Overview of the Belle II experiment

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on behalf of the Belle II collaboration

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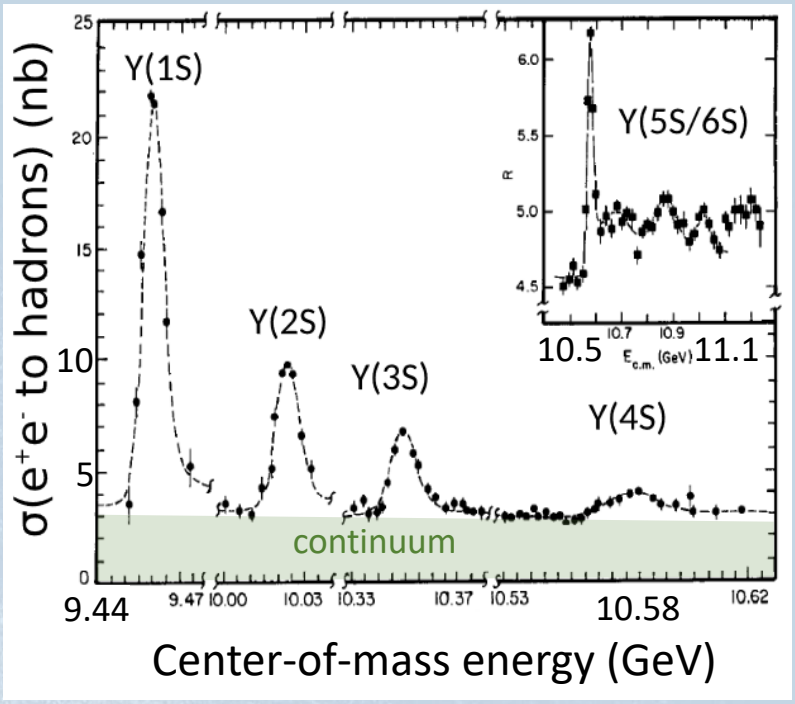
Rencontres du Vietnam Flavour Physics Conference 2022

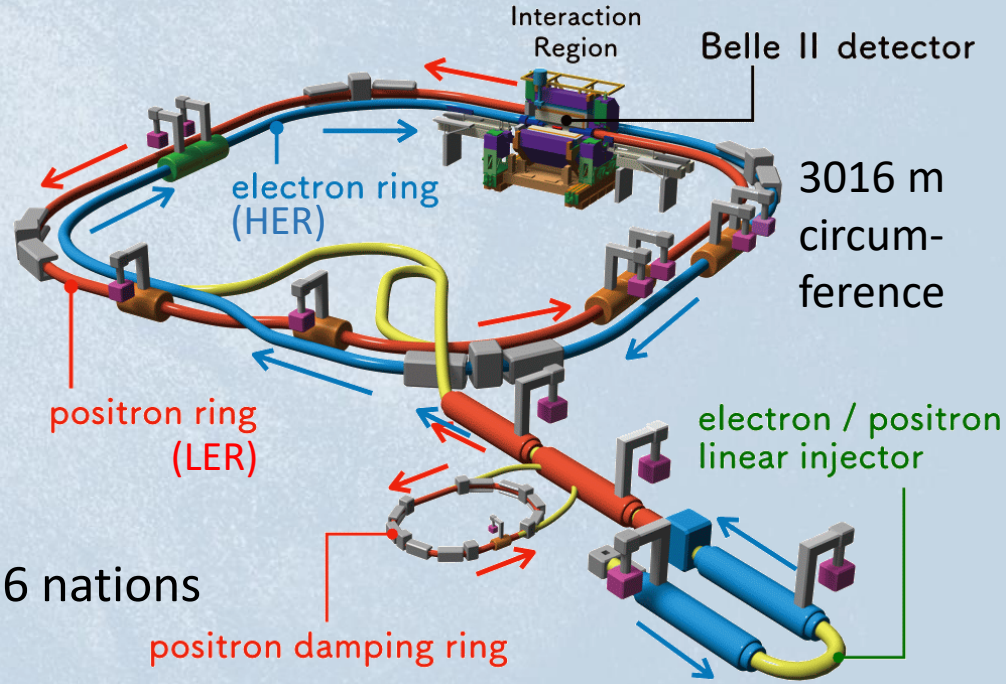
SuperKEKB/Belle II

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

Goal: 50 ab^{-1} (≈ KEKB x 50 ≈ 50e9 $B\bar{B}$)

- 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

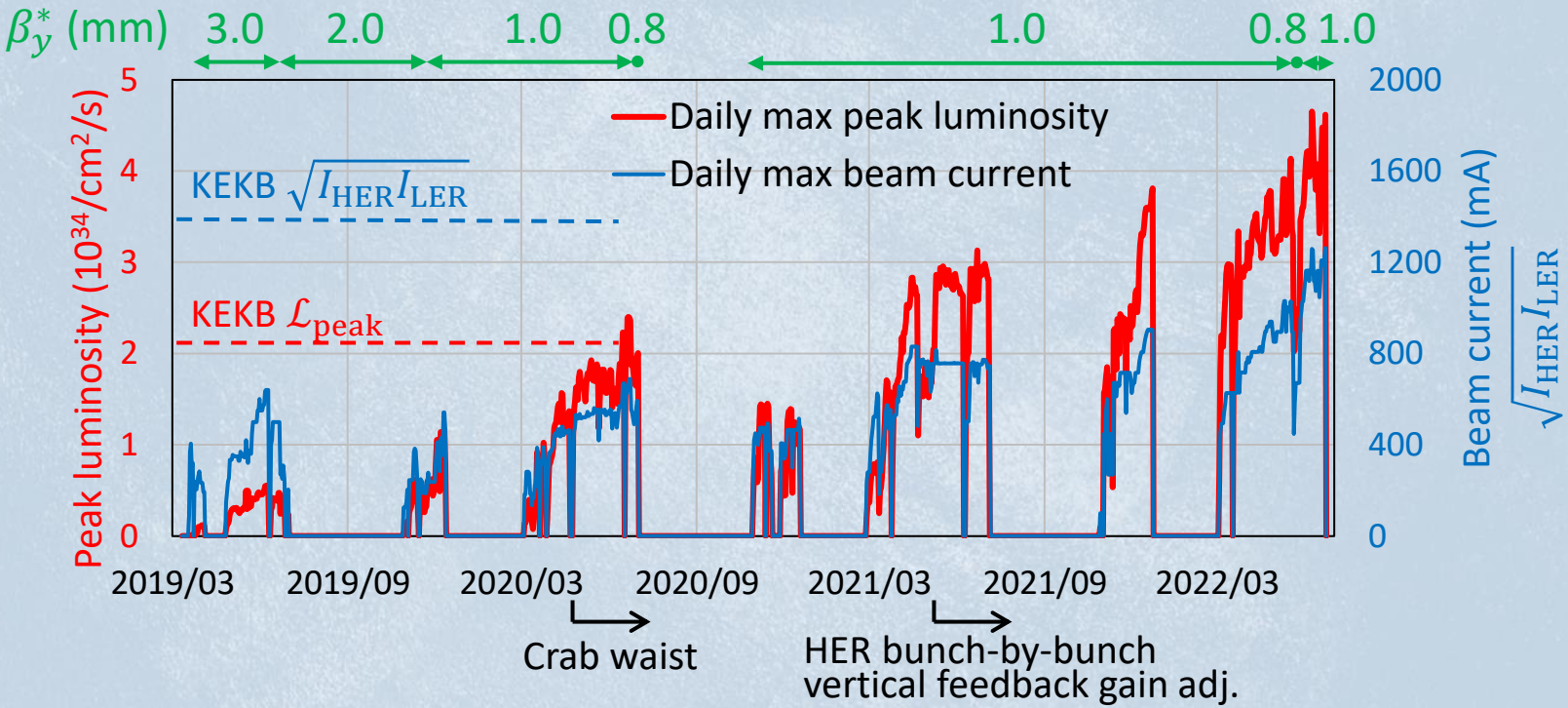
Belle II collaboration:
~1100 researchers, 126 institutions, 26 nations

SuperKEKB performance

The world smallest vertical β function (β_y^* = 0.8 mm) and beam size ($\sigma_y^* \approx$ 200 nm) 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

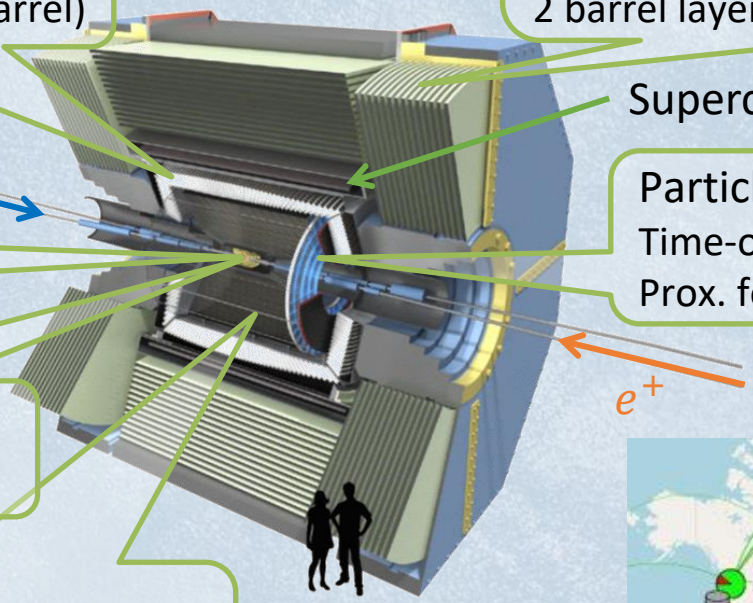
A general purpose hermetic spectrometer upgraded from Belle for
- ✓ tolerance of considerably higher beam background and higher event rate
- ✓ better performance

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

Superconducting solenoid (1.5 T)

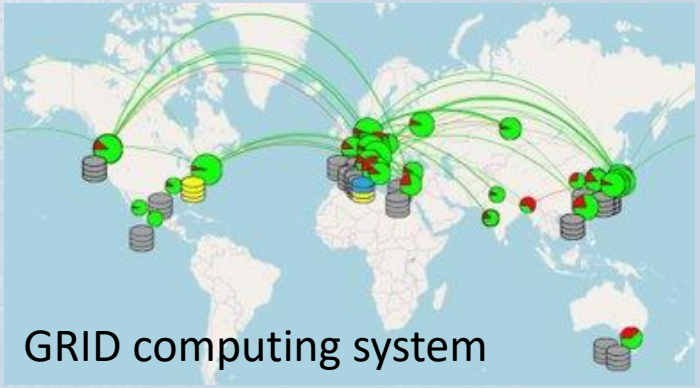
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

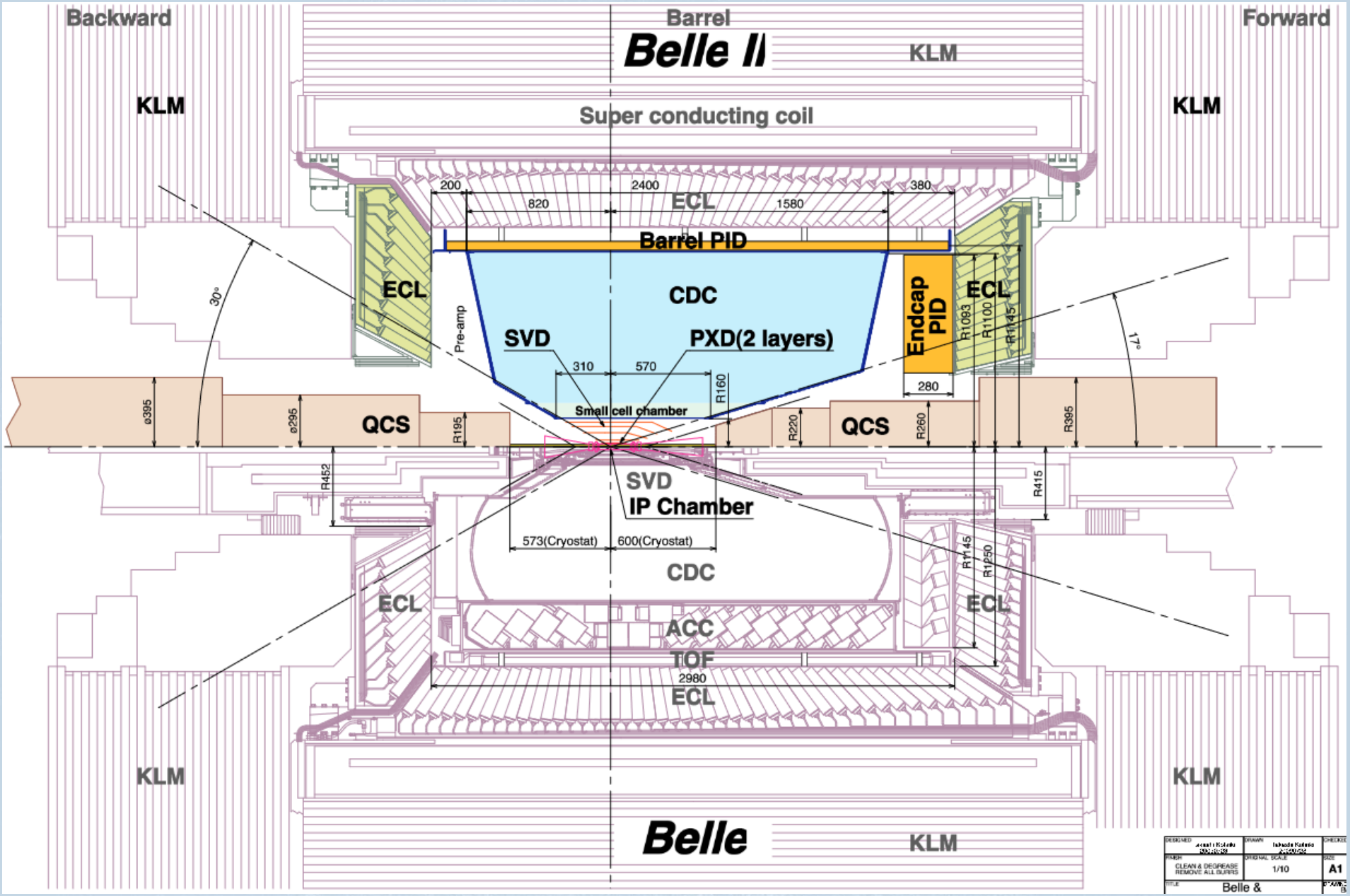


Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

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

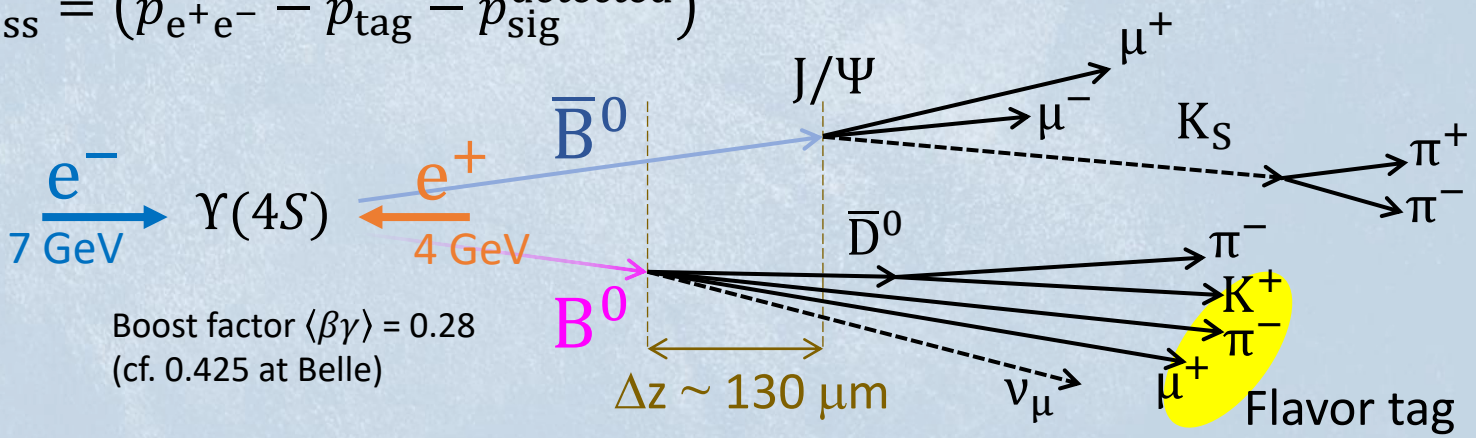

GRID computing system


Backward
Barrel
Forward
Belle II
KLM
Super conducting coil
200
2400
380
820
ECL
1580
Barrel PID
ECL
CDC
Endcap PID
ECL
Pre-amp
SVD
PXD(2 layers)
R1093
R1100
R1145
30°
17°
310
570
R160
280
ø395
ø295
QCS
R195
R220
QCS
R260
R395
Small cell chamber
R452
SVD
IP Chamber
R415
573(Cryostat)
600(Cryostat)
CDC
R1145
R1250
ECL
ECL
ACC
TOF
2980
ECL
KLM
KLM
KLM
KLM
Belle
KLM
CLEAN & DEGREASE
REMOVE ALL BURRS
1/10
A1
Belle &

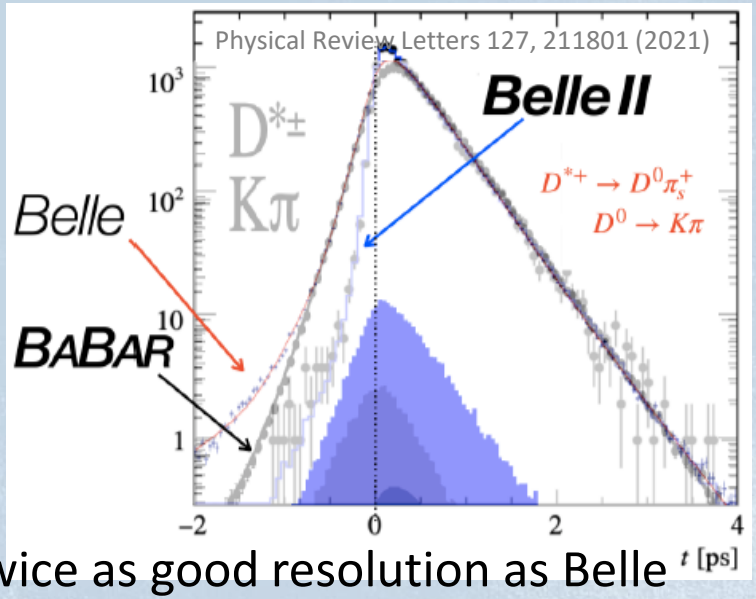
Belle II features

- ✓ e^+e^- collision at (or around) $\Upsilon(4S)$
  - Well-known initial state kinematics
  - $B\bar{B}$ production from $\Upsilon(4S)$ without extra energy
  - No event pile-up
- ✓ Hermetic Belle II detector capable of detecting charged particles and reconstructing neutrals (γ, π^0, K_L^0, etc) with high efficiencies.

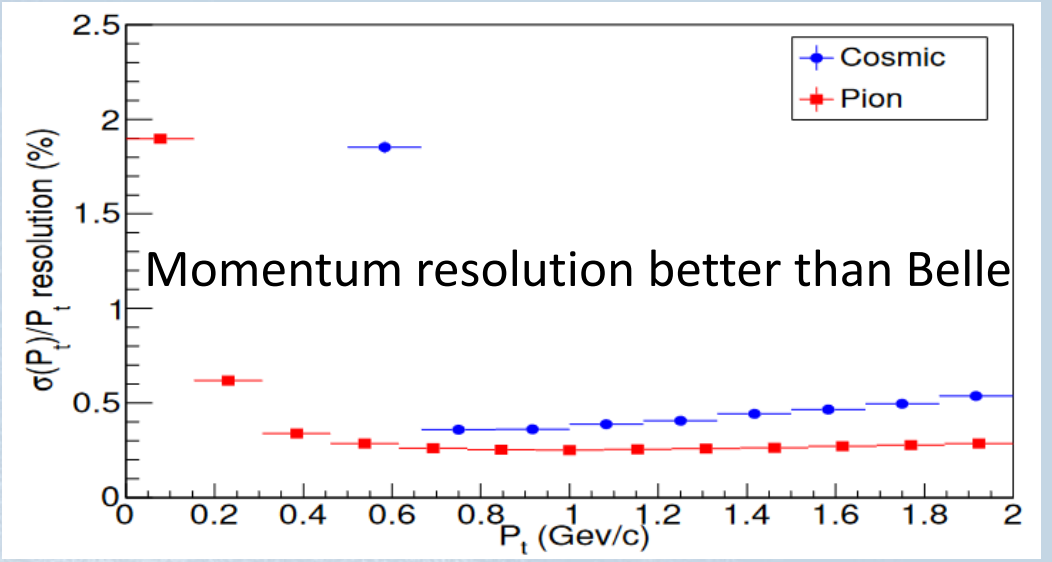
- ➢ Tagging one of the B's to infer the other B flavor and momentum.
  - Powerful S/N separation
  - $m^2_{\mathrm{miss}} = \left(p_{e^+e^-} - p_{\mathrm{tag}} - p^{\mathrm{detected}}_{\mathrm{sig}}\right)^2$

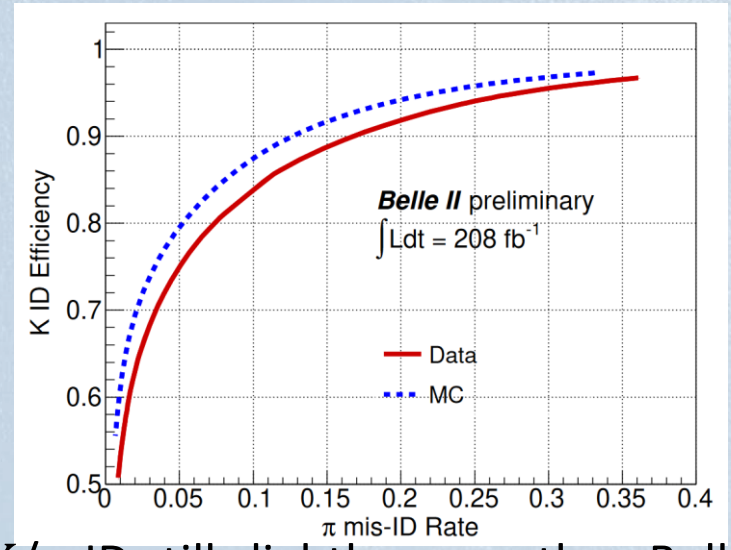


Performance

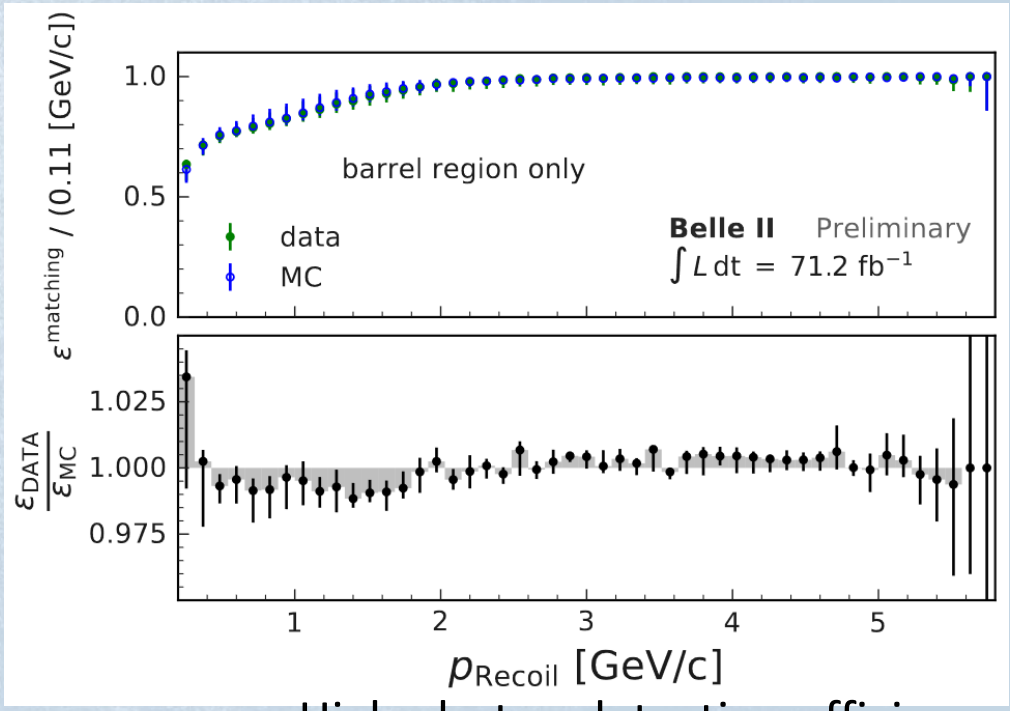


Twice as good resolution as Belle





K/π ID still slightly worse than Belle but improving



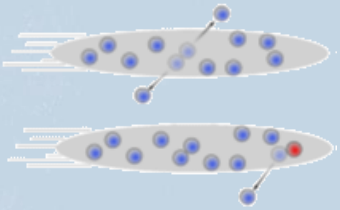
High photon detection efficiency

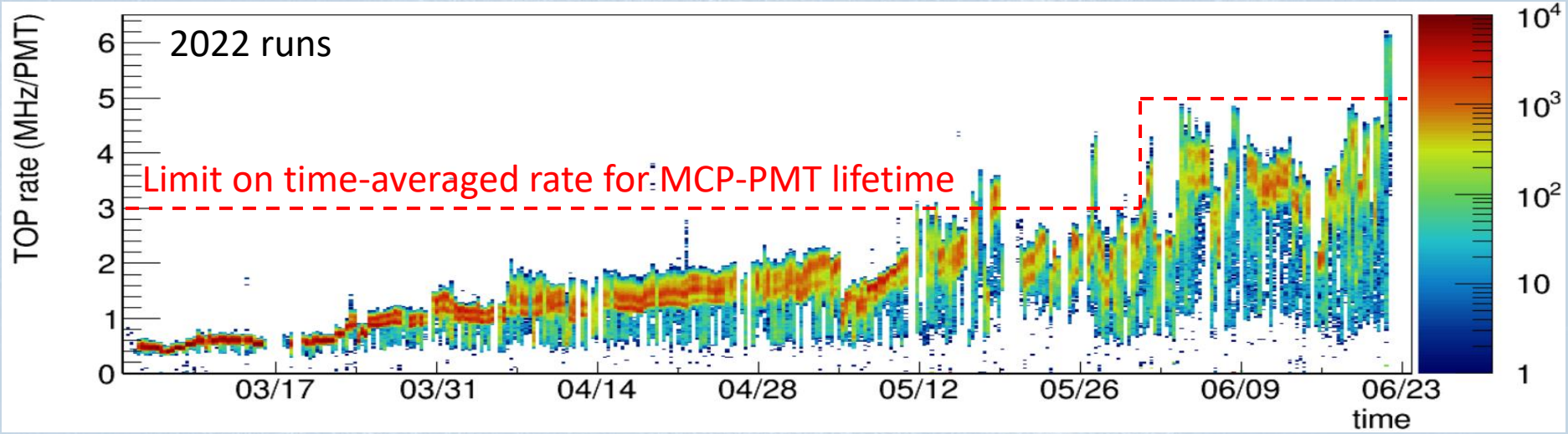
Beam background

HER: High Energy Ring (electron)
LER: Low Energy Ring (positron)

- 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 $\propto I \cdot (P_{\mathrm{dynamic}} + P_{\mathrm{base}}) \propto \sim I^2$
- HER/LER synchrotron radiation $\propto IE^4/\rho^2$
- HER/LER beam injection

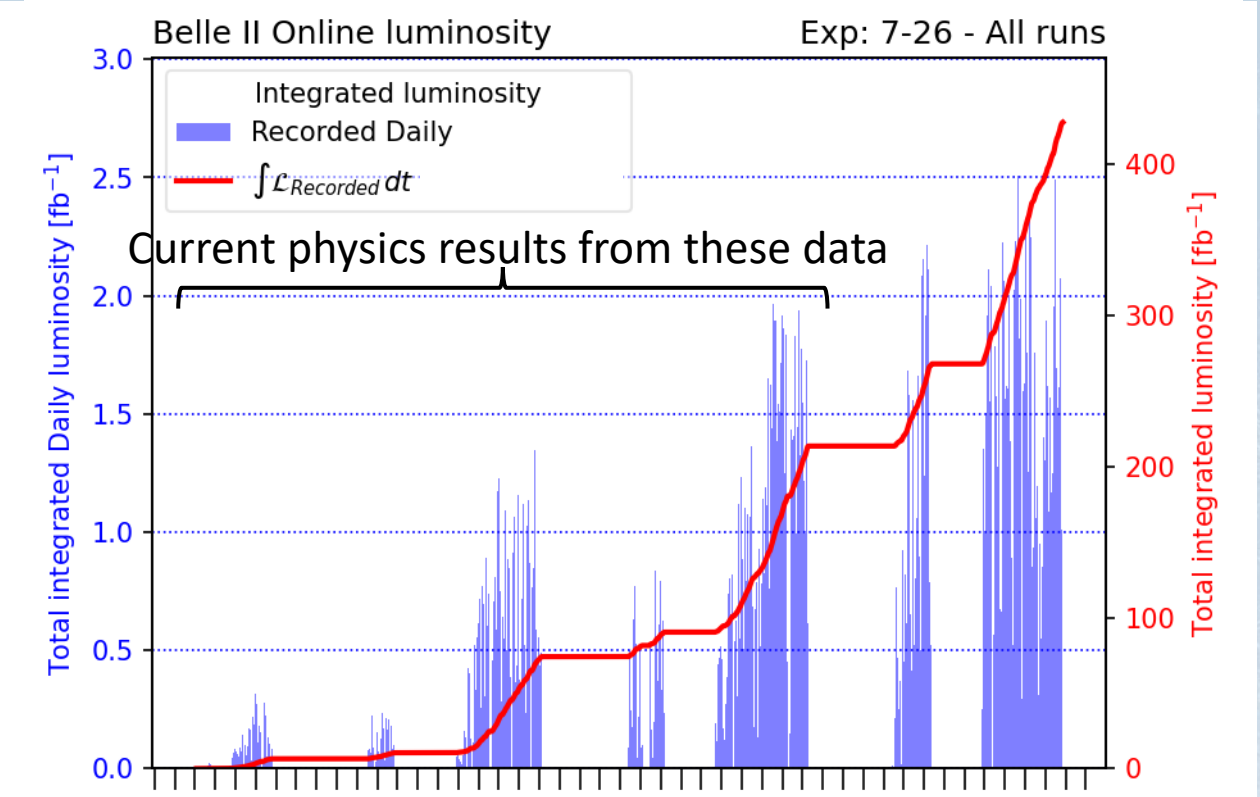
(Present major beam backgrounds are written in red.)

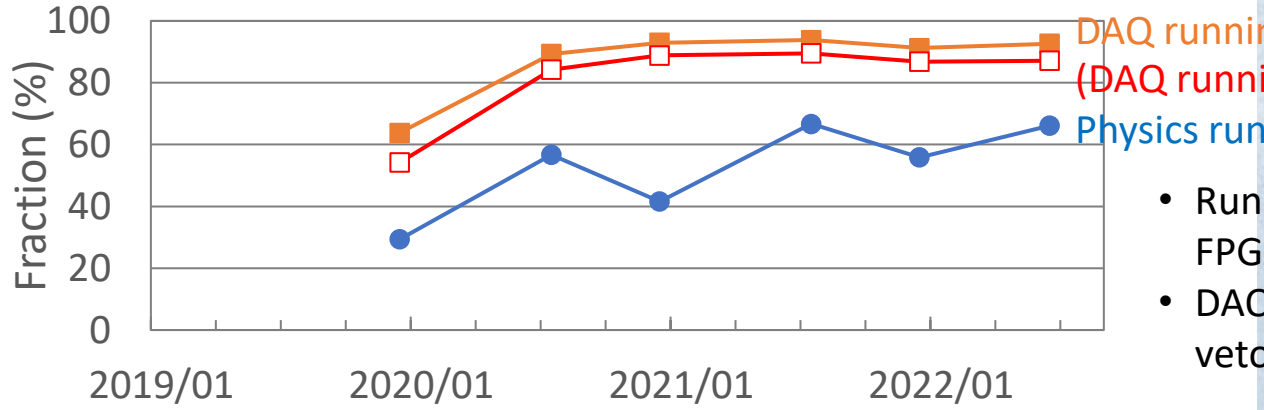




- The beam backgrounds have been reduced mainly by vacuum scrubbing with the beam, adding beam collimators, and relocation of a collimator. They are basically under control by fine tuning of the collimators without diminishing the accelerator performance.
- However, damage of the collimator heads by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

Operation / Integrated luminosity





Recorded 424 fb^{-1}

- 362 fb^{-1} at $\Upsilon(4S)$
  cf. BaBar: 424 fb^{-1} at $\Upsilon(4S)$
- 42 fb^{-1} at $\Upsilon(4S)$ – 60 MeV
- 19 fb^{-1} around 10.75 GeV in 2021 autumn to study new structure $\Upsilon(10753)$ observed by Belle in $\pi^+\pi^-\Upsilon(nS)$ transition

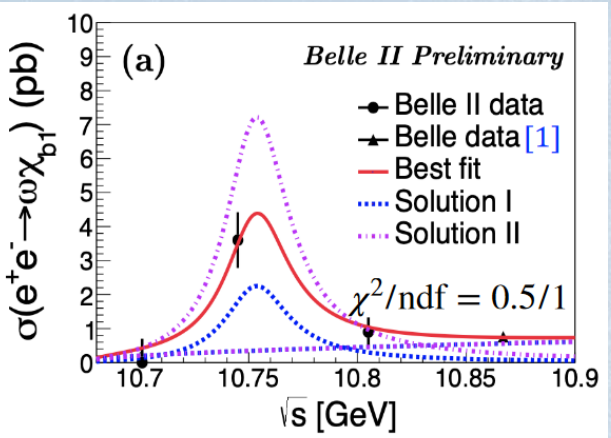
- Run stop mainly by SEU of front-end FPGAs and beam aborts
- DAQ dead time mostly due to trigger veto for injection background

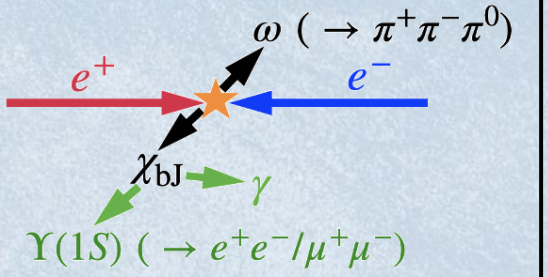
Physics results

- 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”

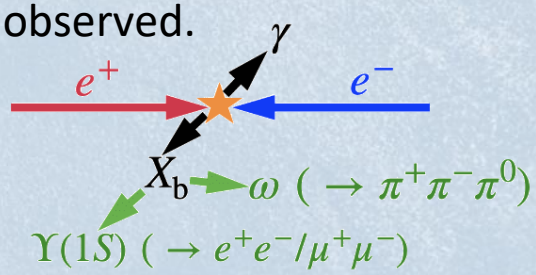
First observation of $\Upsilon(10753) \to \omega\chi_{bJ}$ as predicted

PRD 104, 034036 (2021)





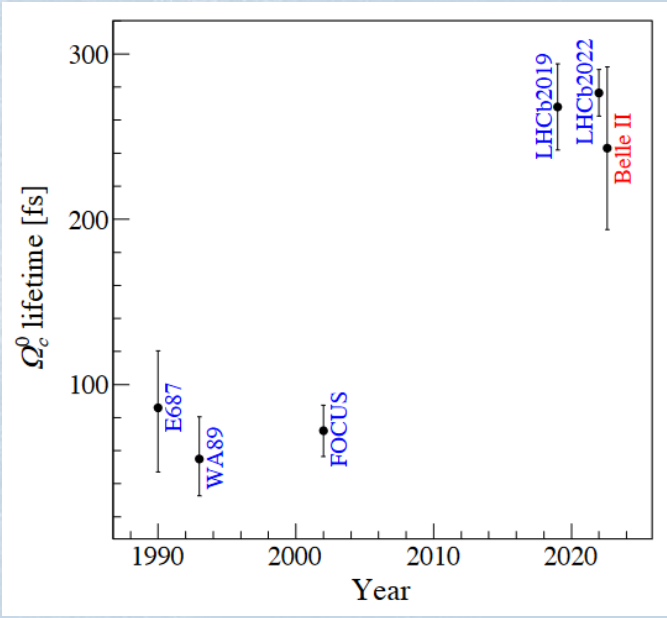
No significant X_b (bottomonium counterpart of X(3872)?) signals were observed.



[1] PRL 113, 142001(2014)

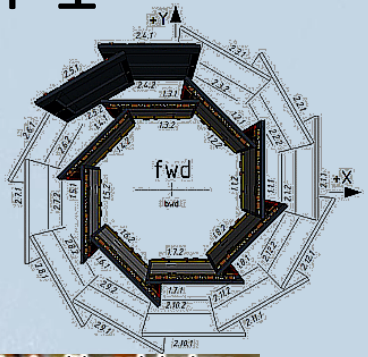
Belle II preliminary

$\tau(\Omega_c^0) = 243 \pm 48 \pm 11$ fs
stat. syst.



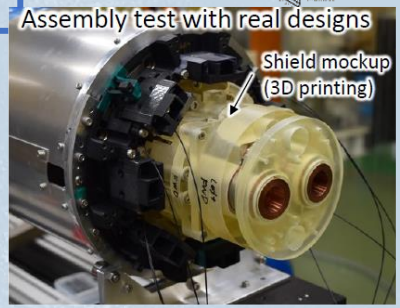
(from July 2022 until October 2023)

Major upgrade in Long Shutdown 1



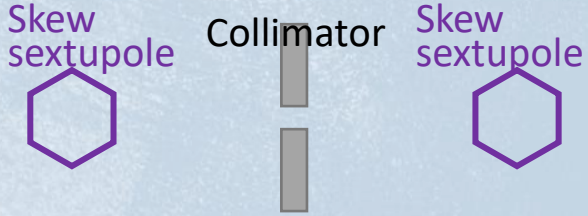
Belle II detector upgrade

- Exchange of PXD (pixel detector) with the full 2nd layer
- TOP conventional MCP-PMT replacement (TBD)
- Migration to new back-end readout (COPPER → PCIe40)



Beam background mitigation

- Additional shield on the QCS(*) bellows
- Additional shield for neutron background
- Installation of a non-linear collimator



Protection of machine and Belle II

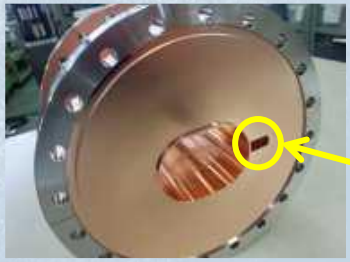
- Collimator heads of more robust material
- Faster beam abort system

Beam kick by skew sextupole:

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

Improvement of beam injection

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

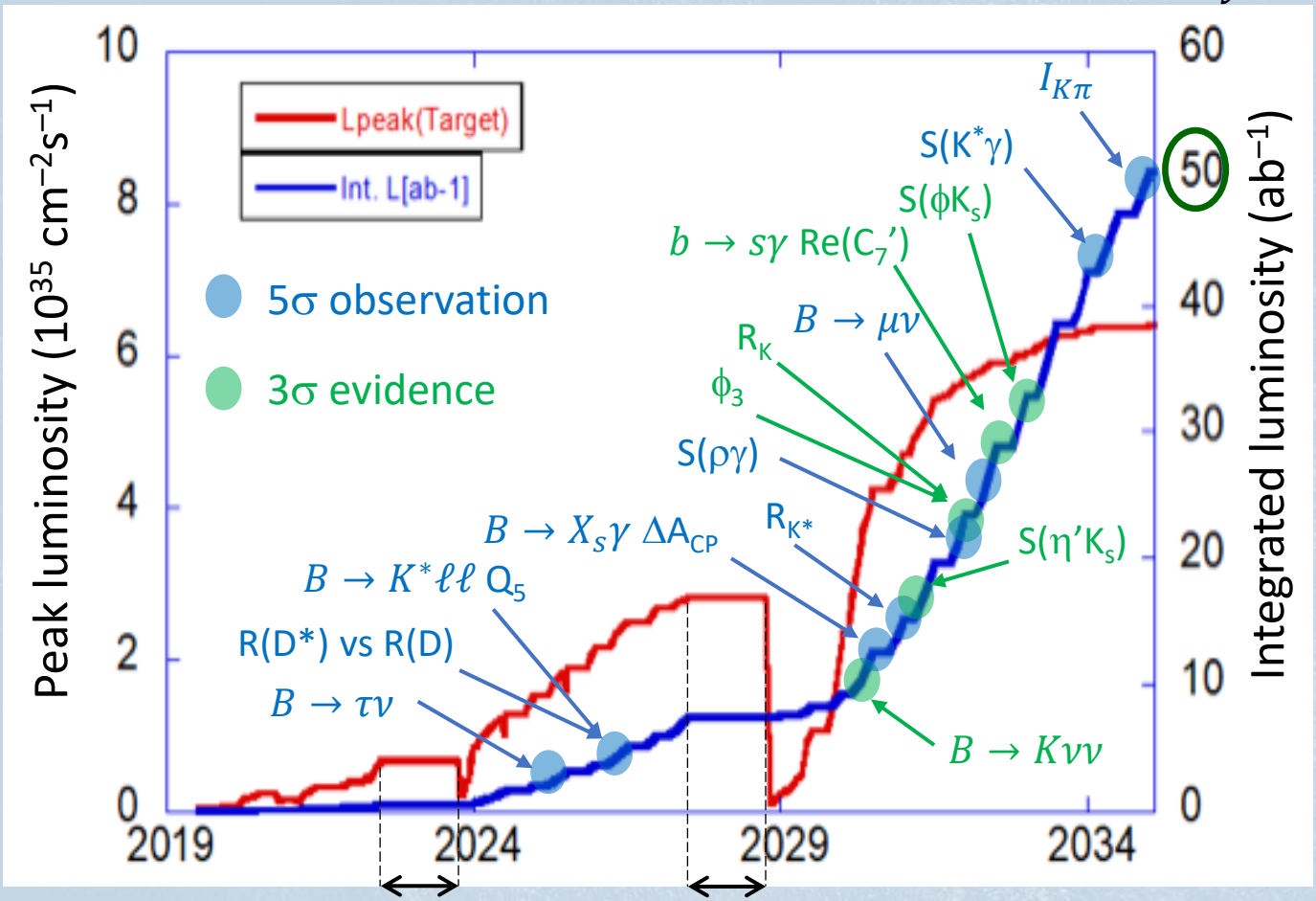


Beam channel for injection

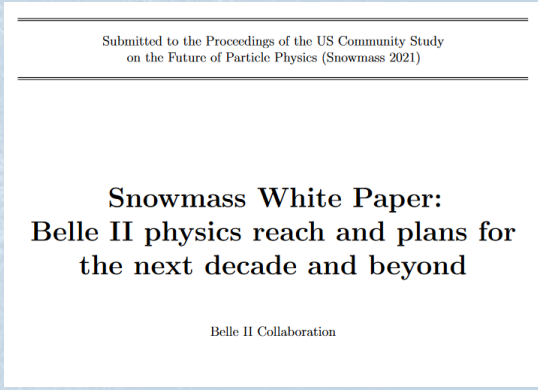
QCS: Final focusing system

Prospects

Will finish Long Shutdown 1 to be back in operation from October 2023.
Squeeze β_y^* down to 0.5-0.6 mm and increase the beam current.
Accelerator upgrade in Long Shutdown 2 to achieve β_y^* = 0.3 mm



arXiv: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

Broad Belle II physics reach

Summary

SuperKEKB/Belle II: Precision measurement of B, D, τ 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: 4.7×10^{34} cm^{-2}s^{-1}
  - Goal: 50 ab^{-1}
- ➢ Hermetic state-of-the-art Belle II detector
  - Tolerant of considerably higher beam background and higher event rate
  - Improved performance
- Recorded 424 fb^{-1} ($\approx$ 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