Belle II status and prospects for exotic hadron spectroscopy

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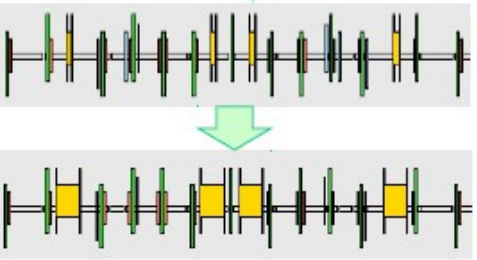
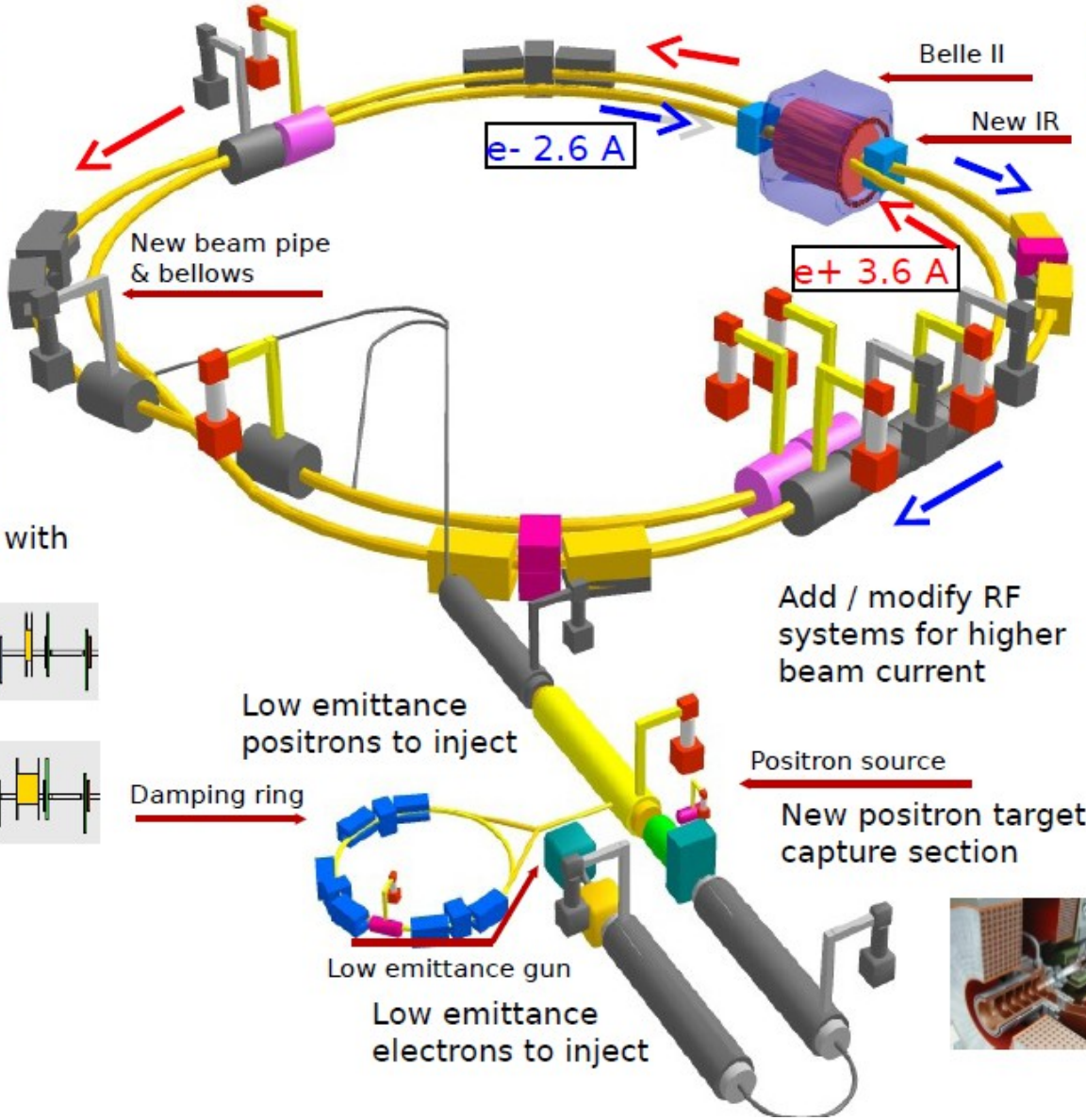
Super KEKB

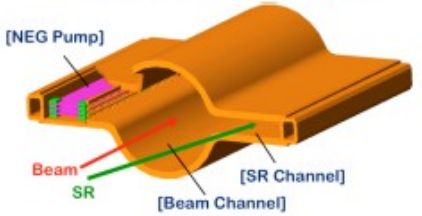
Replace short dipoles with longer ones (LER)





New superconducting /permanent final focusing quads near the IP

TiN-coated beam pipe with antechambers



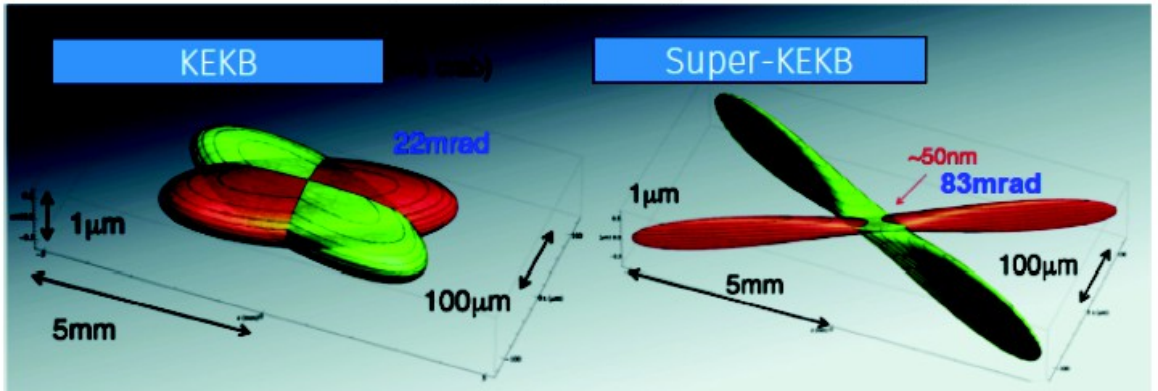
Add / modify RF systems for higher beam current

Redesign the lattices of HER & LER to squeeze the emittance

New positron target / capture section

SuperKEKB

Nano-beam scheme firstly proposed by P. Raimondi for SuperB



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

factor 20

factor 2-3

reduced boost

factor~ 40-50

Lorentz factor

beam current

$$\text{Luminosity } L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

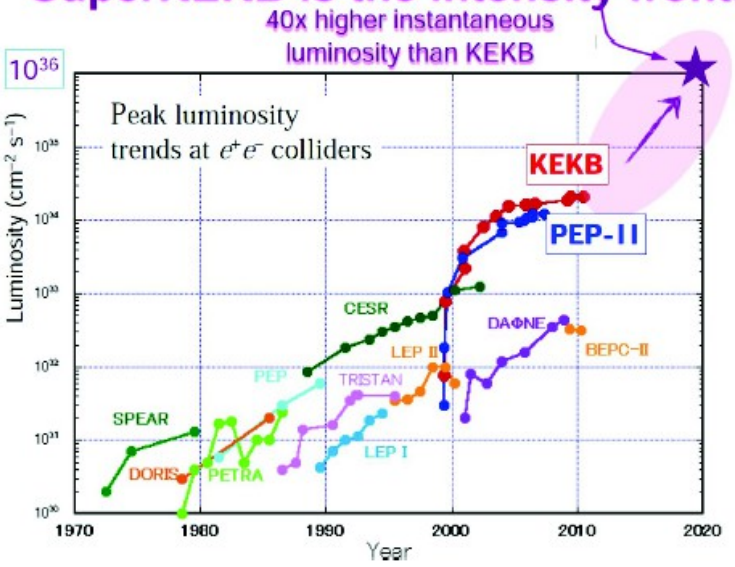
Beam size ratio at IP

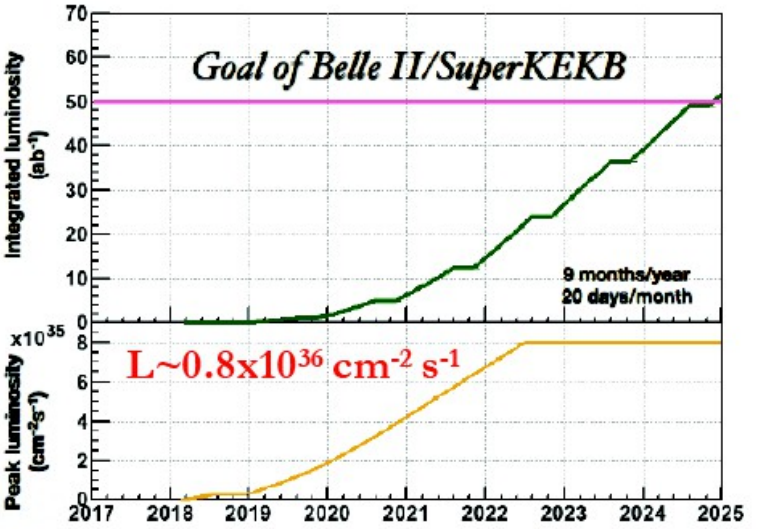
vertical beta function at IP

Geometrical reduction factors

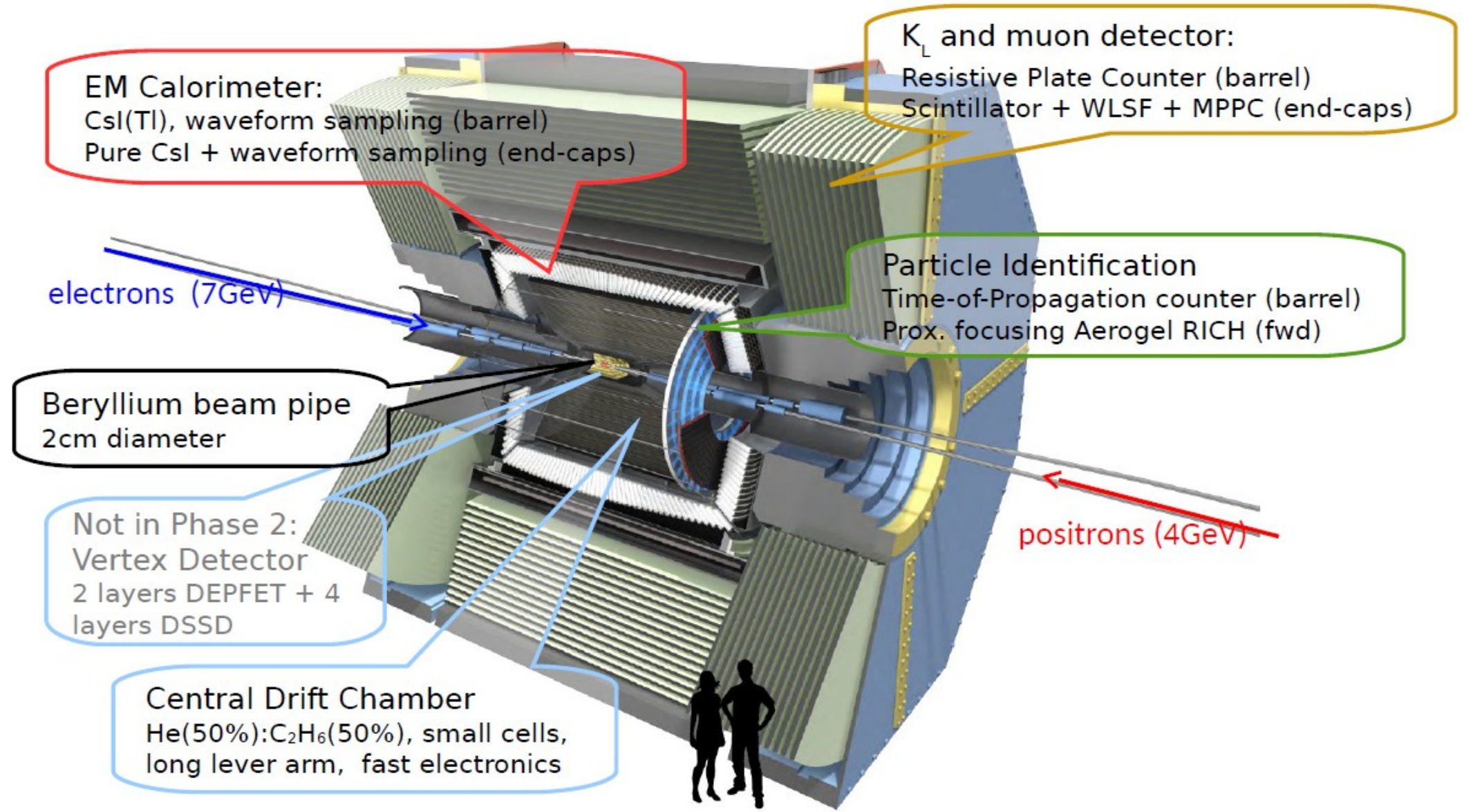
SuperKEKB is the intensity frontier

40x higher instantaneous luminosity than KEKB

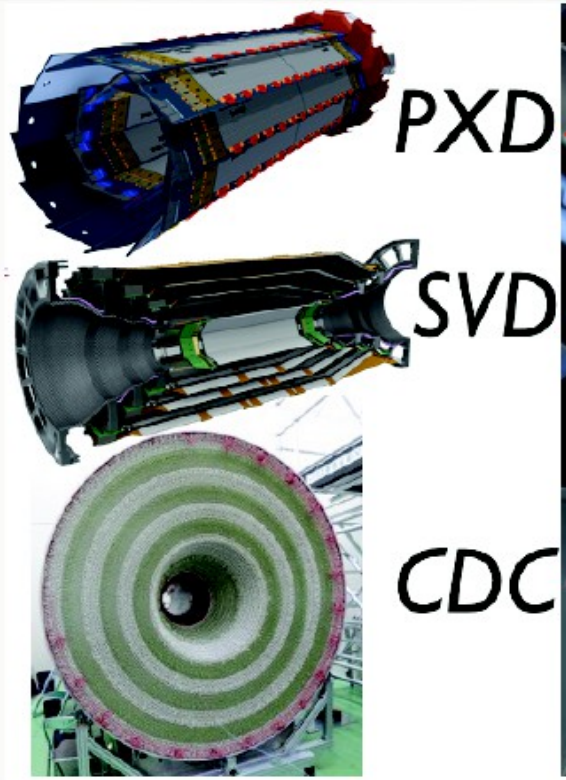


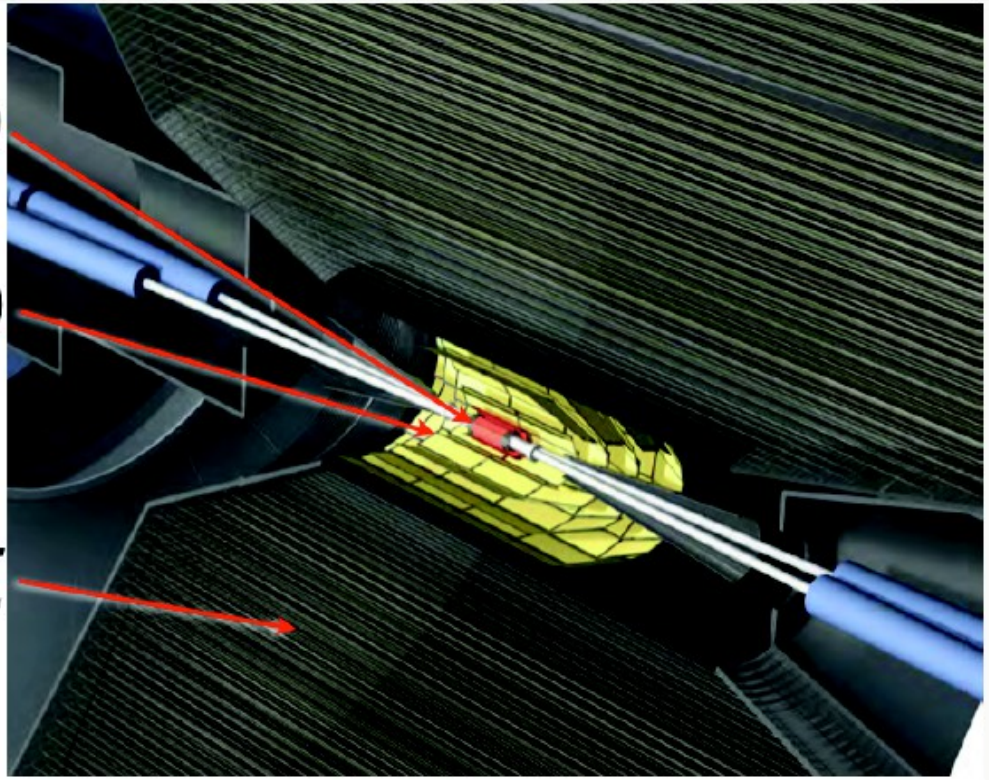


Belle II


EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)
K_L and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)
electrons (7GeV)
positrons (4GeV)
Beryllium beam pipe
2cm diameter
Not in Phase 2:
Vertex Detector
2 layers DEPFET + 4 layers DSSD
Central Drift Chamber
He(50%):C_2H_6(50%), small cells,
long lever arm, fast electronics

Tracking system





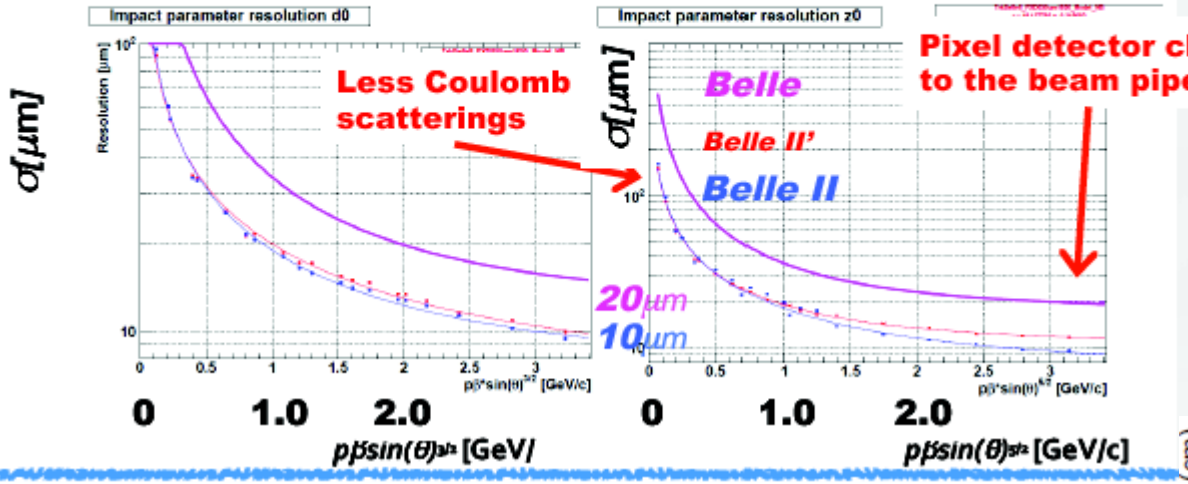
Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20$ μm (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100$ μm, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\%p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\%p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

Vertexing performance

Expected performance

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

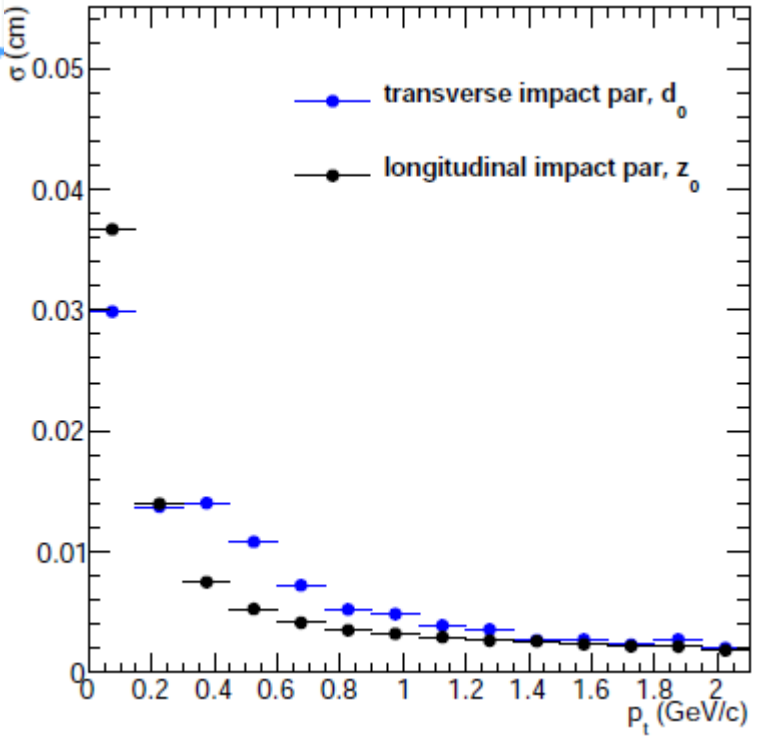
Significant improvement in IP resolution!



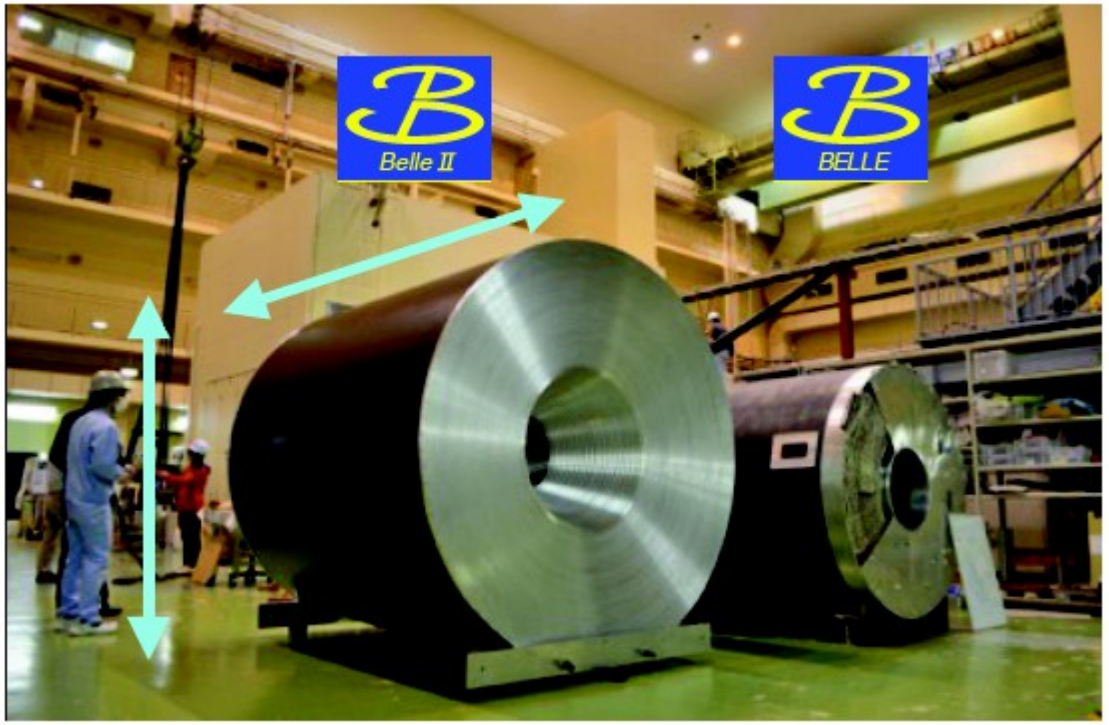
- Extrapolations of detector performance confirmed after beam-test results, and realistic software implementation

- Currently, in spite of $\langle\beta\gamma\rangle^{\text{Belle II}} = 28/44 \cdot \langle\beta\gamma\rangle^{\text{Belle}}$

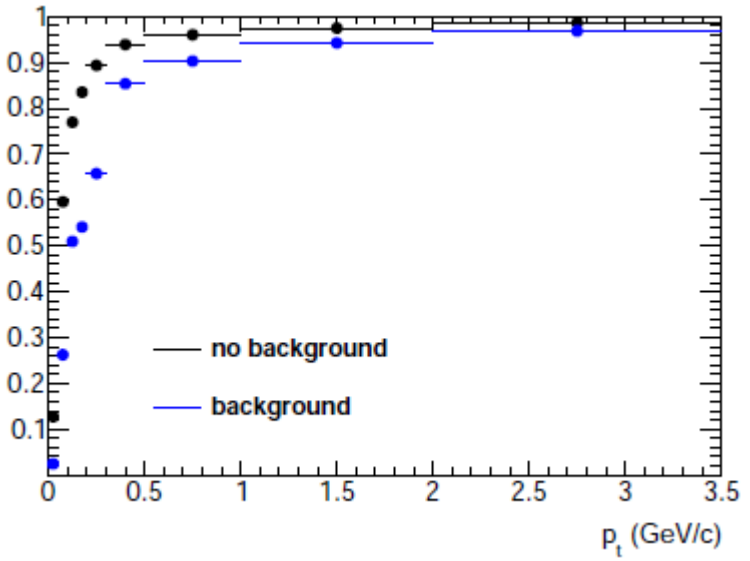
$$\sigma_{\Delta t}^{\text{Belle II}} \sim \frac{3}{4}\sigma_{\Delta t}^{\text{Belle}}$$

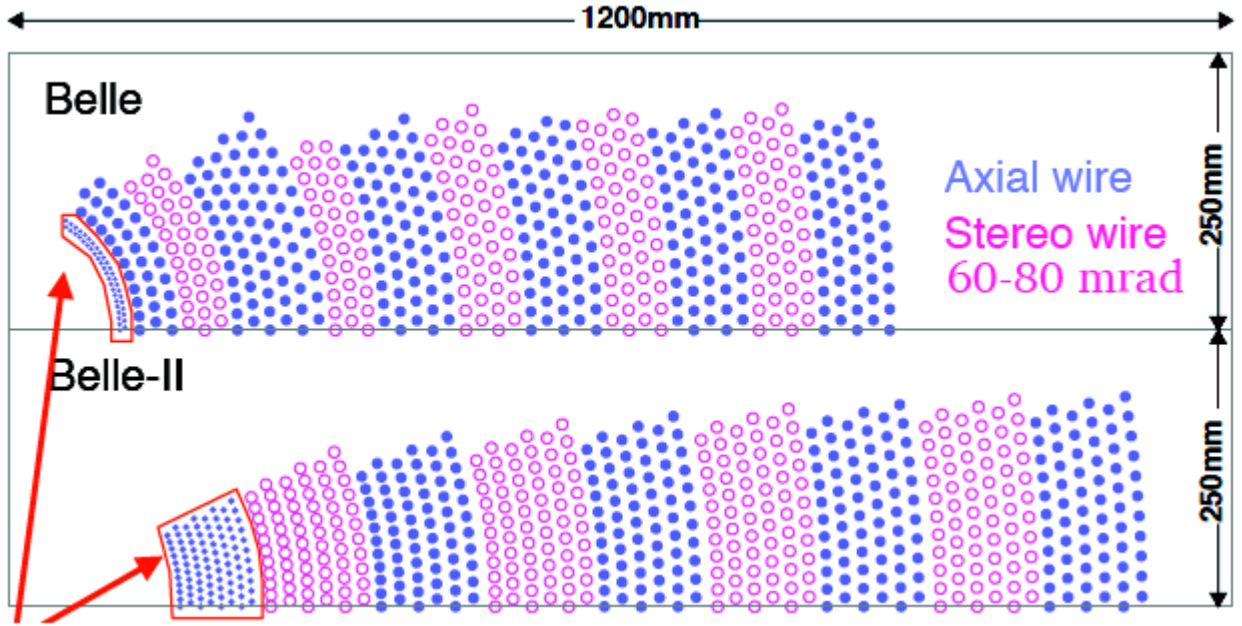


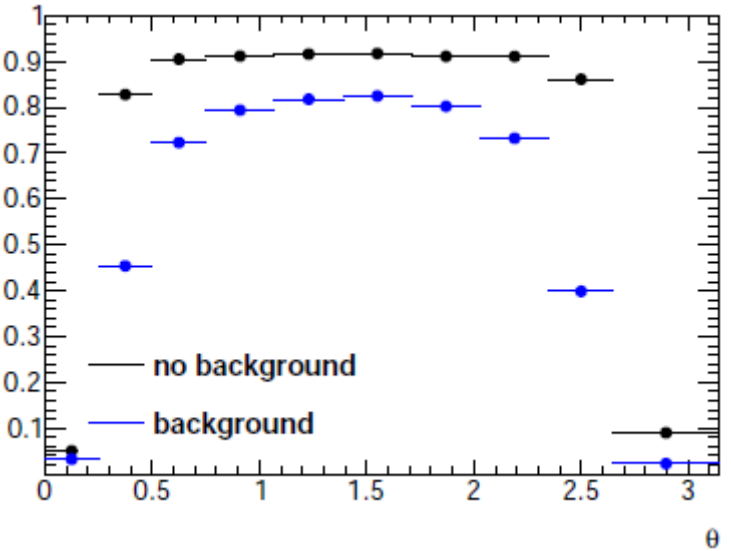
Central Drift Chamber



Track reconstruction efficiency



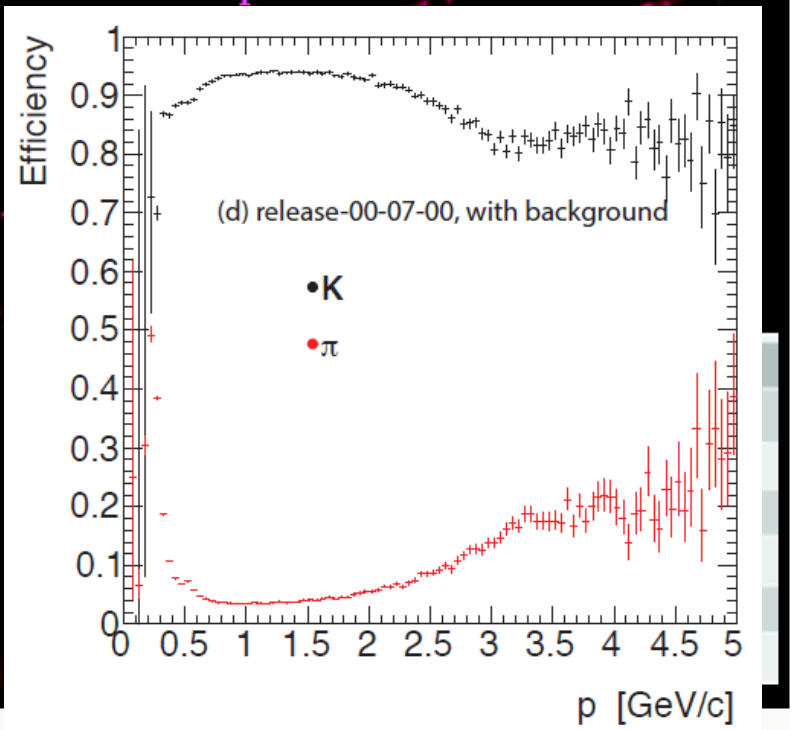


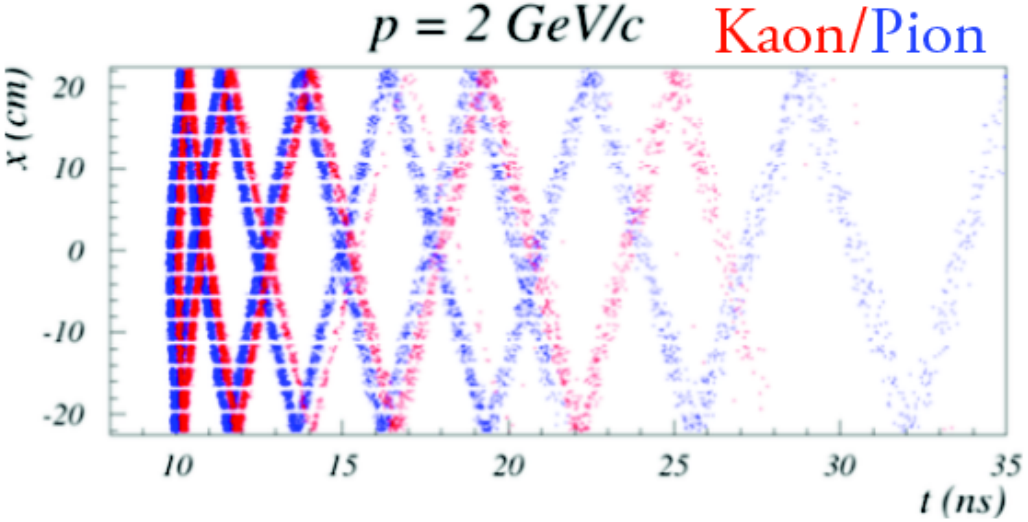


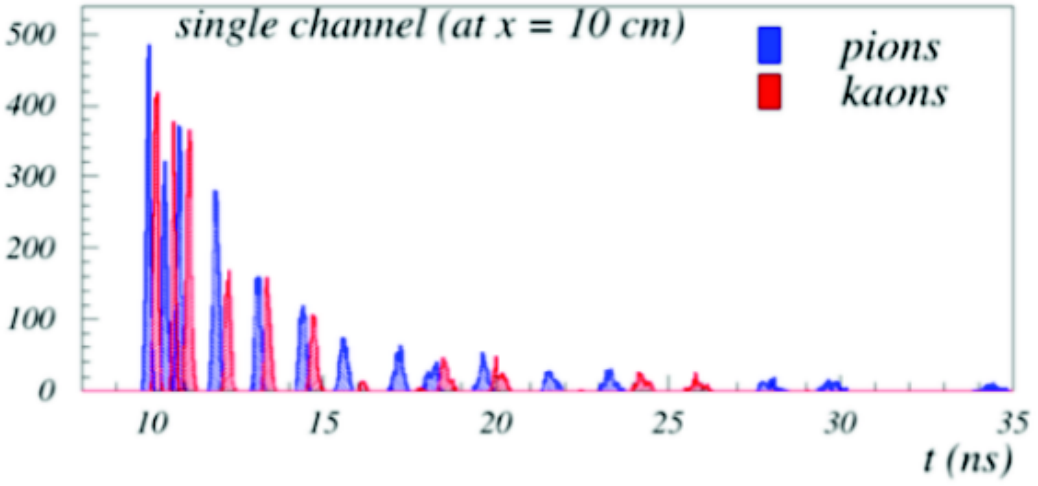
Barrel PID: Time of Propagation

Cherenkov ring imaging with precision time measurement (better than 100ps)

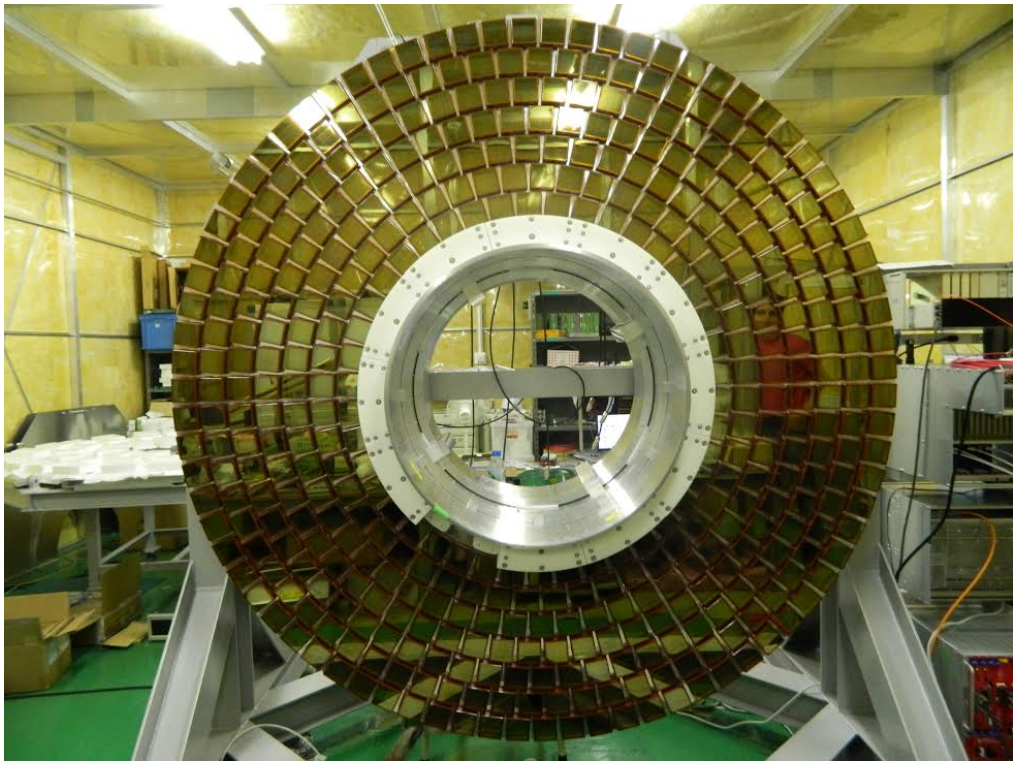
Installation completed! 2016, May 11

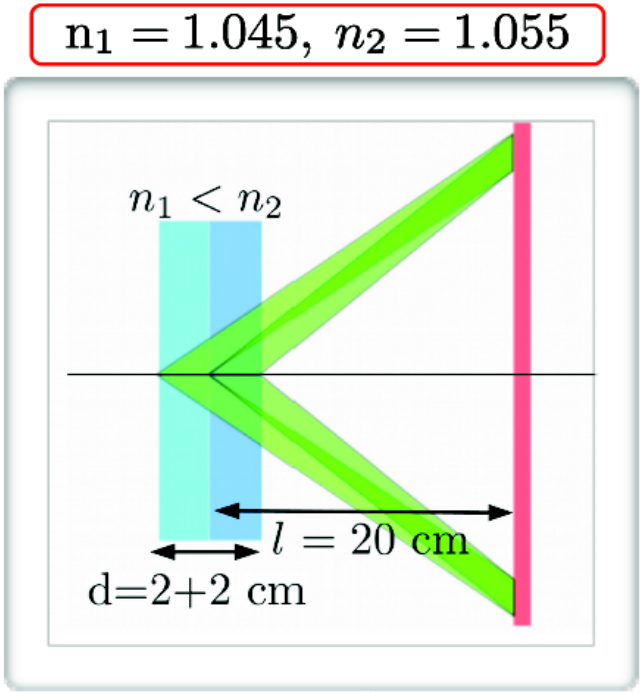


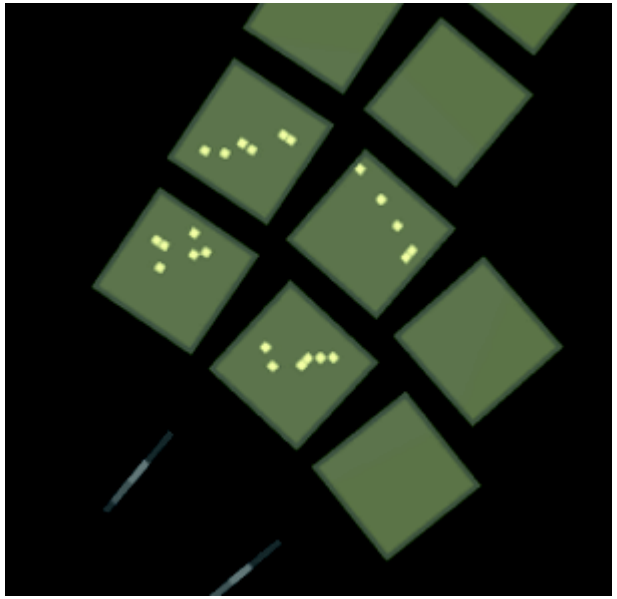


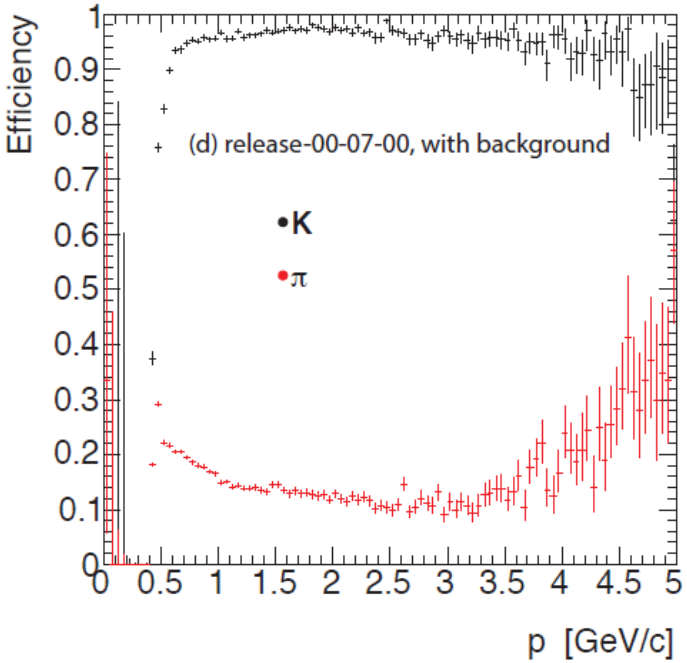


Forward PID: Aerogel RICH

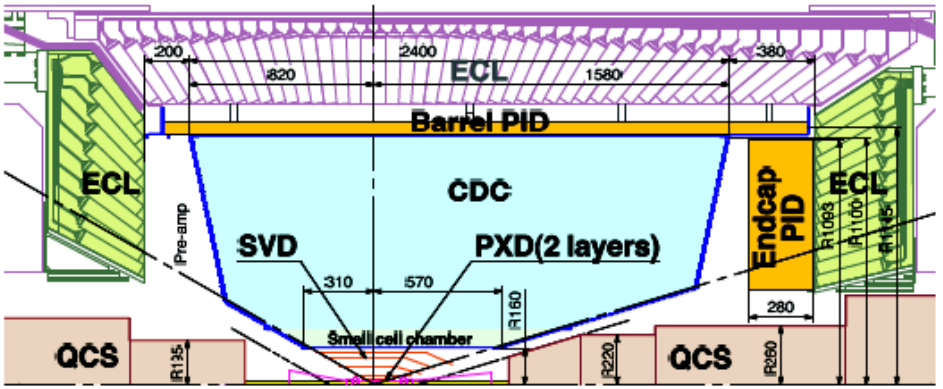






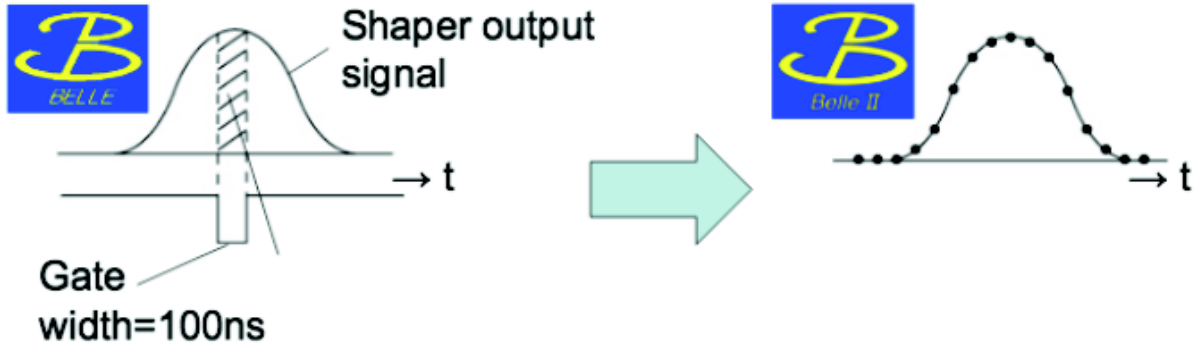


Electromagnetic Calorimeter

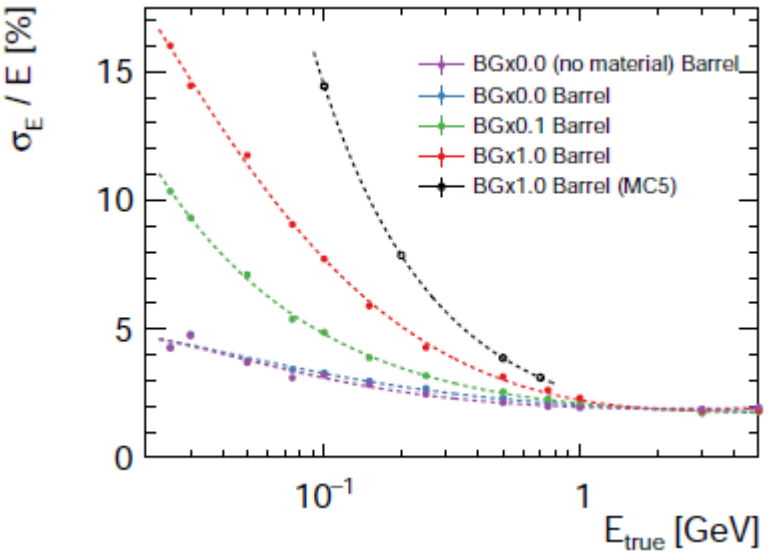


Belle calorimeter: 8736 CsI(Tl) crystals
6624 Barrel
1152 Fwd Endcap
960 Bwd Endcap

- High rates (machine+physics) ⇒ upgrade of electronics
  - shorter signal shaping (1000ns —> 500ns)
  - the waveform is sampled (~2MHz)
  - waveform fit to extract signal time and amplitude



Energy resolution vs background



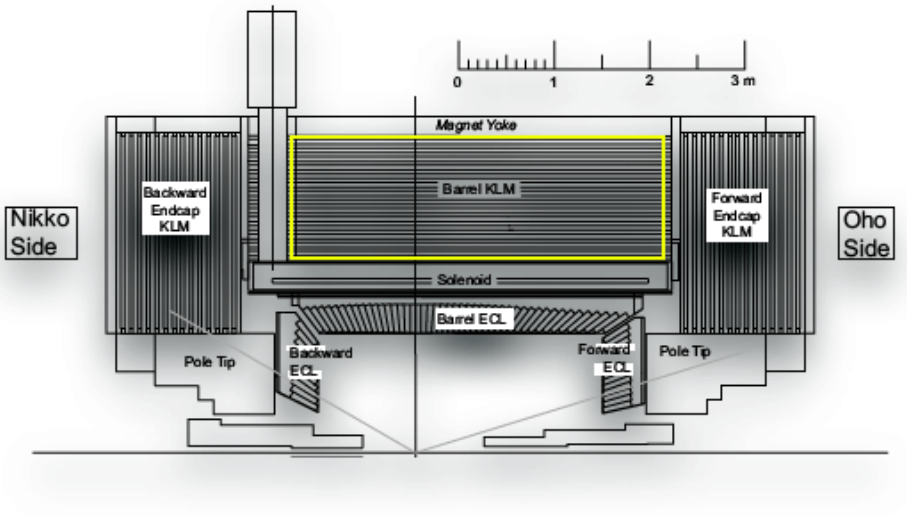
Belle II ECL trigger efficiency (simulation) compared to Belle ECL efficiency

Physics trigger: E_{tot} > 1 GeV

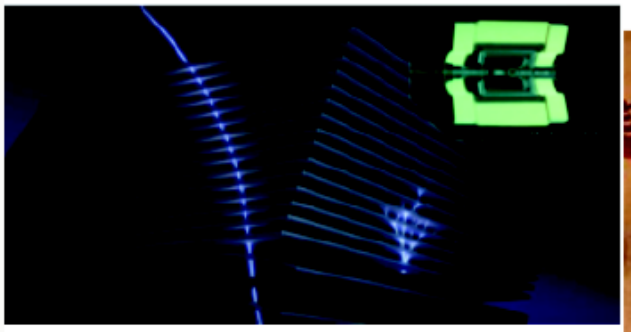
	ε_{phys} (total)	ε_{signal}	ε_{bkg}
Belle	99.42 %	88.70 %	10.72 %
Belle II	99.90 %	99.12 %	0.78 %

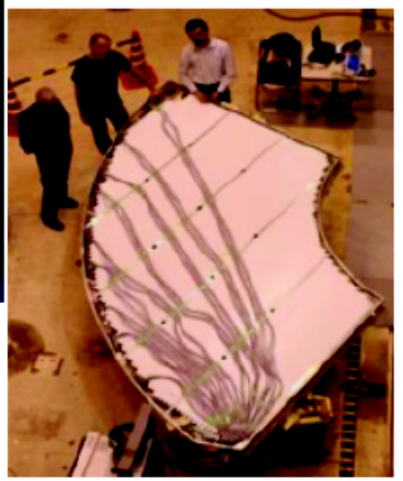
The KLong and Muon detector

- 14 iron layers 4.7cm thick
- 15 barrel active layers
  - ✓ 2 x [scintillator strips + WLS + SiPM] ⇐ **NEW**
  - ✓ 13 x [double glass RPC + 5 cm orthogonal phi, z strips]
- 14 endcap active layers
  - ✓ 14 x [scintillator strips + WLS + SiPM] ⇐ **NEW**



- All endcap active layers + 2 innermost layers in barrel replaced with scintillator strips to resist neutron background
- Installation is complete
- Commissioning with cosmic rays ongoing

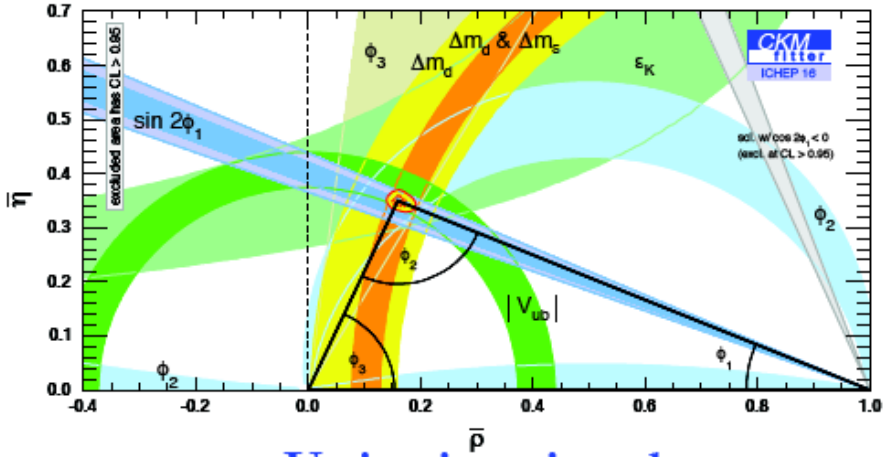




Physics program

- **CPV in B decays** ($B \to J/\psi K^0, K^0\pi^0\gamma, K\pi$)
- **(Semi)leptonic B decays** ($B \to D^{(*)}l\nu, \pi l\nu, \tau\nu, \mu\nu$)
- **Rare B decays** ($B \to K\nu\nu, X_s\gamma, X_s ll, \gamma\gamma$)
- **Charm physics** ($D \to l\nu$, mixing, CPV)
- **LFV** tau decays ($\tau \to 3l, l\gamma$)
- **Dark Sector, Spectroscopy** (early physics)

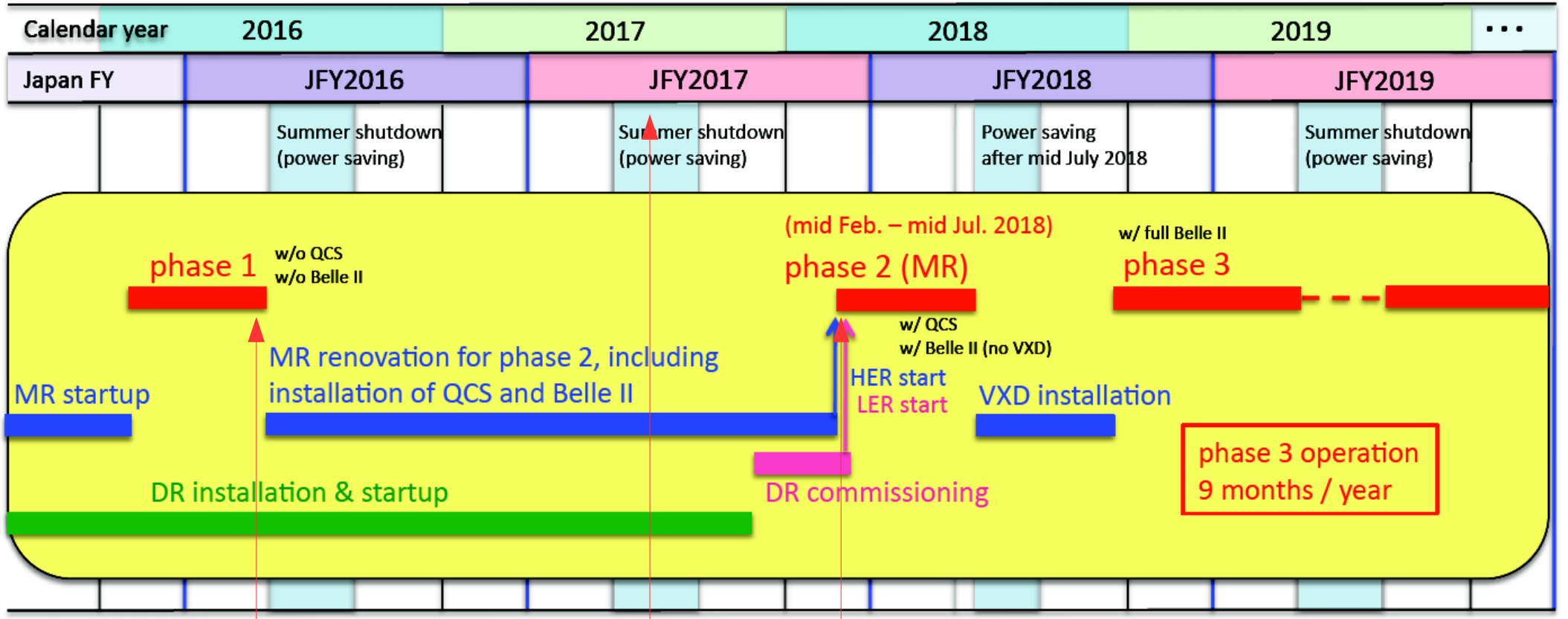
CKM matrix
sides and angles



Unitarity triangle

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb

Schedule

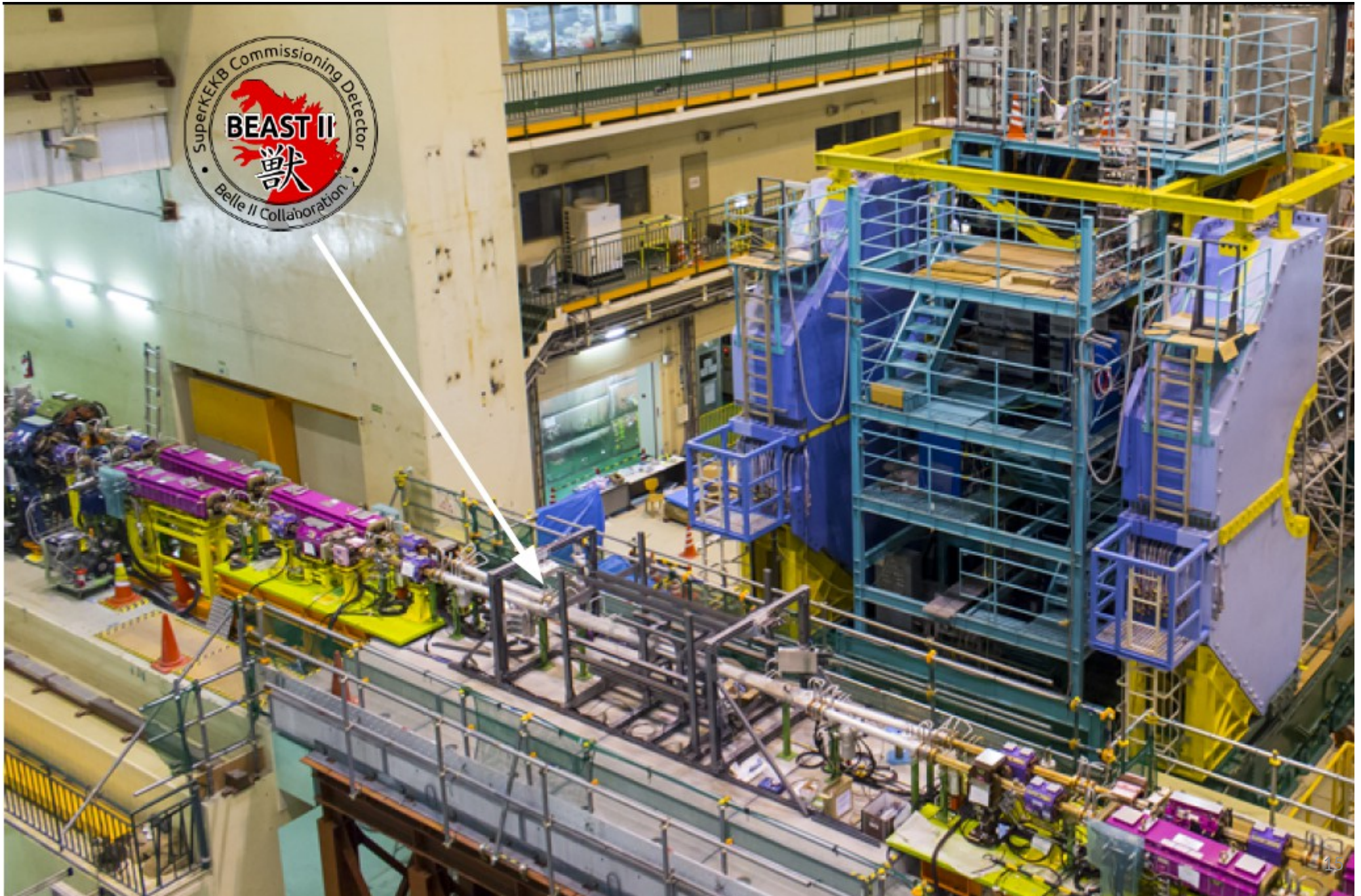


BEAST

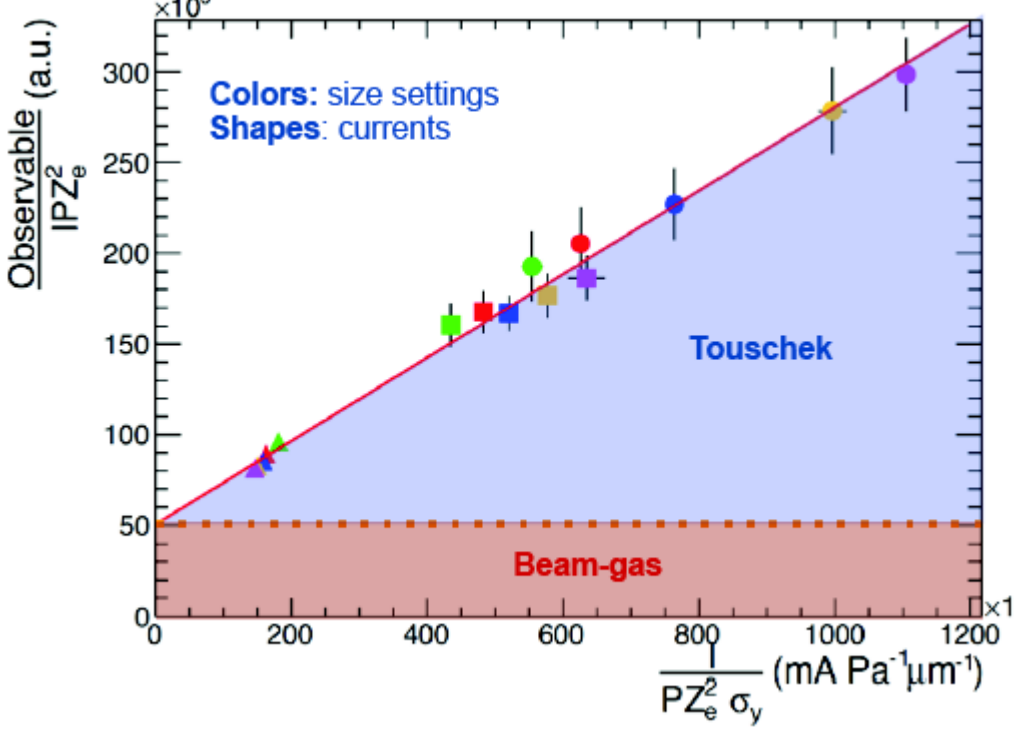
We are here

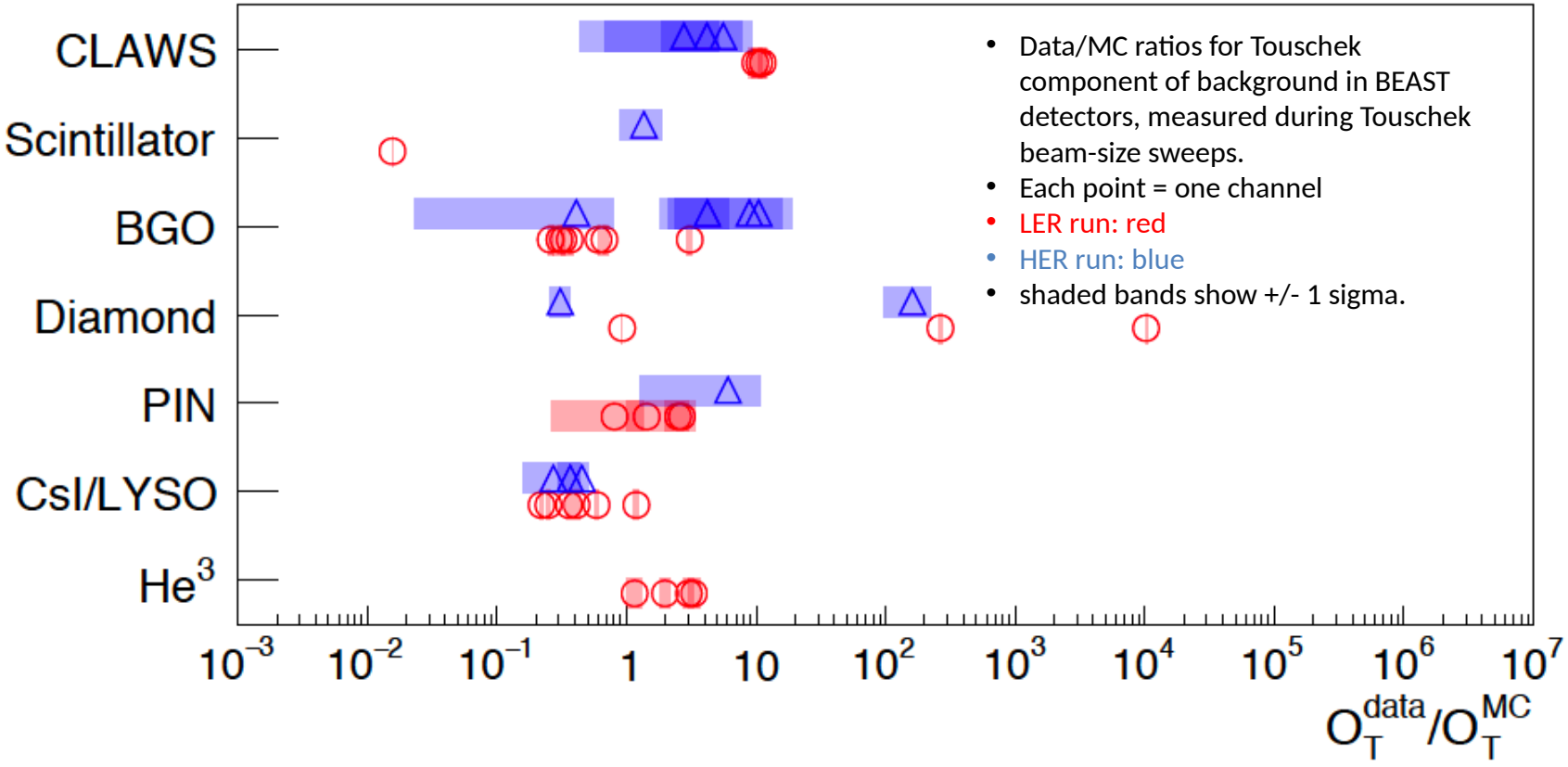
Start of phase II

BEAST


SuperKEKB Commissioning Detector
BEAST II
獣
Belle II Collaboration

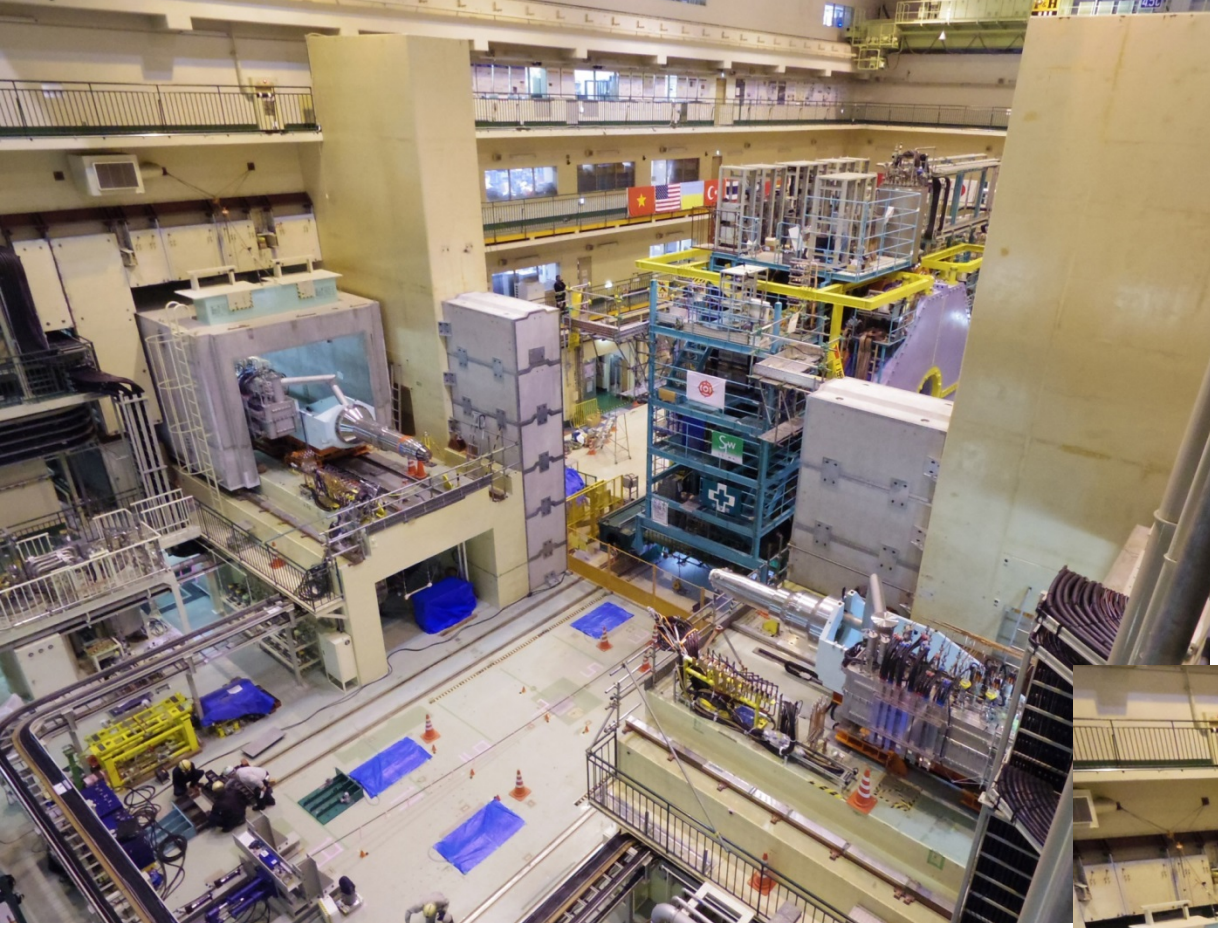
BEAST Result
Touschek Scattering



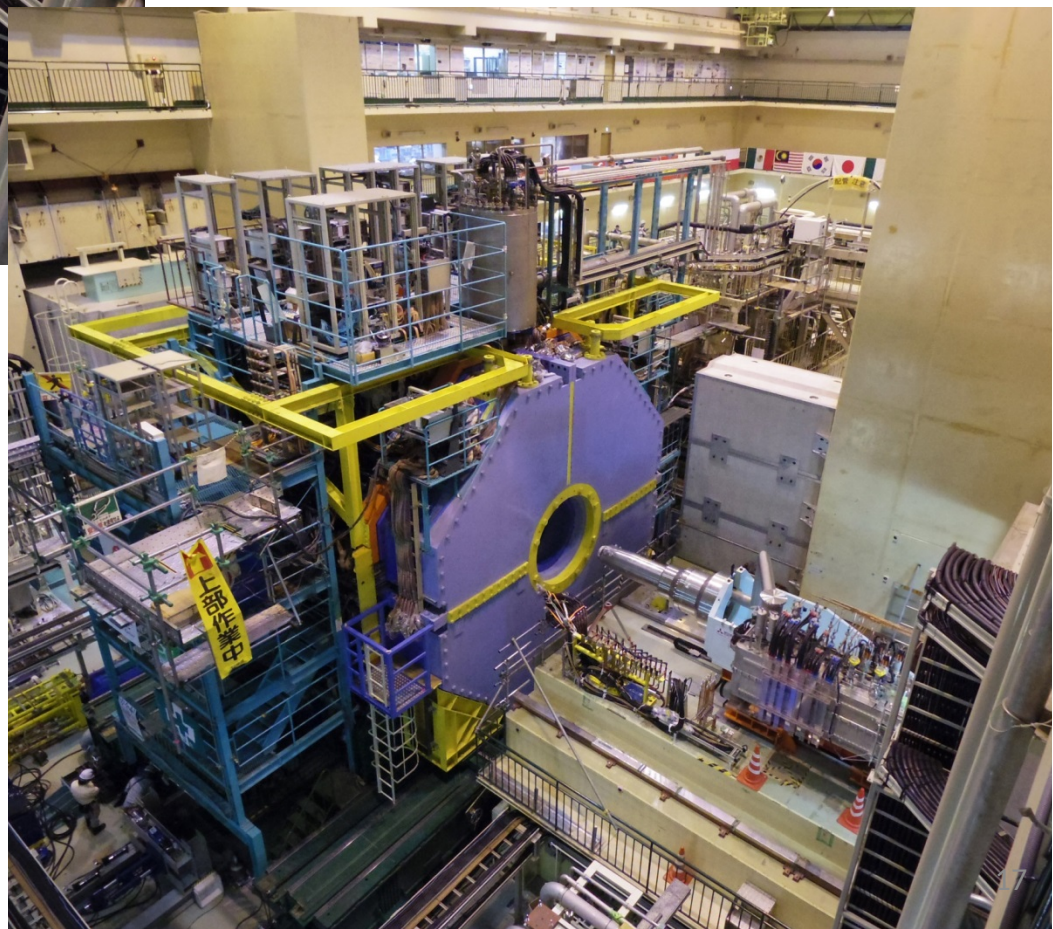


- Data/MC ratios for Touschek component of background in BEAST detectors, measured during Touschek beam-size sweeps.
- Each point = one channel
- LER run: red
- HER run: blue
- shaded bands show +/- 1 sigma.

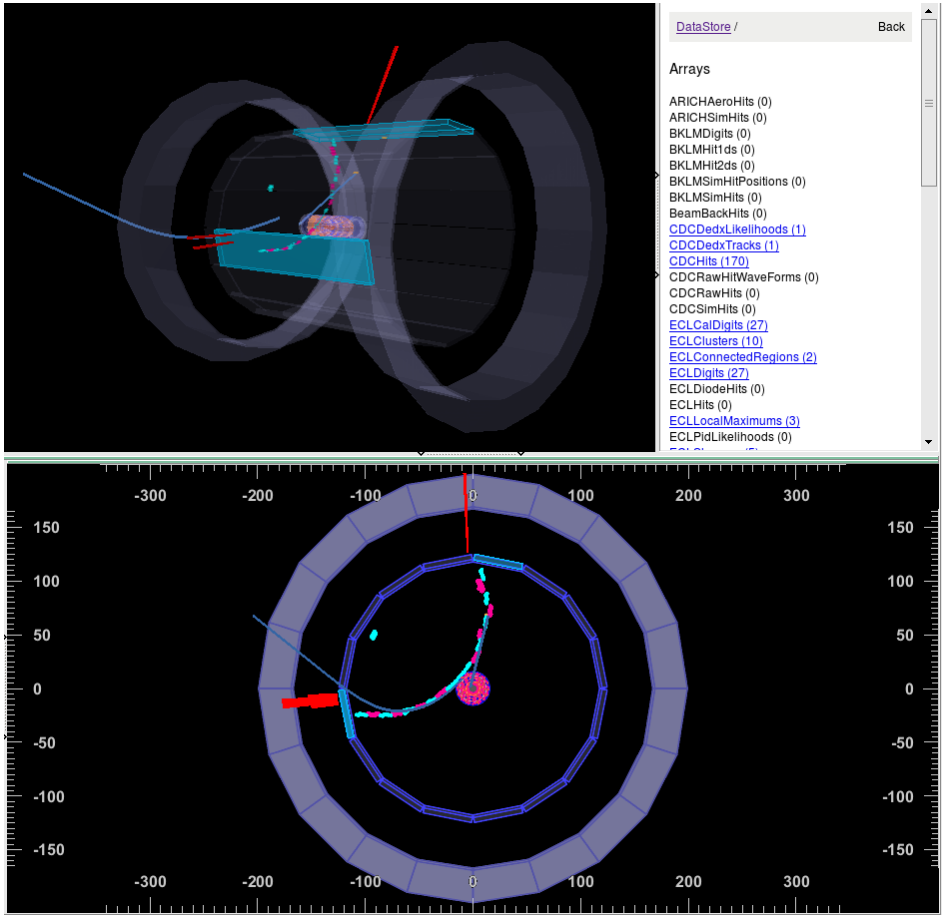
Belle II roll-in

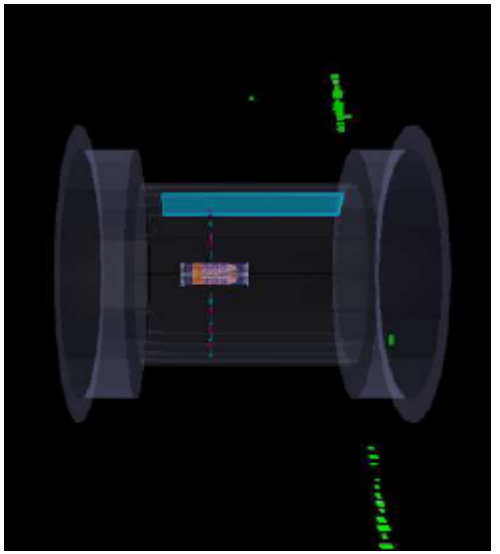


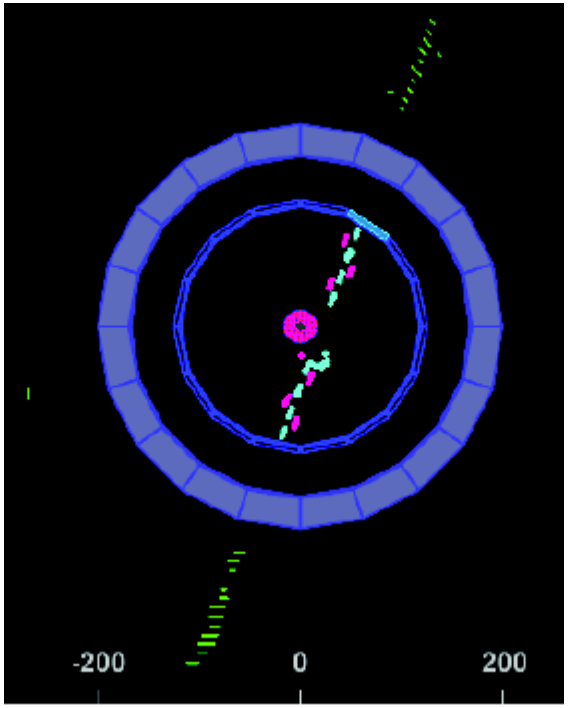
April 11



Cosmic ray run (June)



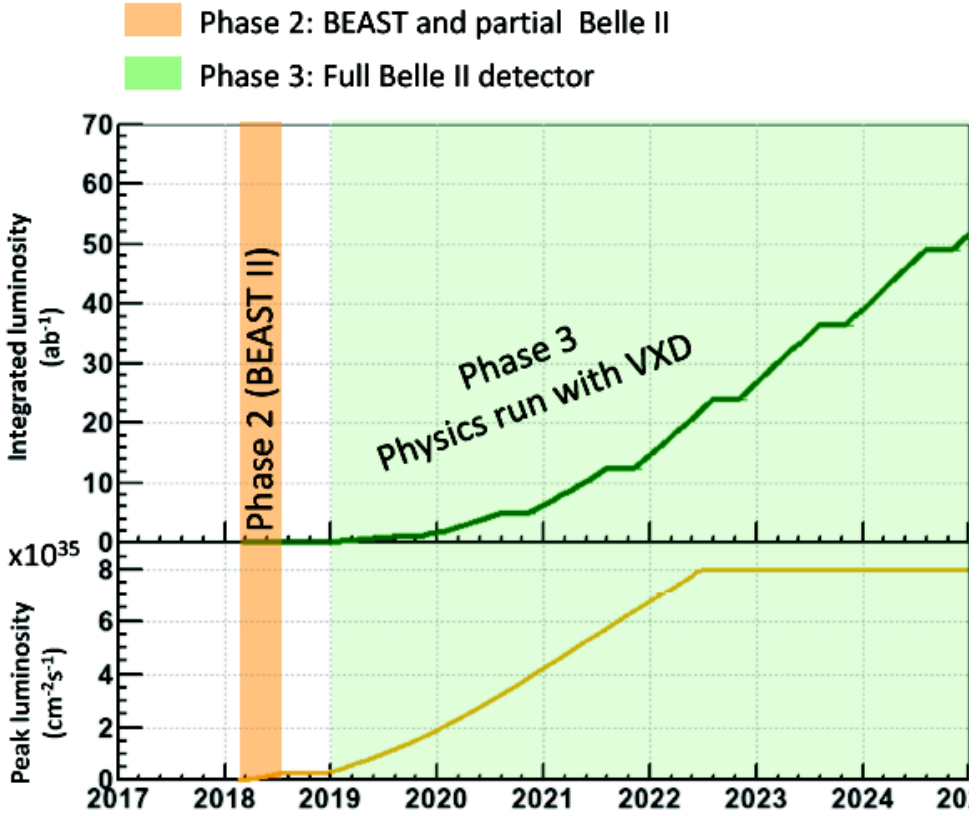




- Systems included: CDC, TOP, ECL, KLM

- Magnetic field: 1.5 T

Phase II



Commissioning of accelerator and detectors

- Start beginning of 2018, duration ~5 months
- Beam collisions with focusing magnets (QCS)
- Target luminosity is 10^{34} cm^{-2}s^{-1}
- ~20-40 fb^{-1} for physics analyses
- W/o vertex detector → no time dependent measurements,

What can be done with Phase 2 data?

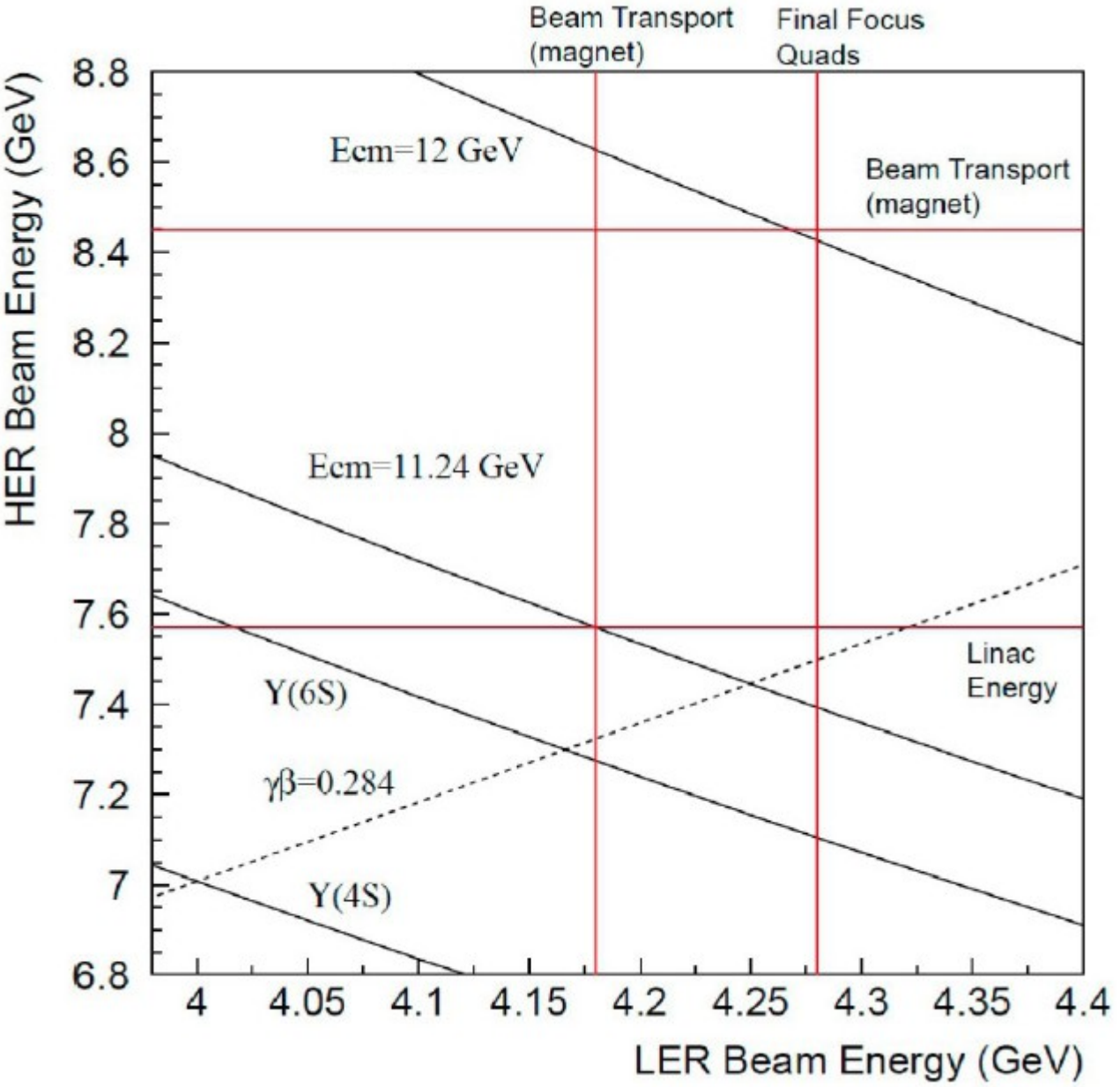
➔ Background studies
➔ Detector and trigger performance studies
➔ Simulation validation
➔ Exercising of calibration and alignment procedures
➔ Reconstruction algorithm tuning
➔ Physics measurements

Energy scan

Existing datasets [fb^{-1}]:

	CLEO	BaBaR	Belle
Y(1S)	1.2		6
Y(2S)	1.2	14	25
Y(3S)	1.2	30	3
Y(4S)	16	433	711
Y(5S)	0.1	3.3	36
Y(6S)			5.5
Off res.	17	54	100

High energy is most promising

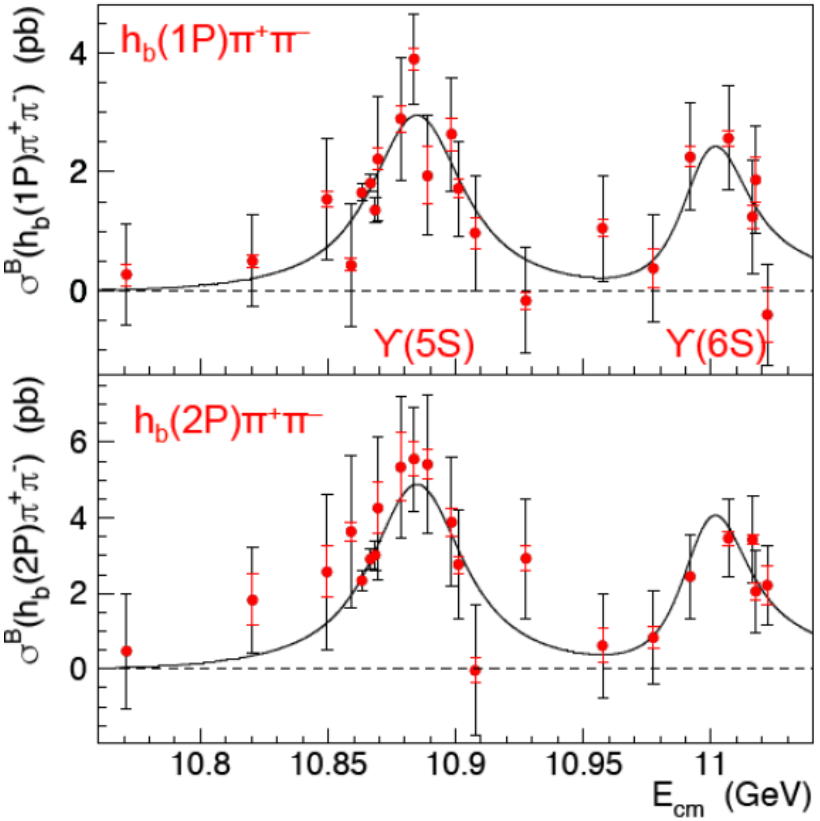


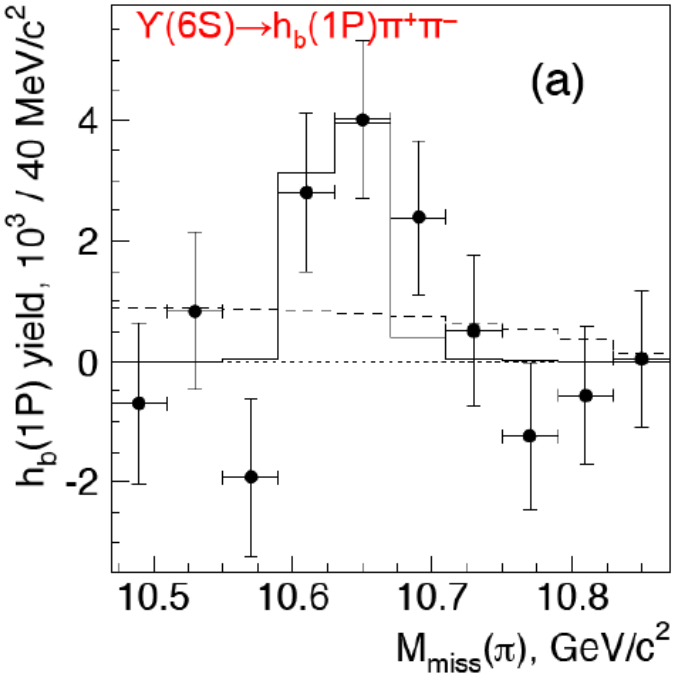
Zb's @ Belle

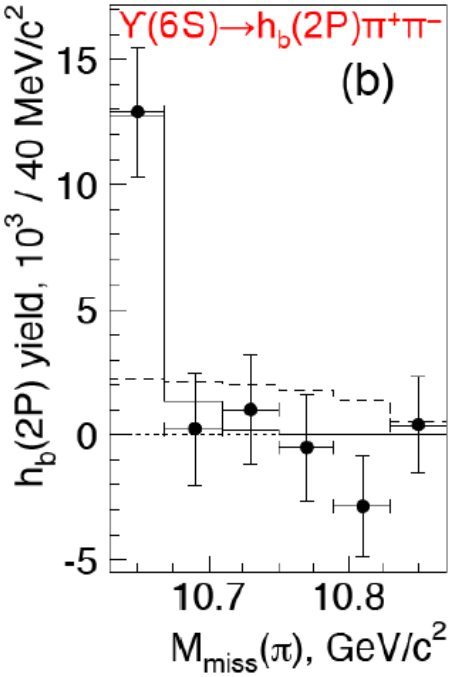
- $Z_b^{\pm}(10610)$ and $Z_b^{\pm}(10650)$ is discovered in $\Upsilon(nS)\,\pi^{\pm}$ and $h_b(mP)\,\pi^{\pm}$ @ $\Upsilon(5S)$

PRL 108, 122001 (2012)

- $Z_b^{0}(10610)$ is observed in $\Upsilon(nS)\,\pi^{0}$ @ $\Upsilon(5S)$ PRD 88, 052016 (2013)
- $Z_b^{\pm}(10610) \to B^{*}B$ and $Z_b^{\pm}(10650) \to B^{*}B^{*}$ observed at $\Upsilon(5S)$ (dominant decay channels) PRL 116, 212001 (2016)
- 3.3σ for $Z_b^{\pm}(10610)$ at $\Upsilon(6S)$ PRL 117, 142001 (2016)







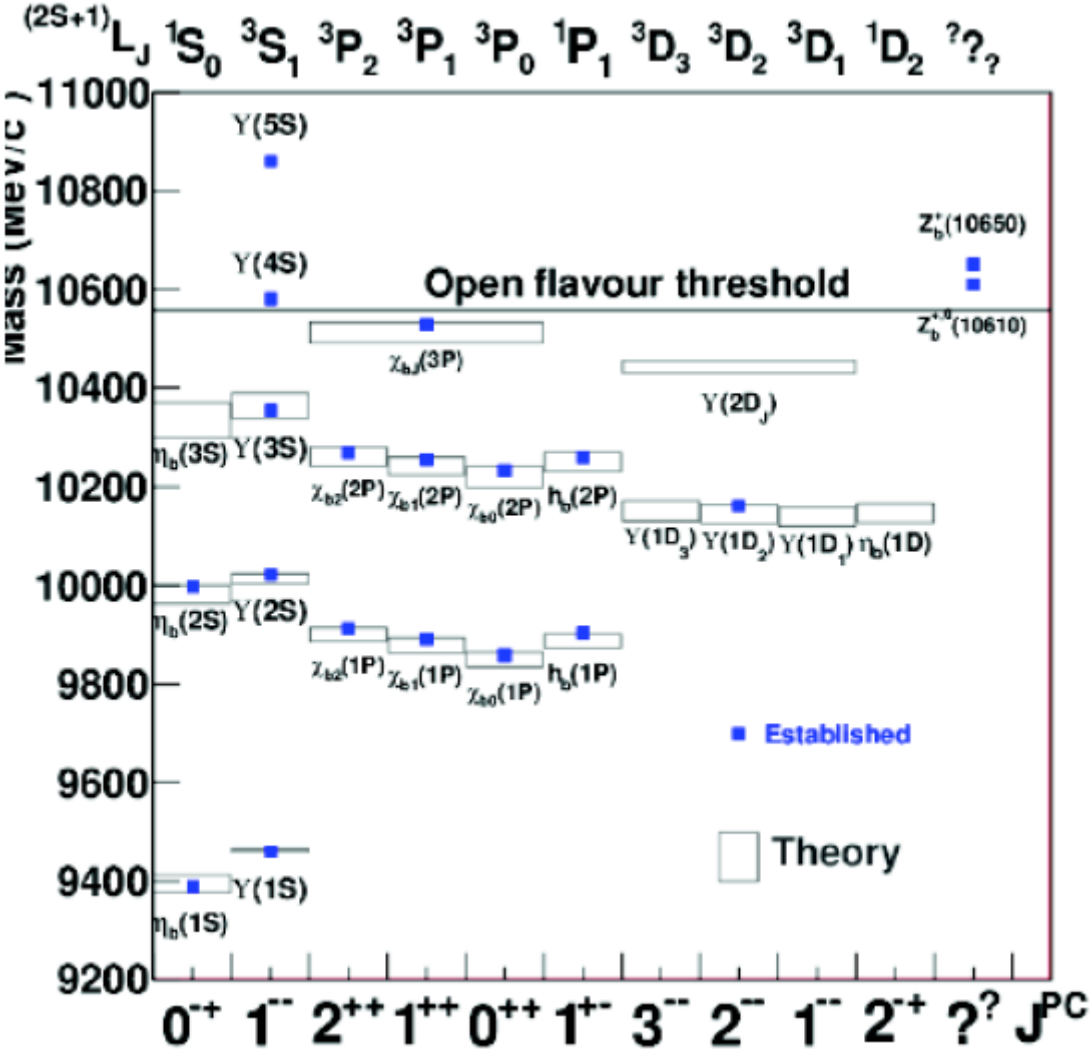
Study of Y(6S) decays

Quarkonia transitions, Y(6S) decays to known states:

- Y(nS) ππ and Y(mD) ππ
- Y(nS) η and Y(mD) η
- Y(nS) K^+K^-
- χ_b(mP) ω

Search for new conventional bottomonia states:

- hb(3P) by ππ
- Y(2D) by ππ & η



Search for exotic states

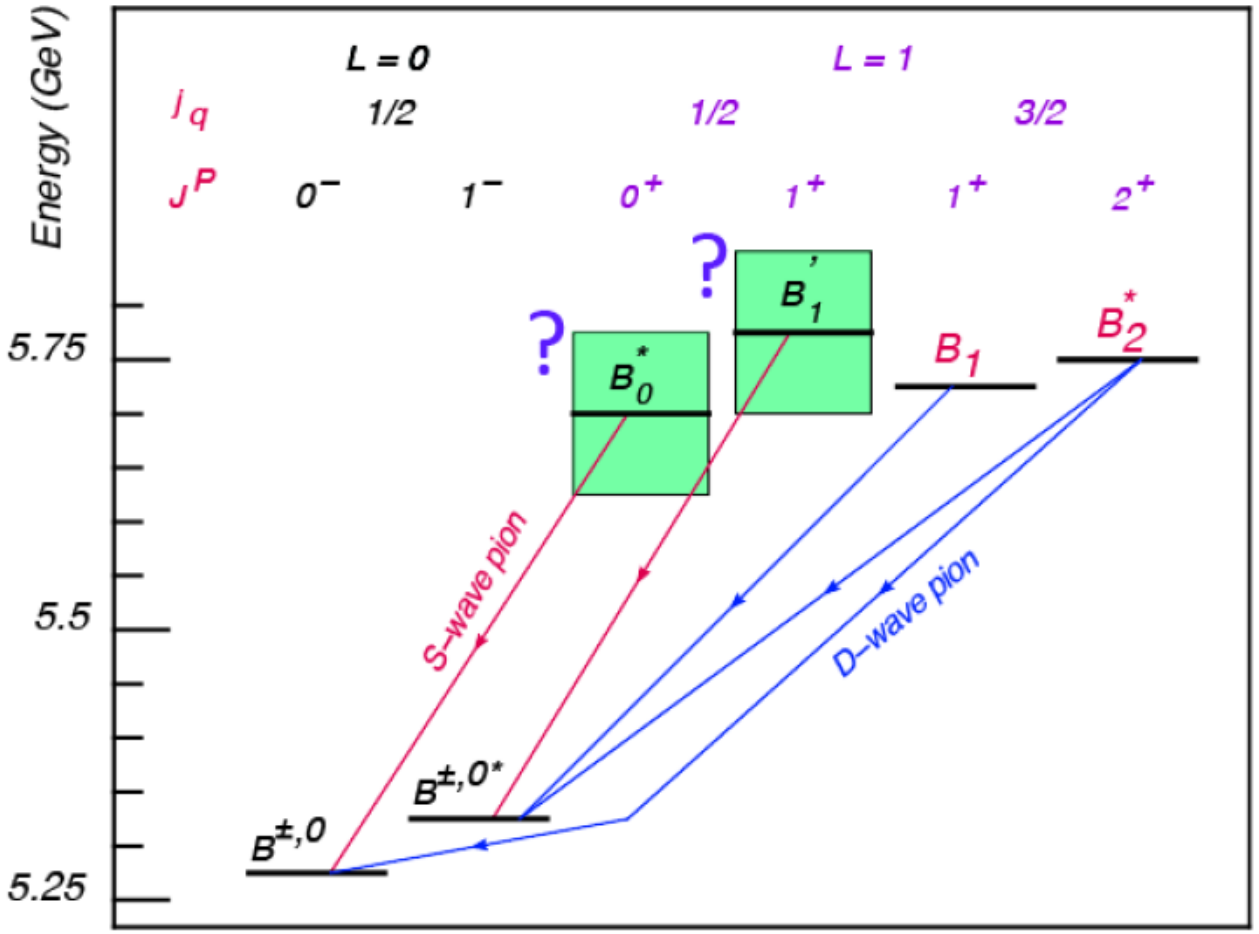
Search for exotic states in Y(6S) decays to:

- $Z_b^{\pm}\pi^{\mp} \rightarrow \Upsilon(nS)\,\pi^+\pi^-$
- $Z_b^{\pm}\pi^{\mp} \rightarrow h_b(mP)\,\pi^+\pi^-$
- $Z_b^{\pm}\pi^{\mp} \rightarrow \eta_b\,\pi^+\pi^-$
- $W_b^{0}\pi^+\pi^-$ with $W_b^{0} \rightarrow \eta_b\pi,\ \chi_b\pi,\ \Upsilon(nS)\rho$
- $X_b^{0}\gamma$ with $X_b^{0} \rightarrow \Upsilon(1S)\omega$
- BB*

B** spectroscopy

Y(6S) is close to B B** threshold

Combination	Treshold, GeV/c^2
B(*) $\overline{B}$**	11.00 – 11.07
Bs(*) $\overline{Bs}$**	11.13 – 11.26
Λb $\overline{\Lambda}$b	11.24
B** $\overline{B}$**	11.44 – 11.49
Bs** $\overline{Bs}$**	11.48 – 11.68
Λb $\overline{\Lambda}$b**	11.53
Σb(*) $\overline{\Sigma}$b(*)	11.62 – 11.67
Λb** $\overline{\Lambda}$b**	11.82 – 11.84



Low multiplicity events

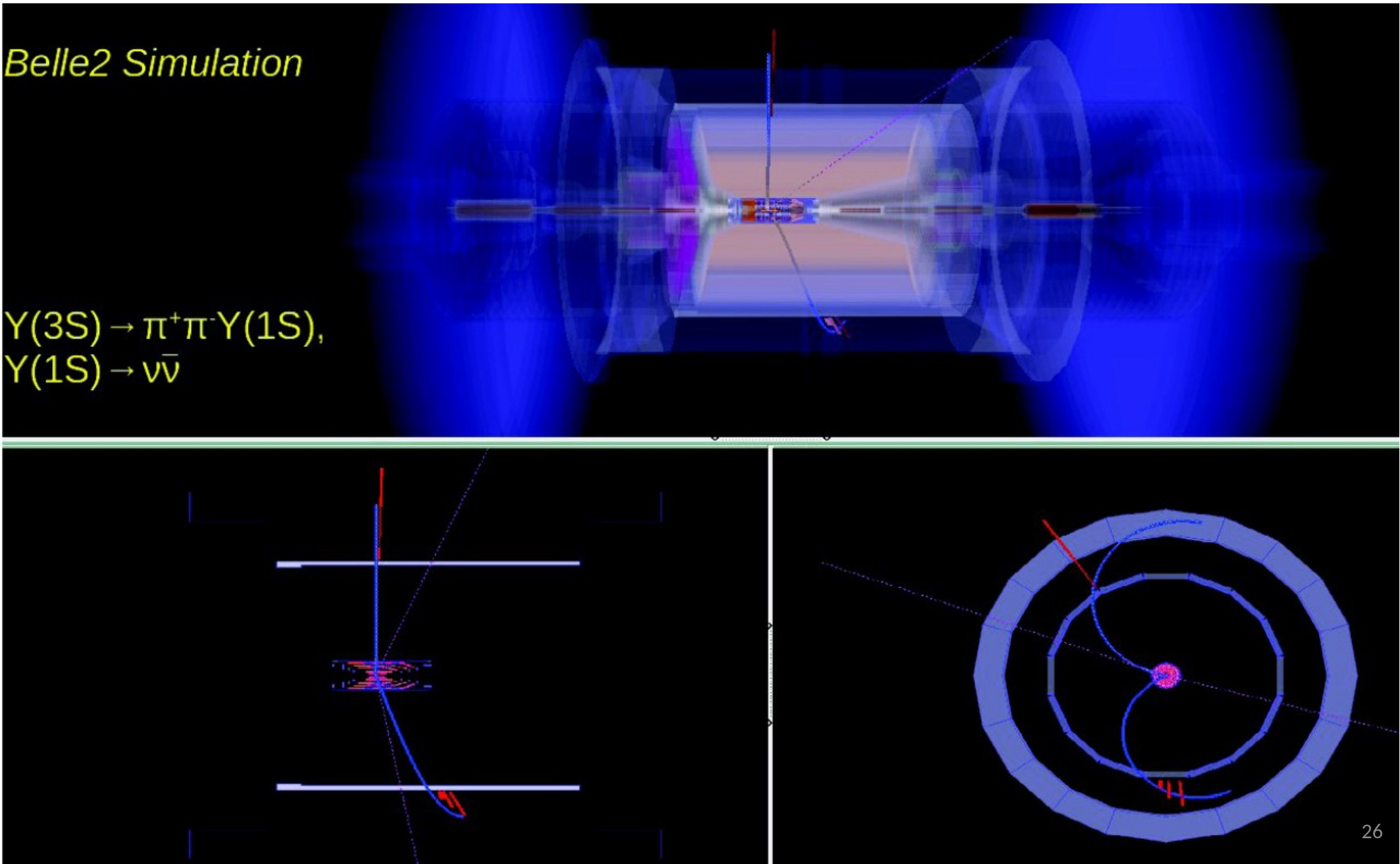
Trigger:

- ~100% efficient for B and charm decays
  - Low multiplicity events challenging because of large QED background
- Belle trigger was not optimized for low multiplicity
- Improvements of level 1 (L1) hardware trigger at Belle II:
  - Data rate increased from 16 to 190 Mbps
  - Logic implemented in FPGAs instead of hard coded
- Software based high level trigger (HLT) runs full reconstruction

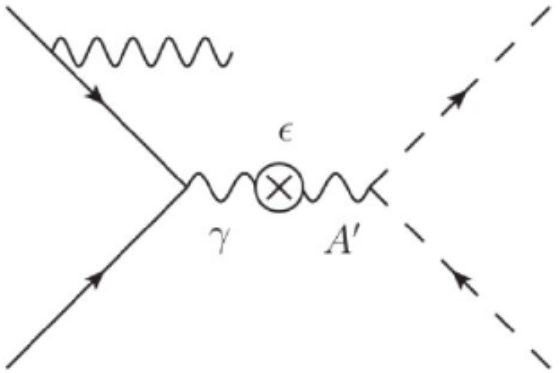
Development of triggers for low multiplicity:

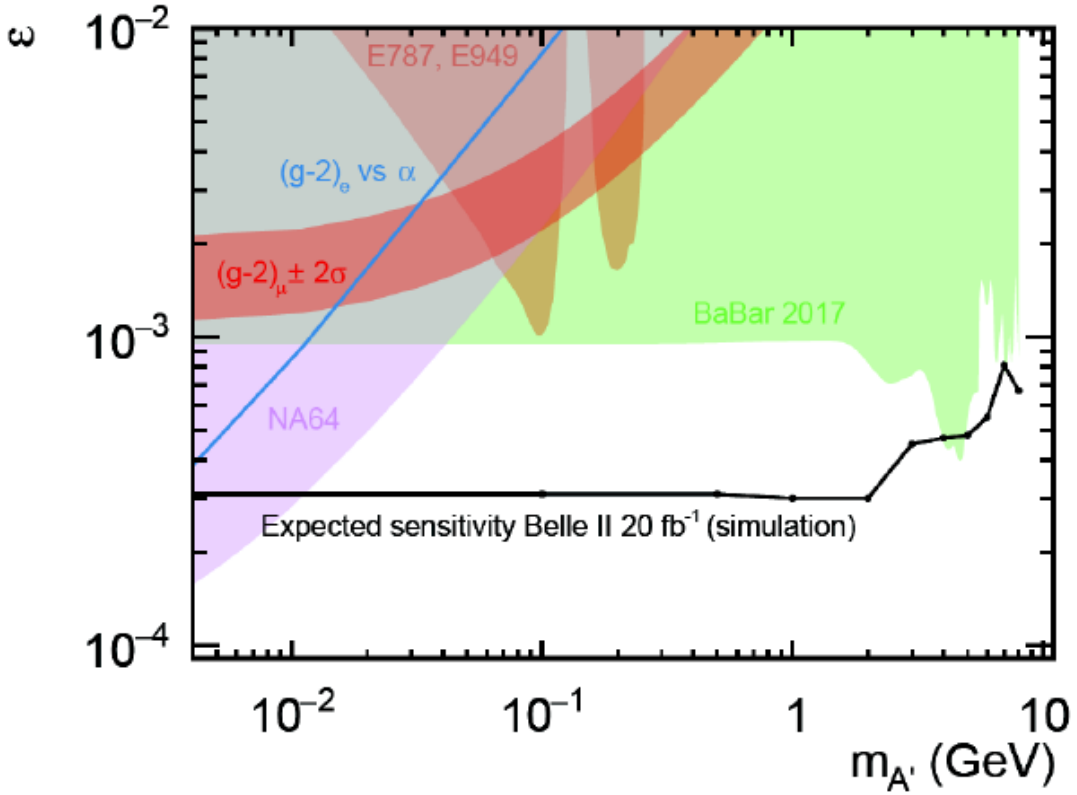
- Search for new physics in low multiplicity events with phase 2 data

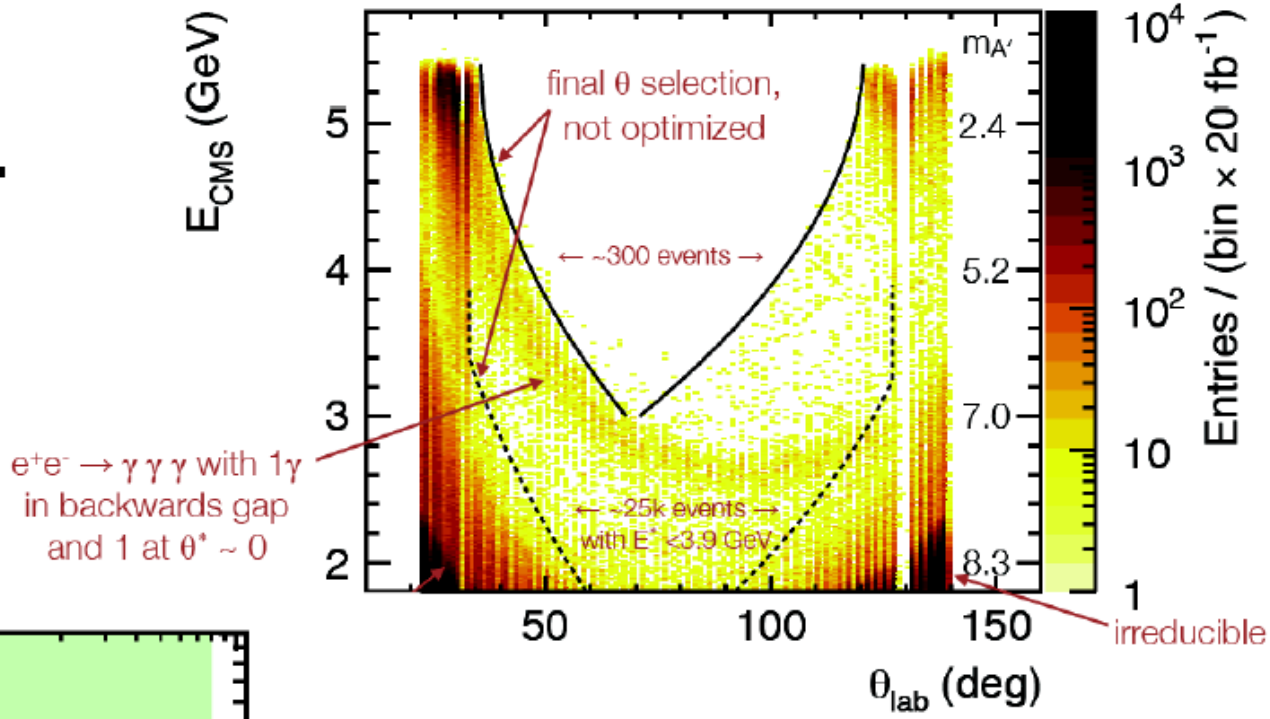
Invisible decays of Y(nS)



Dark Photon A’







- Kinetic mixing with SM photon

$$\sigma \propto \varepsilon^2 \alpha^2 \left(1 - m_{A'}^2 / E_{CM}^2\right) / E_{CM}^2$$

- Relevant for phase 2:
  Decay A’ → invisible
- Requires single photon trigger
  → Challenge: background

Summary

- Belle II phase 2 will start in 2018
- Accelerator and detector are commissioning. Expecting 20-40 fb^{-1} of data w/o vertex detector

- First physics opportunities:
  - Exotic states and bottomonium studies @ Y(6S)
  - Dark photon search with single photon trigger

- More details in The Belle II Physics Book (to be submitted to PTEP)

- Stay tuned for news from Belle II
  - https://twitter.com/belle2collab
  - https://www.facebook.com/belle2collab