Status of the Belle II experiment and ML applications to the particle physics experiments

2022/3/24

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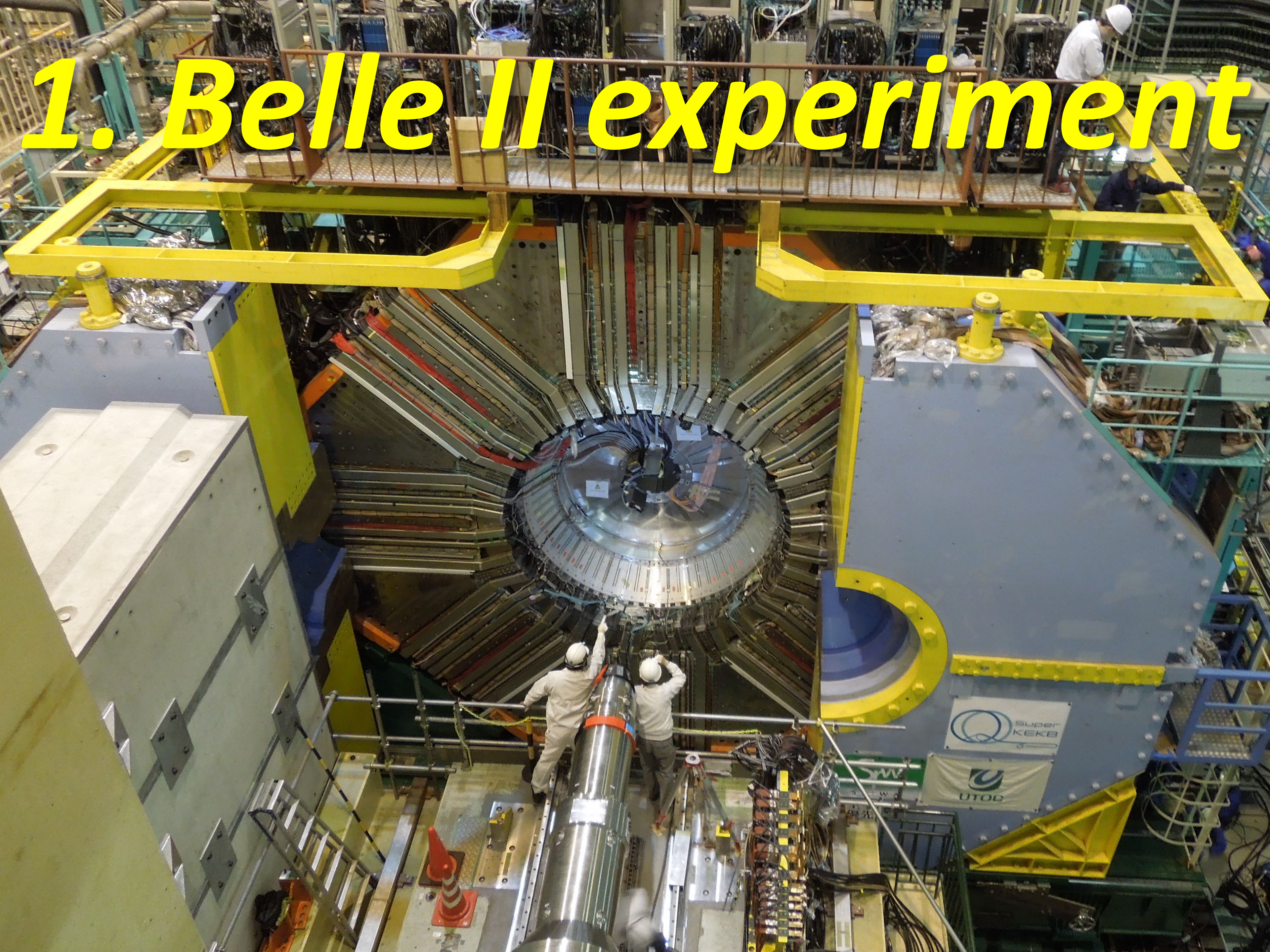
Osaka U., RCNP, Osaka U., IDS

Contents

Skip if time is short

1. Belle II experiment



1-1: Introduction

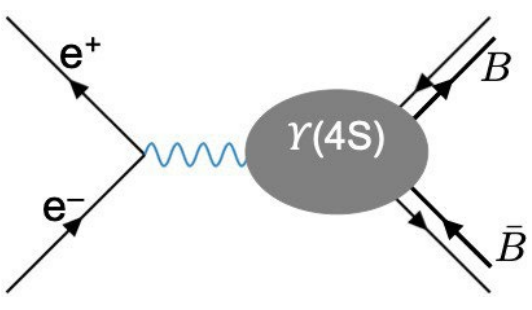
The SuperKEKB / Belle II experiment

⇩

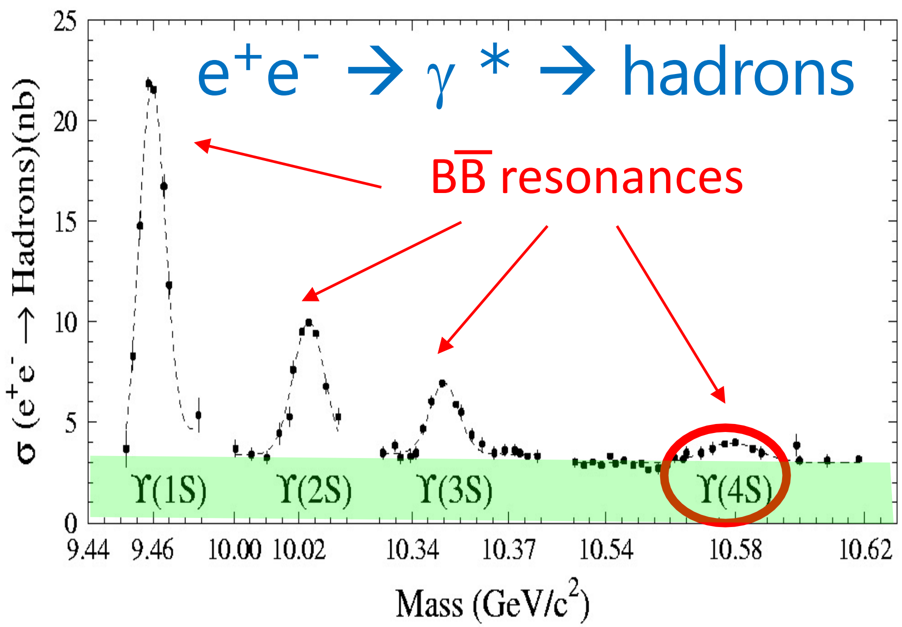
Upgrade of the KEKB / Belle

B-factory experiment **in Japan**

Produces huge amount of $B\bar{B}$ mesons pairs on the ϒ(4s) resonance



$$\sqrt{s} = 10.58\ GeV$$



1-1: Introduction

The SuperKEKB / Belle II experiment

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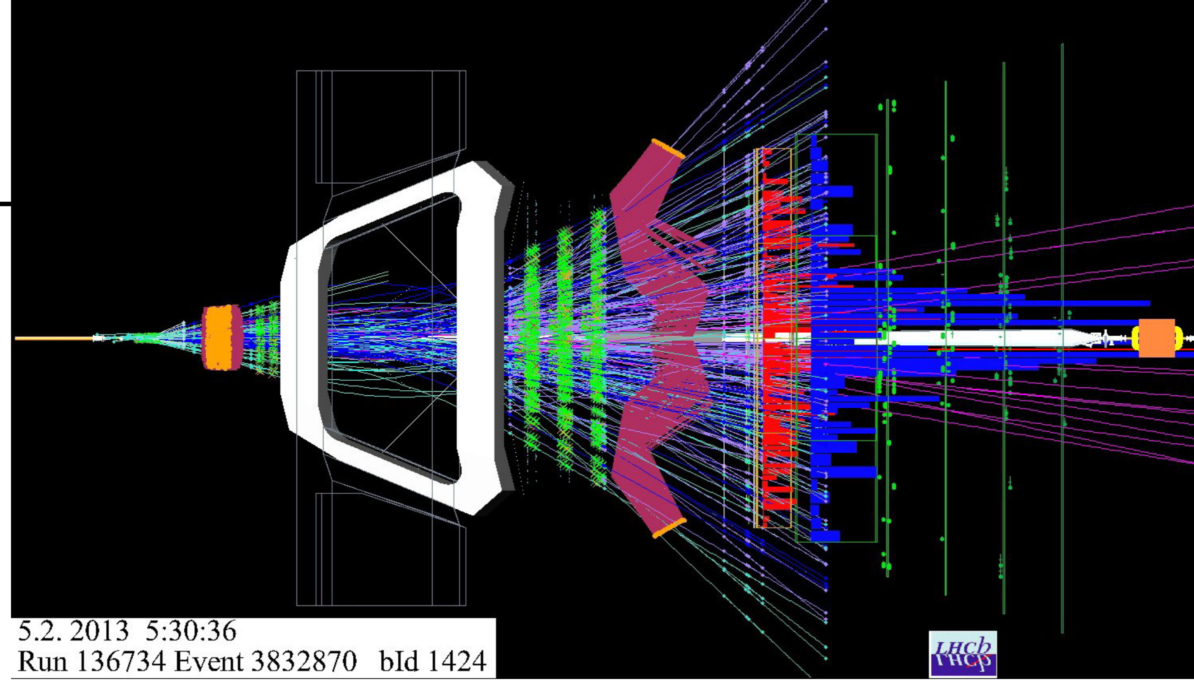
Upgrade of the KEKB / Belle
B-factory experiment **in Japan**

Produces huge amount of $B\bar{B}$ mesons pairs on the Υ(4s) resonance

"Luminosity frontier experiment"

Low energy experiment indirectly probing high energy using ***high statistics data***

Production of B Mesons



Hadron collider:

- Production of b hadrons in strong interaction

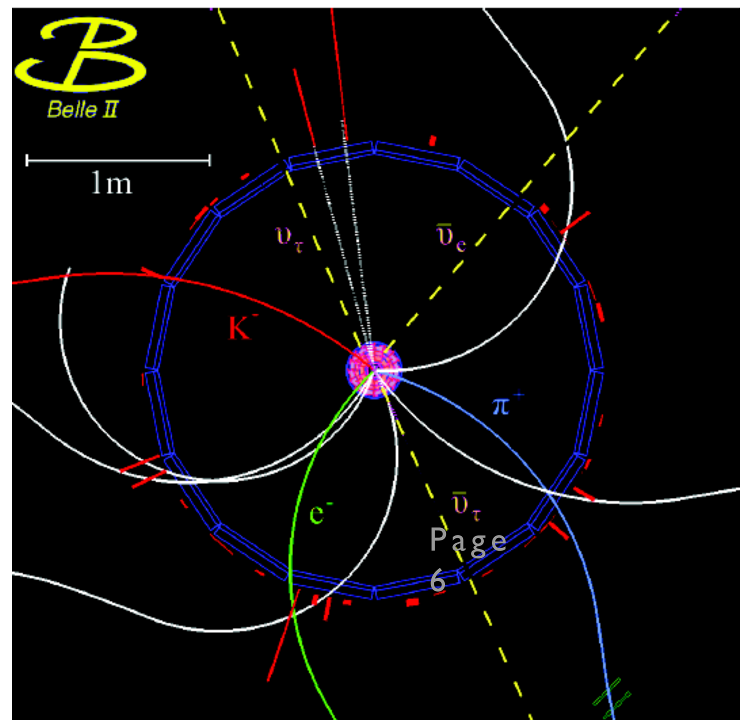
→ Vertexing

B factory:

- $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$

→ Known properties of events and B mesons

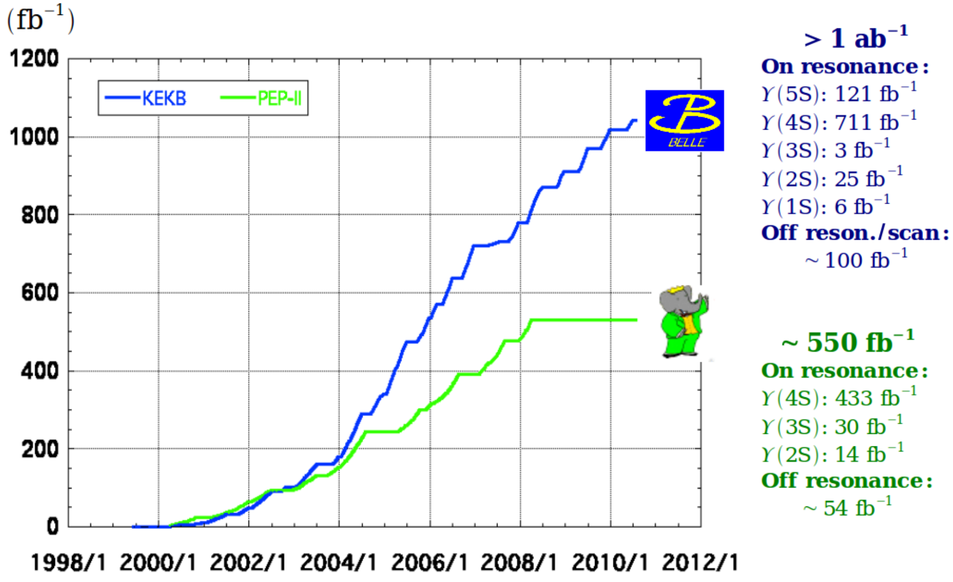
➢ Unique opportunities

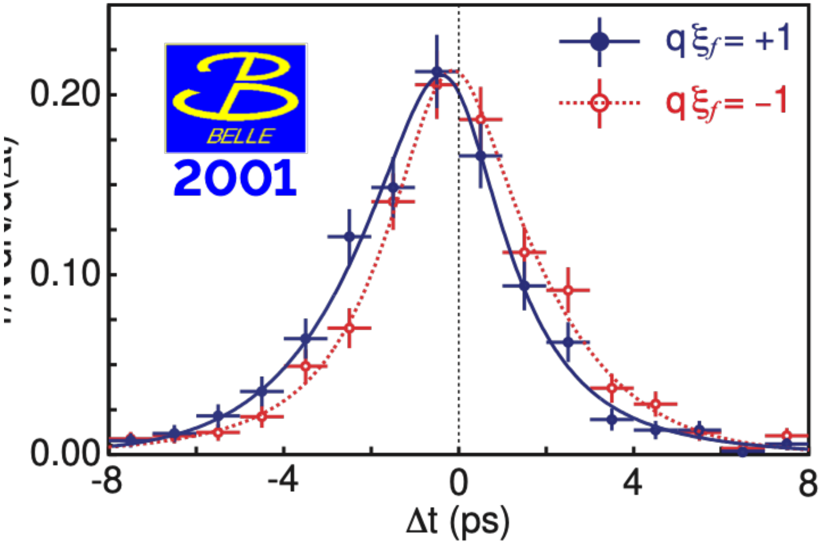


(Past)B-factory in KEK Japan

In 1999 – 2010, KEKB/Belle accumulated
~800 million BB pairs, and
observe the CP violation in the B meson sector

Integrated luminosity of B factories





→Confirm the prediction of the Kobayashi-Maskawa theory

SuperKEKB project

The observed CP violation is too small to explain
the number of surviving matter particles in the current universe

→ It is important to search for the new laws of physics
(= hidden laws of physics in the early universe)

KEKB has been upgraded to SuperKEKB
for more precise experiment to probe the early universe

Design luminosity of the SuperKEKB accelerator

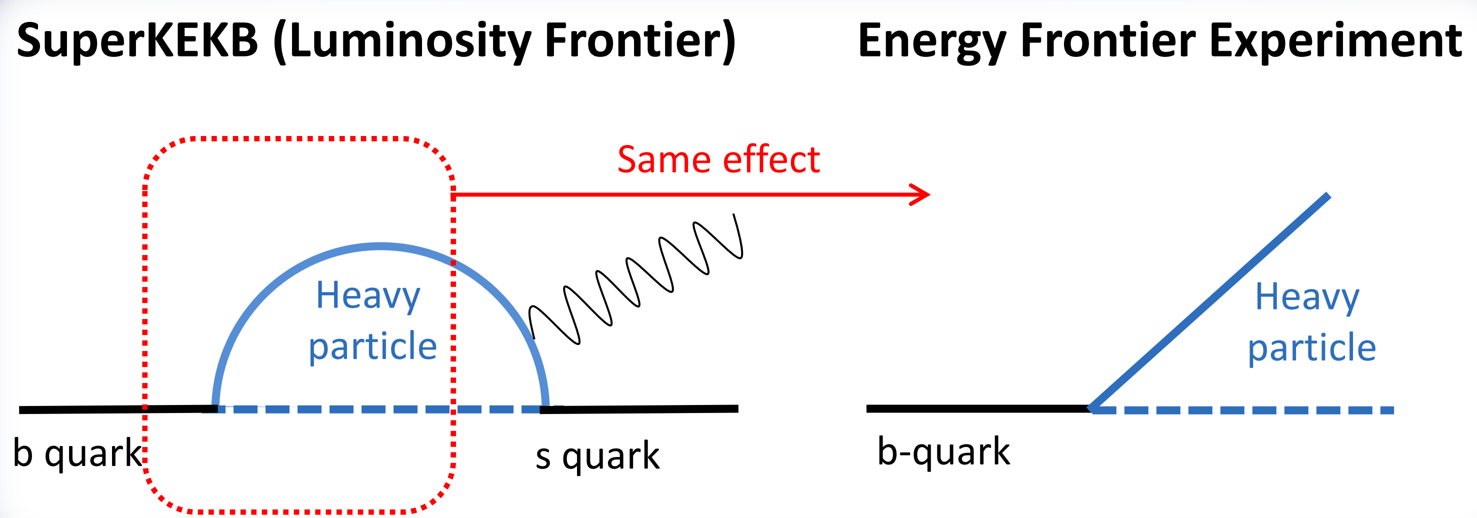
x30 of the KEKB's world record

to accumulate high statistics of $50ab^{-1}$ data

→ Probe > O(TeV) energy scale

SuperKEKB/Belle II Experiment

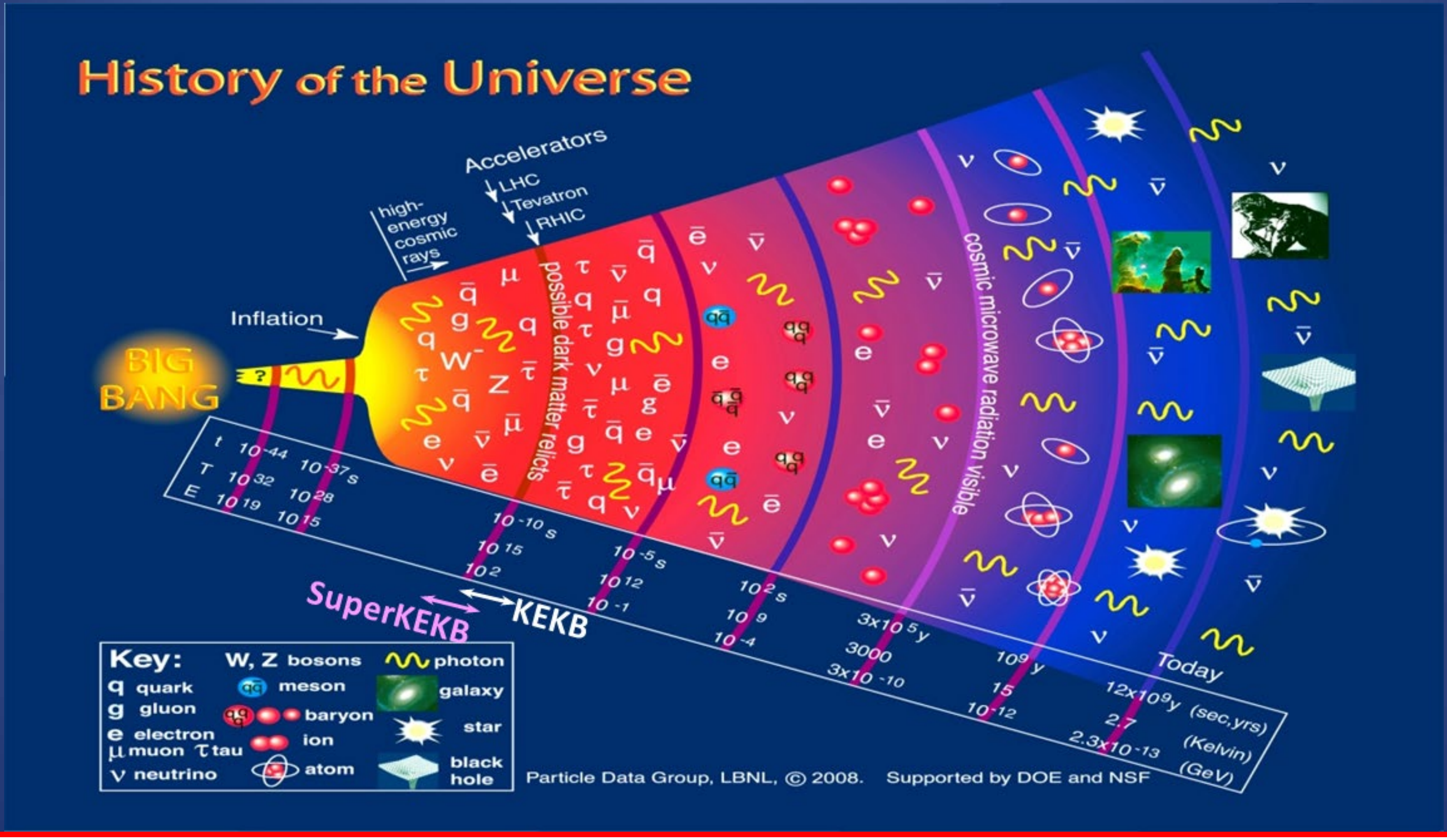
Low energy experiment <u>indirectly probing the higher energy based on the high statistics data</u>



Key of SuperKEKB → "High statistics data"

SuperKEKB/Belle II Experiment

Low energy experiment <u>indirectly probing the higher energy based on the high statistics data</u>



Key of SuperKEKB → "High statistics data"

Strategies for increasing Luminosity

Three Key factors for a factor of ~30 gain

Beam-beam parameter

Beam current

Lorentz factor

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

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Classical electron radius

Beam size ratio@IP 1 ~ 2 % (flat beam)

Vertical beta function @ IP

(1) Smaller β_y^*

(2) Increase beam currents

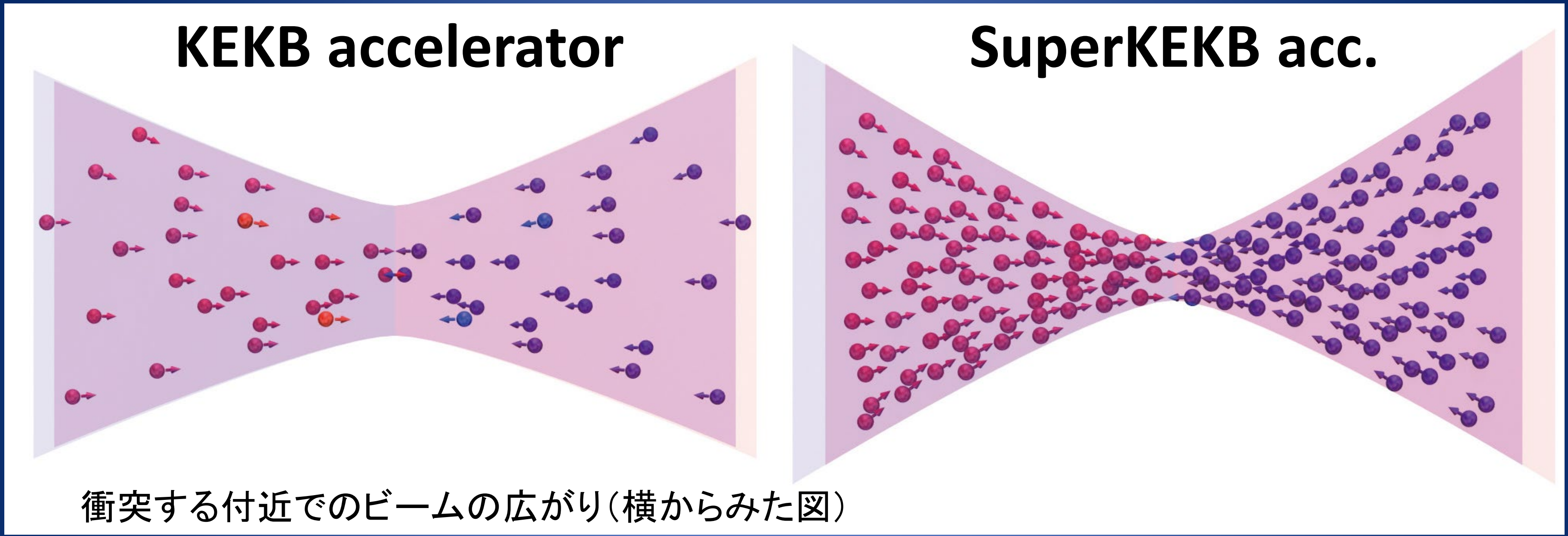
(3) Increase ξ_y

"Nano-Beam" scheme

First proposed by P.Raimondi for SuperB

Collision with very small spot-size beams

Strategies for increasing Luminosity

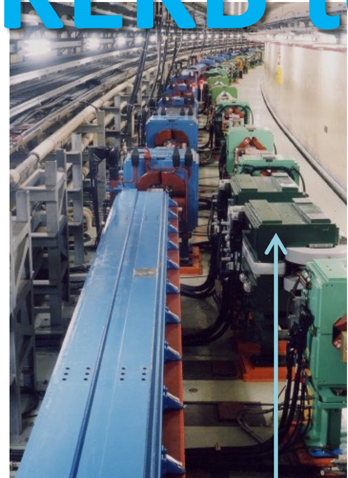


1/20 Beam size x 1.5 beam current

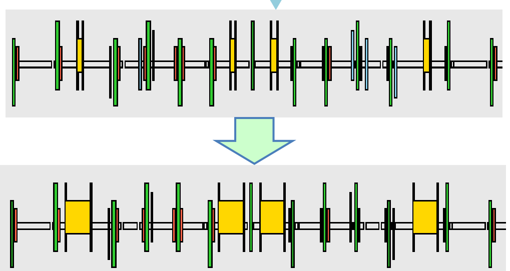
→ 30 times higher Luminosity

To get the higher luminosity,
KEKB was upgraded to SuperKEKB

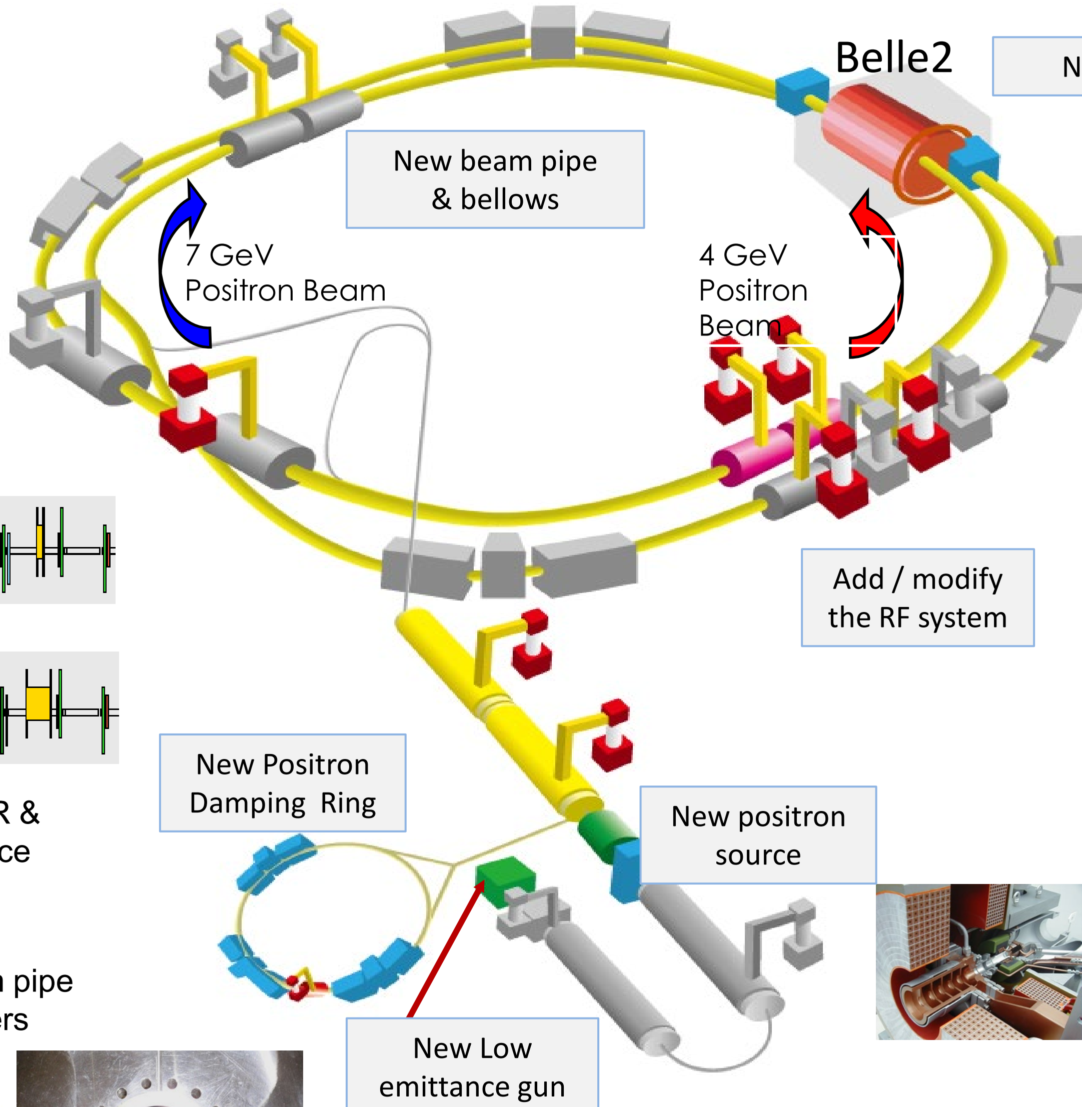
KEKB to SuperKEKB How to upgrade

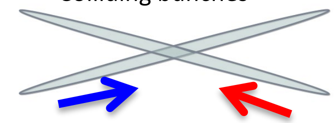


Replace short dipoles with longer ones (LER)

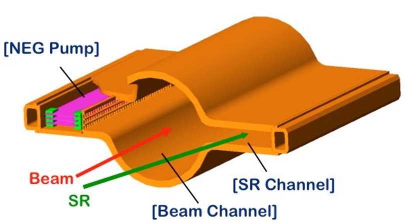


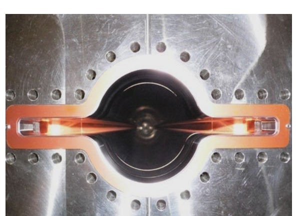
Redesign the lattices of HER & LER to squeeze the emittance





TiN-coated beam pipe with antechambers

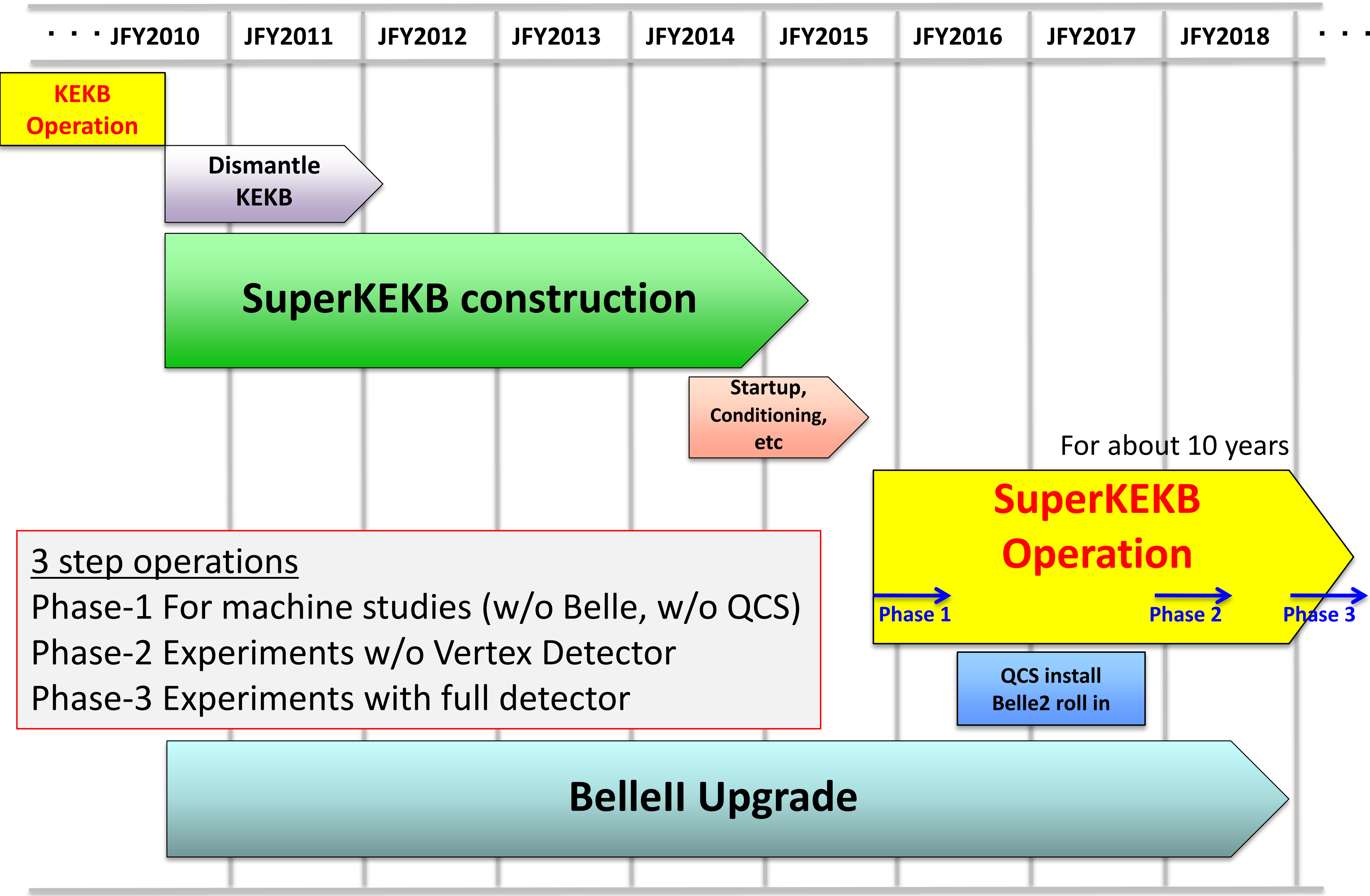




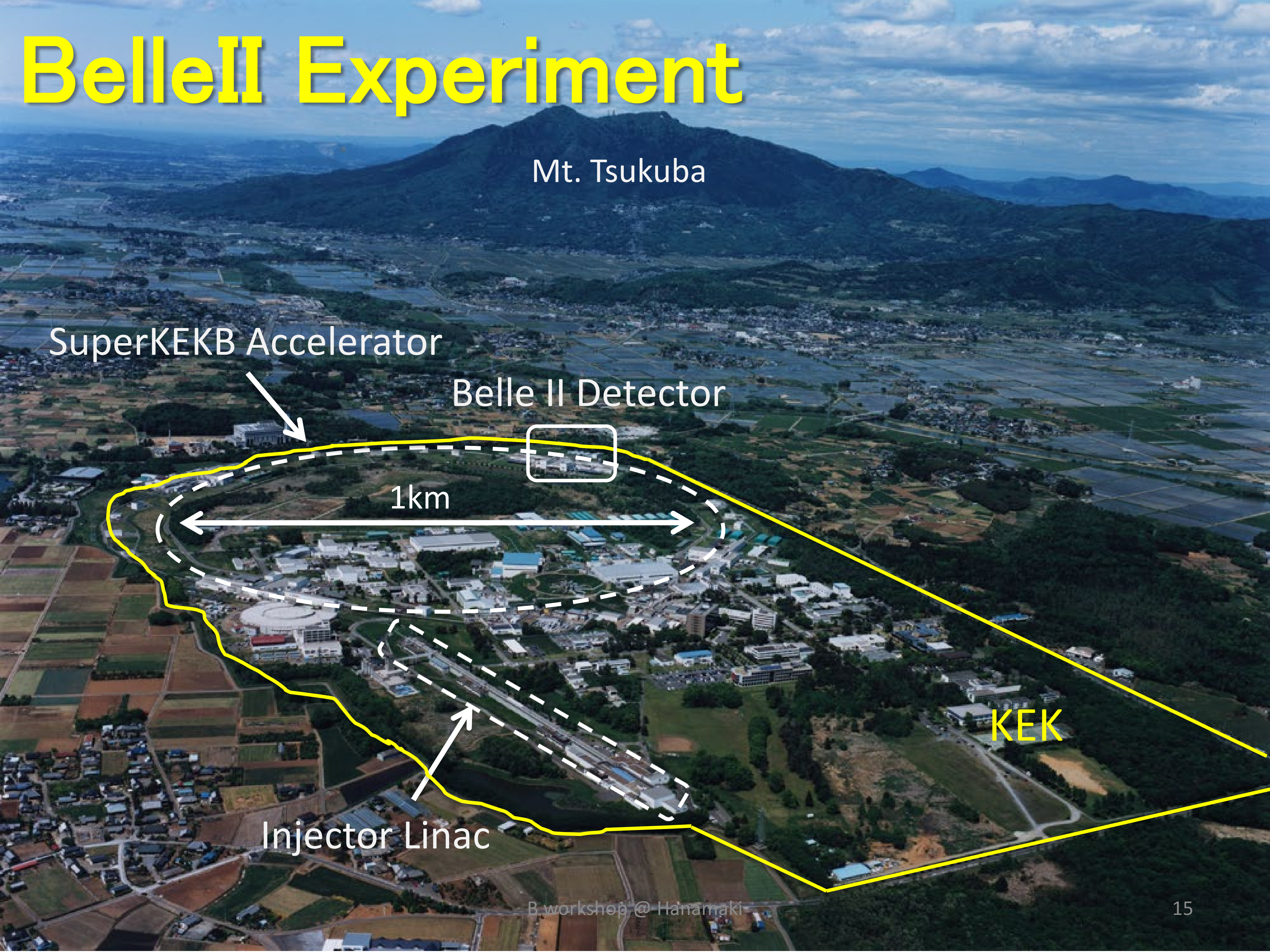
To get x30 higher luminosity

Belle I to Belle II

K. Akai



BelleII Experiment



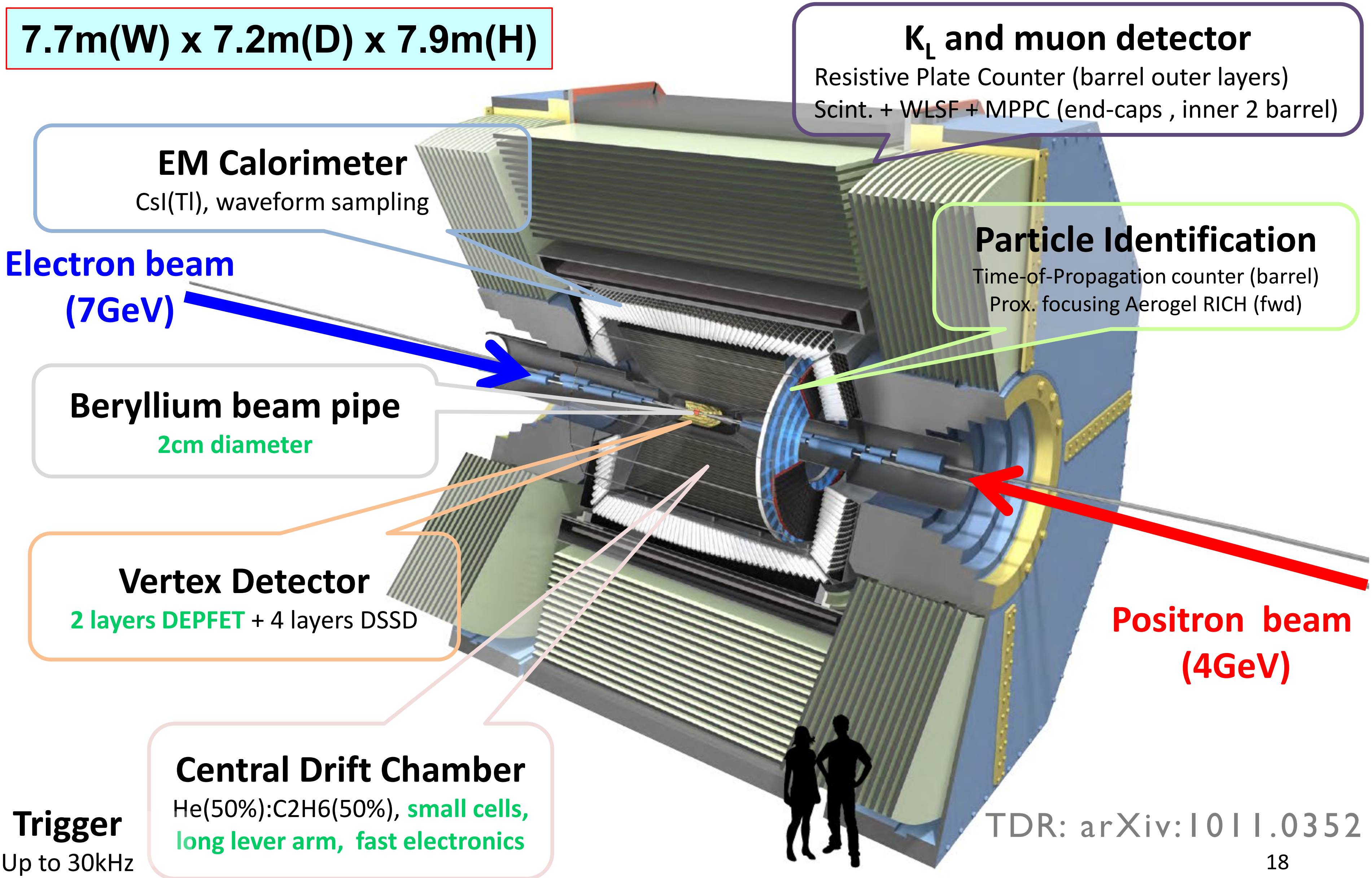
BelleII Experiment

Huge amount of elementary particles are produced

BelleII Experiment

BelleII Detector
7.7m(W) x 7.2m(D) x 7.9m(H)

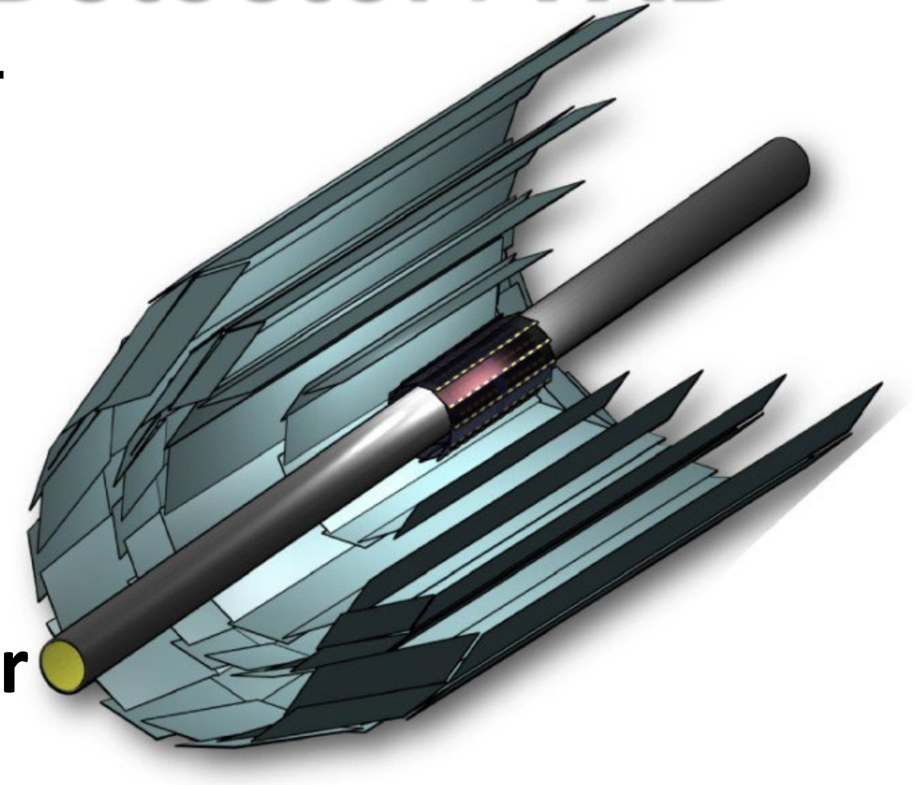
Belle II Detector



Trigger
Up to 30kHz

Belle II Vertex Detector：VXD

VXD = PXD + SVD



PXD : PiXel Dector

DEPFET(DEPleted p-channel FET)

2 Layers （r =**14**, 22mm)

SVD : Silicon Vertex Detector

DSSD (Double Sided Silicon Strip)

4 Layers（r = 38, 80, 115, 140 mm）

Belle II VXD covers r = 14mm - 140mm area

BelleI : SVD only (4 layers DSSD r=**20** – 88 mm)

20→14mm x2 better impact parameter resolution $(14/20)^2$

Belle II Vertex Detector：VXD

Installed in 2018.

PXD
1^{st} layer and
2 ladders of 2^{nd} layer

SVD
4 layers

News: In 2022-23, do a long shutdown (LS1) and replace with a 2-layer PXD.

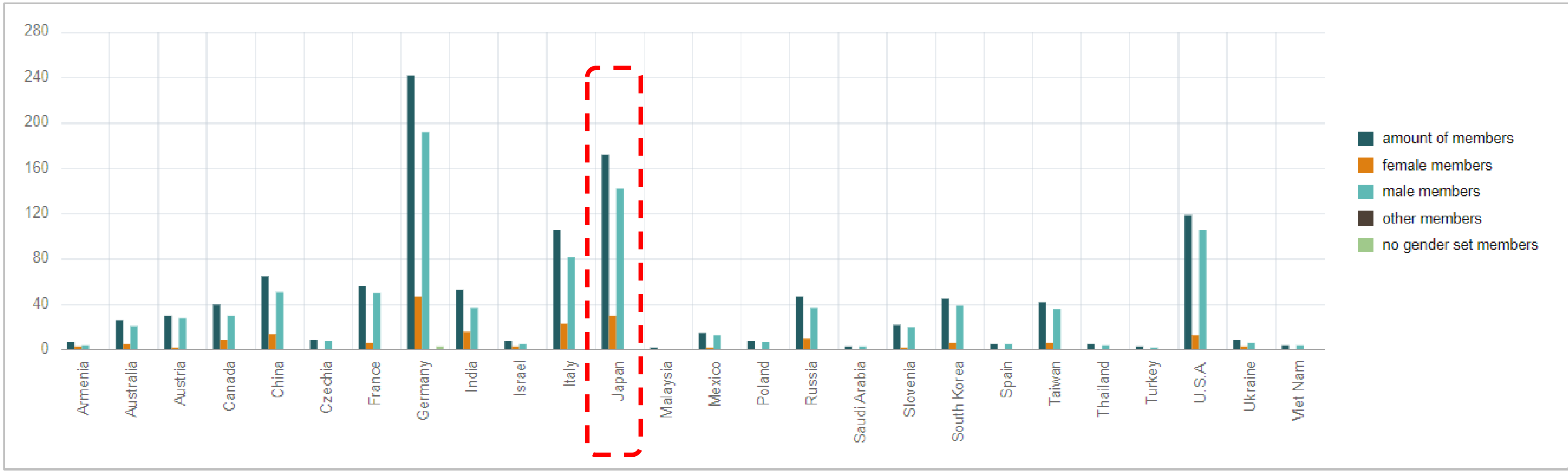
Geography of the International Belle II collaboration

Belle II now has grown to ~1100 researchers from 26 countries (121 institutes)

cf. Belle
~400 collaborators
13 countries, 57 institutes

Youth and potential: There are ~330 graduate students in Belle II

Japanese Participation



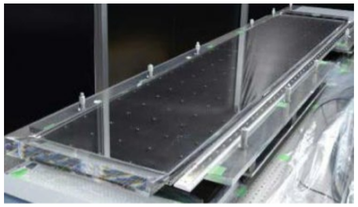
2nd largest group in Belle II

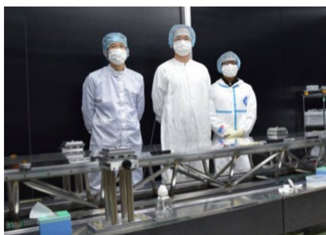
172 members from 16 institutes

Chiba, Hiroshima, IPMU, KEK, Kitasato, Nagoya, Nara-WU, Niigata, NPC, Okinawa, Osaka-City, Toho, Tohoku, Tokyo-Met., U. Tokyo, Yamagata

Japanese Contribution

TOP（Nagoya, KEK）

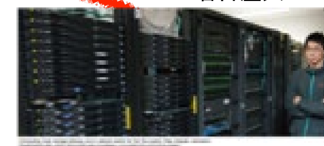


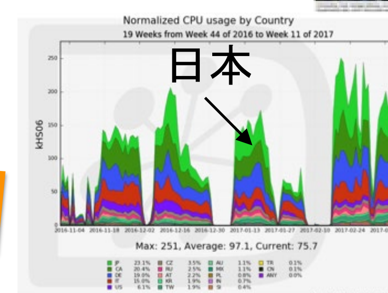


ECL（Nara W.）

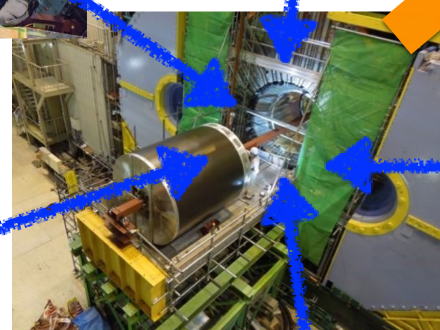
Computing（KEK+ Universities）

名古屋大KMI

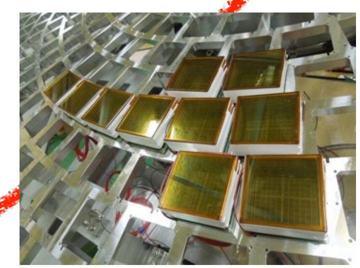


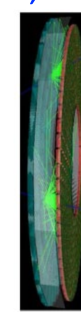


モンテカルロ事象
生成に対する国別
貢献度

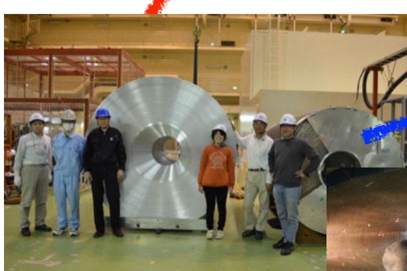


A-RICH（Tookyo. M., Niigata, Chiba, Toho, KEK）





CDC（Osaka-City, NPC, KEK）



SVD（U.Tokyo, IPMU, Tohoku, KEK）

Trigger・DAQ（KEK）

1-2: Operation Status + Recent Results

First collision after 5.5 years construction

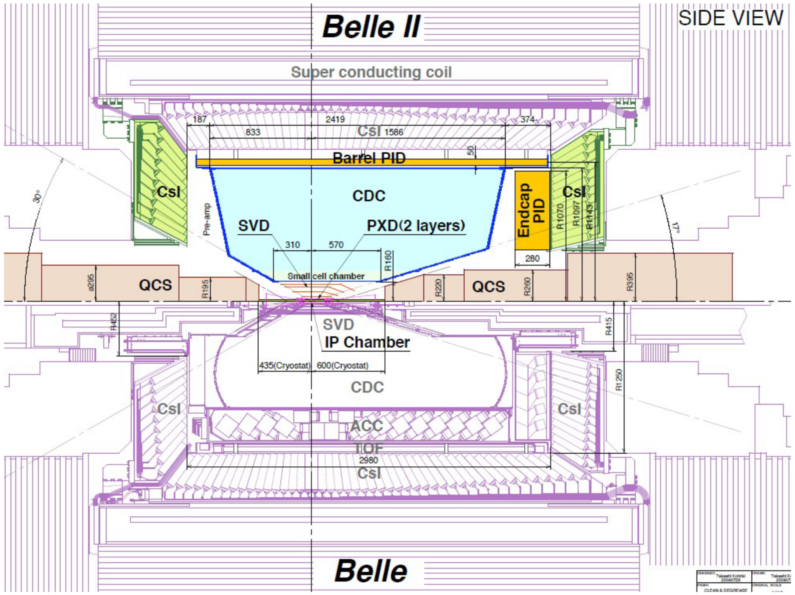
First hadronic event

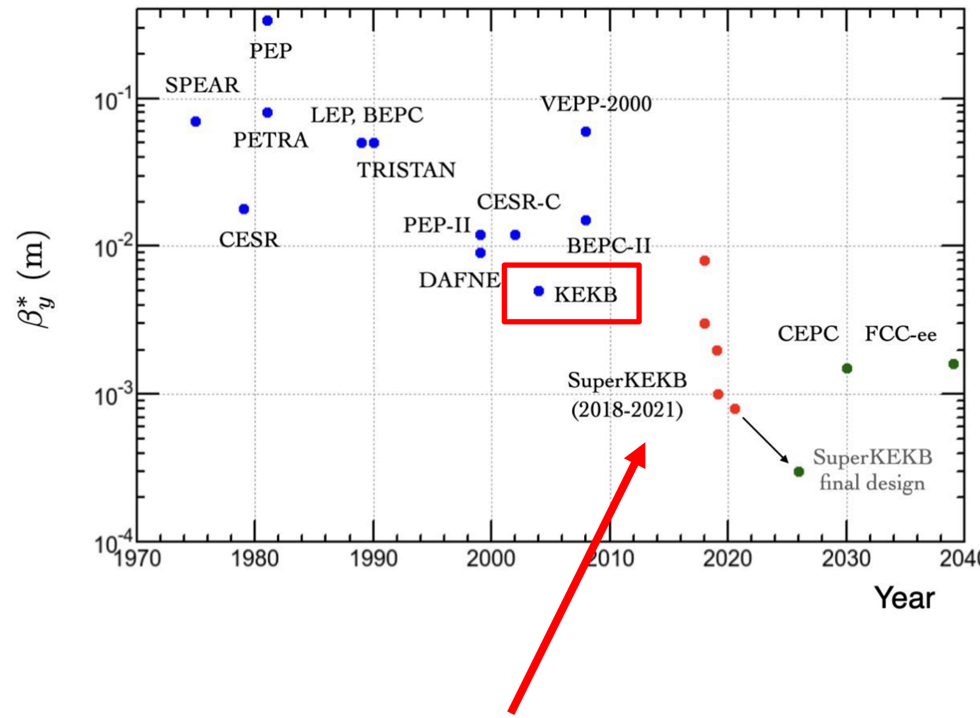
April. 26, 2018 0:38
Belle II control room

Belle II

Super KEKB

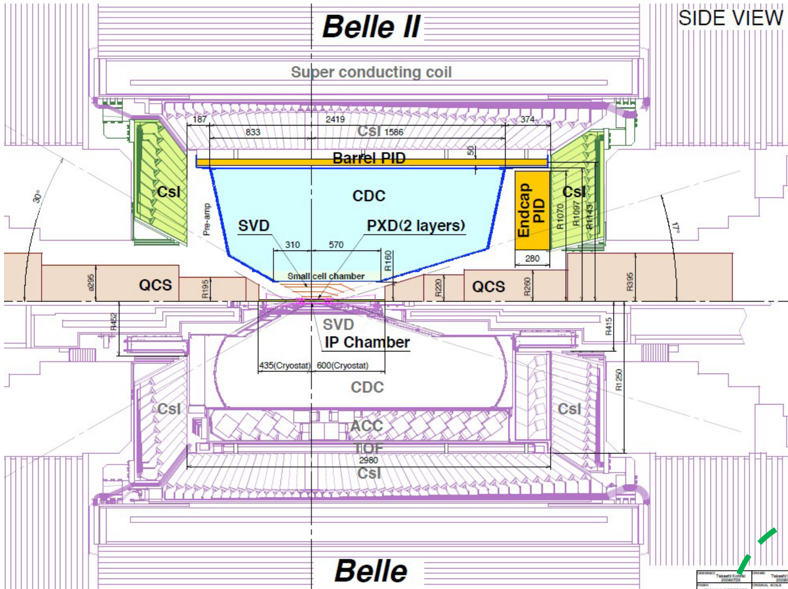
SuperKEKB Status

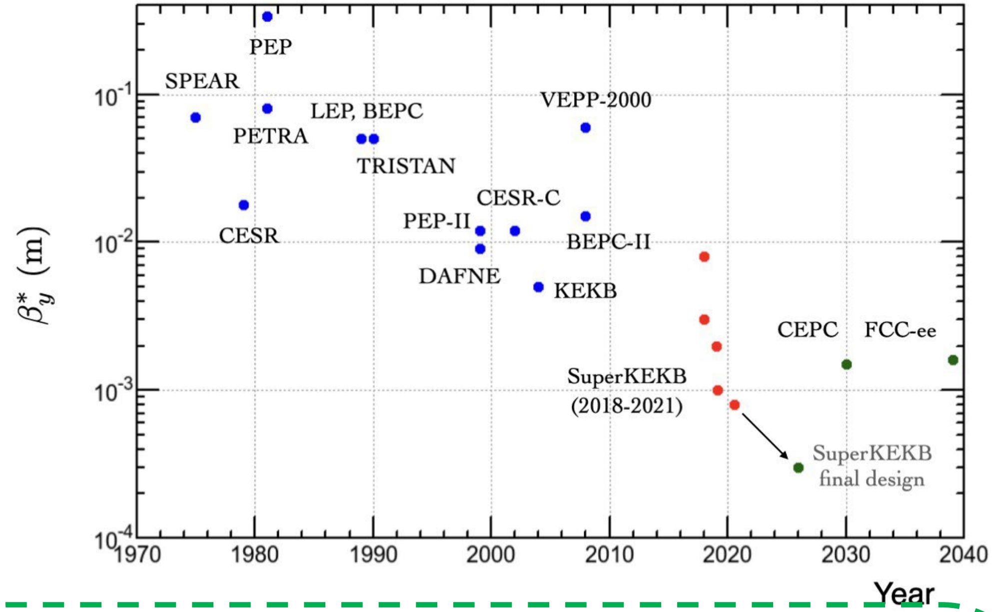


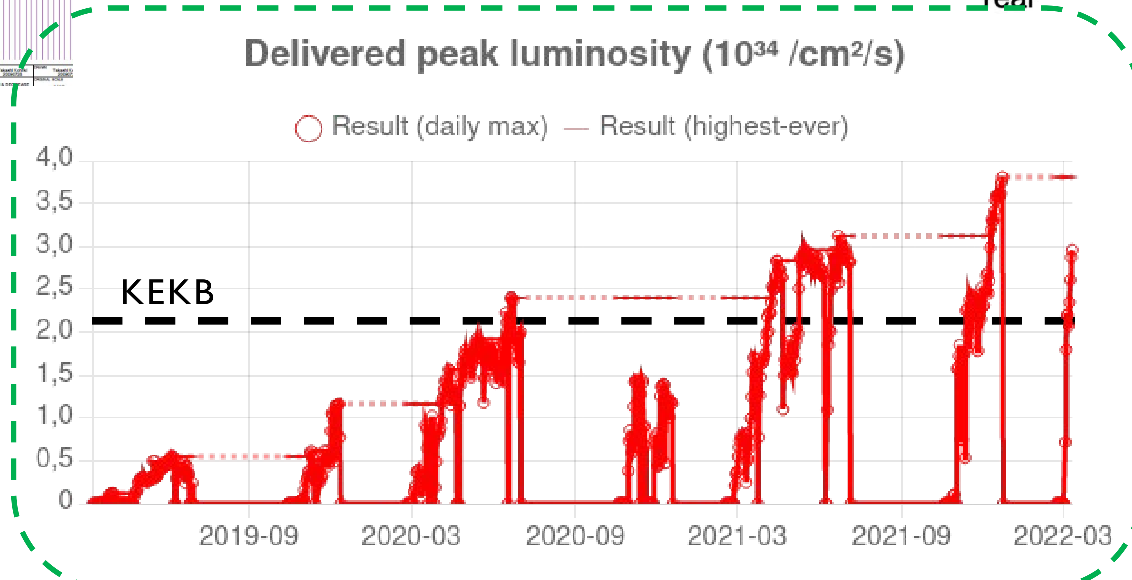


We squeeze the beam smaller than KEKB

SuperKEKB Status







Data Taking Status

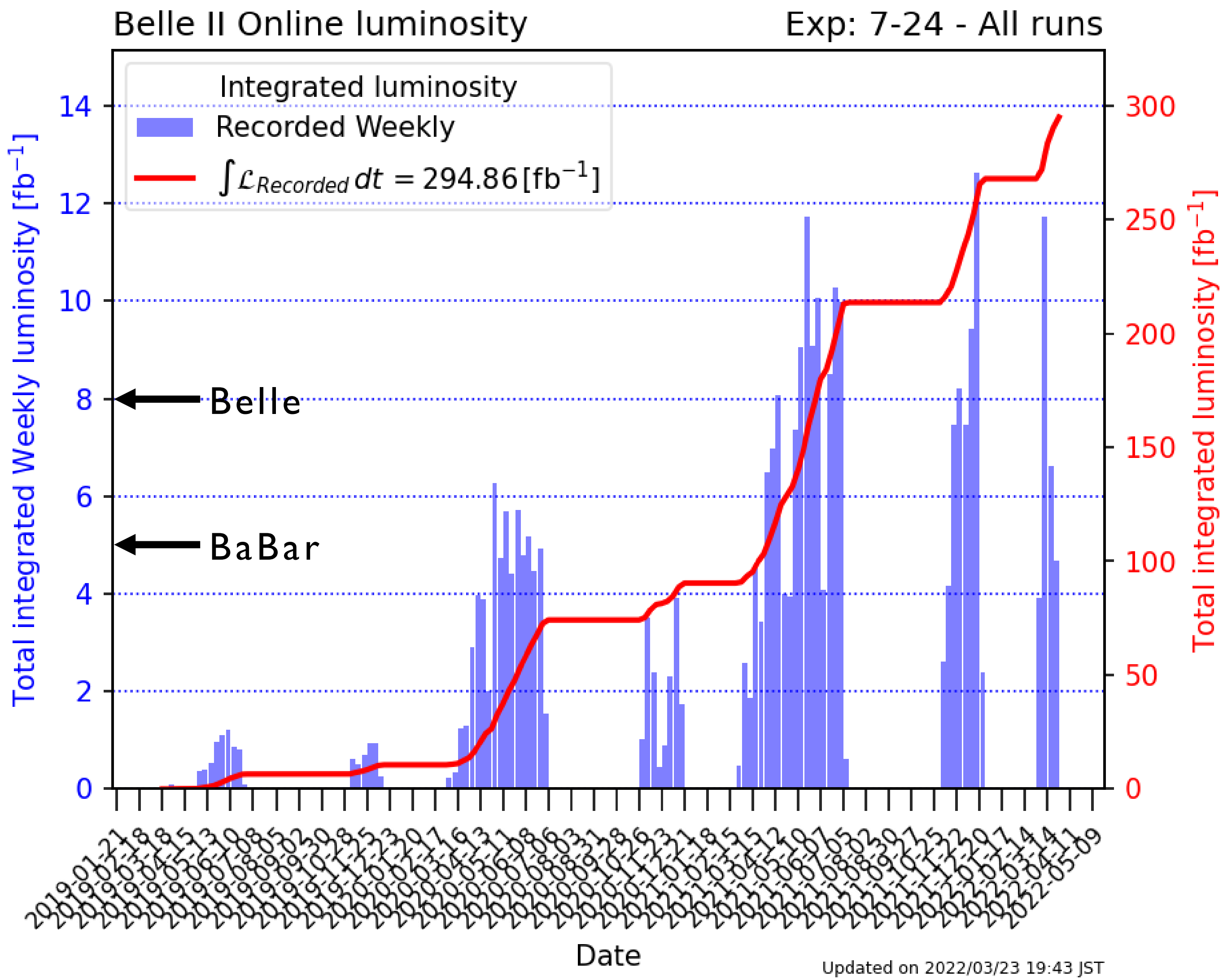
Commissioning run in 2018

Physics run Started 2019

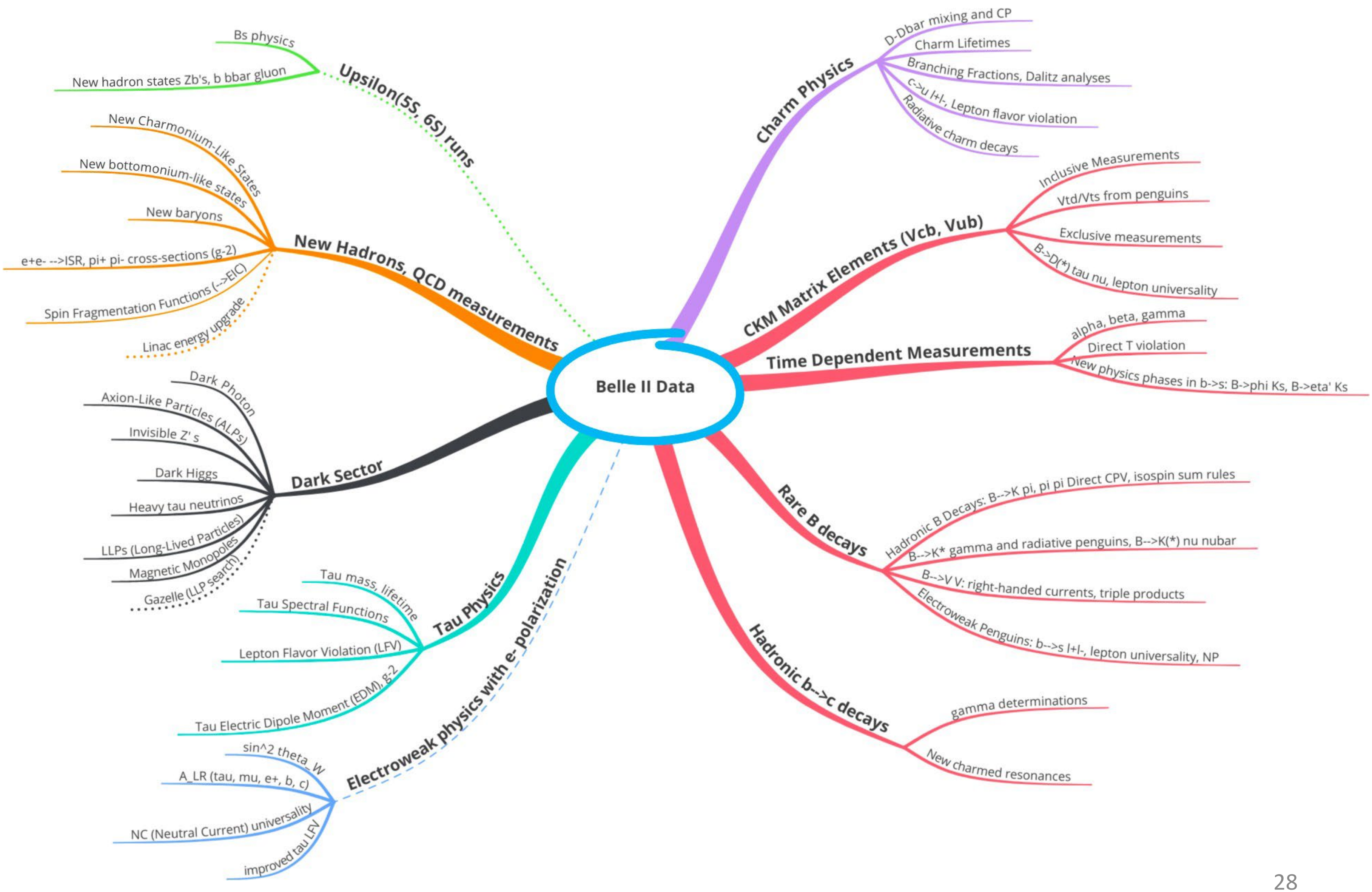
Collected $0.3\ ab^{-1}$ so far

BaBar : $0.5\ ab^{-1}$

Belle : $1.0\ ab^{-1}$



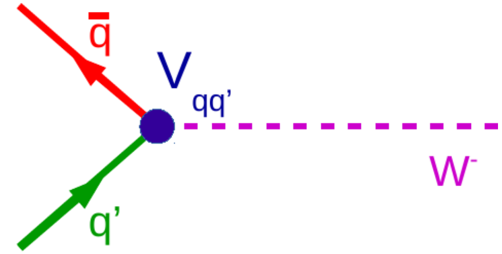
Belle II Physics



CKM Parameters

Cabibbo-Kobayashi-Maskawa (CKM) matrix

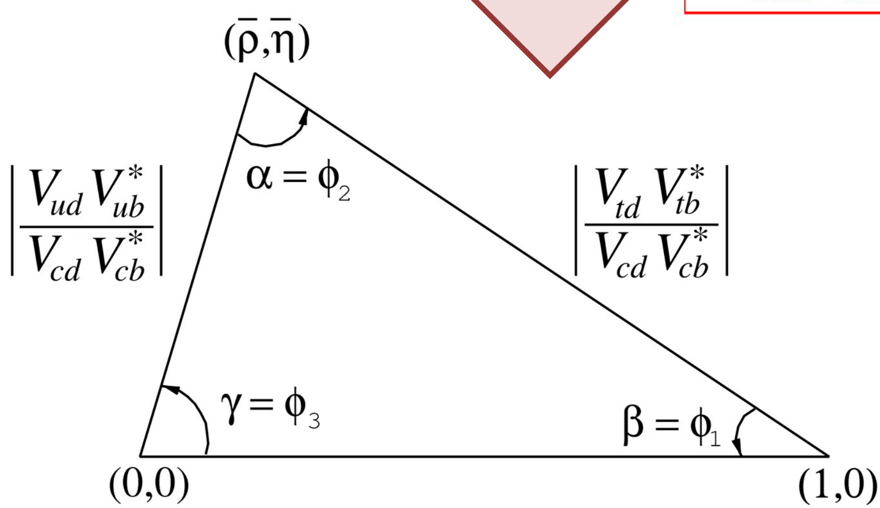
- Three generation of quarks.
- Each element ($V_{qq'}$) describes mixing of quacks via weak interaction in Standard Model (SM).



$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Unitarity triangle



$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

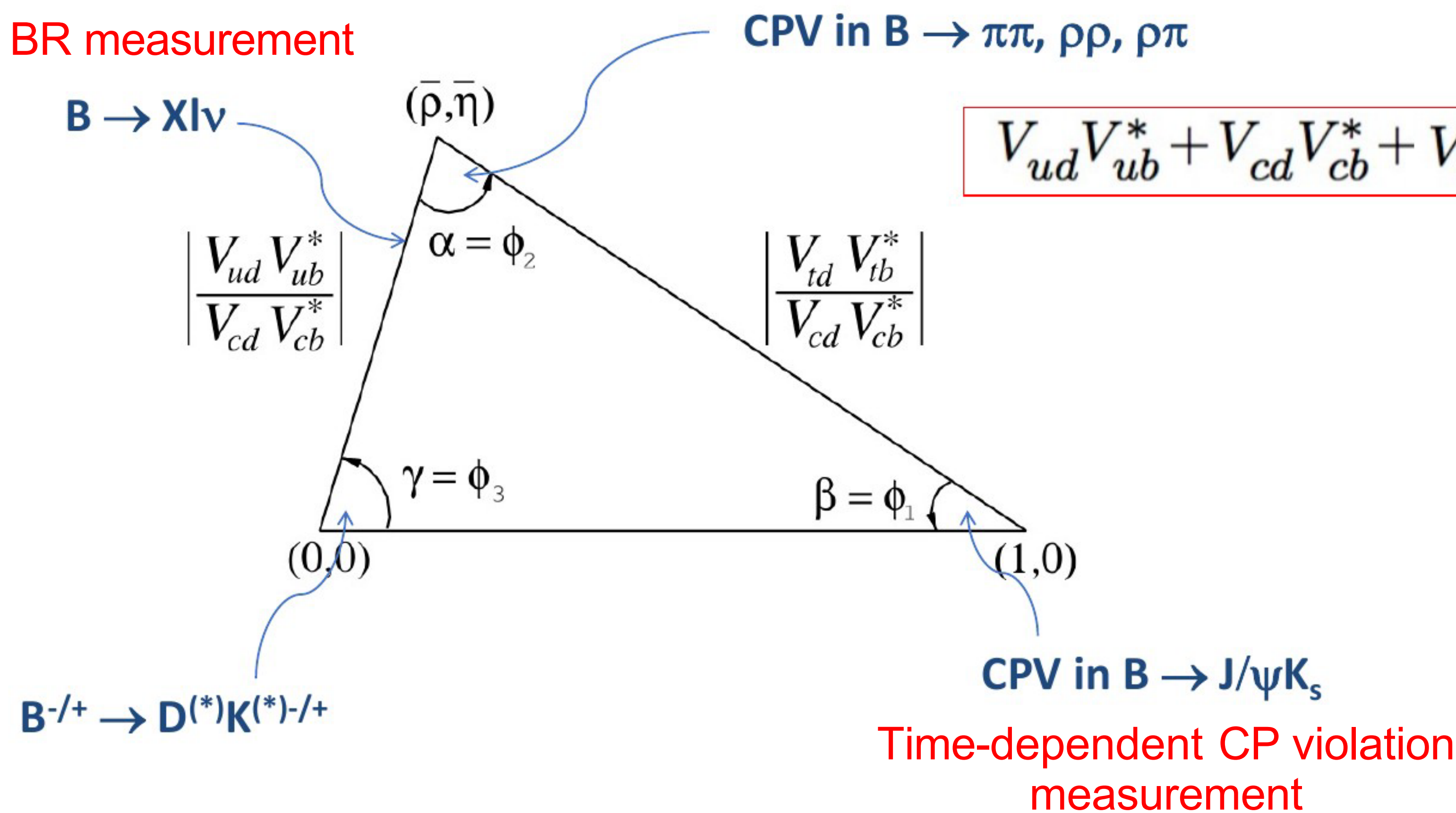
$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

CKM Parameters

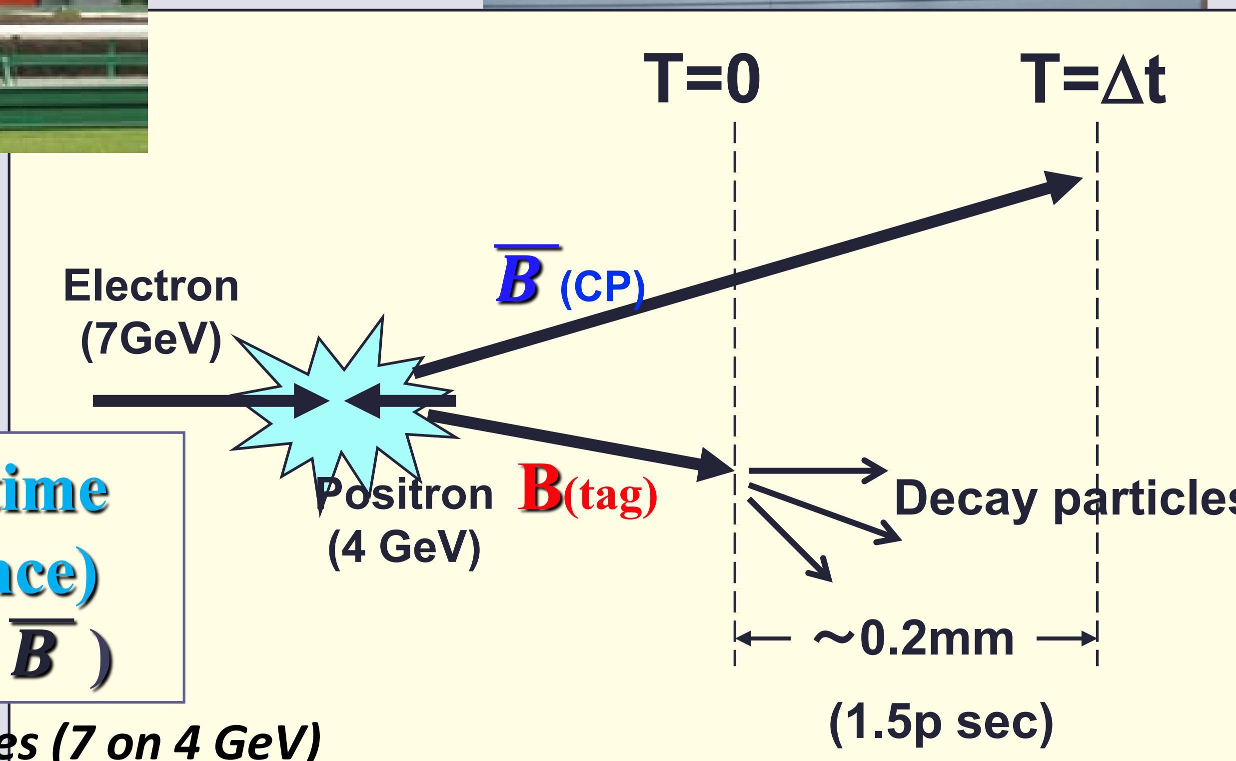
- In SM, CP violation arises via a non-zero phase of the CKM matrix.
- Precise measurement on UT angles and sides is a good test on SM.

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



Time Dependent CP Violation

Time Dependent CP Violation

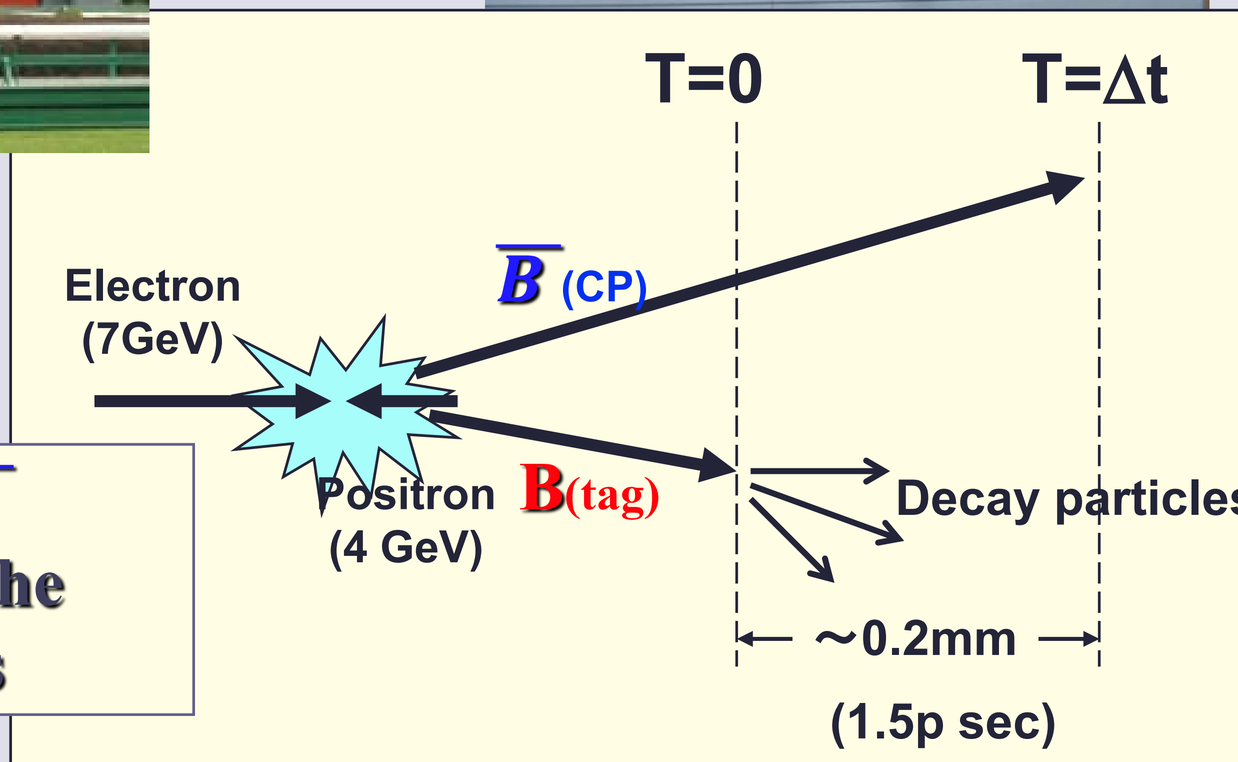


Measure Decay time (→distance) and flavor (B or $\overline{B}$)

Asymmetric beam energies (7 on 4 GeV)

The decay distance increase ~7

Time Dependent CP Violation



Flip B and $\overline{B}$ and compare the distributions

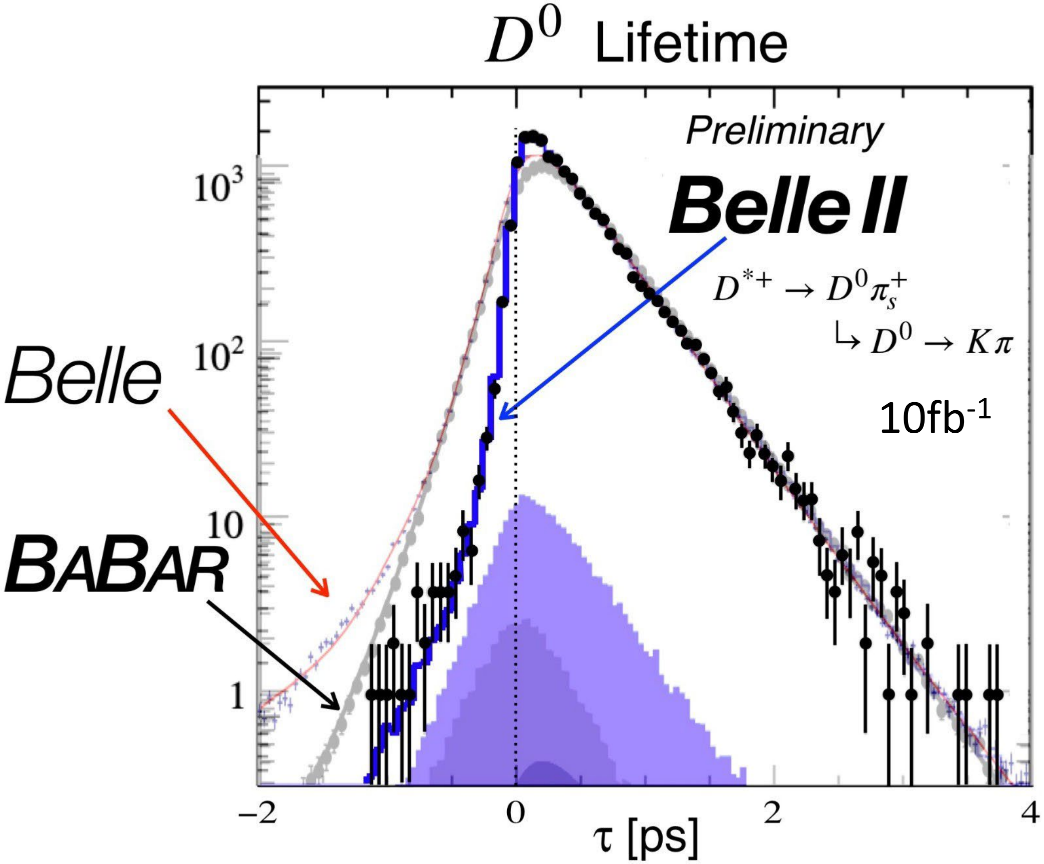
Measurement of the Time Dependent CP Violation

Key

Vertexing and Tagging performance

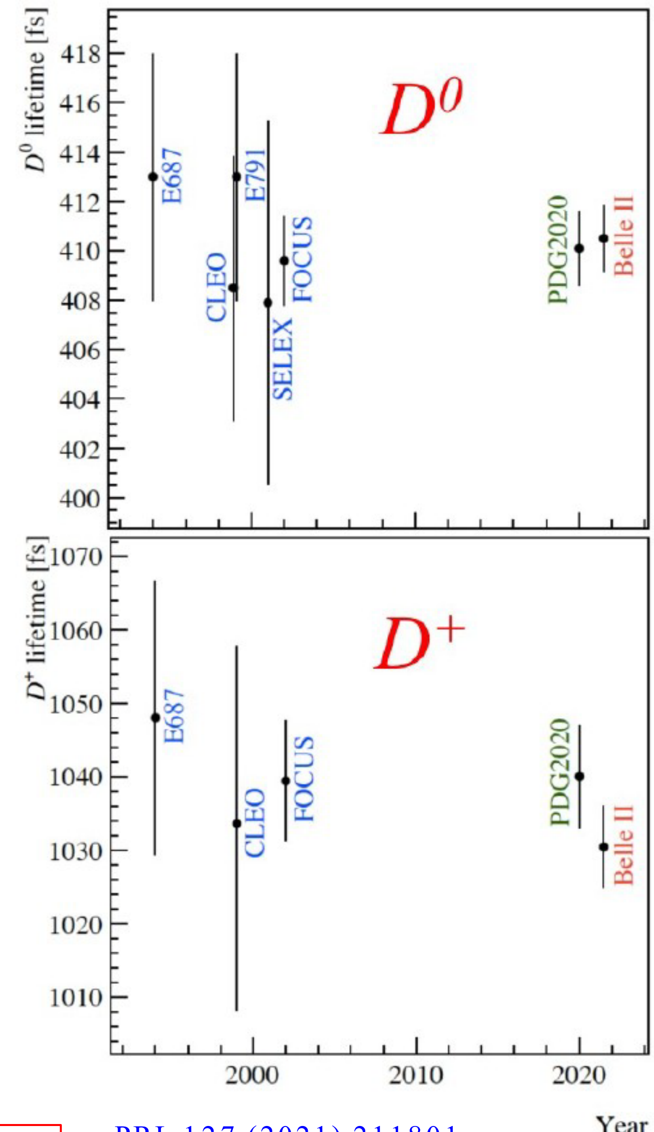
→ **We'll show the D lifetime measurements and Tagging performance first**

D Lifetime measurements



$$\tau(D^0) = 410.5 \pm 1.1 \pm 0.8 \text{ fs}$$

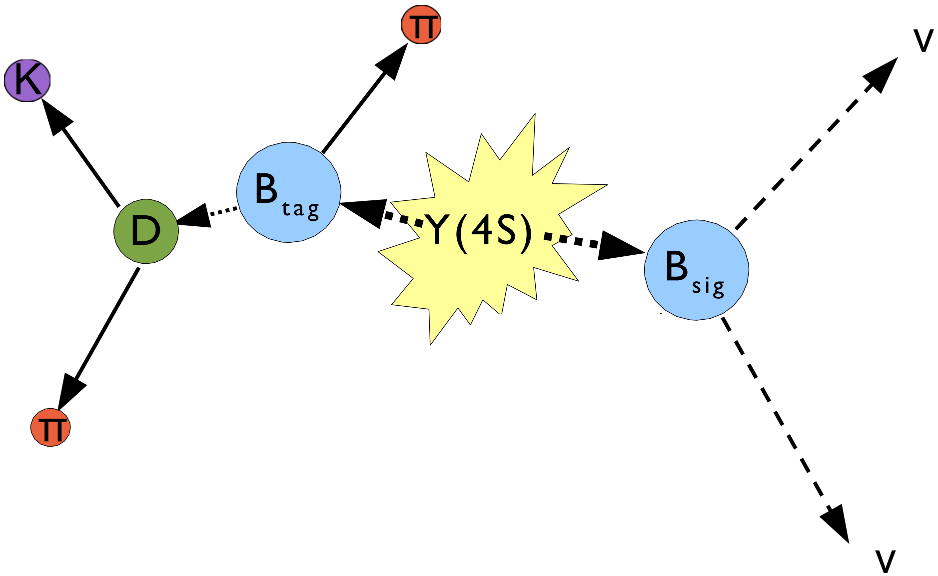
$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1 \text{ fs}$$



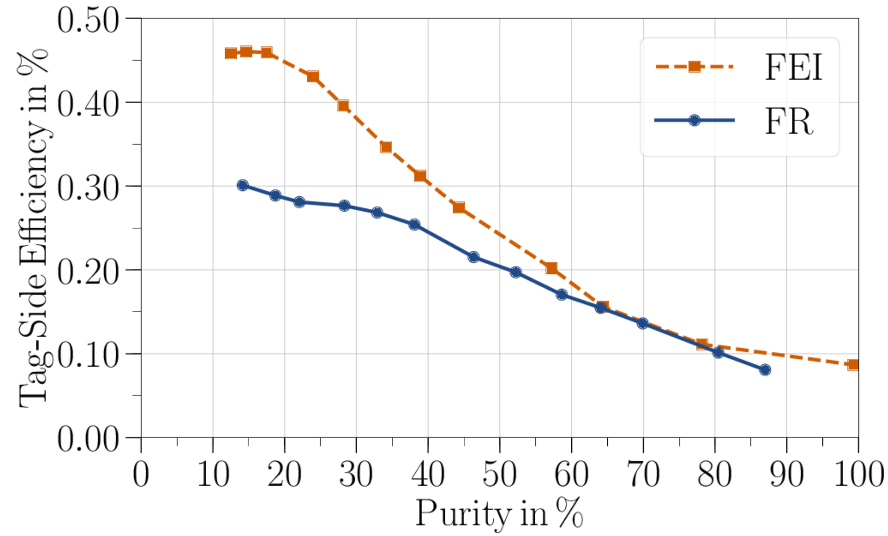
PRL 127 (2021) 211801

Results more precise than the World average
Proof of excellent vertexing performances

Reconstruction of Undetected Particles



Comput. Softw. Big Sci. 3 (2019) 1, 6

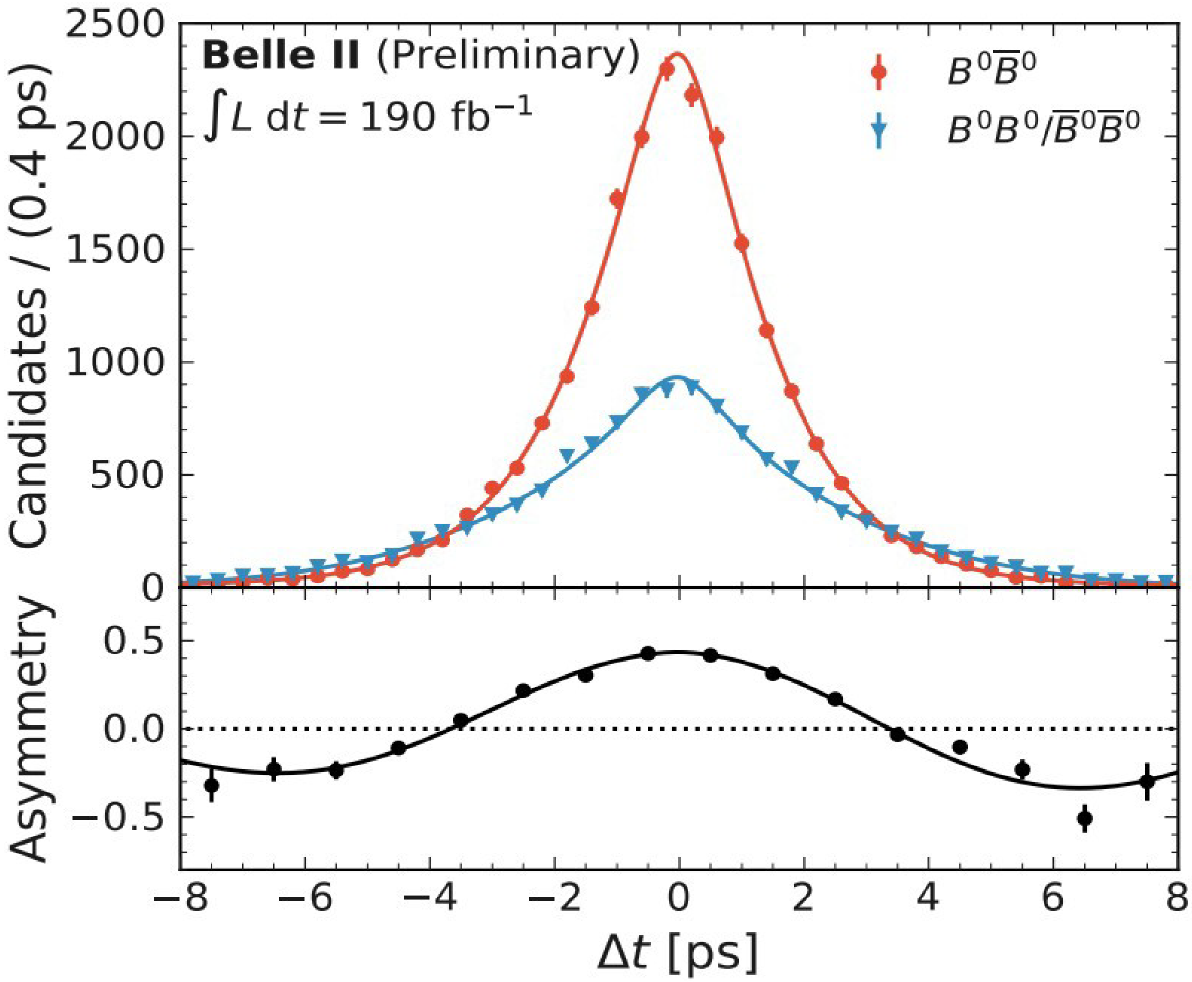


Full reconstruction of B_{tag} decay in >5000 decay chains with MVA tool.

→ New Full Event Interpretation (FEI) package for Belle II

30-50% higher tagging efficiency with same purity, than the Belle version (FR)

Time Dependent Mixing asymmetry (not CPV)

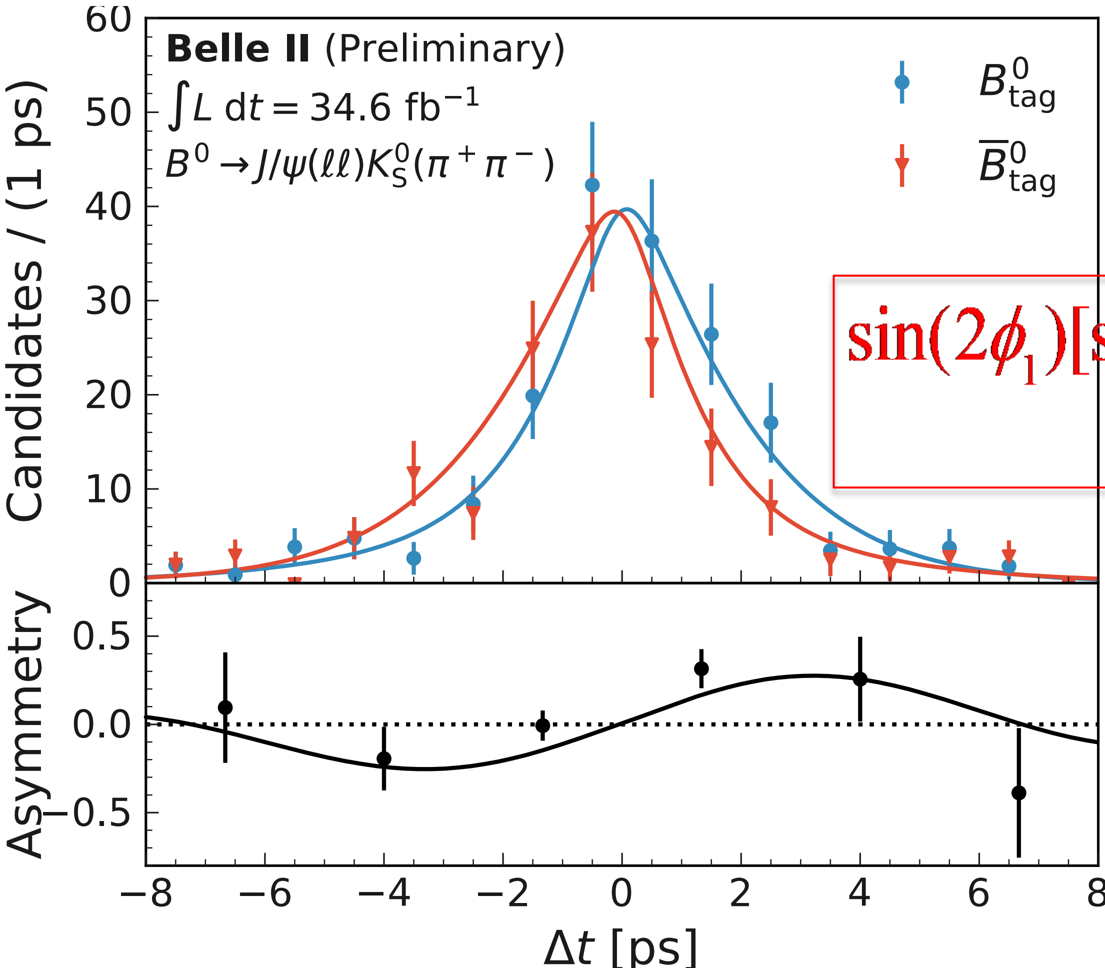


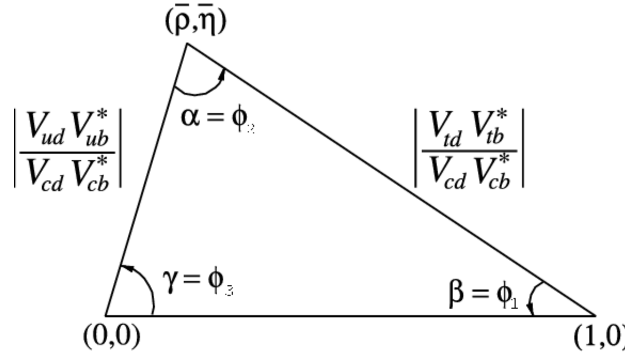
Δm_d = (0.516 ± 0.008 (stat.) ± 0.005 (syst.)) ps^{-1}

World average: 0.5065 ± 0.0019 ps^{-1}

Result compatible with world average

Hint of time-dependent CPV from Belle II (2.7σ significance)





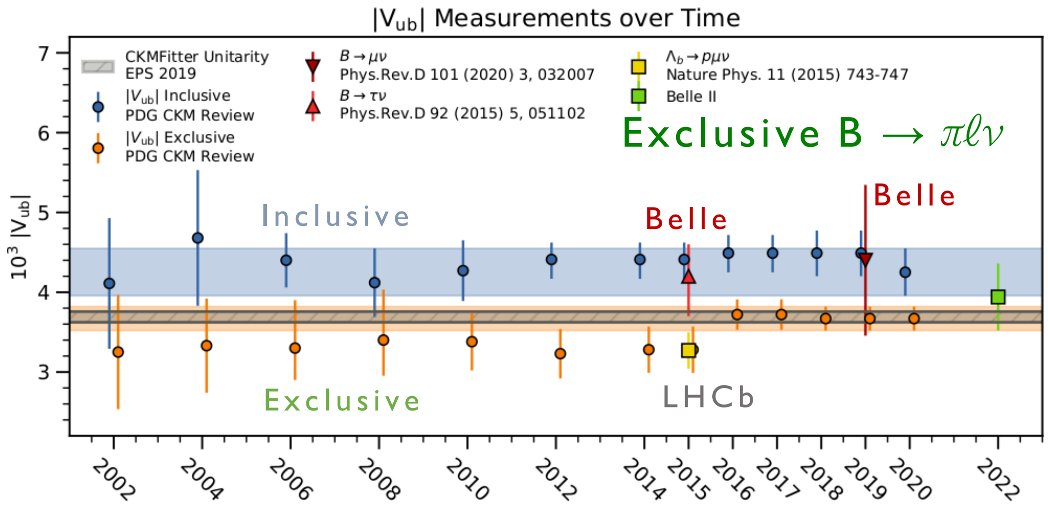
$$\sin(2\phi_1)[\sin(2\beta)] = 0.55 \pm 0.21 \pm 0.04$$

(WA=0.685±0.019)

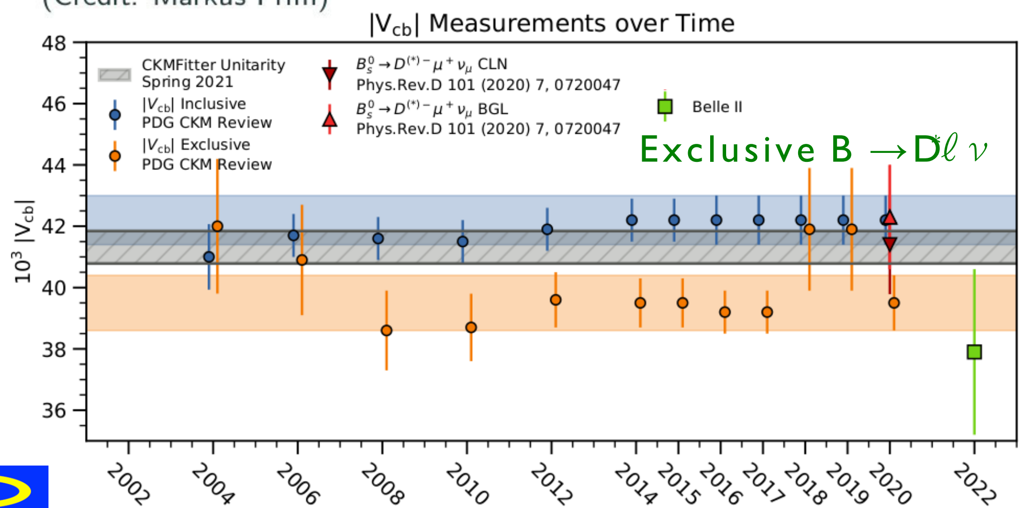
Expect updates in summer 2022 (x6 more data)

V_{ub} V_{cb}
Related analyses

Preliminary V_{xb} Measurements



(Credit: Markus Prim)



Further measurements

- Exclusive $B \rightarrow \rho\ell\nu$
  arXiv:2111.00710
- Inclusive $B \rightarrow X_u e\nu$
  arXiv:2103.02629

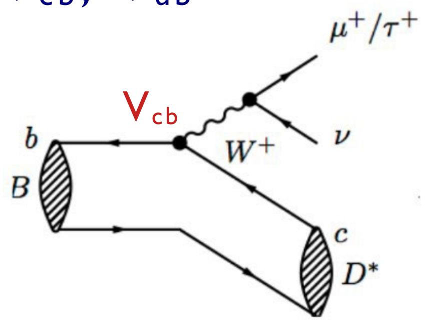
- Exclusive $B^- \rightarrow D^0\ell\nu$
  arXiv:2110.02648
- Inclusive $B \rightarrow X_c\ell\nu$
  arXiv:2111.09405

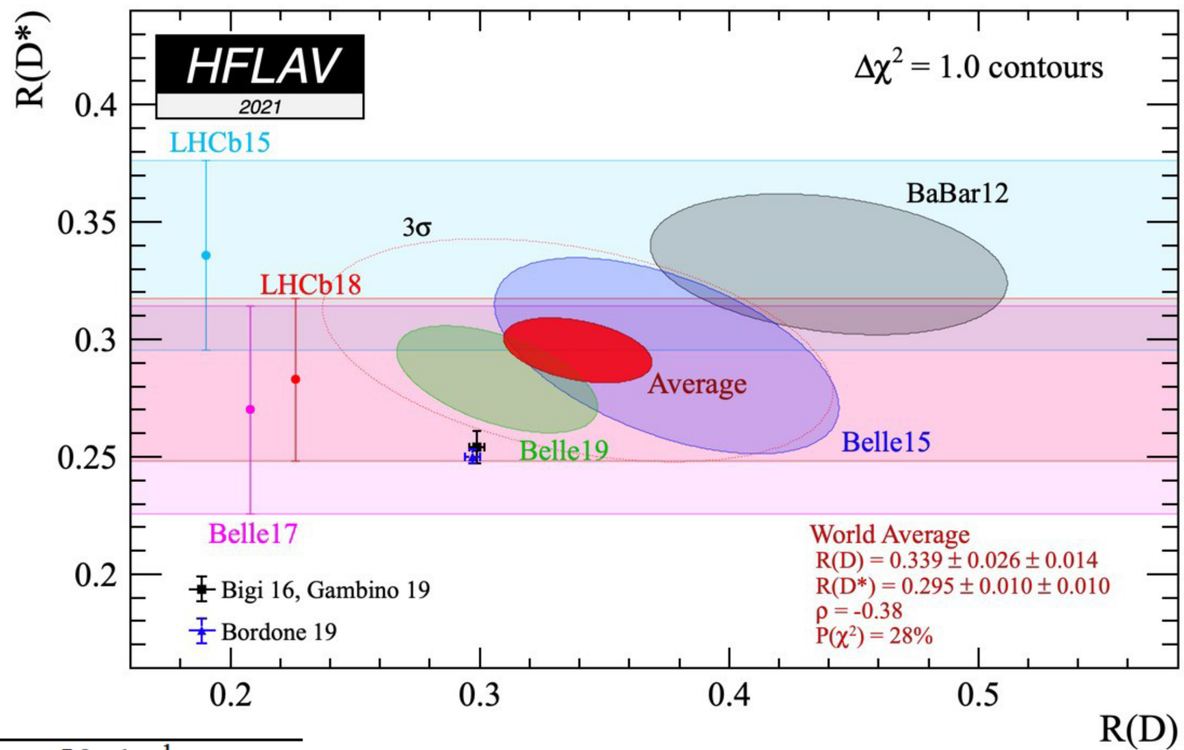
Belle II

Semileptonic Decays

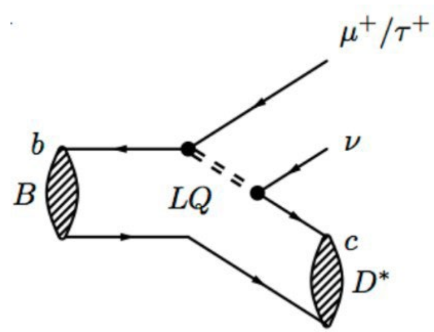
Measurement of SM parameters:
V_{cb}, V_{ub}

$$R_{D^{(*)}} = \frac{Br(B \to D^{(*)}\tau\nu_\tau)}{Br(B \to D^{(*)}\ell\nu_\ell)}$$





Search for NP:

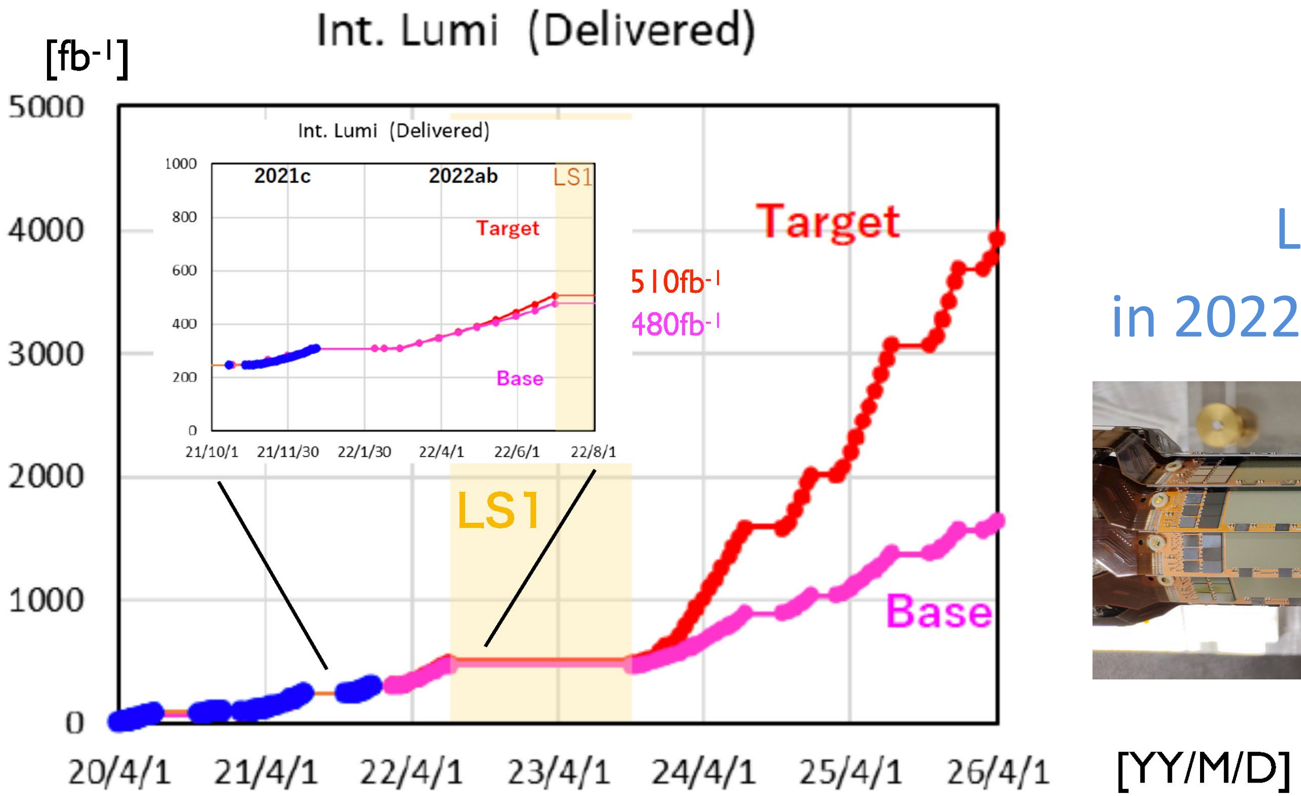


	$5\ ab^{-1}$	$50\ ab^{-1}$
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

Latest Belle measurement with semileptonic tags brings down to the WA discrepancy to 4→3σ

Prospects

Projection of Integrated Luminosity delivered by SuperKEKB



Long Shutdown

in 2022-2023 to install PXD2