Belle II early physics program of bottomonia spectroscopy

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on behalf on Belle II collaboration

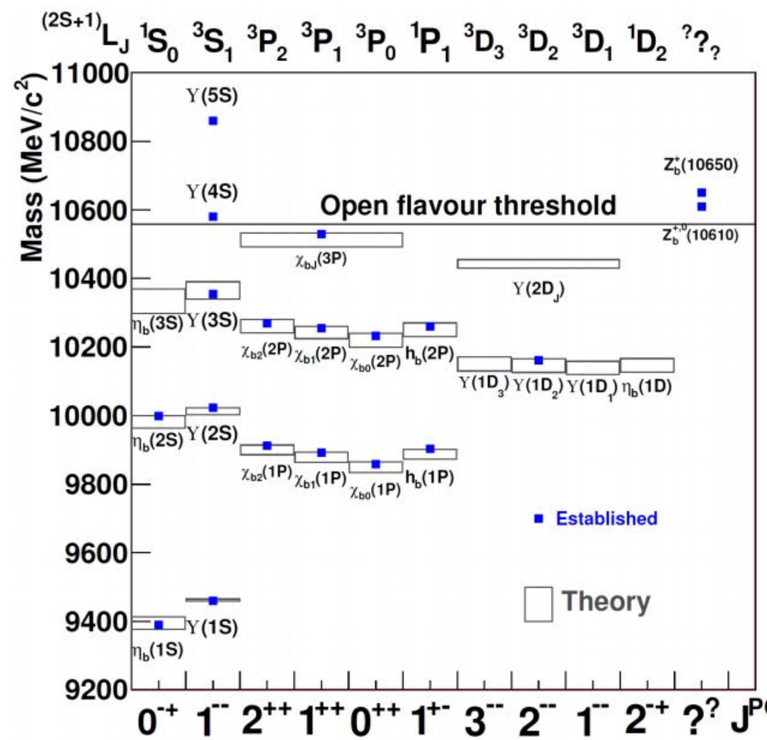
XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2016)

11-15 April 2016, DESY Hamburg

Physics at B-Factory

- CP Violation
  - CKM matrix elements: V_{ub}, V_{cb}.
  - CPV in charm sector
- Bottomonium spectroscopy
- Unanticipated New Particles
  - XYZ hadrons. *Eg. X(3872), Y(4260),* $Z_c^{\pm}$, $Z_b^{\pm}$
- Beyond the SM
  - B→ $X_s l^+ l^-$ probe the Flavor changing neutral currents
  - Lepton flavor violating.
  - B→τν, $D^{(*)}$τν probe the charged Higgs.
  - Light dark matter particles and dark photon (See DIS2016 talk by G.Inguglia)
  - ……

- Challenge in Bottomonia Spectroscopy
  - Some predicted but not observed
  - Some observed but not predicted
  - Precise measurements



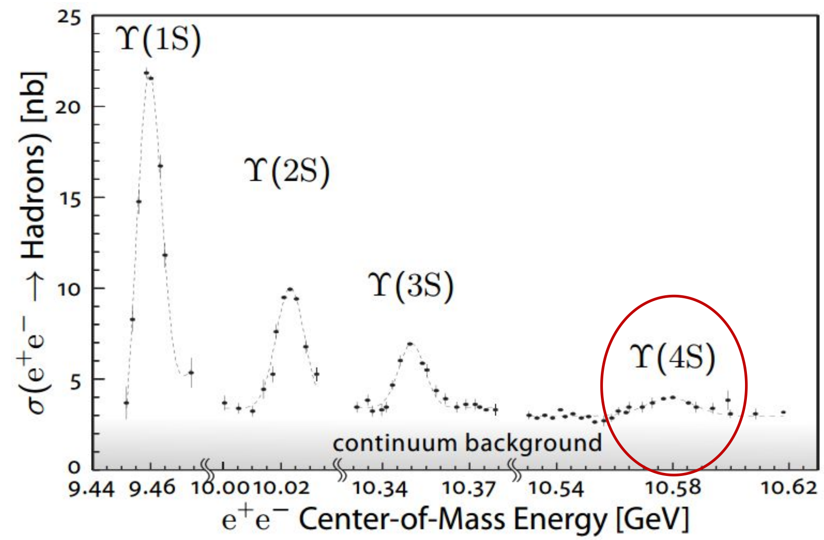
First Generation of B-factories

☐ BaBar at PEP-II, SLAC

- 9GeV(e^-)X3.1GeV(e+), βγ-0.56
- Peaking luminosity
  ~ $1.2X10^{34}$ $cm^{-2}s^{-1}$

☐ Belle at KEKB, KEK

- 8GeV(e^-)X3.5GeV(e+), βγ-0.43
- Peaking luminosity
  $2.11X10^{34}$ $cm^{-2}s^{-1}$ (world record)
- Total data 1 ab^{-1}

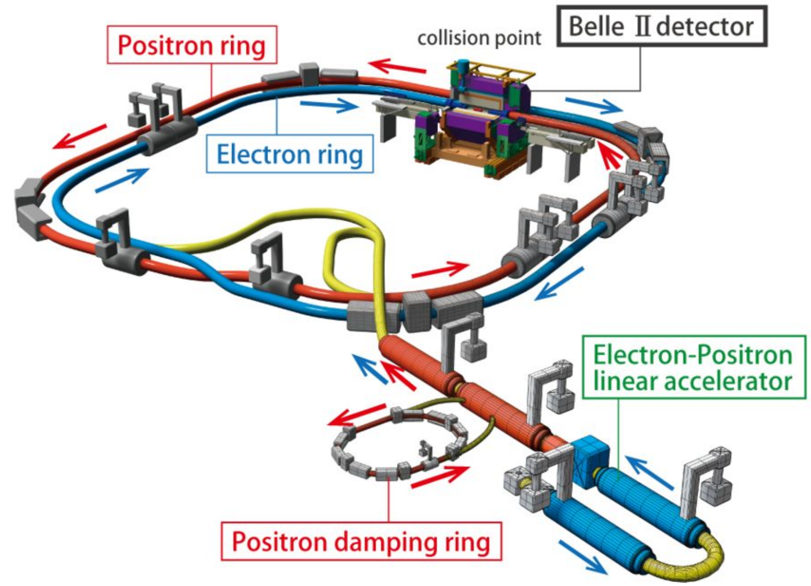


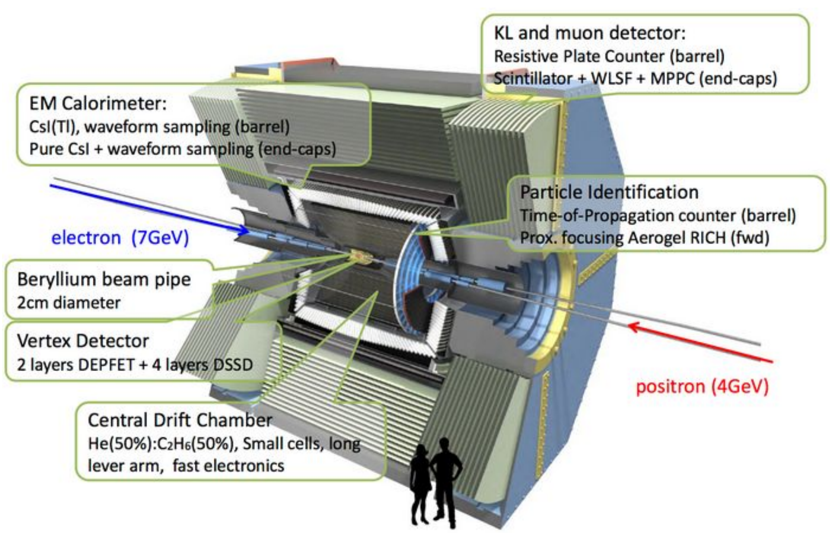
Mainly at Υ(4S), E_{CM} = 10.58 GeV
BR(Υ(4S)→ $B\bar{B}$) > 96%

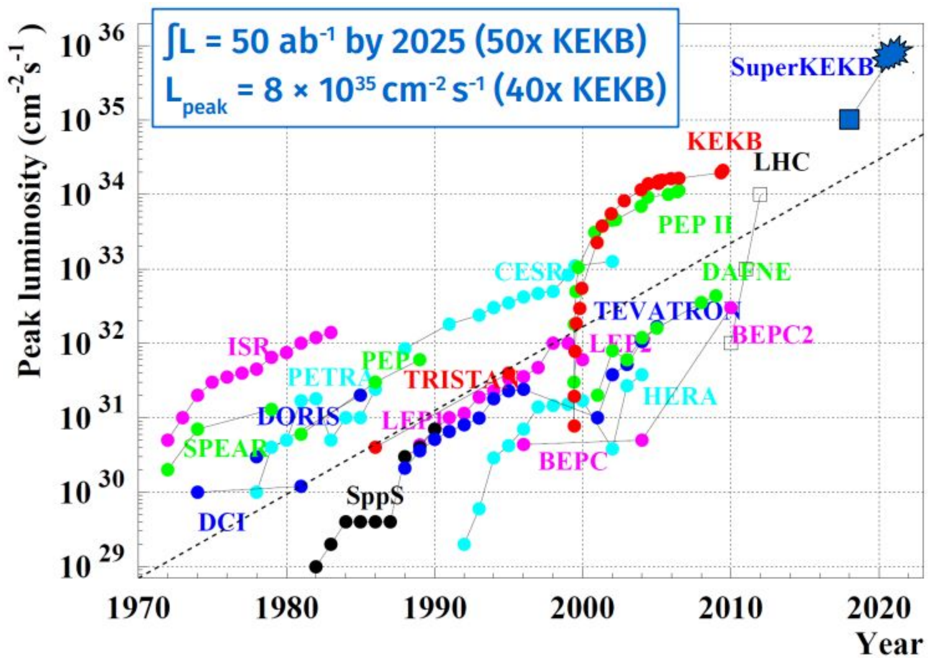
Experiment	Scans/Off. Res.	$\Upsilon(5S)$		$\Upsilon(4S)$		$\Upsilon(3S)$		$\Upsilon(2S)$		$\Upsilon(1S)$	
		10876 MeV		10580 MeV		10355 MeV		10023 MeV		9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan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

Existing e⁺e⁻ datasets collected near Υ resonances.

SuperKEKB/Belle II Upgrade







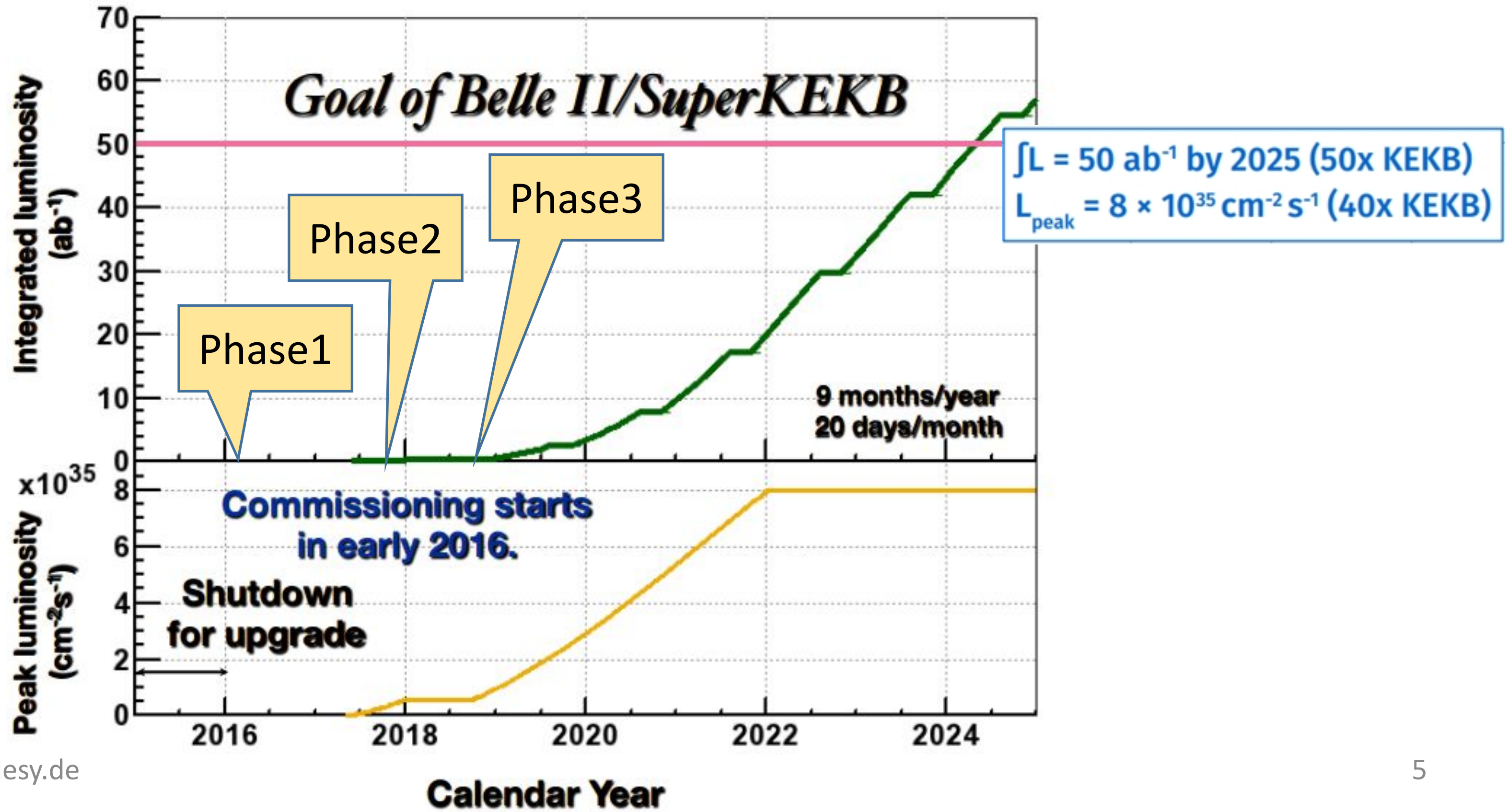
See DIS2016 talk by C.Marinas

BEAST II Schedule

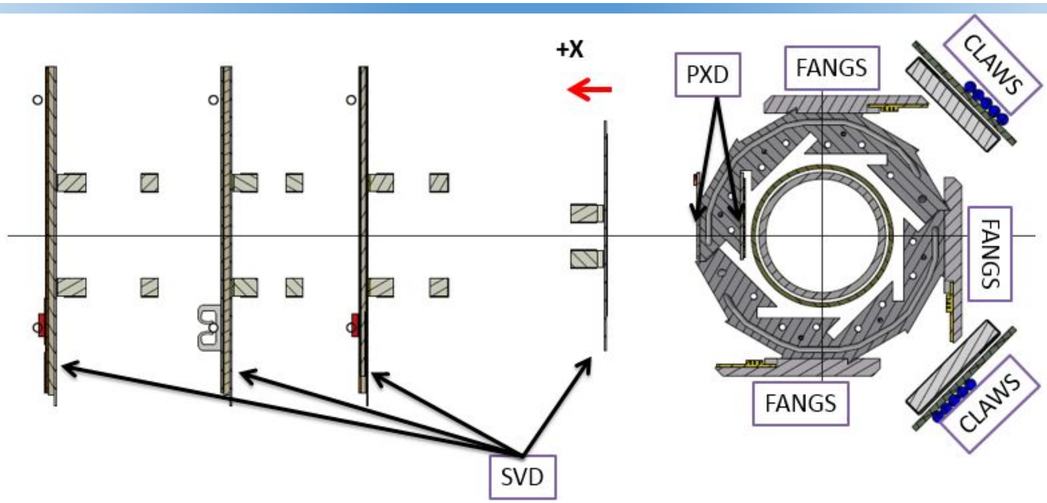
Beam Exorcism for A STable experiment (**BEAST II**)

To characterize beam-induced backgrounds near the interaction point (IP)

- Phase 1 (2016.2-6): Beam commissioning, without collisions & Belle II
- Phase 2 (2017.11-2018.3): partial Belle II is rolled in, no vertex detector, collision tuning starts.
- Phase 3 – Physics Run (2018.10-): Full Belle II



Towards First Physics: Phase 2



Layout of the BEAST2 inner detector elements for Phase 2.

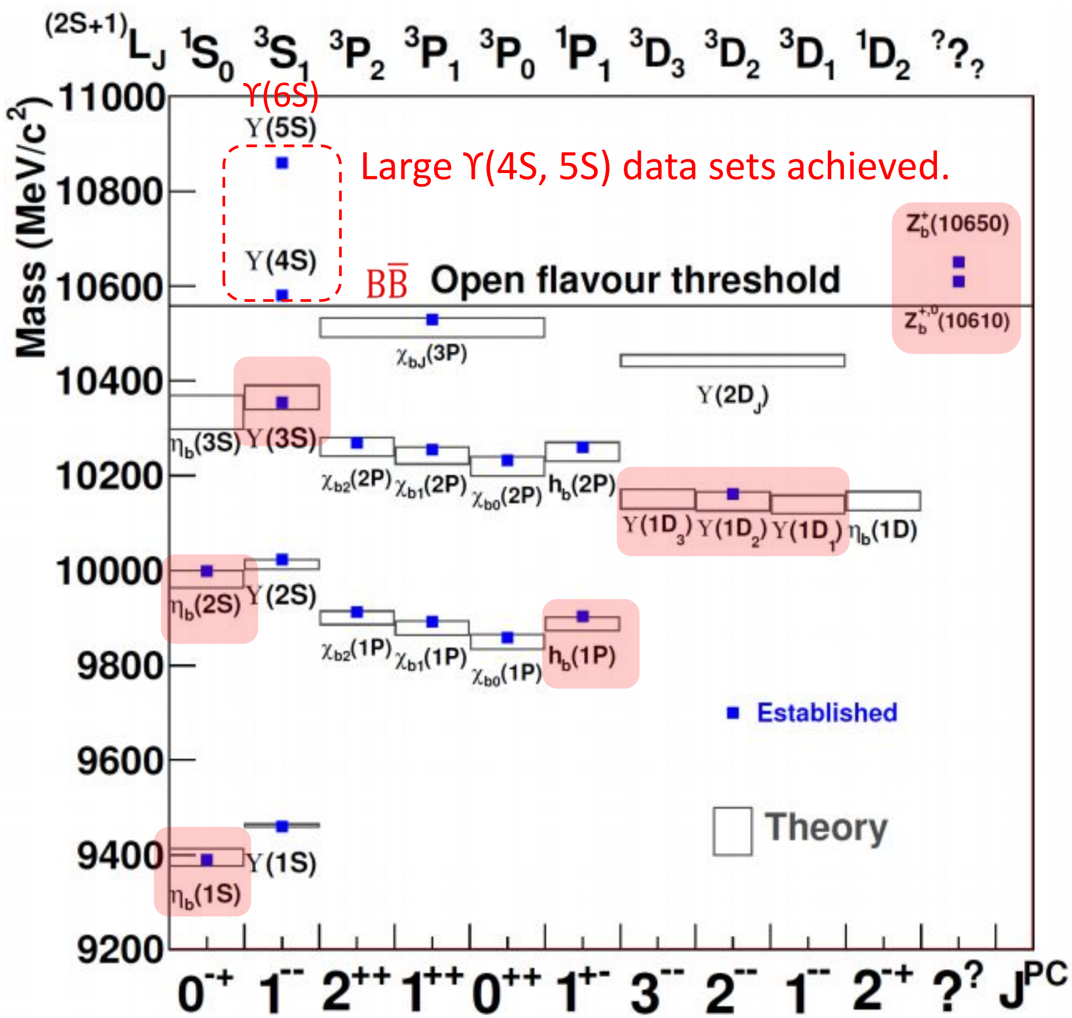
Goals of Phase 2

- Achieve luminosity of 10^{34} cm^{-2} s^{-1}, understand the background for safe operation of vertex detector(VXD).

Opportunities for first physics?

- Plan for 4-5months of machine studies, 1-2months may contain physics data taking.
- Maximum possible energy 11.06 - 11.25 GeV, energy spread assumed to be ~5MeV.
- Stable operation close to $\Upsilon(4S)$ preferred
- Efficiency losses for low P_t particles, no appreciable losses in photon efficiency.
- particle identification may not be fully reliable.
- **Rough estimate of integrated luminosity (20±20 fb^{-1})**

Early Physics: Bottomonia Spectroscopy

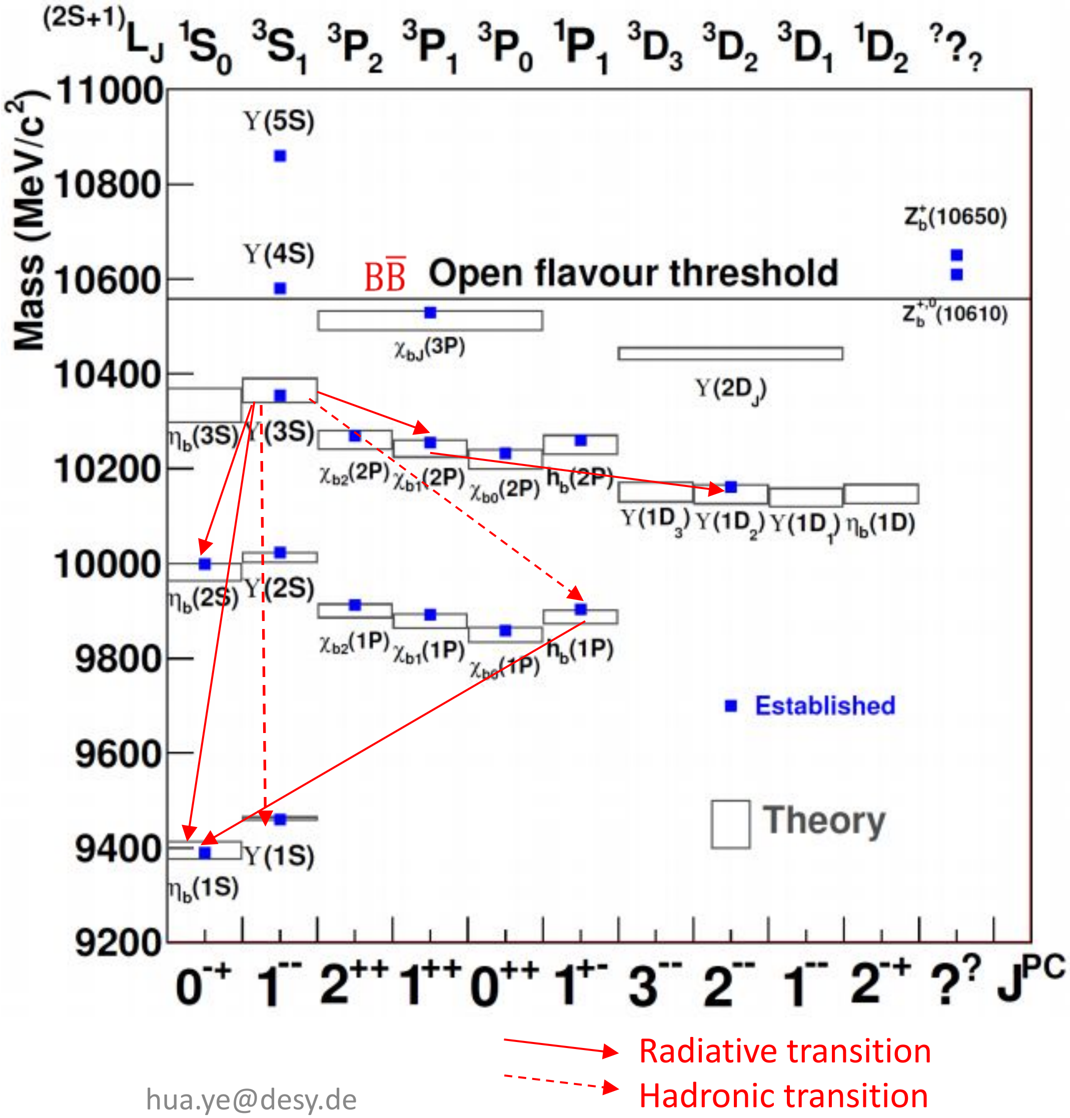


- **Early Physics:**
  physics program in the early data taking period of Belle II (Phase 2 and early Phase 3)

- **Above ϒ(5S)**
  - Charged bottomonium-like states

- **Bellow ϒ(4S):** The ϒ(3S) offers greatest access to lower bottomonium states
  - Study of η_b(1S,2S)
  - h_b(1P) and ϒ(n^3D_1) Studies
  - Analyses with converted photons to improve resolution.
  - Hadronic/Radiative transitions.

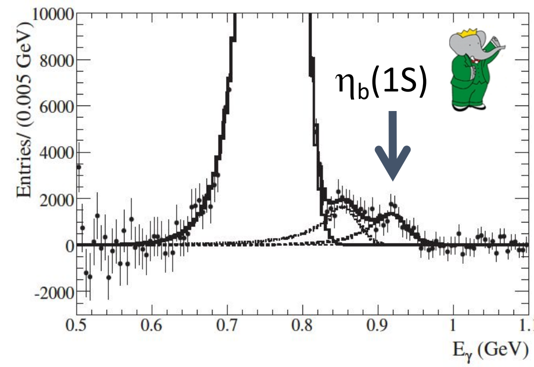
Bellow Υ(4S)



- A significant increase in scientific potential could be achieved with about 200 fb^{-1} $Y(3S)$ data (~7X Babar), to study of the bottomonium system.
- From a machine operations standpoint, it may also be desirable to begin with a "low" energy.
- Several important parameters that either need to be measured or have conflicting experimental results in need of resolution, including masses and widths of the η_b states, χ_{b0} widths, the mass splitting of the $Y(1D)$ states, and the $B(Y(3S) \rightarrow \gamma\chi_b(1P))$ branching fractions.

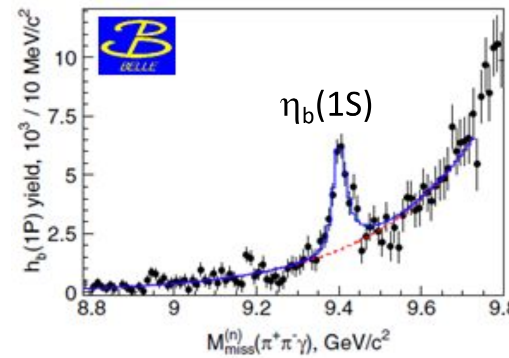
Study of η_b(1S,2S) at Υ(3S)

$\Upsilon(3S)\to\gamma\eta_b(1S)$



PhysRevLett.101.071801

$h_b(1P,2P)\to\gamma\eta_b(1S)$



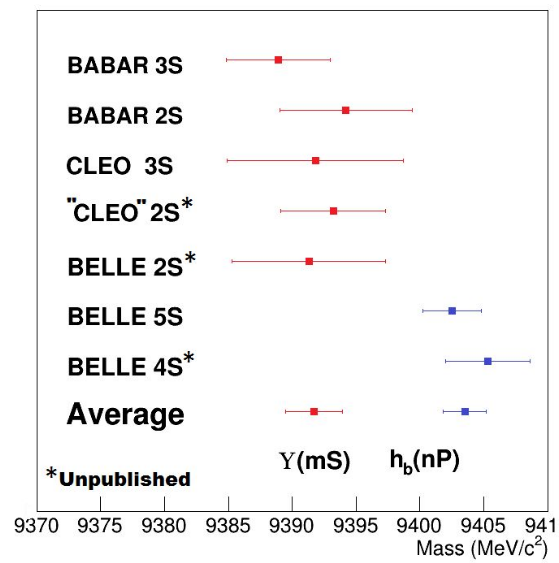
PhysRevLett.109.232002

Measured by BaBar, Belle, and CLEO

- $\Upsilon(2,3S)\to\gamma\eta_b(1S)$, $h_b(1,2P)\to\gamma\eta_b(1S,2S)$
- Evidence of $h_b(2P)\to\gamma\eta_b(2S)$
- Measured $\eta_b(1S)$ mass disagree at the ~ 3.5σ level.
- Further measurements of $\eta_b(2S)$ are needed.

Potential at Belle II

- radiative transition $\Upsilon(3S) \to \gamma\ \eta_b(1S,2S)$
  - Given $B(\Upsilon(3S) \to \gamma\ \eta_b(1S)) \sim 5\times10^{-4}$, one expects ~800 $\eta_b(1S)$ /fb^{-1}, assuming an efficiency of ~ 40%.
- $\Upsilon(3S) \to \pi^0 h_b(1P)\to\gamma\eta_b(1S)$
  - Expects ~350 $\eta_b(1S)$ /fb^{-1}
- $\Upsilon(3S) \to \gamma\chi_{b0}(2P) \to \eta\ \eta_b(1S)$
  - No previous searches, theory prediction: $B(\chi_{b0}(2P) \to \eta\ \eta_b(1S))\sim10^{-3}$
  - Expects ~10 $\eta_b(1S)$ /fb^{-1}
  - Require a 200fb^{-1} $\Upsilon(3S)$ sample



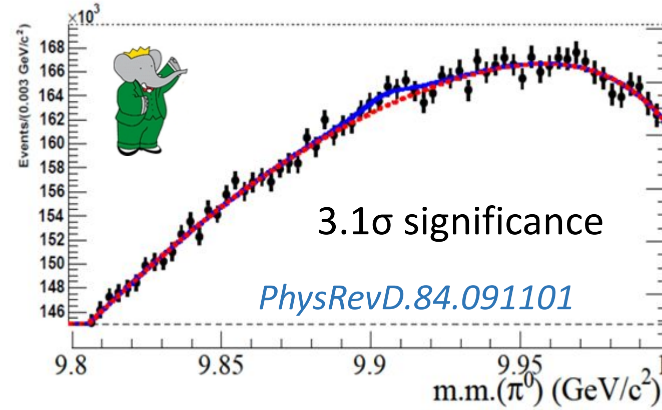
$\eta_b(1S)$ mass measurements

$h_b(1P)$ and $\Upsilon(n^3D_1)$ Studies at $\Upsilon(3S)$

Study of $h_b(1P)$ at $\Upsilon(3S)$

BaBar searched $h_b(1P)$ in two decay channels

- $B(\Upsilon(3S) \to \pi^+\pi^- h_b(1P)) < 1.2 \times 10^{-4}$
- $B(\Upsilon(3S) \to \pi^0 h_b(1P) \to \gamma\eta_b(1S)) = (4.3 \pm 1.4) \times 10^{-4}$



$\Upsilon(n^3D_1)$ Measurements

- Only one (of 6 predicted) D-wave bottomonium state, $\Upsilon(1^3D_1)$ has been observed.
- Predictions from theory: Limited mass range, very narrow, decays dominantly to $\gamma\chi_{b0}(nP)$ (~70+%)

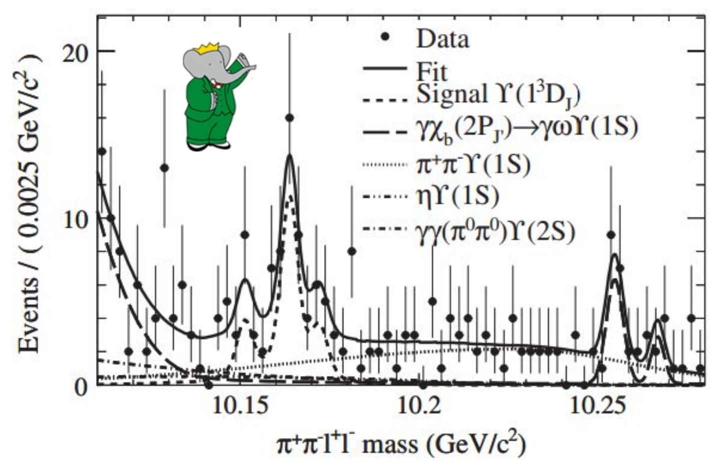
$\Upsilon(1^3D_1)$	10145-10155MeV	$\Upsilon(1^3D_2)$	10163.7 ± 1.4MeV
$\Upsilon(1^3D_3)$	10168-10172MeV	$\Upsilon(2^3D_2)$	10420-10460MeV

7-9 times increase of Babar statistics is needed.

Opportunity for Belle II early Physics:

- 4γ mode: $\Upsilon(3S) \to \gamma\chi_{bJ}(2P) \to \gamma\,\Upsilon(1D) \to \gamma\chi_{bJ}(1P) \to \gamma\,\Upsilon(1S)$
- $\Upsilon(n^3D_1)$ ($J^{PC}=1^{--}$) can be directly studied via a beam energy scan.

Babar: *$Y(3S) \to \gamma\gamma Y(1^3D_2) \to \pi^+\pi^- Y(1S)$*



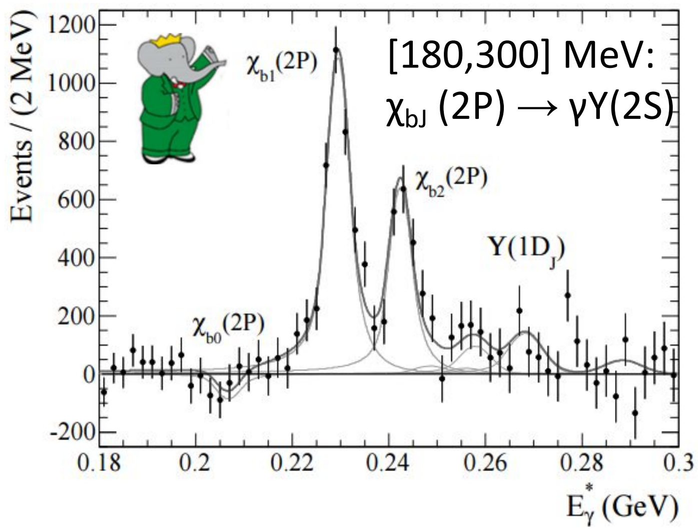
PhysRevD.82.111102

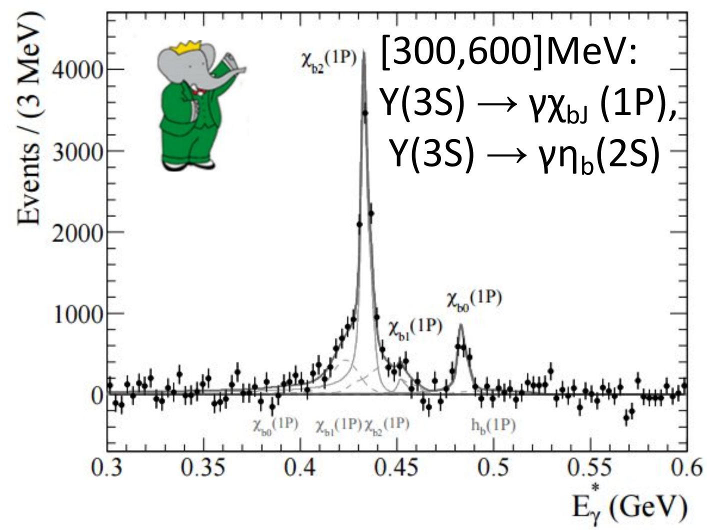
Analysis with converted photons

- BaBar used photons converting into e^+e^- pairs in detector material to study radiative bottomonium decays.
- Although the efficiency for converted photon reconstruction is much lower than that for calorimetry (by a factor of 20-40), energy resolution is improved (e.g. from 25MeV to 5 MeV for $\eta_b(1S)$ transitions)

Based on the 30fb^{-1} $\Upsilon(3S)$ sample of Babar

PhysRevD.84.072002





- Most of photon conversions occur at an inner radius before entering drift chamber, resulting in better energy resolution since less multiple scattering.

Hadronic/Radiative transitions

- Hadronic transitions and decays
  - $\pi^+\pi^-$ transitions: $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)$, $\chi_{bJ}(2P)\to\pi^+\pi^-\chi_{bJ}(1P)$, $\Upsilon(1D)\to\pi^+\pi^-\Upsilon(1S)$
  - η transitions: $\Upsilon(3S)\to\eta\Upsilon(1S)$, $\Upsilon(1D)\to\eta\Upsilon(1S)$
  - ω transitions: $\chi_b(2P) \to \omega\, \Upsilon(1S)$

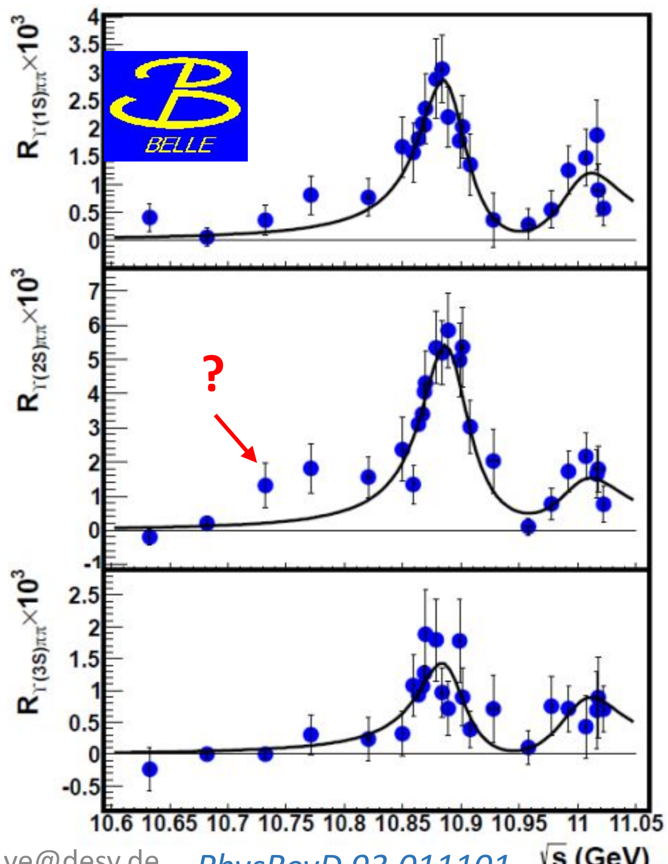
- Radiative decays
  - Calibrate the EM Calorimeter.
  - $\Upsilon(3S)\to\gamma\chi_b(1P)$ difficult to measure due to overlapping photon transitions.
  - $\chi_{b0}(2P)\to\gamma\Upsilon(2S)$ only reached a significance of 2.2σ.
  - $\Upsilon(1D)$ in 4γ mode:

    $\Upsilon(3S)\to\gamma\chi_{bJ}(2P)\to\gamma\Upsilon(1D)\to\gamma\chi_{bJ}(1P)\to\gamma\Upsilon(1S)$

Above Υ(4S): Ecm Scan

Sparing studies of the rigion between 10.6 GeV and 11.25 GeV

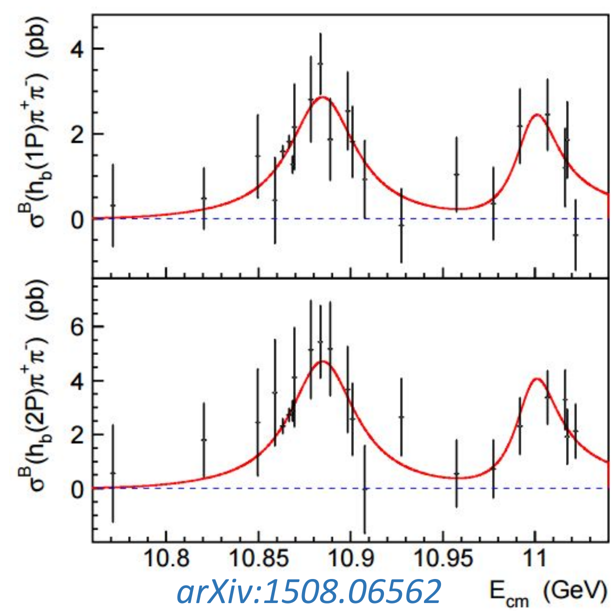
- In 2008, Babar published results used 3.3fb^{-1} data with 300points.
- Belle first collected 8fb^{-1} scan data, then followed by 19 points of about 1 fb^{-1} each in the range from 10.77 to 11.02GeV.
- Belle also accumulated 6fb^{-1} data at Υ(6S).



PhysRevD.93.011101

Expect to study during Phase2

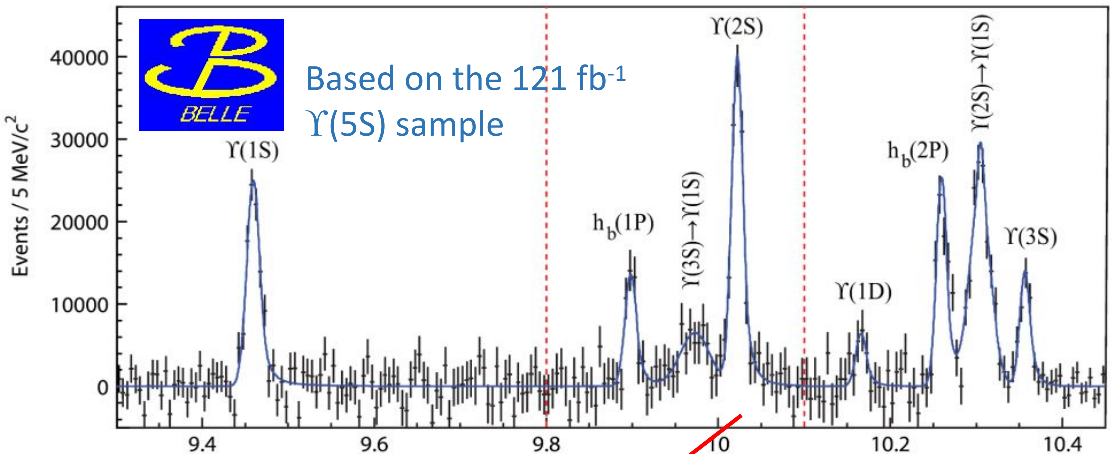
- Rb=σ($b\bar{b}$)/σ($\mu^+\mu^-$)
- σ(Υ(nS)ππ) and σ(h_b(nP)ππ) (potentially search for Z_b states)
- σ($B^{(*)}B^{(*)}$)and σ ($B_s^{(*)}B_s^{(*)}$)



arXiv:1508.06562

Charged bottomonium-like states: $Z_b^{\pm}$

Anomalously large $\Upsilon(5S) \rightarrow \pi\pi\Upsilon(1S,2S,3S)$ and $\pi\pi h_b(1P, 2P)$ transitions led to discovery of $Z_b^{\pm}$.



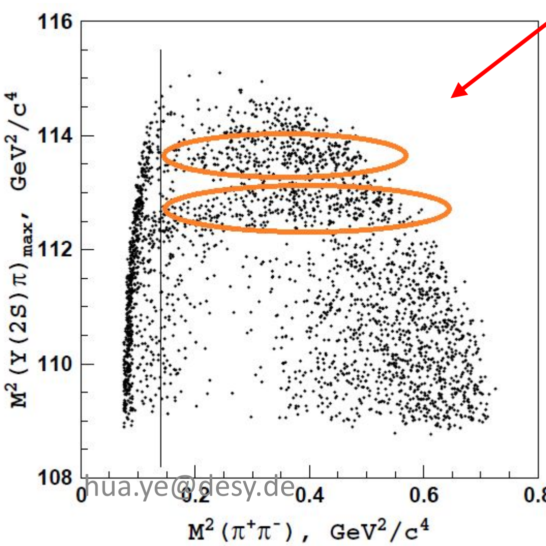
PhysRevLett.108.032001

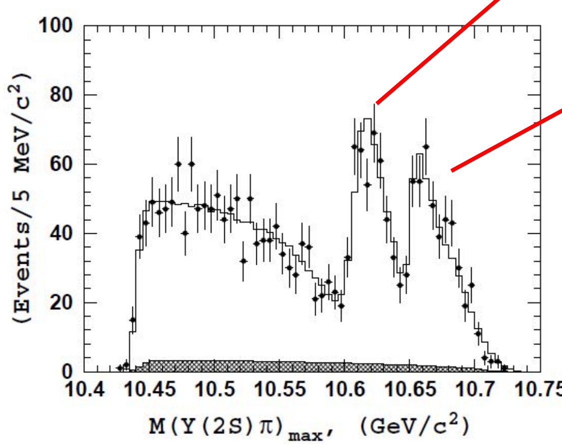
$M_{miss}(\pi\,\pi)$ (GeV/c²)

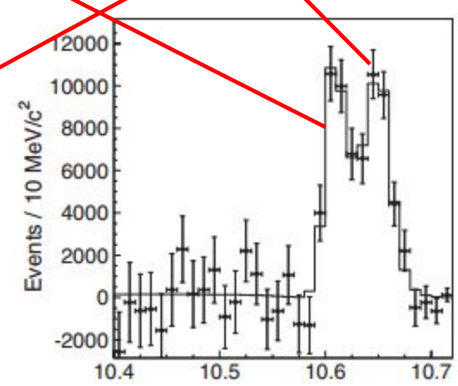
The spectrum of $M_{miss}(\pi)$ for $Y(5S) \rightarrow B\bar{B}^{*}\pi$ decays shows clear $Z_b(10610)$ signal, while $Y(5S) \rightarrow B^{*}\bar{B}^{*}\pi$ shows the $Z_b(10650)$ signal.

arXiv:1209.6450

$Z_b^{\pm}(10610)$ $Z_b^{\pm}(10650)$







$M(h_b(1P)\pi)$ (GeV/c²)

PhysRevLett.108.122001

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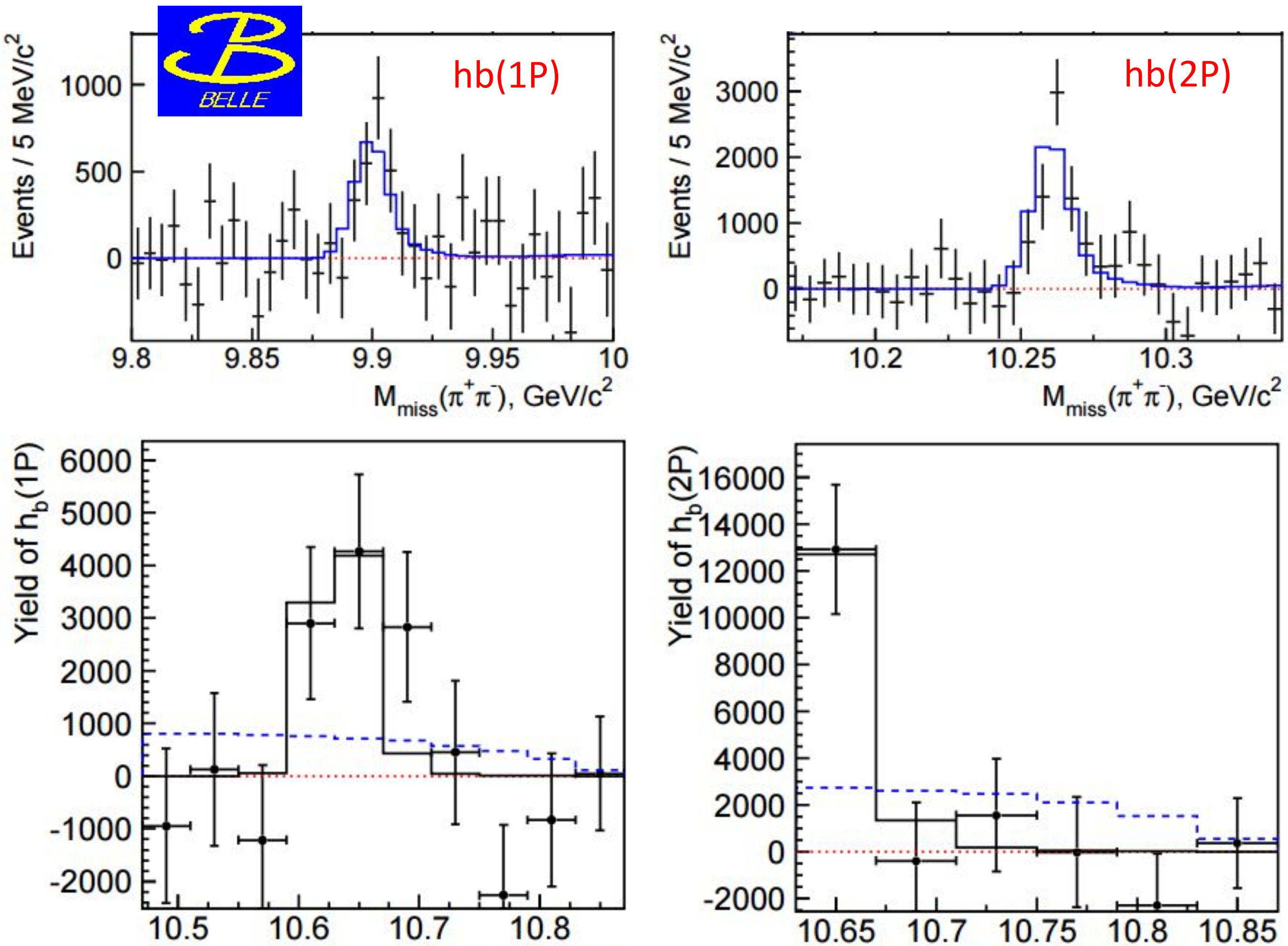
Search $Z_b^{\pm}$ states from Υ(6S)

What is the situation at Υ(6S)?

- Base on the $6fb^{-1}$ data collected by Belle



The fixed shape Zb fit is favored compared to the phase space fit by 3.4σ and 4.7σ for the hb(1P) and hb(2P), respectively.

Resonance structure in Υ (6S)⟶ππΥ(nS) decays are not fully studied.

arXiv:1508.06562

Summary

Belle II will be the new intensity frontier experiment with ultra high luminosity, aiming of precise measurements and searching for new physics in bottomonium mass range.

Belle II physics data taking will start in 2018, first data with partial detector in 2017.

Various **bottomonia spectroscopy** topics that could be considered in the early data taking phase for Belle II is covered. Considering the detector condition of BEAST II Phase2, many of the proposed analyses are not overly sensitive to particle identification, nor to vertex finding precision, but mostly limited to existing sample sizes at specific collision energies.

Thank you!