Commissioning results for the CSNS Linac

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May 16, 2017

On behalf of CSNS physics group

Outline

- Introduction
- Chopping experiments(LEBT)
- RF tuning (Buncher cavities, DTL tank1-3)
- Transverse matching
- Orbit correction
- Summary

Introduction: the CSNS Project

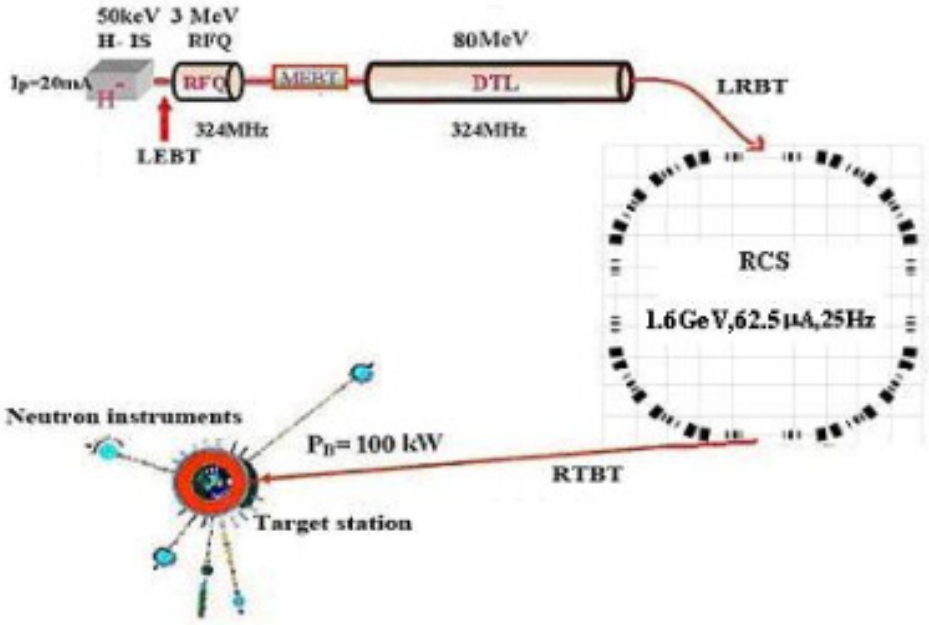
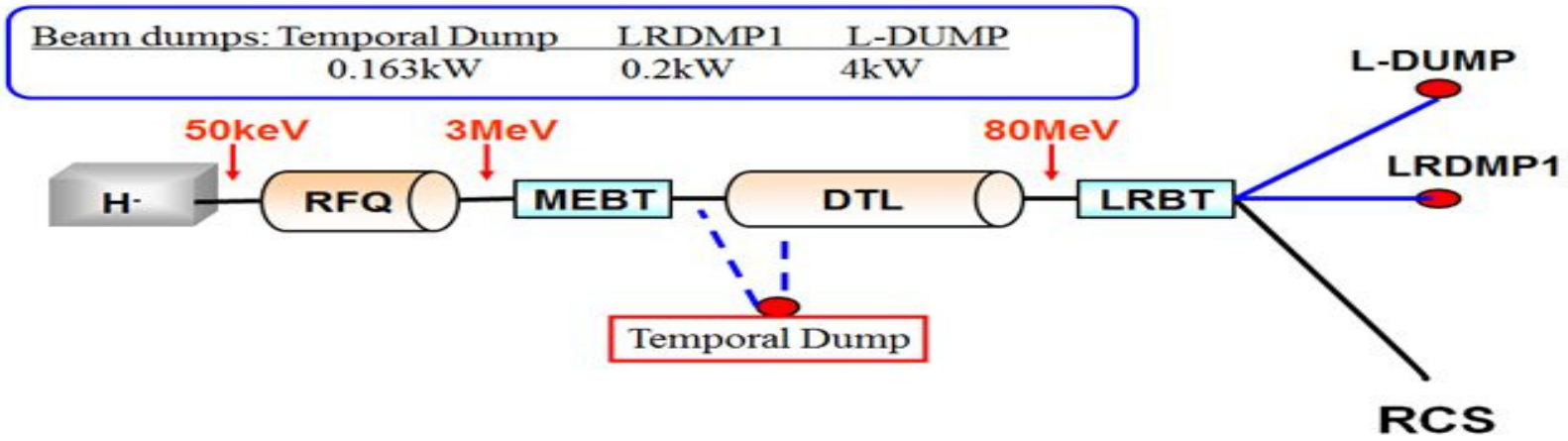


Figure 1.2-1 Layout of CSNS accelerators

Parameters:

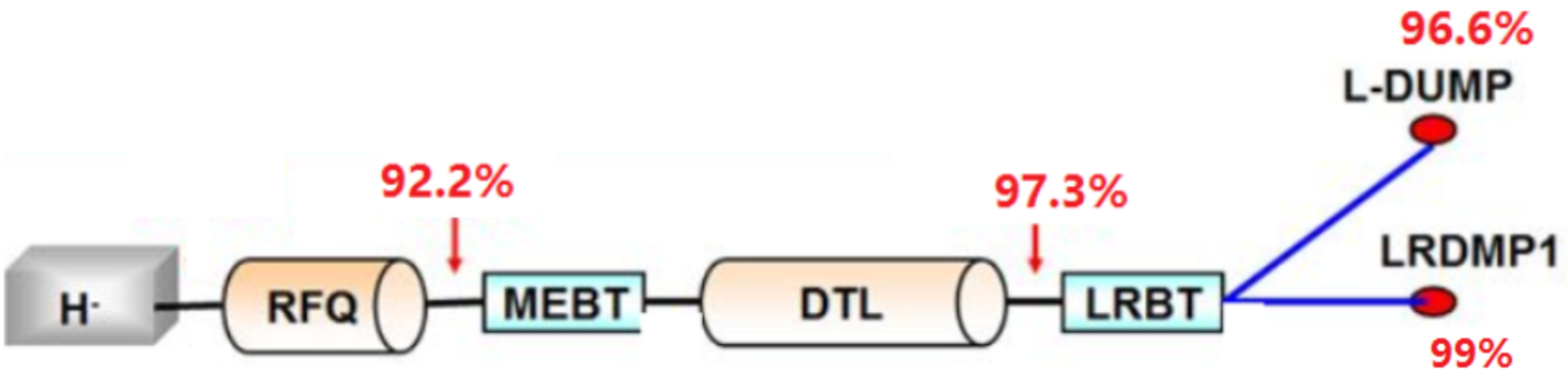
Project phase	I	II
Beam ave.power,kW	100	500
Proton energy, GeV	1.6	
Linac energy, MeV	80	300
Repitition rate,Hz	25	
Macro duty factor,%	1.1	1.7
Macro ave.I,mA	15	40

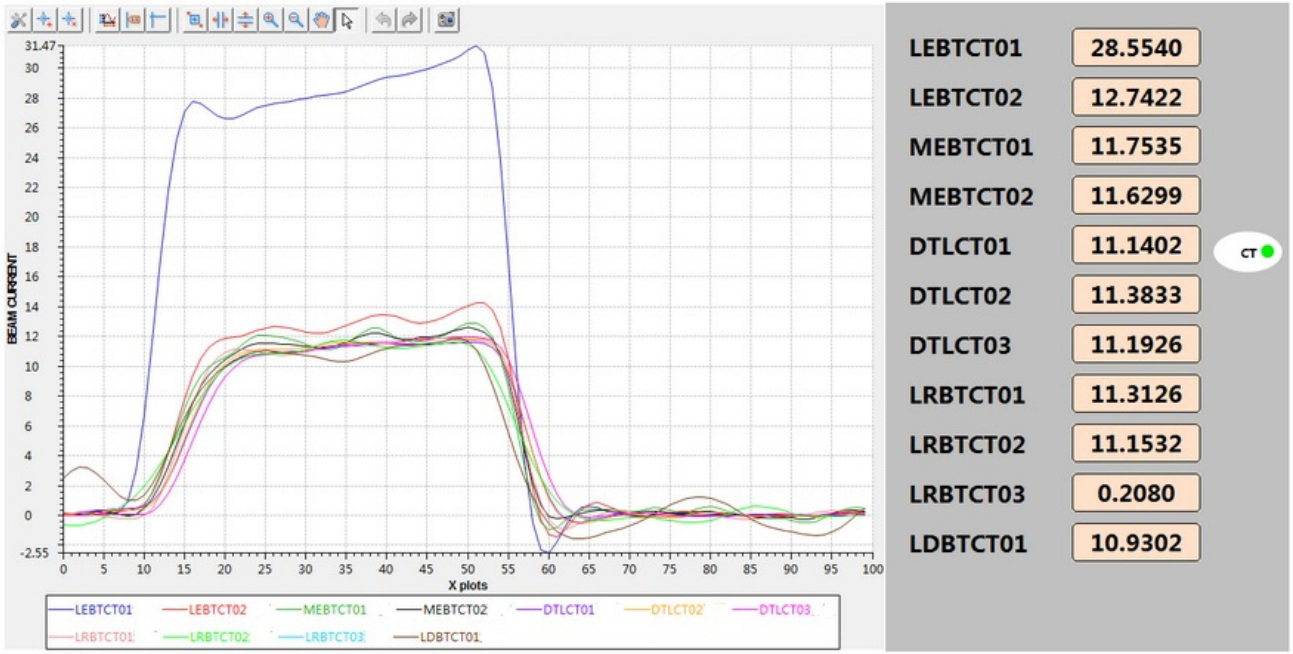
CSNS Linac



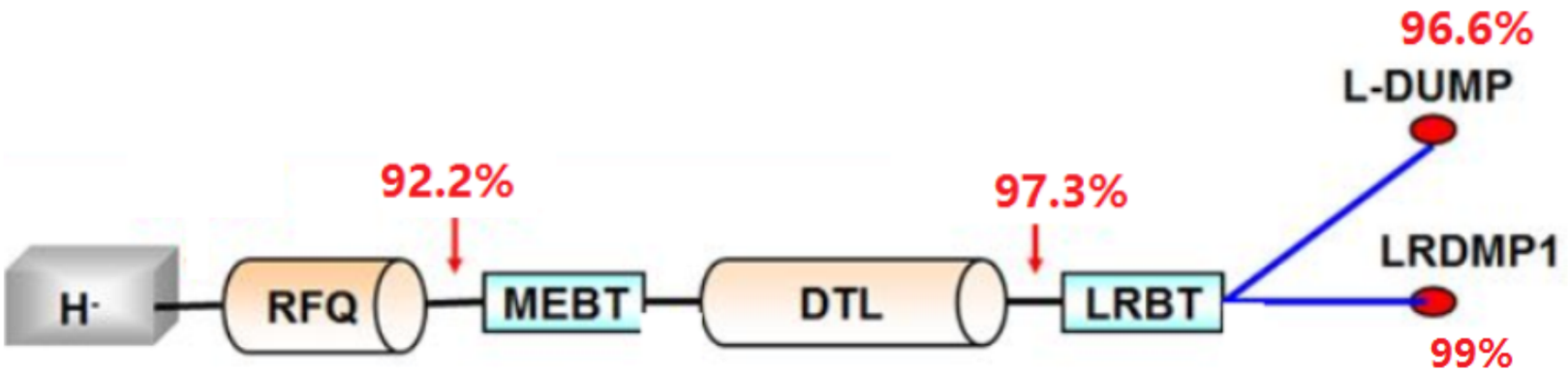
- **Run #1**
  Front end, full power
  (500μs,25Hz, chopped)
- **Run #2**
  DTL tank1, reduced beam power
  (200μs,5Hz, chopped)
- **Run #3**
  DTL tank1,full power
  (500μs,25Hz, chopped)
- **Run #4**
  DTL tank1-3, reduced beam power
  (100μs,1Hz, unchopped)

Beam transmission



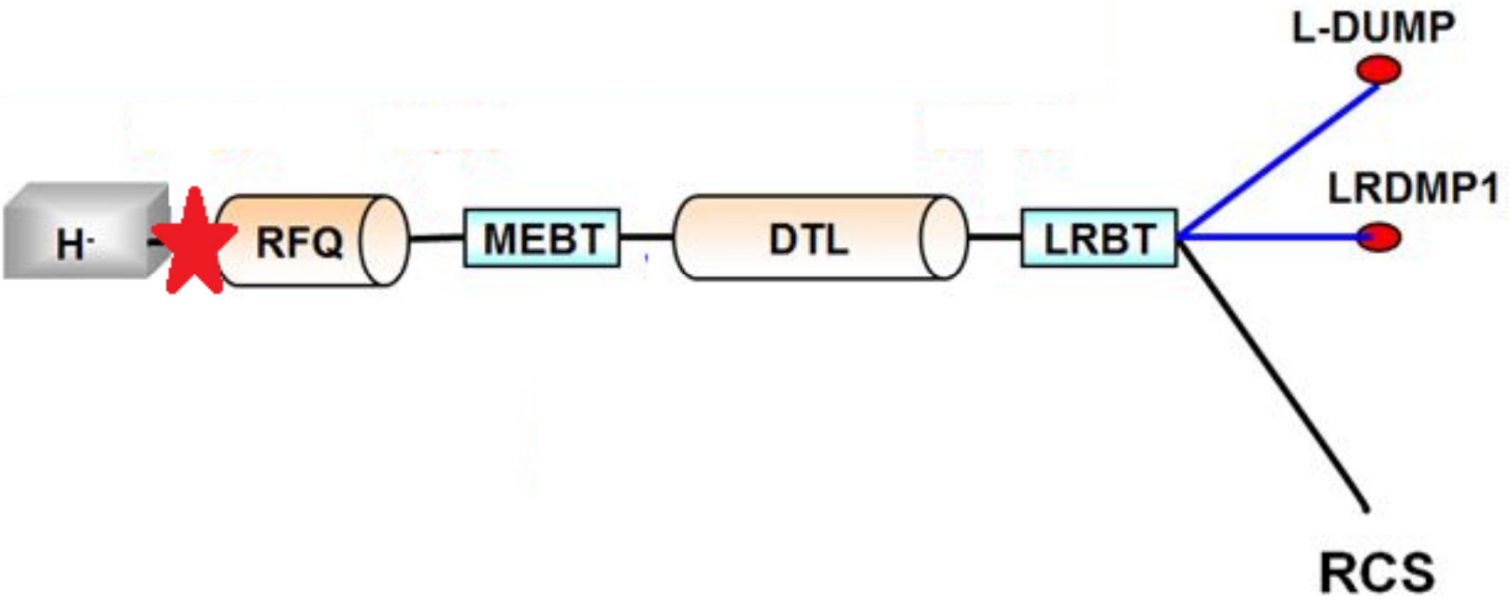


Beam transmission



	April 24	May 10
RFQ	92.2%	94%
DTL	97%	99%
LRBT	99%	100%
LDBT	97%	100%

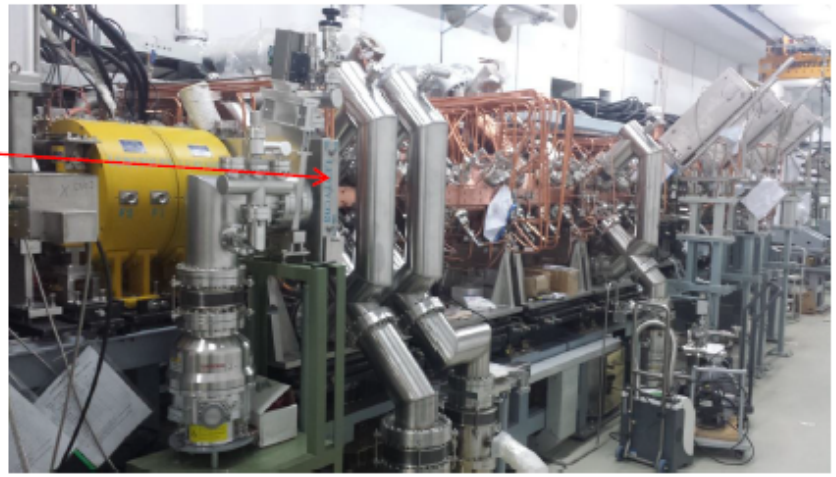
Chopping experiments

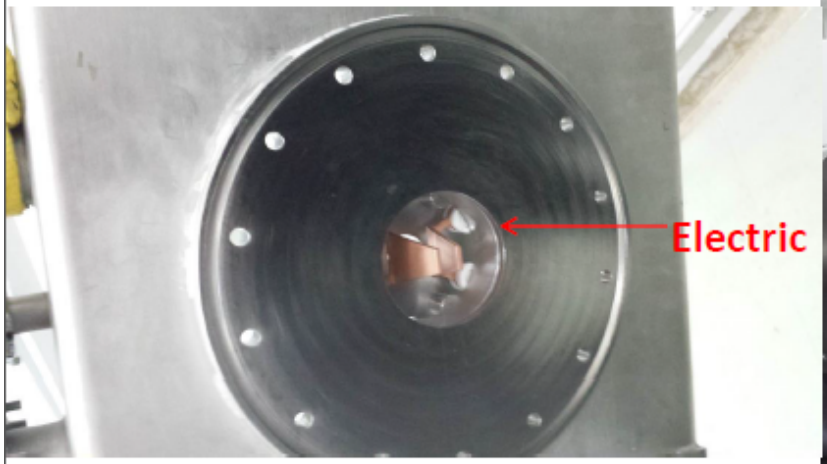


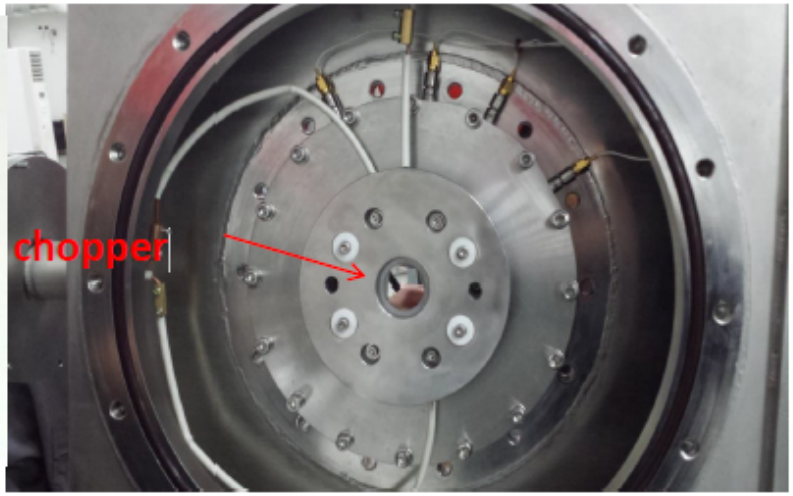
Chopping experiments

--from H.F. Ouyang, FE group, CSNS

A electric chopper located in the third chamber of LEBT just before the entrance of RFQ to chop beam to the required structure for RCS

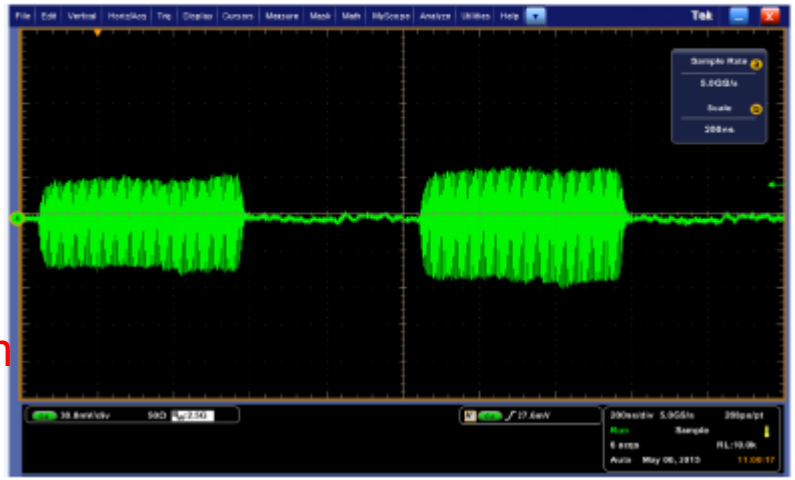






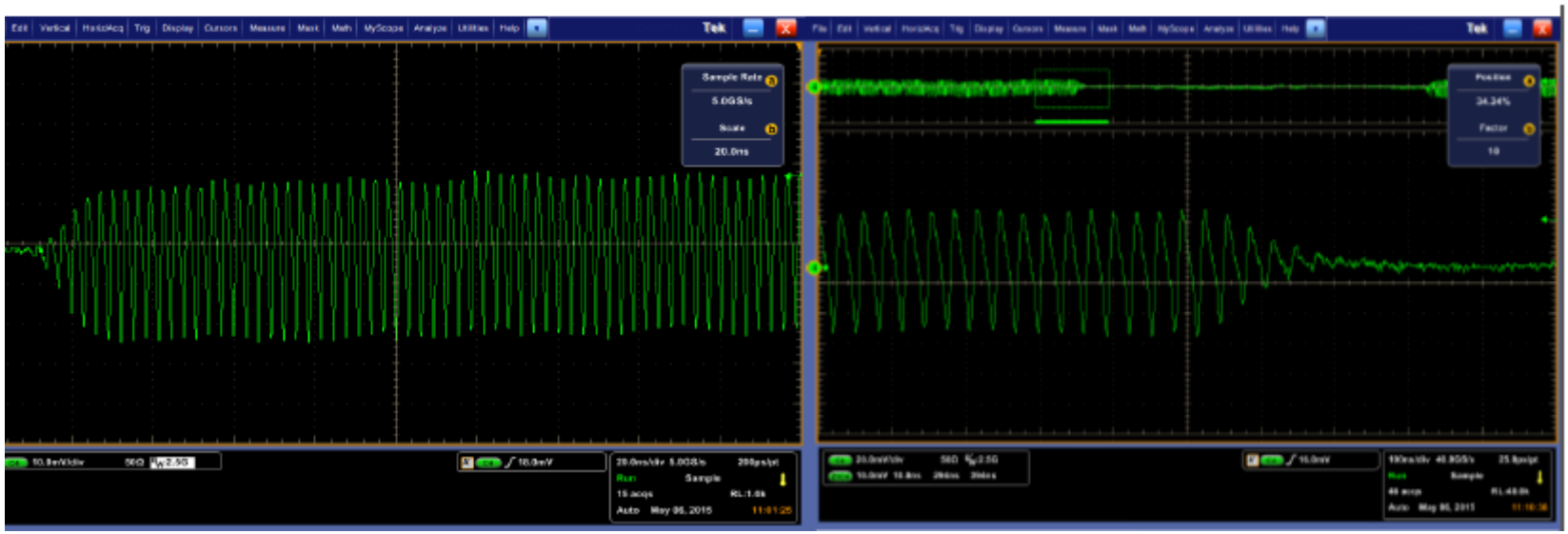
Chopping experiments

Beam structure: 100us, 1Hz (37mA)
Chopping structure: 500ns, 1MHz
Applied chopping voltage: 3.8kV
Theoretical chopping voltage: 3.7kV



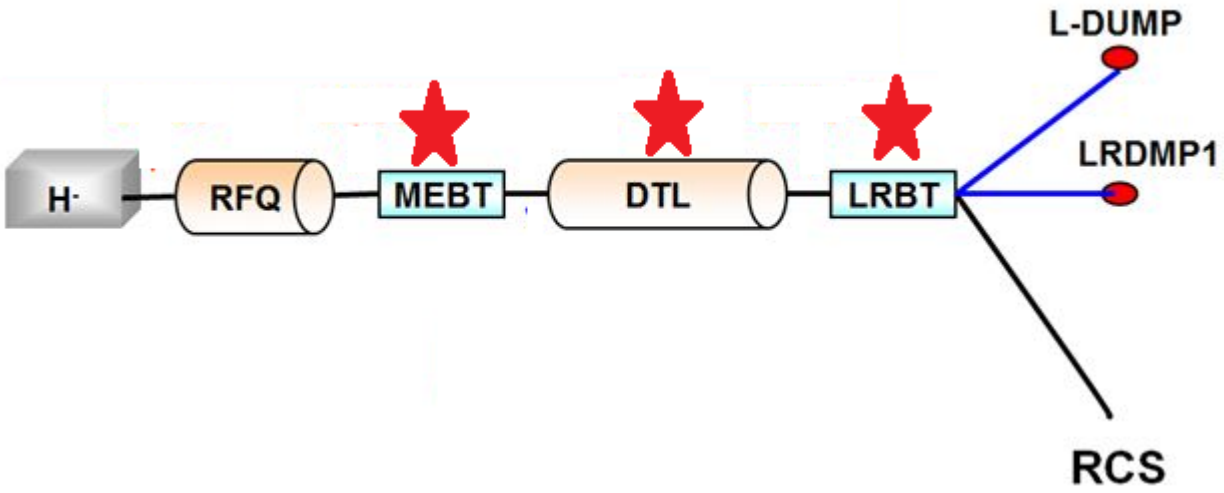
1MHz, 500ns signal after chopping

Both the rise/fall time for the chopped beam is about 4-5 periods of the working RF (1 period T=3.086ns)

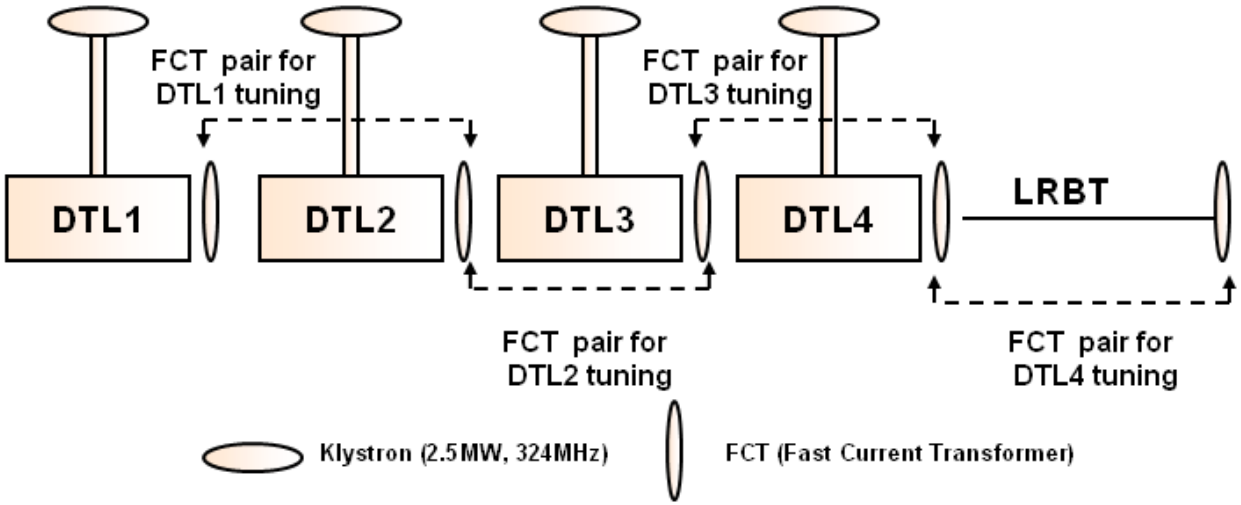


Measured effect of chopper on the beam

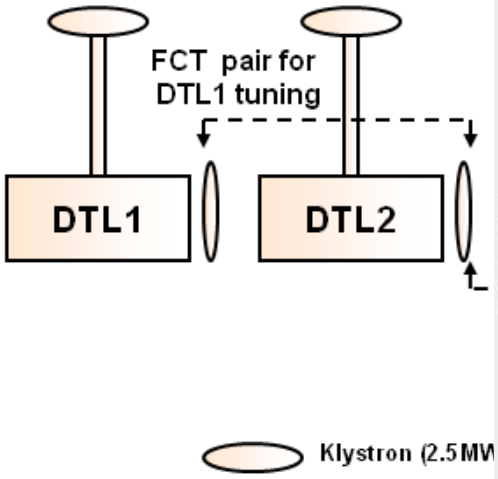
RF Tuning

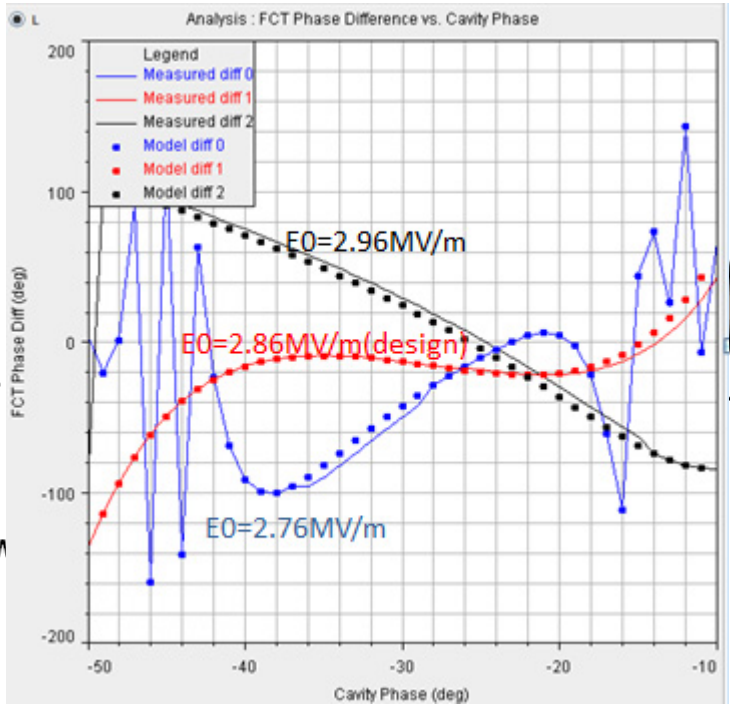


Phase Scan Signature Matching Technique



Phase Scan Signature Matching Technique

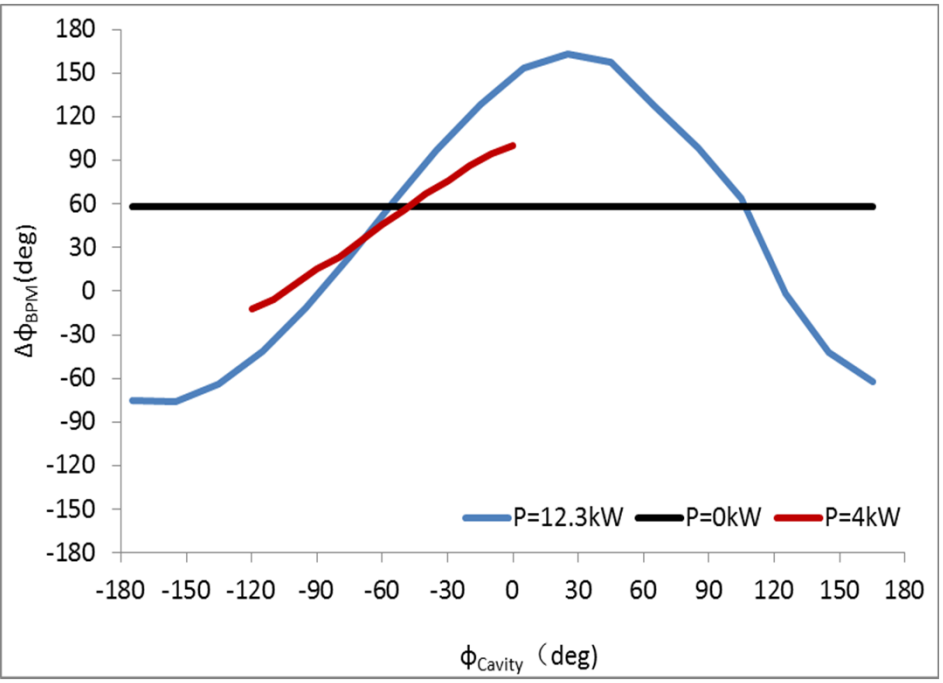


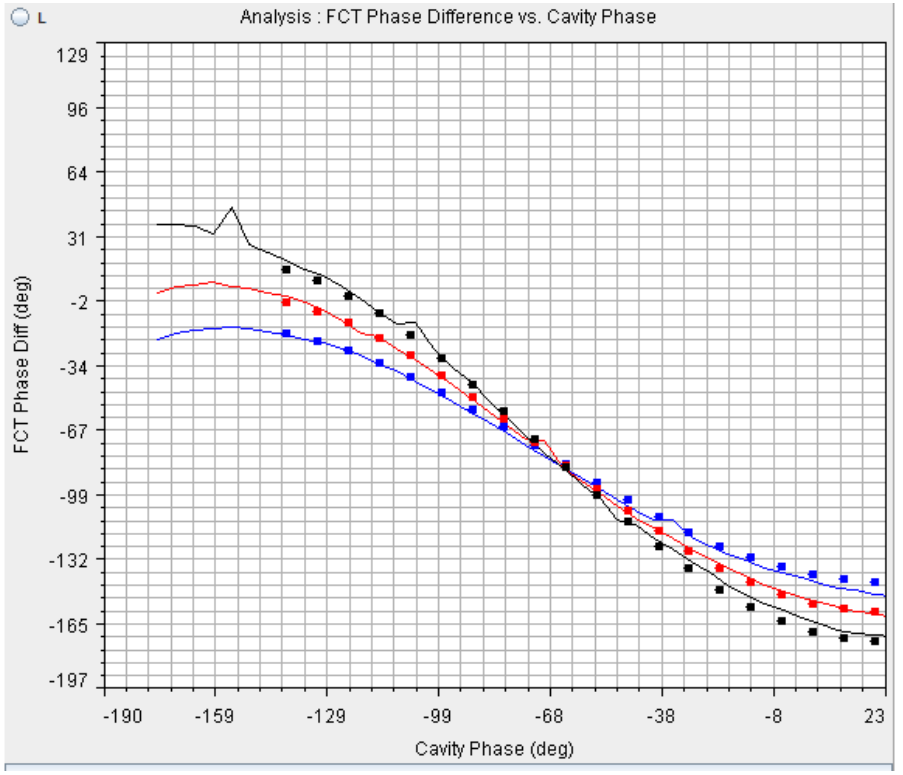


Model:
Input energy
RF amplitude
Cavity phase offset

Buncher01

XAL, Pasta (an RF phase scan and tuning application





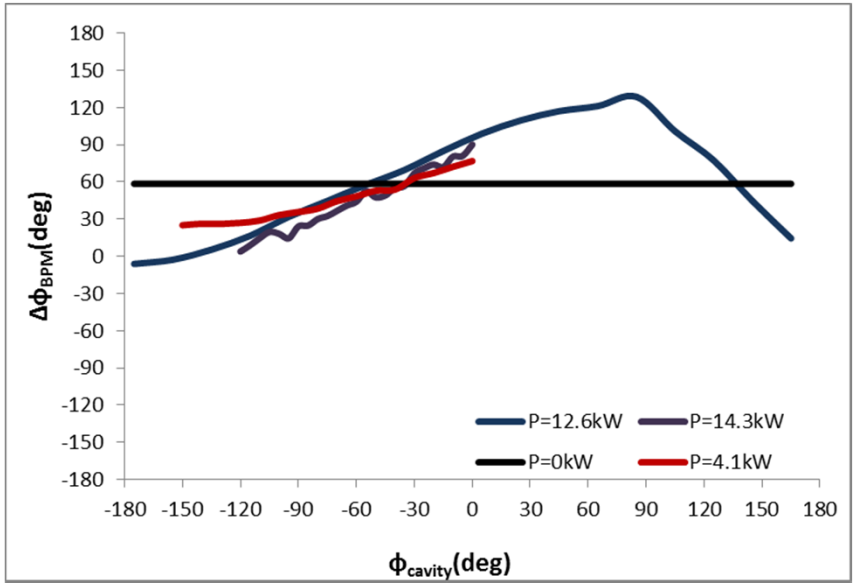
Measured phase differences with two BPMs

Φ_{cavity}=-55°

Measured phase differences with two F

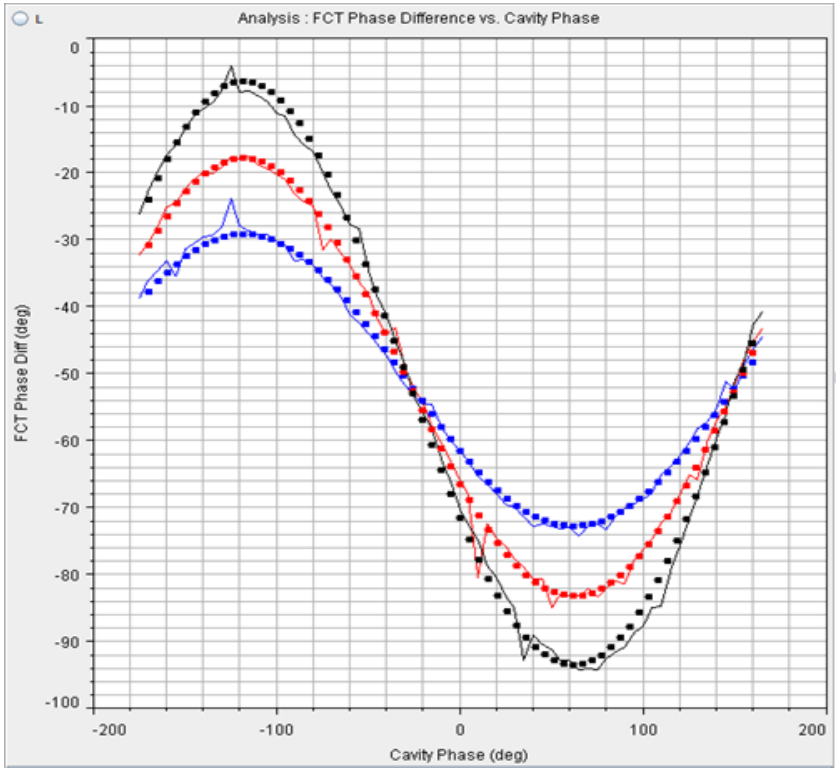
Φ_{cavity} =-60.097°

Buncher02



With two BPMs

Φ_{cavity}=-30°



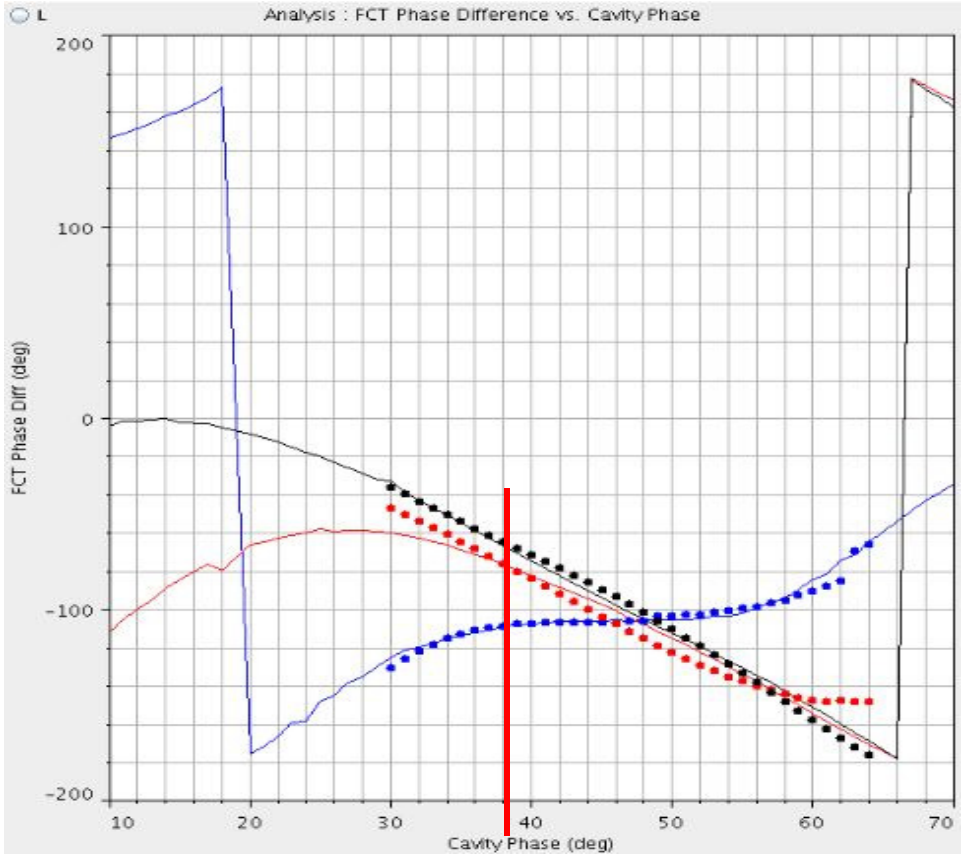
With two FCTs

Φ_{cavity} =-27.857°

DTL 1-3　RF set points

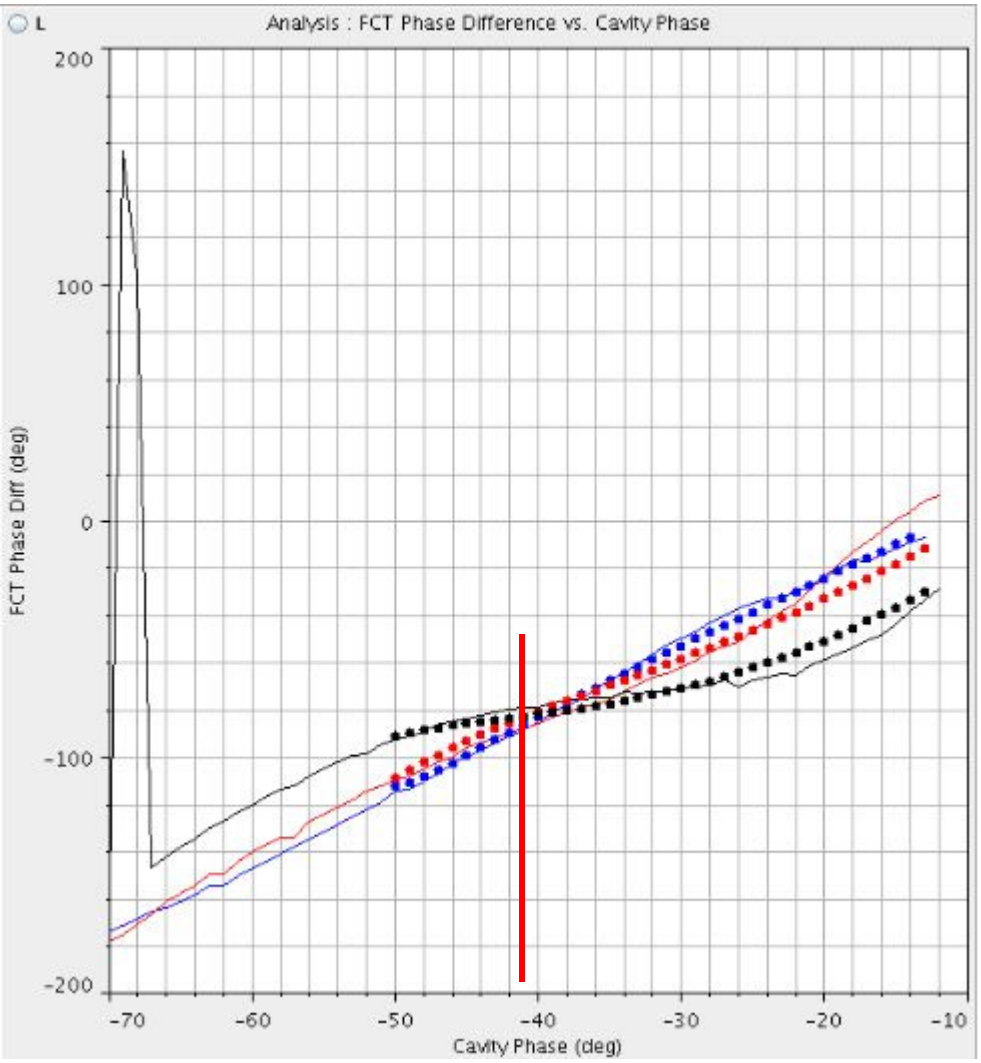
Setting DTL RF amplitude and phase

XAL, Pasta (an RF phase scan and tuning application)



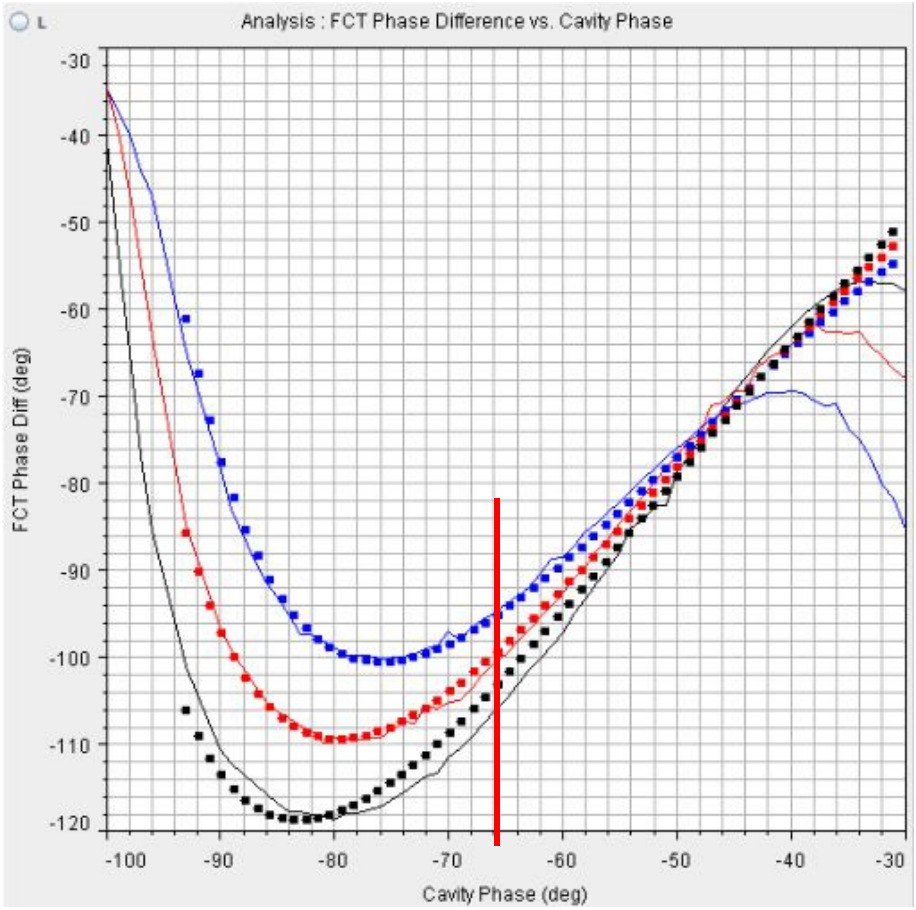
	DTL1	Design
Φ_{cavity}（degree）	41	-35
Amp	6333	2.86MV/m
W_{RFQ}(MeV)	3.029	3.0258
W_{DTL1}(MeV)	21.802	21.67

Signature matching



	DTL2	Design
Φ_{cavity}（degree）	**-40**	-25
Amp	5020	2.96MV/m
W_{RFQ}(MeV)	21.802	21.669
W_{DTL1}(MeV)	41.52	41.415

Signature matching



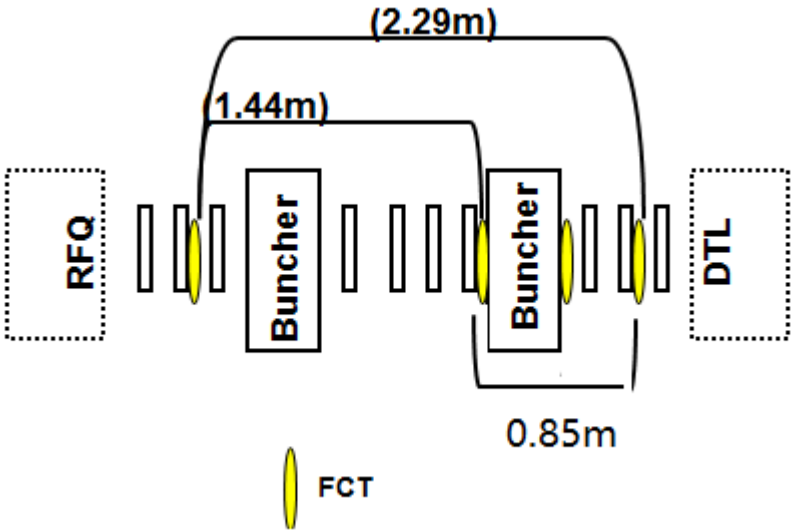
Signature matching

	DTL3	Design
Φ_{cavity}（degree）	**-66**	-25
Amp	6033	2.96MV/m
W_{RFQ}(MeV)	41.52	41.415
W_{DTL1}(MeV)	60.917	61.072

Energy measurement (Time of Flight method)

The design energy of beam output from the RFQ is **3.0258**MeV

Monitoring the beam energy with TOF (Time Of Flight) method： 3.02±0.015MeV



Short pair 1: L=1.44m, N=19βλ

Short pair 2: L=0.85m, N=11βλ

Long pair: L=2.29m, N=30βλ

$$W = m_0 c^2 \left(\frac{1}{\sqrt{1 - v^2/c^2}} - 1 \right)$$

$$v = \frac{L}{nT + \Delta t}$$

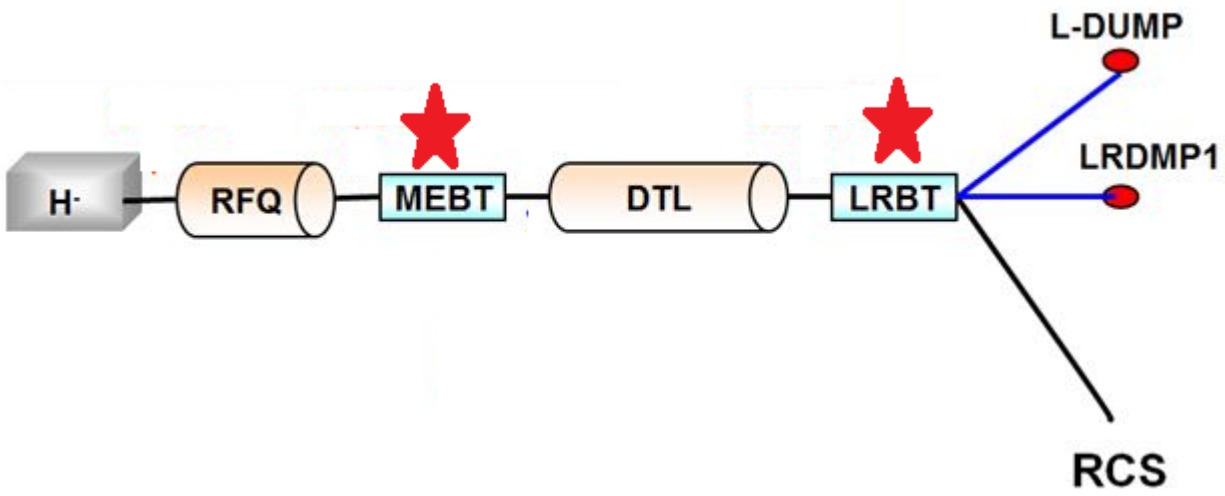
Table 2: Beam energy from two methods

	Design [MeV]	Phase scan [MeV]	TOF [MeV]
RFQ	3.026	3.029	3.027 ±0.01
DTL1	21.669	21.802	21.685±0.01
DTL2	41.415	41.52	41.566±0.14
DTL3	61.072	60.917	61.09±0.34

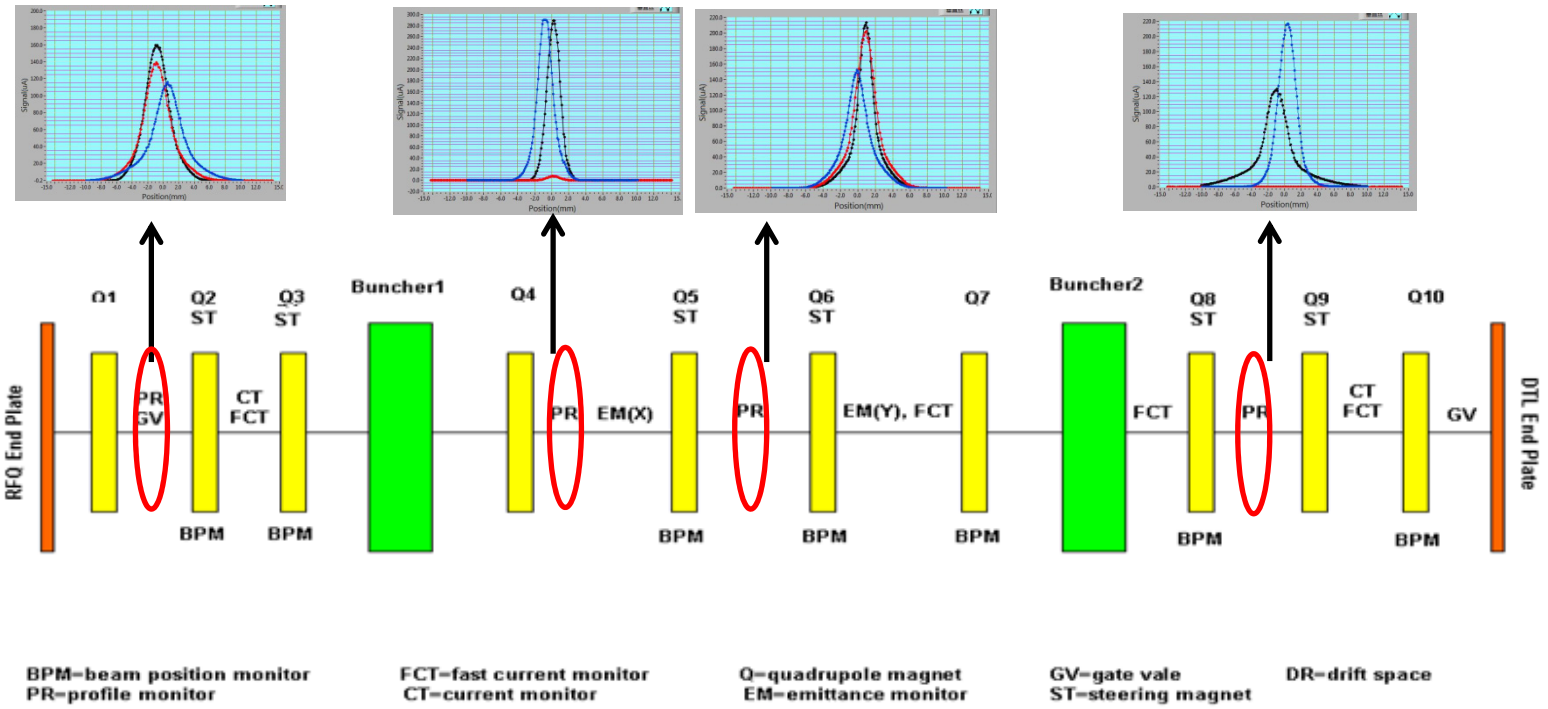
The energy deviation is all< 1%

Transverse Matching

1. MEBT : RFQ->DTL
2. LRBT: DTL-> LRBT triplet section

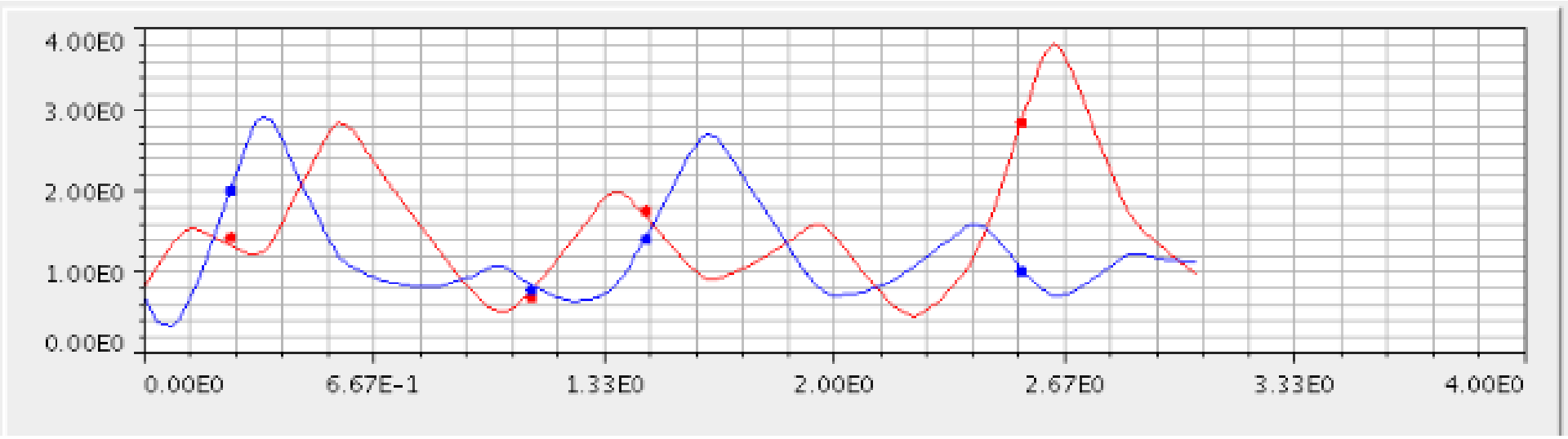


Transverse emittance measurement



4 wire scanners are used

Wireanalysis, XAL

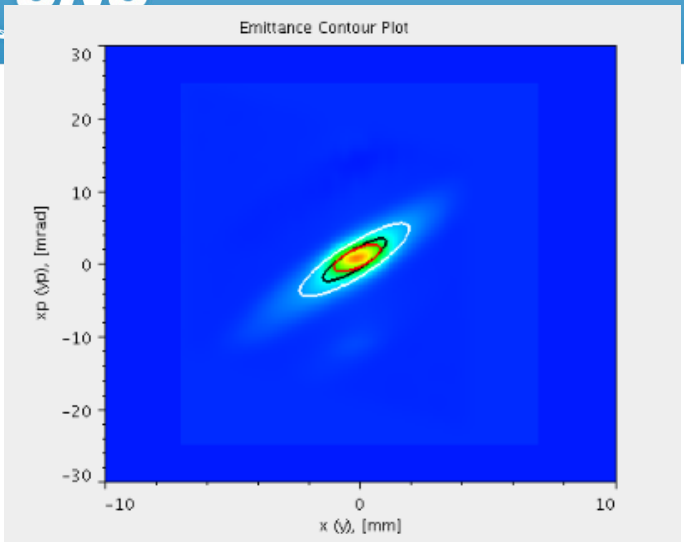


Beam RMS size along the MEBT

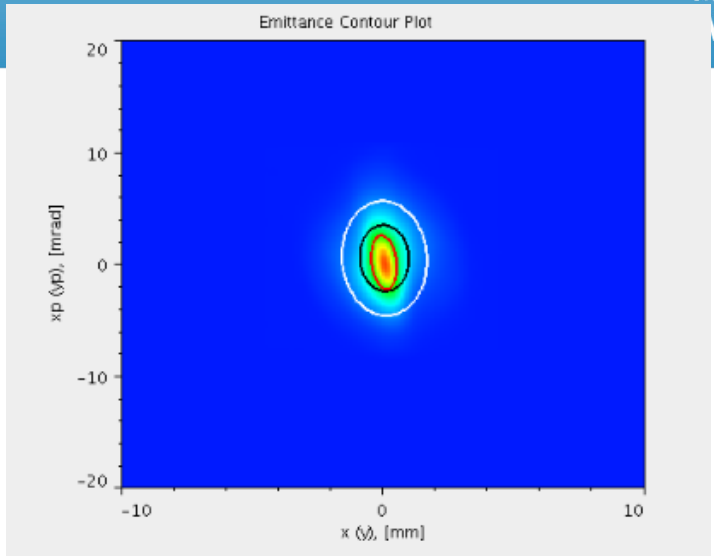
Red line represent X direction
Blue line represent Y direction

Table 1: Twiss Parameters at the MEBT entrance (I=10mA)

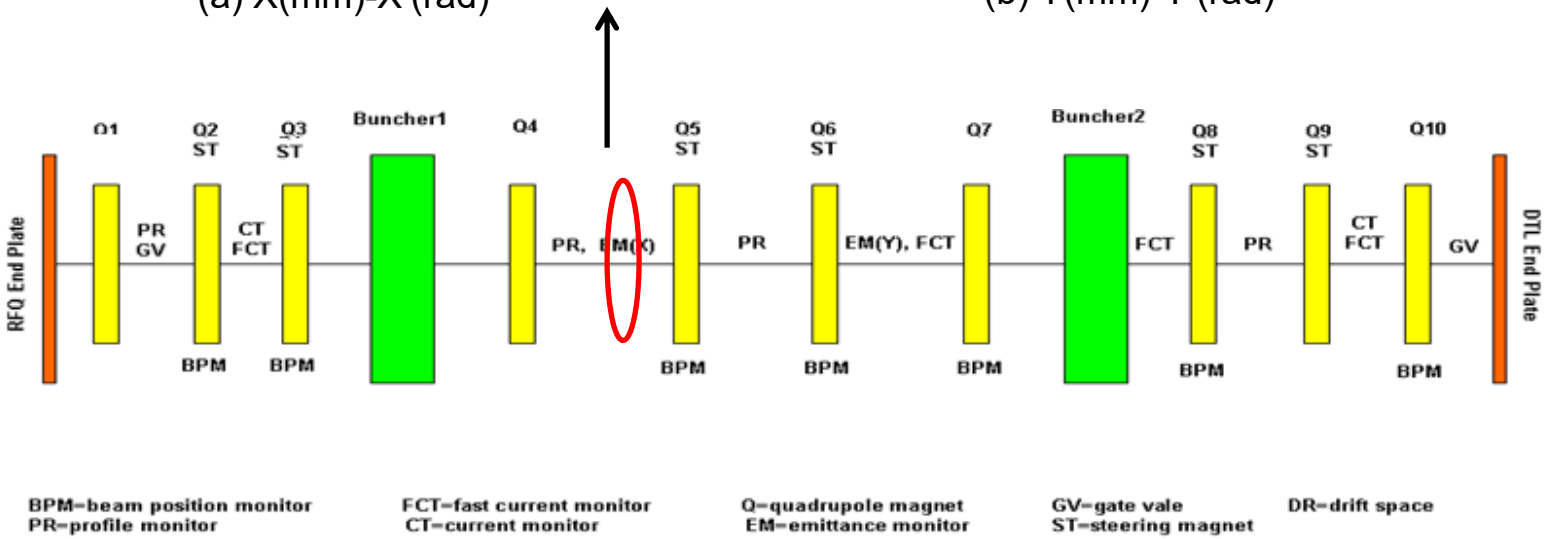
	α	β [mm/mrad]	Emittance rms, normalized [πmm mrad]
Horizontal			
Measured	*-1.716*	0.256	0.215
Simulated	*-1.773*	0.233	0.215
Vertical			
Measured	*1.944*	0.173	0.211
Simulated	*0.639*	0.074	0.212



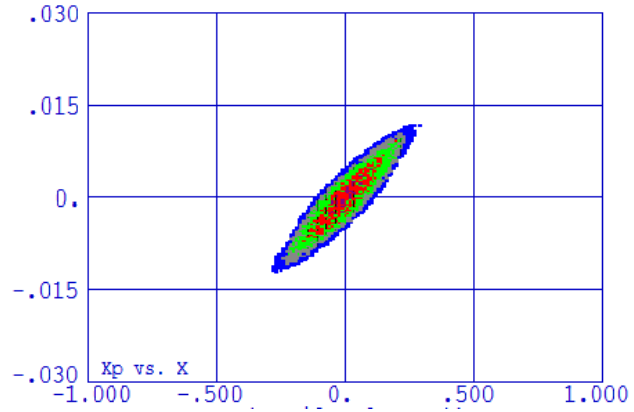
(a) X(mm)-X'(rad)



(b) Y(mm)-Y'(rad)

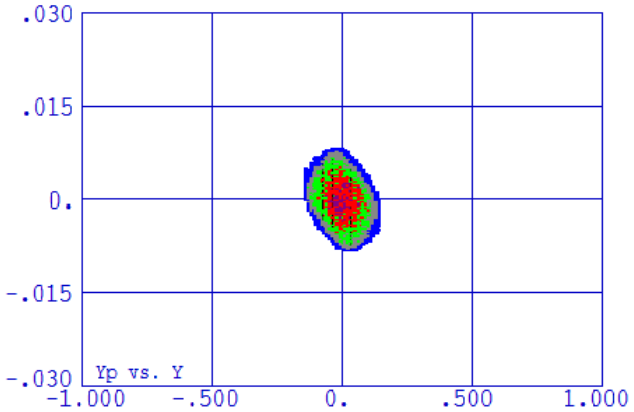


Simulated beam distribution at the EM location



X’（rad）

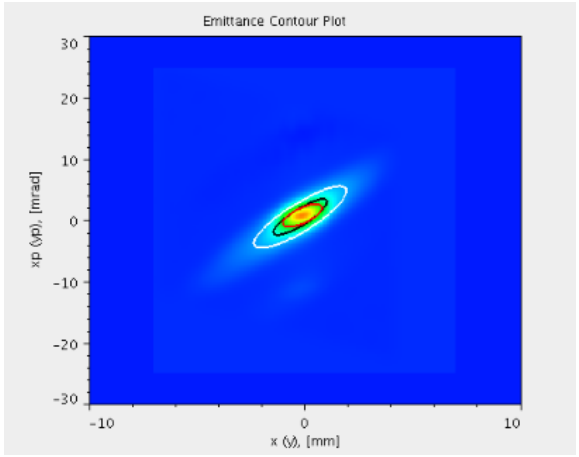
X（cm）



Y’（rad）

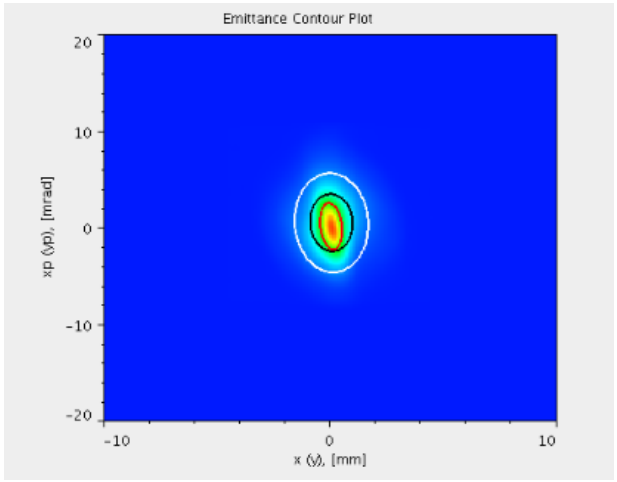
Y（cm）

Measured beam distribution at the EM location



X’（mrad）

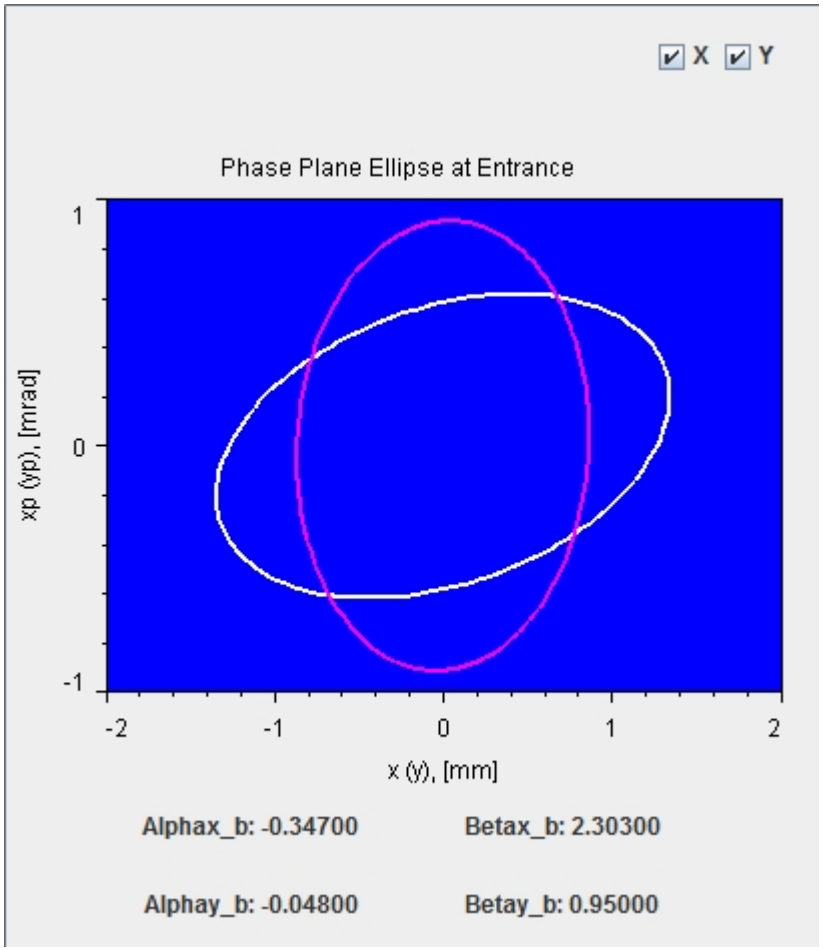
X（mm）

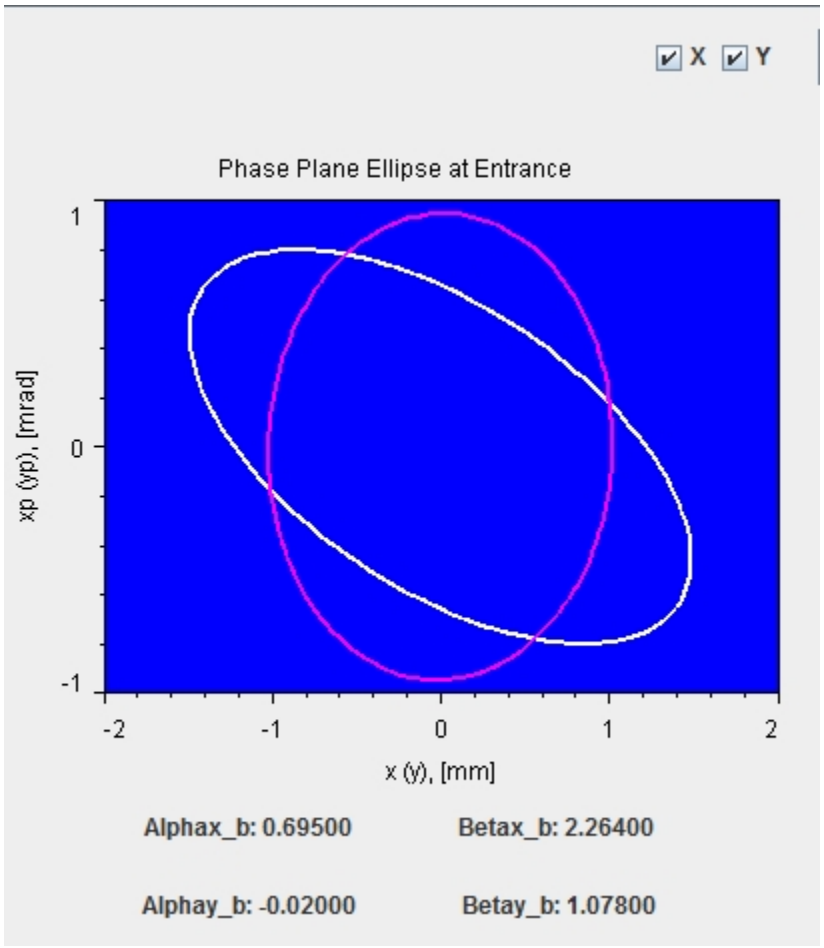


Y’（mrad）

Y（mm）

LRBT matching



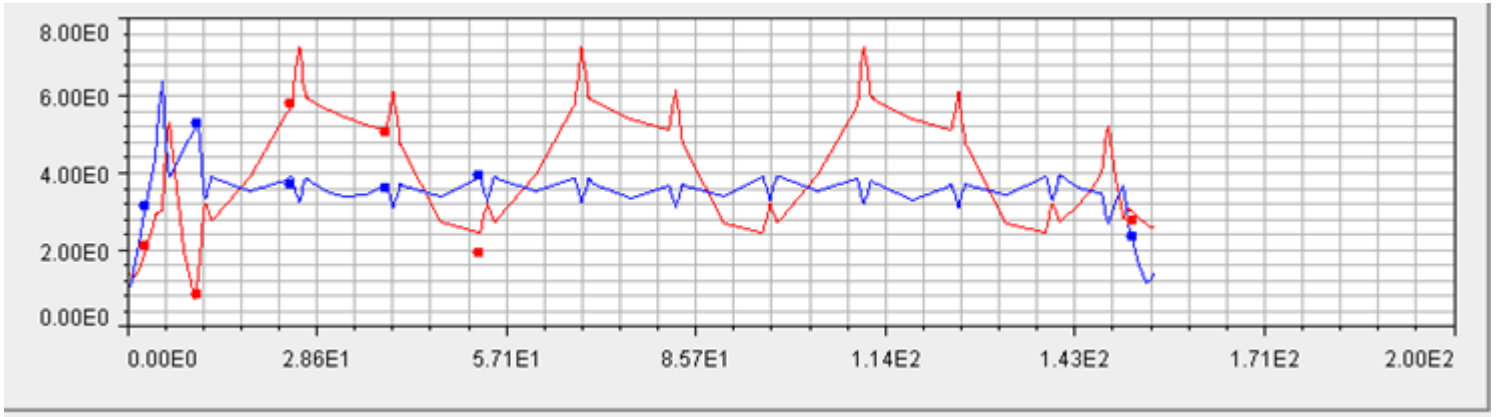


Simulation data (with PARMILA)

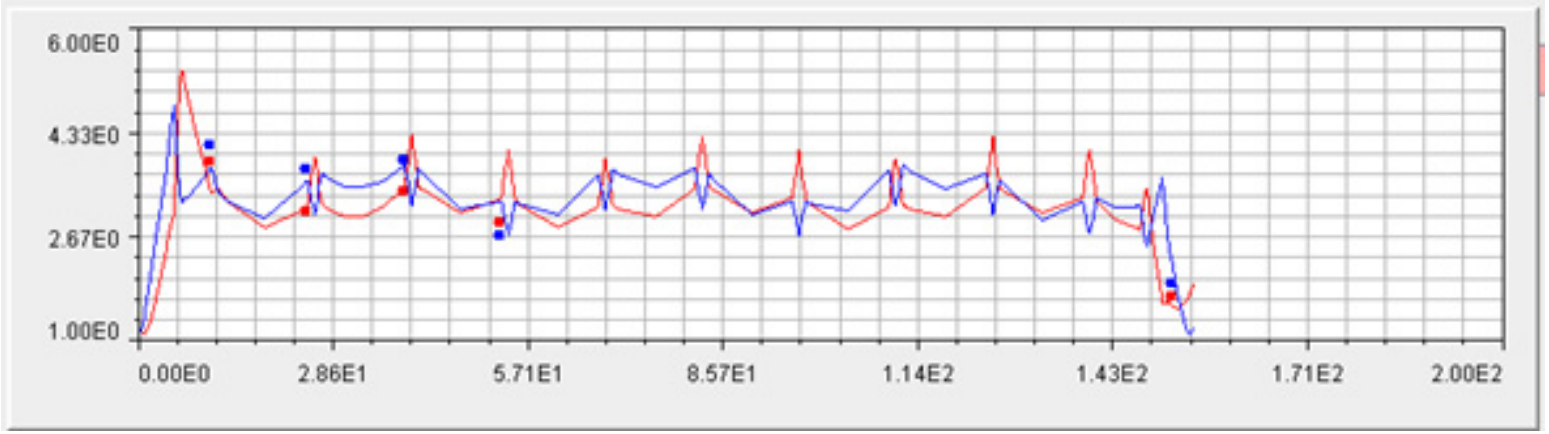
Measurement data(with XAL)

LRBT matching

Before matching



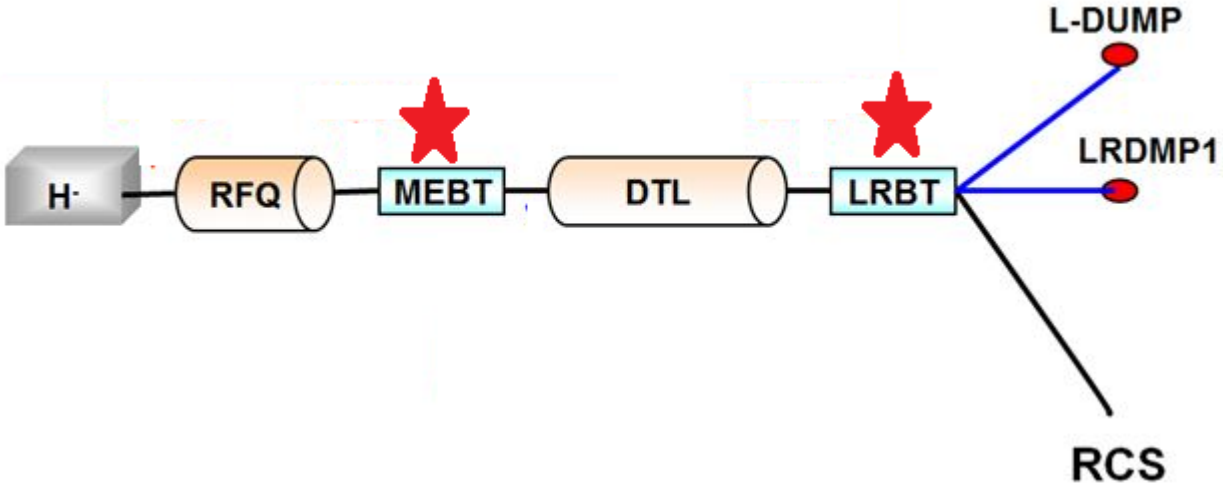
After matching



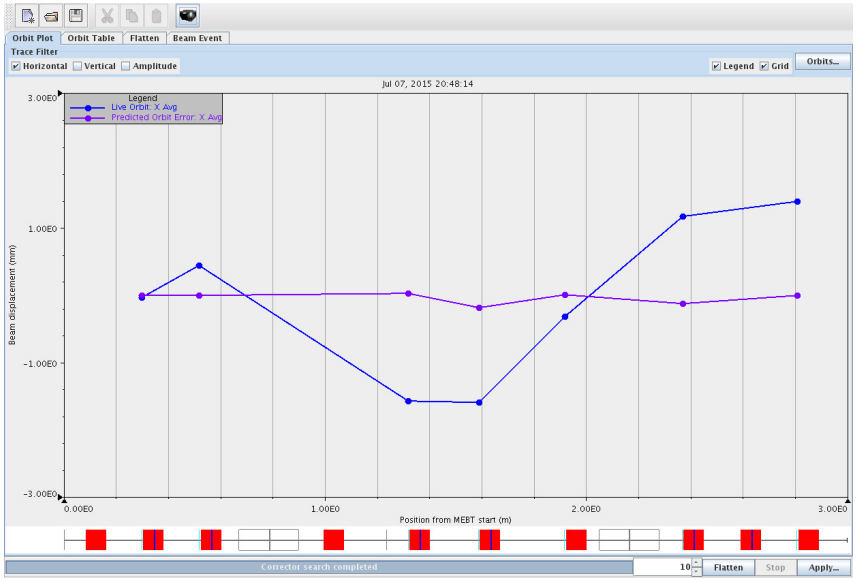
Red line represent X direction
Blue line represent Y direction

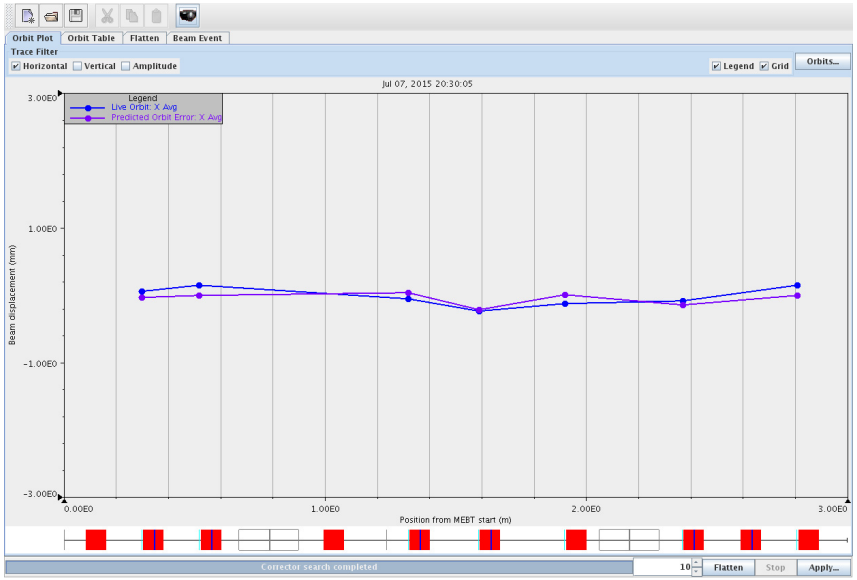
Orbit correction

1. MEBT
2. LRBT



MEBT orbit

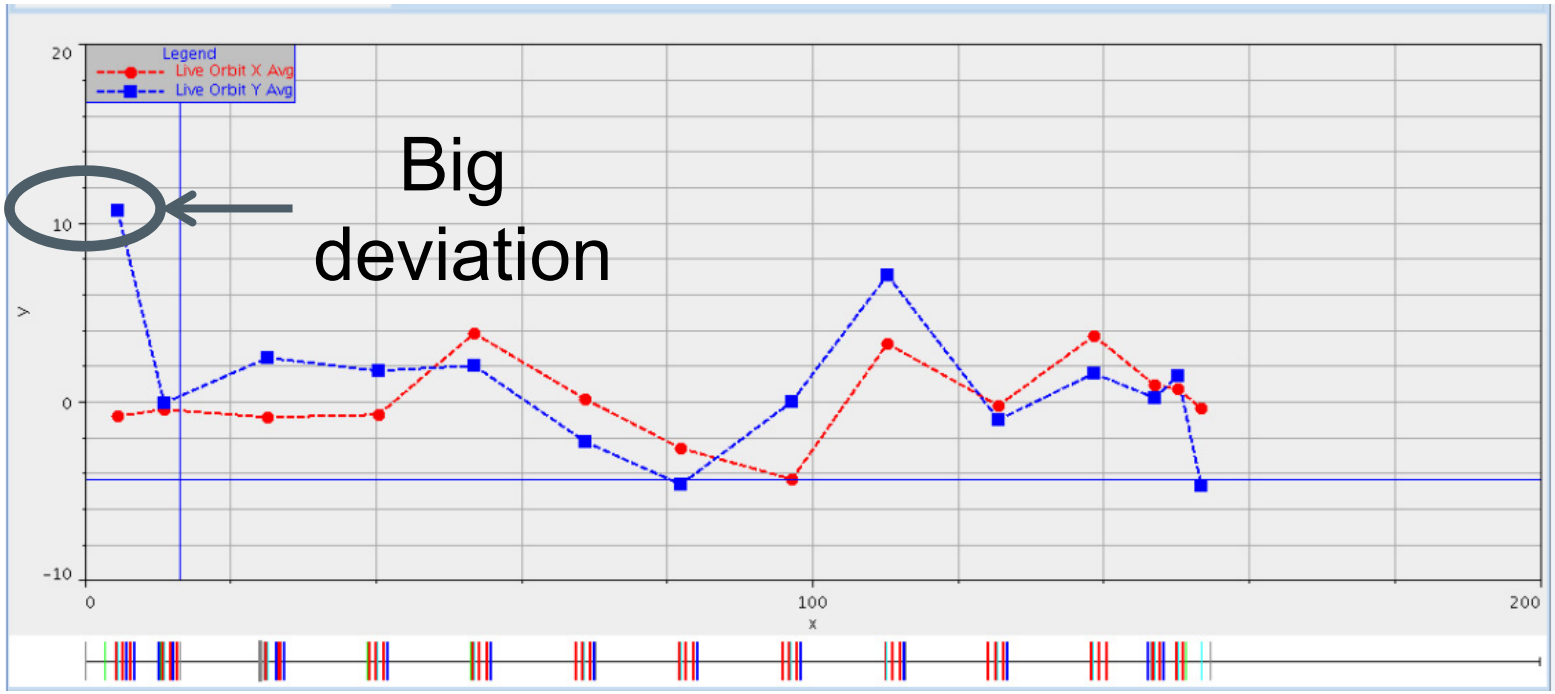




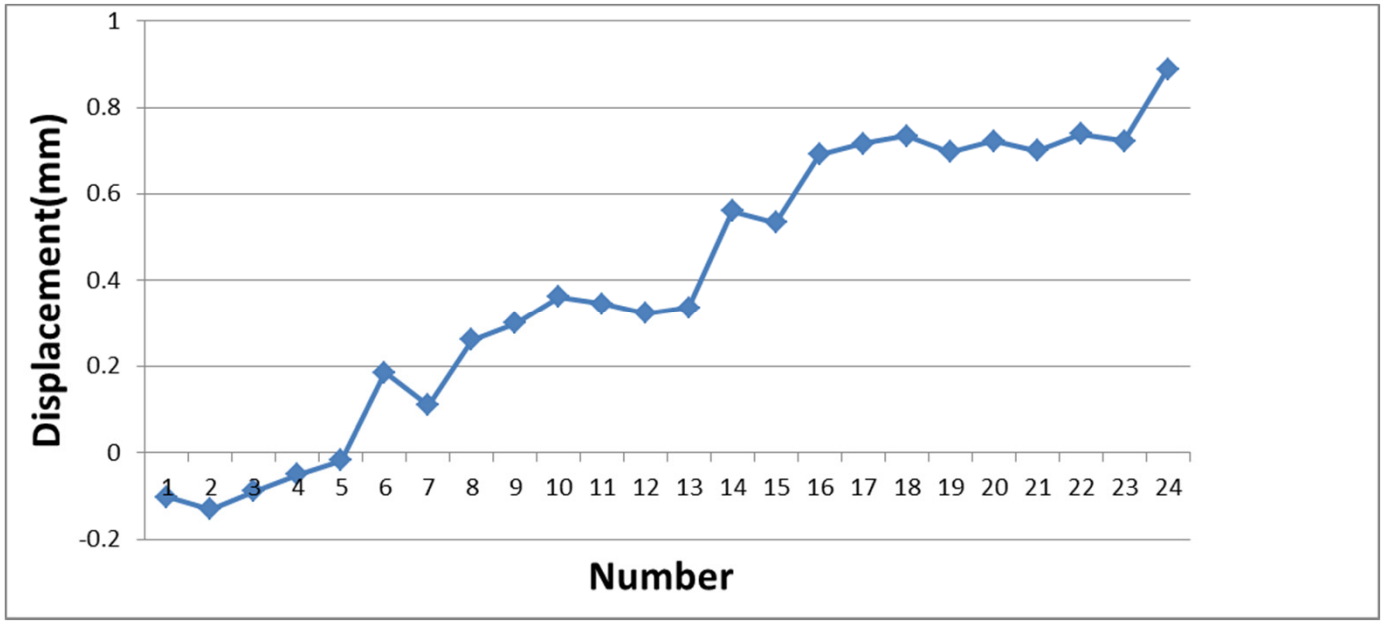
before correction
maximum: ± 1.5mm

after correction
maximum: ± 0.15 mm

LRBT orbit

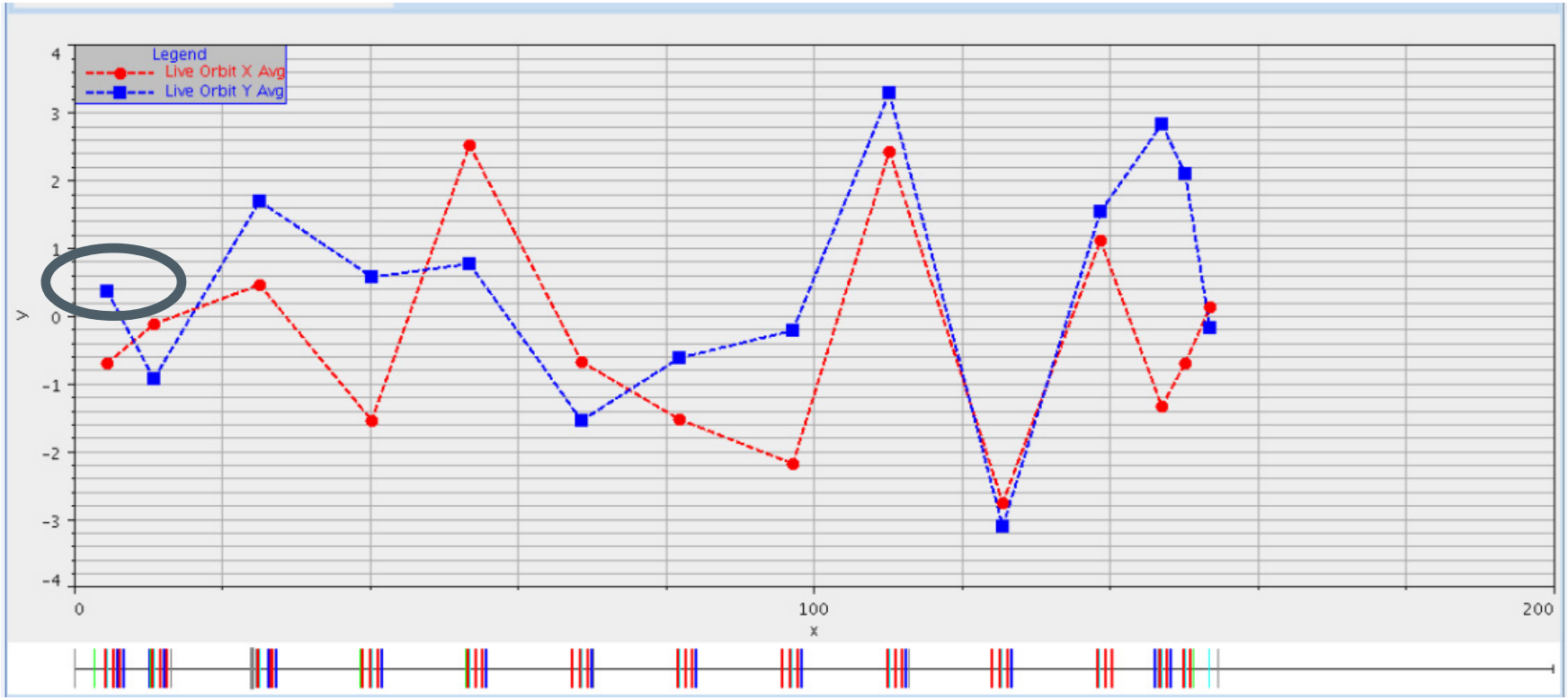

Legend
Live Orbit X Avg
Live Orbit Y Avg
Big deviation
20
10
0
-10
y
0
100
200
x

Why?

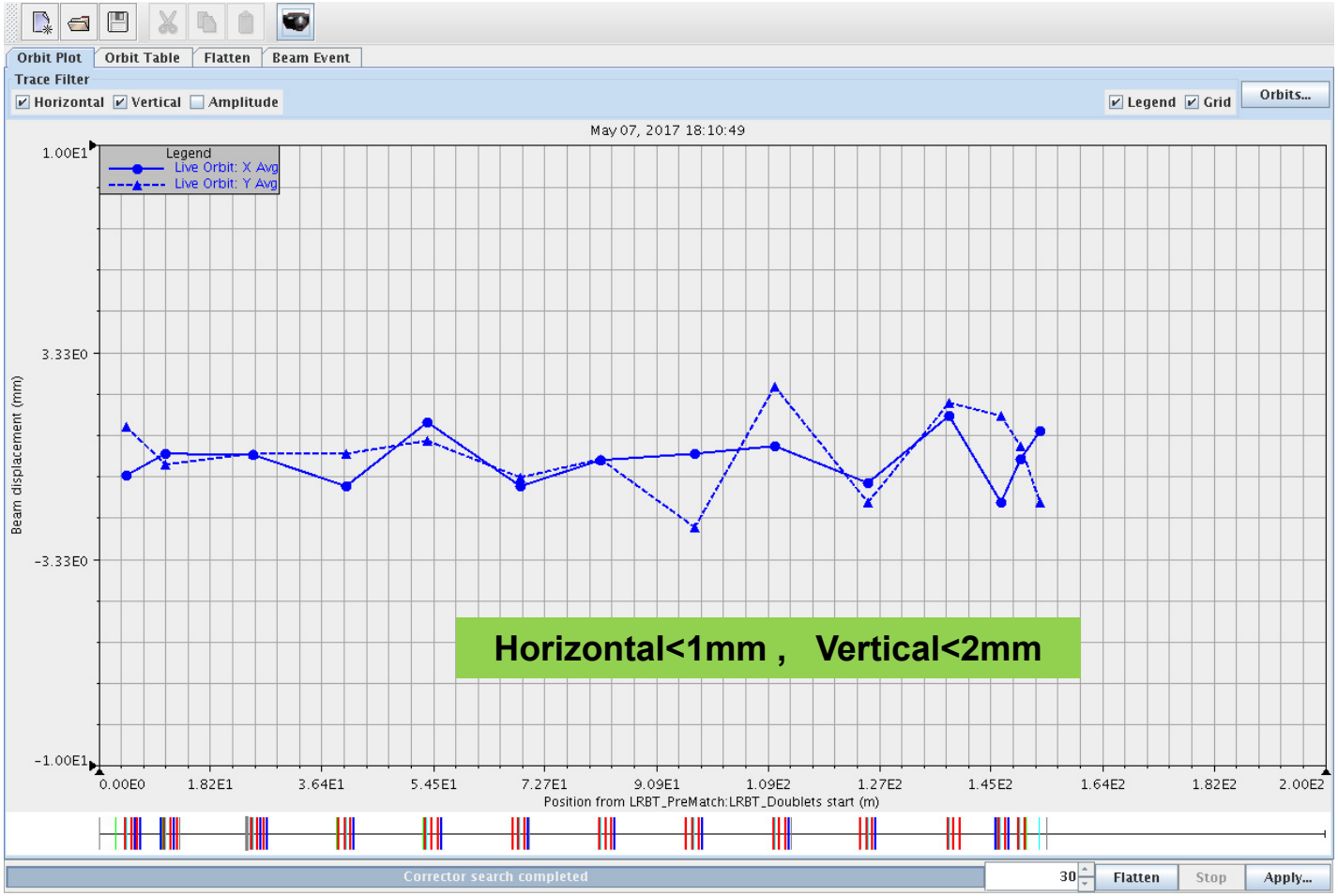


0.8/35447.722mm=0.023mrad

LRBT orbit after correcting MEBT corrector



LRBT orbit after correction



Summary

- The Front-end and DTL1-3 have been fully commissioned, the primary design goals of peak current, transverse emittance and beam energy have been achieved.
- The DTL tank output energy, measured by phase scan method, agrees well with that measured by time-of-flight method.
- Because the presence of beam halo, we need to do more work on the MEBT transverse matching.

Thank you!