Rare B Decays at Belle II

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On Behalf of the Belle II Collaboration

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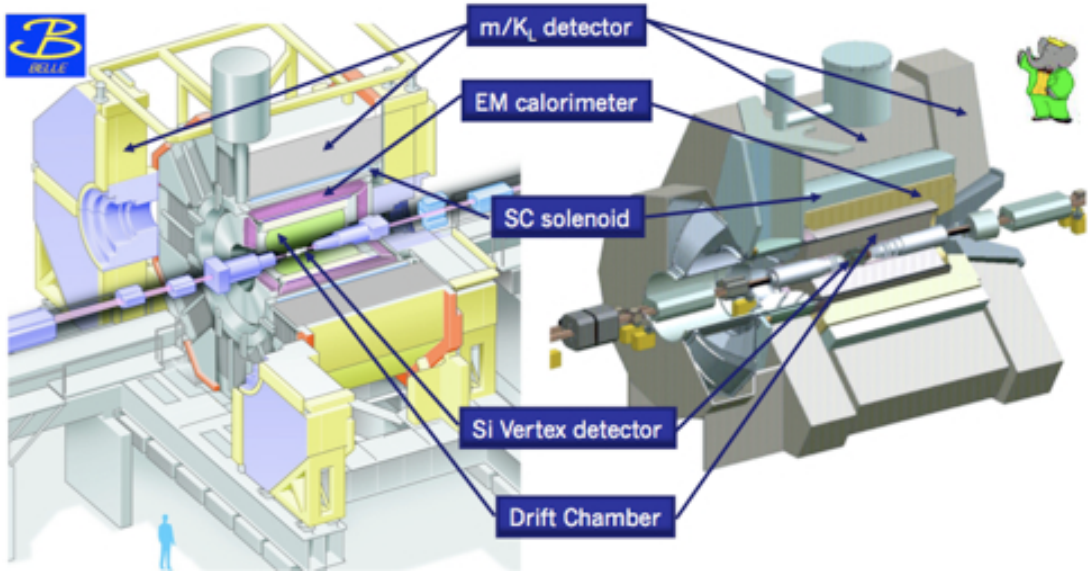
Outline

- Motivation for the e^+e^- B factory
- The **SuperKEKB** collider
- The **Belle II** detector
- The **Prospects** of **rare B decays at Belle II**

The 1st-generation *B* factories

"*B* factory": High-luminosity, asymmetric-energy e^+e^- collider operating at $\sqrt{s} = 10.59$ GeV to produce $e^+e^- \to \Upsilon(4S) \to B\bar{B}$



https://www2.kek.jp/proffice/archives/feature/2010/BelleBaBarBook.html

Belle in Japan
1999-2010
~1000 fb^{-1}= 1 ab^{-1}

BaBar in the US
1999-2008
~500 fb^{-1}= 0.5 ab^{-1}

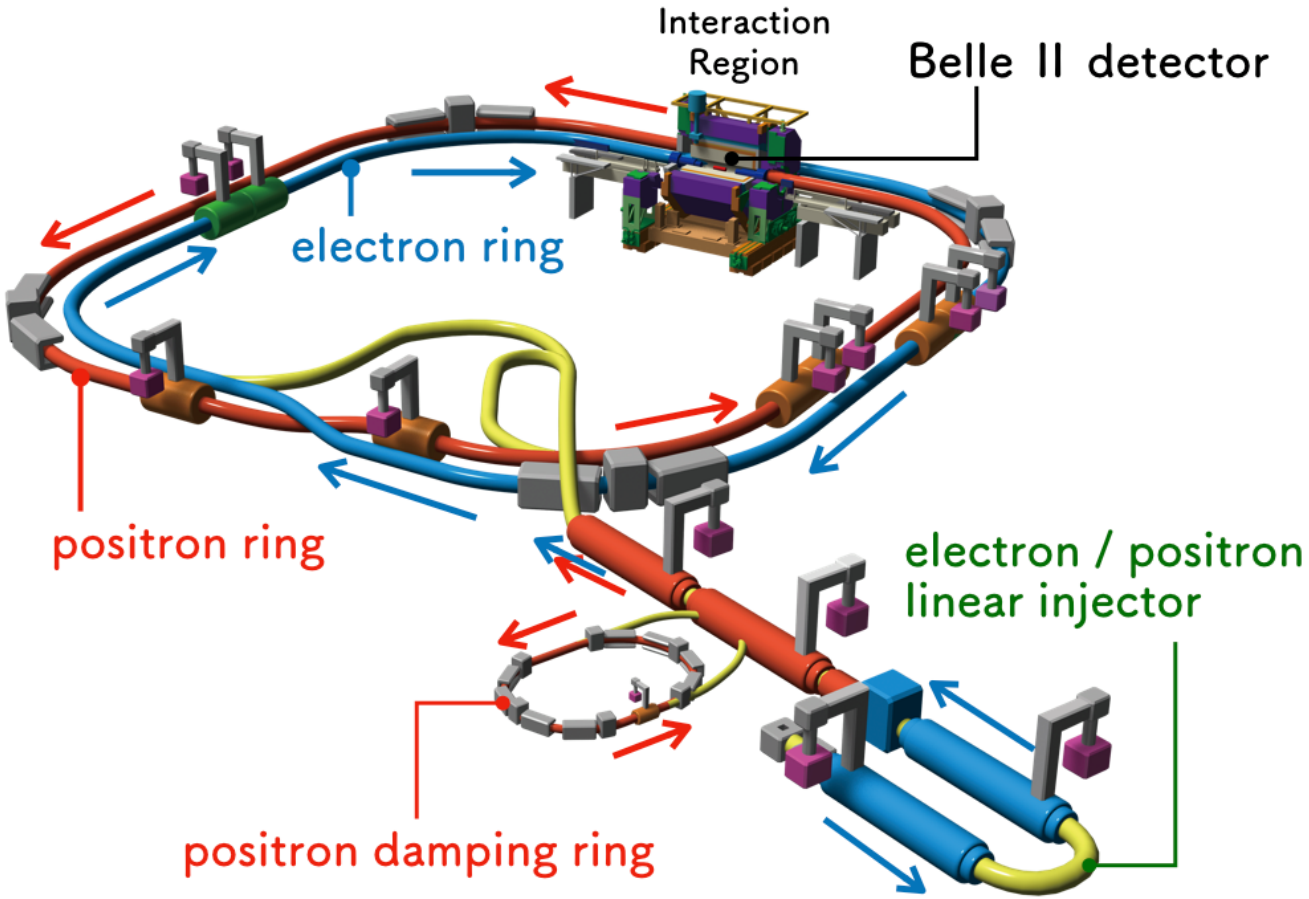
Initial goal: test the CP-violation mechanism of the SM

The 2nd-generation *B* factories: Belle II and LHCb

Property	LHCb	Belle II
$\sigma_{\bar{b}b}(nb)$	~150,000	~**1**
$\int Ldt\ (fb^{-1})\ by\ 2027$	~**25**	~50,000
Background level	**High**	Low
Typical efficiency	**Low**	High
π^0, K_S efficiency	**Low**	High
Initial state	**Not well known**	Well known
Decay-time resolution	Excellent	**Good**
Collision spot size	**Large**	Tiny
Heavy bottom hadrons	B_s, B_c, b-baryons	**Partly B_s**
τ physics capability	**Limited**	Excellent
B-flavor tagging efficiency	**3.5-6%**	36%

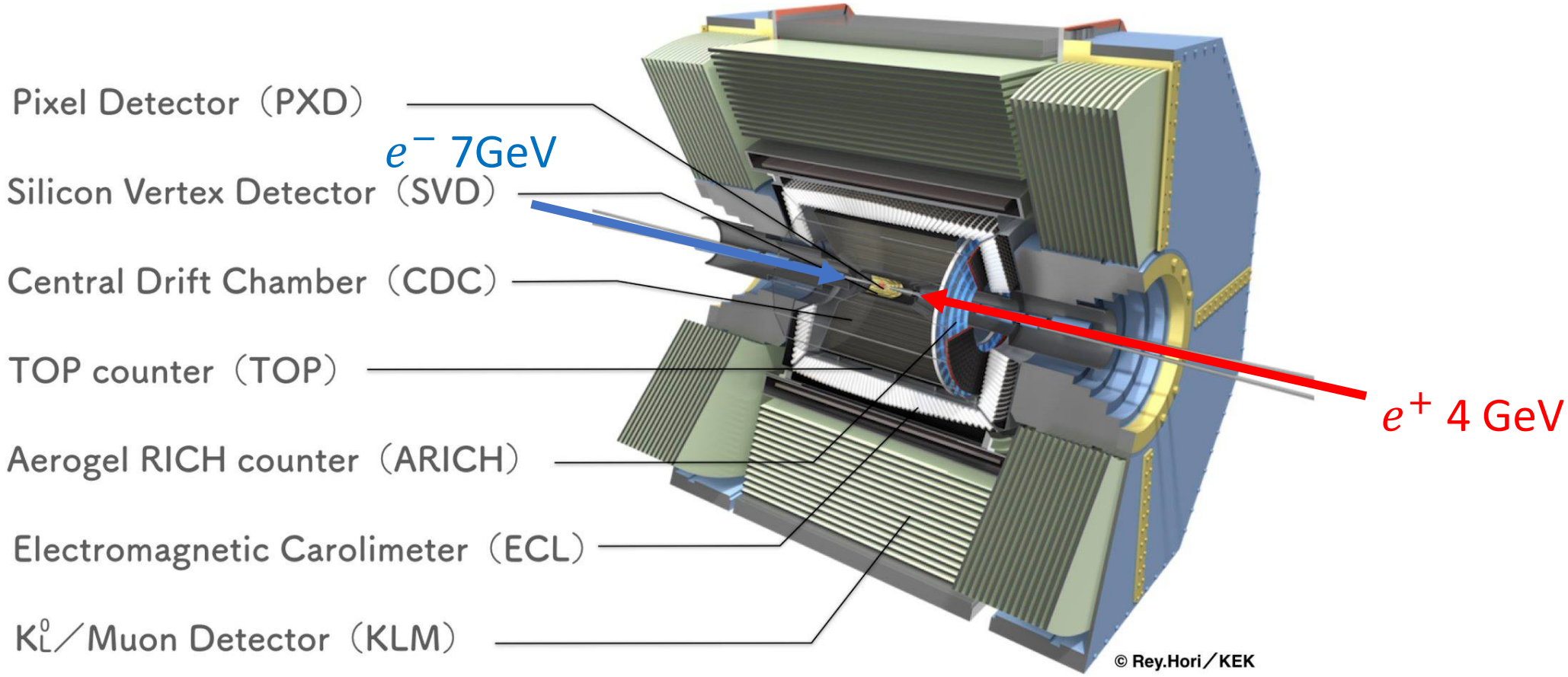
Reference: Abi Soffer, Intensity Frontier in Particle Physics, October 2019, Taipei

SuperKEKB collider



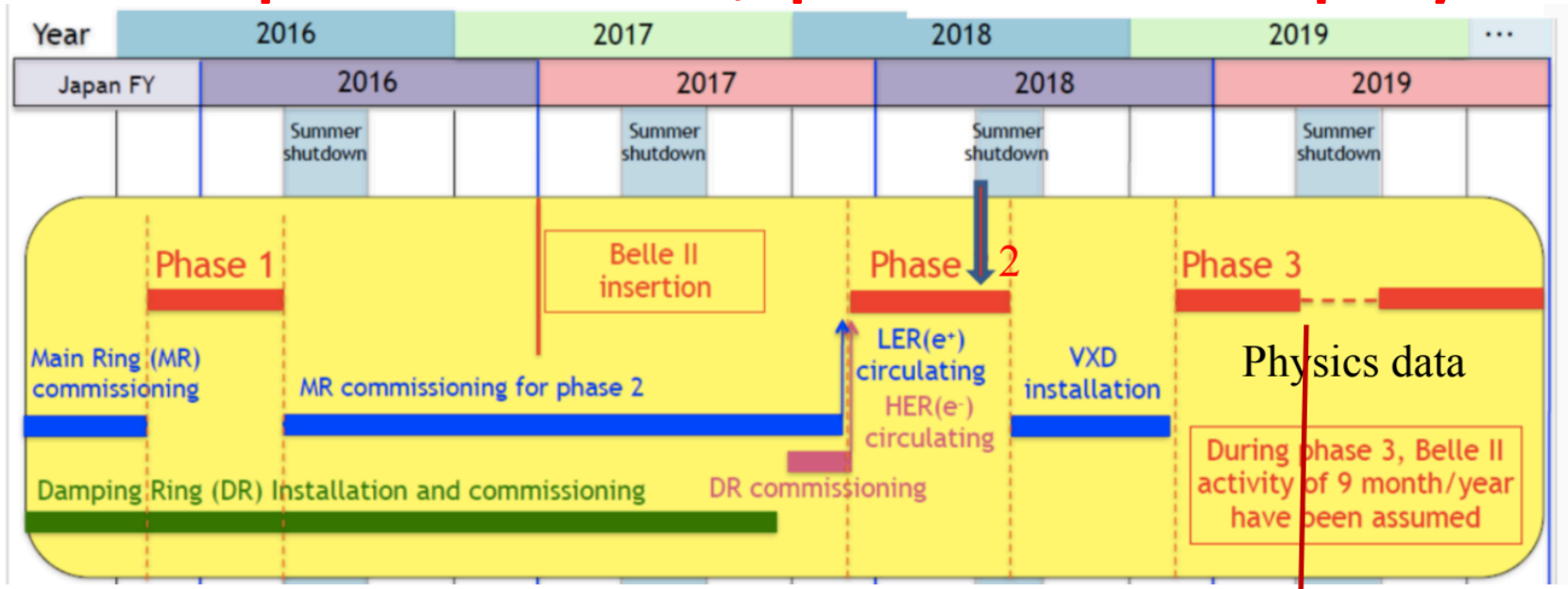
The electron and positron rings are about **3-km-long**. The tunnel used for SuperKEKB is the same as KEKB.

Belle II detector



PXD, TOP and ARICH are new designs; SVD, CDC, ECL and KLM are upgraded from original designs in Belle.

Start-up schedule, phase 3 for physics data



First collisions, 26 April, 2018

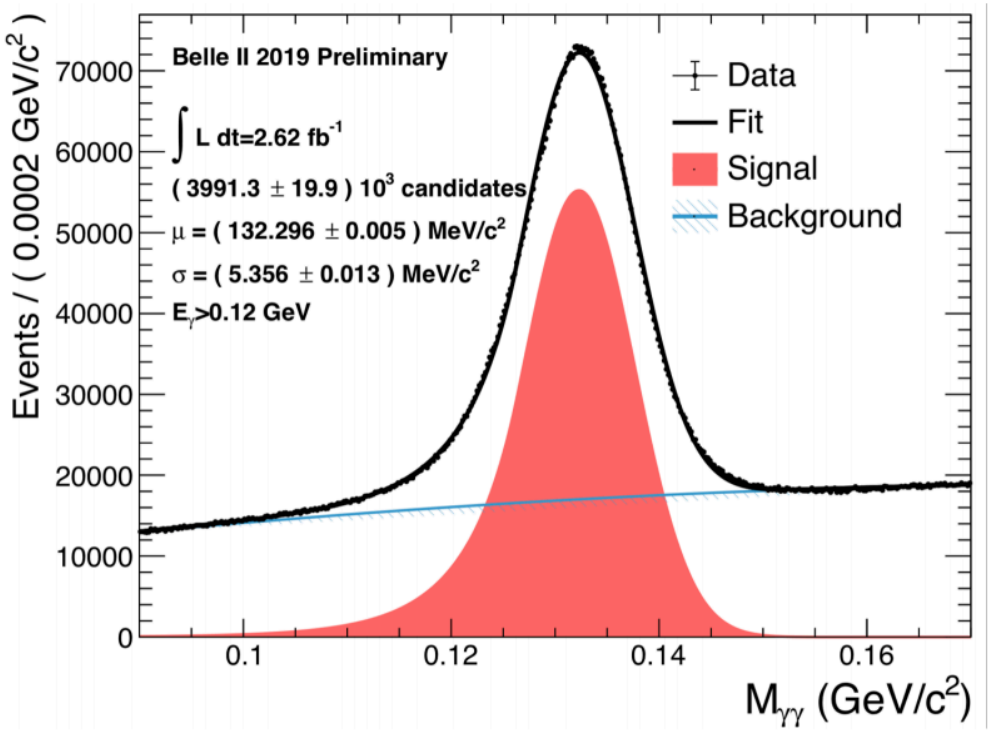
- Collected ~ 5 fb^{-1}
  - 0.5% of Belle
- Mostly at $L \sim 0.5\times10^{34}\ cm^2s^{-1}$
  - 25% of KEKB
- Reached $L \sim 1.2\times10^{34}\ cm^2s^{-1}$
  - With high background
  - Ongoing work on background

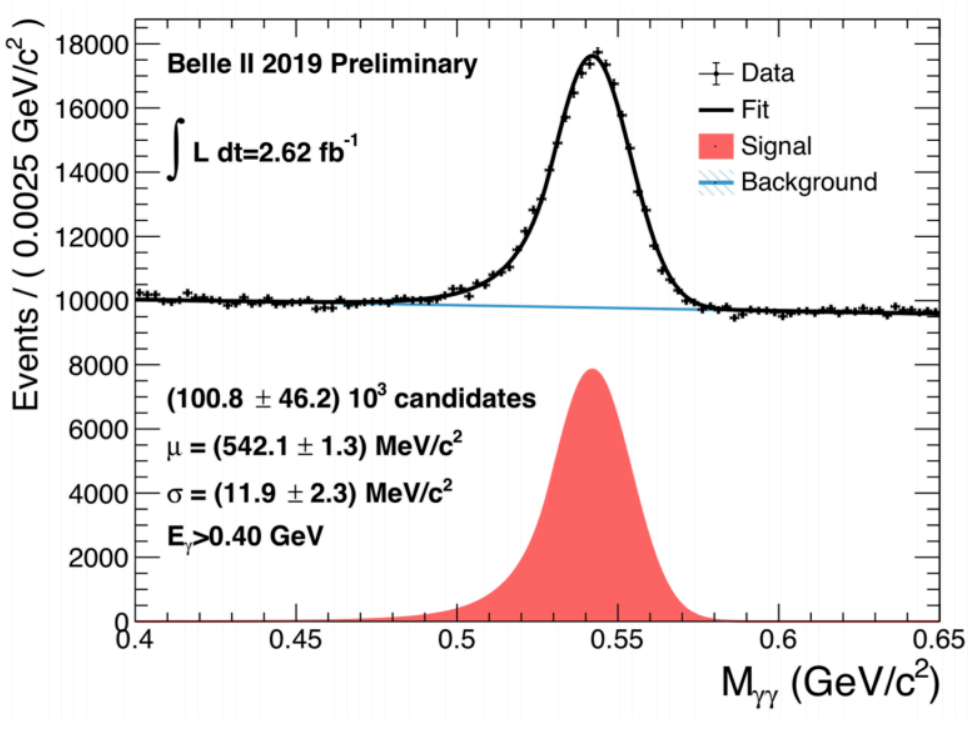
Detector performance and rediscovery of known physics

- Current integrated luminosity, ~$5 fb^{-1}$ is similar to that of CLEO in mid-90's
- Used mostly for **validating detector performance and commissioning**
- Please check the talks:
  - **Belle II Status and prospects, Speaker**: Tadeas Bilka
  - **First results on DM searches at Belle II, Speaker**: Michael de Nuccio

π^0 and $\eta \to \gamma\gamma$

BELLE2-NOTE-PL-2019-019

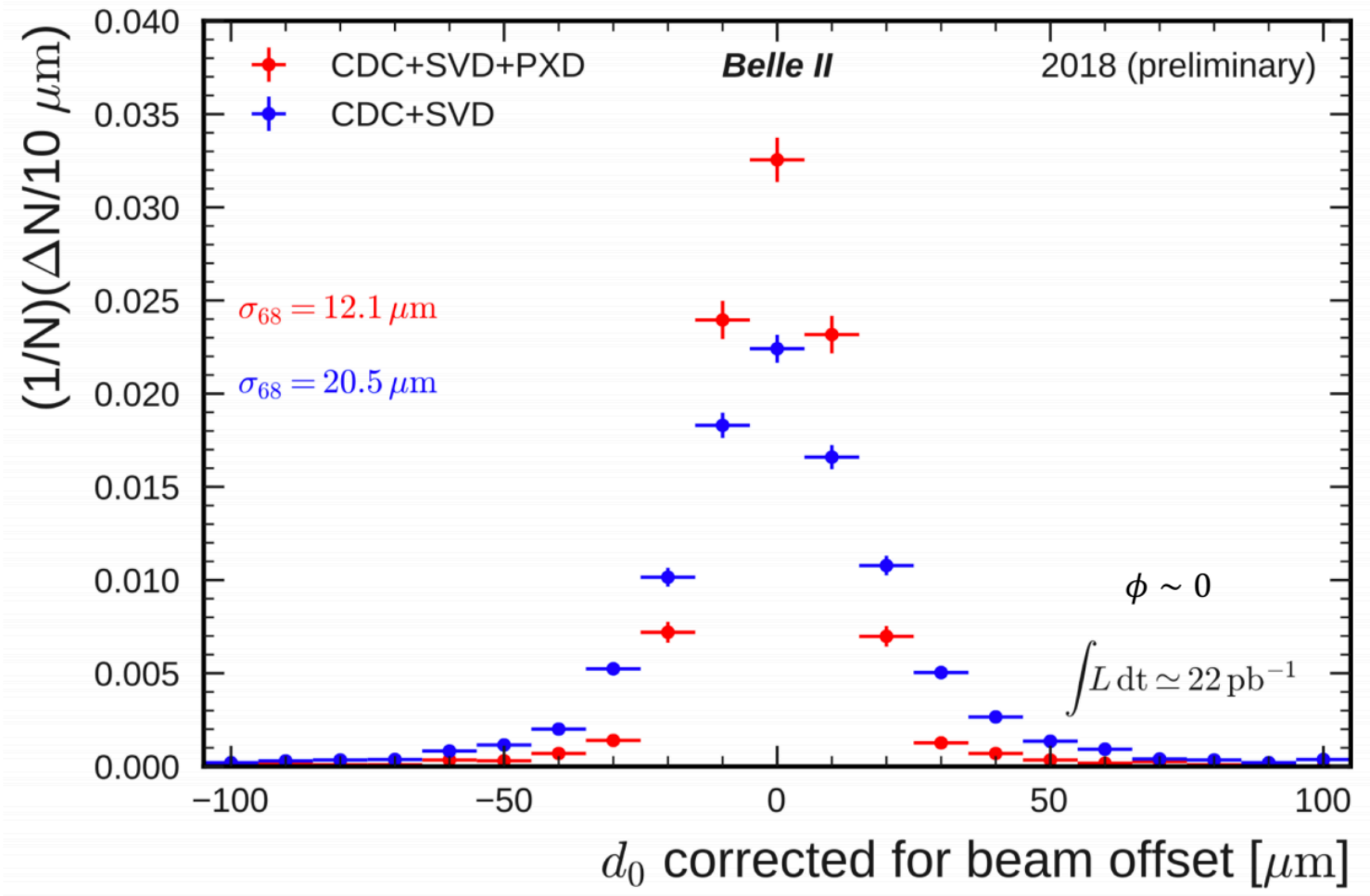




- Photon selection:
  E_9/E_{21} (energy in 9 crystals / energy in 21 crystals) > 0.9

Tracking resolution

BELLE2-NOTE-PL-2018-037



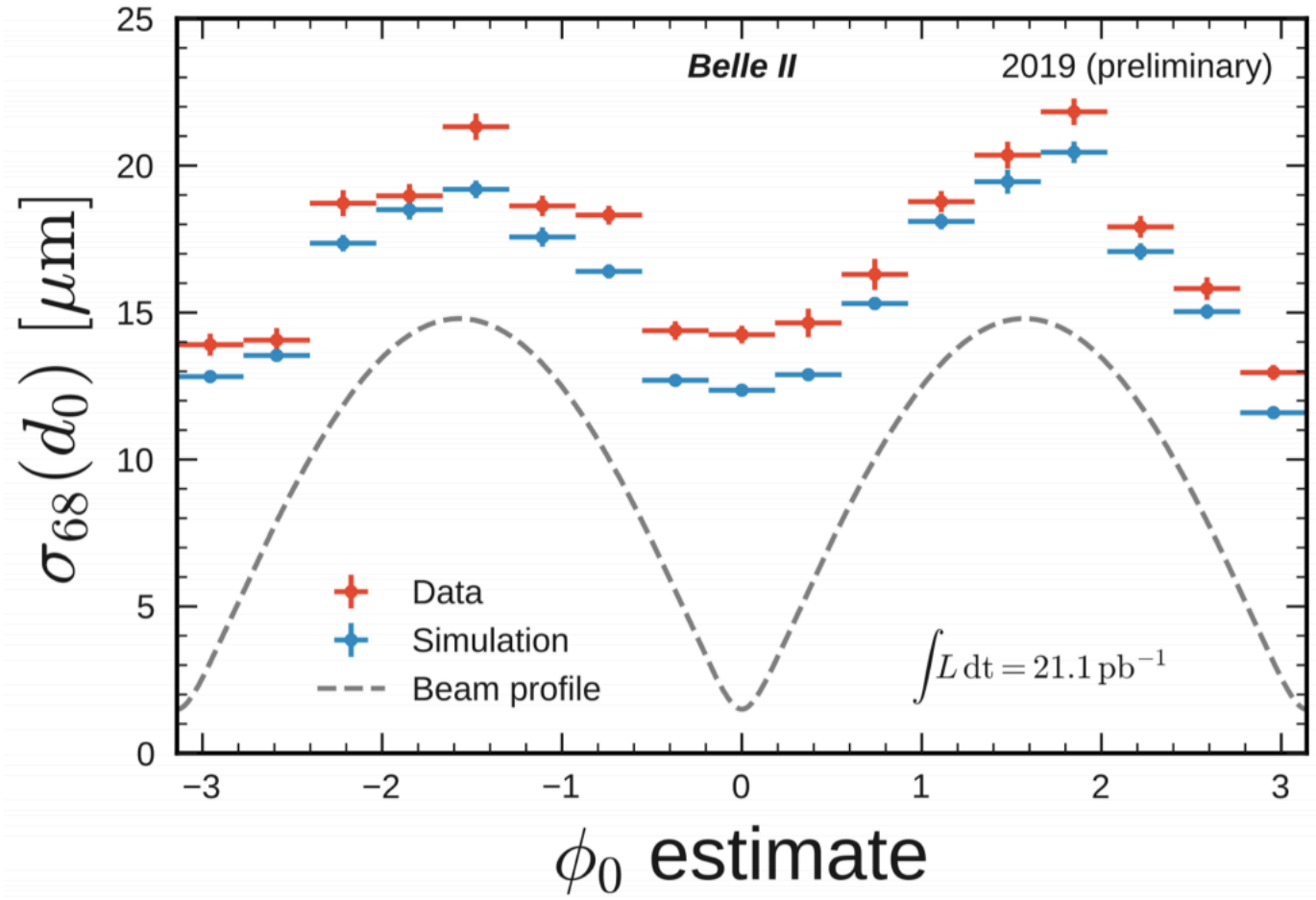
d_0 resolution ~ 12.1 μm in data,
10 μm in simulation

d_0 corrected for beam offset [μm]
= Impact parameter of track wrt. the beam.
Sign(d_0) = sign of track "angular momentum" in $\hat{z}$

Tracking resolution

BELLE2-NOTE-PL-2019-011

Difference wrt. expected beam profile gives the ϕ-dependent detector resolution

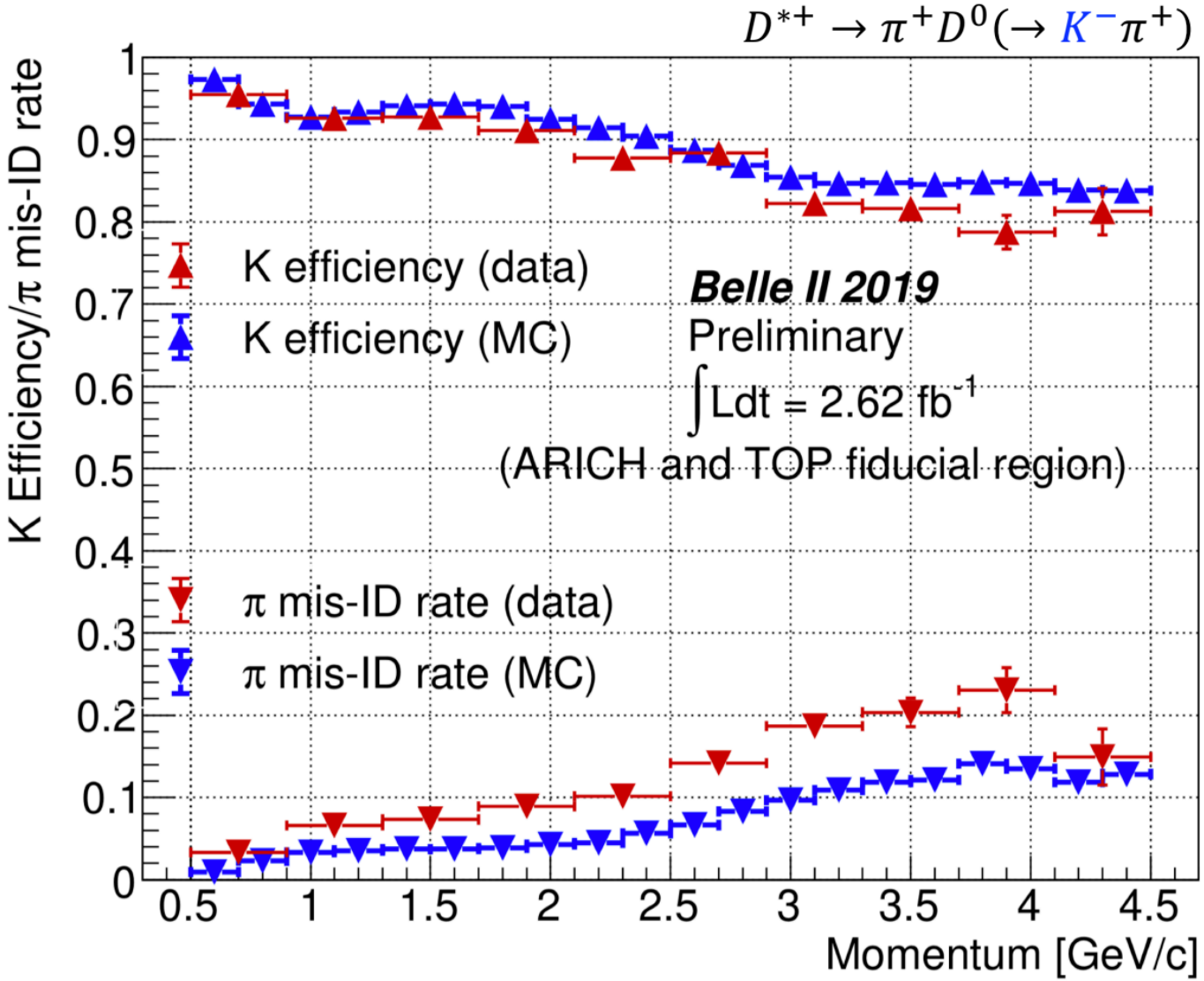


Hadron-ID performance

BELLE2-NOTE-PL-2019-022

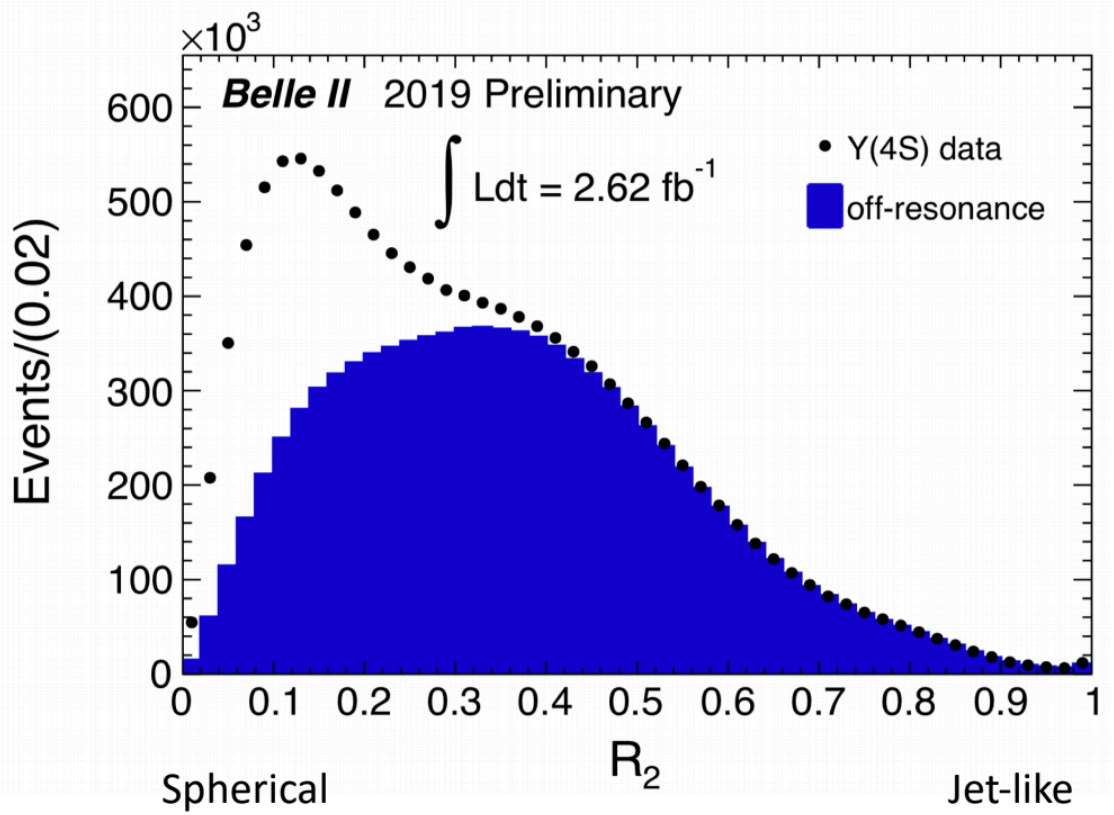
Kaon candidate selection:

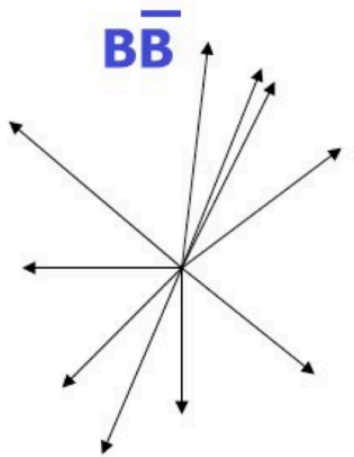
$$\frac{L_K}{L_K + L_\pi} > 0.5$$

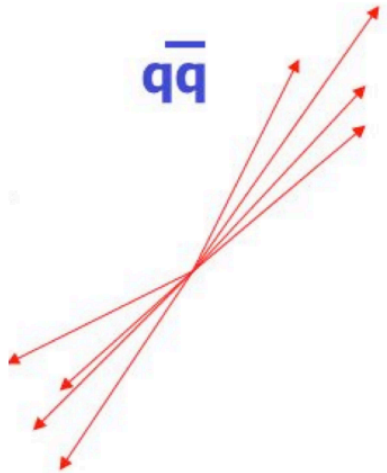


Event Topology tells us we are producing B's

BELLE2-NOTE-PL-2019-017





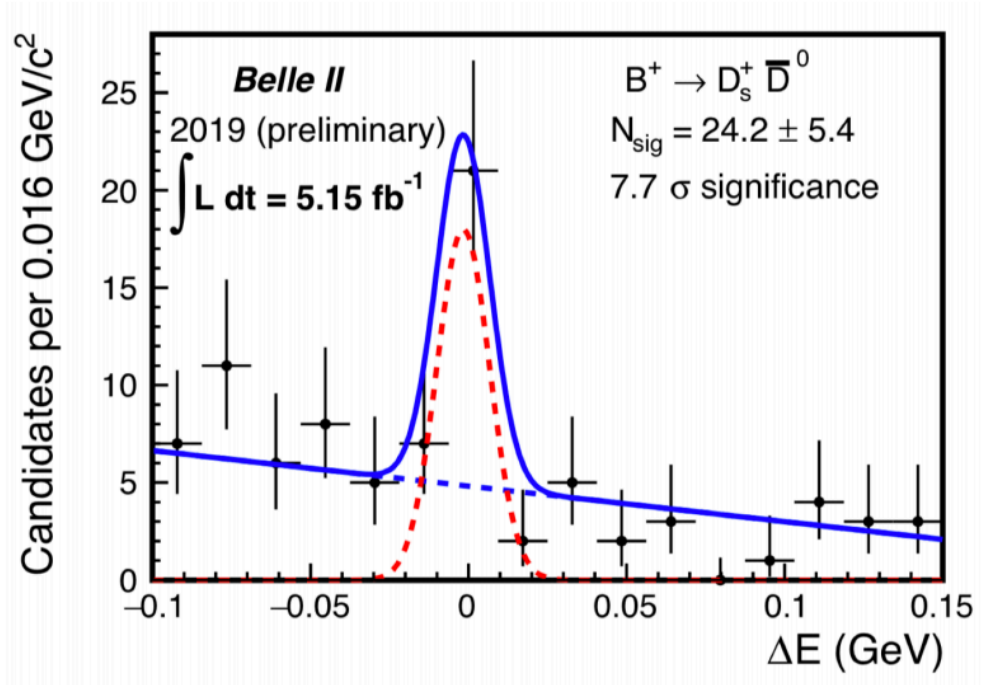


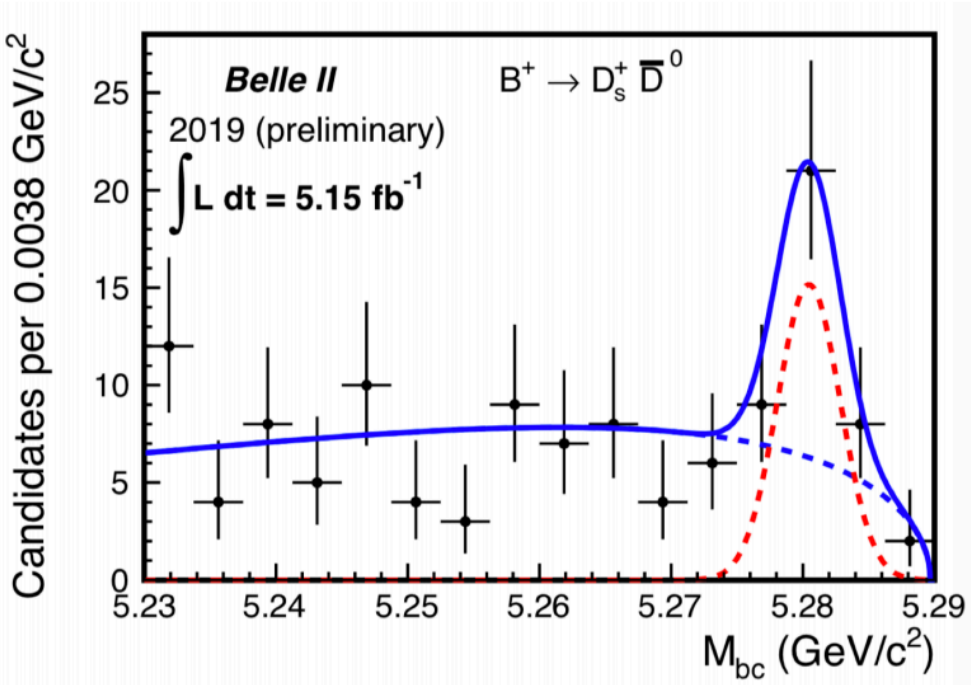
→We are running on the $\Upsilon(4S)$ resonance

B-meson decays

BELLE2-NOTE-PL-2019-026

- $B^+ \to \overline{D}^0 D_s^+$





$$\Delta E \equiv E_B^* - \sqrt{s}/2$$

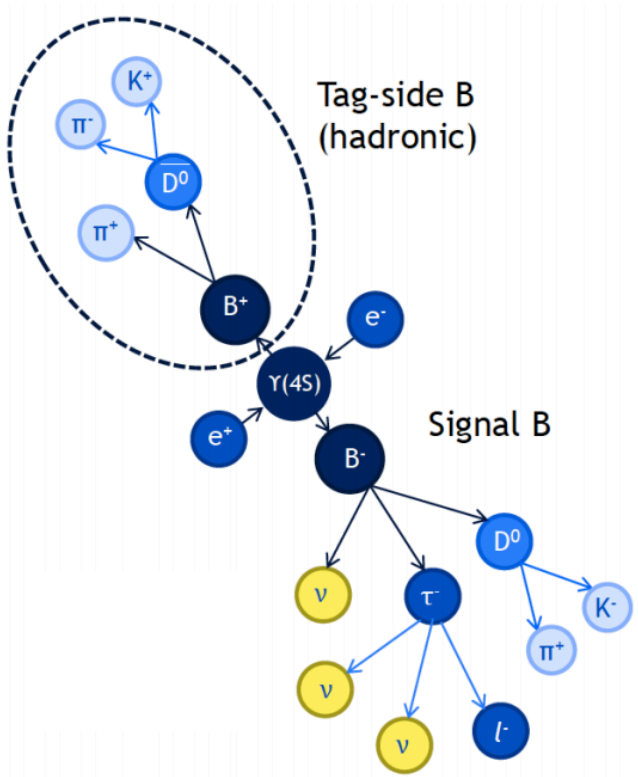
$$M_{bc} \equiv \sqrt{\frac{s}{4} - p_B^{*\,2}}$$

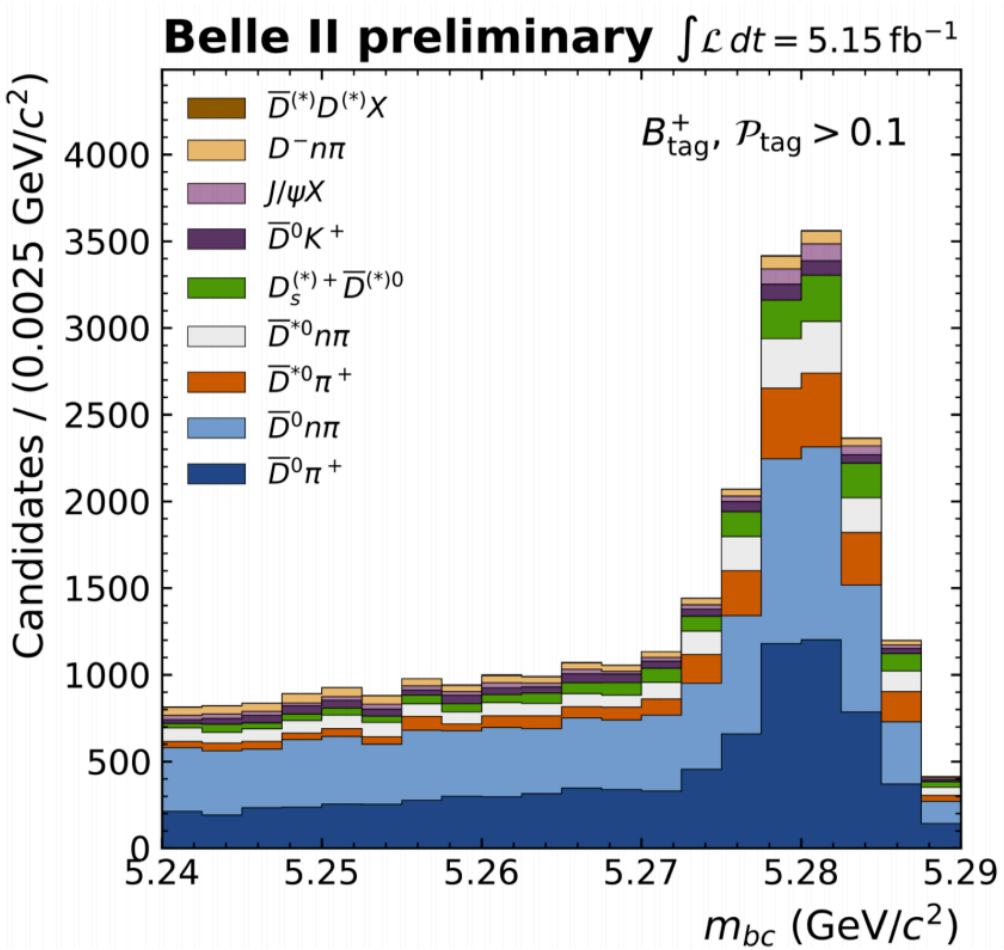
$e^+e^- \to B\bar{B}$ full-event interpretation (FEI)

BELLE2-NOTE-PL-2019-030

Important B-factory technique:

- Reconstruct one the "tag" B meson to detect the "signal" B in multiple-neutrino modes ($B \to \tau\nu$, $D\tau\nu$, $D^*\tau\nu$, $\tau\tau$, $K\nu\bar{\nu}$, $K\tau\tau\ldots$) or inclusive studies ($KX_{c\bar{c}}$, $X_u\ell\bar{\nu}\ldots$)





Expected Luminosity in the Near Term

	Until 2020/7/1				Until 2021/3/31			
	Int. L [fb^{-1}]	L_p [E34]	I_{max} [A]	β_y^* [mm]	Int. L [fb^{-1}]	L_p [E34]	I_{max} [A]	β_y^* [mm]
Base (conservative) plan	100	2.2	0.8	1				
Possible (expected) plan	150	3.5	0.9	1				
Case N1: 6.5 months operation	150	3.5	0.9	1	500	9.5	1.1	0.5
Case N2: 5.4 months operation	150	3.5	0.9	1	320	8.1	1	0.5

Reference: Y. Suetsugu, B2GM, 2020.Feb.03

The Int. L will be **100 - 150 fb^{-1}** until 2020/7/1 (**10%~15%** of Belle), and **320 – 500 fb^{-1}** until 2021/3/31 (**32%~50%** of Belle).

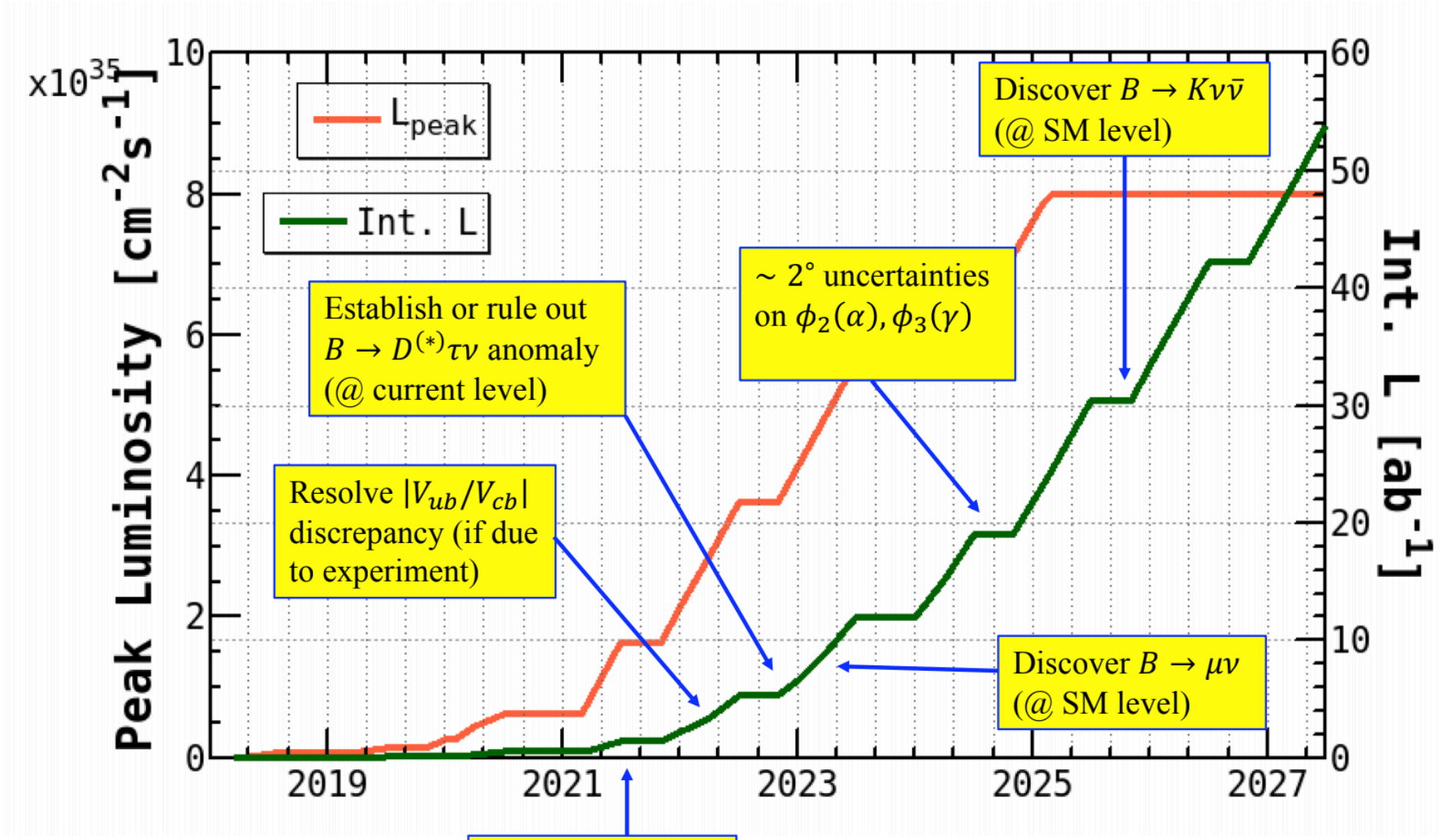
Expected Luminosity in the Middle Term

	Until 2022/3/1				Until 2023/3/31			
	Int. L [ab^{-1}]	L_p [E34]	I_{max} [A]	β_y^* [mm]	Int. L [ab^{-1}]	L_p [E34]	I_{max} [A]	β_y^* [mm]
Case M1: FY2020 6.5 months PXD exc. 2022	1.5	19	1.3	0.3	3.4	26	1.7	0.3
Case M2: FY2020 5.4 months PXD exc. 2021	0.6	16	1.1	0.3	3.4	25	1.6	0.3
Case M3: FY2020 5.4 months PXD exc. 2022	1.2	17	1.2	0.3	2.7	24	1.6	0.3

Reference: Y. Suetsugu, B2GM, 2020.Feb.03

The Int. L will be **0.6 – 1.5 ab^{-1}** until 2022/3/1 (**60%~150%** of Belle), and **2.7 – 3.4 ab^{-1}** until 2023/3/31 (**270%~340%** of Belle).

Guaranteed physics



Prospects of rare B decays at Belle II

- Established or rule out $B \to D^{(*)}\tau\nu$ anomaly
- Discover $B \to \mu\nu$
- Discover $B \to K\bar{\nu}\nu$
- Many more unclear B decays listed in the PDG

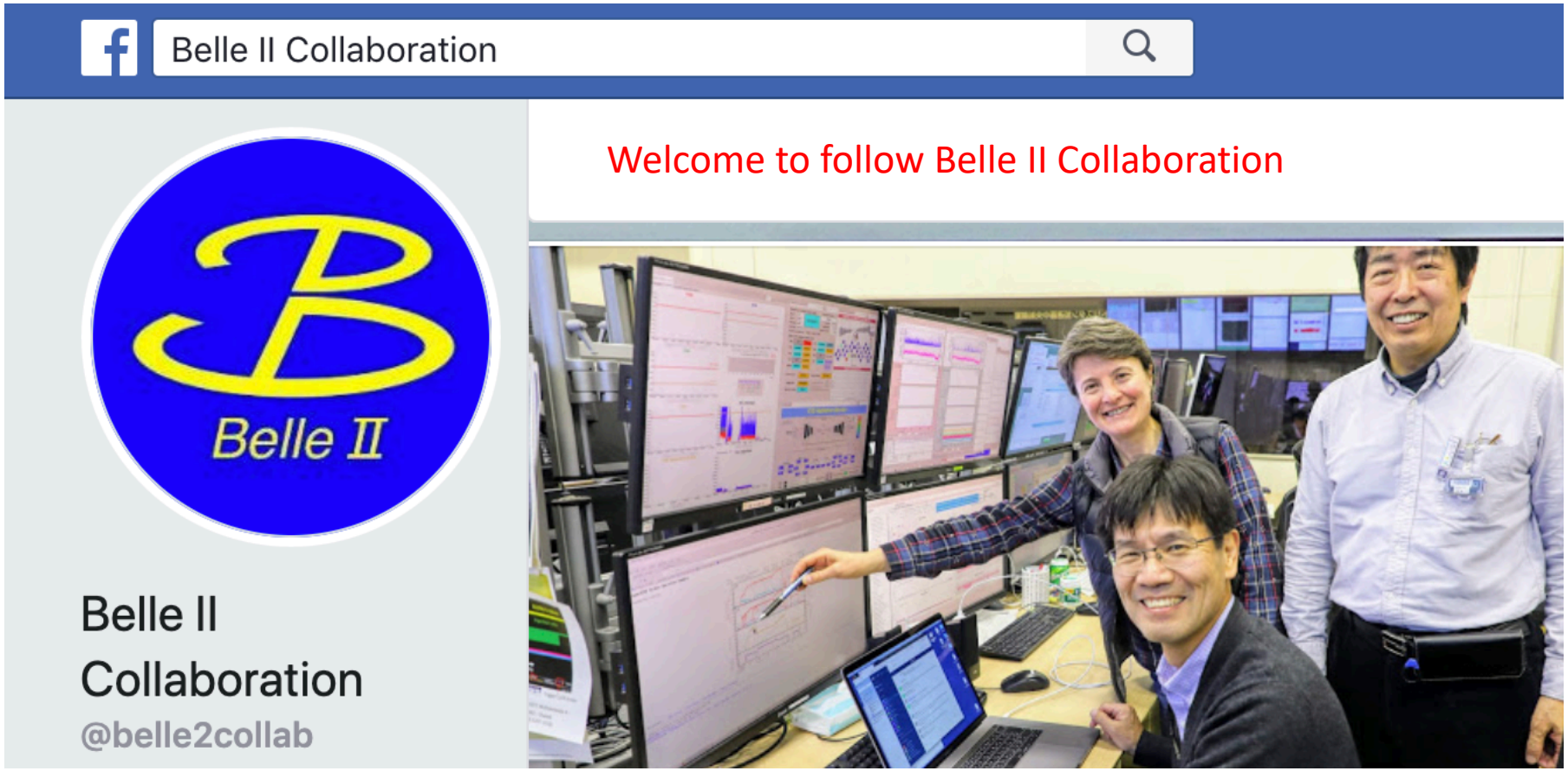
Summary

- Belle II began taking physics data in 2019, involving significant improvements over BaBar and Belle
- Peak luminosity already ~25% that of KEKB
- Integrated luminosity ~5 fb^{-1} used for commissioning and some unique measurements
- Will reach Belle's integrated luminosity in 2022

- The experiment is on its way to groundbreaking measurements

Backup

The new record of the peak luminosity



The photograph indicates the peak luminosity of Belle II experiment reached $\mathbf{105.43 \times 10^{32} / cm^2 / sec}$ in the evening of December 3, 2019. Credit: KEK Outreach Committee.