Status of CSNS Beam Commissioning

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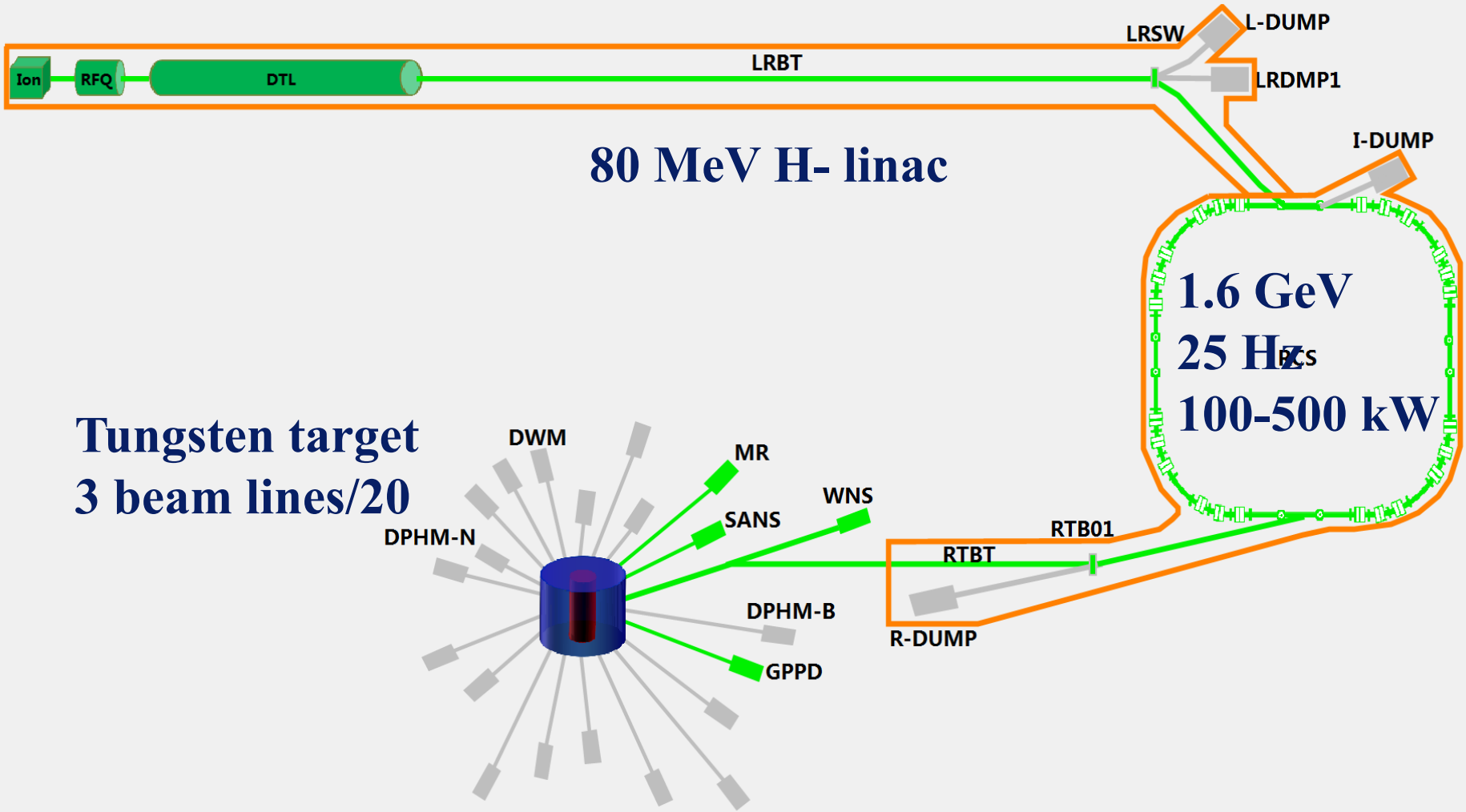
CSNS CHINESE ACADEMY OF SCIENCES

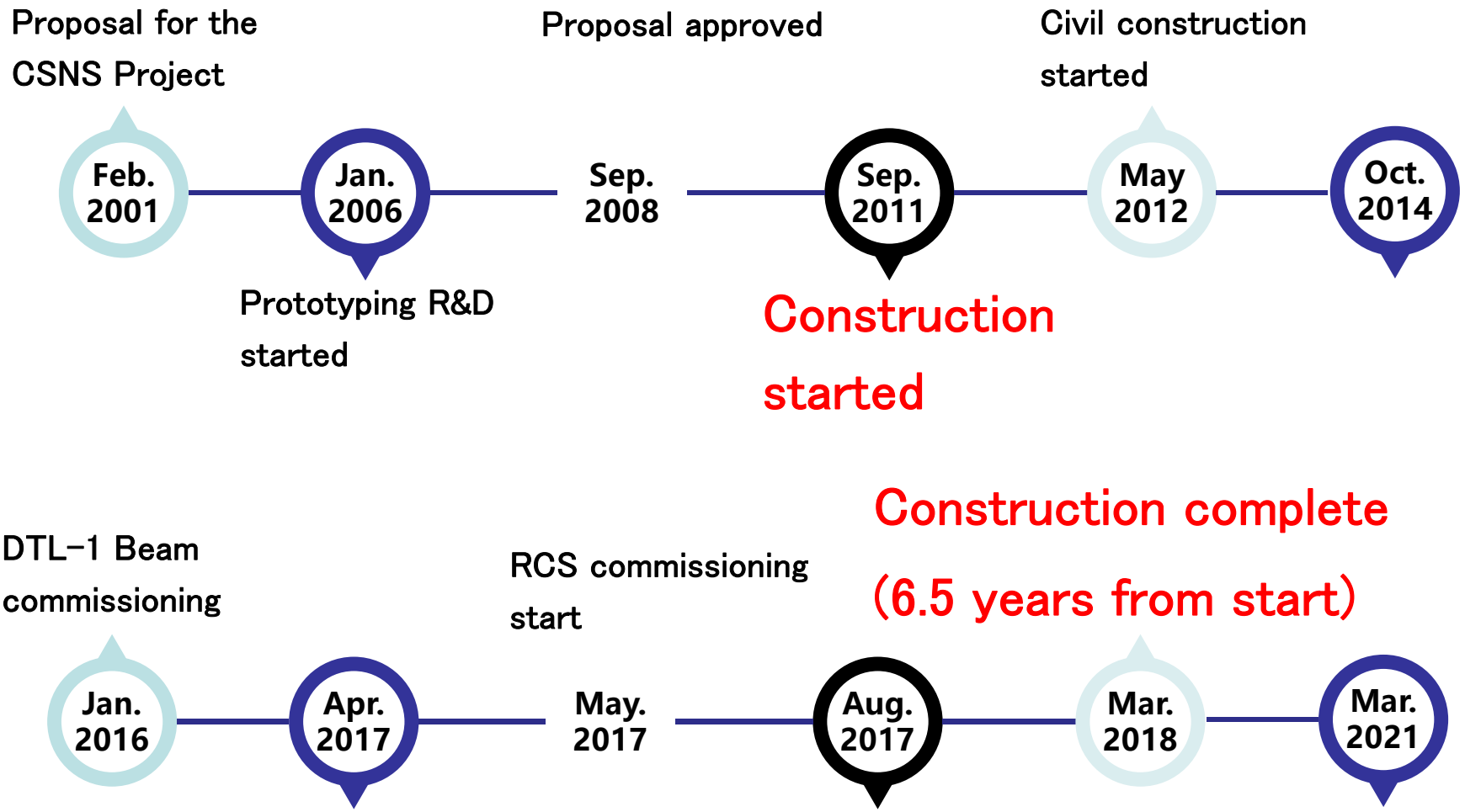
Outline

- Project Overview
- Linac Beam Commissioning
  - Front end
  - DTL linac
- RCS beam commissioning
  - DC mode
  - AC mode
- Summary

Project Overview



Key Milestones



Location of CSNS

- Established on Feb. 19th 2013, to construct and manage the CSNS
- Located in Dongguan, Guangdong Province

The Campus of Dongguan Branch

SNS CHINESE ACADEMY OF SCIENCES

散裂中子源
China Spallation Neutron Source

The Campus of Dongguan Branch

Before ground breaking

The Campus of Dongguan Branch

Before ground breaking

CSNS Campus, Aug. 2017

The Campus of Dongguan Branch

Before ground breaking

CSNS Campus, Aug. 2017

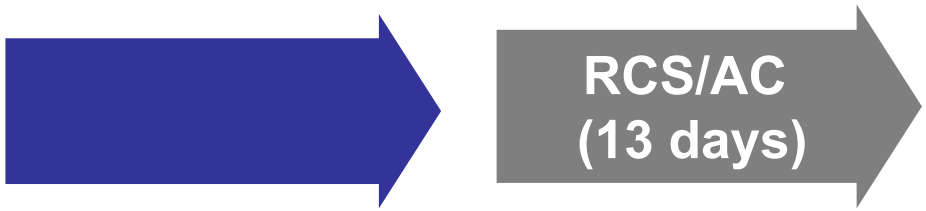

中国散裂中子源装置地A点拍摄（09.5.9）
Before ground breaking
CSNS Campus, Aug. 2017

Commissioning with 60 MeV linac beam

Commissioning with 60 MeV linac beam

RCS/AC
(13 days)

Commissioning with 60 MeV linac beam



Commissioning with 60 MeV linac beam

Commissioning with 60 MeV linac beam

2017.04.15~04.24

Commissioning with 60 MeV linac beam

Commissioning with 60 MeV linac beam

Commissioning with 60 MeV linac beam

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

First beam on target, first neutron beam

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)	RCS/AC (18 days)	First beam on target, first neutron beam
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20		

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

RCS/AC (18 days)	First beam on target, first neutron beam
2017.07.21~07.28	

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

RCS/AC (18 days)	First beam on target, first neutron beam
2017.07.21~07.28	2017.08.11~08.28

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

	RCS/AC (18 days)	First beam on target, first neutron beam
2017.07.21~07.28	2017.08.11~08.28	2017.08.28

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

RCS/AC (8 days)	RCS/AC (18 days)	First beam on target, first neutron beam
2017.07.21~07.28	2017.08.11~08.28	2017.08.28

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

RCS/AC (8 days)	RCS/AC (18 days)	First beam on target, first neutron beam	Increase beam power to 10 kW
2017.07.21~07.28	2017.08.11~08.28	2017.08.28	

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20
RCS/AC (8 days)	RCS/AC (18 days)	First beam on target, first neutron beam	Increase beam power to 10 kW
2017.07.21~07.28	2017.08.11~08.28	2017.08.28	2017.11.01~11.09

Beam Commissioning (2017)

Commissioning with 60 MeV linac beam

Linac (10 days)	RCS/DC (10 days)	RCS/AC (13 days)	RCS/DC (8 days)
2017.04.15~04.24	2017.05.26~06.07	2017.06.30~07.12	2017.07.13~07.20

RCS/AC (8 days)	RCS/AC (18 days)	First beam on target, first neutron beam	Increase beam power to 10 kW
2017.07.21~07.28	2017.08.11~08.28	2017.08.28	2017.11.01~11.09

It took 67 days to reach 10% of design beam power!

Beam commissioning (2018)

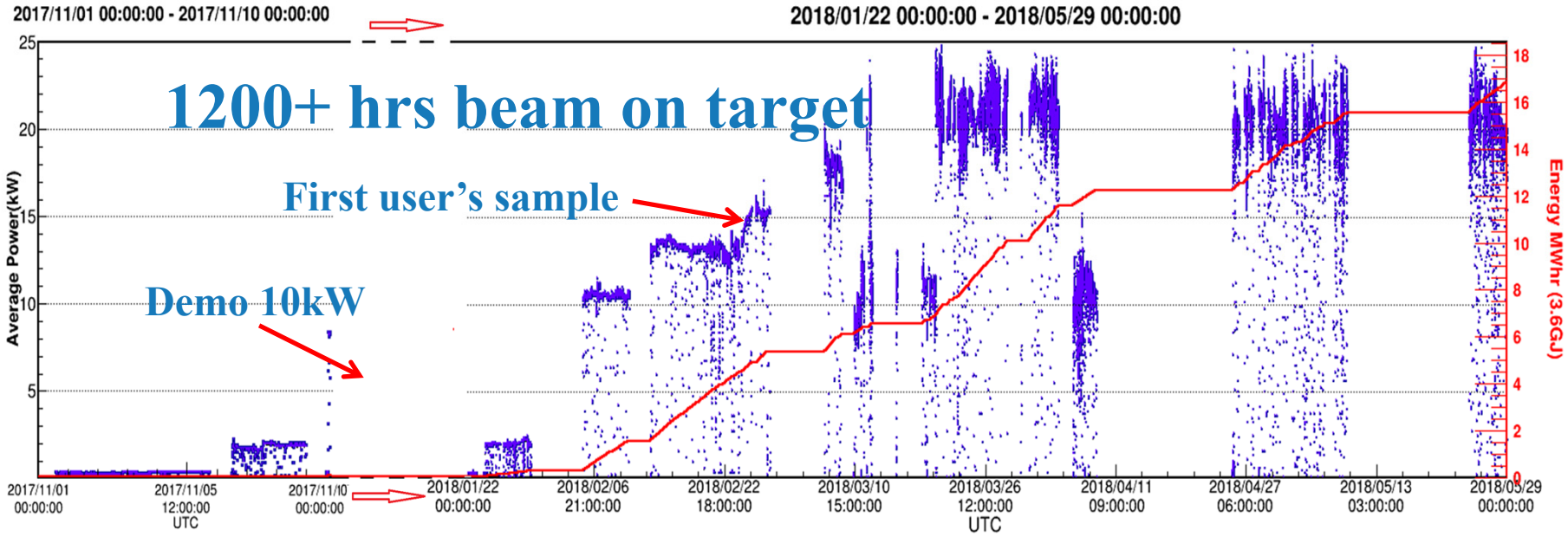
Commissioning with 80MeV linac beam (18 days)

2018.01. 4~01.13 **Linac**

2018.01.14~01.17 **RCS/DC**

2018.01.18~01.21 **RCS/AC**

2018.01.22~ **Test operation + beam commissioning**



Beam commissioning (2018)

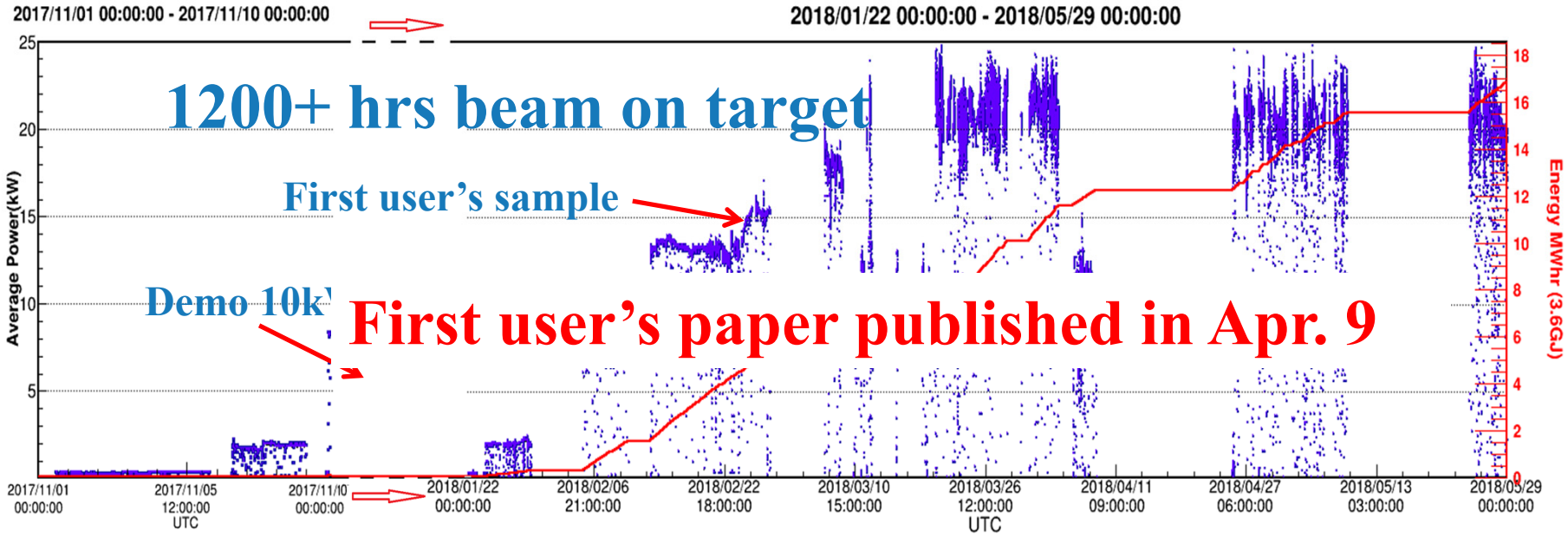
Commissioning with 80MeV linac beam (18 days)

2018.01. 4~01.13 **Linac**

2018.01.14~01.17 **RCS/DC**

2018.01.18~01.21 **RCS/AC**

2018.01.22~ **Test operation + beam commissioning**



Commissioning Schedule

IS+LEBT	2015.4.14 - 2015.4.14
RFQ+MEBT	2015.4.15 - 2015.7.15
DTL1	2015.12.28 - 2016.2.26
DTL2-4+LRBT	2016.11.20 - 2016.12.20
RCS+RTBT	2016.12.25 - 2017.6.16
RTBT （on target)	2017.6.17 - 2017.9.30
First neutron beam	2017.9.30
10kW	2017.9.30 - 2017.12.31
To acceptance goal	2017.12.31
Official acceptance	2018.3
100kW	2018.3.1-2021.3.1

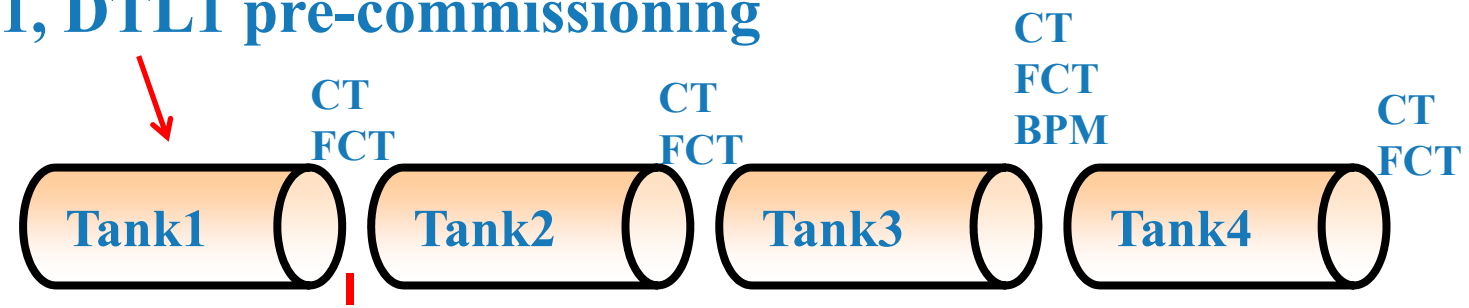
Commissioning Schedule

		In practice
IS+LEBT	2015.4.14 - 2015.4.14	
RFQ+MEBT	2015.4.15 - 2015.7.15	
DTL1	2015.12.28 - 2016.2.26	**2016.1.9**
DTL2-4+LRBT	2016.11.20 - 2016.12.20	**2017.4.14–2017.4.24**
RCS+RTBT	2016.12.25 - 2017.6.16	**2017.5.27–2017.8.27**
RTBT （on target)	2017.6.17 - 2017.9.30	**2017.8.28**
First neutron beam	2017.9.30	**2017.8.28**
10kW	2017.9.30 - 2017.12.31	**2017.10.25- 2017.11.9**
To acceptance goal	2017.12.31	**2017.11.9**
Official acceptance	2018.3	**2018.3**
100kW	2018.3.1-2021.3.1	2018.3-?

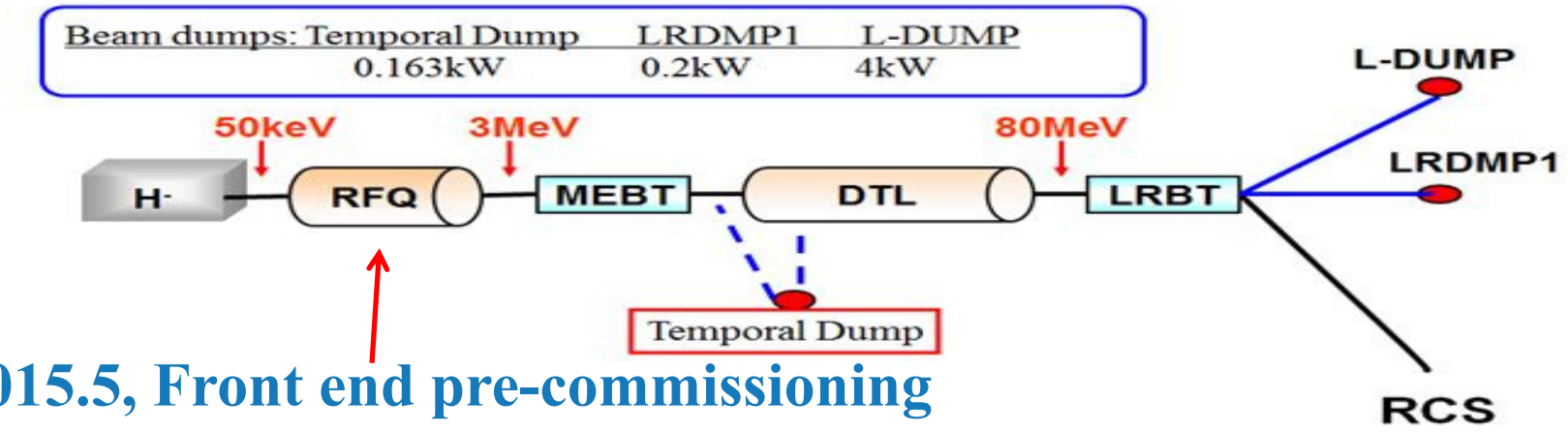
Linac Commissioning

LEBT, RFQ and MEBT

2016.1, DTL1 pre-commissioning

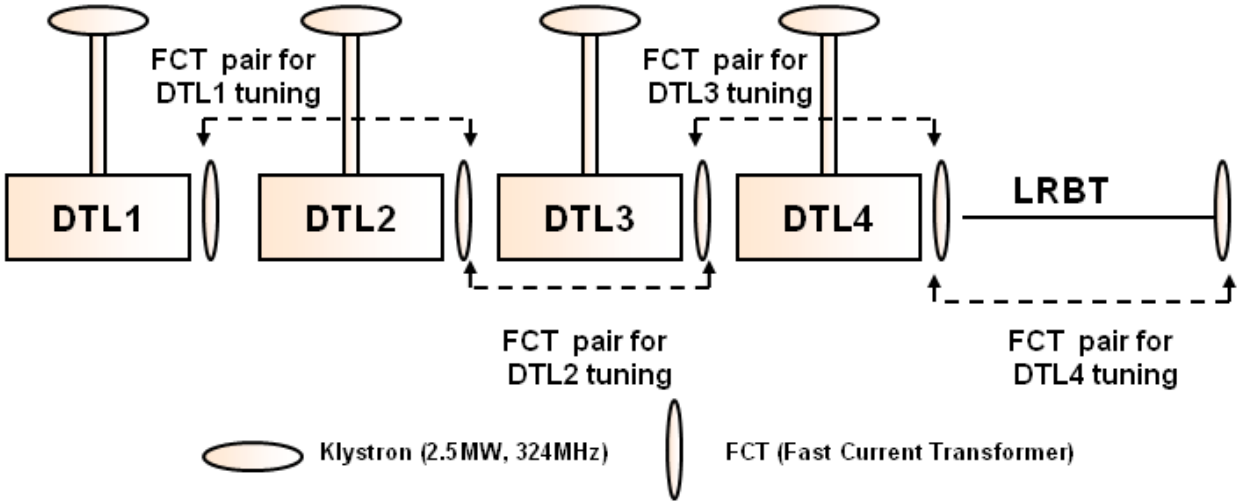


Temporal Beam Diagnostic system:
1BPM,1CT,2FCT,1 QEM,1 x-y steering magnet,1EM,1WS
1 Energy degrader /Faraday cup,1 Beam dump(0.163kW)

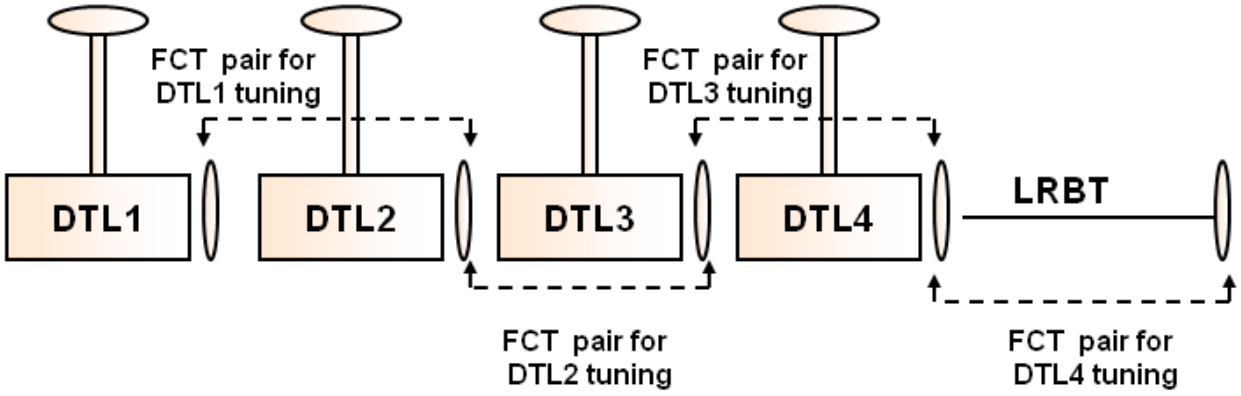


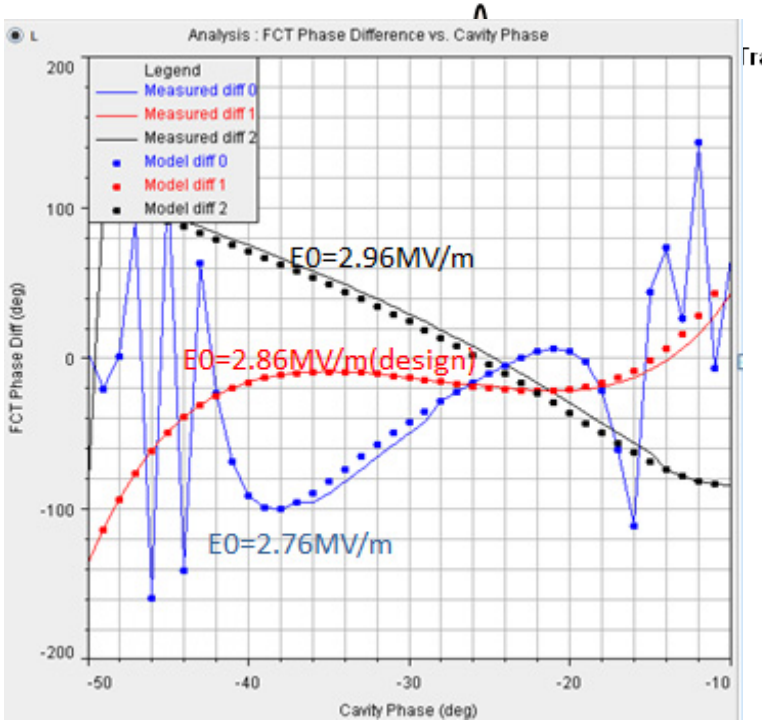
2015.5, Front end pre-commissioning

Phase Scan Signature Matching Technique



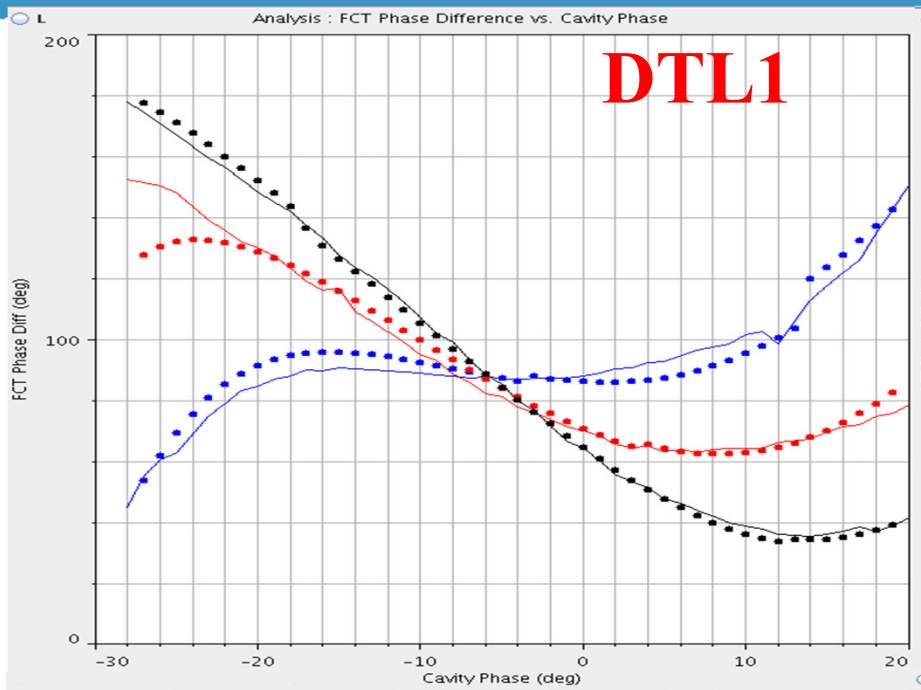
Phase Scan Signature Matching Technique

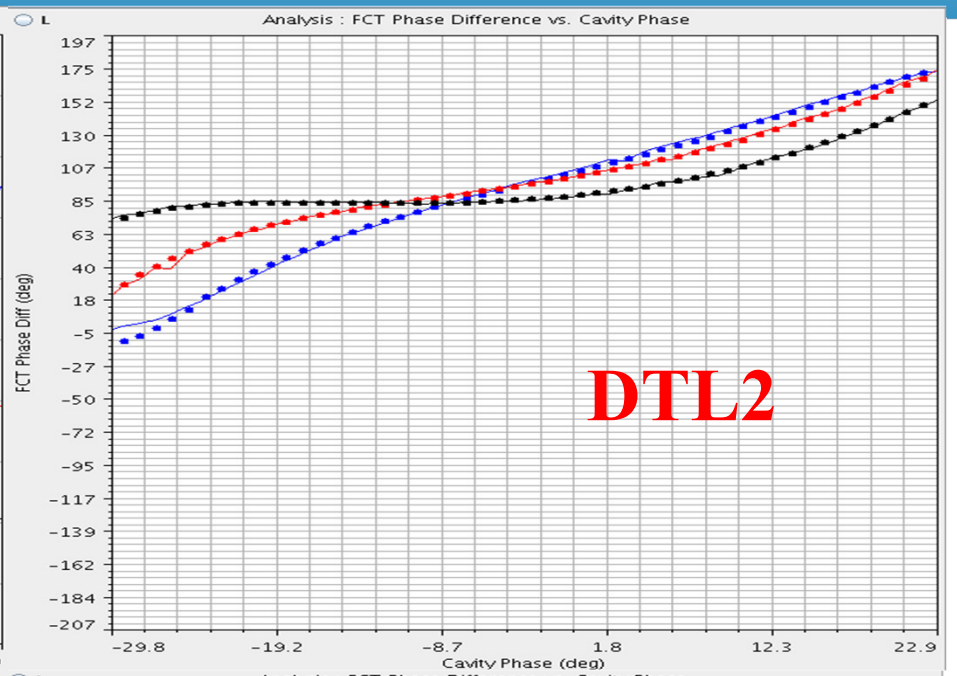


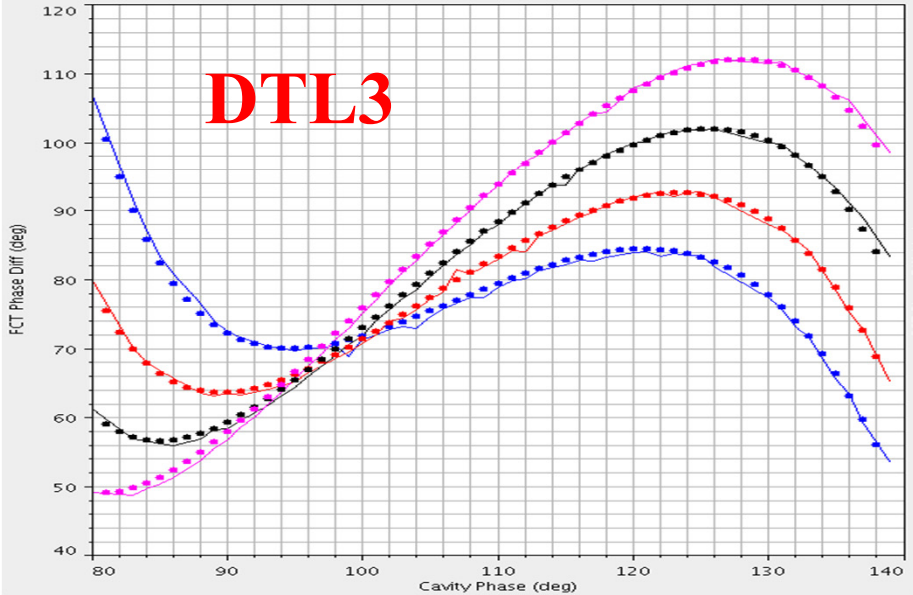


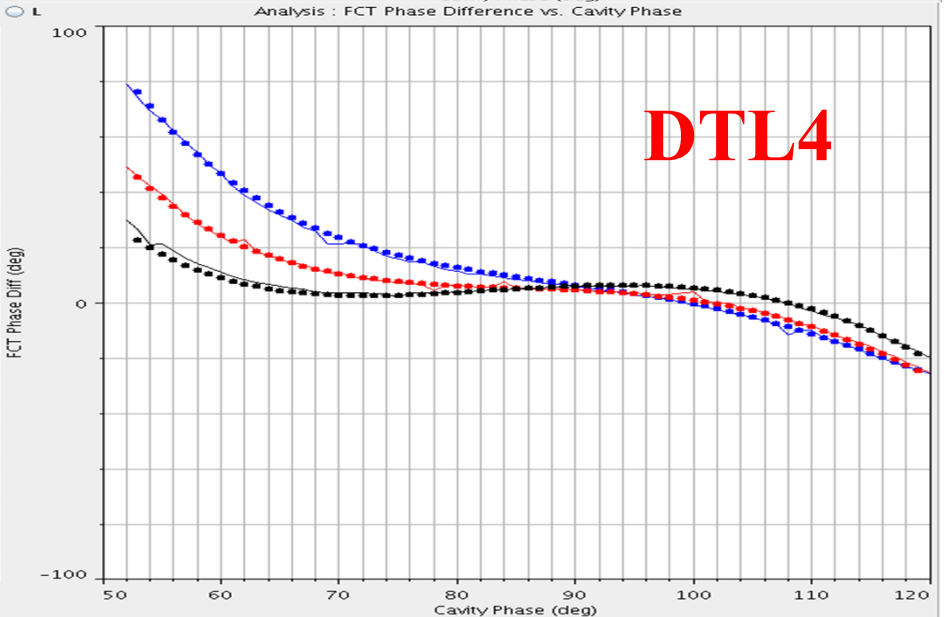
Model:
Input energy
RF amplitude
Cavity phase offset

Phase Scan for 4 DTL tanks

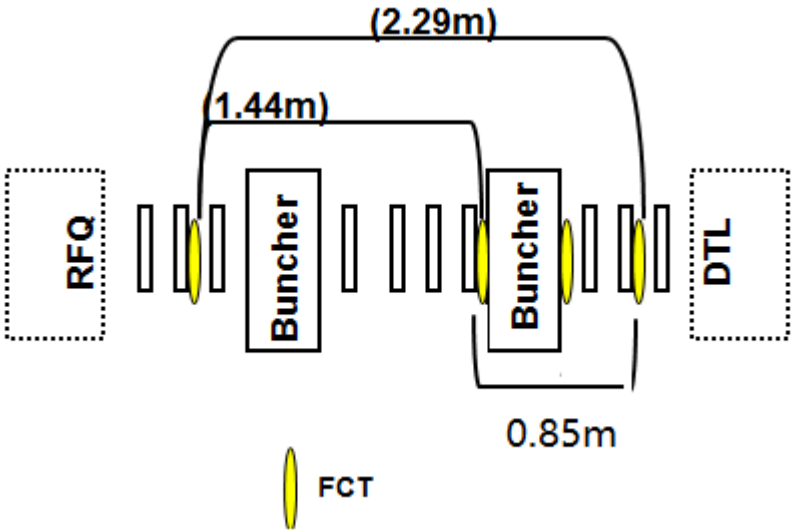








Energy measurement



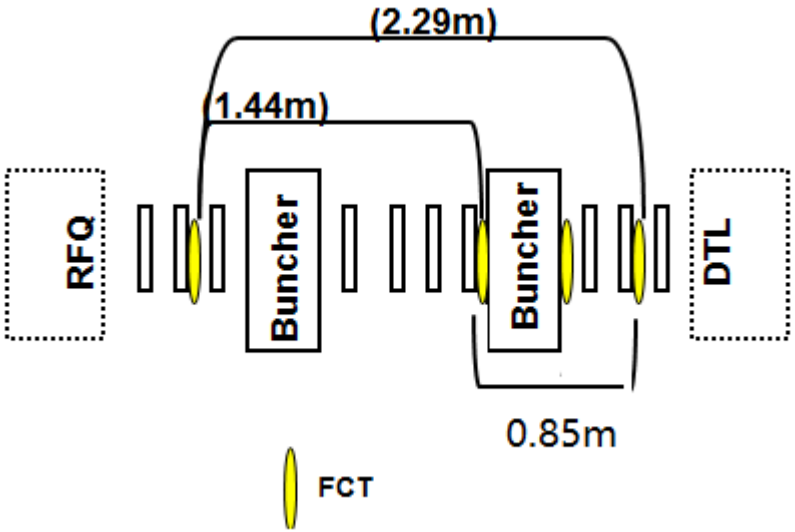
$$W = m_0 c^2 \left(\frac{1}{\sqrt{1 - v^2/c^2}} - 1 \right)$$

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

Short pair 1: L=1.44m, N=19βλ
Short pair 2: L=0.85m, N=11βλ
Long pair: L=2.29m, N=30βλ

	ΔW(ToF)	ΔW (Phase scan)
RFQ	0.1%	0.12%
DTL1	+0.2%	+0.01%
DTL2	+0.26%	+0.09%
DTL3	+0.47%	-0.03%
DTL4	+0.3%	+0.1%

Energy measurement



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	ΔW(ToF)	ΔW (Phase scan)
RFQ	0.1%	0.12%
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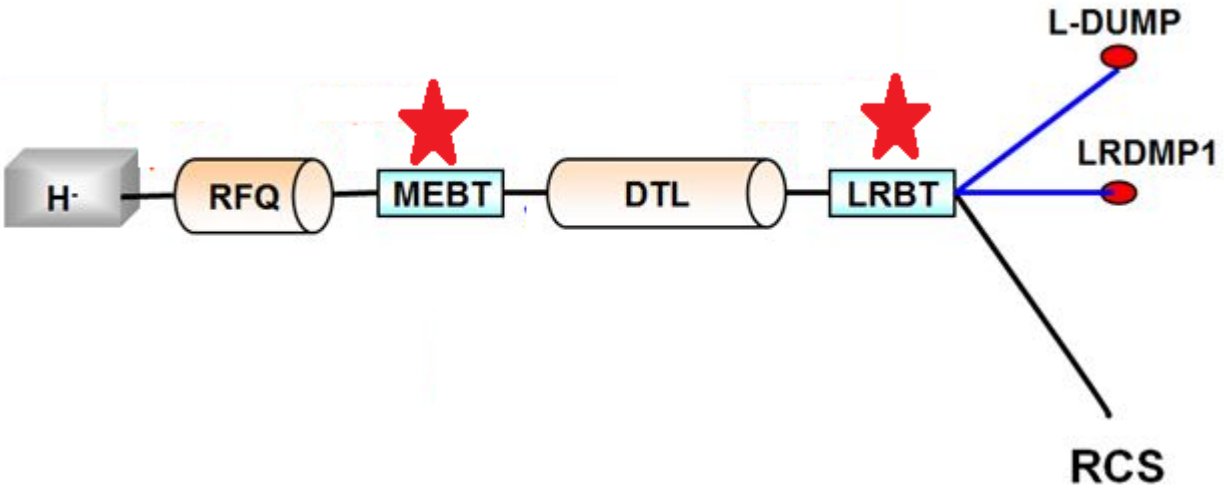
DTL2	+0.26%	+0.09%
DTL3	+0.47%	-0.03%
DTL4	+0.3%	+0.1%

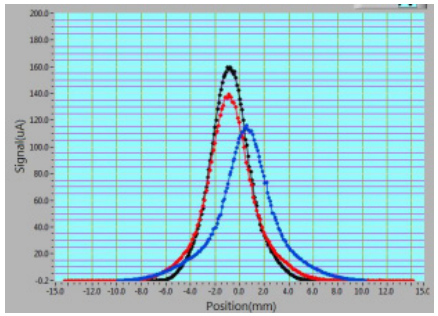
The energy deviation is all< 0.5%

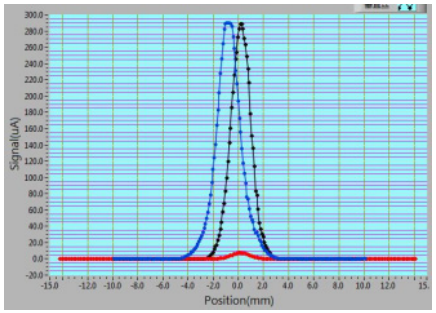
Transverse Matching

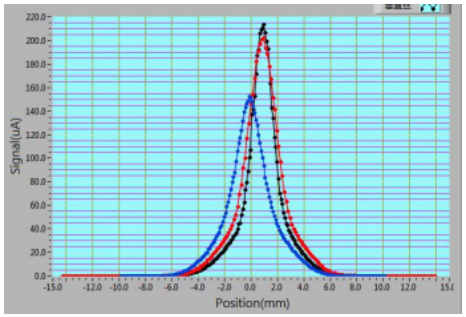
- **MEBT : RFQ->DTL**
- **LRBT: DTL-> LRBT triplet section**

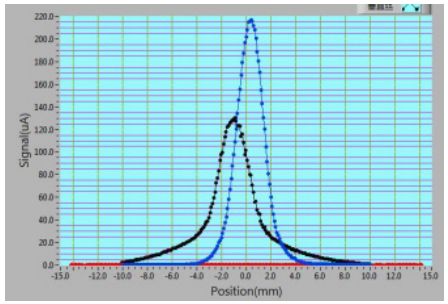


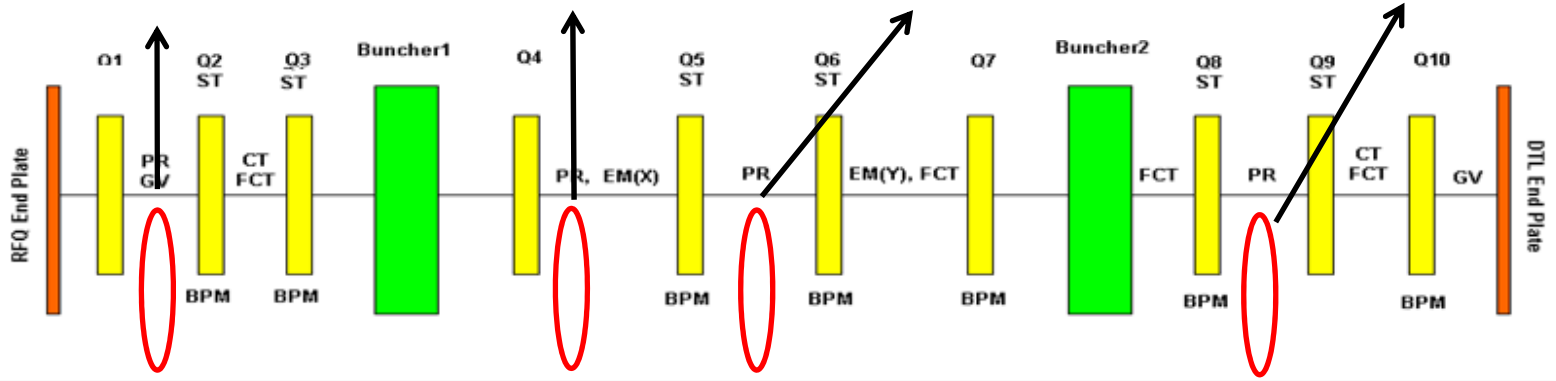
Transverse matching (MEBT)

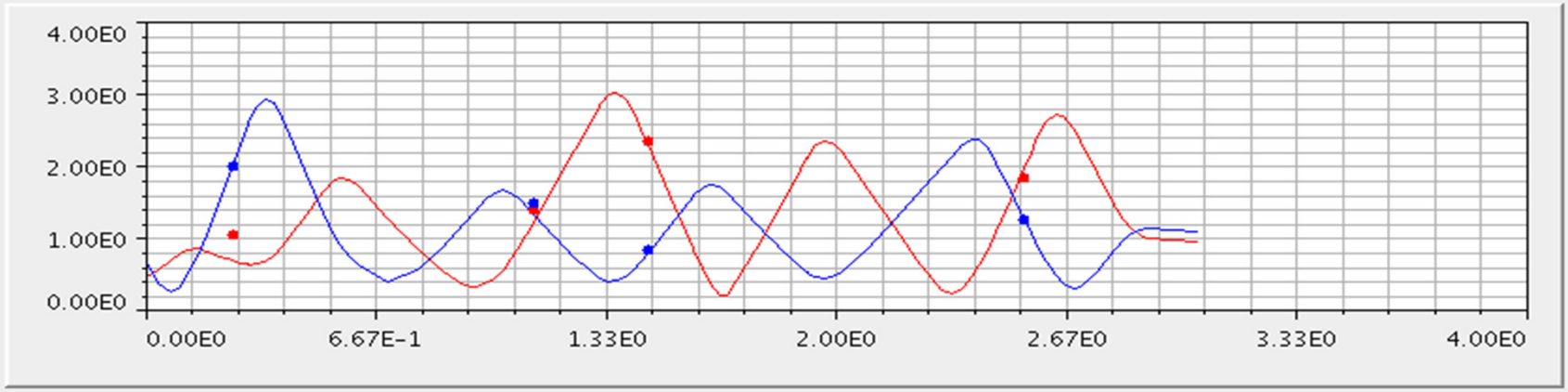






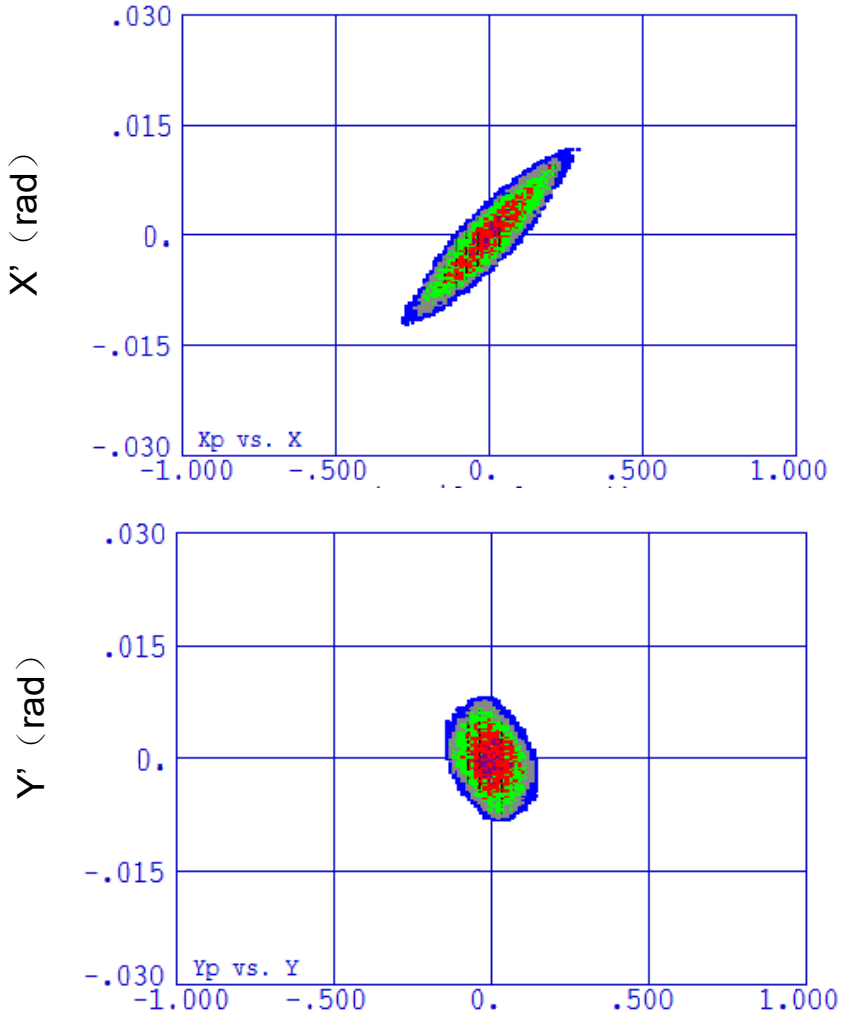




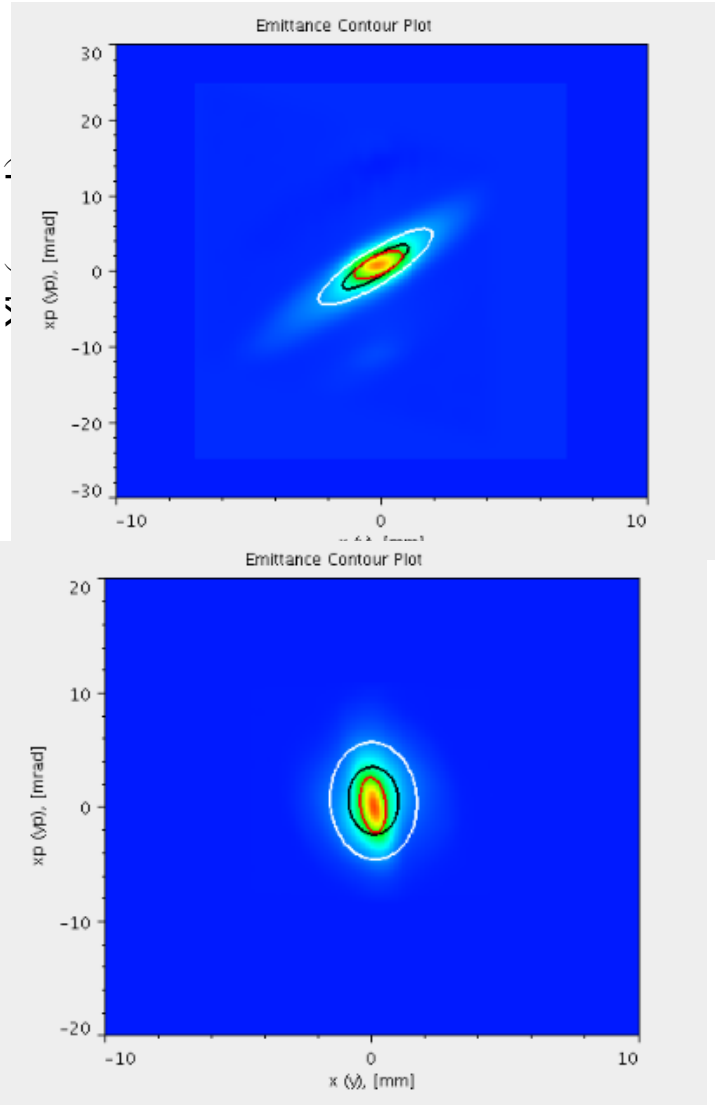


Emittance measurement (MEBT)

Simulated beam distribution at the EM location

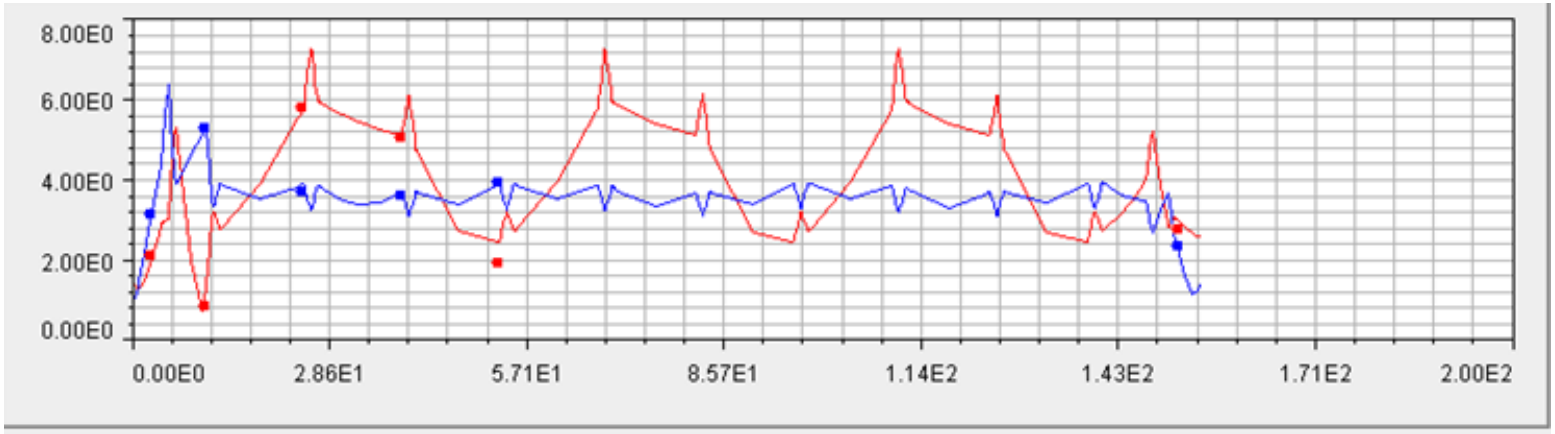


Measured beam distribution at the EM location

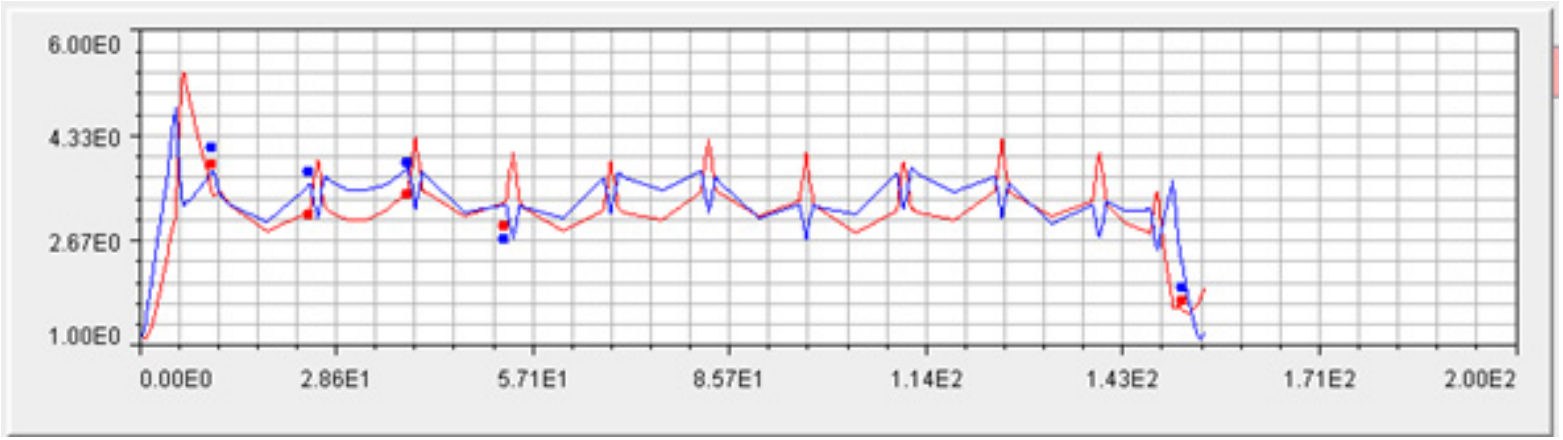


Transverse matching (LRBT)

Before matching

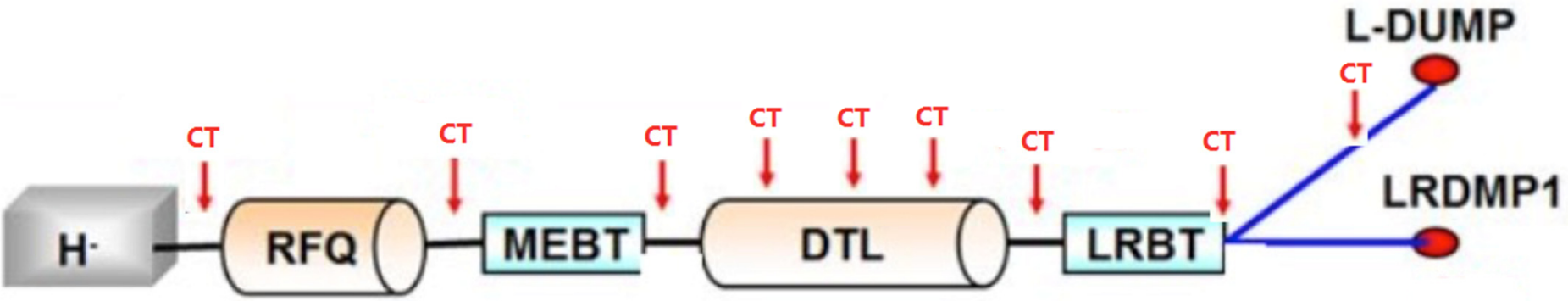


After matching

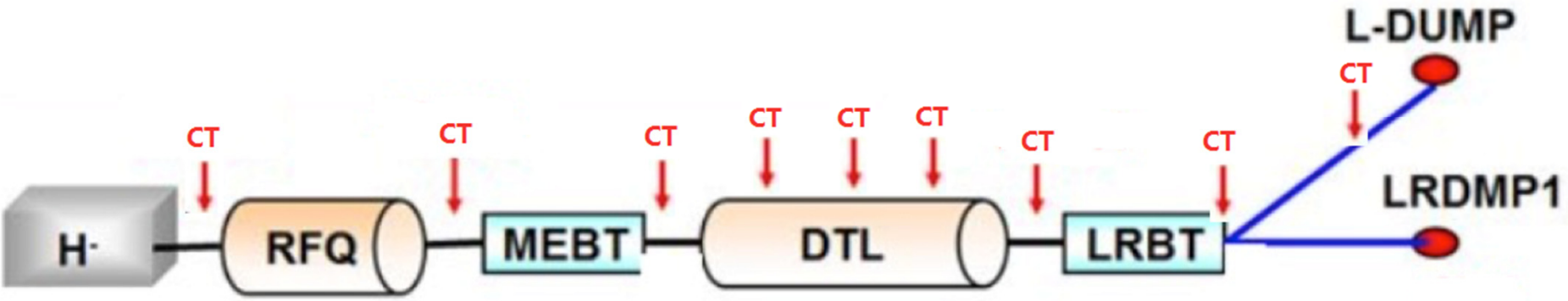


Red line represent X direction
Blue line represent Y direction

Beam transmission

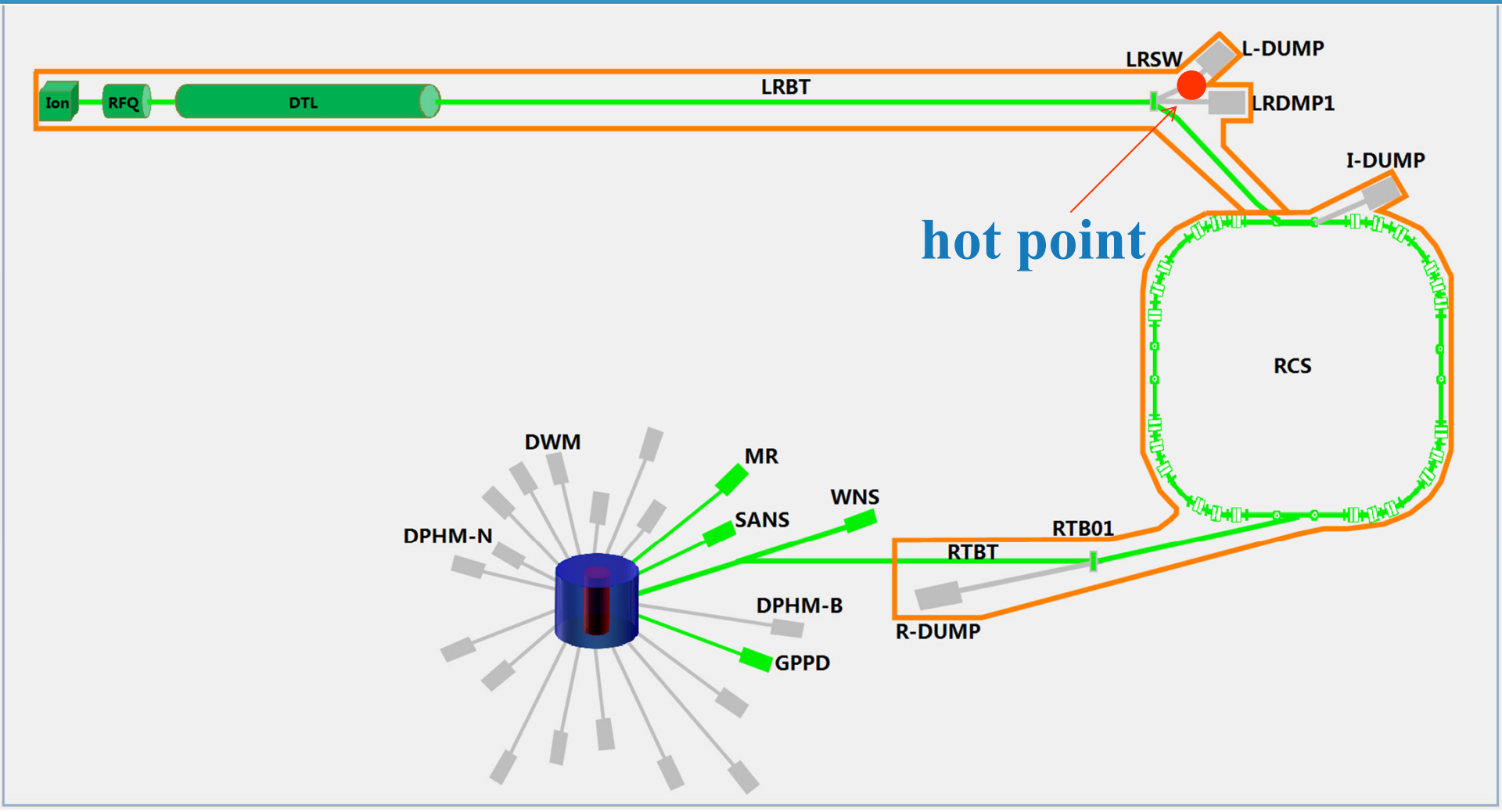


Beam transmission



	Transmission rate
RFQ	~94%
DTL	~97%
LRBT	~100%
LDBT	~100%

Beam loss caused by stripped protons in linac&LRBT



Residual gas stripping?

Magnetic stripping? **From ion source?**

Beam loss caused by stripped protons in linac&LRBT

Residual gas stripping?

Magnetic stripping? **From ion source?**

Beam loss caused by stripped protons in linac&LRBT

Residual gas stripping?

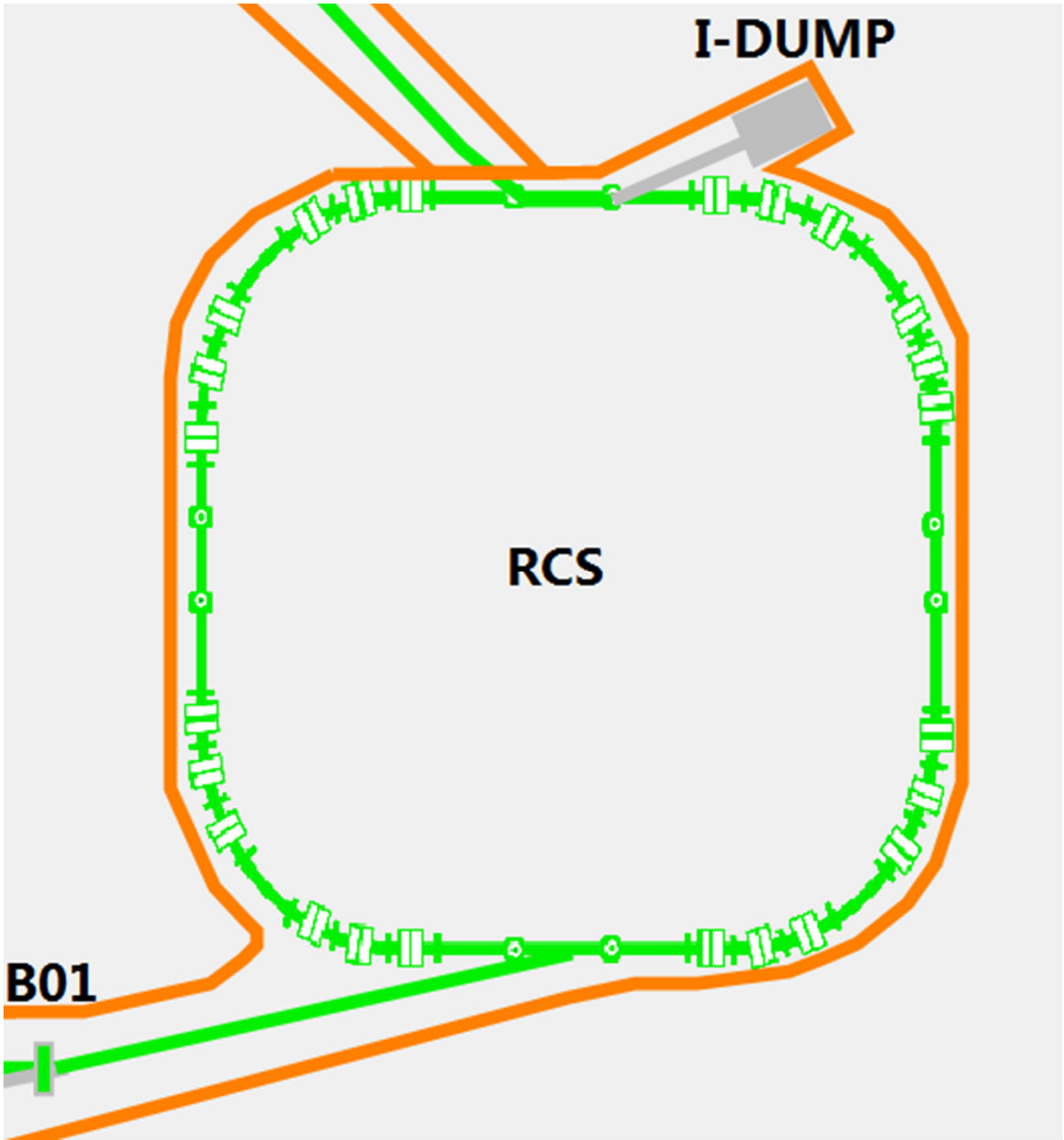
Magnetic stripping? **From ion source?**

RCS Commissioning

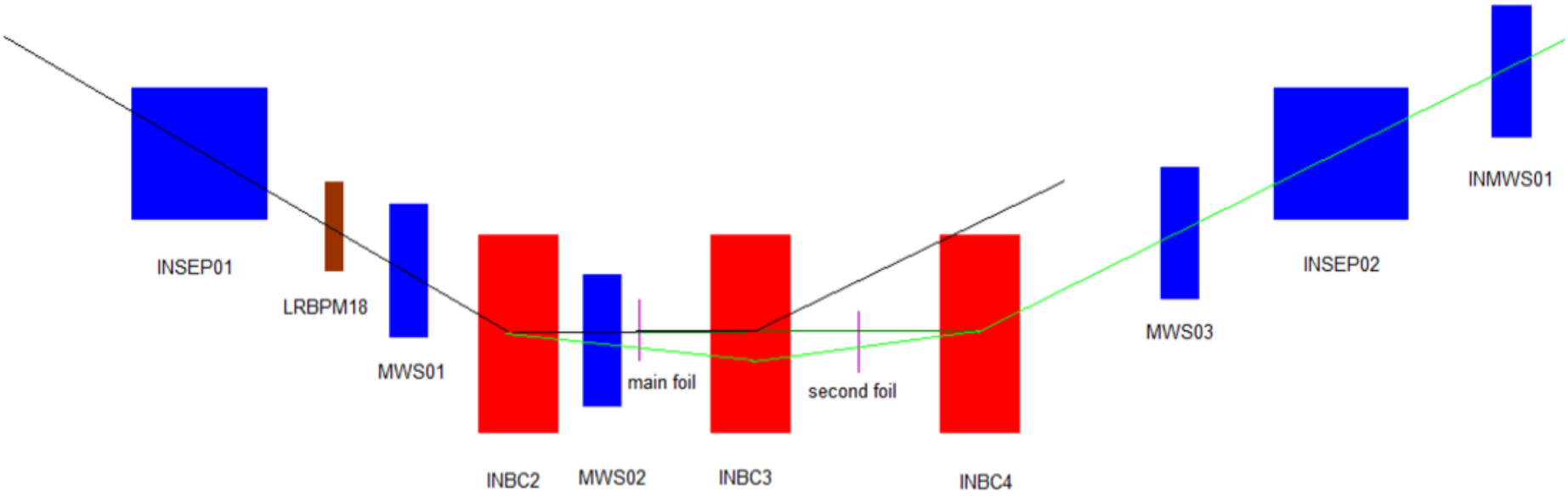
RCS Dry Running

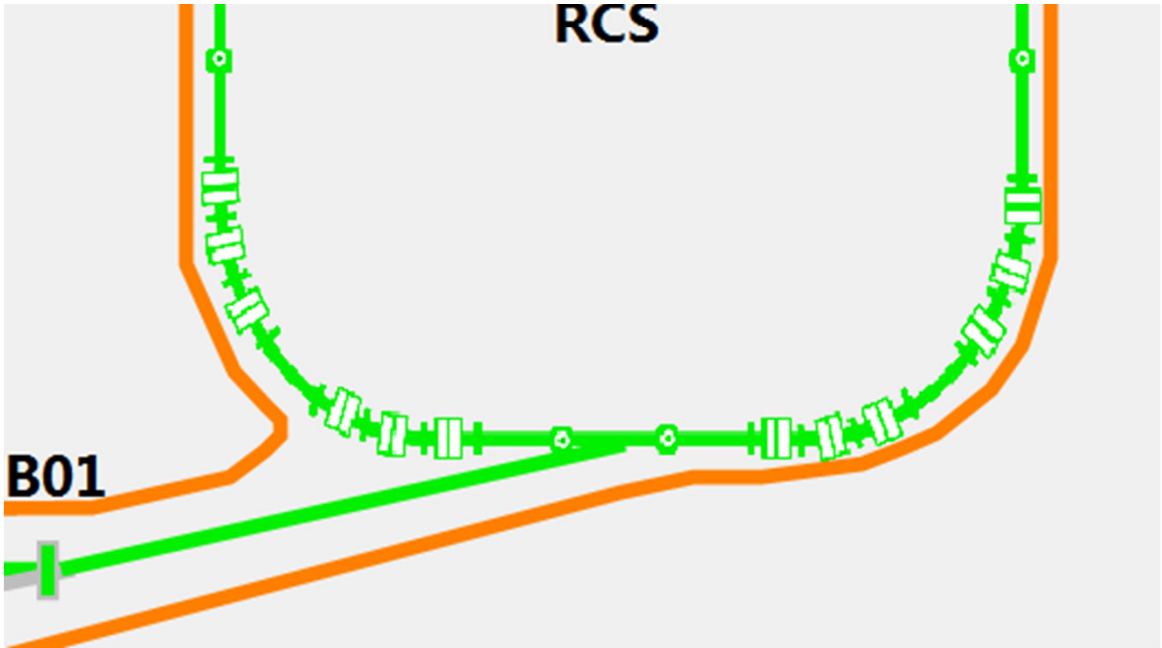
- A week per time, 2 times
- Problem found:
- Water leakage was found in one cavity.
- Cooling tubes of two AC magnets were burned through.
- 17 chokes had strong vibration and had been returned to the manufacture to repair.
- Ceramic vacuum chamber Broken
- Arc of extraction kicker
- ……

Beam Commissioning to Inj. Dump



Beam Commissioning to Inj. Dump





Injection with 60MeV beam

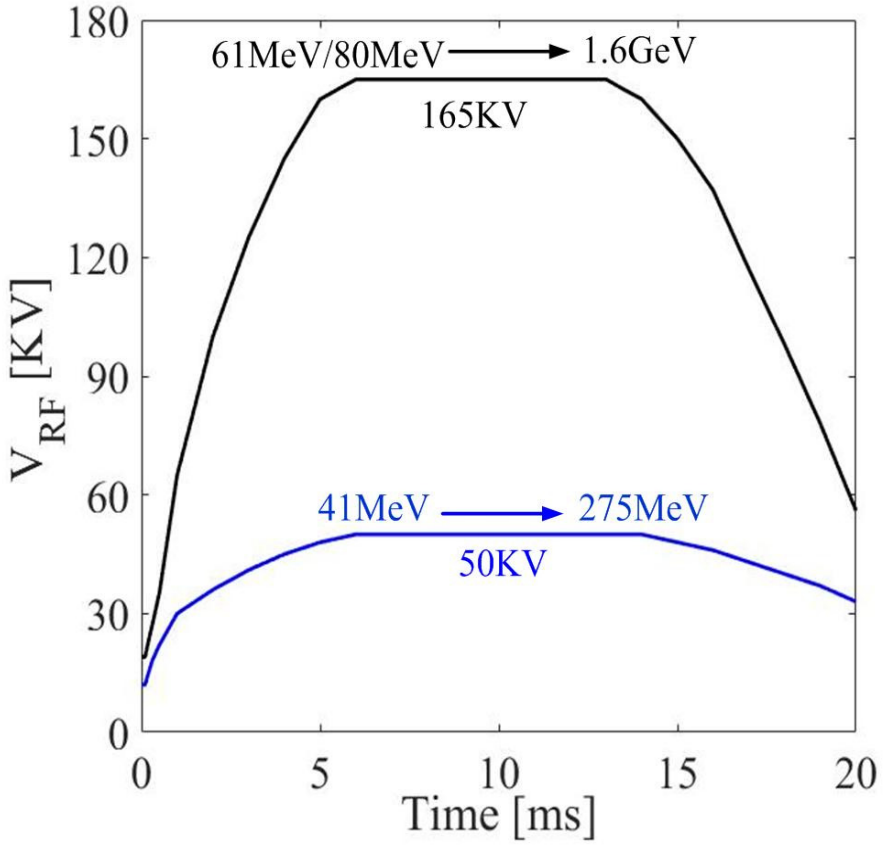
Beam energy	61.07MeV	81MeV
Magnetic rigidity(T/m)	1.147	1.319
B field (T)	0.143	0.164
RF frequency (MHz)	0.906	1.022
B(I) (A)	305.7	351.6

Injection with 60MeV beam

Beam energy	61.07MeV	81MeV	41.3MeV(h=3)
Magnetic rigidity(T/m)	1.147	1.319	0.938
B field (T)	0.143	0.164	0.117
RF frequency (MHz)	0.906	1.022	1.135
B(I) (A)	305.7	351.6	206.7

Injection with 60MeV beam

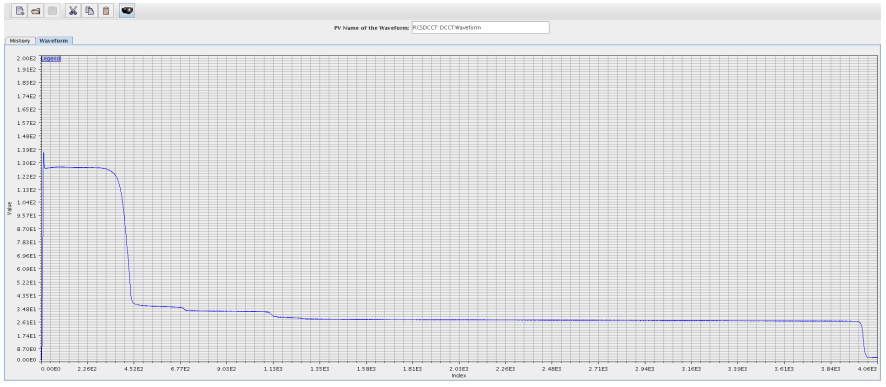
Beam energy	61.07MeV	81MeV	41.3MeV(h=3)
Magnetic rigidity(T/m)	1.147	1.319	0.938
B field (T)	0.143	0.164	0.117
RF frequency			1.135
B(I) (A)			206.7



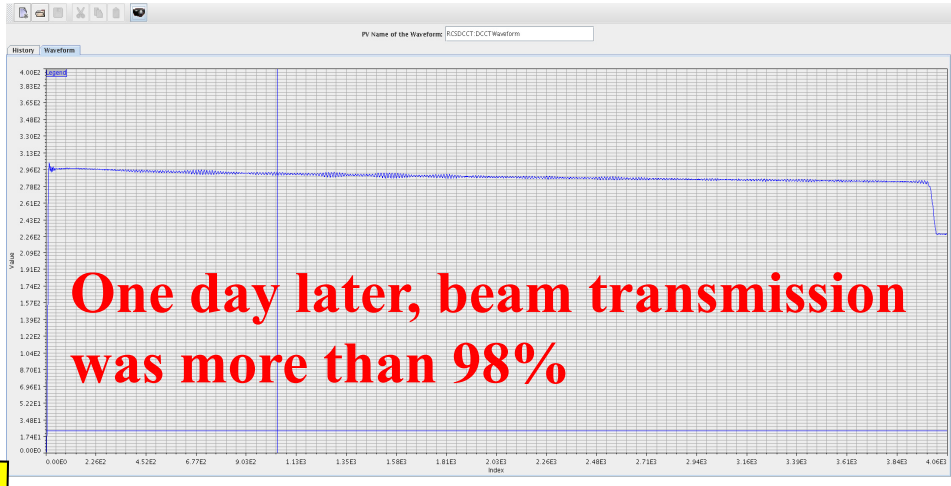
RCS Beam Commissioning-DC mode

- ✓ To control the beam loss during the beam commissioning, the single shot beam mode is adopted. In the first step, the beam commissioning was started in DC mode without acceleration.
- ✓ In May 31st, the first beam was injected into the RCS, and successfully accumulated in the RCS.
- ✓ In June 5th, the first beam was extracted to RCS dump.

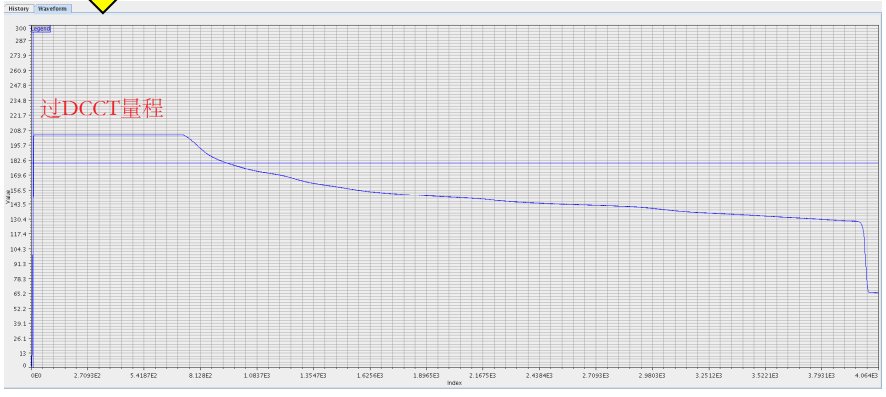
Accumulation and extraction

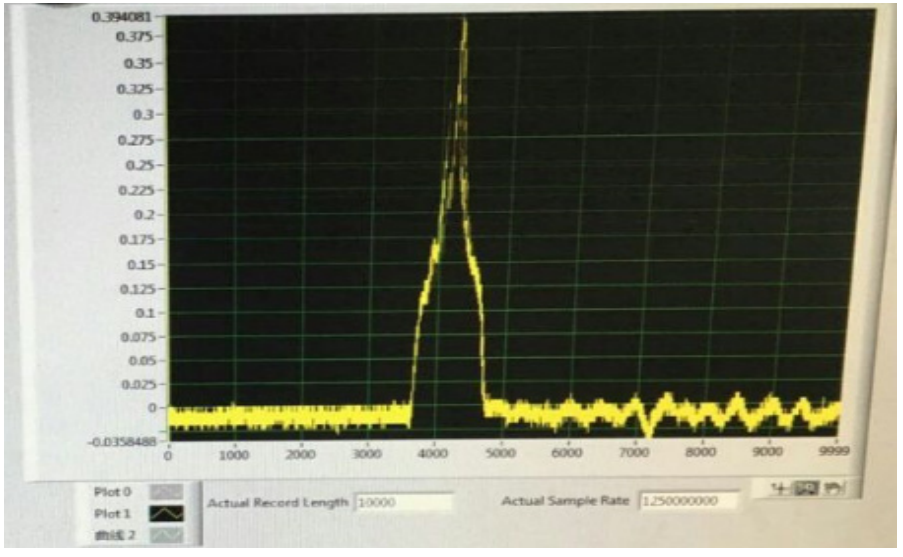


1. Optimization of RF pattern
2. Optimization of the B field

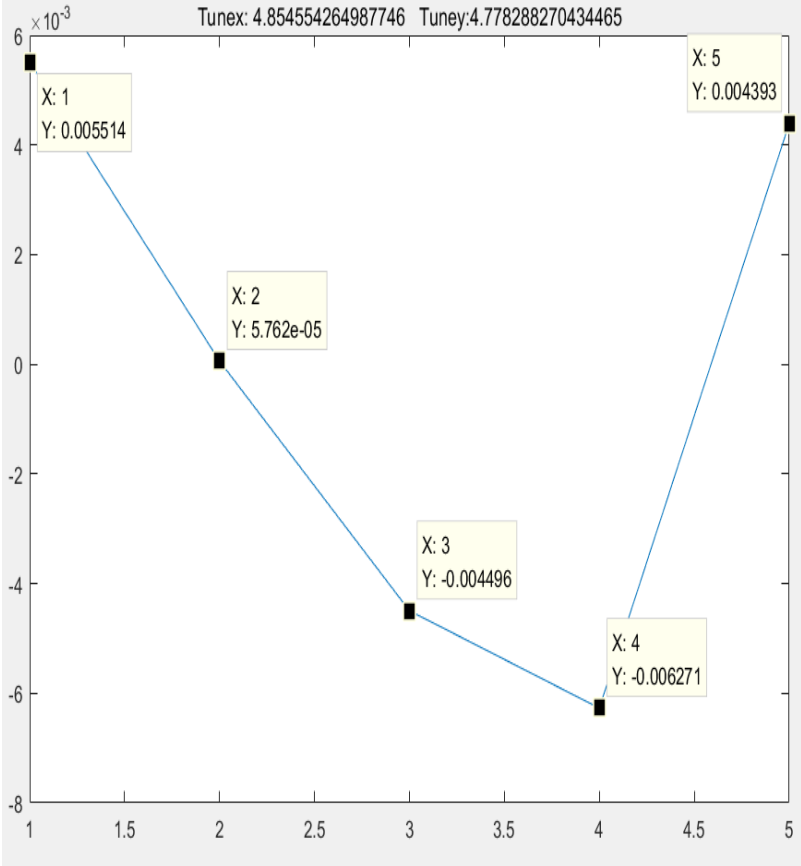


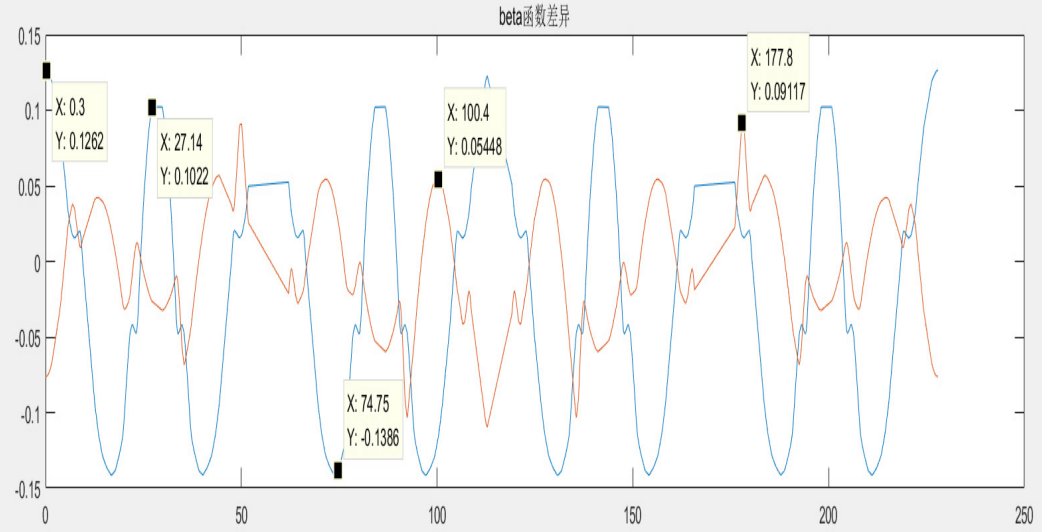
3. Height of Injection bump

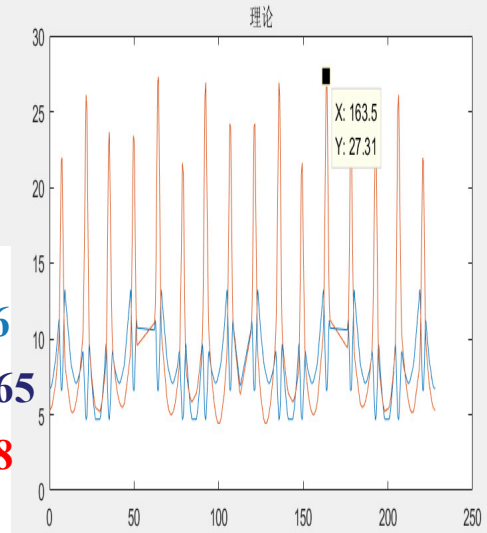


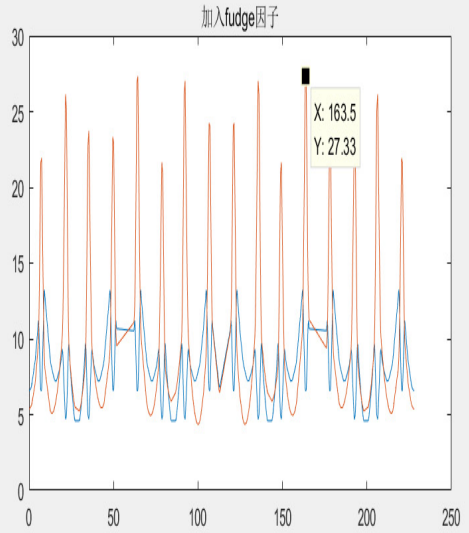


Fudge factor by response matrix









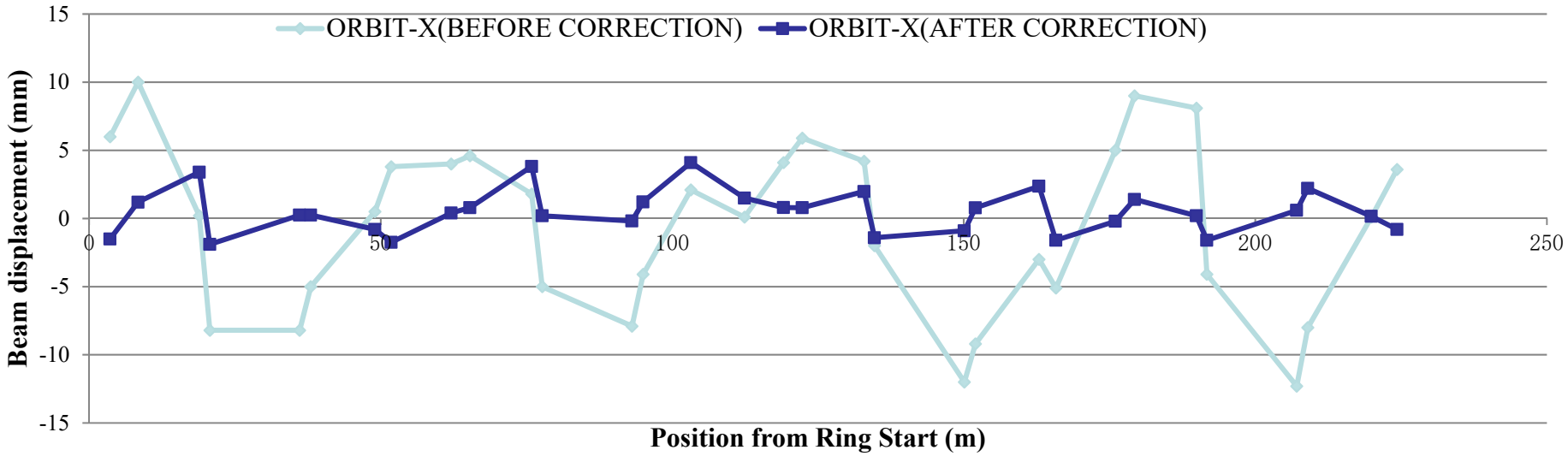
Nominal tune: Tunex/tuney: 4.8532/ 4.7816

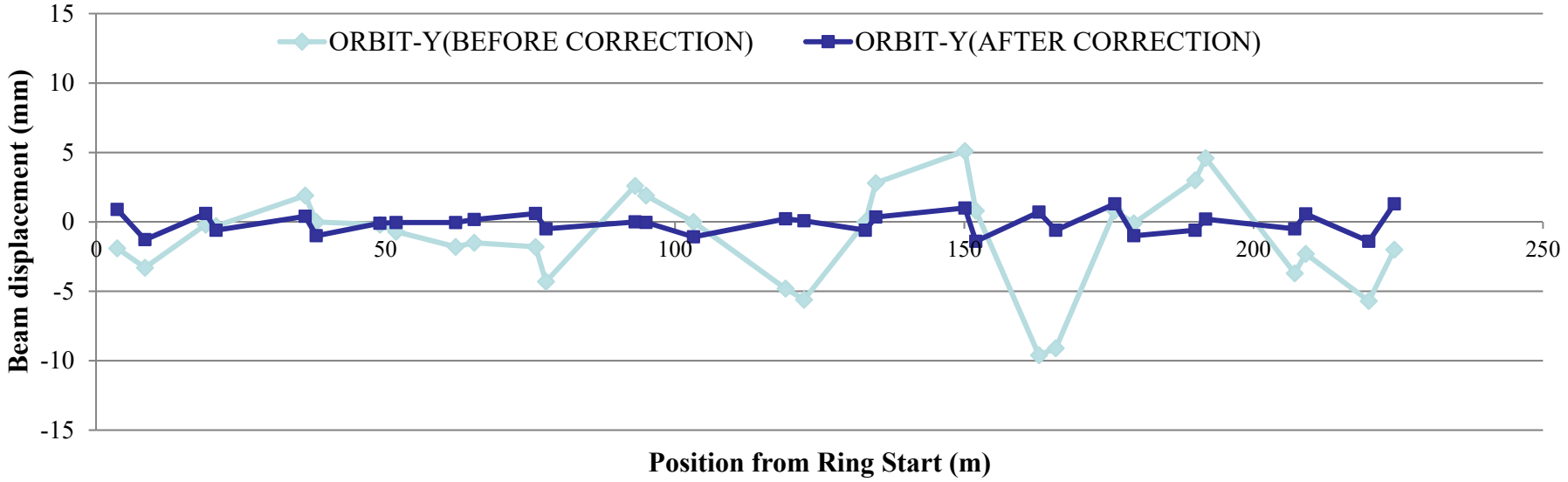
Measured tune: Tunex/tuney: 4.8568/ 4.7765

After correction: Tunex/tuney: 4.854/ 4.778

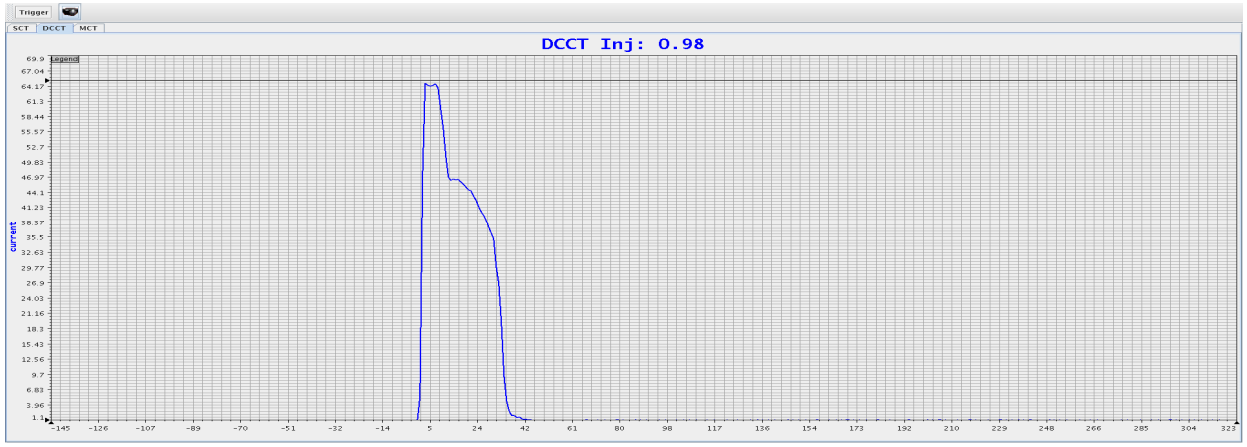
Max. beta-beating :0.12

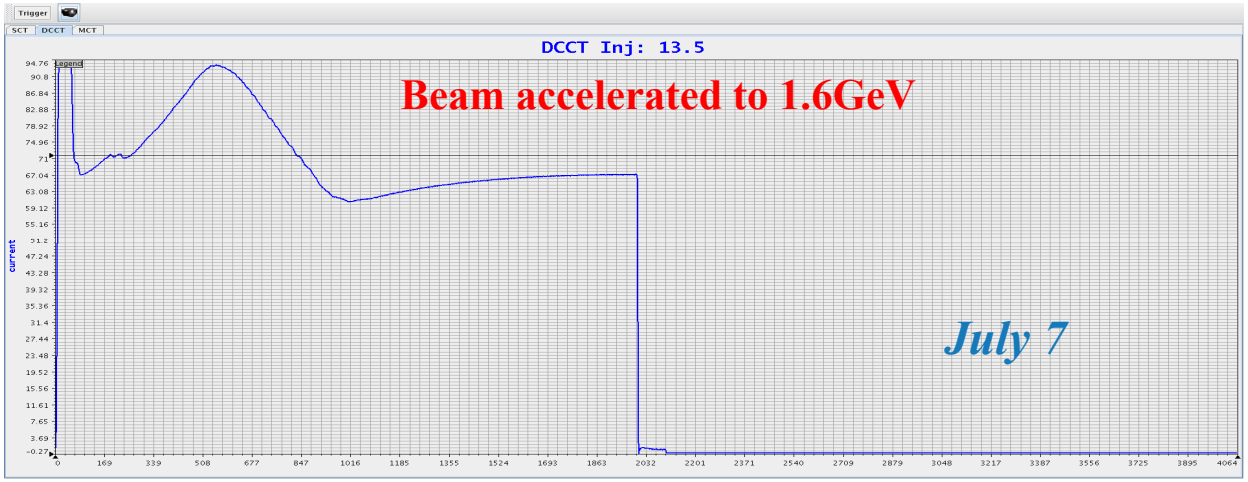
COD correction





RCS Beam Commissioning-AC mode



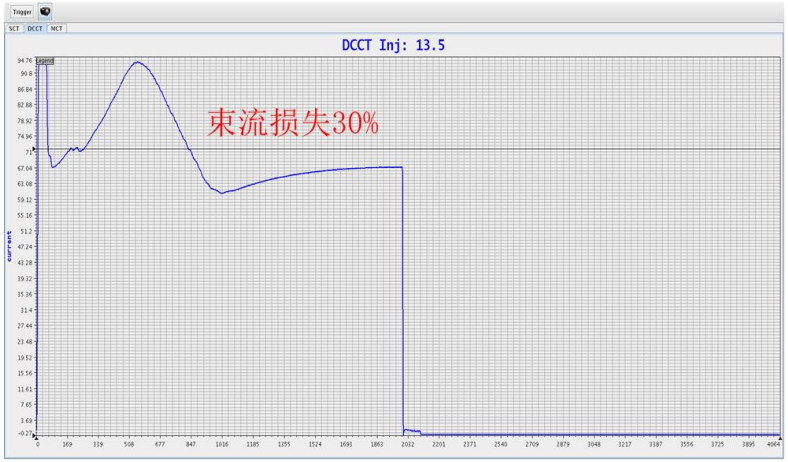


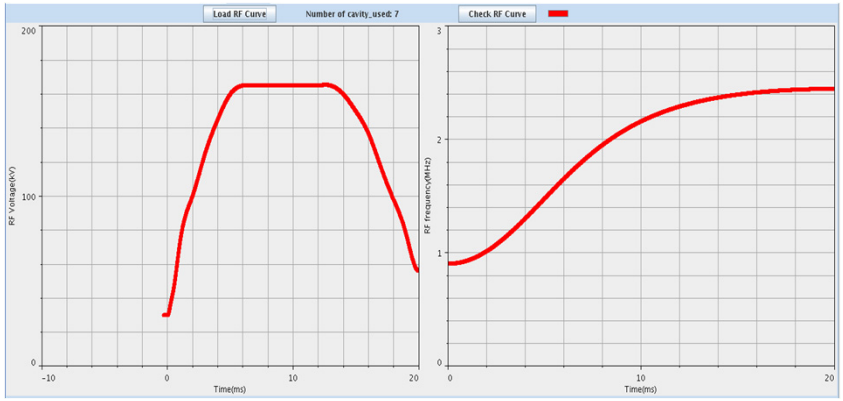
Beam life time is 2ms in the first shot.

Shift timing between RF and B field, then major part of beam was accelerated to 1.6GeV and extracted.

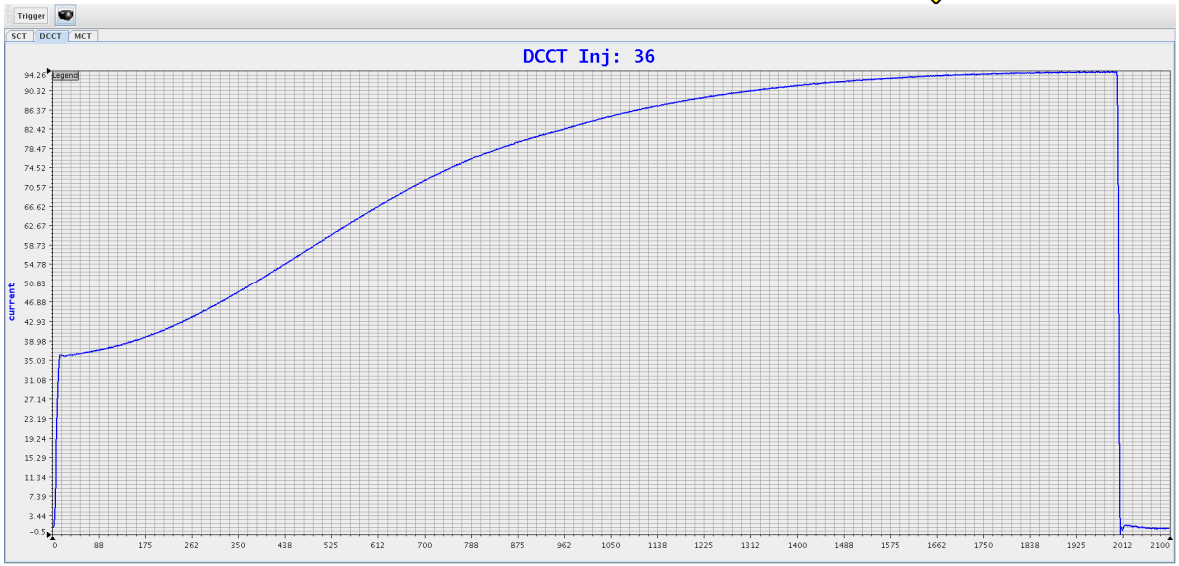
July 7, the first beam was accelerated from 60MeV to 1.6 GeV

RF parameter optimization



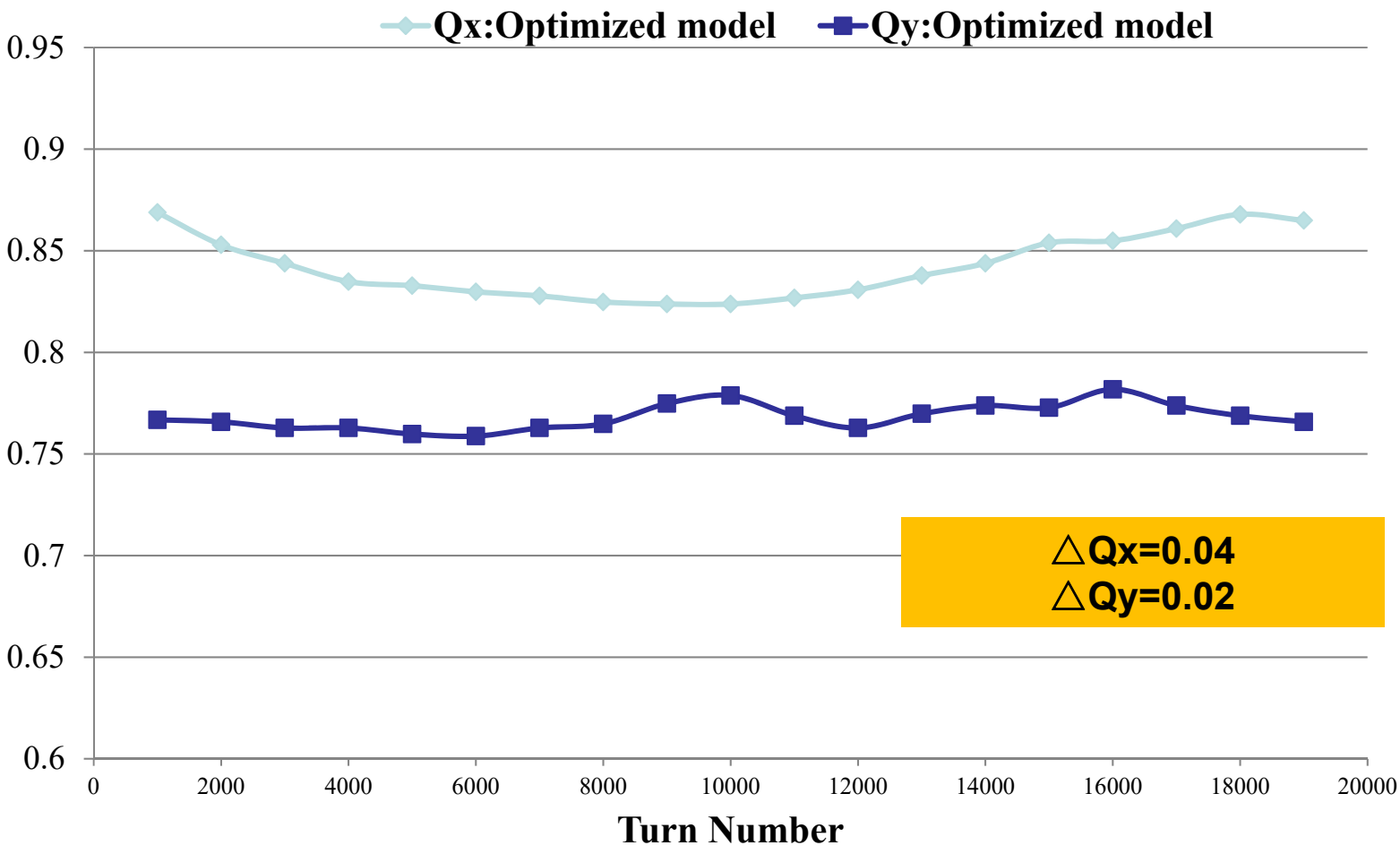


Tuning RF amplitude frequency curve, phase



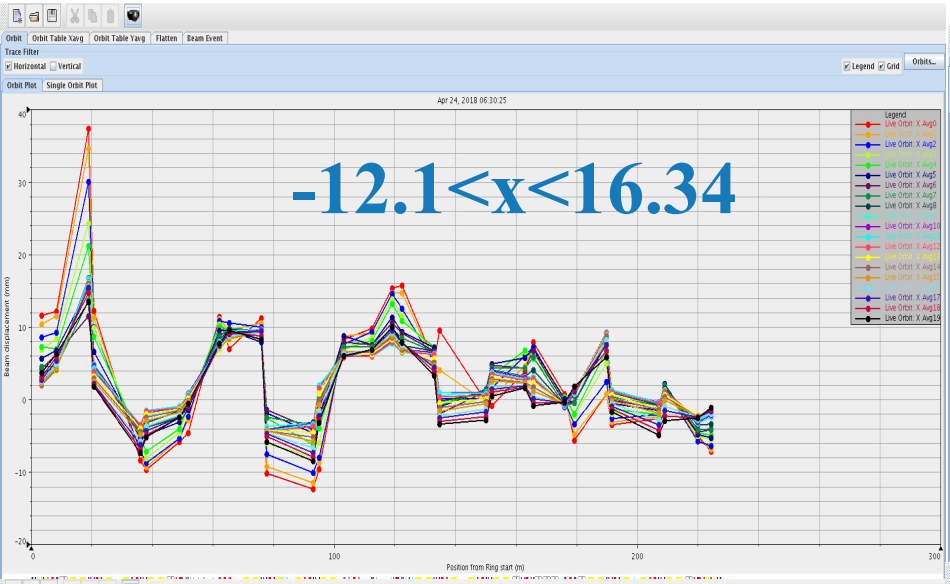
Finally reached about 99% beam transmission

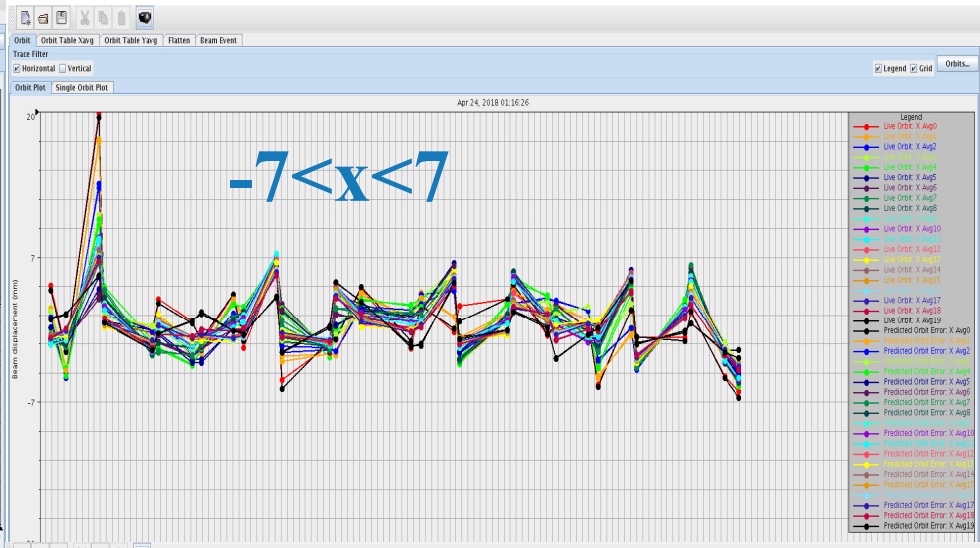
Tune in one cycle

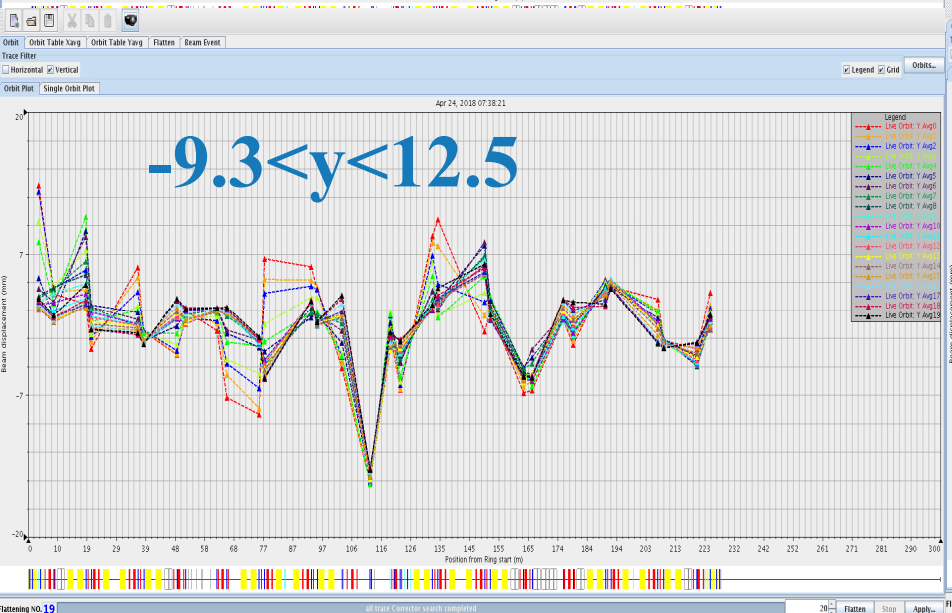


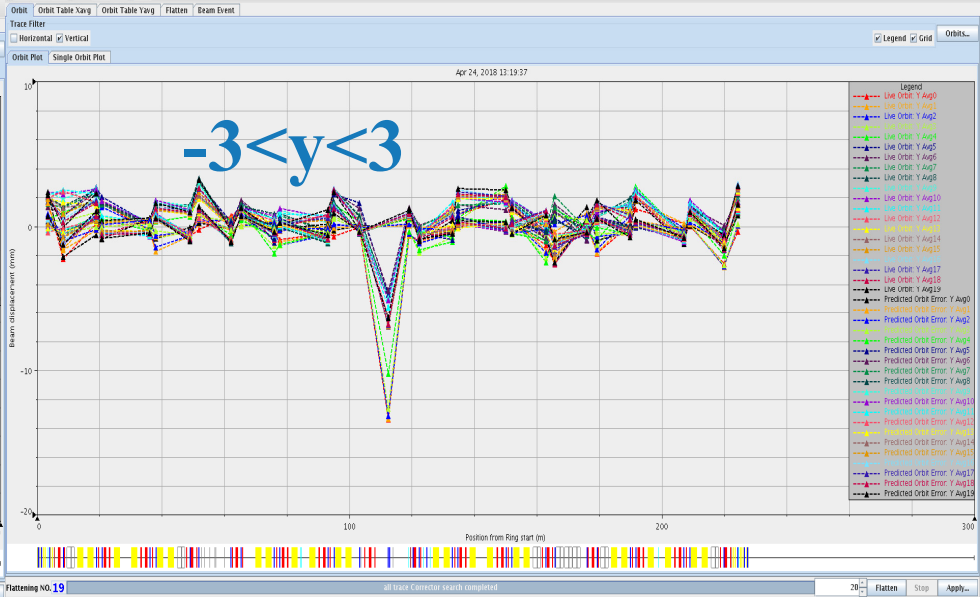
COD correction

20 orbits at 20 different energy points were chosen to display and correction.



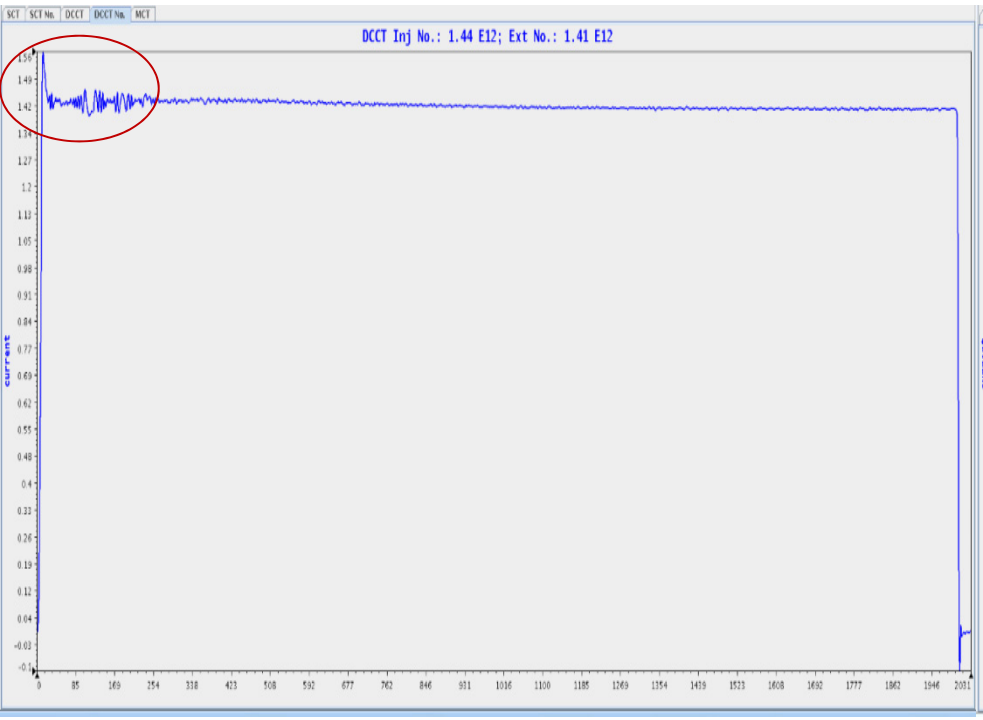




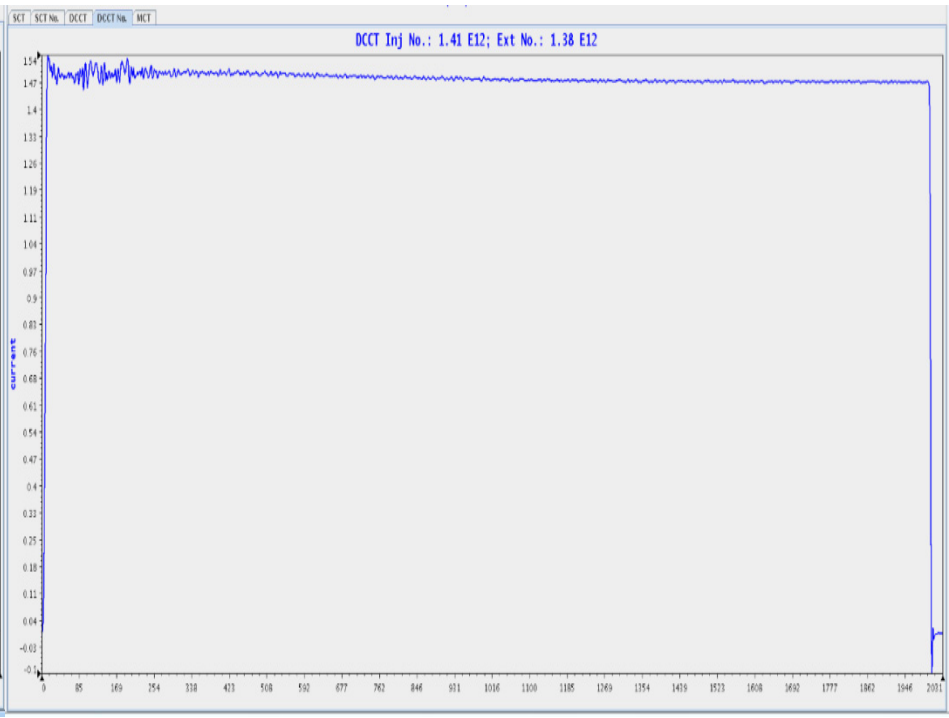


Fixed bump injection and painting injection

Compared to the painting injection, there is more beam loss during the injection process for the fixed bump injection.



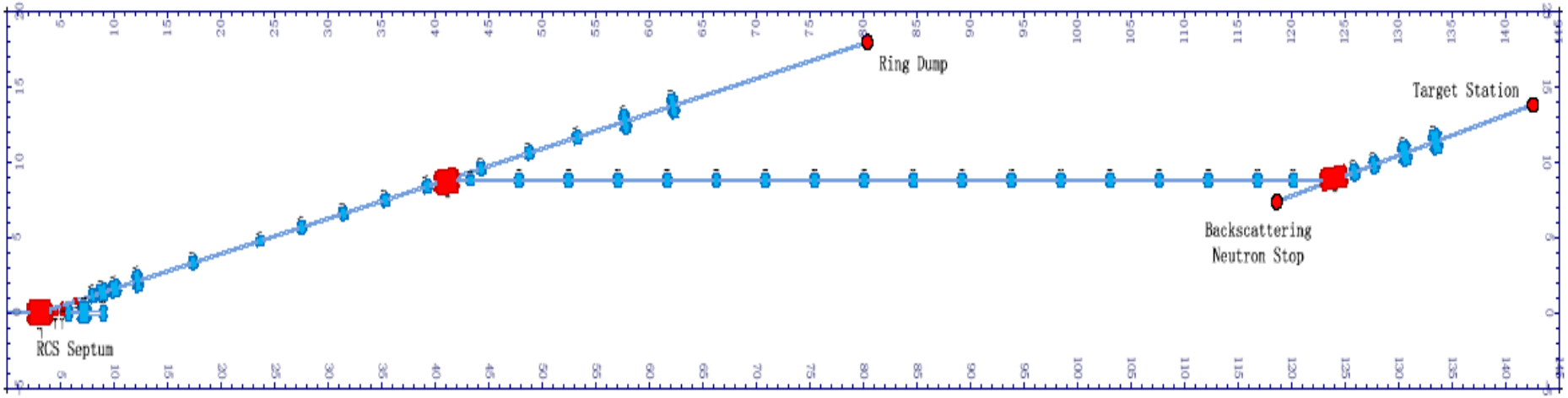
Fixed bump injection



Painting injection

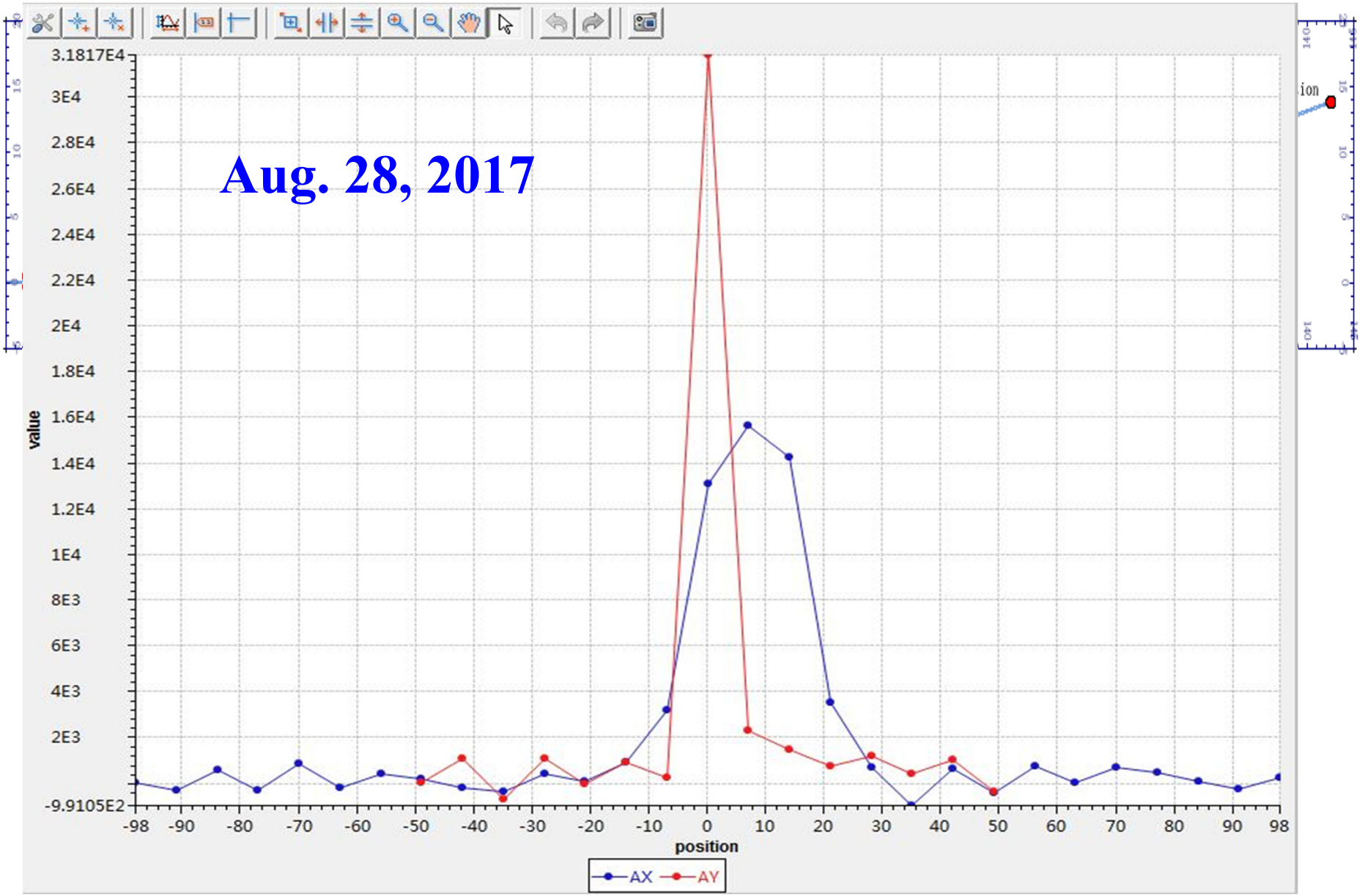
The first beam on the target

散裂中子源
China Spallation Neutron Source



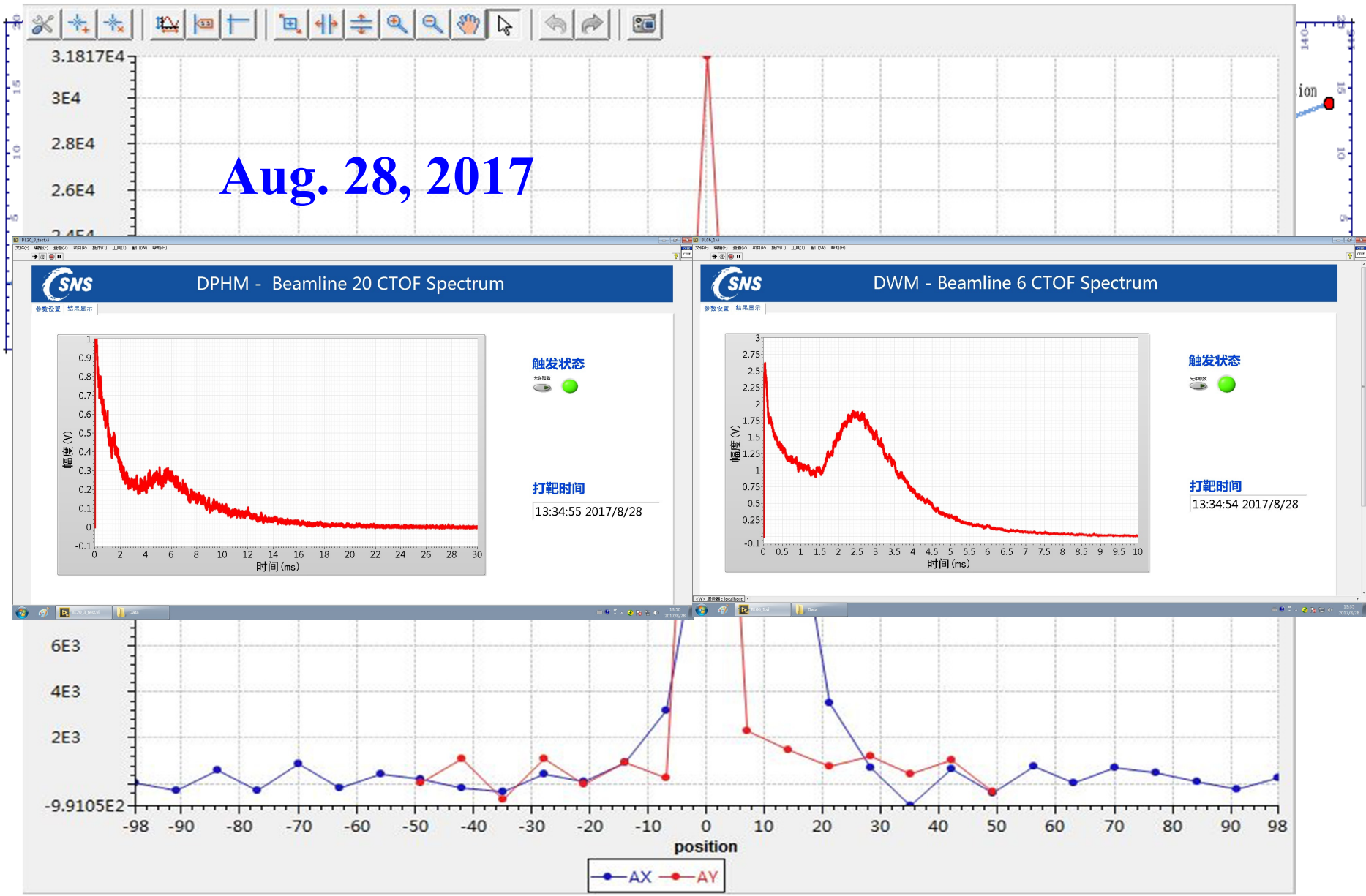
The first beam on the target

散裂中子源
China Spallation Neutron Source



The first beam on the target

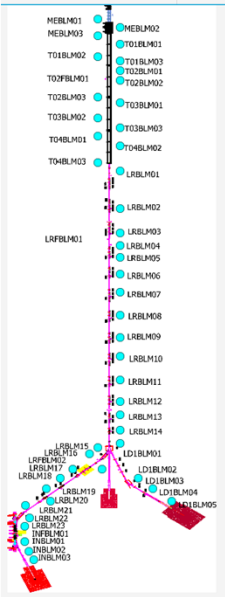
散裂中子源
China Spallation Neutron Source



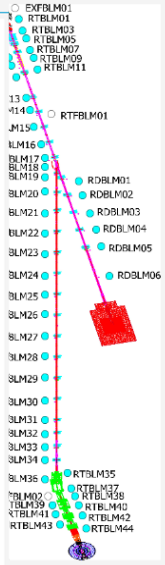
Beam loss and control

散裂中子源
China Spallation Neutron Source

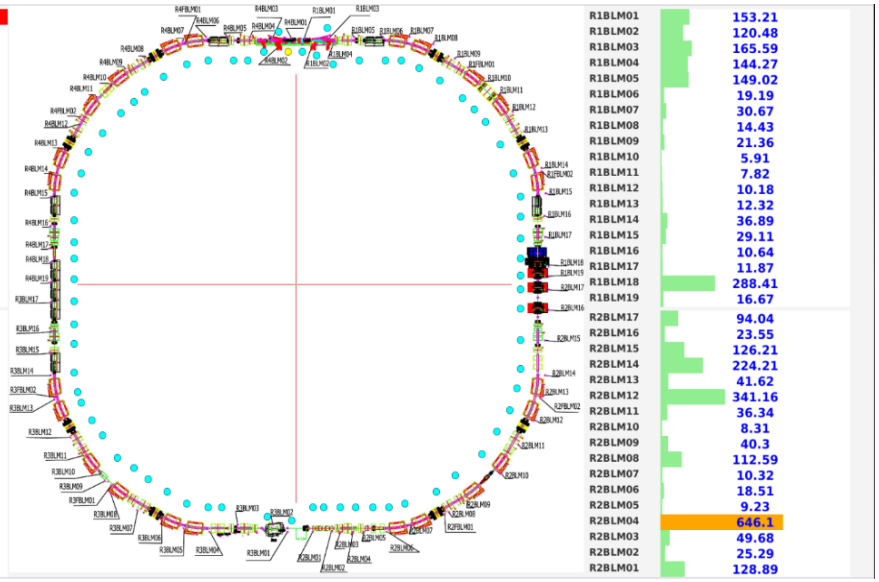
2018/03/27 08:35:26



MEBLM01	28.36	LRBLM09	3.75
MEBLM02	45.96	LRBLM10	8.75
MEBLM03	240.45	LRBLM11	6.56
T01BLM01	0.62	LRBLM12	5.31
T01BLM02	52.49	LRBLM13	-0.31
T01BLM03	88.44	LRBLM14	-41.85
T02BLM01	8.44	LD1BLM02	21.57
T02BLM02	-29.38	LD1BLM01	0.63
T02BLM03	-43.46	LRBLM15	8.12
T03BLM01	-72.49	LRBLM16	12.81
T03BLM02	-81.92	LRBLM17	-9.69
T03BLM03	-0	LRBLM18	4.38
T04BLM01	7.19	LRBLM19	5.31
T04BLM02	-78.74	LRBLM20	718.51
T04BLM03	63.78	LRBLM21	12.19
LRBLM01	-0.31	LRBLM22	44.36
LRBLM02	-0.63	LRBLM23	81.85
LRBLM03	193.88	INBLM01	908.89
LRBLM04	71.56	INBLM02	190.37
LRBLM05	24.06	INBLM03	266.23
LRBLM06	-1.88	LD1BLM03	-22.2
LRBLM07	1.25	LD1BLM04	8.75
LRBLM08	14.06	LD1BLM05	-5.62



RTBLM01	48.43	RTBLM13	11.87	RTBLM26	5.94
RTBLM02	7.19	RTBLM14	5.62	RTBLM27	23.44
RTBLM03	6.87	RTBLM15	5	RTBLM28	26.57
RTBLM04	5	RTBLM16	12.5	RTBLM29	23.75
RTBLM05	3.44	RTBLM17	49.66	RTBLM30	22.82
RTBLM06	2.81	RTBLM18	17.19	RTBLM31	29.36
RTBLM07	3.75	RTBLM19	3.75	RTBLM32	27.16
RTBLM08	3.75	RTBLM20	3.44	RTBLM33	6.25
RTBLM09	10.31	RTBLM21	3.44	RTBLM34	39.06
RTBLM10	4.38	RTBLM22	2.5	RTBLM35	6.25
RTBLM11	2.5	RTBLM23	-4.06	RTBLM36	2.19
RTBLM12	6.56	RTBLM24	5.31	RTBLM37	14.69
		RTBLM25	5	RTBLM38	4.06
				RTBLM39	25.94
				RTBLM40	-45.91
				RTBLM41	17.49
				RTBLM42	3.44
				RTBLM43	3.75
				RTBLM44	7.19
				RDBLM01	232.86
				RDBLM02	88.45
				RDBLM03	192.51
				RDBLM04	35.92
				RDBLM05	32.49
				RDBLM06	122.77

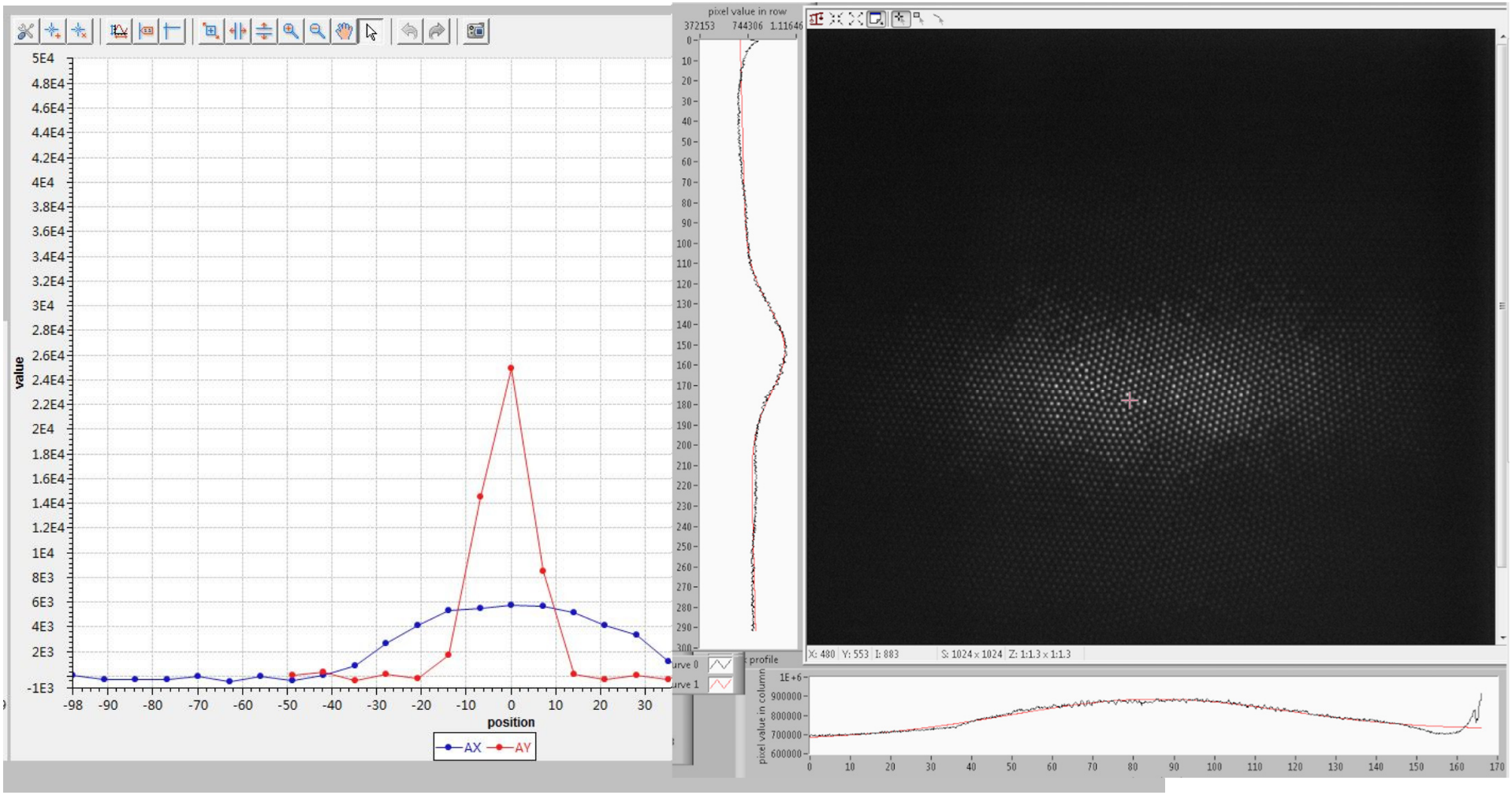


R4BLM01	1373.25	R1BLM01	153.21
R4BLM02	112.19	R1BLM02	120.48
R4BLM03	79.98	R1BLM03	165.59
R4BLM04	16.72	R1BLM04	144.27
R4BLM05	27.27	R1BLM05	149.02
R4BLM06	22.11	R1BLM06	19.19
R4BLM07	29.12	R1BLM07	30.67
R4BLM08	178.54	R1BLM08	14.43
R4BLM09	53.36	R1BLM09	21.36
R4BLM10	24.23	R1BLM10	5.91
R4BLM11	15.12	R1BLM11	7.82
R4BLM12	14.54	R1BLM12	10.18
R4BLM13	80.18	R1BLM13	12.32
R4BLM14	18.79	R1BLM14	36.89
R4BLM15	13.33	R1BLM15	29.11
R4BLM16	67.76	R1BLM16	10.64
R4BLM17	21.3	R1BLM17	11.87
R4BLM18	47.66	R1BLM18	288.41
R4BLM19	65.58	R1BLM19	16.67
R3BLM17	14.26	R2BLM17	94.04
R3BLM16	10.41	R2BLM16	23.55
R3BLM15	11.14	R2BLM15	126.21
R3BLM14	4.48	R2BLM14	224.21
R3BLM13	21.13	R2BLM13	41.62
R3BLM12	16.37	R2BLM12	341.16
R3BLM11	10.95	R2BLM11	36.34
R3BLM10	6.72	R2BLM10	8.31
R3BLM09	6.31	R2BLM09	40.3
R3BLM08	9.56	R2BLM08	112.59
R3BLM07	7.54	R2BLM07	10.32
R3BLM06	7.65	R2BLM06	18.51
R3BLM05	158.54	R2BLM05	9.23
R3BLM04	10.27	R2BLM04	646.1
R3BLM03	814.82	R2BLM03	49.68
R3BLM02	35.09	R2BLM02	25.29
R3BLM01	37.37	R2BLM01	128.89

From single shot to 10kW

- 2017.10.25~11. 1, optimize the beam loss, RTBT orbit, beam size
- 11. 1, 1Hz, ~ 400W
- 11. 6, shut down, open the tunnel, and measure the residual dose, ~μSv/level
- 11. 6, 5Hz, ~2.5kW
- 11. 9, shut down, open the tunnel, and measure the residual dose, ~μSv/level
- 11. 9, 25Hz, 10kW

Beam profile monitor



Summary

- The beam commissioning with 60 MeV and 80MeV linac beam have been successfully performed;
- The test operation was done, with the max. beam power of 25kW, and beam time more than 1200hrs were provided for the commissioning of neutron spectrometer and the experiment for user's samples;
- After the official acceptance in the coming July, the beam power will be increased step by step, and the facility will open to user;
- The upgrade of the facility, 500kW beam power and more neutron spectrometers, will be started soon.


Thank you!