Workshop for Neutrino Programs with facilities in Japan
Aug 3, 2015 @Tokai-mura

J-PARC Accelerator
- achievement and future upgrade -

Tadashi Koseki

Accelerator Laboratory, KEK
J-PARC Center, KEK&JAEA

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2. Mid-term upgrade plan
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1. Status of accelerator operation and achievements
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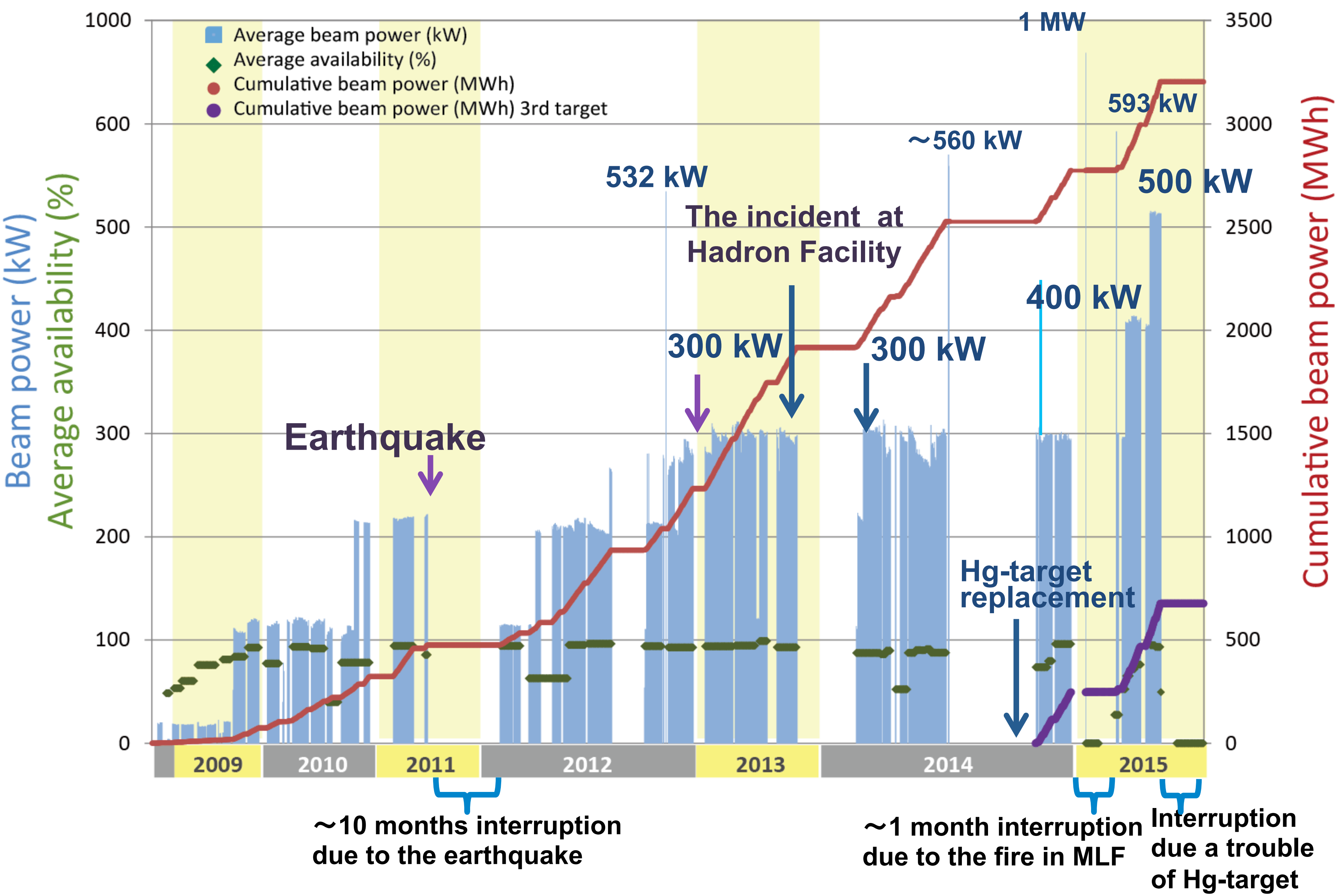
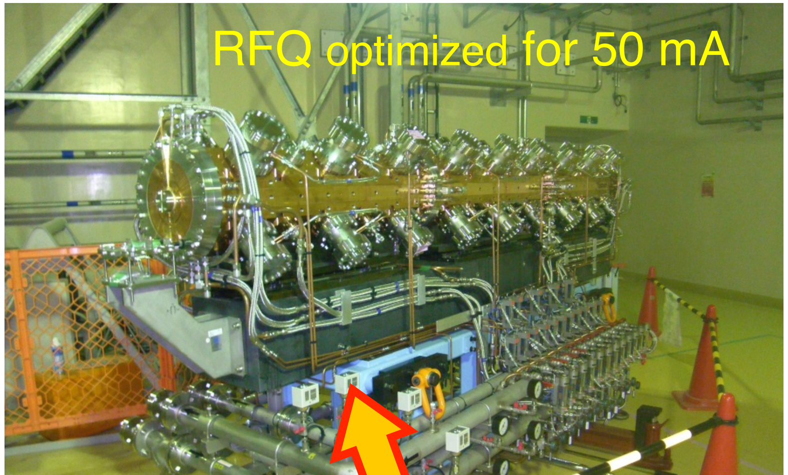
History of beam delivery to the MLF

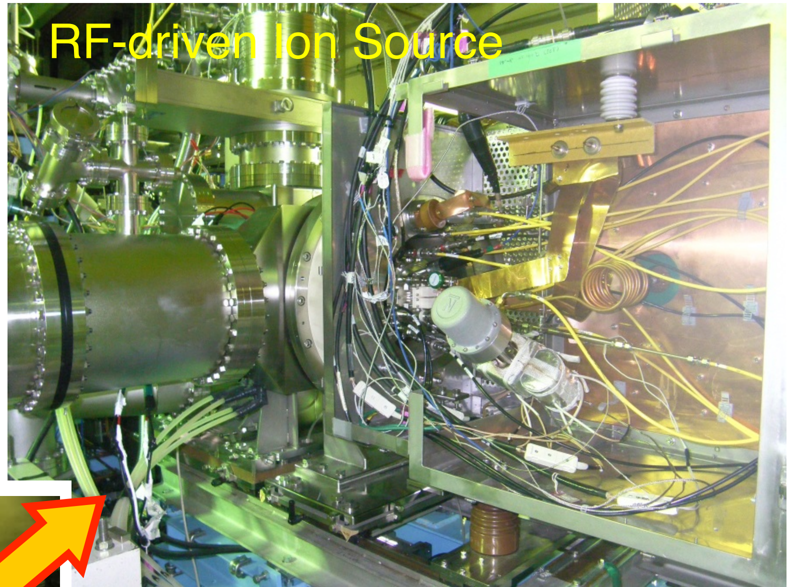
• as of 3rd of June 2015

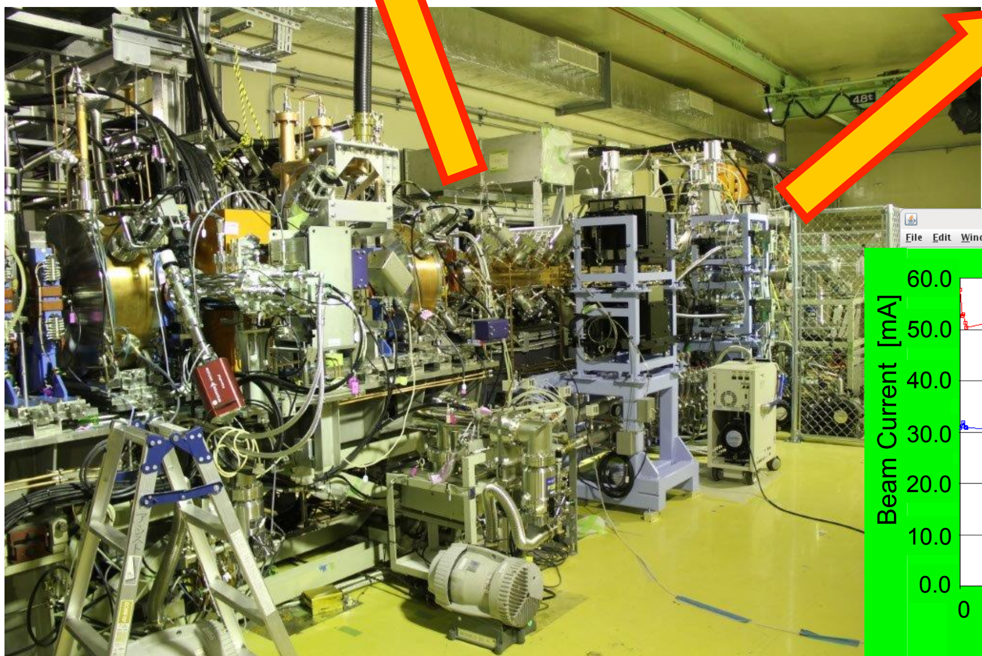


New front-end system of the J-PARC linac

During the 2014 summer shutdown period, the front-end system of the linac was replaced to increase the peak current to 50 mA.

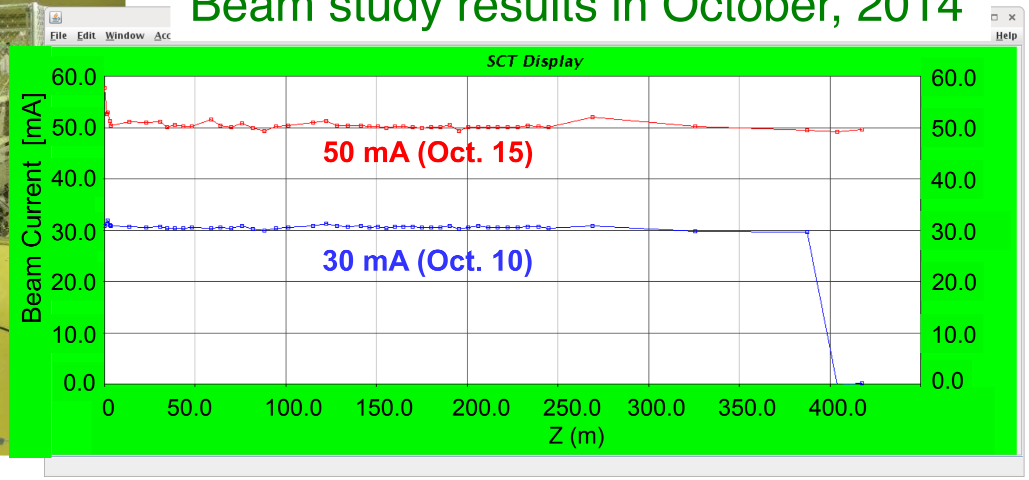




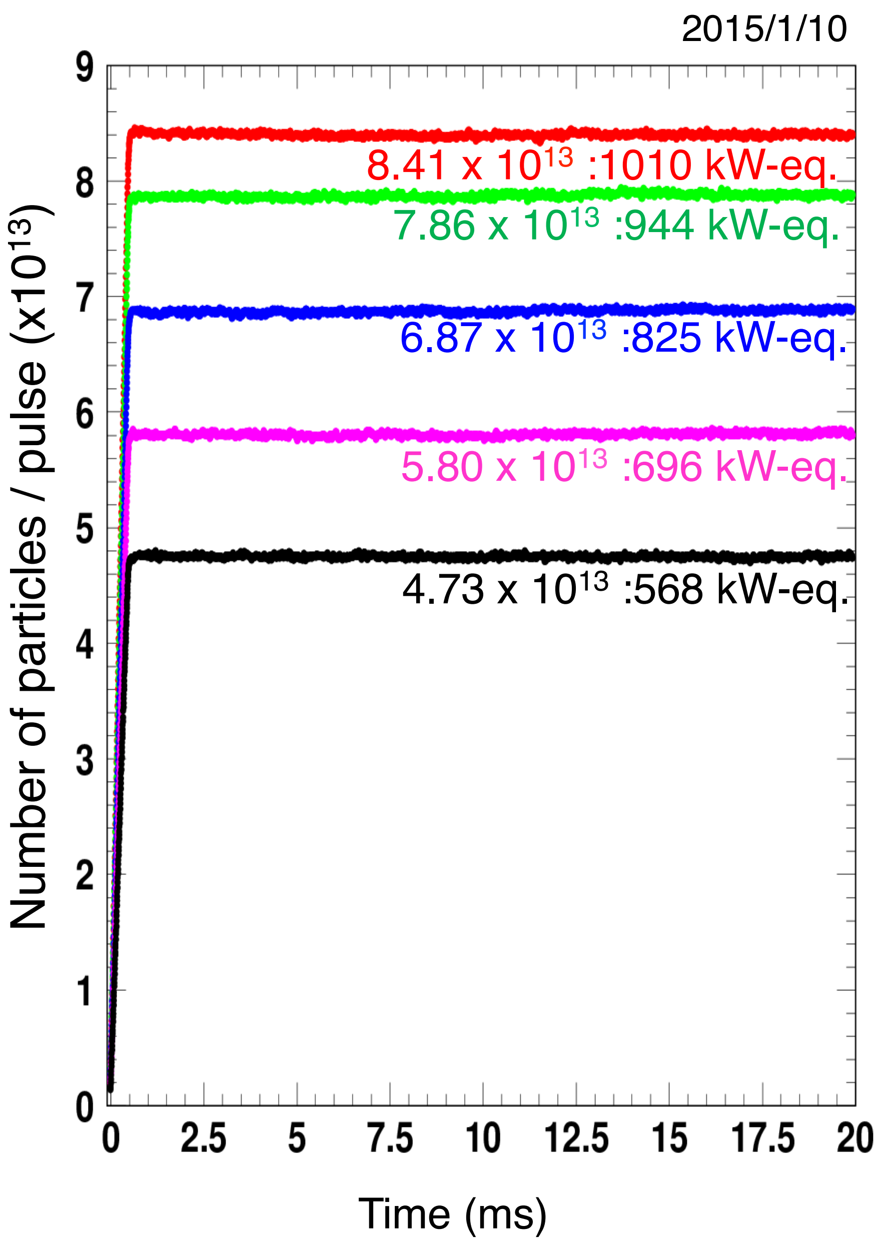


New front-end system in the tunnel.

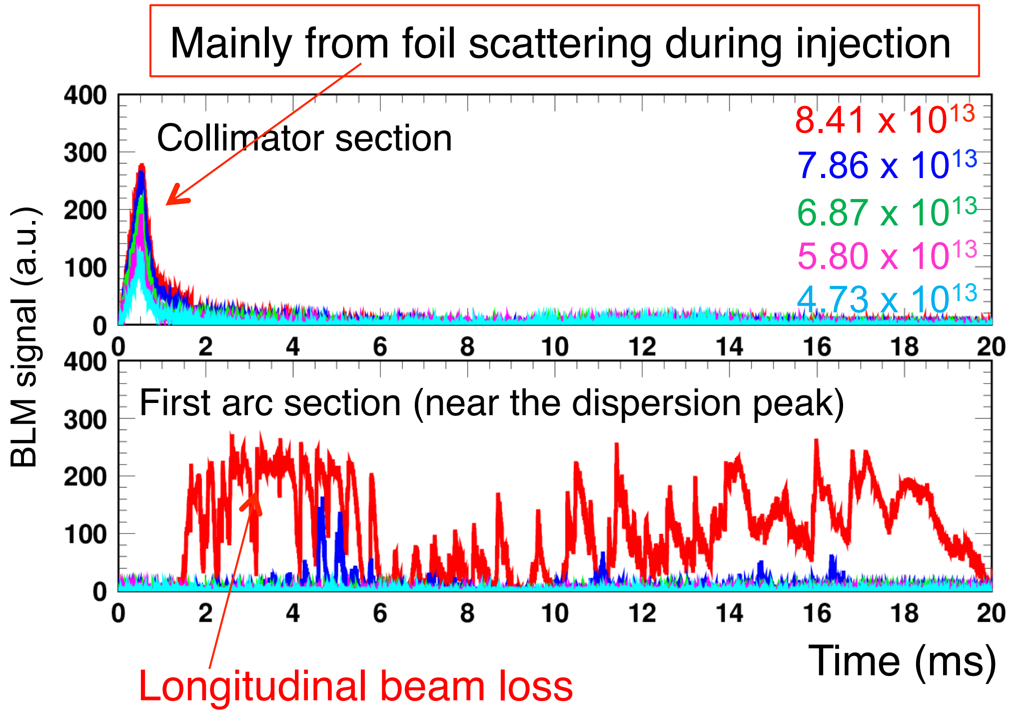
Beam study results in October, 2014



Demonstration of 1 MW-eq. beam

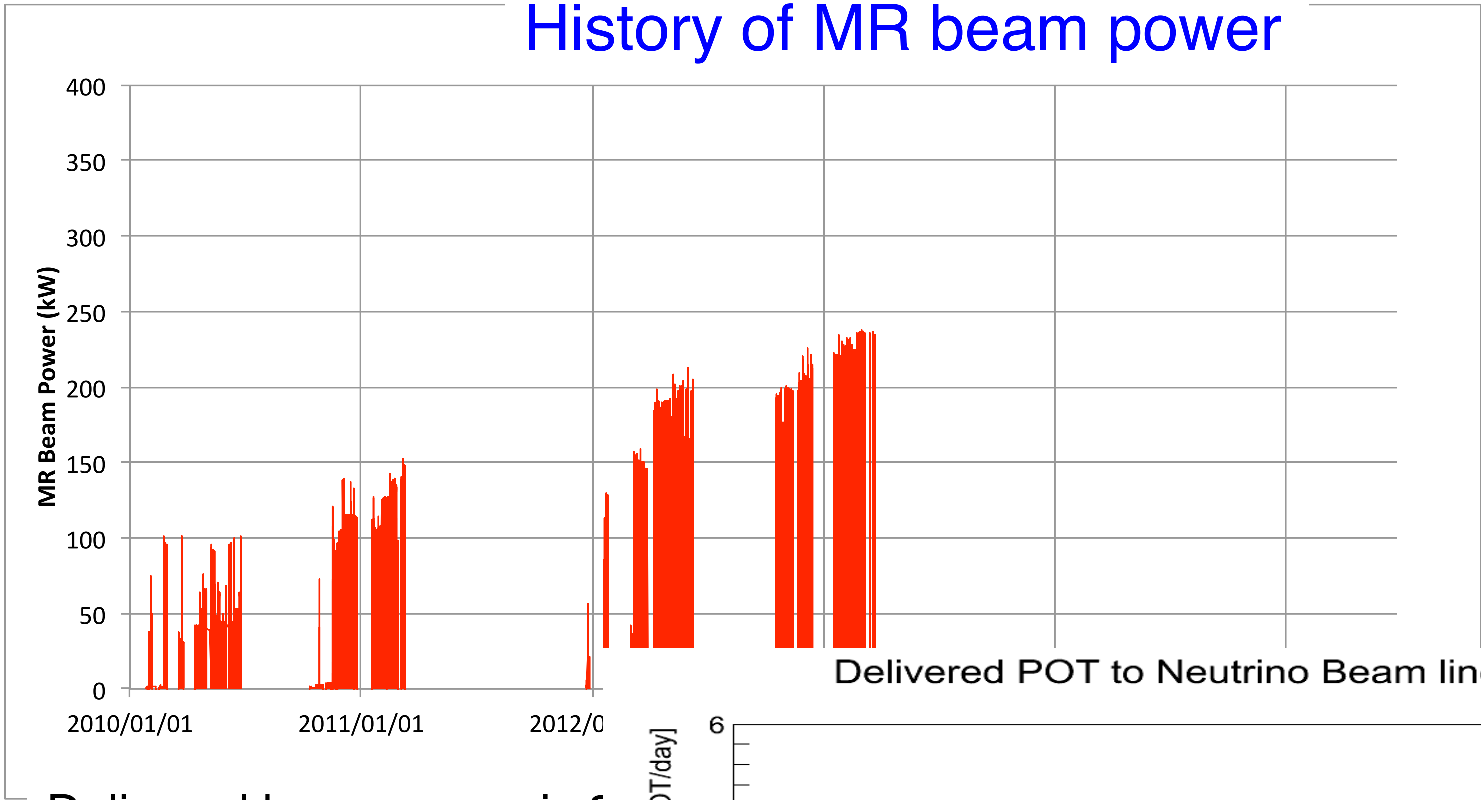


BLM signals @ collimator & arc sections

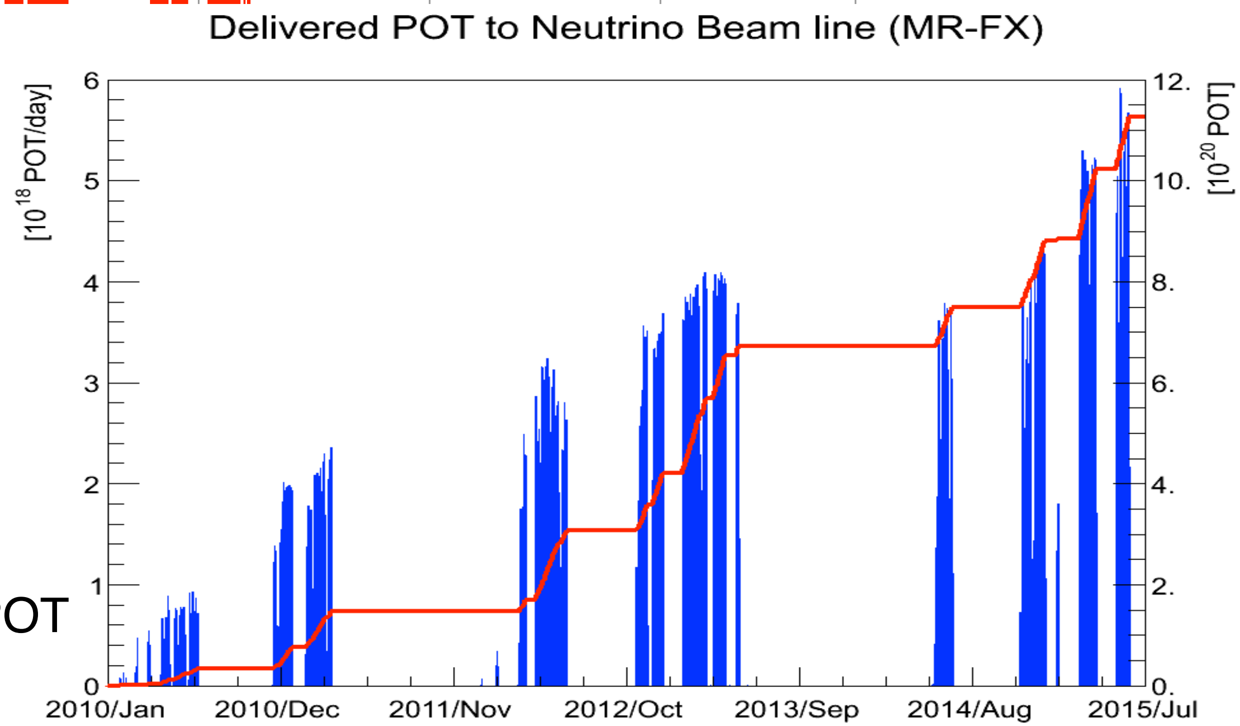


The anode power supplies of the rf power amplifiers is reinforced in the 2015 summer shutdown periods.
After the reinforcement, we will increase beam intensity for user operation toward 1-MW.

History of MR beam power



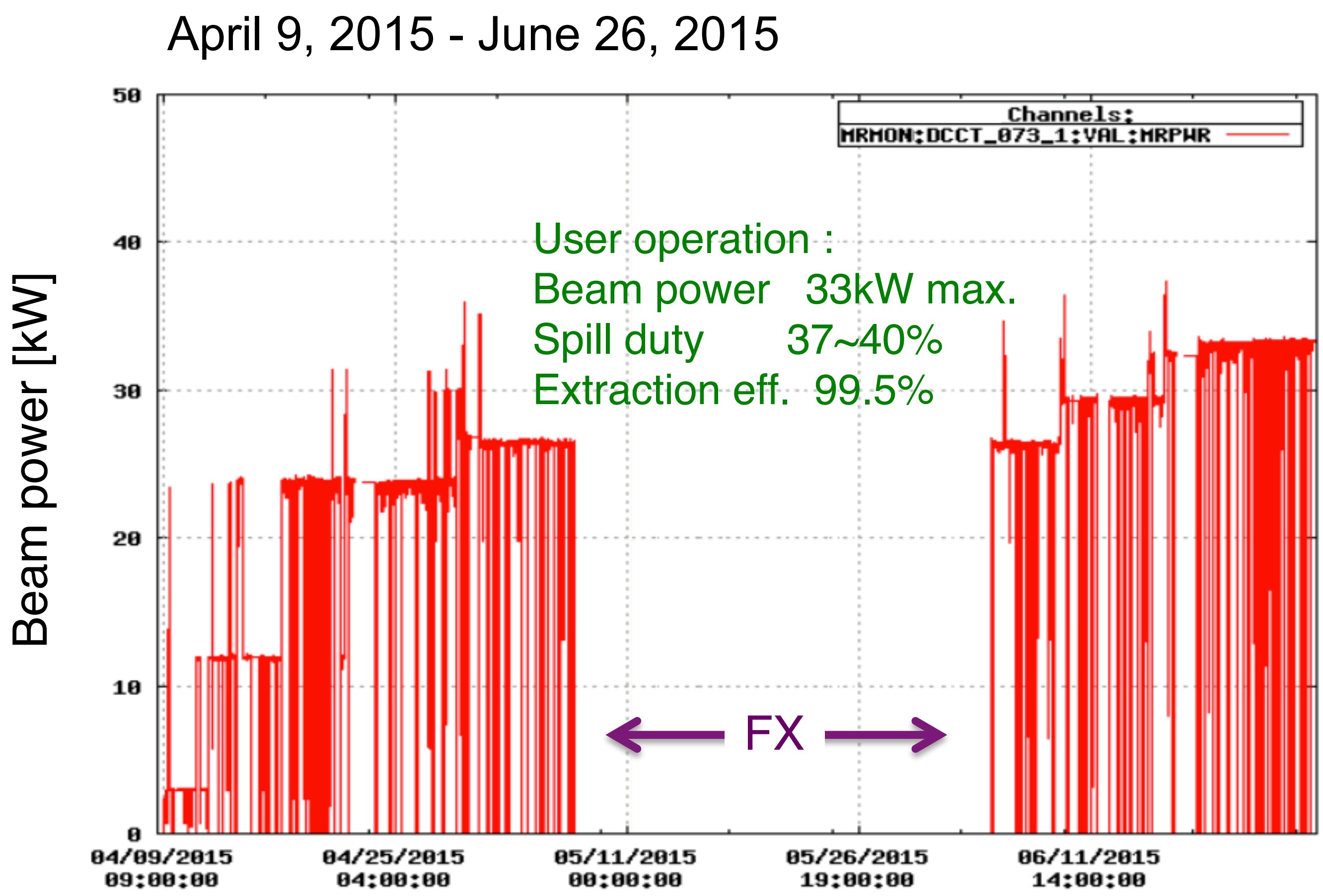
Delivered beam power is 3



Total number is > 1.1×10^{21} POT as of June 3.

Slow extraction operation in April and June, 2015

After the long shutdown for 1 year and 11 months due to the radioactive material leak incident, beam operation resumed for users in the hadron experimental facility.

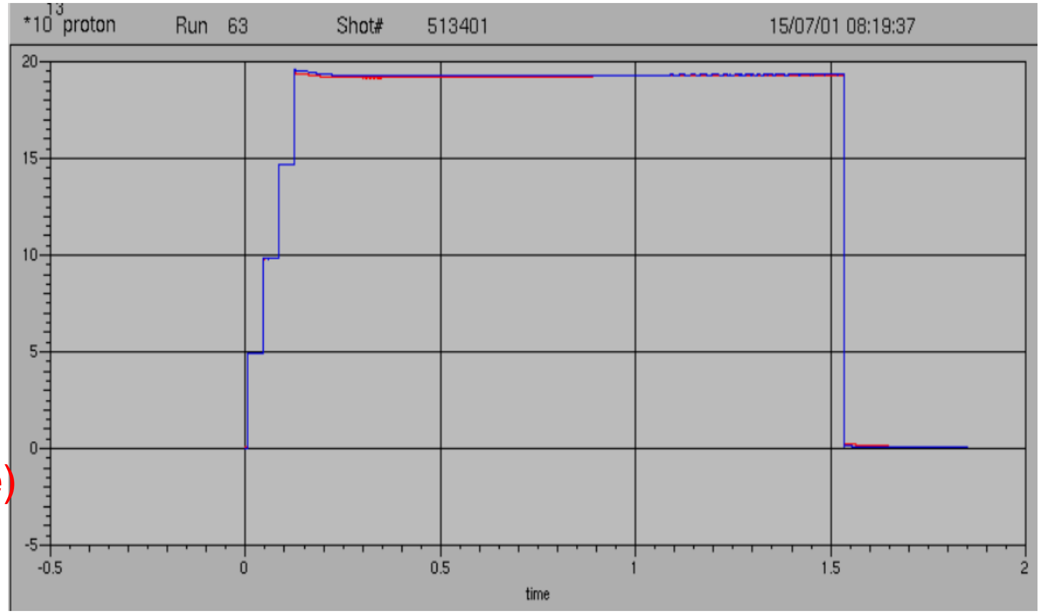


High Intensity beam study in June 2015

- at the present betatron tune (22.40, 20.75)-

Trial with

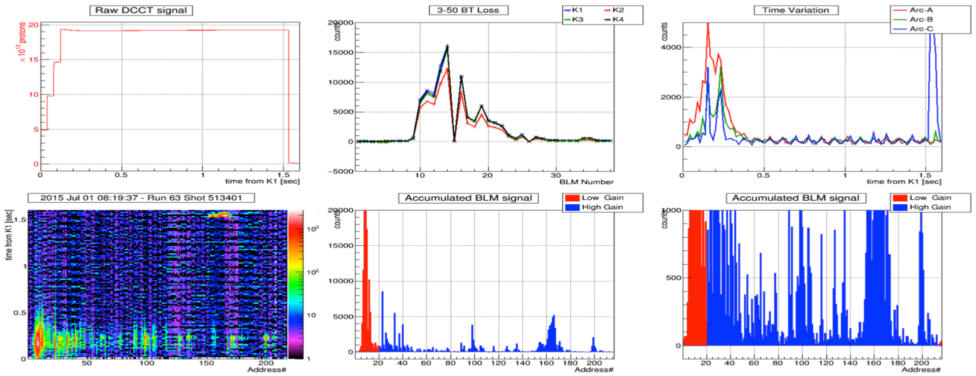
- 2nd Harmonic rf 30 kV
- Intra-bunch FB during Acceleration
- Resonance correction with trim Q and S



Extracted beam : 1.92e14 ppp
(372 kW eq. at the repetition of 2.48 s cycle)

Beam loss distribution

~ 800 W in total



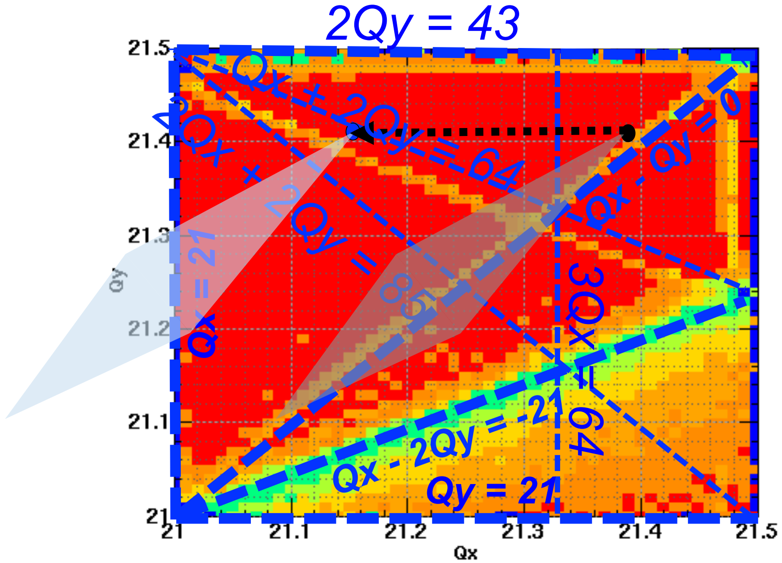
- User operation with ~ 380 kW can be available soon.

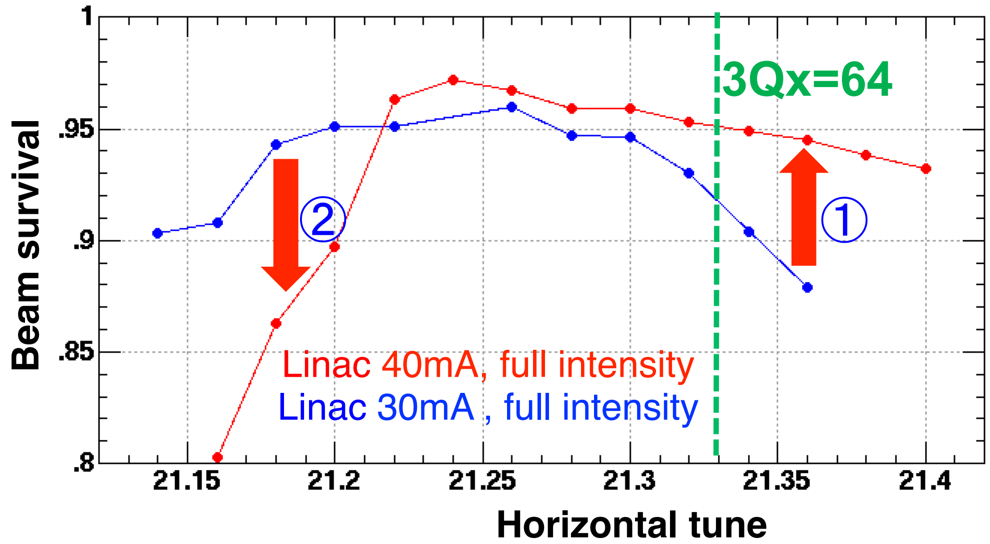
- It is confirmed that design beam power of 750 kW can be almost achieved at the future high-repetition of 1.3 s.

High Intensity beam study in June 2015 (cont'd)

- at the new betatron tune area -

Horizontal tune survey at 3 GeV

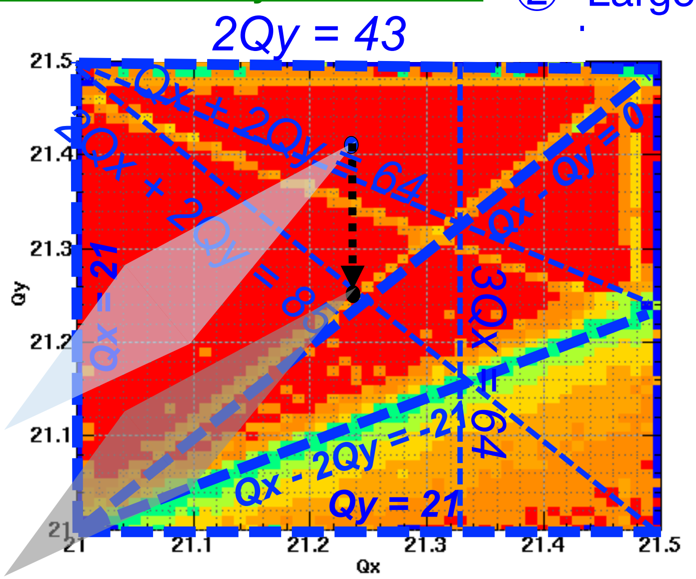


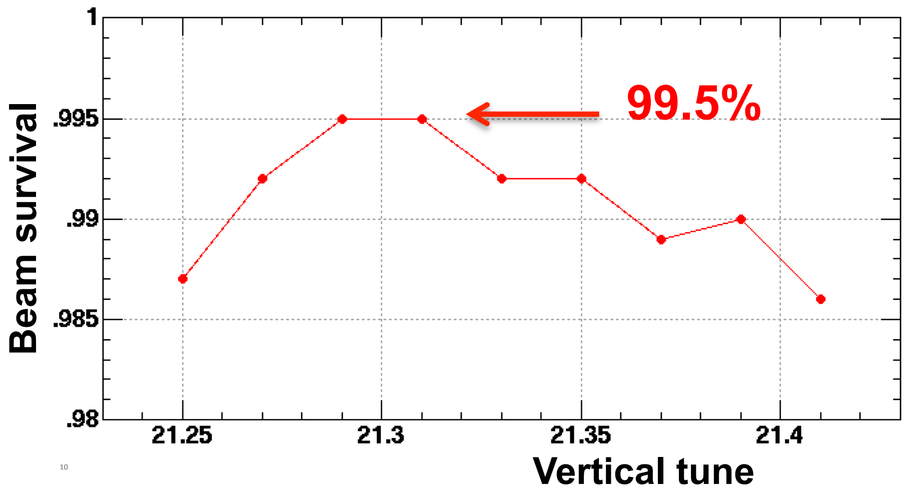


① 3^{rd} Integer resonance correction (3Qx=64) by Trim-Sext.

② Larger tune spread and crossing integer resonance (Qx=21)

Vertical tune survey at 3 GeV

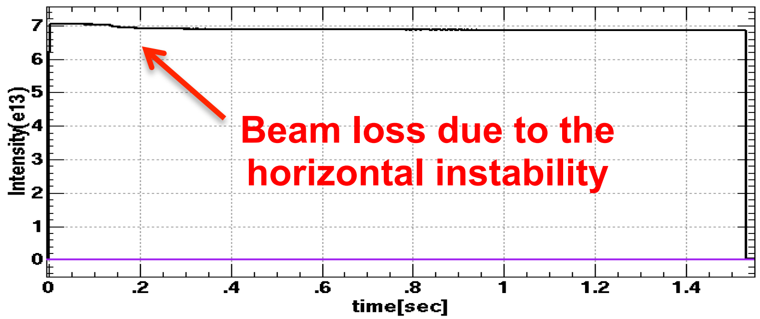




High Intensity beam study in June 2015 (cont'd)

- at the new betatron tune (22.239, 21.310) -

High power trial of 30 GeV acceleration with two bunches



Extracted beam : 6.82e13 ppp (132 kW eq.)

	Beam loss[Watt]	
INJ(K1+K2+K3+K4)	144	7.43e+11
P2 --> +90ms	241	1.00e+12
P2+90ms --> +120ms	31	1.30e+11
P2+100ms ---> EXT		1.83e+11

Total beam loss ~ 420 W

Near future tunable knobs to reduce the beam loss:
Injection kicker, BxB feed-back,
2nd harmonic cavity, VHF cavity, etc.

	Bunch number	repetition period (sec)	Beam power (kW)	Beam loss (kW)	Notes
1	2	2.48	132	0.42	measurement
2	8	2.48	530	1.7	estimation
3	8	1.3	1000	3.2	estimation

The MR has capability to reach 1MW with the high repetition rate operation.

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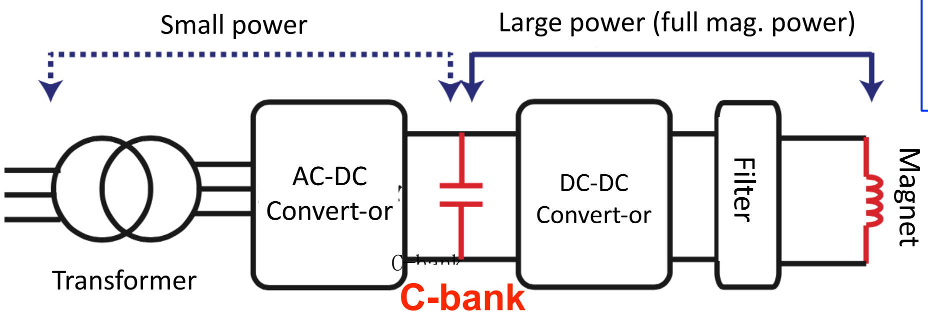
Mid-term plan of MR

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, RF cavities and some injection and extraction devices.
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.

JFY	2014	2015	2016	2017	2018	2019	2020
	Li. current upgrade		New PS buildings				
FX power [kW] (study/trial)	320	> 360	400	450	700	800	900
SX power [kW] (study/trial)	-	33 - 40	50	50-70	50-70	100	100
Cycle time of main magnet PS New magnet PS	2.48 s R&D →	Large scale 1st PS →		Mass production installation/test →	1.3 s	1.3 s	1.2 s
High gradient rf system 2nd harmonic rf system VHF cavity	Manufacture, installation/test → R&D, manufacture, installation/test → R&D →						
Ring collimators		Add.collimators	Add.collimators (3.5kW)				
Injection system FX system	Kicker PS improvement, Septa manufacture /test → Kicker PS improvement, LF septum, HF septa manufacture /test →						
SX collimator / Local shields		Local shields →					
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS					

New power supplies for 1 Hz operation

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

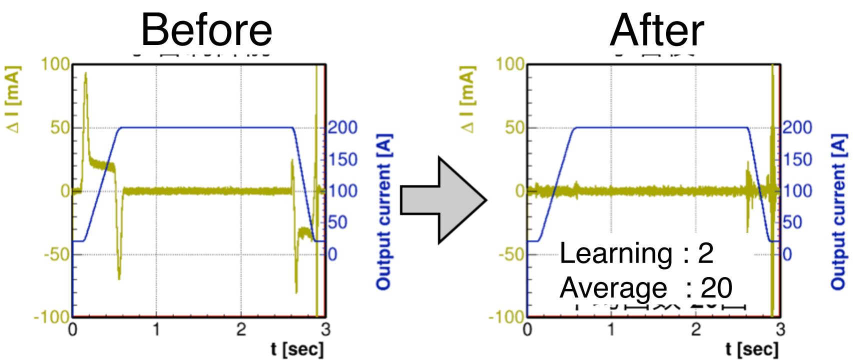


Two large converters and large capacitance for energy recovery, symmetric power module circuit

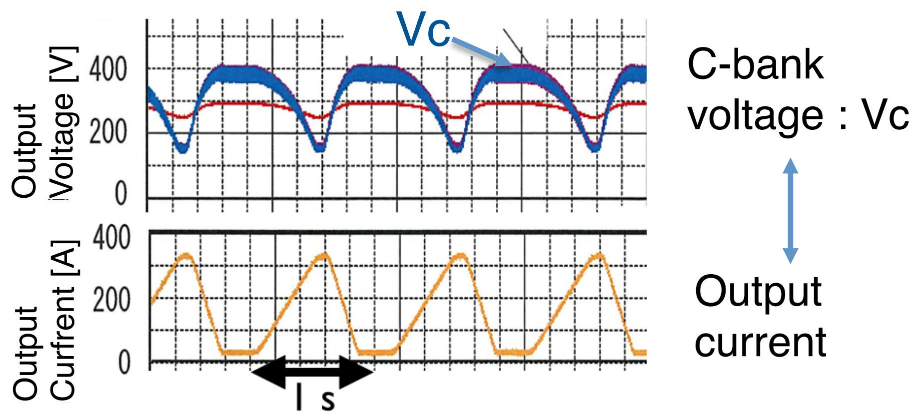
The R&D history:

(1) Proof of principle by a desk-top PS (2012)
(2) R&D of the small prototype PS (2013)
(3) R&D of the middle prototype PS (2014)

- R&D results of the middle scale prototype PS -



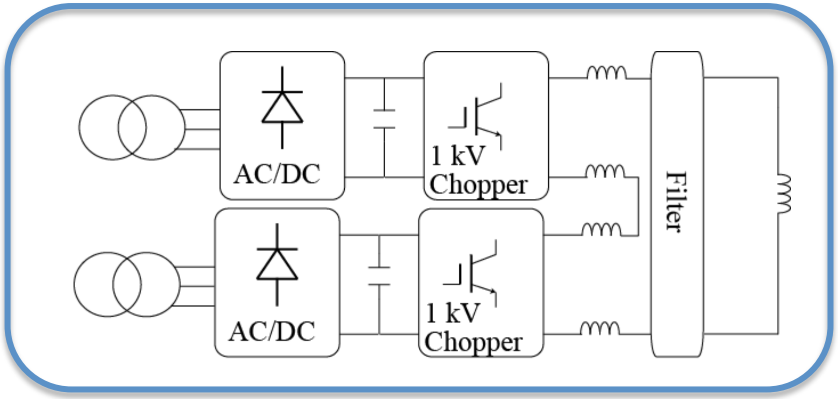
Self-learning control system



Power recovery by C-bank

R&D of new power supplies for 1 Hz operation (cont'd)

Small scale PS for Quad. Magnets in straight section and sextupole magnets

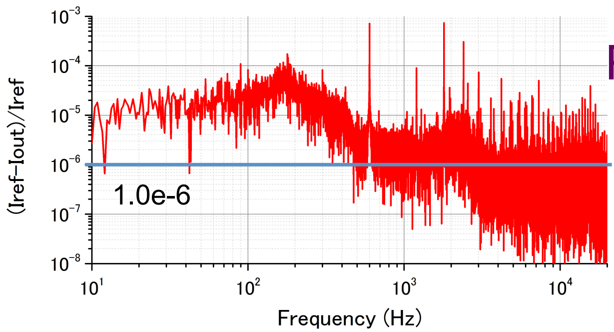


Diode rectifiers, two 1kV choppers are connected in series, symmetric power module circuit

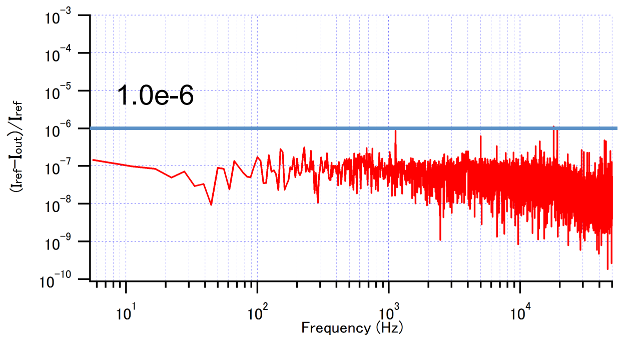
It is possible to build with the combination of existing products.

The model PS system was tested using the real sextupole magnet network.

Current ripple at 30 GeV



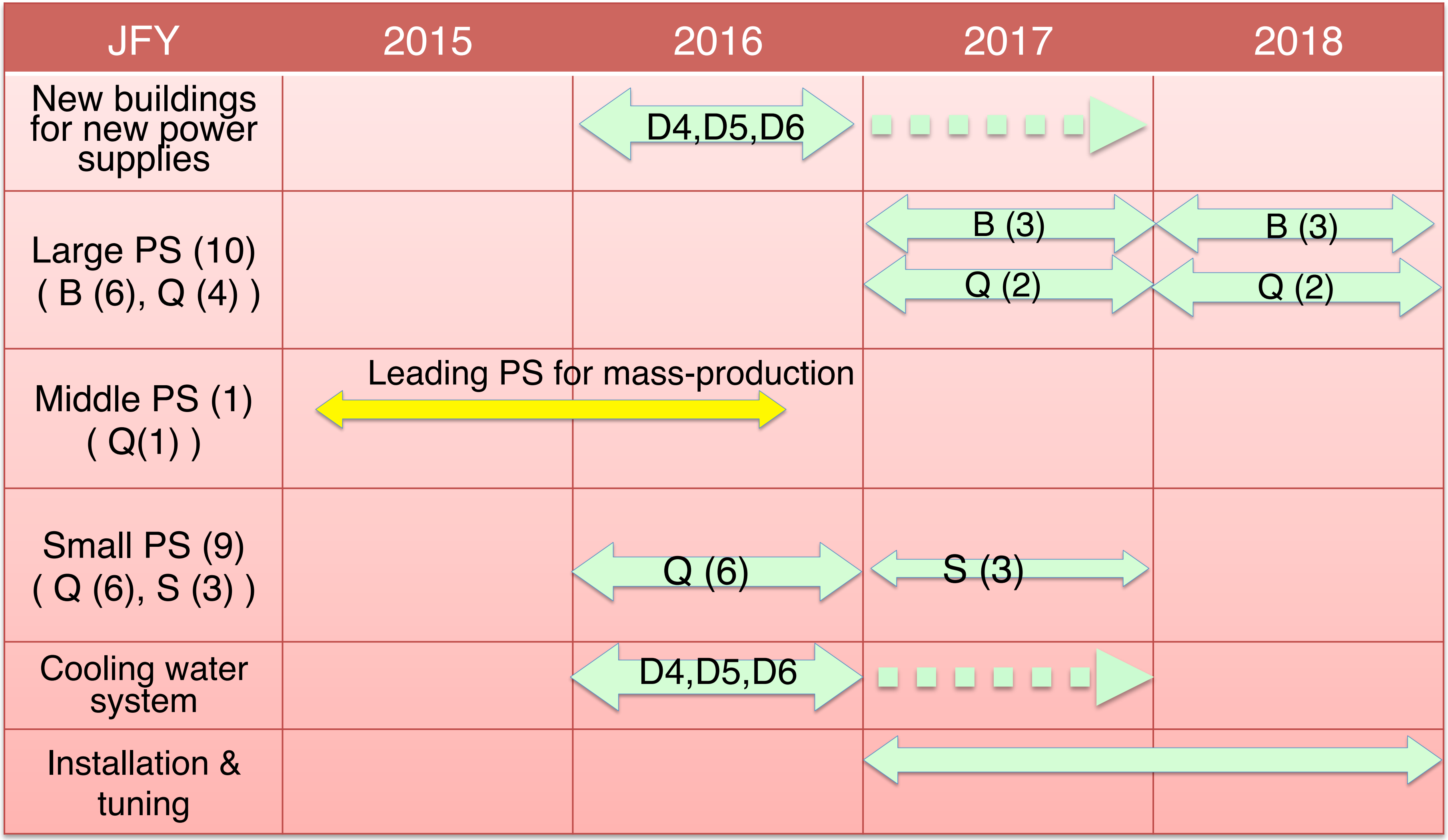
Present IGBT-PS



The new PS

Mass production can be started in JFY2016 if the budget request is approved by the government.

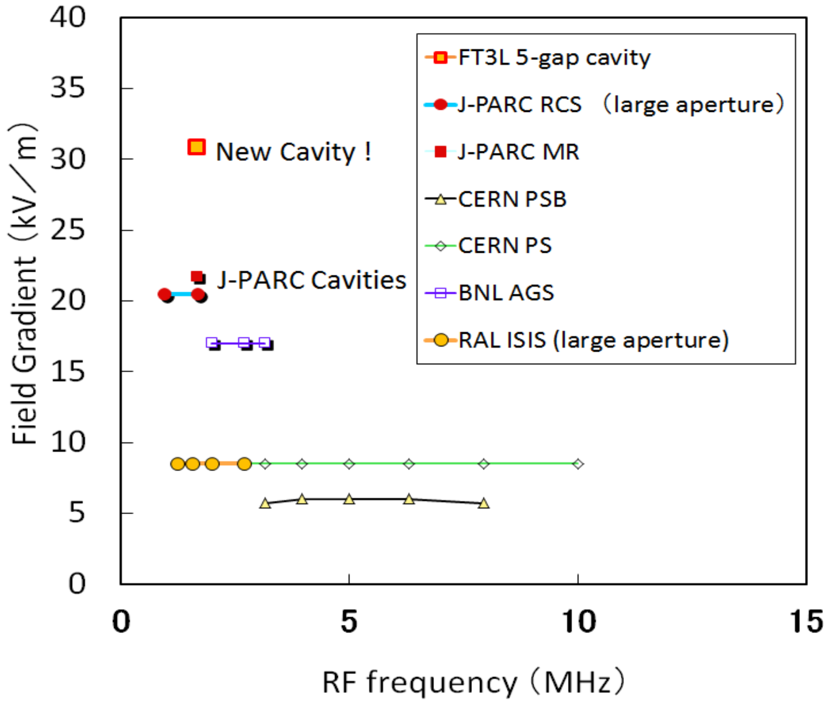
Plan of PS mass production



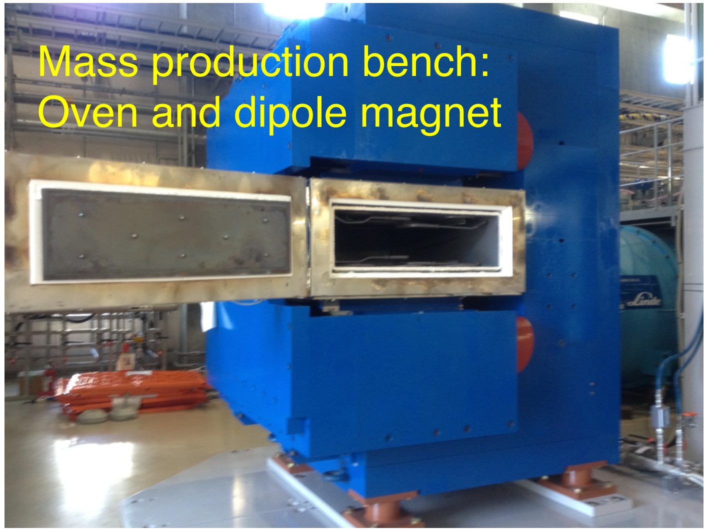
High impedance rf system

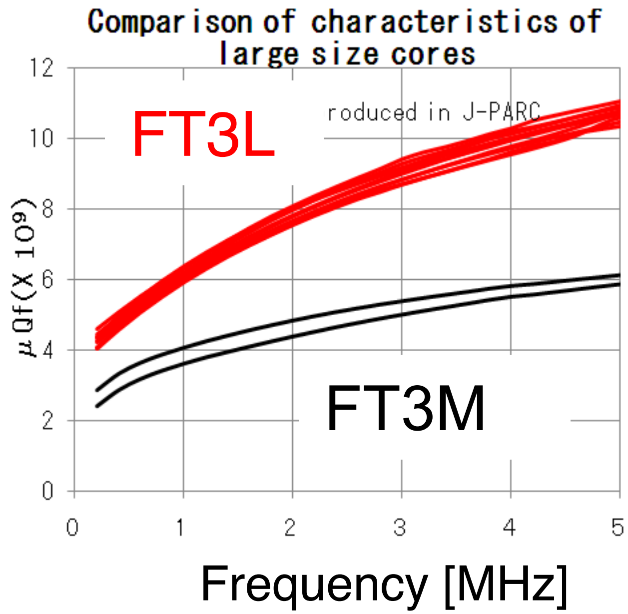
A new type of the magnetic alloy (MA) core, FT3L(made by Hitachi Metal), is adopted to increase shunt impedance of the rf cavity. The core is processed by annealing with magnetic field.

Comparison of field gradient of rf cavities for hadron rings.



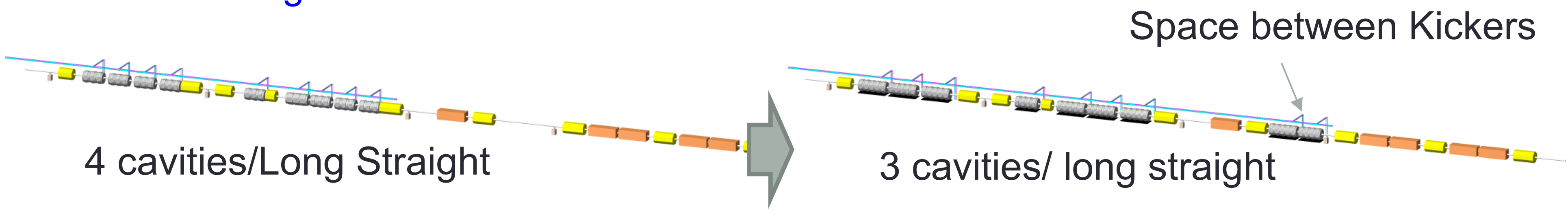
Performance of cavities depends on core materials: ferrite and MA.
J-PARC already achieved very high field gradient.





RF system for high repetition operation

Configuration of rf cavities



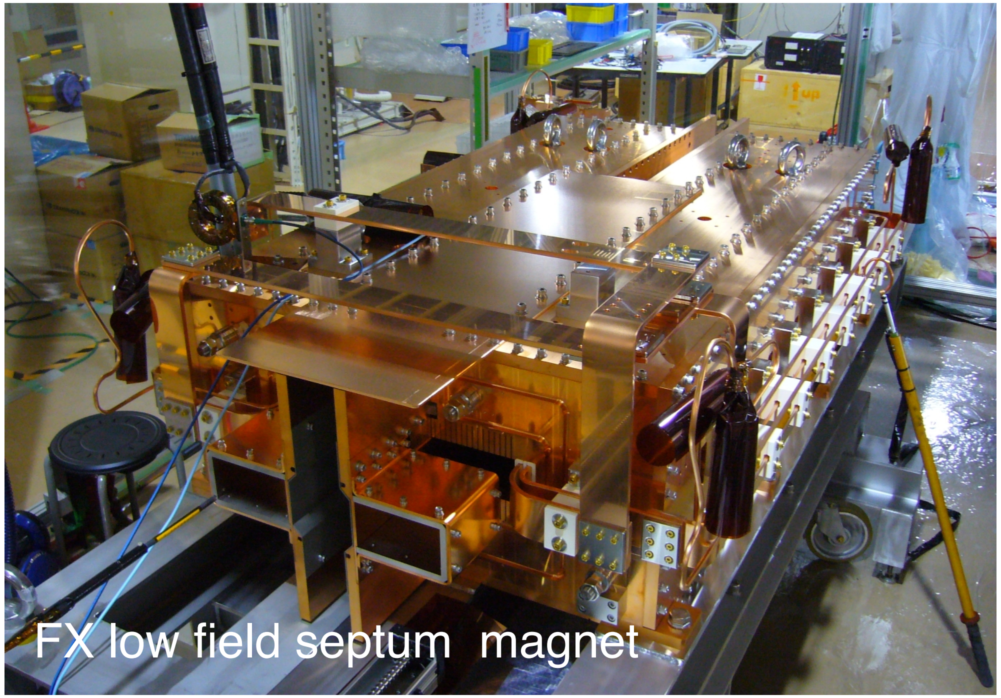
Before Replacement | After Replacement

	2013	2014	2015	2016	2017	2018
	Li 400 MeV	*Li 50mA*				*MR 1.3-sec operation*
Present FT3M cavities	*9*	*8*	*4*	*0*	*0*	*0*
New FT3L Cavities	*0*	*1*	*5*	*9*	*9*	*9*
New FT3L 2^{nd} cavity	*0*	*0*	*0*	*0*	*2*	*2*
Available voltage	*315 kV*	*355 kV*	*485 kV*	*602 kV*	*602 kV*	*602 kV*
(2^{nd} Harmonic)	*(35 kV)*	*(70 kV)*	*(70 kV)*	*(70 kV)*	*(70 kV)*	*80 kV*
Number of cavity cells	*27*	*29*	*36*	*43*	*43*	*43+8(2^{nd})*

Required voltage: 280 kV(~2017), 540 kV(2018~)

Injection and FX septum systems

New injection septum magnet I and FX low field septum for the high repetition rate operation have been manufactured and now tested.



New injection septum:
- Stable (low vibration)
- Small leakage field ~ 10^{-4}
  (the current septum : $4x10^{-3}$)

Eddy current type is adopted to the new FX low field septum
- Small Power Consumption (possible at low cooling capacity)
- Small Leakage Field ∼10^{-4}
  (the current type septum : 10^{-3})
- Stable (low vibration)
- Thin Septum Thickness ∼7 mm
  (the current septum : 9.5mm)

They will be installed in the 2015 summer shutdown.

1. Status of accelerator operation and achievements

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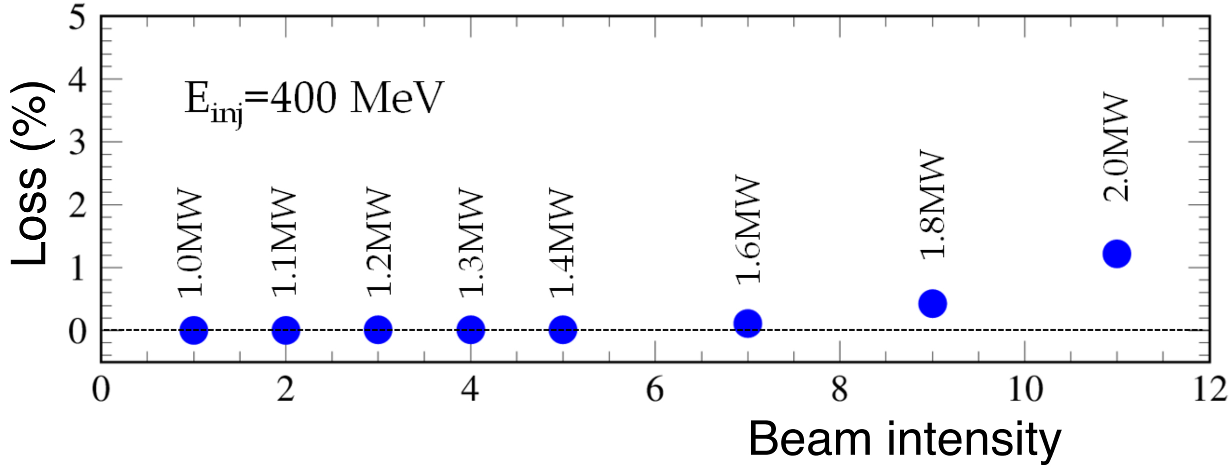
Feasibility of the RCS

Injection beam parameters:
Energy : 400 MeV
Peak current : 50 mA~100 mA
Pulse length: 0.5 ms
Chopper-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 ~4 kW
→ RCS has a feasibility to operate 2 MW

- Linac 100 mA/0.5 ms (50 mA/1.0 ms) operation is required.
  R&D of ion source / long pulse operation of linac
- The rf system should be replaced to compensate a heavy beam loading.
- The collimator capability should be upgraded to get a margin for the beam loss.
- Activation downstream of the charge exchange foils should be reduced.

….

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 mult-MW beam for neutrino experiment are now under discussion.

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

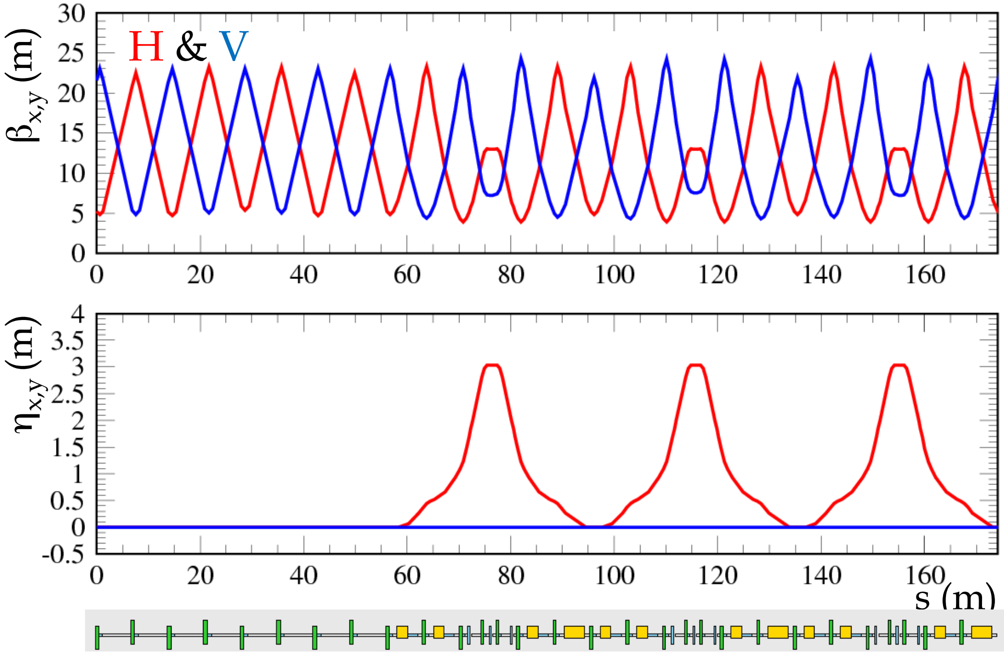
2. Proton linac for neutrino beam production

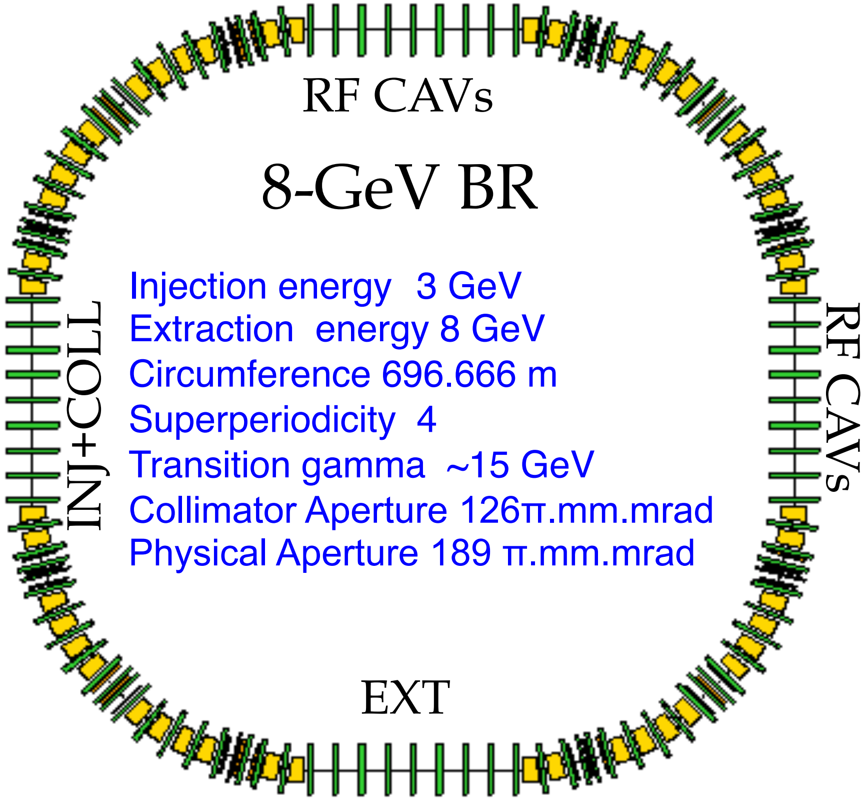
    (Construction site may not be the Tokai campus)

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

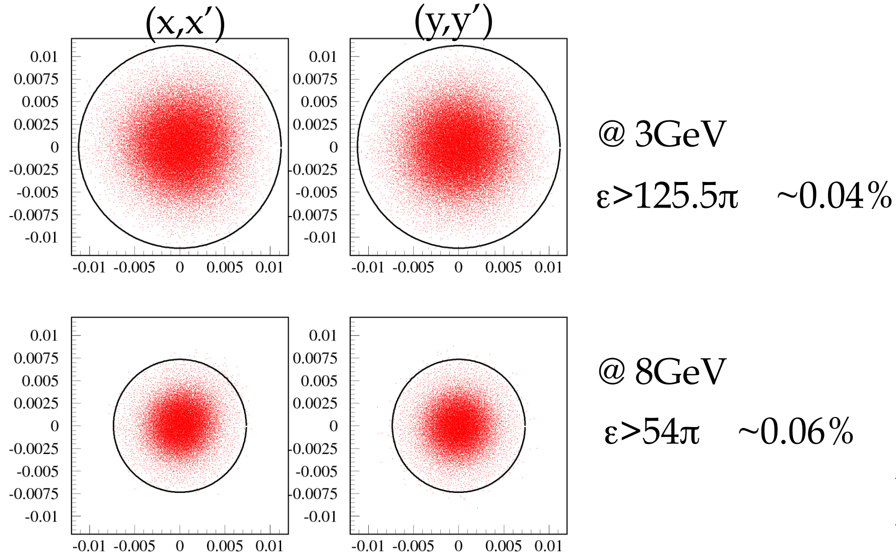
The 8-GeV booster ring

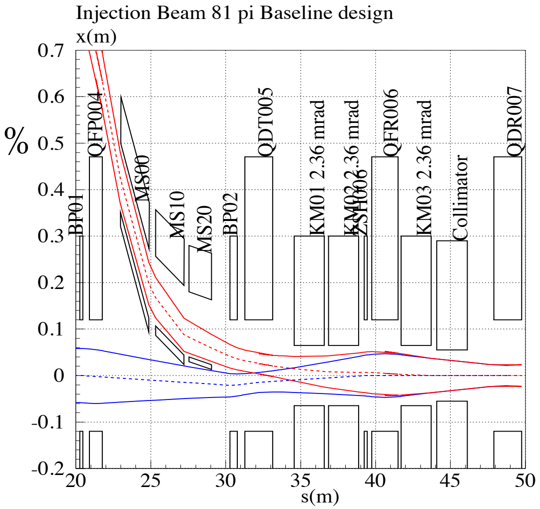
Beta & Dispersion for 1-superperiod





Phase plot @ inj.(3GeV) & extr.(8GeV)





8 GeV injection in the MR using new septa&kickers

RCS : 1.6 MW
MR > 2.6 MW

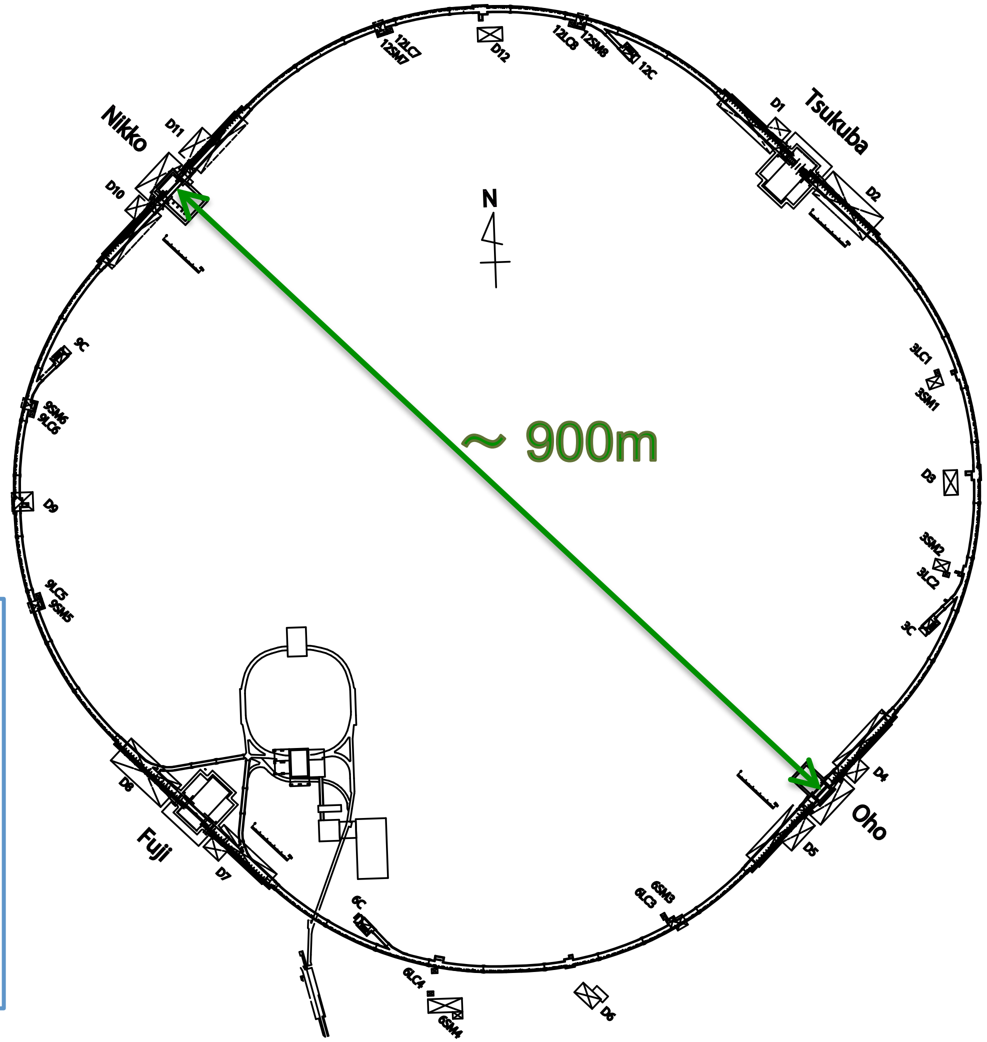
RCS : 2 MW
MR > 3.2 MW

Proton Driver in the KEKB Tunnel

As the post-Super KEKB projects in KEK

KEKB tunnel:

- fourfold symmetric configuration.
- Circumference: ~ 3 km
  - Straight section: beam acceleration
    200 m x 4 = 800 m
  - Arc section: beam transportation to the next straight section.
    550 m x 4 = 2200 m



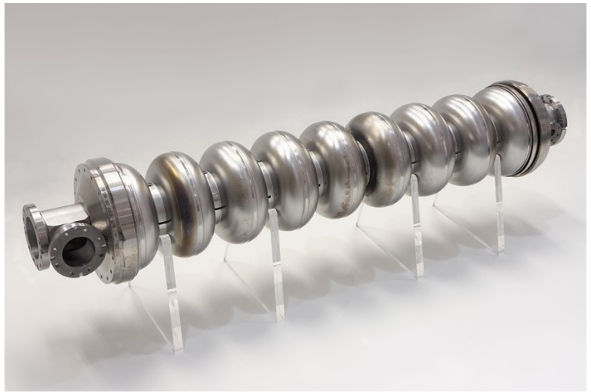
Subjects:

- Feasibility of 9 GeV proton linac in straight sections of 800 m.
  ⇒ High acceleration field is required.
  ⇒ SC accelerator is essential.
- Beam transport at Arc sections.

SC Cavity for 2nd to 4th Straight Sections

For the acceleration in the 2nd to 4th straight section, the ILC cavity is adopted.

<u>ILC cavity</u>



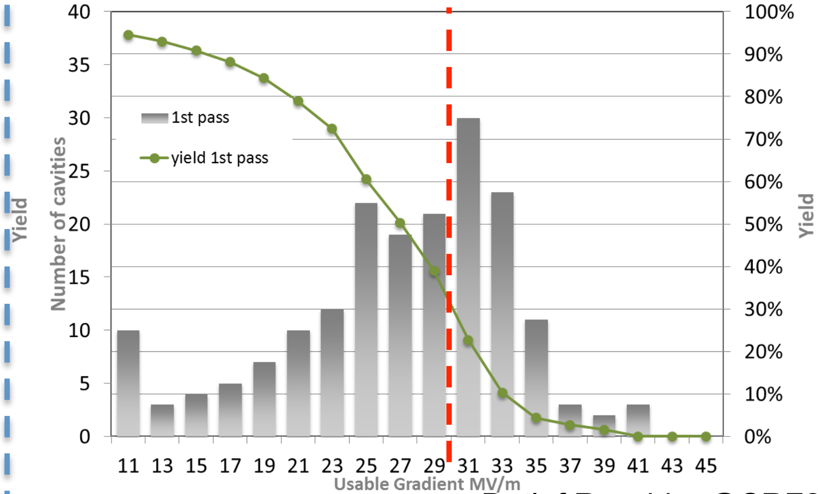
Shape	ellipse
RF frequency	1.3 GHz
# of cells per cavity	9
Quality factor	$> 1 \times 10^{10}$ @ 2K

<u>ILC cryomodule</u>

KEK has rich experience and know-how of ILC cavity and cryomodule fabrication.

Average gradient (E_0)

Yield of usable gradient of 185 ILC cavities as received (European XFEL)



Detlef Reschke @SRF2013

Average **usable** gradient:

(26.2 ± 7.5) MV/m

With the expectation of further R&D, we set the E_0 to **30 MV/m**.

Outline of the Proton Driver using ILC Cavity

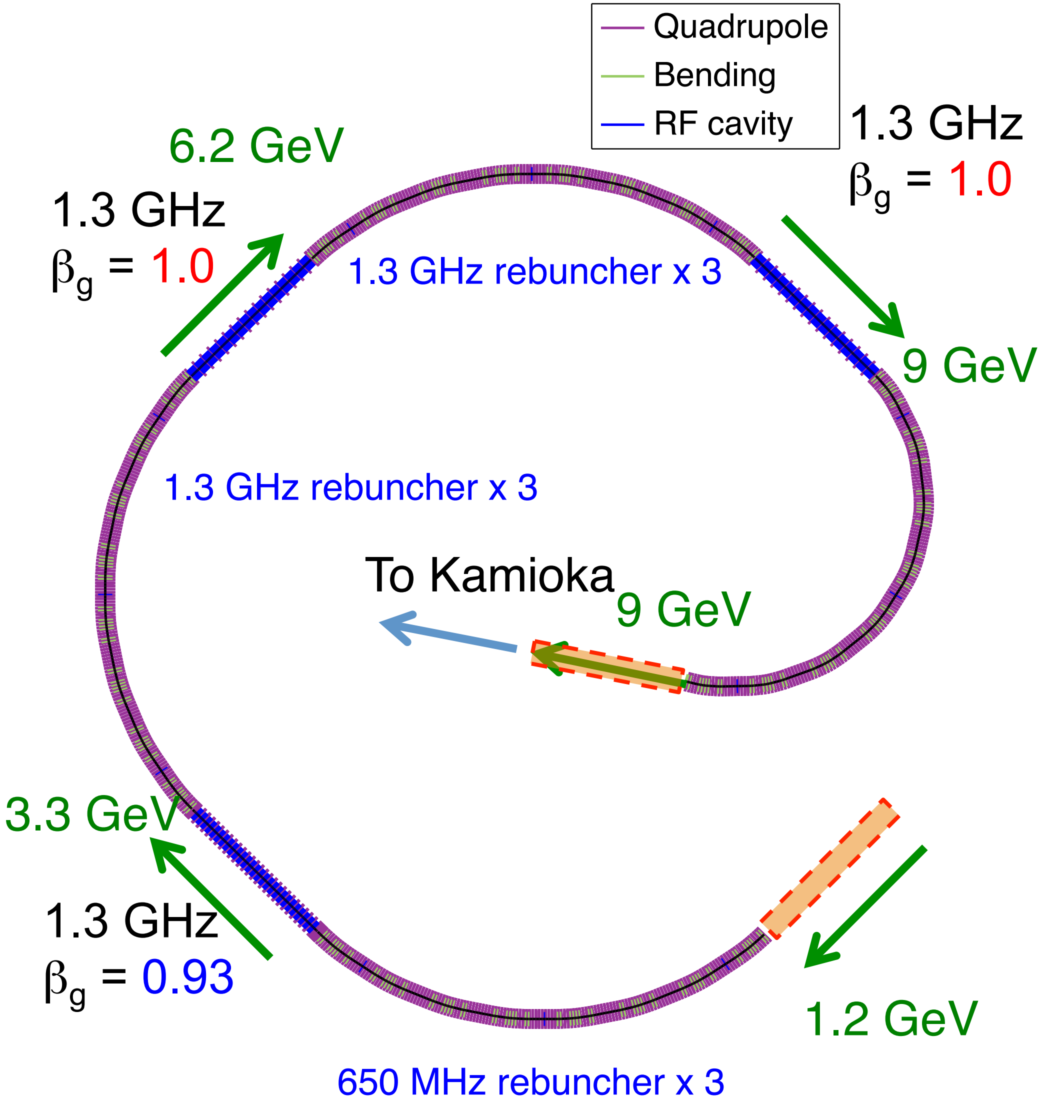
- Outline of acceleration :
  - 1.2 GeV in 1st straight.
  - 3.3 GeV in 2nd straight.
  - +2.9 GeV in 3rd and 4th straight.
    3.3 + 2.9 x 2 = 9.0 GeV

- Peak current : 100 mA (pulse)
- Beam duty : 1 %

- Beam power :
9000 MeV x 0.1 A x 1 % = **9 MW**

- β_g of SC cavities :
  - 2nd straight : β_g = **0.93**
  - 3rd and 4th straight: β_g = **1.0**

- Normalized RMS emittance
  - Transverse : 0.30 π·mm·mrad
  - Longitudinal : 0.37 π·MeV·deg

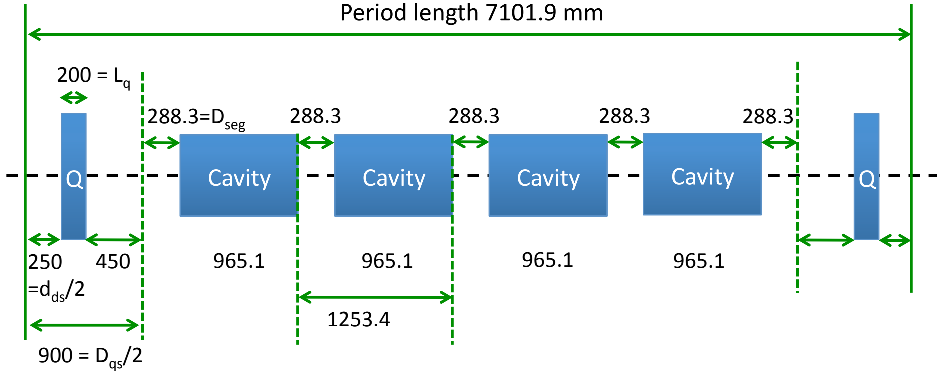


Configuration of the cryomodules

The 2nd straight section:

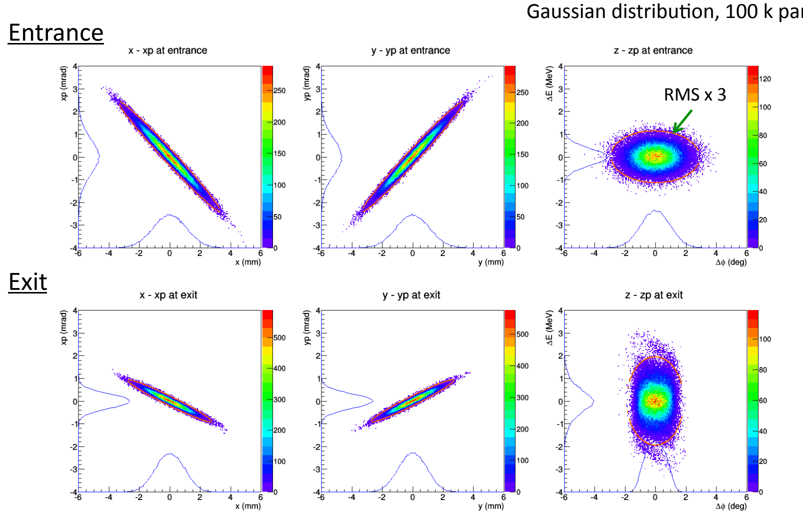
- Doublet lattice with SC quadrupole magnets.
- 4 SC cavities (β_g = 0.93) are in each cryomodule.
- 27 cryomodules are placed in the section.
  7.1 x 27 = 192 m

Filling factor = 0.544



Beam profile at the 2nd straight section

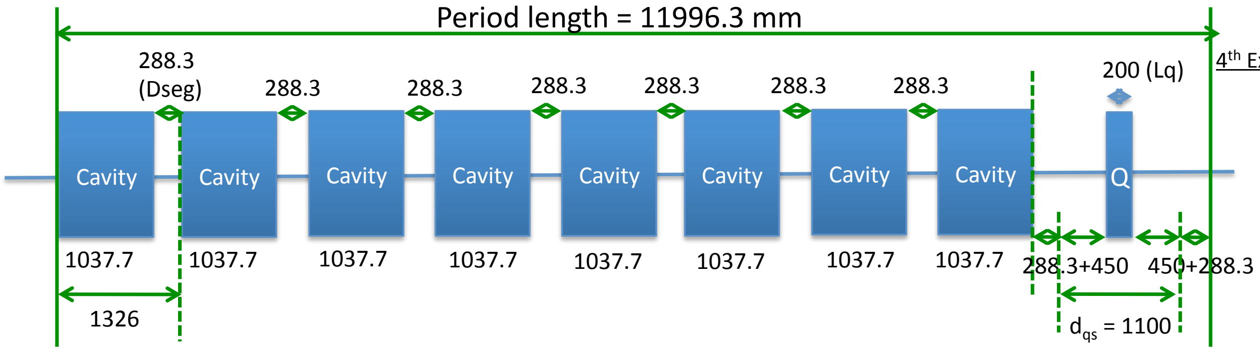
Gaussian distribution, 100 k particles



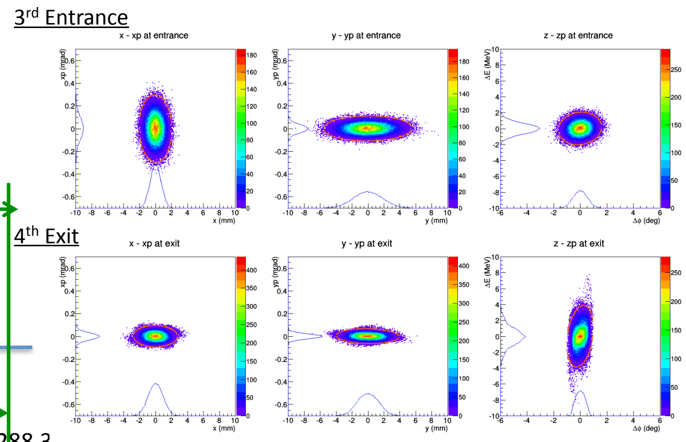
The 3rd and 4th straight section:

- Singlet lattice with a SC quadrupole magnet.
- 8 SC cavities (βg = 1.0) are in each cryomodule.
- 16 cryomodules are placed in each straight section.
  12.0 m x 16 = 192 m

Filling factor = 0.692



Beam profile at the3rd and 4th straight section



R&Ds are necessary : Higher gradient SC cavities, High power target, Horn…

Summary

Status and operation summary:

- Achieved beam power in user operation :
  500 kW for MLF users
  360 kW and 33 kW for the T2K experiment and HD users, respectively.

- High power demonstration :
  1 MW eq. beam is achieved in the RCS
  132 kw eq. beam with two bunches in the MR (It corresponds 530 kW with 8 bunches)
  It shows the MR has a capability to reach beam power ~ 1 MW with the high rep rate operation.

The MR mid-term plan :

- The design power of 750 kW for the FX, and 100 kW for the SX will be achieved in 2018-2019 after the replacement of main magnet power supplies.
- The MR will reach 1 MW with the new power supplies after 2020.

Long-term plan :

- Simulation shows the RCS has a capability to increase beam power ~ 2 MW.
- To achieve multi-MW beam power for neutrino experiment, the 8-GeV booster, the 9-GeV SC linac are now under discussion.