Commissioning Status of CSNS/RCS

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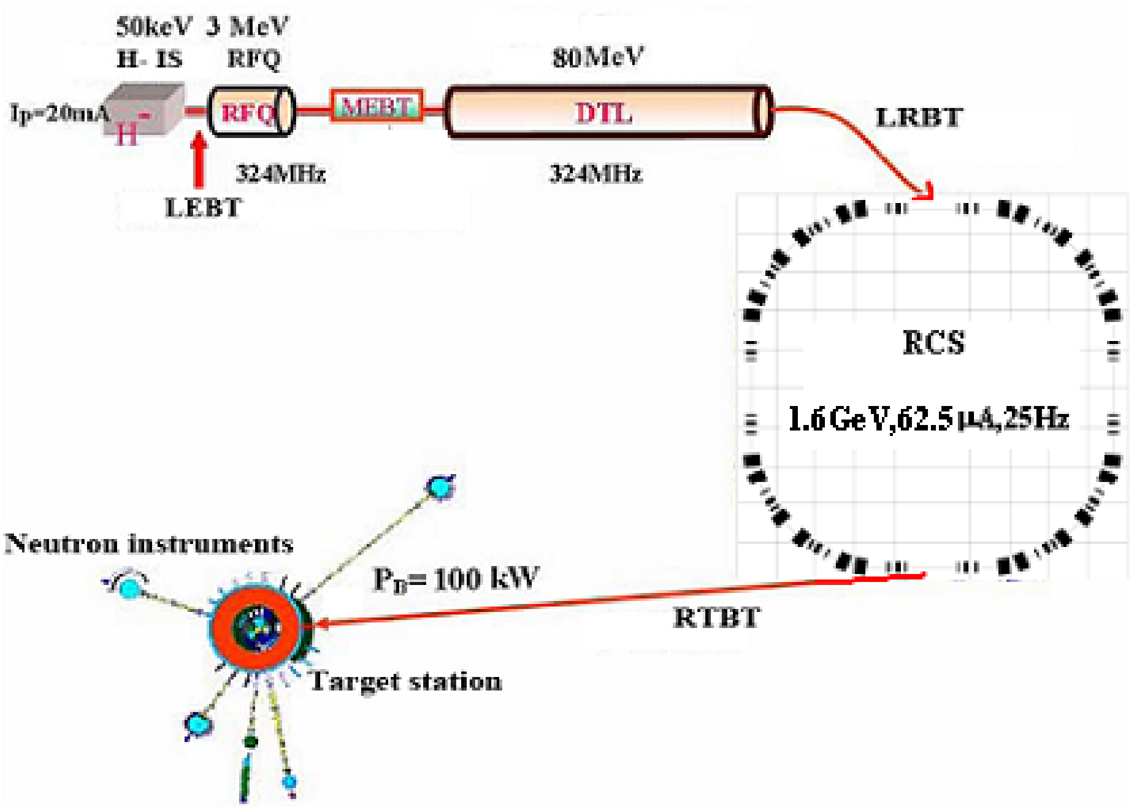
Outline

- Introduction of CSNS/RCS
- Preparation for CSNS/RCS Commissioning
- Stage I Beam Commissioning
- Stage II Beam Commissioning
- Summary

Introduction of CSNS/RCS

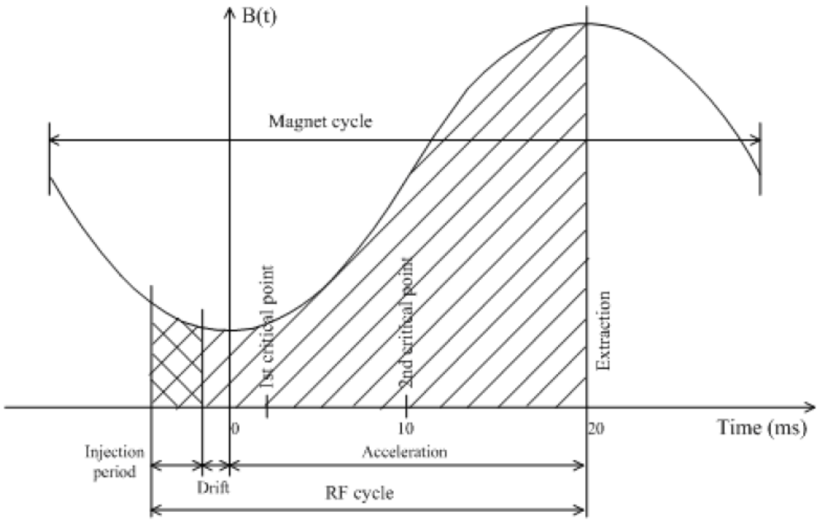


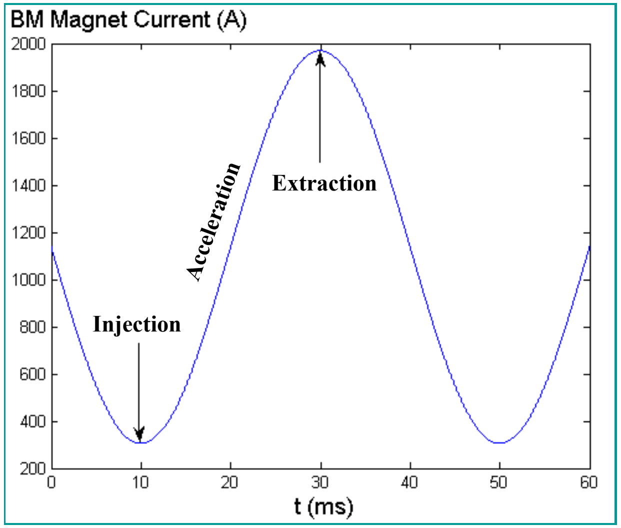
Parameters	Values
Circumference	227.92 m
Repetition Rate	25 Hz
Average current	62.5 μA
Inj. Energy	80 MeV
Ext. Energy	1.6 GeV
Beam Power	100 kW
RF Freq. (MHz)	1.022~2.444
Harmonic	2
Quad	48
Dipole	24
Corrector	16/16
BPM	32/32
Tunes(H/V)	4.86/4.78

Preparation for CSNS/RCS Commissioning

- **Magnet Measurements**
  - Wave Form Compensation for Magnets
  - Fringe Field Interference of Neighbor Magnets
- **Beam Dynamics Study**
  - Fringe Field Effects of Quadrupoles
  - Magnetic Field and RF Frequency Tracking

Wave Form Compensation for Magnets



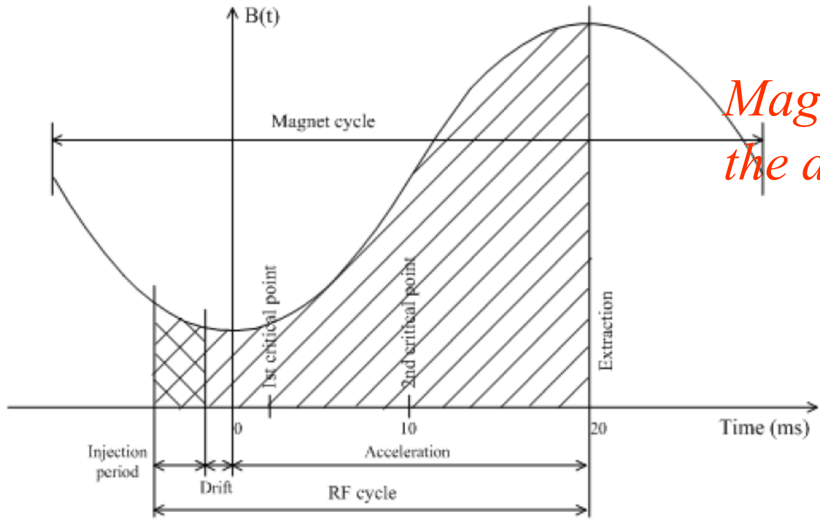


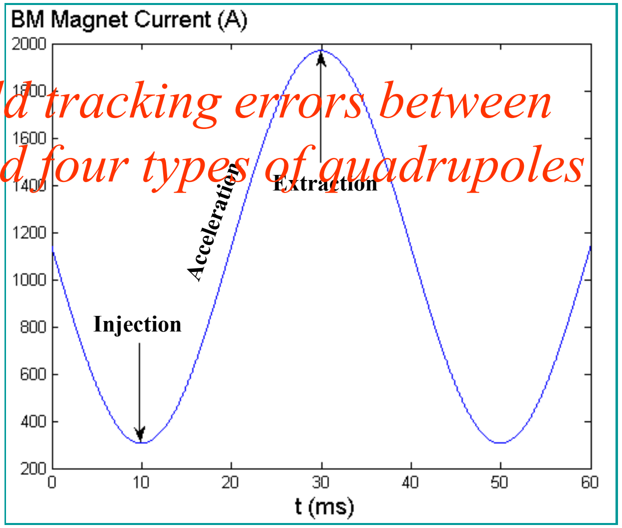
Because of the magnetic saturation and eddy current effects, the magnetic field ramping function of dipoles and quadrupoles is not sine pattern at CSNS/RCS.

	160B	272Q	253Q	222Q	206Q
25Hz-Amp	1	1	1	1	1
50Hz-Amp	3.73E-3	4.26E-3	7.89E-03	6.34E-03	1.98E-02
75Hz-Amp	1.20E-3	0.97E-3	2.18E-03	2.14E-03	7.56E-03
100Hz-Amp	3.83E-4	1.92E-4	5.44E-04	4.20E-04	2.57E-03
125Hz-Amp	1.52E-4	1.15E-4	2.64E-04	1.77E-04	8.29E-04

Higher order time harmonics of magnetic field are not the same for different magnets.

Wave Form Compensation for Magnets





Magnetic field tracking errors between the dipole and four types of quadrupoles

Because of the magnetic saturation and eddy current effects, the magnetic field ramping function of dipoles and quadrupoles is not sine pattern at CSNS/RCS.

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25Hz-Amp	1	1	1	1	1
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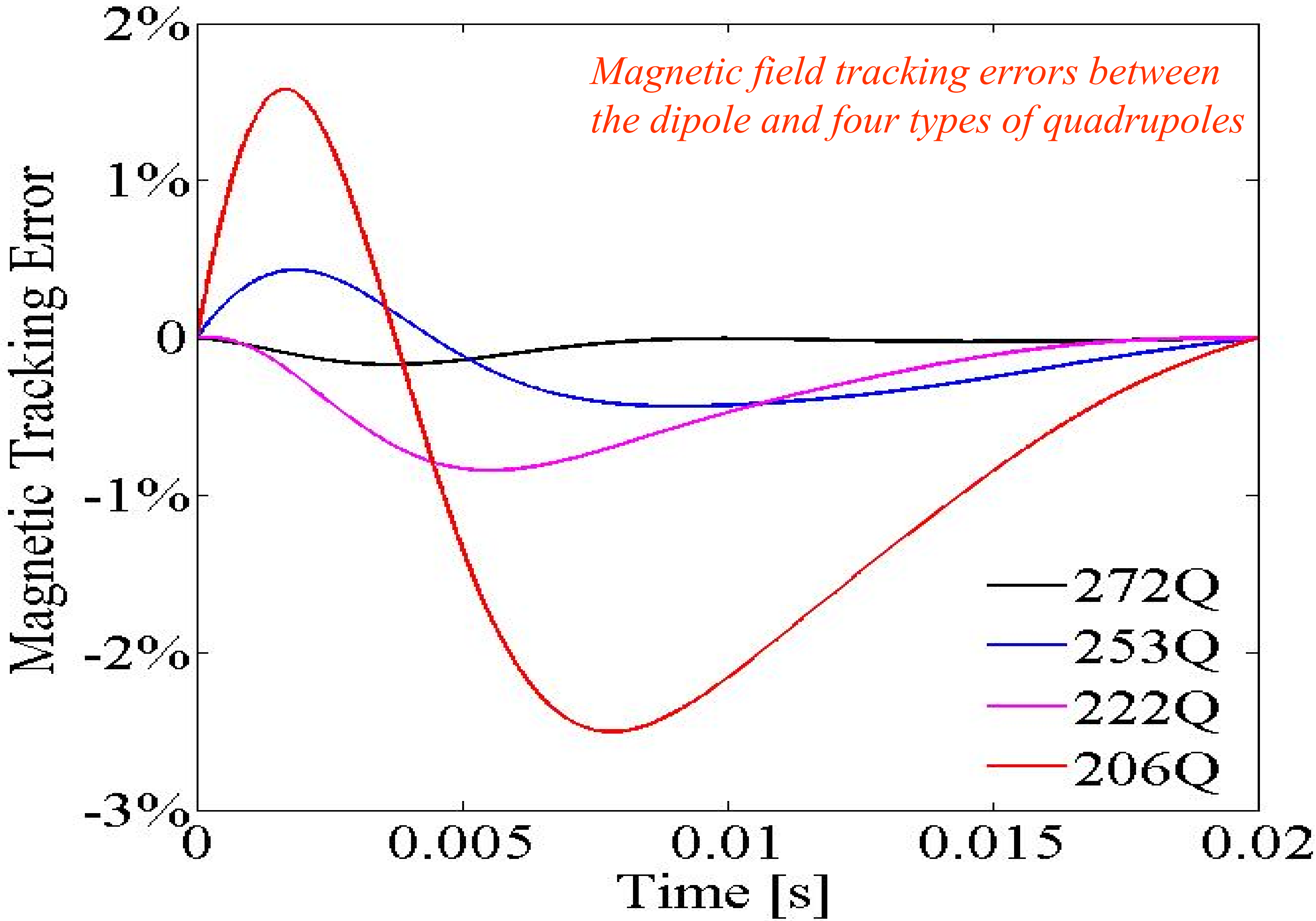
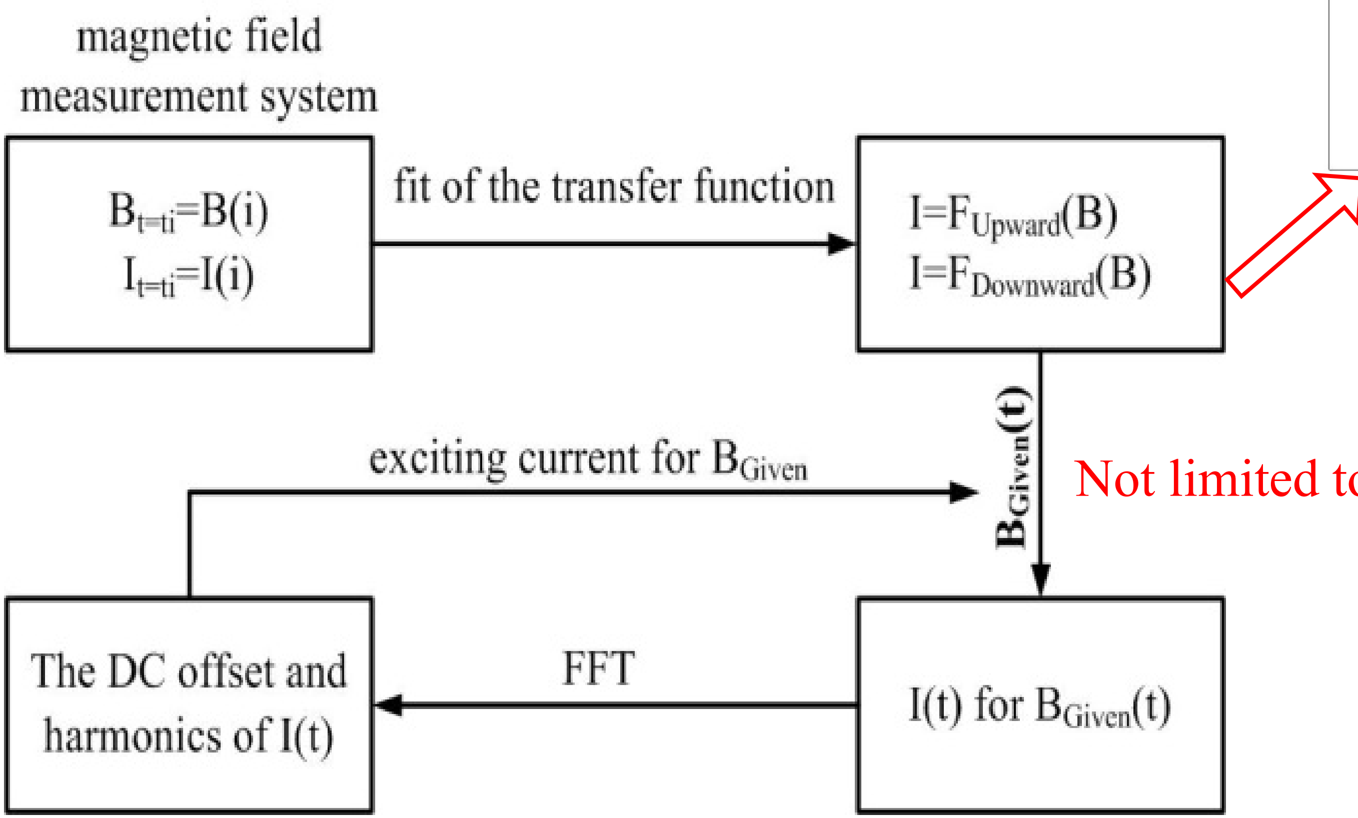
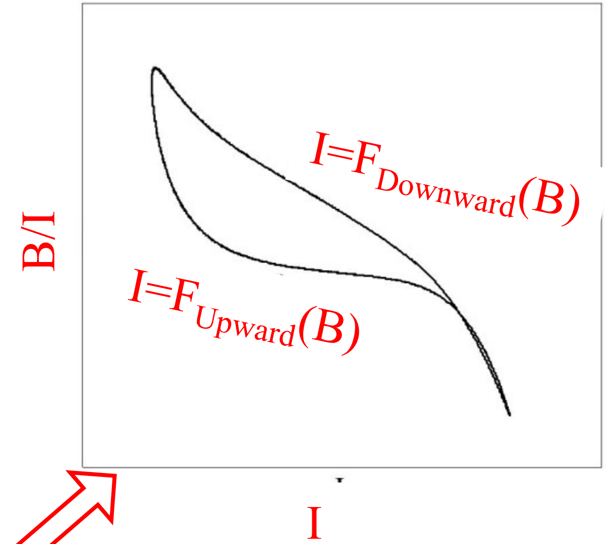
Wave Form Compensation for Magnets



Wave Form Compensation for Magnets

Flow process diagram for the harmonic compensation





Not limited to sine function

Wave Form Compensation for Magnets

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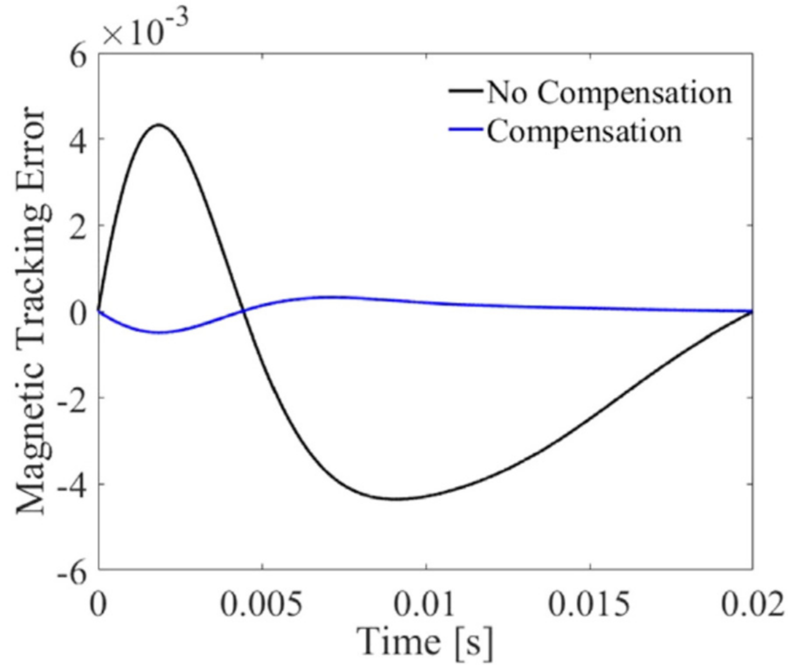
Test on 253Q of CSNS/RCS

	253Q	160B
I_{DC} − Amp.(A)	745.1	1223.0
$I_{25\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	538.5/0	877/0
$I_{50\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	7.02/50.2	6.16/40.0
$I_{75\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	2.94/36.7	3.26/27.5
$I_{100\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	1.14/26.7	1.46/21.8
$I_{125\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	0.50/26.3	0.73/11.4
$GL(BL)_{DC}$ − Amp.	100%	100%
$GL(BL)_{25\ \mathrm{Hz}}$ − Amp./Phase(°)	0.715243/0	0.712699/0
$GL(BL)_{50\ \mathrm{Hz}}$ − Amp./Phase(°)	5.77E−3/104.7	2.66E−3/80.6
$GL(BL)_{75\ \mathrm{Hz}}$ − Amp./Phase(°)	1.57E−3/117.4	8.55E−4/76.8
$GL(BL)_{100\ \mathrm{Hz}}$ − Amp./Phase(°)	4.06E−4/122.8	2.73E−4/74.5
$GL(BL)_{125\ \mathrm{Hz}}$ − Amp./Phase(°)	1.85E−4/98.2	1.08E−4/72.6

Higher time harmonics of magnetic field of 253Q was compensated to the same as 160B

	253Q	160B
I_{DC} − Amp.(A)	746.8	1223.0
$I_{25\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	537.7/0	877/0
$I_{50\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	6.46/27.0	6.16/40.0
$I_{75\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	3.29/20.7	3.26/27.5
$I_{100\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	1.38/14.8	1.46/21.8
$I_{125\ \mathrm{Hz}}$ − Amp.(A)/Phase(°)	0.57/11.7	0.73/11.4
$GL(BL)_{DC}$ − Amp.	100%	100%
$GL(BL)_{25\ \mathrm{Hz}}$ − Amp./Phase(°)	0.712649/0	0.712699/0
$GL(BL)_{50\ \mathrm{Hz}}$ − Amp./Phase(°)	2.56E−3/78.8	2.66E−3/80.6
$GL(BL)_{75\ \mathrm{Hz}}$ − Amp./Phase(°)	7.77E−4/71.5	8.55E−4/76.8
$GL(BL)_{100\ \mathrm{Hz}}$ − Amp./Phase(°)	2.24E−4/61.1	2.73E−4/74.5
$GL(BL)_{125\ \mathrm{Hz}}$ − Amp./Phase(°)	9.41E−5/58.2	1.08E−4/72.6



By performing wave form compensation on 253Q, the magnetic field ramping function was compensated to the same as 160B, and the magnetic field tracking error was reduced from 0.45% to 0.05%.

Wave Form Compensation for Magnets

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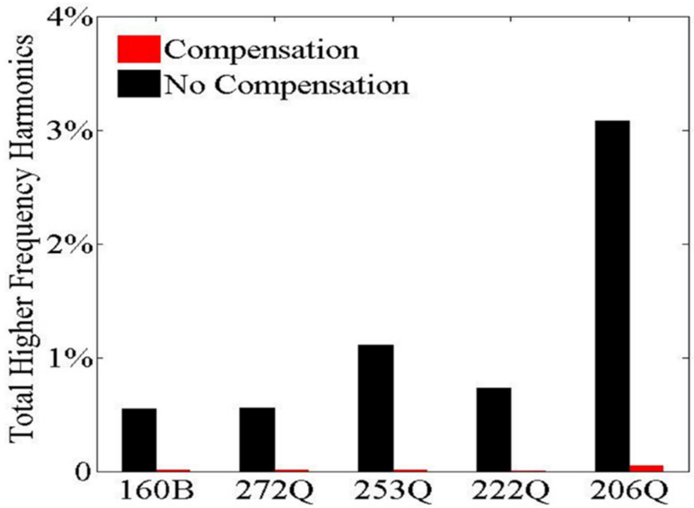
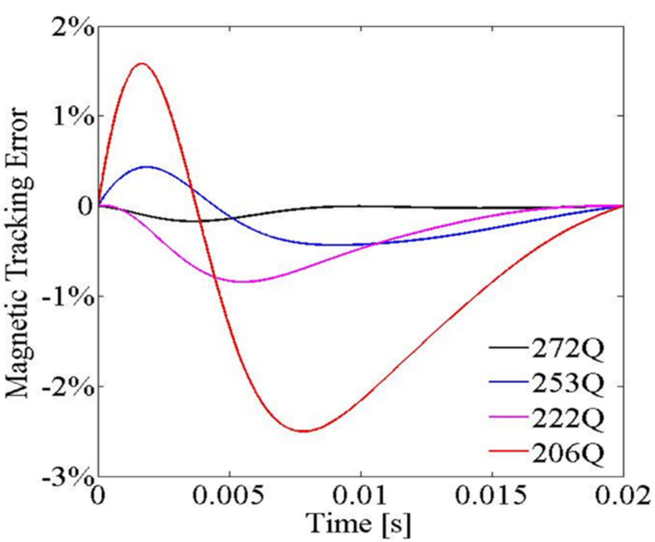
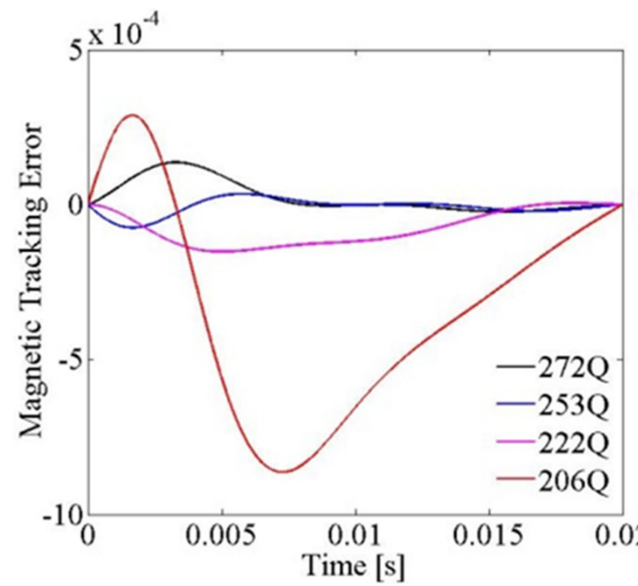
Application of the Method of Wave Form Compensation to CSNS/RCS



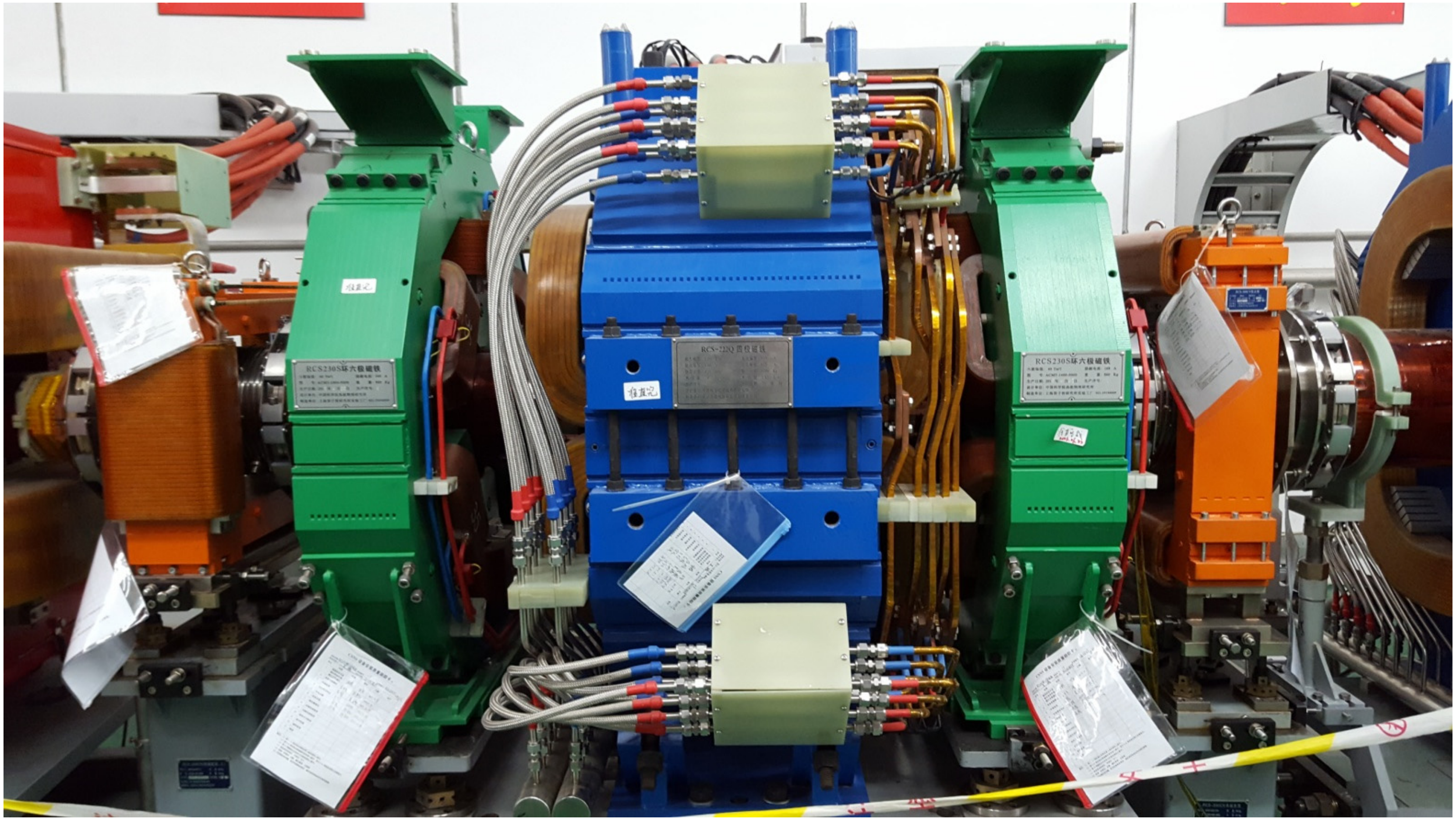
The magnetic field ramping functions for all the magnets were compensated to sine pattern. Higher order time harmonics of magnetic field for all the types of magnets were reduced to almost zero by performing wave form compensation, with only fundamental harmonic remained.



The maximum magnetic field tracking error between the dipole and quadrupoles was reduced from 2.5% to 0.08%.



Fringe Field Interference of Neighbor Magnets



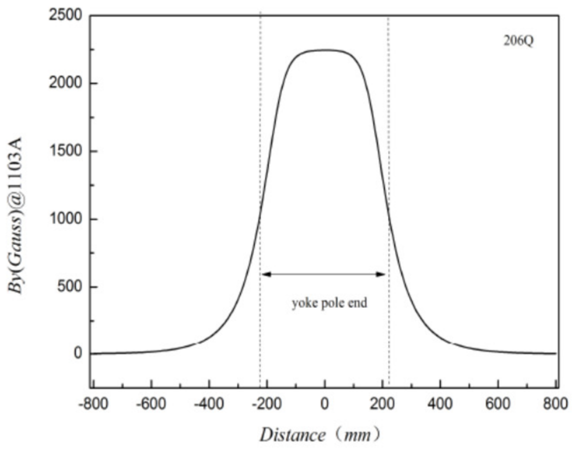
The core-to-core distance between magnets in CSNS/RCS is rather short in some places. The fringe field interference results in integral field strength reduction.

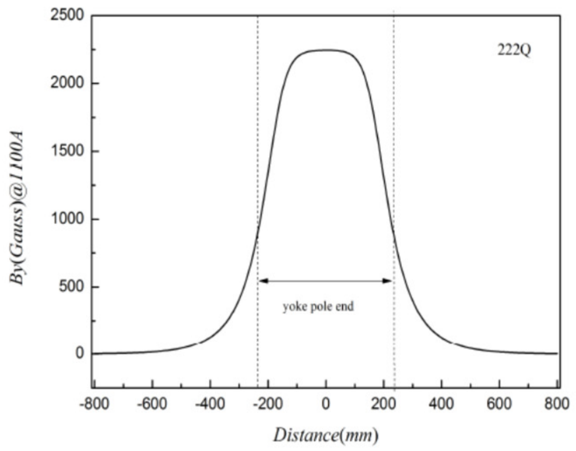
Fringe Field Interference of Neighbor Magnets

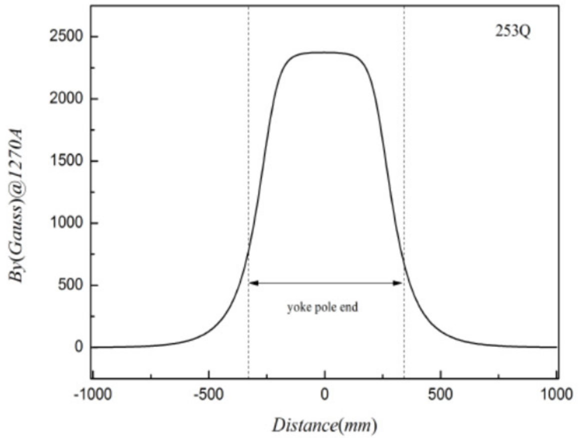
Quadrupole	core-to-core distance (mm)	Integral gradient reduction
R1QF12,R3QF12	206QF- 522-DH	**0.465%**
R2QF12,R4QF12	DH-608-206QF	**0.178%**
R1QF03,R2QF10,R3QF03,R4QF10	272QD-1197-DV-608-206QF	**0.192%**
R3QF01	206QF-670-DH-785-272QD	**0.117%**
R3QD02	206QF-670-DH-785-272QD	**0.444%**
R1QD11,R3QD11,R4QD02	206QF-957-DV-848-272QD	**0.249%**
R1QD02,R2QD11,R3QD02,R4QD11	272QD-1197-DV-608-206QF	**0.007%**
R*QF04, R*QF09	230S-575-222Q-500-230S	**2.22%**

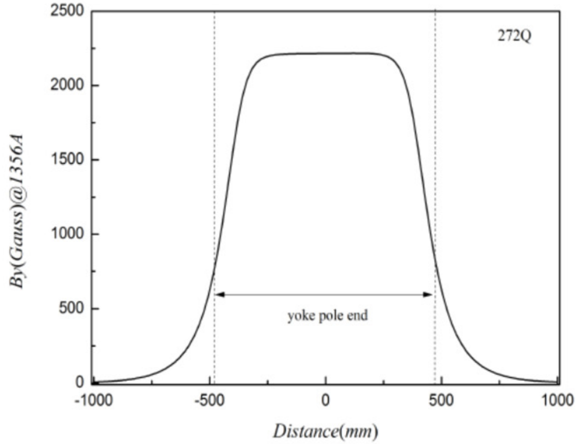
Fringe Field Effects of Quadrupoles

To reduce space-charge effect, CSNS/RCS employs large aperture quadrupoles. Fringe field effect is an important issue.





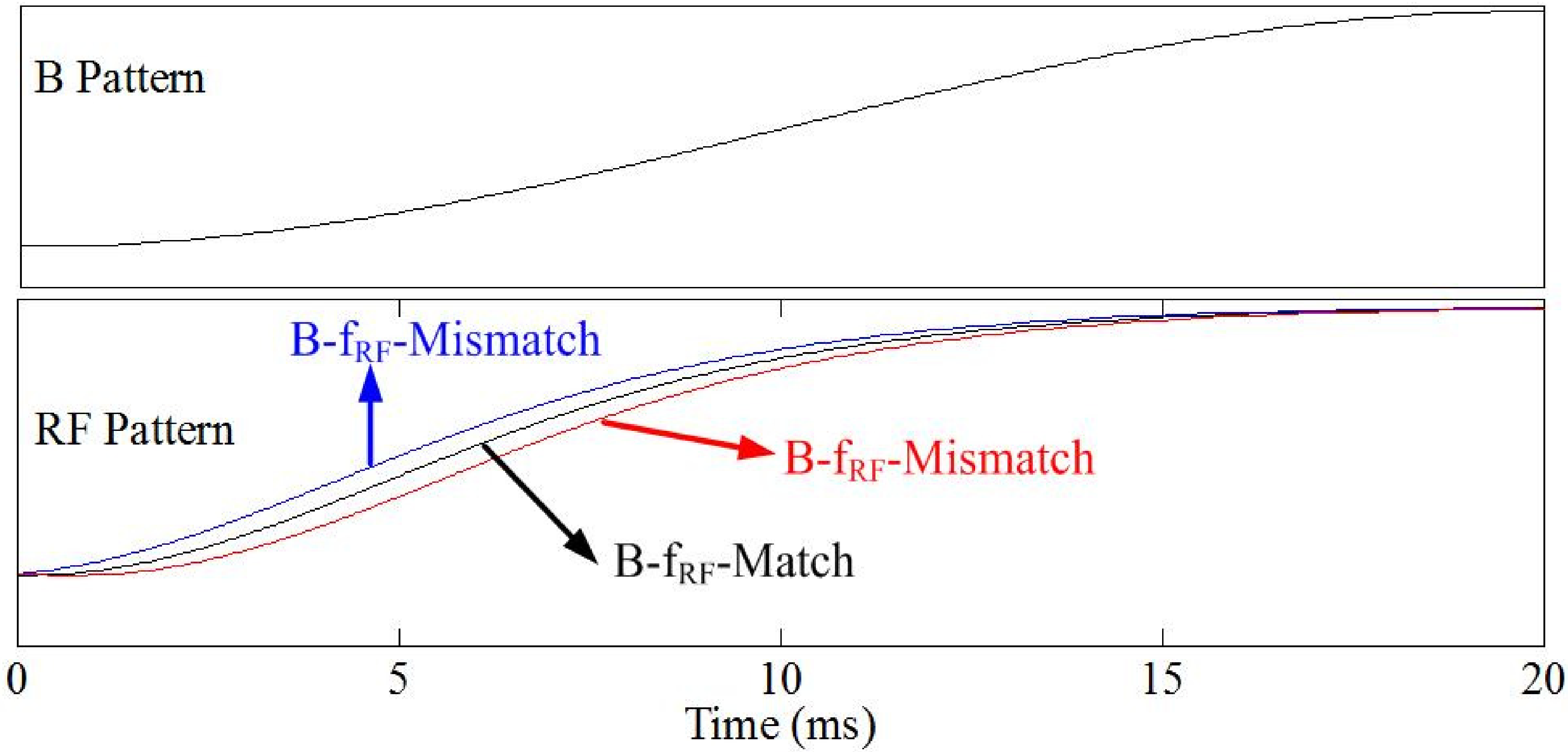




- The lattice design of is based on hard edge model, and the designed tune is **4.86/4.78**.
- The tune of the designed Lattice is **4.78/4.57** based on soft edge model.
- The lattice was re-matched based on soft edge model. The tune was re-matched to **4.86/4.78.**

Magnetic Field and RF Frequency Tracking

The match of the dipole magnetic field ramping function and the RF frequency ramping function is an important issue.



A code was developed to study the dipole magnetic field and RF frequency tracking at CSNS/RCS.

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Stage I Beam Commissioning

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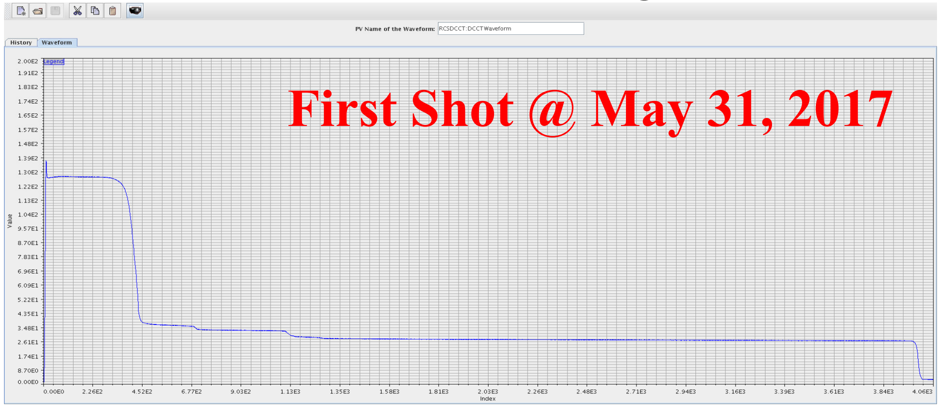
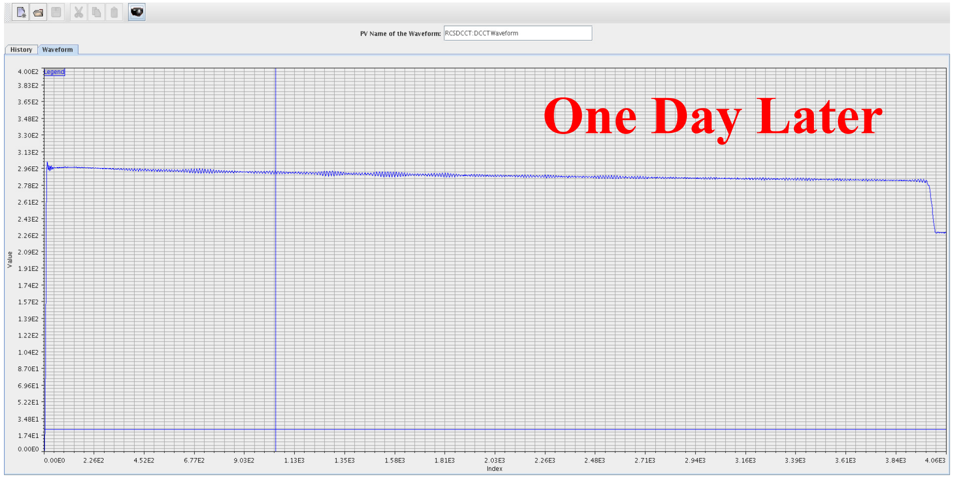
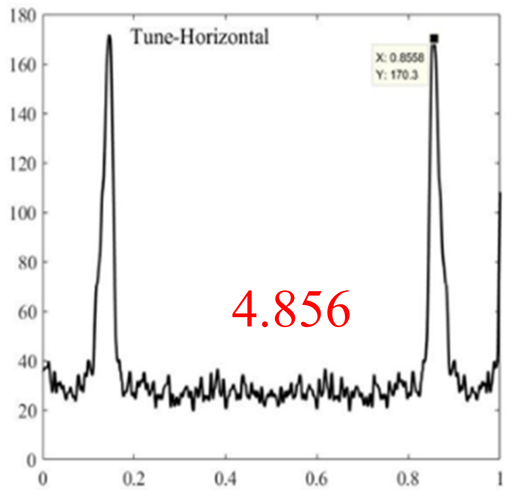
- Stage Ⅰ beam commissioning of CSNS/RCS was started in May 2017 with the injection energy of 61MeV.
- To control the beam loss during the beam commissioning, the single shot beam mode was adopted.
- The beam commissioning was started in DC mode without acceleration.

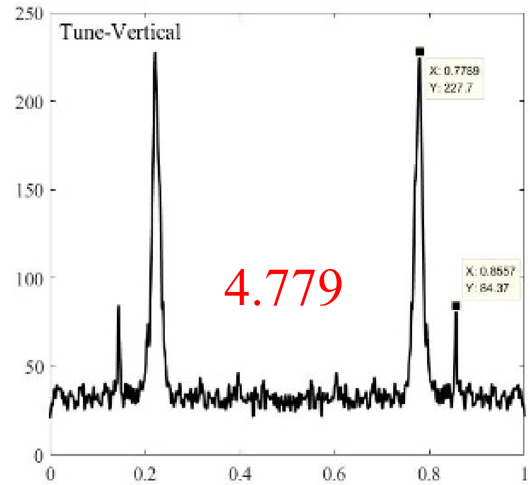




After the optimization of B field, RF pattern and the injection, the beam transmission achieved ~100% one day later.

Parameters Measurement in DC mode





The measured tune is very close to the design value (4.86, 4.78).

Stage I Beam Commissioning

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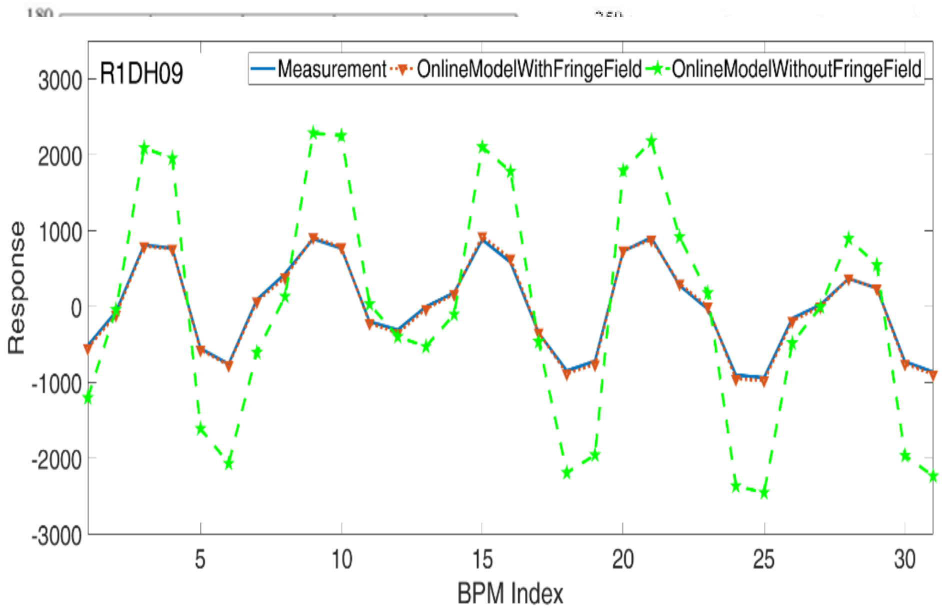

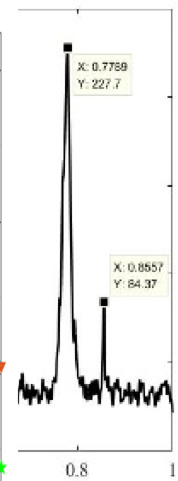

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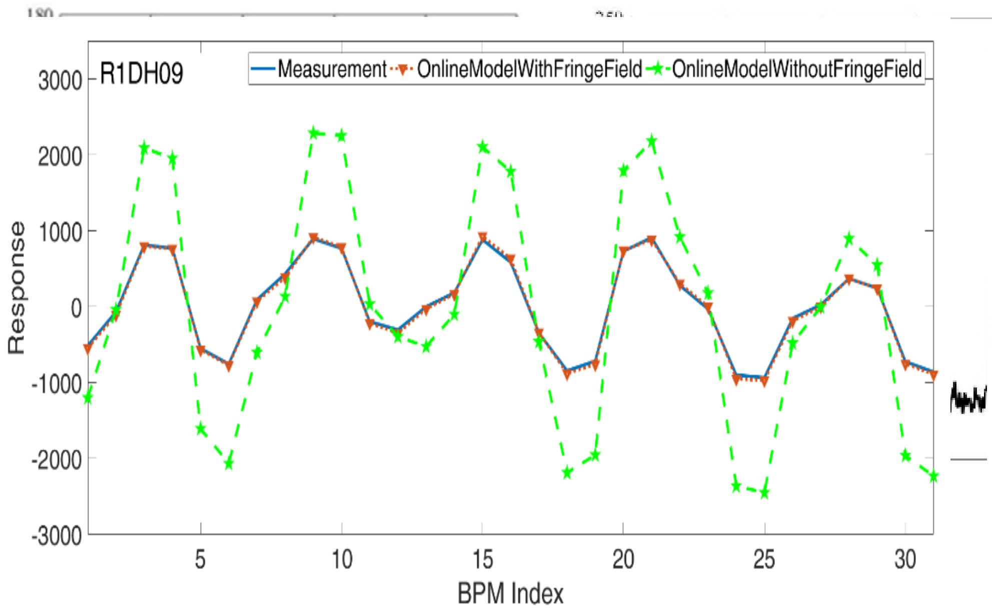

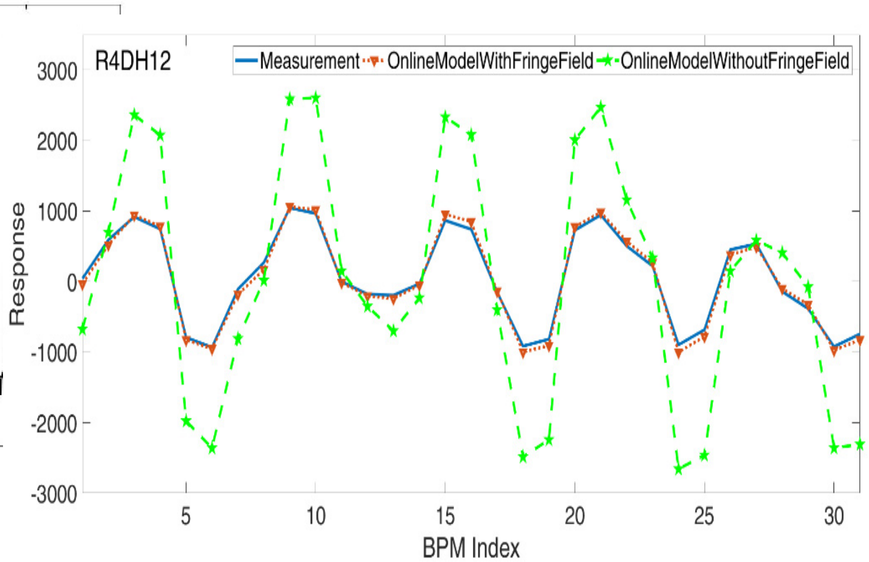

Stage I Beam Commissioning

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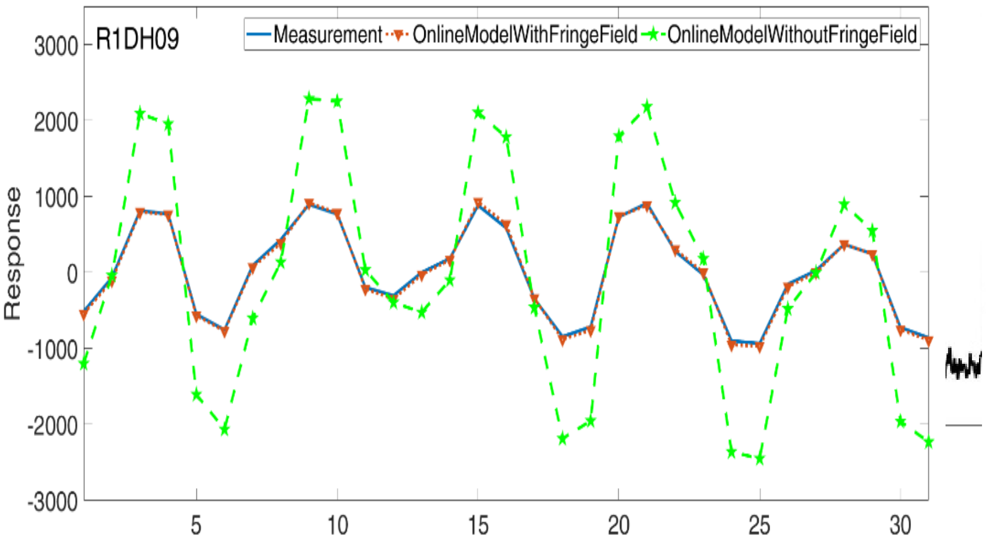

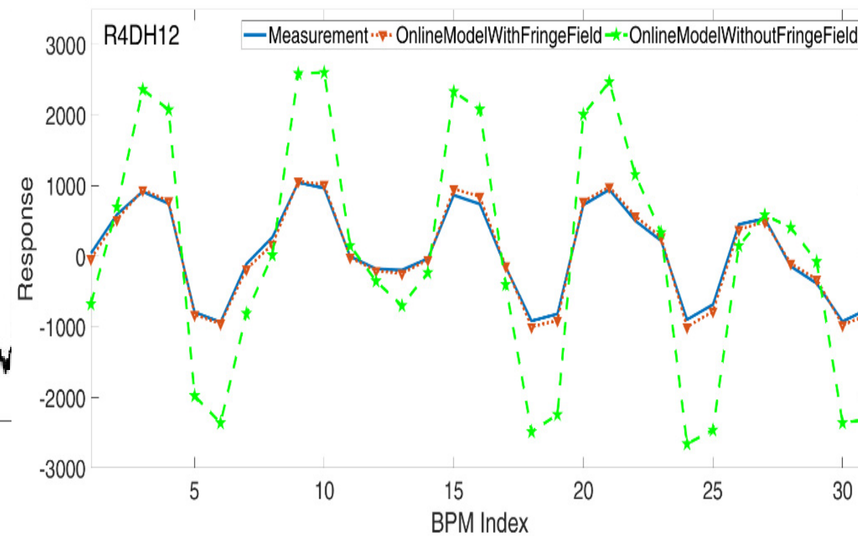

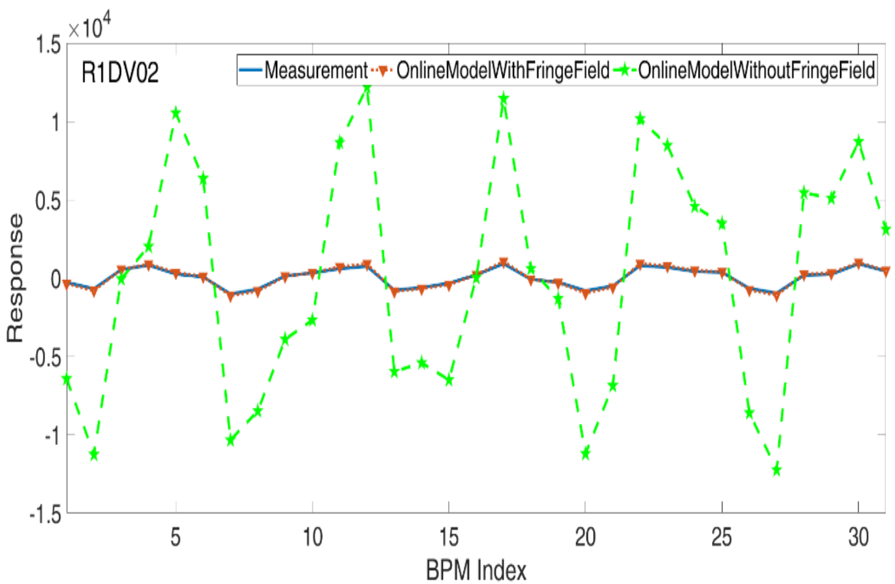

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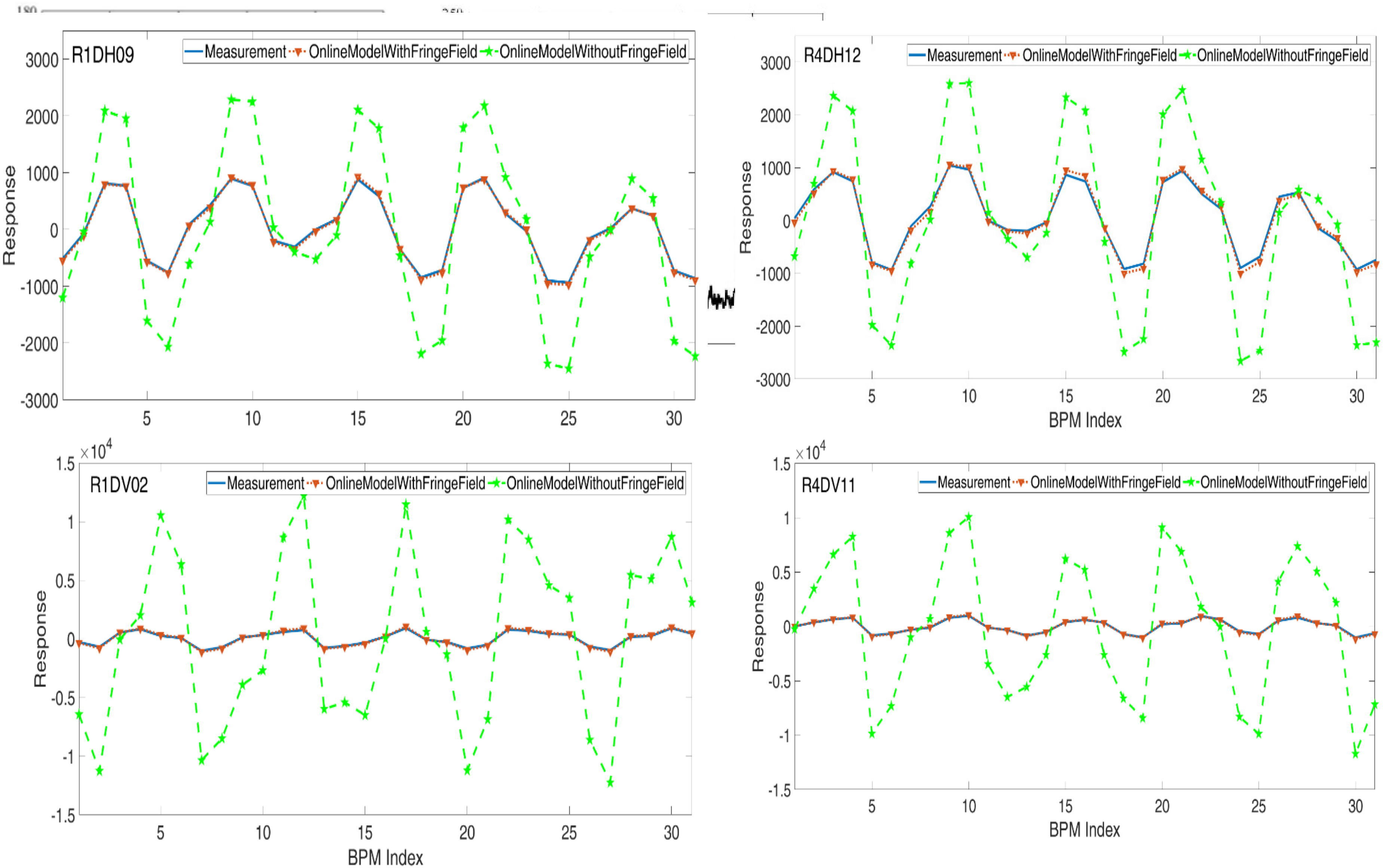

Stage I Beam Commissioning

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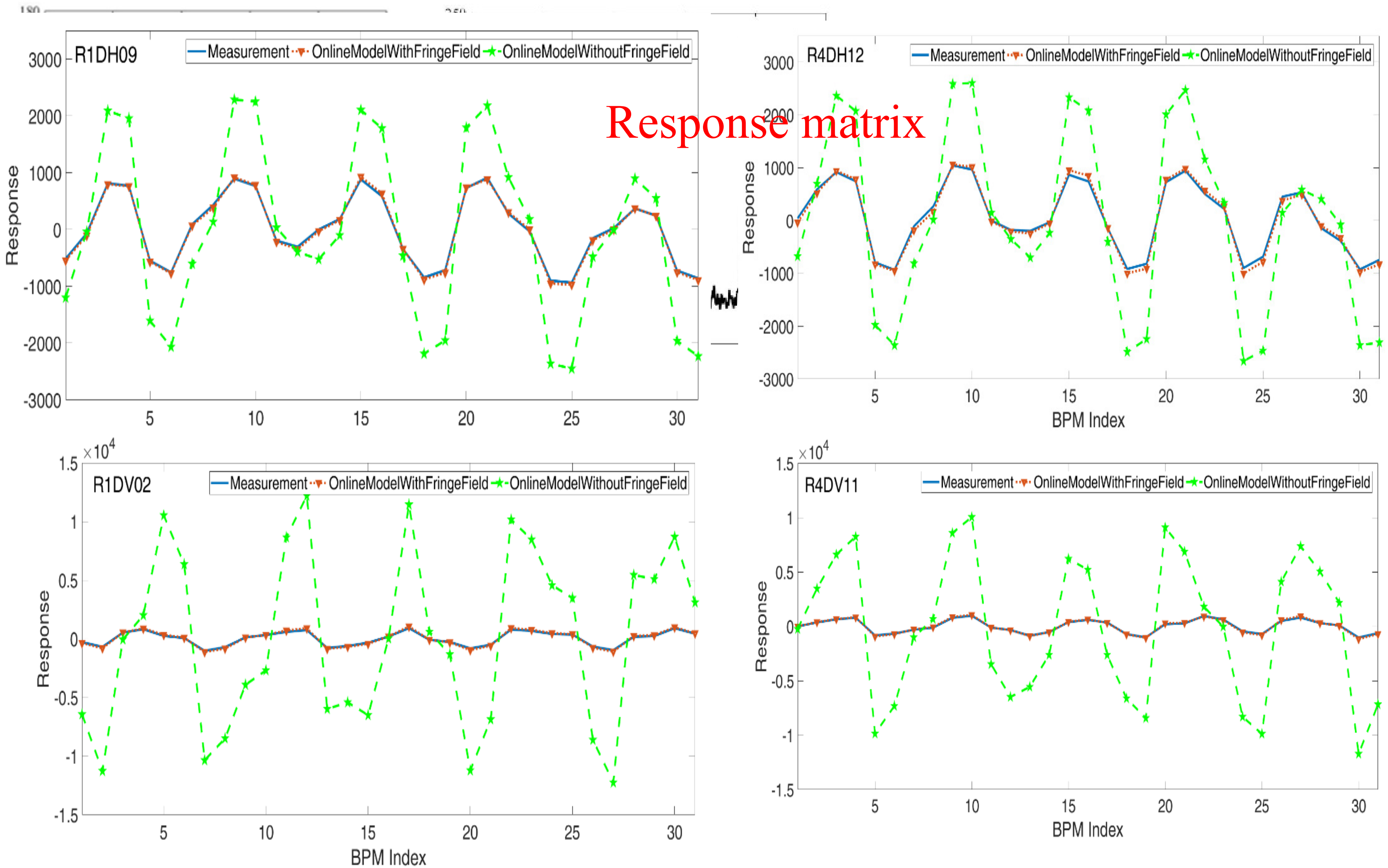

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Stage I Beam Commissioning

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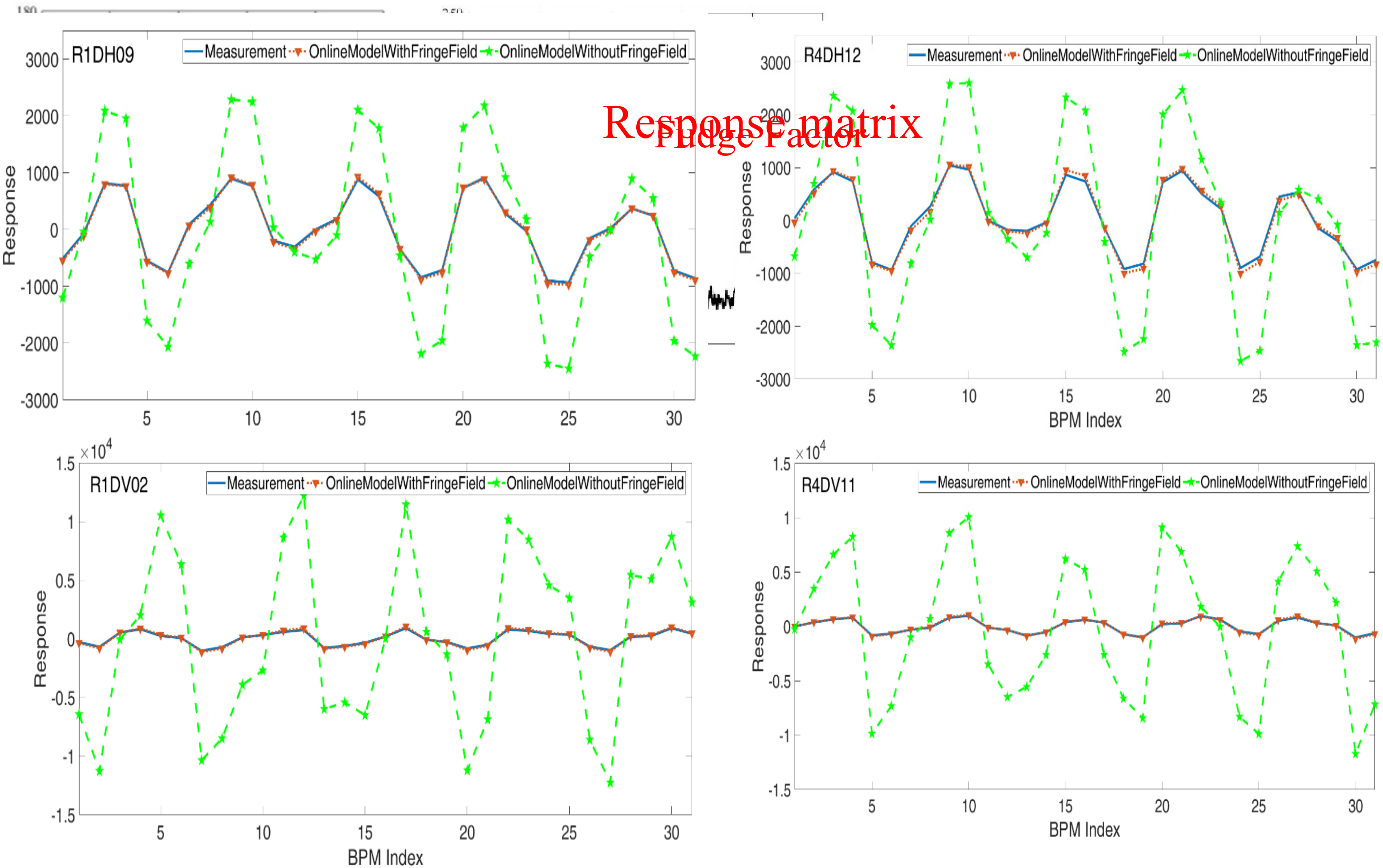
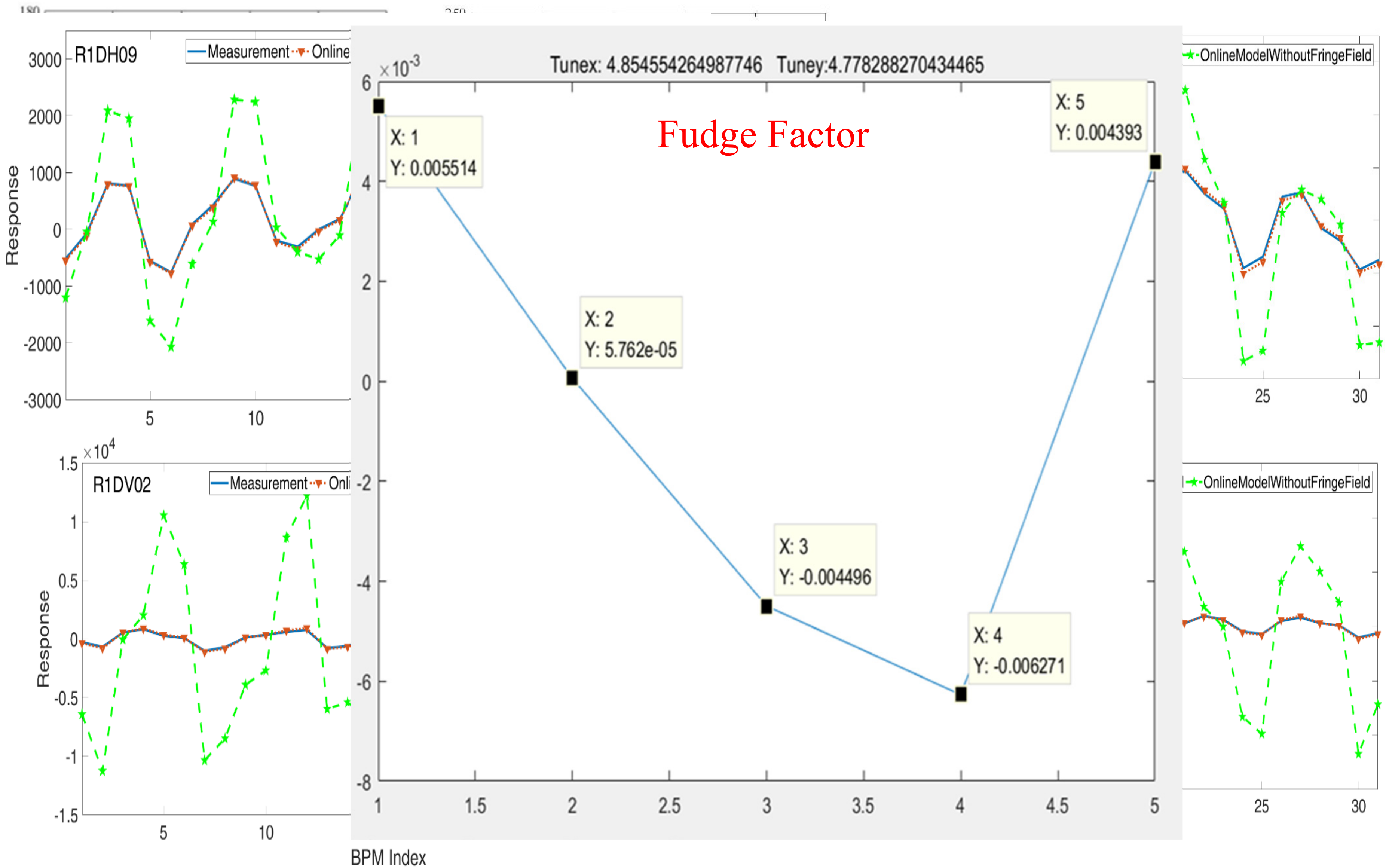
Parameters Measurement in DC mode

Response matrix

Fudge Factor

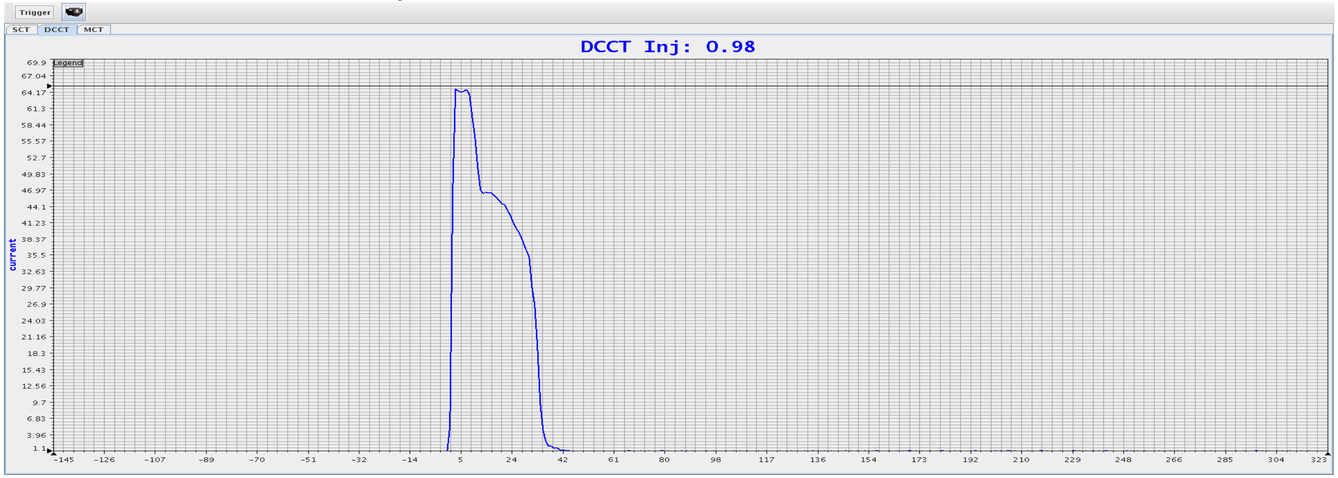


Parameters Measurement in DC mode



Stage I Beam Commissioning

- Beam commissioning in AC mode was started on July 7, 2017. The first beam shot was injected and accumulated successfully.
- The beam life time is only ~3 ms.



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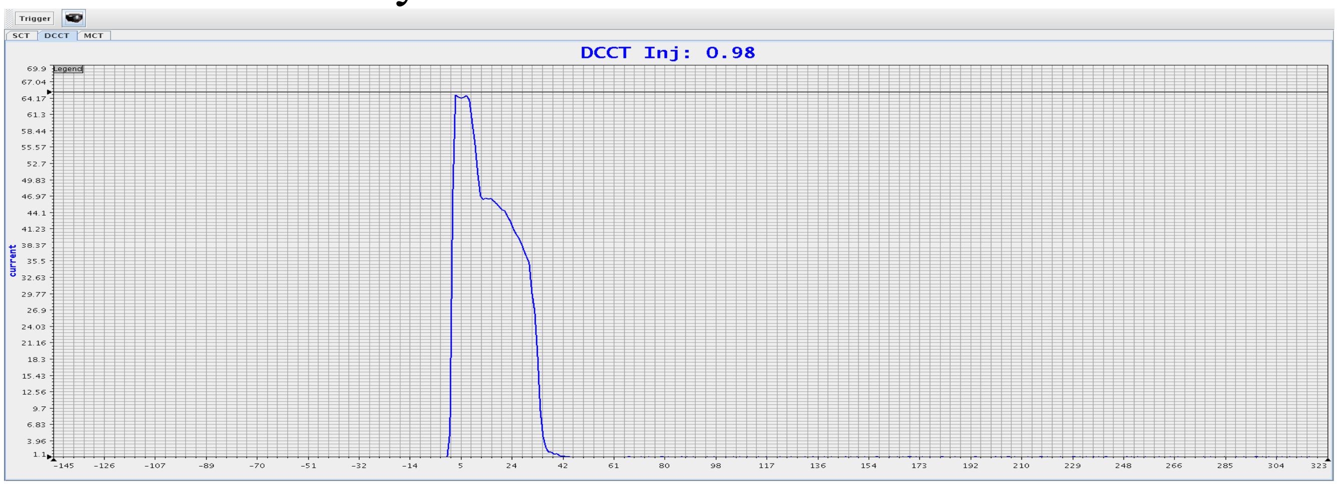

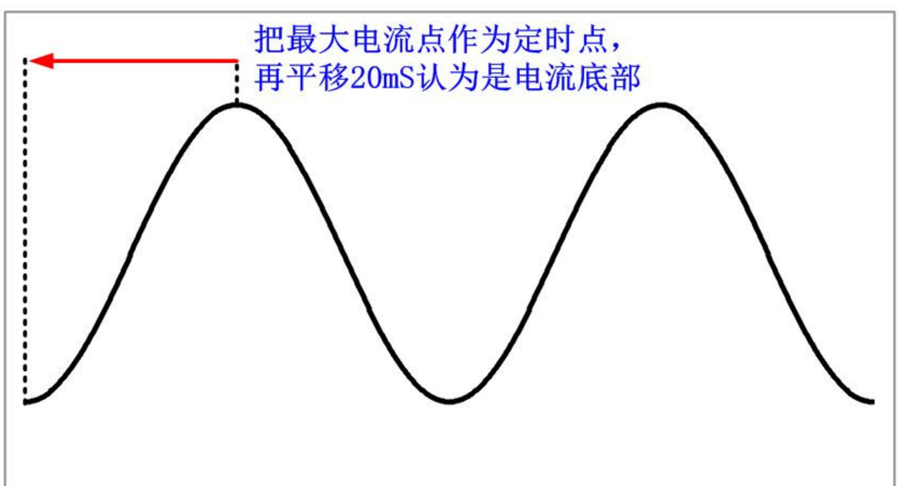

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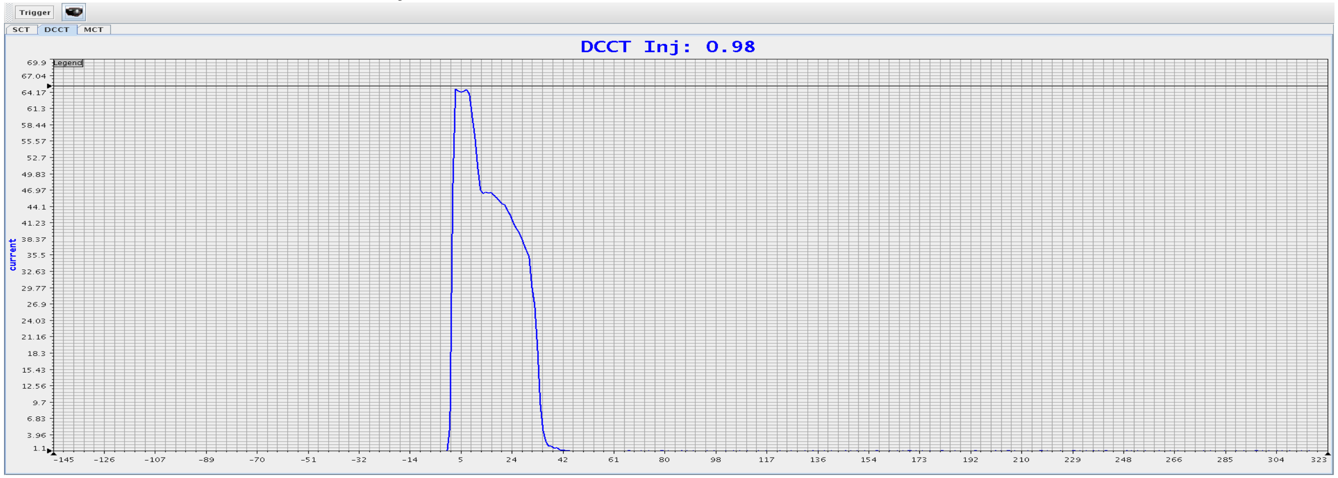

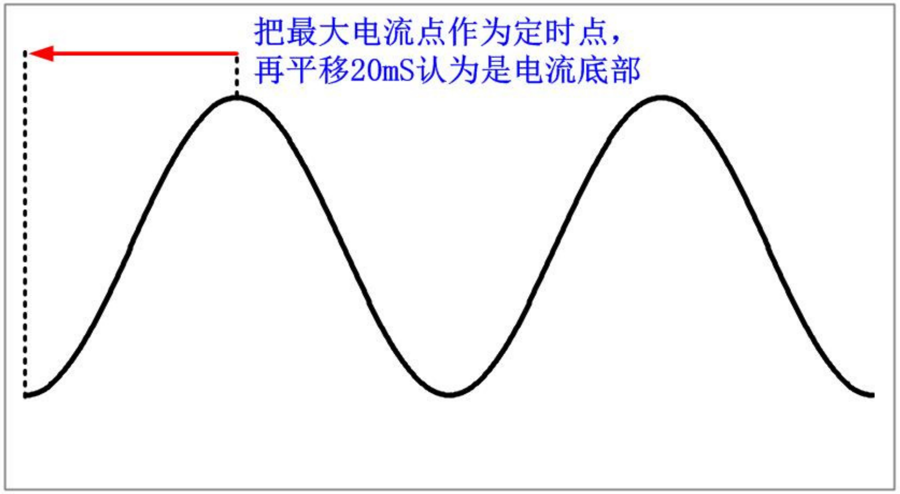

- The timing of magnet power supply was checked.
- The timing error of magnet power supply was about 140 µs.

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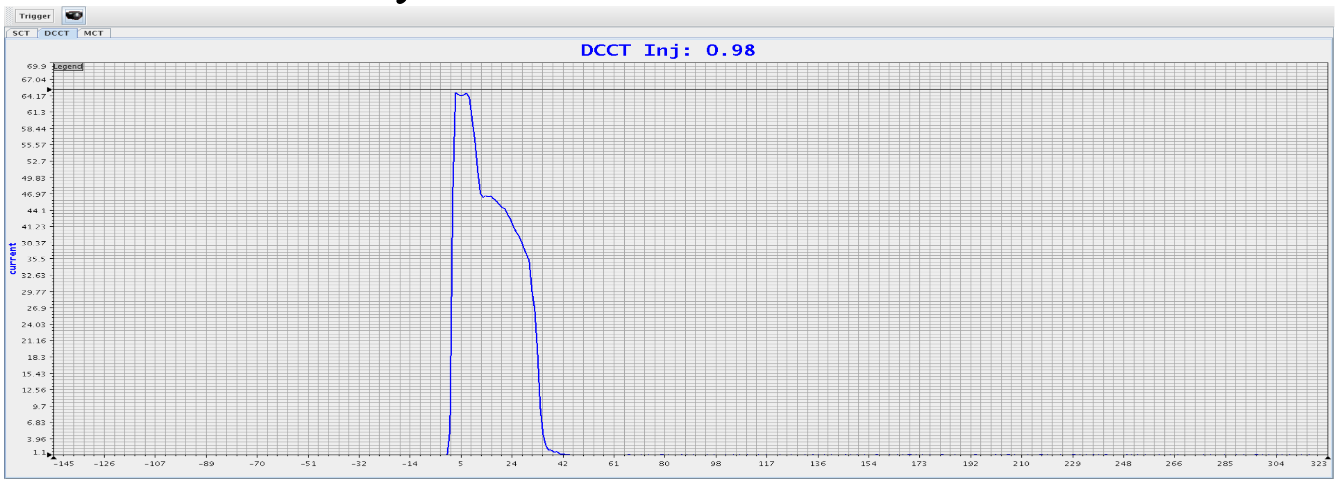

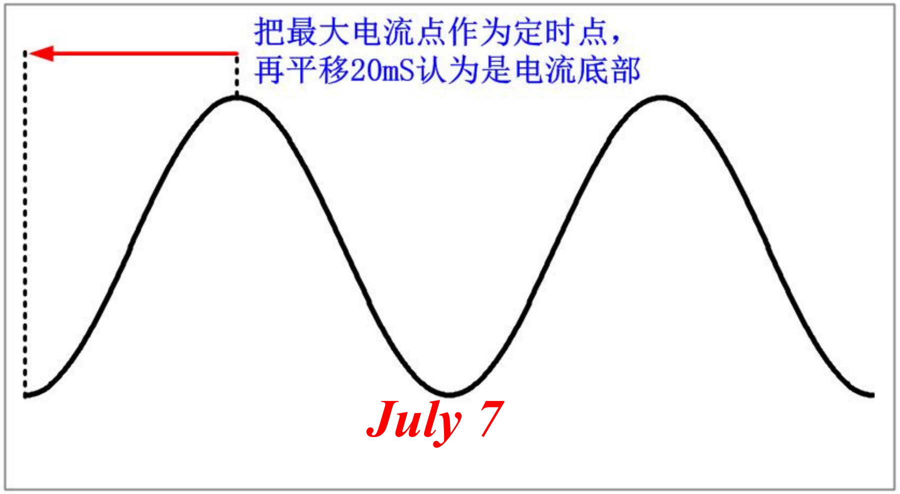

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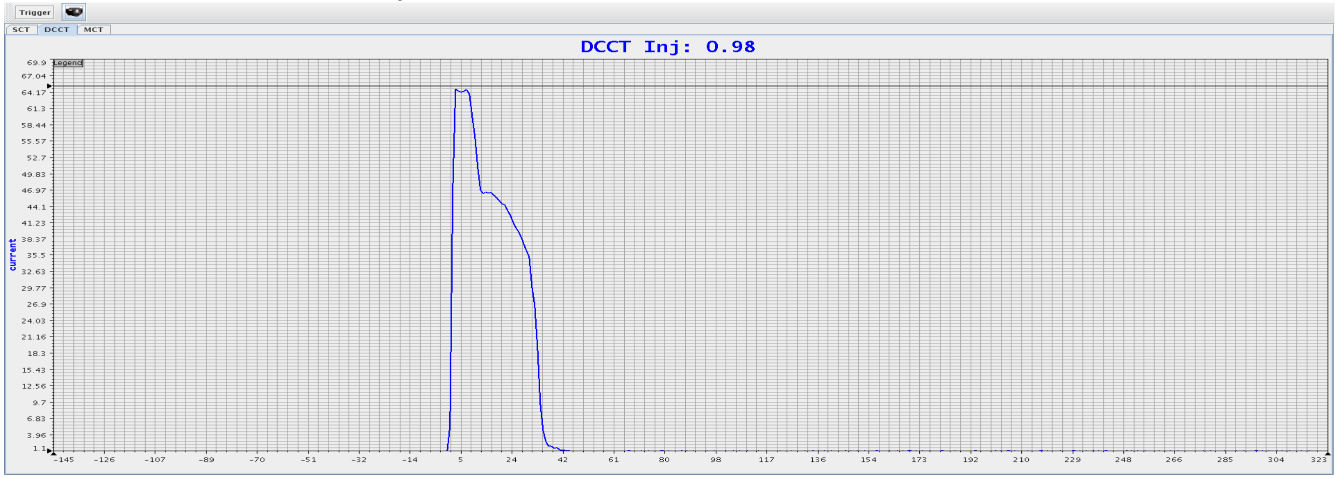

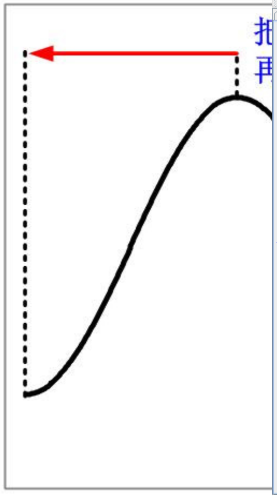

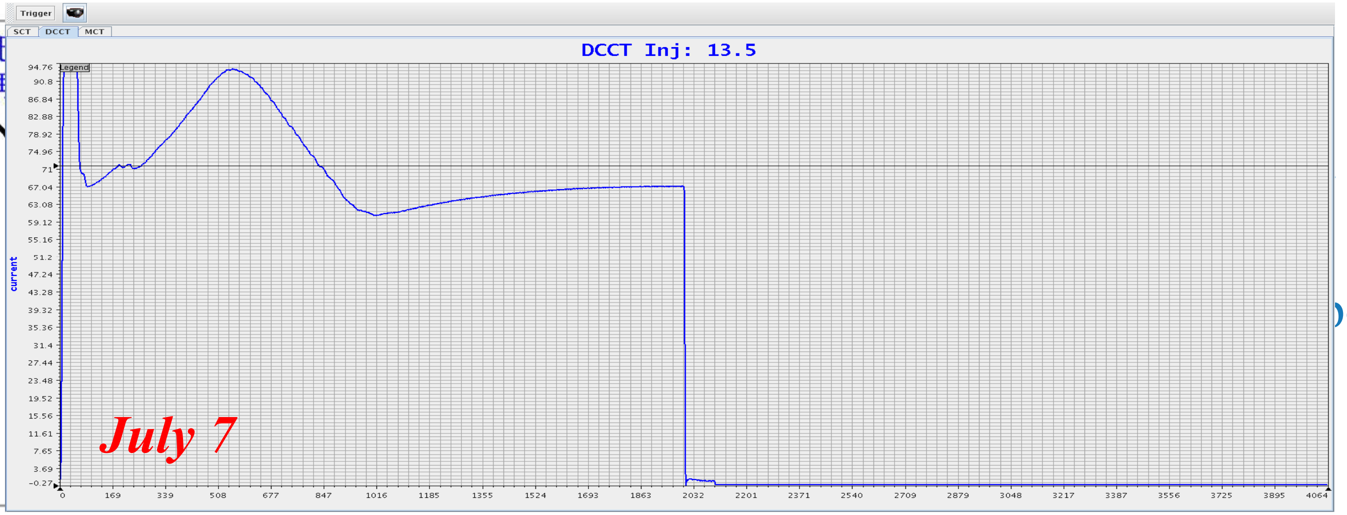

supply was

power supply

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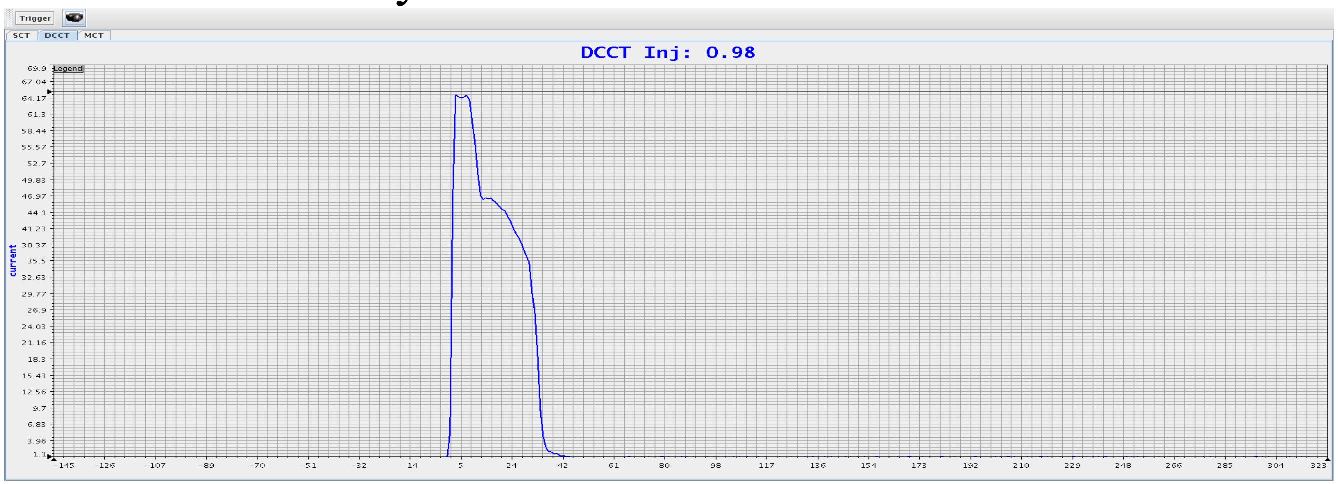

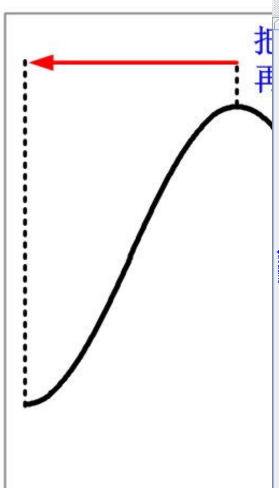

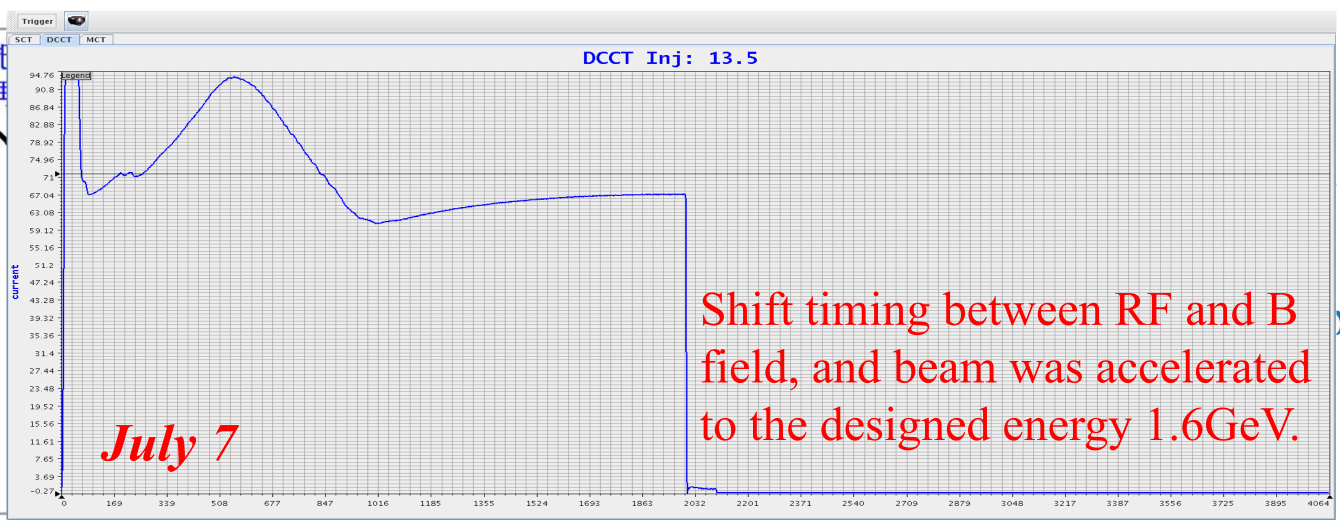

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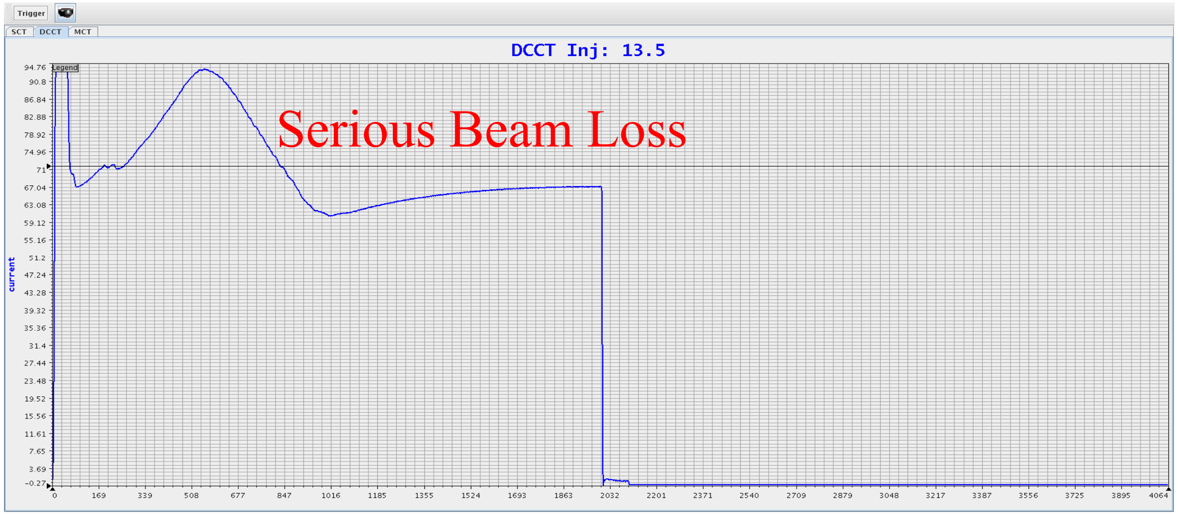
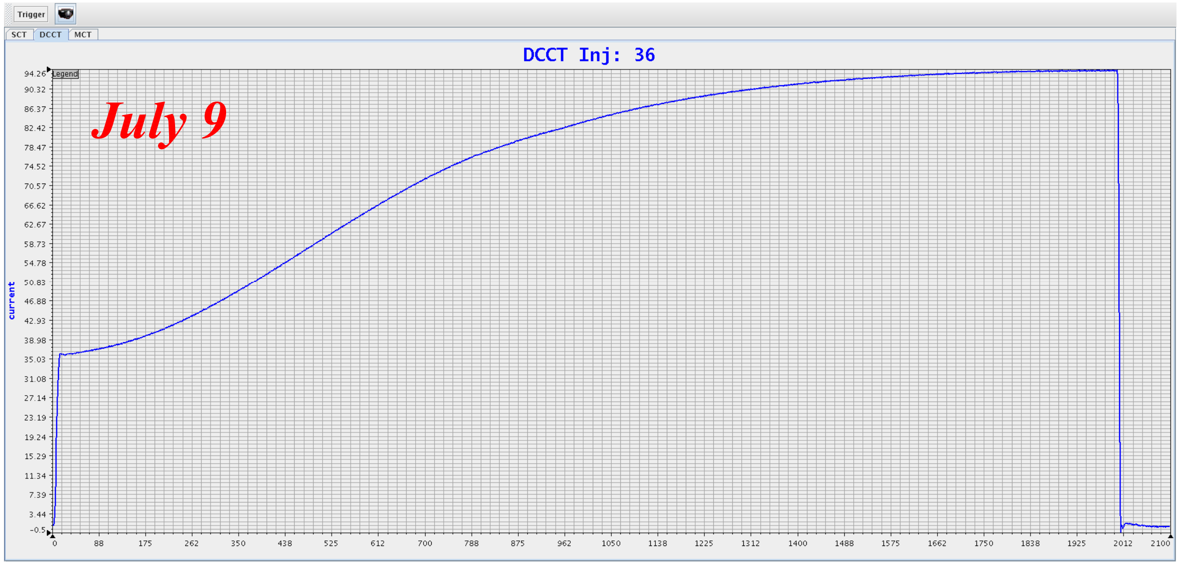
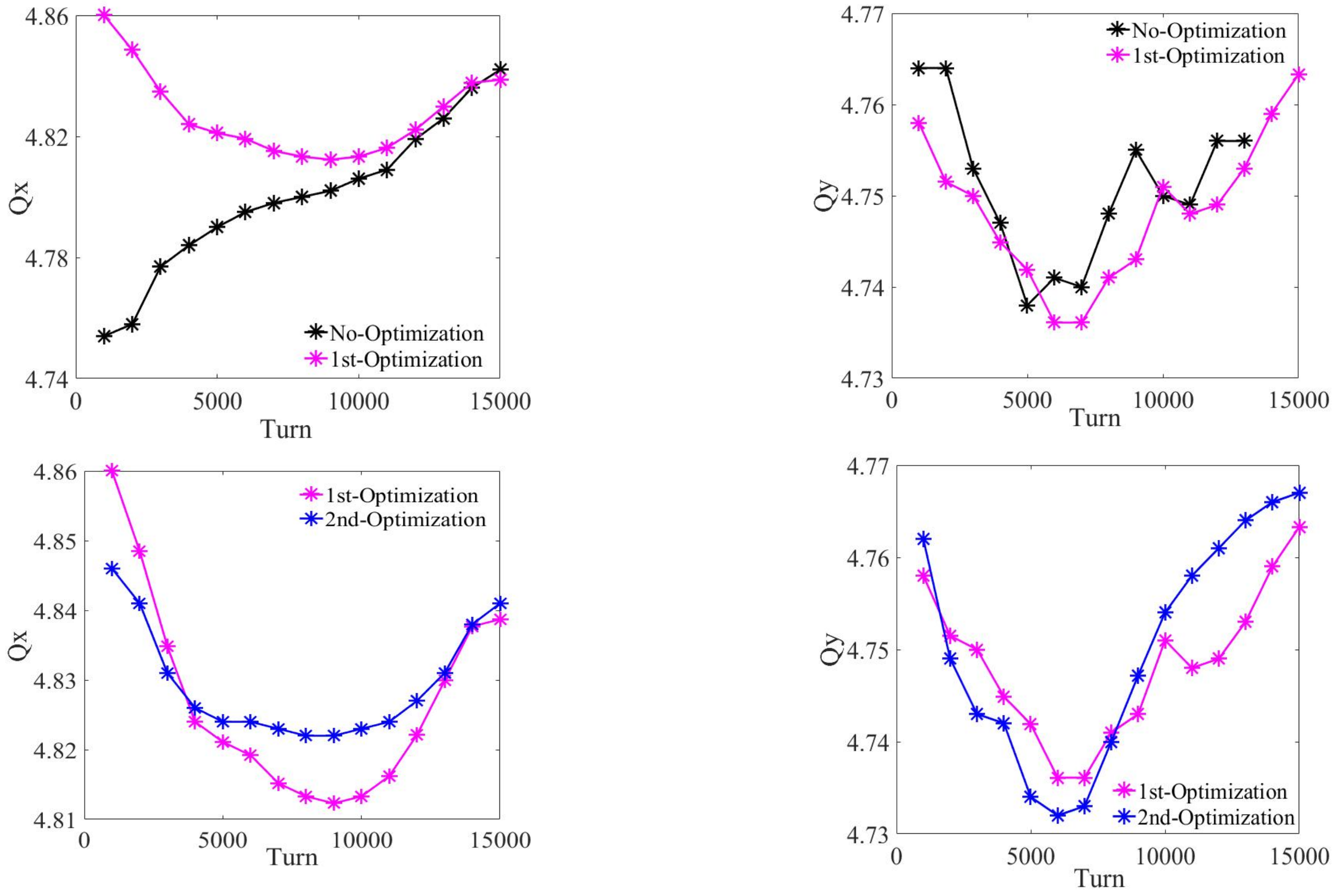
Stage I Beam Commissioning



- Increase RF Voltage, tune the RF frequency ramping curve
- The designed RF voltage is 165 KV, and the real voltage is only 140KV



Stage I Beam Commissioning



- Optimize the tune during acceleration process.
- The B(G)-I for RCS magnets in 61MeV~1.6GeV mode was not measured.
- The error of the set-point for quadrupole and dipole power supply is very large.

Stage Ⅱ Beam Commissioning

- StageⅡbeam commissioning of CSNS/RCS was started on January 15, 2018 with the injection energy of 80 MeV.
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.

Stage Ⅱ Beam Commissioning

- StageⅡbeam commissioning of CSNS/RCS was started on January 15, 2018 with the injection energy of 80 MeV.
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.

B-Injection Energy Match

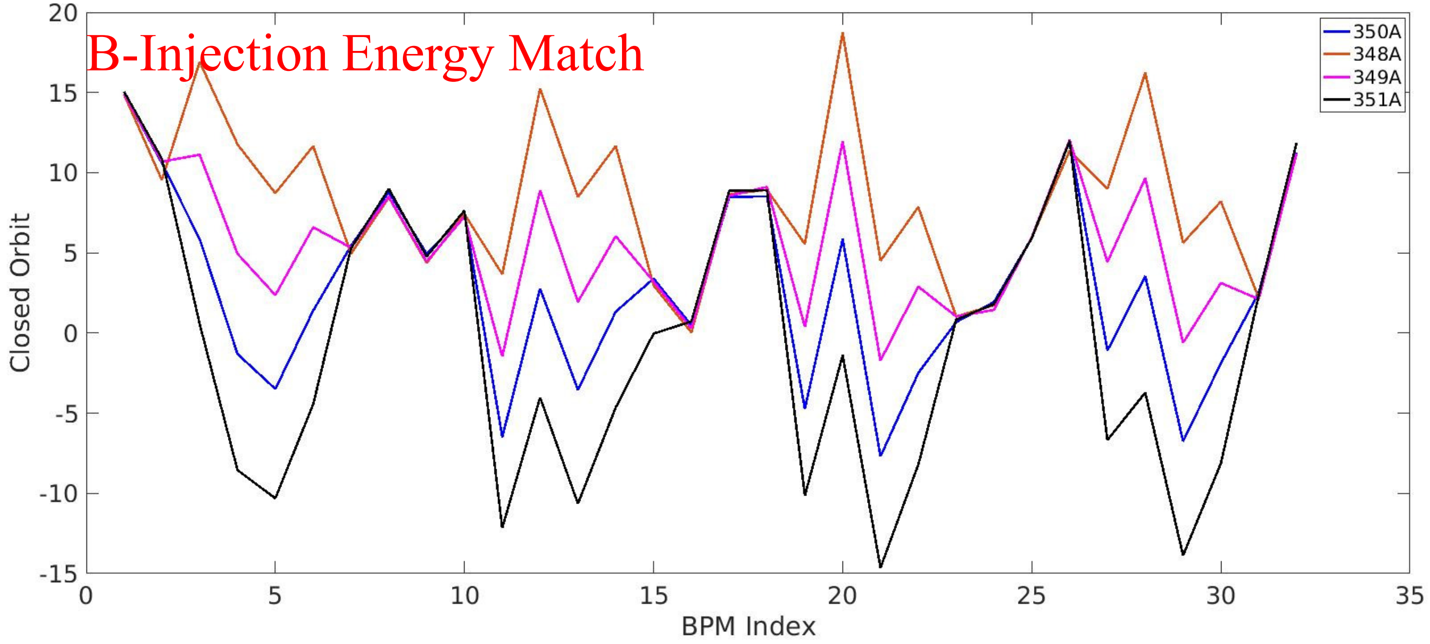
Stage Ⅱ Beam Commissioning

散裂中子源

China Spallation Neutron Source

CSNS CHINESE ACADEMY OF SCIENCES

- StageIIbeam commissioning of CSNS/RCS was started on January 15, 2018 with the injection energy of 80 MeV.
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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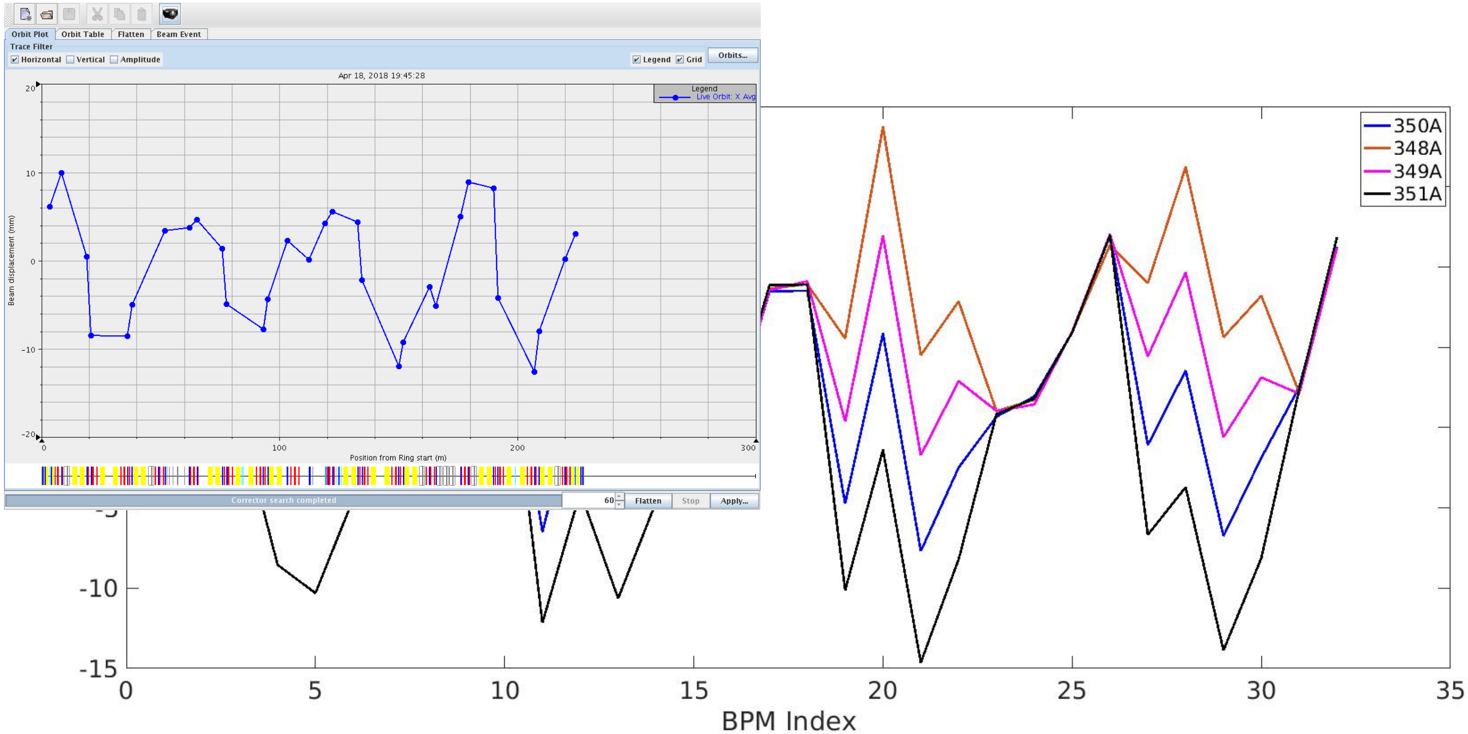
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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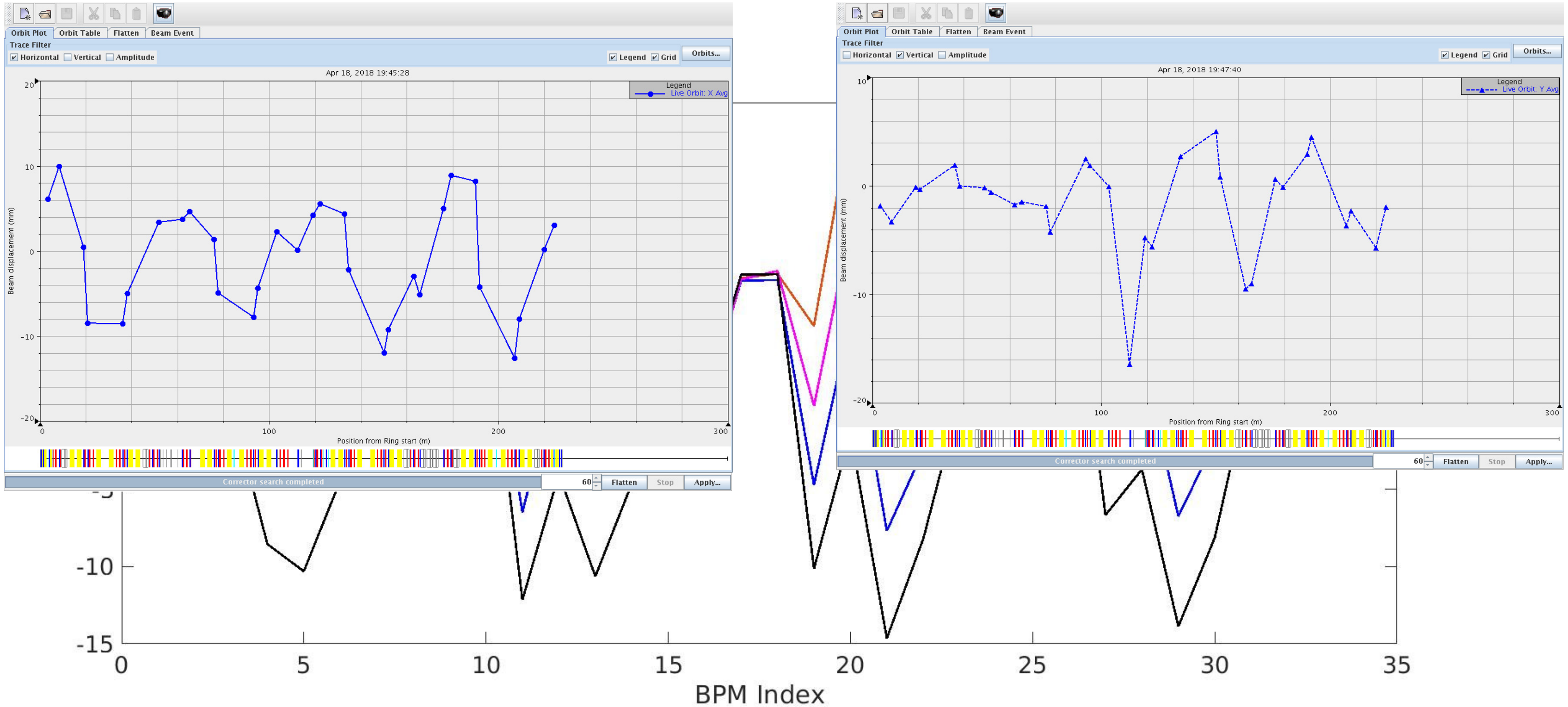

Stage Ⅱ Beam Commissioning

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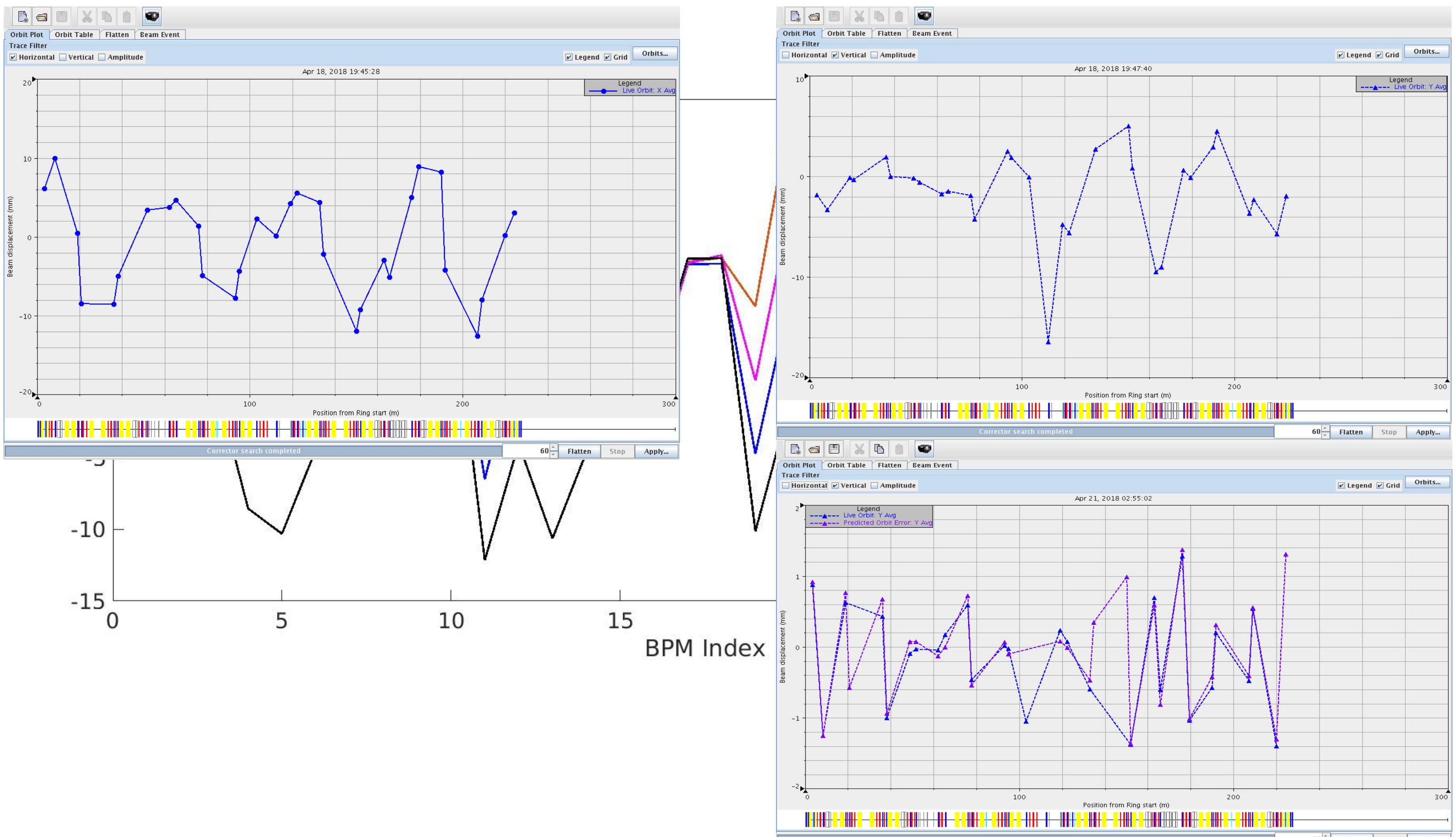

Stage Ⅱ Beam Commissioning

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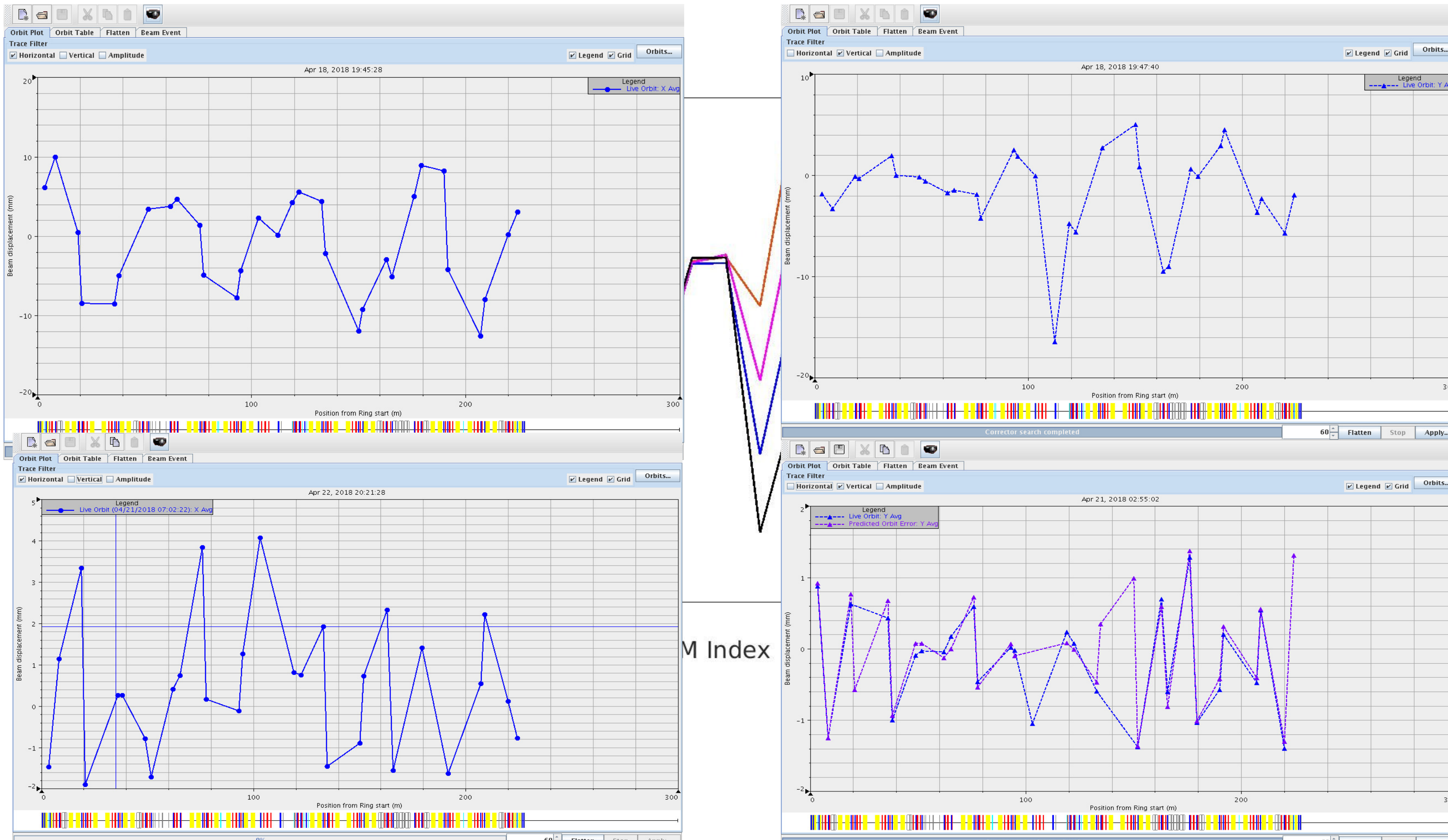
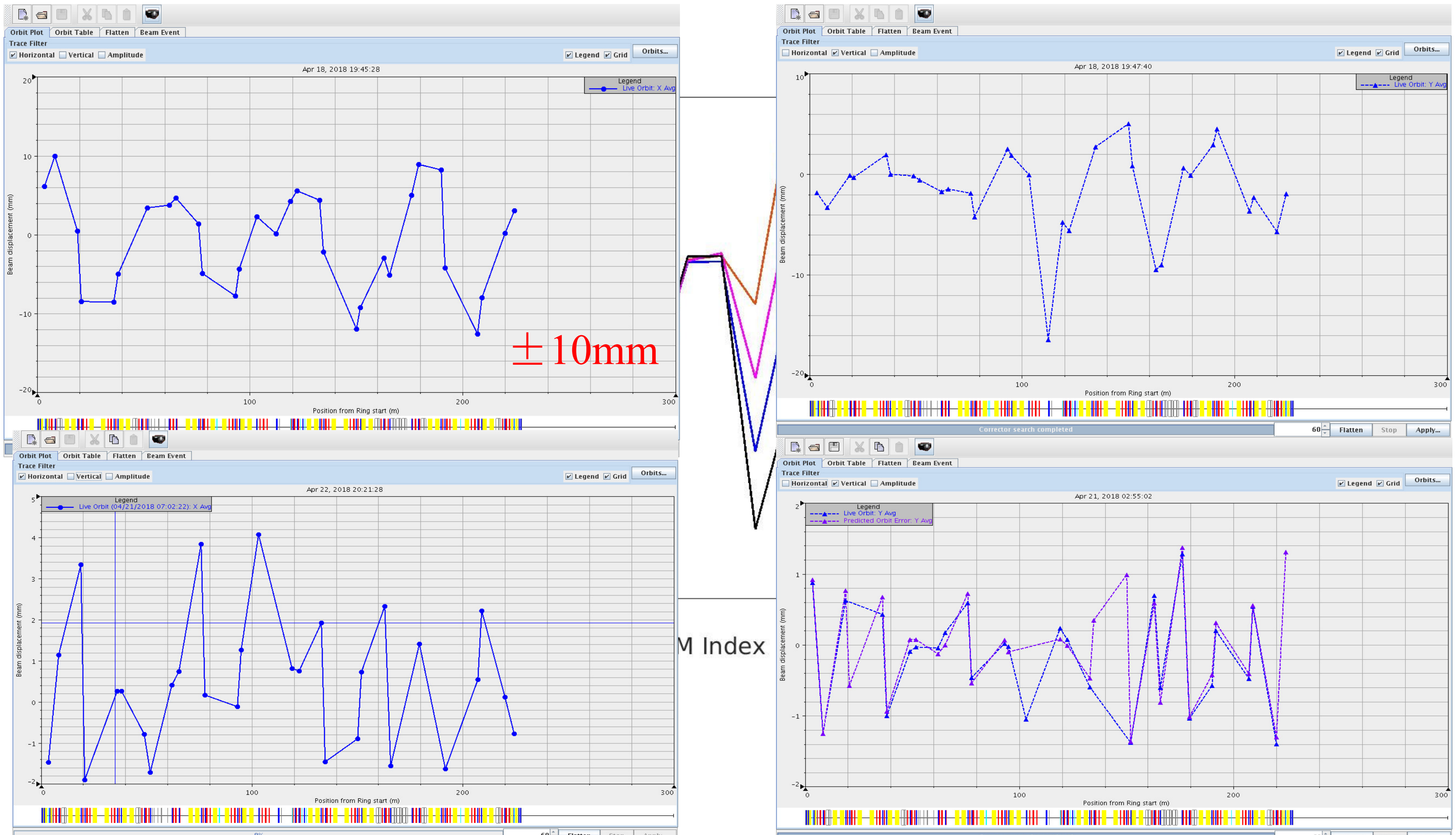


Stage Ⅱ Beam Commissioning

SNS CHINESE ACADEMY OF SCIENCES

散裂中子源 China Spallation Neutron Source

- StageⅡbeam commissioning of CSNS/RCS was started on January 15, 2018 with the injection energy of 80 MeV.
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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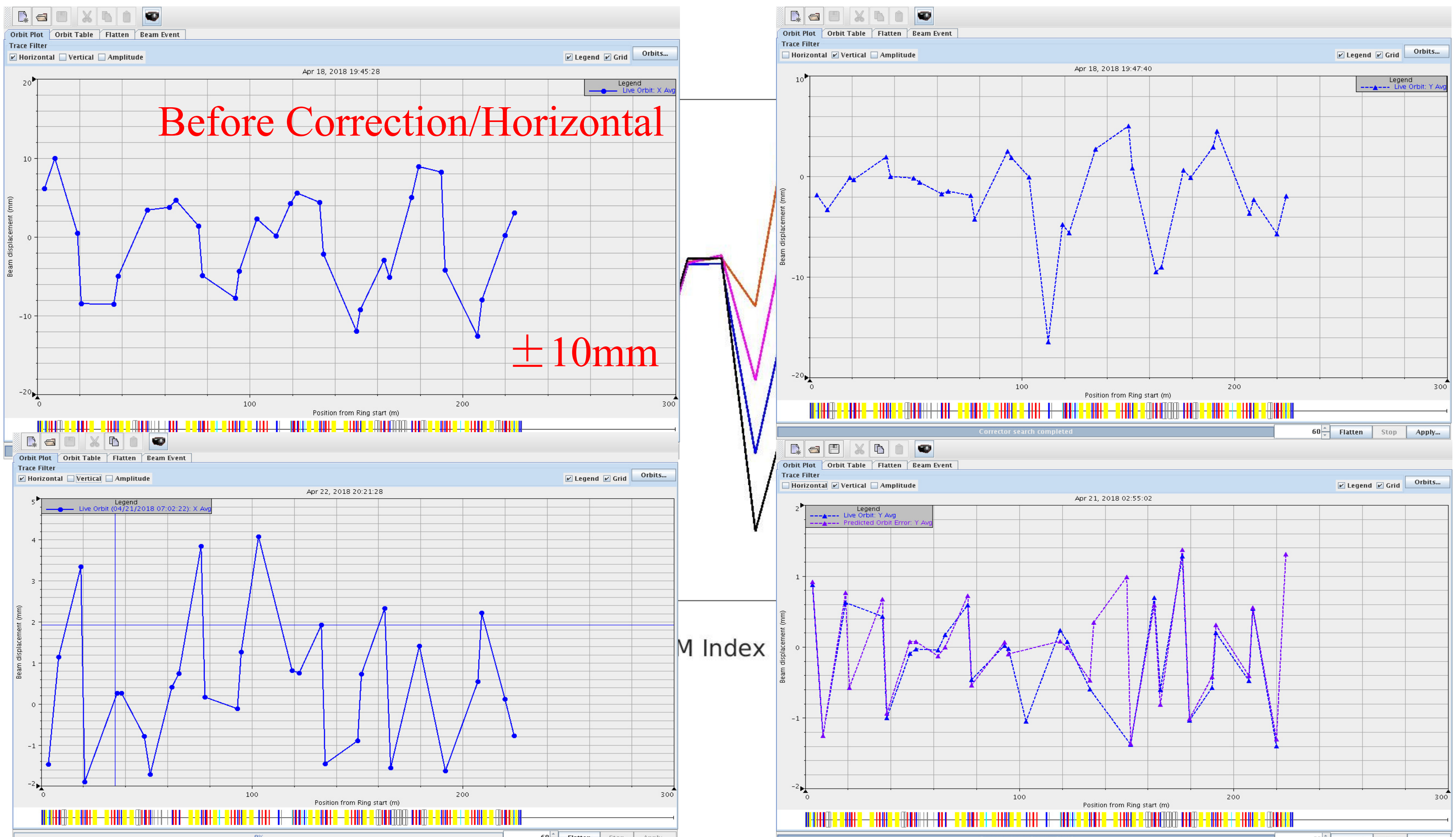
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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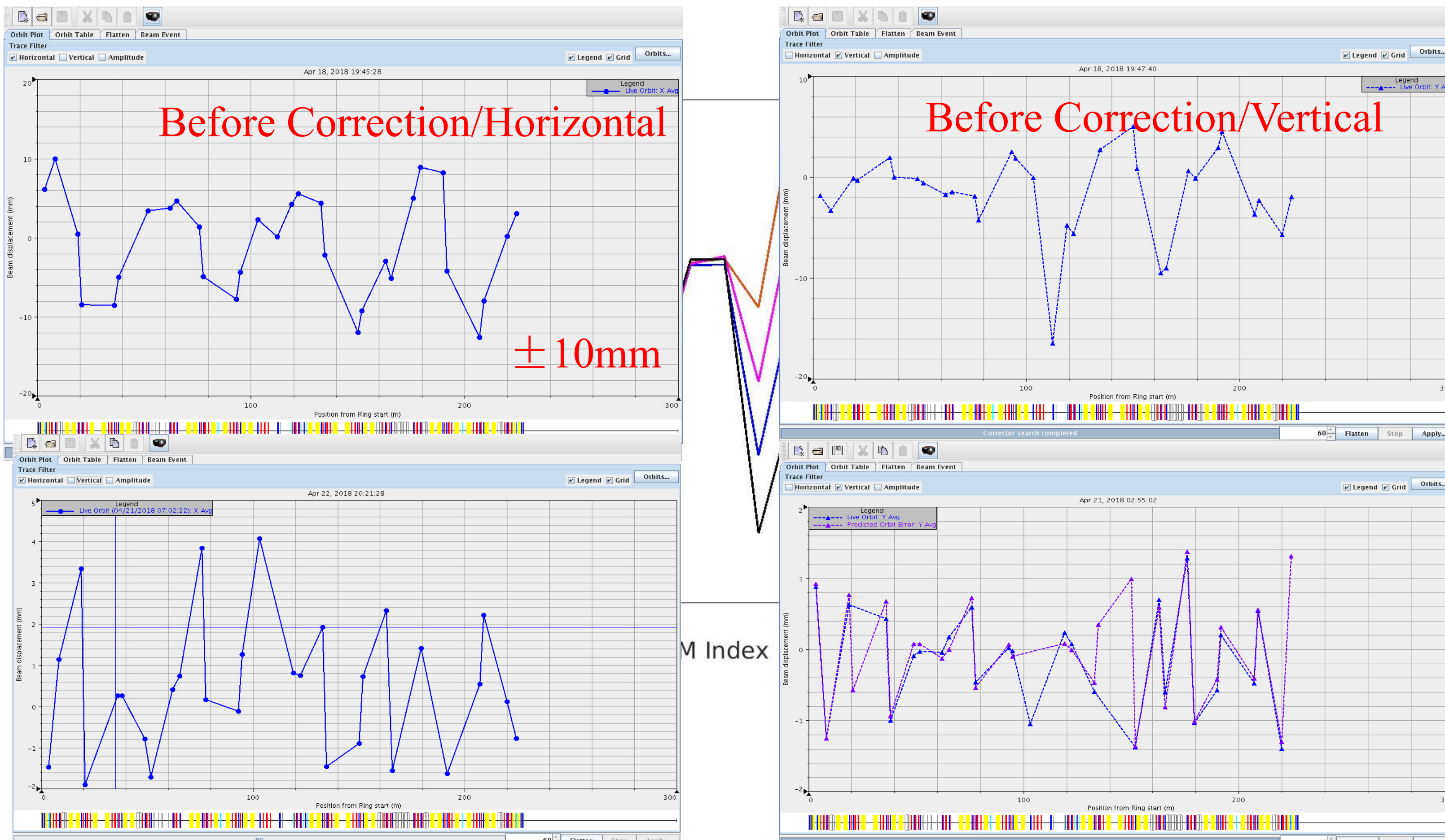
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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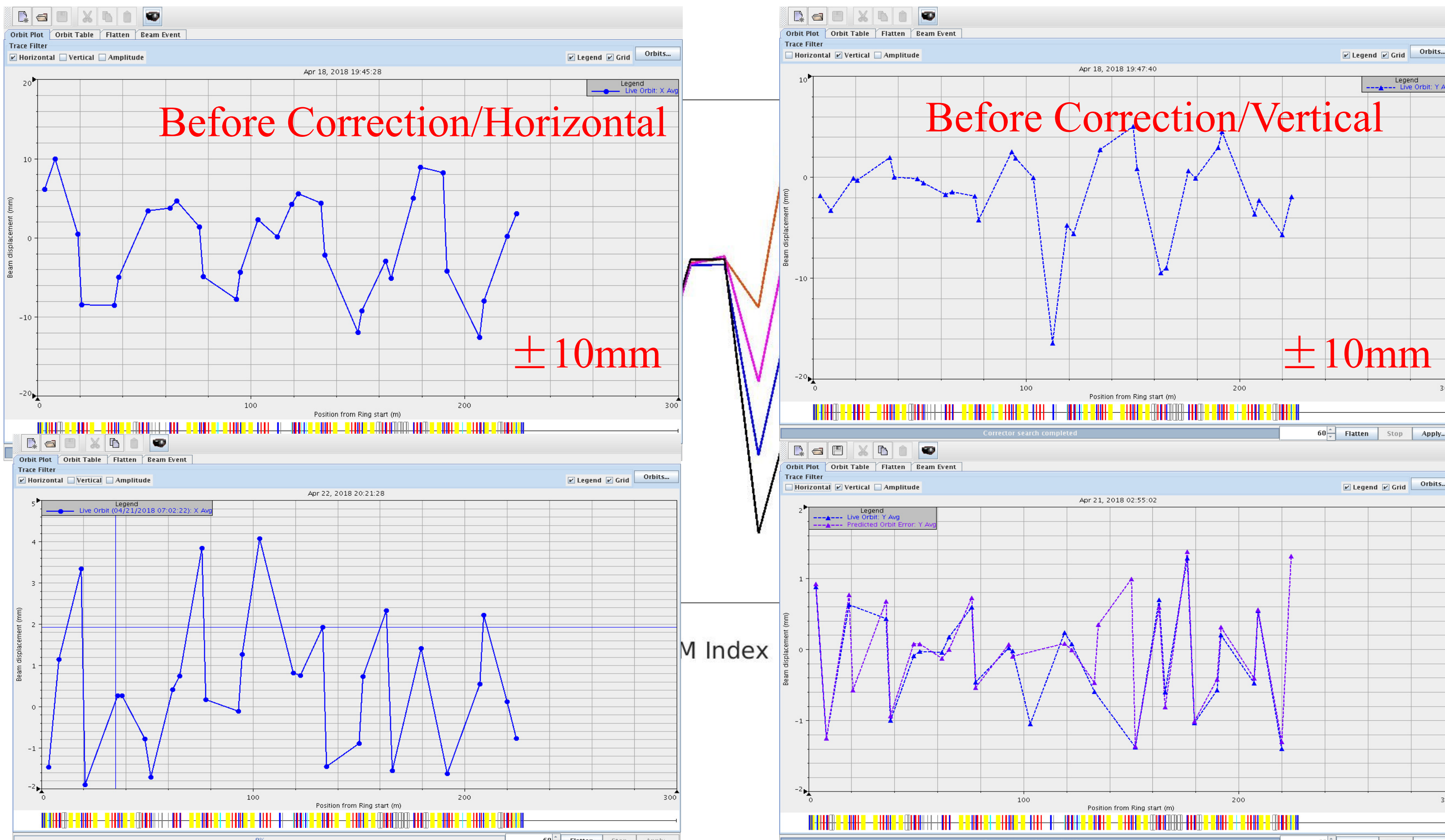
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

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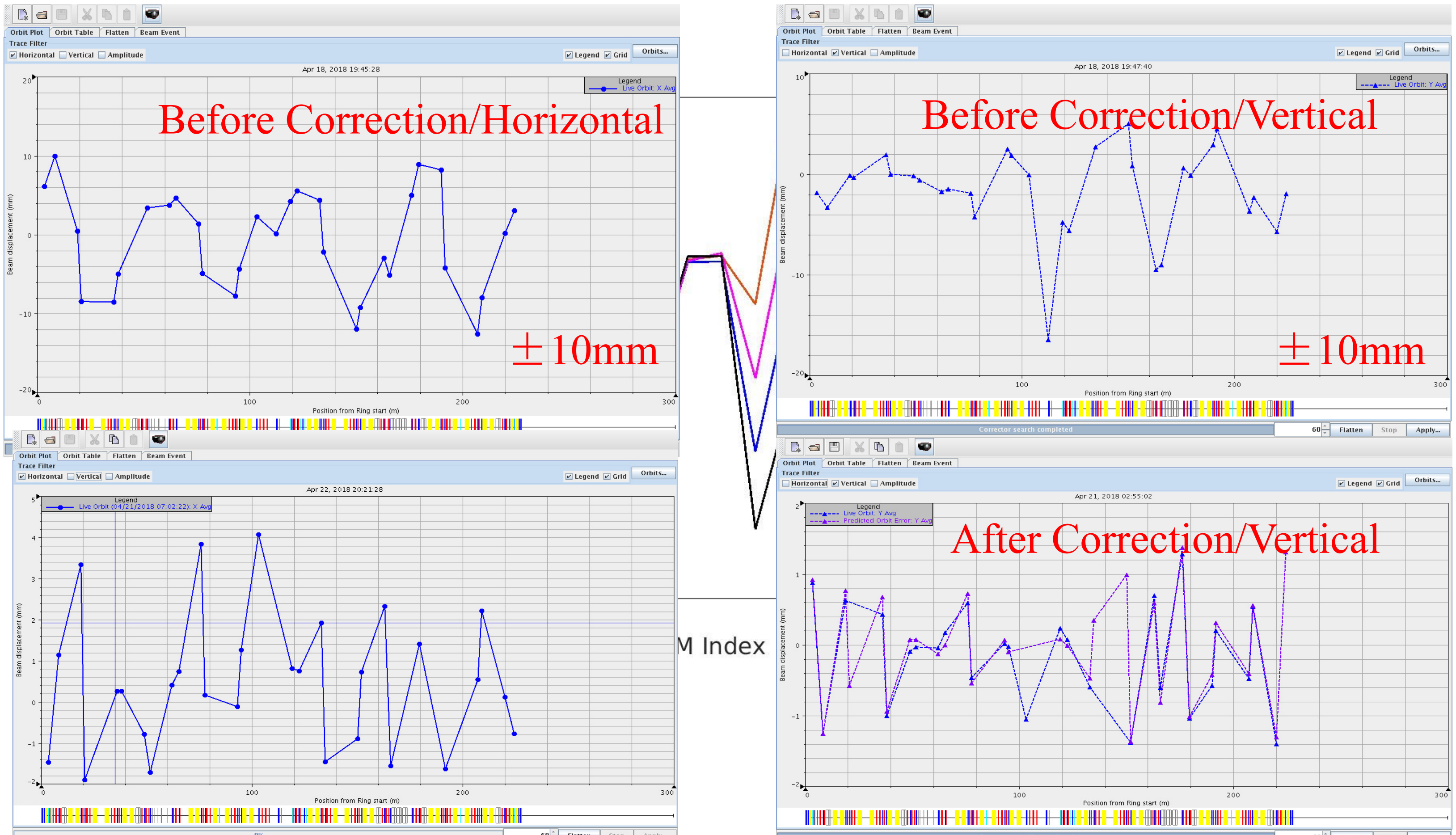
- The beam commissioning was started in DC mode without acceleration.
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

散裂中子源
China Spallation Neutron Source

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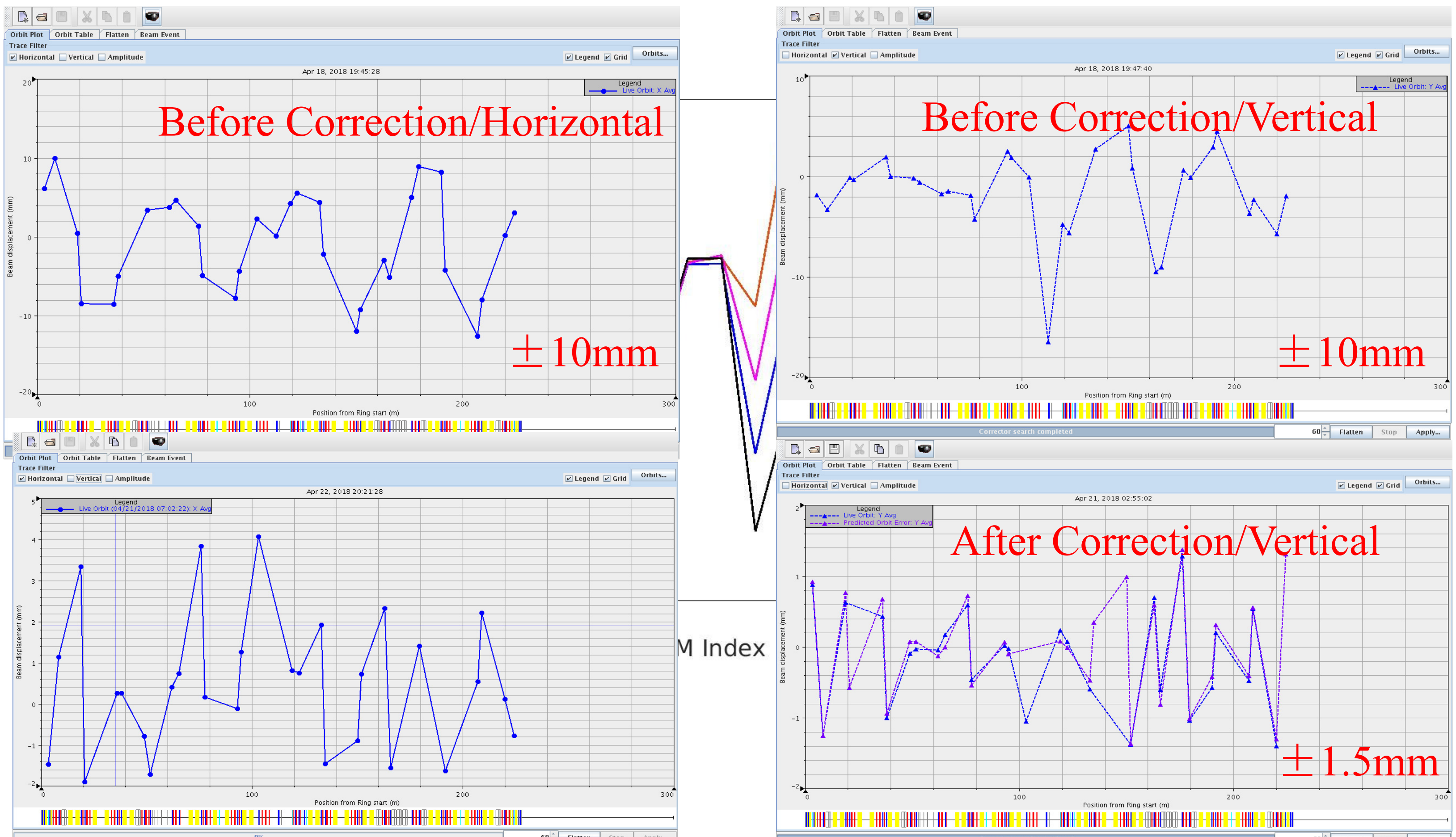
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

散裂中子源
China Spallation Neutron Source

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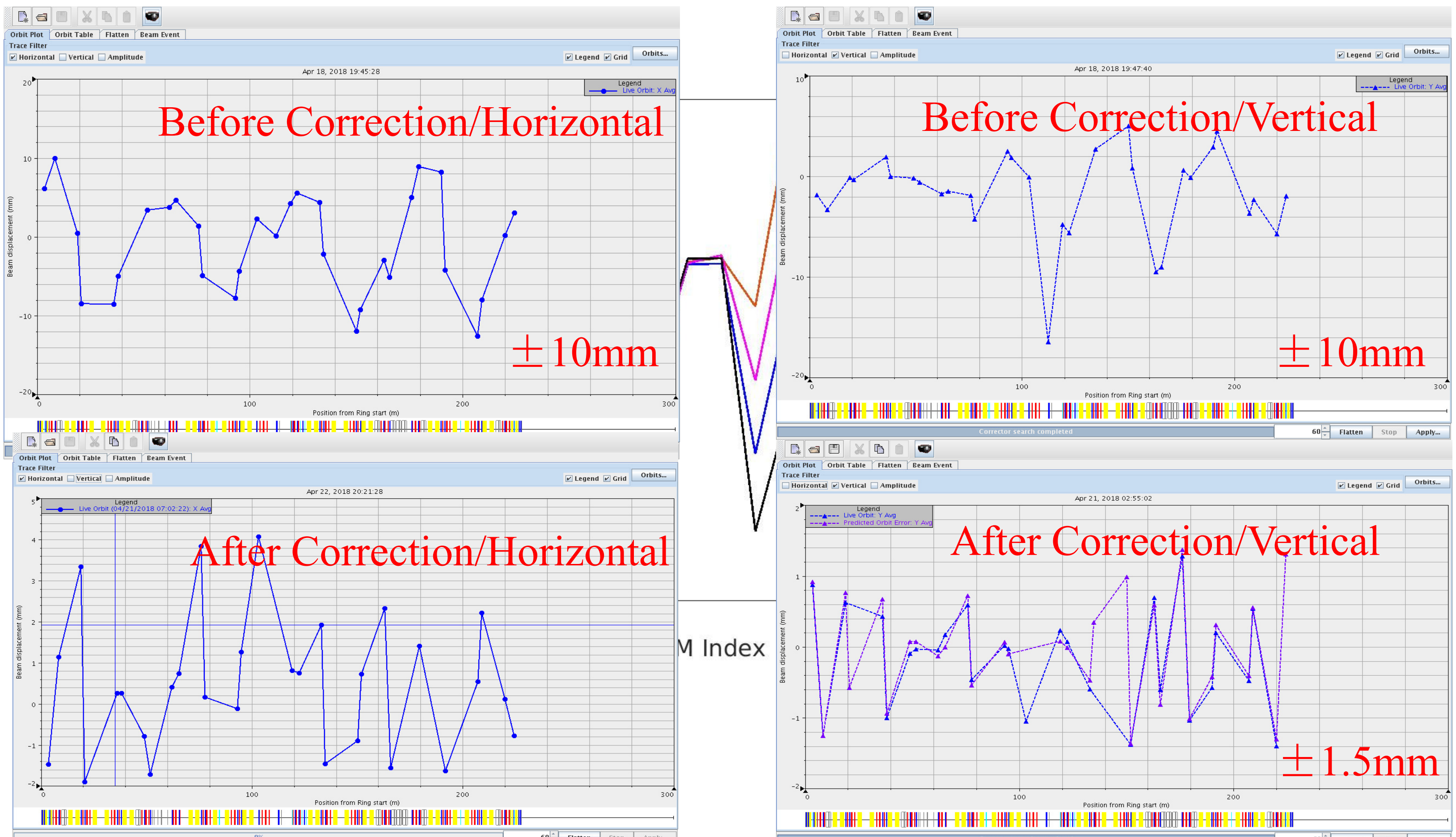

Stage Ⅱ Beam Commissioning

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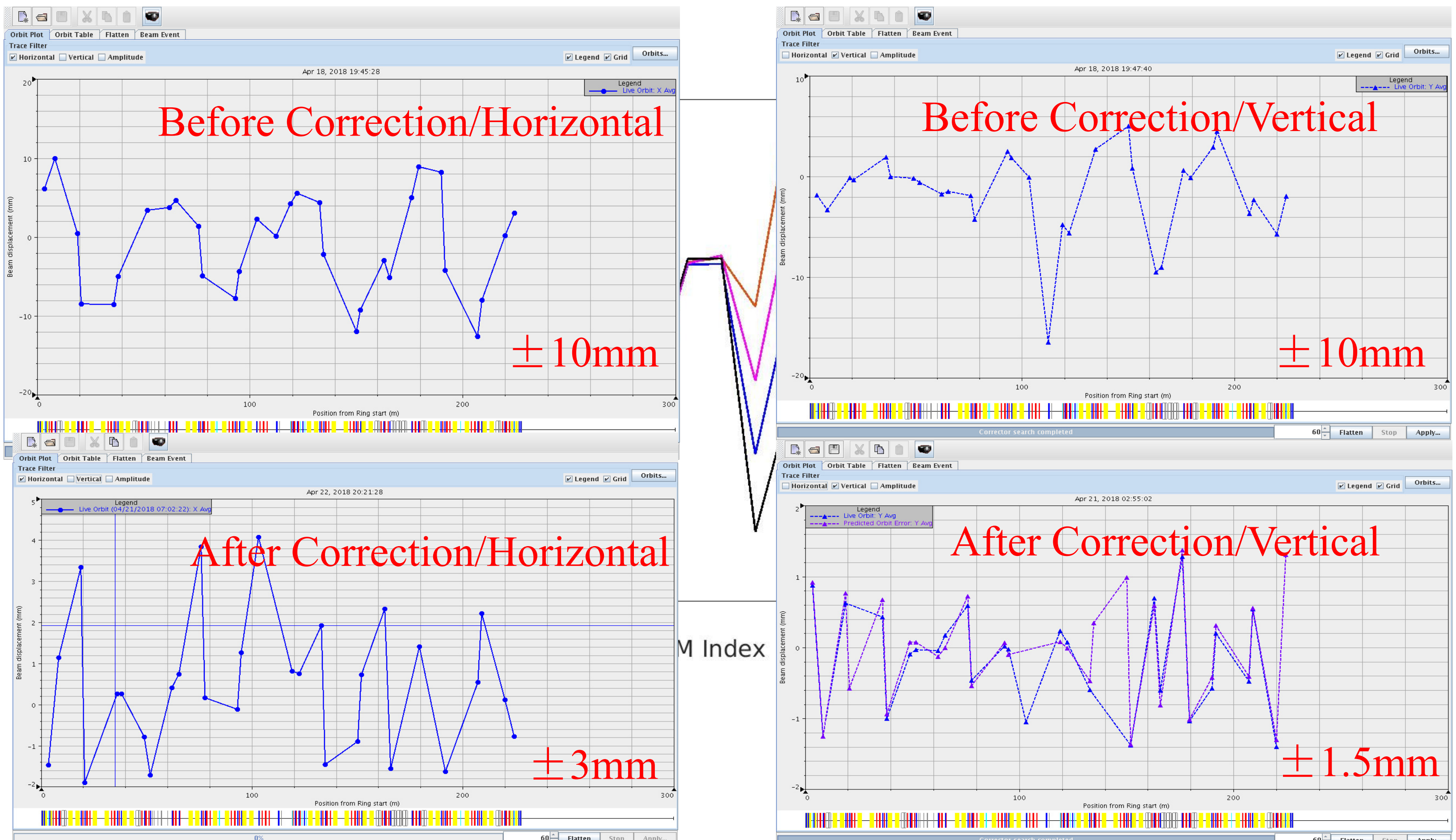

Stage Ⅱ Beam Commissioning

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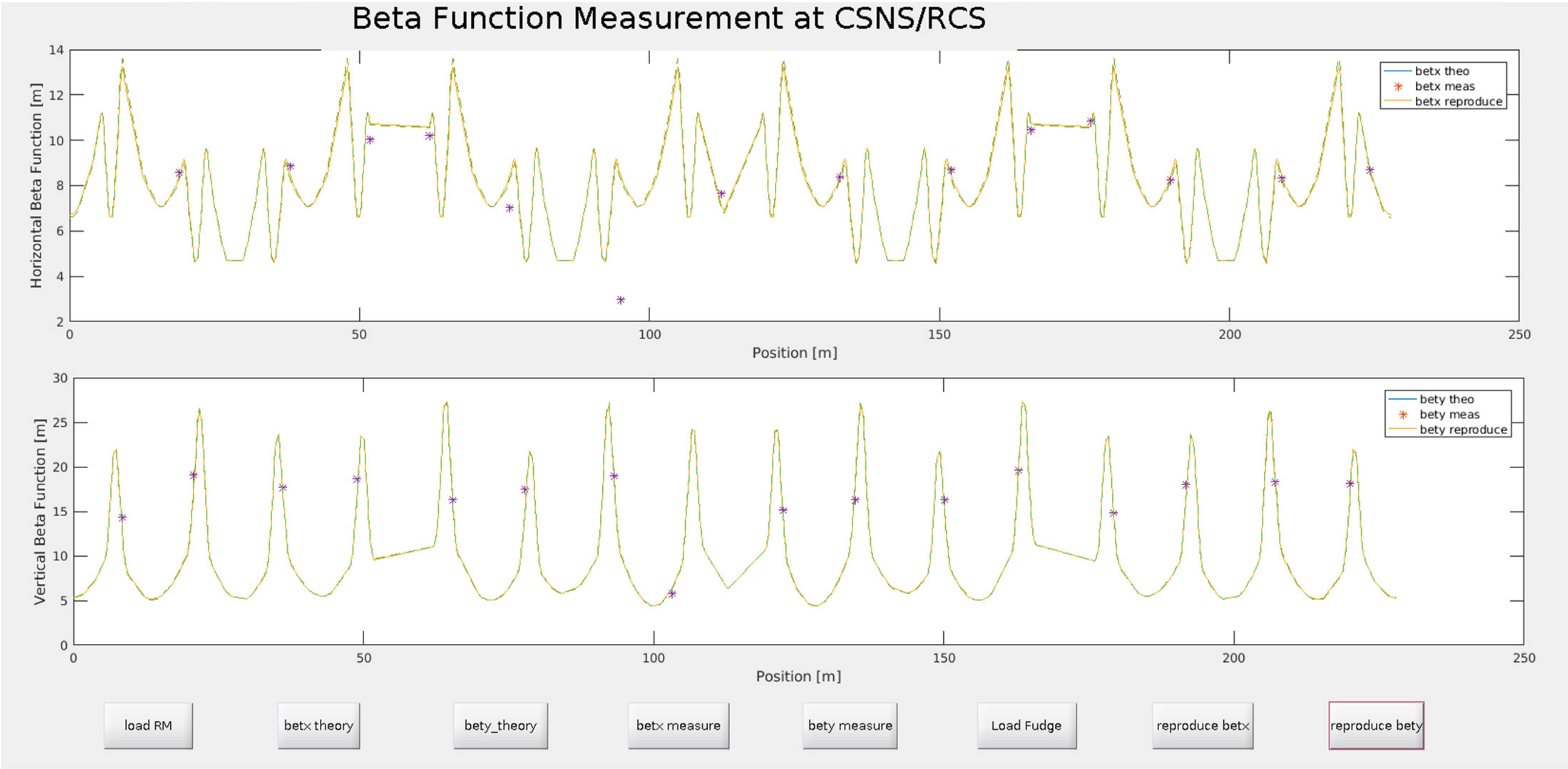
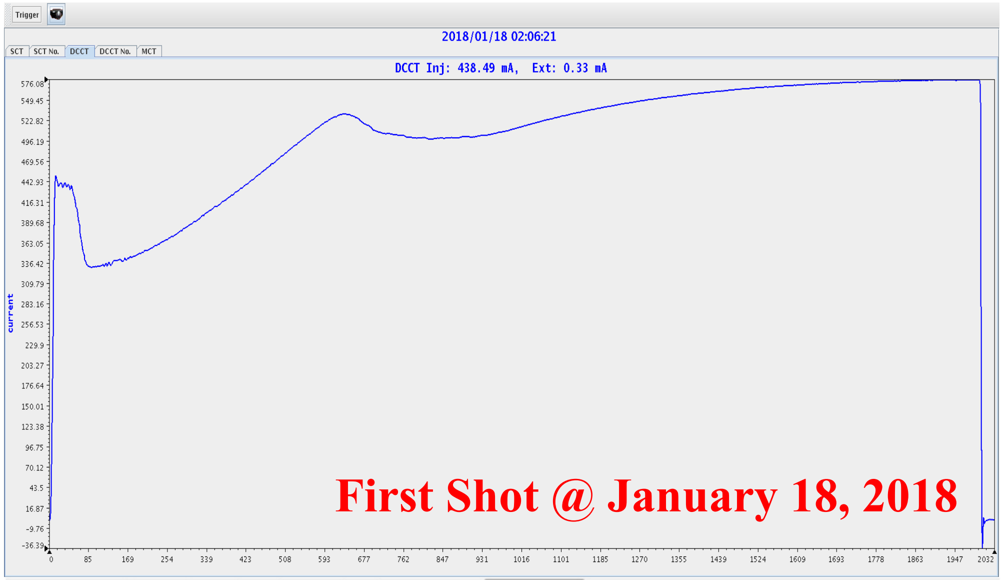
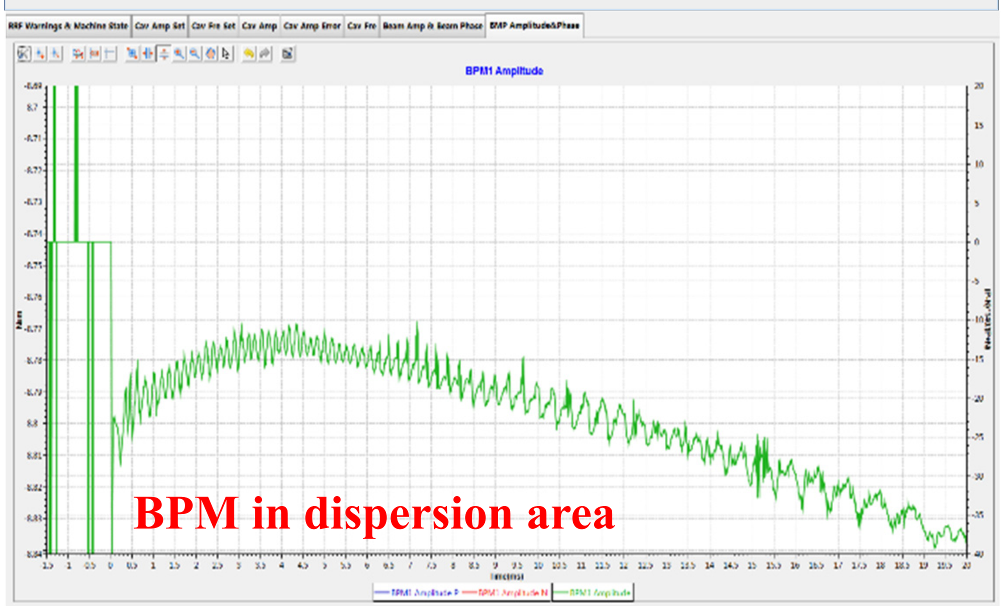
- The beam transmission rate achieved 100% on the same day.



Stage Ⅱ Beam Commissioning

- The AC mode beam commissioning was started on January 18, 2018

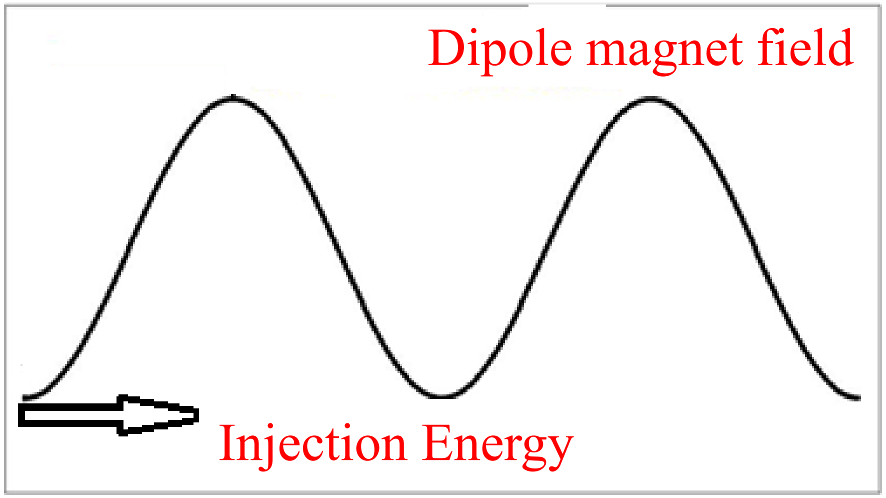


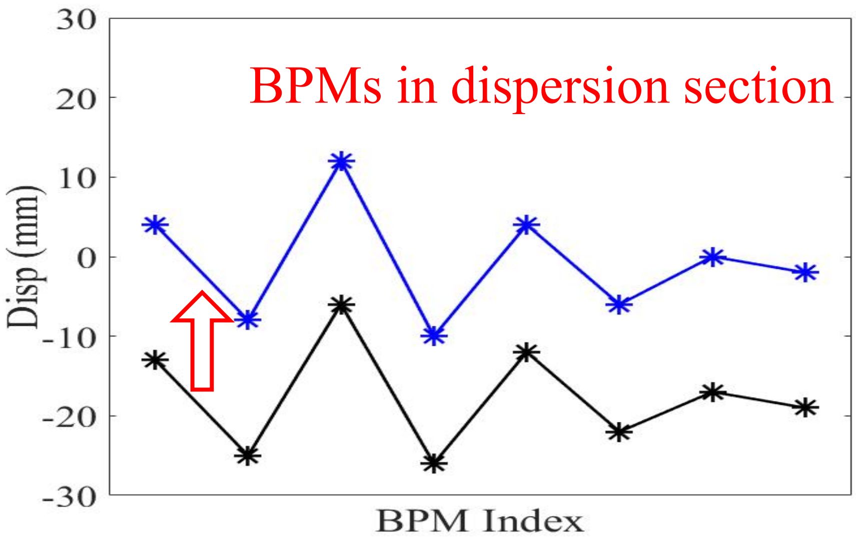


Timing error between Magnet power supply and RF

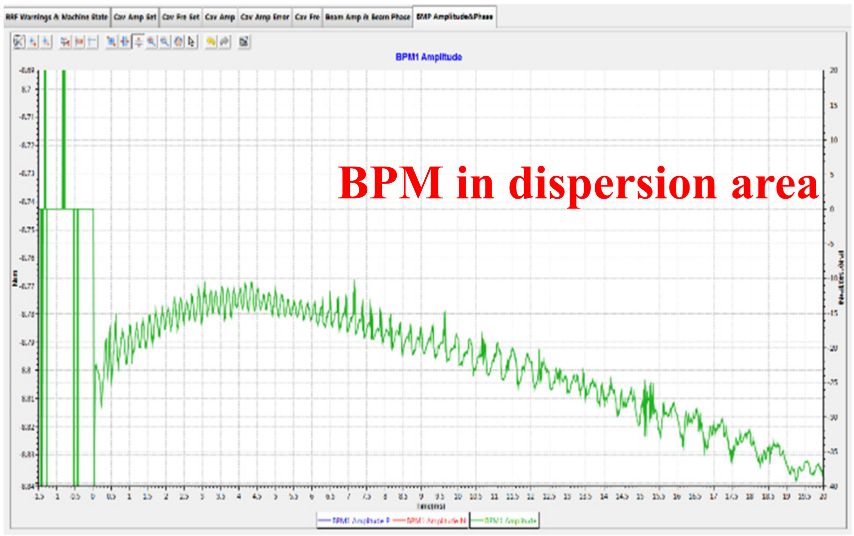
Stage Ⅱ Beam Commissioning

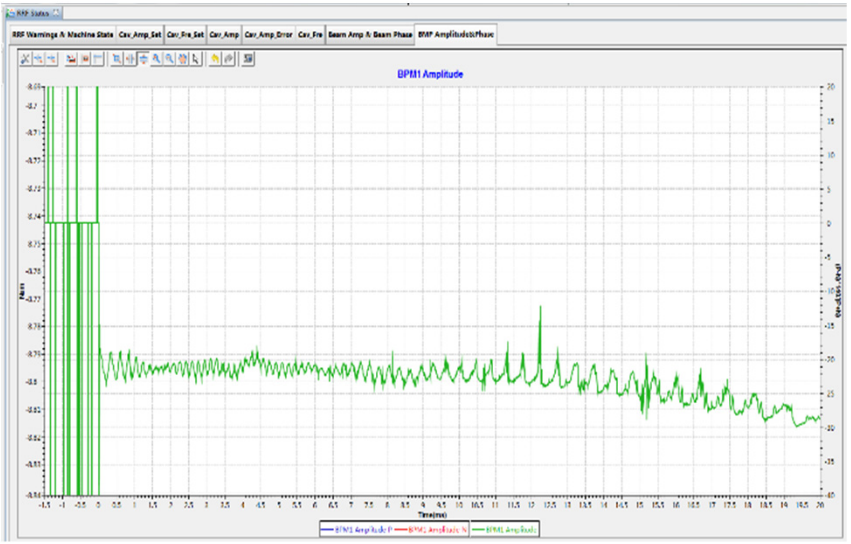
- @ RF-OFF
- The timing of magnet power supply was shifted to match the injection beam
- The match of the bottom of dipole magnetic field and injection energy was performed.

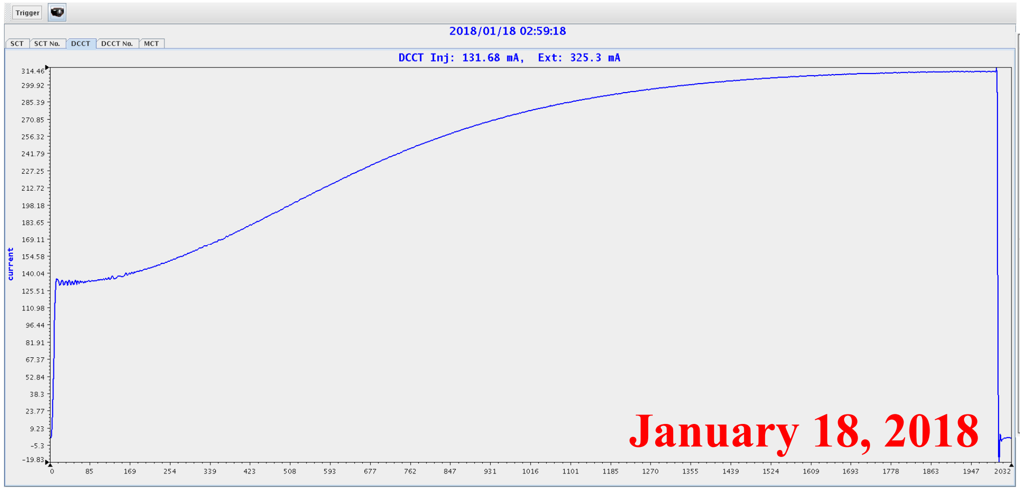


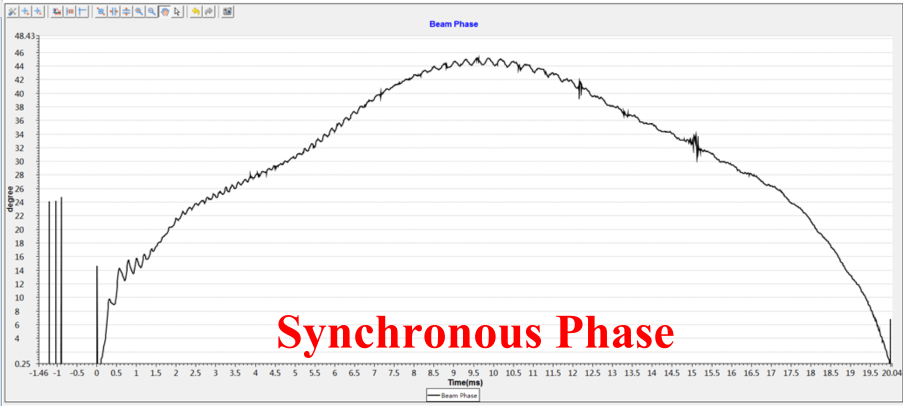


- The RF frequency ramping function was matched with the magnet ramping function.









Stage Ⅱ Beam Commissioning

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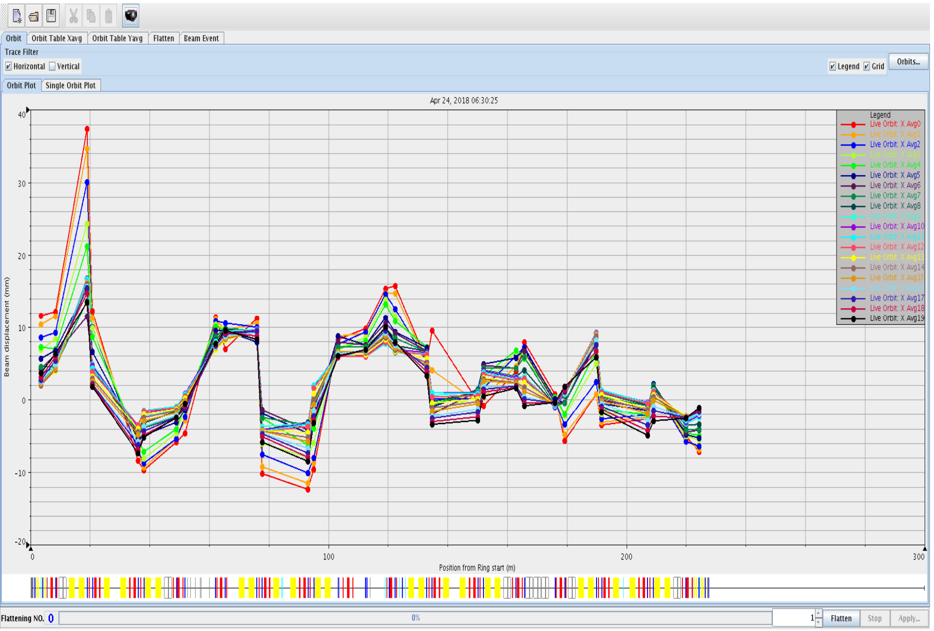
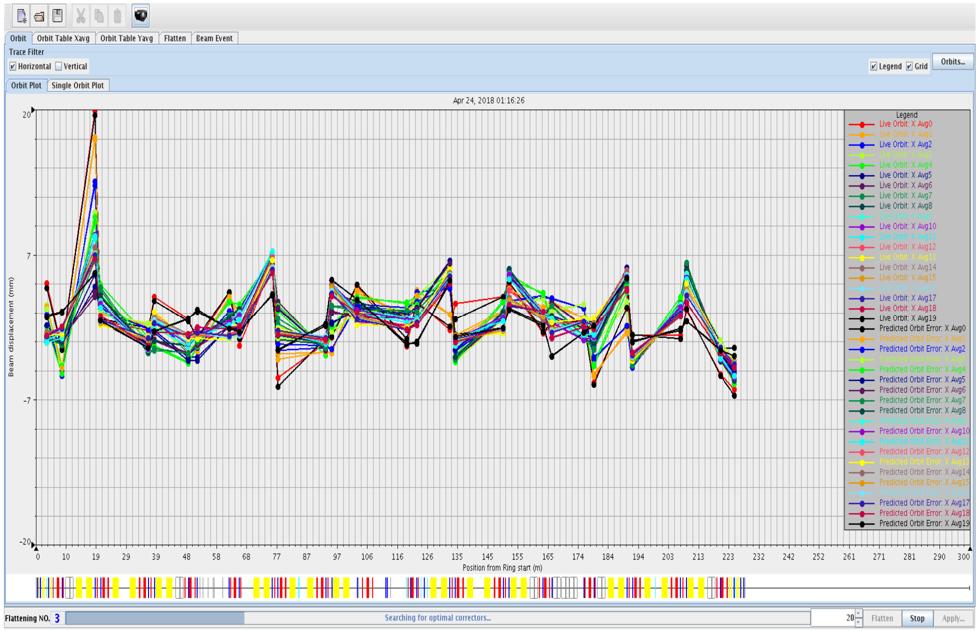
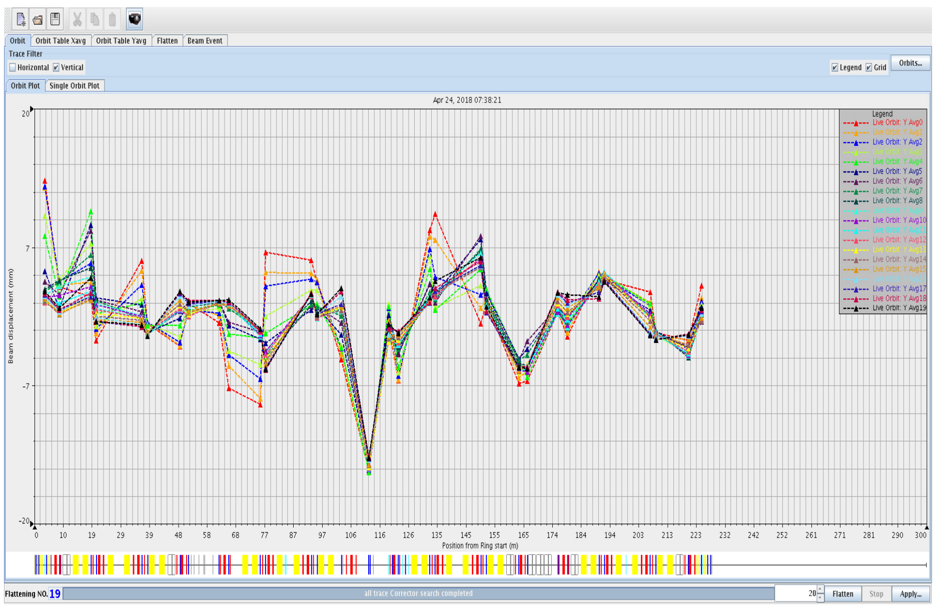
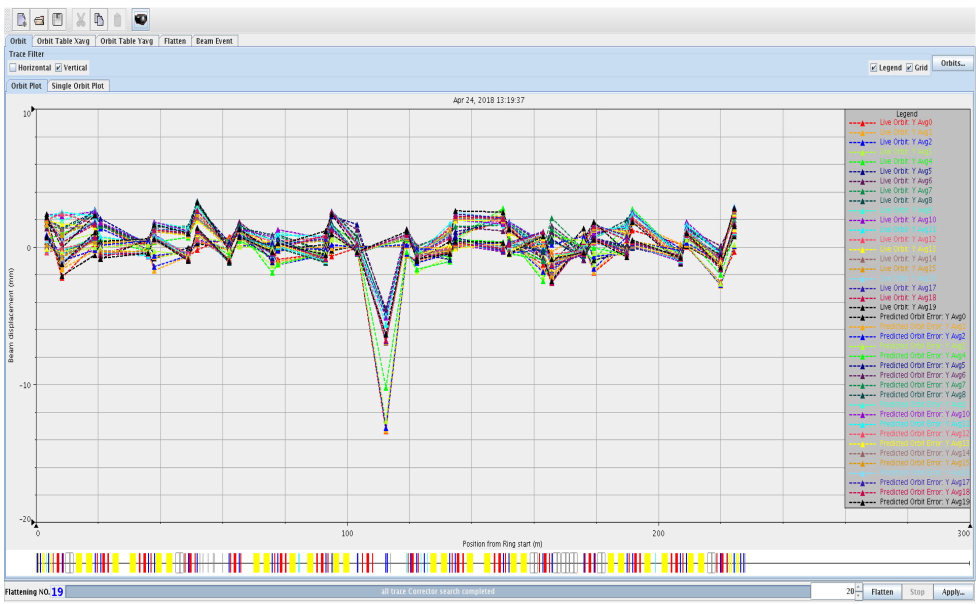
散裂中子源

China Spallation Neutron Source





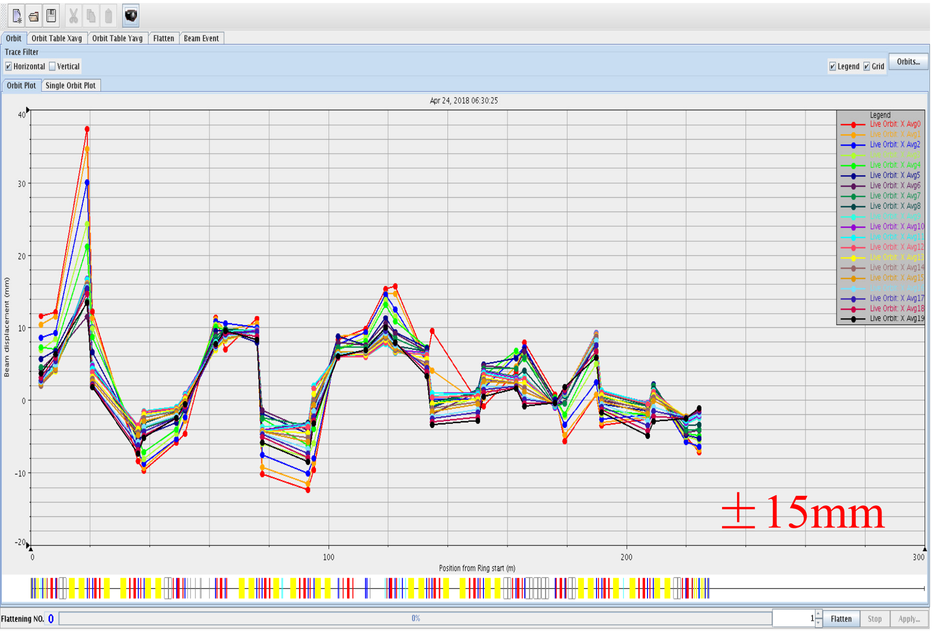


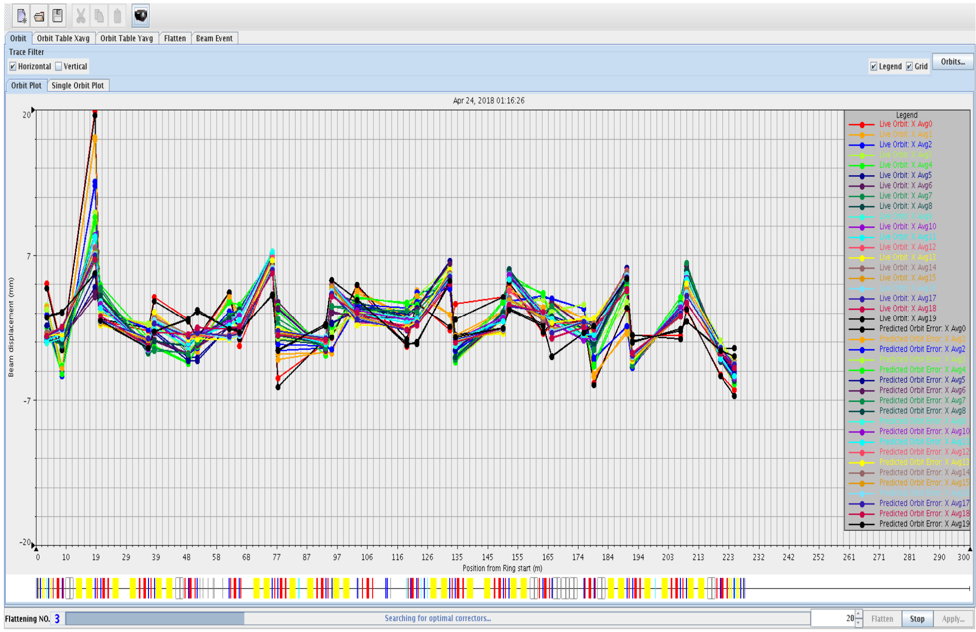


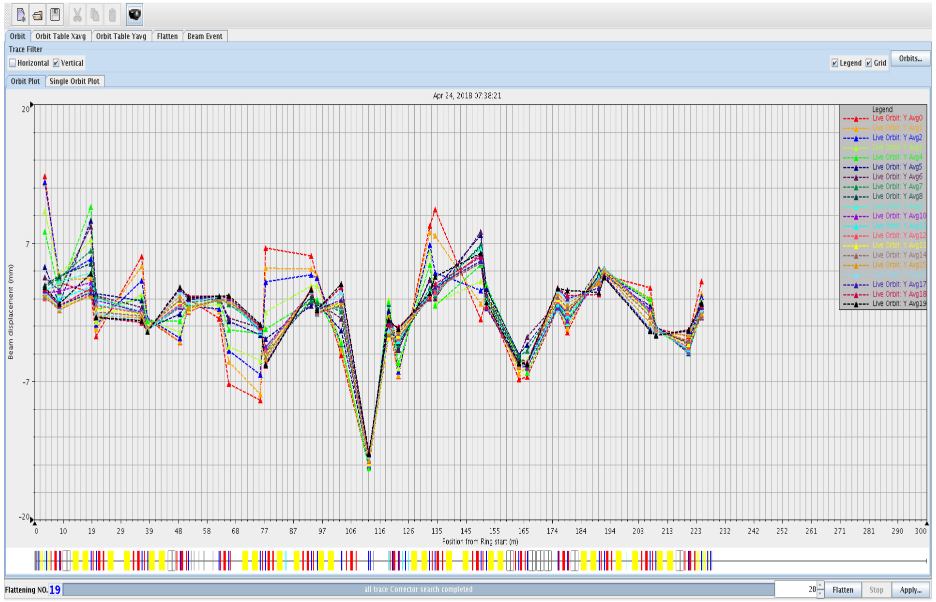
Stage Ⅱ Beam Commissioning

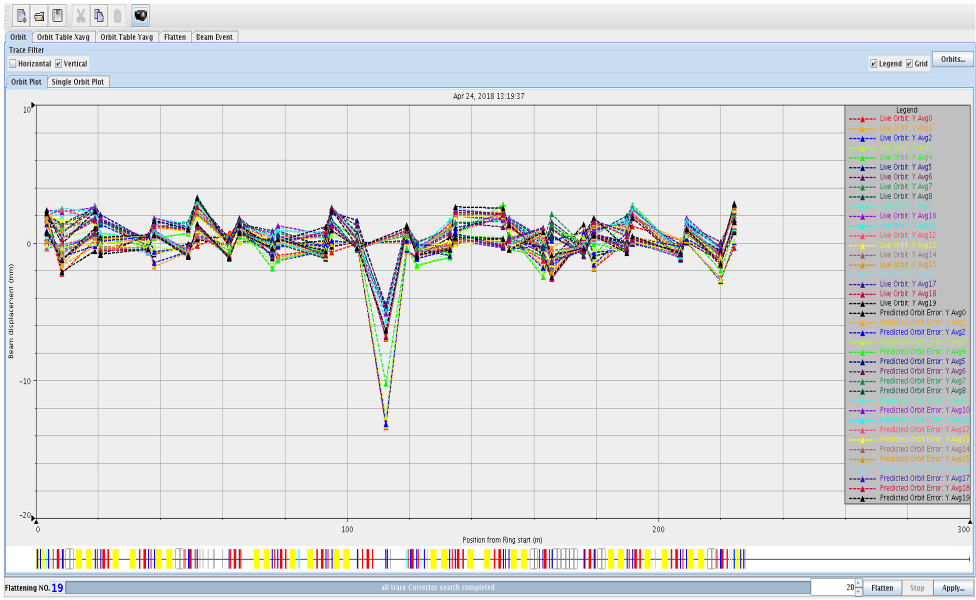
SNS CHINESE ACADEMY OF SCIENCES

散裂中子源 China Spallation Neutron Source







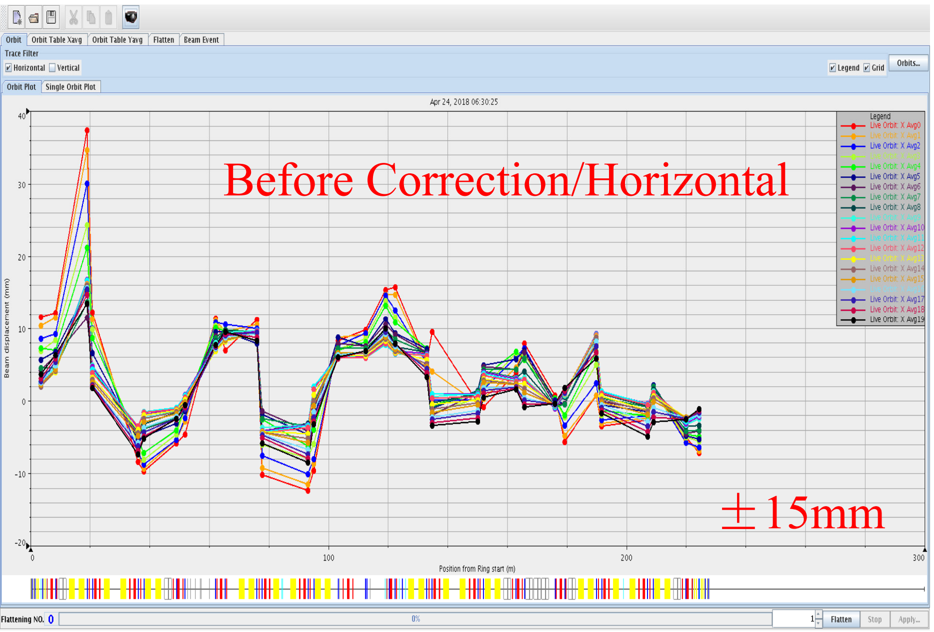


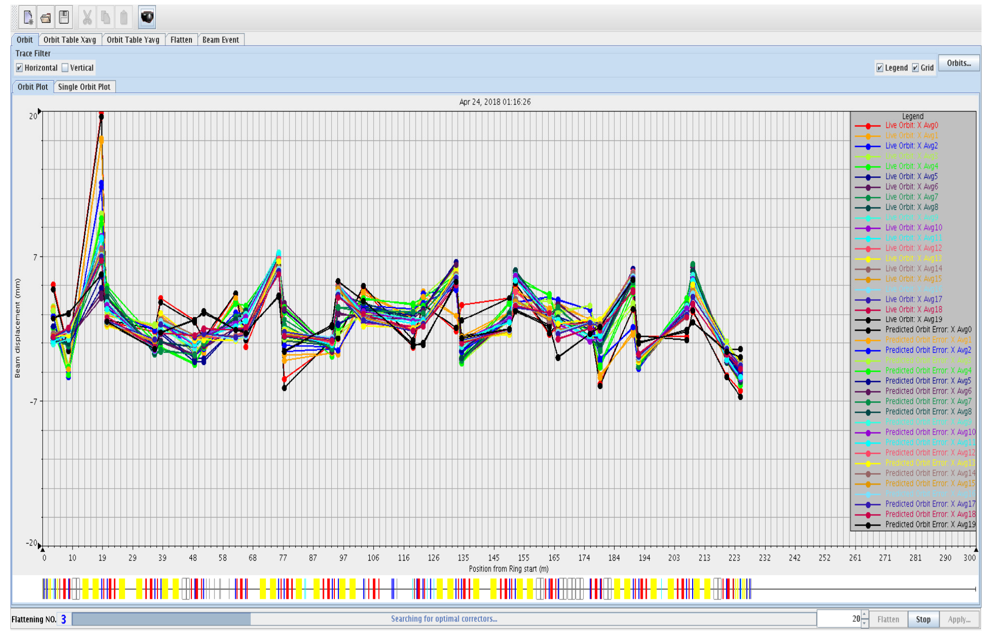
Stage Ⅱ Beam Commissioning

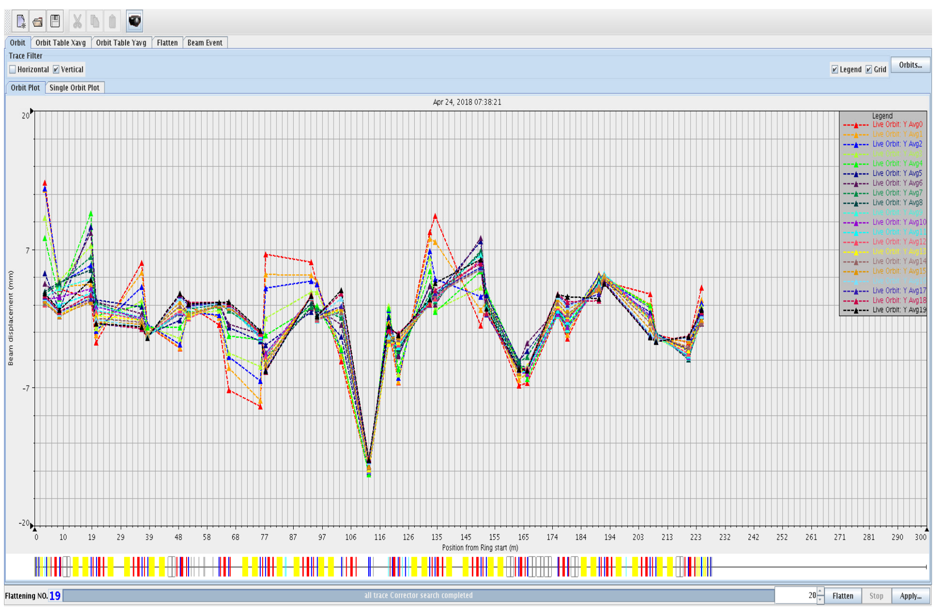
散裂中子源

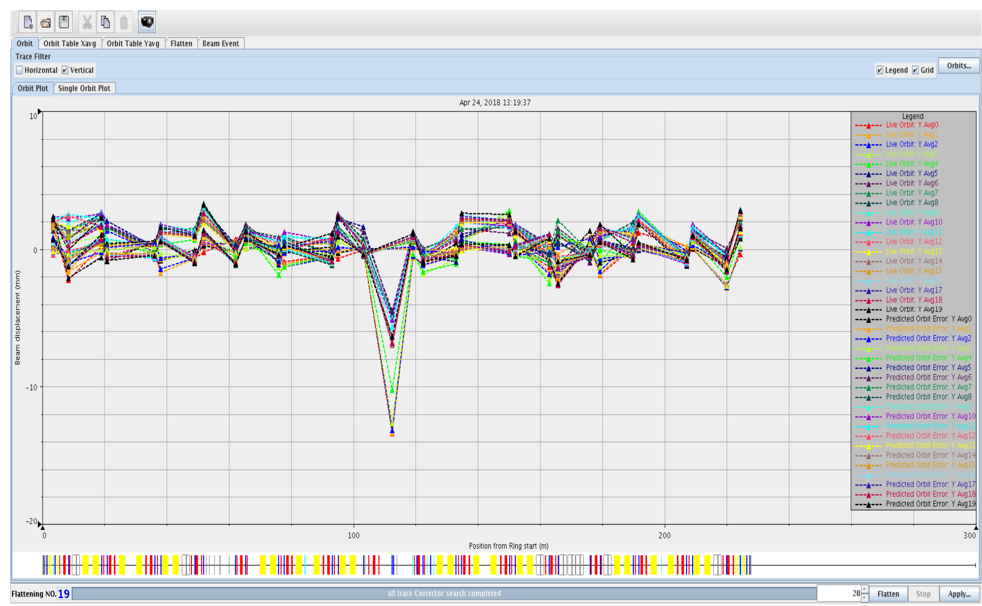
China Spallation Neutron Source

SNS CHINESE ACADEMY OF SCIENCES



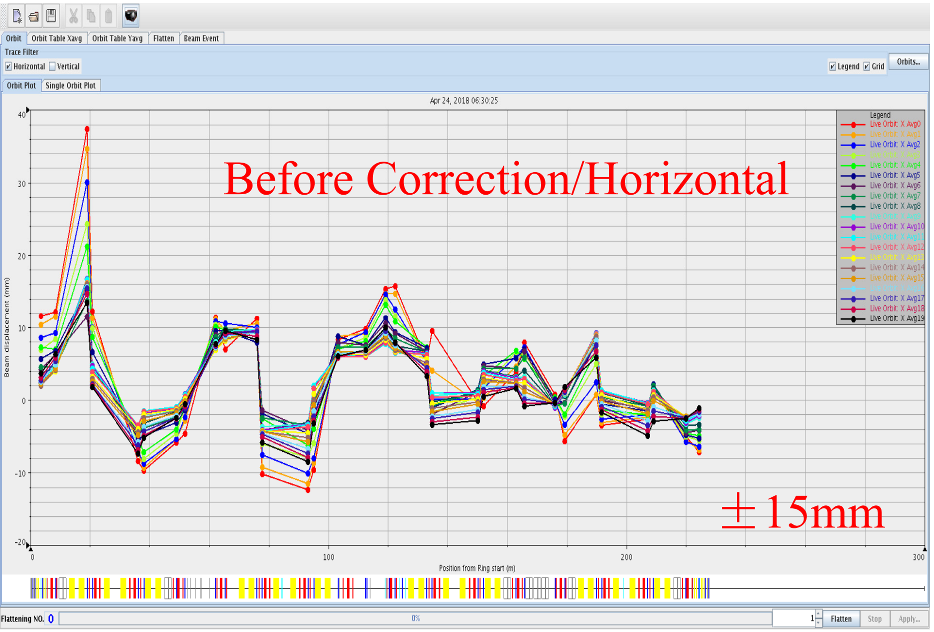


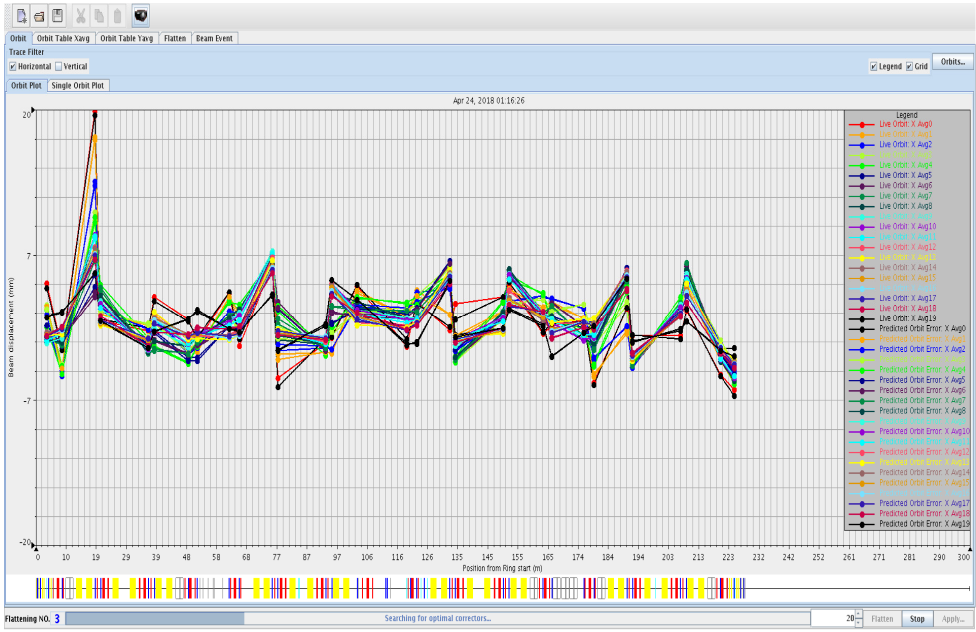


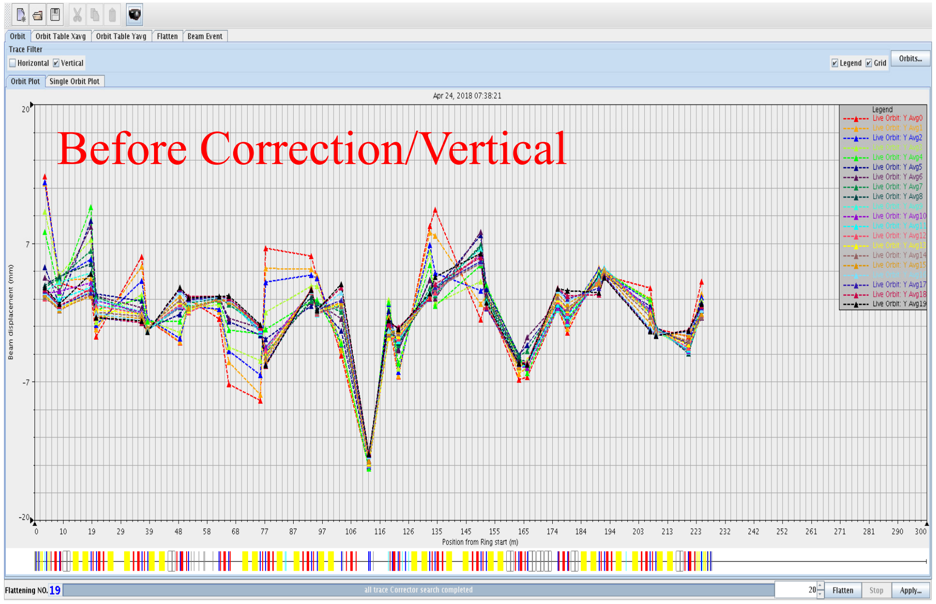


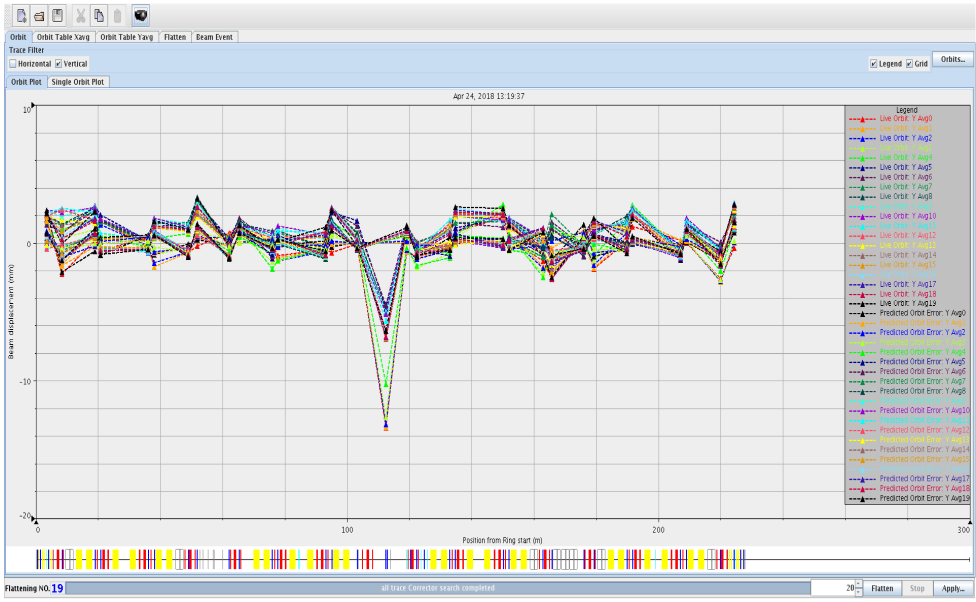
Stage Ⅱ Beam Commissioning

散裂中子源
China Spallation Neutron Source









Stage Ⅱ Beam Commissioning

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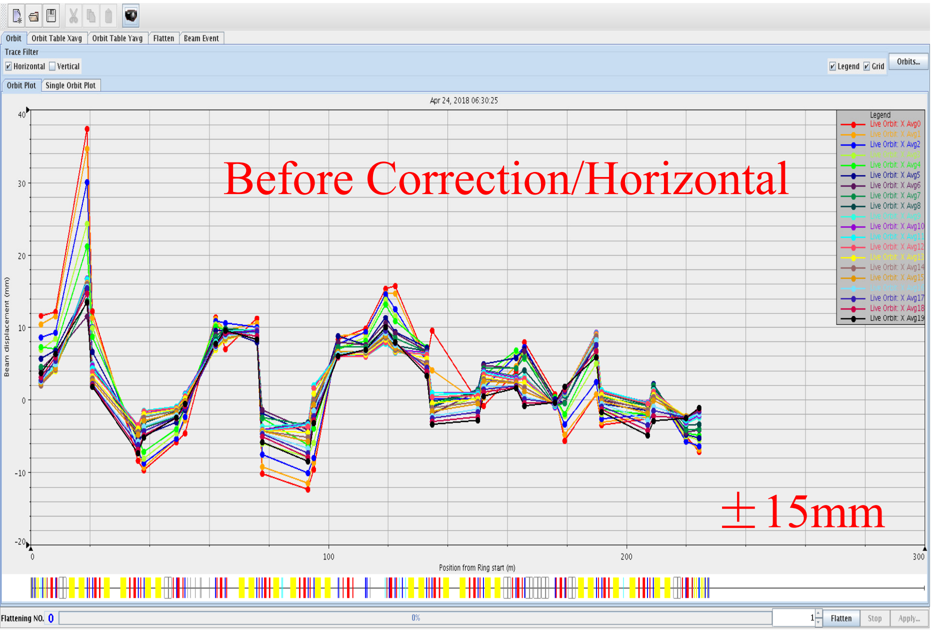

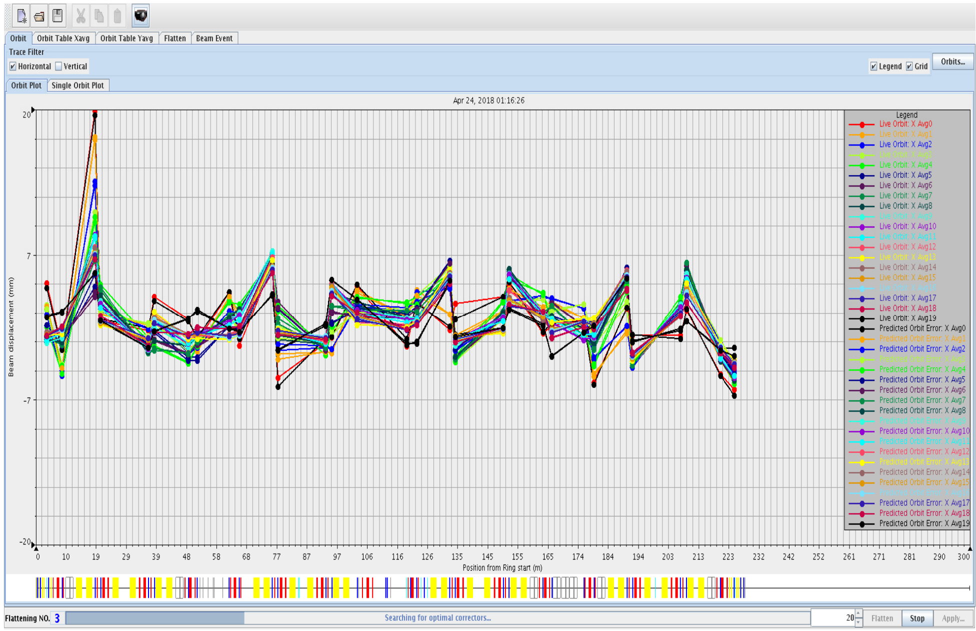

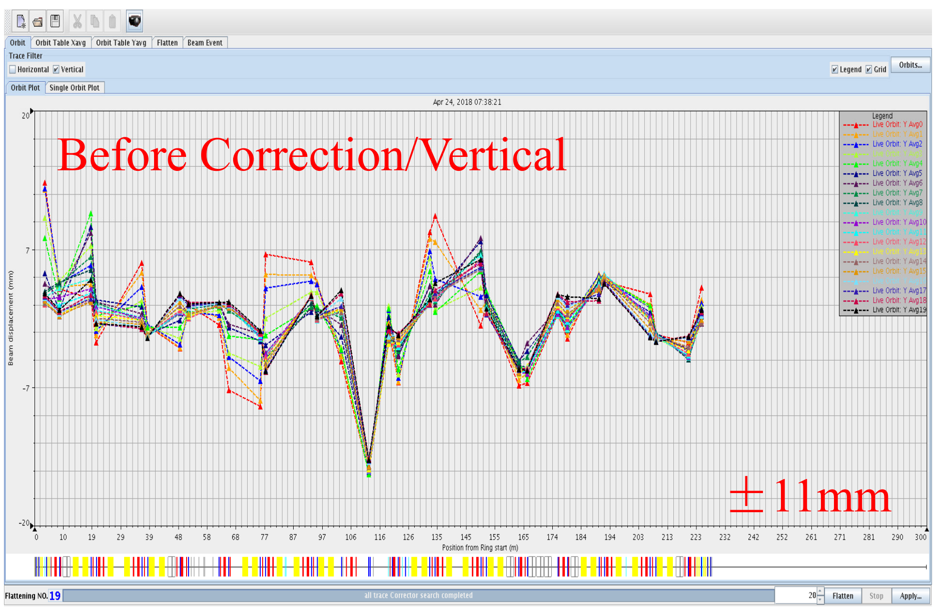

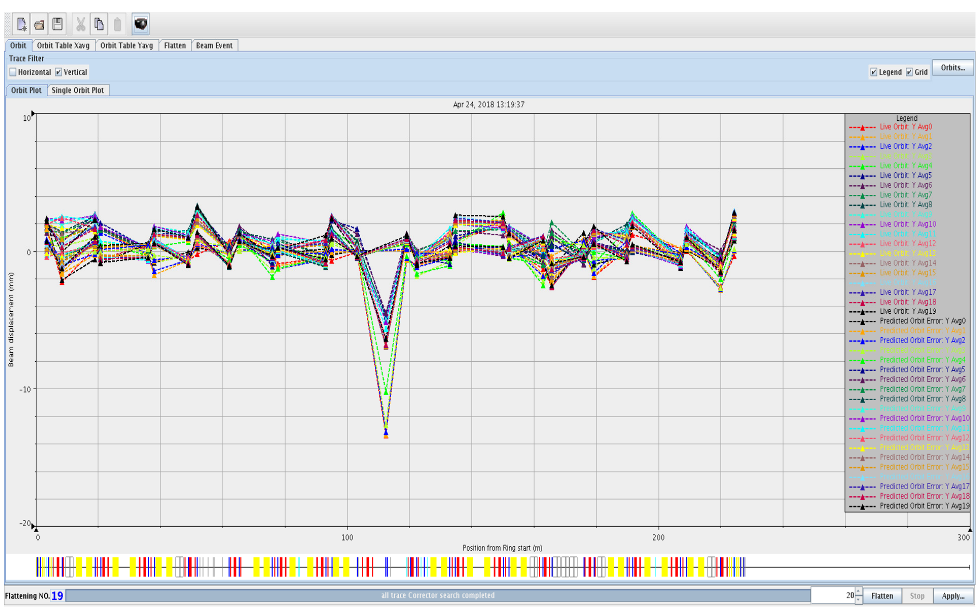

Stage Ⅱ Beam Commissioning

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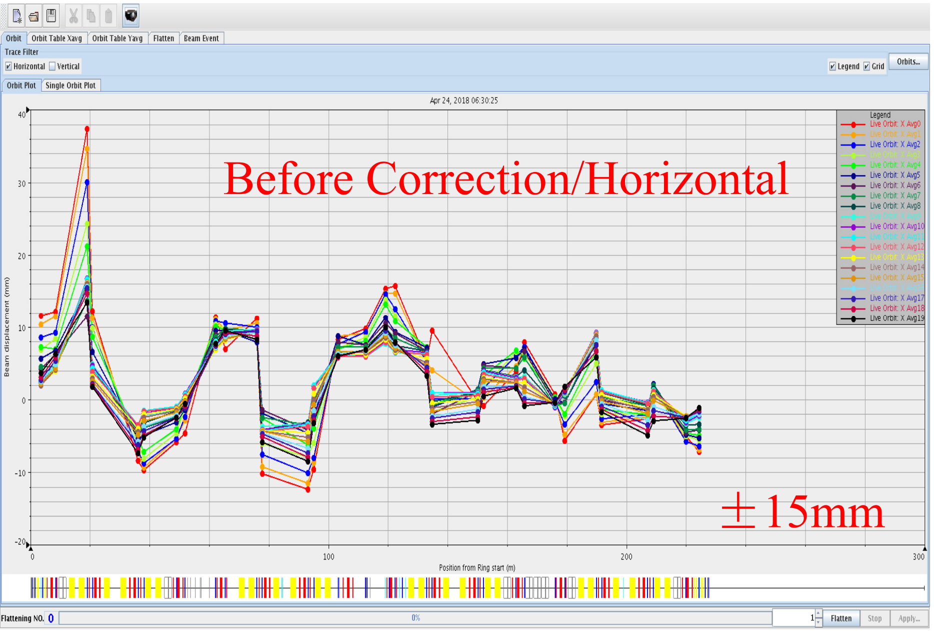
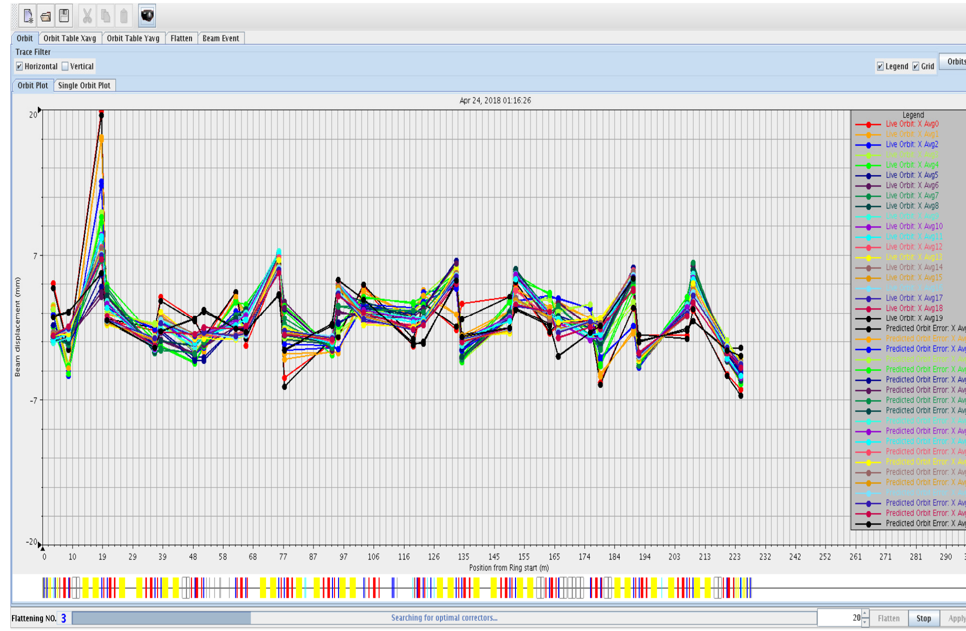
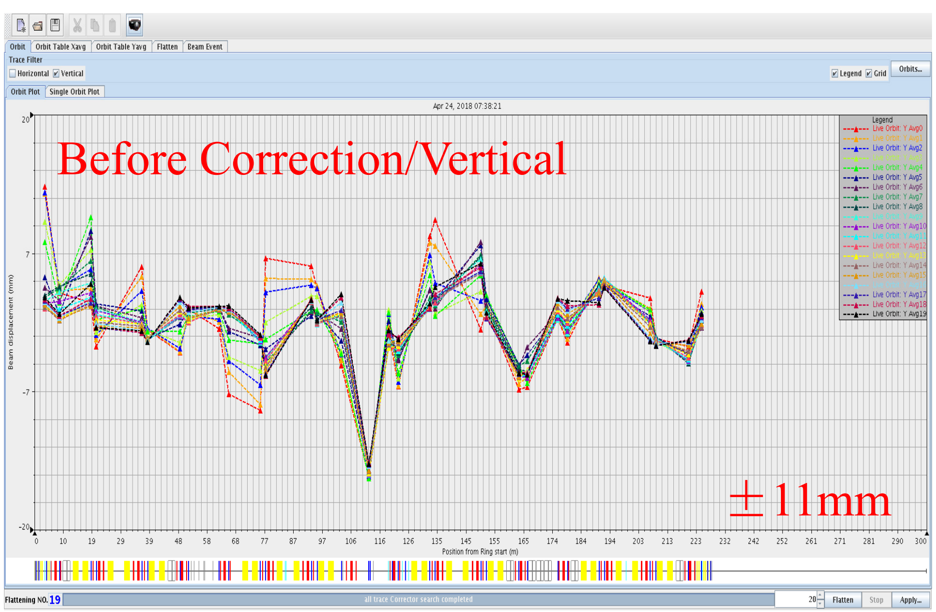
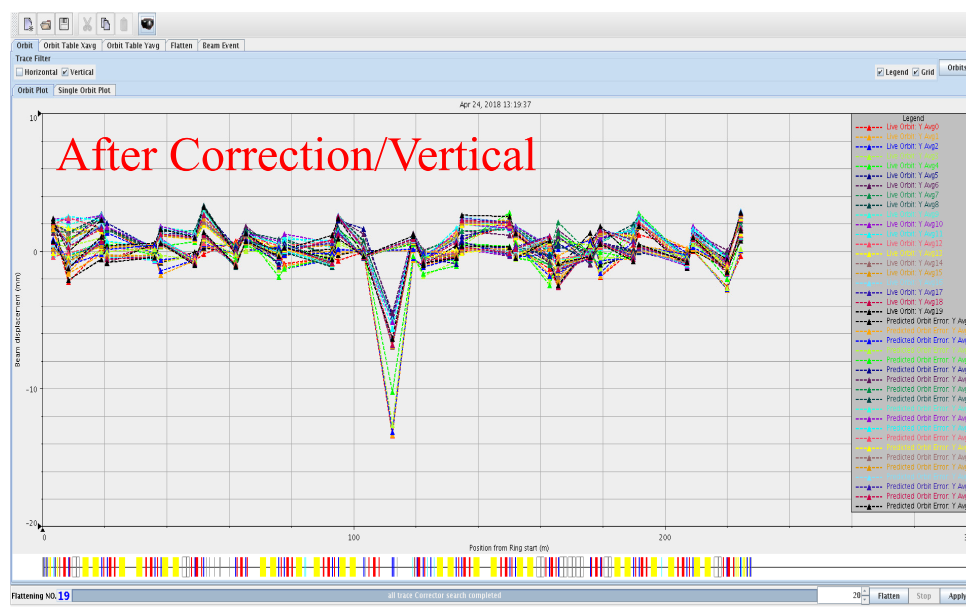
散裂中子源

China Spallation Neutron Source









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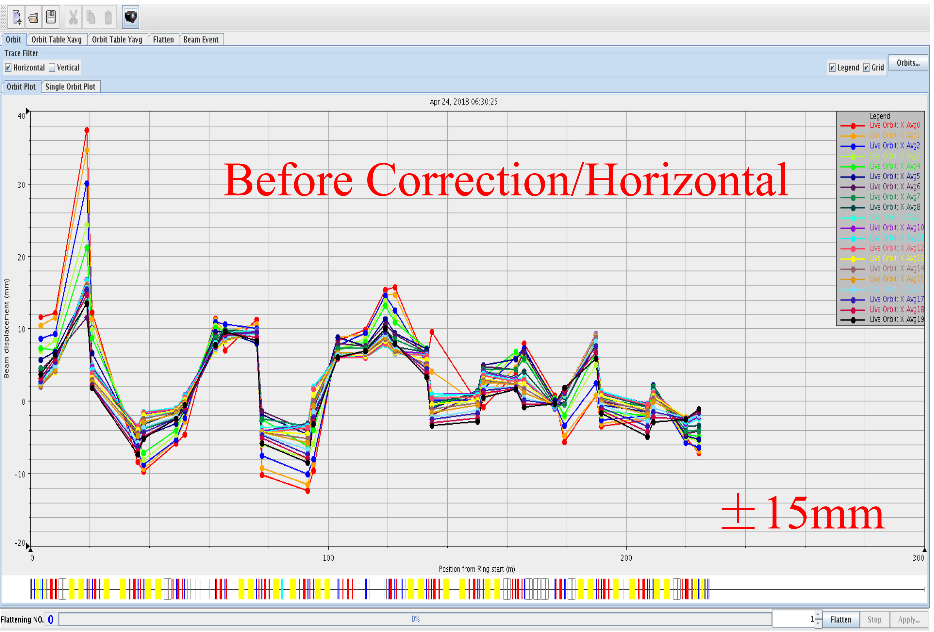
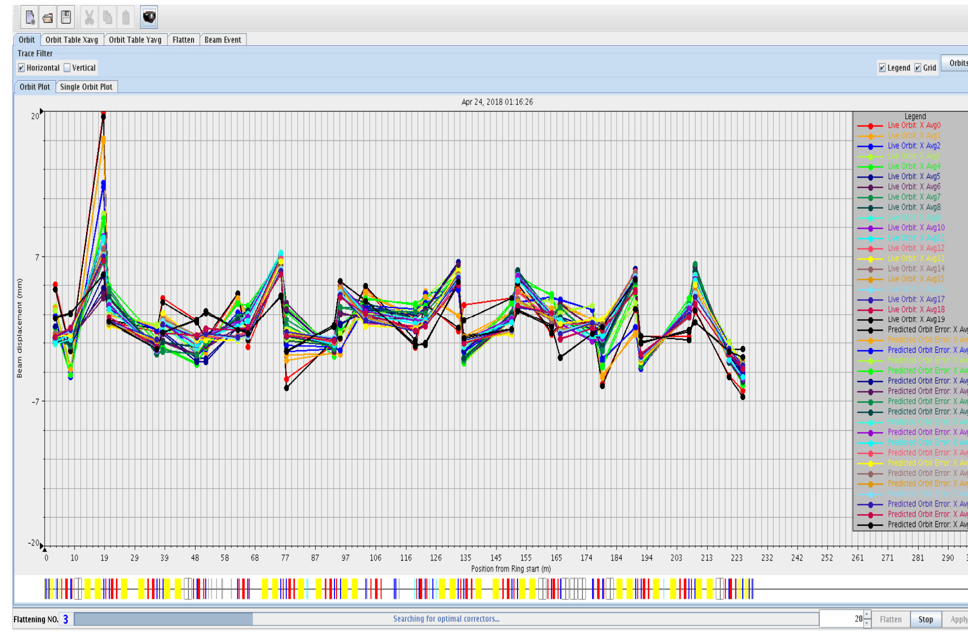
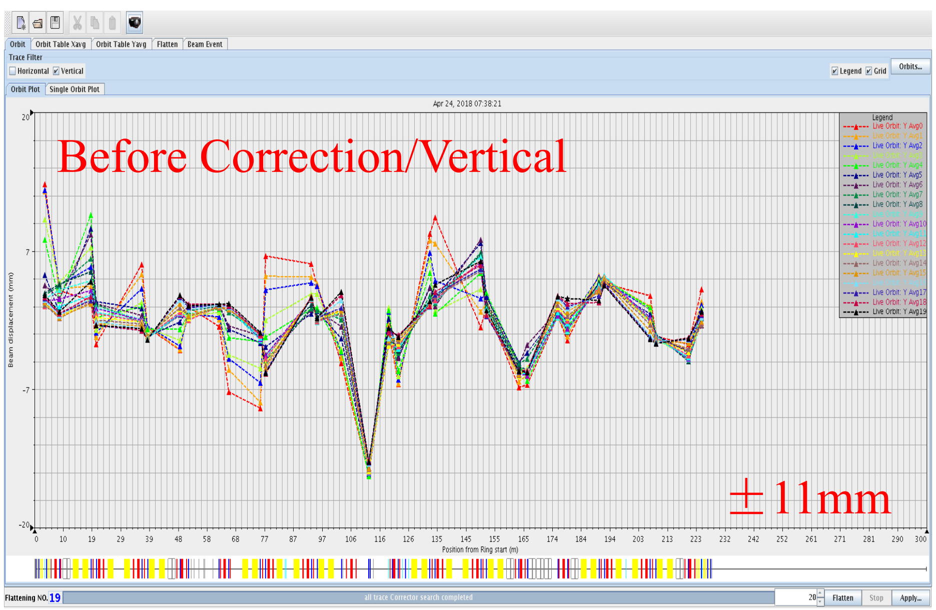
Stage Ⅱ Beam Commissioning

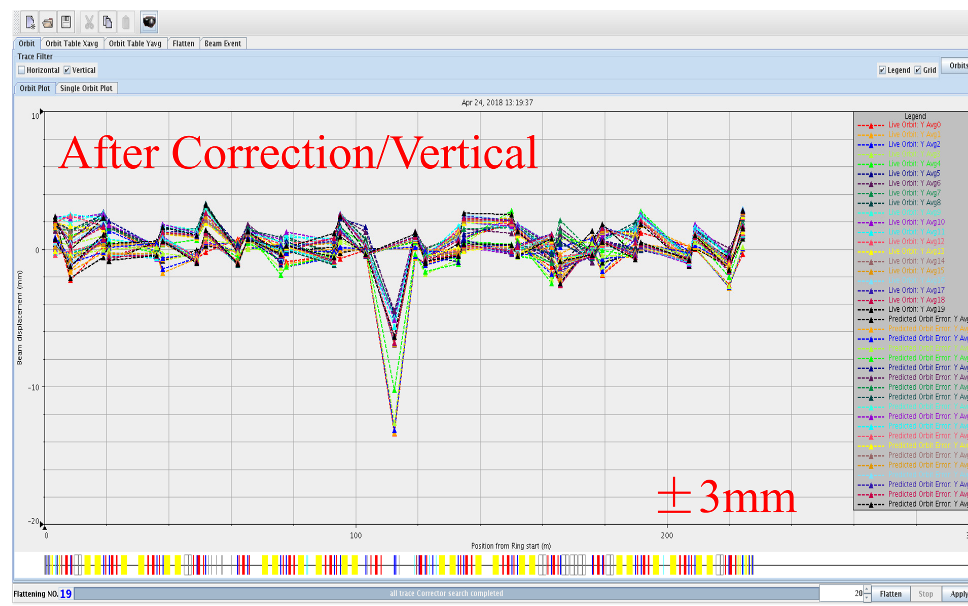
散裂中子源

China Spallation Neutron Source









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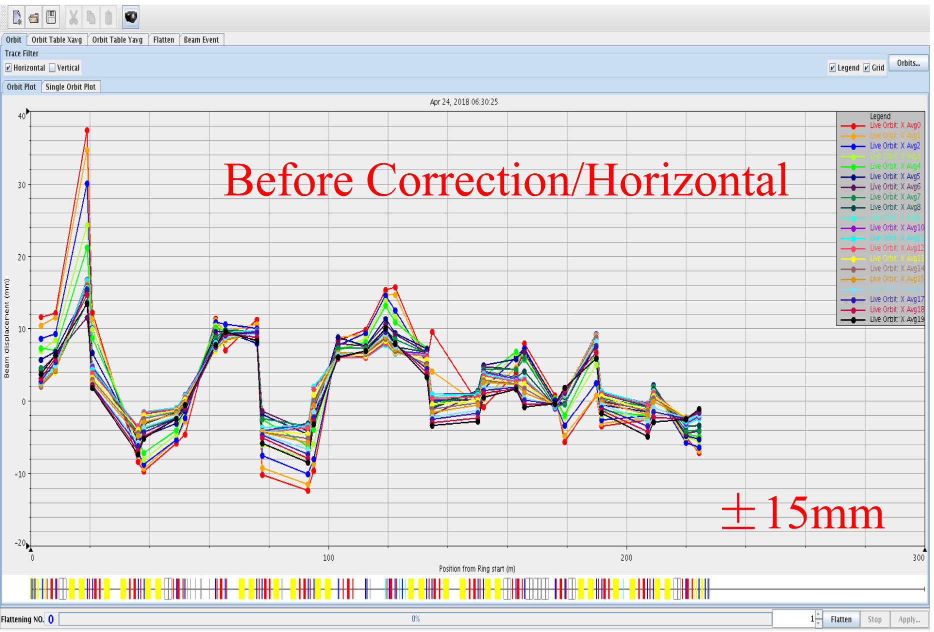
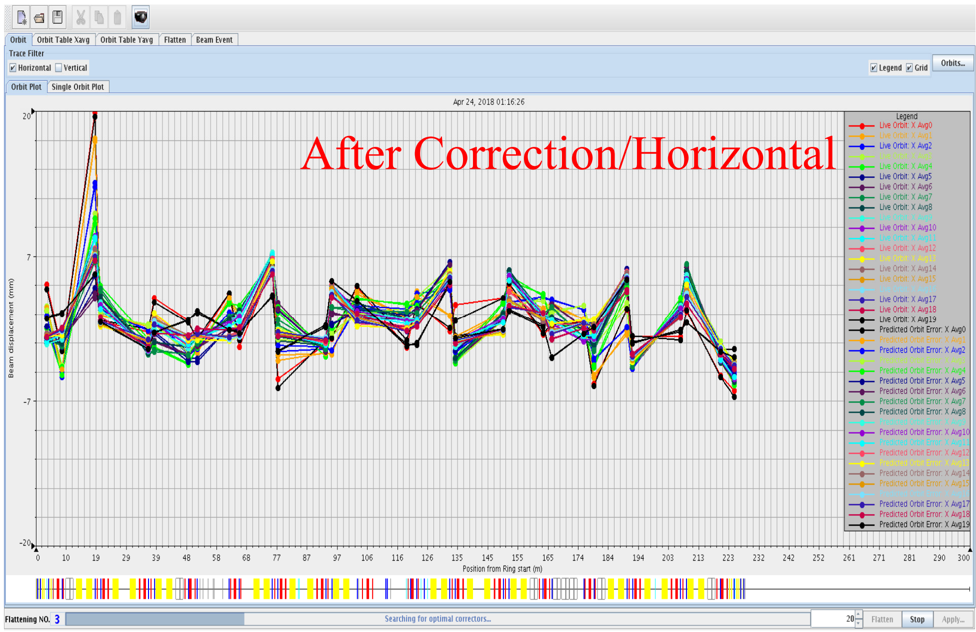
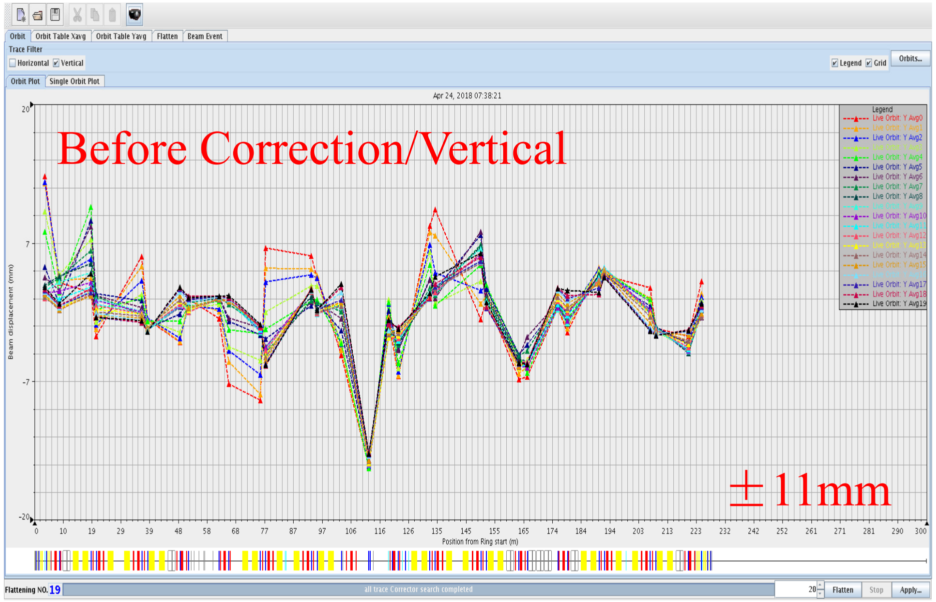
CHINESE ACADEMY OF SCIENCES

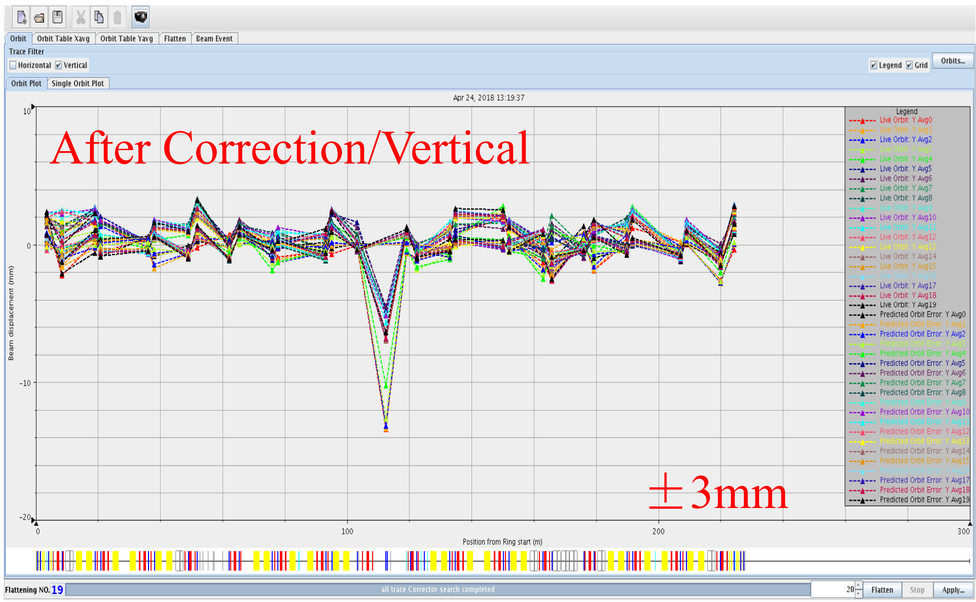
Stage Ⅱ Beam Commissioning

散裂中子源
China Spallation Neutron Source





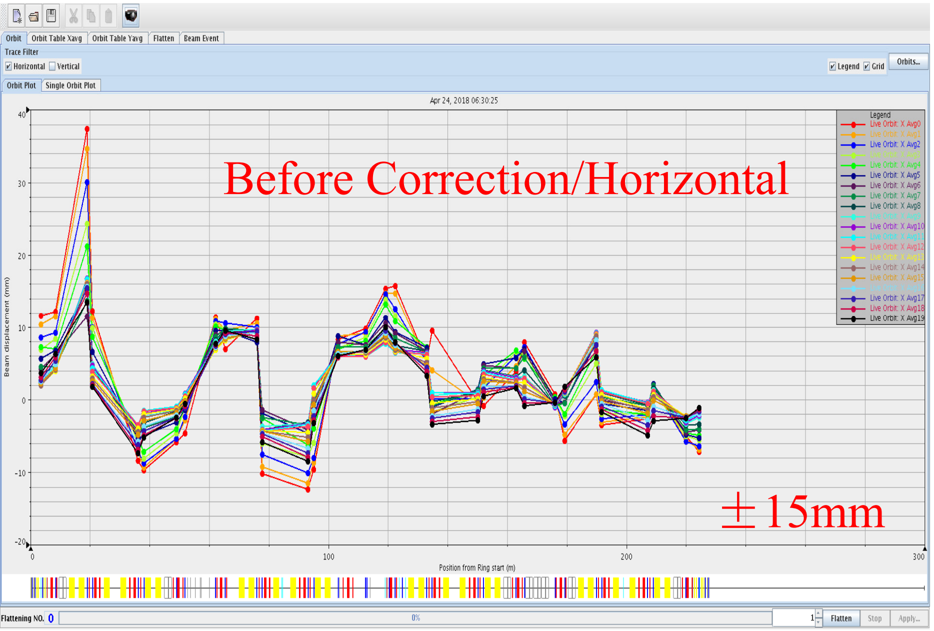


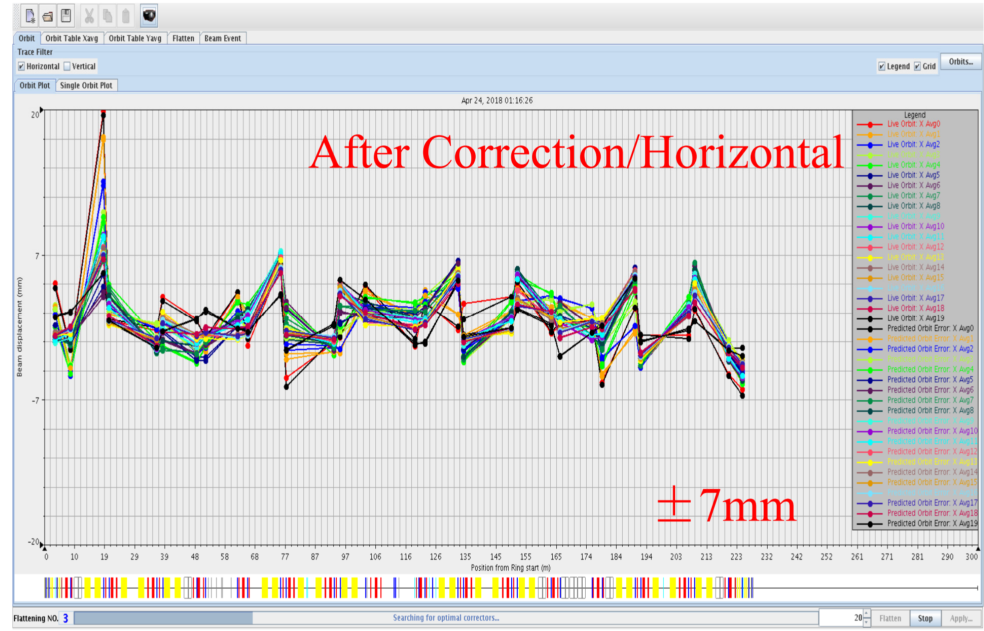


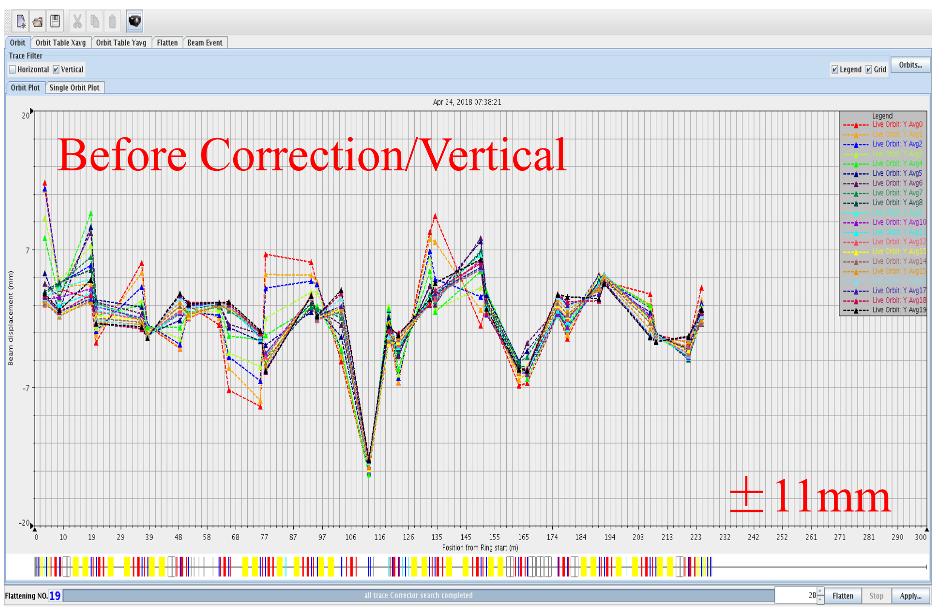
Stage Ⅱ Beam Commissioning

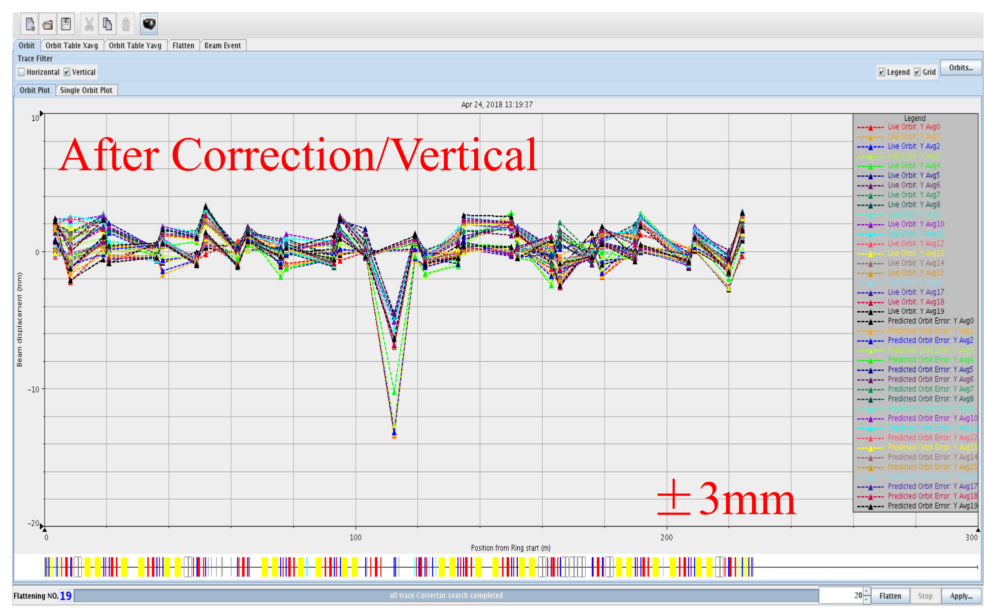
散裂中子源

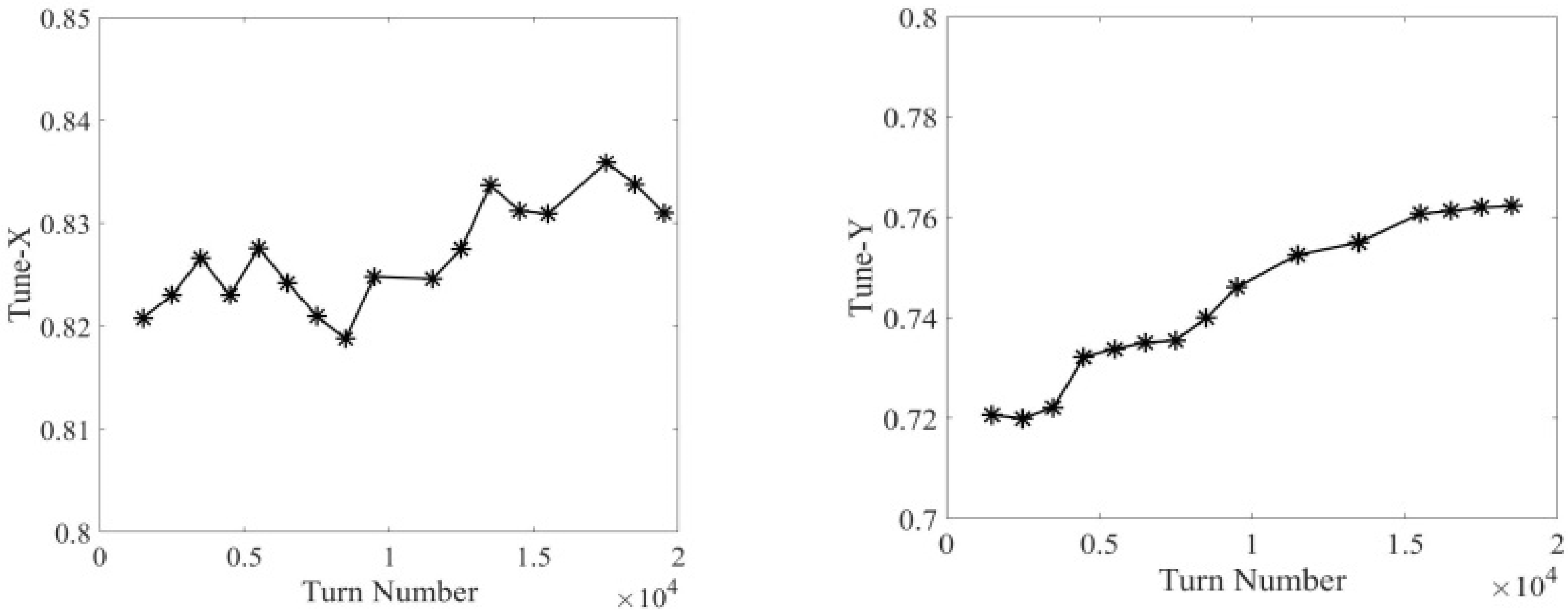
China Spallation Neutron Source







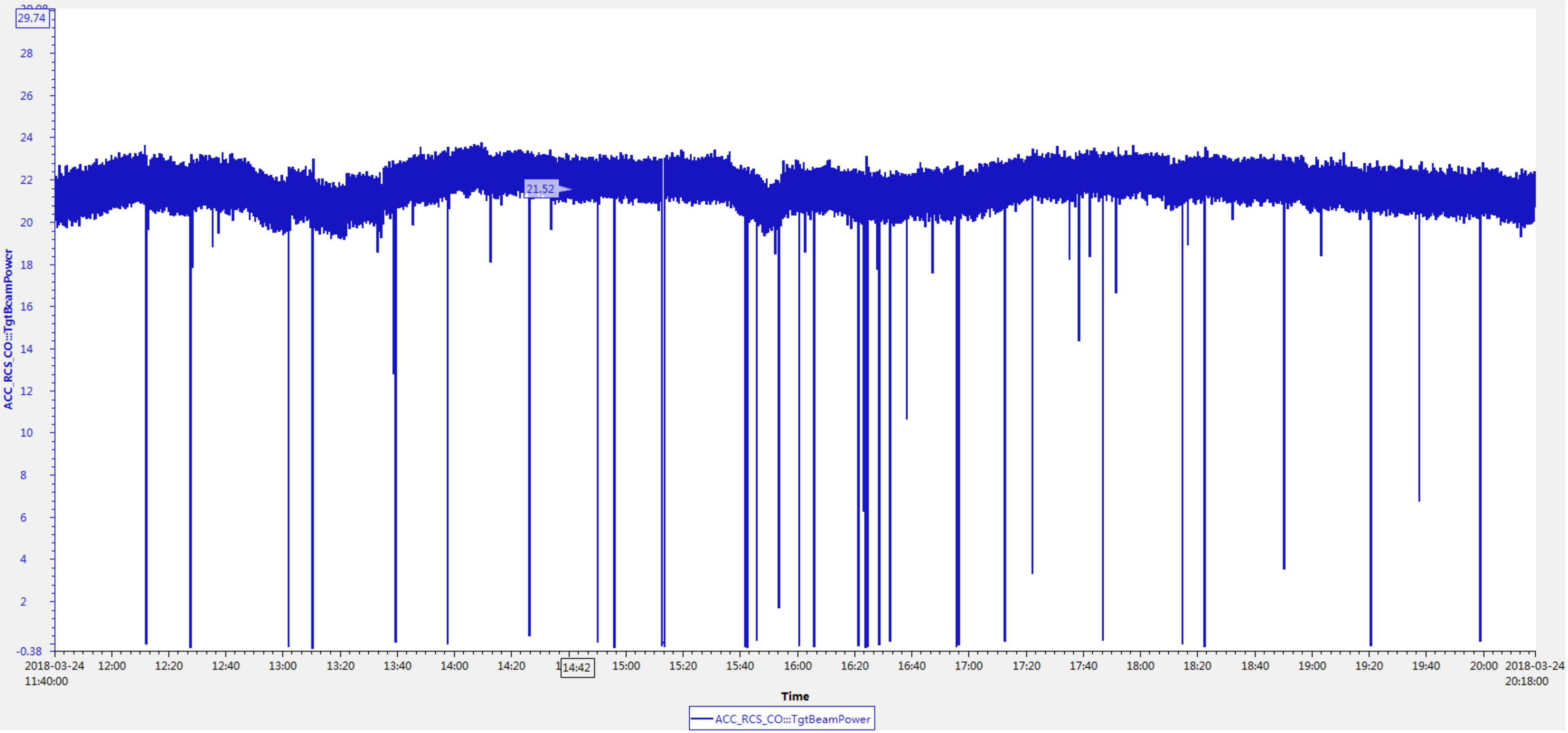




Tune variation during the acceleration process. The variation of horizontal tune is less than 0.02, and the variation of vertical tune is about 0.04.

Operation for User Experiment

2018.01.15~01.21 CSNS/RCS Commissioning
2018.01.22~ Operation for User Experiment@10kW
March, 2018~ Operation for User Experiment@20kW



Summary

- Careful preparation work was performed before the beam commissioning
  - Systematic magnet measurements
  - Wave form compensation for RCS magnets
  - Study on the effects of fringe field and interference of quadrupoles
- The beam commissioning of CSNS/RCS went smoothly
- Plan for next stage
  - Operate for user experiment
  - Optimizing the performance of AC mode, and increase the beam power
    - Orbit correction in AC mode
    - Parameters measurement in AC mode, optimization of online-model
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THANK YOU FOR YOUR ATTENTION!