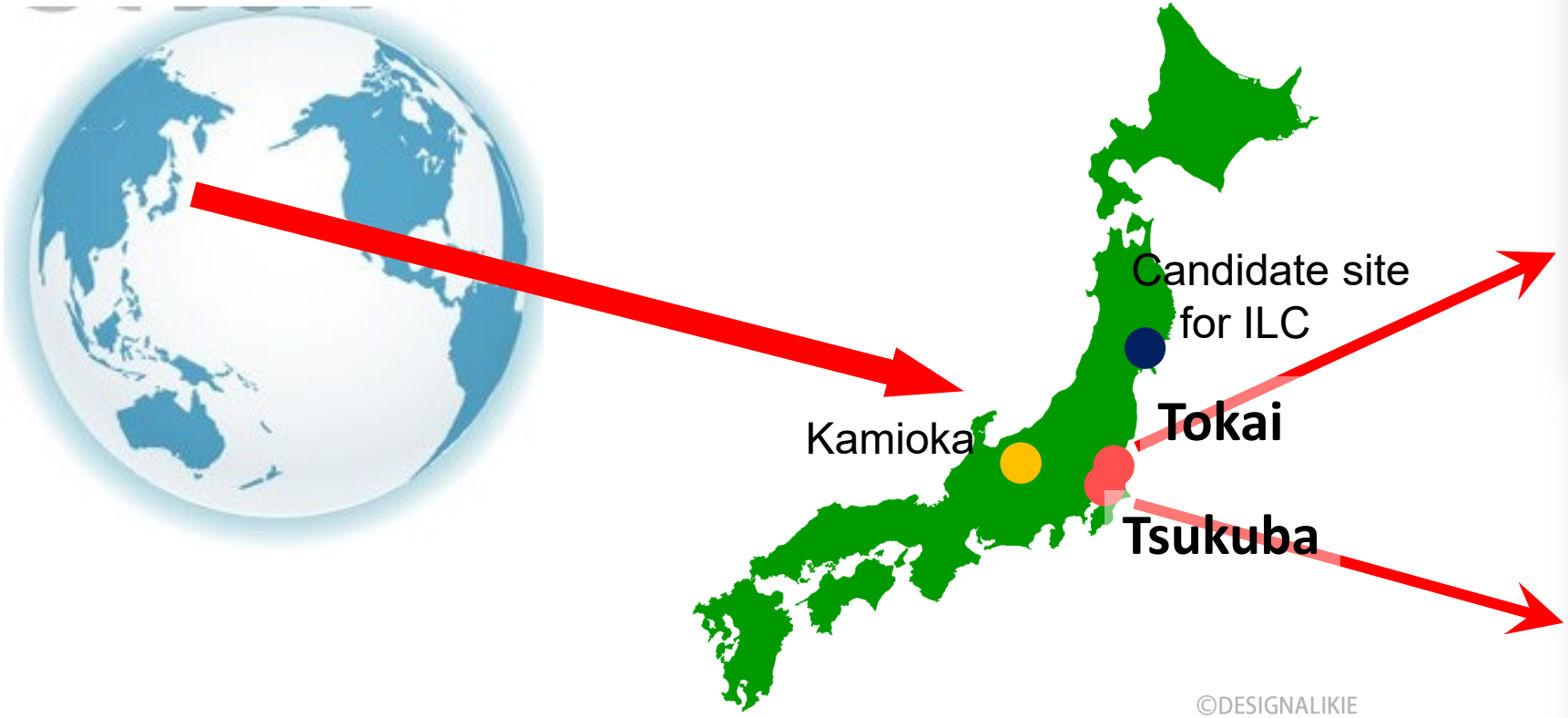
KEK, High Energy Accelerator
Research Organization

KEK's Physics Program in the next 10 years

April 13, 2023

M.Yamauchi
KEK

KEK Geography



J-PARC: high intensity proton accelerator complex jointly operated by KEK and JAEA

KEK Tsukuba: SuperKEKB, PF, ATF

Physics Programs at KEK

- Experimental program at KEK
  - Flavor physics using high intensity proton beam at J-PARC
    - KOTO ($K_L \to \pi^0 \nu\nu$)
    - COMET (μ-e conversion)
    - μ g-2/EDM

    } Covered in Naohito Saito's talk at the town hall meeting in Chicago
  - → Belle II at SuperKEKB e^+e^- collider
  - T2K long baseline neutrino experiment : covered by Naohito Saito
- Experiments conducted jointly with ICRR U. of Tokyo
  - HyperKamiokande : covered by Masato Shiozawa at the town hall meeting in Chicago
  - → KAGRA
- → International Linear Collider (ILC)

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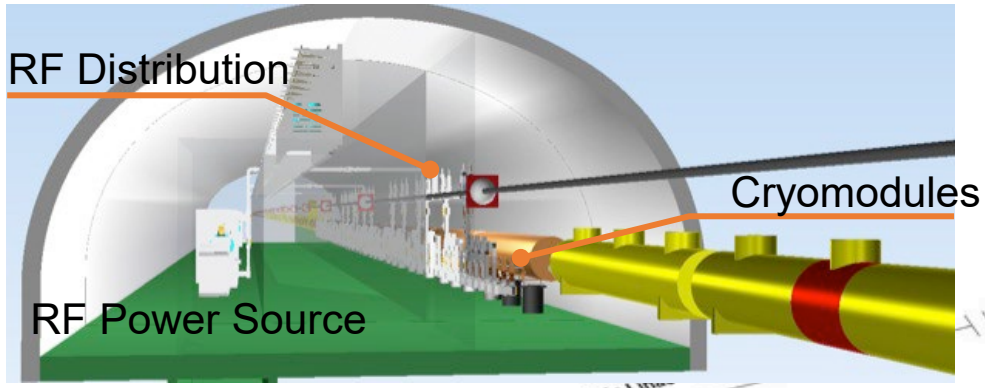
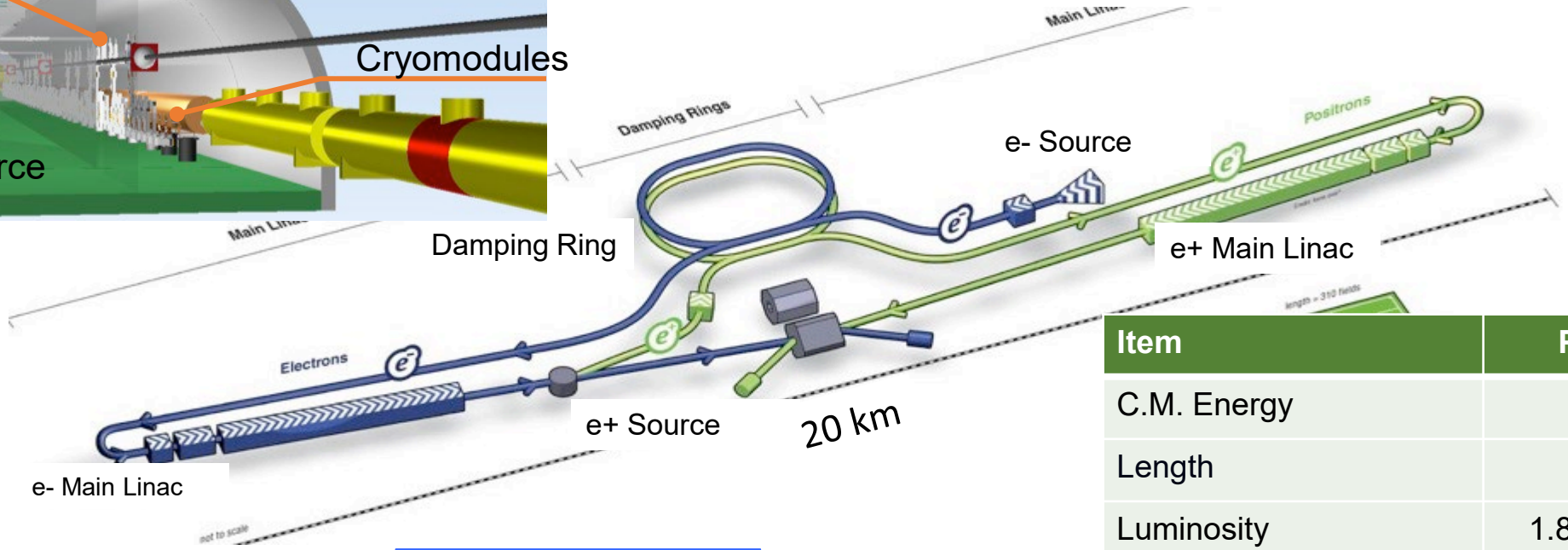
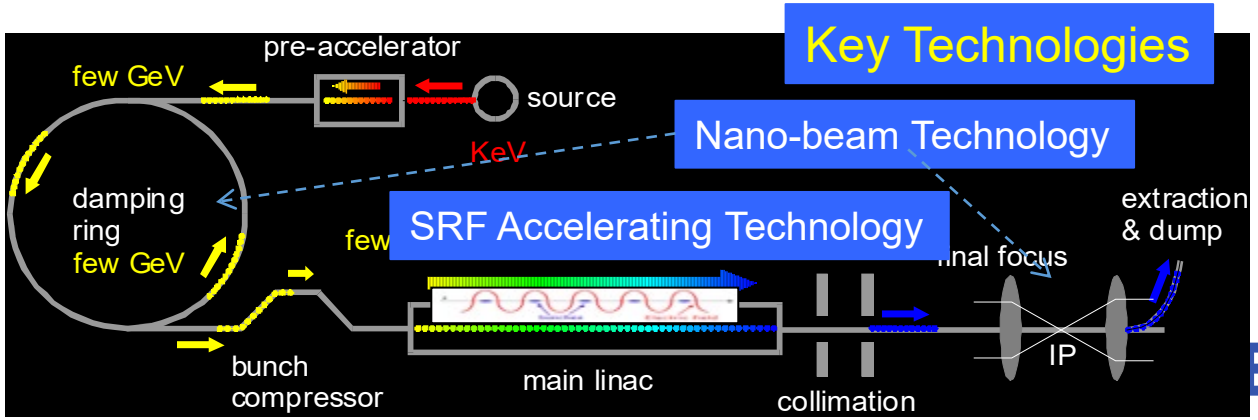
International Linear Collider (ILC)







Item	Parameters
C.M. Energy	250GeV
Length	20km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	**7.7** nm
SRF Cavity G. Q_0	**31.5** MV/m Q_0 = 1x10 ^{10}

Early history of ILC

- In 2004, ICFA chose the cold technology for LC as a global project, and set up a global team (GDE) for design and coordination of R&D for the ILC. After eight years of works, the TDR of the ILC was published in 2013.

- In 2012, after the discovery of the Higgs boson at LHC, KEK and the Japanese HEP community proposed to the Japanese Government to host the ILC in Japan as a global project.

- In the 10 years since then, the Japanese government has considered hosting the ILC through discussions at the ILC Advisory Panel of MEXT, consultation with the Science Council of Japan, and dialogue with other governments, but has yet to reach a conclusion that the ILC should be hosted in Japan.

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Recent development of ILC

- ICFA established an International Development Team (IDT) and asked it to explore the possibility of the phased implementation of the ILC. The IDT submitted a proposal to establish a preparatory laboratory (Pre-lab) in June 2021, which was deemed premature by the Japanese MEXT, because there was no outlook for international cost sharing for the ILC.

- KEK, jointly with IDT, is starting the ILC Technology Network (ITN) for the implementation of time-critical work packages selected among the ones originally identified in the Pre-lab proposal.

- The IDT organized International Expert Panel, composed of physicists with extensive experience in international collaborations and channels of dialogue to national governments. As a first step, the Panel is identifying issues to be considered when realizing a large-scale accelerator as a global project. When this is completed, a forum for explanation and discussion will be held, inviting government officials from various countries.

Situation in Japan

- The Japanese MEXT is well aware of the significance of promoting particle physics research internationally, and understands that the activities of physicists to realize the future accelerator should be appropriately supported. In this regard, MEXT is increasing its support for HL-LHC in addition to the domestic programs such as SuperKEKB and HyperKamiokande.

- In the same context, MEXT has allocated 9.7 oku JPY (~US$7.4 million) to KEK for JFY 2023 for the ILC development, double the what has been allocated up to now. This budget is expected to last for five years.

- KEK's stance on ILC
  - We will strive to realize the ILC as a global project in collaboration with IDT and the physics communities in the world.
  - In addition, we are working strategically to gain broad consensus in Japan so that we can host the ILC with the support of the Federation of the Diet Members and the supporting organization in the industrial sector.
  - In the next step, KEK will take an initiative in the ITN, as the Japanese government intends to actively support the technological development for the ILC.

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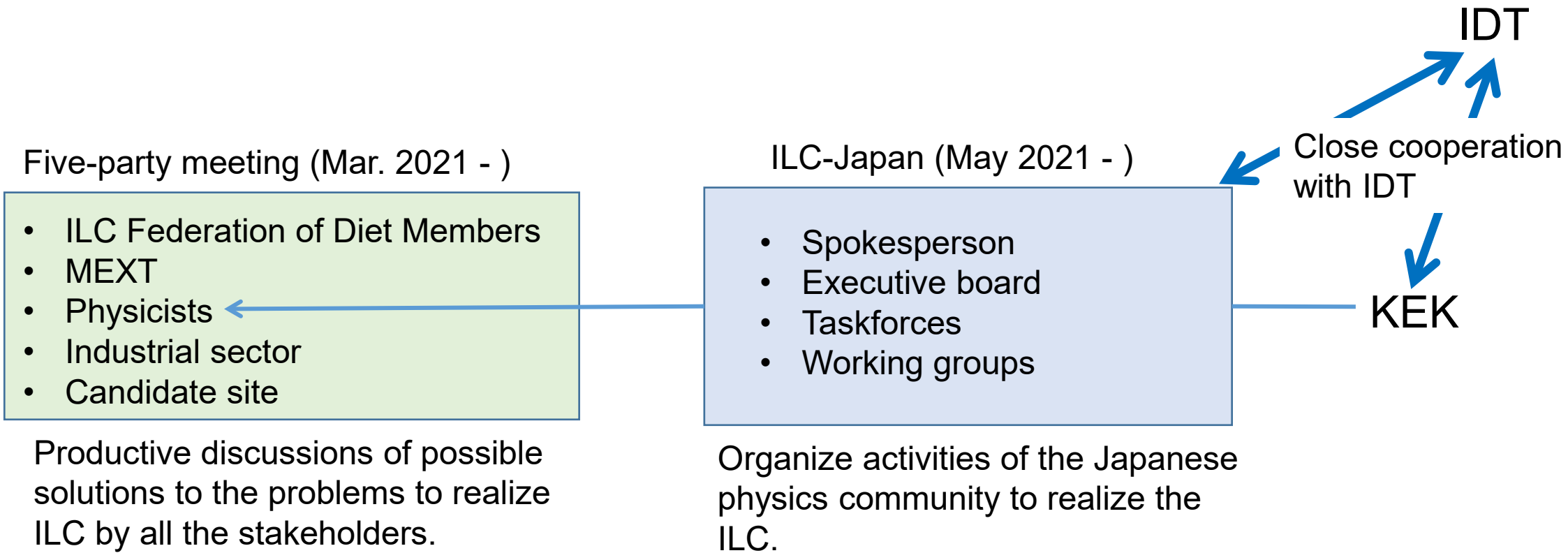
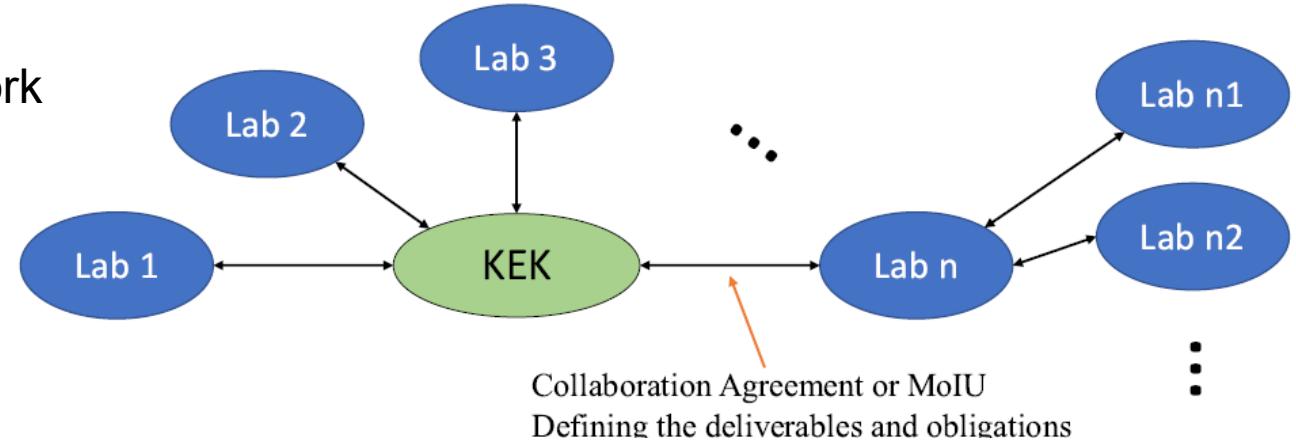
ILC Promotion Scheme in Japan



Starting ILC Technology Network (ITN)

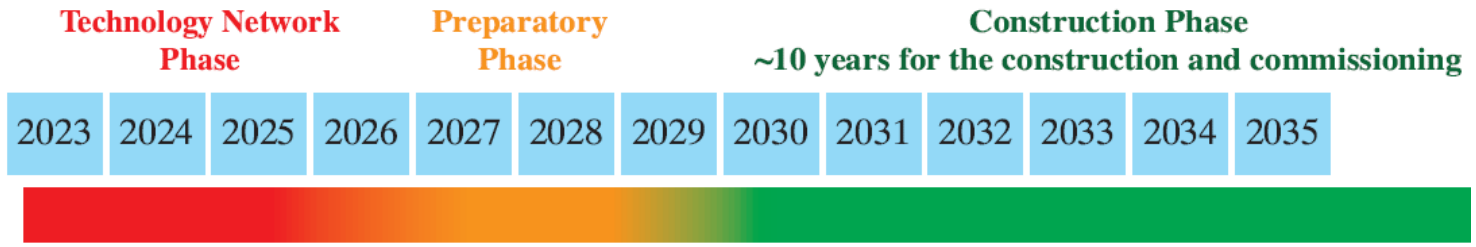
- The ITN is a network of the accelerator laboratories jointly initiated by KEK and IDT. It will be launched by agreements between KEK and a partner laboratory which define the deliverables and obligations.
- In Europe, CERN plays a coordinating role. Main contracts for flow of funds will be made between CERN and KEK, and subsequent contracts between CERN and European labs in the cases where money flow is needed.
- Delegations from IDT and KEK have so far visited management of the three US laboratories and discussed their possible participation in the ITN. We also subsequently visited the US DOE in January 2023 to make a proposal for the collaboration with the US laboratories by expanding the existing US-Japan Cooperation Program. We are currently awaiting a response from DOE.
- We will have an AsiaHEP meeting soon, where we will solicit Asian scientists to join the ITN. A group of accelerator scientists in Korea is already exploring the possibility of participation.

Proposed framework of the ITN



ILC timeline

A model for ILC project phases – the most optimistic case



Note: It assumes that obstacles like pandemics, international tensions and global economic turmoil will be timely resolved.

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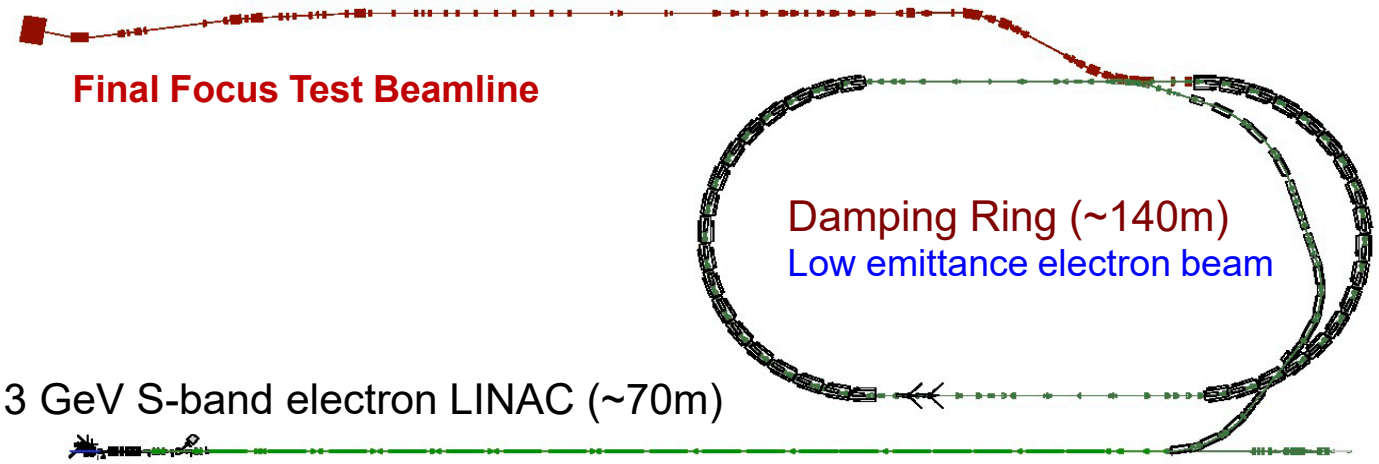
Accelerator Test Facility (ATF) at KEK

Achieved 40 nm beam size
equivalent to 7 nm at ILC.

Goal 1: Establish technology
for small beam size
Goal 2: Stabilize beam position



Superconducting Accelerator Test Facility (STF) at KEK

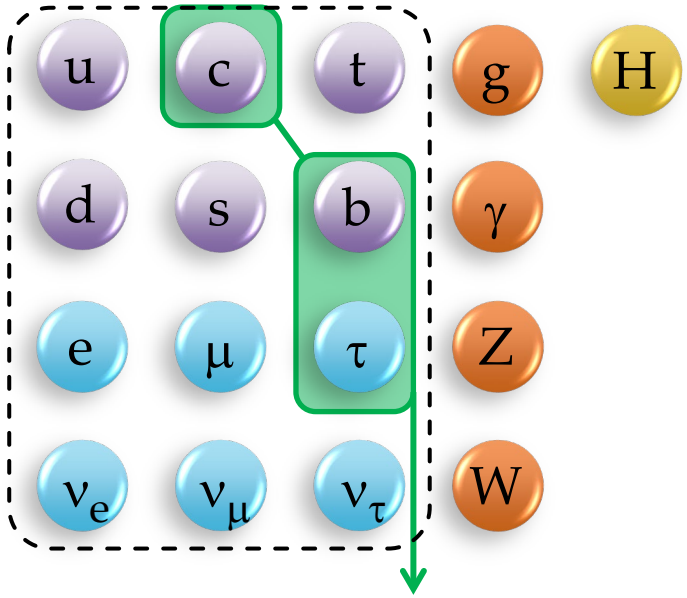
- 1.3 GHz superconducting system is operated with beam loading similar to that of the ILC.
- Fourteen superconducting cavities were installed and operated successfully with the beam load.

Physics at Belle II

Goal: Uncover BSM (Beyond the Standard Model) physics

Standard Model particles

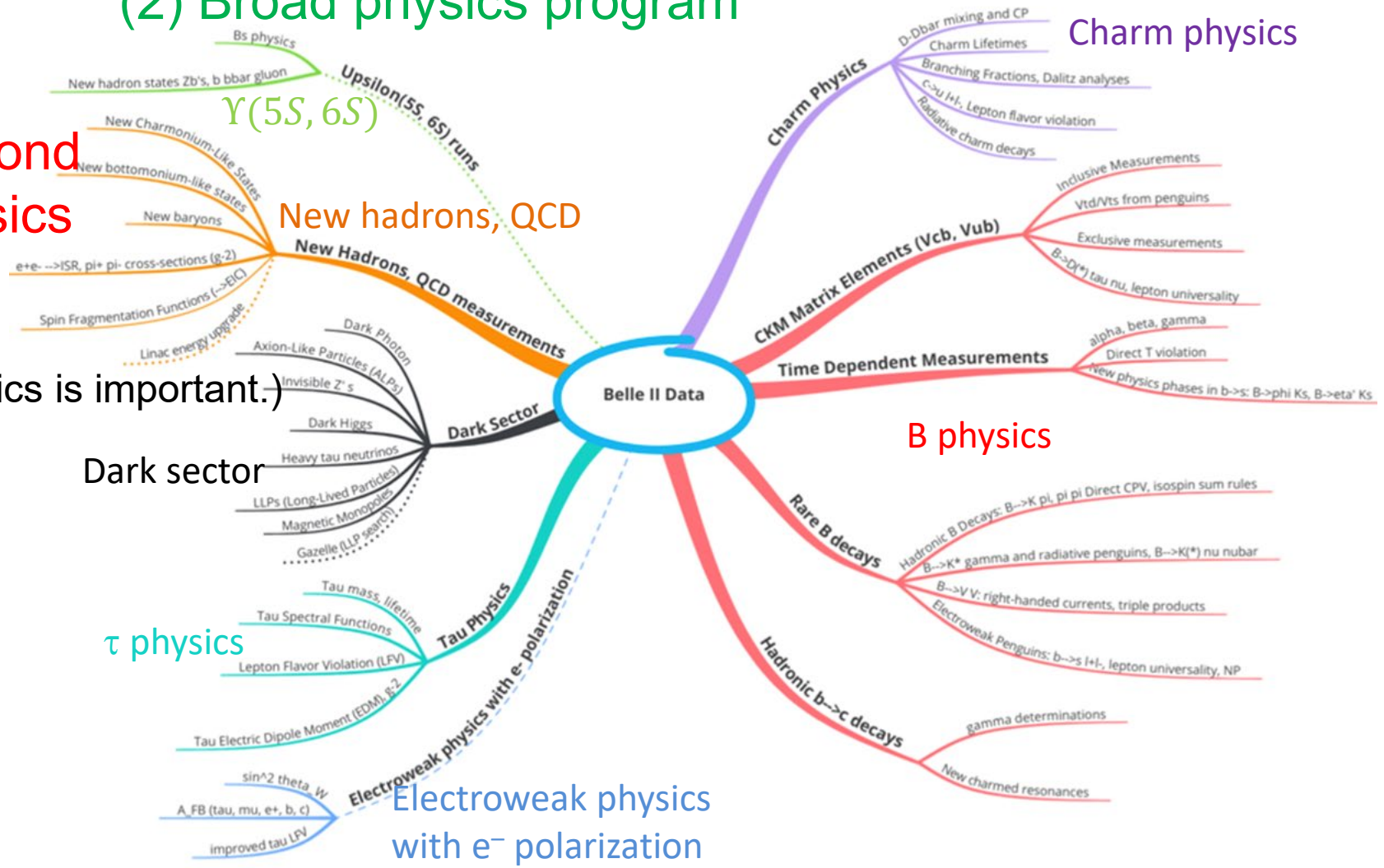
(Comprehensive search for BSM physics is important.)



(1) Large statistics

Billions of c, b, τ particles are produced in a clean environment at the SuperKEKB factory

(2) Broad physics program



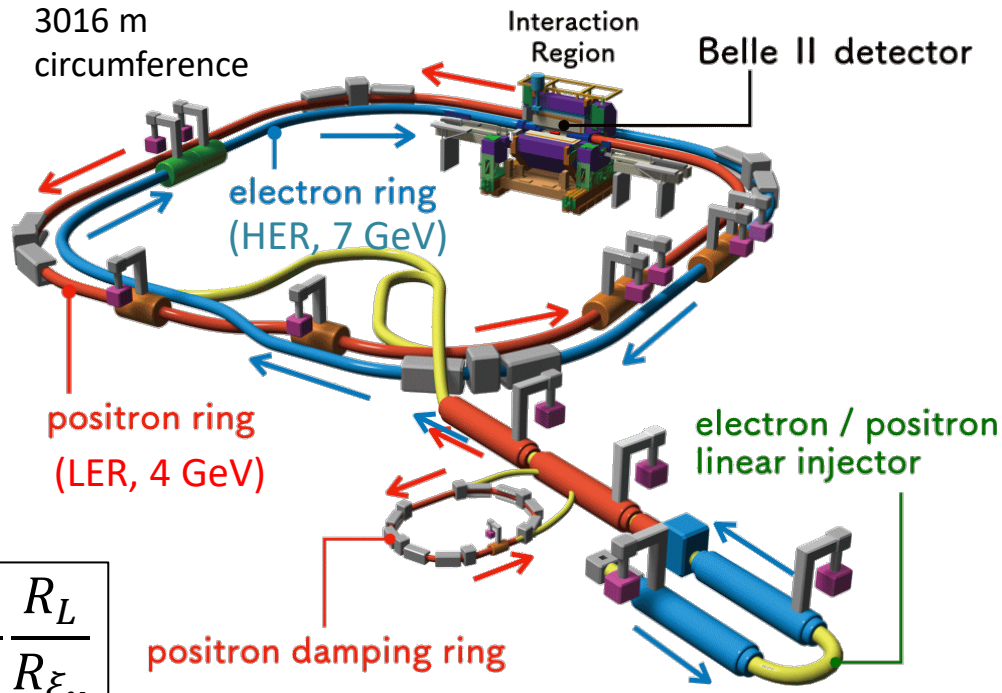
(3) High precision measurement

Access higher energy scales via quantum effects than are directly reachable at current or future colliders.

e.g. $\Lambda < \sim 1000$ TeV in B^0 mixing ($\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda^2}\mathcal{O}_{\Delta F=2}$) [arXiv:1302.0661]

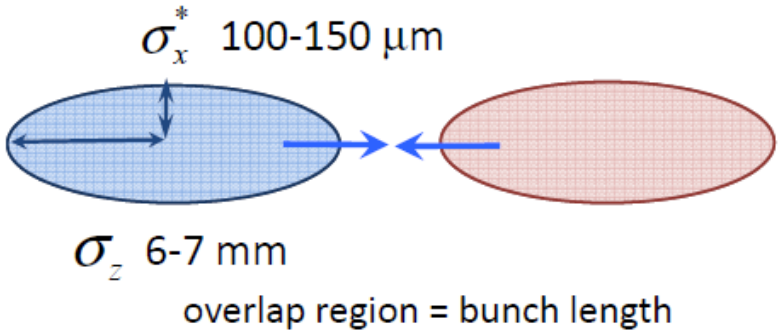
SuperKEKB

- Asymmetric e^+e^- collider operating mainly at the $\Upsilon(4S)$
- World's highest peak luminosity
  $\mathcal{L} = 4.7 \times 10^{34}$ cm^{-2}s^{-1} (= KEKB x 2.2 = PEP-II x 3.9)
  owing to
  - Nano-beam scheme
    - World's smallest vertical beam size at IP ($\sigma_y^* \approx 200$ nm)
  - Powerful injector Linac
    - Compensate the short beam lifetime due to narrow dynamic aperture

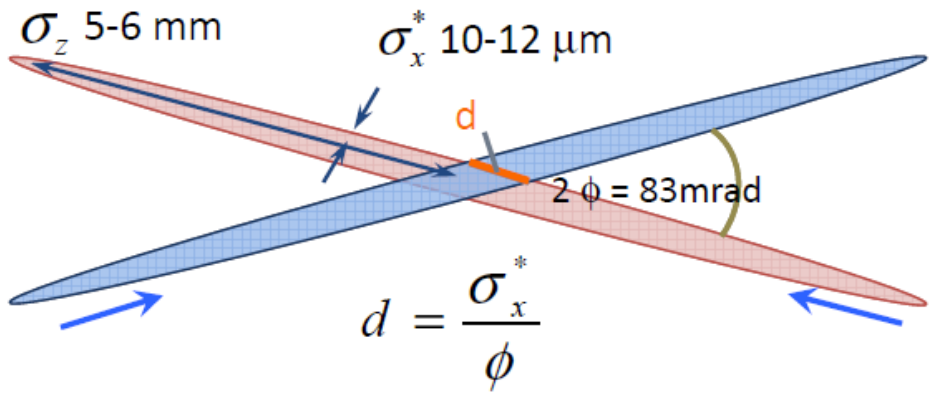


$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta^*_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

KEKB head-on (crab crossing)



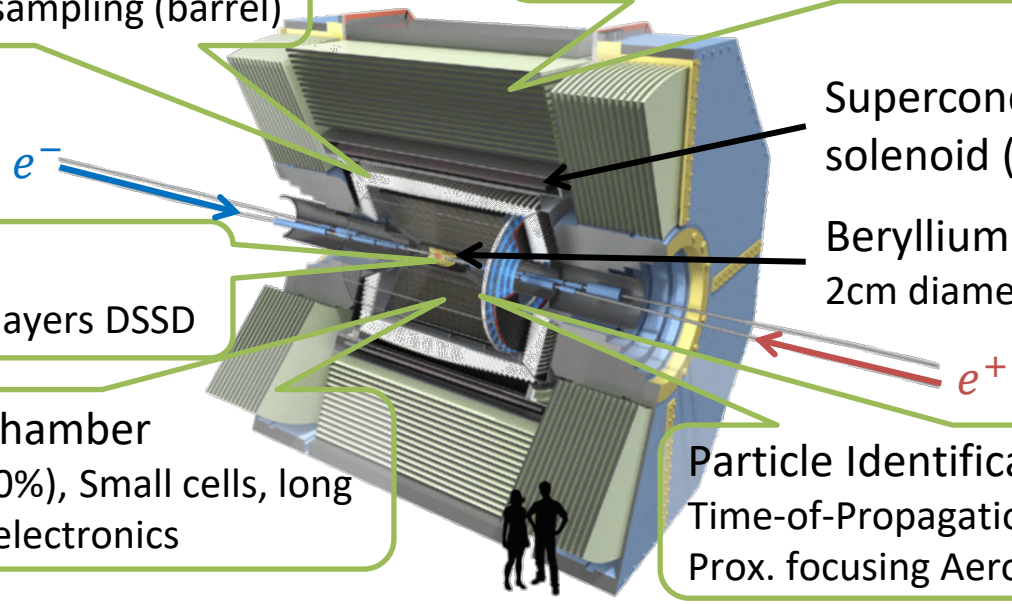
Nano-Beam SuperKEKB



Belle II detector

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

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



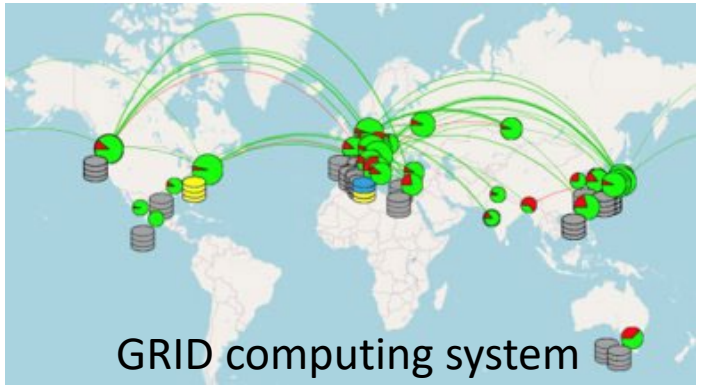
Superconducting solenoid (1.5 T)

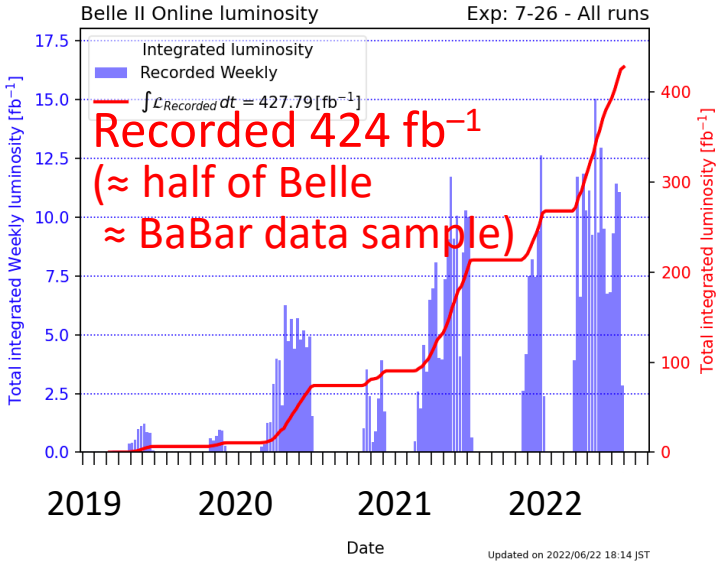
Beryllium beam pipe
2cm diameter

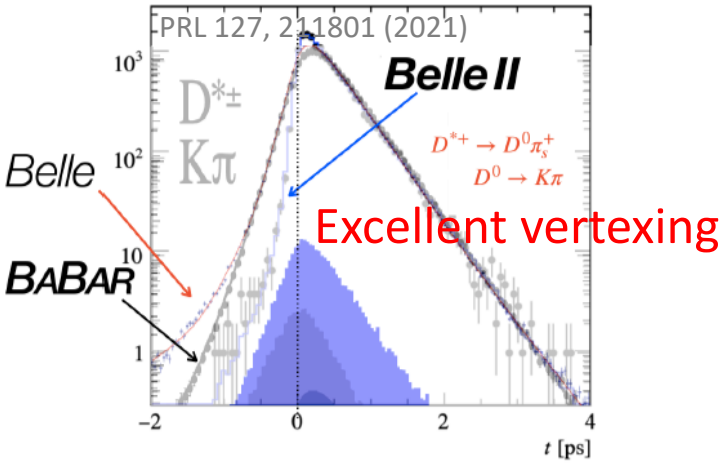
Vertex Detector
2 layers DEPFET + 4 layers DSSD

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

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

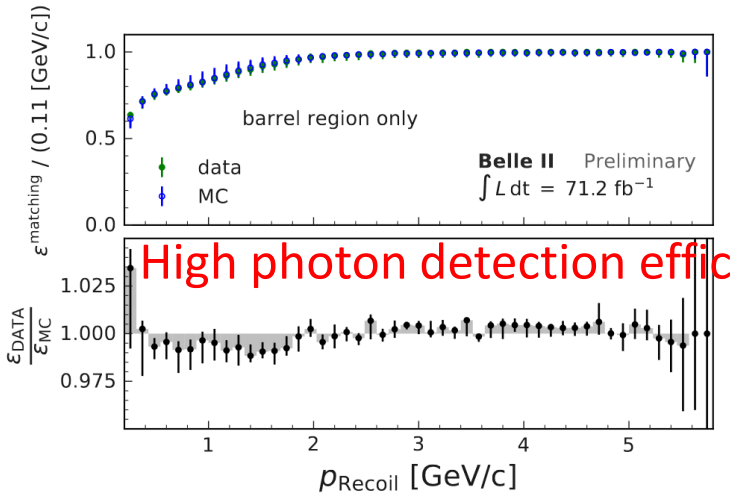






Excellent vertexing

Twice as good resolution as Belle



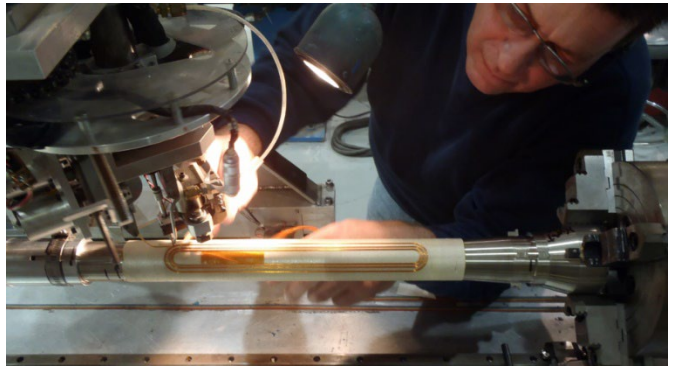
High photon detection efficiency

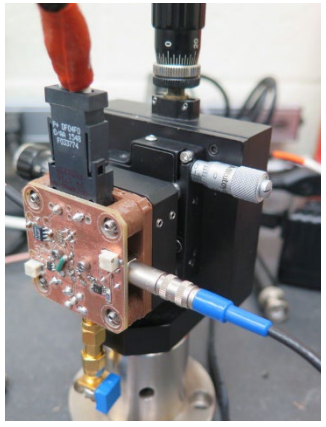
- Capable of reconstructing neutrals (π^0, K_L^0, η, etc) with high efficiencies
- Good lepton and hadron identification
- High trigger efficiency, including for low multiplicity events

US contributions and collaborations

SuperKEKB

Constructed



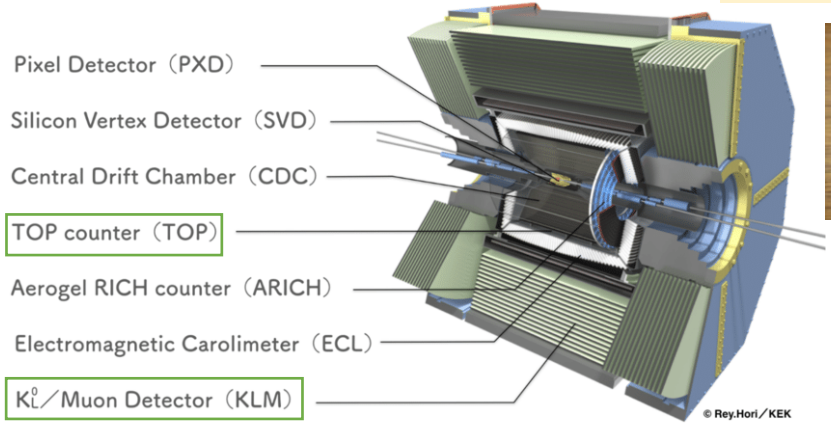


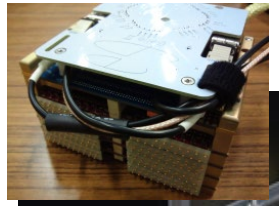
- QCS(*) corrector magnets by BNL
  * QCS: Final focusing system
- X-ray beam size monitor with SLAC and Hawaii
- Single stretched wire system to measure the field center and angle of Q magnets by FNAL
- Quadrupole field vibration measurement system with BNL
- Dithering feedback systems with SLAC
- Large angle beamstrahlung monitor with Wayne State

On-going

- Digital IP feedback system with SLAC
- Polarized electron source with BNL, JLab
- Spin rotator for polarized beams with BNL

Belle II





Constructed

- TOP detector quartz bars from US
- TOP front-end electronics by Hawaii
- Barrel KLM scintillator module by Virginia Tech (Scintillator by FNAL)
- KLM readout by Hawaii

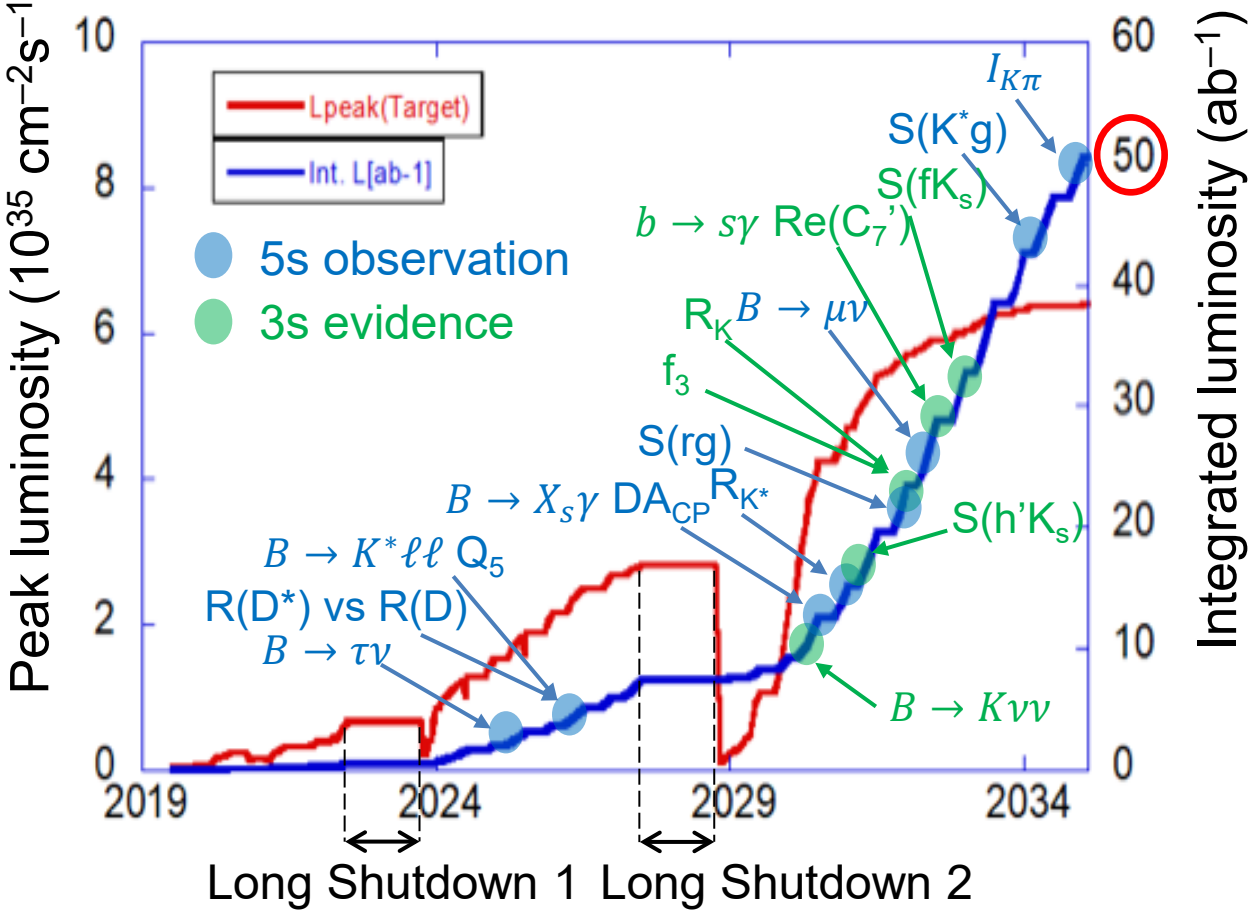
On-going

- Beam background study and mitigation
- Raw data center at BNL
- TOP/KLM operation: US Belle II universities
- TOP L1 trigger with Pittsburgh, Hawaii
- New readout ASIC for detector upgrade by Hawaii

Prospects toward 50 ab^{-1}

Boost up the peak luminosity

Squeeze $\sigma_y^* \approx 200$ nm → 50 nm, and increase $I \approx 1$ A → 3 A



1. Long shutdown 1 (Jul 2022 – Dec 2023)
   - Detector upgrade
   - Beam background mitigation
   - Improvement of beam injection
2. Run 2 (Dec 2023 –)
   - Extensive machine tuning and studies toward $\mathcal{L} = 2.4 \times 10^{35}$ cm^{-2}s^{-1} (≈ KEKB x 10)
3. Long shutdown 2 (To be confirmed)
   - Need new ideas and technology for upgrade of SuperKEKB interaction region to enable $\mathcal{L} = 6 \times 10^{35}$ cm^{-2}s^{-1}
     e.g. QCS (final focusing system) upgrade with Nb$_3$Sn

➢ Many challenges and R&D items ahead of us
→ Need more collaborative work in the framework of
   - SuperKEKB International Task Force
   - US-Japan Cooperation Program, etc.

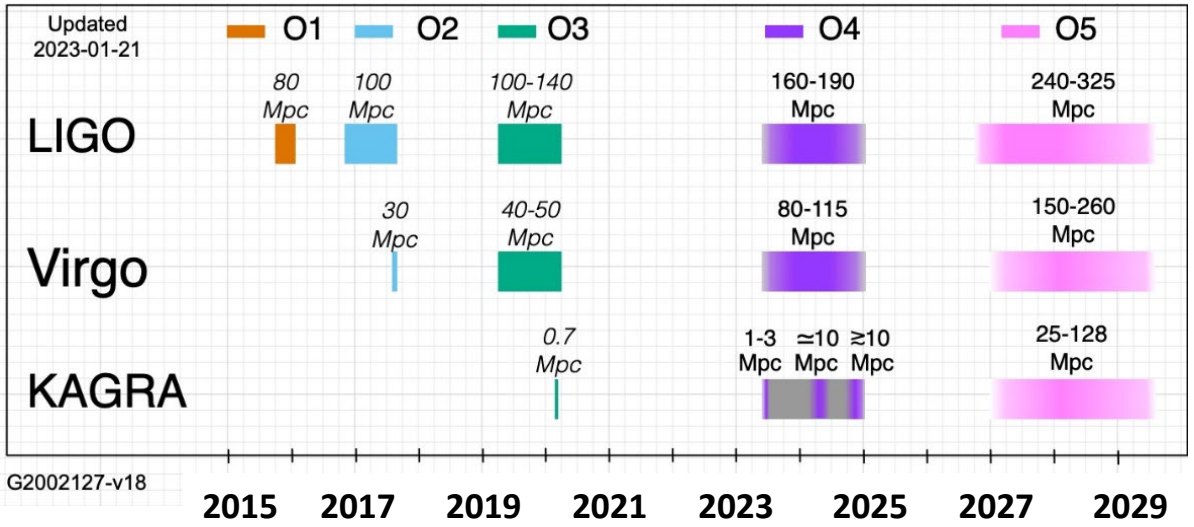
Many physics discoveries are expected.
Support of US colleagues and contributions to SuperKEKB/Belle II are appreciated.

Gravitational Wave Detection, KAGRA

ICRR, KEK, NAOJ

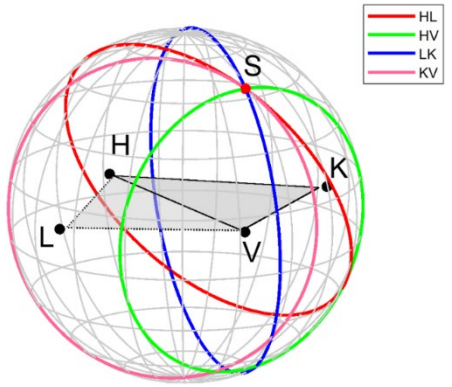
- 3km laser interferometer
- Underground site
  for low seismic noise
- Cryogenic sapphire mirrors
  to reduce thermal noise.

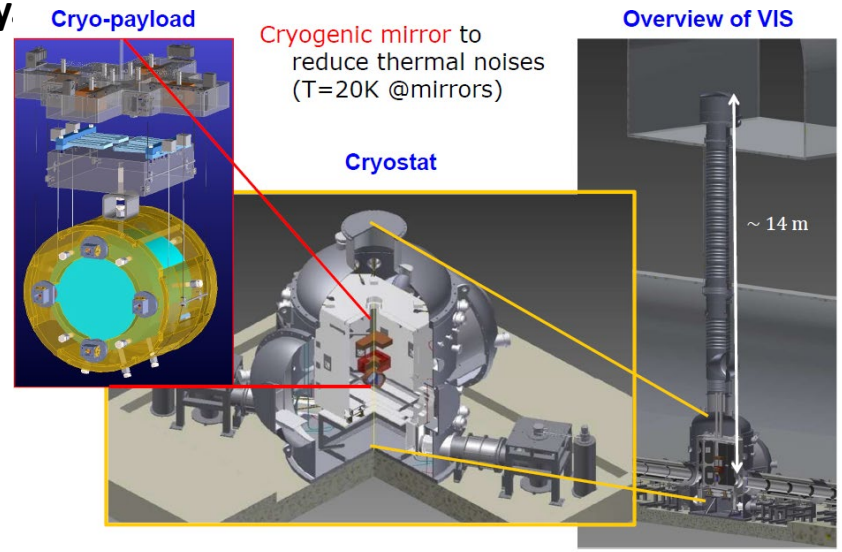
LIGO-Virgo-KAGRA Observing Run Schedule (O1-O5)



4th observing run (O4) is planned to start at May 24th 2023.

3 or more detectors are necessary to determine source location accurately.
KAGRA is 4th detector.





Conclusions

- KEK is starting the ILC Technology Network with the labs in the world for the implementation of time-critical ILC development. MEXT has doubled the budget for this purpose, which is expected to last for five years.
- KEK, jointly with IDT, will make every effort to reach out to the physics community around the world so that the ILC can be realized as a global project. In addition, we are working strategically with the supporting organizations to gain broad consensus in Japan so that we can host the ILC.

- The physics program of Belle II has outstanding potential for discovering BSM physics over the next decade.
- KEK will continue efforts to push the peak luminosity and to secure operation time.
- The broad program of Belle II physics as well as the exciting possibility of BSM physics discoveries in searches unique to Belle II will be enhanced by US investment in Belle II and SuperKEKB and their upgrades.
- See also the talk by Jake Bennett at P5 town hall meeting in Chicago: https://indico.fnal.gov/event/58272/
- Many opportunities for initiatives by early career researchers.

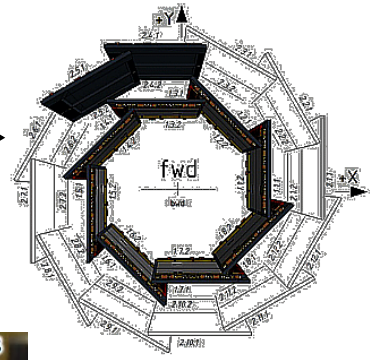
Backup

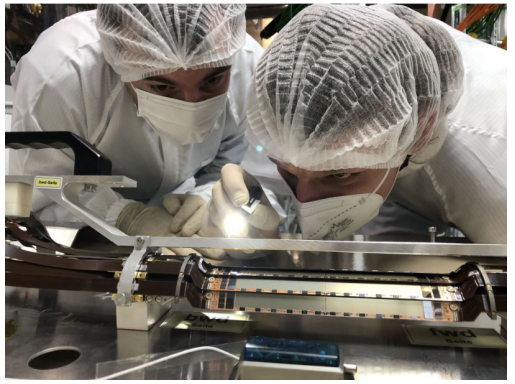
(from July 2022 until December 2023)

Major upgrades in Long Shutdown 1

Belle II detector upgrade

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

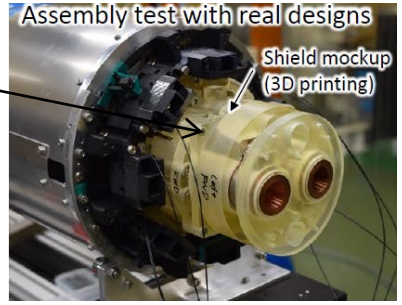




PXD2 arrived at KEK on Mar. 16.

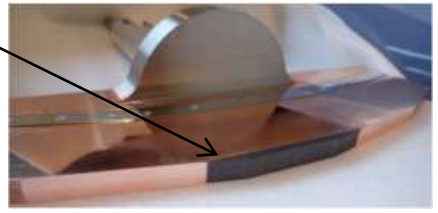
Beam background mitigation

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



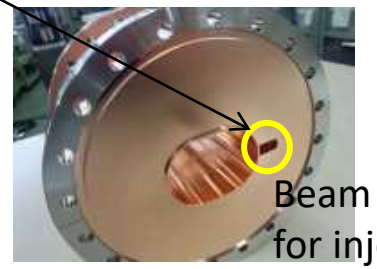
Protection of machine and Belle II

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



Improvement of beam injection

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



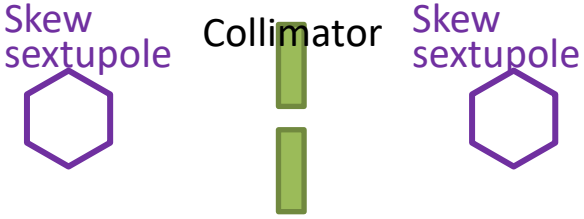
Beam channel for injection

* QCS: Final focusing system

Non-linear collimator

Beam kick by skew sextupole:

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



The beamline for the non-linear collimator is under construction.