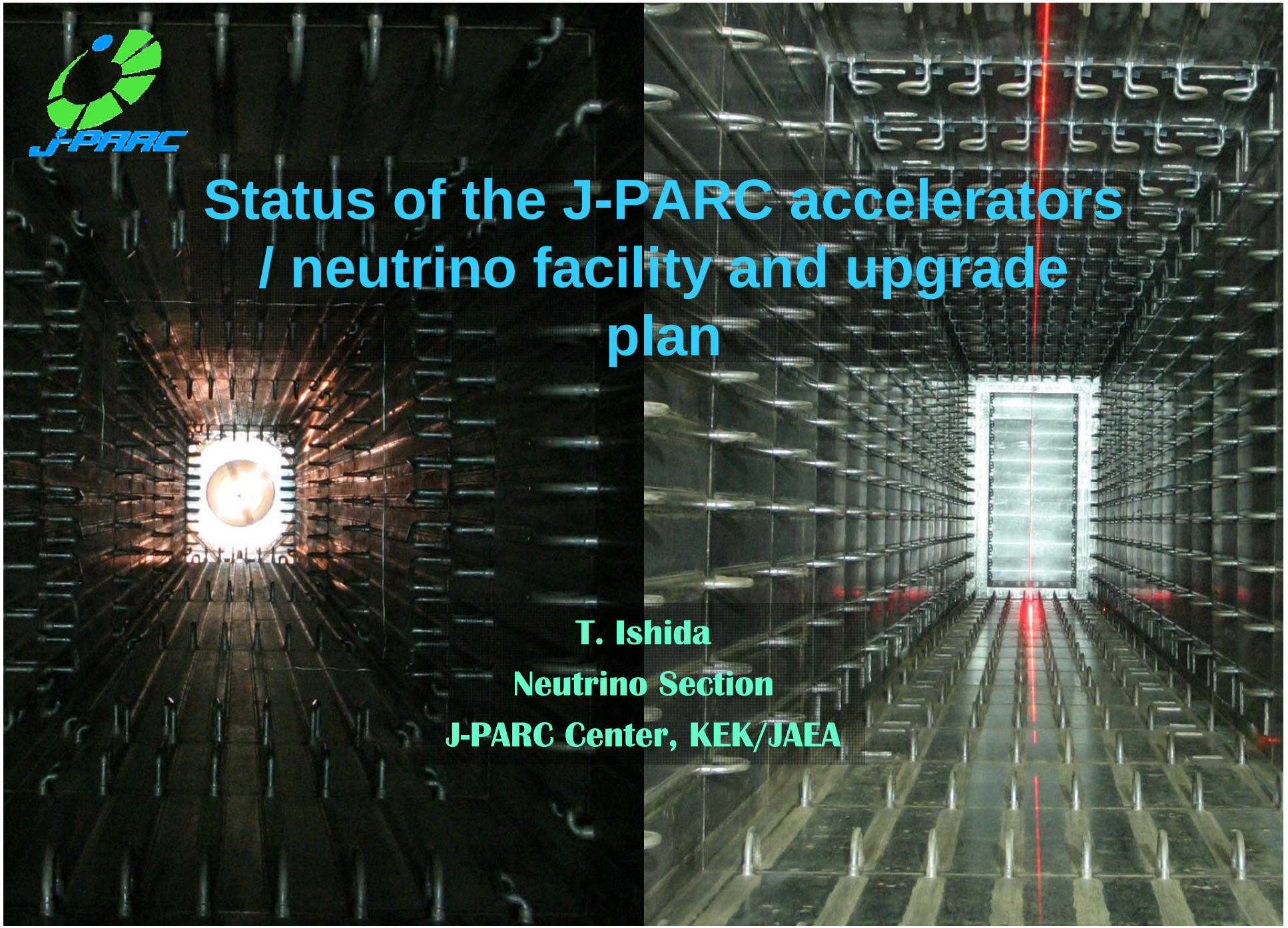

Status of the J-PARC accelerators / neutrino facility and upgrade plan

T. Ishida

Neutrino Section

J-PARC Center, KEK/JAEA

Contents

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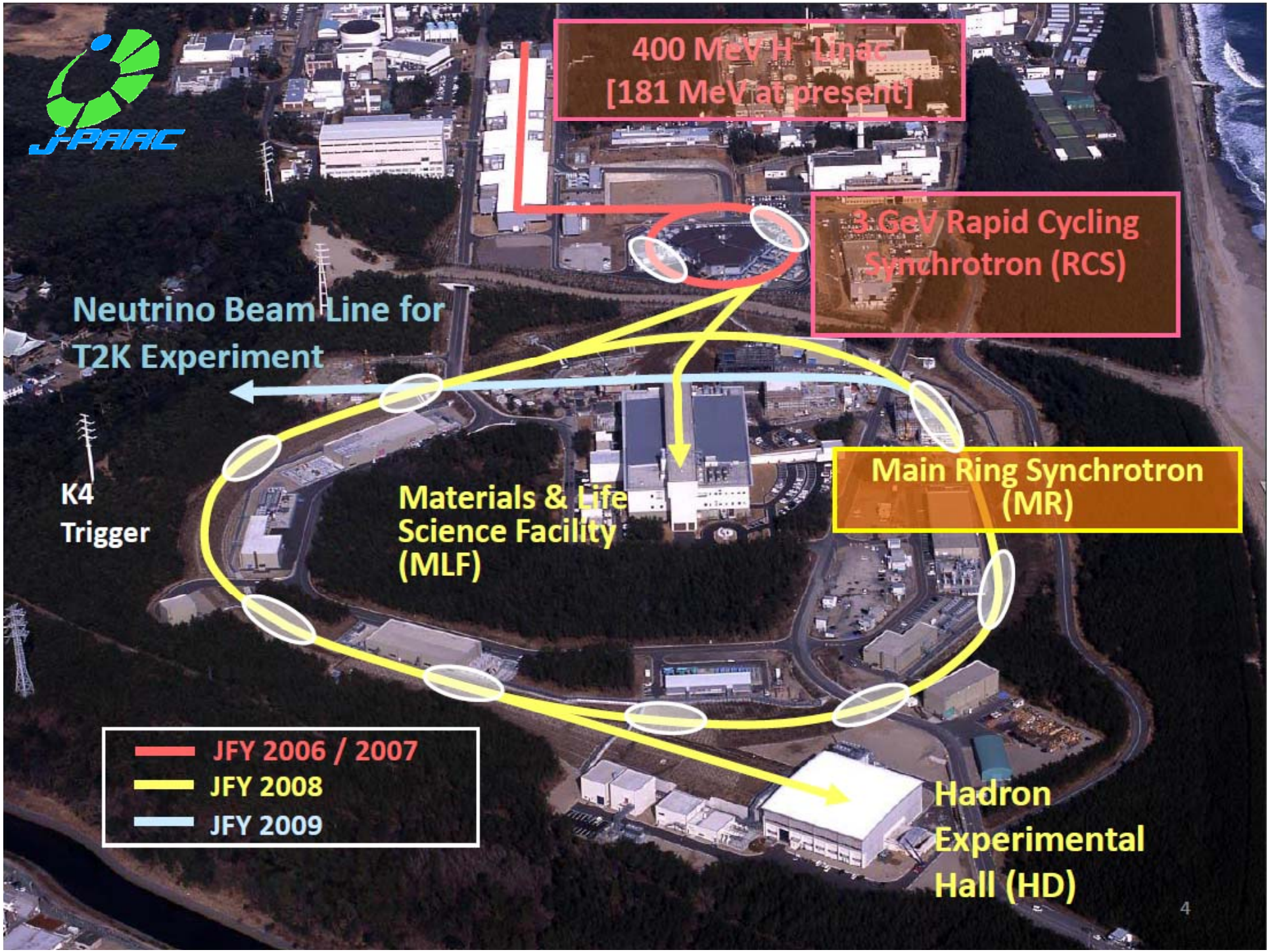
- Status of the accelerators
- Prospect of the medium-term plan (2013-2017)
- Status of the neutrino experimental facility and upgrade plan
- Summary

- Materials courtesy
  - Accelerator division colleagues
    - T.Koseki @ T2K collaboration meeting, Oct.3, 2013
    - Y.Sato @ Neutrino frontier WS, Dec.7, 2013
    - N.Yamamoto @ T2K collaboration meeting, Jan.23, 2014
  - KEK Beam-line group
    - M.Tada/T.Sekiguchi/Y.Yamada/Y.Oyama…
  - C.J.Densham (STFC RAL) @ Hyper-K EU OpenM., Dec.2013
  - …

Status of the Accelerators


J-PARC
400 MeV H⁻ Linac
[181 MeV at present]
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line for T2K Experiment
K4 Trigger
Materials & Life Science Facility (MLF)
Main Ring Synchrotron (MR)
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron Experimental Hall (HD)

History of beam delivery from RCS to MLF (May'08 – Mar'13)

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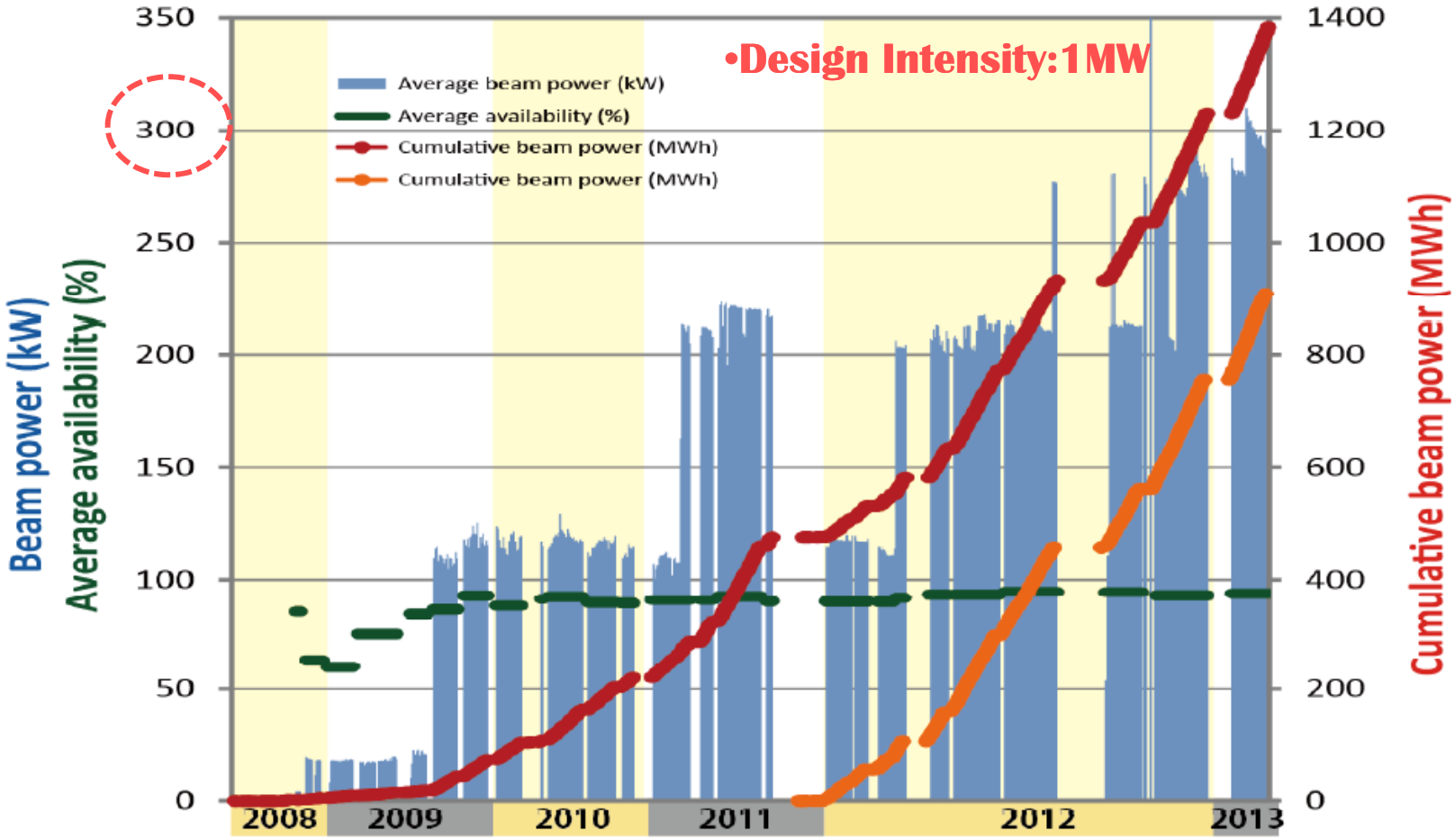

- Beam delivery of ~300kW started in Jan.2013.
- High power beam study performed in Apr.2013.
  - 556kW beam power was successfully demonstrated.

Delivered POT to neutrino facility

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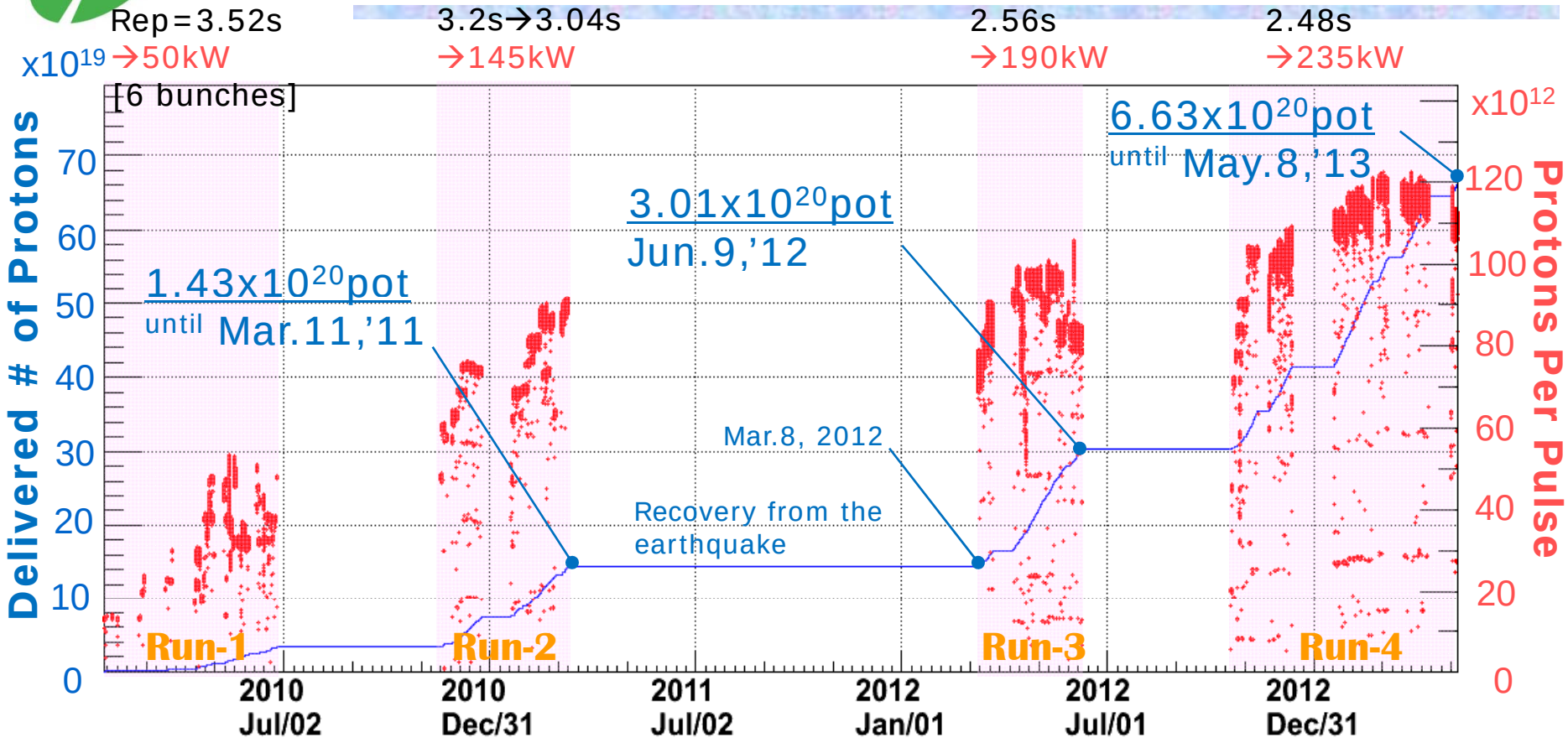

- Stable operation at ~220kW (235kW for trial)
  - >1.2x10^14ppp (1.5x10^13x8b) is the world record of extracted protons per pulse for synchrotrons.
- Accumulated *pot* : 6.63x10^20 by May.8 (6.39x10^20pot by Apr.12).
- Accumulated # pulses : 1.2x10^7, no replacements for horns/target

History + near-term upgrade plan of MR-FX (Dec.2011 - Mar.2015)

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Periods	Expected beam power	Improvements / Cycle time
Dec. 2011 → Jun. 2012	100 ~ 200kW (MLF : 300kW)	Cycle time 3.2s → 2.56s Beam loading compensation
Jul. 2012 → Sep. 2012	shutdown	Ring collimator upgrade (0.45 kW → 2 kW) 9th RF system
Oct. 2012 → Jul. 2013	200 ~ 250kW (MLF: 300kW)	Cycle time 2.48s Second harmonic cavities
Aug. 2013 → Feb. 2014	shutdown	[Linac upgrade] Ring collimator upgrade (2 → 3.5kW) Titanium chambers Injection kicker improvement
Mar. 2014 → Jun. 2014	220 ~ 250kW (MLF : 300 kW)	Cycle time 2.40s (2.32s)
Jul. 2014 → Sep. 2014	shutdown	[Linac front-end (IS+RFQ) upgrade] Titanium chambers
Oct. 2014 → Mar. 2015	220 ~ 400kW (MLF : 500 ~ 600kW)	Cycle time 2.40s (2.32s)

LINAC energy upgrade / works at RCS (2013)

- Upgrade of LINAC
  - 21 ACS cavities along with 2 bunchers and de-bunchers were installed.
  - Energy upgrade to 400MeV.
  - Front-end(IS/RFQ) test on-going for installation in 2014
  - Both critical for ~MW operation

- RCS
  - Realignment of magnets after the earthquake
  - Installation of new PS for Shift-Bump

MR Injection Collimator Upgrade

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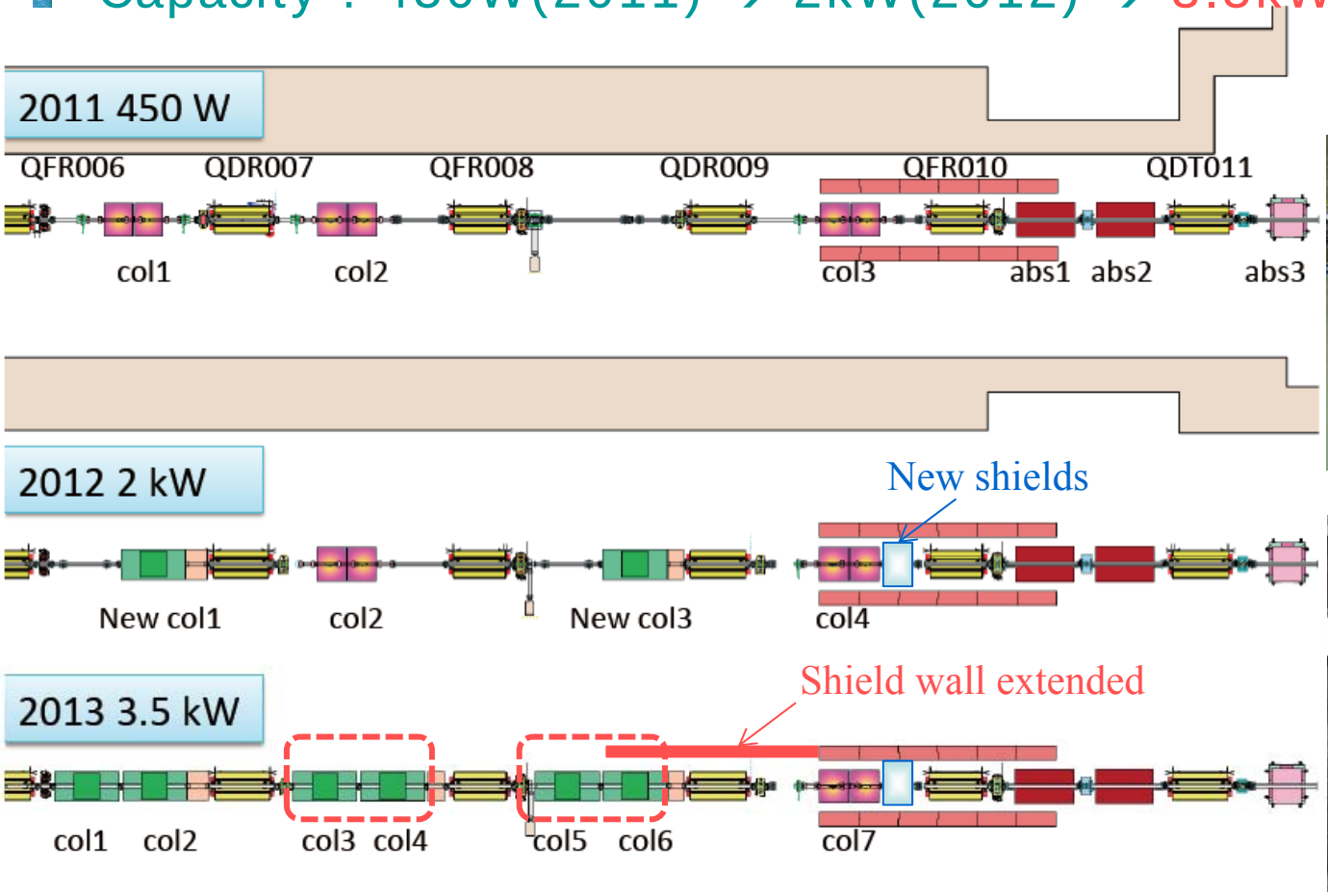
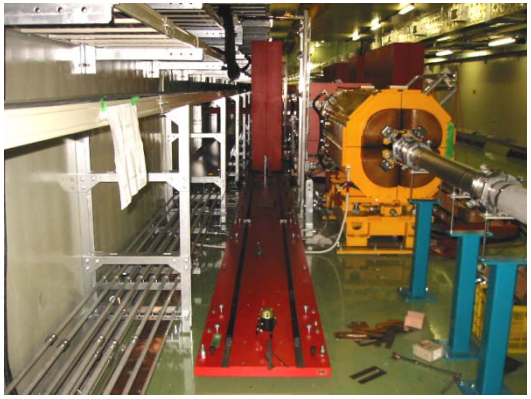
- Collimator #2 replaced by a new two-unit collimator
- Additional two-unit collimator installed.
- Capacity : 450W(2011) → 2kW(2012) → 3.5kW (2013)





Replacement of beam ducts

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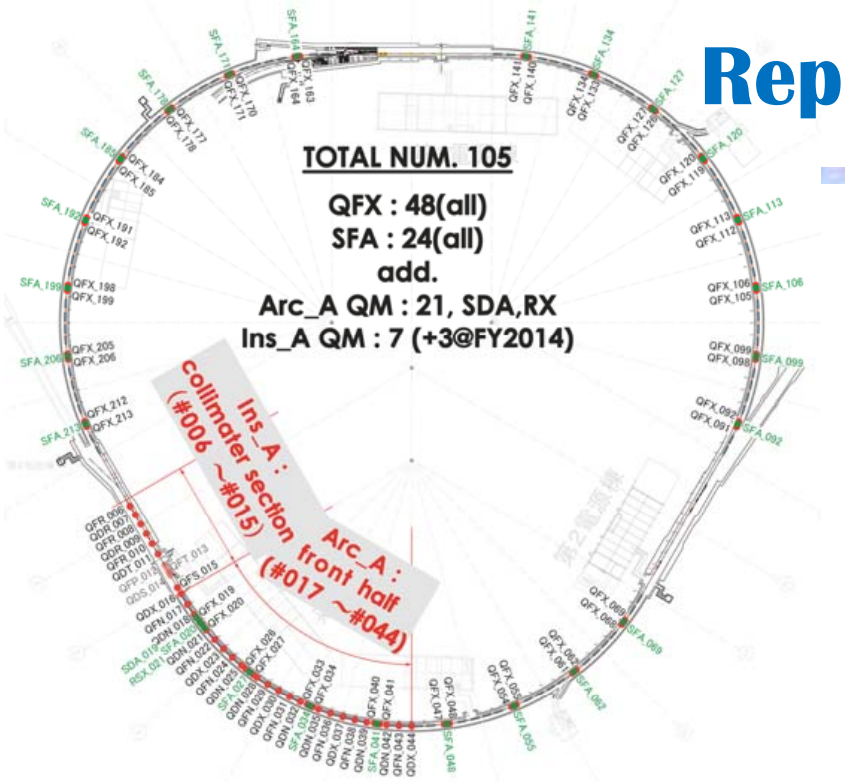

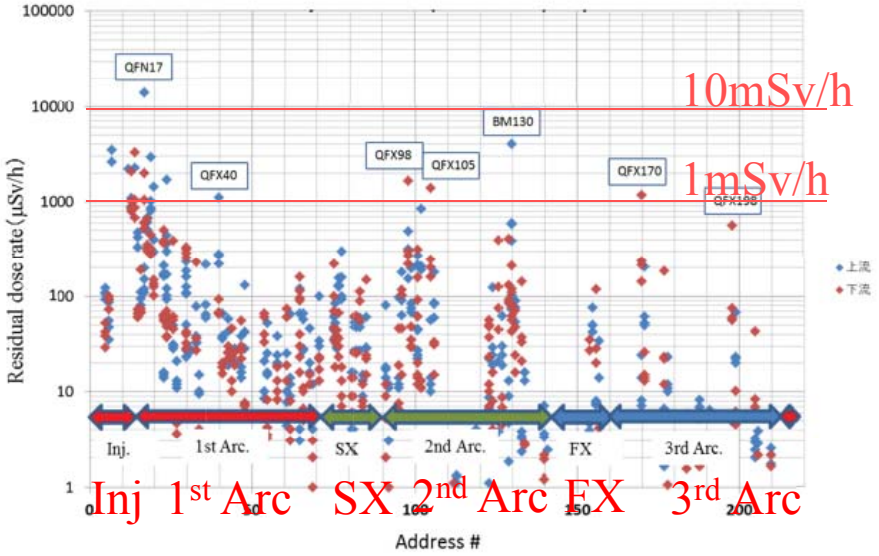

- Part of quad/sext beam ducts replaced with new ducts made of Ti
- For ones at dispersion peak in ARC section, horizontal aperture is enlarged.

Injection kicker improvements

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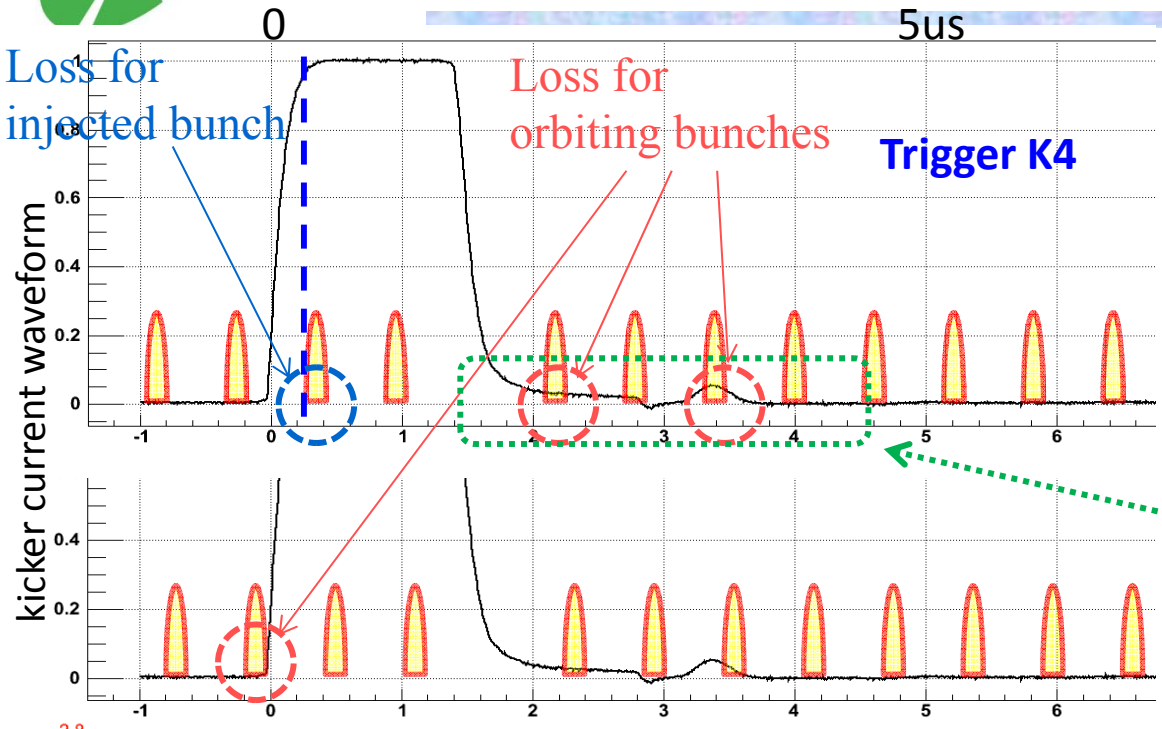
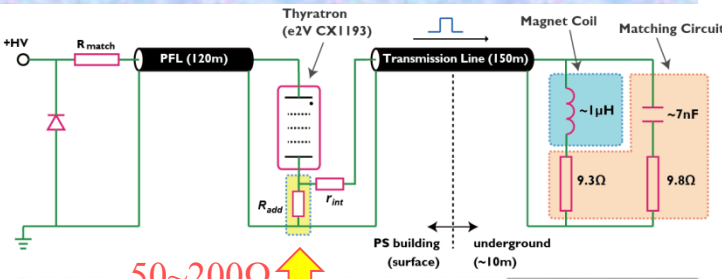
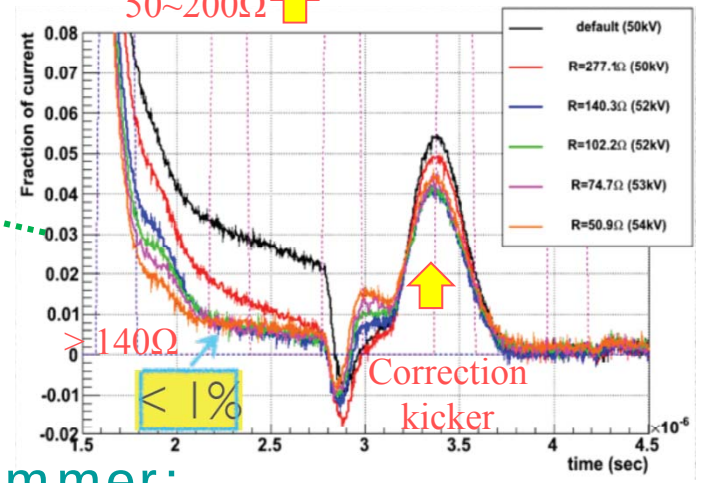
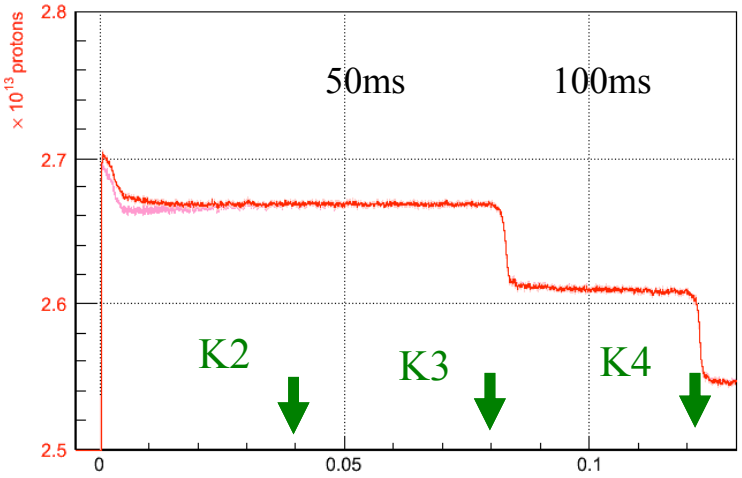




50~200Ω





- By 2013 summer:
  - Try to reduce current rise time (380ns) by optimizing matching capacitor : -60ns
  - Reduce tail in the waveform by introducing a resister to thyratron
- By 2014:
  - Introduce correction kicker magnet to compensate extra kicks at tail

Prospect of the medium-term plan (2013 - 2017)

Mid-term plan of Main Ring

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JFY	2011	2012	2013	2014	2015	2016	2017
			400MeV Linac	IS/RFQ			
Beam Power(FX)[kW]	150	200	240	250~400			750
rep. rate	3.04 s	2.56 s	2.48 s	2.40s	2.32s		1.3 s
New PS	R&D				construction/Test		
RF Cavity	#7,8	#9					
High Grad. Cav.	R&D			Production, Construction, Test			
Collimator	addition sheild	collimator (2kW)	collimator(3.5kW)				
Inj. & FX	New Inj. Kickers	Kicker PS rework/ New Septum construction					
Beam Power(SX) :[kW]	3	10	25	25~50			100
Collimator/ Shielding	SX Collimator	septa Power supplies					
Replace. Equi. made of Titanium		Sept. Mg. Endplate	ES septum	Local shielding			

- FX: rep rate: 0.4→ ~1Hz by replacing magnet PSs / RF cavities
  - A new budget is needed for replacing MR main magnet power supplies.

Power supply development

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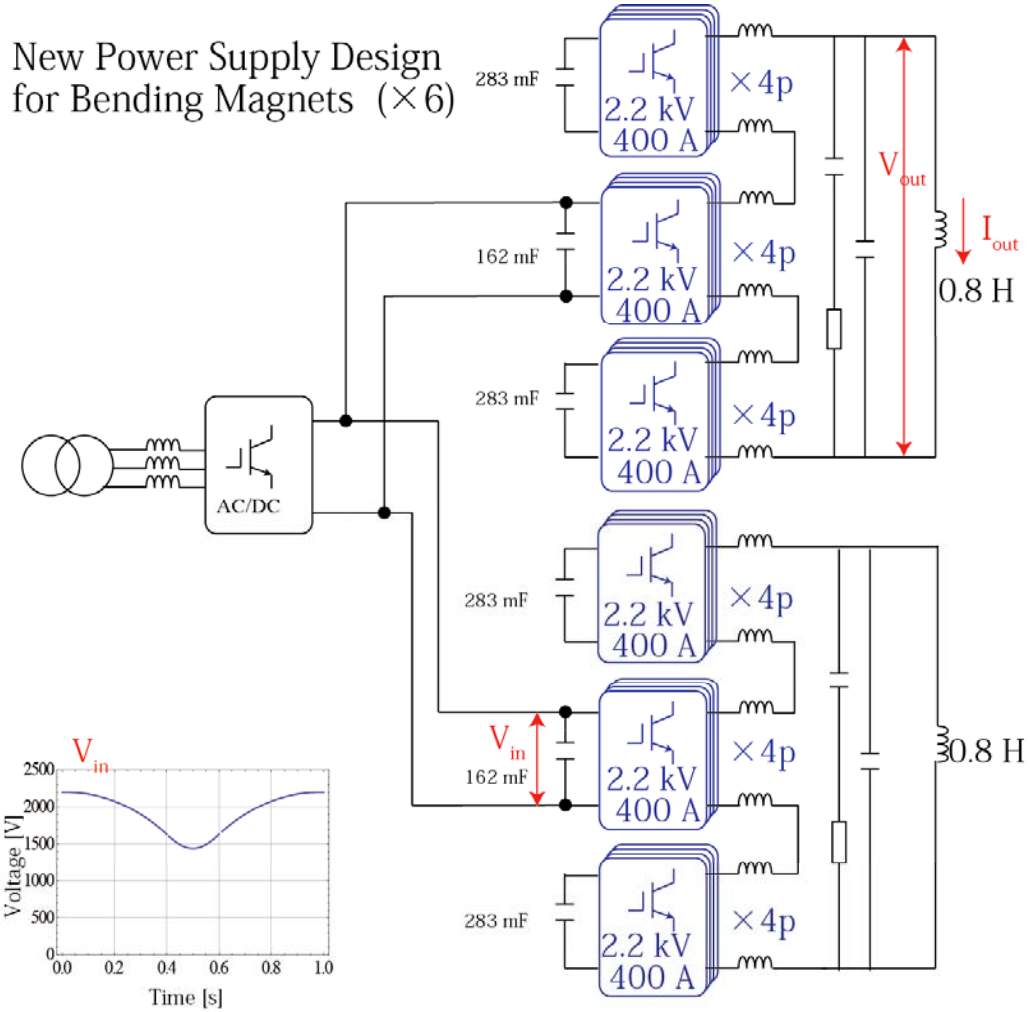

- Divide load to reduce output voltage
- Fast switching NPC Chopper(2 kV)
- Capacitor bank for energy recovery

- All technologic steps for mass production to be done in FY2014

High gradient RF system

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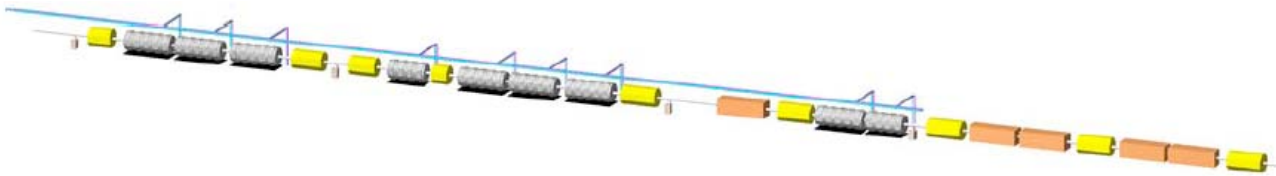
Current situation : 3gap X 9 = 27 gaps

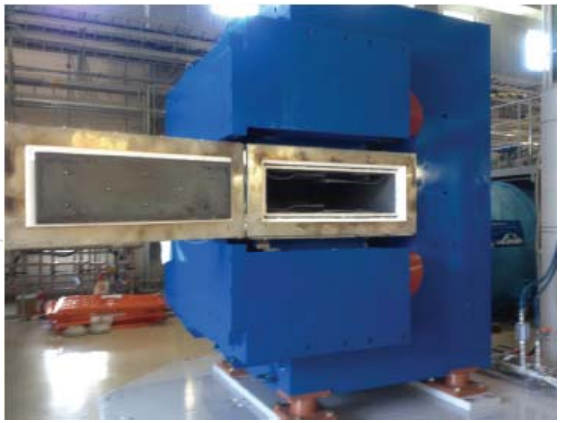
Total RF voltage ~ 270 kV

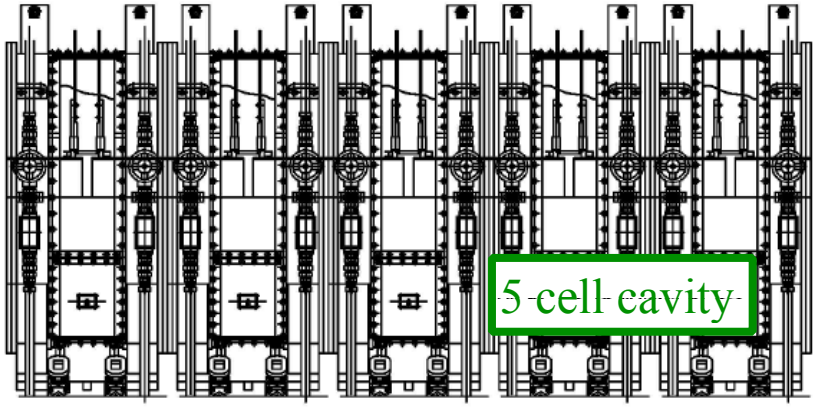


After replacement : 4gap X 2 + 5gap X 7 = 43 gaps

Total RF voltage ~ 450 kV + 20% margin

The mass production bench
(large magnet and oven)





- Mass production of the high impedance core (FT3L) started Jul.2013~ (Hitach material Co.)
- Ready to install in FY2015

Beam simulation
[Current Main Magnet PS / 2.4s]

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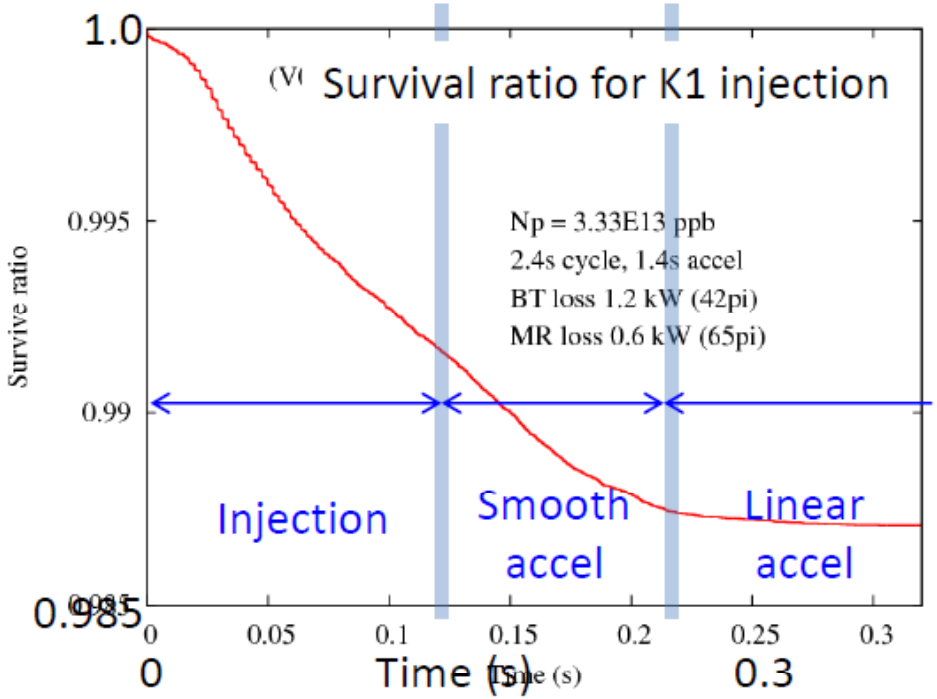

2.6E14ppp, 2.4s cycle,
1.4s accel, 0.88s decel
BT 1.2 kW loss (42pi cut),
MR 525 kW (65pi cut)
MR 0.49 kW loss

Fundamental RF: 100 kV ->240 kV
2nd harmonic RF: 70 kV

525kW

RCS conditions: 800kW, full errors, 400 MeV 100pi painted injection
MR conditions:
Bunching factor ~0.2 at injection
65pi cut, Alignment errors, measured multipole,
Sum resonance corrected (we have Skew Qs)
Chromaticity fully corrected, No instabilities

MR total loss is acceptable for maintenance.

Y.Sato

Beam Simulation
[New Main Magnet PS / 1.3s]

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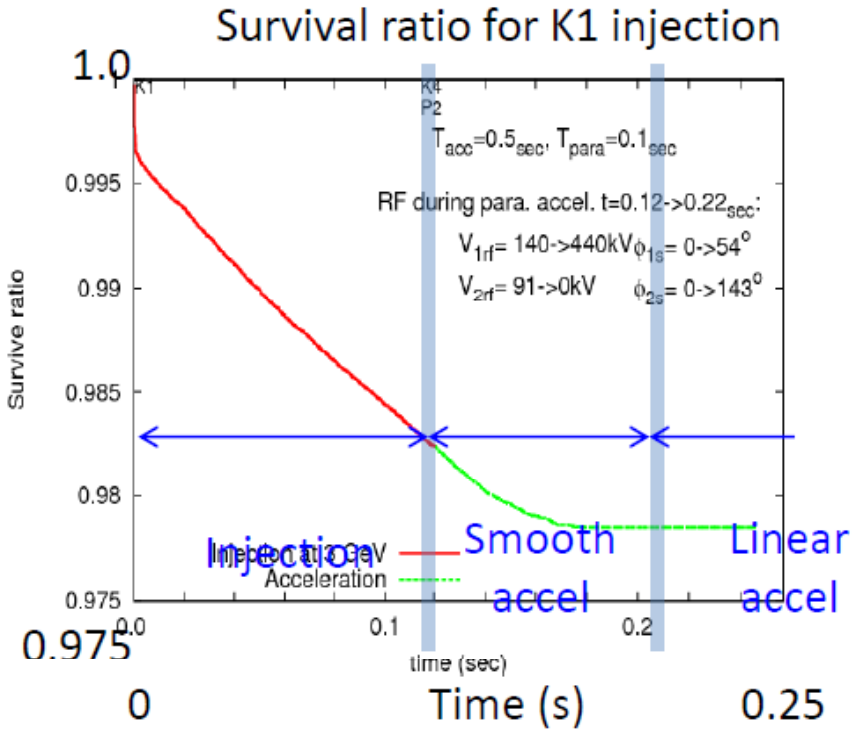

2.0E14ppp
1.3s cycle, 0.5s accel
BT 1.3 kW loss (60 pi cut),
MR 727kW (65pi cut)
MR 1.11 kW loss

Fundamental RF: 140 -> 440 kV
2nd harmonic RF: 91 -> 0 kV
During accel. Φ_2s >0

727kW

RCS conditions: 600kW, full errors, 400 MeV centered
MR conditions:
Bunching factor ~0.3 at injection
65pi cut, Alignment errors, measured multipole,
Sum resonance corrected (we have Skew Qs)
Chromaticity fully corrected, No instabilities

MR total loss is acceptable

Need to be very careful for beam-loss through residual dose measurements etc.

Status of the neutrino experimental facility and upgrade plan*

*: Very preliminary. Need to start investigation

The neutrino experimental facility

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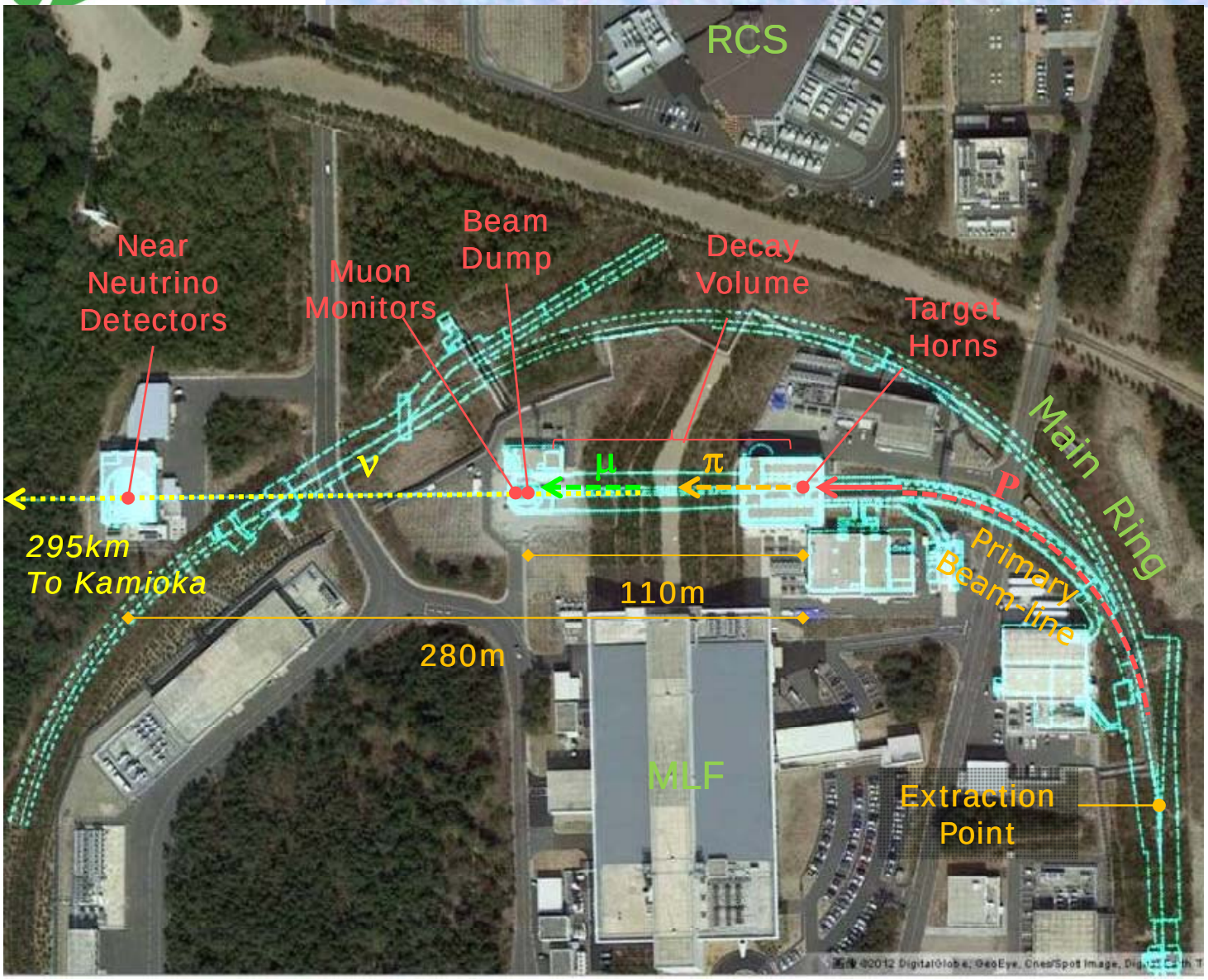

Secondary Beam-line

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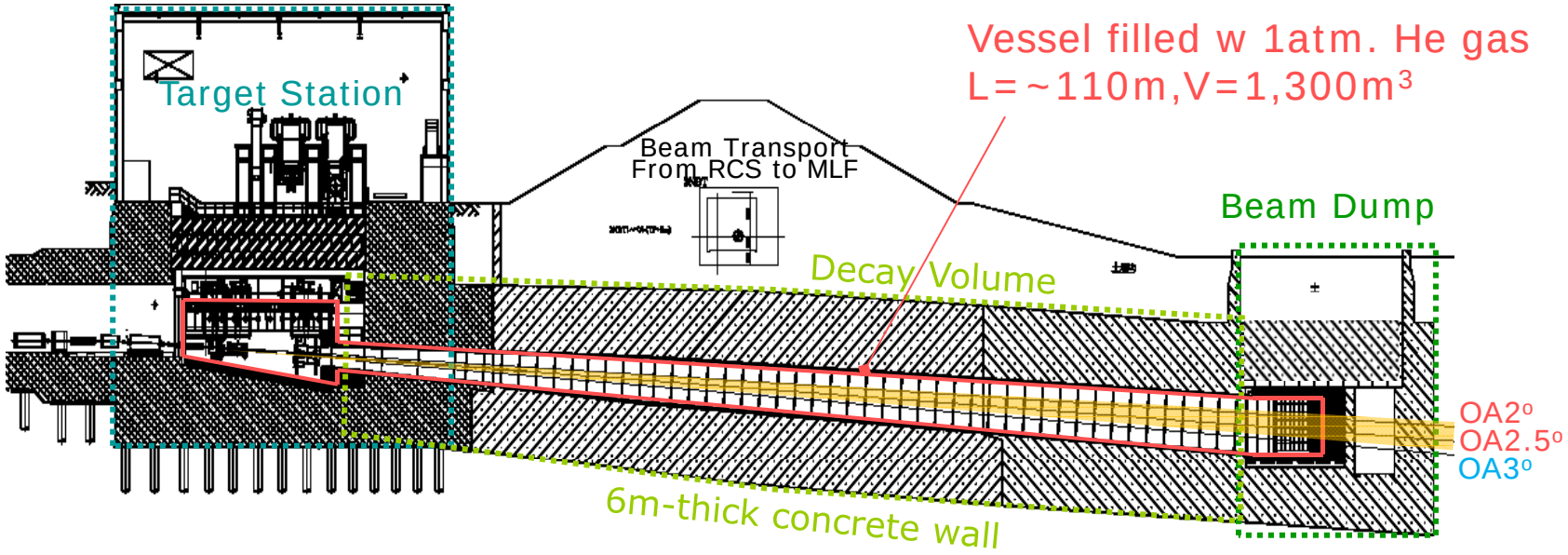

- Target Station(TS), Decay Volume(DV), & Beam Dump(BD)
  - TS: He-cooled graphite target, 3 magnetic horns, remote maintenance
  - DV: 94m-long tunnel with rectangular cross section
  - BD: hadron absorber made of large graphite blocks, surrounding iron shields
- Enclosed in a gigantic helium vessel, 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 ~4MW beam.

Target Station (TS)

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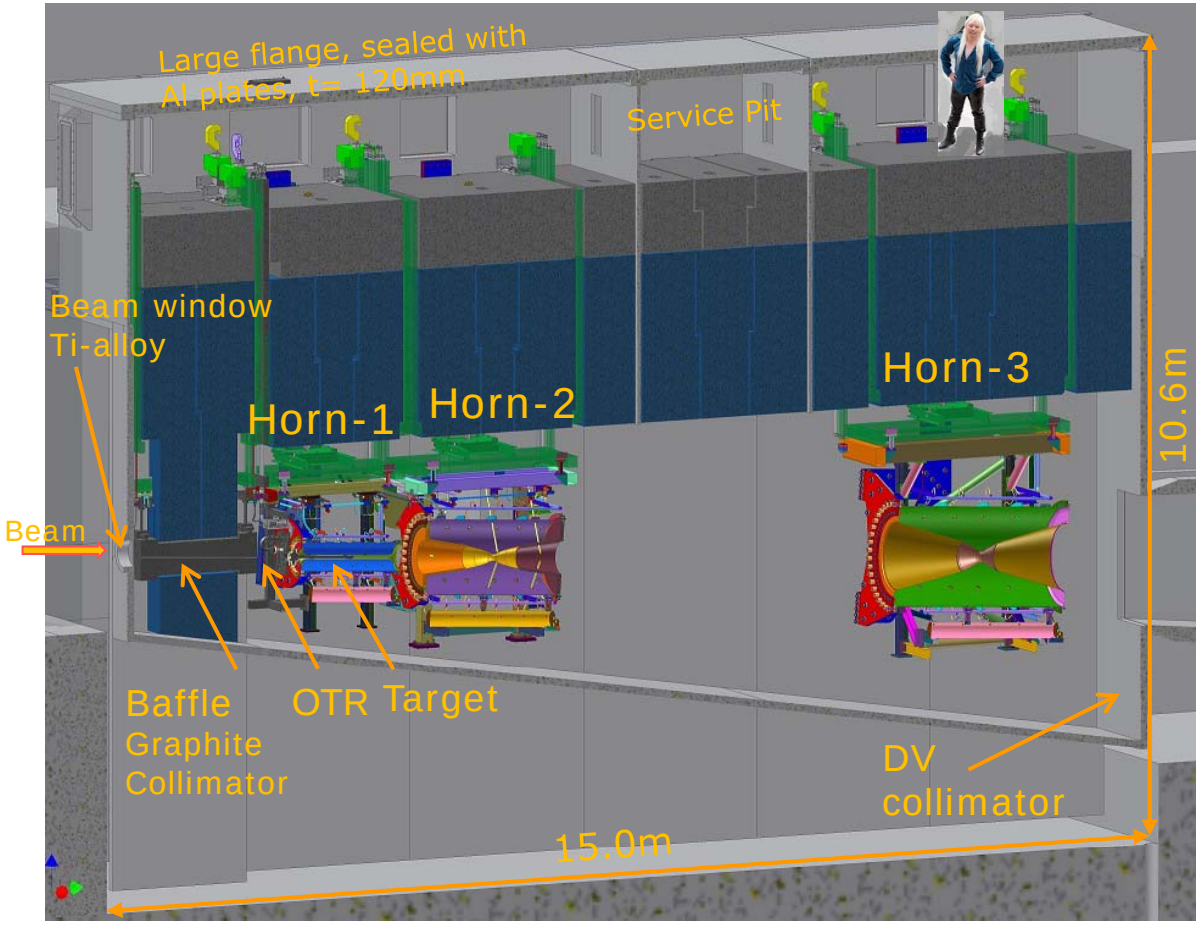

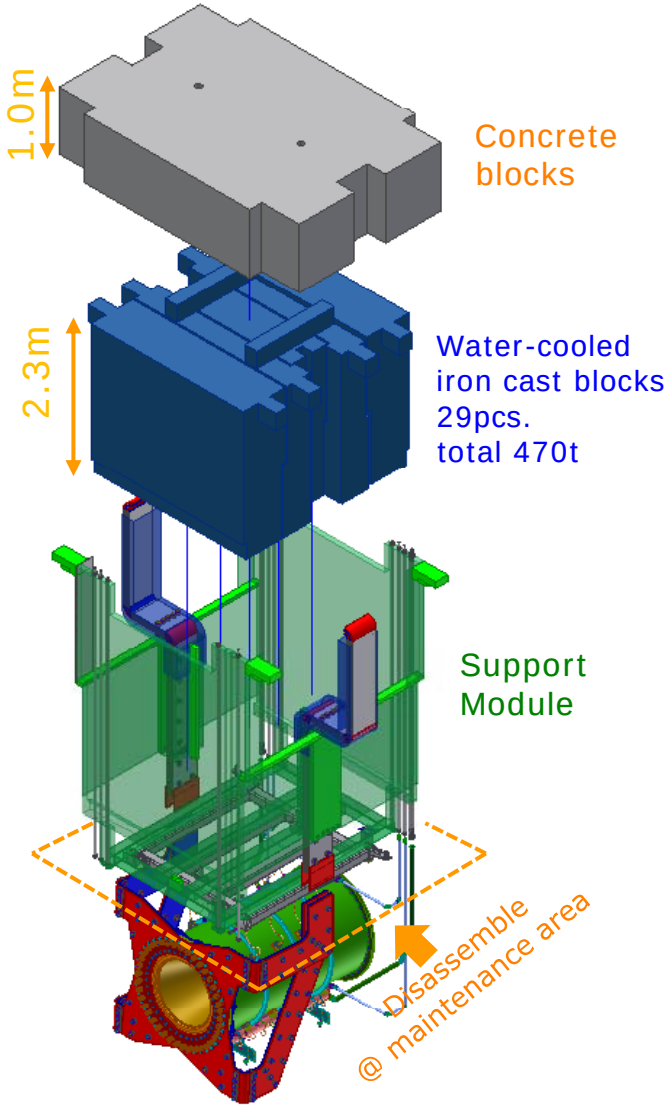

- Horns / a baffle are supported from the wall of vessel by support modules.
- Apparatus on the beam-line are highly irradiated after beam. Remote maintenance is key issue.

Replacement of all horns
2013 shutdown – Apr. 2014 (On-going)

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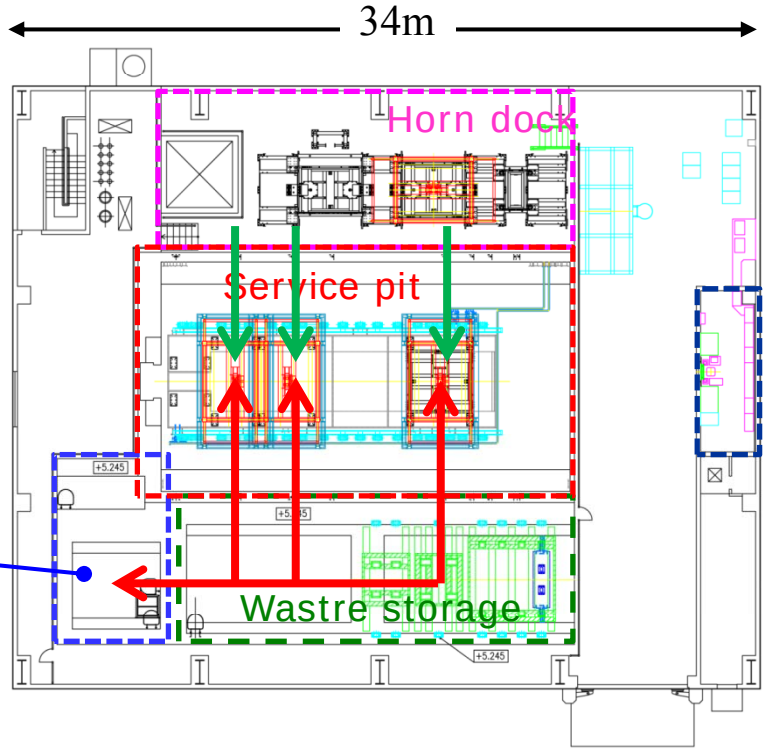
- H_2 production by water radiolysis ($2H_2O \rightarrow 2H_2+O_2$)
  - H_2 density after 1 week of 220kW beam: **1.6 %** (near horn)
  - Need to two ports to force gas to flow in horns (now only one)
- Tiny water leak (5~10L/day) happened since fall, 2012
  - More leak with beam
    - ***We decided to replace all horns to spares***



Maintenance area

Control room

Every process managed remotely at control room

Remote maintenance of Horn-3
Nov. – Dec. 2013

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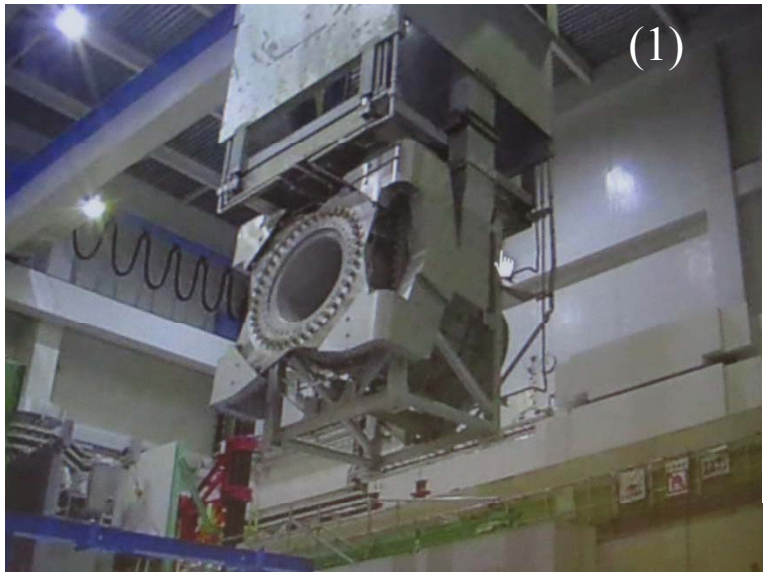

- Work started from Horn-3, expected to be less radio-active.

(1)Take out old horn (Nov.26)
(2) insert new horn (Nov.29)
(3) old horn to casket (Dec.10)

Vessel inspection (Nov.27)

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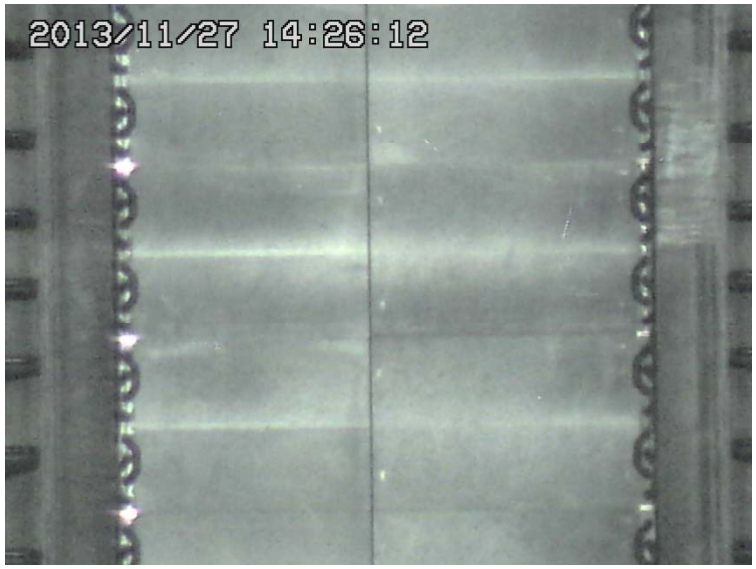

- No damage was seen on the hadron absorber / decay volume.

Horn-2 test operation for anti-neutrino running

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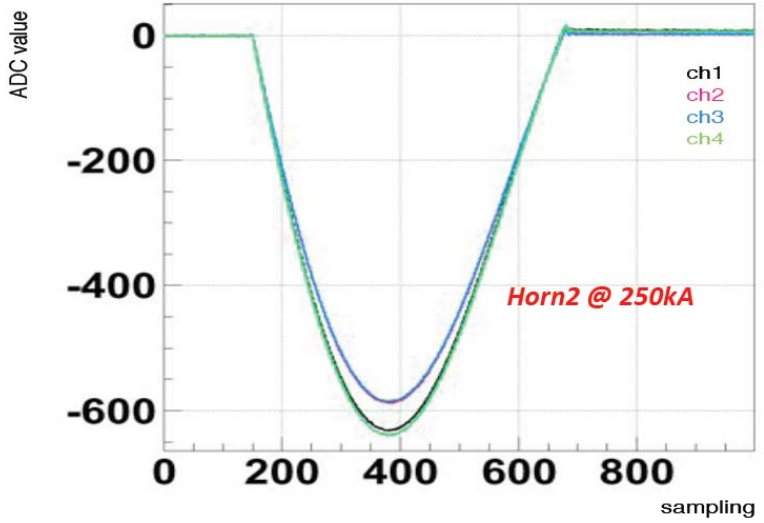
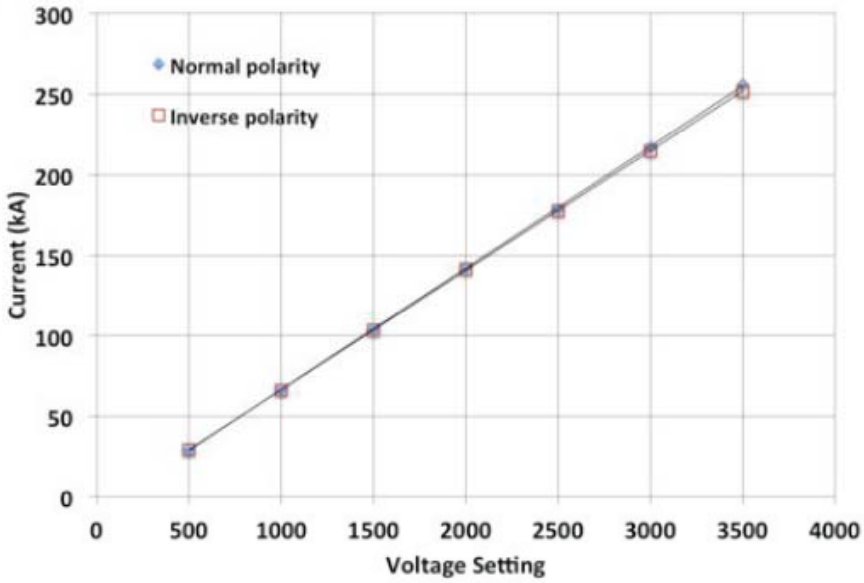
- Inverse polarity operation tested for Horn-2
  - 250kA operation succeeded.
  - Good linearity
  - Good current balance





Status of Horn Power Supply

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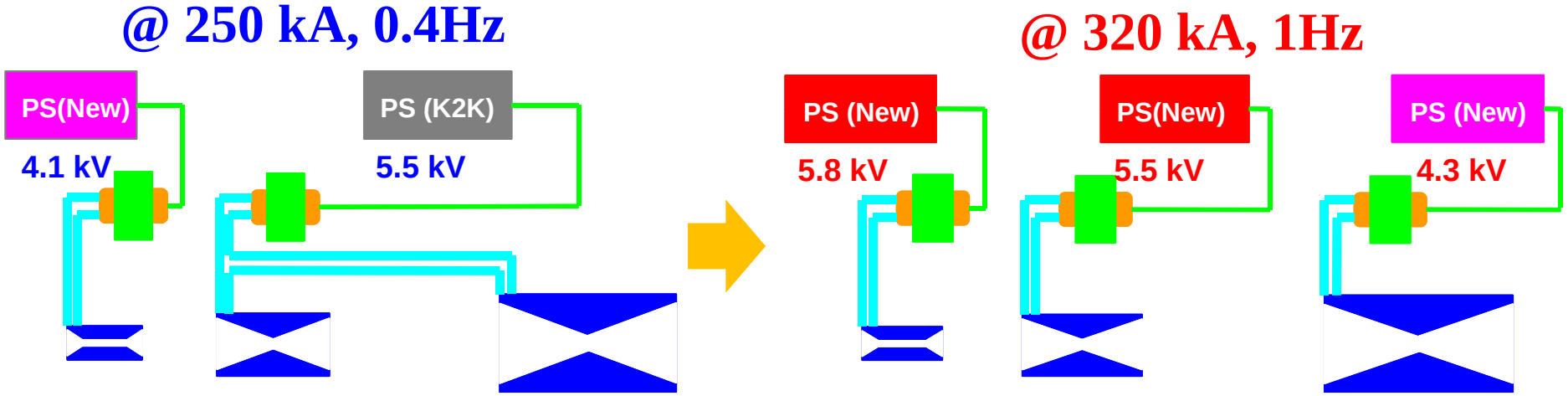

- New power supply production for 1Hz operation,
  - Designed for 320kA operation
  - Energy recovery (~50% of stored energy recycled)
  - Low input load
    - Each horn is operated with individual power supply
    - Low impedance striplines are also developed
- Production on going, operation scheduled in fall 2014
  - Possibly postponed due to tight budget situation (?)

Upgrades for neutrino facility

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- NU beamline upgrade is necessary
  - In FY2013, water drainage from NU2(TS) 20 times + NU3 23 times (too many !)
  - Reinforce capacity of cooling power and irradiated water treatment (dilution/drainage)
- New facility buildings with large DP tanks are necessary

Critical components

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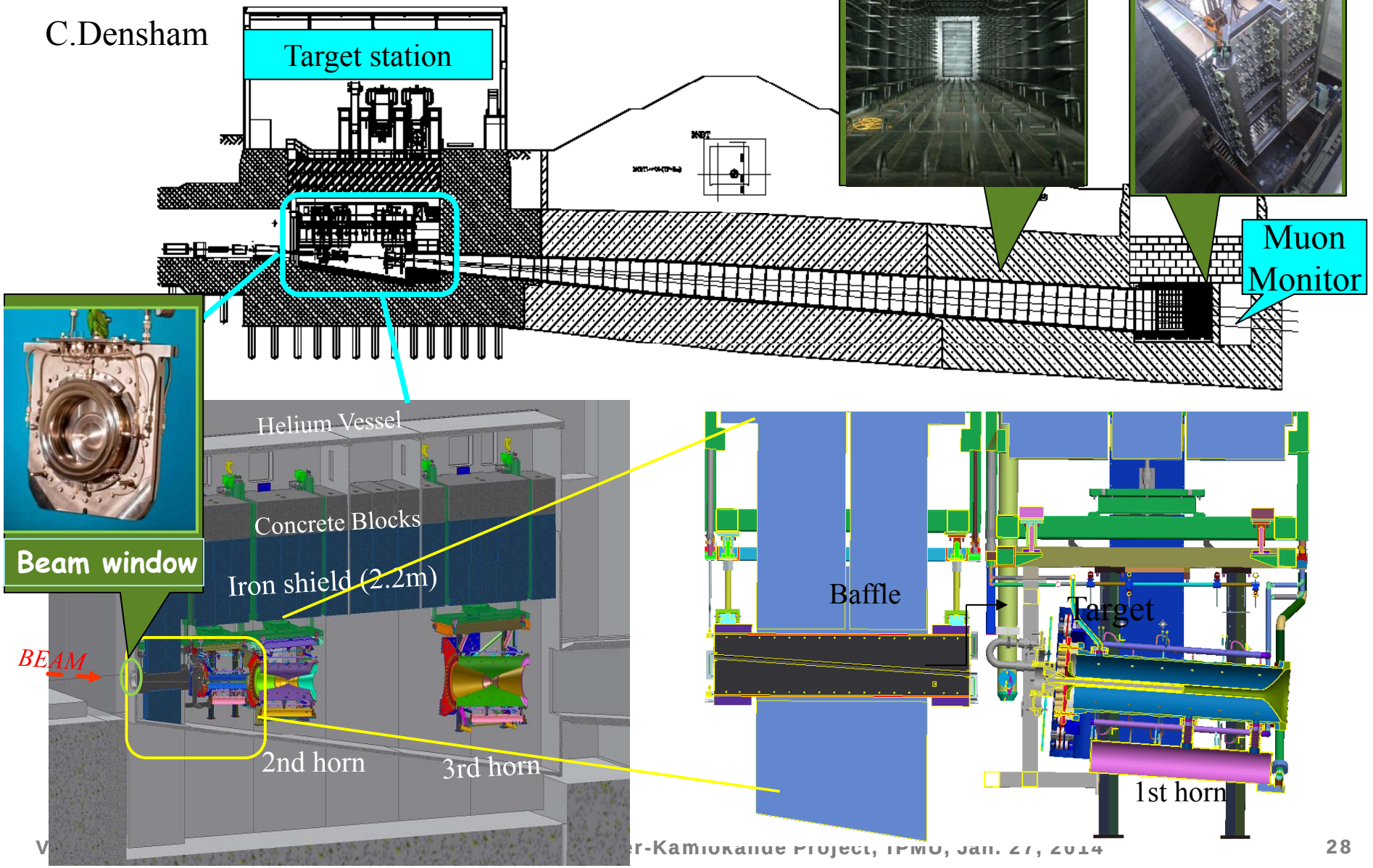
C.Densham



Target & horn

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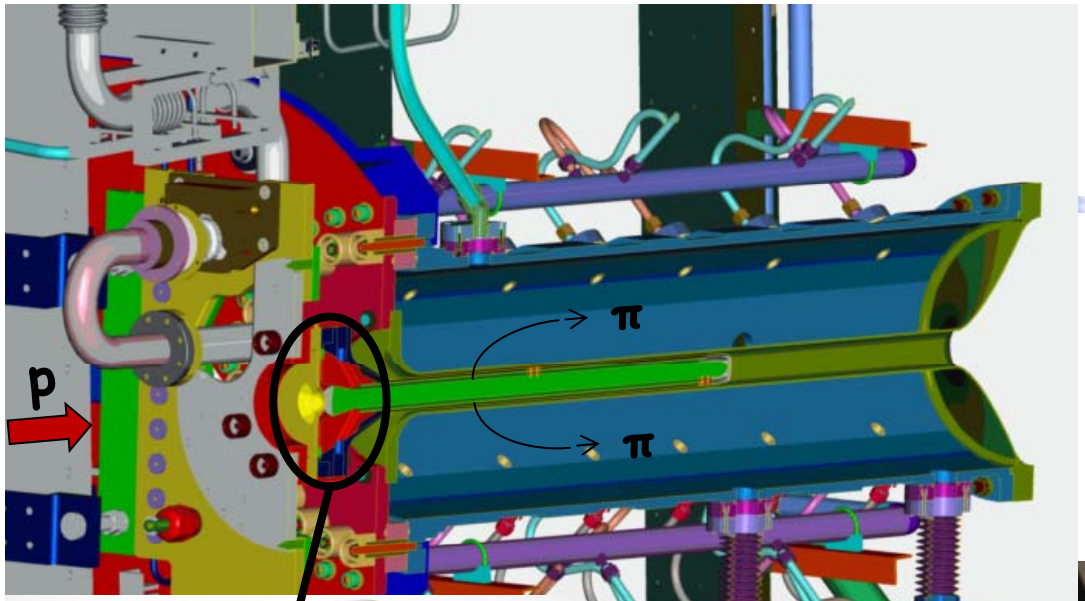
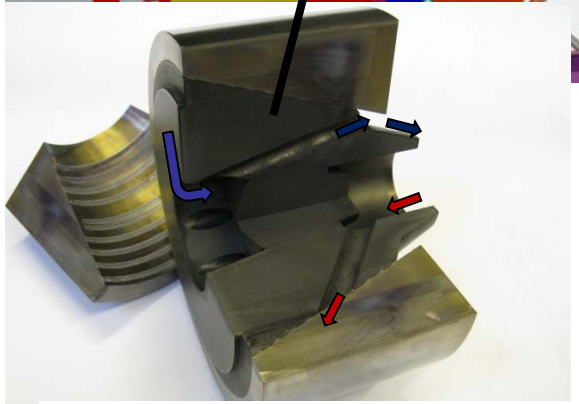
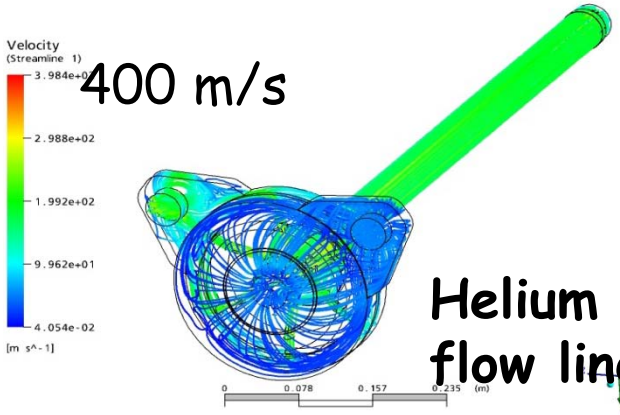
- Helium cooled graphite rod
- Design beam power: 750 kW
  (heat load in target c.25 kW)
- Beam power so far: 230 kW
- 1st target & horn currently being replaced after 4 years operation, 7e20 p.o.t.







Target exchange system

Secondary beam component limitations for >1MW operation

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- Beam windows (target station and target) C.Densham
  - Radiation damage & embrittlement of Ti6Al4V alloy
  - Stress waves from bunch structure
  - Is beryllium a better candidate?
- Target
  - Radiation damage of graphite
    - Reduction in thermal conductivity, swelling etc
  - Structural integrity & dimensional stability
  - Heat transfer
  - High helium volumetric flow rate (and high pressure or high pressure drops)
- Horn-1
- OTR, beam monitors
- Target station emission limitations

Doubled rep.rate: Impact to target

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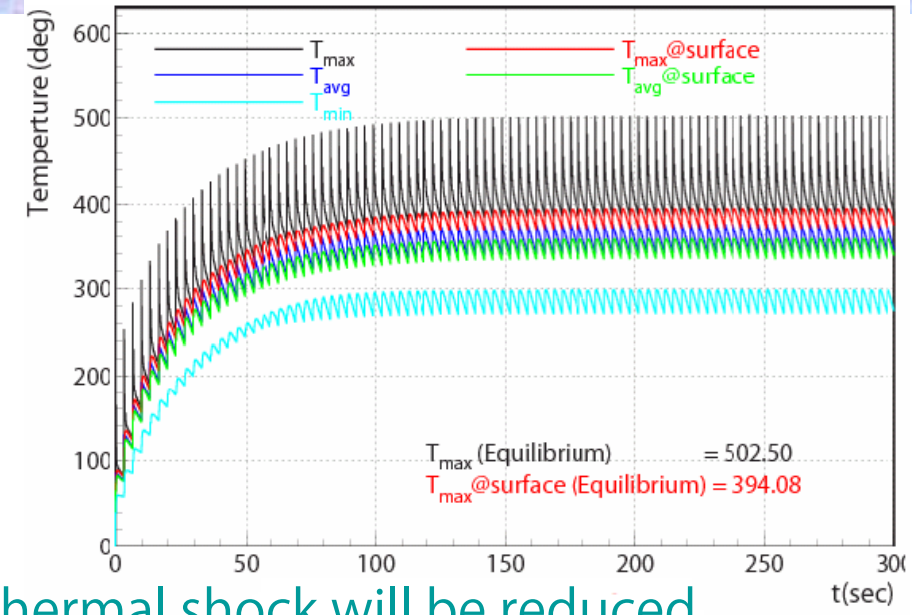
Temperature of target as func. of time



- Instantaneous heat deposit / thermal shock will be reduced
  - With 750kW beam (30GeV,3.3x10^{14}ppp): $\Delta T = 200K/spill$, σ_{eq}=7.2MPa
  - Safety factor = Strength(37MPa) / Stress x fatigue(0.9) = ~3.5 ($\propto$ 1/ppp)
- Keep temperature of graphite around 400~800℃
  - Slow down degradation of thermal conductivity by rad. damage (0.25DPA/yr)
- Oxidization due to contamination in He gas reduces graphite strength
  - Assuming O_2=100ppm and temperature =700°C, safety factor >2 for **5 yrs**.

⇒ **T.Nakadaira, talk at Neutrino Beam Instrumentation WS (NBI2010)**
http://kds.kek.jp/materialDisplay.py?contribId=7&sessionId=4&materialId=slides&confId=5611

Summary

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J-PARC

- Achieved beam power for user operation:
  - 300kW for MLF / 235kW in max. for the T2K experiment
- To increase #p/bunch
  - MR collimator capability 3.5kW
  - LINAC energy upgrade to 400MeV, frontend upgrade to be in 2014
- MR 750kW operation → doubled rep rate option is chosen
  - R&D for MR magnet power supplies well in progress
  - Higher gradient RF core to be ready for installation in 2015
- Neutrino beam-line
  - No essential troubles for critical components so far.
  - Works on-going to replace all 3 horns/target.
  - Replacement of Horn-3 completed, radiation well under control.
- Upgrade of Neutrino beam-line
  - Doubled rep.rate: less thermal shock for target / beam window.
  - Horn: triple PS operation is necessary for 1Hz (320kA) operation.
  - New facility buildings are needed with larger DP tanks
  - Worth to start discussion / investigation ASAP to make concrete upgrade plan.
    Contribution from international community is highly appreciated.