INTER-UNIVERSITY RESEARCH INSTITUTE CORPORATION
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

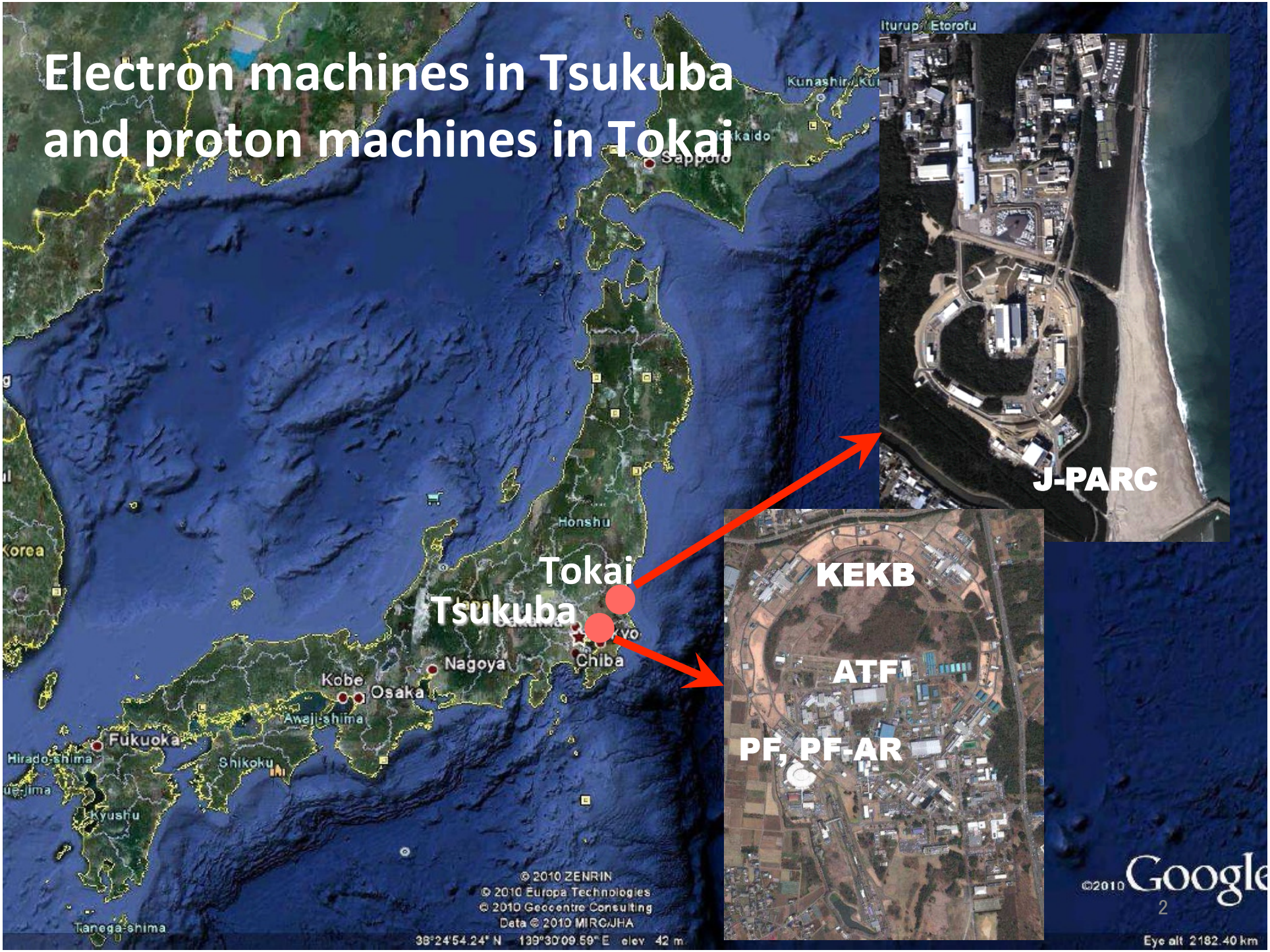
Status and future plan of KEK and J-PARC

Yasuhiro Okada
Executive Director, KEK

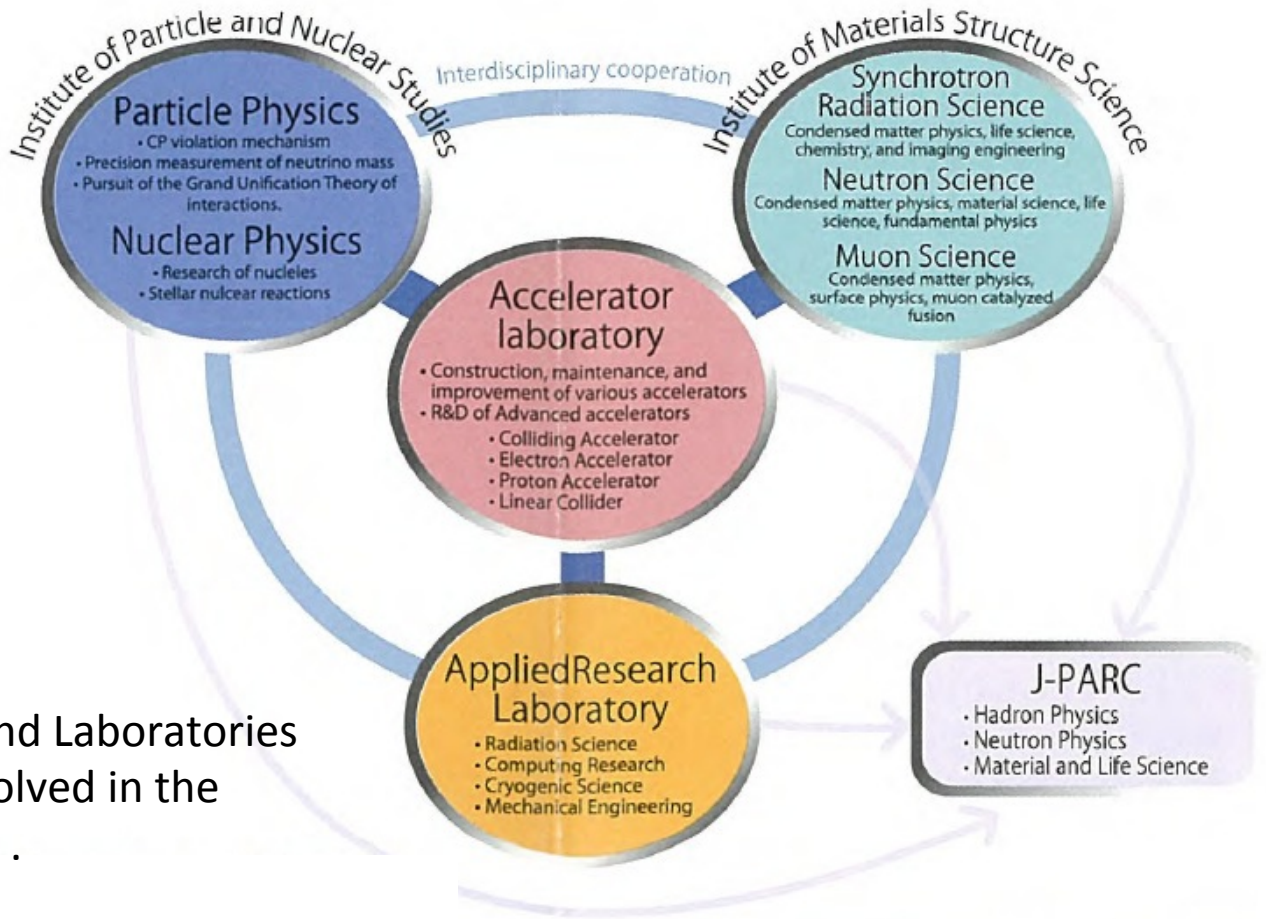
June 15, 2015

CAP 2015 Congress, Edmonton, Canada

Electron machines in Tsukuba and proton machines in Tokai



- KEK is Inter-University Research Institute Organization, first established in 1971 as National Laboratory for High Energy Physics
- An International Center of Accelerator Science
- Cover wide range of scientific fields
- Construction of J-PARC started as a joint project of KEK and Japan Atomic Energy Agency (JAEA) in 2001



All institutes and Laboratories are deeply involved in the J-PARC project .

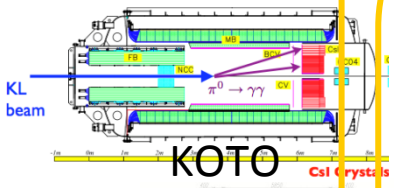
KEK Roadmap 2013

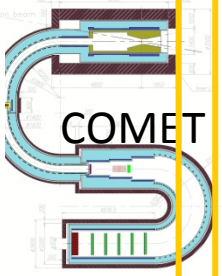
KEK established the 2nd roadmap in 2013 for research strategies taking into account input from relevant research communities such as particle and nuclear physics, neutron, muon and photon science communities.

1. Preamble
2. Long-Term Prospects and KEK's Role for Each Research Area
3. Strategy for Next Five Years (2014-2018)
   - 3.1 J-PARC
   - 3.2 SuperKEKB/Belle II
   - 3.3 LHC/ATLAS
   - 3.4 ILC
   - 3.5 Photon Science (Synchrotron Radiation Research)
   - 3.6 New Development of Accelerator and Detector Technologies
4. Summary

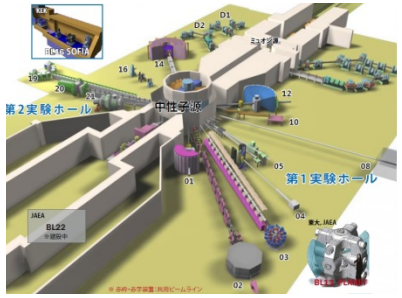
http://legacy.kek.jp/Roadmap/index-en.html

Particle and Nuclear Physics





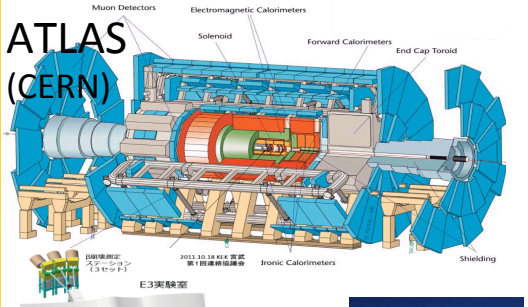
Material Structure and Life Sciences



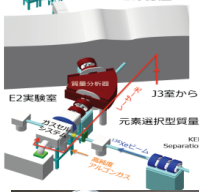
Material and life science facility

(neutron and muon beams)

J-PARC



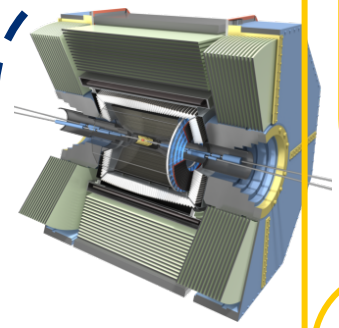
ATLAS
(CERN)



KISS
(RIKEN)

UCN
(RCNP)

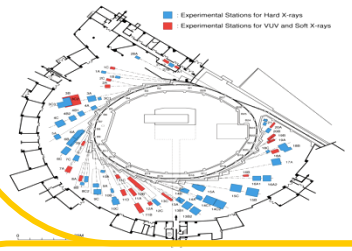
QUIET
(Atacama)



Belle-II
(KEKB)

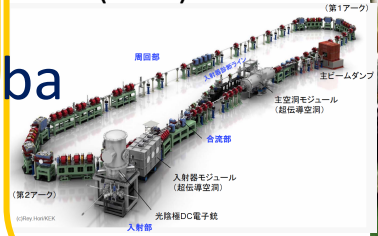
KEK Tsukuba

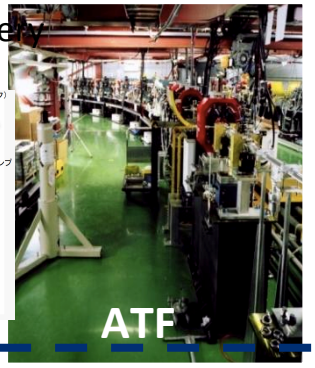
PF & PF-AR: Light source



Accelerator Development

Compact Energy Recovery Linac (cERL)





HEP programs at KEK

- Neutrino program
  - T2K long baseline neutrino experiment

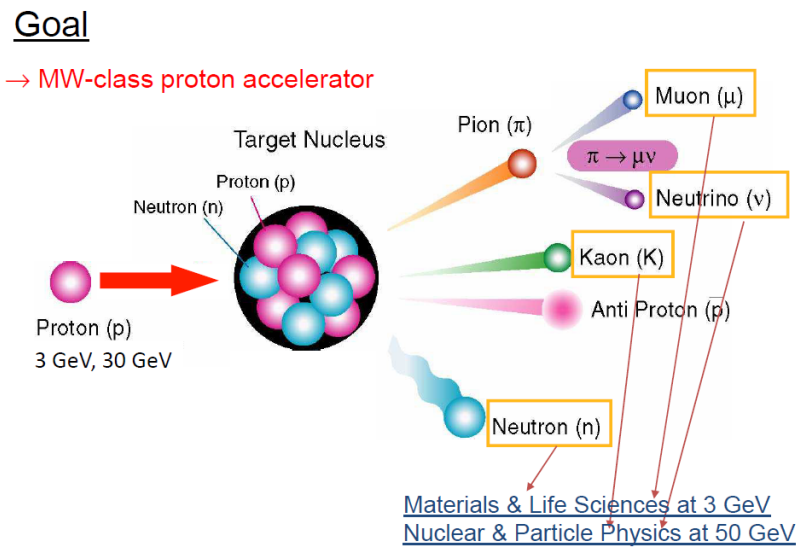
  J-PARC -----> 295km ----> SuperKamiokande
  - Future roadmap: 750kW upgrade and HyperKamiokande
- Flavor physics program
  - SuperKEKB and Belle II

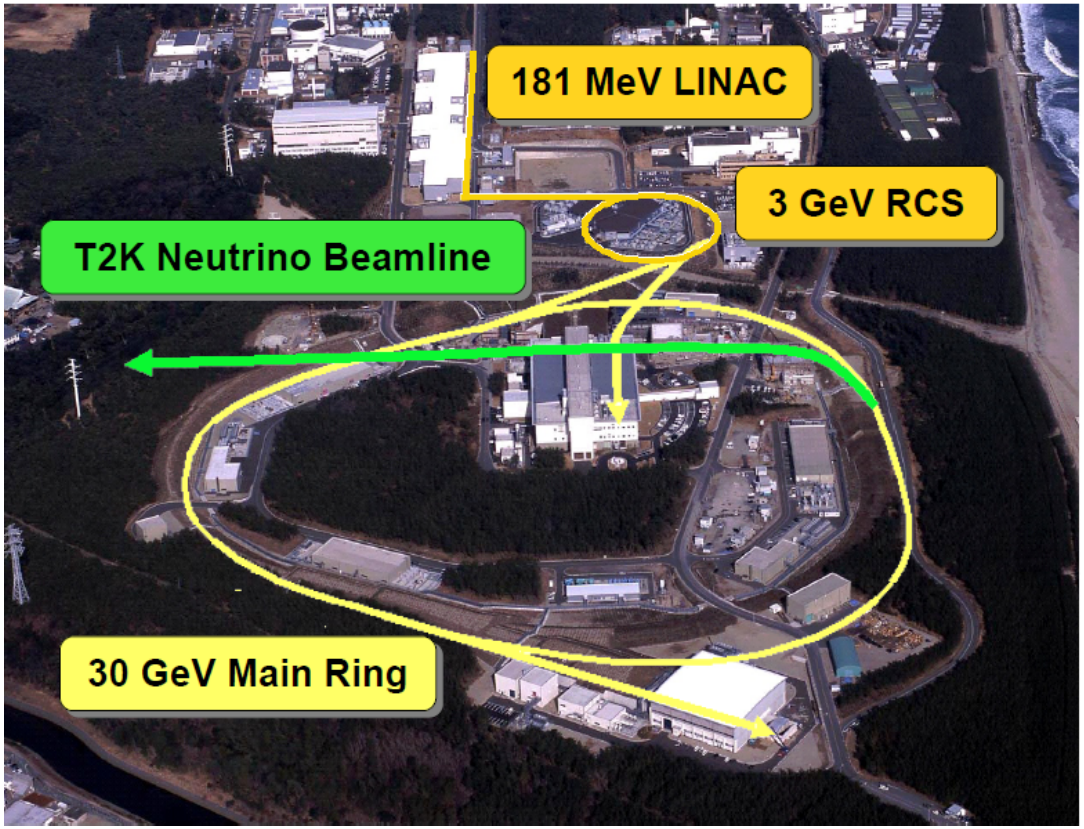
  Super high lum. B factory at $8\times10^{35}/cm^2/s$

  ~5×10^{10} B, D, τ sample expected in ~2024
  - KOTO $K_L \rightarrow \pi^0\nu\nu$ at J-PARC
  - COMET $\mu \rightarrow e$ conversion search at J-PARC
  - g_μ-2/μEDM measurement at J-PARC MLF
  - Neutron EDM measurement at TRIUMF
- Energy frontier program
  - ATLAS at LHC
  - ILC

J-PARC

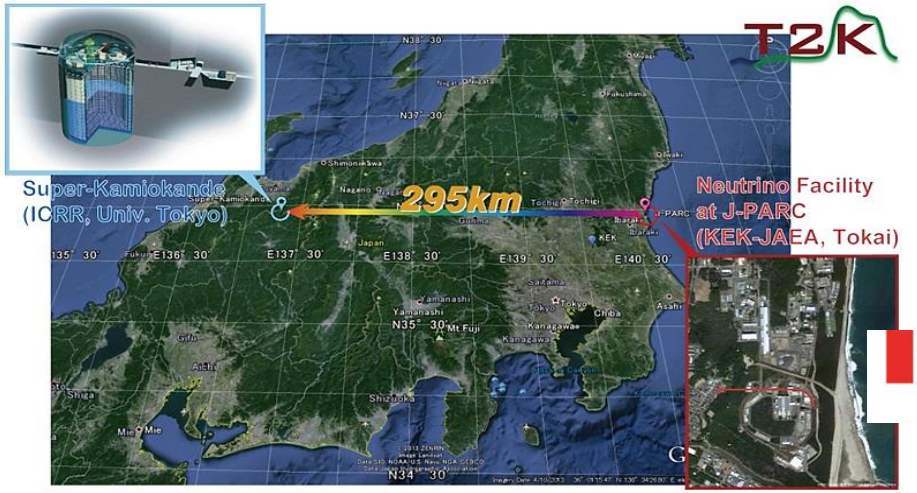
- Located in Tokai, 60km N.E. of KEK
- Completed in 2009
- Design goal
  - RCS: 1MW
  - MR: 750kW





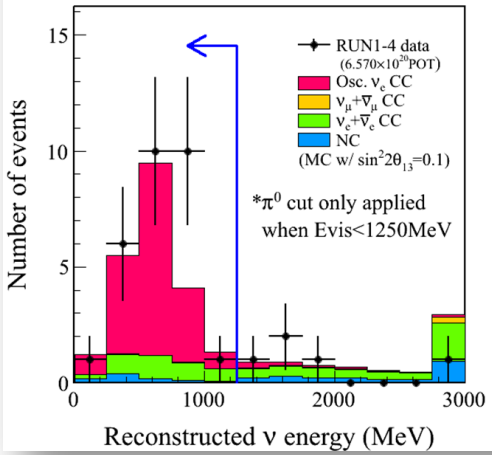
Joint project of KEK & Japan Atomic Energy Agency (JAEA)

T2K: Long Baseline Neutrino Experiment



~500 members, 61 Institutes, 12 countries

- Stable operation at ~230kW achieved
- 7.39x10^{20} POT by June
  - >1.2x10^{14}ppp(1.5x10^{13}x8b) is the *world record* of extracted protons per pulse for synchrotrons
  - first anti-ν running in 2014
  - Data :6.57x10^{20}POT by 2013

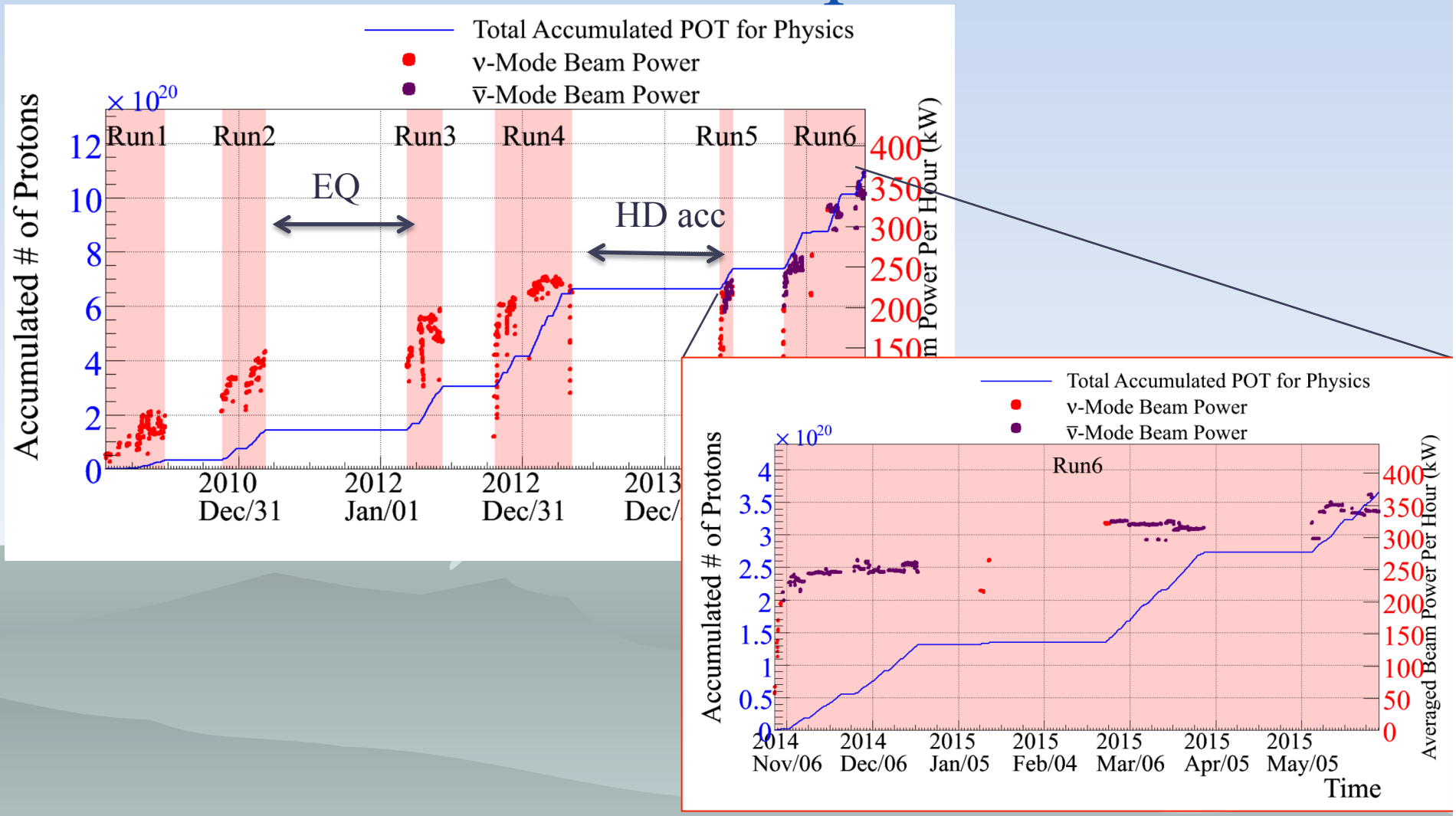


- 28 ν_e candidates events were observed while background expectation is 4.9
- Observation of ν_e appearance with 7.3σ significance
- Slightly larger than δ_{CP}=0 expectation→constraint on δ_{CP}

The electron appearance from muon neutrino beams

Discovery of the muon neutrino to the electron neutrino oscillation

Accumulated # of protons



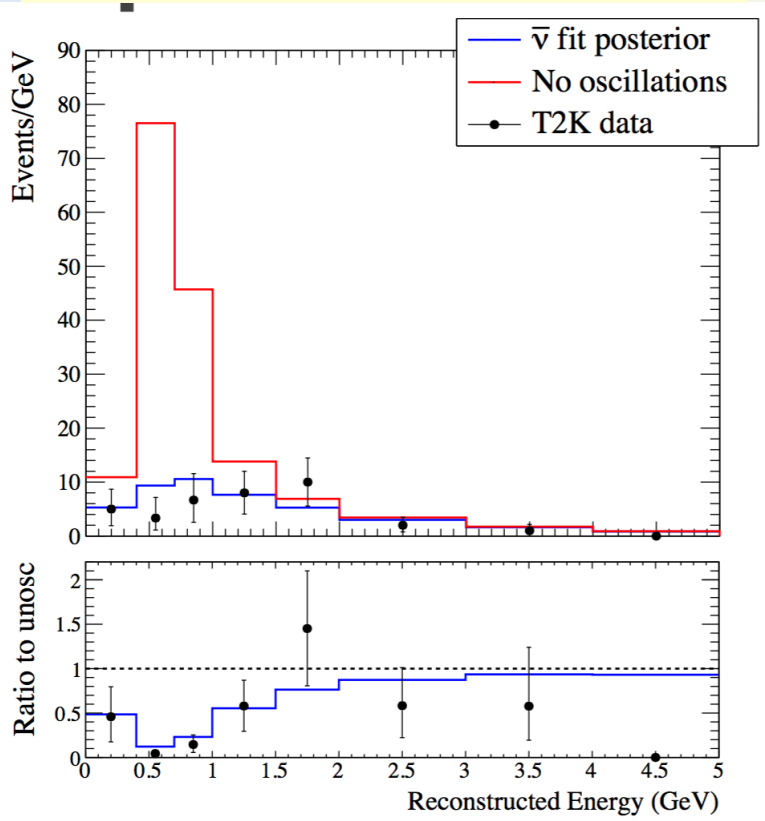
- Stable operation at **~345kW** achieved!
- 11×10^{20} (total) = 7.0×10^{20} (ν) + 4.0×10^{20} (ν-bar) accumulated (Jan 23, 2010 ~ Jun.1 , 2015)

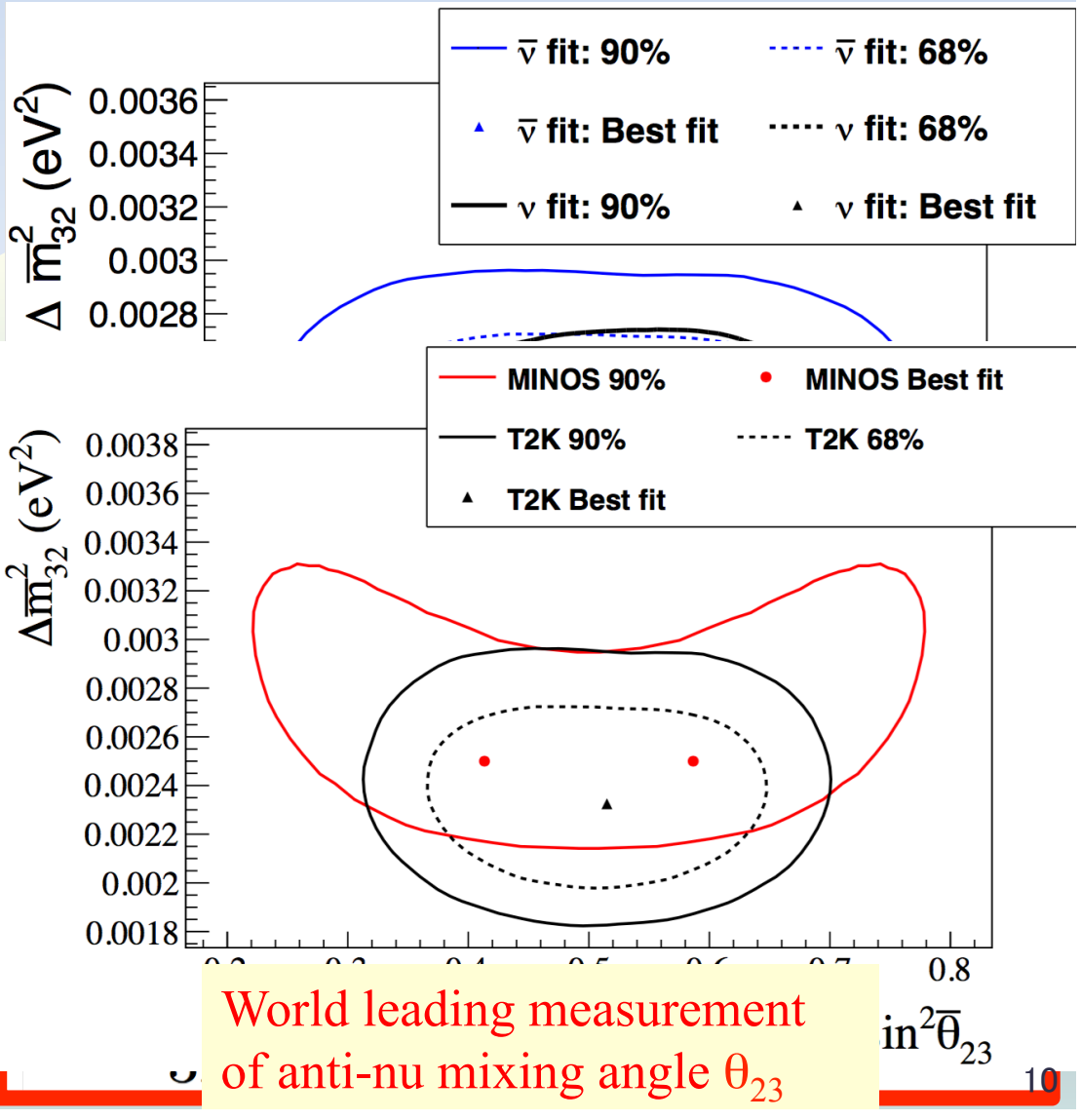
Latest nmbar disappearance results

- First physics result from anti-nu data
- 2.315x10^{20}POT by Mar. 13, 2015

Released on May 18, 2015

17 single μ-like events





World leading measurement of anti-nu mixing angle θ_{23}

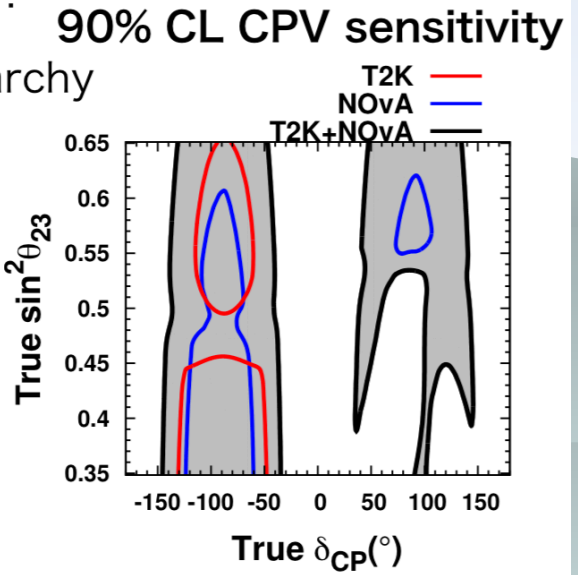
Long term goals

- Long Term: ~5 years **w/ 750kW beam**
  - CPV up to a **2.5σ level of significance**
  - $\delta(\Delta m^2_{32}) < 10^{-4}eV^2$, $\delta(\sin^2 2\theta_{23}) \sim 0.01$, θ_{23} octant determination if $|\theta_{23}-45^\circ|>4^\circ$
  - Various neutrino and anti-neutrino interaction measurements
  - Search for exotic ν oscillation scenario: Sterile neutrino, Lorentz Violation, CPT Symmetry, Neutrino mass by TOF.
  - Contribution to the determination of mass hierarchy

PTEP

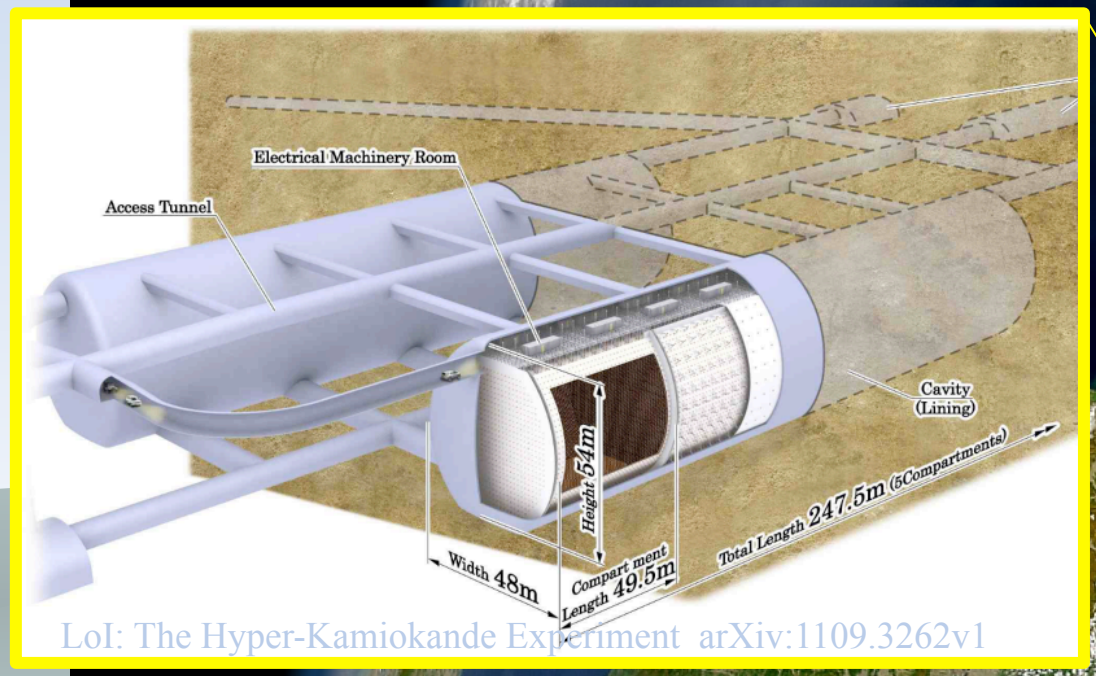
Prog. Theor. Exp. Phys. **2013**, 00000 (41 pages)
DOI: 10.1093/ptep/0000000000

Neutrino Oscillation Physics Potential of the T2K Experiment



Next generation LBL experiment

J-PARC → Hyper-Kamiokande



LoI: The Hyper-Kamiokande Experiment arXiv:1109.3262v1

with realization of

- J-PARC MR at beam power of ~1MW (>=750kW)
- New 1Mt Water Ch det: Hyper-Kamiokande

ICRR-IPNS MoU on Hyper-K

ハイパーカミオカンデ計画における協力についての覚

機構素粒子原
究
ーカミオカン
想
あることを認
ハ
まえつつ、協
計
進体制や予算
含
る。

とし、２者間
により更新できるものとする。

- This does not mean that the HK project is the main IPNS project, (yet).
- IPNS and ICRR are willing to help the collaboration to prepare the proposal, via (for example) forming a review panel.

速器研究機構
研究所

所長　梶田　隆章　　所長　山内　正則

MEMORANDUM OF UNDERSTANDING

of the cooperation in the Hyper-Kamiokande project

January 31, 2015

THE INSTITUTE FOR COSMIC RAY RESEARCH OF THE UNIVERSITY OF TOKYO and THE INSTITUTE OF PARTICLE AND NUCLEAR STUDIES OF THE HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION have reached agreement regarding cooperation in promoting the advanced nucleon decay and neutrino experiment program, Hyper-Kamiokande, by understanding that the program would make significant progress in a wide range of fields in physics and astronomy. It is also agreed to review and develop the program in its comprehensive aspects including promoting organization and budget measures.

This agreement is effective for two years from January 31, 2015 and is able to be updated upon the discussion between the two organizations.

T. Kajita

Prof. Takaaki KAJITA

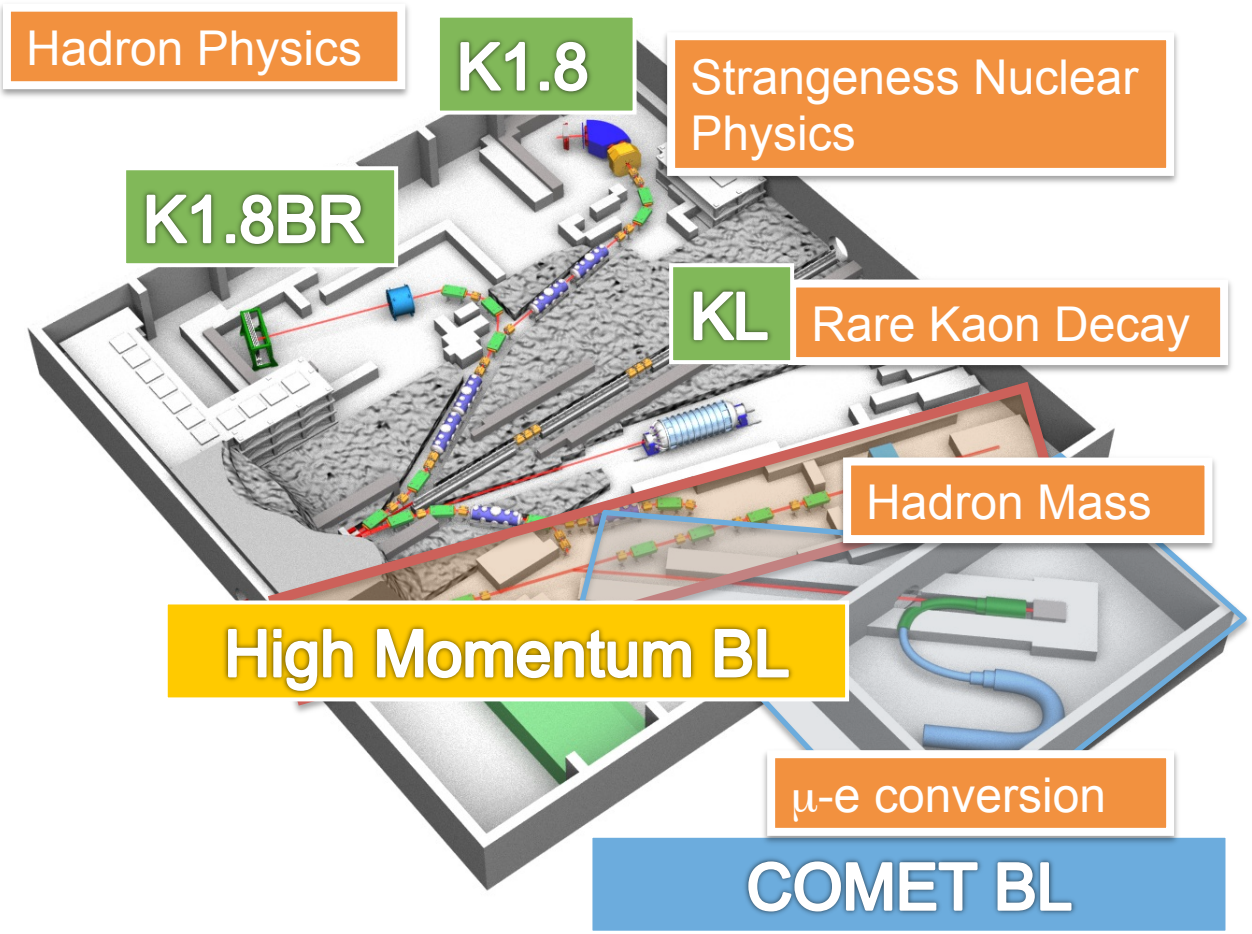
Director
Institute for Cosmic Ray Research,
The University of Tokyo

M. Yamauchi

Prof. Masanori YAMAUCHI

Director
Institute of Particle and Nuclear Studies,
High Energy Accelerator
Research Organization

Nuclear & Particle Physics with J-PARC Hadron Beam



International Collaboration Experiments

KOTO
Search for CPV in KL->πνν
(Physics Run started)

COMET (Phase I)
Search for Lepton Flavor Violation
(Under construction)

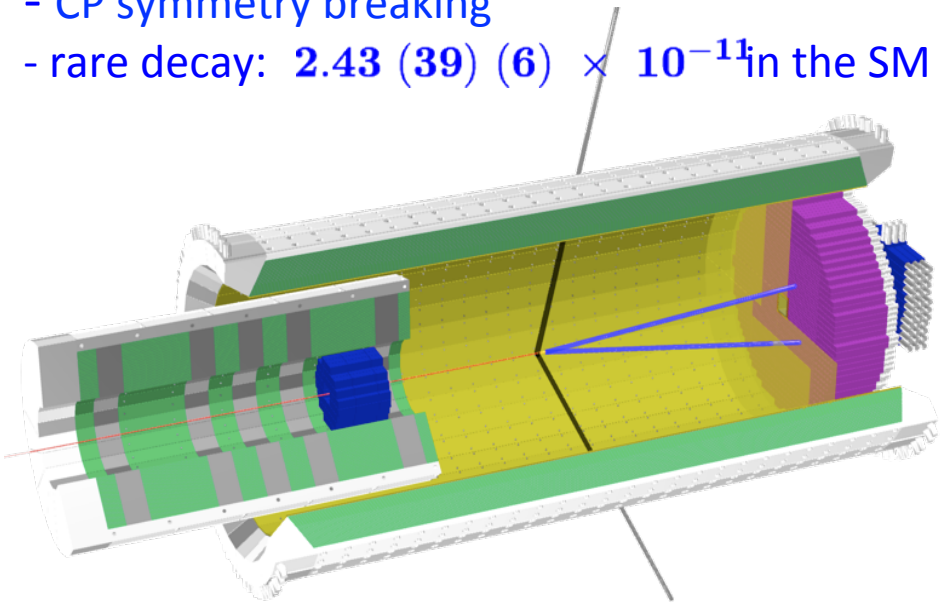
Muon g-2/EDM
(R&D phase)

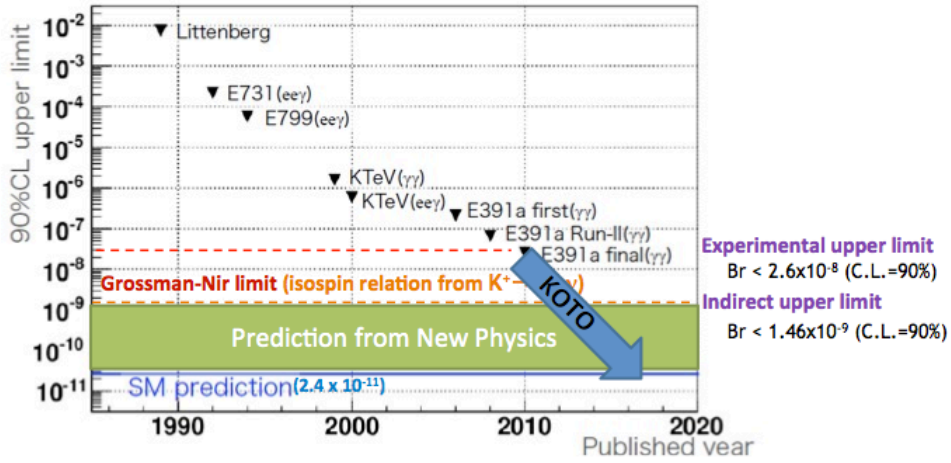
J-PARC KOTO experiment

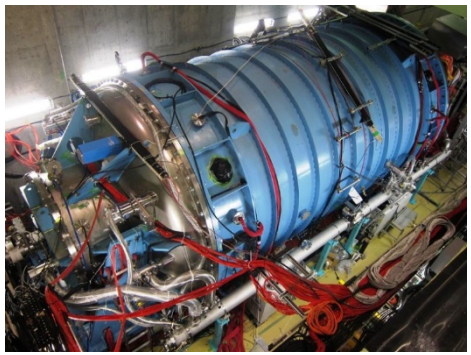
65 participants from Japan, US, Korea, Taiwan, Russia

$K_L \longrightarrow \pi^0 \nu\bar{\nu}$

- CP symmetry breaking
- rare decay: $2.43\ (39)\ (6) \times 10^{-11}$ in the SM



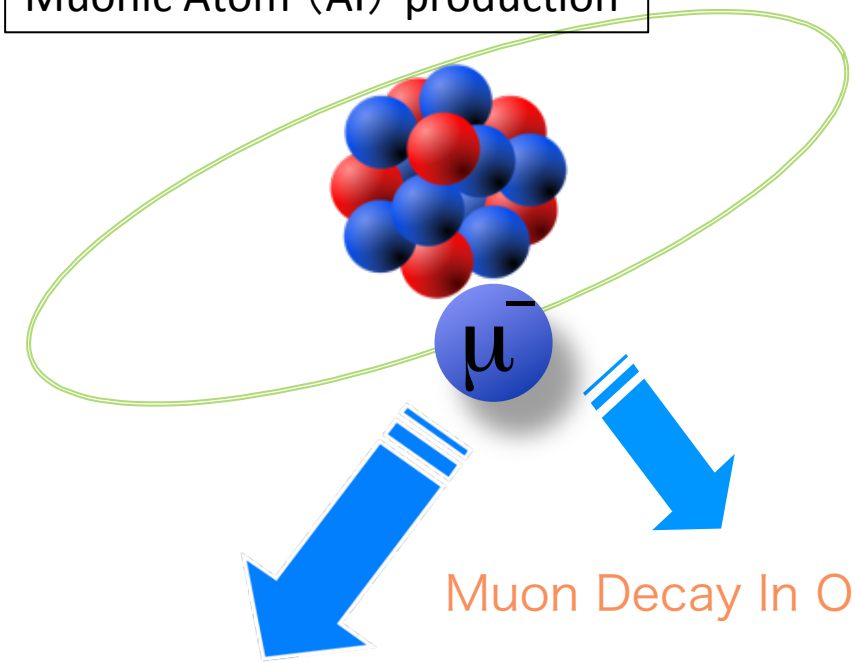




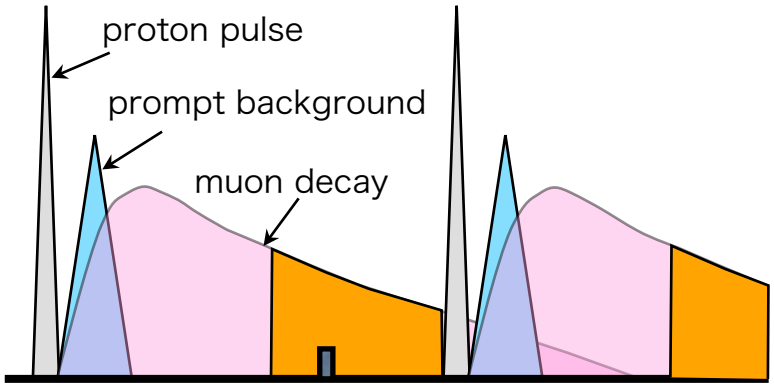
- **CsI calorimeter** to measure $\pi^0 \longrightarrow \gamma\gamma$
- background rejection:
  hermetic extra-particle detection (“veto”)
- Trigger/DAQ (37k channels):
  waveform digitization (14bits, 125MHz ADC), pipeline readout

COMET Experiment at J-PARC

Muonic Atom（Al）production



Muon Decay In Orbit



$\pi^-+(A,Z)\rightarrow(A,Z\text{-}1)^*$, $(A,Z\text{-}1)^*\rightarrow\gamma+(A,Z\text{-}1)$, $\gamma\rightarrow e^+e^-$

Prompt timing

Other sources

μ^- decay-in-flight, e^- scattering, neutron streaming

$$R_{ext}=\frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}<10^{-9}$$

nuclear muon capture

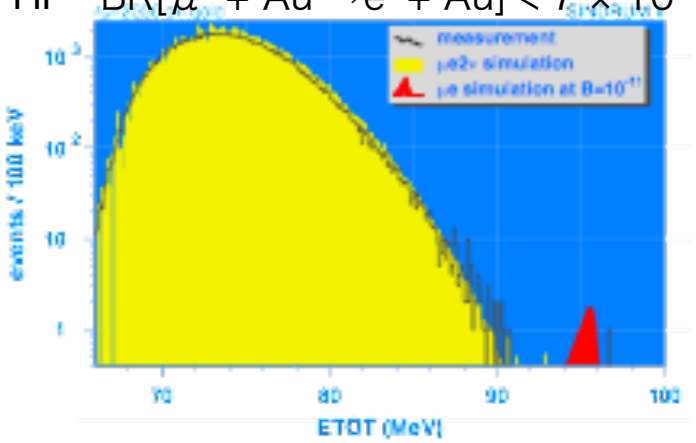
$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

μ-e conversion

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

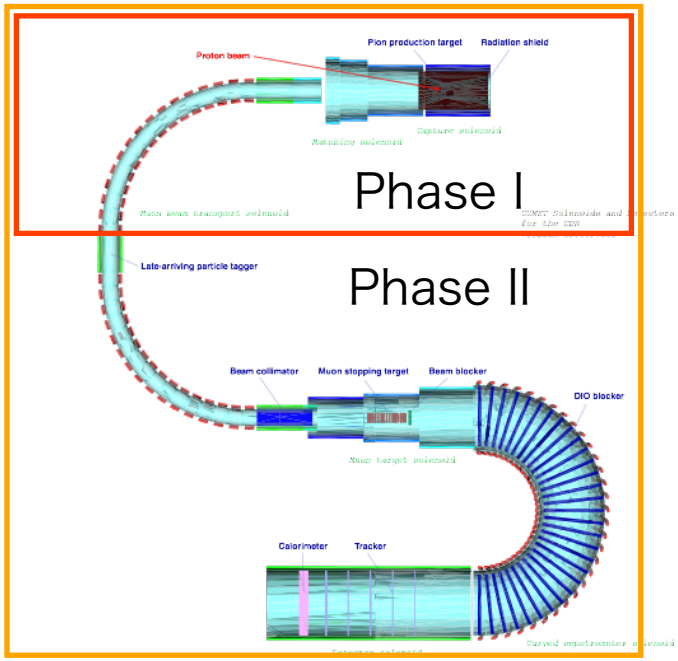
- $E_{\mu e(Al)} \sim m_\mu - B_\mu = 105\text{MeV}$
  - B_μ: binding energy of the 1s muonic atom

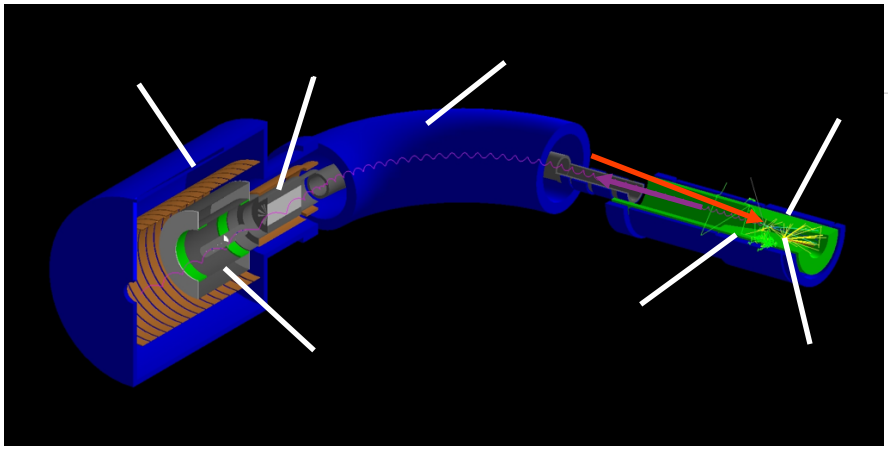
SINDRUM II $BR[\mu^- + Au \rightarrow e^- + Au] < 7 \times 10^{-13}$



COMET Phase I & II

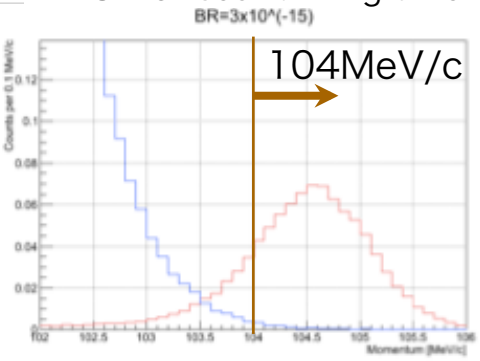
- Phase I
  - Detailed understanding of the beam background and achieving the sensitivity of < 10^{-14} (100 better than the current limit)
  - 8GeV, 3.2kW beam, ~90-days DAQ (Graphite as a primary target)
- Phase II
  - 8GeV, 56kW beam, 1-year DAQ (Tungsten as a primary target)
  - COMET final goal Sensitivity < 10^{-16}
- Proton beam extinction (w/o extraction) of 10^{-12} has been already achieved (Req. < $10^{-9\sim10}$)





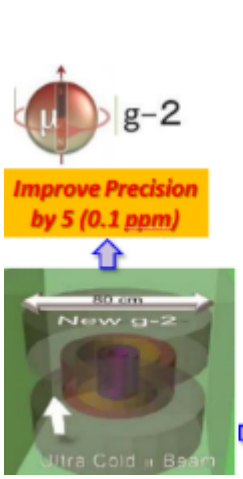
Phase I background

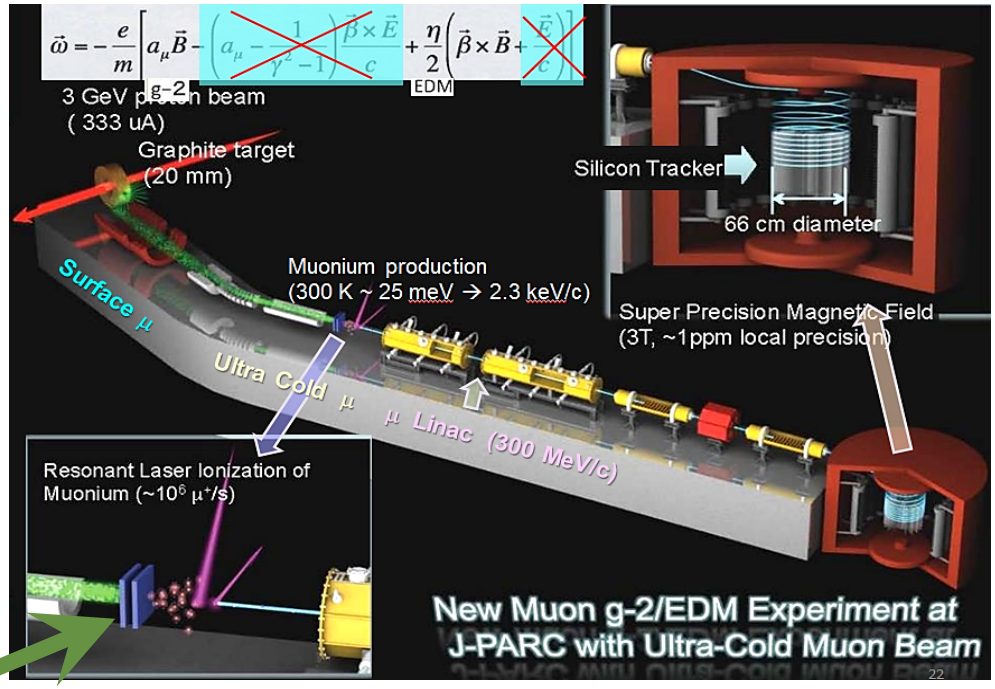
0.03 BG expected
In 7.8×10^{6} sec running time



Phase I
2013-2015
Facility construction
2013-2016
Magnet construction & installation
2016-2017
Eng. run & Physics run
Phase II
Eng. run in 2020(?)

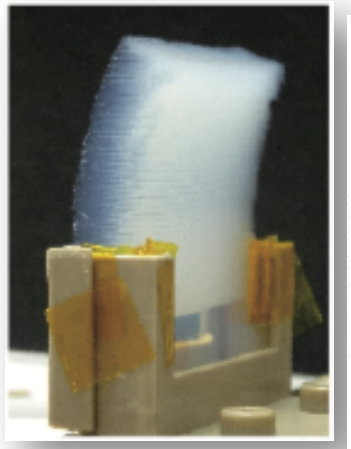
Muon g-2 @ J-PARC

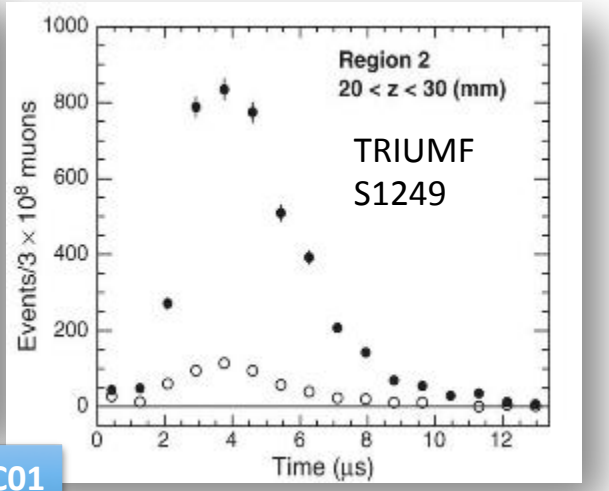




- **Muonium production is improved by > 10 !**

Laser-drilled aerogel produces more muonium!





PTEP 2014 (2014) 091C01

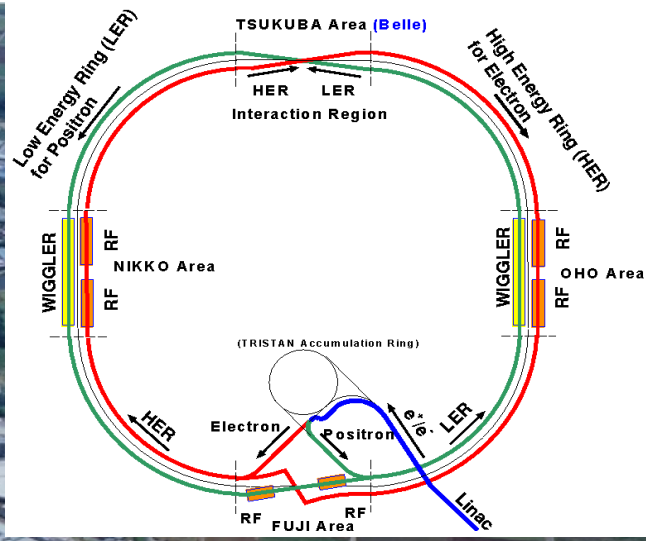
Intended Schedule

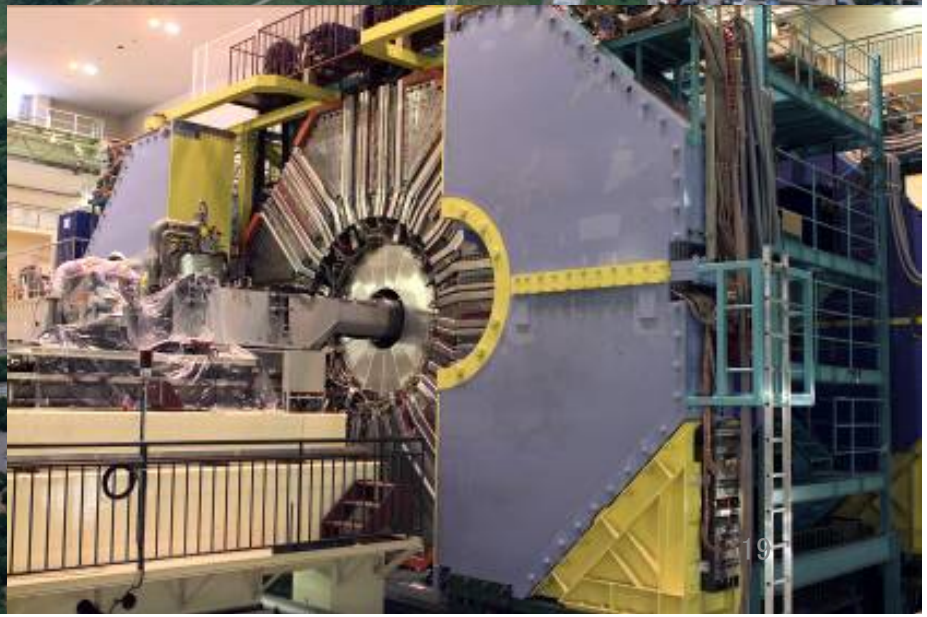
	2013	2014	2015	2016	2017	2018
Muon Sournce	R&D / Design		Technical design report	Construction		Experiment
Muon LINAC	R&D / Design			Construction		
Ultra-Precision Magnet	R&D / Design			Construction		
Detector	R&D / Design			Construction		

136 members from 49 institutes in 8 countries

KEKB and Belle

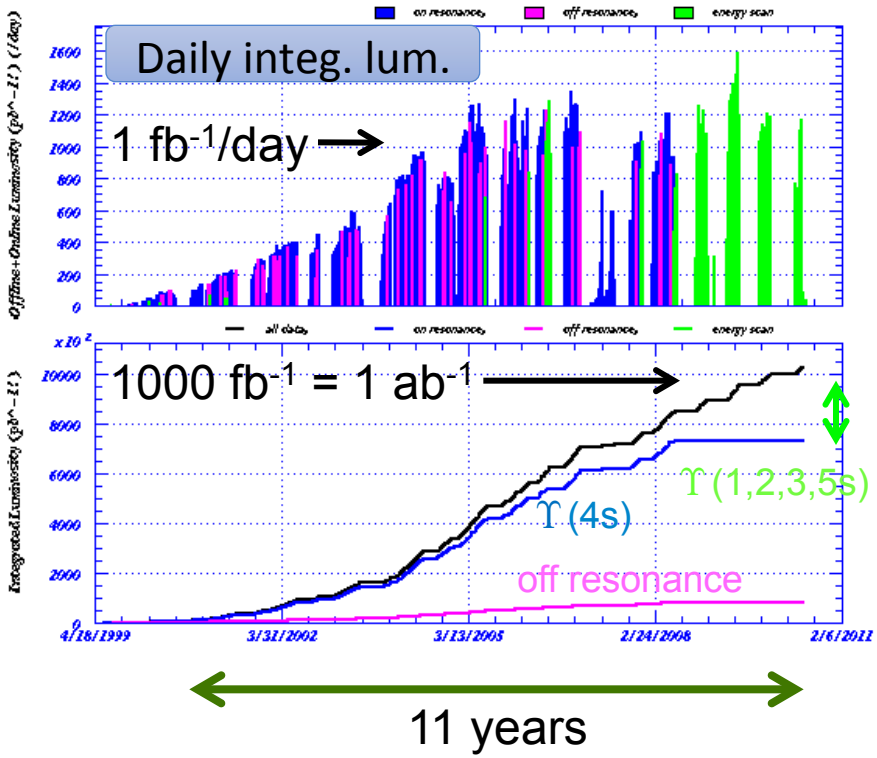
SuperKEKB and Belle II



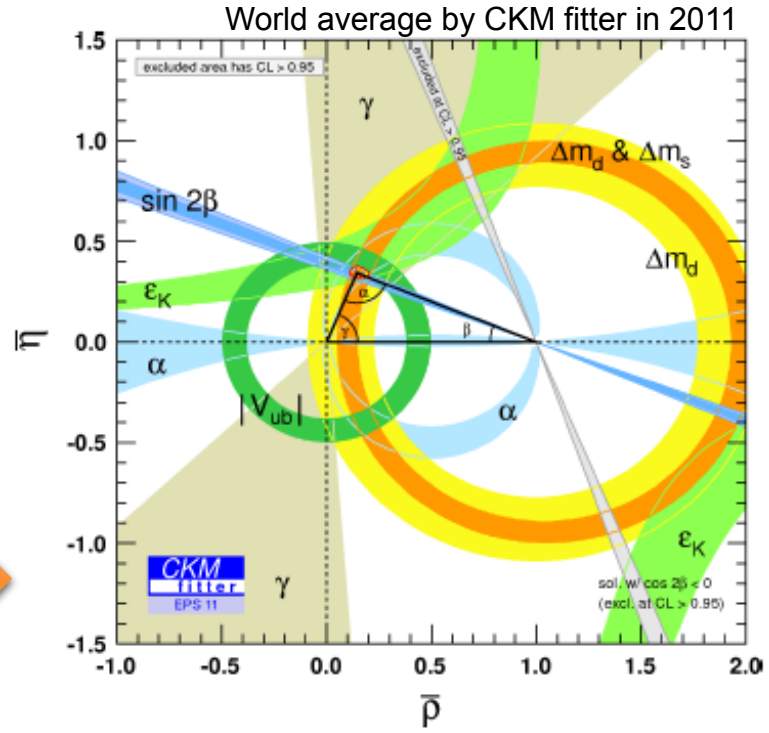


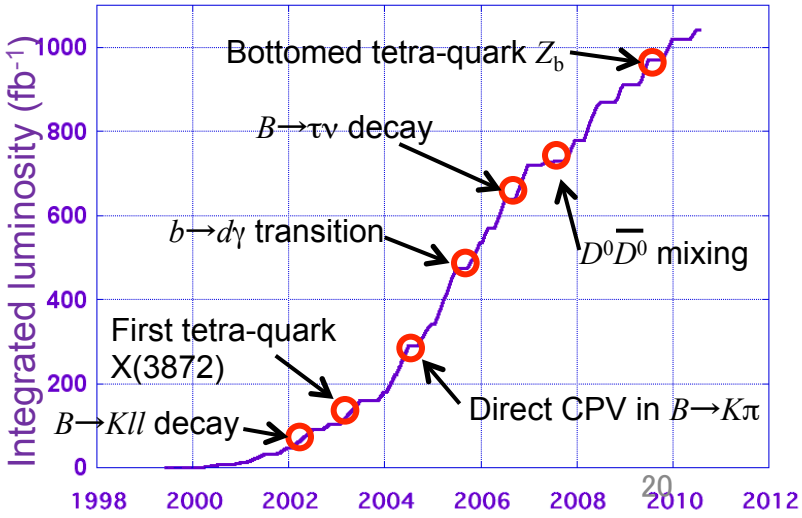
Achievements of KEKB and Belle

$L_{peak} = 2\times10^{34}/cm^2/s$

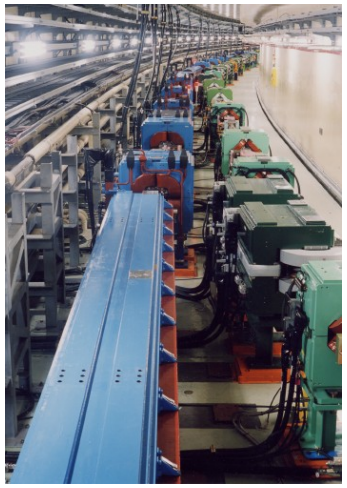


World average by CKM fitter in 2011

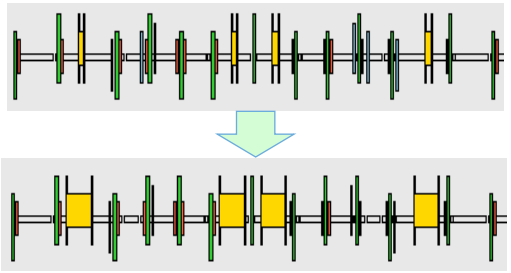




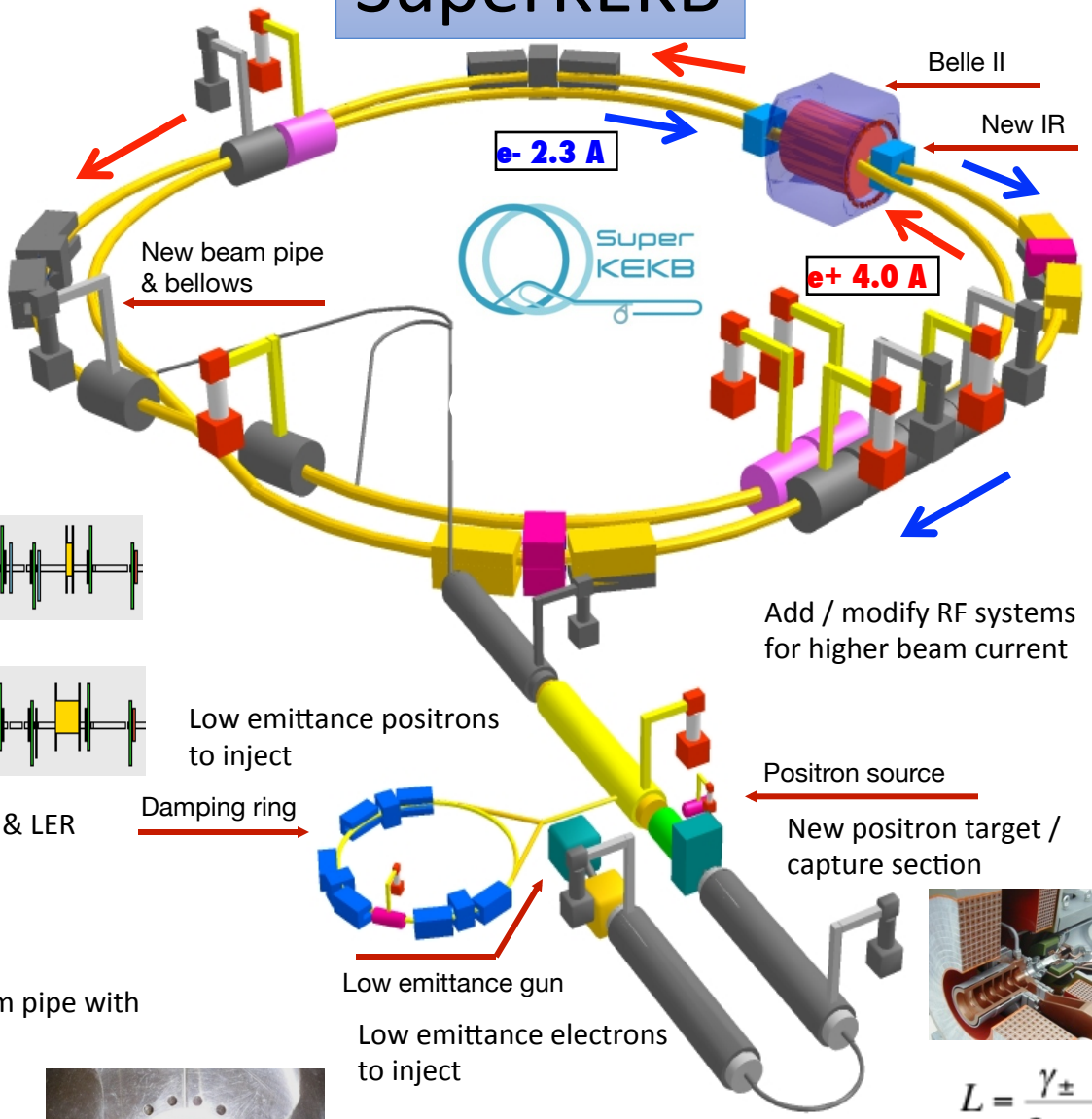
SuperKEKB



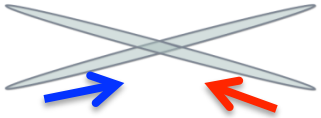
Replace short dipoles with longer ones (LER)



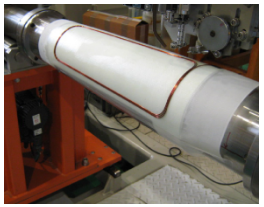
Redesign the lattices of HER & LER to squeeze the emittance



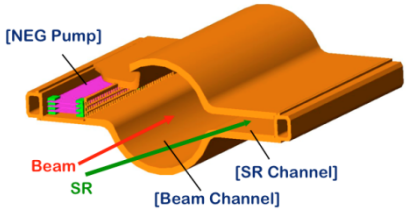
Colliding bunches

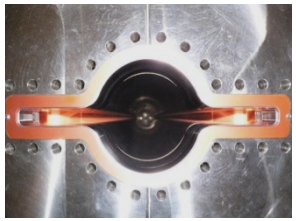


New superconducting / permanent final focusing quads near the IP



TiN-coated beam pipe with antechambers



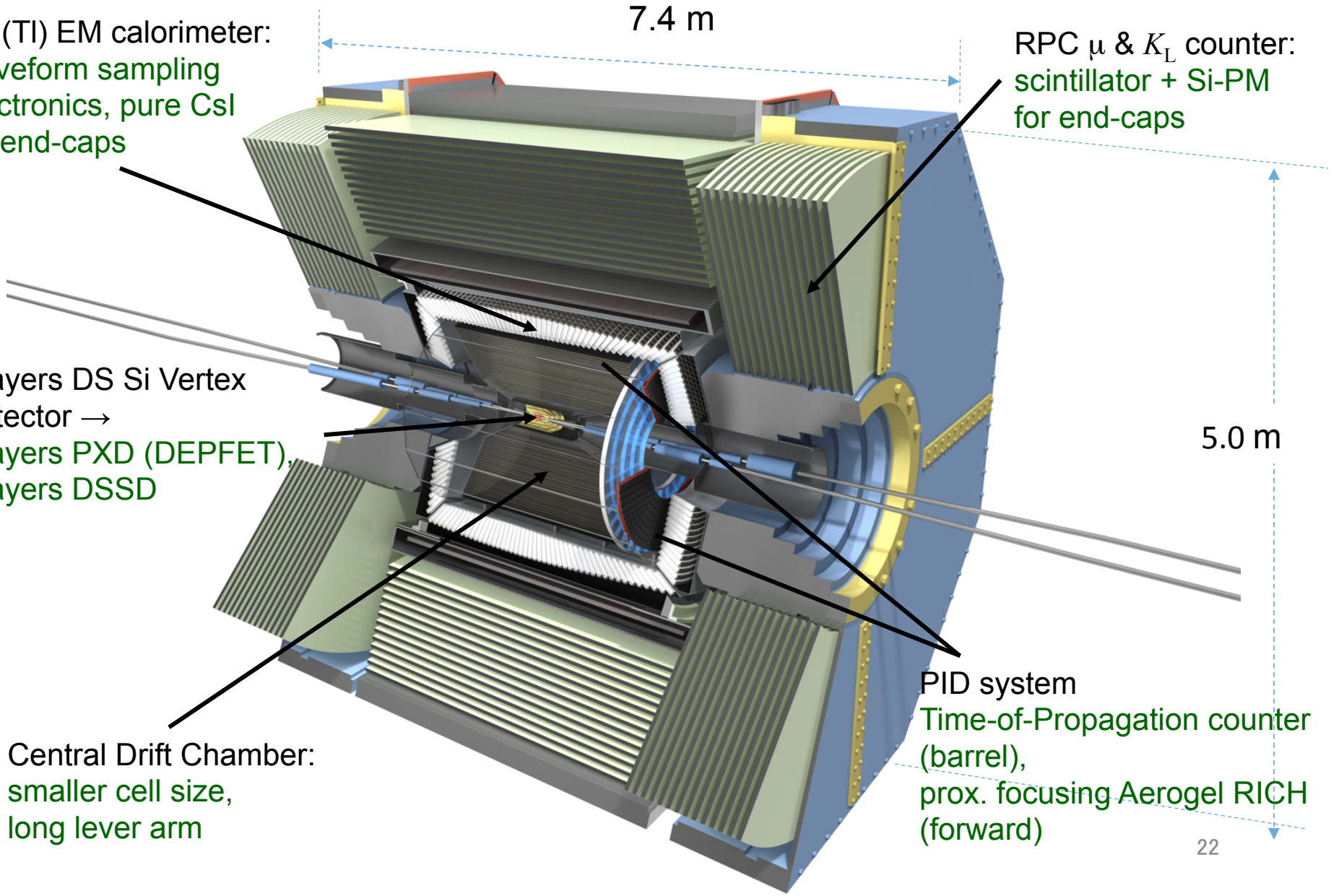


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

$L=8\cdot10^{35}\ s^{-1}cm^{-2}$

x 40 Gain in Luminosity

Belle II Detector Upgrade

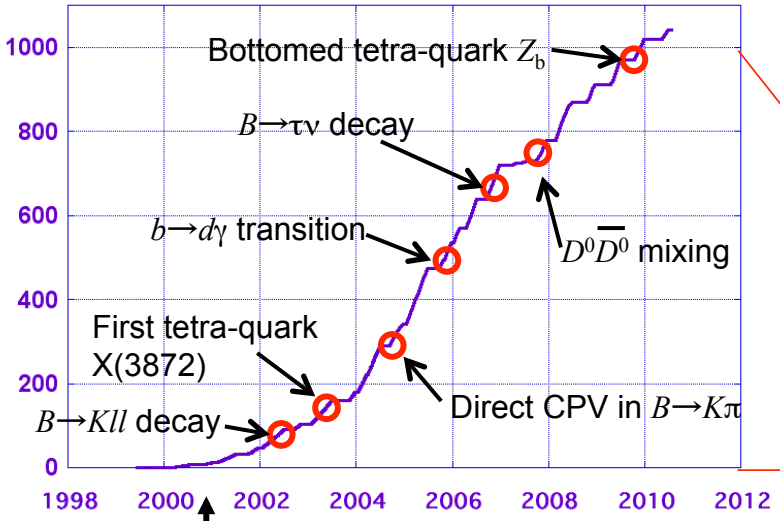


Belle II Collaboration

- **600 collaborators from 100 institutions in 23 countries**
- **Spokesperson: Tom Browder (Hawaii)**
- **Series of open collaboration meetings in 2008.03 ~2015.**

Belle II

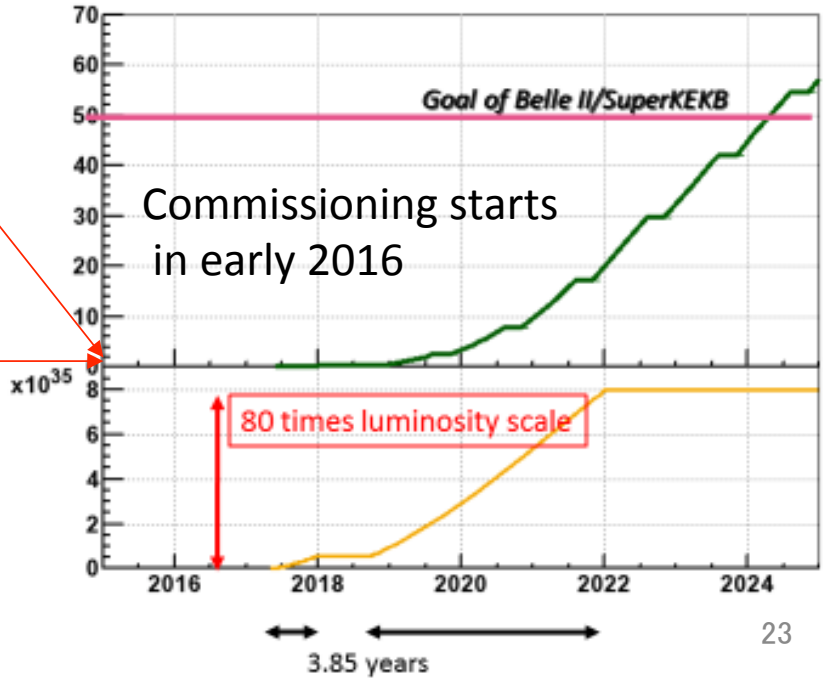
fb^{-1}



Belle

Discovery of
CP violation in B decays

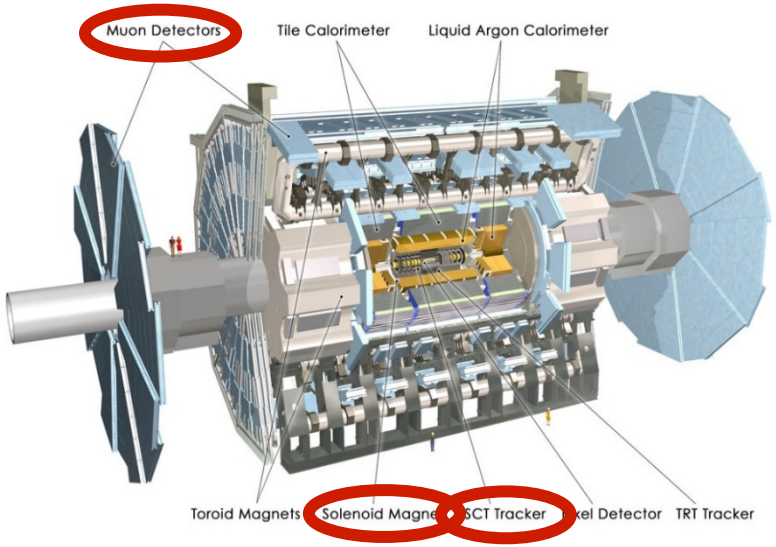
ab^{-1} =1000fb^{-1} Targeted luminosity



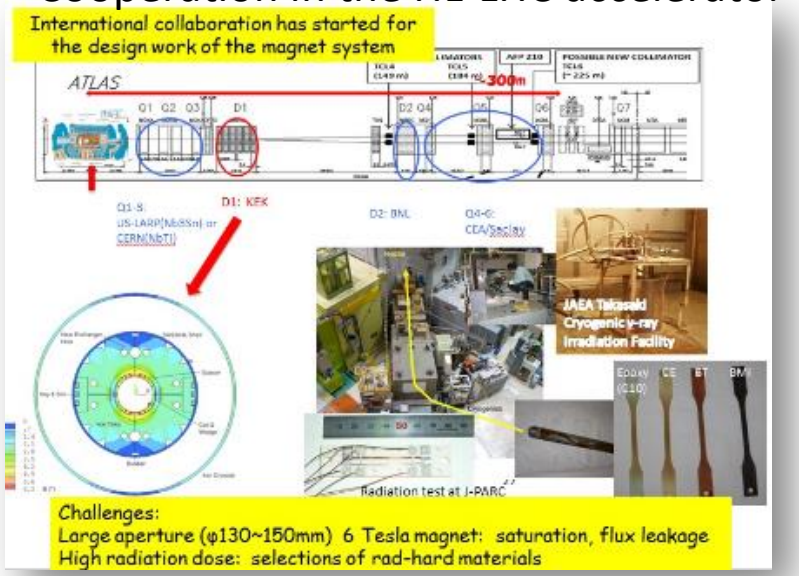
LHC detector/accelerator

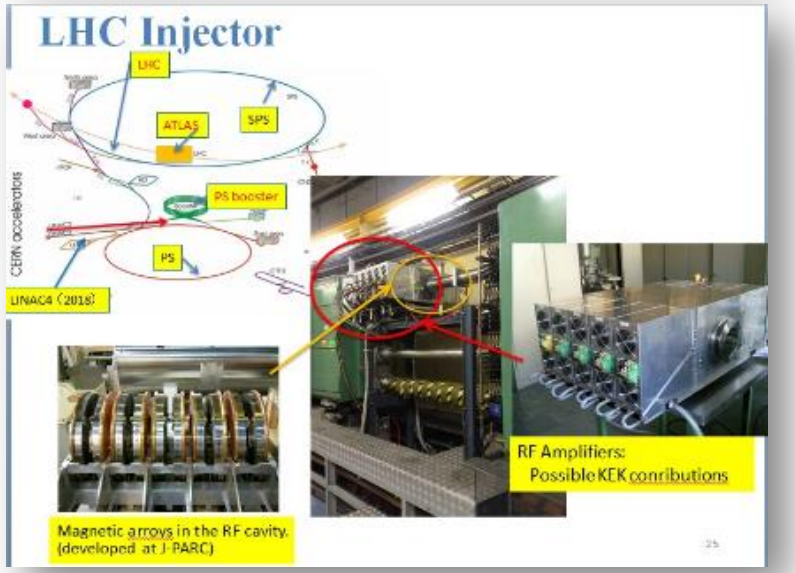
Contributions to the LHC accelerator
Participation in the ATLAS experiment
Cooperation toward the HL-LHC and ATLAS upgrade

KEK delivered 16 focusing quads.



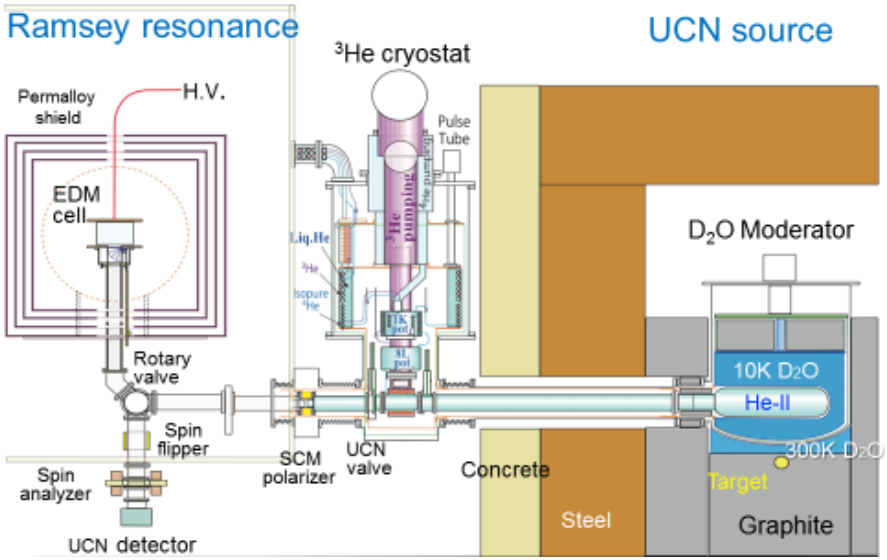
Cooperation in the HL-LHC accelerator

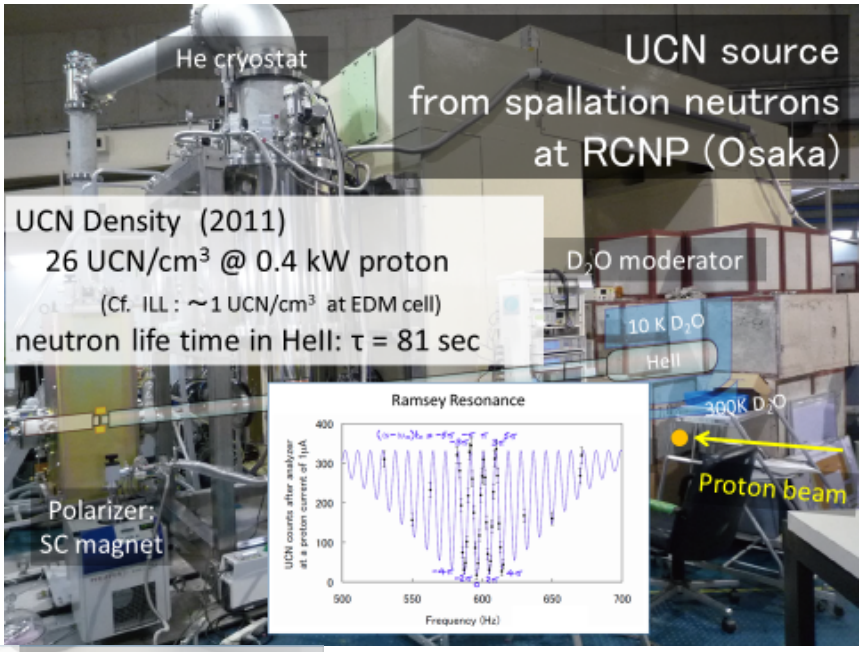


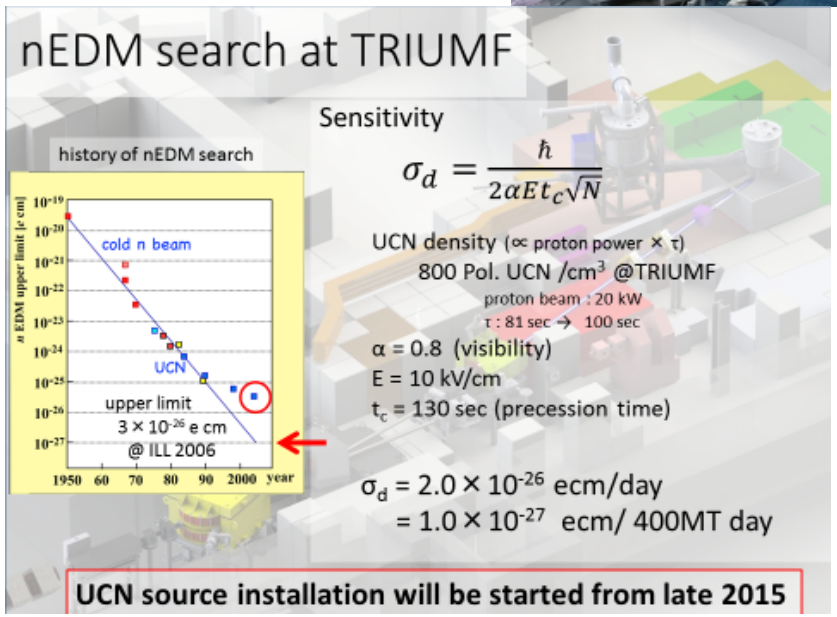


Collaboration between Canada and Japan for the neutron EDM experiment

UCN – EDM apparatus

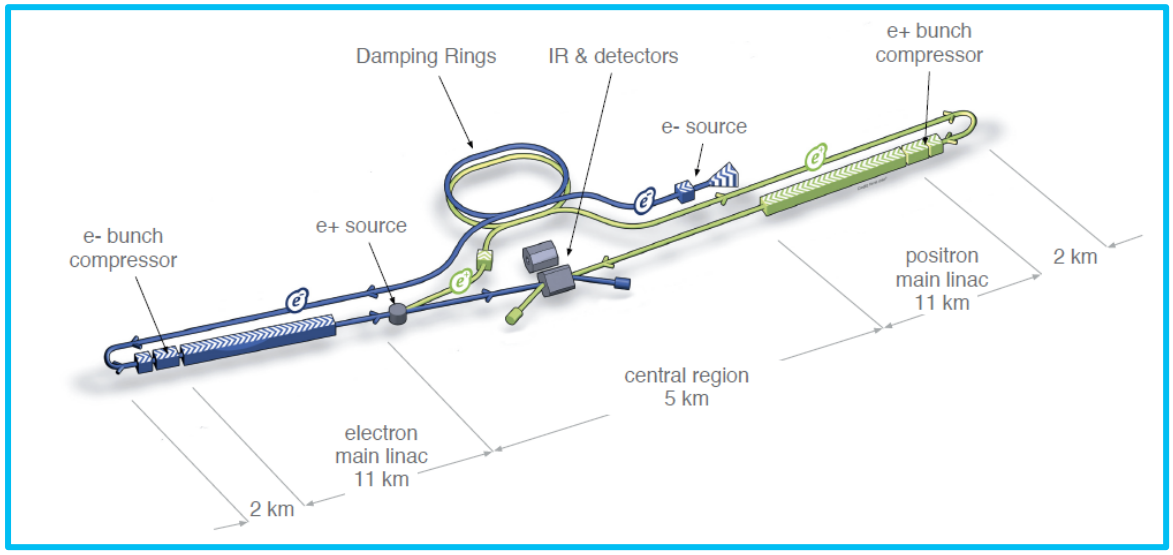


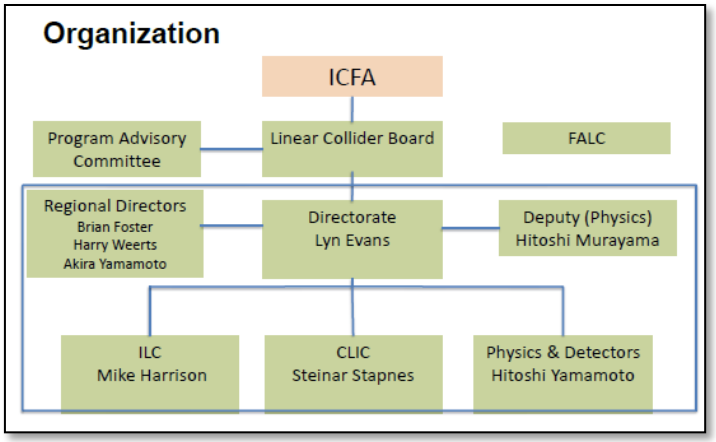




International Linear Collider (ILC)

- The next generation e+e- collider (500GeV, upgradable to 1TeV)
- Design work and accelerator R&D have been carried out in a global framework. The ILC TDR was completed by Global Design Effort (GDE) in 2013 and the next phase of design and R&D works has started under the leadership of Linear Collider Collaboration (LCC).
- Discovery of a Higgs particle at LHC in July 2012 set a clear physics target of the initial stage of ILC.

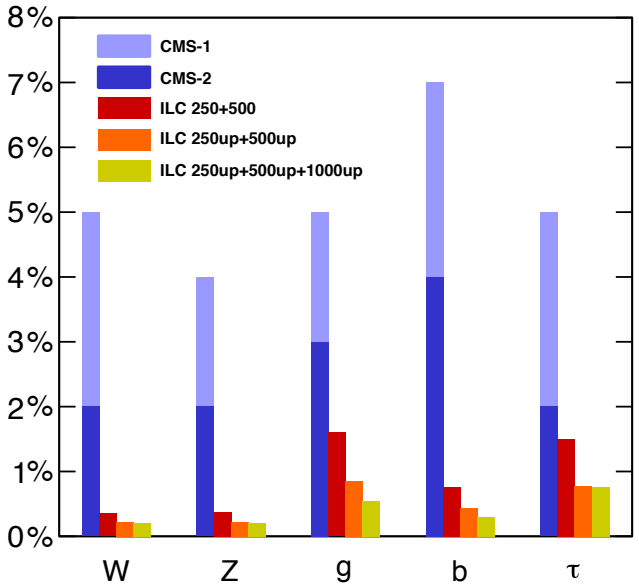




Physics at ILC

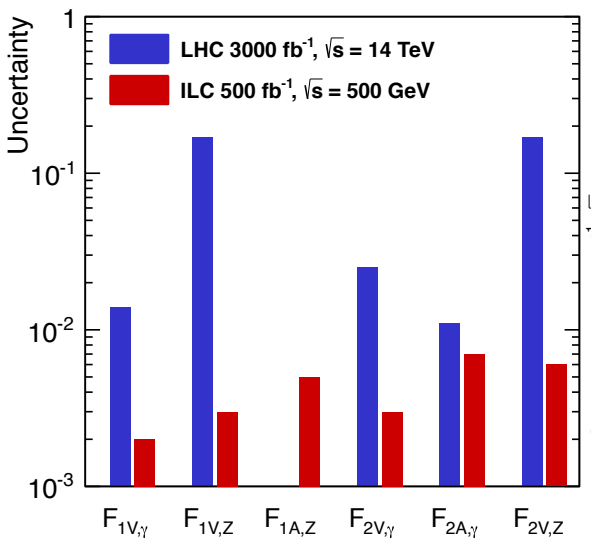
Explore physics law beyond the TeV scale by precise measurements of Higgs bosons, top quarks etc. , and searching for new particles and new phenomena.

Higgs coupling determination



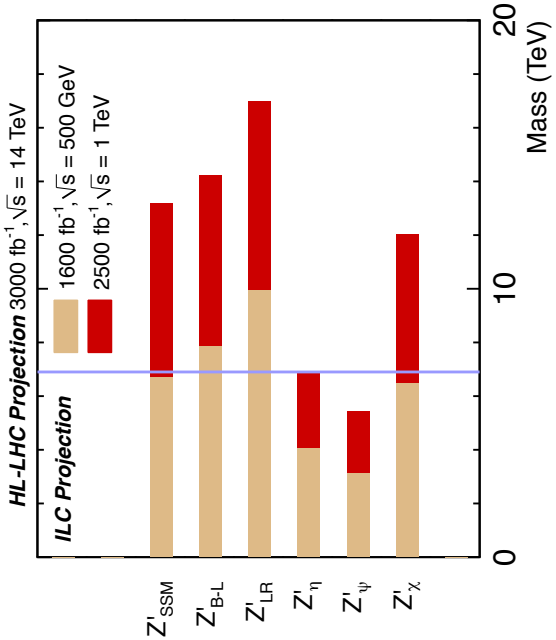
Results taken from Snowmass 2013 study

Top anomalous coupling

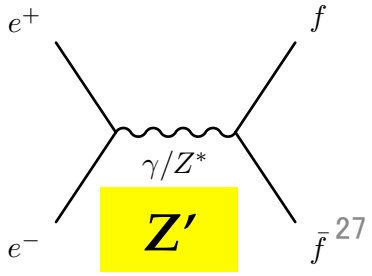


Snowmass 2013 study

Z' effect



Snowmass 2013 study



In 2012

- Japan Association of High Energy Physicists (JAHEP) subcommittee report on Future Projects on High Energy Physics in February 2012.
- Discovery of a Higgs boson in July 2012
- JAHEP "A Proposal for a Phased Execution of the International Linear Collider Project" October 2012

"… JAHEP proposes that ILC be constructed in Japan as a global project with the agreement of and participation by the international community….."

Since then, the Japanese HEP community and KEK have been vigorously promoting the ILC project to the academic sector, the industrial sector, policy makers in Japan and the international HEP community

Statements on ILC hosted in Japan

The European Strategy for Particle Physics Update 2013
ACFA/AsiaHEP Statement on the ILC (September 2013)
P5 report (May 2014)
ICFA statements (January and July 2014)

KEK's efforts toward realization of ILC

- KEK proposed to host ILC in Japan, which is under careful consideration in the Japanese Government.
- KEK's role to push the ILC project forward
  - Continue accelerator R&D program at ATF, STF and CFF facilities collaborating with the international team.
  - Provide the ILC committees with appropriate information to help their timely conclusion.
  - Develop a KEK's evolution plan to prepare for green light given by MEXT.

ILC Recent progress of KEK-ATF

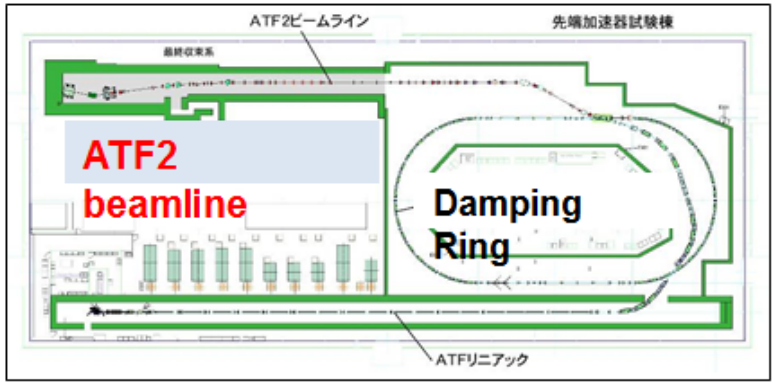
ATF2: Final focus Test beamline

Goal-1: Develop final focus system for ILC

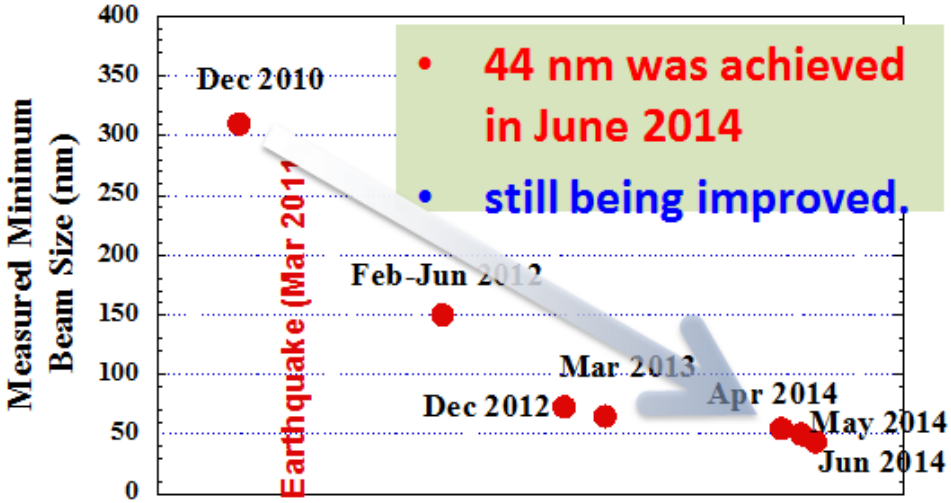
→ 37 nm vertical beam size at IP

Goal-2: Develop beam position stabilization in a few nm

→ Study of Intra-train feedback has been started.

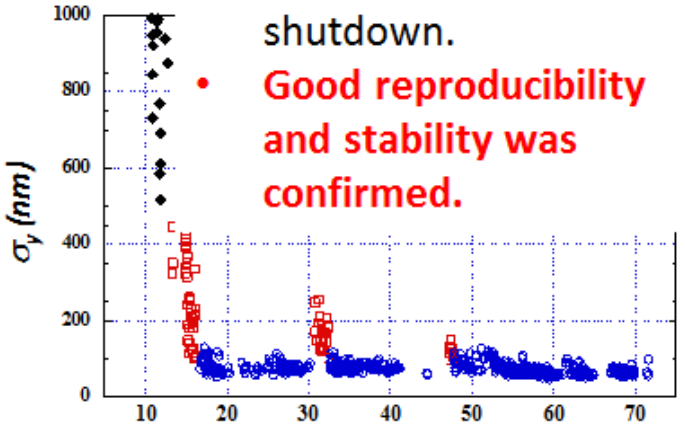


History of measured minimum beam size



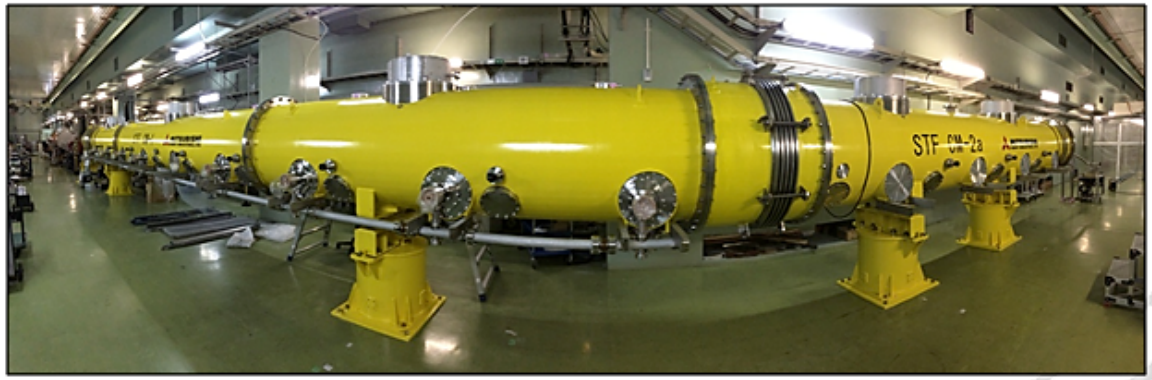
Presented by K.Kubo at IPAC2014

- Small beam size (<50 nm) was recovered in a day from an accelerator shutdown.
- **Good reproducibility and stability was confirmed.**



Time (hours) from operation start after 3 days shutdown

ILC STF Accelerator under construction



CM-1 cavities: Average Gradient 36MV/m before installation

STF Accelerator parameters
Beam Energy : 418MeV
Beam Charge : 2nC/bunch, 2437bunch, 0.9ms, 5Hz
Beam current: 5.7mA in train
Bunch train: 369ns spacing

Beam Dump

Chicane 2

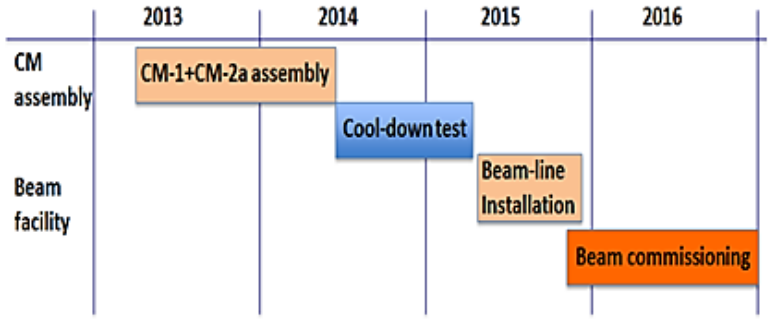
ILC-type Cryomodule (CM-1)
(8 SC cavities + SC-quad/BPM)
+
half-size Cryomodule (CM-2a)
(4 SC cavities)

Chicane 1

Capture Cryomodule
(2 SC cavities)

Photo-cathode RF-gun

Plan of STF Start-up schedule

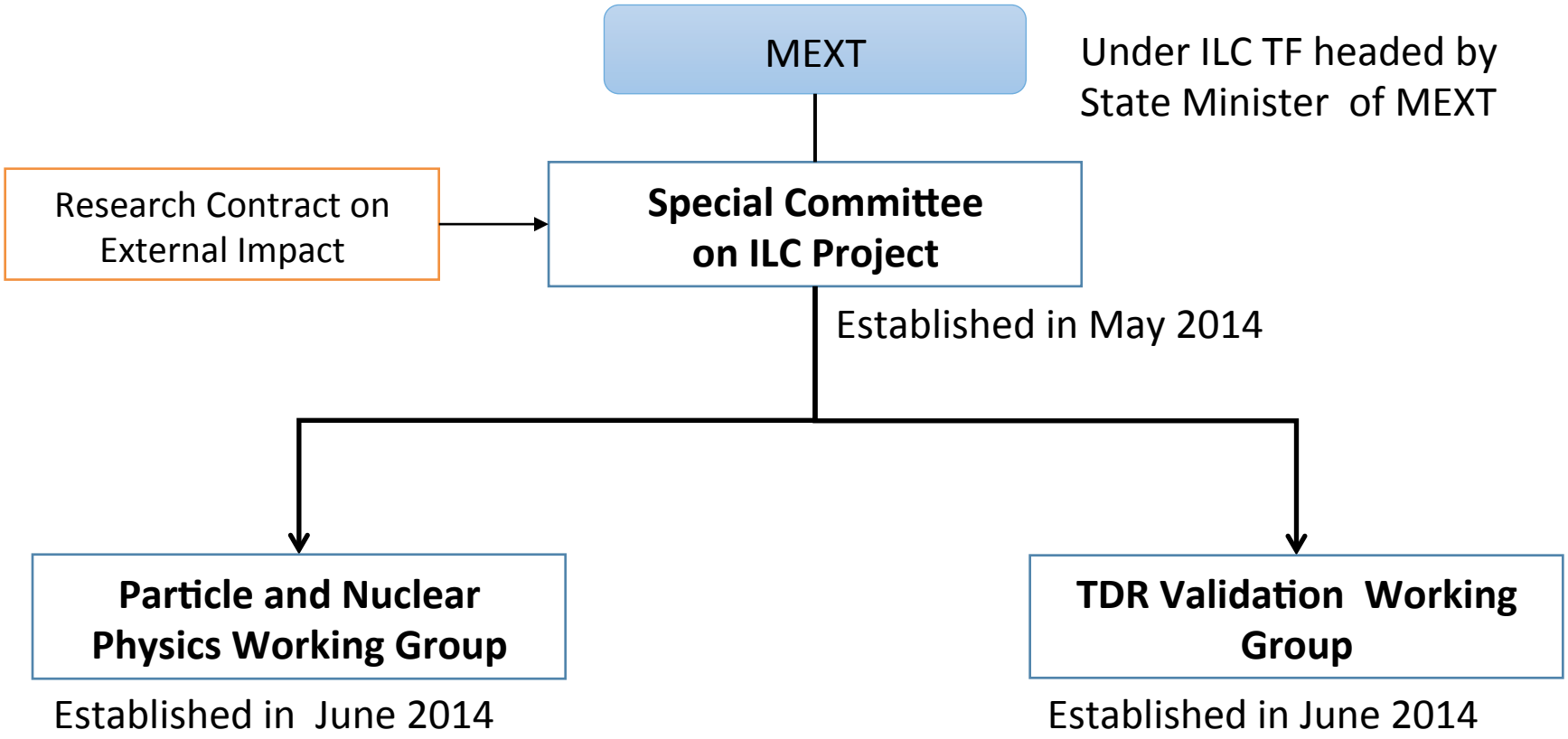


Actions on the ILC project in MEXT

MEXT= Ministry of Education, Culture, Sports , Science &Technology in Japan

- On May 27, 2013, the DG of Research Promotion Bureau, MEXT, sent a letter to the President of Science Council of Japan (SCJ) and asked for advice on ILC project promotion in Japan .
- In response to this letter, SCJ set up a special committee to investigate requirements for construction and operation of the ILC, its scientific merits, and its role in science in general.
- A report from SCJ was sent on September 30, 2013. SCJ agreed scientific importance of the ILC project, and recommended to study issues to be clarified to host the ILC with involvement of the government as well.
- MEXT has set up an ILC Task Force chaired by MEXT State Minister for the investigations.
- Special Committee for the ILC Project by academic experts was established under the ILC Task Force in May 2014.

Special Committee on ILC Project in Japan



- Reports from both WG were presented at the 3rd Special committee meeting on April 22, 2015.
- Human resource issue, technical feasibility, and R&D status are investigated this year.

Based on SCJ's recommendations, Special Committee investigates critical issues required to judge hosting ILC or not by 2016.

Active supports from policy makers, industrial sector in Japan

- Federation of Diet Members for ILC (since 2008, more than 150 members)
  The third visit to US in April 2015 to discuss promotion of the ILC project
- Advanced Accelerator Association Promoting Science & Technology (AAA)
  (since 2008, 100 companies and 40 universities and research institutions)

ILC Tokyo Event on April 22, 2015 during Asian Linear Collider Workshop 2015

ILC Tokyo Statement
http://www-conf.kek.jp/alcw2015/Tokyo_Statement.html

Dr. Lyn Evans
LCC Director

Mr. Ryu Shionoya
Diet member
Former MEXT Minister

KEK
High Energy Accelerator Research Organization

Summary and conclusions

- KEK has diverse program in particle physics.
  - Long baseline neutrino program with upgrade plan to HyperKamiokande.
  - Flavor physics program at SuperKEKB and J-PARC.
  - Energy frontier program: ATLAS and ILC
- Hosting ILC has been proposed to Japanese government, which is being intensively investigated at the special ILC committee. KEK will :
  - Continue accelerator R&D program at ATF, STF and CFF facilities collaborating with the international team.
  - Provide the ILC committees with appropriate information to help their timely conclusion.
  - Develop a KEK's evolution plan to prepare for green light given by MEXT.