Exotic and conventional bottomonium physics prospects at

Belle II

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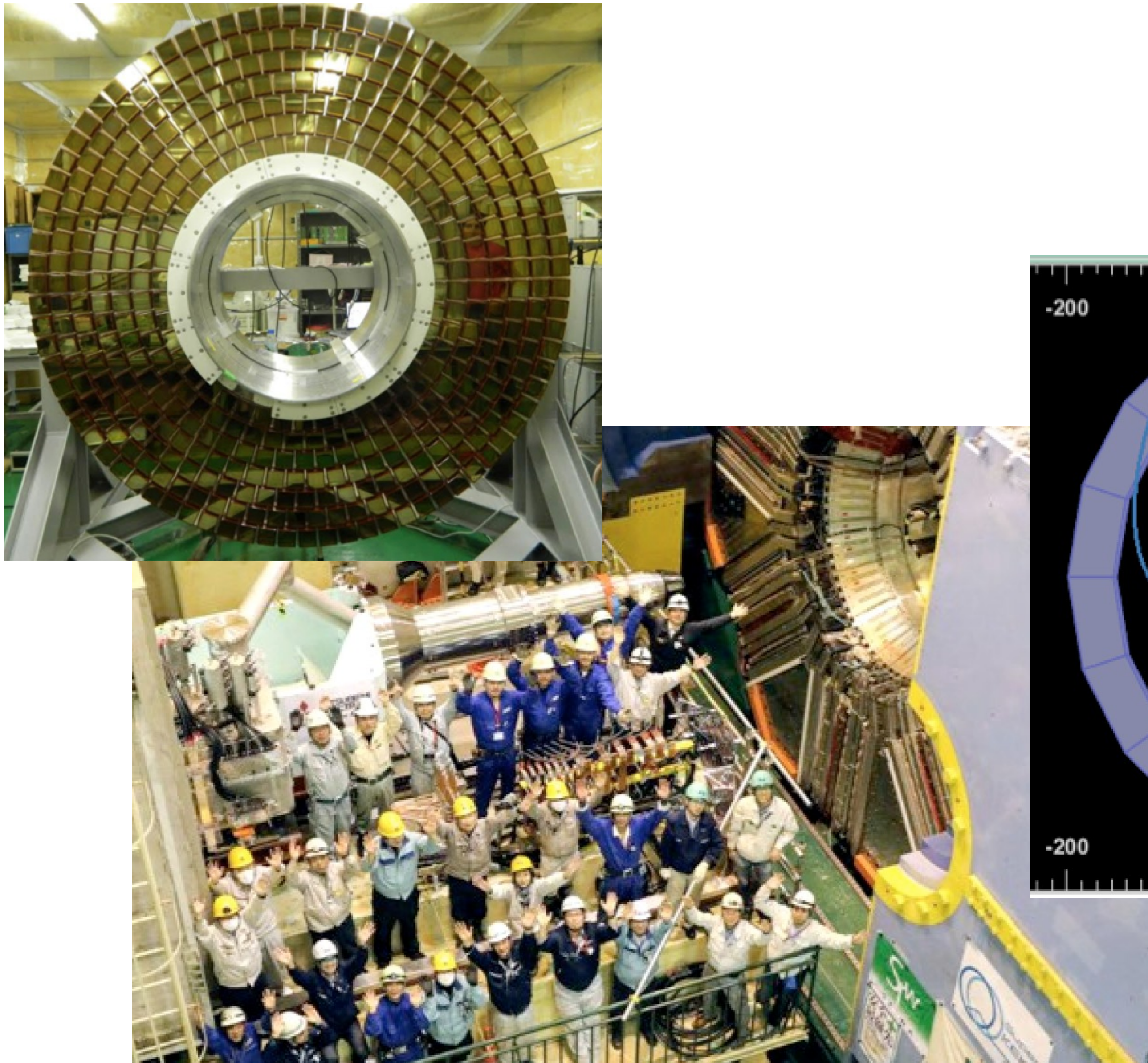
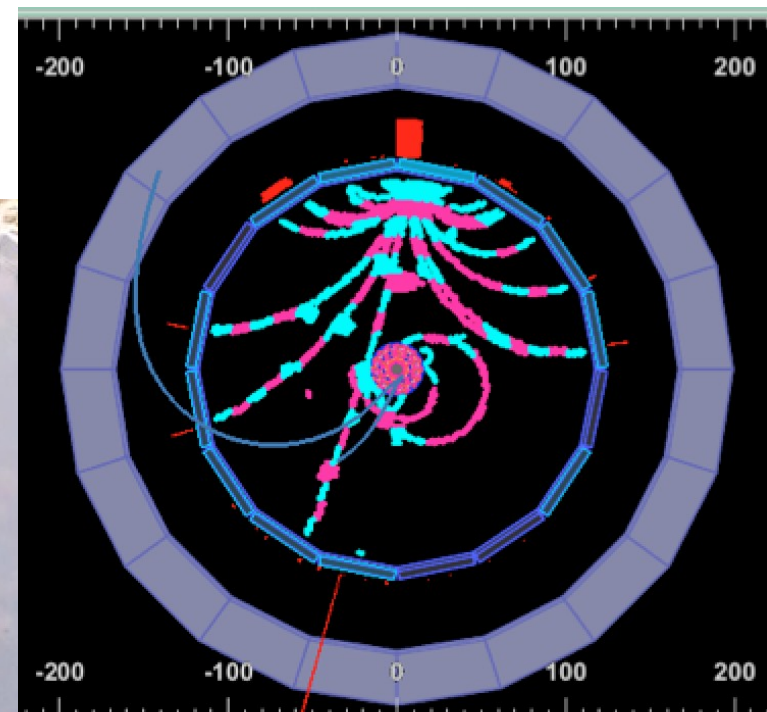
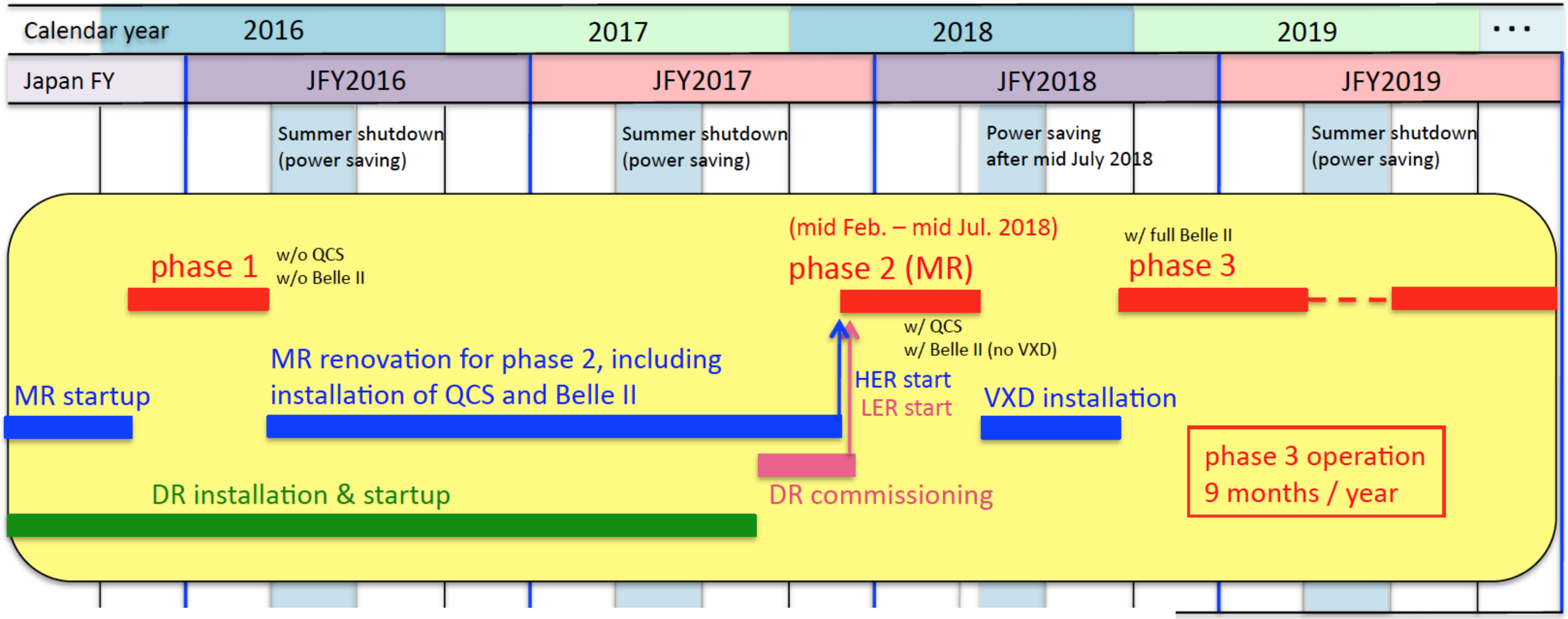




PANIC 2017, Beijing

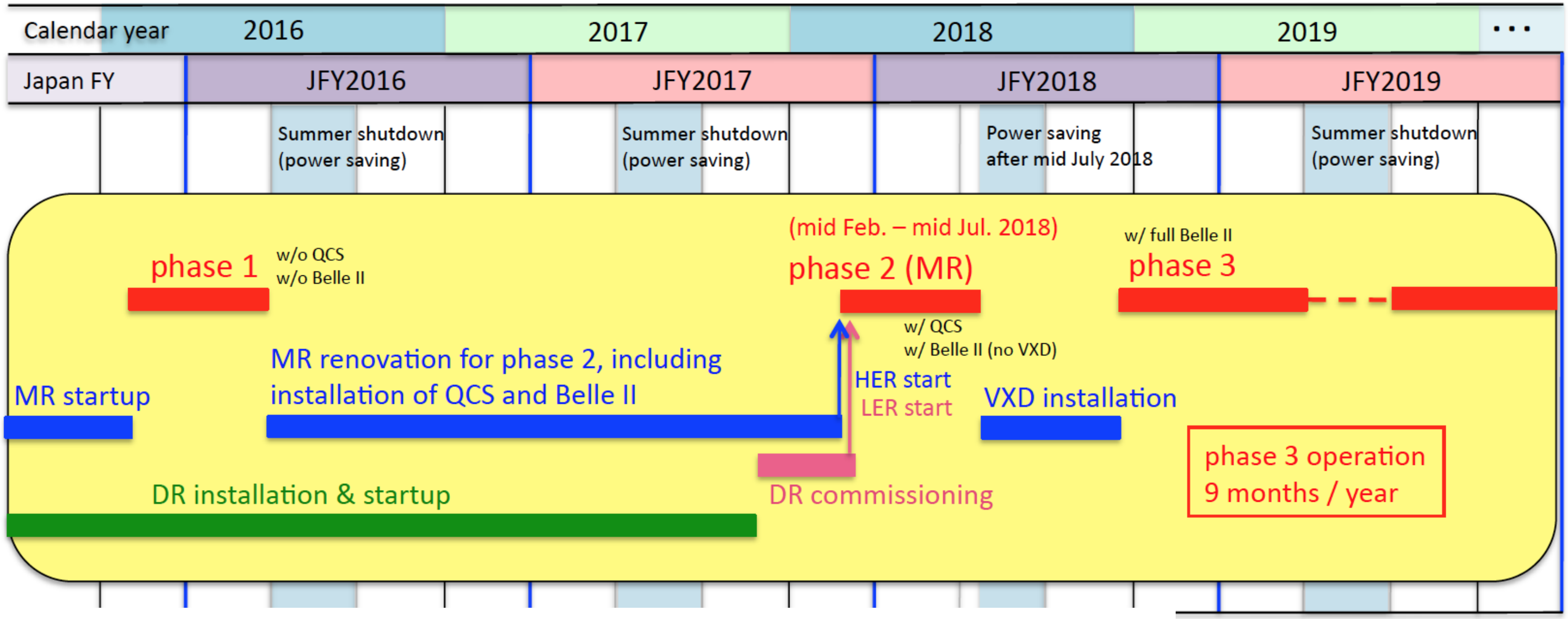
KEKB short term plans: startup schedule



- Summer 2017: global cosmic ray run
- September 2017: ARICH and forward ECL
- October 2017: start Beast Phase II VXD commissioning
- Nov 2017 - Summer 2018: Phase 2 commissioning, with two main goals:
  - ✓ tune SuperKEKB with nano-beams - eventually reach KEKB design luminosity
  - ✓ ensure background levels are compatible with vertex detector operation
  - ✓ then, if compatible with the above, also do some physics without vertex detectors
- Summer 2018: install vertex detectors
- End 2018: full detector operation - start of Physics run

11/4: Belle-II roll in

KEKB short term plans: startup schedule



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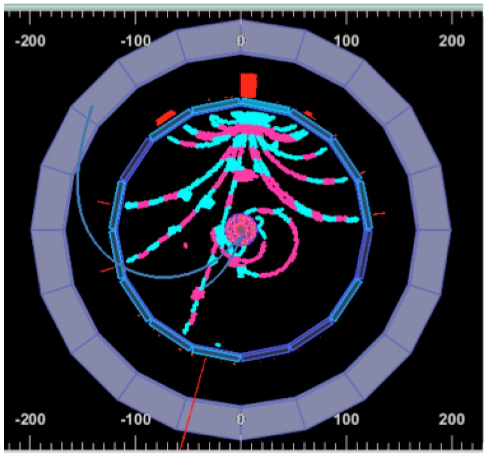
6/2017: cosmics in B field



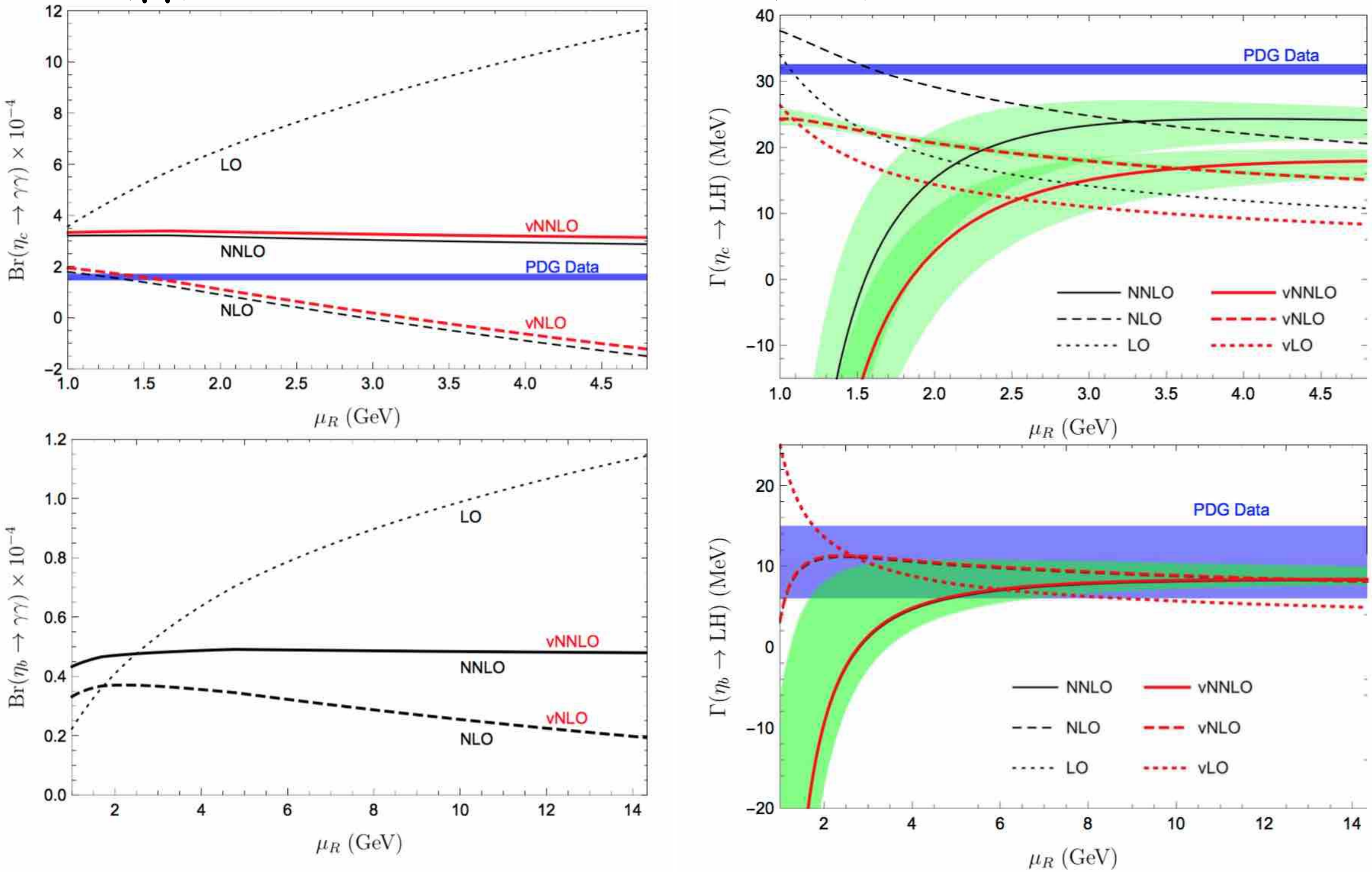
Bottomonium physics from Υ(4,5S): $\eta_b \to \gamma\gamma$

Chung, Lee, Yu , PLB697 (2011) 48-51

$\Gamma(\gamma\gamma)$ $\Gamma(LH)$

η_c

η_b



Bottomonium physics from Υ(4,5S): $\eta_b \to \gamma\gamma$

Chung, Lee, Yu (2011)

$\Gamma[\eta b(1S) \to \gamma\gamma] = 0.512 \pm 0.095$ keV,

$\Gamma[\eta b(2S) \to \gamma\gamma] = 0.235 \pm 0.043$ keV

→

$B[\eta b(1S) \to \gamma\gamma] \sim 5 \times 10^{-5}$

$B[\eta b(2S) \to \gamma\gamma] > 1 \times 10^{-5}$

Y(4S) → η $h_b(1P)$ → γ $\eta_b(1S)$

η → γγ soft

$\eta_b(1S)$ → γγ hard

All neutral final state
Trigger on hard γγ pair not possible due to $e^+e^- \to \gamma\gamma$ QED background

Trigger on soft dipion pair + hard γγ is the solution

Y(4S) → η $h_b(1P)$ → γ $\eta_b(1S)$

η → $\pi^+\pi^-\pi^0$

$\eta_b(1S)$ → γγ hard

~0.5 Millions $\eta_b(1S)$ ($\eta \to \pi\pi\pi$)
in 50/ab of Y(4S)
~ 15 full reconstructed $\eta_b(1S) \to \gamma\gamma$

Y(5S) → $\pi^+\pi^-$ $h_b(1P)$ → γ $\eta_b(1S)$

$\eta_b(1S)$ → γγ hard

~2.5 Millions $\eta_b(1,2S)$
in 10/ab of Y(5S)
~ 100 full reconstructed $\eta_b(1,2S) \to \gamma\gamma$

Motivations for non-Υ(4S) running

Particles	Threshold, GeV/c^2
$B^{(*)}\bar{B}^{**}$	11.00 – 11.07
$B_s^{(*)}\bar{B}_s^{**}$	11.13 – 11.26
$\Lambda_b\,\bar{\Lambda}_b$	11.24
$B^{**}\bar{B}^{**}$	11.44 – 11.49
$B_s^{**}\bar{B}_s^{**}$	11.48 – 11.68
$\Lambda_b\,\bar{\Lambda}_b^{**}$	11.53 – 11.54
$\Sigma_b^{(*)}\,\bar{\Sigma}_b^{(*)}$	11.62 – 11.67
$\Lambda_b^{**}\,\bar{\Lambda}_b^{**}$	11.82 – 11.84

Energy	Outcome	Lumi (fb^{-1})	Comments
Υ(1S) On	N/A	60+	-No interest identified -Low energy
Υ(2S) On	New physics searches	20+	-Requires special trigger
Υ(1D) Scan	Particle discovery	10-20	-Already accessible in B Factories?
Υ(3S) On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 3
Υ(3S) Scan	Precision QED	~10	-Understanding of beam conditions needed
Υ(2D) Scan	Particle discovery	10-20	-Unknown mass
>Υ(4S) On	Particle discovery?	10+?	-Energy to be determined
Υ(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

Y(6S) Yb? Y(2D) Y(1D)

Experiment	Scans/Off. Res.	Υ(5S) 10876 MeV		Υ(4S) 10580 MeV		Υ(3S) 10355 MeV		Υ(2S) 10023 MeV		Υ(1S) 9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

Scenarios for Phase-II

Where to run for Ldt ~ 10 fb^{-1}?

- E = 10.65 GeV

Dip in Rb , just on B*B* threshold

- E = 10.75 GeV

On the first $Z_b\pi$ threshold

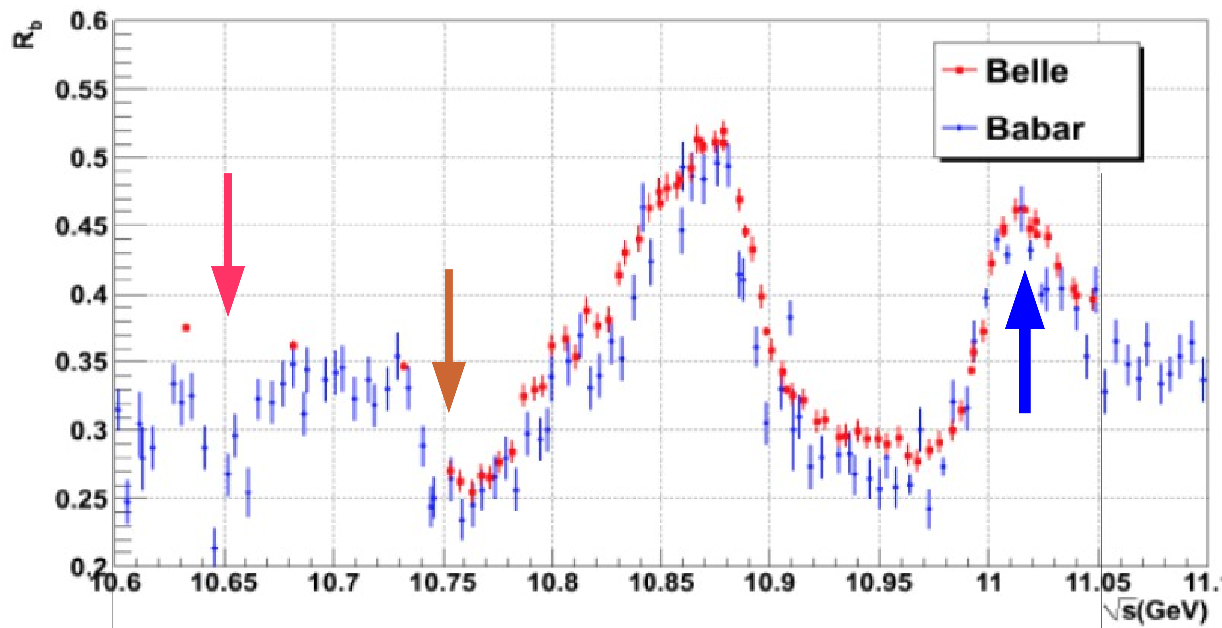
Above Rb drop at 10.74

Bump observed in R_Υ

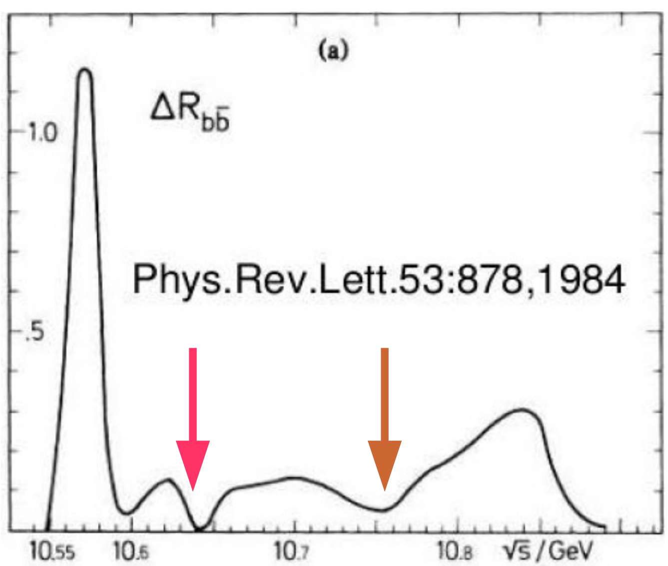
- E = 11.02 GeV

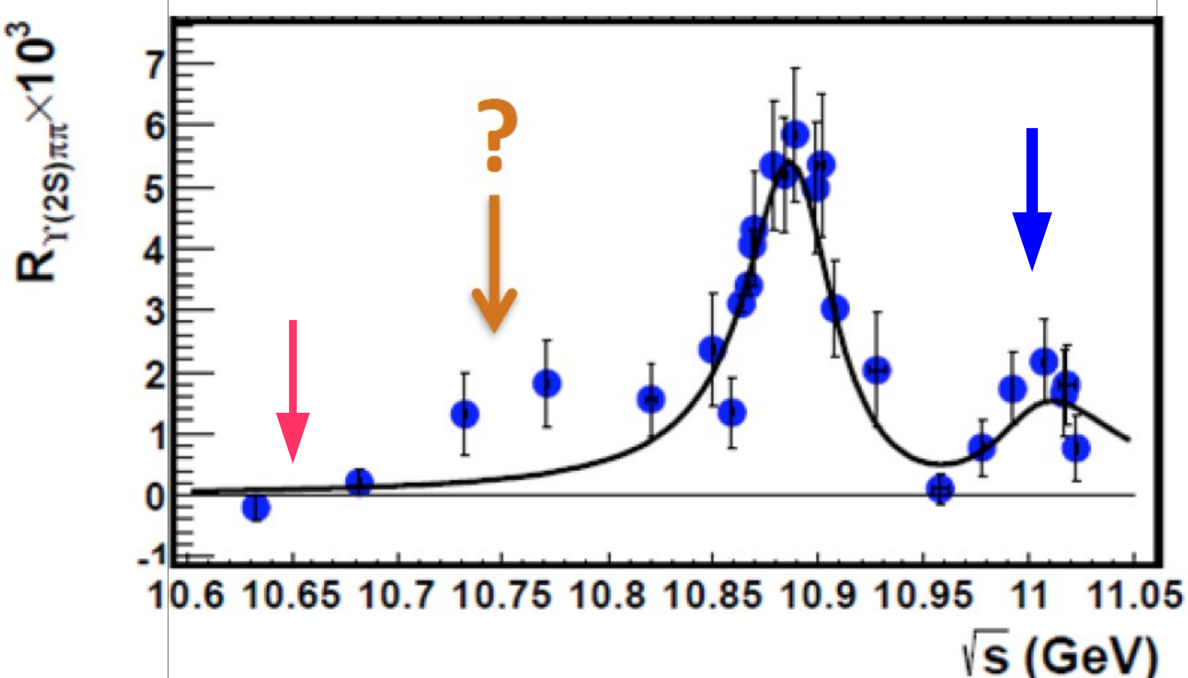
Y(6S) peak,

6pt scan (1 fb^{-1} each) in Belle-I

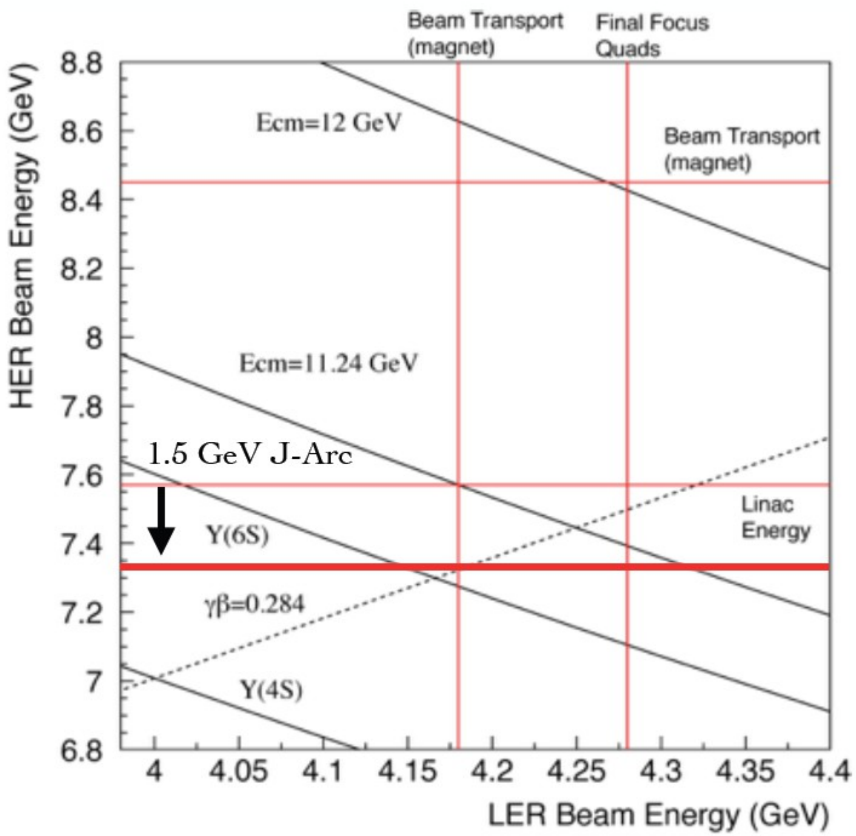


Note: features predicted by theory (coupled channel model)





Super KEKB limitations



Y(4S)
HER: 7 GeV
LER: 4 GeV

A - B sector : 1 backup unit
C - 2 sector: 1 backup unit
3 - 5 sector: 1 backup unit
(1 unit = 160 MeV)

C - 2 → 2 backup units in Phase 3

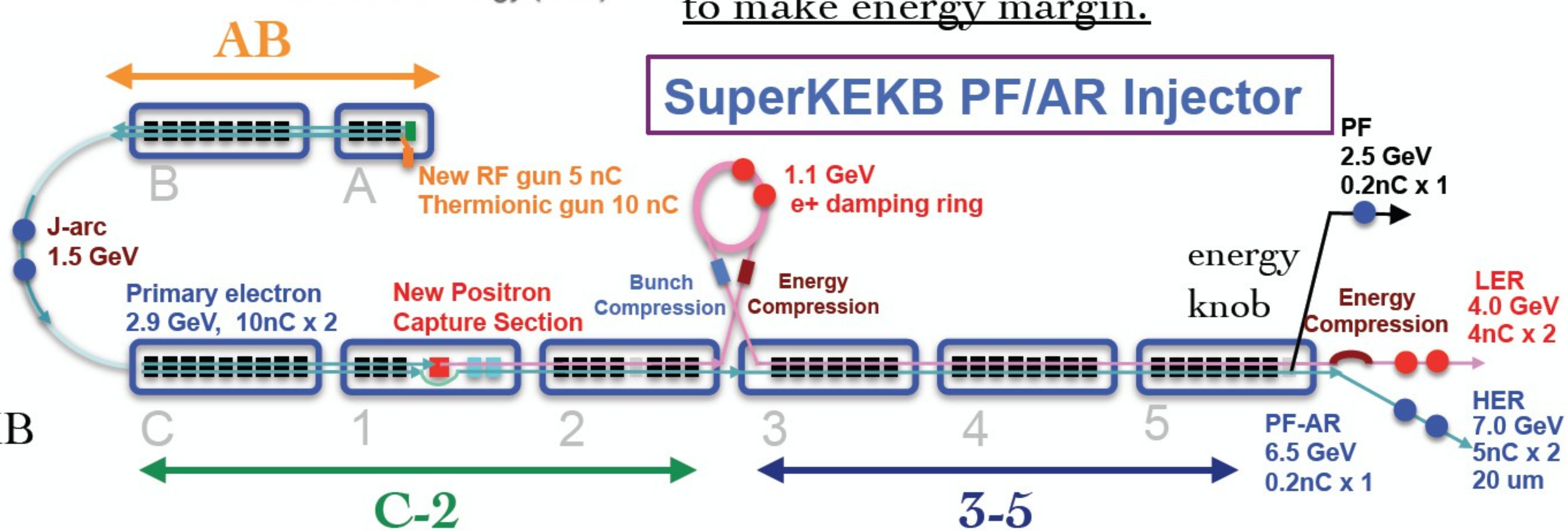
Y(6S)
HER: 7.30 GeV
no backup unit in C - 5 sector(max 7.35 GeV)
LER: 4.16 GeV
no backup unit in 3 - 5 sector(max 4.18 GeV)

Risk at higher beam energy

<u>The old accelerating structures should be replaced to make energy margin.</u>

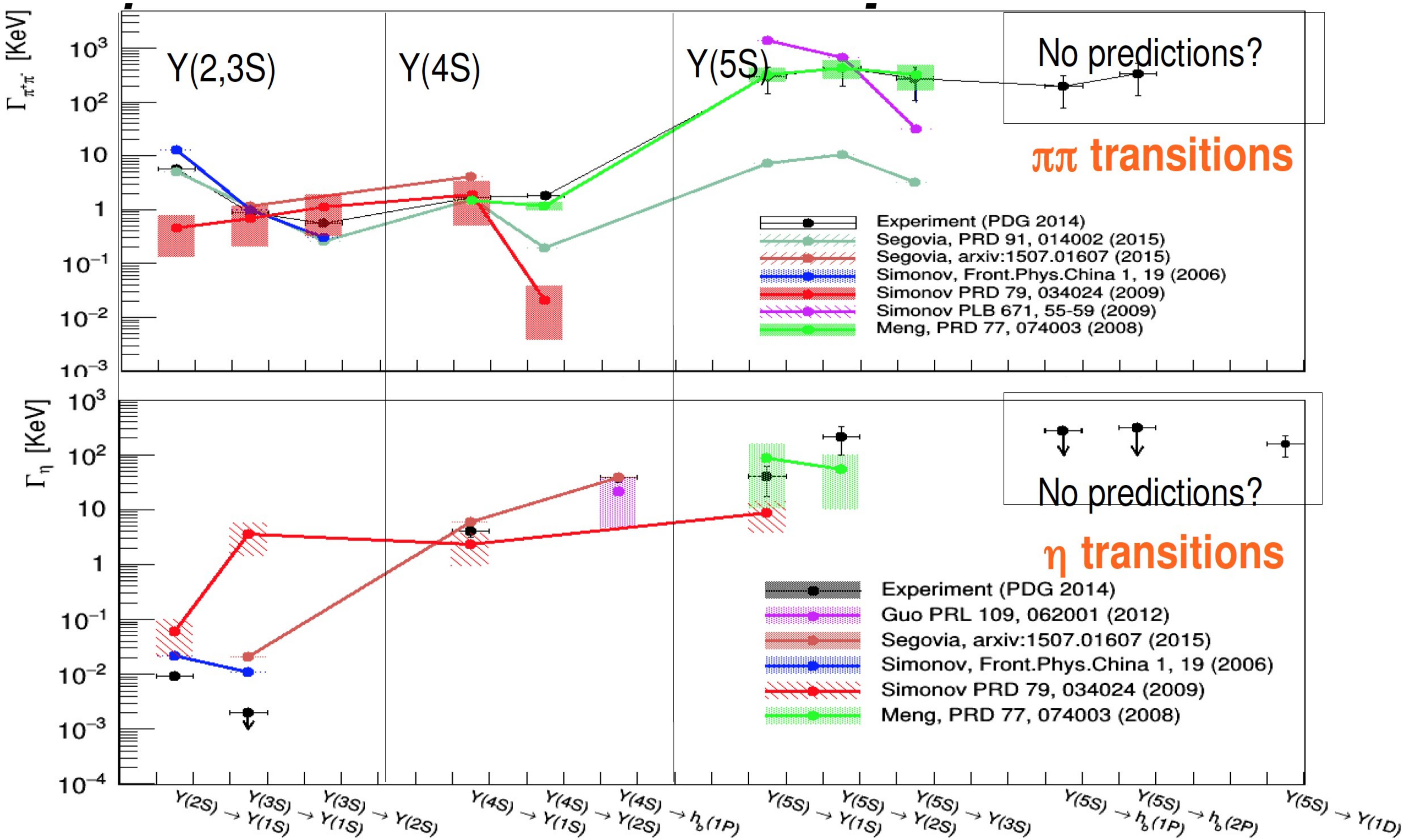
1.5 GeV Arc

-0.2 GeV from KEKB



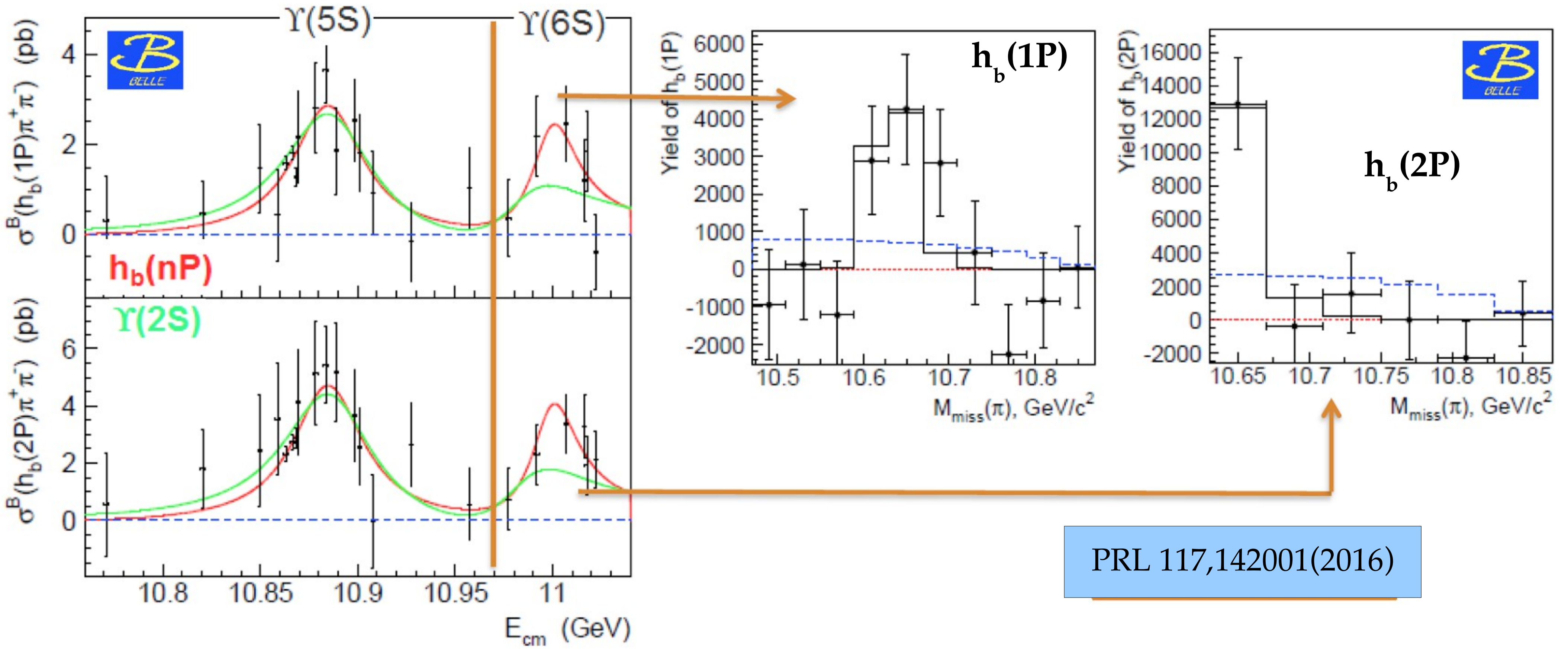
The puzzle of eta / dipion transitions in bottomonium

Still lacking a unified theoretical model to describe the observed evolution of the cross section



Belle results on $e^+e^- \to h_b(1,2P)\pi\pi$

The analysis of the 6 points (1 fb^{-1} each) in the proximity of the Y(6S) show a clear evidence of dipion transitions to both the h_b states. The small statistics does not allow to quantify the fractions decaying via $Z_b(10610)$ and $Z_b(10650)$.



PRL 117,142001(2016)

Belle II is planning to take more data at Y(6S) during the first or second year of data taking

Belle II and the new forms of matter

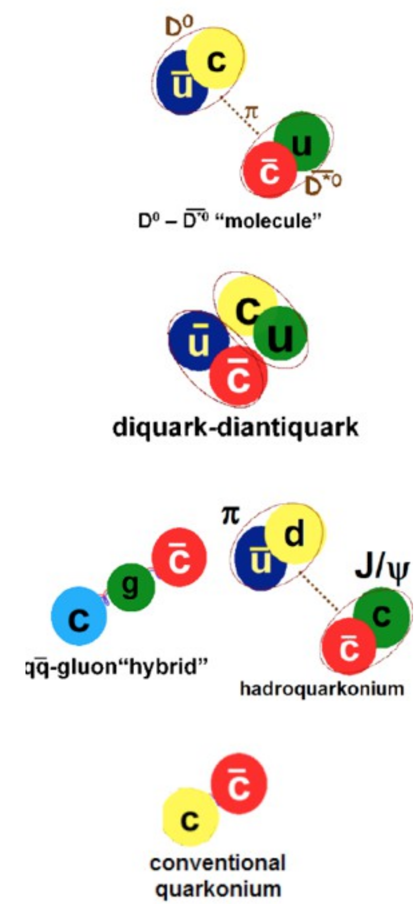
Meson Molecules (Guo et al, ArXiV 1705.00141)
weakly bound states of two mesons

Tetraquarks (Polosa et al, PRD89, 114010 (2014))
Diquark-antidiquark states bound by the color force

Hybrids (Barnes et al, PRD 52,5242 (1995))
colored $Q\overline{Q}$ states with a bound excited gluon

Hadroquarkonium (Dubinskij et al, PLB 671, 82 (2009))
$Q\overline{Q}$ bound state surrounded by a cloud of light quarks

Standard quarkonia (Swanson, PRD 91, 034009 (2015))

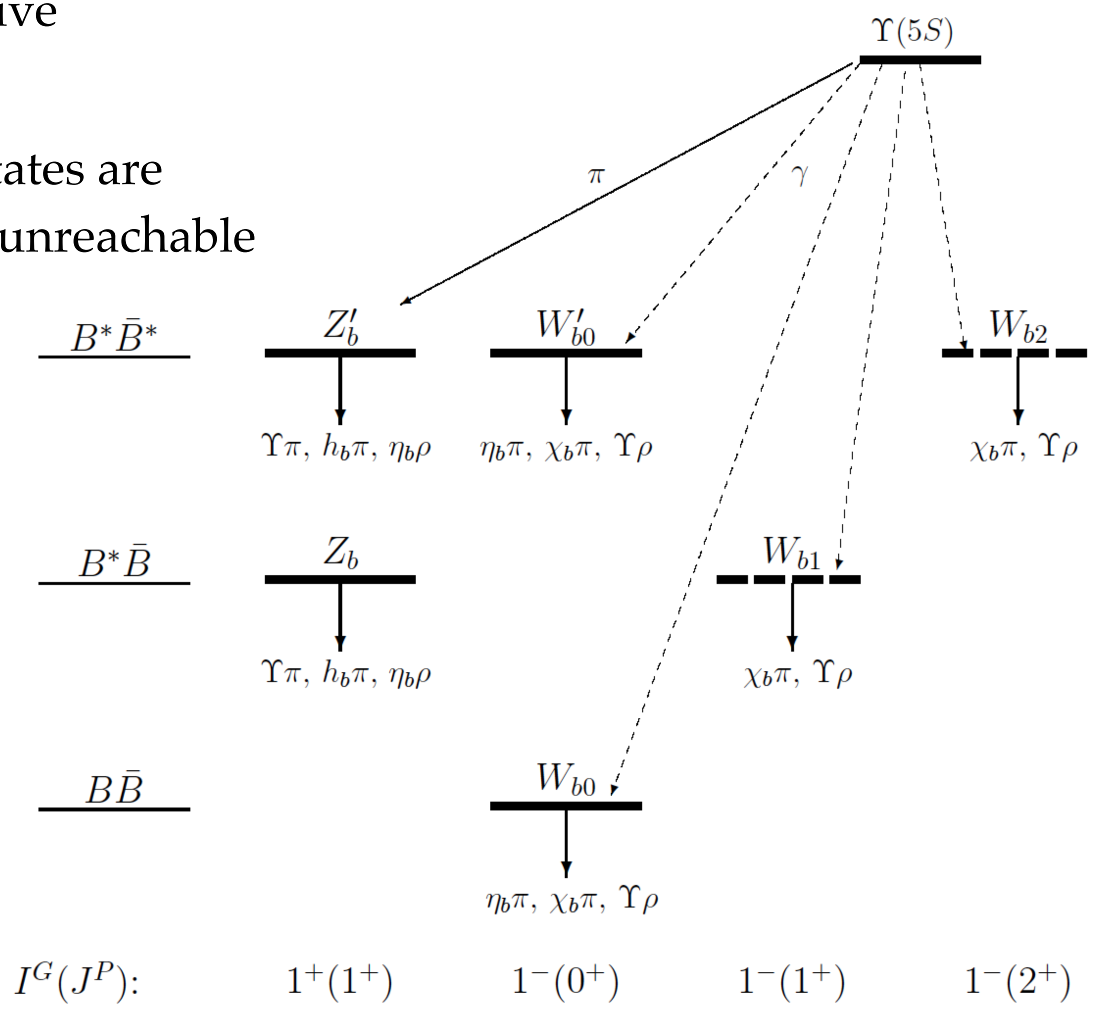


Molecules from Υ(6S)

(Voloshin at B2TIP-2016)

The molecular model of the Z_b states predicts neutral partners (W_b) with J=0,1,2 which are expected on the same energy range, and should be reachable from Υ(5,6S) via radiative transitions.

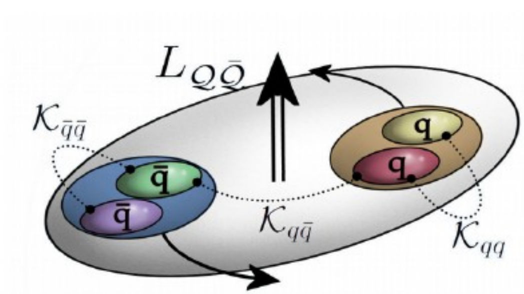
Further hadronic transitions to W_b states are expected above W_b threshold (11.3) unreachable at present.



Tetraquarks between Υ(5S) and Υ(6S)

Ali (B2TIP Krakov)

Label	J^{PC}	charmonium-like State	charmonium-like Mass [MeV]	bottomonium-like State	bottomonium-like Mass [MeV]
X_0	0^{++}	—	3756	—	10562.2
X_0'	0^{++}	—	4024	—	10652.2
X_1	1^{++}	$X(3872)$	3890	—	10607.2
Z	1^{+-}	$Z_c^+(3900)$	3890	$Z_b^{+,0}(10610)$	10607.2
Z'	1^{+-}	$Z_c^+(4020)$	4024	$Z_b^+(10650)$	10652.2
X_2	2^{++}	—	4024	—	10652.2
Y_1	1^{--}	$Y(4008)$	4024	$Y_b(10891)$	10891.1
Y_2	1^{--}	$Y(4260)$	4263	$Y_b(10987)$	**10987.5**
Y_3	1^{--}	$Y(4290)$ (or $Y(4220)$)	4292	—	**10981.1**
Y_4	1^{--}	$Y(4630)$	4607	—	11135.3
Y_5	1^{--}	—	6472	—	13036.8



The tetraquark model (Maiani et al., Ali et al.) predicts a full spectrum of states in both bottomonium and charmonium region.

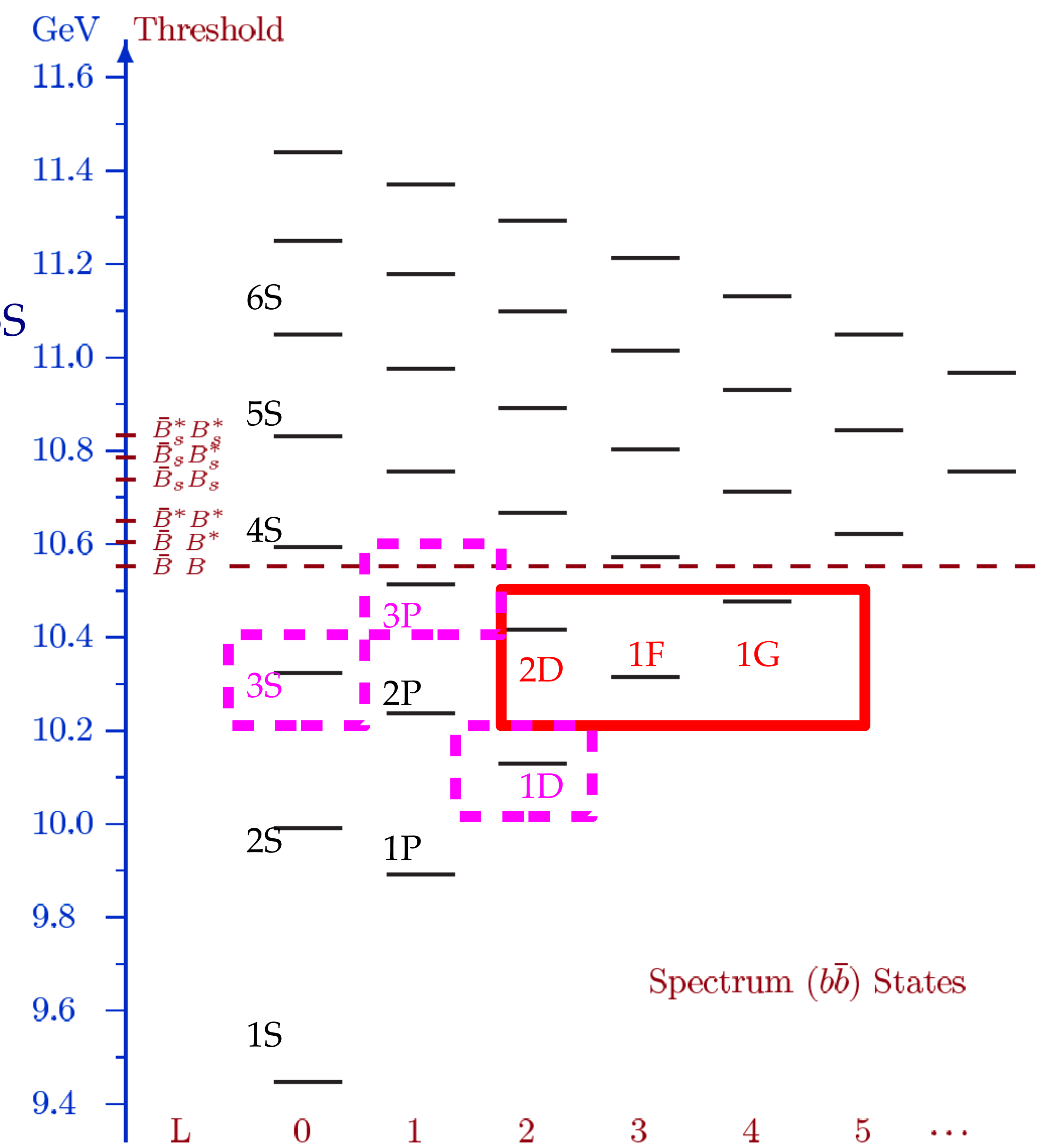
Missing pieces of spectrum below threshold

Below threshold:
* 3S: $\eta_b(3S)$ not yet observed by anyone, maybe reachable from $h_b(3P)$?
* 3P: $\chi_b(3P)$ discovered at LHC, not yet resolved, can we see them from 4S?
  $h_b(3P)$: too high to be reached from 5S via Z_b, maybe from 6S? How?

* 1D states : triplet states BEST STUDIED from 3S, singlet (2^{-+}) *maybe* reachable from $h_b(2P)$.We plan to scan the 1^{--} region.

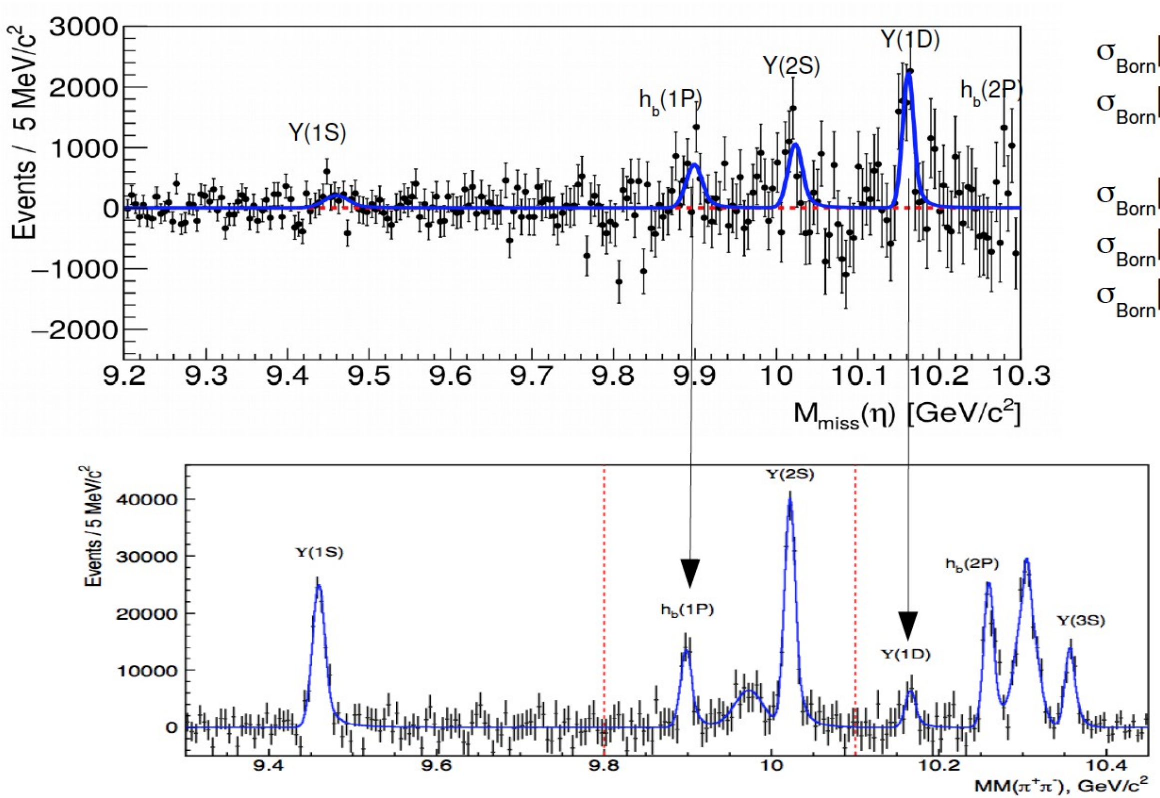
* 2D, 1F, 1G: totally unknown
We propose to search for the lowest member of the 2D triplet with a scan.
The others *may* be reached from 6S.

The 1F triplet $2,3,4^{++}$ is very close in mass to Y3S, but may be reached from the 2D triplet via E1 radiative transitions.



From Υ(5S,6S): Υ(1,2D) searches in Belle II

Eta vs dipion transitions with 120 fb^{-1} at Υ(5S)



$\sigma_{Born}[e^+e^- \to \eta\, \Upsilon_{1,2}(1D)] = (1.50 \pm 0.30 \pm 0.20)$ pb

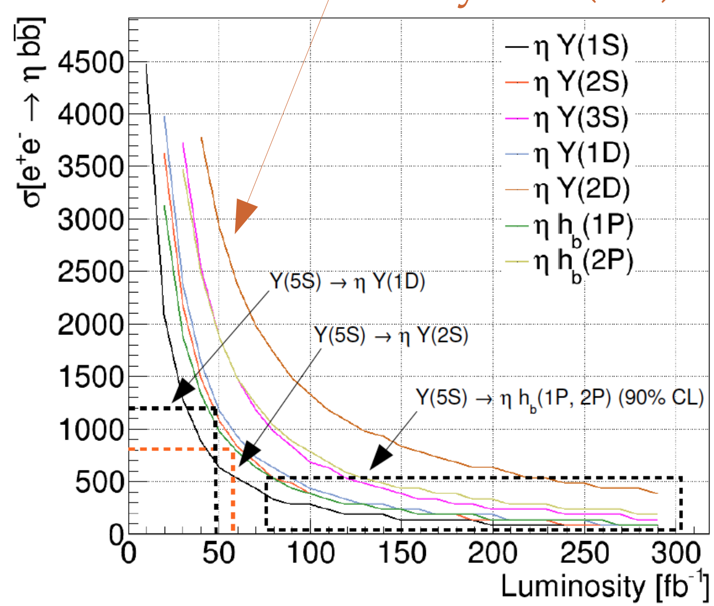
$\sigma_{Born}[e^+e^- \to \eta\, \Upsilon(2S)] = (0.97 \pm 0.31 \pm 0.19)$ pb

$\sigma_{Born}[e^+e^- \to \eta\, \Upsilon(1S)] < 0.61$ pb

$\sigma_{Born}[e^+e^- \to \eta\, h_b(1P)] < 0.92$ pb

$\sigma_{Born}[e^+e^- \to \eta\, h_b(2P)] < 0.69$ pb

5 σ level for discovery of Υ(2D)

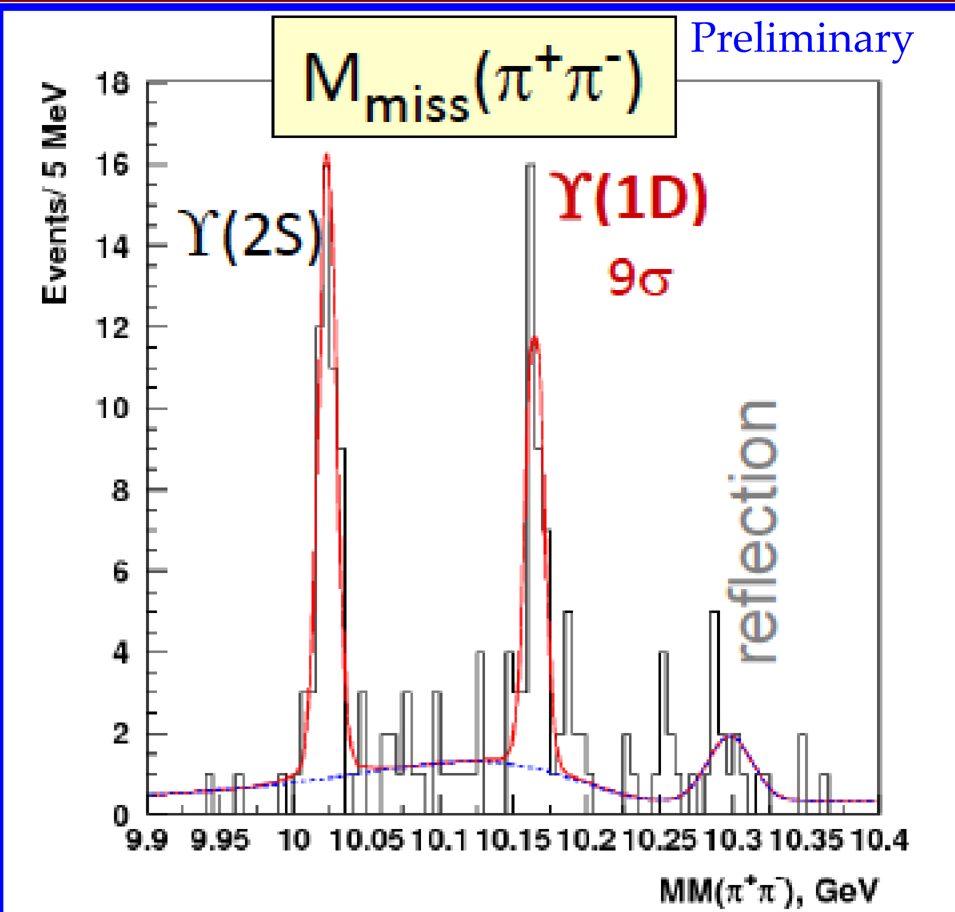


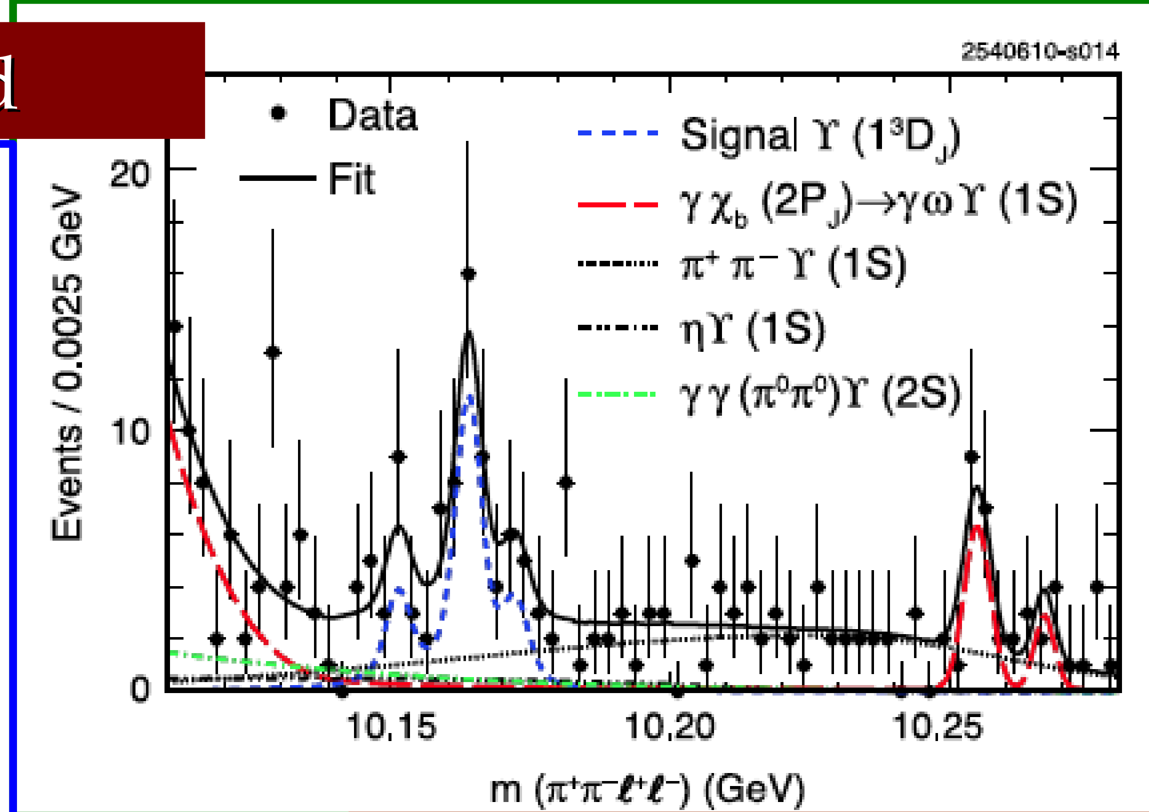
- Dipion transitions main discovery tool for charged bottomonia (more Z_b's?)

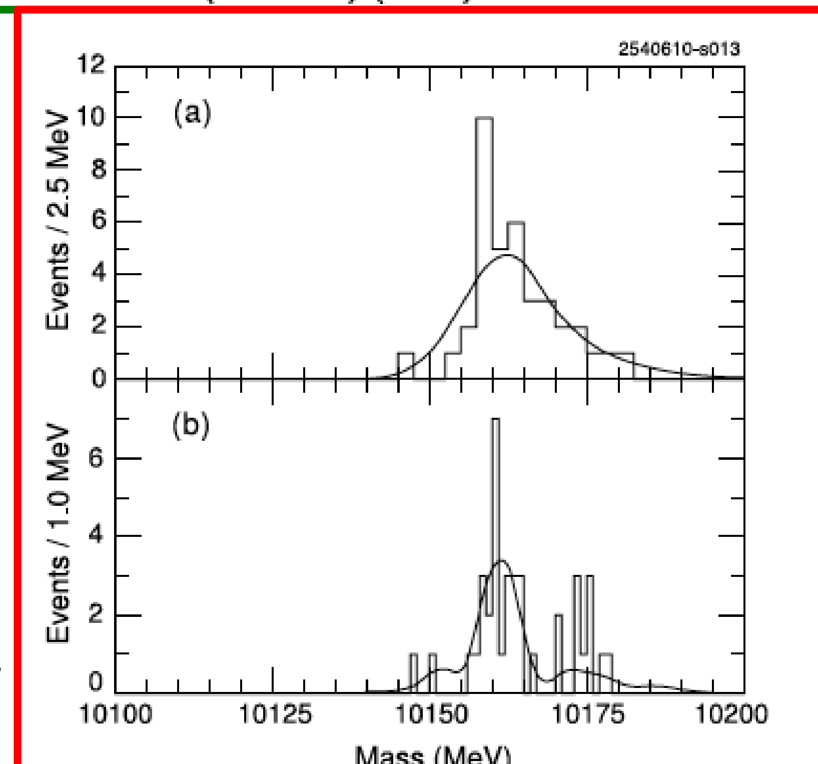
- Eta transitions : best pathway to Υ(2D)?

- Υ(6S) running will be staged: first 10 fb^{-1} , ... 50 fb^{-1}, ... 150 fb^{-1}

$\Upsilon(1D)$ triplet still unresolved





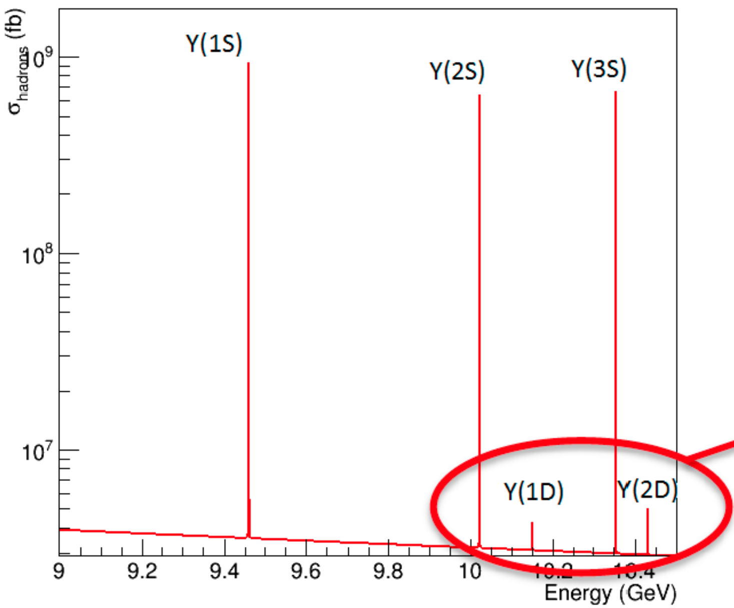


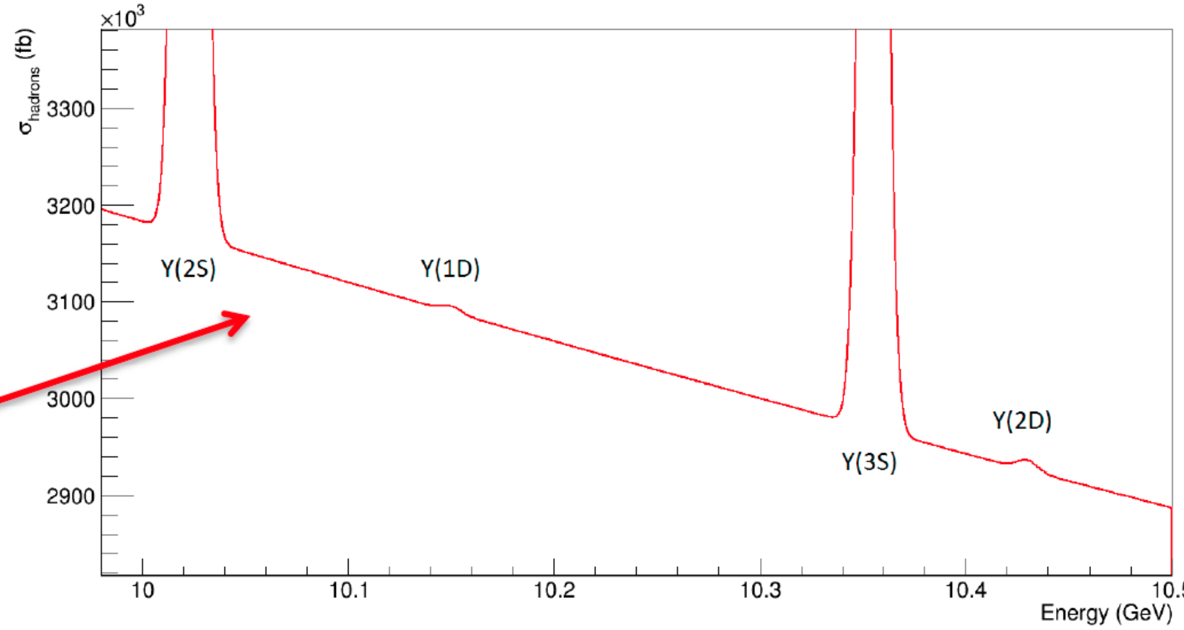
Belle (from 5S) Proc. EPS-HEP 2013	$10164.7 \pm 1.4 \pm 1.0$ MeV
BaBar (from 3S) PRD82 (2010) 111102	$10164.5 \pm 0.8 \pm 0.5$ MeV
CLEO (from 3S) PRD70 (2004) 032001	$10161.1 \pm 0.6 \pm 1.6$ MeV

Scanning $\Upsilon(1,2^3D_1)$?

Observable : e+e- to hadrons

Continuum cross section: $\sigma = N_c Q_f^2 \frac{86.8 \text{ nb}}{s\,(\text{GeV}^2)}$





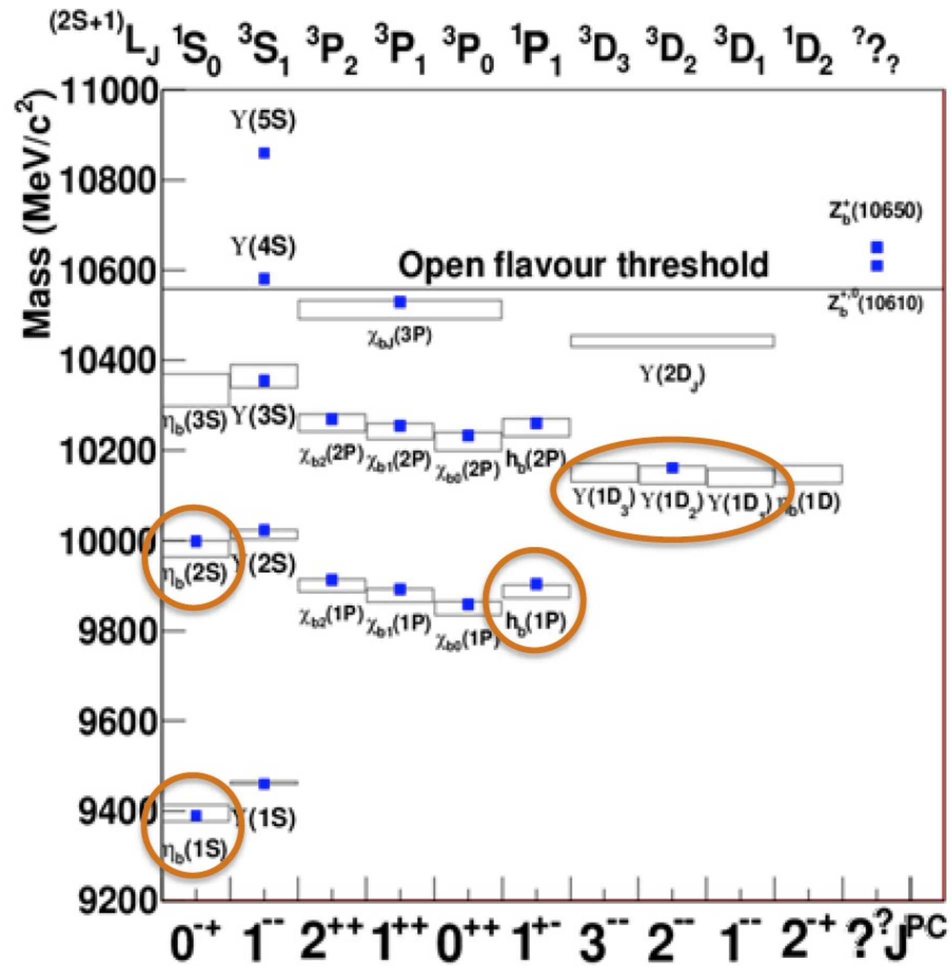
Search for 1D: 7 point scan (5 MeV steps) around 10.15 GeV

Search for 2D: 7 point scan (5 MeV steps?) around 10.43 GeV

IF the 2S scan is successful, we may envisage a longer run on 2D peak and search for 1F states (single photon spectrum, probably large background from ISR Υ(3S))

A rich physics program at Υ(3S)

- **200fb^{-1} ~7xBaBar (Phase 3+)**
- $\Upsilon(1^3D_J)$ triplet
  - J=1,3 yet to be discovered
  - Pathways: 4γ, $2\gamma 2\pi$, incl. γ
- $\eta_b(1S,2S)$
  - Confirm $m(\eta_b(1S,2S))$
  - $\Upsilon(3S) \to \gamma\ \eta_b(2S)$
  - $\chi_{b0}(2P) \to \eta\ \eta_b(1S)$
- Hadronic ($\pi^o,\pi^+\pi^-,\eta,\omega$) decays
  - $\Upsilon(3S) \to \pi^o h_b(1P)$, $\eta\Upsilon(1S)$
  - $\Upsilon(1D) \to \eta\Upsilon(1S)$
  - $\chi_b(2P)$: $\omega\Upsilon(1S)$, $\pi^+\pi^-\chi_{bJ}(1P)$
- Radiative transitions



Antinuclei in Y(3S) decays

CLEO results :

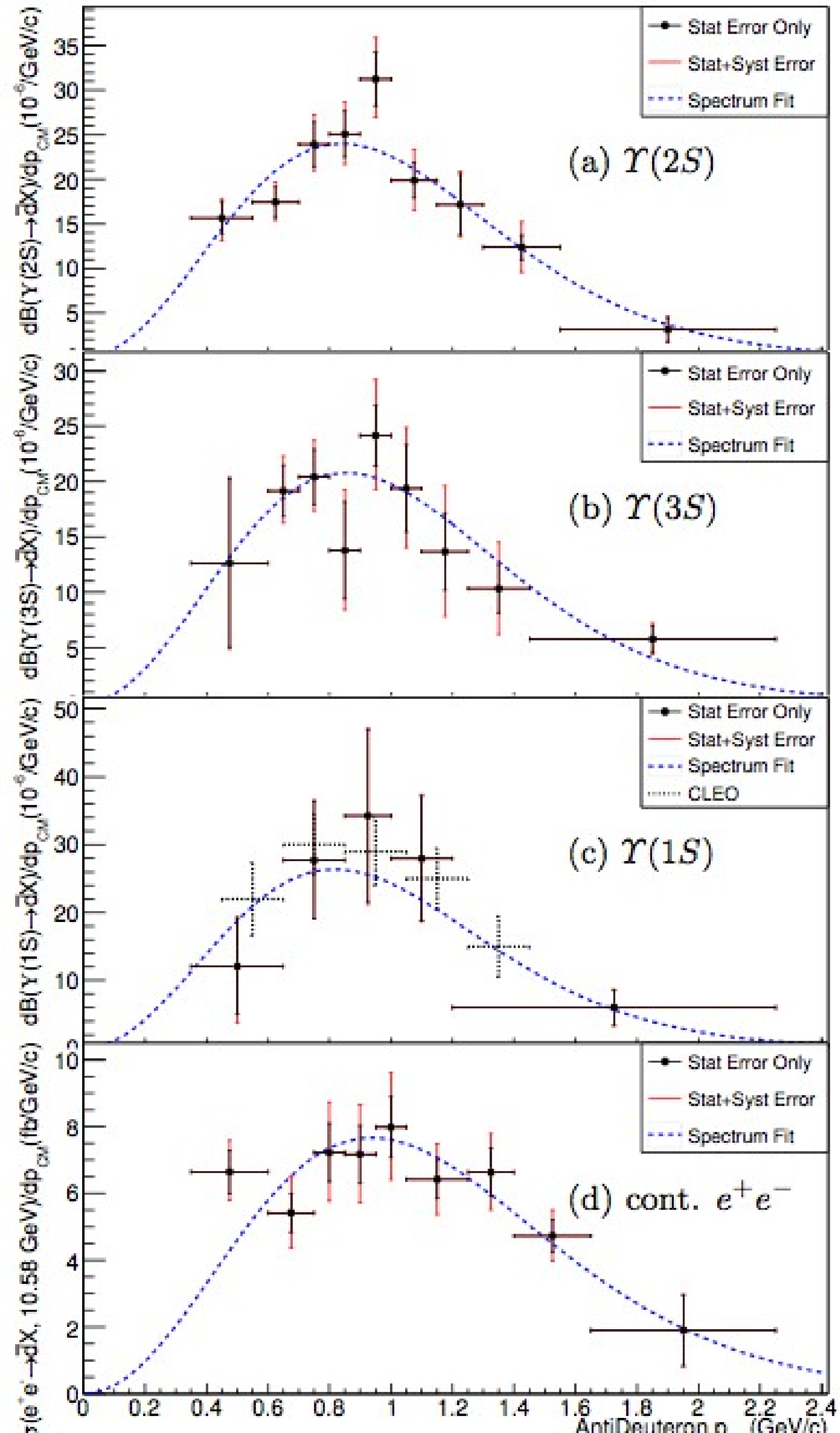
$$\mathcal{B}^{\,\rm dir}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.$$

$$\mathcal{B}\,(\Upsilon(2S) \to \bar{d} + X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}.$$

BABAR results :

Resonance	Onpeak	# of Υ Decays	Offpeak
$\Upsilon(4S)$	$429\,\mathrm{fb}^{-1}$	463×10^6	$44.8\,\mathrm{fb}^{-1}$
$\Upsilon(3S)$	$28.5\,\mathrm{fb}^{-1}$	116×10^6	$2.63\,\mathrm{fb}^{-1}$
$\Upsilon(2S)$	$14.4\,\mathrm{fb}^{-1}$	98.3×10^6	$1.50\,\mathrm{fb}^{-1}$

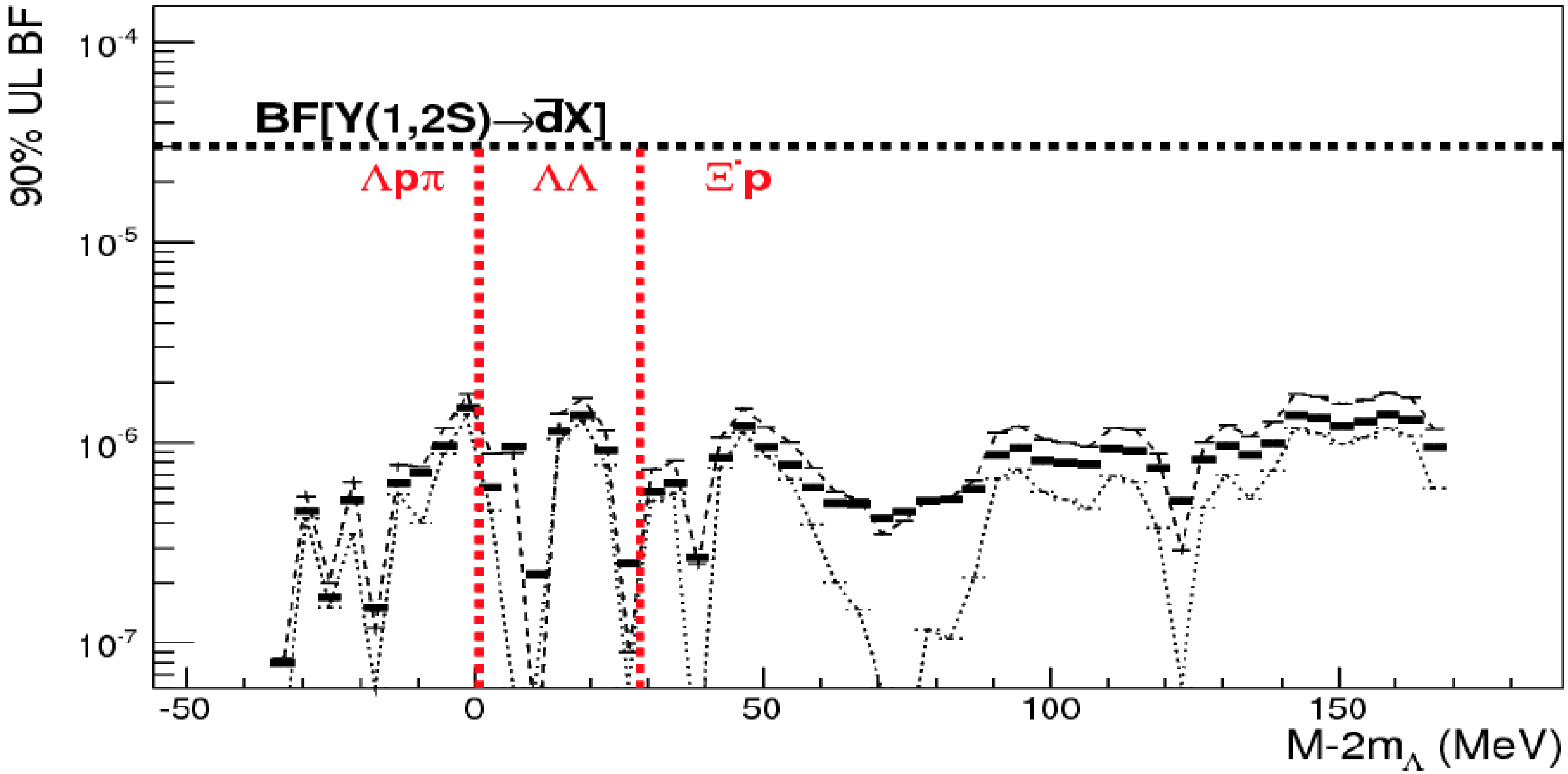
Process	Rate
$\mathcal{B}(\Upsilon(3S) \to \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-}$
$\mathcal{B}(\Upsilon(2S) \to \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-}$
$\mathcal{B}(\Upsilon(1S) \to \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-}$
$\sigma(e^+e^- \to \bar{d}X)$ $[\sqrt{s} \approx 10.58\,\mathrm{GeV}]$	$(9.63 \pm 0.41^{+1.17}_{-1.01})$ fb
$\dfrac{\sigma(e^+e^- \to \bar{d}X)}{\sigma(e^+e^- \to \mathrm{Hadrons})}$	$(3.01 \pm 0.13^{+0.37}_{-0.31}) \times 10^{-}$



Production mechanism still unclear: coalescence?
Associated $d\bar{d}$ production not checked by Babar
Good target for future Y(3S) decays samples

Υ(3S) to exa-quarks

Belle has extensively searched for the weakly bound Jaffe's H-dibaryon in Υ(1,2S) in a broad mass range, setting limits at O(10^{-1}) the measured deuteron production



Belle-II will further investigate these channels, both with fully reconstructed final modes, and in missing mass.

Wrapping it up ....

Belle II will tackle most of the physics questions opened by the first generation on B-factories to understand the nature of bottomonium like states and to complete the standard spectrum.

Belle showed that Υ(6S) running may have a large physics potential, even starting from the first period of data taking.

Hints for an exotic state at 10.75 GeV suggest further studies: and a fine scan through the whole Υ(4S-6S) region will be needed.

At least 200 fb^{-1} at (and about) the Υ(3S) peak are needed to address the following hot topics :

- *Rare η transitions* - *Spectroscopy of D waves*
- *Hindered radiative transitions* - *Exaquarks in Υ decays*

Scans of the Υ(1D) and Υ(2D) regions are being planned as well

Looking forward showing first results from Belle II in end 2018

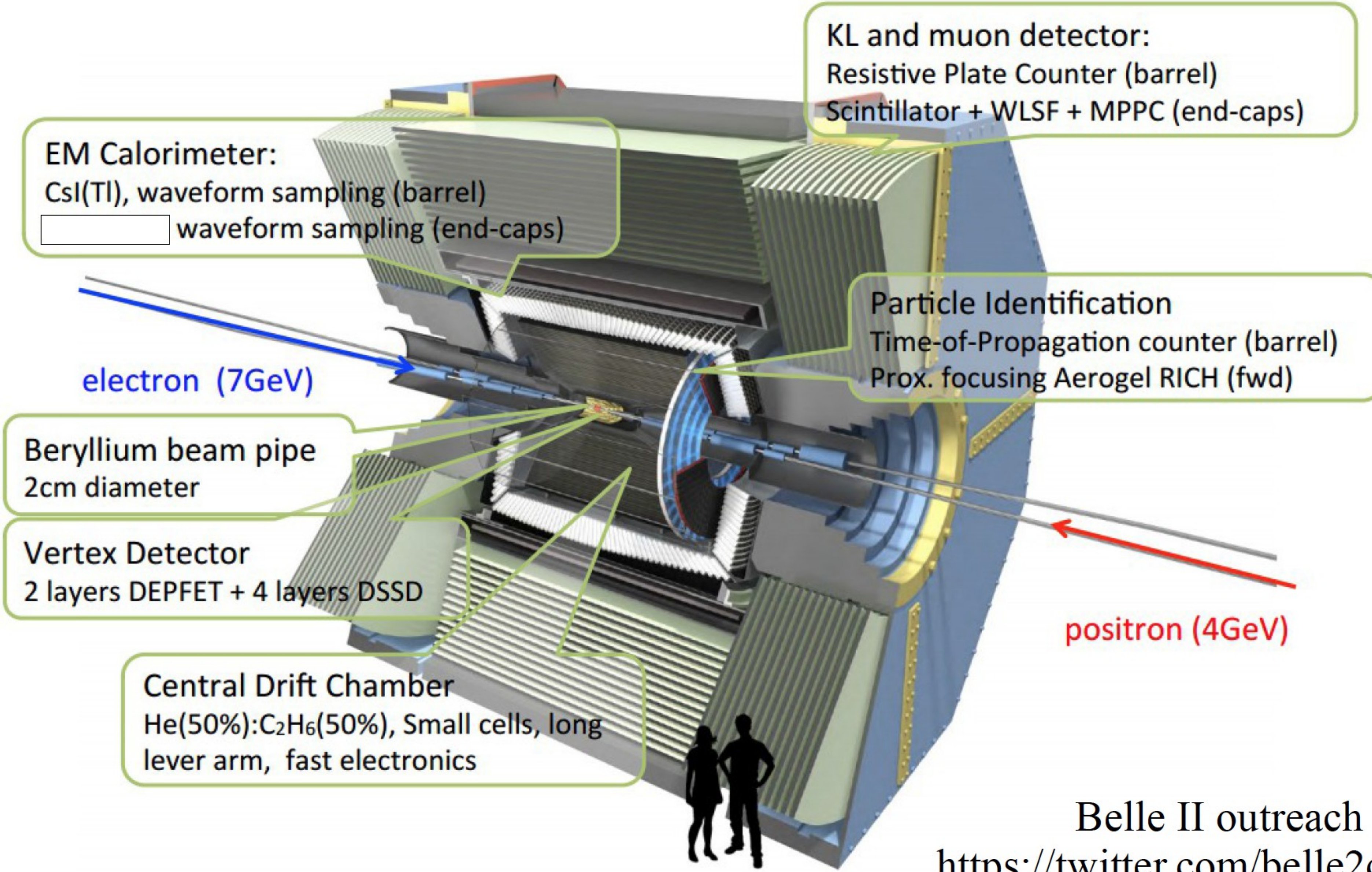
谢谢

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle [85, 86] (12.8), *BABAR* [87] (8.6)	2003	OK
		(<2.2)		$p\bar{p} \to (\pi^+\pi^- J/\psi) + \ldots$	CDF [88–90] (np), DØ [91] (5.2)		
				$B \to K(\omega J/\psi)$	Belle [92] (4.3), *BABAR* [93] (4.0)		
				$B \to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), *BABAR* [96] (4.9)		
				$B \to K(\gamma J/\psi)$	Belle [92] (4.0), *BABAR* [97, 98] (3.6)		
				$B \to K(\gamma\psi(2S))$	*BABAR* [98] (3.5), Belle [99] (0.4)		
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [100] (8.1), *BABAR* [101] (19)	2004	OK
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007	NC!
				$e^+e^- \to J/\psi\ (\ldots)$	Belle [54] (5.0)		
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^- \to \gamma(D\bar{D})$	*BABAR* [27] (np), Belle [21] (np)	2007	OK
$Y(4008)$	$4008^{+121}_{-\ 49}$	226 ± 97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle [104] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	$15^{+11}_{-\ 7}$	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [106, 107] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (5.5)	2007	NC!
$Z_2(4250)^+$	$4248^{+185}_{-\ 45}$	$177^{+321}_{-\ 72}$	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	*BABAR* [108, 109] (8.0)	2005	OK
					CLEO [110] (5.4)		
					Belle [104] (15)		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO [111] (11)		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [111] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [107] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [112] (3.2)	2009	NC!
$Y(4360)$	4353 ± 11	96 ± 42	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$	*BABAR* [113] (np), Belle [114] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	$107^{+113}_{-\ 71}$	?	$B \to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007	NC!
$X(4630)$	$4634^{+\ 9}_{-11}$	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle [25] (8.2)	2007	NC!
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$	Belle [114] (5.8)	2007	NC!
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^-\Upsilon(nS))$	Belle [37, 117] (3.2)	2010	NC!

P.

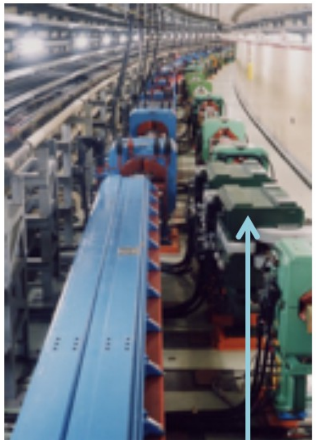
Belle-II Detector

[Belle II TDR, KEK Report 2010-1]

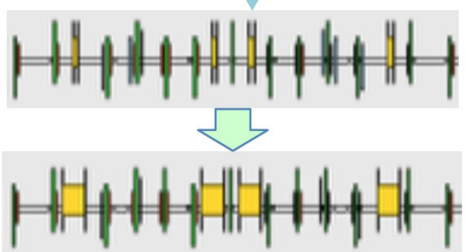


Belle II outreach
https://twitter.com/belle2collab/
https://www.facebook.com/belle2collab/

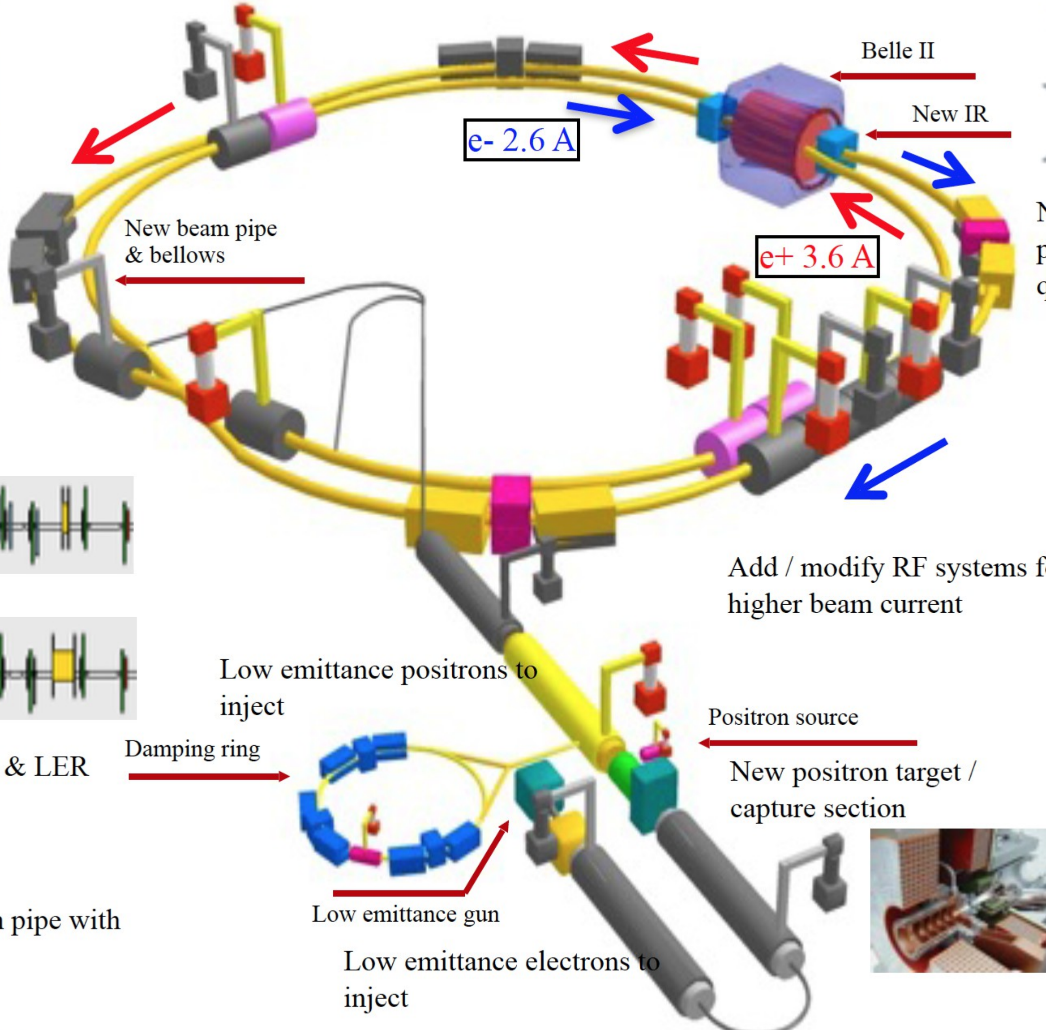
KEKB → Super-KEKB

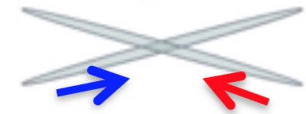


Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance





New superconducting / permanent final focusing quads near the IP

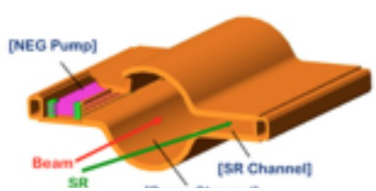
Add / modify RF systems for higher beam current

Low emittance positrons to inject

New positron target / capture section

Low emittance electrons to inject

TiN-coated beam pipe with antechambers



To obtain x40 higher luminosity

	Energy (GeV) LER/HER	β_y^* (mm) LER/HER	ε_x (nm) LER/HER	ξ_y LER/HER	φ (mrad)	I_{beam} (A) LER/HER	Luminosity ($cm^{-2}s^{-1}$) x 10^{34}
KEKB Achieved	3.5/8.0	5.9/5.9	18/24	0.129/0.090	11	1.64/1.19	2.11
SuperKEKB	**4.0/7.0**	**0.27/0.41**	**3.2/2.4**	**0.09/0.09**	**41.5**	**3.6/2.62**	**80**