Status and prospects of KEK research activities

Yasuhiro Okada (KEK)

April 14, 2023

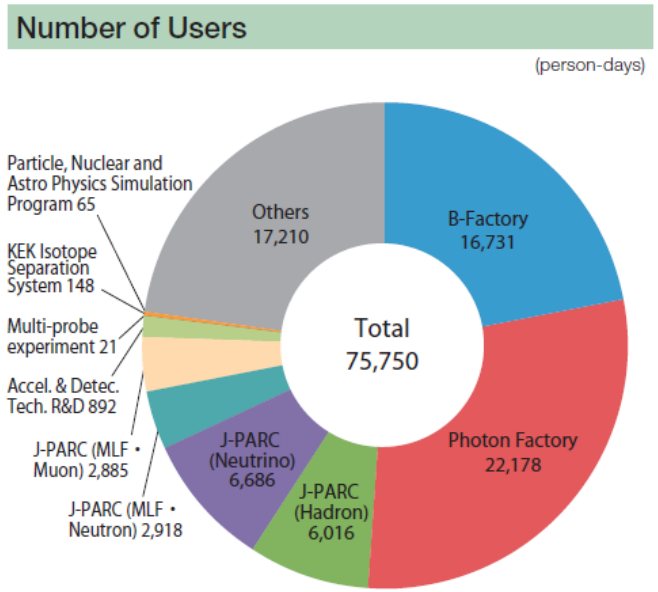
Asian Forum for Accelerators and Detectors 2023, Melbourne

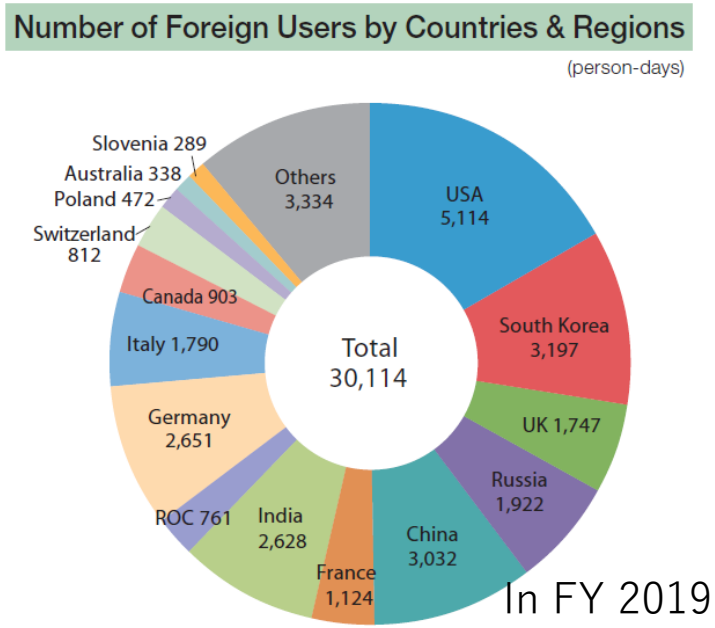
Insight through Accelerators.

KEK

High Energy Accelerator Research Organization (KEK)

- KEK is an Inter-University Research Institute Corporation, first established in 1971 as National Laboratory for High Energy Physics.
- Now, KEK covers a wide area of scientific fields from particle and nuclear physics to materials and life sciences by constructing and operating large accelerator facilities.
- We have about 700 permanent staff, 100 students, and 8,000 users/year.
- KEK is one of leading accelerator science centers worldwide.





Insight through Accelerators.
KEK

In FY 2019 before Covid-19

Two campuses of KEK

J-PARC:
High intensity proton accelerator complex jointly operated by KEK and Japan Atomic Energy Agency (JAEA)

Proton accelerators in Tokai

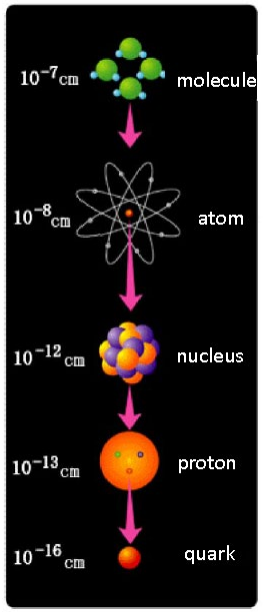
KEK Tsukuba:
SuperKEKB, PF,ATF

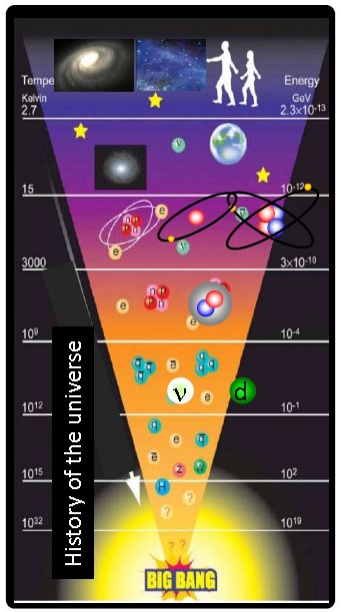
Electron-based accelerators in Tsukuba

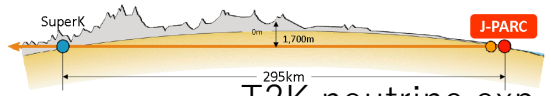
Insight through Accelerators.
KEK

Diversity in accelerator-based sciences

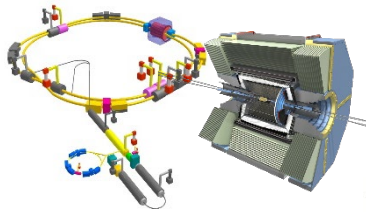
Pursuing fundamental laws of nature



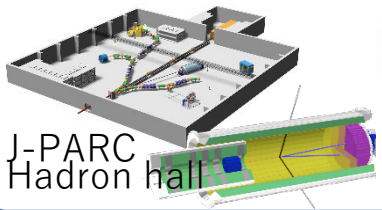




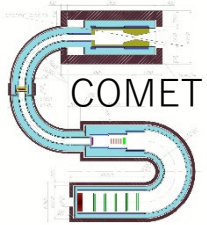
T2K neutrino exp.



SuperKEKB and Belle II



J-PARC Hadron hall



COMET

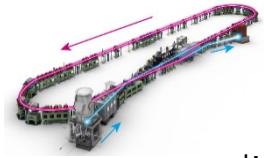
Basic science

Material science and its applications

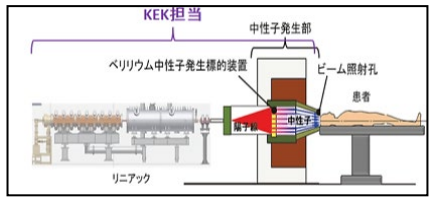
KEK

Technical developmer and its applications

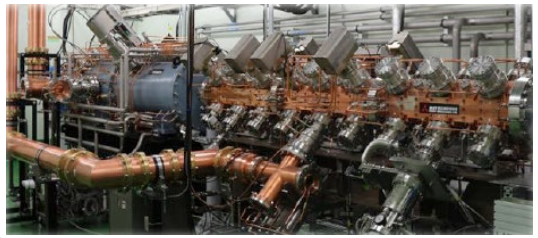
Superconducting accelerator



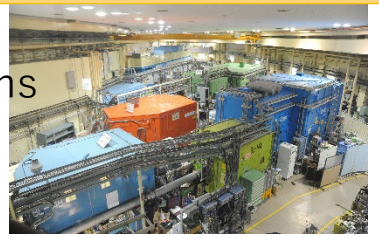
Energy recovery linac



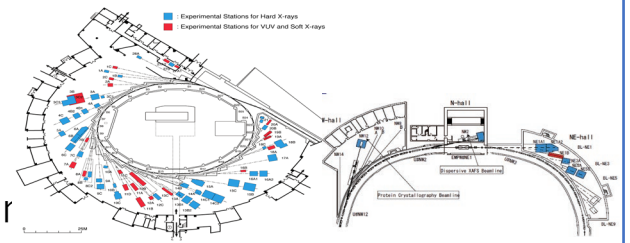
Accelerator-based BNCT

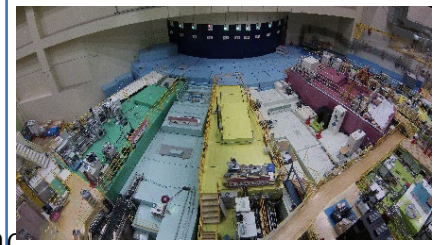


Pursuing origin of function in materials

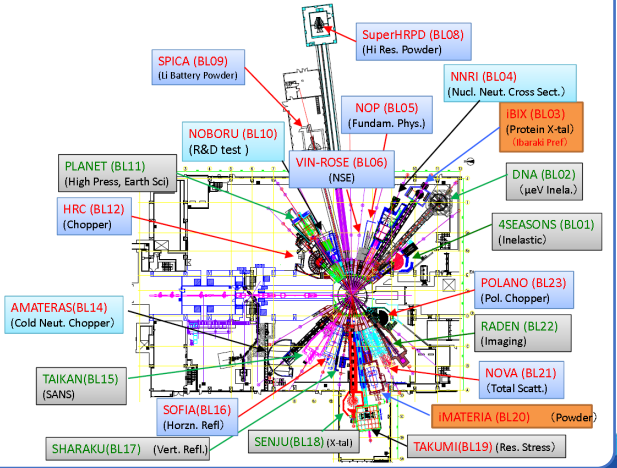


Photon factory X-ray as a probe





J-PARC MLF neutron and μ as a probe



KEK Roadmap 2021 and KEK-PIP 2022

KEK produces two documents for establishing KEK's research strategy and a project implementation plan (PIP) for a mid-term goals/plans period (6 years). KEK will carry out ongoing projects and promote to realize new projects based on KEK Roadmap 2021 and KEK-PIP 2022 for the period of FY 2022-FY2027. https://www.kek.jp/en/roadmap-en/

Research Strategy for FY2022-FY2027

1. J-PARC (Neutrino, Hadron, Neutron, Muon)
2. SuperKEKB/Belle II
3. LHC/ATLAS (including HL-LHC)
4. ILC (preparation for a global project)
5. Photon Factory (including planning for future facilities)

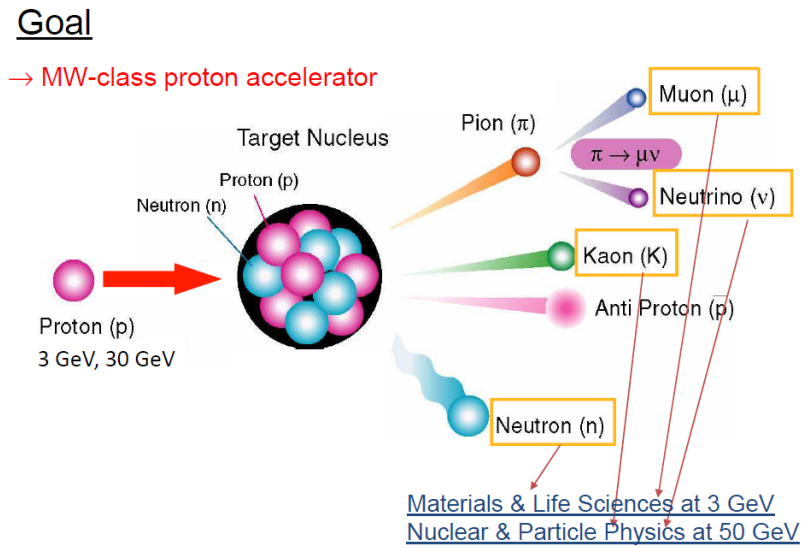
+ other important projects

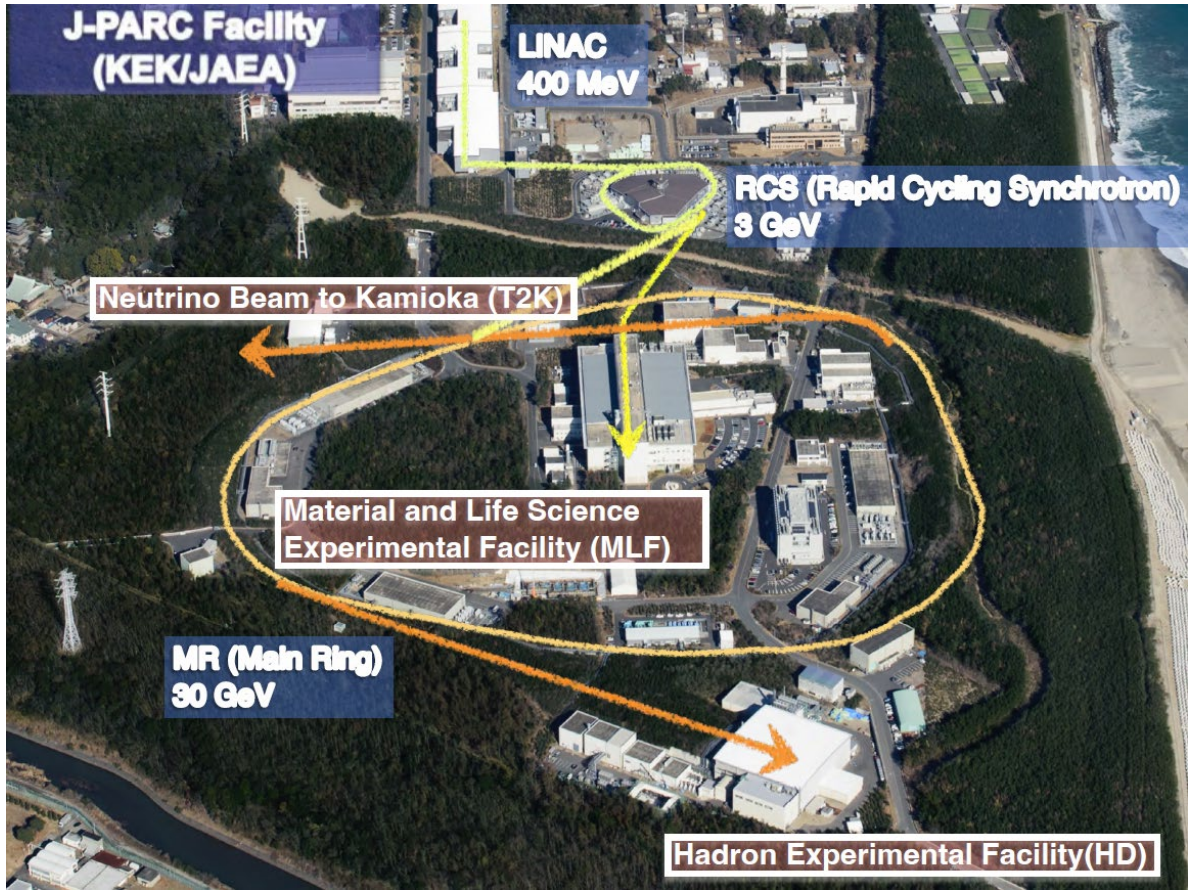
KEK Roadmap and KEK PIP page
https://www.kek.jp/en/roadmap-en/

Insight through Accelerators.
KEK

J-PARC

- Located in Tokai, 60km N.E. of the KEK Tsukuba campus
- Completed in 2009
- Design goal
  - RCS: 1MW
  - MR: 750kW

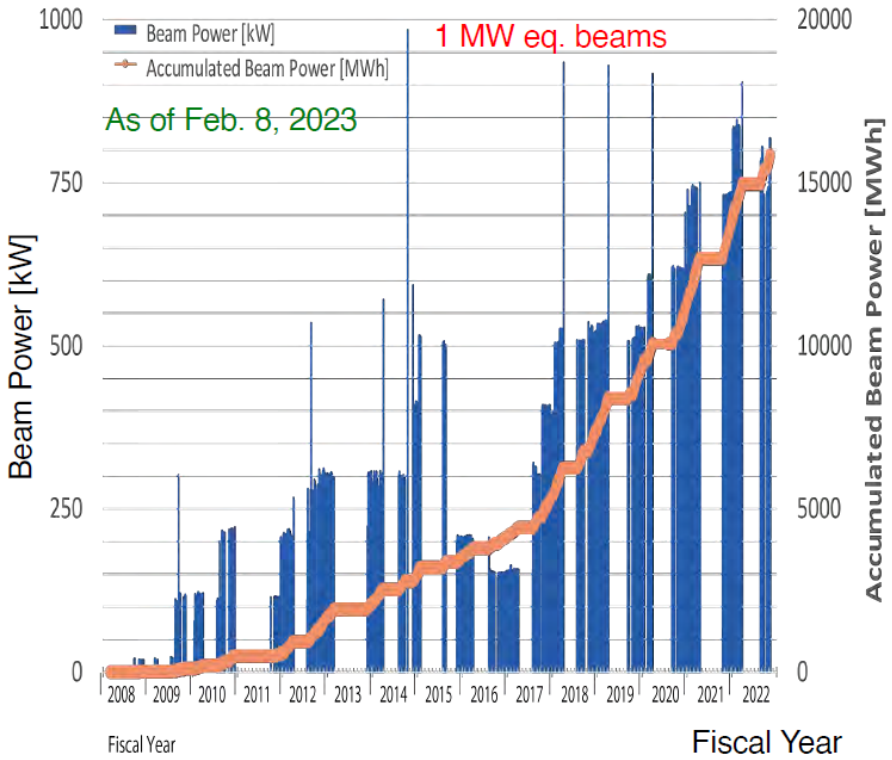




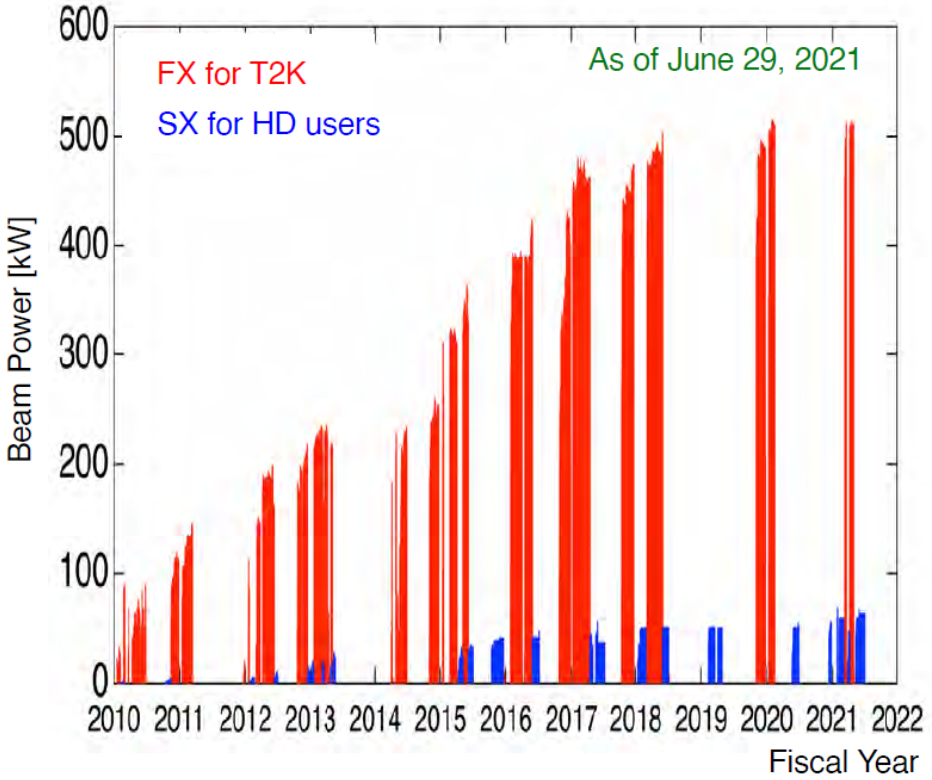
Joint project of KEK & Japan Atomic Energy Agency (JAEA)

Insight through Accelerators.
KEK

Beam power history of MLF and MR



Over the past few years, beam power has been steadily increased by ~100 kW in each year.
Beam power will be increased to 900 kW in April 2023.

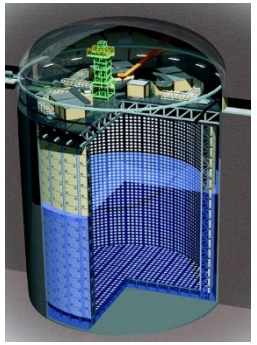


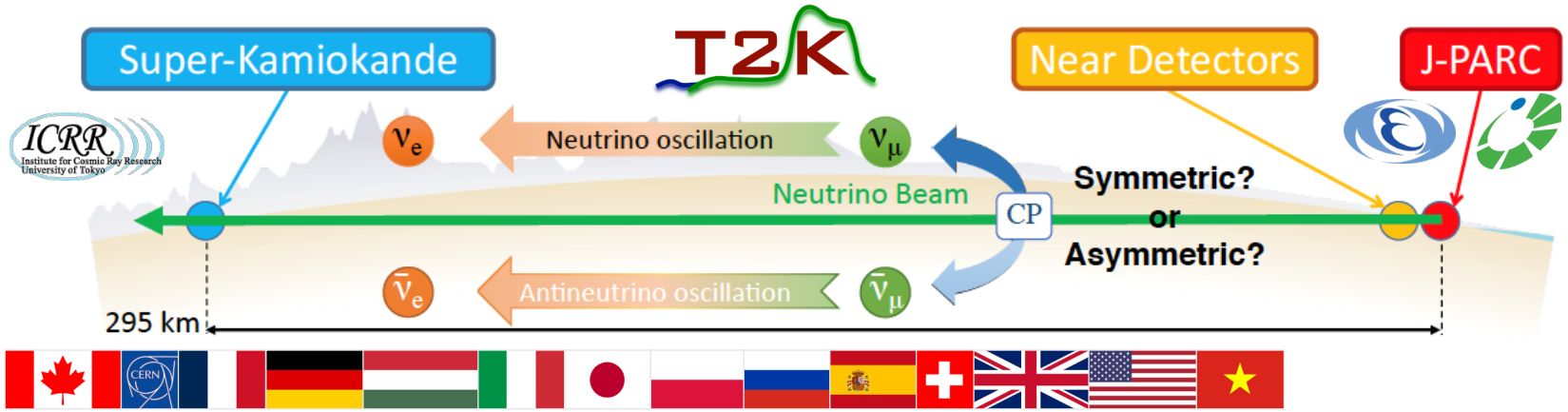
FX: ~ 515 kW (2.7 x10^{14} ppp), the world highest ppp in synchrotrons
SX: ~ 64 kW (7.0 x10^{13} ppp) with the world highest extraction efficiency of 99.5 %

6

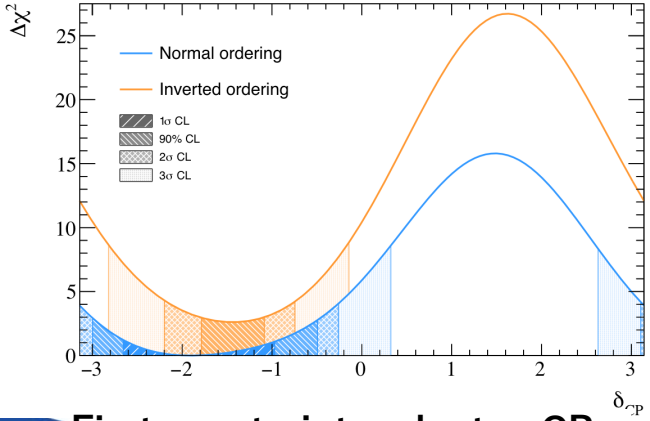
T2K: Long baseline neutrino oscillation experiment

- Search for *lepton CP violation*

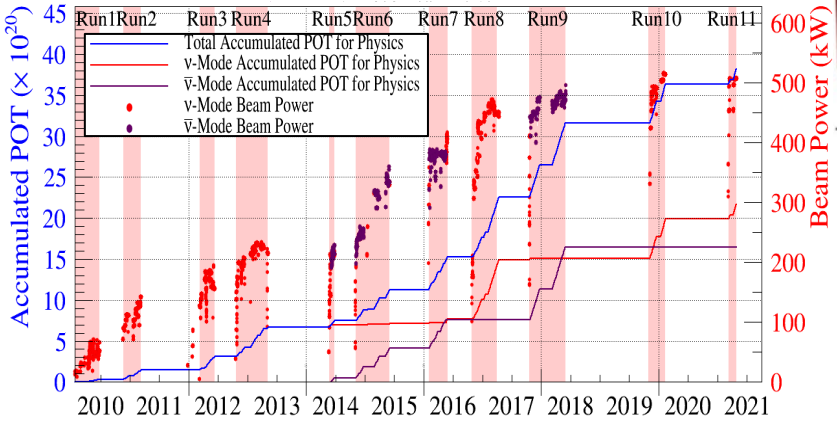


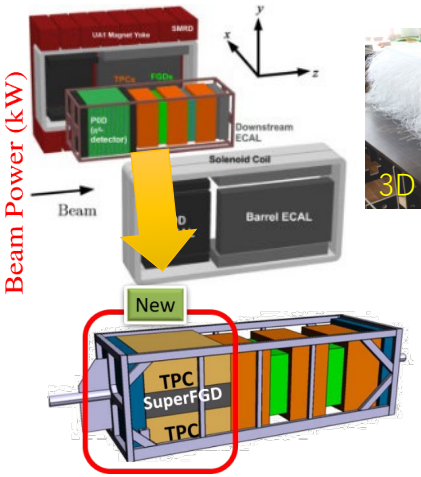


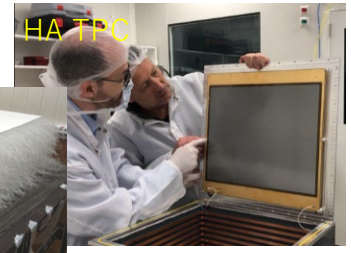
~470 members, 74 Institutes, 13 countries



First constraint on lepton CP asymmetry has been obtained.







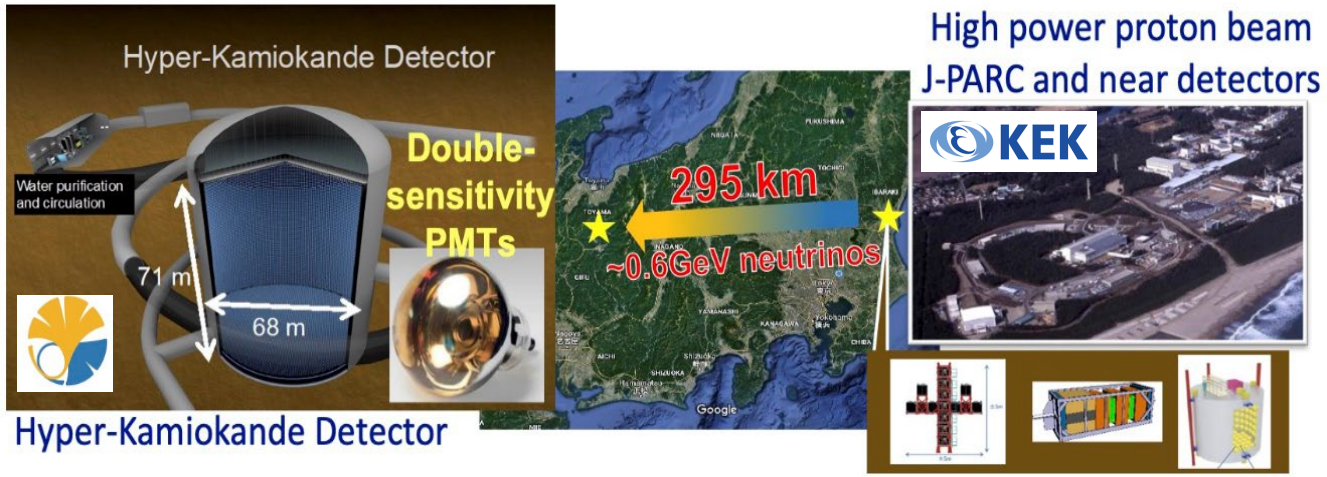
High power neutrino beam; ~520kW (achieved)

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

Precise measurement with doubled data by ~2026 is expected.

Hyper-Kamiokande (HK) project

- 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.



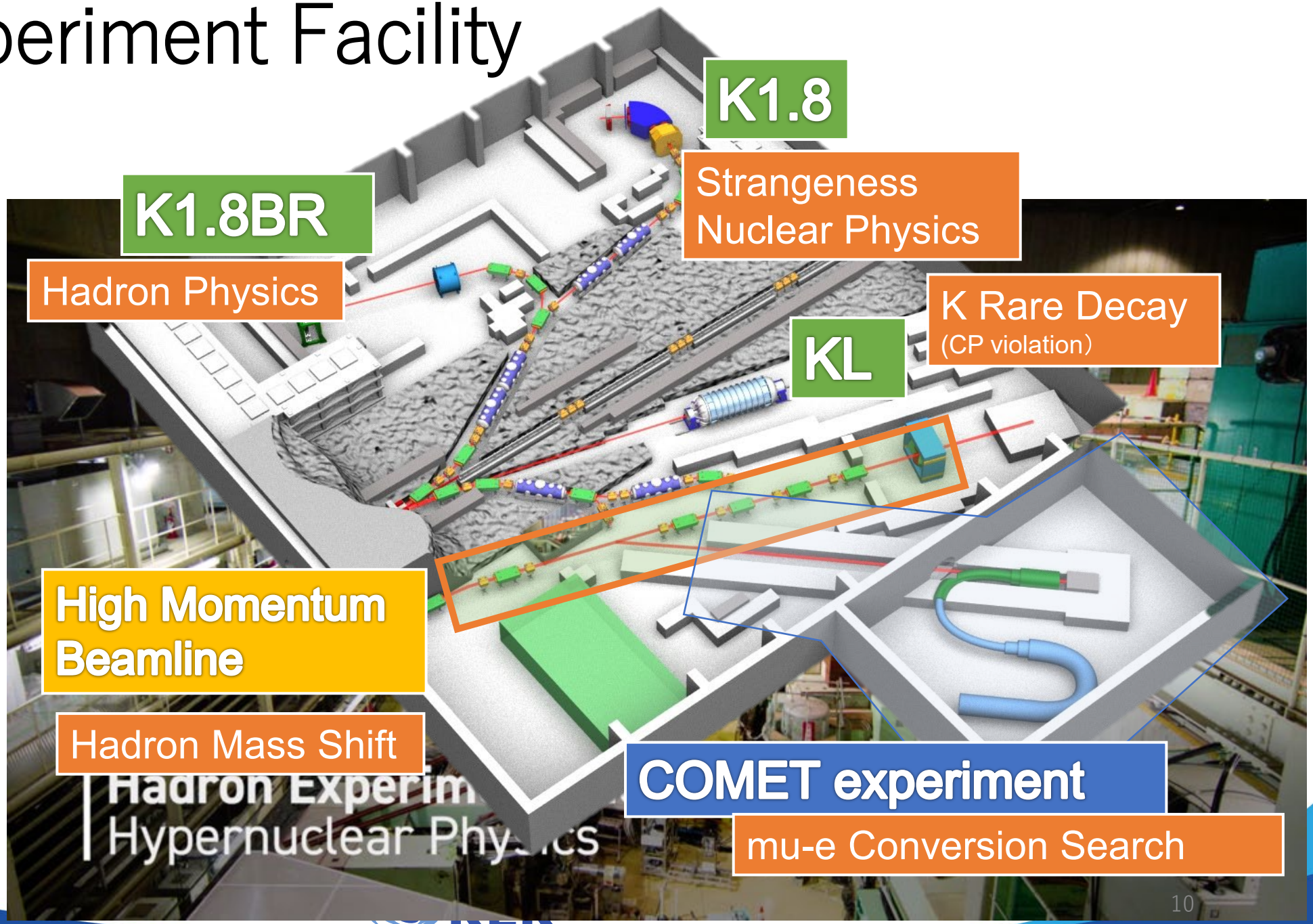
Hadron Experiment Facility

Search for new physics
KOTO
$KL \rightarrow \pi 0 \nu\nu$ search
In operation

COMET
μ −e conversion search
Under construction

Muon g-2/EDM
In preparation at MLF

Understanding state of nuclear matter, hadron physics
Strangeness nuclear physics
High momentum beamline

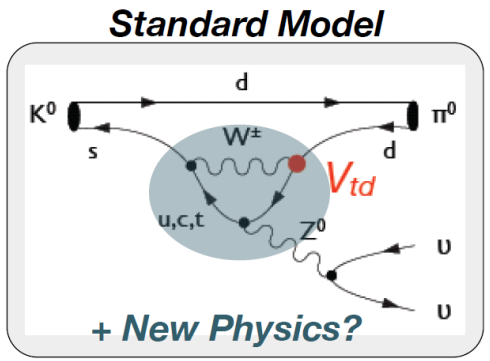


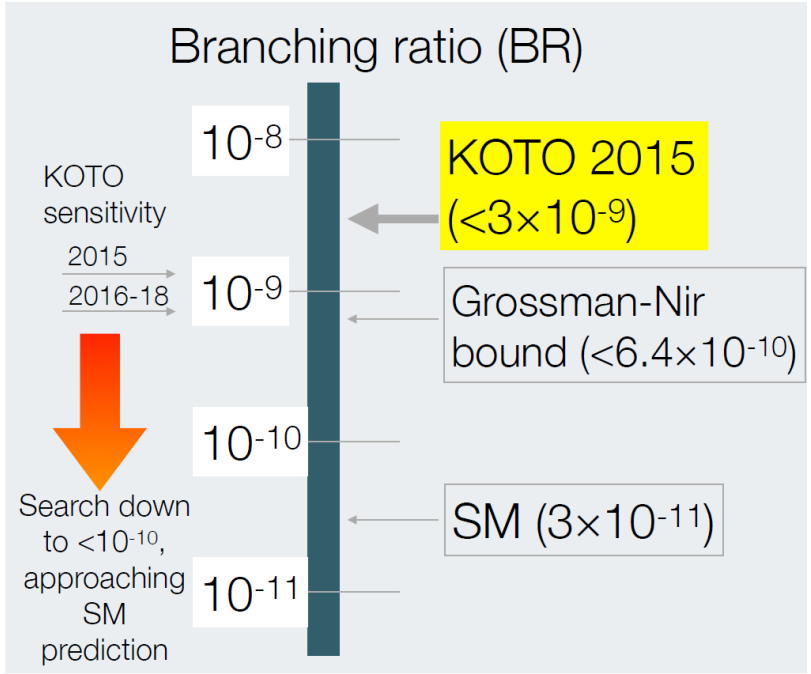
KOTO

Search for CP-violating rare decay $KL \rightarrow \pi 0 \nu\nu$

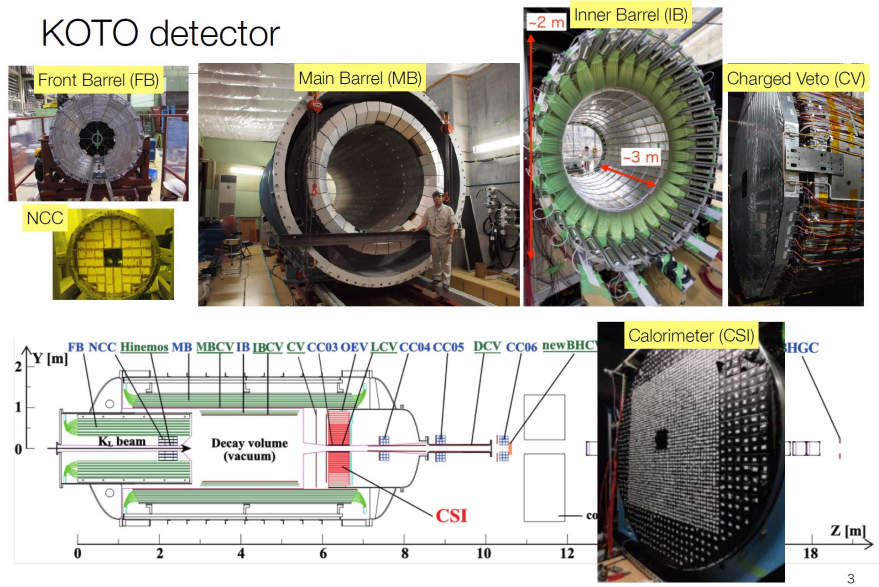
- Feature of $K_L \rightarrow \pi^0 \nu\nu$ decay
  - CP violating process
  - Suppressed in Standard Model; BR(SM)=3×10^{-11}
  - ~2% theoretical uncertainty

➔ Good probe to search for New Physics beyond SM

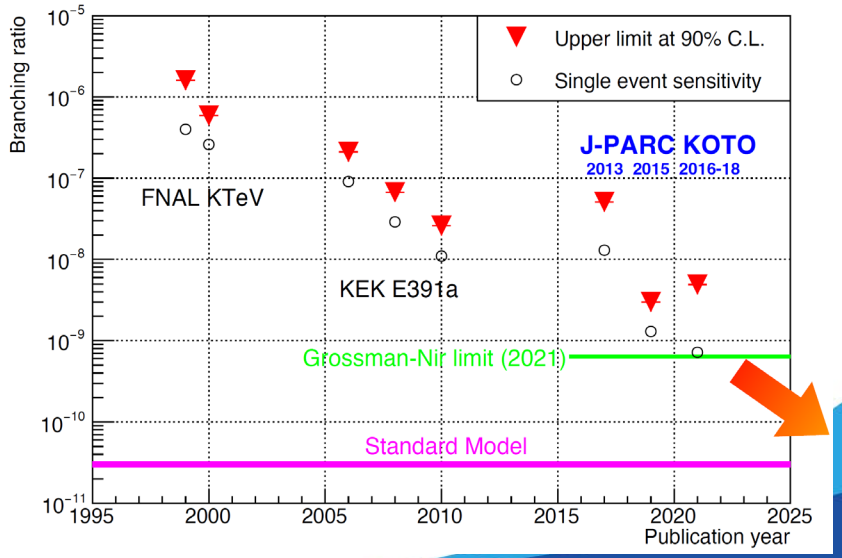




Grossman-Nir bound: indirect limit from relation to BR($K^+ \rightarrow \pi^+\nu\nu$); Calc'd from NA62 results (2021) with 1σ region



$K_L \rightarrow \pi^0 \nu\nu$ search history including KOTO



Insight through Accelerators.
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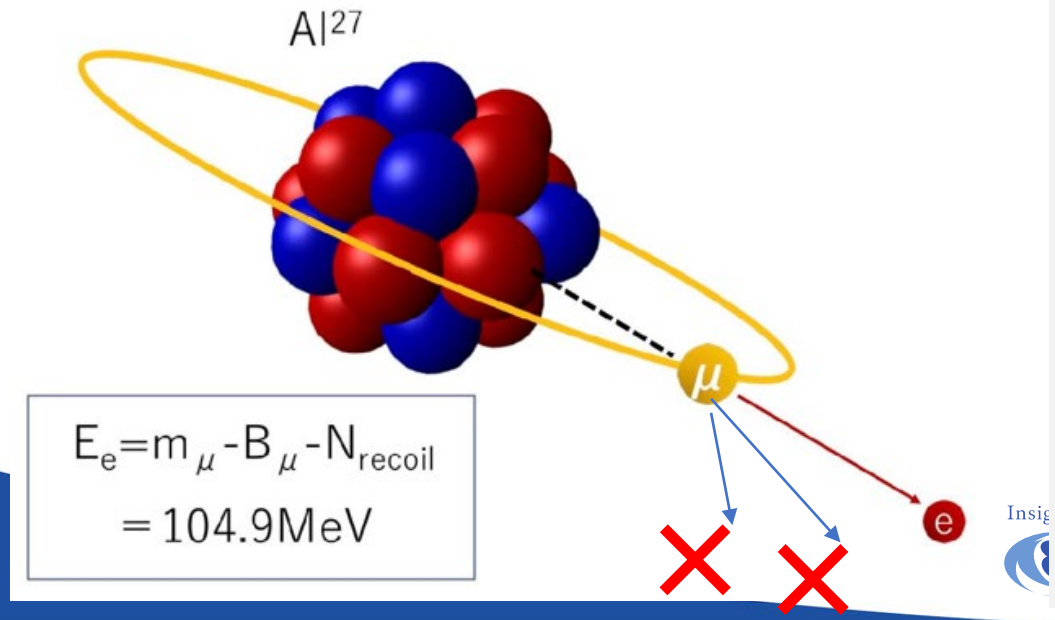
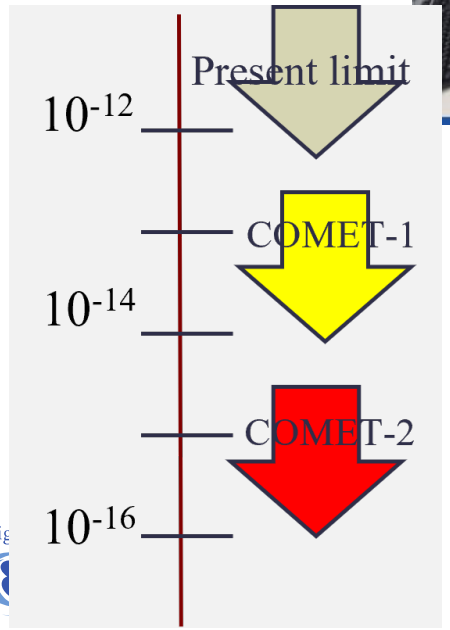
COMET experiment

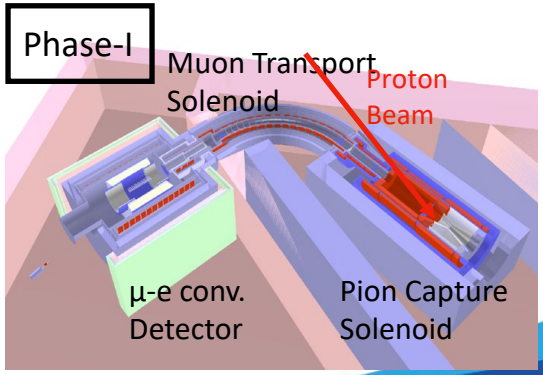
search for mu-e conversion down to the level of 10^{-16}

- Muons is x200 heavier brother of electron
- Muon is not stable and decay in ~ 2micro seconds to an electron and 2 neutrinos
- Try to find undiscovered muon “decay” to one electron without any neutrinos
  - Aim 100 times higher sensitivity than past experiments for the first phase
  - Eventually in future 2nd phase, 10,000times higher sensitivity is envisioned
- International collaboration composed of 49 institutes from 20 countries

Engineering run done recently

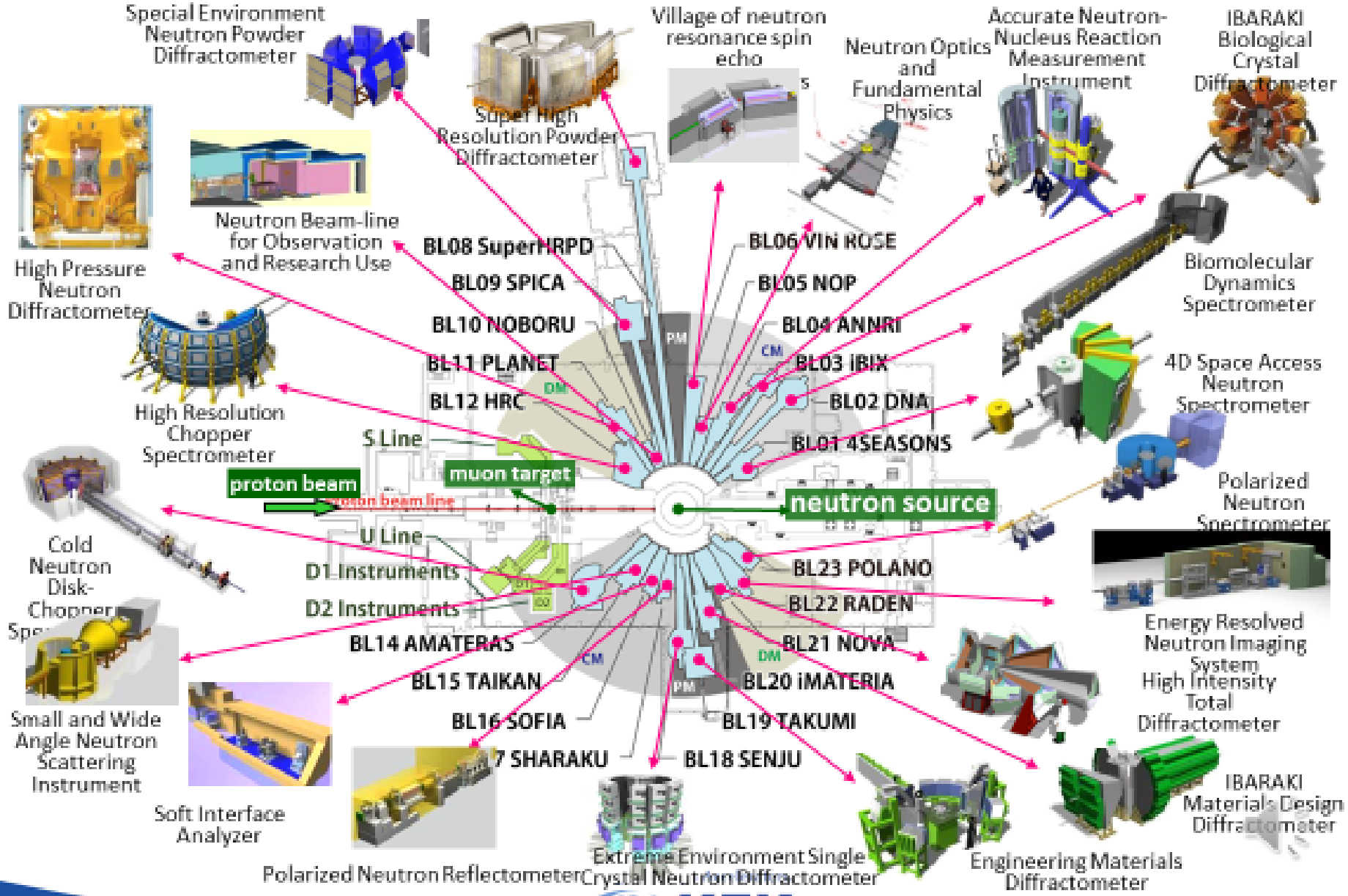




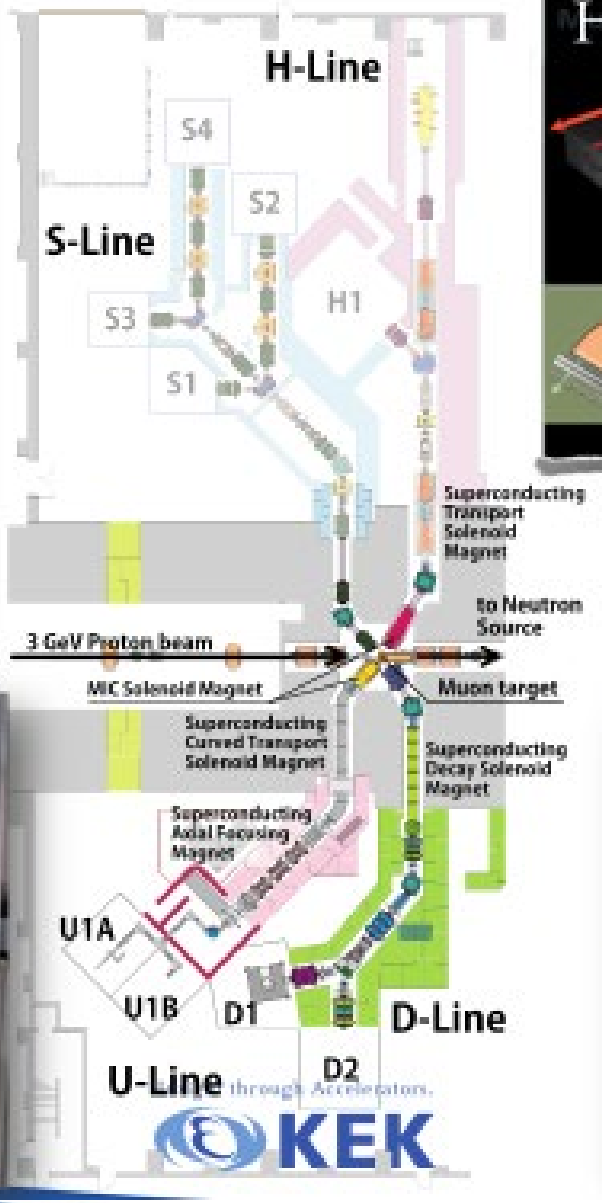


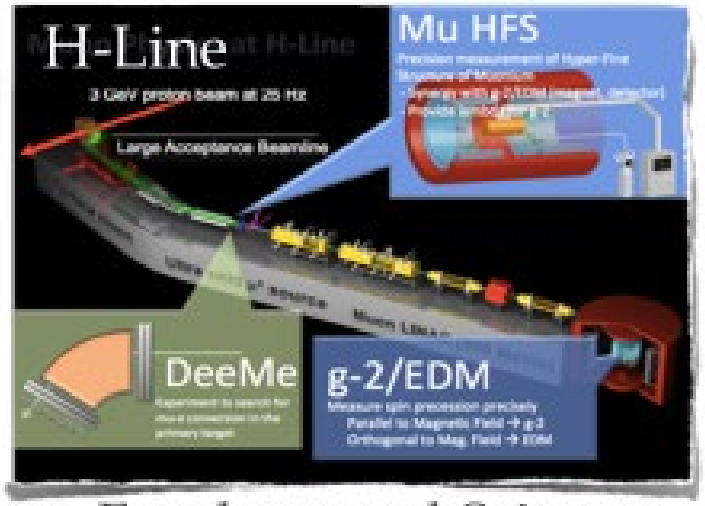
Neutron instruments in MLF

23 beam ports
21 in operation



Muon Facility MUSE @ MLF





Fundamental Science with a large scale international coll.

A recent research highlight in the muon facility

Non-destructive elemental analysis of a medicine bottle that cannot be opened

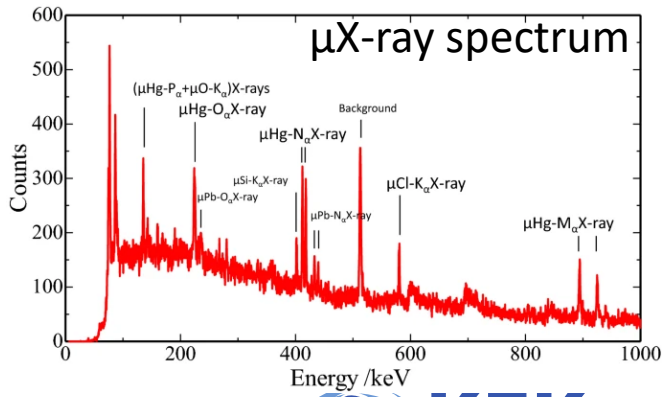
- ✓ The lid is stuck and impossible to open.
- ✓ Possibility of chemically unstable in the atmosphere

Muonic X-ray elemental analysis non-destructively revealed that the material inside the bottle is Hg_2Cl_2.

Kōan's Drug box

The medicine bottle

OGATA Kōan (緒方 洪庵)
1810~1863 (Edo period)
Doctor, *Rangaku* scholar



Significant impact on the public

Newspapers (5 major National newspapers etc.)

- *The Asahi Shimbun* (*'21/3/19*)
- *The Yomiuyri Shimbun* (*'21/4/30*)
- *The Mainichi Shimbun* (*'21/5/12*)
- *Nihon Keizai Shimbun* (*'21/5/13*)
- *The Sankei Shimbun* (*'21/5/25*)
- *etc.*

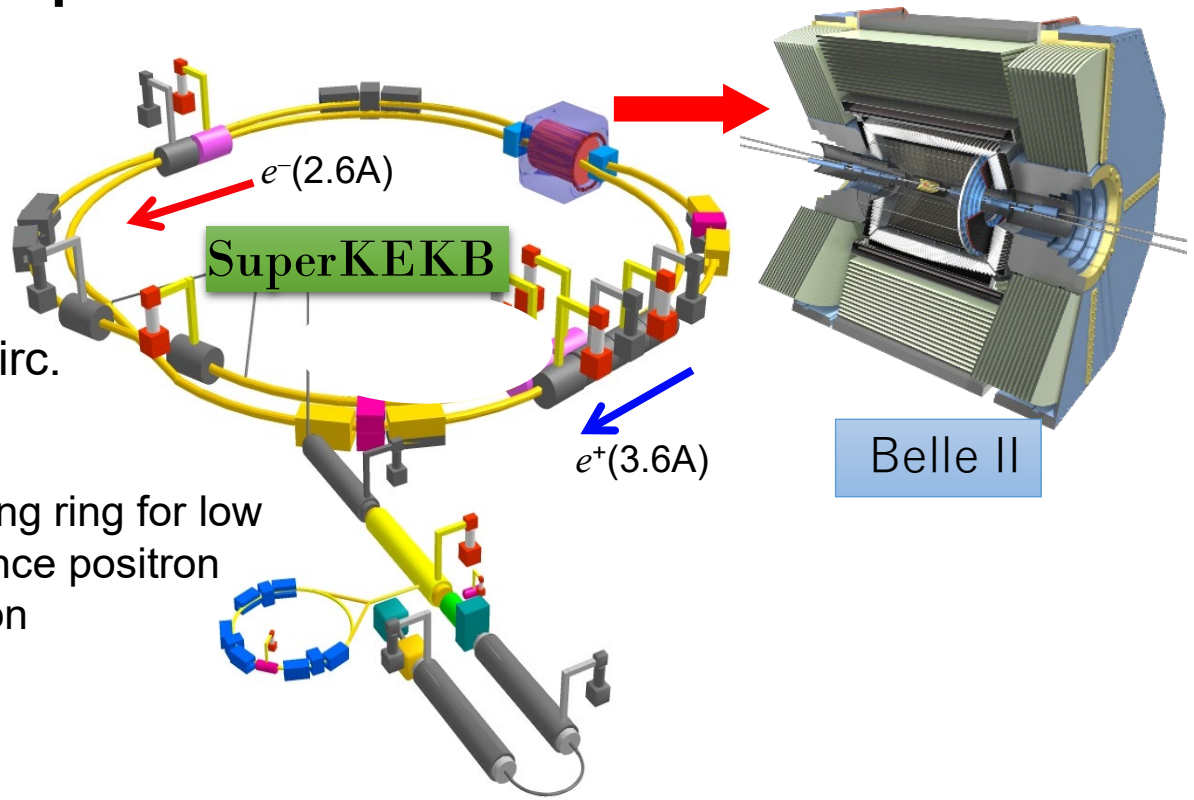
TV news

- *NHK General TV* (*'21/6/8*)
- *etc.*

K. Shimada-Takaura, et al., J. of Natural Medicines 75, (2021) 532.

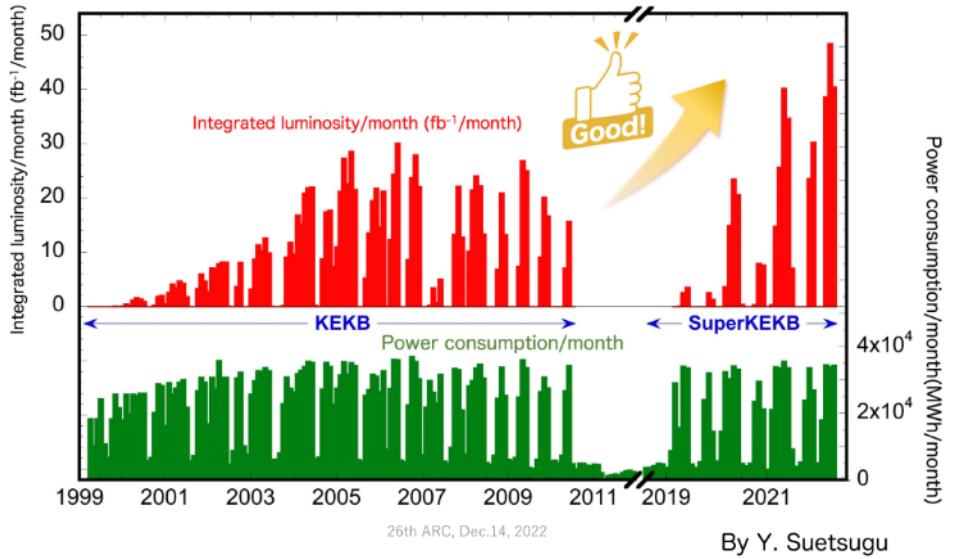
SuperKEKB and Belle II

L_{peak}=4.7x10^{34}/cm^2/s



3km circ.

Damping ring for low emittance positron injection



Twice better luminosity than KEKB with similar power consumption.

- Asymmetric e^+e^- collider at $\Upsilon(4s)$ with target L=6x10^{35}/cm^2/s
- ~10^{11} B, D and τ measured with vertex reconstruction and PID
- Physics run started March 2019.
- Belle II collaboration consists of 1100 physicists from 27 countries/regions

Belle II

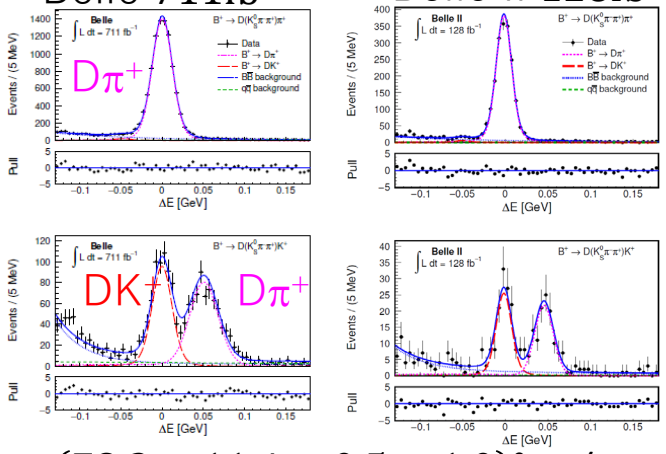
Insight through Accelerators.

KEK

Recent physics data analyses

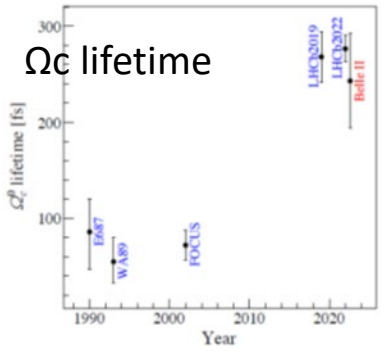
Belle II data is not a tiny addition to Belle. Good detector and good analysis method give a significant improvement

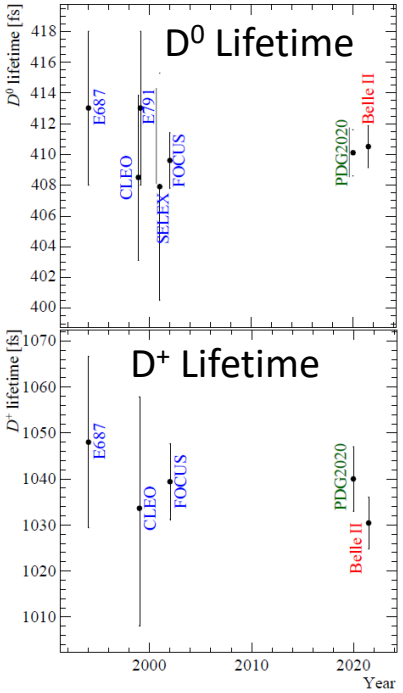
Belle 711fb^{-1} | Belle II 128fb^{-1}



$\phi_3 = (78.3 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$ (was $\pm 15^\circ$)

World leading charm lifetime measurement with excellent vertex resolution

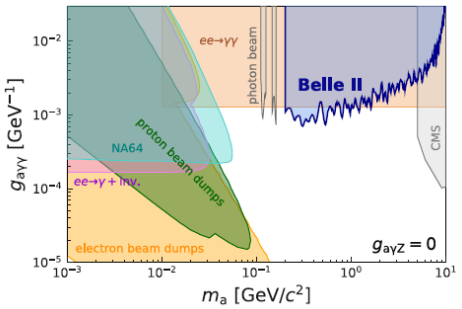




Phys. Rev. Lett. 127, 211801 (2021)
Phys. Rev. Lett. 130, 071802 (2023)
Phys. Rev. D 107, L031103 (2023)

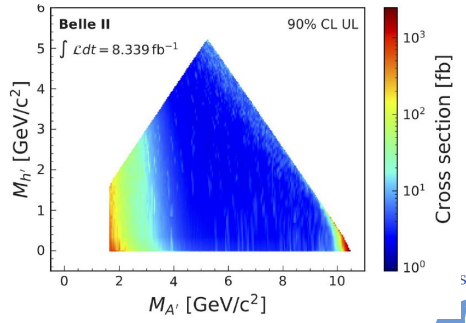
L1 trigger compatible with Dark sector searches. Setting new exclusion regions

ALP (0.4fb^{-1})



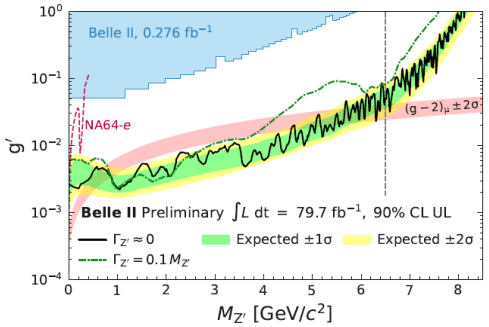
Phys. Rev. Lett. 125, 161806 (2020)

Darkhiggsstrahlung (8.34fb^{-1})



Phys. Rev. Lett. 130, 071804 (2023)

Z' in L_μ-L_τ model (79.7fb^{-1})

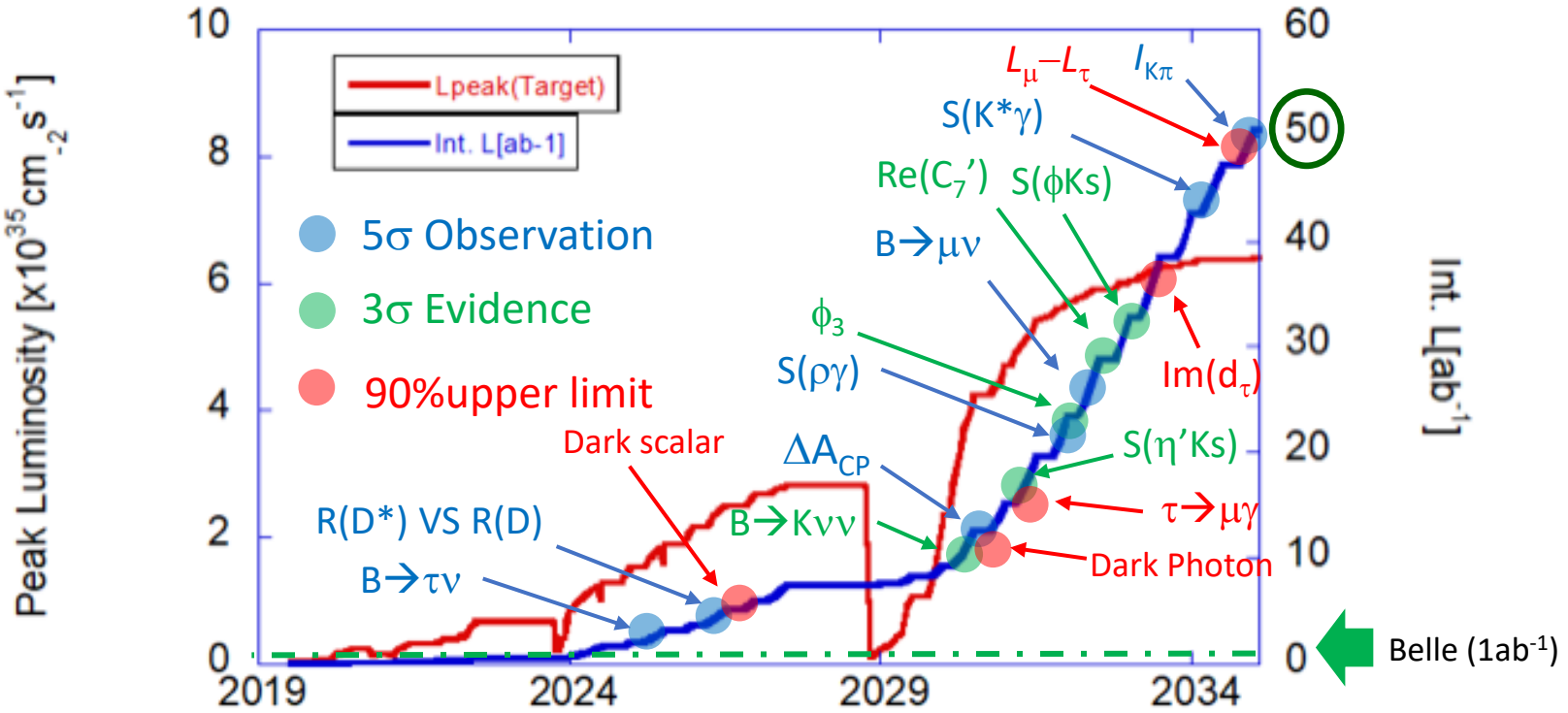


submitted to PRL in 2022

A. Ishikawa @KEK RPC

sight through

Expectation of possible new evidences and observations



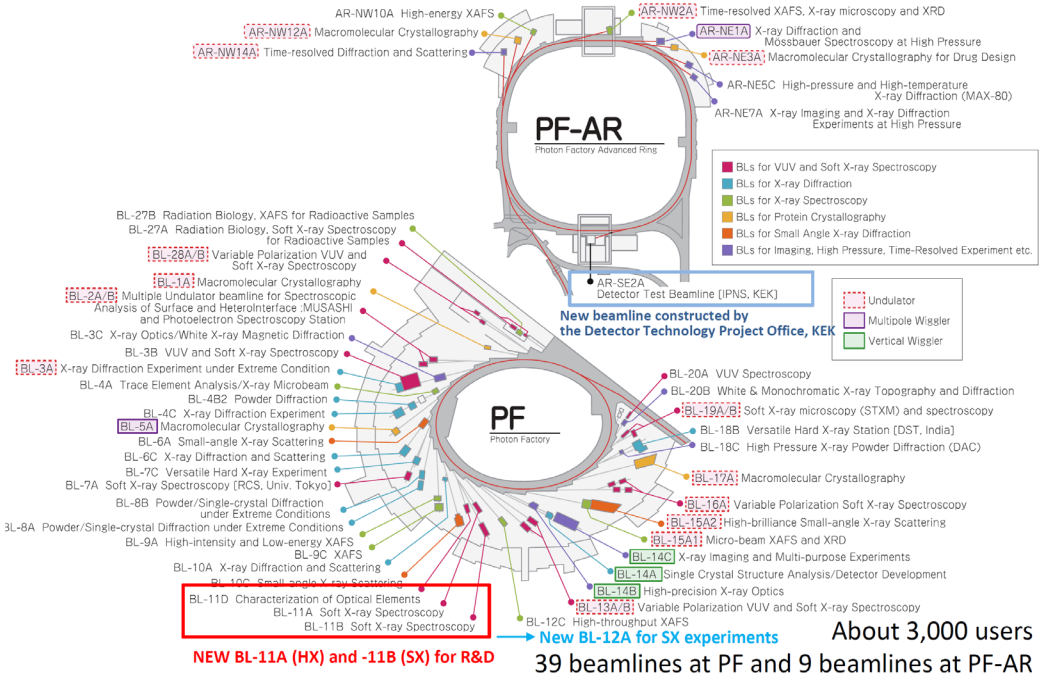
There may be new findings even with small amount of data

Insight through Accelerators.
KEK

Photon Factory

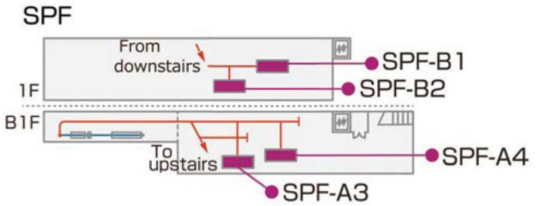
PF : 2.5 GeV, 450mA e^- (since 1982)
PF-AR : 6.5 GeV, 60mA e^- (since 1997)

KEK is working on planning of a new synchrotron light source facility.
A multi-function R&D beamline is constructed for R&D purpose.



Slow positron facility

A unique facility for studying surface of materials

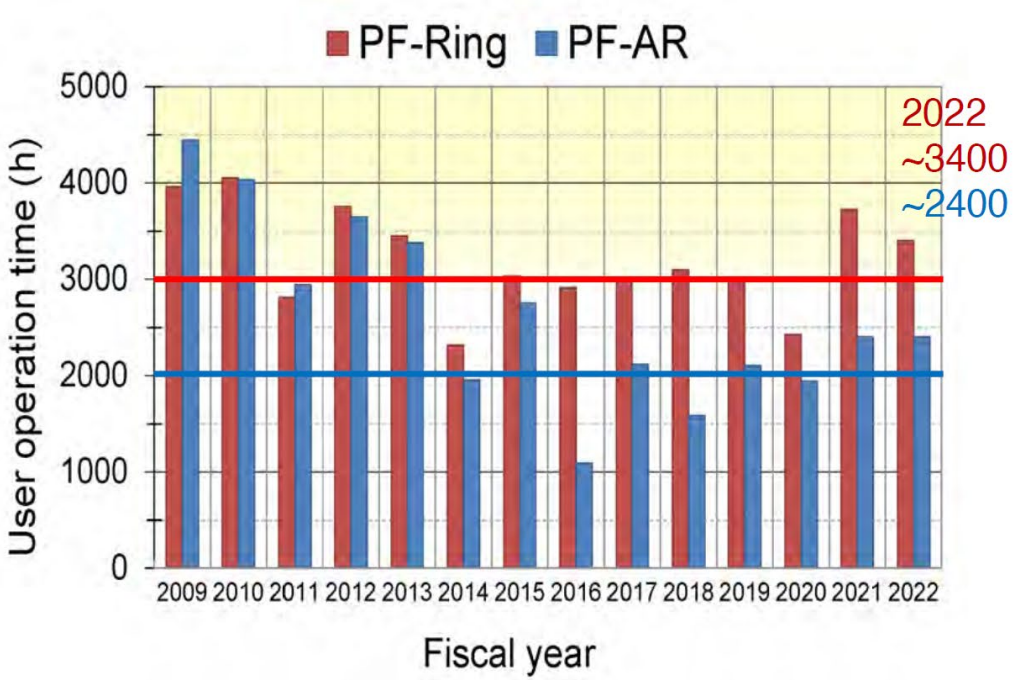


Insight through Accelerators.
KEK

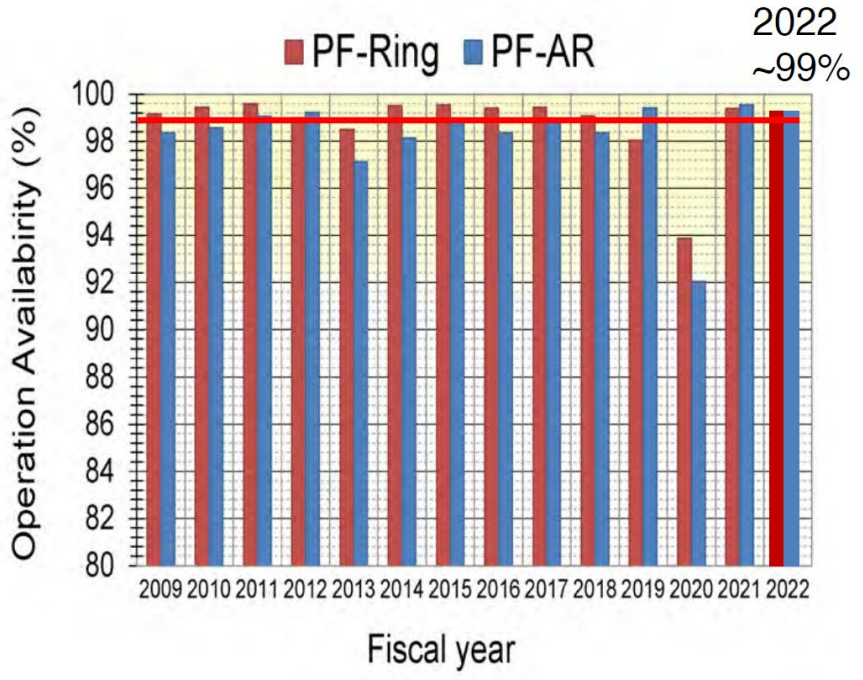
SPF (Slow Positron Facility)

PF/PF-AR operation

Statistics of user operation of PF / PF-AR

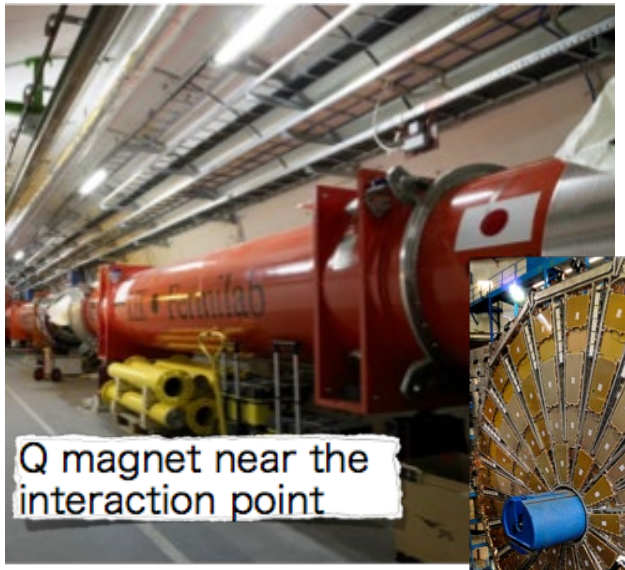


Operation time was gradually decreasing since FY 2011 due to the increase of an electric power cost after the earthquake. For the last several years, much effort was made to secure over 3,000 hours for PF and 2,000 hours for PF- AR.

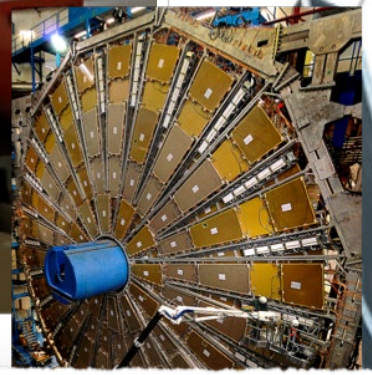


Average availability > ~99 %
Continuous and regular maintenance prevents troubles of accelerators.

Japanese Activities at LHC/ATLAS



Q magnet near the interaction point

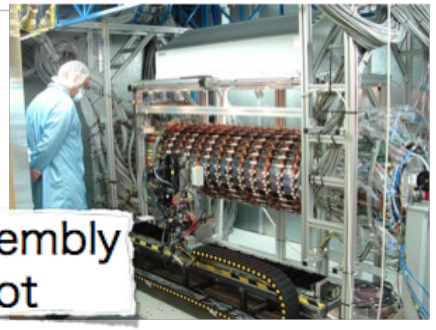


30% chamber,
100% ASIC for electronics

Critical contributions
- pixel/SCT operation
- muon trigger responsibility
- computing
- physics analysis
- trigger coordinator
- collaboration board chair

100% 20%

Solenoid at CERN before installation

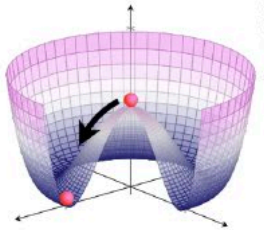


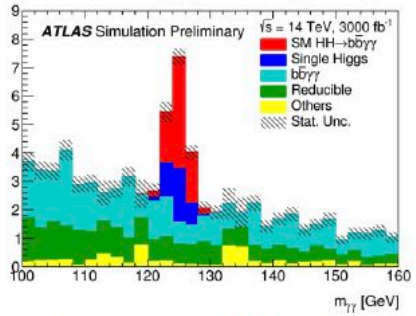
module assembly by KEK robot

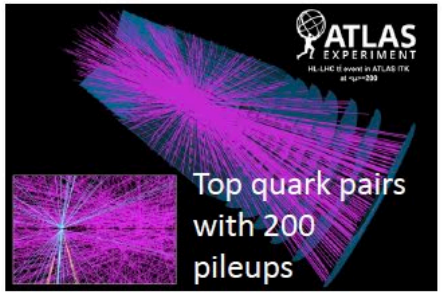
ight through Accelerators.
KEK

High-Luminosity LHC upgrade

- × 10 data allows as to search for new physics by not only direct searches but also precise measurement of the Higgs couplings.

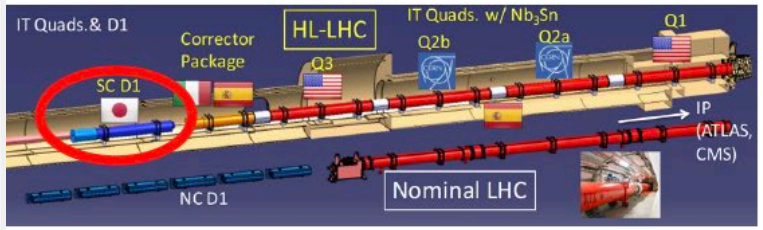


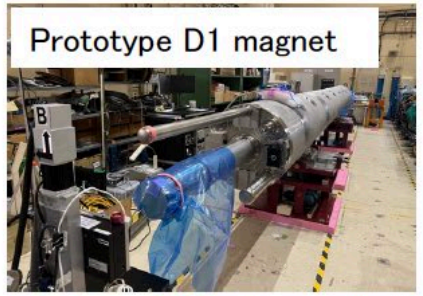




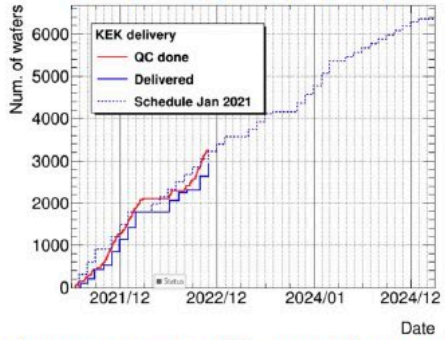
LHC → HL-LHC: × 10 data
× 10 faster readout
× 10 finer granularity
× 10 radiation hardness

- Seven meters prototype of the beam separation dipole magnet (D1 magnet) completed.
- Production of the real magnet started

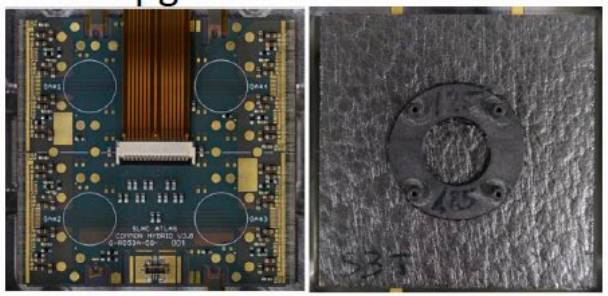




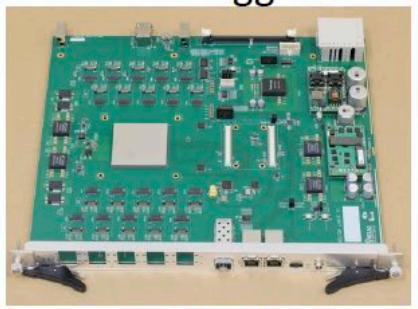
- KEK/Japan group plays leading role on upgrades of the inner trackers and muon trigger.



Good progress on silicon strip production

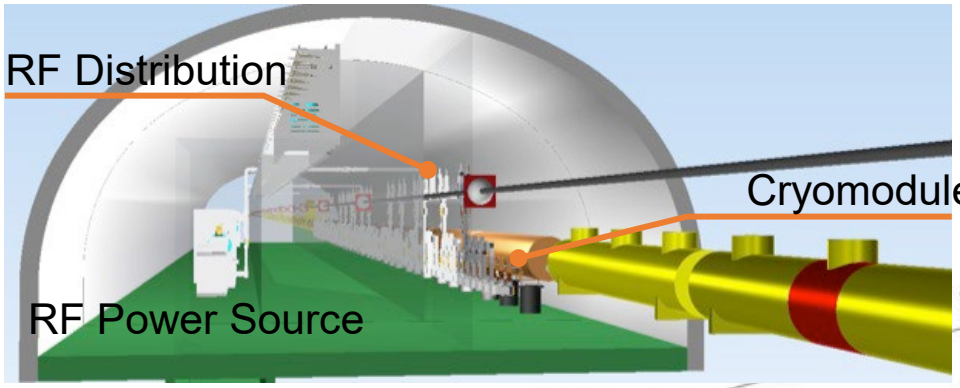


Preproduction Silicon pixel module starts soon

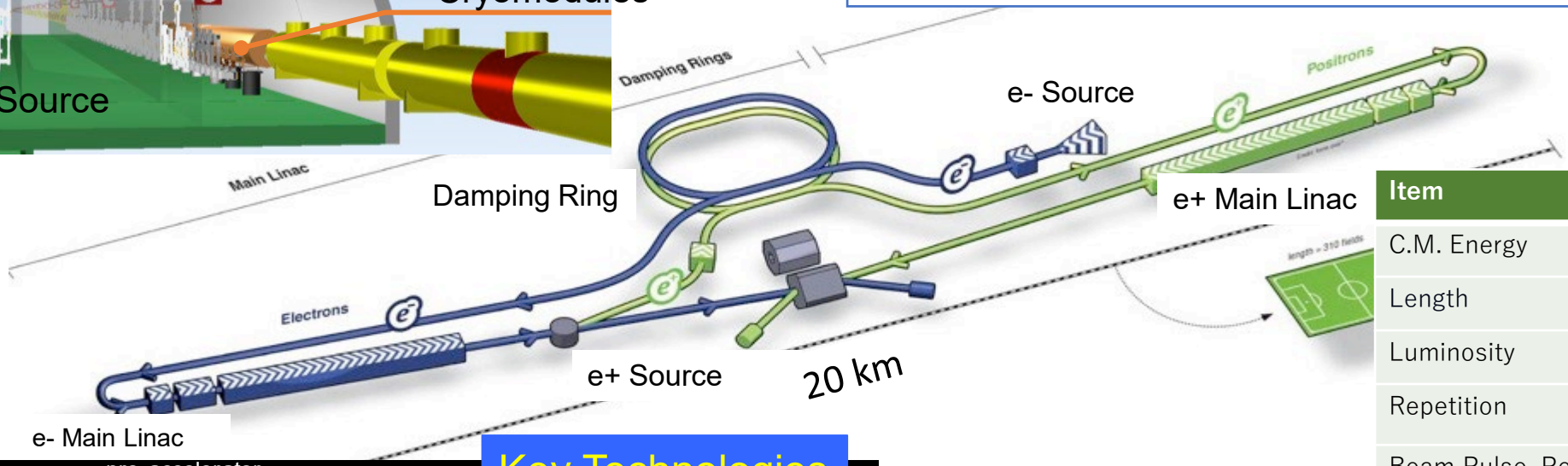


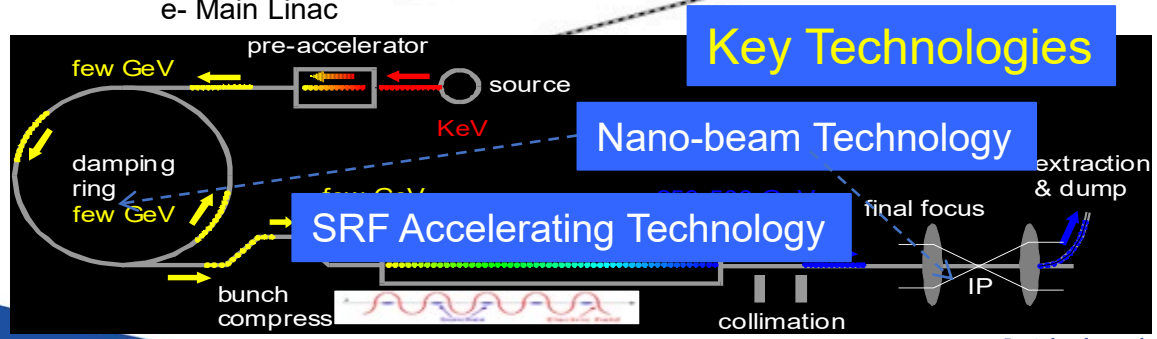
Muon trigger board prototype in good shape

International Linear Collider (ILC)



ILC has been developed by the international HEP community and supported by European strategy, US P5, etc. Its design has been conducted by the initiative of ICFA.





Key Technologies

Nano-beam Technology

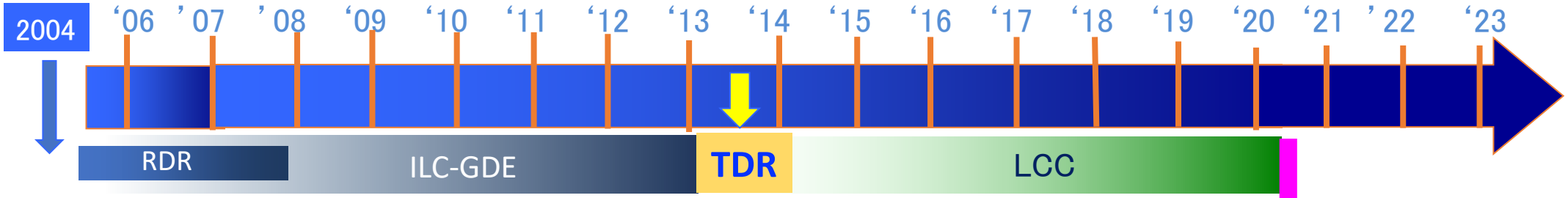
SRF Accelerating Technology

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	**5.9** nm
SRF Cavity G. Q_0	**31.5** MV/m Q_0 = 1x10^{10}

Insight through Accelerators.

KEK

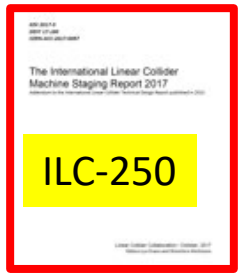
History of ILC Collaboration



Technology selection

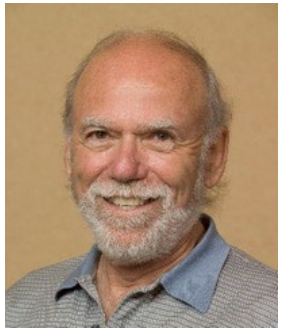
ILC technical design

TDR:
49 countries
392 institutions
>2400 researchers



*I*nternational
*D*evelopment
*T*eam

Tatsuya Nakada (EPFL)
IDT chair



Barry Barish
GDE director
(the Nobel Prize winnerin 2017)

Lyn Evans
LCC director
(former LHC project manager)

LHC

European XFEL

LCLS-II

Recent history of ILC

- The International Committee for Future Accelerators (ICFA) established the IDT in August 2020 to realize the ILC in multiple-stages, and in June 2021 the IDT published the report on overall design of the Pre-lab and 18 work packages to be implemented there. At the same time, the Japanese physics community submitted a report to MEXT on the progress of the ILC over the past three years.
- MEXT set up an ILC Advisory Panel to evaluate these reports and published a recommendation in February 2022.
  - ✓ The panel recognizes the academic significance of particle physics research and the importance of the research field, including that of a Higgs factory, and understands the value of international collaborative research. However, the panel found that it is still premature to proceed into the ILC Pre-lab phase, which is coupled with an expression of interest to host the ILC by Japan as desired by the research community proposing the project.
  - ✓ The panel recommends that the development of the key technology for the next-generation accelerator such as ILC should continue by further strengthening the international collaboration among institutes and laboratories, shelving the question of hosting the ILC.
  - ✓ For realizing a very large project such as the ILC, cultivating a framework where the related countries can exchange information on their situations and discuss required steps would be important.
- KEK and IDT proposed a plan for ILC promotion by forming ILC Technology Network (ITN) and International Expert Panel (IEP) at the ICFA meeting in March 2022. ICFA supported this proposal.

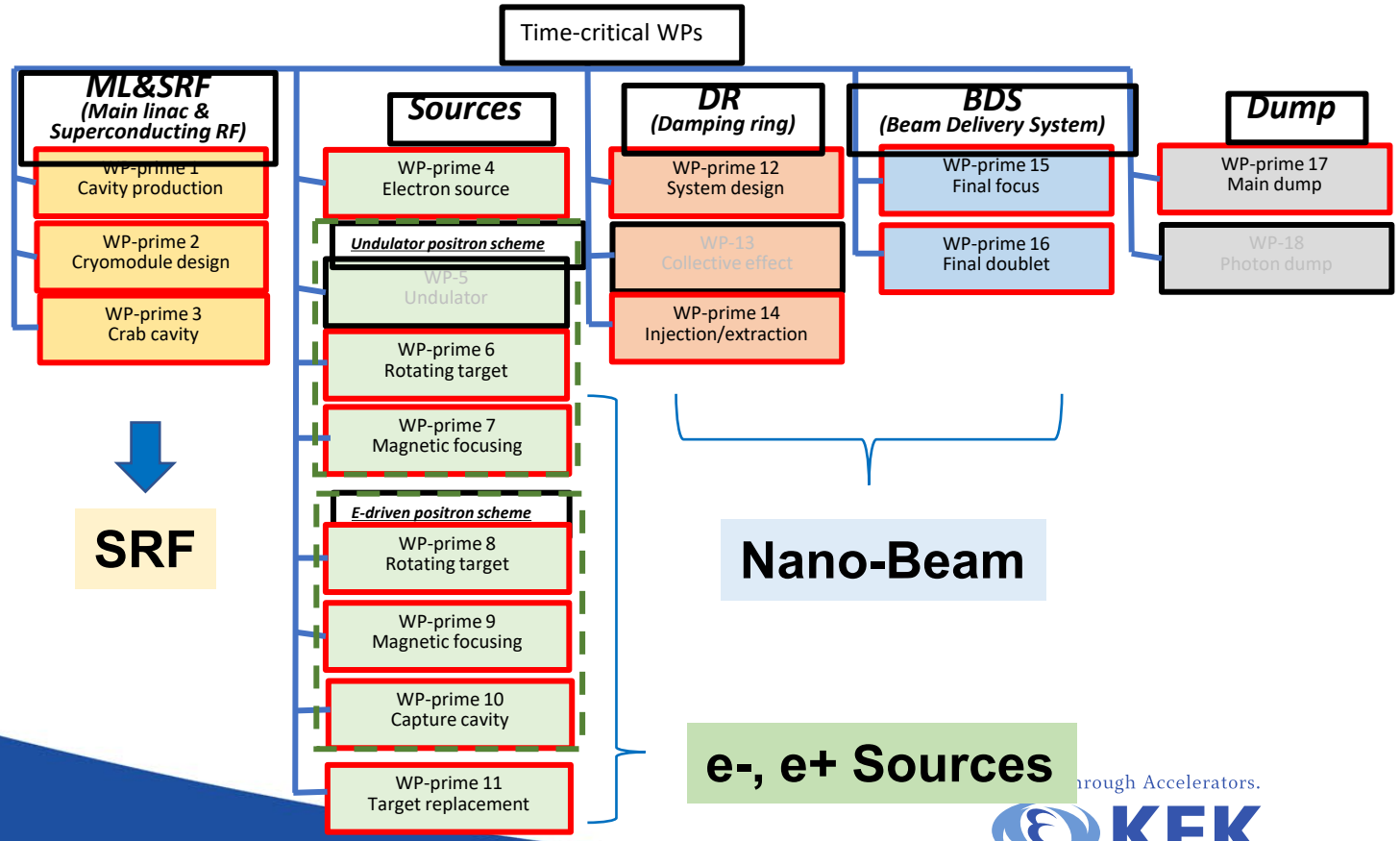
Current status of ILC project

- KEK and IDT are in the process of initiating a new international collaborative framework (ITN) that covers urgent accelerator R&D works. The prioritized work packages are selected by the IDT accelerator working group. A new R&D grant for accelerator technology developments is awarded to KEK.

- IDT set up an International Expert Panel in July 2022 and had regular meeting to discuss a process to implement a global large accelerator project. It will continue to deepen the discussions.

- These progress and plan were reported at the ICFA meeting in March 2023, and ICFA decided to continue the IDT activity.

Prioritized WP for ILC Technology Network



WPP	1	Cavity production
WPP	2	CM design
WPP	3	Crab cavity
WPP	4	E- source
WPP	5	
WPP	6	Undulator target
WPP	7	Undulator focusing
WPP	8	E-driven target
WPP	9	E-driven focusing
WPP	10	E-driven capture
WPP	11	Target replacement
WPP	12	System design
WPP	13	
WPP	14	Injection/extraction
WPP	15	Final focus
WPP	16	Final doublet
WPP	17	Main dump

SRF

e-, e+ Sources

Nano-Beam

rough Accelerators.

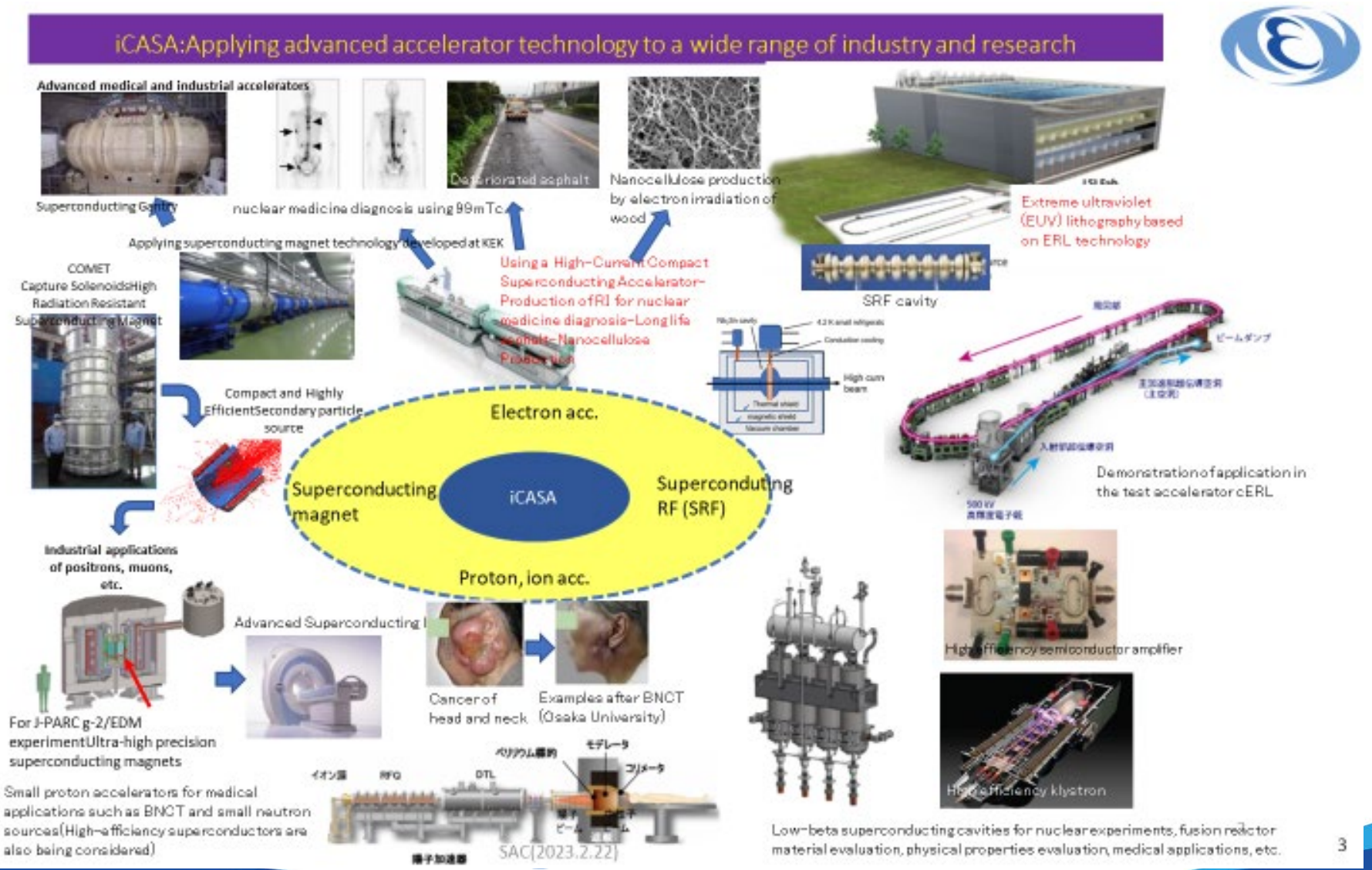
KEK

ILC technology developments at KEK

ATF: Technology to handle nano-size beam
STF: Technology to assemble and operate superconducting cavities
CFF: Technology to manufacture superconducting cavities

Application of Accelerators

Innovation Center for Applied Superconducting Accelerators (iCASA) established in April 2022



Summary

- KEK has diverse science programs from particle and nuclear physics to materials and life sciences based on large accelerator facilities.
- Particle physics programs include SuperKEKB/Belle II, neutrino programs (T2K and construction of Hyper-K), Kaon and muon precision experiments at J-PARC.
- For materials and life sciences, KEK has four beam infrastructures (photon, neutron, muon, slow positron) .
- KEK is also preparing for future. KEK is leading efforts to realize the ILC starting as a Higgs factory with worldwide HEP communities.