Status of Belle II

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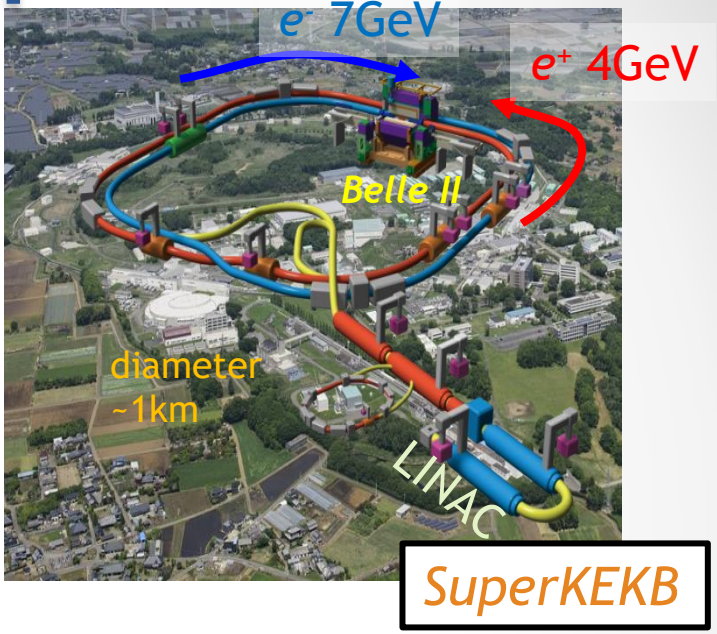
Feb. 14, 2019

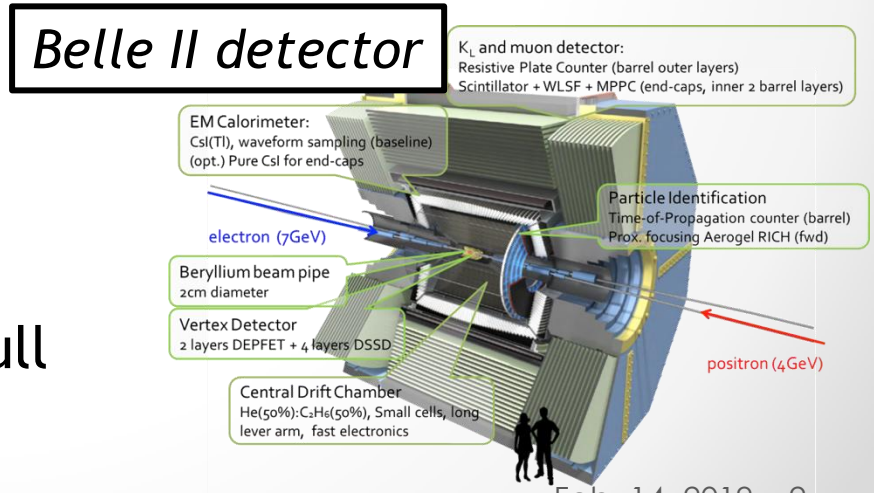
6th KEK Flavor Factory Workshop

Belle II and SuperKEKB

- SuperKEKB collider at KEK
  - e^+-e^- collider with $\sqrt{s}$ of 10.58 GeV = $M_{\Upsilon(4S)}$
    - Asymmetric beam: e^+ 4 GeV , e^- 7 GeV
  - World-highest design luminosity:
    $L = 8.0 \times 10^{35}\ cm^{-2}s^{-1}$
    - x40 larger lum. than KEKB



- Belle II experiment
  - Intensity frontier experiment to discover and understand physics beyond the SM
  - Belle II detector
    - General purpose 4 π spectrometer
    - Tolerable to high beam background
    - Improved particle identification
    - Excellent vertex resolution

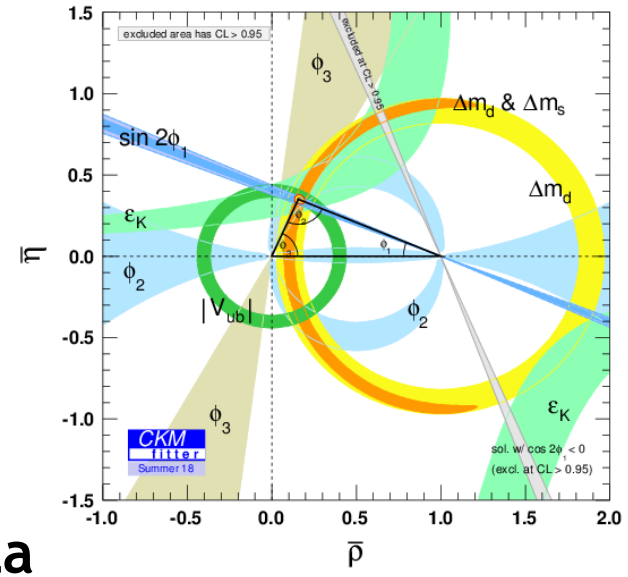


- SuperKEKB and Belle II will start full physics run in 2019 Spring.

Physics at Belle II

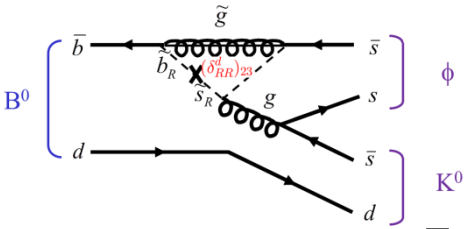
Previous B-factories(Belle,BaBar) verified Kobayashi-Maskawa mechanism for CP violation in the SM

- **Measurements consistent with the CKM unitarity triangle**

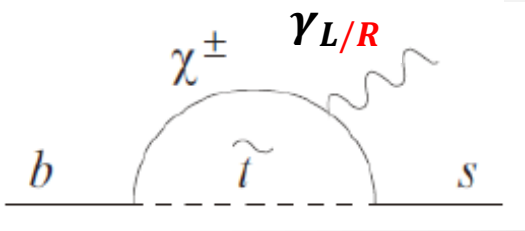


Belle II will search for the New Physics beyond the SM with x50 flavor (b/c/τ…) data

- **New CPV phases**
- **Multiple Higgs**
- **new FCNC, RH current etc.**
- **Tau LFV decays**



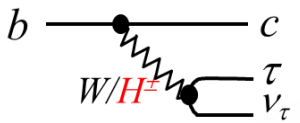
New CPV phase in b→sq$\bar{q}$



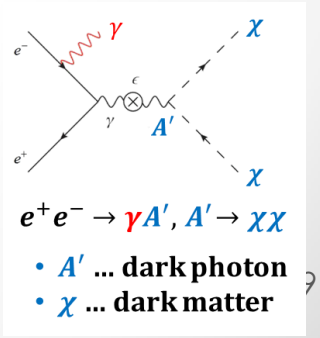
Right handed current in b→sγ

- **Dark photon by single photon trigger**

…



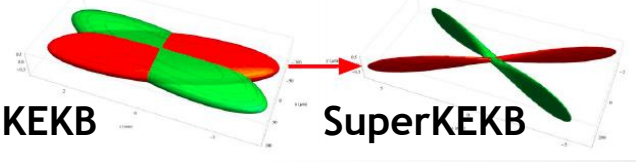
R(D),R(D*) in B→D(*)τν



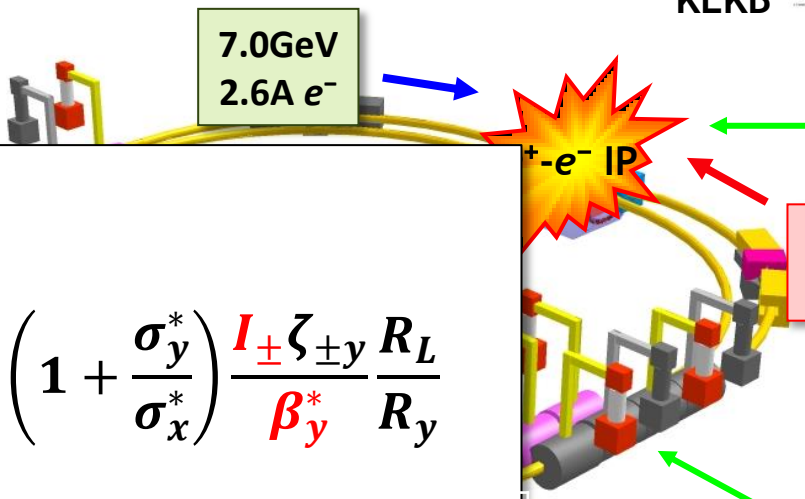
SuperKEKB Accelerator

Change of the collision energy to increase beam lifetime

$\sigma_y = 940\text{nm}$ $\begin{cases}\sigma_y = 62\text{nm (HER)} \\ \sigma_y = 48\text{nm (LER)}\end{cases}$



Nano-beam scheme



New final focusing magnets

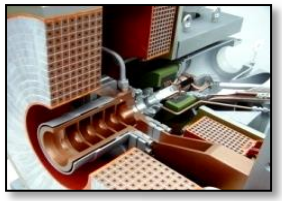
Key upgrades:

$$\text{Luminosity} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

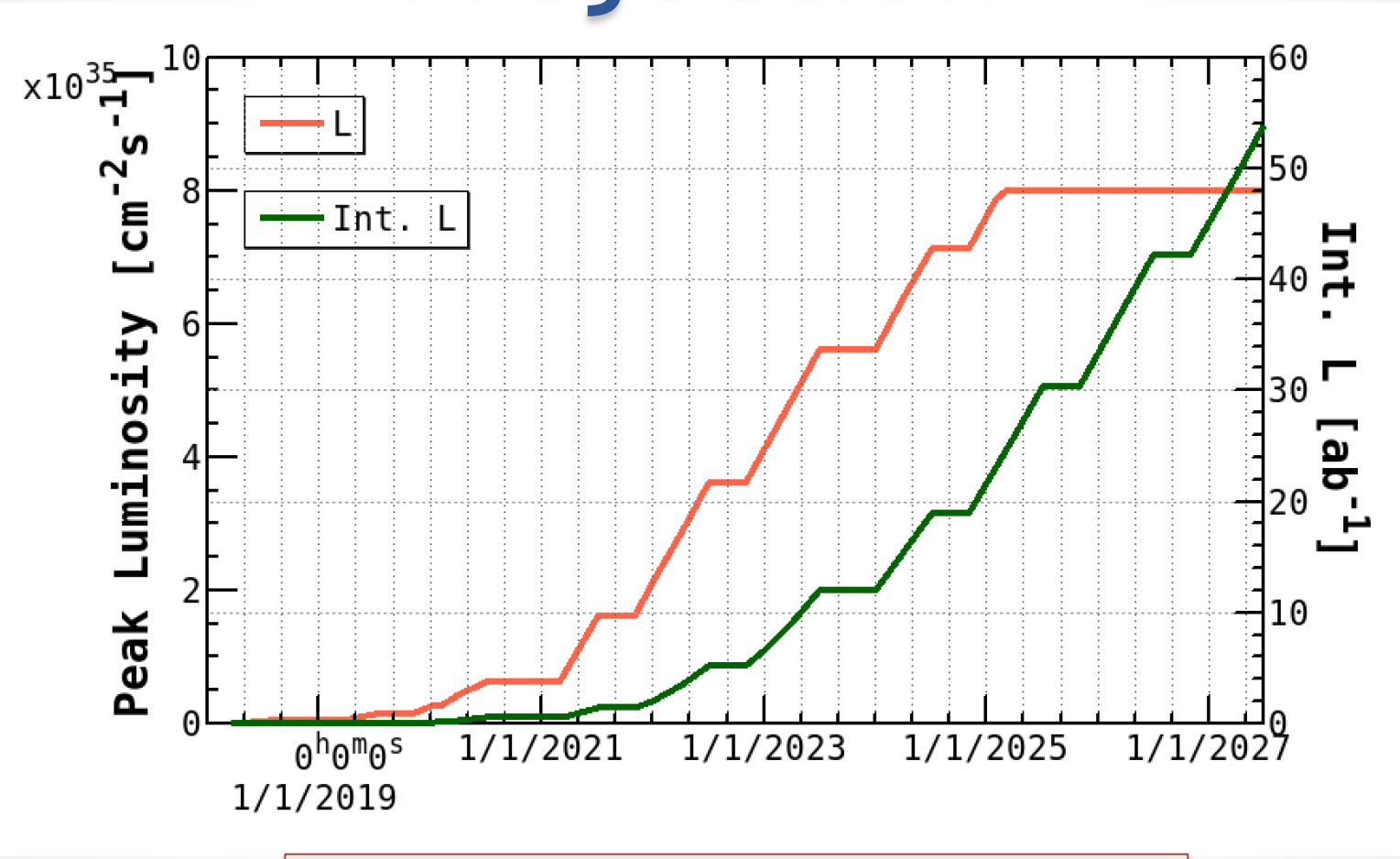
	KEKB (HER/LER)	SuperKEKB (HER/LER)	
β_y^* (mm)	5.9/5.9	0.30/0.27	x20
I_{beam} (A)	1.19/1.64	2.6/3.6	x2
$\mathcal{L}$ ($cm^{-2}s^{-1}$)	2.11×10^{34}	80×10^{34}	x40
$\int \mathcal{L}dt$ (ab^{-1})	1	50	x50

More RF cavities to increase the beam currents

Positron source

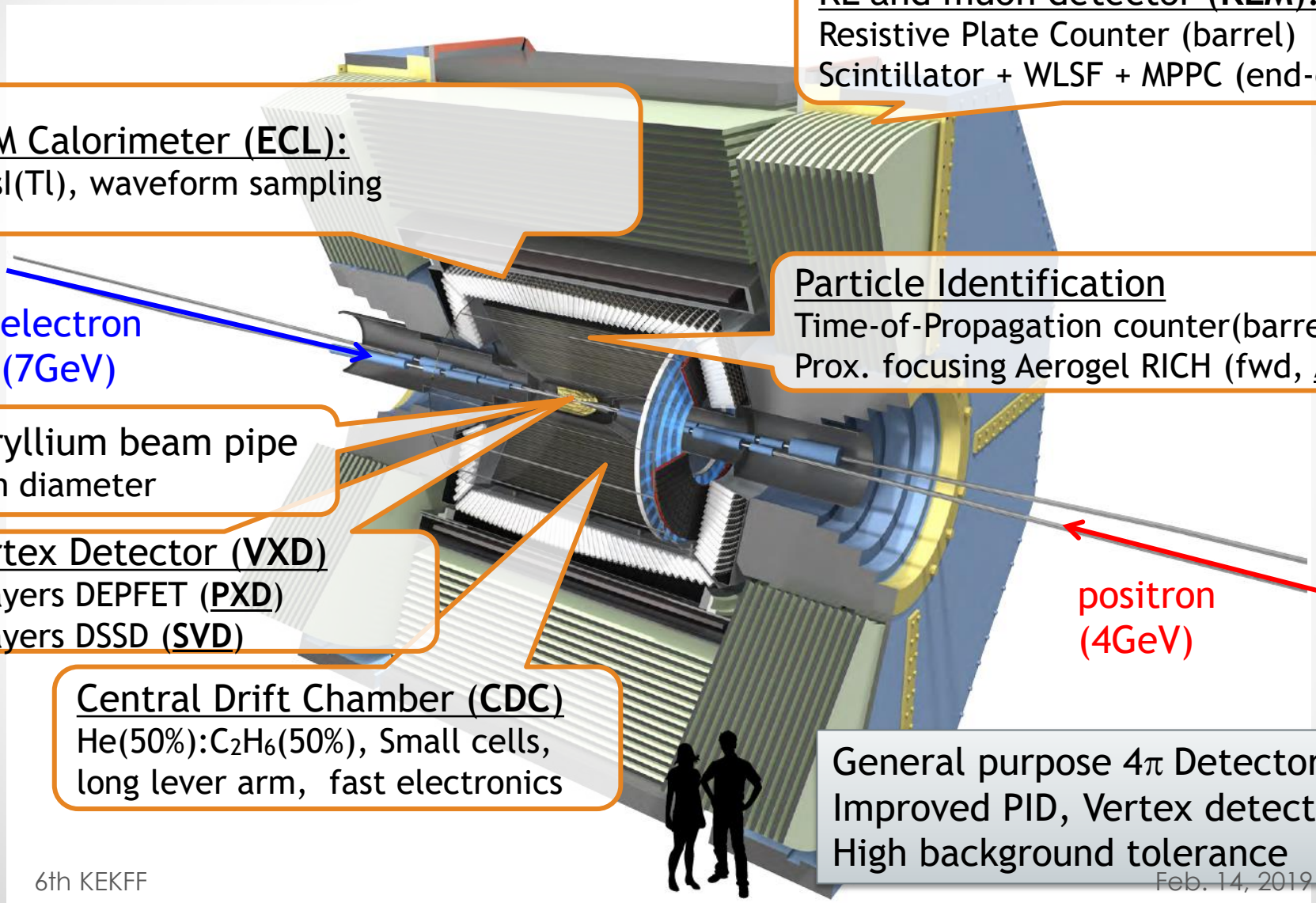


SuperKEKB Luminosity Projection



Accumulate 50ab^{-1}, x50 of Belle/KEKB

Belle II Detector



KL and muon detector (**KLM**):
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter (**ECL**):
CsI(Tl), waveform sampling

electron
(7GeV)

Particle Identification
Time-of-Propagation counter(barrel, **TOP**)
Prox. focusing Aerogel RICH (fwd, **ARICH**)

Beryllium beam pipe
2cm diameter

Vertex Detector (**VXD**)
2 layers DEPFET (**PXD**)
4 layers DSSD (**SVD**)

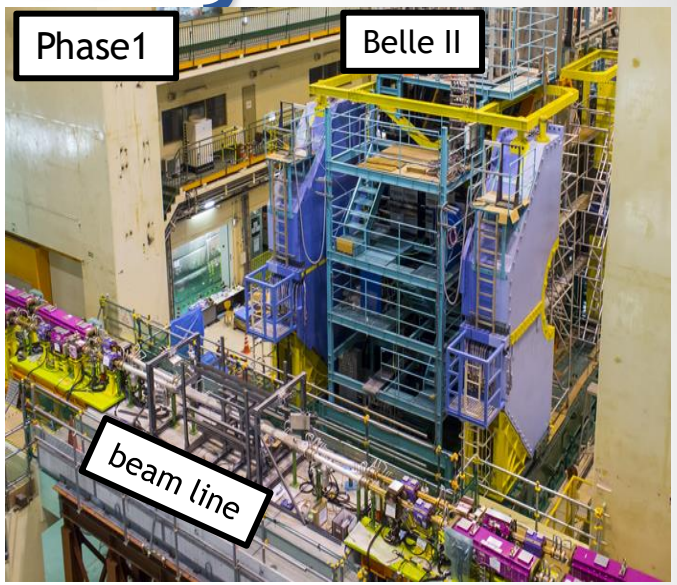
positron
(4GeV)

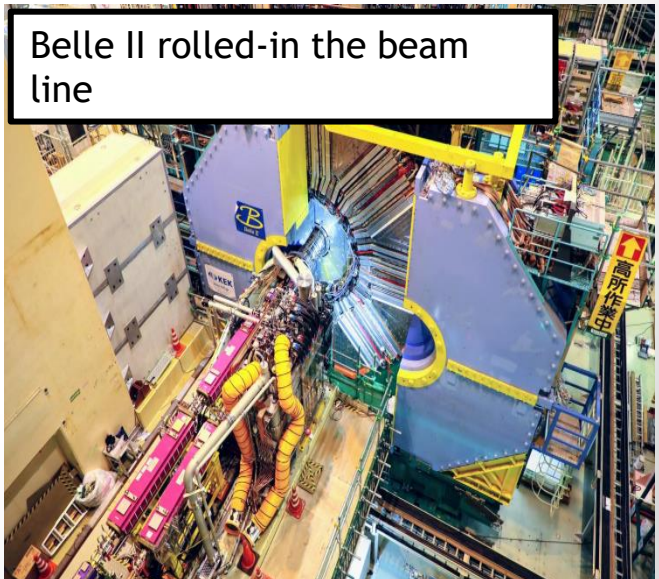
Central Drift Chamber (**CDC**)
He(50%):C_2H_6(50%), Small cells,
long lever arm, fast electronics

General purpose 4π Detector
Improved PID, Vertex detector
High background tolerance

Belle II and SuperKEKB Upgrade History

- 2010, Belle and KEKB operation completed
  - Started upgrade to Belle II and SuperKEKB
- 2016 Phase 1 Commissioning
  - SuperKEKB single beams
  - no collisions, without Belle II
- 2017 Belle II Detector rolled-in to the beam line
- **2018 March-July Phase 2 Commissioning**
  - First e+e- collisions at SuperKEKB
    - Confirm the nano-beam scheme
  - **Data taking with Belle II Detector (w/o VXD, but background detectors (BEASTII)**
    - Confirm the background condition for final VXD
- **2019 March- Phase 3 Operation**
  - **Physics run with the full Belle Detectors with the VXD (PXD+SVD) installed**
  - **Aim at the design luminosity 8×10^{35} /cm^2/s**
  - **Search for the new physics**

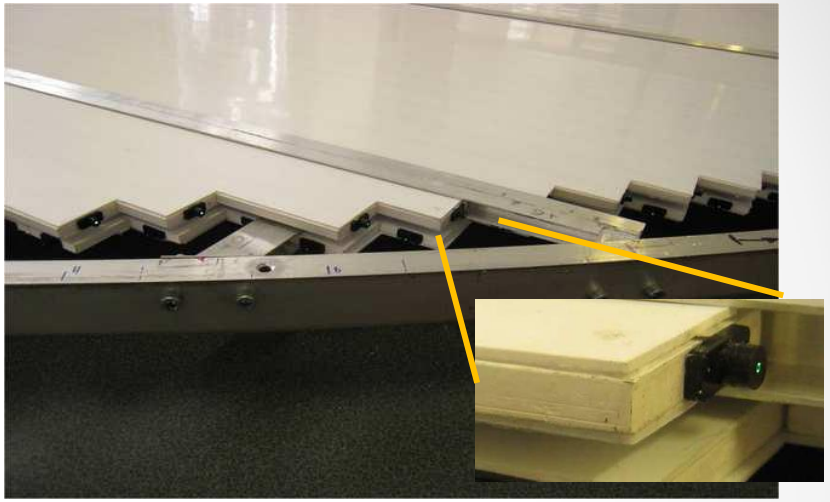


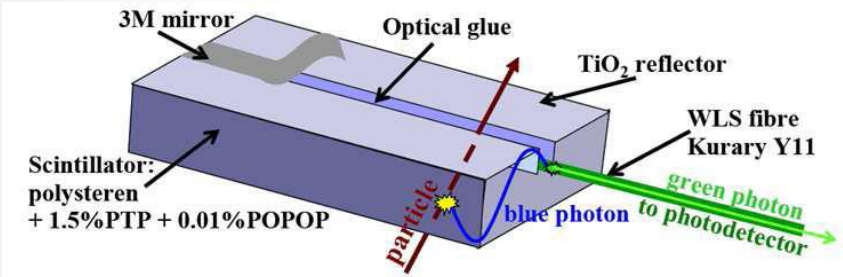


KLM

- Reuse glass resistive plate chamber RPC for most of Barrel layers
- **<u>Replace RPC with scintillator + MPPC for endcap and innermost two layers in barrel</u>**
  → reduce deadtime

Scintillator Module



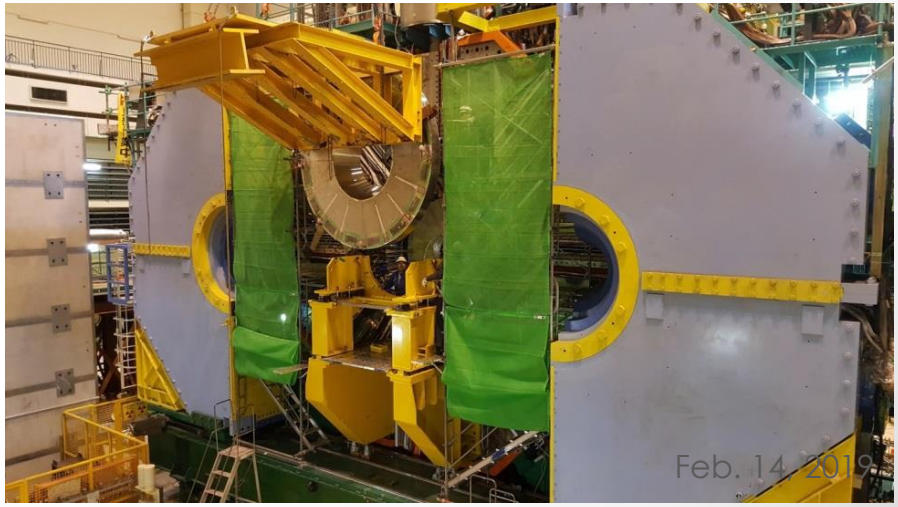


Scintillator modules have been installed in 2013-2014

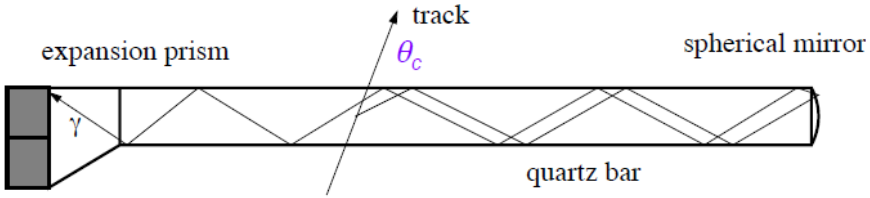
ECL

- Use Belle ECL CsI(Tl) crystals and PIN diodes
  - **30cm long CsI(Tl) (16.1X0)**
  - **2x(2cm2) PIN diodes**
  - **2 preamplifiers**
- Readout electronics has been upgraded
  - Shorter shaping time 0.5 μs
  - Waveform sampling

  → Reduce background noise effect
- Endcap Belle ECL have been installed again in 2017-2018



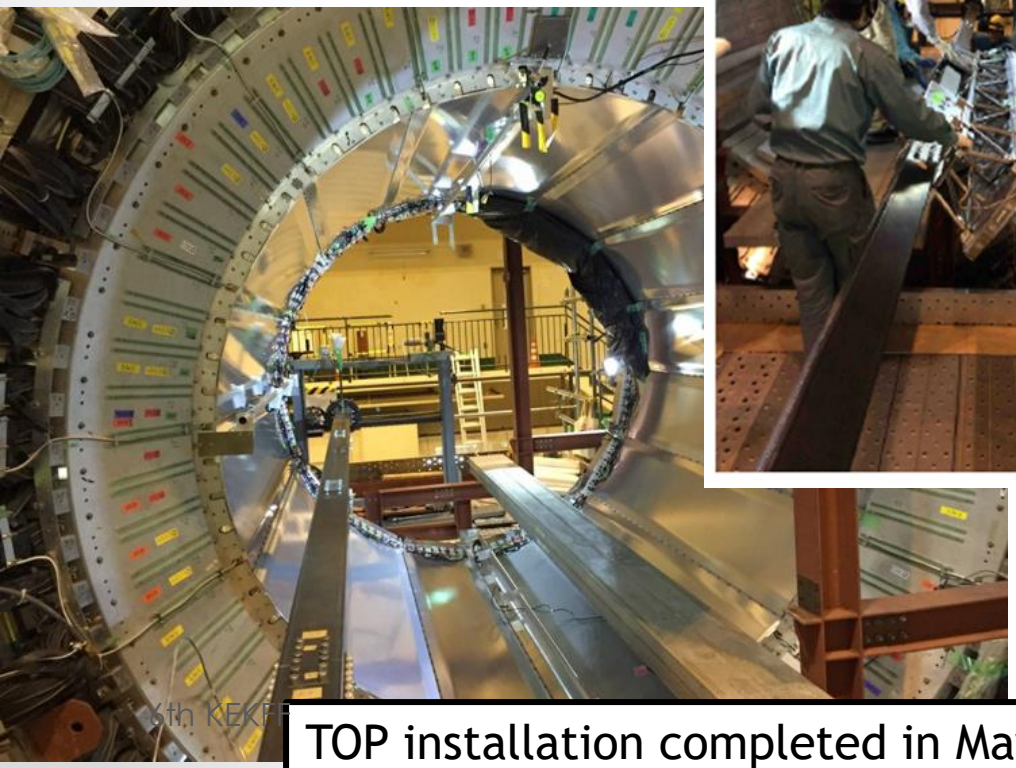
TOP

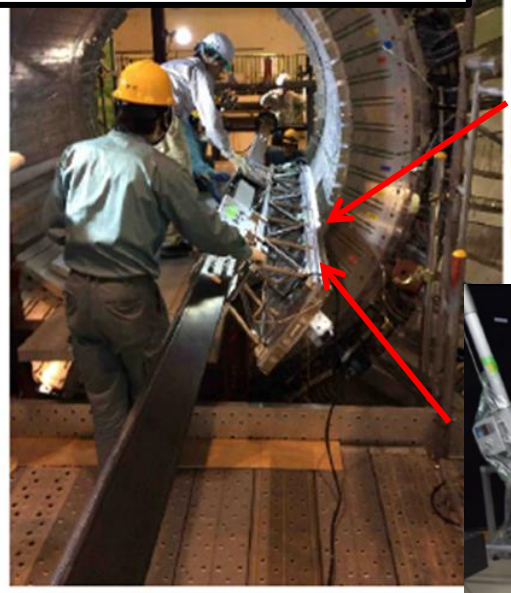


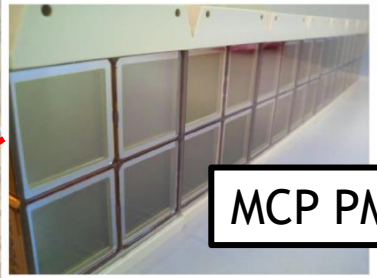
Barrel PID (TOF+ACC in Belle) is replaced with TOP counter

- TOF + Cherenkov Ring Image
- Consists of quartz bar radiator and MCP PMTs

First module installed in Feb. 2016







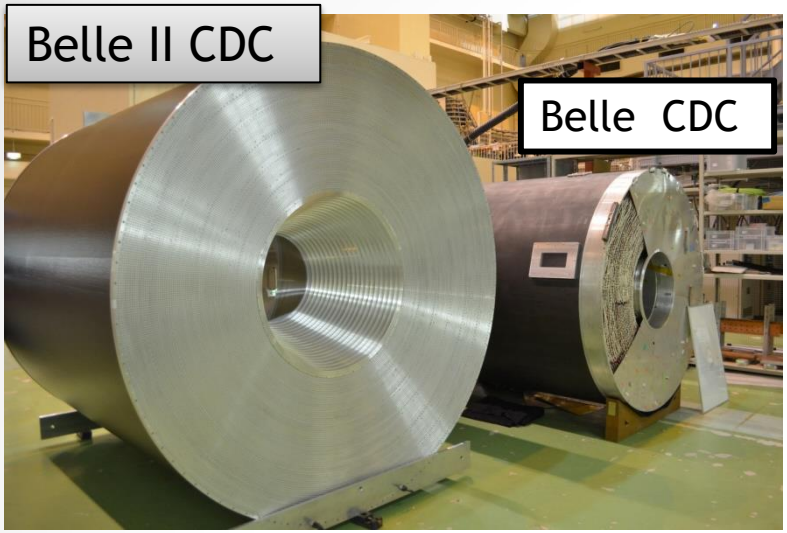
MCP PMTs

Quartz bar radiator

TOP installation completed in May 2016

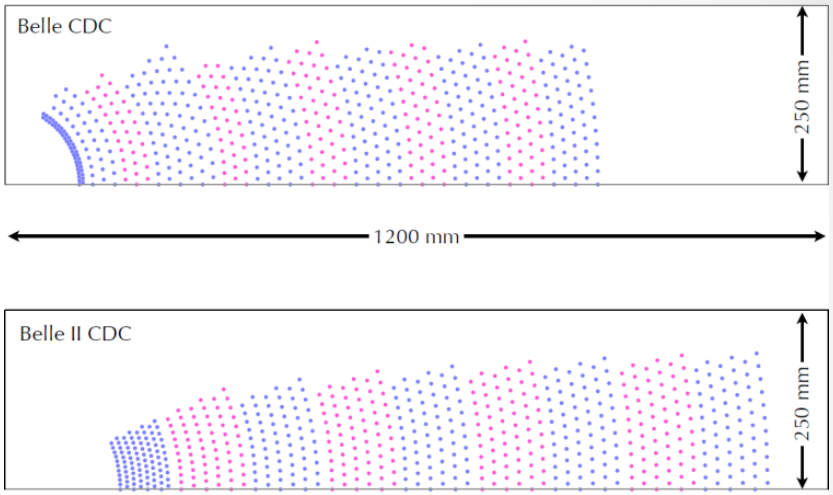
CDC

Belle II CDC



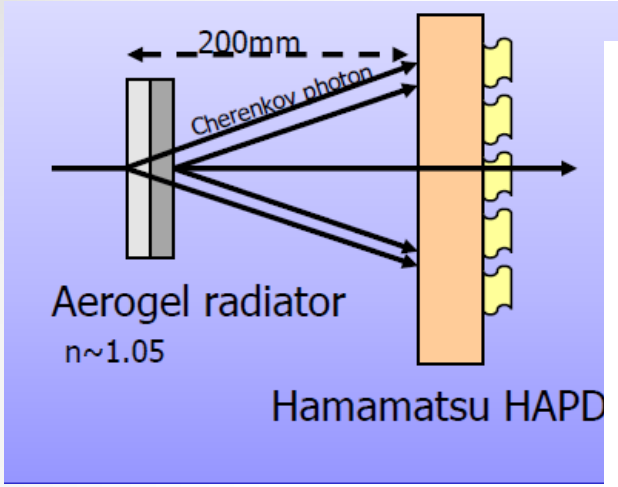
CDC Installed in Oct. 2016

Upgraded to new CDC
with **smaller cell, longer lever arms**



	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	$He:C_2H_6$	$He:C_2H_6$
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

ARICH

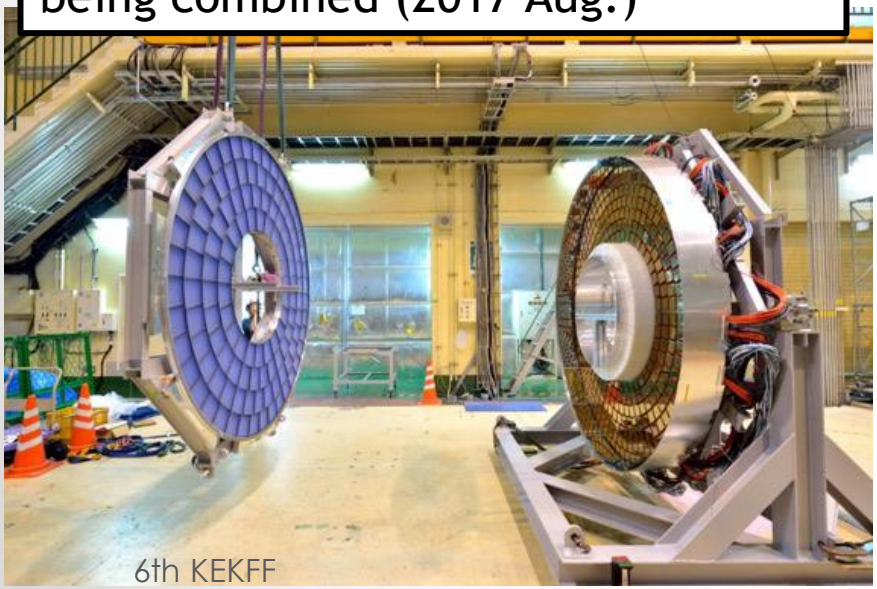


Ring image observed in the cosmic ray run

Forward endcap PID is upgraded from threshold type Cherenkov counter (ACC) to **ring image Cherenkov counter (ARICH)**

- Aerogel as radiator
- Hybrid Avalanche Photo Detector (HAPD)

Completed Aerogel and HAPD planes being combined (2017 Aug.)



Installation to Belle II performed 2017 Sep.-2018 Jan.

BEAST II Detectors in Phase 2

BEAST II detectors installed in VXD volume

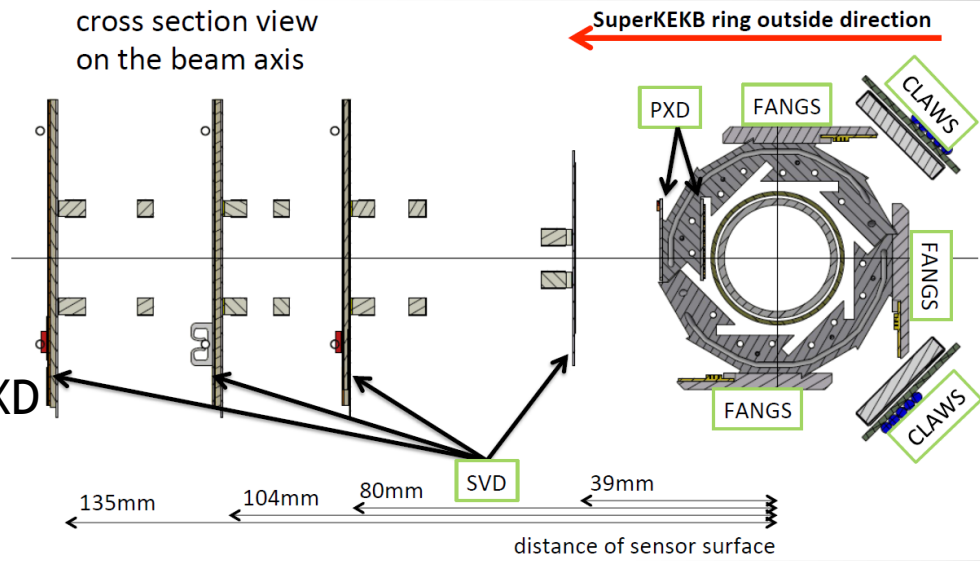
- **1 sector of PXD and SVD**

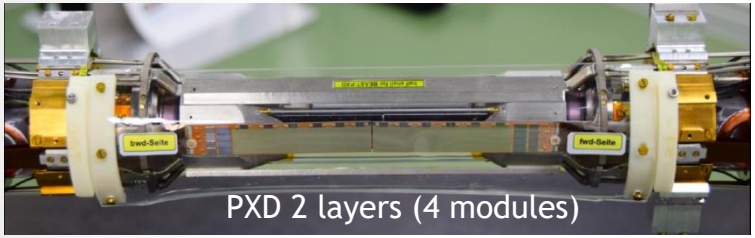
→ confirm the safe operation in phase3

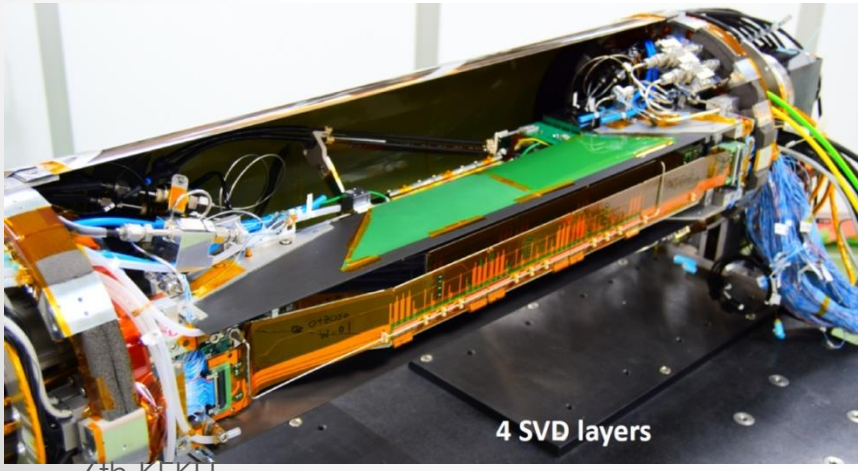
- **Detectors for the background study**

→ Understand the beam background components and their time evolution

→ Confirmed BG acceptable for Phase 3 VXD

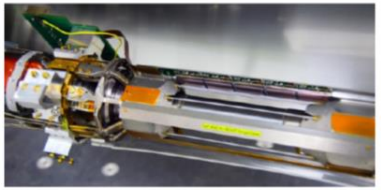




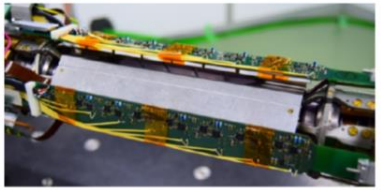


Phase 2 BEAST

- FANGS
3 staves installed and working at a time
Digital and analog parts OK. Chip tuning OK.
(FE-I4 ATLAS Near Gamma Sensors)

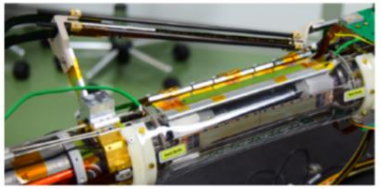


- CLAWS
2 staves installed
Functionality verified
(sCintillation Light And Waveform Sensors)



- PLUME
2 ladders installed
Threshold study and noise maps. Temperature evolution with time. Data transfer stability

(Pixelated Ladder with Ultra-Low Material Embedding)



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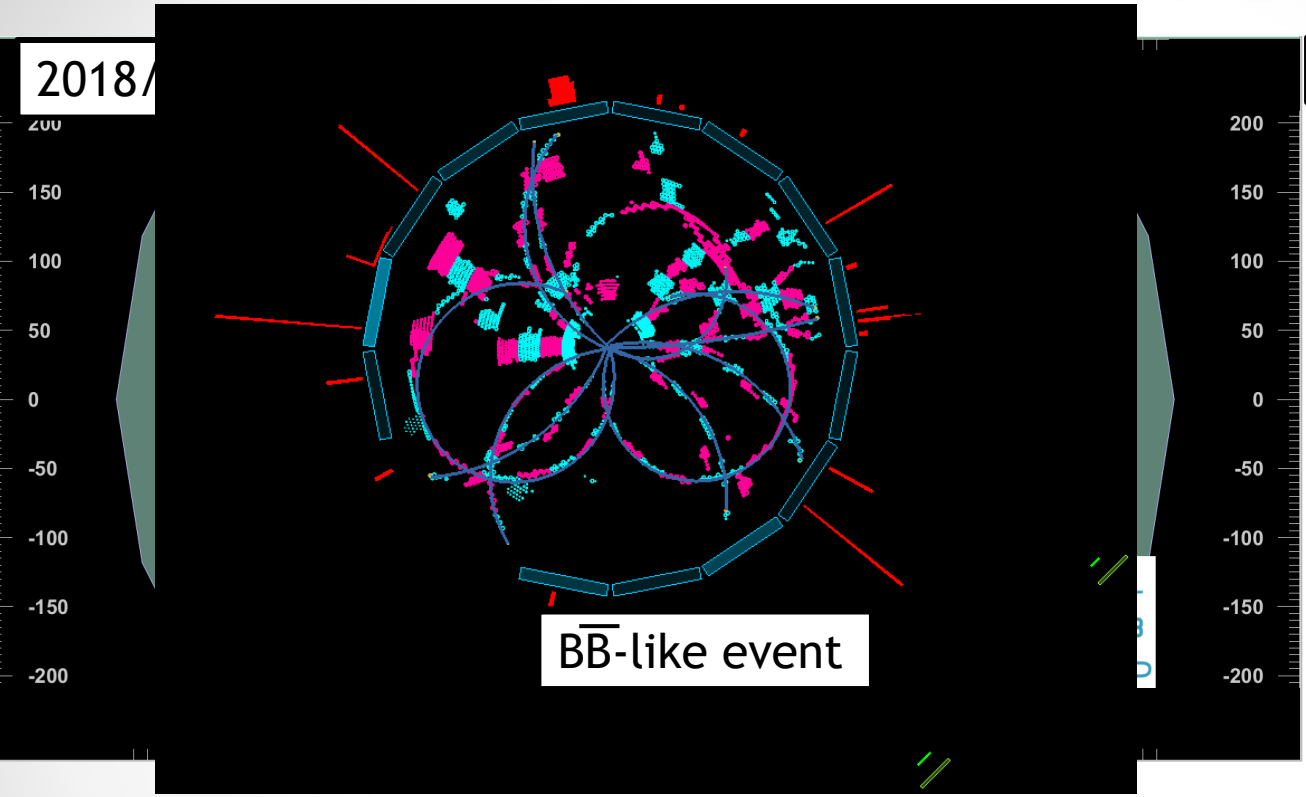
First e^+e^- collisions

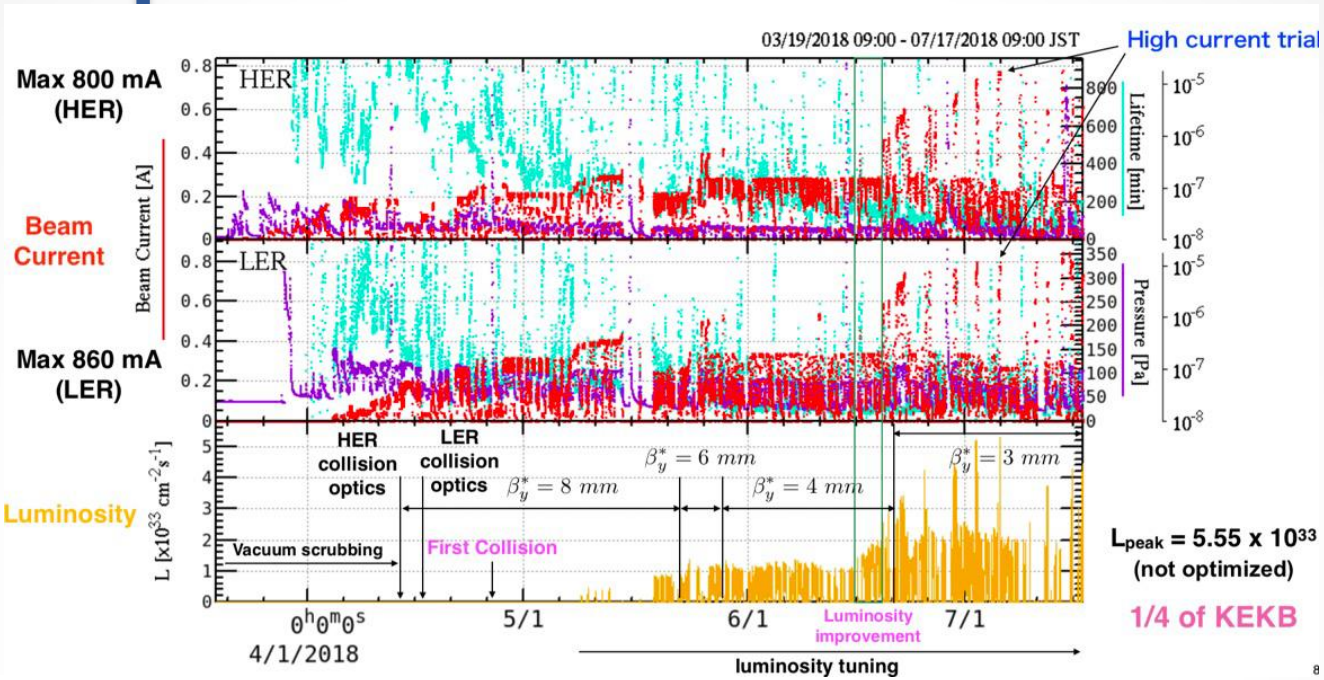


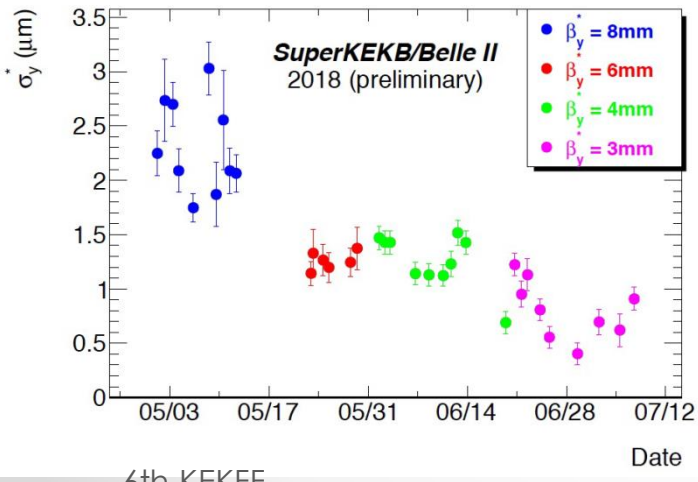
SuperKEKB Control Room

Belle II Control Room

- Achieved the first collisions on Apr 26
- Not only Bhabha, $q\bar{q}$ but also the first B-meson pair production candidate event was observed

SuperKEKB in Phase2



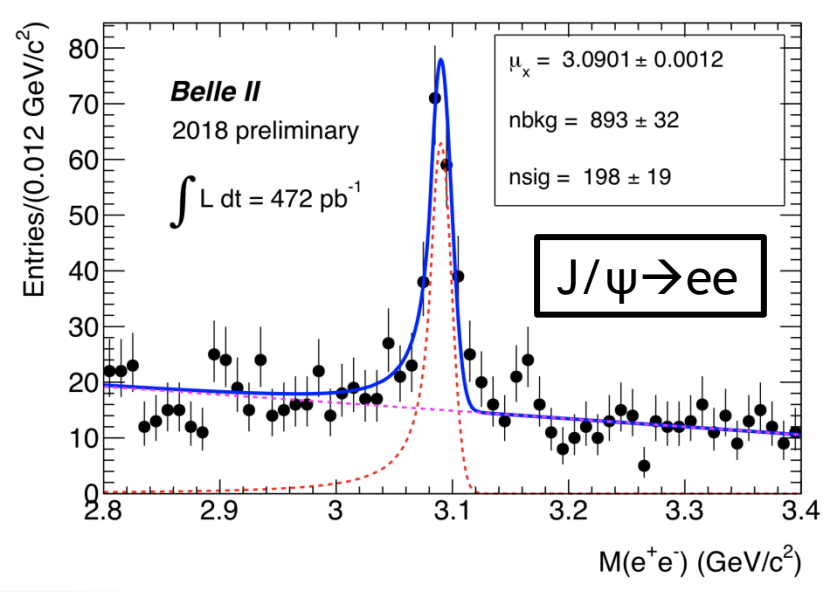


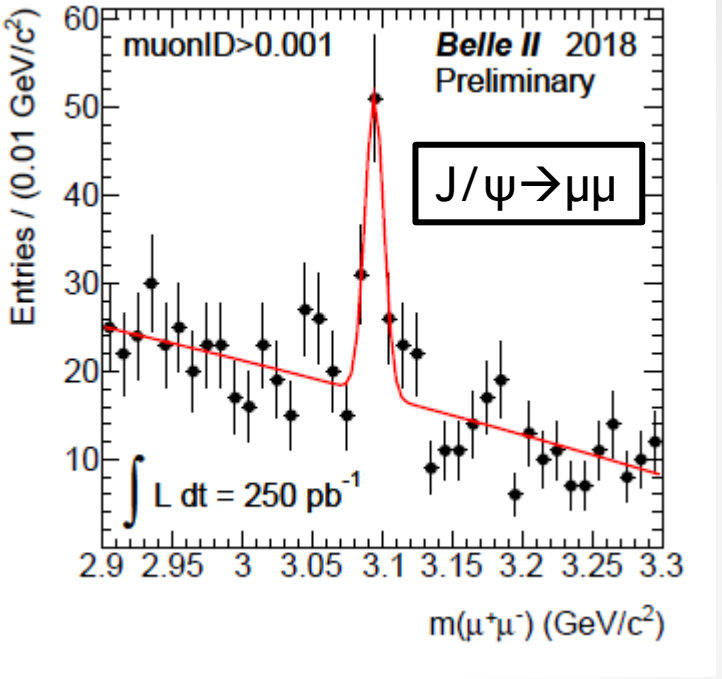
Priority is given to SuperKEKB tuning in Phase 2

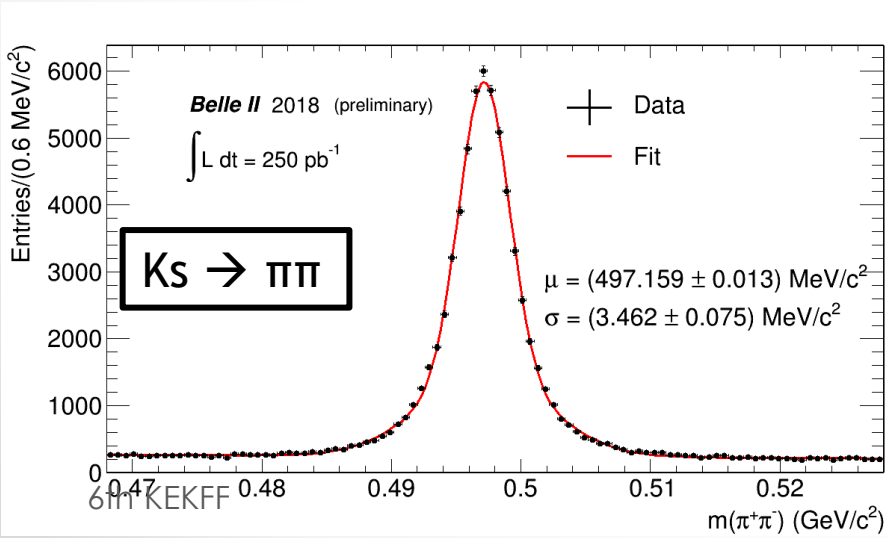
L_{peak} = 5.55 x 10^{33} cm^2/s
Belle II recorded ~ 500 pb^{-1}

Confirmed the collisions with the nano-beam scheme
Succeeded to reduce β_y^* to 3 mm, σ_y^* ~ 400 nm
(Final target β_y^* = 0.3 mm)

Track Reconstruction



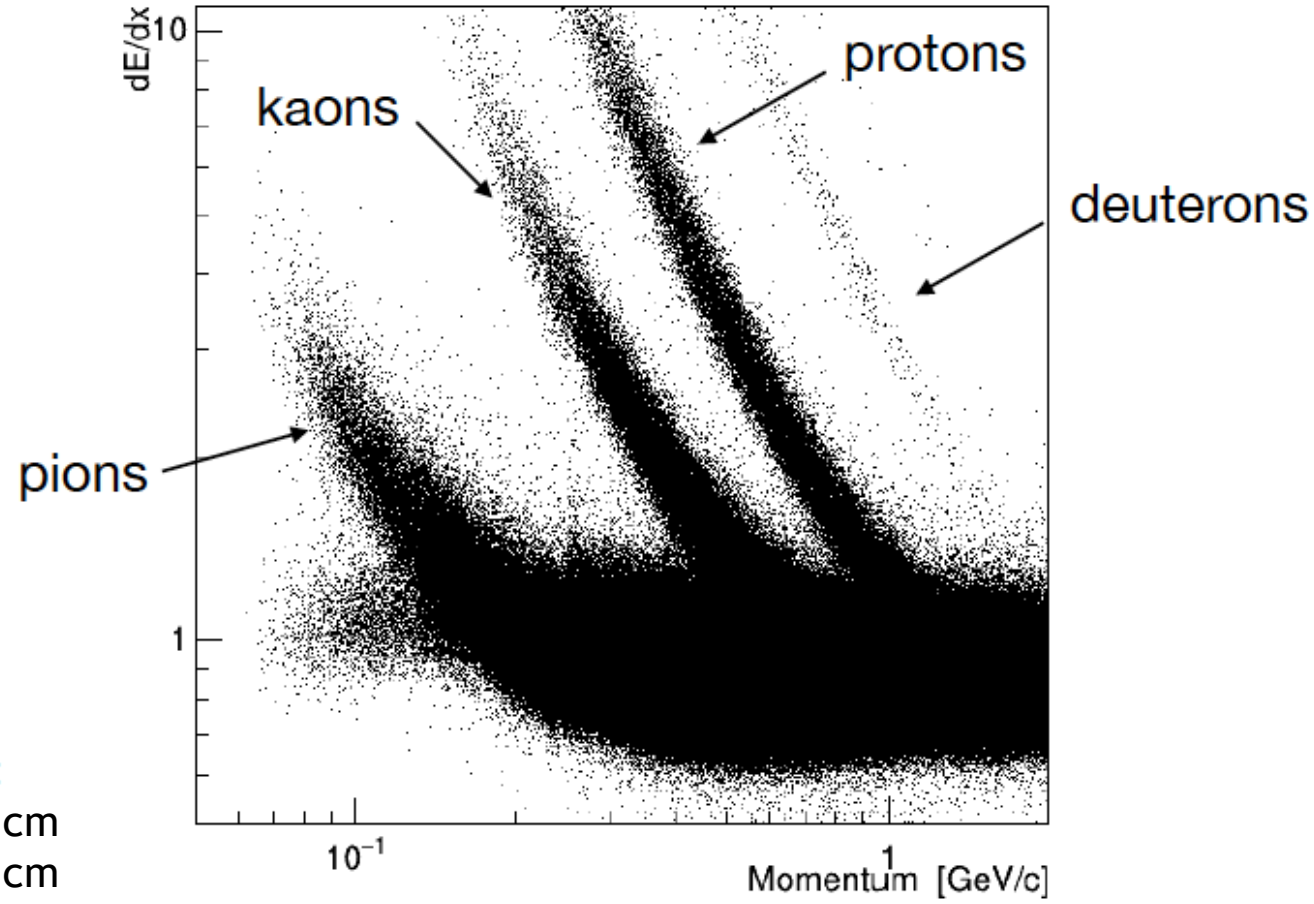




- Tracks have been reconstructed with CDC and VXD (partially installed).
- Detector alignment and B-field well understood.
- Mass resolution well understood with MC

CDC dE/dx

Clear separation in dE/dx observed → CDC particle identification



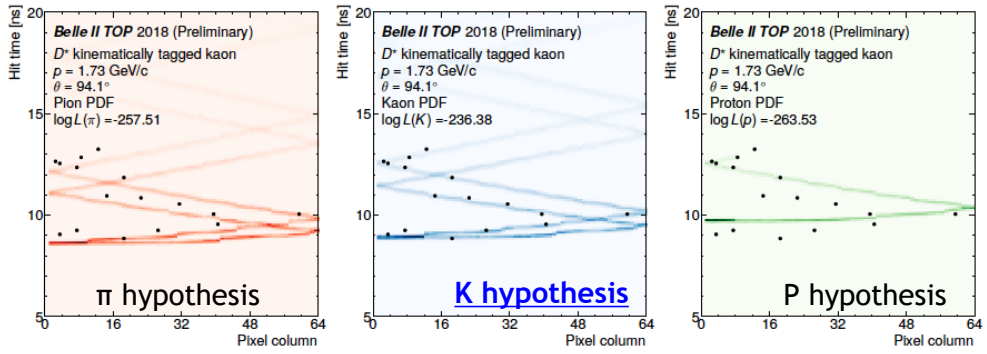
Extra cuts:
- |d0| < 1 cm
- |dz| < 3 cm
- # layers hit > 20

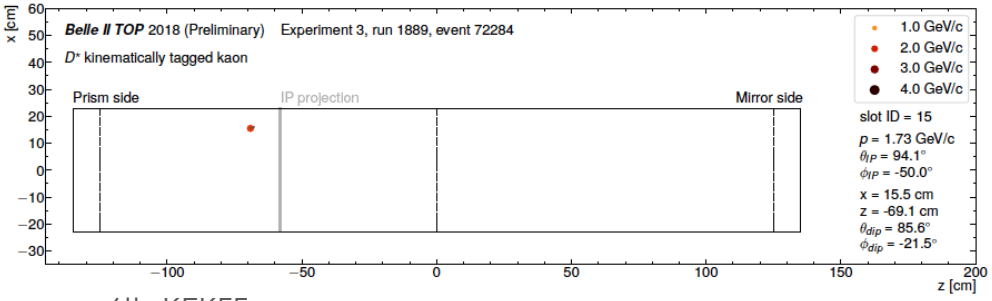
Kaon Identification

Cherenkov Photons observed by TOP

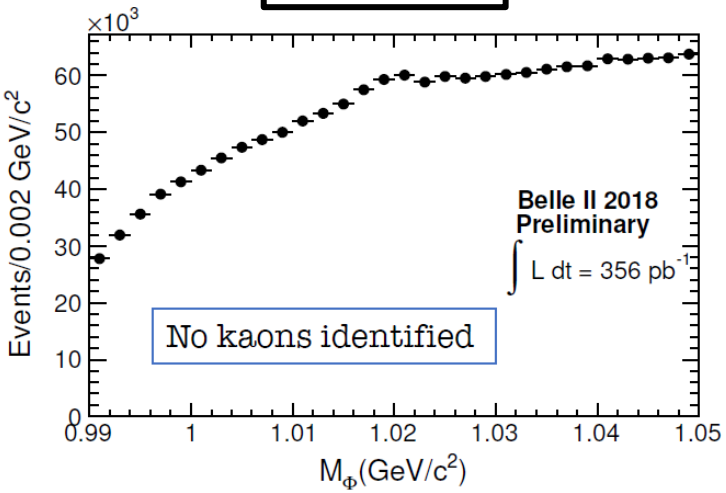
$D^{*+} \rightarrow D^0\pi^+$; $D0 \rightarrow K^-\pi^+$ event

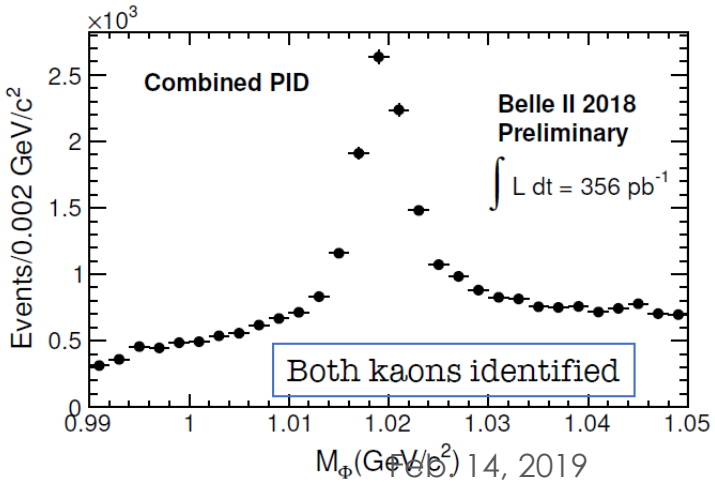
- K track tagged by slow π+
- Check consistency of the Cherenkov photon hit timing pattern





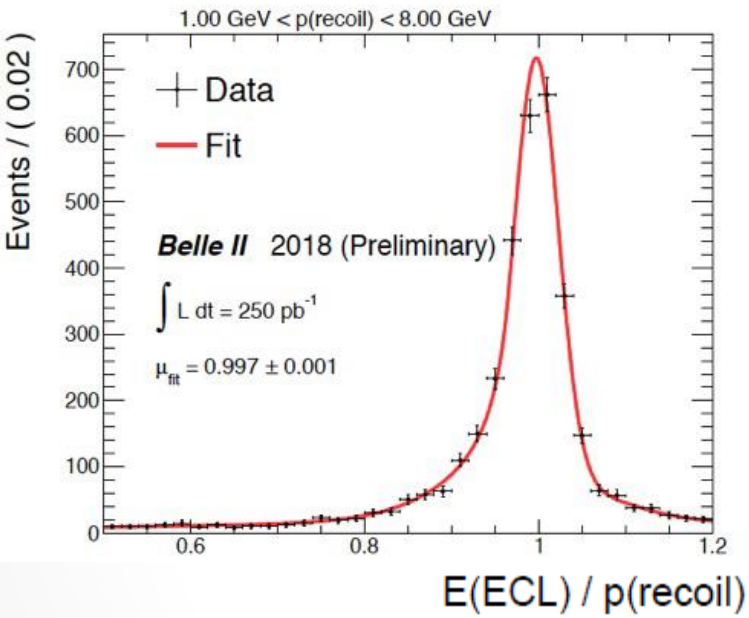
Φ→ K^+K^-



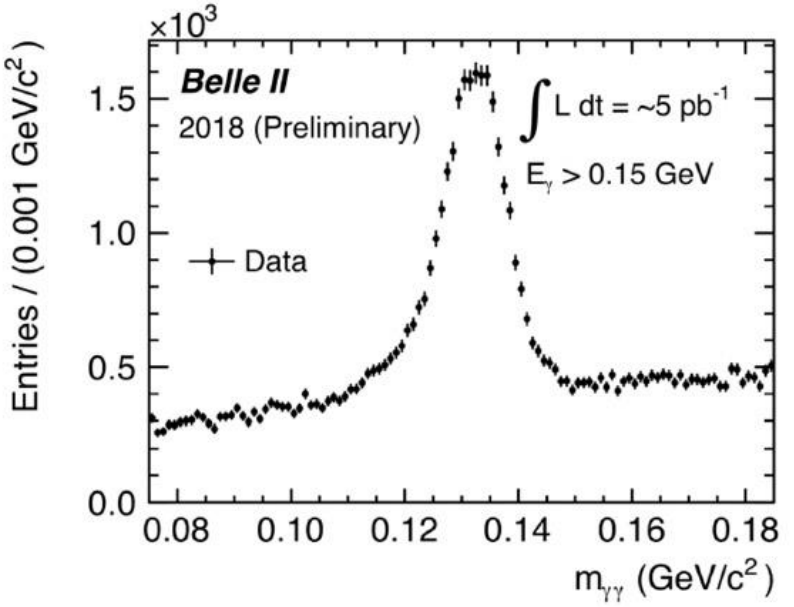


Photon Reconstruction

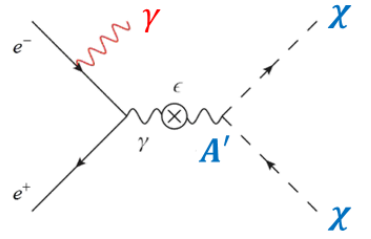
$e^+e^- \rightarrow \mu^+\mu^-\gamma$



$\pi^0 \rightarrow \gamma\gamma$



- Good reconstruction of both single photons and pairs
- Ready for the "dark sector" search – single photons

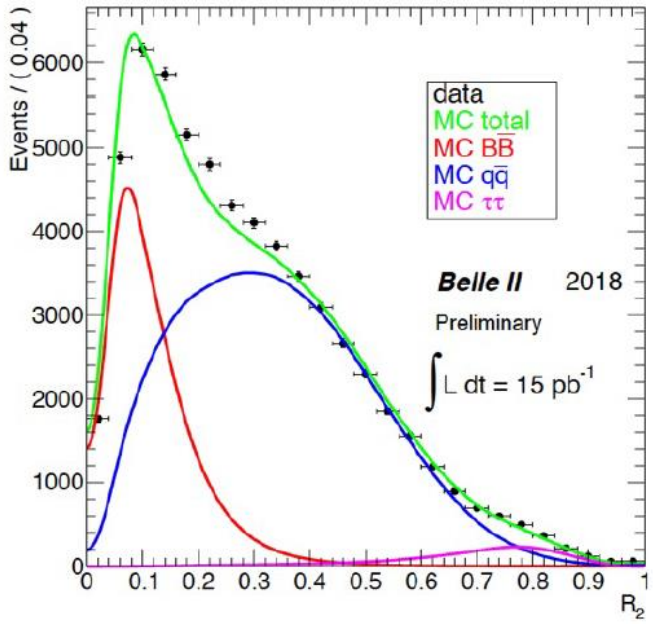


$e^+e^- \rightarrow \gamma A', A' \rightarrow \chi\chi$

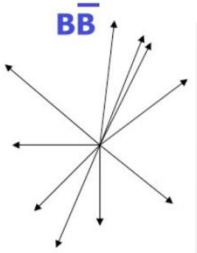
- A' ... dark photon
- χ ... dark matter

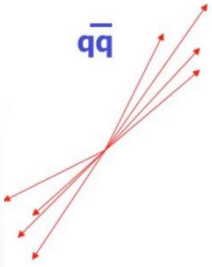
Rediscovery of B mesons

Event Shape Distribution
(Fox-Wolfram R2)

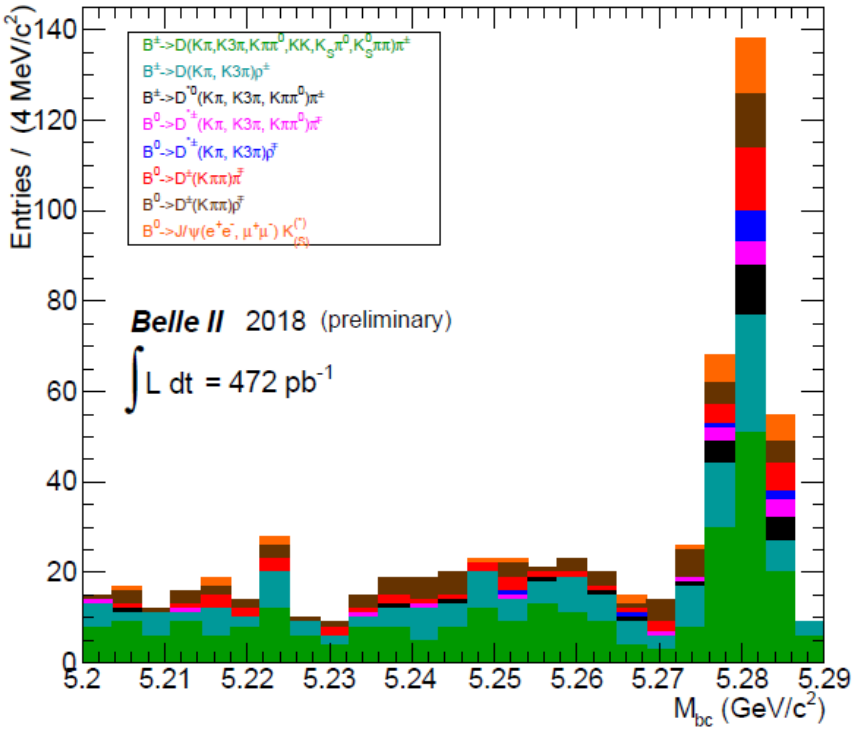


Spherical R_2 Jet-like





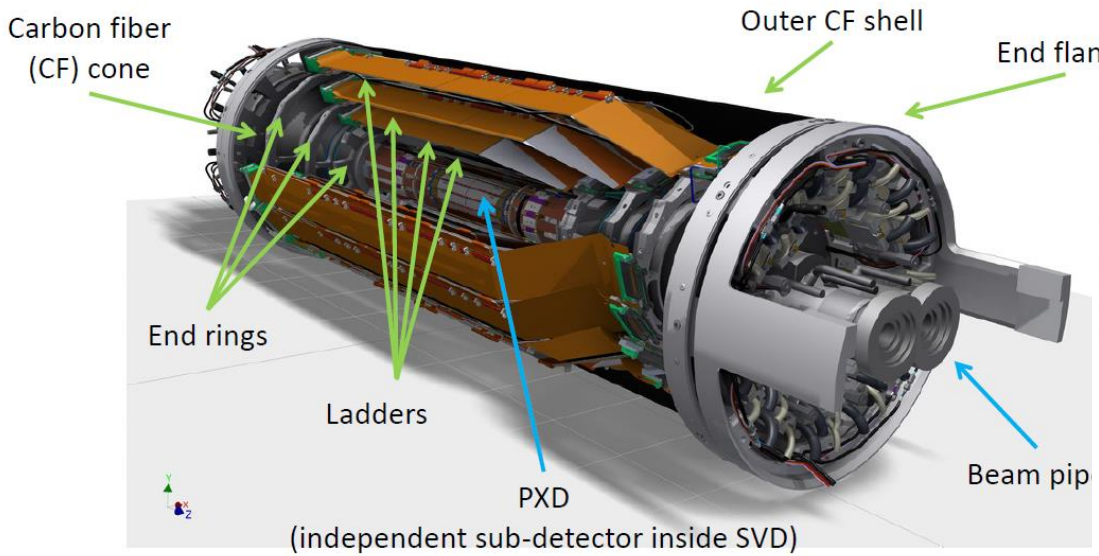
$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$



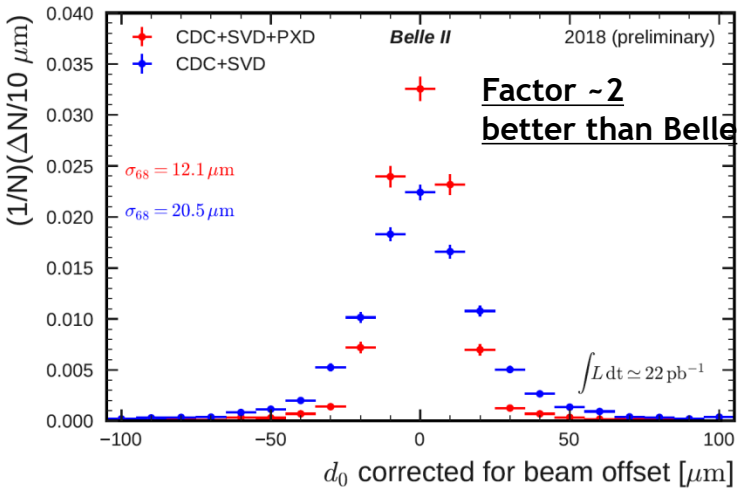
- Clearly observed the excess of $B\bar{B}$ events in early phase 2 Data
- "Rediscovered" reconstructed B mesons.

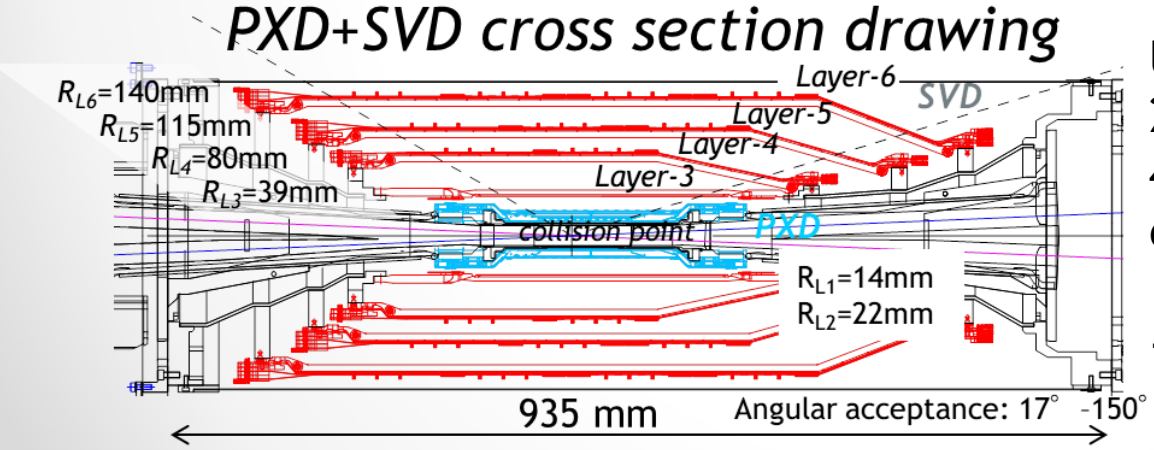
Full reconstruction analysis chain is working well.

Phase 3 Vertex Detector



Transverse Impact parameter resolution with VXD in Phase 2 data





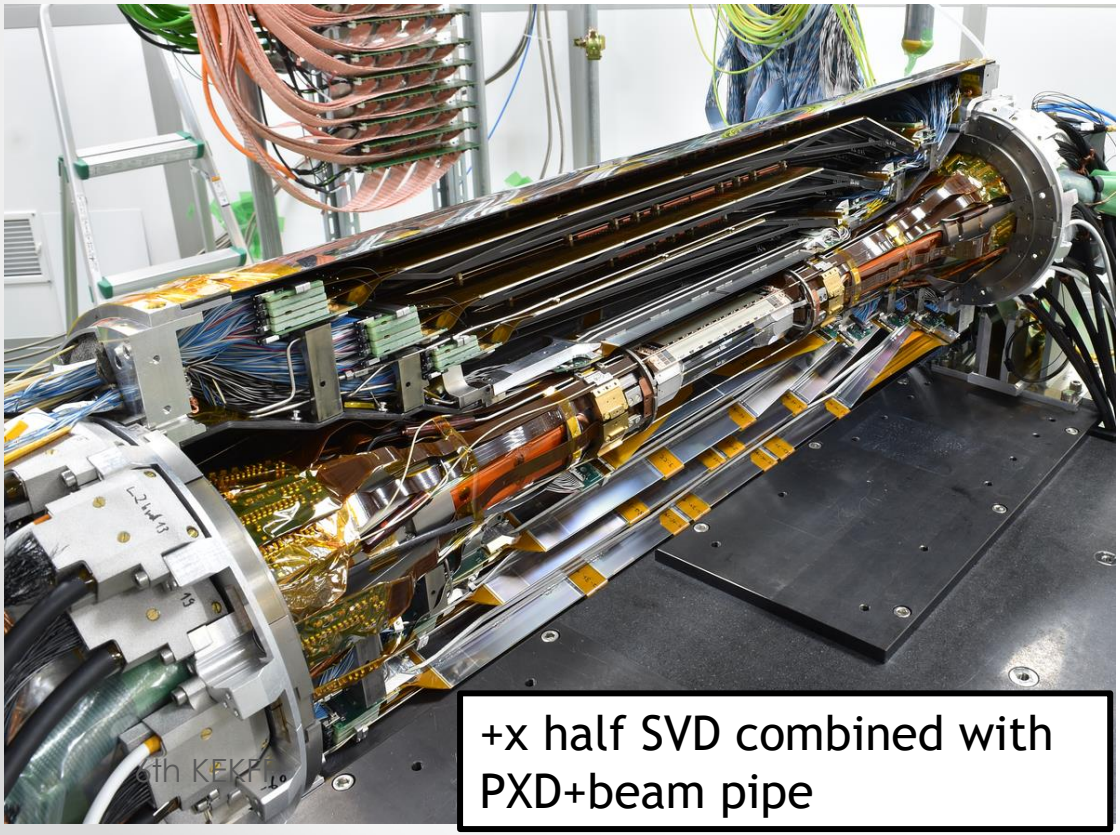
Upgrade to
2 Layer DEPFET Pixel Detectors
4 Layer Double-Sided Silicon Strip detectors

→ Resolution significantly improve

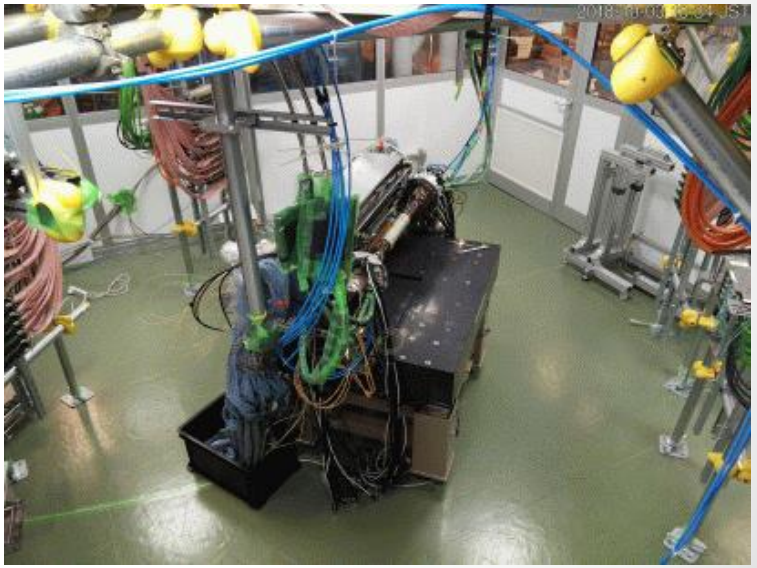
Phase3 VXD Assembly

2nd Half-SVD completed (2018 July)

PXD mounted on the beam pipe (2018 Sep.)



+x half SVD combined with PXD+beam pipe

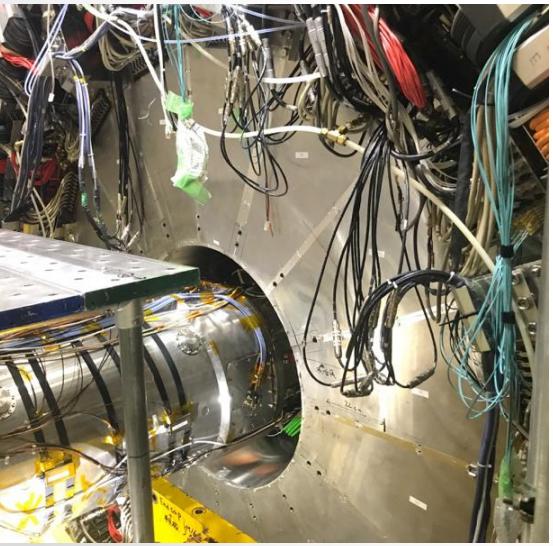


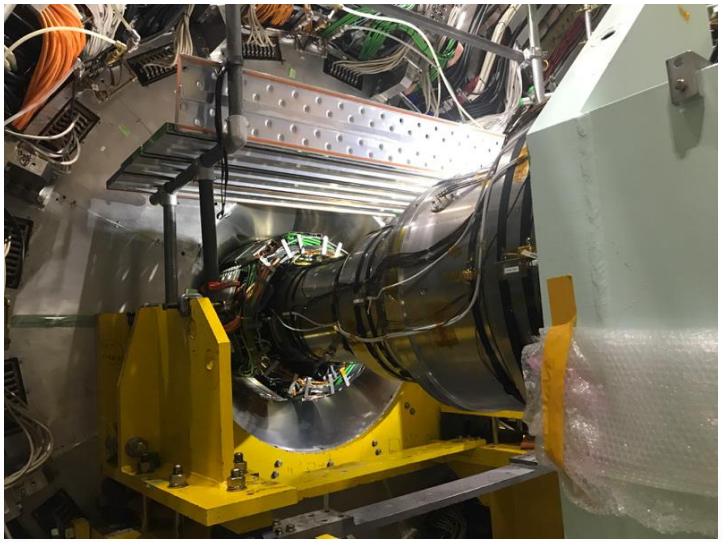
VXD assembly completed in 2018 Oct.

- PXD full layer 1 + 2 layer 2 ladders

→ Full layer1+2 PXD installation planned in 2020

Phase3 VXD Installation





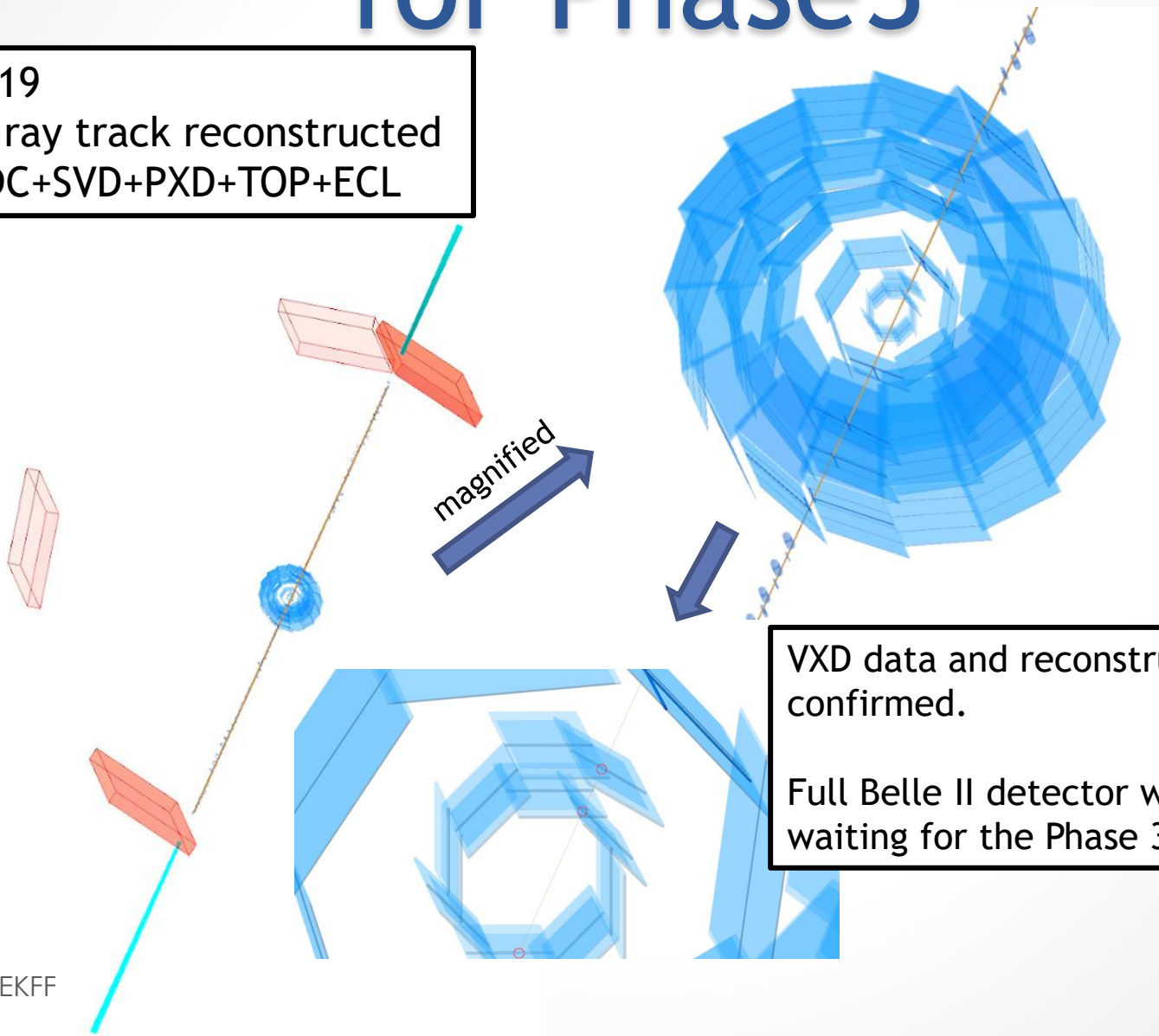
2018 Nov. VXD installed in Belle II

2019 Jan.
Endcap and QCS has been inserted

→ Preparing for SuperKEKB Phase3 Operation in March

VXD Ready in Belle II for Phase3

Jan. 2019
Cosmic ray track reconstructed with CDC+SVD+PXD+TOP+ECL



VXD data and reconstruction has been confirmed.

Full Belle II detector with the VXD is waiting for the Phase 3 collision data!

Early Phase3 Physics

- Luminosity will depend on machine and detector performance
- Plausible assumption of about 10fb-1 by summer 2019

Semileptonic
- B→ π l ν and ρ l ν untagged (CLEO saw a signal with 2.66 fb^{-1})

Time Dependent B and D measurements
- D lifetimes (2 fb^{-1})
- Doubly Cabibbo suppressed $D^0 \rightarrow K^+ \pi^-$, $D^0 \rightarrow K^+ \pi^- \pi^0$ (10 fb^{-1})
- B lifetimes (2-10 fb^{-1})
- Time dependent B-anti B mixing (10 fb^{-1})

Verification of full Belle II physics performance

Radiative/Electroweak Penguins
- B→K* γ (b→s) (2 fb^{-1}) rediscover penguins
- B→Xs γ (b→s) (~10 fb^{-1} but *needs off-resonance data taking*)

Hadronic B decays (not time dependent)
- B→K π (b→u) (10 fb^{-1})
- B→ Φ K (b→s) (10 fb^{-1})
- B→J/ψ K (with more significance 2-10 fb^{-1})

++ Dark Sector Physics

Summary

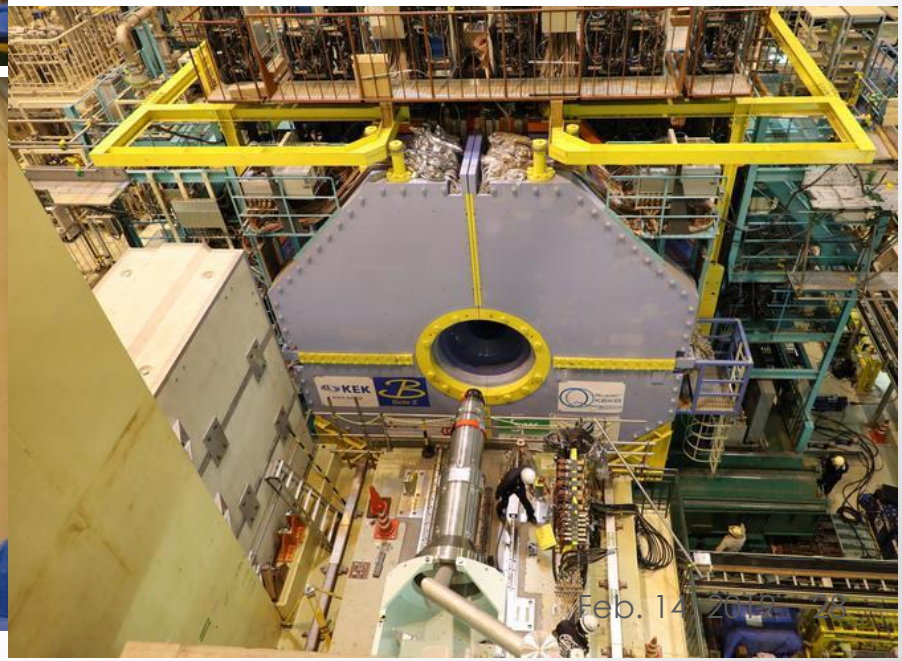
- Belle/KEKB has been upgraded to Belle II/SuperKEKB

- First collisions has been performed in phase 2 commissioning
- SuperKEKB verified the nano-beam scheme
- Detector performance has been confirmed with the phase 2 data

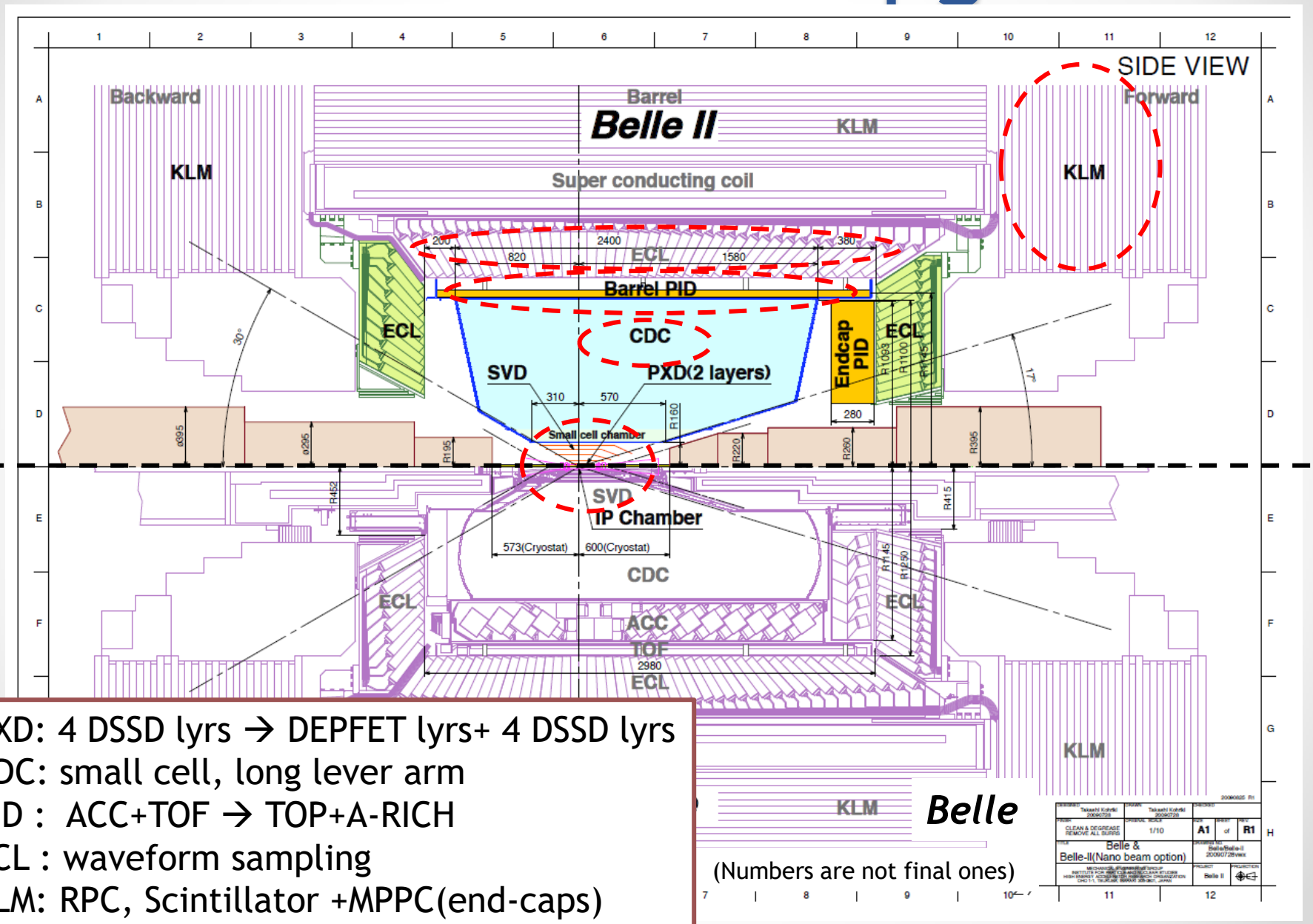
- VXD has been assembled and installed in Belle II for phase 3 physics run
- SuperKEKB phase 3 run will start soon in March 2019
- New physics search with the Belle II/SuperKEKB will start

Belle II Roll-in

Belle II moved to the beam line on Apr. 11, 2017



Belle → Belle II Upgrade



VXD: 4 DSSD lyrs → DEPFET lyrs+ 4 DSSD lyrs
CDC: small cell, long lever arm
PID : ACC+TOF → TOP+A-RICH
ECL : waveform sampling
KLM: RPC, Scintillator +MPPC(end-caps)