



J-PARC and Beam-line Upgrade

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On behalf of the Neutrino Experimental Facility Group

J-PARC Center, KEK/JAEA



Introduction

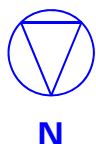


J-PARC Neutrino Experimental Facility

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- Conventional horn-focused beam-line, designed/constructed for T2K (Tokai-to-Kamioka) long base-line neutrino oscillation experiment & for its future upgrade
 - ◆ Superconducting Combined Function Magnets (SCFM) at the primary proton beam-line
 - ◆ First application of off-axis configuration, angle adjustable between $2 \sim 2.5^\circ$
 - ◆ Design intensity = 750kW

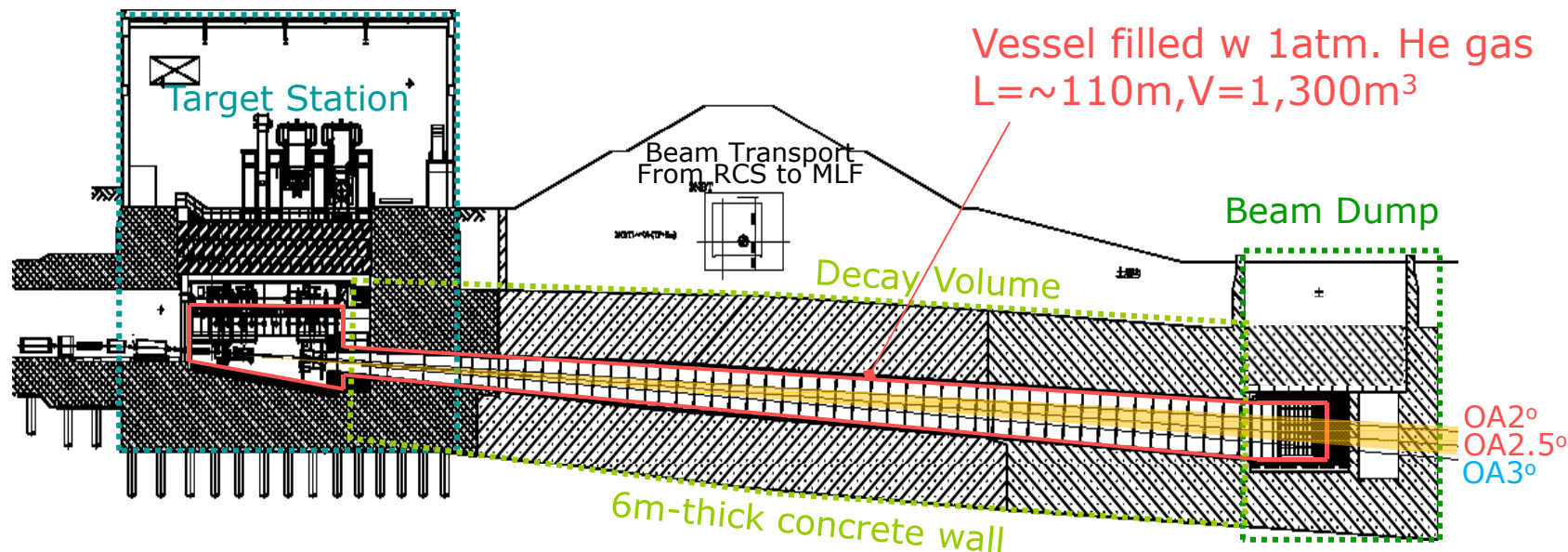
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Secondary Beam-line

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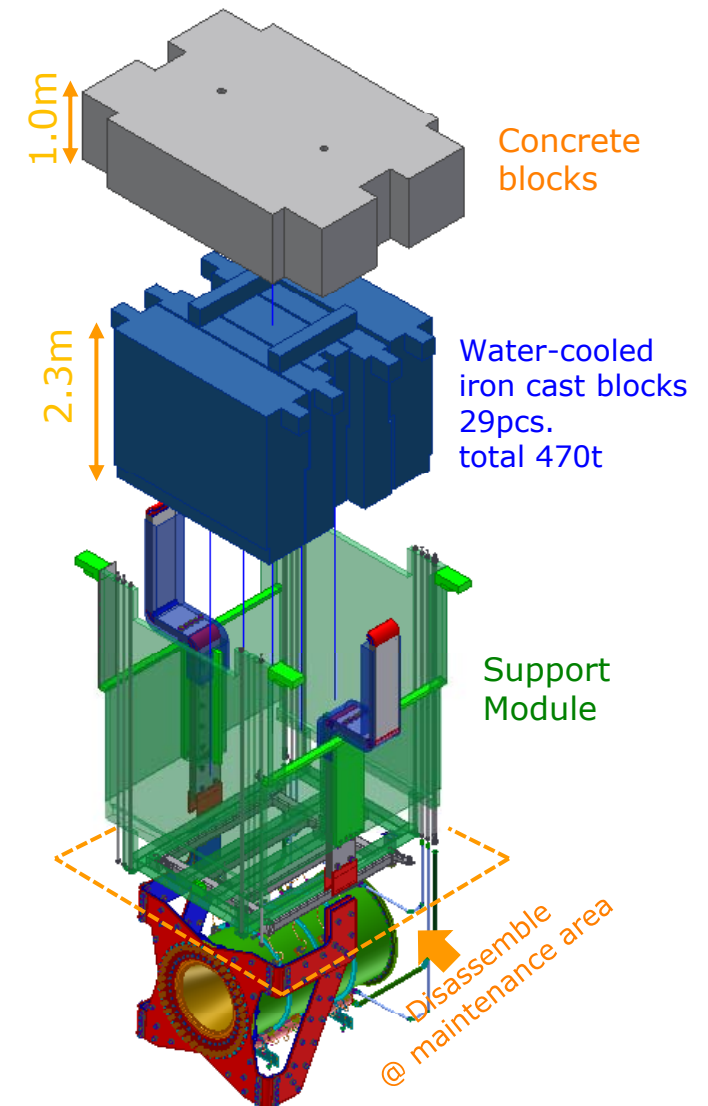
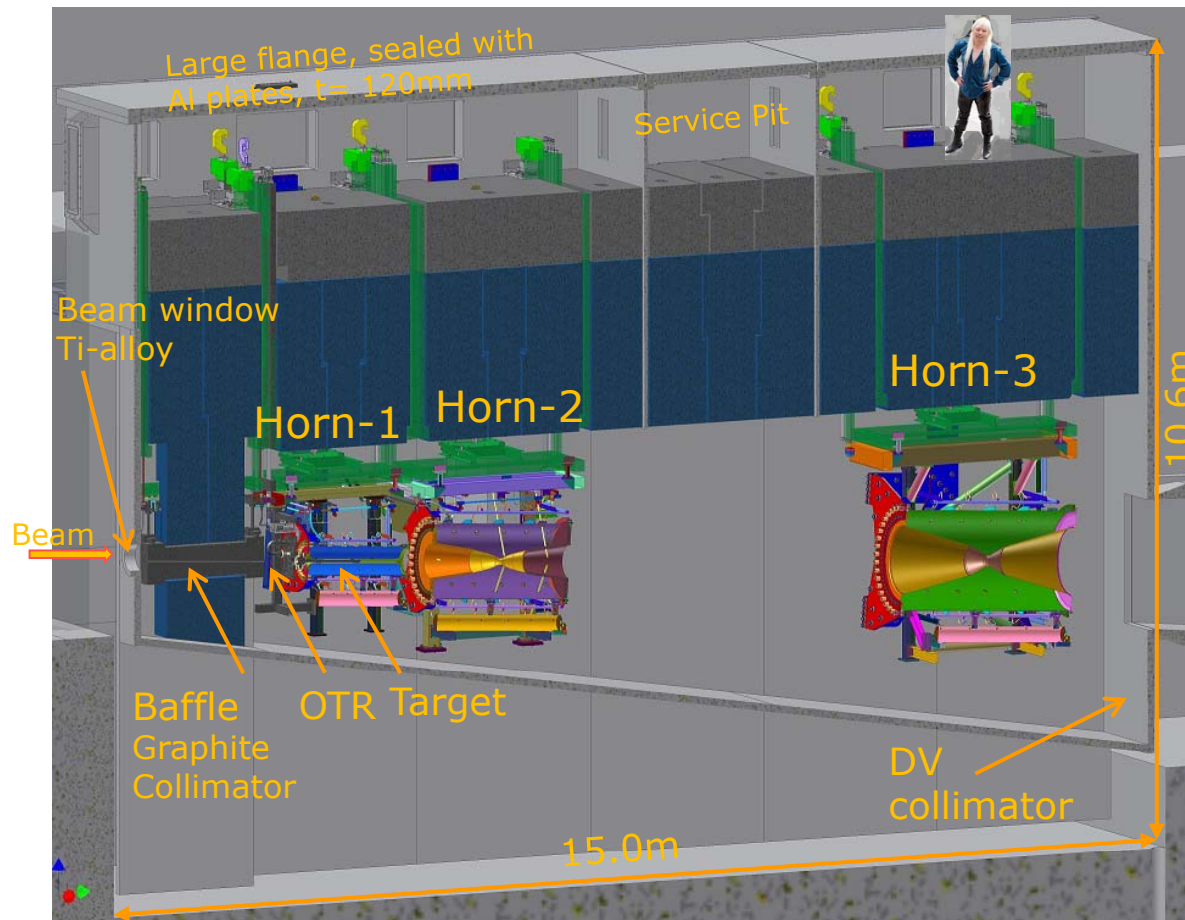


- Target Station(TS), Decay Volume(DV), & Beam Dump(BD)
 - ◆ TS: He-cooled graphite target, 3 magnetic horns, remote maintenance
 - ◆ DV: 94m-long tunnel with rectangular cross section
 - ◆ BD: hadron absorber made of large graphite blocks, surrounding iron shields
- Enclosed in a gigantic helium vessel, made of carbon steel plates.
 - ◆ He atmosphere prevents nitrogen oxide (NO_x) production / oxidization of apparatus.
- Iron plates of the vessel are cooled by water circuits.
 - ◆ Maintenance is not possible after beam operation due to irradiation.
 - ◆ Radiation shielding / cooling capacity were designed to accept up to $\sim 4\text{MW}$ beam.



Target Station (TS)

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- Horns / a baffle are supported from the wall of vessel by support modules.
- Apparatus on the beam-line are highly irradiated after beam. Remote maintenance is key issue.



Horns in the TS Vessel

Horn-2
[downstream]

Horn-3
[upstream]

remote
Connections
Horn ~ support

Clearances
~30mm

Supply helium ducts
covering bus-bars

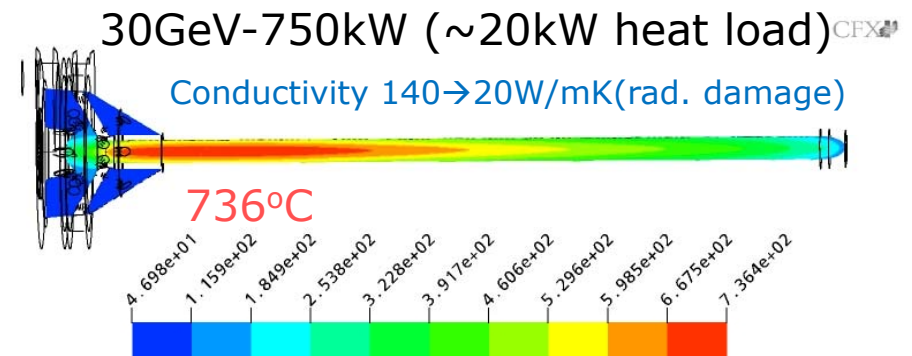
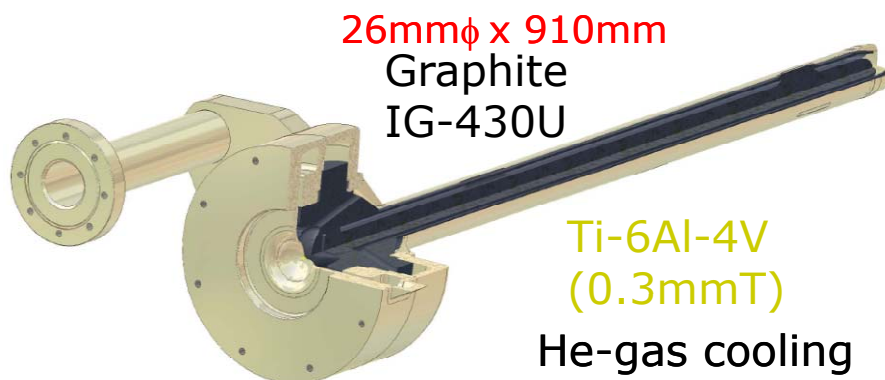
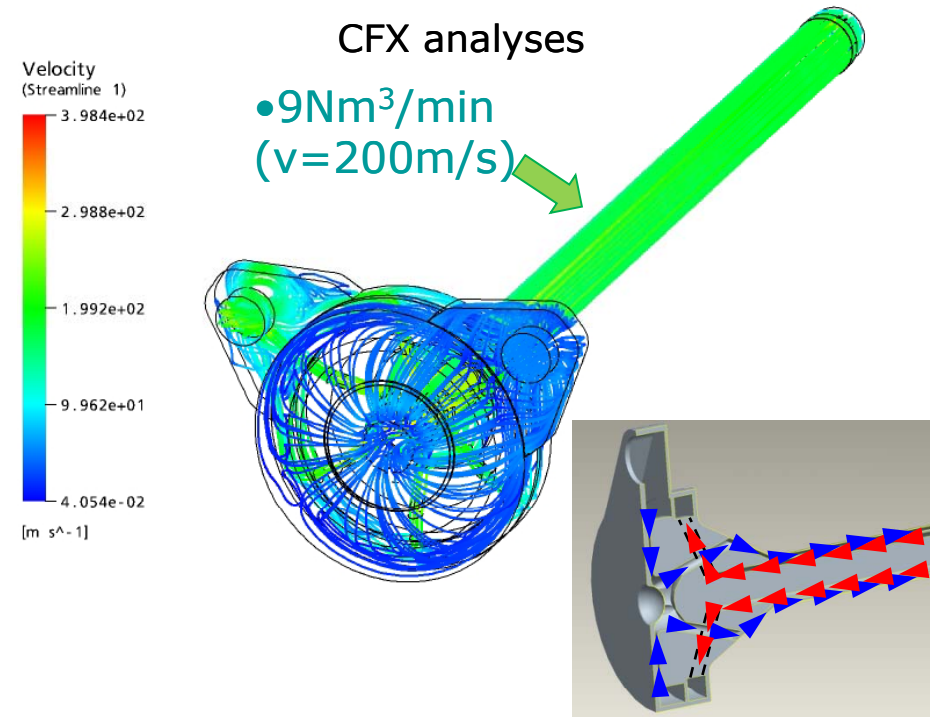
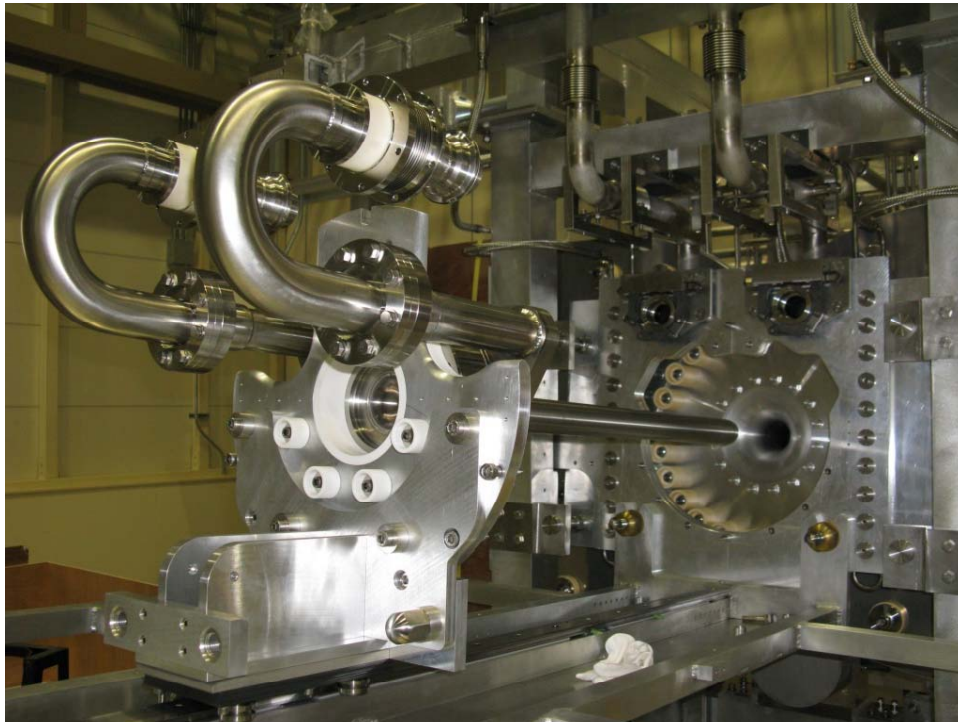
- Integrated # of pulses (~Run-3): ~8M
- Current stability ~2%
- Alignment precision of horns :
0.3mm(x), 1mm(y), 1mm (z-beam)

Photos on Sep., 2009 (before Physics Run)



T2K Target

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$\Delta T \sim 200\text{K}$ $\sim 7\text{MPa}$ (Tensile strength 37MPa)

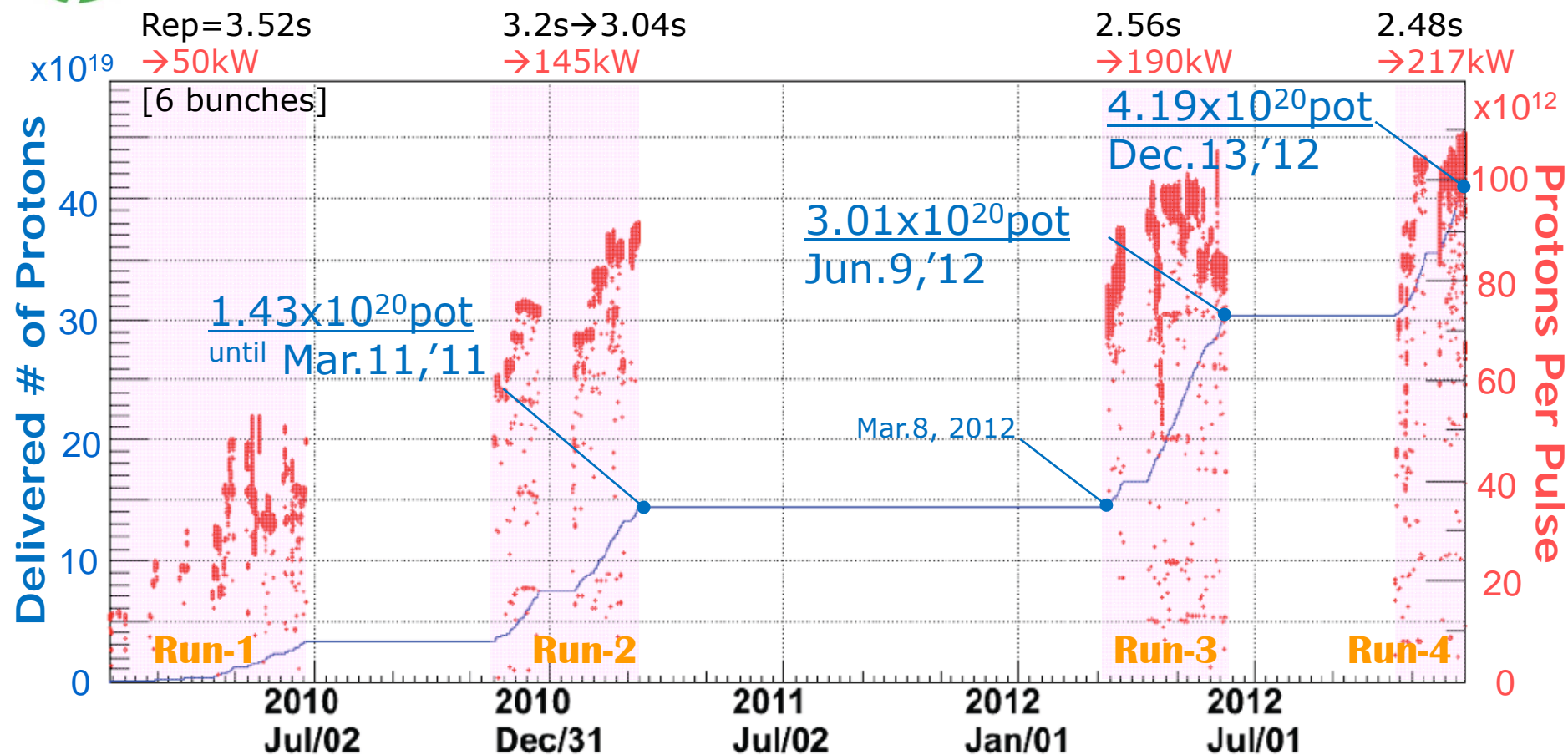


Recent Status of Accelerator / Beam-line Operation



MR Fast Extraction : Delivered POT to Neutrino Facility

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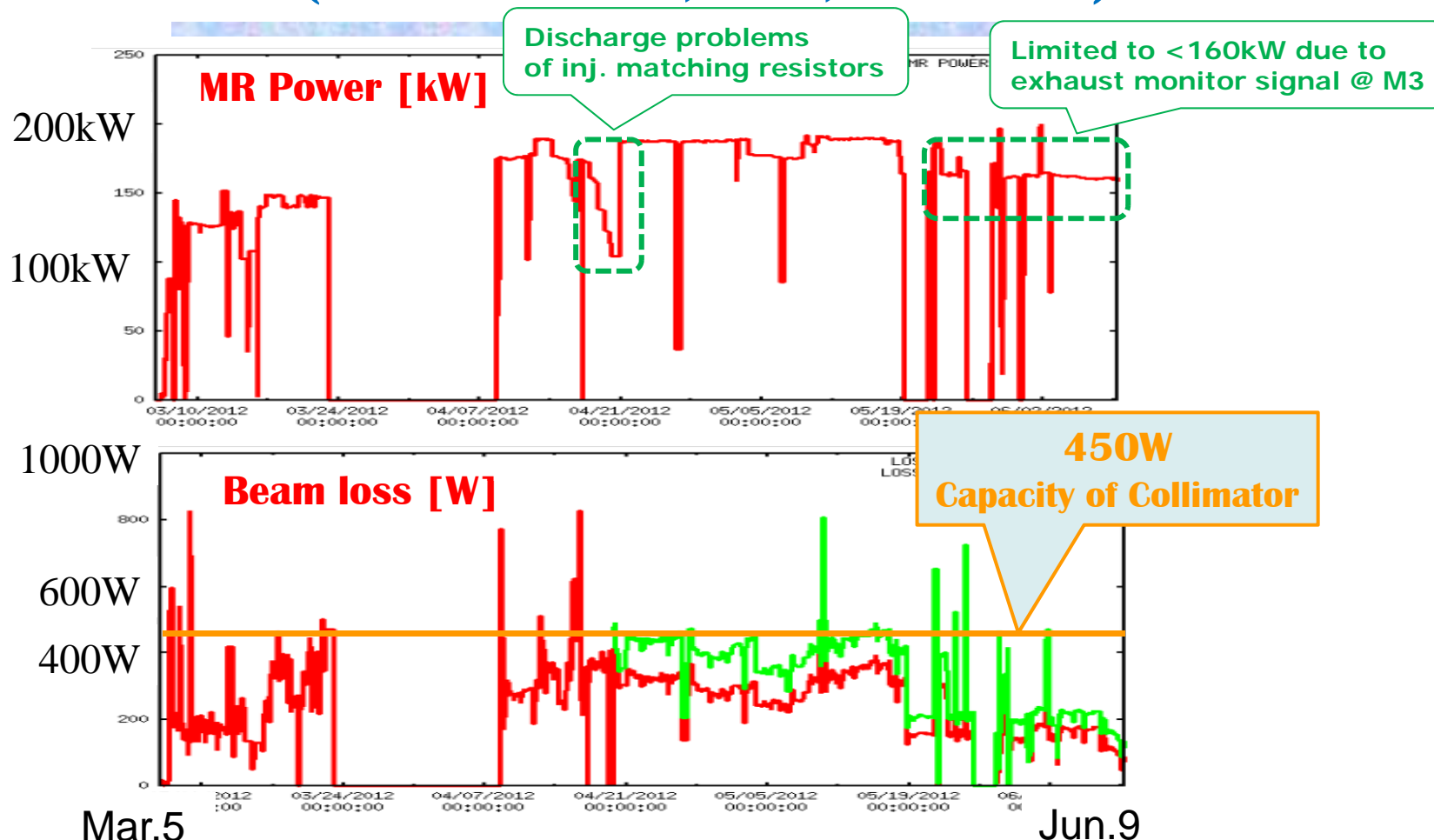
- Stable operation at $\sim 210\text{kW}$ achieved, $>1.0 \times 10^{14}\text{ppp}$ ($1.35 \times 10^{13} \times 8\text{b}$) is the world record of extracted protons per pulse for synchrotrons.
- Accumulated POT = $4.19 \times 10^{20}\text{pot}$



High power operation in FX mode

(March 5 - June 9, 2012, 160-190kW)

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- Delivered beam power limited by beam loss at injection/collimator section
- Ring collimator upgrade was being taken place during 2012 summer shutdown.
The capacity is now enlarged from 450W to 2kW.
- The 9th RF system (2nd harmonic cavity to reduce space-charge effect) installed.

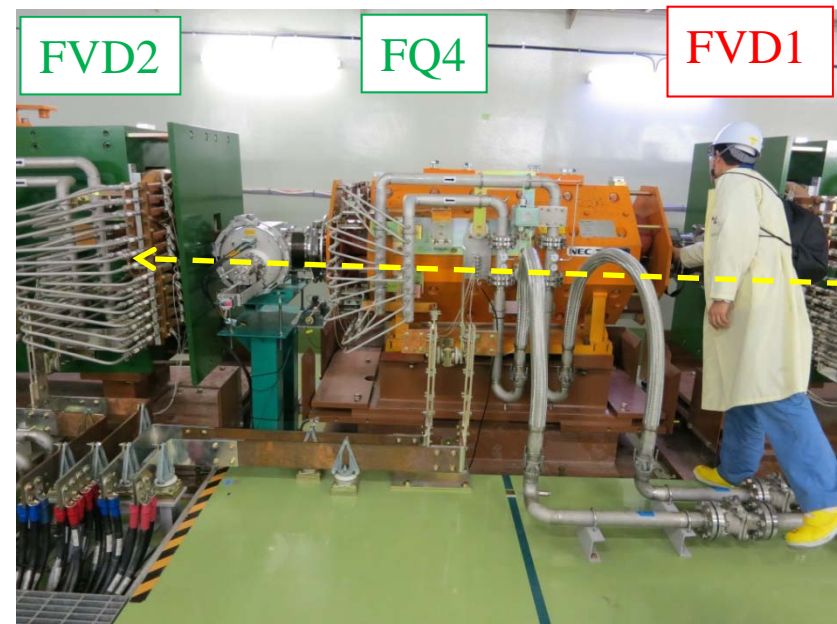
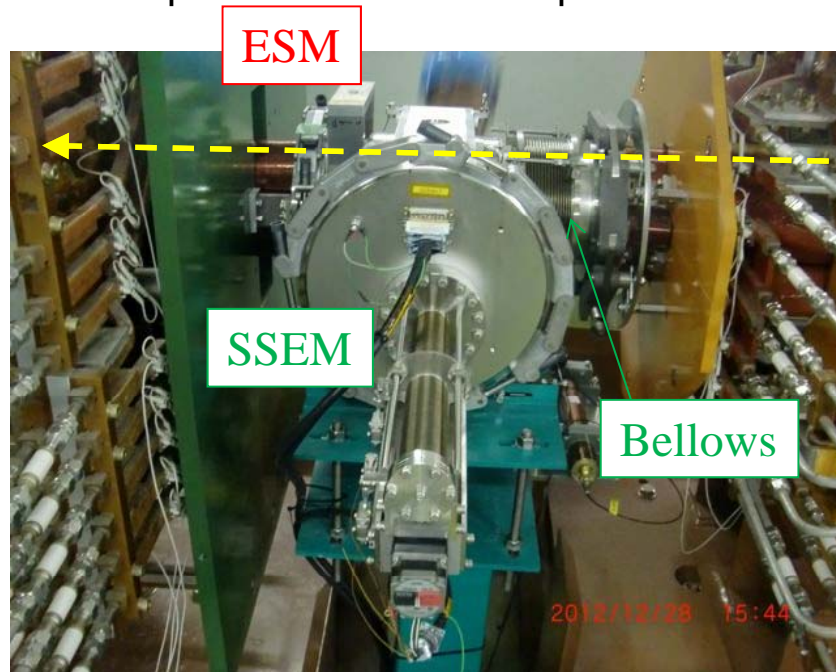


Vacuum Leak at Primary Beam-line

[Dec.12, 2012]

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- Final Focusing Section: 4xQ / 1x(H+Steering) / 2x(V+Steering)
- Trouble happened **during beam tuning** to increase power (210→217kW)
 - ◆ Unexpected turning-off of 1 bending magnet (FVD1, 25mrad bend) without alarm.
 - ◆ Beam hit the beam duct and beam monitors (SSEM/ESM).
 - ◆ The vacuum leak at a feed-through of ESM.
- Fixing work was completed during new-year holidays.
 - ◆ Replace the broken ESM by spare. Vacuum is now low enough for beam operation.
- Countermeasure
 - ◆ Improve the machine protection interlock (MPS) during the beam tuning.



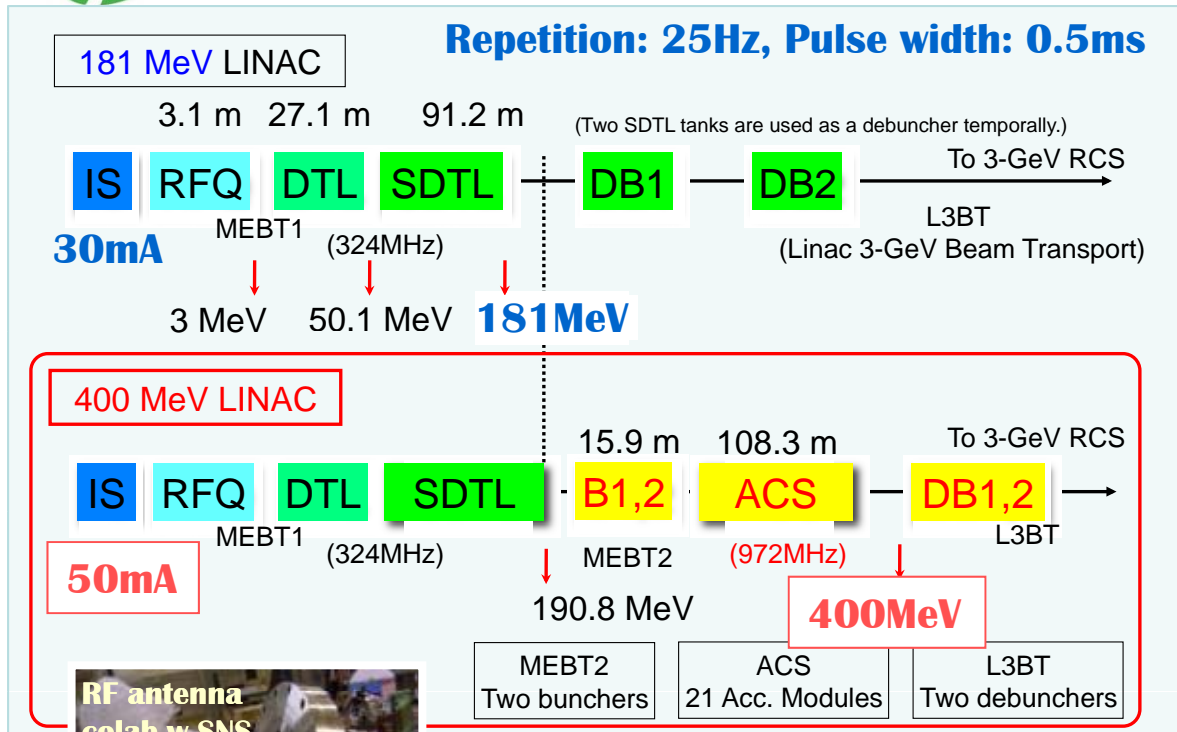


Beam-line Upgrade for 750kW (future MW) Beam



LINAC Upgrade

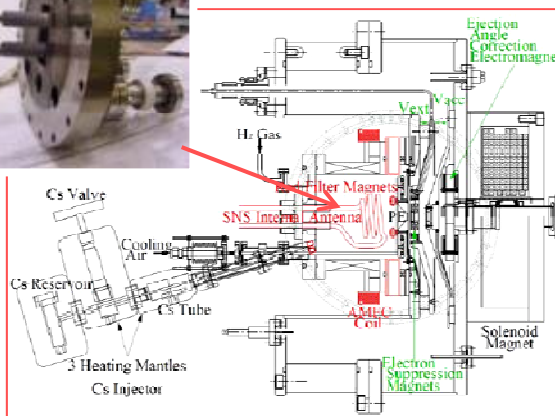
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■ New accelerating structure, ACS, will be installed to **increase** the extracted beam energy from 181MeV to 400MeV

■ Front-end part (IS+RFQ) will be replaced to **increase** peak current from 30mA to 50mA

■ These installations are **scheduled in 2013 shutdown**

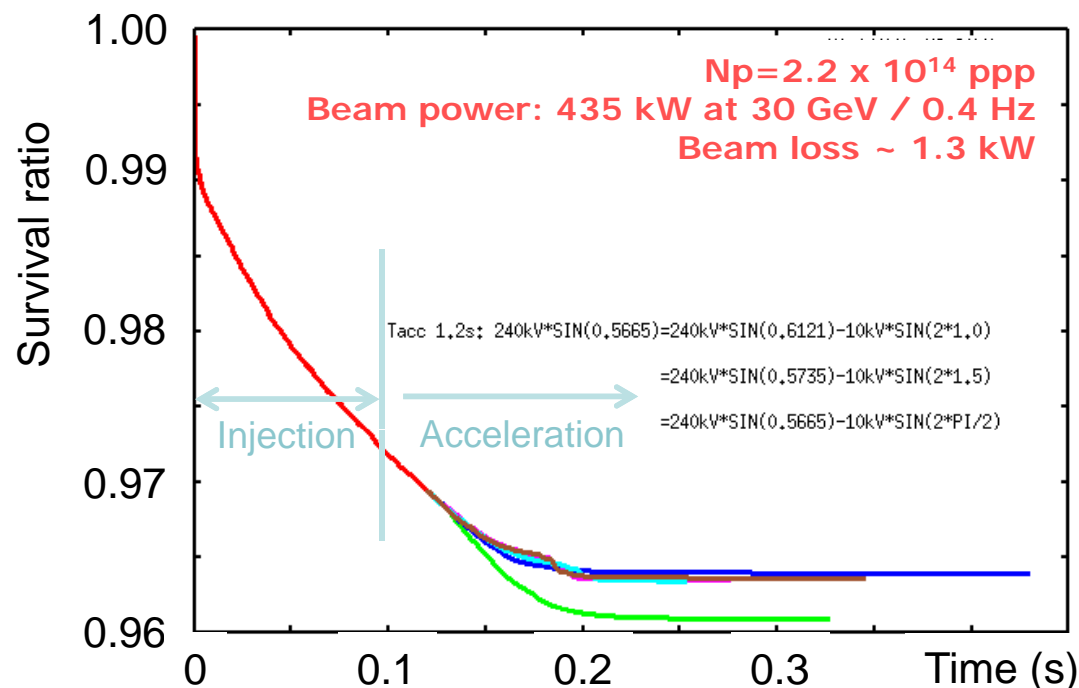




For Higher Beam Power in MR Fast Extraction

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Tracking simulation of the MR fast extraction with space charge effect



- Number of particles in one pulse is limited by the beam loss due to the space charge effect

◆ ~450kW is estimated upper limit with current apparatus

- To achieve higher beam power :

1. Higher beam energy than 30 GeV (Original plan)
2. **Higher repetition rate than 0.4 Hz**

* The saturation effect deteriorates field quality of main magnets.

Total power consumption:

$$P_{50\text{GeV}} = 2 \times P_{40\text{GeV}} = 4 \times P_{30\text{GeV}}$$

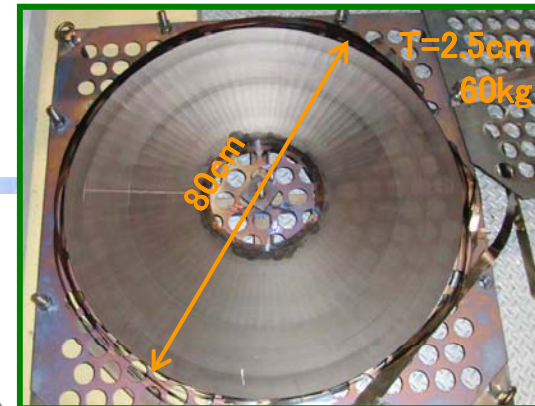
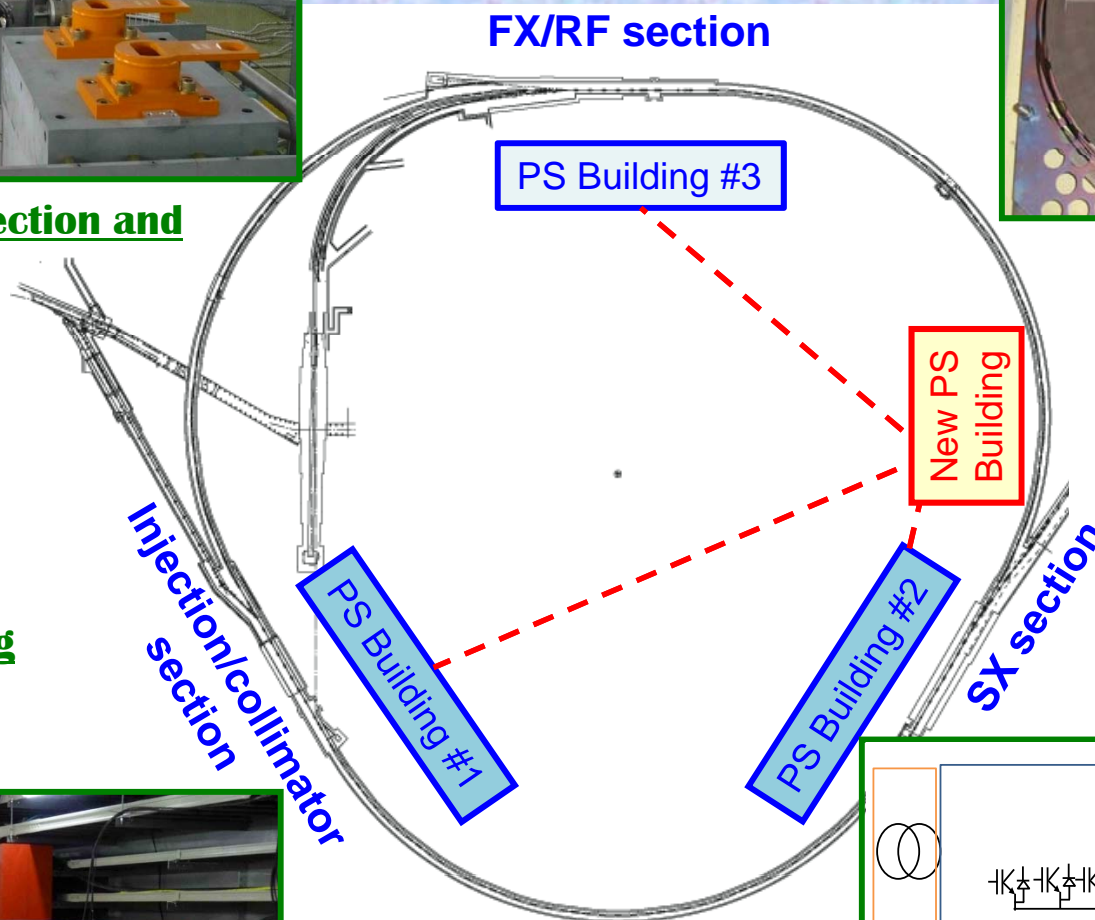


(3) Upgrade of injection and extraction devices

(4) Upgrade of ring collimator section
2kW→3.5kW



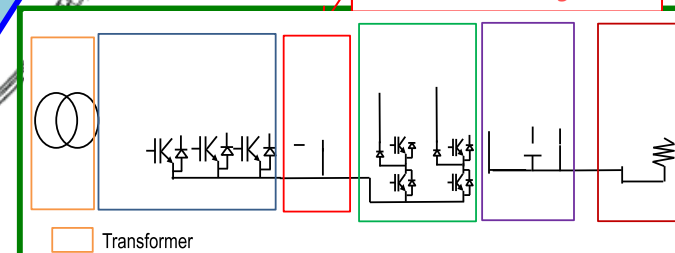
For 1 Hz Operation



(2) Replacement of the rf cavities

New magnetic core material, which has x2 times higher impedance than present one, is developed.

Condenser bank
For energy recovery



(1) Replacement

All the main magnet power supplies will be replaced with newly developed high rep./low ripple PS. A new PS building to be constructed.



The Medium-Term Plan of the MR-FX until 2017

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JFY	2011	2012	2013	2014	2015	2016	2017
			LINAC upgrade				
FX power [kW]	150	200	300	400			750
Cycle time of main magnet PS New magnet PS for high rep.	3.04 s	2.56 s	2.4 s	<div> <div>R&D</div> <div>Manufacture installation/test</div> </div>			1.3 s
Present RF system New high gradient rf system	Install. #7,8	Install. #9	<div> <div>R&D</div> <div>Manufacture installation/test</div> </div>				
Ring collimators	Additional shields	Add.collimators and shields (2kW)	Add.collimators (3.5kW)				
Injection system FX system	New injection kicker	<div> <div>Kicker PS improvement, Septum 2 manufacture /test</div> <div>LF septum, PS for HF septa manufacture /test</div> </div>					

- Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities
- A new budget is needed for replacing MR main magnets.

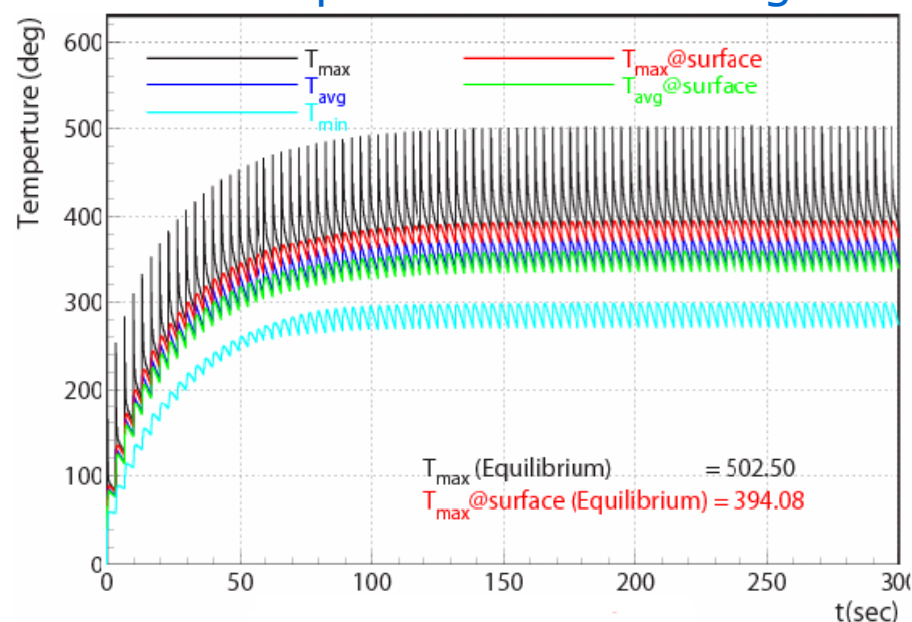


Doubled Rep.rate: Impact to Neutrino Facility ?

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- **Instantaneous thermal shock** will be reduced for equipments directly exposed to beam (Target, beam window, profile monitor, beam dump etc.)
 - ◆ Target: $\Delta T = 200\text{K/spill}$, $\sigma_{eq} = 7.2\text{MPa}$ @ $750\text{kW}(30\text{GeV}, 3.3 \times 10^{14}\text{ppp})$
 - ◆ Safety factor = ~ 3.5 for original rep.rate.
 - ◆ Cyclic fatigue may be severer.
- **Total heat load will stay same.**
 - ◆ **Apparatus designed for 750kW**, except for beam dump/decay volume (3MW/4MW).
 - * Over 750kW beam, need to reinforce cooling capacities
 - Need to upgrade all cooling machineries in the utility buildings (such as heat exchangers, pumps...)

Temperature of the target





Doubled Rep.rate:

Impact to Horn / Horn PS ?

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- For 1 Hz operation, dual or preferably triple PSs are necessary.
 - ◆ Reduce input load of each PS, greatly reduces risk of failure.
 - ◆ Open way to operate horns with (250kA →) 320kA.
- Cyclic fatigue
 - ◆ 1 Hz ~ 2×10^7 pulses/year \Leftrightarrow designed to survive 10^8 pulses
- Low inductance and low resistance strip lines.
 - ◆ Shorter, wider and narrower gaps.
 - ◆ Capacity for strip line cooling : 400kW → To be improve to 750kW.
- Hydrogen production in the horns
 - ◆ Recombination system installed at He gas line, while He gas in current horns cannot be circulated (only one port for He gas).
 - ◆ Spare horns have two ports and forced circulation is possible.
- Possible schedule
 - ◆ Production of new horns & striplines to be completed in 2013.
 - ◆ Replacement of horns to be completed within three years.

After replacing horns to new ones, ready for 1Hz- 750kW.

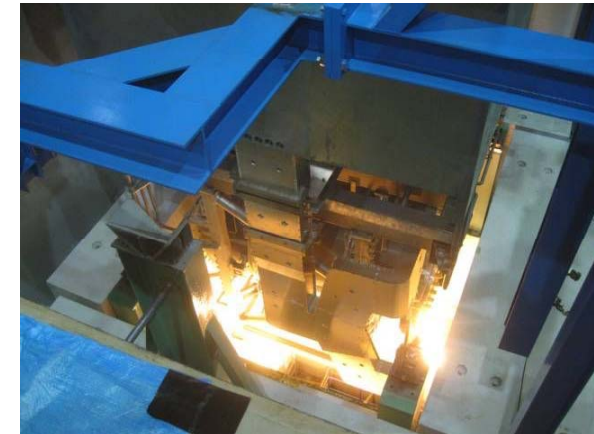


Remote Maintenance of Horn-3 [Summer, 2011]

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To maintenance area



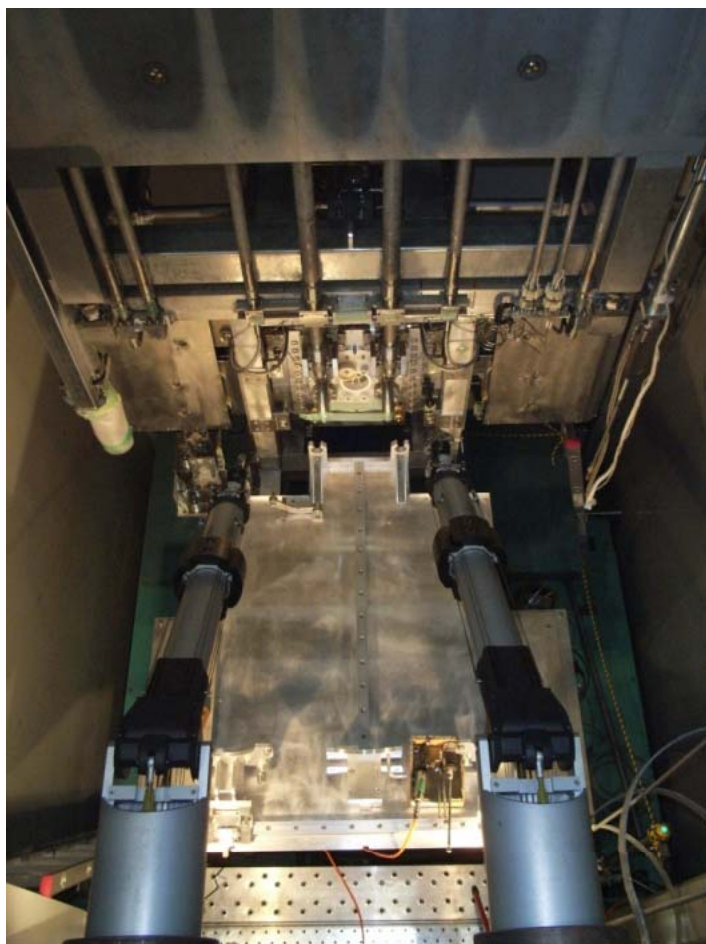
- **Positioning accuracy**
By crane : < 2 cm
With guide : a few mm
cf. clearance ~30 mm

- Scheme worked very nicely.
 - ◆ Only a few hours to move Horn-3 from vessel to maintenance area.
- Radiation level outside of TS became several x 10uSv/h at most (Horn: ~10mSv/h)
 - ◆ Need to add shields, redefine radiation controlled area at TS
- Horn stacked on the way back to vessel, due to interference with DV collimator support at downstream
 - ◆ Need better control for tilt of horn (by using counter weight etc.)

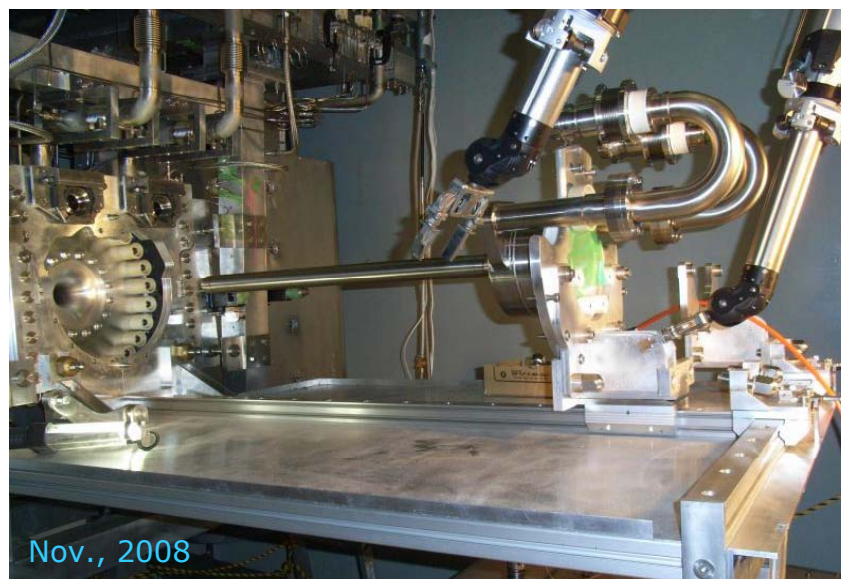
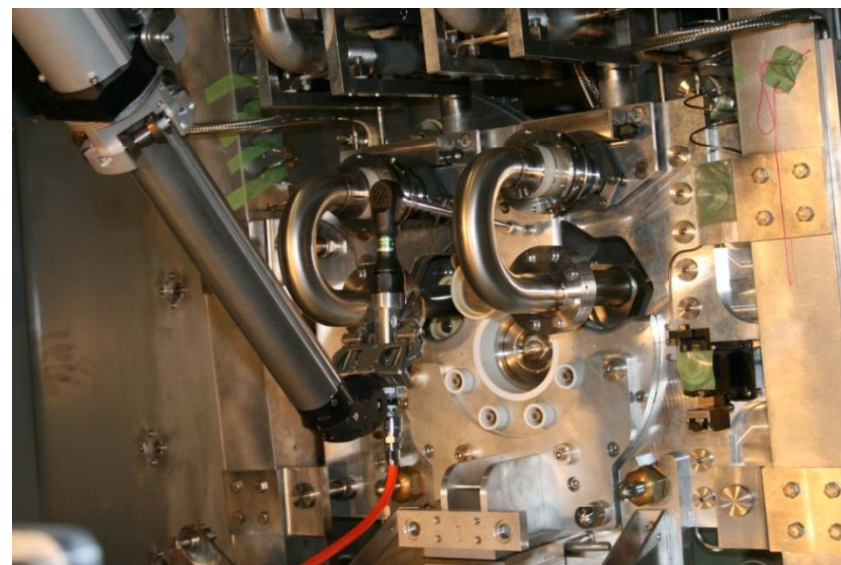


Target Remote Replacement

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- Remote maintenance area at TS
- R&D still on-going by RAL-KEK-TRIUMF

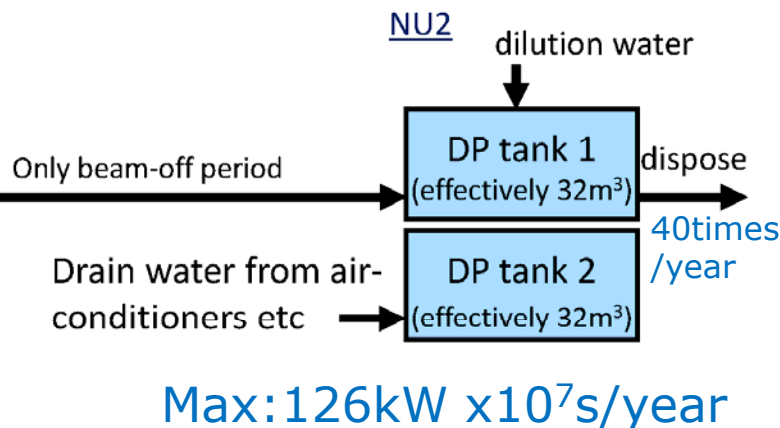
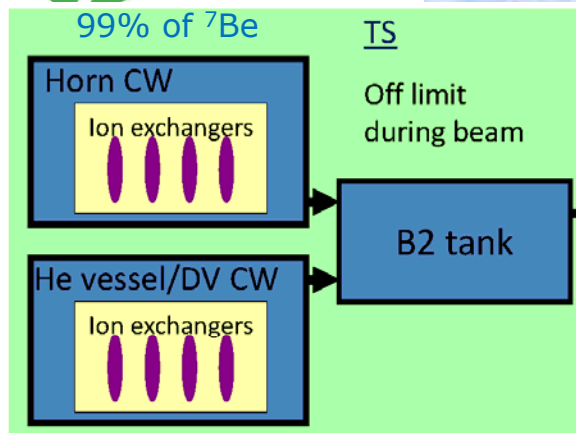


Nov., 2008

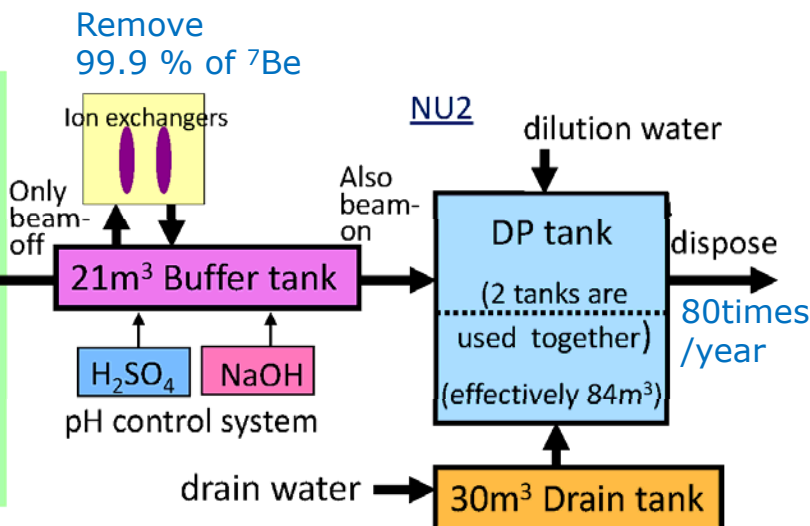
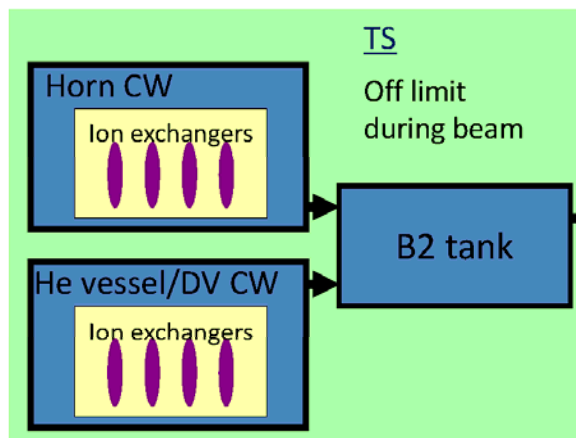


Upgrade for Radioactive Water Disposal

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- ^3H in disposed water must be <42Bq/cc
- For Run-2, 27GBq of ^3H produced.
 - ◆ 22dilution/disposal x 32m³ DP tank were performed.



- Upgrade allows 80 x 84m³ in a year.
- ^7Be in disposed water must be <1.2GBq/year
 - ◆ 0.52GBq for Run-2 with 99% reduction.
 - ◆ 99.9% required for 750kW.

The present limit of ^3H disposal corresponds to ~500kW beam.
Change of dilution/disposal cycle and/or tank truck are needed.



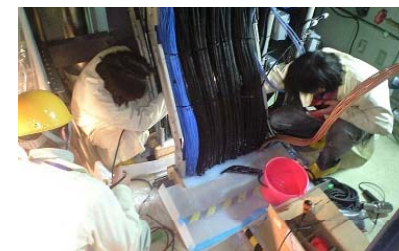
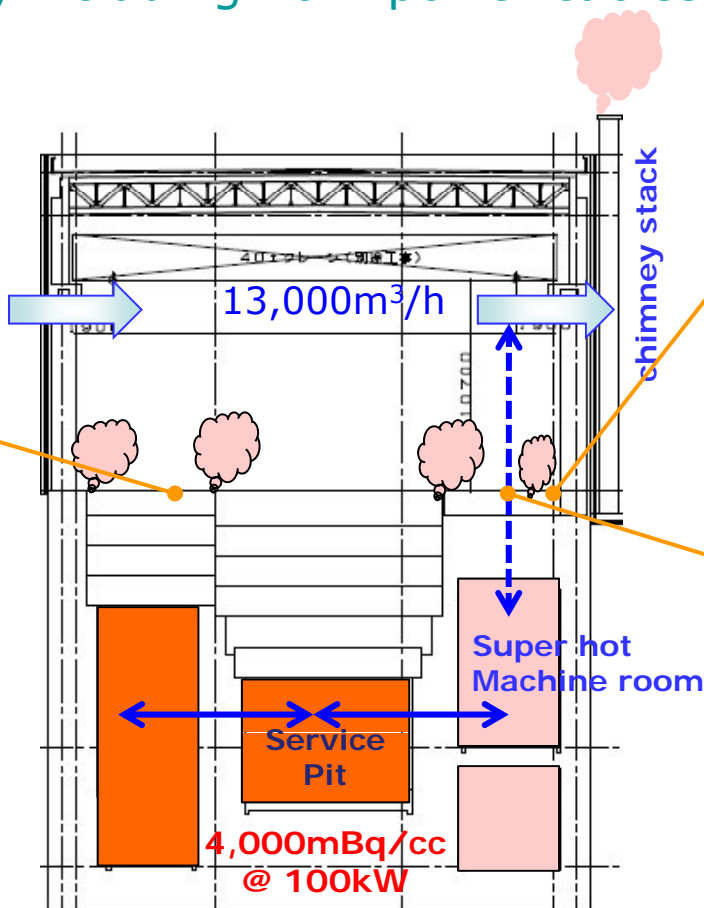
Radiation in TS Exhaust Air

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- Service pit / storage area covered with concrete blocks.
- More cable penetrations, including horn power cables.



Put backup material and caulking cover block surface by air-tight sheet



Silicon to cable holes/smoke tests



Doubled air-tightened dampers for exhaust lines



Radiation in TS Exhaust Air

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Radiation in exhaust air of TS was being the bottleneck of our beam power

	Observed	Acceptable <0.5m
2010 Jan.-Feb.	1.5mBq/cc (20kW)	~7kW
* Air tightening for floor blocks, seal cable penetration holes, & smoke tests		
2010 Feb.-Mar.	0.5(20)→0.8(27kW)	~17kW
* Add MVDs for ducts to underground rooms / cover block floor by water-proof sheets		
2010 Jun.	0.1~0.15(50kW)	170kW
* Add blocks to gaps at shield floor, upgrade of air-tightened doors		
2010 Nov.~2011 Feb.	0.28(105)→0.4(125kW)	160kW
* Add second layer of sheets		
2011 Mar.	0.3(145kW)	240kW
* Install bypass line to 1F vent line		
2012 Mar.~Apr.	0.13(145)→0.16(176kW)	550kW
* Balloon sheet installation		
2012 May.~Jun.	→ 0.1mBq/cc(190kW)	950kW

Acceptable beam is being improved by 2 order, now ~ 1MW



4. Summary

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■ Upgrade of J-PARC accelerators

- ◆ To increase #p/bunch
 - ▶ Increase MR collimator capability (2012 Summer; done)
 - ◆ Upto 450W → 2KW(2012) → 3.5kW(2013)
 - ▶ LINAC frontend upgrade (2013 Summer)
 - ◆ Ion source, RFQ : 30mA → 50mA
 - ▶ LINAC energy upgrade to 400MeV (2013 summer)
- ◆ To realize MR 750kW operation, doubled rep.rate option is chosen.
 - ▶ Need to replace all magnet power supplies in ~5yrs
 - ▶ Need higher gradient RF core.

■ Upgrade of Neutrino beam-line

- ◆ Doubled rep.rate: plausible to reduce thermal shock(target/beam-window...)
- ◆ Horn : dual / triple PS operation is necessary.
- ◆ Need to improve strip lines and their cooling (current limit: 400kW)
- ◆ Current horns to be replaced in 3 yrs. Need to establish remote maintenance.
- ◆ Radioactive drainage: improved to manage ~500kW.
- ◆ Exhaust air at TS : Two order of magnitude improved, now ~950kW.