J-PARC accelerators: Status and upgrade plan

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- Status of the accelerators
- Prospect of the medium-term plan: 2013-2017
- (Conceptual studies for MW beam)
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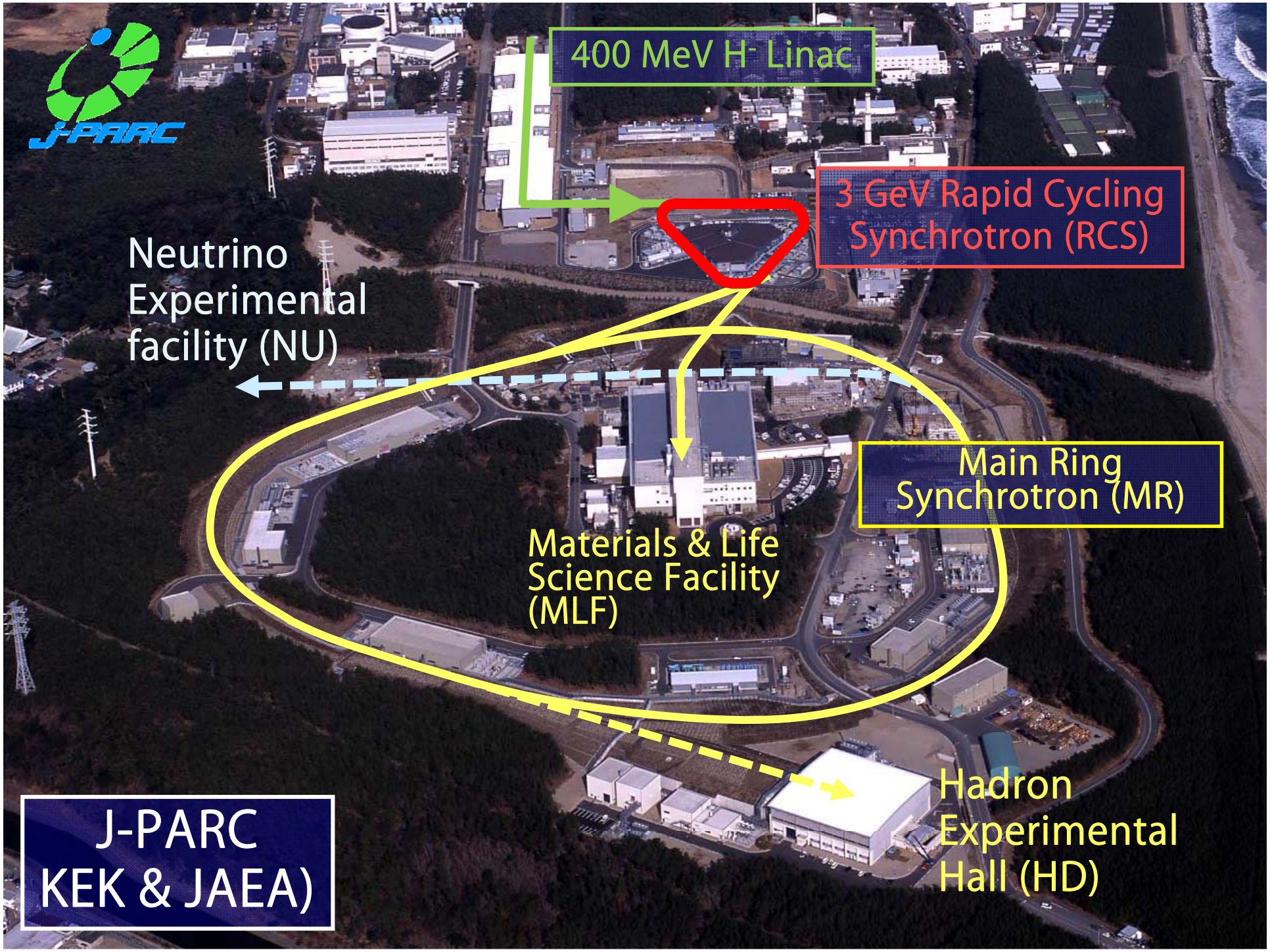
- Materials taken from "The 2nd International Symposium on Science at J-PARC", Tsukuba, Japan, Jul 12-15, 2014
  - K. Hasegawa (LINAC)
  - P.K. Saha (RCS)
  - T. Koseki (Overall/MR)
  - S. Igarashi (MR multi-MW)
  - …

http://j-parc.jp/symposium/j-parc2014/


J-PARC
400 MeV H- Linac
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Experimental facility (NU)
Main Ring Synchrotron (MR)
Materials & Life Science Facility (MLF)
Hadron Experimental Hall (HD)
J-PARC
KEK & JAEA)

History of beam delivery from RCS to MLF

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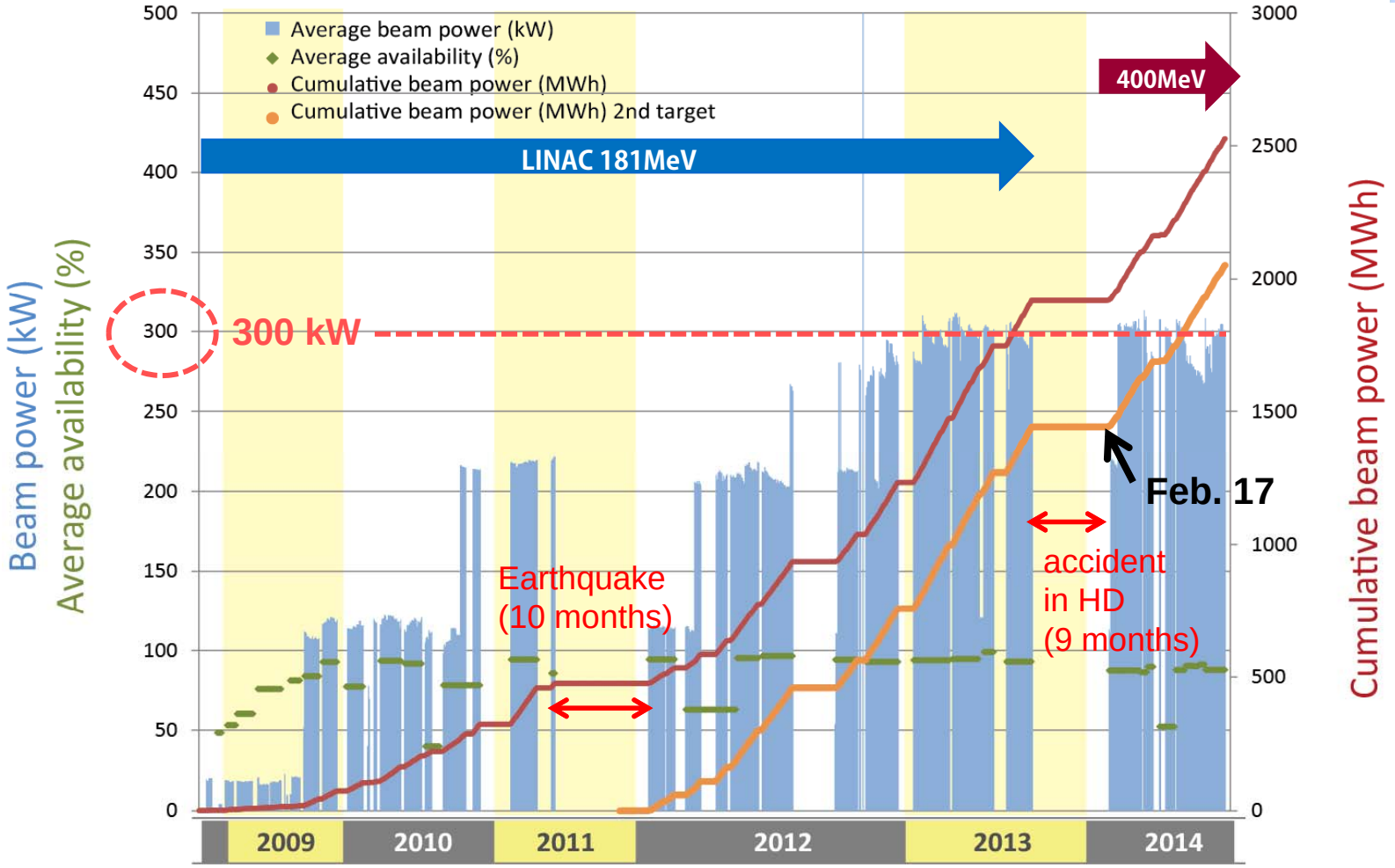
* as of June 26, 2014

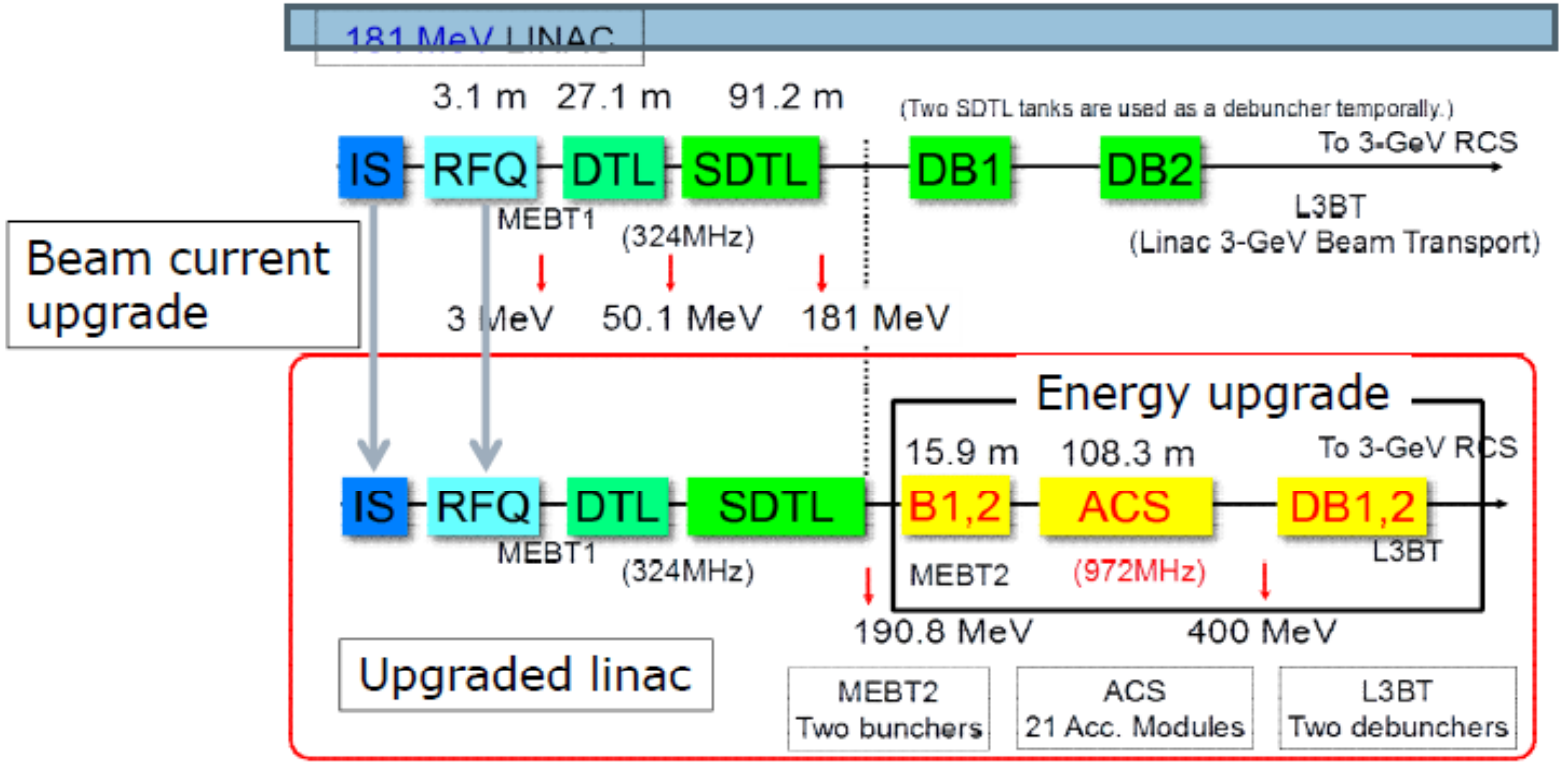


- 3GeV beam power from RCS to MLF is increased steadily up to 300 kW
- After 9 month of shutdown due to the accident at the HD hall, beam operation was resumed in Feb.2014.

K.Hasegawa

Upgrade of J-PARC Linac

- The original design intensity (400 MeV, 50mA) is necessary for the J-PARC facility to reach nominal performance (Beam power: 1MW@RCS, 0.75MW@MR)
- Energy is upgraded with ACS (Annular-ring Coupled Structure), and beam current is upgraded by replacing with new ion source and RFQ.



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P.K.Saha

Injection energy vs. space charge tune depression

H. Hotchi

E_{inj}=181 MeV
24.5 mA linac peak current
x 0.60 chopper beam-on duty
x 235 turns (0.5 ms)
x 25 Hz
→540 kW at 3 GeV
(4.5E13/pulse)

Laslet value at injection;

$$\Delta\nu = -\frac{n_t r_p}{2\pi\beta^2\gamma^3\varepsilon}\frac{1}{B_f} \approx -0.24$$

ε=216π mm mrad
for both cases

Design operation:

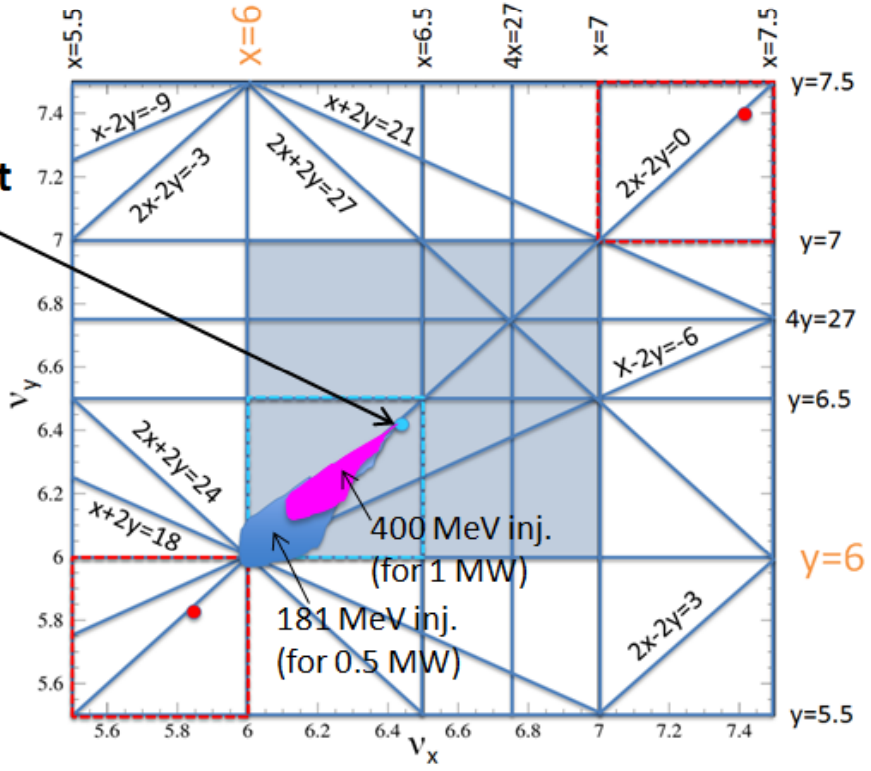
E_{inj}=400 MeV
50 mA linac peak current
x 0.53 chopper beam-on duty
x 307 turns (0.5 ms)
x 25 Hz
→1 MW at 3 GeV
(8.3E13/pulse)

Laslet value at injection;

$$\Delta\nu = -\frac{n_t r_p}{2\pi\beta^2\gamma^3\varepsilon}\frac{1}{B_f} \approx -0.15$$

Why 400 MeV injection?
Direct space charge effect is much severe at 181 MeV as compared to that at 400 MeV.

Operating Point (6.45,6.42)



Tune diagram

ACS Structure

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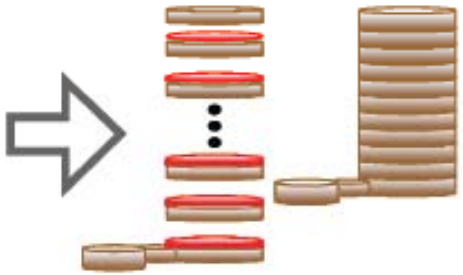
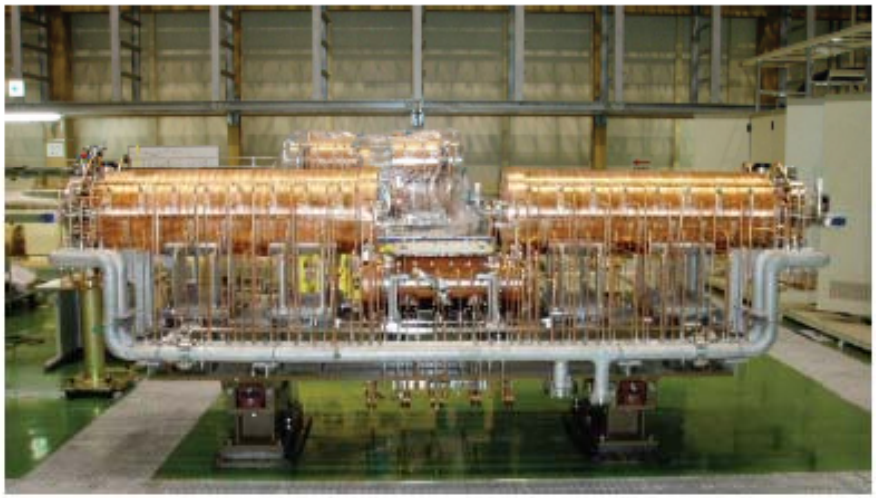
ACS
"Cell"



Brazed Joint



The lowest energy ACS module

ACS modules were installed in the tunnel

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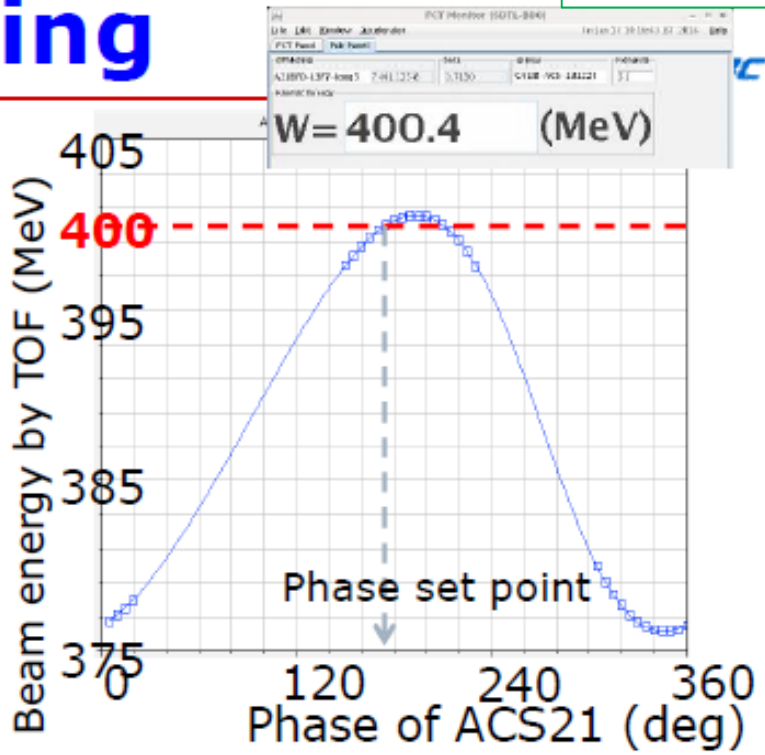
Beam Commissioning

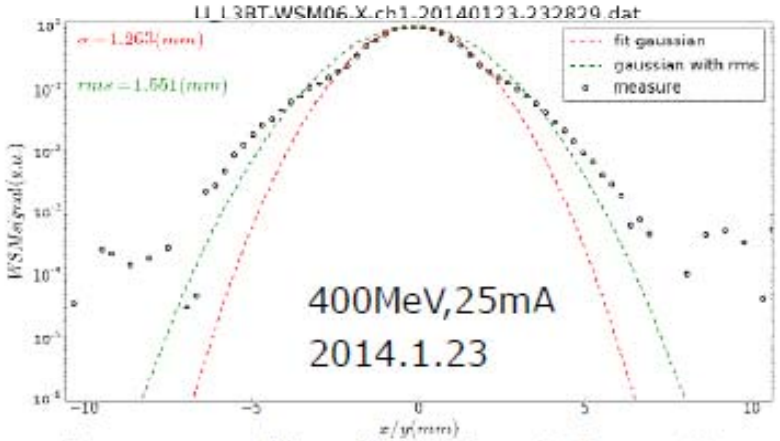
Beam commissioning

- Dec.16 – Dec. 29: Tuning FE to ACS14
- Jan.7 – Jan.9 SDTL matching
  (ACS conditioning for 6 days)
- Jan. 16: Restart ACS tuning
- Jan. 17: Achievement of 400 MeV

We started user operation, but need more study time:

- Halo formation is observed in the ACS section. Proper matching is needed by help of longitudinal monitors.
- Radioactivity is higher at some points of ACS.





Beam profile after the ACS section

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Injection painting parameter dependence of beam loss

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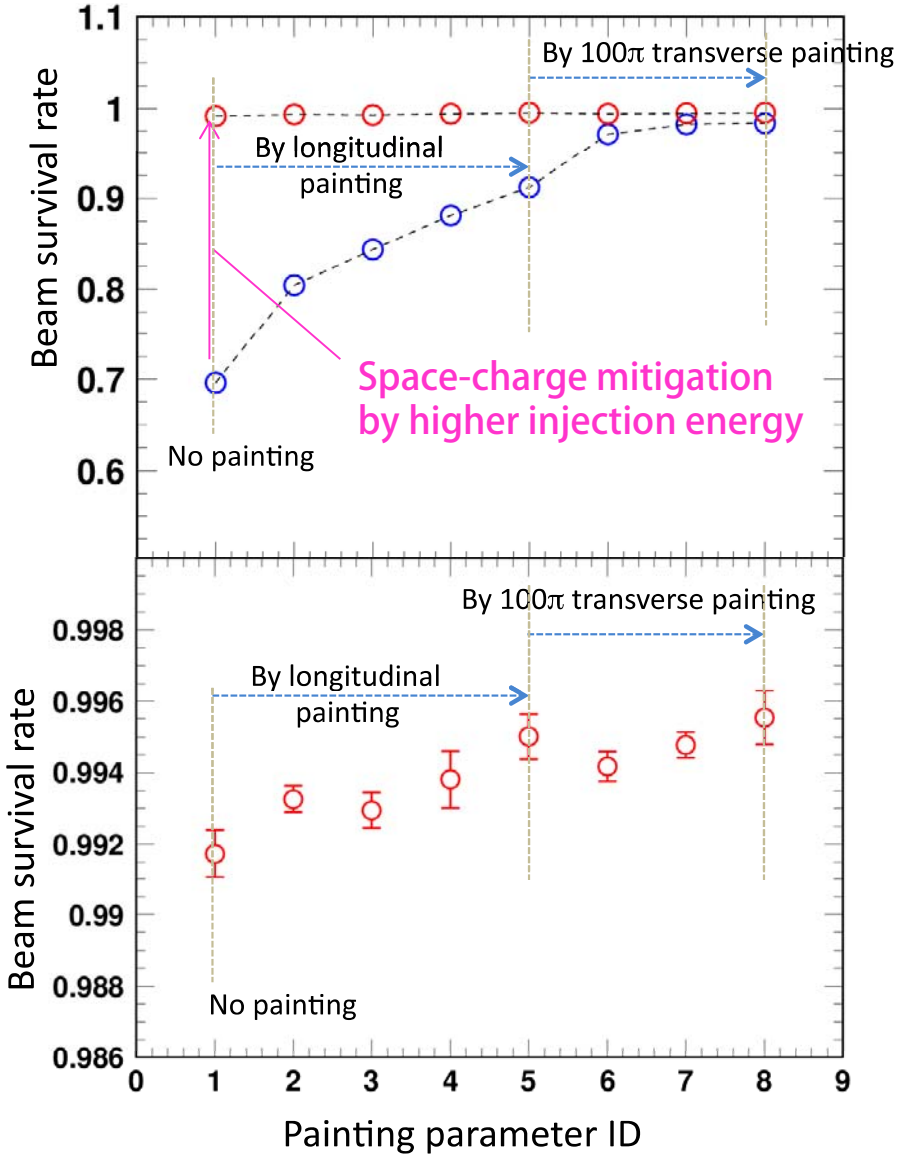
○ : E_{inj}=181 MeV, 539 kW-eq. intensity (Run#44, Nov. 2012)

○ : E_{inj}=400 MeV, 553 kW-eq. intensity (Run#54, Apr. 2014)

Transverse Longitudinal

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



- Excellent ability of injection painting and big gain from the upgraded injection energy

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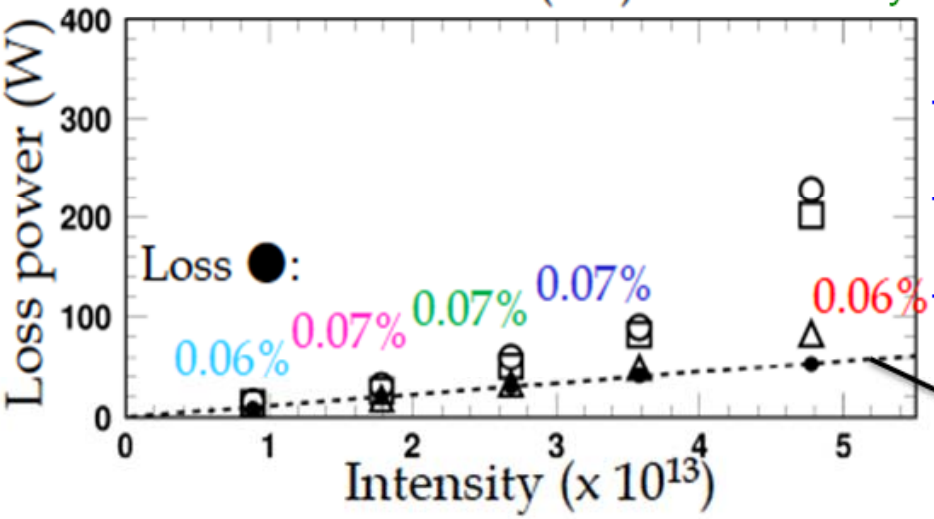
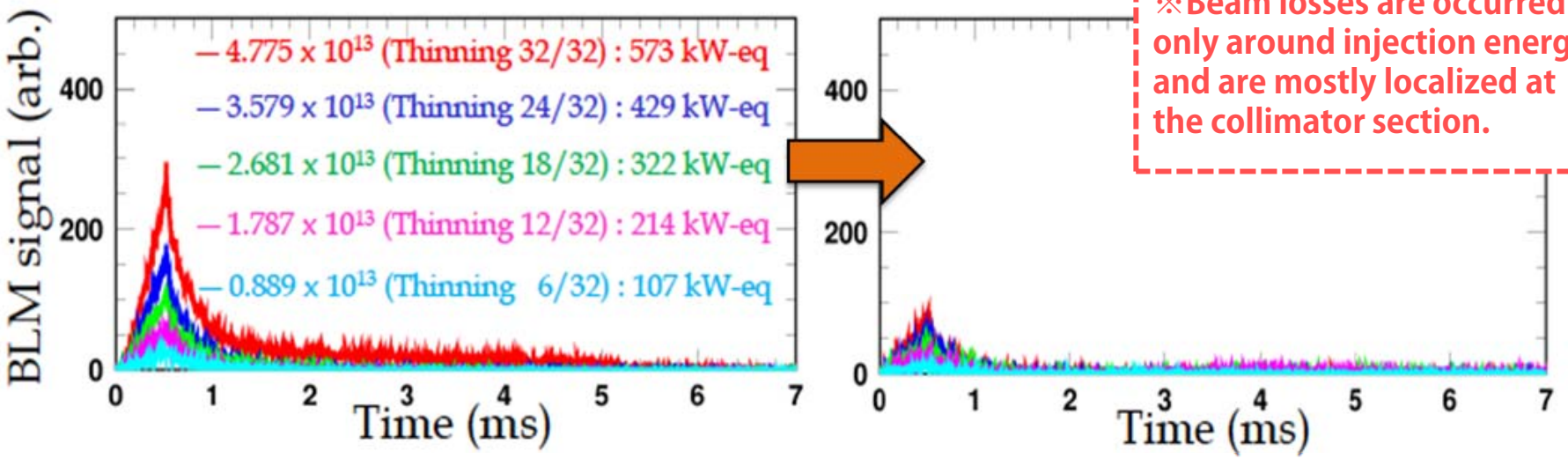
Minimization of beam loss

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

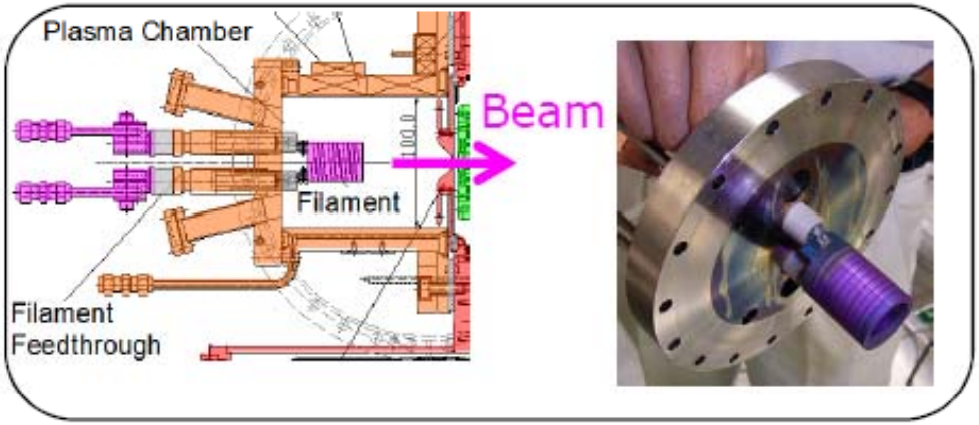


※Beam losses are occurred only around injection energy, and are mostly localized at the collimator section.

Beam loss of the RCS is well understood and minimized.

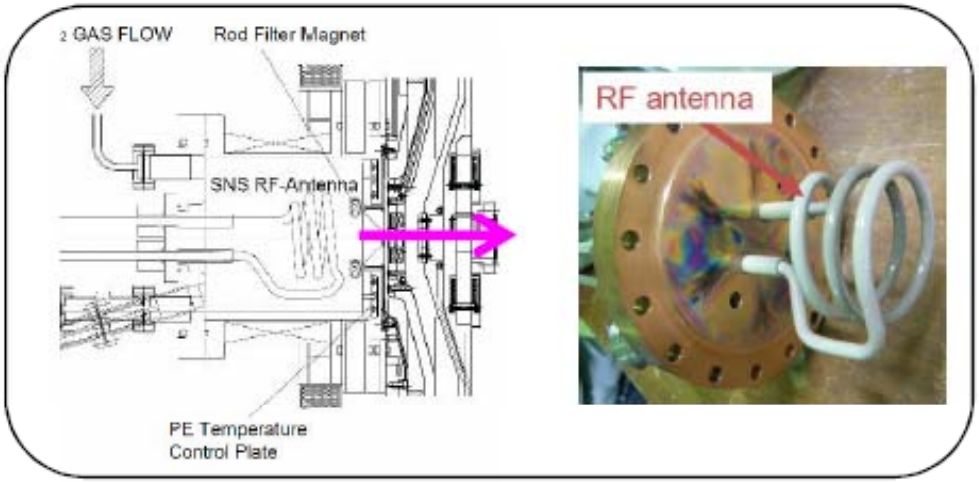
Front End: New Ion Source and RFQ

Ion source



New

- Filament -> RF-driven
- Cs free -> Cs seeded



RFQ

- Structure: Bolt -> Brazed
- Beam dynamics design for higher beam current

New

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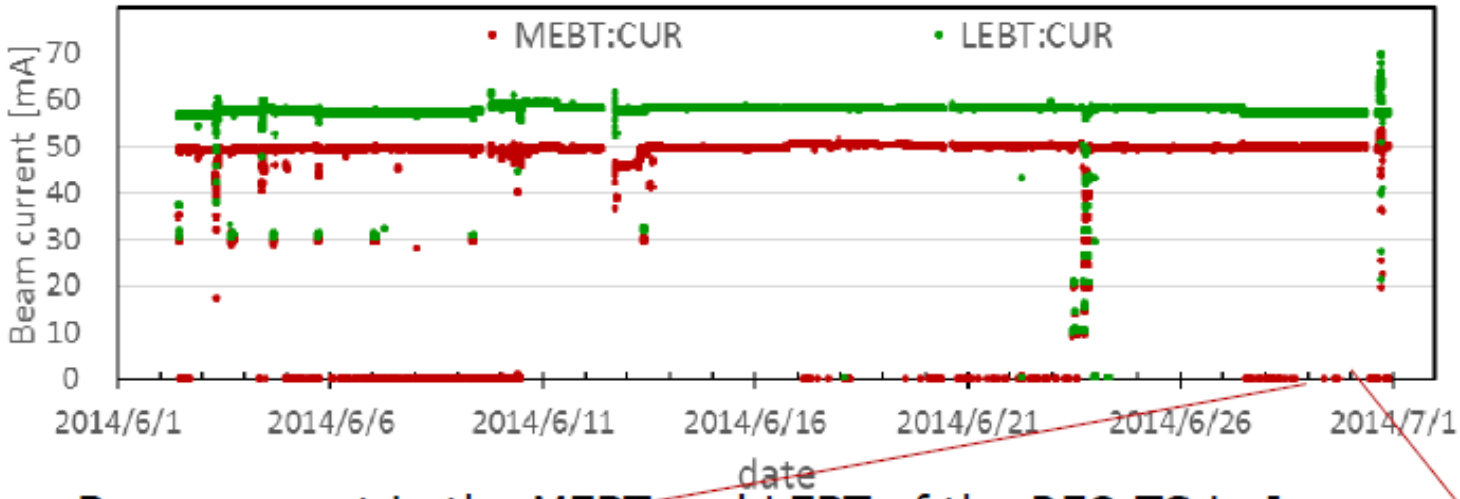
Long Time Operation of Front End Test Stand

- We have a long time operation from June 2 to June 30.
- The typical beam currents in MEBT/LEBT are 50/58 mA, but stability(RF trip) with beam is not enough.
- The new RFQ is going to be installed in this summer. We will increase vacuum pumps to improve stability with beam.



Beam current in the MEBT and LEBT of the RFQ-TS in June.

RF on/off flag for the RFQ on June 29.

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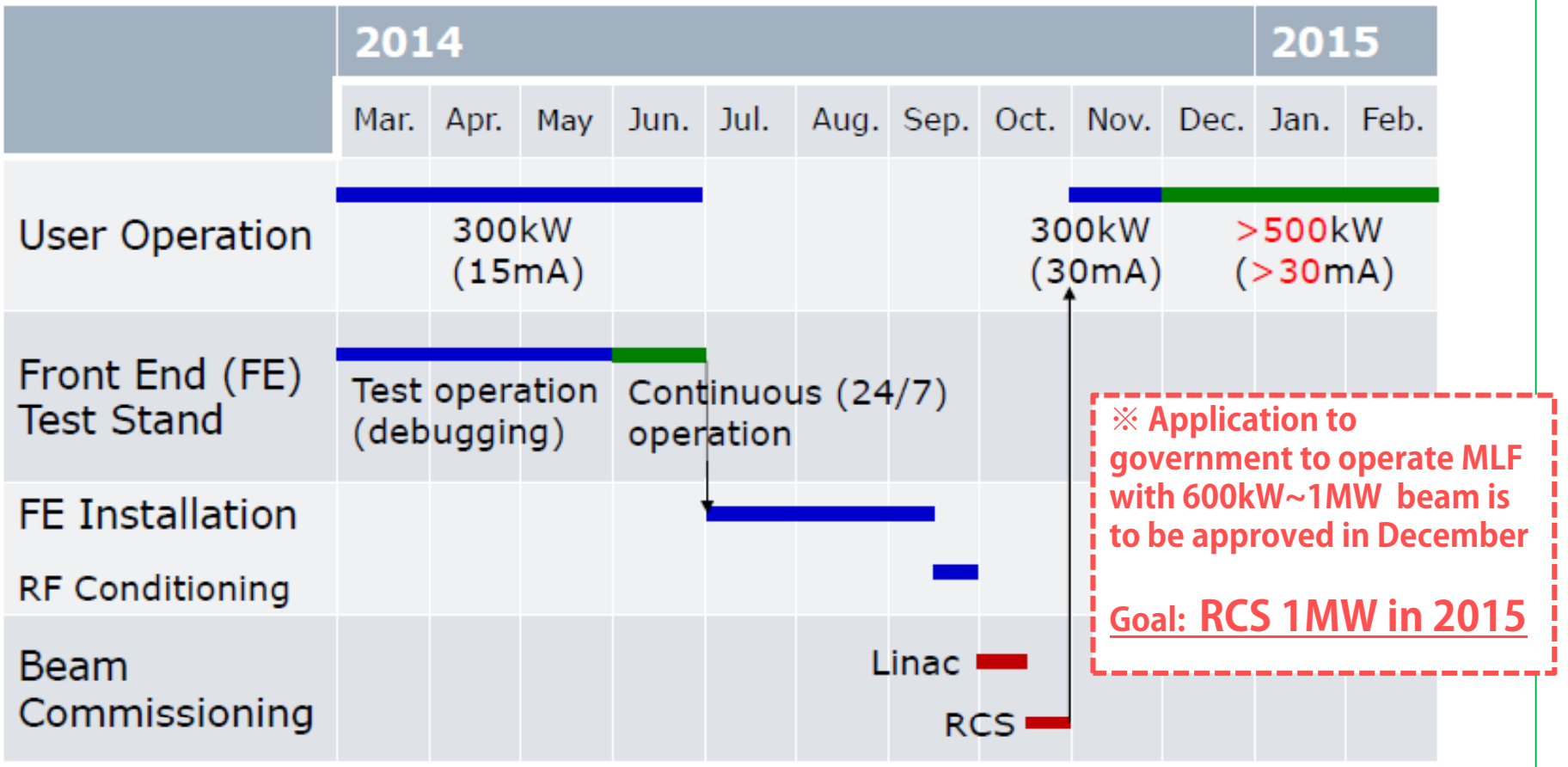
Master Schedule



※ Application to government to operate MLF with 600kW~1MW beam is to be approved in December

Goal: RCS 1MW in 2015

High power demonstration
1 MW-eq.@3GeV
(50mA@Linac)

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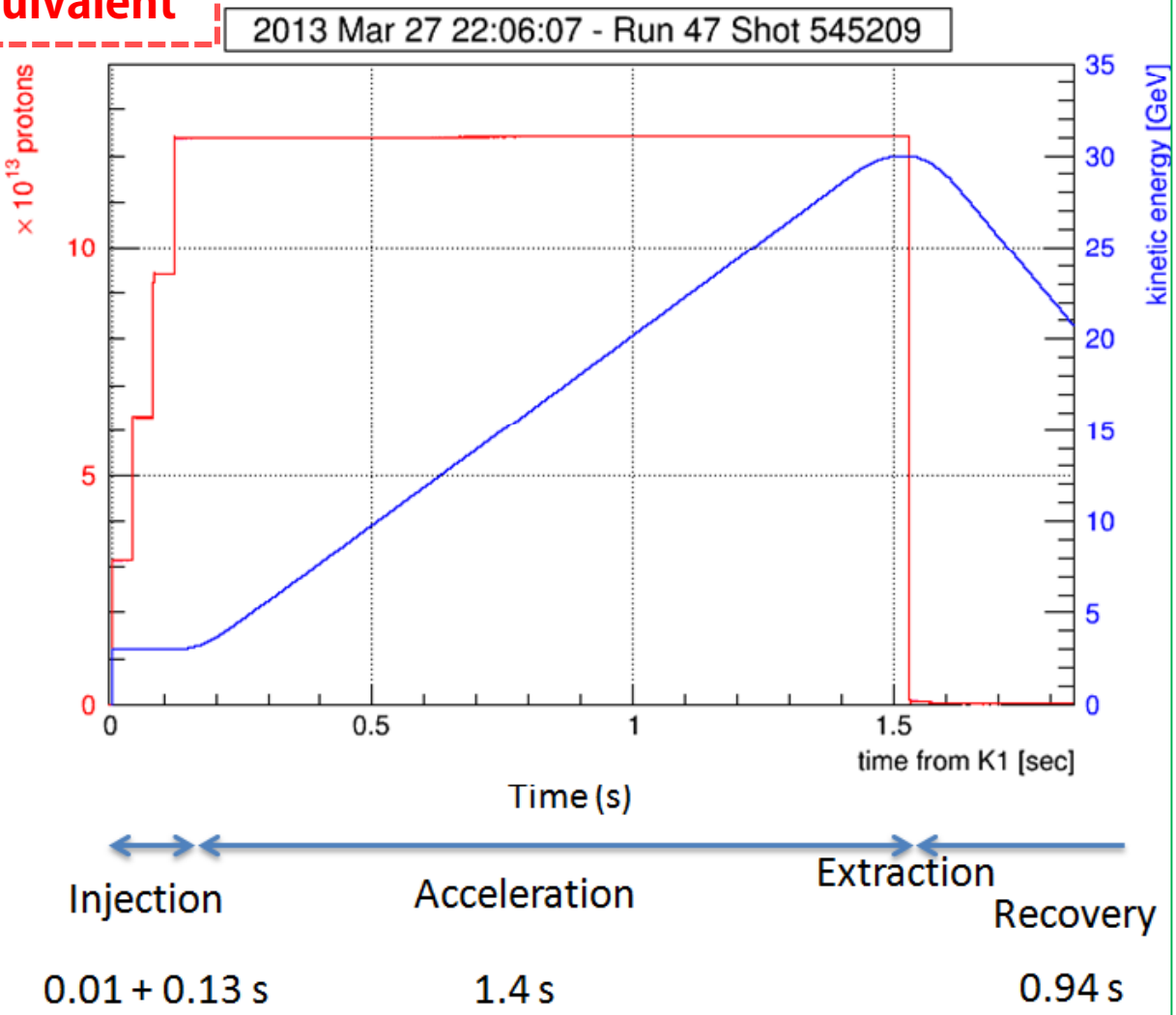
S.Igarashi

Typical Operation Status for Fast Extraction

- Power : 240 kW
- Repetition : 2.48 sec
- 4 batch (8 bunch) injection during the period of 0.13 s
- 1.57e13 protons per bunch (ppb) × 8 @ Injection
- 1.24e14 ppp @ P3 (end of acceleration)
- Loss during the injection period : 243 W
- Loss in the beginning of acceleration (0.12 s) : 53 W
- Loss power is within the MR collimator limit of 2 kW.
- Loss at 3-50BT : 70 W, < 3-50BT collimator limit of 2 kW

RCS 377kW equivalent



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Mid-term plan of MR

FX: The high repetition 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: Parts of stainless steel ducts are replaced with titanium ducts to reduce residual radiation dose.
The beam power will be gradually increased toward 100 kW watching the residual activity.

RCS 600kW$_{eq}$ × Repetition 1.3sec (⇔Original scenario: RCS 1MW$_{eq}$ × 2.1sec)

JFY	2011	2012	2013	2014	2015	2016	2017
			Li. energy upgrade	Li. current upgrade			
FX power [kW] (study/trial)	150	200	200 - 240	200 –300 (400)	→	→	750
SX power [kW] (study/trial)	3 (10)	10 (20)	25 (30)	20-50	→	→	100
Cycle time of main magnet PS New magnet PS for high rep.	3.04 s	2.56 s	2.48 s	R&D	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 septum, 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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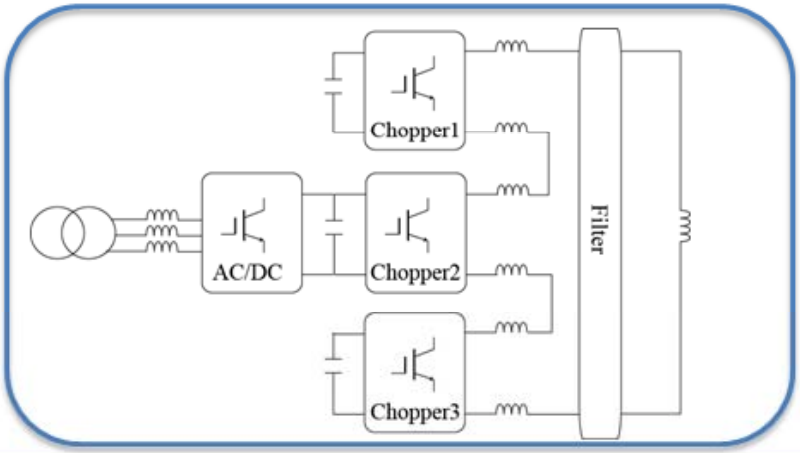
New power supplies for 1 Hz operation

Repetition: "~1sec"

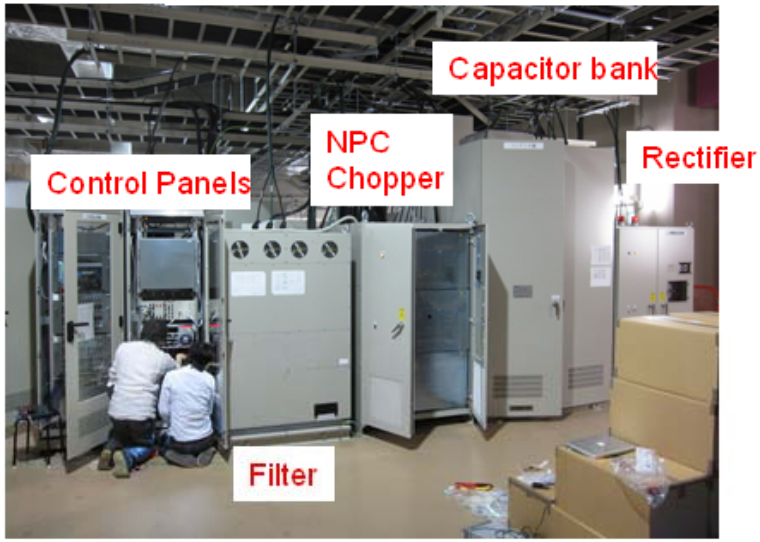
Large scale PS for bending magnets and quad. magnets in arc setions

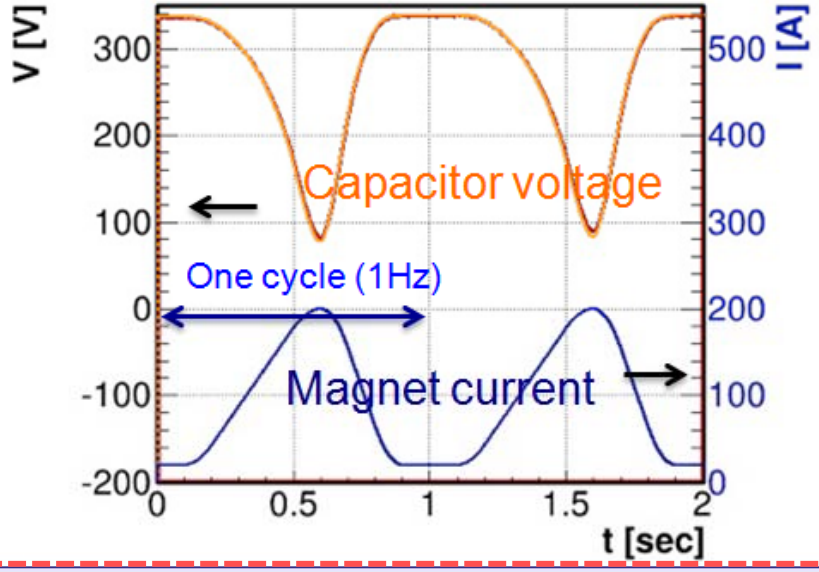


Two large converters and large capacitance for energy recovery, symmetric power module circuit

R&D is now in progress.
The total PS system will be tested in JFY2014

A mini-prototype model test using the real bending magnet and capacitors.





Mass production will start in JFY2015 if the budget request is approved by the government.

High impedance rf system

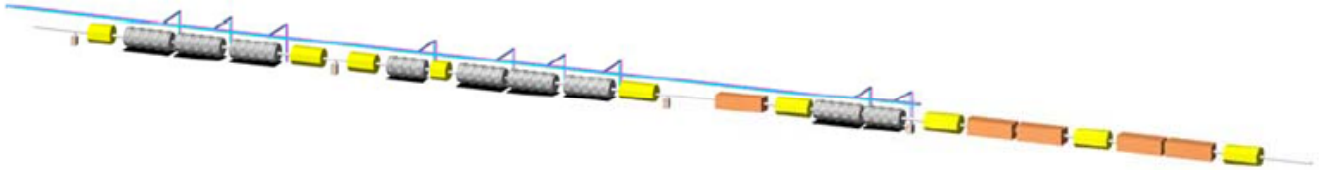
T.Koseki

A new type of the magnetic alloy core, FT3L(made by Hitachi Metal), is adopted to increase shunt impedance of the rf cavity. The core is processed by annealing with magnetic field.

Configuration of rf cavities in the MR

Current situation : 3gap X 9 = 27 gaps

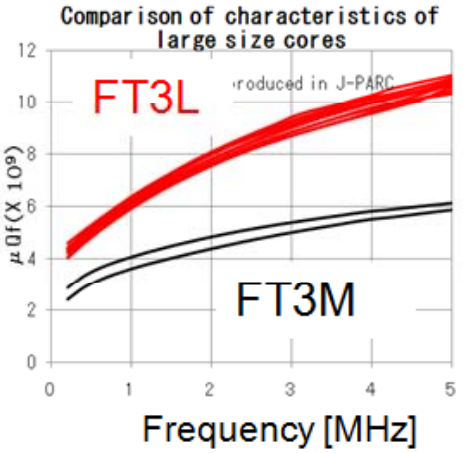
Total rf voltage ~ 270 kV



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

Total rf voltage ~ 540kV

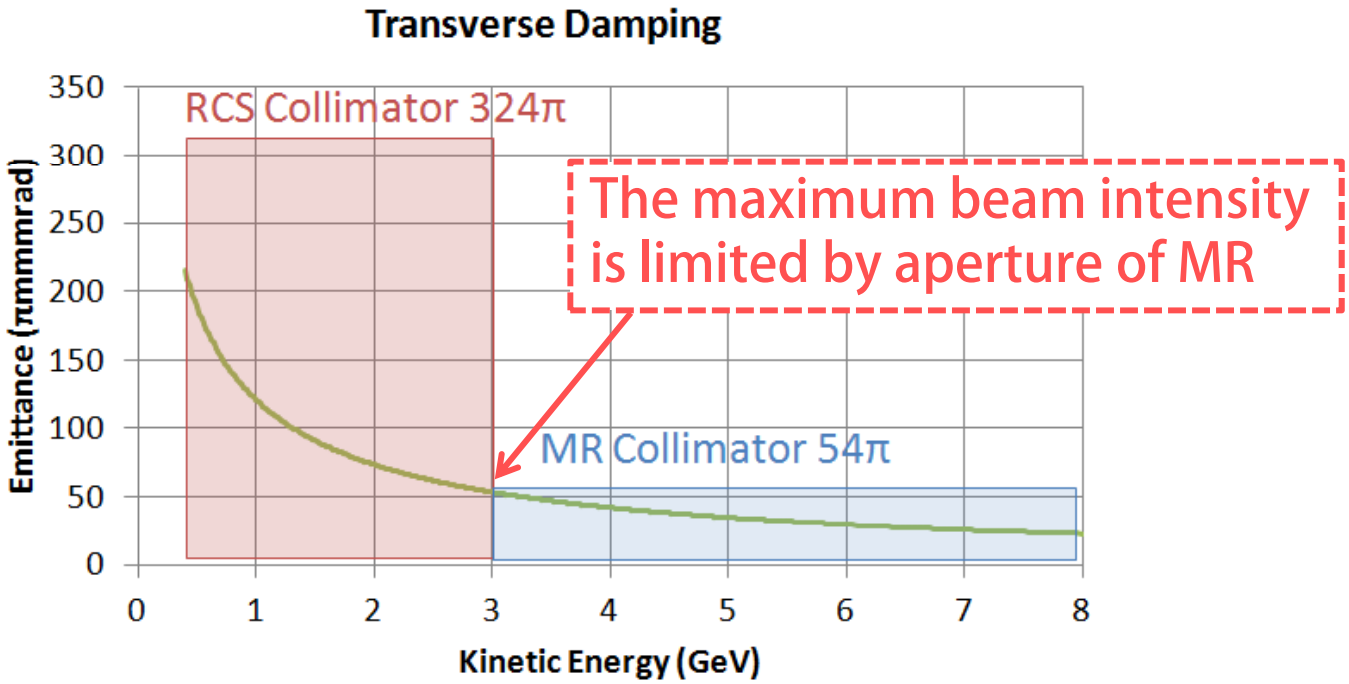
A second harmonic cavity is also installed in the other straight section, INS-A



Budget for the new rf cavities is mostly secured by supplementary budgets in JFY2011 and 2012.

All the cavities will be ready to install in JFY2015.

Adiabatic Damping & Collimator Aperture

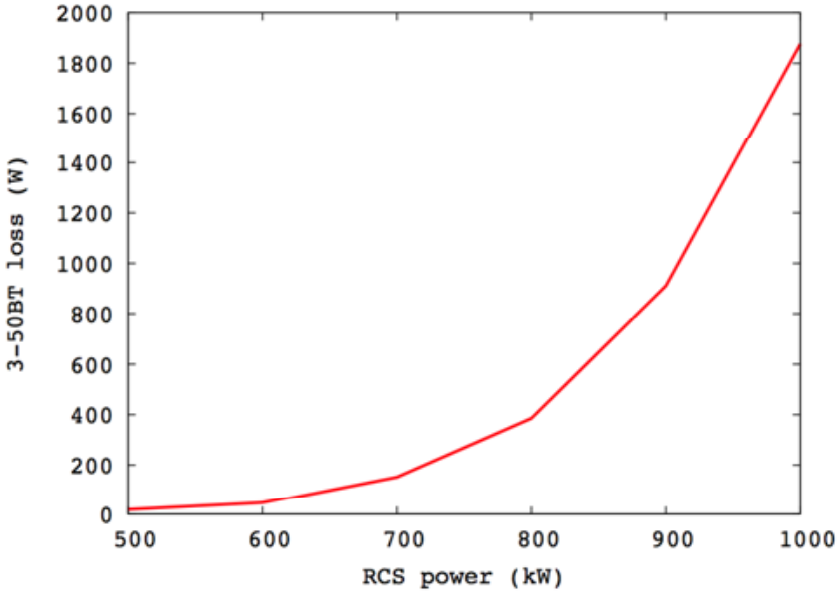


Ring	Beam Emittance	Collimator Aperture	Physical Aperture	Emittance @ Extraction
3GeV RCS 400MeV	216 π	324 π	486 π	54 π
MR	54 π	54 π	81 π	6.7 π

MR Acceptance of RCS Beam

- RCS power will be 1 MW.
- MR will be able to accept the RCS beam of up to ~ 800 kW equivalent.
- MR is a bottle neck.

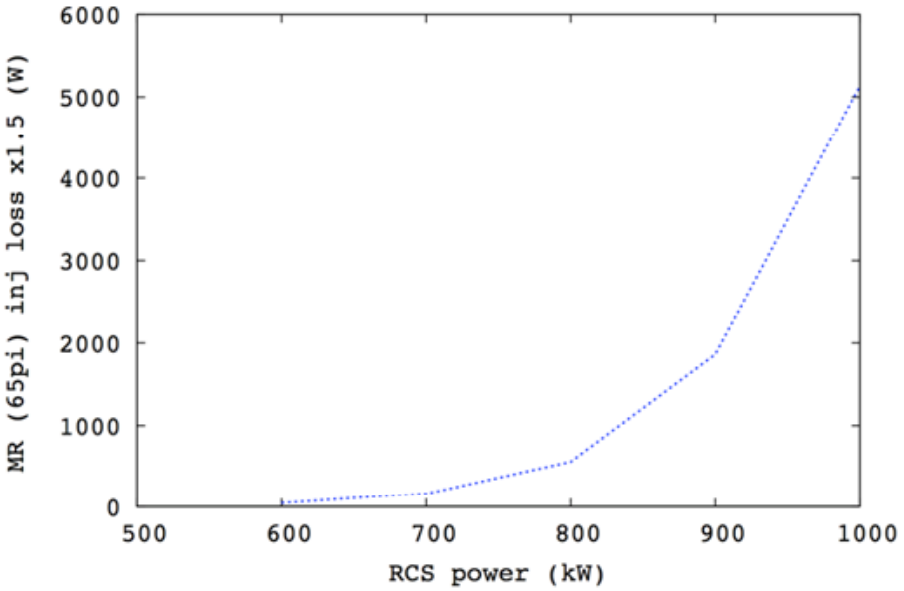
3-50BT Loss (54π cut) for Trep. = 1.3 s



MR Loss (65π cut) for Trep. = 1.3 s

Injection Loss × 1.5

3-50BT Collimator adjusted to 0.9 kW loss



Conceptual studies beyond design power

- **Raise RCS top energy (3→3.4 GeV):**
  - Beam loss can be significantly reduced even with this increase in injection energy. Major upgrades for apparatus in RCS (RF, magnet power supplies, excitation devices, etc.) are required.
- **Enlarge MR aperture:**
  - Construct a new synchrotron in the MR tunnel, which has a larger physical aperture (81 mm・mrad) 128(H)-121(V) mm・mrad.
- **Make a second booster ring:**
  - A new emittance-damping ring with an excitation energy of 8 GeV to be constructed between the RCS and MR.

✓ The first and second options could achieve an intensity equivalent to RCS 1 MW operation, or 1.2~1.3 MW with a 1.2 sec repetition cycle.

✓ With the third option, an 8 GeV booster ring, both transverse emittance and bunch length in the MR will be reduced dramatically.

✓ As a result, an intensity equivalent to RCS 1 MW operation may be possible, corresponding to a beam power of 1.6 MW with a 1 sec cycle.

✓ Furthermore, it may even become possible to double the harmonic number from 9 to 18, realizing a beam power of 2.8 MW with a 1.16 sec repetition cycle.

※ Other concepts to be presented in future

- 9 GeV Proton Linac

For more information, visit slides by T.Koseki / S.Igarashi / T.Maruta

Summary

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J-PARC

- Linac was upgraded successfully to 400 MeV with ACS system.
- Beam loss of RCS is well understood and minimized.
- Linac frontend system will be replaced to increase peak current to 50mA in this shutdown period.
- RCS will deliver design beam power of 1MW to MLF by middle of 2015.

- For Main Ring Fast eXtraction (FX), goal of the 5 year mid-term plan is to realize design power of 750 kW with high repetition rate of 1.3 Hz and beam intensity of RCS ~600kW equivalent.

- The beam intensity of MR is limited by its physical aperture.
- To overcome the limitation, conceptual studies to achieve beam power beyond current design are now under discussion: second booster ring and 9 GeV proton linac.