

# Beam Commissioning of CSNS Accelerators

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*for CSNS accelerator team*

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CAS



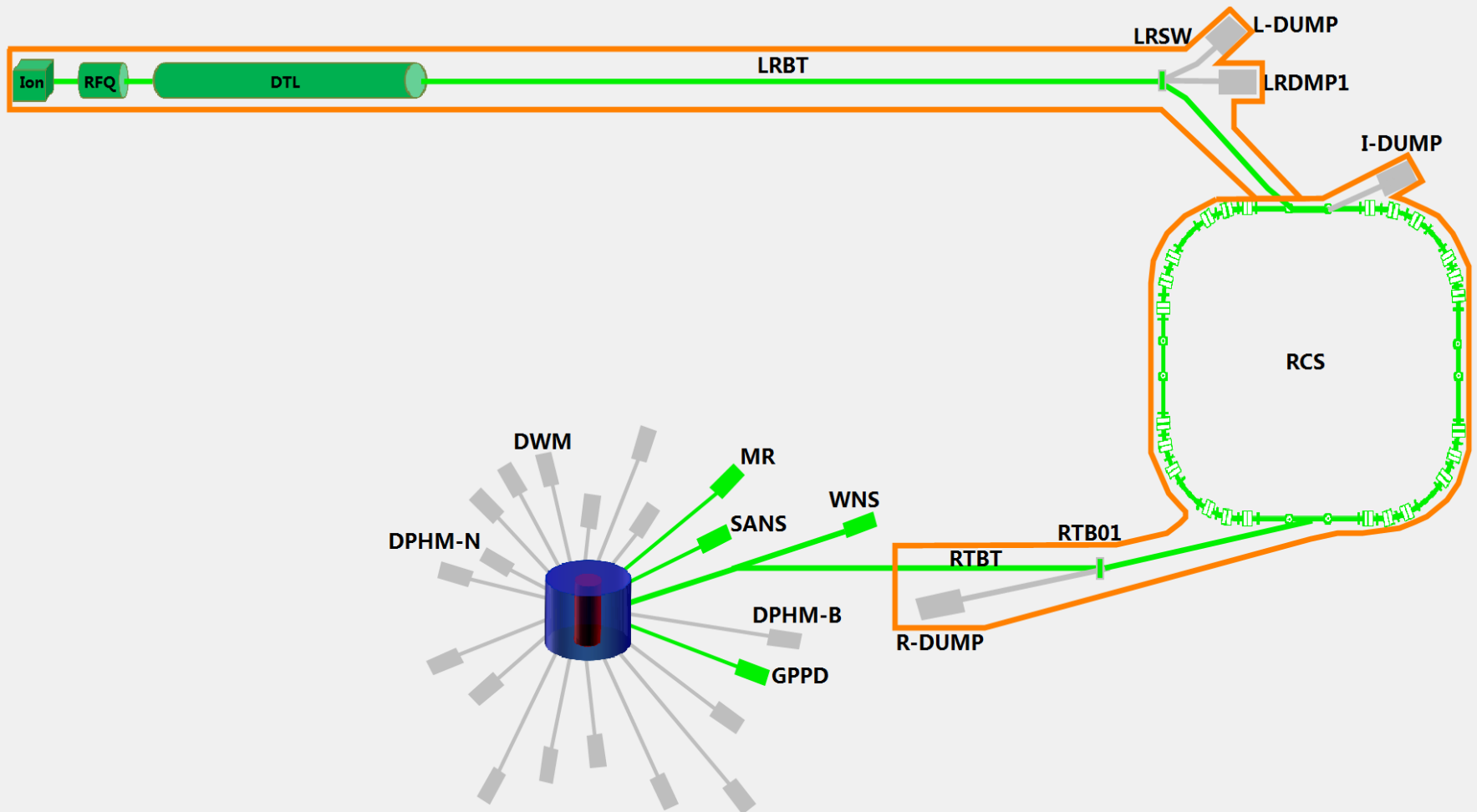
May 3, 2018, Vancouver

# Outline

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

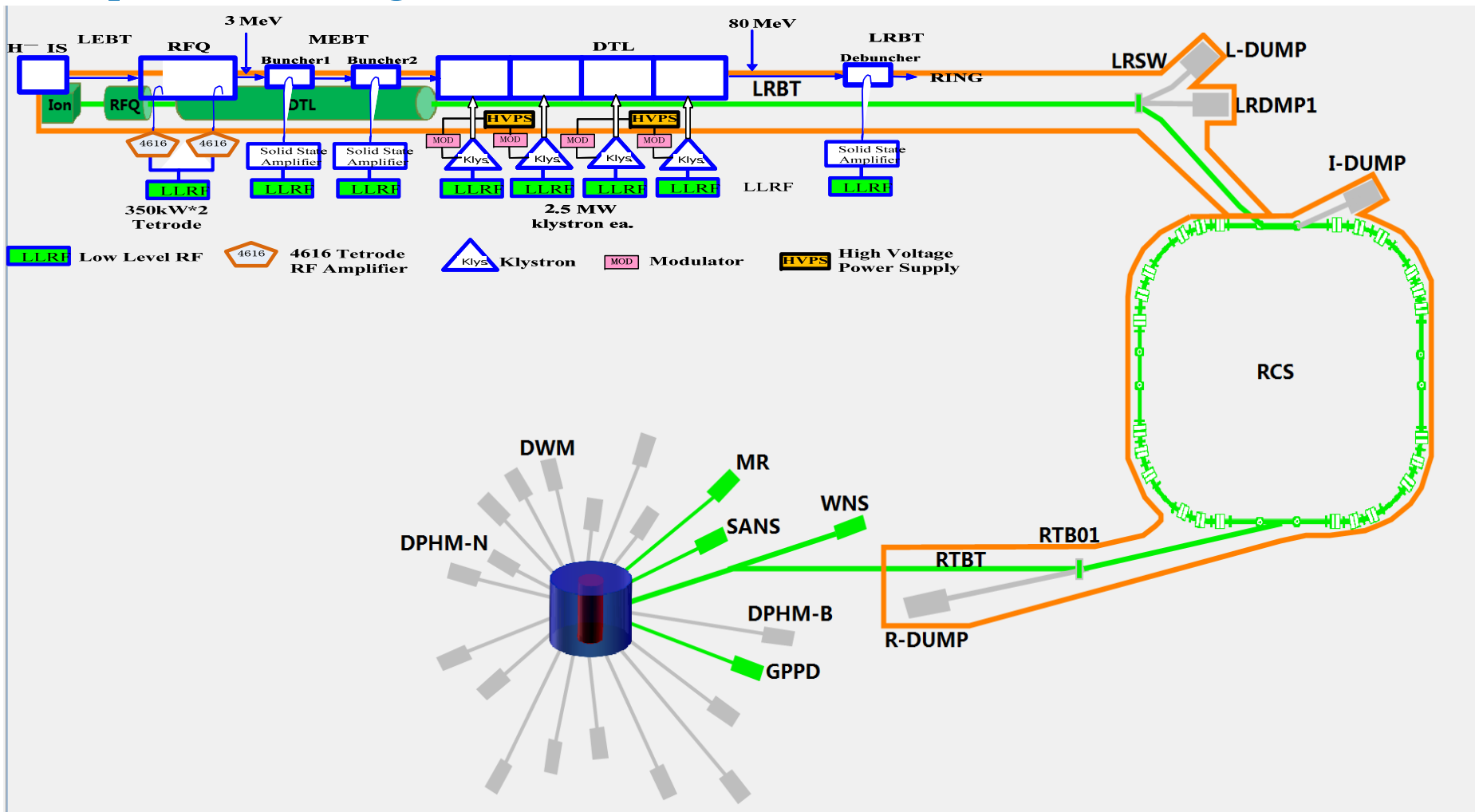
# Project Overview

The phase-I CSNS facility consists of an 80-MeV  $H^-$  linac, a 1.6-GeV RCS, beam transport lines, a target station, and 3 instruments.



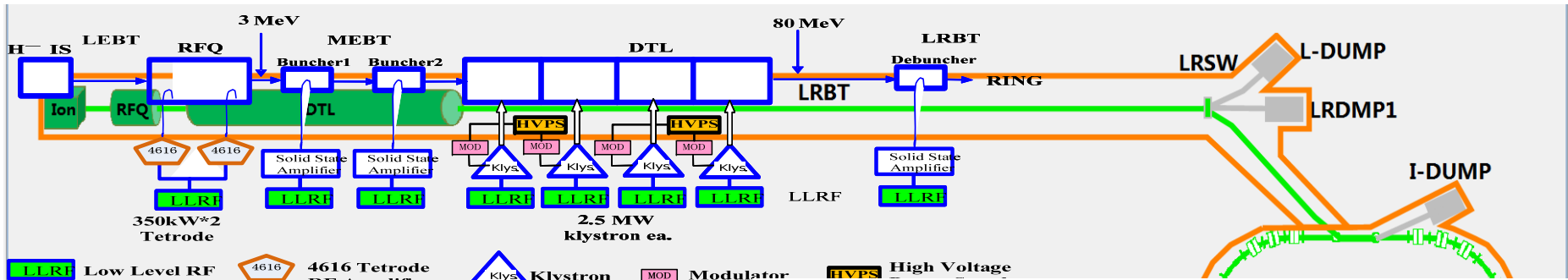
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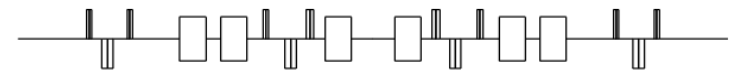


# Project Overview

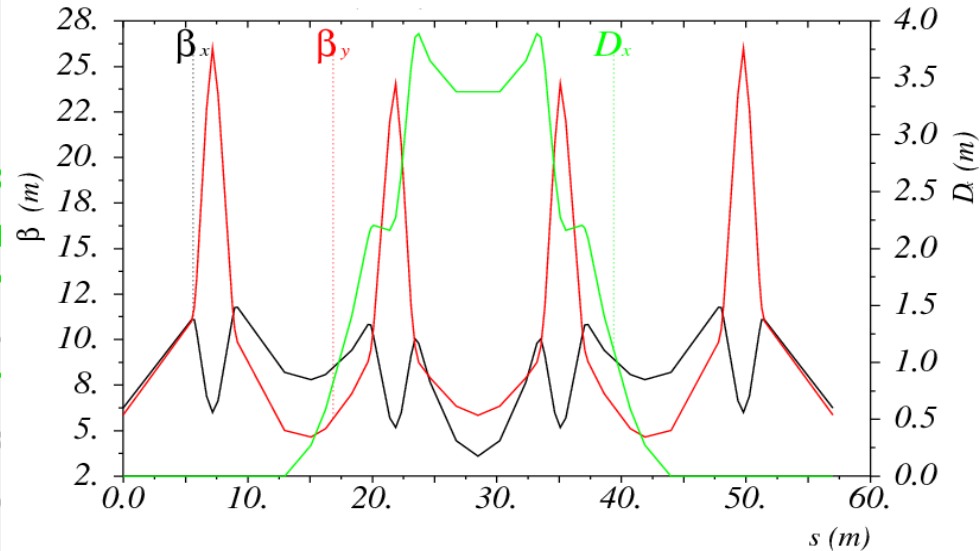
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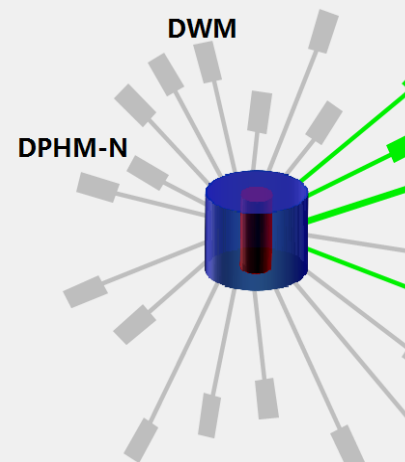
LLRF Low Level RF    4616 4616 Tetrode RF Amplifier    Klys Klystron    MOD Modulator    HVPS High Voltage



CSNS RCS LATTICE

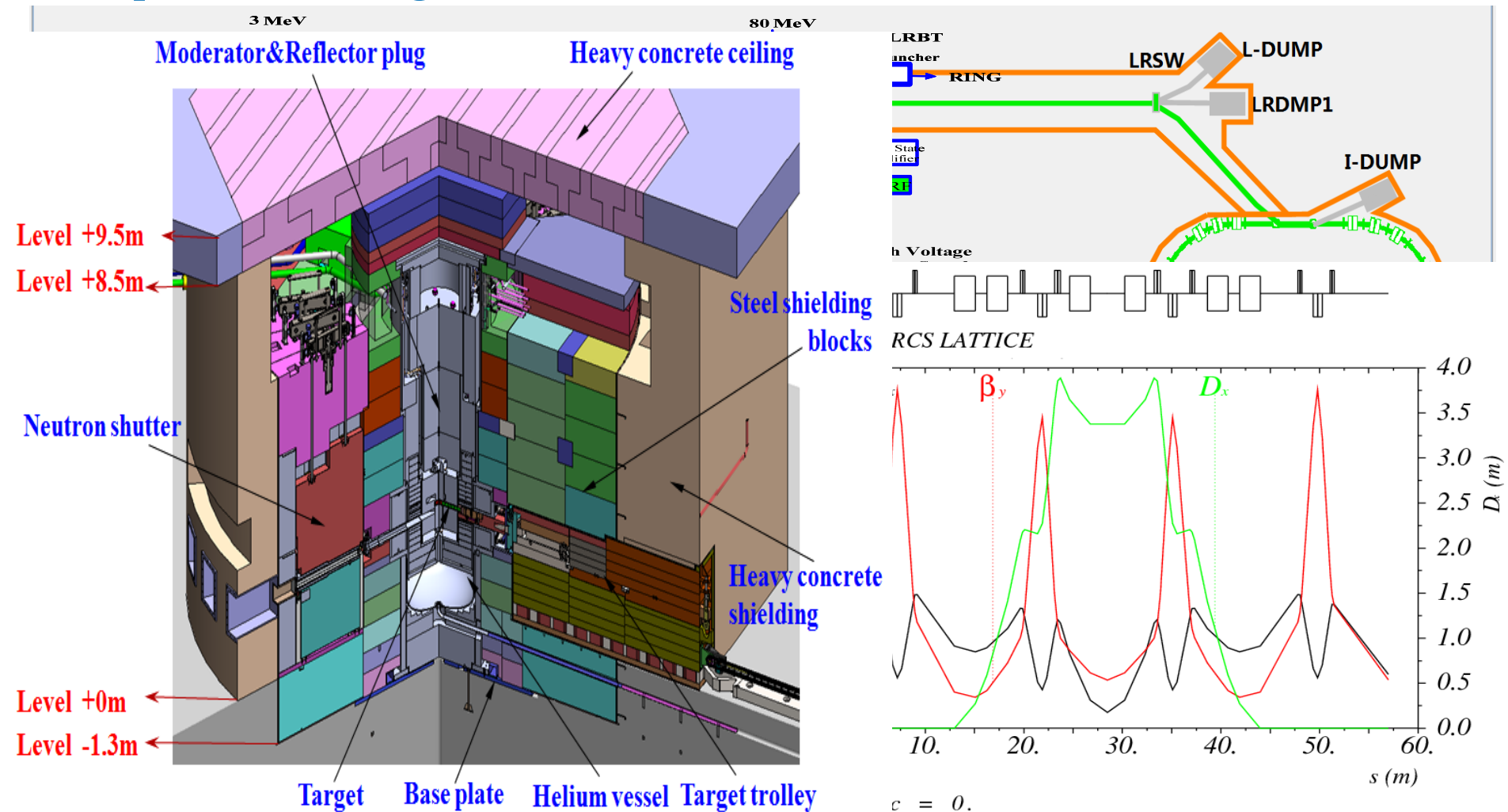


$\delta_E / p_{0c} = 0.$



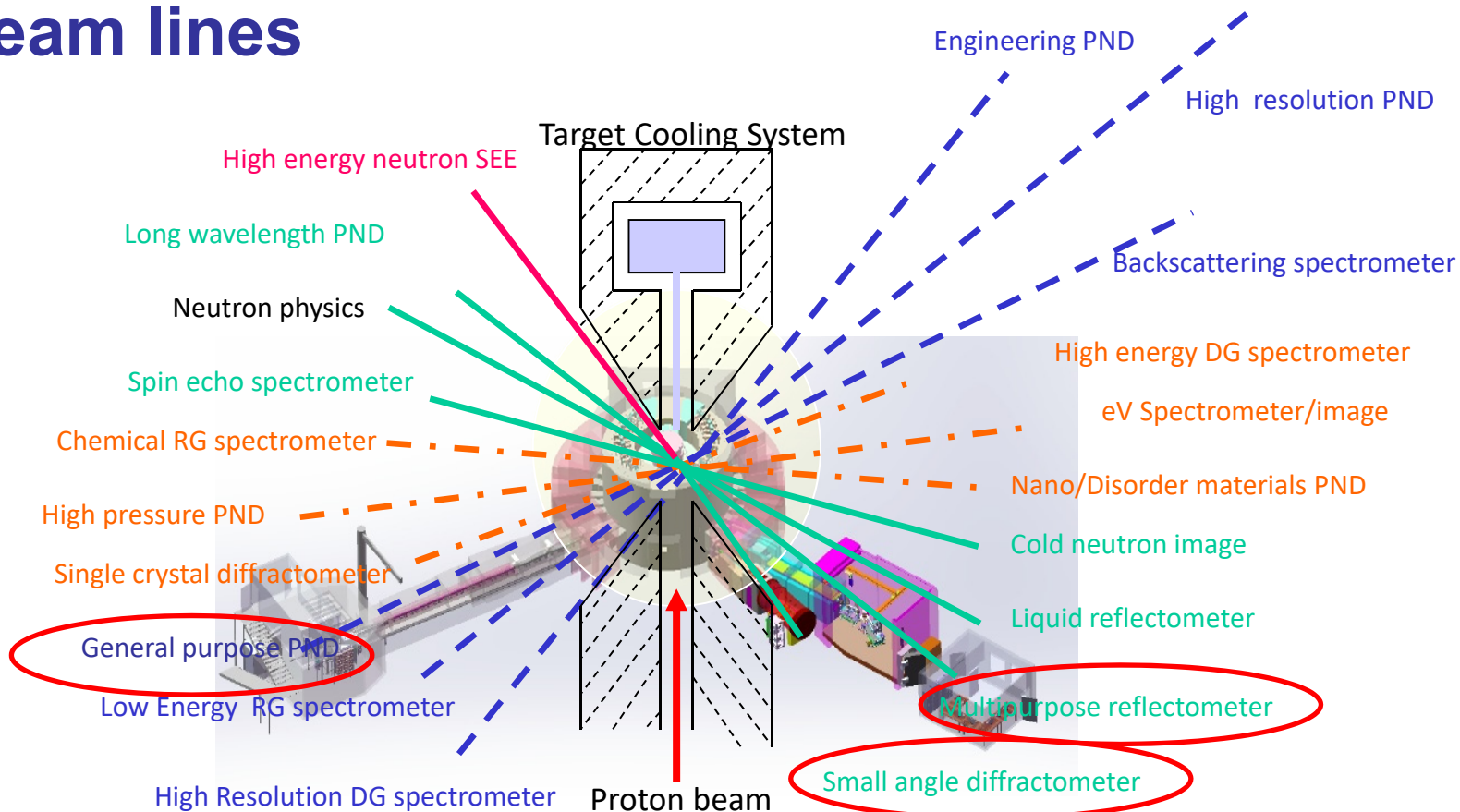
# Project Overview

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# Neutron Instruments

## 20 beam lines



(PND: Powder Neutron Diffractometer; RG/DG: Reversal/Direct Geometry)

Moderator:

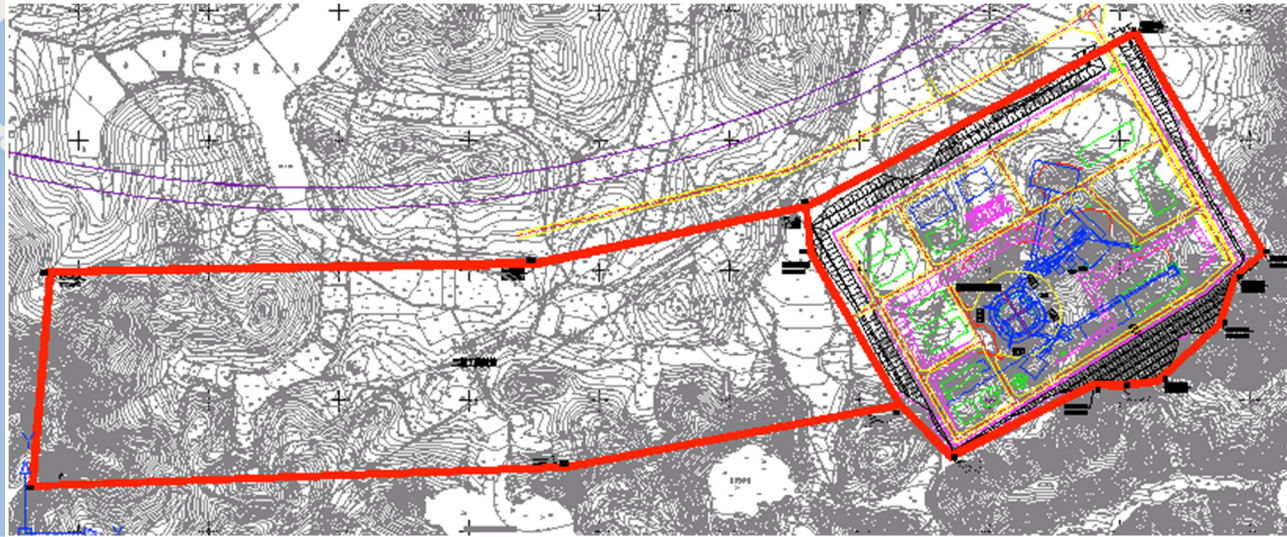
--- D+P, LH2  
(20K)

— C, LH2  
(20K)

- - - D, Water  
(300K)

- Feb. 2001** idea of CSNS discussed
- June 2005** proposal approved in principle by the central government (CD0)
- Jan. 2006** prototyping R&D started
- Sept. 2008** proposal approved
- Oct. 2009** feasibility study report reviewed
- April 2010** site preparation start
- Feb. 2011** feasibility study report approved (CD-1)
- May 2011** preliminary design report approved (CD-2)
- Sept. 2011** construction started (CD-3), component fabrication started
- May 2012** civil construction started
- Oct. 2014** Frontend and LRBT started installation in Linac tunnel
- April 2015** the RCS magnets started installation in RCS tunnel
- May 2015** the Helium Vessel of the target station installed
- Jan. 2016** DTL-1 Beam commissioning
- Apr. 2017** Linac beam commissioning
- May. 2017** RCS commissioning start
- Aug. 2017** first beam on target, first neutron beam
- Mar. 2018** project complete/operation start (6.5 years from start)

## Site Area



- The site of CSNS locates at Dongguan, Guangdong Province.
- The Dongguan local government provided a land of about  $0.67\text{km}^2$  for CSNS campus.  $0.27\text{-km}^2$  is used for the phase-I construction.

中国散裂中子源装置地A点拍摄 (09. 5. 9)

**May 2009: before land breaking**



2011. 8. 18中国散裂中子源装置地A点拍摄

**Aug 2011: land is prepared**



# CSNS site (Aug. 2017)



# The history of beam commissioning(2017)

**2015.5, Front end pre-commissioning**

**2016.1, DTL1 pre-commissioning**

## **60MeV injection beam commissioning**

**2017.04.15~04.24 Linac (10 days)**

**2017.05.26~06.07 RCS/DC (10 days)**

**2017.06.30~07.12 RCS/AC (13 days)**

**2017.07.13~07.20 RCS/DC (8 days)**

**2017.07.21~07.28 RCS/AC (8 days)**

**2017.08.11~08.28 RCS/AC (18 days)**

**2017.08.28 The first beam on target, first neutron beam**

**2017.11.01~11.09 Promote beam power to 10kW**

# The history of beam commissioning (2018)

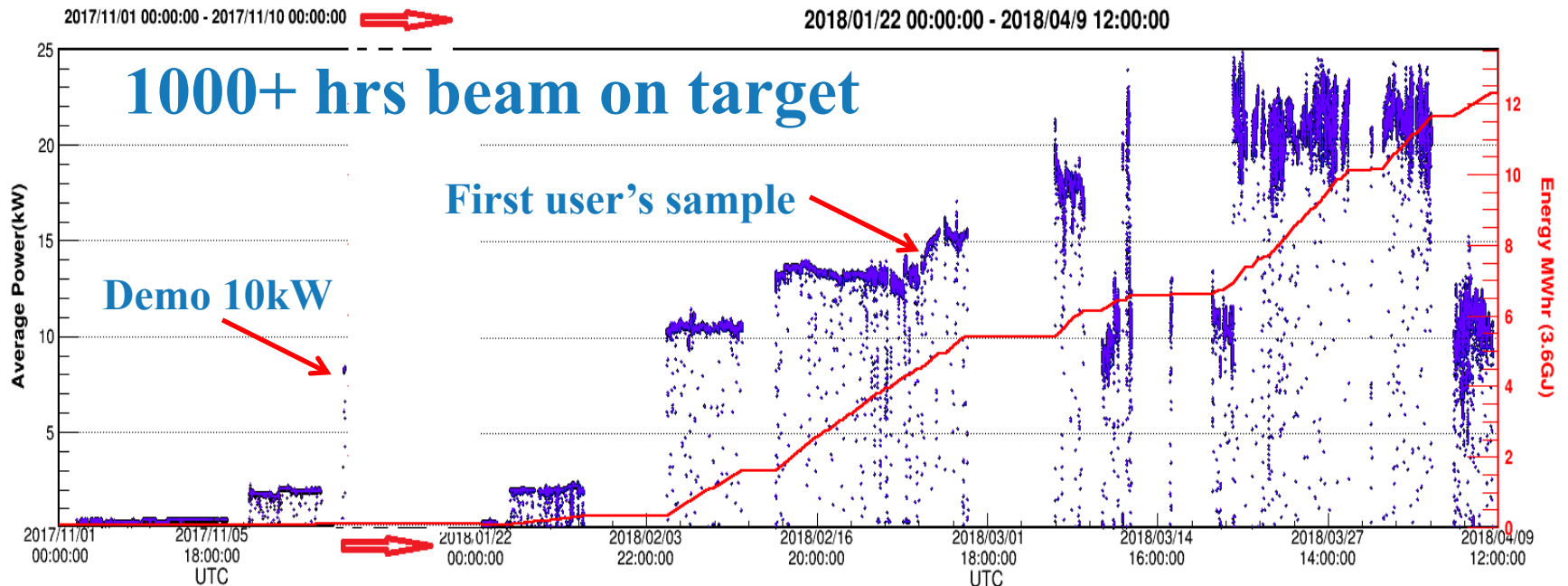
## 80MeV injection beam commissioning

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



# The history of beam commissioning (2018)

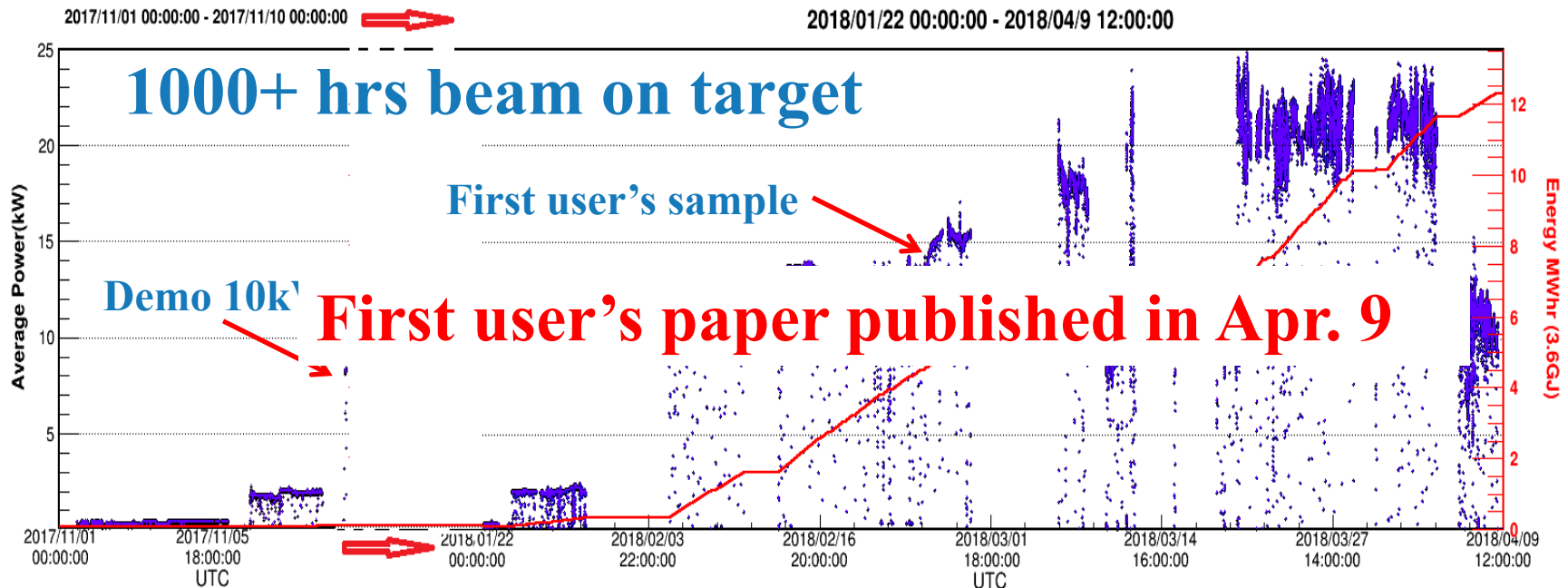
## 80MeV injection beam commissioning

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2018.01.14~01.17 RCS/DC

2018.01.18~01.21 RCS/AC

2018.01.22~ Test operation + beam commissioning



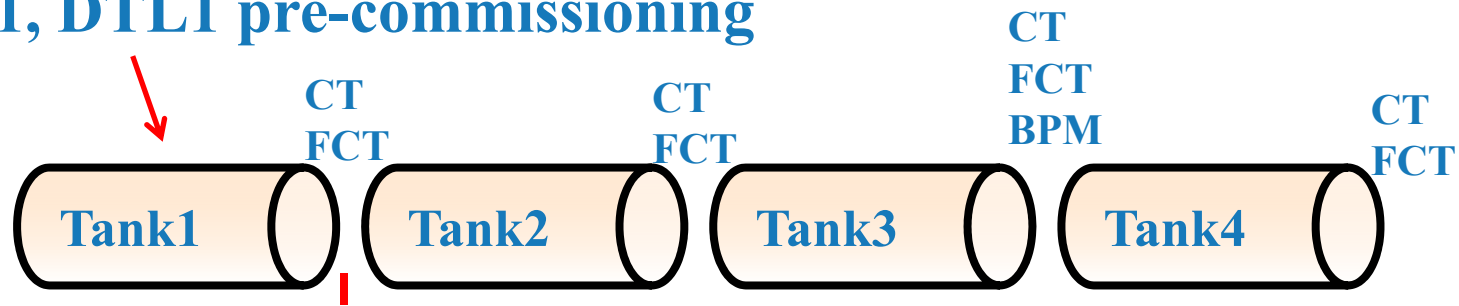
# Commissioning Schedule

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

# Linac Commissioning

# LEBT, RFQ and MEBT

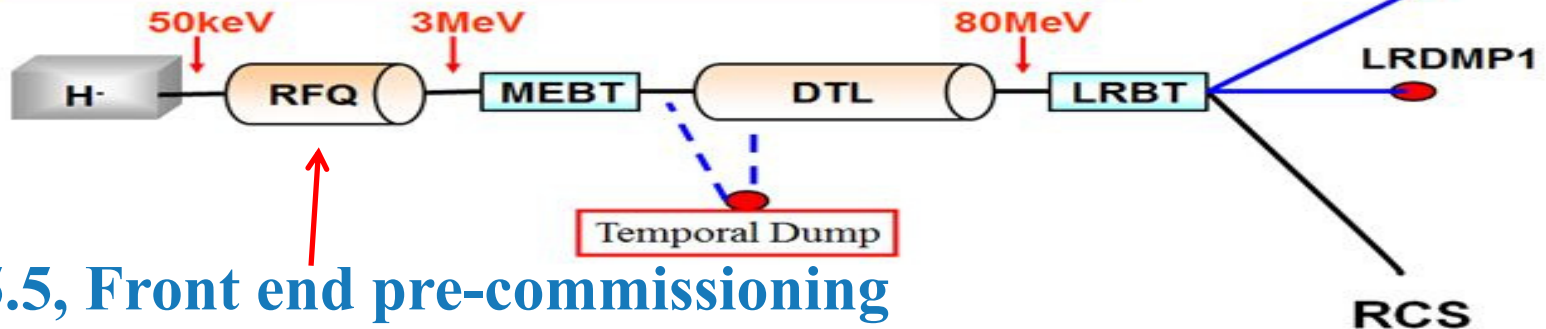
2016.1, DTL1 pre-commissioning



Temporal Beam Diagnostic system:

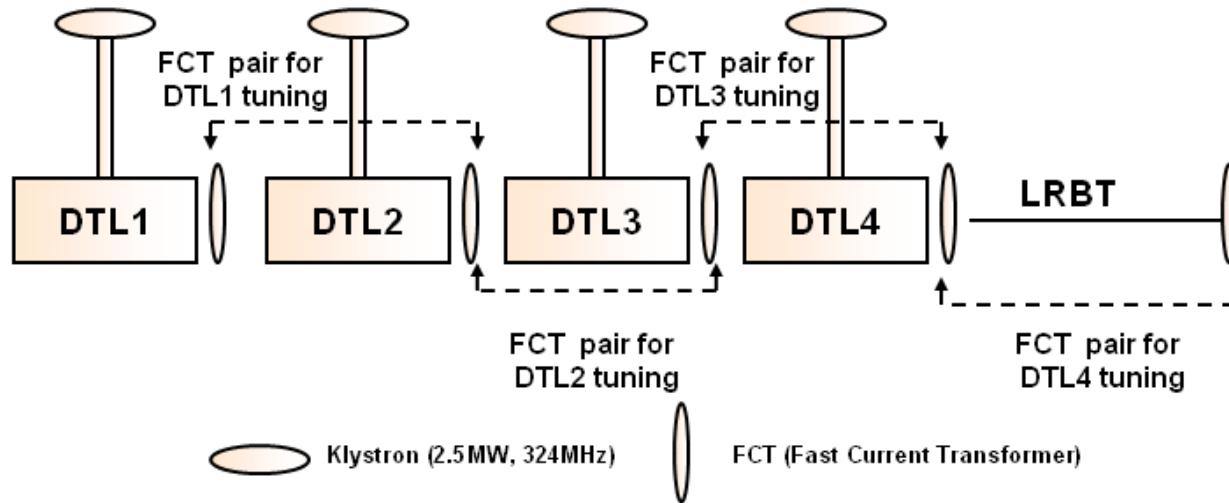
1BPM, 1CT, 2FCT, 1 QEM, 1 x-y steering magnet, 1EM, 1WS  
 1 Energy degrader /Faraday cup, 1 Beam dump(0.163kW)

Beam dumps: Temporal Dump	LRDMP1	L-DUMP
0.163kW	0.2kW	4kW

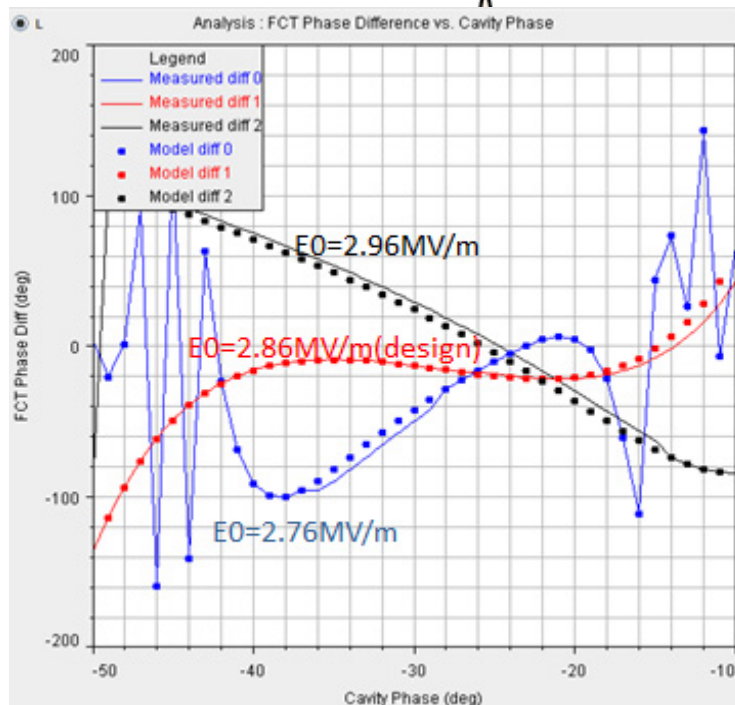
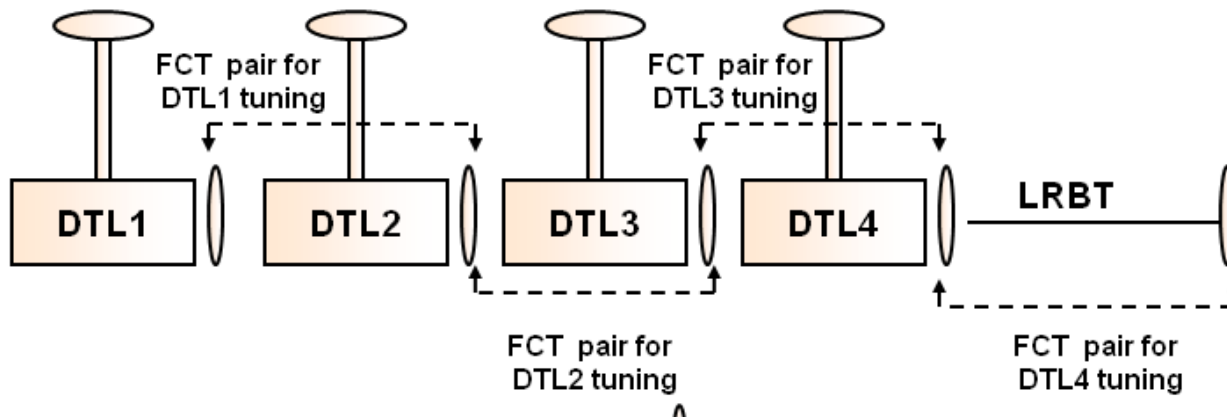


2015.5, Front end pre-commissioning

# Phase Scan Signature Matching Technique



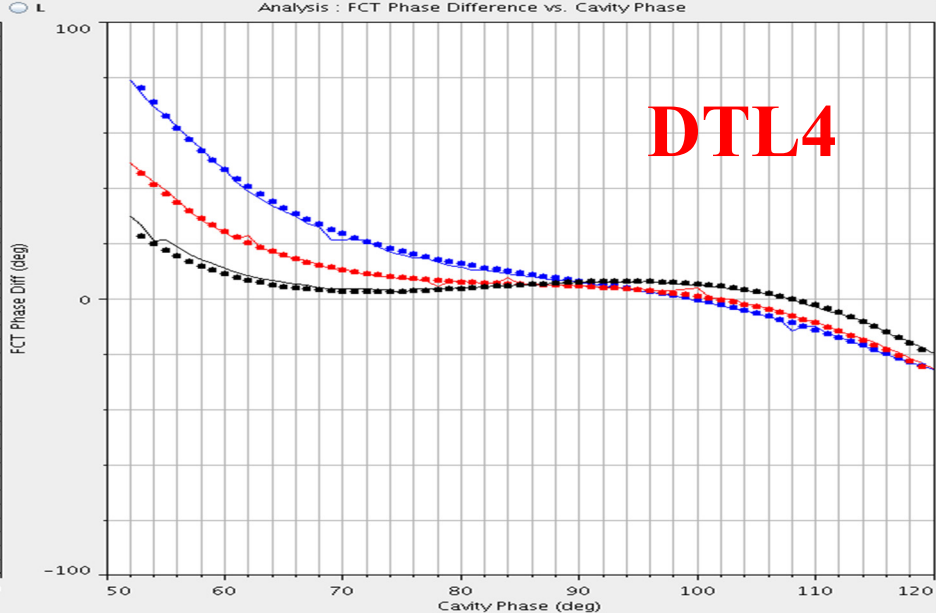
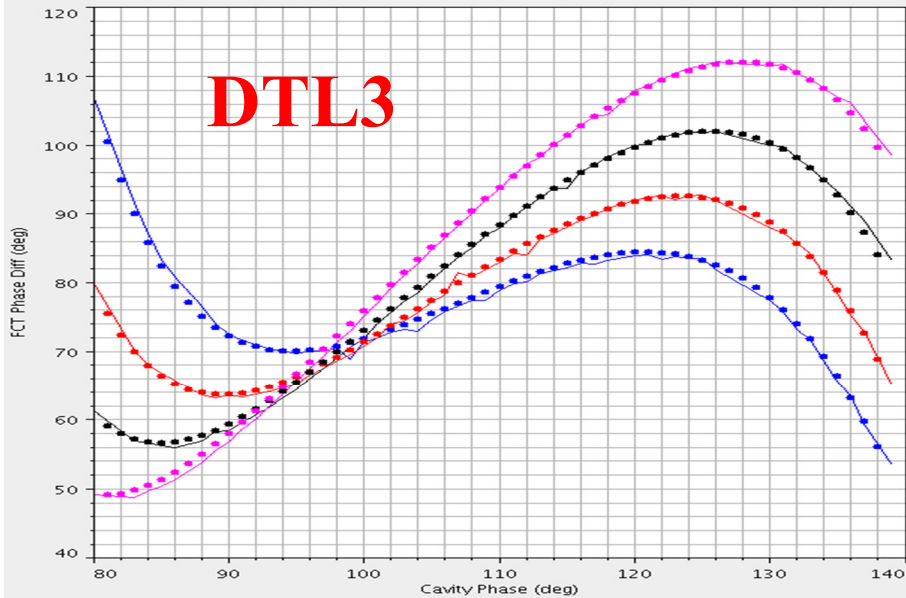
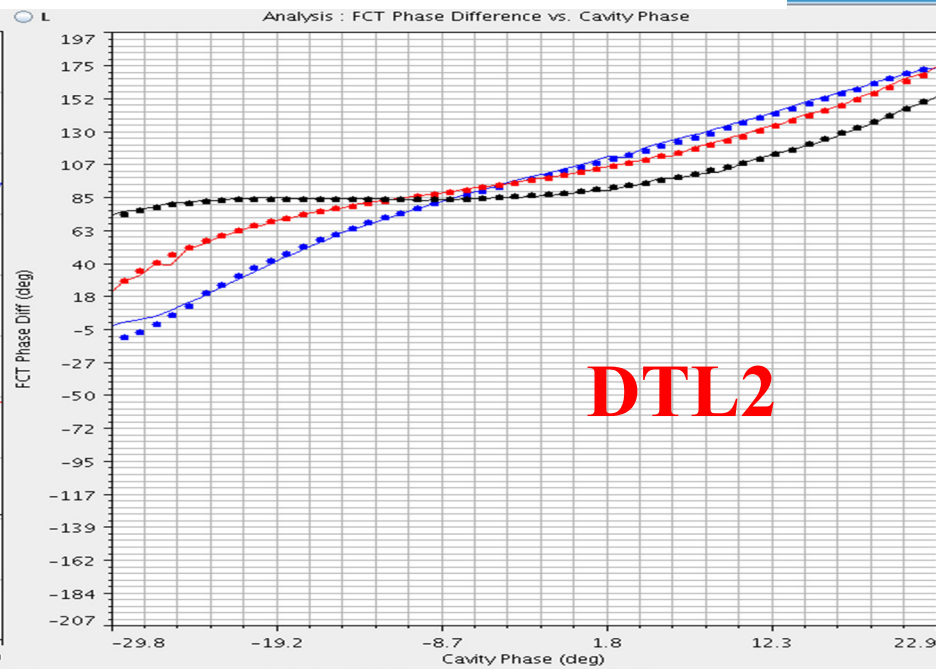
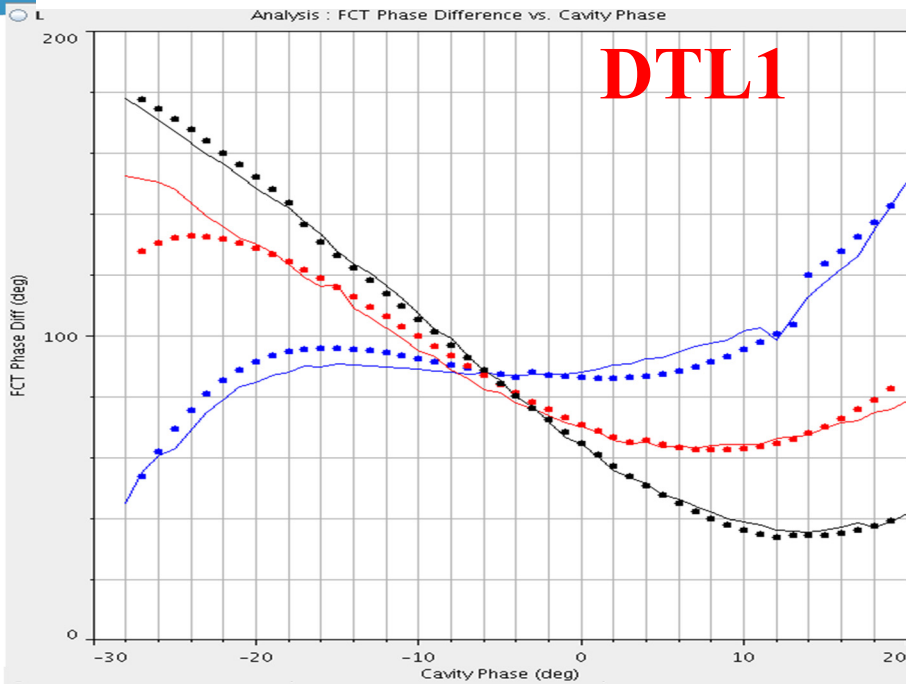
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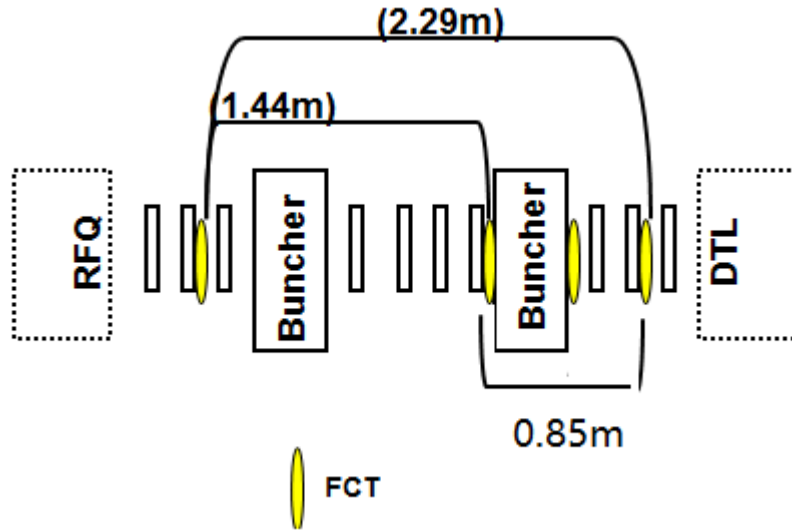
(transformer)

**Model:**  
 Input energy  
 RF amplitude  
 Cavity phase offset

# Phase Scan for 4 DTL tanks



# Energy measurement



Short pair 1:  $L=1.44\text{m}$ ,  $N=19\beta\lambda$

Short pair 2:  $L=0.85\text{m}$ ,  $N=11\beta\lambda$

Long pair:  $L=2.29\text{m}$ ,  $N=30\beta\lambda$

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

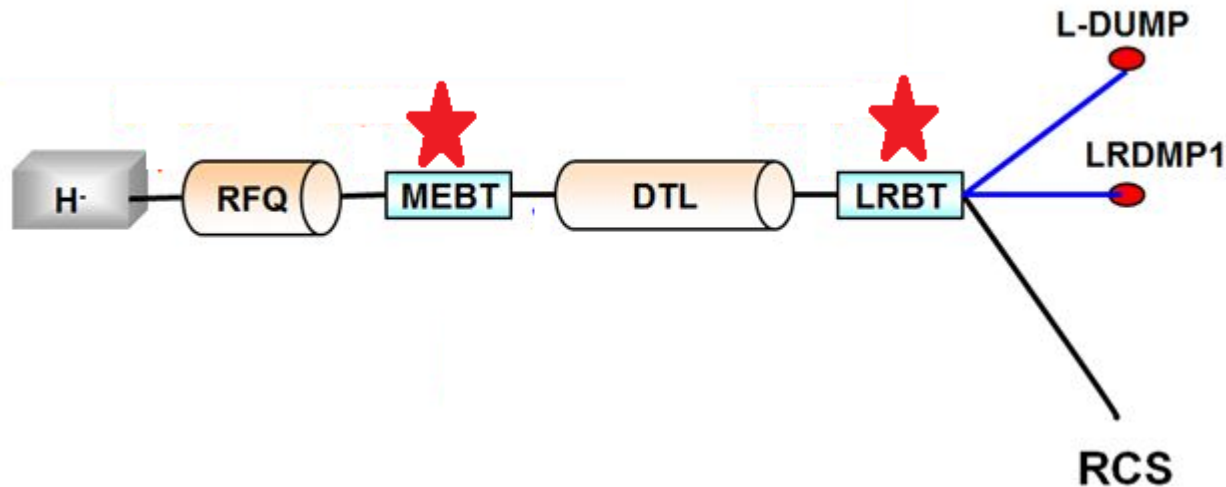
$$v = \frac{L}{nT + \Delta t}$$

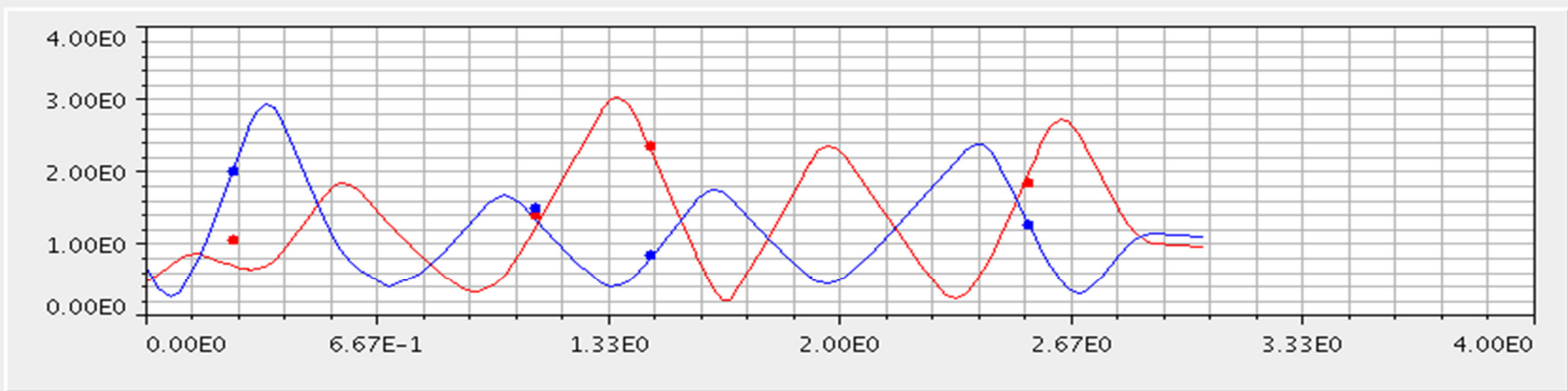
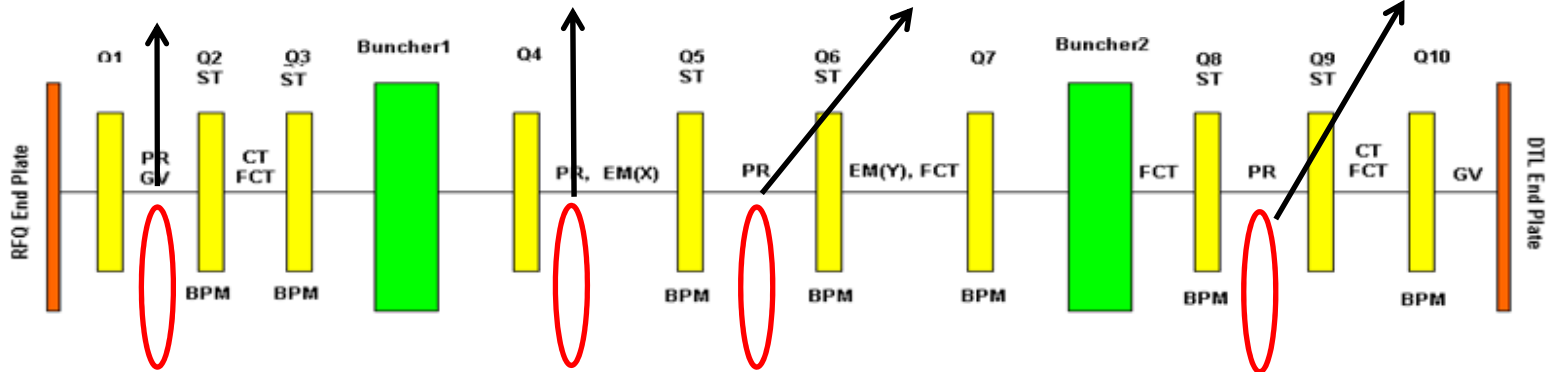
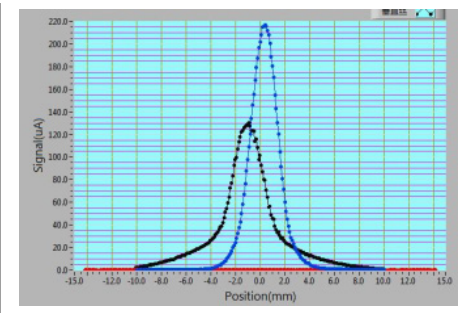
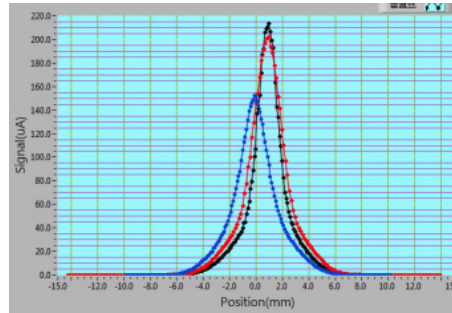
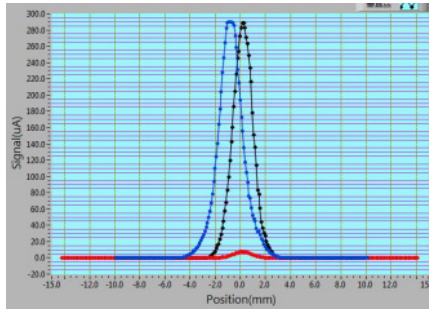
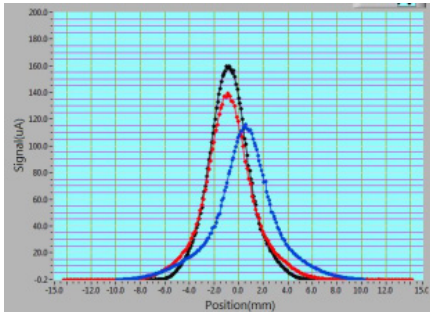
	$\Delta W(\text{ToF})$	$\Delta W(\text{Phase scan})$
RFQ	0.1%	0.12%
DTL1	+0.2%	+0.01%
DTL2	+0.26%	+0.09%
DTL3	+0.47%	-0.03%
DTL4	+0.3%	+0.1%

The energy deviation is all < 0.5%

# Transverse Matching

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



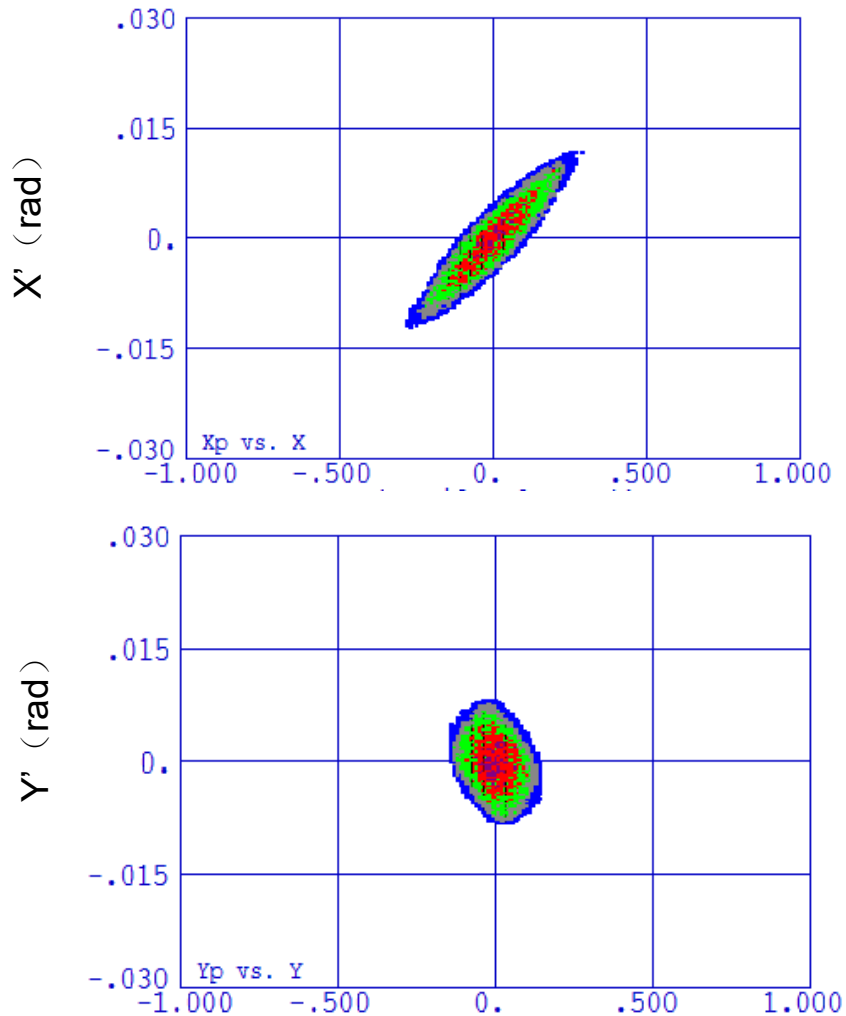




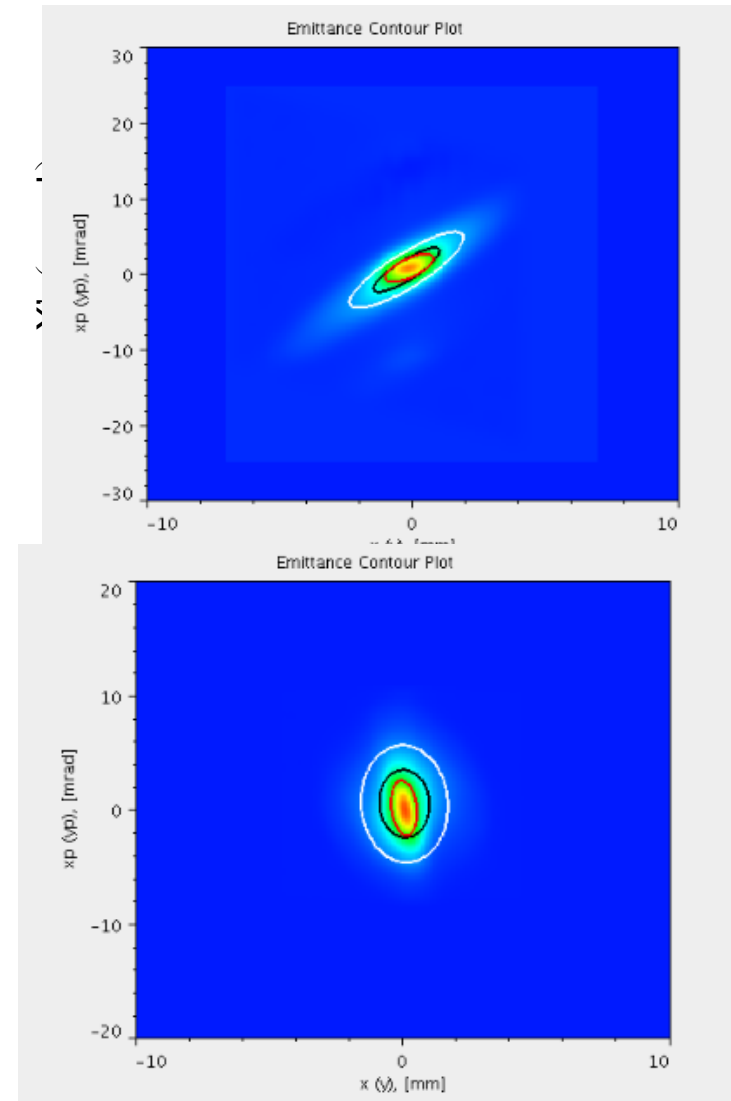
# Emittance measurement (MEBT)

裂中子源  
neutron Source

## Simulated beam distribution at the EM location

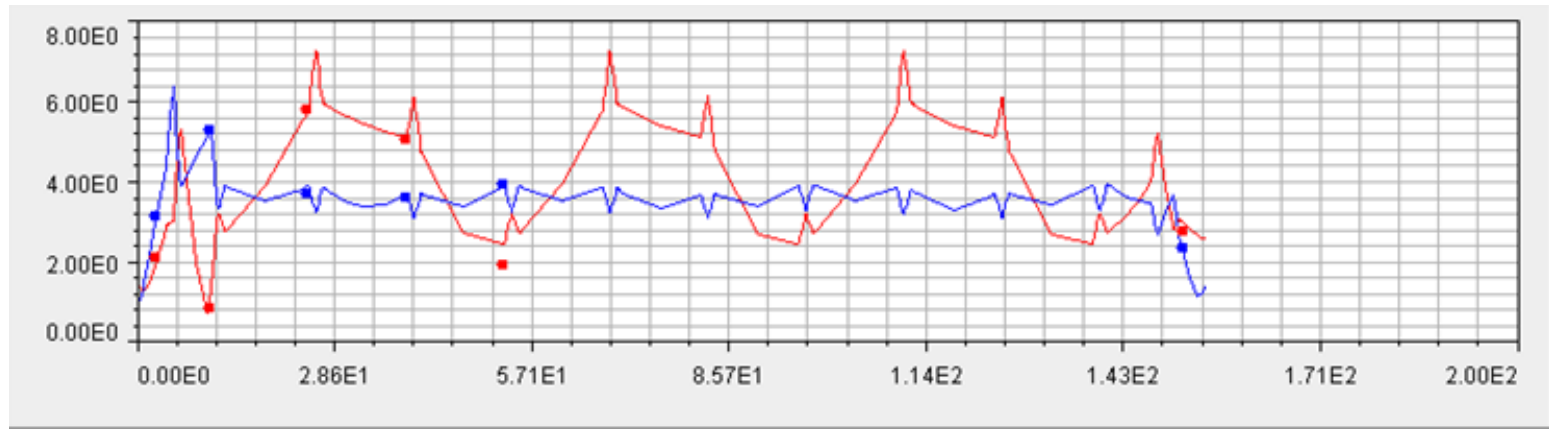


## Measured beam distribution at the EM location

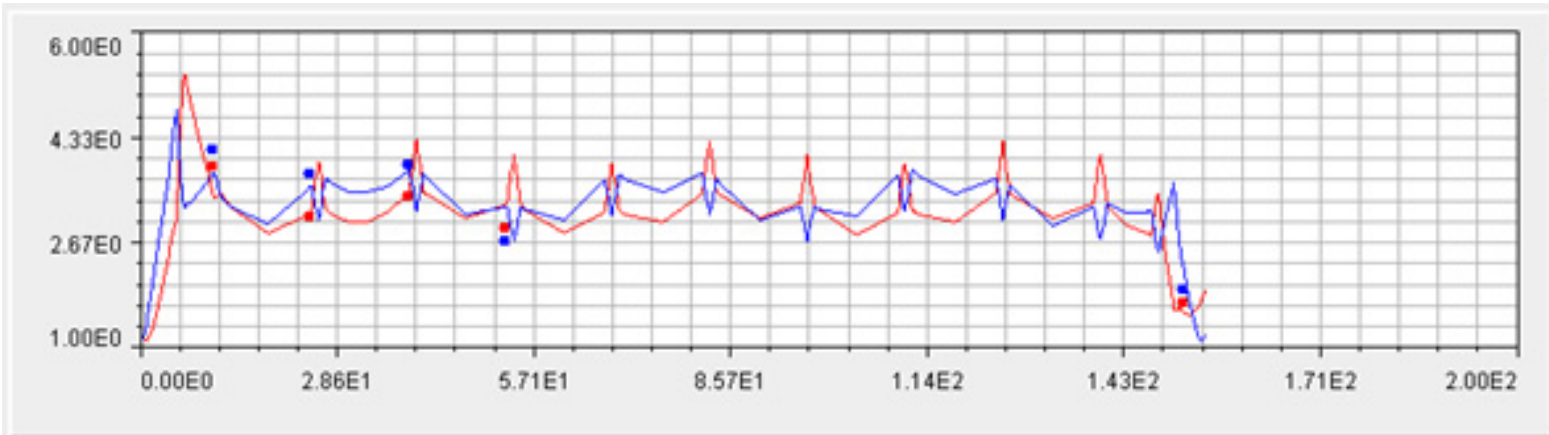


## Transverse matching (LRBT)

Before  
matching

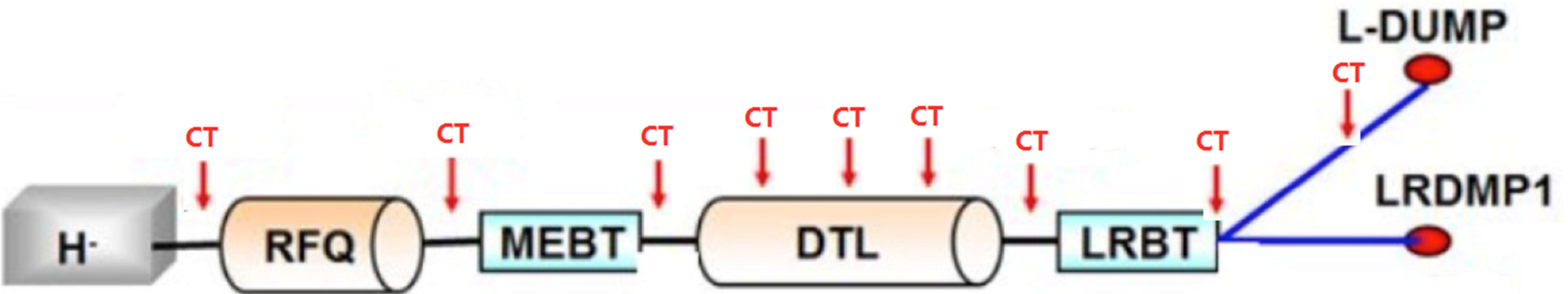


After  
matching



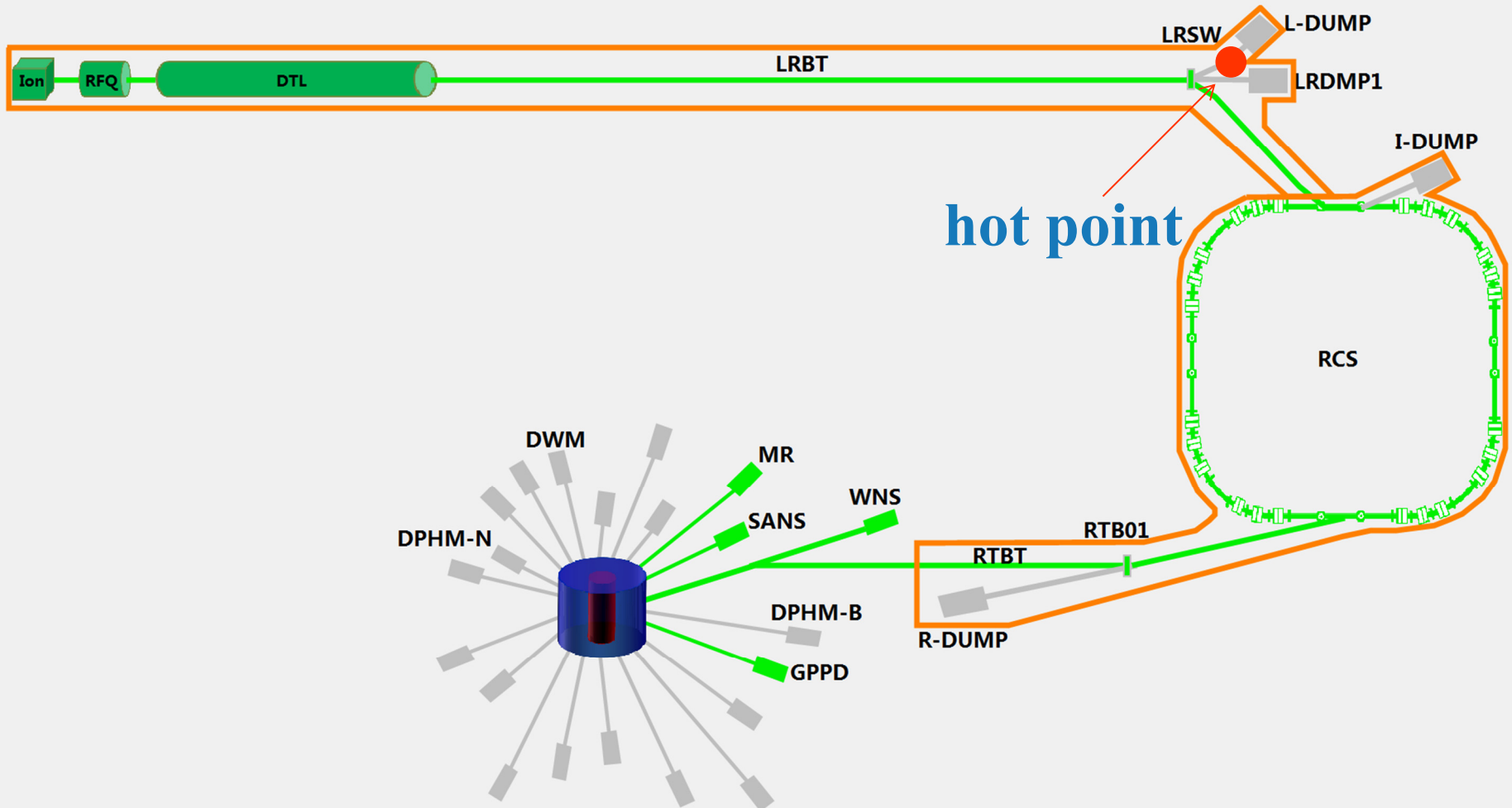
Red line represent X direction  
Blue line represent Y direction

# Beam transmission



	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?

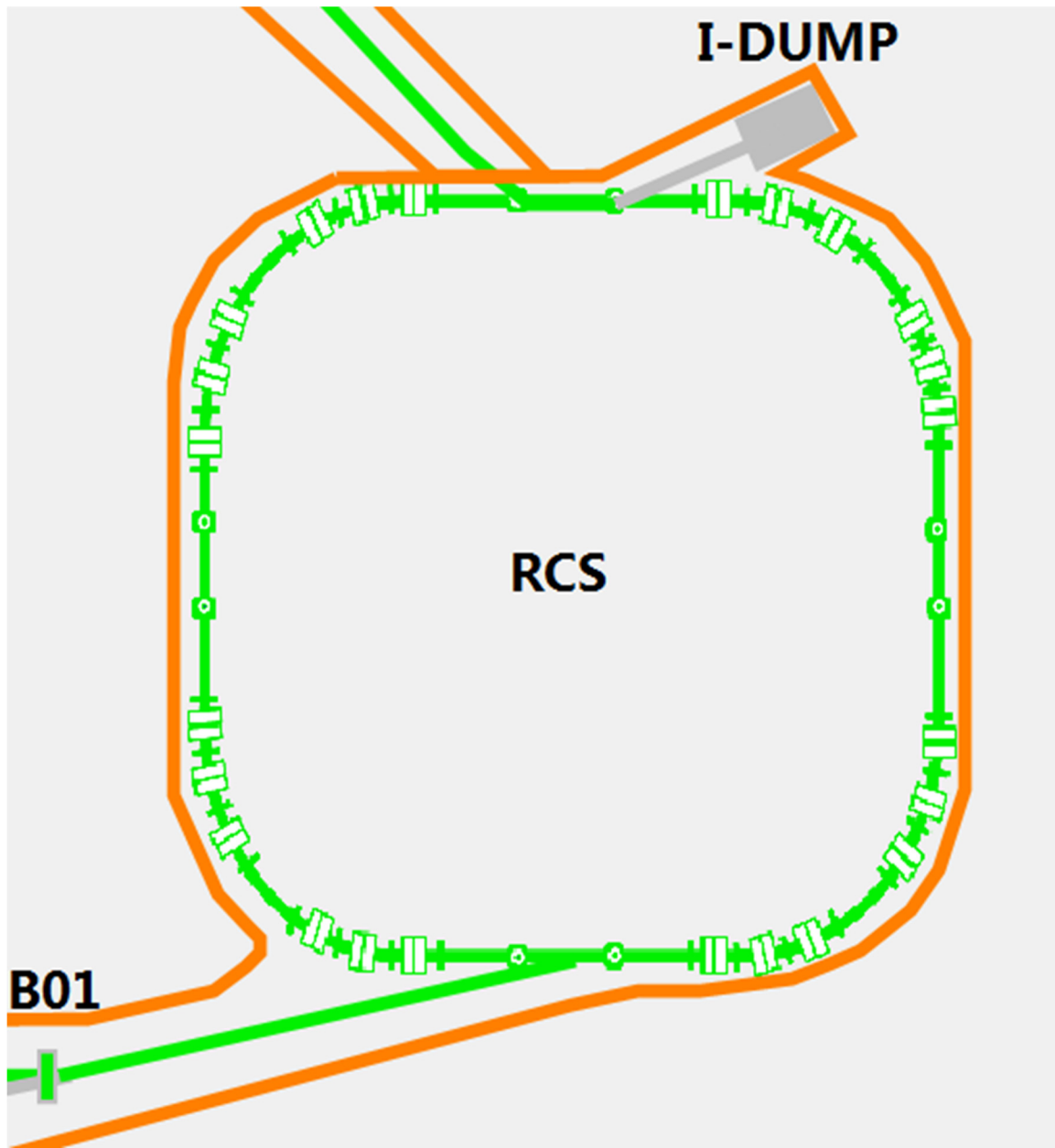
# RCS Commissioning

## **RCS Dry Running**

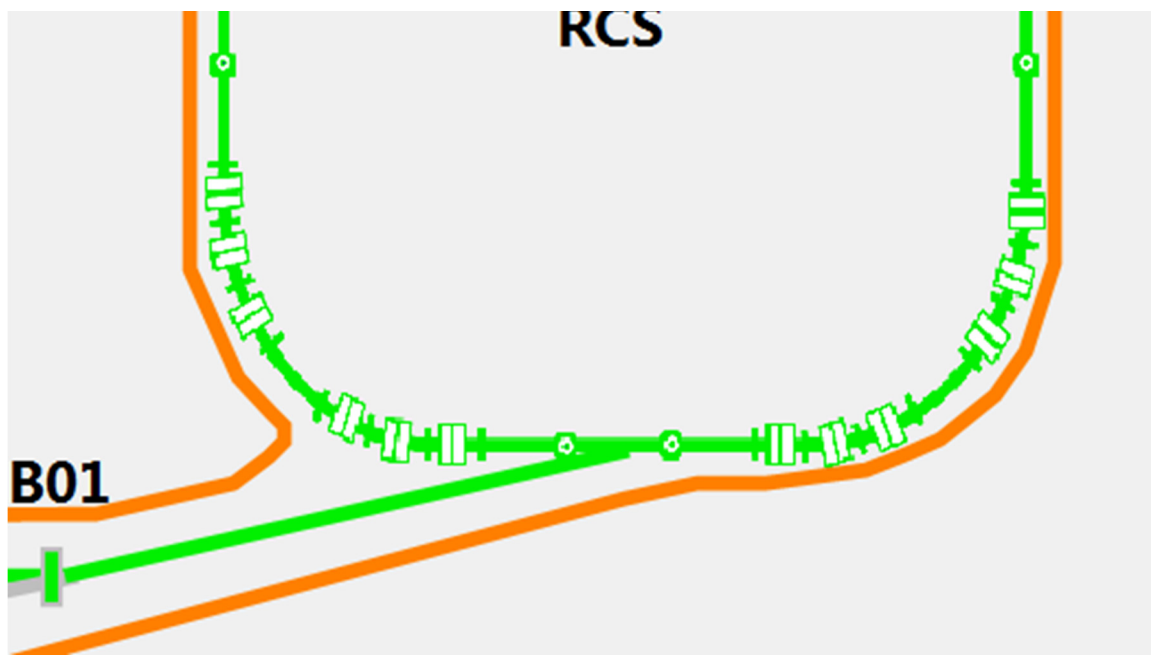
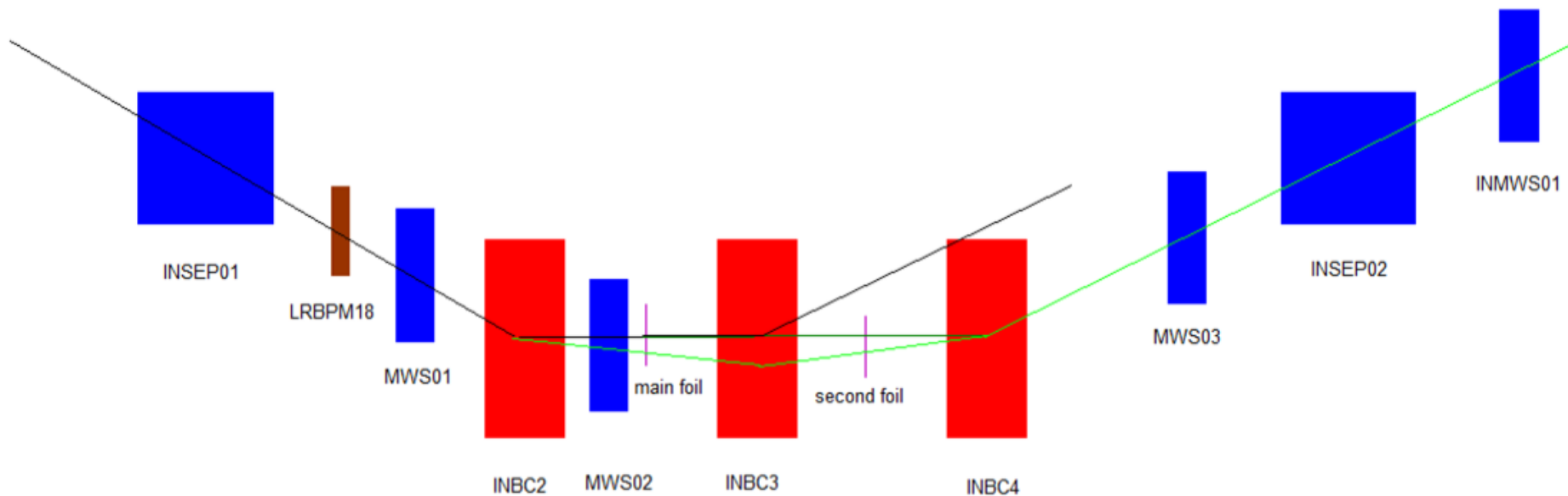
- **A week per time, 2 times**
- **Problem found:**
  - **Water leakage was found in one cavity.**
  - **Cooling tubes of two AC magnets were burned through.**
  - **17 chokes had strong vibration and had been returned to the manufacture to repair.**
  - **Ceramic vacuum chamber Broken**
  - **Arc of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



# Beam Commissioning to Inj. Dump



# Beam Commissioning to Inj. Dump

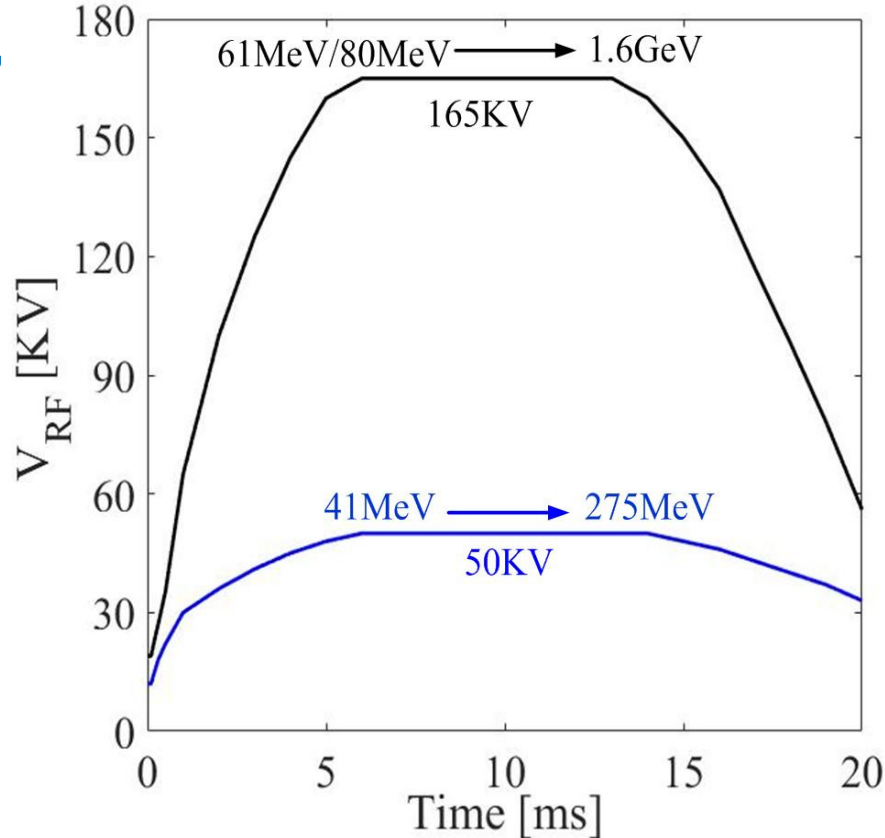


# Injection with 60MeV beam

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

# Injection with 60MeV beam

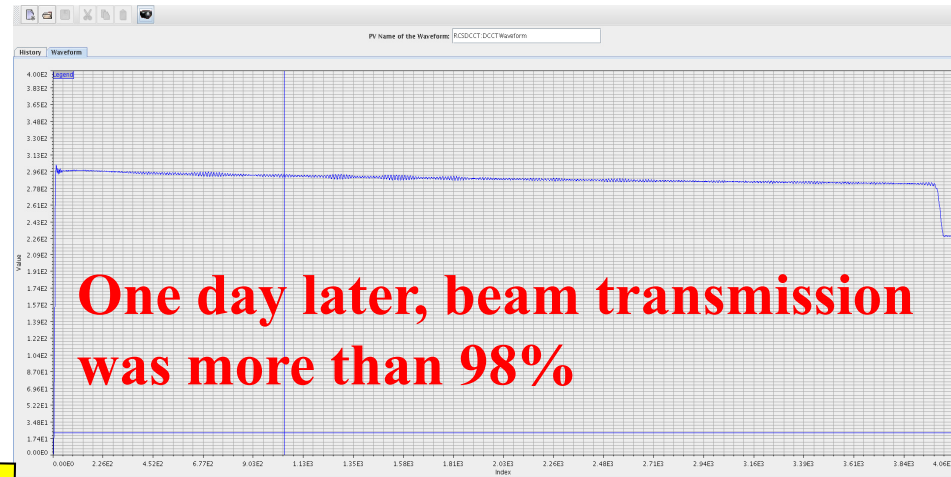
Beam energy	61.07MeV	81MeV	41.3MeV(h=3)
Magnetic rigidity(T/m)	1.147	1.319	0.938
B field (T)	0.143	0.164	0.117
RF frequency			1.135
B(I) (A)			206.7



## RCS Beam Commissioning-DC mode

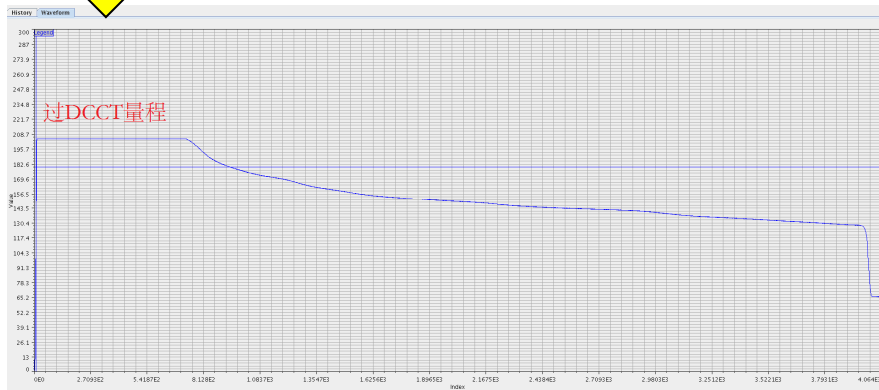
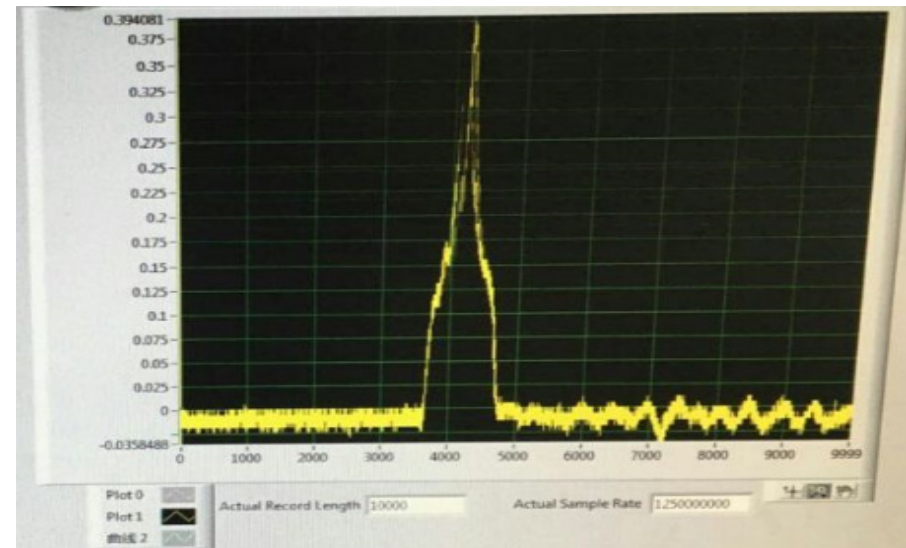
- ✓ To control the beam loss during the beam commissioning, the **single shot** beam mode is adopted. In the first step, the beam commissioning was started in DC mode without acceleration.
- ✓ In **May 31st**, the first beam was injected into the RCS, and successfully accumulated in the RCS.
- ✓ In **June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

# Accumulation and extraction

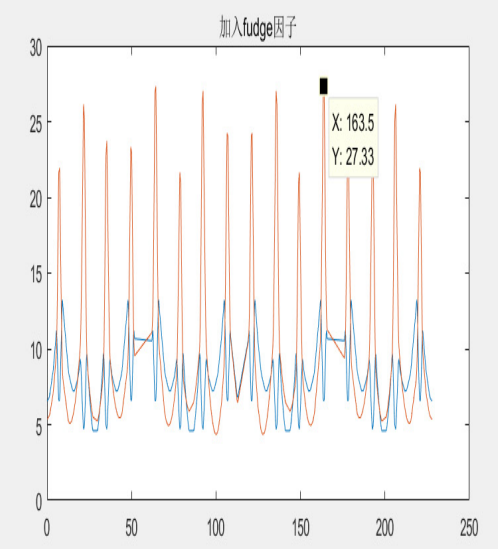
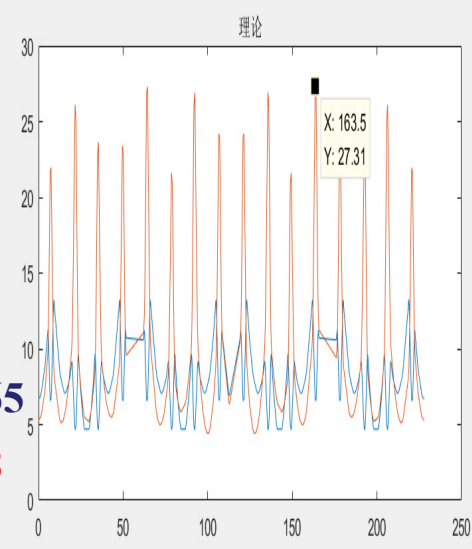
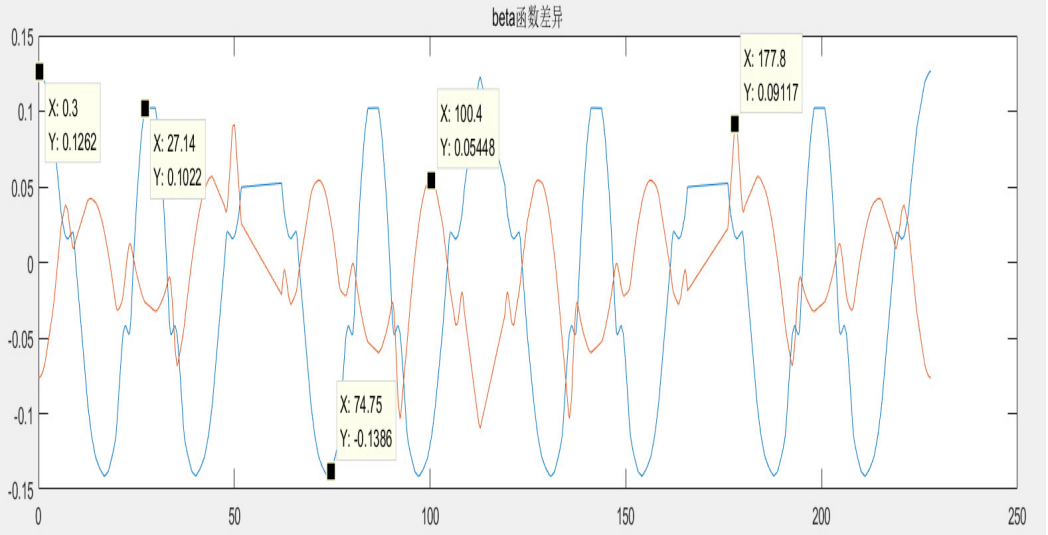
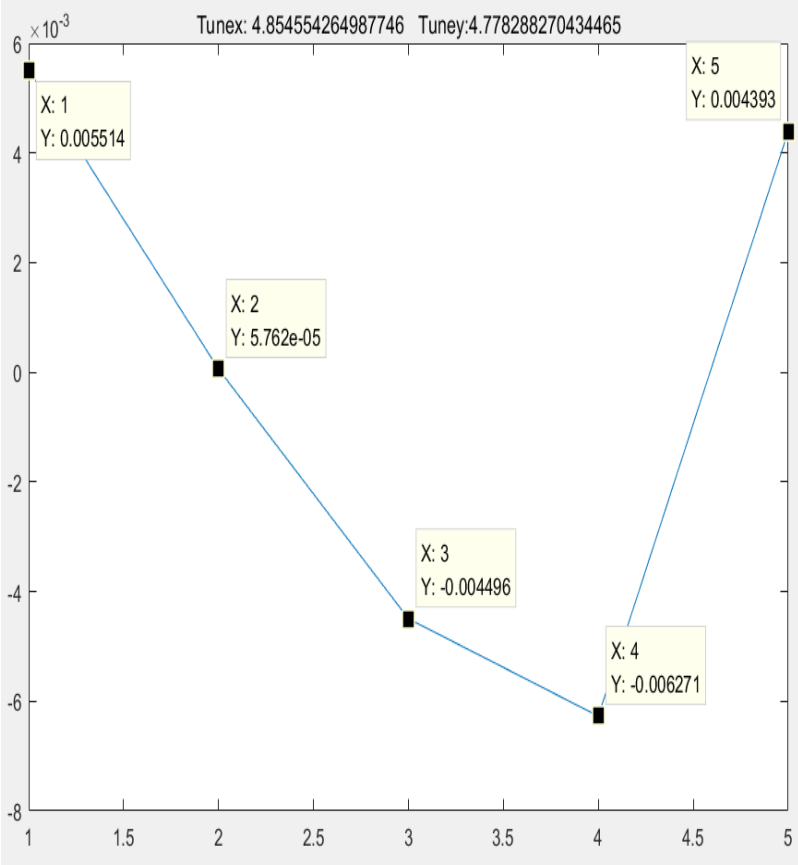


1. Optimization of RF pattern
2. Optimization of the B field

3. Height of Injection bump

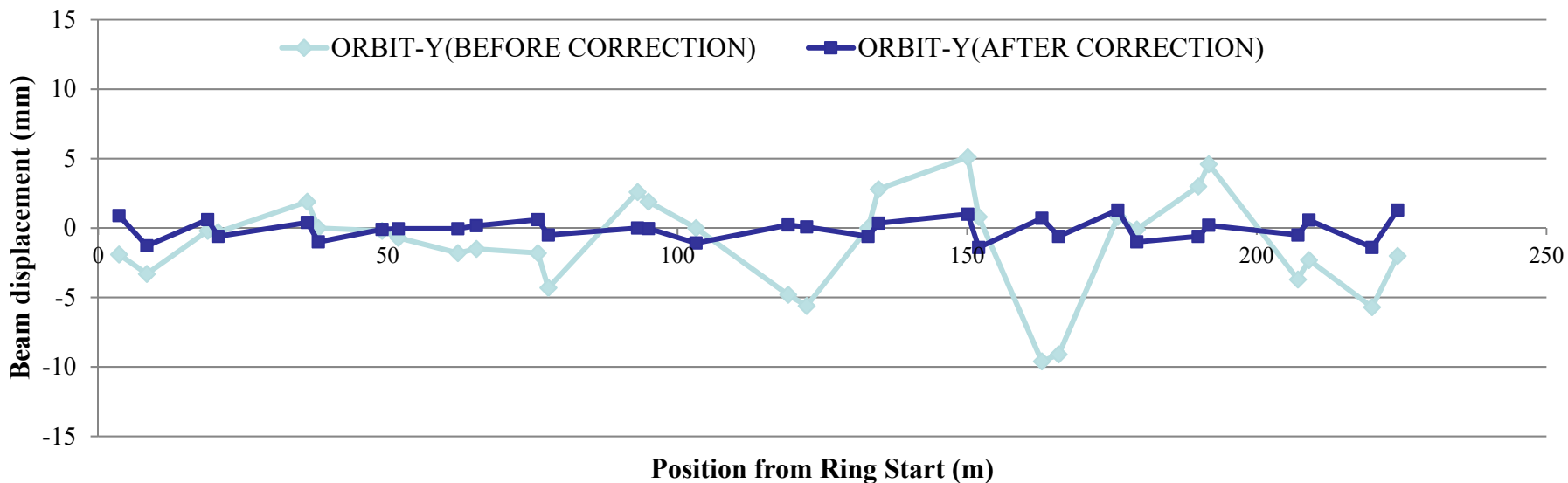
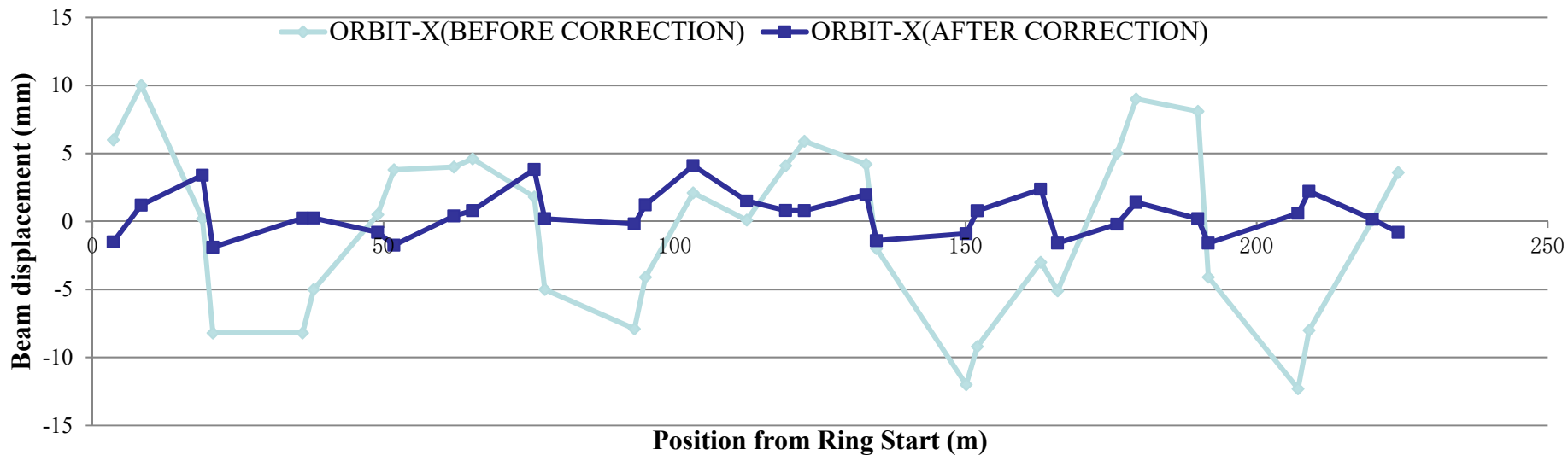


# Fudge factor by response matrix

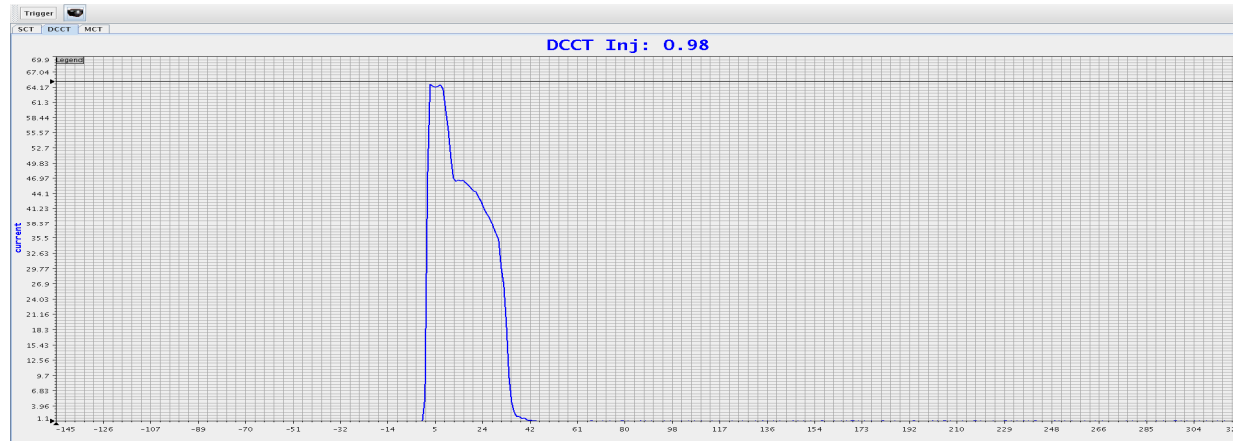


**Nominal tune: Tunex/tuney: 4.8532/ 4.7816**  
**Measured tune: Tunex/tuney: 4.8568/ 4.7765**  
**After correction: Tunex/tuney: 4.854/ 4.778**  
**Max. beta-beating :0.12**

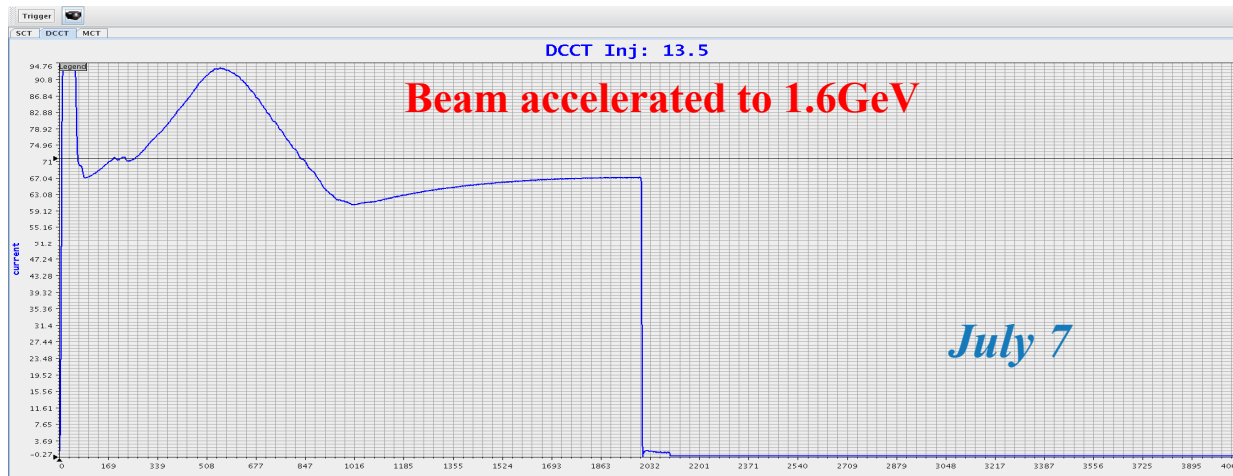
# COD correction



# RCS Beam Commissioning-AC mode



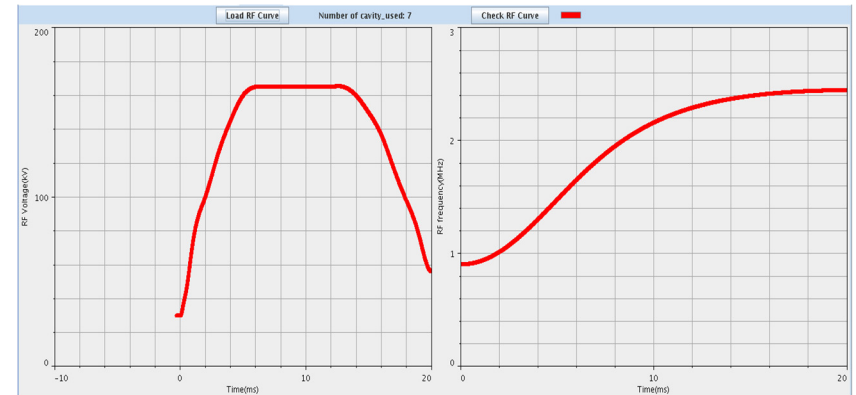
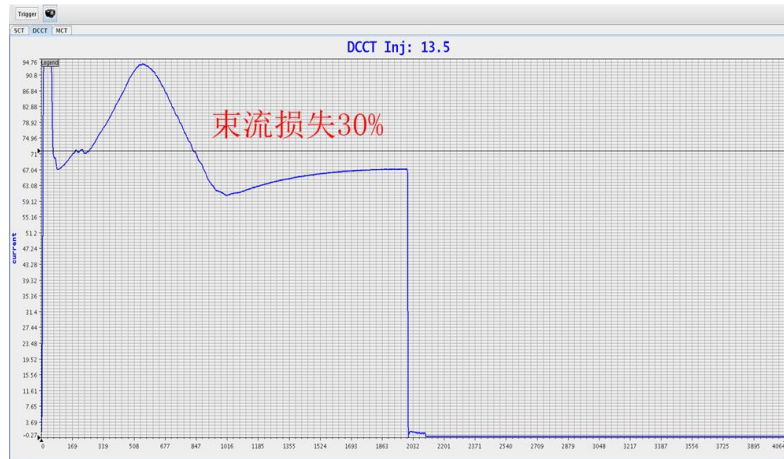
Beam life time is  
2ms in the first  
shot.



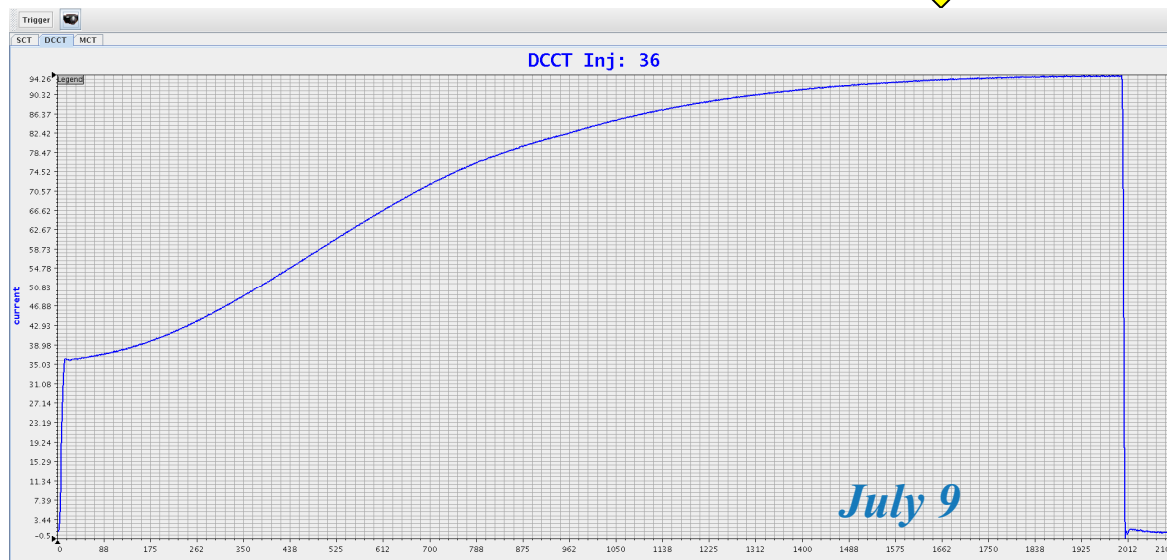
Shift timing between  
RF and B field, then  
major part of beam  
was accelerated to  
1.6GeV and extracted.

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

# RF parameter optimization

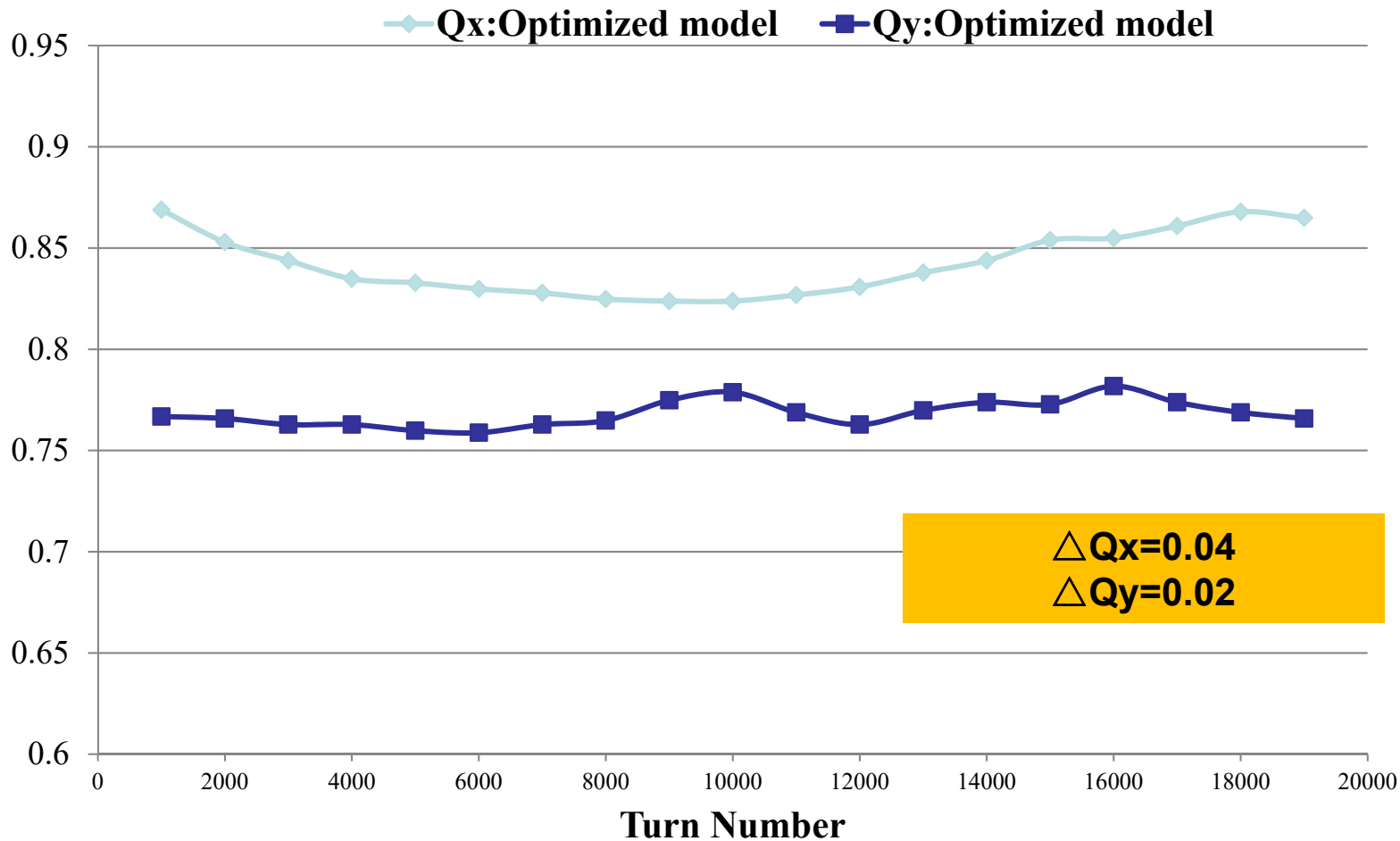


Tuning RF amplitude  
frequency curve, phase



Finally reached  
about 99% beam  
transmission

# Tune in one cycle

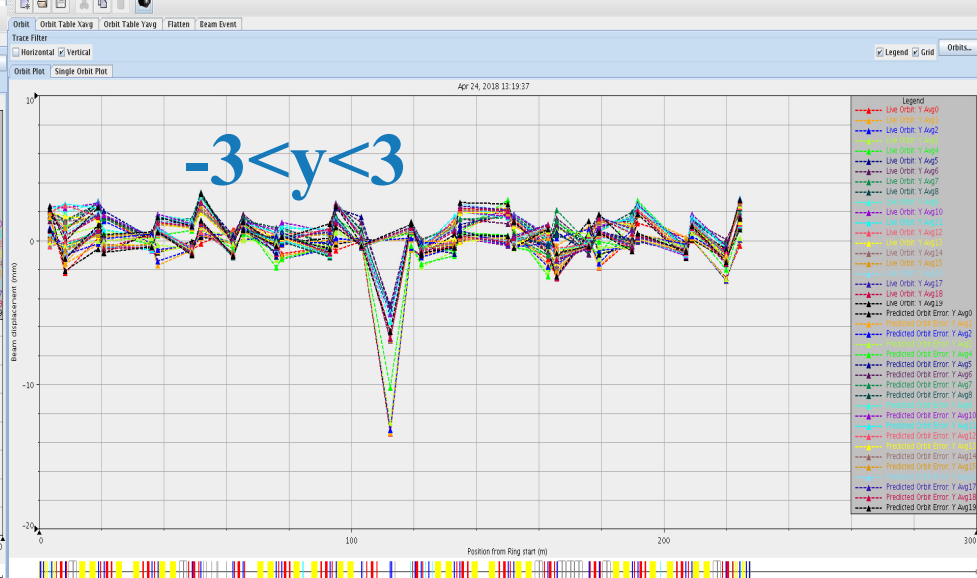
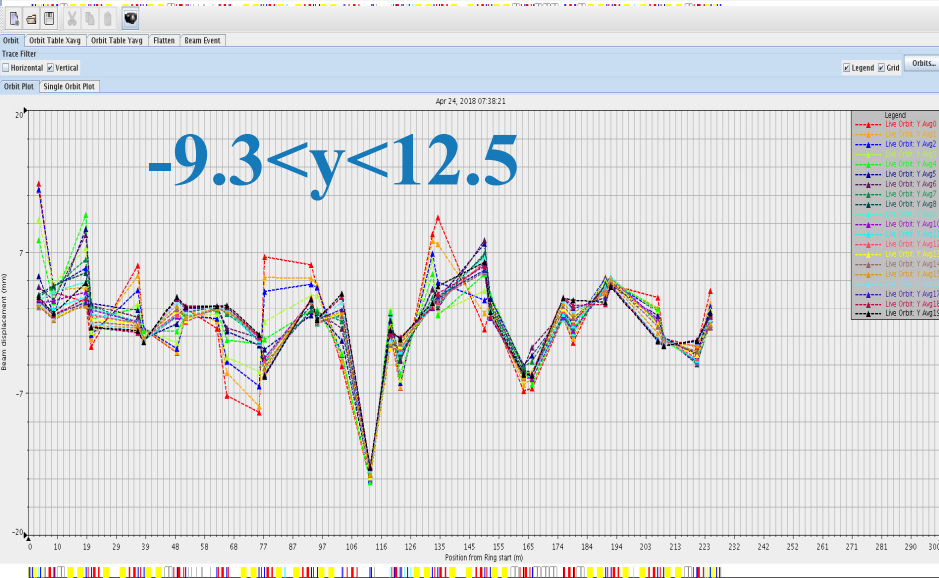
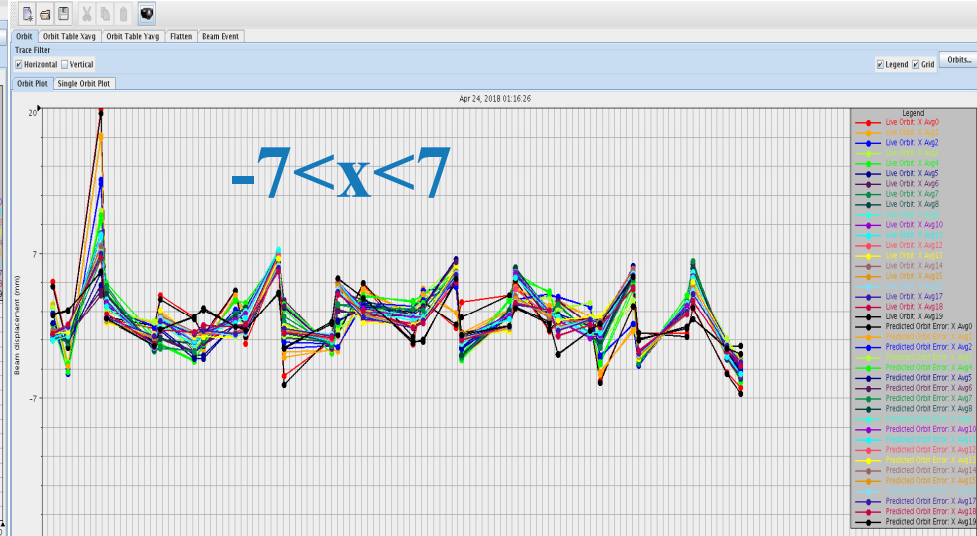
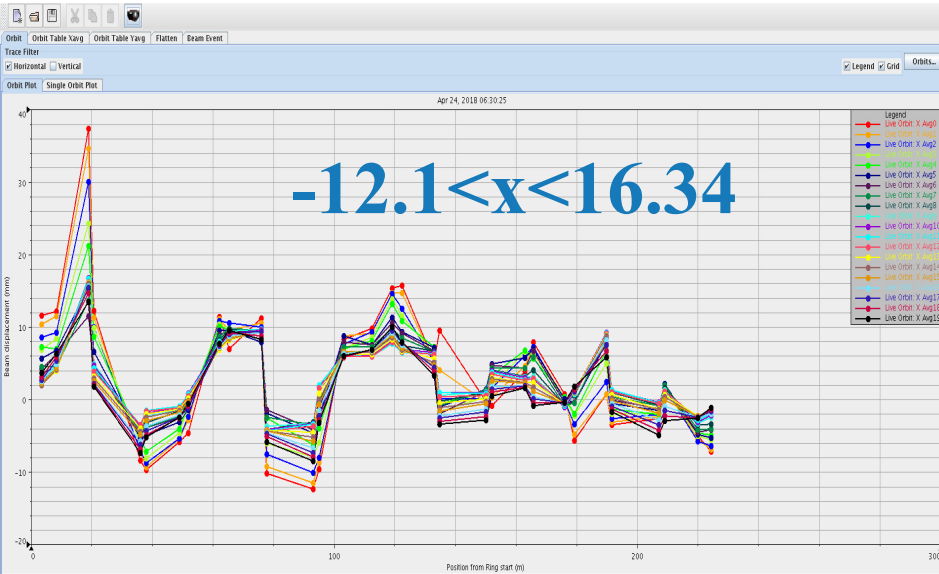


# COD correction

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

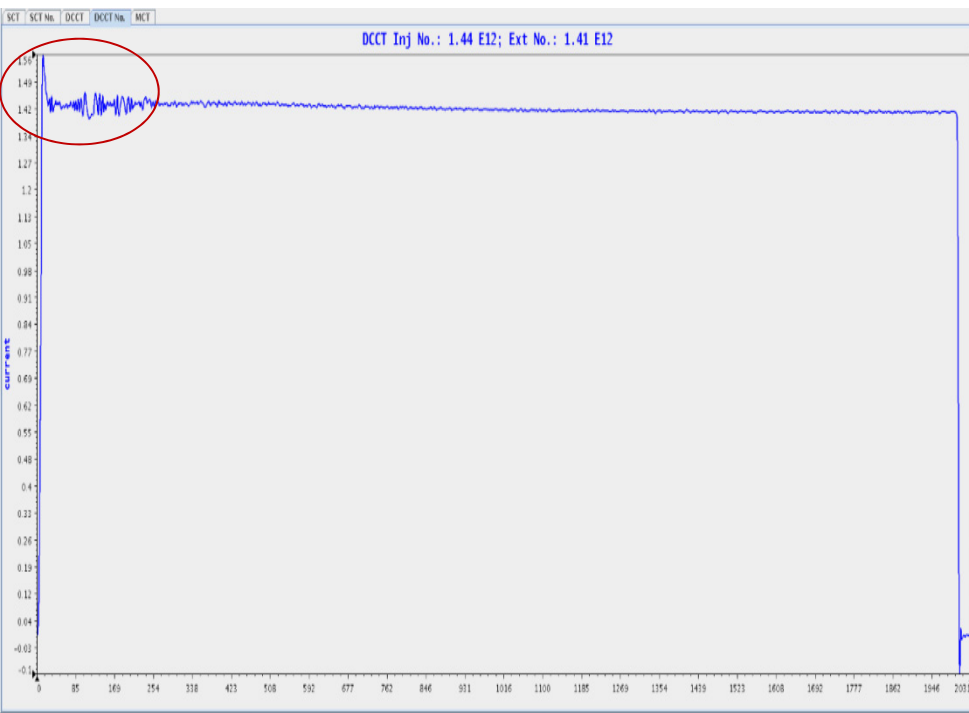
散裂中子源

Spallation Neutron Source

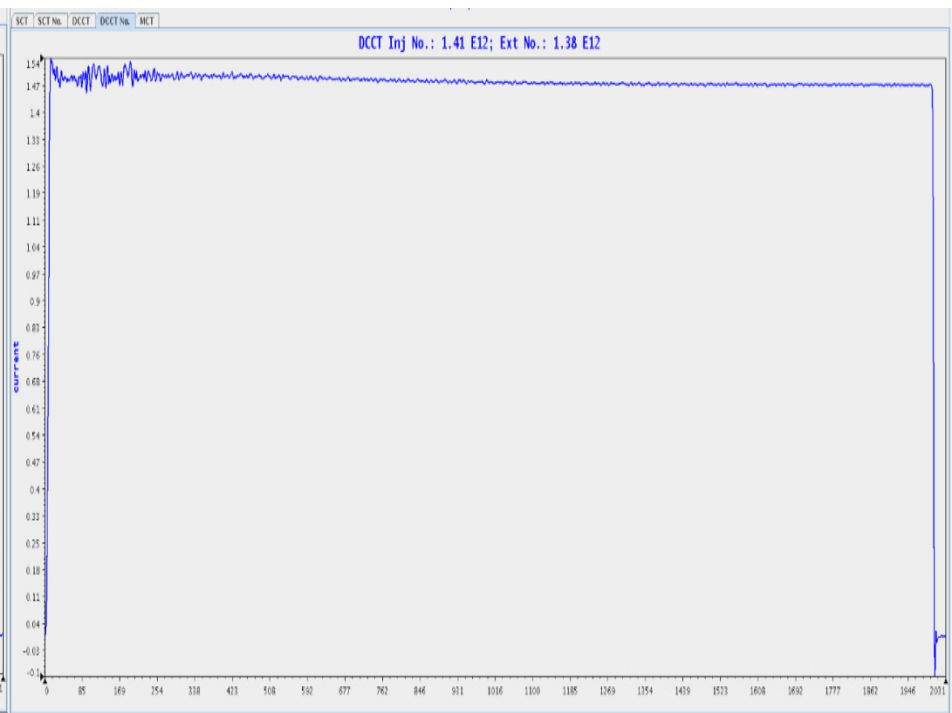


# Fixed bump injection and painting injection

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



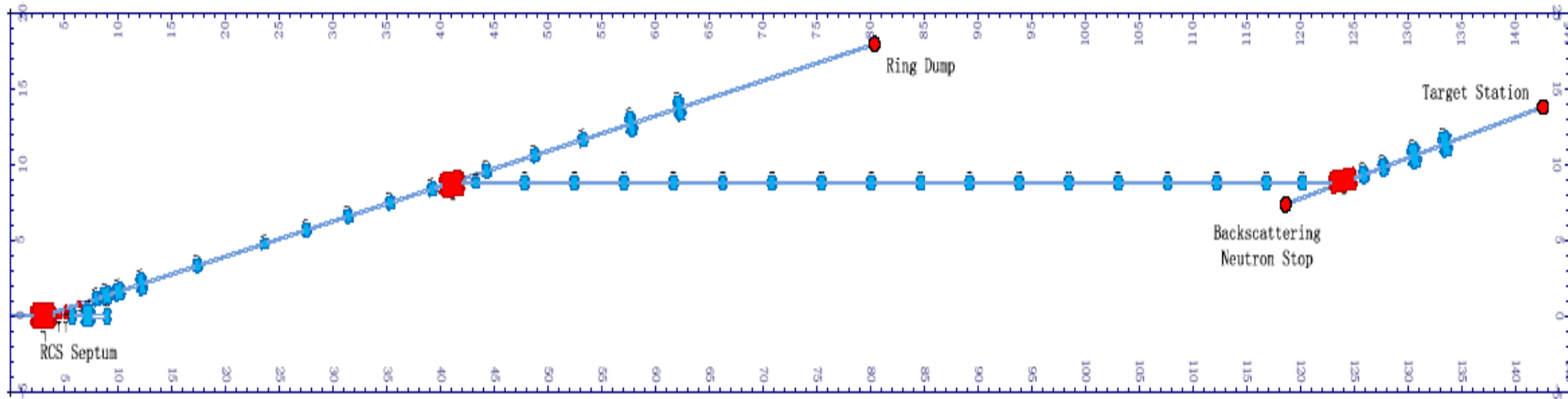
Fixed bump injection



Painting injection

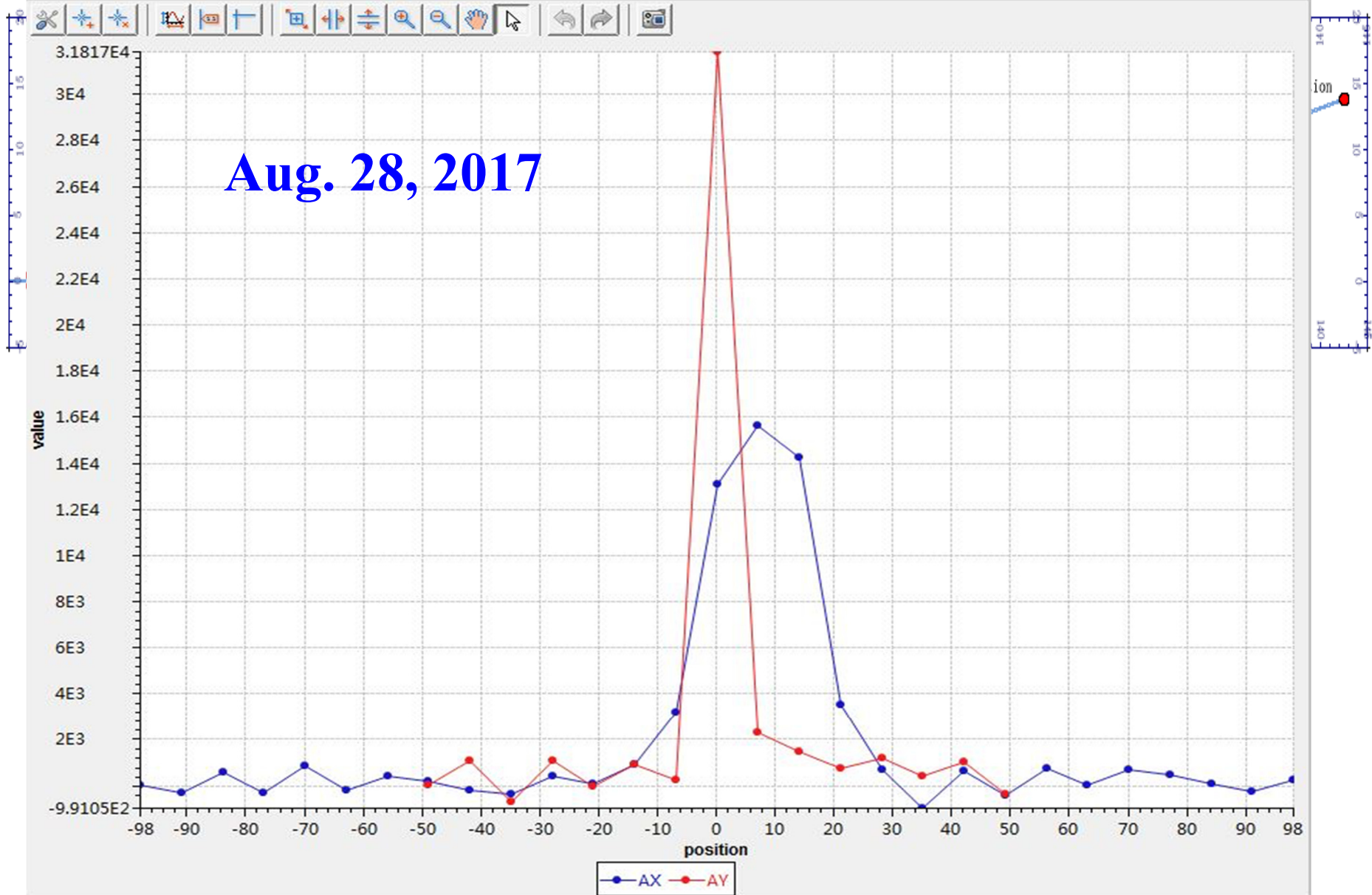
# The first beam on the target

散裂中子源  
Spallation Neutron Source



# The first beam on the target

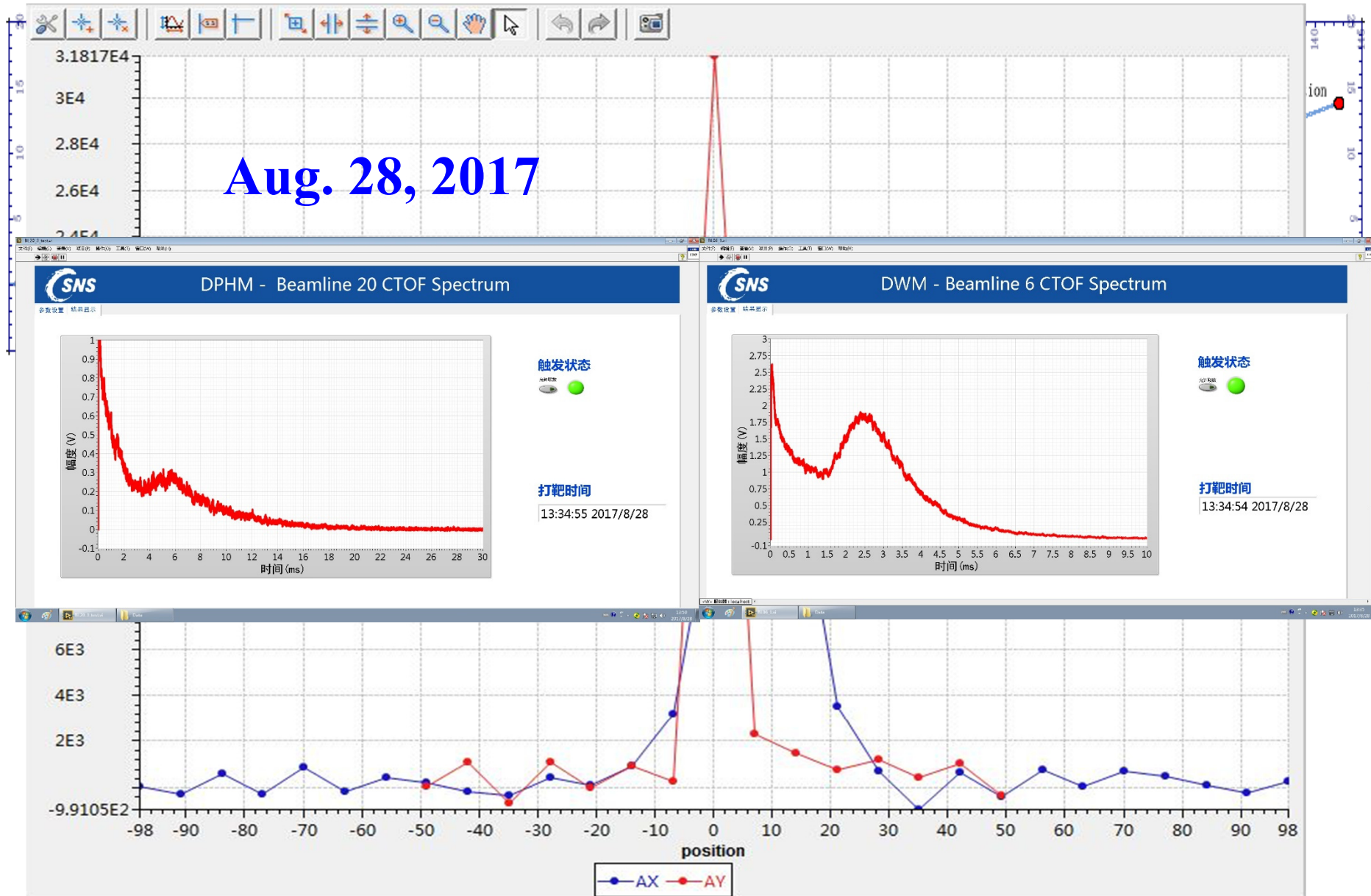
Aug. 28, 2017



# The first beam on the target

散裂中子源  
Spallation Neutron Source

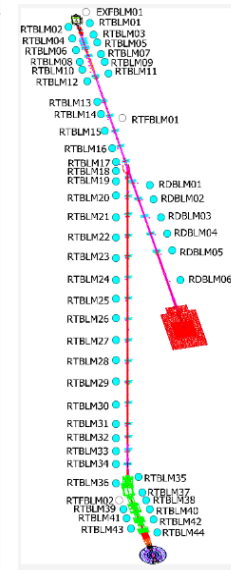
Aug. 28, 2017



# Beam loss and control

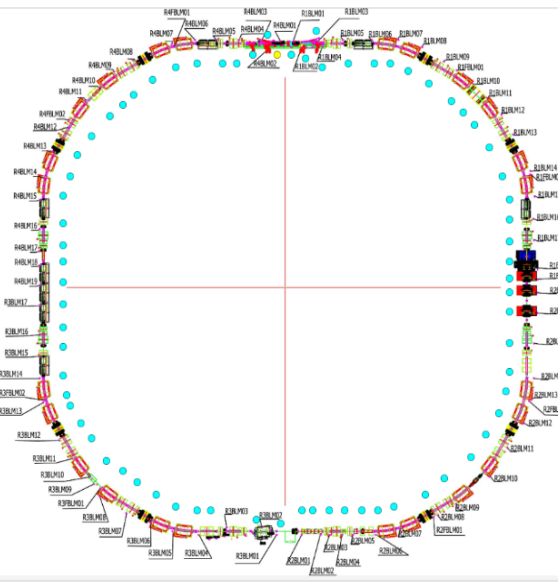
2018/03/27 08:35:26

MEBLM01	28.36	LRBLM09	3.75
MEBLM02	45.96	LRBLM10	8.75
MEBLM03	240.45	LRBLM11	6.56
TO1BLM01	0.62	LRBLM12	5.31
TO1BLM02	52.49	LRBLM13	-0.31
TO1BLM03	88.44	LRBLM14	-41.85
TO2BLM01	8.44	LD1BLM02	21.57
TO2BLM02	-29.38	LD1BLM01	0.63
TO2BLM03	-43.46	LRBLM15	8.12
TO3BLM01	-72.49	LRBLM16	12.81
TO3BLM02	-81.92	LRBLM17	-9.69
TO3BLM03	-0	LRBLM18	4.38
TO4BLM01	7.19	LRBLM19	5.31
TO4BLM02	-78.74	LRBLM20	718.51
TO4BLM03	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	RTBLM26	5.94
RTBLM02	7.19	RTBLM27	23.44
RTBLM03	6.87	RTBLM28	26.57
RTBLM04	5	RTBLM29	23.75
RTBLM05	3.44	RTBLM30	22.82
RTBLM06	2.81	RTBLM31	29.36
RTBLM07	3.75	RTBLM32	27.16
RTBLM08	3.75	RTBLM33	6.25
RTBLM09	10.31	RTBLM34	39.06
RTBLM10	4.38	RTBLM35	6.25
RTBLM11	2.5	RTBLM36	2.19
RTBLM12	6.56	RTBLM37	14.69
RTBLM13	11.87	RTBLM38	4.06
RTBLM14	5.62	RTBLM39	25.94
RTBLM15	5	RTBLM40	-45.91
RTBLM16	12.5	RTBLM41	17.49
RTBLM17	49.66	RTBLM42	3.44
RTBLM18	17.19	RTBLM43	3.75
RTBLM19	3.75	RTBLM44	7.19
RTBLM20	3.44	RDBLM01	232.86
RTBLM21	3.44	RDBLM02	88.45
RTBLM22	2.5	RDBLM03	192.51
RTBLM23	-4.06	RDBLM04	35.92
RTBLM24	5.31	RDBLM05	32.49
RTBLM25	5	RDBLM06	122.77

R4BLM01	1171.24
R4BLM02	112.19
R4BLM03	79.98
R4BLM04	16.72
R4BLM05	27.27
R4BLM06	22.11
R4BLM07	29.12
R4BLM08	178.54
R4BLM09	53.36
R4BLM10	24.23
R4BLM11	15.12
R4BLM12	14.54
R4BLM13	80.18
R4BLM14	18.79
R4BLM15	13.33
R4BLM16	67.76
R4BLM17	21.3
R4BLM18	47.66
R4BLM19	65.58
R3BLM17	14.26
R3BLM16	10.41
R3BLM15	11.14
R3BLM14	4.48
R3BLM13	21.13
R3BLM12	16.37
R3BLM11	10.95
R3BLM10	6.72
R3BLM09	6.31
R3BLM08	9.56
R3BLM07	7.54
R3BLM06	7.65
R3BLM05	158.54
R3BLM04	10.27
R3BLM03	31.02
R3BLM02	35.09
R3BLM01	37.37

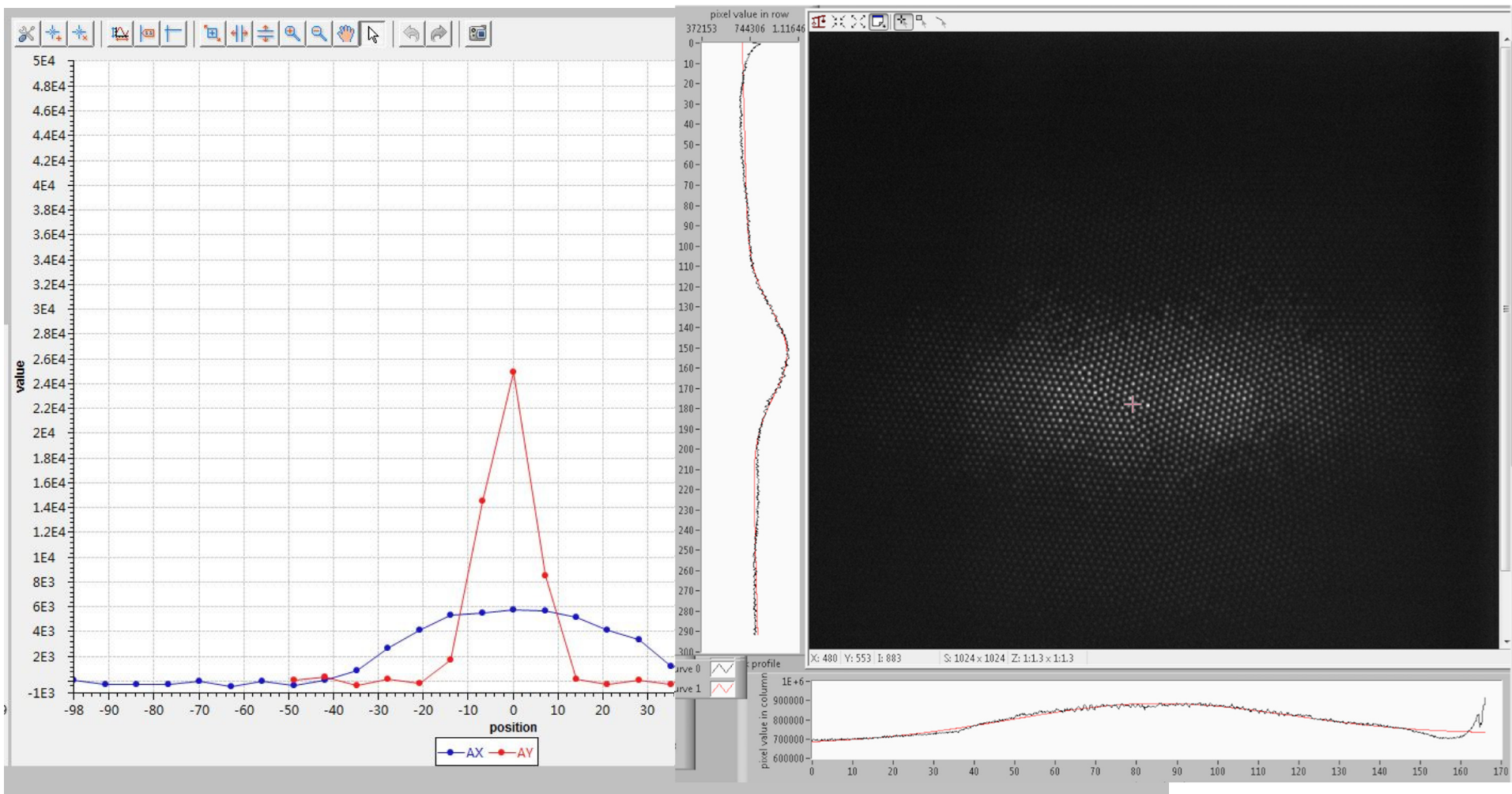


R1BLM01	153.21
R1BLM02	120.48
R1BLM03	165.59
R1BLM04	144.27
R1BLM05	149.02
R1BLM06	19.19
R1BLM07	30.67
R1BLM08	14.43
R1BLM09	21.36
R1BLM10	5.91
R1BLM11	7.82
R1BLM12	10.18
R1BLM13	12.32
R1BLM14	36.89
R1BLM15	29.11
R1BLM16	10.64
R1BLM17	11.87
R1BLM18	288.41
R1BLM19	16.67
R2BLM17	94.04
R2BLM16	23.55
R2BLM15	126.21
R2BLM14	224.21
R2BLM13	41.62
R2BLM12	341.16
R2BLM11	36.34
R2BLM10	8.31
R2BLM09	112.59
R2BLM08	40.3
R2BLM07	10.32
R2BLM06	18.51
R2BLM05	9.23
R2BLM04	646.1
R2BLM03	49.68
R2BLM02	25.29
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, ~ $\mu\text{Sv/level}$
- 11. 6, 5Hz, ~2.5kW
- 11. 9, shut down, open the tunnel, and measure the residual dose, ~ $\mu\text{Sv/level}$
- 11. 9, 25Hz, 10kW

# Beam profile monitor



- **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 1000hrs were provided for the commissioning of neutron spectrometer and the experiment for user's samples;**
- **After the official acceptance in the coming June, 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 conducted soon.**

**Thank you!**

