Status and Physics Prospects of the SuperKEKB Project

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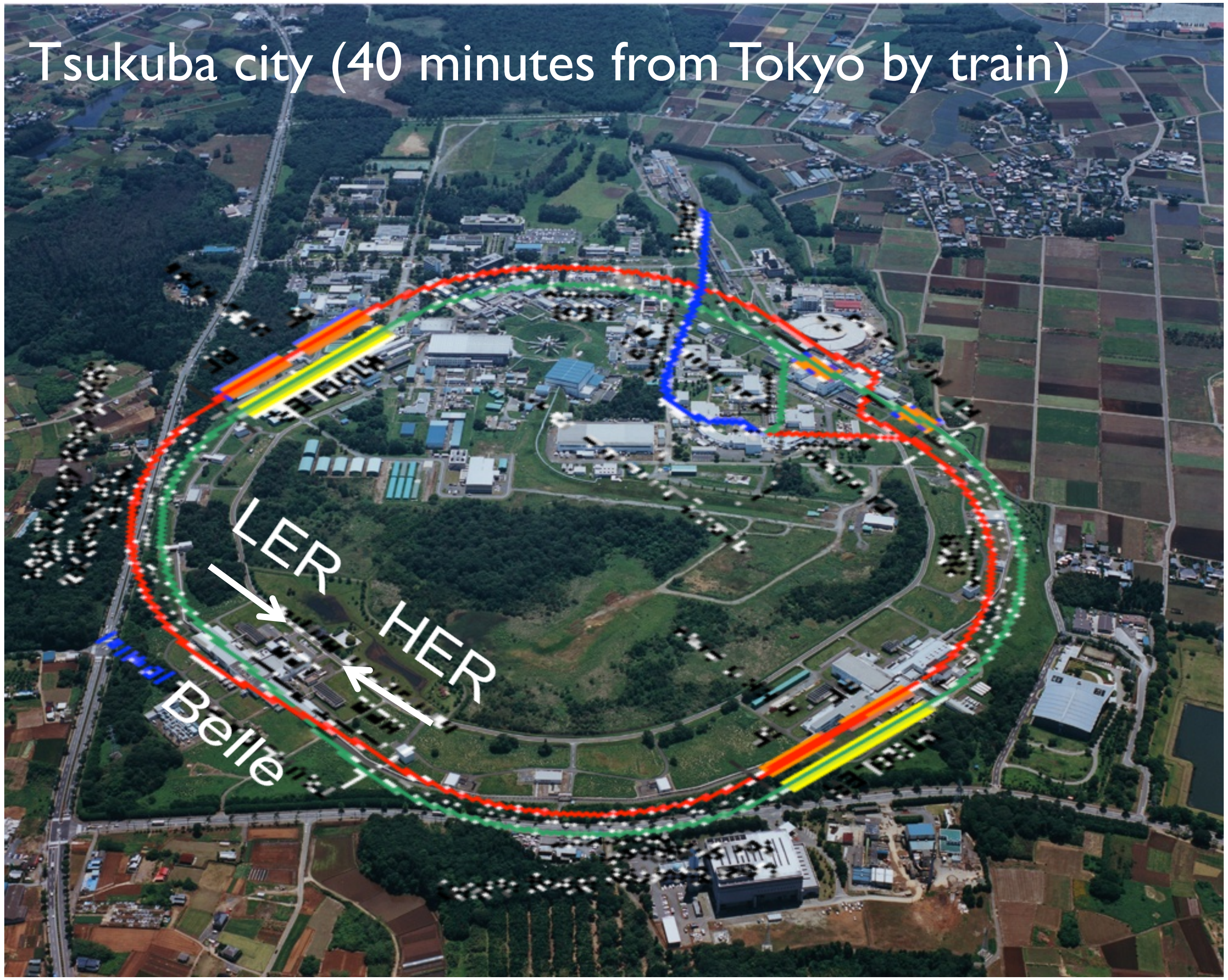
5th March 2011, La Thuile 2011

KEKB Collider



KEKB parameters

- HER (e^-): 8.0 GeV
- LER (e^+): 3.5 GeV
- E_{CMS} = Υ(4S) mass

  → B meson pair

- Peak luminosity

  $= 2.1 \times 10^{34}$ /cm^{2}s

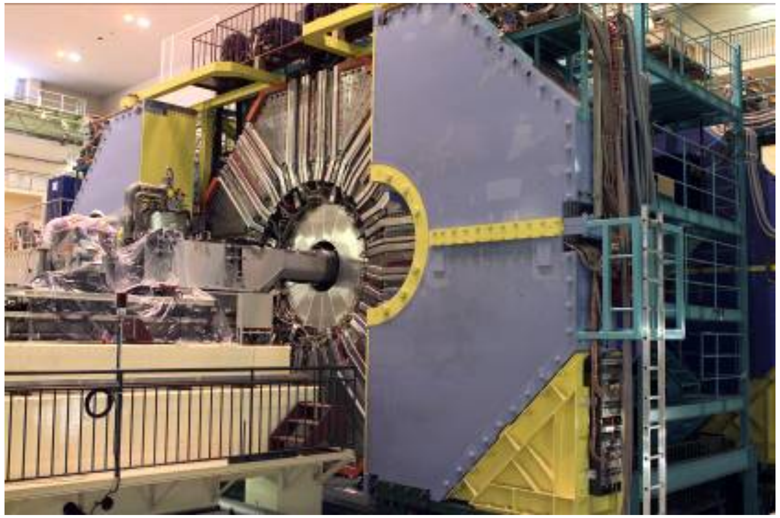
- Integrated luminosity

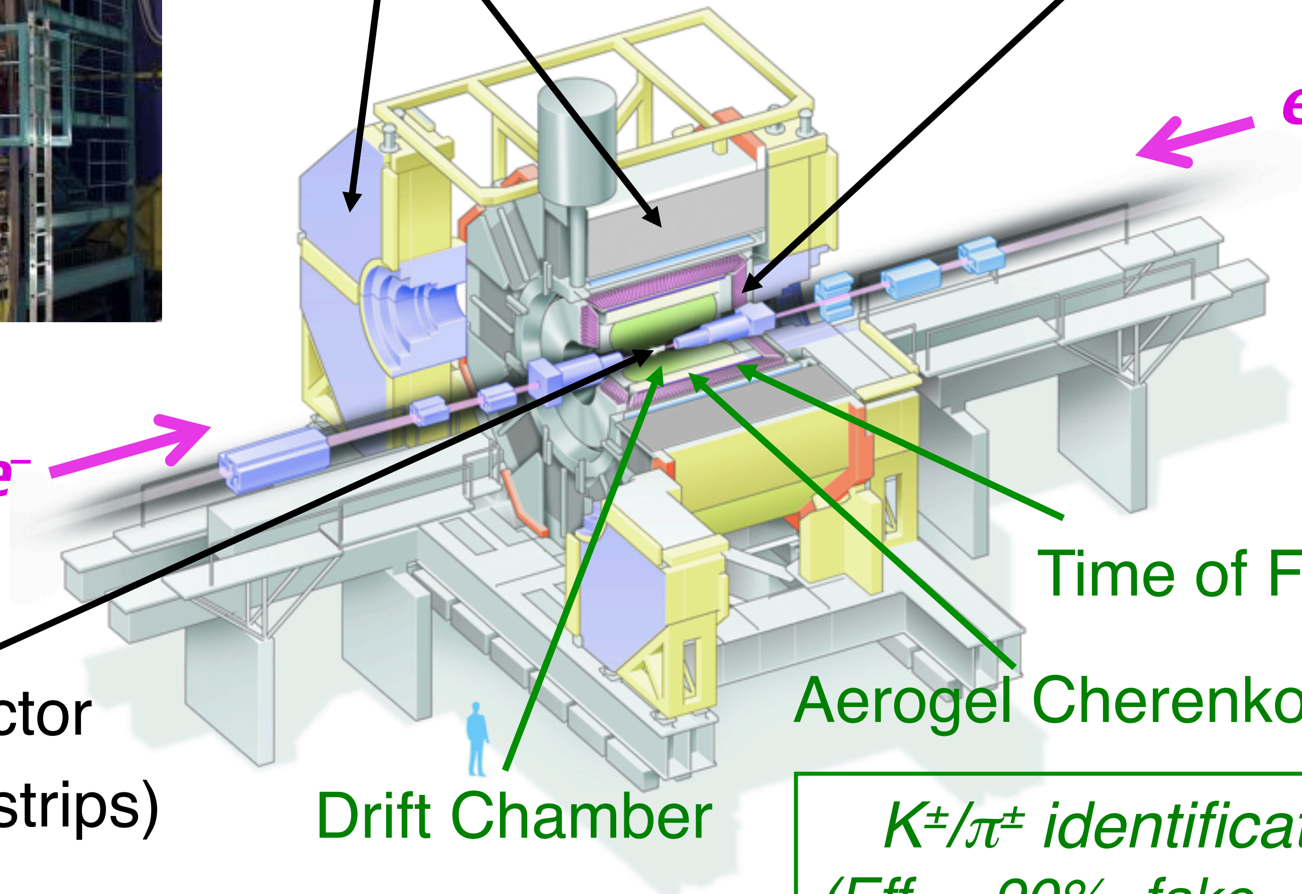
  > 1 ab^{-1}

  (June 1999 - June 2010)

  World records

Belle Detector



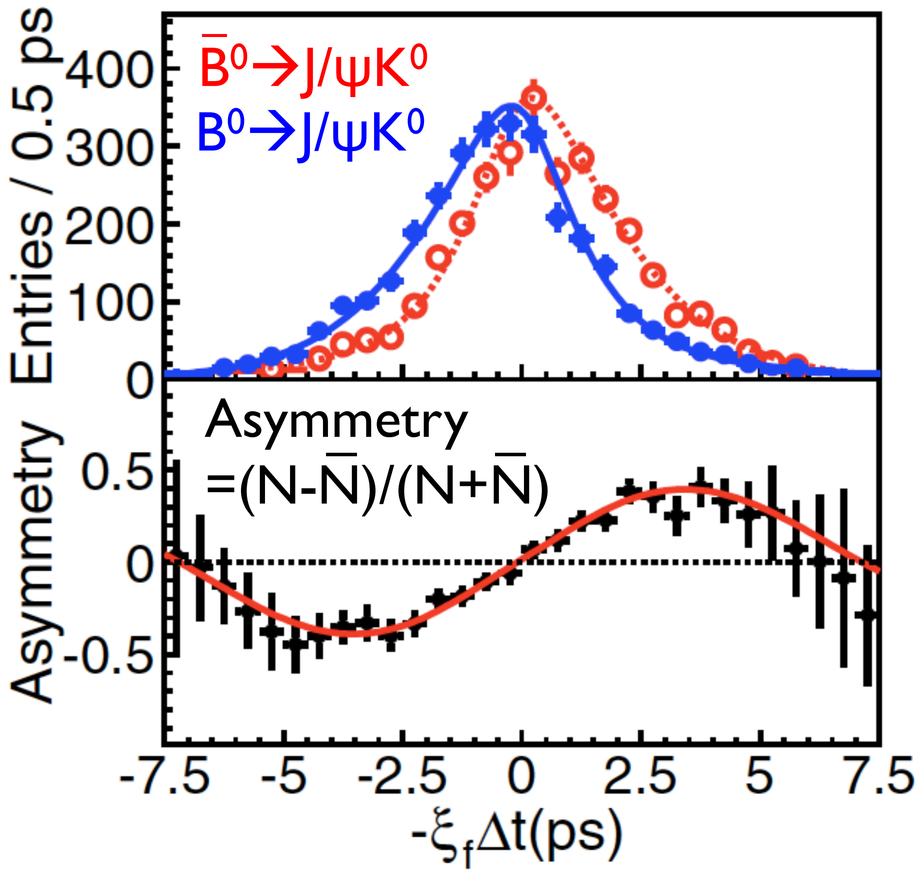


$K^\pm/\pi^\pm$ identification
(Eff. ~ 90%, fake ~ 10%)

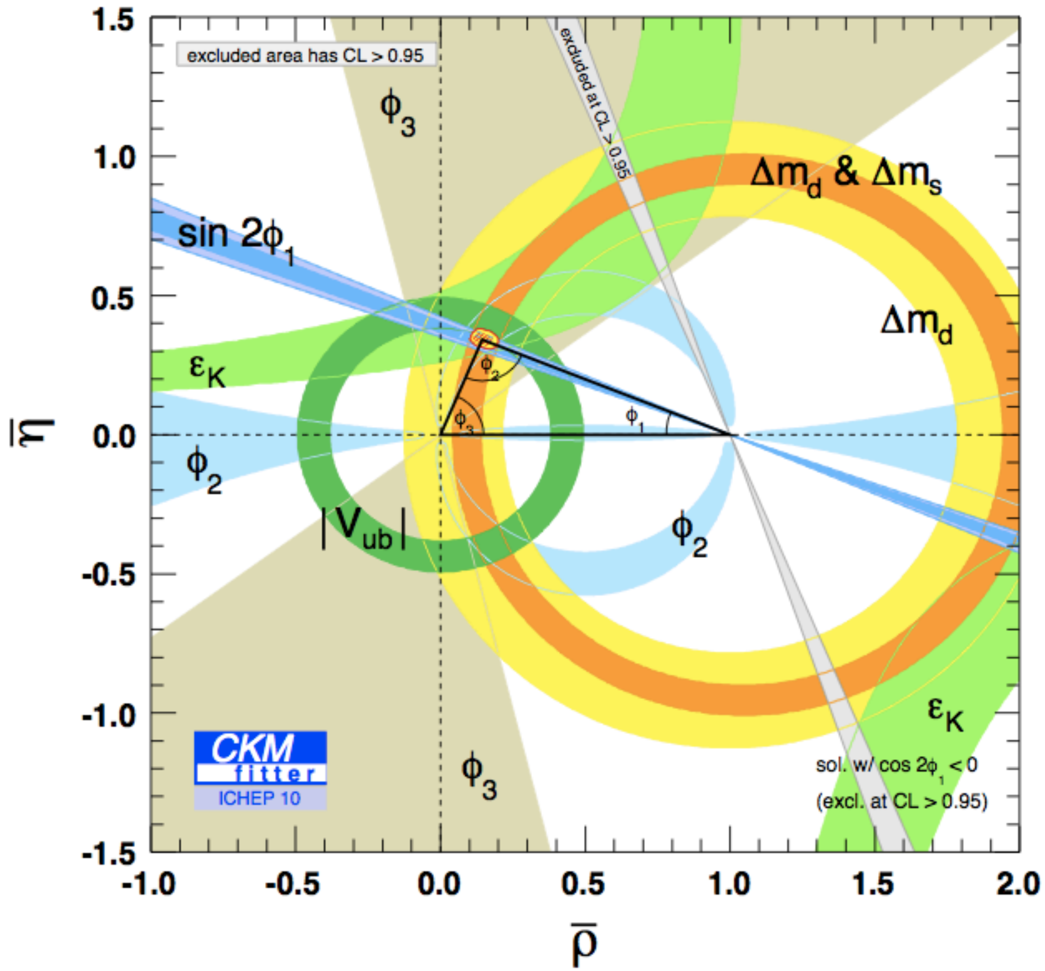
A Success Story at B-Factories

Discovery of *CP* violation in the B system

PRL 98, 031802 (2007), 0.5 ab^{-1}



Measurements of the CKM matrix elements

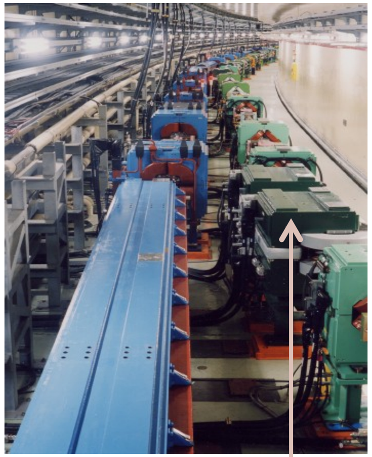


Upgrades

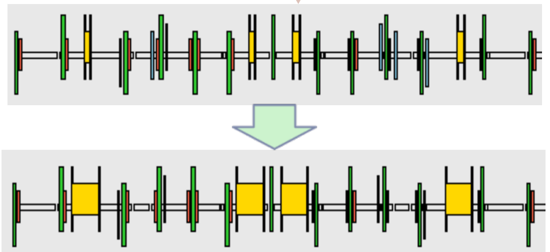
KEK collider Belle detector	→	SuperKEKB collider Belle II detector

SuperKEKB Collider

Approved in 2010.

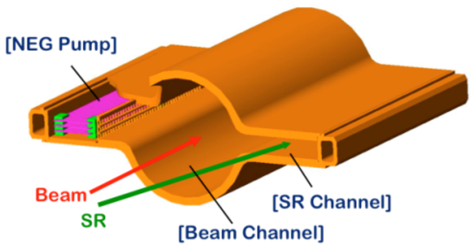


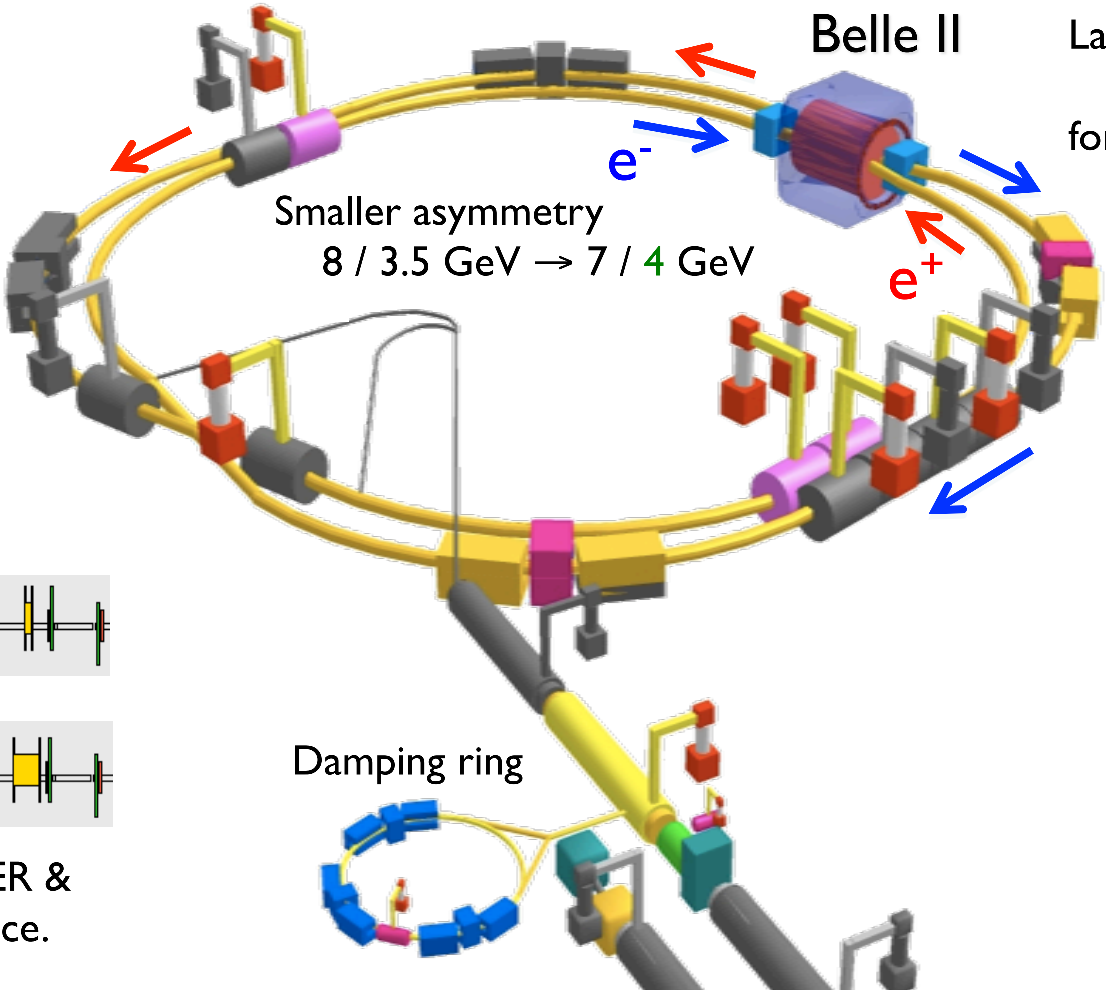
Replace short dipoles with longer ones (LER).



Redesign the lattices of HER & LER to reduce the emittance.

TiN coated beam pipe with antechambers





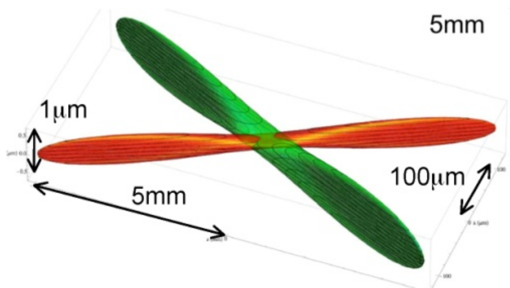
Larger crossing angle
2ϕ = 22 mrad → 83 mrad
for separated final-focus magnets.

High currents

e^-: 2.6 A
e^+: 3.6 A

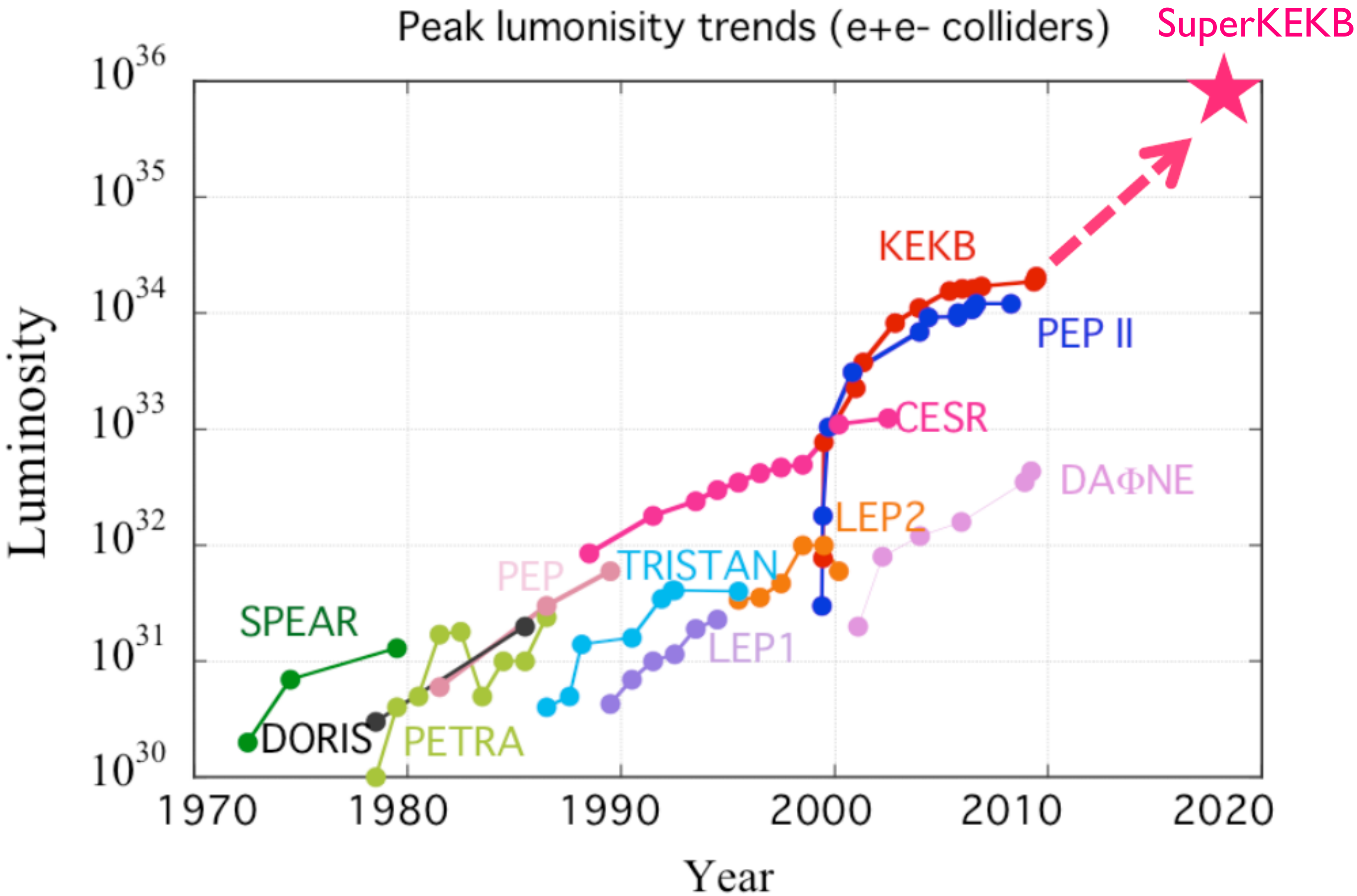
Small beam sizes

σ_x~10μm, σ_y~60nm

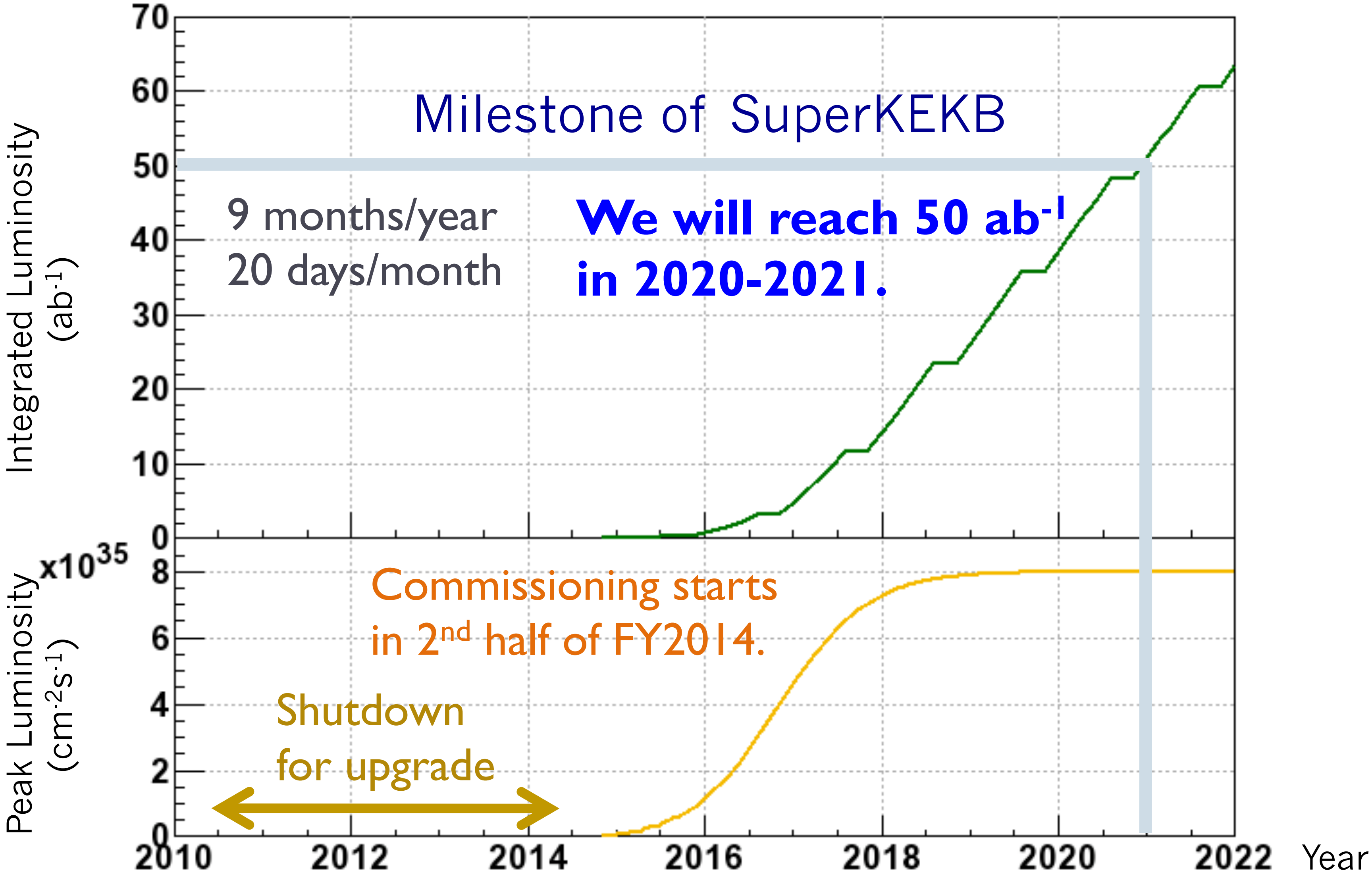


$\mathcal{L} = 8 \times 10^{35}\ \mathrm{cm^{-2}\ s^{-1}}$

Peak Luminosity

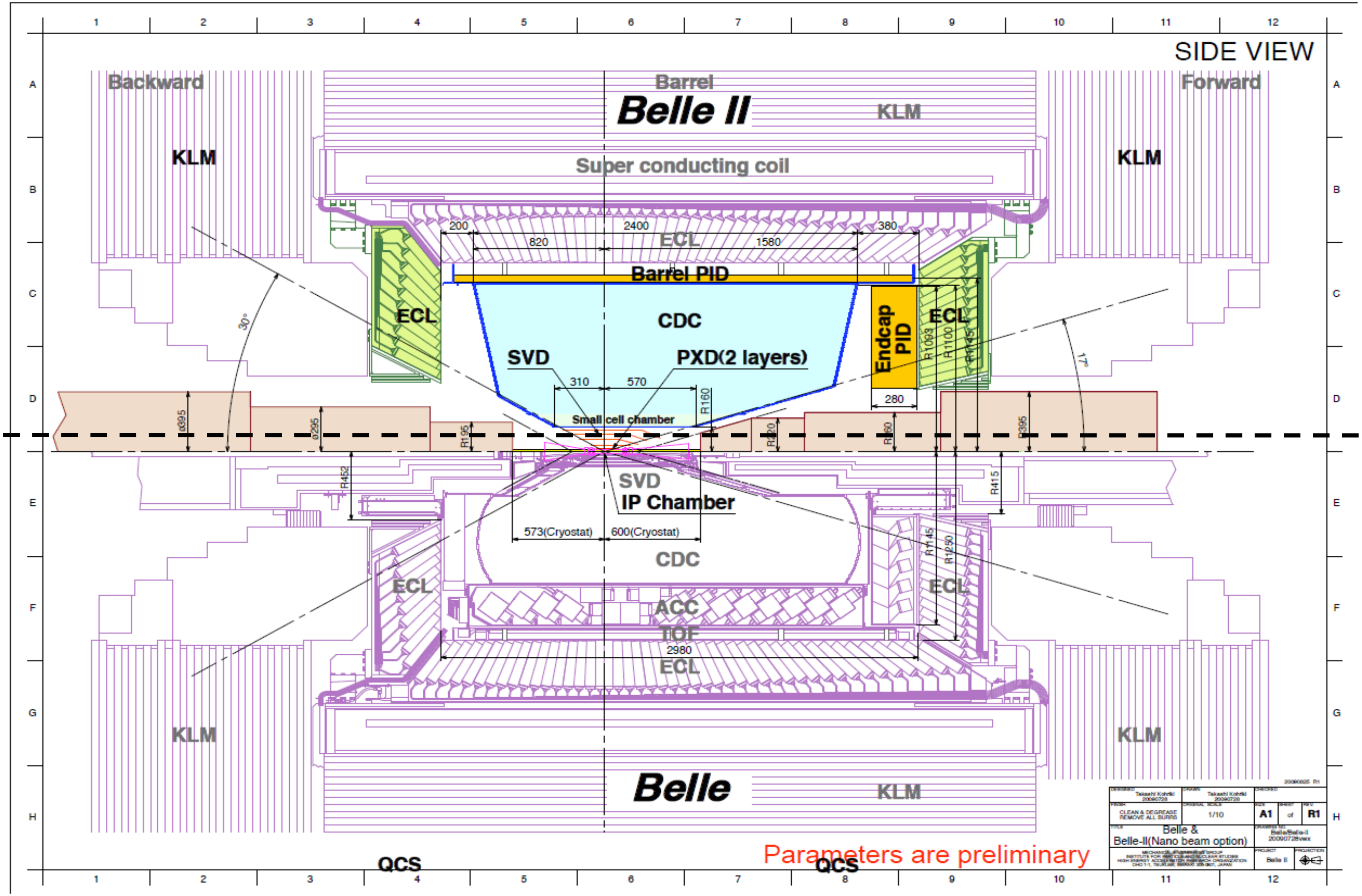


Schedule



Milestone of SuperKEKB
9 months/year
20 days/month
We will reach 50 ab-1
in 2020-2021.
Commissioning starts
in 2nd half of FY2014.
Shutdown
for upgrade
Integrated Luminosity (ab-1)
Peak Luminosity (cm-2s-1)
x10^35
70
60
50
40
30
20
10
0
8
6
4
2
0
2010
2012
2014
2016
2018
2020
2022
Year

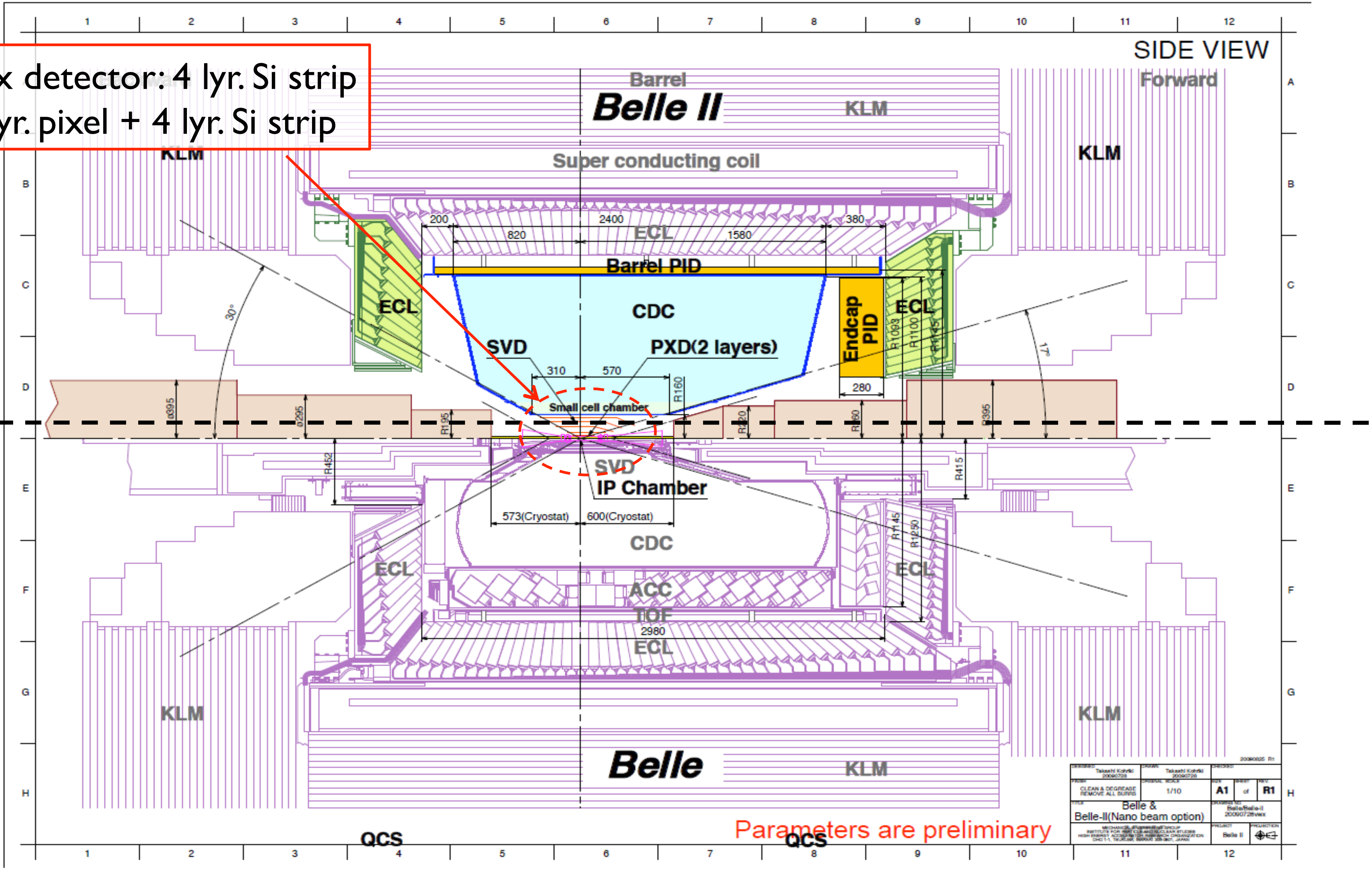
Detector Upgrade



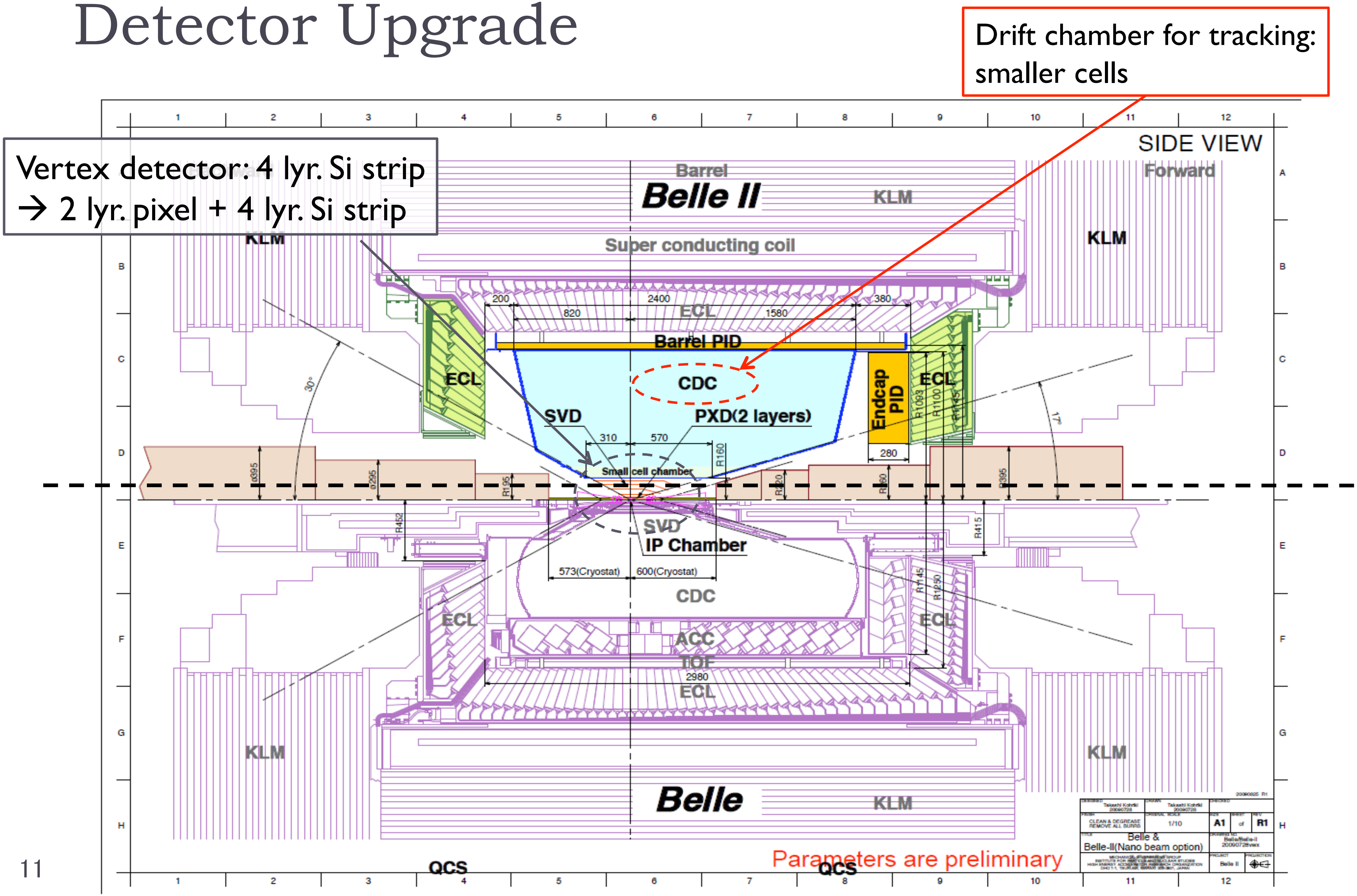
Parameters are preliminary

Detector Upgrade

Vertex detector: 4 lyr. Si strip
→ 2 lyr. pixel + 4 lyr. Si strip



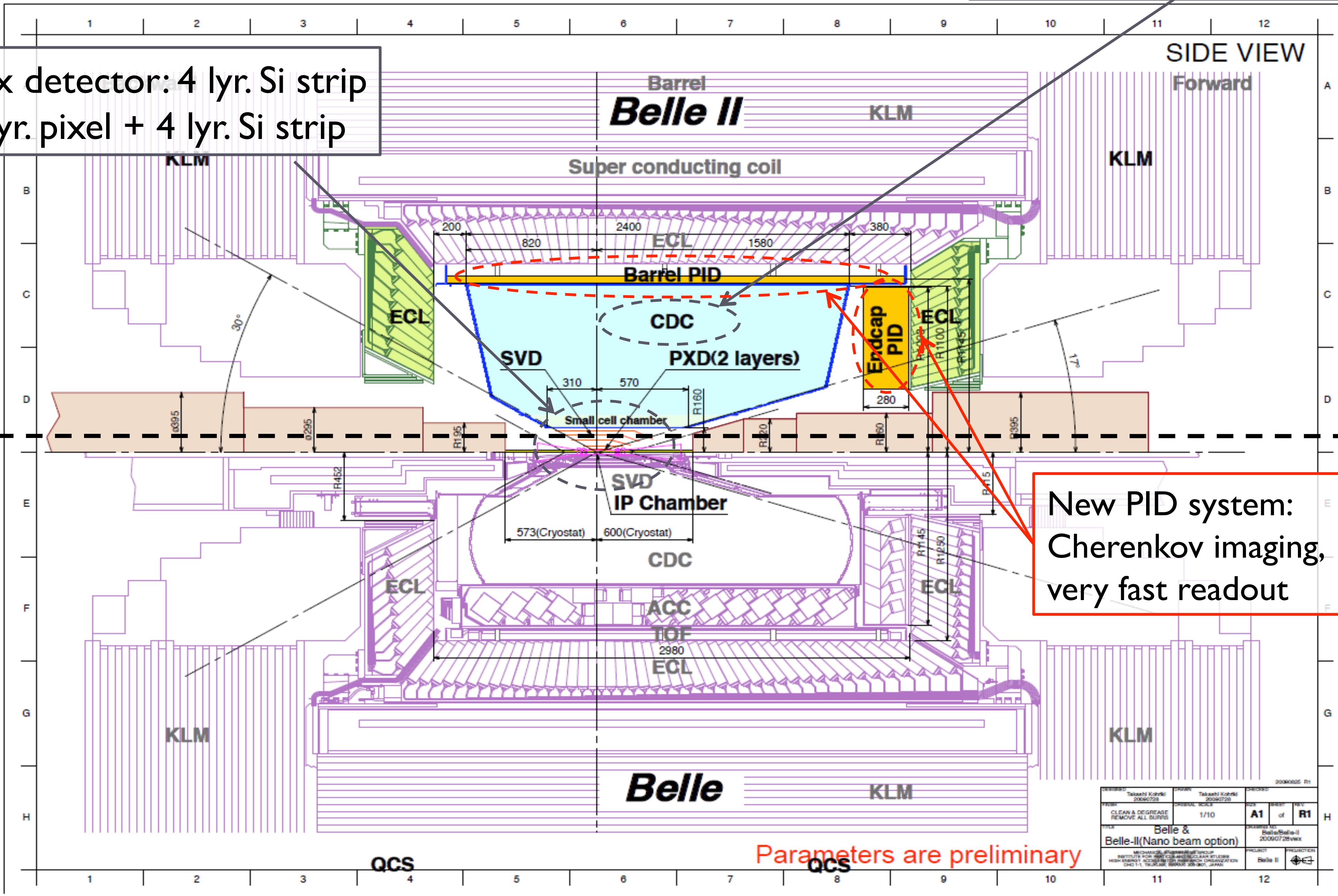
Detector Upgrade



Detector Upgrade

Drift chamber for tracking: smaller cells

Vertex detector: 4 lyr. Si strip
→ 2 lyr. pixel + 4 lyr. Si strip



New PID system: Cherenkov imaging, very fast readout

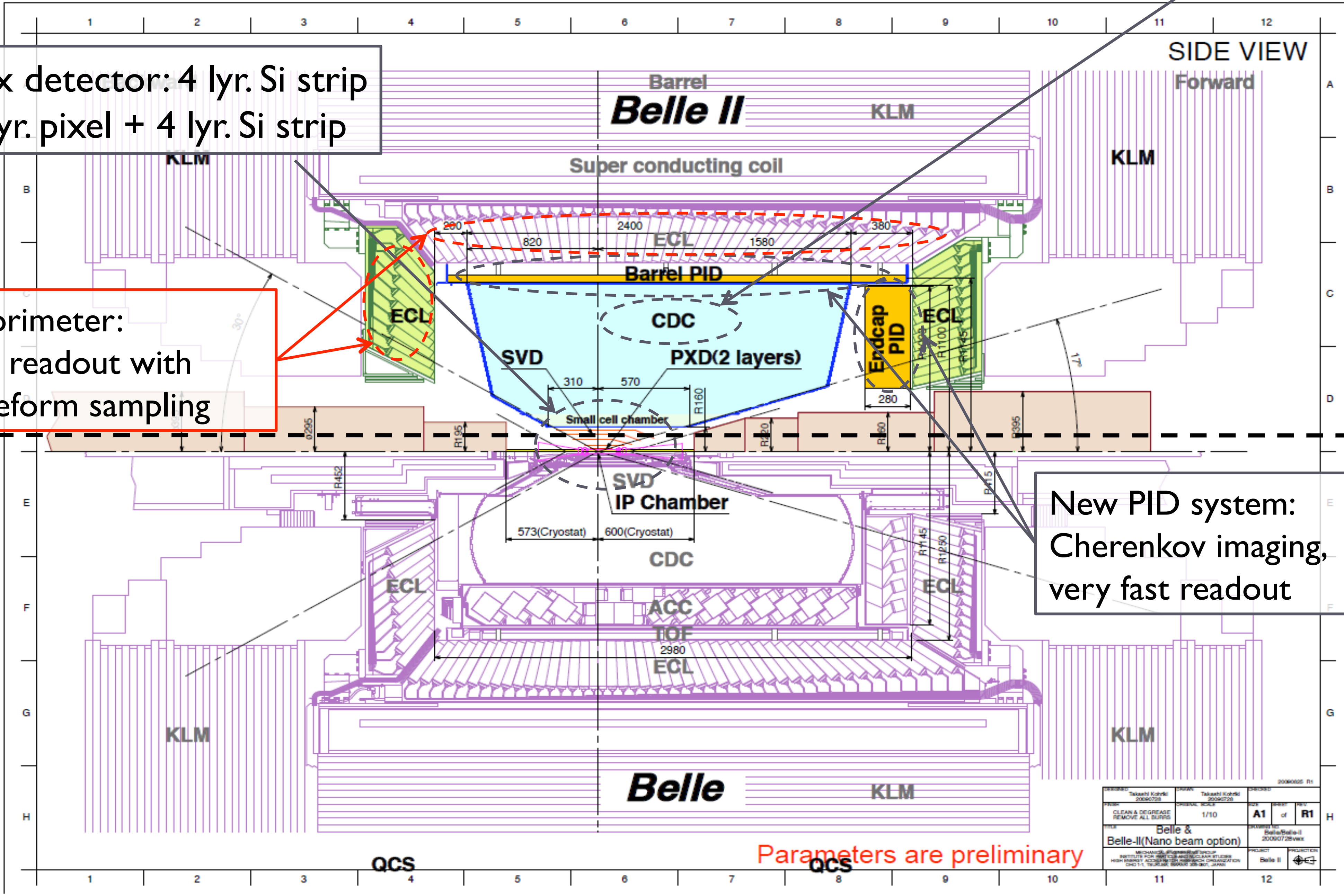
Detector Upgrade

Drift chamber for tracking: smaller cells

Vertex detector: 4 lyr. Si strip
→ 2 lyr. pixel + 4 lyr. Si strip

Calorimeter:
new readout with
waveform sampling

New PID system:
Cherenkov imaging,
very fast readout



Detector Upgrade

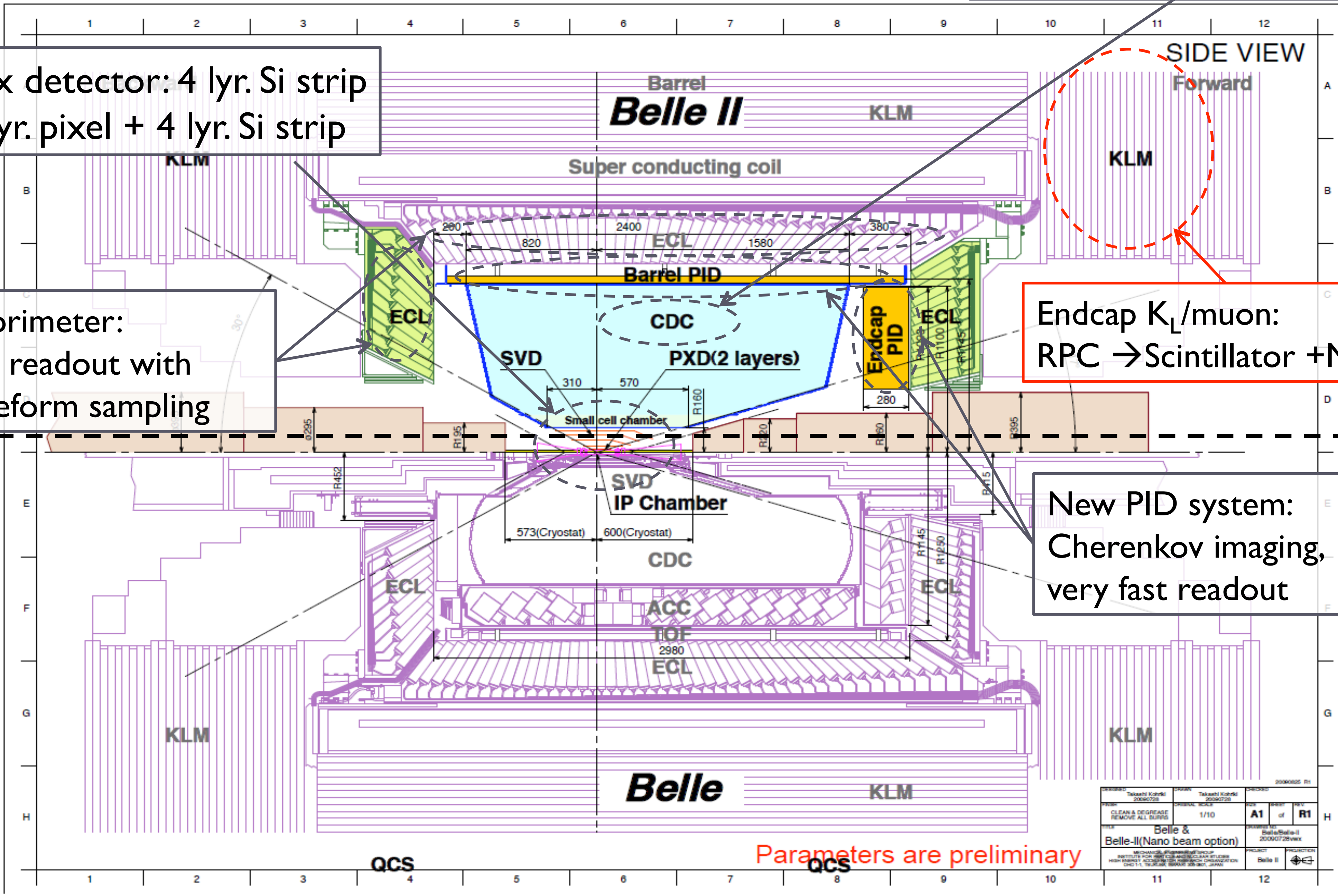
Drift chamber for tracking: smaller cells

Vertex detector: 4 lyr. Si strip
→ 2 lyr. pixel + 4 lyr. Si strip

Calorimeter:
new readout with
waveform sampling

Endcap K_L/muon:
RPC →Scintillator +MPPC

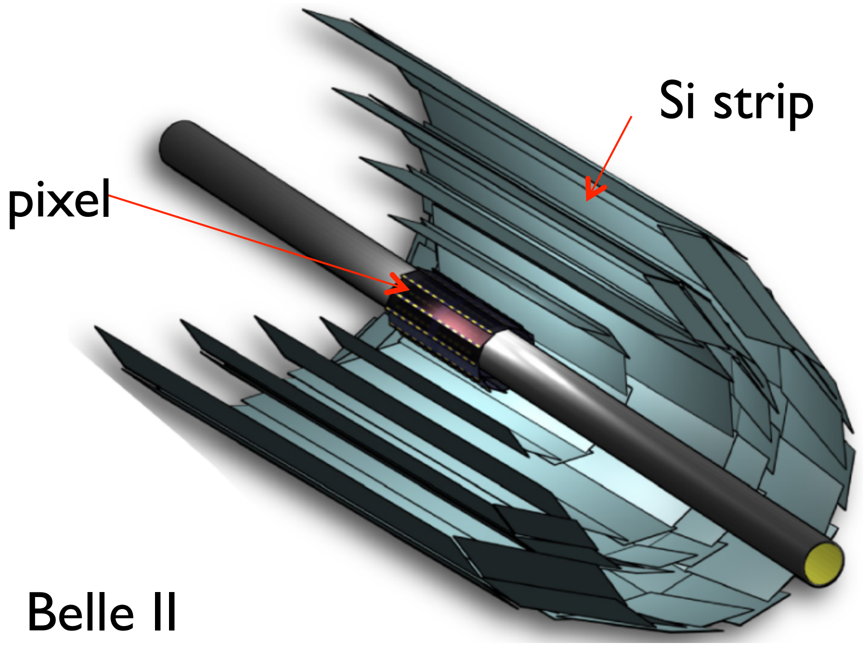
New PID system:
Cherenkov imaging,
very fast readout



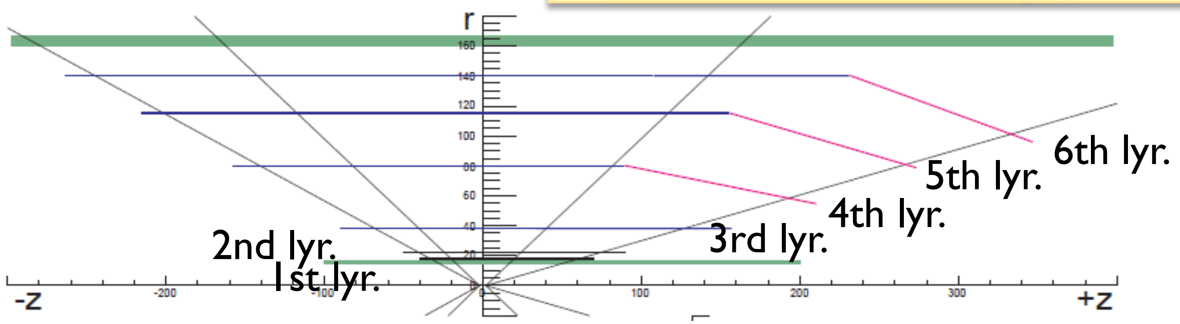
Vertex Detector

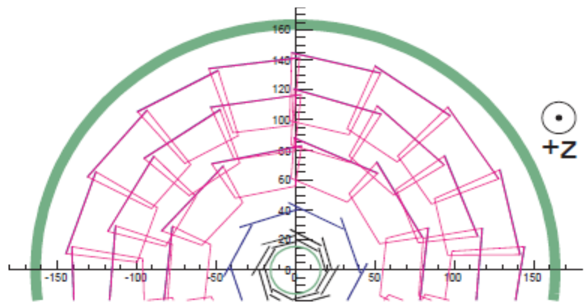
4lyr. Si strip → 2lyr. pixel(DEPFET) + 4lyr. Si strip

Improve decay-time precision and acceptance (K_S's).



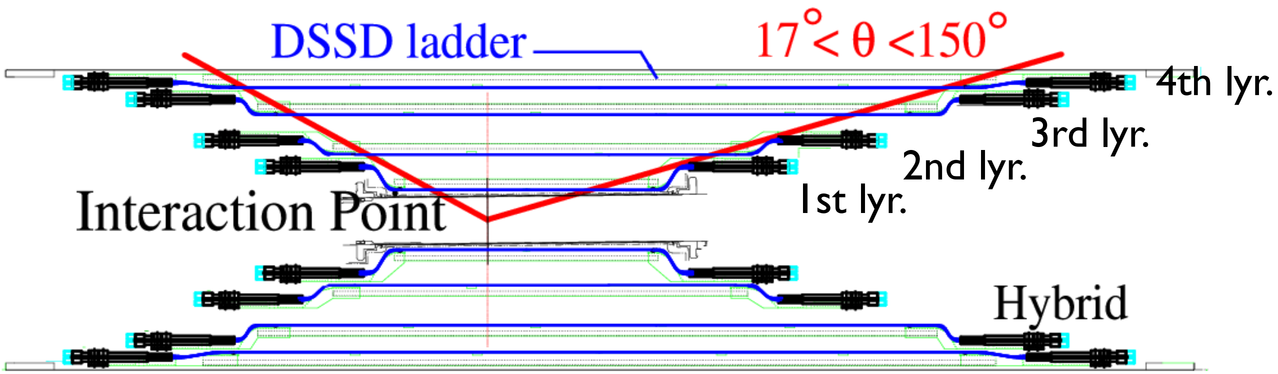
Belle II

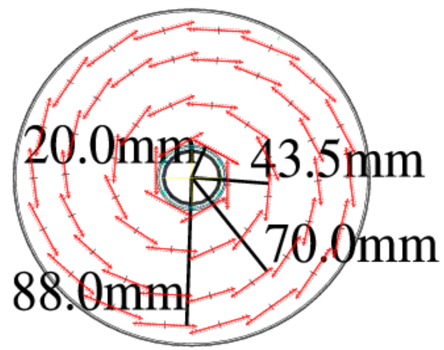




Pixel:
r=14,22mm
Si strip:
r=38,80,115,140mm

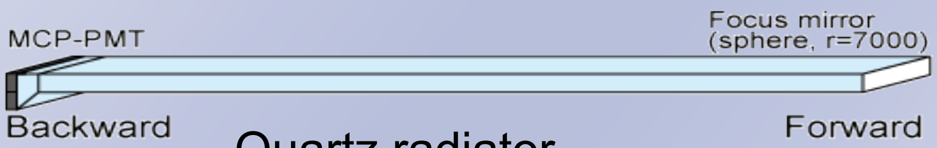
Belle





Particle Identification System at Belle II

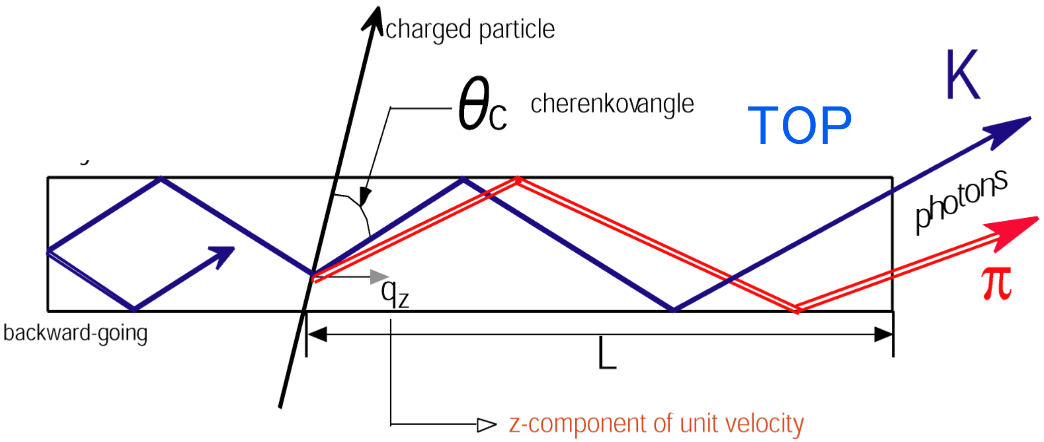
Barrel PID: Time of Propagation Counter (TOP)



Quartz radiator

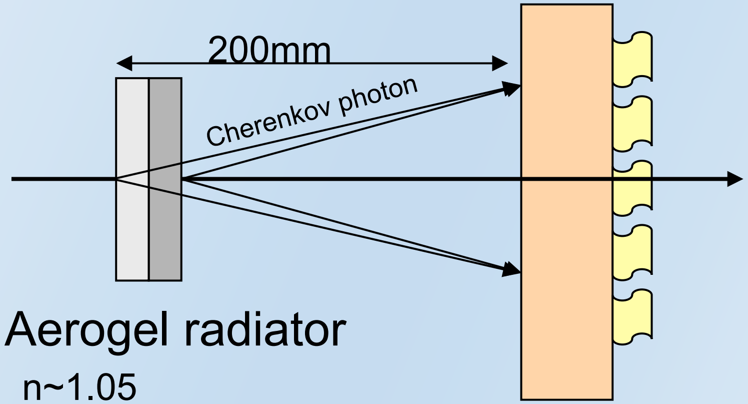
Focusing mirror

Hamamatsu MCP-PMT (measure t, x and y)



Completely different from PID at Belle, with better K/π separation, more tolerance for BG, and less material.

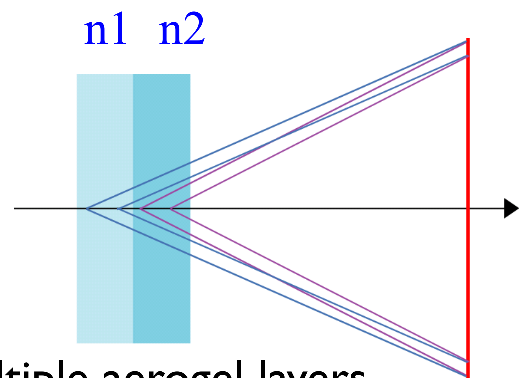
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

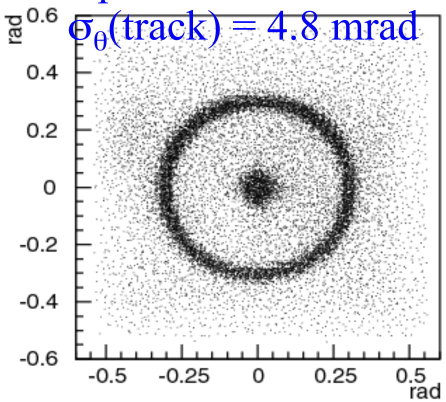
n~1.05

Hamamatsu HAPD
+ new ASIC



Multiple aerogel layers with different indices

σ_θ(1p.e.) = 14.4 mrad
Npe ~ 9.6
σ_θ(track) = 4.8 mrad



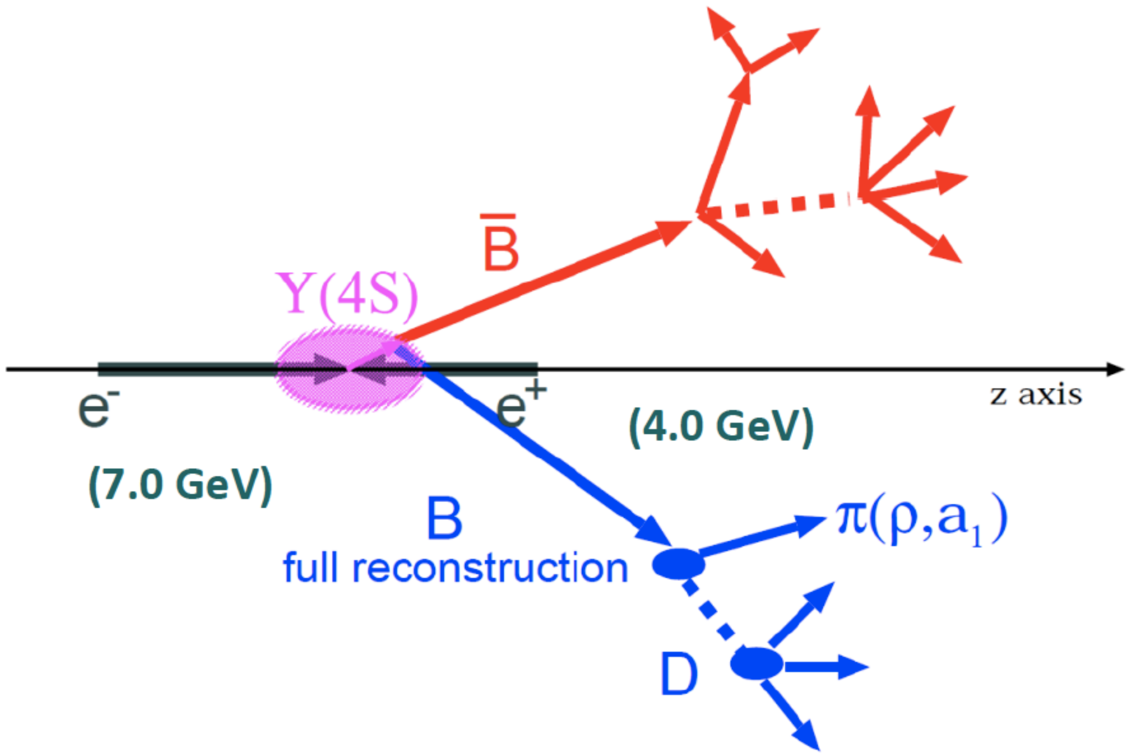
More information of Belle II detector:

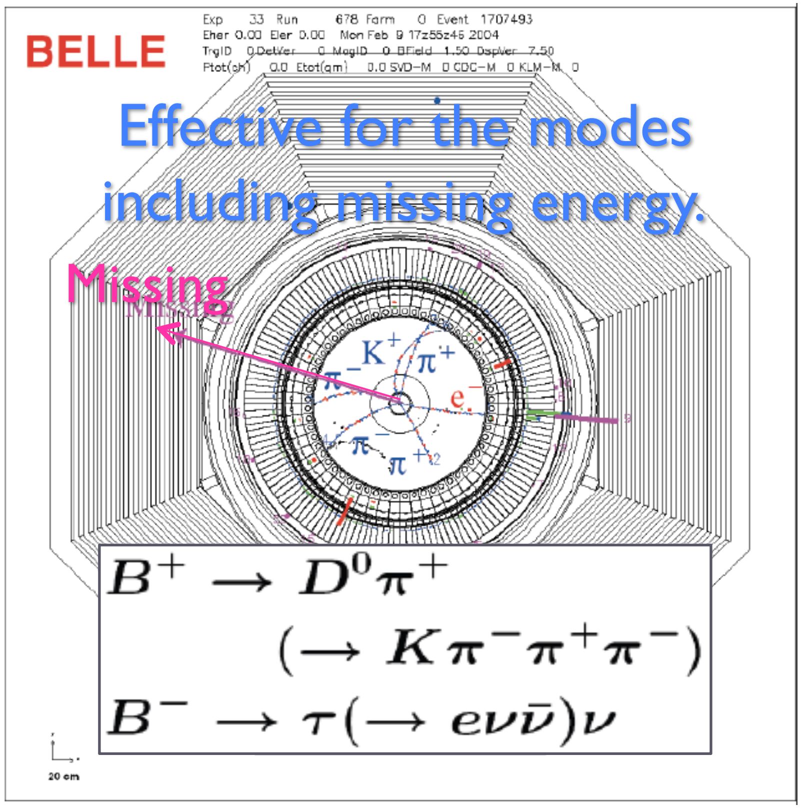
"Belle II Technical Design Report" at arXiv:1011.0352.

Physics at SuperKEKB/Belle II

- A benefit to use $e^+e^- \to \Upsilon(4S) \to B\bar{B}$

One B meson ("tag" side) can be reconstructed in a common decay.
Flavor, charge, and momentum of the other B can be determined.





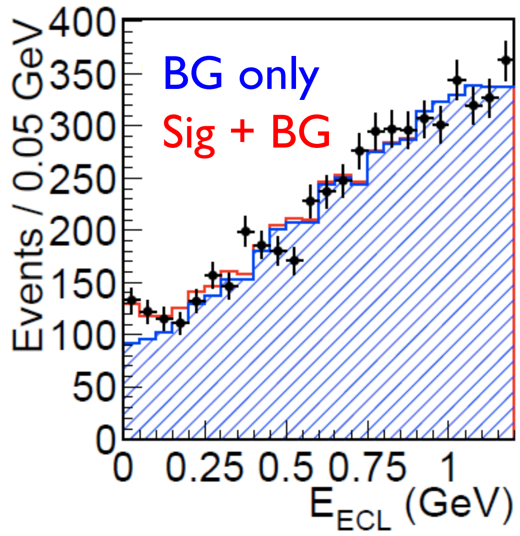
Also possible to partially reconstruct (semileptonically, …).

B→τν

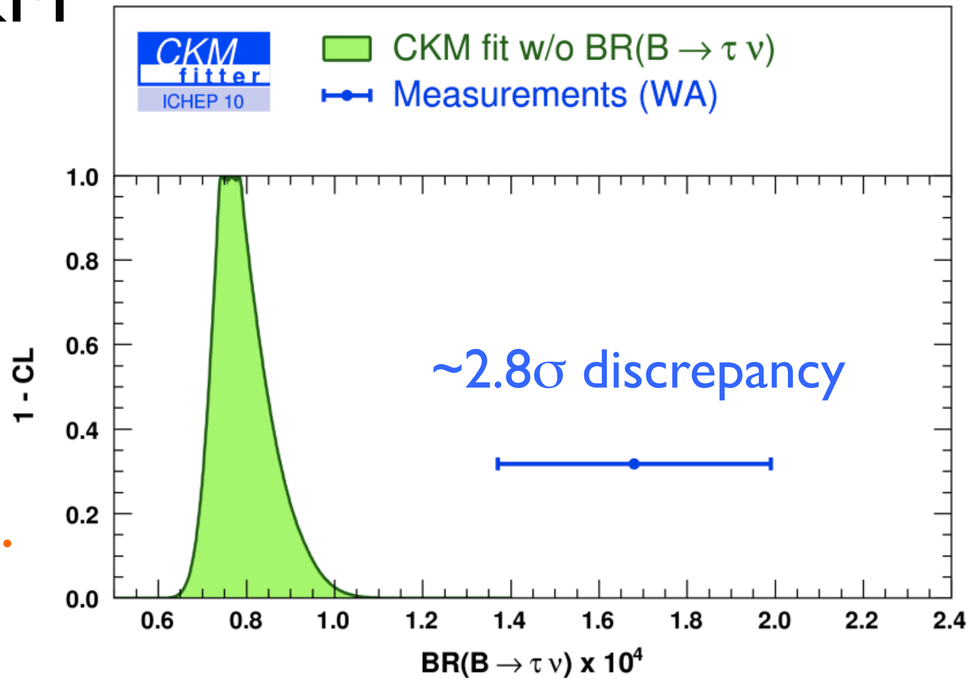
- Evidence obtained at the B factories.

Example w/ semileptonic tag, 0.6 ab^{-1}
PRD 82, 071101 (2010)

$$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau) = (1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})) \times 10^{-4}$$



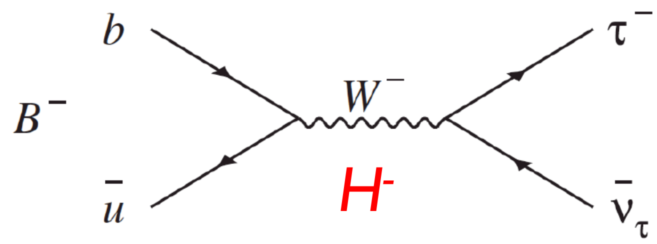
- Tension between the global CKM fit and direct measurement.



Better measurement of B→τν may reveal source of the tension.
Tag-side information is vital for ≥ 2ν's.

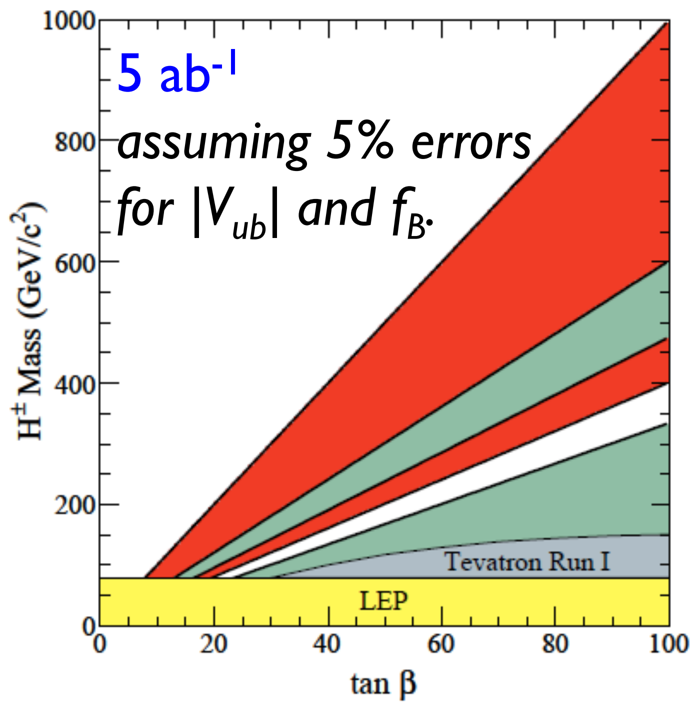
B→τν at Belle II

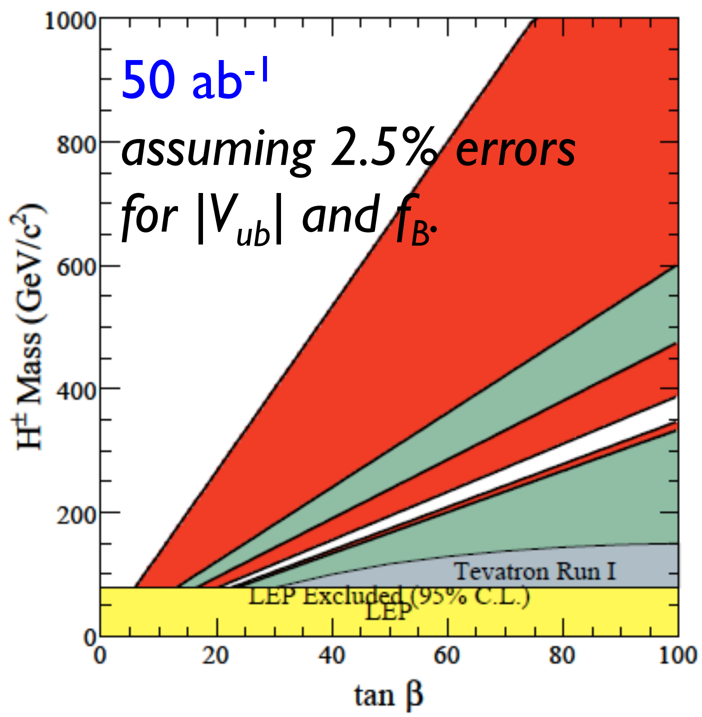
- In Two-Higgs Doublet Model (THDM) Type II, the branching ratio of B→τν can be modified.



$$\mathcal{B}(B^- \to \tau^- \nu) = \mathcal{B}_{\rm SM}(B^- \to \tau^- \nu) \left[1 - \frac{m_B^2}{m_{H^\pm}^2} \tan^2 \beta \right]^2$$

Constrains on $m_{H\pm}$ and $\tan\beta$ can be obtained.



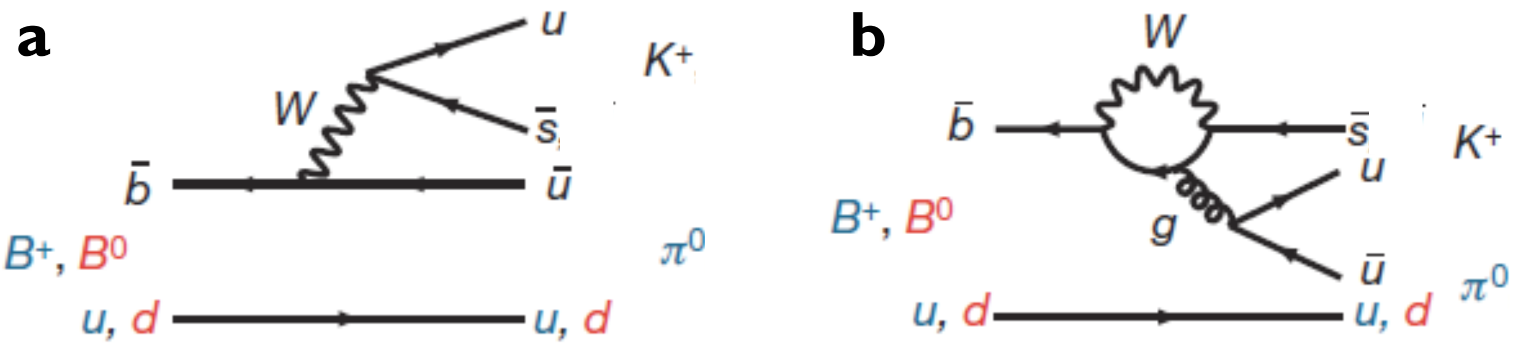


5 σ discovery region

current 95% exclusion

Direct CP Violation for B→Kπ

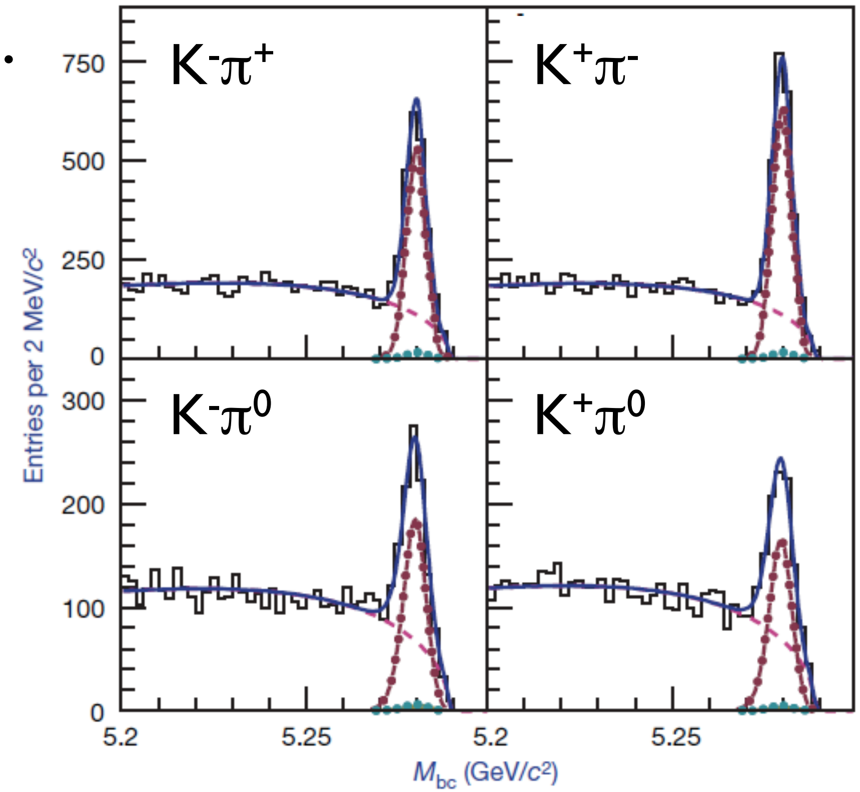
If the only diagrams are **a** and **b**, we expect $\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = 0$



However, significant difference is obtained.

$$\Delta\mathcal{A} = +0.164 \pm 0.037$$

B→Kπ w/ 0.5 ab^{-1}
Nature 452, 332 (2008)



Missing diagrams?

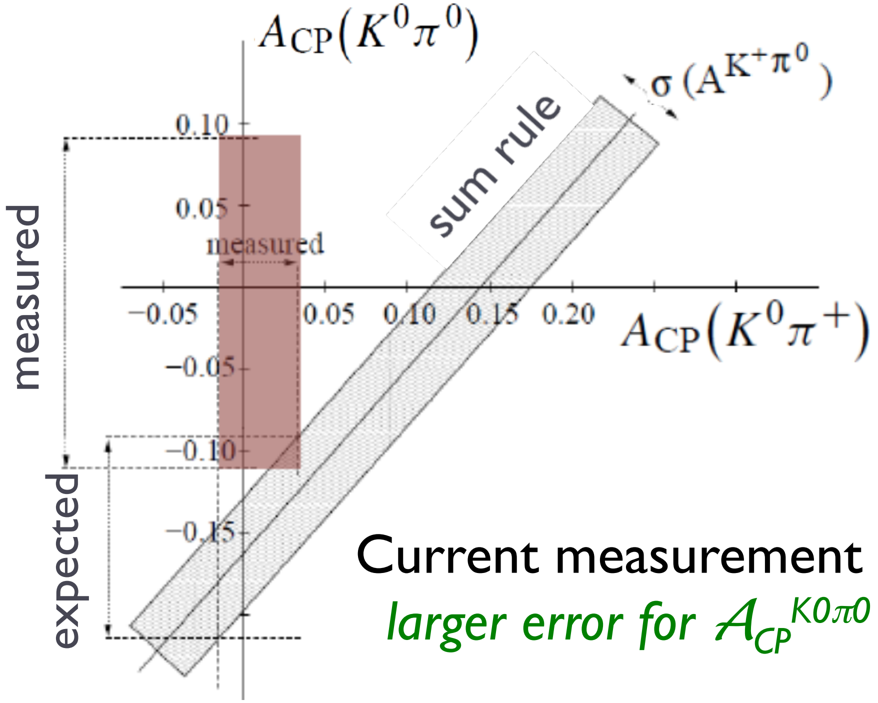
Large theoretical uncertainty…

Direct CP Violation for B→Kπ at Belle II

- We can compare to a model-independent sum rule:

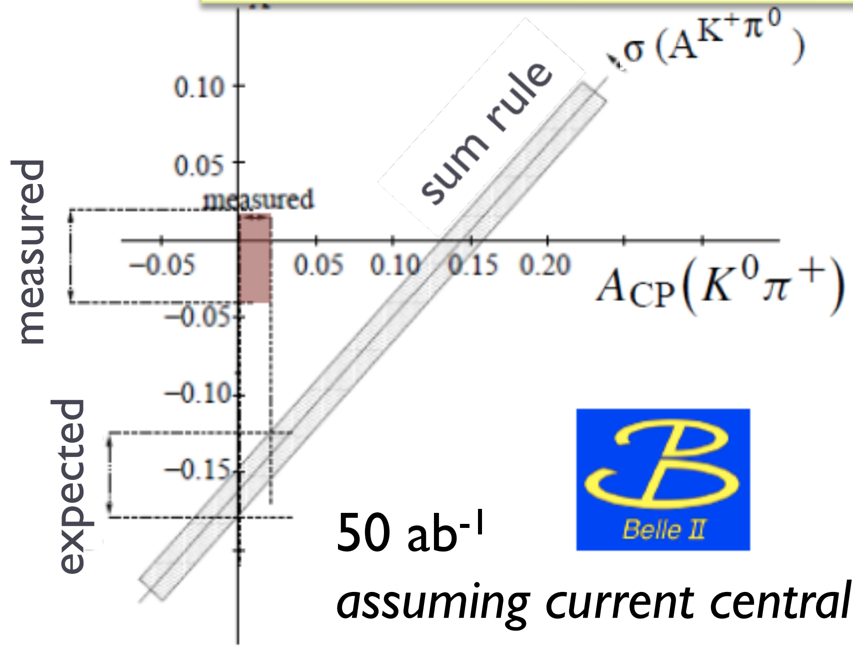
$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}$$
$$= A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

Can be represented as diagonal band (slope precisely known from $\mathcal{B}$ and lifetimes):



Current measurement
larger error for $A_{CP}^{K0\pi0}$

Belle II provides a good environment for the all neutral final state ($K^0\pi^0$).

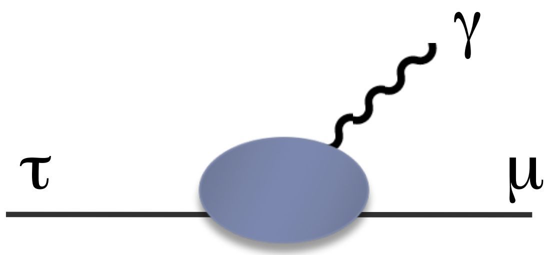


50 ab^{-1}
assuming current central value

Decays of τ

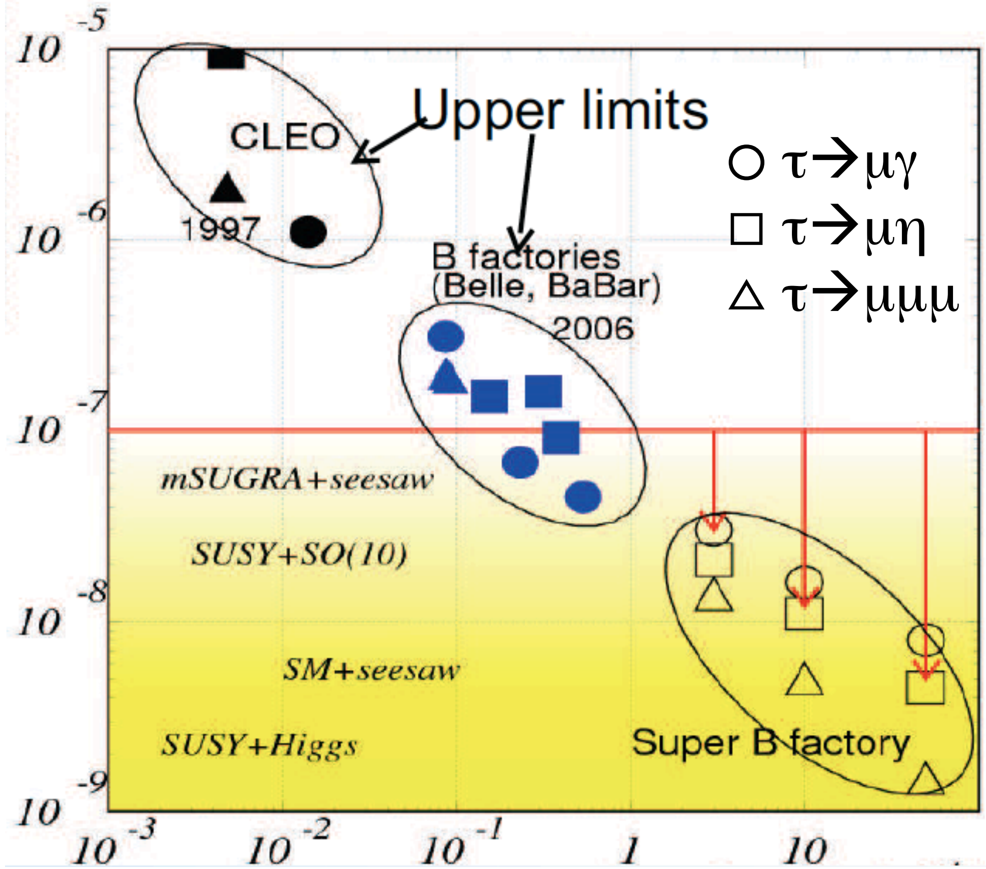
Example: $\tau \rightarrow \mu\gamma$

- Can be enhanced by the effects of new physics in the loop diagram.



model	$Br(\tau\rightarrow\mu\gamma)$
mSUGRA+seesaw	10^{-7}
SUSY+SO(10)	10^{-8}
SM+seesaw	10^{-9}
Non-Universal Z′	10^{-9}
SUSY+Higgs	10^{-10}

Belle II provides good sensitivities on the τ decays.



Integrated luminosity (ab^{-1})

More information of physics prospects:

"Physics at Super B Factory" at arXiv:1002.5012.

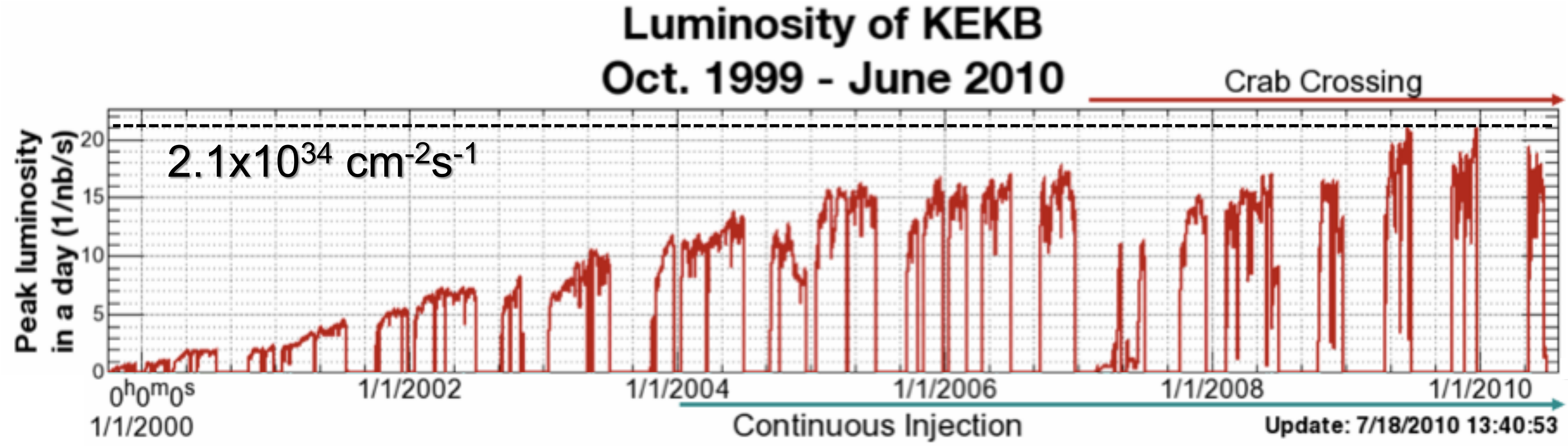
Summary

KEK collider Belle detector	→	SuperKEKB collider Belle II detector
Operation from1999 to 2010. Peak luminosity = 2.1 x 10^{34} / cm^2s. Integrated luminosity = 1.0 ab^{-1}.		Aim to start commissioning in 2014. Target of peak luminosity = 8 x 10^{35} / cm^2s. Target of integrated luminosity = 50 ab^{-1} by 2021.

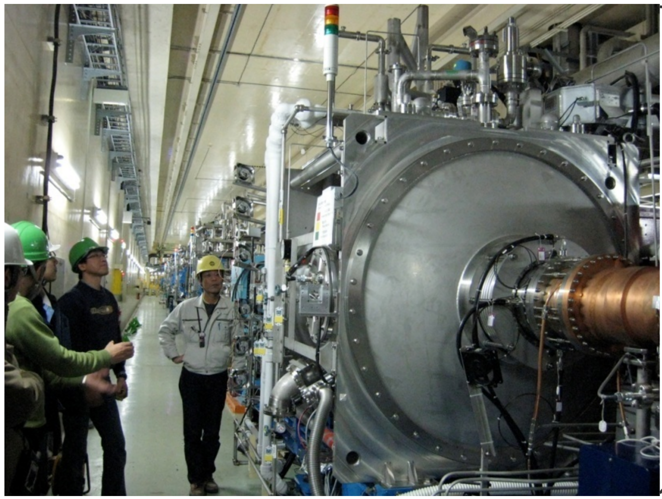
- Significant opportunities to search for new physics at SuperKEKB/Belle II. *($B \to \tau\nu$, $B \to K\pi$, τ decays, etc.)*
- More information:
  - "Belle II Technical Design Report" at arXiv:1011.0352.
  - "Physics at Super B Factory" at arXiv:1002.5012.

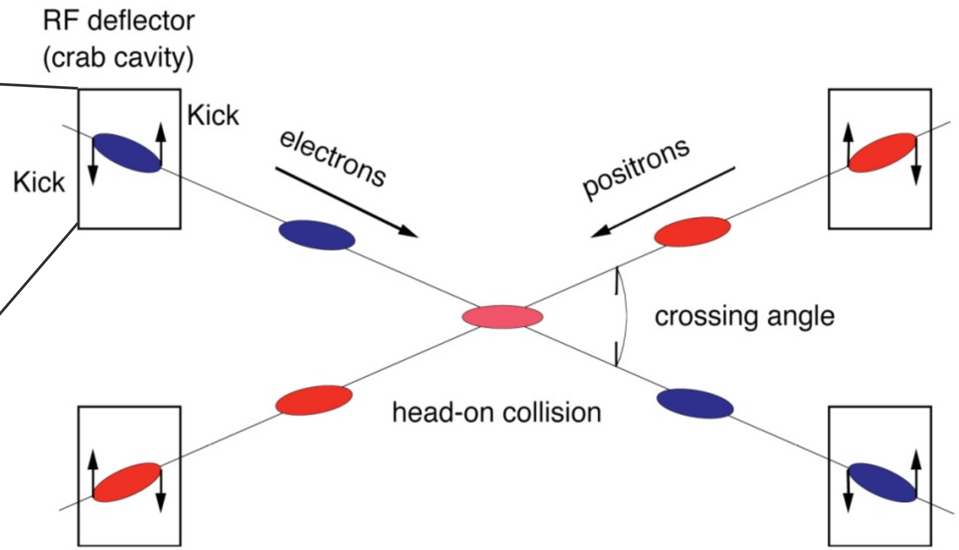
Backup Slides

KEKB Collider



Crab crossing:





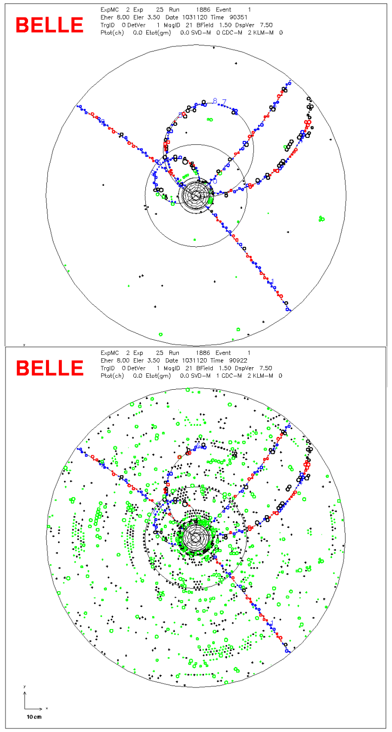
Funds for SuperKEKB

- 100 oku-yen (~100 million dollars) approved in summer 2010.
- Upgrade approved by the cabinet in December 2010.
- Waiting for the final approval by the Diet.

Belle II Detector

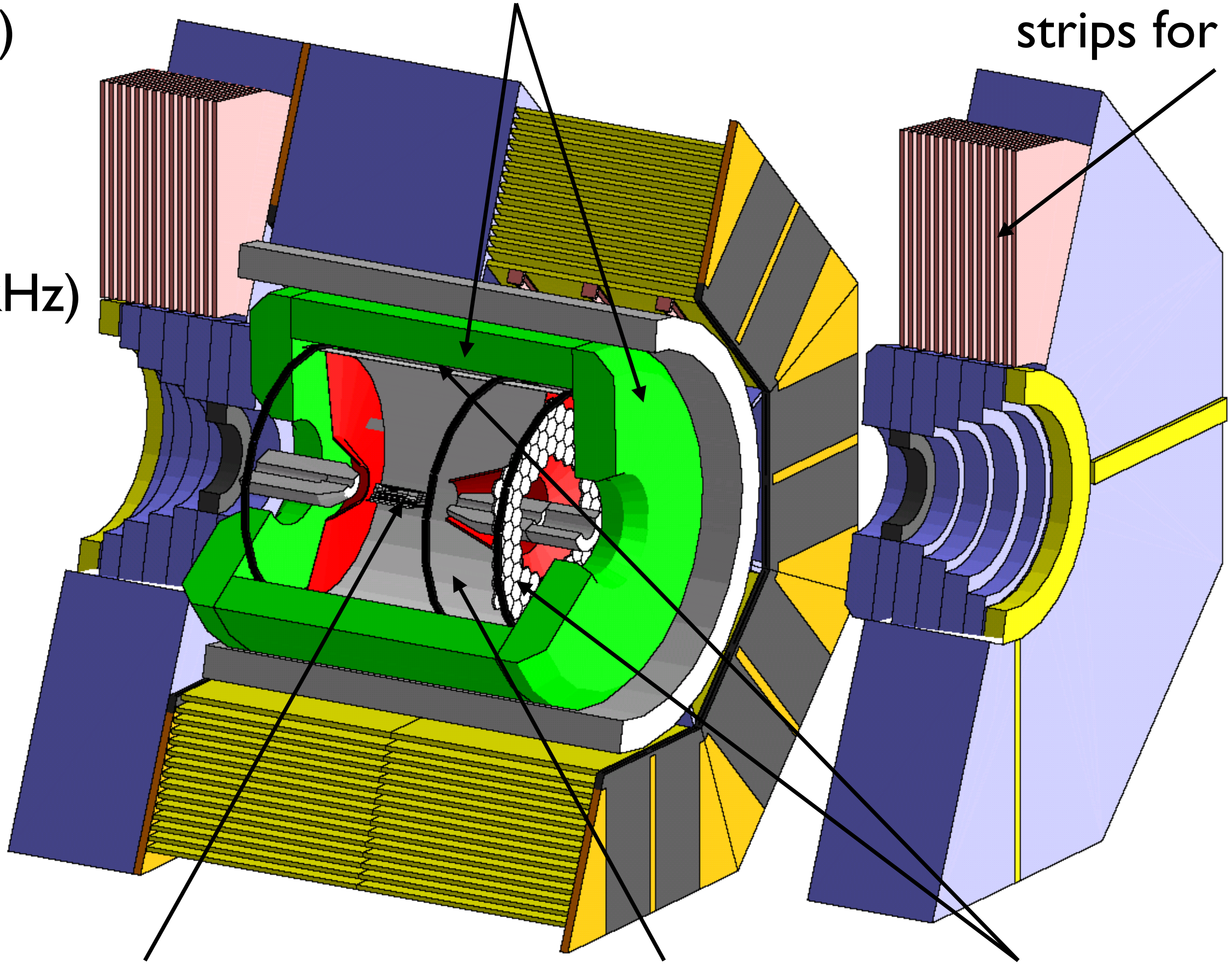
Have to deal with:

- Higher background (10-20x)
  - radiation damage,
  - higher occupancy
- Higher event rates
  - DAQ (L1 trigg. 0.5 →20 kHz)
- Improved performance
  - hermeticity



Calorimeter: waveform sampling

K_L, μ: scintillator strips for endcaps



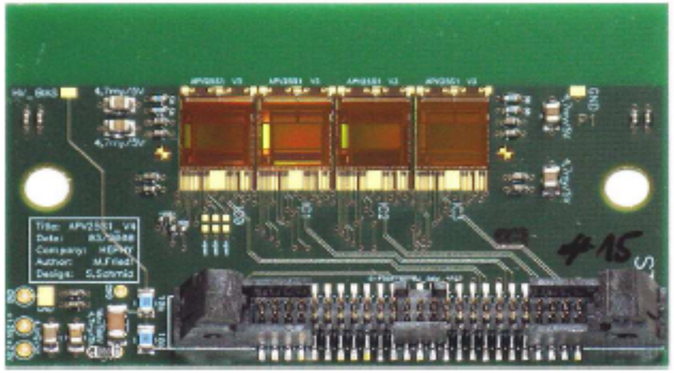
Vertexing:
2 lyrs DEPFET pixel
4 lyrs DSSD

Drift Chamber:
smaller cell size
improved read-out

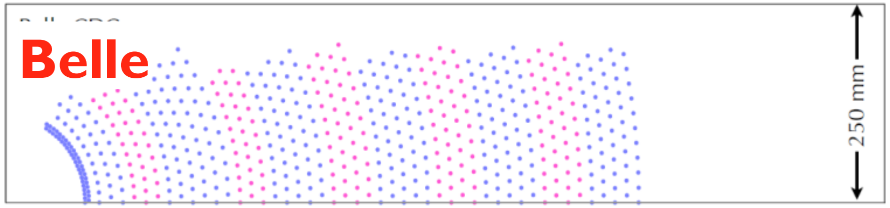
PID:
TOP barrel
ARICH forward

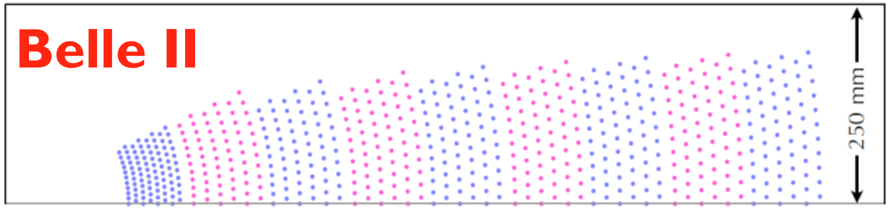
Other Upgrades for Belle II

Silicon vertex detector:
new readout chip (APV25)
shorter integration time (800 ns→50 ns)

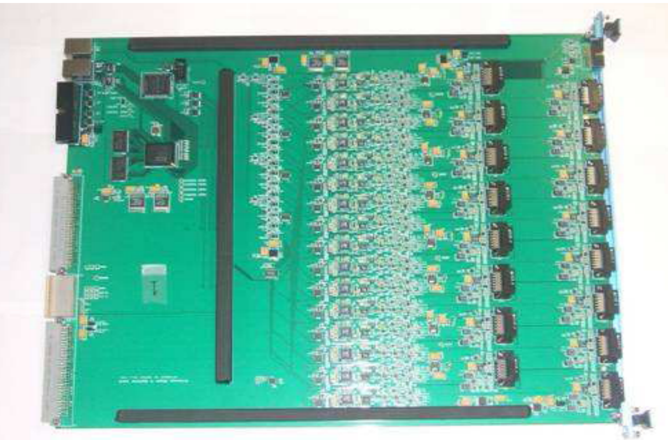


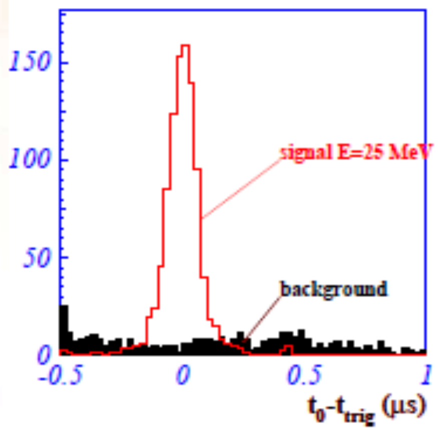
Drift chamber: smaller cells



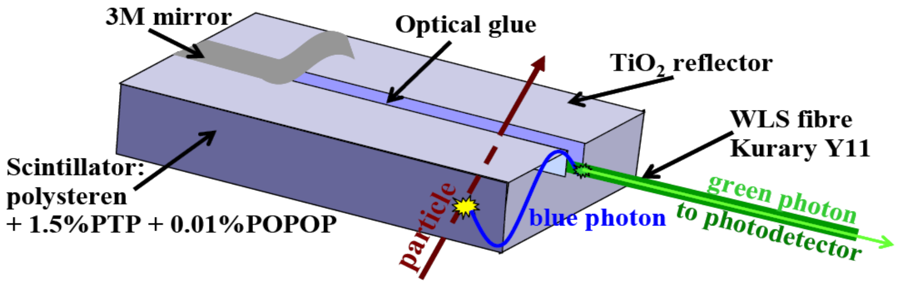


Calorimeter: new readout system with waveform sampling (x1/7 BG reduction)





K_L/Muon detector
RPC→Scintillator+MPPC



Better performance against neutron BG

Expected Performance for Belle II

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 $\sigma_{z_0} \sim 20\ \mu$m (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	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ 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) $\sigma_{dE/dx} = 5\%$
TOP	RICH with quartz radiator	16 segments in ϕ at $r \sim 120$ cm 275 cm long, 2 cm thick quartz bars with 4x4 channel MCP PMTs	8 k	$N_{p.e.} \sim 20$, $\sigma_t = 40$ ps K/π separation : efficiency > 99% at < 0.5% pion fake prob. for $B \to \rho\gamma$ decays
ARICH	RICH with aerogel radiator	4 cm thick focusing radiator and HAPD photodetectors for the forward end-cap	78 k	$N_{p.e.} \sim 13$ K/π separation at 4 GeV/c: efficiency 96% at 1% pion fake prob.
ECL	CsI(Tl) (Towered structure)	Barrel: $r = 125$ - 162 cm End-cap: $z =$ -102 cm and +196 cm	6624 1152 (F) 960 (B)	$\frac{\sigma E}{E} = \frac{0.2\%}{E} \oplus \frac{1.6\%}{\sqrt[4]{E}} \oplus 1.2\%$ $\sigma_{pos} = 0.5$ cm$/\sqrt{E}$ (E in GeV)
KLM	barrel: RPCs end-caps: scintillator strips	14 layers (5 cm Fe + 4 cm gap) 2 RPCs in each gap 14 layers of $(7-10) \times 40$ mm^2 strips read out with WLS and G-APDs	θ: 16 k, ϕ: 16 k 17 k	$\Delta\phi = \Delta\theta = 20$ mradian for K_L ~ 1 % hadron fake for muons $\Delta\phi = \Delta\theta = 10$ mradian for K_L $\sigma_p/p = 18\%$ for 1 GeV/c K_L