Accelerators at KEK

IBIC 2012 @ Tsukuba
Oct. 1, 2012

K. Oide (KEK)

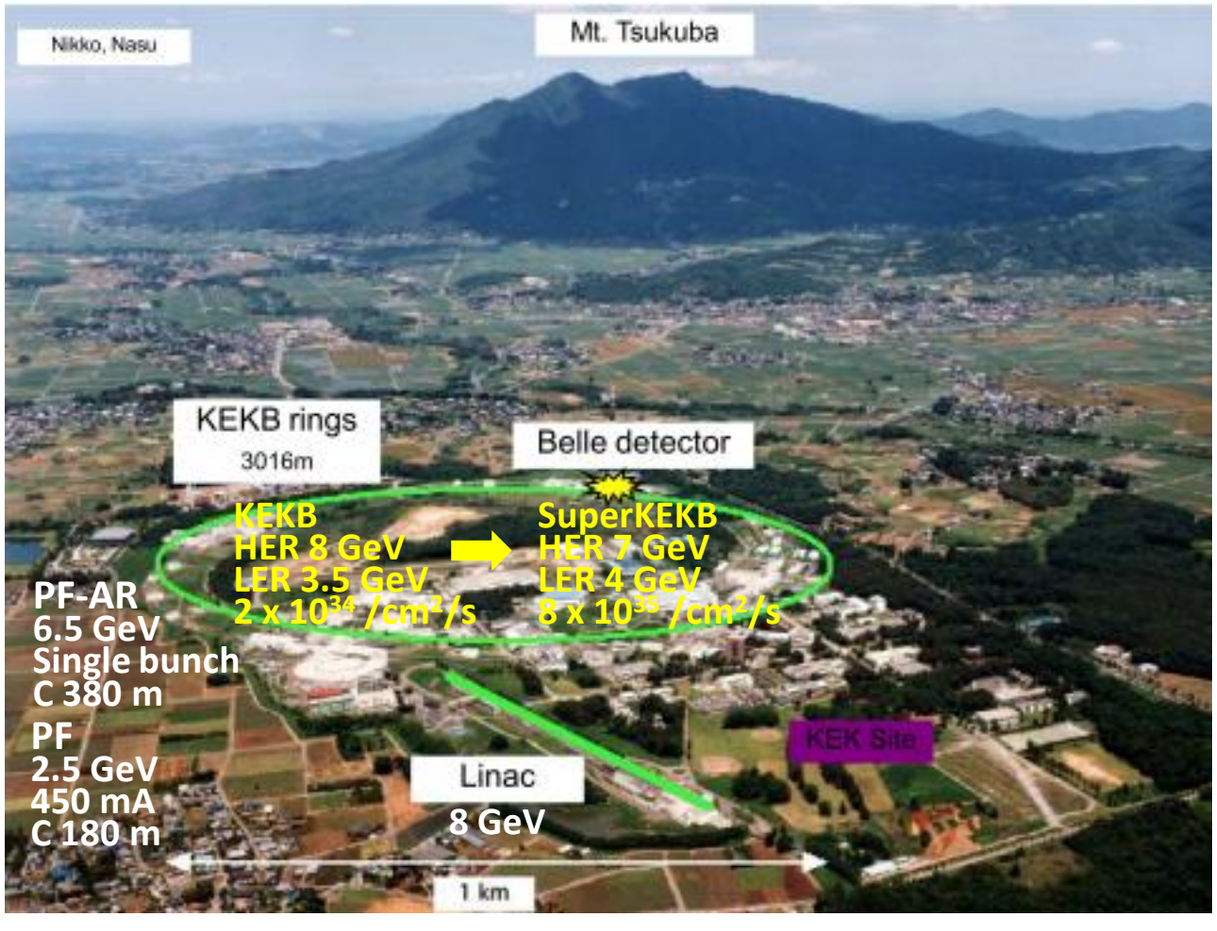
Campus & Accelerators

Accelerators for Inter-University Research

Tsukuba Campus: KEKB, PF, ATF, STF, ERL, others

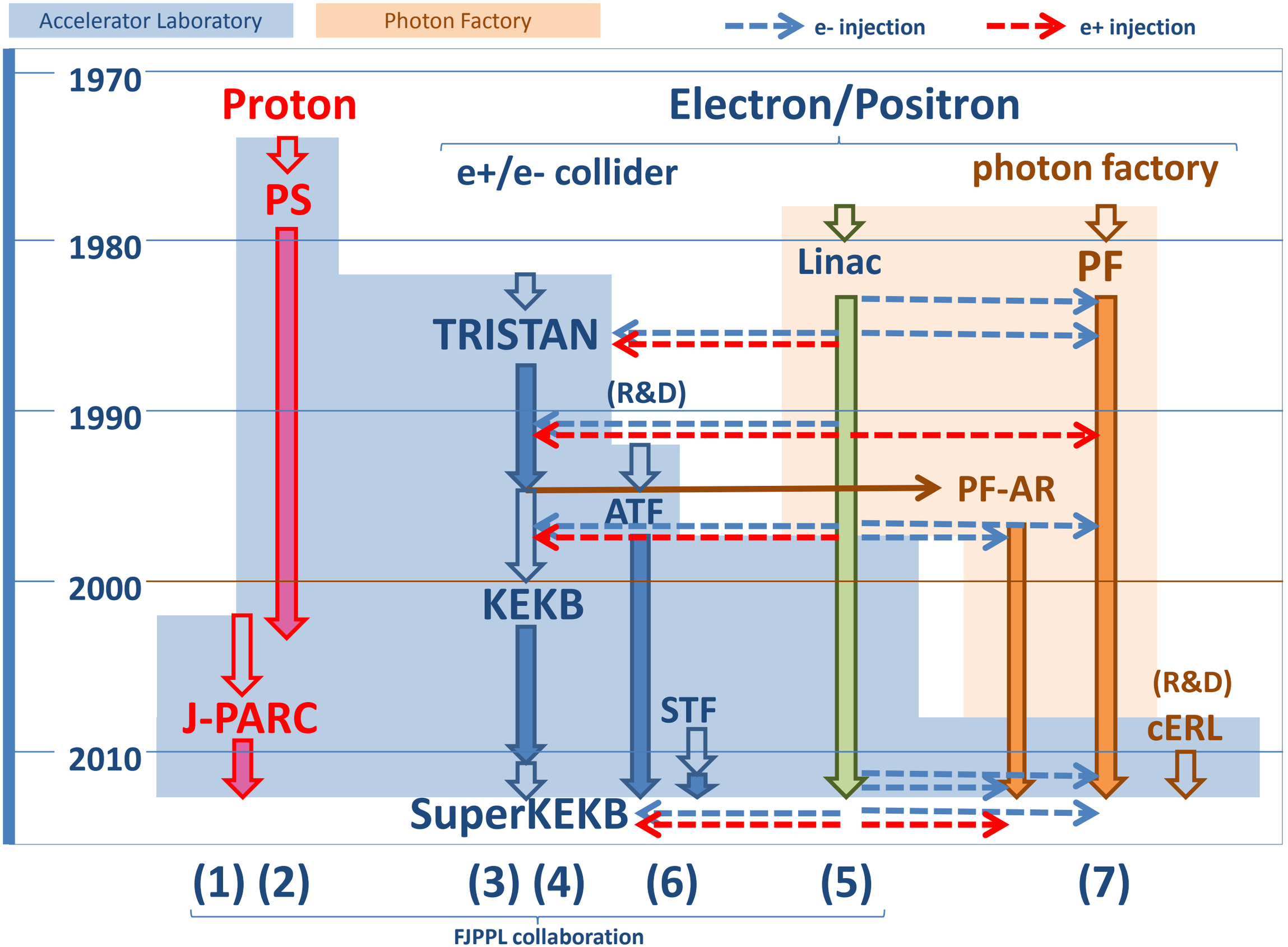
Tokai Campus: J-PARC

Tsukuba Campus

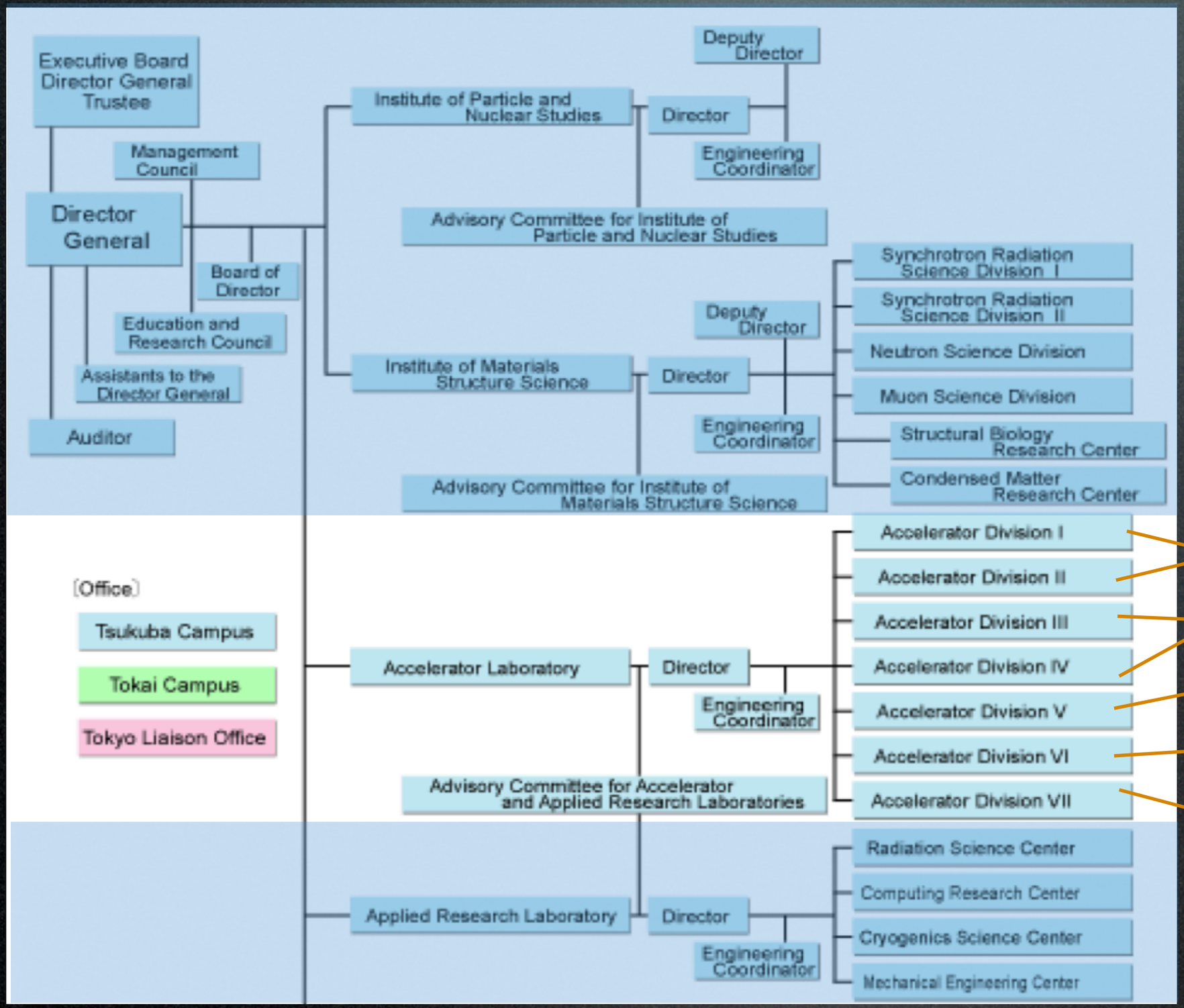


Tokai Campus

The KEK Accelerator History



KEK Accelerator Laboratory



J-PARC (Linac, RCS, MR)

SuperKEKB Rings

e+e- Injector Linac

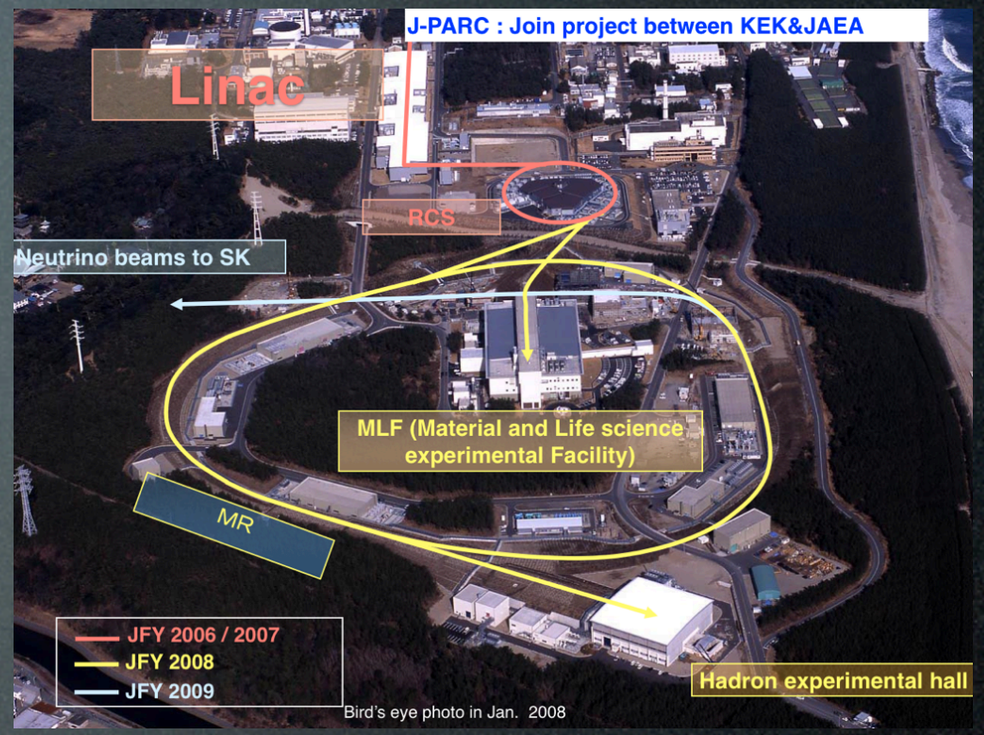
ILC(STF, ATF),
Acc. Theory, etc.

Photon Factory (PF/PF-AR)
Compact ERL

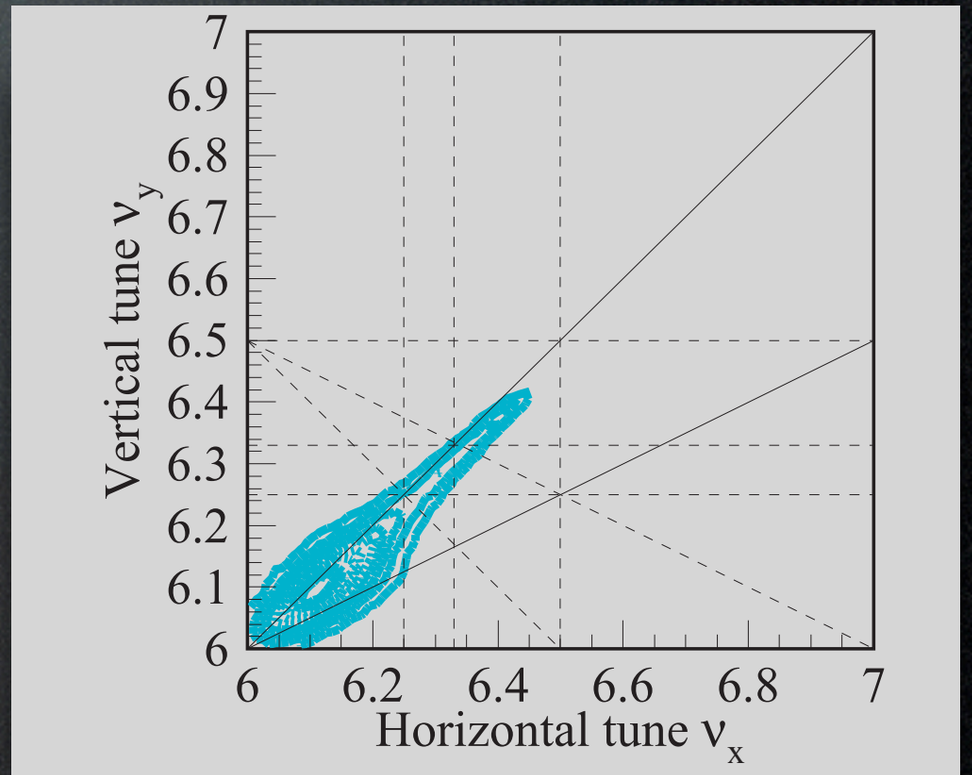
Roughly 35 physicists & engineers per division

J-PARC

- Achieved 300 kW @ RCS (3 GeV) and 200 kW @ MR (30 GeV).
  - 1.3 x 10^{13} protons / bunch
  - high space charge tune shifts: ~ 0.4 @ RCS inj. (180 MeV)



- Also achieved a very high extraction efficiency, 99.5%, at the slow extraction of the MR (14 kW, 30 GeV).
- Control of beam halo, beam loss of the very high intensity bunches.



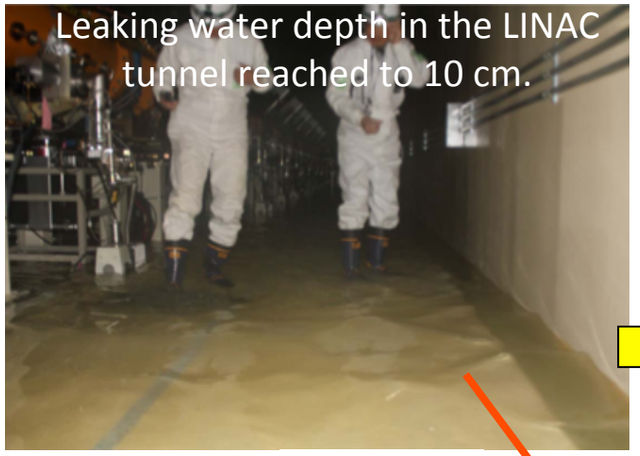
H. Hotch, et al, IPAC'12, THPPP080

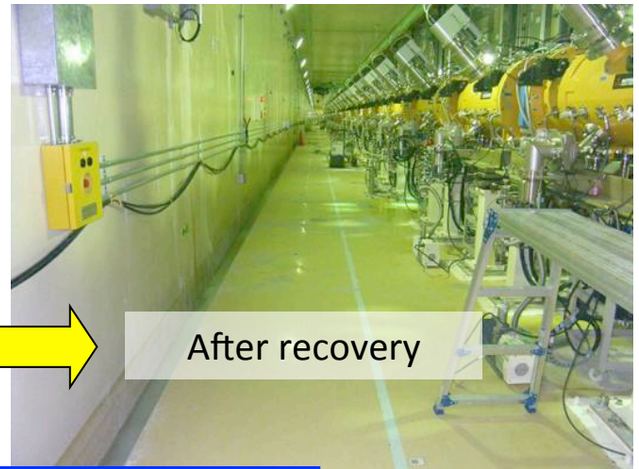
Recovery Status of J-PARC from Damages by the 3.11 Earthquake

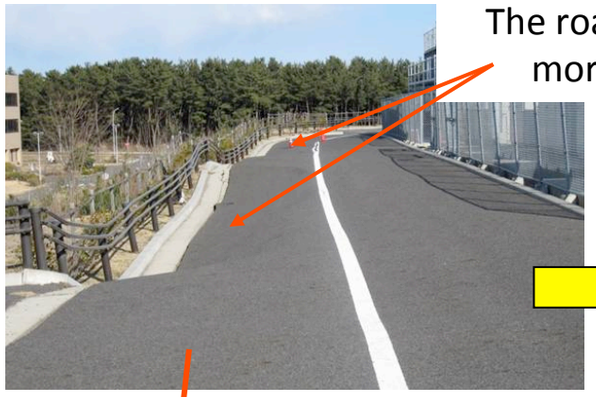
S. Nagamiya, as of May 2012

- Fortunately no victims at J-PARC, but severe damages on the facilities, such as piping systems, power devices, and instruments. We also had land subsidence at many places around buildings, water leaks, and misalignment of electromagnets and shielding blocks.

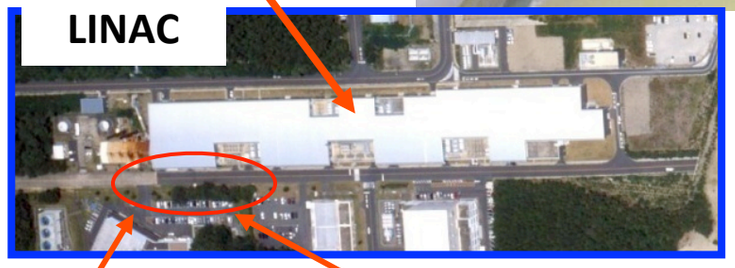
Damages and Recovery Status of Accelerator Facilities







The road around the 3 GeV subsided more than 1 m at many places.



3 GeV Synchrotron

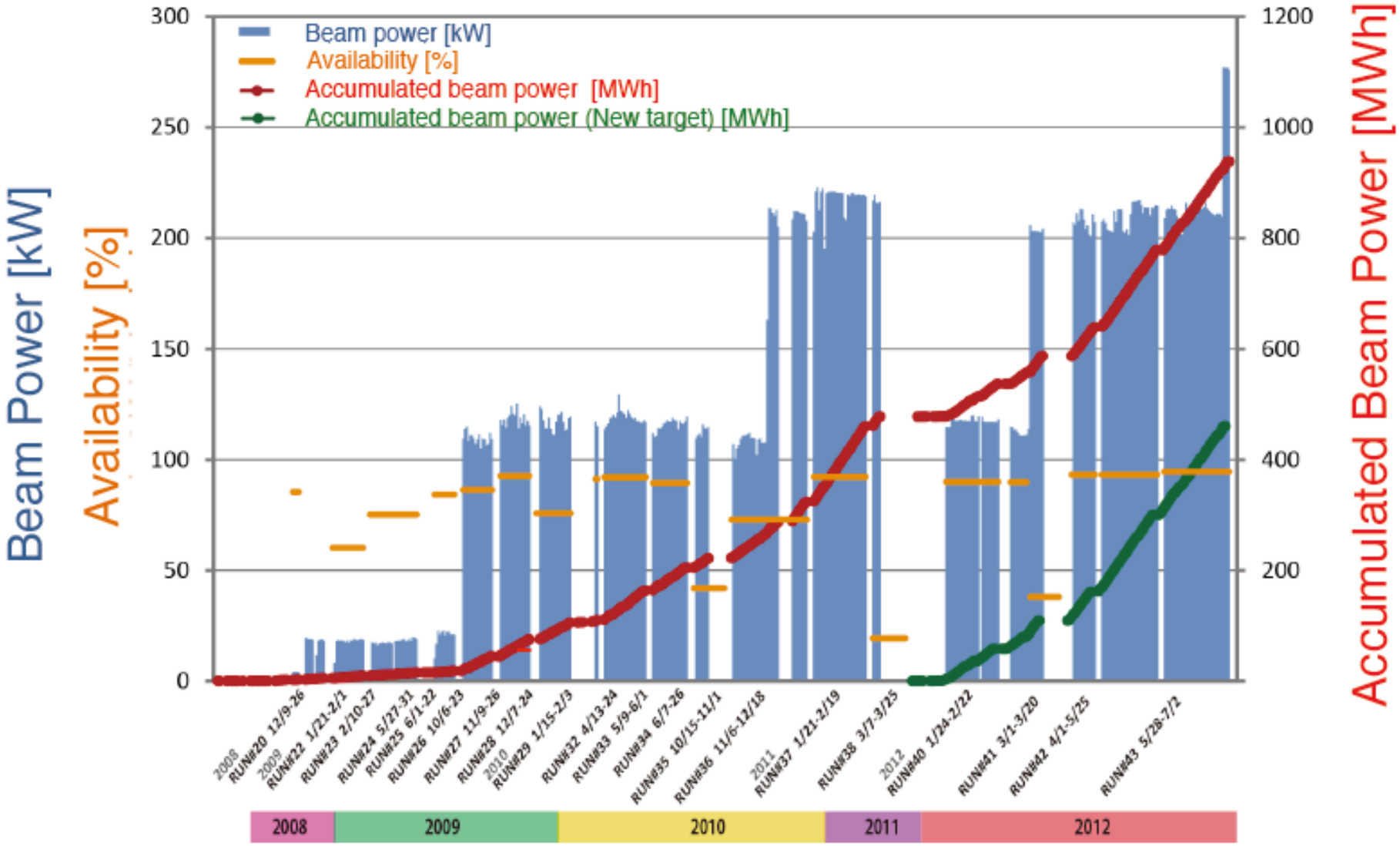
The basis for transformers subsided ~1 m.

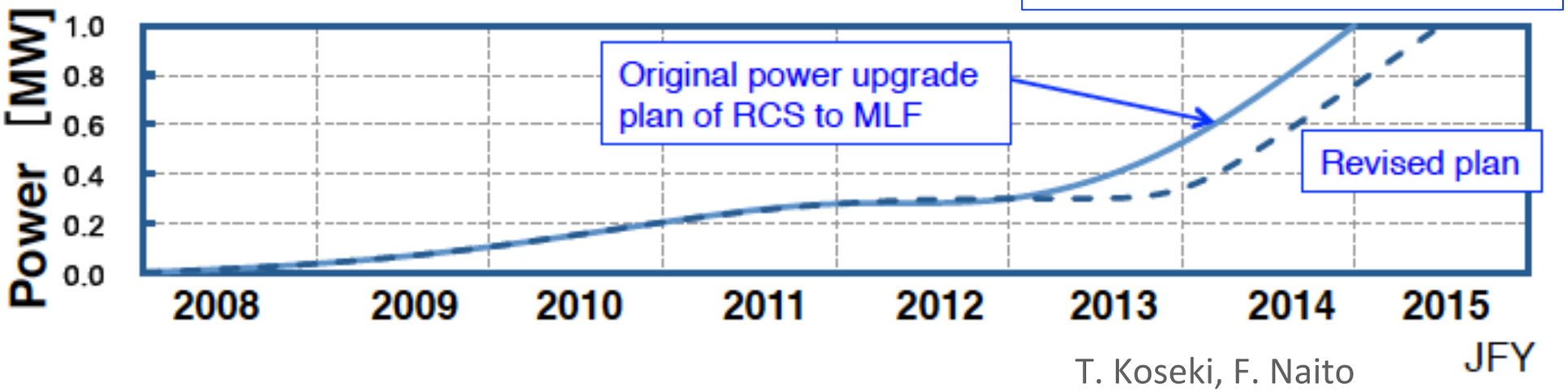
The approach to the LINAC entrance subsided more than 1 m. In contrast, the front road raised a few 10s cm.

Still under the construction

Re-leveled the basis

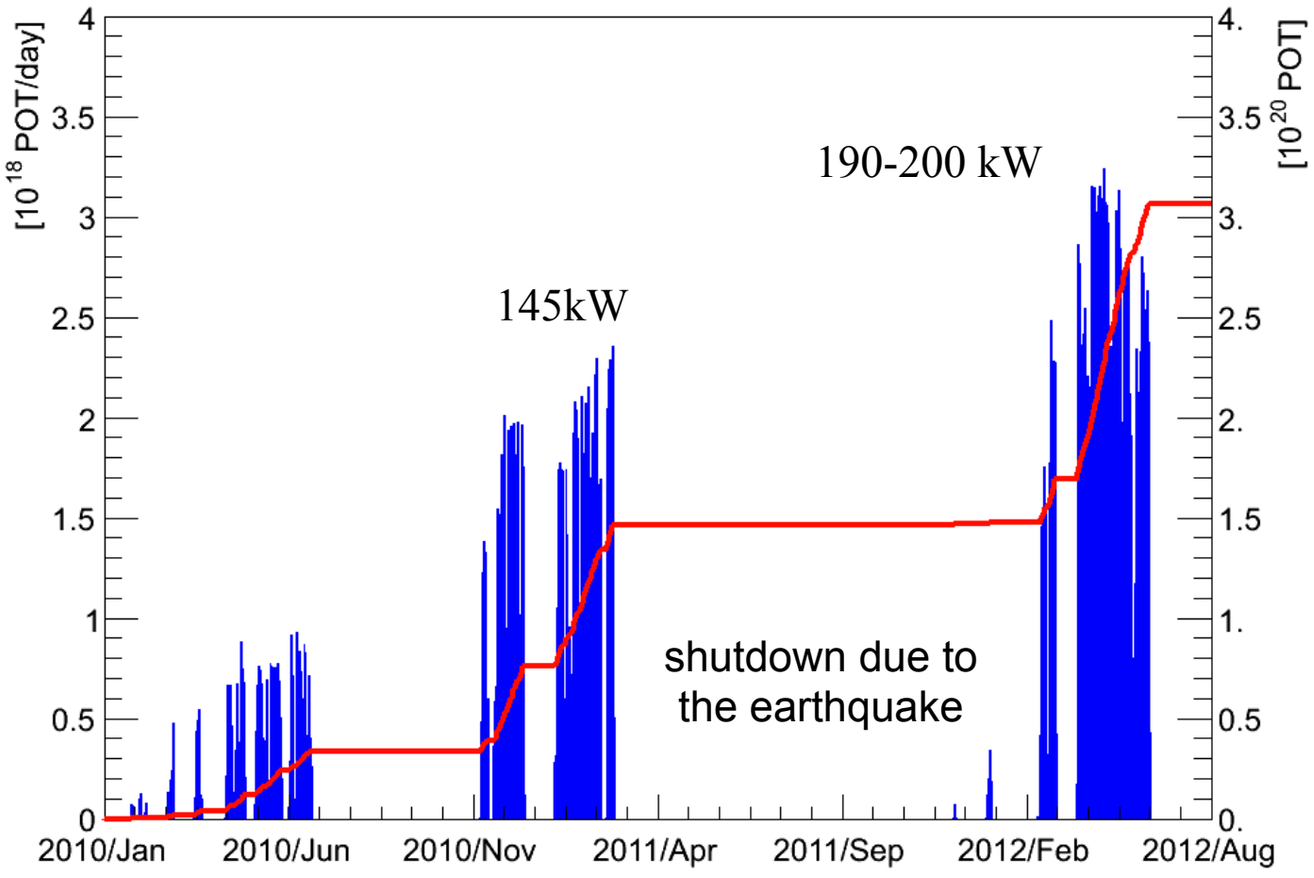
Beam Power of RCS to MLF





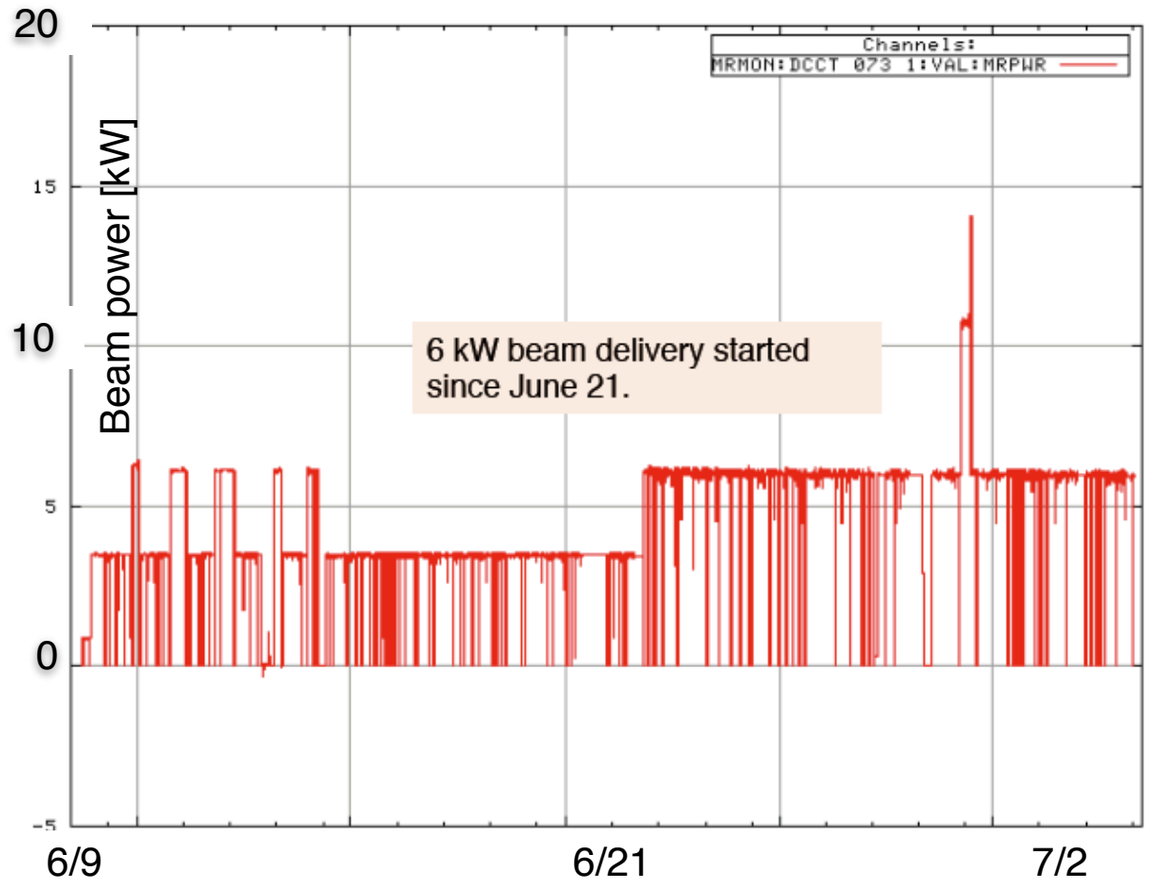
T. Koseki, F. Naito

MR Beam Power to T2K (fast extraction)



Already the highest intensity of proton beams extracted from a synchrotron in the world. T2K has observed 11 electron-neutrino appearance(3.2 σ).

MR Beam Power to the Hadron Experiments (slow extraction)



Extraction efficiency 99.5% has been achieved at 14 kW extraction.

T. Koseki, F. Naito

Upgrade plan of linac

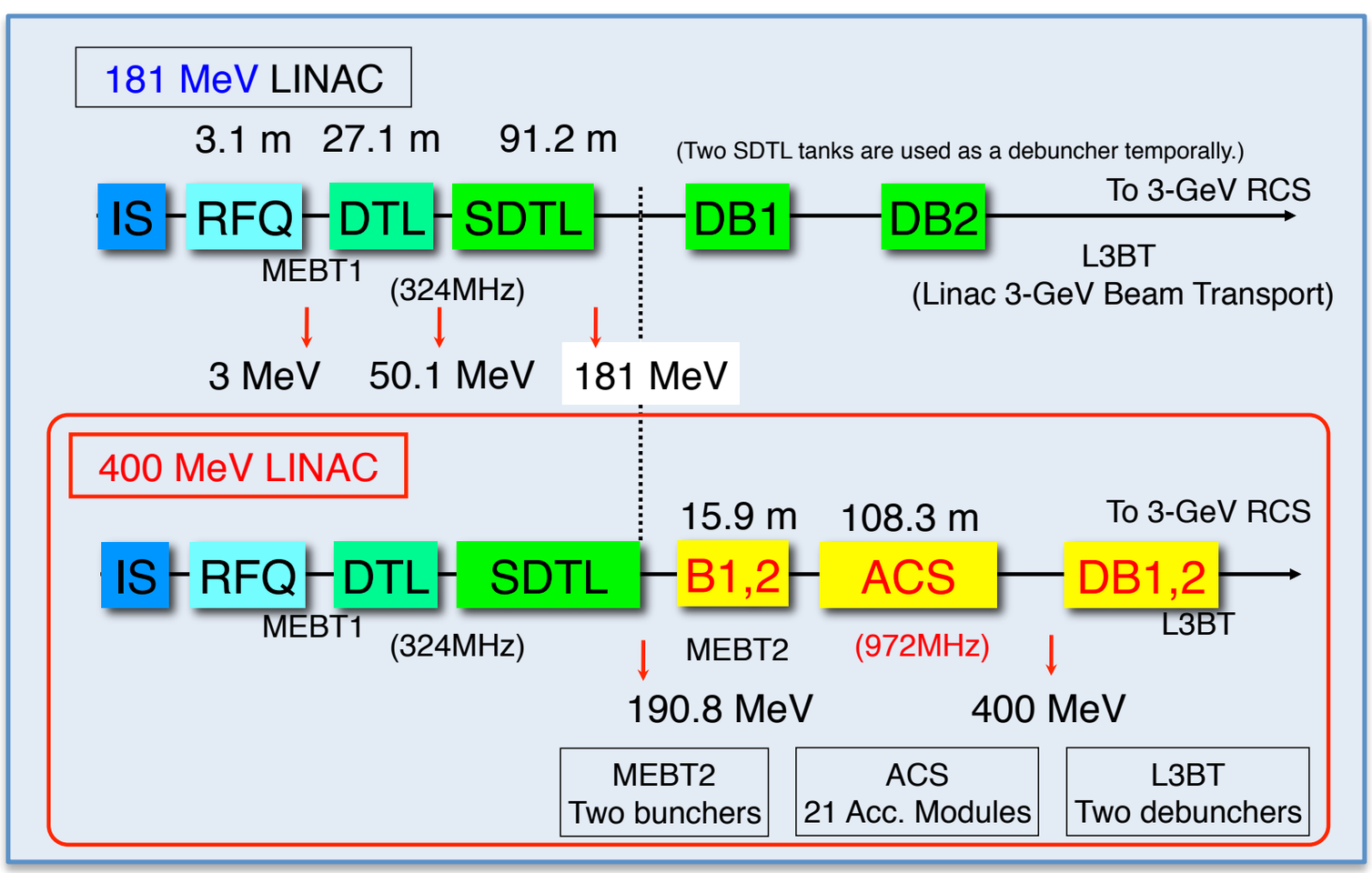
For beam energy:

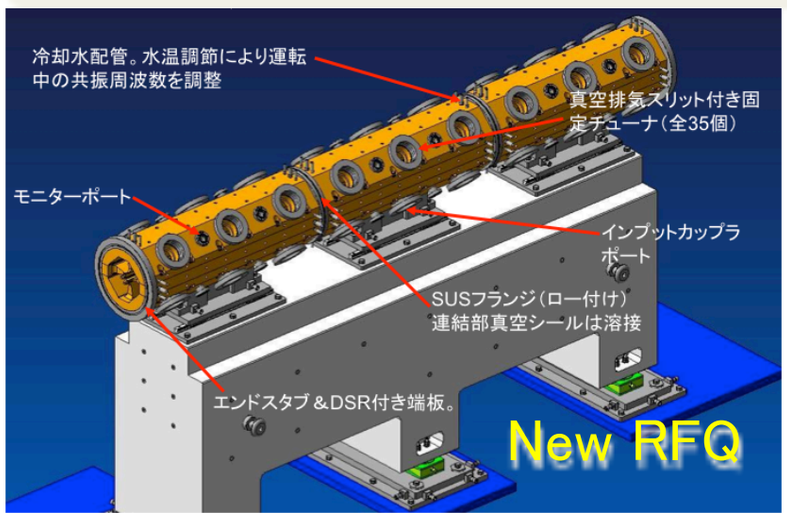
New accelerating structure, ACS(Annular Coupled Structure linac) will be installed to increase the extracted beam energy of the linac from 181 MeV to 400 MeV. Power supplies of RCS injection magnets will also be replaced for adopting 400 MeV injection beam.

For peak beam current:

Front-end part (IS+RFQ) will be replaced for increasing peak current from 30 mA to 50 mA.

In our original plan, installations of the ACS and new front-end are scheduled in 2012 and 2013 shutdowns, respectively. However, we changed the plan after the earthquake as that both the ACS and the new front-end will be installed in 2013 shutdown.

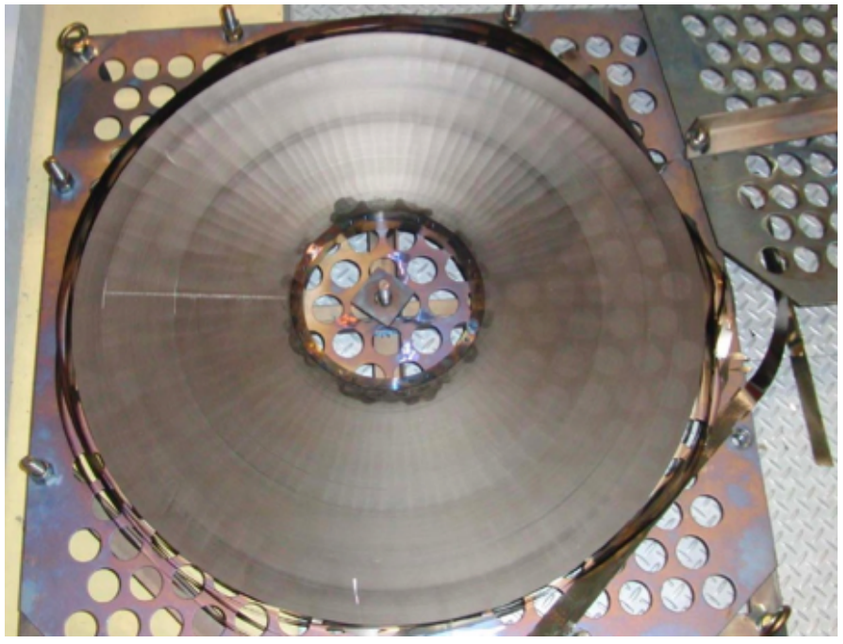




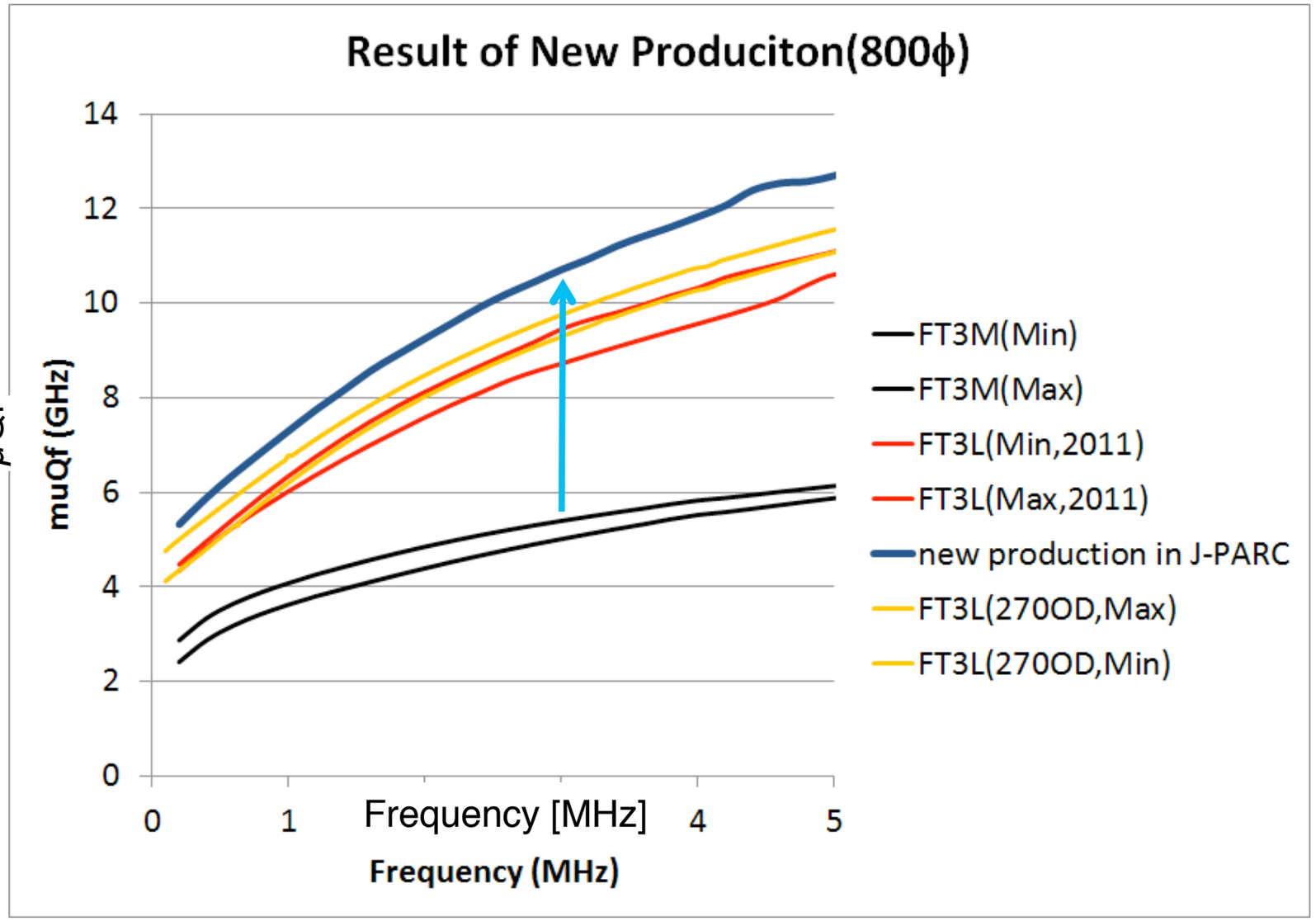
FT3L, New Magnetic Alloy Core for the ring RF cavities

A type of MA cores, FT3L (made by Hitachi metals), which is processed by annealing with magnetic field, shows significantly higher impedance than FT3M, the present core used in J-PARC synchrotrons.
We have manufactured the real size core of FT3L for the rf cavity of the MR in the J-PARC site in collaboration with Hitachi metals.

The first manufactured real size FT3L core



Diameter 80 cm, thickness 2.5 cm, weight 60 kg.



The FT3L core has more than doubled the impedance of FT3M.

A first cavity using the FT3L cores will be fabricated and tested in 2012.

C. Ohmori

KEKB / SuperKEKB

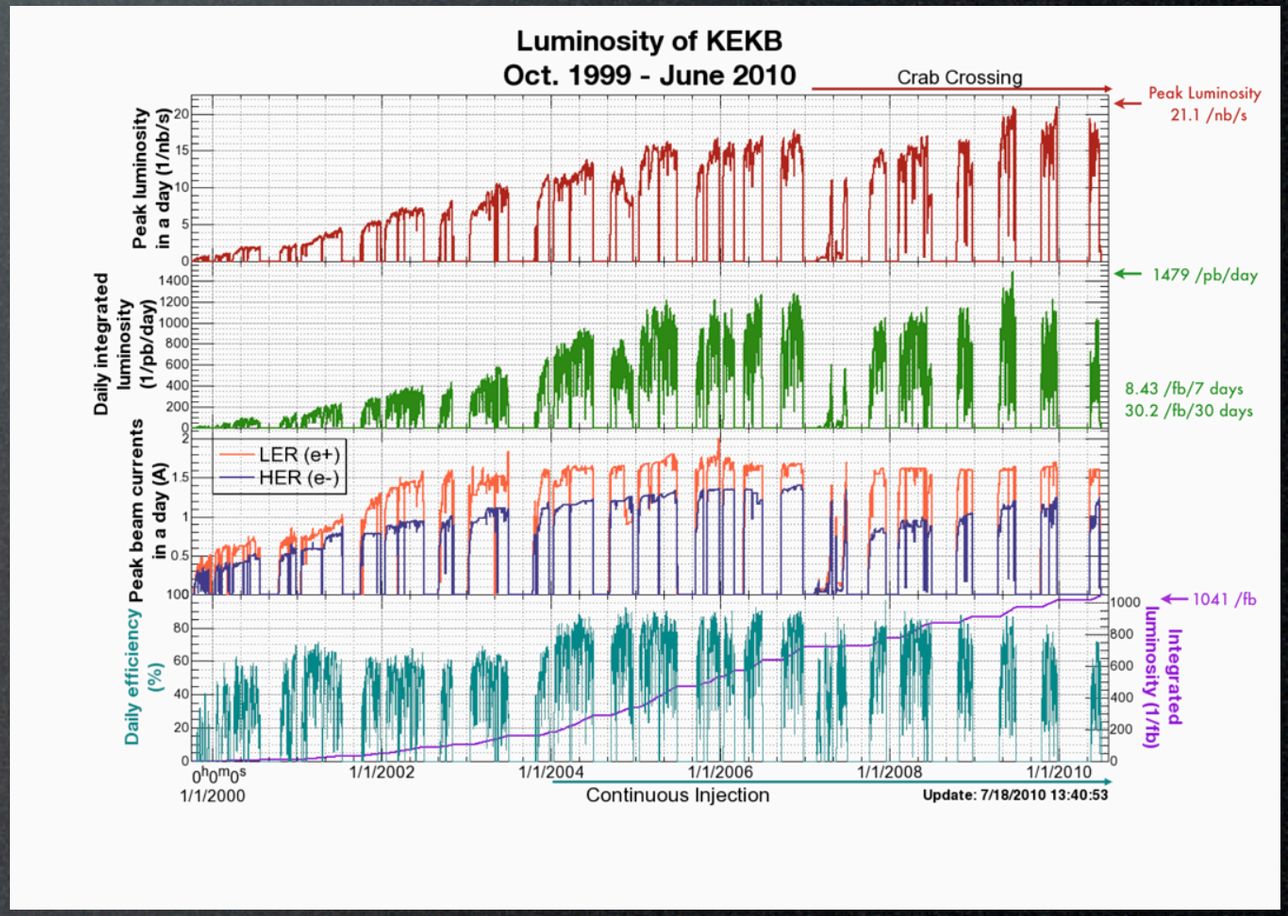
- Achieved 2.1 x 10^{34} $cm^{-2}s^{-1}$, upgrading toward 8 x 10^{35}.
- Spot size at the IP:

Smallest as a ring collider

$(\sigma_x, \sigma_y) = (100, 1)\ \mu m \Rightarrow (10, 0.05)\ \mu m.$

Even smaller!

- Beam-beam parameter reached $\xi_y = 0.09$.
- Small emittance with beam-beam effects and high stored current (3.6 / 2.6 A @ LER/HER).



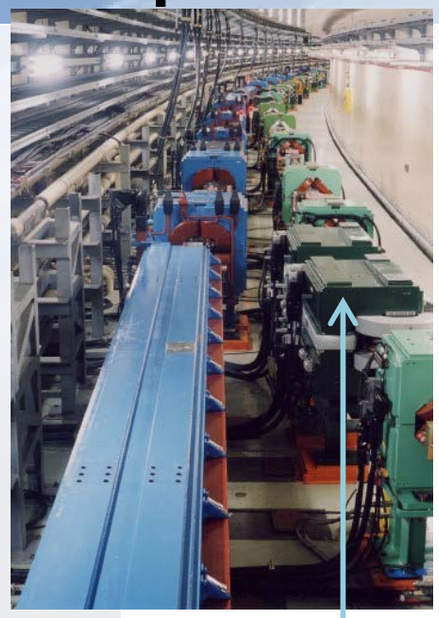
SuperKEKB and Belle II

Belle II

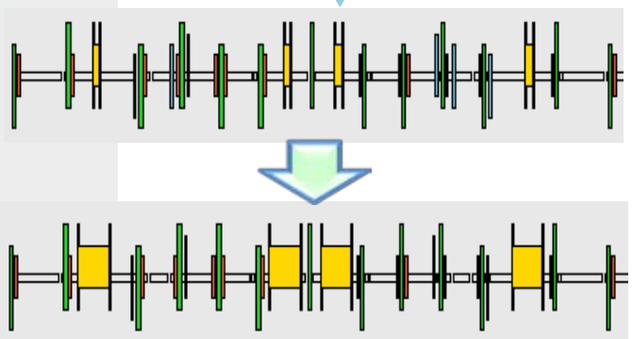
e^+ 4GeV 3.6 A

e^- 7GeV 2.6 A

SuperKEKB



Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

New beam pipe & bellows

New IR

Colliding bunches

New superconducting /permanent final focusing quads near the IP

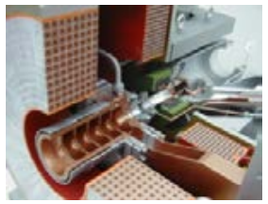
Add / modify RF systems for higher beam current

Low emittance positrons to inject

Damping ring

Positron source

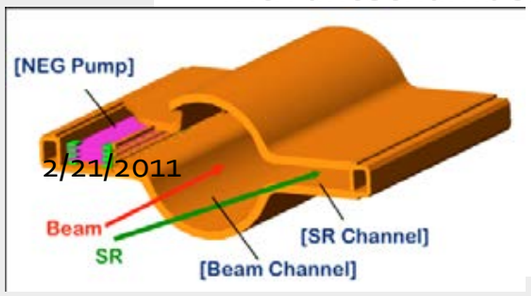
New positron target / capture section

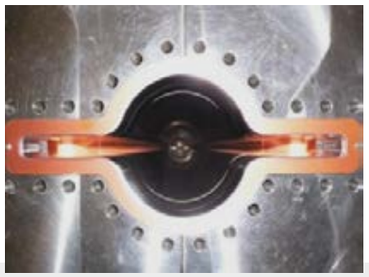


Low emittance gun

Low emittance electrons to inject

TiN-coated beam pipe with antechambers



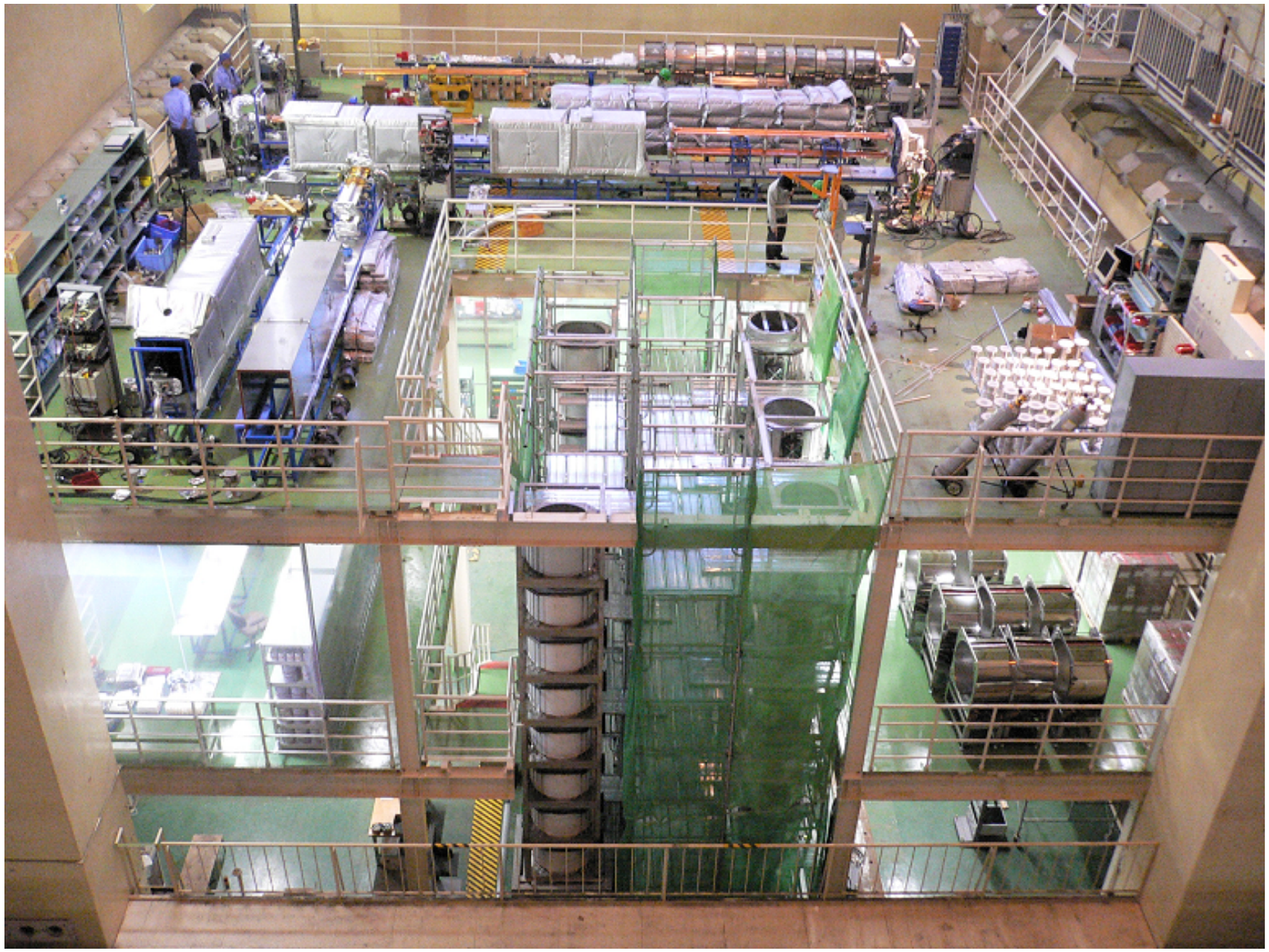


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

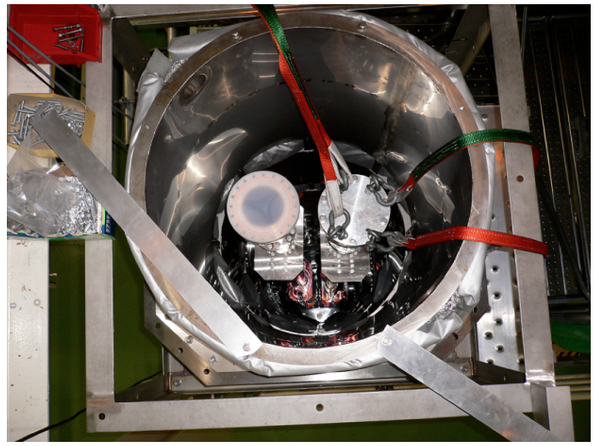
Target: L = $8\times10^{35}/cm^2/s$

Vacuum system

- About 1,100 new beam pipes for SuperKEKB LER are under baking and TiN-coating in house at the Oho experiment hall.



The vacuum processing platform at the Oho exp. hall, incorporating 4 baking stands (B2), inspection & preparation area (B3), and stock area (B4). The 4 + 1 coating units are placed through 3 floors.



Two beam pipes are coated simultaneously in a coating unit.

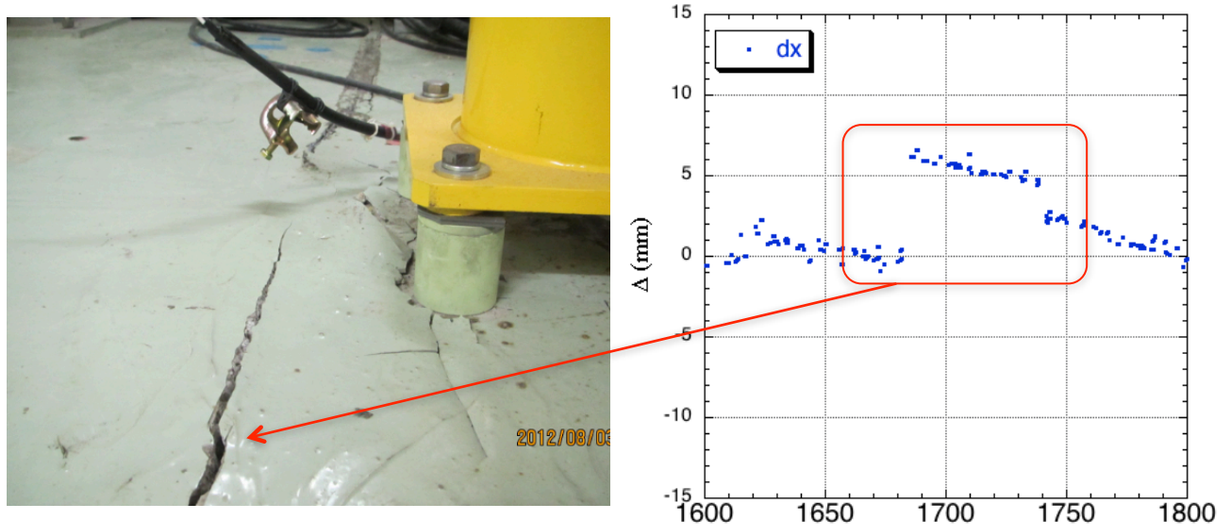
The processed beam pipes

K. Shibata, K. Akai

Magnets

- New dipole magnets for the LER
  - 100 New main dipoles for the LER, have been measured and installed.
- Wiggler magnets
  - will be installed in 2 straight sections in this year.
- Removal of all magnets at Tsukuba for about 400 m around the IR
- Realignment of all magnets over the entire tunnel.
  - measurement and realignment are going on, recovering the large displacement caused by the earthquake.

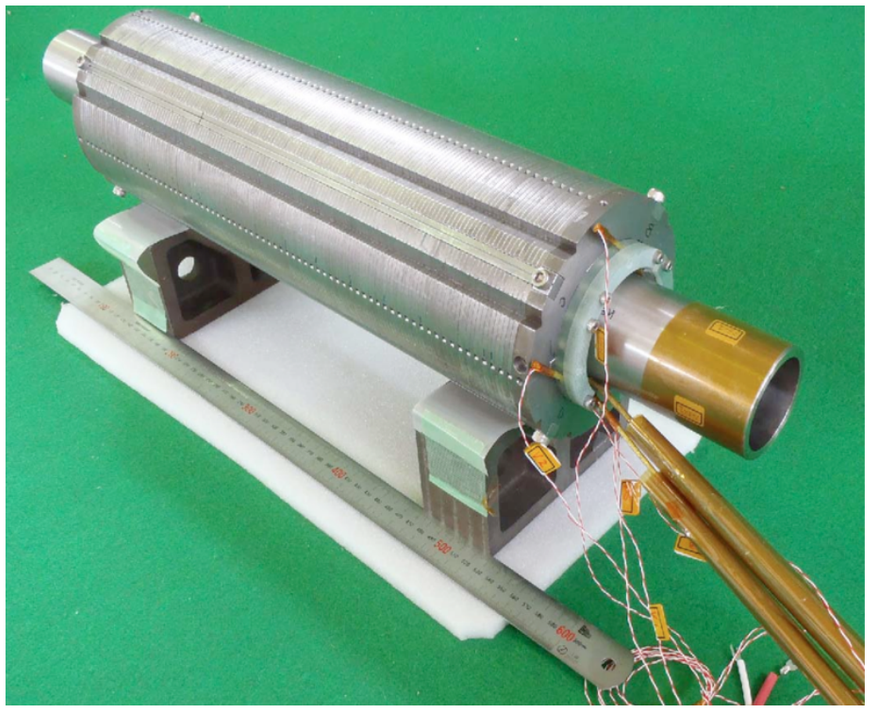
New main dipoles for the LER

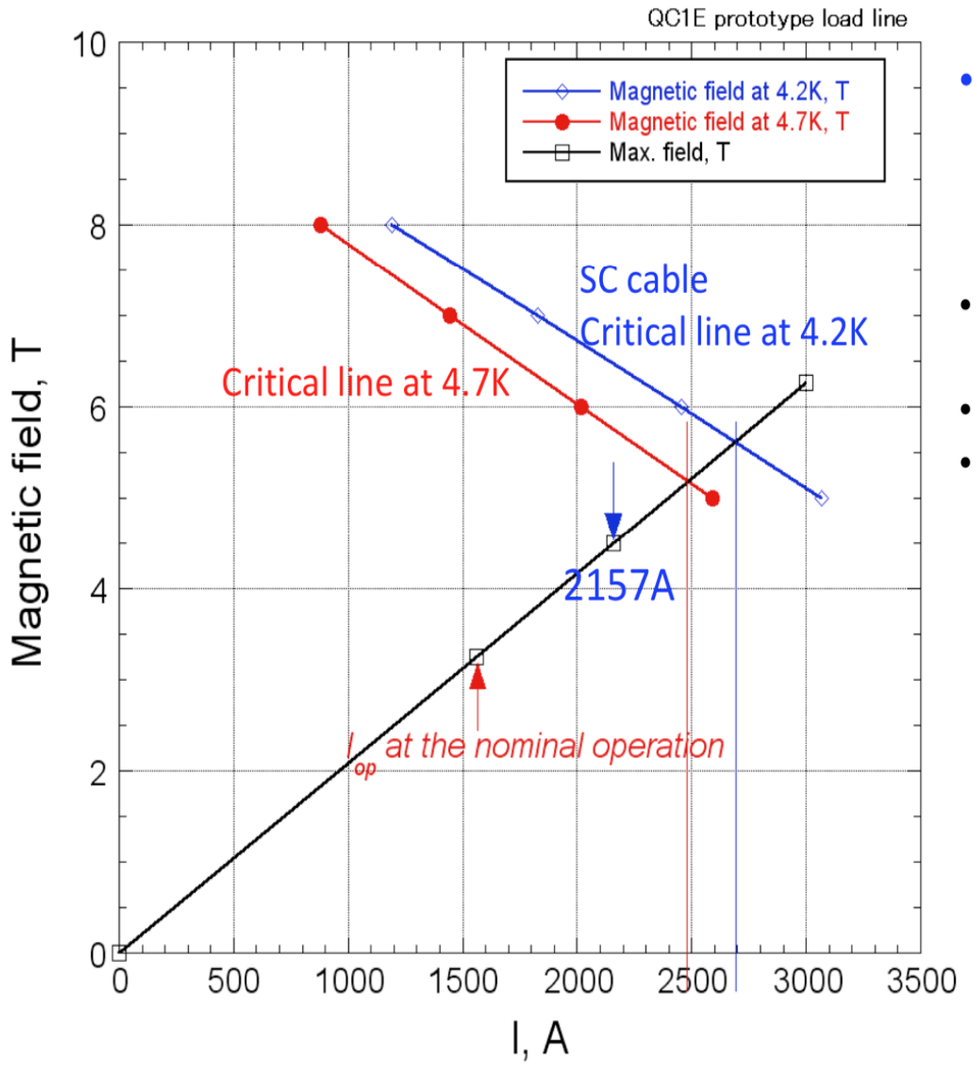


Large displacements of magnets due to the earthquake

A prototype of the superconducting final quad was successful.

Operated without quench up to 2157A, which is enough higher than the design current.





- **設計電流 =1558.5 A (QC1LE)**
  - ***G* = 70.68 T/m**
  - **$\int G\,dl$ = 26.675 T**

- QC1Eプロトタイプは2157Aまでクエンチ無しで励磁に成功。
- $I_{c@4.7\,K}$ = 2480A
- I_{op}＝1558.5A
  - $I_{op}/I_{c@4.7K}$=0.628
  - 2157A/$I_{c@4.7K}$=0.870

QC1Eは十分な運転マージンを持っている。

SuperKEKB Construction Schedule

Revised on Sep. 26, 2012

FY2010 | FY2011 | FY2012 | FY2013 | FY2014

KEKB stop, Construction start

We are here

SuperKEKB commissioning

Dismantle KEKB

Beam pipes and vacuum components
- Fabrication
- Baking, TiN coating
- Install, system check

Magnets and power supplies
- Fabrication
- Field measurement
- Install, alignment, system check

RF system
- Reinforce and rearrange
- System check

Monitor & control, Beam transport
- R&D
- Fabrication
- Install, system check

QCS and IR hardware
- Optics and hardware design, R&D
- Fabrication
- Install, system check

MR infrastructure
- MR buildings construction
- Cooling system reinforcement

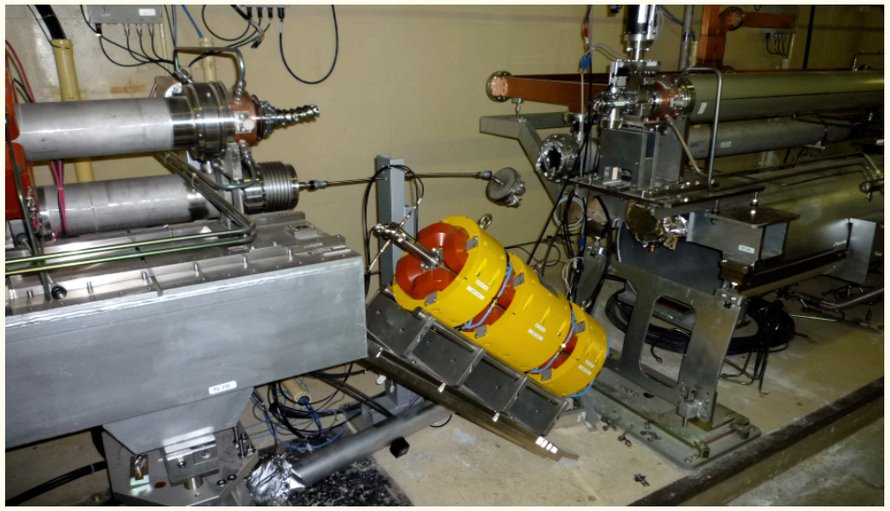
Damping Ring
- Components Fabrication
- DR tunnel construction
- Install, alignment, system check
- DR buildings construction

e+e- Injector
- Upgrade and operation for PF/PF-AR
- Injector low emittance

e+e- Injector Linac

- Top-up injection to SuperKEKB LER (e+, 4 GeV), HER (e-, 7 GeV), and PF (e-, 3 GeV) by pulse-to-pulse switching. One more ring, PF-AR, will join in the near future.
- Synchronization of the rings with different rf frequencies.
- 2 bunch acceleration per rf pulse.
- A new e- rf-gun for a small emittance with a relatively high bunch charge (20 μm @ 5 nC).
- High intensity positron source (4 nC / bunch).

Fell-down quad



Recovered

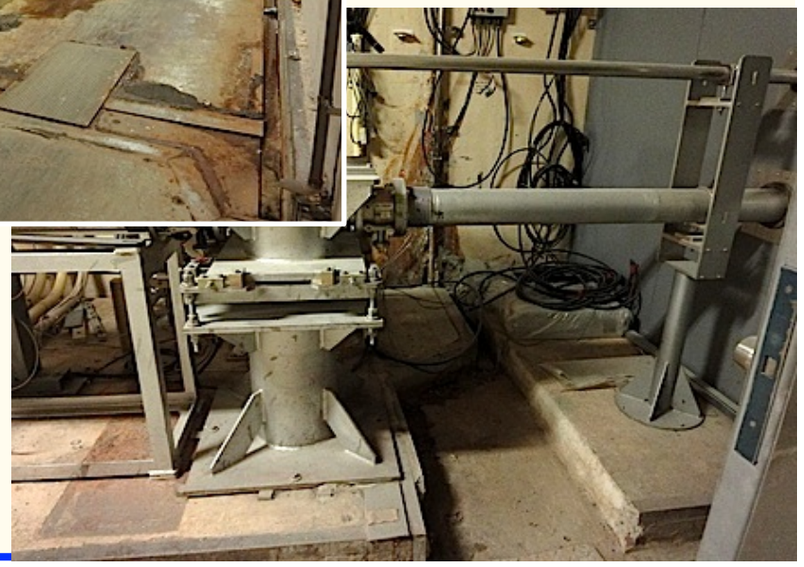
rebuilding laser-alignment system

replacing broken components

Water leakage from tunnel

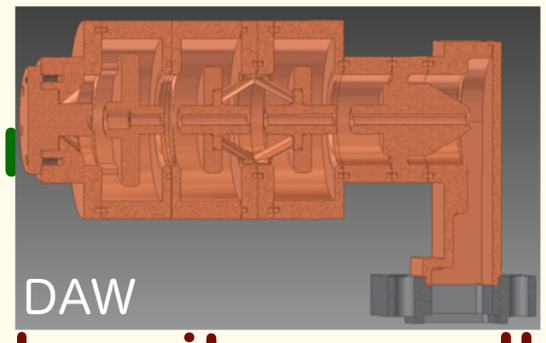
After sealed

Needs more cures for high precision operation



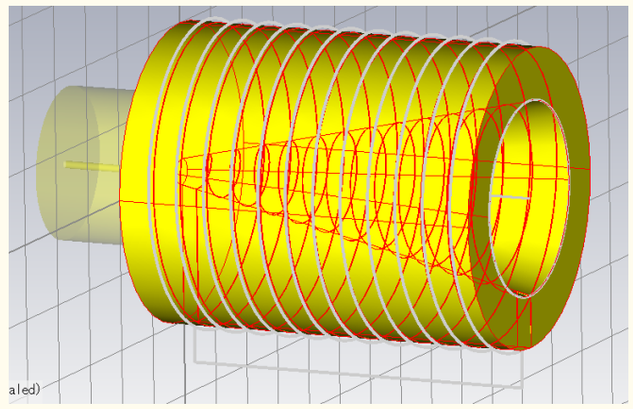
RF Gun Development

- **Photo cathode : stability, longer life, efficiency**
  - At first LaB_6, then Ir_5Ce → 5nC / bunch
- **Laser : higher power, pulse width control**
  - Nd:YAG medium, LD excitation → ~1.5mJ / 30ps / pulse at 266nm
  - Polarization control for slant irradiation
  - In parallel, fiber laser is under development
- **Cavity : better focusing field, higher gradie**
  - DAW (Disk and washer) type cavity
  - Development of quasi-travelling-wave side-coupled cavity as well
- **Test stands**
  - RFgun at A-1 will be constructed this autumn for SuperKEKB
  - RFgun at 3-2 was used to inject into PF with proper synchronization
  - Long-period demonstration will be carried during this autumn

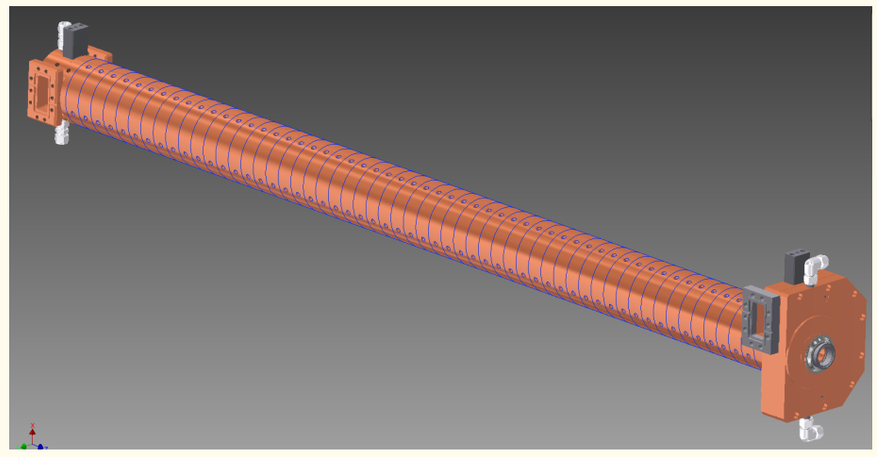


Positron Generator Development

- **Flux concentrator (SLAC-type)**
  - Final optimization of field design and mechanical design. Fabrication soon



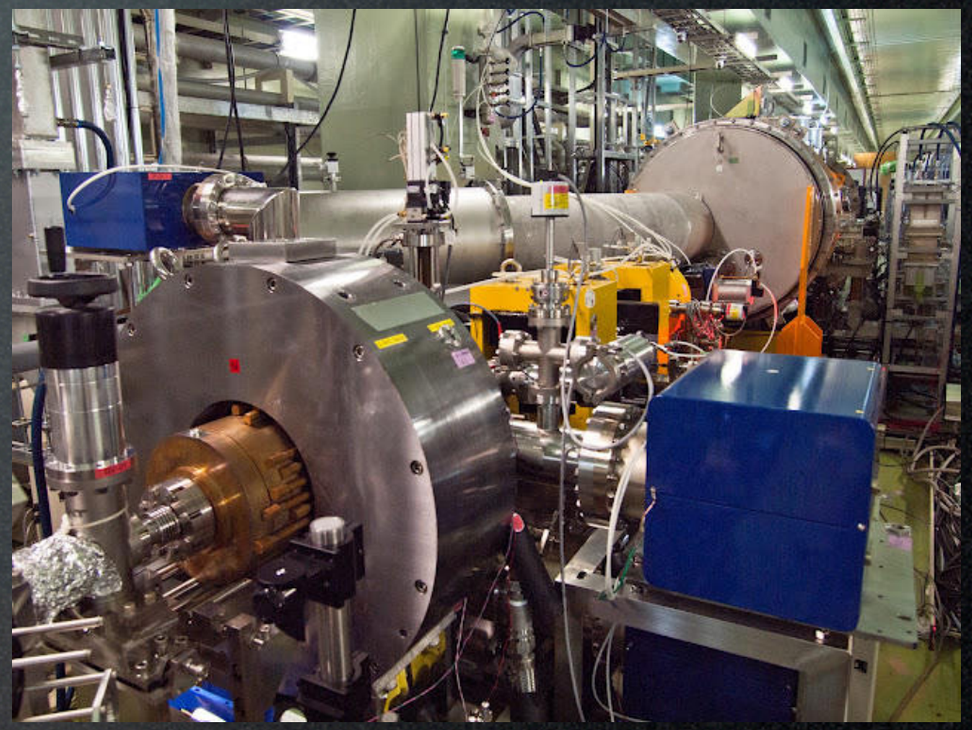
- **Large-aperture S-band (LAS) cavity structure**
  - Positron capture tracking simulation
  - L-band structure as backup with co-linear load



- **Magnet design and fabrication**
  - Solenoid and pulsed steering and quad magnet system
- **4-ring simultaneous injection control including damping ring**
- **Reliability**
  - Strategy for failed component replacement
  - Acceleration gradient distribution and optimization with backups

ATF / STF

- R&D for future linear colliders is one of the main missions of KEK-ACCL.
- ATF: full of innovative beam instrumentations:
  - IP-spot size monitor (Shintake monitor)
  - Laser wires
  - Cavity BPM
  - Bunch-by-bunch collision feedback
  - OTR / ODR / X-ray profile monitors
  - ... and more
- STF & the “Quantum Beam” project:
  - Production / treatment of high-gradient superconducting cavities
  - Acceleration of a long train of bunches

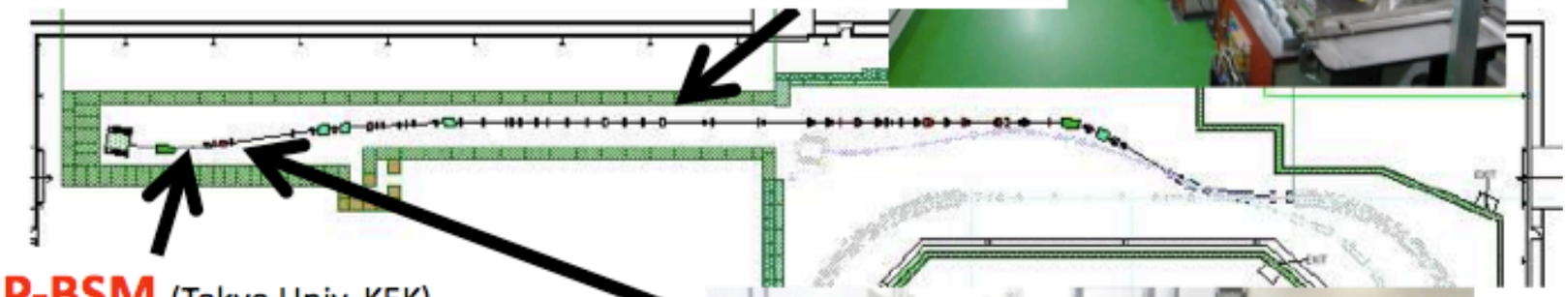


A new RF-gun at STF/Quantum Beam (M. Kuriki)

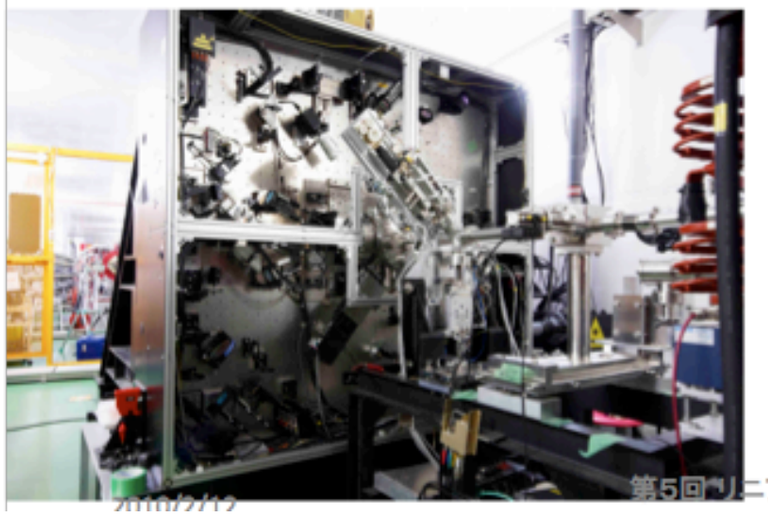
ATF2 Beamline

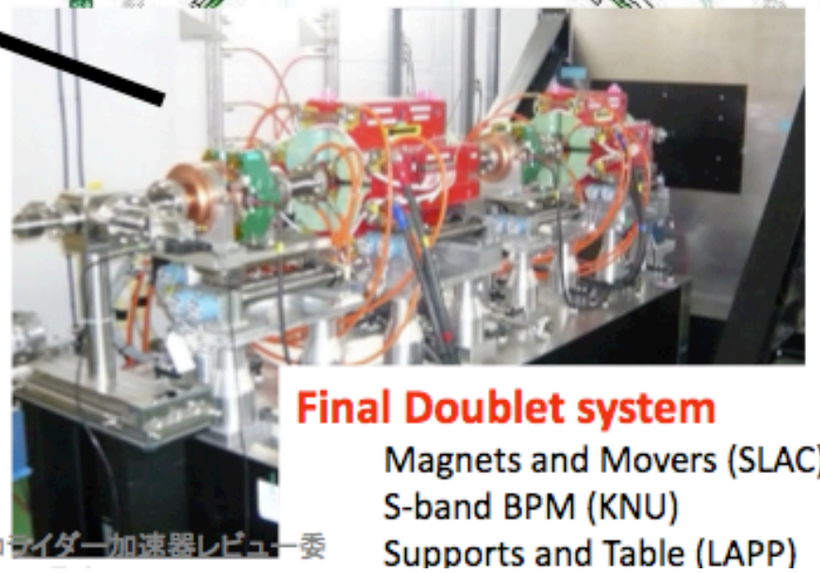
Final Focus beamline

Magnets and Movers (IHEP, SLAC, KEK)
C-band BPM (PAL, SLAC, KEK)
Support Table (KEK)



IP-BSM (Tokyo Univ, KEK)



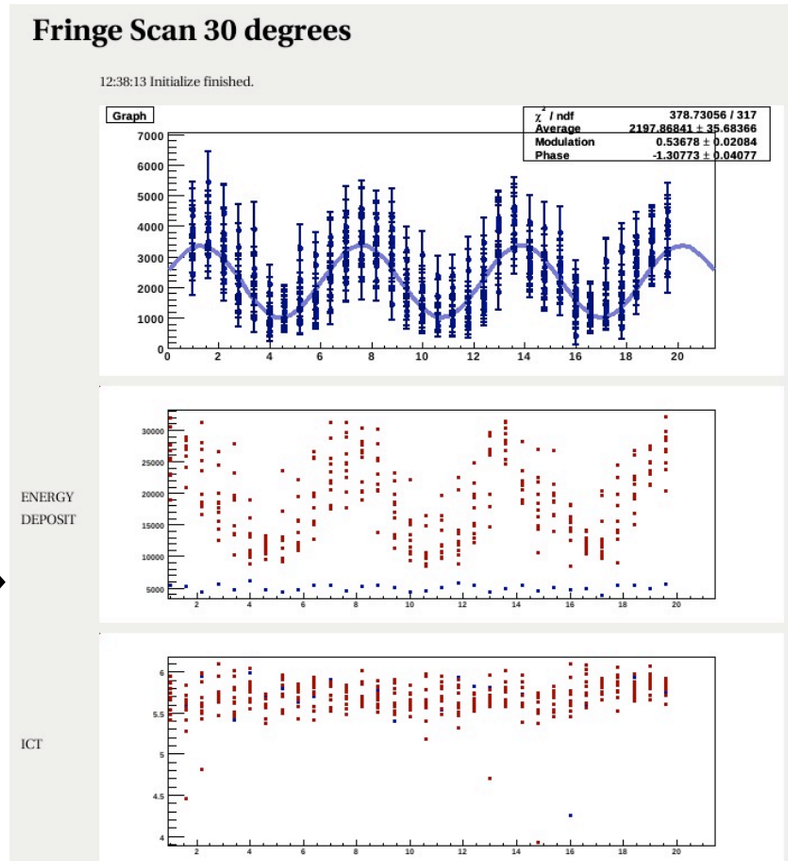


Final Doublet system

Magnets and Movers (SLAC)
S-band BPM (KNU)
Supports and Table (LAPP)

IP-BSM: Before the Earthquake 290 nm

March 2012 165 nm



S. Terunuma, et al

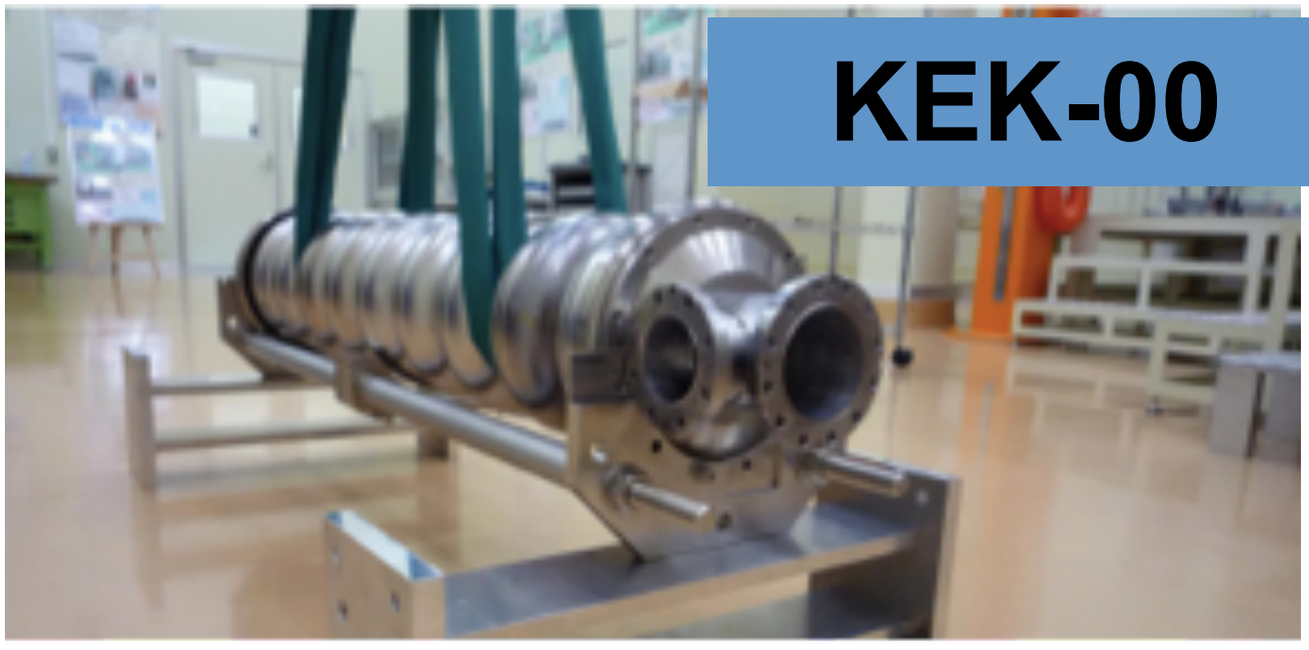
CFF (Cavity Fabrication Facility)

Clean room

Press machine

EBW

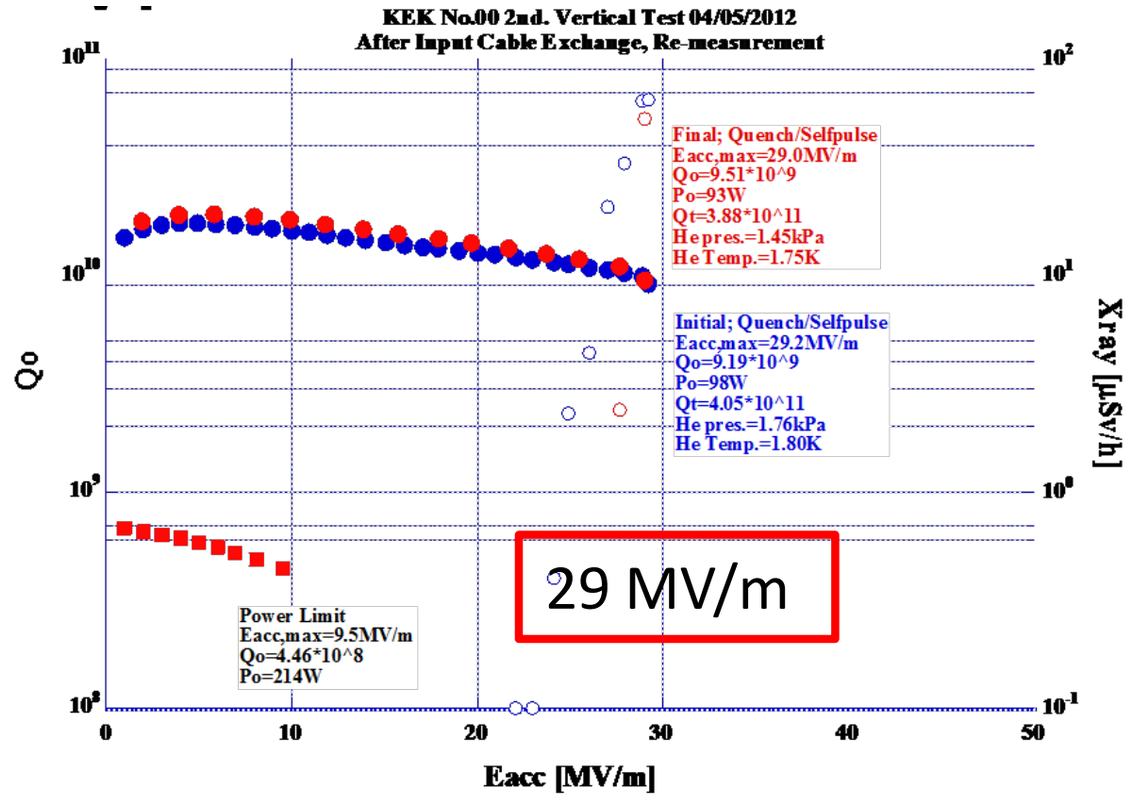
CP



KEK-00

(Press, trim : KEK, EBW : job shop)

Q-E Slope for KEK-00 at 2nd VT

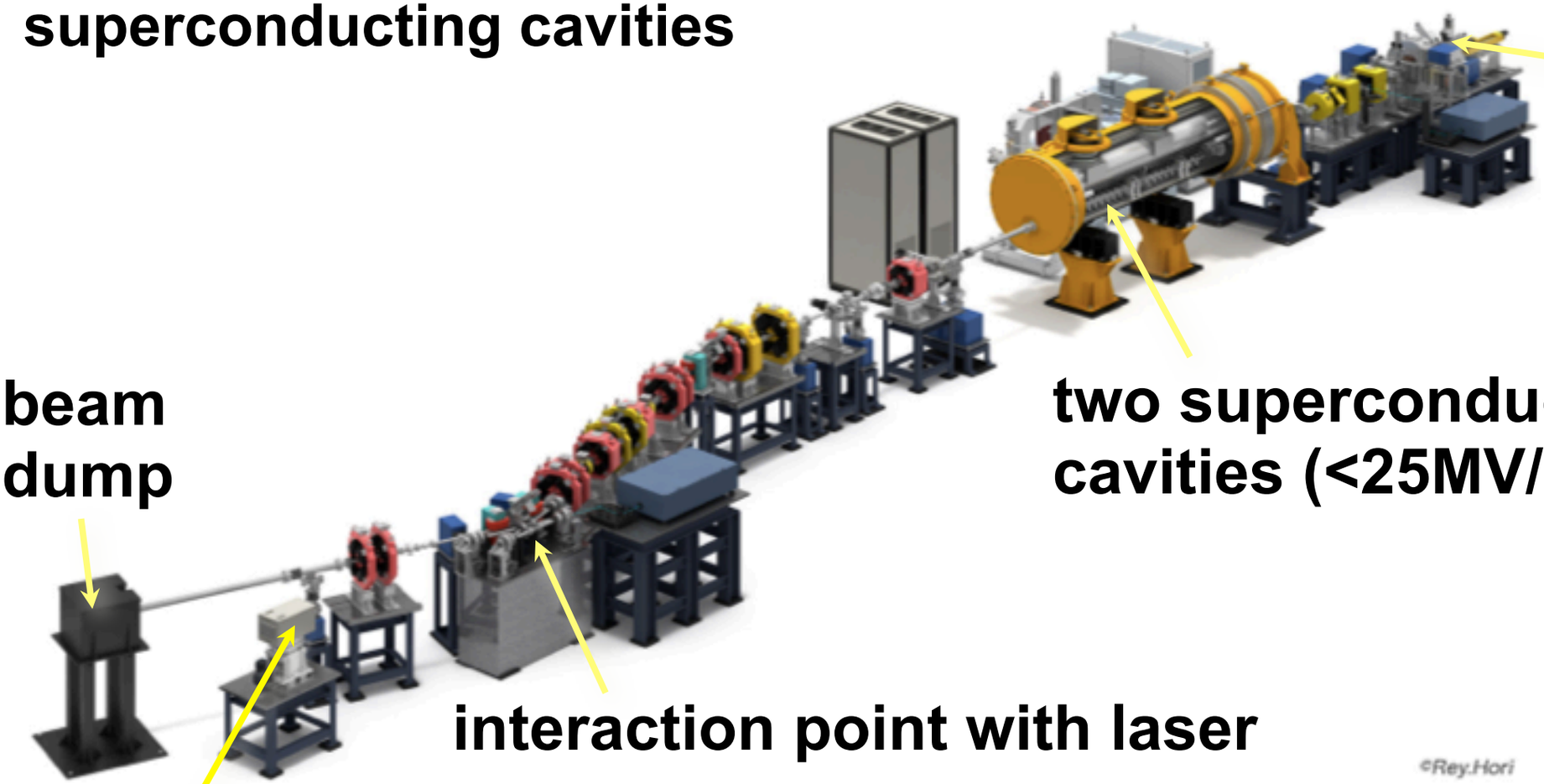


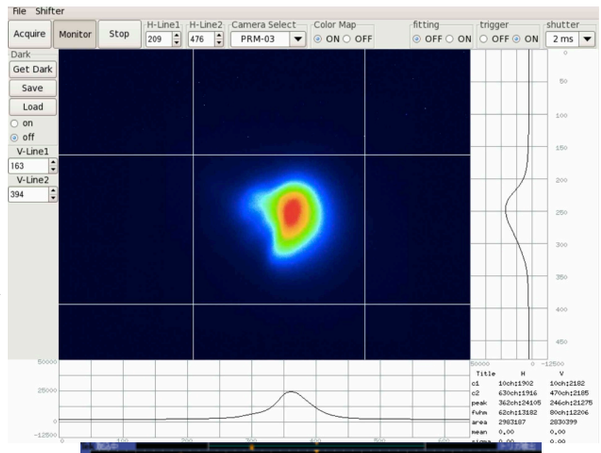
M. Yamanaka, S. Yamaguchi, et al

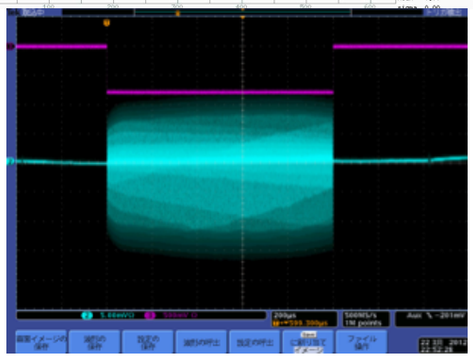
STF Beam operation

Quantum Beam technology project (2008-2012)

- **demonstration of compact X-ray source using superconducting cavities**



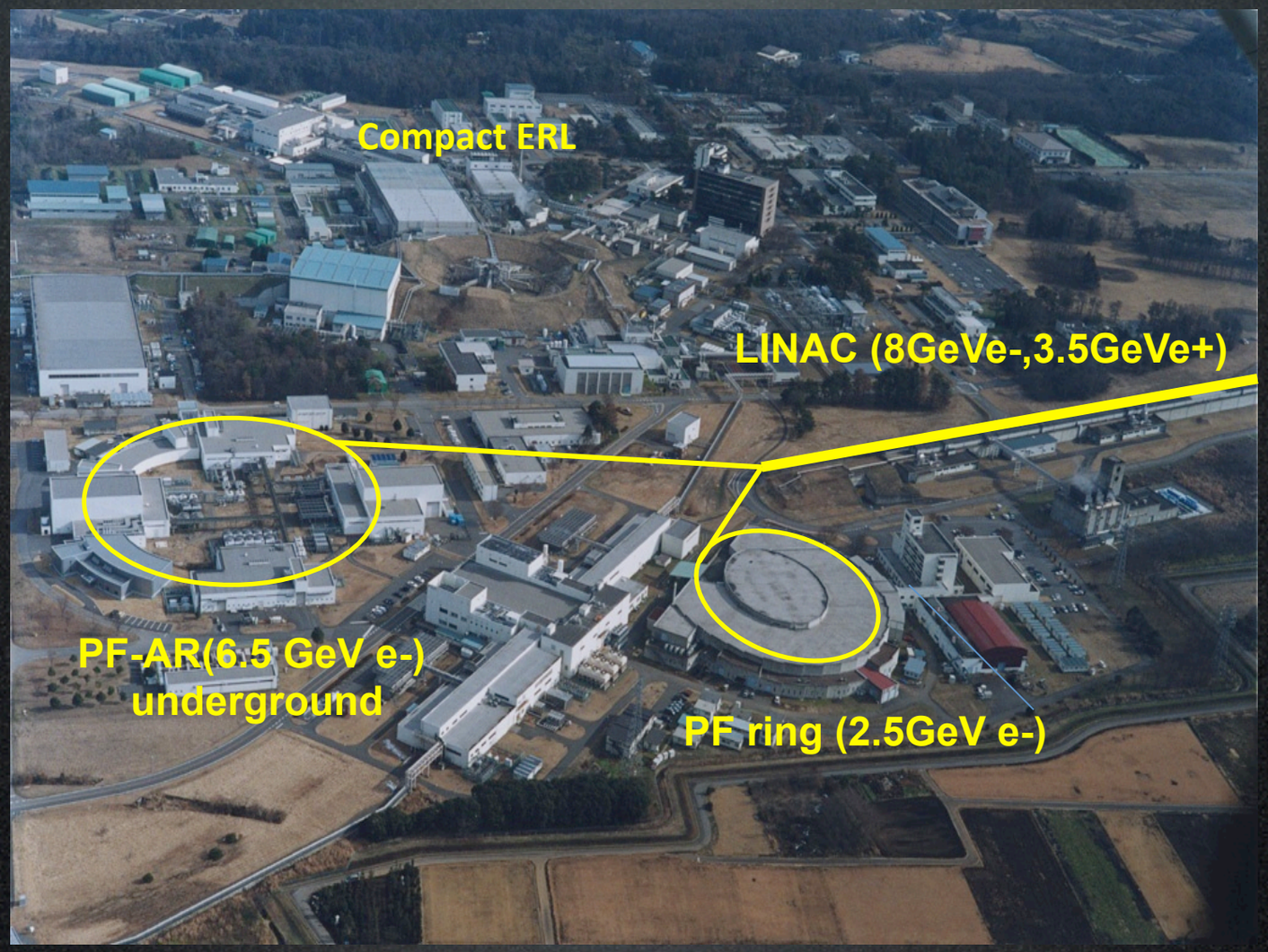




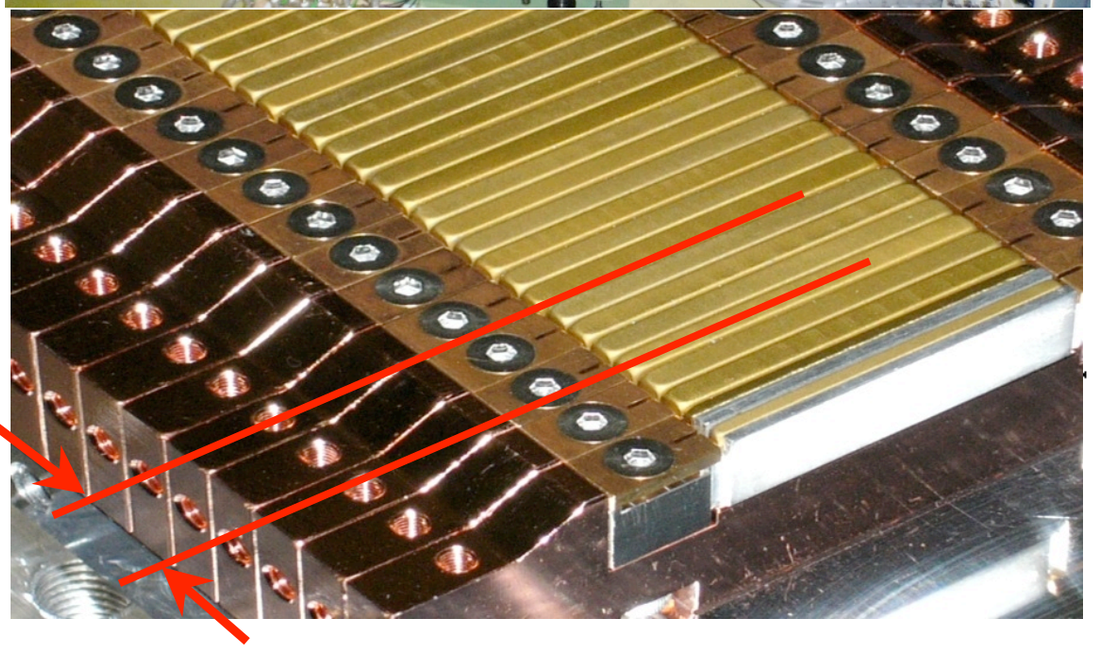
Feb. 27 First beam ext.
Mar. 7 1 ms beam ext.
Apr.13 Beam acc. using SC (40 MeV)
Oct. X-ray expt.

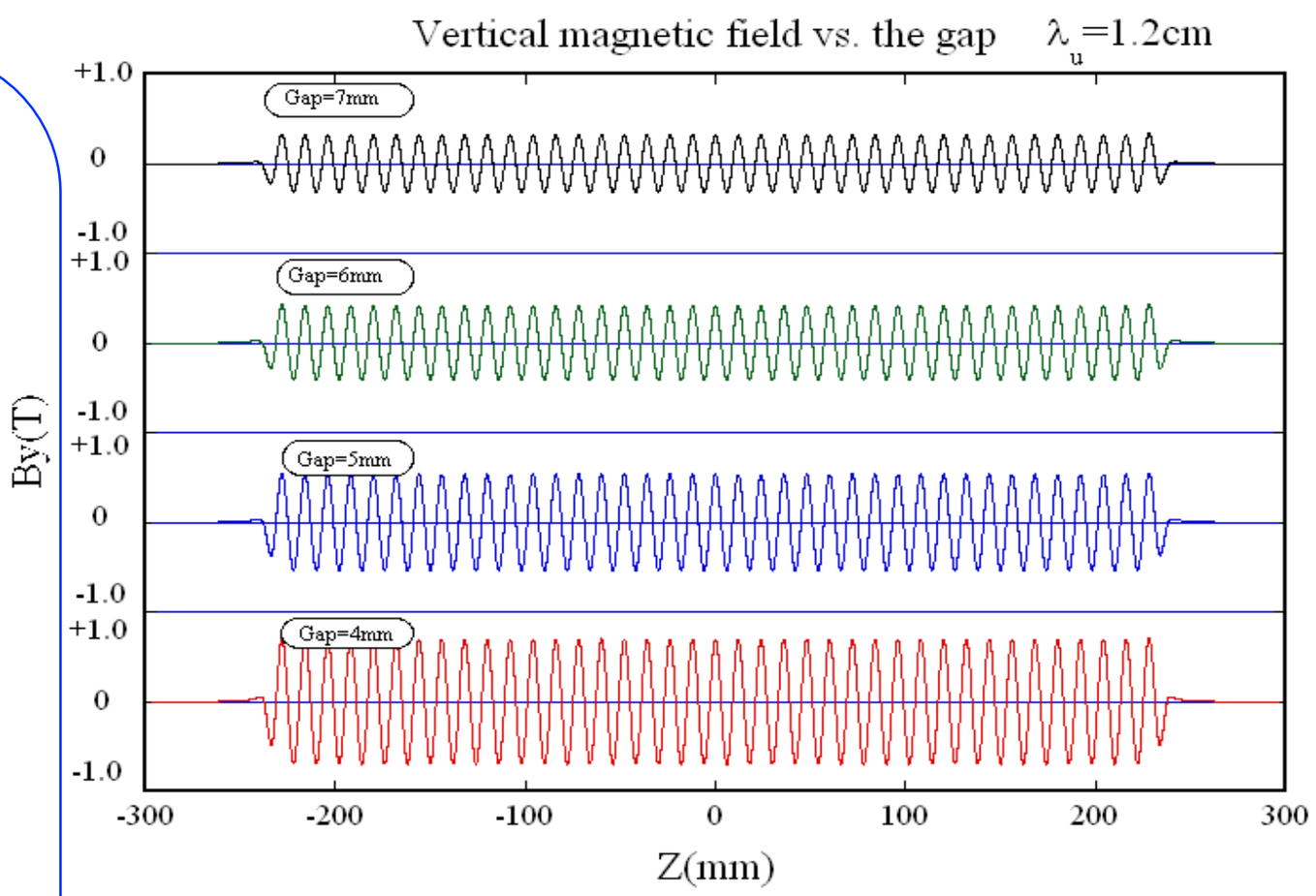
Photon Factory

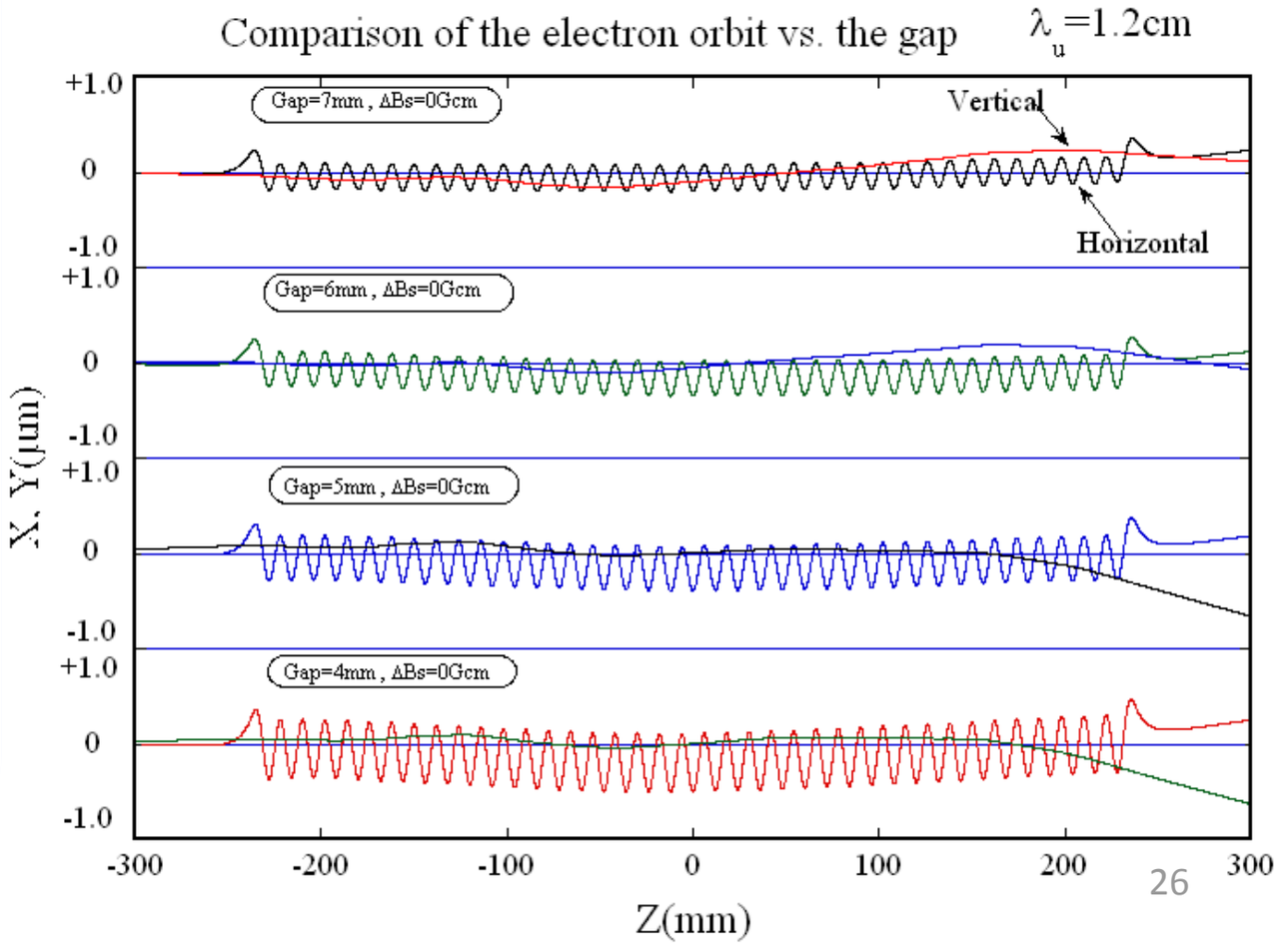
- PF: operated since 1982, two upgrades in 1996 & 2005.
  - 2.5 GeV, ε_x = 35 nm, I = 450 mA, top-up operation
- PF-AR: operated as a dedicated light source since 1998.
  - 6.5 GeV, ε_x = 290 nm, I = 60 mA, single bunch.



Short Gap Undulator #01
with a minimum gap of 4 mm

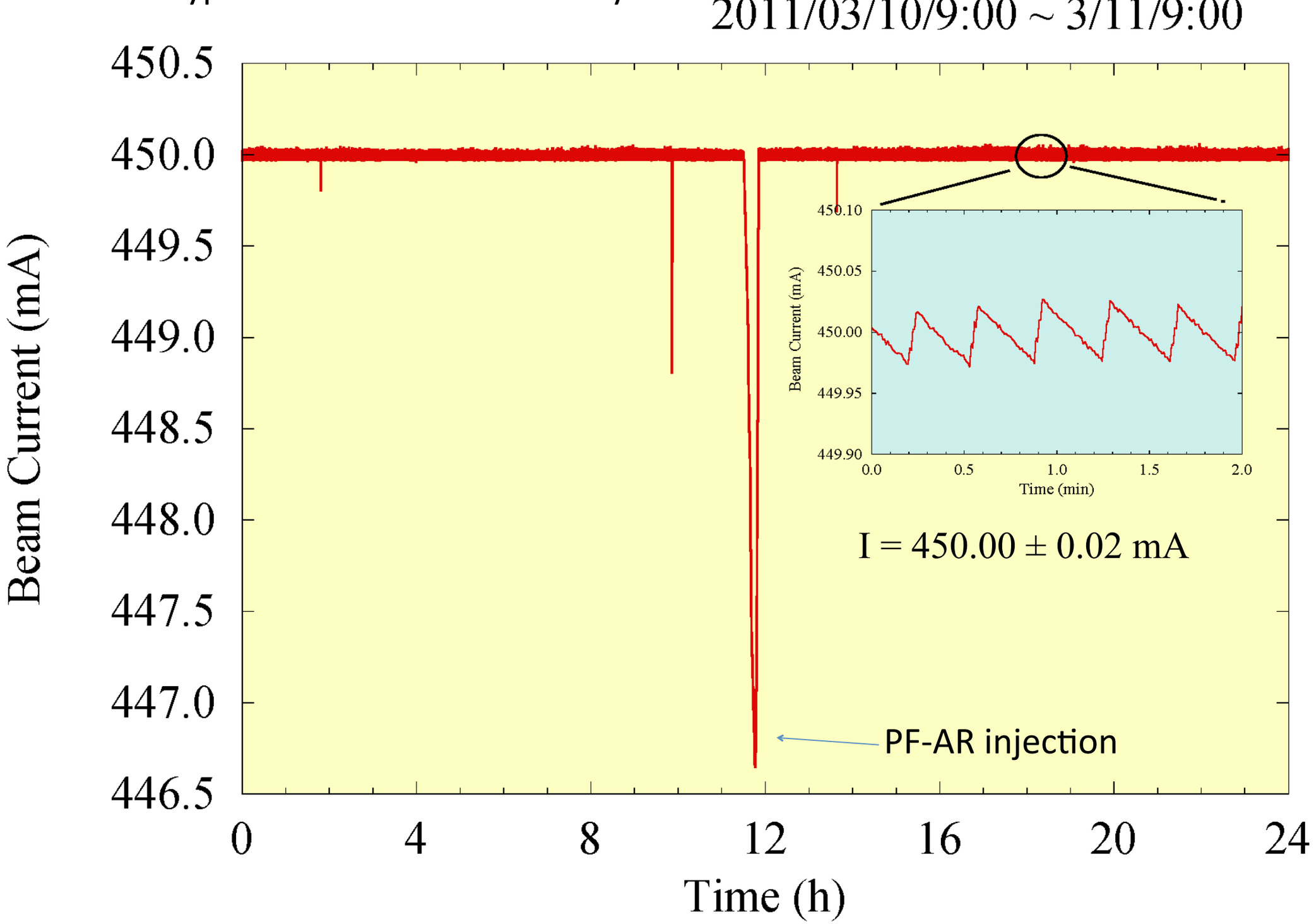






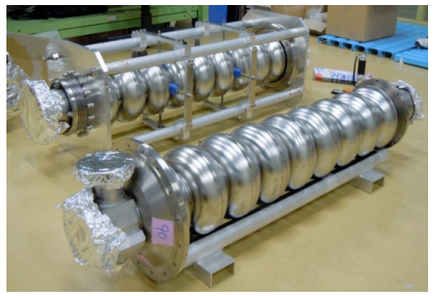
Status of the top-up operation at the PF ring

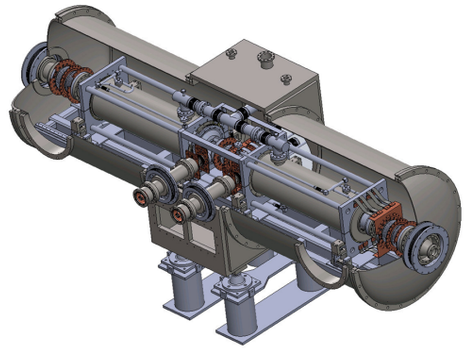
Typical Beam Current in a day



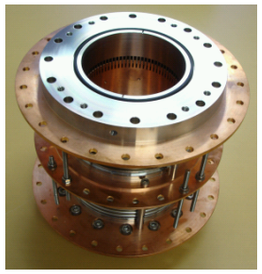
Key components of the Compact ERL at KEK

H. Kawata, et al



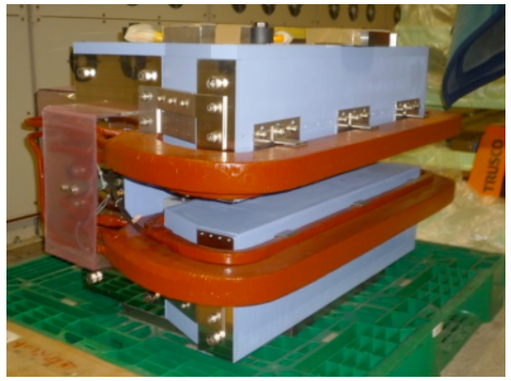


CW Superconducting Cryomodules



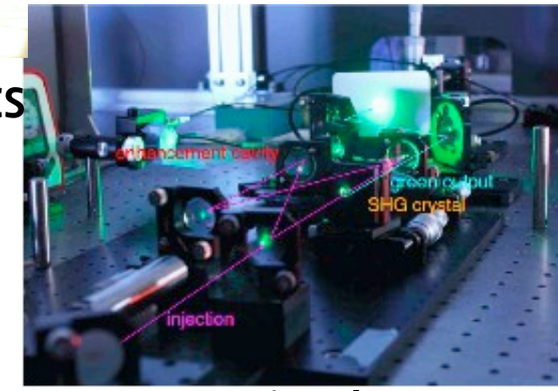
HOM Absorber

300 kW Klystron



Bending magnets

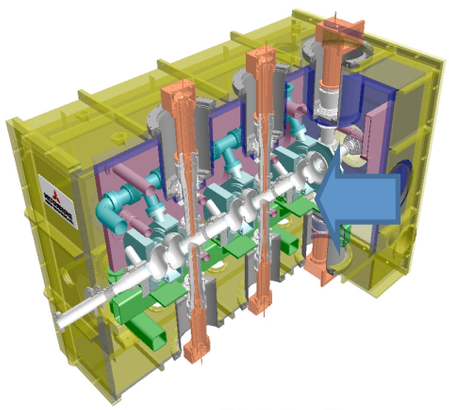
He Cryogenics

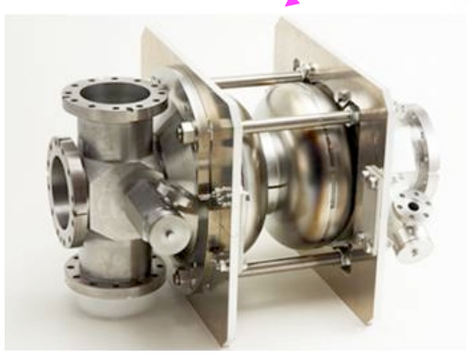


Drive laser

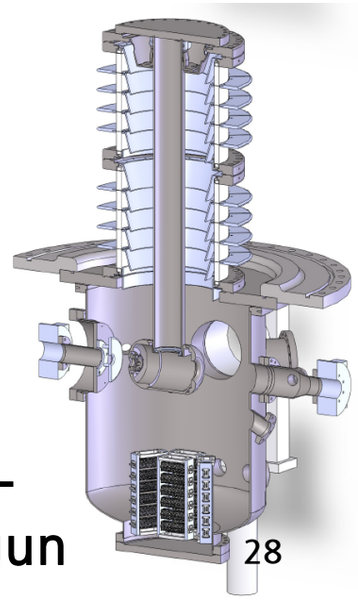
All components are needed for the machine operation, including infra-strunctures.

Beam will circulate in 2013.
The initial goal:
35 MeV, 10 mA, ε_n = 1 μm



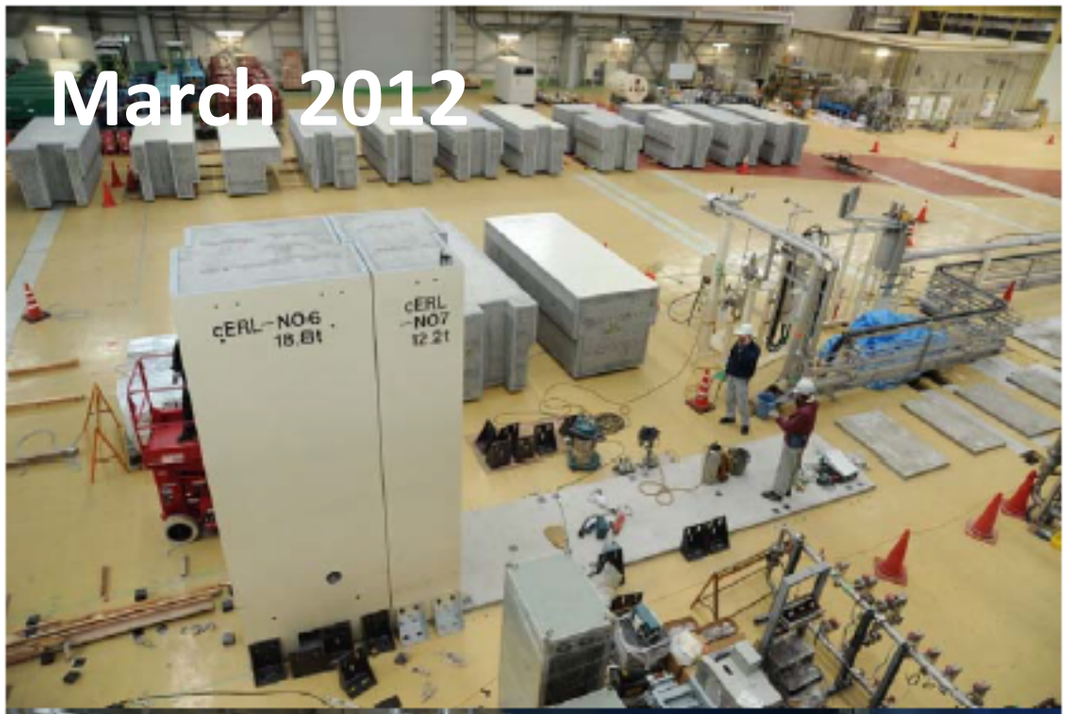


CW Cryomodule for the injector



DC photo-cathode gun

Construction of the Compact ERL at KEK



Construction of the radiation shield is on going and will be completed in the end of this September

Summary:

Please Enjoy the Conference!

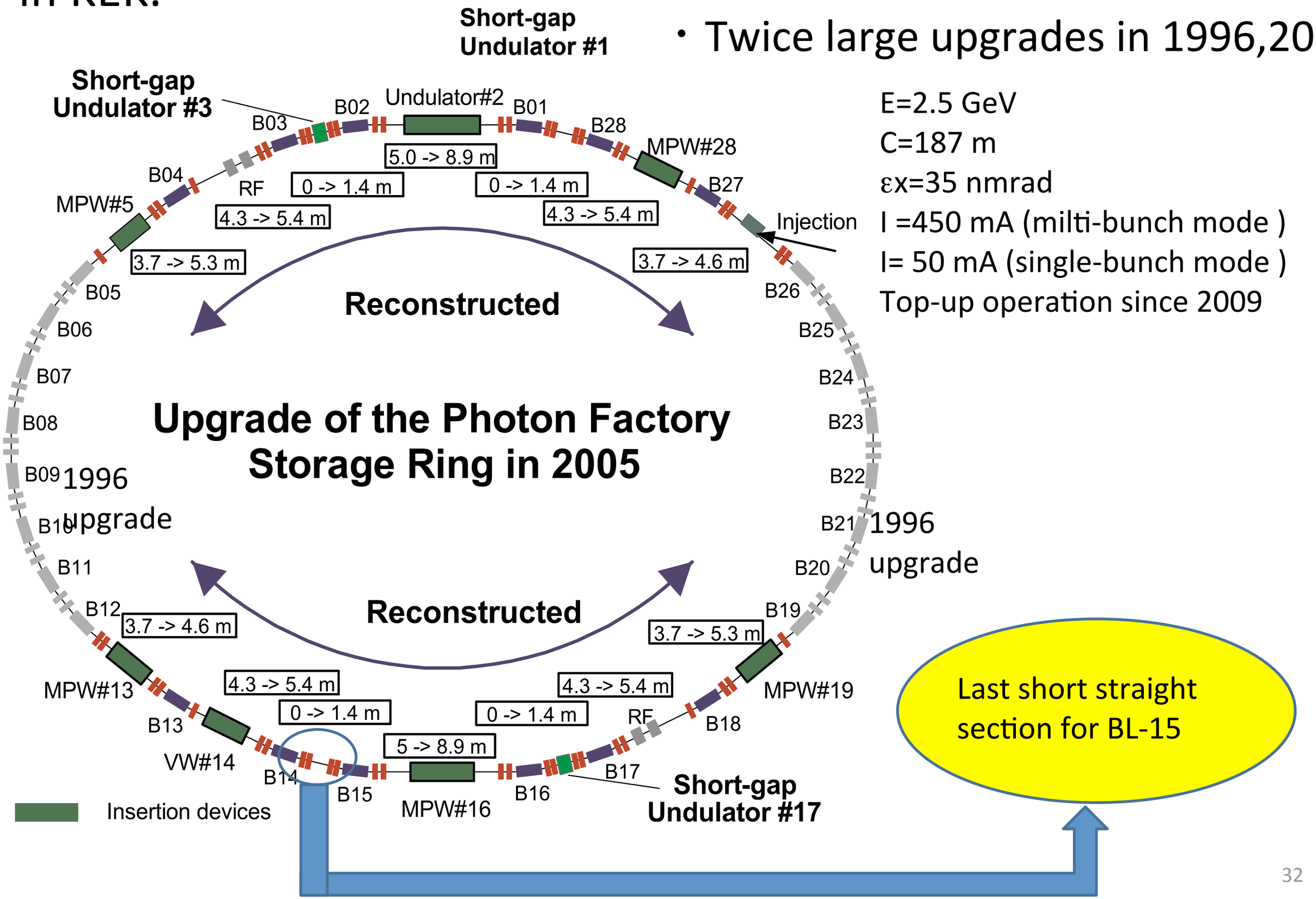
Backup

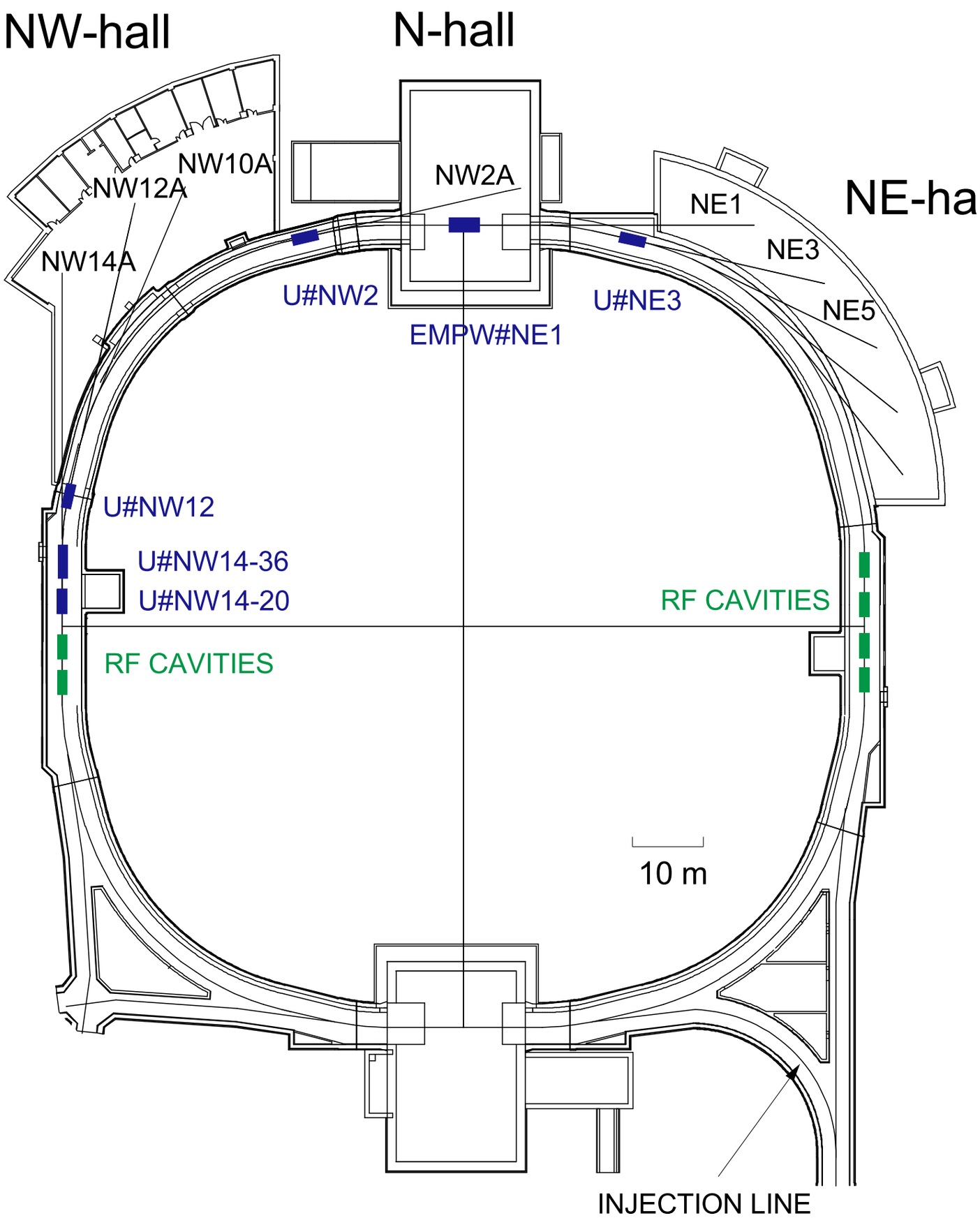
Two existing light sources in KEK.

PF ring

- Operation start in 1982
- Twice large upgrades in 1996,2005

E=2.5 GeV
C=187 m
εx=35 nmrad
I =450 mA (milti-bunch mode)
I= 50 mA (single-bunch mode)
Top-up operation since 2009





PF-AR

- Operation start in 1983

(booster synchrotron for TRISTAN)

- Dedicated SR in 1998
- Upgrade in 2001

E=6.5 GeV

C=377 m

εx=290 nmrad

I= 60-40 mA

- always operating with

single-bunch mode for the pulsed x-ray experiment

Operational Statistics of PF Ring and PF-AR

● PF Ring (2.5 GeV)

Fiscal Year	2005#	2006	2007	2008	2009	2010
Total operation time (h)	3720	5272	5104	5000	4976	5064
Scheduled user time (h)	2640	4248	4296	4032	4008	4080
No. of failures	33	25	23	18	24	18
Total down time (h)	27.5	44.6	91.1	23.8	42.7	29.2
MTBF (h)**	80.0	169.9	186.8	224.0	167.0	226.7
MDT (h)**	0.8	1.8	4.0	1.3	1.8	1.6

*) Any interruptions of the user operation other than regular injections are taken into account as failures.
**) MTBF = (Scheduled user time) / (No. of failures) ,
MDT = (Total down time) / (No. of failures) .
#) Re-commissioning just after the straight-section upgrade.

● PF-AR (6.5 GeV)

Fiscal Year	2005	2006	2007	2008	2009	2010
Total Operation Time (h)	5313	5016	4561	4969	5063	4608
Scheduled User Time (h)	4456	4032	3624	4344	4392	4032
No. of failures	79	51	60	40	41	74
Total Down Time (h)	69.3	55.1	45.2	41.7	91.0	73.7
MTBF (h)**	56.4	79.1	60.4	108.6	107.1	54.5
MDT (h)**	0.9	1.1	0.8	1.0	2.2	1.0

Fiscal Year	2005	2006	2007	2008	2009	2010
RF	6	7	4	5	12	13
Magnet	3	3	2	3	4	0
Injection	1	2	3	4	0	1
Vacuum	1	2	1	0	0	0
Dust trap	11	0	1	0	1	0
ID	5	3	4	3	1	1
Control/ Monitor	1	1	0	0	3	0
Cooling Water	0	1	0	1	1	0
Safety/ Beamline	2	2	2	1	2	2
Earthquake	3	0	2	1	0	0
Electricity	0	4	4	0	0	1
Total	33	25	23	18	24	18

Classification of failures for PF ring

Fiscal Year	2005	2006	2007	2008	2009	2010
RF	12	10	1	4	8	10
Magnet	4	1	1	2	2	10
Injection	4	3	8	9	1	6
Vacuum	2	6	2	0	2	1
Dust trap	37	24	39	15	16	24
Insertion Devices	0	1	0	0	0	0
Control/ Monitor	4	0	1	1	1	2
Cooling Water	5	1	0	3	4	4
Safety/ Beamline	9	4	5	5	7	17
Earthquake	2	0	1	0	0	0
Electricity	0	1	2	1	0	0
Total	79	51	60	40	41	74

Classification of failures for PF-AR

2012/09/07

HOM Absorber

9cell Cavity
with He Jacket

Input Coupler

Just now assembling the components is going

DC Photocathode Gun at KEK

Toward much higher beam current and longer lifetime

Target pressure : 1x10^{-10} Pa

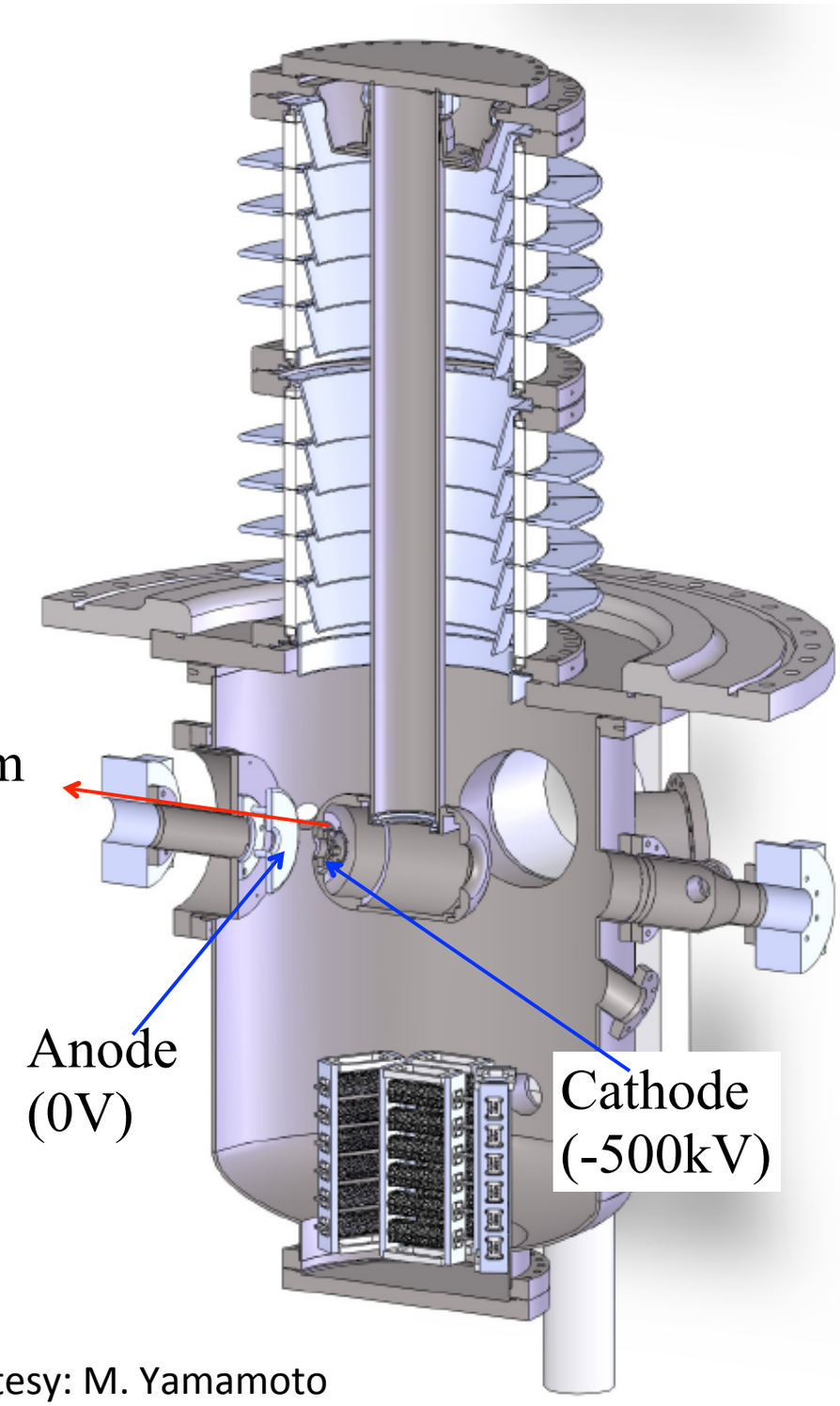
(to preserve the NEA state on the cathode)

- Low outgassing system
  - Titanium chamber, electrode, guard rings
  - Total outgassing rate: ~1x10^{-10} Pa·m^3/s
    (actual measurement)

- Main vacuum pump system
  - 4K Bakeable cryopump
    > 1000 L/s, for CH_4, N_2, CO, CO_2 @1x10^{-9} Pa
    (actual measurement)
  - NEG pump
    > 1x10^4 L/s, for H_2 (design value)

- High voltage insulator
  - Segmented structure
  - Special Al_2O_3 material (TA010, Kyocera)

- 600-kV HV Power Supply system



Courtesy: M. Yamamoto