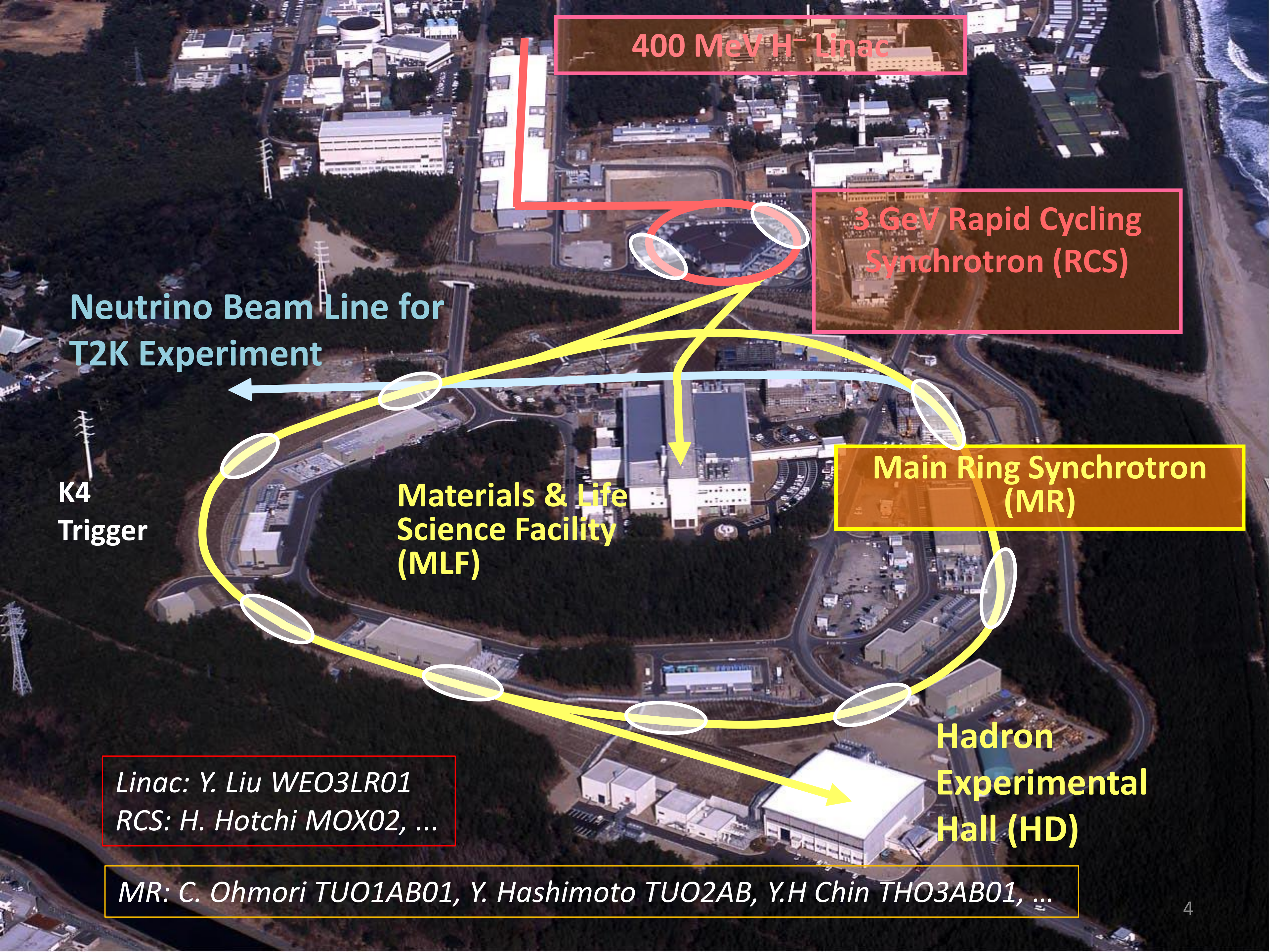
Contents

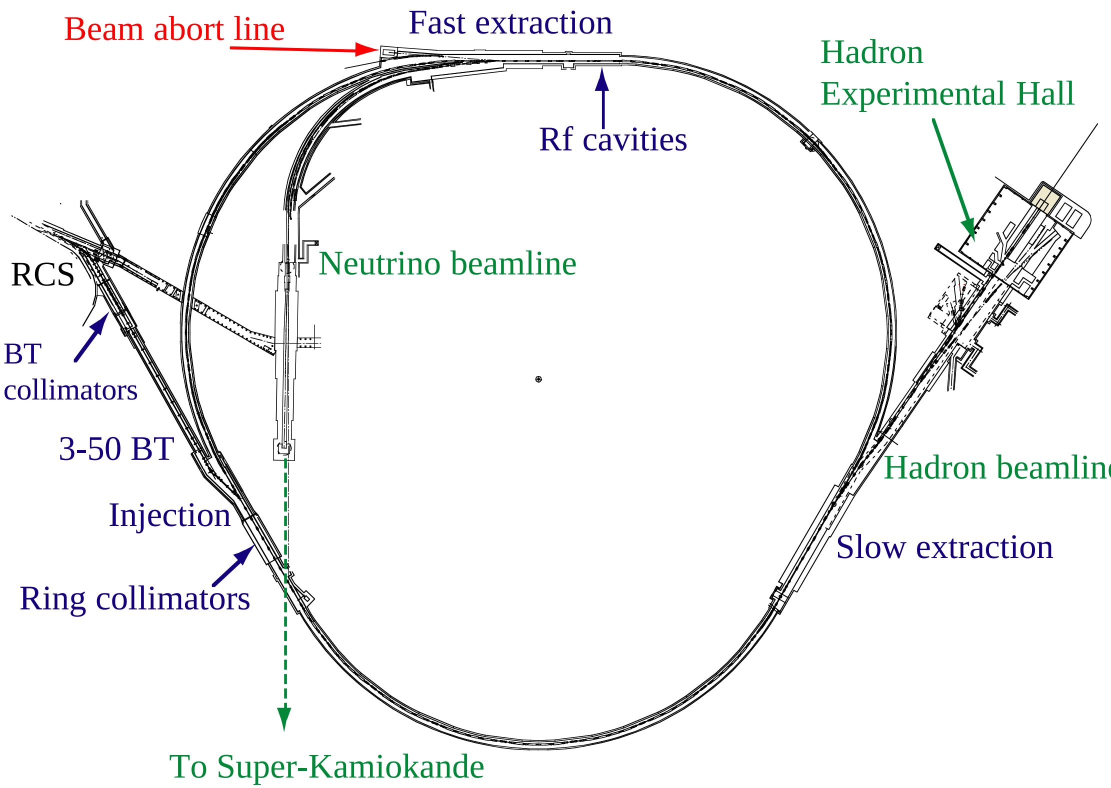
Introduction and achievement of J-PARC MR FX operation


400 MeV H⁻ Linac
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line for T2K Experiment
K4 Trigger
Materials & Life Science Facility (MLF)
Main Ring Synchrotron (MR)
Hadron Experimental Hall (HD)
Linac: Y. Liu WEO3LR01
RCS: H. Hotchi MOX02, ...
MR: C. Ohmori TUO1AB01, Y. Hashimoto TUO2AB, Y.H Chin THO3AB01, ...

Main parameters of MR

Circumference	**1567.5 m**
Cycle time	**6 s for SX**
	2.48 s for FX
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Super-periodicity	**3**
harmonic	**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	**54-70 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)

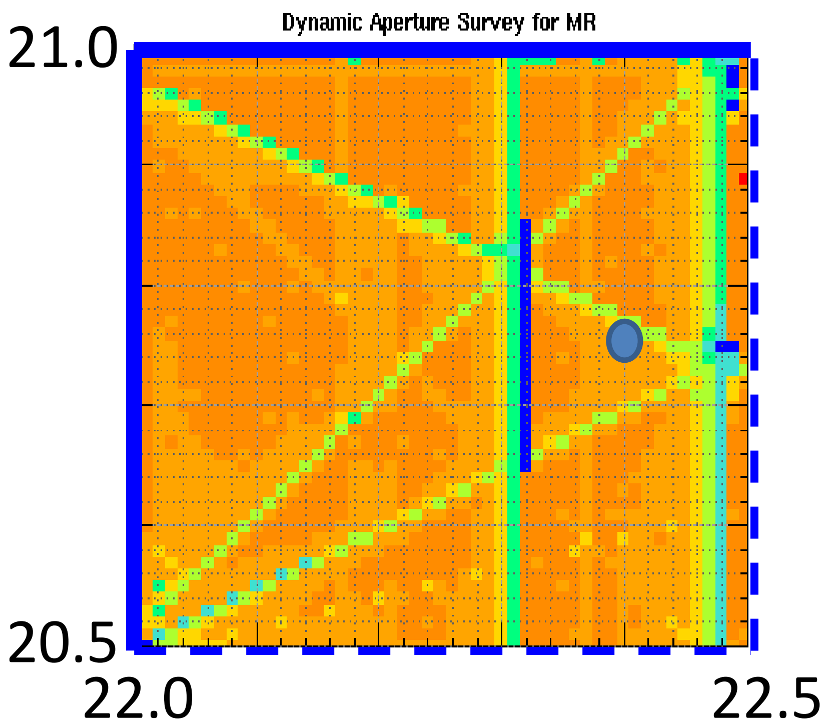
to Hadron experimental Hall

- 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)

FX operation point (22.40, 20.75)



Resonances

Linear Coupling

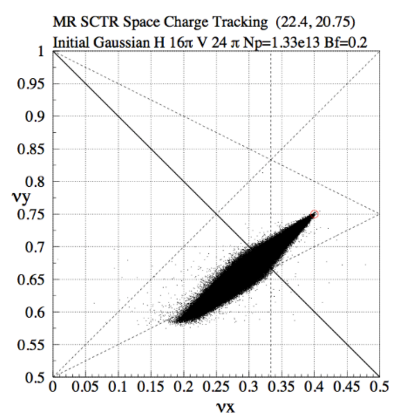
- νx+νy=43
- Rotation of Q magnets and Vertical orbit at sextupole magnets

3rd order

- 3νx=67
- νx+2νy=64
- νx-2νy=-19
- Variation of sextupole magnets

4th order

- 2νx-2νy=3
- Octupole magnets

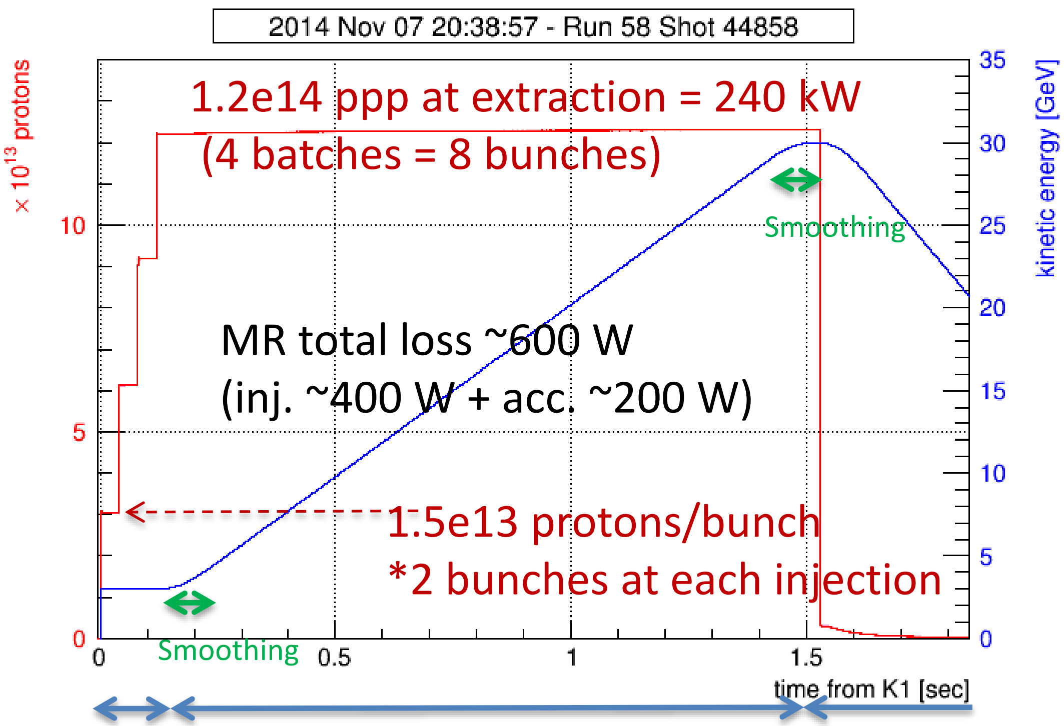


MR 200 kW op. 1.33e11ppb

BF 0.2

Δν ~ 0.2

Typical Operation Status for Fast Extraction



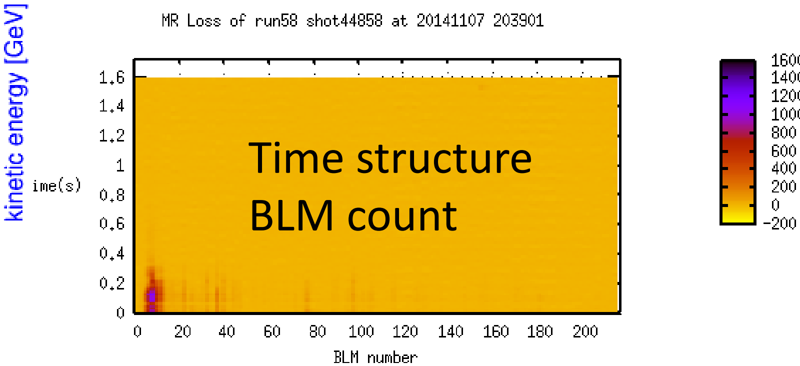
Extraction

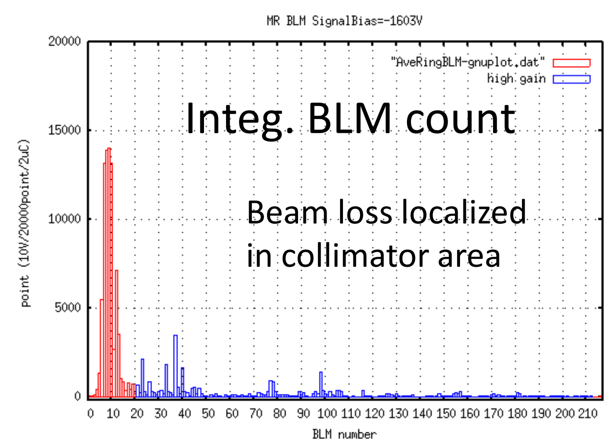
Injection 0.13 s

Acceleration 1.4 s

Recovery 0.95 s

2.48 sec cycle

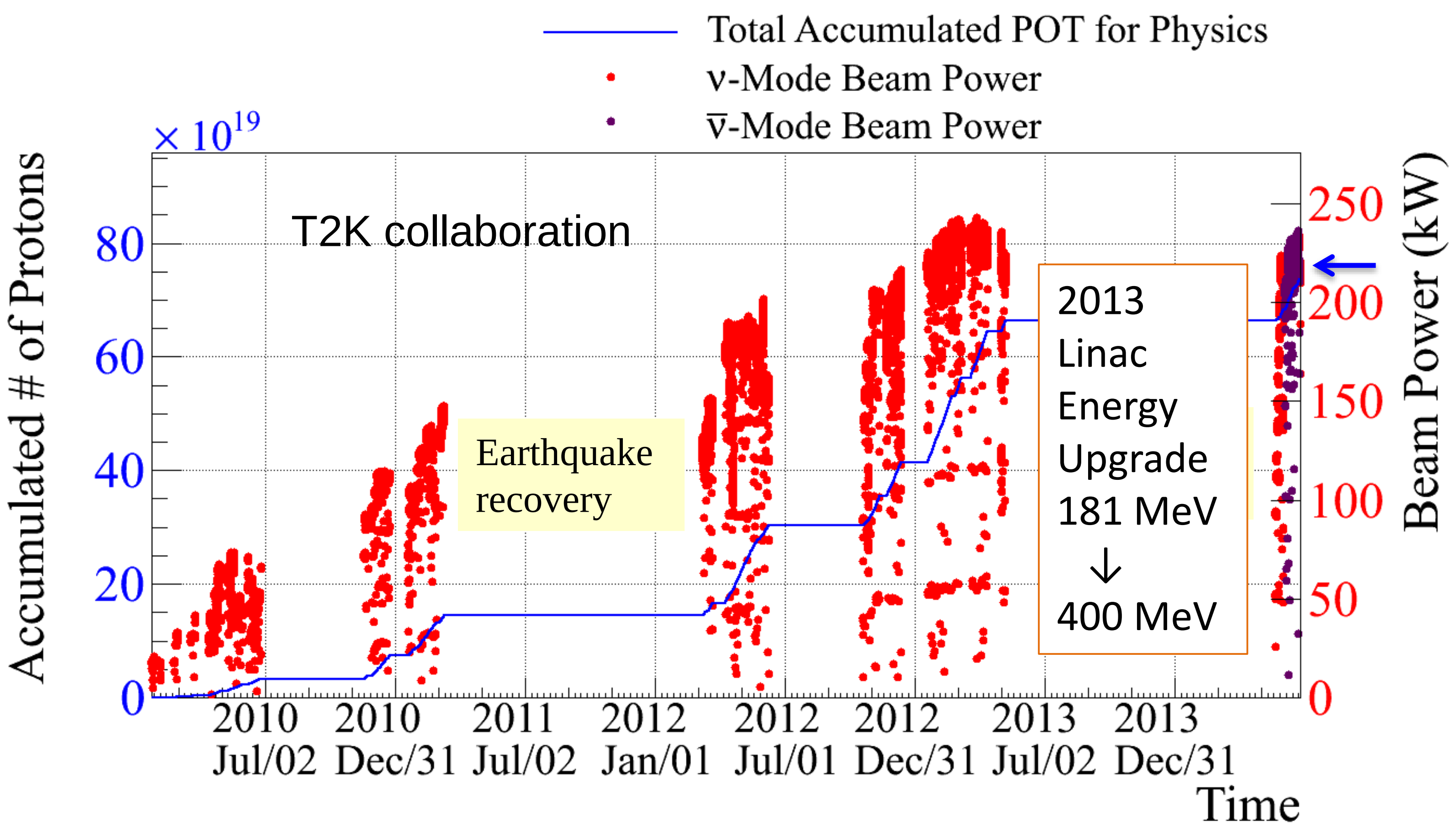




Address in the whole MR

Beam delivery to the T2K experiment

* as of 26th of June 2014

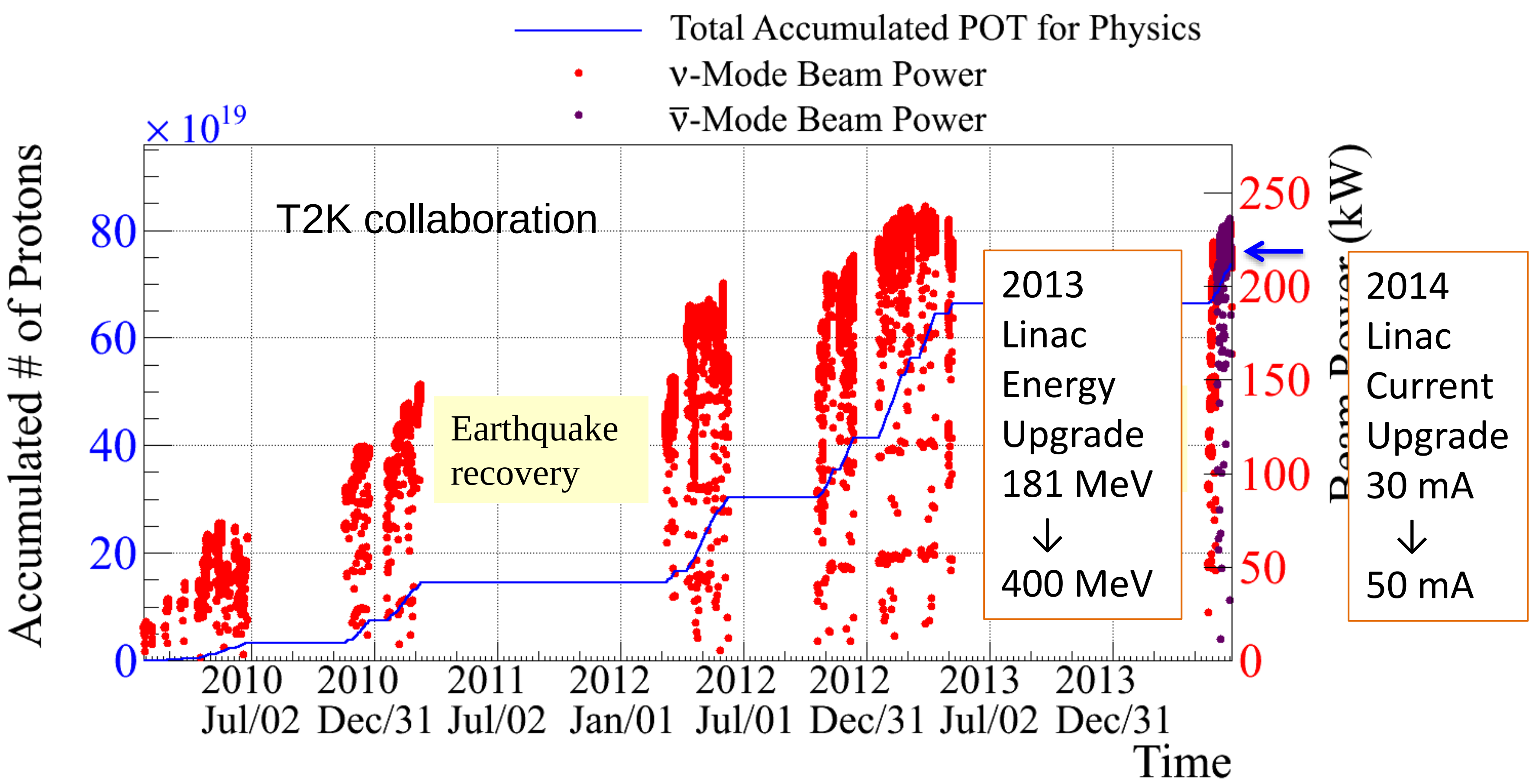


The max. delivered beam power ~ 240 kW (1.24x10^{14} ppp)

Accumulated number of proton ~7.5 x10^{20} POT.

Beam delivery to the T2K experiment

* as of 26th of June 2014



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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.

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
Cycle time of main magnet PS New magnet PS for high rep.	3.04 s	2.56 s R&D	2.48 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)	3.5 kW -> 2 kW	3.5 kW		
Injection system FX system	Inj. kicker	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, LF septum, HF septa manufacture /test					
Ti ducts and SX devices with Ti chamber		SX septum endplate	Beam ducts Insertion Disp. peaks	Beam ducts ESS			

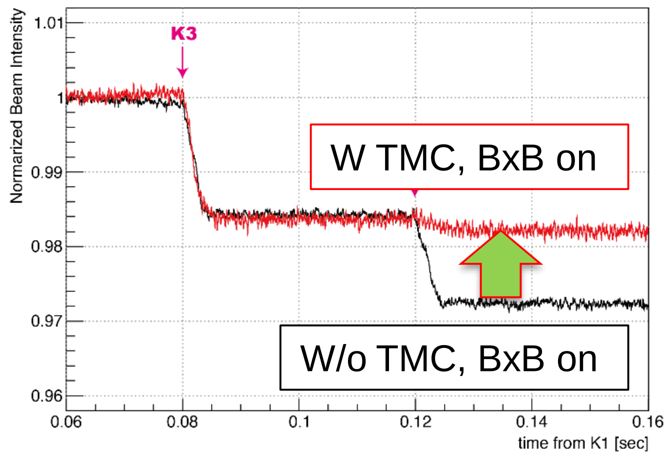
Keys for present operation

Hardware improvements

- Injection kicker wave form:

  Tail field kicking extra angle to circulation beam was improved with tail matching circuit

  T. Sugimoto IPAC14

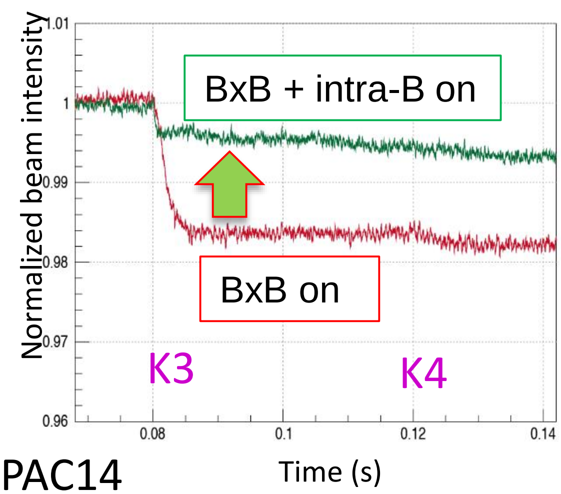


- Transverse feedback

  Intra-bunch feedback in addition with bunch-by-bunch feedback

  Y.H. Chin THO3AB01

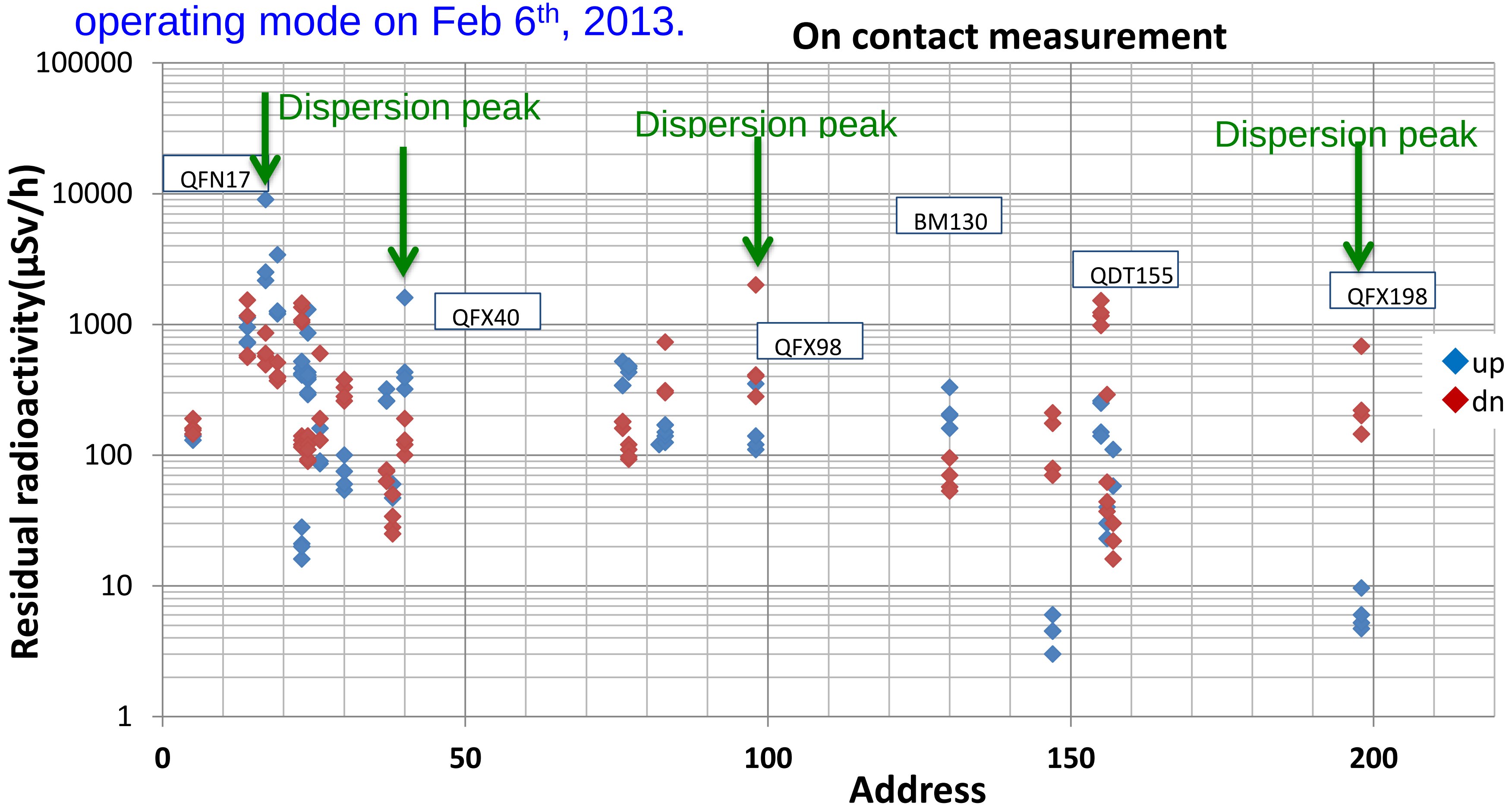
  M. Tobiyama, T. Toyama, K. Nakamura, Y.H. Chin IPAC14



Residual dose

K. Satou

Residual dose measured at seven hours after the beam stop in 215-kW FX operating mode on Feb 6th, 2013.



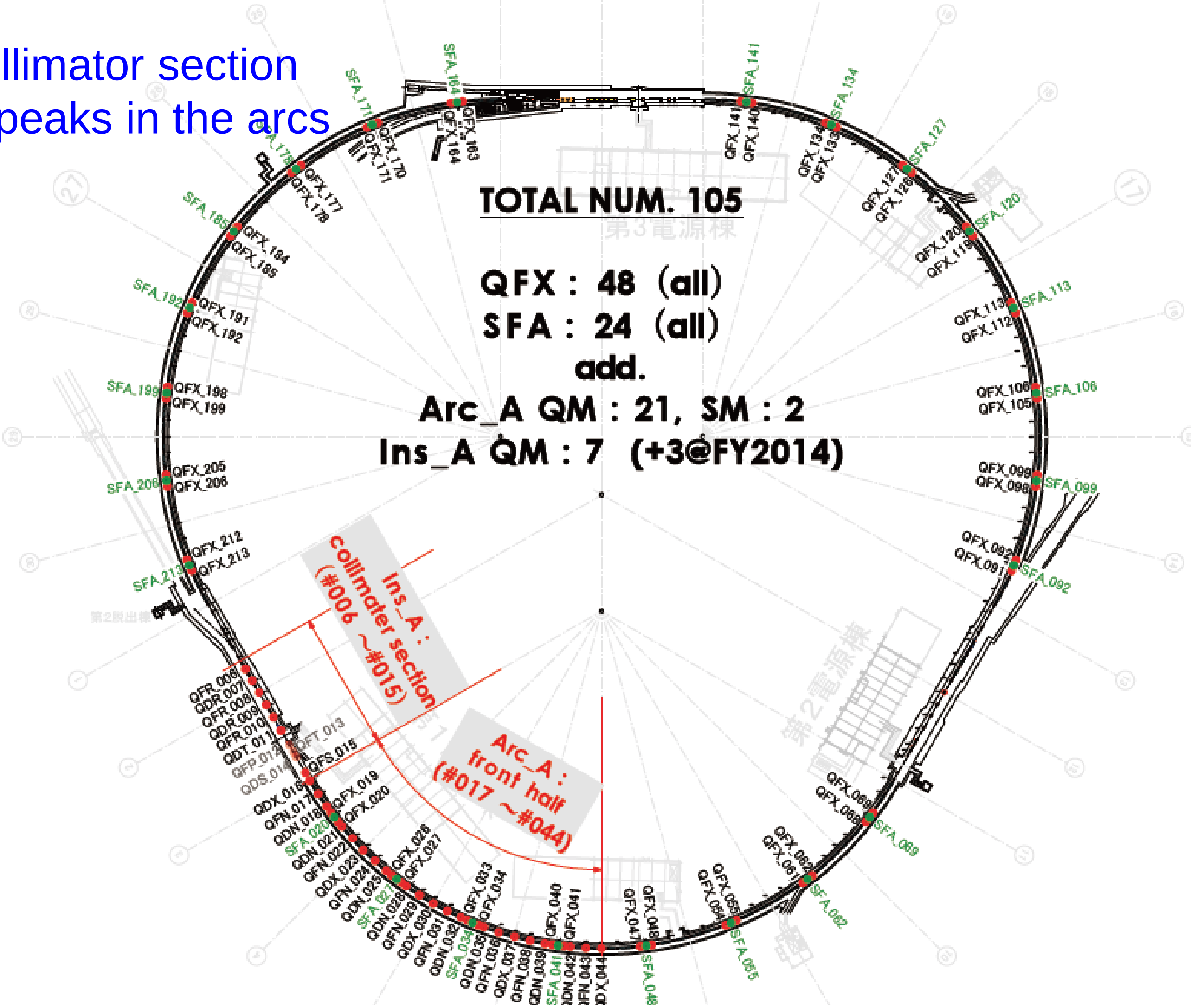
NEEDS TO REDUCE RADIOACTIVITY & TO LOCALIZE BEAM LOSS

Replacement of beam ducts in 2013 shutdown

A part of quadrupole / sextupole beam ducts will be replaced with new ones, which are made of titanium to reduce radiation dose.

- injection/collimator section
- dispersion peaks in the arcs

M. Uota



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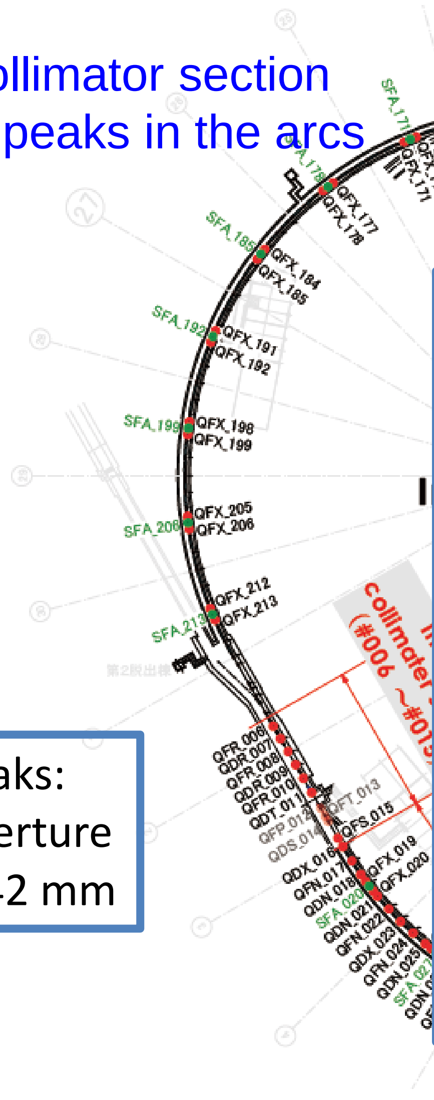
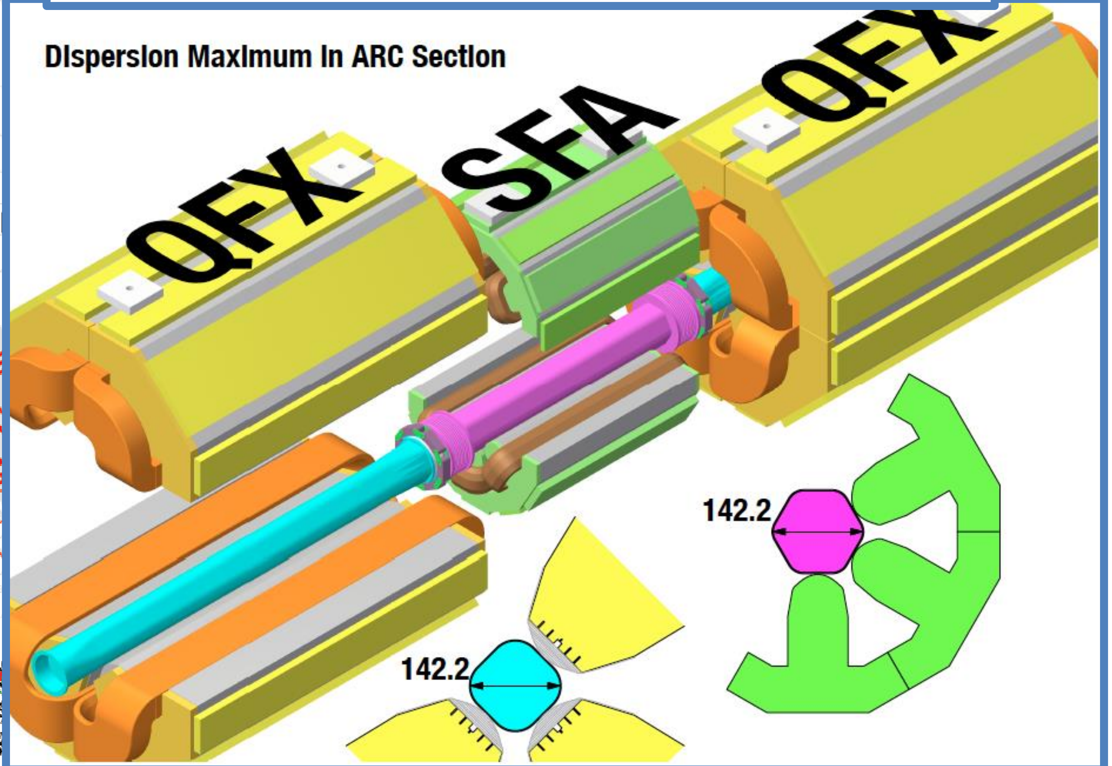


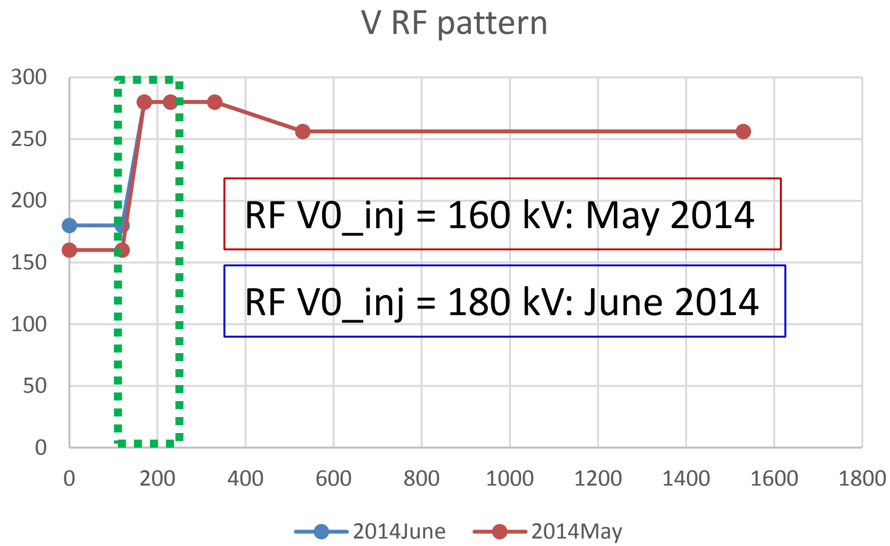
Horizontal aperture of the beam ducts in the dispersion peak sections are enlarged.

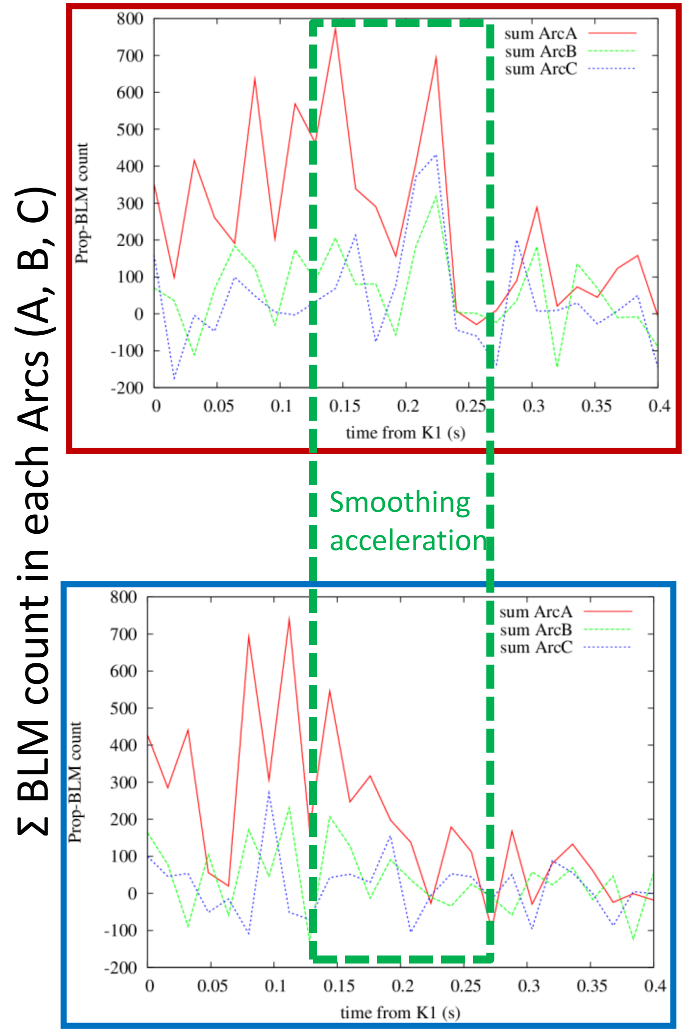


Dispersion Peaks:
Horizontal Aperture
130 mm → 142 mm

Beam loss localization

Y. Sato
F. Tamura
M. Yamamoto

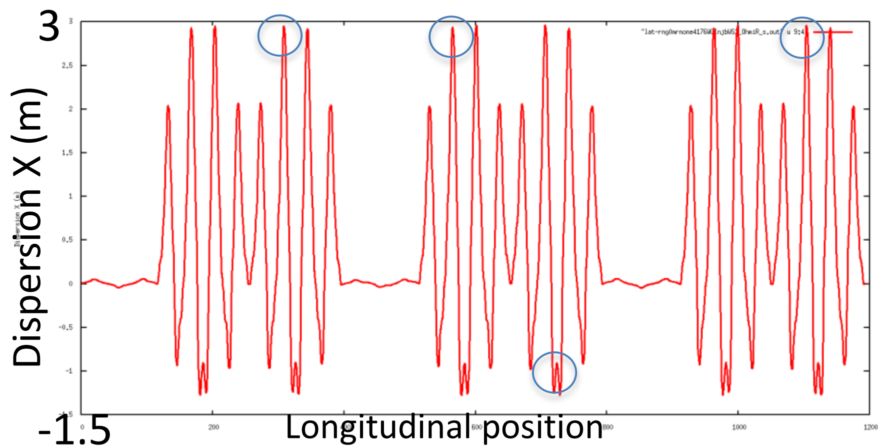




Parameters during injection	V0_inj = 160 kV	V0_inj = 180 kV
Bunching factor	0.15 - 0.30	0.15 - 0.28
Beam loss in injection	~ 0.3%	~0.5%
Simulated long. emitt.	13.5 eVs	12.5 eVs

Balance
- beam loss
- beam loss distribution

Residual dose at Dispersion Peaks: Spring 2013 vs. Spring 2014 (MR ~220kW op.)



Y. Sato
M. Uota
K. Satou

	2013/05/22: 14d after Nu		2014/7/9: 15d after Nu	
QFX 054	250 uSv/h	(SUS)	28 uSv/h	(Ti)
QFX 098	1000 uSv/h	(SUS)	30 uSv/h	(Ti)
BM 130	200 uSv/h	(SUS)	130 uSv/h	(SUS)
QFX 198	460 uSv/h	(SUS)	40 uSv/h	(Ti)

- Beam loss localization
- QFX duct SUS -> Ti
- QFX larger duct (ΔHori = +12 mm)

Reduced radioactive at Dispersion Peaks

Limit of present operation point
&
Tuning for New operation points

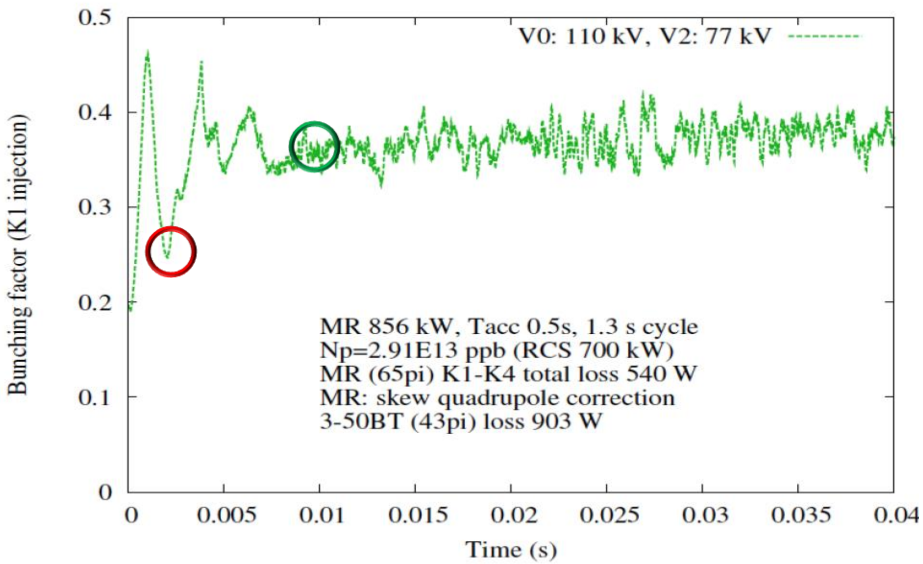
Space Charge Simulation Results near the present operation point (22.40, 20.75)

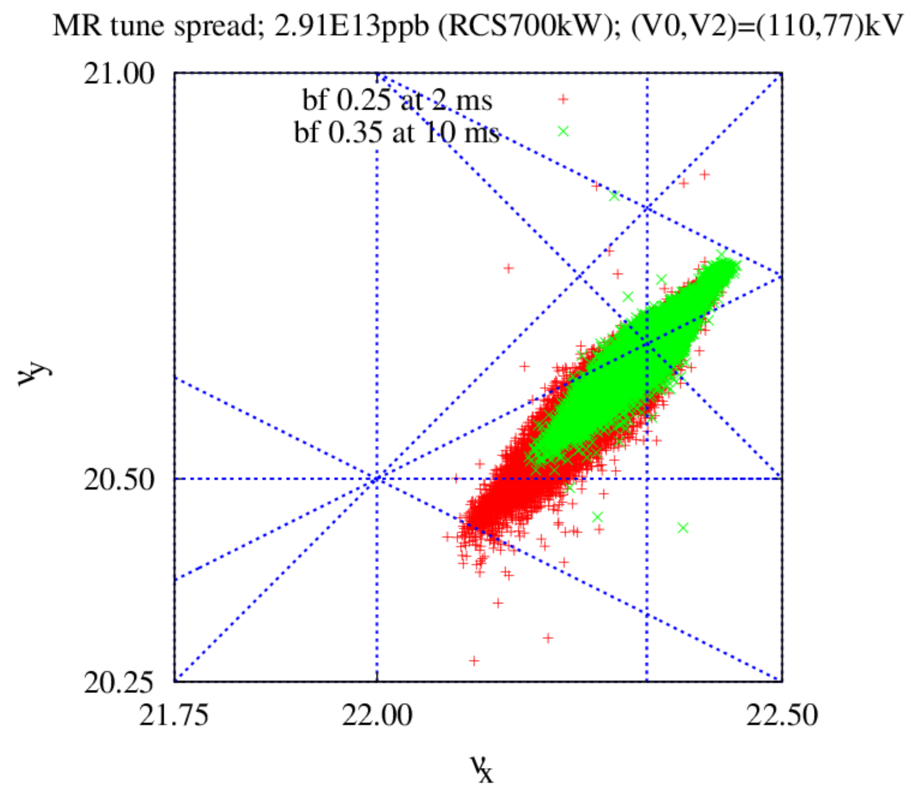
After the injection system upgrade to accept longer bunch,

Y. Sato

2nd harmonic RF approach can be adopt to reduce space charge effect

- RCS 700 kW equivalent 2.91e13 ppb
- 3-50BT: Collimator 43π, 1.0% loss
- RF fundamental 110 kV, 2nd 77 kV





<u>After ideal tunings</u> (no instabilities, corrected sum resonance, …), the highest power would be

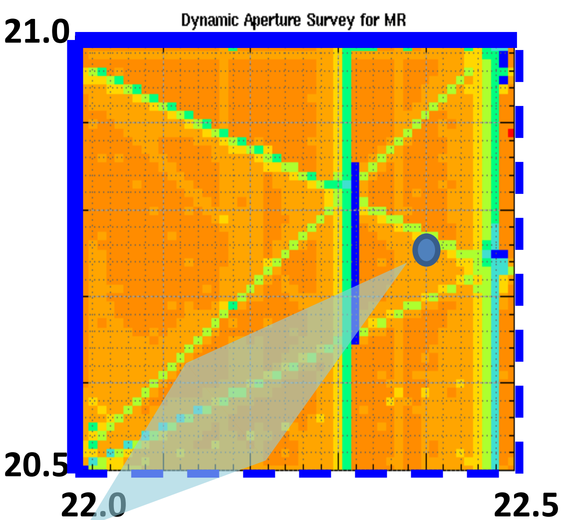
- MR 450 kW w 0.3 kW loss for 2.48 s cycle and
- MR 850 kW w 0.6 kW loss for 1.32 s cycle

at the present operation point.

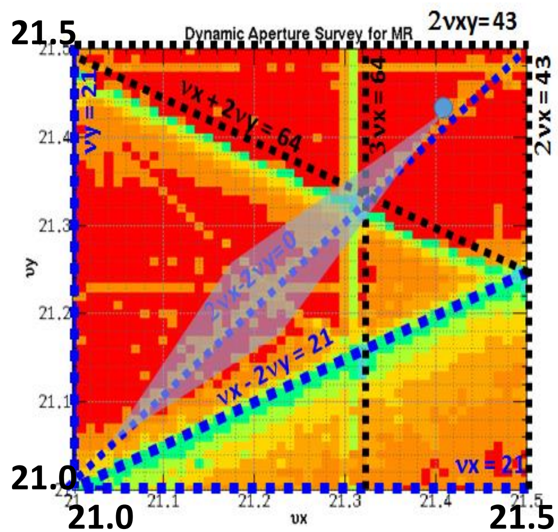
Merits of new operation points

Dynamic aperture survey w SAD by H. Harada

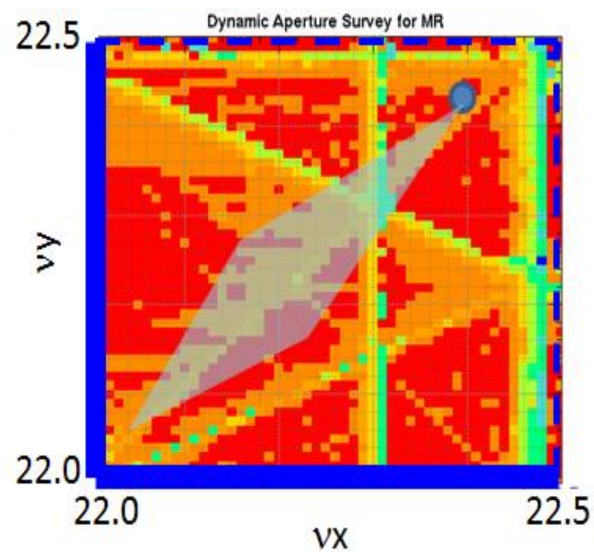
Present point
(22.4, 20.75)



New points A
(~21.4, ~21.4)



New point B
(~22.4, ~22.4)



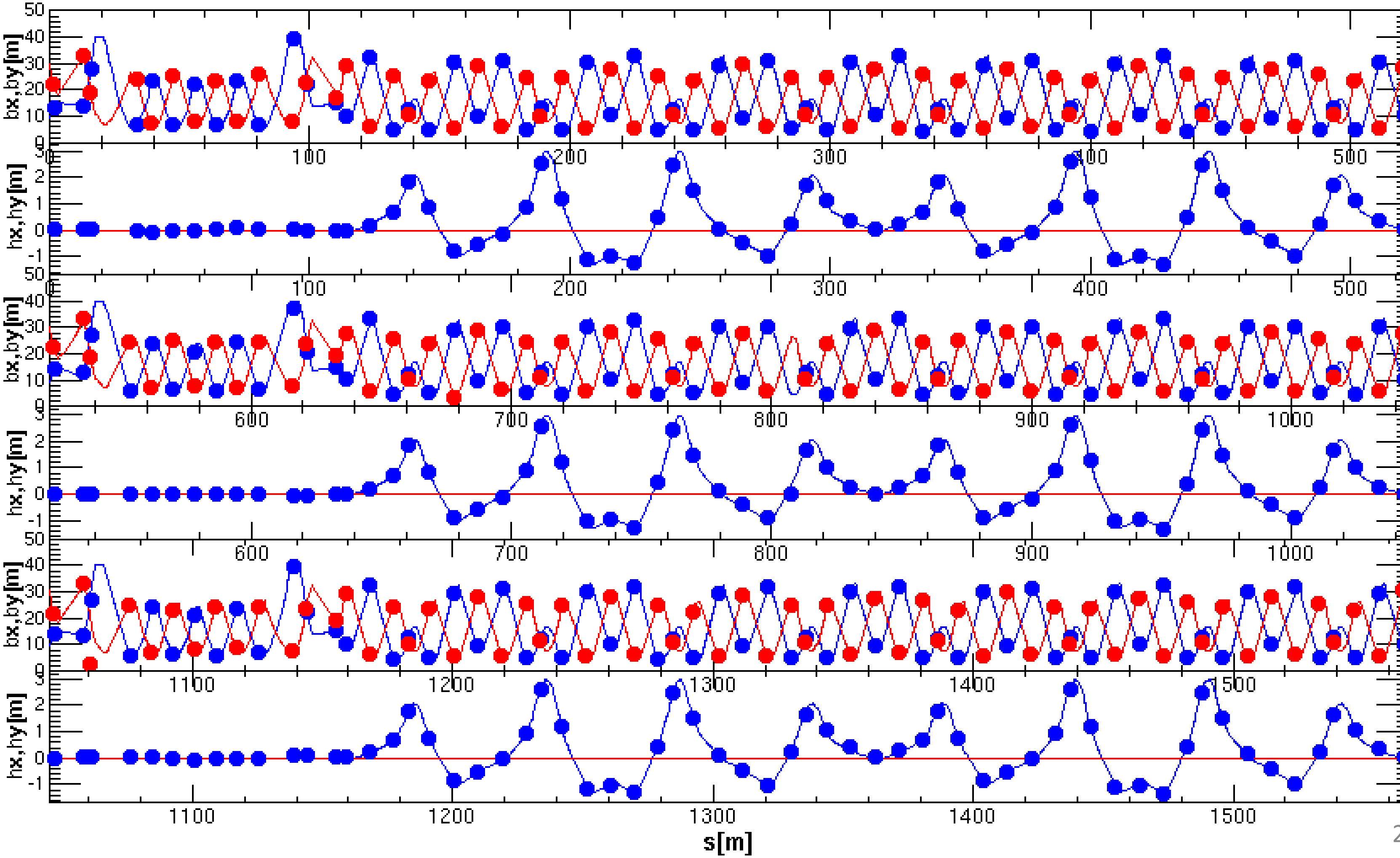
Large tunability for integer/half-integer resonance

- Lower impact for QM ripple (tune fluctuation)
- We can expect less growth rate of vertical beam instability, also

Optics at (22.40, 20.75) at 3 GeV

H. Harada

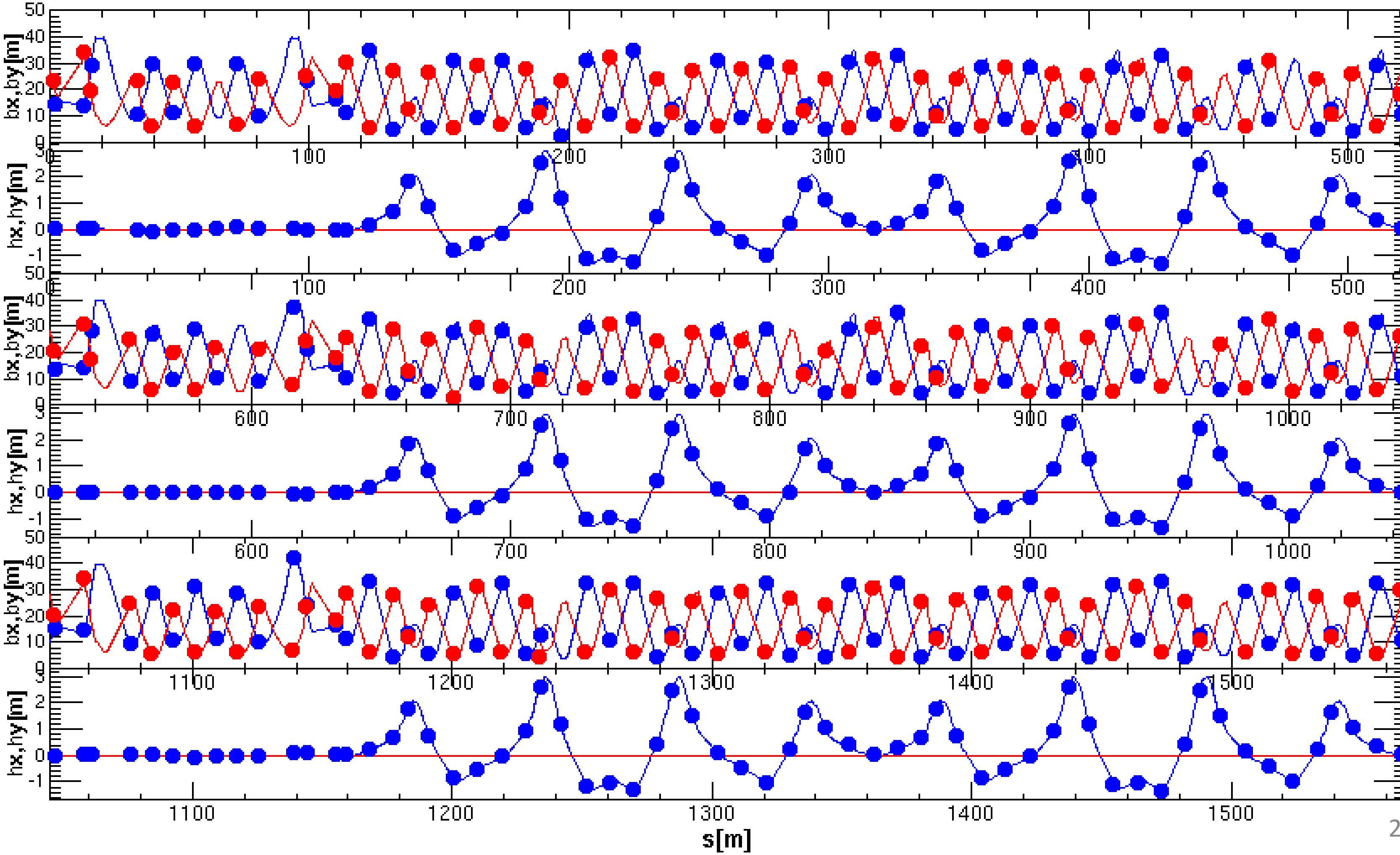
- Measured tune = (22.4018, 20.7484)



Optics at (21.45, 21.42) at 3 GeV

H. Harada

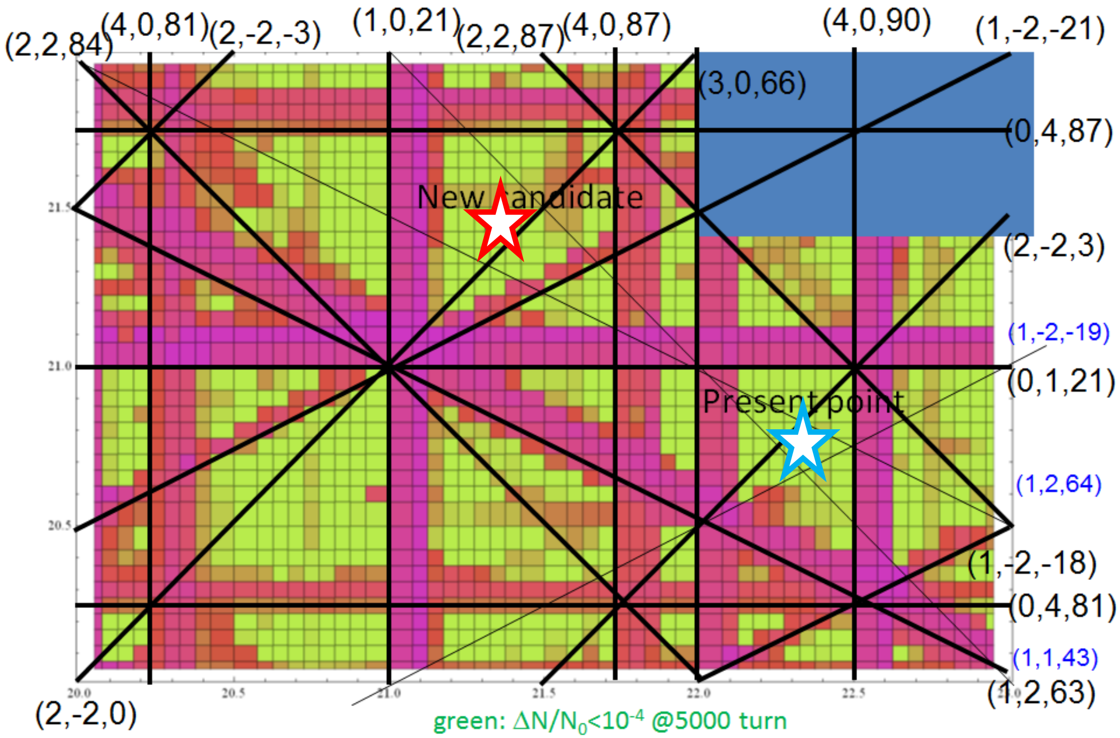
- Measured tune = (21.4536, 21.4189)

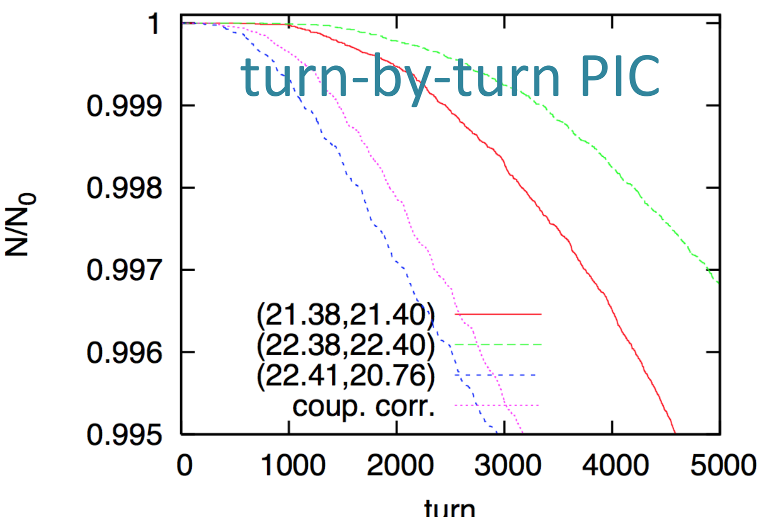


Tune survey w space charge

SCTR simulation K. Ohmi WEO2LR

Beam loss due to space charge; green: better





- *.38,*.40 is better than the present operating point, 22.41,20.76 even coupling correction.
- Why $\nu_x \sim \nu_y$? Better integrability due to angular momentum conservation.

(22.40, 20.75) vs. (21.4, 21.4) for MR 330kW eq. beam in 3 GeV DC

Same conditions:

injected proton properties

aperture at MR col 65~70pi (jaw positions are modified for different Twiss)

RF voltages of RCS ext. and MR inj.

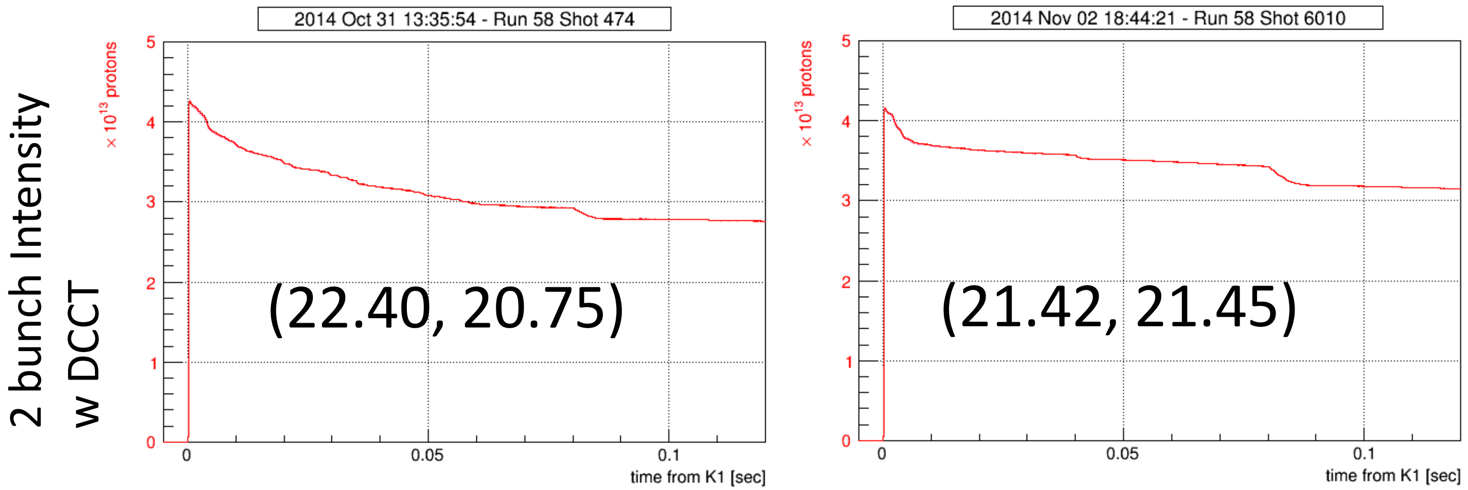
No transverse feedback

Differences:

Tune

Beam optics (Meas. & corr of optics and Inj./Ext matching were done for each points)

Chromaticity corr. roughly optimized for each.

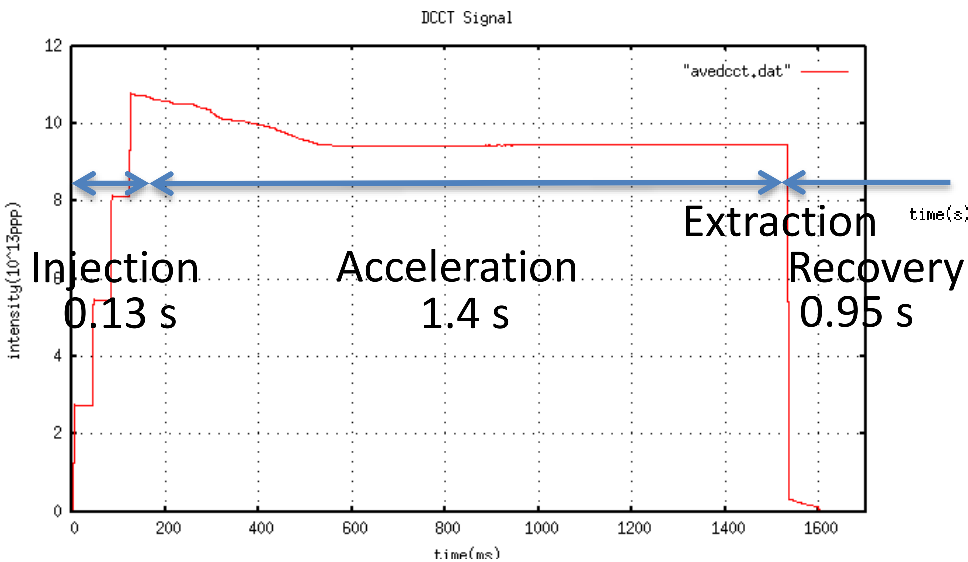


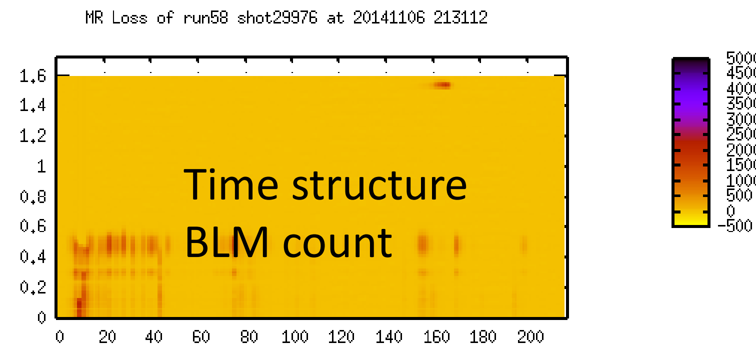
For high intensity beam, (21.4, 21.4) is better than (22.4, 20.75) during injection

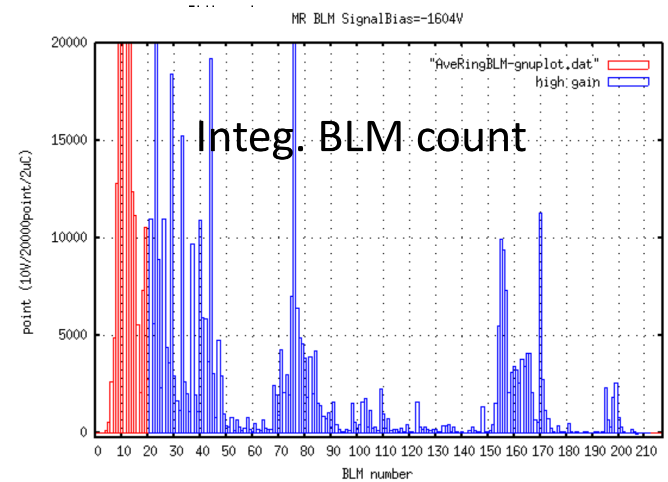
Acceleration tuning at (21.4, 21.4) for MR 210 kW eq. input

To use this point for user operation, we need to optimize

1. Transverse feedback (roughly optimized)
2. Chromaticity patterned correction (roughly optimized)
3. BT/MR collimator balance (roughly optimized)
4. **Bend/Quad control during acceleration** **tune shift is ~0.05 during acceleration**







To take basic data, we measured

- Dispersion during accel.
- Quad linear response to Tune

And we are planning to measure

- Beta during acceleration
- Chromaticity during acceleration

Summary

- MR 240 kW user operation has been performed before/after Linac had been upgraded in energy and current.
- Beam losses have been reduced and localized step by step.
- However, present operation point (22.4, 20.75) has beam intensity limit to touch the half-integer resonance.
- New operation point (21.4, 21.4) has larger tunability for half-integer/integer resonances.
- (21.4, 21.4) shows promising results in 3 GeV DC to seek over 300 kW. To adopt it for user operation, acceleration tuning is one of the big issues. We are taking basic data for the purpose.