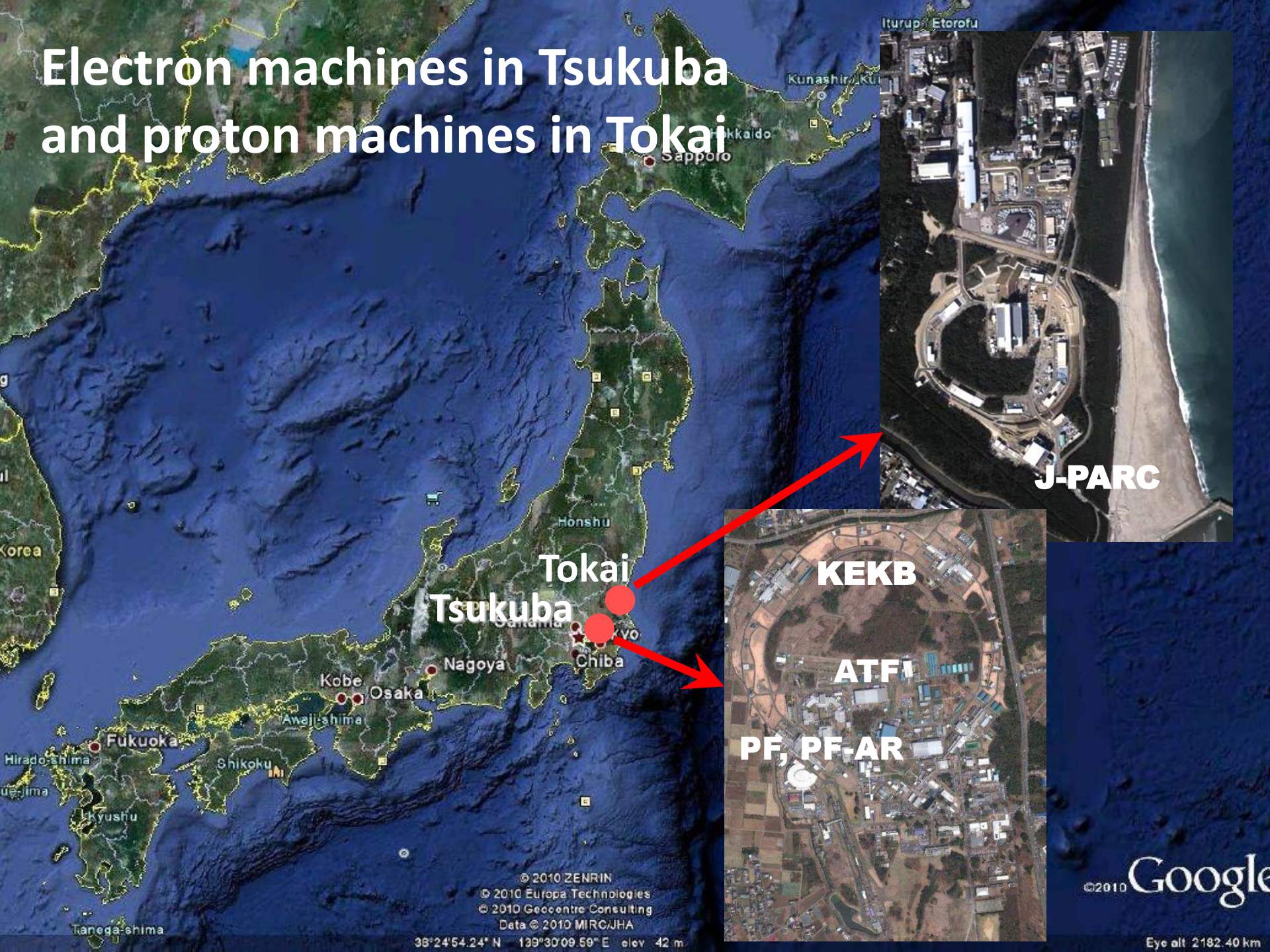
KEK strategy on HEP and Nuclear physics

Katsuo Tokushuku
High Energy Accelerator Research Organization (KEK)

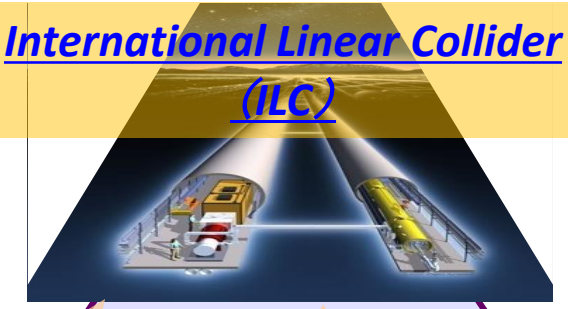
Electron machines in Tsukuba and proton machines in Tokai



Quest for Birth-Evolution of Universe

International Linear Collider (ILC)

Quest for Unifying Matter and Force



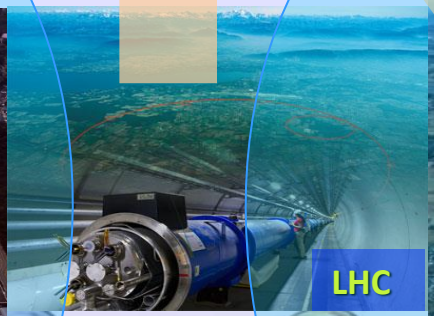
Scientific Activities
Technology Innovations
Talented Human Resources

Lepton CP Asymmetry

Power-Upgrade

Beyond Standard Physics

SuperKEKB



Lepton

Quark

Quest for Neutrinos

ν_τ ν_μ ν_e

[Origin of Matter]

Quest for 6 Quarks

[Origin of Force]

Higgs Particle [Origin of Mass]

Physics at KEK

Energy Frontier

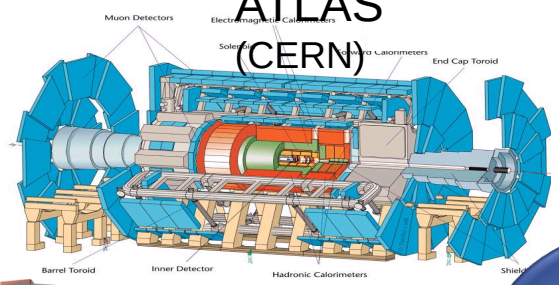
Flavor Physics

Hadron and Nuclear Physics

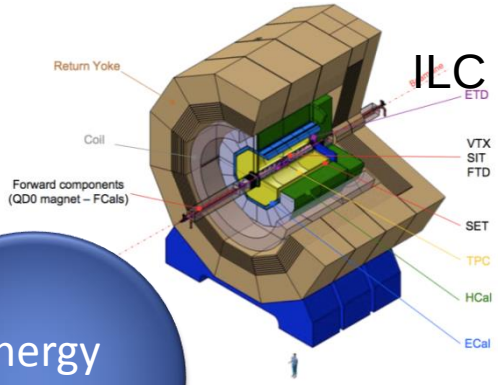
Astro-particle Physics

Theory

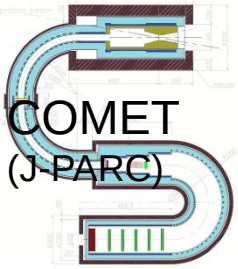
ATLAS
(CERN)



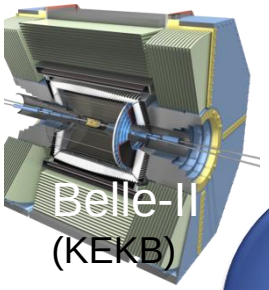
ILC



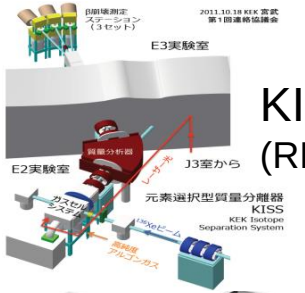
COMET
(J-PARC)



Belle-II
(KEKB)

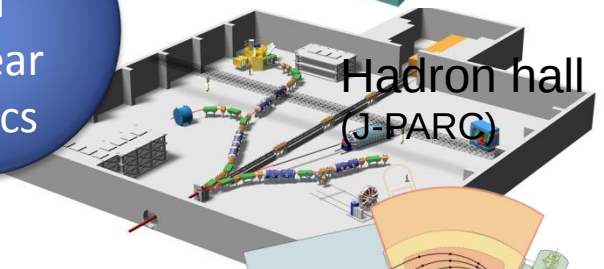


KISS
(RIKEN)

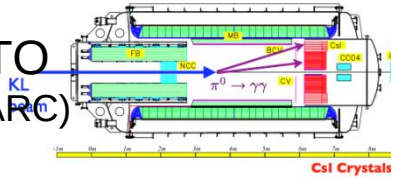


T2K
(J-PARC)

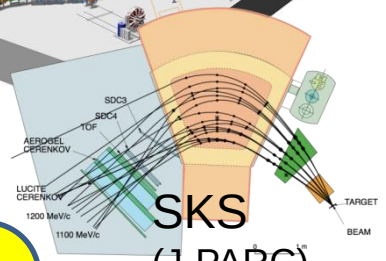
Hadron hall
(J-PARC)



KOTO
(J-PARC)

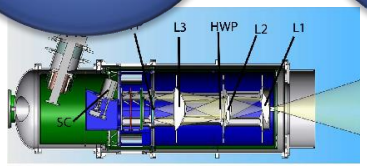


SKS
(J-PARC)



UCN
(RCNP)

QUIET
(Atacama)



PolarBear2
(Atacama)

Theory

String theory
Particle physics
Hadron physics
Cosmo-physics
Lattice simulation

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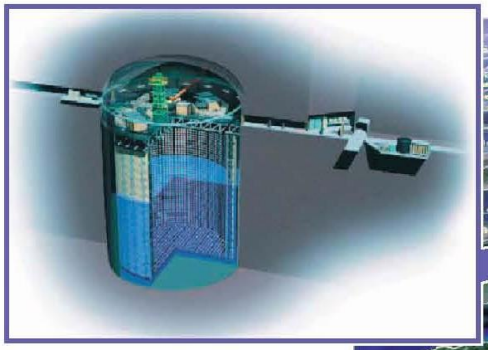
HEP programs at KEK

- 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

T2K (Tokai to Kamioka) experiment

2010~ (Running)



Super-Kamiokande
(ICRR, Univ. Tokyo)

J-PARC Main Ring
(KEK-JAEA, Tokai)

- High intensity ν_μ beam from J-PARC MR to Super-Kamiokande
- Evidence → Observation of $\nu_\mu \rightarrow \nu_e$ (2011-2013)
- Updated goals
  - Precise measurement of ν_e appearance
  - Precise meas. of ν_μ disappearance

→ Measure CPV phase, contribution to mass hier. determ.

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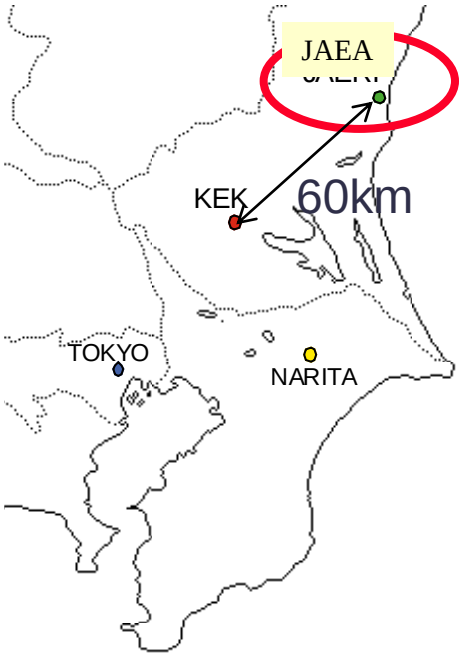
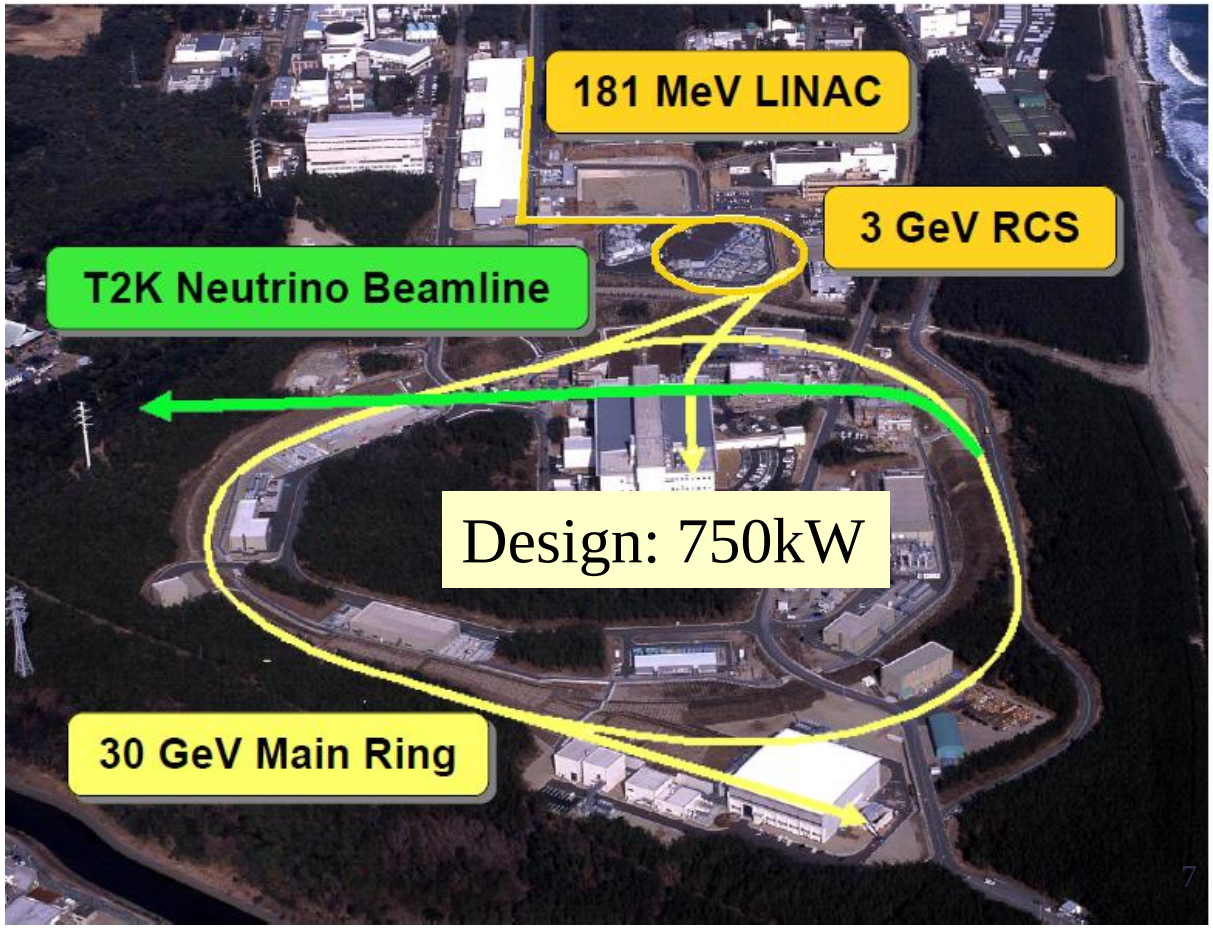
J-PARC

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





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

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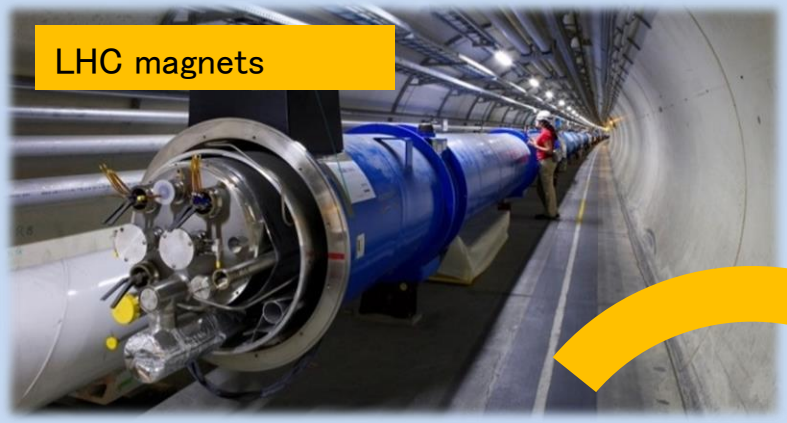
Very fruitful collaboration with CERN



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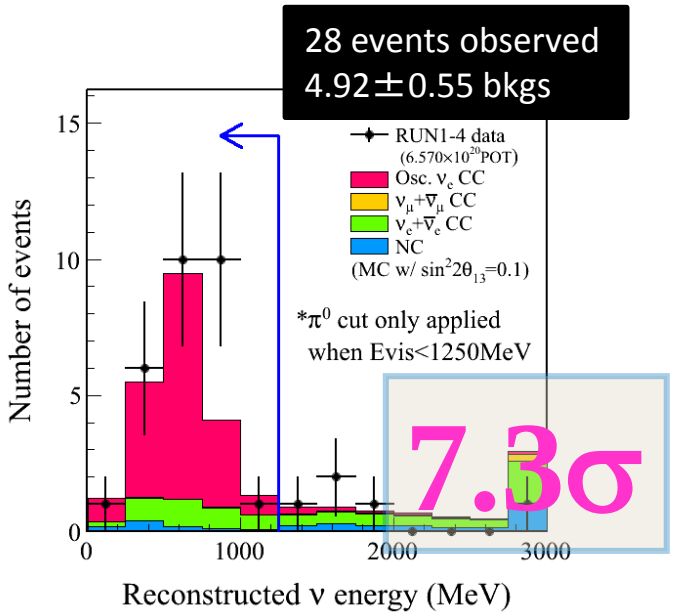
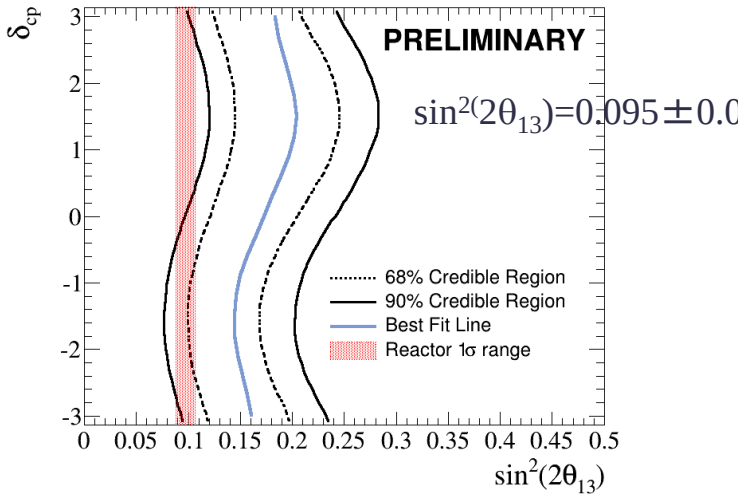
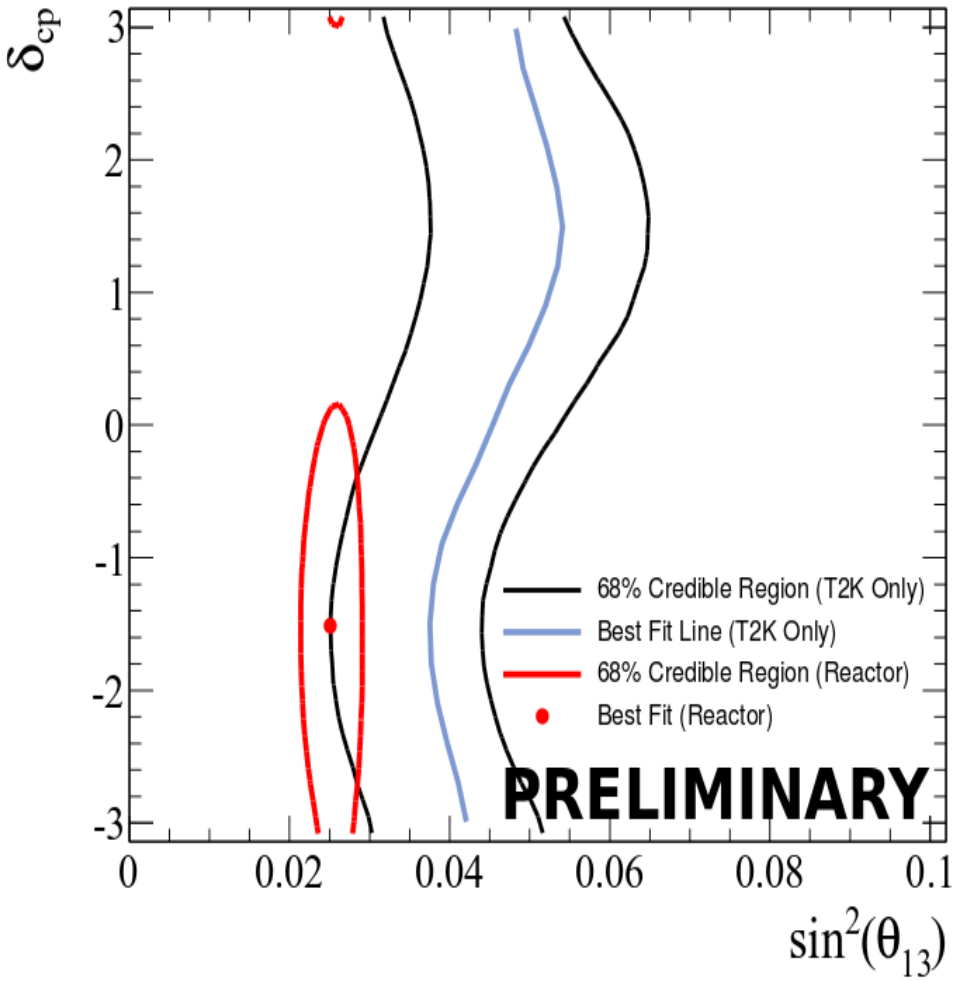
ν_e appearance - latest result -

released in 2014 March







THE FIRST EVER CONSTRAINT ON CP PHASE

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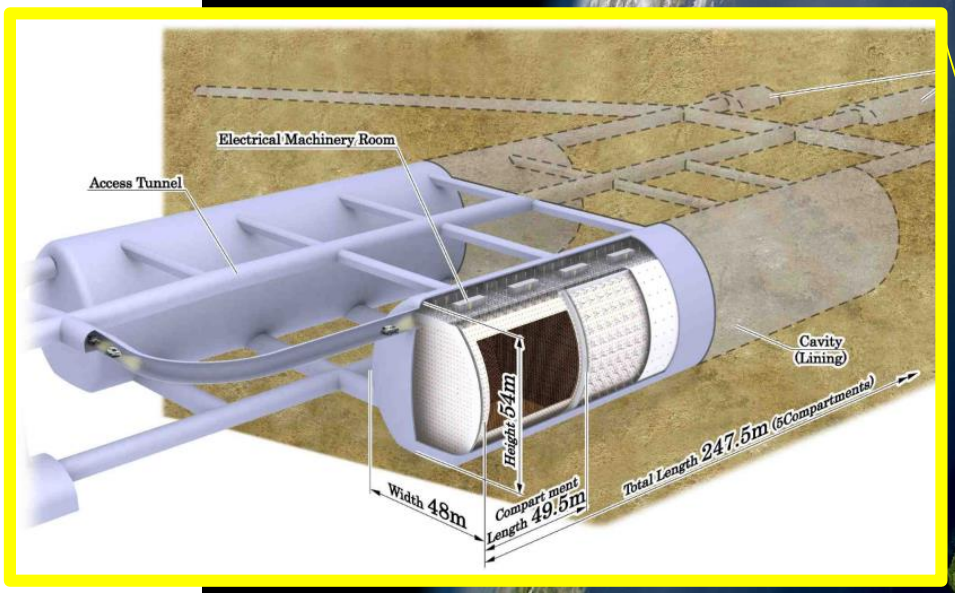
Next generation LBL experiment

J-PARC → Hyper-Kamiokande



LoI: The Hyper-Kamiokande Experiment arXiv:1109.3262v1

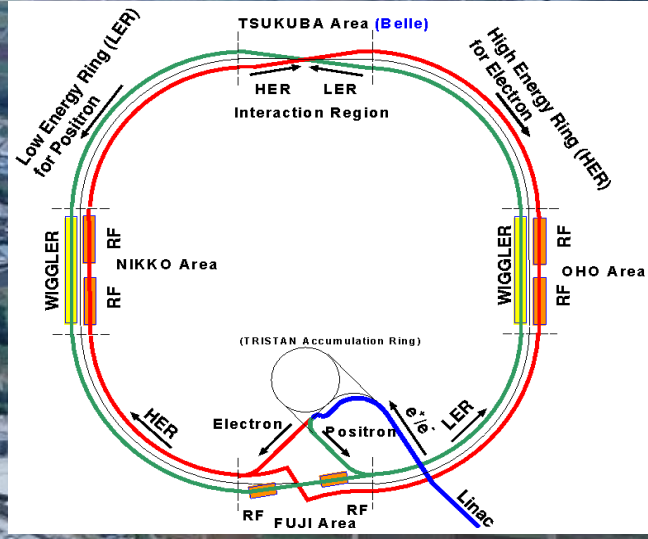
with realization of

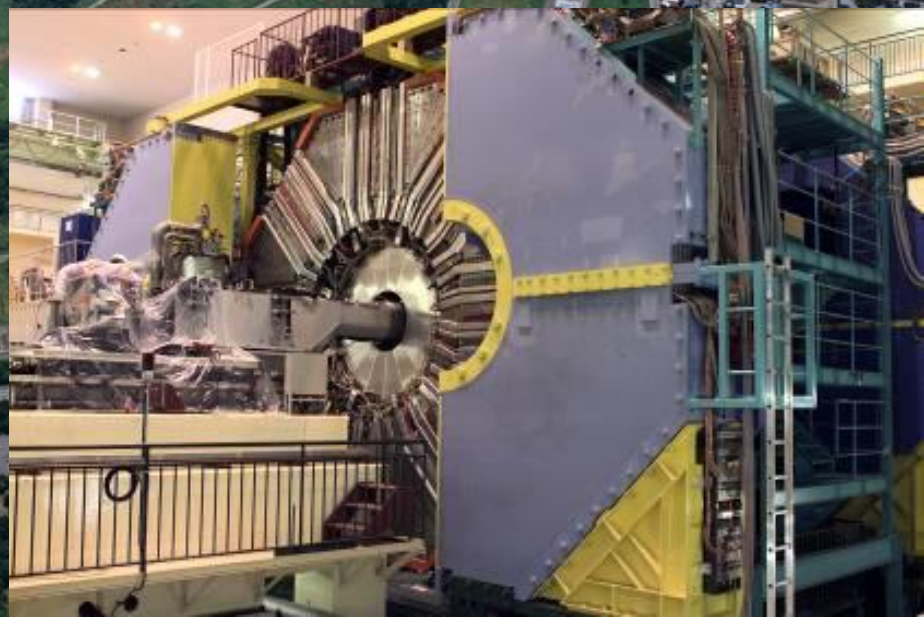
- J-PARC MR at beam power of ~1MW (>=750kW)
- New 1Mt Water Ch det: Hyper-Kamiokande

KEKB and Belle

↓

SuperKEKB and Belle II





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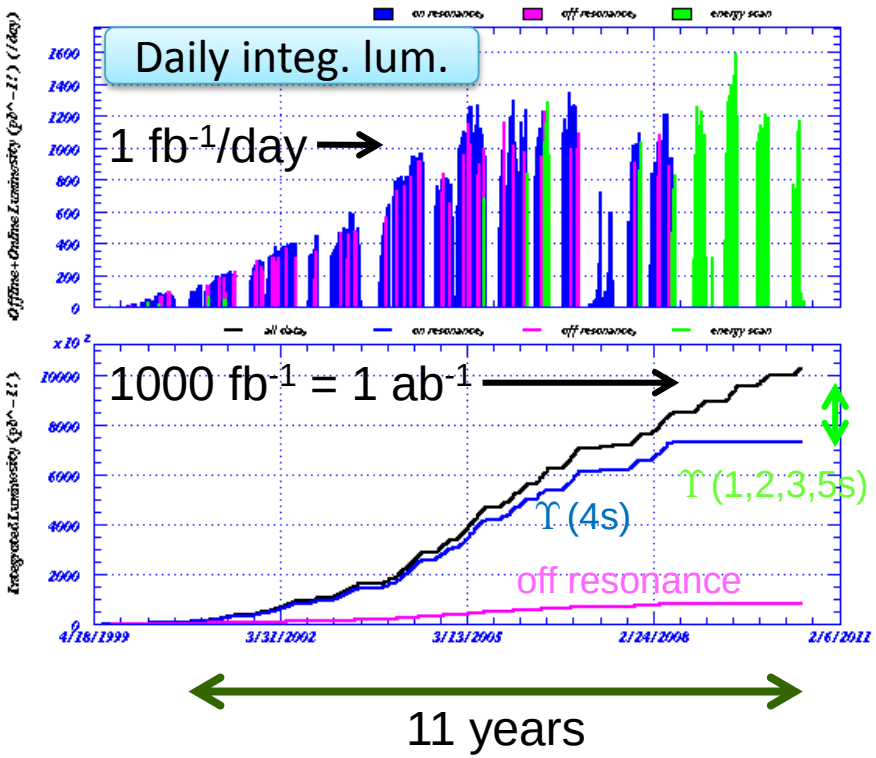
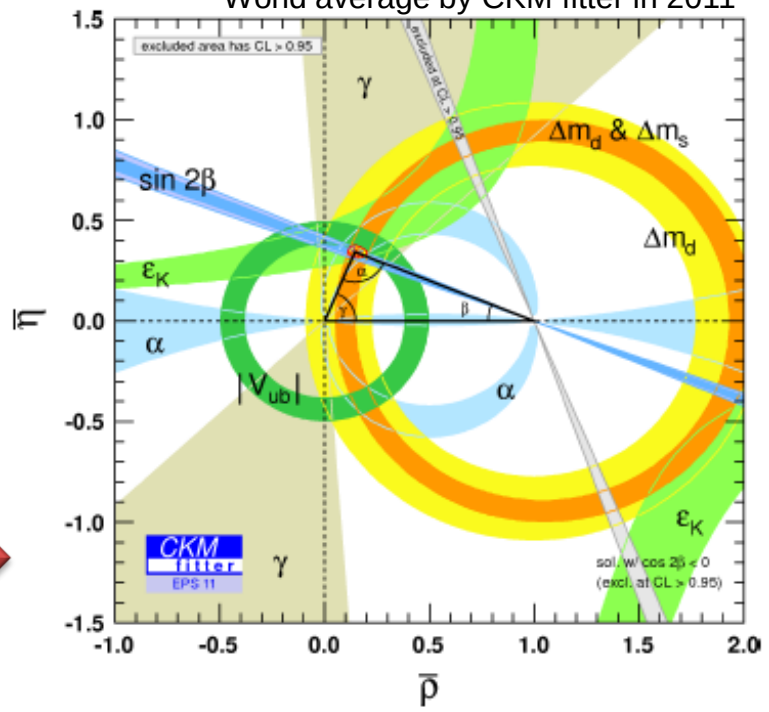
Achievements of KEKB and Belle

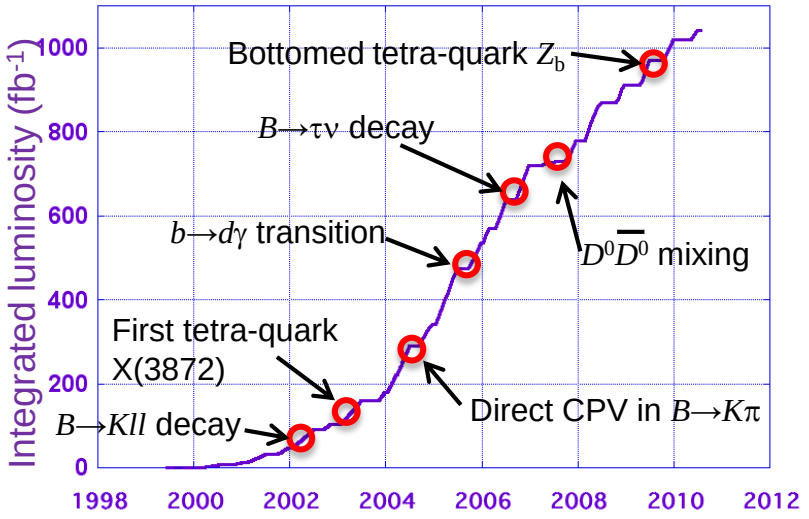
$\mathscr{L}_{peak} = 2 \times 10^{34}/cm^2/s$



11 years

World average by CKM fitter in 2011

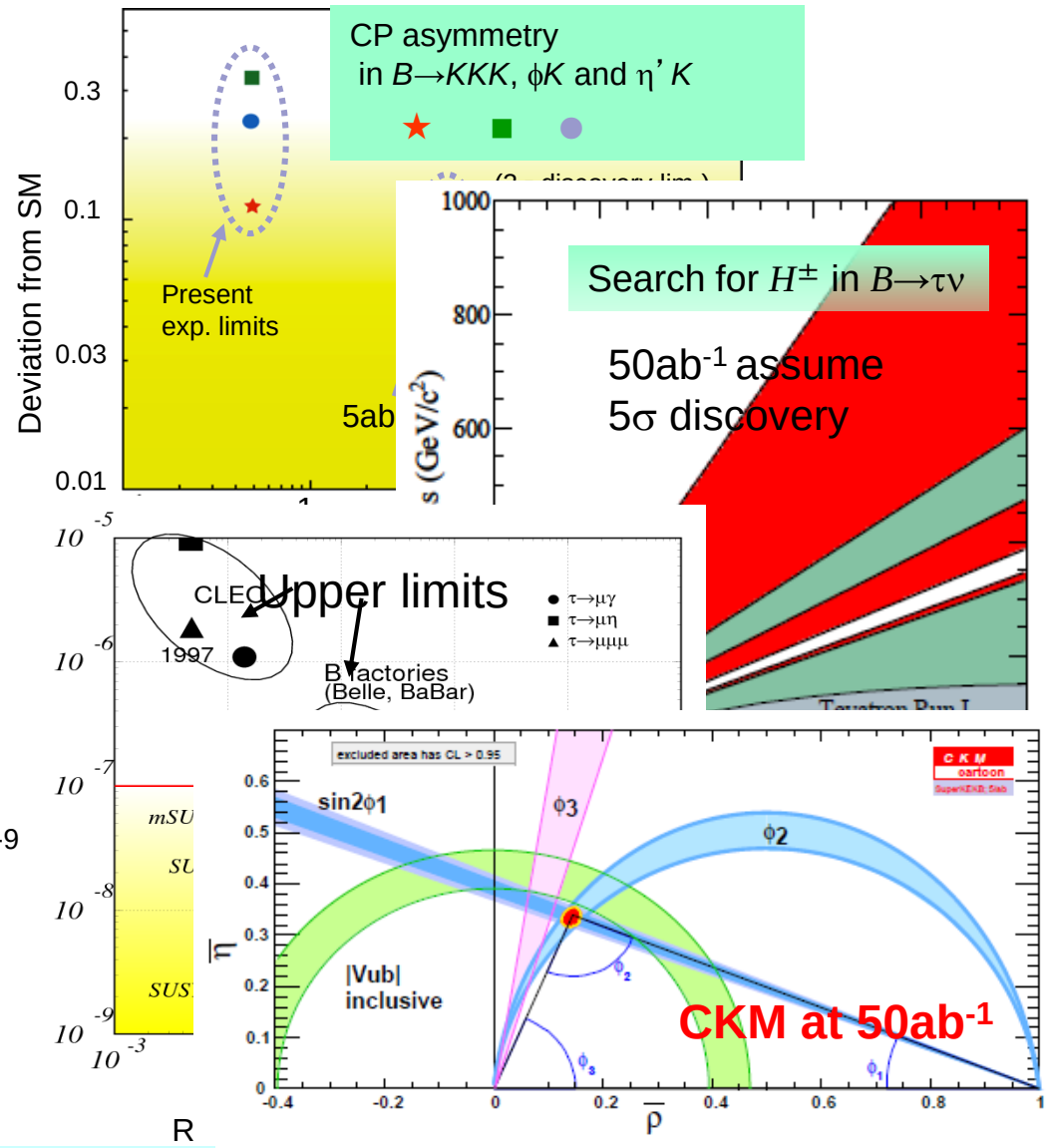




Physics reach at SuperKEKB/Belle II

	Belle' 06 (~0.5ab^{-1})	5ab^{-1}	50ab^{-1}
$\Delta S(\phi K^0)$	0.22	0.073	0.029
$\Delta S(\eta' K^0)$	0.11	0.038	0.020
$\Delta S(K_S K_S K_S)$	0.33	0.105	0.037
$\Delta S(K_S \pi^0 \gamma)$	0.32	0.10	0.03
$Br(X_s \gamma)$	13%		
$A_{CP}(X_s \gamma)$	0.058	0.01	0.005
C_9 [A_{FB}(K*ll)]	---	11%	4%
C_{10} [A_{FB}(K*ll)]	---	13%	4%
$Br(B^+ \to K^+ \nu\nu)$	<9Br(SM)	33ab^{-1} for 5σ discovery	
$Br(B^+ \to \tau\nu)$	3.5σ	10%	3%
$Br(B^+ \to \mu\nu)$	<2.4Br(SM)	4.3ab^{-1} for 5σ discovery	
$Br(B^+ \to D\tau\nu)$	---	7.9%	2.5%
$Br(\tau \to \mu\gamma)$	<45	<30	<8
$Br(\tau \to \mu\eta)$	<65	<20	<4
$Br(\tau \to 3\mu)$	<209	<10	<1
$\Delta \sin 2\phi_1$	0.026	0.016	0.012
$\Delta\Phi_2$ ($\rho\pi$)	68° —95°	3°	1°
$\Delta\Phi_3$(Dalitz)	20°	7°	2.5°
ΔV_{ub} (incl.)	7.3%	6.6%	6.1%

X10^{-9}



Physics at Super B Factory [hep-ex/0406071]

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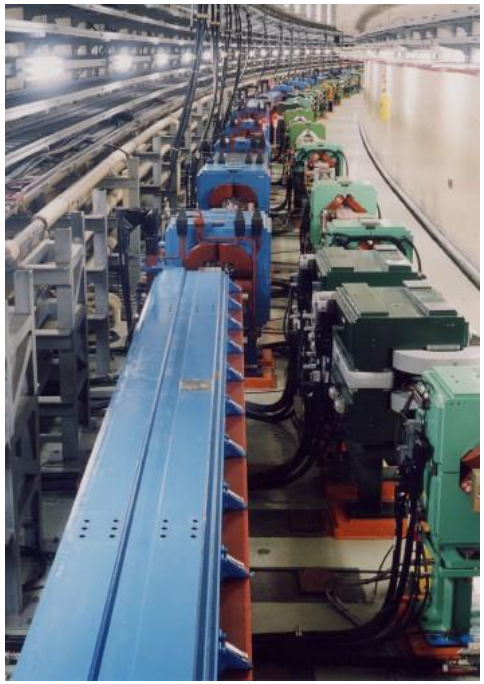
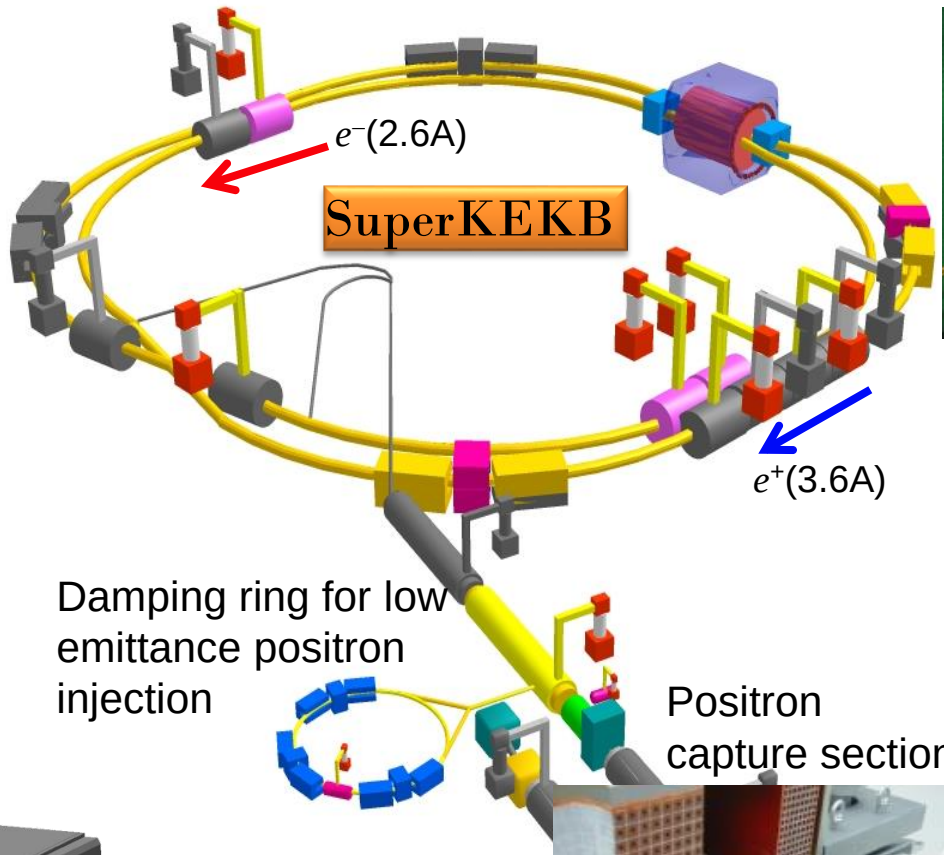
Accelerator upgrade

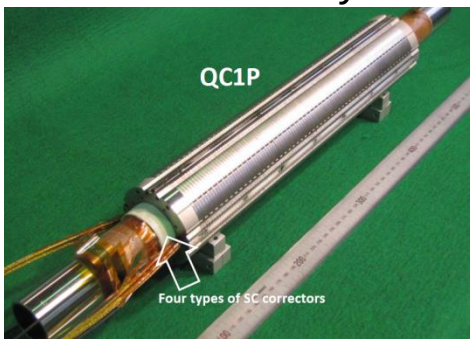
Super KEKB

Low emittance lattice





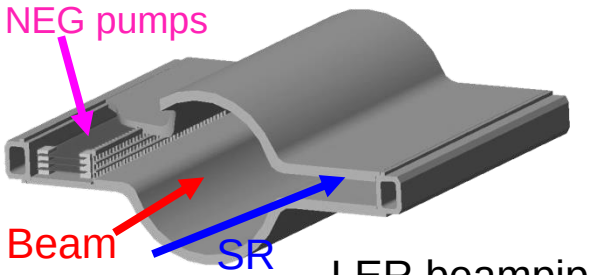
IR with β_y*=0.3mm
SC final focus system



Add RF systems for higher beam current

Damping ring for low emittance positron injection

Positron capture section



LER beampipe to suppress photoelectron instability

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SuperKEKB – Machine parameters

SuperKEKB

Parameter	Units	KEKB		SuperKEKB	
		HER (e^-)	LER (e^+)	HER (e^-)	LER (e^+)
Circumference	m	3016		3016	
Energy	GeV	8	3.5	7	4
Crossing angle	mrad	22		83	
β_x at IP	cm	120	120	2.5	3.2
β_y at IP	mm	5.9	5.9	0.30	0.27
ε_x (emittance)	10^{-9} m	24	18	4.6	3.2
Emittance ratio	%			0.35	0.40
σ_z	mm	6	6	5	6
Beam current	mA	1400	2000	2600	3600
σ_x at IP	10^{-6} m	150	150	11	10
σ_y at IP	10^{-9} m	940	940	62	48
ξ_x (tune shift)				0.0028	0.0028
ξ_y		0.090	0.129	0.0875	0.09
Luminosity	$cm^{-2}\ s^{-1}$	2×10^{34}		8×10^{35}	

Higher beam current

Nanobeam

x40

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Belle-II Collaboration

Belle II

- 600 collaborators from 100 institutions in 23 countries
- Spokesperson:

  Tom Browder (Hawaii)
- Series of open collaboration meetings in 2008.03 ~2015.2

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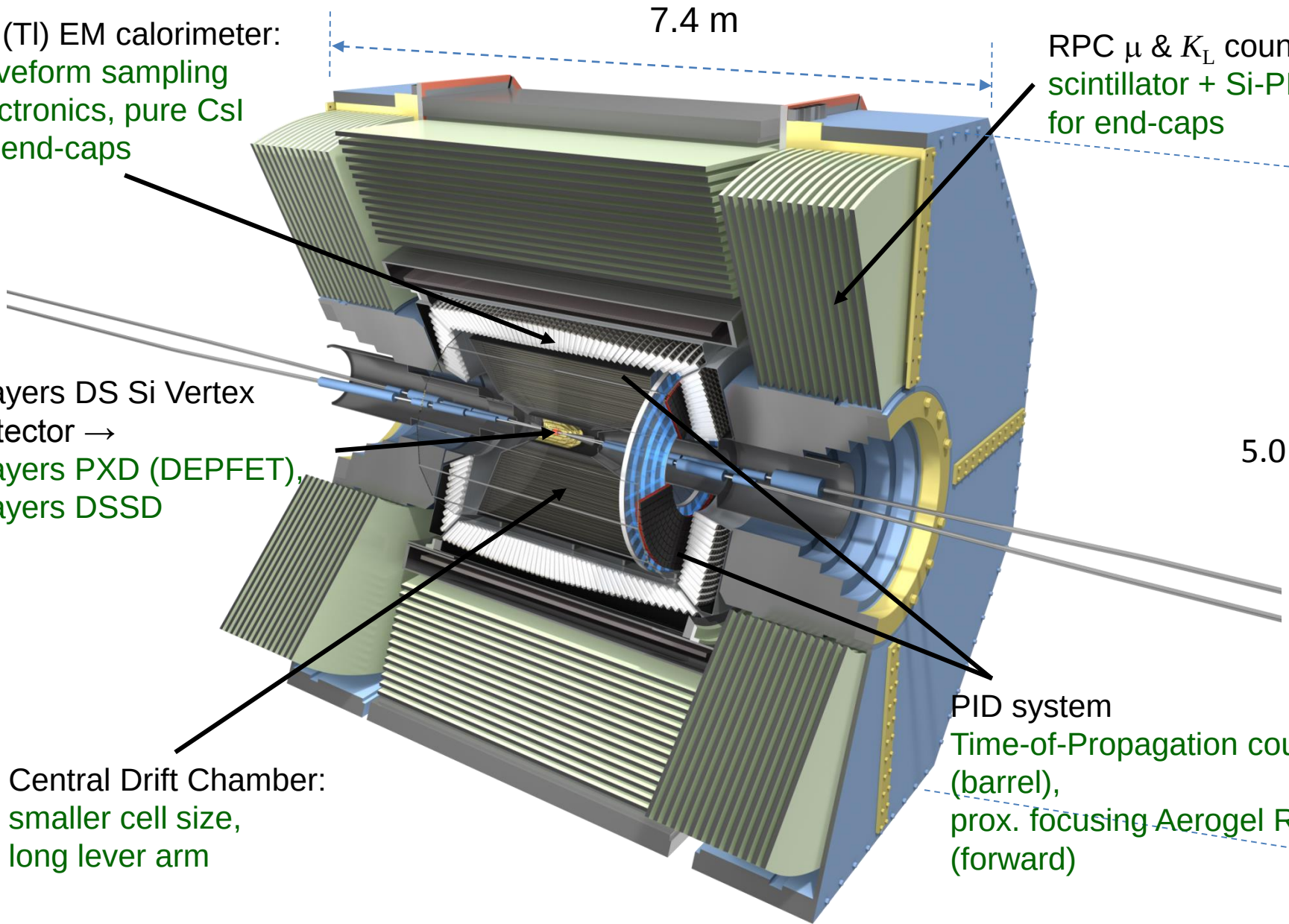
Belle II Detector Upgrade

Belle II



CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for end-caps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps

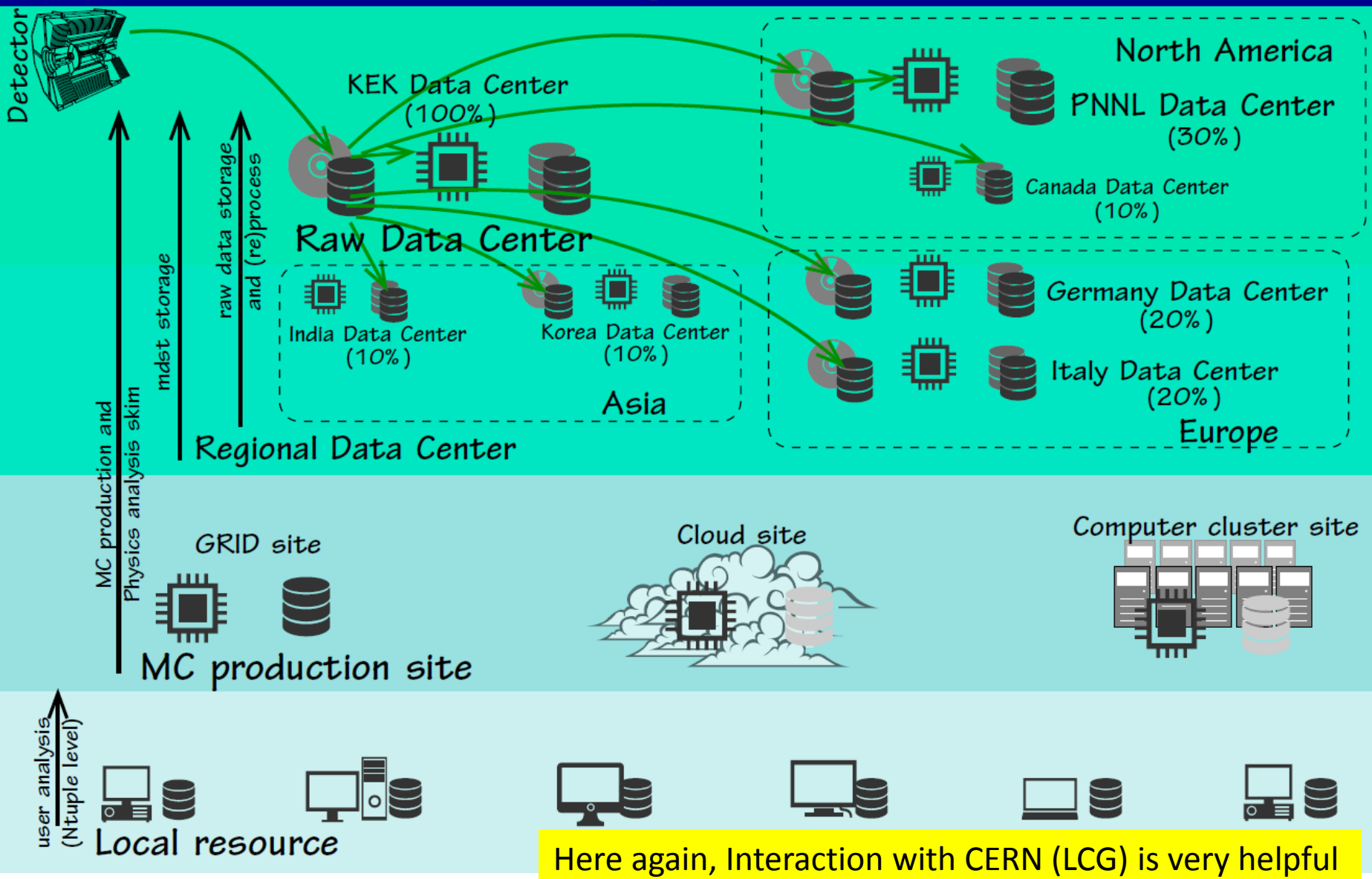
4 layers DS Si Vertex Detector →
2 layers PXD (DEPFET),
4 layers DSSD

Central Drift Chamber:
smaller cell size,
long lever arm

PID system
Time-of-Propagation counter (barrel),
prox. focusing Aerogel RICH (forward)

modified Belle II Computing Model

after Year 4 (raw data part)



Here again, Interaction with CERN (LCG) is very helpful

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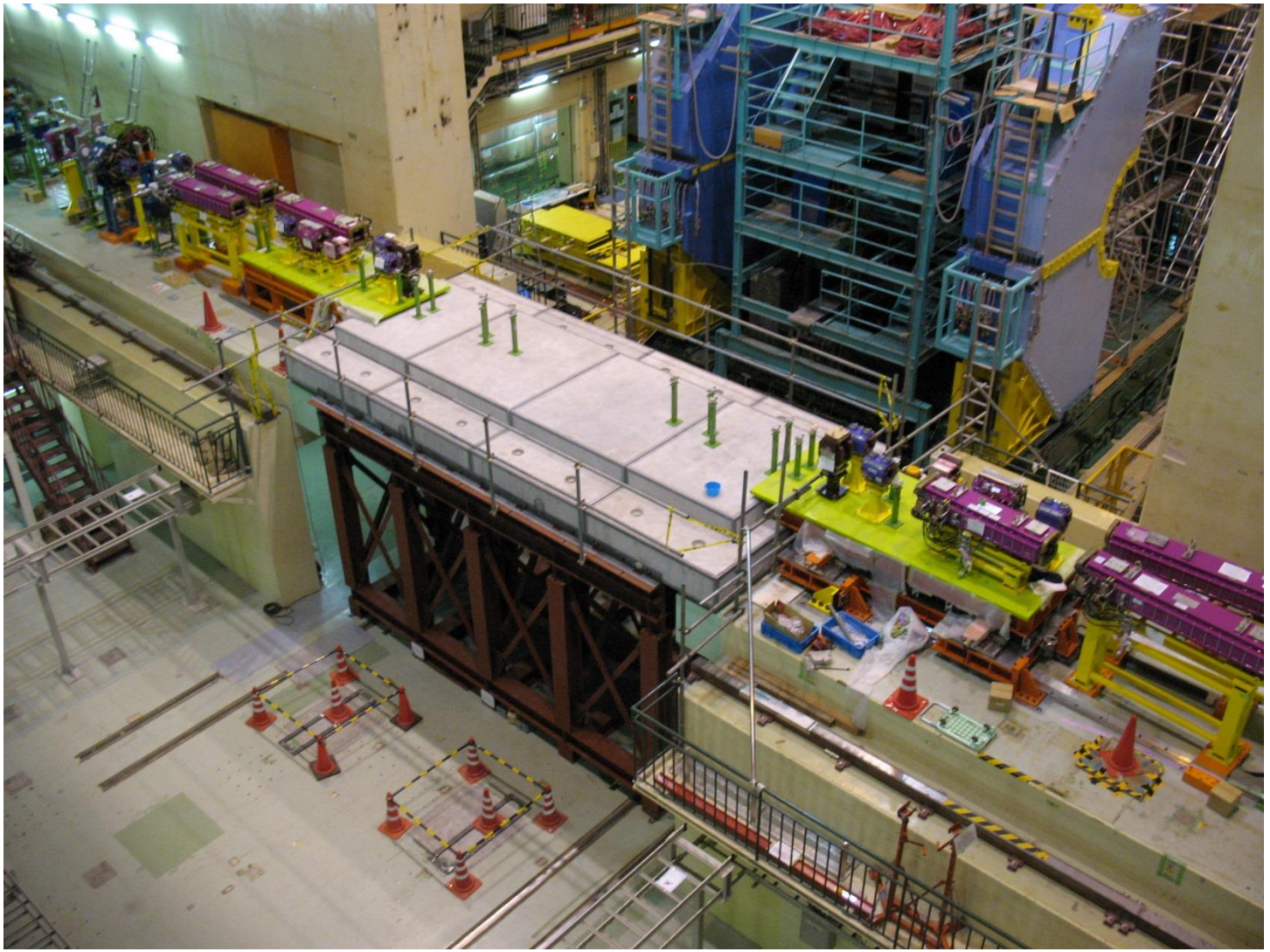
Interaction Region



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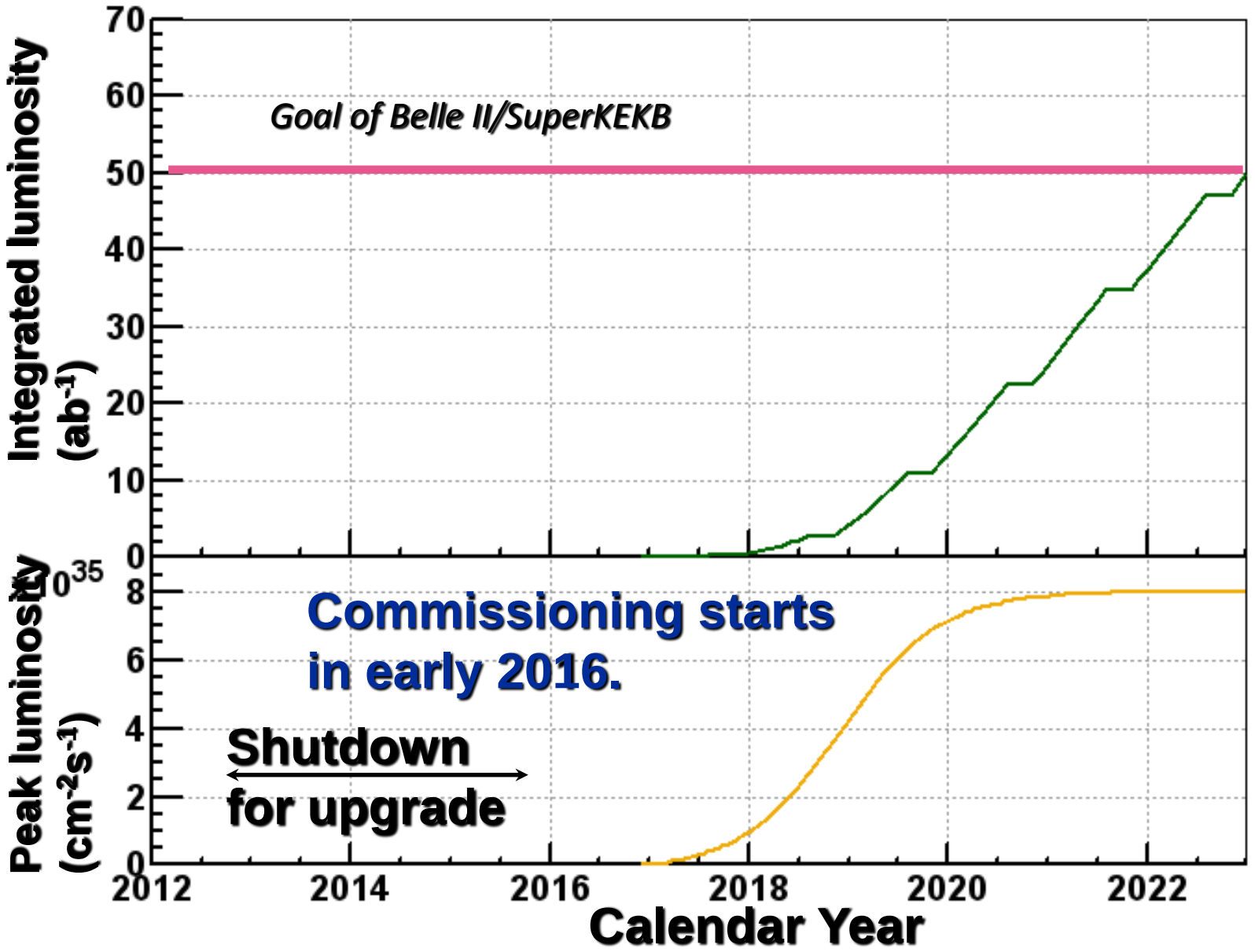
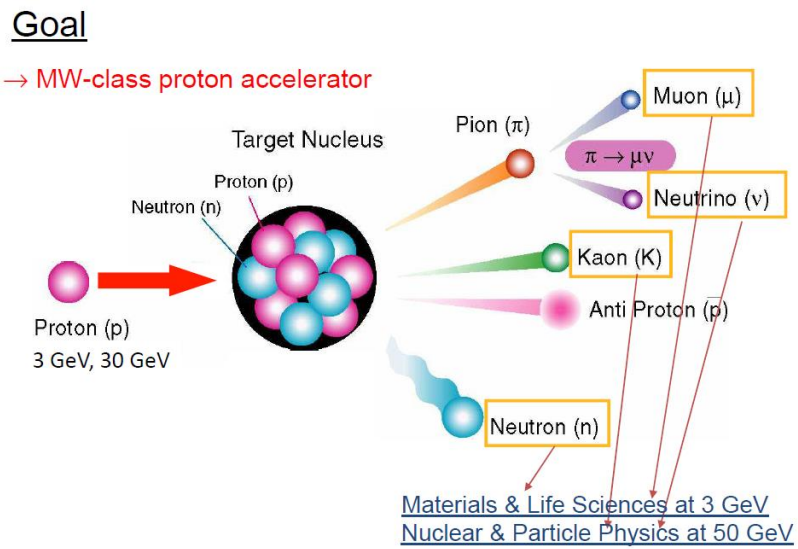
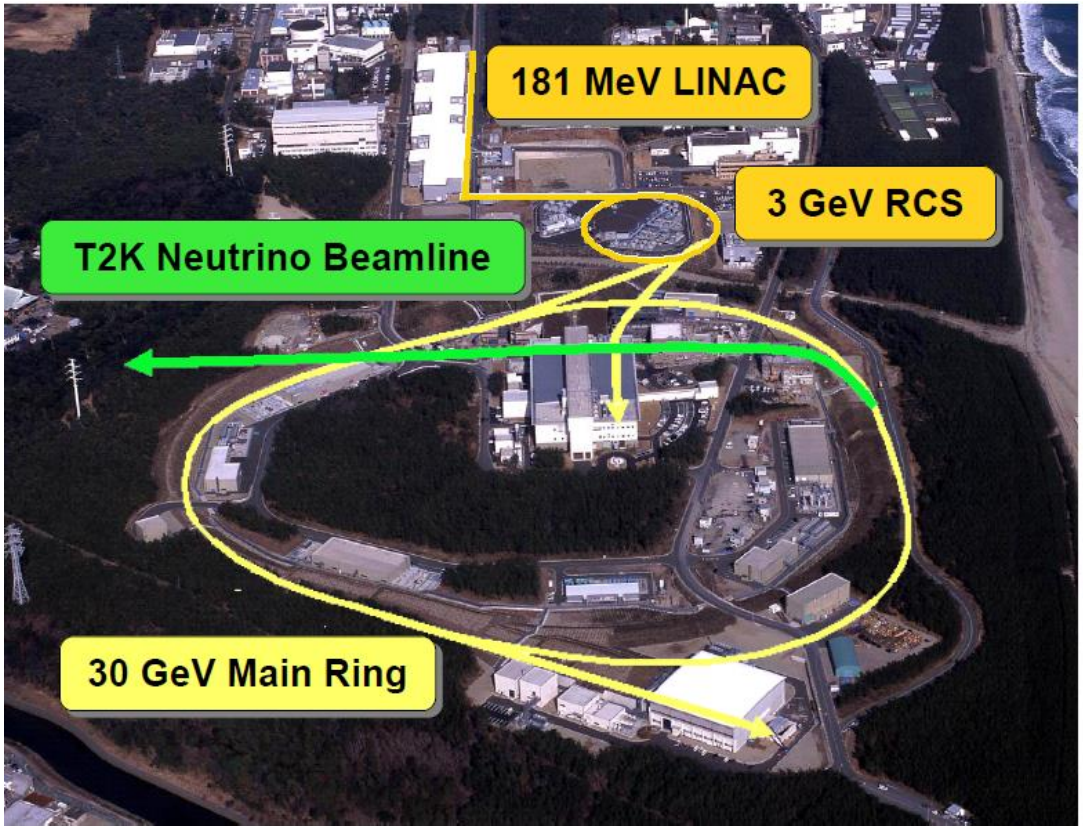
SuperKEKB luminosity projection



J-PARC

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





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

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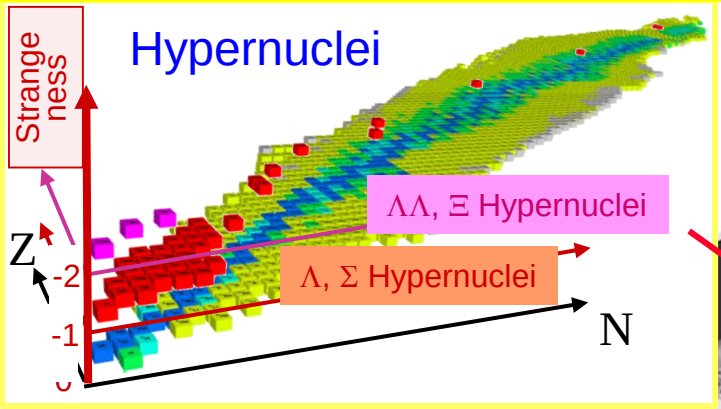
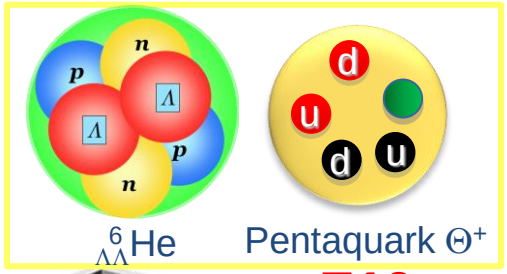
Nuclear & Particle Physics with J-PARC Hadron Beam

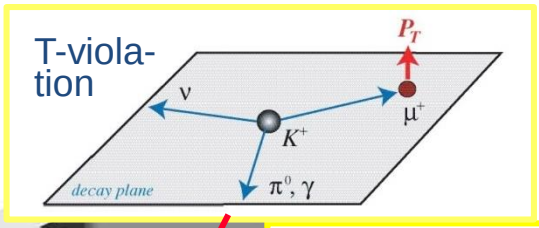
Since 24/April/2015 the normal operation has re-started!

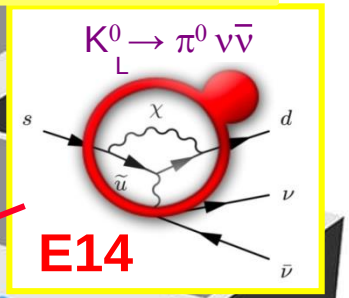




$^{6}_{\Lambda\Lambda}$He Pentaquark Θ+

E19





E14

Implantation of Kaon and the nuclear shrinkage

SKS

K1.8

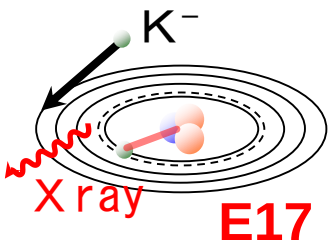
K1.8BR

KL

K1.1

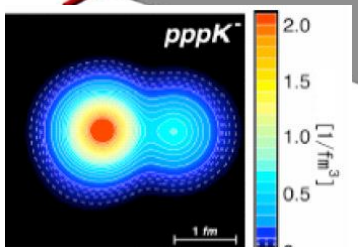
High p (not yet)

K1.1BR

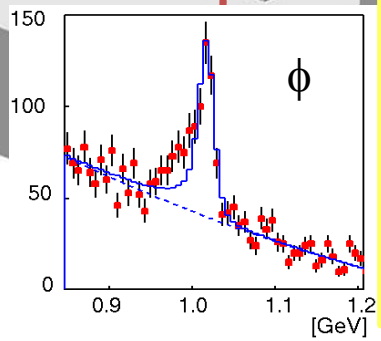


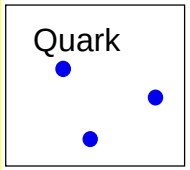
E17

Kaonic atom

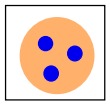


Kaonic nucleus





Free quarks



Bound quarks

Why are bound quarks haevier ?
Mass without Mass Puzzle

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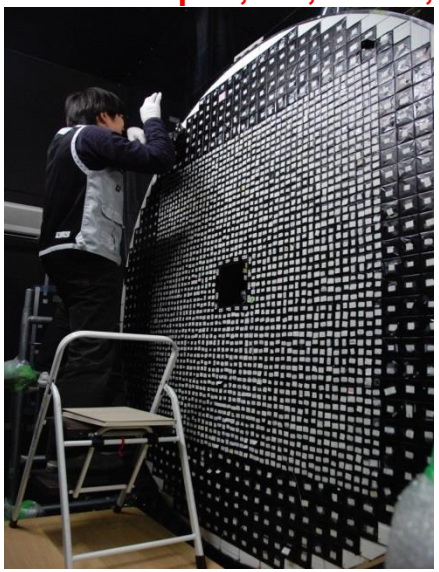
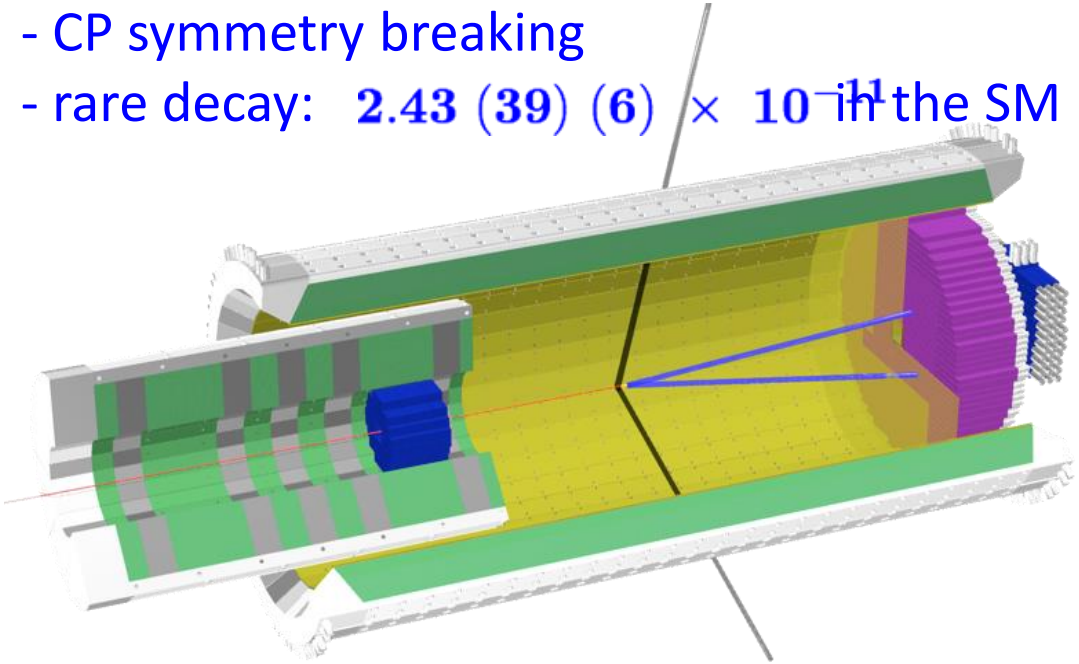
J-PARC KOTO experiment

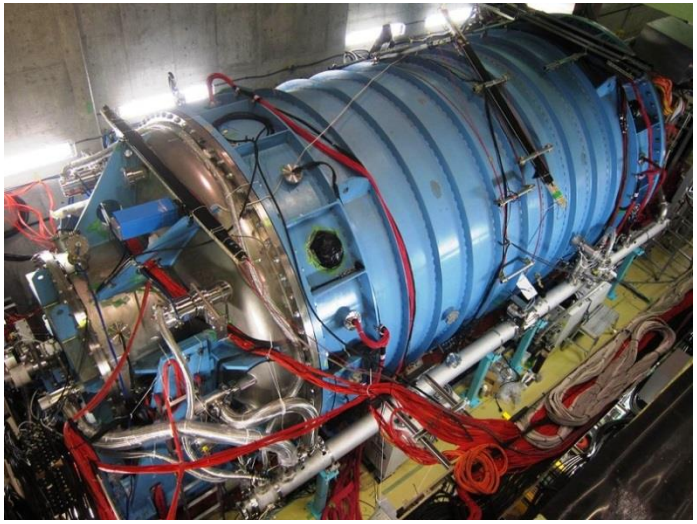
65 participants from Japan, US, Korea, Taiwan, Russia



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

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





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

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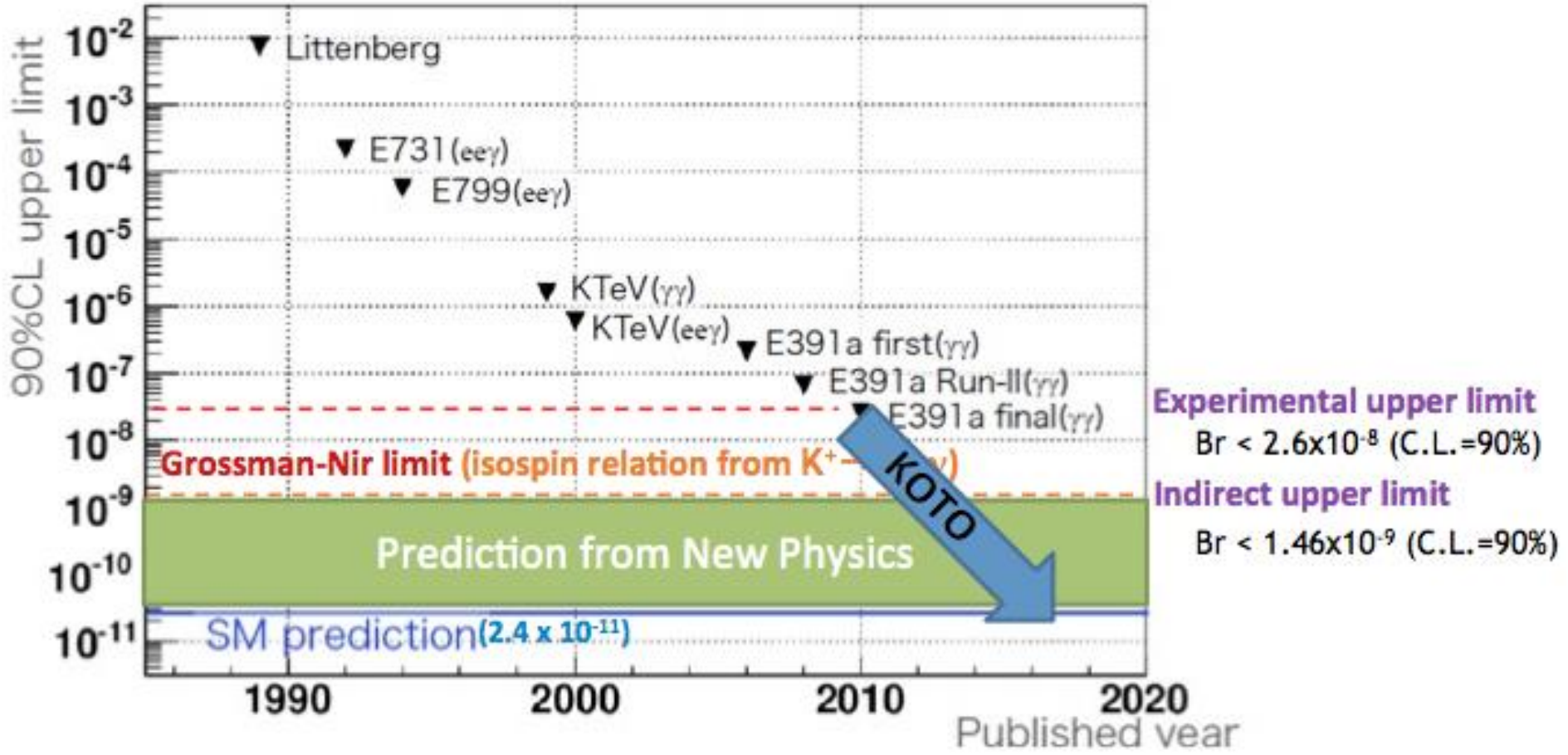
Branching ratio for $K_L \rightarrow \pi^0\nu\nu$



COMET Experiment at J-PARC

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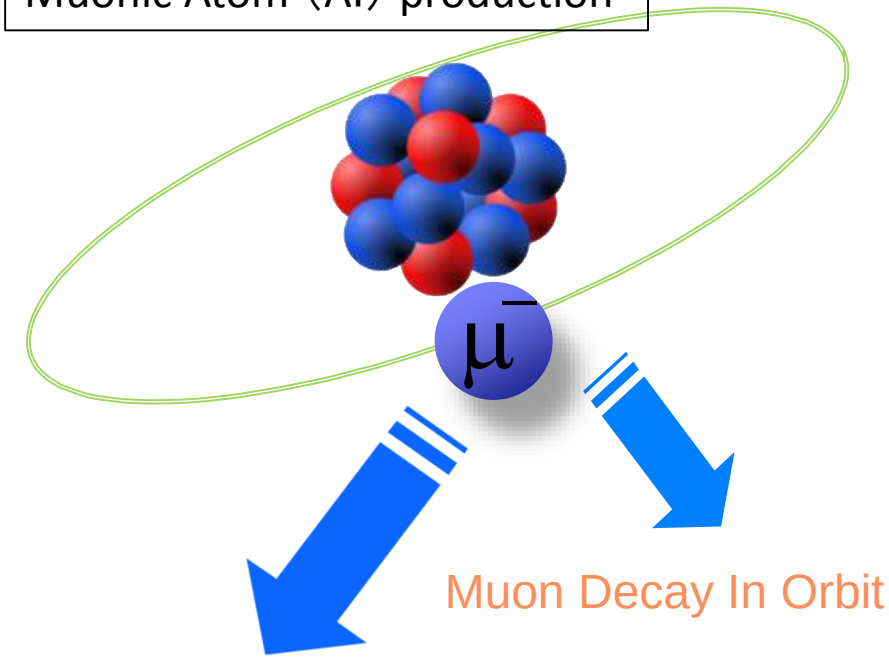
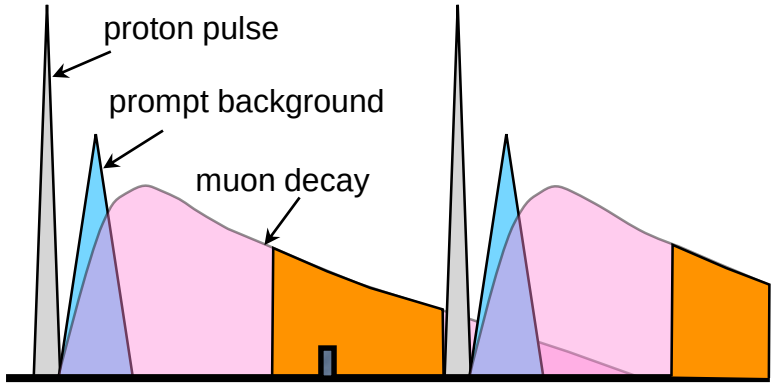
Muonic Atom（Al）production



Muon Decay In Orbit



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

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

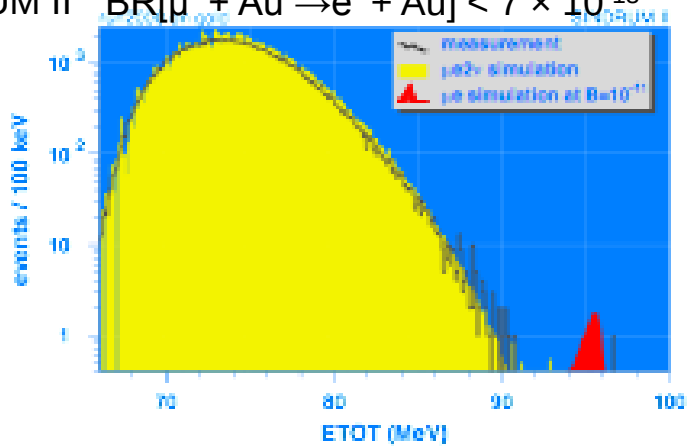
$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

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



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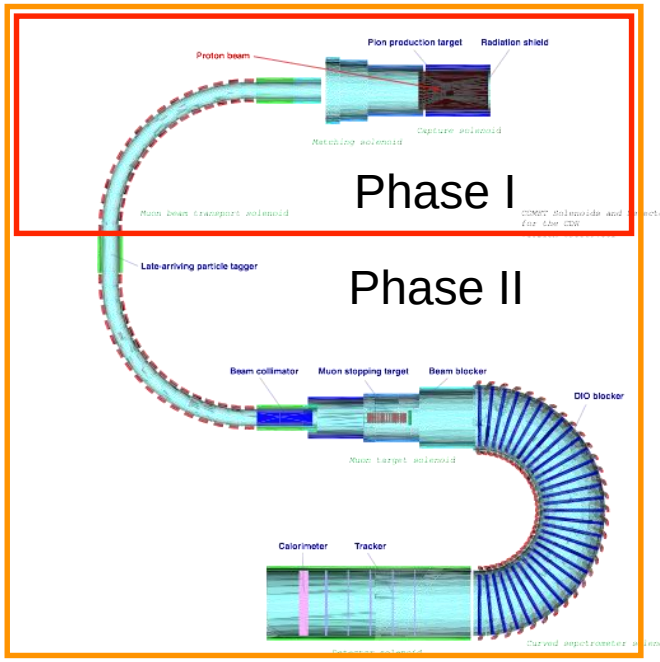
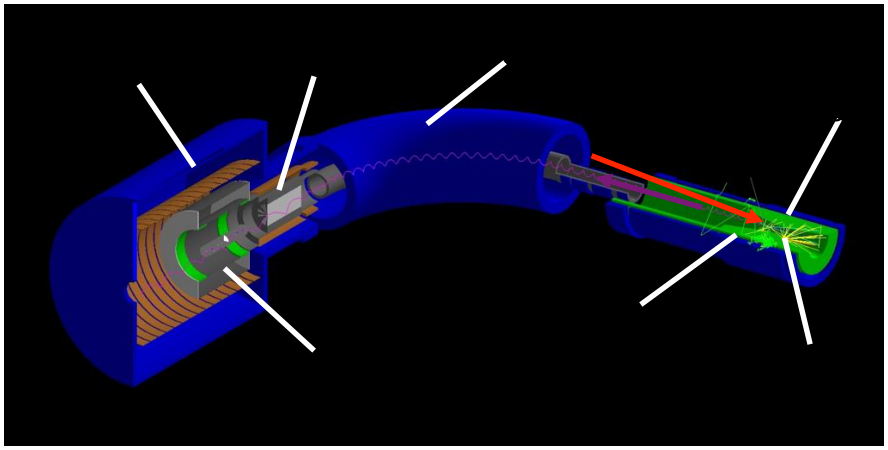
COMET Phase I & II

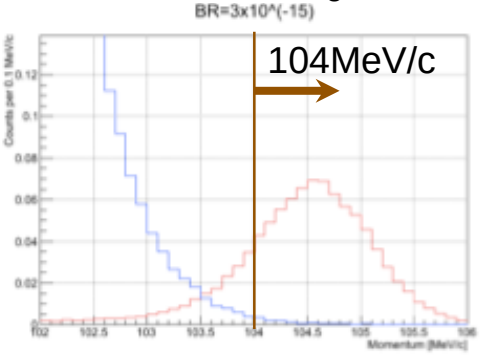
- Phase I
  - Detailed understanding of the beam background and achieving the sensitivity of < 10^{-14} (100 better than the current limit)
  - 8GeV, 3.2kW beam, ~90-days DAQ (Graphite as a primary target)
- Phase II
  - 8GeV, 56kW beam, 1-year DAQ (Tungsten as a primary target)
  - COMET final goal 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 7.8x10^6 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(?)

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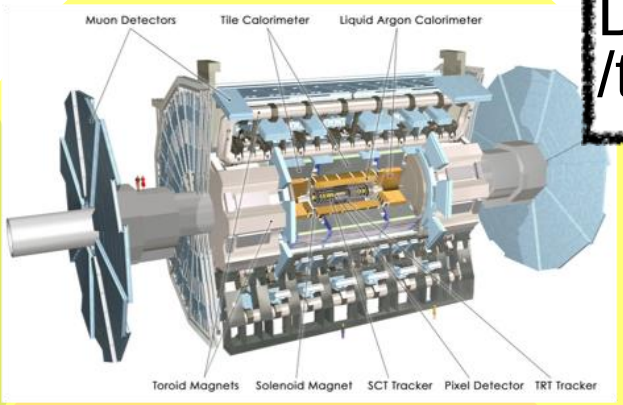
KEK (Japan group) Contributions to LHC/ATLAS

Accelerator



Detector /trigger

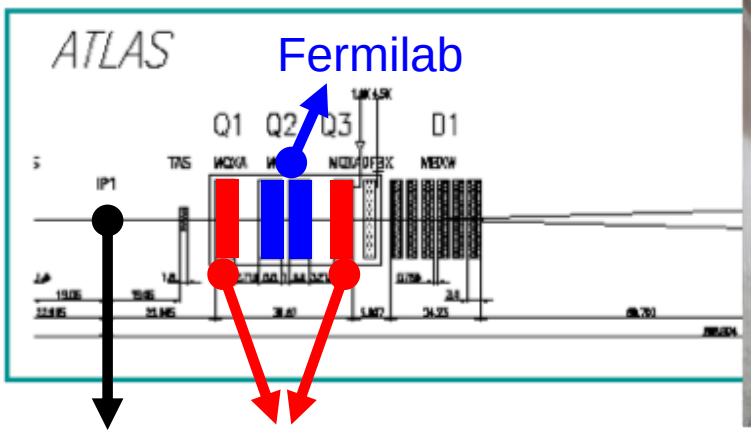
Computing

Person power (operation)

Critical Contributions to Everywhere

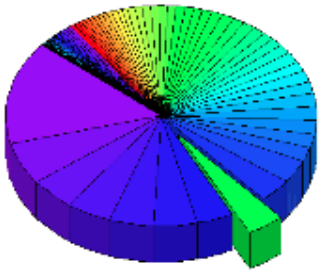
Accelerator / Computing

- Focusing magnets (Inner Triplet Quadrupoles)
  - Two types of magnets are developed at KEK and Fermilab separately



- Grid computing
- Tier-2 at Tokyo

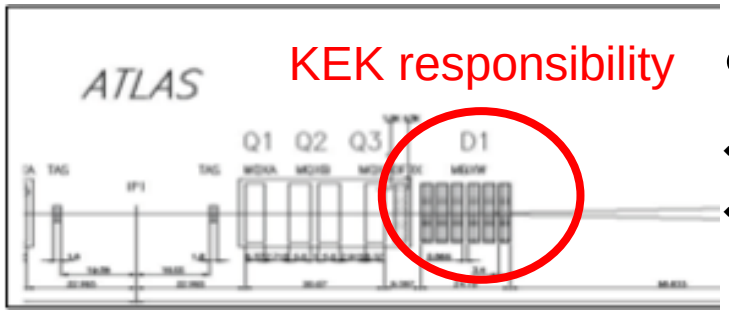
#jobs processed at each site



Tokyo

HL-LHC

- KEK contribution to Accelerator
  - LHC separation magnets (D1)
  - PS Booster RF amplifier



- Challenge
  - large aperture
  - high radiation dose

- Planned major upgrade of ATLAS detector
  - Replacement of tracker
    - ✓silicon pixel
    - ✓silicon strip
  - Replacement of endcap muon electronics

Contributions to almost all parts

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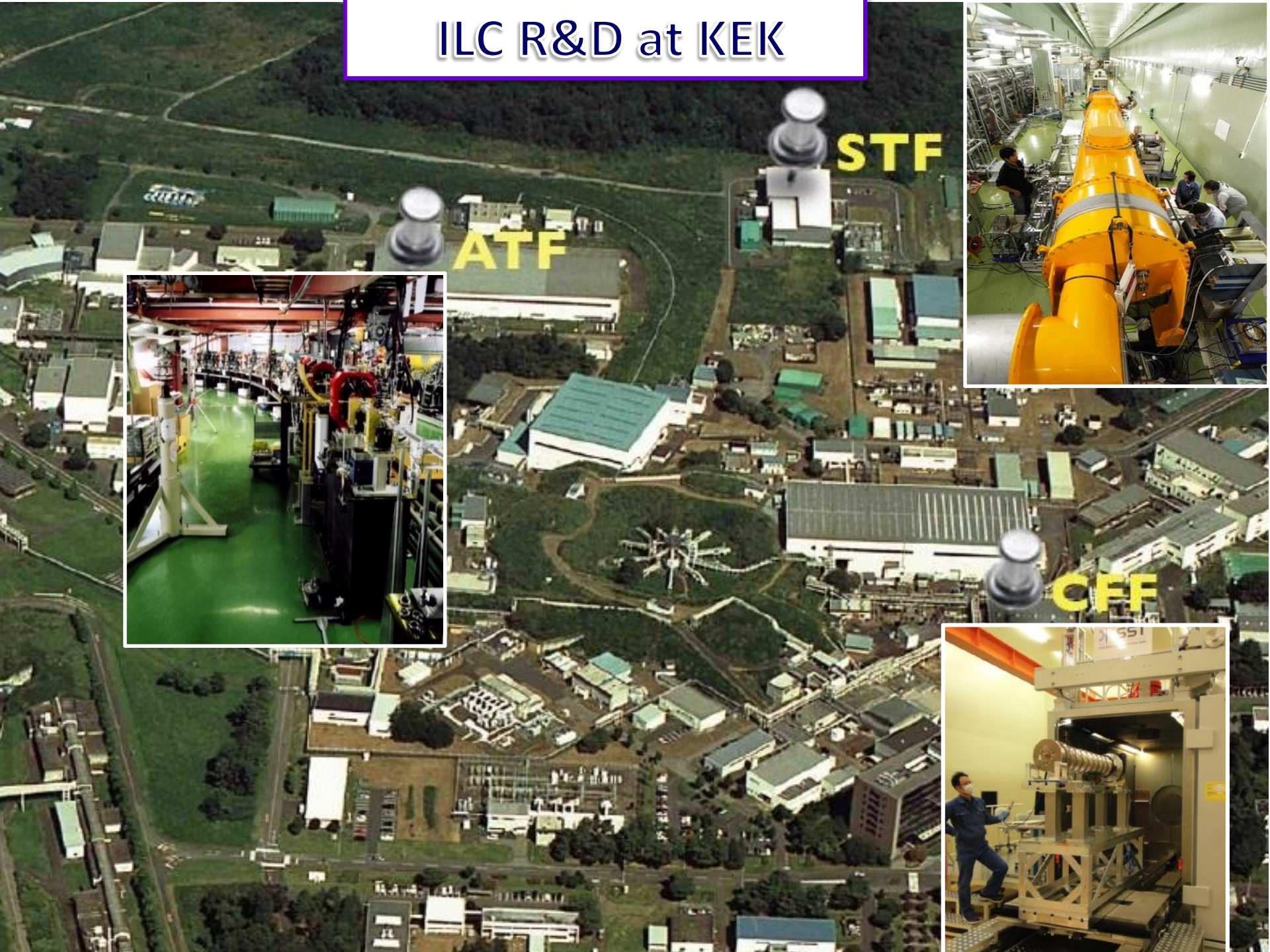
International Linear Collider

- 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 R&D at KEK



Achievement at ATF

ILC Recent progress of KEK-ATF

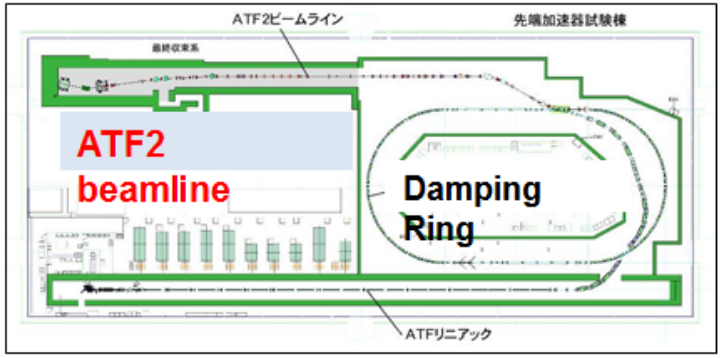
ATF2: Final focus Test beamline

Goal-1: Develop final focus system for ILC

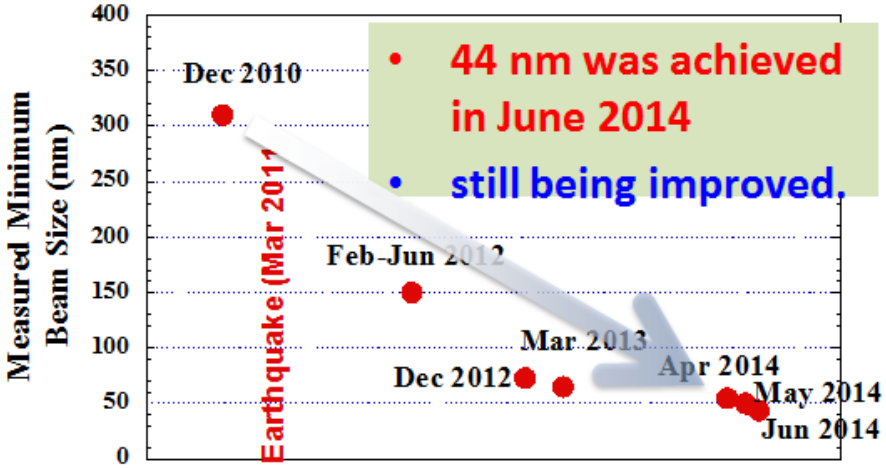
→ 37 nm vertical beam size at IP

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

→ Study of Intra-train feedback has been started.

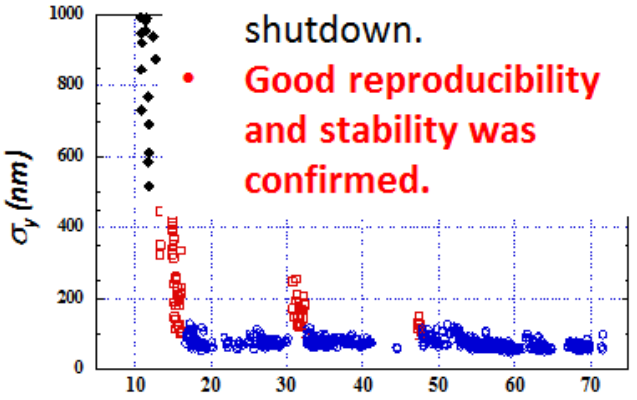


History of measured minimum beam size



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

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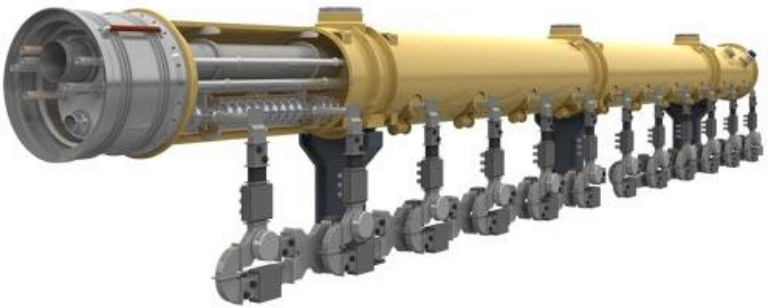
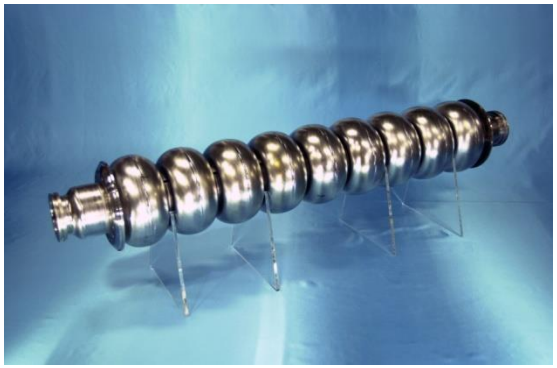
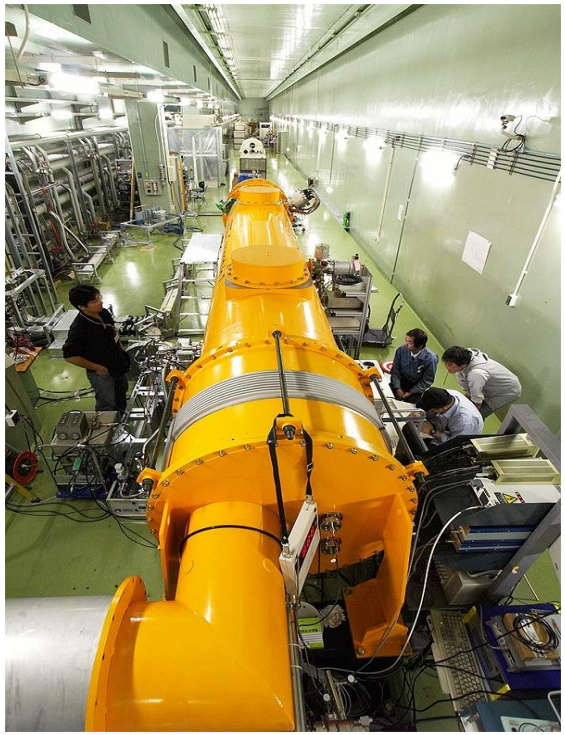
Superconducting Accelerator Test Facility







STF Accelerator

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

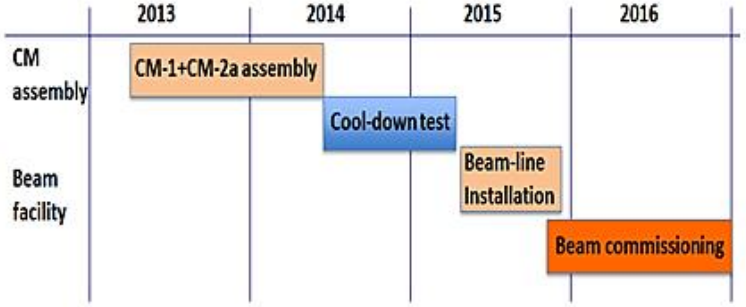
ILC-type Cryomodule (CM-1)
(8 SC cavities + SC-quad/BPM)
+
half-size Cryomodule (CM-2a)
(4 SC cavities)

Chicane 1

Capture Cryomodule
(2 SC cavities)

Photo-cathode RF-gun

Plan of STF Start-up schedule



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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 and two working groups. KEK will do:
  - 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.

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Hyper Kamiokande?

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Recommendation of JAHEP sub-comm.

Feb 2012

The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e+e- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.

- **Should the neutrino mixing angle θ_{13} be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations.** This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.

It is expected that the Committee on Future Projects, which includes the High Energy Physics Committee members as its core, should be able to swiftly and flexibly update the strategies for these key, large-scale projects according to newly obtained knowledge from LHC and other sources.

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KEK roadmap

2013

At the neutrino facility, a significant improvement in the measurement precision of the T2K experiment will be pursued. In addition, new research plans will be developed for the next generation of long-baseline neutrino oscillation experiments, while relevant preparatory studies are pushed forward in parallel.

….. During the period covered by this Roadmap, KEK will collaborate with the Institute of Cosmic Ray Research at the University of Tokyo on refining the proposal for the next long-baseline experiment and will work toward realization of a MW-class proton beam at J-PARC. The latter effort will evolve into studies on further upgrades of the accelerator and neutrino beam line, R&D on which will be pursued in parallel. …

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Master Plan of big science project

2014

‘Nucleon decay and neutrino oscillation experiment with a large advanced detector’ (Hyper-K) is selected as one of 27 high priority programs in the Master plan set by Science Council of Japan (SCJ).

However, it was not yet selected in the (immediate) roadmap set by the mext (based on the SCJ master plan)

There is no formal report on the assessment but…

- The physics case is well accepted.
- Task share among the international participants are not clear.

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ICRR-IPNS MoU

ハイパーカミオカンデ計画に

東京大学宇宙線研究所及び高エネル
究所は、次世代核子崩壊・ニュートリ
想には物理学及び天文学の発展のため
ハイパーカミオカンデ研究者グループ
計画構想の具体化に向けた検討を進め
含む計画推進に必要な事項について、

この合意は、平成２７年１月３１日
により更新できるものとする。

平成２７年１月３１日

東京大学宇宙線研究所

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

M. Yamauchi

Prof. Masanori YAMAUCHI
Director

KEK
High Energy Accelerator Research Organization

MoU on HK btw IPNS&ICRR

Jan 31, 2015

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MoU on HK:

- This does not mean that the HK project is the main IPNS project, (yet).
- It is the collaboration's task to make the project realistic (within expected resource/time scale).
- IPNS and ICRR are willing to help the collaboration to prepare the proposal, via (for example) forming a review panel.