Status of SuperKEKB and Belle II Experiment

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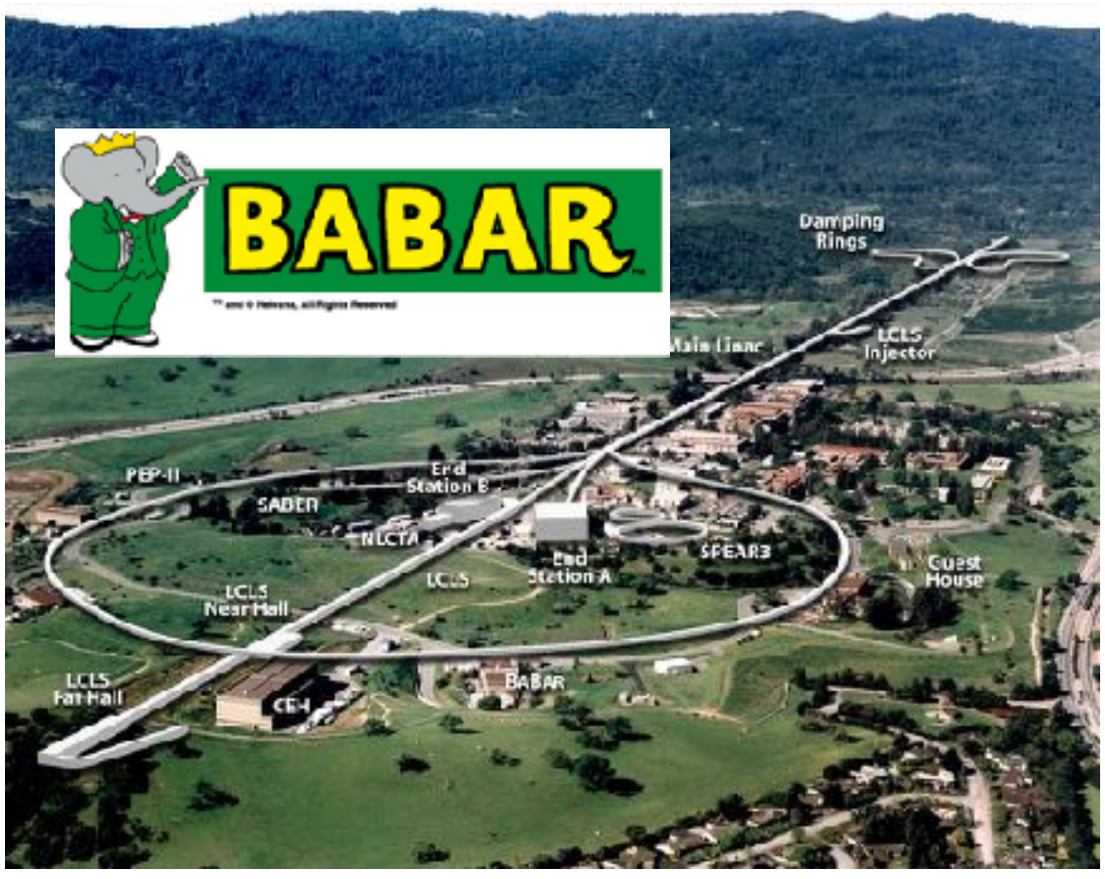
November 25, 2016

The B Factories

A e^+e^- collider runs at Y(4S) resonance to produce B meson pairs.

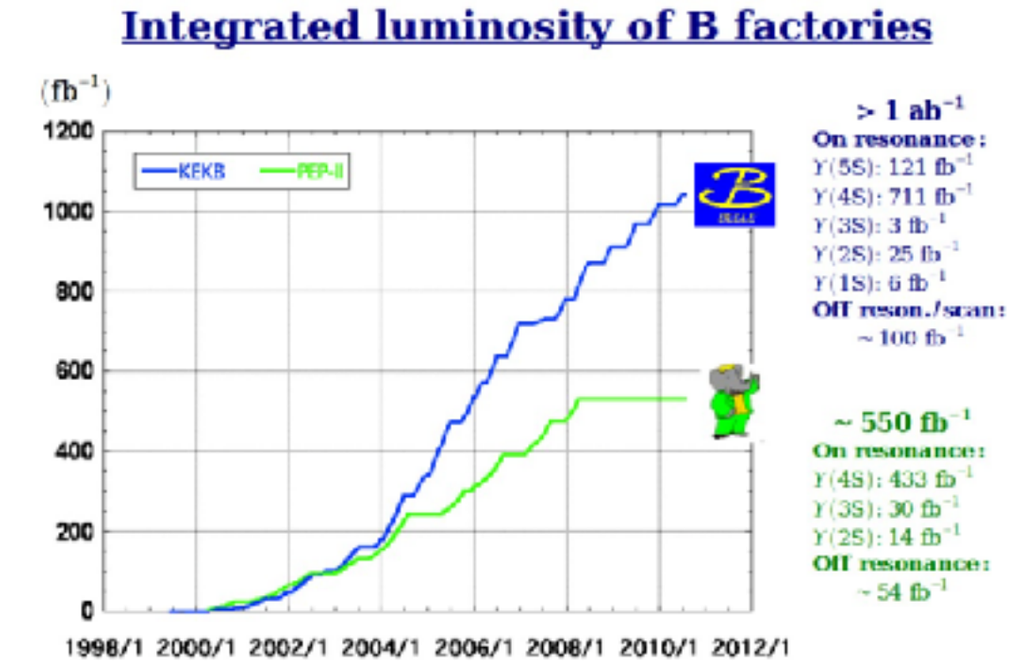
Belle/KEKB at KEK (Japan)

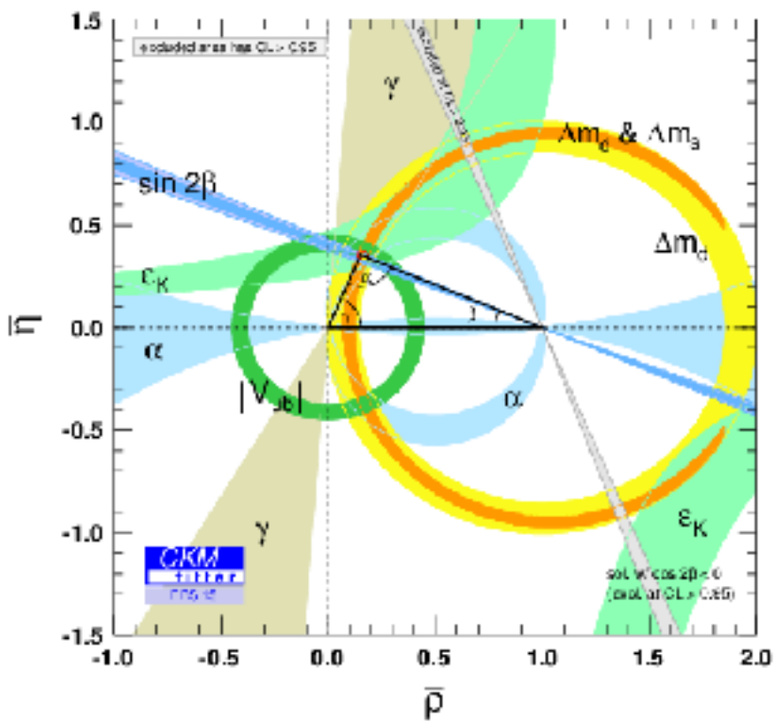


BaBar/PEP-II at SLAC (USA)

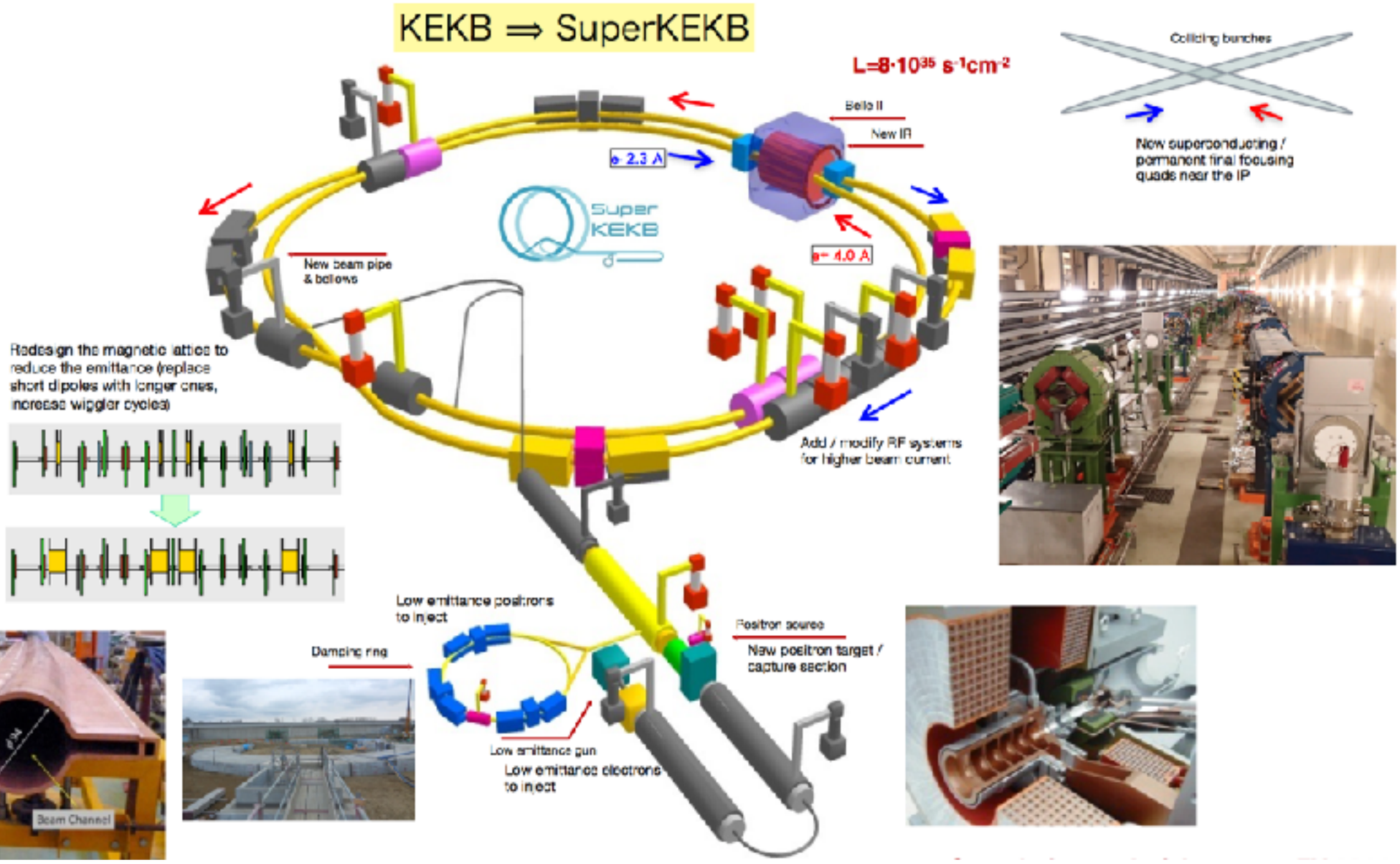
Physics Highlights

- Collected ~1.5 ab^{-1} of data
- Measurement of the Unitarity triangle, and CKM parameters
- Observation of direct CP violation in B decays
- Observation of D meson mixing
- Observation of new (X, Y, Z) hadrons
- Search for rare tau decays
- Constraints on new physics
- Direct searches for light Higgs, dark photon, etc.





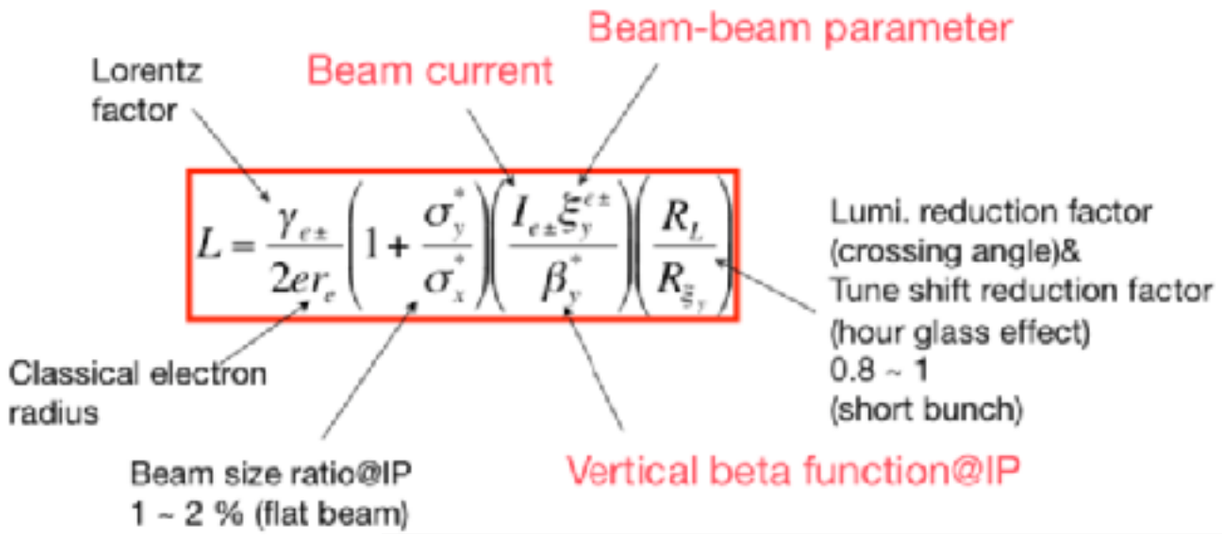
SuperKEKB



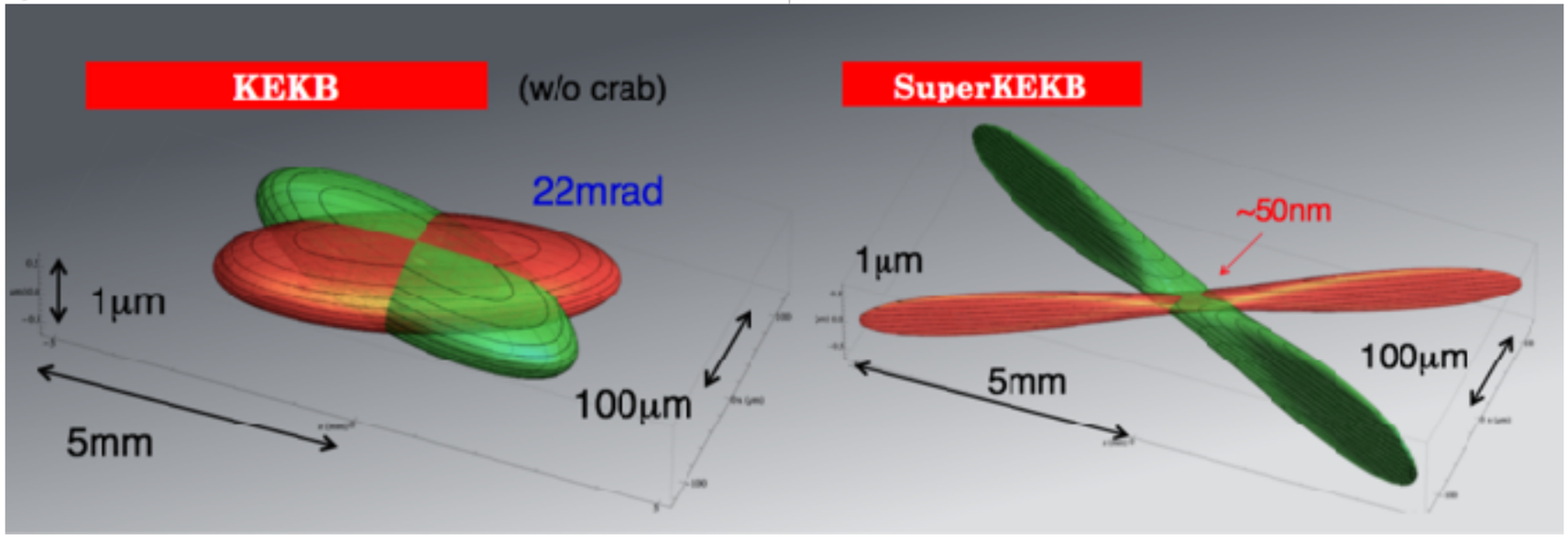
Replace beam pipes with TiN-coated beam pipes with antechambers (reduced Sync Rad.)

Target integrated luminosity for Belle II/SuperKEKB: ~50 ab^{-1}

SuperKEKB: Nano-Beam

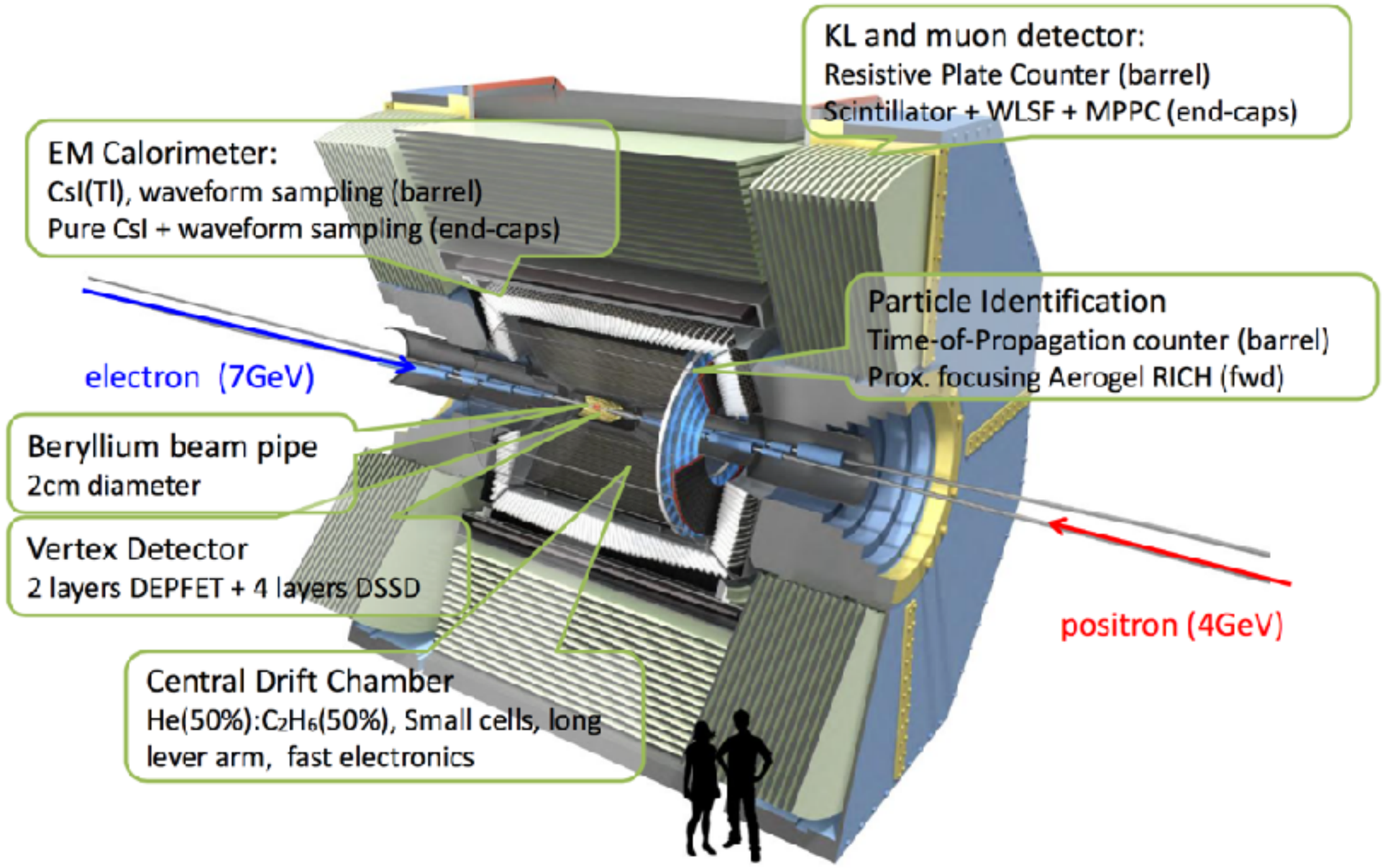


- Nano beam:
  - Small current increase (2-3x)
  - Smaller β_y^* (20x) via superconducting focus magnets
- Challenge of beam backgrounds

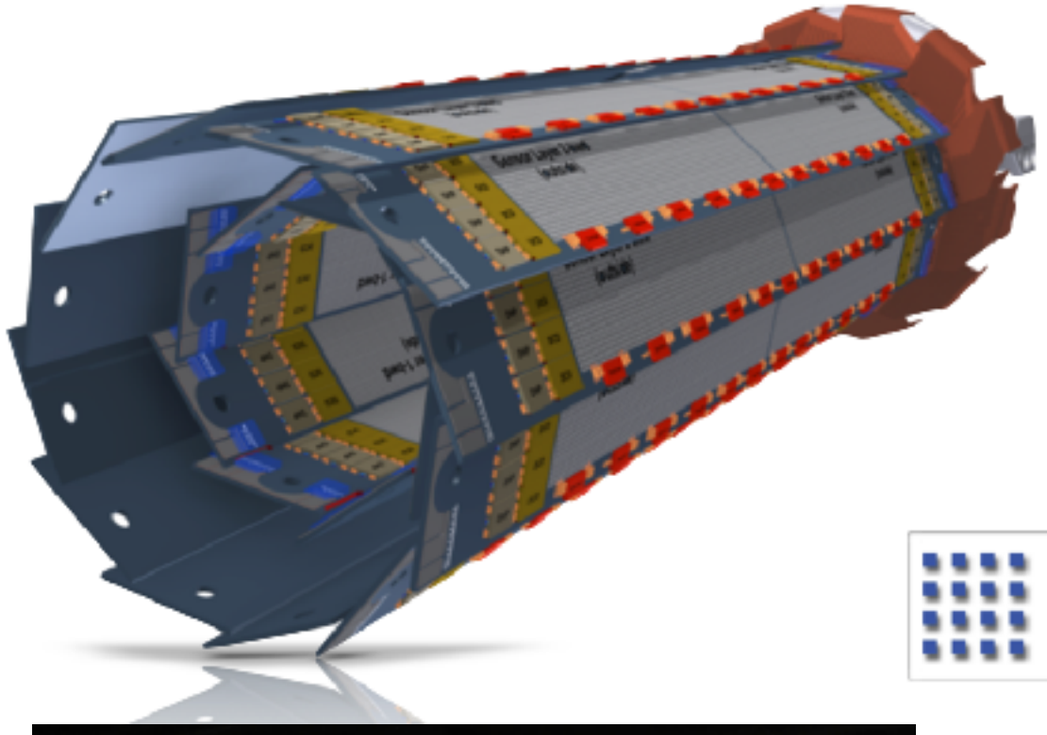


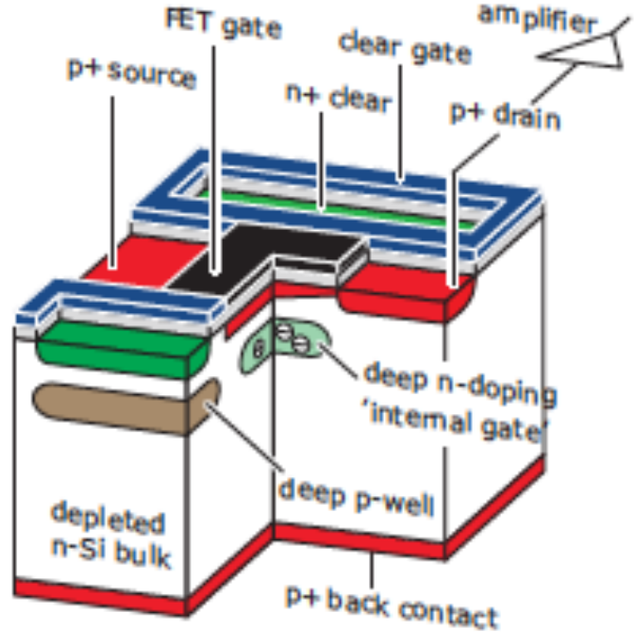
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

Belle II Detector



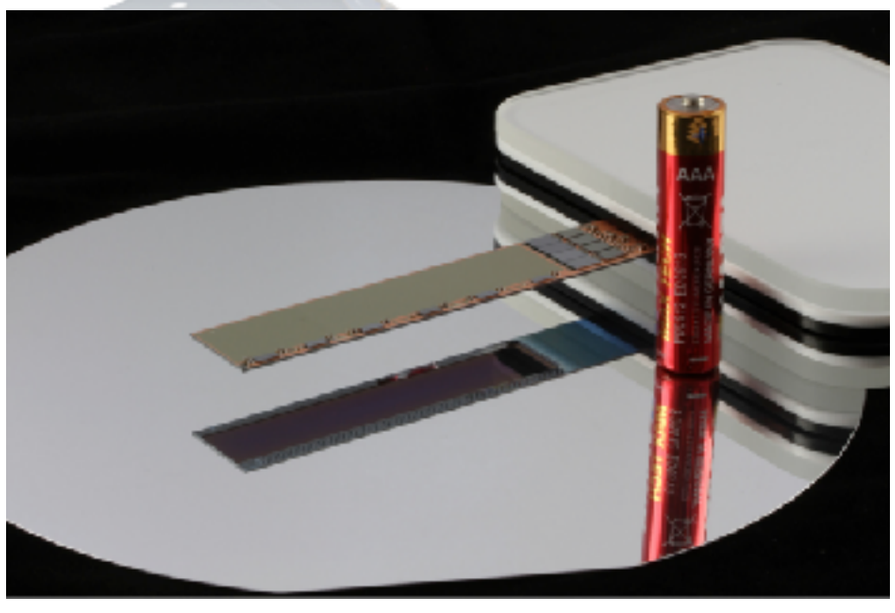
Belle II: PXD





PXD

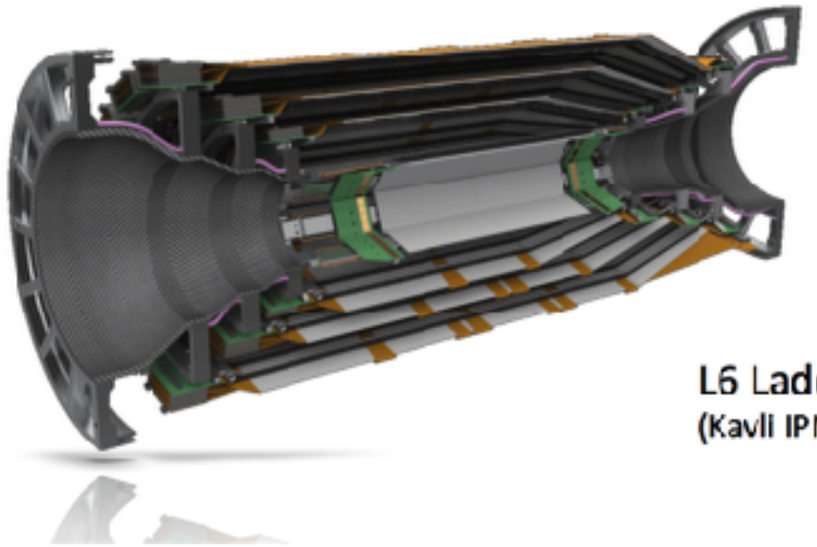
PXD: 2 layers of DEPFET
R = 14, 22 mm
Si thinned to 75 µm
8 (L1) / 12 (L2) self-supporting ladders

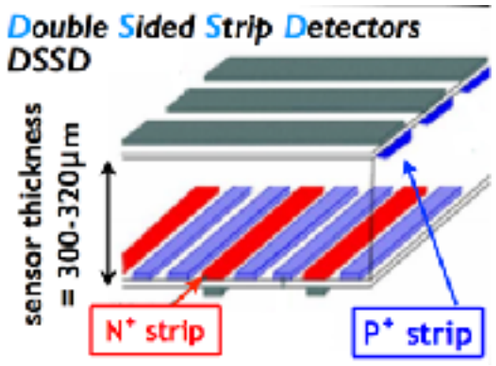


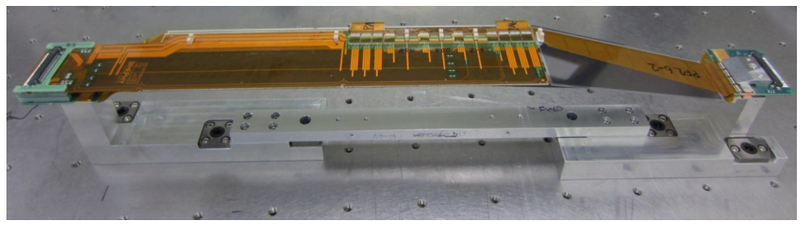
Full sized pixel detector module 0

Mechanical mockup

Belle II: SVD

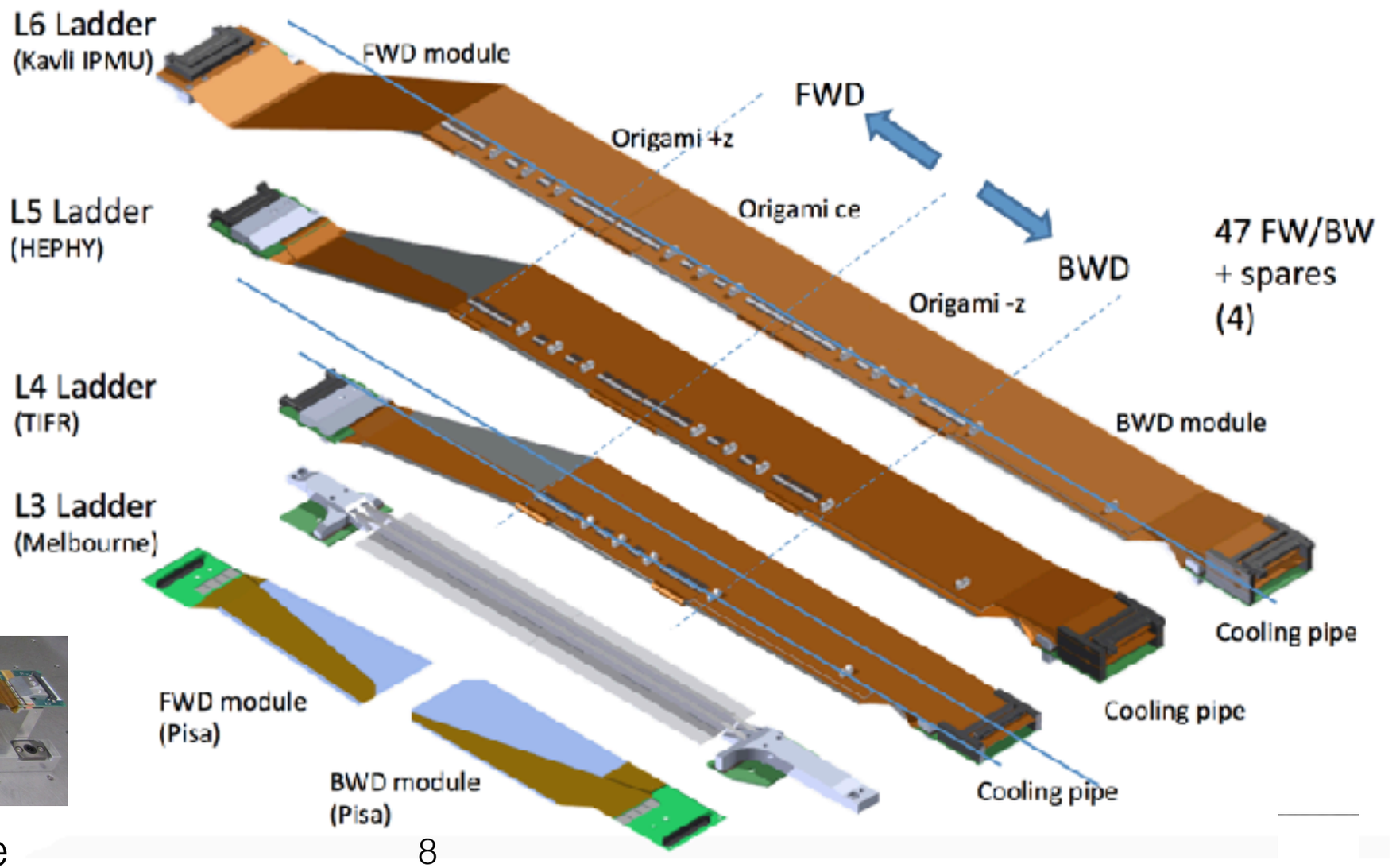






L4 mechanical prototype

Exploded View



Belle II: VXD Beam Test at DESY

:- combined beam test PXD+SVD

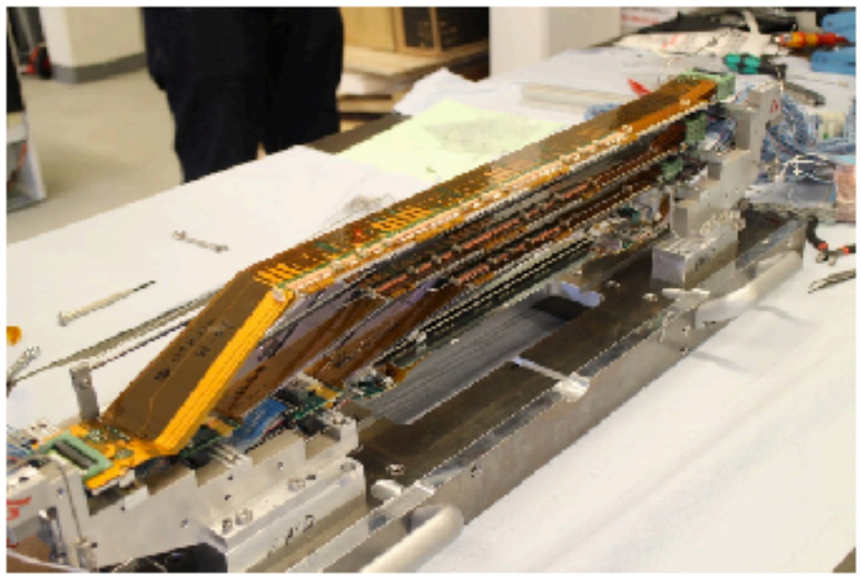
:- e^- beam, momentum 2-5GeV

:- full readout chain, Beast II geometry

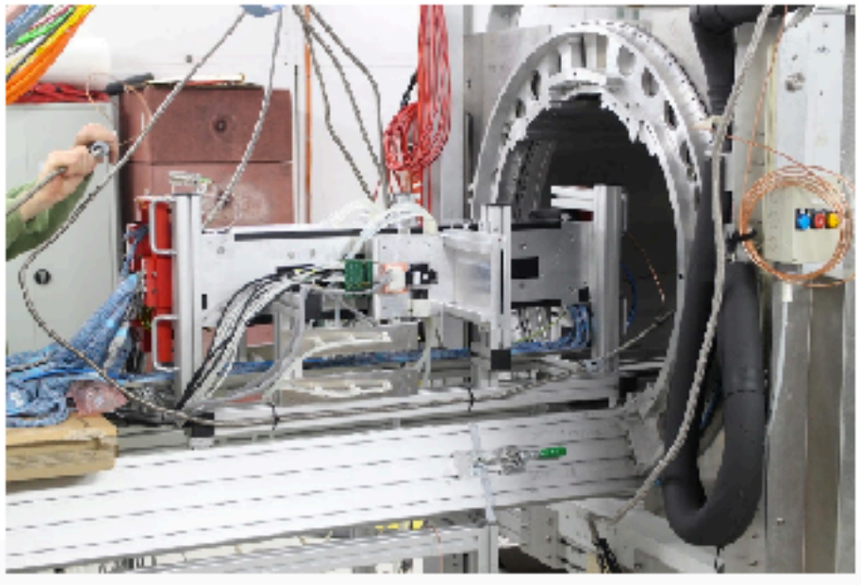
:- B-field in PCMag: 0-1T

:- total of ~340 runs in 4 weeks

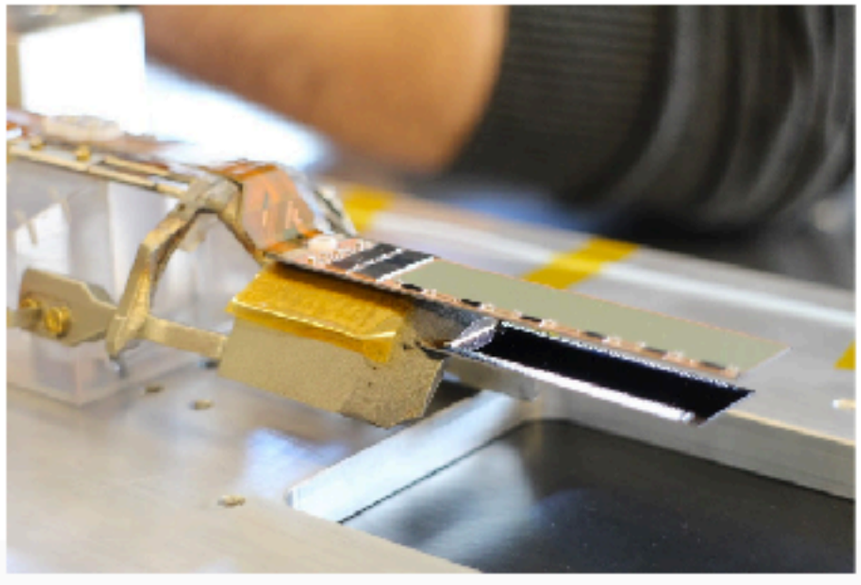
4 SVD ladders (L3-L6)



VXD + Tel + Magnet



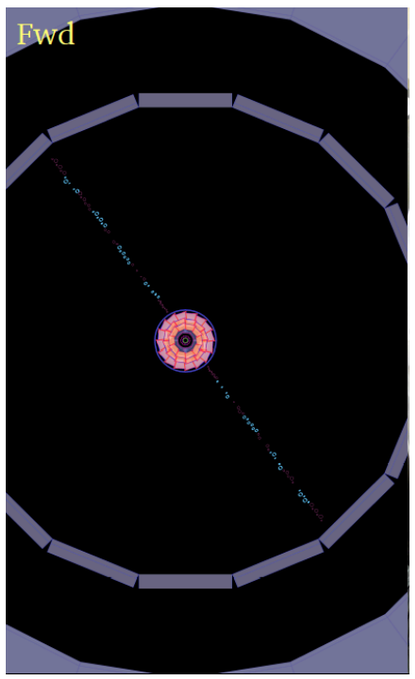
2 PXD half-ladders (L1-L2)

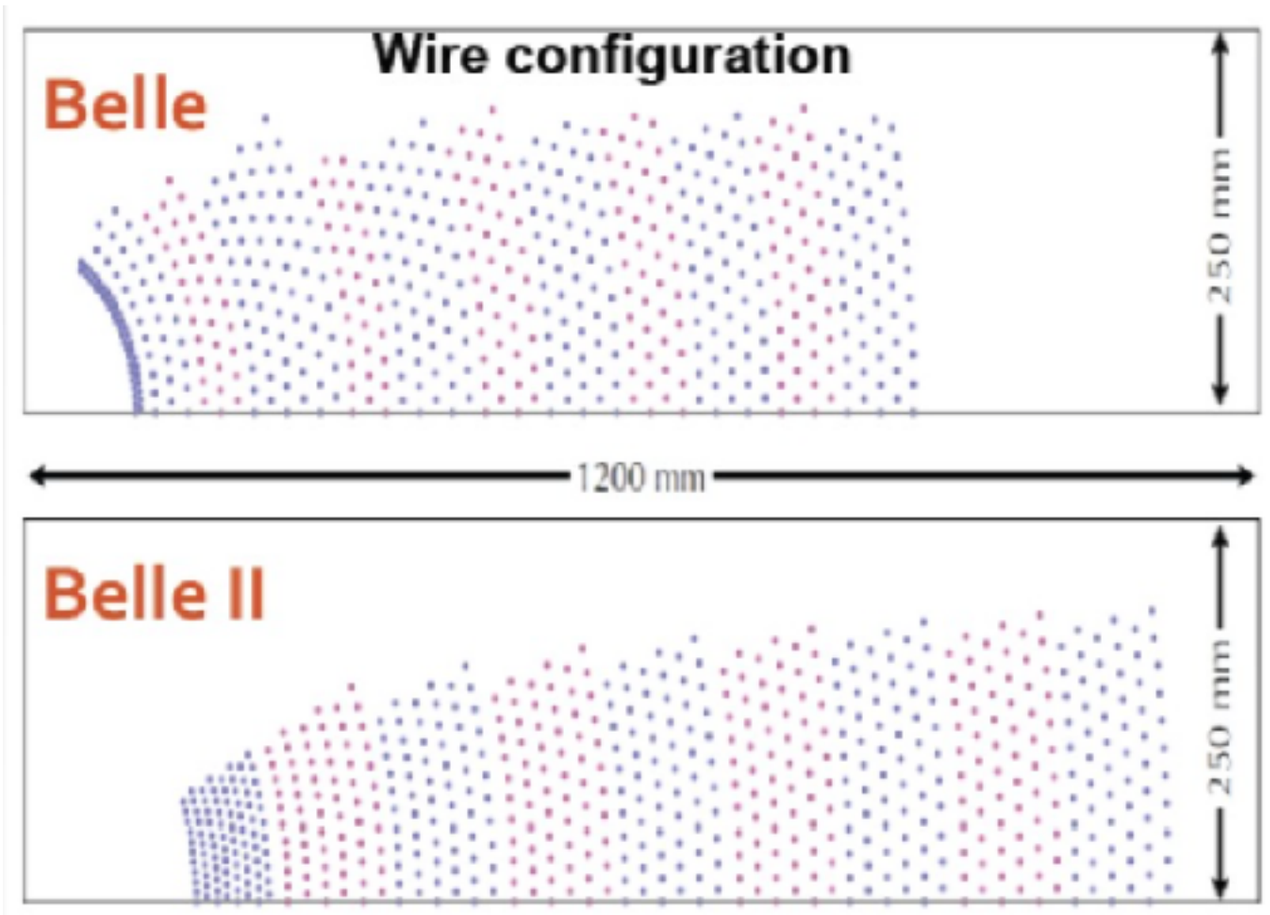


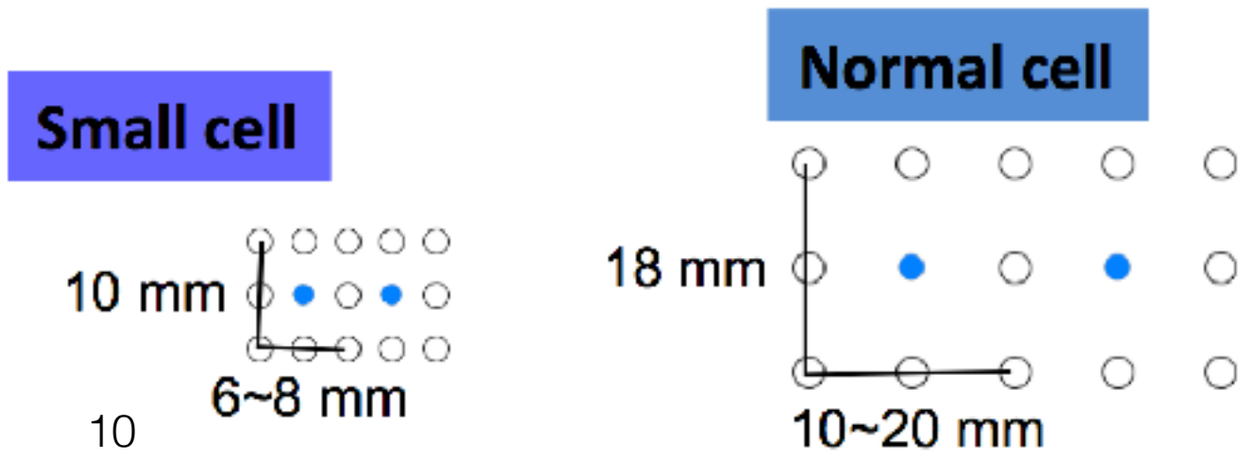
Belle II: CDC

- Belle II CDC will be larger than Belle CDC with smaller cells
- Improved p and dE/dx resolution
- Stringing completed in January 2014 with 51456 wires
- Installed to Belle II in October 2016

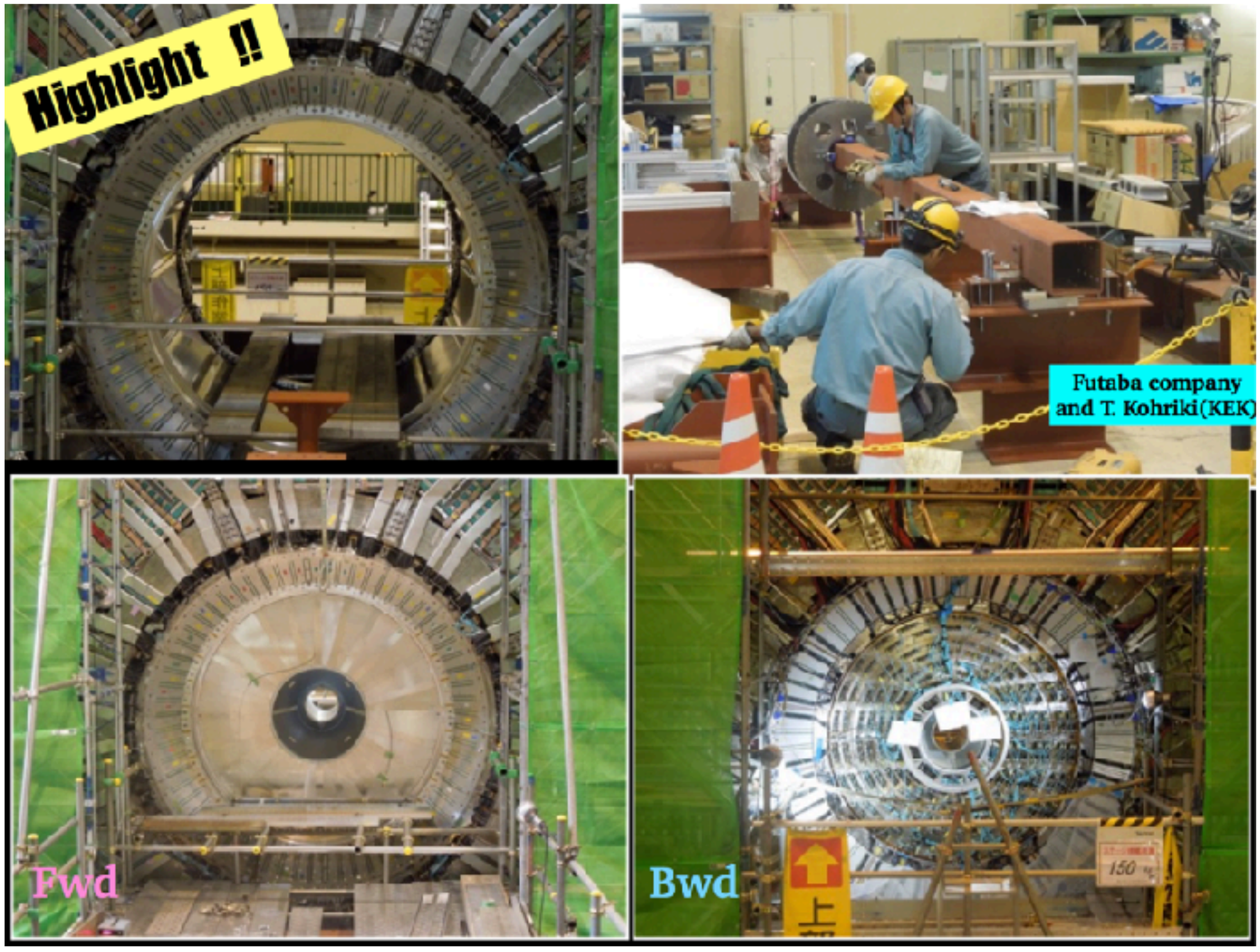
Cosmic-ray test





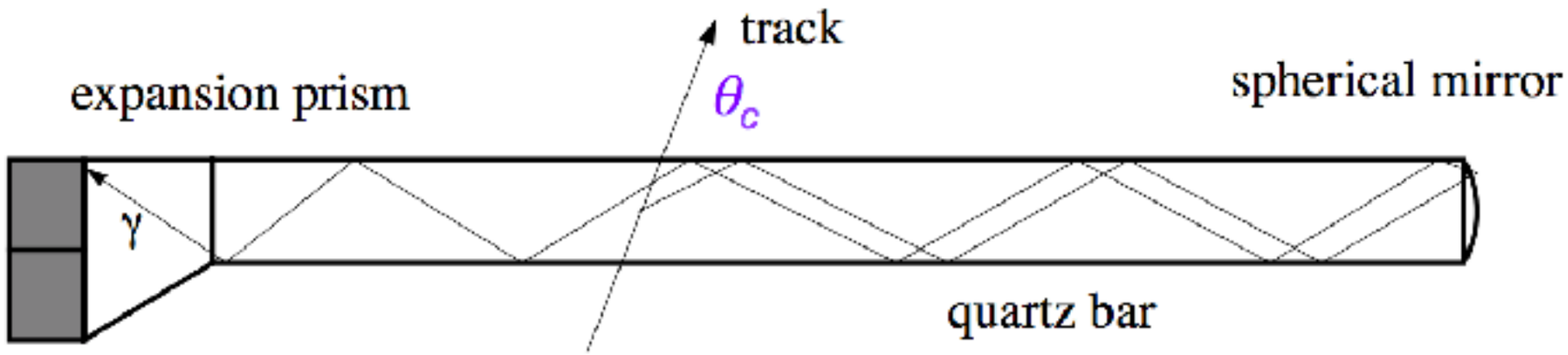


Belle II: CDC Installation

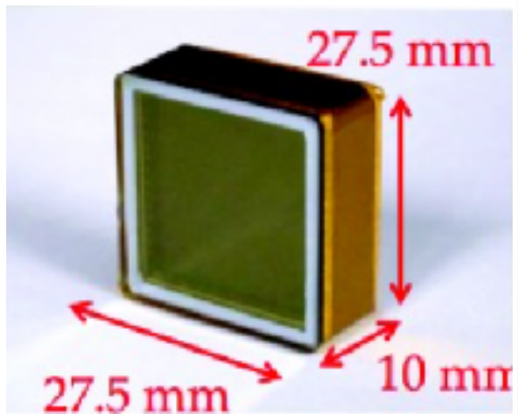


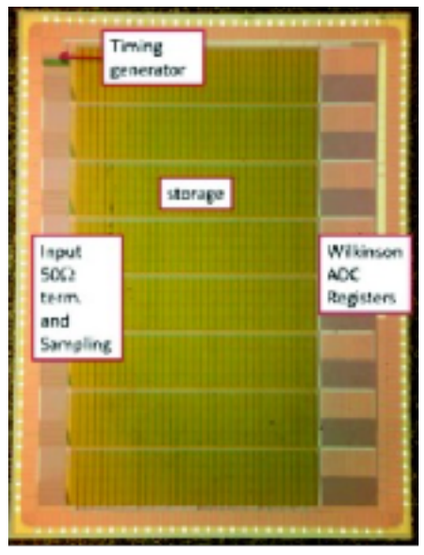
CDC installation in October

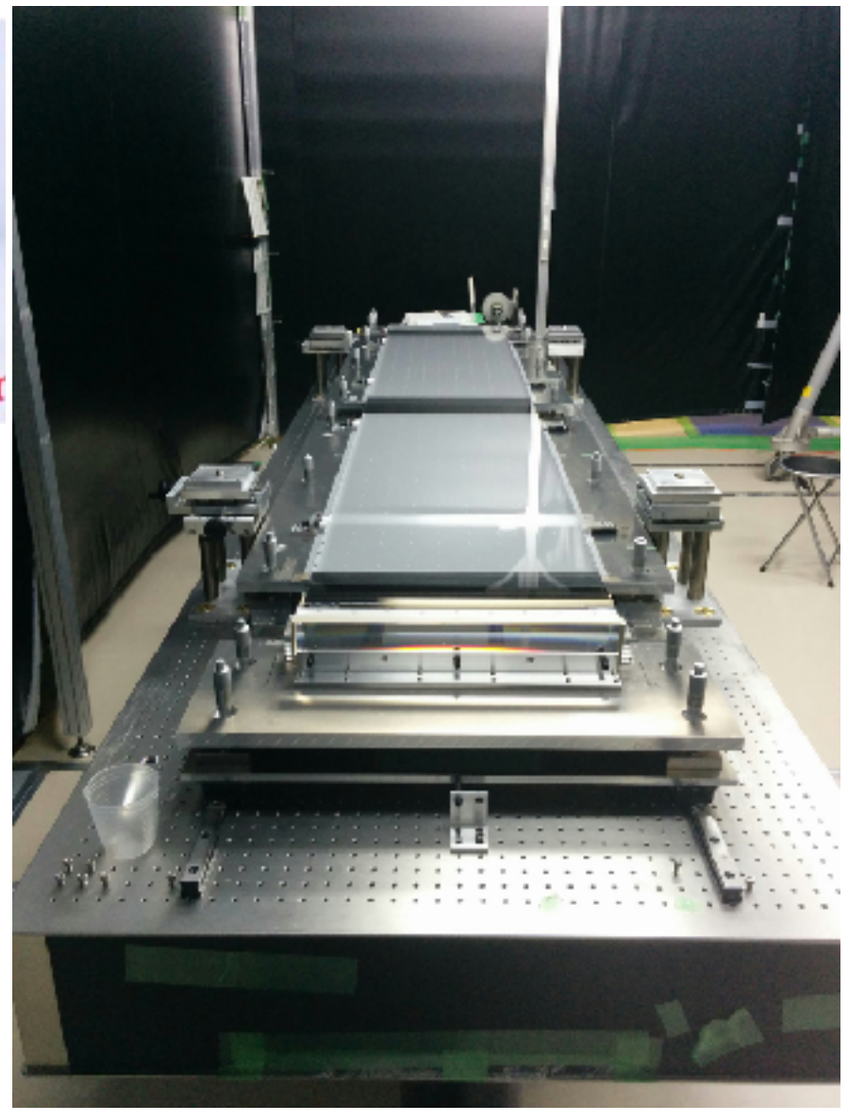
Belle II: TOP



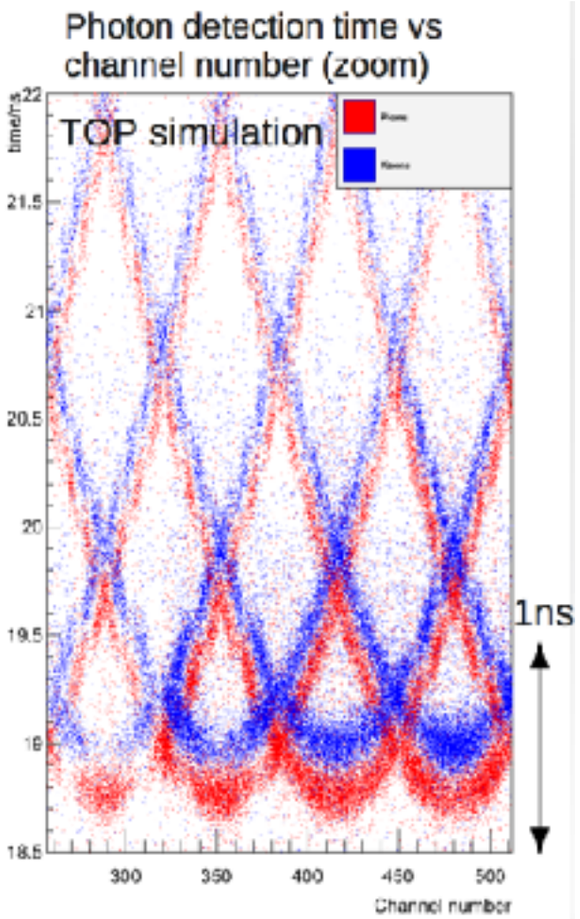
- The imaging Time of Propagation sub-detector (TOP or iTOP) will be used for particle identification in the barrel region of Belle II
- Each TOP module consists of two quartz bars, one mirror, one prism, and an array of photo-detectors to collect Cherenkov photons from charged tracks
- To distinguish between kaons and pions, the photo-detectors should have excellent position and timing resolution
- This is achieved by using MCP-PMTs and new waveform sampling electronics

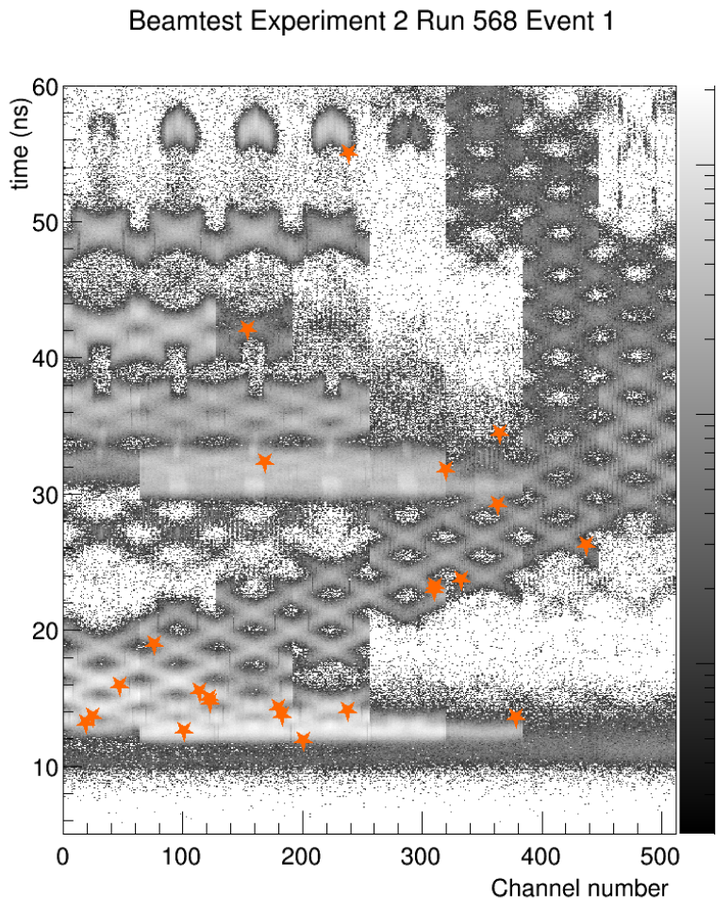






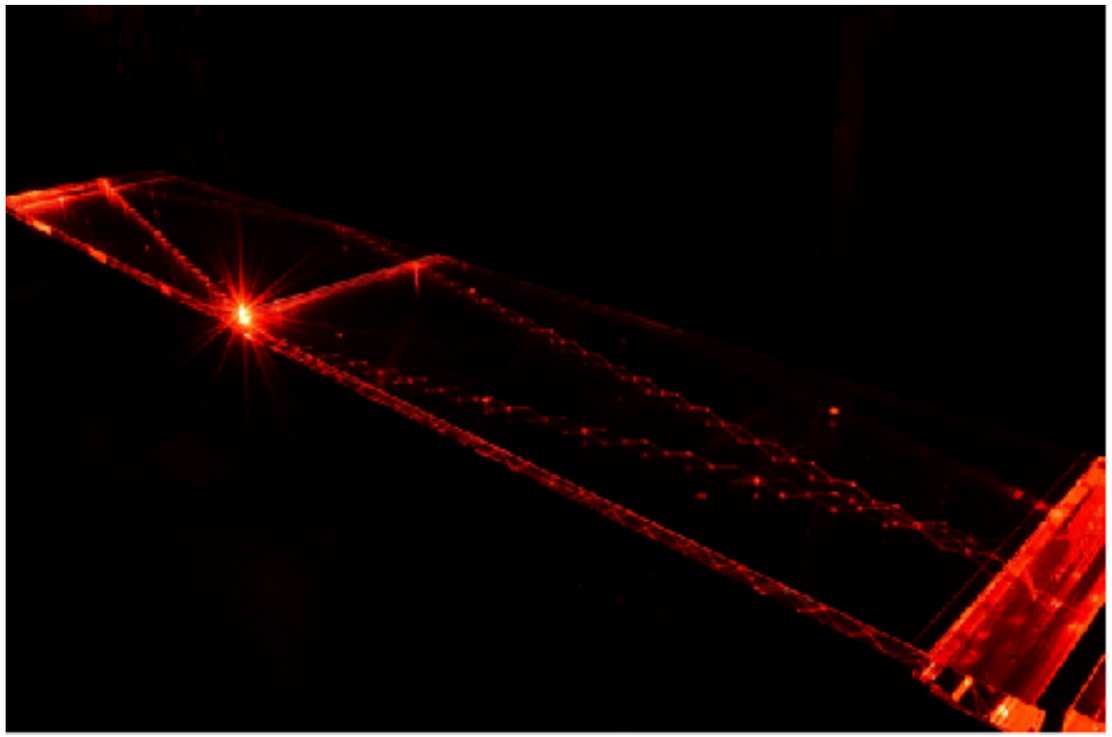
Belle II: TOP

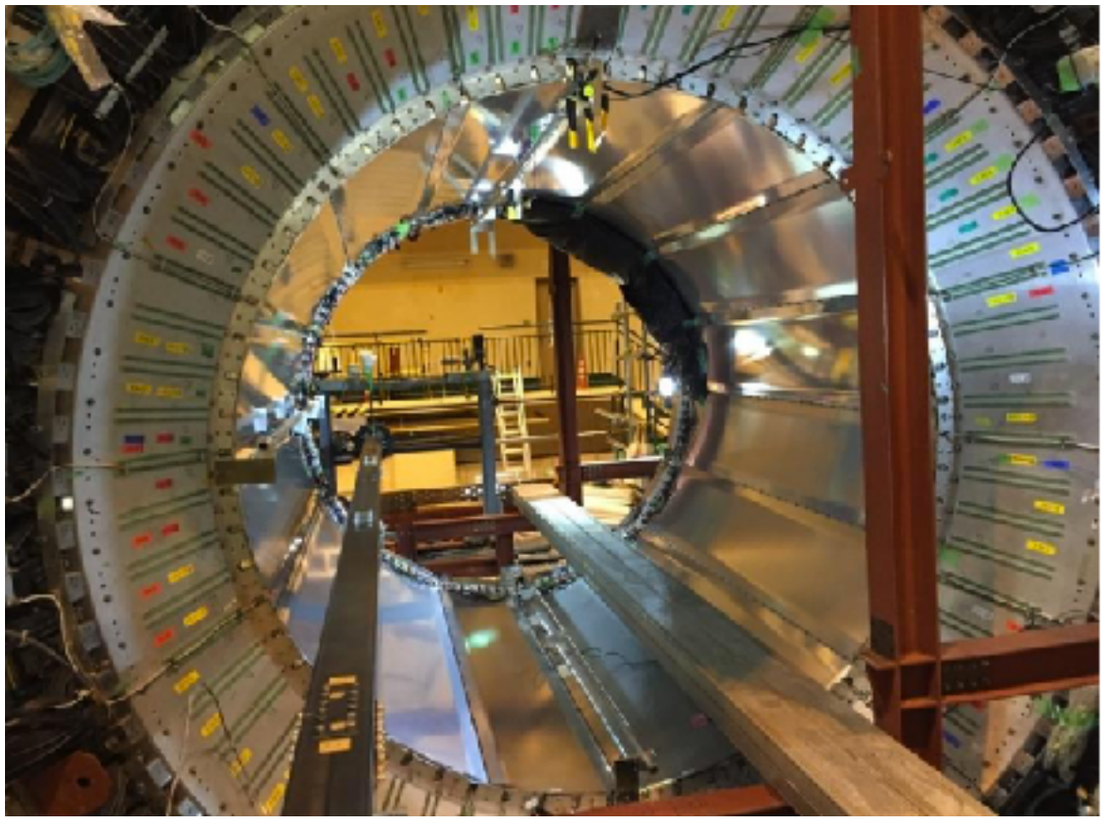




- TOP modules have been tested at beam test at SPring-8 LEPS in 2013, and good agreement between data and MC simulation has been obtained, with timing requirement ~O(100ps)
- All modules have been assembled (the optical and mechanical parts) and installed to Belle II.
- Firmware testing is underway.

Belle II: TOP

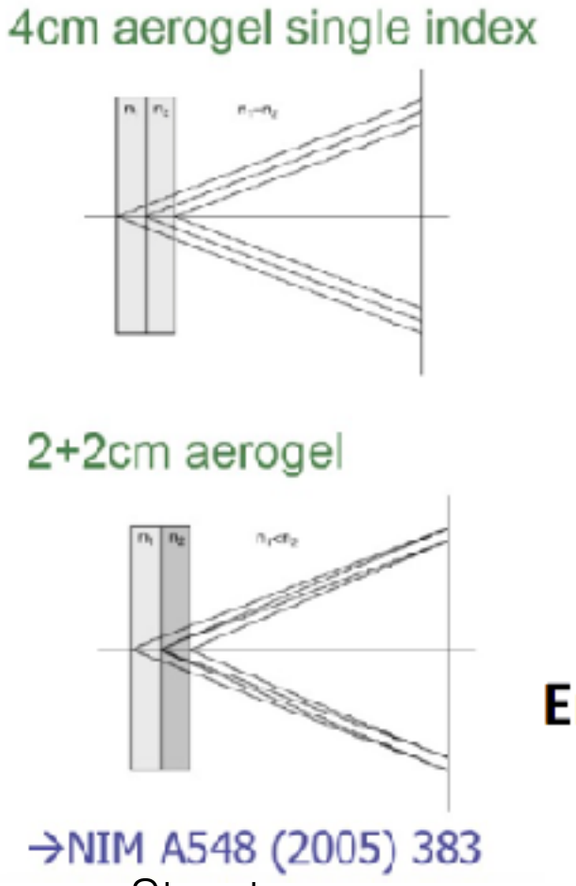


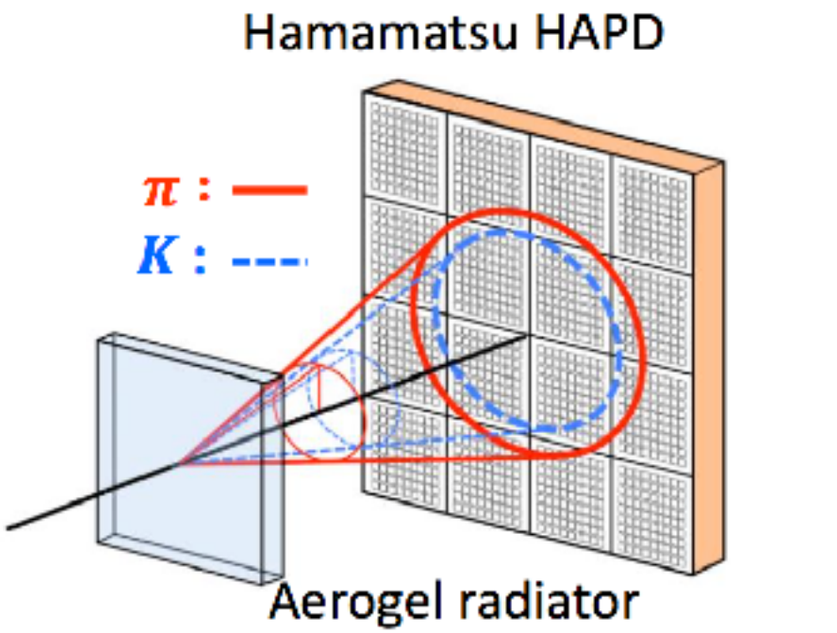


All modules were installed by May 2016

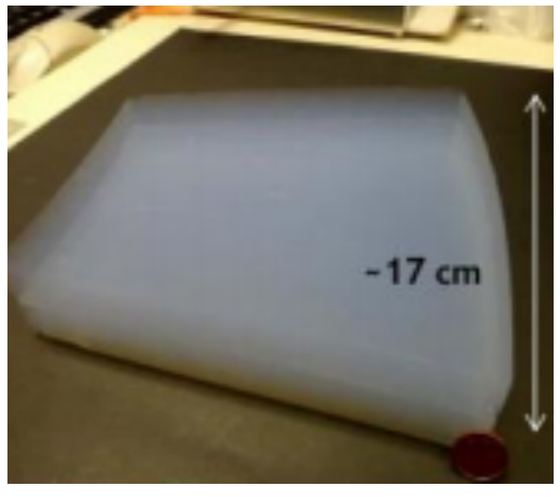
Belle II: ARICH

- Aerogel Ring Imaging Cerenkov (ARICH) detector will be used for particle identification in the forward end cap
- 420 Hybrid Avalanche Photo Detectors (HAPD), each with 144 channels
- Two layers of aerogel lead to better photon yield, while not affecting resolution

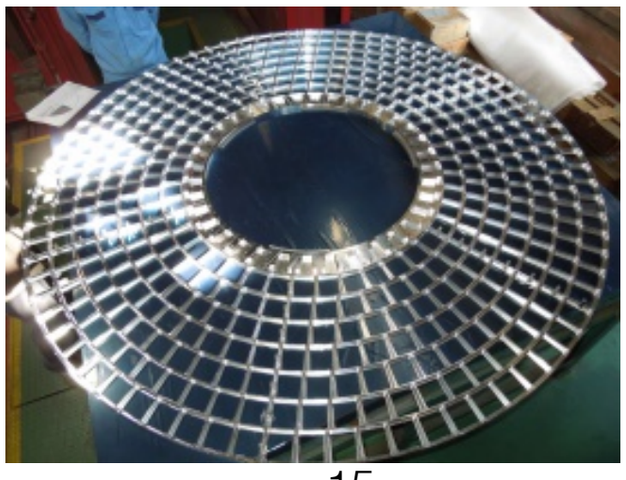




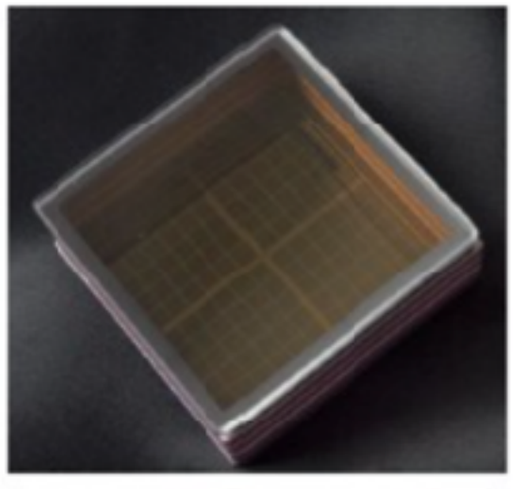
Aerogel



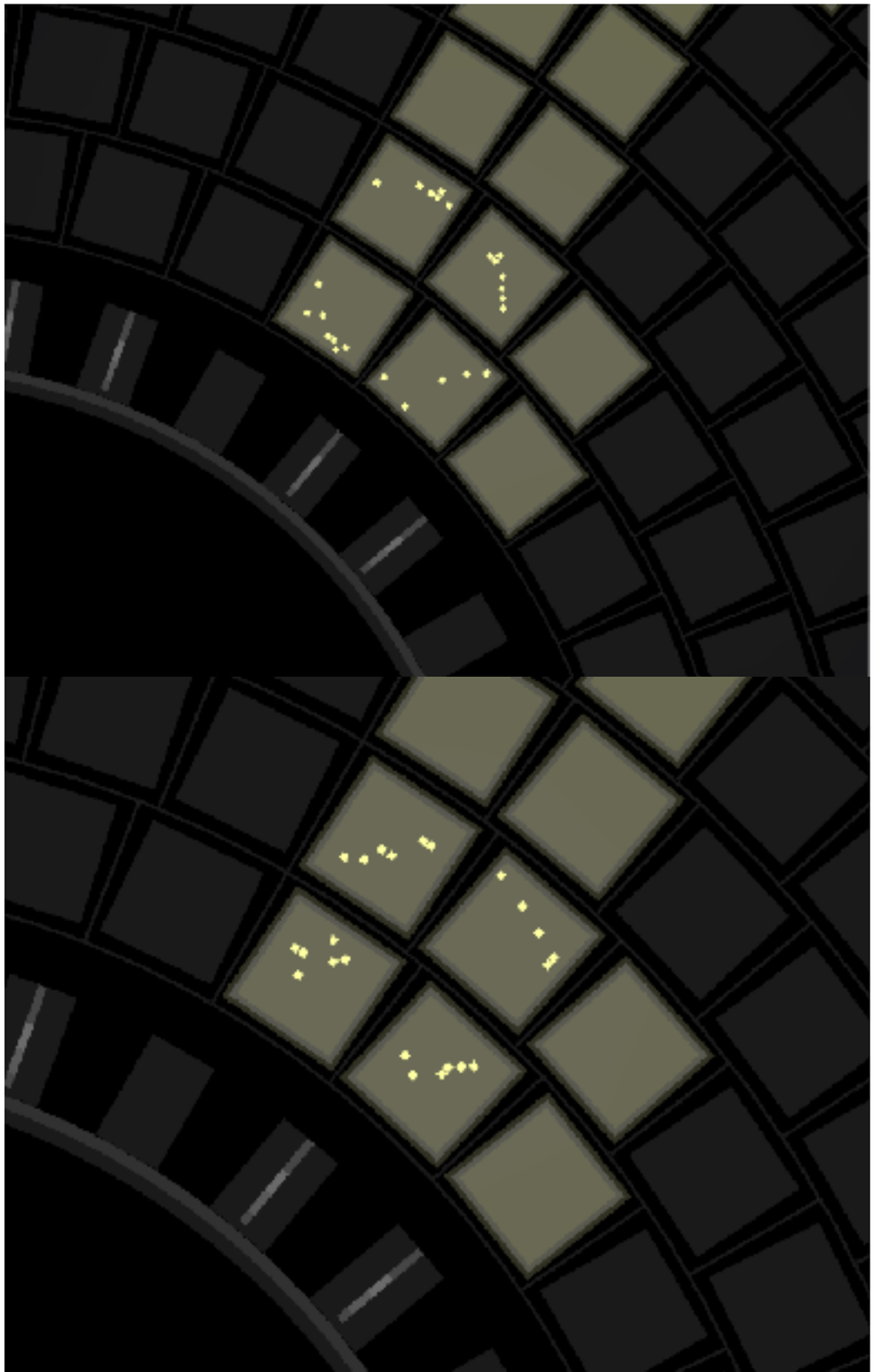
Structure

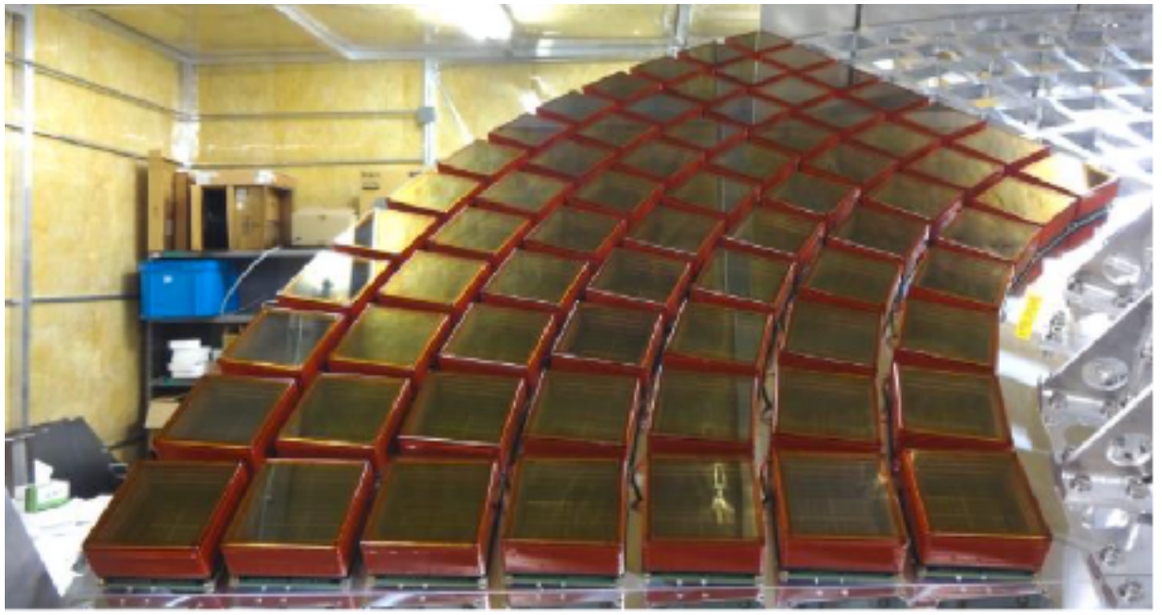


HAPD



Belle II: ARICH

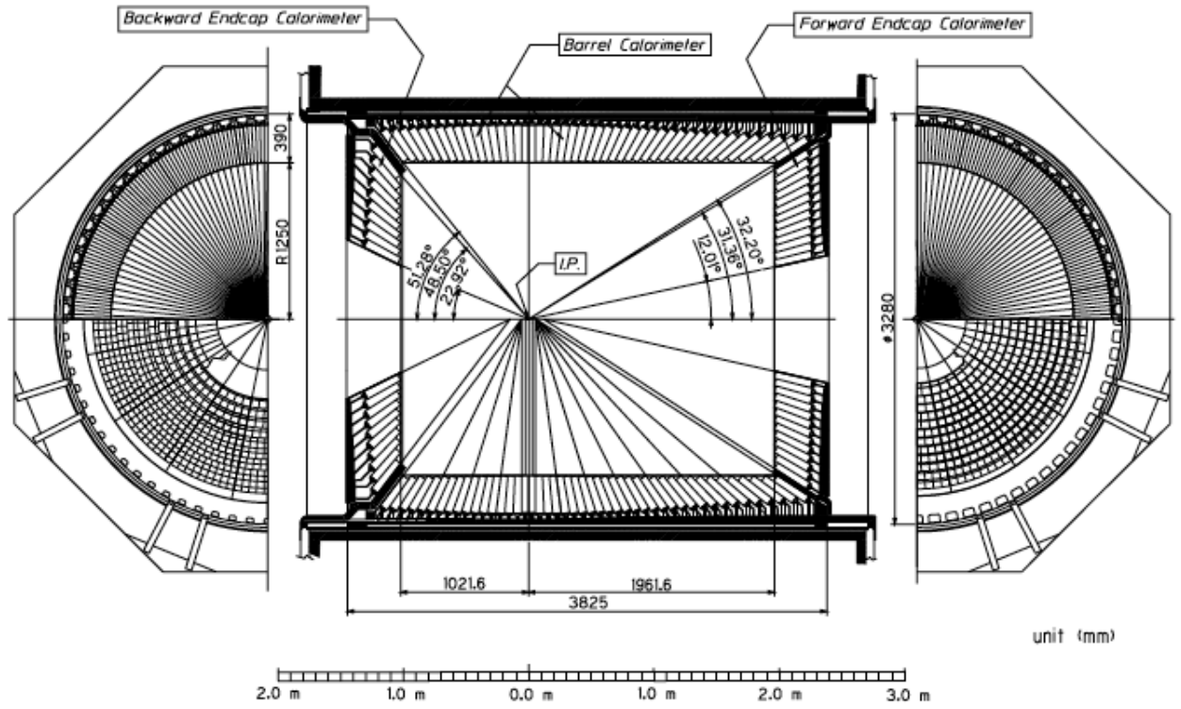


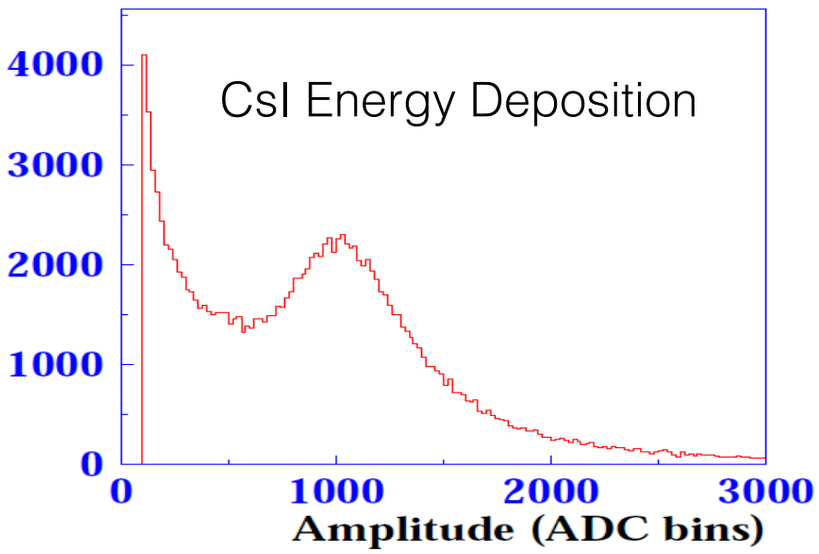


One sector of the ARICH has been instrumented (top) and Cherenkov rings were observed (left)

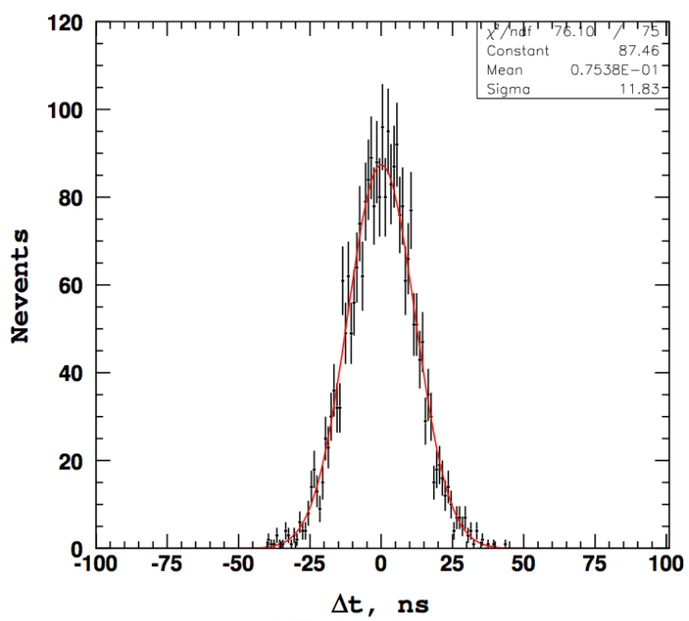
Belle II: ECL

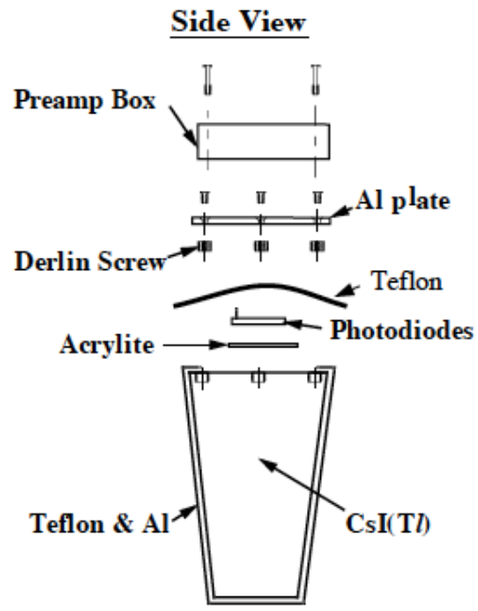
- Upgrades for high backgrounds:
  - Barrel: CsI(Tl) crystals reused, new electronics for waveform sampling
  - Endcaps: old crystals refurbished, bias filter is modified
- Cosmic ray test is on going





Time resolution is about 4.5 ns for a 100 MeV hit



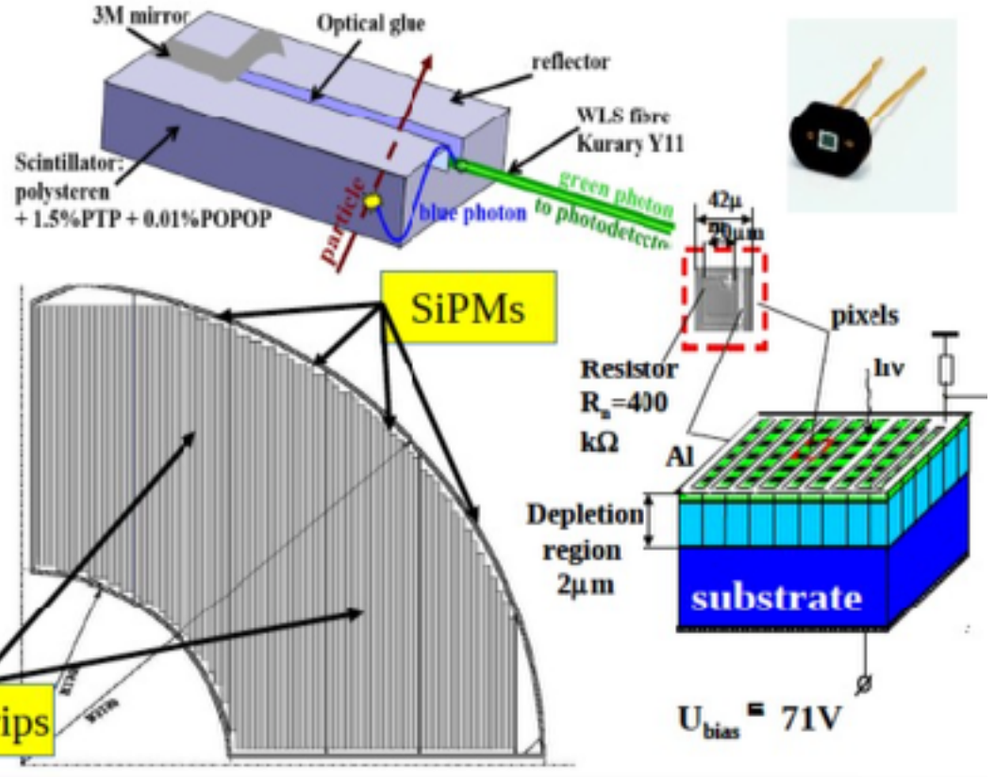


Belle II: KLM

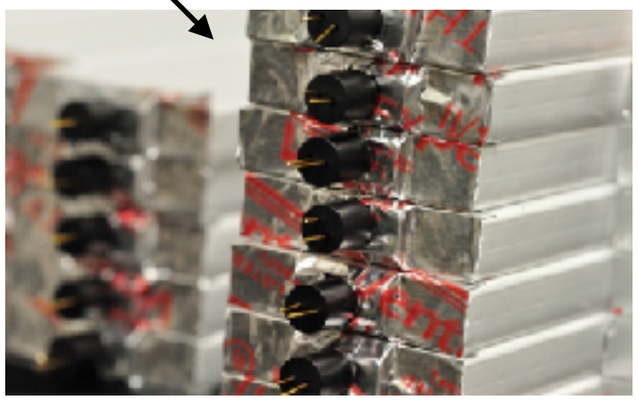
- Endcaps and parts of the barrel KLM RPCs of Belle will be replaced with scintillators due to increased backgrounds expected in Belle II
- Barrel KLM was the first sub-detector to be installed in Belle II

TDR efficiencies for RPC

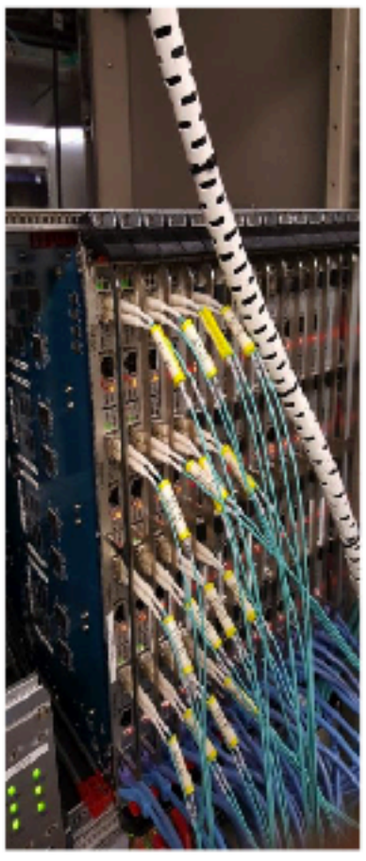
Layer	Endcap forward	
	KEKB	SuperKEKB
0	0.91	0.0
1	0.93	0.0
2	0.94	0.0
3	0.94	0.0
4	0.94	0.0
5	0.92	0.0
6	0.93	0.0
7	0.92	0.0
8	0.92	0.0
9	0.90	0.0
10	0.87	0.0
11	0.82	0.0
12	0.78	0.0
13	0.77	0.0
14	N/A	N/A



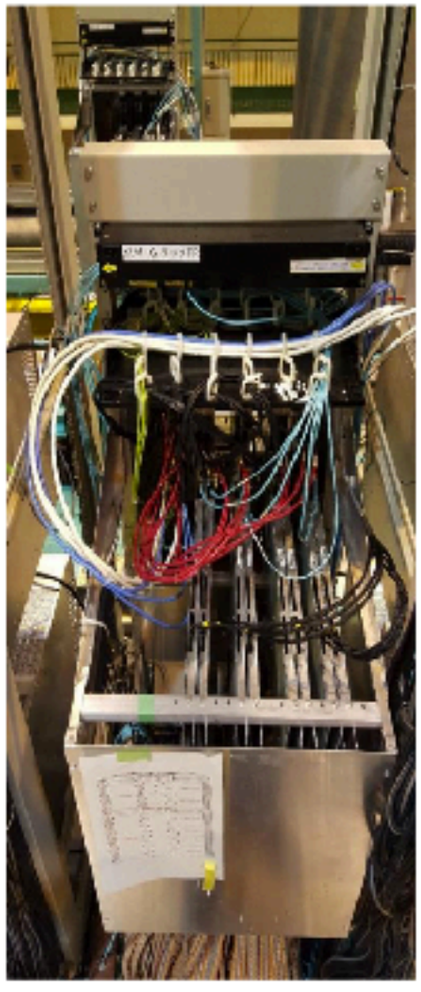
Scintillators for barrel and endcap



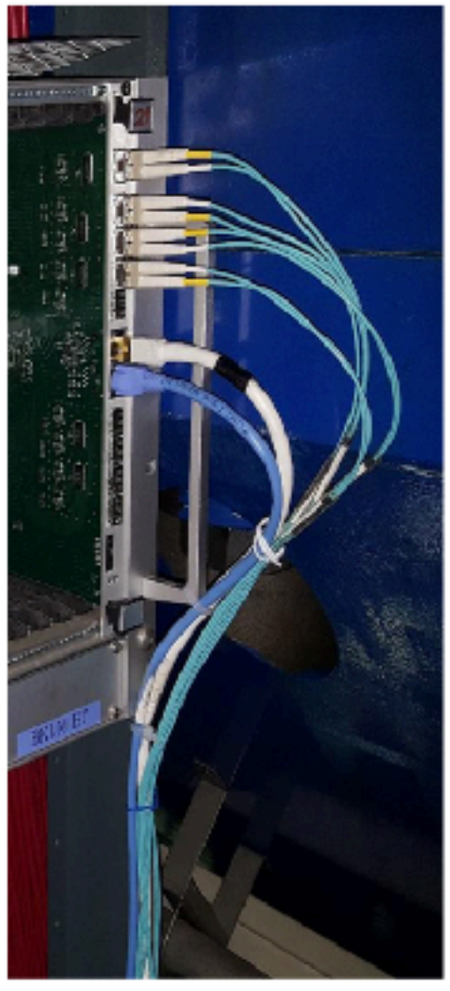
Belle II: KLM



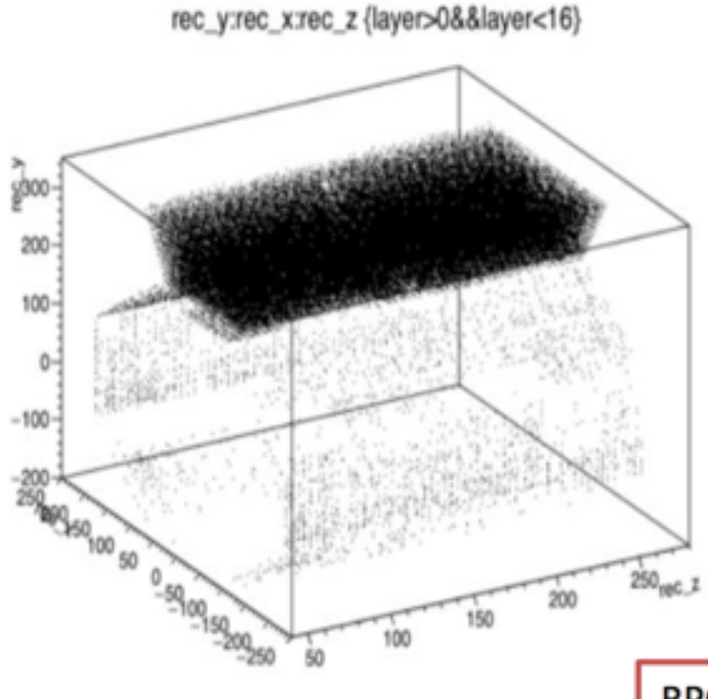
Ehut:
CPR7001-4 for barrel

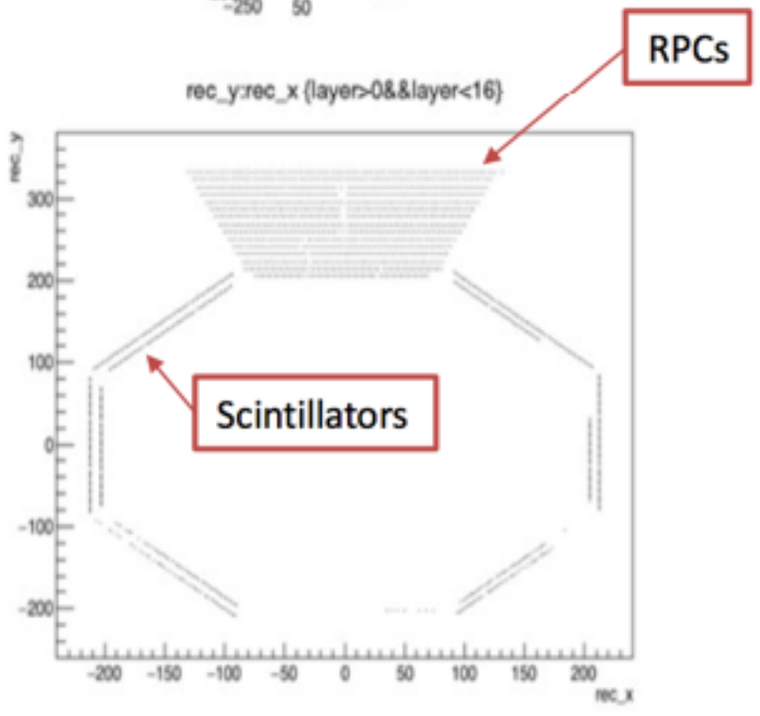


Top of yoke:
BFR 9UVME



Around detector:
BB7 data concentrator





Recent 2D hits in BF (RPC+ Scint)
Plot: Yinghui Guan

Belle II: DAQ & Trigger

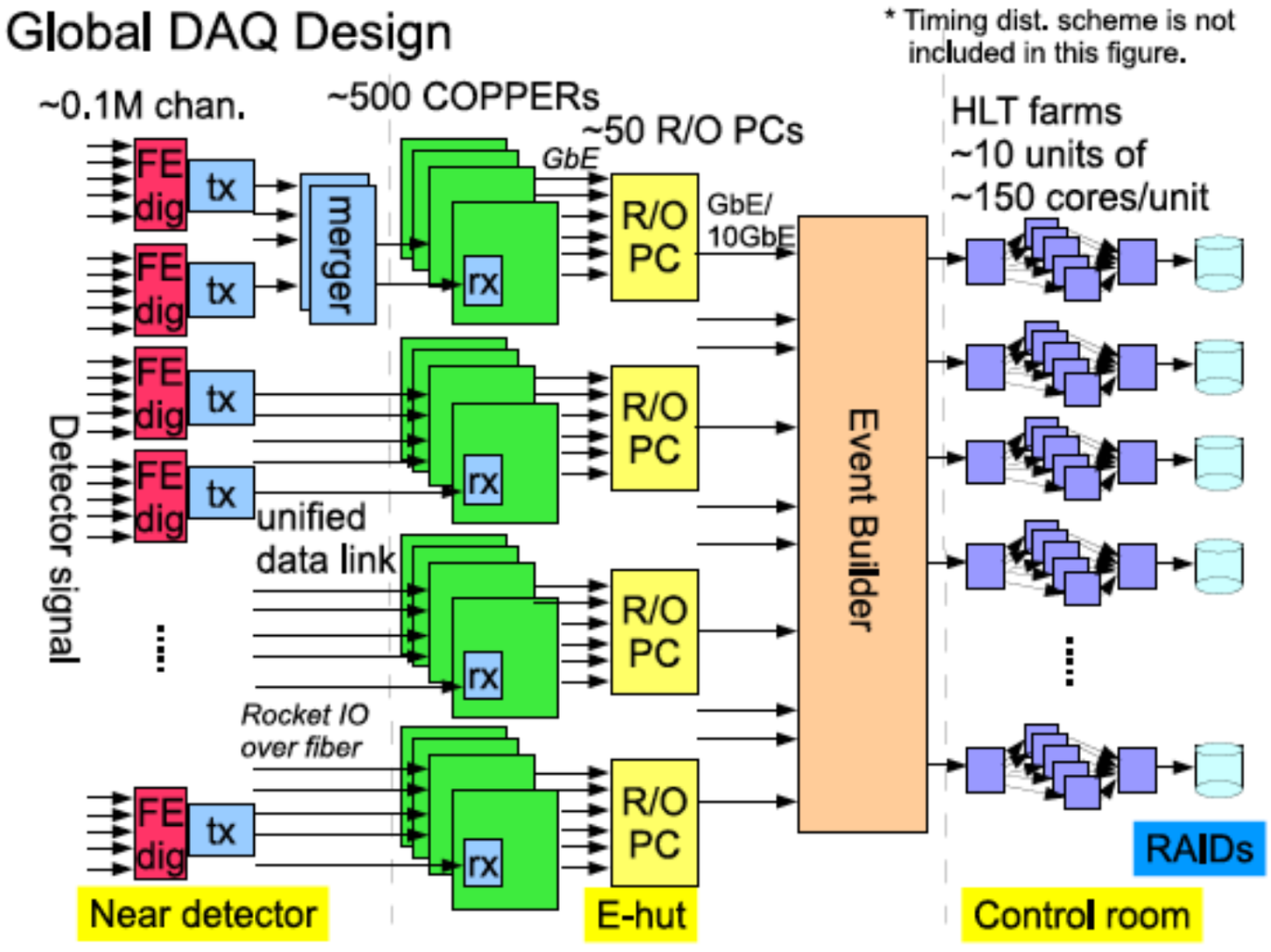


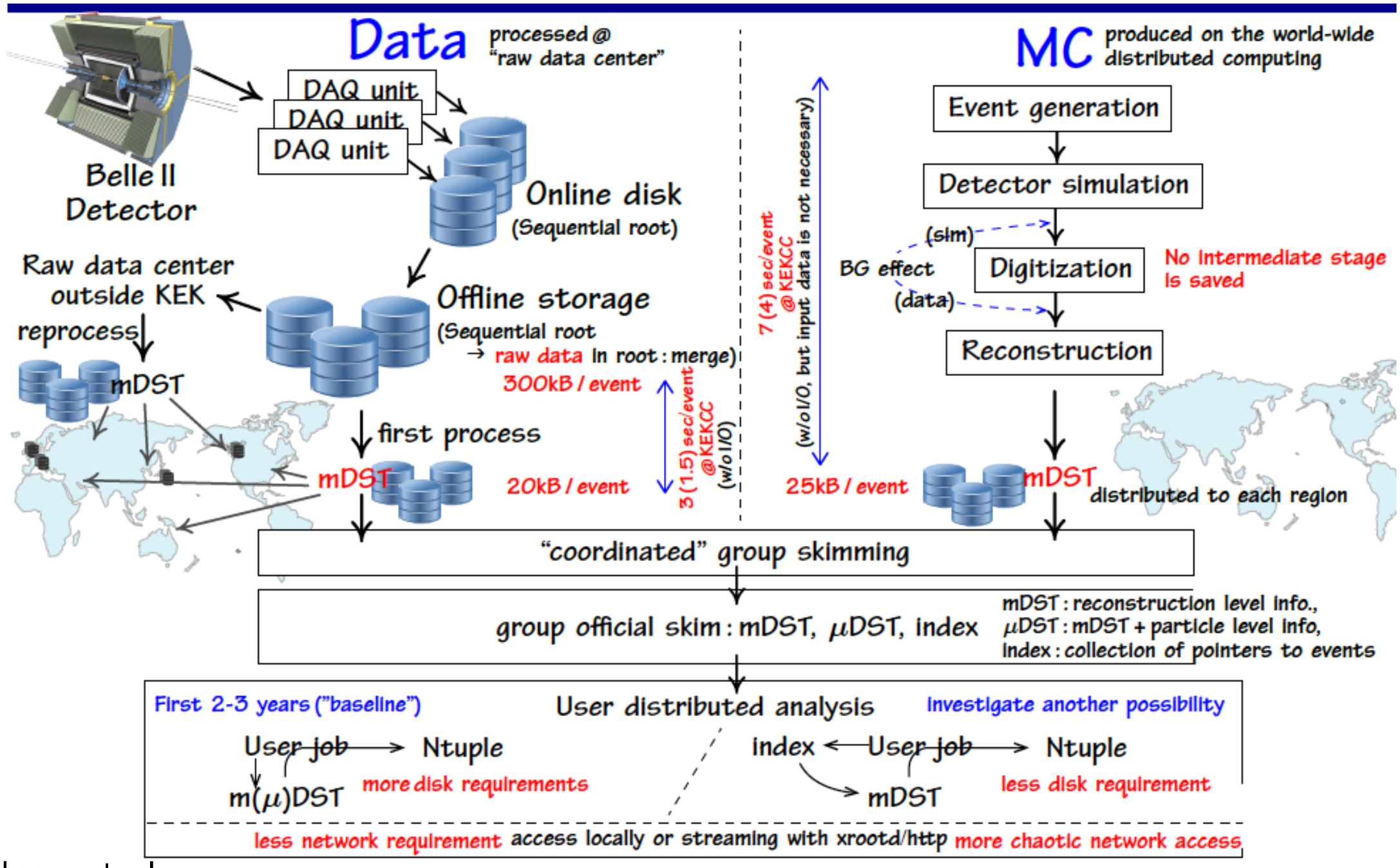
Figure 13.1: *Conceptual design of Belle II DAQ system.*

Front-end electronics in Belle II

<u>High speed fiber connections</u> not masses of cables !!

Large numbers of FPGAs (Field Programmable gate arrays) on front-end; large number of CPUs. Probabilty of SEU (single event upset) is not small.

Belle II: Data Flow



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Belle II: BEAST

Beam Exorcism for A STable experiment

BEAST PHASE I:

Feb-June 2016

(Belle II roll-in in March 2017).

PHASE II Operation: Starts in ~Nov 2017 (TBC) [Begin with damping ring commissioning; First collisions; *limited physics without vertex detectors*]

Phase III: Belle II Physics Running:

late 2018 [vertex detectors in]

QCSL at the IP, Aug 2016

QCSR will be at KEK, Dec 2016

Summary of Belle II Physics

BELLE2-NOTE-0021

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$	± 0.012	± 0.008	6
α		$\pm 2^\circ$	$\pm 1^\circ$	
γ	$\pm 14^\circ$	$\pm 6^\circ$	$\pm 1.5^\circ$	
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	± 0.053	± 0.018	>50
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	± 0.028	± 0.011	>50
$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	± 0.100	± 0.033	44
$\lvert V_{cb}\rvert$ incl.	$\pm 2.4\%$	$\pm 1.0\%$		< 1
$\lvert V_{cb}\rvert$ excl.	$\pm 3.6\%$	$\pm 1.8\%$	$\pm 1.4\%$	< 1
$\lvert V_{ub}\rvert$ incl.	$\pm 6.5\%$	$\pm 3.4\%$	$\pm 3.0\%$	2
$\lvert V_{ub}\rvert$ excl. (had. tag.)	$\pm 10.8\%$	$\pm 4.7\%$	$\pm 2.4\%$	20
$\lvert V_{ub}\rvert$ excl. (untag.)	$\pm 9.4\%$	$\pm 4.2\%$	$\pm 2.2\%$	3
$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	96 ± 26	$\pm 10\%$	$\pm 5\%$	46
$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	5σ	$>> 5\sigma$	>50
$R(B \to D\tau\nu)$	$\pm 16.5\%$	$\pm 5.6\%$	$\pm 3.4\%$	4
$R(B \to D^*\tau\nu)$	$\pm 9.0\%$	$\pm 3.2\%$	$\pm 2.1\%$	3
$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40		$\pm 30\%$	>50
$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55		$\pm 30\%$	>50
$\mathcal{B}(B \to X_s\gamma)$ [10^{-6}]	$\pm 13\%$	$\pm 7\%$	$\pm 6\%$	< 1
$A_{CP}(B \to X_s\gamma)$		± 0.01	± 0.005	8
$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	± 0.11	± 0.035	> 50
$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	± 0.23	± 0.07	> 50
C_7/C_9 $(B \to X_s\ell\ell)$	$\sim 20\%$	10%	5%	
$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	± 0.3		
$\mathcal{B}(B_s \to \tau^+\tau^-)$ [10^{-3}]		< 2		

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$	$\pm 2.9\%$	$\pm(0.9\%\text{-}1.3\%)$	> 50
$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$	$=(3.5\%\text{-}4.3\%)$	$\pm(2.3\%\text{-}3.6\%)$	3-5
y_{CP} [10^{-2}]	$1.11 \pm 0.22 \pm 0.11$	$=(0.11\text{-}0.13)$	$=(0.05\text{-}0.08)$	5-8
A_Γ [10^{-2}]	$-0.03 \pm 0.20 \pm 0.08$	± 0.10	$=(0.03\text{-}0.05)$	7 - 9
$A_{CP}^{K^+K^-}$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06	15
$A_{CP}^{\pi^+\pi^-}$ [10^{-2}]	$0.55 \pm 0.36 \pm 0.09$	± 0.17	± 0.06	> 50
$A_{CP}^{\phi\gamma}$ [10^{-2}]	± 5.6	± 2.5	± 0.8	> 50
$x^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	± 0.14	± 0.11	3
$y^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	± 0.08	± 0.05	15
$\lvert q/p\rvert^{K_S\pi^+\pi^-}$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	± 0.10	± 0.07	5-6
$\phi^{K_S\pi^+\pi^-}$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	± 6	± 4	10
$A_{CP}^{\pi^0\pi^0}$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	± 0.29	± 0.09	> 50
$A_{CP}^{K^0_S\pi^0}$ [10^{-2}]	$-0.10 \pm 0.16 \pm 0.09$	± 0.08	± 0.03	> 50
$\mathcal{B}r(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	$\pm 30\%$	$\pm 25\%$	2
	$\tau \to \mu\gamma$ [10^{-9}]	< 45	< 14.7	< 4.7
	$\tau \to e\gamma$ [10^{-9}]	< 120	< 39	< 12
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0	< 3.0	< 0.3

Potential new physics:

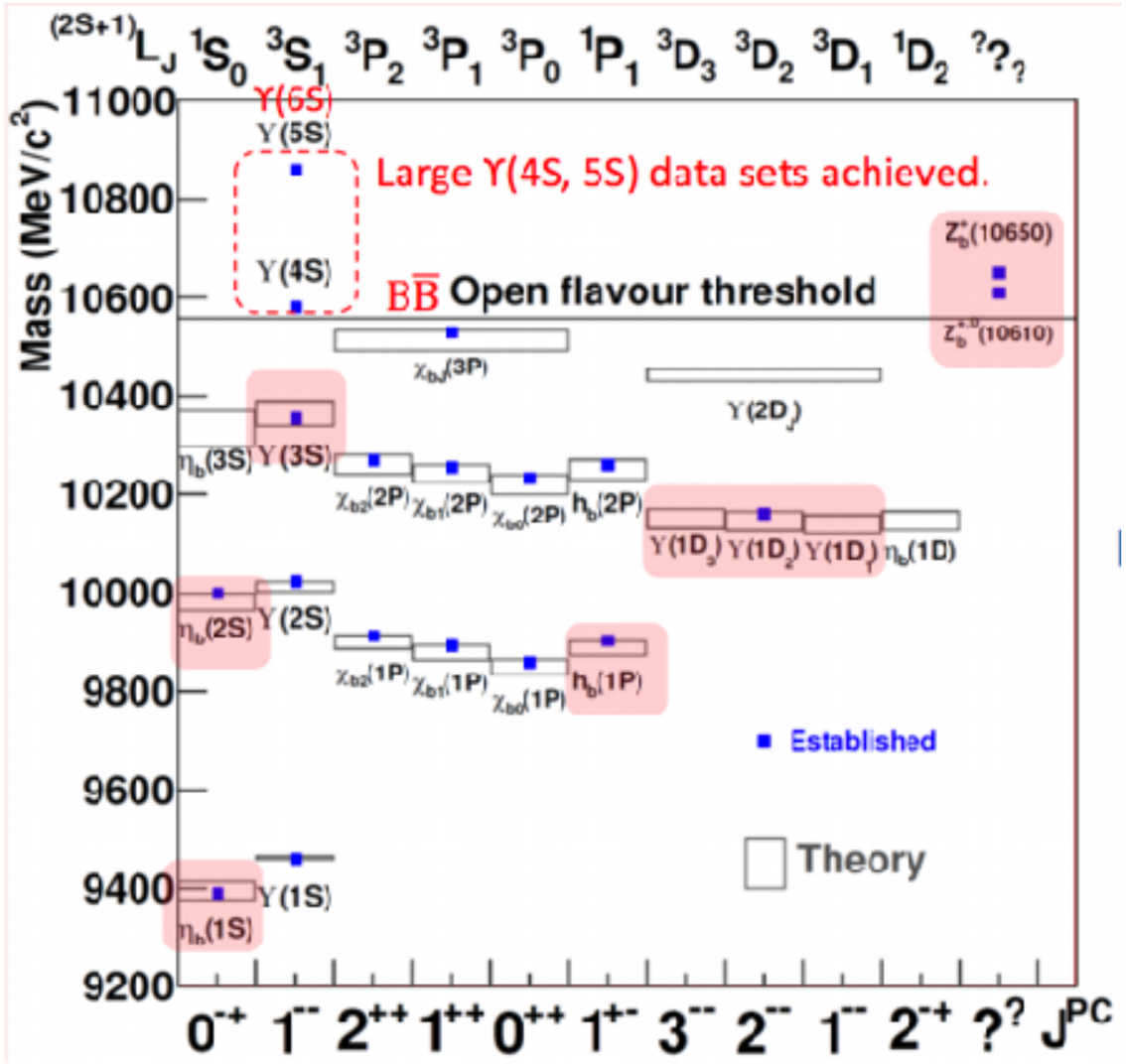
- Flavor changing neural currents
- Probing charged Higgs
- New sources of CPV
- Lepton Flavour Violation
- Dark sectors

Physics: Phase II

Latest Proposal:

Once collisions and luminosity are established, record ~2 fb^{-1} at the Upsilon(4S); verify functionality of Belle II; check B meson reconstruction.

Take remaining ~20 fb^{-1} at the peak of the Upsilon(6S) (build a unique dataset for strong interaction physics to provide initial early Belle II physics publications.)



Above Υ(5S):

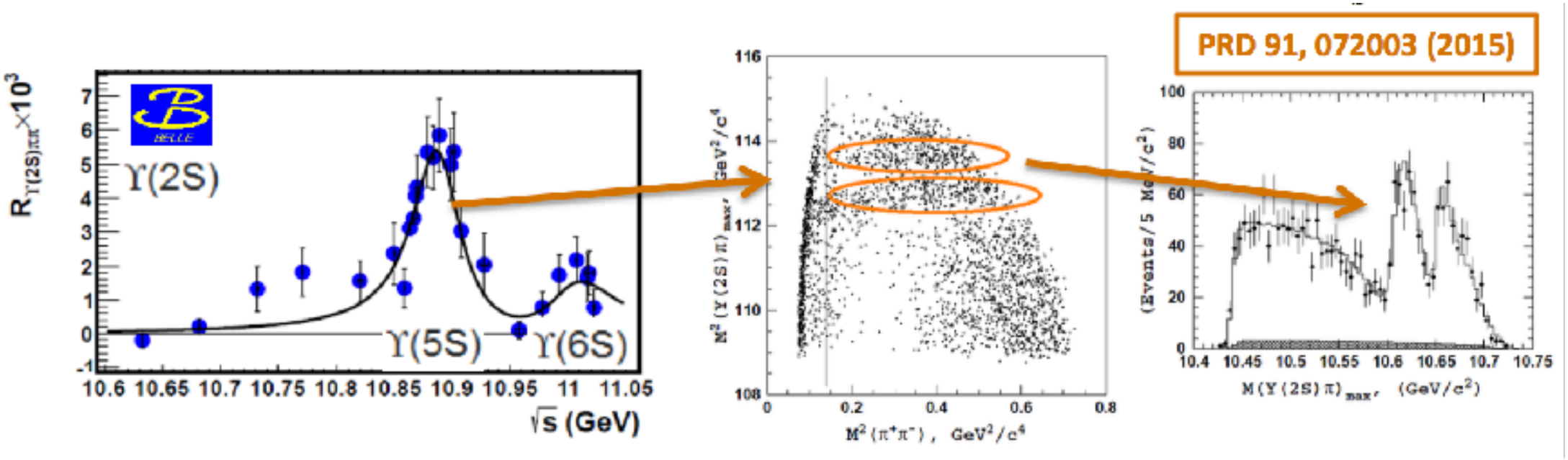
- Charged bottomonium-like states

Bellow Υ(4S):

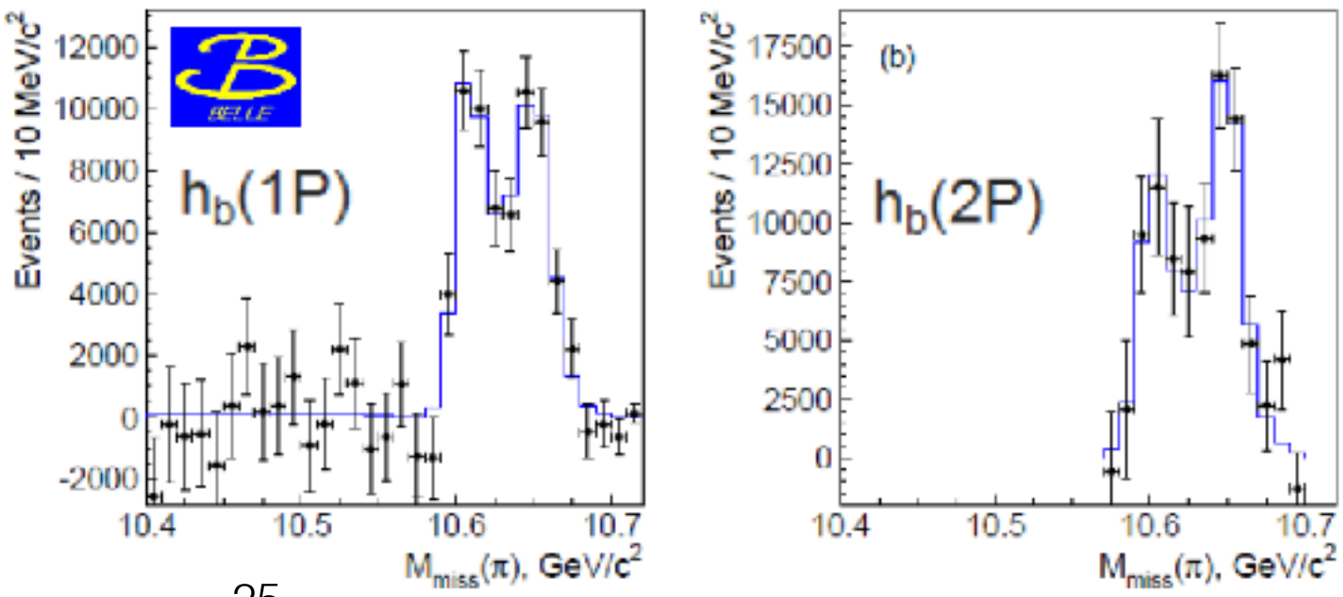
- Study of $\eta_b(1S, 2S)$
- $h_b(1P)$ and $\Upsilon(n^3D_1)$ studies
- Analyses with converted photons to improve resolution
- Hadronic / Radiative transitions

Physics: $Z_b^{\pm}(106XX)$

Anomalous $\Upsilon(5S)\to\pi\pi\Upsilon(pS)$ transitions led to discovery of $Z_b^{\pm}(106XX)$

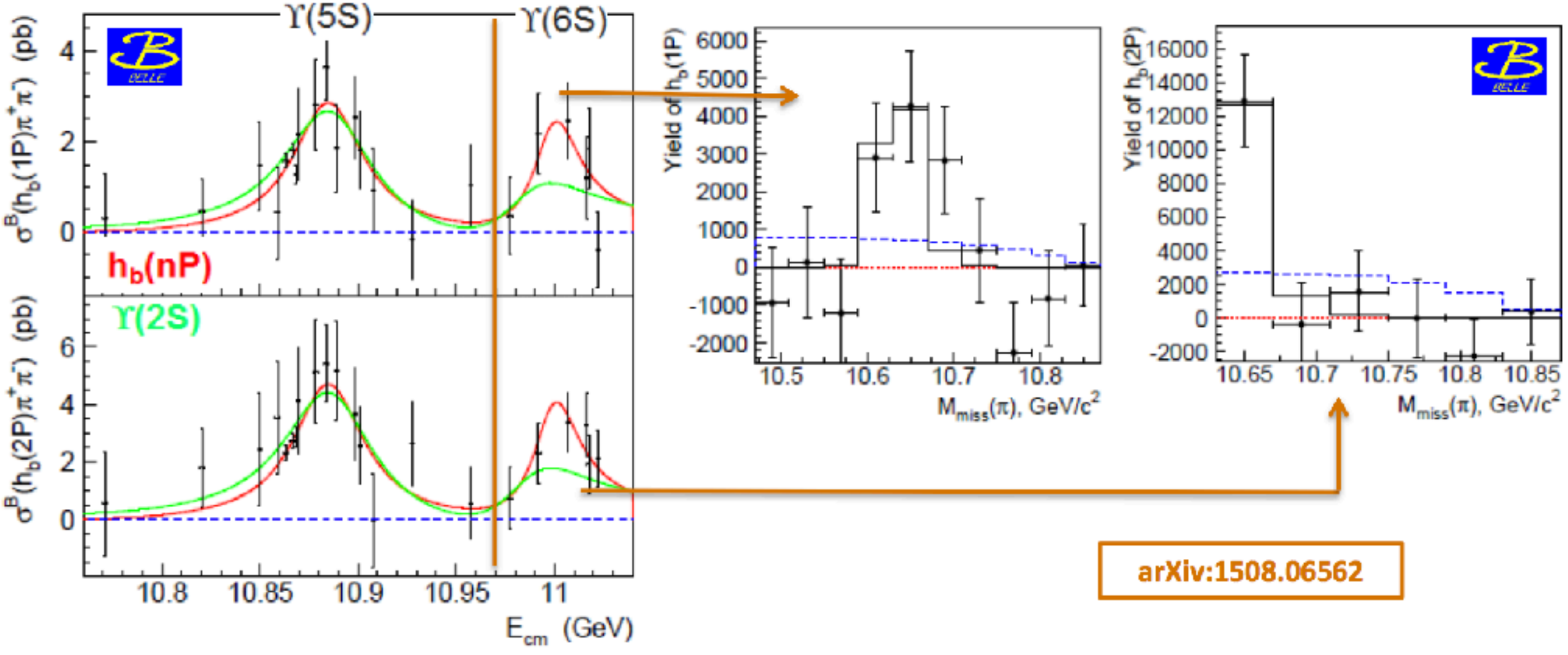


Similar for $\Upsilon(5S)\to\pi\pi h_b(nP)$



Physics: $Z_b^{\pm}(106XX)$

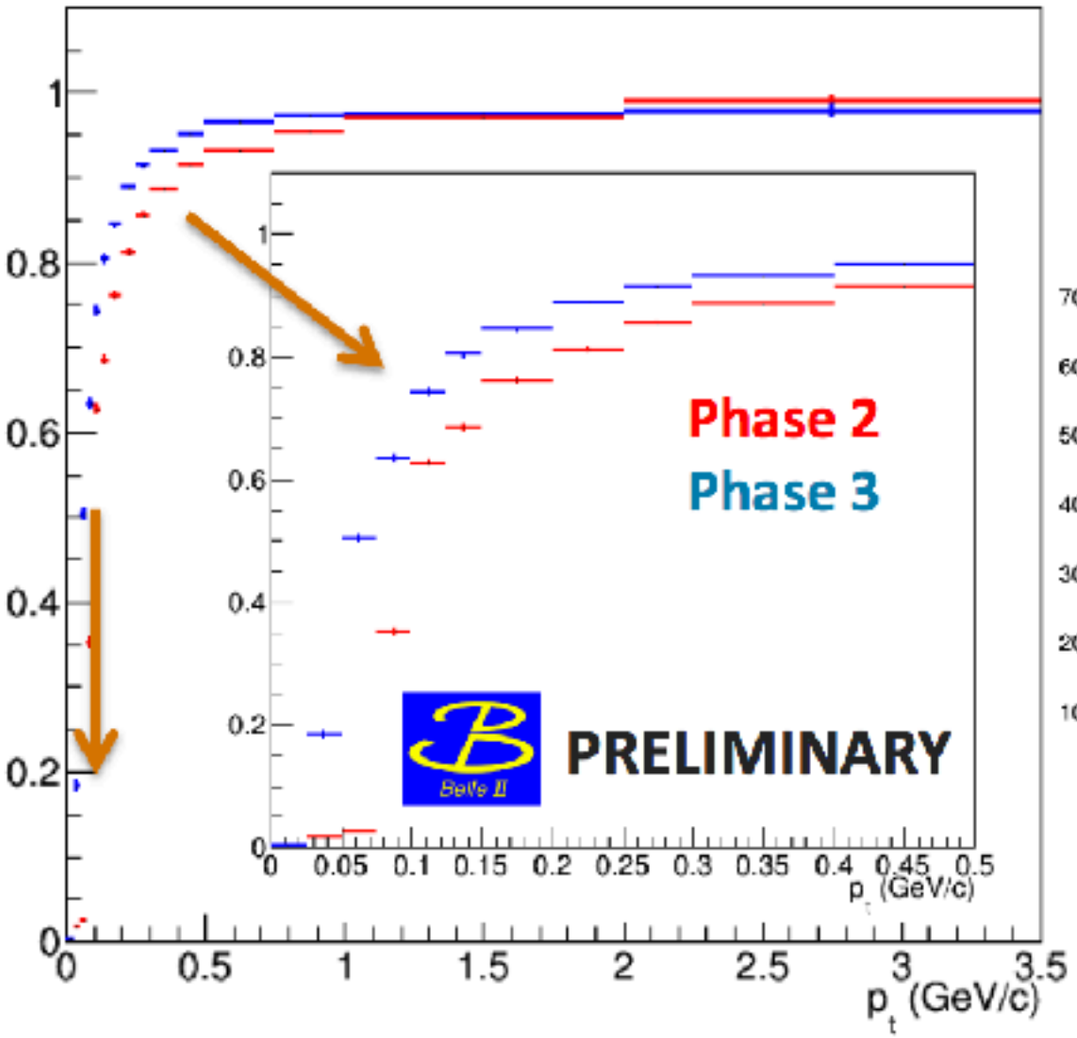
Preliminary evidence for $\Upsilon(6S)\to\pi\pi h_b(nP)$, via $\pi Z_b^{\pm}(106XX)$ decay

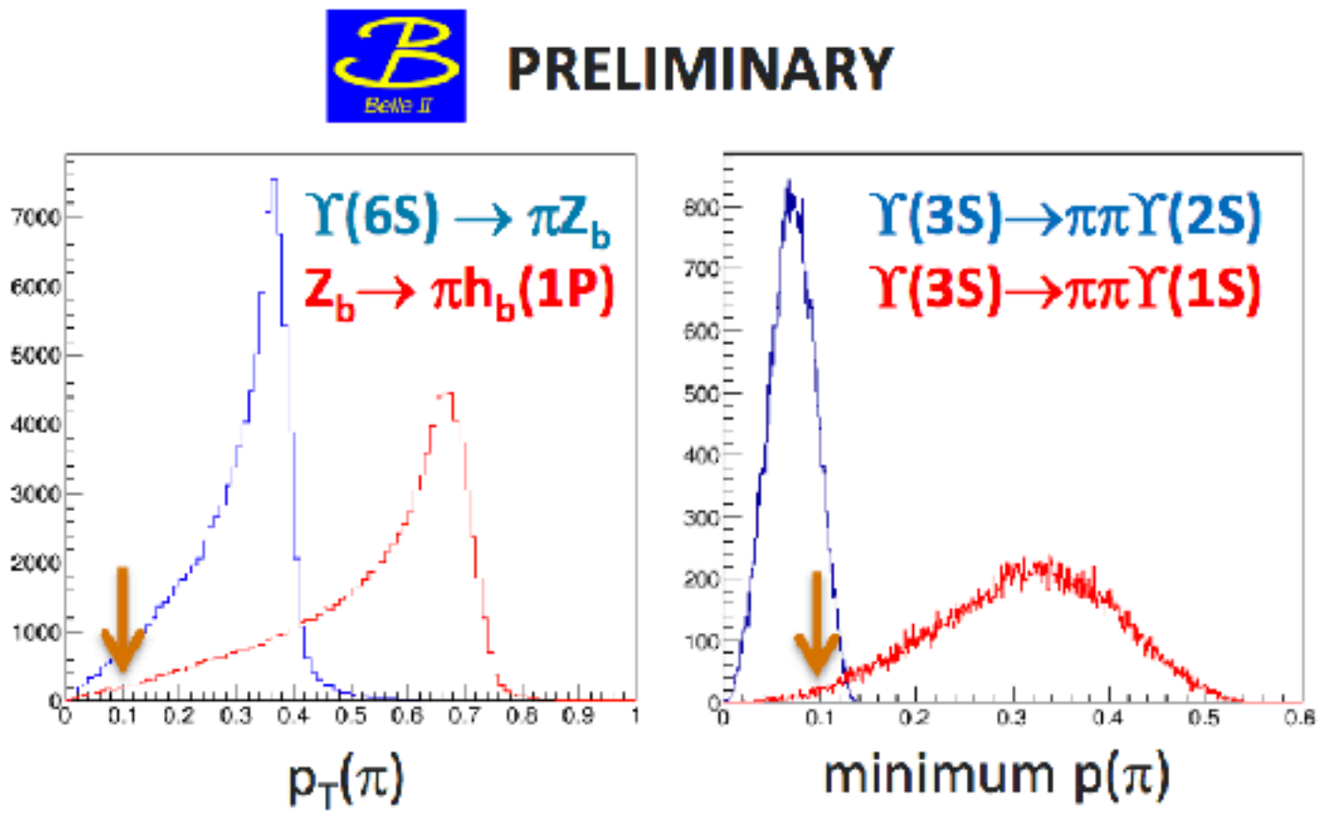


Resonance structure of $\Upsilon(6S)\to\pi\pi\Upsilon(pS)$ decays not fully studied

Physics: Phase II Feasibility

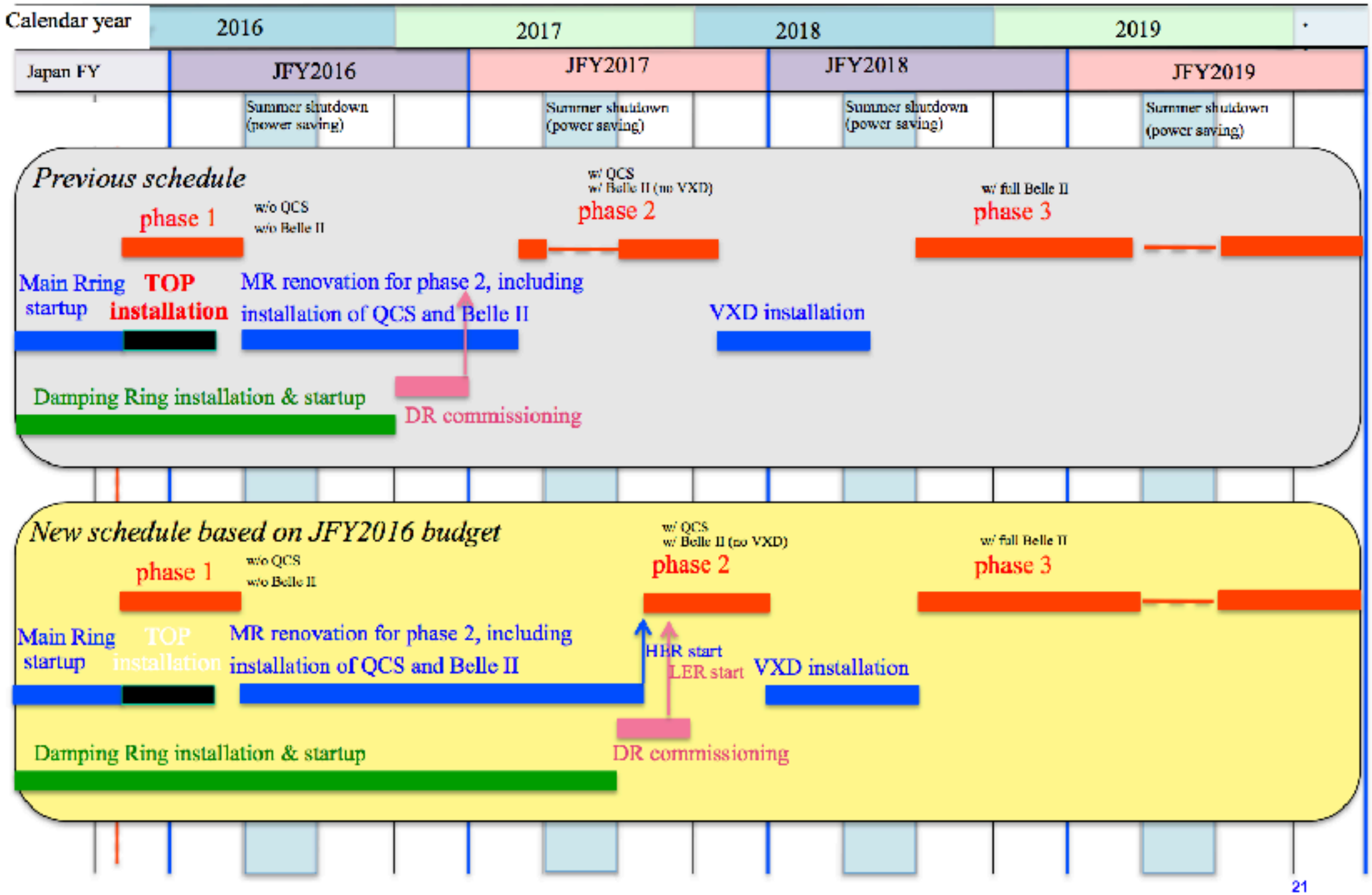
- Lack of vertex detector diminishes low p_T track reconstruction
- $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(2S)$ infeasible, but $\Upsilon(6S)\to\pi Z_b\to\pi h_b(nP)$ unaffected



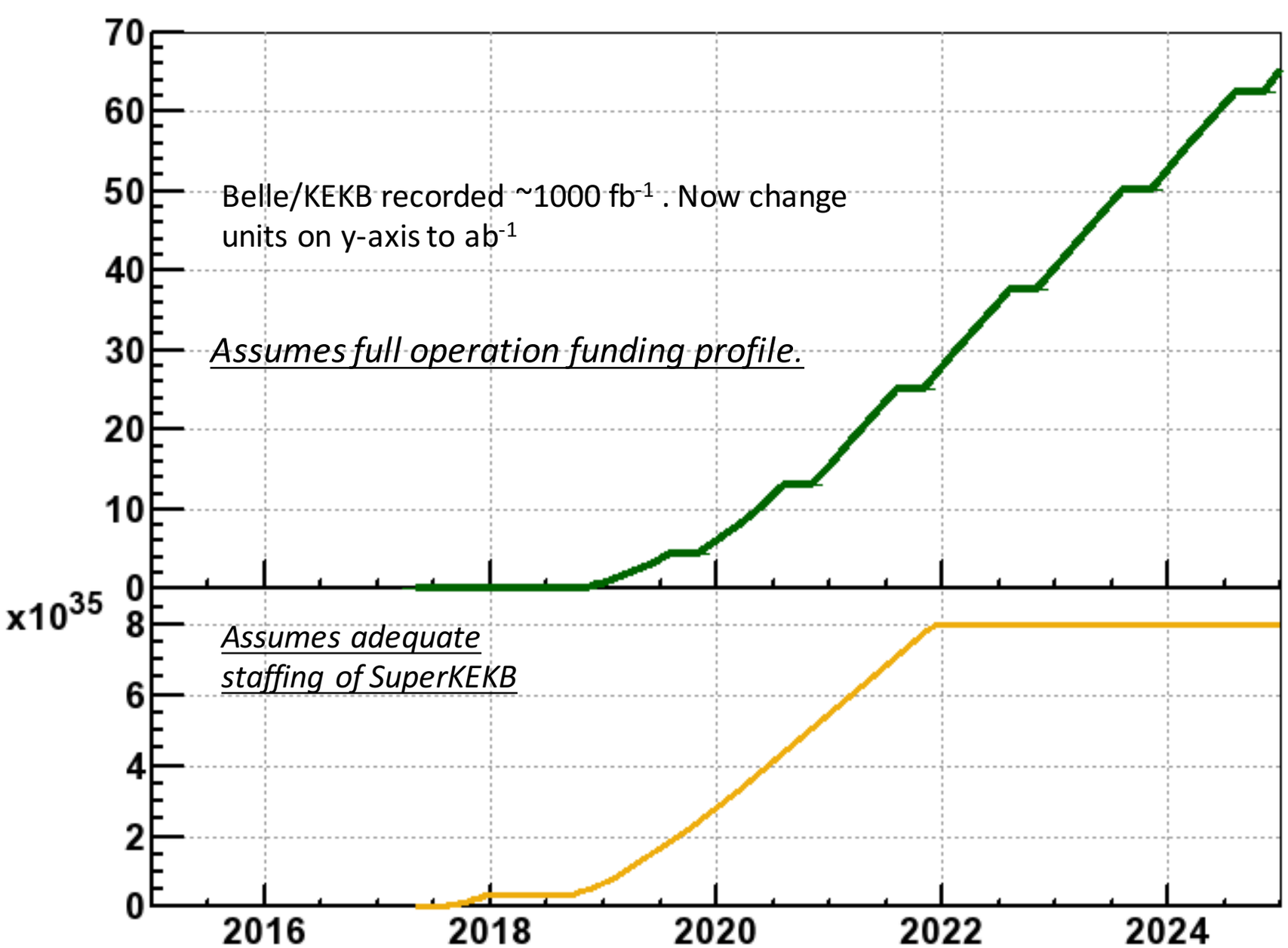


B. Fulsom, B2TiP, May 2016

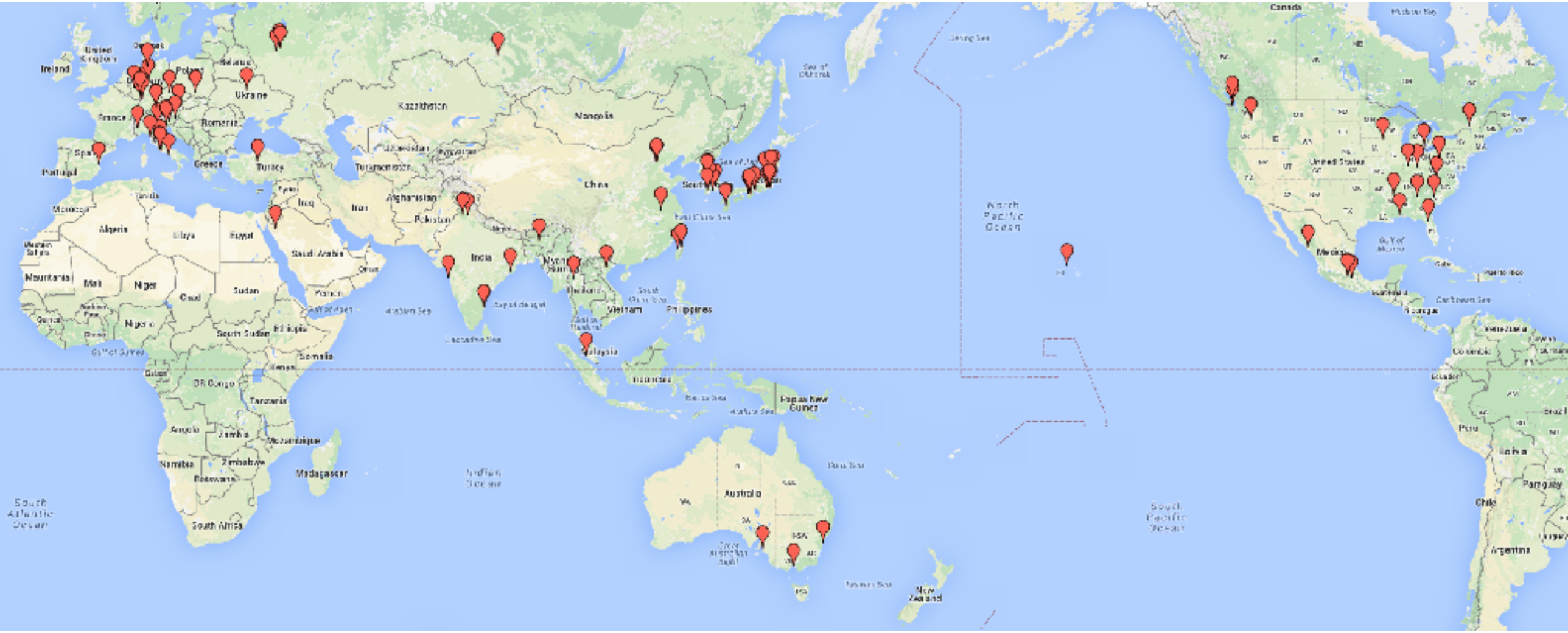
Schedule


Calendar year
2016
2017
2018
2019
Japan FY
JFY2016
JFY2017
JFY2018
JFY2019
Summer shutdown (power saving)
Summer shutdown (power saving)
Summer shutdown (power saving)
Summer shutdown (power saving)
Previous schedule
phase 1
w/o QCS
w/o Belle II
w/ QCS
w/ Belle II (no VXD)
phase 2
w/ full Belle II
phase 3
Main Rring startup
TOP installation
MR renovation for phase 2, including installation of QCS and Belle II
VXD installation
Damping Ring installation & startup
DR commissioning
New schedule based on JFY2016 budget
phase 1
w/o QCS
w/o Belle II
w/ QCS
w/ Belle II (no VXD)
phase 2
w/ full Belle II
phase 3
Main Ring startup
TOP installation
MR renovation for phase 2, including installation of QCS and Belle II
HER start
LER start
VXD installation
Damping Ring installation & startup
DR commissioning
21

Luminosity Profile



Belle II Collaboration



696 colleagues, 101 institutions, 23 countries/regions

Summary

- B-factories had some rich and successful physics results and many hints of new physics.

- Belle will be upgraded to Belle II to further explore these opportunities.

- BEAST phase I has finished and phase II will start from November 2017. Collision data on Y(6S) will be taken.

- The target integrated luminosity for physics data is 50 ab^{-1}, which is much larger than the current data set.