Status of Belle II

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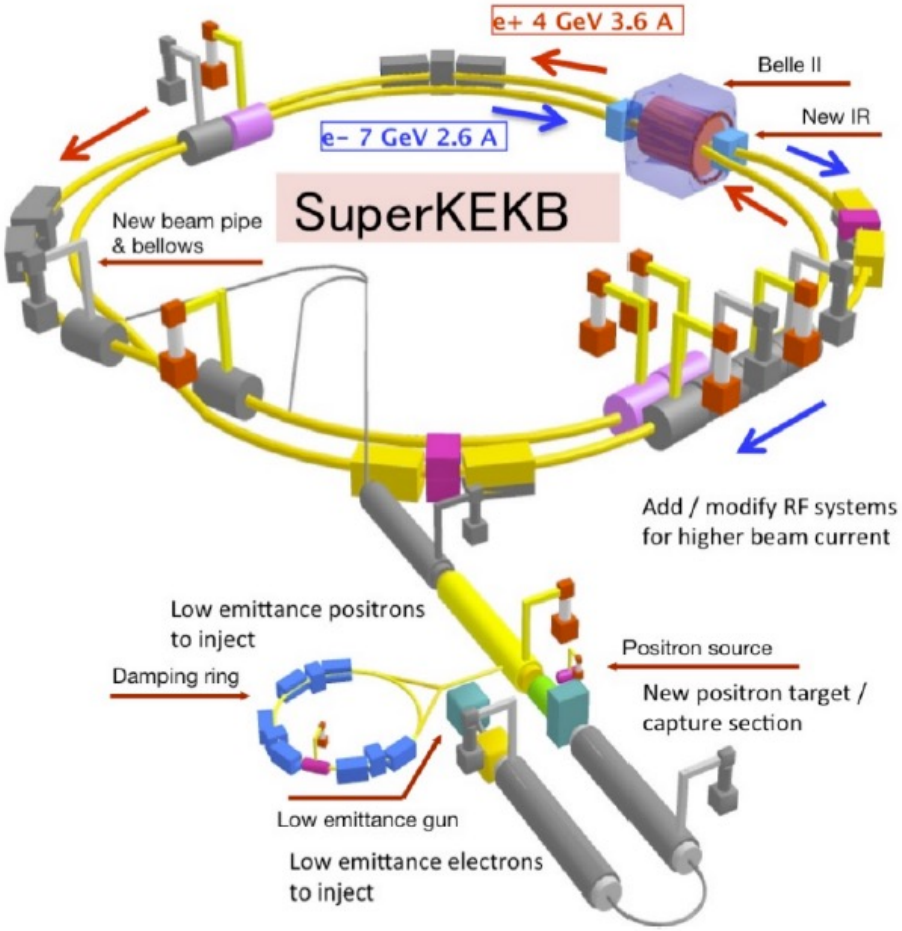
MPI for Physics, Munich, Germany

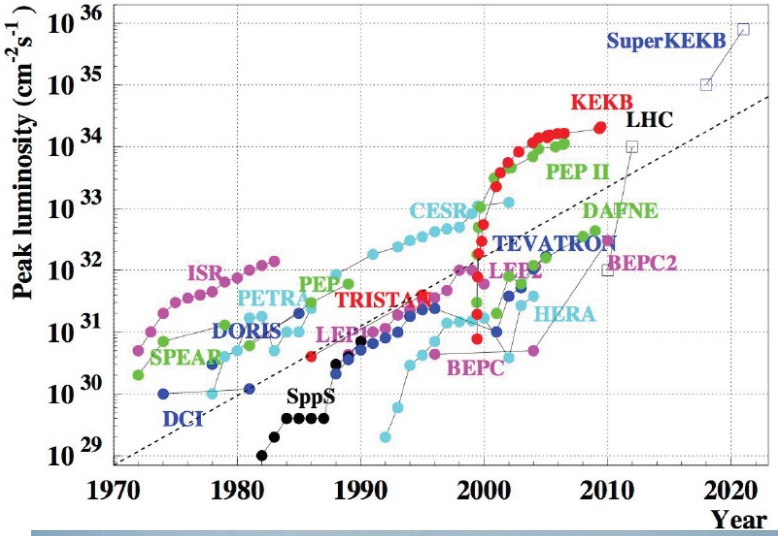
Belle II Germany Meeting, September 20th, 2021

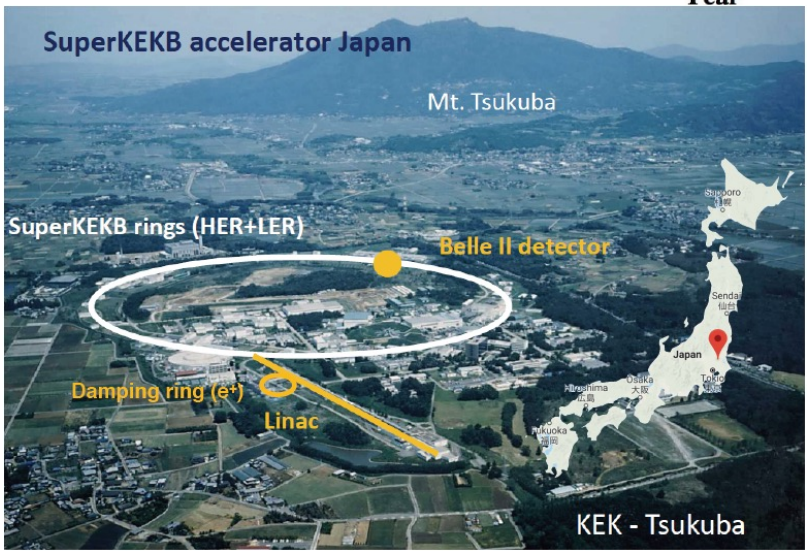
A Super B-Factory

- Belle (KEKB) and BaBar (PEPII), as the first generation of B factory, collected ~1.5 ab^{-1} of Y(4S) data.
- They have impressive discoveries and observations in B physics, charm, τ, exotic particles, dark sector, etc.
- Upgrade to Belle II and SuperKEKB is necessary for the further study of the physics beyond Standard Model.
- B factory advantages:
  - Well defined initial state
  - Low physics backgrounds and higher trigger efficiency
  - Excellent neutral particle reconstruction
  - Can measure absolute branching fractions
  - Etc...

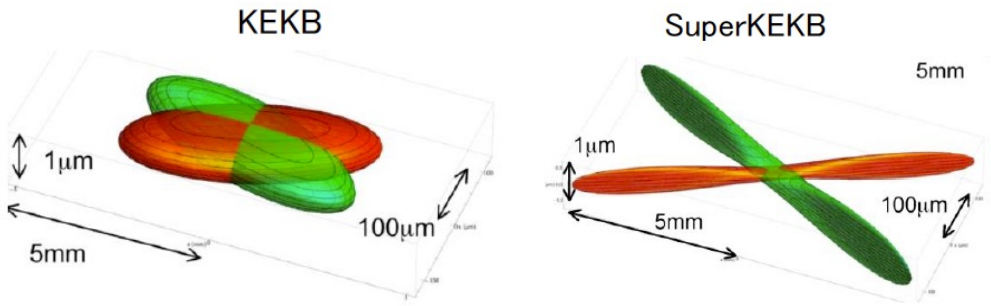
SuperKEKB


e+ 4 GeV 3.6 A
Belle II
New IR
e− 7 GeV 2.6 A
SuperKEKB
New beam pipe & bellows
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring
Positron source
New positron target / capture section
Low emittance gun
Low emittance electrons to inject


Peak luminosity (cm^{-2}s^{-1})
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
1970
1980
1990
2000
2010
2020
Year
SuperKEKB
KEKB
LHC
PEP II
CESR
DAFNE
TEVATRON
BEPC2
ISR
PEP
PETRA
TRISTAN
LEP2
HERA
DORIS
LEP
SPEAR
BEPC
SppS
DCI


SuperKEKB accelerator Japan
Mt. Tsukuba
SuperKEKB rings (HER+LER)
Belle II detector
Damping ring (e+)
Linac
KEK - Tsukuba

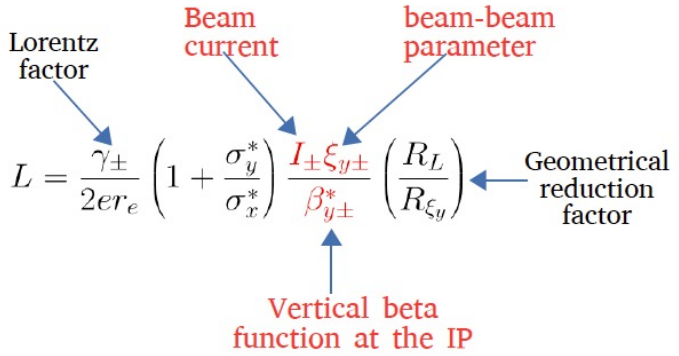
Nano-Beam Scheme



LER / HER	KEKB	SuperKEKB	Effect
Energy [GeV]	3.5 / 8	4.0 / 7.0	boost x 2/3
Crossing angle $2f_x$ [mrad]	22	83	
β_y^* [mm]	5.9 / 5.9	0.27 / 0.30	L x 20
$I_\pm$ [A]	1.64 / 1.19	2.8 / 2.0	L x ~1.5
$\varepsilon_y = \sigma_y \times \sigma_{y'}$ [pm]	140 / 140	13 / 16	
$\xi_y \sim (\beta_y^*/\varepsilon_y)^{1/2} / \sigma^*_x$	0.129 / 0.09	0.09 / 0.09	L x 1
Luminosity [10^{34} cm^{-2} s^{-1}]	2.1	60	L x 30

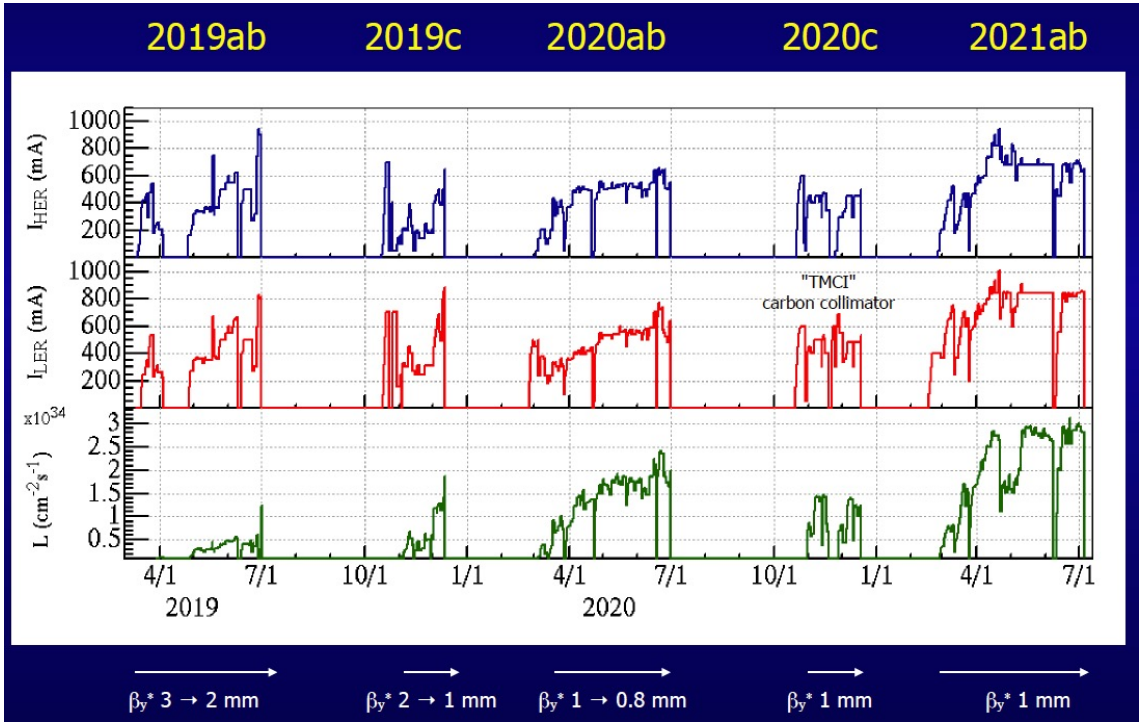
Goals:
Instantaneous lumi.: ~6 x 10^{35} cm^{-2} s^{-1}
Integrated lumi.: 50 ab^{-1}

Challenges:
Much higher backgrounds



SuperKEKB: Current Status

Peak Luminosity: 3.12 x 10^{34} cm^{-2} s^{-1}



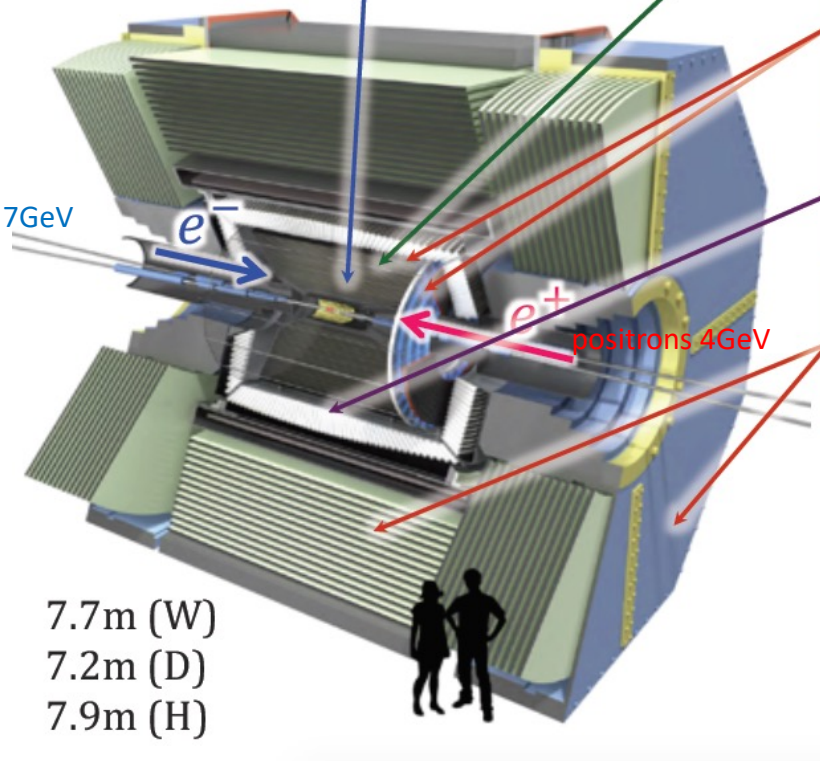
Summary of Phase 3
From Y. Ohnishi

Phase 1:
Feb - June 2016
Background, Vacuum Scrubbing,
RF system
No Belle II

Phase 2:
Feb – Jul 2018
Belle II without VXD
First collisions on Apr. 26, 2018

Phase 3:
Mar 2019 – now and continue
Physics data taking
Full Belle II

Belle II Detectors



Strip and pixel vertex detector
- Inner 2 layers: Pixel detector
- Outer 4 layers: Strip detectors

Drift chamber (p, PID)
- Longer lever arm than Belle
- Smaller cell size than Belle

PID detectors (K/π separation)
- Barrel: Time-Of-Propagation counters
- Endcap: Aerogel RICH
- Wrong PID: x0.5 smaller than Belle

EM calorimeter (E_e, E_γ)
- CsI(Tl) + wave-form sampler

$K_L^0\mu$ detector
- Outer barrel: RPC (streamer mode)
- Endcap, inner barrel: Sci. + WL shifter

Fast and broadband DAQ
- Maximum operable L1 rate: 30 kHz
- Typical data size: 1 MB/event

Trigger system
- Tracking + PID + E_e, E_γ + muon
- L1 trigger latency: 5 μs

Belle II TDR arXiv: 1011.0352

Belle II Collaboration

26 countries/regions, 123 institutions, ~1100 active members

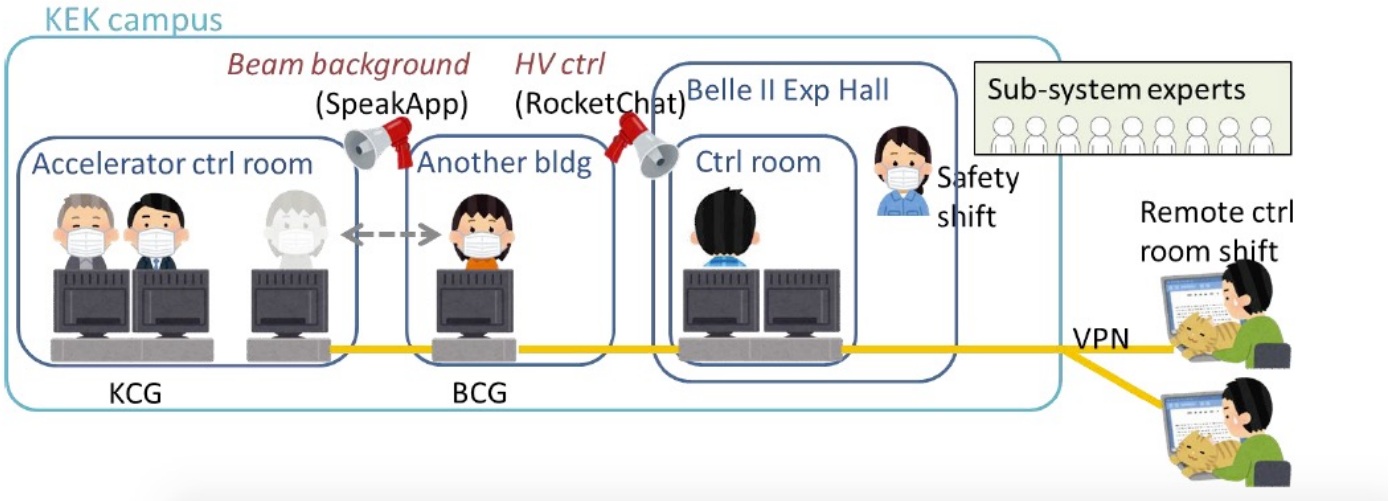
Operation Under COVID-19

Limited number of people (~50) in KEK staying for several months or longer.

- Keep minimizing person-to-person contact, avoiding 3C, and taking hygiene.

Operation by people traveling to KEK in turns → mainly by remote people.

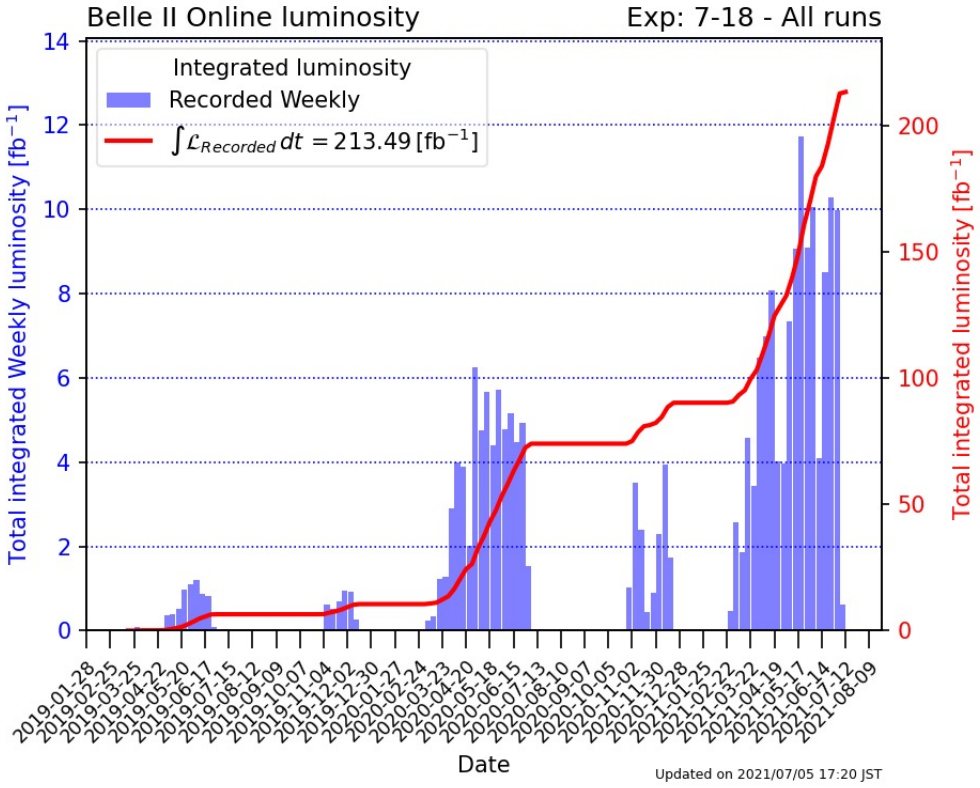
- Control room shift: 2 local → 2 remote + 1 local shifters
  … Remote shifters are actively working, and load on local people has been reduced.
- BCG shift: accelerator control room → another bldg.



From K. Matsuoka

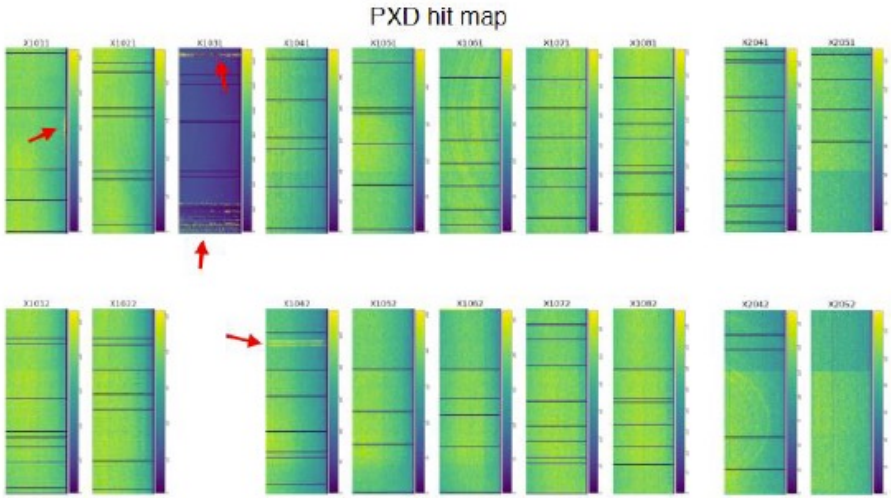
2021ab Run Summary

- L1 NN track trigger since March 20.
- HLT filtering since March 24 (exp 17).
- Pre-scale of L1 Bhabha trigger since April 4 (exp 18).
- Overall data taking efficiency in 2021ab is 89.5% (target is 90%).
- Off-resonance runs: 2.6 fb^{-1} in April and 6.2 fb^{-1} in June.
- Integrated luminosity for 2021ab: 123.17 fb^{-1}
- Total integrated luminosity since phase 3: 213.49 fb^{-1}

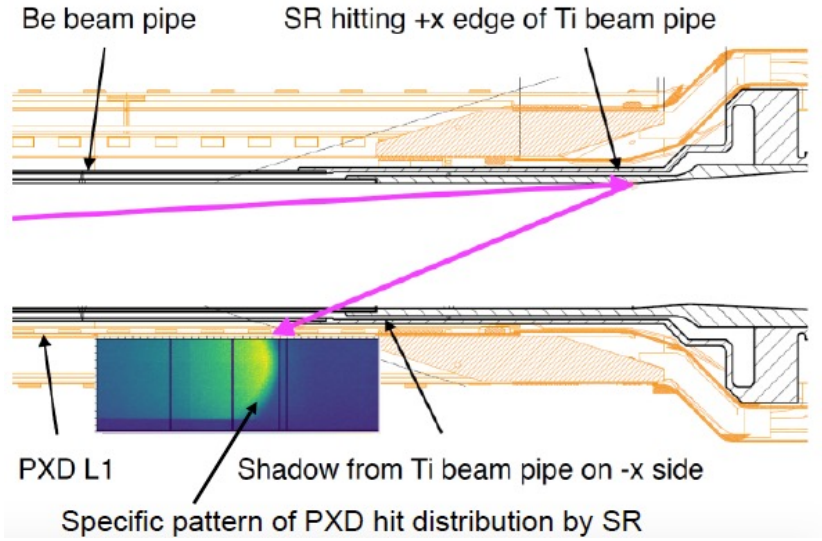


Detector Issues in the Operation

- Detector lifetime (in particular TOP counter)
  - The Touschek and beam gas backgrounds should be kept constant to keep the MCP-PMT QE within an acceptable level.
  - Major limiting factor of the beam current and luminosity.
- Accidental huge beam loss which may cause permanent damages
  - PXD, diamond readout and collimators were damaged by the huge beam loss on May 10.
  - It's still unresolved what caused the huge beam loss.
- Synchrotron radiation from HER on PXD which should be carefully monitored.



Damages on PXD after May 10 beam loss.



From C. Niebuhr

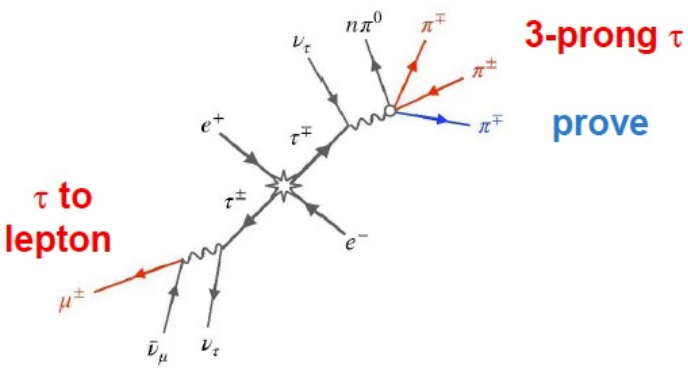
Short Term Run Plan

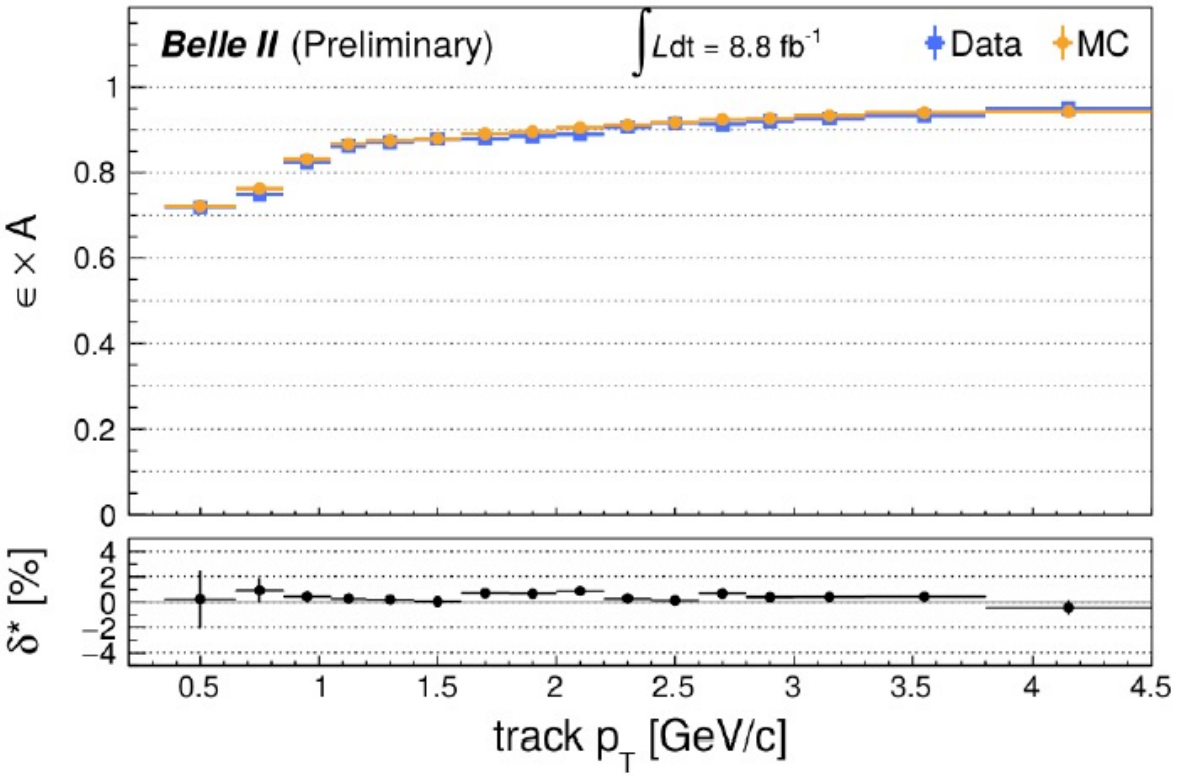
- Collect as much data as possible to produce as many physics results as possible during LS1 in 2022.
  - Should collect at least 424 fb^{-1} in 2021, which equals to BaBar at Y(4S).
- Priority is put on the luminosity rather than the beam background reduction in terms of accelerator tuning and operation.
- Stable operation is necessary to integrate the luminosity, to make progress in the accelerator tuning and to reduce risk of damaging the detectors and machine components.
- Data taking restart at middle of October.
  - Will take data above the Y(4S) resonance for a few weeks.

Detector Performance: Tracking

Tag and probe with $e^+ e^- \rightarrow \tau^+ \tau^-$

- Identify leptons on the tag side
- Probe 3-prongs on the signal side
- Count the events where an additional prove track is found (N4) or not (N3).
- $\varepsilon \cdot A = N4 / (N4 + N3)$
- ε: tracking efficiency, A: detector acceptance.

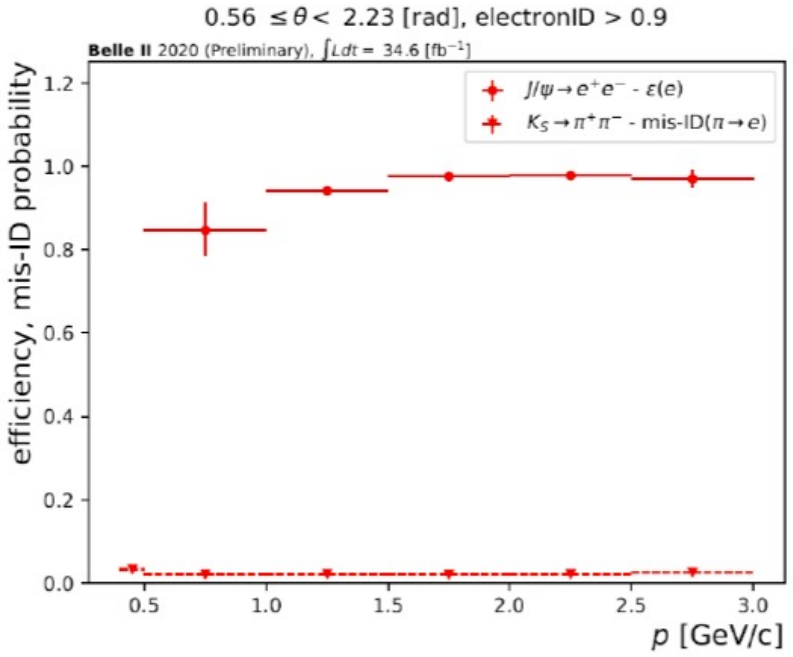


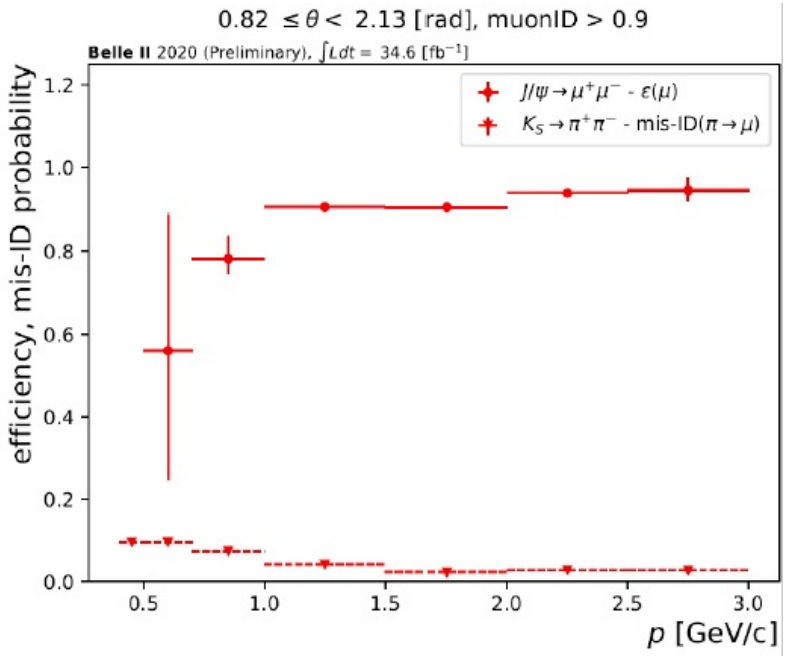


Detector Performance: Lepton PID

- Using fully reconstructed events: $J/\Psi \rightarrow e^+ e^-$, $\mu^+ \mu^-$
- Identification driven by K_L-μ detector (KLM), EM calorimeter (ECL) and dE/dx from central drift chamber (CDC) and vertex detector (VXD).
- The information for each PID detector defines a likelihood for each particle hypothesis. The global PID is defined as:

$$\ell\mathrm{ID} = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$

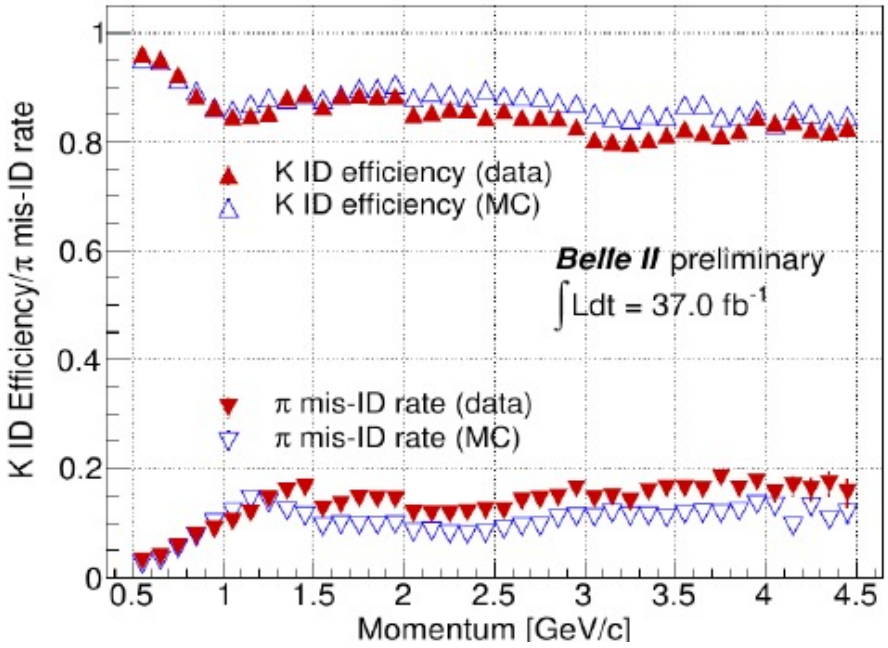


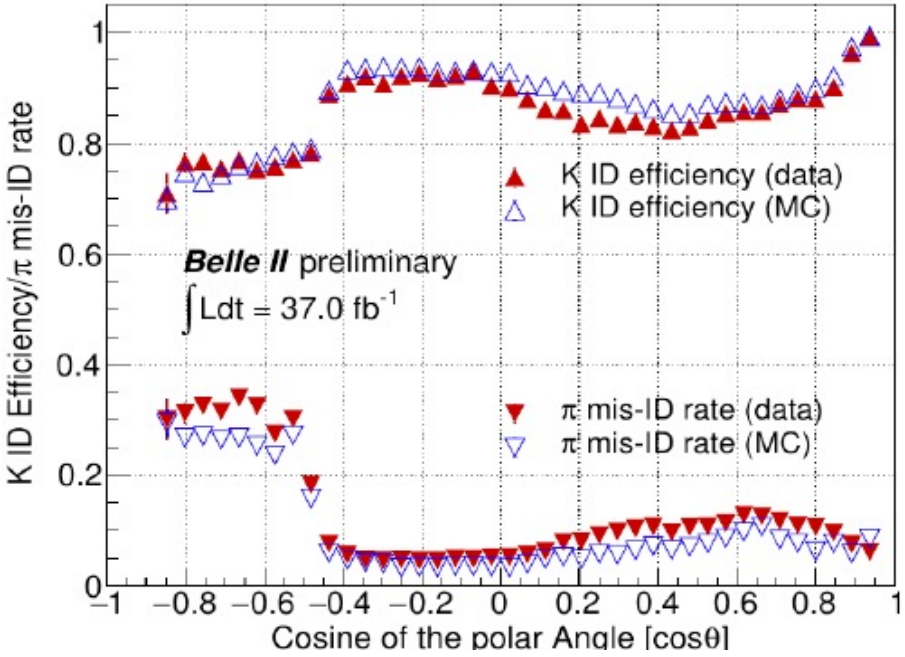


Detector Performance: Hadron PID

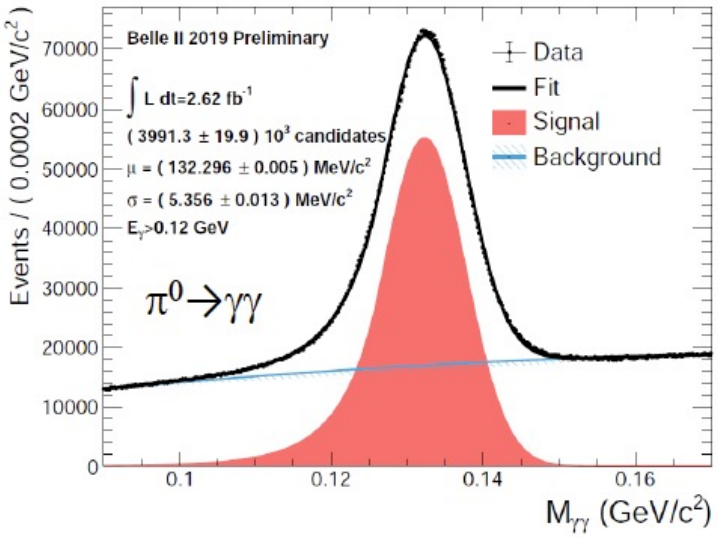
- Using fully reconstructed event: $D^{*+} \to D^0 [K^-\pi^+] \pi^+$
- Identification driven by PID detectors (TOP and ARICH), dE/dx from CDC and VXD.
- The K-π ID is defined as:

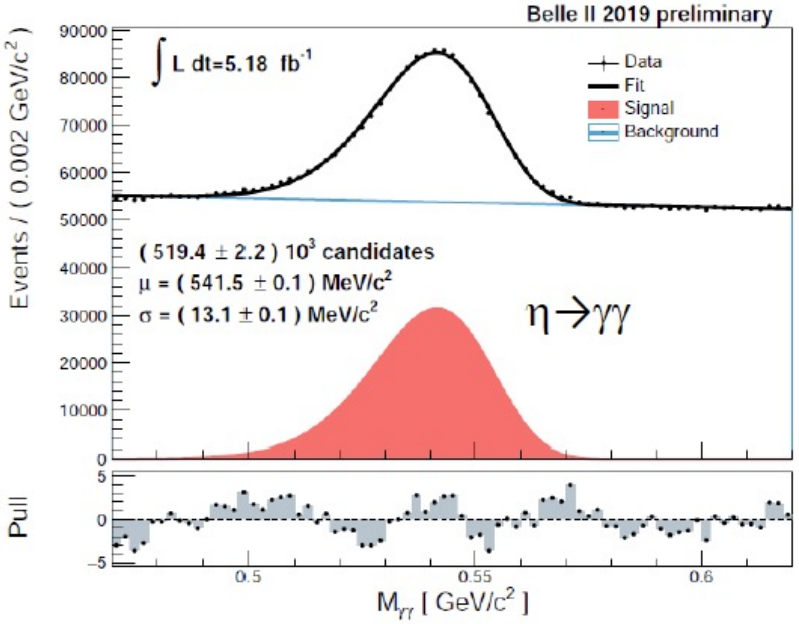
$$K/\pi\text{-ID} = \frac{\mathcal{L}_{K/\pi}}{\mathcal{L}_K + \mathcal{L}_\pi}$$

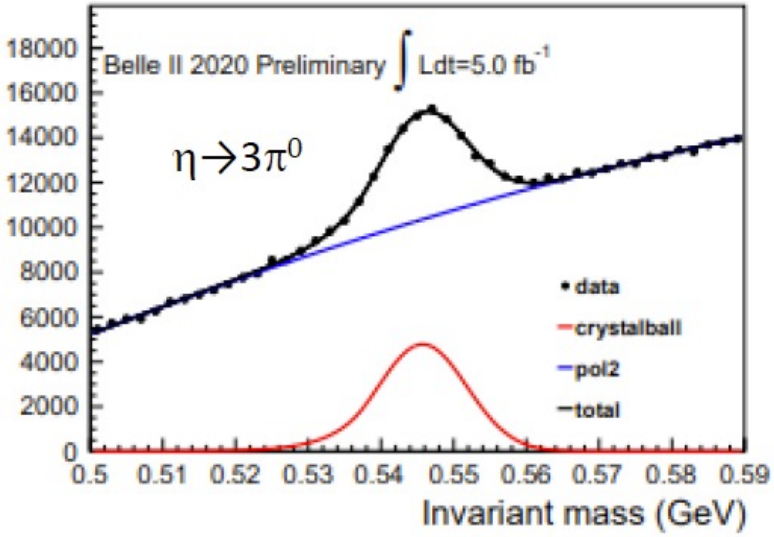




Detector Performance: Neutrals



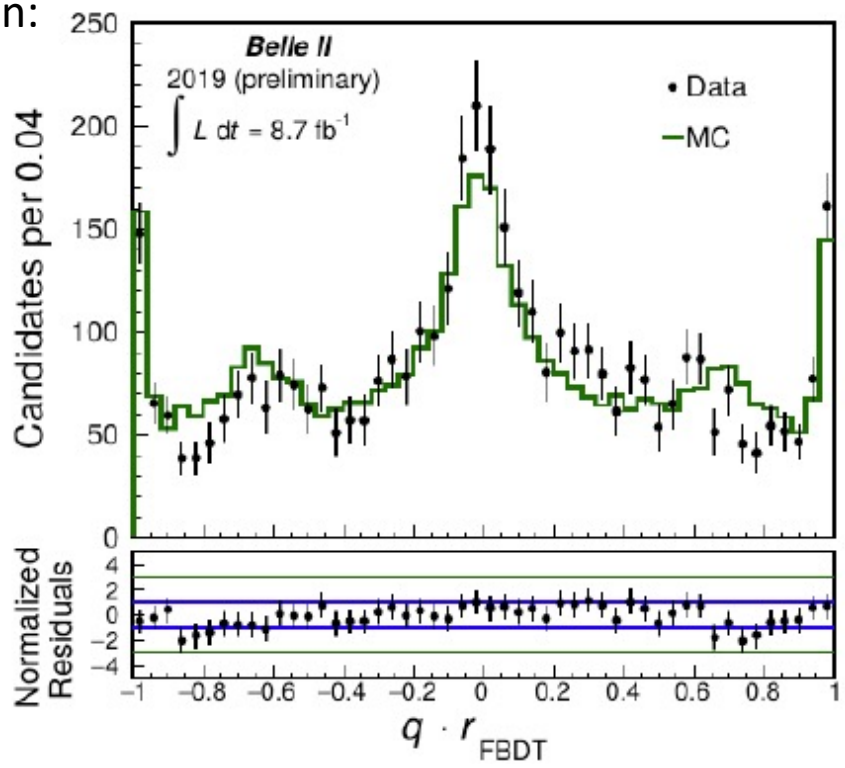


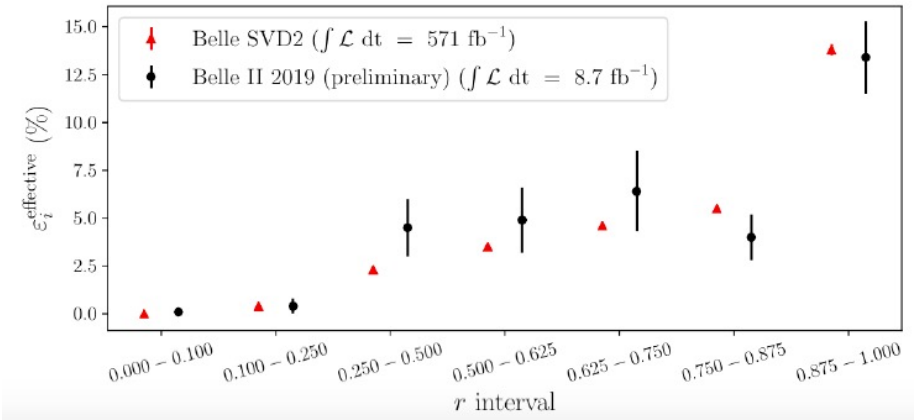


- Better reconstruction due to large solid angle and good uniformity of the detectors
- It's possible to recover Bremsstrahlung photon and detect isolated ISR/FSR.

Detector Performance: Flavor Tagging

- The flavor tagger identifies the tag-side B meson: B^0_{tag} or $\overline{B}^0_{tag}$
- It's crucial for the time dependent CPV measurement
- MVA algorithm combines information from various particles not associated with signal and returns flavor (q) and dilution factor (r).
- Effective flavor tagging efficiency of neutral B: 33.8 ± 3.6(stat) ±1.6(syst) %.
- The efficiency on Belle is 30.1 ± 0.4 %.
- Expectation: ~37% based on MC.
- Published on arxiv: 2008.02707.

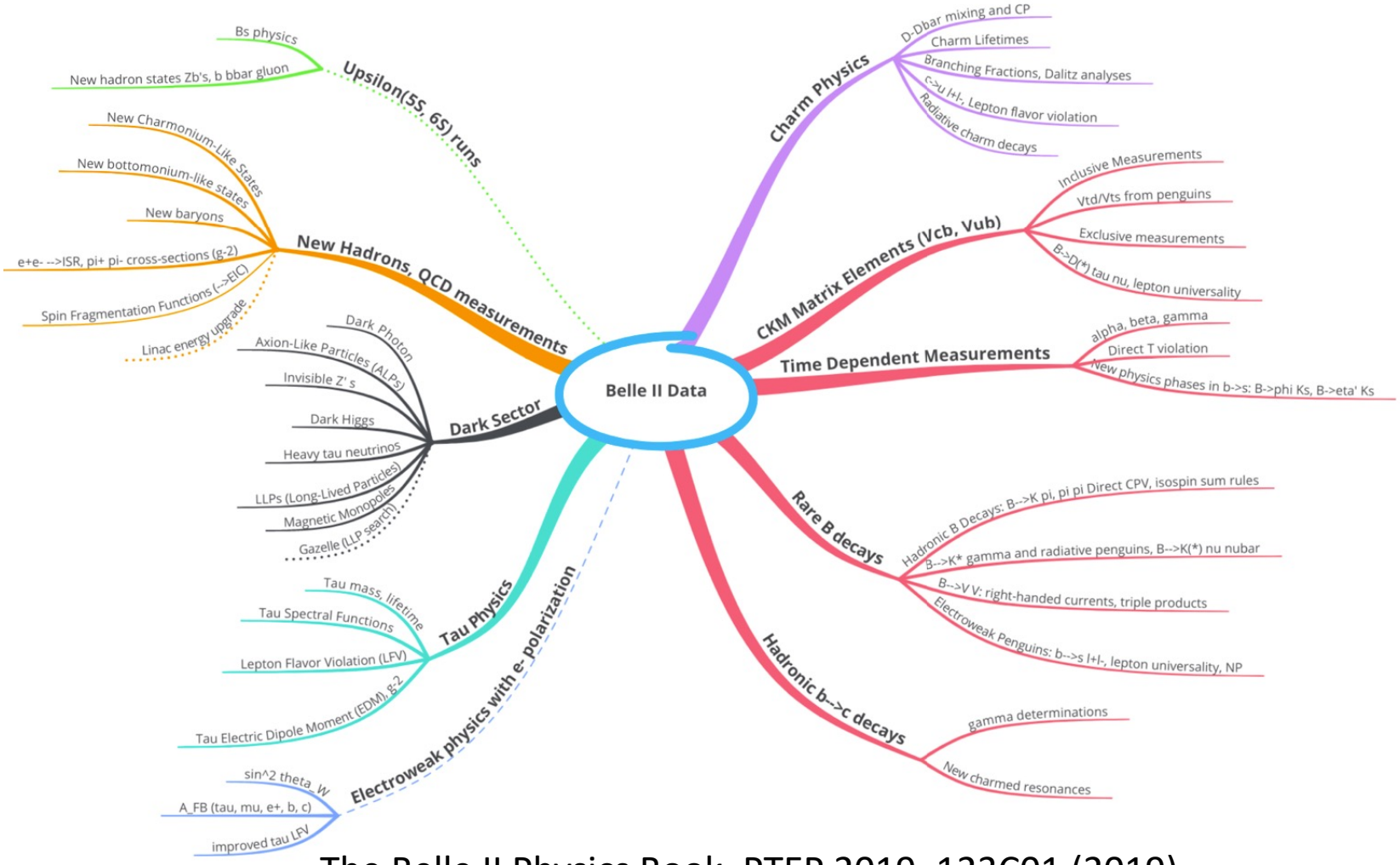




$$\varepsilon_{\text{eff}} = \sum_i \varepsilon_{\text{eff},i} = \sum_i \varepsilon_i \cdot (1 - 2w_i)^2$$

w_i: wrong tagging fraction

Belle II Physics “Mind Map” for Snowmass 2021



The Belle II Physics Book, PTEP 2019, 123C01 (2019)
Snowmass LOIs: confluence.desy.de/display/BI/Snowmass+2021

Status of Belle II Physics

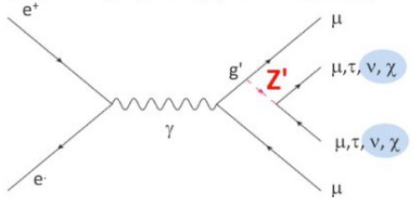
- Three papers have been published or accepted and one more has been submitted (see following slides).
- More studies are under active development:
  - Measurement of CKM elements.
  - Time dependent CPV and mixing.
  - Full event interpretation.
  - Charmless 2-body decays.
  - Probing the Kπ puzzle.
  - Measurement of τ mass.
  - The $R(D^*)$ anomaly.
  - Etc.
- Some of the topics will be covered by talks in the following physics analysis session.

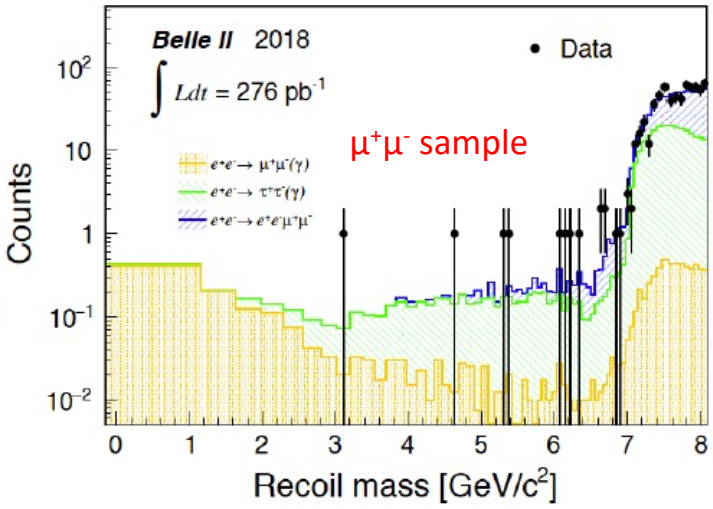
Z’ → invisible

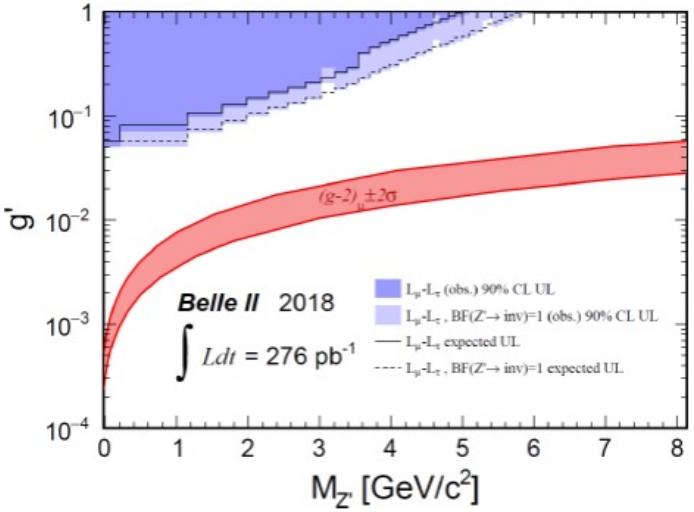
Phys. Rev. Lett. 124, 141801 (2020)
First Belle II physics paper

$L_\mu - L_\tau$ model

$e^+e^- \to \mu^+\mu^- Z'$, $(Z' \to \text{invis.})$

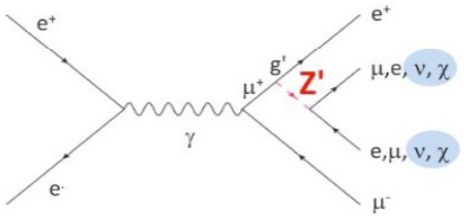


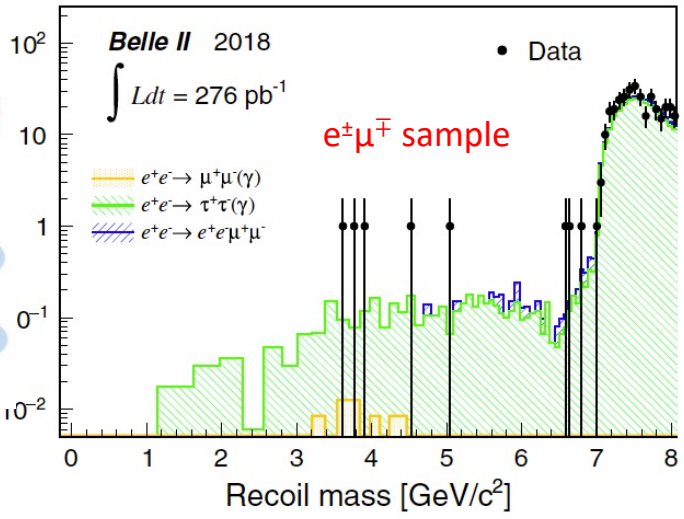


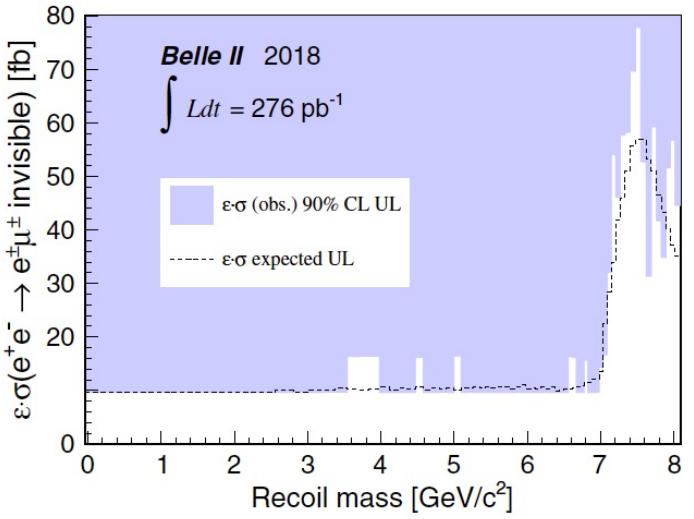


LFV scenario (e - μ coupling)

$e^+e^- \to e^\pm\mu^\mp Z'$, $(Z' \to \text{invis.})$



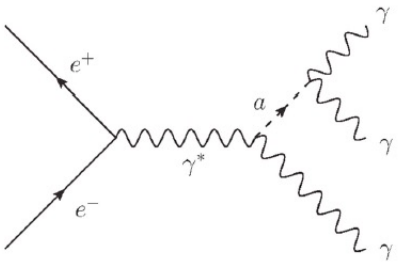


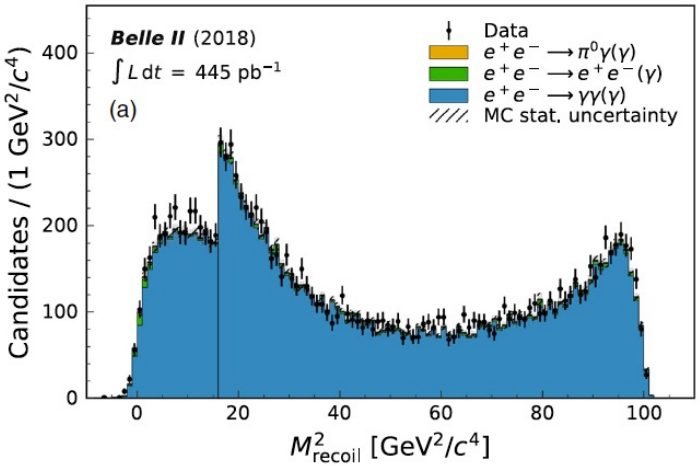


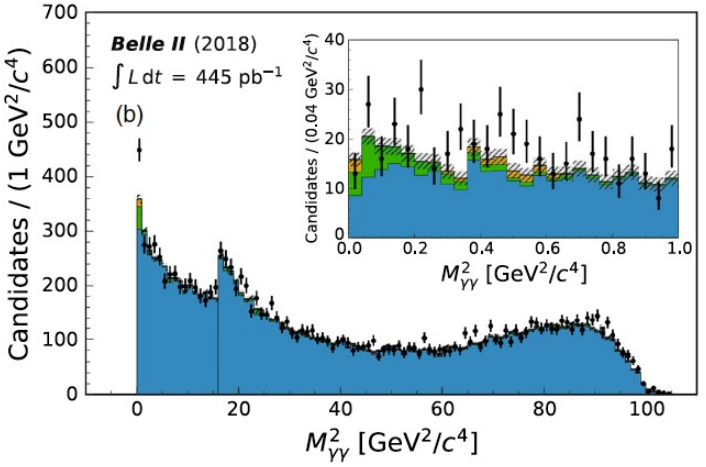
No significant excess in both scenario.

Axion Like Particle

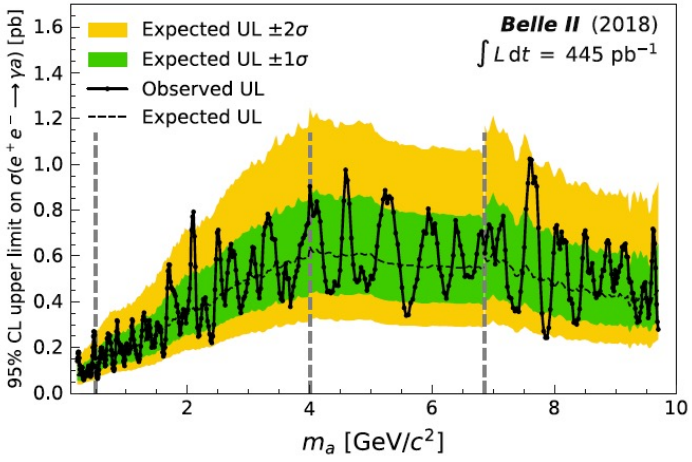
Phys. Rev. Lett. 125, 161806 (2020)
Second Belle II physics paper

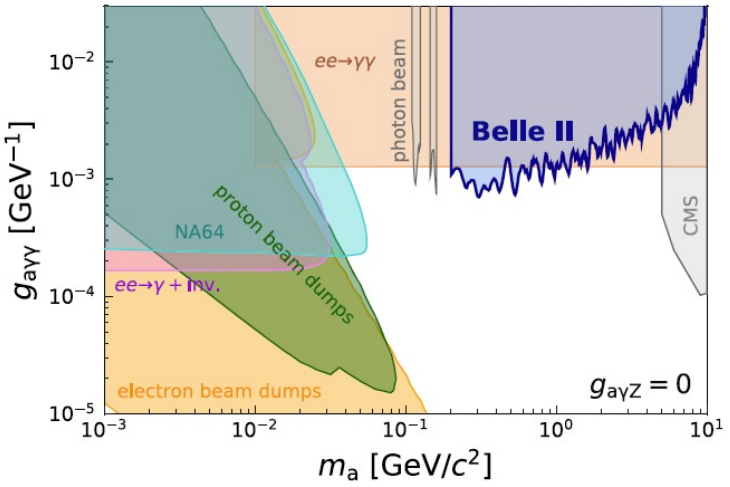






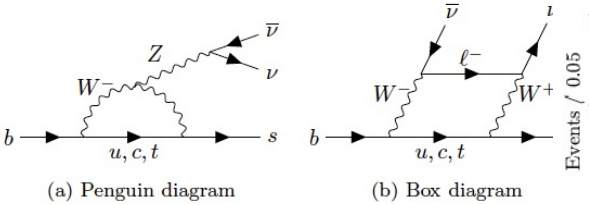
- Axion like particles at low mass are cold dark matter candidates
- Search for 3-photon final states either in:
  - Recoil invariant mass
  - Di-photon mass
- No significant excess.
- Best limits for $0.1 < m_a < 5$ GeV/c^2.

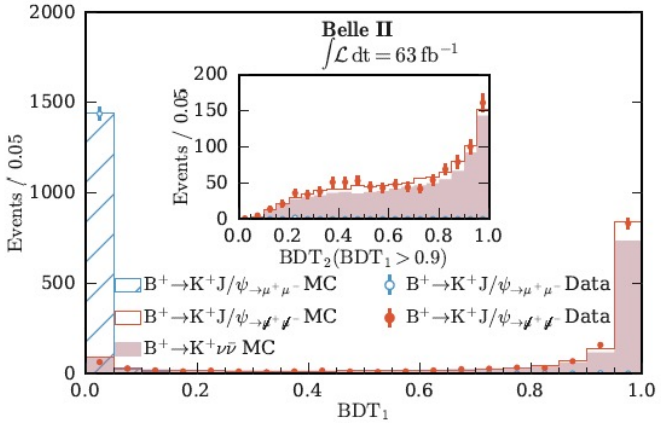


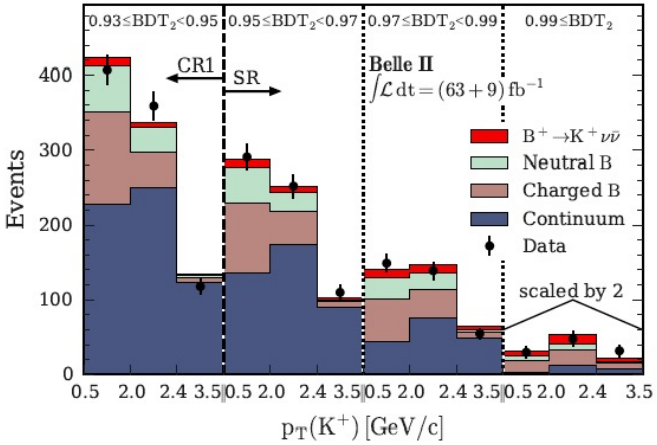


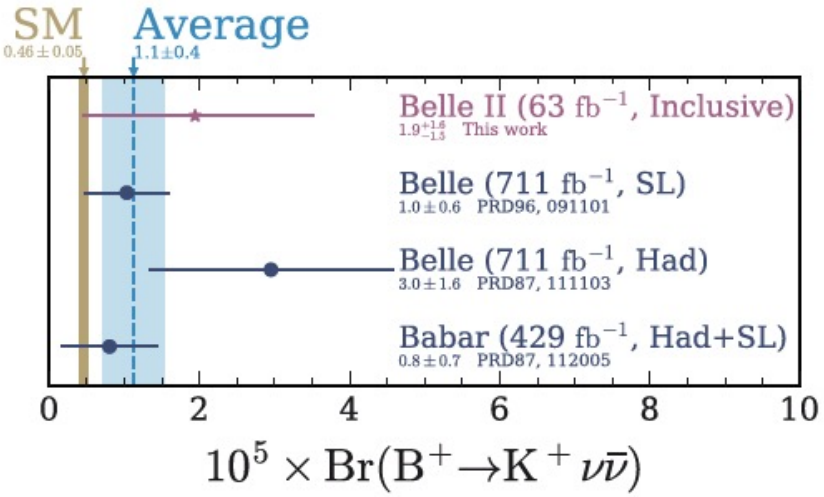
$B^+ \to K^+ \nu\bar{\nu}$

arXiv: 2104.12624
Accepted by PRL
Third Belle II physics paper





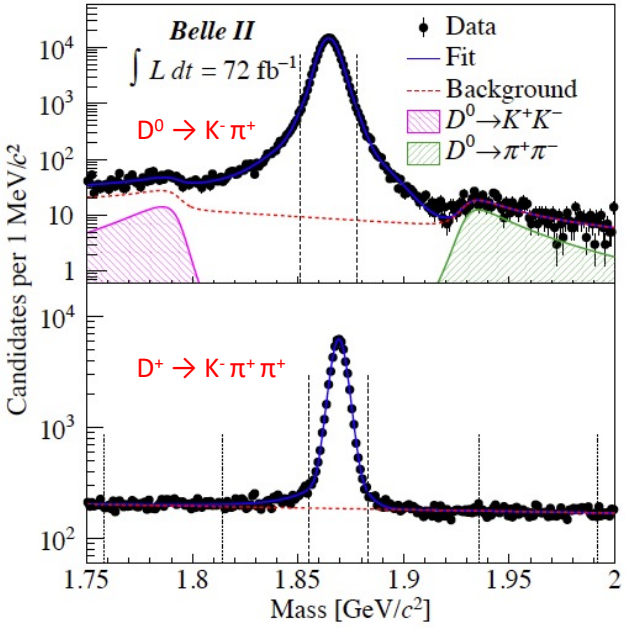


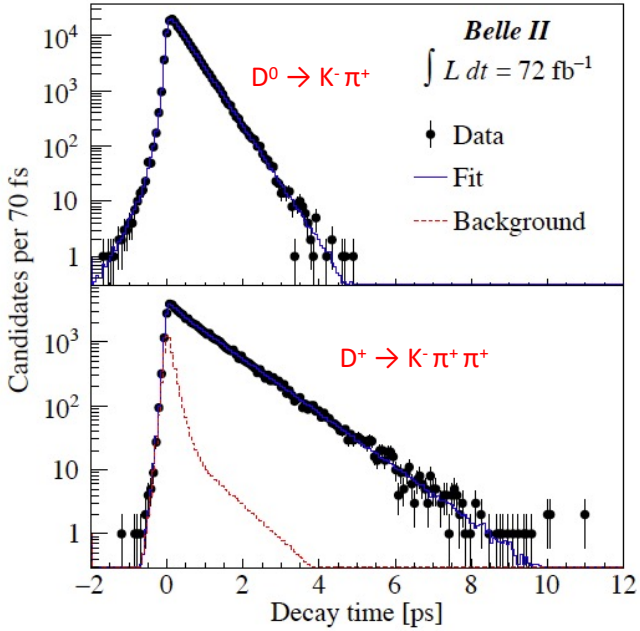


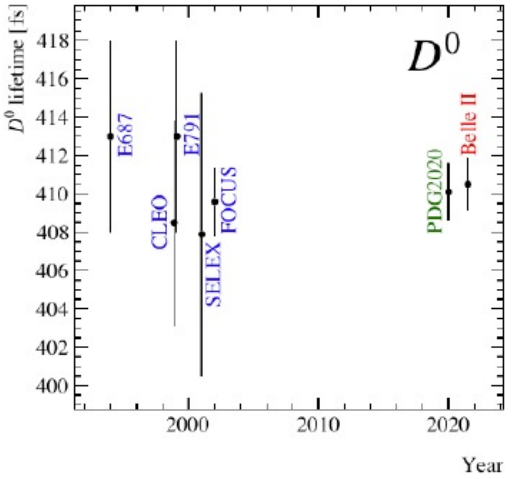
- Flavor Changing Neutral Current process.
- SM prediction: (4.6 ± 0.5) x 10^{-6}.
- Use inclusive tagging method. BDT is used for signal selection.
- ~20x higher signal efficiency than before.
- No significant signal is observed. 90% CL upper limit: 4.1 x 10^{-5}.
- Further improvements need more data, additional channels and improved classifiers.

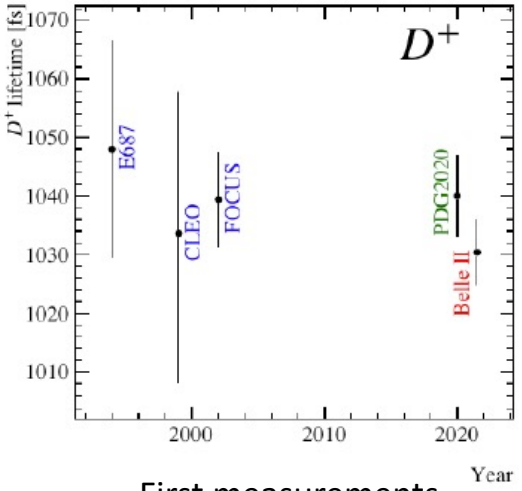
D^0 and D^+ Lifetime

arXiv: 2108.03216
Submitted to PRL









First measurements in ~20 years

World Average

$\tau(D^0) = 410.5 \pm 1.1\,(\text{stat}) \pm 0.8\,(\text{syst})$ fs (410.1 ± 1.5) fs

$\tau(D^+) = 1030.4 \pm 4.7\,(\text{stat}) \pm 3.1\,(\text{syst})$ fs (1040 ± 7) fs

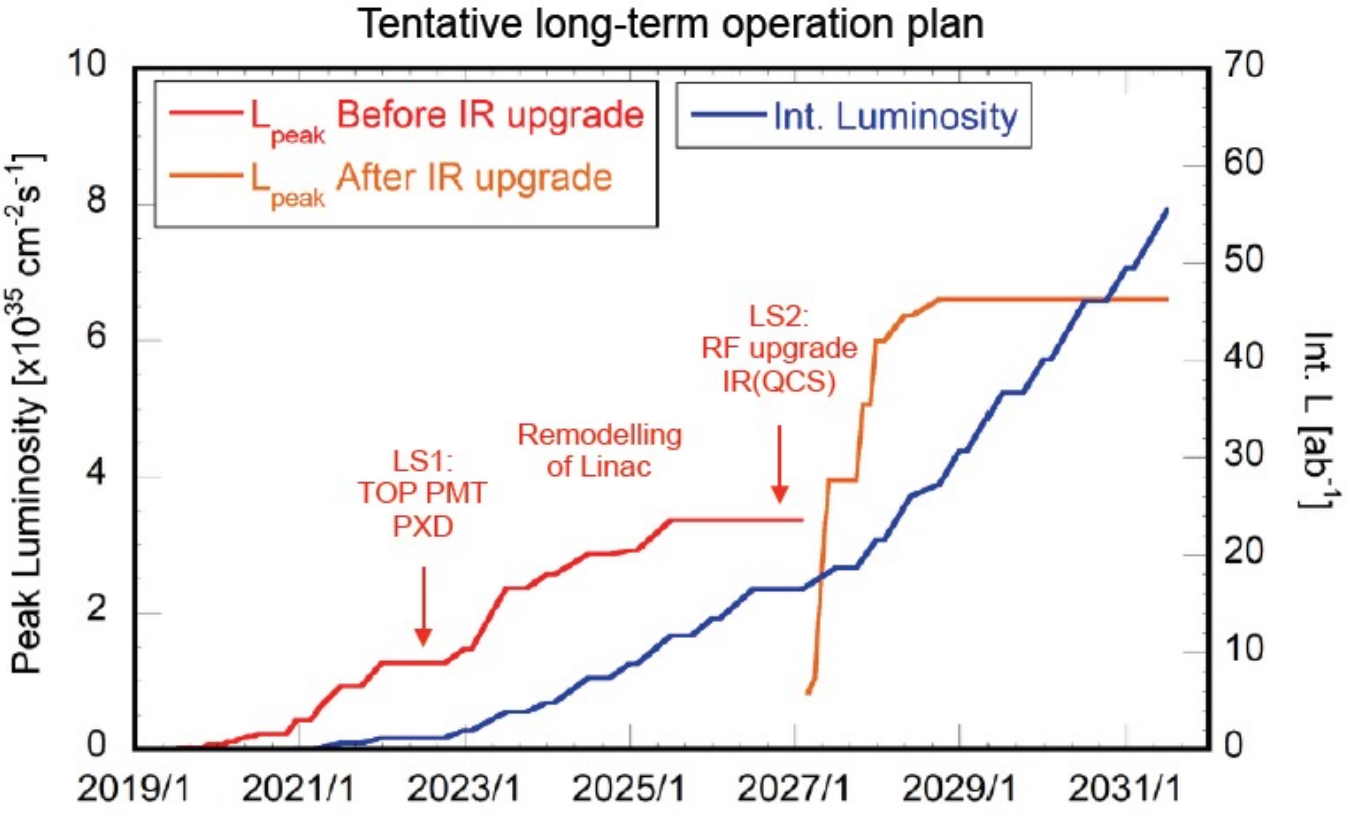
Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total	0.80	3.10

Most precise results to date.
Limited by statistical uncertainty.
Dominant systematics:

- Detector alignments
- Modeling of the background

Belle II & SuperKEKB Prospects

- LS1 in 2022 for PXD and TOP MCP-PMT replacement.
- A possible IR upgrade after 2026.
- Inaugurate an international taskforce of accelerator experts to pursue effective measures for recovering the luminosity profile and reaching target luminosity.



Summary

- Since the start of phase 3 in 2019, SuperKEKB has set a new world record in peak luminosity at 3.12 x 10^{34} cm^{-2} s^{-1} in 2021.
- Belle II has accumulated ~213 fb^{-1} of collision data.
- The Belle II detectors is performing very well.
- Several very promising physics results have been produced with Belle II data.
- More physics results will come out with more data in the future of Belle II.