KEK, High Energy Accelerator
Research Organization

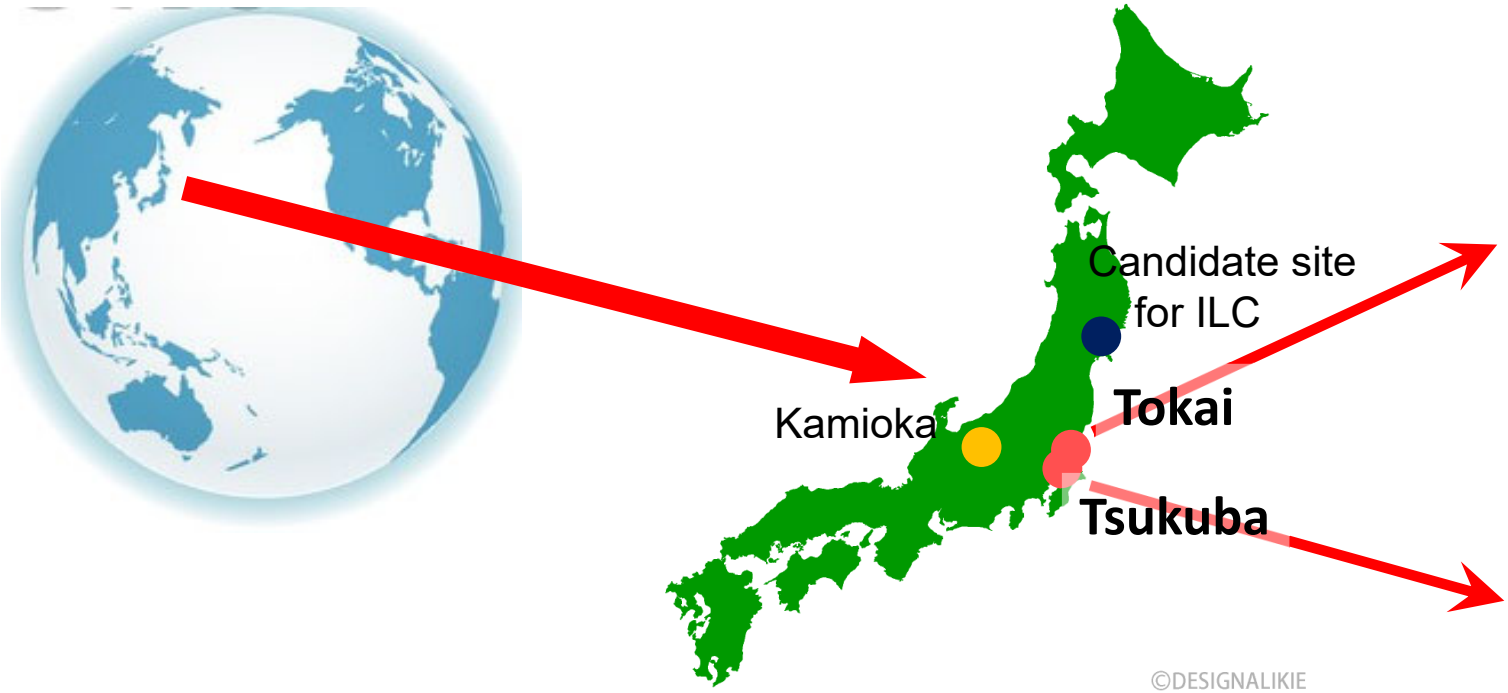
Report from KEK

At US-Japan Meeting 2023 in Hawaii

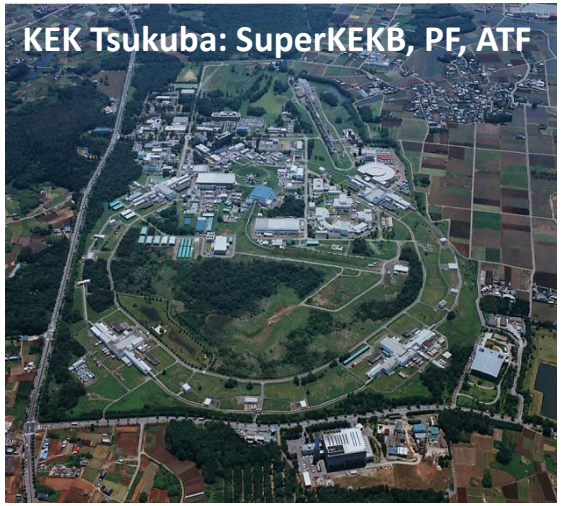
May 22, 2023

M.Yamauchi
KEK

KEK Geography

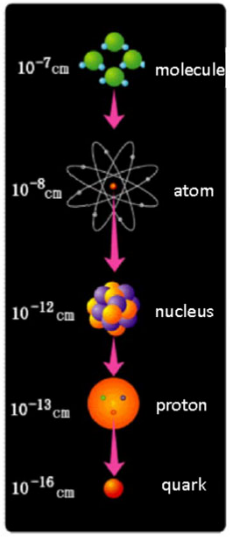


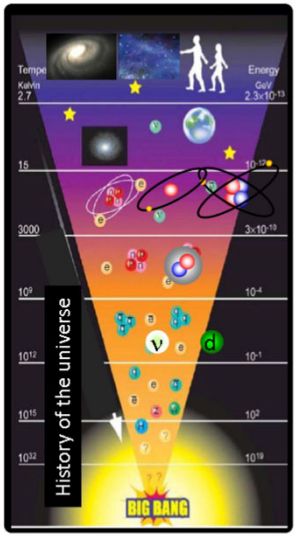
J-PARC: high intensity proton accelerator complex jointly operated by KEK and JAEA



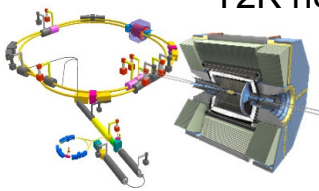
Diverse accelerator-based science and technology at KEK

Pursuing fundamental laws of nature



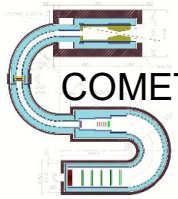


T2K neutrino exp.



SuperKEKB and Belle II

J-PARC Hadron hall



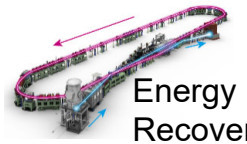
COMET

Basic science / Material science and its applications

KEK

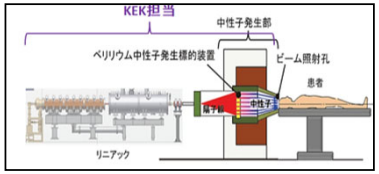
Technical development and its applications

Nano-beam technology



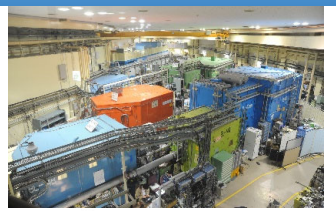
Energy Recovery linac

Superconducting accelerator

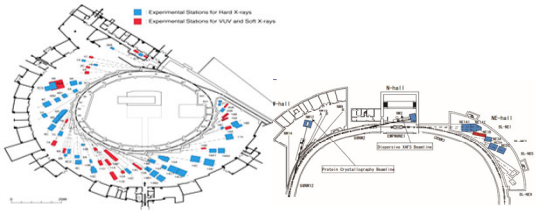


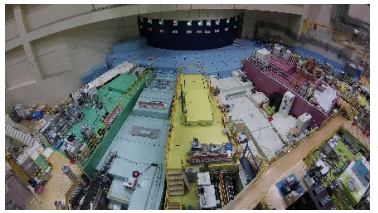
Accelerator-based BNCT

Pursuing origin of function in materials

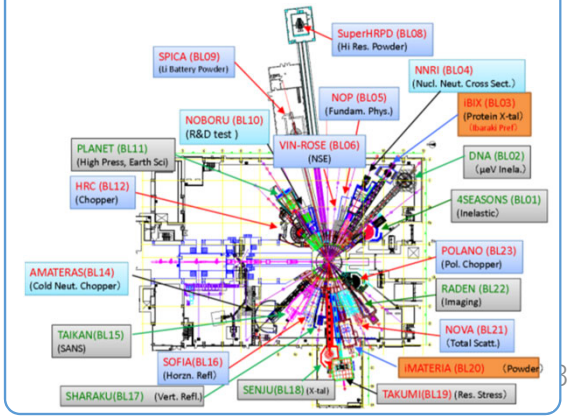


Photon factory X-ray as a probe





J-PARC MLF neutron and m as a probe



Particle physics program at KEK

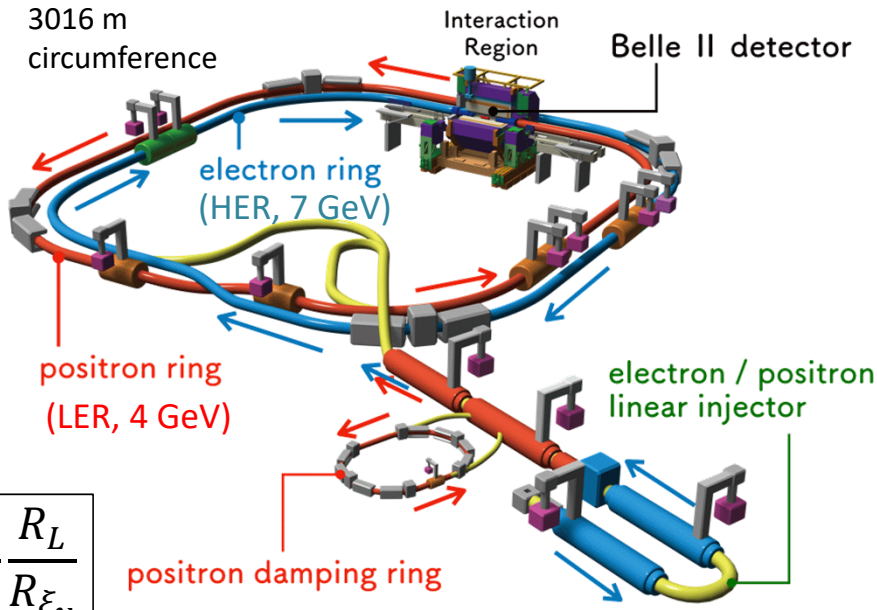
- On-going experiments at KEK
  - Flavor physics using high intensity proton beam at J-PARC
    - KOTO ($K_L \to \pi^0 \nu\nu$)
    - COMET (μ-e conversion)
    - μ g-2/EDM
  - Belle II at SuperKEKB e^+e^- collider
  - T2K long baseline neutrino experiment

- Experiments conducted jointly with the other institutions
  - HyperKamiokande
  - KAGRA
  - LiteBIRD

- International Linear Collider (ILC)

KEK

SuperKEKB

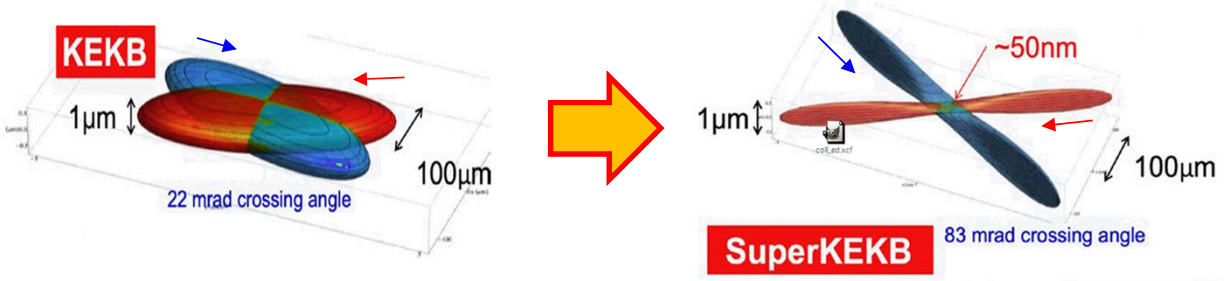


- Asymmetric e^+e^- collider operating mainly at the $\Upsilon(4S)$
- World's highest peak luminosity
  $\mathcal{L} = 4.7 \times 10^{34}$ cm^{-2}s^{-1} (= KEKB x 2.2)
  owing to
  - Nano-beam scheme
    - World's smallest vertical beam size at IP ($\sigma_y^* \approx 200$ nm)

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

  - Powerful injector Linac
    - Compensate the short beam lifetime due to narrow dynamic aperture

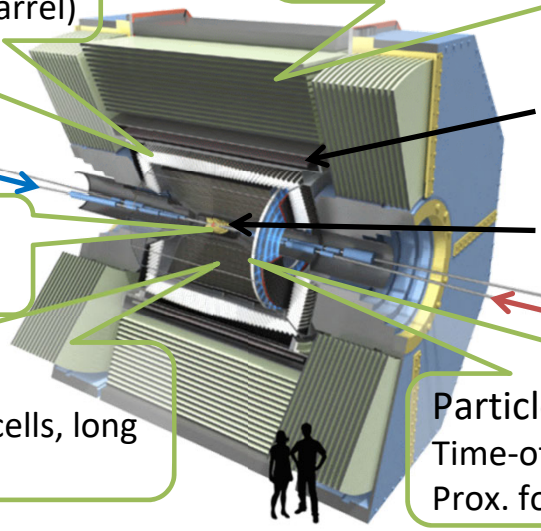
Nano-beam collision scheme



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)



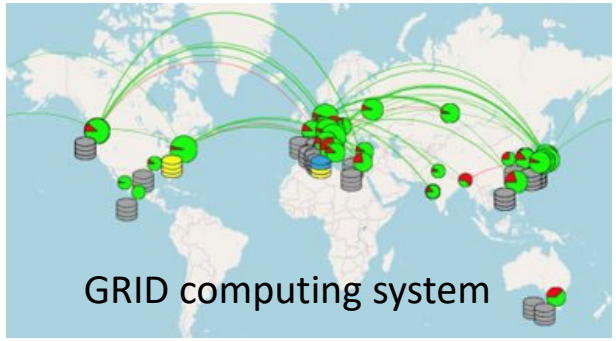
Superconducting solenoid (1.5 T)

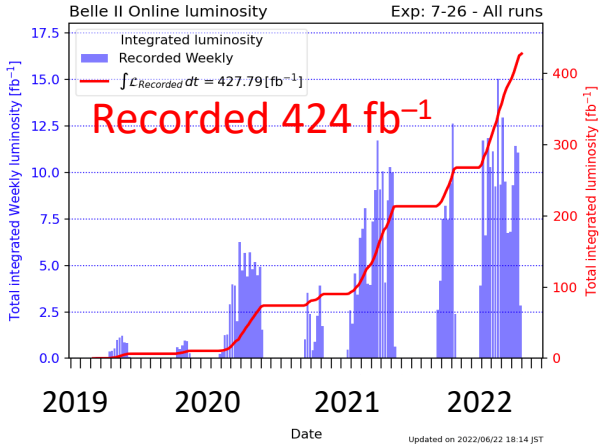
Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

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

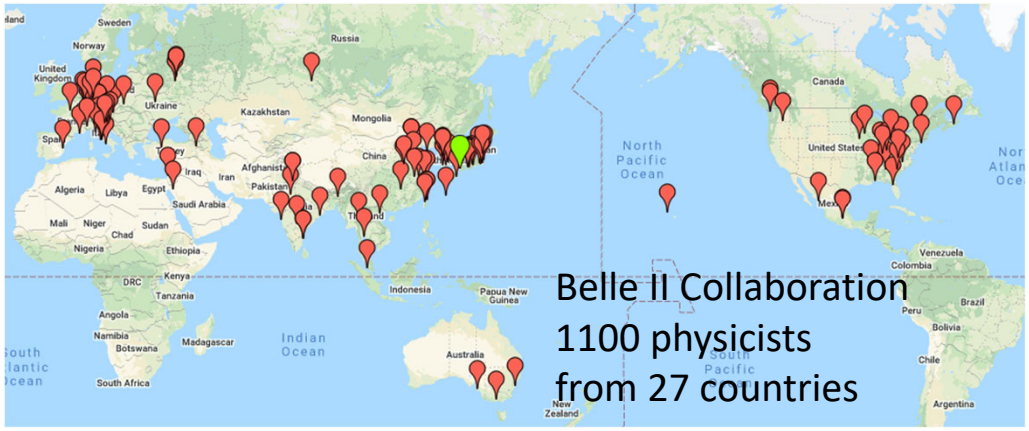
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)





Performance optimized for B, D and τ physics

- 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

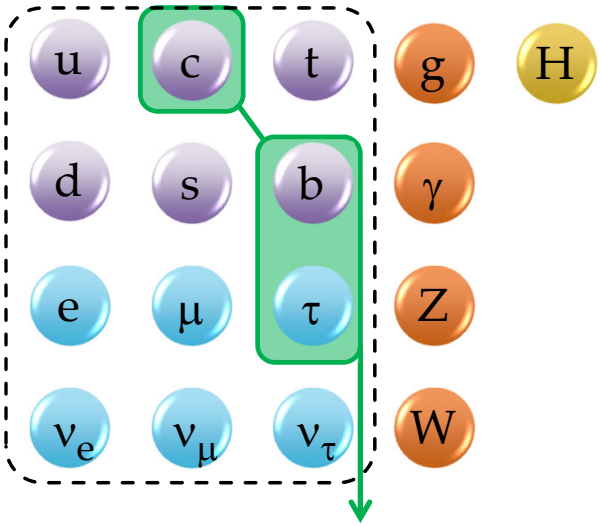


Physics at Belle II

Goal: Uncover BSM (Beyond the Standard Model) physics

Standard Model particles

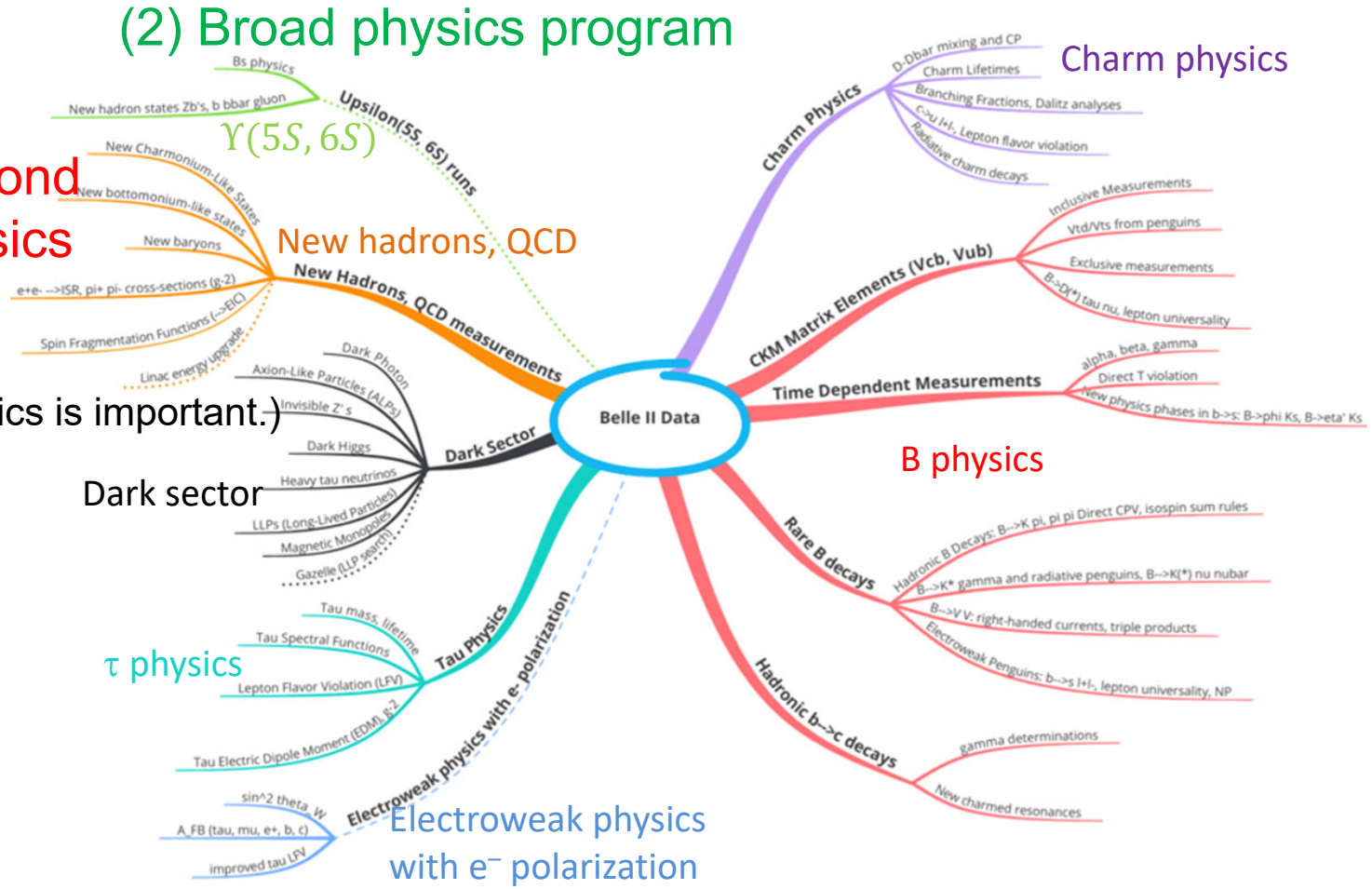
(Comprehensive search for BSM physics is important.)



(1) Large statistics

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

(2) Broad physics program



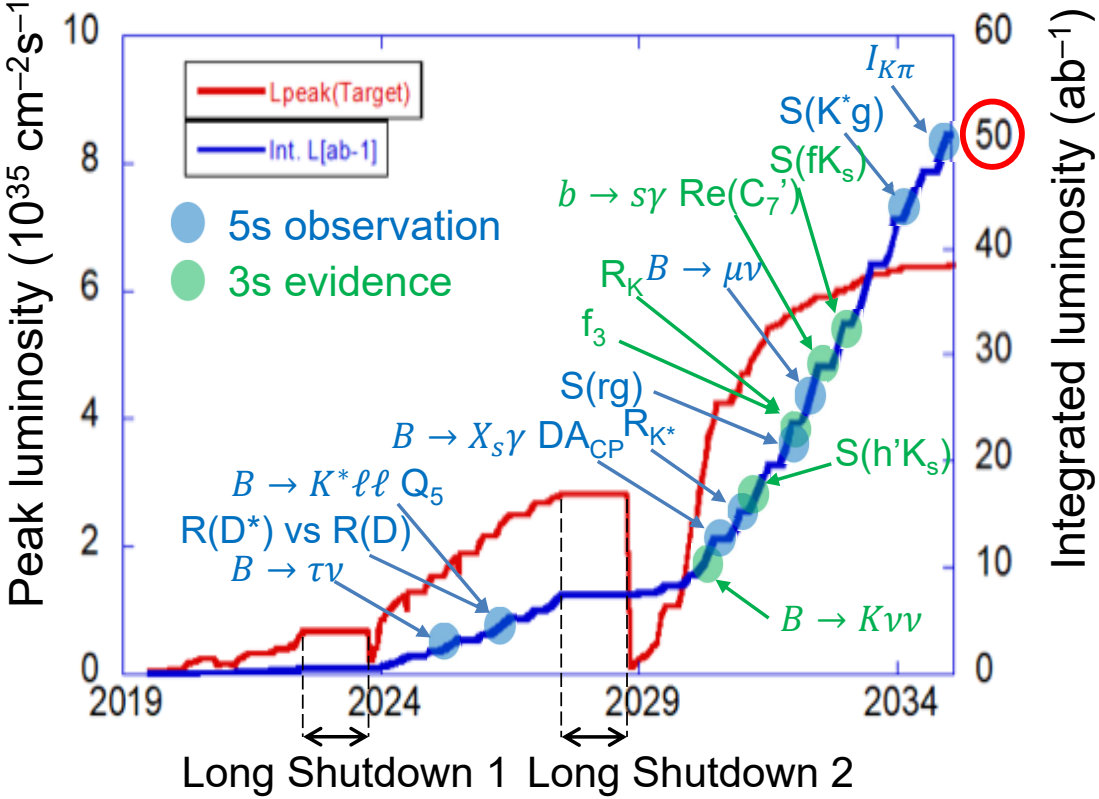
(3) High precision measurement

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]

Future outlook of SuperKEKB/Belle II

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



Boost up the peak luminosity

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.

High Intensity Proton Accelerator Complex operated jointly by KEK and JAEA

- Hadron hall:

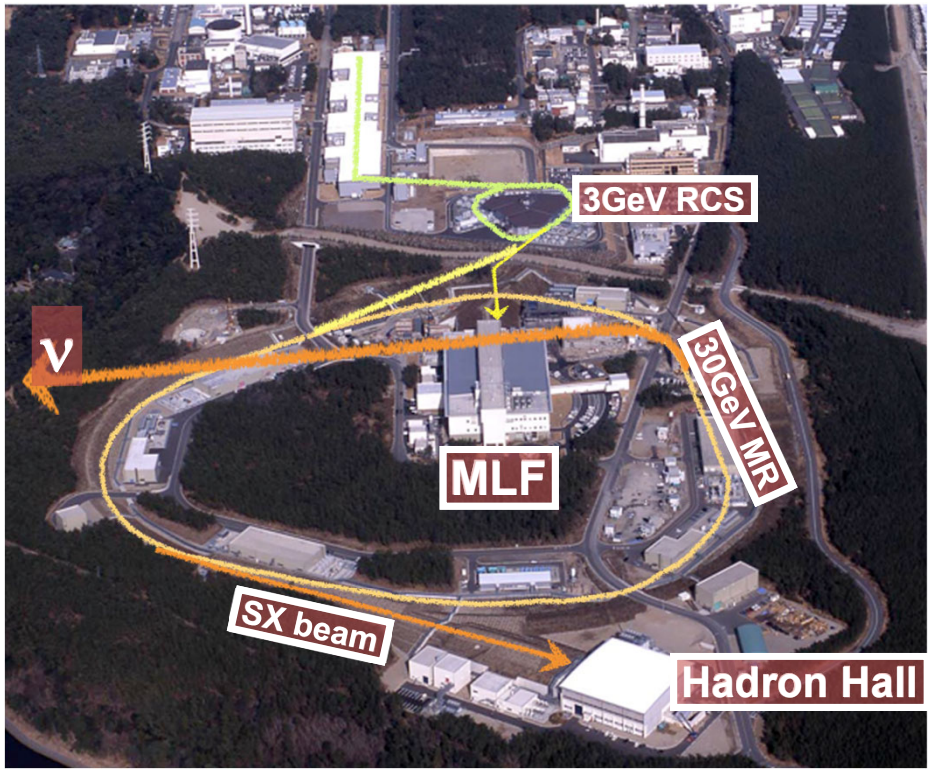
  Particle and nuclear physics experiments with fixed target

- Neutrino facility:

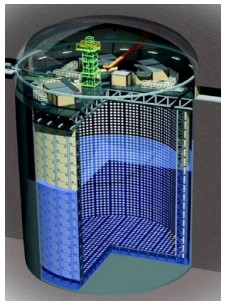
  Neutrino beamline for T2K and upgrade program for HyperKamiokande

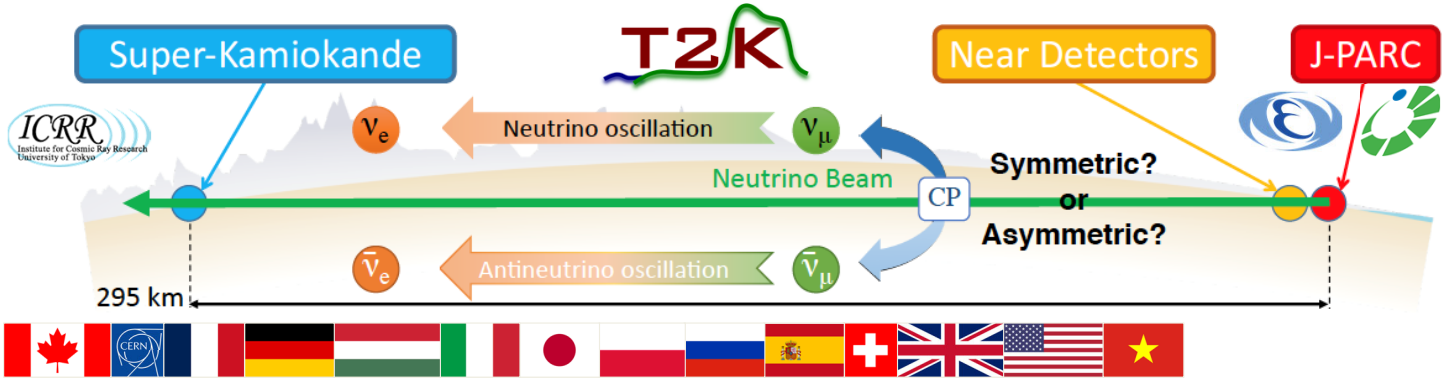
- MLF:

  Material and life science experiments with neutron and muon probes. Muon g-2/EDM experiment will be done at MLF.

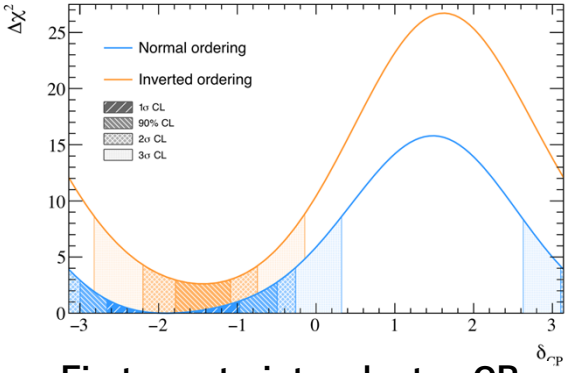


T2K: Long baseline neutrino oscillation experiment

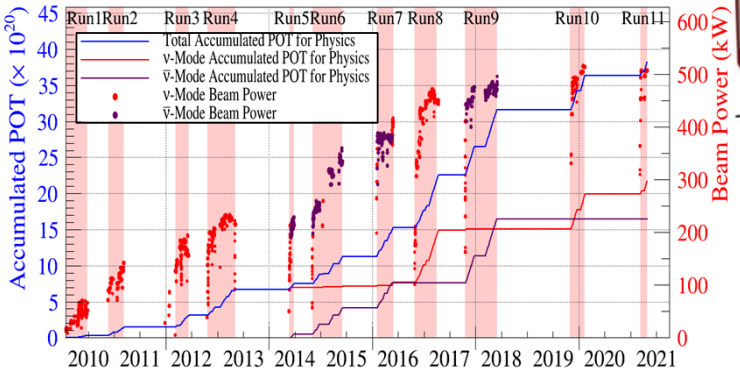


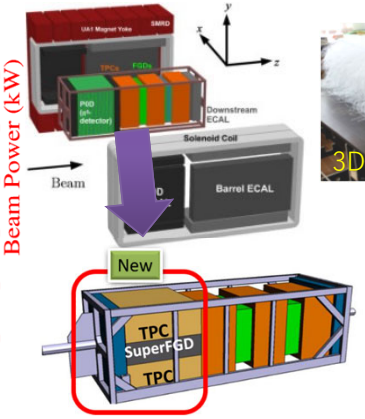


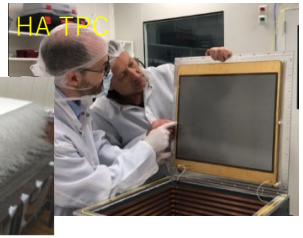
~470 members, 74 Institutes, 13 countries



First constraint on lepton CP asymmetry has been obtained.







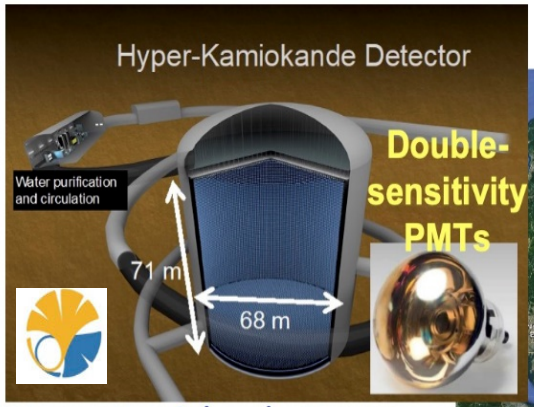
High power neutrino beam; ~520kW (achieved)

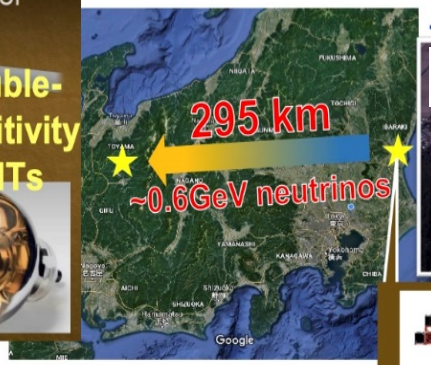
→ **Intensity upgrade up to 1.3MW**
& Near-detector upgrade are on going.

Precise measurement with doubled data by ~2026 is expected.

HyperKamiokande by U.Tokyo

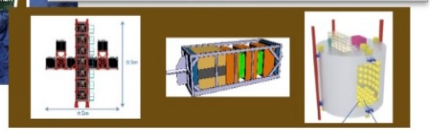
- Project
  - 190kt-FV Hyper-Kamiokande Detector (UT)
  - Upgrade of J-PARC to 1.3MW (KEK)
- Physics goals
  - CPV in neutrino sector
  - Search for proton decay
  - Atm-nu, solar-nu and supernova nu
- International project hosted by U.Tokyo & KEK
- **Funding approved and construction started in 2020**
  - Preparation of cavern excavation, production of PMTs started
  - J-PARC upgrade on-going
- Aiming to start operation in 2027.





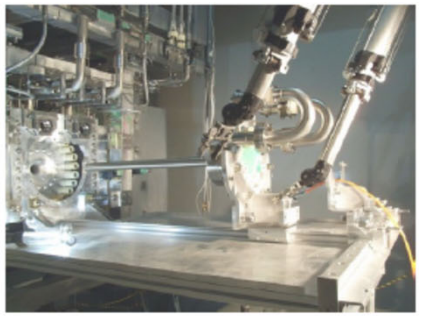
Hyper-Kamiokande Detector

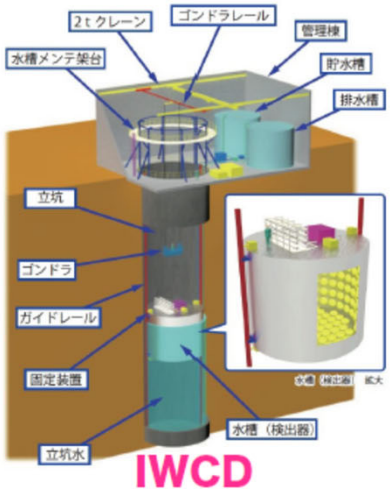
High power proton beam
J-PARC and near detectors



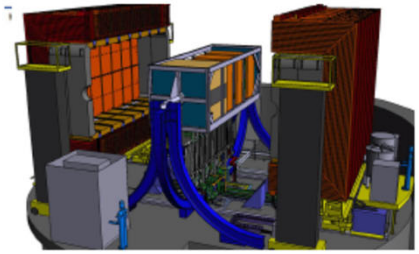
KEK's role in HyperKamiokande program

Neutrino beamline



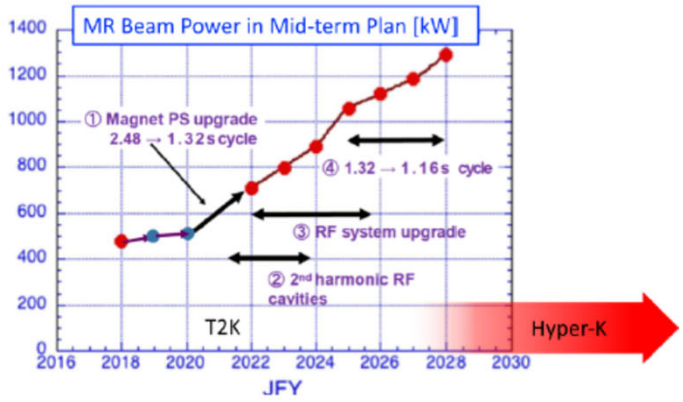


IWCD



ND280

J-PARC Accelerator



- **J-PARC Accelerator/Beamline upgrade**
  - Beam power = 0.5 MW → 1.3 MW (x2.6)
- **J-PARC Near Neutrino detector upgrade**
  - ND280 upgrade, Intermediate Water Cherenkov Detector (IWCD)

μ program at J-PARC

- COMET at Hadron hall

Search for $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$

By measuring delayed monochromatic e^-

Staging approach

Phase-I (2022~): BR < 10^{-14}

with 8GeV 3.2kW beam x 150 days

Phase-II: BR <10^{-16}

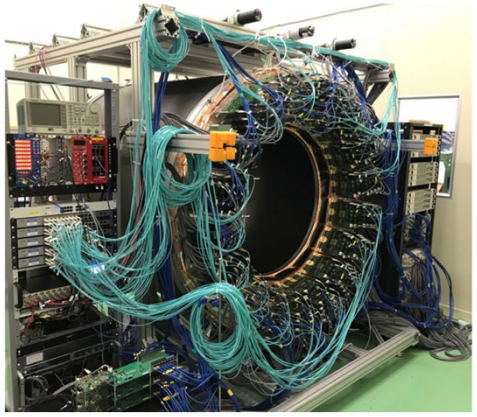
- g-2/EDM at MLF

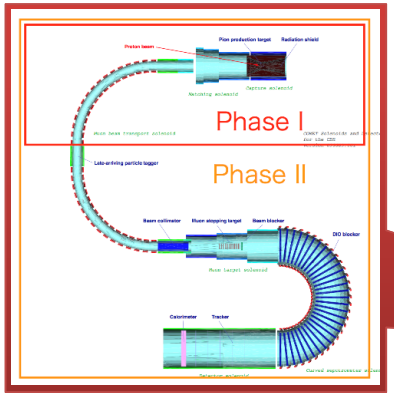
New principle of measurement

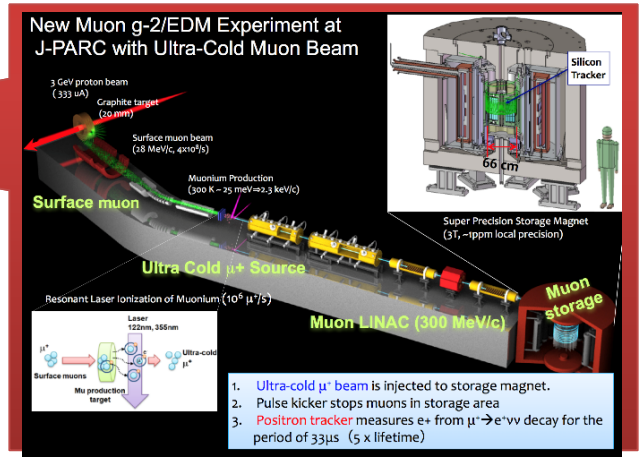
Goal

g-2 : 0.5 ppm → 0.1 ppm

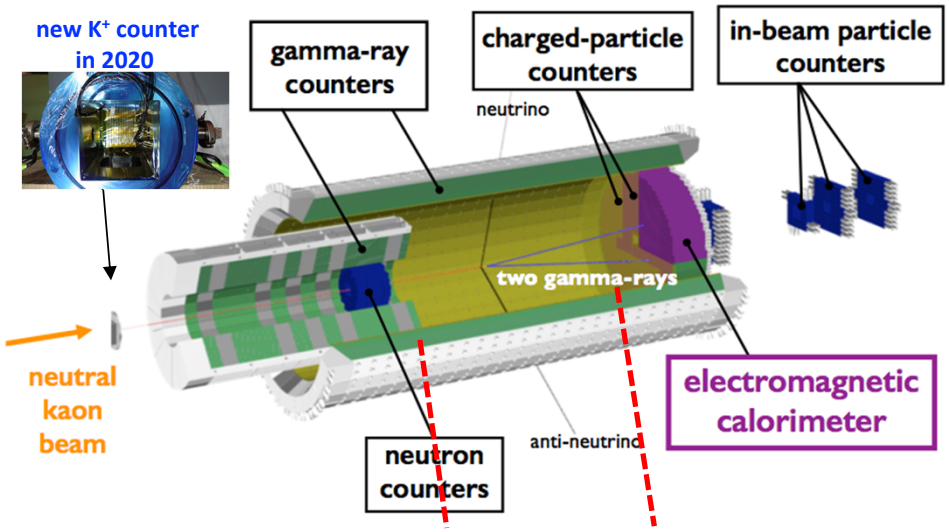
EDM:< 1.8 x 10^{-19} e cm ➔ 2 x 10^{-21} e cm





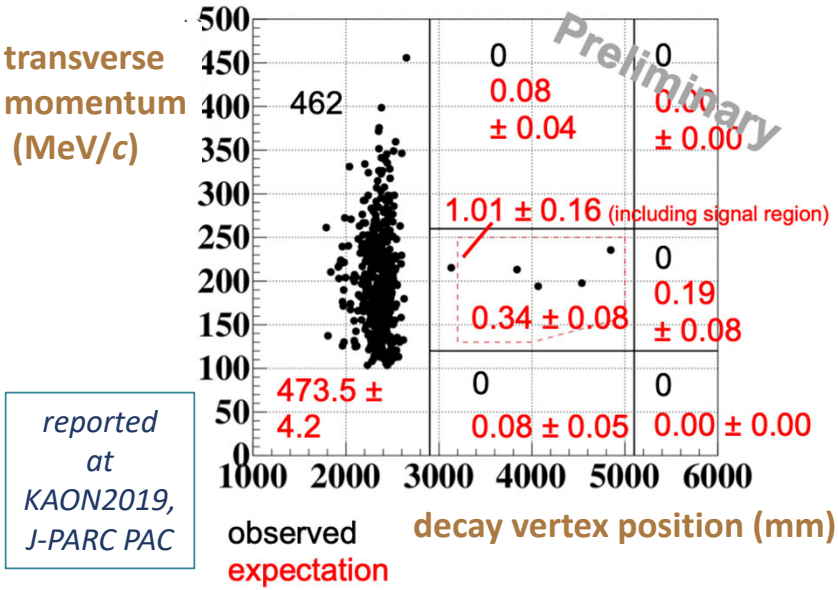


KOTO: Search for $K_L \to \pi^0 \nu\bar{\nu}$



- directly CP-breaking decay
- rare in the SM: 3.0 x 10^{-11}
- sensitive to New Physics,
  including $K_L \to \pi^0 X^0$ (light dark boson)

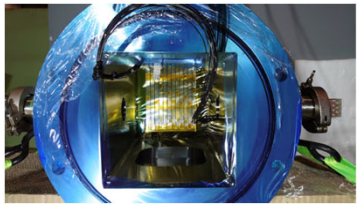
no candidate event in 2015 data;
upper limit 3.0 x 10^{-9} (90% CL)



reported at KAON2019, J-PARC PAC

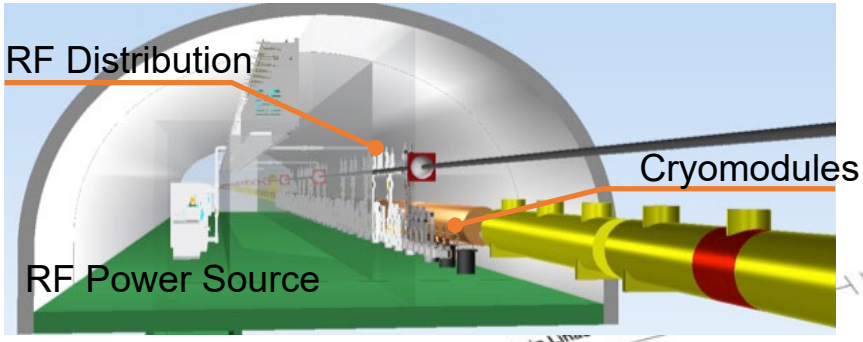
four candidate events in 2016-18 data, with the sensitivity of 7 x 10^{-10}

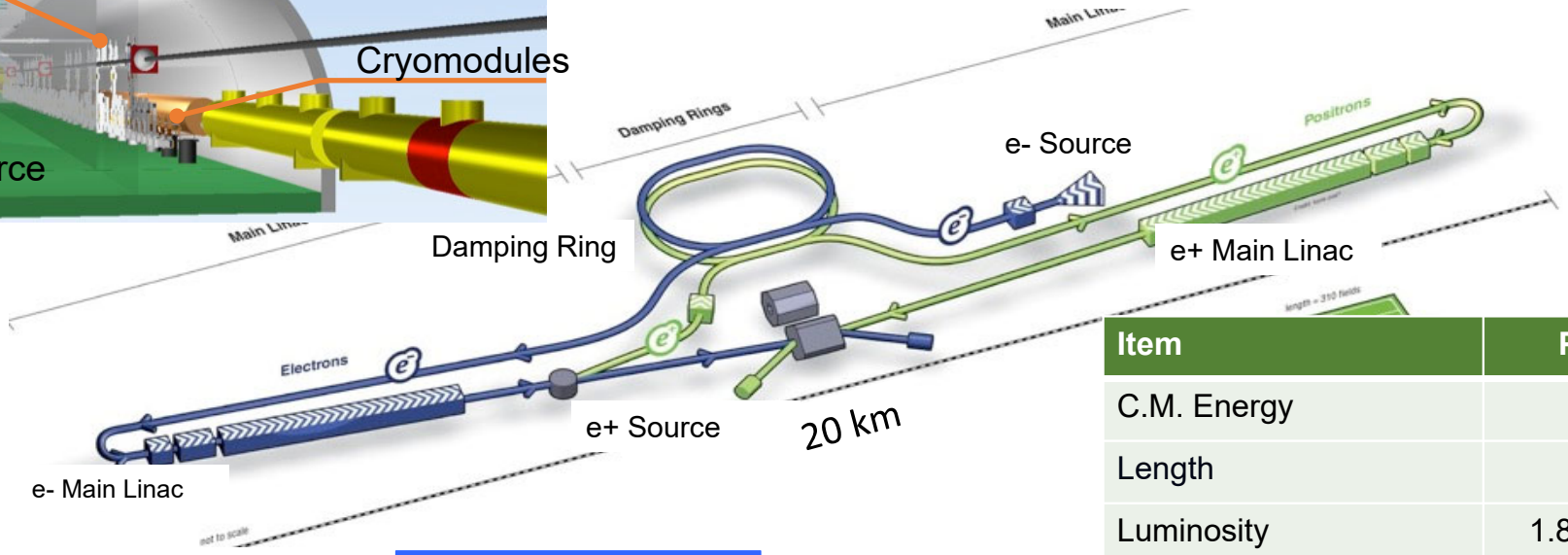
Possible background from K^+ in the KL beam
- Now measuring K^+ flux in the KL beam
- Planning to improve the detector to suppress the background.

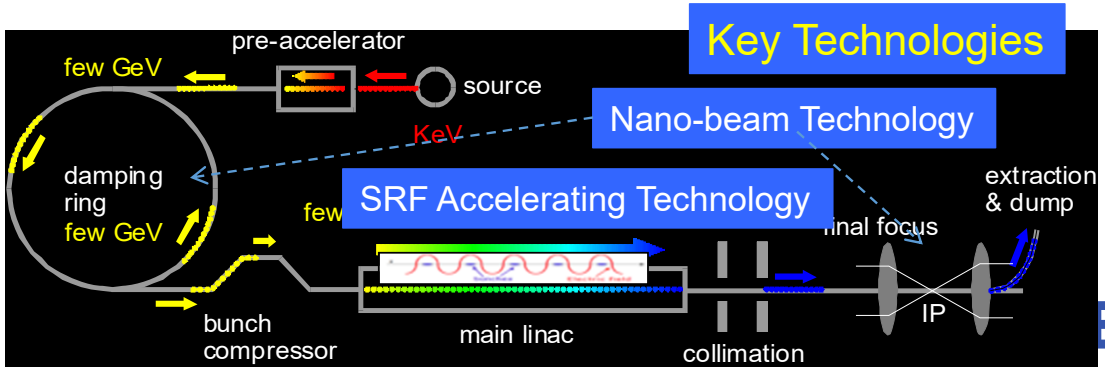


US: DAQ upgrade for higher data rate

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.

KEK

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 such as ILC should be appropriately supported. In this regard, 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.

- The International Development Team (IDT) has been established under ICFA to promote the ILC.

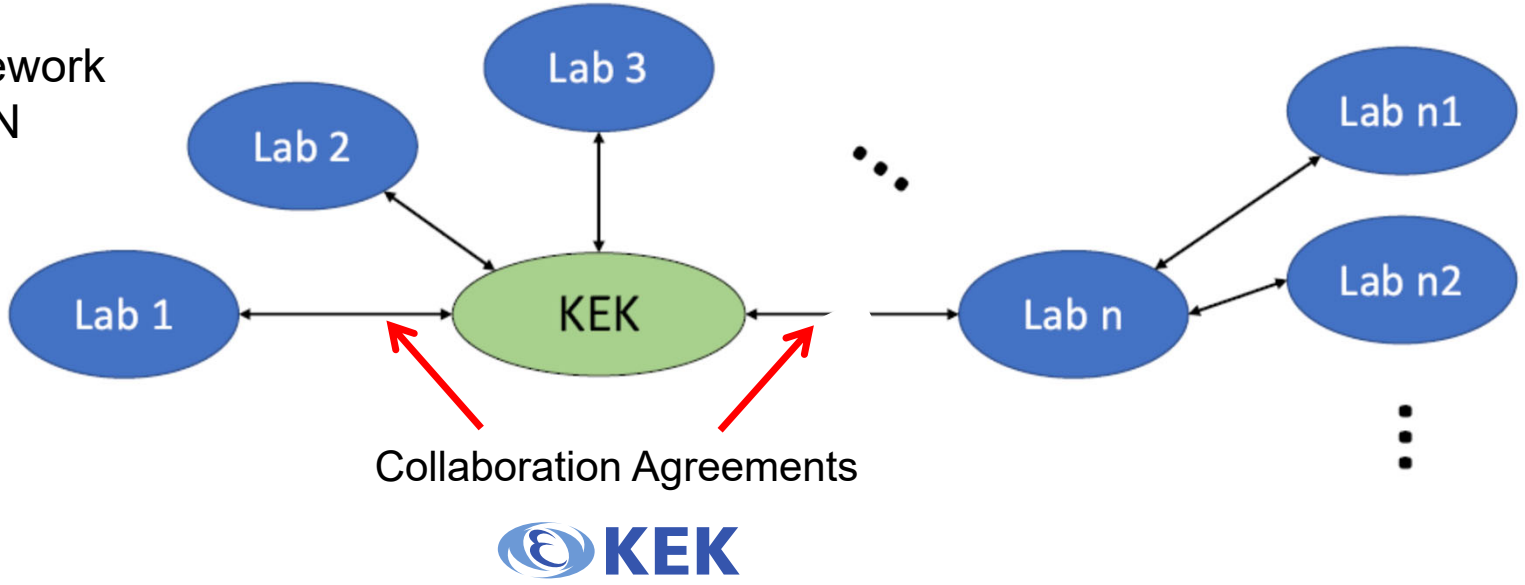
- KEK's stance on ILC
  - We will strive to realize the ILC as a global project in collaboration with IDT and the physics communities in the world.
  - In addition, we are working strategically to gain broad consensus in Japan so that we can host the ILC with the support of the Federation of the Diet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

KEK

Starting up the ITN

- The ITN is jointly initiated by KEK and IDT based on the institutional engagement.
- Discussions have been made with the laboratories worldwide to solicit their participation in the activities.
- It will be launched by agreements between KEK and a partner laboratory which define the deliverables and obligations.

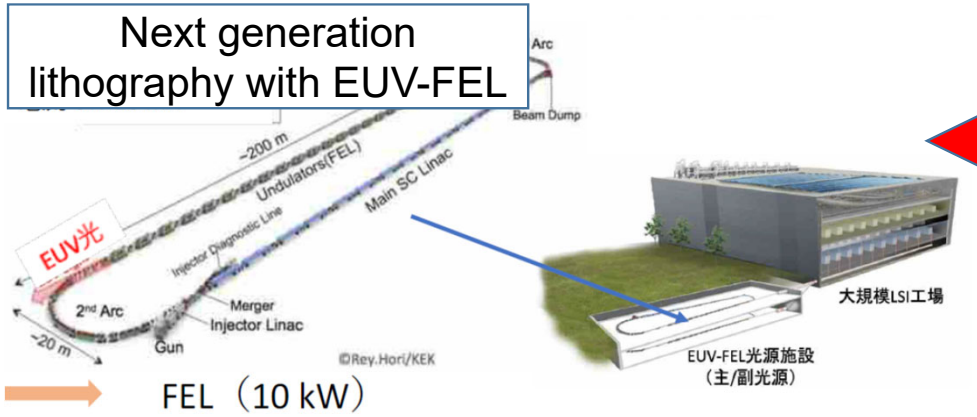
Proposed framework of the ITN



KEK

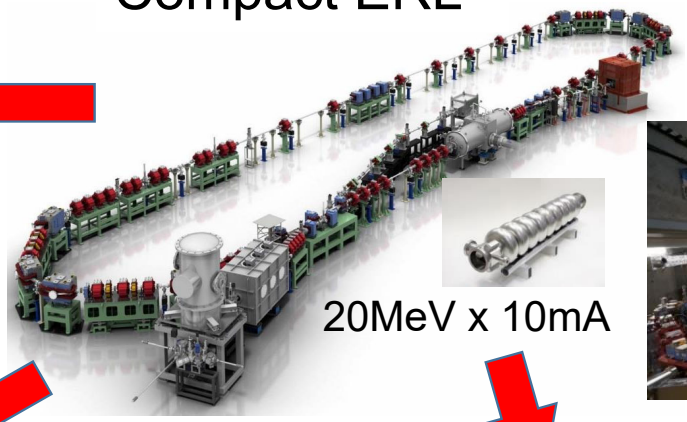
Industrial application of superconducting accelerator

Next generation lithography with EUV-FEL



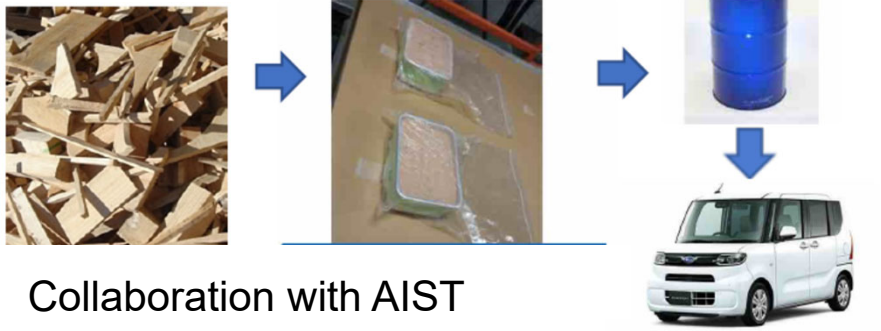
FEL（10 kW）

Compact ERL



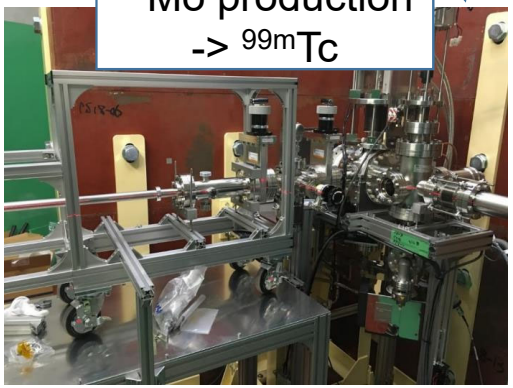
20MeV x 10mA

Bio-ethanol production from wood



Collaboration with AIST

^{99}Mo production -> ^{99m}Tc



High purity ^{99}Mo was extracted in the initial test.

Summary and conclusions

- KEK covers diverse accelerator-based science and technology. Among these, high-energy physics is a centerpiece research field at KEK, and for this purpose, we have the multi-purpose high-intensity proton accelerator complex J-PARC and the high-luminosity electron-positron collider SuperKEKB, where various research programs are being pursued with physicists from the U.S. and around the world.
- In neutrino physics, the ICRR of the University of Tokyo is constructing the Hyper-Kamiokande, which, together with the upgrade of J-PARC at KEK, will dramatically increase the sensitivity of CP non-conservation measurements in neutrinos. This new experiment is scheduled to start in 2027.
- In addition, experiments on μ and neutral K mesons using high-intensity proton beams are being conducted in the Hadron Hall at J-PARC.
- The Japanese physics community and KEK proposed to host the ILC in Japan, which is being considered for realization as a global project. Meanwhile, the International Development Team (IDT) has been established under ICFA to promote the ILC, and Japanese researchers are in discussions with European and U.S. institutions to establish an ILC Technology Network (ITN) in cooperation with the IDT.

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