60 mA Beam Study and Efforts for Beam Loss Mitigation in J-PARC Linac

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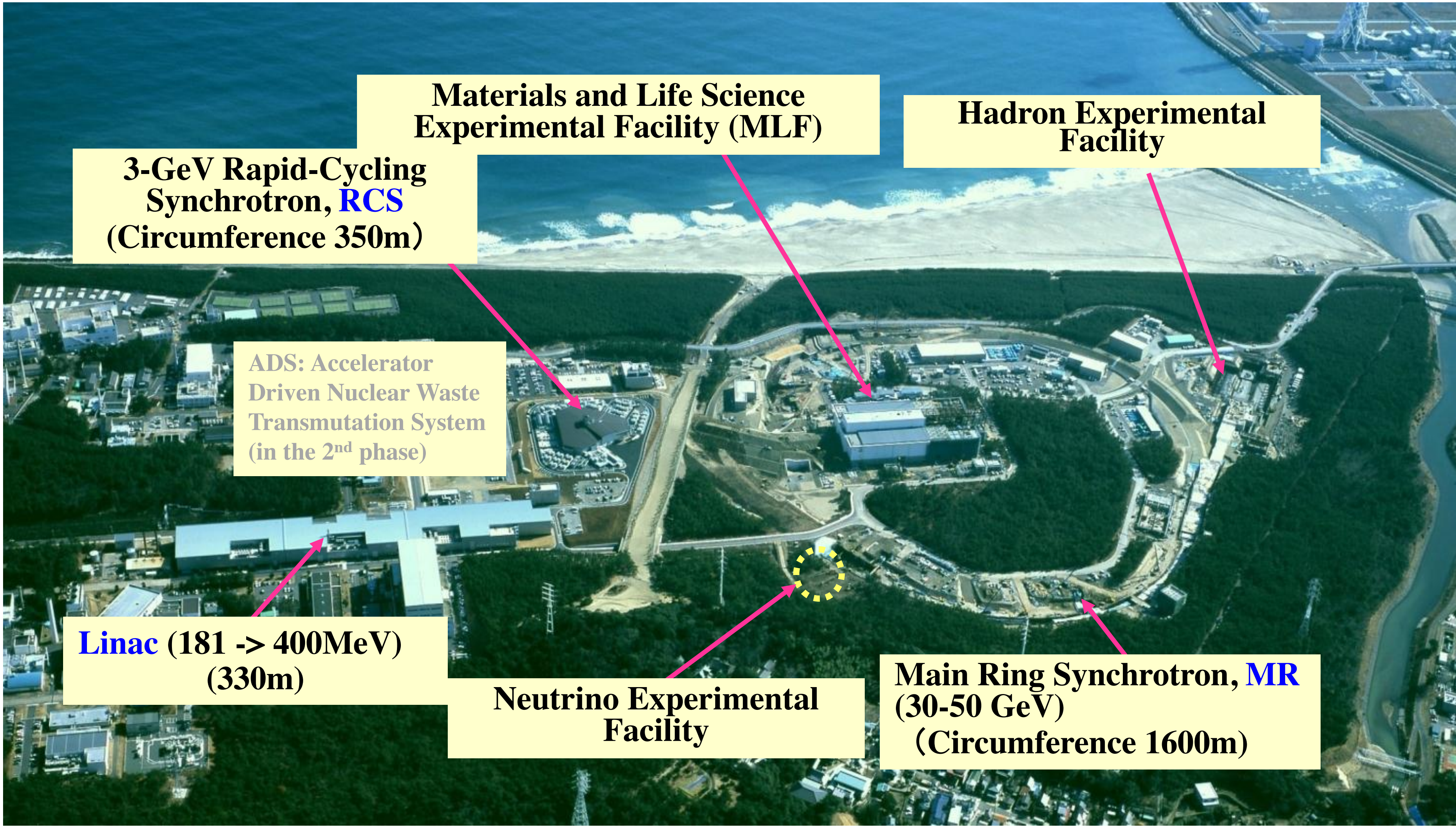
Outlines

- Roadmap of J-PARC LINAC Intensity Upgrade
- Preparation for first beam of 60mA @J-PARC LINAC
- Intermediate results for 60mA studies
- Preparation for 3rd trial for 60mA
- Conclusion and outlook

J-PARC Facility Layout at Tokai, JAEA Site



Multi-Purpose Facility

Joint Project between KEK and JAEA

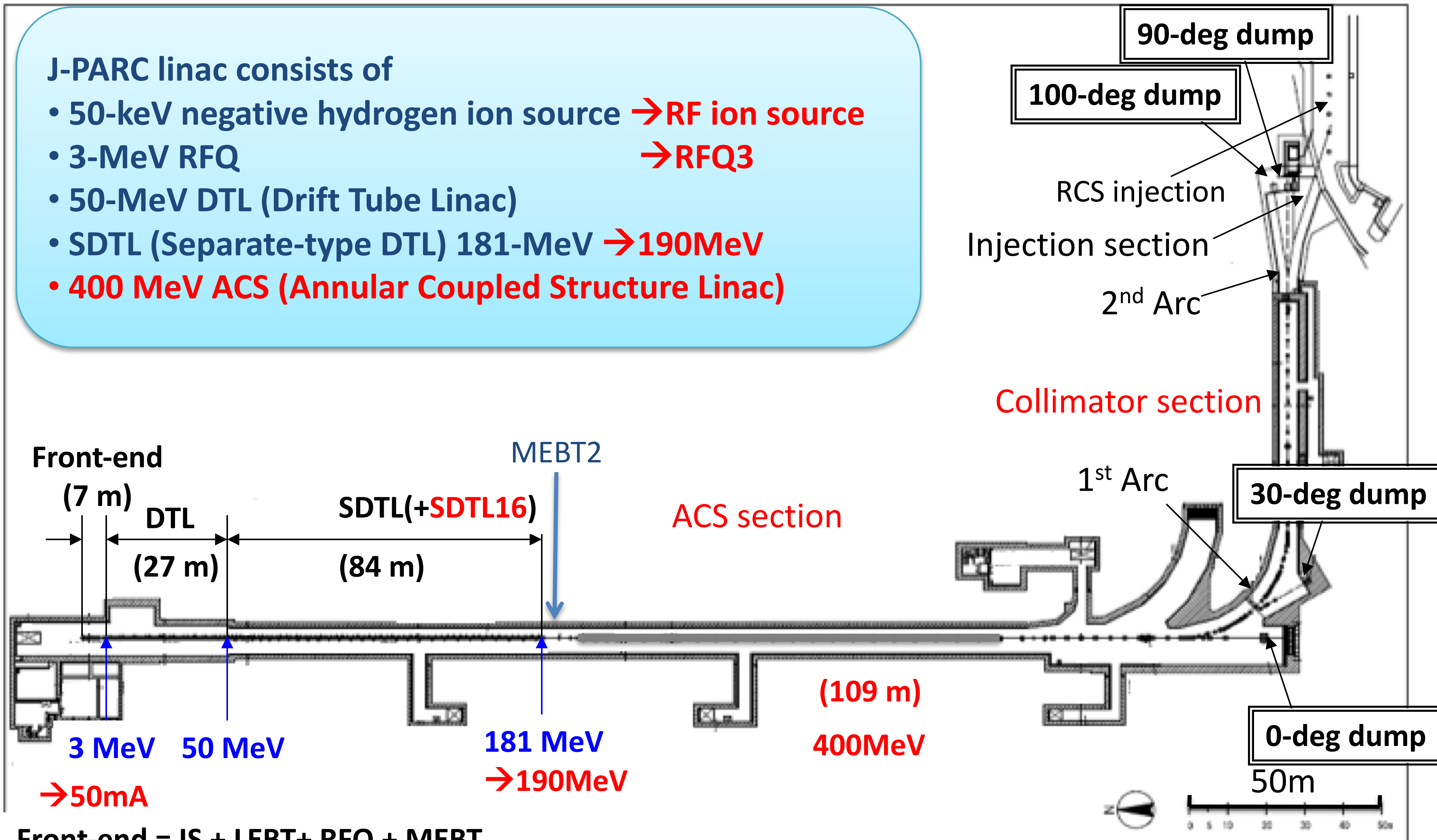
J-PARC Linac Layout and Upgrade Scheme

181/190MeV → 400MeV: installation in 2013 Summer, accomplished in Jan., 2014

15/30mA → 30/50mA: on-line in 2014 Summer, accomplished in Oct. 2014

J-PARC linac consists of

- **50-keV negative hydrogen ion source →RF ion source**
- **3-MeV RFQ →RFQ3**
- **50-MeV DTL (Drift Tube Linac)**
- **SDTL (Separate-type DTL) 181-MeV →190MeV**
- **400 MeV ACS (Annular Coupled Structure Linac)**



Front-end = IS + LEBT+ RFQ + MEBT

Roadmap of J-PARC LINAC Intensity Upgrade

- 181/190MeV → 400MeV: Jan., 2014
  Operation/Study 15/30mA → 30/50mA: Oct. 2014

→400MeV, 50mA: ready for 1MW from RCS (Demo:Dec.2014)

________________________________Design accomplished

- 40mA in Operation: Jan. 2016

Next step: 50→60mA or/and 500→600us: aim at 1.2/1.5MW@MLF

- 1st Trial of 60mA: Jul.5 2017: 68mA(IS) 62mA(MEBT1)
- 2nd Trial of 60mA: Dec.25,26 2017 60mA(DTL no accel.), 57mA(Li)
- 3rd Trial of 60mA: Jul.3, 2018
- 50mA in Operation: Oct. 2018

…

First 60mA Trial on Jul.5：Expected Problems and Countermeasures

Expected Problems

- Key point 1: DTL1

Aperture(deformed by earthquake 2011)

Output power might be near limit (coupler, klystron)

- Key point 2: emittance from ion source
- Current-dependency of RFQ output emittance
- Hardware damage due to errant beam

Countermeasures

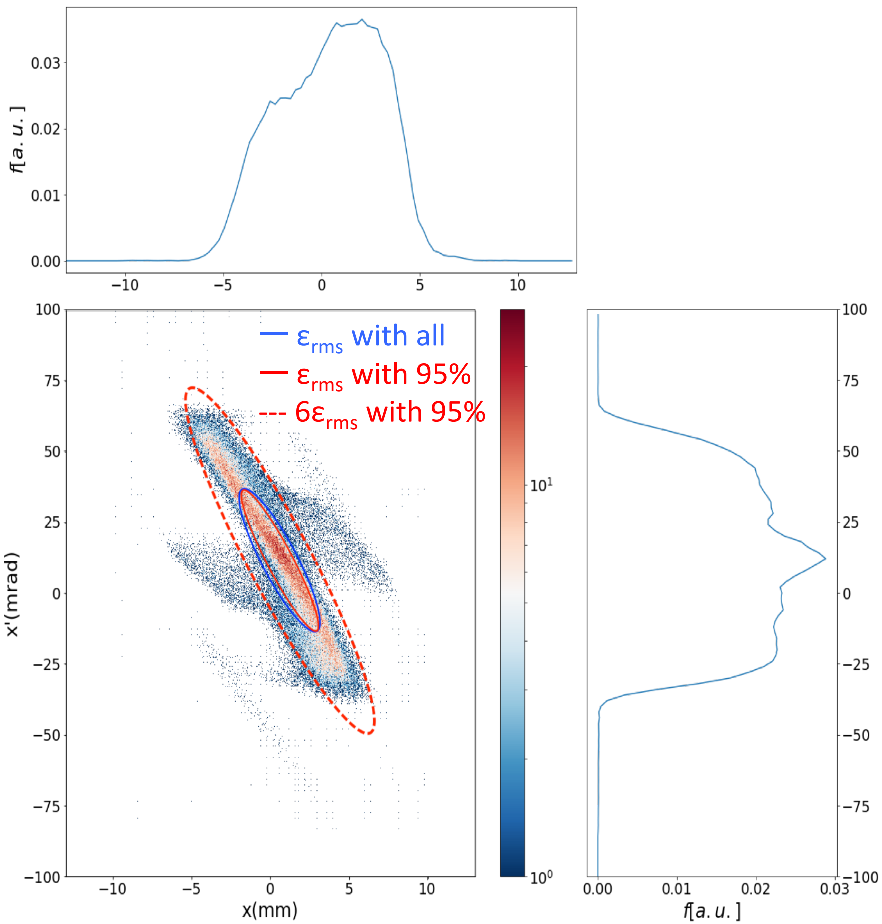
- Simulations investigation
- Prepare lattices for possible larger emittance
- Limit beam pulse to 50us
- With chopped beam with thinning→ difficulties for monitors
- Lattice preparation for reduced tank level of DTL by 5, 10%→ acceptance and beam quality problem (not applied)
- Cavity conditioning before beam study → RFQ：3h; DTL~ACS: 10h+

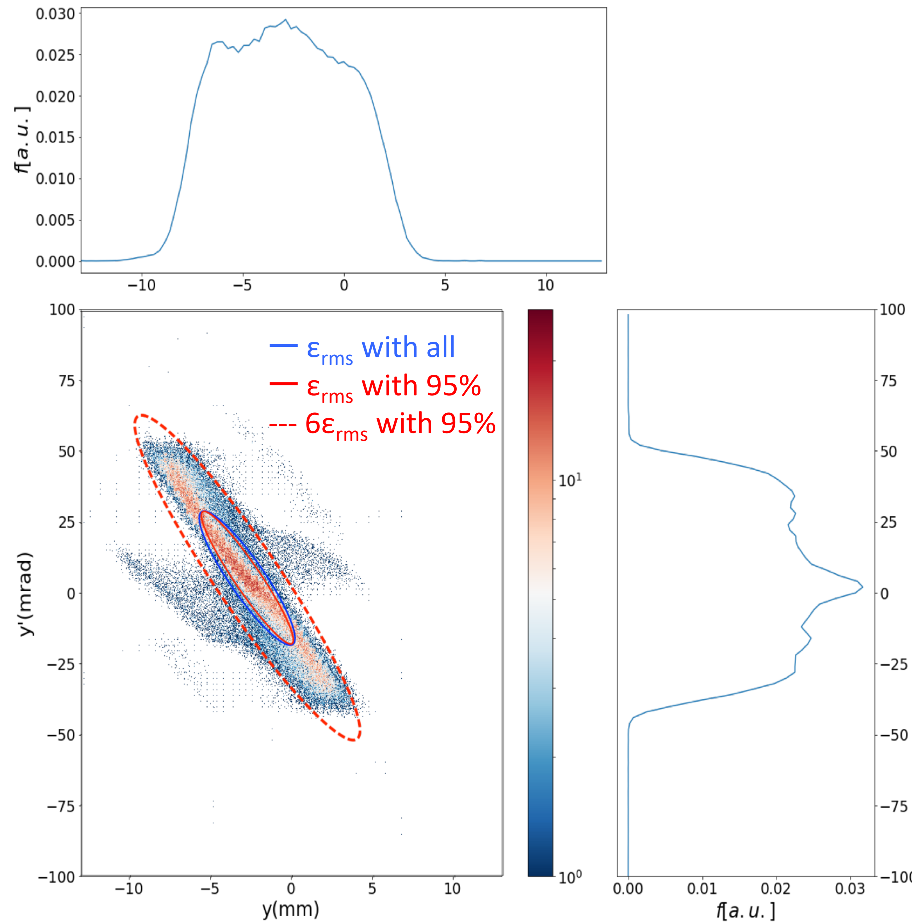
Updated Data of Ion Source

A typical measured transverse distribution at ion source test stand for 66mA

$\varepsilon_{tn.rms|95\%}$=0.2646 mm*mrad

Data by Dr. A.Ueno
New J. Phys. 19 **(**2017**)** 015004





RFQ3 Simulation Study with Input of Measure Ion Source Distribution @66mA (by LINACSrfqSIM)

(*unrealistic input for 30~50mA*)

			Norm. rms (mm*mrad)			trace3d			Envelope (mm)	
	I(mA)	η	ε x	ε y	ε z	ε x	ε y	ε z	rx	ry
(For ref.)	*30.*	*0.95*	*0.26*	*0.26*	*0.32*	*20.68*	*20.92*	*583.35*	*2.16*	*1.23*
(For ref.)	*40.*	*0.94*	*0.24*	*0.24*	*0.33*	*19.07*	*19.04*	*600.90*	*2.15*	*1.21*
(For ref.)	*50.*	*0.93*	*0.22*	*0.23*	*0.34*	*17.81*	*18.02*	*624.95*	*2.12*	*1.20*
	60.	0.91	0.22	0.22	0.34	17.41	17.41	624.50	2.14	1.19
	70.	0.90	0.22	0.21	0.34	17.25	17.08	630.30	2.15	1.20

Decisive effect of RFQ aperture limit at cost of transmission
“Conservation of trans. envelope”

Maybe no worry for downstream aperture

Lattice Preparation for DTL

- (A)40mA lattice for operation
- (B)50mA lattice for beam study

A,B for reference

- (C)40mA lattice scaled for 65mA envelope in DTL

  Same envelop @65mA with A @40mA, i.e. same phase advance
- (D)40mA lattice scaled for 65mA envelope in DTL (Quad+10%)

  Stronger transverse focusing in case of larger emittance
- (E)EP setting for 65mA

Notes

A,B for reference

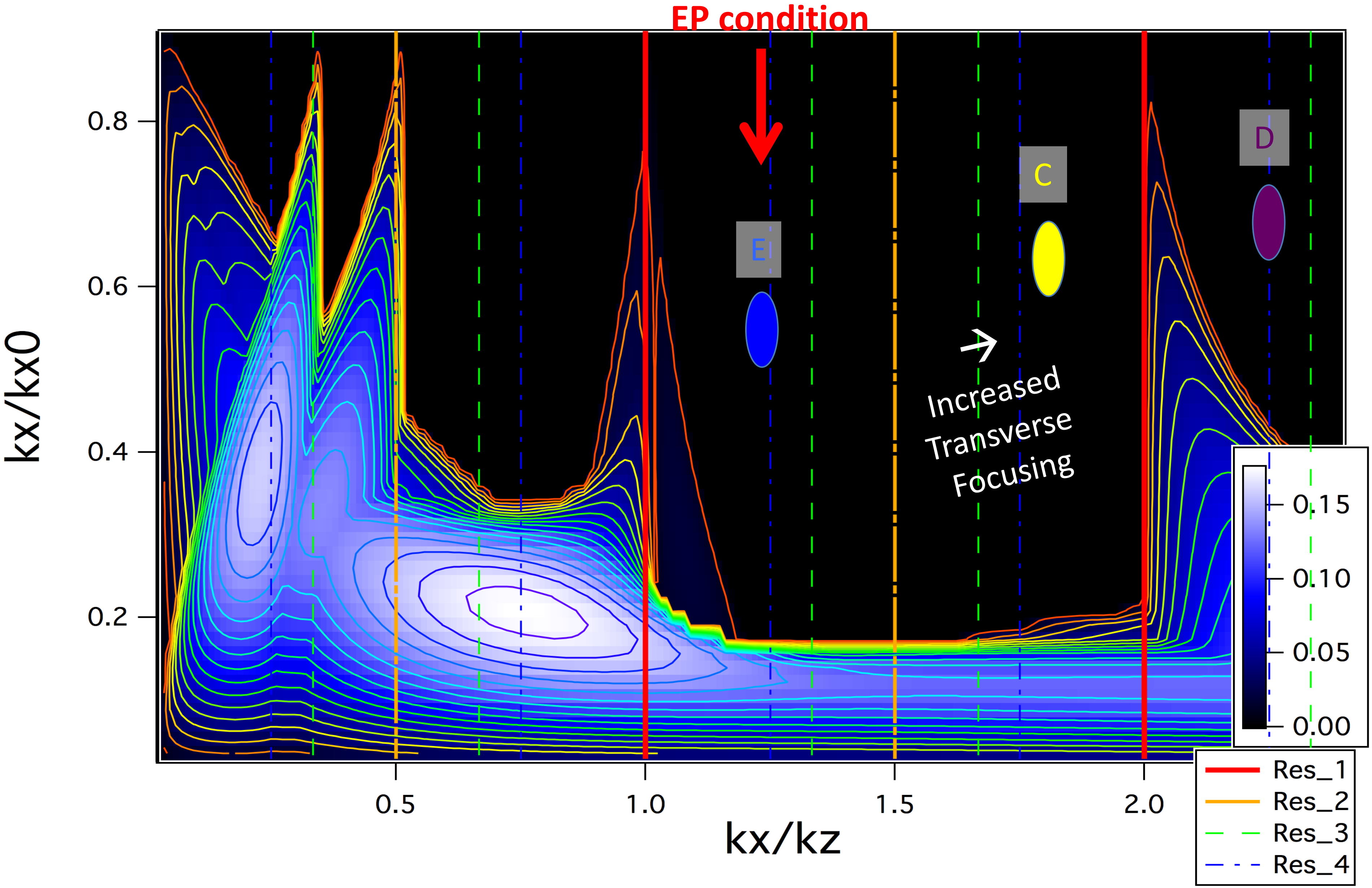
C,D scaled for 65mA with lattice A

Least change on DTL orbit

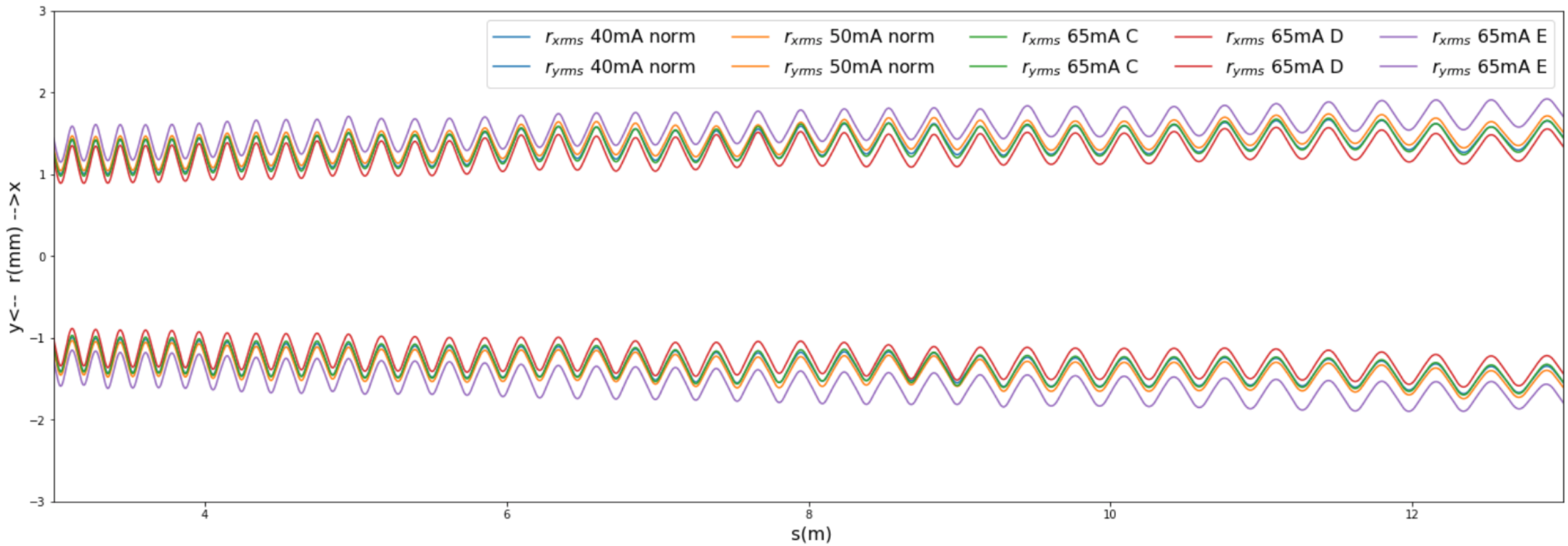
Aperture control

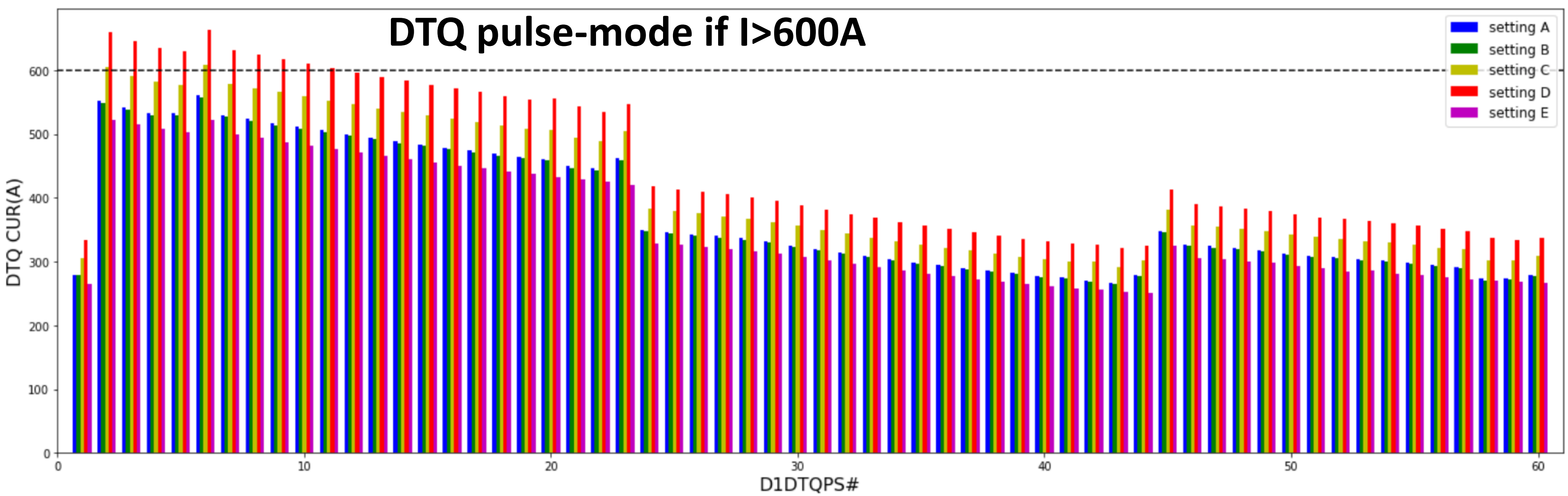
Pulse-operation of DTQ(∀>600A) is needed for (C) and (D)

Tune Diagram for Lattices C,D,E Based on Design Emittance



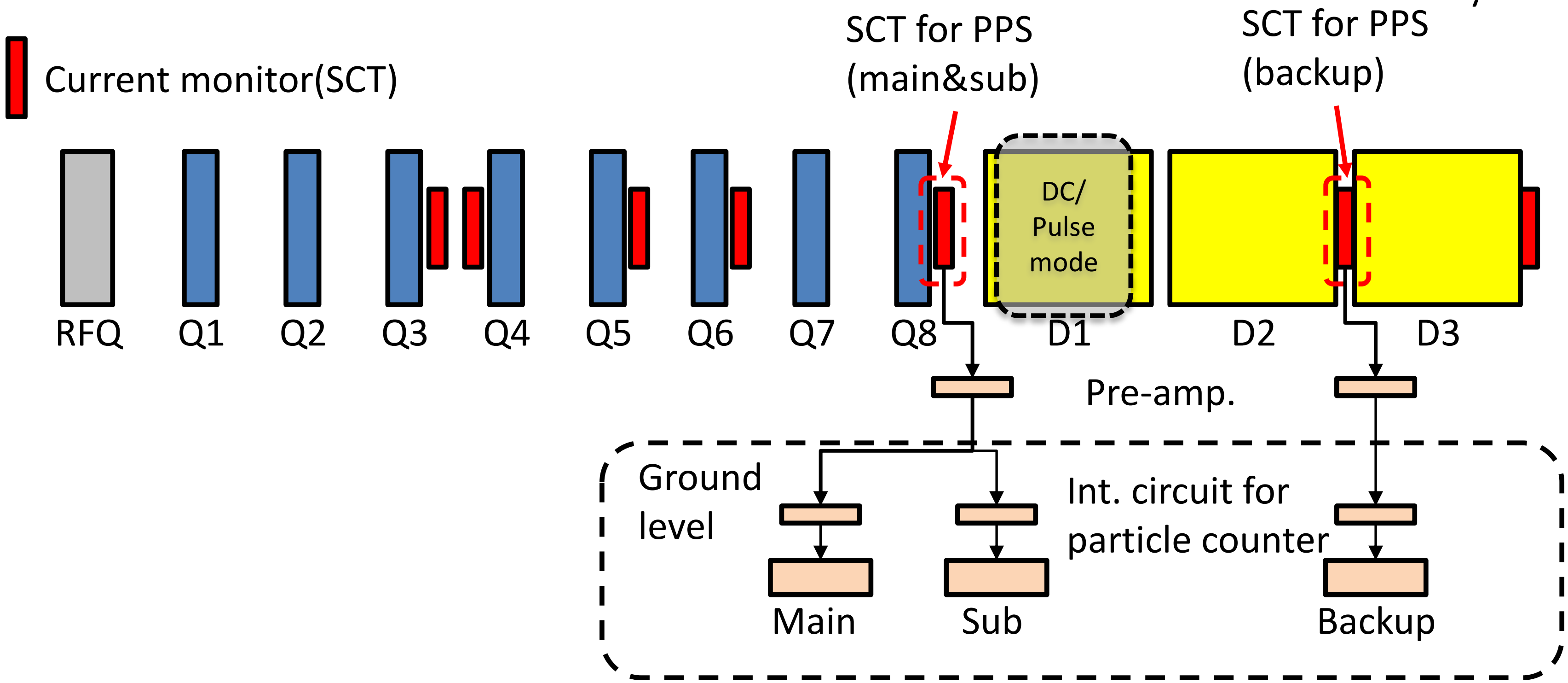
DTL1 DTQPS Settings





PPS-CT System and Correction Scheme

By A. Miura



Structure for PPS-CT system

- Signal of MEBT1_SCT8 is led to ground level, separately integrated and obtained for particle counter for PPS-main and PPS-sub system
- Similar for Signal of DTL2_SCT for PPS-backup system

Purpose of PPS-CT correction

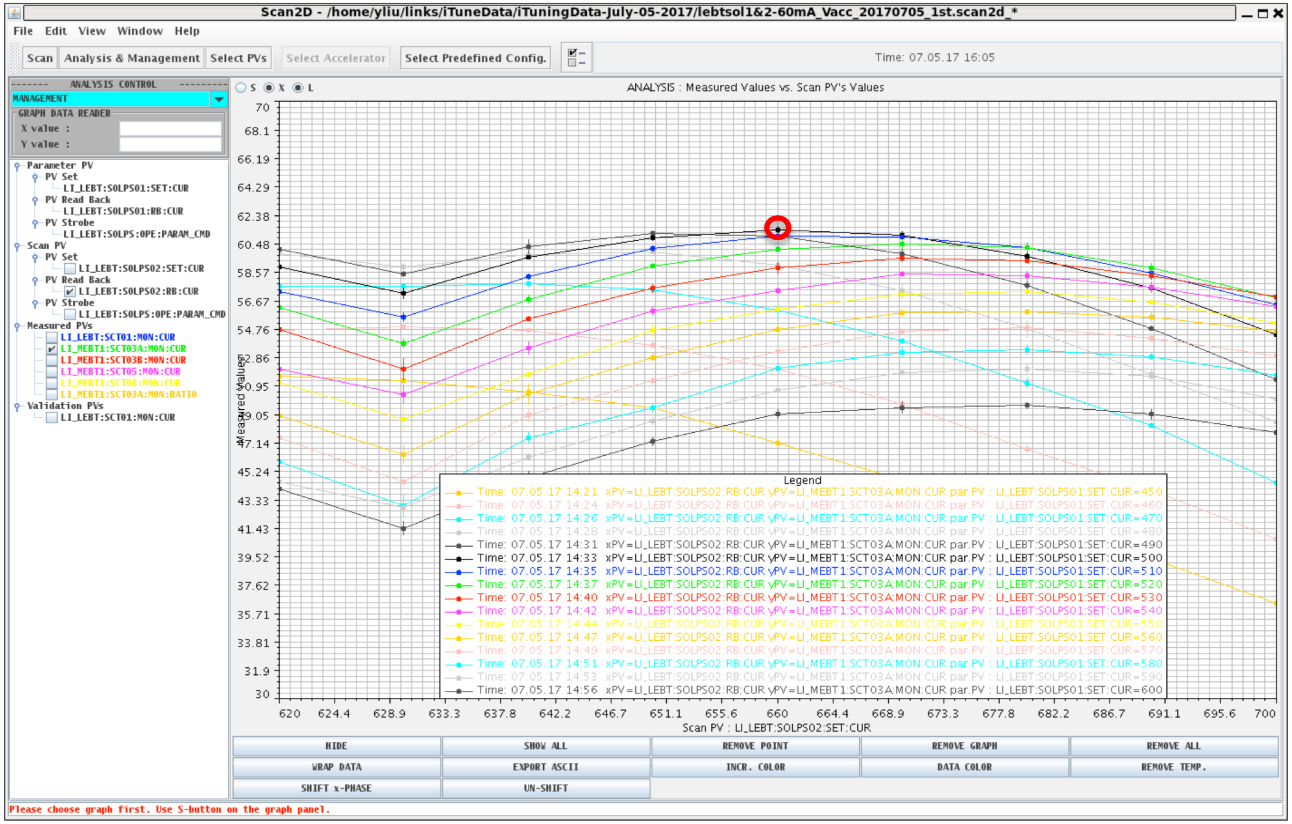
- Correction for using of attenuator for avoiding of integrator over-range for 60mA beam test.
- Correction for noise to the SCT from DTQ in case of pulse operation

“First” 60mA Beam @ MEBT1

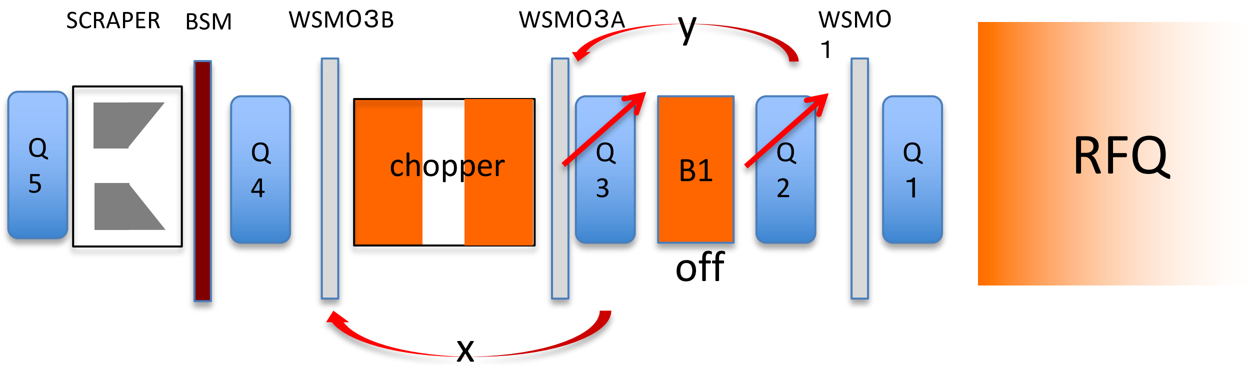
“first” beam @MEBT1:SCT03A: 38mA → 61.3mA (Sol2++, Sol1--)

J-PARC milestone!

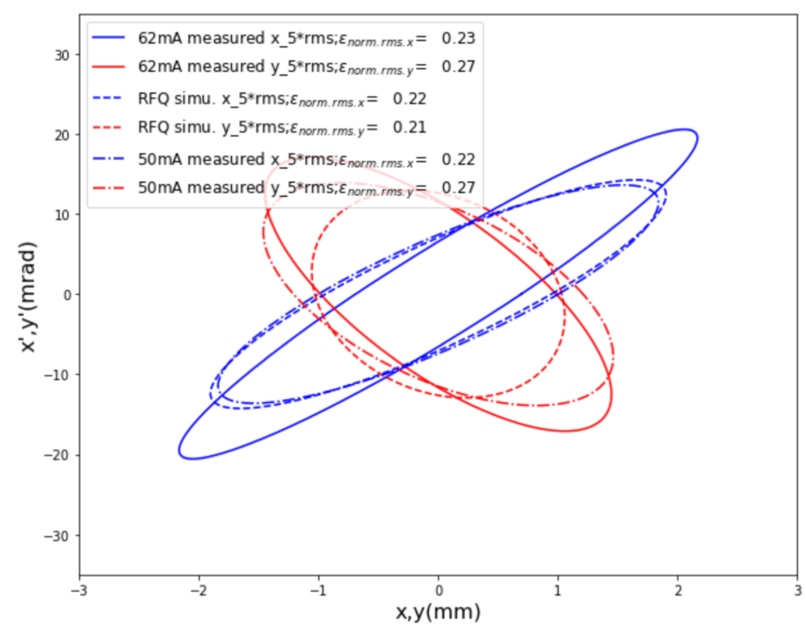
62mA@MEBT1:SCT03B



Result of MEBT1 Q-scan Measurement



G_{Q1}	G_{Q2}	G_{Q3}	WSM03Ax	WSM03Ay	WSM03Bx	WSM03By
-32.44	22.04	-14	-1	-1	1.0888	-1
-32.44	22.04	-16	-1	-1	1.3251	-1
-32.44	22.04	-10	-1	-1	2.426	-1
-32.44	22.04	-14.6	-1	-1	1.1417	-1
-32.44	22.04	-13.4	-1	-1	1.2921	-1
-32.44	22.04	-12	-1	-1	1.7228	-1
-32.44	22.04	-18	-1	-1	2.012	-1
-32.44	22.04	-20	-1	-1	2.6858	-1
-32.44	18	0	-1	1.8063	-1	-1
-32.44	21.4	0	-1	0.55944	-1	-1
-32.44	24	0	-1	0.99798	-1	-1
-32.44	25	0	-1	1.365	-1	-1
-32.44	20.8	0	-1	0.69665	-1	-1



Lesson from First Trial 60mA Beam Study on Jul.5, 2017

- 62mA@MEBT1: J-PARC milestone
- First DTQ pulse operation
- Transverse measurement of 60mA beam with MEBT1 Q-scan was done
- Transmission from IS to MEBT1-SCT3B ~90%
- RFQ output emittance/Twiss is close to expectation

→And not far from 50mA

→Beam loss in RFQ is acceptable for RFQ operation stability

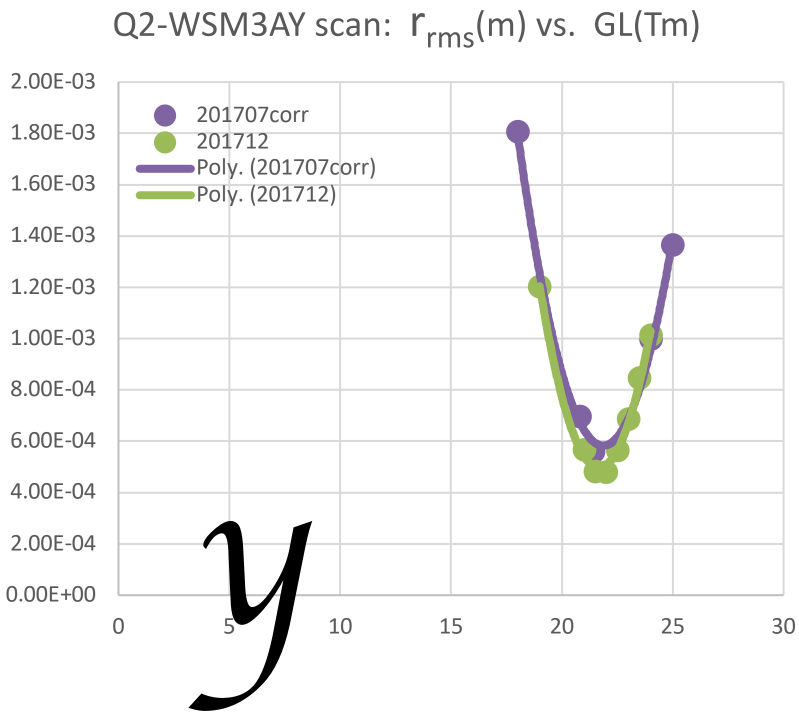
- Chopped beam was used in orbit correction, not-fully chopped beam cause confusing results → un-chopped beam is required for orbit correction in the next study
- PPS backup-system correction is also needed

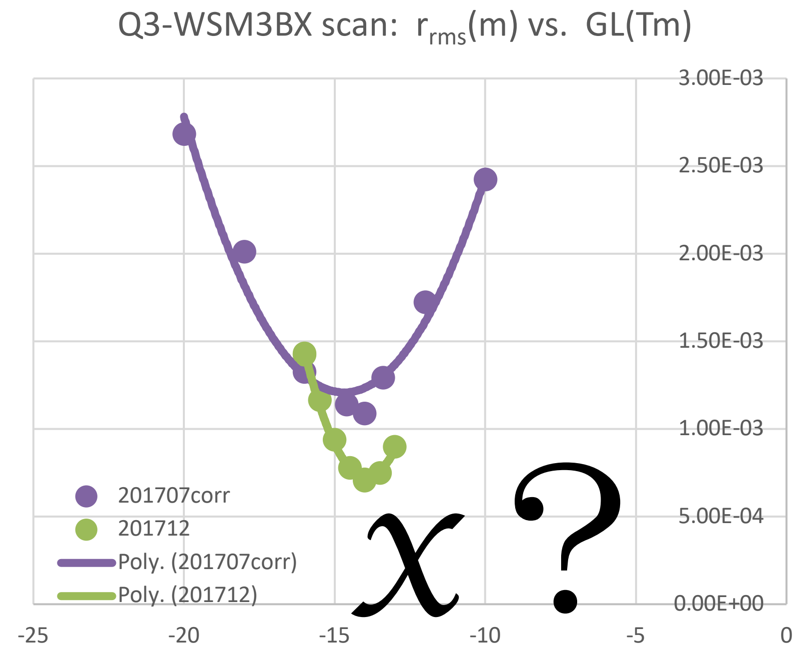
Strategy and Results of
Second 60mA Trial on Dec.25~26, 2018

Improvements and Strategy Based on Lessons from first 60mA Trial

- Improved Q-scan scheme based on Jul.5 result
- Beam profile/position@MEBT1 scraper need to be checked
- MEBT1 Orbit correction condition set to: 50us/3MeV/no-chop
- Sufficient time for PPS correction (main/sub + backup) for DTQ pulse operation
- DTQ “DC mode” E-lattice will be used if MEBT1 Q-scan measurement reproduces Jul.5 result
- A special timing scheme is prepared for possible full acceleration of 50us unchopped beam. Basically chopped beam will be used after orbit correction

Comparison of MEBT1 Q-scan Measurement （Jul.5, Dec.25 ）

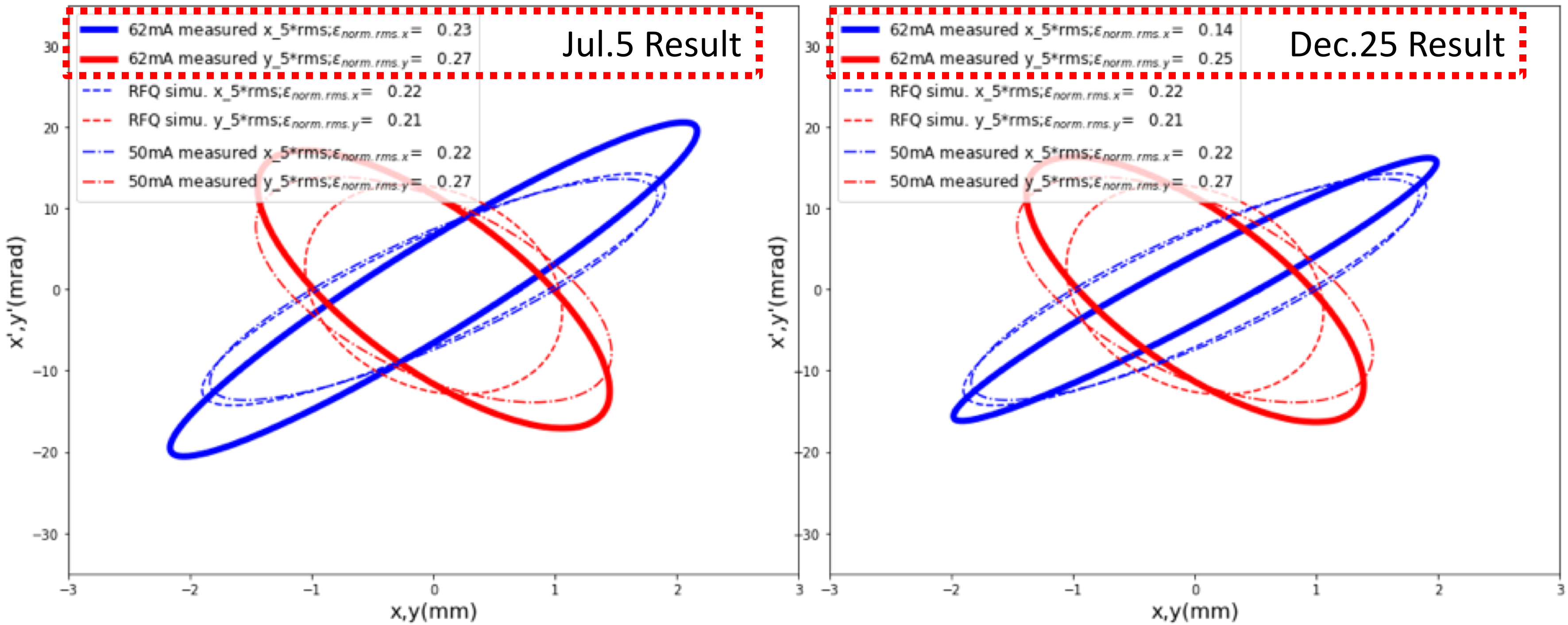




Emittance：X-plane became small（?）、Y-plane reproduced

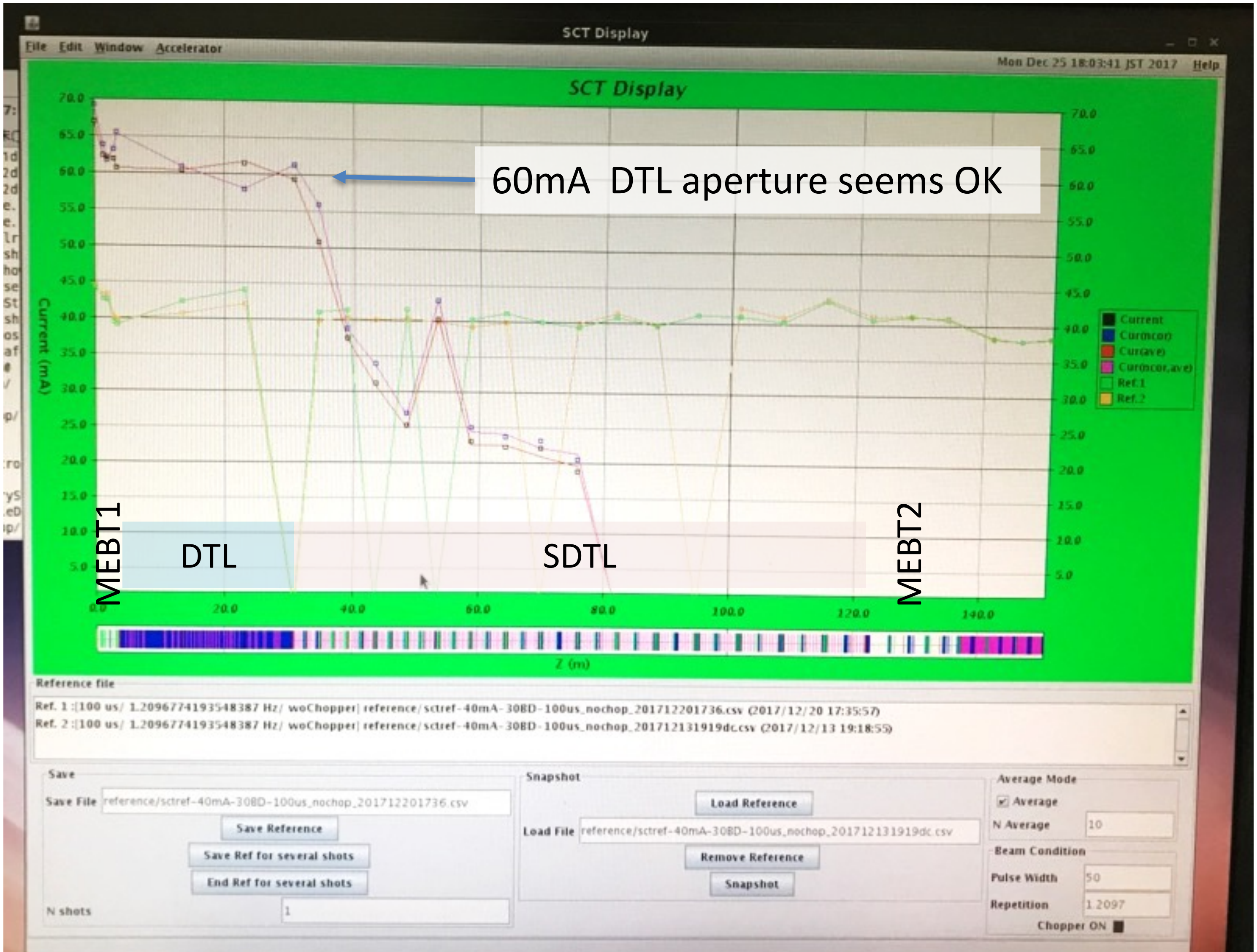
→DTQ DC mode is possible（“E”-lattice ）

Comparison of MEBT1 Q-scan Measurement (60mA Jul.5, Dec.25 with simulation and 50mA)

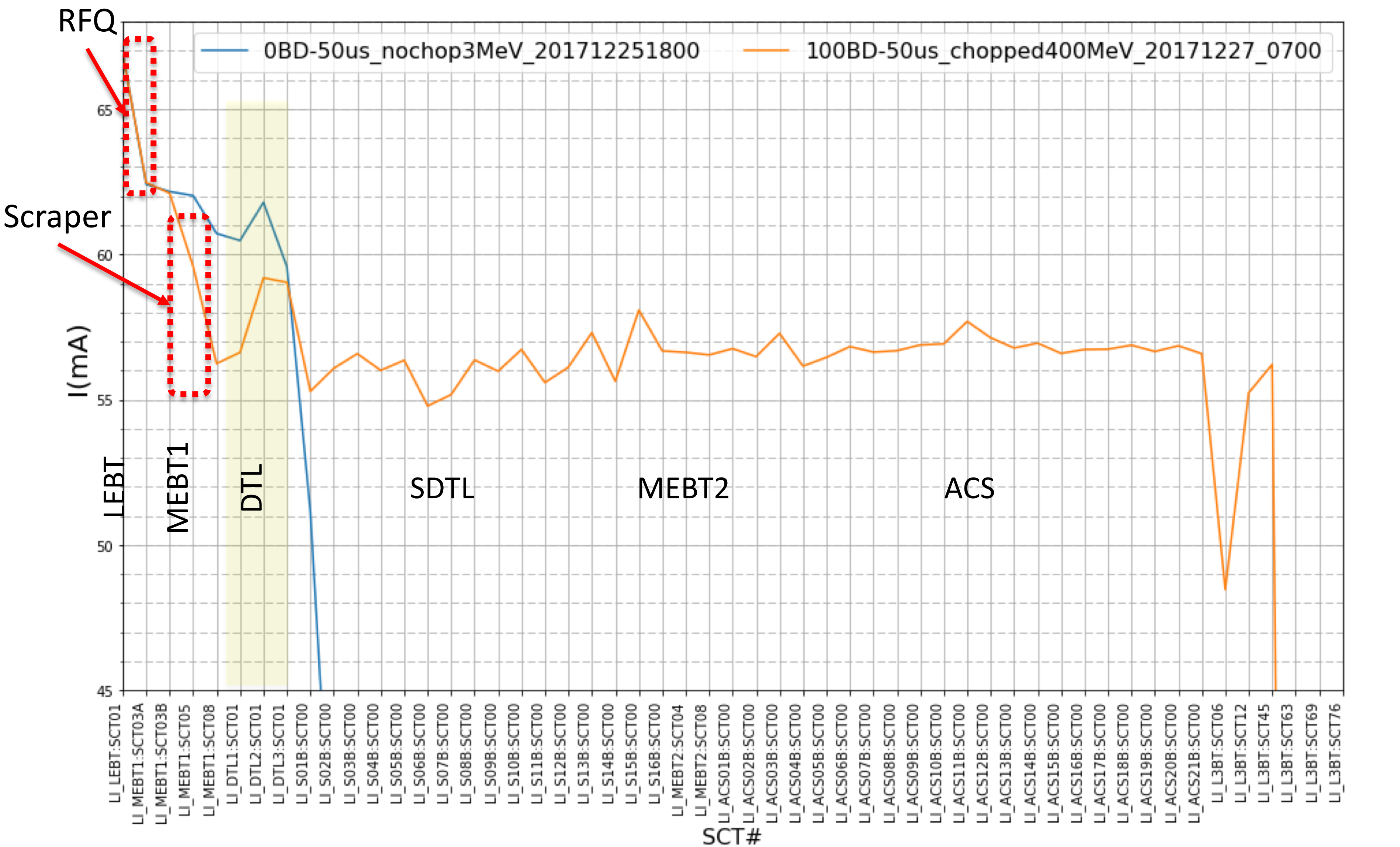


Y-plane: well reproduced
X-plane: emittance is unexpectedly small
Trend is OK

"First Beam" 60mA through DTL
(3MeV,chop off, MEBT1 scraper out)



Transmission: 3MeV(no chop scraper open), 400MeV(chop on scraper at norm.)



Results of Second 60mA Trial Beam Study on Dec. 25~26,2017

- 62mA@MEBT1 was reproduced
- MEBT1 Q-scan results was reproduced
- 60mA/3MeV beam transmitted DTL through DTL.（w/o chop, MEBT1 scraper open）
- 56mA/400MeV（w/ chop）was obtained at Li exit DTL~L3BT ~100%.
- Main beam loss:

  RFQ(halo from IS)

  MEBT1 scraper (need to be analyzed)
- Transverse matching was done for whole Linac, output emittance is 150% of 40mA operation.
- Longitudinal matching was not done
- Possible for RCS injection trial (with fine tuning)

Preparation of
Third 60mA Trial on Jul.3, 2018

Strategy/Steps for Third 60mA Trial Study on Jul.3, 2018

- Reproducibility for $\lesssim$60mA Beam

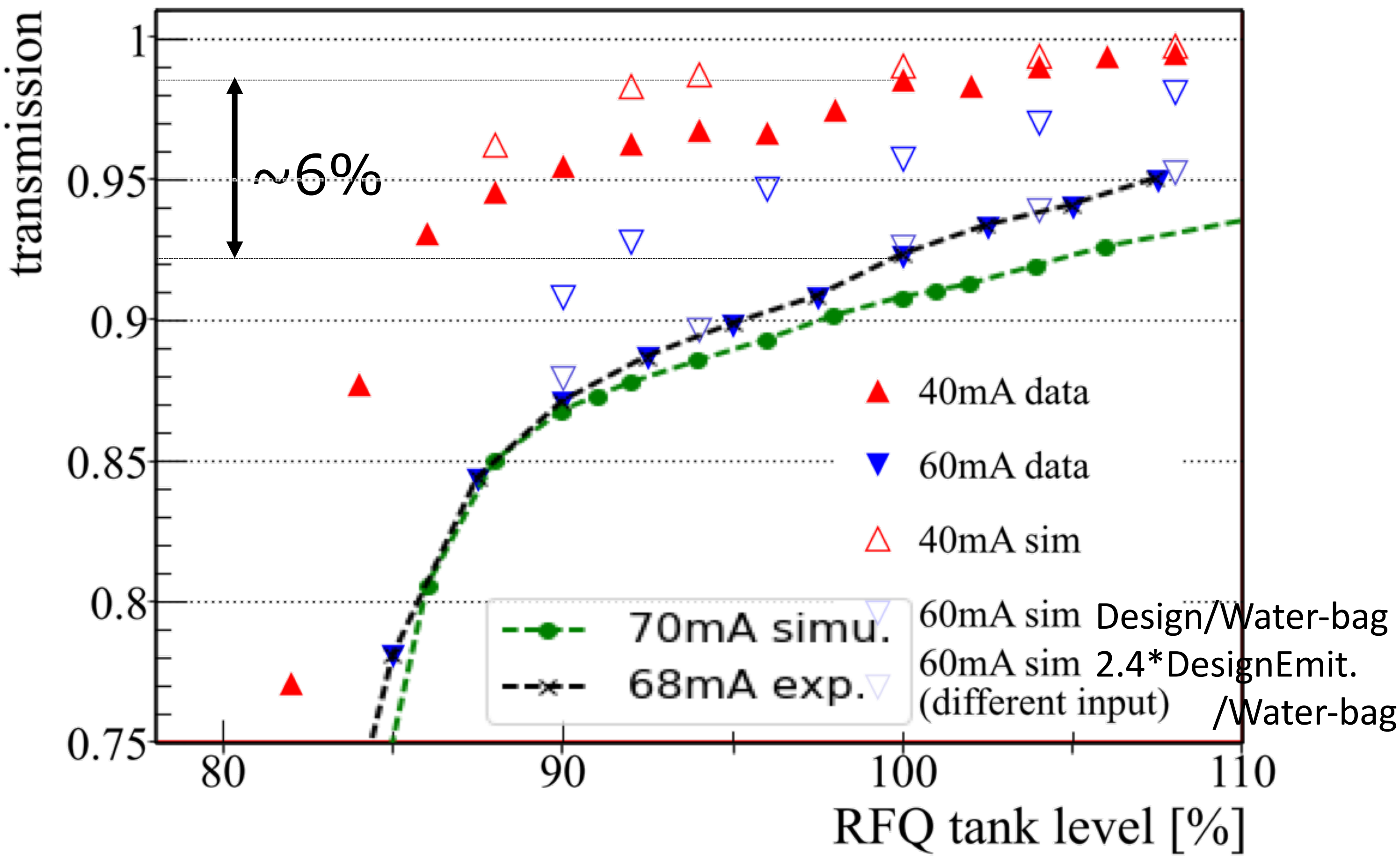
- Realization of 60mA Beam at whole Li

Key point: RFQ/MEBT1 transmission optimization

- Beam property measurement

RFQ transmission

Dr. Otani

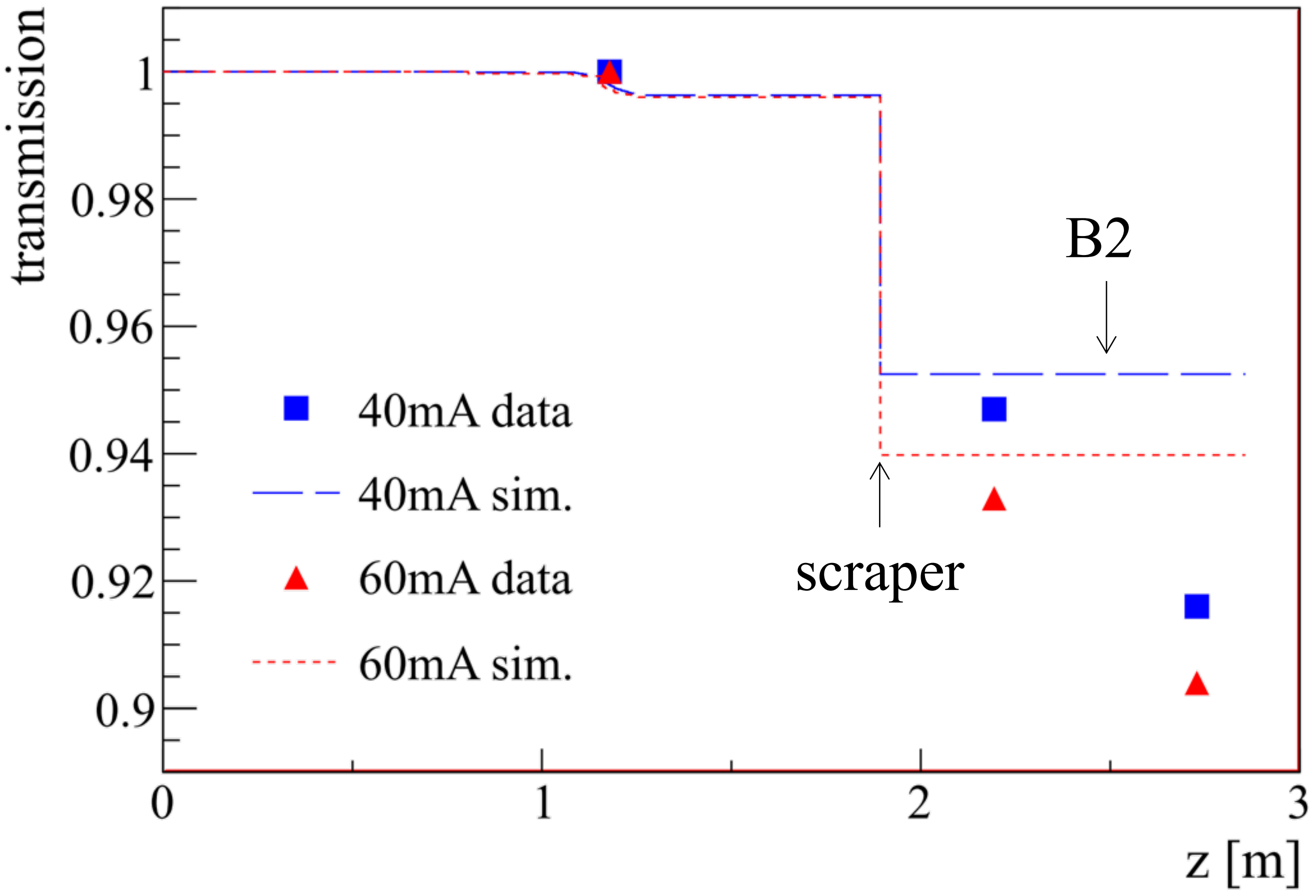


- 40mA and 60mA measured transmission: ~6% difference
- Simulation (with water-bag) is inconsistent for 60 mA

Reason for the different behavior: halo

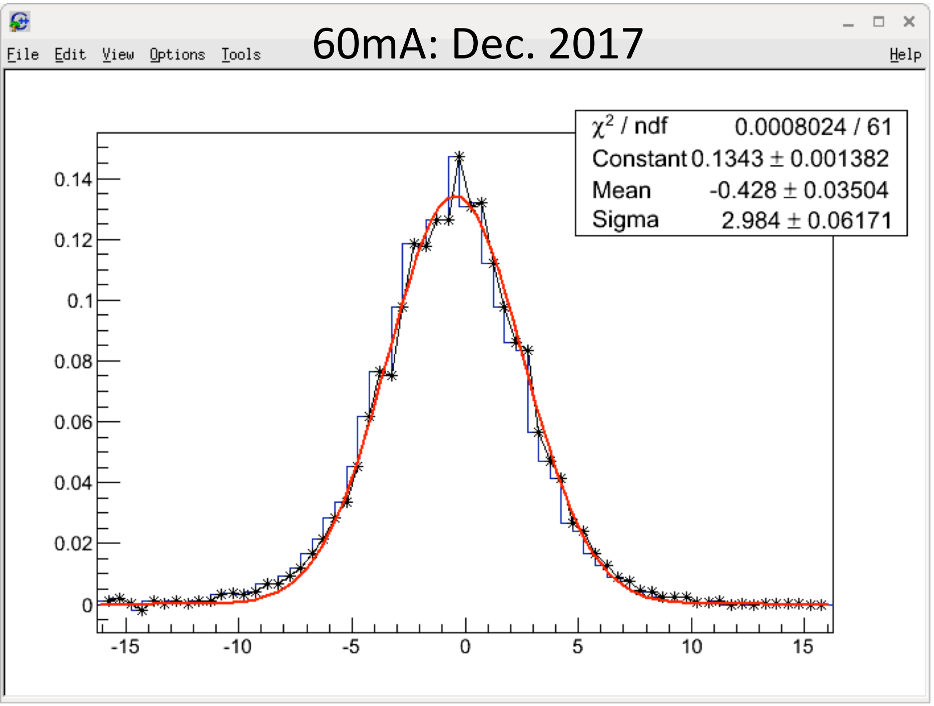
MEBT1 transmission

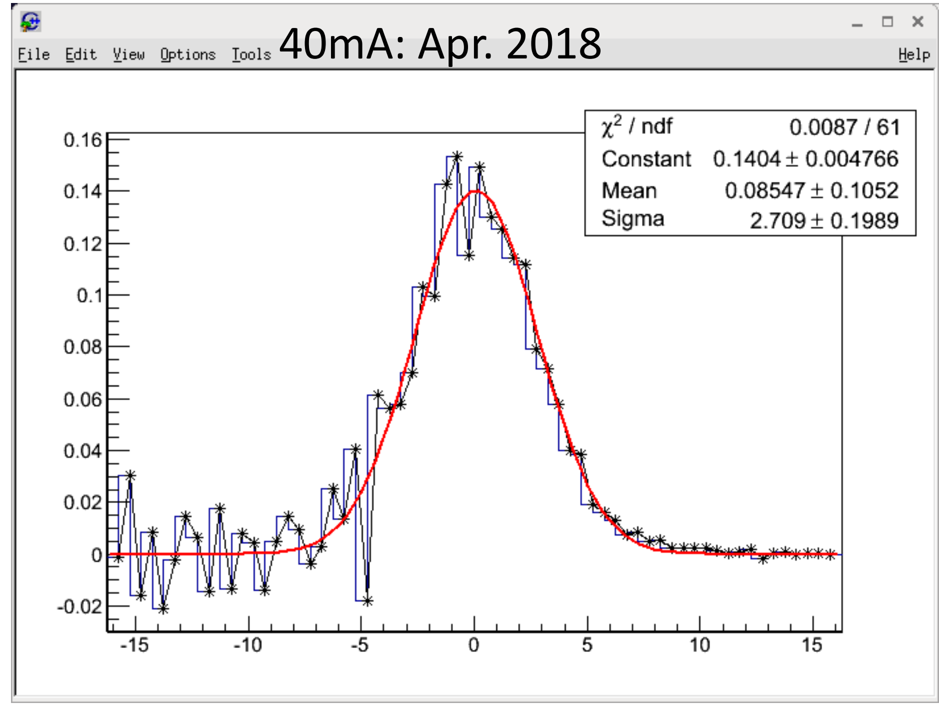
Dr. Otani

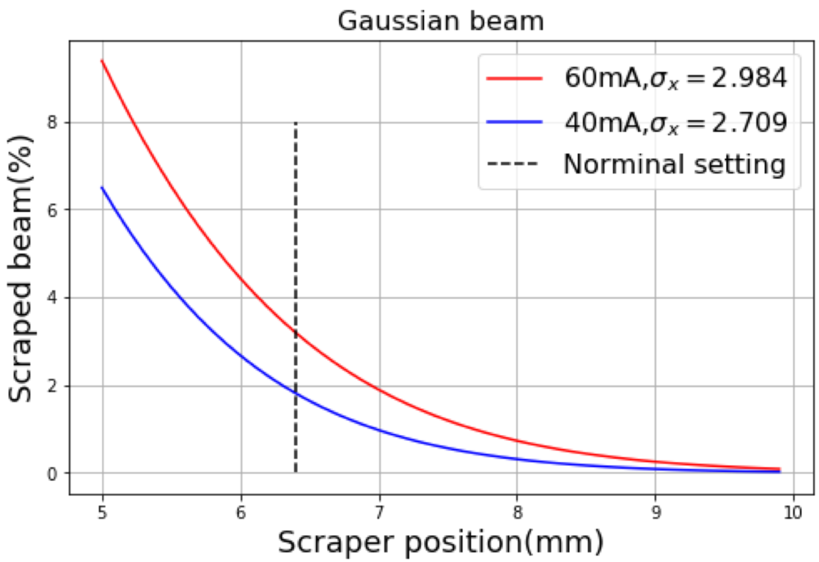


- 40mA and 60mA show similar drop at scraper
- And after buncher2, calibration? orbit?

Measured Horizontal Profile at MEBT1-Scraper







For 40mA operation

This loss also exists

A recognition “Owe to” low total transmission of 60mA

Knobs for Transmission

1 RFQ tank level: abnormal way

transmission vs. emittance

e.g. +2% vs. +5% @tank +6% RFQ stability?

2 MEBT1 lattice optimization

Optimization rx@chopper, rx,y@ bunchers → **+ rx@scraper**

$+\alpha$

3 Increase Scraper aperture

Extinction?

+2% possible

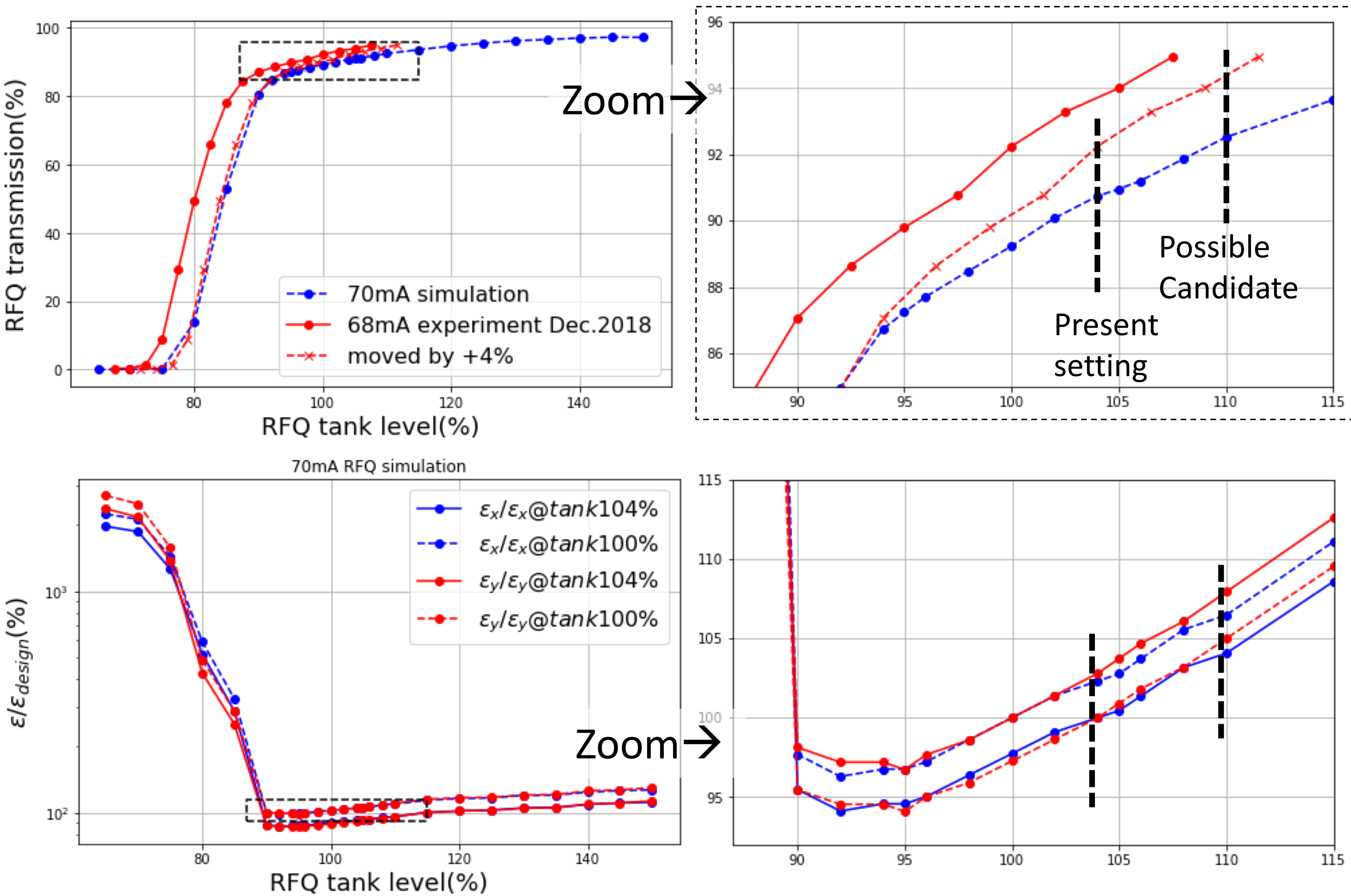
→ Request for IS output current

IS safety? Worse beam quality?

Dec. 2017 (IS)68mA→(Li)57mA (83%)

→ Jul.2018 expectation: (IS)72mA→(Li)62mA (87%)

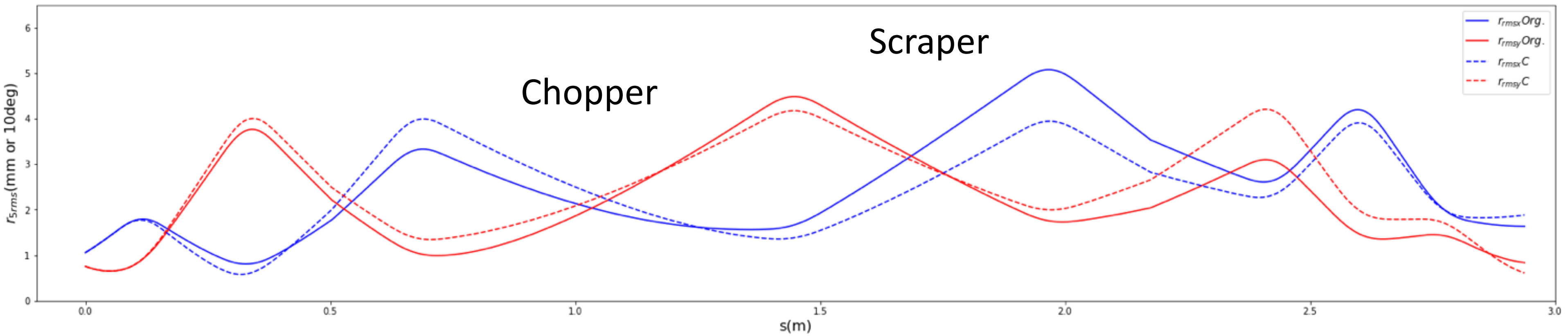
RFQ Simulation vs. Measurement



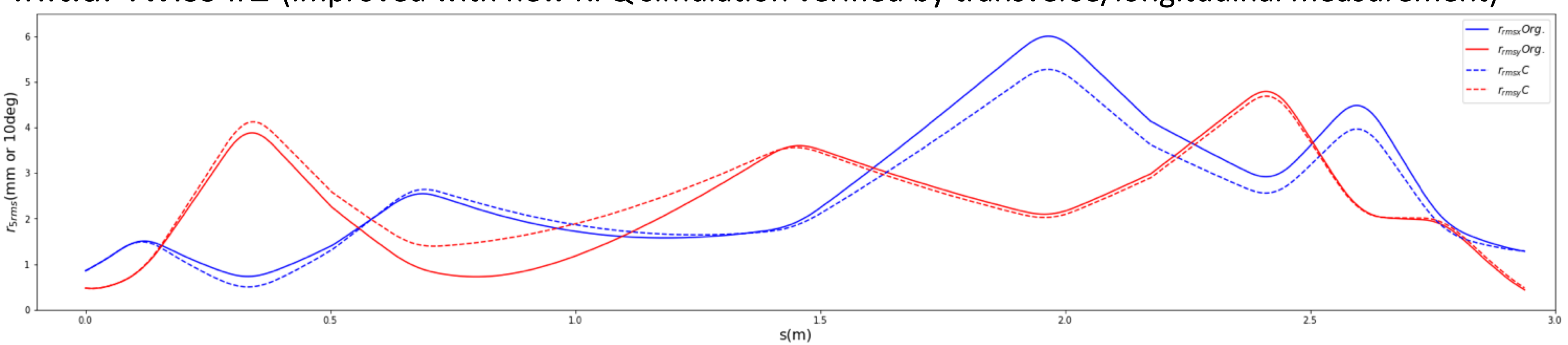
Improvement of Init. Twiss Assumption and Lattice Optimization

Lattice optimization constrain:
@chopper
on scraper (and max. of MEBT1)

Initial Twiss #1 (Org. RFQ simulation + transverse measurement)

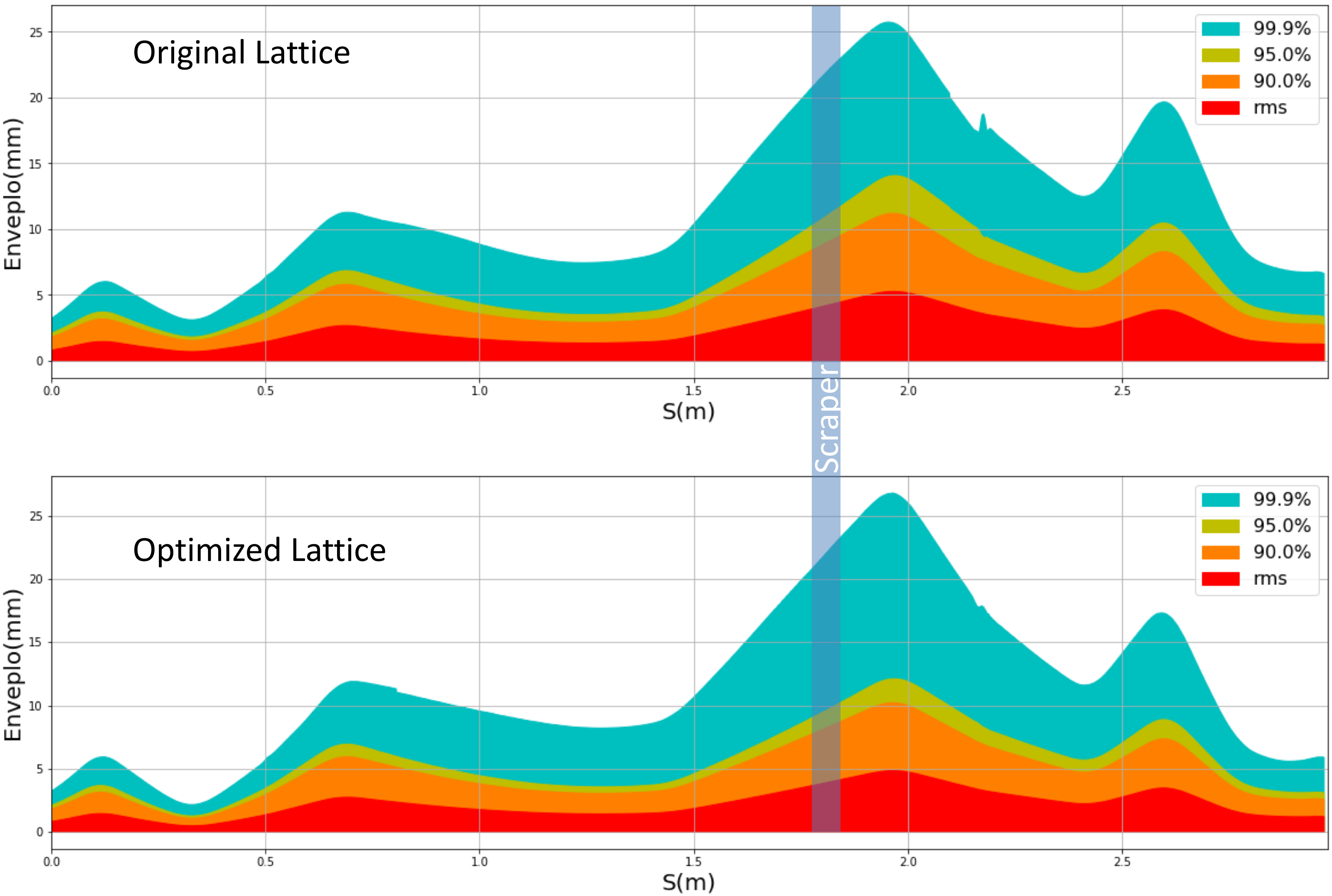


Initial Twiss #2 (improved with new RFQ simulation verified by transverse/longitudinal measurement)



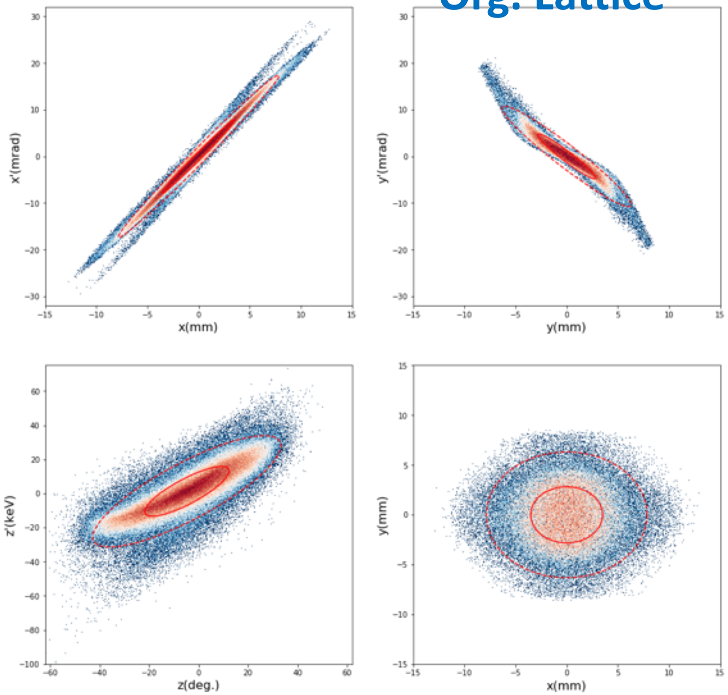
Simulation Comparison for case Initial Twiss #2

with “more Realistic” Init. Distribution (Improved RFQ simu.)

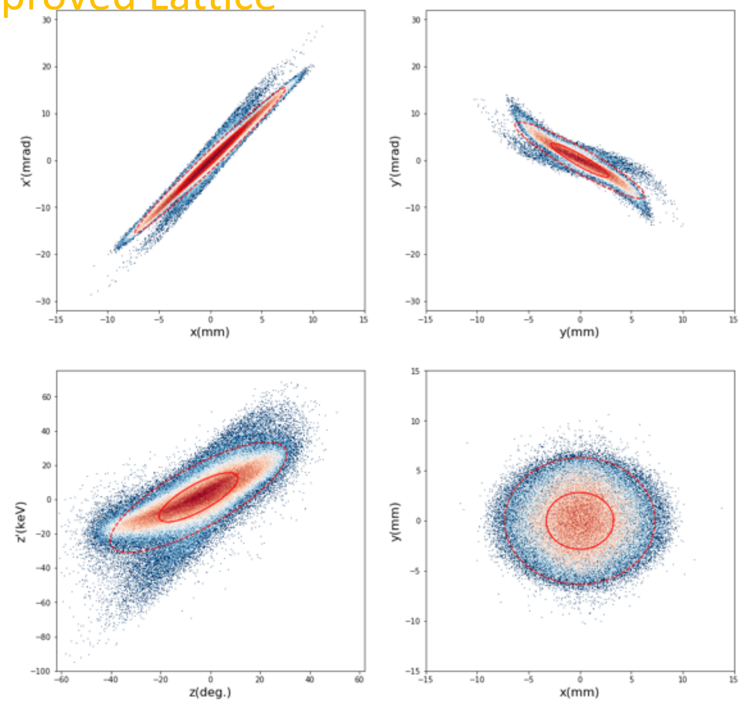


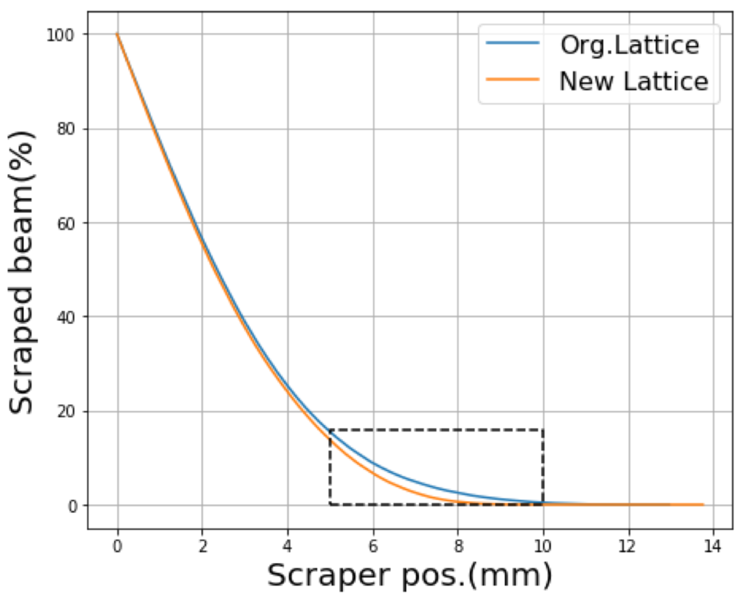
Simulated Distribution & Analysis @Scraper

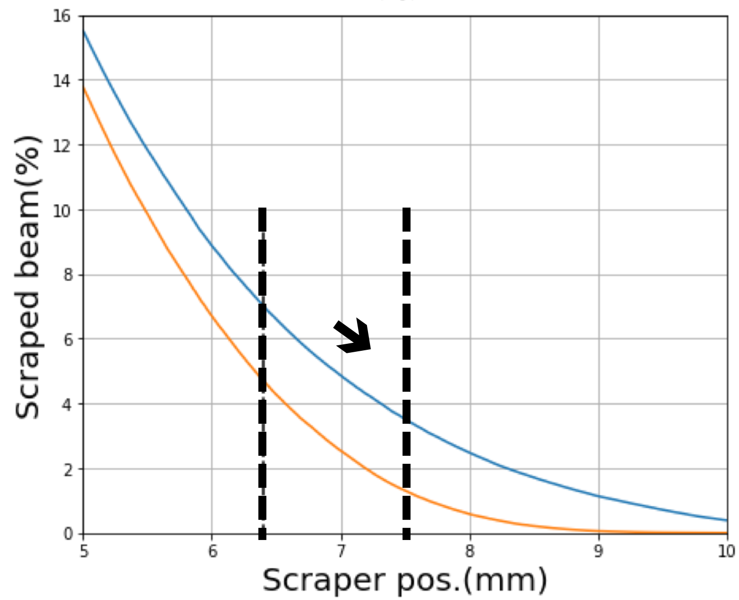
Org. Lattice



Improved Lattice







Conclusion and Outlook

- J-PARC started to prepare for equivalent 1.2 and 1.5MW in near future

Milestones:

first 62mA@MEBT1+measurement on Jul.5 2017;

first 60mA in DTL(no accel.) and 56mA in J-PARC LINAC on Dec. 2017;

3rd Trial of 60mA planned on Jul.3, 2018

- Halo of ~60 mA and its behavior was observed and understood by simulation

  Completely different from 40 mA

  Helpful for ion source development

- For the present ~60 mA beam, countermeasure within accelerator flexibility

  RFQ tank level

  Transmission optimization at MEBT1

- For lattice optimization for ~60mA, similar situation also found for 40mA

  Directly contribution to operation