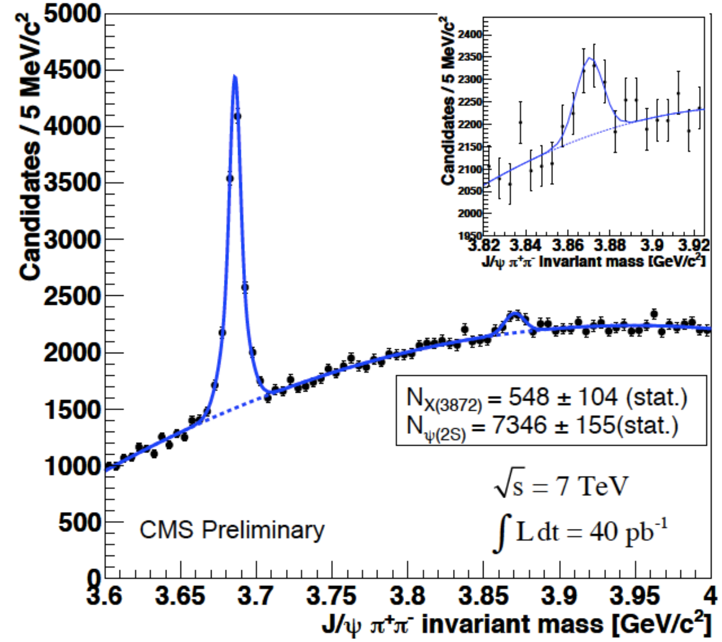
X(3872) at LHC

CMS (40 pb^{-1}, $\sqrt{s}$ = 7 TeV)

CMS PAS BPH-10-018

$$R \equiv \frac{\sigma(pp \to X(3872) + \mathrm{K}\ ) \times Br(X(3872) \to J/\psi \pi^+ \pi^-)}{\sigma(pp \to \psi(2S) + \mathrm{K}\ ) \times Br(\psi(2S) \to J/\psi \pi^+ \pi^-)}$$

$$= 0.087 \pm 0.017 \pm 0.009$$



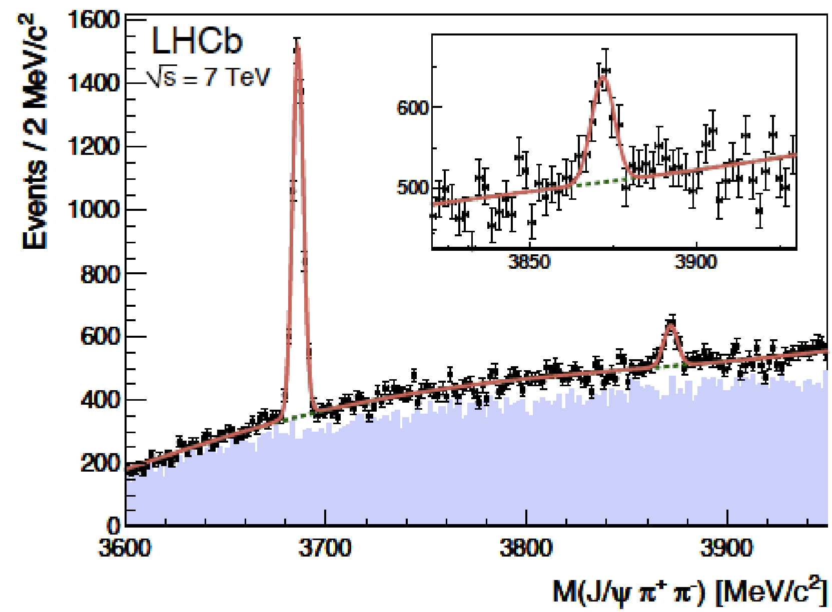
LHCb (34.7 pb^{-1}, $\sqrt{s}$ = 7 TeV)

arXiv: 1112.5310

$$\sigma(pp \to X(3872) + \mathrm{K}\ ) \times Br(X(3872) \to J/\psi \pi^+ \pi^-)$$

$$= [4.7 \pm 1.1 \pm 0.7]\,\mathrm{nb}$$

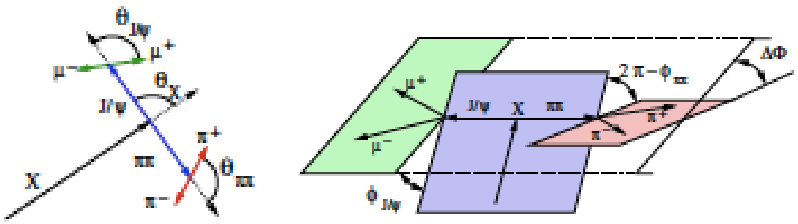
$$M_{X(3872)} = [3871.95 \pm 0.48 \pm 0.12]\,\mathrm{MeV}$$



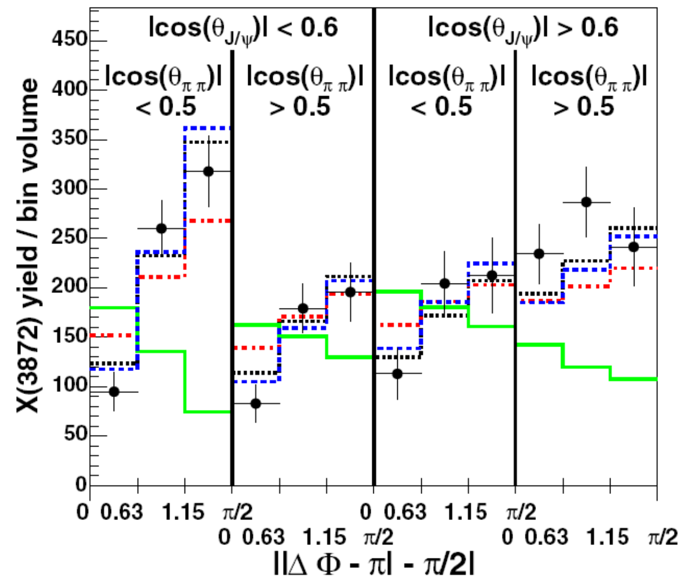
Looking forward to results with >1fb^{-1} data.

J^{PC} of X(3872)

CDF(780pb^{-1}) PRL 98, 132002 (2007)



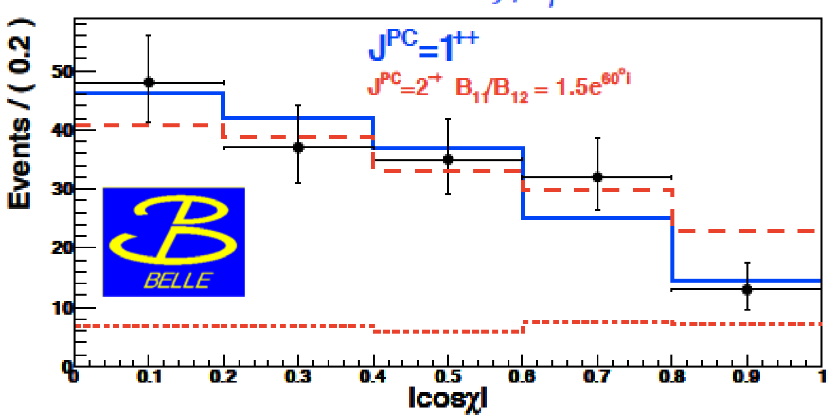
1^{++}
2^{-+}
1^{--}
0^{++}



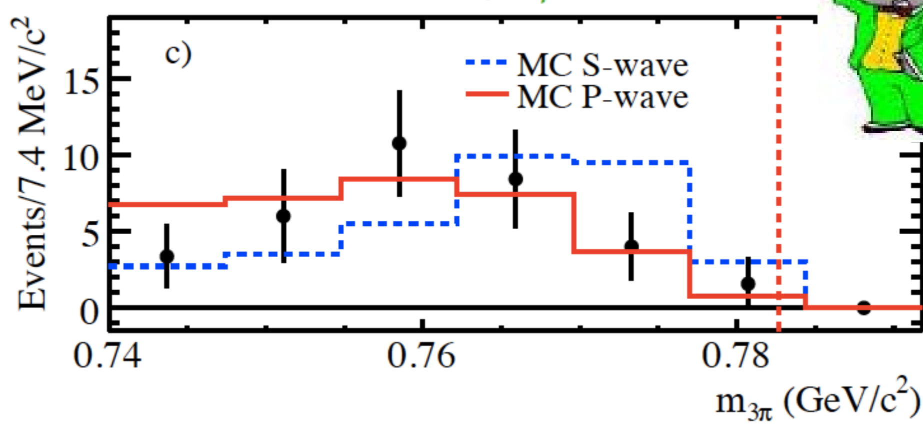
Belle (711fb^{-1}) PRD 84, 052004 (2011)

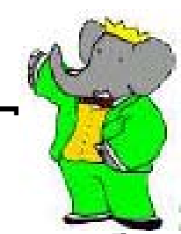
BaBar (420fb^{-1}) PRD 82, 011101 (2010)

Belle $X \to J/\psi\pi^+\pi^-$



BaBar $X \to J/\psi\pi^+\pi^-\pi^0$





- All J^{PC} values other than 1^{++} or 2^{-+} are ruled out with high confidence.
- Need more statistics to distinguish 1^{++} vs 2^{-+}.

Properties of X(3872)

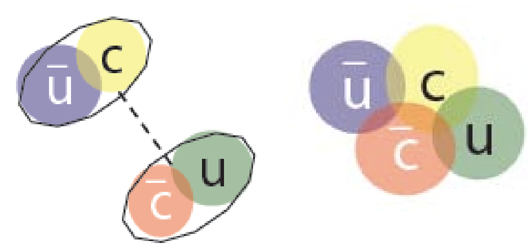
- C = +1 X(3872) → $J/\psi\ \gamma$, $J/\psi\ \rho$ seen
- $J^{PC} = 1^{++}$ or 2^{-+} Angular distribution
- I = 0 No charged partner so far

↔ isospin violating decay X(3872) → $J/\psi\ \rho\ (\pi^+\pi^-)$

- Mass just around $\overline{D^*}D$

$$\begin{cases} M_X - M_{D^{*0}} - M_{\overline{D}^0} = -0.12 \pm 0.35\ \text{MeV} \\ M_X - M_{D^{*+}} - M_{D^-} = -7.74 \pm 0.35\ \text{MeV} \end{cases}$$

- Possible interpretation
  - Conventional $c\bar{c}$: $c_{c1}(2^3P_1)$ for 1^{++}, $h_{c2}(1^1D_2)$ for 2^{-+}
  - Exotics:
    - $D^{*0}\,\overline{D}^0$ molecule : $[c\bar{q}][\bar{c}q]$
    - Tetra-quark : $[cq][\overline{cq}]$



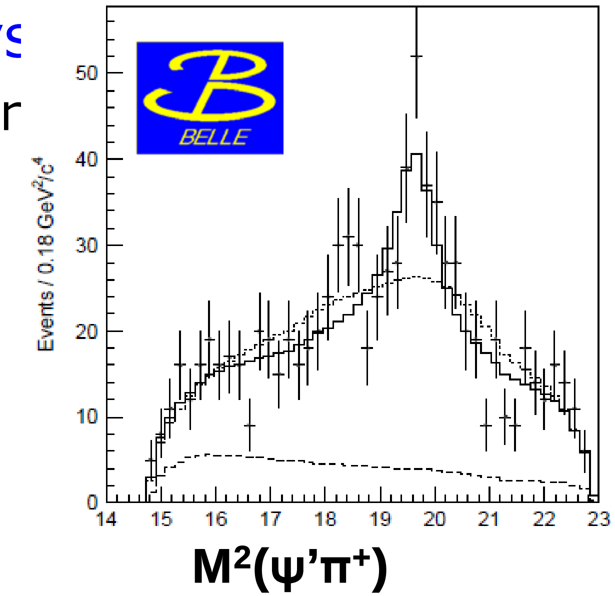
$D^{*0}\,\overline{D}^0$ molecule Tetra-quark

$Z(4430)^+$, $Z(4050)^+$, $Z(4250)^+$ by Belle

- Belle found $Z(4430)^+$ in $B \rightarrow K \pi^+ \psi'$ decays
  - One-dimensional fit on $\psi'\pi^+$ distribution after K*(890) /K*(1430) vetos. PRD80, 031104(2009)
  - Confirmed by analysis with a full Dalitz plot. PRD80, 031104(2009)

$$M = (4443\,^{+15}_{-12}\,^{+19}_{-13})\,\mathrm{MeV}/c^2$$

$$\Gamma = (107\,^{+86}_{-43}\,^{+74}_{-56})\,\mathrm{MeV}$$



- Belle found also another two states, $Z(4050)^+$ & $Z(4250)^+$, in $B \rightarrow K \pi^+ \chi_{c1}$ deca

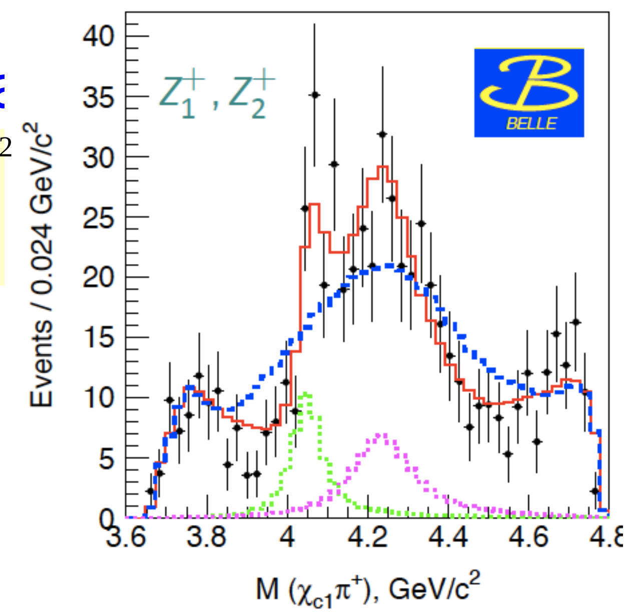
$$M_1 = (4051 \pm 14\,^{+20}_{-41})\,\mathrm{MeV}/c^2$$

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

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

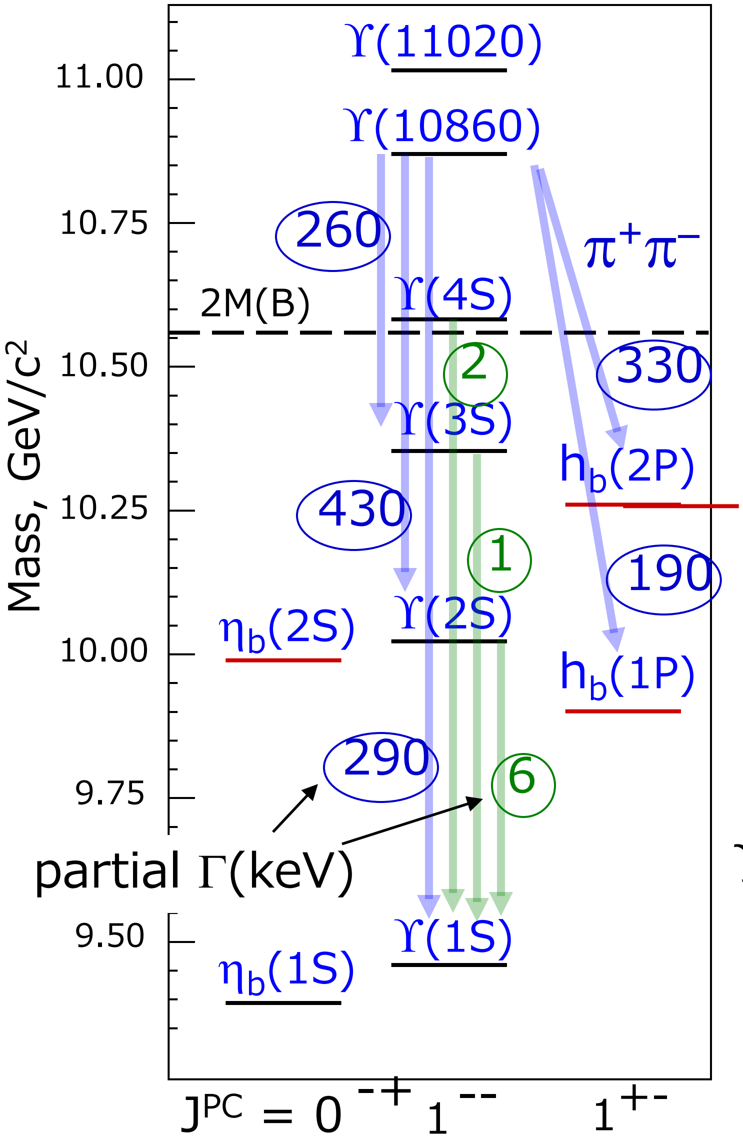
$$\Gamma_2 = (177\,^{+54}_{-39}\,^{+316}_{-61})\,\mathrm{MeV}$$

Their minimum quark content must be exotic: $c\bar{c}u\bar{d}$



Bottomonium-like Exotics

Anomalies in $\Upsilon(5S)$ decay

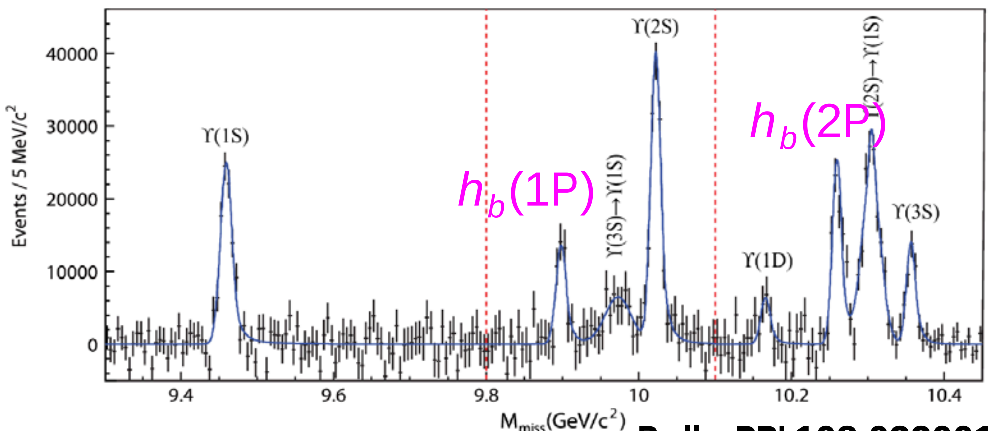


$\Gamma[\Upsilon(\mathbf{5S}) \rightarrow \Upsilon(1,2,3S)\ \pi^+\pi^-]$

$>> \Gamma[\Upsilon(\mathbf{4,3,2S}) \rightarrow \Upsilon(1S)\ \pi^+\pi^-]$

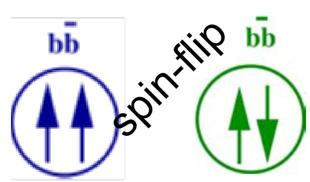
Belle PRL100,112001(2008)

h_b production



Belle PRL108,032001(2012)

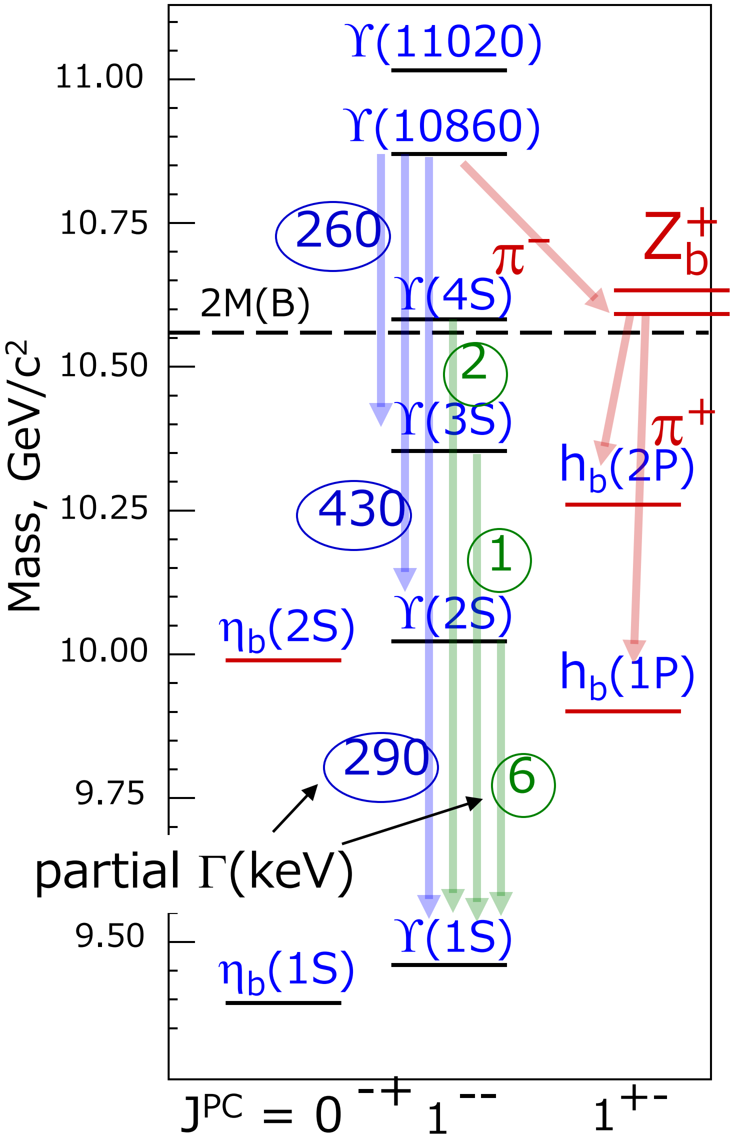
$\Upsilon(\mathbf{5S}) \rightarrow h_b(1,2P)\ \pi^+\pi^-$ are not suppressed



Expect suppression $\sim\Lambda_{QCD}/m_b$

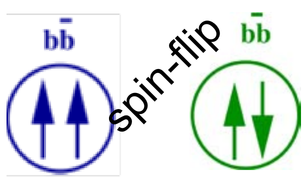
Heavy Quark Symmetry Violation

Anomalies in $\Upsilon(5S)$ decay



h_b production
$\Rightarrow$ via intermediate
charged states Z_b

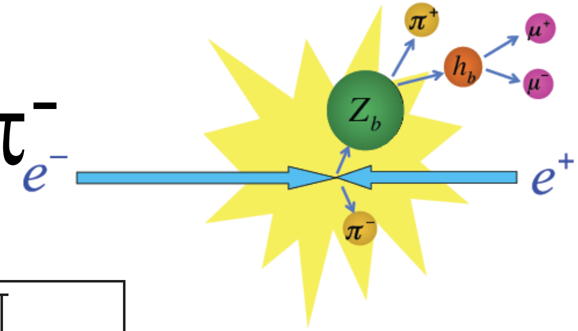
$\Upsilon(\mathbf{5S}) \rightarrow h_b(1,2P)\ \pi^+\pi^-$ are not suppressed

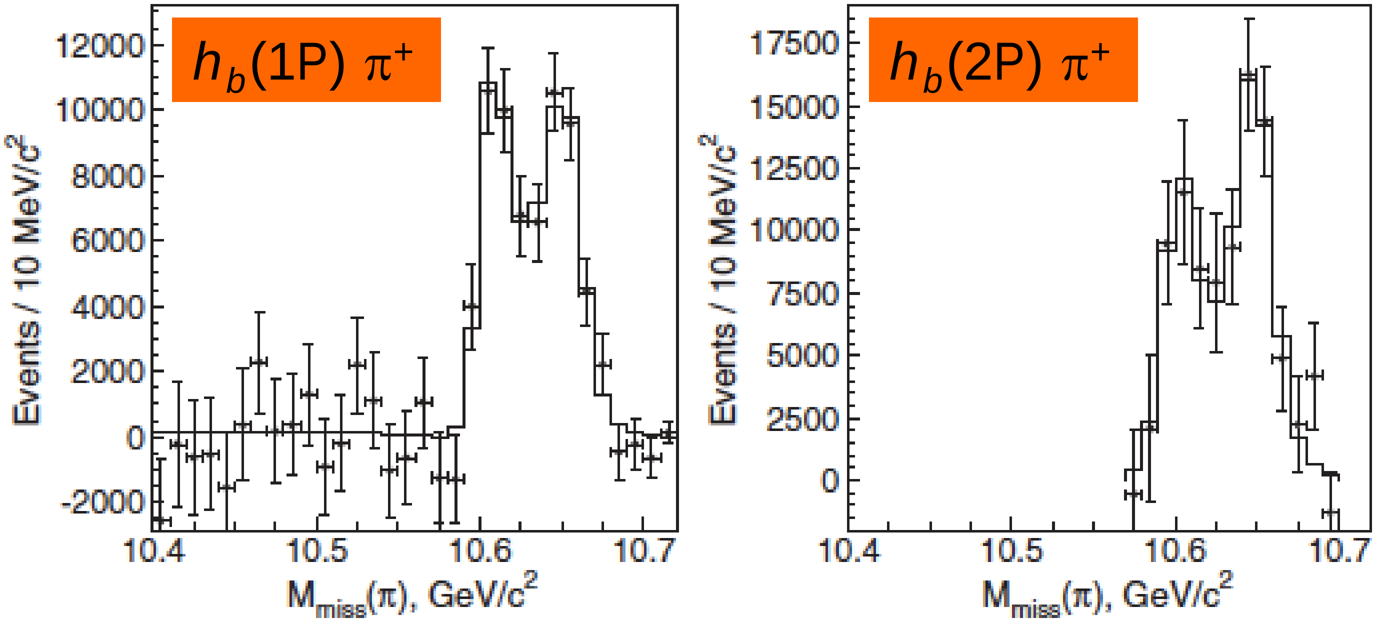


Expect suppression $\sim\Lambda_{QCD}/m_b$

Heavy Quark Symmetry Violation

$h_b\,(1P, 2P)\ \pi^+\ \pi^-$





$M_{miss}(\pi)$ to look at $h_b\ \pi^+$

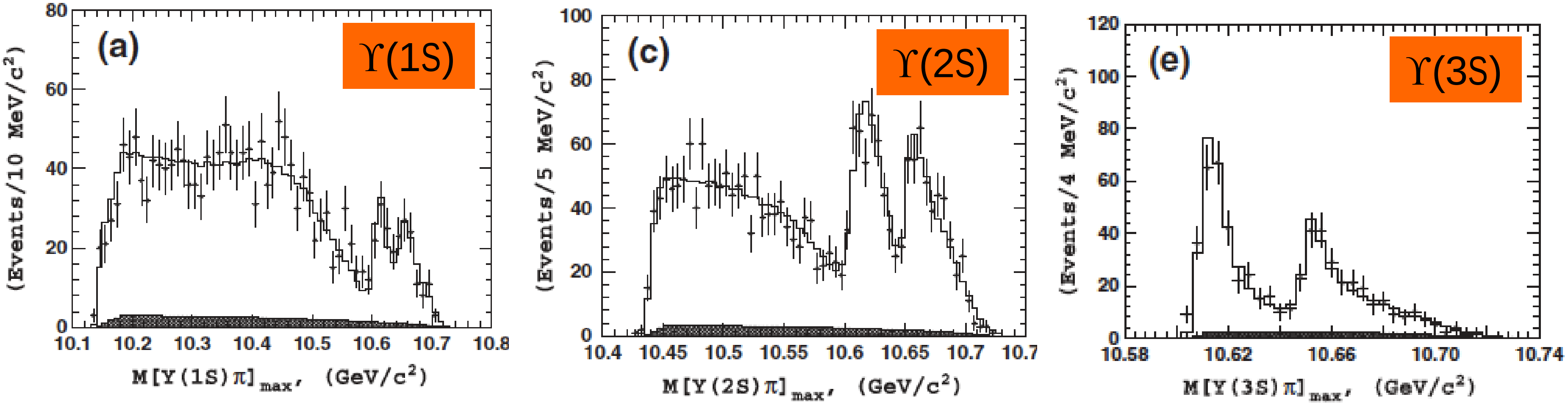
Fit with $A(Z_{b1}^+) + A(Z_{b2}^+) + A(NR)$

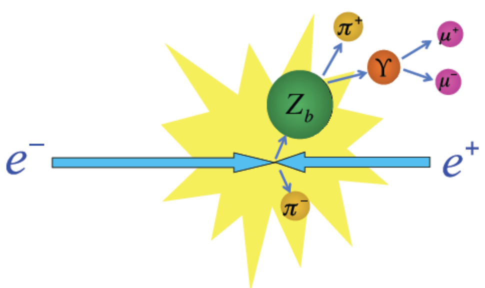
Two peaks at the positions same as $\Upsilon(nS)\pi^+\pi^-$

	$h_b(1P)\pi^+\pi^-$	$h_b(2P)\pi^+\pi^-$
$M[Z_b(10\,610)]$ (MeV/c^2)	$10\,605 \pm 2^{+3}_{-1}$	$10\,599^{+6+5}_{-3-4}$
$\Gamma[Z_b(10\,610)]$ (MeV)	$11.4^{+4.5+2.1}_{-3.9-1.2}$	13^{+10+9}_{-8-7}
$M[Z_b(10\,650)]$ (MeV/c^2)	$10\,654 \pm 3^{+1}_{-2}$	$10\,651^{+2+3}_{-3-2}$
$\Gamma[Z_b(10\,650)]$ (MeV)	$20.9^{+5.4+2.1}_{-4.7-5.7}$	$19 \pm 7^{+11}_{-7}$
Relative normalization	$1.39 \pm 0.37^{+0.05}_{-0.15}$	$1.6^{+0.6+0.4}_{-0.4-0.6}$
Relative phase (deg)	187^{+44+3}_{-57-12}	$181^{+65+74}_{-105-109}$

Charged Bottomonium-like Z_b^+ in $\Upsilon(nS)\pi^+$

Two peaks at the same positions in the 3 modes.



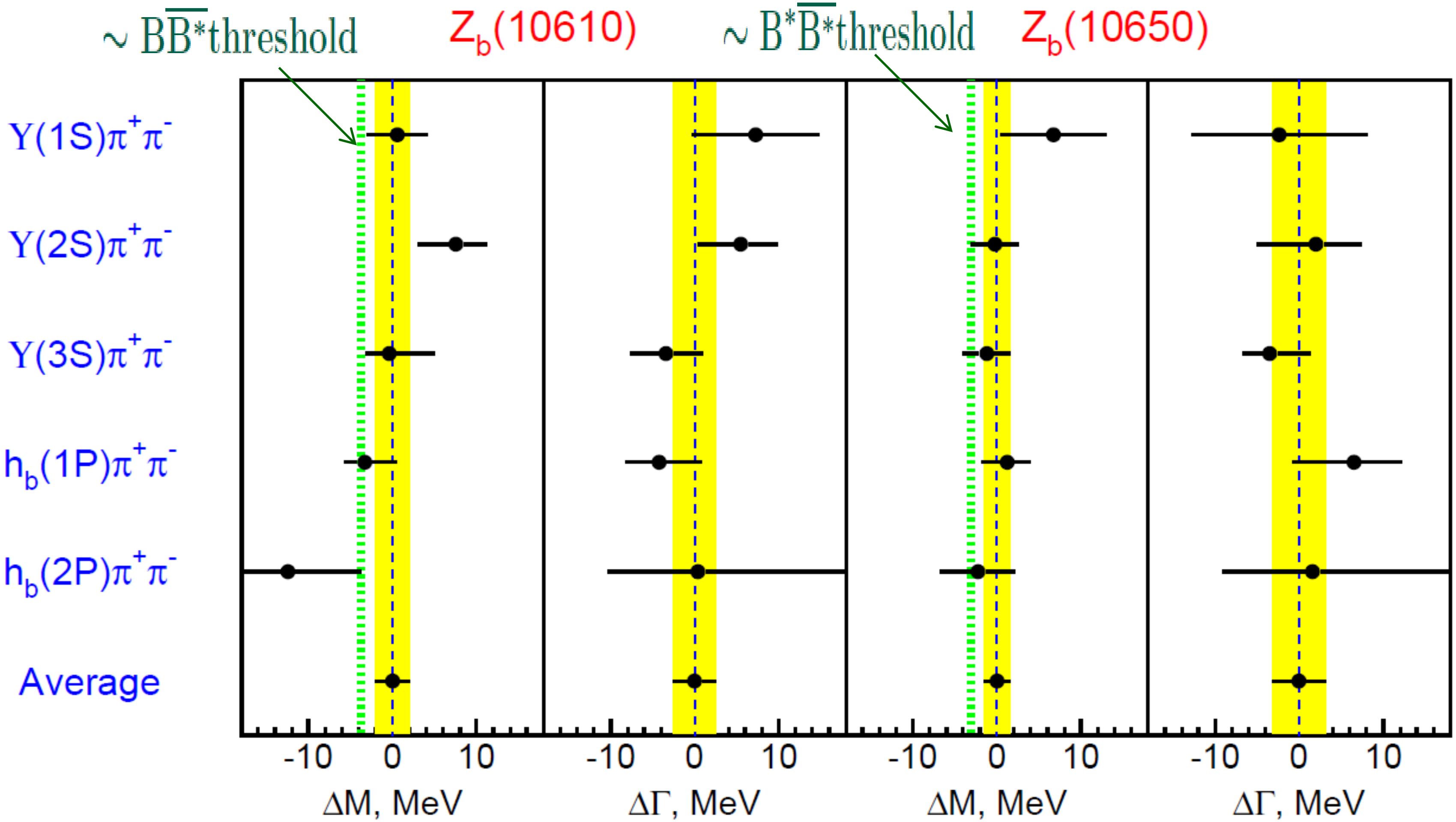


BELLE

Two resonances: $Z_b^+(10510)$, $Z_b^+(10560)$

Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
$M[Z_b(10610)]$ (MeV/c^2)	$10611 \pm 4 \pm 3$	$10609 \pm 2 \pm 3$	$10608 \pm 2 \pm 3$
$\Gamma[Z_b(10610)]$ (MeV)	$22.3 \pm 7.7^{+3.0}_{-4.0}$	$24.2 \pm 3.1^{+2.0}_{-3.0}$	$17.6 \pm 3.0 \pm 3.0$
$M[Z_b(10650)]$ (MeV/c^2)	$10657 \pm 6 \pm 3$	$10651 \pm 2 \pm 3$	$10652 \pm 1 \pm 2$
$\Gamma[Z_b(10650)]$ (MeV)	$16.3 \pm 9.8^{+6.0}_{-2.0}$	$13.3 \pm 3.3^{+4.0}_{-3.0}$	$8.4 \pm 2.0 \pm 2.0$
Relative normalization	$0.57 \pm 0.21^{+0.19}_{-0.04}$	$0.86 \pm 0.11^{+0.04}_{-0.10}$	$0.96 \pm 0.14^{+0.08}_{-0.05}$
Relative phase (deg)	$58 \pm 43^{+4}_{-9}$	$-13 \pm 13^{+17}_{-8}$	$-9 \pm 19^{+11}_{-26}$

$Z_b(10610)$ & $Z_b(10650)$



M=10608.4±2.0 MeV

Γ=15.6±2.5 MeV

M=10653.2±1.5 MeV

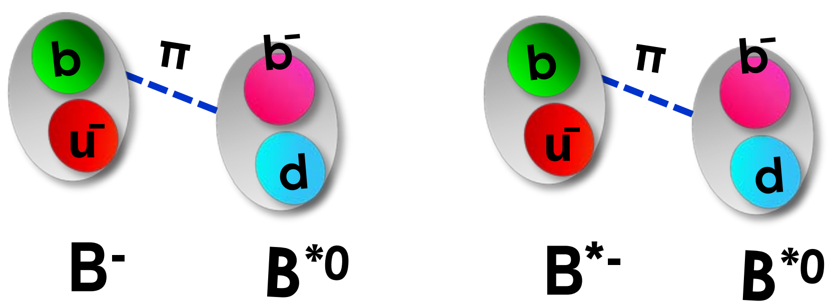
Γ=14.4±3.2 MeV

Molecular Explanation of Z_b^+

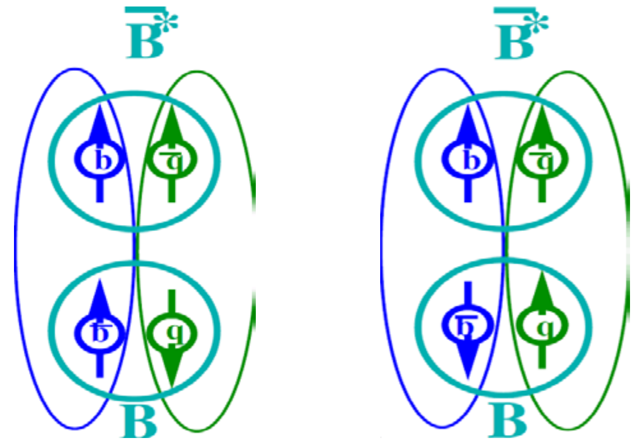
Bondar et al, PRD84,054010(2011)

Proximity to thresholds favors molecule picture

$Z_b^+(10510)$ $Z_b^+(10560)$



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



This model explains

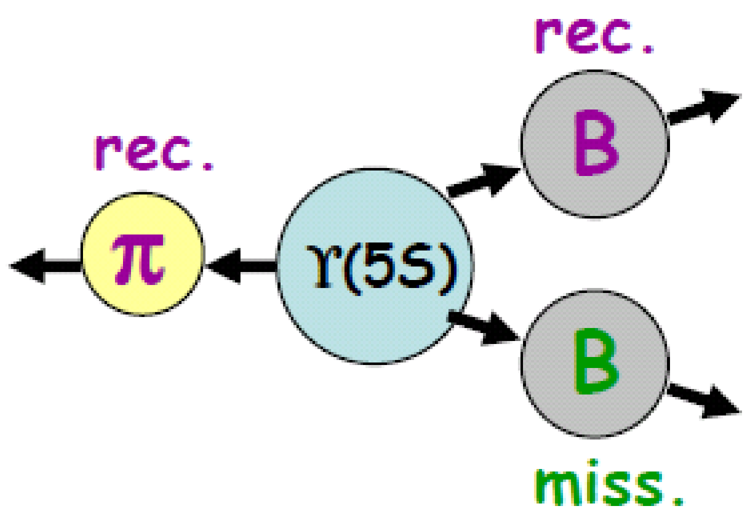
- Why h_b□□ is unsuppressed relative to □□□
- Relative phase ~0 for □ and ~180^0 for h_b
- Production rates of $Z_b(10610)$ and $Z_b(10650)$ are similar widths

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

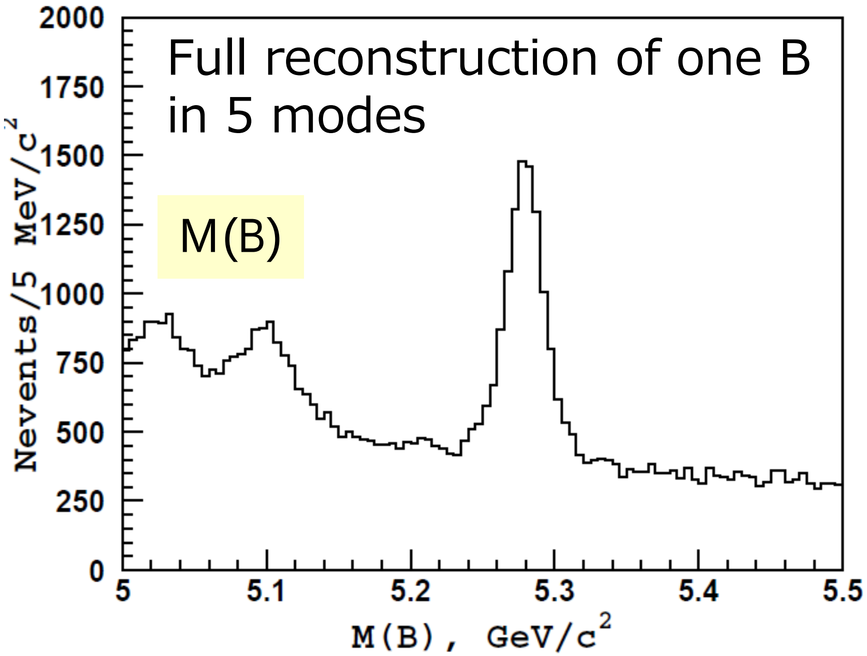
Study of $Z_b \rightarrow B^* \overline{B^{(*)}}$

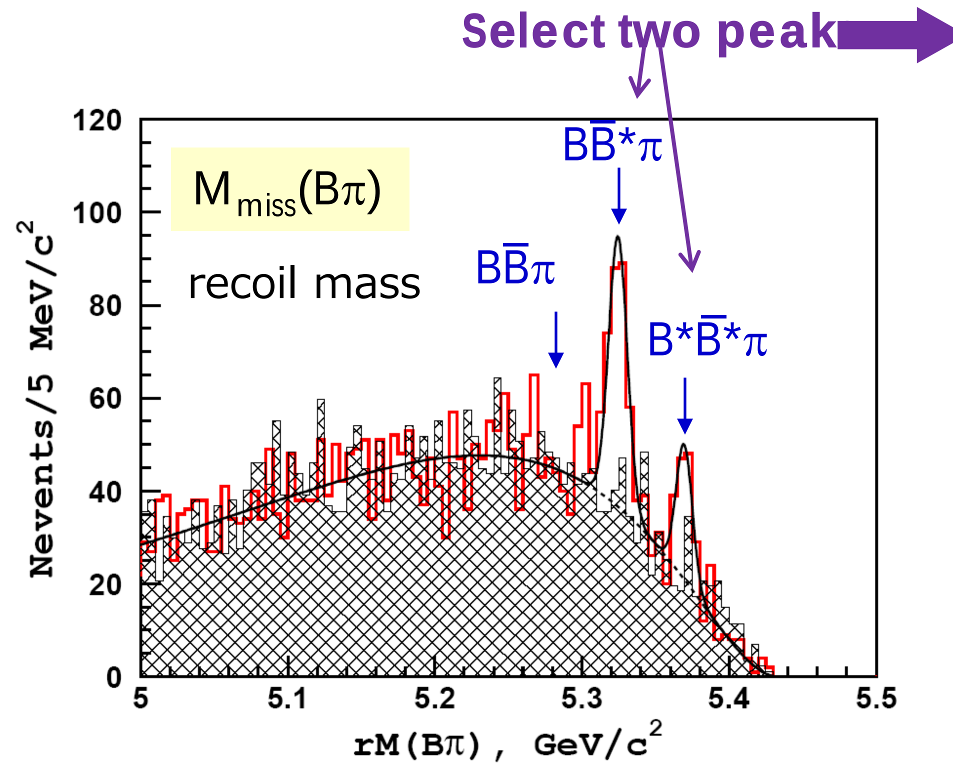
For the $\Upsilon(5S) \rightarrow \overline{B}^* B(^*) \pi^+$ channel:

- Fully reconstruct one B meson in five exclusive decay modes.
- Look at recoil mass of $B\pi$ (for missing B) rM($B\pi$) and of the pion (for two B combination) rM(π).



Clear $B\bar{B}^*\pi$ and $B^*\bar{B}^*\pi$ signals

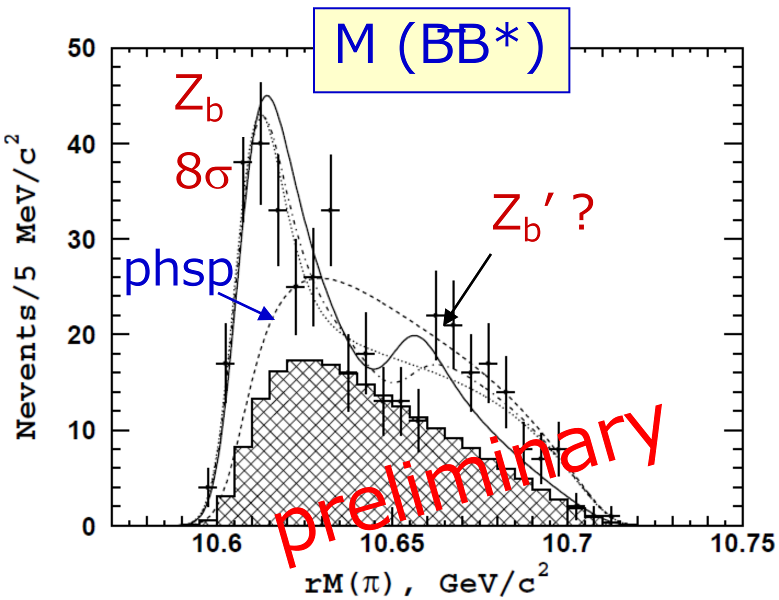


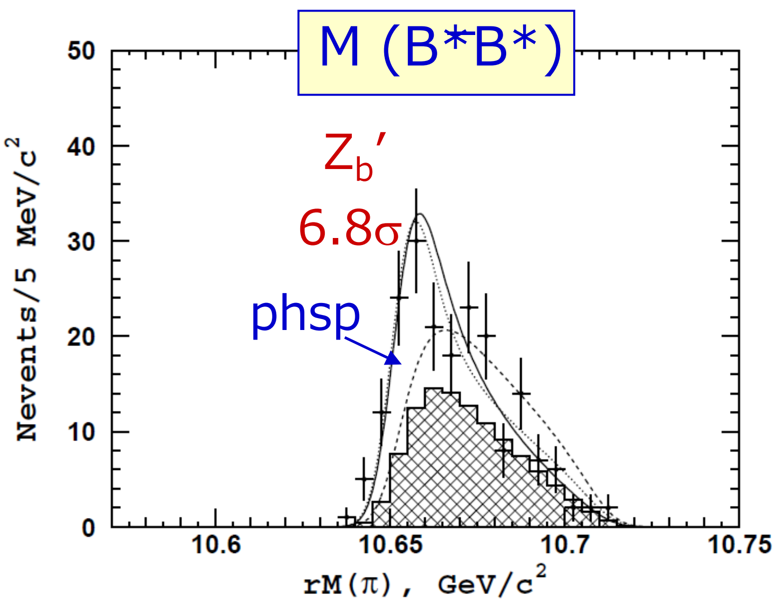


BF[$\Upsilon(5S) \rightarrow B^{(*)}B^{(*)}\pi$] preliminary $121.4\ fb^{-1}$ significance

$B\bar{B}$	<0.60 % at 90% C.L.	
$B\bar{B}^* + \bar{B}B^*$	$(4.25 \pm 0.44 \pm 0.69)$ %	9.3σ
$B^*\bar{B}^*$	$(2.12 \pm 0.29 \pm 0.36)$ %	5.7σ

Observation of $Z_b \to B\bar{B}^*$ and $Z_b' \to B^*\bar{B}^*$





$Z_b' \to B\bar{B}^*$ is suppressed w.r.t. $B^*\bar{B}^*$ despite larger PHSP

Molecule ⇒ admixture of $B\bar{B}^*$ in Z_b' is small

Assuming Z_b decays are saturated by these channels:

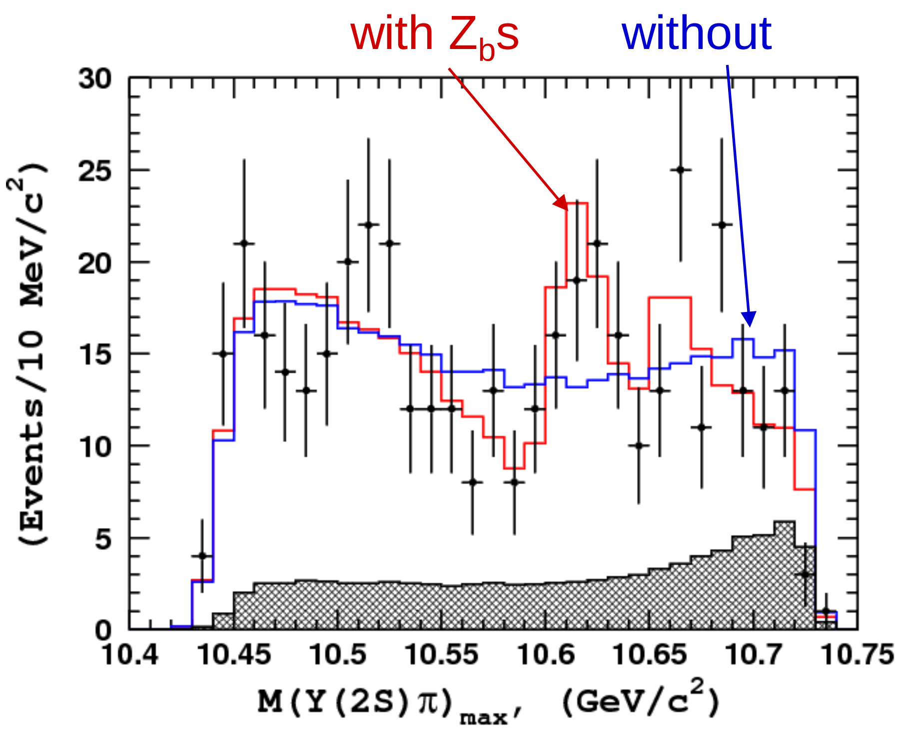
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ± 3.6	–
$B^{*+}\bar{B}^{*0}$	–	73.4 ± 7.0

arXiv:1209.6450

arXiv:1207.4345

Fit $\Upsilon(2S)\pi^0\pi^0$ structure

Dalitz plot analysis $M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$

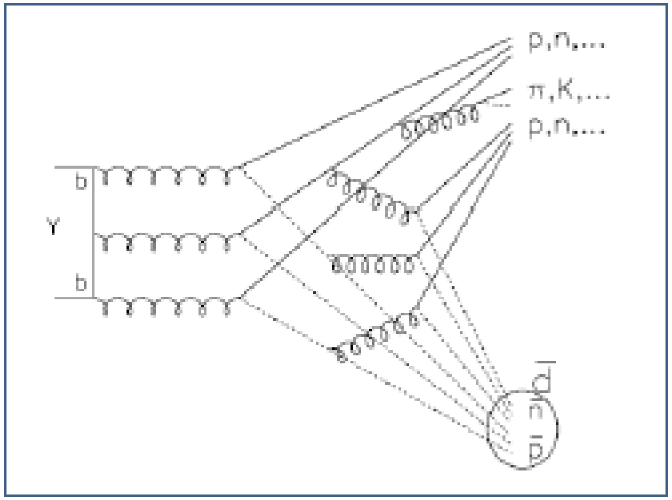


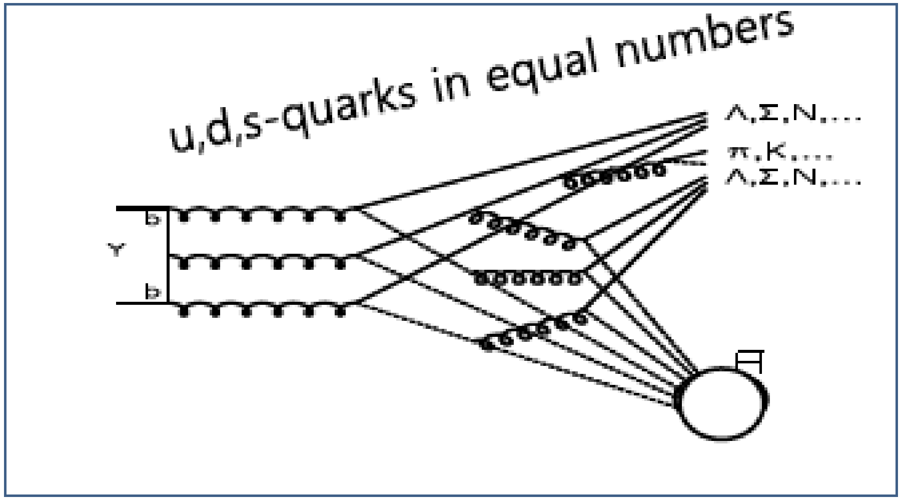
- Clear Z_b^0 signals are seen in $\Upsilon(2S)\pi^0\pi^0$
- Significance of $Z_b^0(10610)$ is 5.3σ (4.9σ with systematics)
- $Z_b^0(10650)$ is less significant (~2σ)
- Fit gives $M(Z_b^0(10610)) = 10609 \pm 8 \pm 6$ MeV

cf: $M(Z_b^+) = 10607.2 \pm 2.0$ MeV

H-Dibaryon search @ Belle

- CLEO's observation:
  Br(Υ(1S) → d + anything)=3×10^{-5} large !
- Belle has (102+158) x 10^6 Υ(1S+2S)





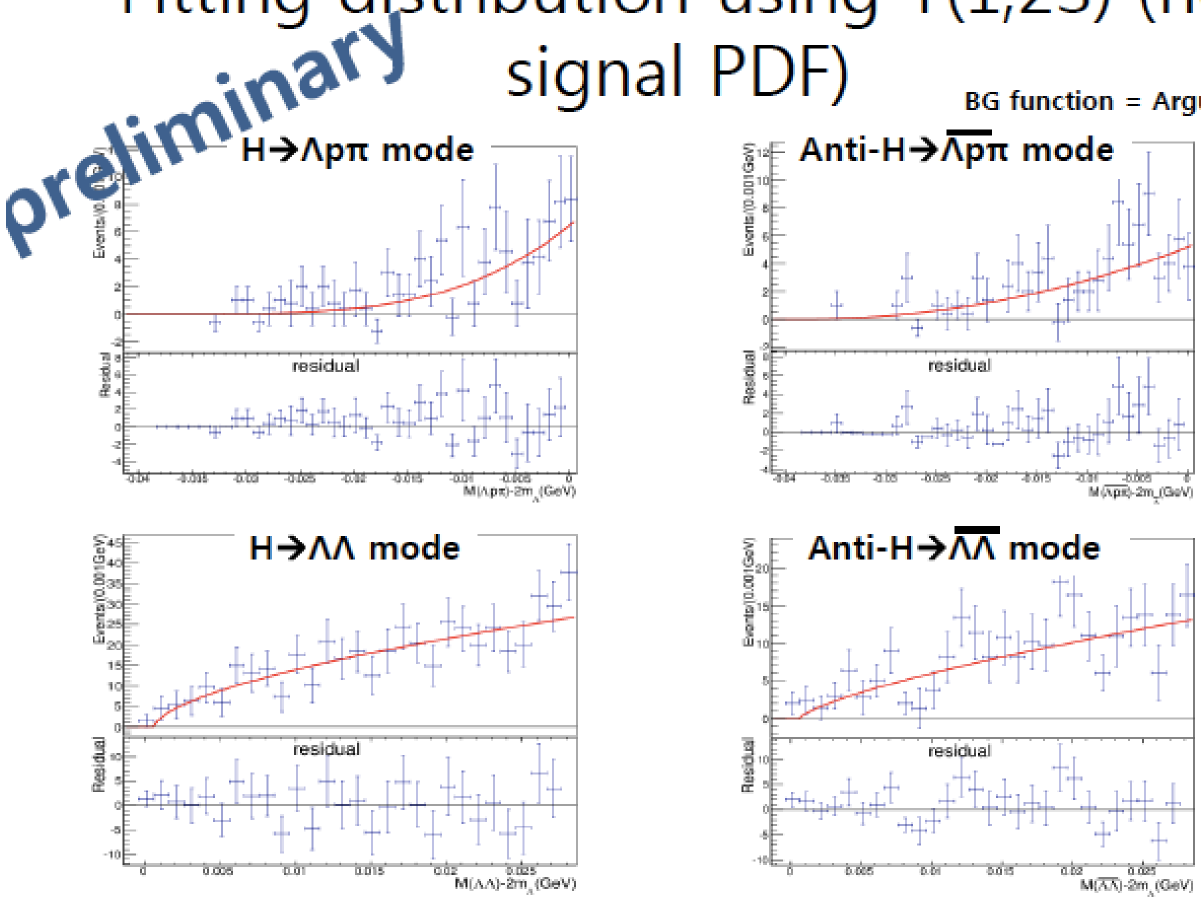
Talk by Bong Ho Kim @ Busan New Hadron WS (Nov.19-21, 2012)

http://newhadron.snu.ac.kr/New_Hadron_Workshop/Home.html

Search Results

Fitting distribution using Υ(1,2S) (no signal PDF)

BG function = Argus



Br (Υ(1S,2S) → H + X) $\lesssim 10^{-6}$ @ 90%CL.

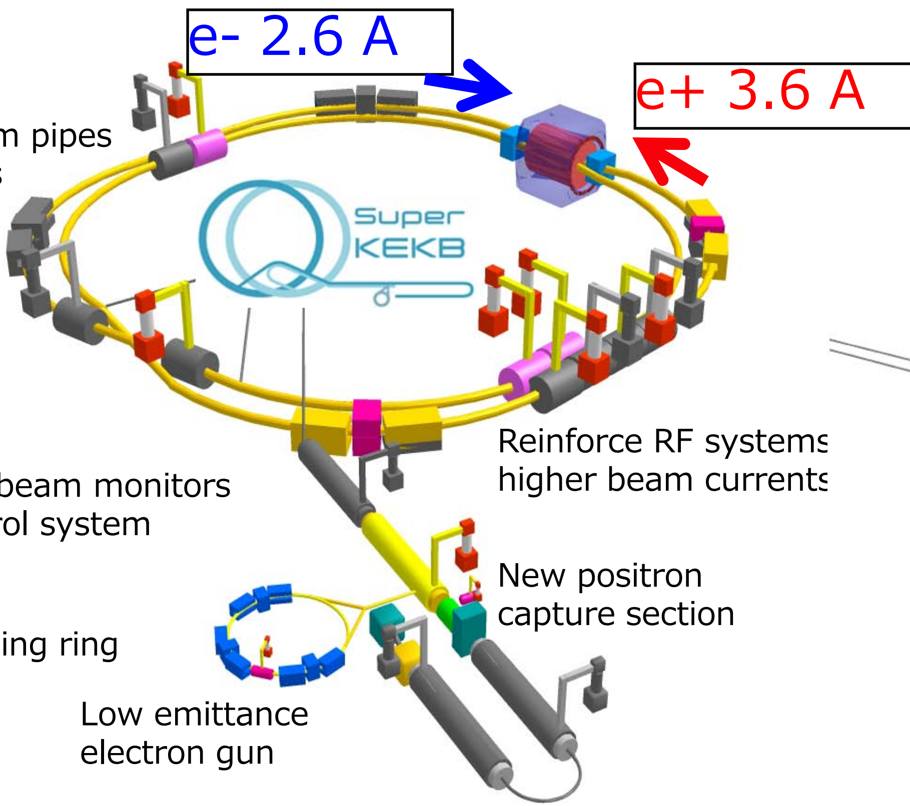
Future Prospects

SuperKEKB/Belle II

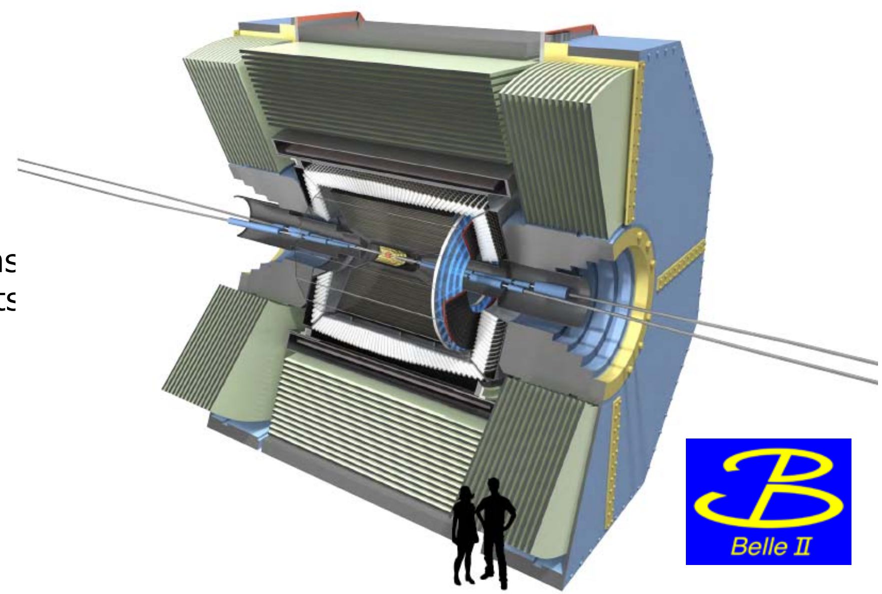
- $L_{peak} = 8 \times 10^{35} cm^{-2} s^{-1}$
  - Higher beam currents
  - Smaller beam size
- $L_{int} = 50 ab^{-1}$ (goal) → $O(10^4)$ X(3872)

Nano-beam crossing

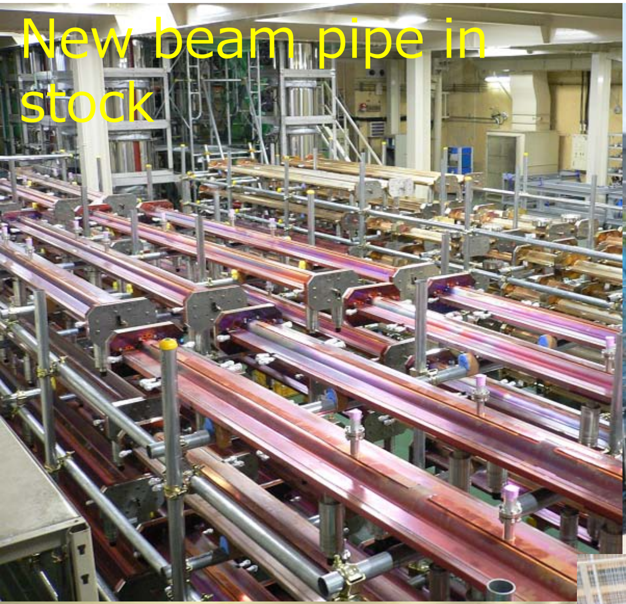
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

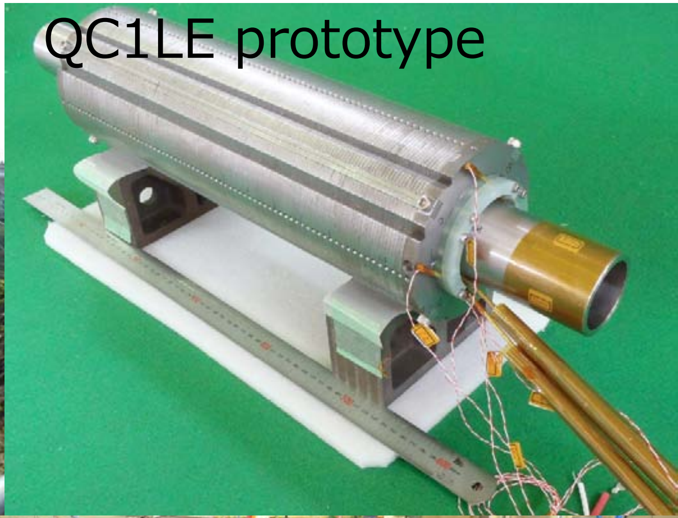


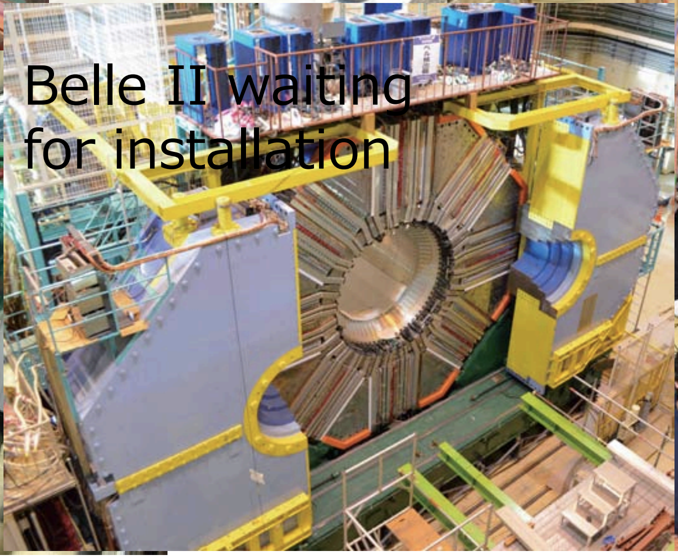
Reinforced background immunity
Improved performance
GRID-based computing

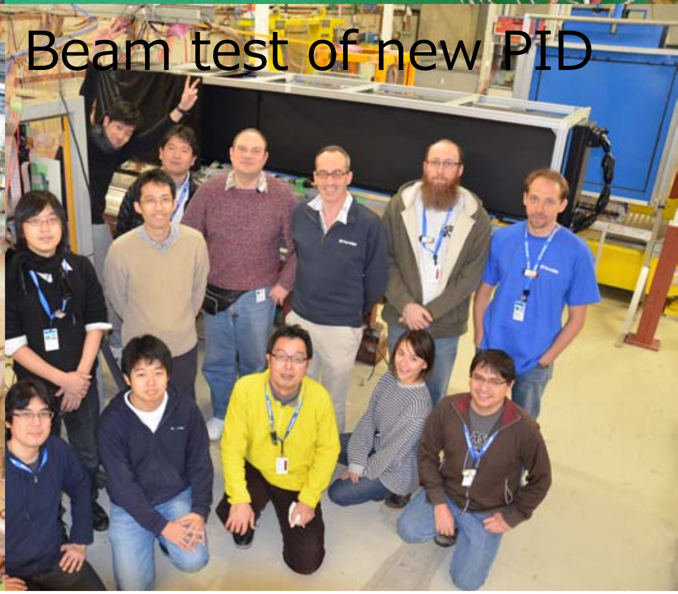


SuperKEKB / Belle II Construction









Beam commissioning: 2015-

Physics run: 2016-

Final Remarks

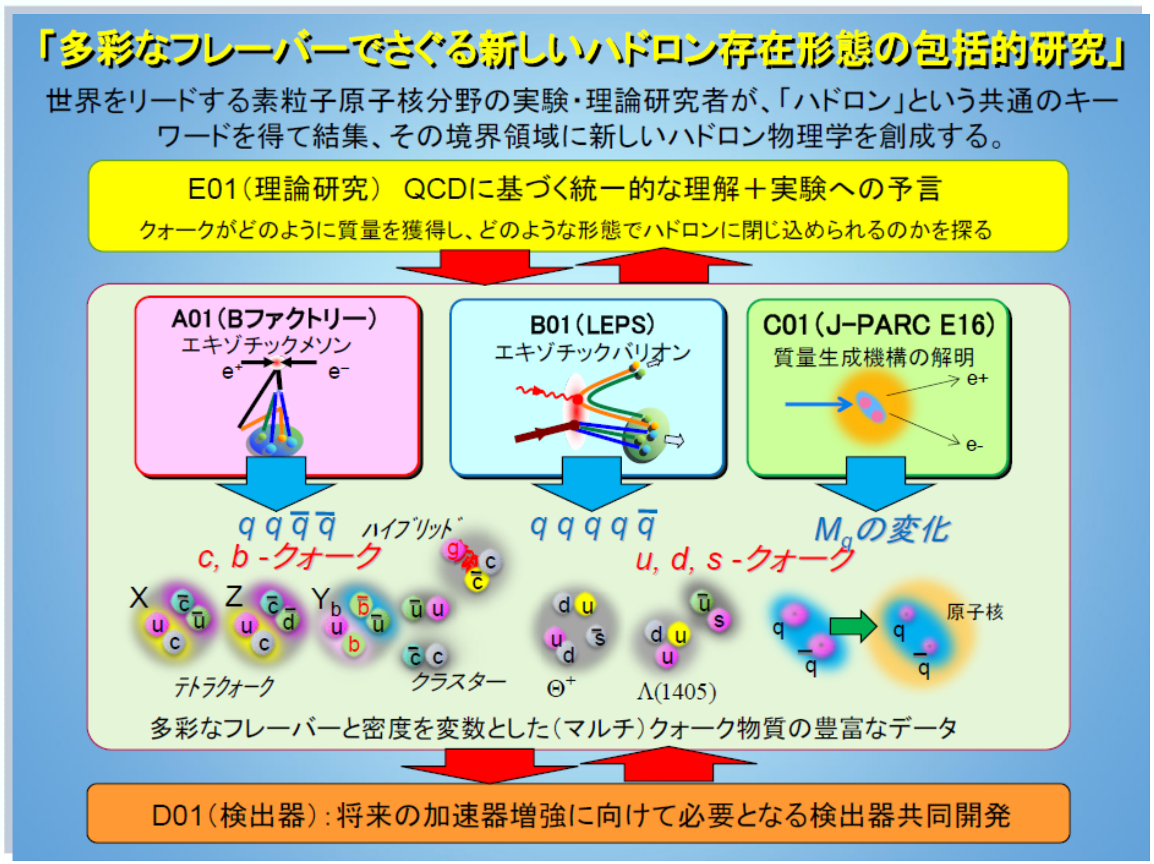
Summary of this talk

- Low energy QCD is one of the least understood area of the SM.
- High luminosity B factories have brought many discoveries of new hadronic states, especially the quarkonium-like exotics
  - Recent discoveries in bottomonium region

    (Molecular picture seem to be favored.)
- More data are expected
  - Other exotics states: H dibaryon, pentaquark (including heavy flavor), T_{cc}(ccud)⋯
  - New data from LHC, SuperKEKB, ⋯−−
- Collaboration w/ lattice QCD is essential.
- Impact on Astro-particle physics and cosmology.

“New Hadron”

Grant-in-aid for innovative scientific research area
”Elucidation of new hadrons with a variety of flavors”.



Crossover

Low energy QCD is one of the least understood part of the SM, and makes a developing interdisciplinary area.

Crossover is important

Particle Physics		Nuclear Physics
Collider	×	Fixed target
Phenomenology (Model)		Lattice QCD

Crossover workshop
新ハドロン x 素核宇宙融合 X HPCI-分野5
2011.6.23-24 @ RIKEN AICS
2012.7.12-13 @ Nagoya

Hadron 2013

(XV International Conference on Hadron Spectroscopy)

- 2013.11.4-8 in Nara (Nara Prefecture New Public Hall)
- Co-chairs:
  - Atsushi Hosaka (RCNP, Osaka)
  - Toru Iijima (Nagoya)
  - Kenkichi Miyabayashi (Nara)
- About 200 participants
- Main topics include
  - Spectroscopy of light- and heavy-quark mesons
  - Baryons
  - Quarkonia
  - Glueballs, hybrids, and multiquarks
  - Phenomenological models
  - Effective field theories
  - QCD on the lattice
  - Hadron structure
  - Hadrons in matter
  - Heavy-ion collisions
  - Future facilities

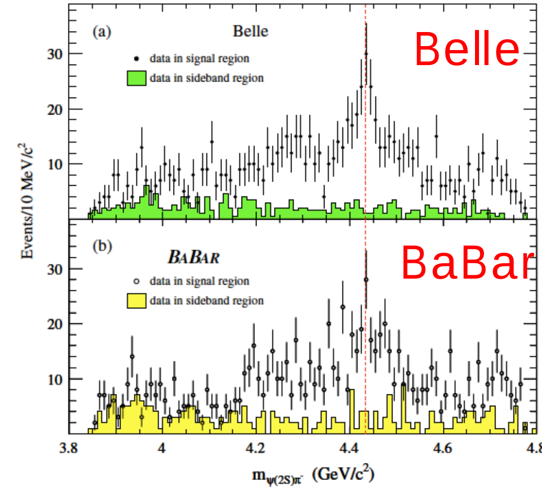
Thank you !

Backup Slides

Z^+ (cont'd)

- BaBar does not confirm Z+'s
  - $Z(4430)^+$ search in $B \to K\pi^+\psi'$
  - $Z(4050)^+/Z(4250)^+$ search in $B \to K\pi^+\chi_{c1}$
  - Excess is < 2σ w.r.t. $K\pi$ reflection.

PRD79, 112001(2009)

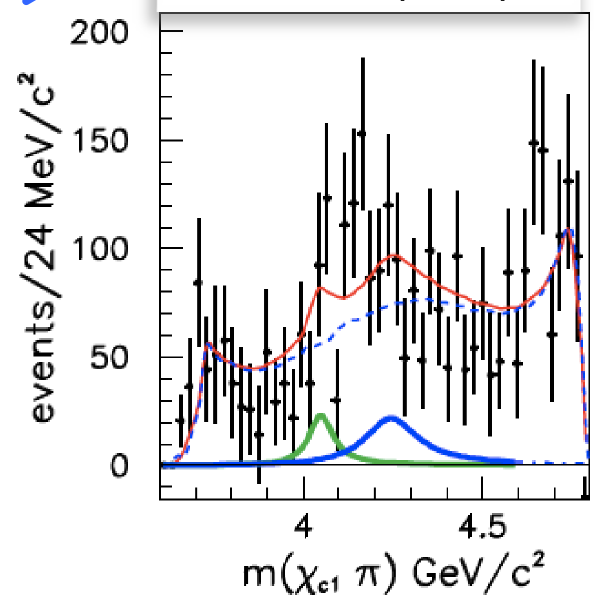


- But, do not rule out Belle's results.
  - UL is statistically compatible with Belle results

$$Br(\overline{B}^0 \to Z^+K^-) \times Br(Z^+ \to \pi^+\psi'/\chi_{c1})$$

	BaBar U.L.	Belle
$Z(4430)^+$	< 3.1 (95%CL)	$4.1 \pm 1.0 \pm 1.4$
$Z(4050)^+$	< 1.8 (90%CL)	$3.0^{+1.5}_{-0.8}{}^{+3.7}_{-1.6}$
$Z(4250)^+$	< 4.0 (90%CL)	$4.0^{+2.3}_{-0.9}{}^{+19.7}_{-0.5}$

PRD85, 052003(2012)



Note: In the BaBar analyses, Z^+ amplitudes are added Incoherently, therefore, interference effects are not included. They are included in the Belle analyses (see S.Olsen's summary talk at CHARM2012, and also backup) .

Exotics in light flavors ?

- e$^+$e$^-$ ISR :

  Y(4260) → $\pi^+ \pi^- J/\psi$; Y(4360) → $\pi^+ \pi^- \psi$□

  ➡ Y(2175) → $\pi^+ \pi^- \phi$ ($f_0\, \phi$)

  seen by BaBar, Belle, BES III

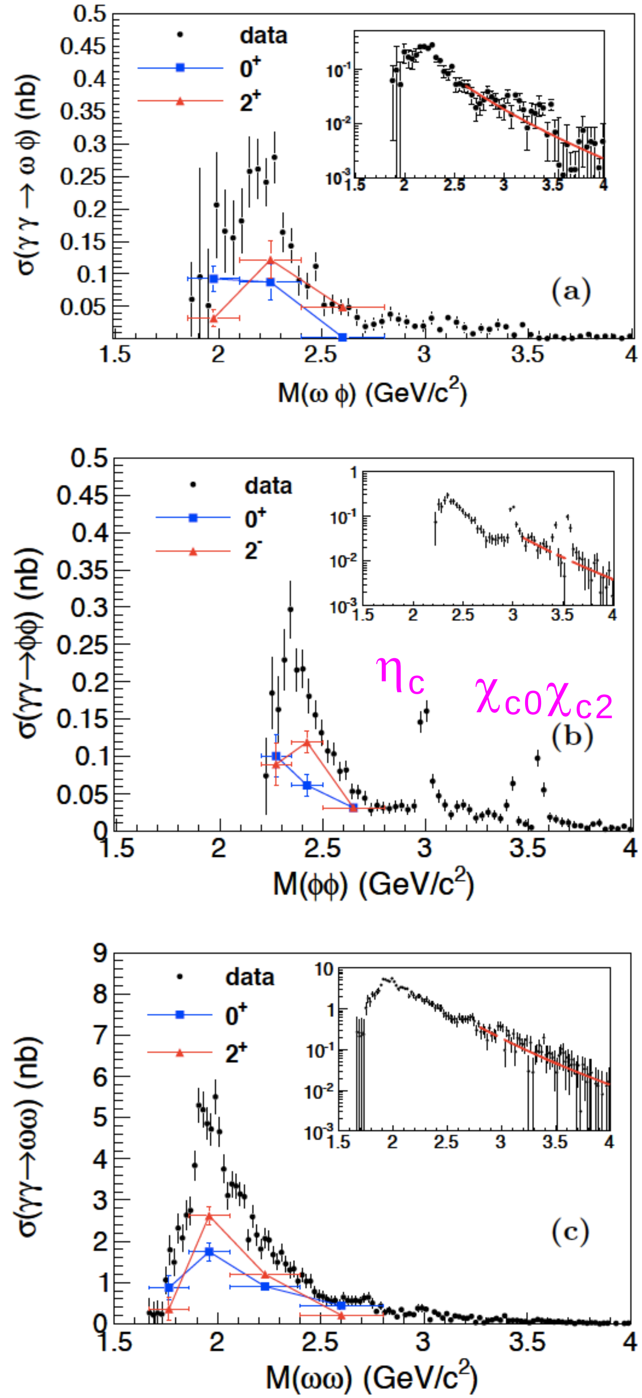
- $\gamma\gamma$ (two-photon)

  X(3915) → $\omega\, J/\psi$; X(4350) → $\phi\, J/\psi$

  ➡ What about $\omega\phi$, $\phi\phi$?

$\gamma\gamma \rightarrow VV(\omega\phi, \phi\phi, \omega\omega)$

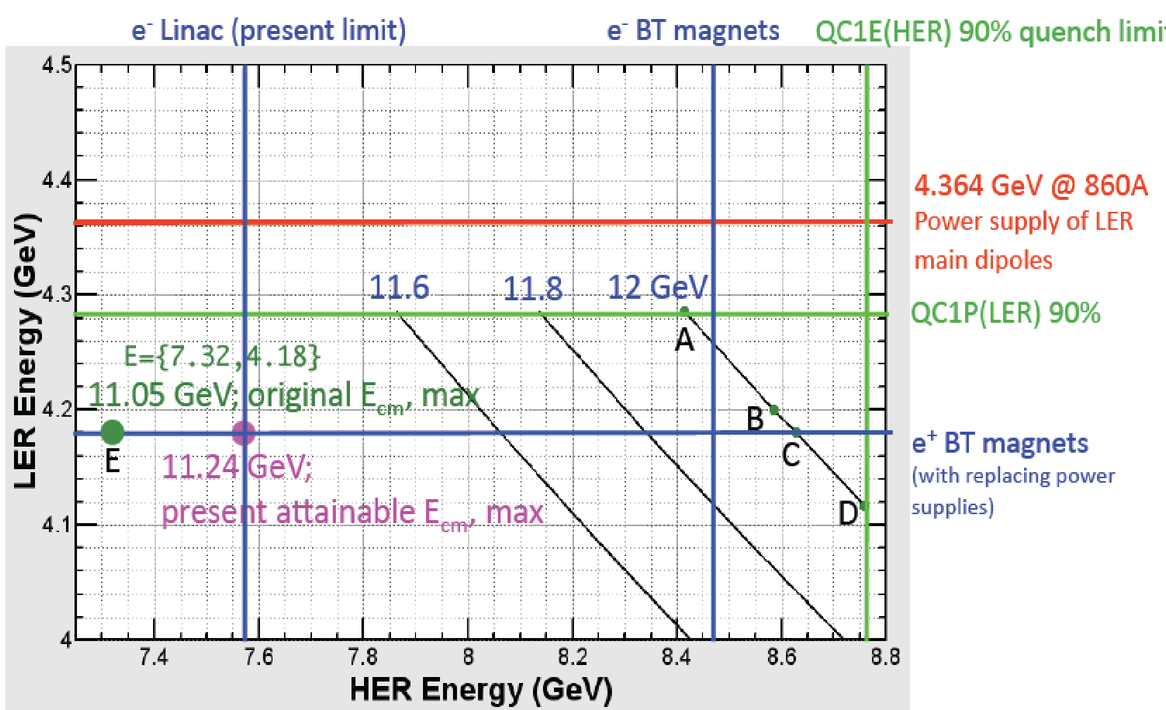
- 870 fb^{-1} near $\Upsilon(nS)[n=1,\cdots 5]$
- 4 charged tracks + π^0;
  $\phi \rightarrow K^+K^-$, $\omega \rightarrow \pi^+\pi^-\pi^0$
- Signals are extracted by fitting distribution for each M(VV) bin.
- Obvious structures in low M(VV) regior
  - J^P of the structure is extracted from angular distributions.



Phys. Rev. Lett. 108, 232001(2012)

Maximum CM energy at SuperKEKB

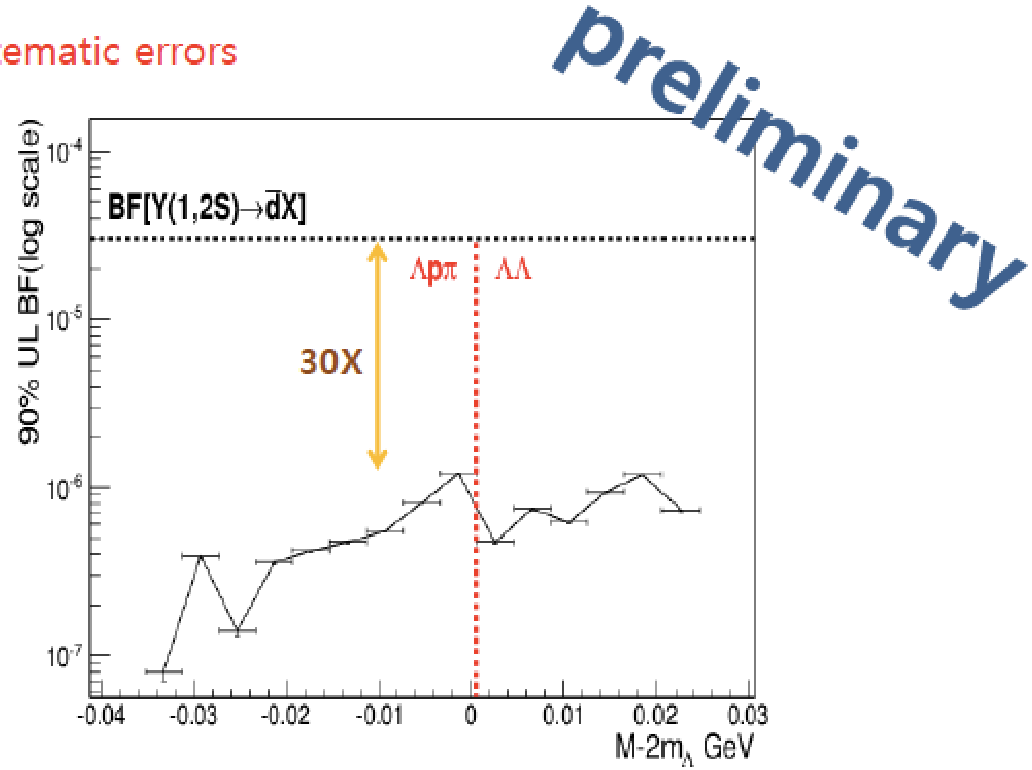
- Want $\sqrt{s} \rightarrow 12$GeV to explore bottomonium spectroscopy.
- Present attainable E_{max} = 11.24 GeV; limited by e^- linac, e^+ BT magnet, QC1E quench limit.
- Study possibility of ramping up HER→8.6 GeV, for example, by S-band linac → C-band.



Preliminary Upper Limit

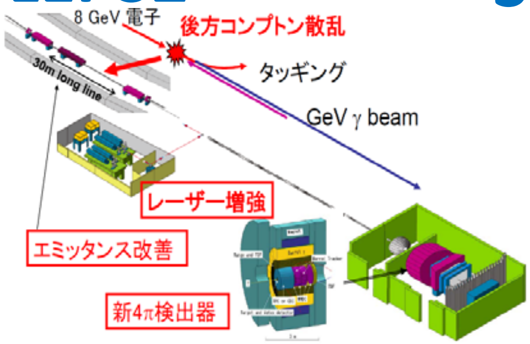
90%UL BF for H-dibaryon

UL with systematic errors

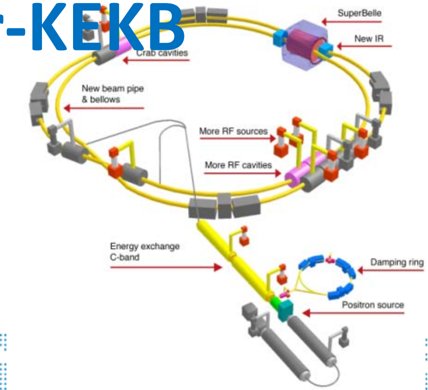


International Cooperation

LEPS2



Super-KEKB

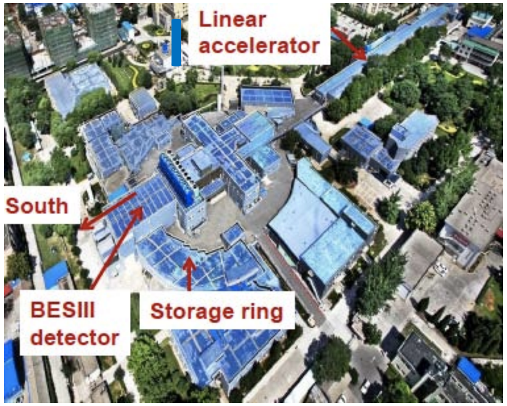


J-PARC

GSI/FAIR

LHC

BEPCII



RHIC

J-LAB