Bianca SCAVINO
bscavino@uni-mainz.de

QCD 18
Montpellier, 6/7/2018

Prospects of conventional and exotic bottomonium physics at Belle II

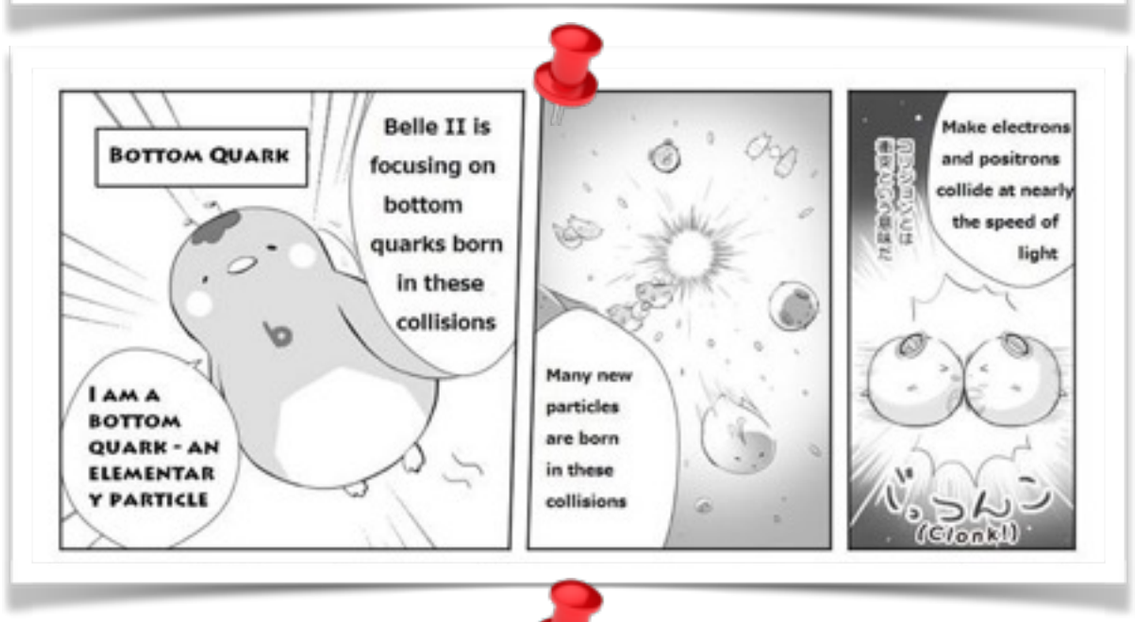
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outlook

- THE EXPERIMENT

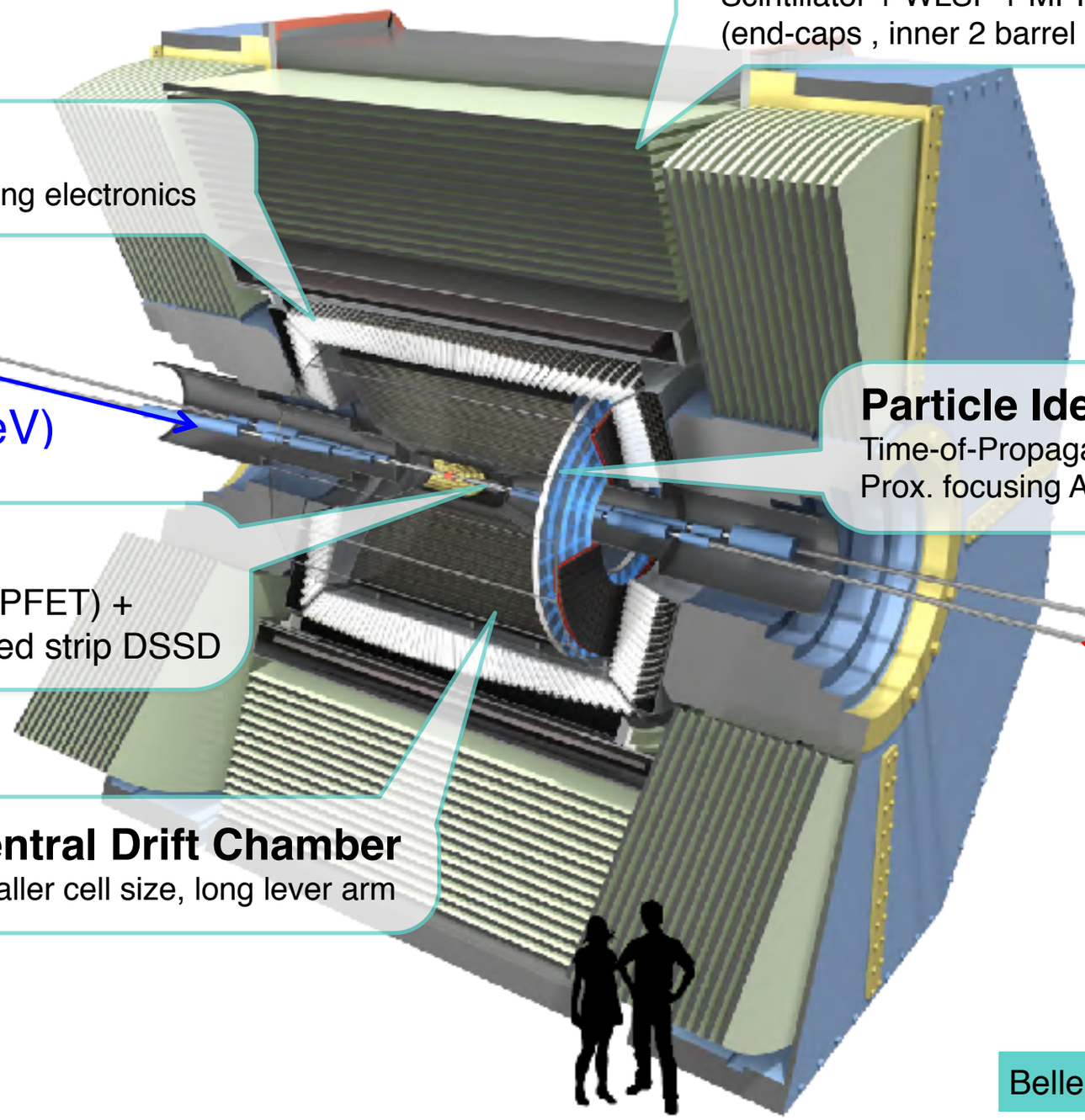
- BOTTOMONIA

- BEYOND BOTTOMONIA



THE EXPERIMENT

The Belle II detector



KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)

EM Calorimeter
CsI(Tl), waveform sampling electronics

electrons (7 GeV)

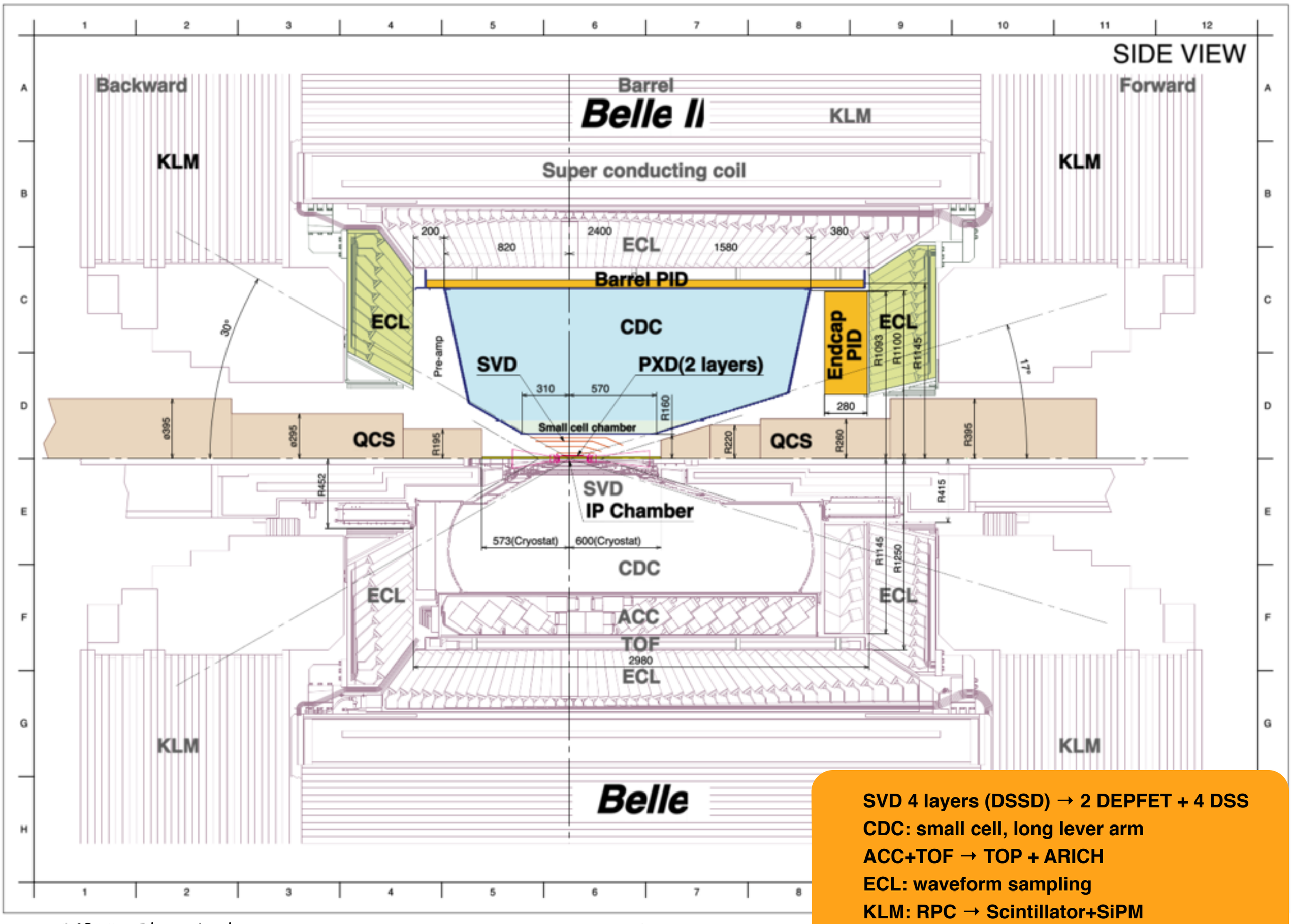
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

positrons (4 GeV)

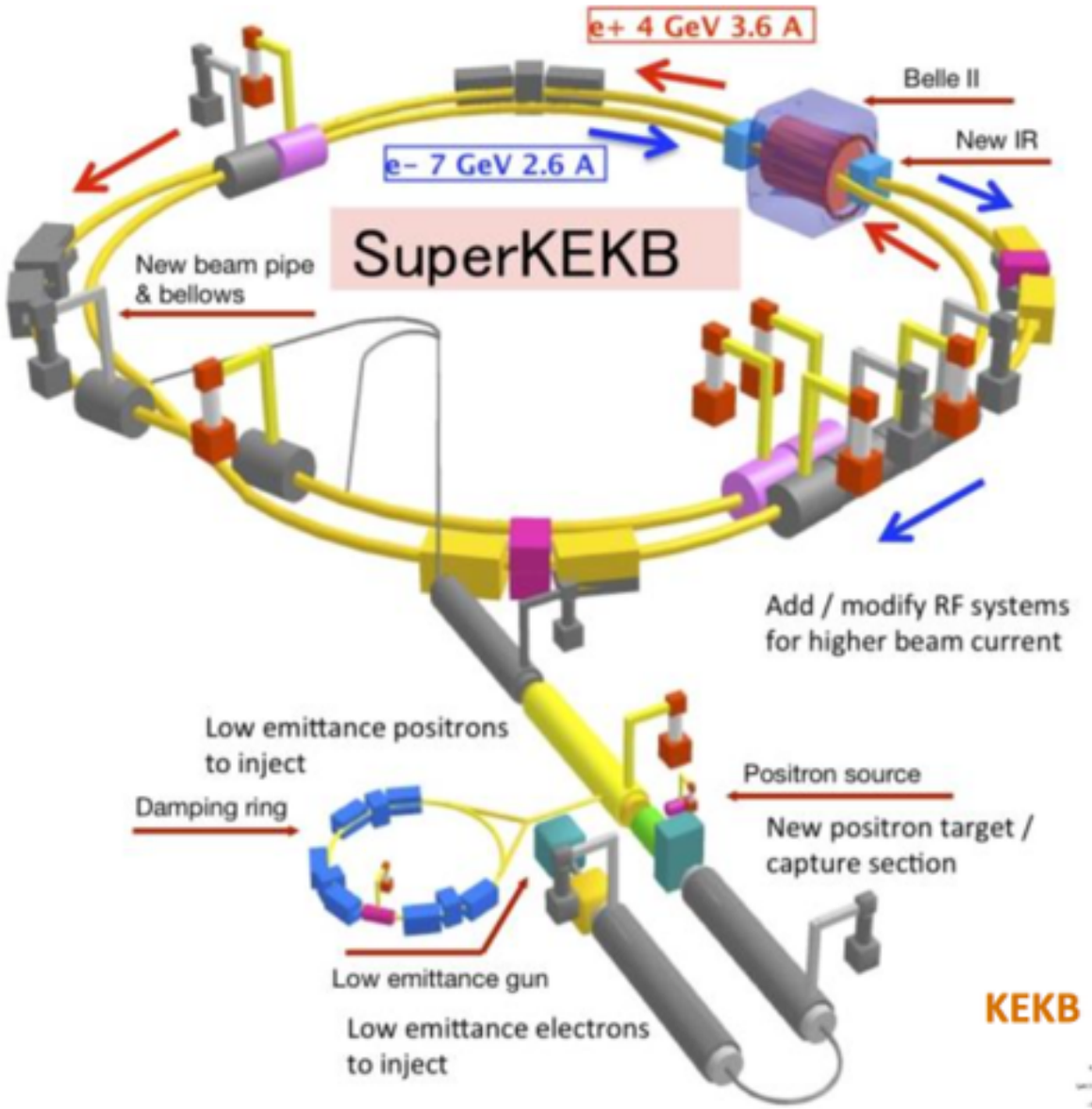
Central Drift Chamber
Smaller cell size, long lever arm

Belle II TDR, arXiv:1011.0352



SVD 4 layers (DSSD) → 2 DEPFET + 4 DSS
CDC: small cell, long lever arm
ACC+TOF → TOP + ARICH
ECL: waveform sampling
KLM: RPC → Scintillator+SiPM

KEKB to SuperKEKB



➡ target luminosity:

$L = 8 \times 10^{35}$ cm^{-2} s^{-1}

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

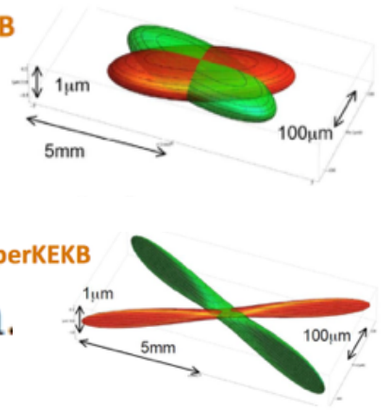
➡ Nano-beam scheme
(P.Raimondi for SuperB)

- double beam currents
- squeeze beam @ IP by 1/20

KEKB to SuperKEKB

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

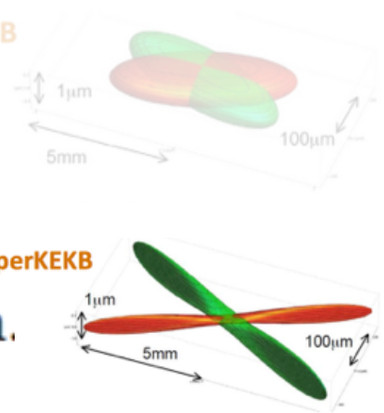
$$\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x} \begin{cases} \sigma_z = 1 \text{ cm} & \text{KEKB} \\ \sigma_z = 0.049 \text{ cm} & \text{SuperKEKB} \end{cases}$$

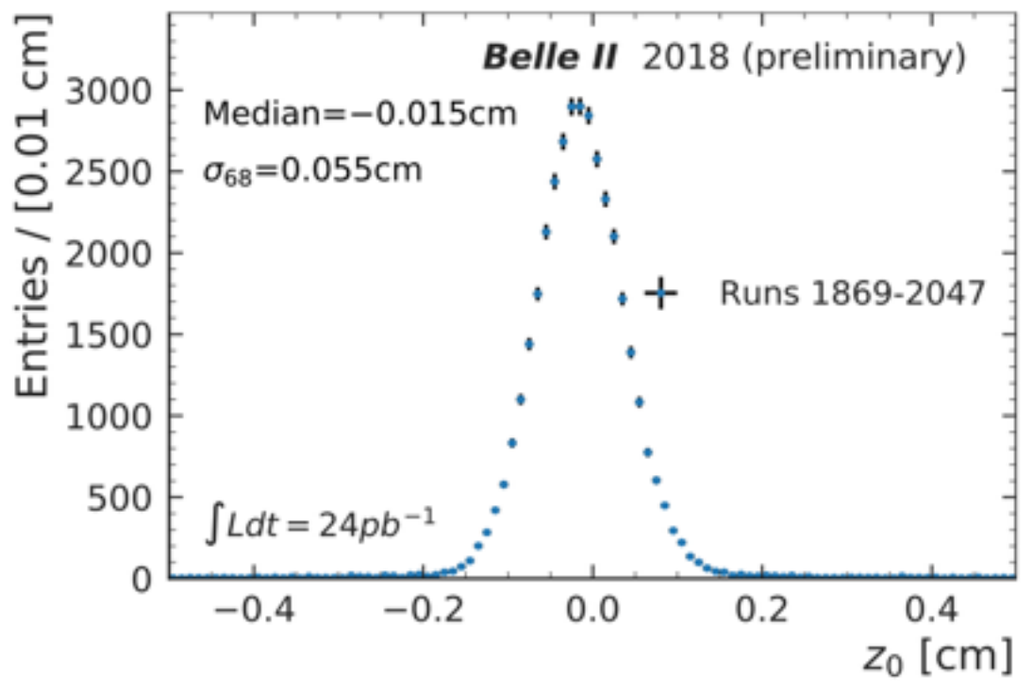


KEKB to SuperKEKB

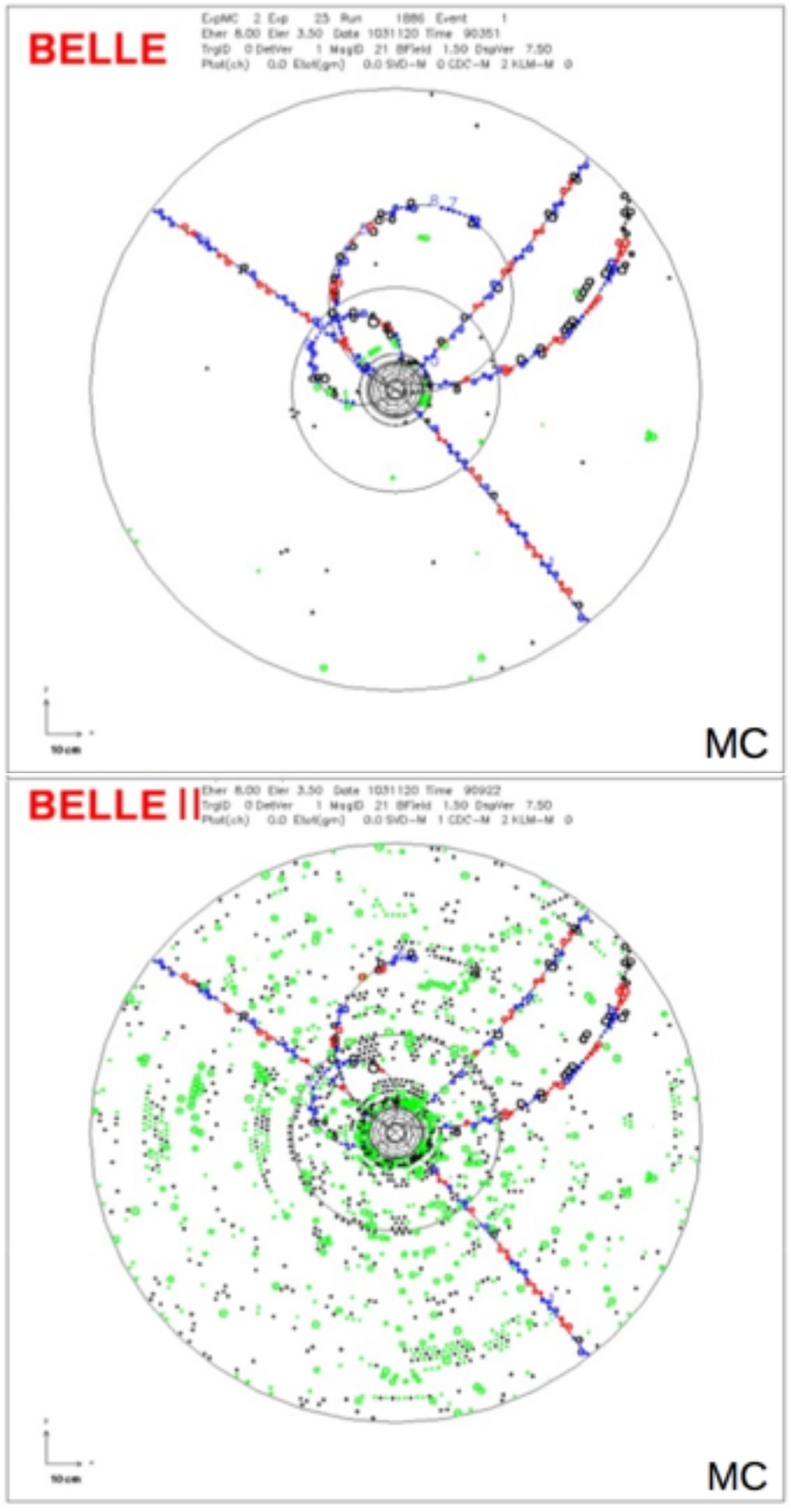
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

$$\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x} \begin{cases} \sigma_z = 1 \text{ cm} & \text{KEKB} \\ \sigma_z = 0.049 \text{ cm} & \text{SuperKEKB} \end{cases}$$





New challenges

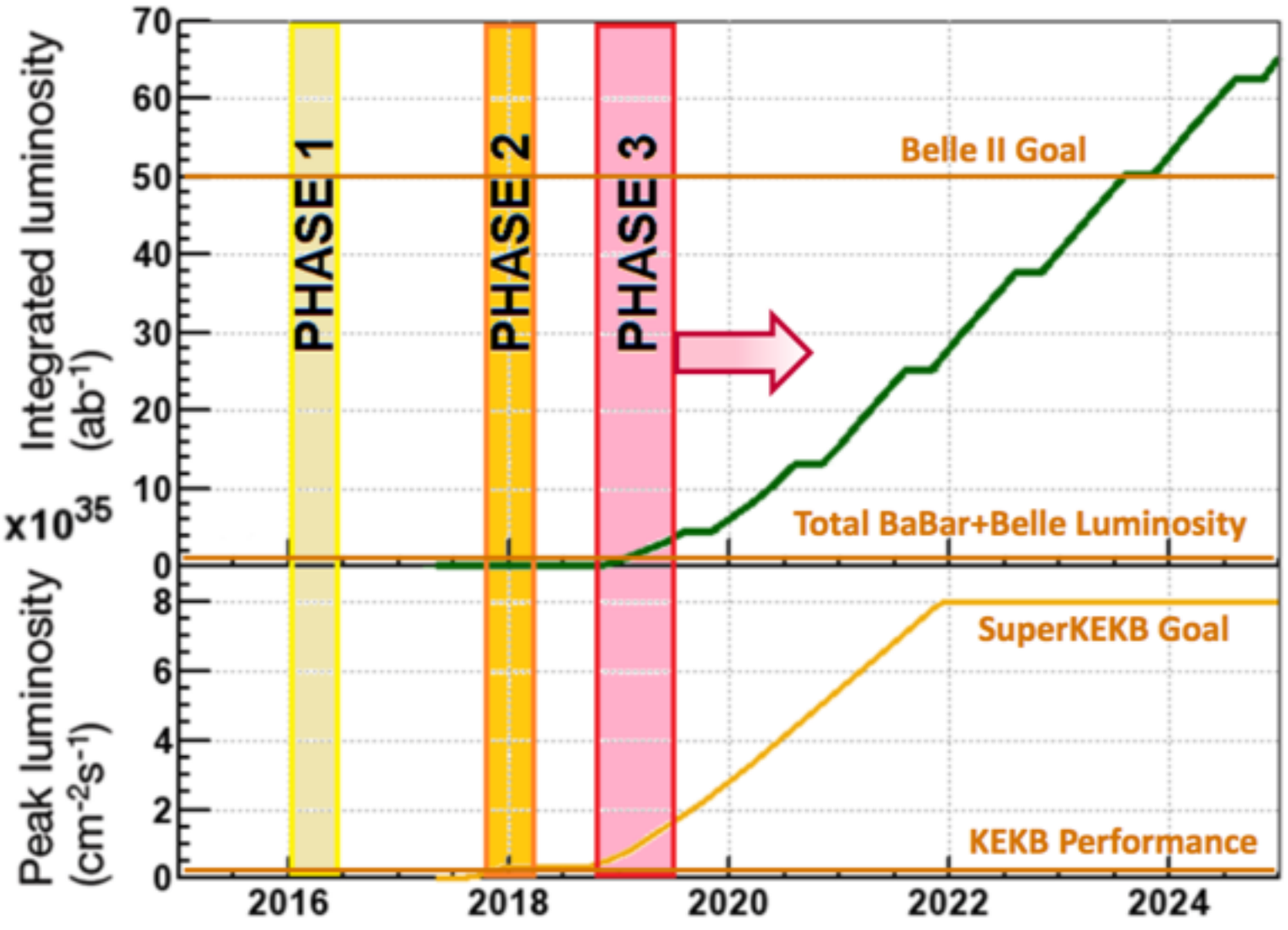


➡ x40 luminosity:

- x40 produced signal events
- Higher background (detector occupancy, fake hits, radiation damage)
- Higher event rate (trigger rate,DAQ, computing)

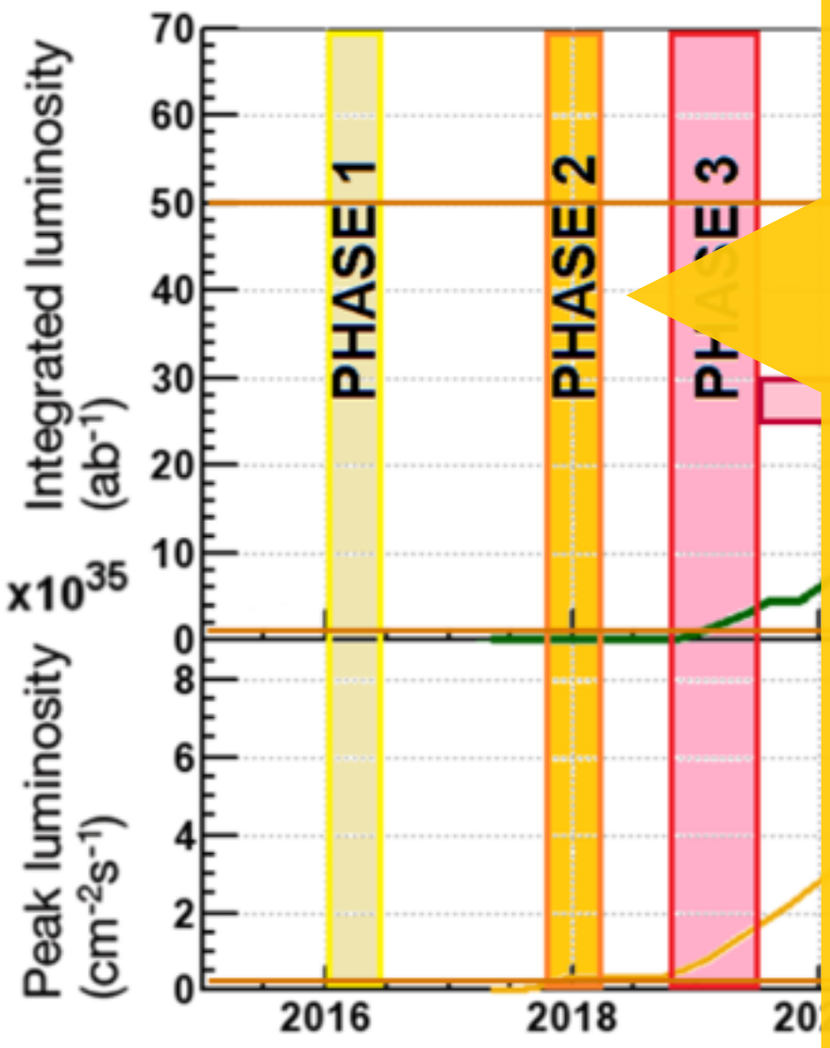
➡ Important to have a dedicated phase for background studies, detector response and alignment

Belle II schedule



- Phase1:
  Accelerator commissioning
  (completed in 2016)
- Detector roll-in
  (April 2017)
- Phase2:
  - Background studies
  - Physics possible
  (April 2018)
- Phase3:
  Full Belle II
  (early 2019)

We are here



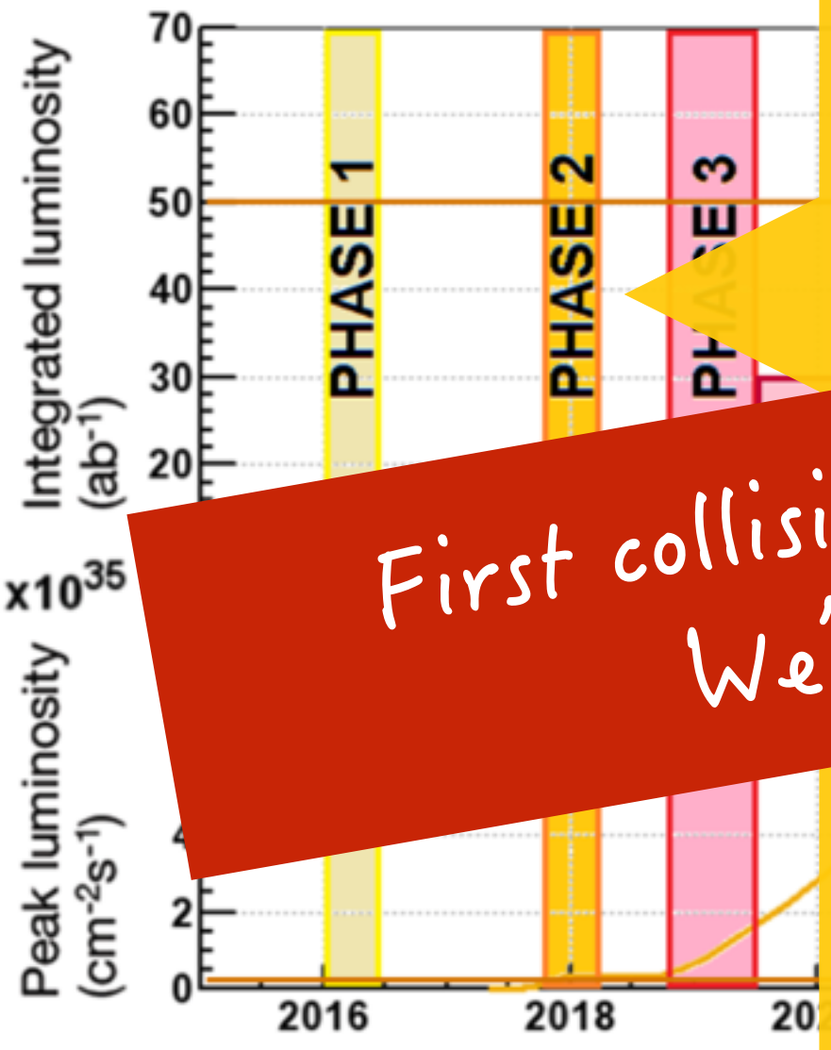
➡ **Goals:**

- **Accelerator operating for the first time with QCS magnets**
- **Verification of nano beam scheme (target L~10^34cm^(-2)s^(-1))**
- **Understand machine background and detector performances**
- **Data taking for physics**

➡ **Detector:**

- **Belle II with no VXD detector but BEAST2 detector**
  → dedicated beam background detectors + 1 VXD ladder per layer

We are here



➡ **Goals:**

- **Accelerator operating for the first time with QCS magnets**
- **Verification of nano bea**
  L~10^3

ctor

First collisions recorded on April 26th!
We're back in the game!

➡ **Detector:**

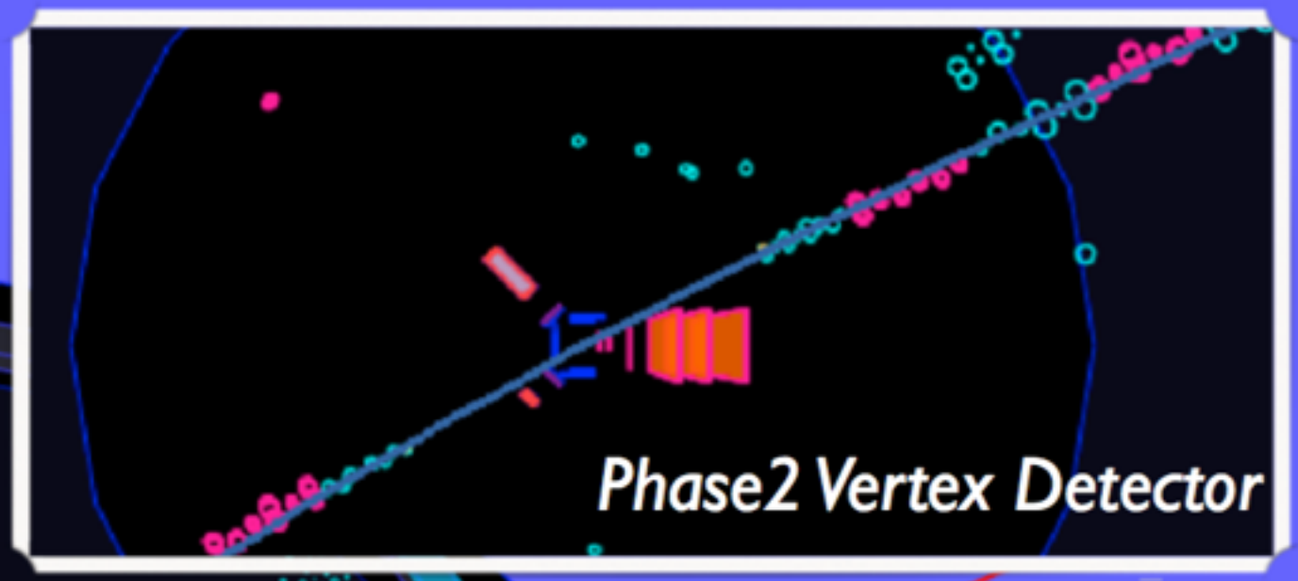
- **Belle II with no VXD detector but BEAST2 detector**
  → dedicated beam background detectors + 1 VXD ladder per layer

-150 -100 -50 0

Bhabha candidate event

exp3 run126 ev73

Apr. 26, 2018



50 0 -50 00

CDC hits

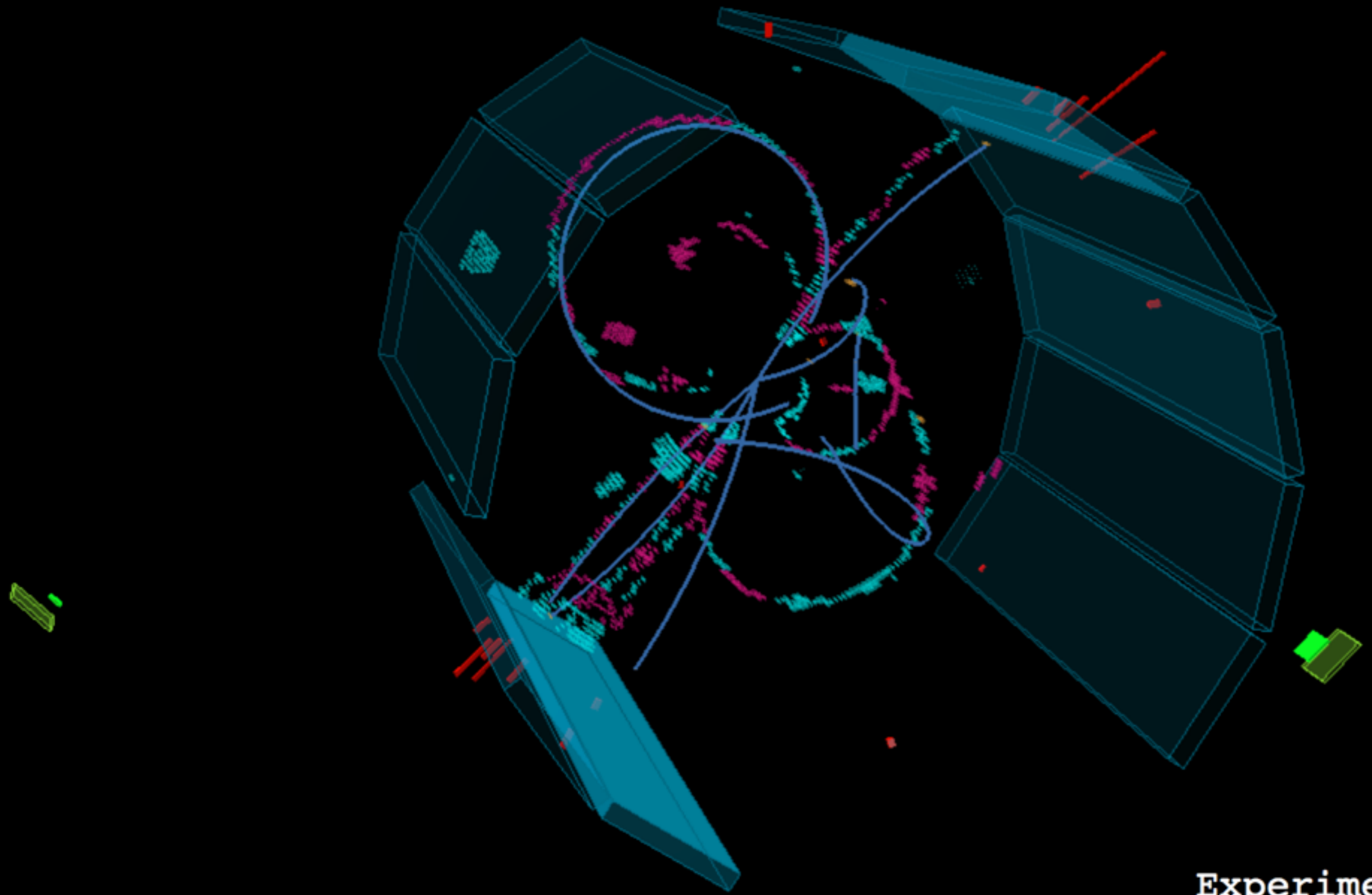
TOP bar

ECL hit

Belle II

Super KEKB

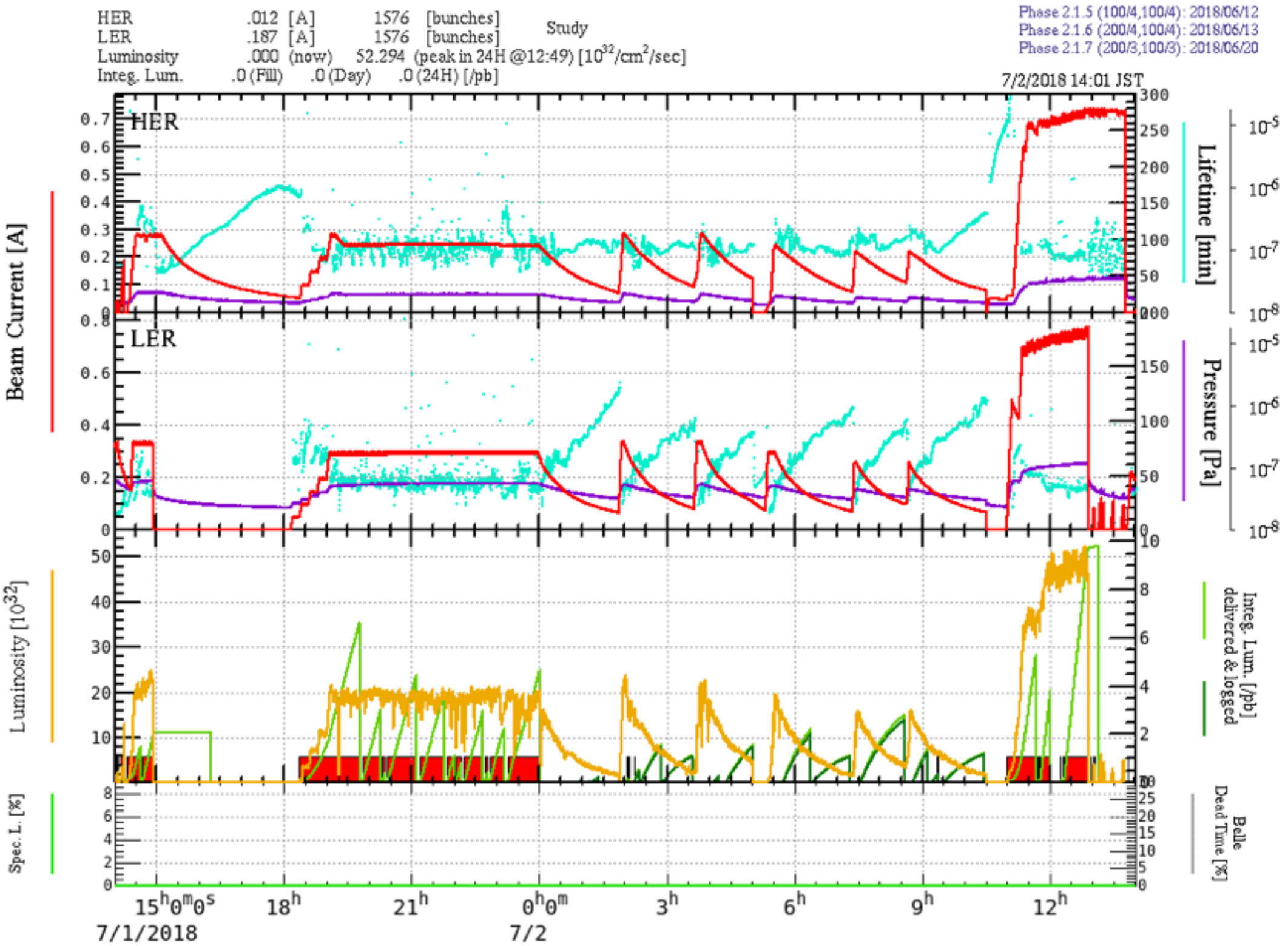
Luminosity Run, 26th April 2018 First Hadronic Event



Experiment 3
Run 125
Event 223

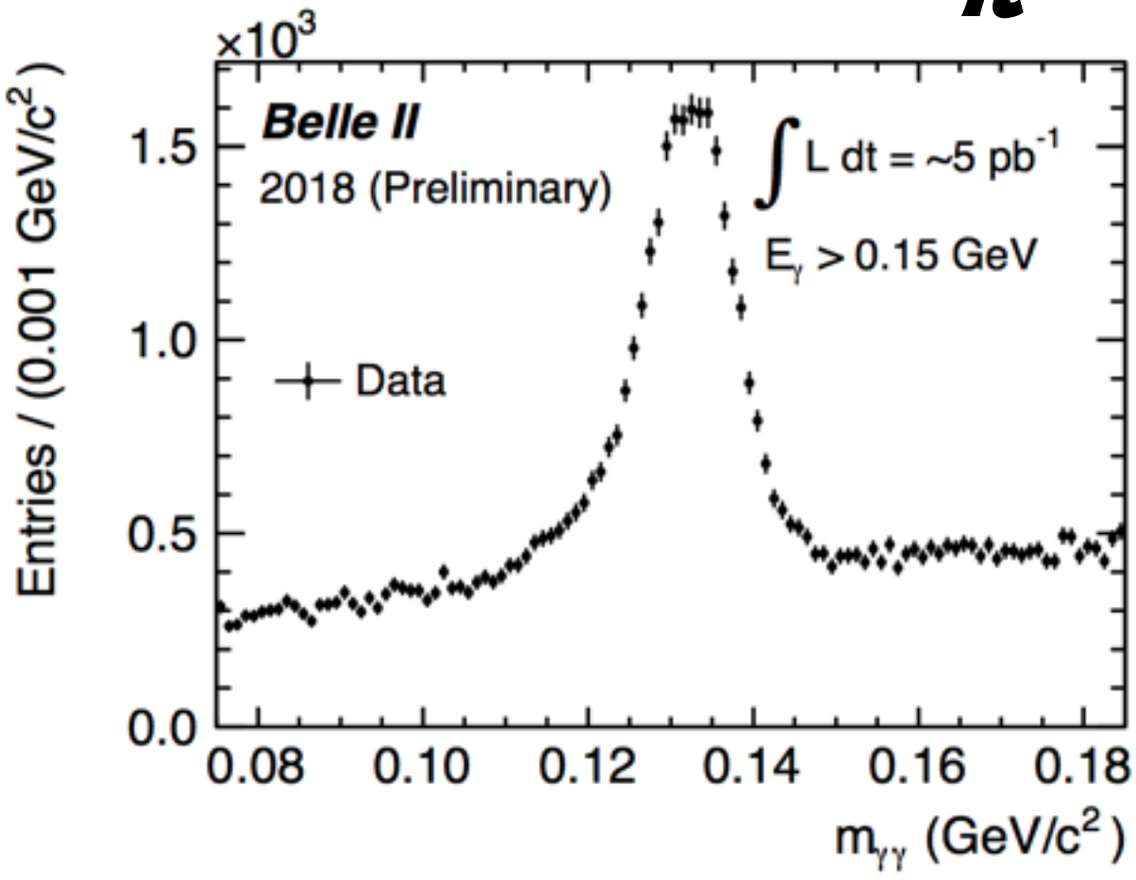
note: vertex detector not shown

Current status of the accelerator

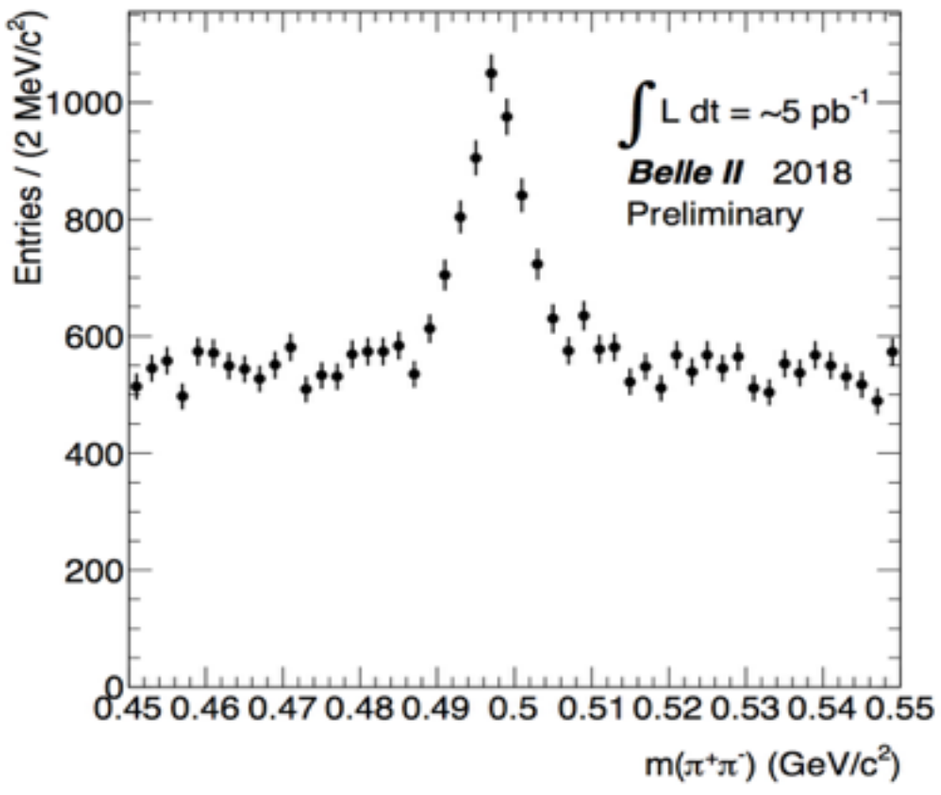


First "rediscoveries"

π^0

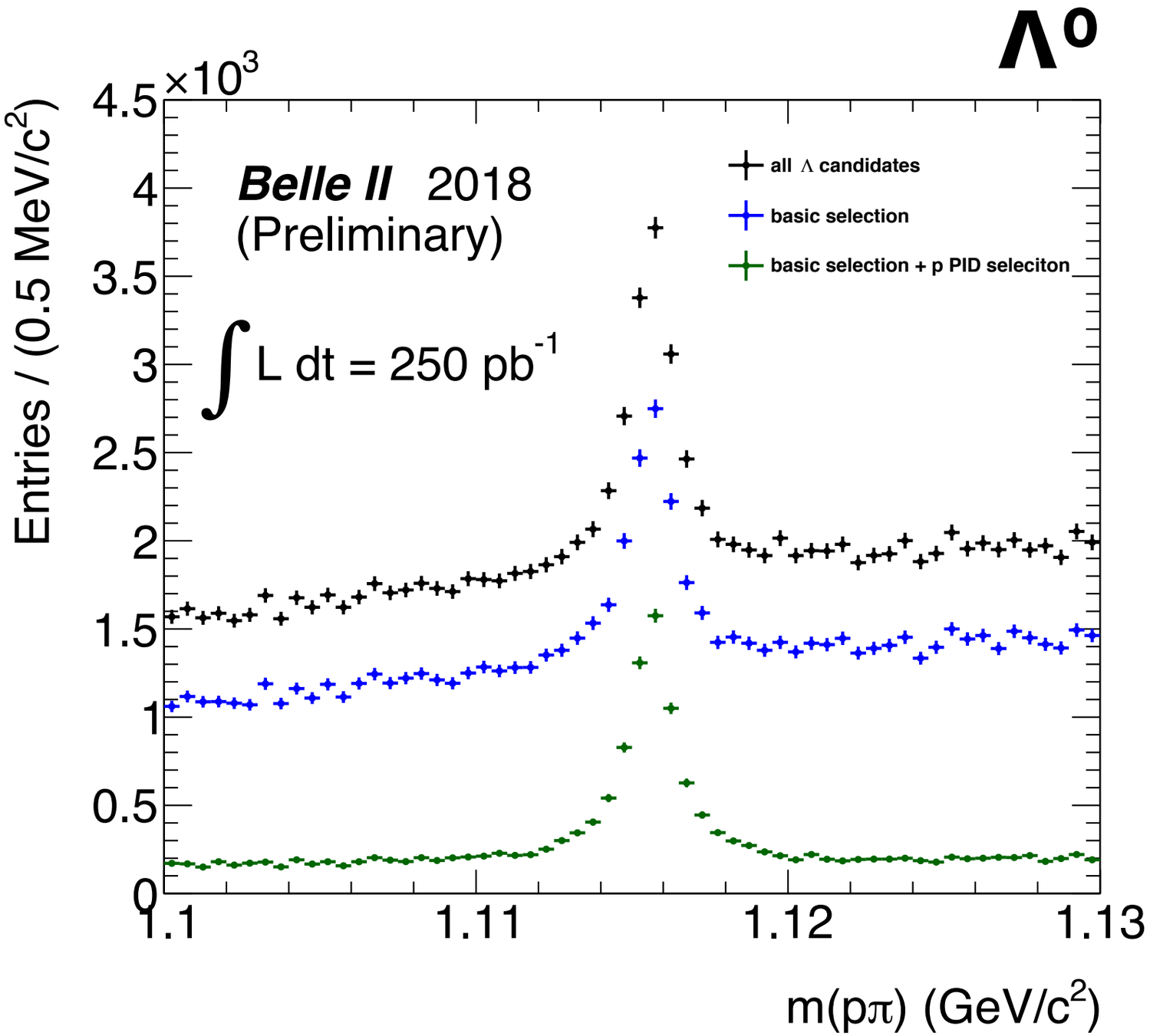


Ks



- Evidence of Ks and π_0 (~5 pb^{-1})
- Very early stage of data taking, preliminary plots
- Calibration at the first stage

First "rediscoveries"

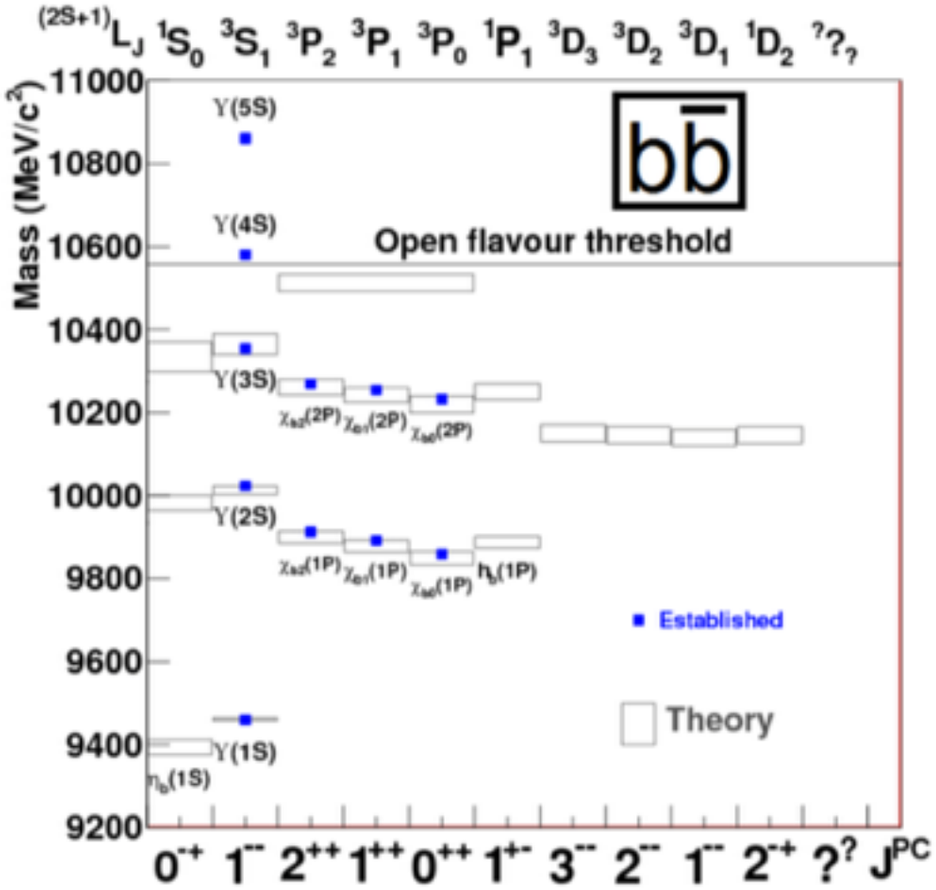


BOTTOMONIA

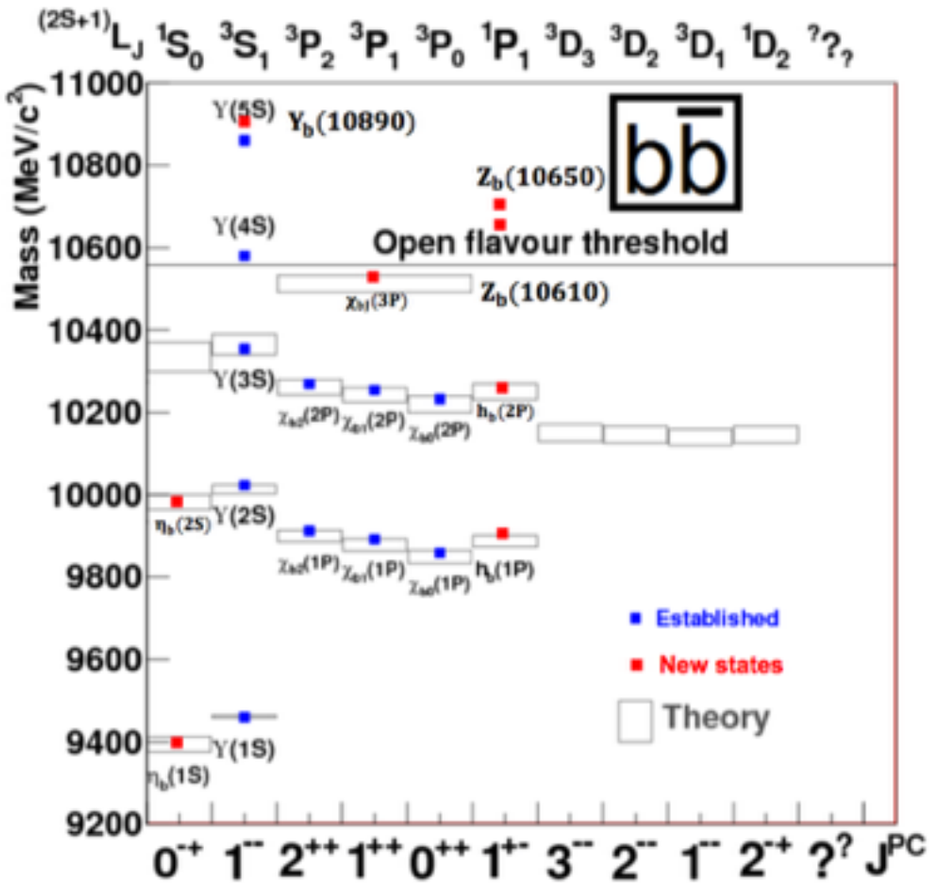
- Selected topics -

Bottomonium spectra

~1999



at post B-factories era



Current samples in fb^{-1} (millions of events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII							

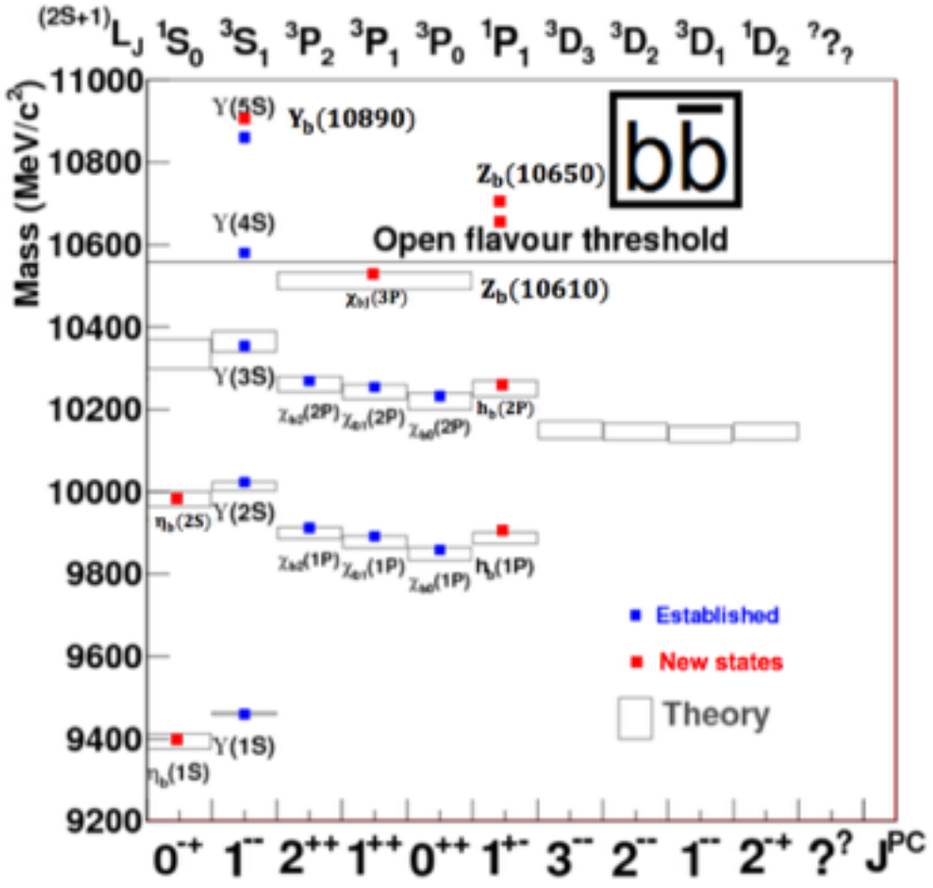
Bottomonium spectra

- Achievement in Belle
  - discovery of η_b, h_b
  - discovery of Z_b (exotic nature of above threshold Y state)

Channel	Fraction, % $Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.54^{+0.16+0.11}_{-0.13-0.08}$	$0.17^{+0.07+0.03}_{-0.06-0.02}$
$\Upsilon(2S)\pi^+$	$3.62^{+0.76+0.79}_{-0.59-0.53}$	$1.39^{+0.48+0.34}_{-0.38-0.23}$
$\Upsilon(3S)\pi^+$	$2.15^{+0.55+0.60}_{-0.42-0.43}$	$1.63^{+0.53+0.39}_{-0.42-0.28}$
$h_b(1P)\pi^+$	$3.45^{+0.87+0.86}_{-0.71-0.63}$	$8.41^{+2.43+1.49}_{-2.12-1.06}$
$h_b(2P)\pi^+$	$4.67^{+1.24+1.18}_{-1.00-0.89}$	$14.7^{+3.2+2.8}_{-2.8-2.3}$
$B^+\bar{B}^{*0}+\bar{B}^0B^{*+}$	$85.6^{+1.5+1.5}_{-2.0-2.1}$	...
$B^{*+}\bar{B}^{*0}$	...	$73.7^{+3.4+2.7}_{-4.4-3.5}$

PRL 116 (2016) 212001

at post B-factories era



Current samples in fb^{-1} (millions of events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII							

➡ **below Y(4S):**

- bottomonium study/search
- new physics in decay (DM / light Higgs)
- anti-nuclei production (possible DM application)
- baryon physics

- 300 fb^{-1} @Y(3S): order of magnitude increase

Current samples in fb^{-1} (millions of events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII			**300(1200)**	**$5x10^4$($5.4x10^4$)**	**1000(300)**	**100+400(scan)**	**3.6%**

➡ **above Y(4S):**

- exotica discovery
- precision Z_b mass measurement

- 1ab^{-1} @Y(5S): also B_s physics
- 100 fb^{-1}@Y(6S) + ~400 fb^{-1} scan

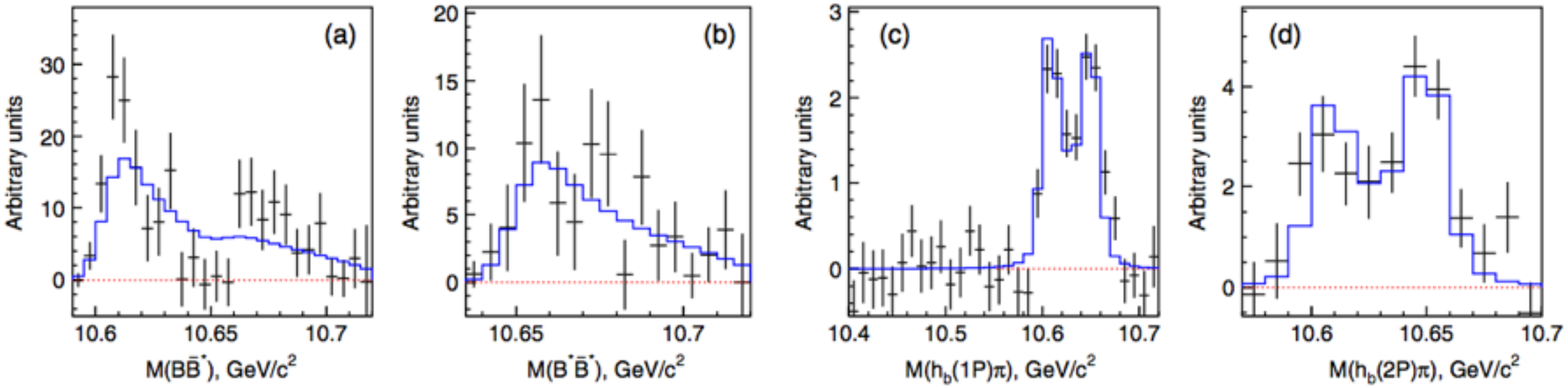
Current samples in fb^{-1} (millions of events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII			**300(1200)**	**5x10^4(5.4x10^4)**	**1000(300)**	**100+400(scan)**	**3.6%**

Precision study: Z_b masses

- open question: Z_b masses are below or above $B^{(*)}B^*$ thresholds?
- fundamental question to understand their nature

Phys. Rev. D 93, 074031 (2016)



➡ **Belle II**

- 1ab^{-1} @ Y(5S): determine if they are located above or below the open threshold

estimate of the Zb location with respect to the thresholds:

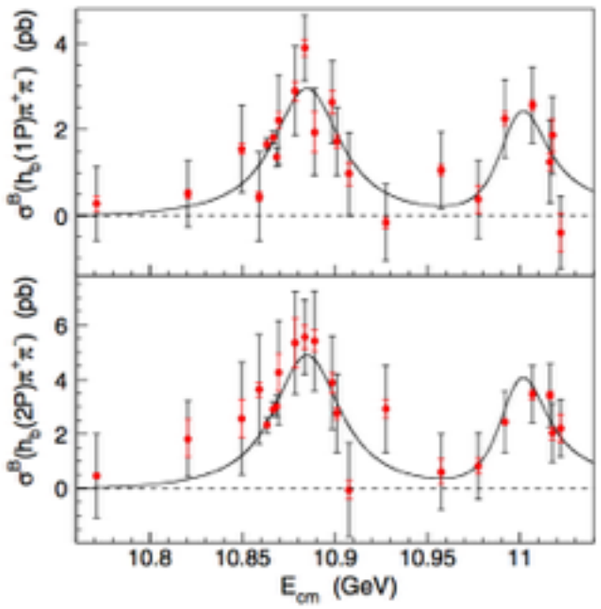
$$\varepsilon_B(Z_b) = (0.60^{+1.40}_{-0.49} \pm i0.02^{+0.02}_{-0.01})\ \text{MeV},$$
$$\varepsilon_B(Z_b') = (0.97^{+1.42}_{-0.68} \pm i0.84^{+0.22}_{-0.34})\ \text{MeV},$$

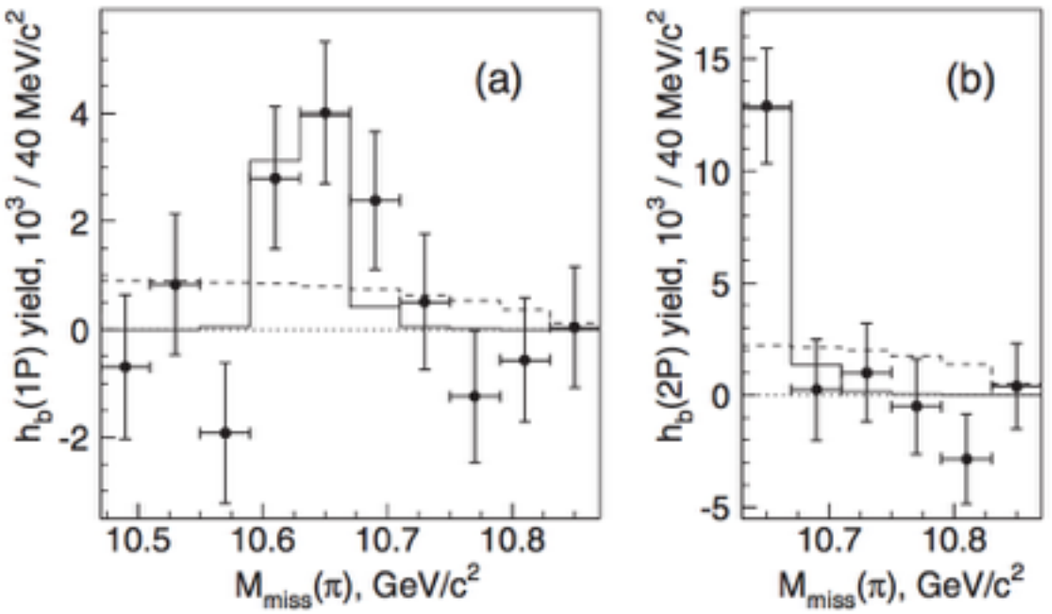
$$\varepsilon_B(Z_b) \equiv M(B\bar{B}^*) - M(Z_b),$$
$$\varepsilon_B(Z_b') \equiv M(B^*\bar{B}^*) - M(Z_b'),$$

New states: $Z_b^{\pm}$ from Y(6S)

PRL 117, 142001 (2016)

- Belle energy scan, search for Y(6S)→$\pi^+ \pi^- h_b$(1P,2P) decay
- Observation of Z_b(106XX) state, but unable to resolve them





➡ **Belle II**

- Understand Y(6S)→ Z_b decay
  - Y(6S) → $\pi^+ \pi^- h_b$(1P,2P)
  - Y(6S) → $\pi^+ \pi^-$ Y(1S,2S,3S)

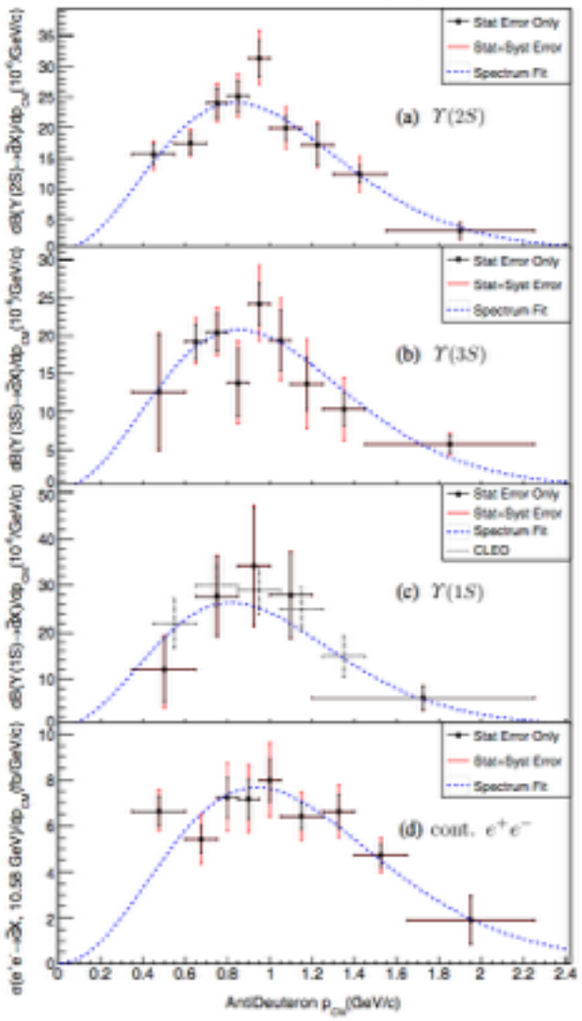
BEYOND BOTTOMONIA

- Selected topics -

(Anti)deuteron from Υ(3S)

PRD 62, 043003 (2000)

Phys.Rev. D89 (2014) no.11, 111102



Process	Rate
$\mathcal{B}(\Upsilon(3S) \to \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(2S) \to \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(1S) \to \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-5}$
$\sigma(e^+e^- \to \bar{d}X)$ $[\sqrt{s} \approx 10.58$ GeV]	$(9.63 \pm 0.41^{+1.17}_{-1.01})$ fb
$\frac{\sigma(e^+e^- \to \bar{d}X)}{\sigma(e^+e^- \to \text{Hadrons})}$	$(3.01 \pm 0.13^{+0.37}_{-0.31}) \times 10^{-6}$

- $\bar{d}$ in cosmic ray have long since been considered a probe for supersymmetric relics in the galactic halo
- $\bar{d}$ production described with coalescence models tuned on HEP data
- need of further constrain in the production model

➡ CLEO and Babar measured the $\bar{d}$ spectrum (no dedicated PID or tracking)

➡ **Belle II:**

- dedicated tracking and PID
- collect ~3×10^4 $\bar{d}$
- world best estimate of coalescence parameter
- search for excited nucleons (d*)
- $d\bar{d}$ associated production

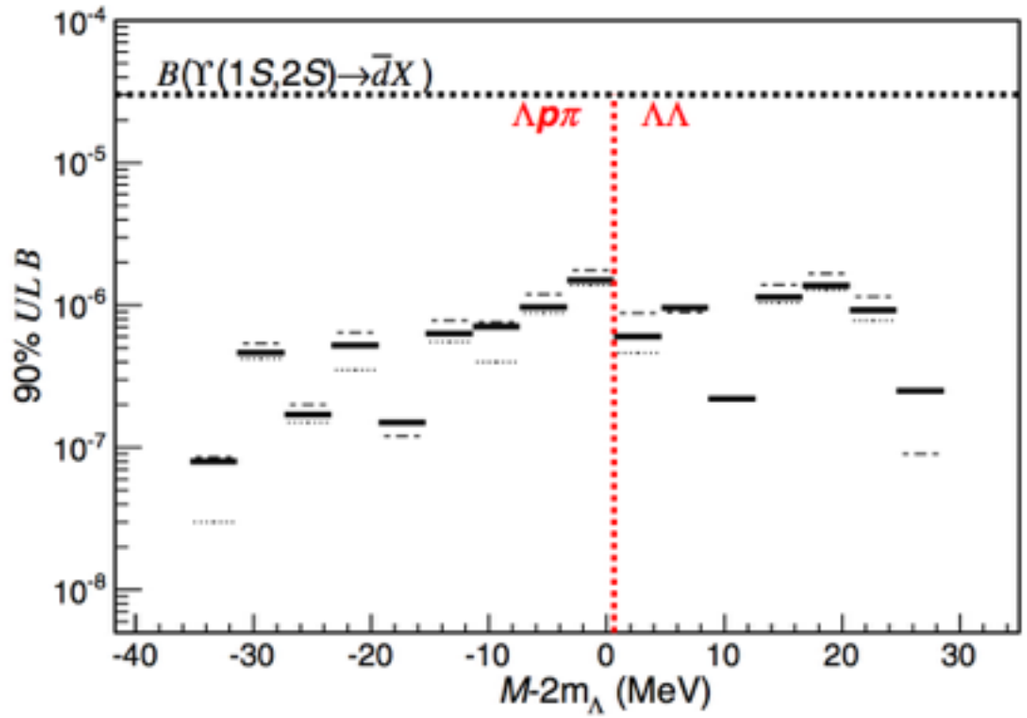
Λ-Λ interaction

➡ From Belle:

- No sign of weakly bound H dibaryon

- Near threshold enhancement in exclusive annihilations
  Y(1S,2S) → $\Lambda\bar{\Lambda}$ X (still not published)

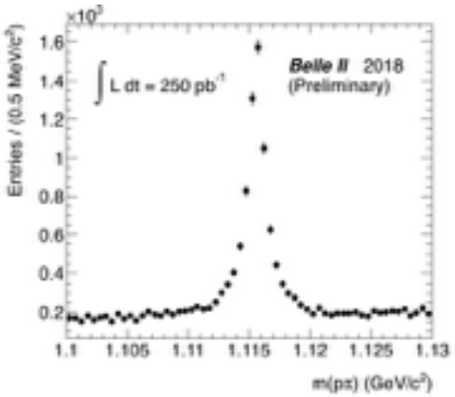
Phys. Rev. Lett. 110, 222002



➡ **Belle II**

- search for H dibaryon in missing mass (Y(3S) → Λ Λ H + hadrons)
- high statistics study near threshold

Rough extrapolation for 300 fb^{-1} Y(3S)
~60 Million events with one Λ or Λ
~3 Million events with one Λ Λ pair



Conclusions

- SuperKEKB is completing the commissioning phase

- Phase2 data taking started:
  - first collisions registered 2 months ago!
  - effort to understand machine and the backgrounds, detector response, and test the software

- Physics run will start at the beginning of 2019

- Potential for bottomonia physics in several different aspects

The fun just started..Stay tuned!

Conclusions

- SuperKEKB is completing the commissioning phase

- Phase2 data taking started:
  - first collisions registered 2 months ago!
  - effort to understand machine and the backgrounds, detector response, and test the software

- Physics run will start at the beginning of 2019

- Potential for bottomonia physics in several different aspects

The fun just started..Stay tuned!