

# Overview of the Belle II experiment

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on behalf of the Belle II collaboration

# SuperKEKB/Belle II experiment

$e^+e^-$  collider mainly at  $\sqrt{s} = 10.58$  GeV  
to produce  $B$ ,  $D$ ,  $\tau$ , etc.

Goal:  $50 \text{ ab}^{-1}$  ( $\approx \text{KEKB} \times 50 \approx 50\text{e9 } B\bar{B}$ )

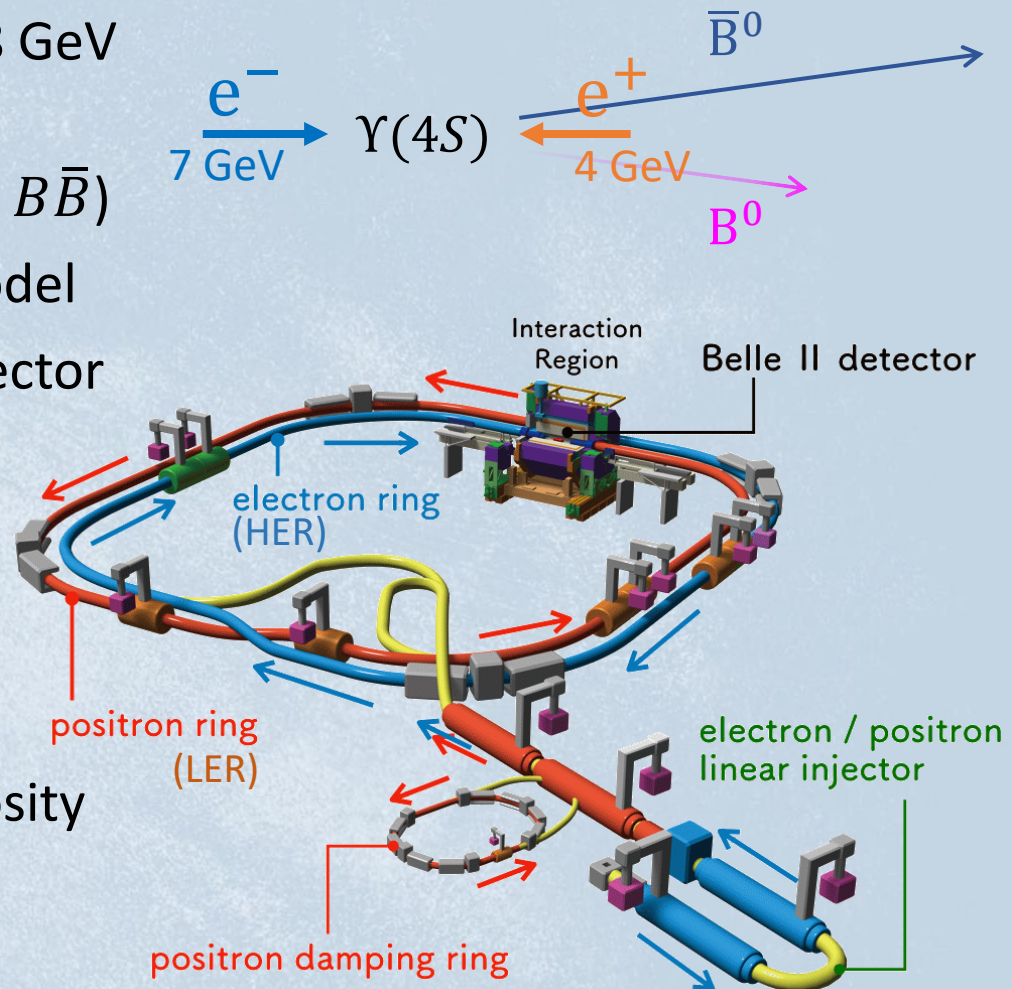
- Precise test of the Standard Model
- New Physics search incl. dark sector
- Research of exotic hadrons

## Keys to success

- Machine tuning for high luminosity
- Beam background mitigation

Belle II collaboration:

~1100 researchers, 126 institutions, 26 nations

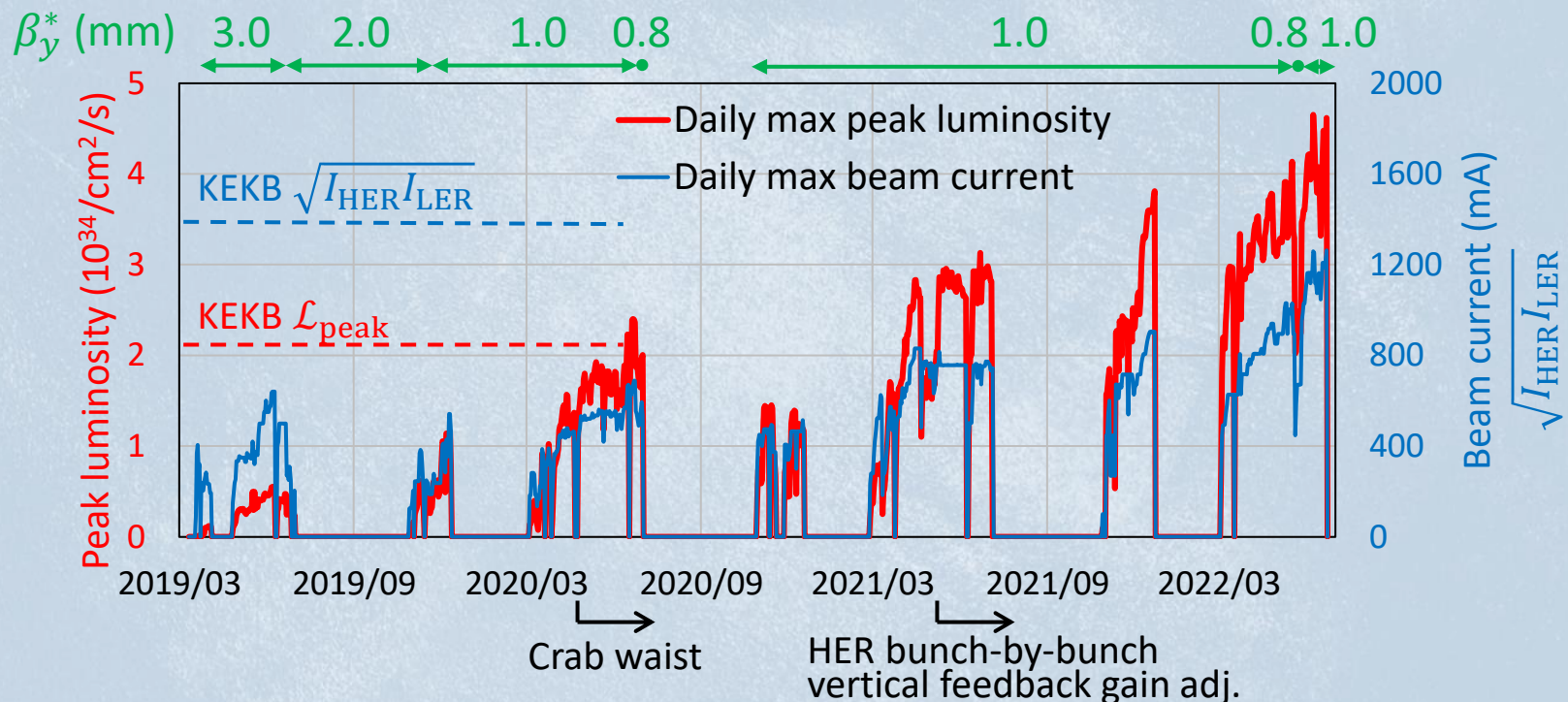


# SuperKEKB performance

The world smallest vertical  $\beta$  function ( $\beta_y^*$ ) and beam size ( $\sigma_y^*$ ) at the interaction point with the “nano-beam scheme”.

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

(cf. KEKB 5.9 mm)



Keep updating the world record of the peak luminosity.

# Belle II detector

A general purpose hermetic spectrometer upgraded from Belle for

- ✓ tolerant of considerably higher beam background and higher event rate
- ✓ better performance

EM Calorimeter:

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

KL and muon detector:

Resistive Plate Counter (barrel)  
Scintillator + WLSF + MPPC (end-caps)

Superconducting solenoid (1.5 T)

Particle Identification

Time-of-Propagation counter (barrel)  
Prox. focusing Aerogel RICH (fwd)

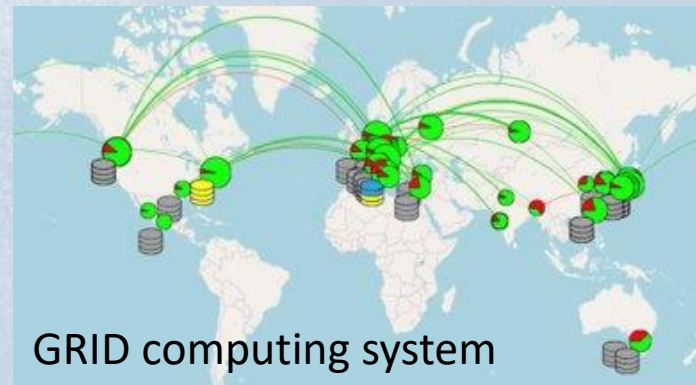
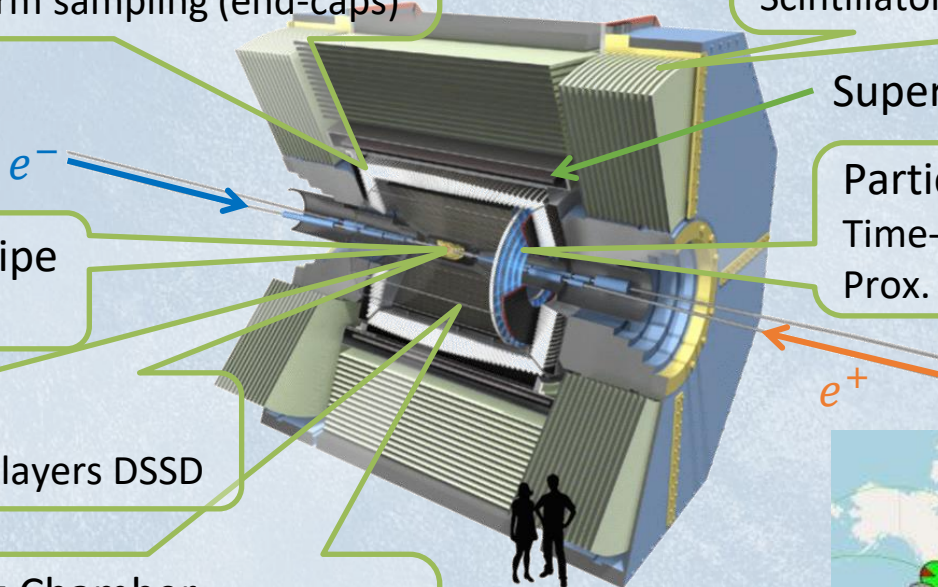
Beryllium beam pipe  
2cm diameter

Vertex Detector

2 layers DEPFET + 4 layers DSSD

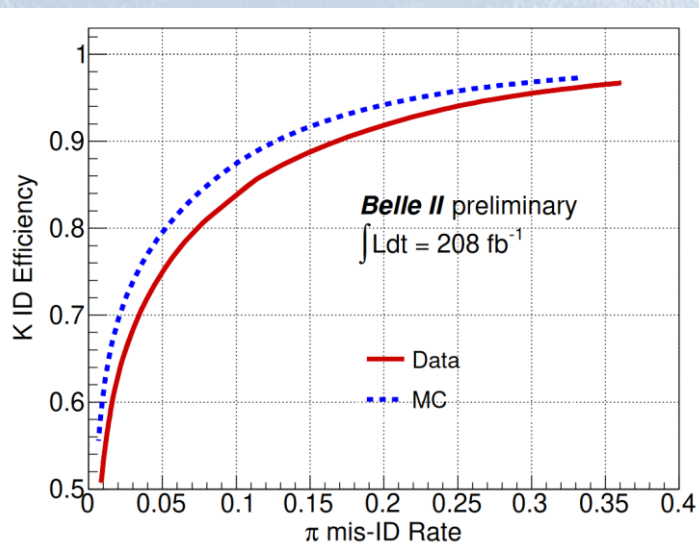
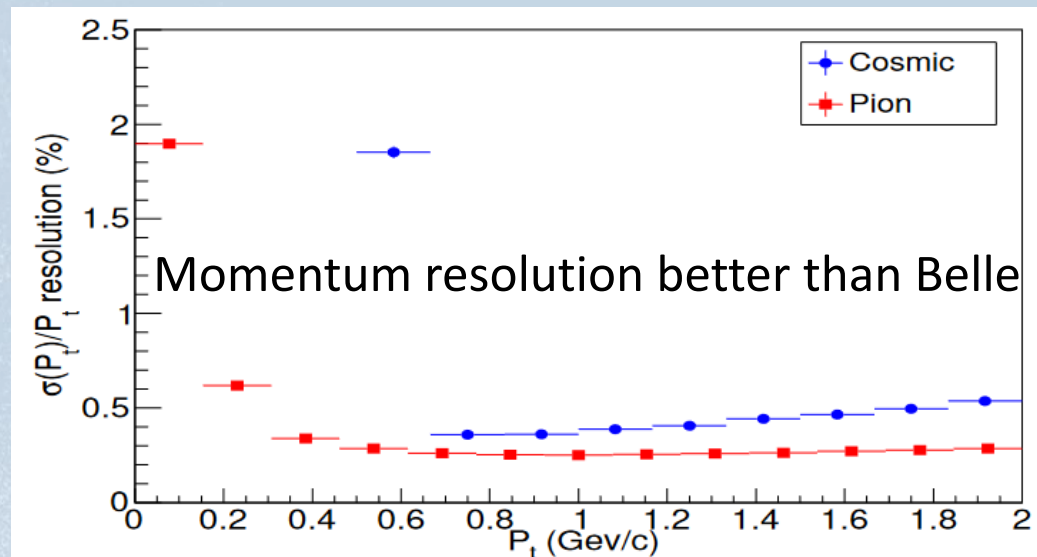
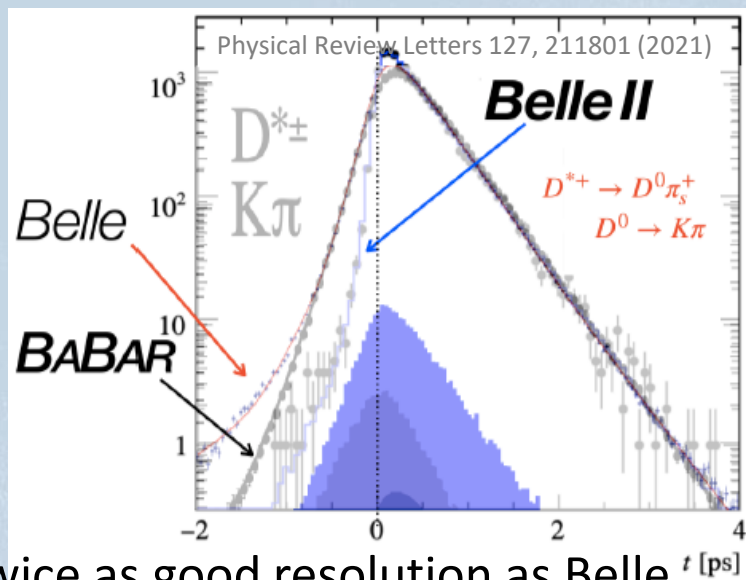
Central Drift Chamber

He(50%):C<sub>2</sub>H<sub>6</sub>(50%), Small cells, long  
lever arm, fast electronics

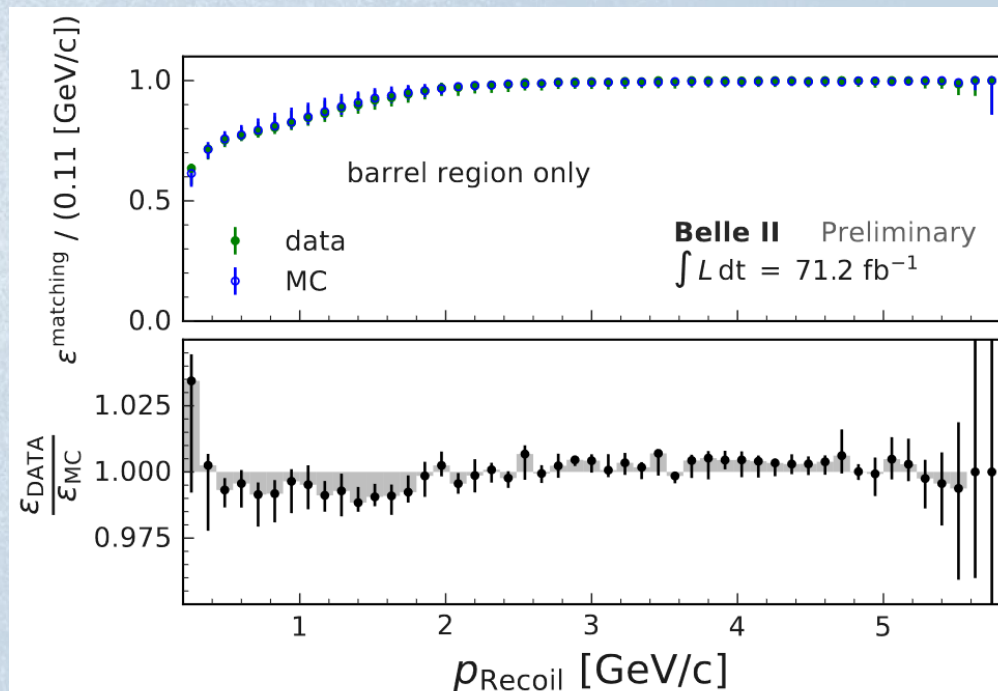




# Performance



$K/\pi$  ID still slightly worse than Belle but improving

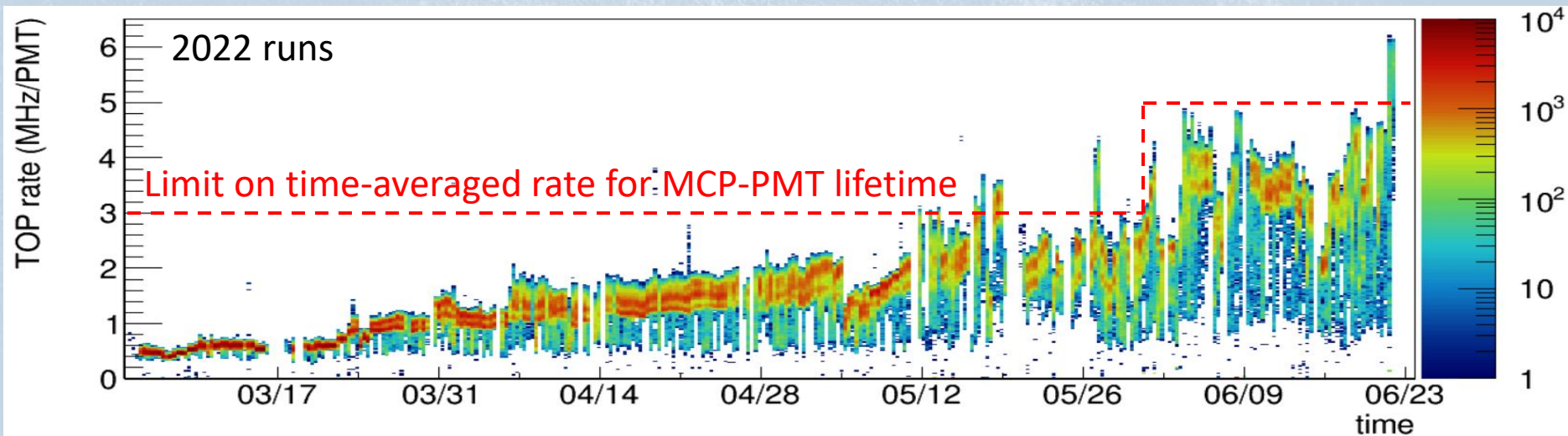
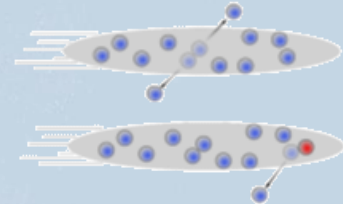


High photon detection efficiency

# Beam background

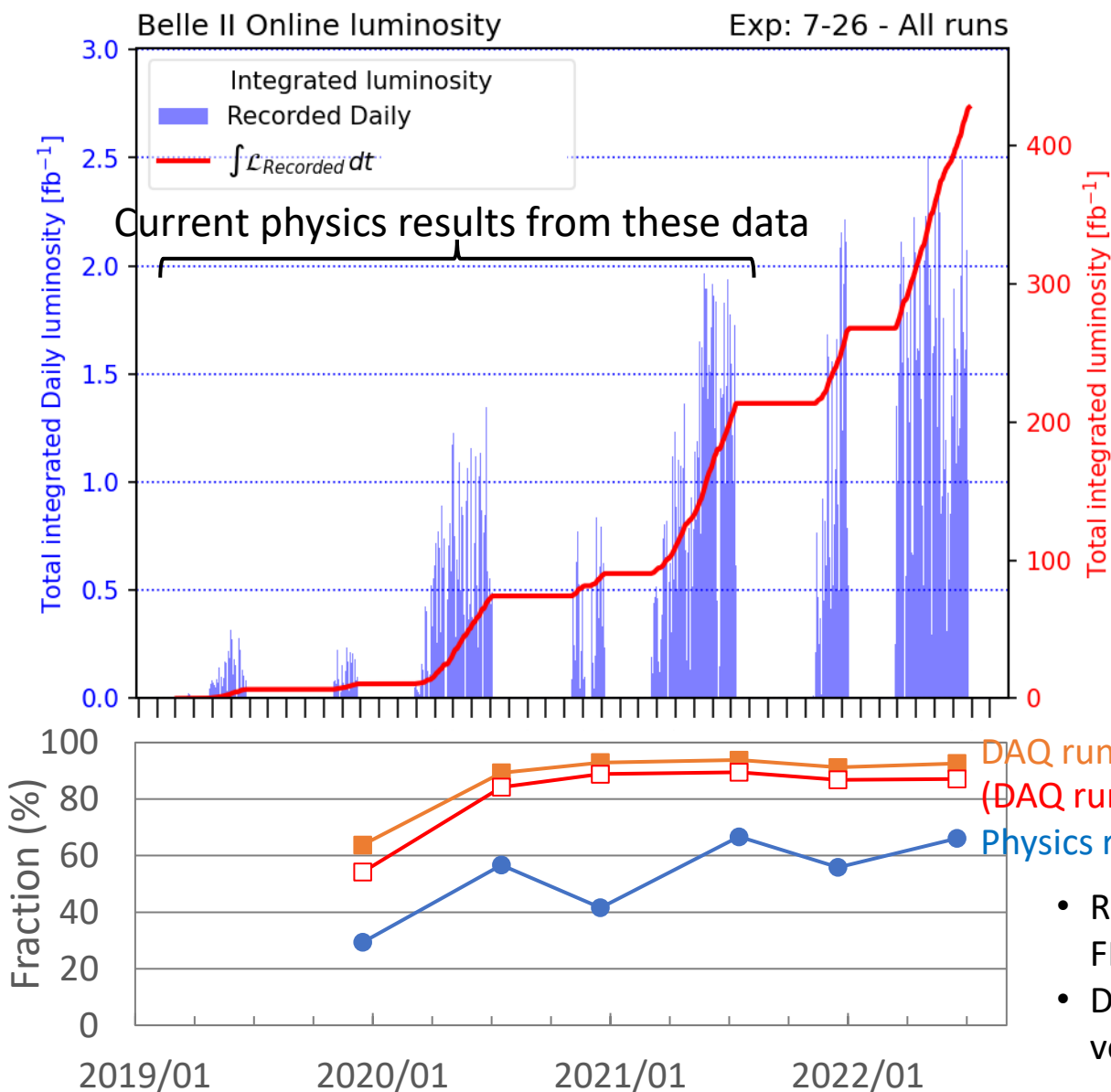
- Collision events (radiative Bhabha, two-photon)  $\propto \mathcal{L}$
- HER/LER Touschek scattering  $\propto I^2 / (\sigma n_b E^3)$
- HER/LER beam-gas scattering  $\propto I \cdot (P_{\text{dynamic}} + P_{\text{base}}) \propto \sim I^2$
- HER/LER synchrotron radiation  $\propto I E^4 / \rho^2$
- HER/LER beam injection

(Present major beam backgrounds are written in red.)



- ❖ The beam backgrounds have been reduced mainly by vacuum scrubbing with the beam, adding beam collimators, and relocation of a collimator. They are basically under control by fine tuning of the collimators without diminishing the accelerator performance.
- ❖ However, damage of the collimator heads by sudden beam loss of unknown cause increased the storage-beam and injection background significantly.

# Operation / Integrated luminosity



**Recorded 424 fb<sup>-1</sup>**

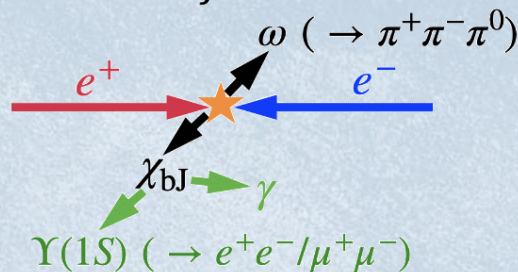
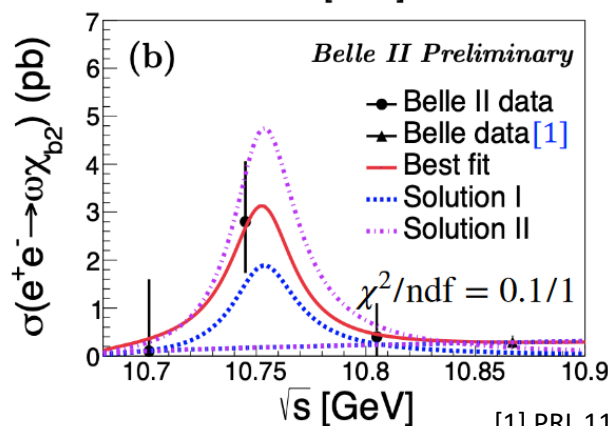
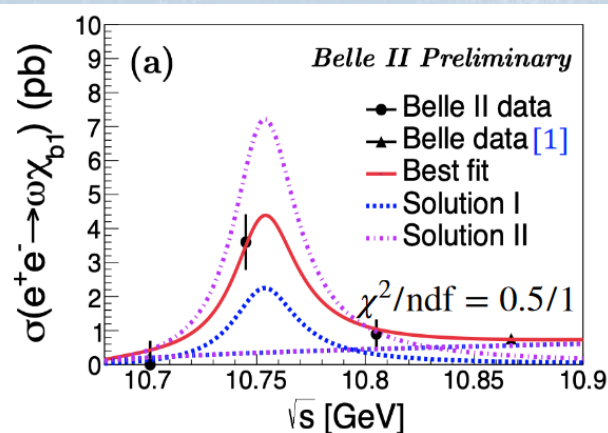
- 362 fb<sup>-1</sup> at  $\Upsilon(4S)$   
cf. BaBar: 424 fb<sup>-1</sup> at  $\Upsilon(4S)$
- 42 fb<sup>-1</sup> at  $\Upsilon(4S)$  – 60 MeV
- 19 fb<sup>-1</sup> around 10.75 GeV in 2021 autumn

- Run stop mainly by SEU of front-end FPGAs and beam aborts
- DAQ dead time mostly due to trigger veto for injection background

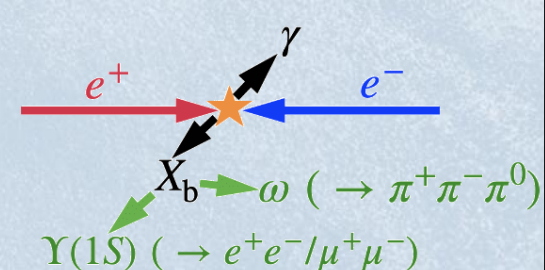
# Physics results

- H. Svidras, “Electroweak and radiative penguin decay at Belle and Belle II”
- P. Lewis, “Semileptonic Decays at Belle and Belle II”
- F. Pham, “Recent Belle and Belle II Results on Hadronic B decay”
- L. Polat, “Dark Sector and Tau Physics at Belle and Belle II”

## First observation of $\Upsilon(10753) \rightarrow \omega \chi_{bJ}$



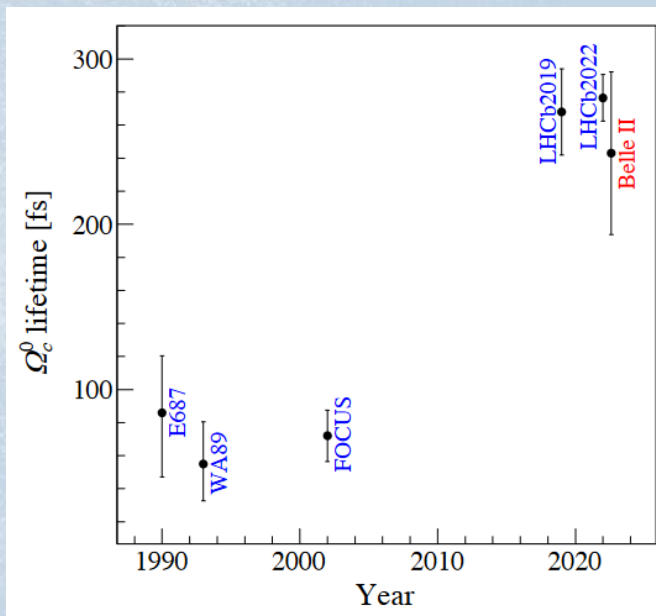
No significant  $X_b$  signals were observed.



Belle II preliminary

$$\tau(\Omega_c^0) = 243 \pm 48 \pm 11 \text{ fs}$$

stat. syst.



# Major upgrade in Long Shutdown 1

## Belle II detector upgrade

- Exchange of PXD (pixel detector) with the full 2<sup>nd</sup> layer
- TOP conventional MCP-PMT replacement (TBD)

## Beam background mitigation

- Additional shield on the QCS<sup>(\*)</sup> bellows
- Additional shield for neutron background
- Installation of a non-linear collimator

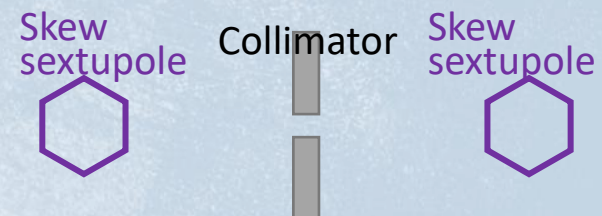
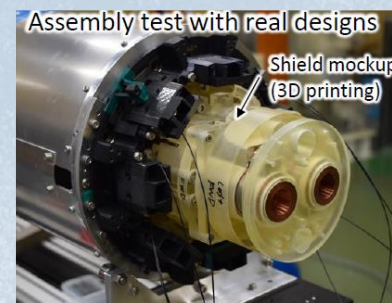
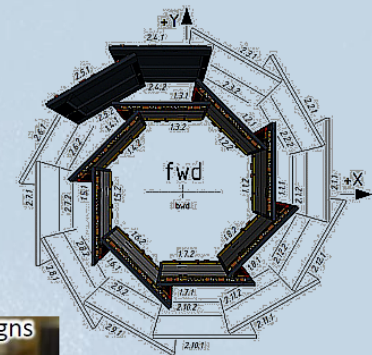
## Protection of machine and Belle II

- Collimator heads of more robust material
- Faster beam abort system

## Improvement of beam injection

- Enlarged beam pipe at the HER injection
- Pulse-by-pulse beam control for Linac

QCS: Final focusing system



Beam kick by skew sextupole:

$$\Delta p_y = \frac{SK_2}{2}(y^2 - x^2), \quad \Delta p_x = SK_2xy$$



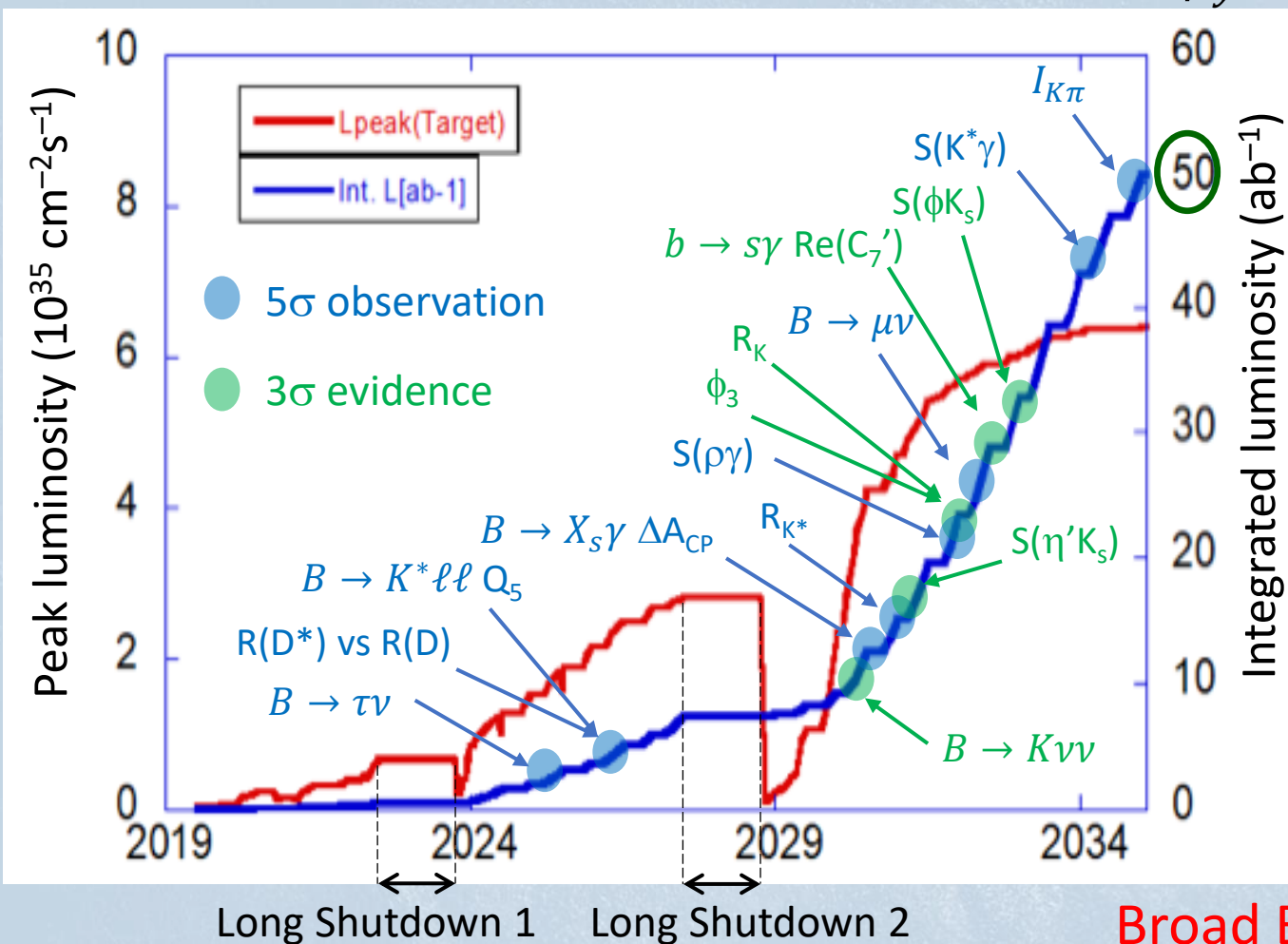
Beam channel for injection

# Prospects

Will finish Long Shutdown 1 to be back in operation from October 2023.

Squeeze  $\beta_y^*$  down to 0.5-0.6 mm and increase the beam current.

Accelerator upgrade in Long Shutdown 2 to achieve  $\beta_y^* = 0.3$  mm



[arXiv:2207.06307](https://arxiv.org/abs/2207.06307)

Submitted to the Proceedings of the US Community Study  
on the Future of Particle Physics (Snowmass 2021)

Snowmass White Paper:  
Belle II physics reach and plans for  
the next decade and beyond

Belle II Collaboration

# Summary

SuperKEKB/Belle II: Precision measurement of  $B$ ,  $D$ ,  $\tau$  decays for indirect New Physics search in wide flavor physics

➤ High luminosity super B-factory machine

- World record of peak luminosity with the nano-beams:  $4.7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Goal:  $50 \text{ ab}^{-1}$

➤ Hermetic state-of-the-art Belle II detector

- Tolerant of considerably higher beam background and higher event rate
- Improved performance
- Recorded  $424 \text{ fb}^{-1}$  ( $\approx \text{BaBar}$ ) and produced competitive physics results
  - Catching up the precedent B-factory experiments and LHCb
  - Unique results on dark sector search and quarkonium physics
- Continue to pursue higher luminosity of SuperKEKB
  - Expect several improvements in Long Shutdown 1
  - Back in operation from October 2023