Prospects for Hadron Physics

at Belle II

Roberto Mussa – INFN Torino

Bormio 29/1/2014

Outline

N	Title	Year	Cites
1	X(3872)	2003	739
2	Large CPV	2001	618
3	$B \to X_s \gamma$	2001	381
4	CP in $B^0 \bar{B}^0$	2002	326
5	D0 mixing	2007	292
6	Y(3945)	2005	290
7	$B \to \tau\nu$	2006	277
8	$2c\bar{c}$	2002	272
9	$b \to s\gamma$	2004	265
10	$D_s^*(2317)$, $D_{s1}(2460)$	2003	258
11	D^{**}	2004	249
12	Z(4430)	2008	235
13	D_{sJ}	2006	221
14	X(3940) in $2c\bar{c}$	2007	204

Bottomonium and Charmonium spectra
Charmed+Beauty Mesons+Baryons
Charged Bottomonia

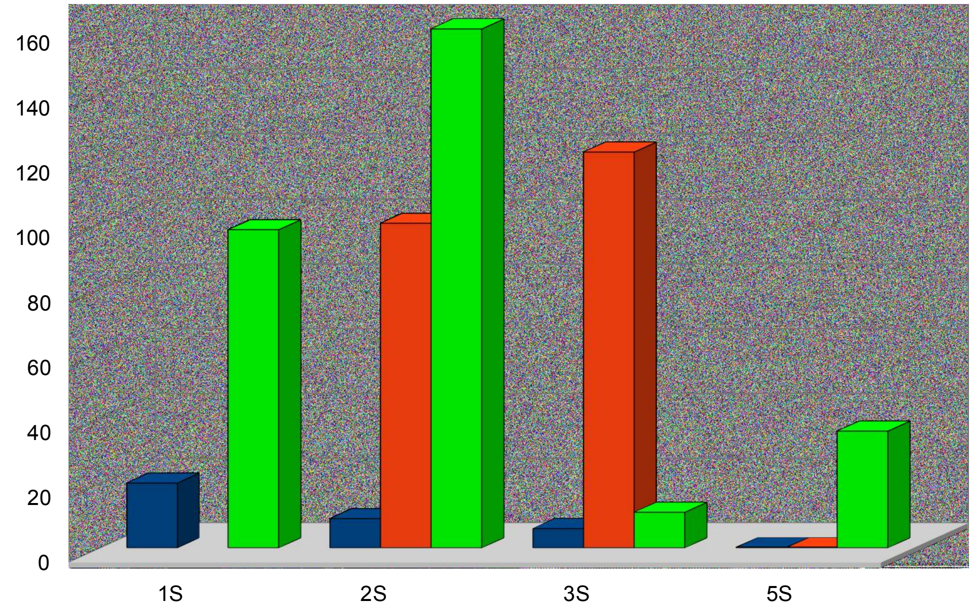
High Energy Scans at ~11 GeV
ISR scans on Charmonium region
Double Charmonium
Hyperons and Dibaryons in Upsilon decays

Belle-II @ superKEKB: collaboration, machine, detector

Data samples (units 10^6)

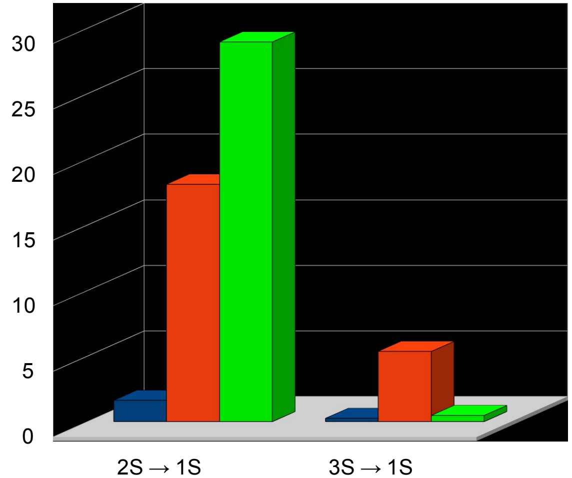
Y(nS) Peak Running
2002-3: CLEO-III 1,2,3S
2006: Belle 3,5S
2007: Belle 5S
2008: Babar 2,3S
Belle 1,2,5S
2009: Belle 2,5S

Decays on Resonance Peak



Y(2,3S) Peak Bonus:
Tagged 1S from
$\Upsilon(2,3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$

PI+PI-Tagged Decays

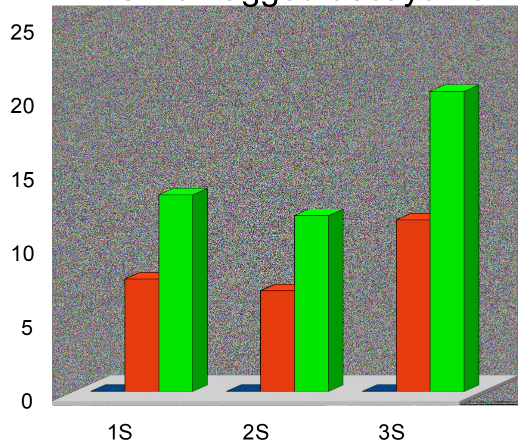


Y(4S) Peak Running

$e^+e^- \rightarrow \Upsilon(nS)\ \gamma_{ISR}$

$\sigma(1S@10580) = 19$ pb
$\sigma(2S@10580) = 17$ pb
$\sigma(3S@10580) = 29$ pb
(*) untagged γ_{ISR}

ISR untagged decays from 4S

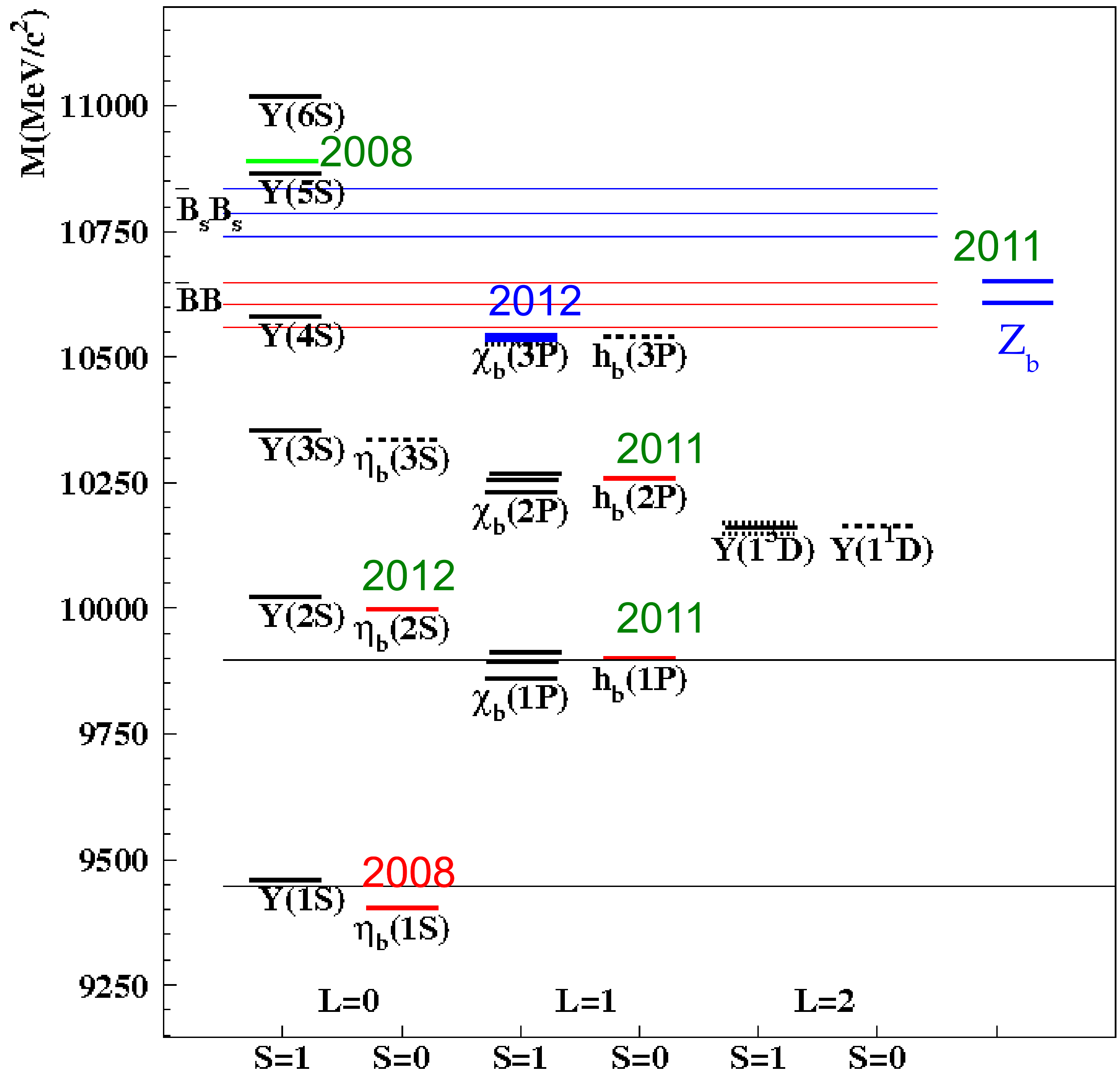


→ With 50 ab^{-1} at 4S: 0.95,0.85,1.45 G at 1,2,3S

Bottomonium 2008-12

5 amazing years for bottomonium spectroscopy:

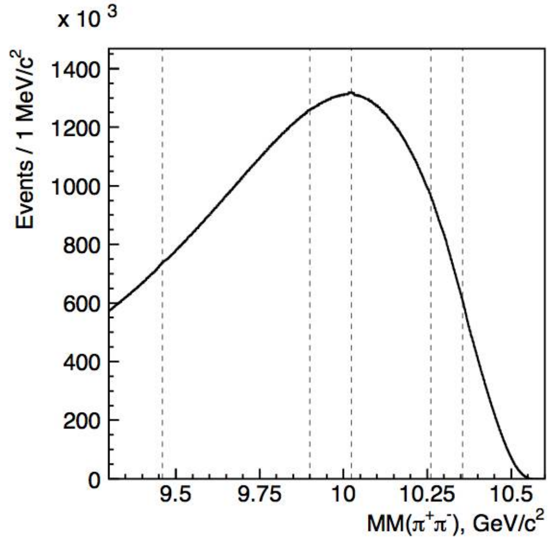
- Υ_b / Υ(5S):observation of large dipion transitions to Υ(1,2,3S) from 20 MeV above 5S peak
- Discovery of η_b(2008)
- Discovery of the triple cascade $\Upsilon_b \rightarrow Z_b \rightarrow h_b \rightarrow \eta_b$
  * 4 parabottomonia
  * 2 charged bottomonia
- Discovery (ATLAS) of χ_b(3P)

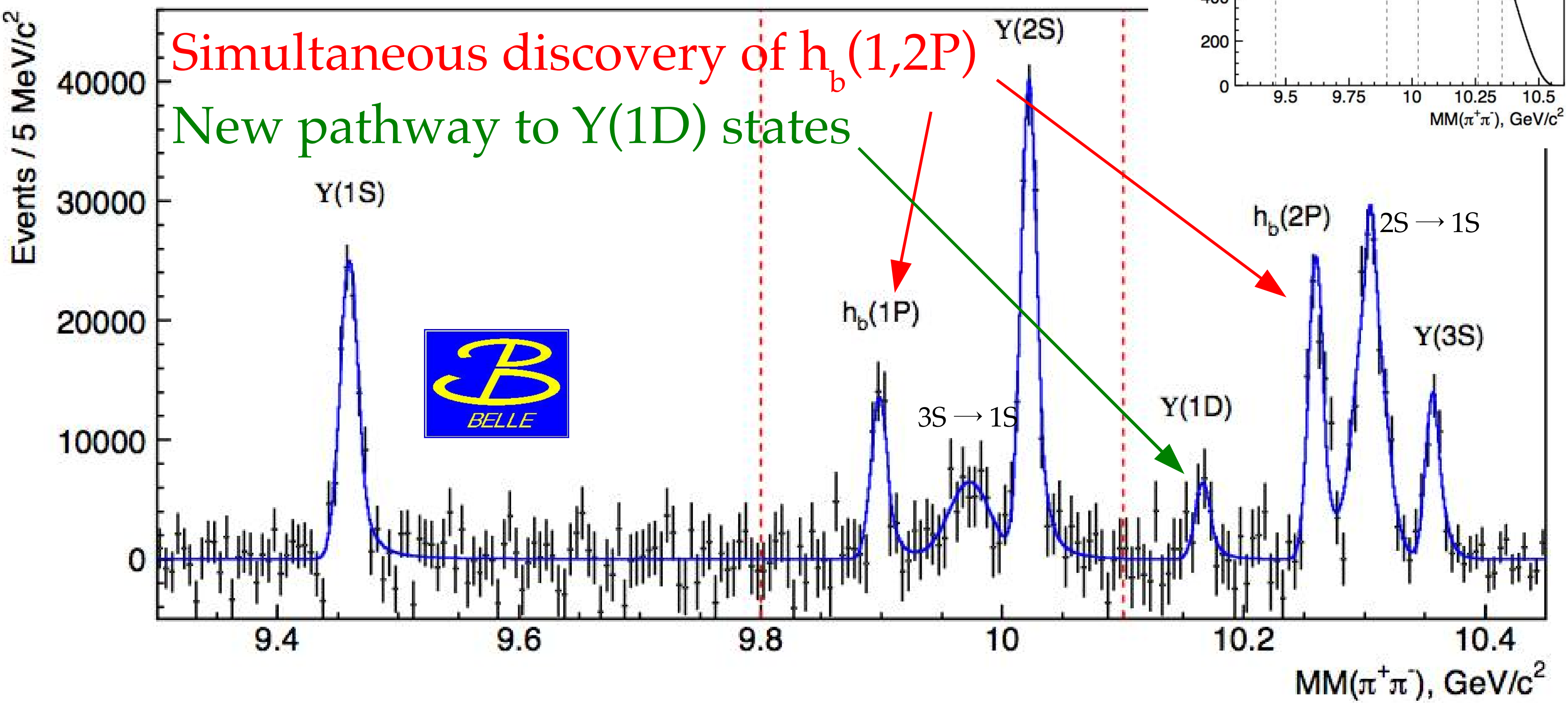


h_b(1,2P) from Υ(5S)

PRL108,032001

Inclusive search : $e^+e^- \to \Upsilon(5S) \to \pi^+\pi^- + \ldots$



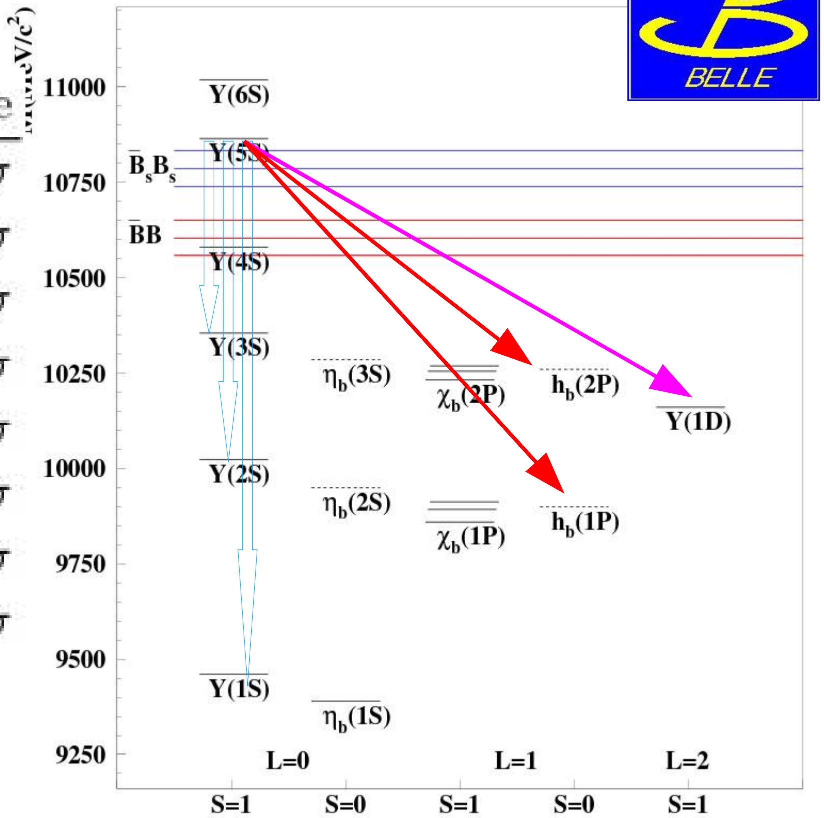


Residuals of the dipion recoil mass spectrum

h_b(1,2P) from Υ(5S)

PRL108,032001

	Yield, 10^3	Mass, MeV/c^2	Significance
$\Upsilon(1S)$	$105.2 \pm 5.8 \pm 3.0$	$9459.4 \pm 0.5 \pm 1.0$	$18.2\,\sigma$
$h_b(1P)$	$50.4 \pm 7.8^{+4.5}_{-9.1}$	$9898.3 \pm 1.1^{+1.0}_{-1.1}$	$6.2\,\sigma$
$3S \to 1S$	56 ± 19	9973.01	$2.9\,\sigma$
$\Upsilon(2S)$	$143.5 \pm 8.7 \pm 6.8$	$10022.3 \pm 0.4 \pm 1.0$	$16.6\,\sigma$
$\Upsilon(1D)$	22.0 ± 7.8	10166.2 ± 2.6	$2.4\,\sigma$
$h_b(2P)$	$84.4 \pm 6.8^{+23.}_{-10.}$	$10259.8 \pm 0.6^{+1.4}_{-1.0}$	$12.4\,\sigma$
$2S \to 1S$	$151.7 \pm 9.7^{+9.0}_{-20.}$	$10304.6 \pm 0.6 \pm 1.0$	$15.7\,\sigma$
$\Upsilon(3S)$	$45.6 \pm 5.2 \pm 5.1$	$10356.7 \pm 0.9 \pm 1.1$	$8.5\,\sigma$

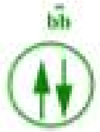


Significance after correcting for systematics effects: $h_b(1P)$ 5.5σ, $h_b(2P)$ 11.2σ

Masses very close to the COG of χ states, as expected from one gluon exchange.

$\Delta M_{HF}(1P) = 1.6 \pm 1.5$ MeV/c^2 $\quad \Delta M_{HF}(2P) = 0.5^{+1.6}_{-1.2}$ MeV/c^2

Ratio of spin flip vs noflip dipion transitions totally unexpected from theory....


spin-flip

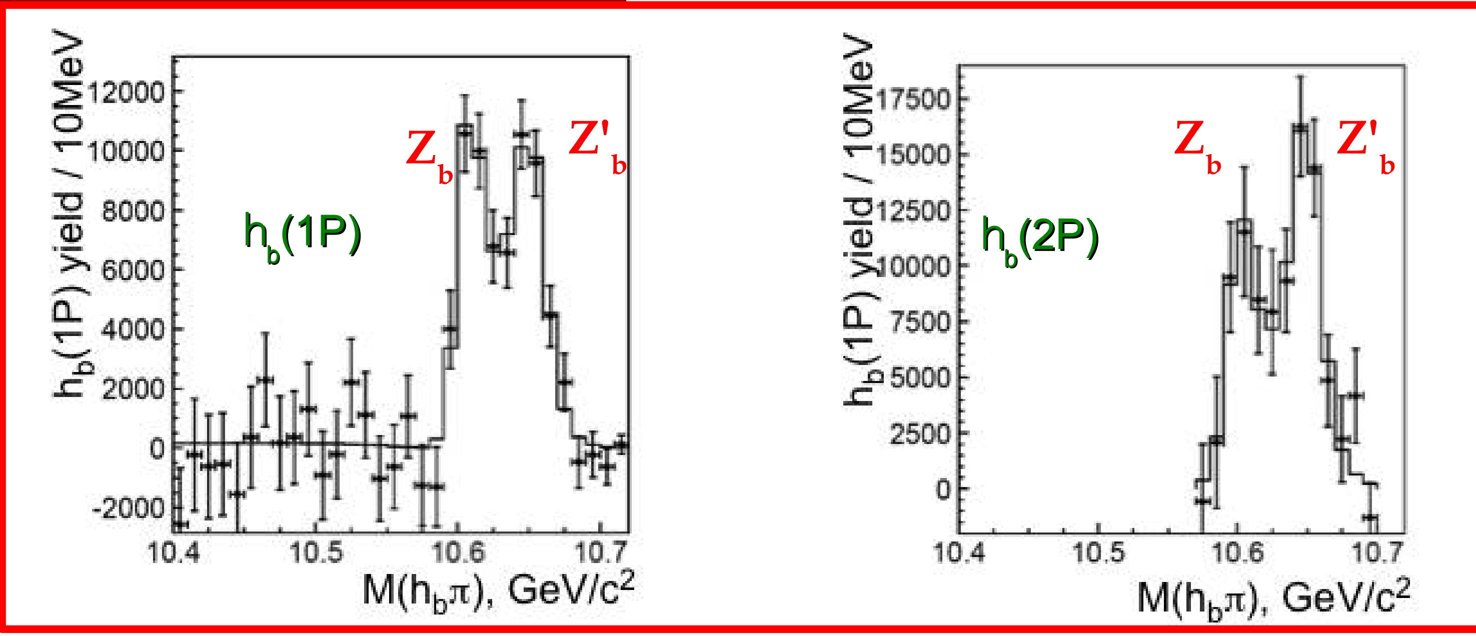
$$\frac{\Gamma[\Upsilon(5S) \to h_b(nP)\pi^+\pi^-]}{\Gamma[\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-]} = \begin{cases} 0.46 \pm 0.08^{+0.07}_{-0.12} & \text{for } h_b(1P) \\ 0.77 \pm 0.08^{+0.22}_{-0.17} & \text{for } h_b(2P) \end{cases}$$

no spin-flip

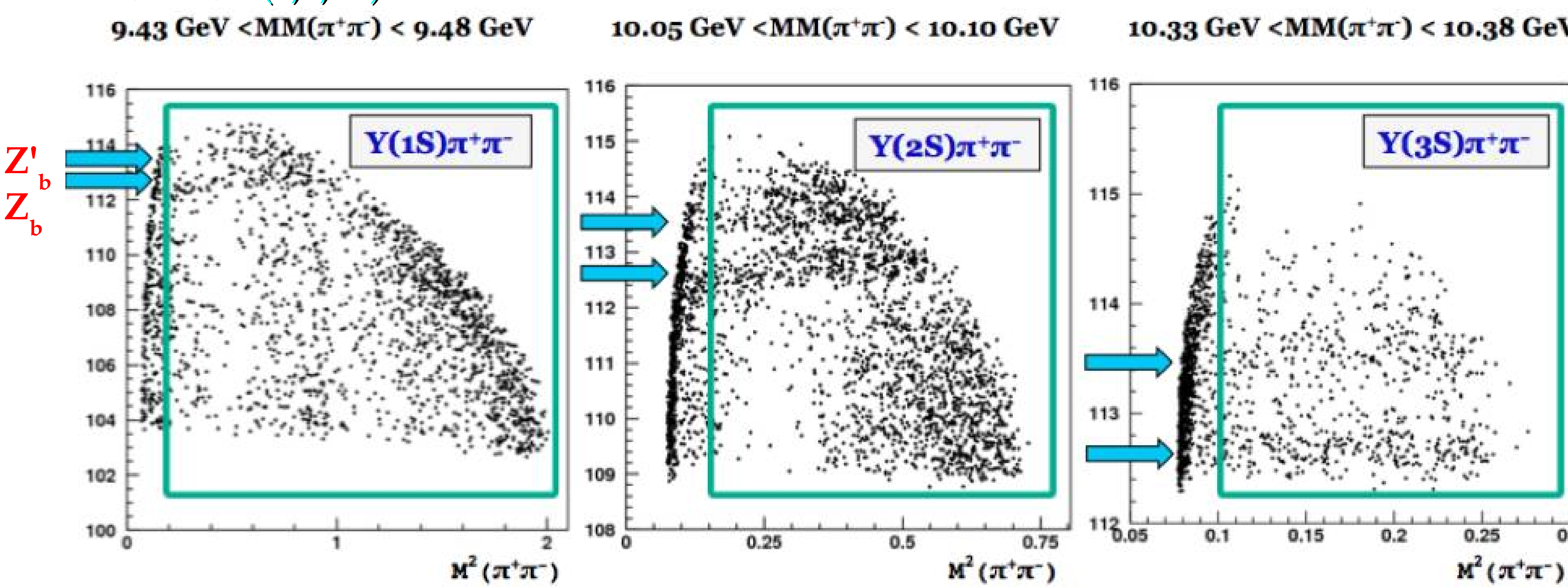
Charged Bottomonia : Z_b's

The two charged bottomonium states are observed in single pion recoil in 5 processes:

- inclusive Υ(5S) decays to h_b(1,2P)



- Dalitz plot of exclusive Υ(5S) dipion transitions to Υ(1,2,3S)

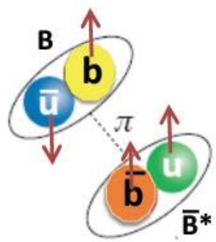


Z_b parameters

PRL108,122001(2011)

Belle discovered two charged bottomonium-like resonances:

Z(10610)

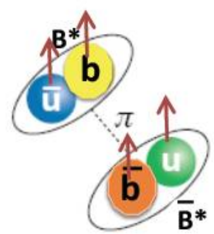


M=10607.2±2.0 MeV

Γ=18.4±2.4 MeV

$M_B + M_{B^*} = 10604.5 \pm 0.6$ MeV

Z(10650)

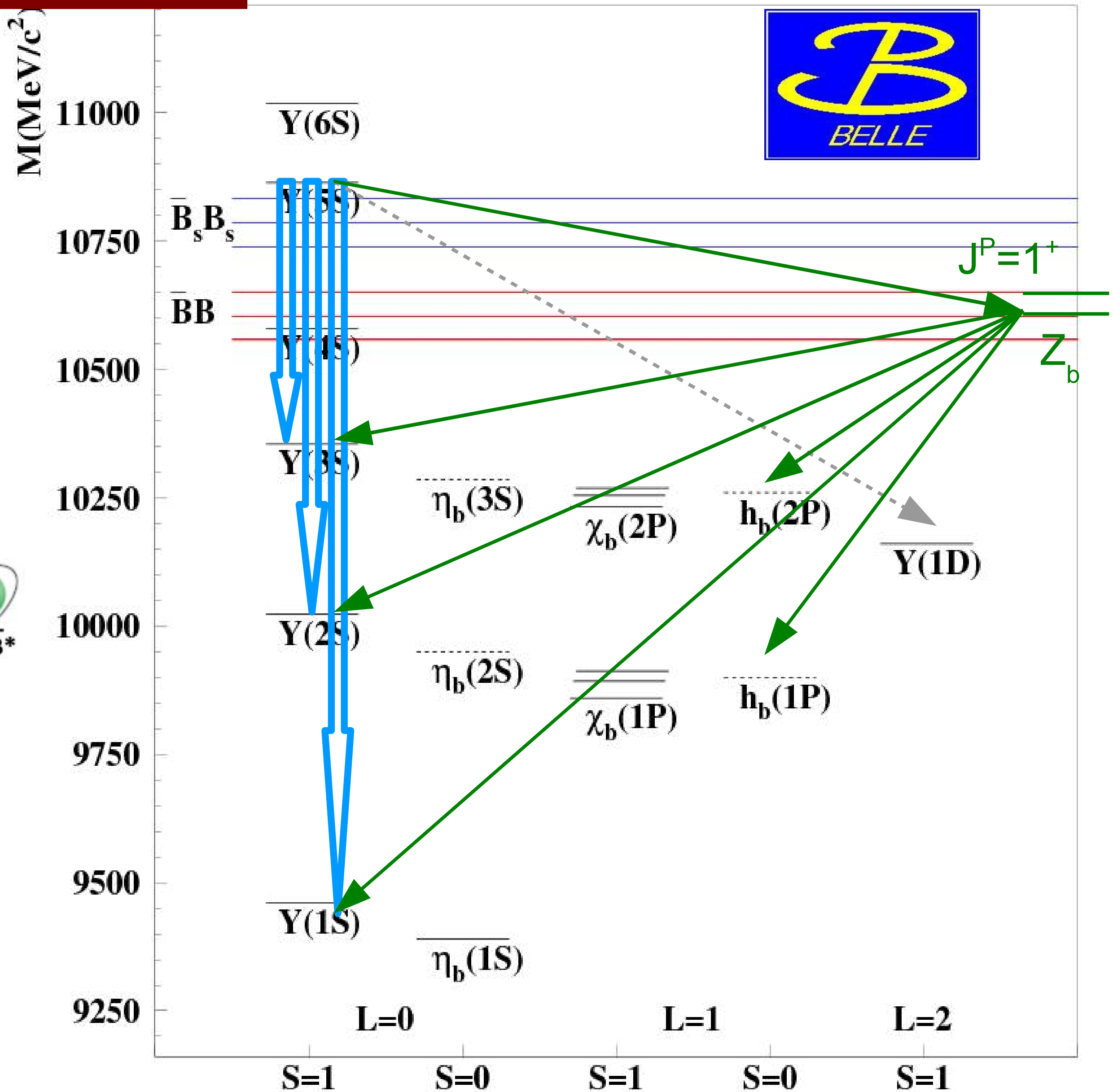


M=10652.2±1.5 MeV

Γ=11.5±2.2 MeV

$M_{B^*} + M_{B^*} = 10650.2 \pm 1.0$ MeV

Analysis of angular distributions suggests $J^P=1^+$ for both these states. Observation of Zb decays to BB* and B*B* is consistent with molecular nature of the charged bottomonia. (Voloshin, Bondar, et al)



ArXiV:1207.4345:

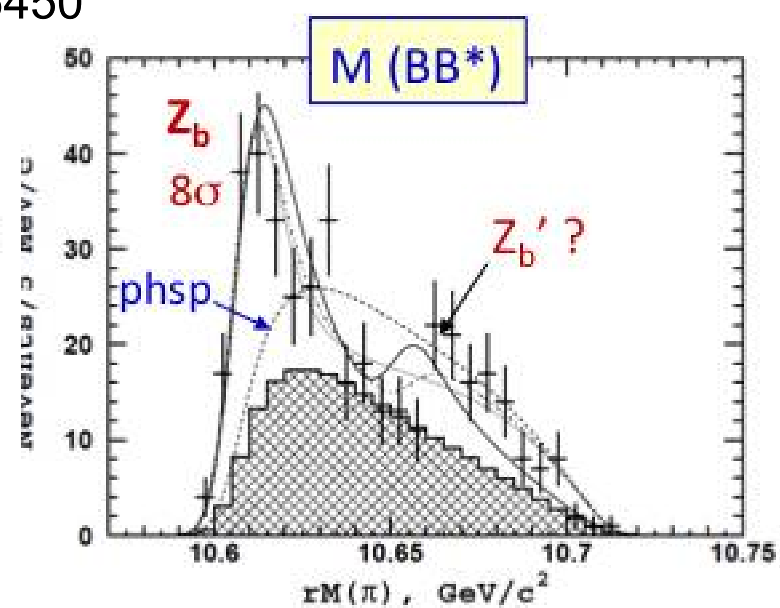
Evidence of neutral partner of lower Zb in $\Upsilon\pi^0$ with 4.9 sigma significance

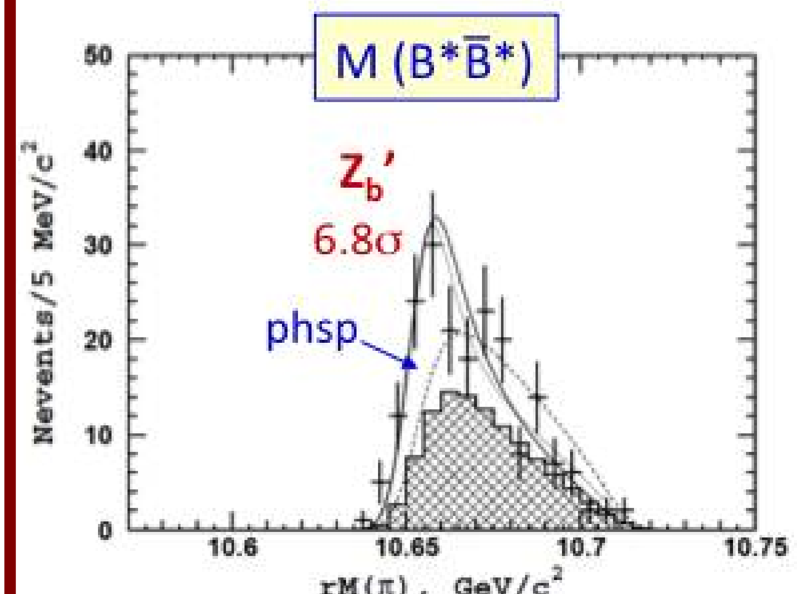
$Z_b \to \overline{B}B^*+B\overline{B^*}, B^*\overline{B^*}$

ArXiV:1209.6450

BF[$\Upsilon(5S) \to B^{(*)}\overline{B}^{(*)}\pi$]	preliminary Belle 121.4 fb^{-1}	significance
$B\overline{B}$	<0.60 % at 90% C.L.	
$B\overline{B}^* + B\overline{B}^*$	(4.25 ± 0.44 ± 0.69) %	9.3σ
$B^*\overline{B}^*$	(2.12 ± 0.29 ± 0.36) %	5.7σ

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





Belle-II: future prospects

Neutral partners of Zb states
proposed by Bondar et al.

arXiv:1105.5829

$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} - \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

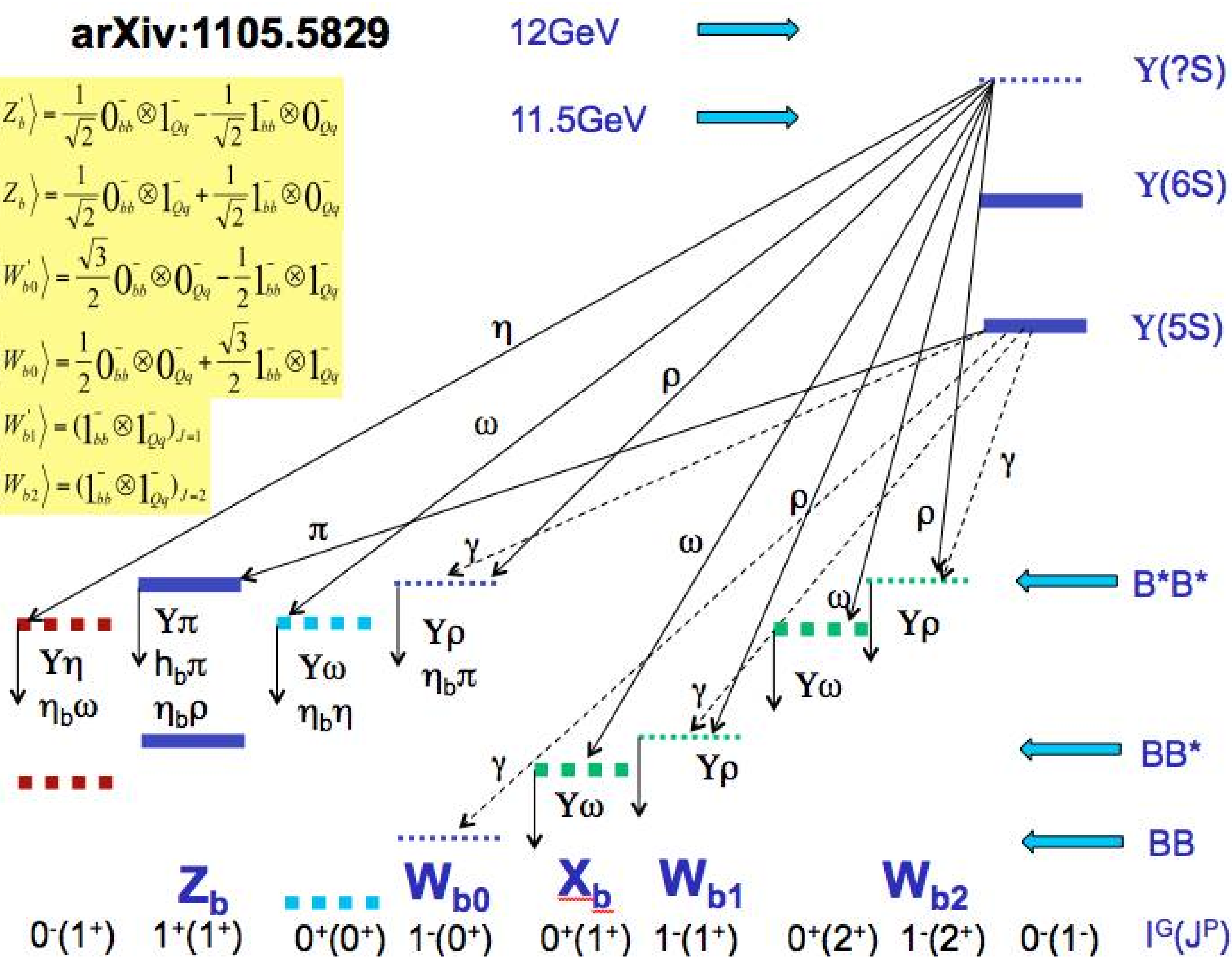
$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} + \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

$$|W_{b0}'\rangle = \frac{\sqrt{3}}{2} 0^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}} - \frac{1}{2} 1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}}$$

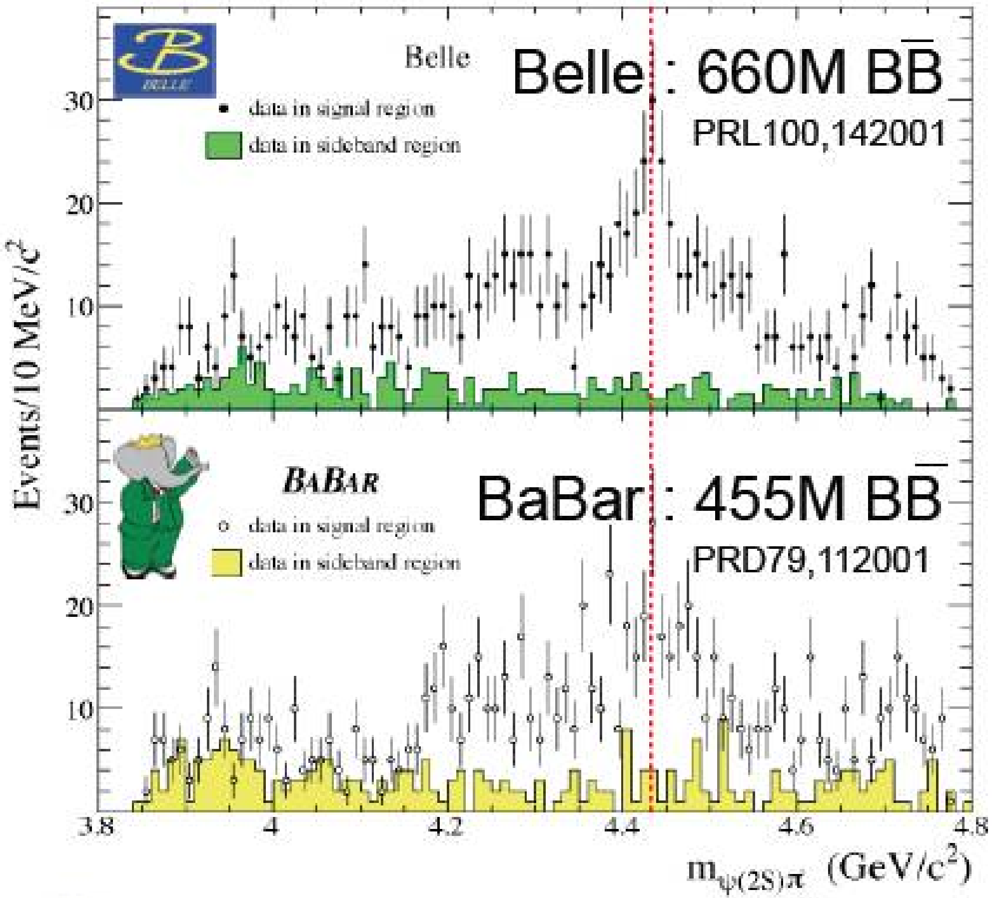
$$|W_{b0}\rangle = \frac{1}{2} 0^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}} + \frac{\sqrt{3}}{2} 1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}}$$

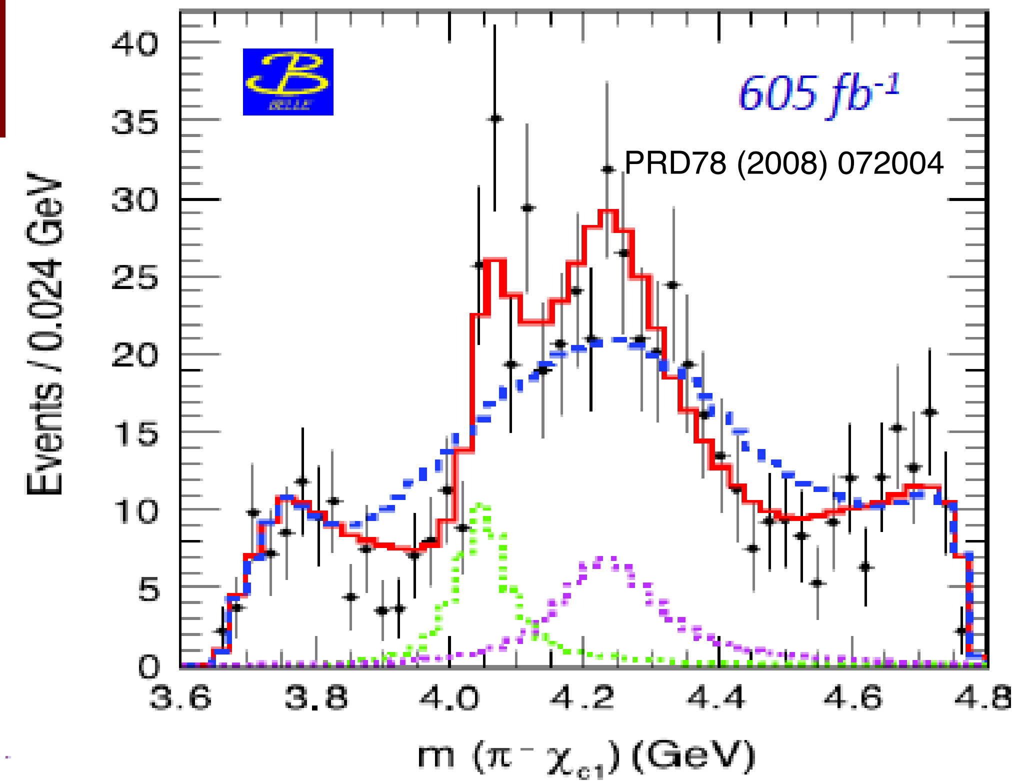
$$|W_{b1}'\rangle = (1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}})_{J=1}$$

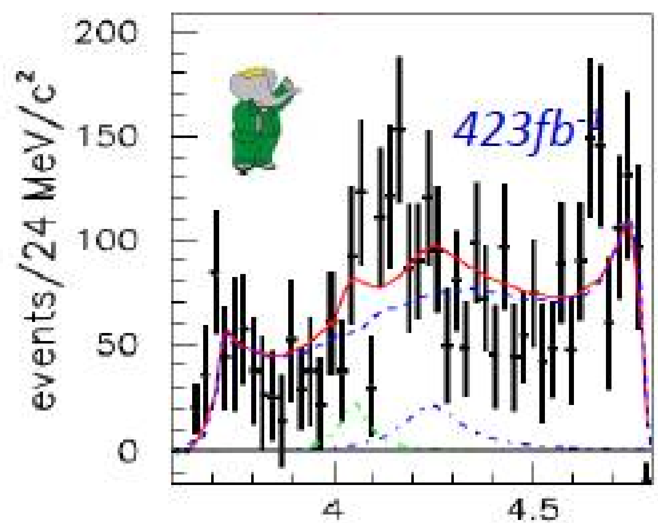
$$|W_{b2}\rangle = (1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}})_{J=2}$$

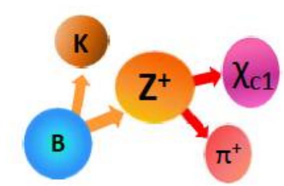


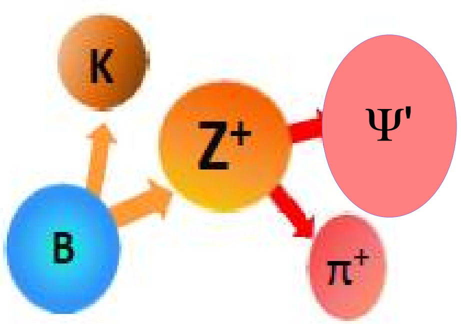
Open questions: B → K Z_c











Belle observed 3 charged peaks in B decays to charmonium + K

cc=Ψ' > Zc(4430)

cc=χ_{c1} > Zc(4050,4250)

Never confirmed by Babar

LHCb will have the final word?

Open questions: X(3872) → γ (J/ψ , ψ ')

Babar [*PRL 102 (2009), 132001*]:

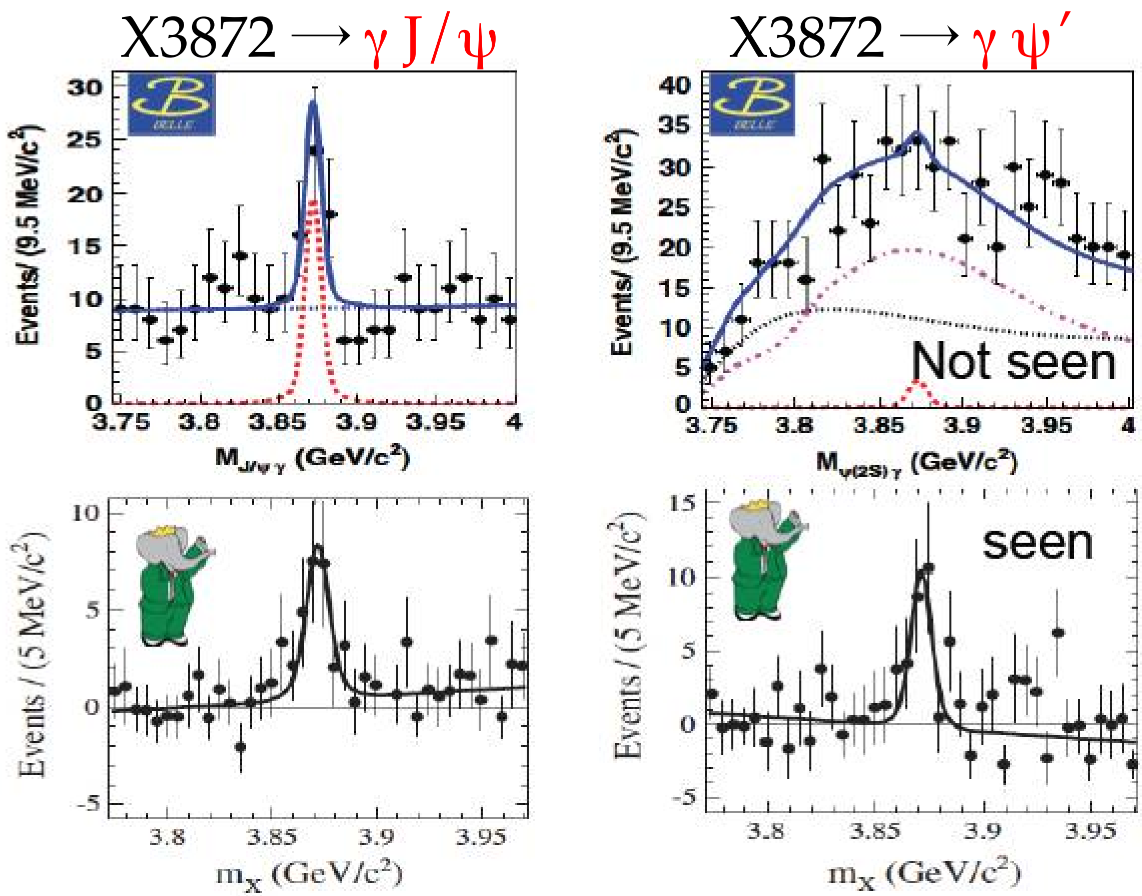
evidence of radiative decay to both J/ψ and ψ' :

$$\frac{BR(X3872 \to \gamma\, \psi')}{BR(X3872 \to \gamma\, J/\psi)} = 3.4 \pm 1.4$$

- disfavors the molecular model,
- favors $J^{PC}=1^{++}$
- disfavors $J^{PC}= 2^{-+}$

Belle [*PRL 102 (2009), 132001*]:

confirms radiative decay to J/ψ but not to ψ'

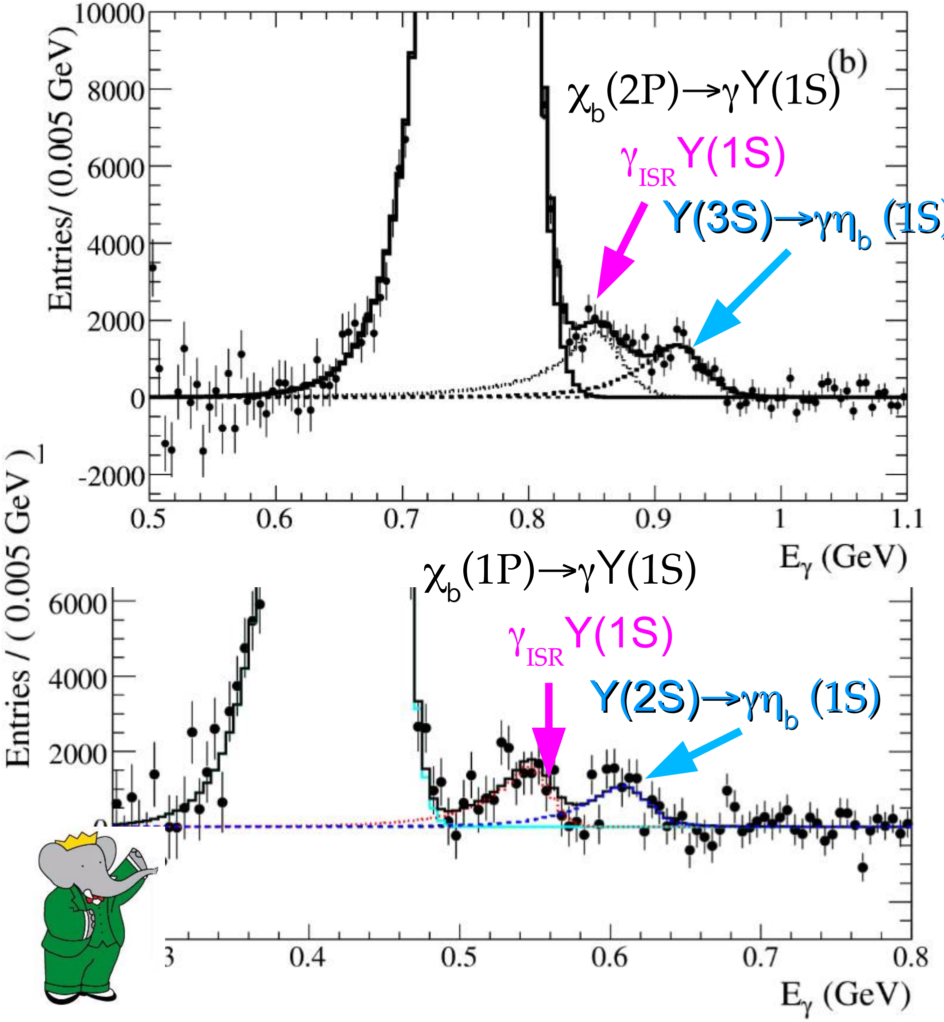


Statistically limited: challenge for Belle-II

Maybe possible at BES-III (poster by S.Braun) or LHCb

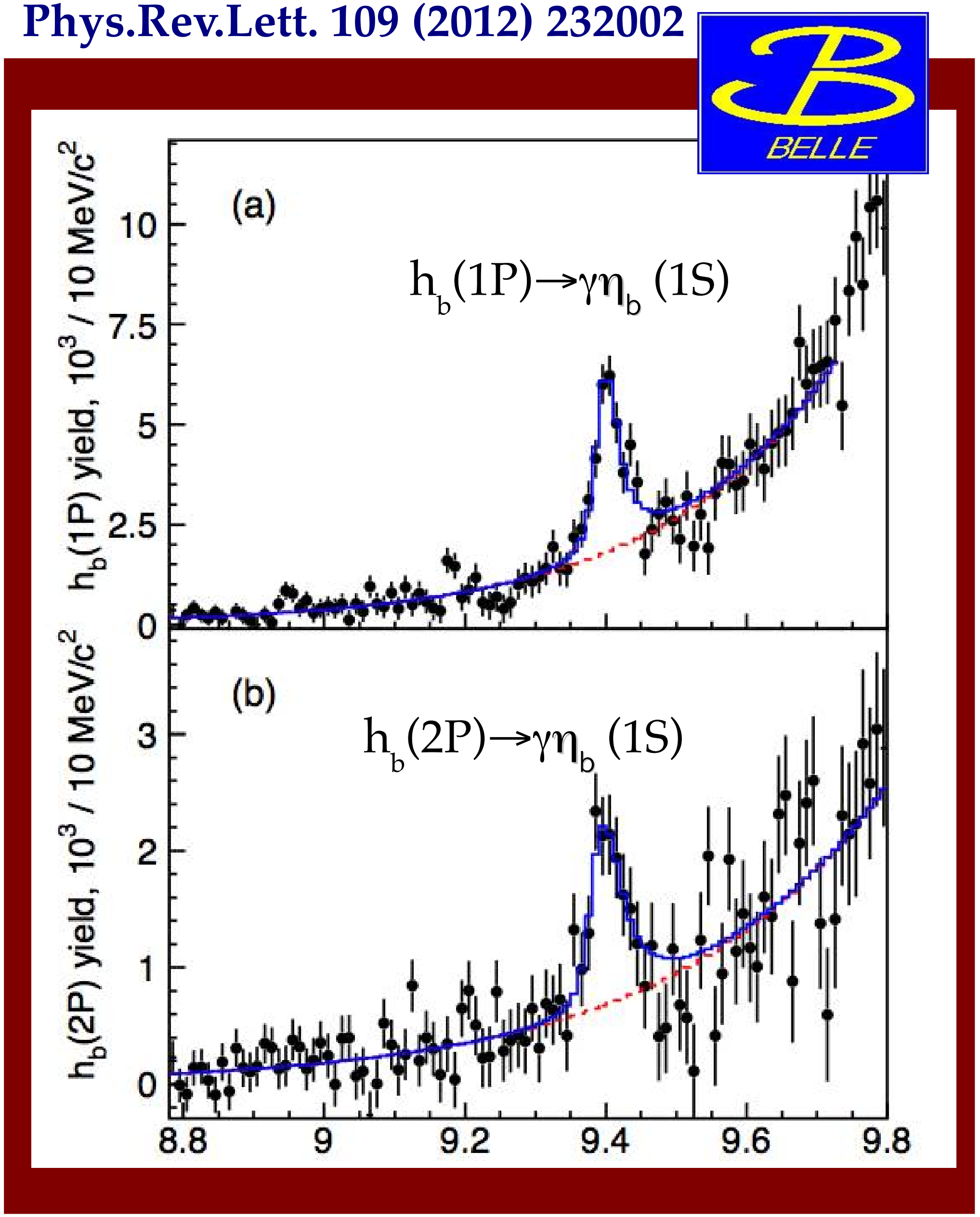
Rediscovery of η_b

Babar 2008:



PRL 101,071801(2008)
PRL 103,161801(2009)

Phys.Rev.Lett. 109 (2012) 232002



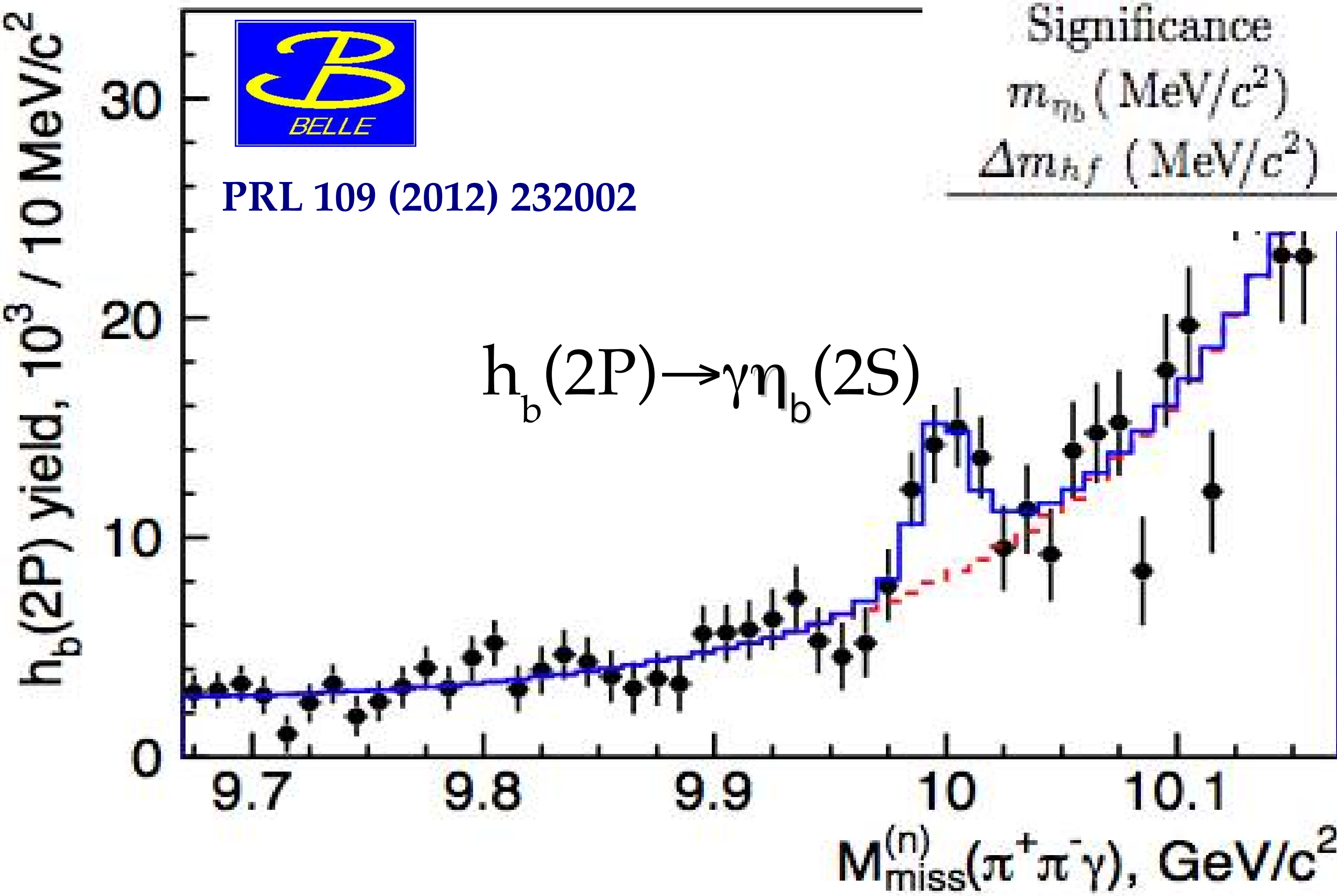
Sideband subtracted spectrum of $\pi\pi\gamma$ recoil at the h_b peaks.

Discovery of $\eta_b(2S)$

$Ldt = 121.4\ fb^{-1}(5S) + 12\ fb^{-1}$ (scan)

Transition	$h_b(2P) \to \eta_b(2S)$
Yield $\times 10^{-3}$	25.8 ± 4.9
BR $\times 10^{2}$	$49.2 \pm 5.7^{+5.6}_{-3.3}$
Significance	4.2σ
m_{η_b} (MeV/c^2)	$9999.0 \pm 3.5^{+2.8}_{-1.9}$
Δm_{hf} (MeV/c^2)	$24.3^{+4.0}_{-4.5}$

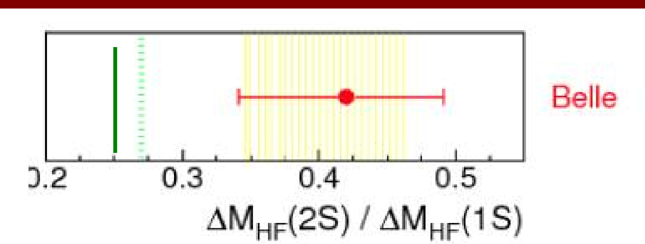
PRL 109 (2012) 232002



Sideband subtracted spectrum of $\pi\pi\gamma$ recoil at the h_b (2P) peak.

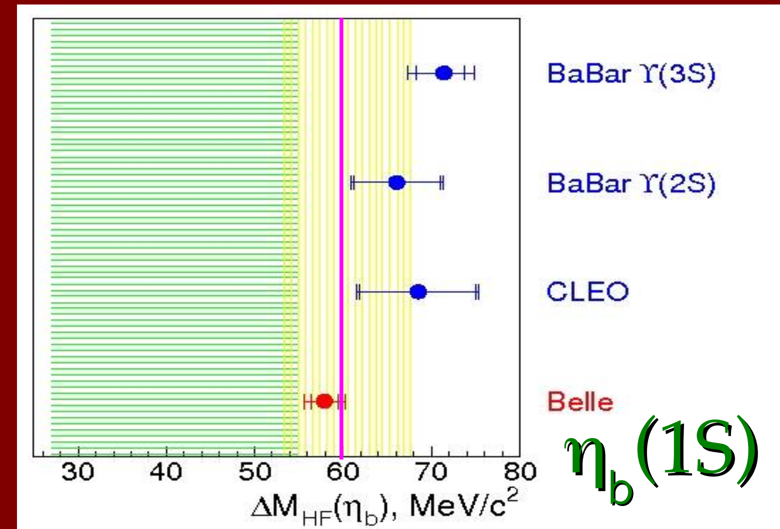
Parabottomonia vs theory

$\eta_b(2S)$ vs $\eta_b(1S)$



- PNRQCD@NLL PRL92,242001(2004)
- Lattice QCD PRD82,114502(2010)
- Godfrey-Isgur, PRD32,189 (1985)

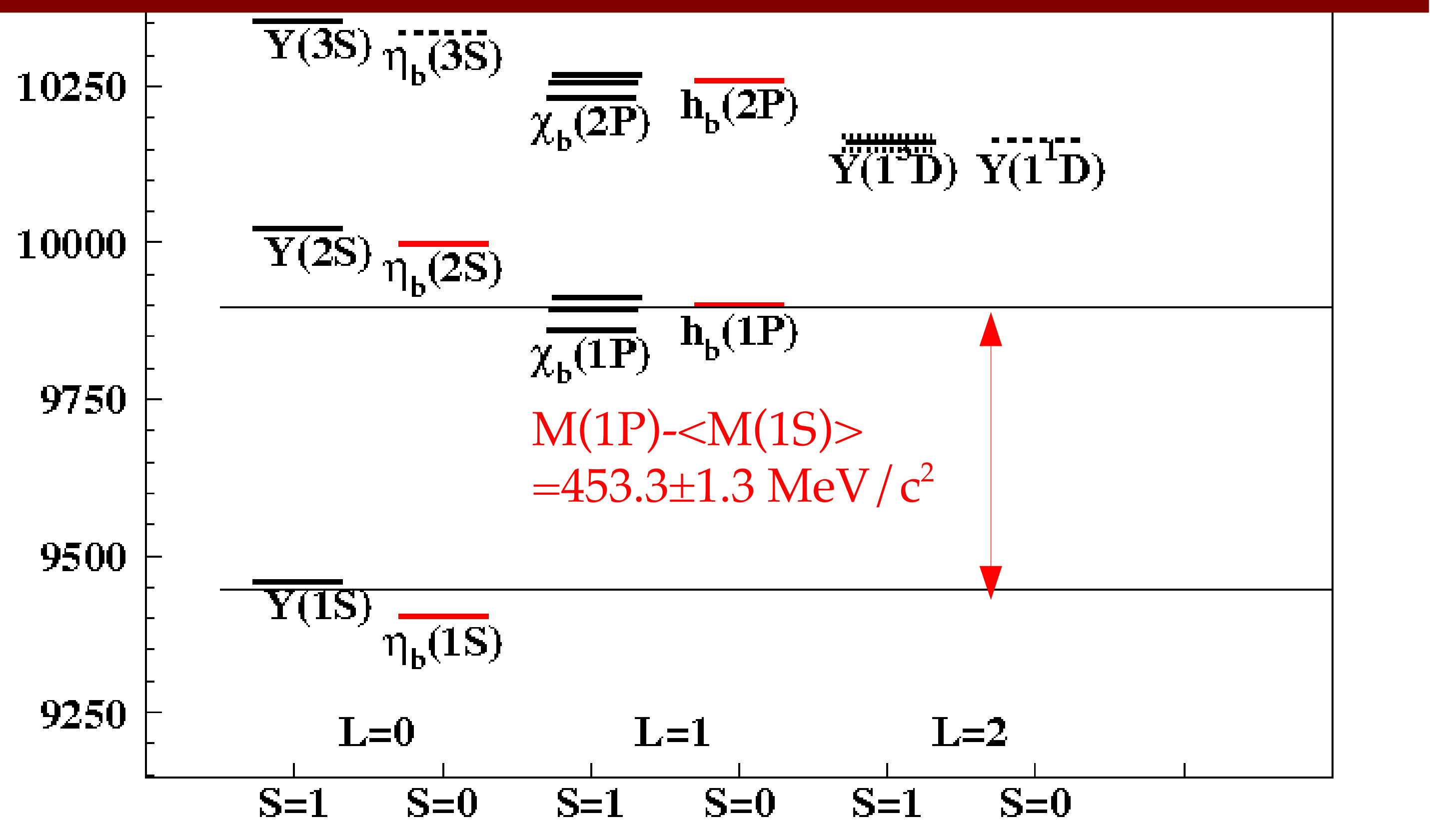
10 MeV discrepancy w/ earlier Babar and CLEO results



$\eta_b(1S)$

Some tension with the most accurate NRQCD prediction , but very close to lattice QCD (Meinel) predictions.

Spin averaged 1P-1S splitting seems not to depend on scale



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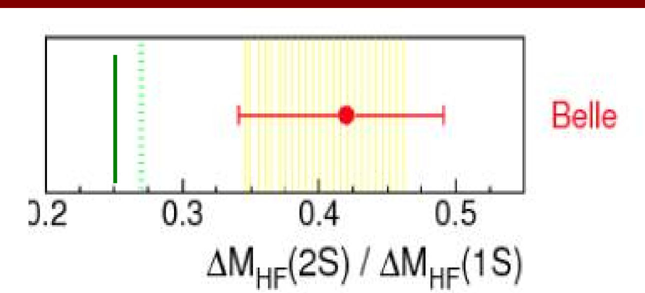

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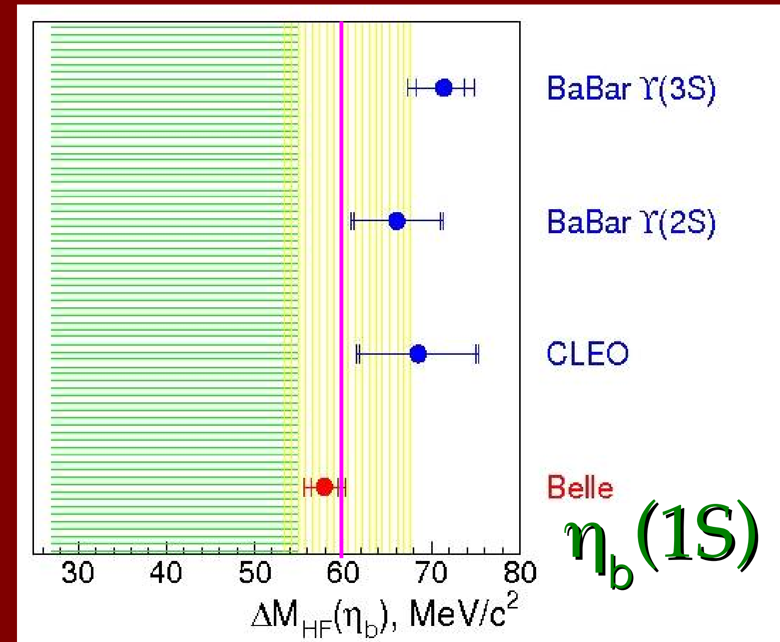
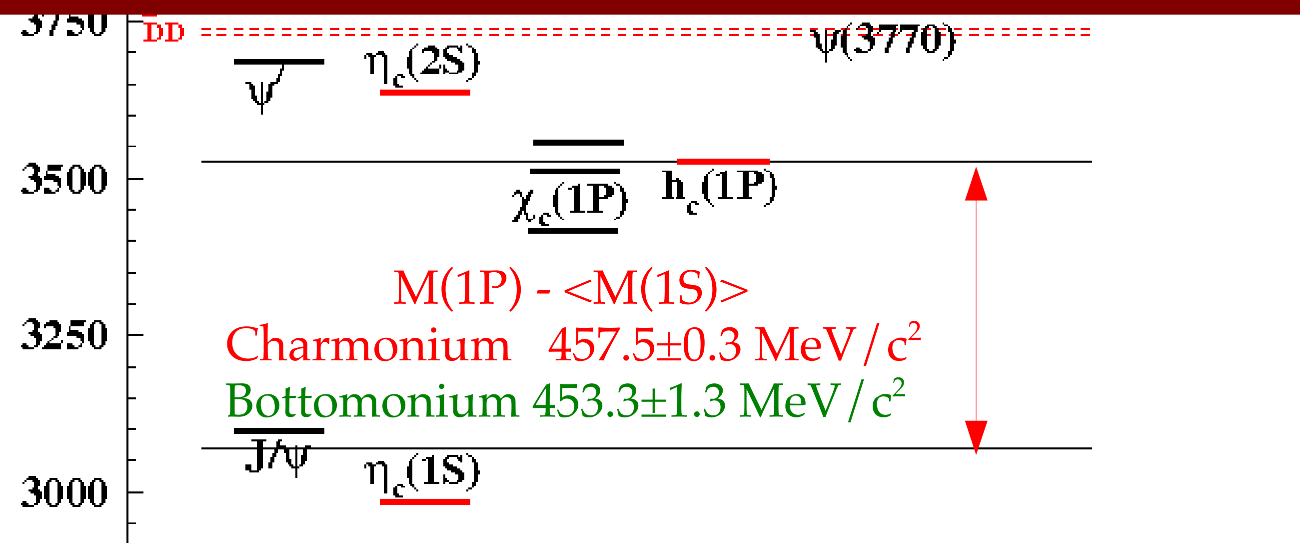
10 MeV discrepancy w/ earlier Babar and CLEO results:
Skewed lineshape as in charmonium?



$\eta_b(1S)$

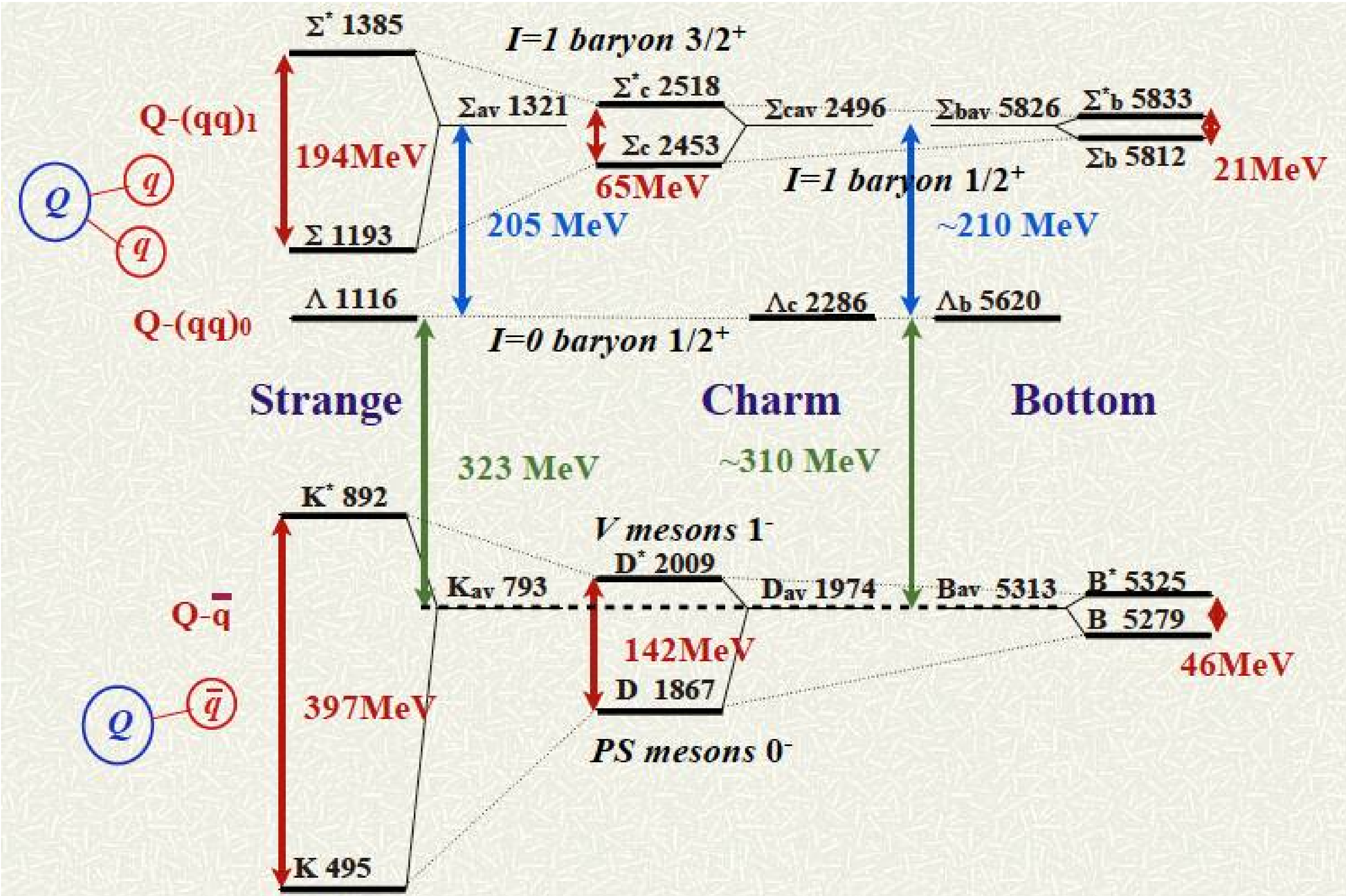
Spin averaged 1P-1S splitting seems not to depend on scale: only 1% difference with charmonium: similarly, the tensor-vector splitting remains constant also in D,Ds.



	$c\bar{u}$	$c\bar{d}$	$c\bar{s}$	$c\bar{c}$	$b\bar{b}$
$M(2^+)$-$M(1^-)$, in MeV/c^2	452 ± 2	449±4	461±2	458.3±0.1	452.3±0.6

Charmed and Beauty hadron spectra

From Oka's talk at Hadron 2013



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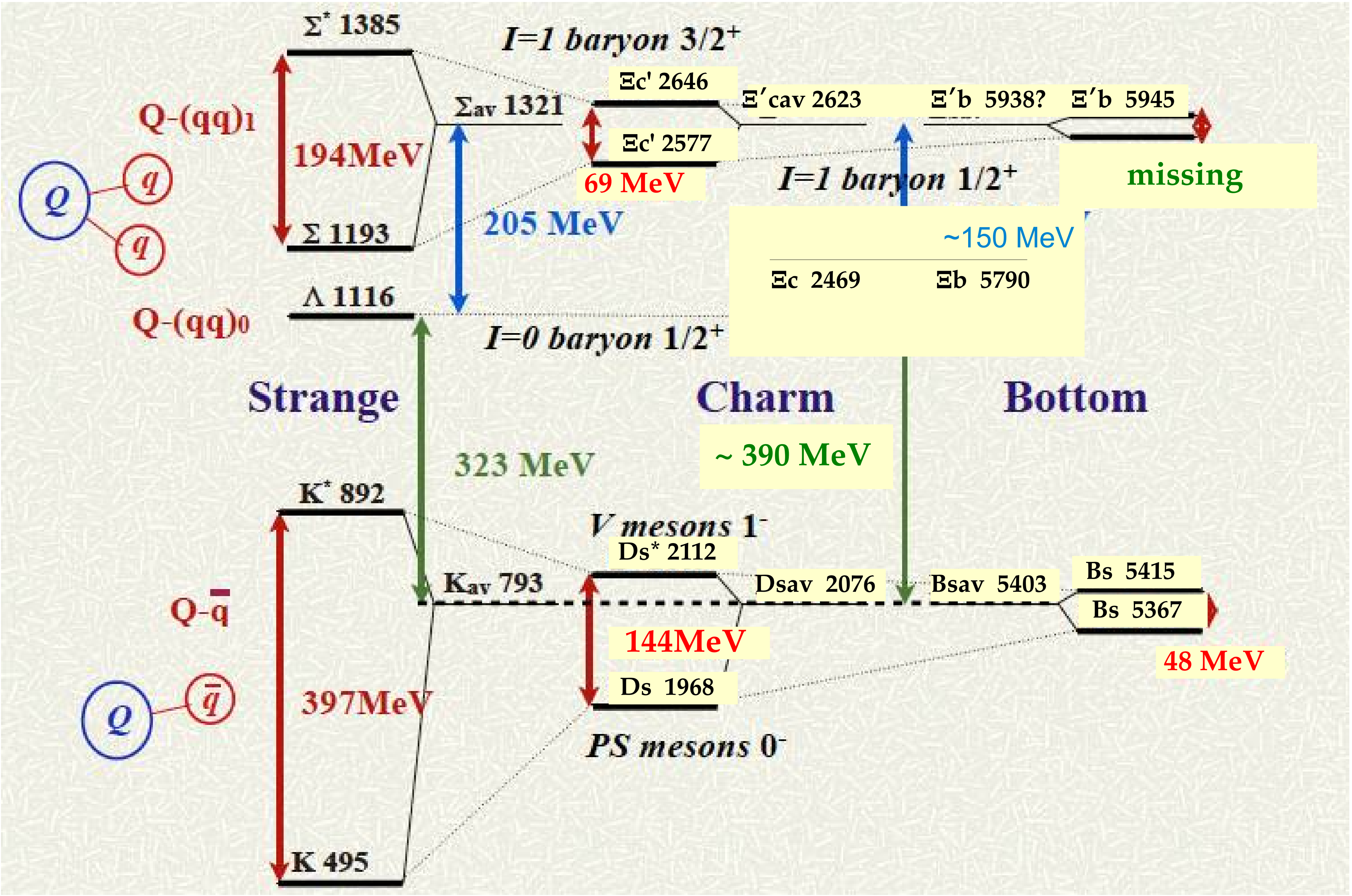


Belle-II: future prospects

Search for $\eta_b(1S) \to \gamma\gamma$

via exclusive channel: $\pi^+\pi^-\gamma(\gamma\gamma)$!!

NRQCD NNLL prediction:

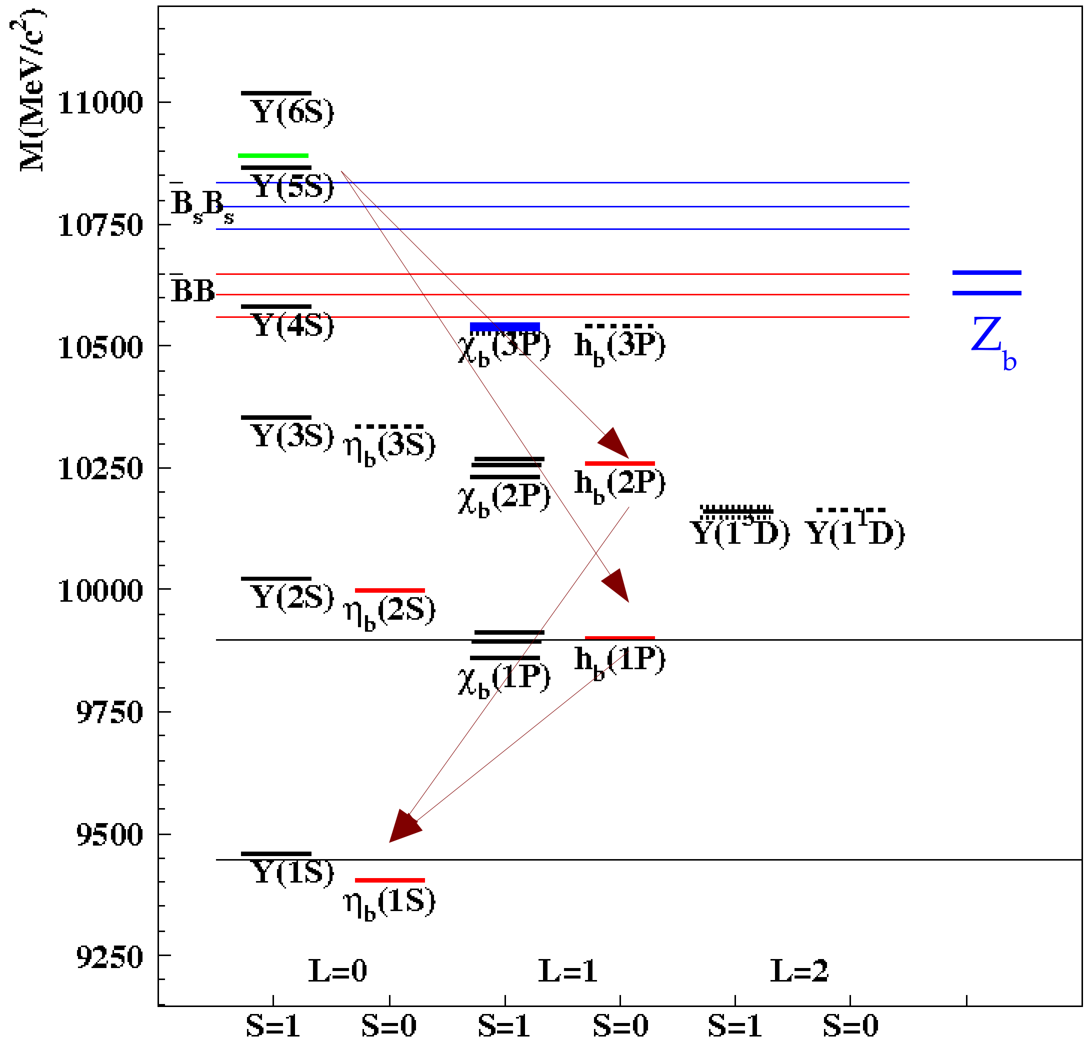
Penin et al., NP B699(2004),183

$\Gamma(\eta_b(1S) \to \gamma\gamma) = 0.66 \pm 0.09$ keV

With $\Gamma(\eta_b) = 10$ MeV,

$BR(\eta_b(1S) \to \gamma\gamma) = 0.66 \times 10^{-4}$

~25 events with 1 ab^{-1} at Y(5S)



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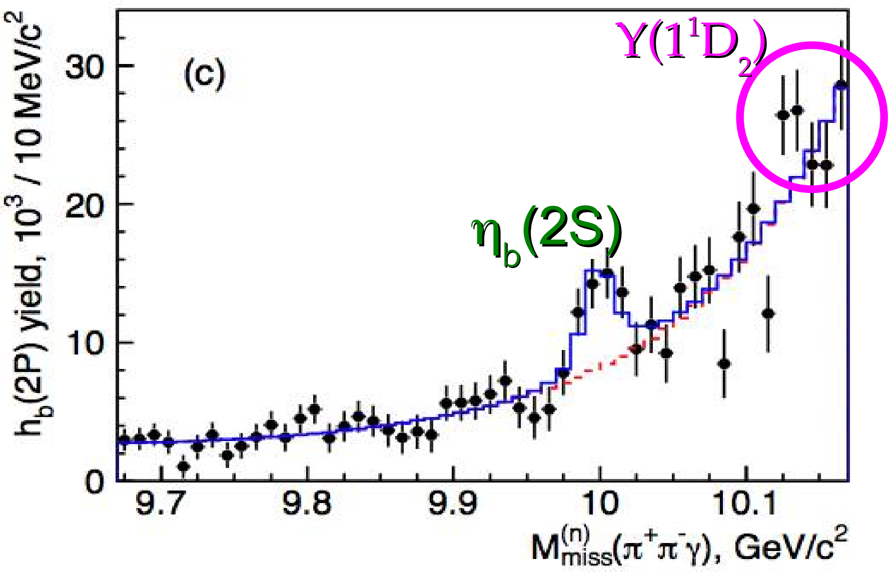
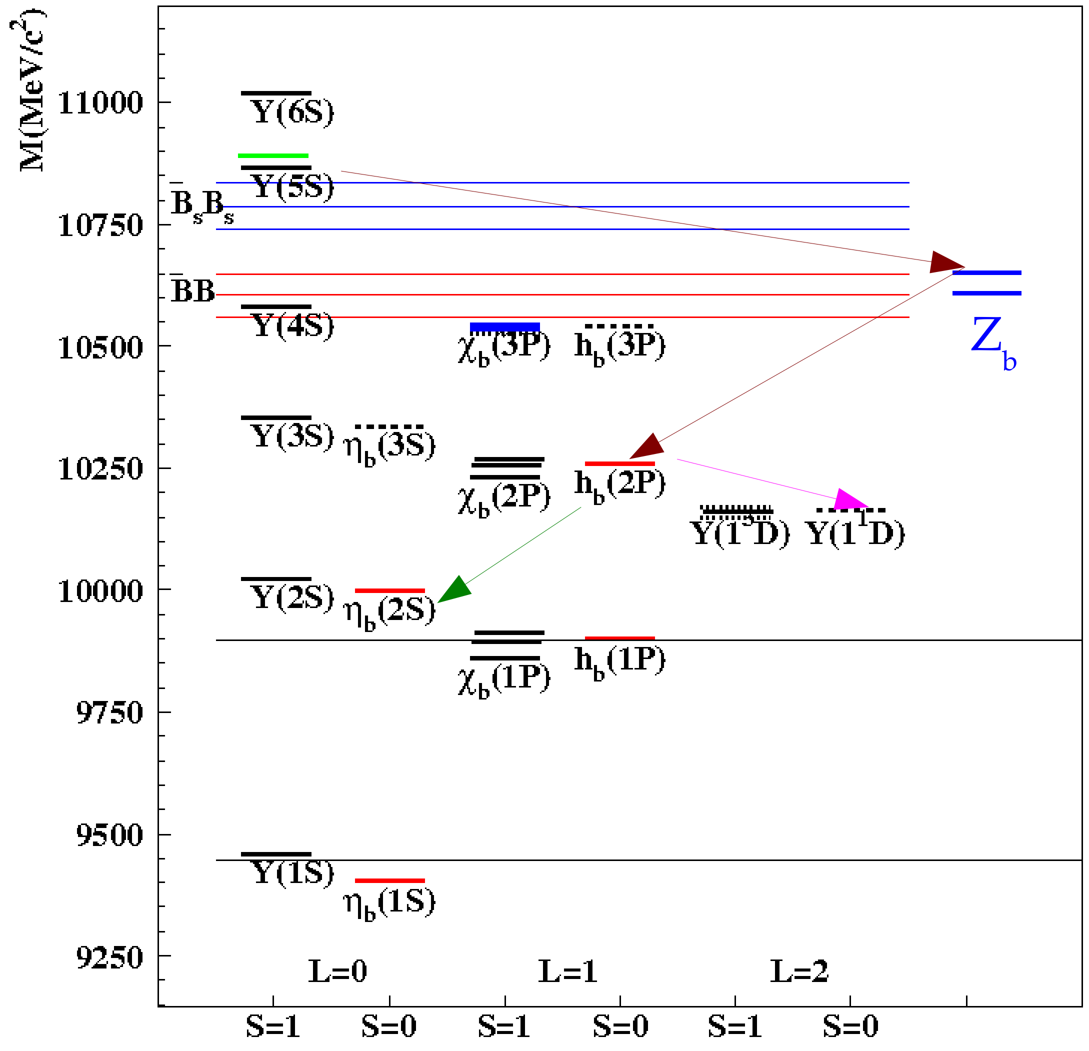
Search for S=0 D-wave state via $h_b(2P)$





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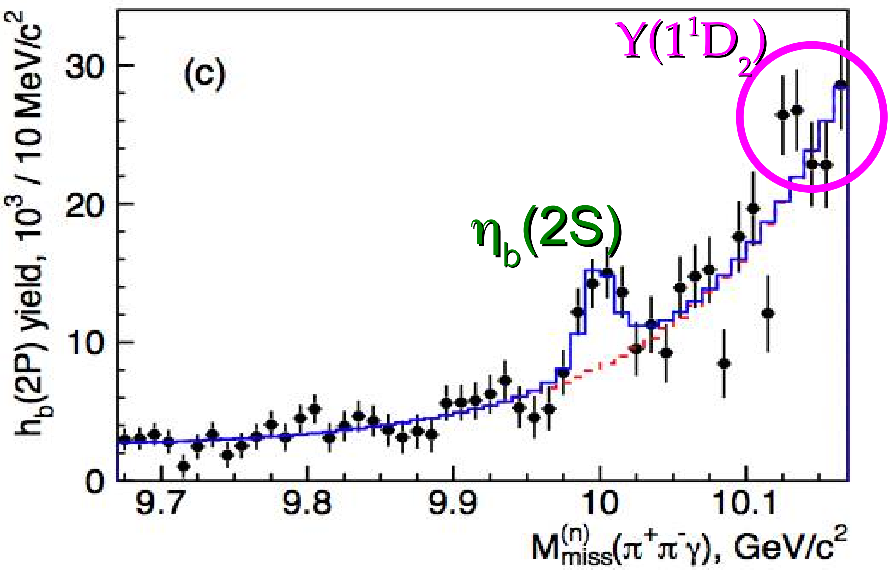
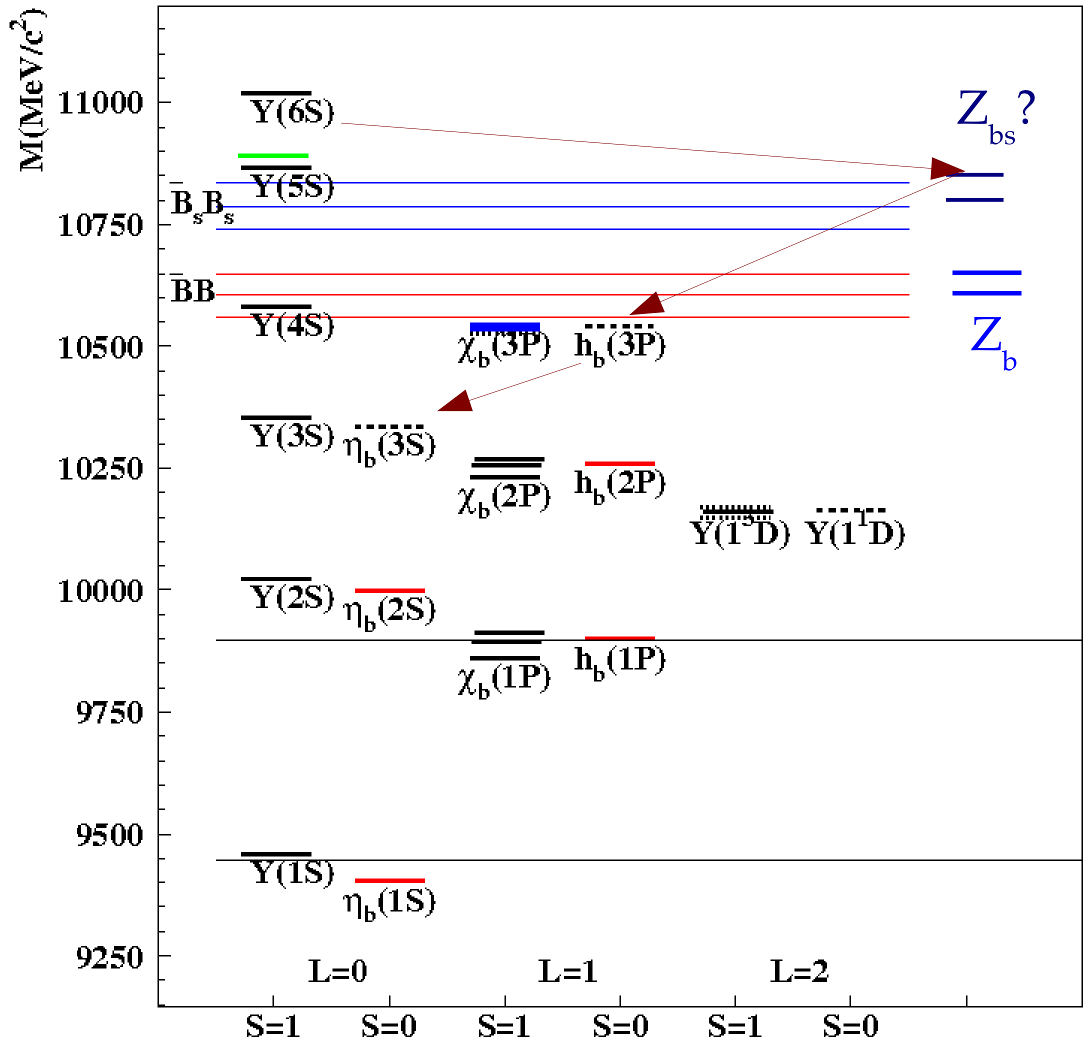


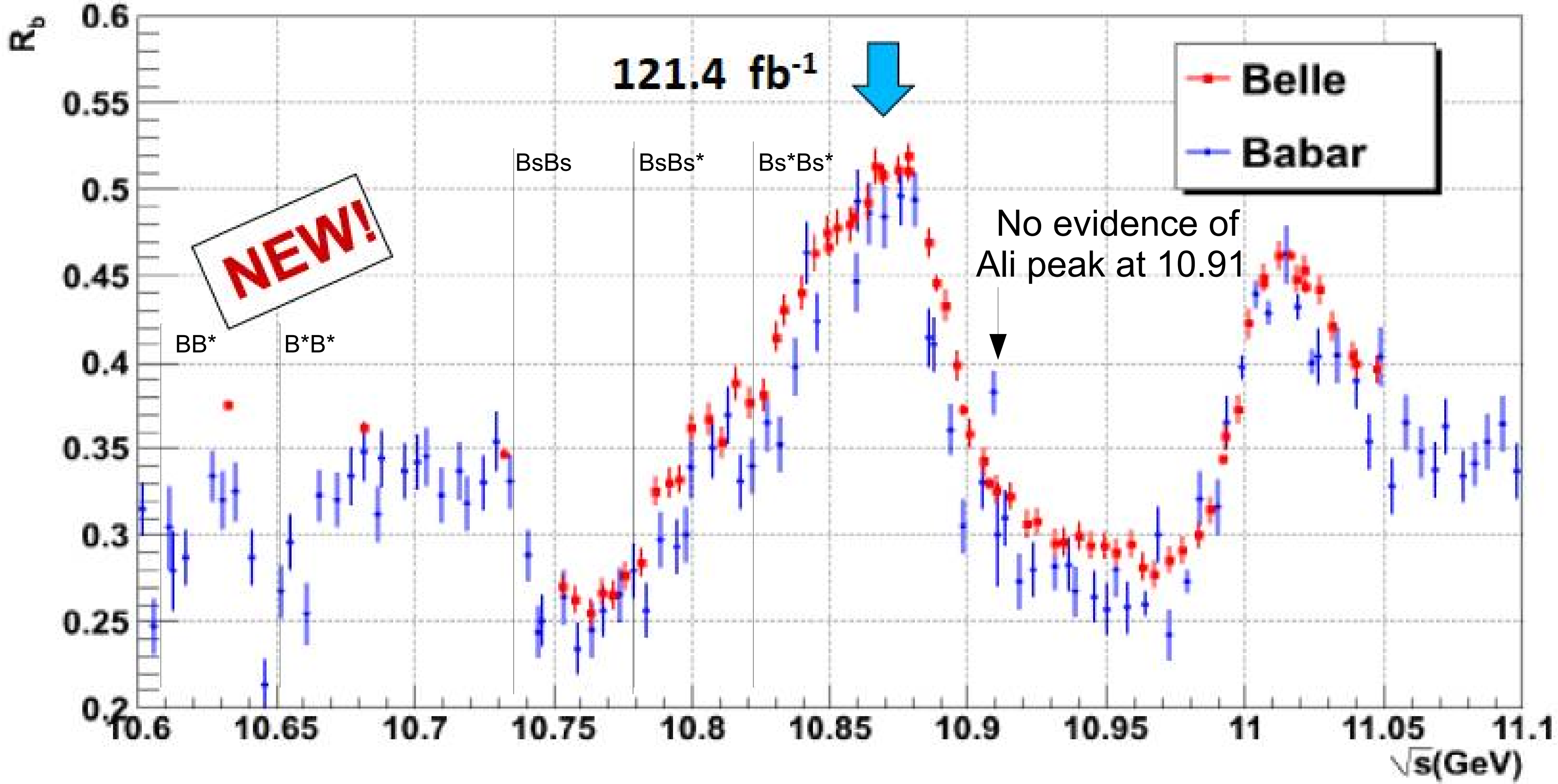
$Y(6S) \rightarrow h_b(3P)$ via Z_{bs} states?

$h_b(3P) \rightarrow \gamma\, \eta_b(3S)$?



Scans of the $b\bar{b}$ threshold region

BaBar scans: - 132 points, 25/pb, 10.54,11.2 GeV
Belle scans: - 61 points, 50/pb, 10.75-11.05 GeV
- 16 points, 1/fb, 10.63-11.02 GeV



Future prospects at Belle-II: Full reconstruction of all B(*)B(*)+pion components

Scans of the $c\bar{c}$ threshold region: ISR

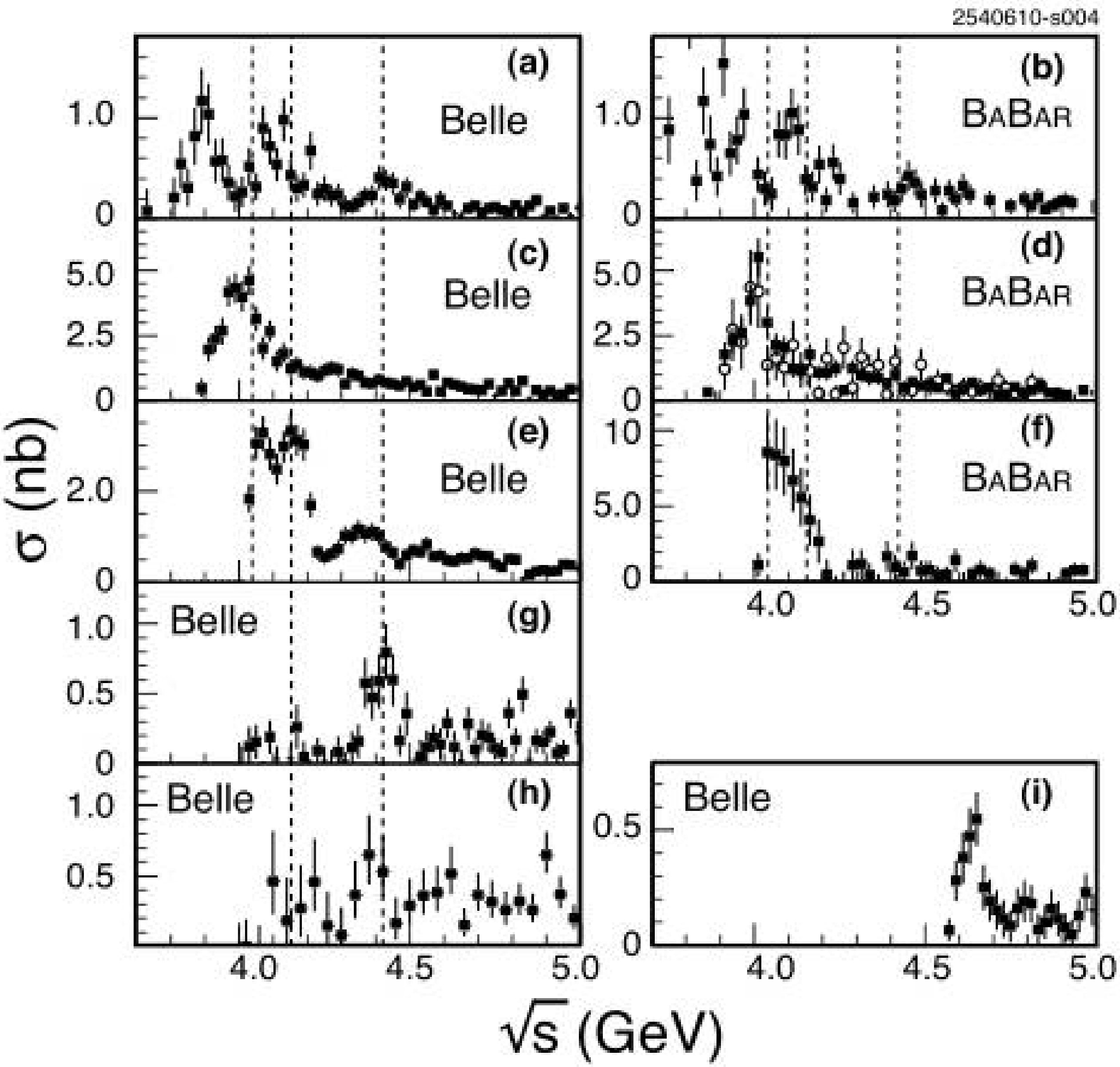
DD

D*D

D*D*

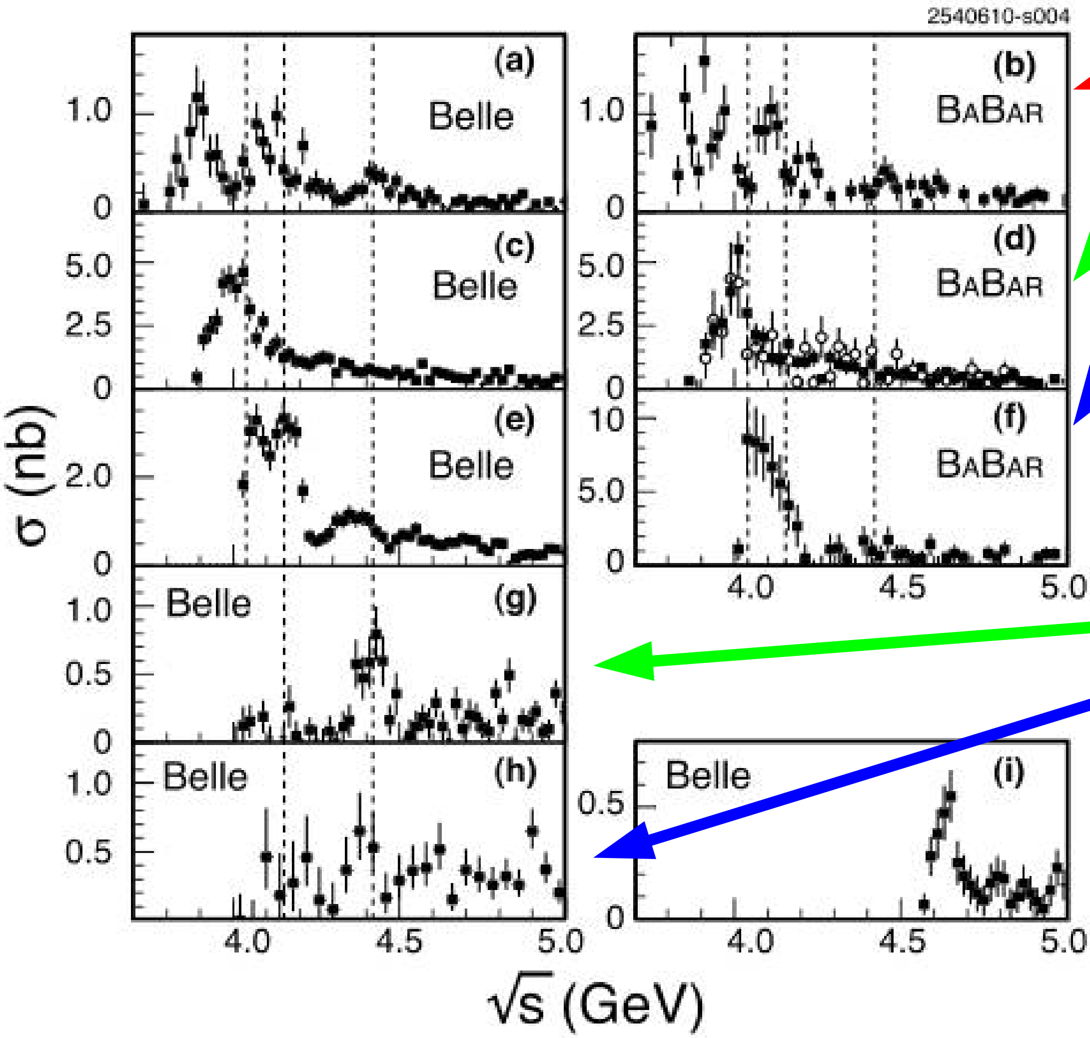
DDπ

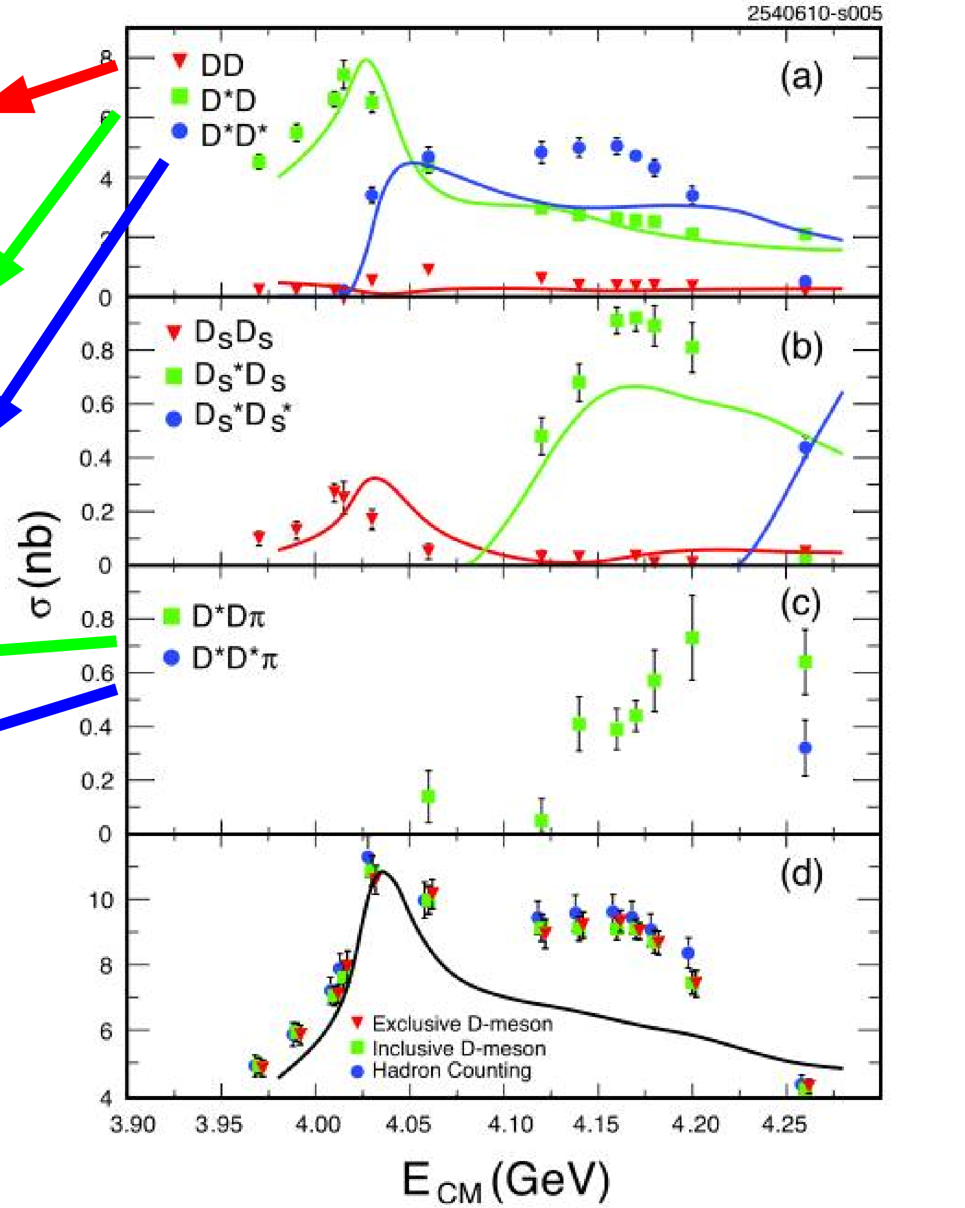
DD*π



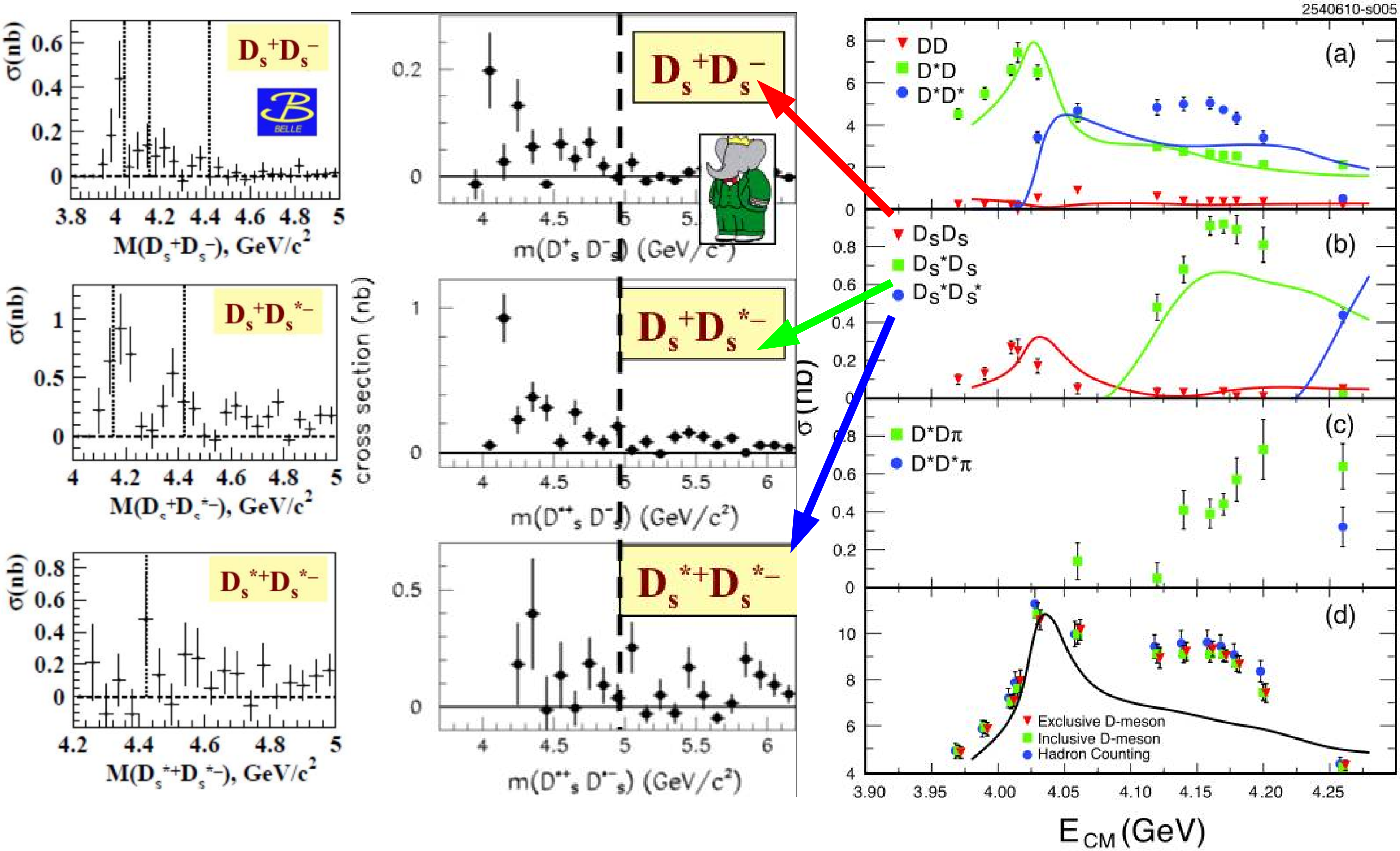
$\Lambda_c \overline{\Lambda}_c$

Full decomposition of R:Babar / Belle vs CLEO-c

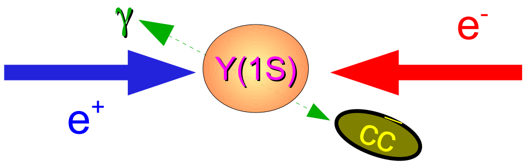




Full decomposition of R:Babar / Belle vs CLEO-c



$\Upsilon(1S) \to \gamma$ +charmonium



All limits above th.predictions

$BR(\Upsilon(1S) \to f)*10^6$	90%CL UL
$\Upsilon(1S) \to \gamma\chi_{c0}$	650
$\Upsilon(1S) \to \gamma\chi_{c1}$	23
$\Upsilon(1S) \to \gamma\chi_{c2}$	7.6
$\Upsilon(1S) \to \gamma\eta_c$	57
$\Upsilon(1S) \to \gamma$ X3872 $\to \gamma\, \pi^+\pi^-$ J/ψ	1.6
$\Upsilon(1S) \to \gamma$ X3872 $\to \gamma\, \pi^+\pi^-\pi^0$ J/ψ	2.8
$\Upsilon(1S) \to \gamma$ X3915 $\to \gamma\, \omega$J/ψ	3.0
$\Upsilon(1S) \to \gamma$ Y4140 $\to \gamma\, \phi$J/ψ	2.2

PRD82(2010),051504R

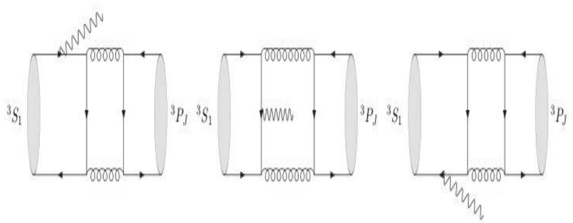
BELLE

NRQCD predictions

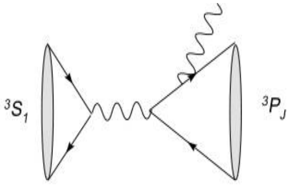
[K. T. Chao et al., hep-ph/0701009]

QCD	QCD+QED
4.0	3.2
4.5	9.8
5.1	5.6
2.9	4.9

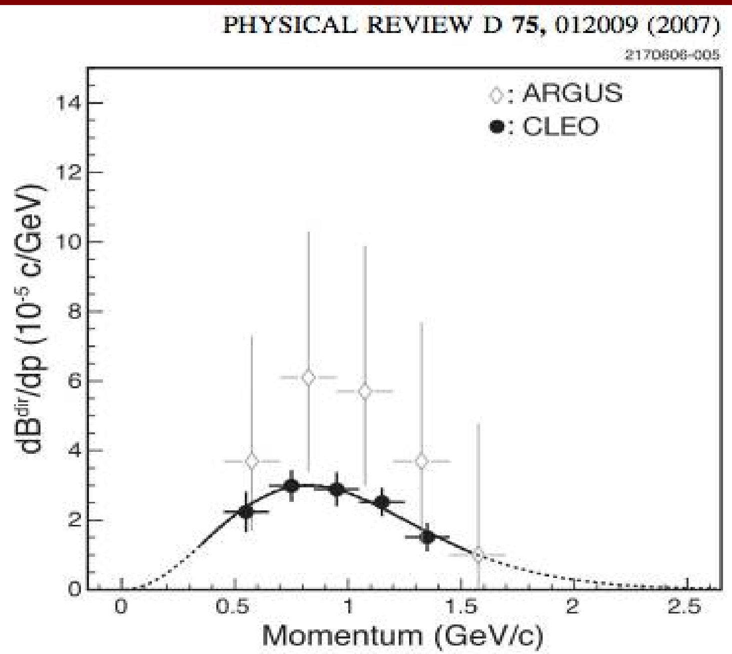
QCD

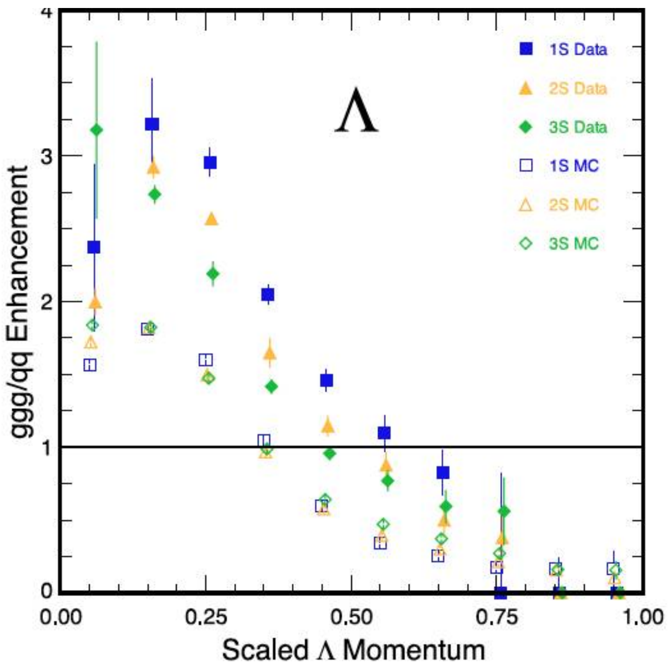


QED



Search for H dibaryon





Former observations by ARGUS and CLEO
Z.Phys. C39 (1988) 177 Phys.Rev. D76 (2007) 012005

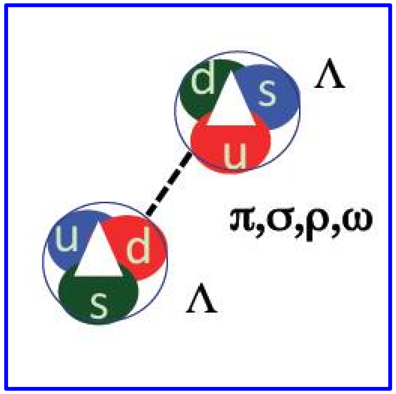
- Inclusive production of (anti)deuteron in Y(1,2S) decays :

$$\mathcal{B}^{\rm dir}(\Upsilon(1S)\to\bar{d}X) = (3.36\pm0.23\pm0.25)\times10^{-5}.$$

$$\mathcal{B}(\Upsilon(2S)\to\bar{d}+X) = (3.37\pm0.50\pm0.25)\times10^{-5}.$$

- Enhanced (3x) production of low momentum hyperons in hadronic events from bottomonium decays w/respect to continuum.

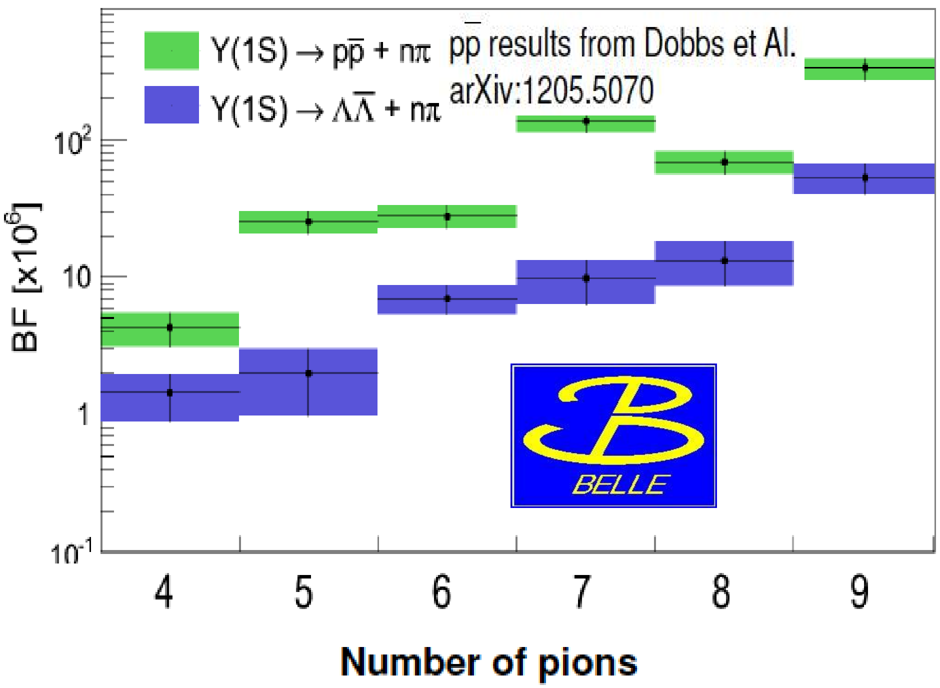
BELLE has exploited the Y(1,2S) record samples to search for the long sought H-dibaryon : (*Jaffe, PRL38 (1977),195*)
A tightly bound tri-diquark, or a loosely bound S=2 hypernucleus?

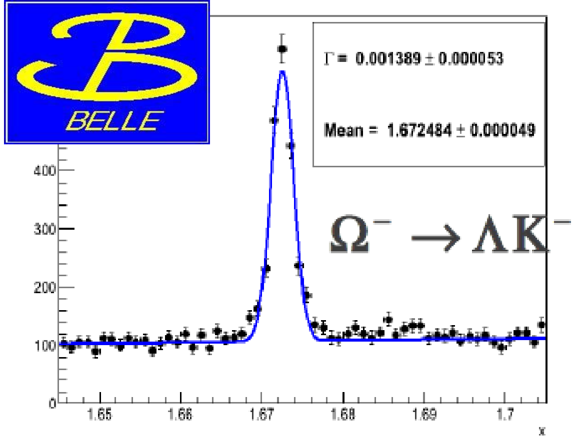


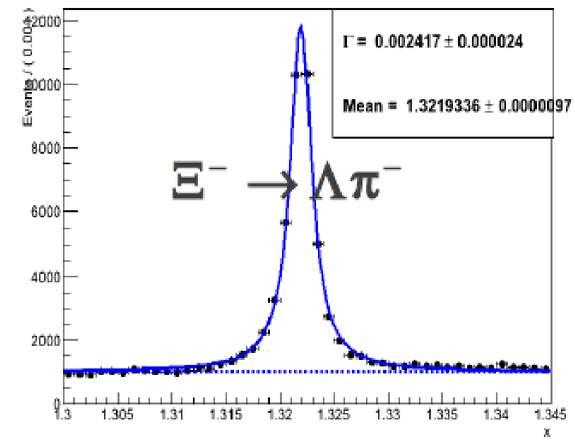
Hyperon and dibaryon studies

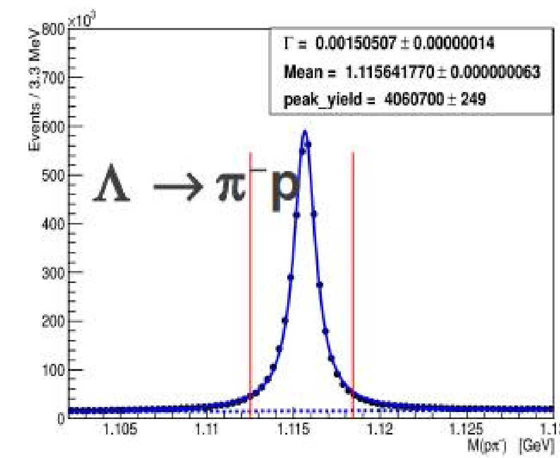
Many studies ongoing from Y(1,2S) decays, and from continuum:

- pentaquark searches,
- exclusive BR($\Lambda\bar{\Lambda}$+ n pions)
- inclusive production of hyperons
- $\Lambda\Lambda$ and $\Xi^{-}p$ (+cc) correlations
- antideuteron spectra (and more)







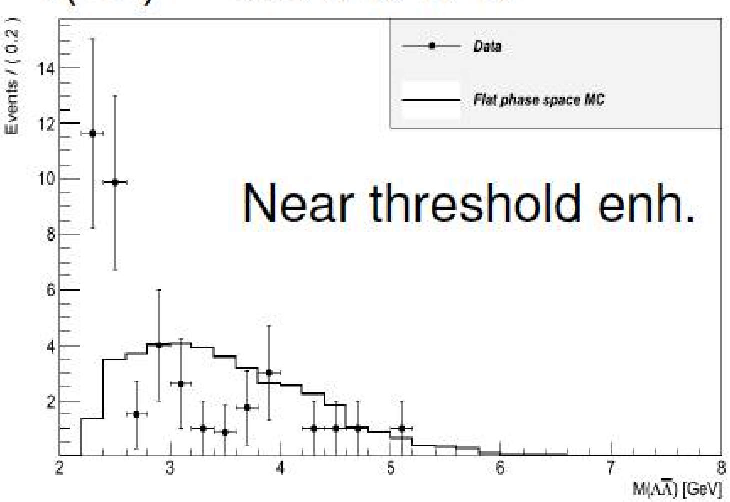


Search for $\Lambda\bar{\Lambda}$ threshold enhancements

BELLE analysed ~50 exclusive channels with hyperon-antihyperon pairs + up to 6 light hadrons and with (0,1) neutral pion.

Both Y(1,2S) data and continuum were analysed.

Y(1S) → $\Lambda\bar{\Lambda}\,\pi^+\pi^-K^+K^-$

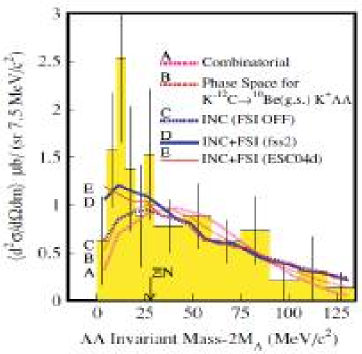


Significance of the near threshold enhancement (in σ's)

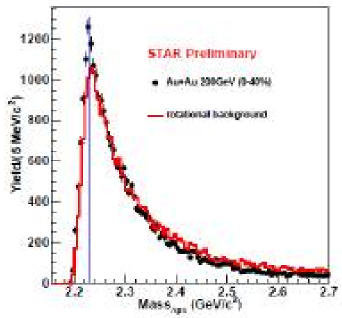
Final state X	$\Upsilon(1S) \to X$	$\Upsilon(2S) \to X$	$e^+e^- \to q\bar{q} \to X$
$\Lambda\bar{\Lambda} + \pi^+\pi^-$	2.16		1.83
$\Lambda\bar{\Lambda} + K^+K^-$	2.94	4.60	
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	2.96	3.07	4.23
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-$	4.61		6.08
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}$	2.06		0.57
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)$	0.31	2.97	3.76
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	0.36		3.75
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	<0.1		0.83
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)$	0.50	0.29	
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	1.95		2.36
$\Lambda\bar{\Lambda} + K^+K^-\ \pi^0$			1.51
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	<0.1	0.36	4.27
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	<0.1		2.33
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$	<0.1		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	1.38	0.25	2.10
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	1.28	<0.1	1.28
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	<0.1		

Search for H dibaryon

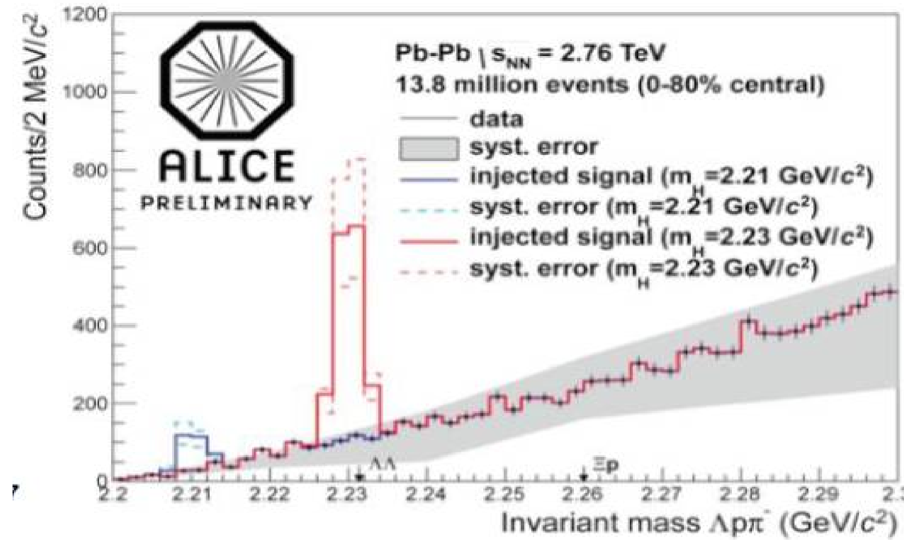
Recently studied by E522,STAR,ALICE



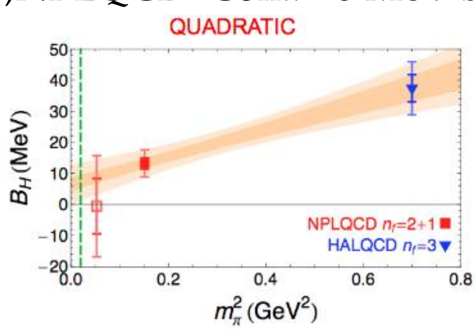
KEK-PS
E522(2007)



RHIC-STAR
detector
(2011)

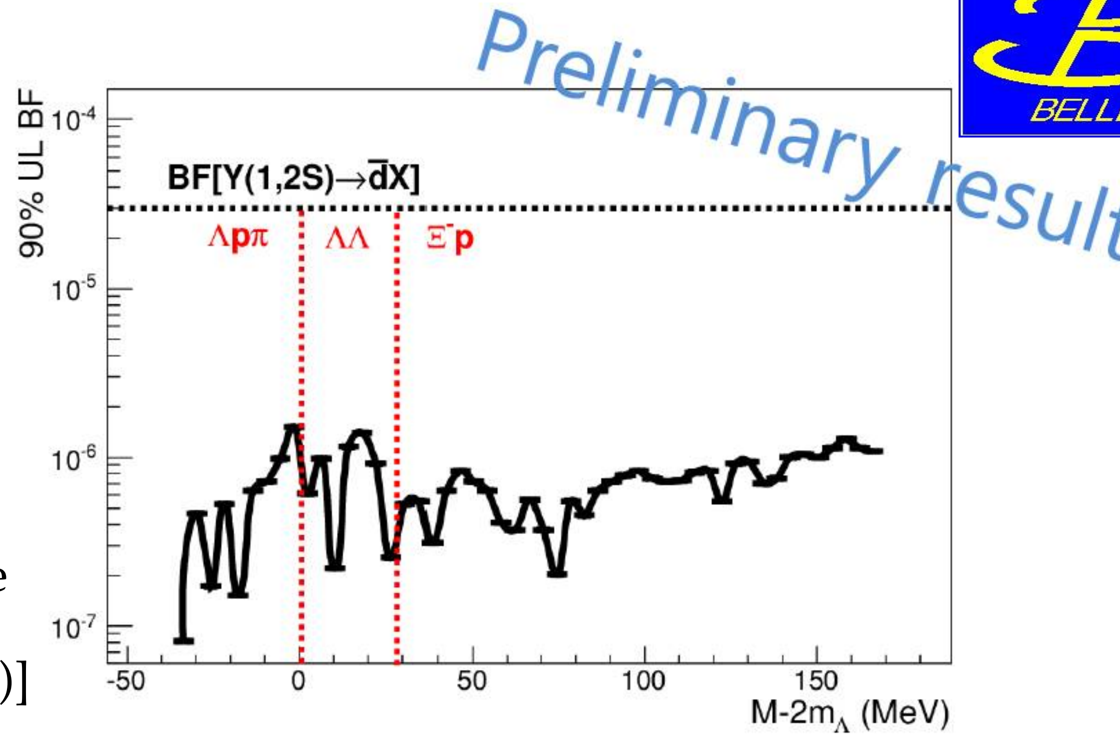


Theory: recent lattice calculations
HALQCD,NPLQCD Coll.: ~8 MeV binding



Belle has searched for H dibaryon in the folllowing channels:

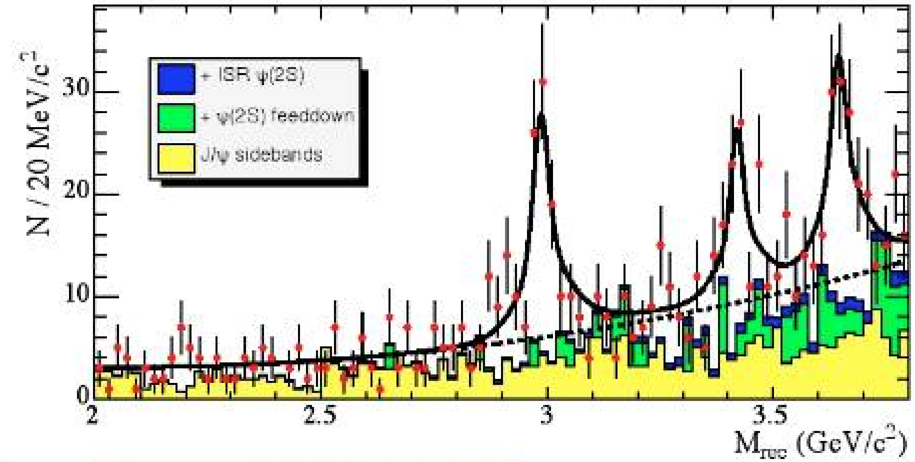
- Λπp + ΛΛ(+cc) [PRL 110, 222002 (2013)]
- Ξ p (+cc) [preliminary]

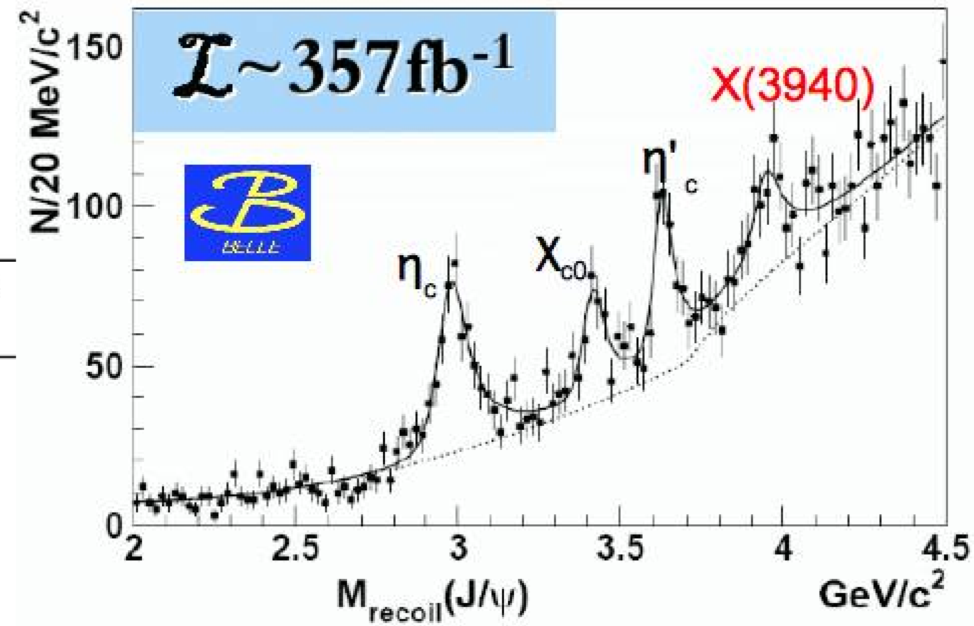


Double $c\bar{c}$: J/ψ recoil method

The double charmonium process was discovered by Belle by studying the momentum spectrum of J/psi .
By plotting the mass of particles recoiling against the J/psi , Belle observed the peaks of charmonium C=0 states and discovered X(3940). This reaction challenges our understanding of perturbative QCD. Leading order prediction was O(0.1) the observed value. NLO calculations 'almost' solved the discrepancy.

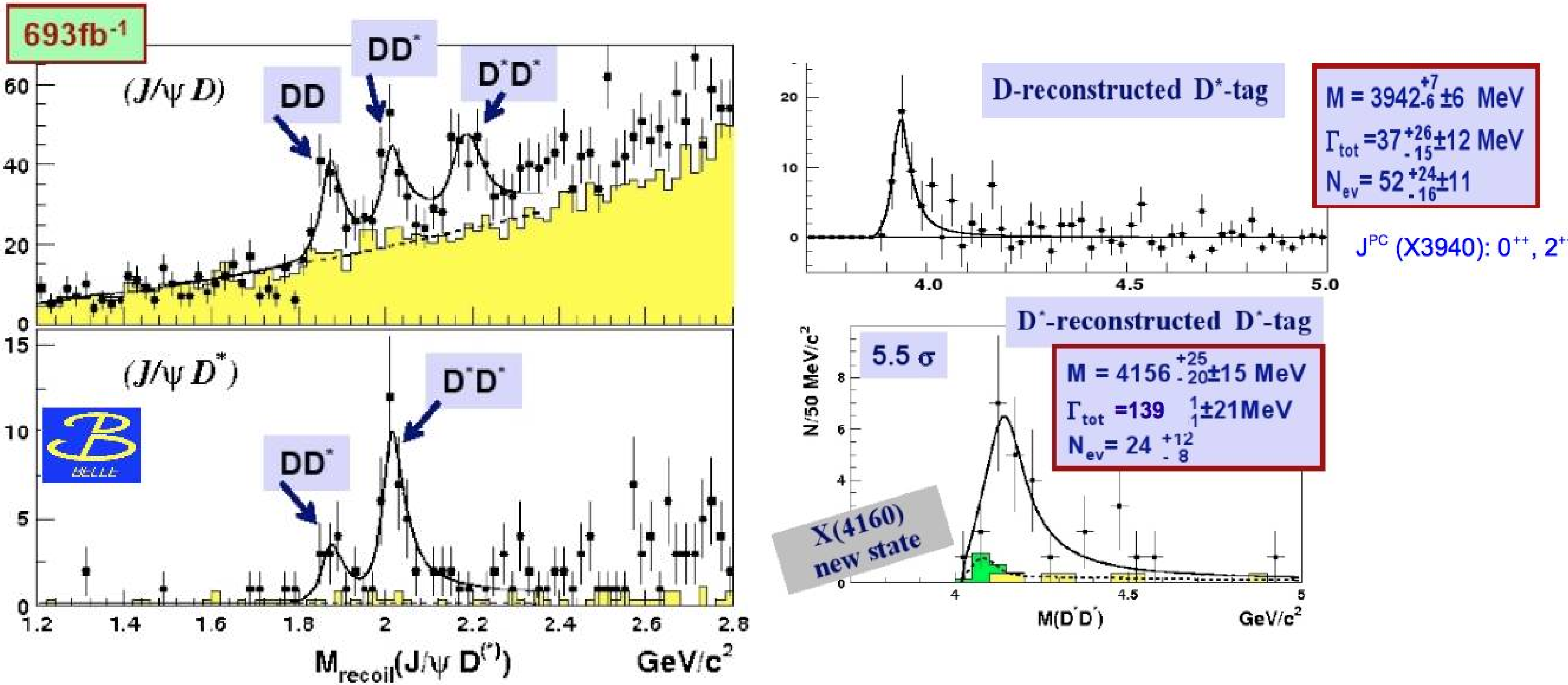
$J/\psi\ (c\bar{c})_{res}$		$\eta_c(1S)$	χ_{c0}	$\eta_c(2S)$
Belle	$\sigma \times \mathcal{B}_{>2}$ [fb]	$25.6 \pm 2.8 \pm 3.4$	$6.4 \pm 1.7 \pm 1.0$	$16.5 \pm 3.0 \pm 2.4$
BaBar	$\sigma \times \mathcal{B}_{>2}$ [fb]	$17.6 \pm 2.8^{+1.5}_{-2.1}$	$10.3 \pm 2.5^{+1.4}_{-1.8}$	$16.4 \pm 3.7^{+2.4}_{-3.0}$
NRQCD:	σ [fb]			
Braaten&Lee[1]		3.78 ± 1.26	2.40 ± 1.02	1.57 ± 0.52
...with relativistic corr^{ns}:		$7.4^{+10.9}_{-4.1}$	–	$7.6^{+11.8}_{-4.1}$
Liu,He,&Chao[2]		5.5	6.9	3.7
Zhang,Gao,&Chao[3]		14.1	–	–





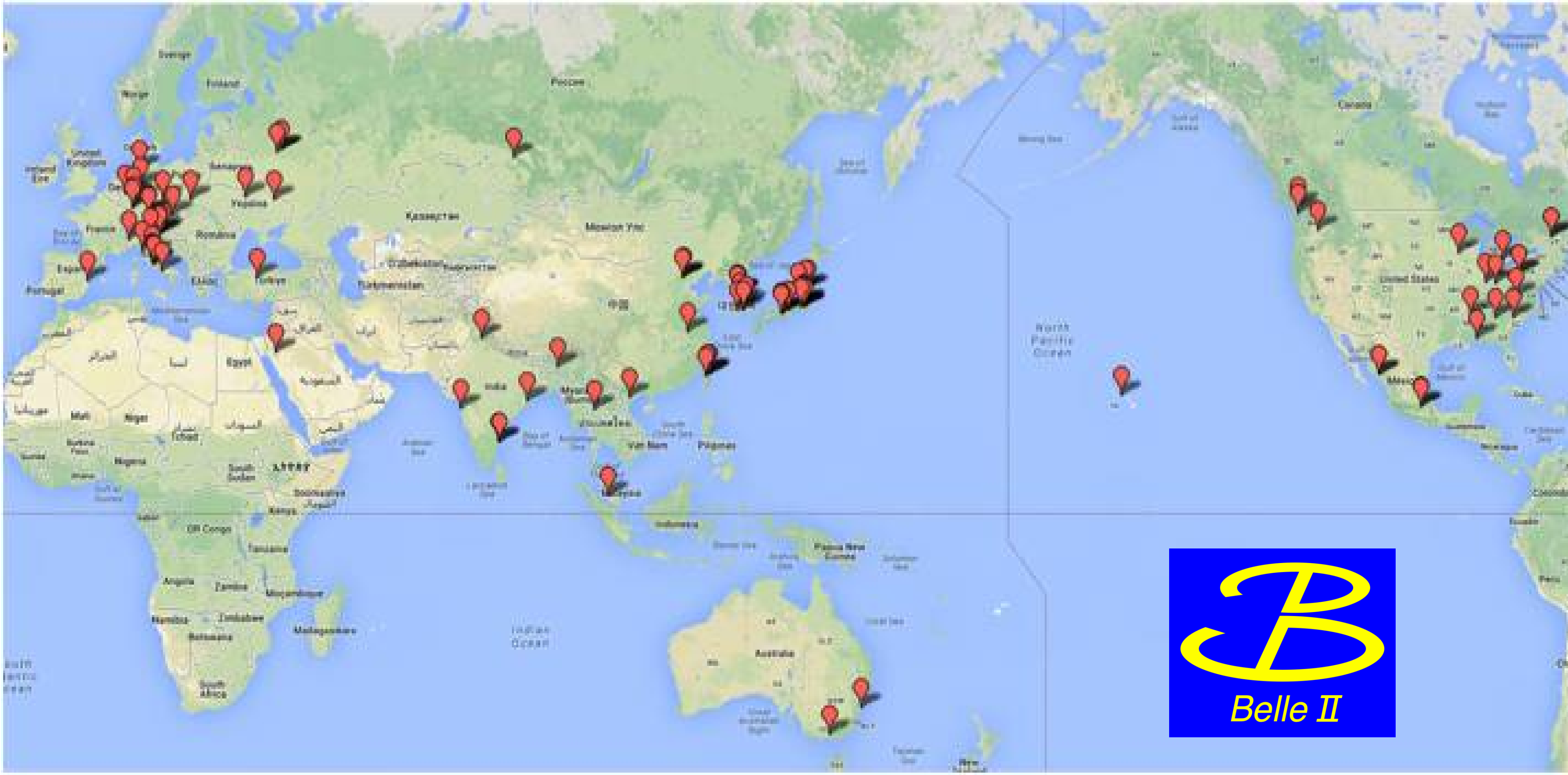
Double $c\bar{c}$: J/ψ+D recoil method

Full reconstruction of one additional D meson and plot of the mass recoiling against the J/ψ+D system allowed to confirm X(3940) and find one more state at 4156 MeV.



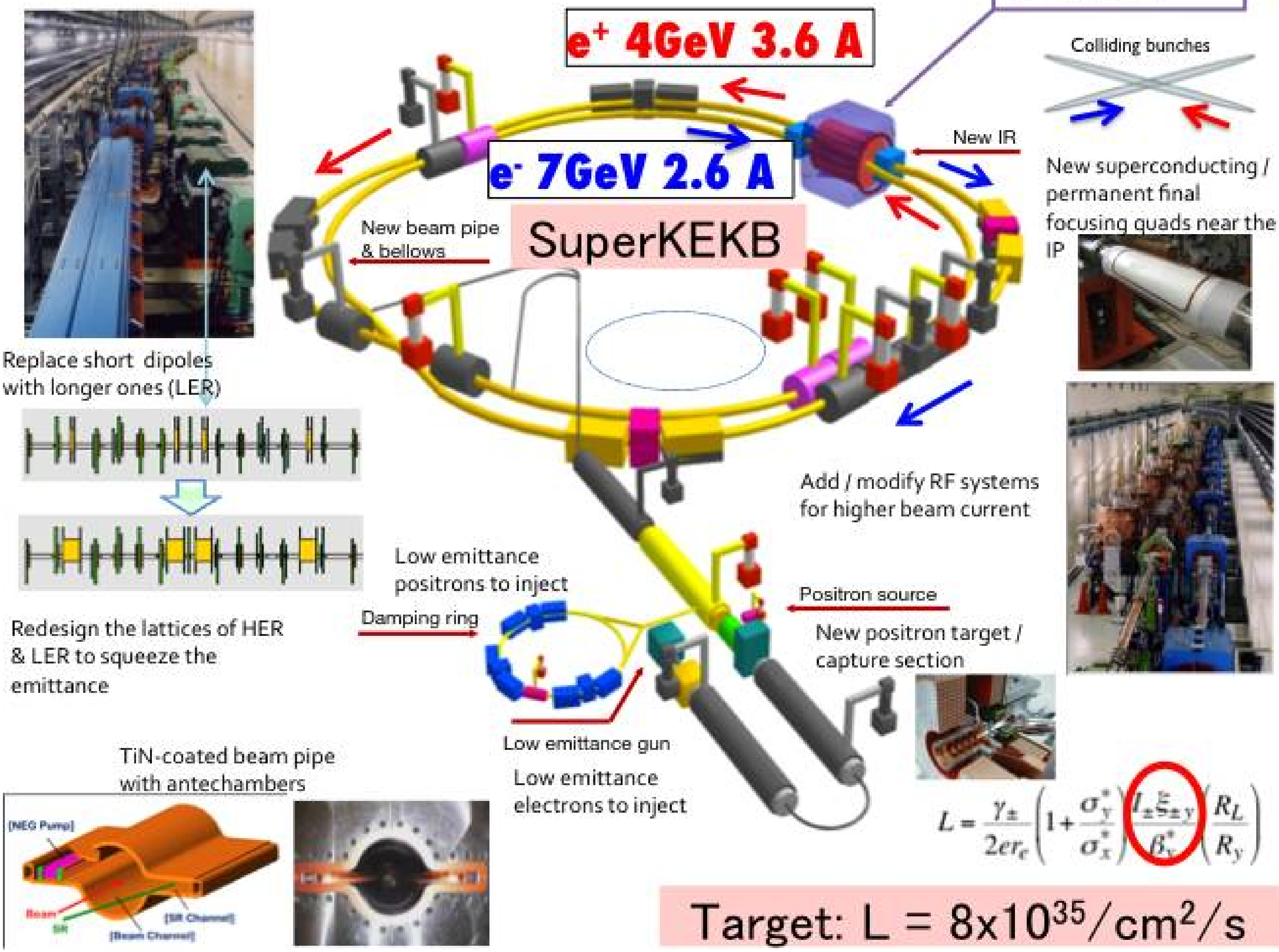
Future prospects at Belle-II: Full reconstruction of χ_c or η_c will allow to exploit the recoil technique and scan the charmonium(-like) C=-1 states.

Belle-II Collaboration

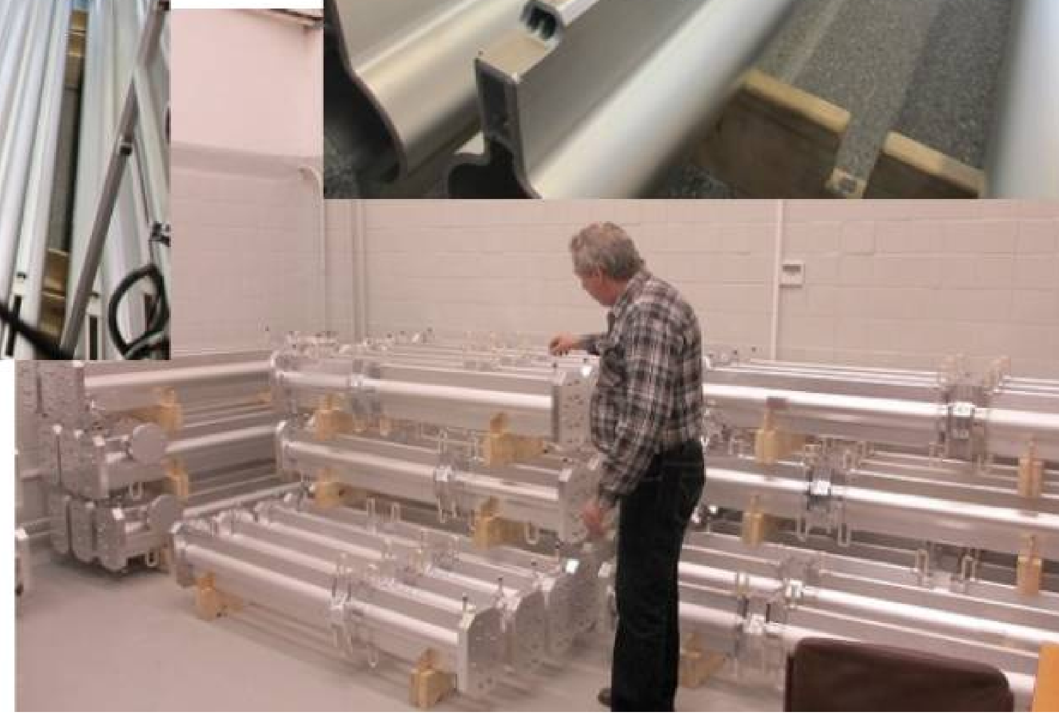


23 countries,
94 institutions,
560 collaborators

KEKB upgrade



New beam pipe



LER magnets installation

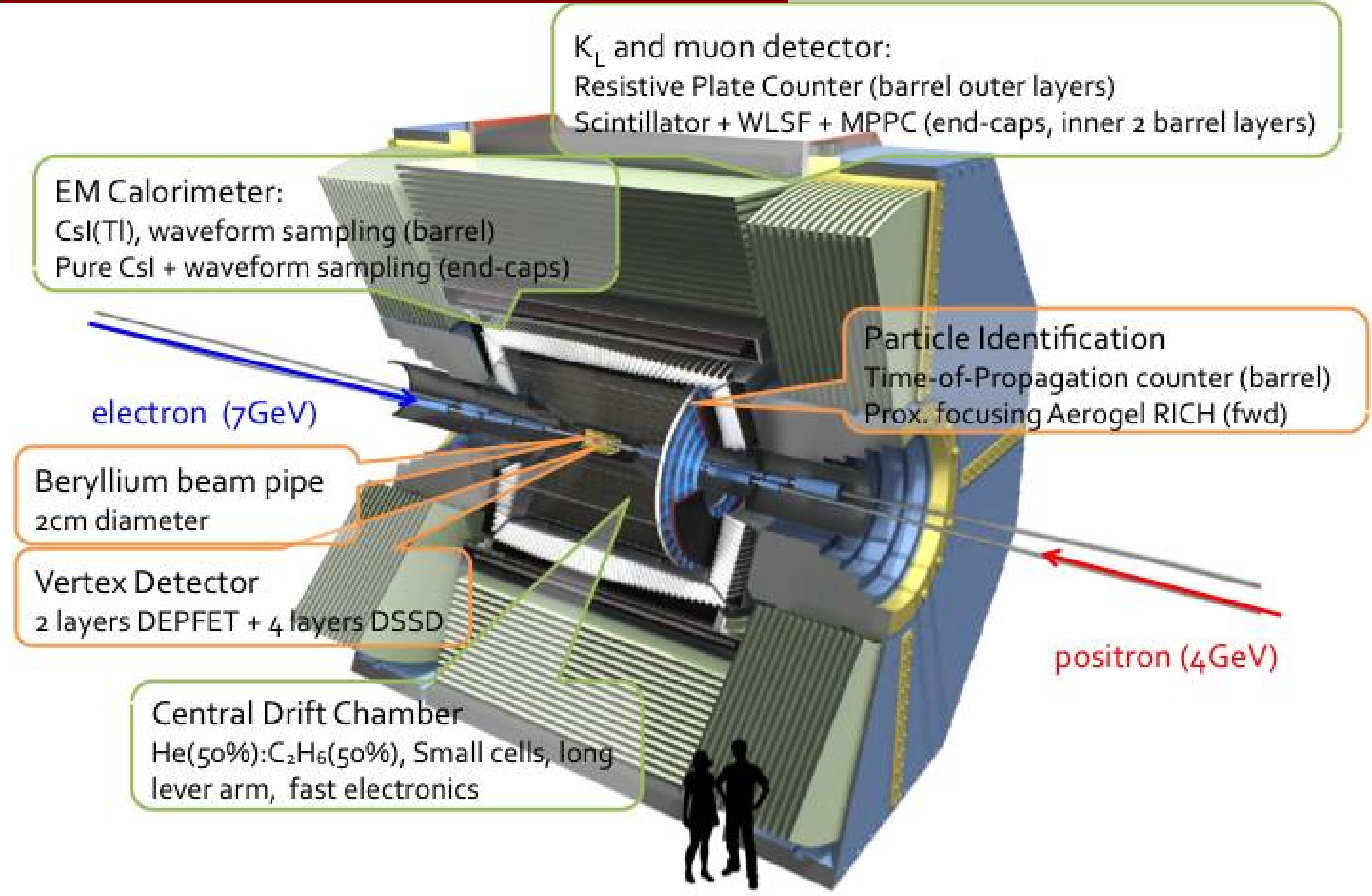
field measurement

move into tunnel

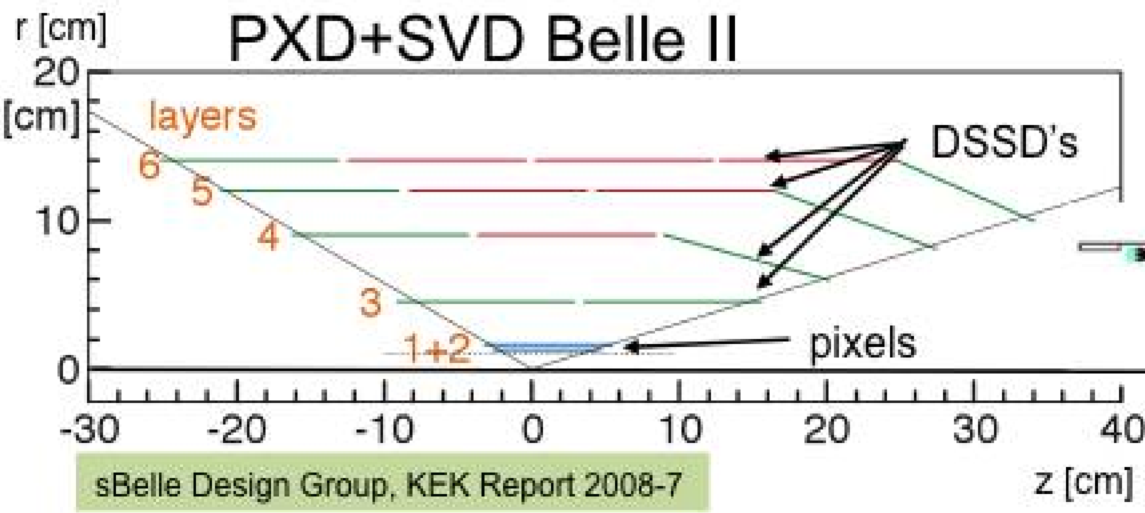
carry on an air-pallet

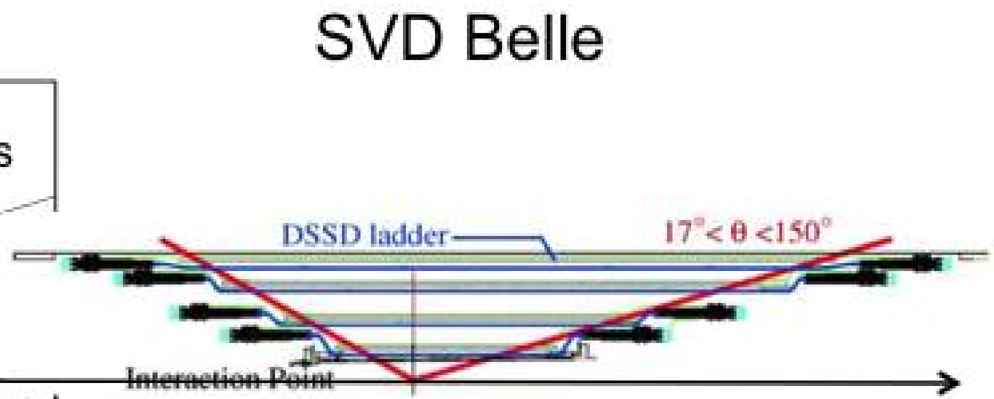
carry over existing HER dipole

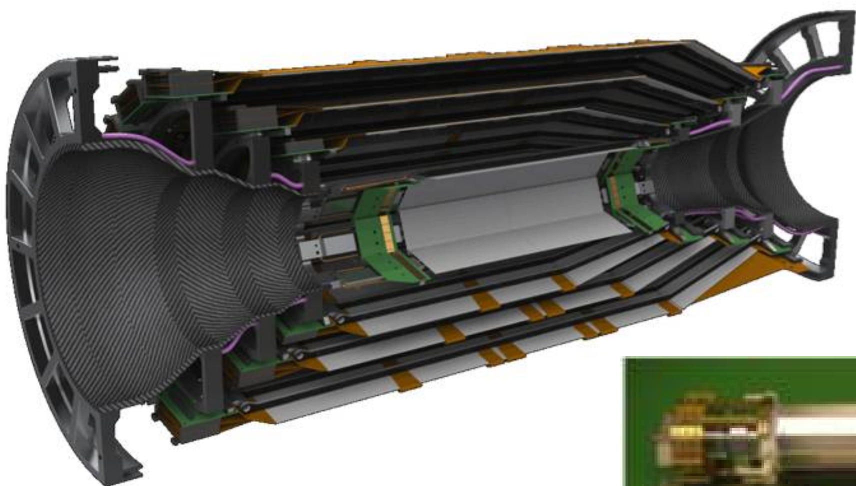
Belle-II: Detector

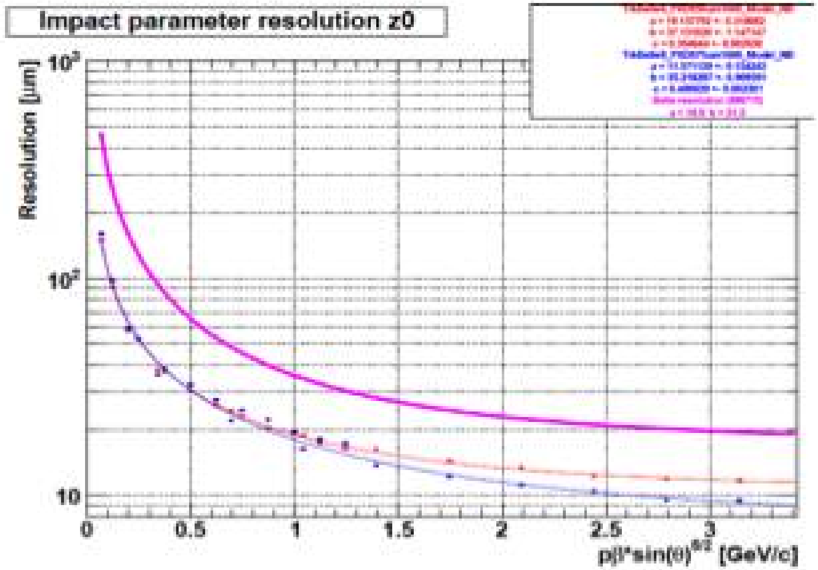


Belle-II: Vertex detectors

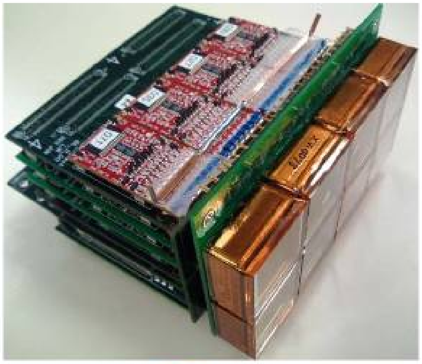




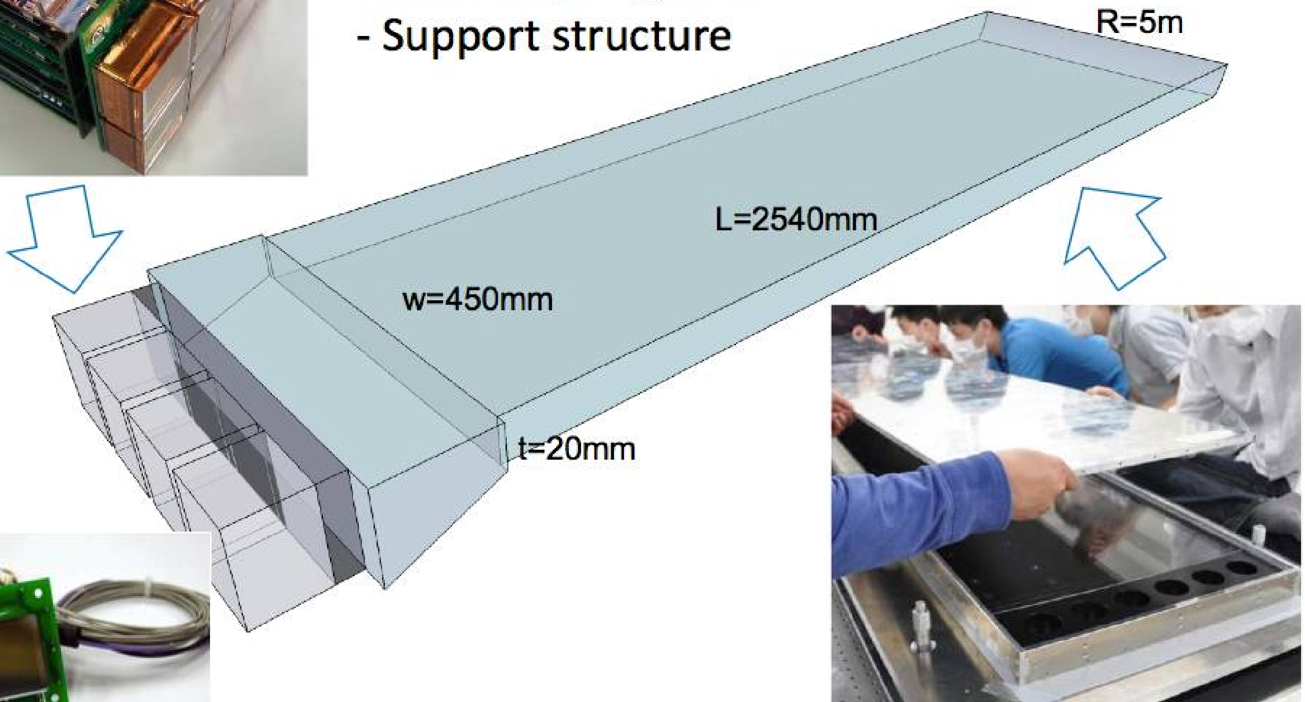


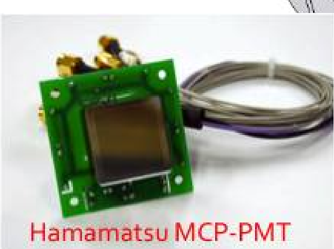


Belle-II: Barrel PID

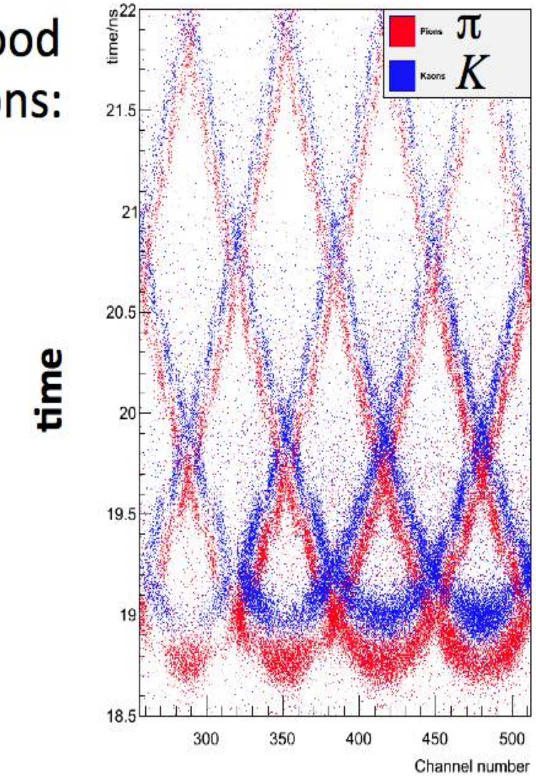


- Quartz radiator, mirror and wedge
- MCP-PMT
- Waveform digitizer
- Support structure





Likelihood Functions:

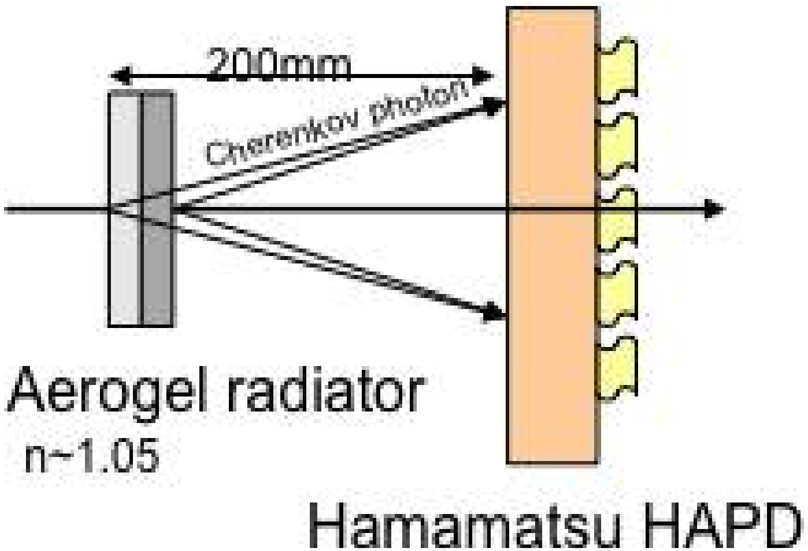


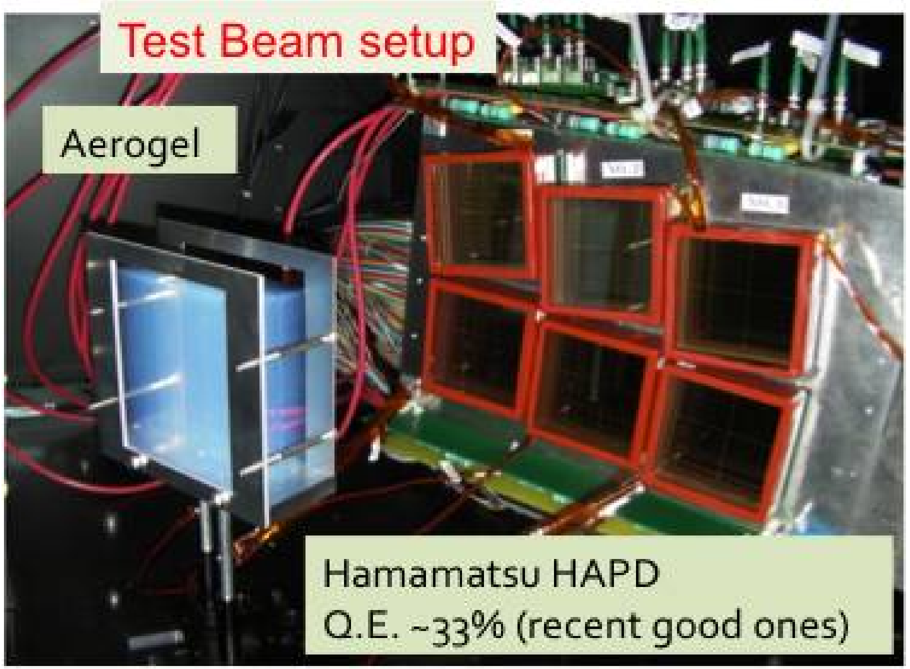
Challenging time resolution (100 ps)

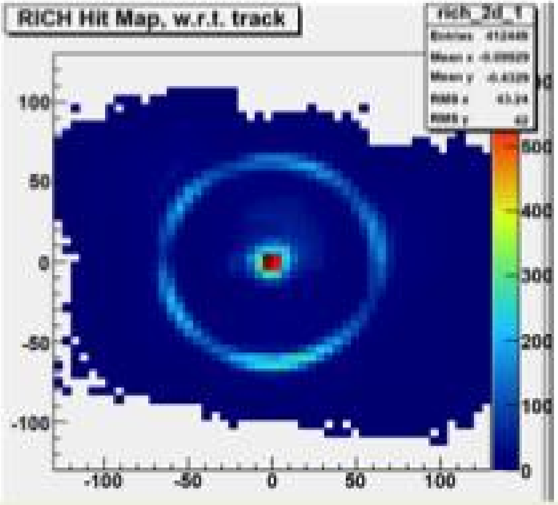
	ππ eff.	fake	ργ eff.	fake
TOP	98.1%	2.9	99.0	1.9
Belle	88.5	11.6	87.5	10.0

⇒ *substantial improvement over Belle. This will help for, e.g., separating $D_s^+ \to K^- K^+ \pi^+$ from $D^+ \to K^- \pi^+ \pi^+$, removing $D^0 \to K^- \pi^+ \pi^0$ from $D^0 \to K^- K^+$, etc.*

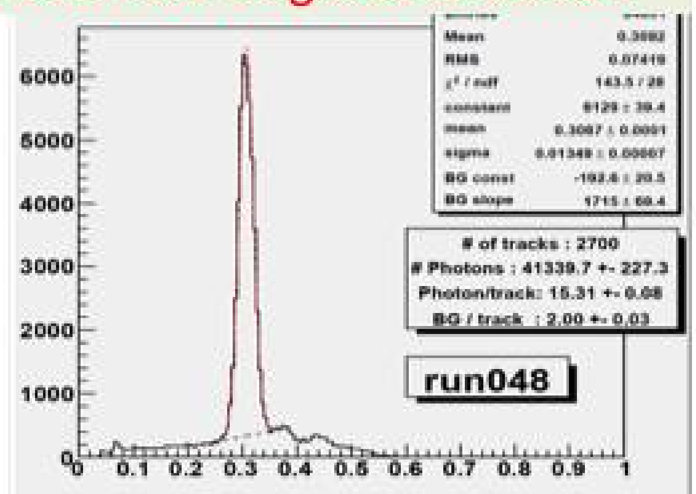
Belle-II: Forward PID







Cherenkov angle distribution

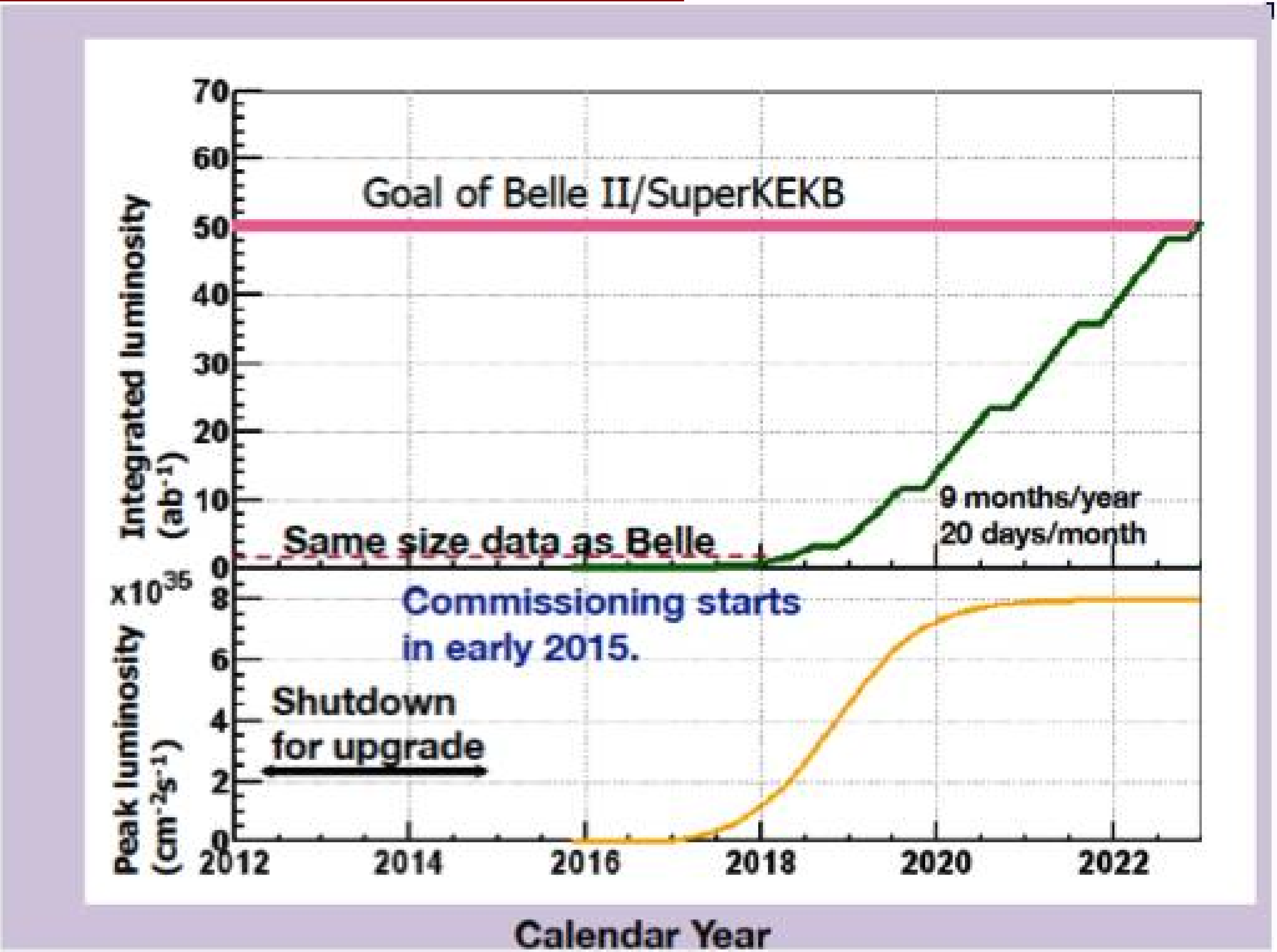


Single photon angle resolution σ_0 = 13.5mrad
# of photoelectrons Npe = 15.3

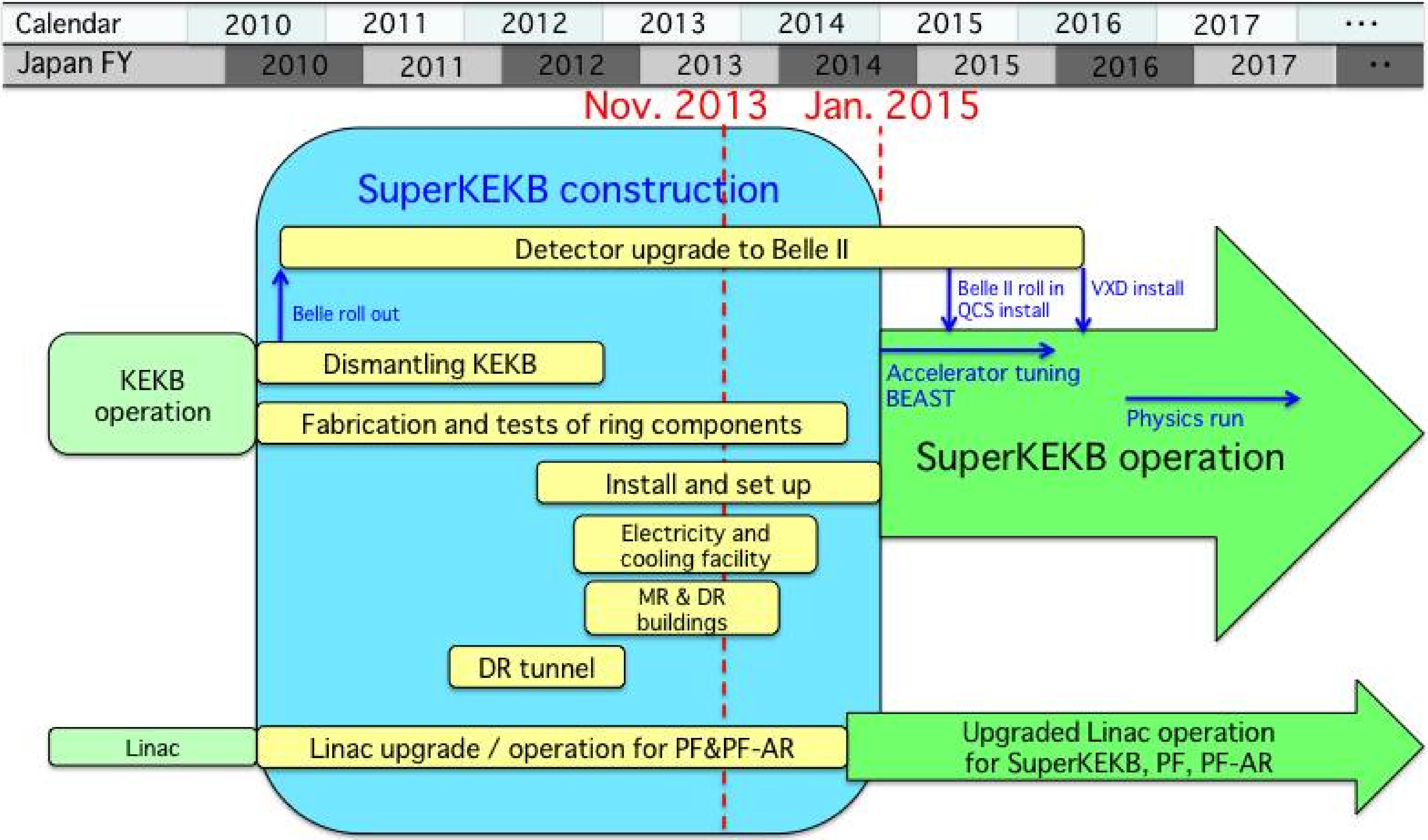
31

6.6 σ π/K at 4GeV/c !

Belle-II: Luminosity



SuperKEKB: Schedule



Summary

In the last decade, B-factories have found most of the still missing pieces in bottomonium and charmonium spectra. S and P wave spectra below thresholds are almost complete: only the 2nd radial excitations (singlet 3S and 3P, doublet 3S) are missing.

Many new questions arose from unexpected states across and above thresholds: Belle, Babar and BES-III are discovering a plethora of new states, the so called XYZ mesons, which require a spectroscopy with new degrees of freedom (tetraquarks, molecules, hybrids).

Precise tests of NRQCD will require O(10^9) samples of Y(1,2,3S) decays or larger.

Charged bottomonia (Zb states) have provided unique pathways to discover the missing spin singlet states. Their understanding is tightly coupled to the study of the charmonium-like counterparts (Zc states) observed by Belle and BES-III. Running at or above Y(5S) is compulsory for making further progress on this topic.

Bottomonia provides also a unique environment for the study of hyperon-nucleon interactions, as their annihilations produce slow hyperons in large quantities, and are the only mesons which can produce nuclei (from deuteron to He-4).
Possible studies include further searches for the long sought H-dibaryon.

Belle-II is designed to run at 40 times higher luminosity, to accumulate 50 ab^{-1} of data by 2022, and will start physics running in 2016.