The Belle II Experiment:

Status & Prospects

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Belle II

A super B-factory?

- B factories
  - BaBar (PEPII) & Belle (KEKB) stopped in 2008/2010 after accumulation of 1000 fb^{-1}
    - Modest energy $\sqrt{s}$ = 10.58 GeV
  - Confirmed the CKM picture in Standard Model with very successful analysis techniques

- New inputs
  - ATLAS / CMS → Higgs but no non-SM particles
  - LHCb intriguing tensions in flavour physics

- Assets
  - Clean environment (few particles / event)
  - Known initial state → kinematic constraints
  - Neutral particle reconstruction -> π^0, η, γ

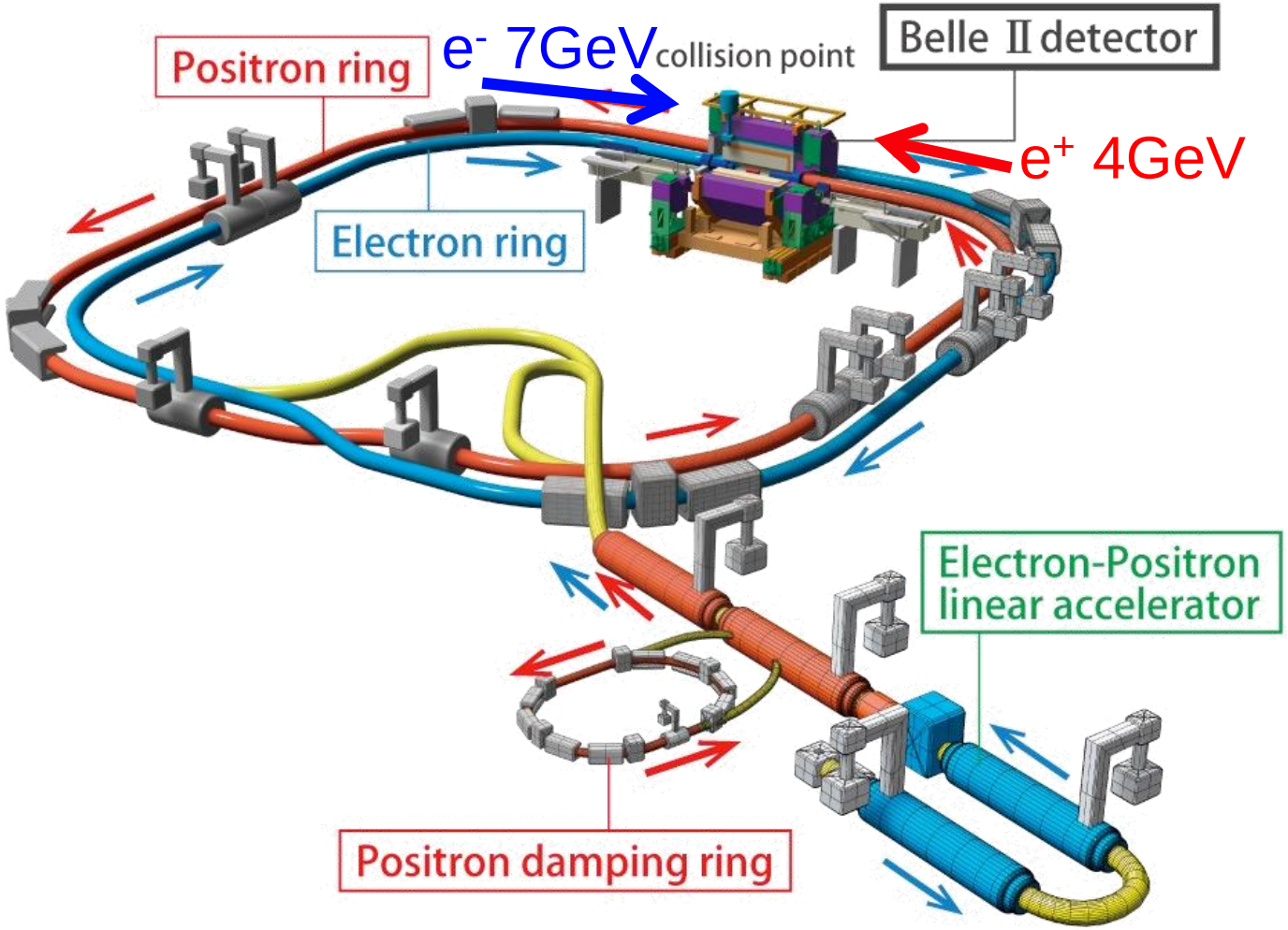
- Motivations for a super B-factory
  - Complementary search for New Physics / LHC ⇒ indirect
  - Precision test of Standard Model
  - Direct search for new light particles
  - Hadronic physics

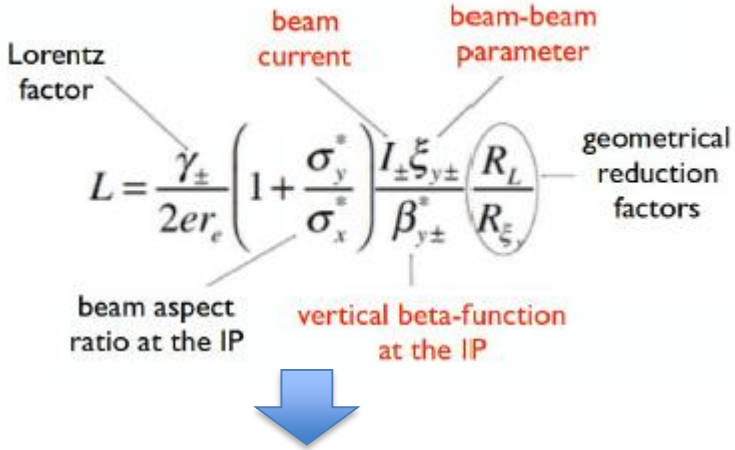
Luminosity frontier

Outline

- The projects
  - SuperKEKB & Belle II
- Status
  - Luminosity, data taking & performance results
  - First results
- Prospects
  - Next expected results
  - SuperKEKB & Belle II in the next 10 years

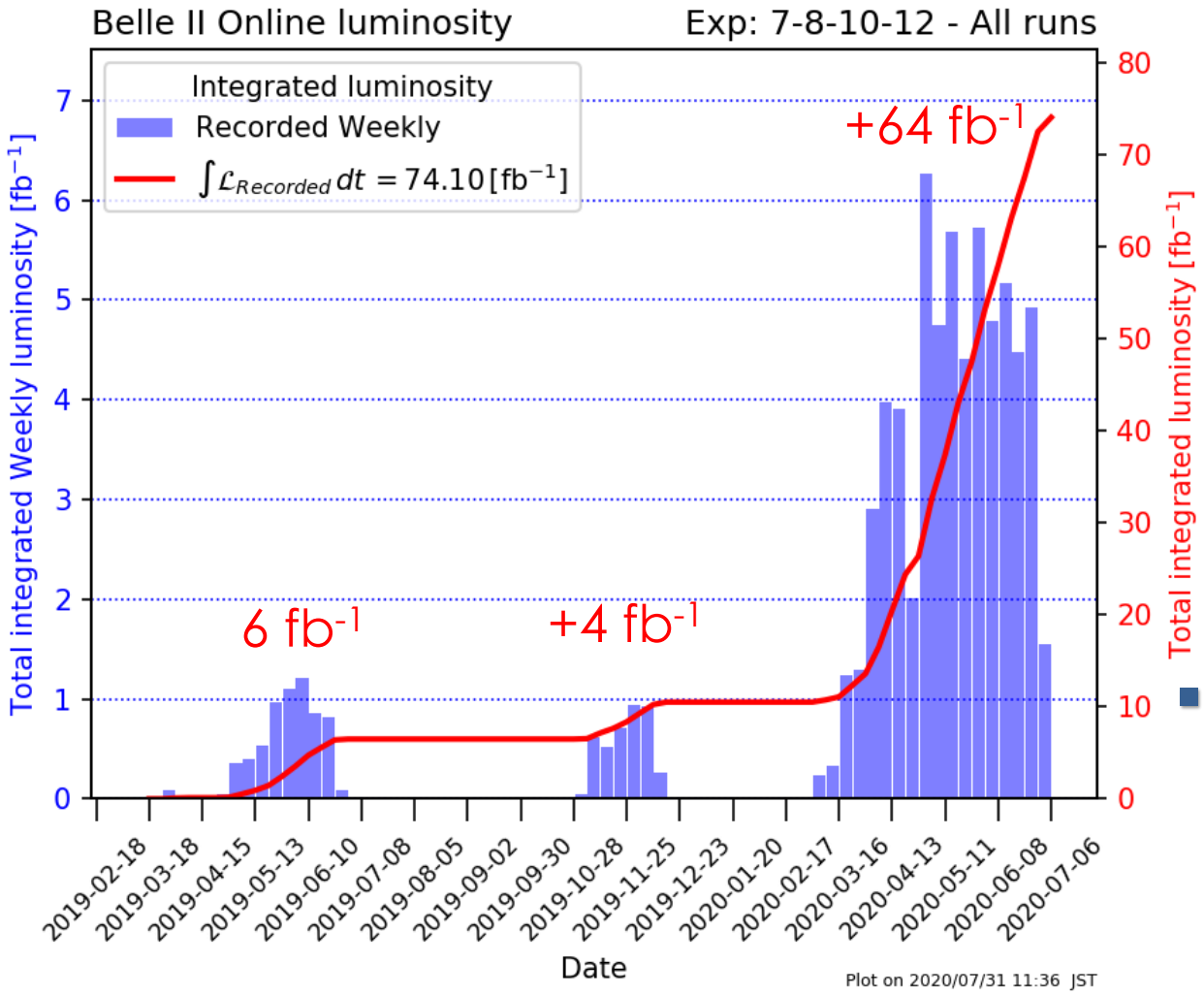
SuperKEKB collider





Nano-scale beam size:
$\sigma_x \times \sigma_y \sim 10\mu m \times 60$ nm

SuperKEKB / Belle II Luminosity status



Machine progress

	KEKB	SuperKEKB	
		2020	Nominal
Energy (GeV) LER/HER	3.5 / 8	4 / 7	
Current (A) LER/HER	1.6/1.2	0.7/0.6	3.6 / 2.6
"Beam size" β_y^* (mm)	5.9	0.8	0.3
Instant. Lumi. ($cm^{-2}.s^{-1}$)	2.1×10^{34}	< 2.4×10^{34}	~6×10^{35}

First collisions April 2018

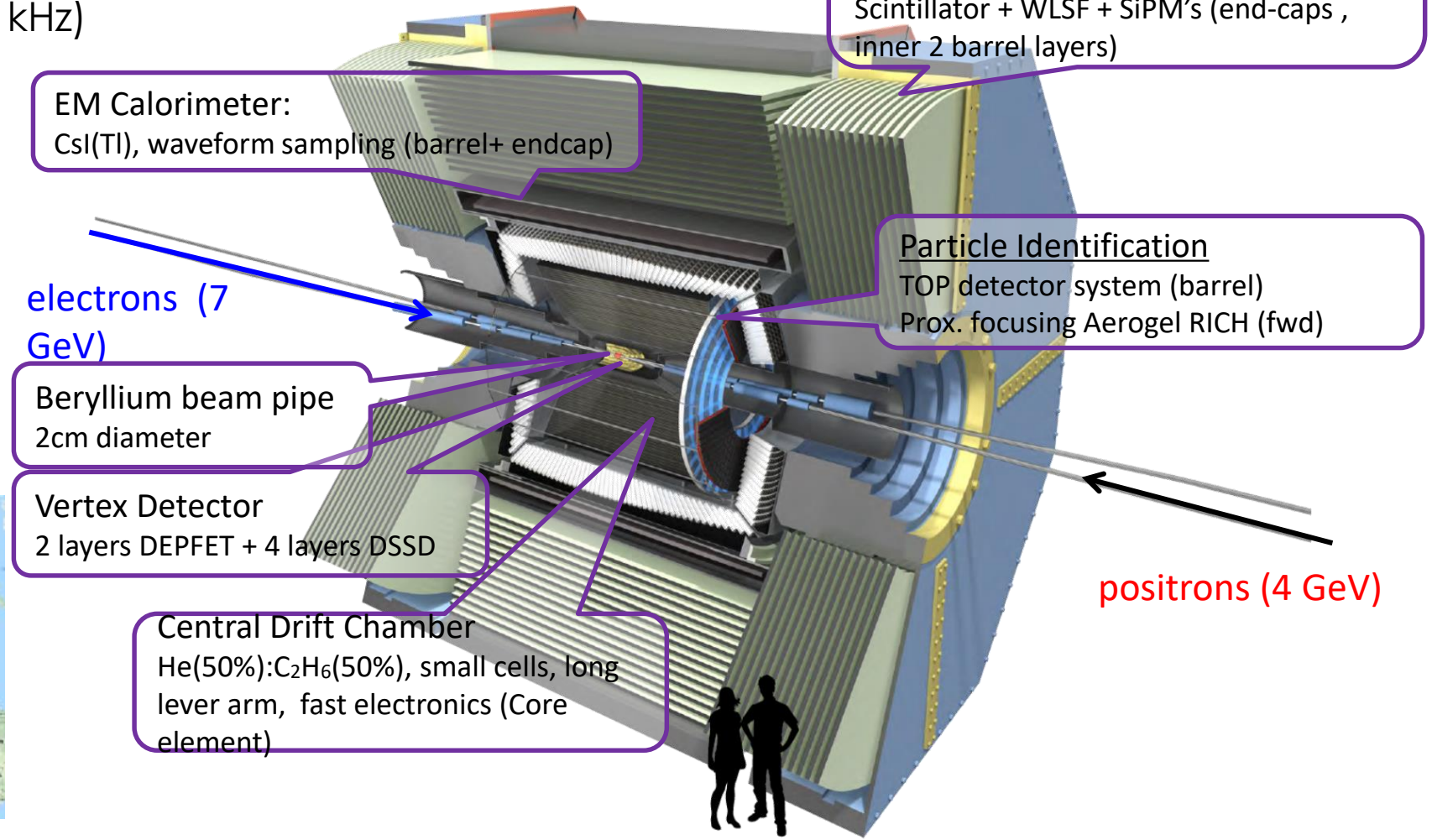
Final goal 50 ab^{-1}

Data taken

- On-resonance 74 fb^{-1}
  - Analysis ready in Summer 2020 exploit ~35 fb^{-1}
  - Analysis ready in Winter 2019-20 exploit < 10 fb^{-1}
- Off-resonance 6 fb^{-1} ($M_{\Upsilon(4S)}$ -60MeV)

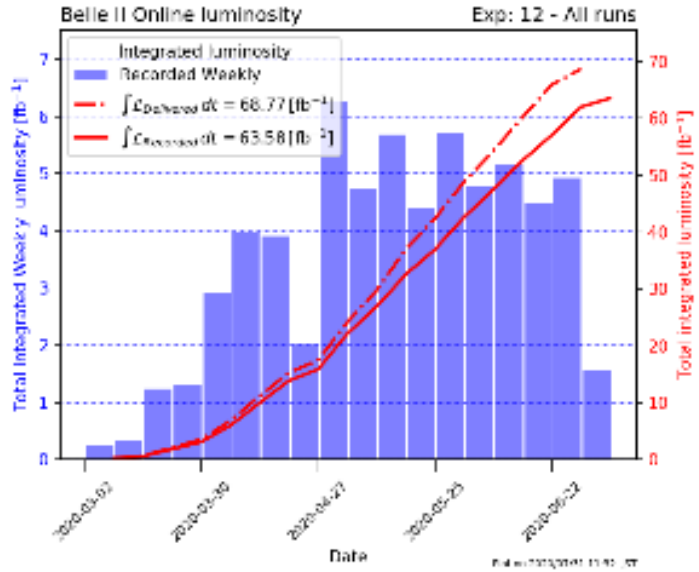
Belle II detector

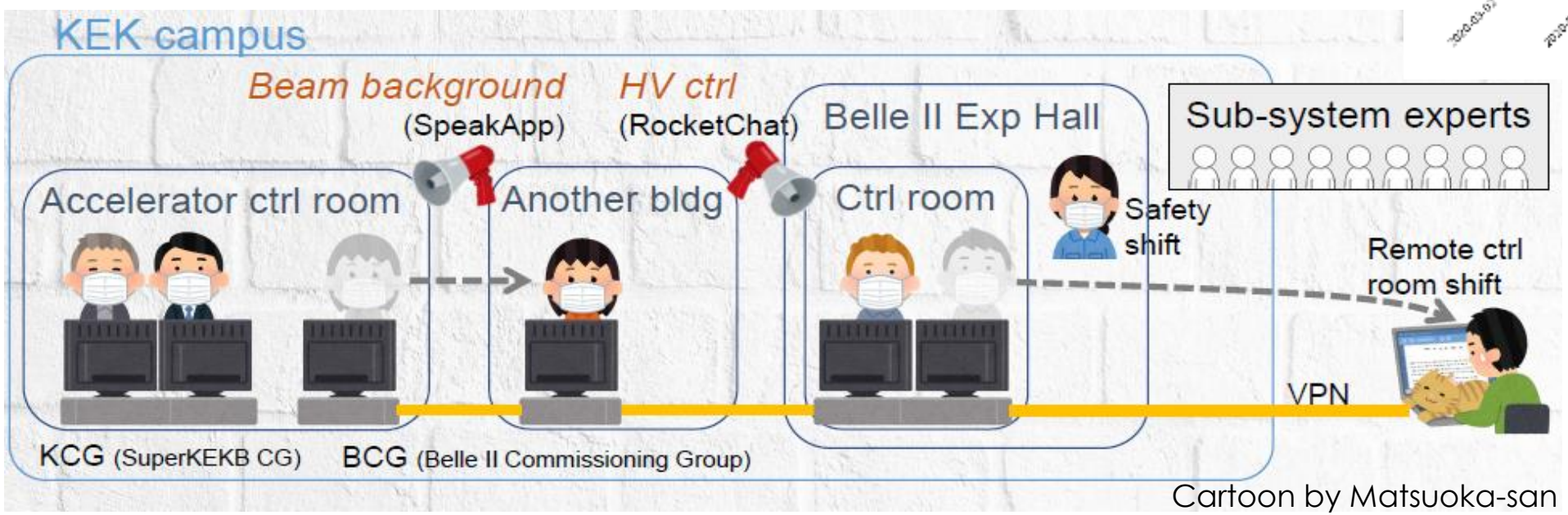
Planned for better performances / Belle even with: { higher beam background
higher trigger rate (30 kHz)



Special data taking conditions in 2020

- Non-stop operation with COVID-19 pandemic
  - Strong developments for close to or fully remote sub-system operation
  - Huge commitment from Japanese colleagues & residents in Japan
    - Only 40 people on site from March to July





Cartoon by Matsuoka-san

Belle II operation

- Data taking efficiency 84%

- Main issues
  - TOP MCP-PMT QE decrease with total charge
  - VXD (PXD-SVD) occupancy
  - Synchrotron radiations

- Beam Background
  - Mitigation measures with additional collimators
  - Data – MC agreement O(1) !

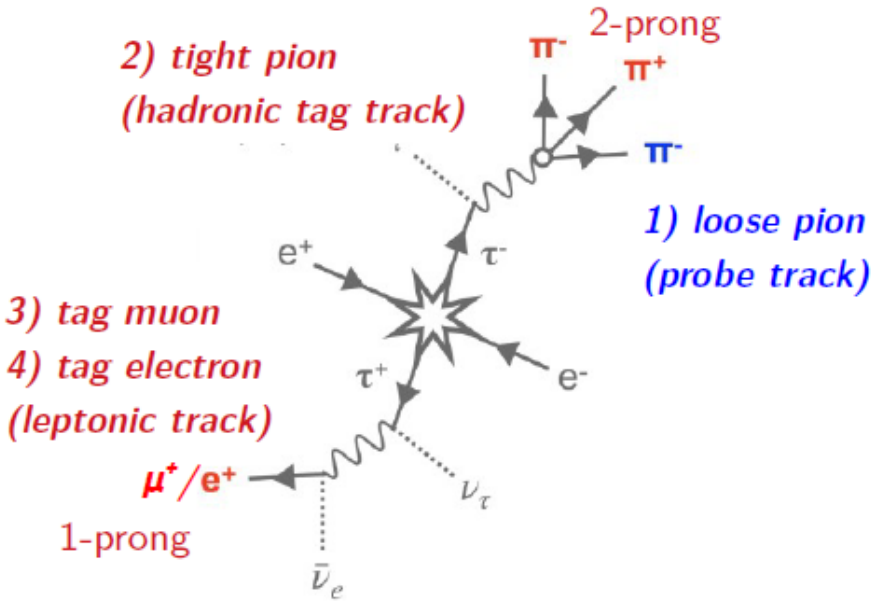
SLIDE NOT READY

Tracking performance

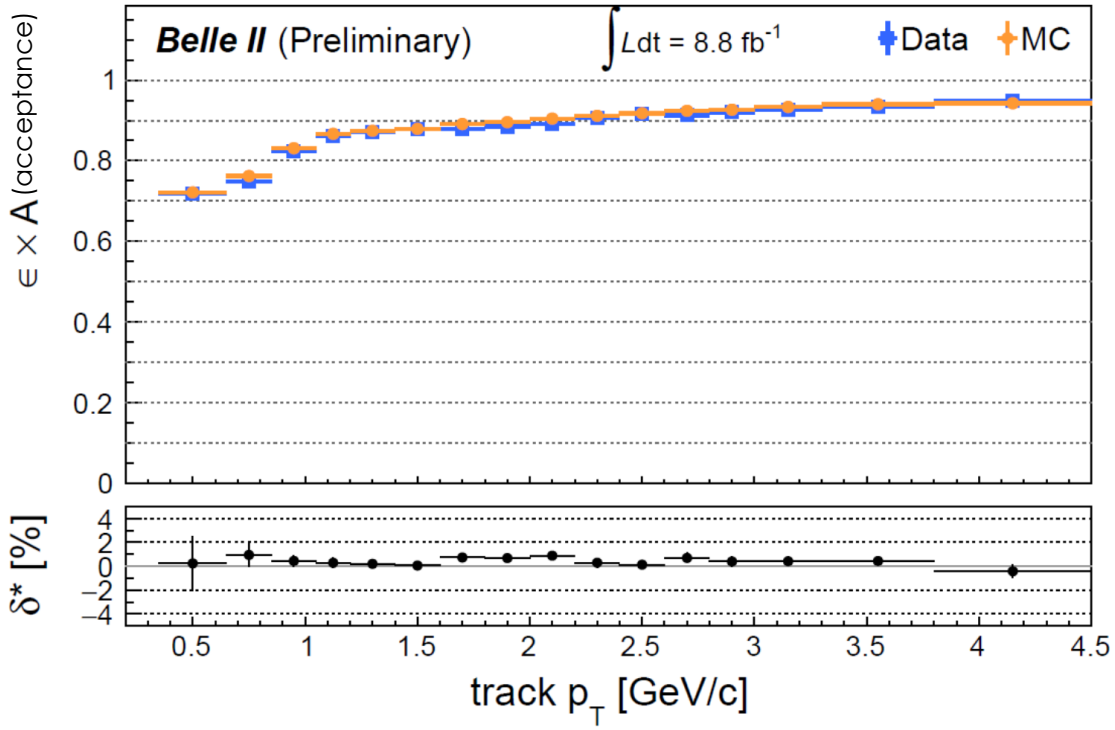
BELLE2-NOTE-PL-2020-014

- tag & probe technique with e+e- →τ+τ-
  - Lepton-ID tags the event
  - 3 prongs provide probe

} 4 charged tracks expected



efficiency $\varepsilon = \dfrac{N_{\text{evts}}(4\text{tracks})}{N_{\text{evts}}(4\text{tracks}) + N_{\text{evts}}(3\text{tracks})}$



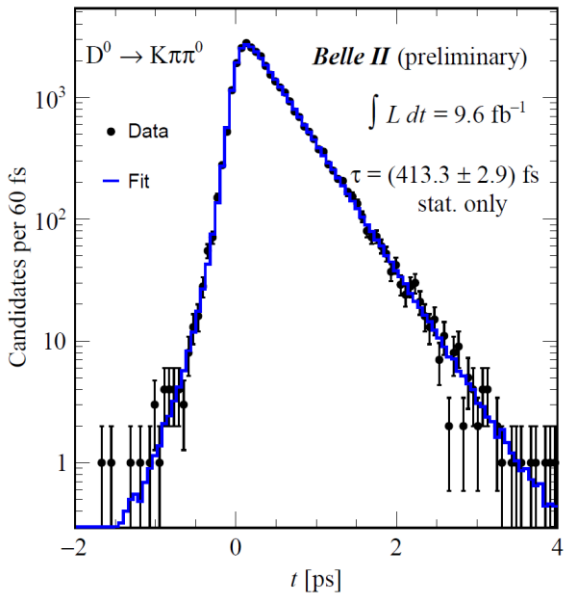
$$\delta^* = 1 - \frac{\varepsilon_{\text{data}}}{\varepsilon_{\text{MC}}}$$

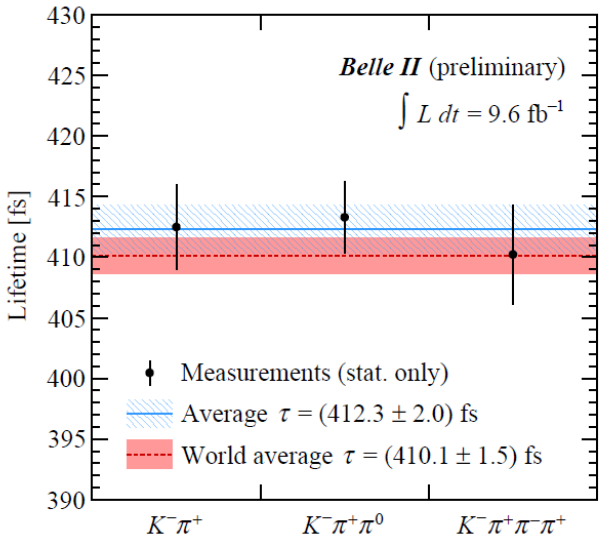
Vertexing performances

- **D0 lifetime**

BELLE2-NOTE-PL-2020-008

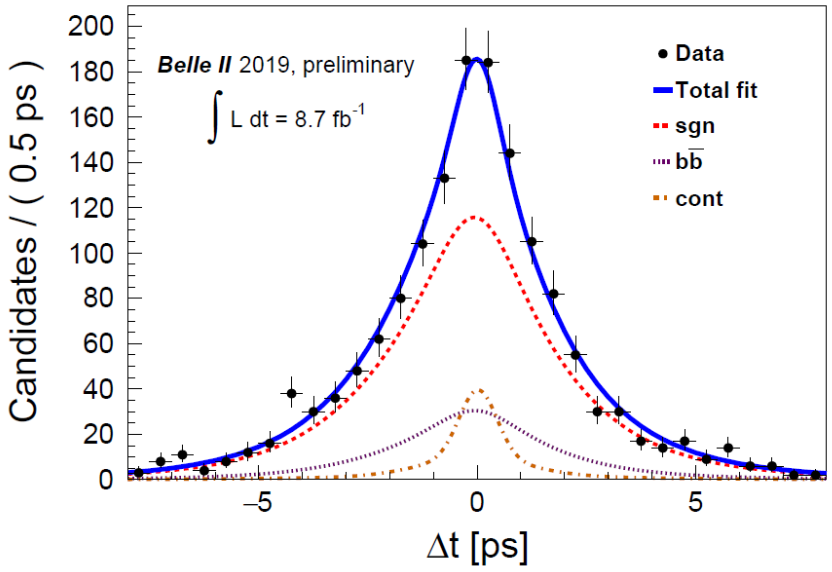
  - Measured with 3 channels: $K^-\pi^+$, $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$
  - Estimated position resolution ~40 μm





BELLE2-NOTE-PH-2019-017

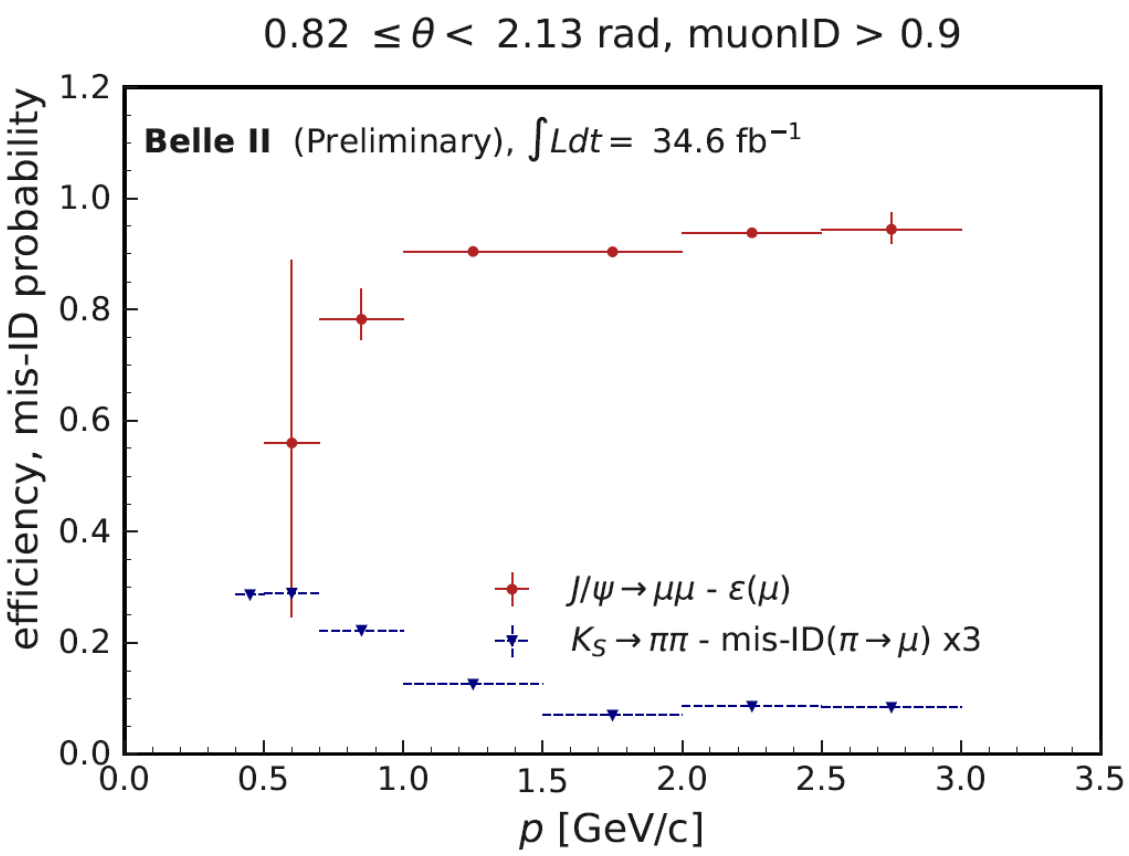
- **B0 lifetime**
  - Smaller Y(4S) boost: 0.42 (Belle) → 0.28 (Belle II)
  - Average distance between B-mesons 200μm → 120 μm
  - Hadronic channels $B \to D^{(*)-}\ \pi+/\rho^+$
  - Estimated resolutions
    - Time: $\Delta t \sim 1$ ps ↔ $\Delta t \sim 80$ μm
    - Dominated by "tag"-side

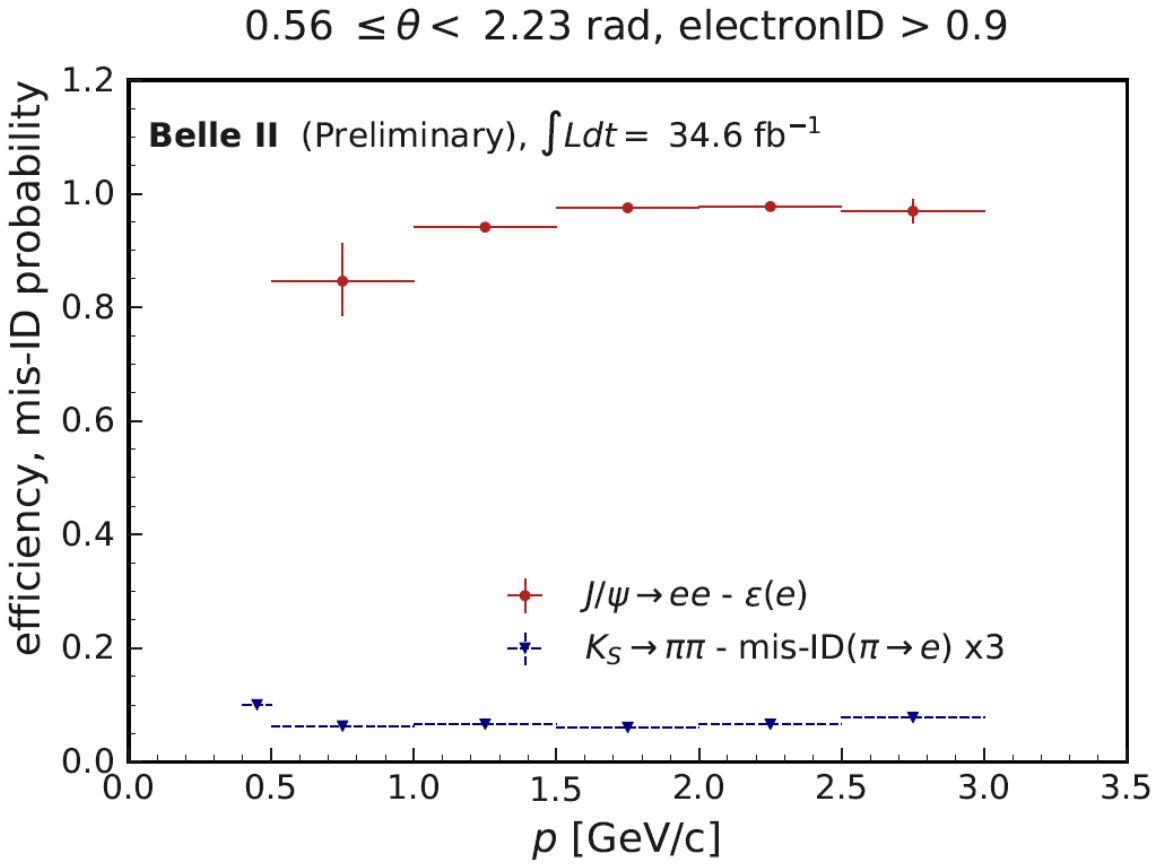


Particle identification: leptons

- Using fully reconstructed channels

$$\text{lepton}-\text{ID} = \frac{\mathcal{L}_{\text{lepton}}}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$

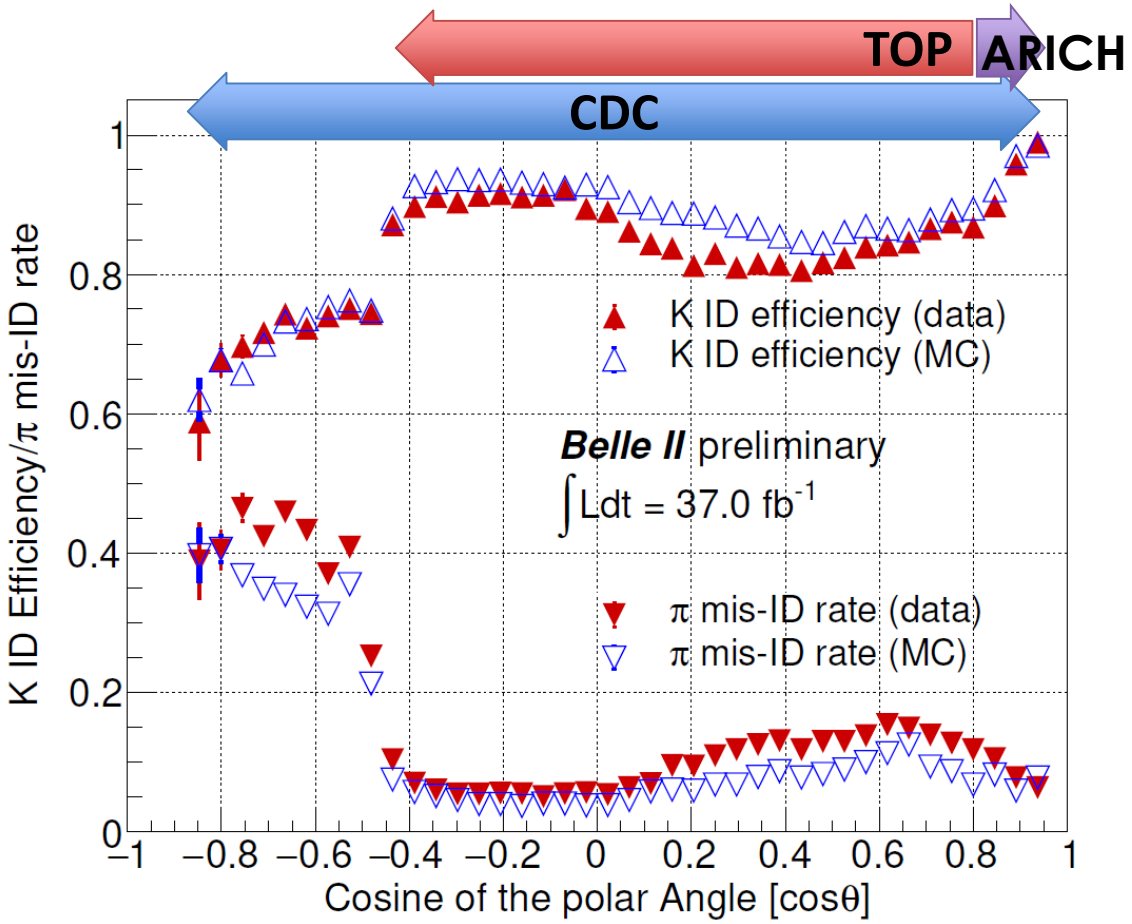




Particle identification: hadrons

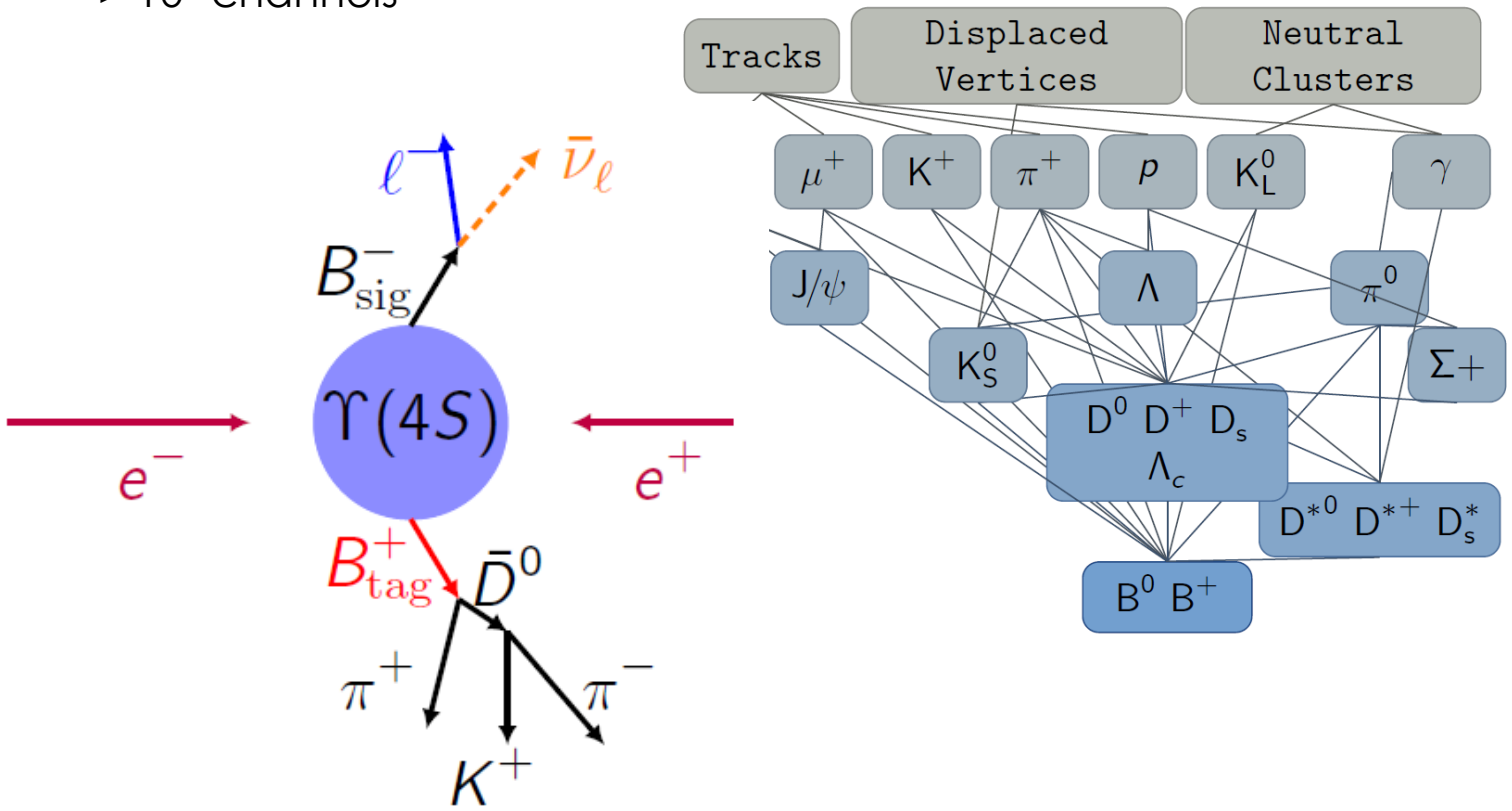
- Using fully reconstructed channels
  - $D^{*+} \rightarrow D^0(K^-\pi^+)\ \pi+$

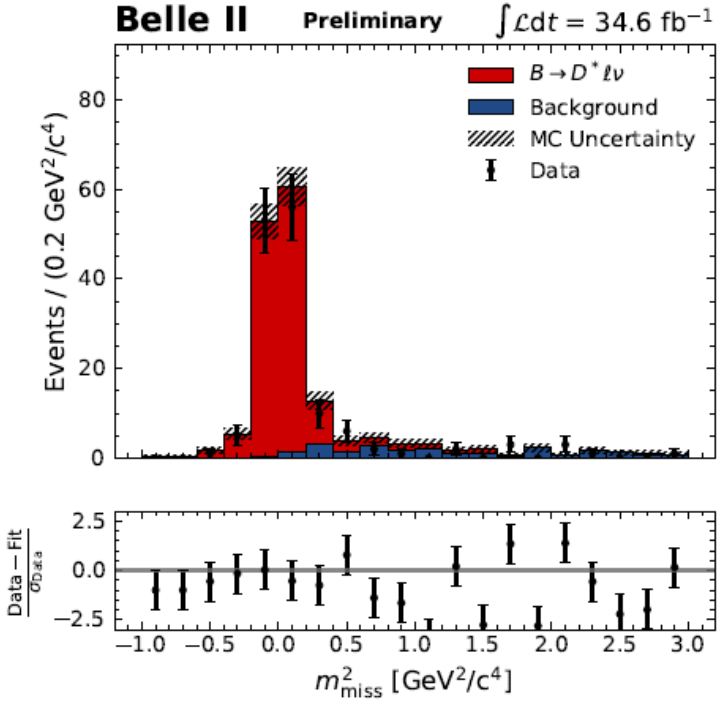
$$K/\pi\text{−ID} = \frac{\mathcal{L}_{K/\pi}}{\mathcal{L}_K + \mathcal{L}_\pi}$$



Full Event Interpretation

- B-reconstruction in tag-side
  - > 10^4 channels





Dark sector

- Early Belle II publications
  - Z' to invisible
  - APLS to photon

See talk by **Marcello Campajola** "Dark Sector first results at Belle II"

Slides not even drafted beyond this point

Time-dependent analysis for B-physics

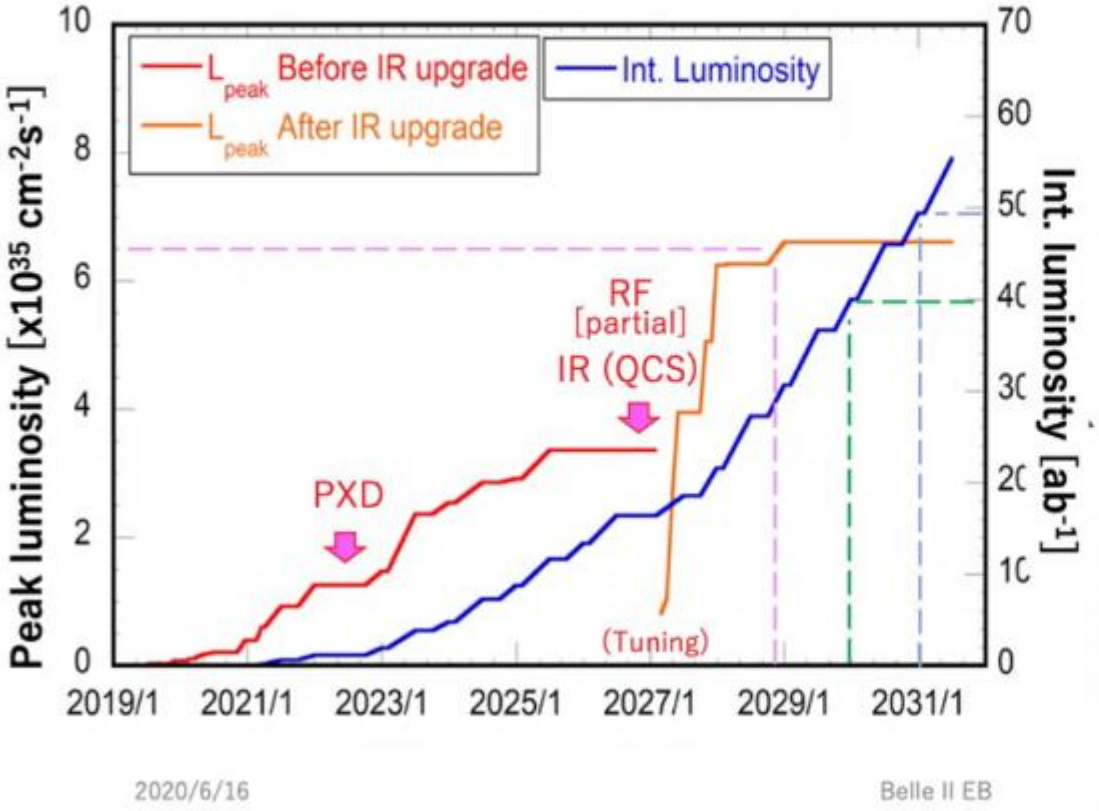
- Remind lifetime
- Introduce Mixing

Semileptonic B-decays

Charmonia

Prospects for SuperKEKB schedule overview

Update plan (Roadmap 2020)



- Peak luminosity 6E35 $cm^{-2}s^{-1}$ in ~2028
- Integrated luminosity 40 ab^{-1} in ~2029 (50 ab^{-1} in ~2030)
- PXD exchange in 2021~2022
- IR (QCS and its beam pipes etc.) upgrade in 2026
- Partial RF-power upgrade (2 stations) in 2026
- β_y^*=0.3 mm in 2026 after IR upgrade, and ~0.5 mm before that
- Max. beam currents: LER 2.8 A, HER 2.0 A (1761 bunches) in 2027
- Basically, 8 moths' operation per year.

[Investment in equipment]

- QCS and its beam pipes etc.
- Partial RF-power upgrade (2 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade

2020/6/16 Belle II EB 4

Prospects for Belle II

- 2022
  - On-going DAQ board replacement
  - Complete PXD
  - TOF replacement

- 2026
  - SuperKEKB (see previous slides) introduce long shutdown
  - Detector upgrades
    - VXD
    - PID
    - KLM

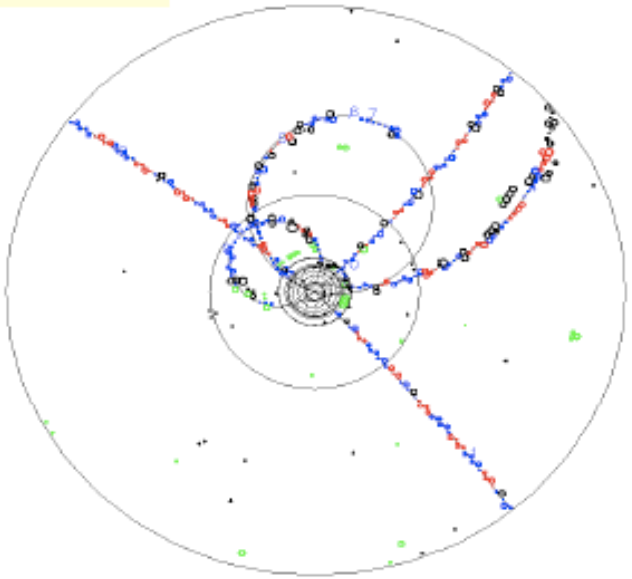
- Shor term
  - March 2021 :140-240 fb^{-1}
  - July 2022: 1 ab^{-1}
  - Detail expected analysis

Summary

SUPPLEMENTARY SLIDES

Beam-induced backgrounds

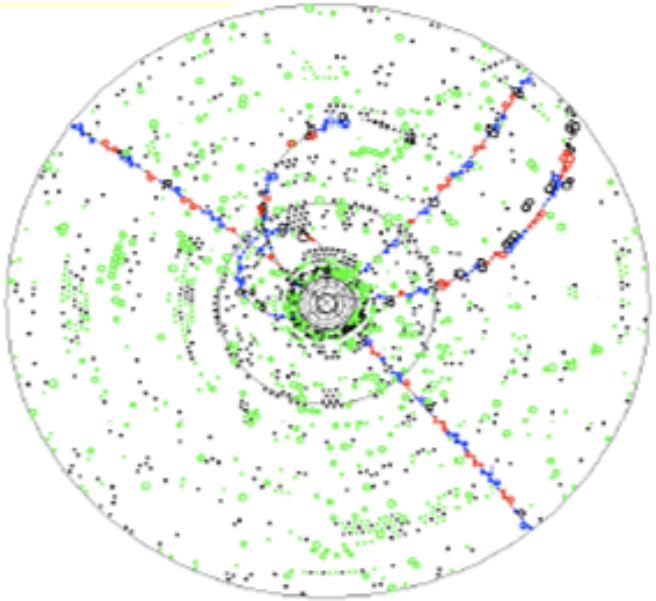
Life without ....
Belle



Responsible for:

- ~50% of ECL energy
- >99% innermost layer hits

... and with beam-background
Belle II



- Single beam effects
  - Touschek
  - Beam-gaz
  - Synchrotron radiation
- Beam-beam effects
  - Radiative Bhabha
  - QED pairs

The collider

e^+ 4GeV 3.6 A

e^- 7GeV 2.6 A

SuperKEKB

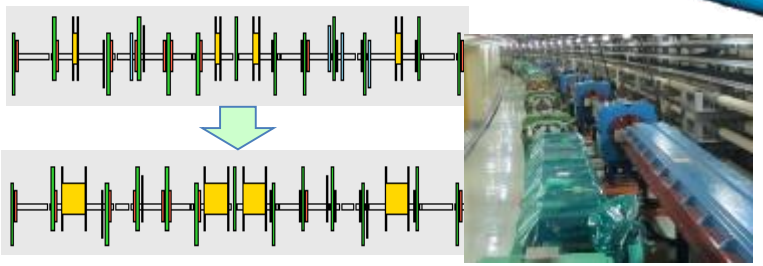
Target: L = $8 \times 10^{35}/cm^2/s$

New superconducting /permanent final focusing quads near the IP

New IR

Colliding bunches

Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

Add / modify RF systems for higher beam current

Positron source

New positron target / capture section

Damping ring

@1.1 GeV

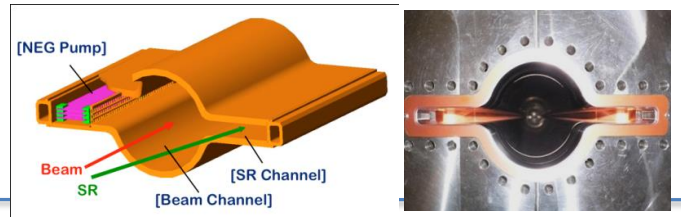
To inject low emittance positrons

Low emittance gun

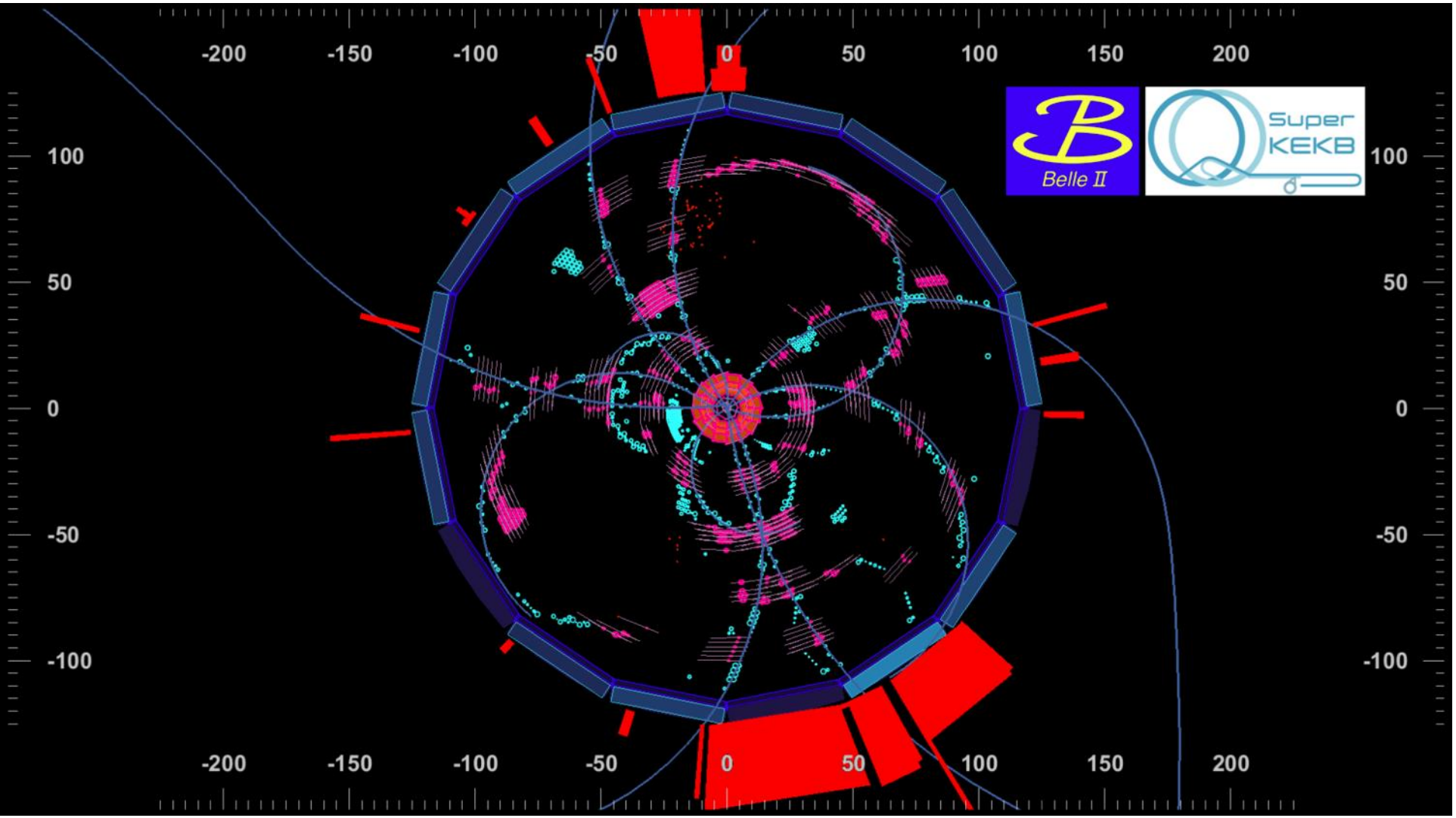
To inject low emittance electrons

TiN-coated beam pipe with antechambers

Cu for wigglers and Al alloy for the rest



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


-200
-150
-100
-50
0
50
100
150
200
100
50
0
-50
-100
Belle II
Super KEKB

Tracking fake

$$r_{\text{fake}} = \frac{N_{\text{evts}}(5\text{tracks})}{N_{\text{evts}}(5\text{tracks}) + N_{\text{evts}}(4\text{tracks})}$$