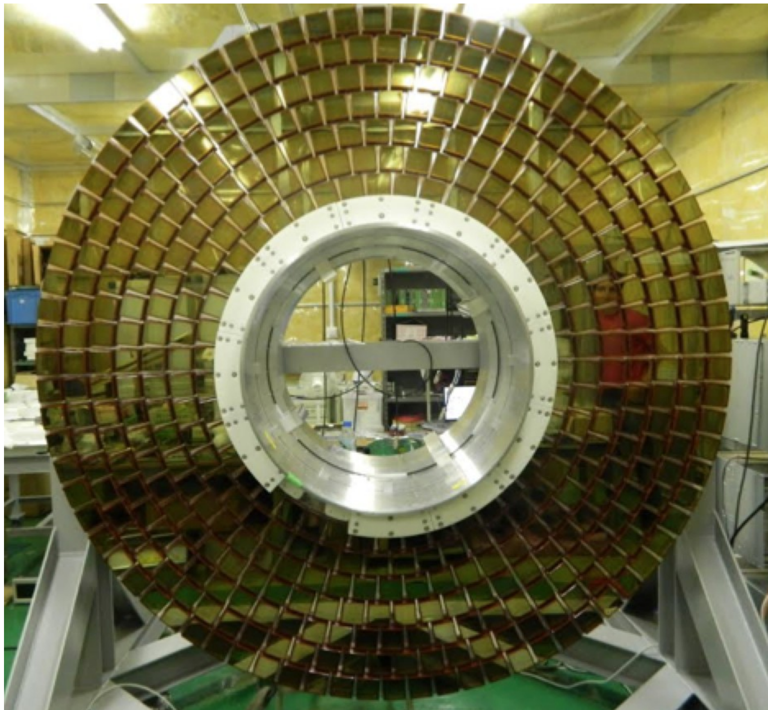
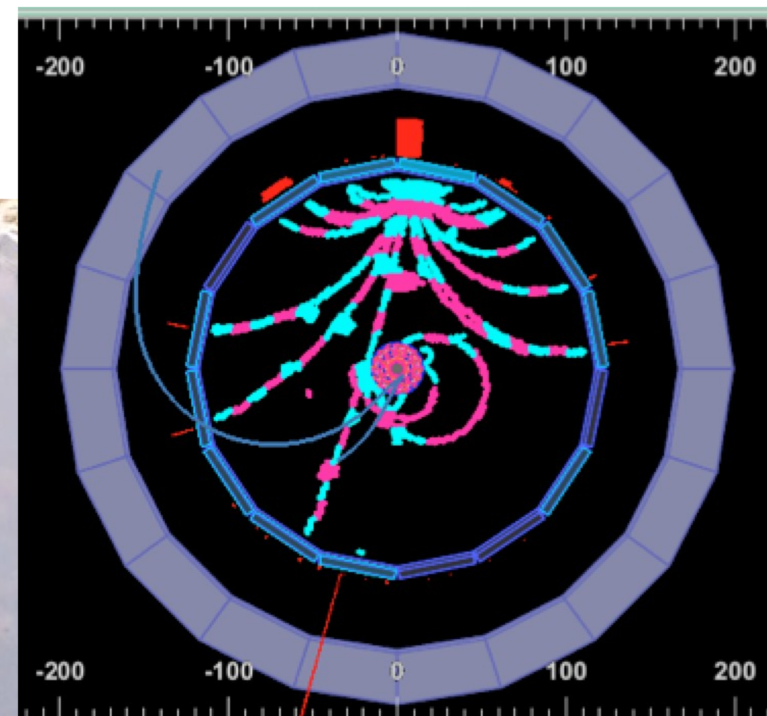
Hadron Physics at Belle II

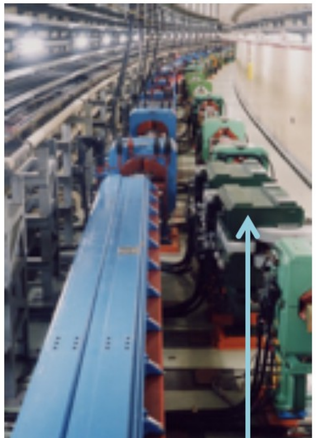


Roberto Mussa
INFN Torino

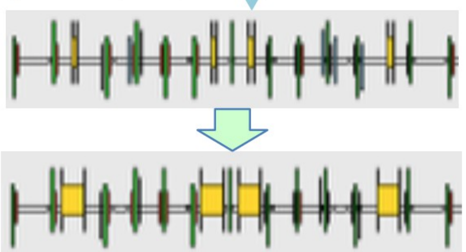


CERN July 17-18, 2017

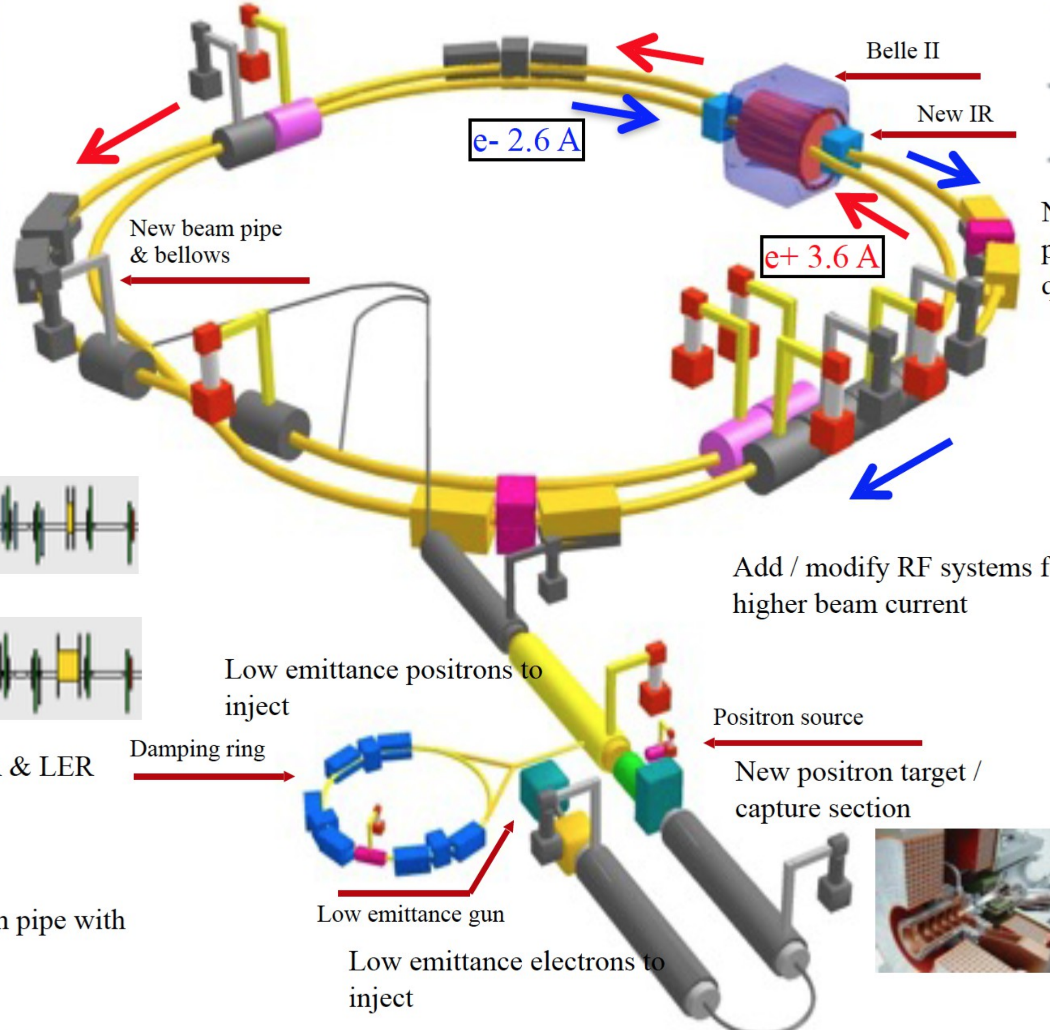
KEKB → Super-KEKB



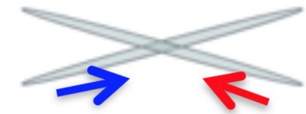
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches

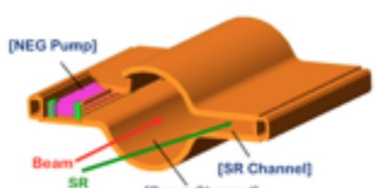


New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

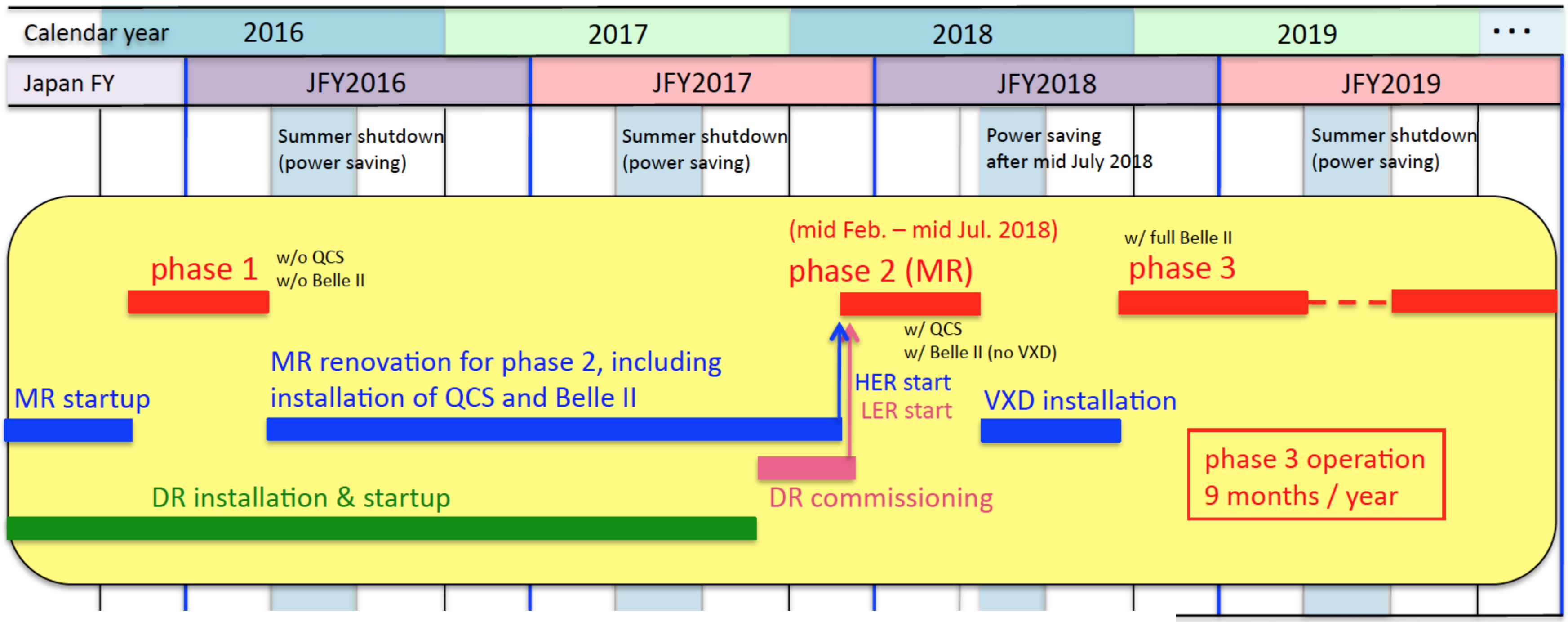
TiN-coated beam pipe with antechambers



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**

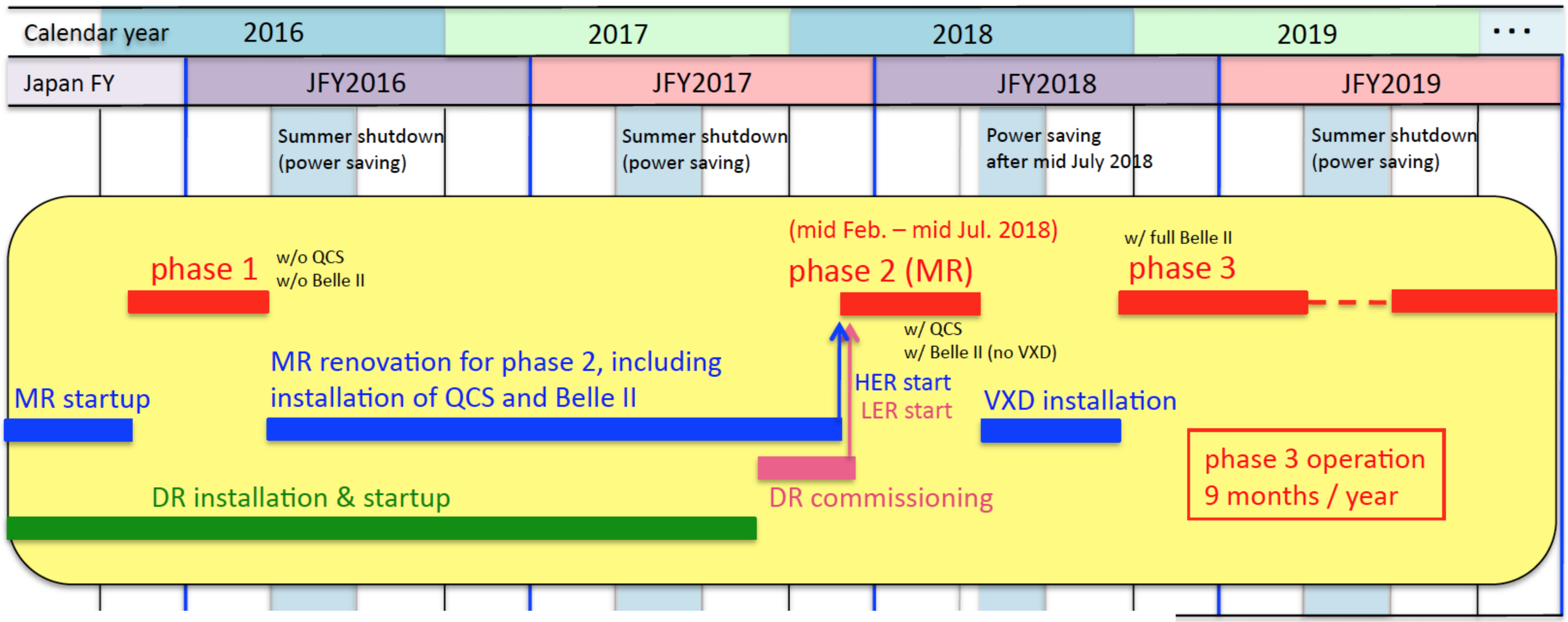
KEKB short term plans: startup schedule



- 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

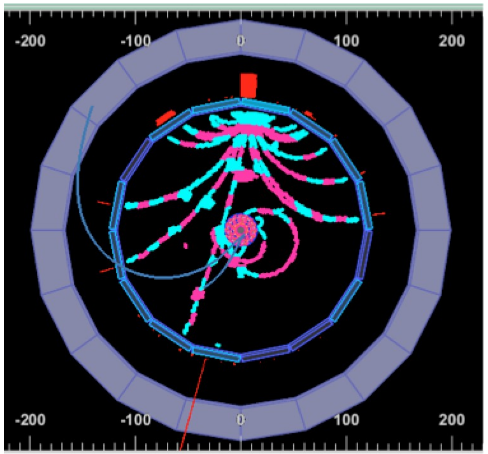
11/4: Belle-II roll in

KEKB short term plans: startup schedule

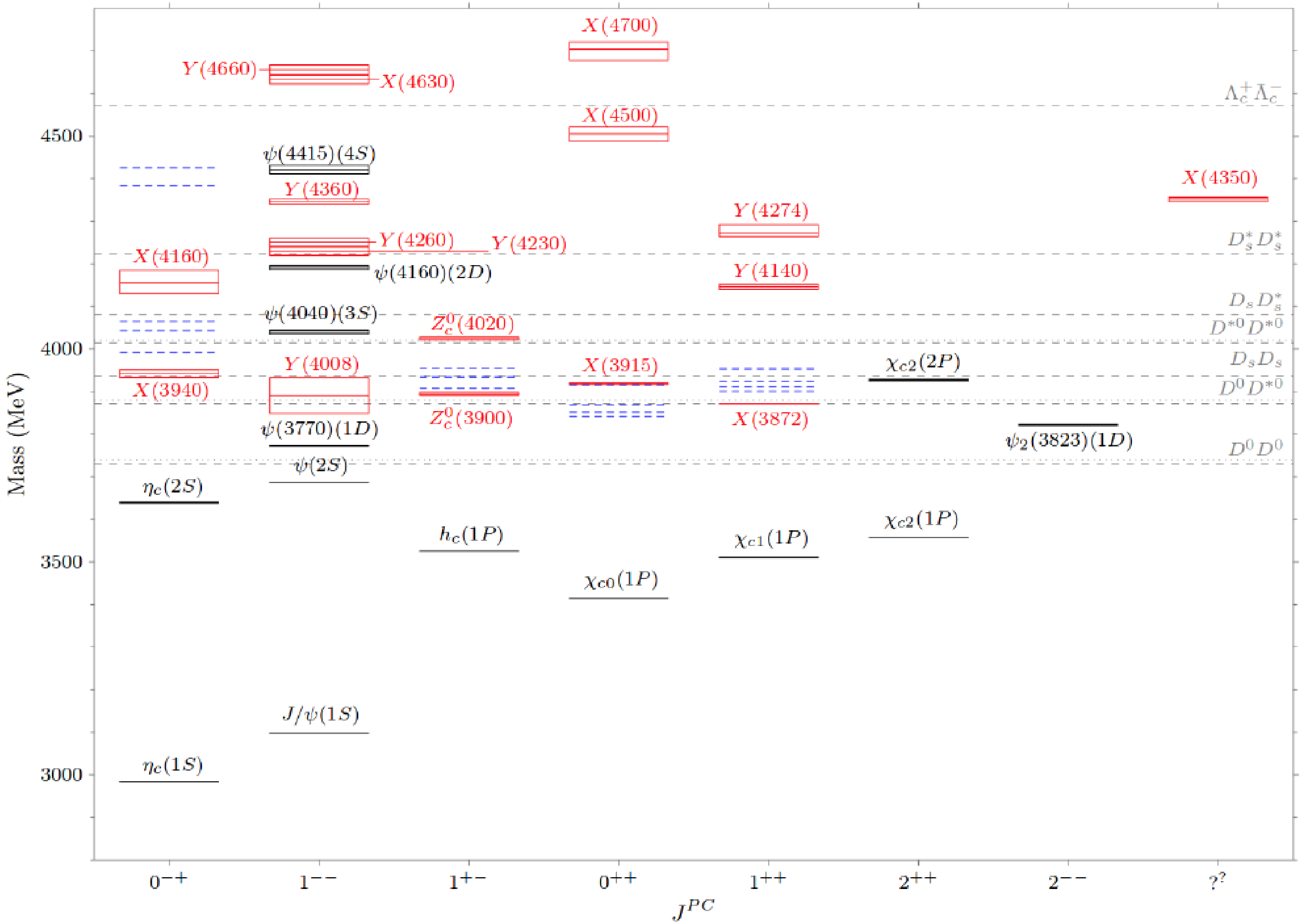


- Summer 2017: global cosmic ray run
- September 2017: ARICH and forward ECL
- October 2017: start Beast Phase II VXD commissioning
- Nov 2017 - Summer 2018: Phase 2 commissioning, with two main goals:
  - ✓ tune SuperKEKB with nano-beams - eventually reach KEKB design luminosity
  - ✓ ensure background 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

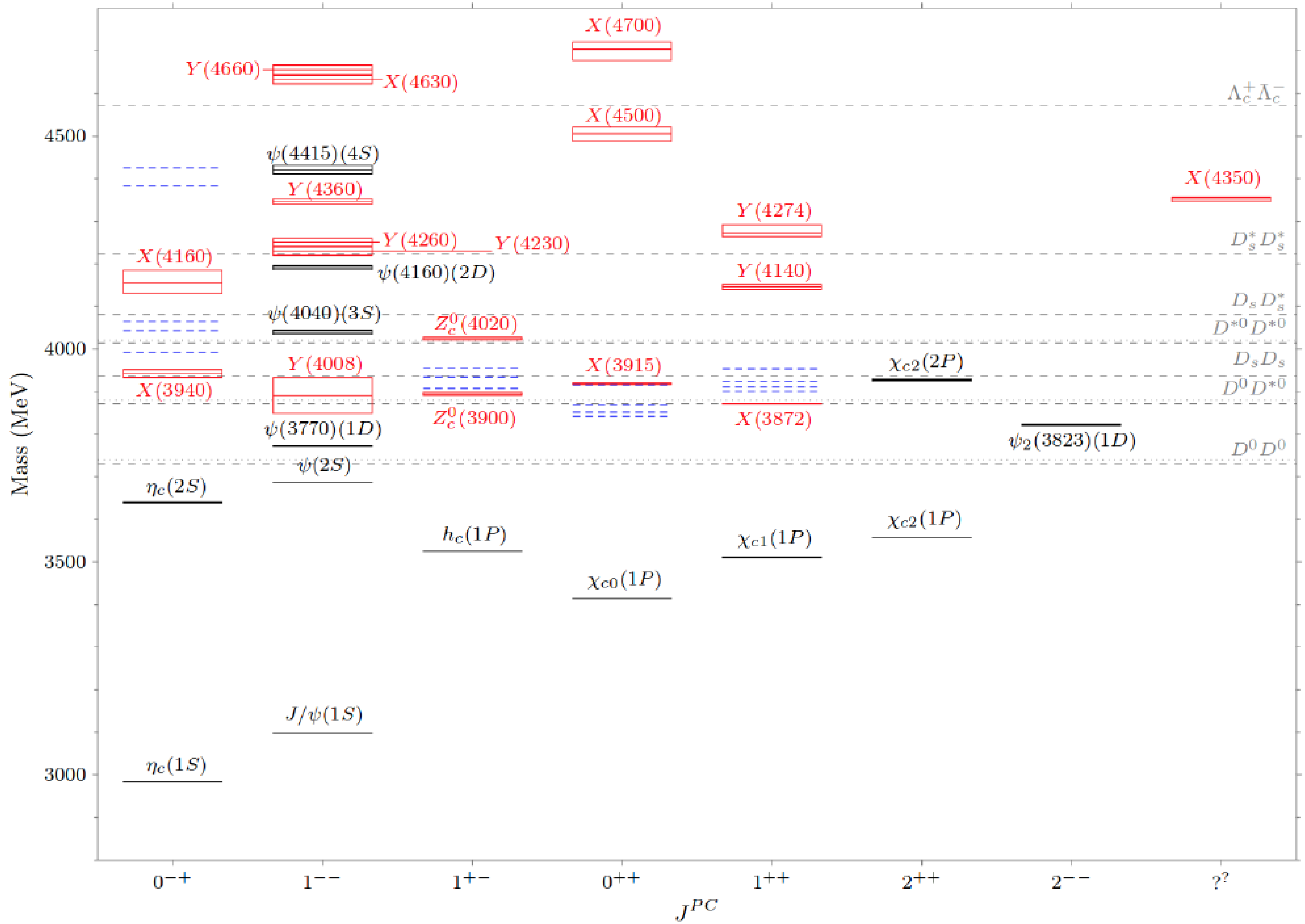
6/2017: cosmics in B field



The legacy of 1^{st} generation B-factories…

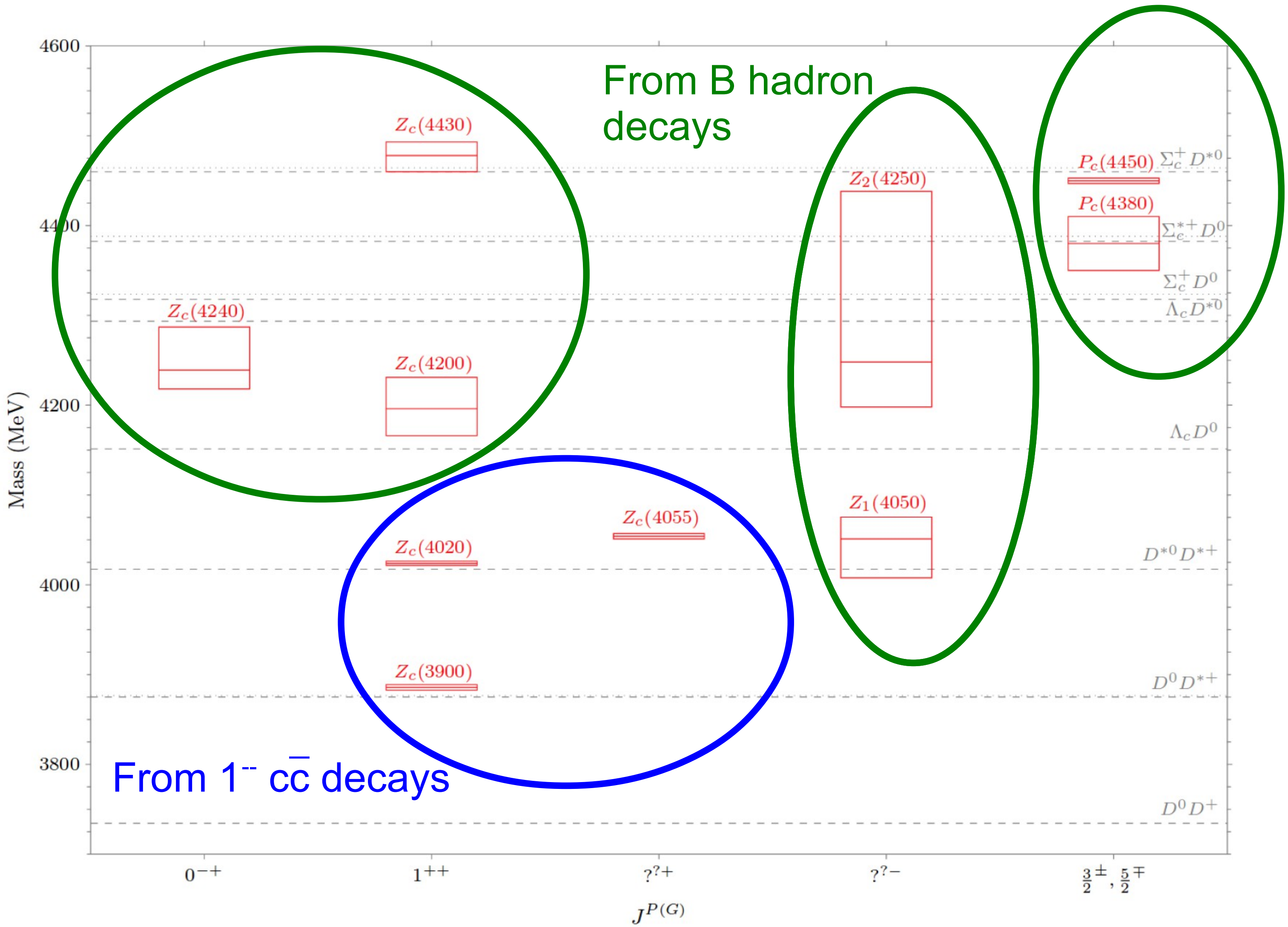


The legacy of 1st generation B-factories...



Challenge for the new generation: sort out this mess...

Charged charmoniumlike: width vs production mechanism



Motivations for non-Υ(4S) running

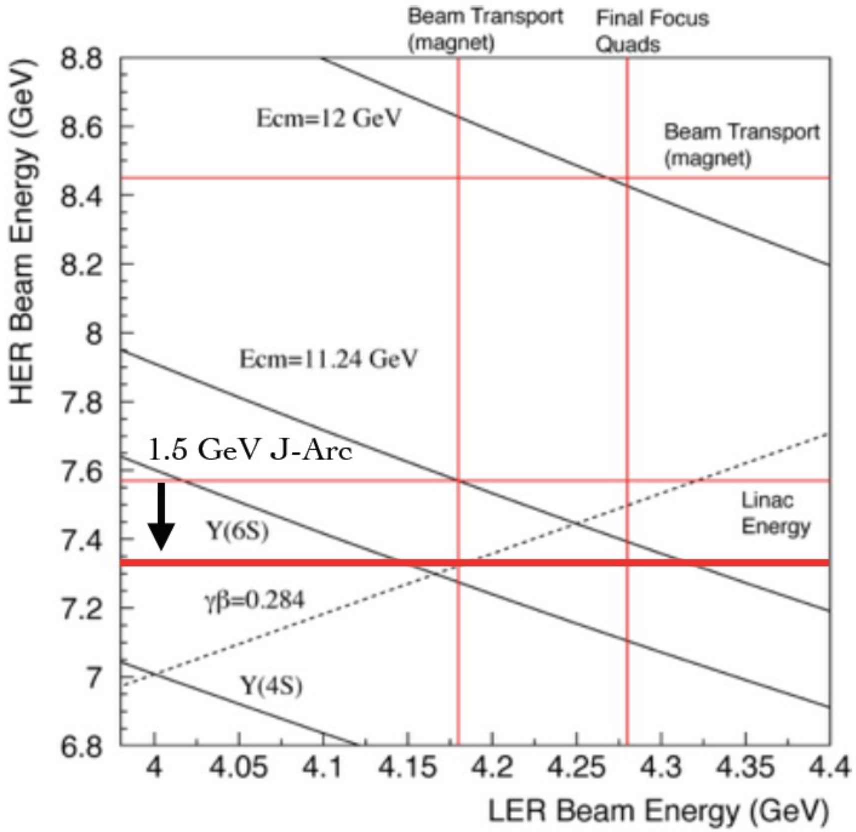
Energy	Outcome	Lumi (fb^{-1})	Comments
Υ(1S) On	N/A	60+	-No interest identified -Low energy
Υ(2S) On	New physics searches	20+	-Requires special trigger
Υ(1D) Scan	Particle discovery	10-20	-Already accessible in B Factories?
Υ(3S) On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 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

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

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

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

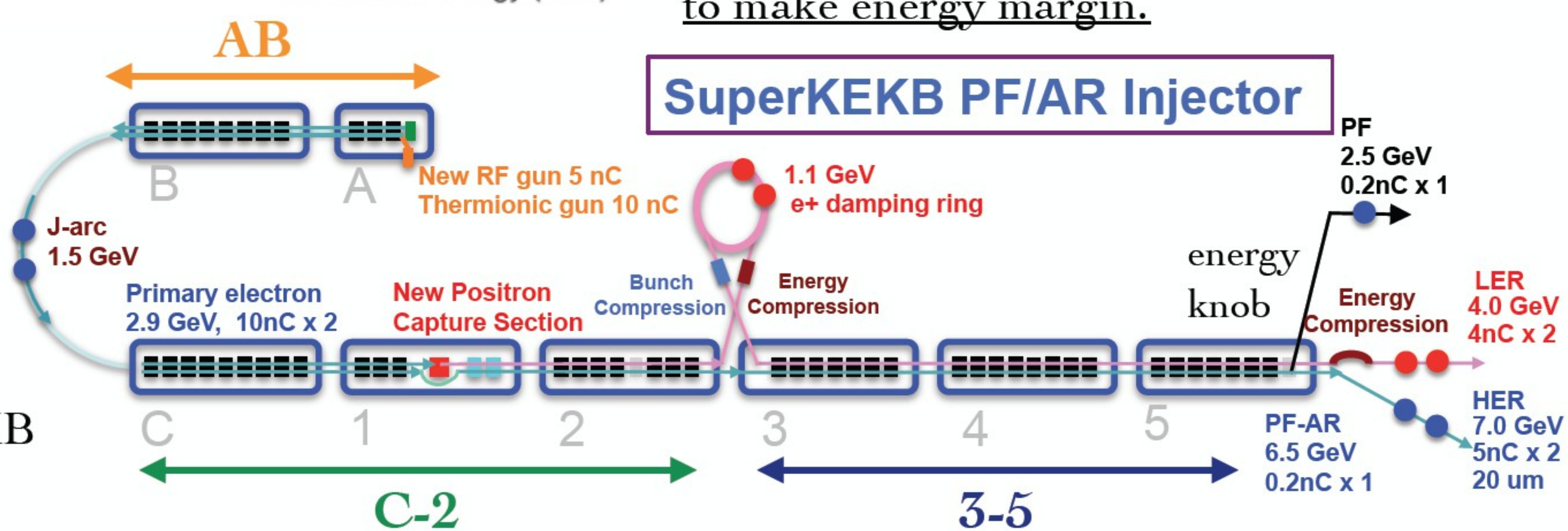
Y(6S)
HER: 7.30 GeV
no backup unit in C - 5 sector(max 7.35 GeV)
LER: 4.16 GeV
no backup unit in 3 - 5 sector(max 4.18 GeV)

Risk at higher beam energy

The old accelerating structures should be replaced to make energy margin.

1.5 GeV Arc

-0.2 GeV from KEKB



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

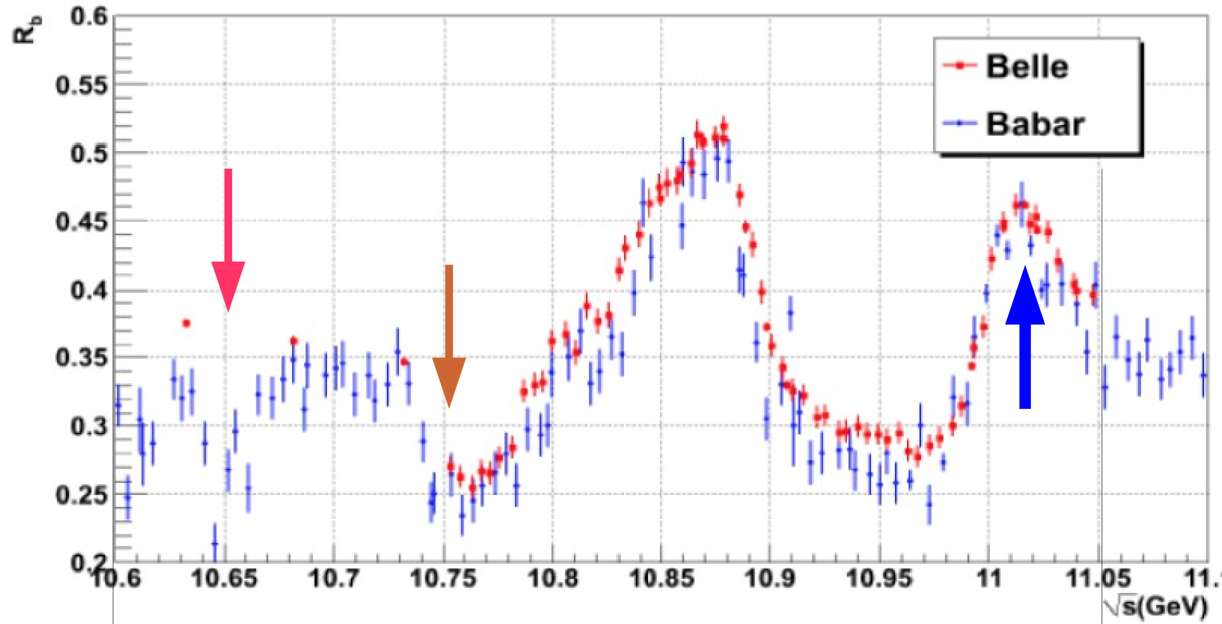
Above Rb drop at 10.74

Bump observed in R_Y

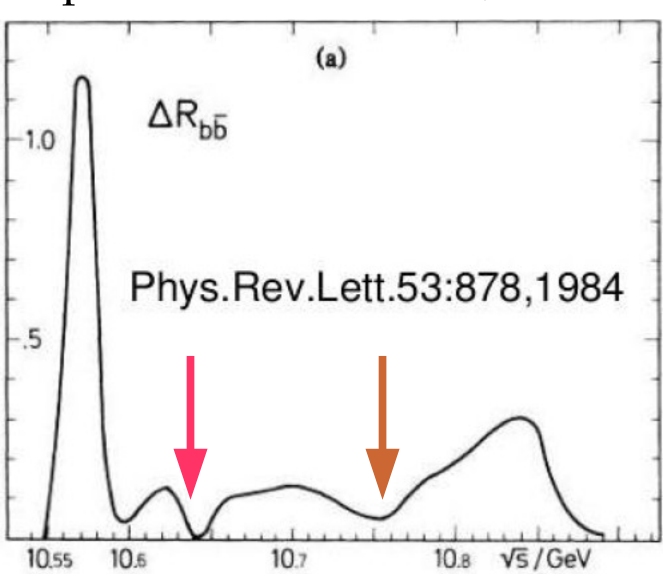
- E = 11.02 GeV

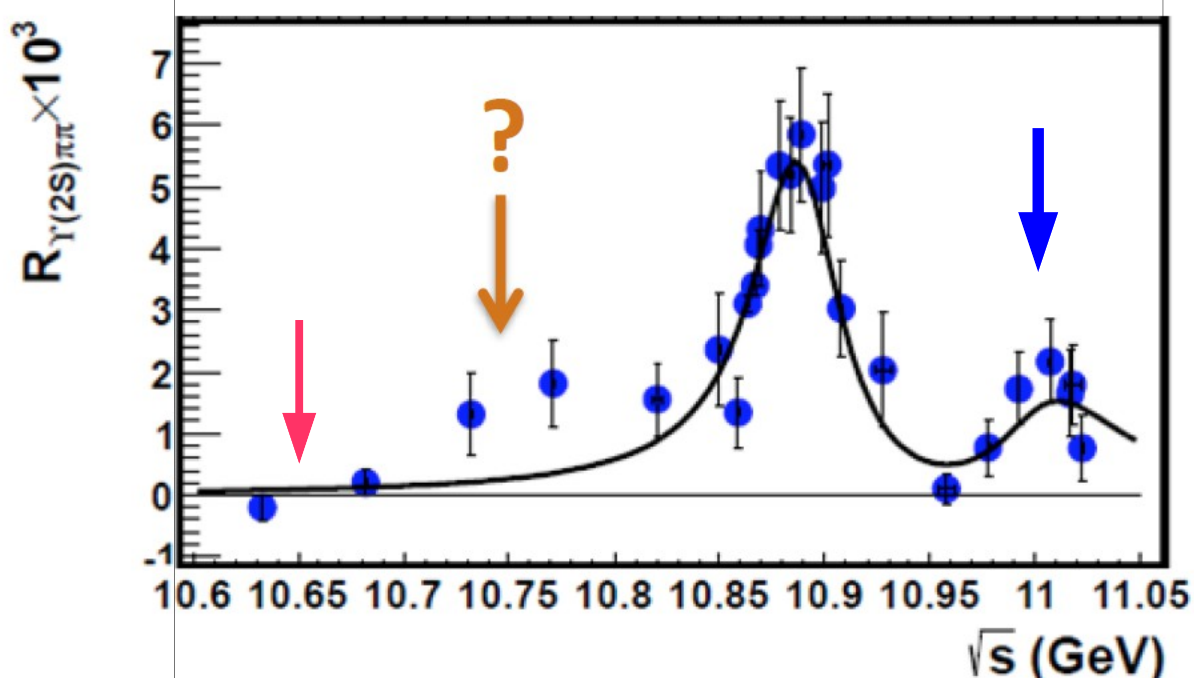
Y(6S) peak,

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



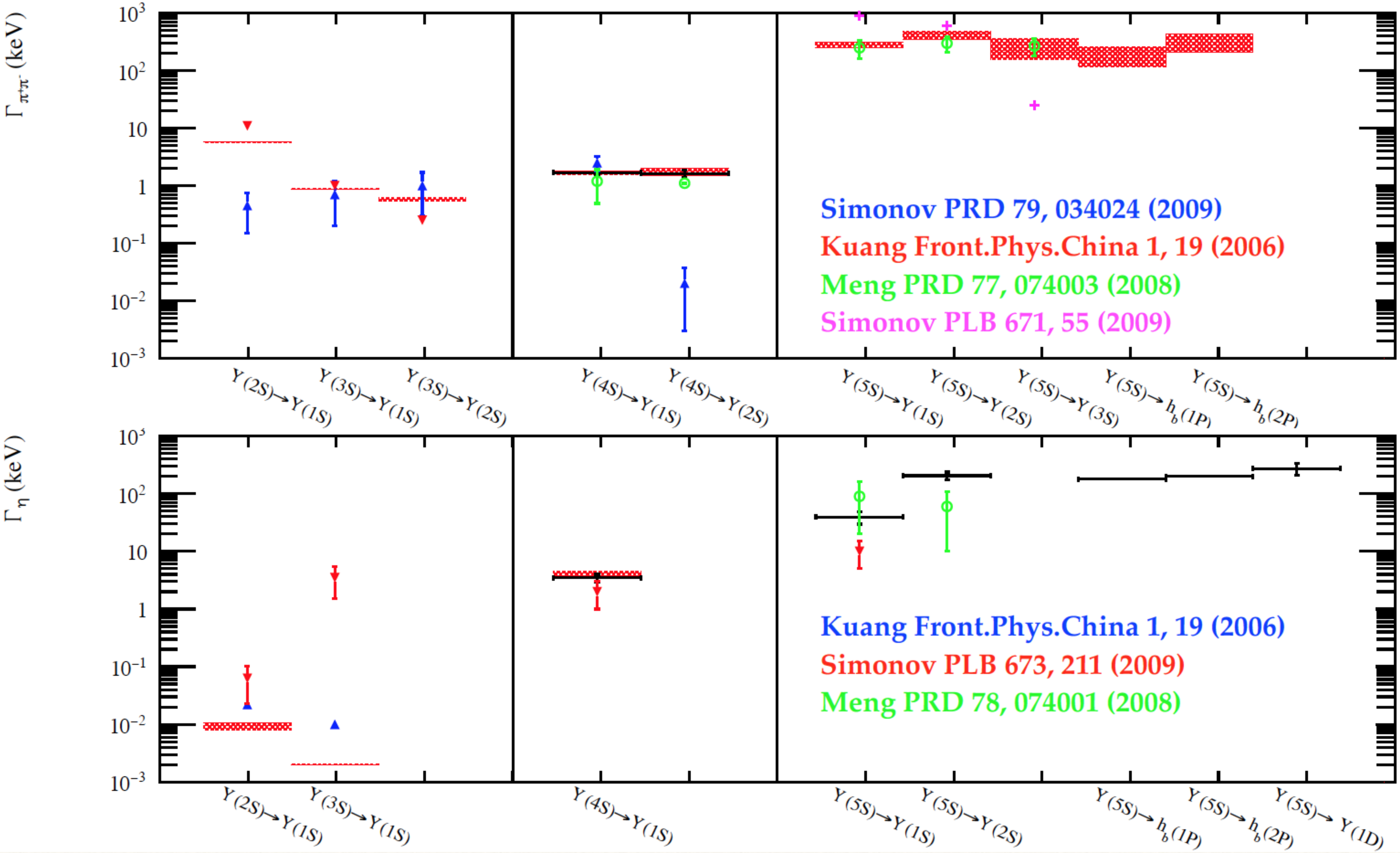
Note: features predicted by theory (coupled channel model)





The puzzle of eta / dipion transitions in bottomonium

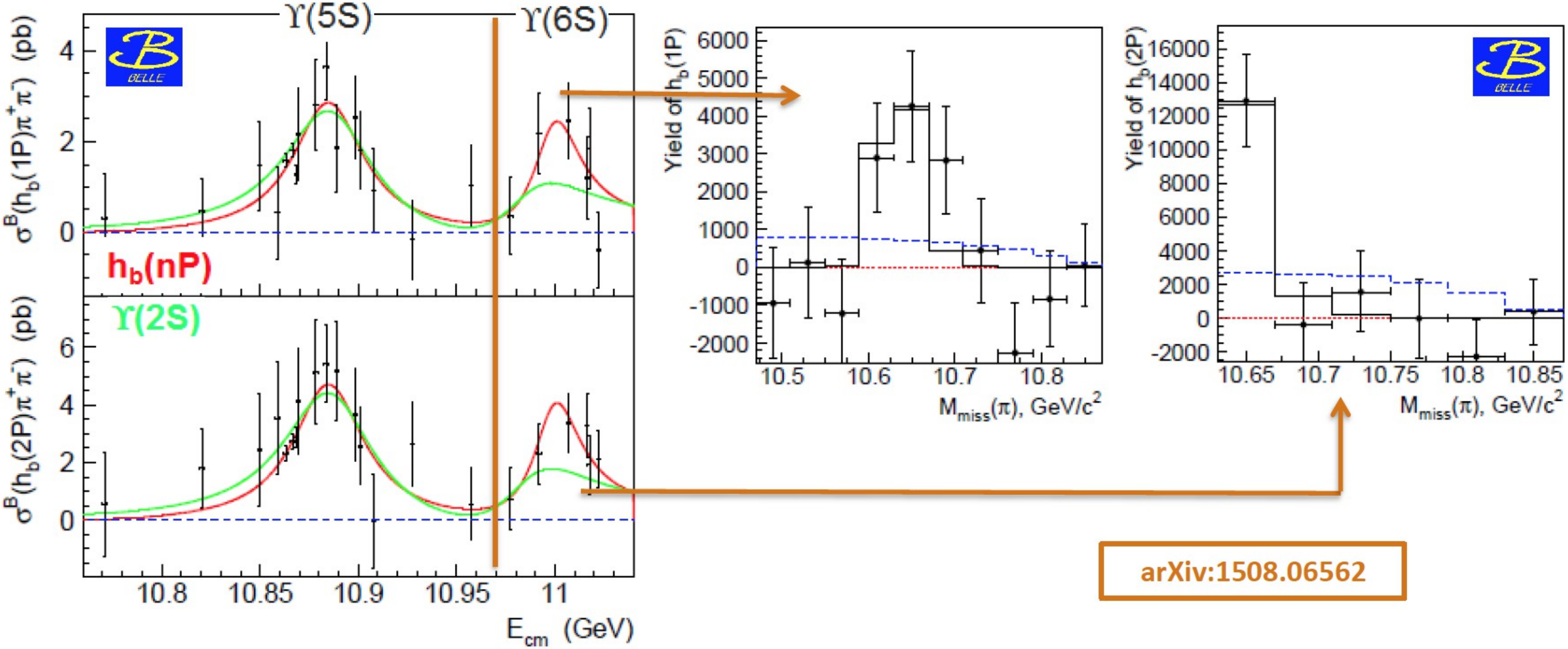
Still lacking a unified theoretical model to describe the observed evolution of the cross section



$\Upsilon(6S)$ results in Belle-I

PRL117 (2016),142001

- Preliminary evidence for $\Upsilon(6S)\to\pi\pi h_b(nP)$, via $\pi Z_b^{\pm}(106XX)$ decay



arXiv:1508.06562

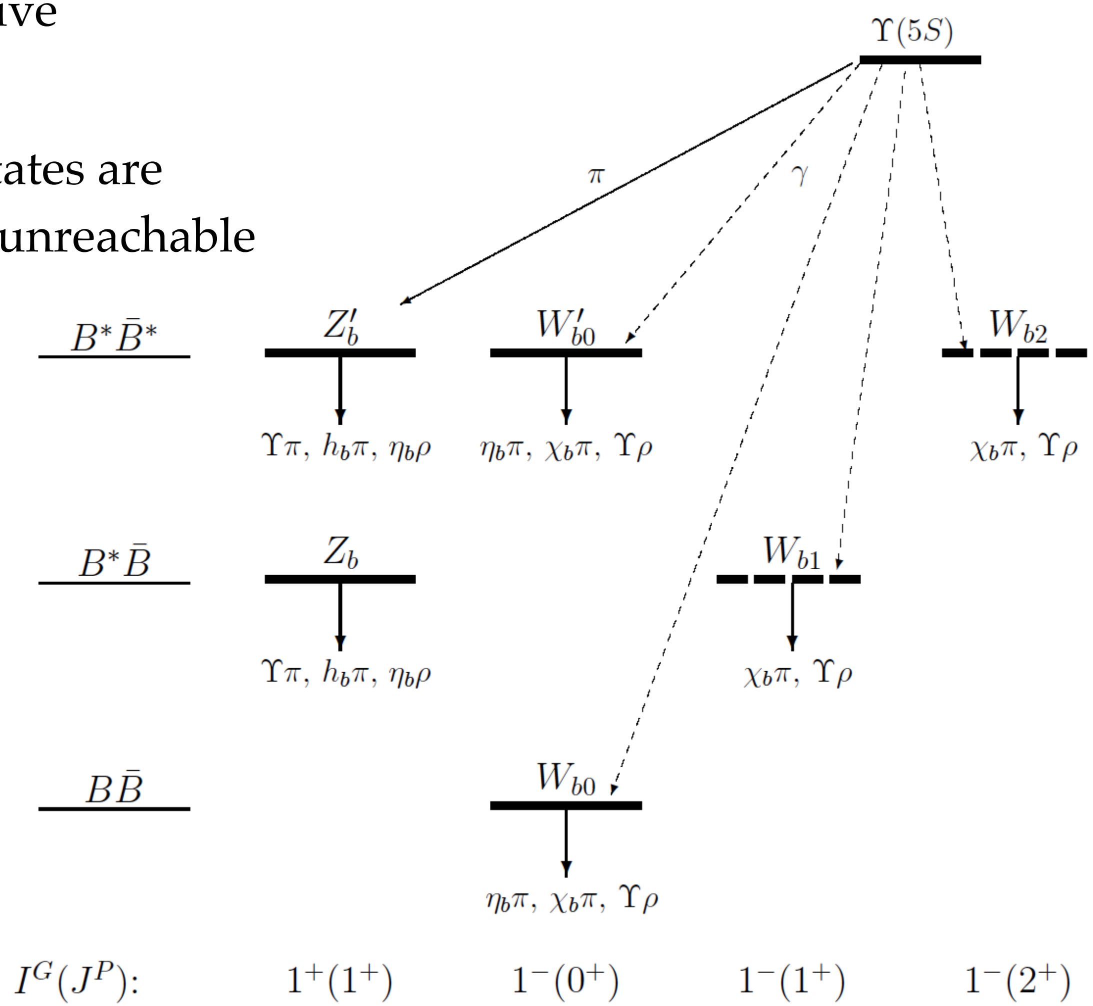
- Resonance structure of $\Upsilon(6S)\to\pi\pi\Upsilon(pS)$ decays not fully studied

Y(6S) prospects in Belle-II

(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 Y(5,6S) via radiative transitions.

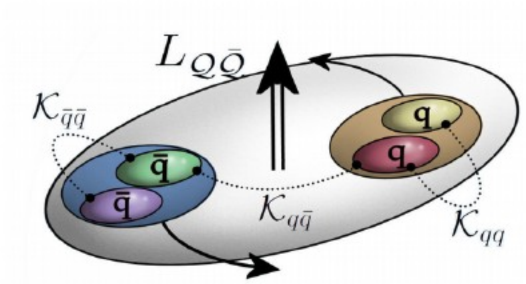
Further hadronic transitions to W_b states are expected above W_b threshold (11.3) unreachable at present.



Y(6S) prospects in Belle-II

Ali (B2TIP Krakov)

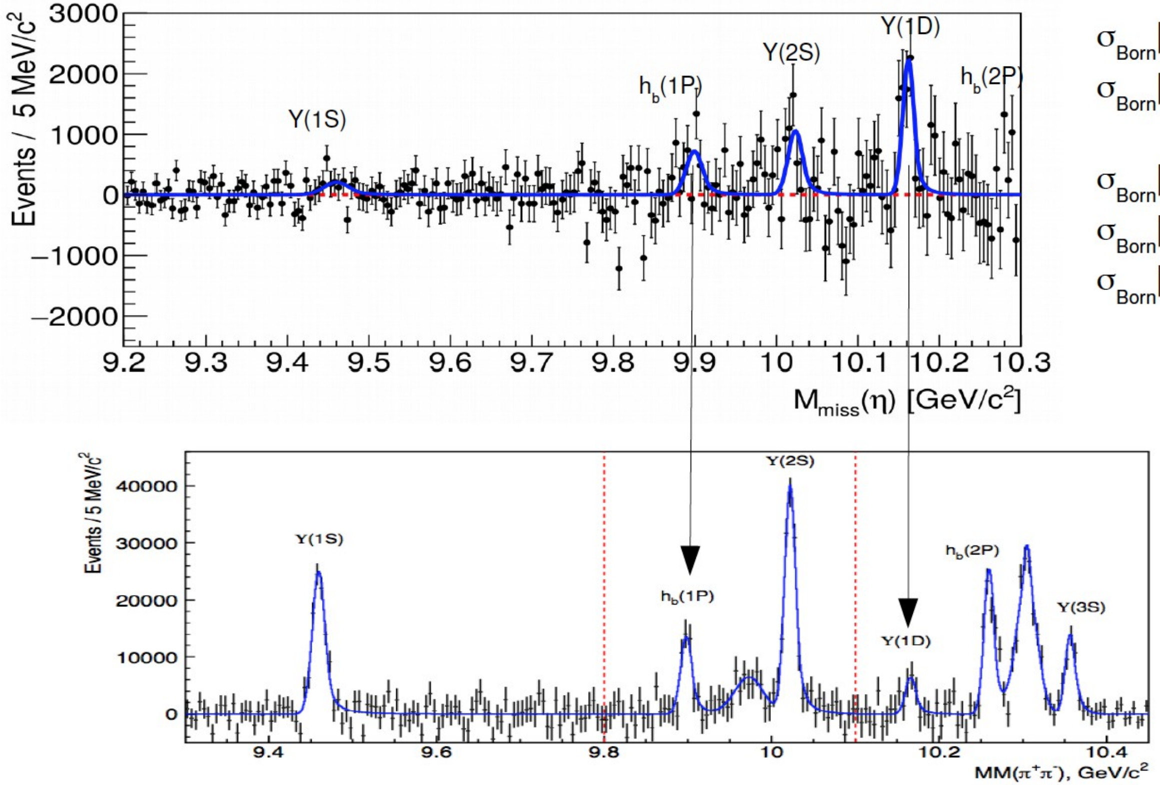
Label	J^{PC}	charmonium-like State	charmonium-like Mass [MeV]	bottomonium-like State	bottomonium-like Mass [MeV]
X_0	0^{++}	—	3756	—	10562.2
X_0'	0^{++}	—	4024	—	10652.2
X_1	1^{++}	$X(3872)$	3890	—	10607.2
Z	1^{+-}	$Z_c^+(3900)$	3890	$Z_b^{+,0}(10610)$	10607.2
Z'	1^{+-}	$Z_c^+(4020)$	4024	$Z_b^+(10650)$	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.) predicts a full spectrum of states in both bottomonium and charmonium region. We need to better understand the nature of both Y(5S) and Y(6S) .

From Y(6S): Y(1,2D) searches in Belle-II

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



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

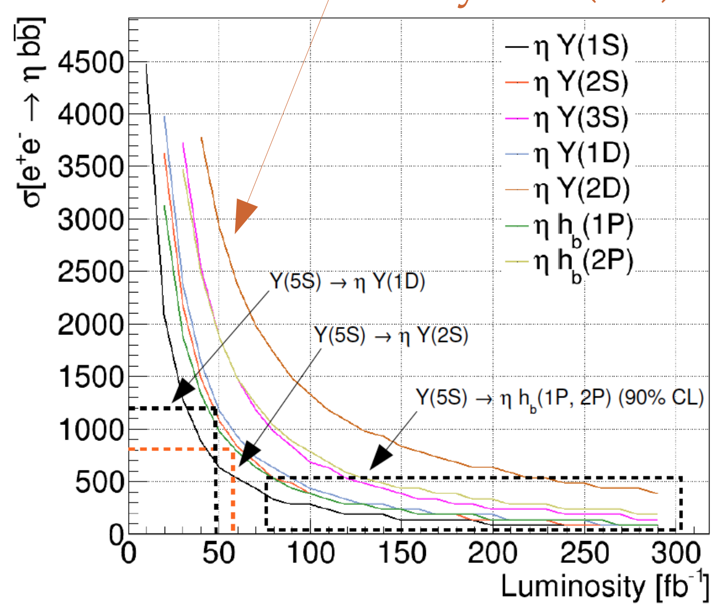
$\sigma_{Born}[e^+e^- \to \eta\ Y(2S)] = (0.97 \pm 0.31 \pm 0.19)$ pb

$\sigma_{Born}[e^+e^- \to \eta\ Y(1S)] < 0.61$ 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 Y(2D)

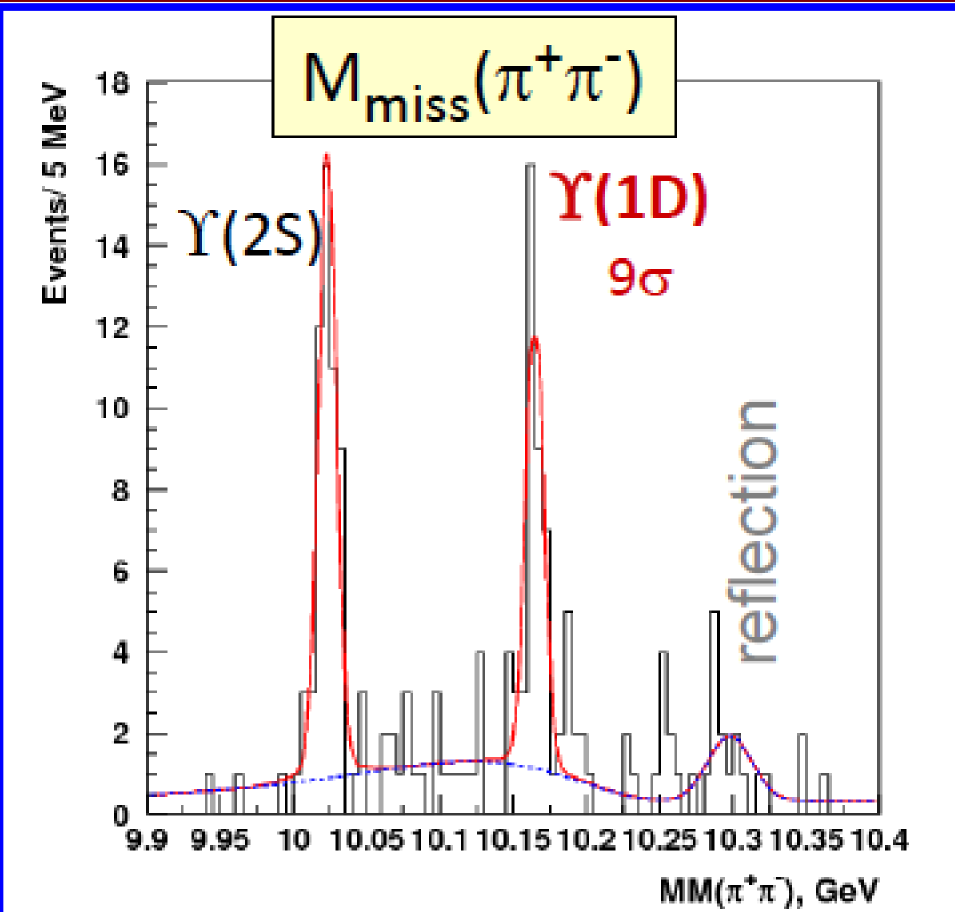


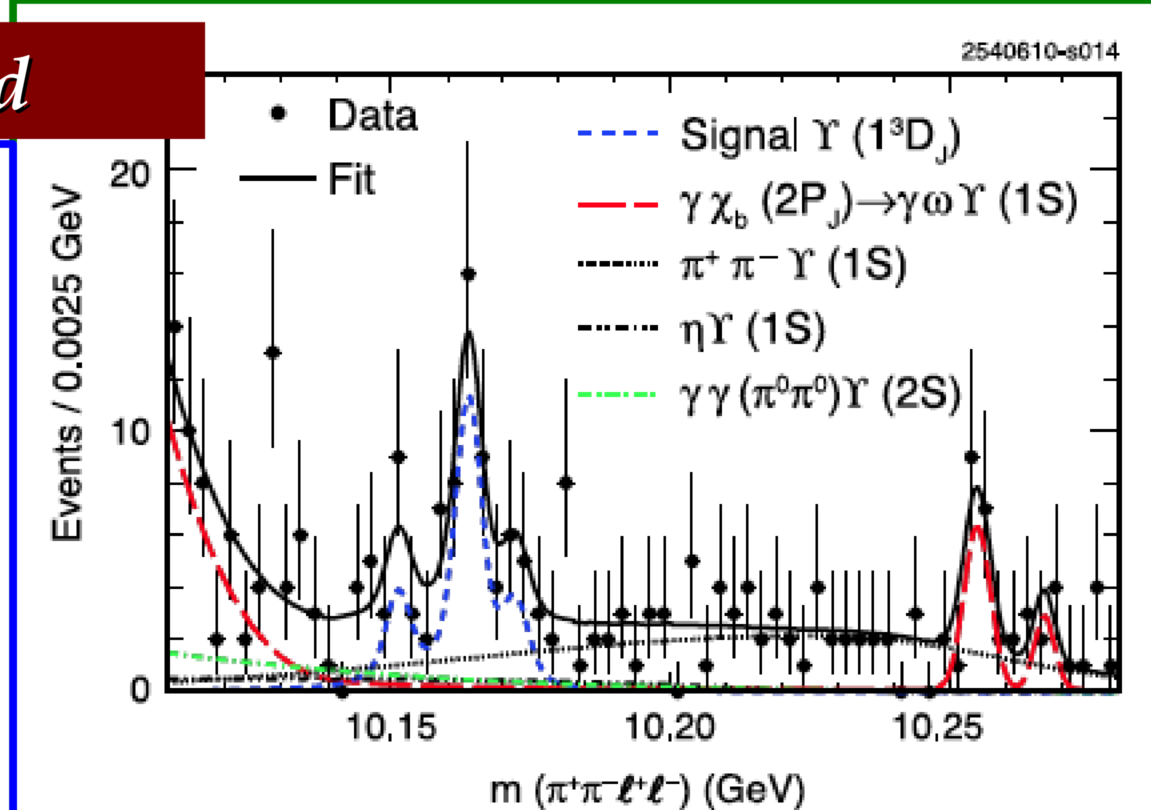
- Dipion transitions main discovery tool for charged bottomonia (more Z_b's?)

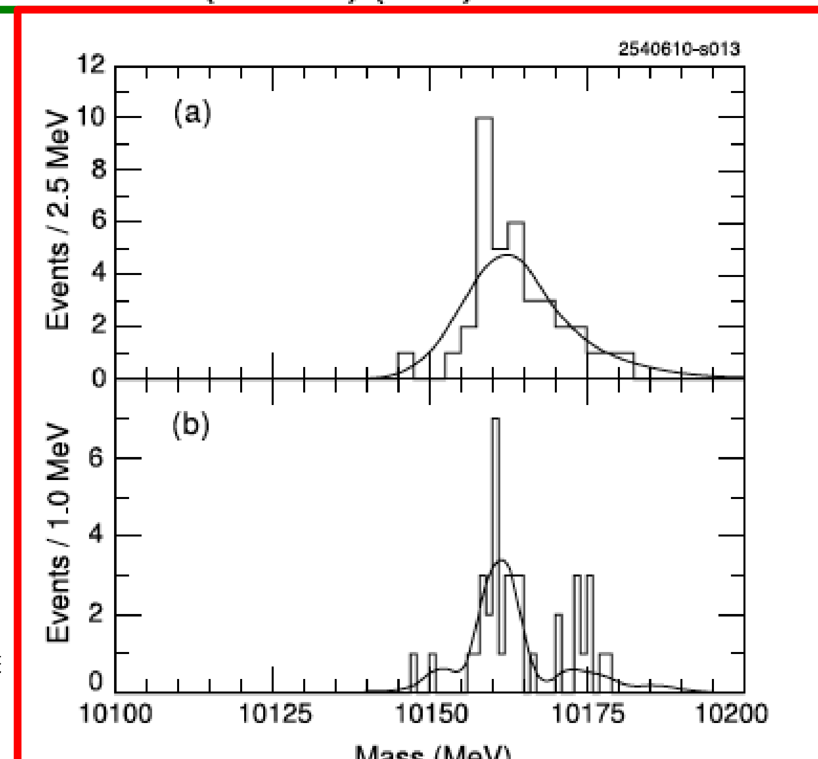
- Eta transitions : best pathway to Y(2D)?

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

Υ(1D) triplet still unresolved







Belle (from 5S) 10164.7 ± 1.4 ± 1.0 MeV

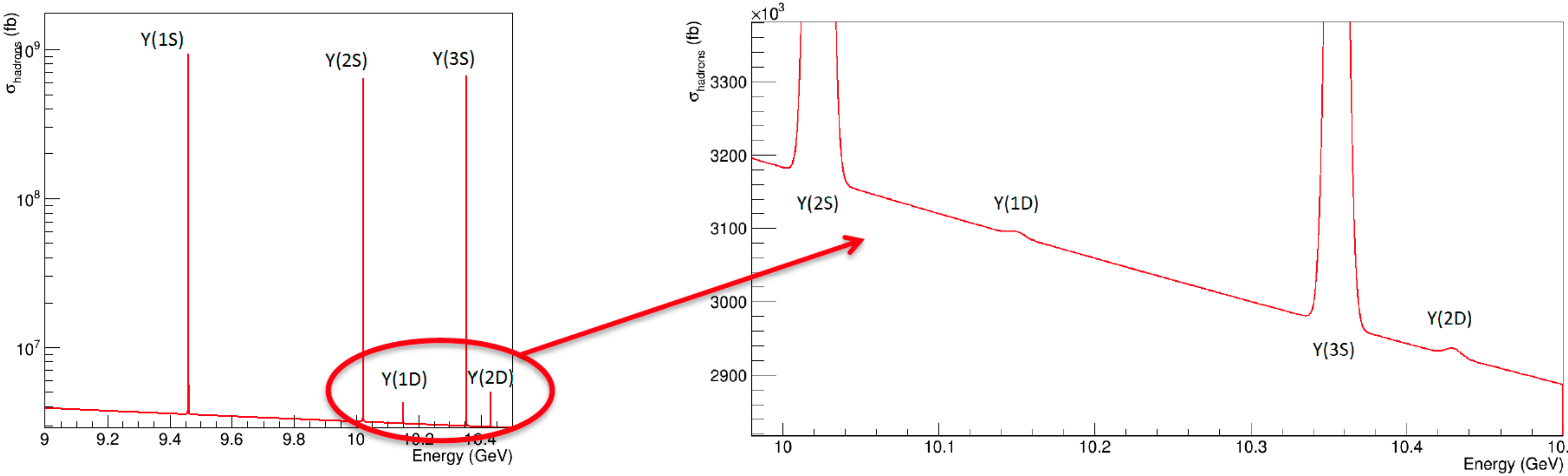
BaBar (from 3S) 10164.5 ± 0.8 ± 0.5 MeV

CLEO (from 3S) 10161.1 ± 0.6 ± 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))

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?

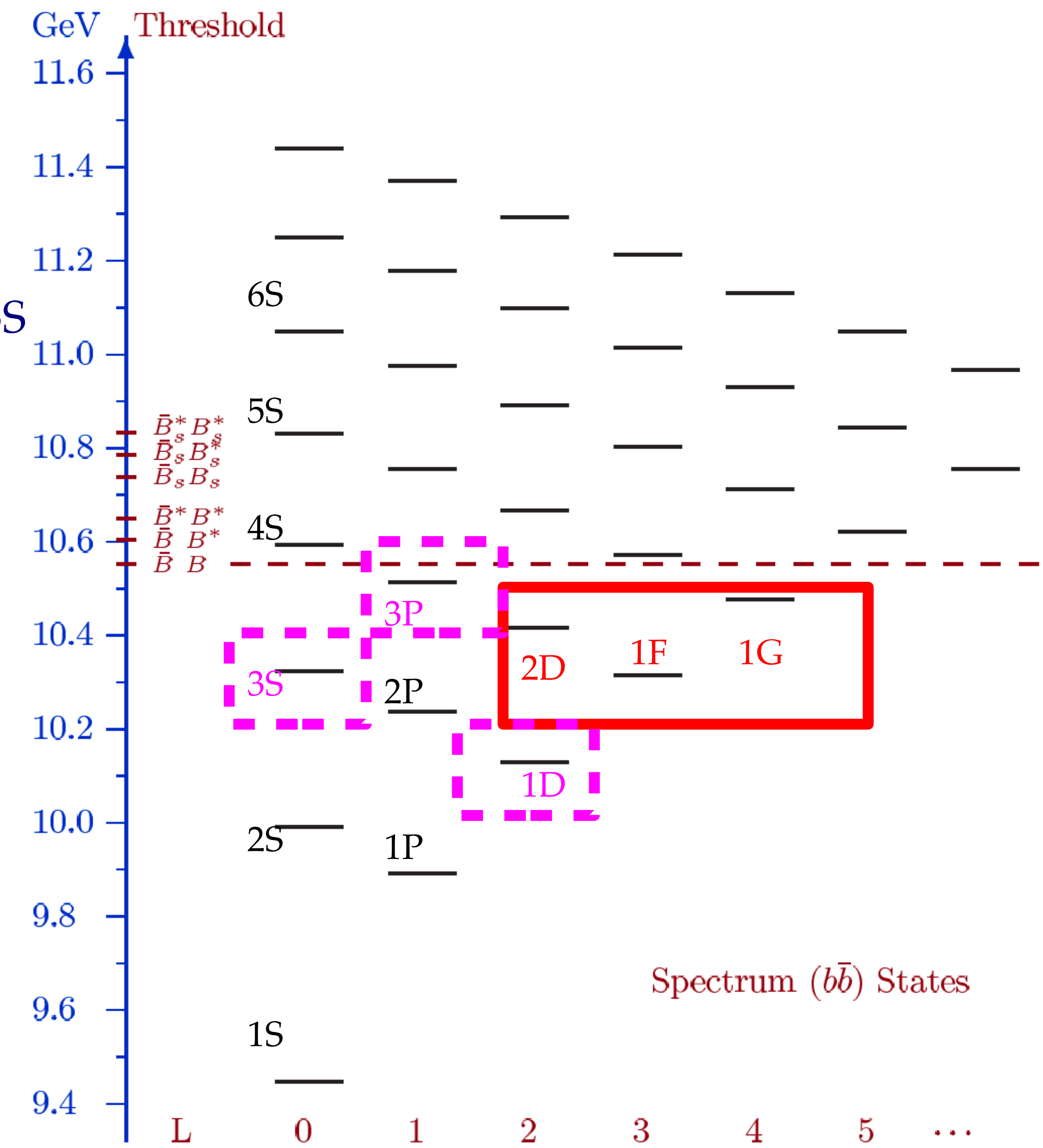
  $h_b(3P)$: too high to be reached from 5S via Z_b, maybe from 6S? How?

* 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.



Antinuclei in Y(3S) decays

CLEO results :

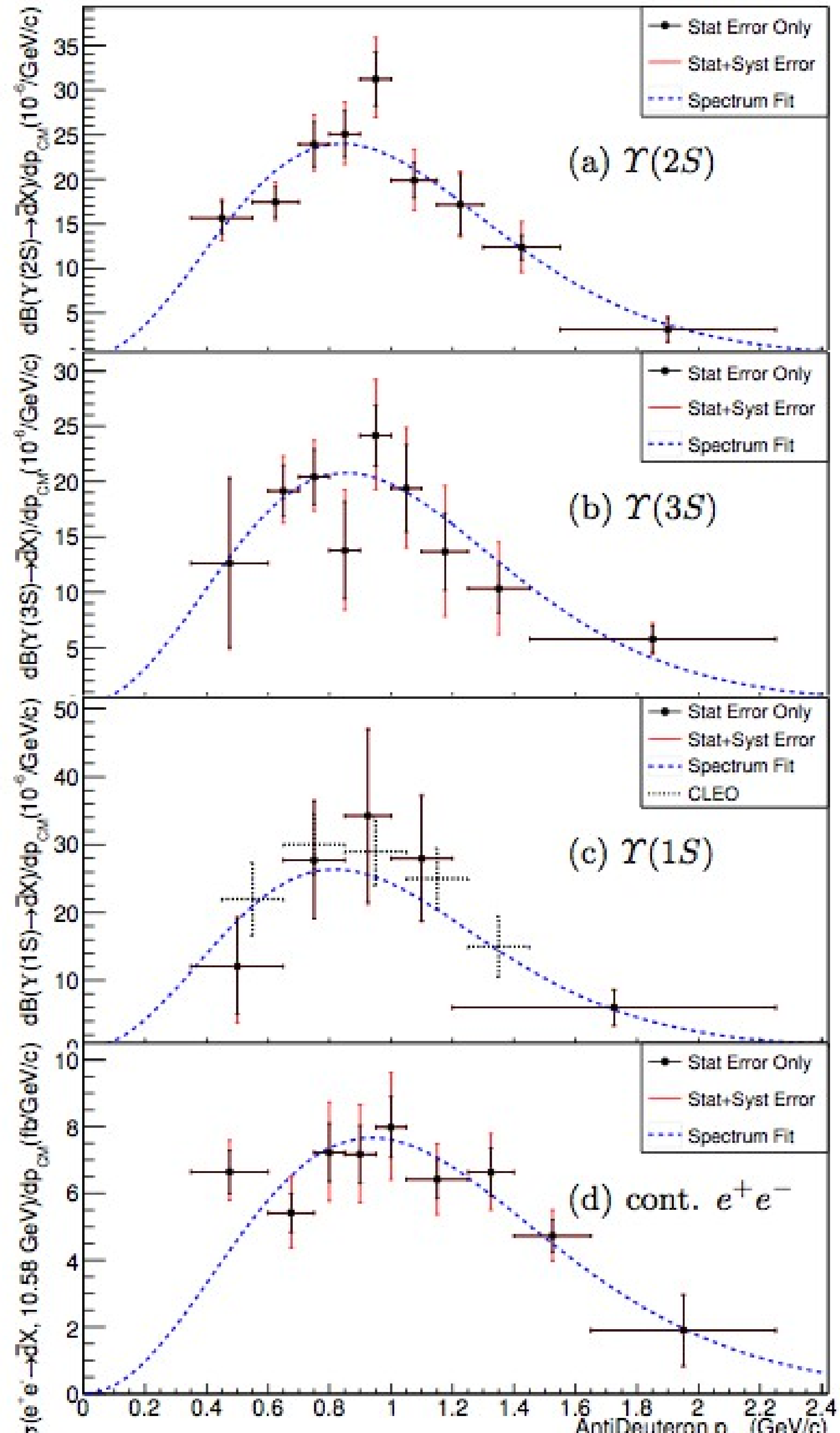
$$\mathcal{B}^{\rm dir}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.$$

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

BABAR results :

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

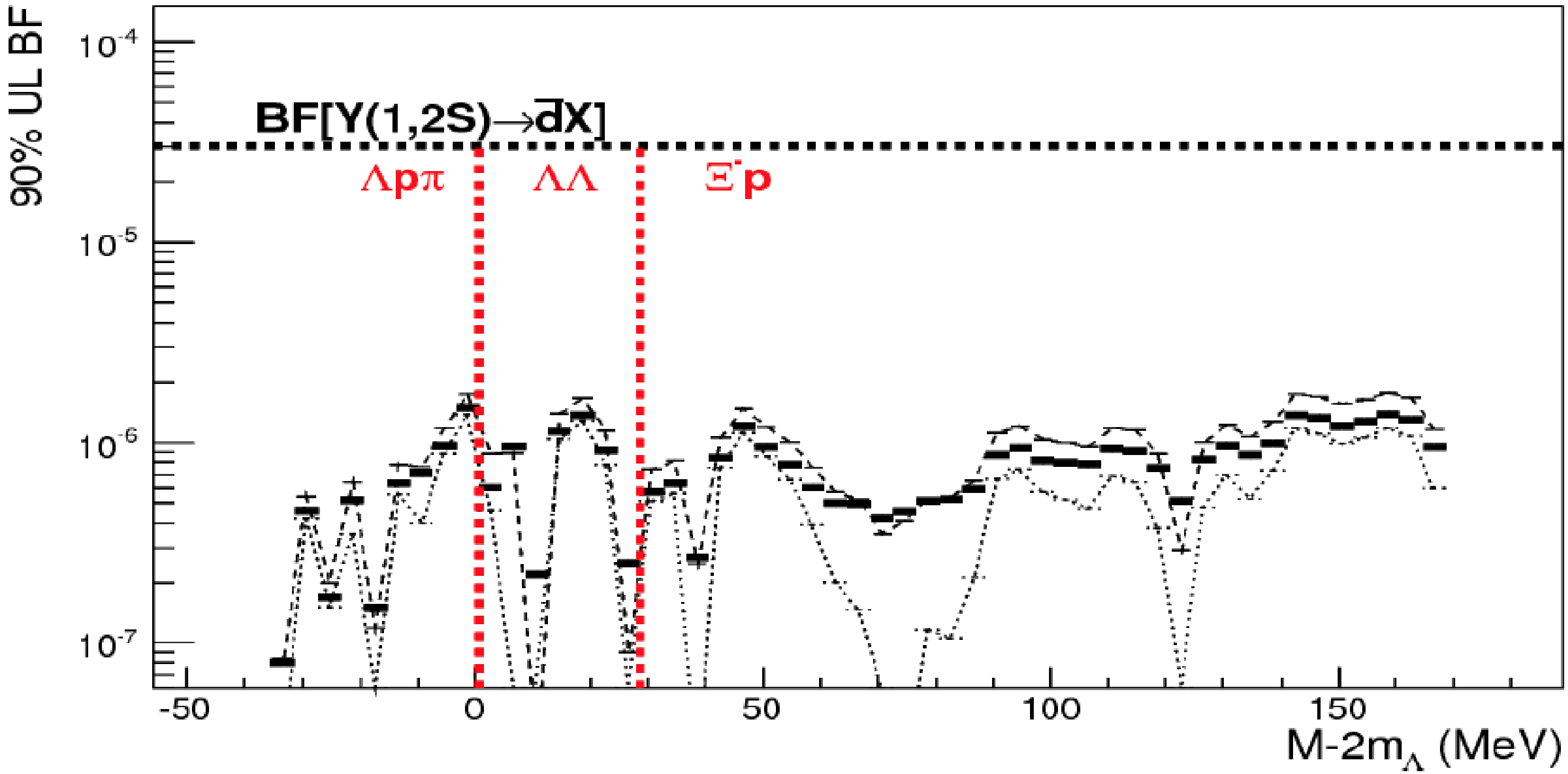
Process	Rate
$\mathcal{B}(\Upsilon(3S) \to \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-}$
$\mathcal{B}(\Upsilon(2S) \to \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-}$
$\mathcal{B}(\Upsilon(1S) \to \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-}$
$\sigma(e^+e^- \to \bar{d}X)$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



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.

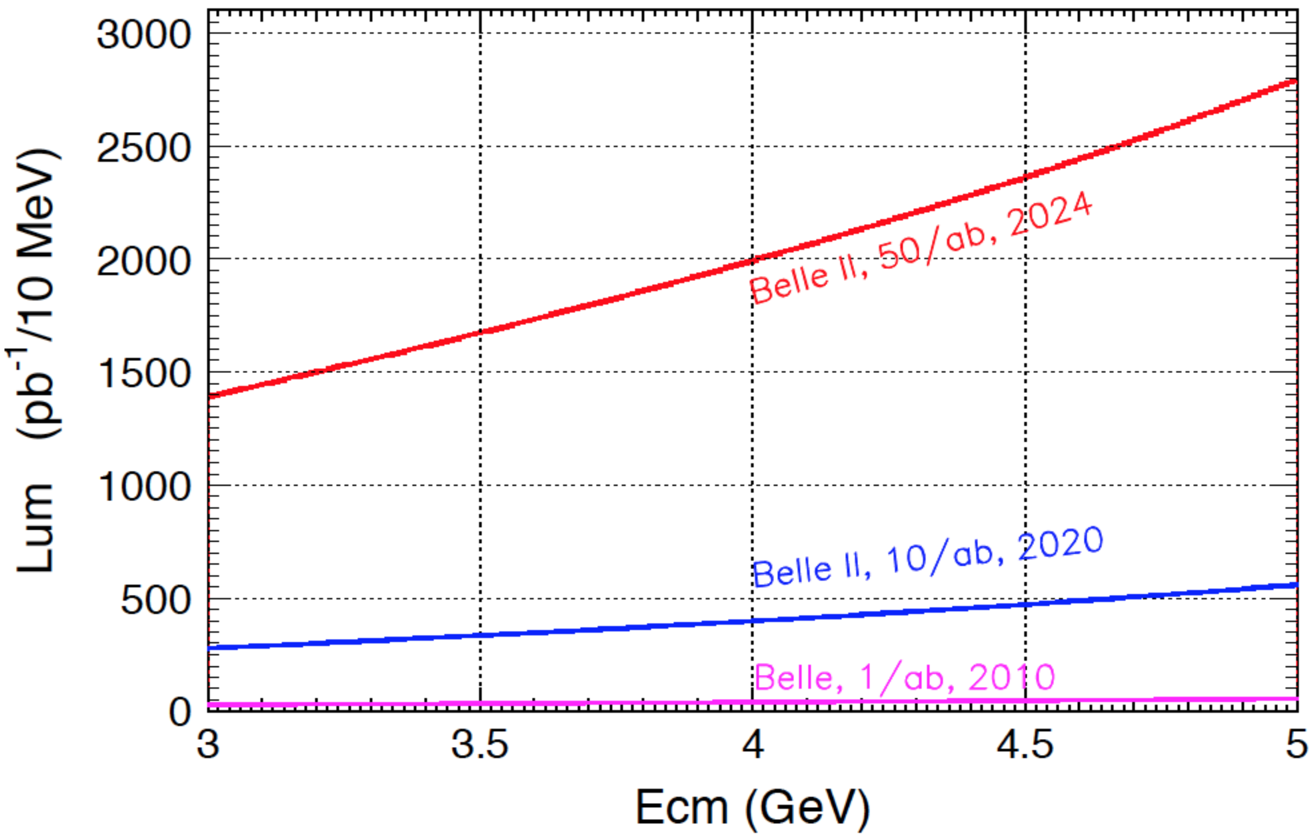
$Y(4S)$ running : ISR luminosity

Access to vector states

Detailed scan of all hadronic transitions

Complementary to detailed searches at BES-III

Statistical sensitivities for 10(50) fb^{-1} are given below:

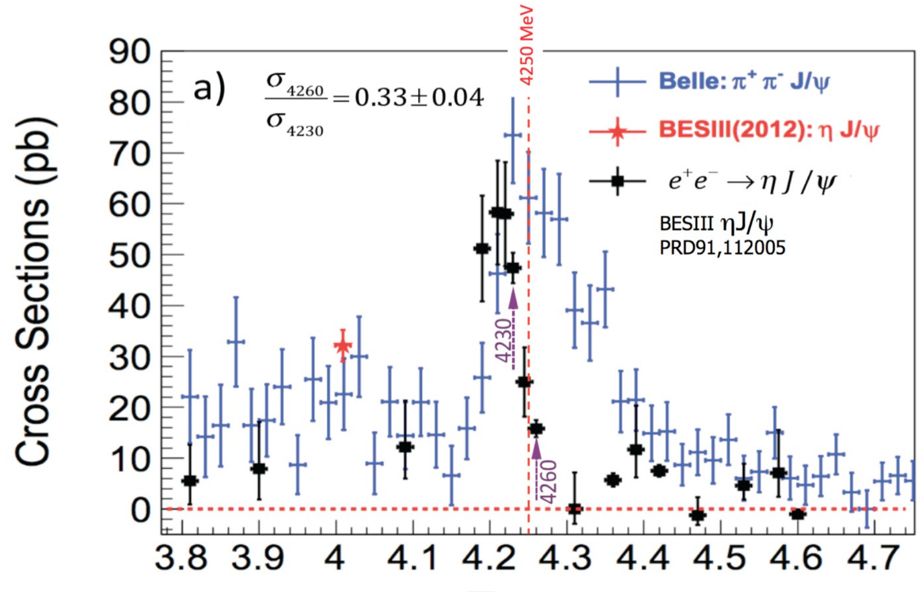


Golden Channels	$E_{c.m.}$ (GeV)	Statistical error (%)	Related XYZ states
$\pi^+\pi^- J/\psi$	4.23	7.5 (3.0)	$Y(4008)$, $Y(4260)$, $Z_c(3900)$
$\pi^+\pi^-\psi(2S)$	4.36	12 (5.0)	$Y(4260)$, $Y(4360)$, $Y(4660)$, $Z_c(4050)$
$K^+K^- J/\psi$	4.53	15 (6.5)	Z_{cs}
$\pi^+\pi^- h_c$	4.23	15 (6.5)	$Y(4220)$, $Y(4390)$, $Z_c(4020)$, $Z_c(4025)$
$\omega\chi_{c0}$	4.23	35 (15)	$Y(4220)$

Y(4260) news from BES-III

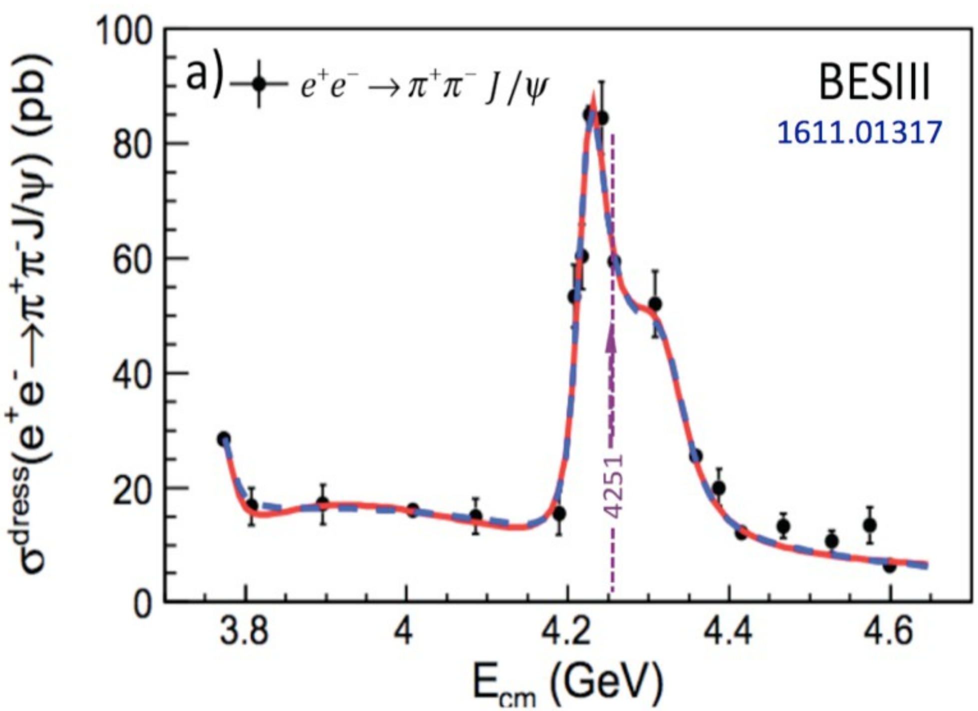
Y(4260)→ηJ/ψ ?

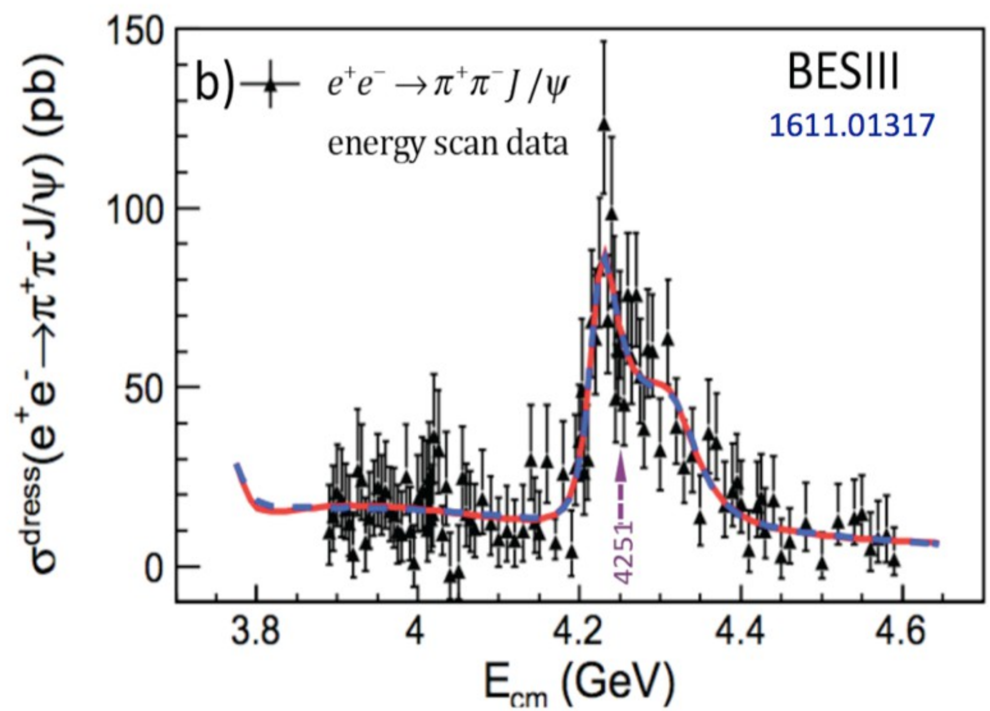
The Y(4260) may actually be the sum of two states, as suggested by high statistics scans and eta transitions:



2 BW res. fit preferred over 1 BW res. fit by >7σ

$$M_1 = 4220 \pm 4\ \mathrm{MeV}/c^2 \qquad \Gamma_1 = 44 \pm 5\ \mathrm{MeV}$$
$$M_2 = 4320 \pm 13\ \mathrm{MeV}/c^2 \qquad \Gamma_2 = 101^{+27}_{-22}\ \mathrm{MeV}$$





Wrapping it up ....

Belle-II hopes to do some valuable physics even during phase-II run , without low momentum tracking , and no vertexing.

A pilot run on Y(6S) peak, even with only 20fb^{-1} , will give us about the 10x data taken in Belle-I. But it is quite risky in phase II This will be a pilot run, to plan future studies in this interesting region.

Searches for exotics are been proposed at 10.65+10.75 GeV

At least 300 fb^{-1} at (and about) the Y(3S) peak are needed to address the following hot topics :

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

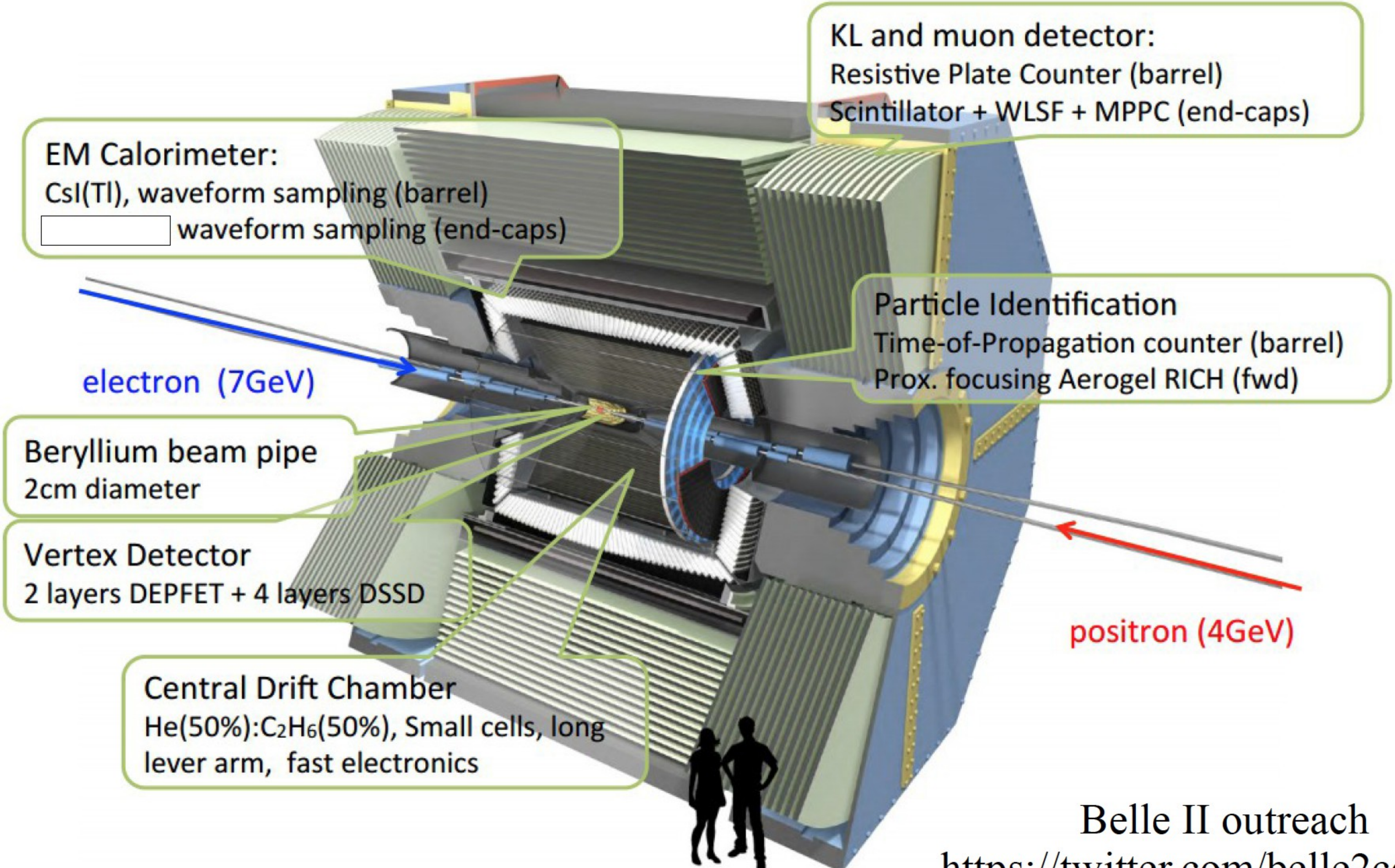
Scans of the Y(1D) and Y(2D) regions are being planned as well
Looking forward showing first results from Belle-II in end 2018

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!

H

Belle-II Detector

[Belle II TDR, KEK Report 2010-1]



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