Status of J-PARC

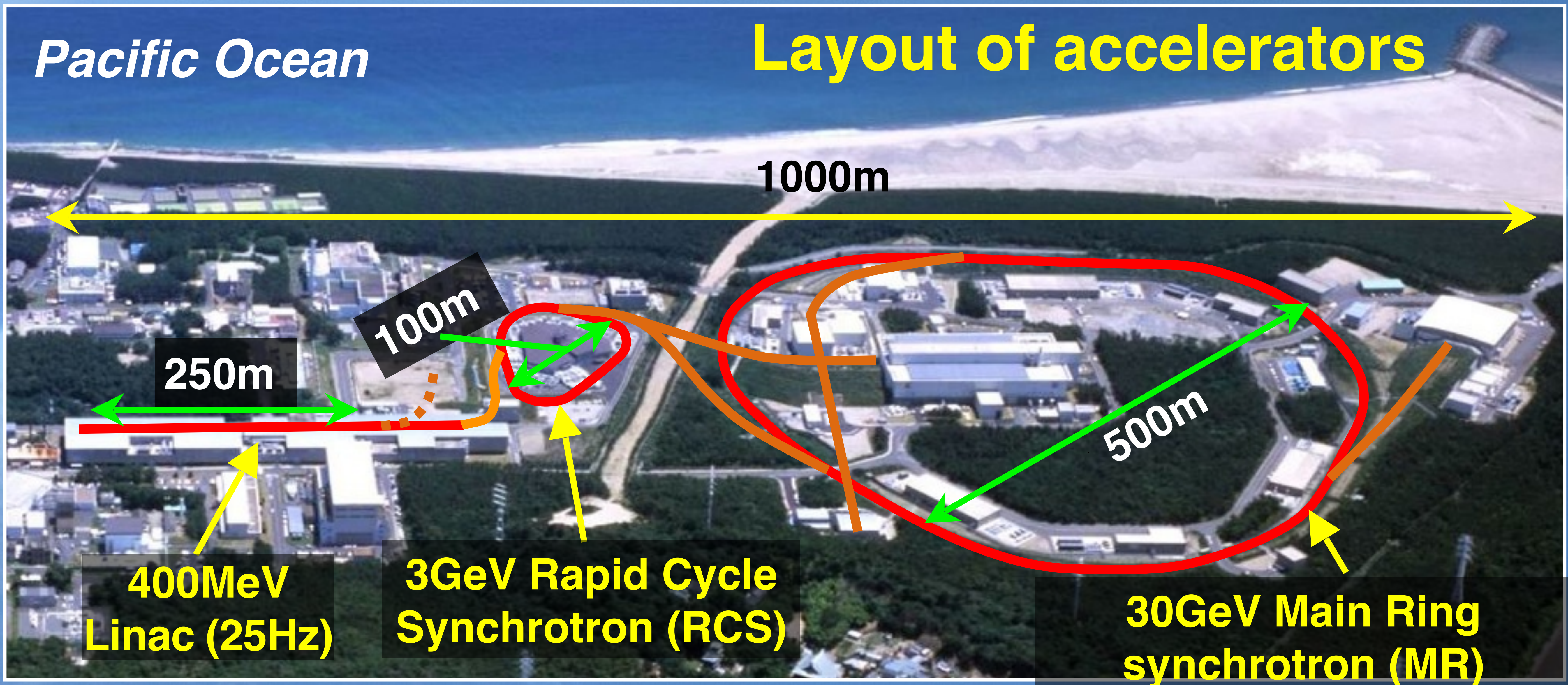
Outline:
- Introduction
- Accelerators
- Future plan
- Examples of experiment
- Summary

High energy accelerator research organization(KEK) / J-PARC center

Fujio Naito

J-PARC

Introduction to Japan Proton Accelerator Research Complex

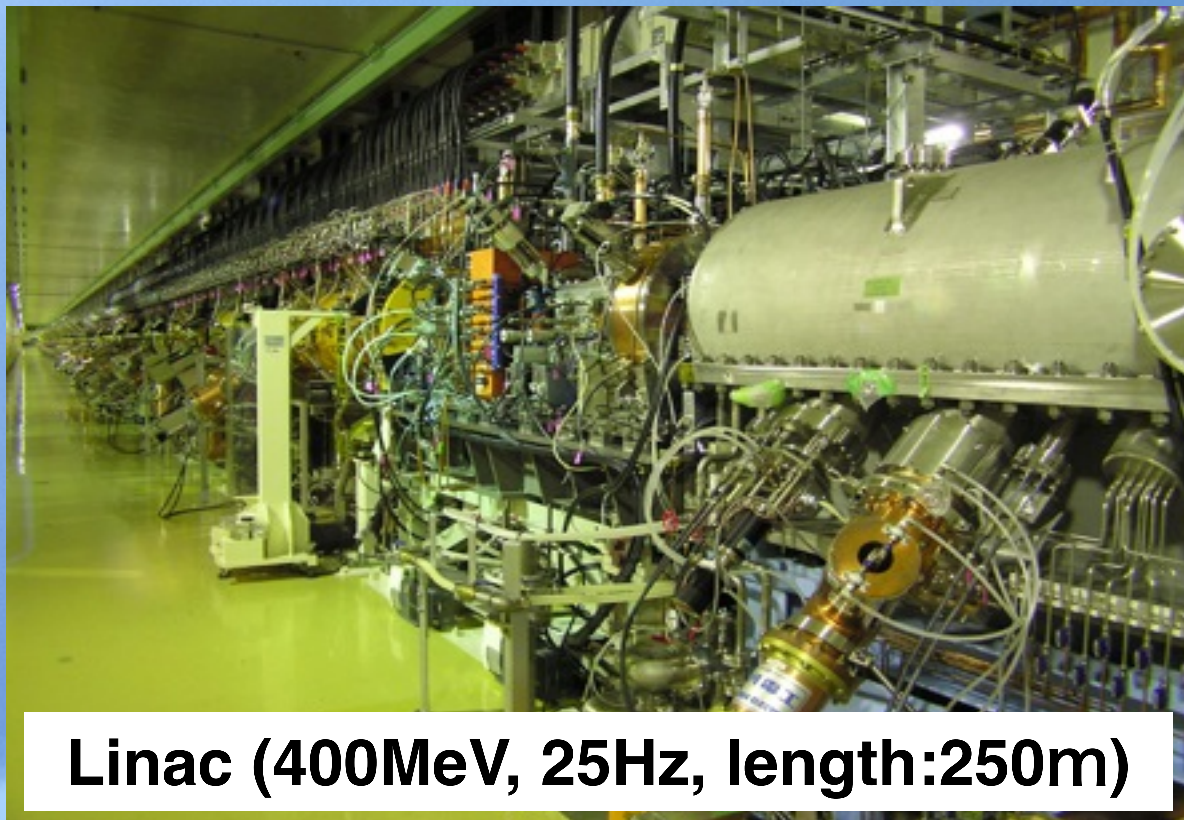


Constructed jointly by KEK and Japan Atomic Energy Agency (JAEA)

Construction period: 2001 -> 2007

Beam commissioning period: 2007 -> 2009

View of accelerators



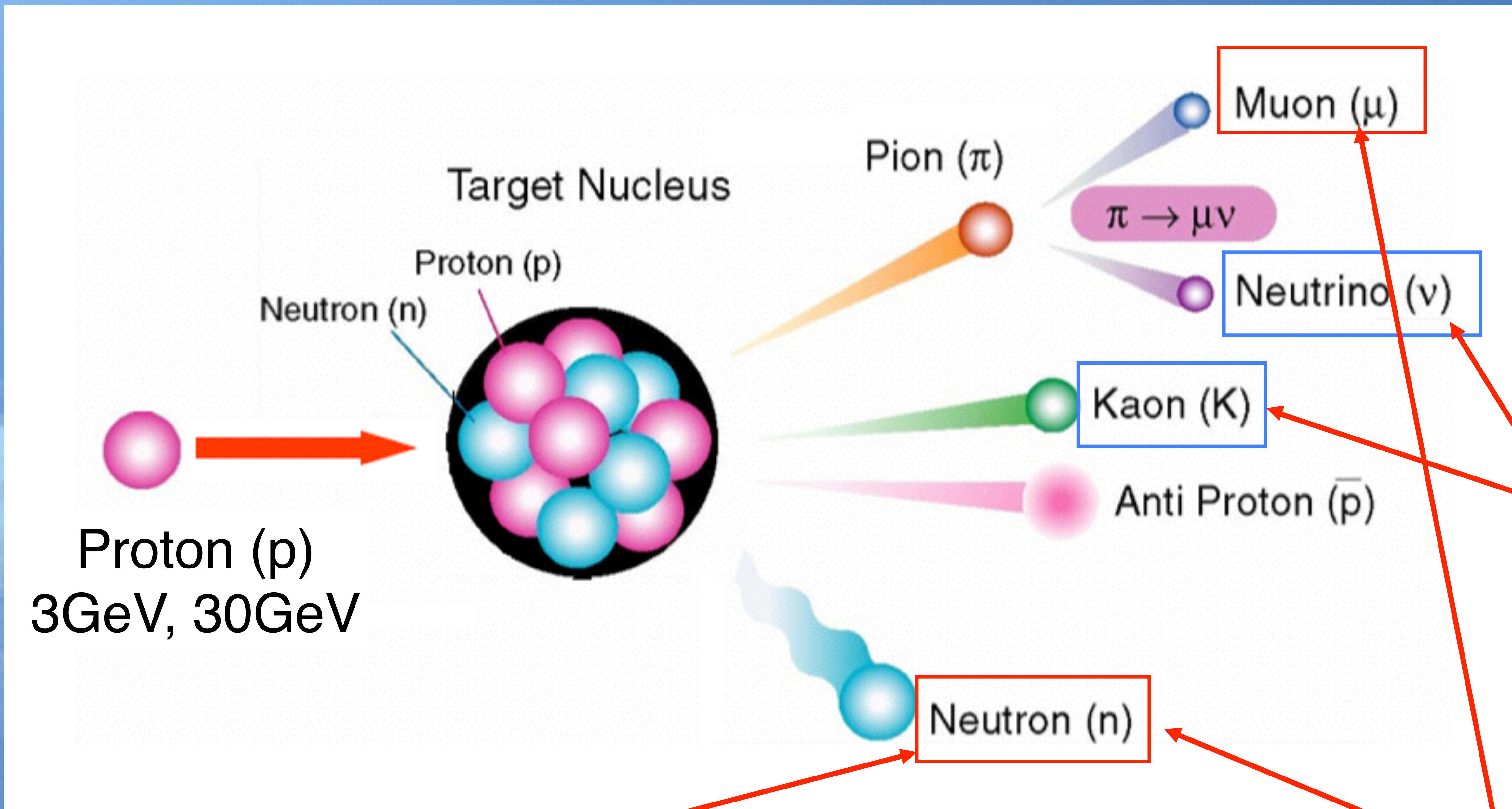
Linac (400MeV, 25Hz, length:250m)

RCS (3GeV, 25Hz, ø100m)

MR(30GeV, Period:2.48~6sec, ø500m)

ν-beam line (Super Conducting Mag.)

Goals at J-PARC



Need to have high-power proton beams

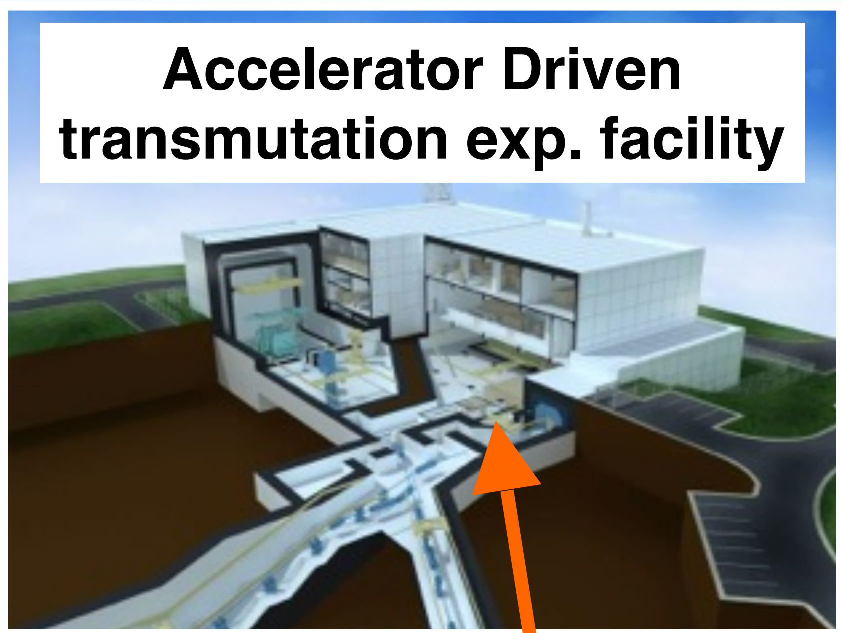
→ MW-class proton accelerator

Materials & Life Sciences at 3 GeV (1MW)

Nuclear & Particle Physics at 30 GeV (750kW)

R&D toward Transmutation at 0.4 GeV

Facilities


Accelerator Driven
transmutation exp. facility

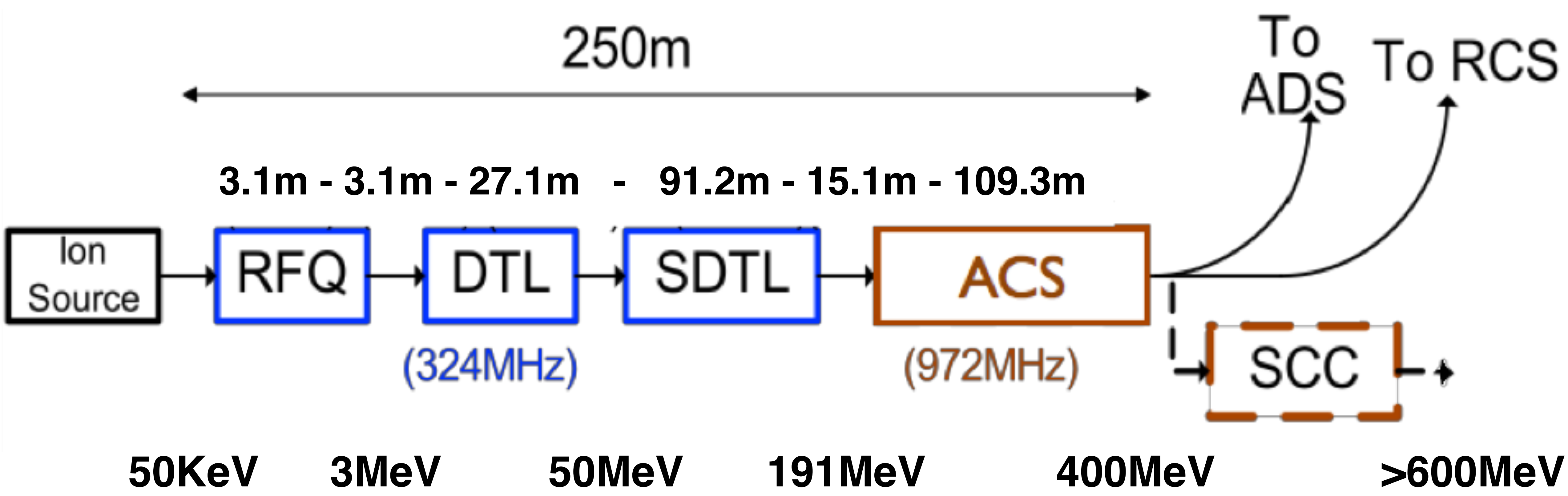

Material & Life science
exp. Facility (MLF)


Neutrino beam line

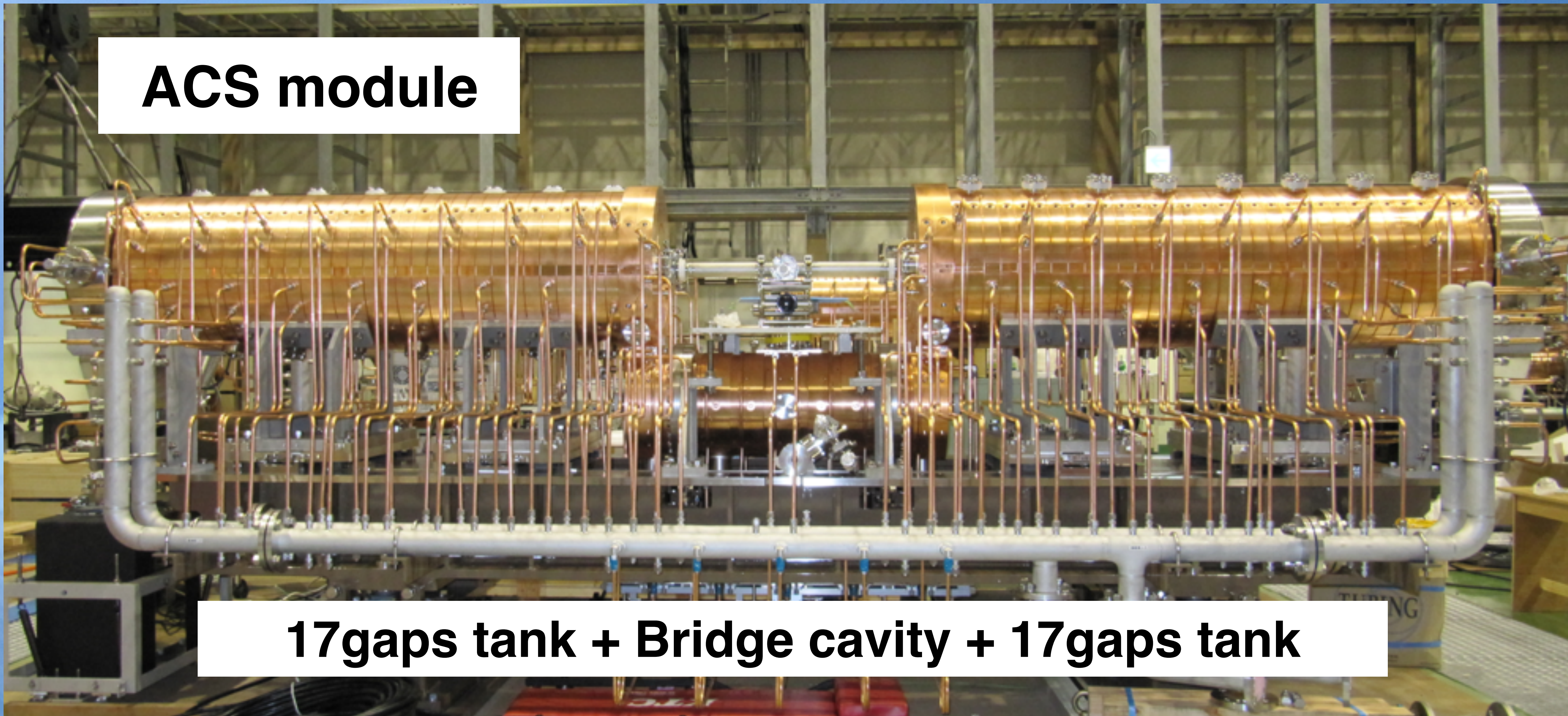

Hadron exp. Hall

Accelerstors: Linac (400MeV)

- **Major Parameters**
  - Accelerated particles: H^- (negative hydrogen ion)
  - Energy: 400MeV (Jan., 2014), > 600 MeV with SCL (in the future)
  - Peak current: 15~20mA → 30 mA (Oct. 2014)
  - → 50 mA for 1MW at 3GeV(2015)
  - Repetition: 25 Hz (additional 25 Hz for ADS application)
  - Pulse width: 0.5 ms(beam pulse), 0.65 ms (RF pulse)

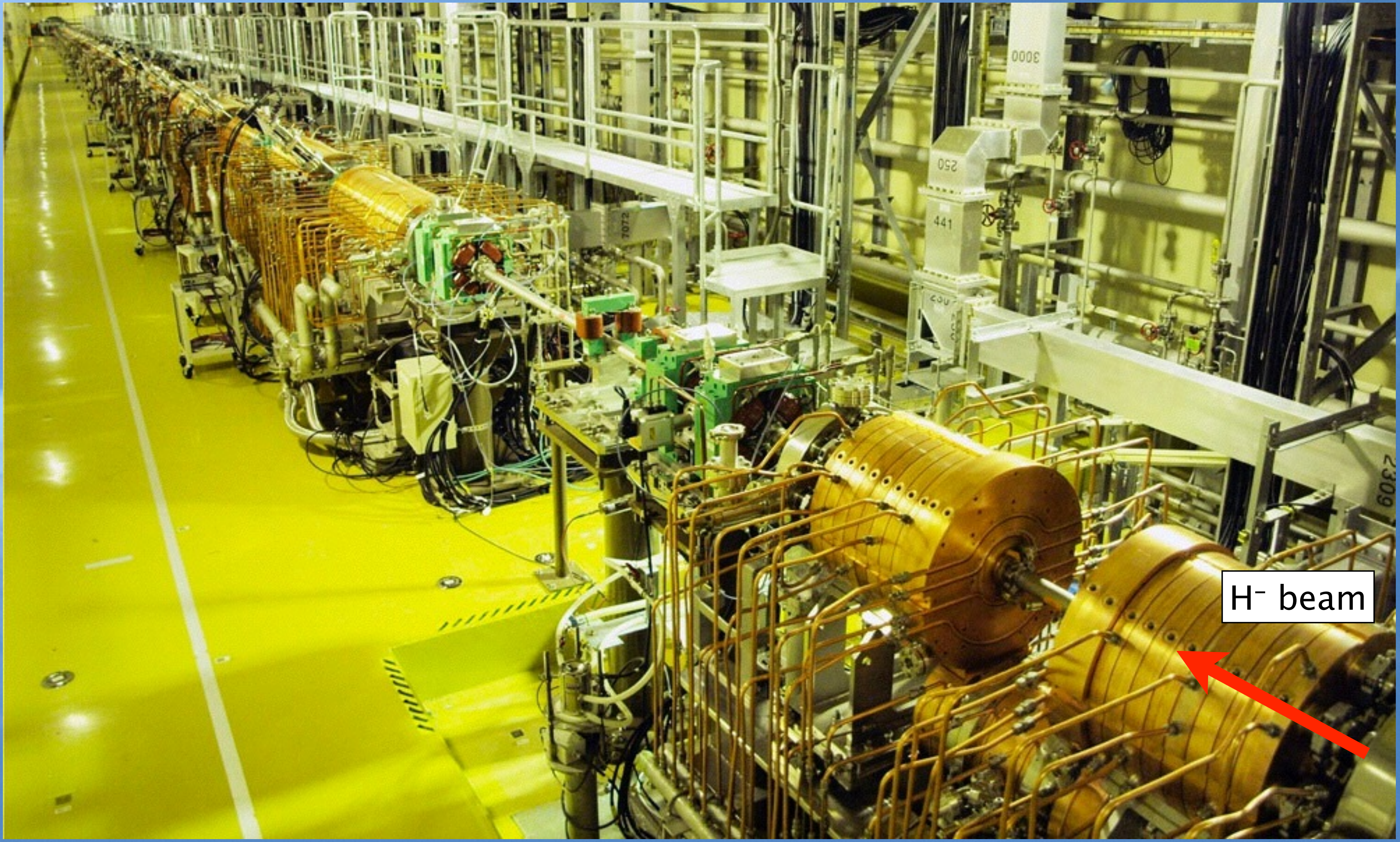


Annular-ring Coupling Structure linac



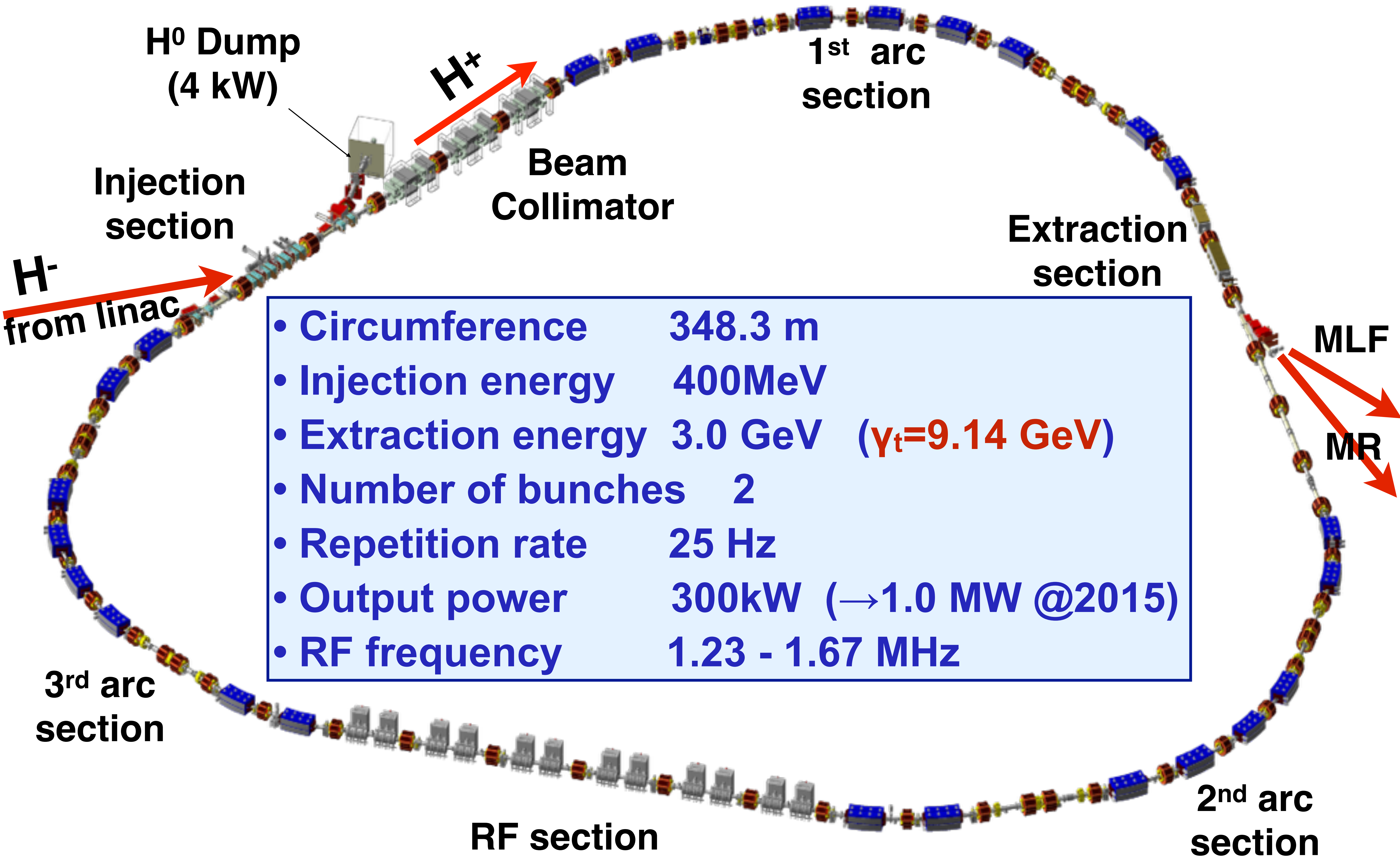
ACS cavity has been developed in collaboration with INR.

Installed ACS linac



(16. Nov. 2013)

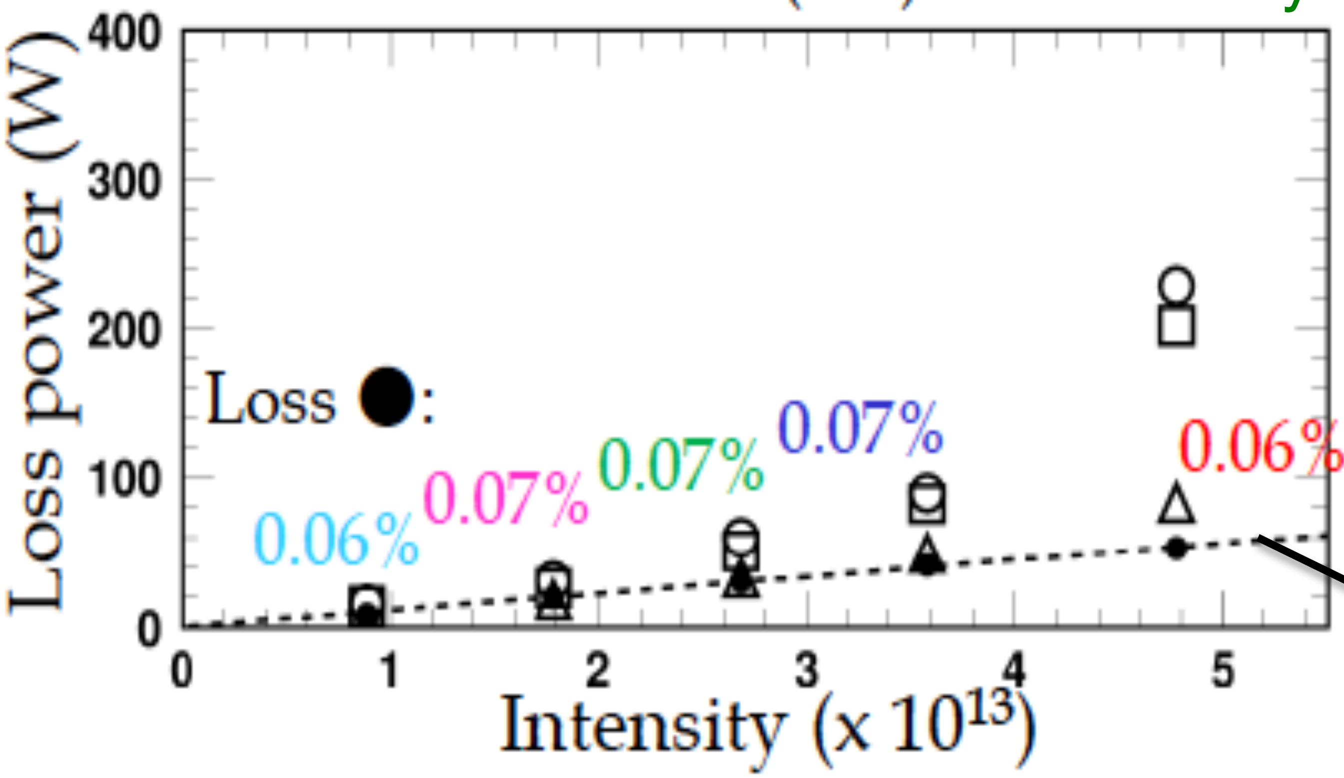
RCS (3GeV)



- Circumference 348.3 m
- Injection energy 400MeV
- Extraction energy 3.0 GeV (γ_t=9.14 GeV)
- Number of bunches 2
- Repetition rate 25 Hz
- Output power 300kW (→1.0 MW @2015)
- RF frequency 1.23 - 1.67 MHz

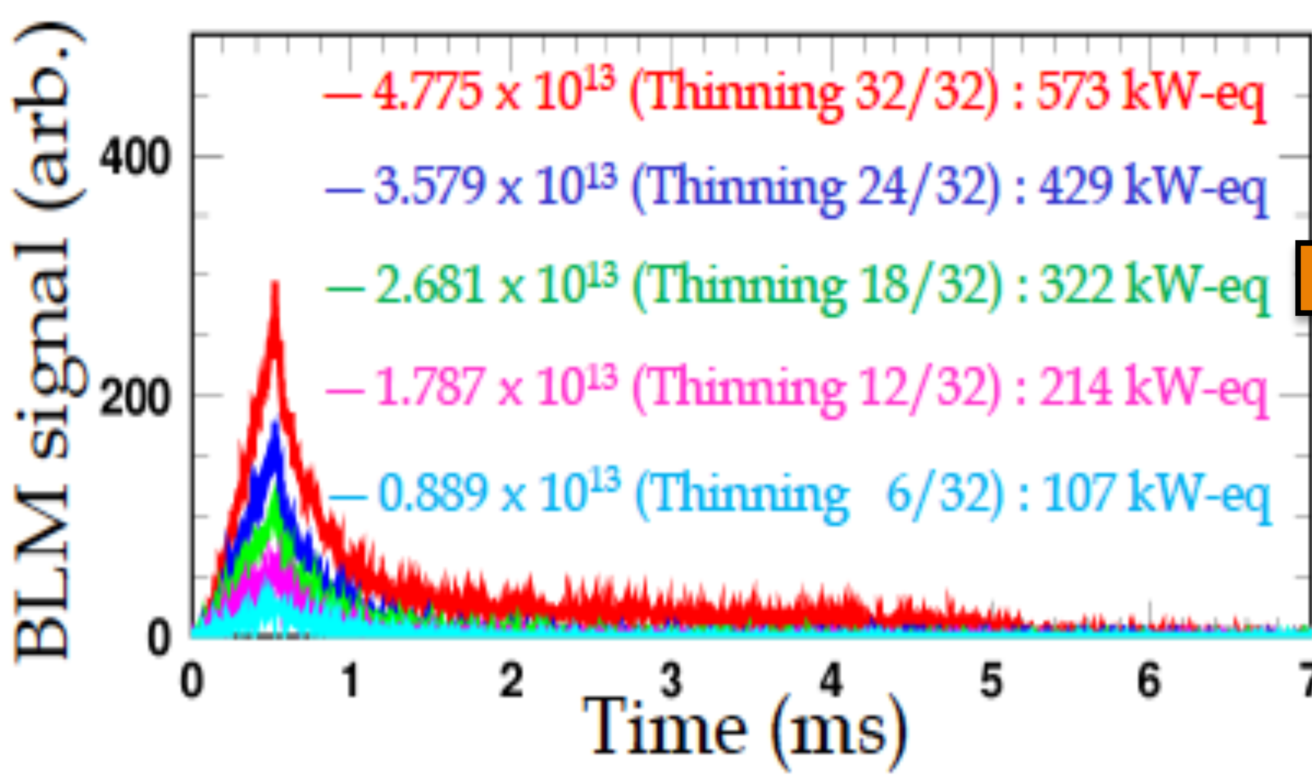
Minimization of beam loss

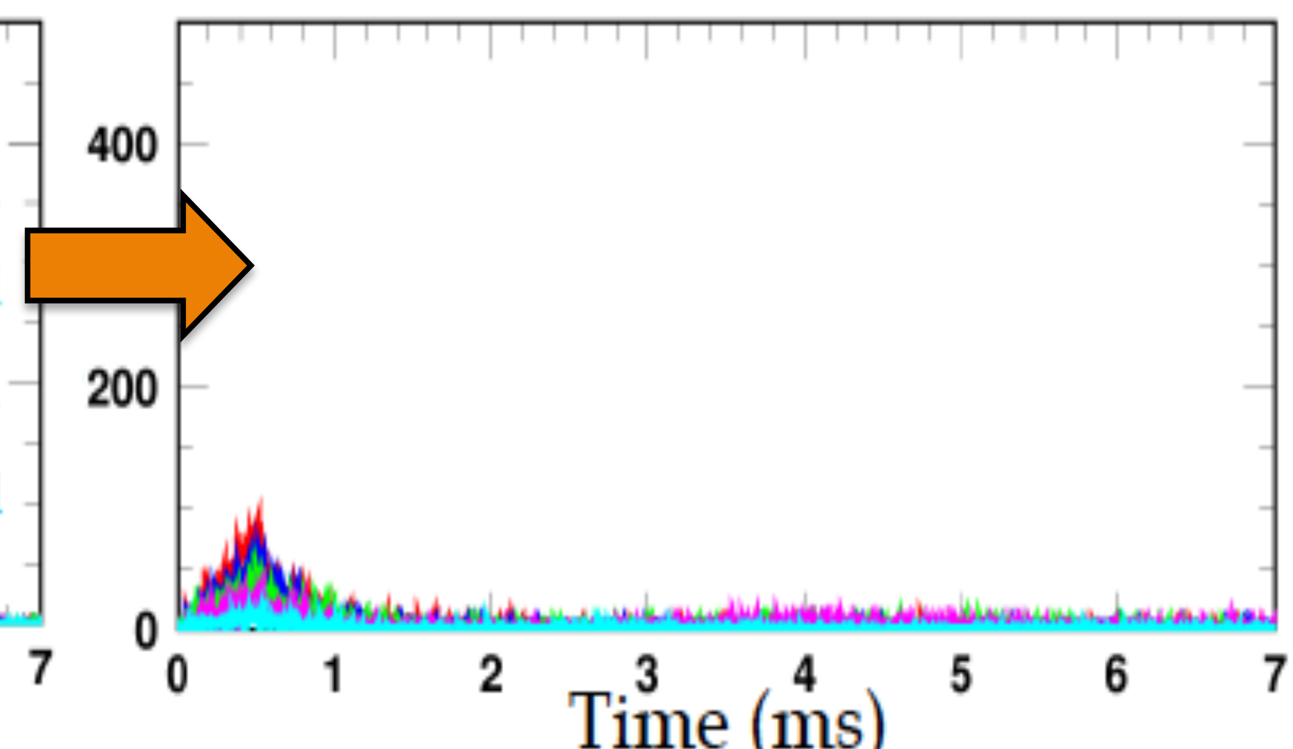
Results of beam study in the end of June, 2014.



- Momemtum spread of the injection beam
  dp/p : 0.106 % → 0.066 % : ○→□
- Mismatch correction of the Twiss parameters of the injection beam :□→△
- Operating point
  (νx, νy)=(6.45,6.42) →(6.38, 6.42):△→●

Beam loss due to the foil scattering





Beam loss of the RCS is well understood and minimized.

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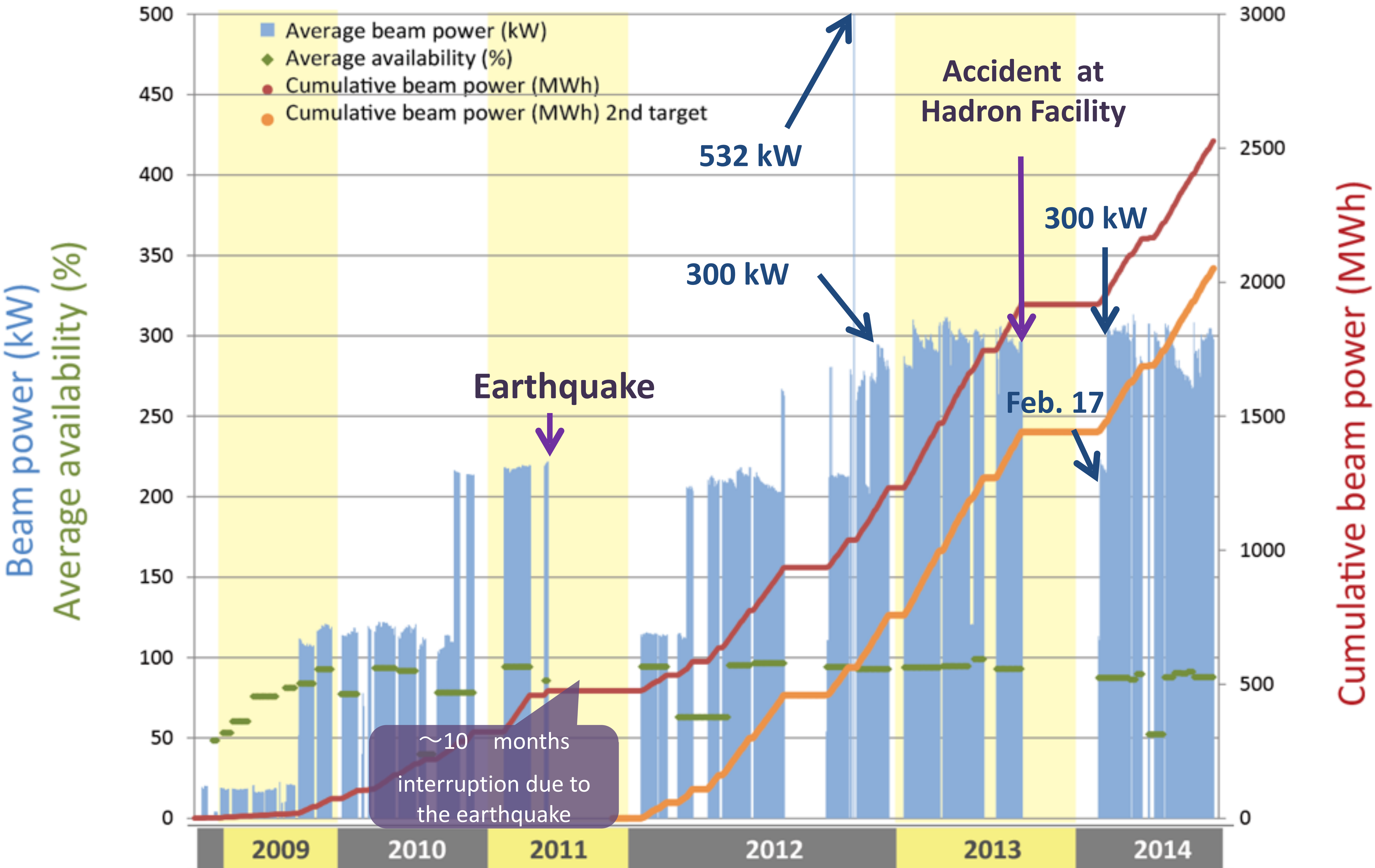
History of Beam Power on MLF target

as of June 26th 2014



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MR (30GeV)

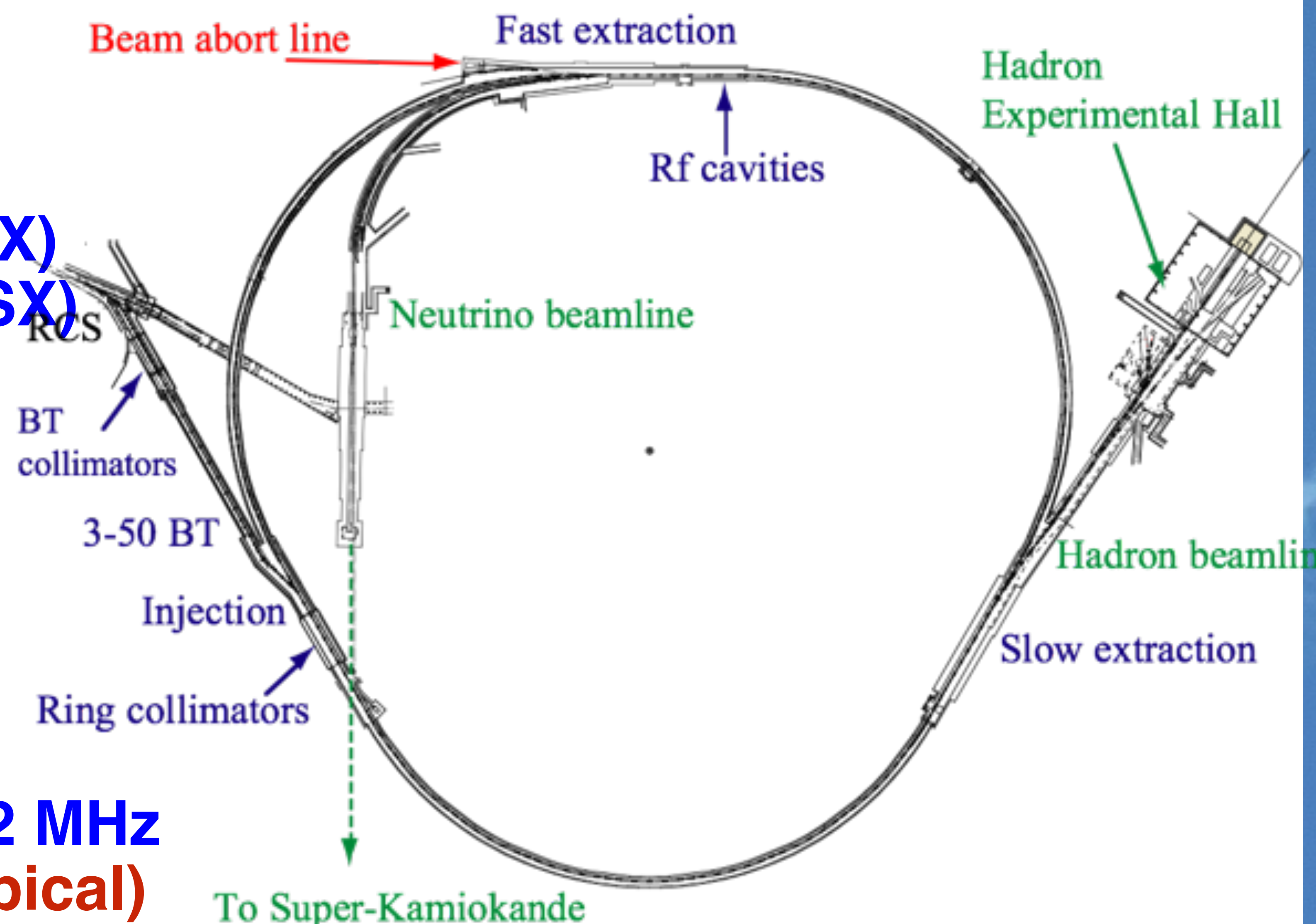
Parameters:

Circumference 1567.5 m
Repetition period
2.48 s for Fast extraction (FX)
6.00 s for Slow extraction (SX)

Injection energy 3 GeV
Extraction energy 30 GeV

h 9
Number of bunches 8

Rf frequency 1.67 - 1.72 MHz
Transition γ j 31.7 (typical)



Three dispersion free straight sections of 116-m long:
- Injection and collimator systems
- Slow extraction (SX) to Hadron experimental Hall
- MA loaded rf cavities and Fast extraction(FX) (beam is extracted inside/outside of the ring)

outside: Beam abort line
inside: Neutrino beamline (intense ν beam is send to SK)

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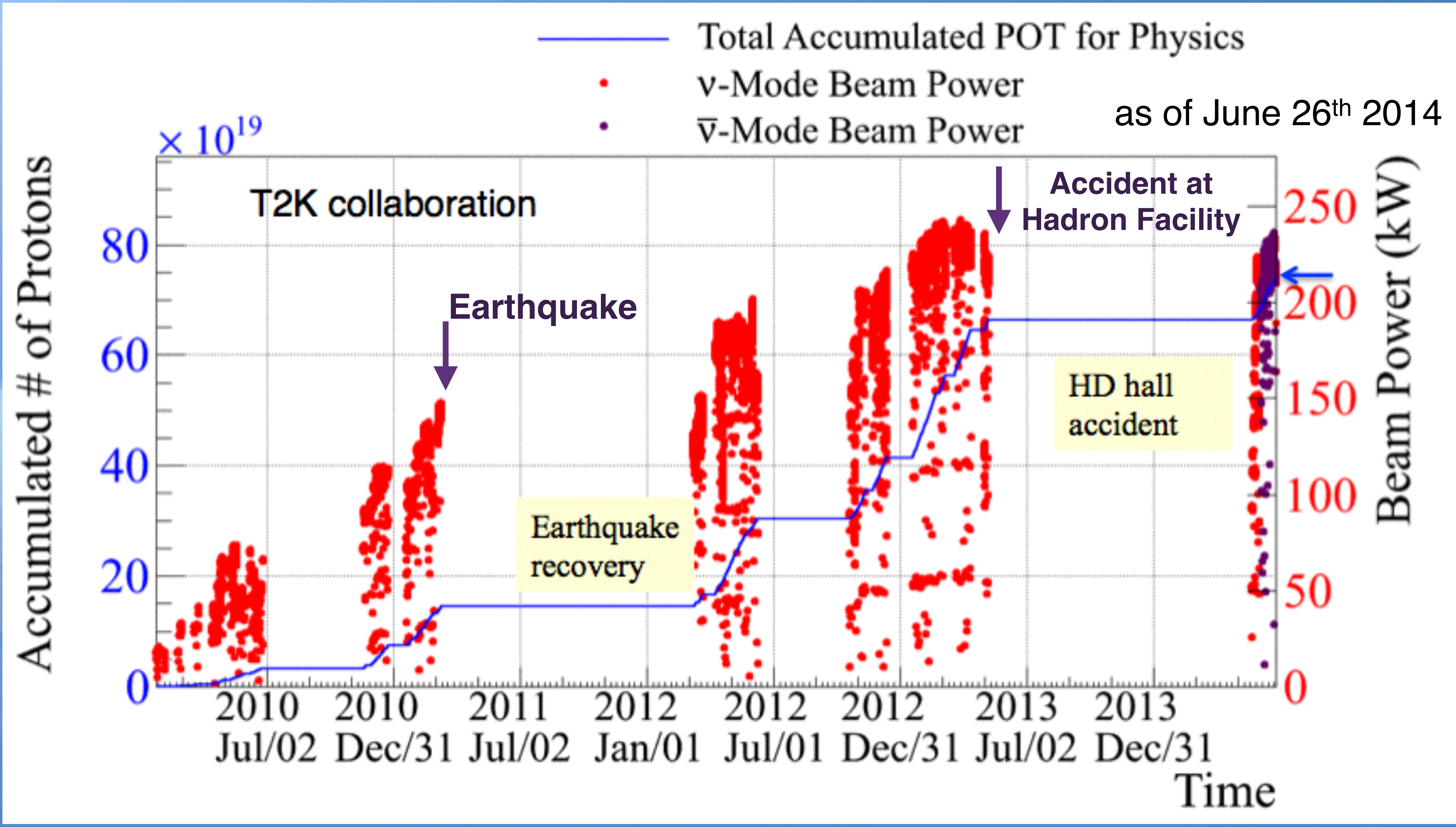
History of Beam Power on T2K target

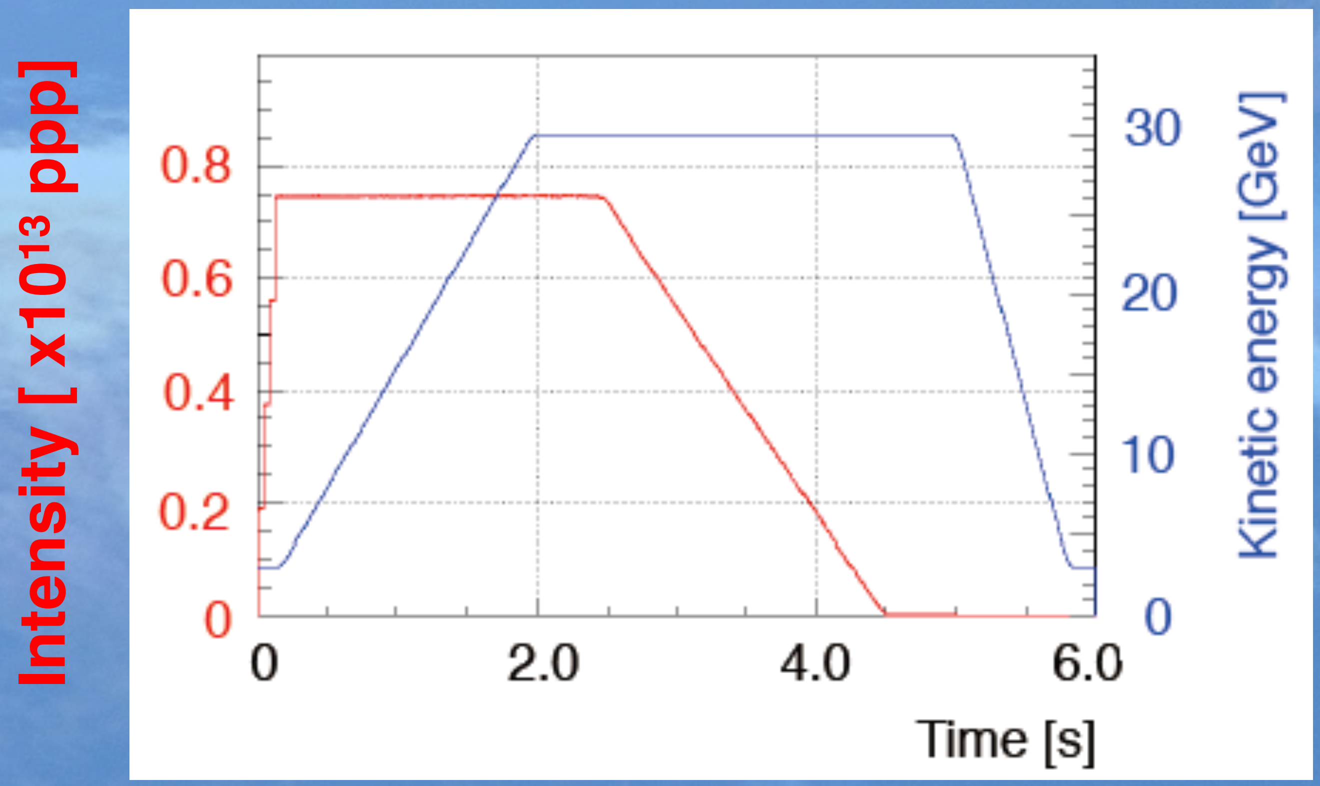


The max. delivered beam power ~240kW (1.24×10^{14} ppp)

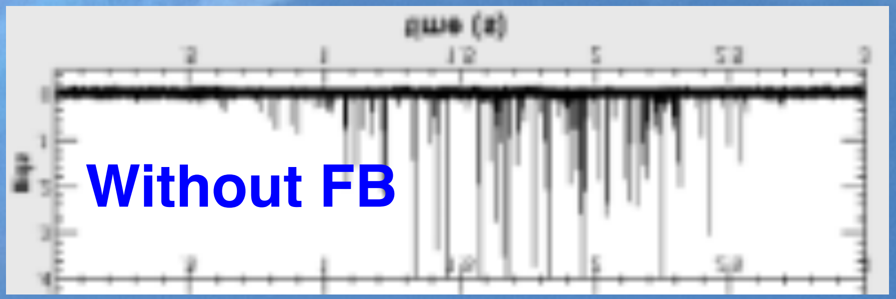
Accumulated number of proton ~7.5×10^{20} POT

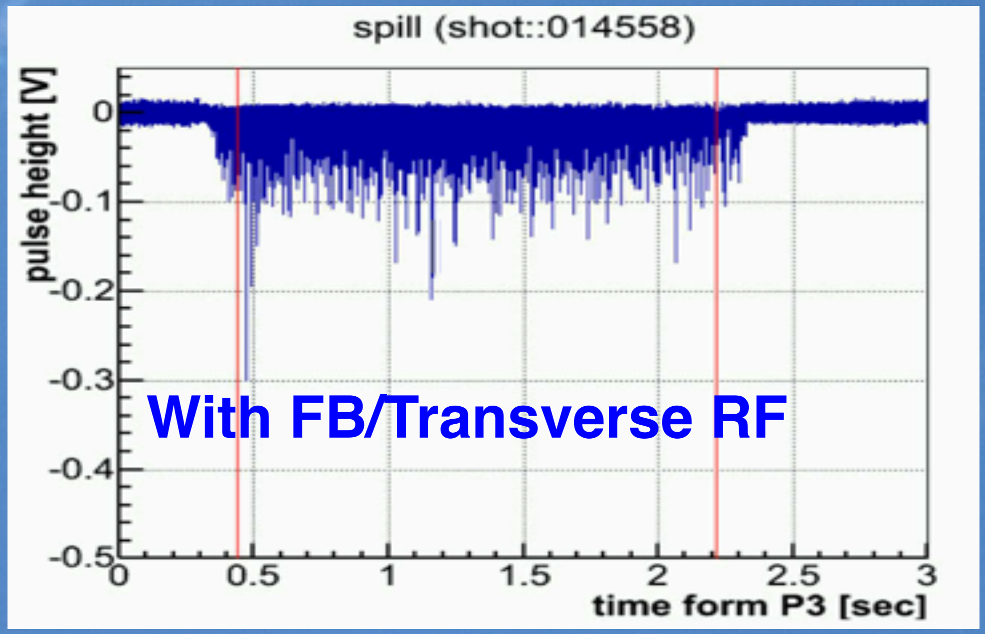
Slow Extraction

- Third-integer resonance extraction (ν_x=67/3)
- Extraction efficiency ~99.5% with DB scheme
- Maximum beam power 20kW for users and 30kW for study
- Problem on time structure of the beam:
  Duty factor of spill 3% -> ~ 43% with spill feedback and transverse rf.



$$Duty = \frac{\left(\int_0^T I\,dt\right)^2}{\int_0^T dt \int_0^T I^2\,dt}$$

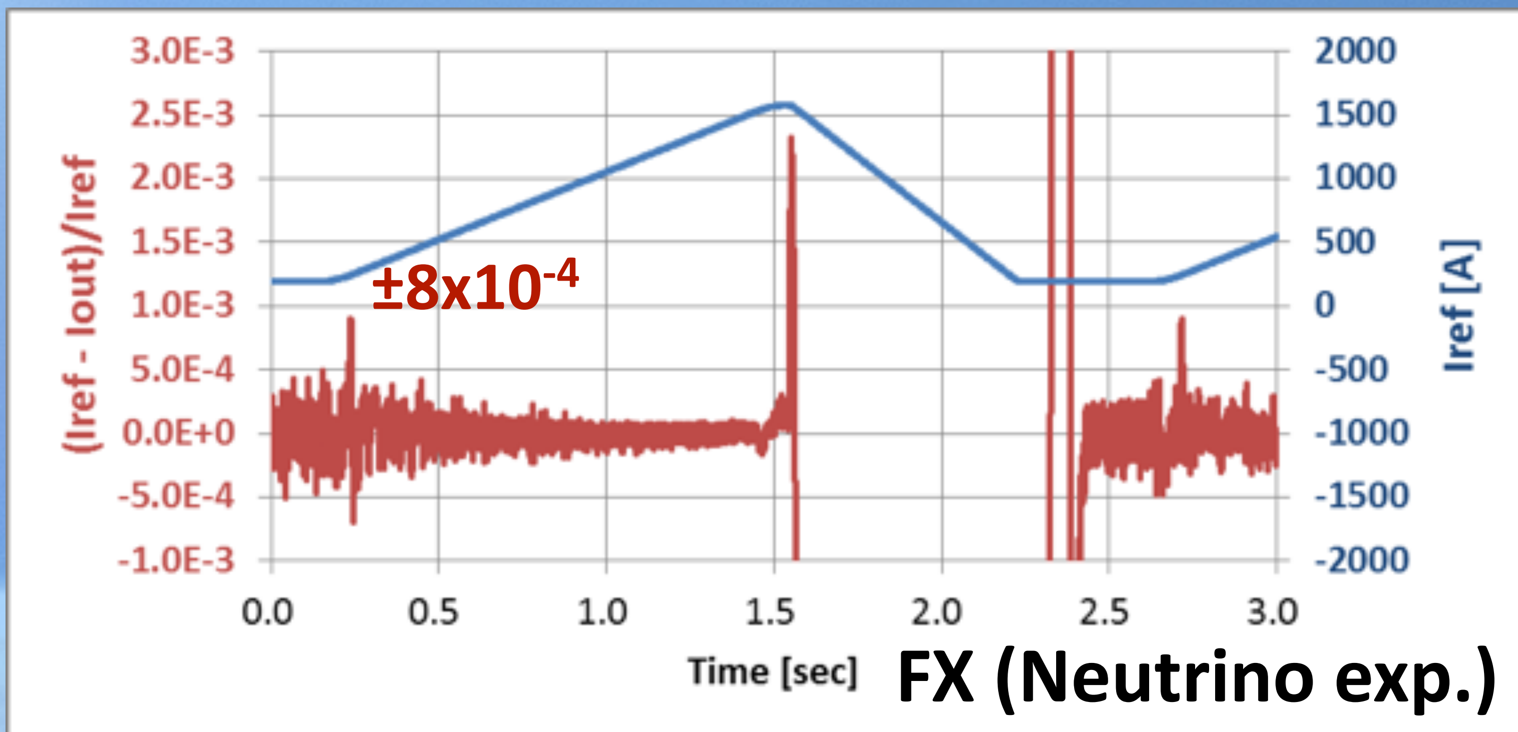




Duty factor ~43 % at 15 kW

Issue of MR

Current pattern & deviation of MR main magnets

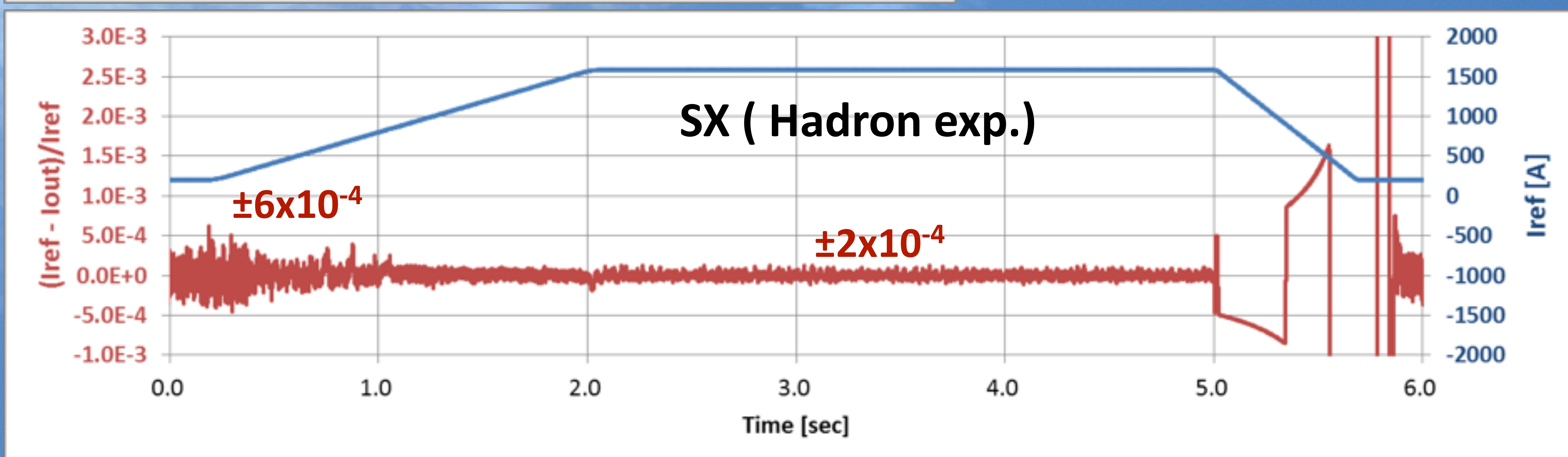


Blue : Ref. current pattern

Red : Current deviation

$=(I_{ref} - I_{out})/I_{ref}$

- Ripple: ~10^{-4} → ≦ 2×10^{-6}
- Tracking error : 5~8×10^{-4}→≦ 1×10^{-5}



Medium-term plan in JFY2013-2017

Linac : 400MeV upgrade in 2013&2014 (done)
RCS : 1MW by 2015
MR-FX : 750kW by 2017 with ~1sec repetition rate
MR-SX : 100kW by 2017

The mid-term plan of MR for the 5 years from JFY2013 to JFY2017 were endorsed by the review committee meeting held in March - May of 2012 in MEXT.

MEXT (Ministry of Education, Culture, Sports, Science and Technology in Japan)

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Mid-term plan of MR

FX: The high rep. rate scheme is adopted to achieve the design beam intensity, 750 kW.
Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.
SX: After replacement of stainless steel ducts to titanium ducts to reduce residual radiation dose, 50 kW operation for users will be started. Beam power will be gradually increased toward 100 kW carefully watching the residual activity. Local shields will also be installed if necessary.

JFY	2011	2012	2013	2014	2015	2016	2017
			Li. energy upgrade	Li. current upgrade			
FX power [kW] (study/trial) SX power [kW] (study/trial)	150 3 (10)	200 10 (20)	200 - 240 25 (30)	200 –300 20-50	(400)		750 100
Cycle time of main magnet PS New magnet PS for high rep.	3.04 s	2.56 s R&D	2.48 s		Manufacture installation/test		1.3 s
Present RF system New high gradient rf system	Install. #7,8	Install. #9 R&D		Manufacture installation/test			
Ring collimators	Additional shields	Add.collimators and shields (2kW)	Add.collimators (3.5kW)				
Injection system FX system	Inj. kicker	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, LF & HF septa manufacture /test					
SX collimator / Local shields	SX collimator				Local shields		
Ti ducts and SX devices with Ti chamber		SX septum endplate	Beam ducts	Beam ducts ESS			

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High impedance rf system

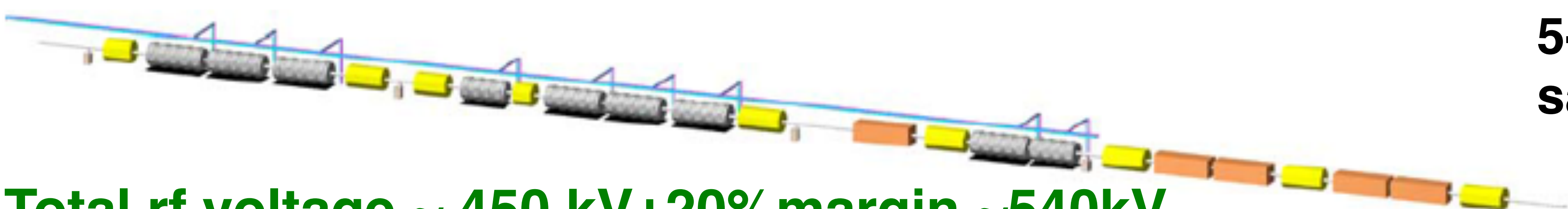
The rf cavities will be replaced with the higher impedance system using FT3L.
Budget for the new rf cavities has been mostly secured by supplementary budgets in JFY2011 and 2012. All the cavities will be ready to install in JFY2015.

(FT3L: magnetic alloy Fine-Met)

Total rf voltage ~ 270 kV

Current situation : 3gap X 9 = 27 gaps

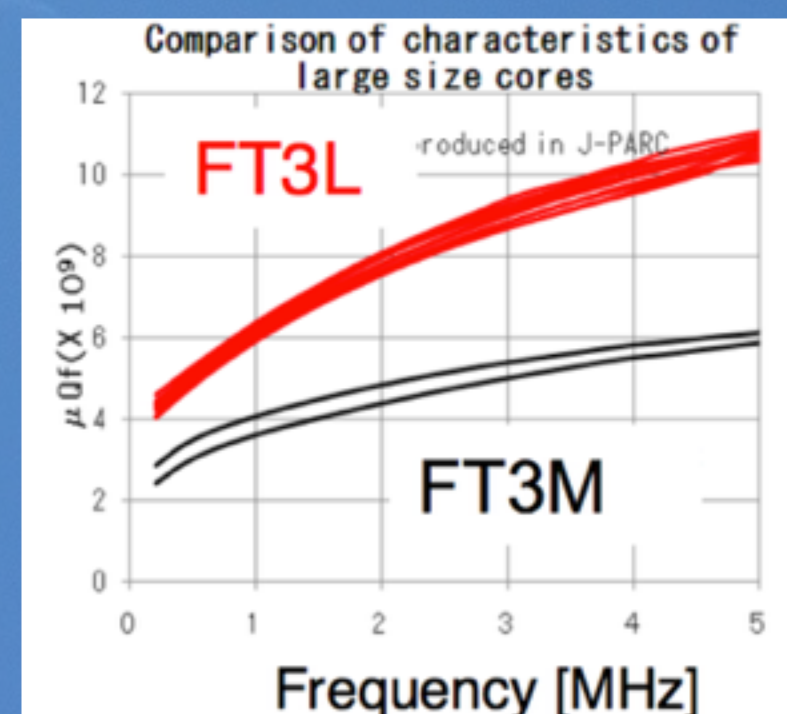
FT3L gap impedance is 40% higher than present one.
5-cell cavity can be driven by same PS and AMP !



Total rf voltage ~ 450 kV+20%margin ~540kV

After replacement : 4gap X 2 + 5gap X 7 = 43 gaps **& 2nd Harmonic Cavity**

5-gaps FT3L cavity:16KVp/gap

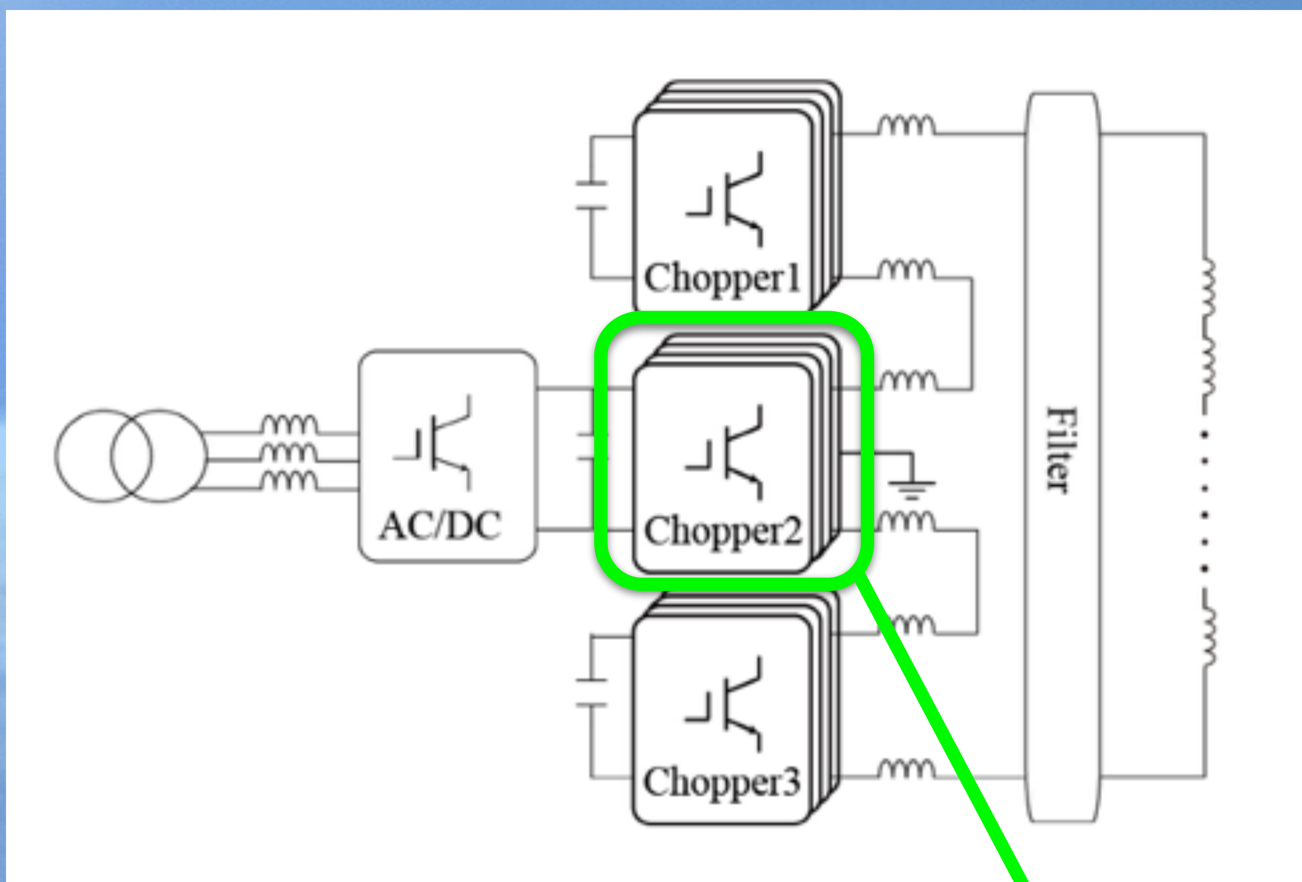


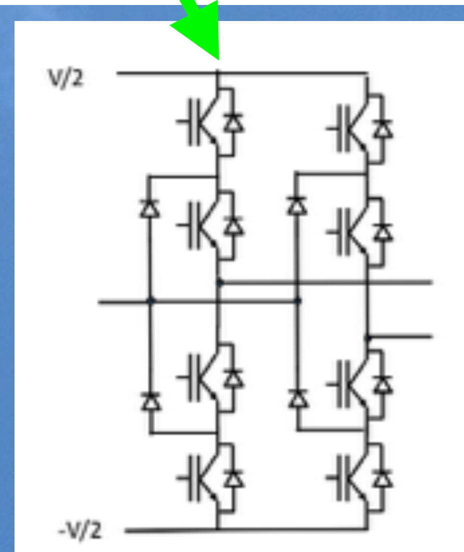
New magnet power supply for MR

- **Repetition : 2.48 → 2.40 → ~1.3 sec**
- **Ripple : ~10^{-4} → ≦ 2×10^{-6}**
- **Tracking error : ~5×10^{-4} → ≦ 1×10^{-5}**

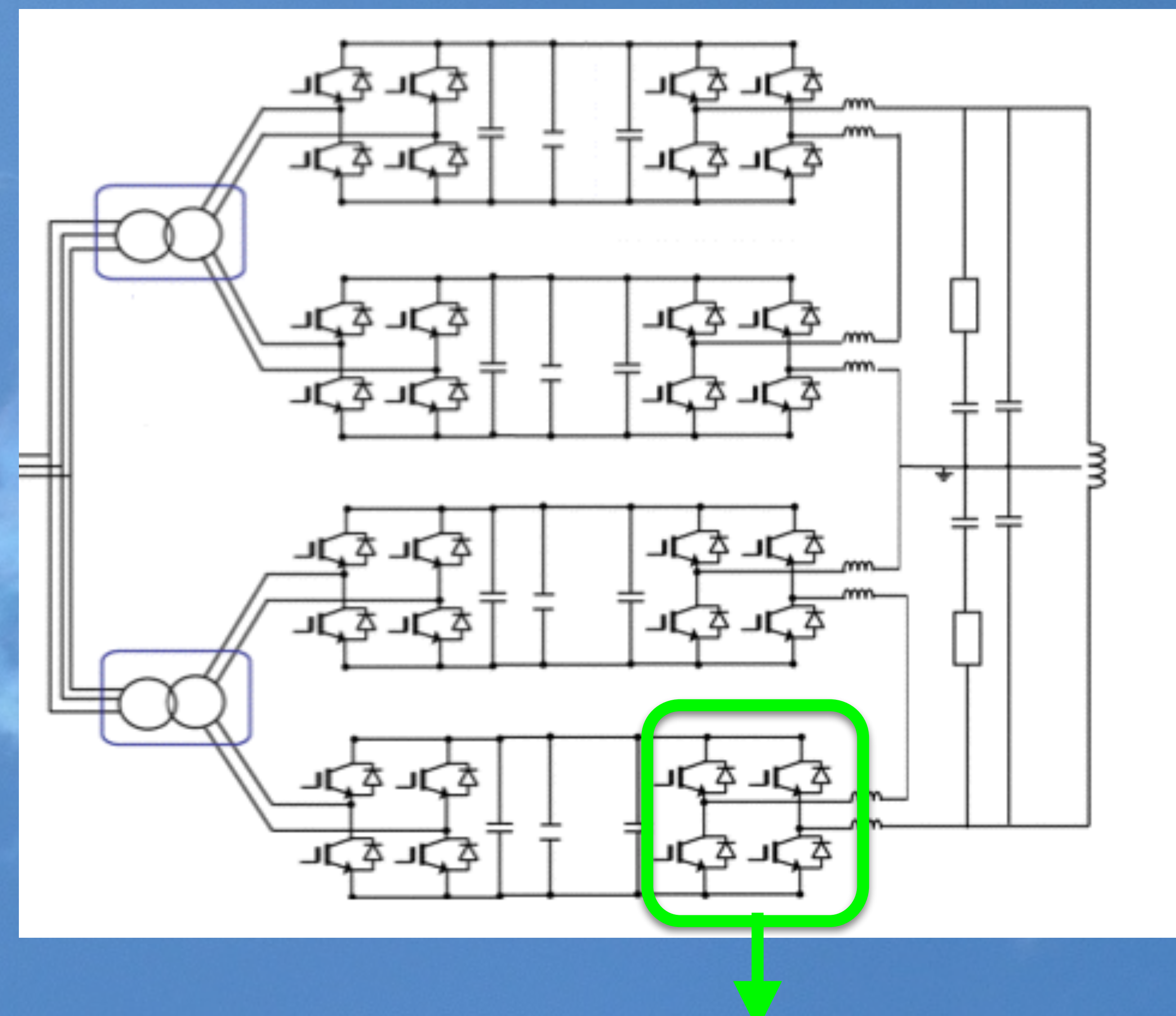
FX : 240 kW ⇒ 750 kW

SX : 24 kW ⇒ 100 kW





Neutral-Point-Clamped (NPC) chopper
2kV 400A 4kHz

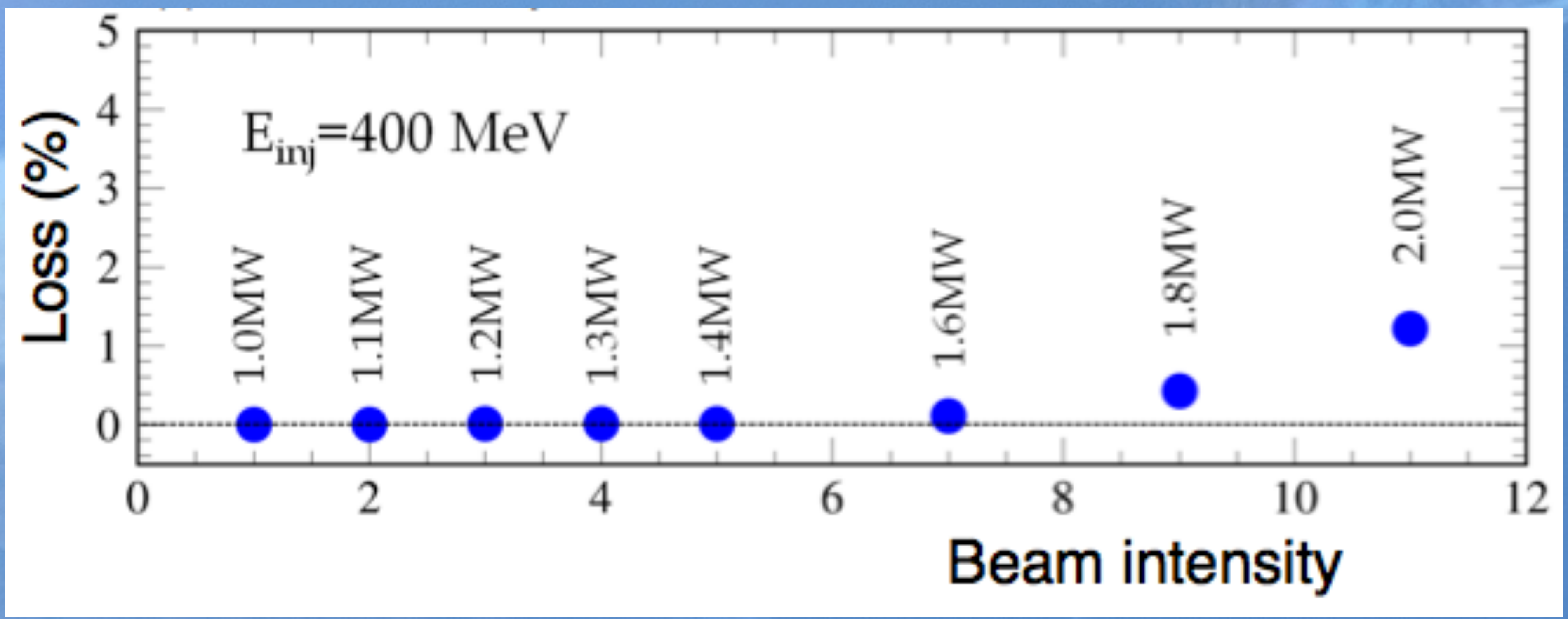


H-bridge chopper
2.5kV 450A 1kHz

Long-term plan

Feasibility of the RCS

Injection beam parameters:
Energy : 400MeV
Peak current : 50 ~ 100mA
Pulse length : 0.5ms
Chopped beam on duty : 0.53



RCS intensity	Loss	Loss power at 25 Hz
1.0 MW	~0.3%	400 W
1.1 MW	~0.3%	440W
1.2 MW	~0.3%	480 W
1.3 MW	~0.3%	520 W
1.4 MW	~0.3%	560 W
1.6 MW	~0.5%	1067 W
1.8 MW	~0.7%	1680 W
2.0 MW	~1.5%	4000 W

RCS collimator limit ~ 4kW -> RCS has a feasibility to operate 2MW beam.
Linac is required to operate the beam of 100mA/0.5ms (or 50mA/1.0ms).
-> 100mA ion source.
-> RF system to compensate the heavy beam loading.
-> The collimator which has a enough margin for the beam loss.
-> Reduction of the activation by the charge exchange foil.

Long-term plan

Future proton driver for long-baseline neutrino experiment

The maximum beam intensity is limited by the physical aperture of the MR.

The scenarios for achieving much larger beam power than the design specification for neutrino experiment are now discussed.

1. Booster ring for the MR (emittance damping ring)

   The BR with an extraction energy ~ 8 GeV, is constructed between the RCS and the MR

2. New proton linac for neutrino beam production

   (Construction site may not be the Tokai campus)

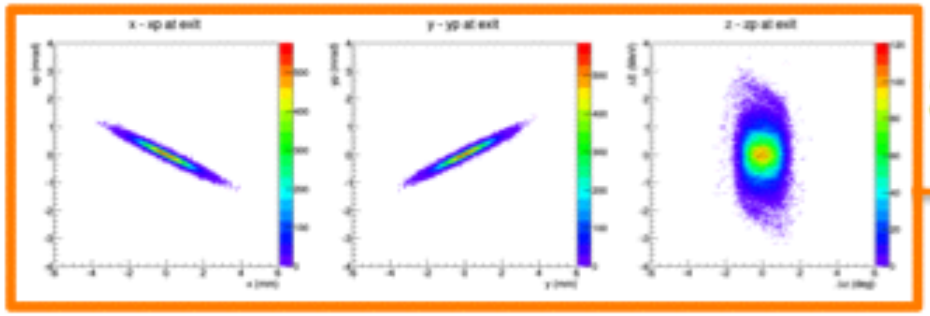
   - Linac with an beam energy > 9 GeV
   - The MR is operated only for the SX users

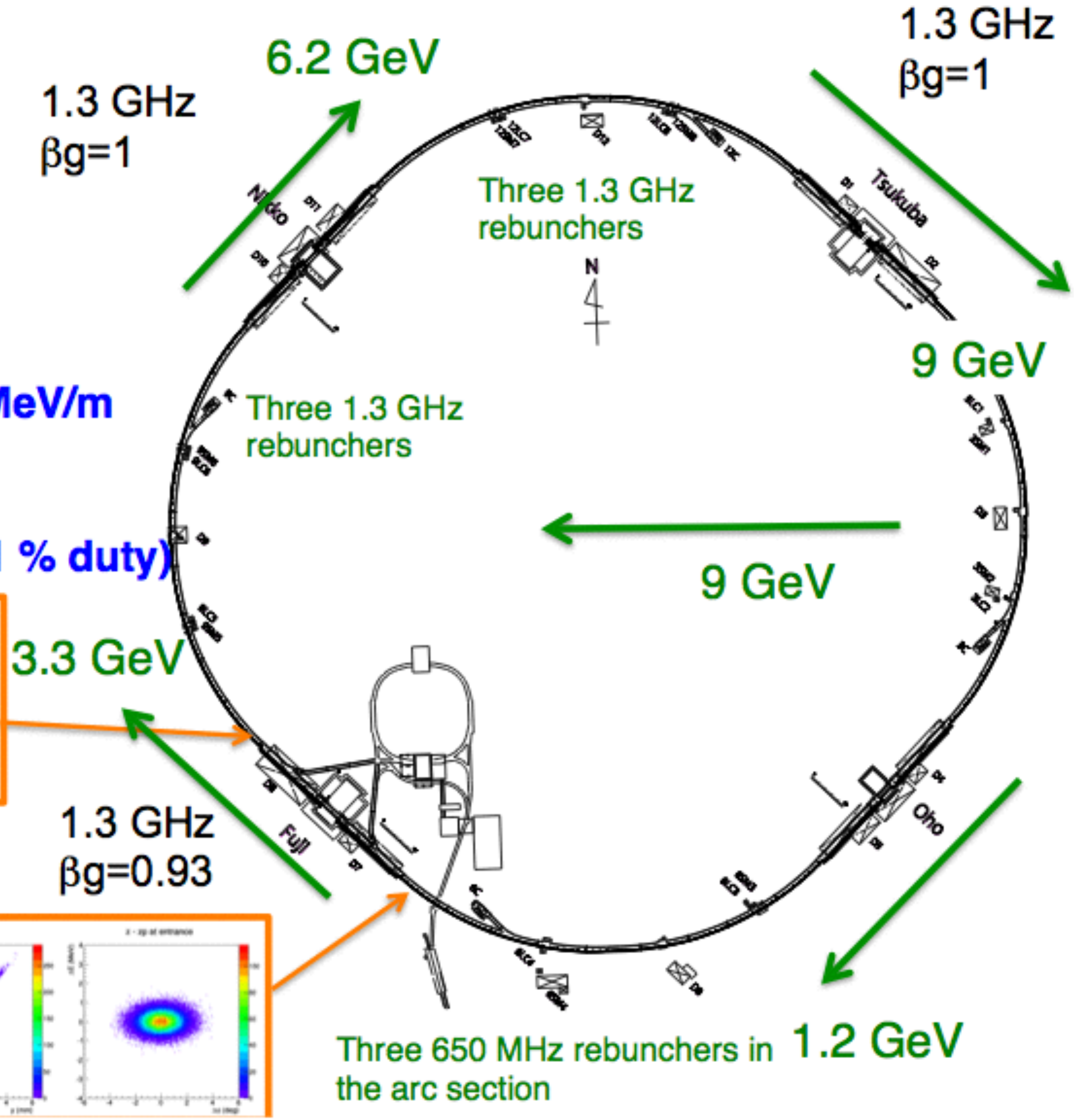
Linac based proton driver for ν exp.

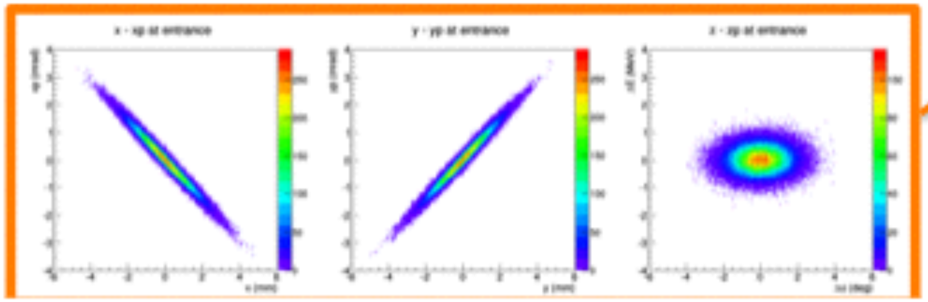
KEKB tunnel:
Circumference ~3 km
LS section 200 m x 4

Proton linac:
E = 9 GeV
1.3 GHz, 9 cell (ILC)
E0= 30 MV/m
Real estate grad. 10.9, 14.9 MeV/m

Beam power > 9 MW
(9GeV x 0.1 A x 1 % duty)

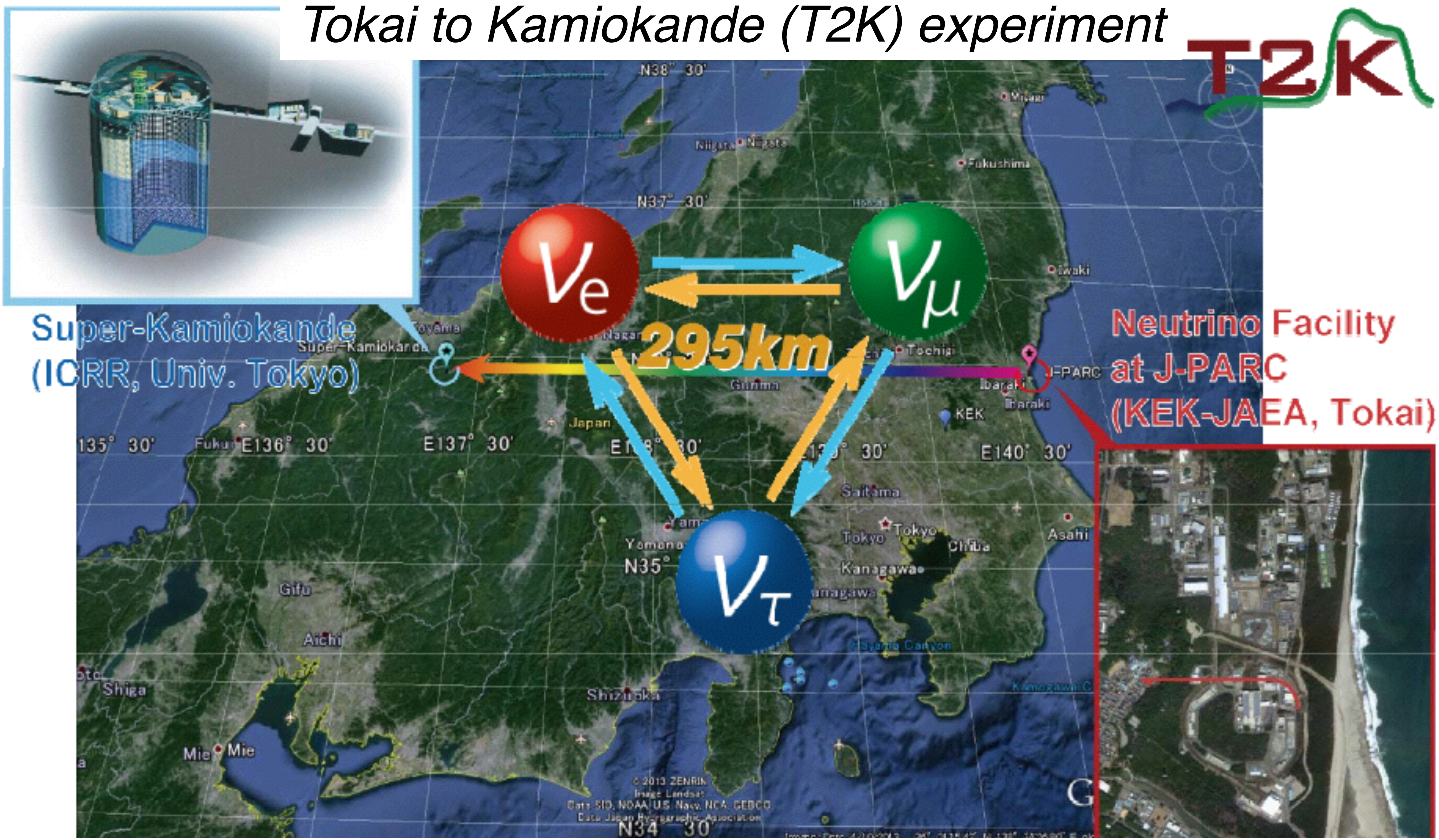






Examples of experiment

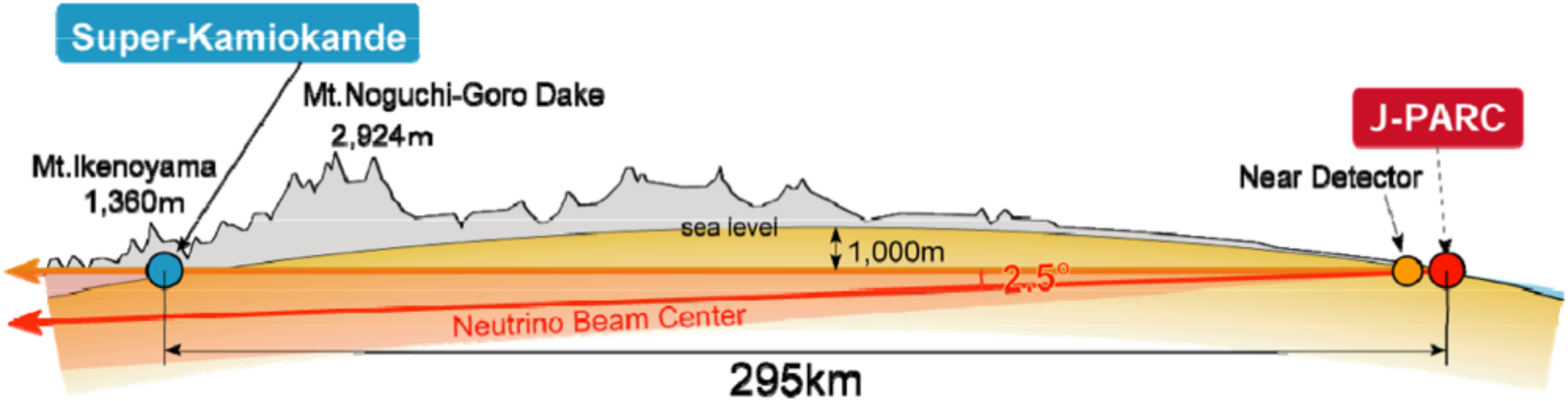
Tokai to Kamiokande (T2K) experiment

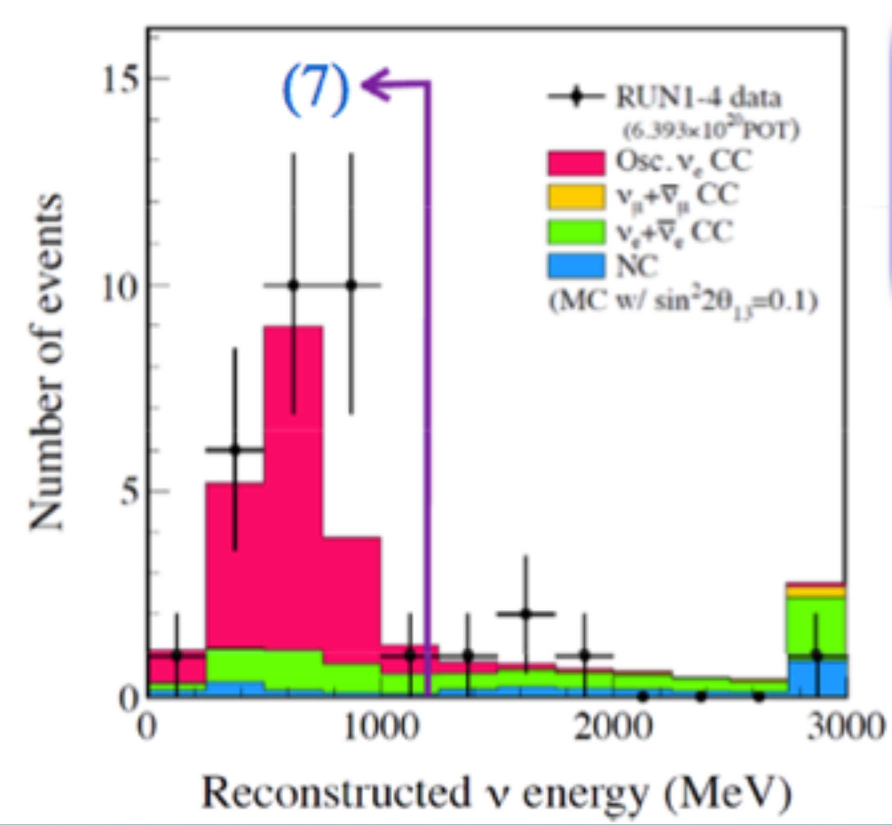


Discovery of ν_μ -> ν_e oscillation (ν_e appearance)

Precise measurement on ν_μ -> $\nu_{\tau(x)}$ oscillation (ν_μ disappearance)

Results of T2K

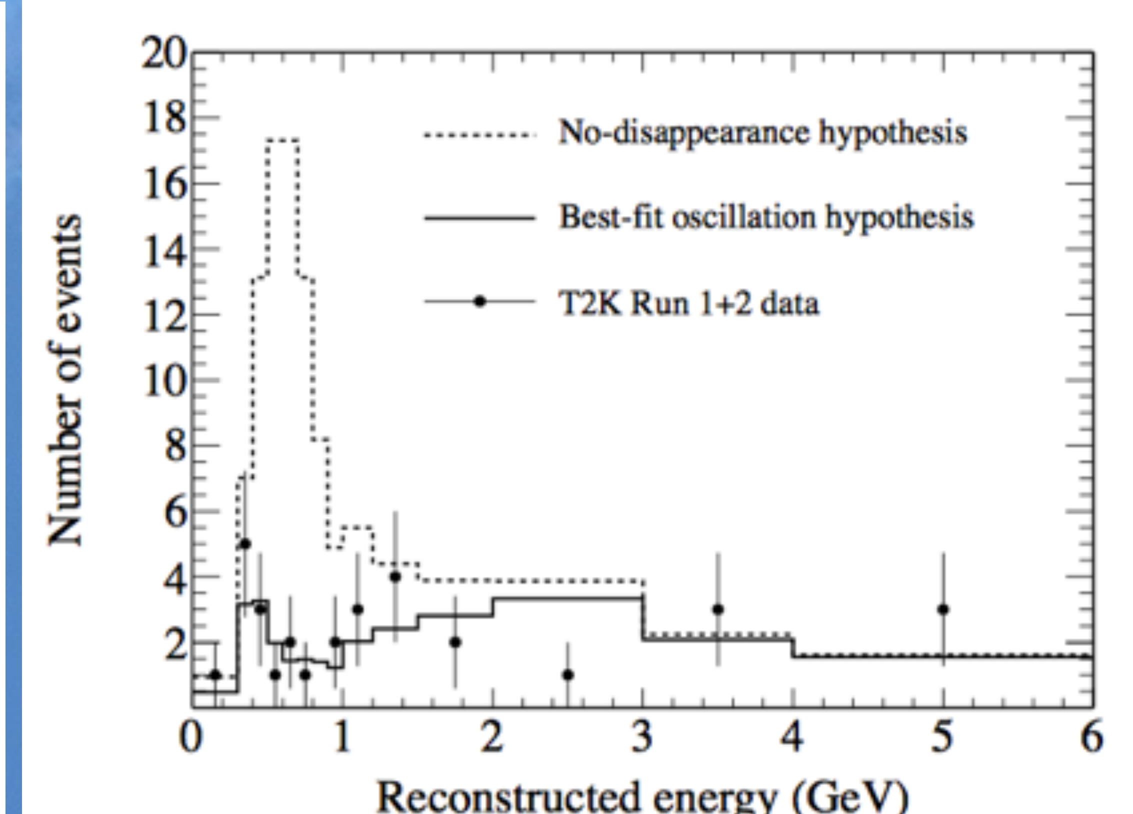




ν_e candidate = 28 events

Expected
20.44 ± 1.80
for $\sin^2 2\theta_{13}=0.1$

4.64 ± 0.52
for $\sin^2 2\theta_{13}=0.0$



Appearance

Disappearance

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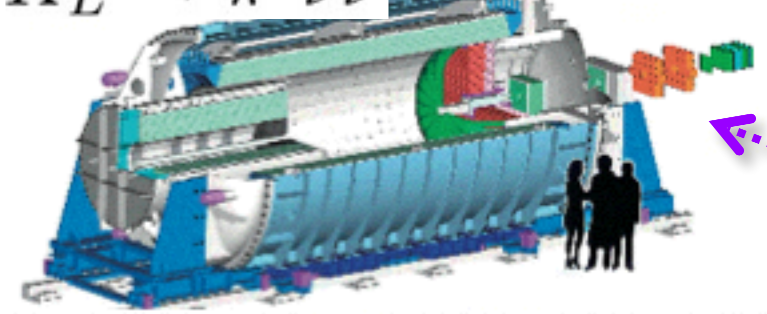
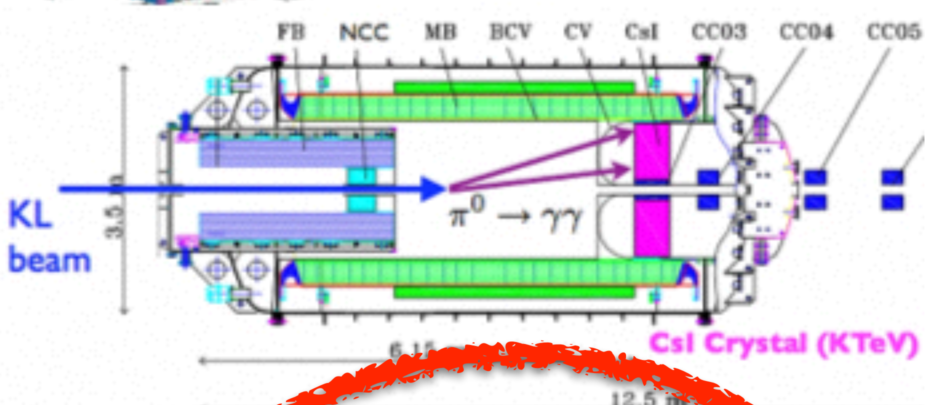
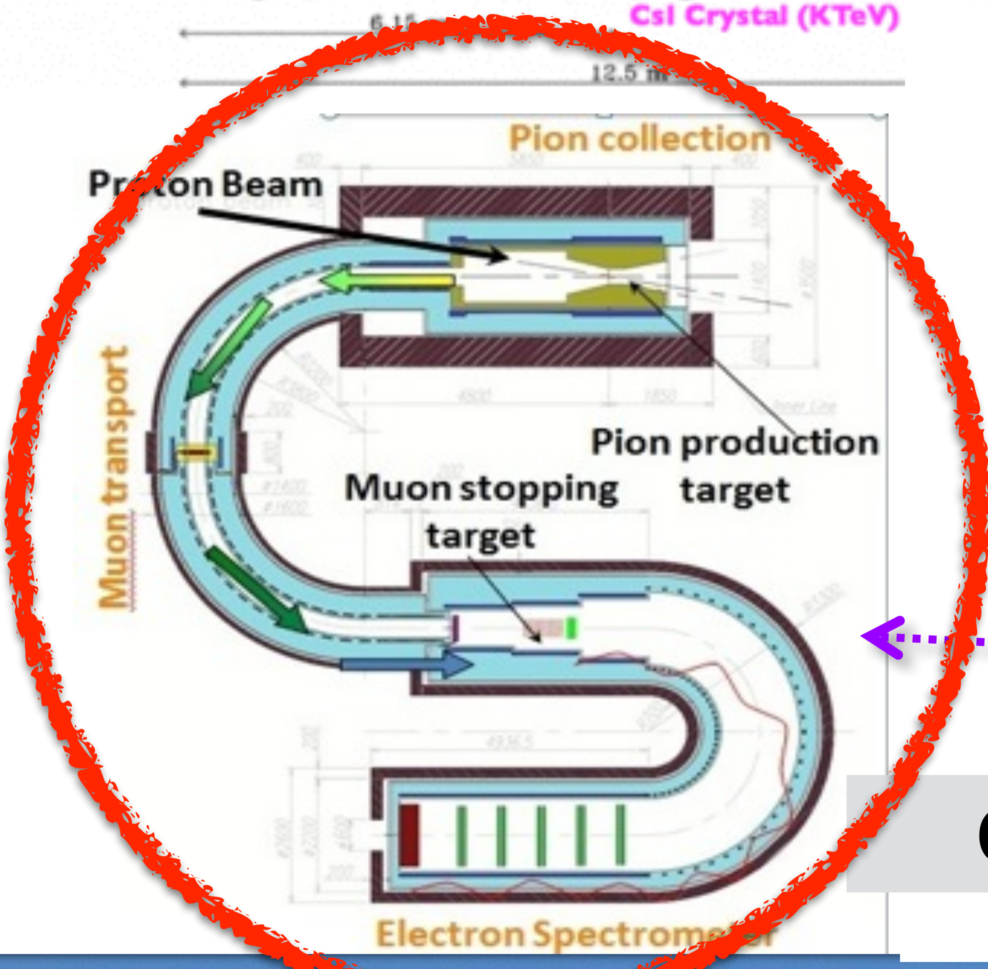
Experiments in Hadron Facility

KOTO : Direct CPV rare decay

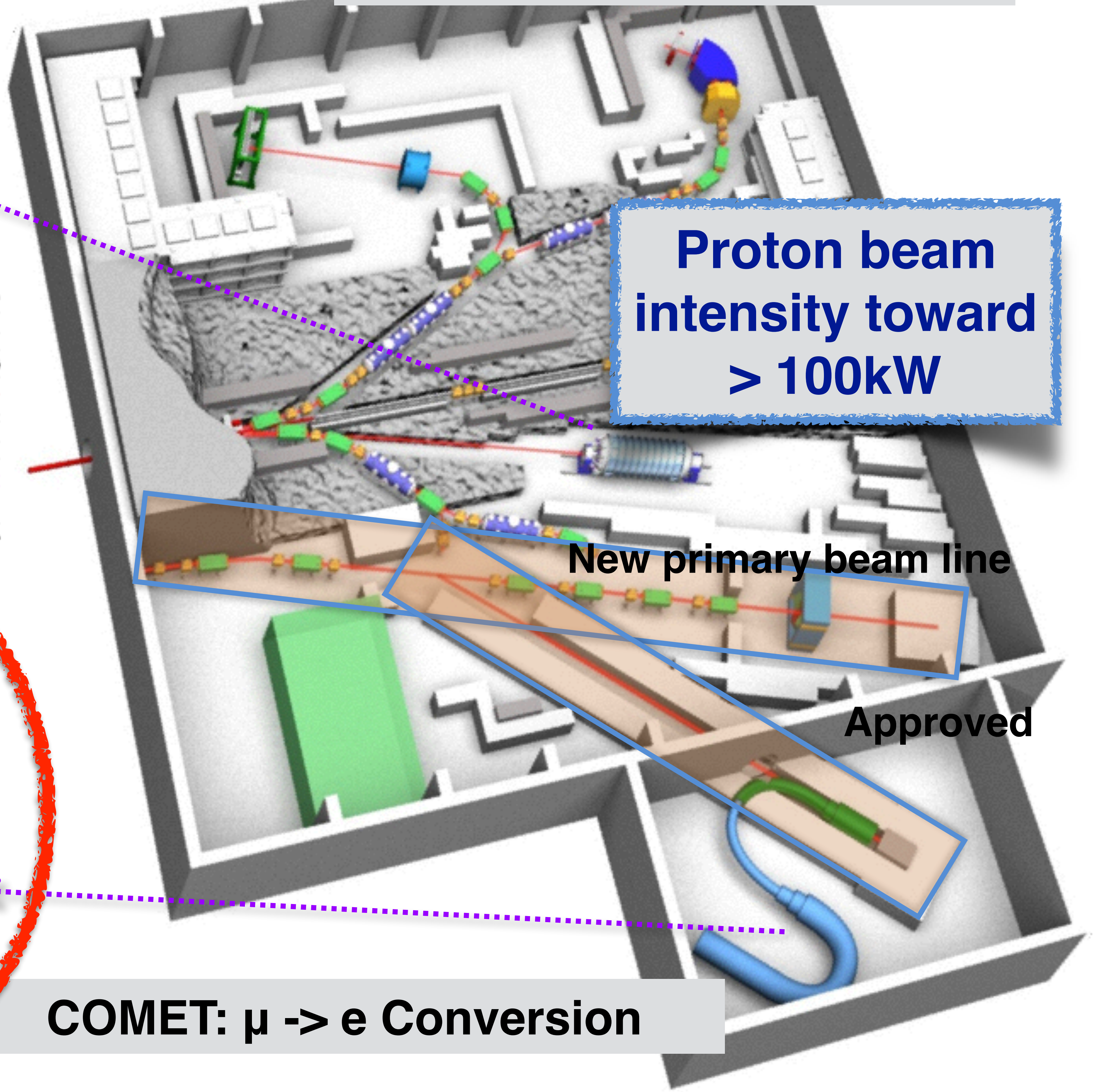
$K_L \to \pi^0 \nu\nu$





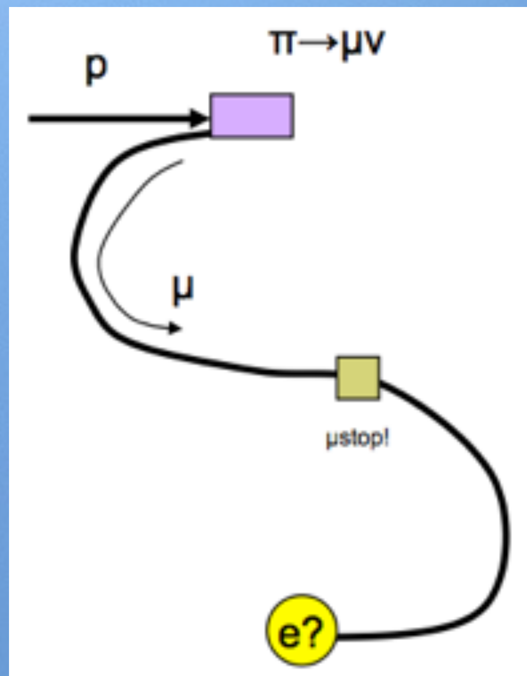


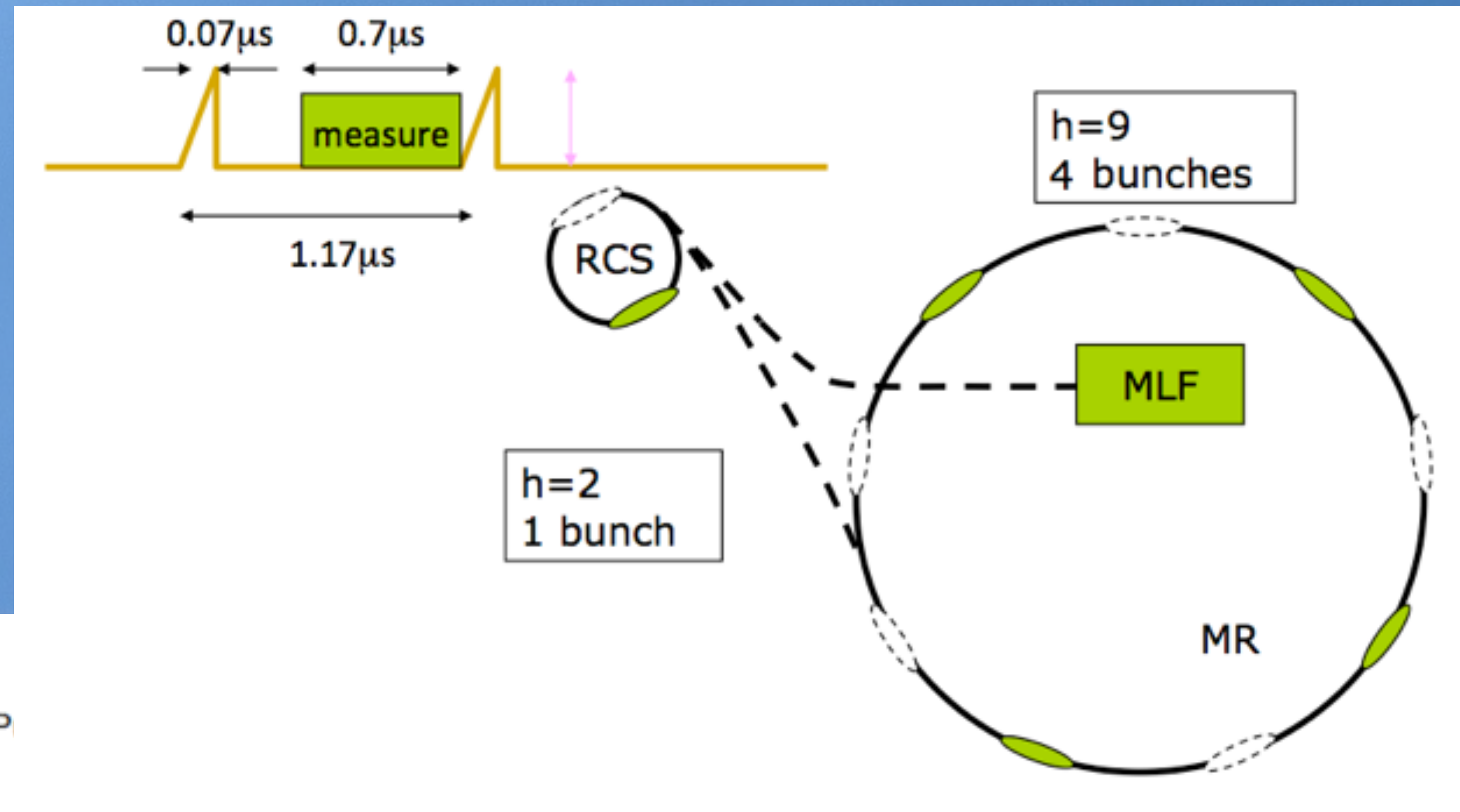
Strangeness Nuclear Physics

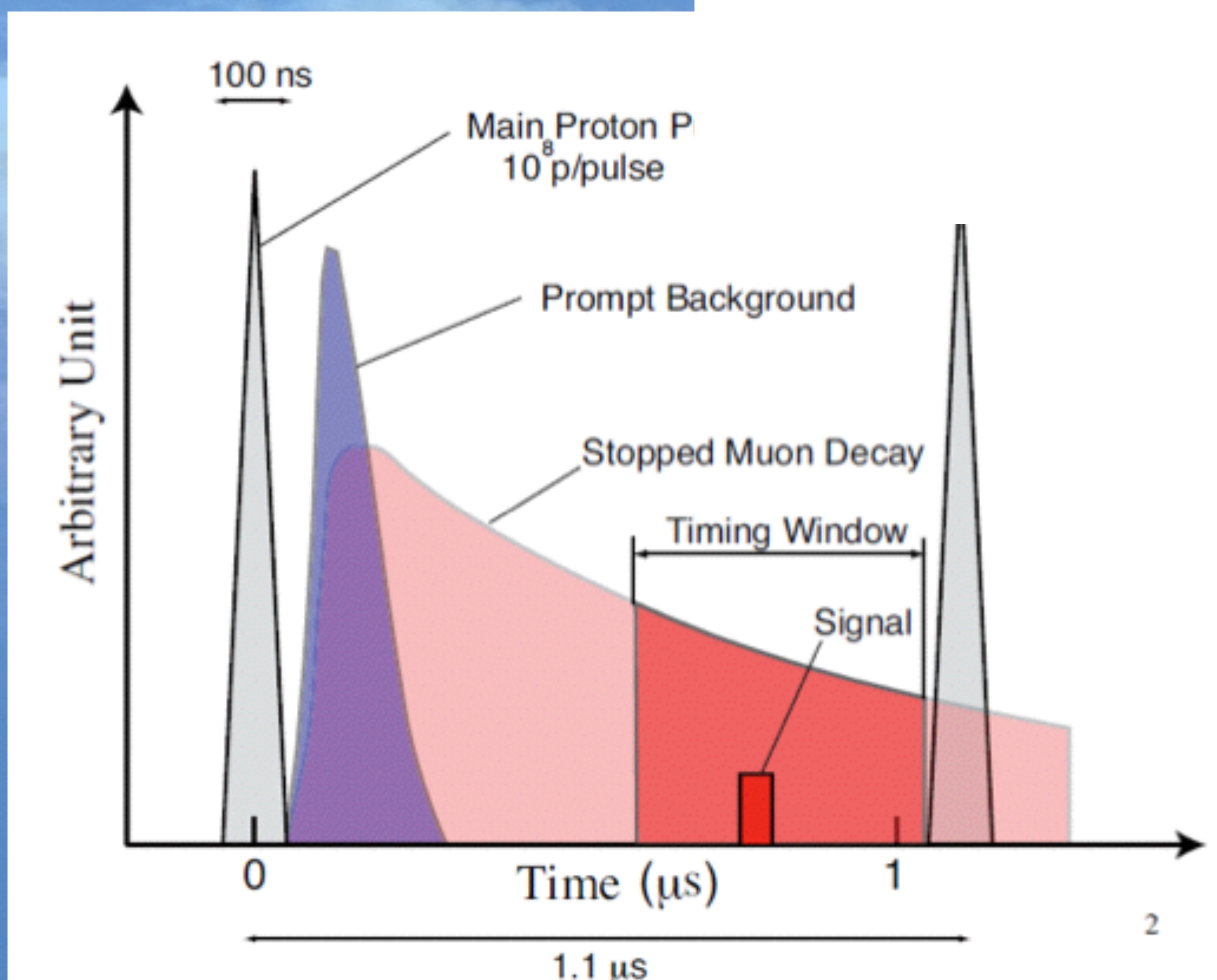


COMET: μ -> e Conversion

COMET: μ -> e Conversion







Most important point: There is no beam between the bunches.

Extinction: A residual to primary ratio of the beam intensity

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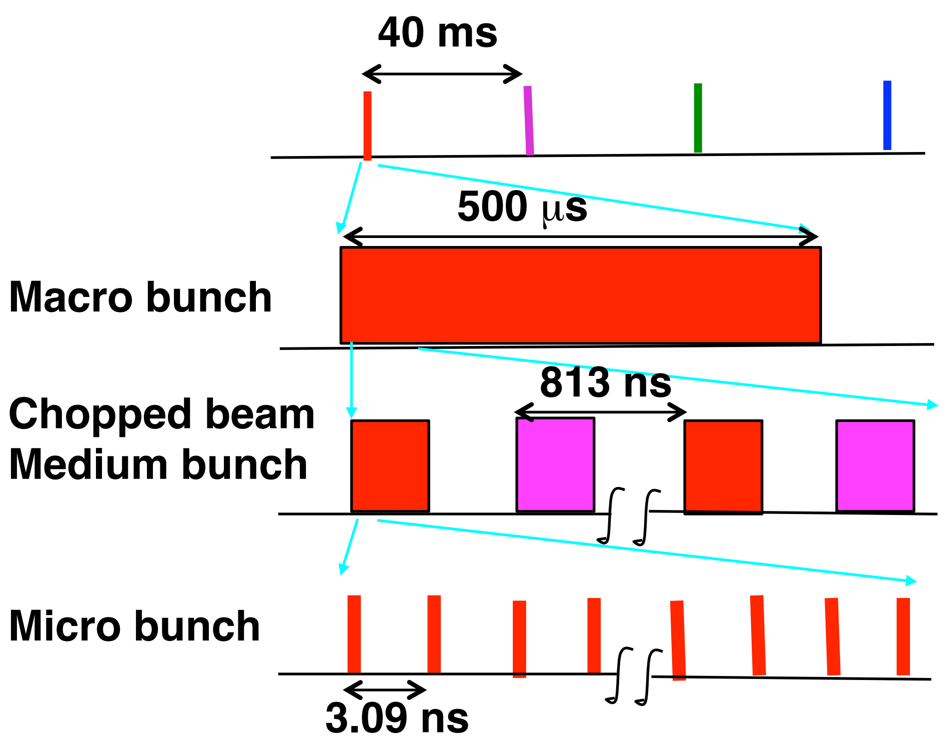
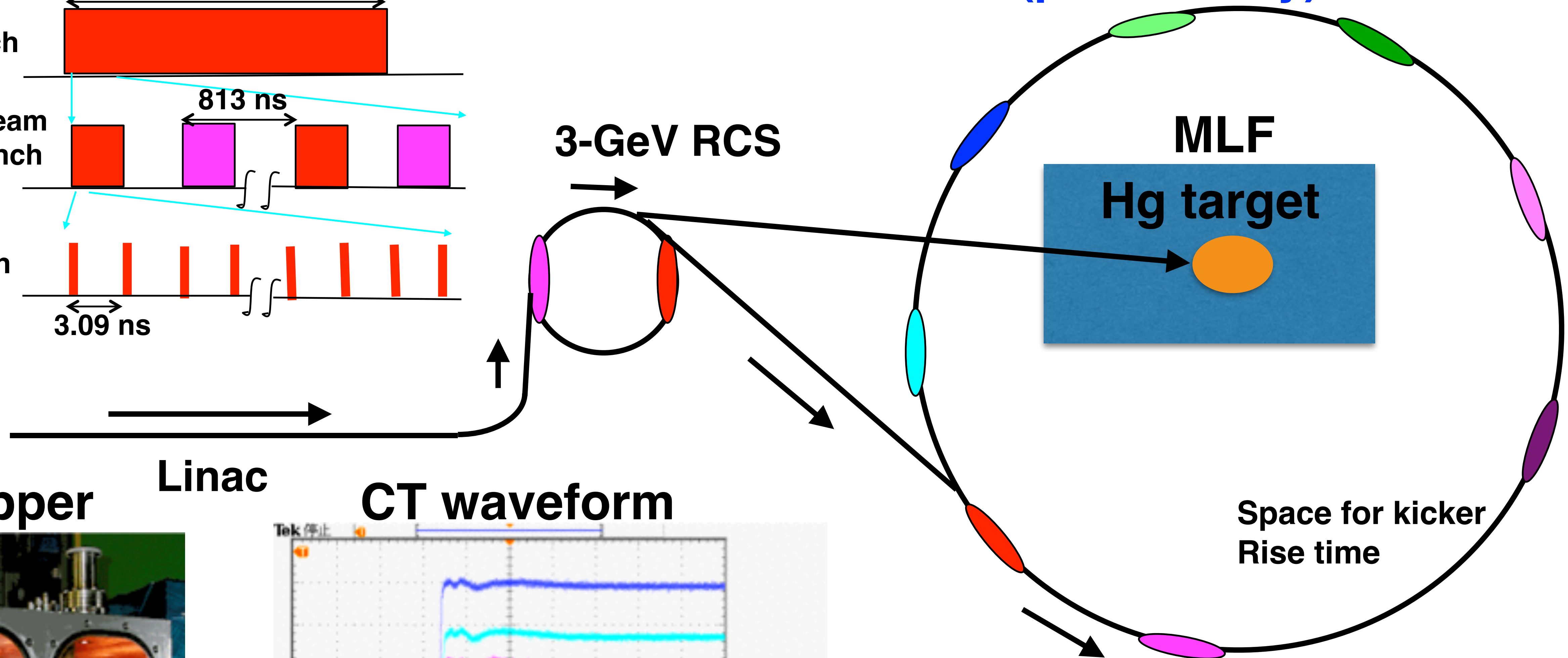
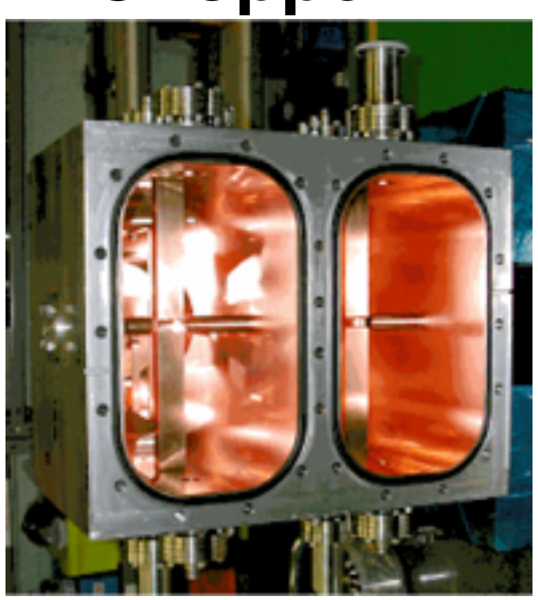
Beam chopping system of Linac

Neutron production rate of the full chopped beam has been measured by MLF target.
—> Extinction level (preliminary) ~1.1×10^{-7}

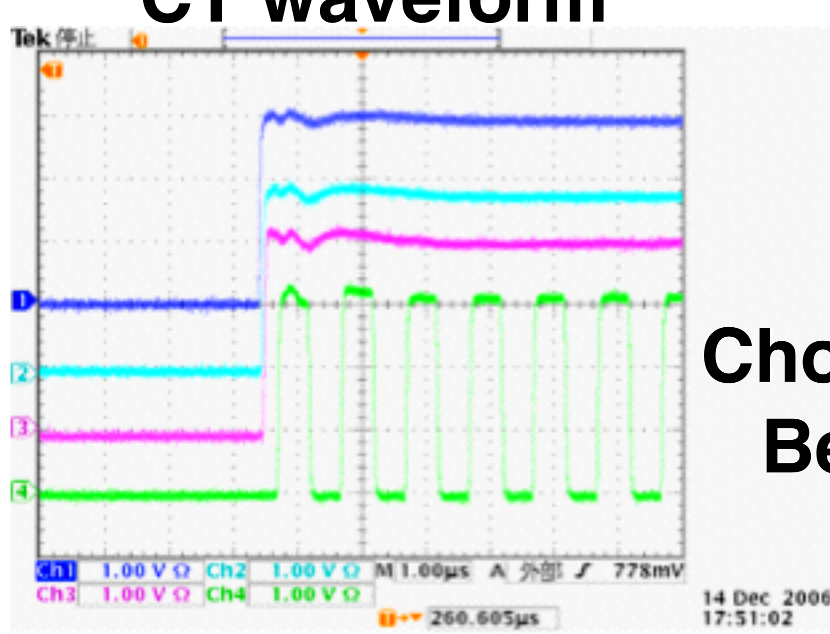




Chopper



CT waveform



Chopped Beam

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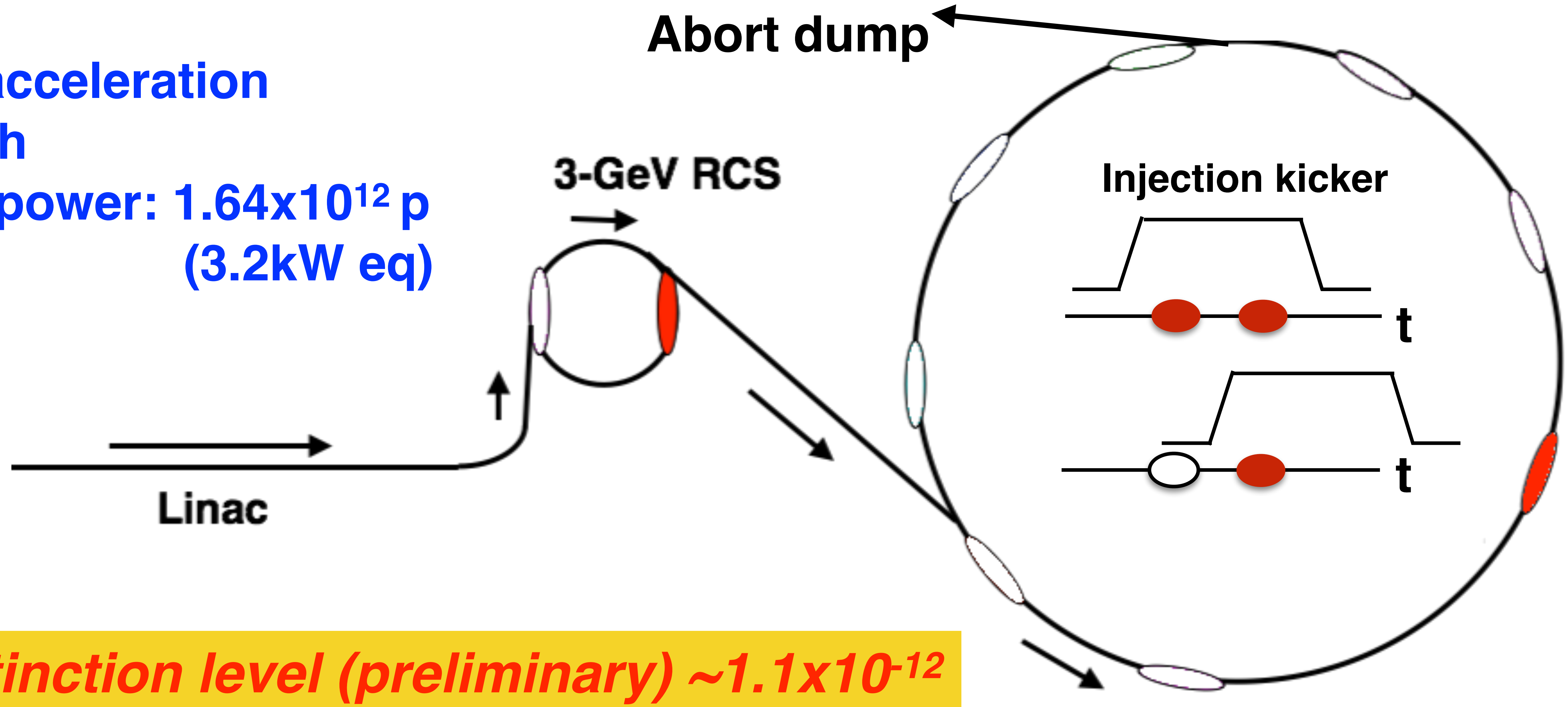
Beam injection scheme of MR

Purge of the almost empty bunch by delaying the injection kicker timing.
Suppression of the beam leakage from RF bucket by the higher RF voltage.

8GeV acceleration
1 bunch
beam power: 1.64×10^{12} p
(3.2kW eq)



—> Extinction level (preliminary) $\sim 1.1 \times 10^{-12}$

COMET phase-1 requires the extinction level $< 10^{-9}$

Summary

Summary

J-PARC are delivering the 300kW proton beam to MLF and the 220kW beam to T2K.

RCS has succeeded the deliver of 594kW eq. proton beam to MLF. Beam power will be increased up to 1MW until the next summer.

MR is going to increase the beam power more than 300kW for T2K by a fine treatment of the beam loss.

Design beam power of 750kW for MR will be achieved by replacing the magnet power supply until JFY2017.

T2K discovered the appearance of ν_e converted from ν_μ. Beam study for COMET experiment is being continued.

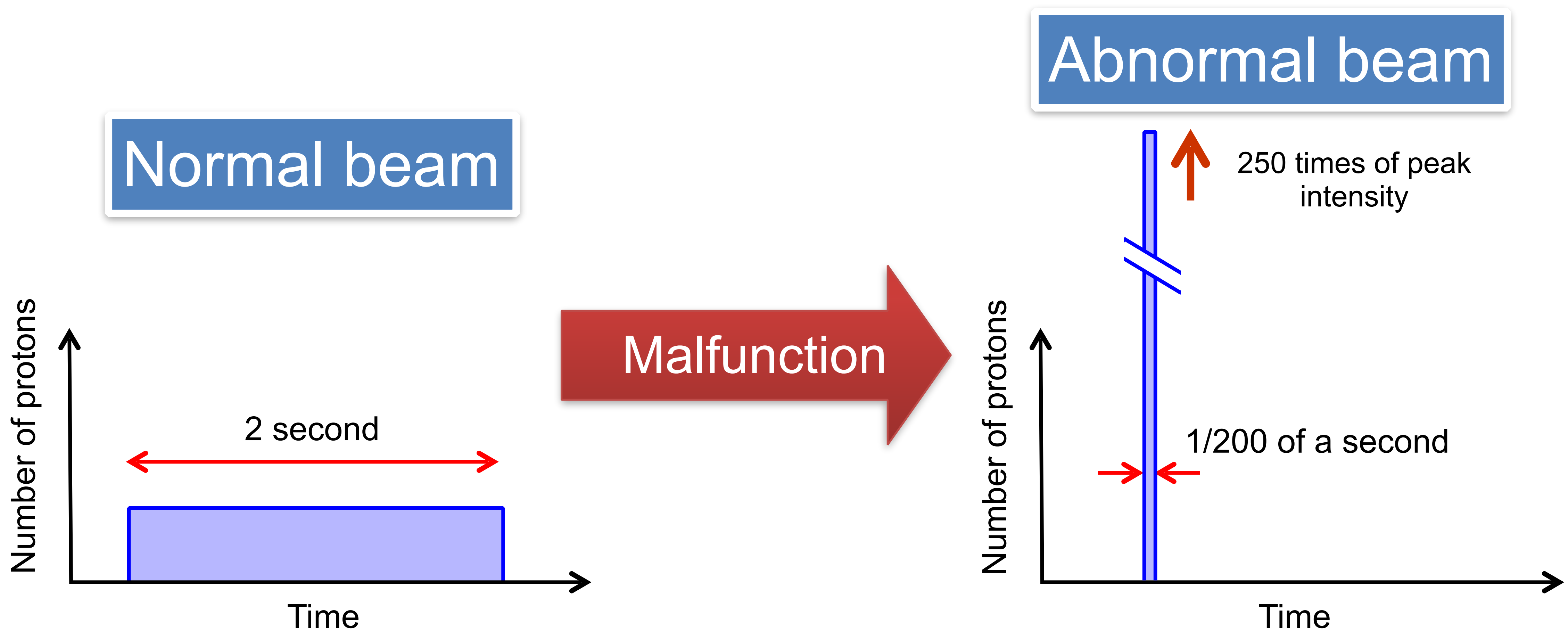
Thank you for your attention !

Spare slides

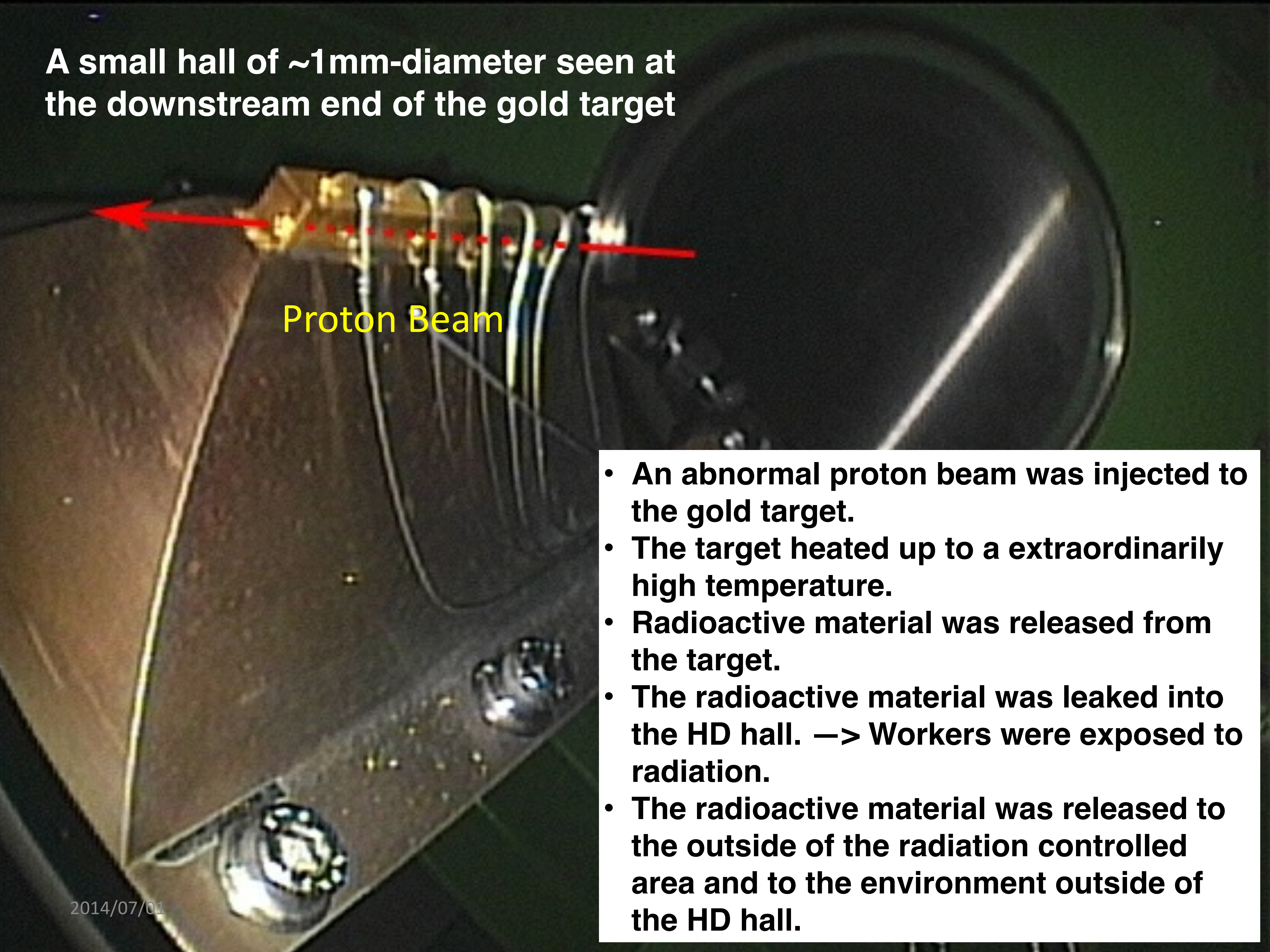
Accident of hadron hall

- At around 11:55 on May 23 2013, the power supply system of a special magnet in the 50 GeV Synchrotron malfunctioned.

→$2x10^{13}$ protons were extracted in a very short period of 5 milliseconds, while in normal operation $3x10^{13}$ protons should have been slowly extracted over 2 seconds.

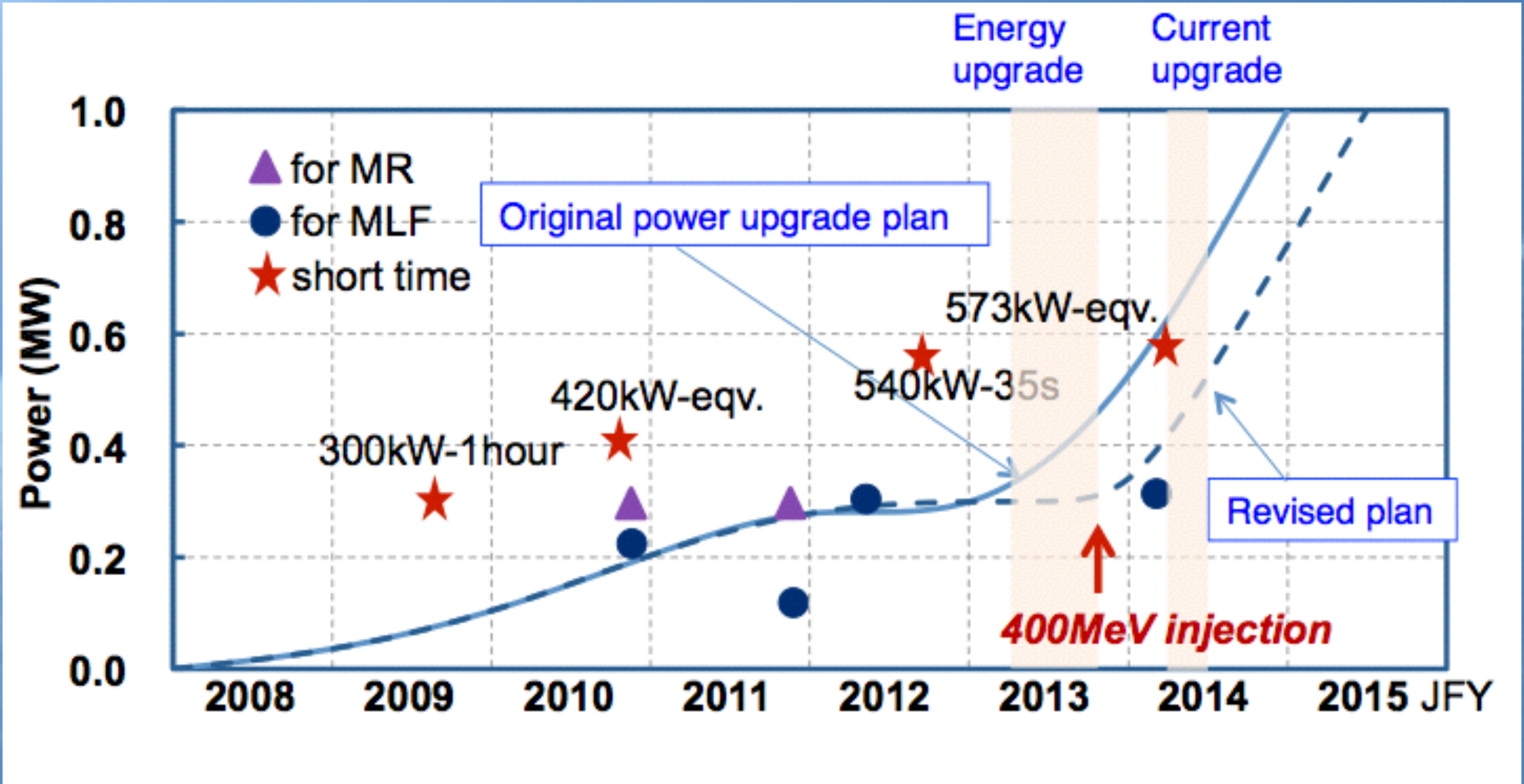


A small hall of ~1mm-diameter seen at the downstream end of the gold target



- An abnormal proton beam was injected to the gold target.
- The target heated up to a extraordinarily high temperature.
- Radioactive material was released from the target.
- The radioactive material was leaked into the HD hall. —> Workers were exposed to radiation.
- The radioactive material was released to the outside of the radiation controlled area and to the environment outside of the HD hall.

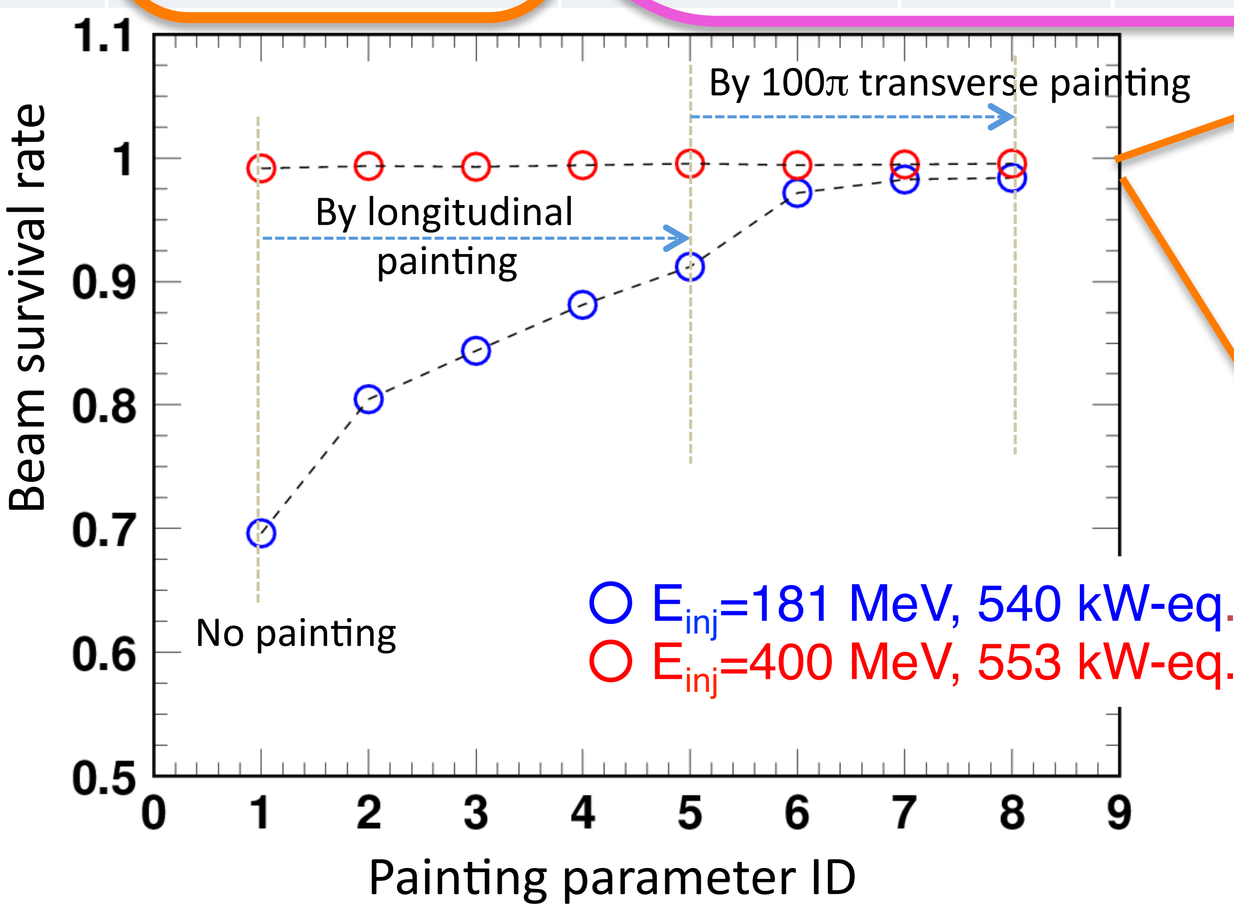
Mid-term plan of RCS

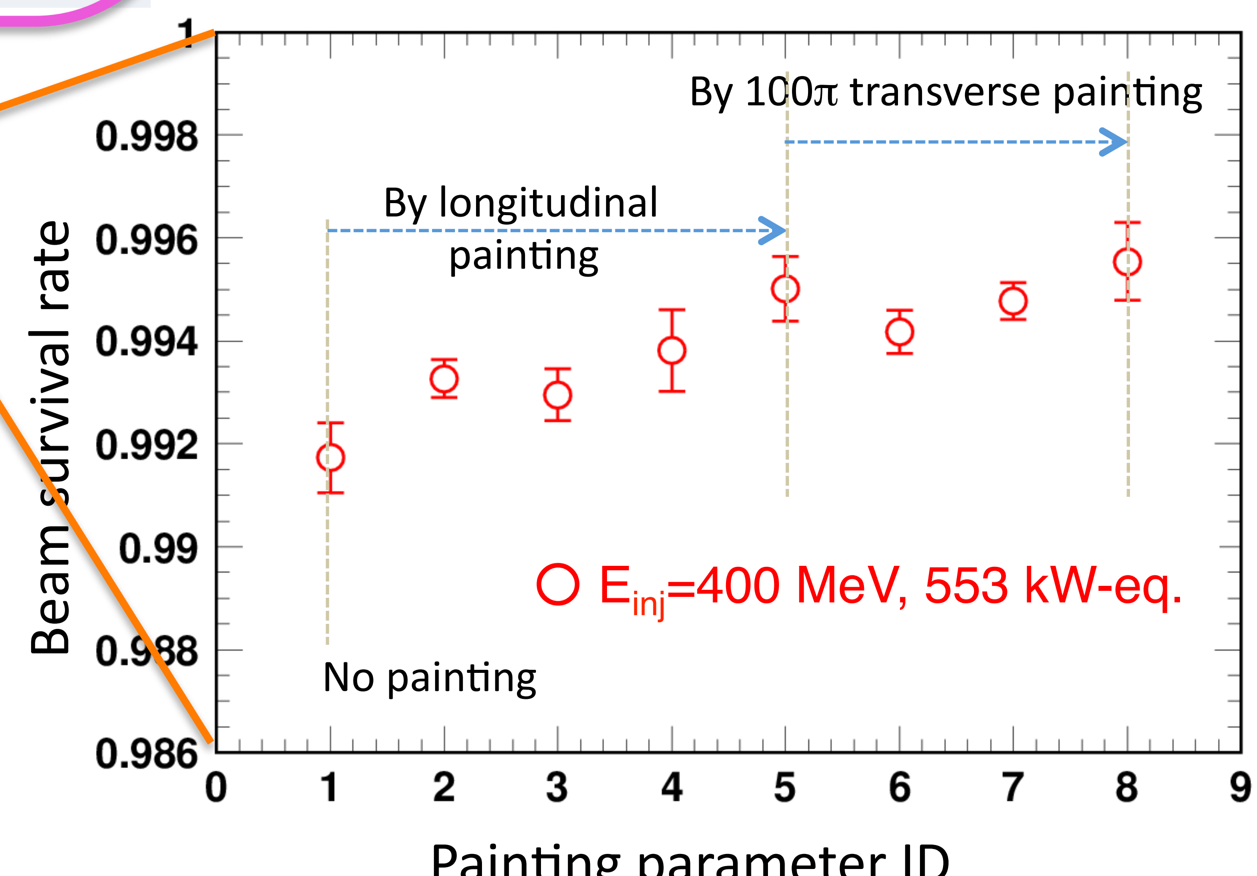


User operation of the 1MW beam power will start in JFY2015.

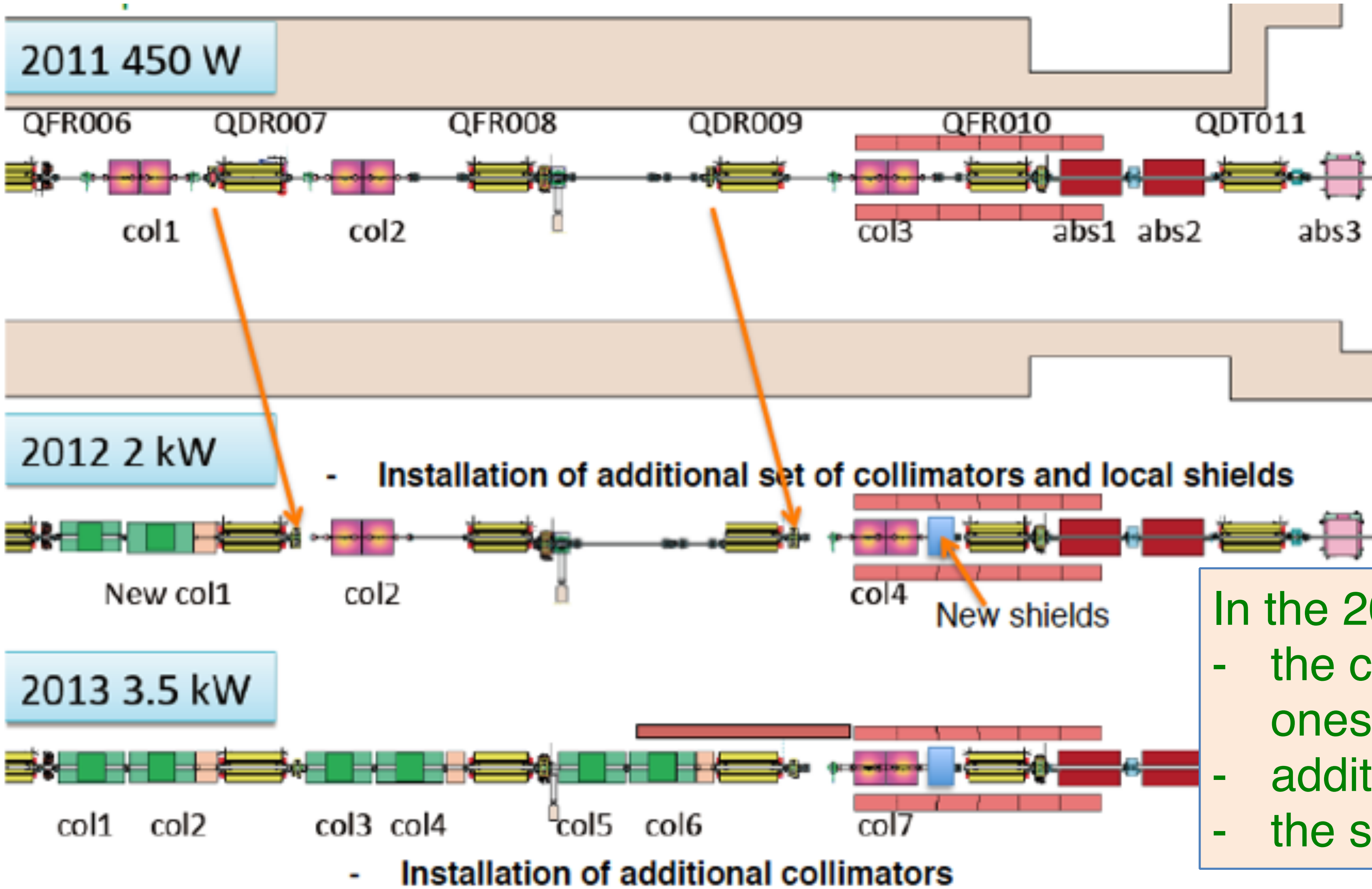
Painting parameter dependence of beam loss

ID	Trans.-paint (π mm mrad)	RF V_2/V_1 (%)	ϕ_2 (deg)	dp/p (%)
1	-	-	-	-
2	100	-	-	-
3	-	80	-100	-0.0
4	-	80	-100	-0.1
5	-	80	-100	-0.2
6	100	80	-100	-0.0
7	100	80	-100	-0.1
8	100	80	-100	-0.2





Upgrade of MR ring collimator section



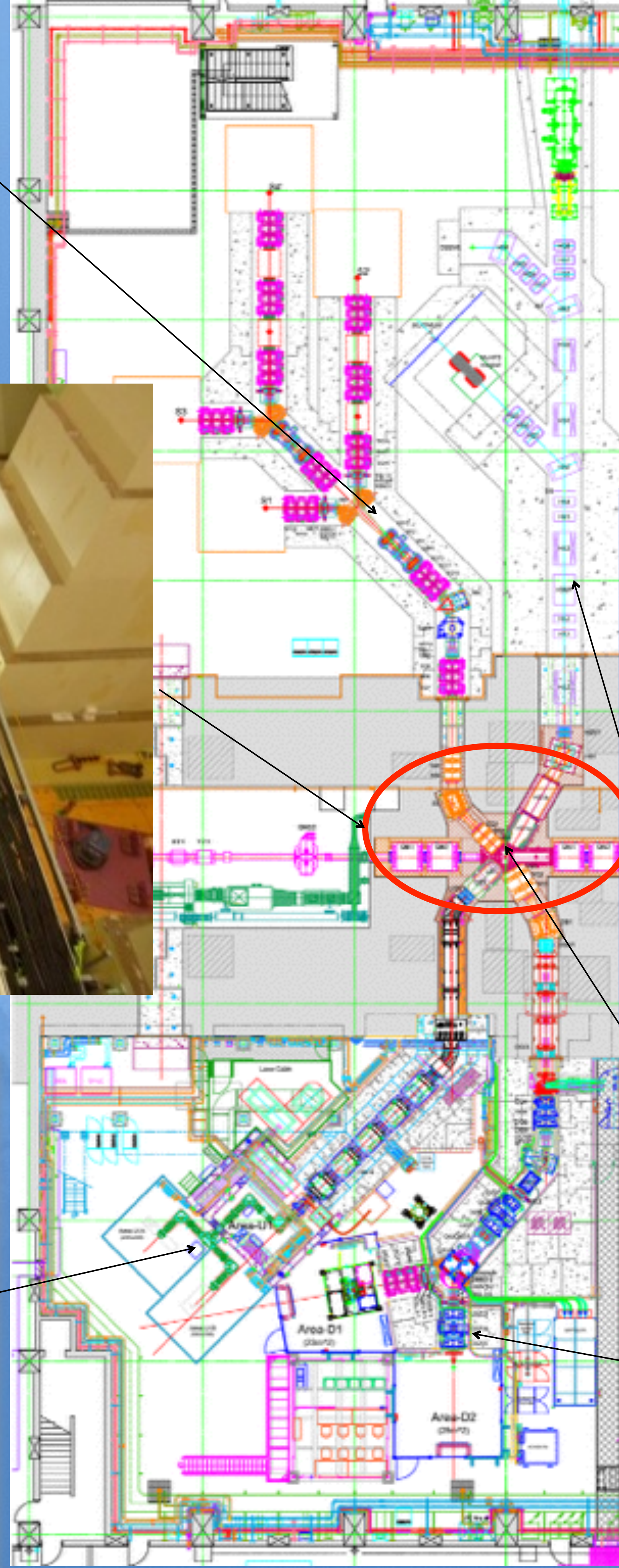
In the 2013 shutdown,

- the collimator#2 is replaced by new ones (two-unit collimator)
- additional two-unit is installed
- the shield walls is extended.

μ-on beam lines

S-Line(in 2 years)

Surface μ^+(30 MeV/c)
For material sciences



H-Line(in 3 years)

Surface μ^+ For **HF**, **g-2** exp.
e^- up to 120 MeV/c For **DeeMe**
μ^- up to 120 MeV/c For μCF

Monochromatic μ^+(up to 10 MeV) for Muon Microscopy

Muon Target

U-Line(Commissioning)

Surface μ^+(30 MeV/c)
Cloud μ^-(up to 45 MeV/c)

Ultra Slow μ^+(0.05-30keV)
For multi-layered thin foils, nano-materials, catalysis, etc

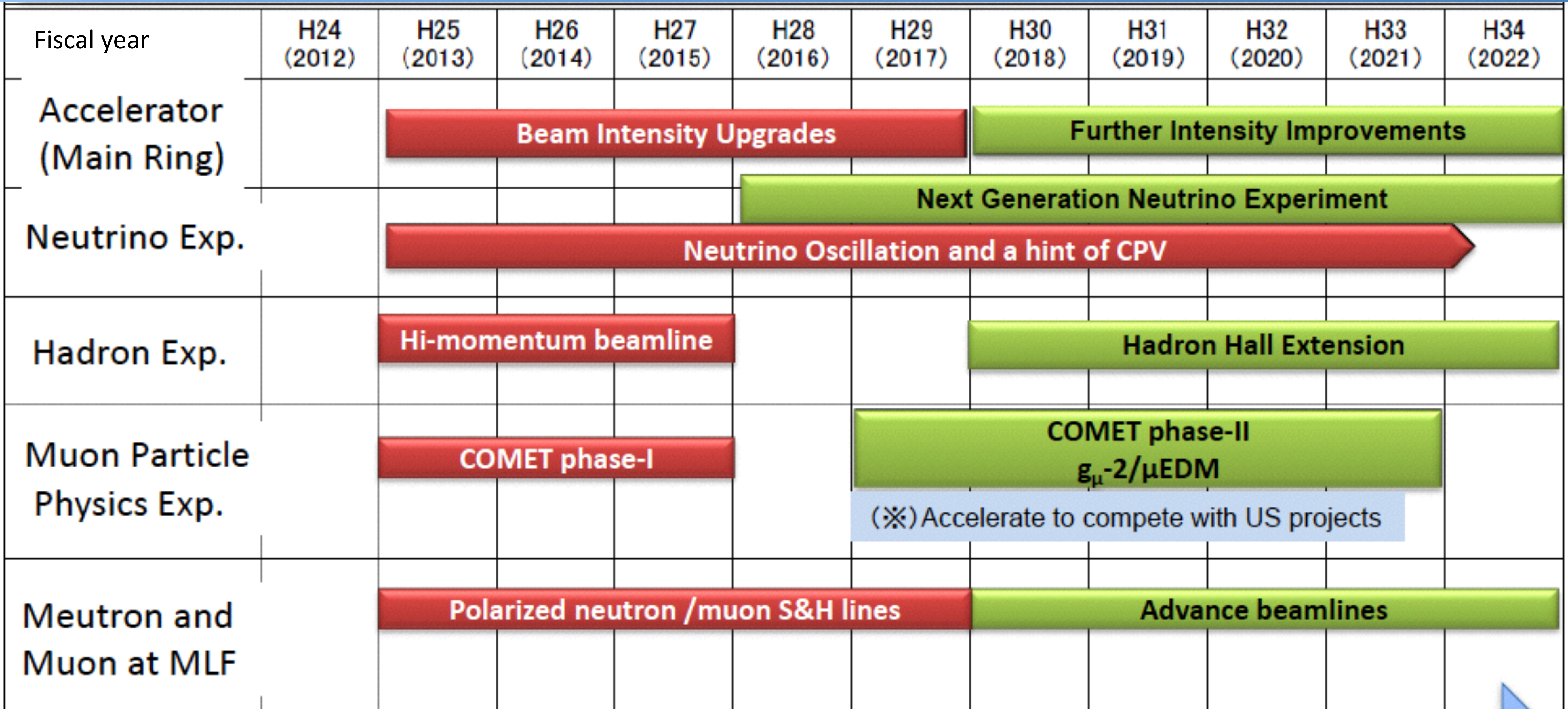
D-Line(*In Operation*)

Surface μ^+(30 MeV/c)
Decay μ^+/μ^-(5-120 MeV/c)

Users' RUN is undergoing!

Long-term plan of science at J-PARC

"Elucidation of the origin of matter with an upgrade of J-PARC experimental facility" is the goal submitted to science council of Japan.



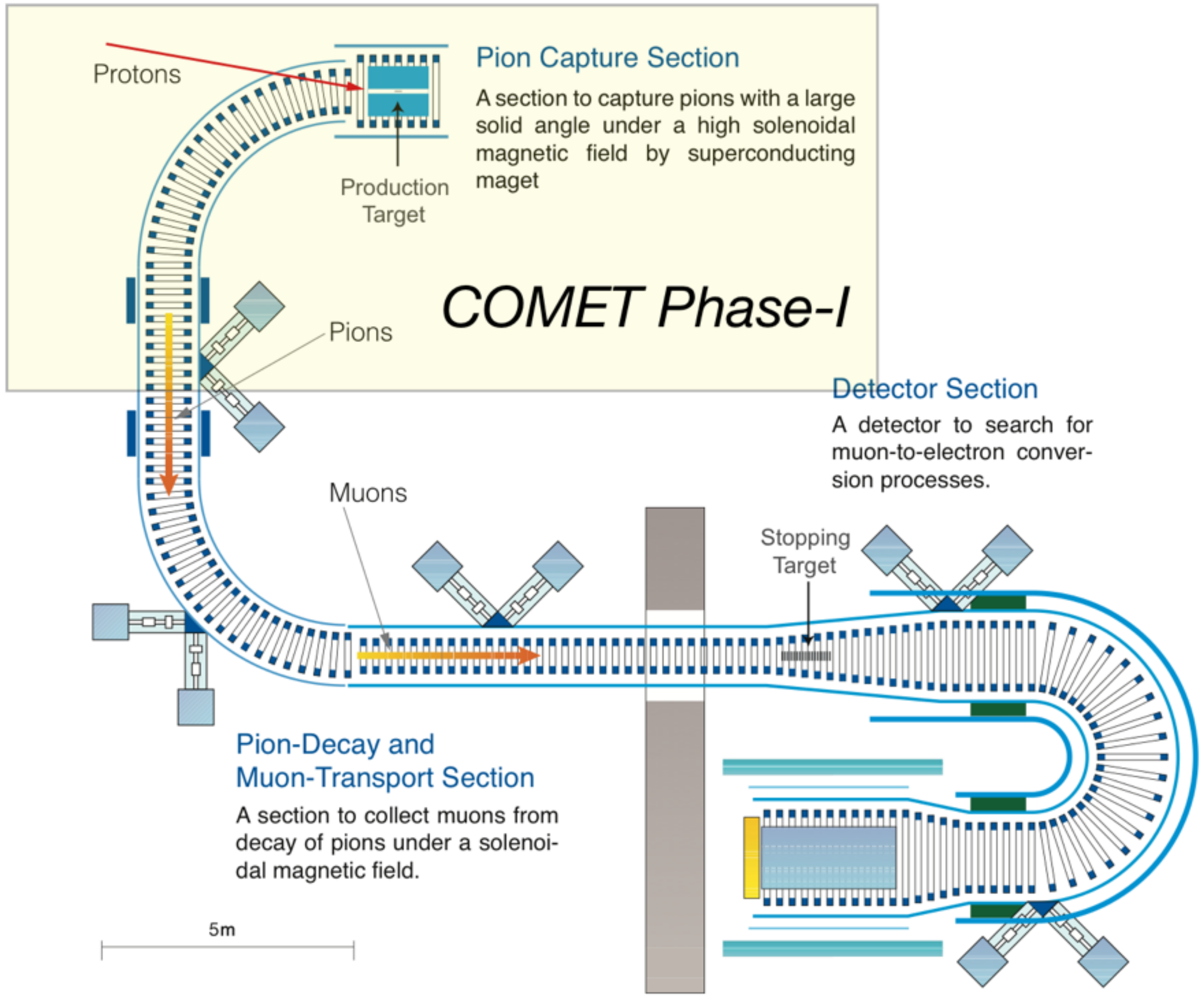
Oversea projects (start year)

NOvA at Fermilab (2014-)

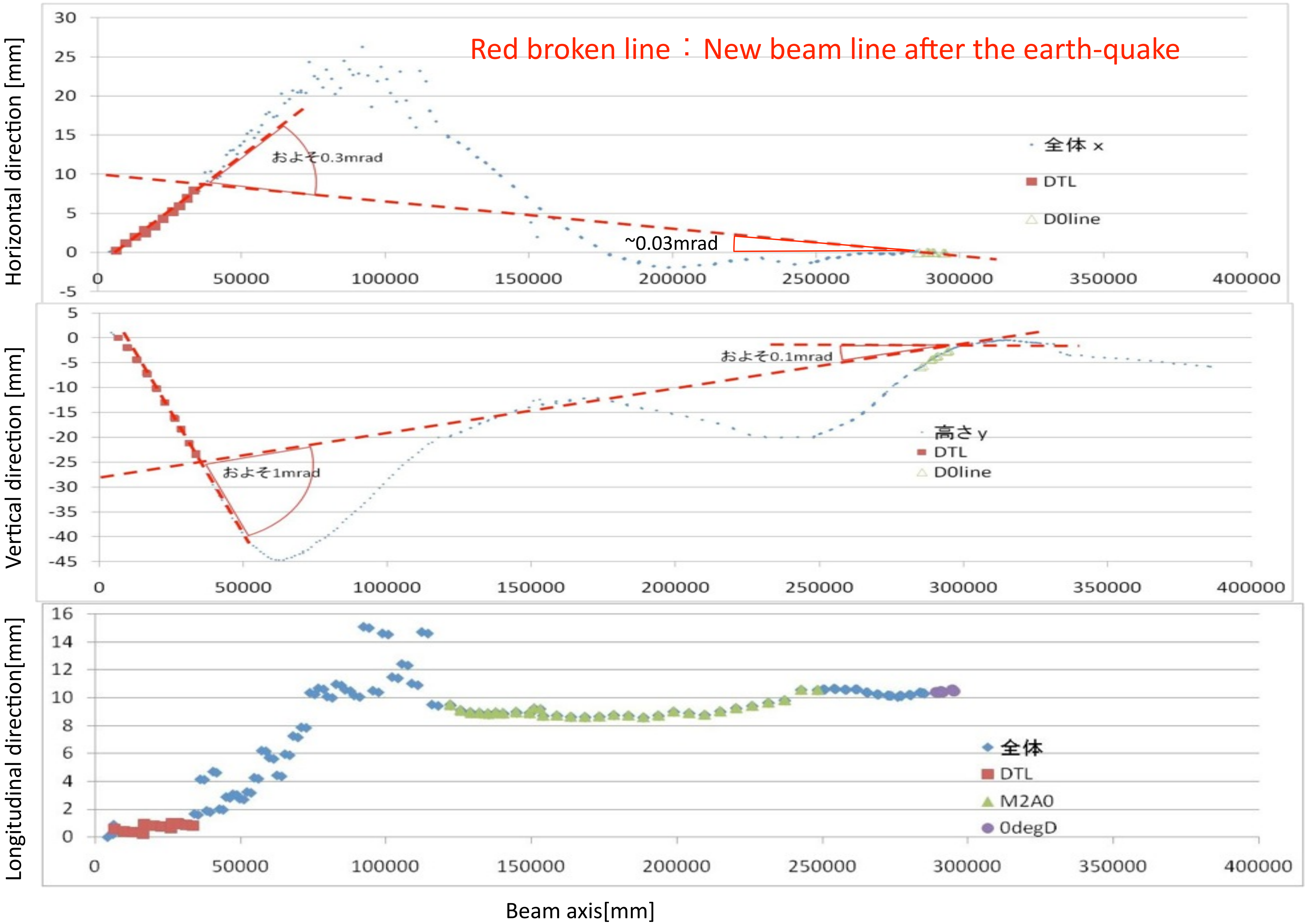
g-2 at Fermilab (2016 -)

FAIR at GSI (2018 -)

Mu2e at Fermilab (2021 -)


Protons
Pion Capture Section
A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting maget
Production Target
COMET Phase-I
Pions
Detector Section
A detector to search for muon-to-electron conversion processes.
Muons
Stopping Target
Pion-Decay and Muon-Transport Section
A section to collect muons from decay of pions under a solenoidal magnetic field.
5m

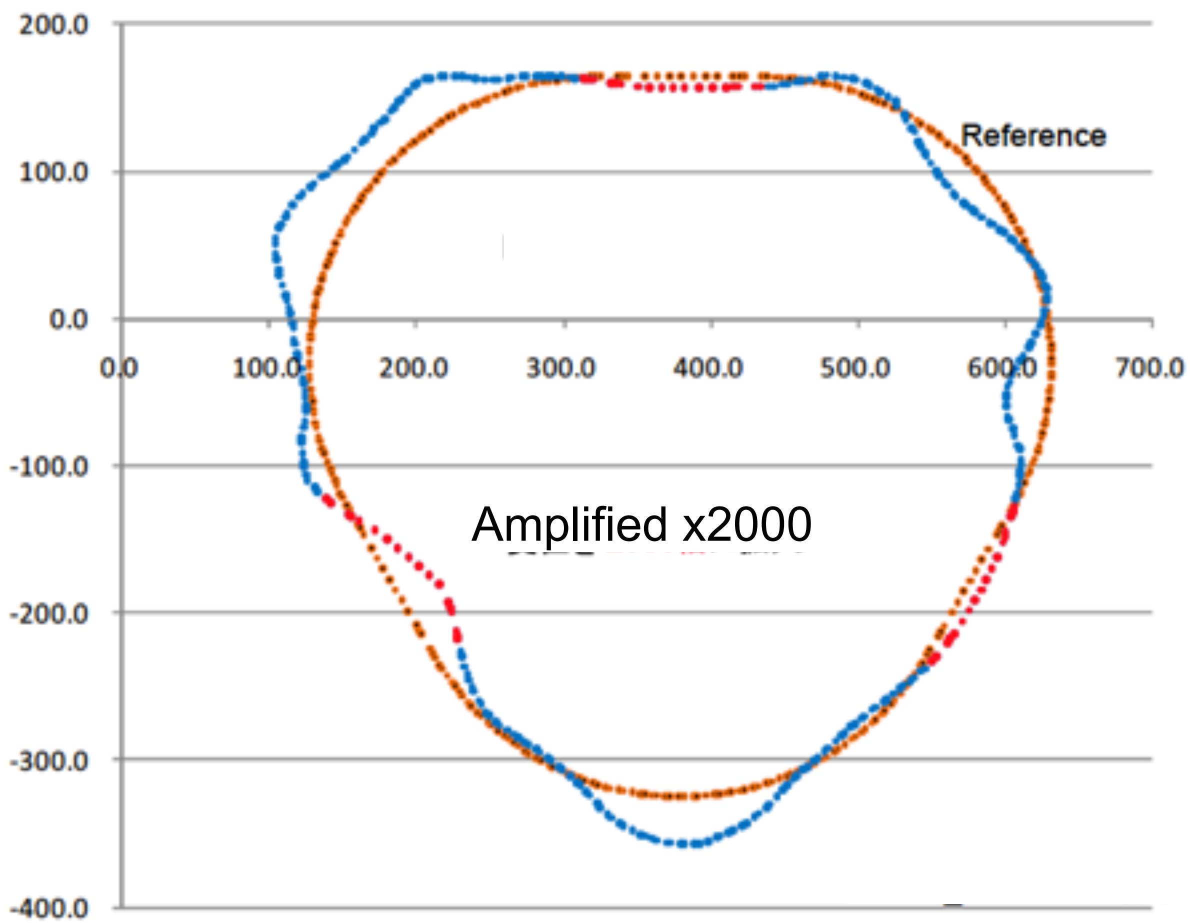
Linac measured position (Apr. 2011)



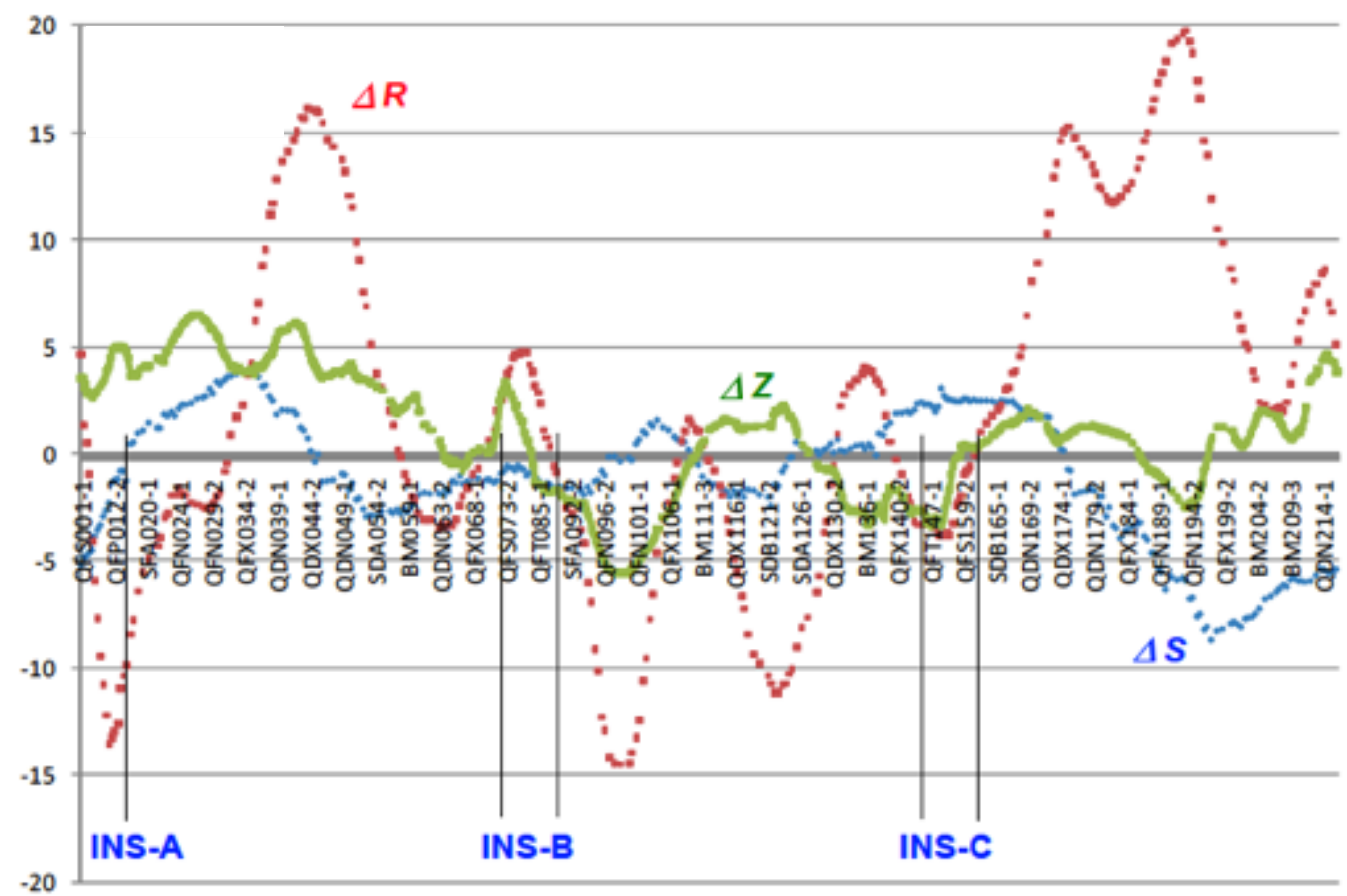
Main Synchrotron Ring (MR, 30GeV)

- There were no serious damages on all MR equipment/instruments, such as magnets.

  It, however, appeared they misaligned in both vertical and horizontal directions.
- Some magnets misaligned greatly are re-aligned with replacing a stage.
- Inspection of the RF power amplifying system has been completed.



Orange : Reference positions of the magnet
Blue & Red: Measured positions after the earthquake (Please note the magnitude of displacement is amplified x2000.)



Magnet displacement from the reference line
Green : vertical direction
Red : horizontal direction
Blue : beam deirection