The SuperKEKB and Belle II Status

Doris Yangsoo Kim
Soongsil University

April 23, 2021

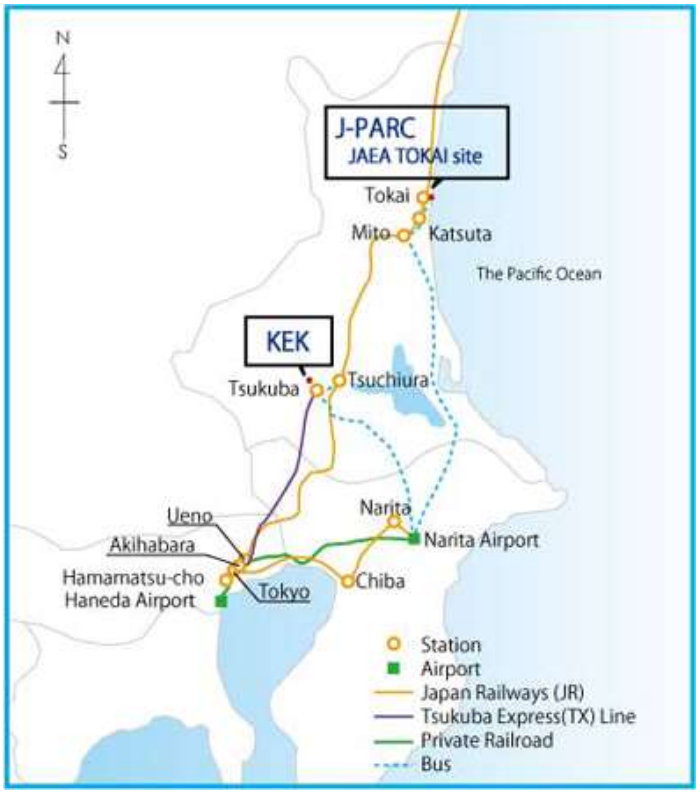
Korean Physical Society (Virtual) Spring Conference

Focus Session

Contents

- The SuperKEKB Collider
- The Belle II Experiment
- The First Physics Results from Belle II
- Summary

KEK
(High Energy Accelerator Research Organization)



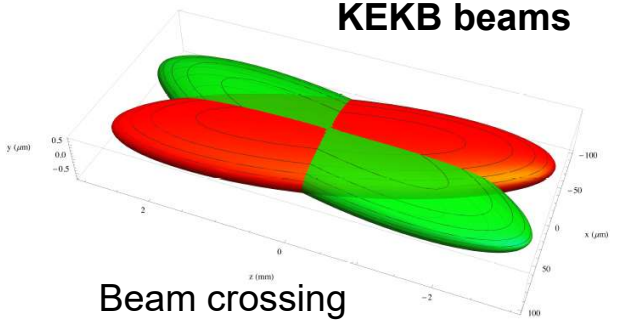
- Established in 1997.
- This inter-university research institute consists of two campuses
  - Tsukuba Campus
    - SuperKEKB (electron positron collider)
  - Tokai Campus
    - J-PARC (proton accelerator)

THE SUPERKEKB COLLIDER

KEKB to SuperKEKB: Interaction Region

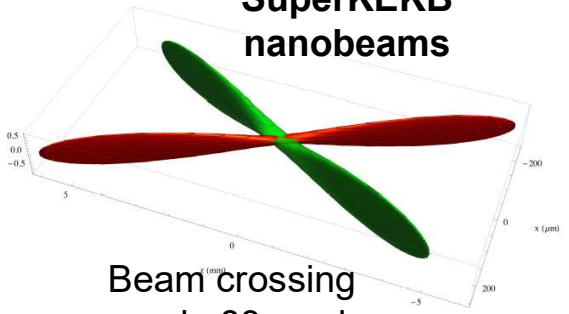
- Nano beam scheme + Crab waist optics
- Target: vertical beta function β_y^* 5.9 mm (KEKB) to 0.3 mm (SuperKEKB)
- Increase beam currents $I_{e\pm}$
- Increase beam-beam interaction ξ_y

KEKB beams



Beam crossing angle 22mrad

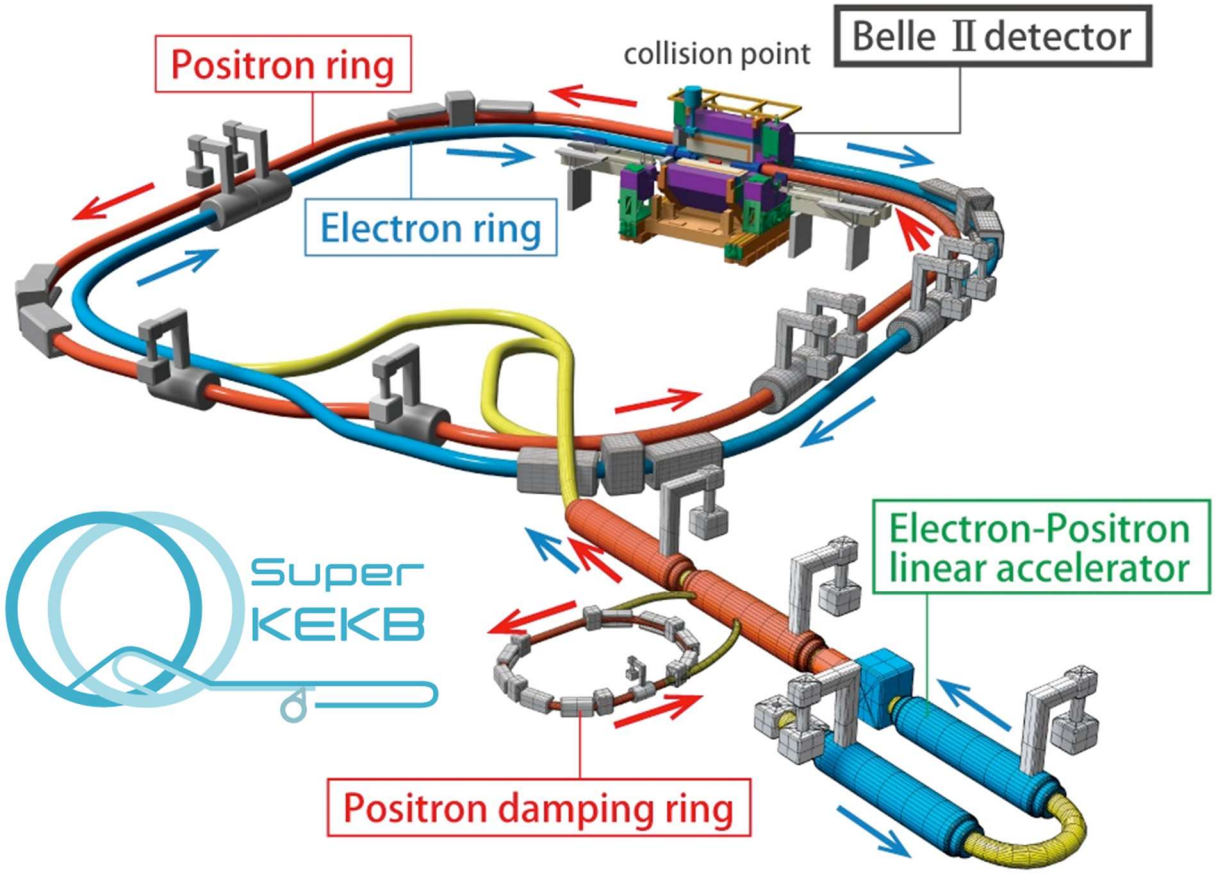
SuperKEKB nanobeams



Beam crossing angle 83mrad

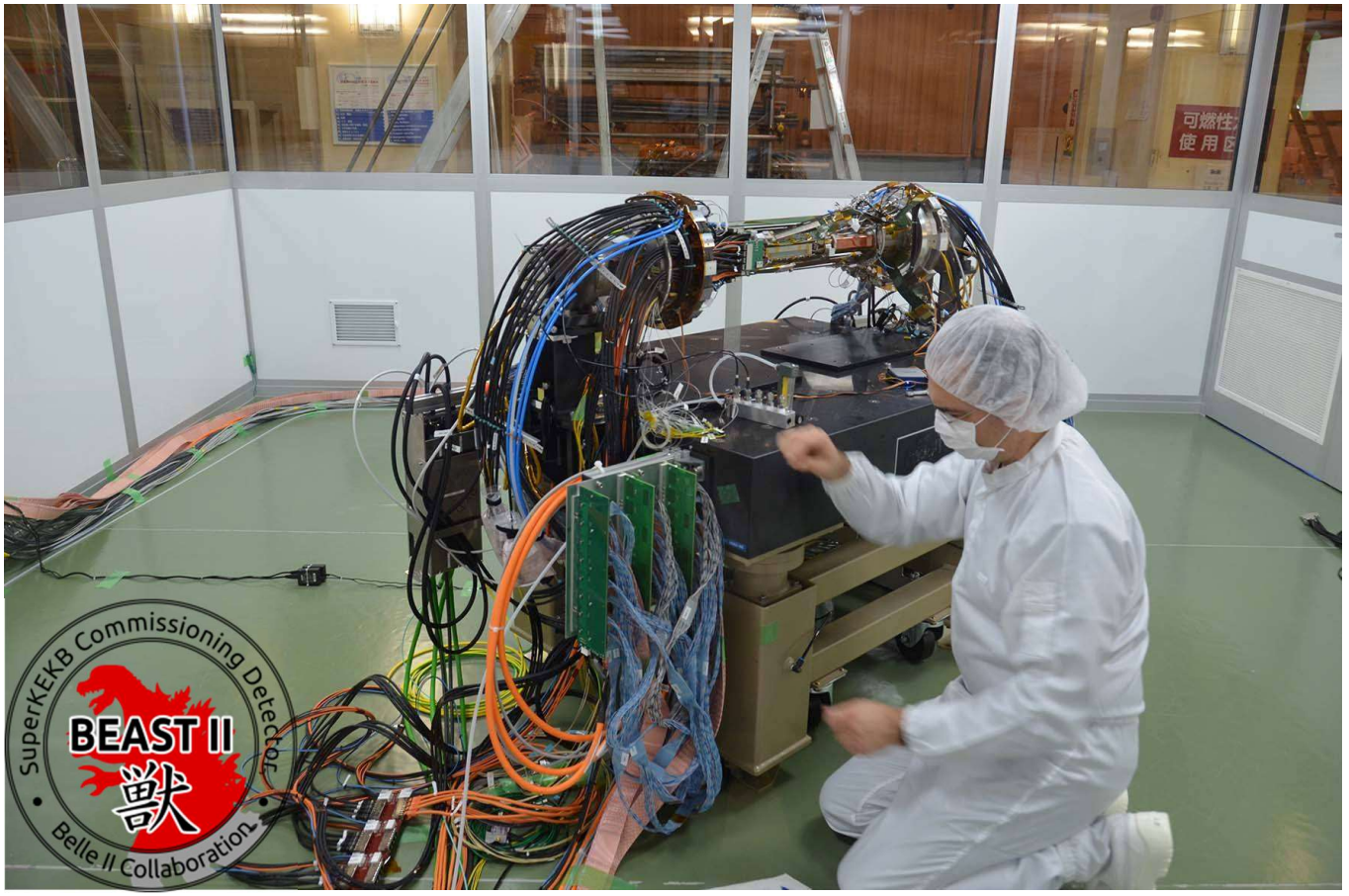
$$L = \frac{\gamma_{e\pm}}{2e\,r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\cdot\xi_{y,e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

KEKB to SuperKEKB Accomplished



- New 3km positron ring ready for Phase I (2016)
  - Single beam with simple background detector.
- Positron damping ring added for Phase II (2018)
  - Beast II + outer Belle II with beam colliding.
- Phase III started February 2019 with the full Belle II detector.
- The nominal energy for run is at Upsilon(4s) with 7 GeV electron and 4 GeV positron beams.
  - Other energies also included.

BEAST II



1/8th of the Belle II vertex detector for Phase II.

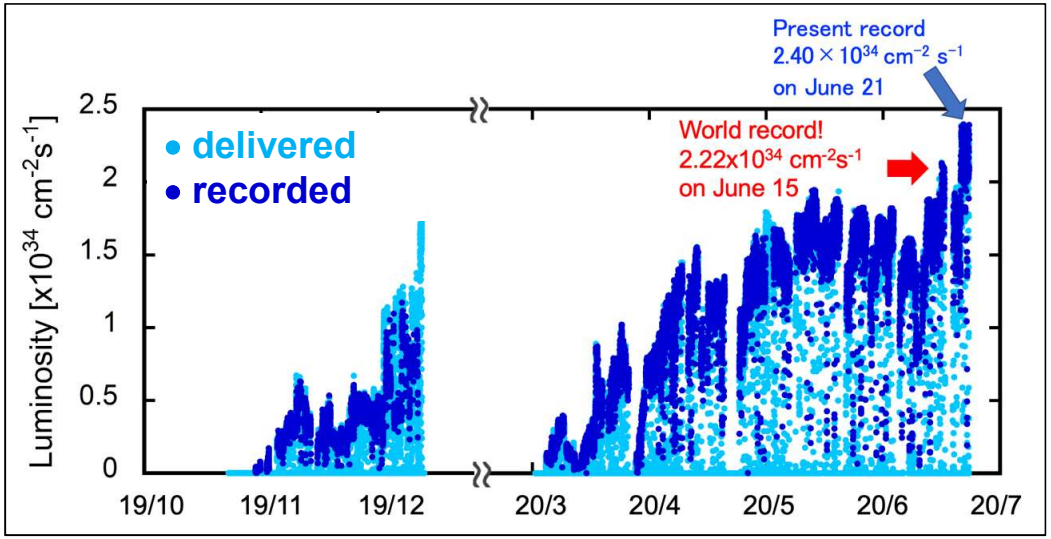
Beam Collisions

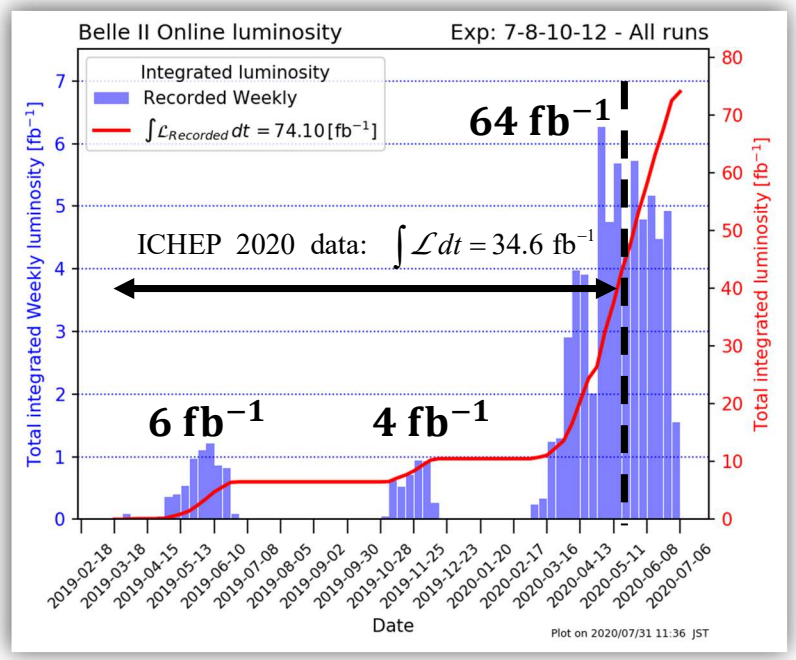
The first beam collision April 26, 2018
Phase II

The Phase III first collision event

SuperKEKB Luminosity: World Record

- SuperKEKB/Belle II are operating under Covid-19 pandemic, minimizing risk of infection.
  - The on-site shifts were rearranged to minimize personal contacts.
  - And reclaimed the luminosity record on June 2020! (Previous by LHC.)

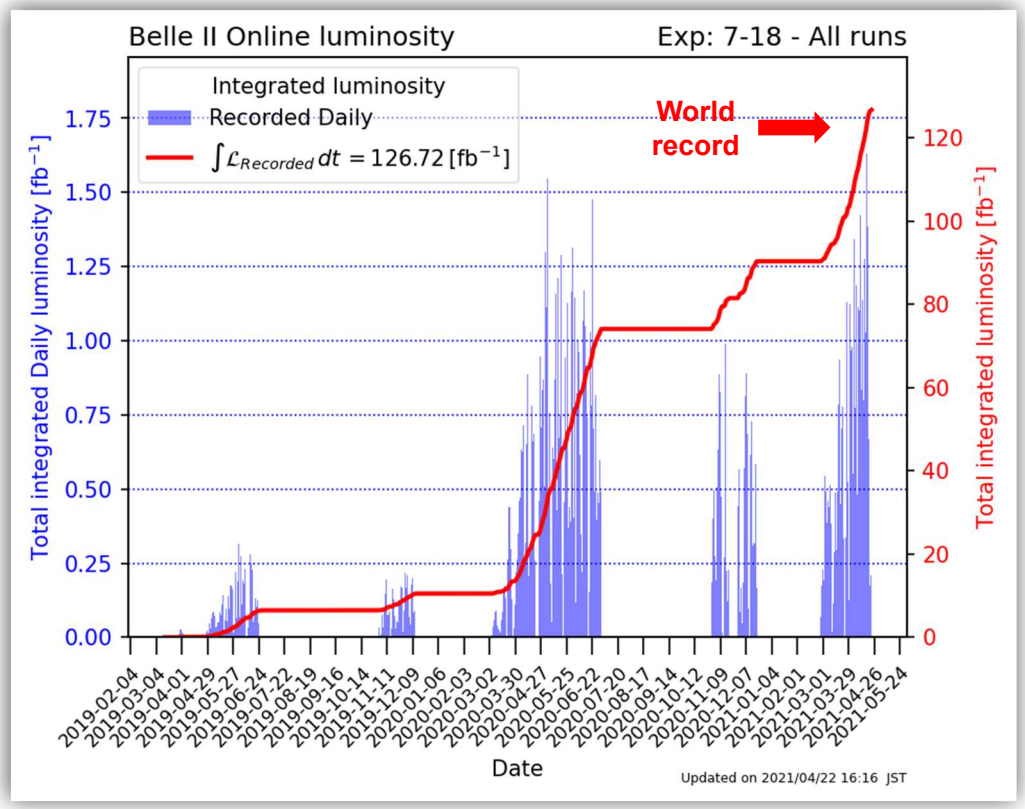




https://cerncourier.com/a/kek-reclaims-luminosity-record/

SuperKEKB Luminosity: Current Status

- Fall 2020 two months of running
  - Installed a new LHC style pure carbon collimator. Unfortunately, this increased instabilities in the beam.
  - Also two weeks lost due to a bad dust event.
- Feb 2021
  - Went back to the original collimator type.
  - A new world record of 1.63 fb^{-1}/ day of **daily integrated luminosity** on April 21, 2021.
    (previous 1.48 fb^{-1}/ day by KEKB)



https://confluence.desy.de/display/BI/Belle+II+Luminosity

THE BELLE II EXPERIMENT

The Belle II Collaboration

- Europe 43%
- Asia 22%
- Japan 16%
- America 15%
- Russia 4%

- As of April 2021,
- 1,000 members, 120 institutes, 26 countries
- From South Korea, 40 members from 9 institutes

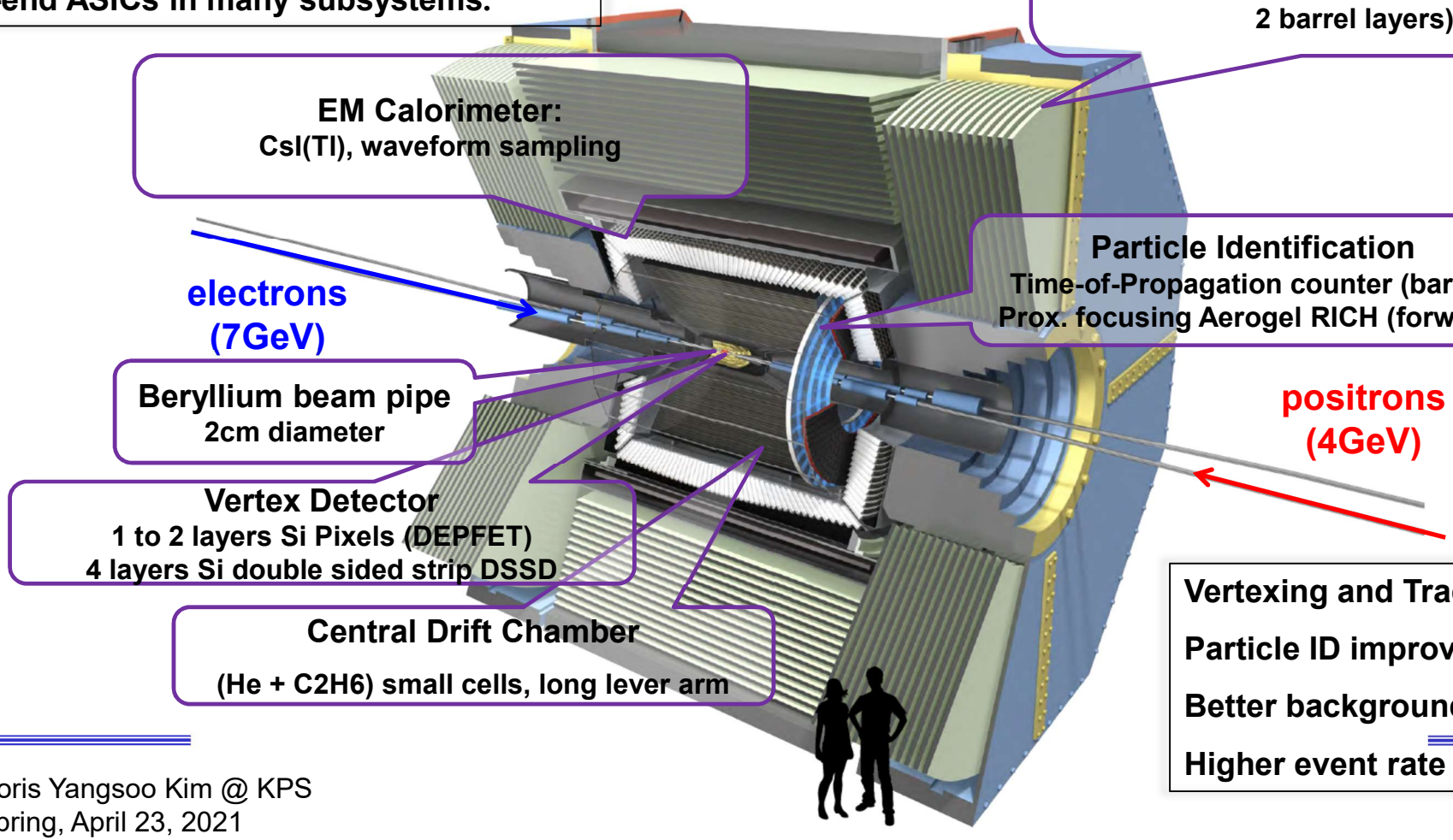
The Belle II Detector

7.4 m

Pixelated photo sensors in TOP/ARICH/KLM
Front-end ASICs in many subsystems.

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

EM Calorimeter:
CsI(Tl), waveform sampling



electrons (7GeV)

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

Beryllium beam pipe
2cm diameter

positrons (4GeV)

Vertex Detector
1 to 2 layers Si Pixels (DEPFET)
4 layers Si double sided strip DSSD

Central Drift Chamber
(He + C2H6) small cells, long lever arm

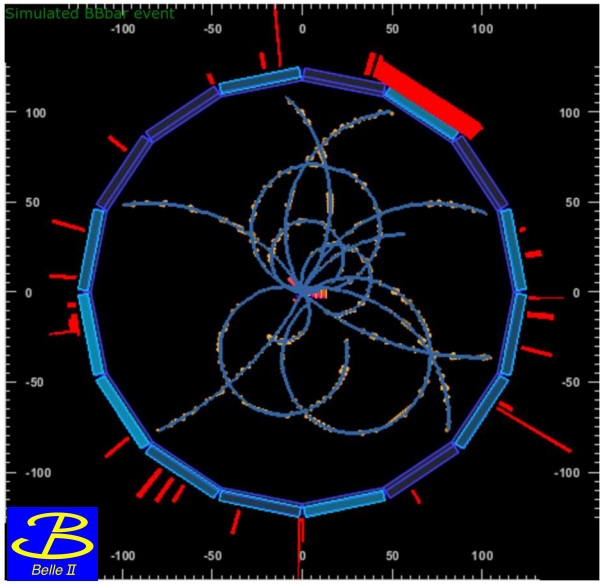
Vertexing and Tracking Improved
Particle ID improved
Better background insensitivity
Higher event rate

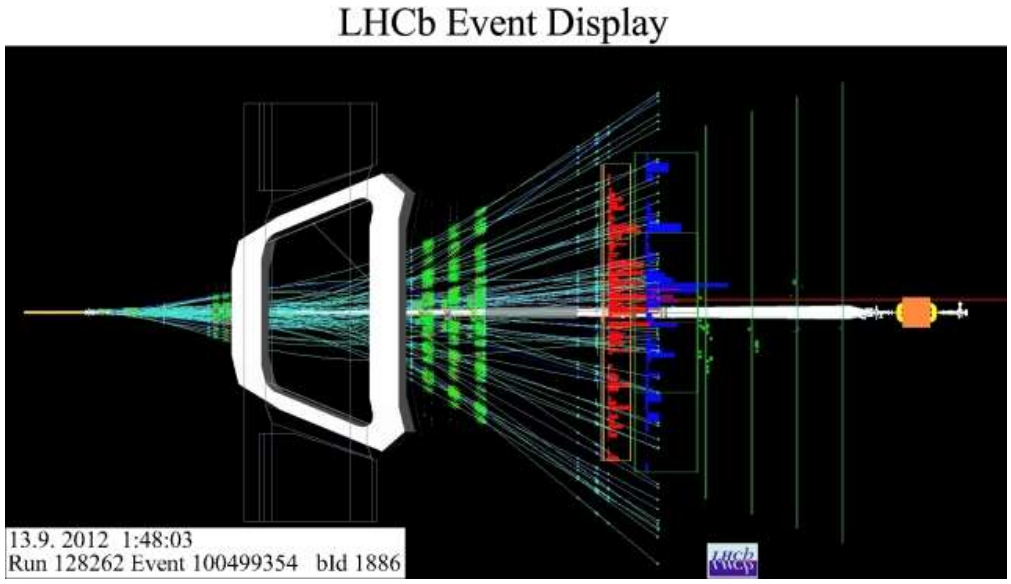
Belle II Experiment in Nutshell

- Belle II Plan: collecting 50 ab^{-1} as e^+e^- collisions at Upsilon(4S) and nearby
  - About 50 times larger than its predecessor, Belle with 1.05 /ab
- Upsilon(4S) decays into B B meson pairs coherently with no additional fragments.
  - High tagging efficiency of B decays (Belle II 34% vs LHCb 5%)
  - Full event reconstruction tagging possible
- Direct detection of neutrals such as γ, π^0, K_L.
- A hermitic detector:
  - Detection of neutrinos or invisibles as missing energy/momentum.
- Large τ samples: Search for LFV τ decays at $O(10^{-9})$.
  - Detect both e and μ.

Belle II and LHCb

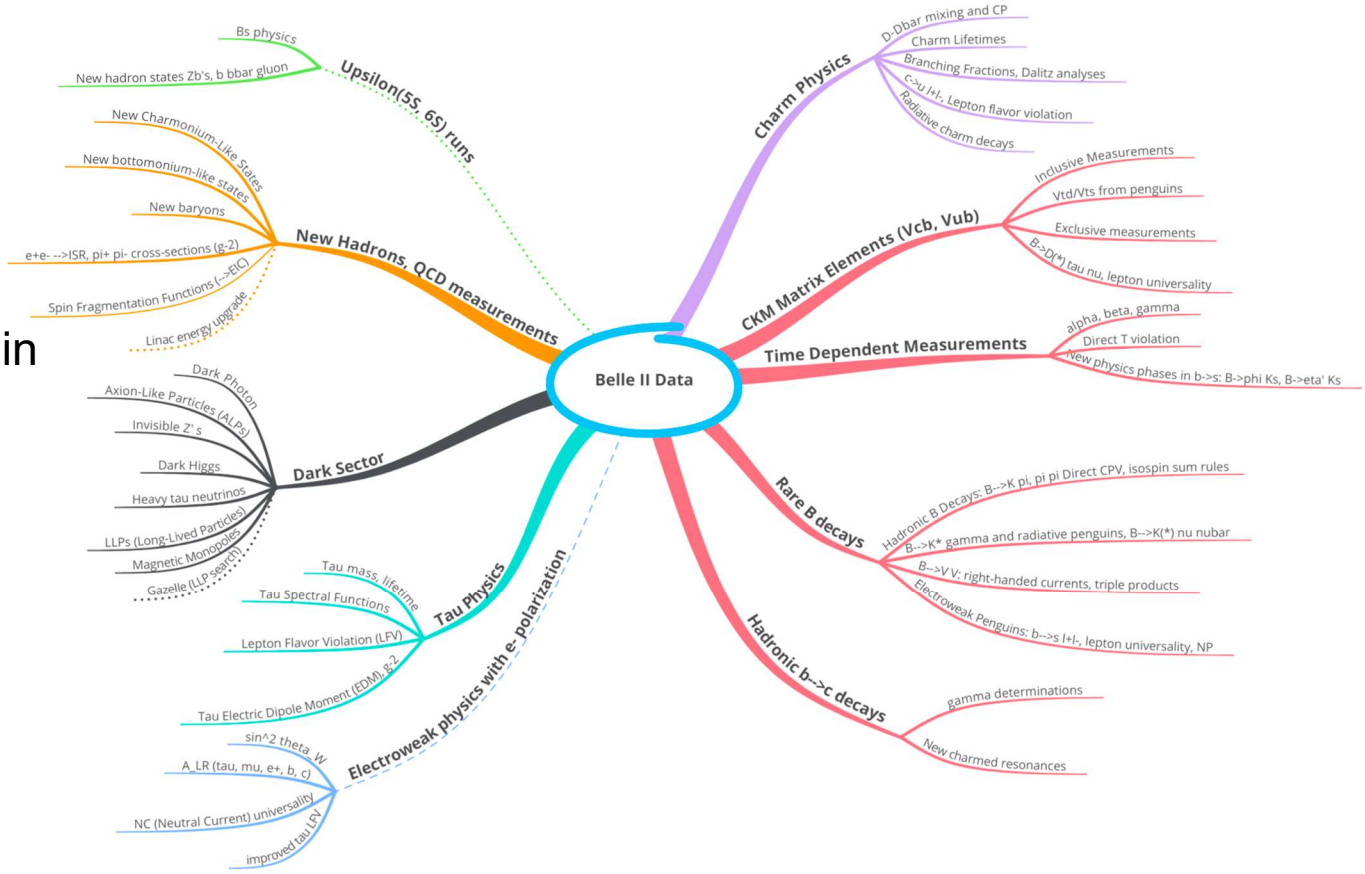
- Belle II and LHCb have different systematics
  - Two experiments are required to establish NP.
  - LHCb: large $b\bar{b}$ cross-section (LHCb 1 fb^{-1} ~ Belle II 1 ab^{-1}). Good sensitivity and S/N with di-muon modes and charged tracks with a vertex.





Belle II Physics Prospects

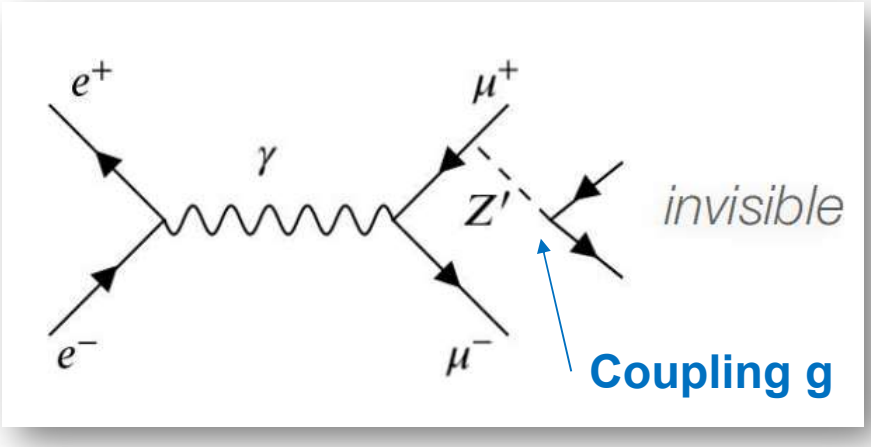
- Dark sector
- Long lived particles
- Next precision CKM measurements
- CP violation in $b \to s$ penguin decays
- Lepton flavor violation in τ decays
- FCNC
- Charm decays
- τ physics
- Hadron spectroscopy



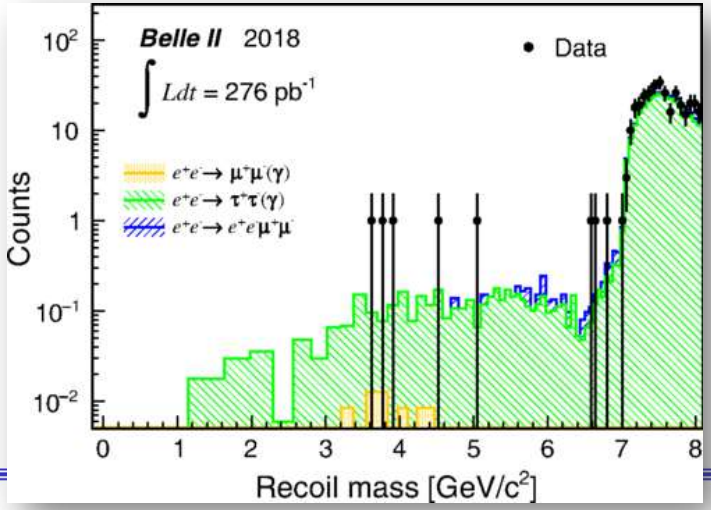
https://confluence.desy.de/display/BI/Snowmass+2021

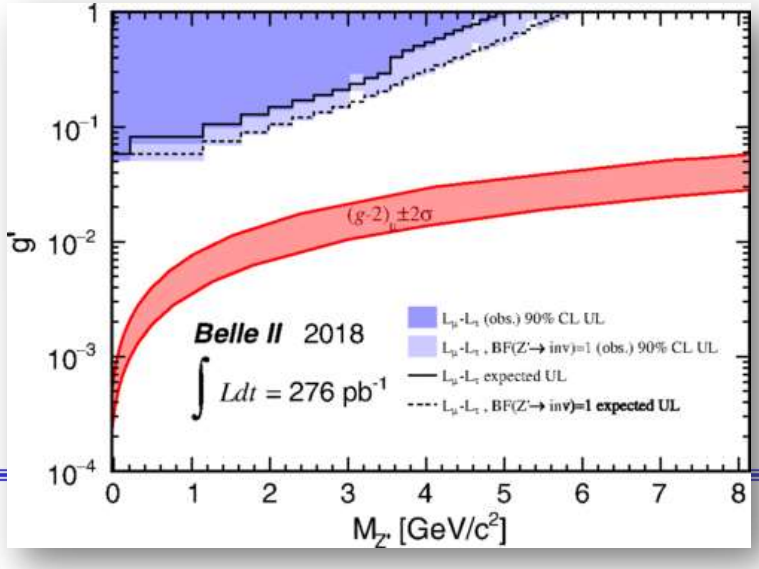
THE FIRST RESULTS FROM BELLE II

The First Physics Paper: Z′ Search

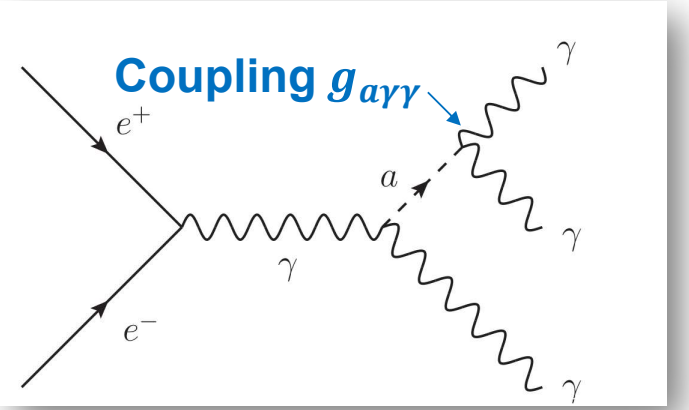


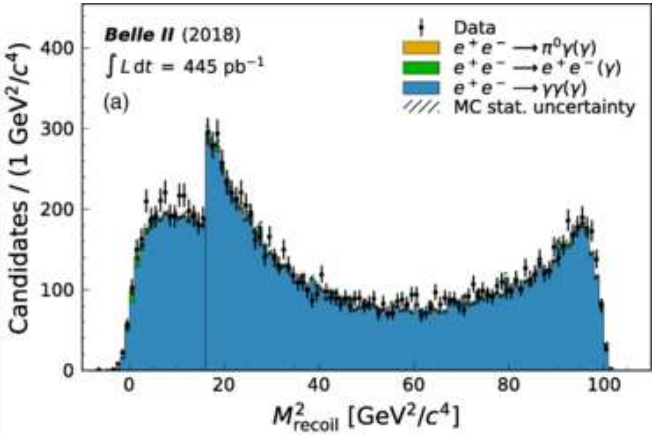
- A new result on the dark sector ($Z' \rightarrow$ nothing) recoiling against di-muons or electron-muon pair: Phys. Rev. Lett. 124, 141801 (2020).
- Both possibilities are poorly constrained at low Z' mass.
  - The di-muon case could explain the muon g-2 anomaly.

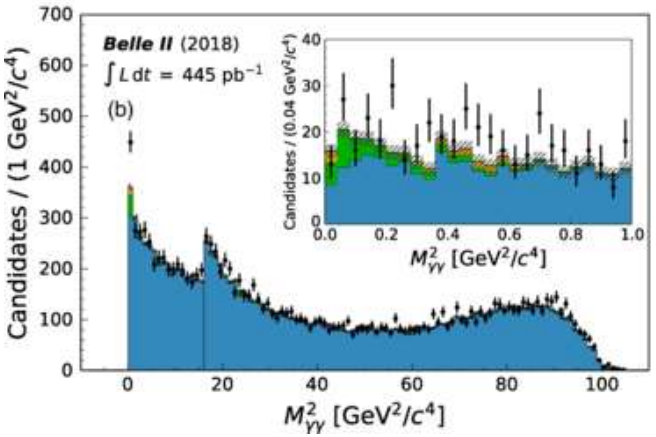




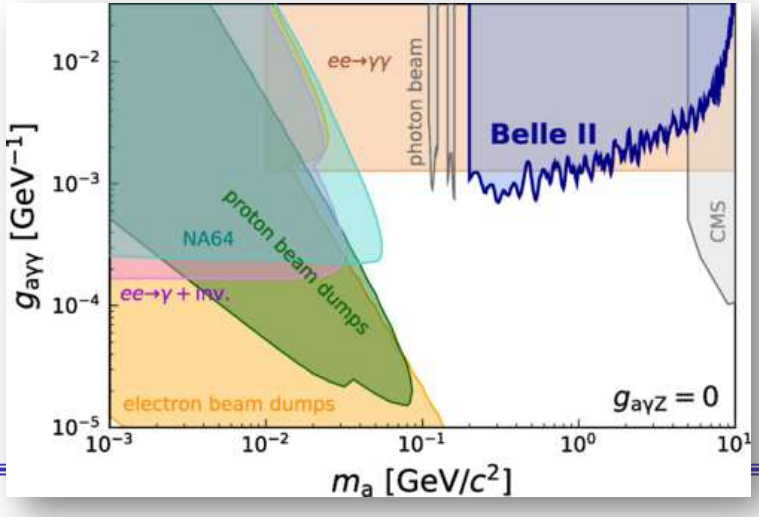
Search for Axion Like Particles



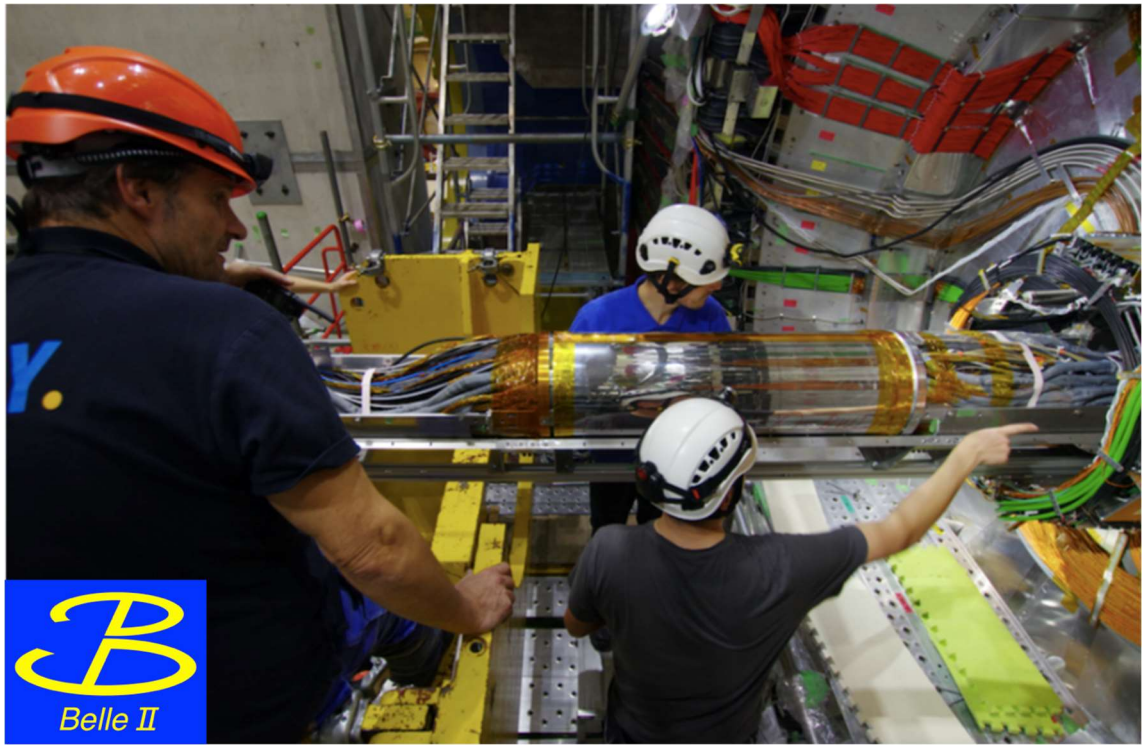




- Axion like particles at low mass are cold dark mater candidates: Phys. Rev. Let. 125, 161806 (2020)
- They couple naturally to photons.
- Look for 3-photon final states via ALP-strahlung in
  - Recoil invariant mass for high m_a.
  - Di-photon mass for low m_a.



The Belle II Vertex Detector



Installation of the vertex detector. November 21, 2018

- PXD: Layer 1 and partial Layer 2
- SVD: all 4 layers

Charm Lifetime

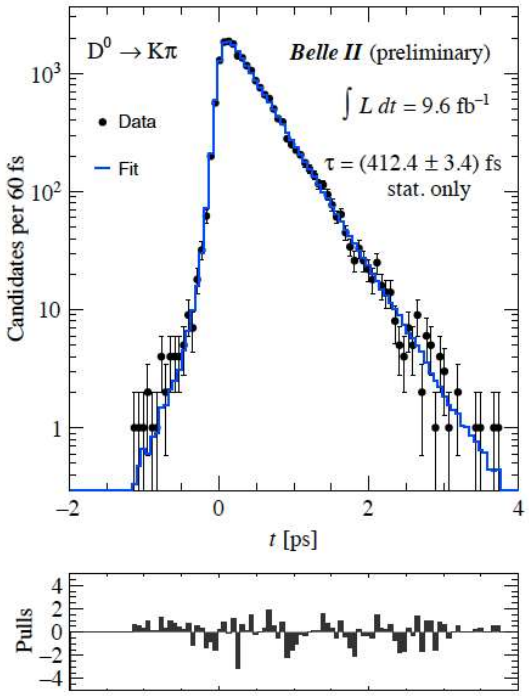
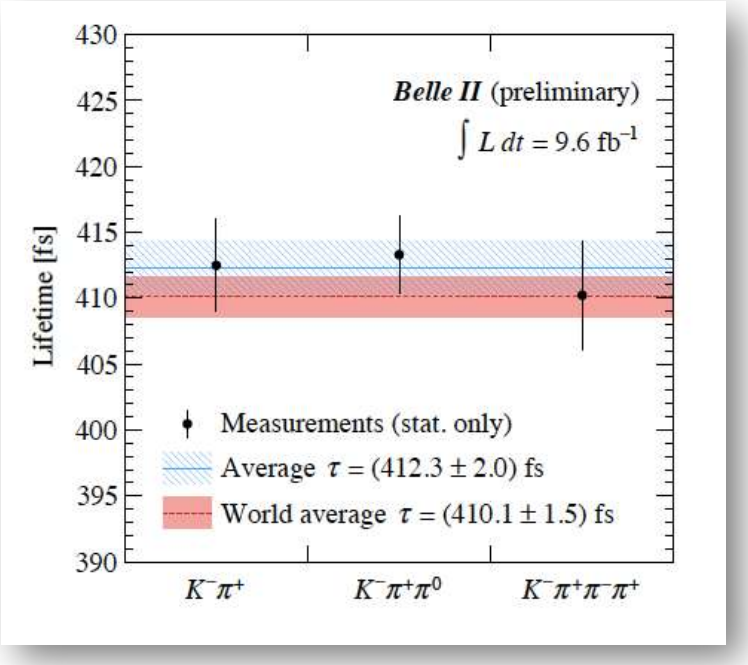
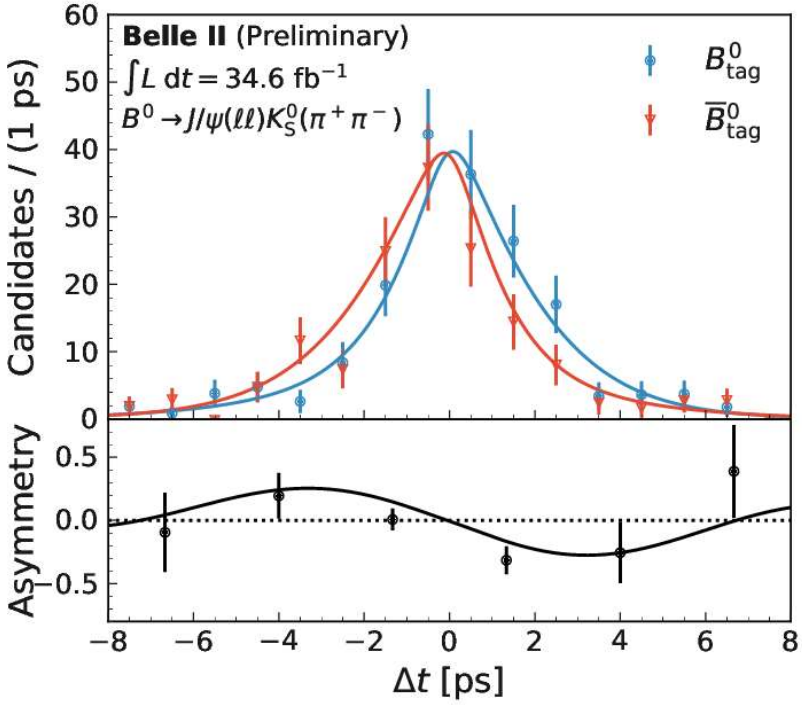


Figure 2: Fit to the proper-time distributions of D^*-tagged $D^0 \to K^-\pi^+$ candidates reconstructed with 2019 Belle II data. The extracted lifetime in this channel is (412.4 ± 3.4) fs, the estimated average proper time resolution is (97 ± 8) fs.

The new pixel detector improved the lifetime resolution of the charm particles by a factor of 2 with respect to the previous Belle detector.



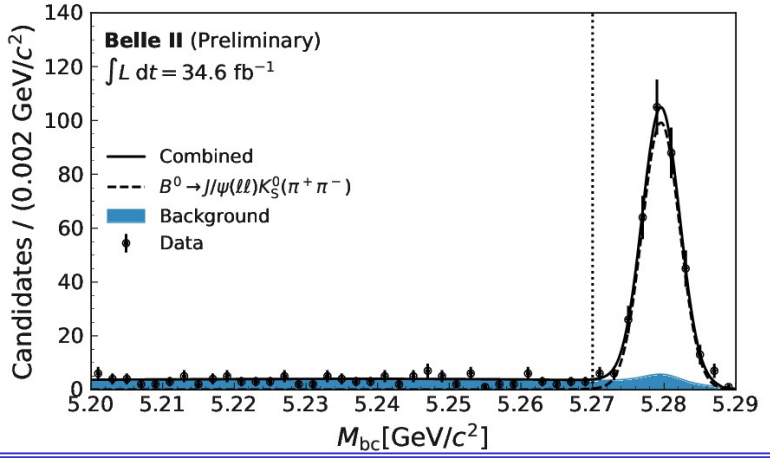
Time Dependent CPV and Mixing



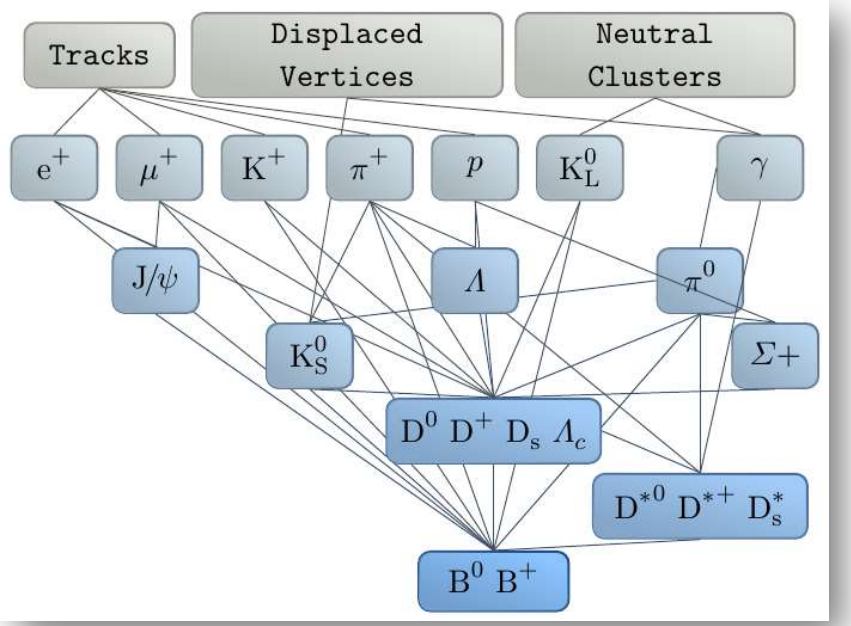
Belle II: $S_f \approx \sin 2\phi_1 = 0.55 \pm 0.21 \pm 0.04.$

W. A.: $S_f \approx 0.691 \pm 0.017.$

- The golden channel $B^0 \to J/\psi(ll)K^0_S(\pi^+\pi^-)$ is studied and the time dependent CPV parameter $\sin 2\phi_1$ is extracted.
- CPV is assumed only from the B^0 mixing ($A_{CP} = 0$).
- The wrong sign tag ratio $w = (20.9 \pm 2.1)\%$ is obtained from the $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$ sample where $\Delta m_d = (0.531 \pm 0.046 \pm 0.013)\ \mathrm{ps}^{-1}$.

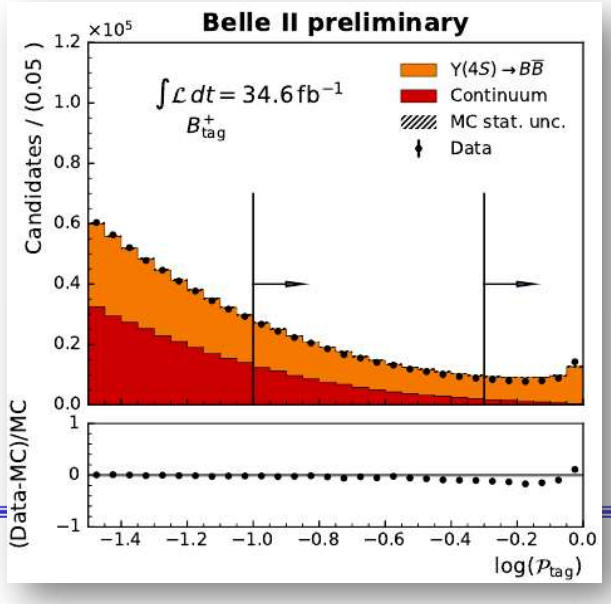


Full Event Interpretation

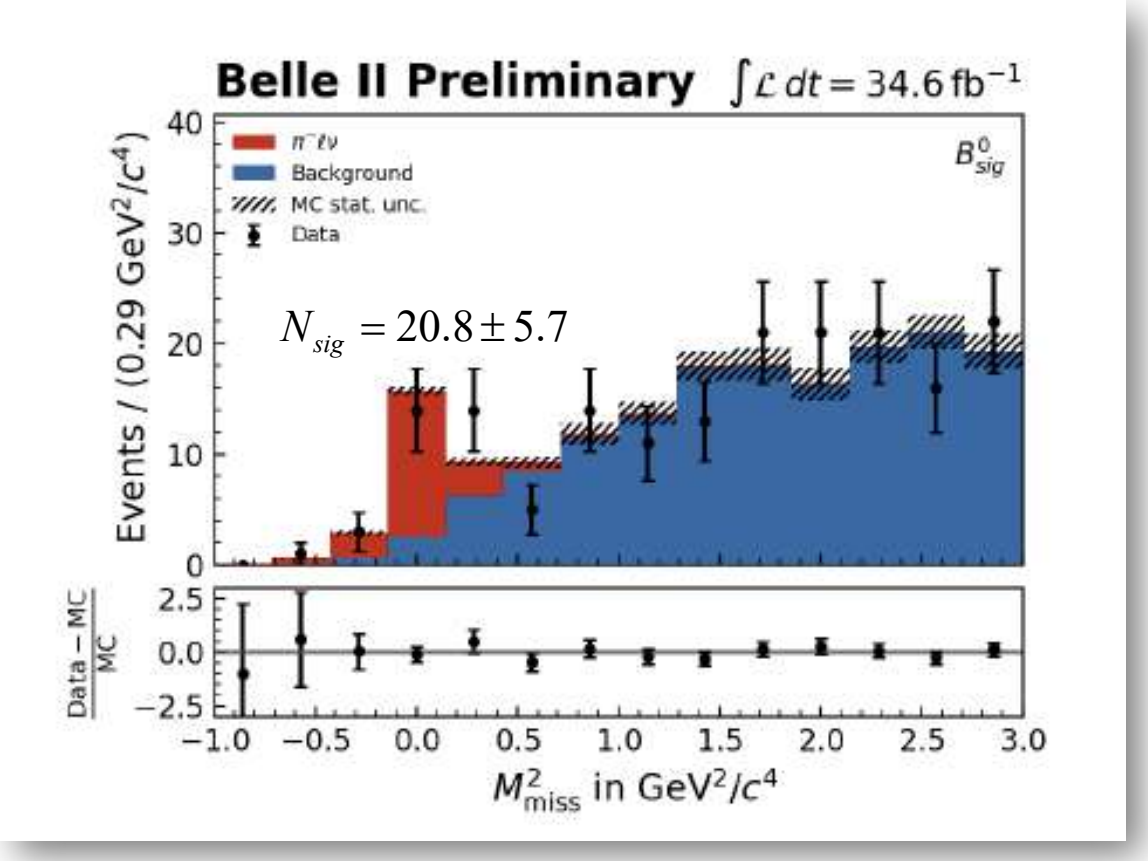


Hierachial reconstruction is performed to obtain both B mesons.

- Traditionally, at Upsilon(4s), one B (tag) is reconstructed first. The rest of the event is considered as a signal B. https://arxiv.org/abs/2008.02707
- Another tool (FEI) is developed based on Boosted Decision Tree.
  T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019)



$|V_{ub}|$: Exclusive $B \to \pi\, l\nu$



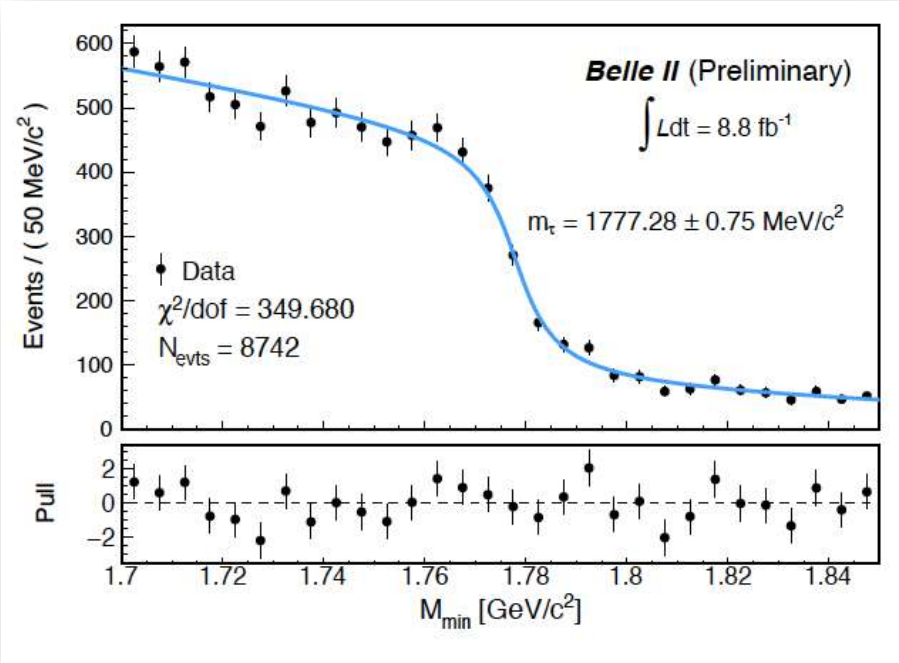
- Here is an example of FEI applied to a semileptonic decay of B meson.
- Measurement of branching fraction and Lattice QCD calculation result can extract $|V_{ub}|$ at q^2(max).

$$BF(B^0 \to \pi^- l^+ \nu) = [1.58 \pm 0.43(\text{stat}) \pm 0.07(\text{sys})] \times 10^{-4}$$

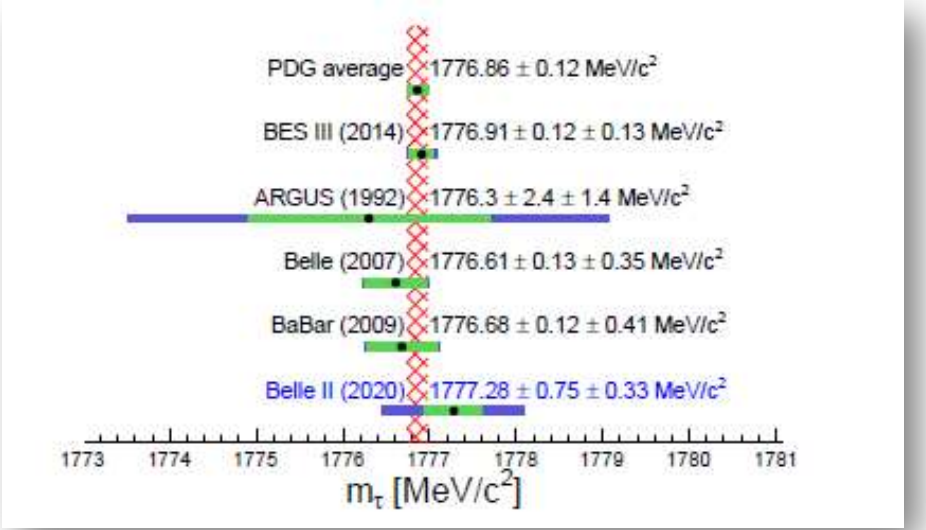
https://arxiv.org/abs/2008.08819

τ Mass Measurement

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$



- Select one-prong τ and 3-prong τ pair events.
- The mass is measured from the threshold of the pseudomass variable.



https://arxiv.org/abs/2008.08819

SUMMARY

Covid Management

- International travel is strictly limited.
- SuperKEKB/Belle II established protocols to maximize safety of the on-campus researchers.
- Increased number of remote shifters around the world.
- Situation has been manageable.

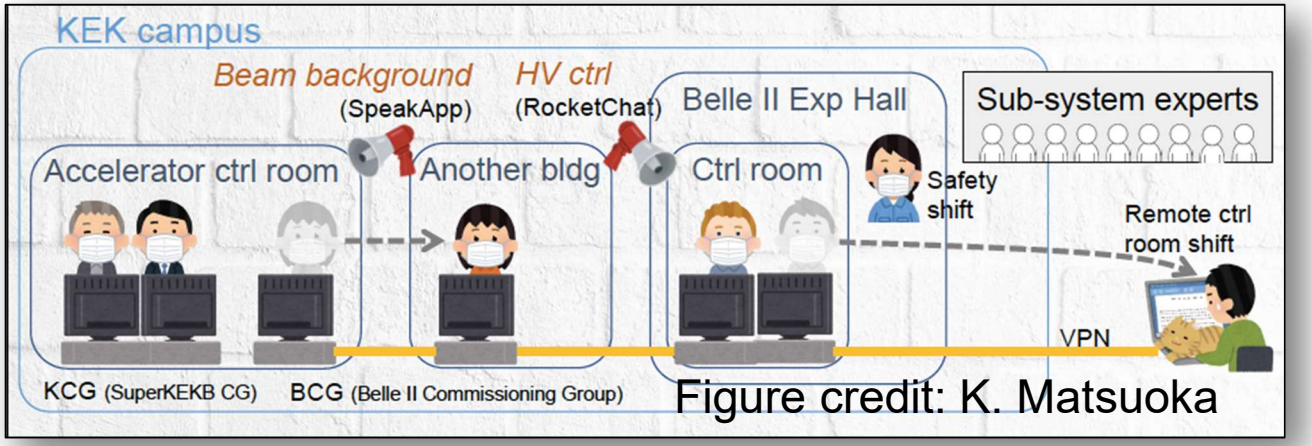


Figure credit: K. Matsuoka

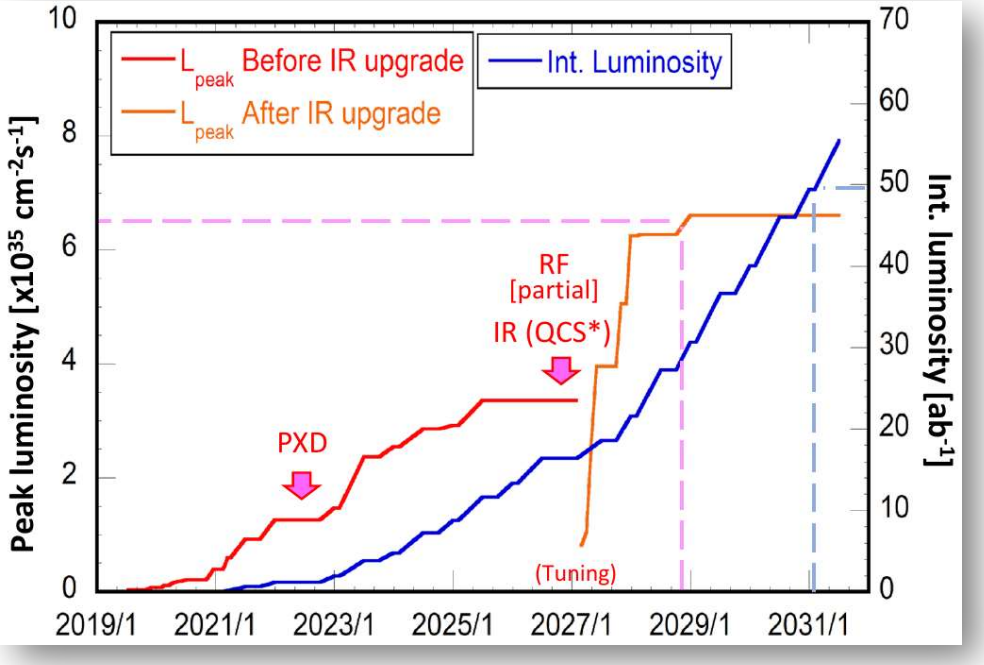
- Starter Kit Workshop for newbies is now remote.
- Online Sphinx documentation is provided for self-study.

Korean Contributions at Belle II

- Belle II member institutes
  - Chonnam, Gyeongsang, Hanyang
  - KISTI, Korea, Kyungpook
  - Seoul, Soongsil, Yonsei
- Activities
  - SVD assembly
  - CDC track trigger firmware
  - ECL trigger construction
  - DAQ slow control
  - Data production and simulation validation
  - Data handling system (AMGA)

Remote Kbelle meeting
November 2020

Near Term Prospects and Luminosity Plan



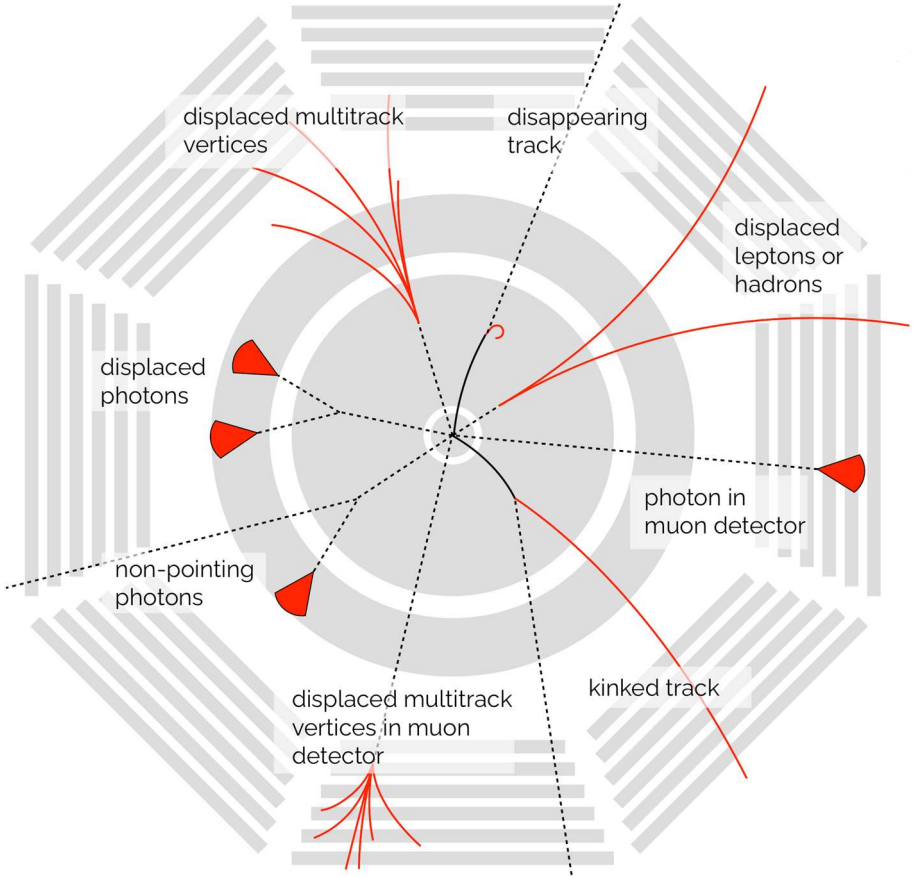
- In general, SuperKEKB will run 8 months per year.
- Immediate $L_{peak} \sim 1$ or $2 \times 10^{35} cm^{-2} s^{-1}$
- 2021-2022: PXD exchange.
- 2026: Partial RF-power upgrade. IR upgrade.
  - β_y^* ~ 0.5 mm before 2026. 0.3 mm after 2026.
- Next $L_{peak} \sim 6.5 \times 10^{35} cm^{-2} s^{-1}$ to reach 50 ab^{-1}
- Long term R & D for
  - Beam polarization upgrade
  - Ultra high luminosity $4 \times 10^{36} cm^{-2} s^{-1}$ for 250 ab^{-1}

Summary

- SuperKEKB has achieved $L_{peak} = 2.4 \times 10^{34} cm^{-2} s^{-1}$, the world record.
  - It is a super B factory now.
- Belle II has started producing new results, including a world leading results in dark sector with limited Phase II data: Z′ and ALP papers
  - More updates are coming with Phase III data
- Belle II rediscovered many flavor physics signatures based on the early Phase III data: 12 conference papers at arXiv/Belle II docs
  - Reports at ICHEP 2020, Moriond 2021.
- Belle II is planning to collect 50 ab^{-1} by 2030. This is a very exciting time to do flavor physics, looking for physics beyond the Standard Model.

EXTRA

Long Lived Particles



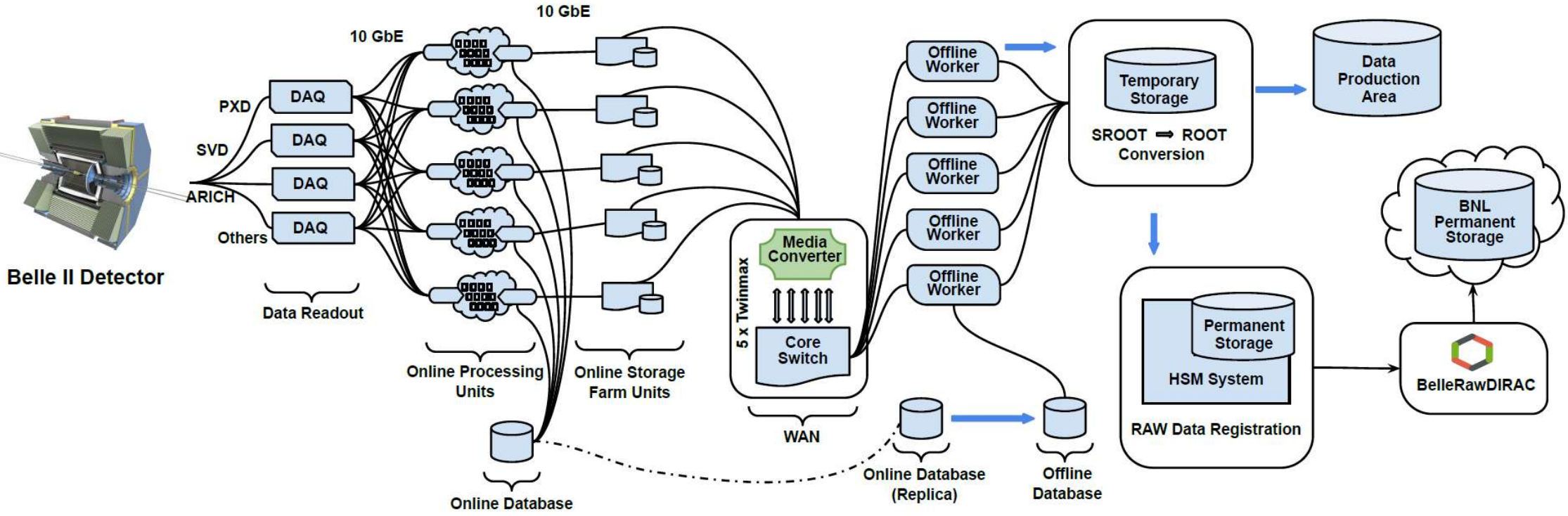
- December 2020, FSP Workshop focusing on feasibility studies

  https://indico.belle2.org/event/2920/
- Additional displacement vertex trigger is needed to enhance the LLP sensitivities.
- A Snowmass White Paper including a proposal of the Gazelle detector

  https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF6_RF0_Torben_Ferber-020.pdf

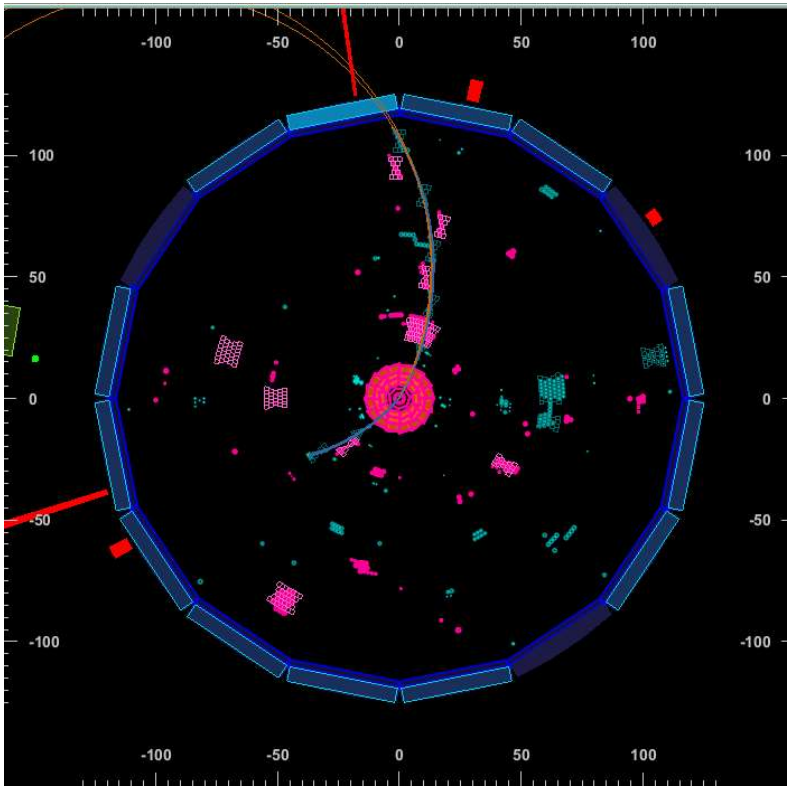
The Belle II Data Operating System

Belle II will collect 2 × 60 petabytes at 50 ab^{-1}. The worldwide Belle II Grid is deployed to handle data processing.



https://link.springer.com/article/10.1007/s41781-020-00045-9

Neural Net Hardware Track Trigger



- A single hidden layer with 81 neurons and 27 inputs to select single track events.
- To the left is an event candidate with a one-prong $\tau+$ and 2nd one-prong $\tau-$.