Open meeting for the Hyper-Kamiokande Project @ IPMU
Aug. 22, 2012

Upgrade plan of J-PARC accelerator

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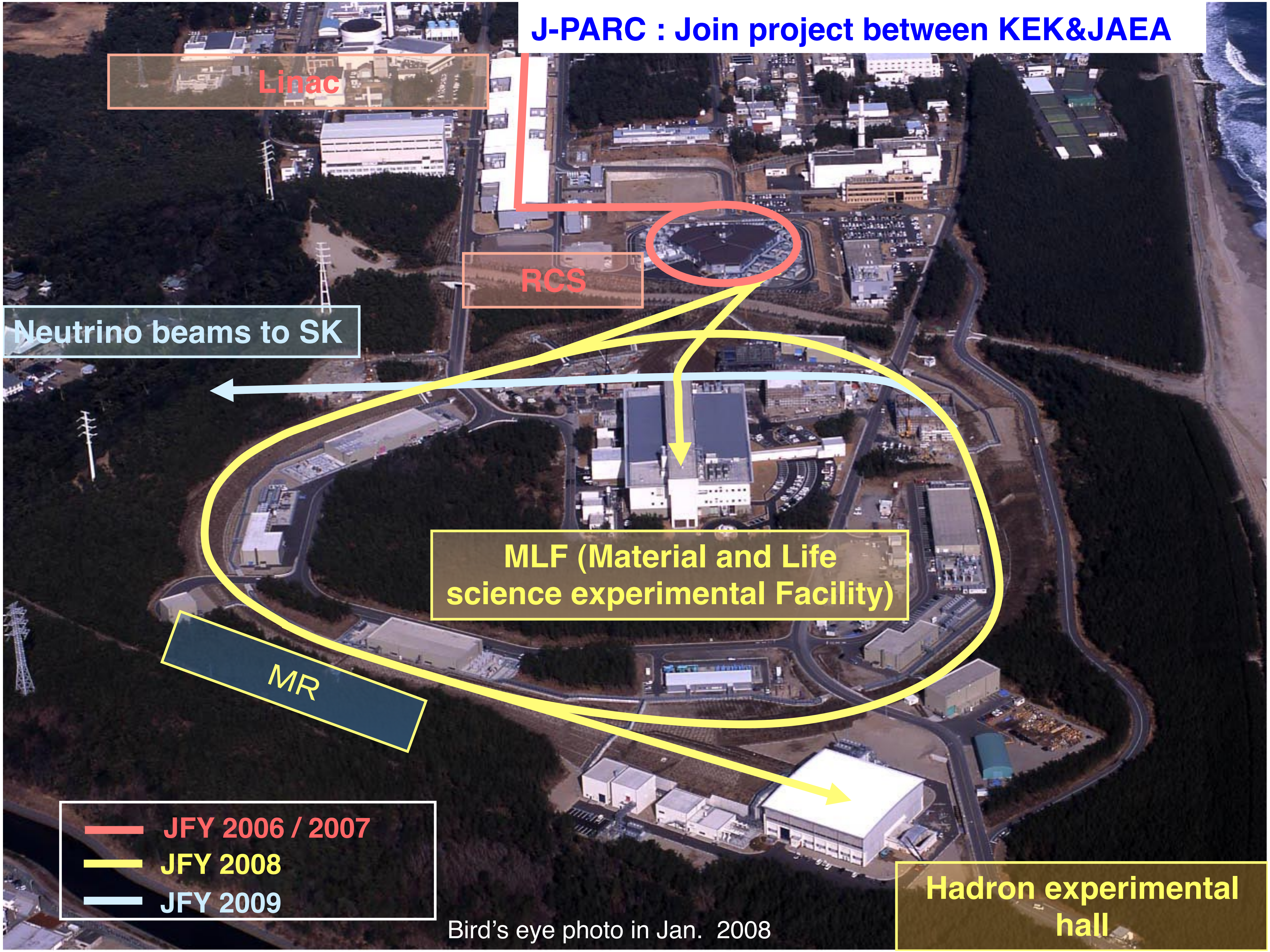
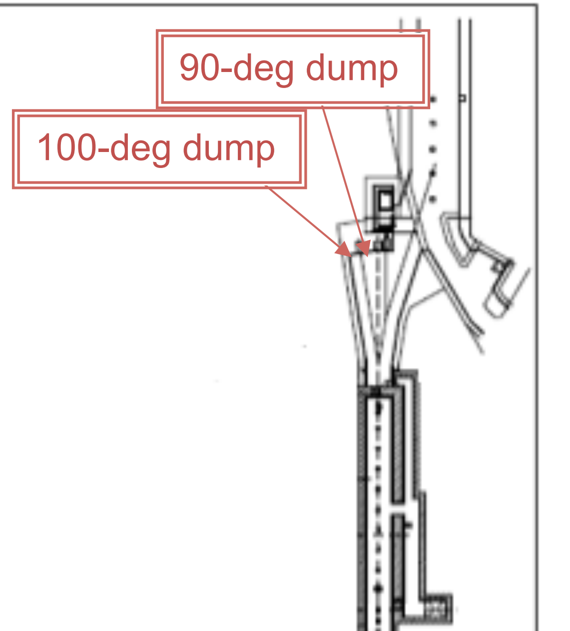
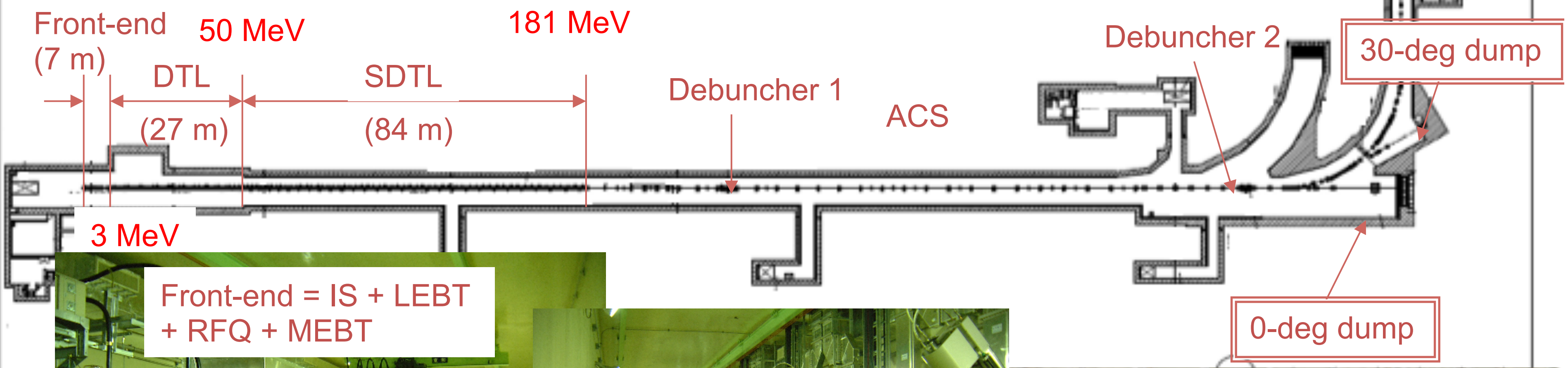
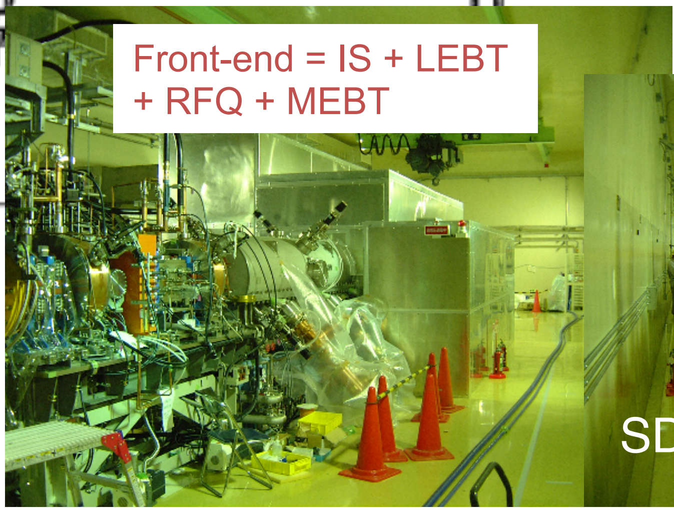

J-PARC : Join project between KEK&JAEA
Linac
RCS
Neutrino beams to SK
MLF (Material and Life science experimental Facility)
MR
JFY 2006 / 2007
JFY 2008
JFY 2009
Bird's eye photo in Jan. 2008
Hadron experimental hall

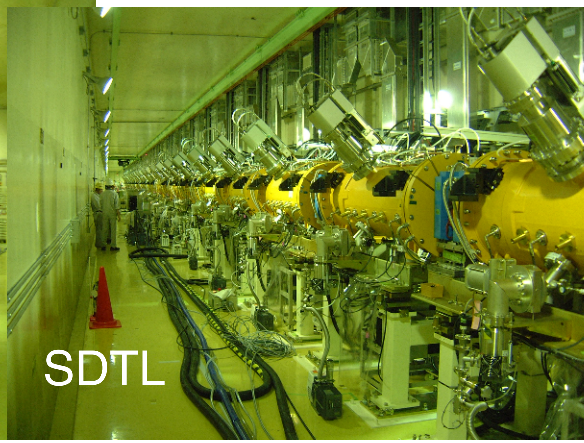
Linac

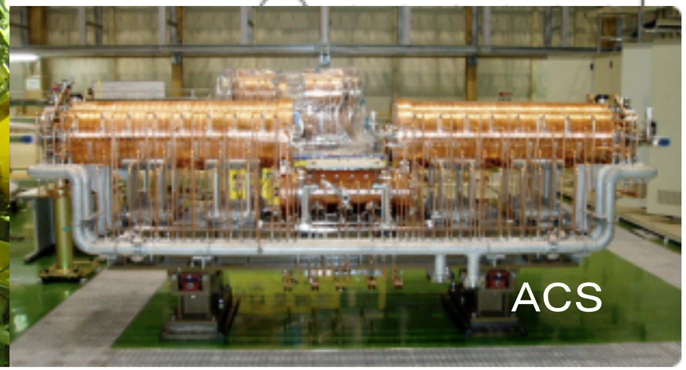
- **Particle:** **H^-**
- **Energy:** **181 MeV at present**
  400 MeV by installing ACS in 2013
  (Construction of ACS has been started.)
- **Peak current:** **30 mA at 181 MeV**
  50 mA at 400 MeV in 2013
- **Repetition:** **25 Hz**
- **Pulse width:** **0.5 msec**





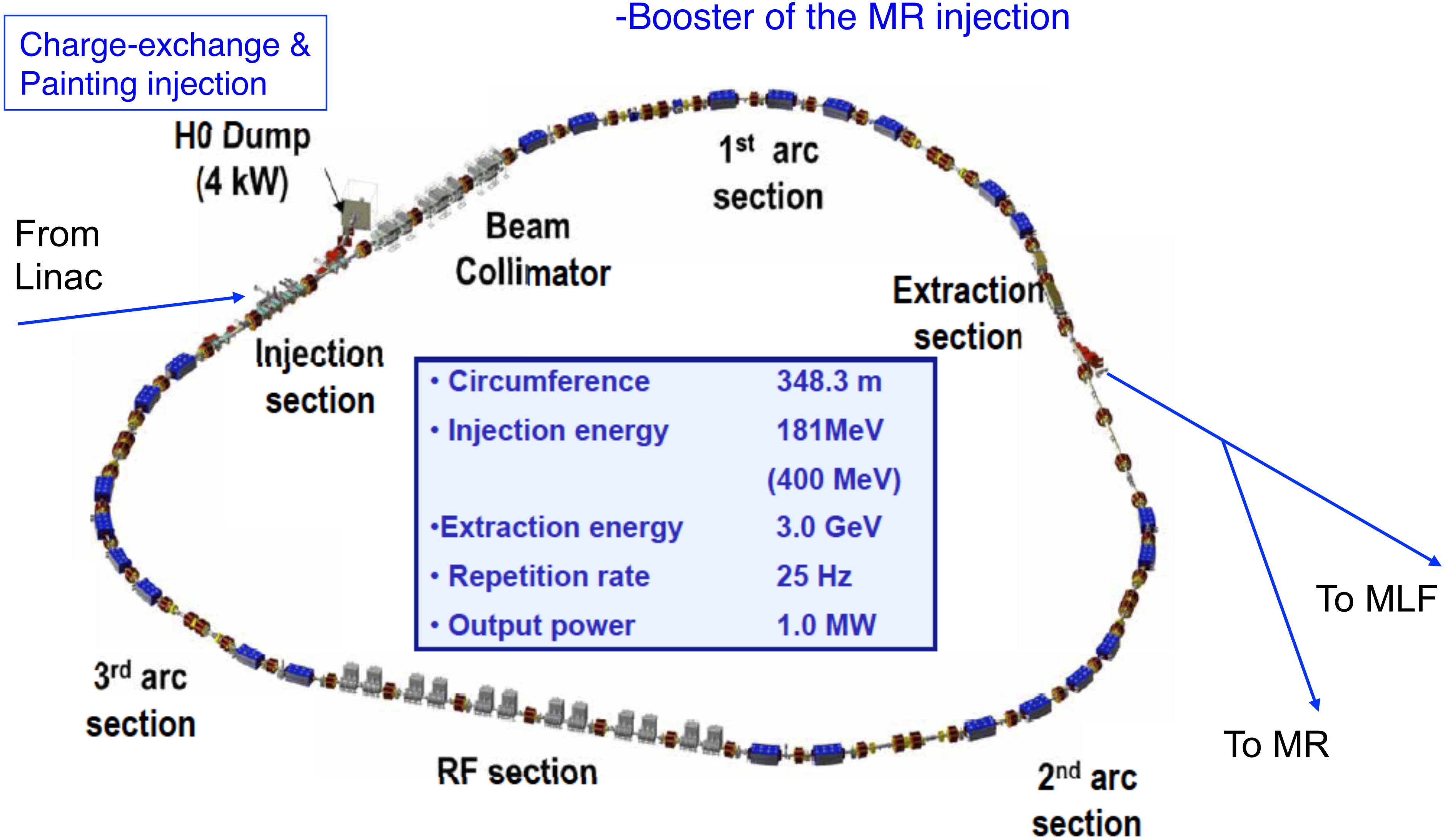






RCS (Rapid Cycling Synchrotron)

Multi-purpose machine:
-Proton driver for neutron/muon production
-Booster of the MR injection



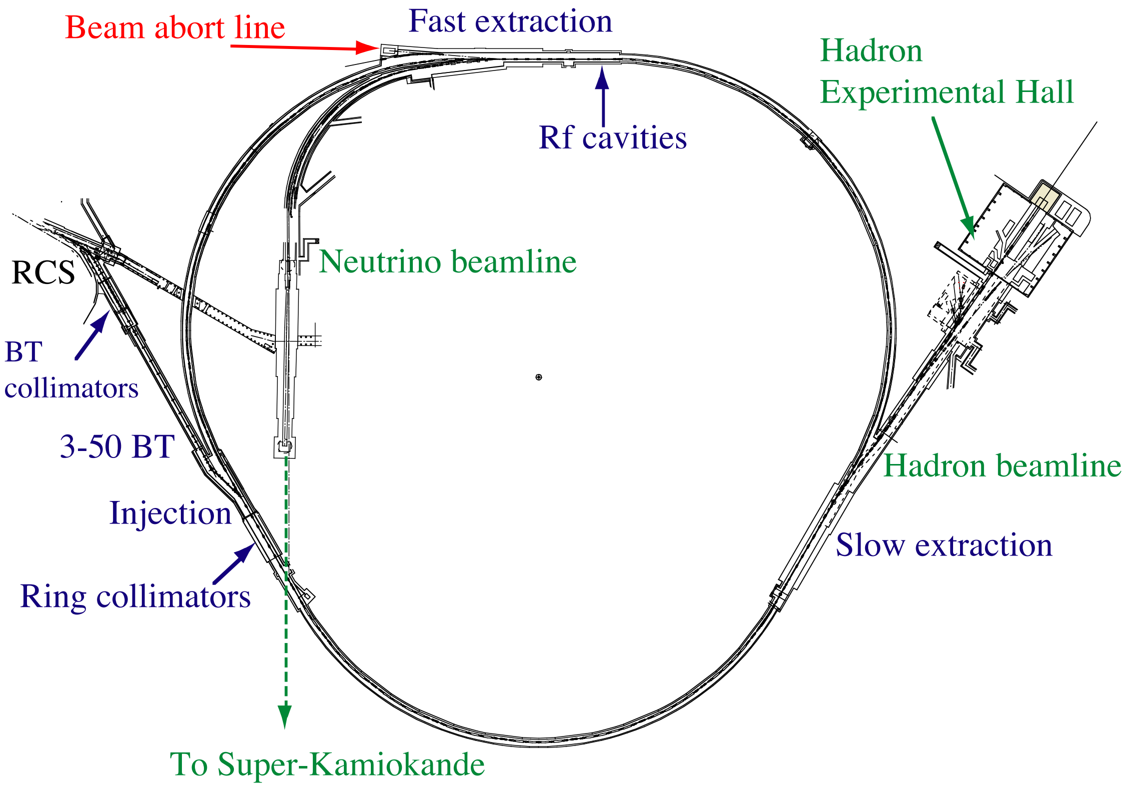
• Circumference	348.3 m
• Injection energy	181MeV
	(400 MeV)
•Extraction energy	3.0 GeV
• Repetition rate	25 Hz
• Output power	1.0 MW

Main parameters of MR

Circumference	**1567.5 m**
Repetition rate	**~ 0.17 Hz for SX**
	0.3 ~ 0.4 Hz for FX
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Superperiodicity	**3**
h	**9**
Number of bunches	**8**
Rf frequency	**1.67 - 1.72 MHz**
Transition γ	**j 31.7 (typical)**

Physical Aperture

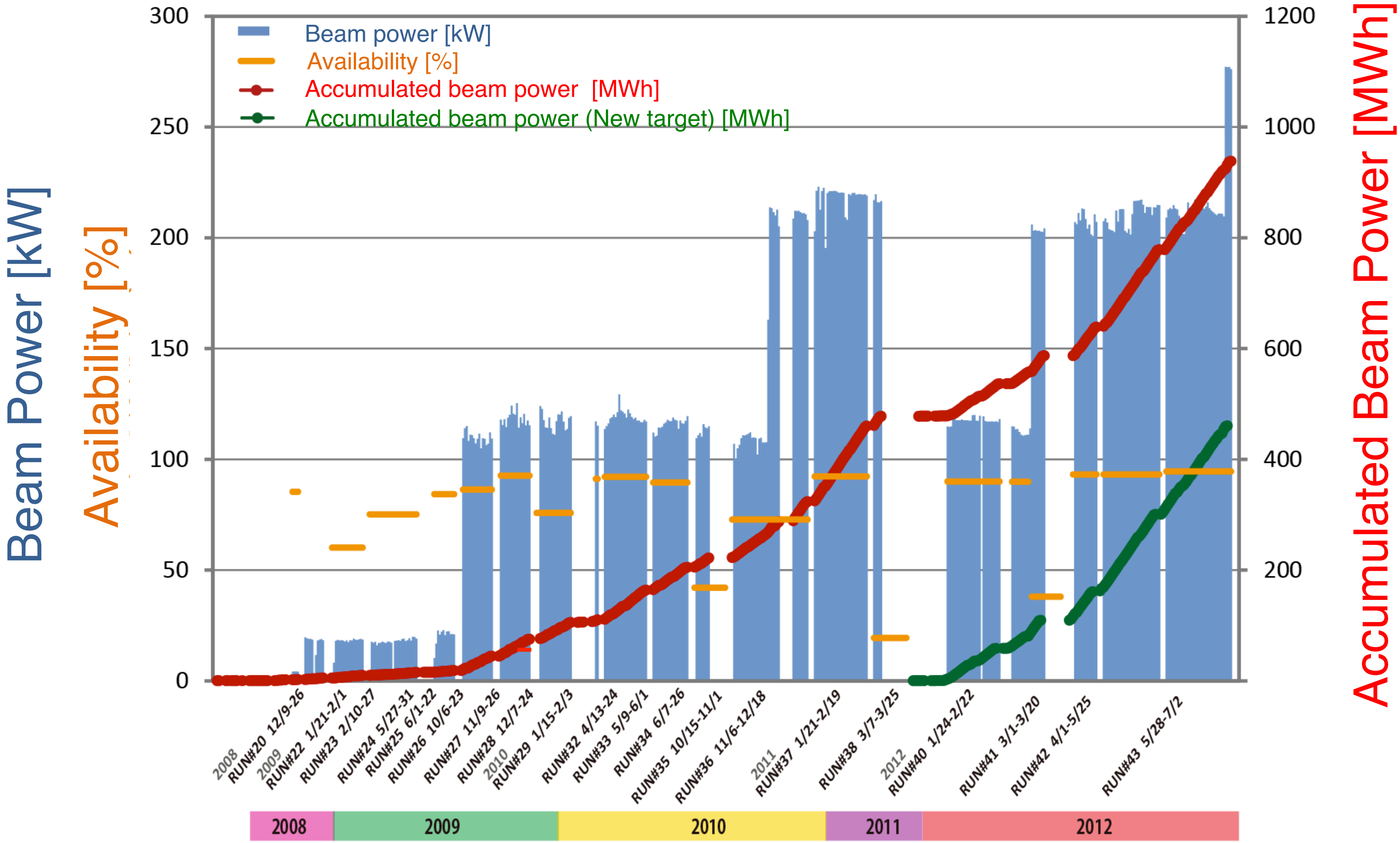
3-50 BT Collimator	**54-65 π.mm.mrad**
3-50 BT physical ap.	**> 120 π.mm.mrad**
Ring Collimator	**54-65 π.mm.mrad**
Ring physical ap.	**> 81 π.mm.mrad**



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)

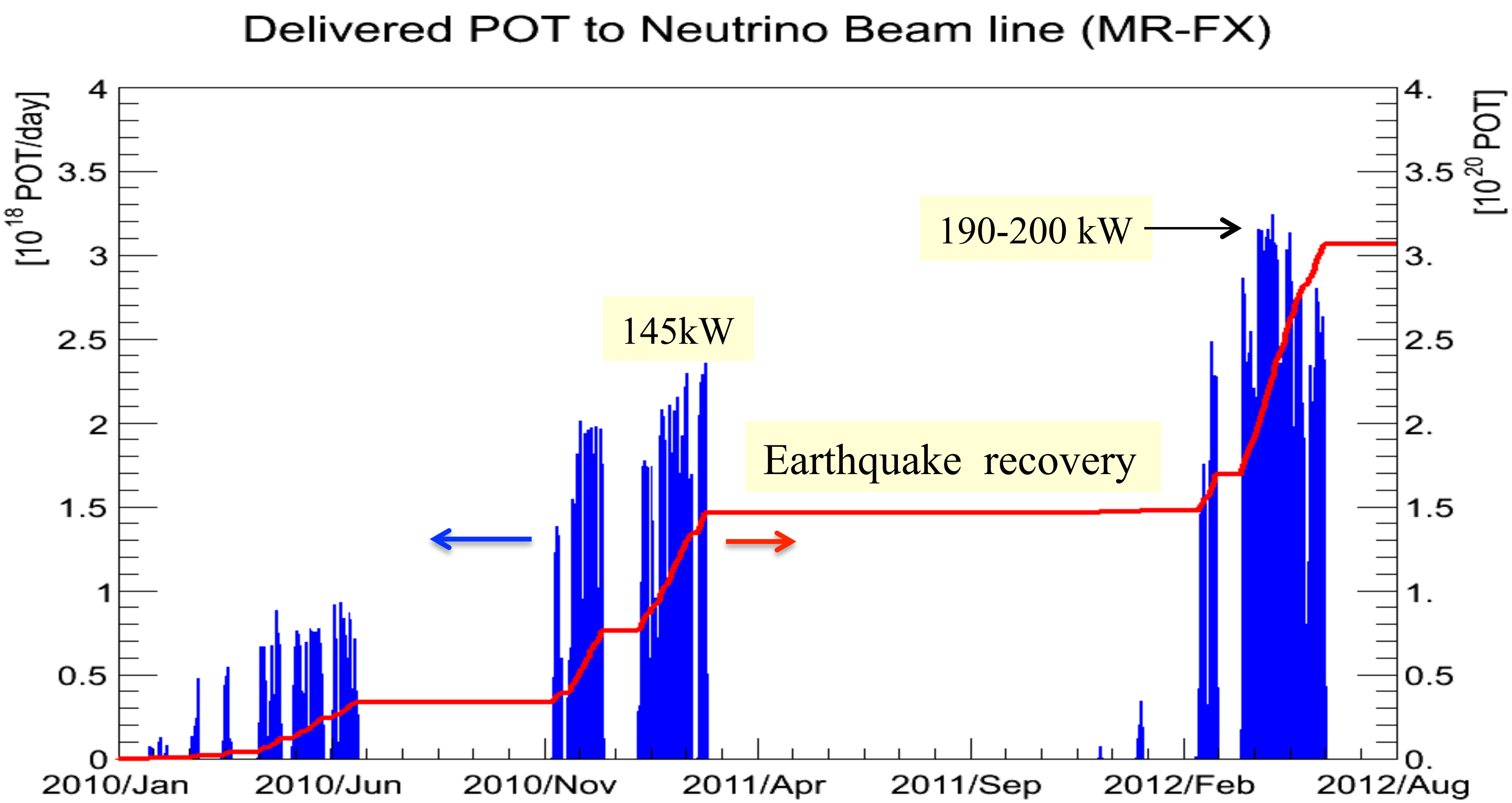
Status of accelerator operation

History of beam delivery from RCS to MLF



In the last three days, 275 kW beam was delivered from the RCS to the MLF.
Stable operation of 275 kW was successfully demonstrated.

History of delivered beam to the T2K experiment

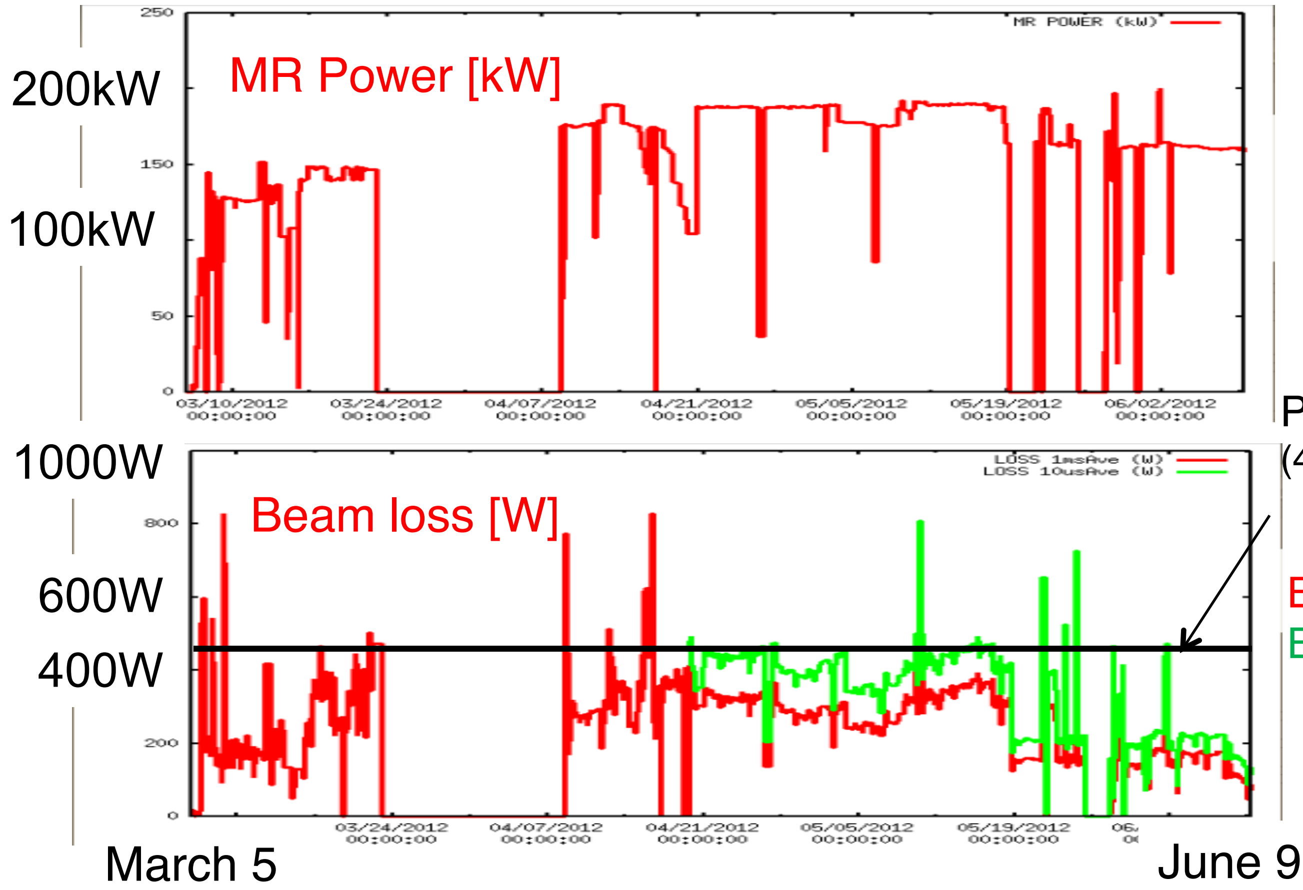


Operation for beam delivery to the T2K experiment before summer 2012 was finished on June 9, accumulated ~3x10^{20} POT

（K2K: 1.0 x10^{20} pot/ 4 years）

High power operation in FX mode (March 5 to June 9, 2012)

Delivered beam power to the T2K experiment ; 160 - 200 kW
MR cycle time is 2.56 s.
The number of extracted protons is 100 Tppp for 188 kW.
- The world largest extraction ppp in synchrotrons.



Present limit of beam loss
(450W, capacity of the MR collimator)

Beam loss(1ms average)
Beam loss(10 μs average)

Delivered beam power is limited by beam loss in the collimator section.

The 5-year medium term plan 2013~2017

The 5 year review of the J-PARC project by MEXT has been held in March – May 2012. The medium term plan is endorsed by the review committee.

Upgrade plan of linac

The design specification of the J-PARC facility (e.g. 1MW@RCS, 0.75MW@MR) cannot be realized with the present 181 MeV/30 mA linac.

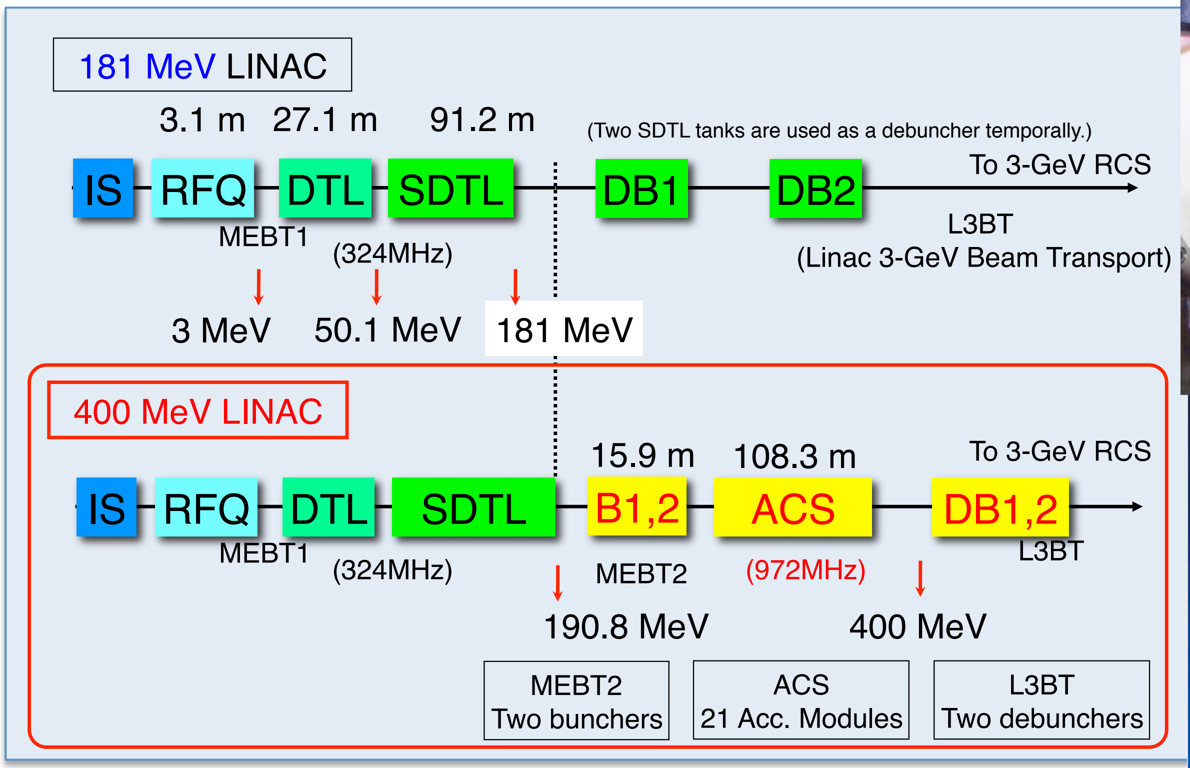
For beam energy (Small emittance beam for the RCS injection) :

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.

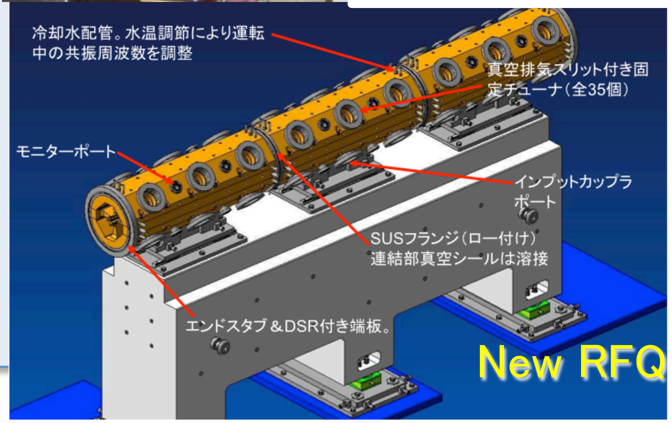
For peak beam current :

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

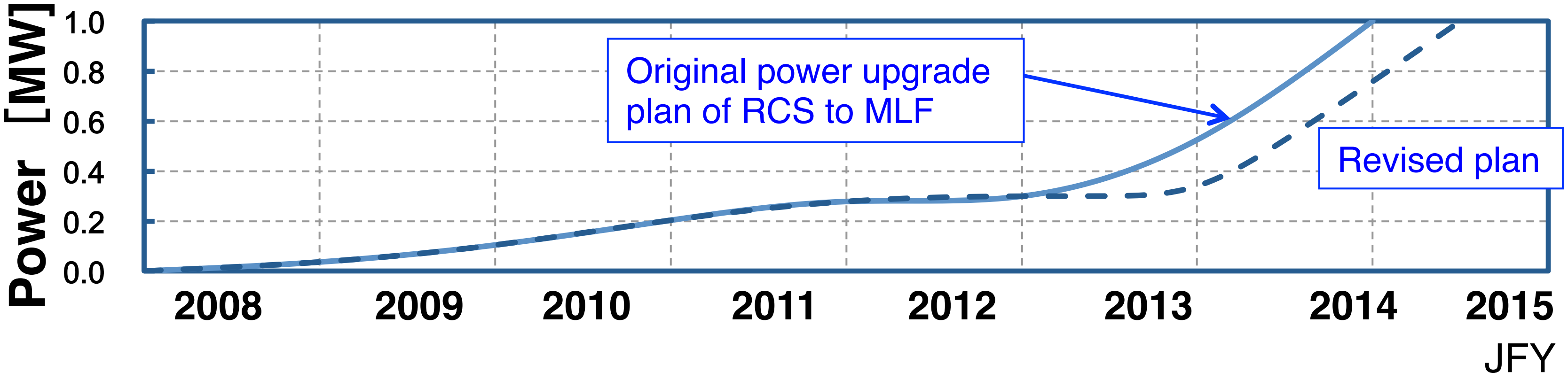
Installations of the ACS and new front-end are scheduled in 2013 shutdown.

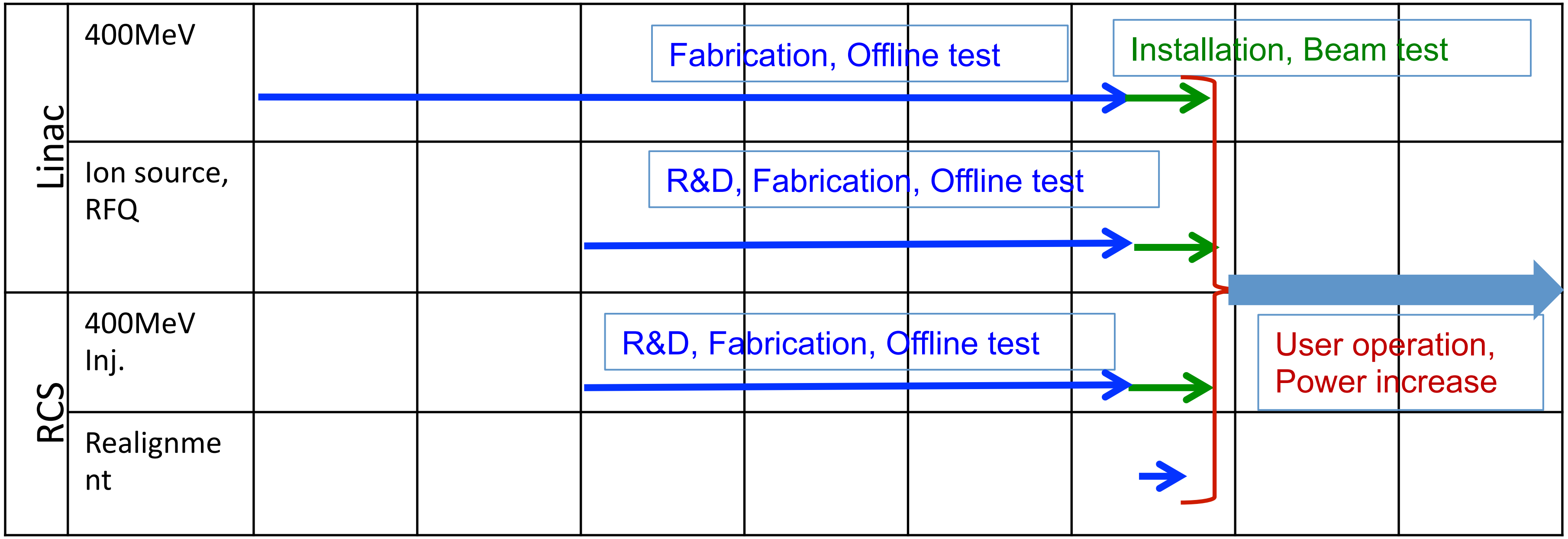


New ion source using rf antenna
(Collaboration with SNS)



Power upgrade for Linac & RCS

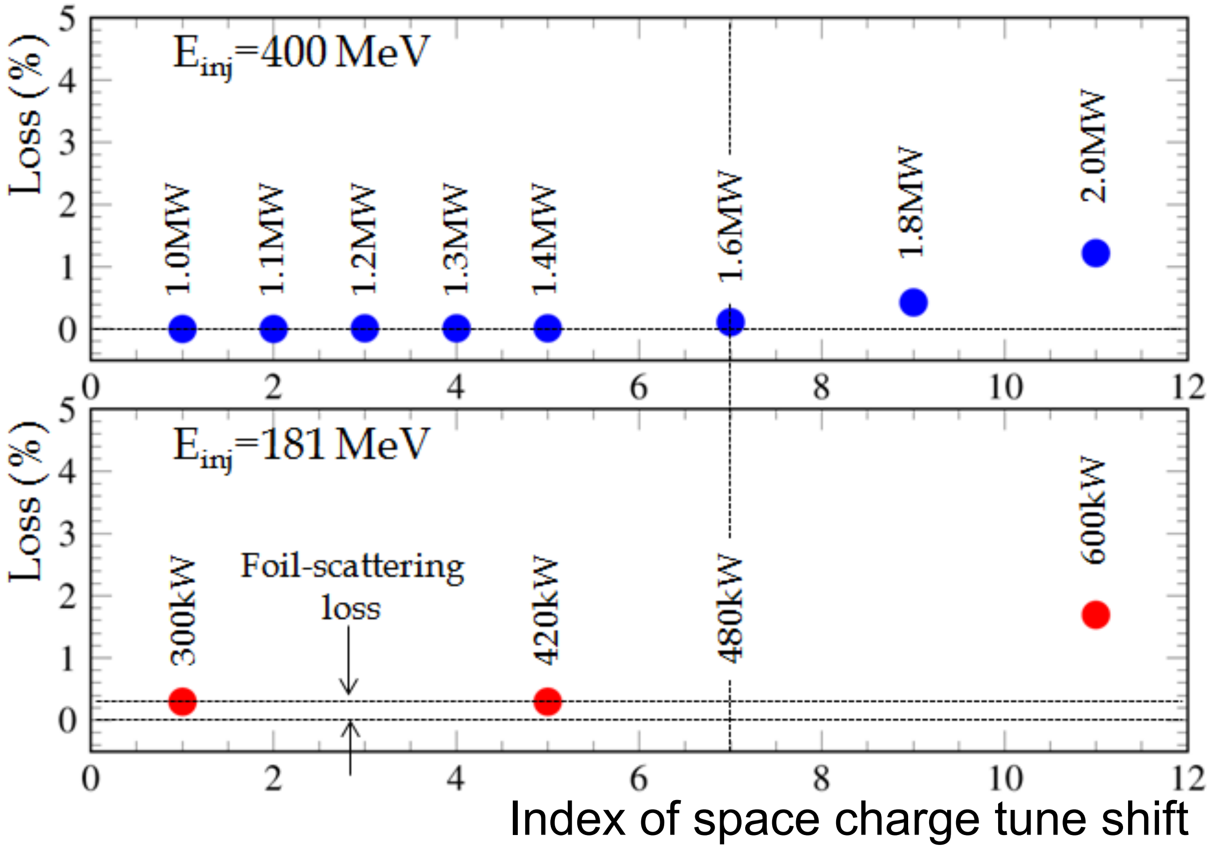




Budget for the Linac and the RCS upgrade is mostly secured.

We revise the power-up curve after the earthquake: shifted 6 months.

Limitation of the RCS beam power



Space-charge tune shift of the 600 kW operation at 181 MeV injection is equivalent to the 2 MW operation at 400 MeV injection.

Summery of 400 MeV inj.

RCS intensity	Particle Loss	Loss power at 25 Hz (for MR)
1.0 MW	~0.3%	400 W (64 W)
1.1 MW	~0.3%	440W (70 W)
1.2 MW	~0.3%	480 W (77 W)
1.3 MW	~0.3%	520 W (83 W)
1.4 MW	~0.3%	560 W (90 W)
1.6 MW	~0.5%	1067 W (170 W)
1.8 MW	~0.7%	1680 W (269 W)
2.0 MW	~1.5%	4000 W (640 W)

RCS collimator limit ~4 kW
RCS has a feasibility to operate 2 MW
(2MW is twice of design beam power)

→ 600 kW operation will be tested in autumn 2012. It gives useful information about the intensity limitation of the RCS.

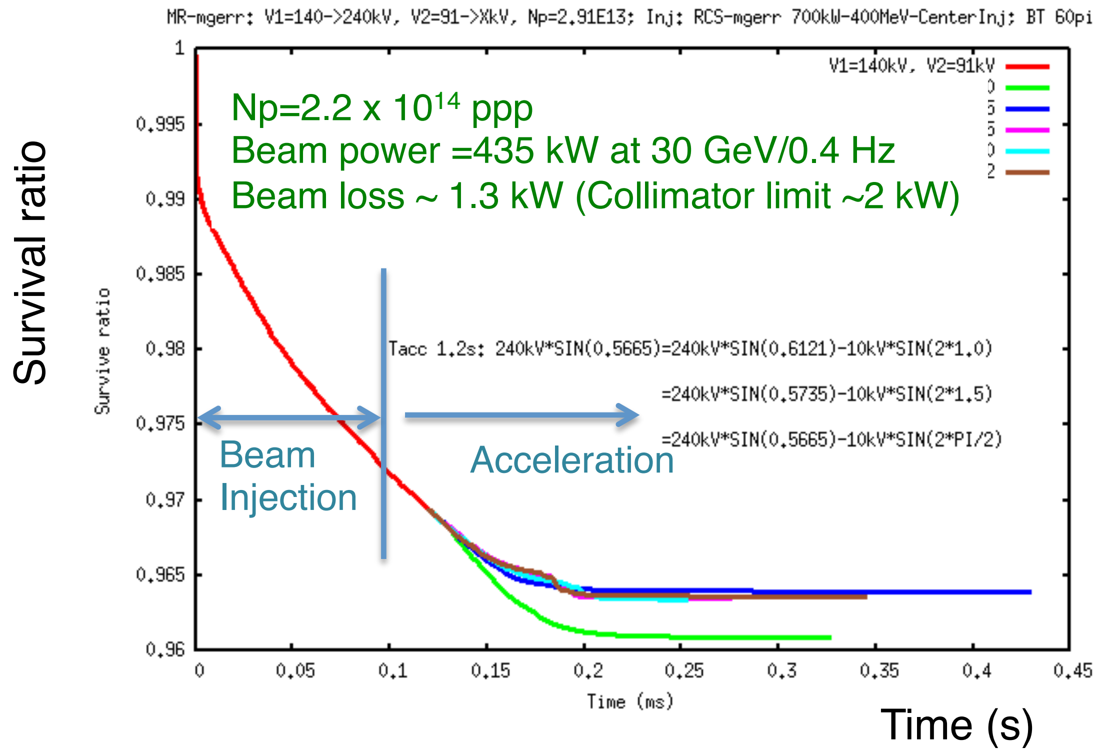
100 mA ion source is required for 2 MW operation of the RCS: R&D is necessary.

Near future operation plan of MR-FX

Periods	Expected beam power	Improvements / Cycle time
2011. 6-11	shutdown	Ring collimator shields, 7th and 8th RF systems, New injection kicker
2011. 12 - 2012. 6	100 - 200 kW (RCS 300 kW eq.)	Cycle time 3.2 -> 2.56 Beam loading compensation
2012. 7 – 9	shutdown	Ring collimator upgrade (0.45 -> 2 kW) 9th RF system
2012. 10 – 2013. 7	> 200 kW (2012.10~) (RCS 300-400 kW eq.)	Cycle time 2.48 -> 2.4 s Second harmonic cavities
2013. 8 – 2013. 1	shutdown	Ring collimator upgrade (2 kW -> 3.5 kW) Linac upgrade
2014. 2 – 2014. 6	> 300 kW (RCS > 600 kW eq.)	Cycle time 2.4 s

Mid-term plan: For higher beam power in MR Fast Extraction

Tracking simulation of the MR fast extraction operation
with space charge effect



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

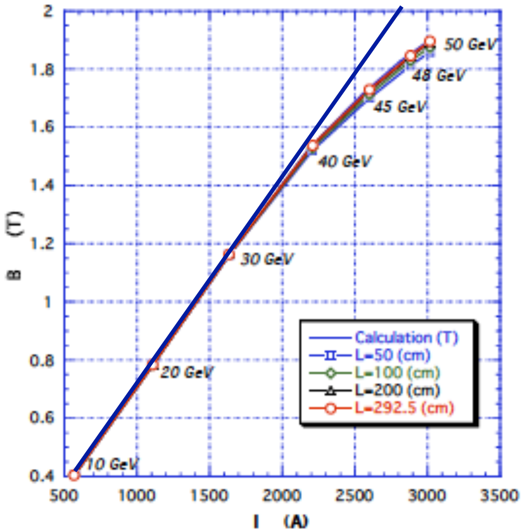
For more beam power,

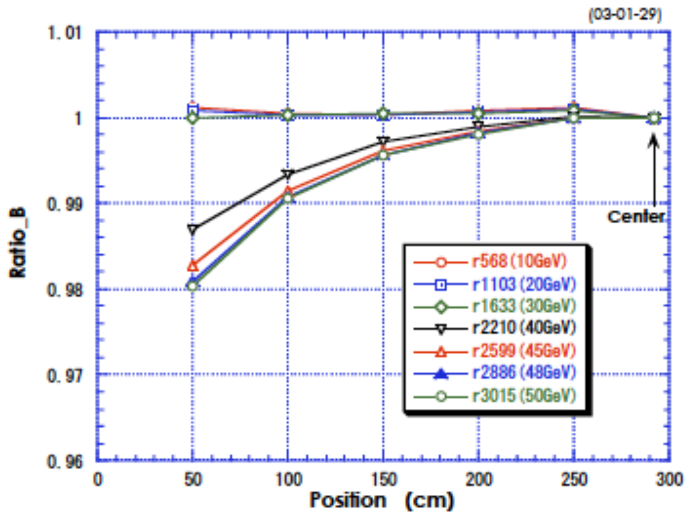
- higher beam energy than 30 GeV : Original plan
- higher repetition rate than 0.4 Hz.

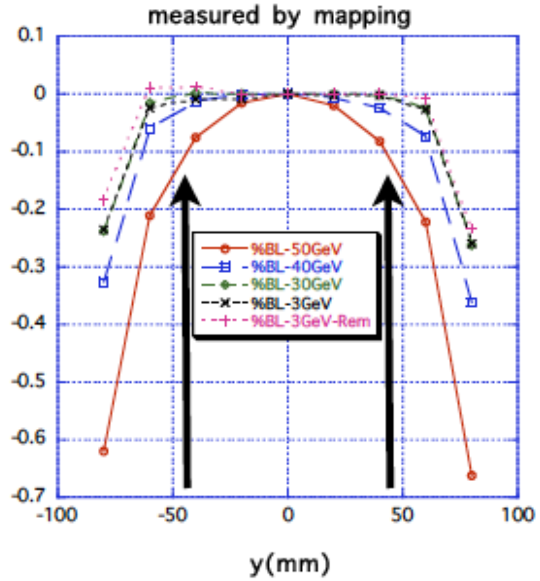
--> We choose the scenario of increasing repetition rate ~ 1Hz

Magnet saturation in the 50 GeV operation

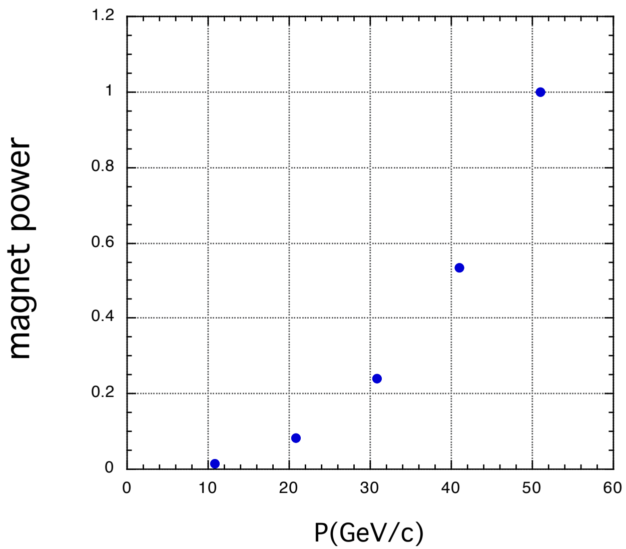
Results of field measurements for dipole magnets







Total magnet power



- The saturation effects deteriorate the field quality of the main magnets

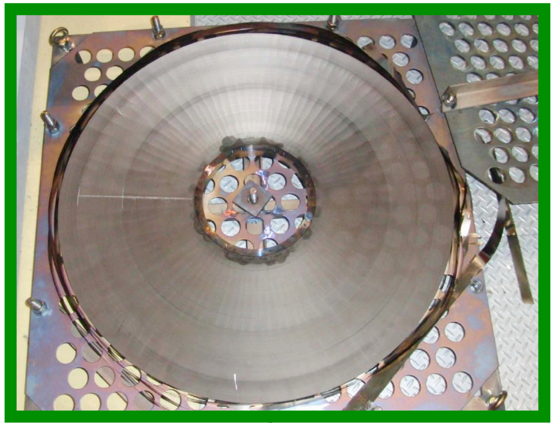
- Magnet power P

$$P_{50GeV} = 2P_{40GeV} = 4P_{30GeV}$$

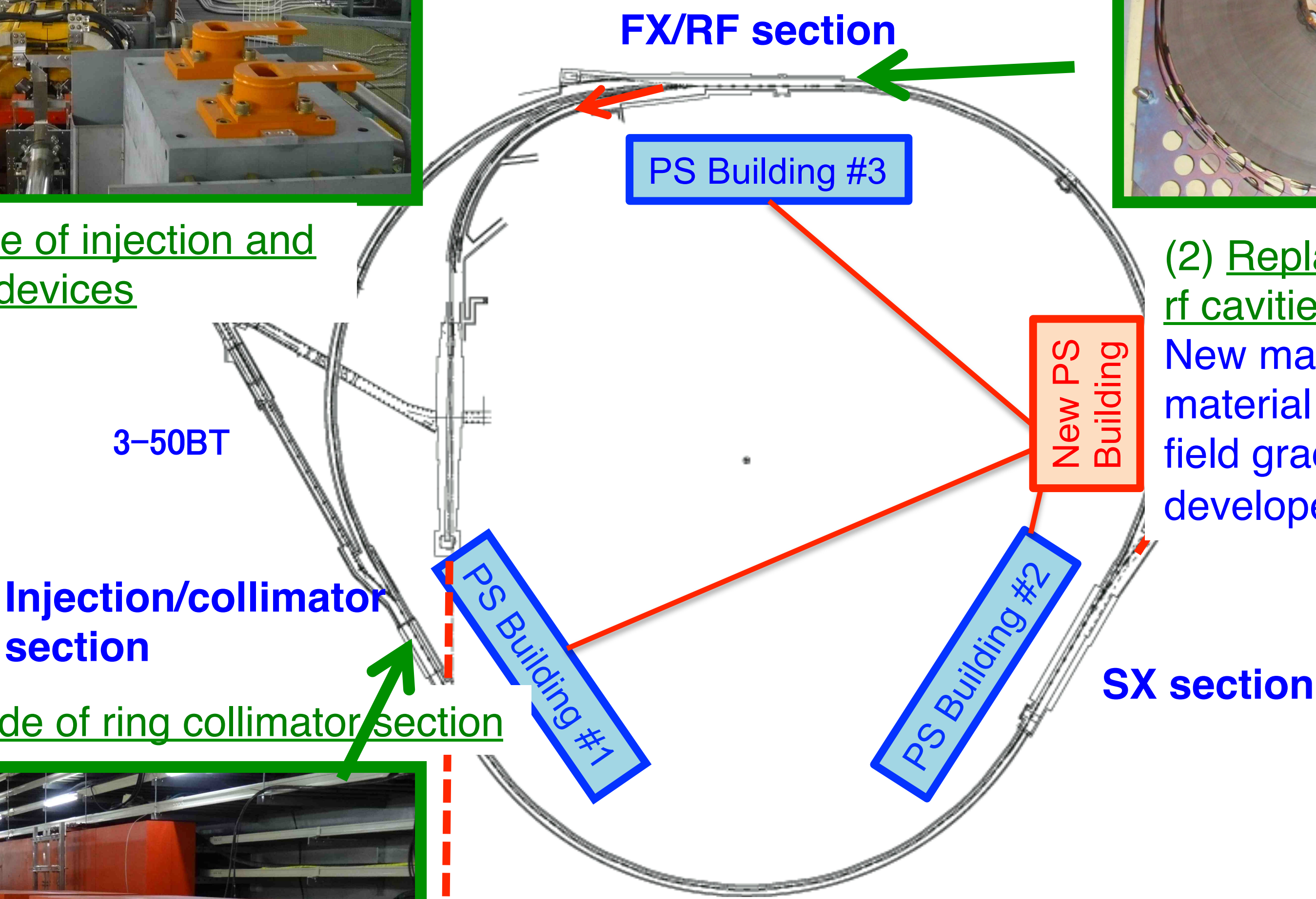
Total magnet power of the 50 GeV operation is four times larger than the 30 GeV case. The high electric cost is fatally disadvantageous especially in the situation after the earthquake disaster in Japan.

For 1 Hz cycle operation: four improvements

(3) Upgrade of injection and extraction devices



(2) Replacement of the rf cavities
New magnetic core material for the higher field gradient system is developed and tested.



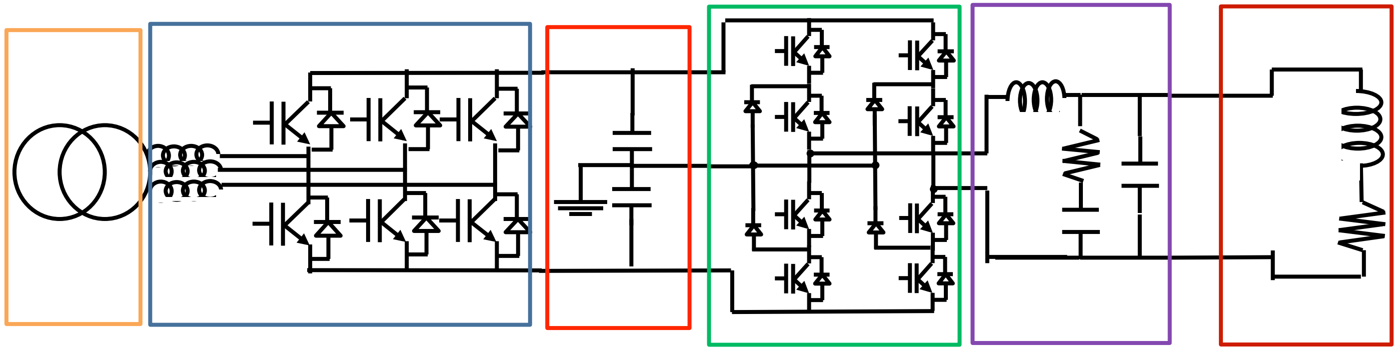
(4) Upgrade of ring collimator section

(1) Replacement of the magnet power supplies
All the main magnet power supplies will be replaced with newly developed high rep./low ripple PS. A new PS building will be added.

On going R&Ds (1)

- Power supply for main magnets-

- High rep rate (~1 Hz): Energy recovery using condenser bank
- Small current deviation: Current feedback, voltage feed-forward, NPC chopper..



Transformer

3ΦPWM converter: 1 kHz, control input voltage and voltage of condenser bank

Condenser bank: Film condenser, 70 mF, 3 kV, store ~ 200 kJ

NPC chopper: control output current/voltage

Filter : switching ripple reduction (5 kHz)

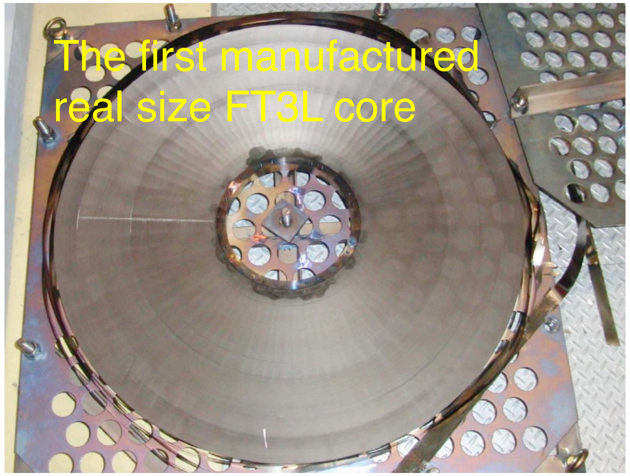
Magnets:

- A small scale prototype model is manufactured and testing in 2011/2012.
- A real scale prototype for one of the quadrupole families will be manufactured and tested in 2012 and 2013.
- Technical review committee meeting for the power supply R&D will be held in October 2nd , 2012.

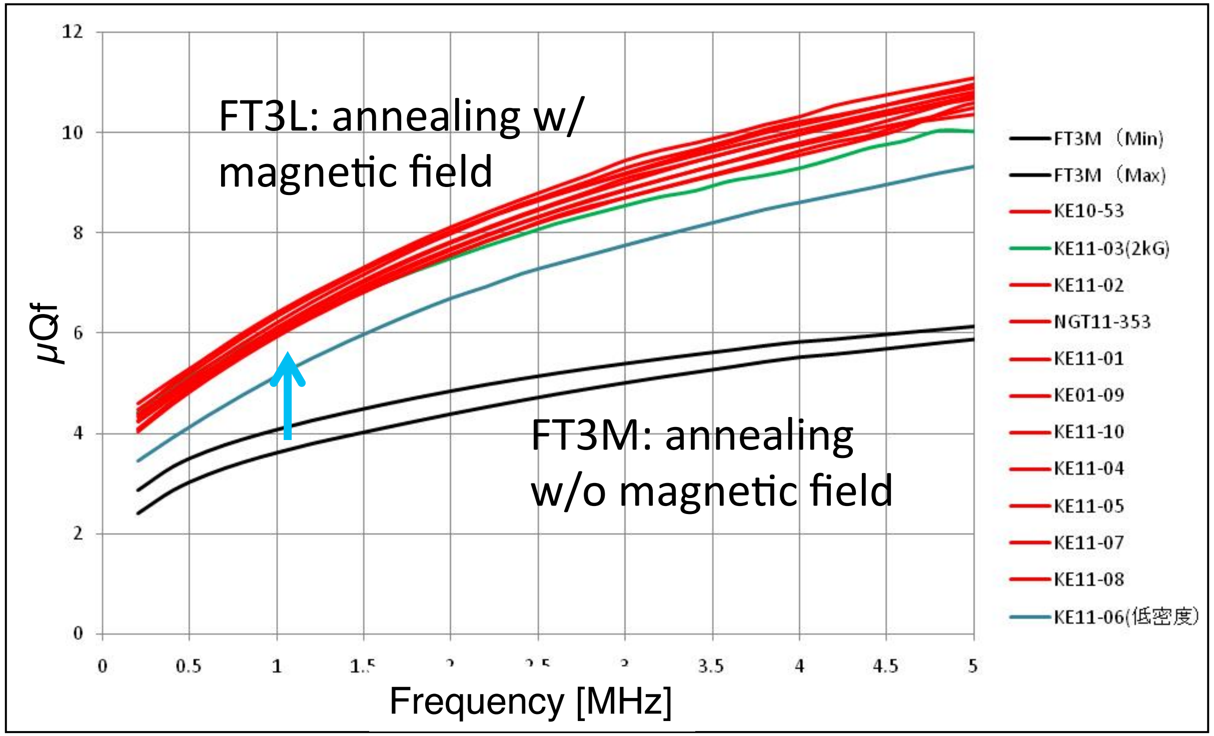
On going R&Ds (2)

- MA (Magnetic Alloy) loaded rf cavity with higher shunt impedance -

A type of MA cores, FT3L (made by Hitachi metals), which is processed by annealing with magnetic field, shows 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.



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



The FT3L core has the impedance approximately twice of the FT3M.

Six FT3L cores are used at one gap of the cavity tank in the #9 cavity, which is installed in the 2012 summer shutdown.

The medium-term plan of the MR-FX until 2017

We adopt the high repetition rate scheme 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.

JFY	2011	2012	2013	2014	2015	2016	2017
			Li. 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 R&D	2.4 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**	New injection kicker	Kicker PS improvement、Septum 2 manufacture /test LF septum, PS for HF septa manufacture /test					

Long-term plan
2018 ~

For the MR, scenarios for Multi-MW output beam power for neutrino experiment are being discussed .

1. Large aperture MR

   Enlarging the physical aperture from 81 to > 120 πmm.mrad

   A new synchrotron in the MR tunnel

2. Second booster ring for MR (emittance damping ring)

   A ring with extraction energy ~ 8 GeV, between the RCS and the MR

3. New rapid cycling synchrotron using 3 GeV RCS beam

   - as a proton driver for neutrino beam production
   - as an injector of MR, which is exclusively operated for the SX users

4. New rapid cycling synchrotron using the upgraded ~1 GeV linac beam

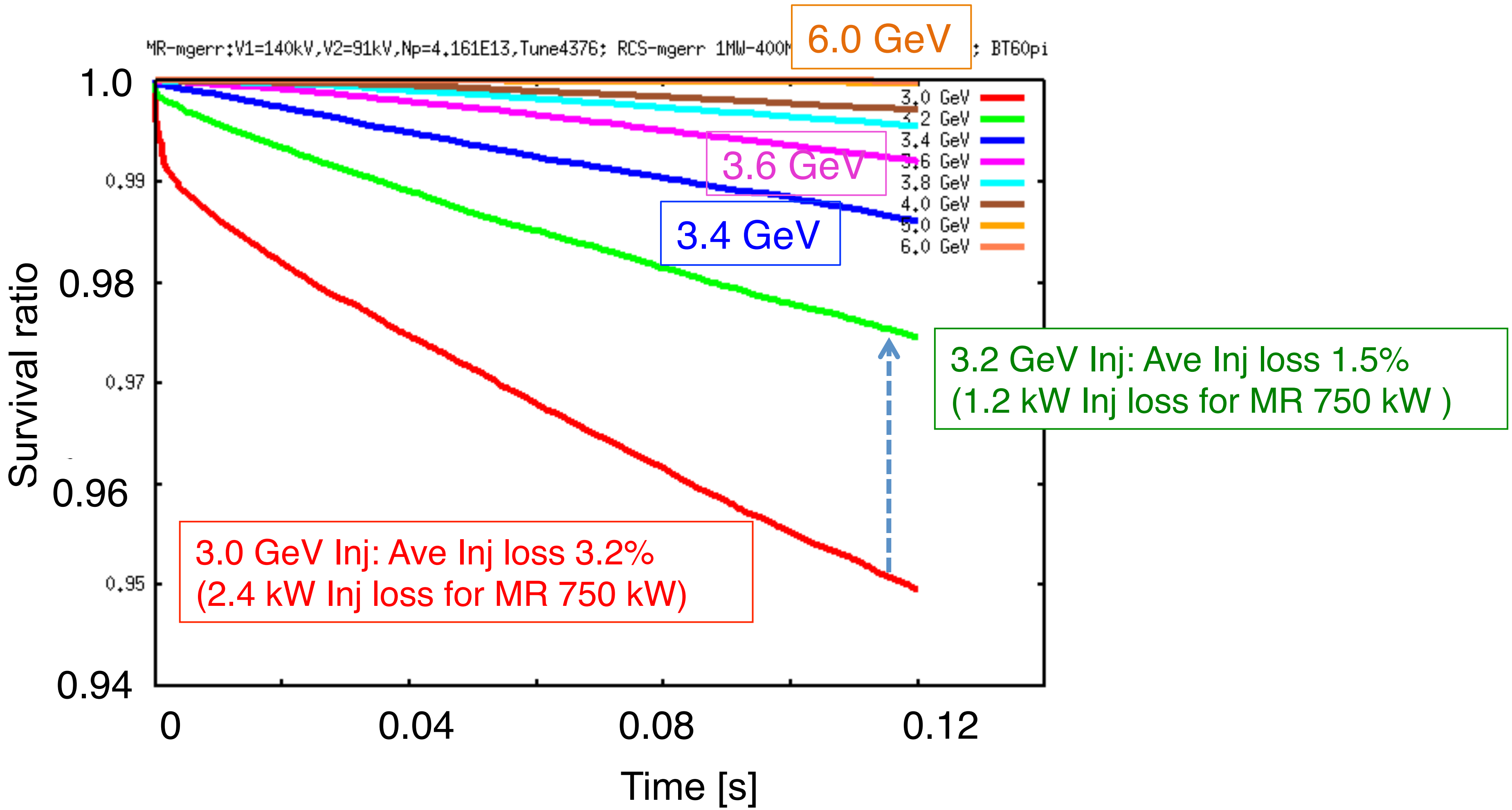
   - as a proton driver for neutrino beam production
   - as an injector of MR, which is exclusively operated for the SX users

….

The detailed scheme of the future MW proton driver is discussed in the next five years and prepare to submit budget proposal to the government in 2018 or later.

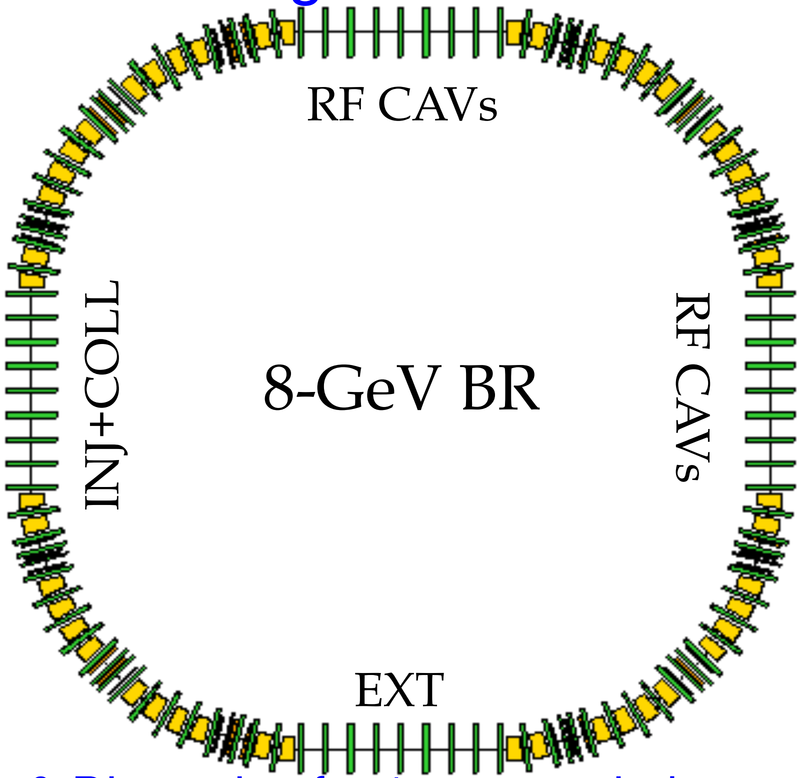
Injection energy and beam loss in the MR

Simulation of beam survival in the injection period of the MR
for the RCS 1MW eq. beam (4e13 ppb)

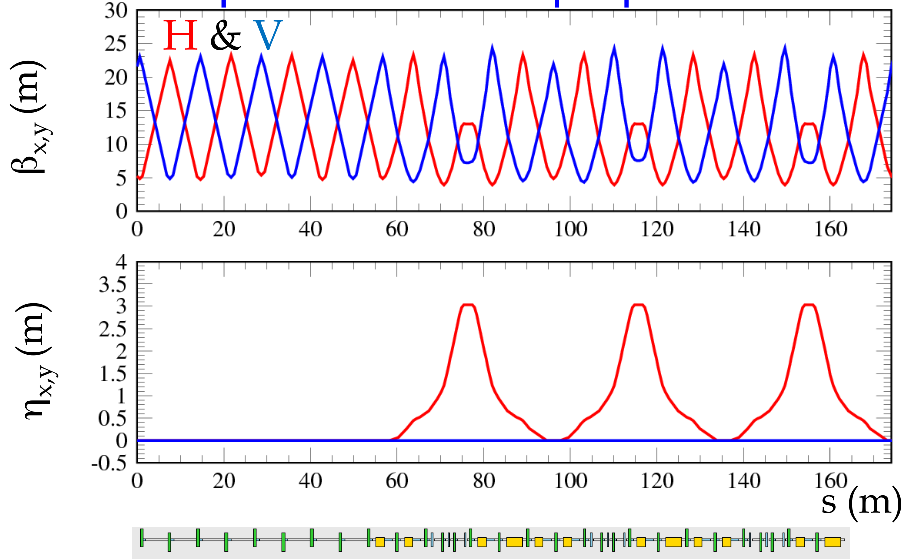


Beam survival ratio is drastically increased
by higher beam momentum.

Design of the 8-GeV BR : Lattice & parameters



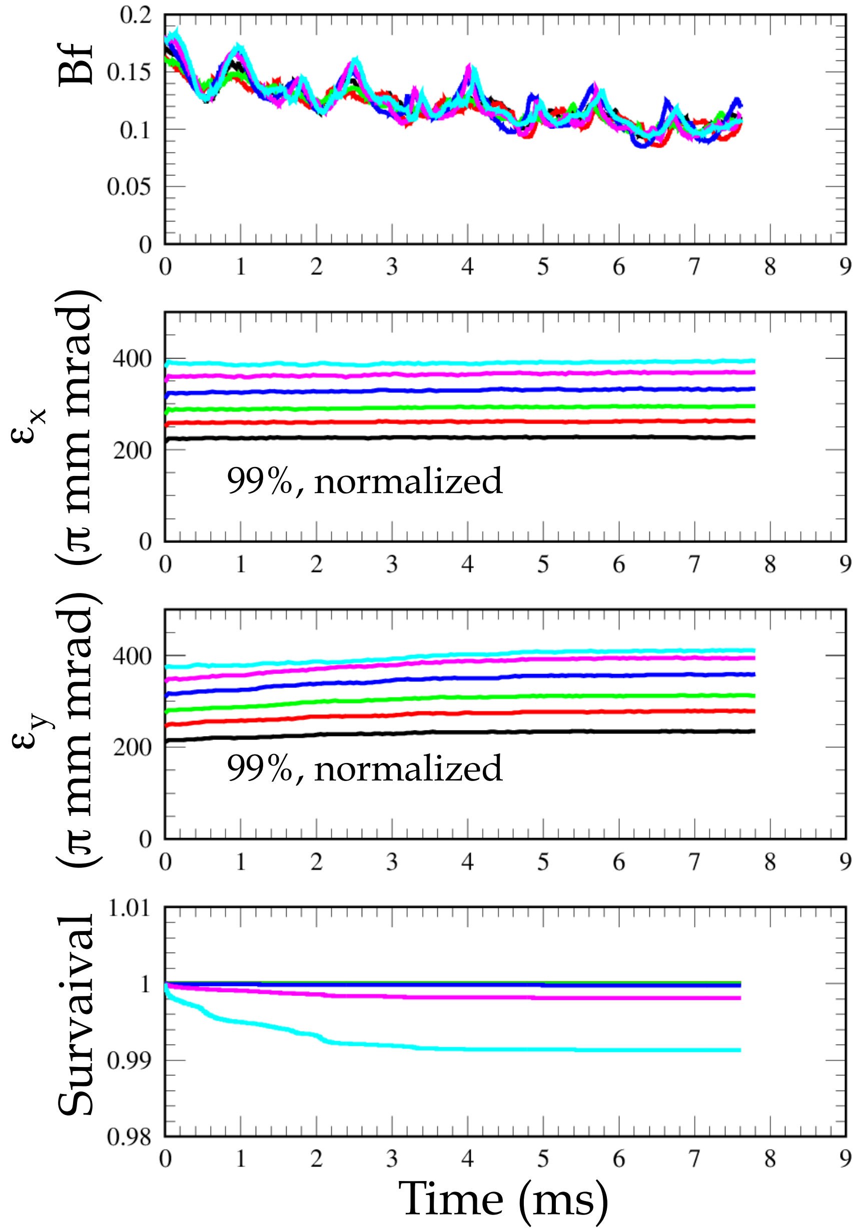
Beta & Dispersion for 1-superperiod



Parameters of the RCS and 8 GeV BR

	3-GeV RCS	8-GeV BR
Circumference	348.333 m	696.666 m
Super-periodicity	3	4
Injection energy	400 MeV	3 GeV
Extraction energy	3 GeV	8 GeV
Repetition	25 Hz	25 Hz
Ramping pattern	Sinusoidal	Sinusoidal
Transition energy	9 GeV	15 GeV
Harmonic number	2	4
Number of bunches	2	2
Momentum acceptance	±1%	±1%
Ring acceptance	486 π mm mrad	189 π mm mrad
Collimator aperture	324 π mm mrad	126 π mm mrad

Design of the 8-GeV BR：Simulation results (1)



With imperfections measured in the RCS

- 1.0 MW beam from the RCS
- 1.2 MW
- 1.4 MW
- 1.6 MW
- 1.8 MW
- 2.0 MW

RCS intensity	Survival	Loss power
1.0 MW	99.998%	3.2 W
1.2 MW	99.998%	3.8W
1.4 MW	99.997%	6.7W
1.6 MW	99.977%	59W
1.8 MW	99.815%	533 W
2.0 MW	99.123%	2806W

Collimator capacity of the 8-GeV BR:
4 kW（as same as the RCS collimator）

Design of the 8-GeV BR：Simulation results (2)

Estimated by βγ scaling

RCS intensity (MW)	$\varepsilon_{x99.8\%}/\varepsilon_{y99.8\%}$ at 14.2 ms (π mm mrad)	$\varepsilon_{x99.8\%}/\varepsilon_{y99.8\%}$ at 20 ms (π mm mrad)	MR beam power (MW) assuming 1-s cycle
1.0	35.0/36.5	31.1/32.5	1.6
1.2	39.9/42.4	35.4/37.7	1.9
1.4	44.1/47.2	39.2/42.0	2.2
1.6	49.4/54.0	44.0/48.0	2.6
1.8	55.0/60.1	48.9/53.4	2.9
2.0	57.9/62.4	51.5/55.5	3.2

8-50BT & MR collimators : 54-60π mm.mrad

Beam loss @ 8-50 BT collimator

0.2% particle loss ⇒ 1.71 kW if assuming 3.2 MW from MR

Loss capacity of the 8-50BT collimator: 2kW（as same as the 3-50BT collimator）

Summary

Operation summary:

MR delivered 160 – 200 kW beam to theT2K experiment.

- 160 – 200 kW beam was delivered, 212 kW equivalent beam was demonstrated in single shot mode.

The 5-year midium term plan : (2013 - 2017)

- The special 6-month shutdown for the linac upgrade is scheduled In 2013 for installation of the ACS and the front-end section in summer/autumn.

- Beam power > 200 kW will be continuously delivered to the T2K experiments before 2013 summer shutdown. After the linac upgrade, beam power 300 - 400 kW will be delivered.

- Goal of the 5 year mid-term plan is 750 kW for the FX. The basic scenario is high repetition rate of 1 Hz with 30 GeV.

Long-term plan (2018 -)

- Discussion on some scenarios for Multi-MW output beam power for neutrino experiment have been started.

- As one of the feasible schemes, new 8-GeV booster ring, an emittance damping ring for the MR injection, is under discussion.
- In this scheme, it would be possible to 2.2 / 3.2 MW beam output from the MR if the RCS could extract 1.4 / 2.0 MW equivalent beam.