Belle II status and prospects for flavor physics

Jing-Ge Shiu/NTU
On behalf of the Belle II collaboration

LHCP2017

The Fifth Annual Conference
on Large Hadron Collider Physics
May 15-20, 2017, Shanghai , China

Belle II status and prospects for flavor physics

Outline

- SuperKEKB and Belle II
- Status and schedule
- Physics prospect

Belle II status and prospects for flavor physics

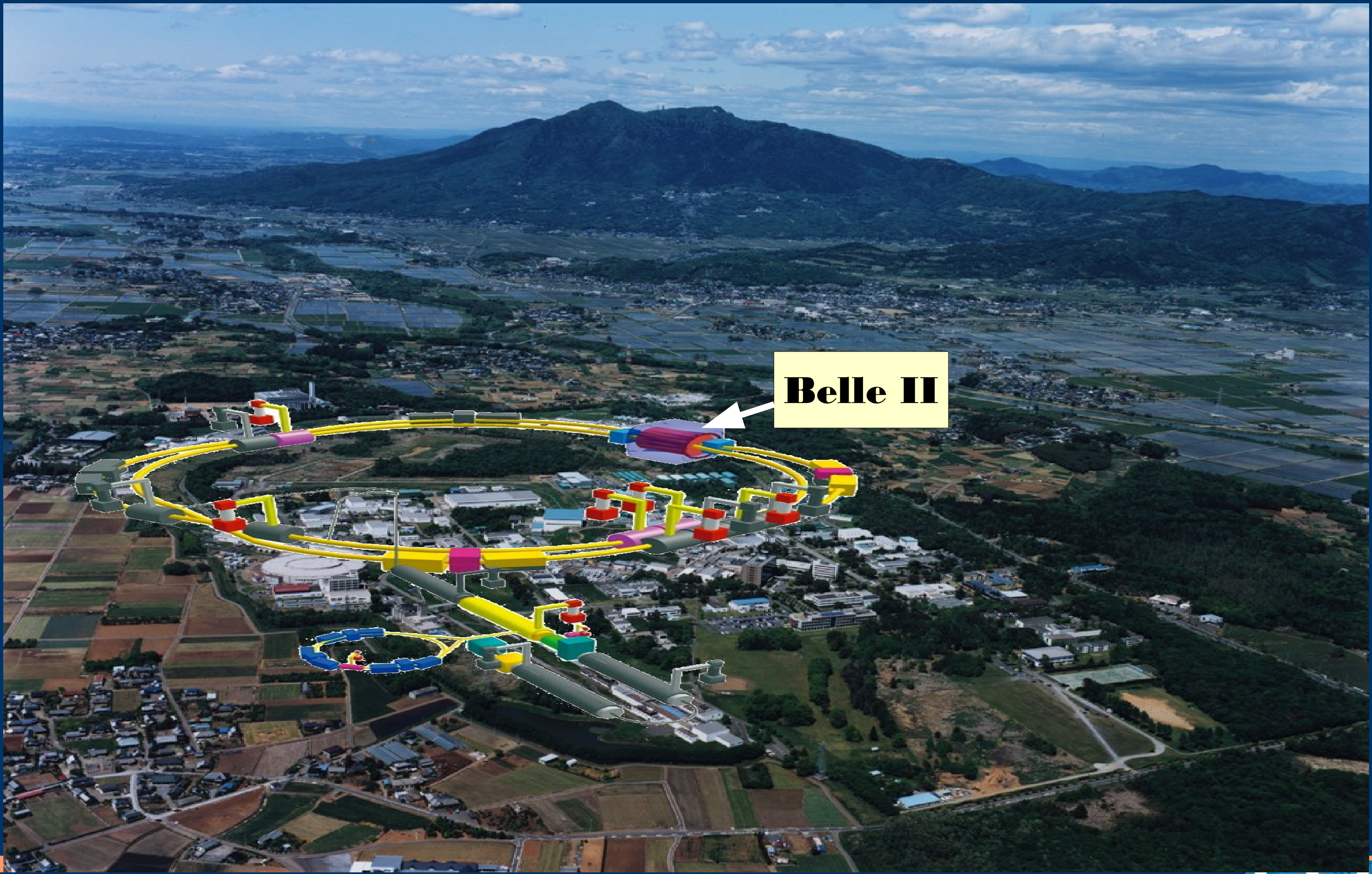
Outline

- SuperKEKB and Belle II
- Status and schedule
- Physics prospect

SuperKEKB @

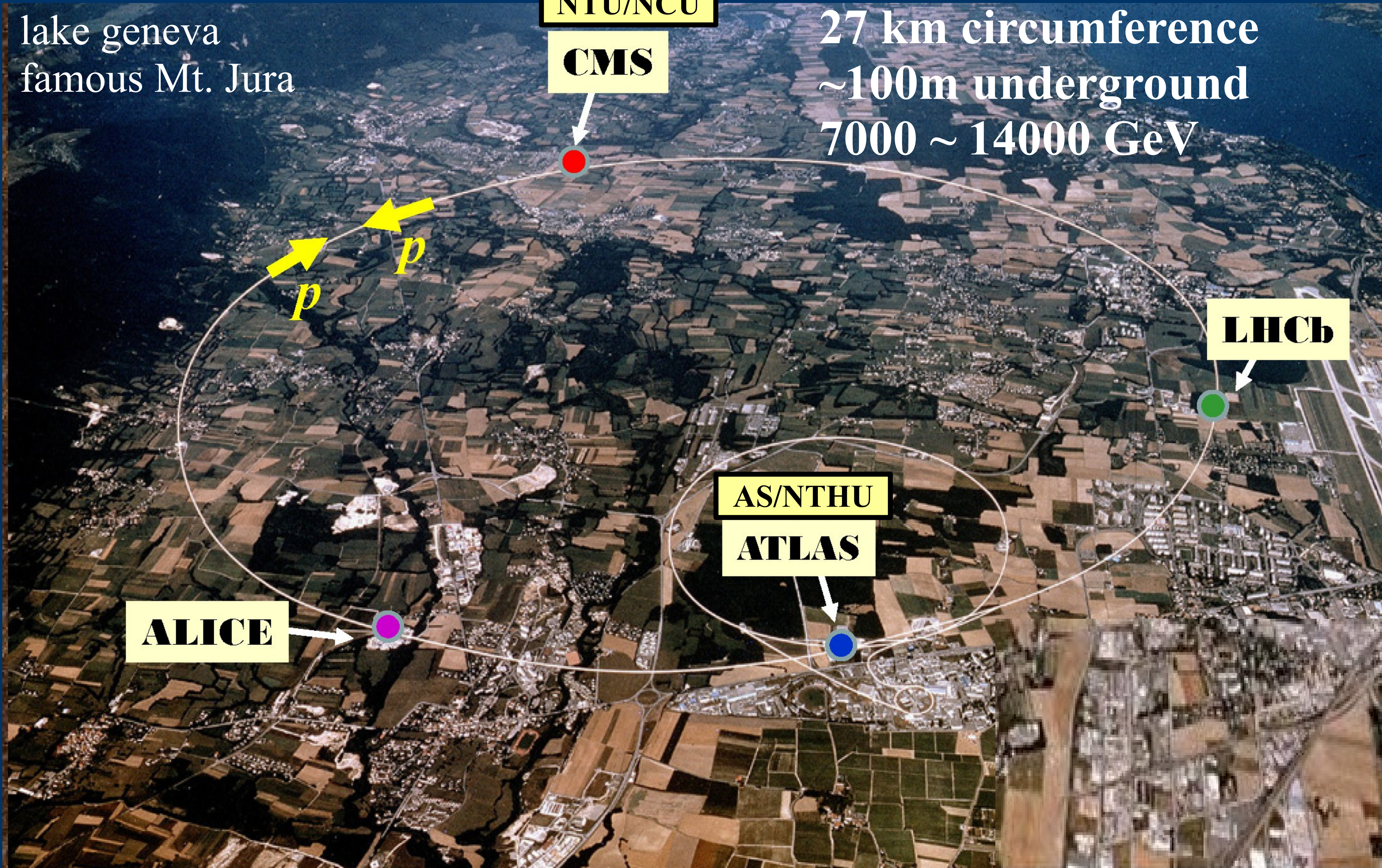
KEK 大学共同利用機関法人 高エネルギー加速器研究機構

Tsukuba, ~ 1.5 hours away from Tokyo
lake Kasumigaura（霞ヶ浦）
famous Mt. Tsukuba



LHCP 2017

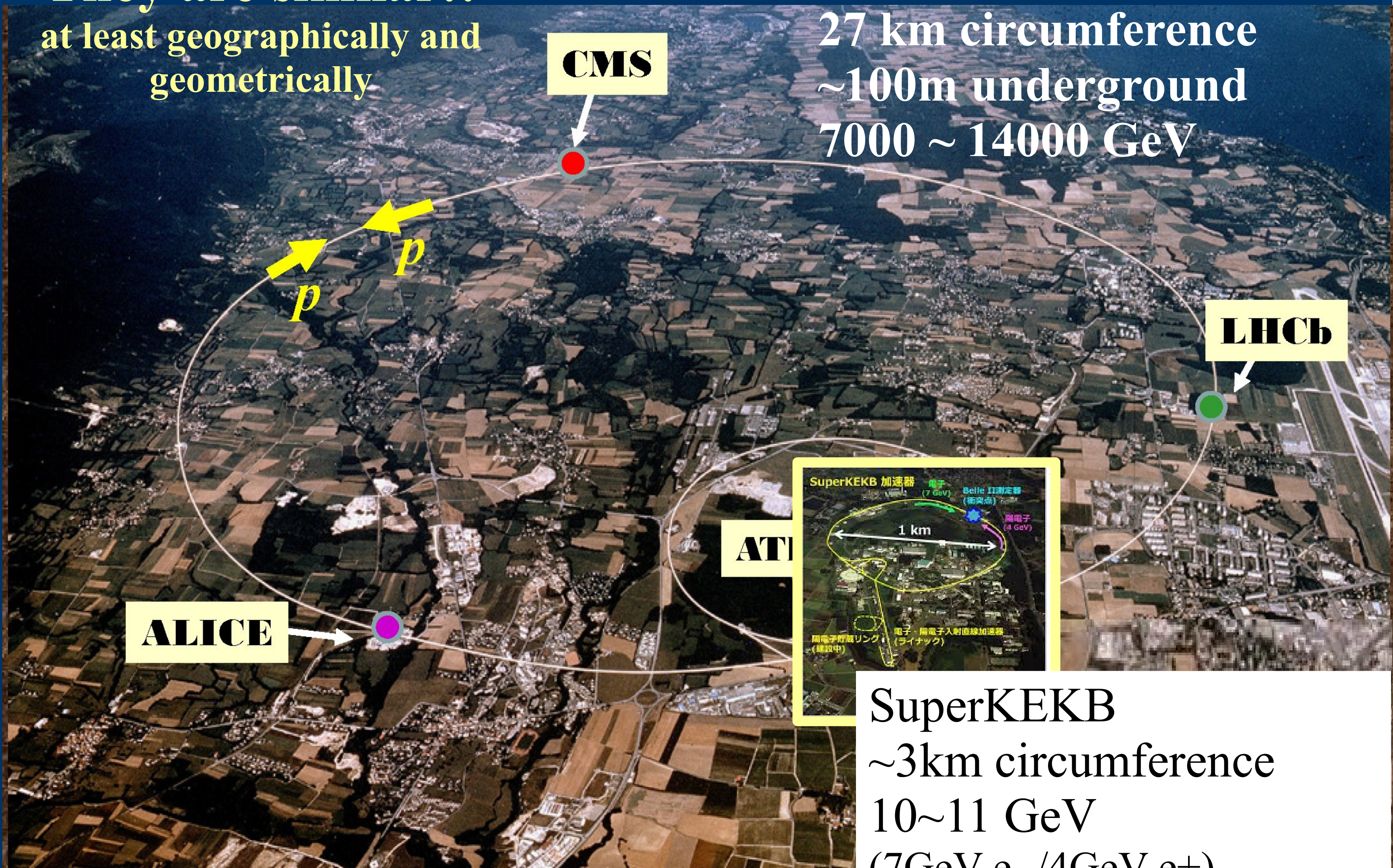
LHC
27 km circumference
~100m underground
7000 ~ 14000 GeV



They are similar!!

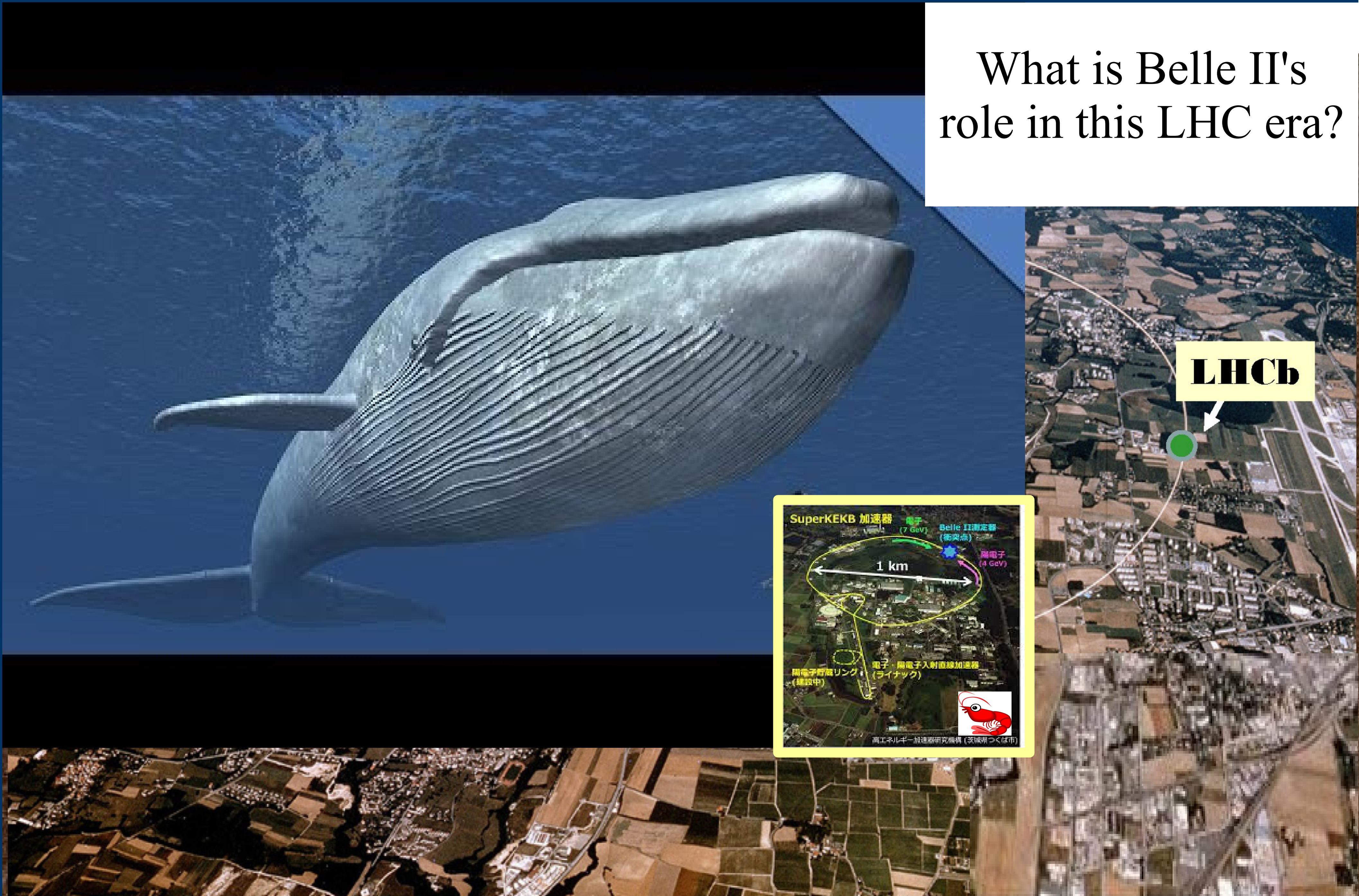
at least geographically and geometrically

LHC
27 km circumference
~100m underground
7000 ~ 14000 GeV



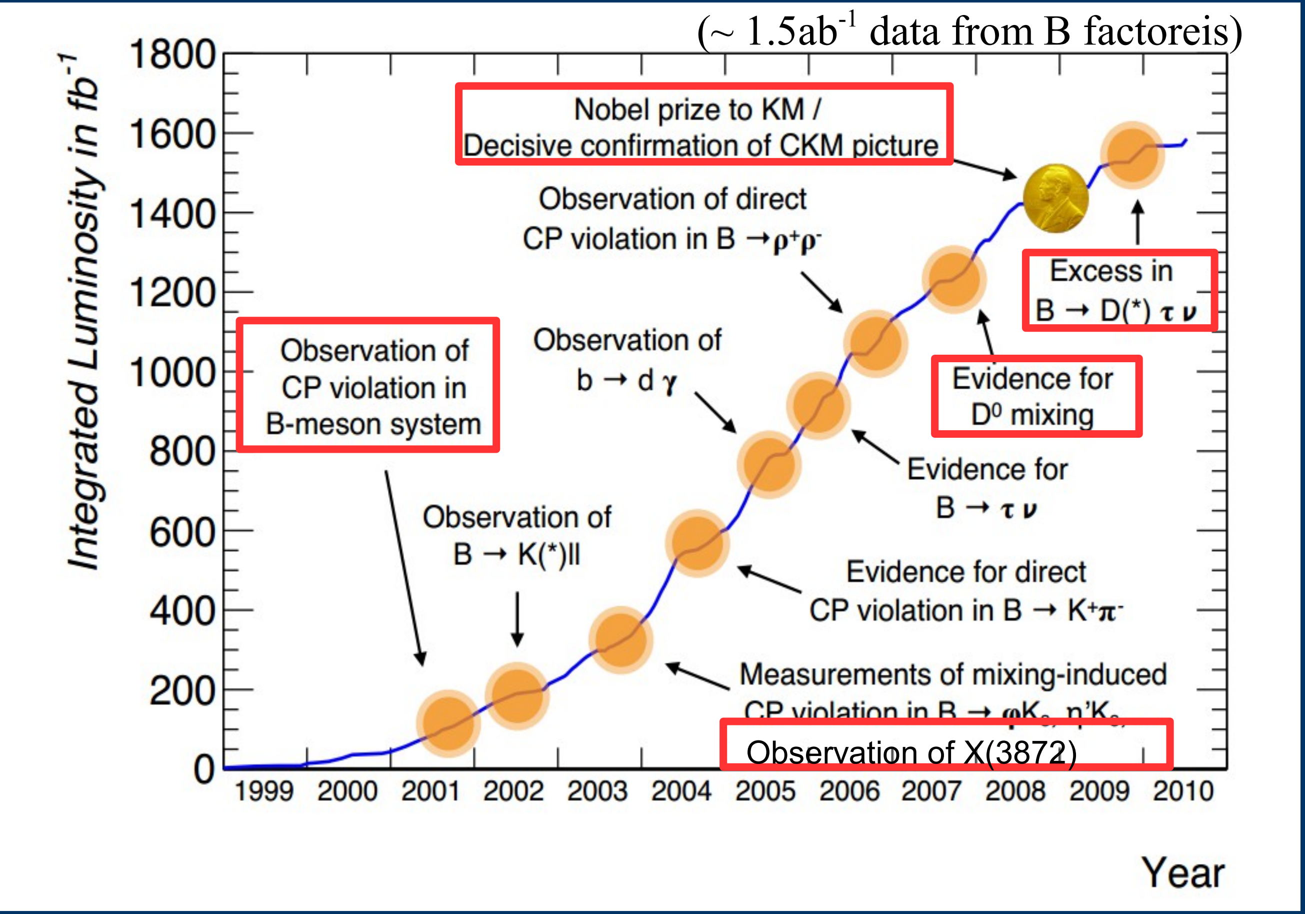
SuperKEKB
~3km circumference
10~11 GeV
(7GeV e- /4GeV e+)

What is Belle II's role in this LHC era?



Why Belle II

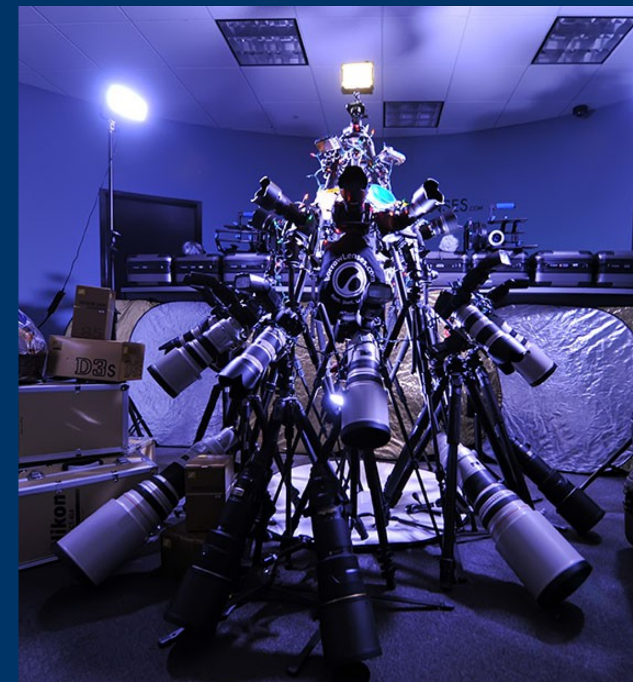
Last generation B factories achieved a great success in B (charm, τ) physics studies and explored possible new physics



However, there are still remaining puzzles and open questions

- large CPV in the universe
- how "standard" is the SM (where is the NP)?
- those "dark" things …..

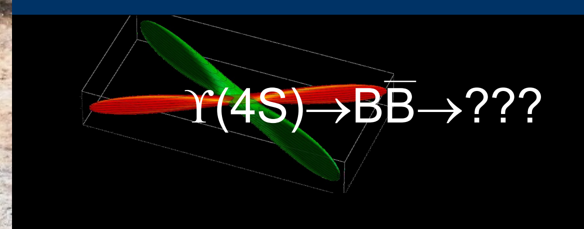
Why Belle II



Energy frontier
→ powerful in energy scale to search for new particles and physics. (LHC)

complementary with each other

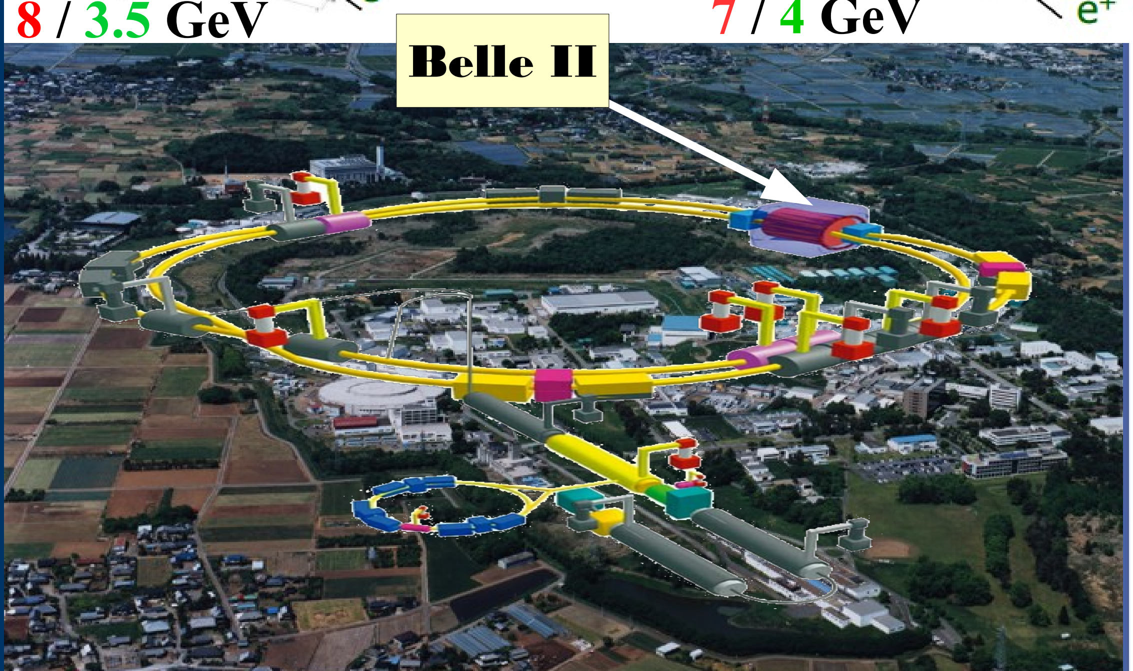
Precision/intensity frontier
→ focus on a certain energy range for precision measurements to search for anomalies from the SM and new physics from rare decays (SuperKEKB + Belle II)

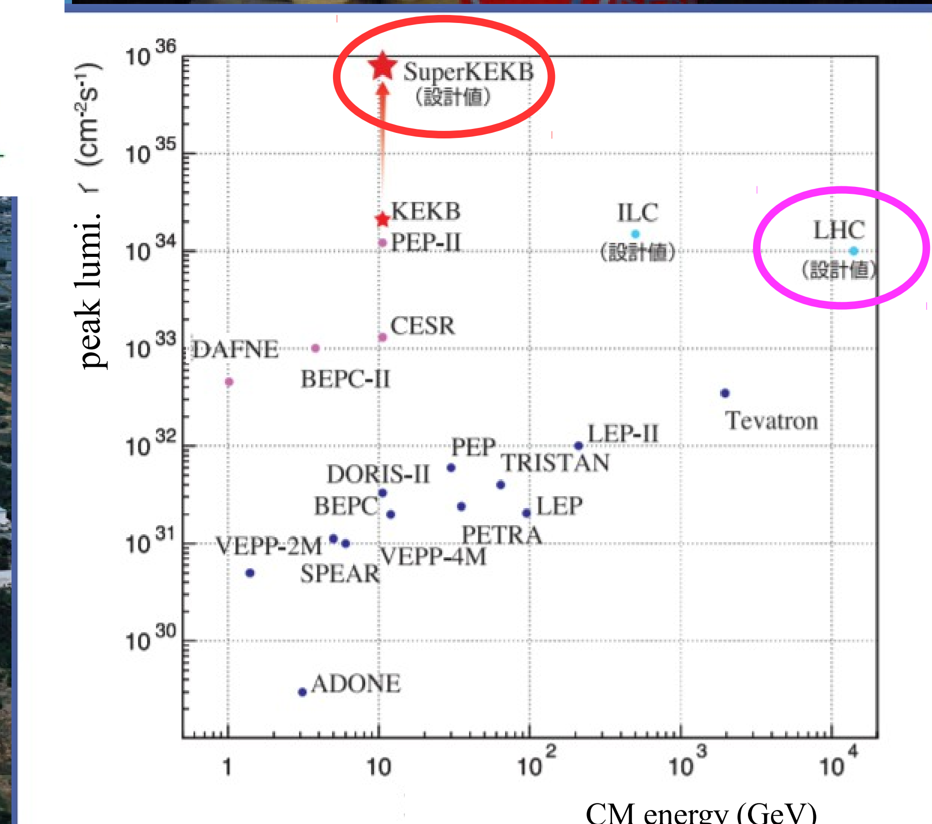


SuperKEKB: why not just keep running KEKB/Belle

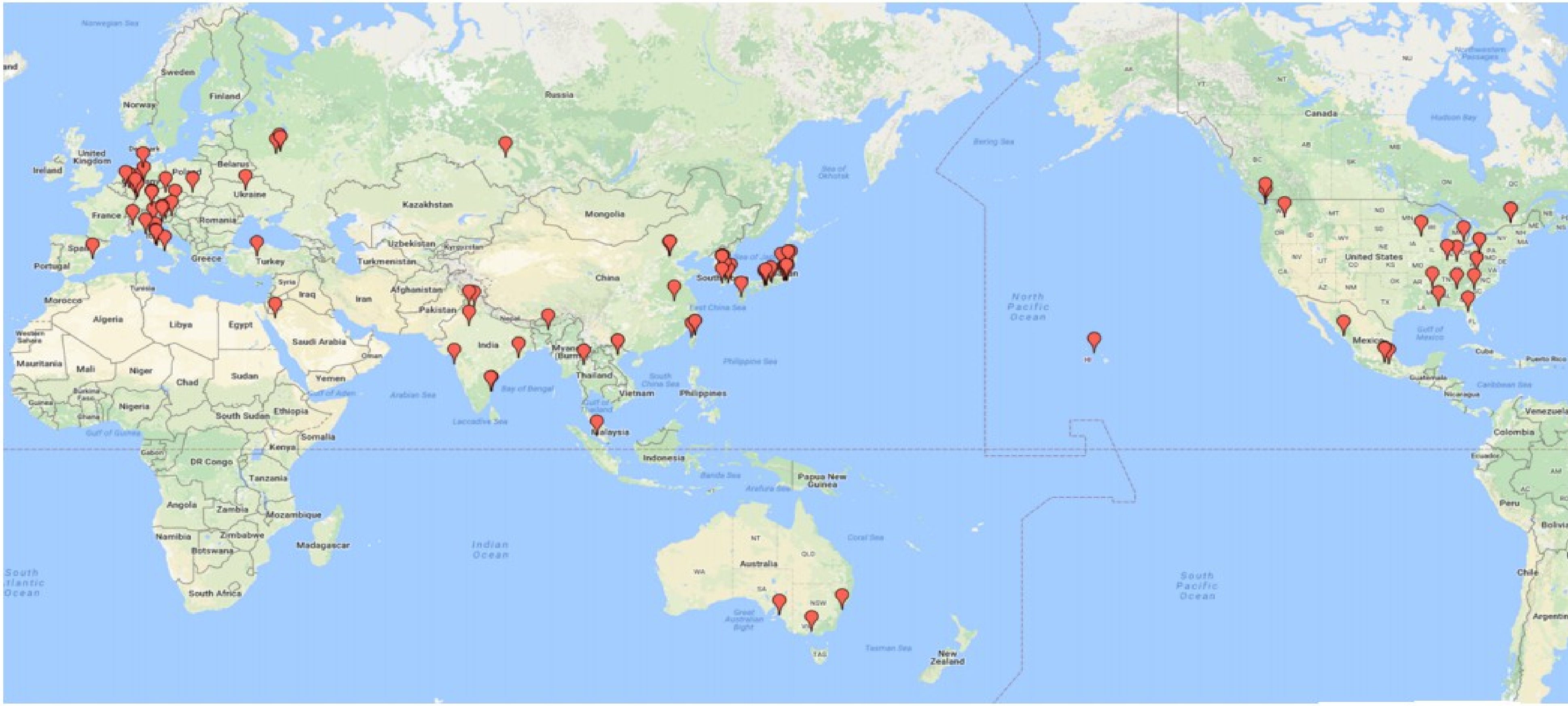
founded in 2008, groundbreaking in 2011

- peak luminosity 8×10^{35} $cm^{-2}s^{-1}$ (40 x KEKB)
- → nano beam with higher beam currents
- Belle II: $50ab^{-1}$ data (50 x Belle)
- → high precision measurements; rare decays





Belle II Collaboration



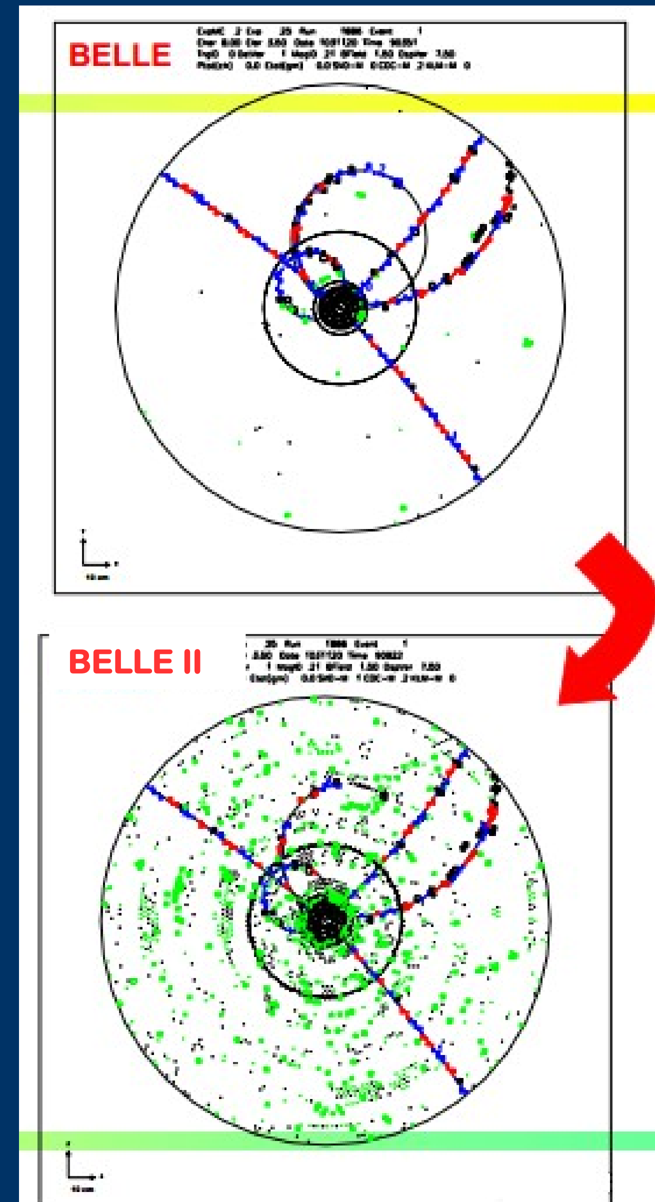
>700 members
101 institutions

Requirements for the Belle II detector

(critical issues at L = $8x10^{35}/cm^2/s$)

- Higher event rate
  - ➔higher trigger rate, DAQ, computing
- Higher background
  - ➔radiation damage → **BEAST2**
  - ➔occupancy
  - ➔fake hits and pile-up noise
- $\beta\gamma$ reduced by a factor of 1.5

- Upgrade
  - ➔better vertexing/tracking
    - ➢ pixel + silicon strip **(VXD)**
    - ➢ new CDC larger volumn smaller cell
  - ➔better particle identification
  - ➔faster readout electronics and computing
  - ➔faster and flexible trigger system
    - ➢ z-vertex trigger to reduce background



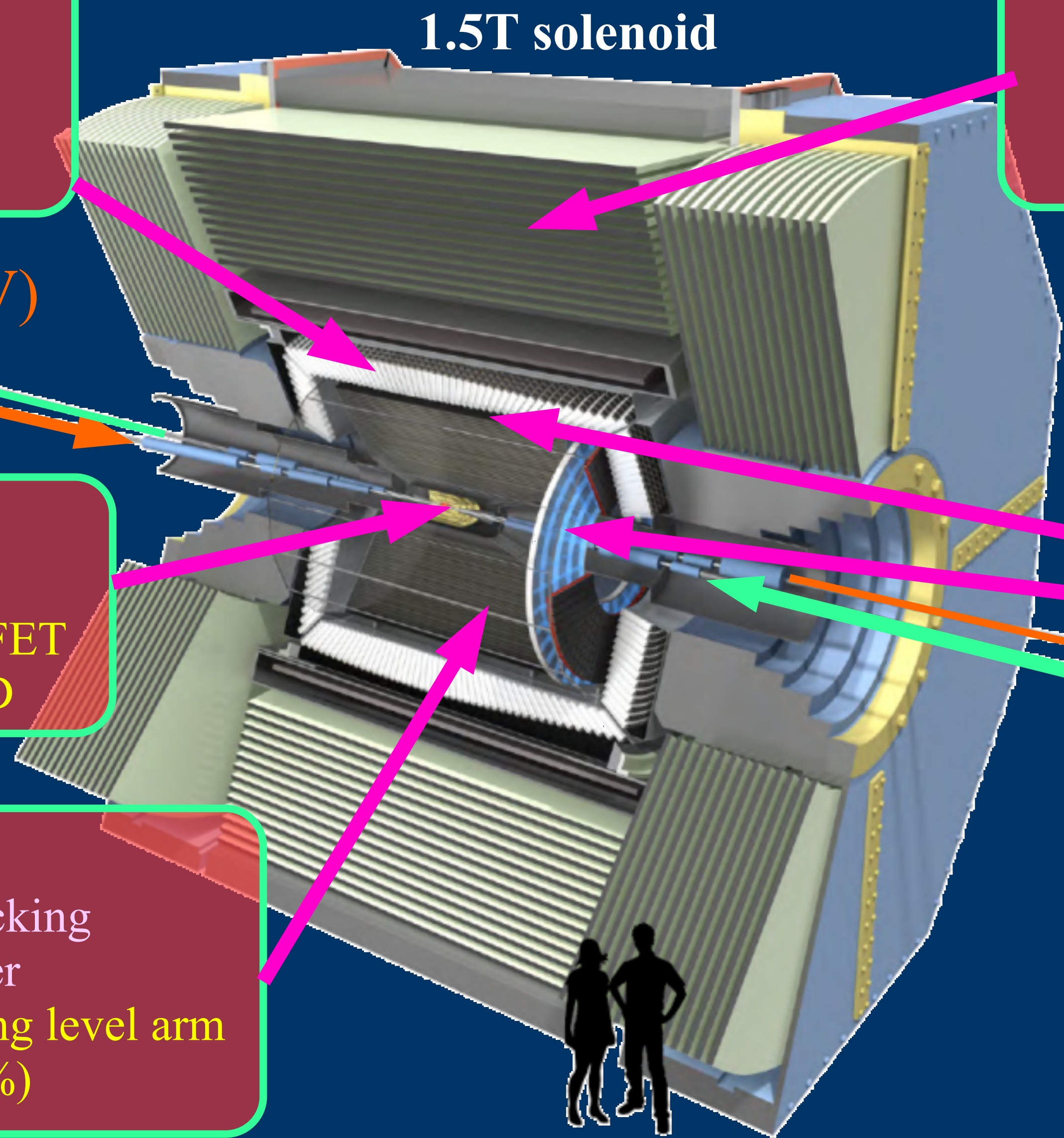
Belle II

TDR : arXiv:1011.0352v1 [physics.ins-det]

based on Belle but with upgrades/renovations

ECL
photon, electron
CsI(Tl)
waveform sampling

KLM
Klong, muon
RPC+scintillator (barrel)
scintillator (end-caps)



TOP/RICH
particle identification
TOP(barrel): DIRC
RICH(fwd): aerojel

VXD
vertexing
PXD: 2 layers DEPFET
SVD: 4 layers DSSD

CDC
charged particle tracking
track z-vertex trigger
smaller cell size, long level arm
He(50%)+C_2H_6(50%)

trigger rate ~ 20 kHz
GRID computing

Most sub-detectors will be ready in 2017.

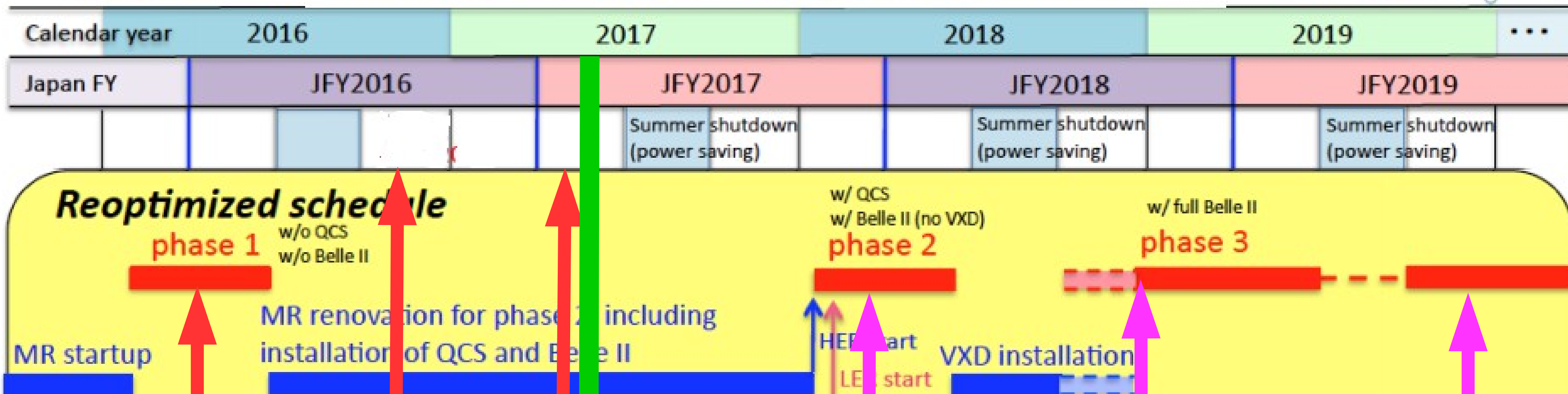
LHCP 2017

Belle II status and prospects for flavor physics

Outline

- SuperKEKB and Belle II
- Status and schedule
- Physics prospect

Schedule in the coming years



now

Belle II roll-in

CDC in

VXD installation (SVD+PXD)

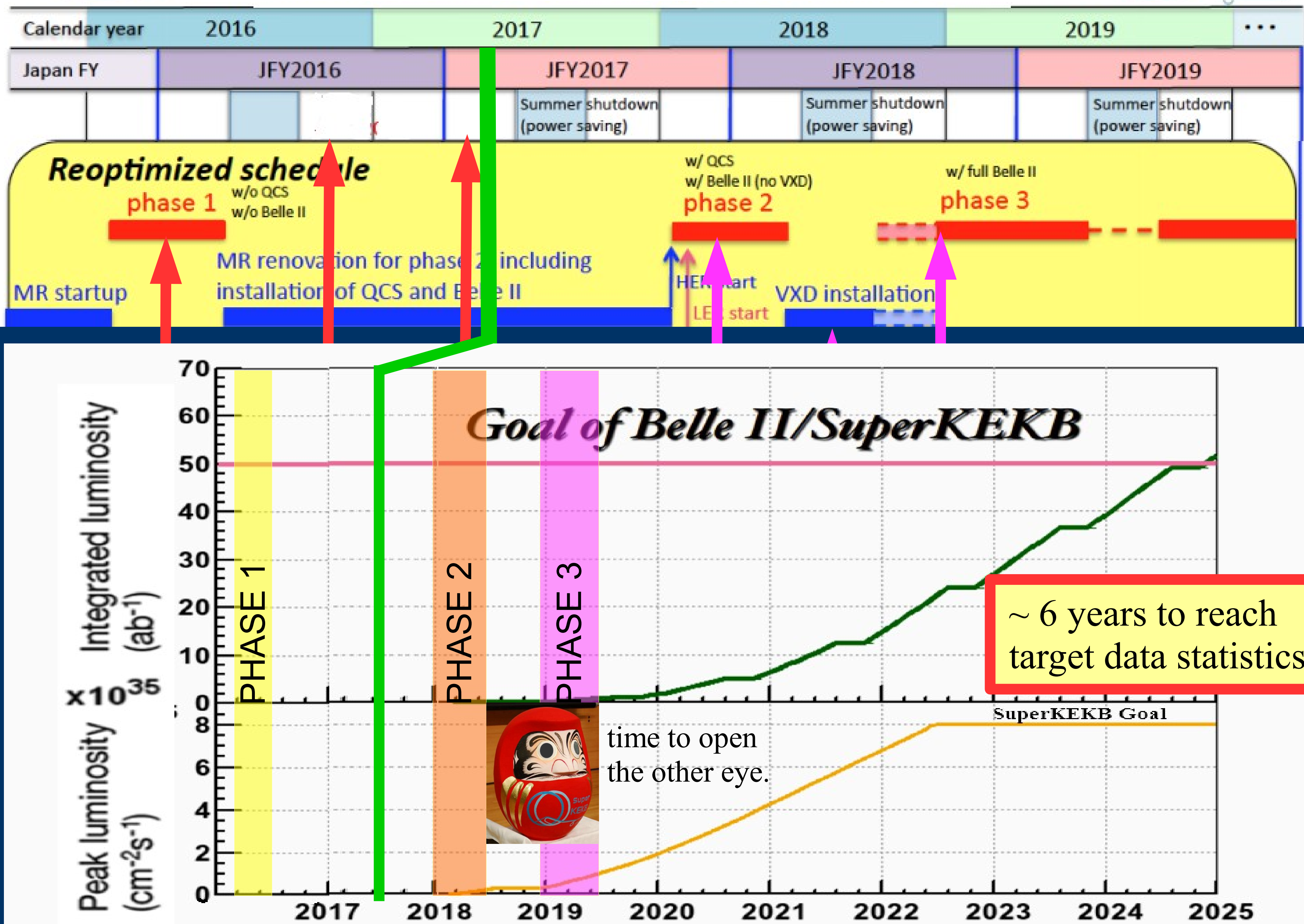
keep running,
and running,
and running,
…..

Phase 1: beam practice
BEAST2 phase 1
no collision
no Belle II
background study

Phase 2: beam collision
BEAST2 phase 2
no VXD

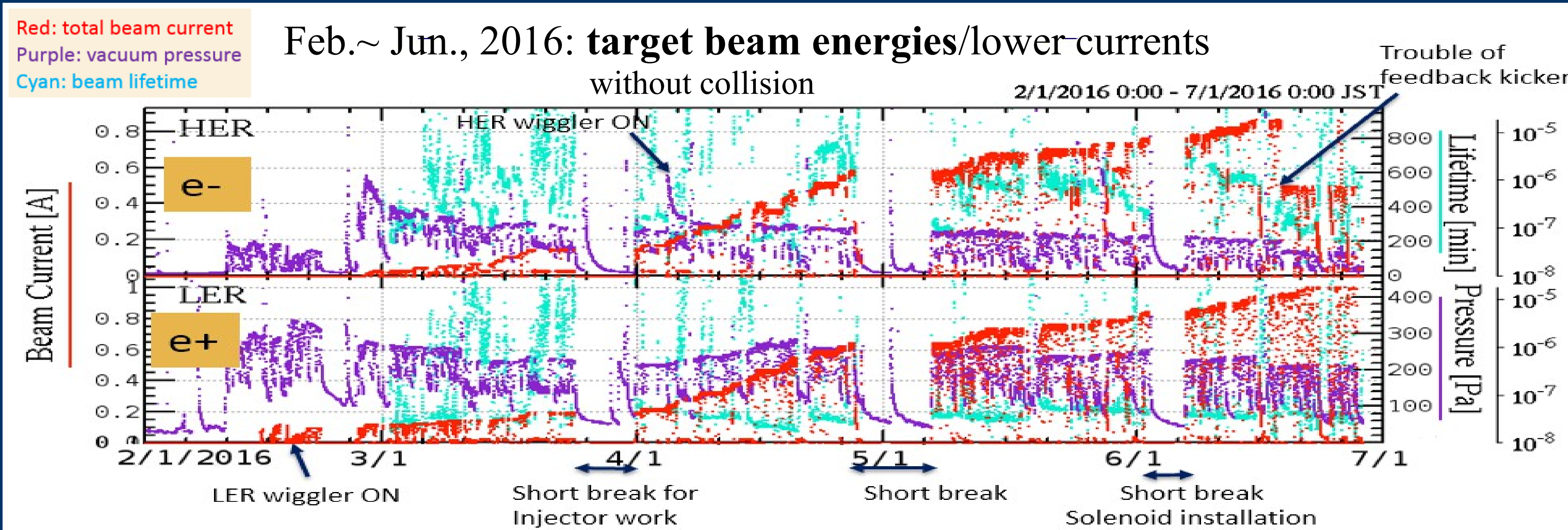
Phase 3: increasing lumi.
full Belle II
physics run 1

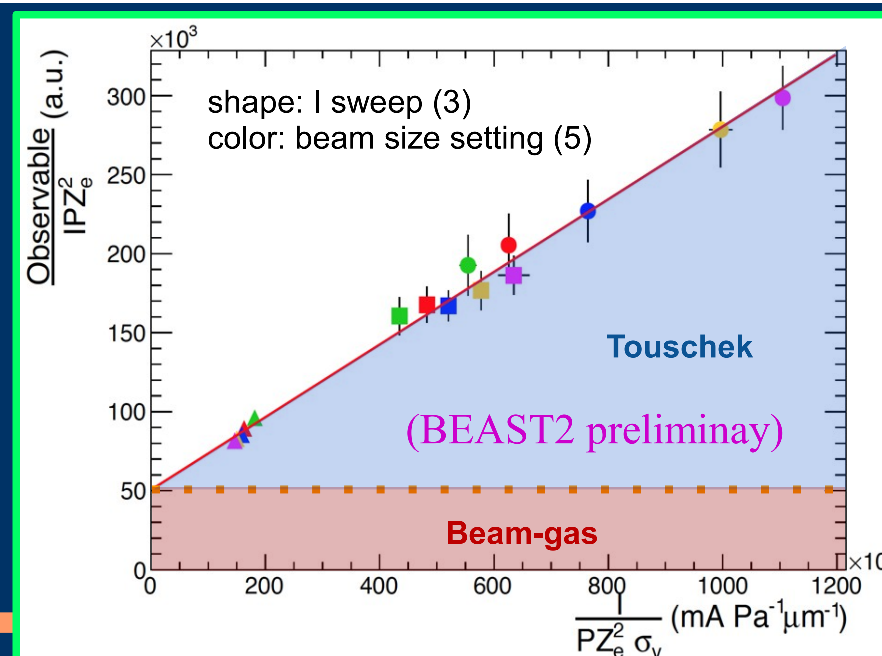
Schedule in the coming years



~ 6 years to reach target data statistics

SuperKEKB/BEAST2 phase 1 opeation





Phase 1,

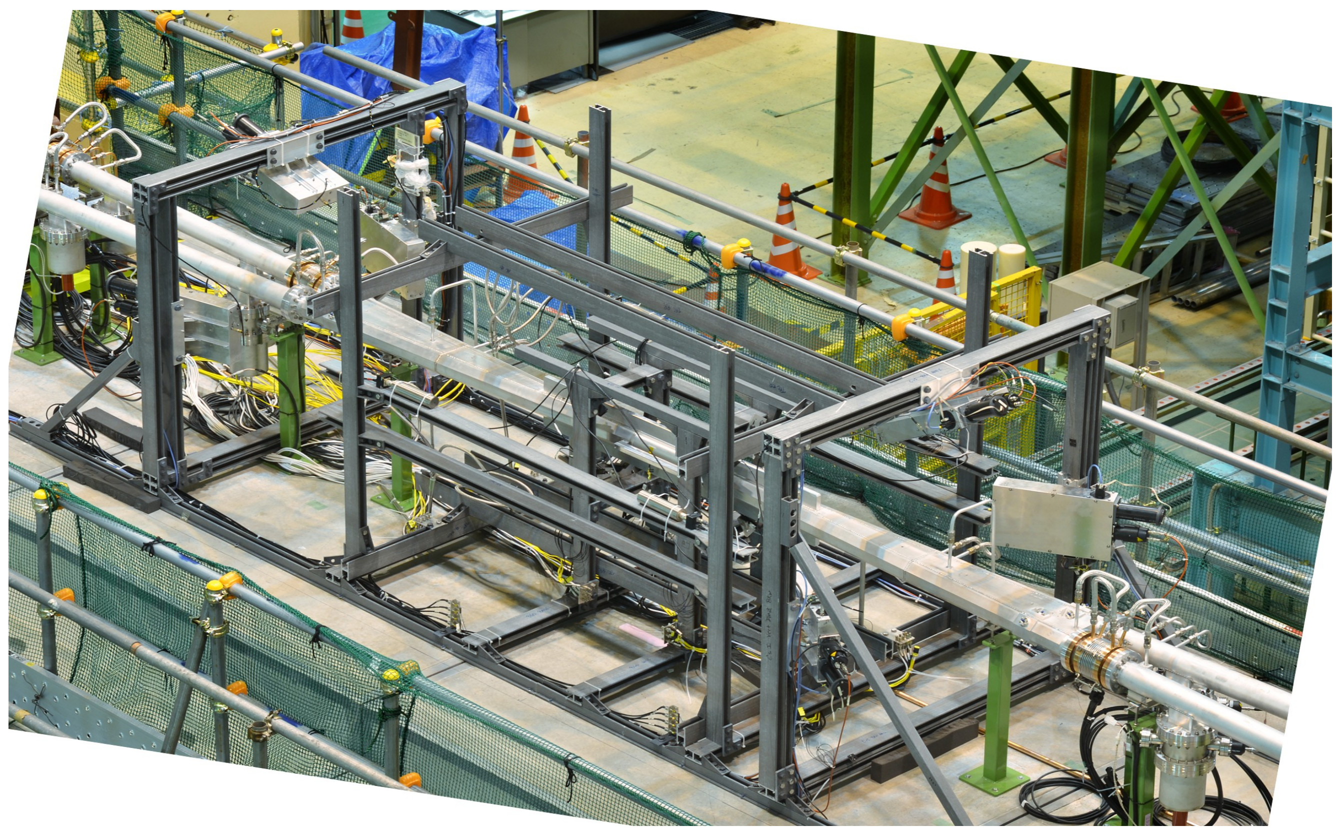
Beast2

Done!! 卒業

has paved the road for the beauty.
(~1 year ago)

2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

beam BG/machine study



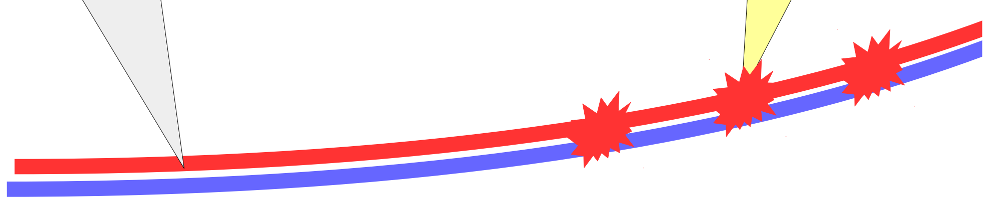
Phase 2, ring a Bell for a new era to come.

Beast2 with partial Belle II,
some measurements possible.

2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

early 2018
collision tuning
partial Belle II
(no vertexing)

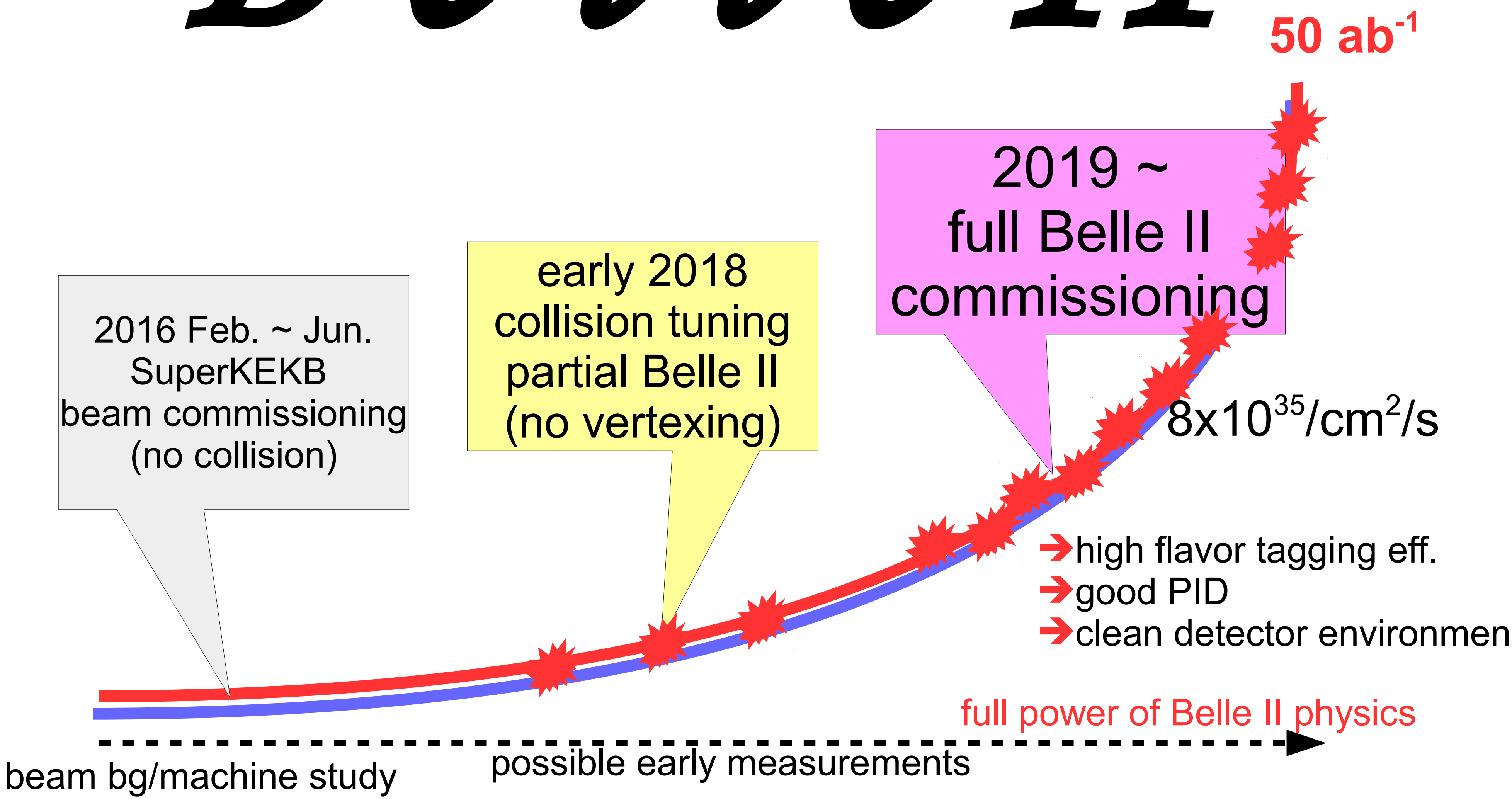
- ➔achieve 10^{34} /cm^2/s (KEKB/Belle peak)
- ➔stable run close to $\Upsilon(4S)$ preferred
- ➔PID not fully reliable
- ➔Integrated luminosity ~(20 ± 20 fb^{-1})



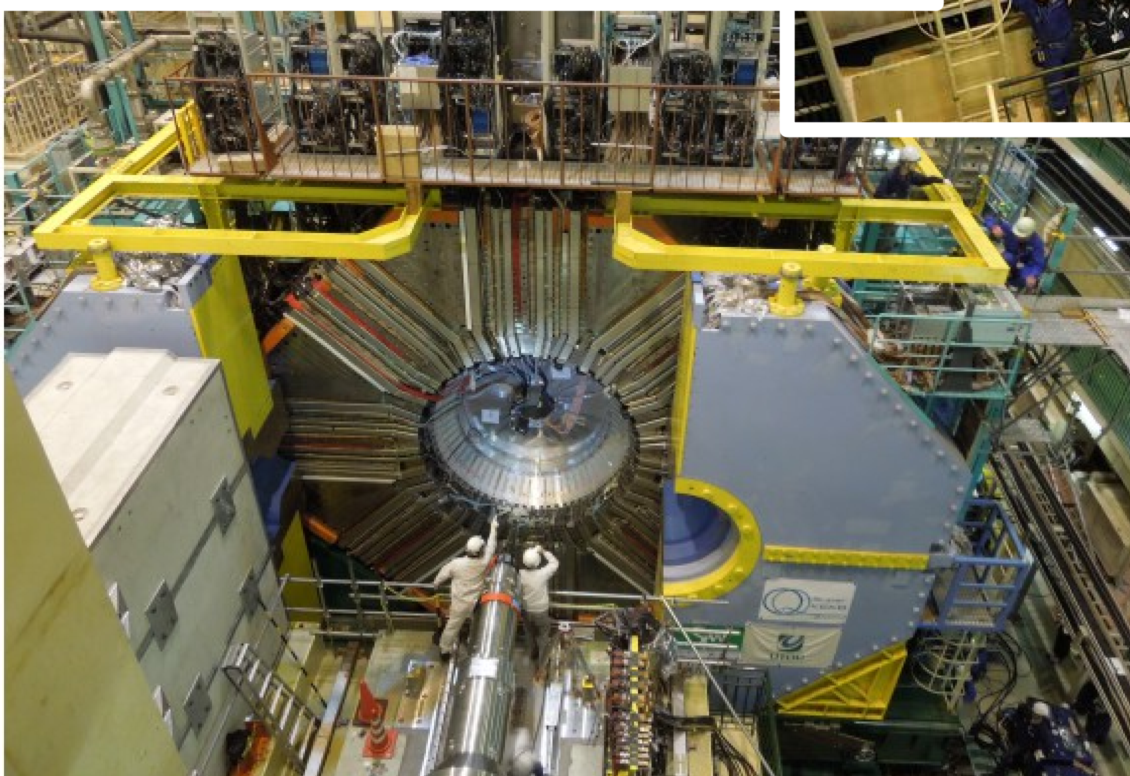
Important milestone for Belle II

beam bg/machine study — possible early measurements

Phase 3 and beyond, Belle II



Belle II roll-in (April 11, 2017)



Belle II
in position now
~~(VXD)~~

Belle II status and prospects for flavor physics

Outline

- SuperKEKB and Belle II
- Status and schedule
- Physics prospect

Belle II physics prospect

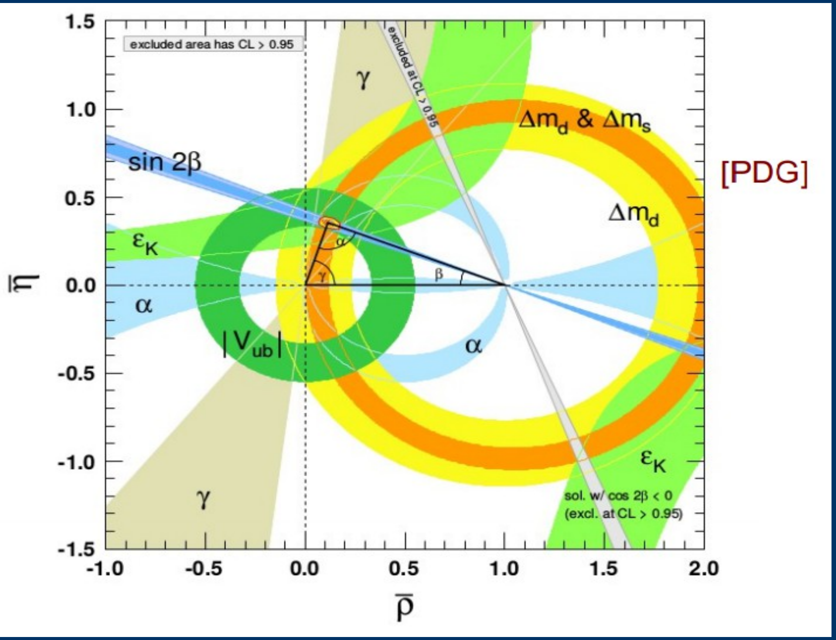
- B physics
  - ➔precision measurements of CKM elements
  - ➔rare B decays
  - ➔other B decay physics, ...
- Charm physics (Mixing, CPV in charm, rare charm decays,...)
- τ physics (LFV, CPV, ...)
- Others
  - ➔bottomonium spectrum
  - ➔exotics state (tetraquark, …)
  - ➔other new physics searching (Higgs BSM, dark sector, leptoquark, …)

★ advantage on decays with neutral particles in the final states.

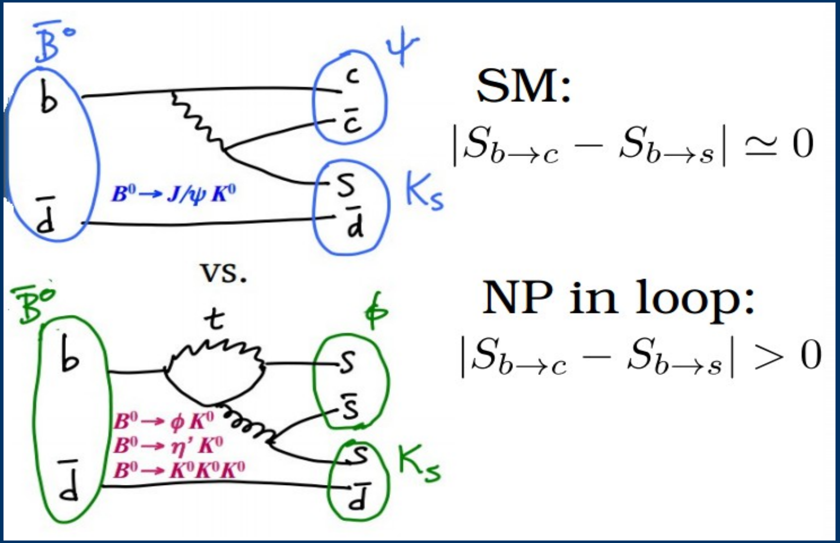
P. Urquijo, “Physics prospects at the Belle II experiment”, Nucl. Part. Phys. Proc. 263-264 (2015) 15-23
P. Krizan, “Flavour physics at B factories”, Phys. Sci. T158 (2013) 014024
more about Beyond the standard Model @Belle II and B2TiP, Y. Okada, May 3.

Belle II physics prospect – CKM

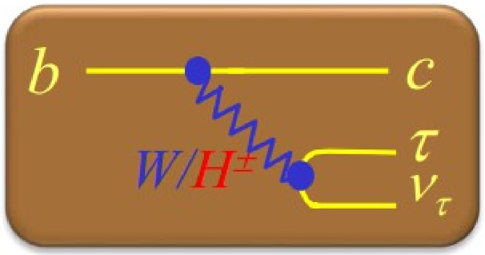
- does the unitary triangle really a triangle?
  current $\alpha+\beta+\gamma = (175\pm9)^{o}$ (PDG)
  → Belle II expects to improve the precision
  $\beta \sim 0.3^{o}$, $\alpha \sim 1.0^{o}$, $\gamma \sim 1.5^{o}$
  (precision 5~10% → 1~3%)



- precision measurements of $\sin(2\beta)=\sin(2\phi_1)$
  remains an important topic to check the consistency of the Unitary triangle and to search for new source of CPV
  e.g. $\Delta S = \sin(2\beta_{\phi k_S^0}) - \sin(2\beta_{J/\psi k_S^0})$
  → with $50ab^{-1}$ data, Belle II can reach 5σ even with a small deviation ΔS ~0.02



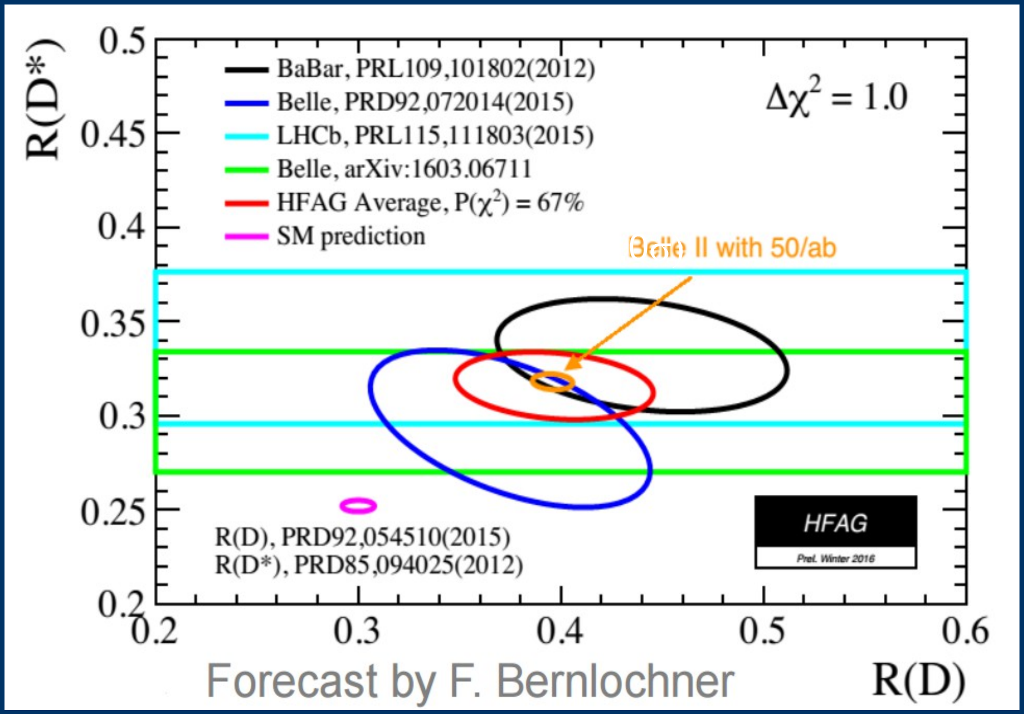
Belle II physics prospect　$B \to D(*)\,\tau\nu$

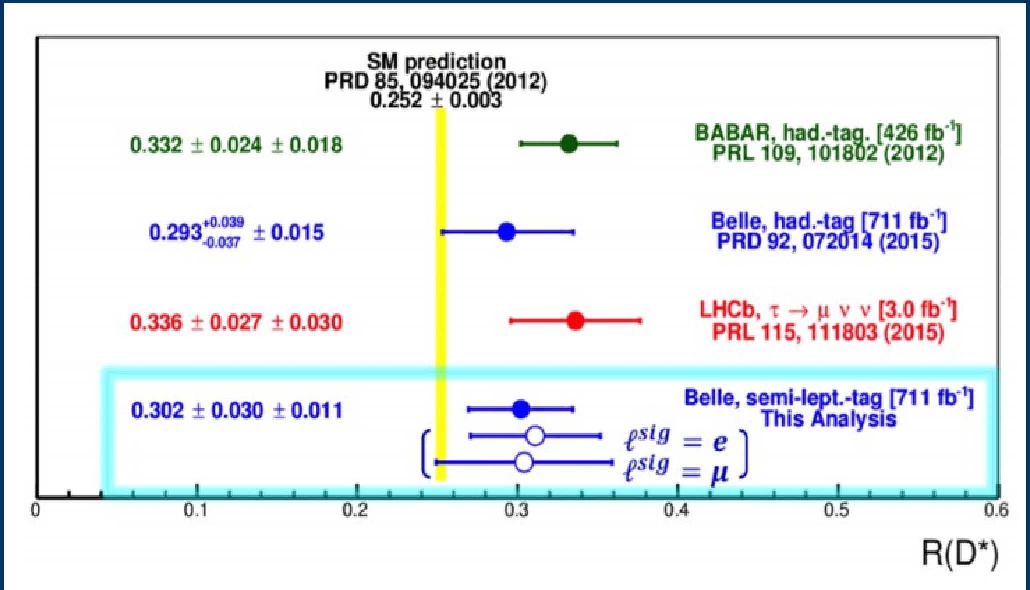


$$R(D^{(*)}) = \frac{\Gamma(B^0 \to D^{(*)} \tau \nu)}{\Gamma(B^0 \to D^{(*)} l \nu)_{l=\mu,e}}$$

sensitive to H-b-c coupling

larger BF in the SM (~1%)
smaller theoretical uncertainty of R(D)
discrimination of W and H by differential distribution

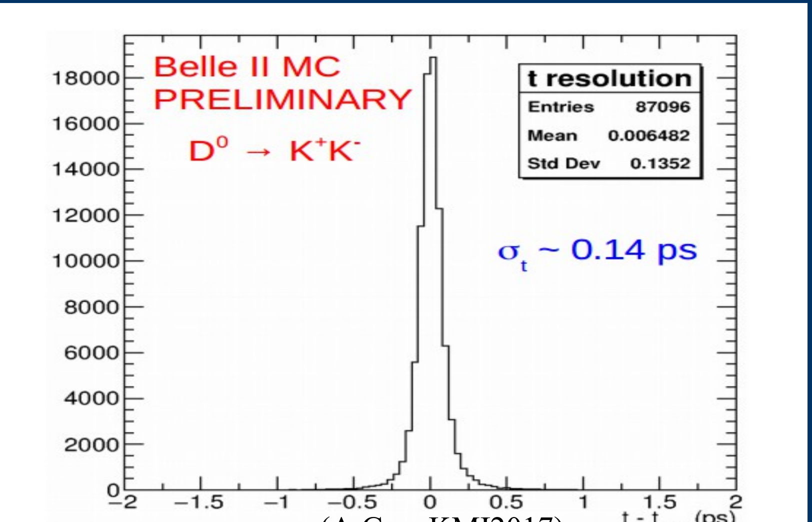




new Belle measurement　[hep-ex 1603.06711]
$R(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst})$ (13.8 σ)

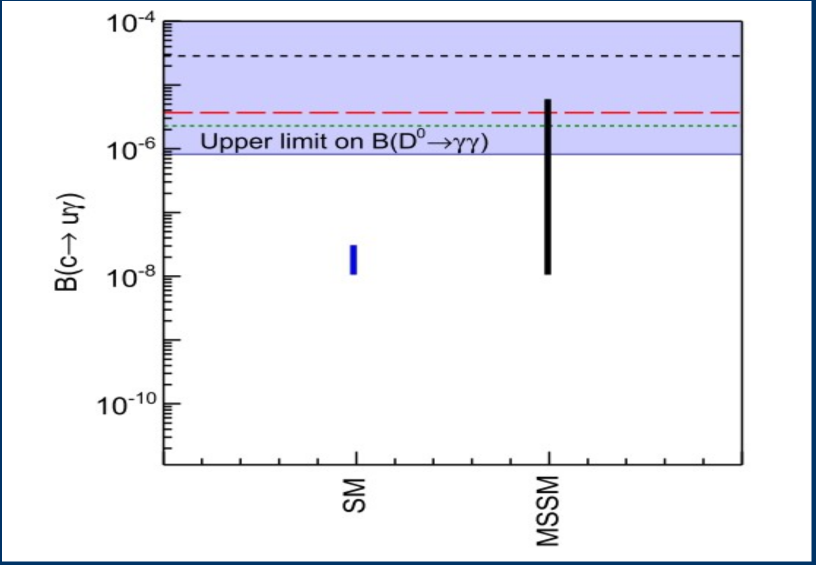
Belle II physics prospect – charm physics

- B factories discovered the D^0 -$\overline{D}^0$ mixing.
  - ➔ Belle II will improve the measurements of the mixing parameters and look for CPV.
  - ➔ proper time resolution for D^0 decays ~ 0.14 ps



(A.Gaz, KMI2017)

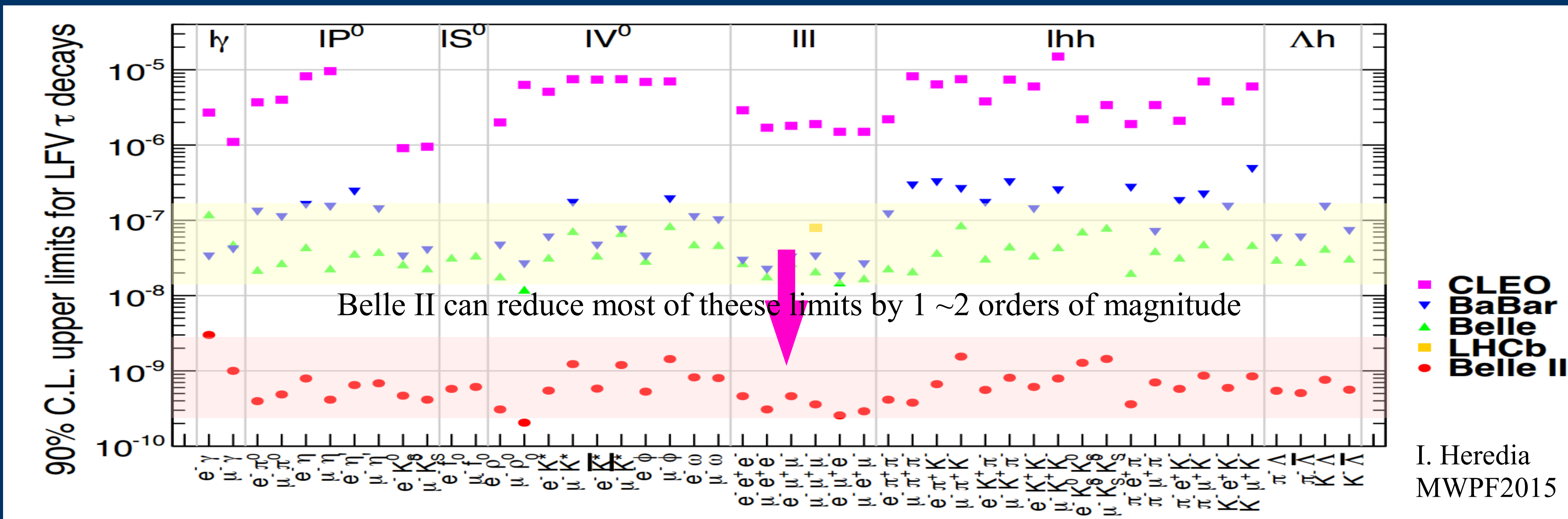
- Rare charm decays, e.g.
  - ➔ $D^0 \to \gamma\gamma$
  - ➔ predicted BF a few x 10^{-8}
  - ➔ Belle result 8.5×10^{-7} @ 90%CL (PRD 93, 051102(R), 2016; 832 fb^{-1} data)
  - ➔ expected to reach 10^{-7}~10^{-8} (with full Belle II data)



LHCP 2017

Belle II physics prospect – tau LFV

LFV is suppressed in SM → a few models predict enhancements within Belle II's reach.



$\tau \to \mu\gamma$

main background from $ee \to \mu\mu\gamma_{ISR}$

reduce sensitivity by a factor ~7

$\tau \to \mu\mu\mu$

very clean mode

reduce sensitivity by a factor of 50

	$\mathcal{B}(\tau\to\mu\gamma)$	$\mathcal{B}(\tau\to\mu\mu\mu)$	
mSUGRA+seesaw	10^{-7}	10^{-9}	PRD 66(2002) 115013
SUSY+SO(10)	10^{-8}	10^{-10}	PRD 68(2003) 033012
SM+seesaw	10^{-9}	10^{-10}	PRD 66(2002) 034008
Non-Universal Z'	10^{-9}	10^{-8}	PLB 547(2002) 252
SUSY+Higgs	10^{-10}	10^{-7}	PLB 566(2003) 217

possible reach by Belle II (50 ab^{-1}) $<10^{-9}$ $< 10^{-10}$ → good to test NP

Summary

- The SuperKEKB + Belle II will be ready for commissioning soon
  - 40x higher instantaneous lumi.
  - 50 ab^{-1} data statistics.
  - Belle $\rightarrow$ Belle II
- SuperKEKB first beam circulations in 2016
  - Belle II roll-in in April
  - prepare 1st collision in early 2018
- Physics commissioning with full Belle II in early 2019.
  - precision measurements of CKM
  - B, charm and τ physics
  - exotics states, dark sector, light Higgs, ….
- A friendly competition and complementarity with other experiments (LHCb, BESIII), a new and exciting era to explore the physics frontier.

BACKUP

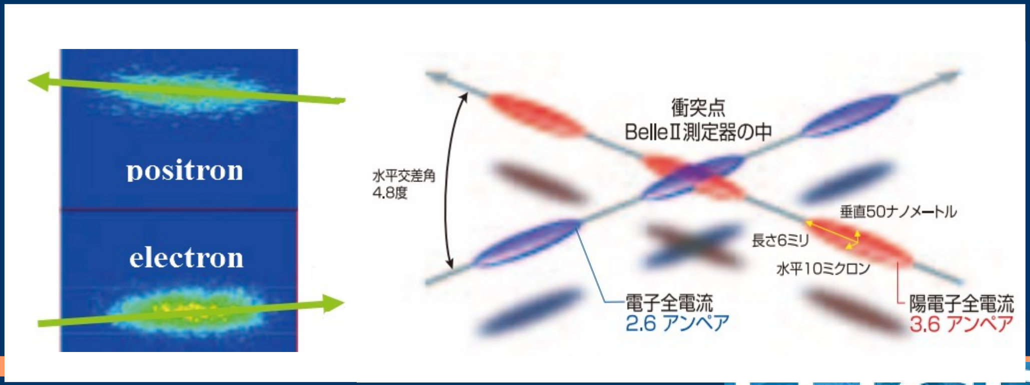
Luminosity of KEKB and SuperKEKB

	KEKB achieved		SuperKEKB nano-beam		
	LER	HER	LER	HER	
E_{beam} (GeV)	**3.5**	**8**	**4**	**7**	→ $\beta\gamma \sim 2/3$
I_{beam} (A)	**1.6**	**1.2**	**3.6**	**2.6**	→ factor 2
β_y (mm)	**5.9**	**5.9**	**0.27**	**0.30**	→ factor 20
luminosity ($cm^{-2}s^{-1}$)	**2.1×10^{34}**		**8.0×10^{35}**		→ factor 40

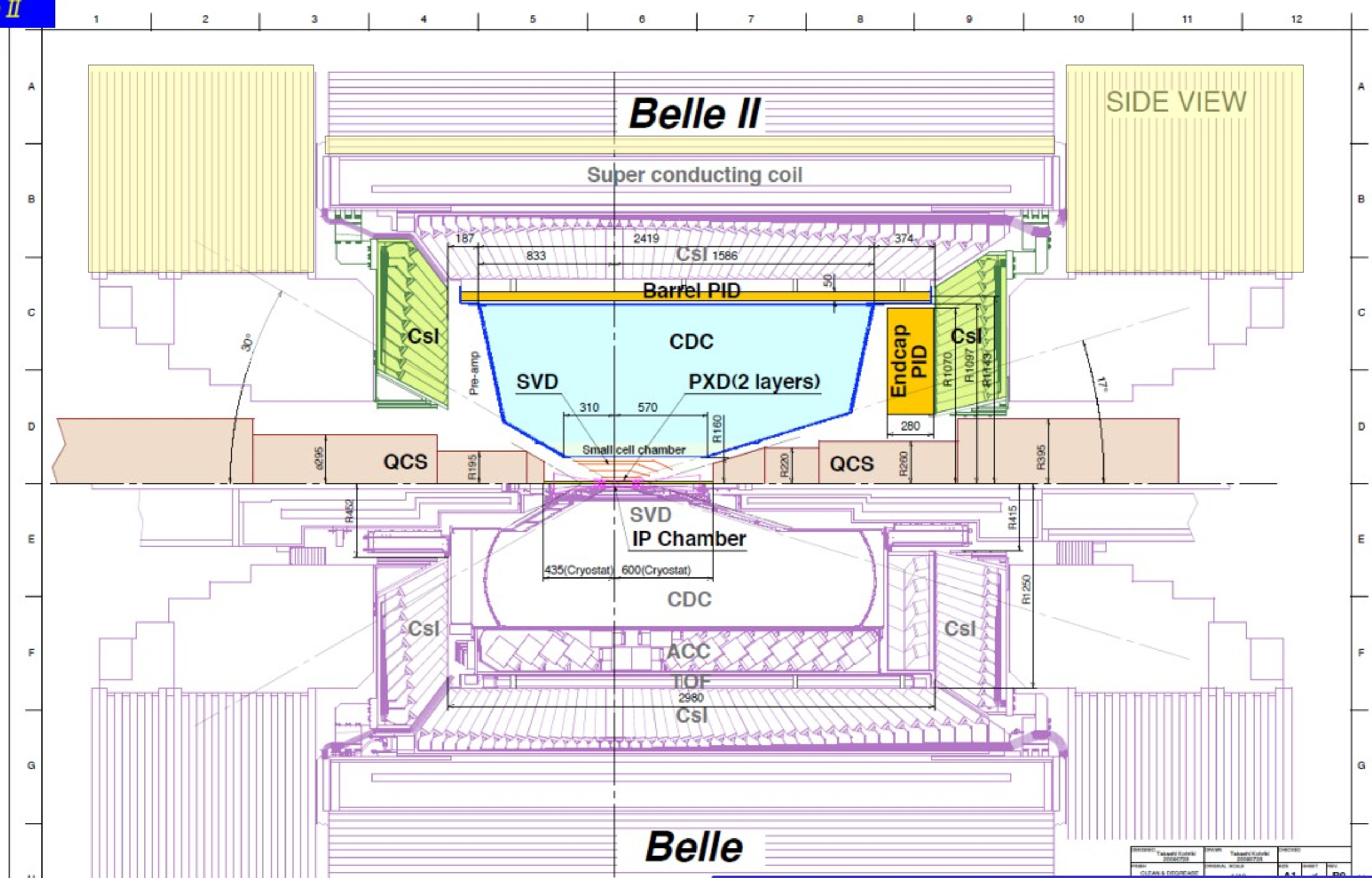
$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\frac{R_L}{R_{\xi_y}}$$

nano beams with high beam currents
low emittance 4.6 nm /3.2 nm

→ high intensity frontier



Belle II (top) compared with Belle (bottom)



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm

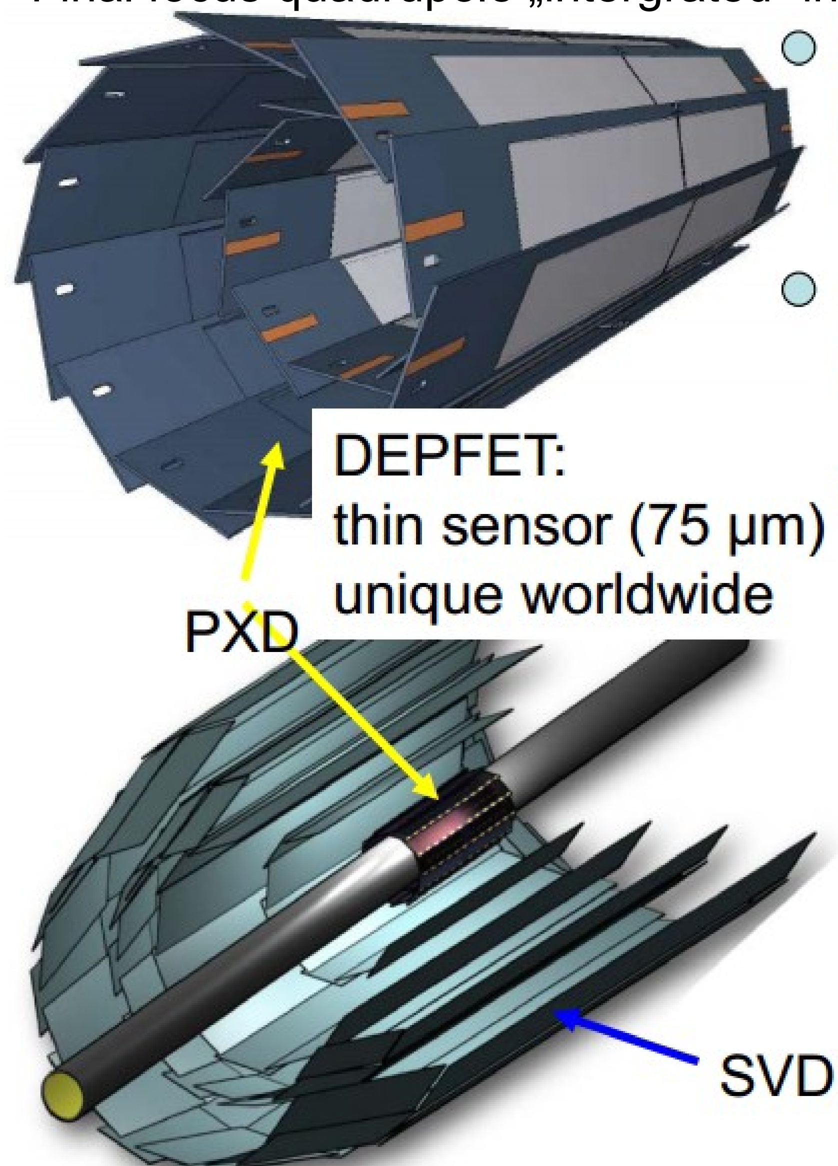
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

VXD = PXD + SVD

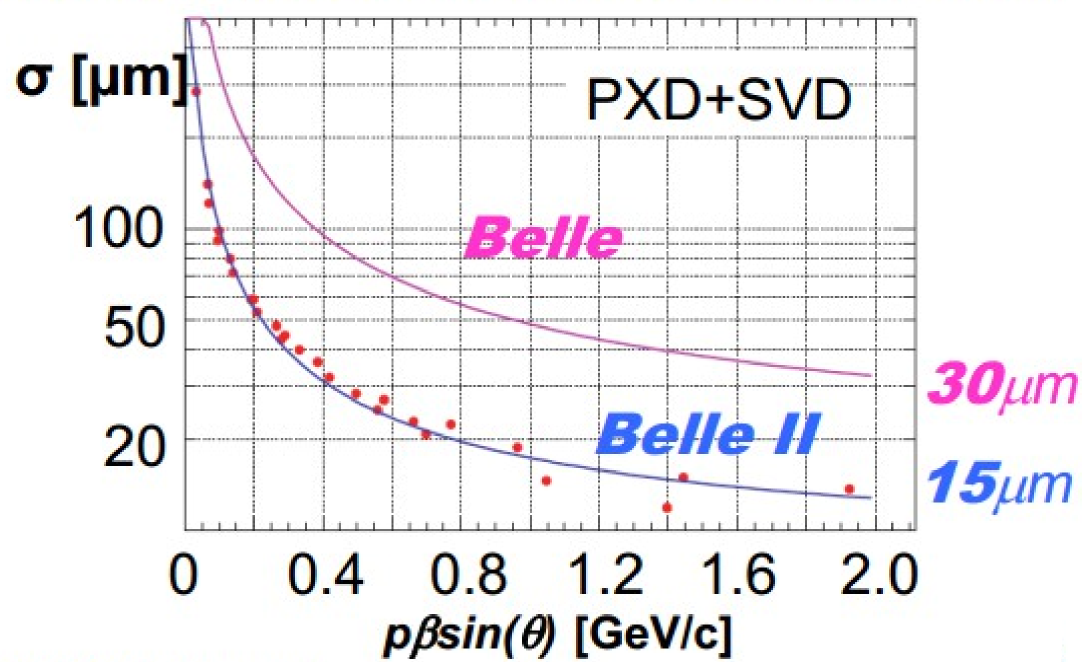
SuperKEKB: Nano beam option, 1 cm radius of beam pipe
Final focus quadrupole „intergrated" into vertex detector.

„PXD"

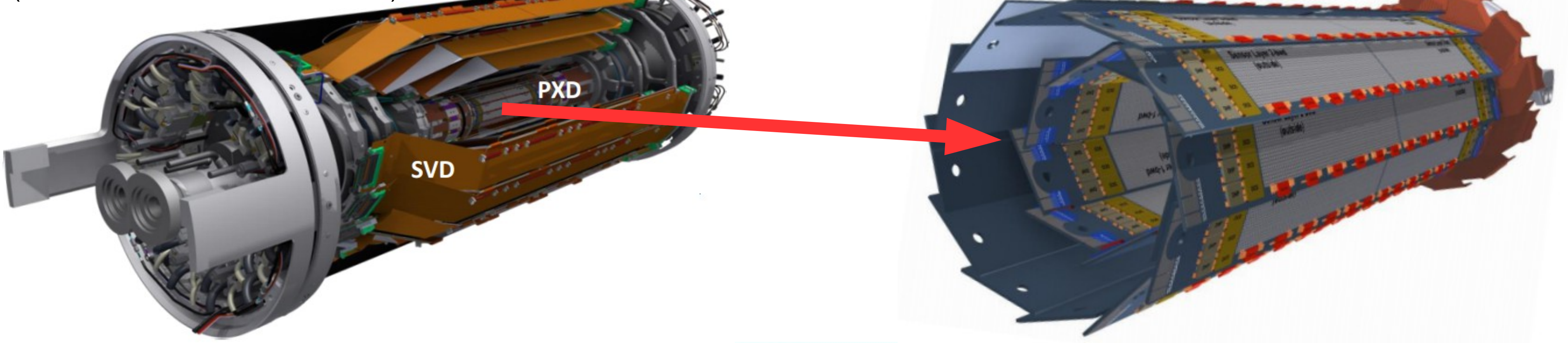
- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 μm (!), pixel size ~50 x 50 μm²
  L = 12 cm
- 4 layer Si strip detector (DSSD) ← „SVD"
  (R = 3.8, 8.0, 11.5, 14.0 cm)
  L = 60 cm



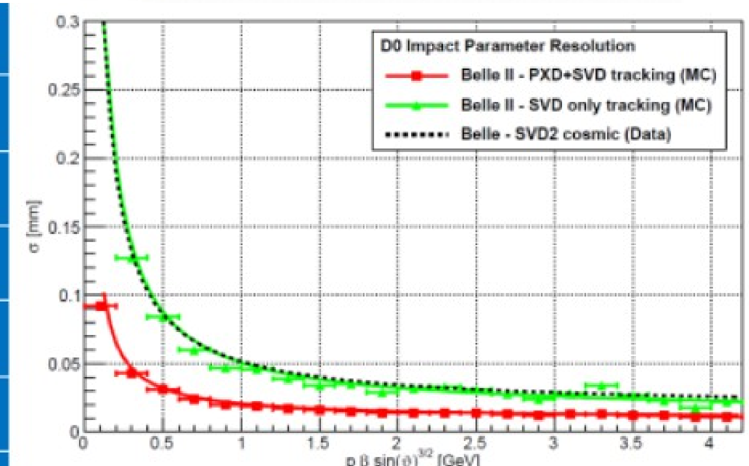
Significant improvement in z-vertex resolution

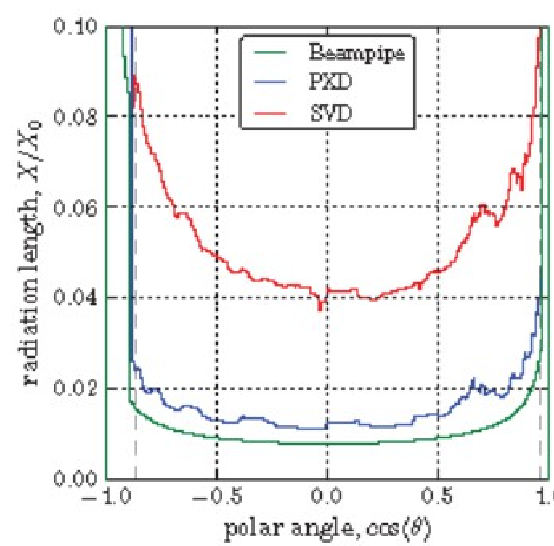


(C. Marinas, DPG Münster 2017)



	Belle II PXD
Occupancy	0.4 hits/μm²/s (3% max)
Radiation	2 Mrad/year
	$2 \cdot 10^{12}$ 1 MeV n_{eq} per year
Integration time	20 μs
Momentum range	Low p (50 MeV - 3 GeV)
Acceptance	17º-155º
Material budget	0.21% X_0 per layer
Resolution	15 μm (50x75 μm²)



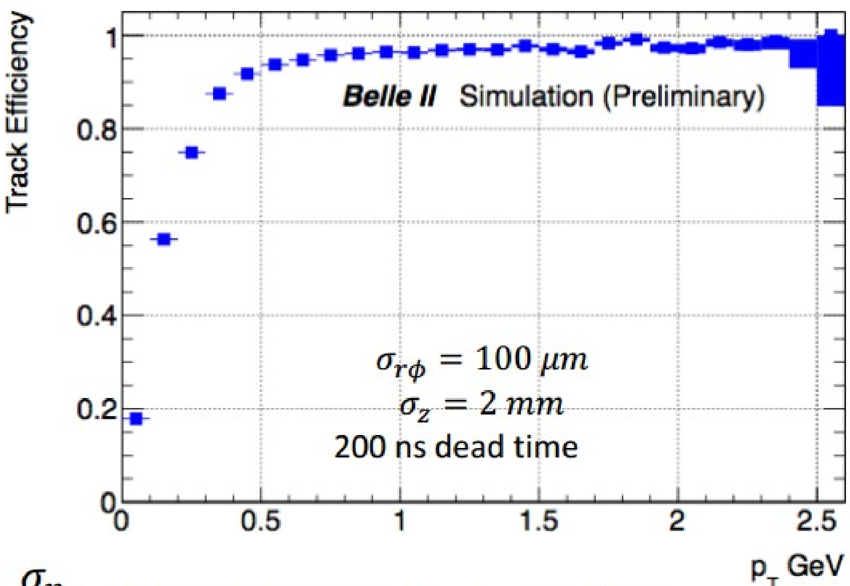


- Impact parameter resolution (15 μm), dominated by multiple scattering mainly in BP → Pixel size (50 x 75 μm²)
- Lowest possible material budget (0.21% X_0/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services in physics acceptance

CDC
(central drift chamber)

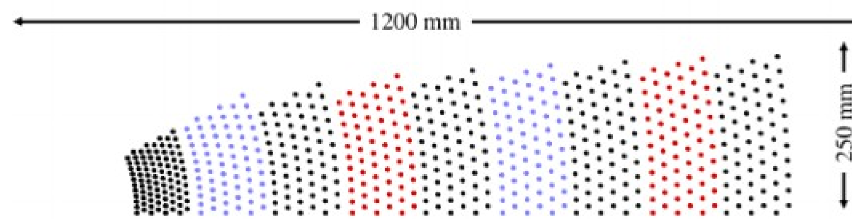
Three important roles:

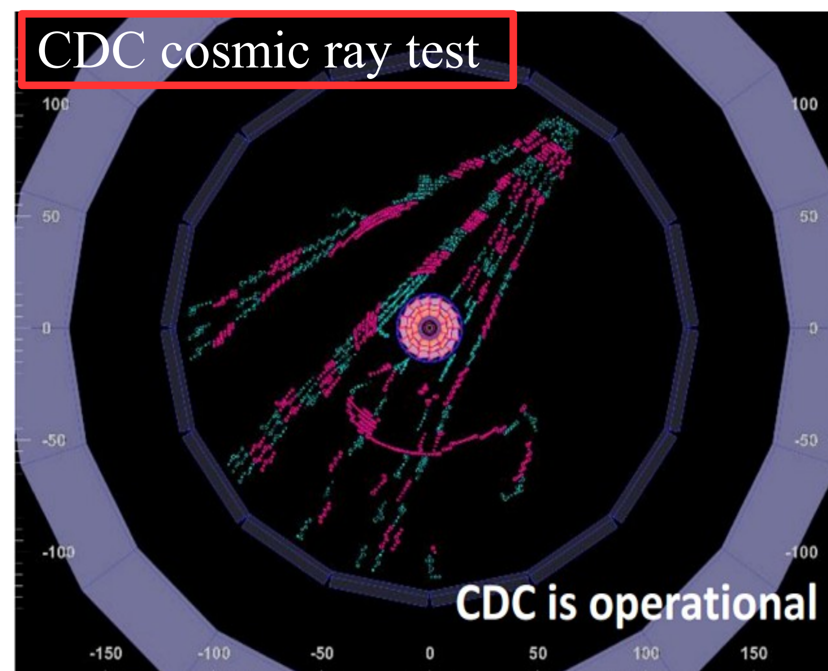
- Track reconstruction and momentum determination
- Particle identification via dE/dx
- Trigger for background rejection



$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

$$\sigma\left(\frac{dE}{dx}\right)\Big|_{MIP} \sim 5\%$$

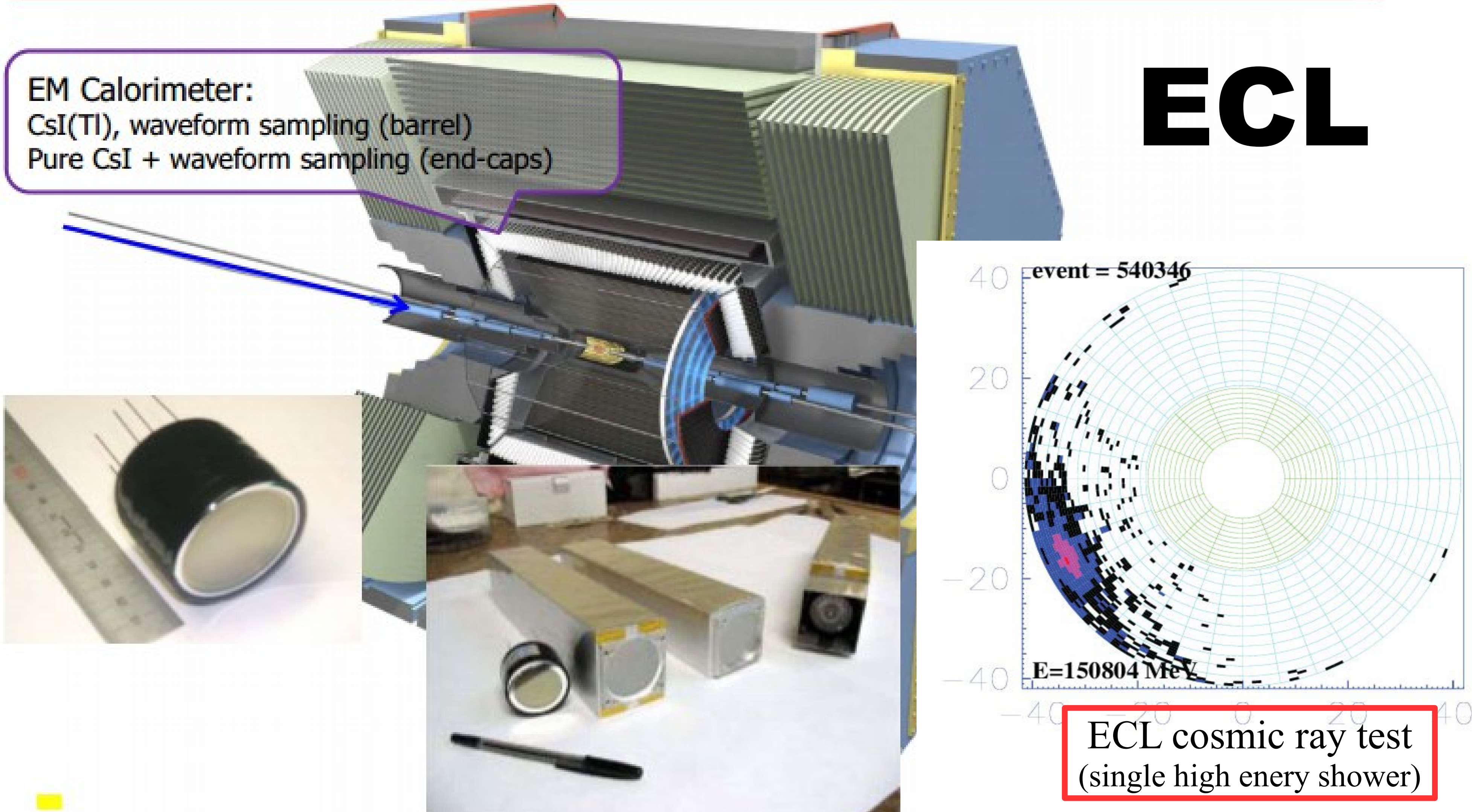




EM calorimeter: upgrade needed because of higher rates (electronics → waveform sampling) and radiation load (endcap, replace some fraction of crystals CsI(Tl) → pure CsI)

ECL

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)



ECL cosmic ray test
(single high enery shower)

Particle Identification devices

Barrel PID: TOP (Time Of Propagation)

(DIRC)

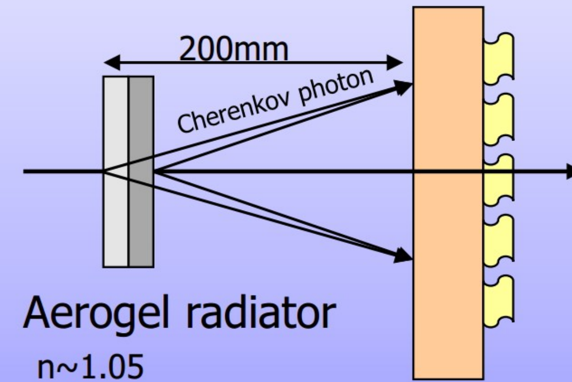
Quartz radiator

Focusing mirror

Small expansion block

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

EndCap PID: aerogel RICH

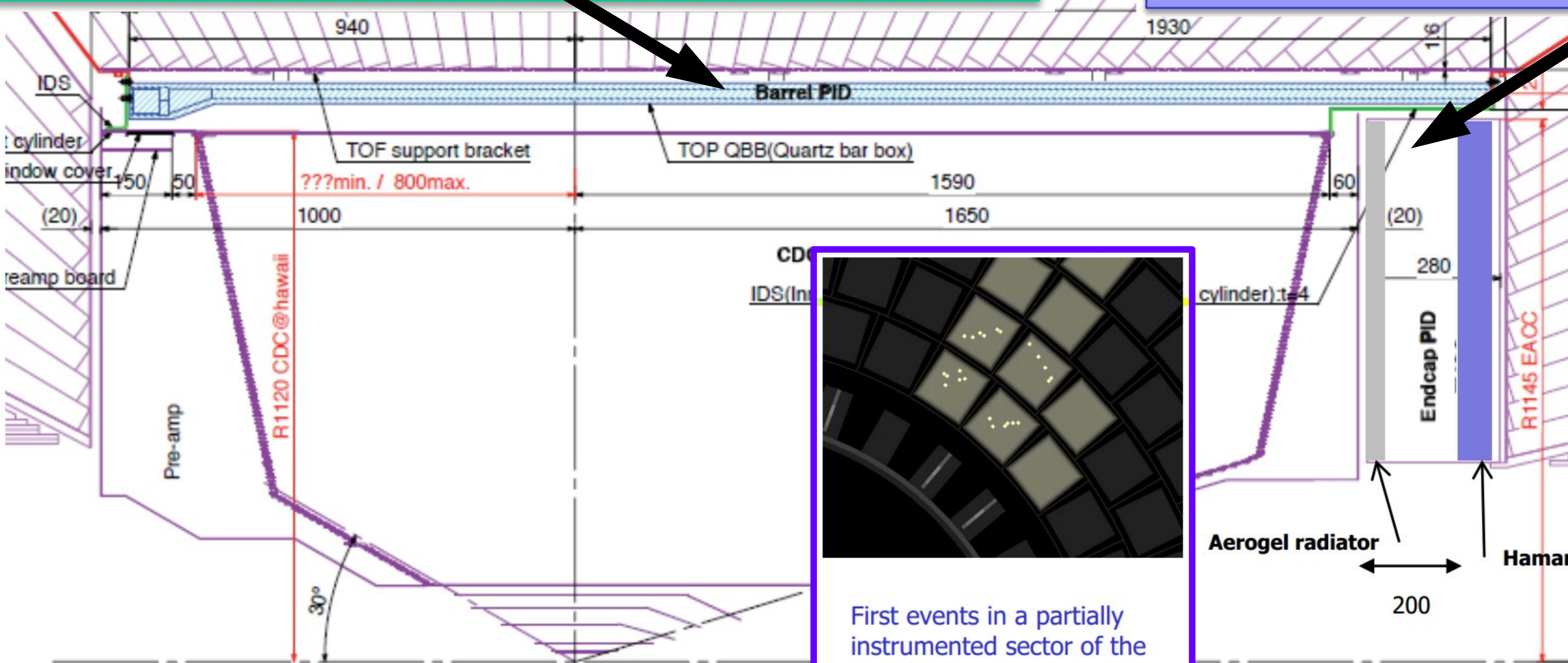


Aerogel radiator

n~1.05

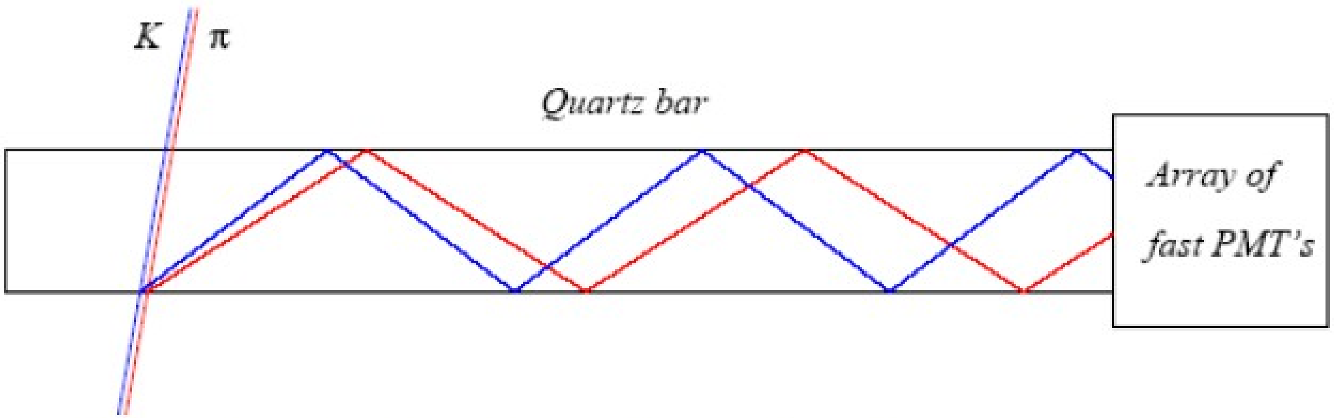
Hamamatsu HAPD

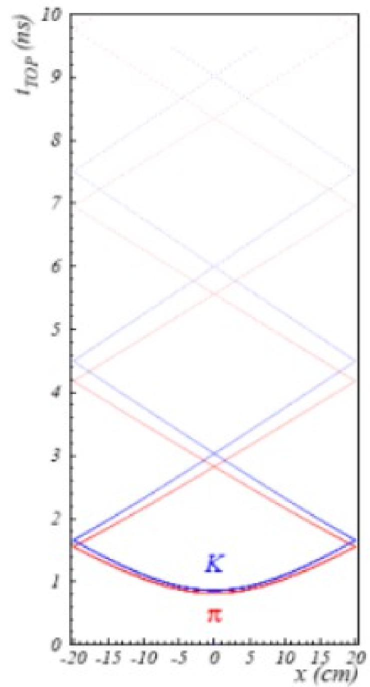
+ new ASIC



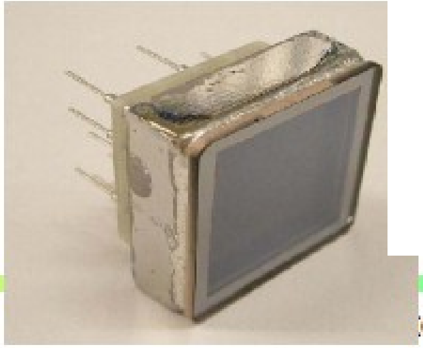
First events in a partially instrumented sector of the ARICH.

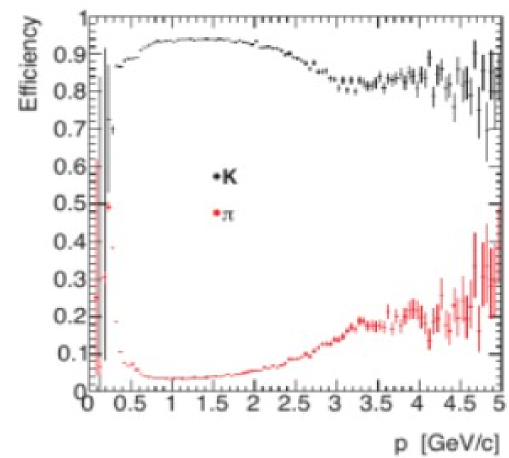
Barrel PID: TOP (Time Of Propagation)



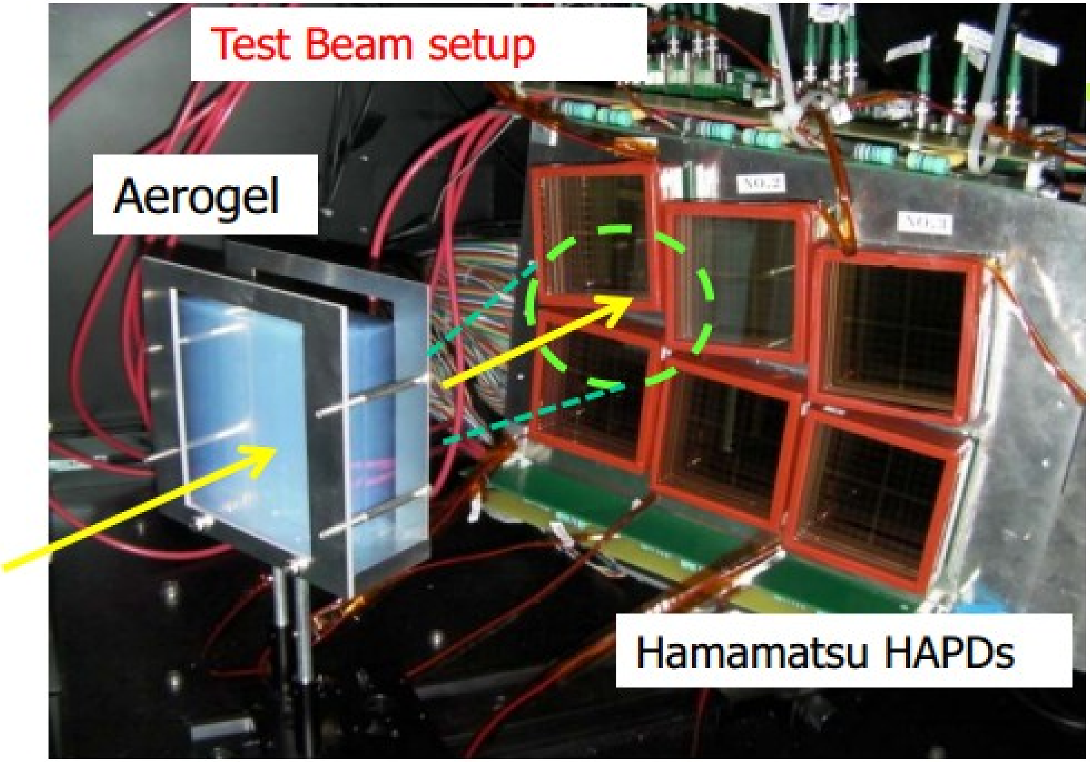


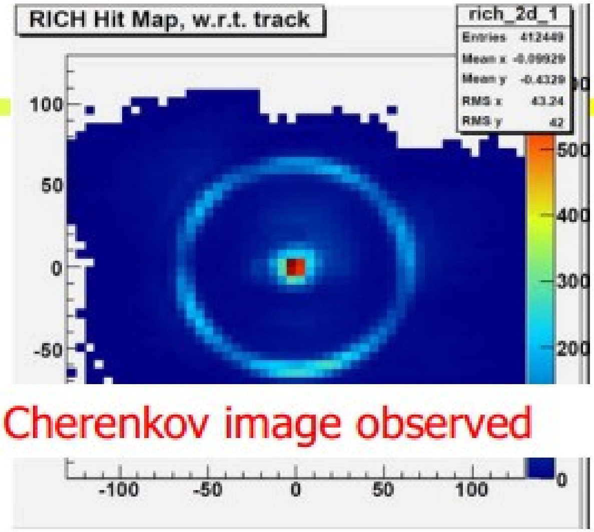
- Cherenkov ring imaging with precise time measurement.
- Uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5





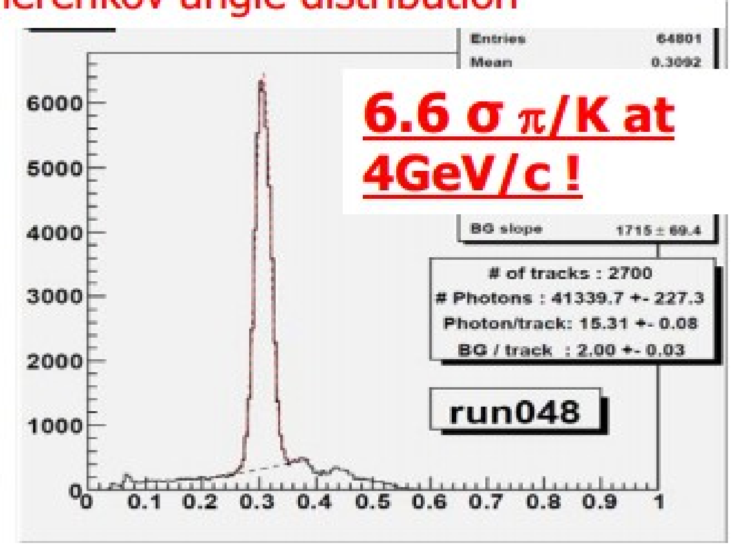
EndCap PID: ARICH (aerogel RICH)

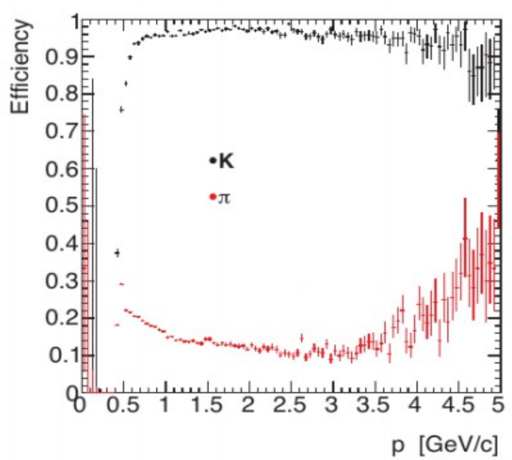


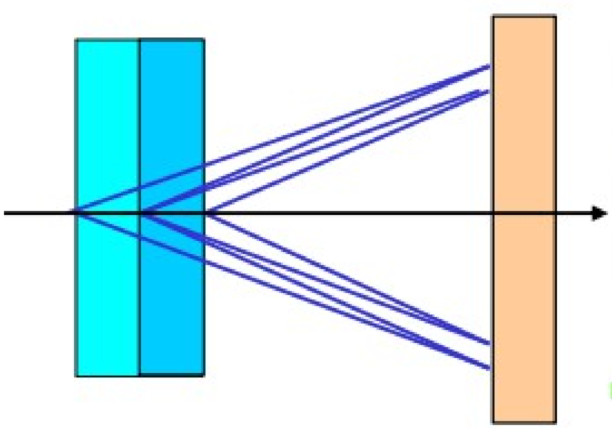


Clear Cherenkov image observed

Cherenkov angle distribution



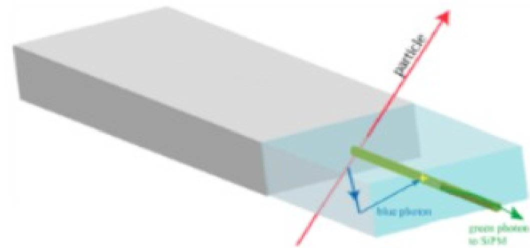


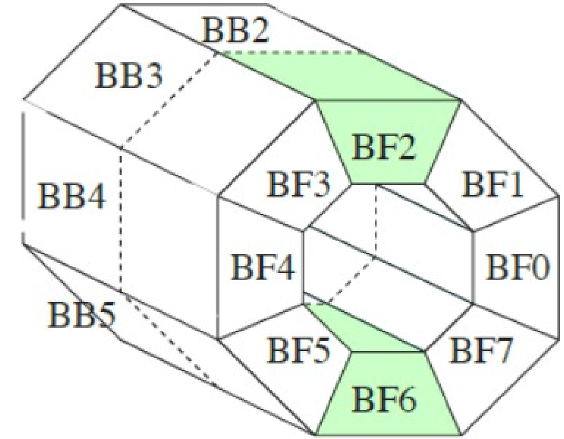


Peter Križan, Ljubljana

KLM (K$_L$ and muon detector)

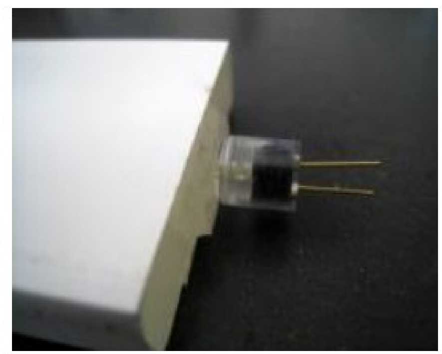
Interleaved with the iron plates of the flux return yoke

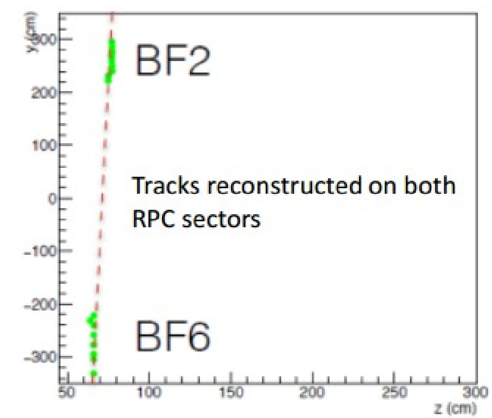




- Barrel:

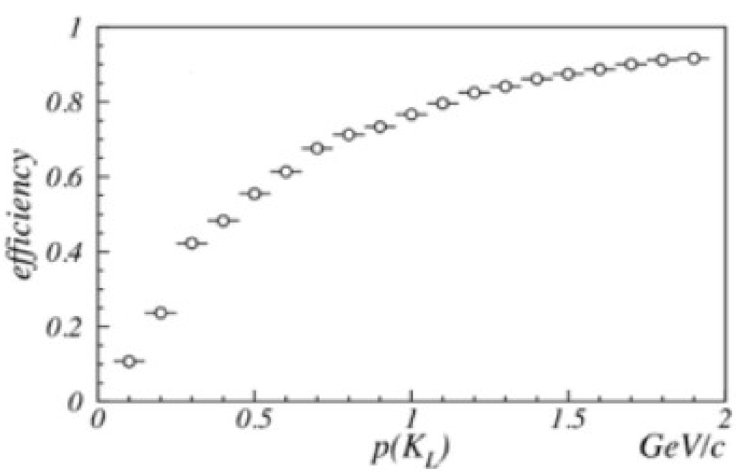
Belle RPCs reused
Two inner layers replaced by scintillator strips
Scintillator strips with WLS fibers
Hamamatsu SiPM S10362

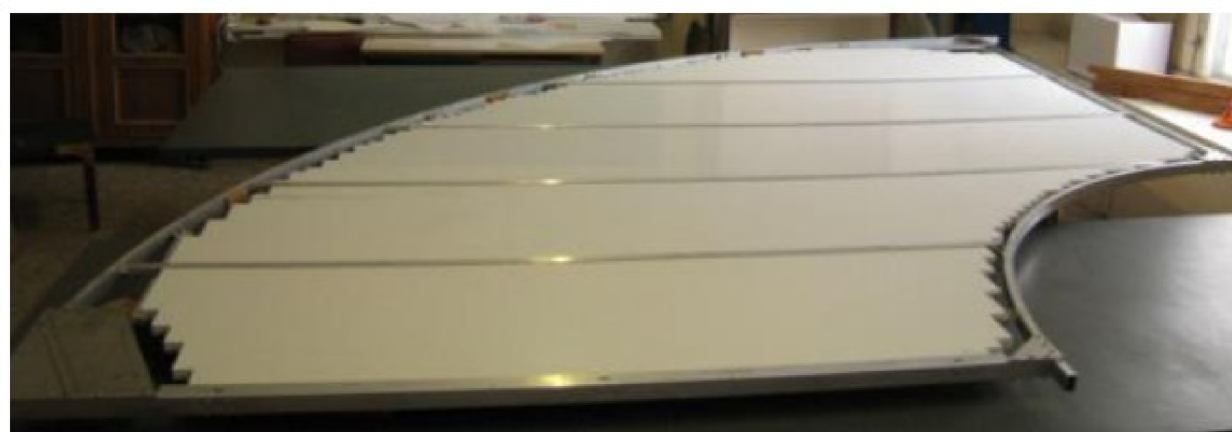




- Endcap:

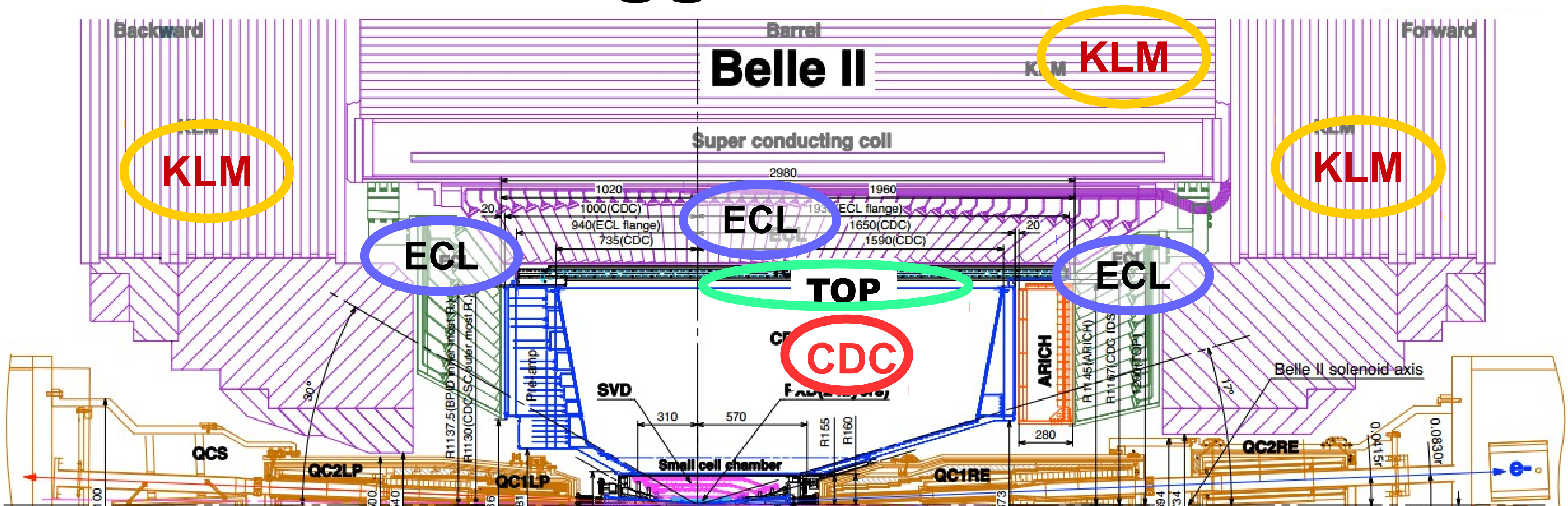
RPCs replaced with polystyrene scintillators
99% geometrical acceptance. σ ~ 1ns





(C. Marinas, DPG Münster 2017)

L1 trigger and DAQ

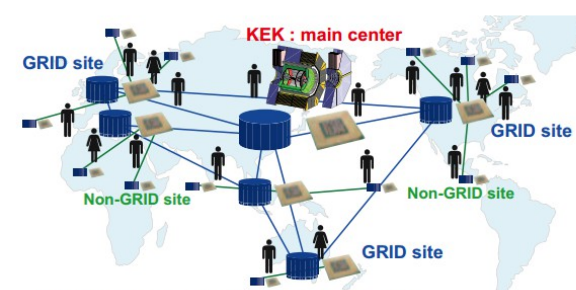


Belle II Level 1 trigger
(CDC + ECL + TOP + KLM)

beam collision 254 MHz
nominal beam background rate ~10 MHz
interested physics event rate ~20 kHz
L1 max. latency 5 μs
L1 z-vertex trigger
L1 Global Reconstruction Logic

DAQ and analysis software

BASF2
(ROOT/C++/Python)



Distributed computing scheme of the Belle II experiment.

LHCb vs SuperKEKB

+ LHCb

large samples (but low efficiencies)

exclusive decays

B_s oscillations

B_c, bottom baryons

$B^0_{s,d} \to \mu\mu$

$B \to J/\psi K_S$

$D^0 \to K^+\pi^-, K^+K^-$

+ SuperKEKB

all final states measurable,
esp. those with photons, neutrinos

+ inclusive decays

rare decays, such as

$B^+ \to l^+\nu, B^+ \to K^+\nu\overline{\nu}$

$b \to s\gamma, b \to sl^+l^-$

$B \to J/\psi\phi, \pi\pi, \rho\pi, \rho\rho, \pi\pi\pi$

$D^0\overline{D}^0$ mixing

$e^+e^- \to \tau^+\tau^-$

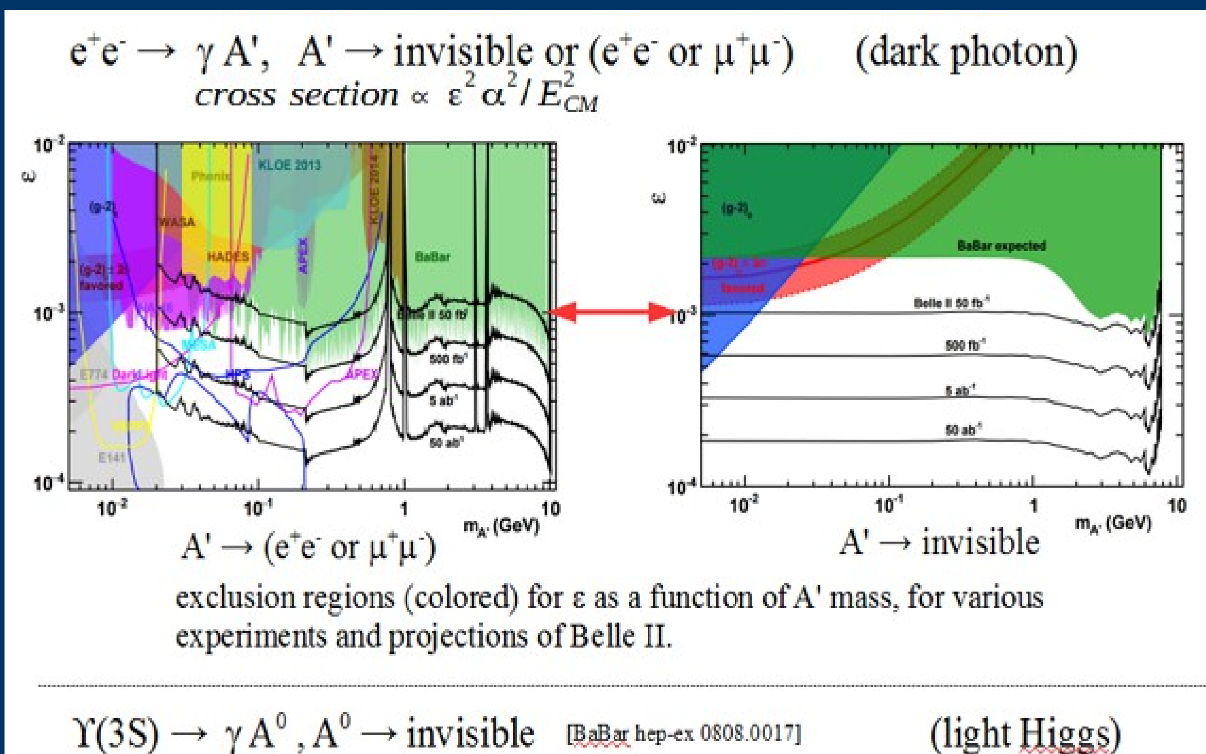
LHCb and SuperKEKB will run concurrently. → largely complementary

(Several working groups organized to assess the possible physics topics)

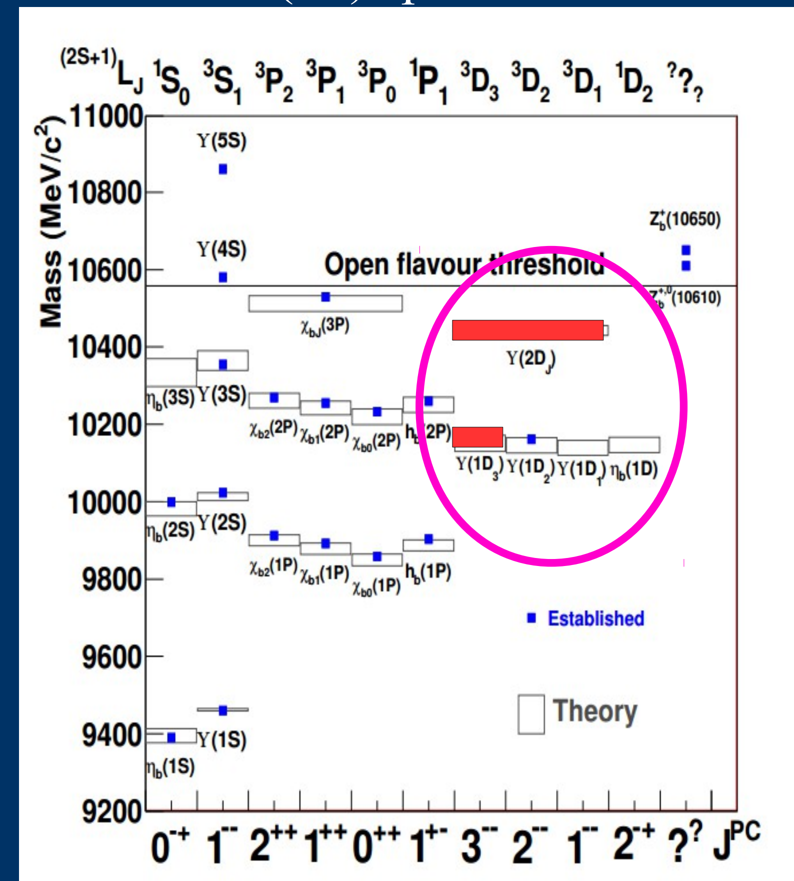
potential early physics topics

Phase 2&3 possible to collect 300fb^{-1} data

- bottomonium
  - improving measurements (e.g. $\eta_b(nS)$, $h_b(nP)$)
  - searching for "missing" particles (e.g. $\Upsilon(1D,2D)$)
- BSM physics: dark photon/light Higgs



$\Upsilon(3S)$ spectrum



$\Upsilon(1D_2)$ has been measured by CLEO/BaBar.

$\Upsilon(1D_1)\Upsilon(1D_3)\Upsilon(2D)$ are not seen yet.