



# BEPCIIU commissioning and HEPS operation

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*Institute of High Energy Physics*  
*Chinese Academy of Sciences*

# BEPCII-U: upgrade program of BEPCII

## ■ BEPCII:

### – HEP

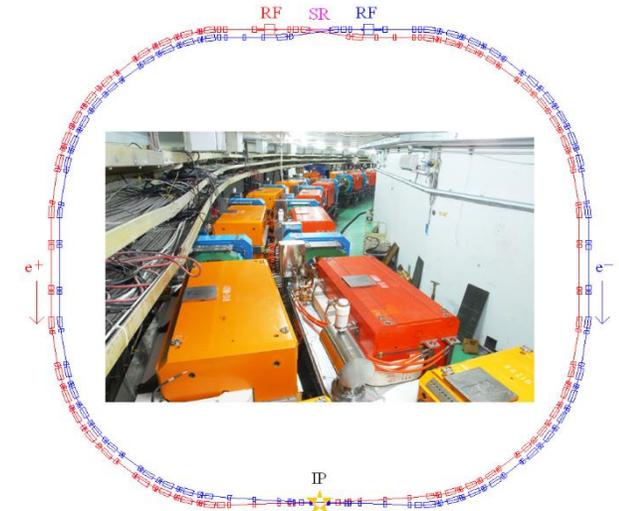
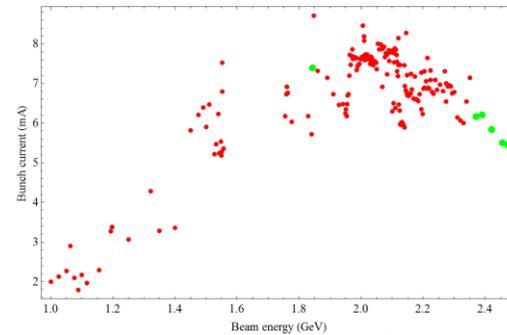
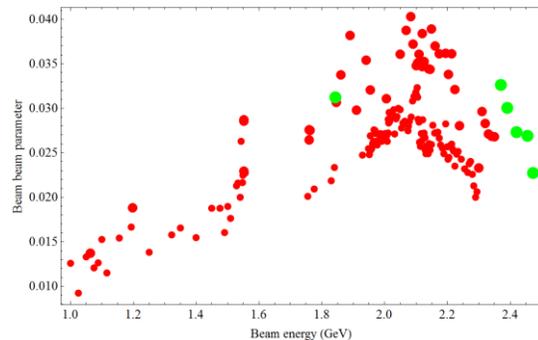
- Beam energy range 1-2.1 GeV
- Optimized beam energy 1.89 GeV
- Beam current 910 mA
- Luminosity  $1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$  @1.89 GeV

### – Synchrotron radiation

- Beam energy 2.5 GeV
- Beam current 250 mA

## • BEPCII-U: Increase luminosity at **higher** Energy

- Squeeze bunch length and  $\beta_y^*$  by increasing RF voltage + Increase beam current



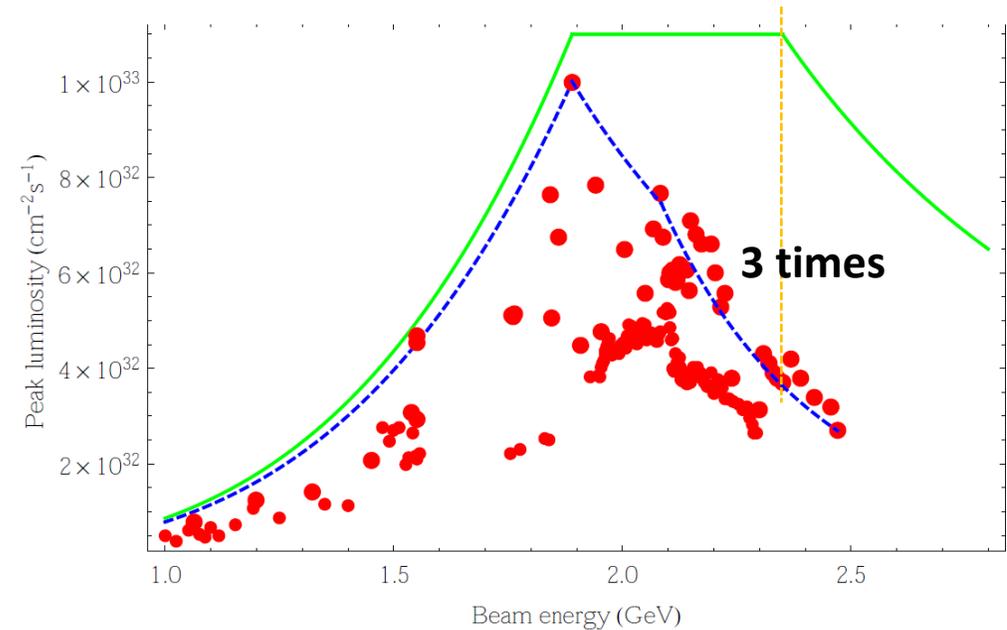
2023/01/07 18:18:47		
Luminosity	10.50	E32/cm <sup>2</sup> /s
e+ e-		
Energy [GeV]	1.8935	1.8935
Current [mA]	885.64	843.00
Lifetime [hr]	1.61	1.94
Inj.Rate [mA/min]	0.00	0.00

# Design parameters before / after upgrade

Beam Energy: 2.35GeV

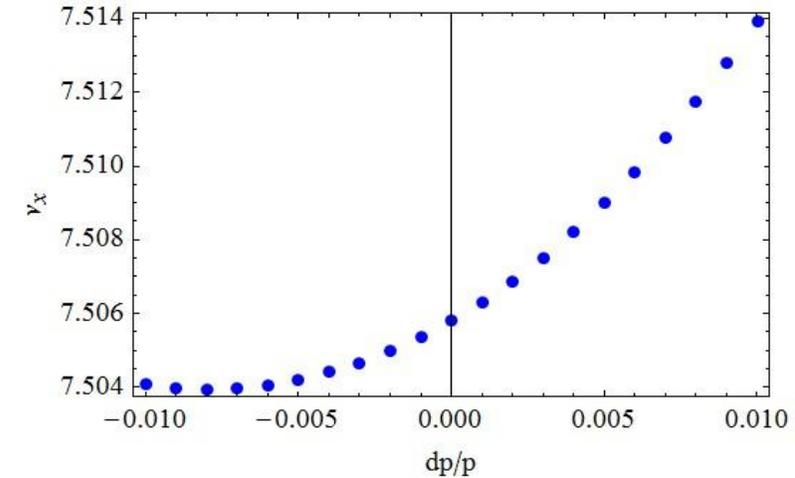
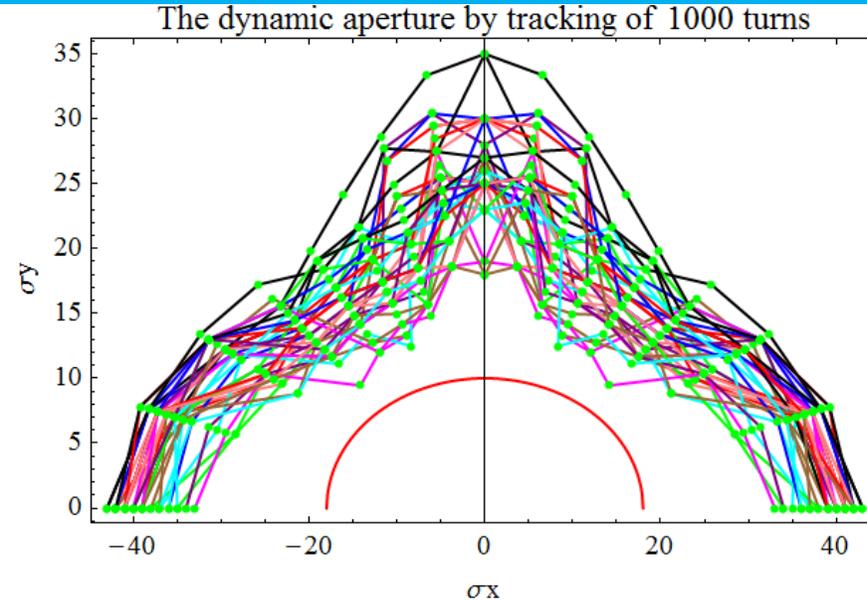
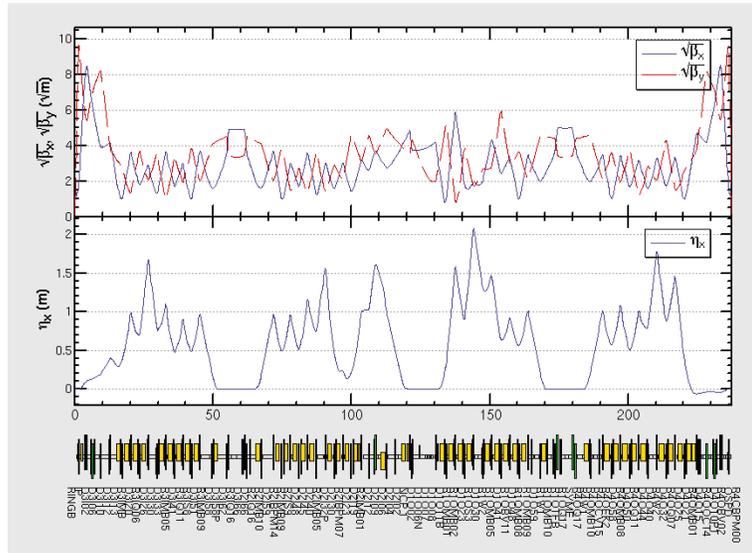
	BEPCII@ 1.89GeV	BEPCII@ 2.35GeV	BEPCII-U @ 2.35GeV	BEPCII-U @ 2.8GeV
Lum [ $10^{32}\text{cm}^{-2}\text{s}^{-1}$ ]	10	3.5	11	3.7
$\beta_y^*$ [cm]	1.35	1.5	1.35	3.0
Bunch Current [mA]	920	400	900	450
Bunch Num	120	120	120	120
SR Power [kW]	110	110	250	250
$\xi_{y,\text{lum}}$	0.029/0.041	-	0.022/0.033	0.043
Emittance [nmrad]	122	147	152	200
Coupling [%]	1	0.53	0.35	0.5
Bucket Height	0.008	0.0069	0.011	0.009
$\sigma_{z,0}$ [cm]	1.15	1.54	1.07	1.4
$\sigma_z$ [cm]	1.35	1.69	1.22	1.6
RF Voltage	1.6	1.6	3.3	3.3

## BEPCII-U vs BEPCII



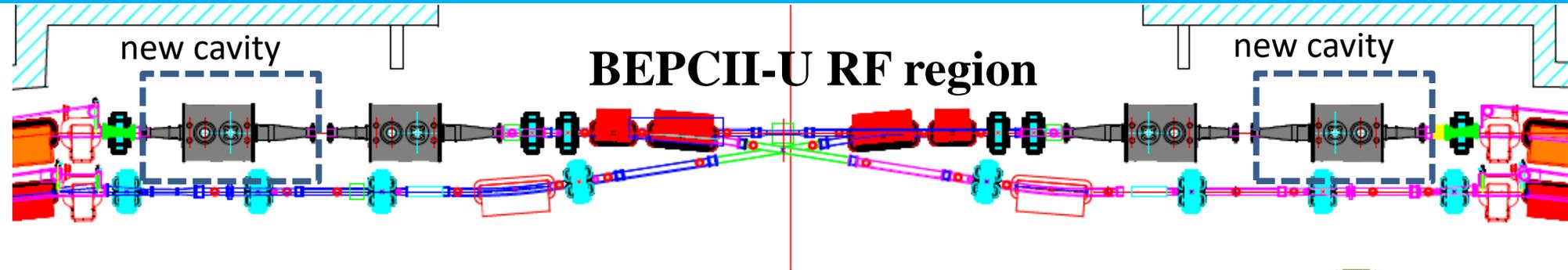
- Luminosity is increased by a factor of **3 @2.35GeV**
- Maximum beam energy is increased from **2.1GeV to 2.8GeV**.

# Lattice modified @ 2.35gev

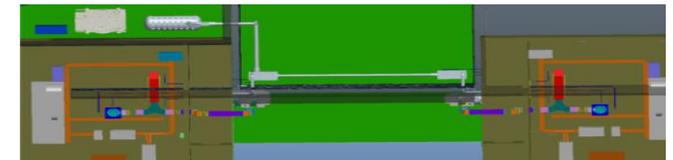
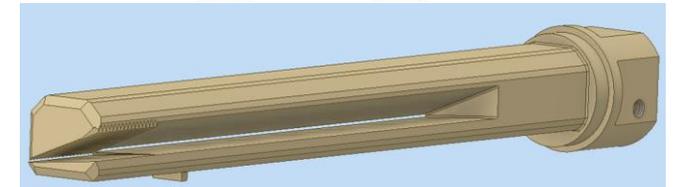
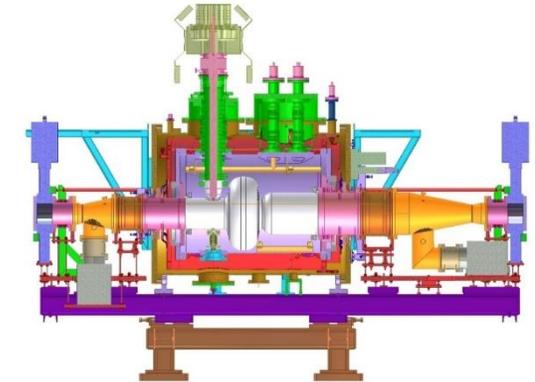


- Local optics redesigned at the RF region
- Global tuning has been done to minimize the emittance
- Dynamic aperture is optimized to ensure enough beam lifetime
- Intensive multiparticle tracking has been done to make sure the luminosity performance

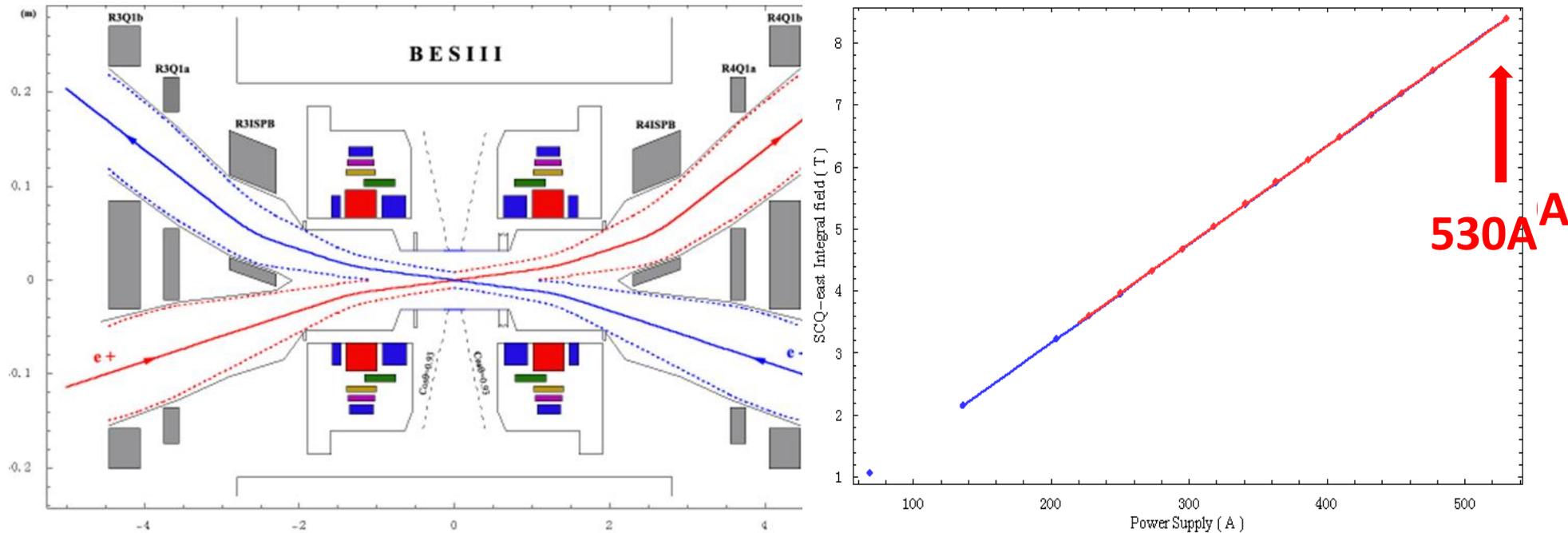
# Hardware upgrade: RF



- **1 existing + 1 new RF Cavity/ per ring**
  - 2 old cavities; 1 backup cavity; 1 new cavity
  - Survey will be kept exactly the same as BEPCII
  - Two sets of 500MHz, 200kW solid state power source are installed
- Cryogenic system: upgraded with a new refrigerator
- Photon absorber capacity upgraded from 110 kW to 250 kW



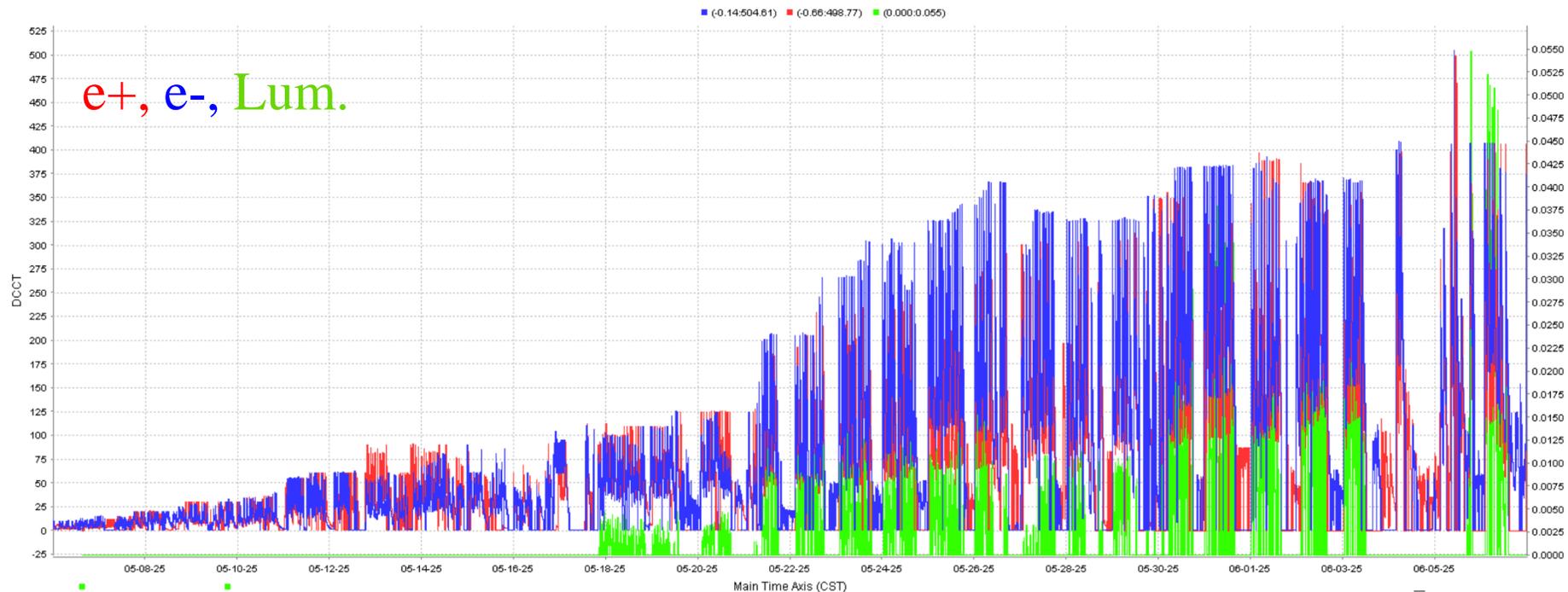
# Hardware upgrade ----SCQ



- The strength of SCQ(Superconducting Quadrupole) is critical for high luminosity at 2.8 GeV (current SCQs exceed quench current limit).
- New SCQs replace existing ones for 2.8 GeV operation.

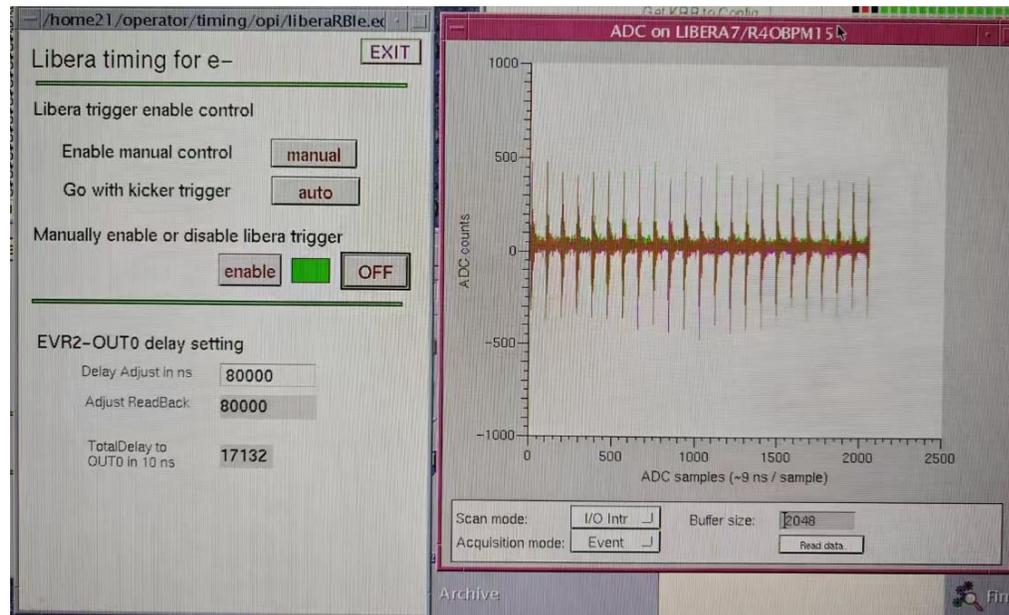
# Schedule

- 2024 .7-12, Shut down for hardware dismantling and installation
- 2025-2028, **Operation at 1.89~2.5GeV, and prepare for energy upgrade**
  - **Current status: Commissioning at 1.89 GeV**
- 2028.6-9, Energy upgrade to 2.8GeV
- 2028.9~2030, Operation at 2.5~2.8GeV

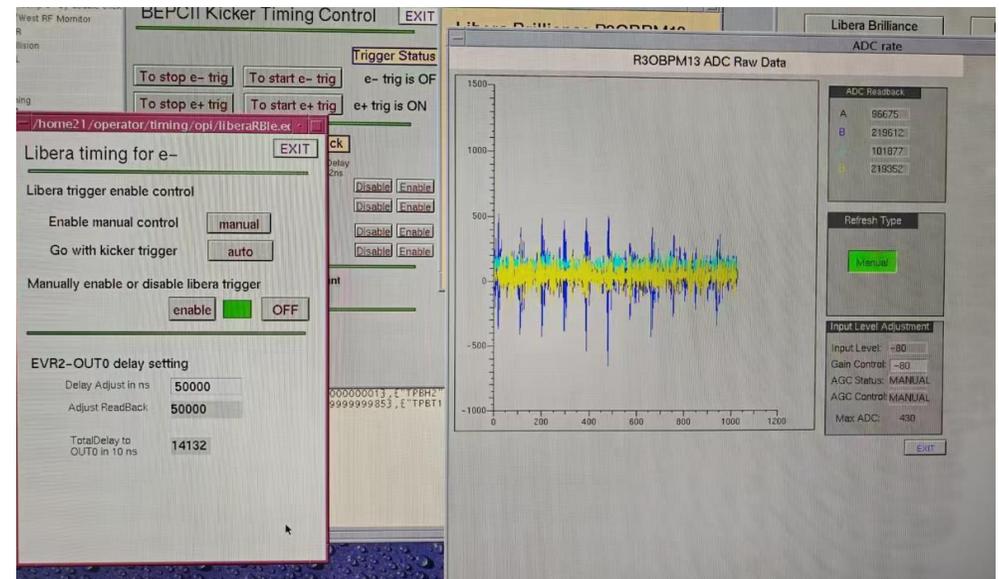


# Beam commissioning w/o RF

- The cryogenic system was ready at May 2<sup>nd</sup>.
- In March and April, commissioning of injection beams at 1.89GeV was conducted without the RF system, with the BPR and BER obtaining beam signals of 80 turns and 100 turns respectively.



BER 120 turns

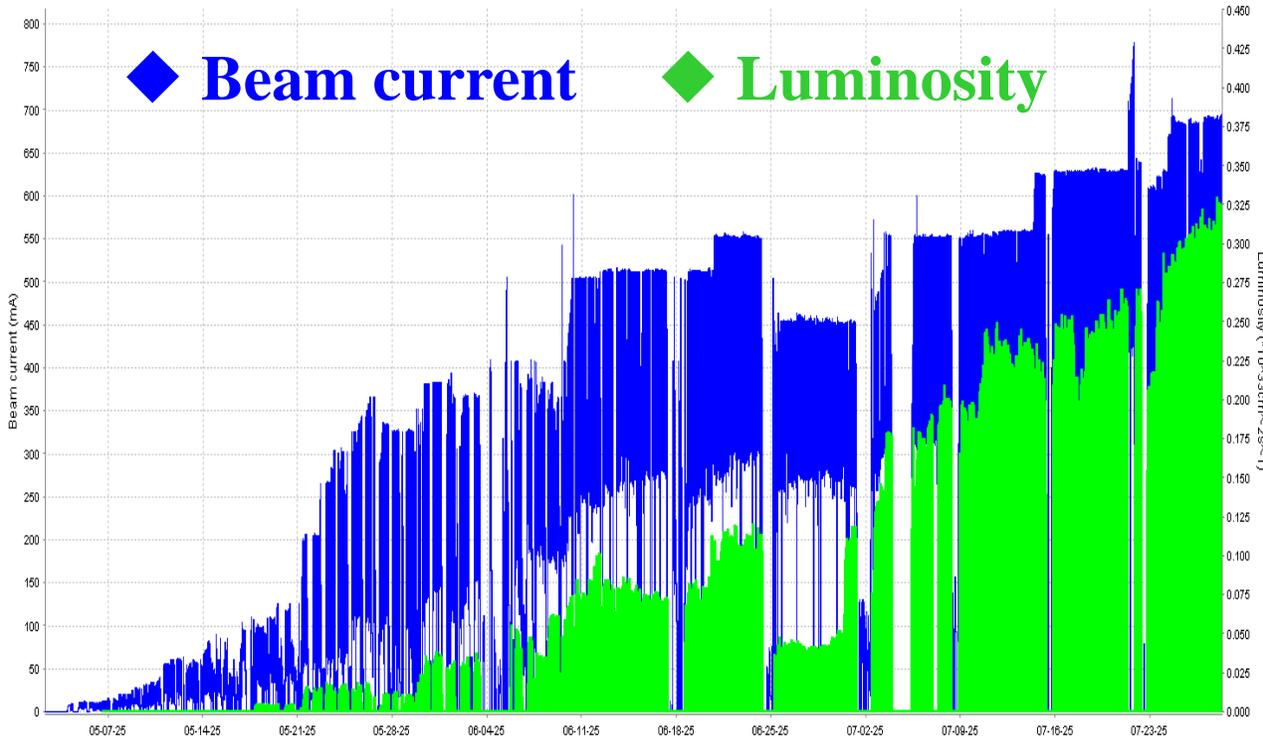


BPR 80 turns

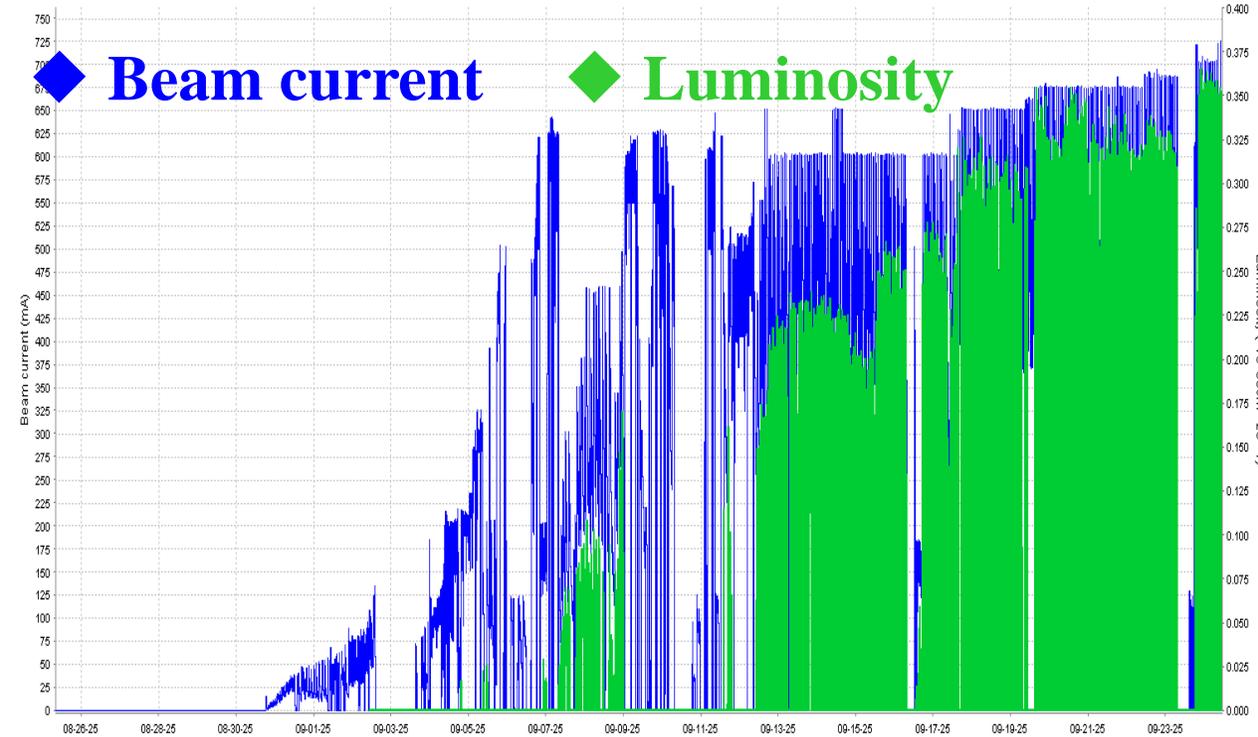
# Status of BEPCII-U operation

May.2 – Sep.30

BEPCII upgrade operates stably & beam current and luminosity increasing steadily



May.2– July.29

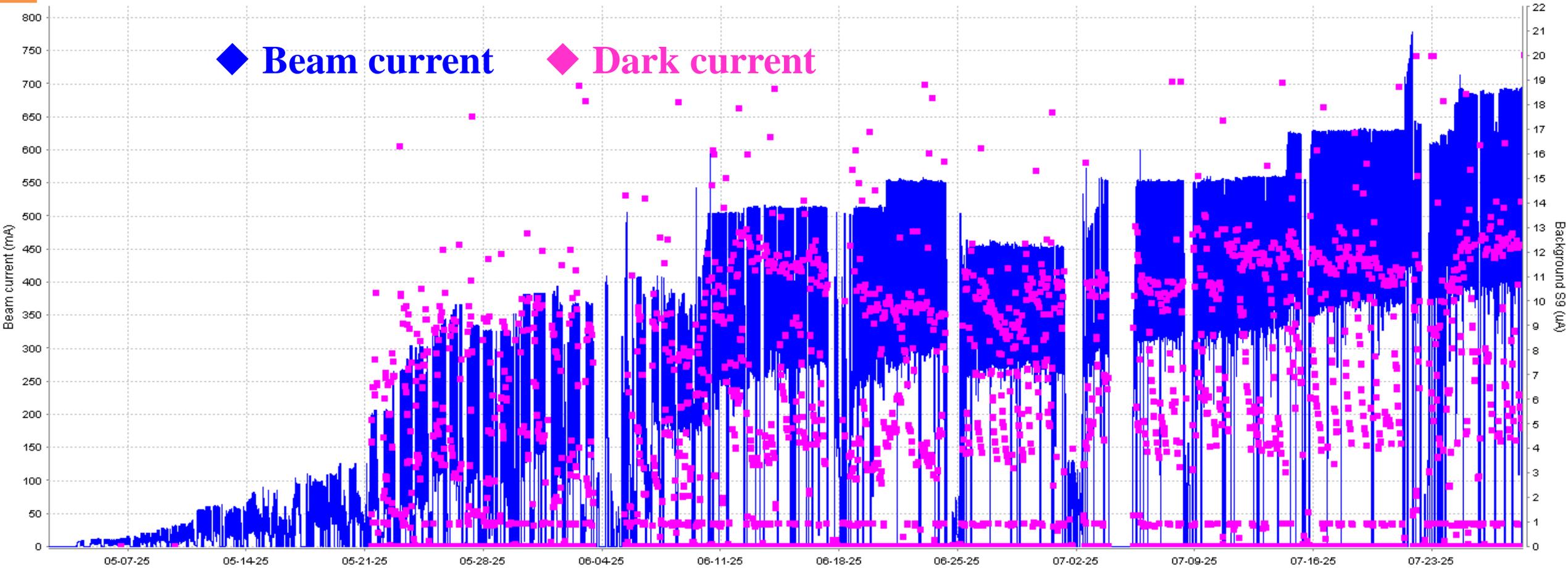


Aug.25– Sep.30

Beam current **720mA/720mA** & Peak luminosity  **$3.8 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$**

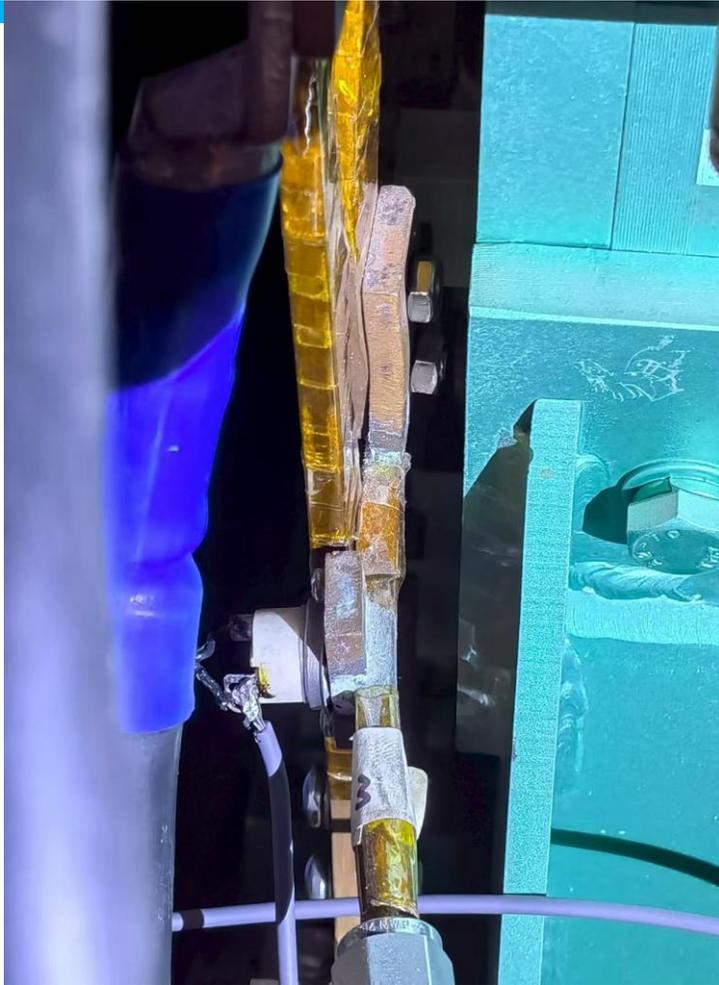
Data taking with **8 beam lines** for BSRF parasitic experiments

# Status of BEPCII-U operation



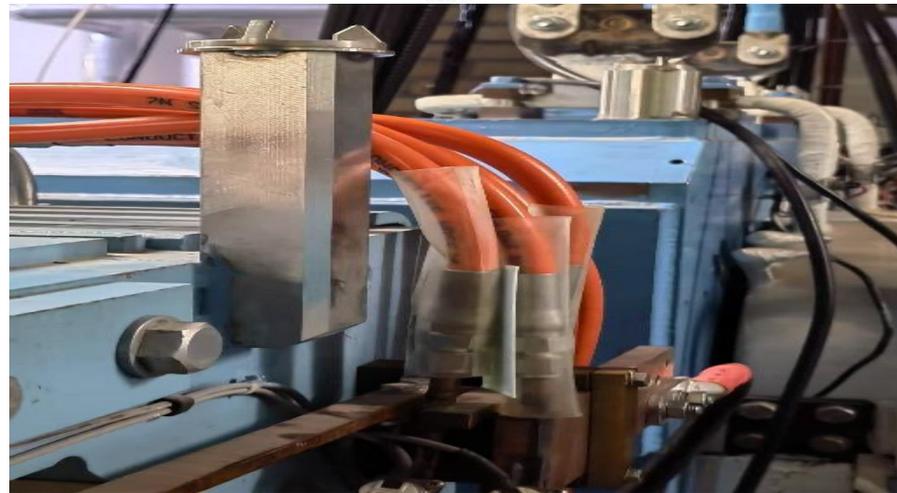
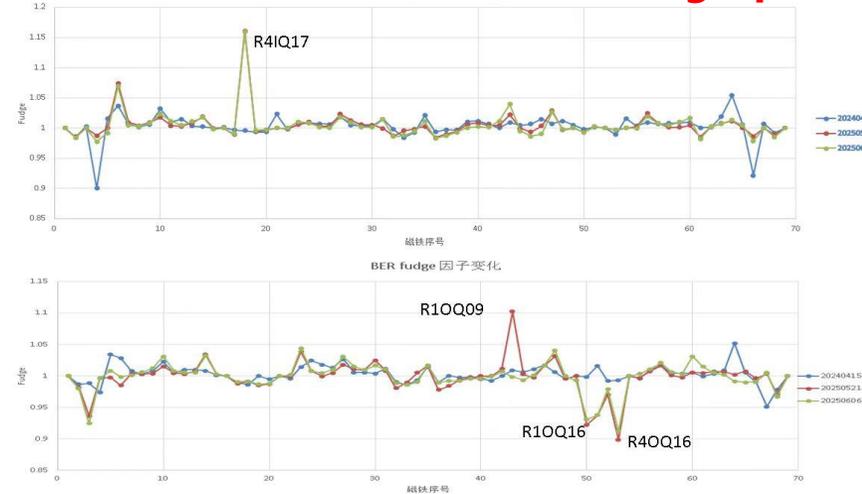
**Vacuum recovery of a new machine by monitoring the background limitation of BES ( $<12\mu\text{A}$ )**  
**Current vacuum of BER ( $5 \times 10^{-9}$  torr @ 720 mA) is better than BPR ( $1 \times 10^{-8}$  torr @ 720 mA)**

# Status of BEPCII-U operation

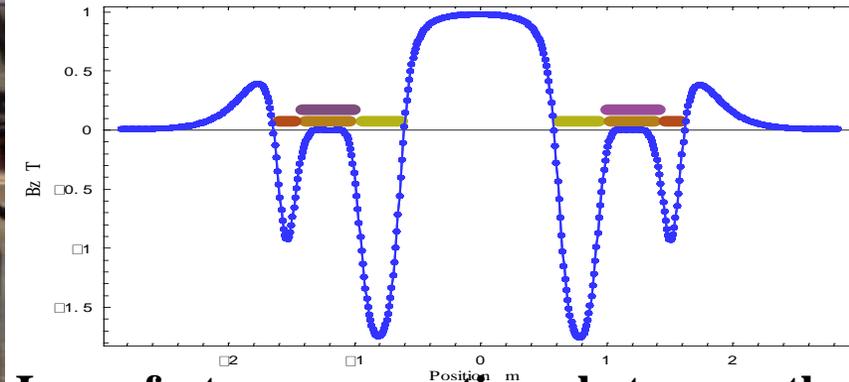
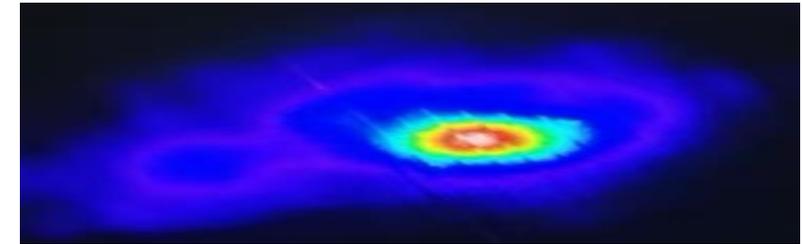
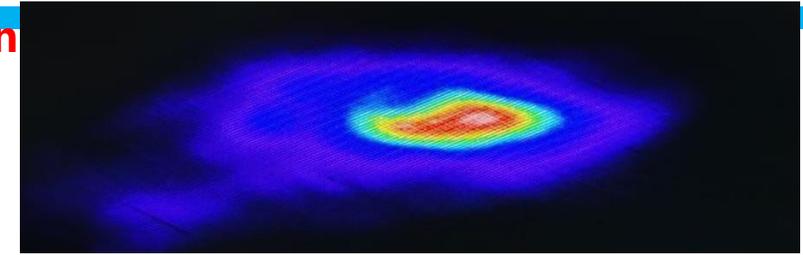


**Magnet short circuit  
Sextupole R3OS4, Jul.22**

## Hardware issues identified during operation



**Magnet short circuit  
Quadrupole R4IQ17, Jun.17**



**Imperfect compensation between the solenoid and the anti-solenoid. Imperfect compensation for the vertical focusing effect of the solenoid.**

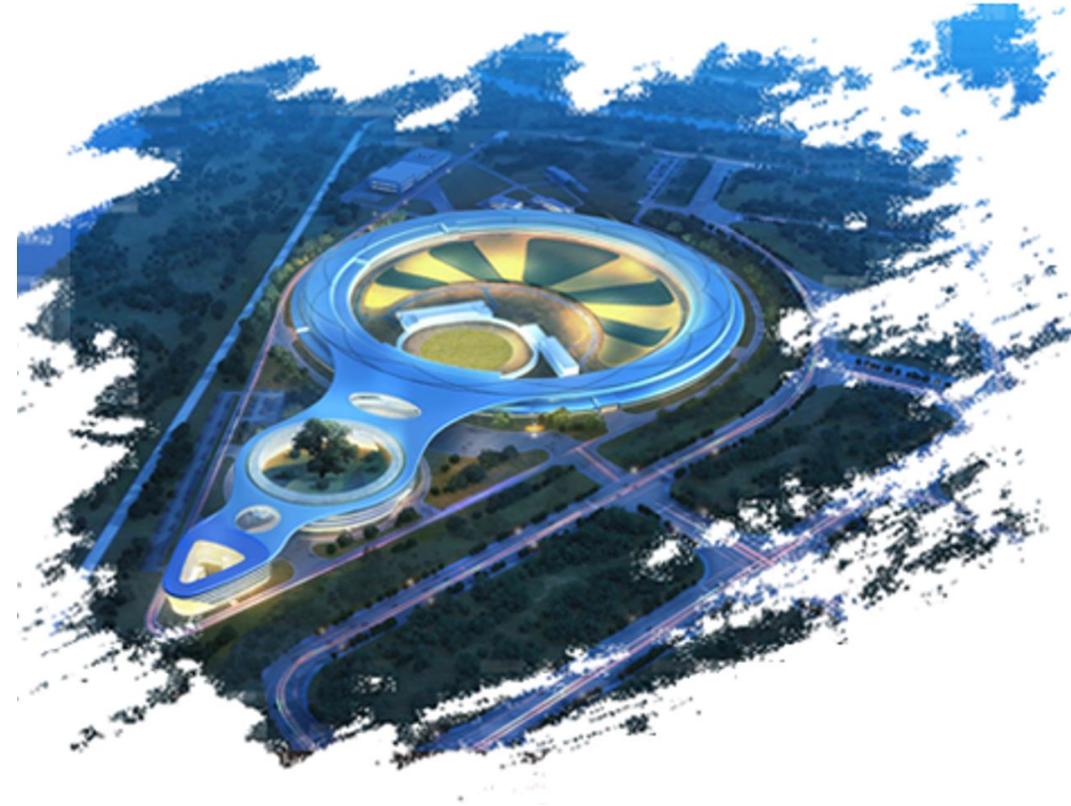
# Current status of BEPCII-U

- As of September 30th, during the past 73 HEP operation days, the maximum beam current and peak luminosity reached **720mA** and  **$3.8 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$**  respectively. The dark current is controlled under **12 $\mu$ A**. The integral luminosity reached **420.4 pb<sup>-1</sup>** and **183** user experiments were finished by BSRF 8 parasitic beam lines.
- **BEPCII is an operational facility with a scheduled BESIII data-taking task and urgent BSRF beam usage demands, resulting in a severe shortage of dedicated beam commissioning time for the accelerator after the upgrade project and its restart.**

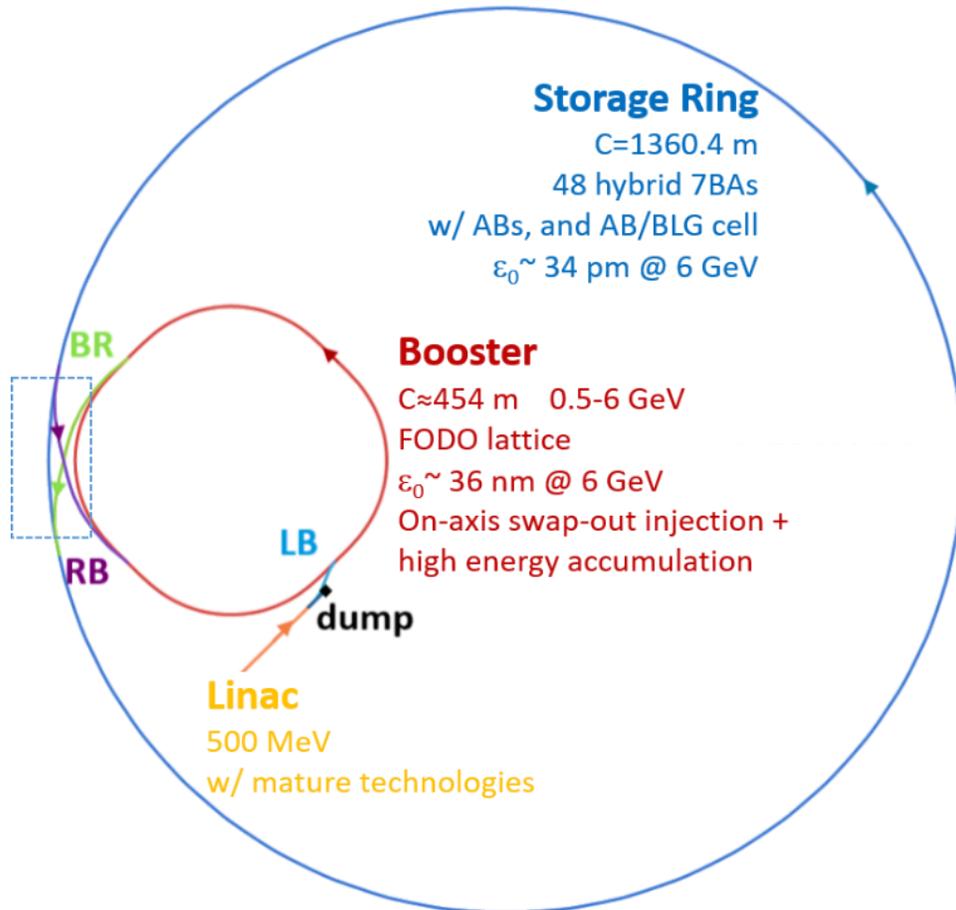
# High Energy Photon Source (HEPS)

4th-generation synchrotron radiation light source

Circumference	1360.4	m
Energy	6	GeV
Emittance	$\leq 0.06$	nm·rad
Brightness	$> 1 \times 10^{22}$	phs/s/mm <sup>2</sup> /mrad <sup>2</sup> /0.1% BW
Beam Line	$\geq 90$	Initially: 14
Photon Energy	0.1-300	keV



# High Energy Photon Source (HEPS)



- **Accelerator complex**

- Linac (500 MeV)
- Booster (500 MeV to 6 GeV, 1 Hz)
- Storage ring (6 GeV, top-up)

Parameter	Value	Unit
Beam energy	6	GeV
Circumference	1360.4	m
Lattice type	Hybrid 7BA	
Hori. Natural emittance	<60	pm·rad
Brightness	$>1 \times 10^{22}$	*
Beam current	200	mA
Injection mode	Top-up	-

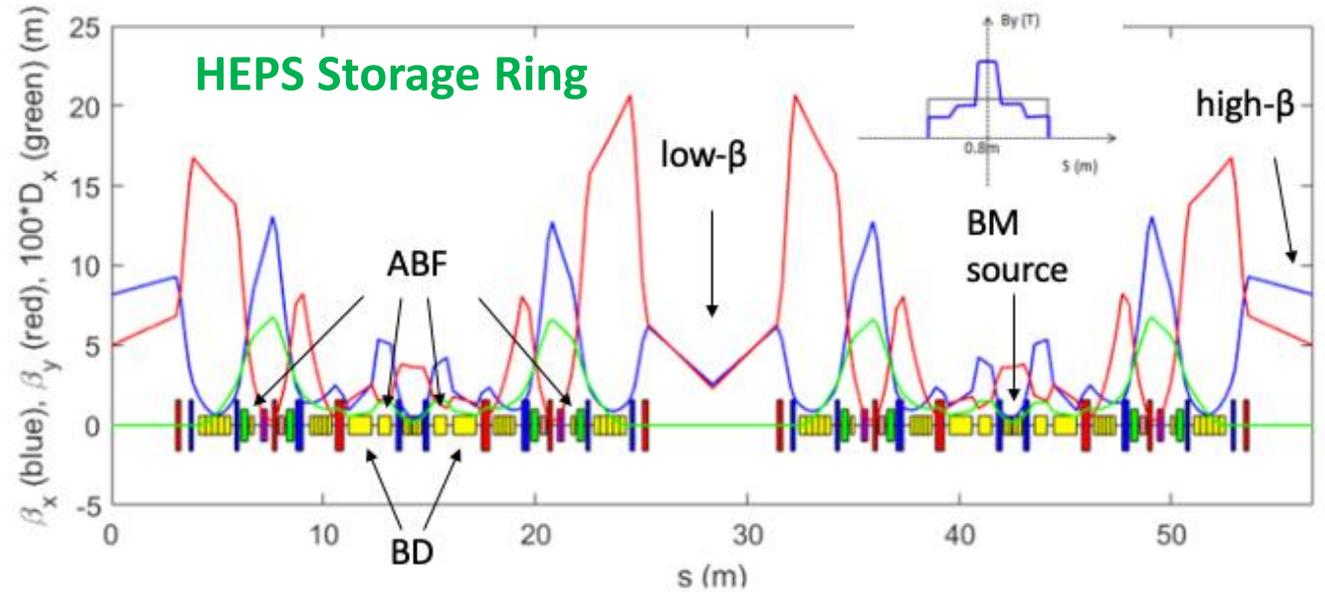
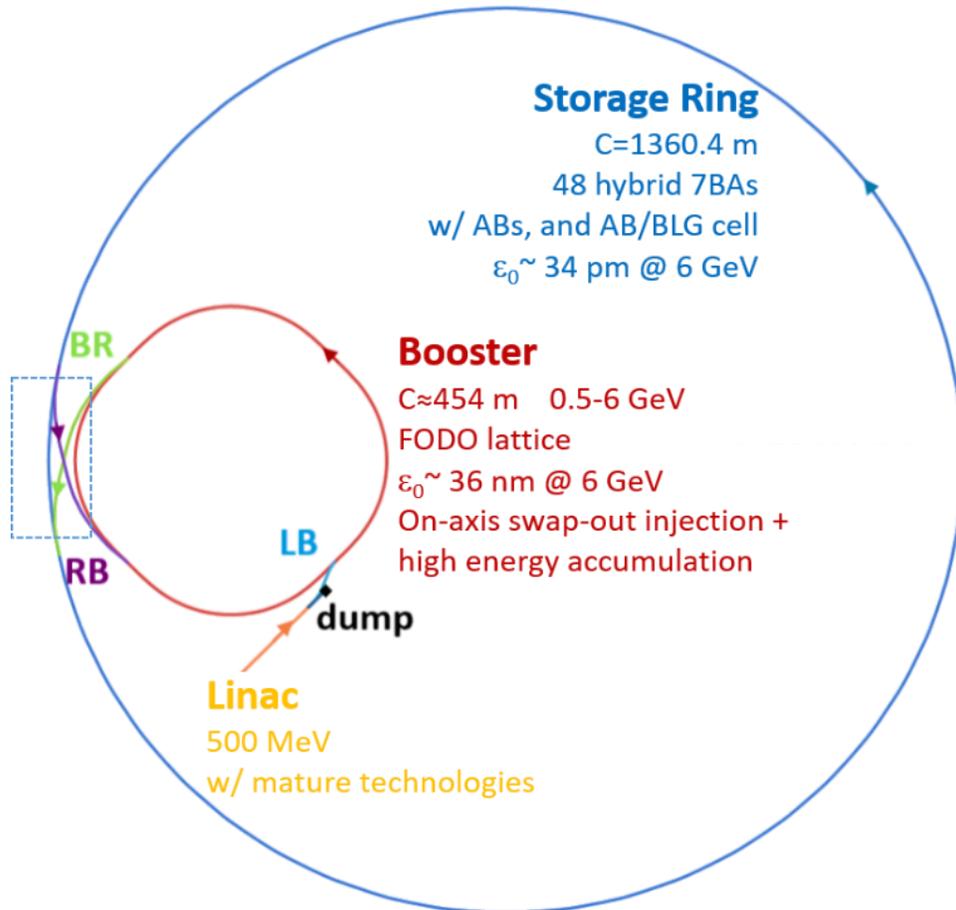
\*: phs/s/mm<sup>2</sup>/mrad<sup>2</sup>/0.1%BW

[1] Y. Jiao *et al.*, *J. Synchrotron Rad.* 25, 1611–1618 (2018).

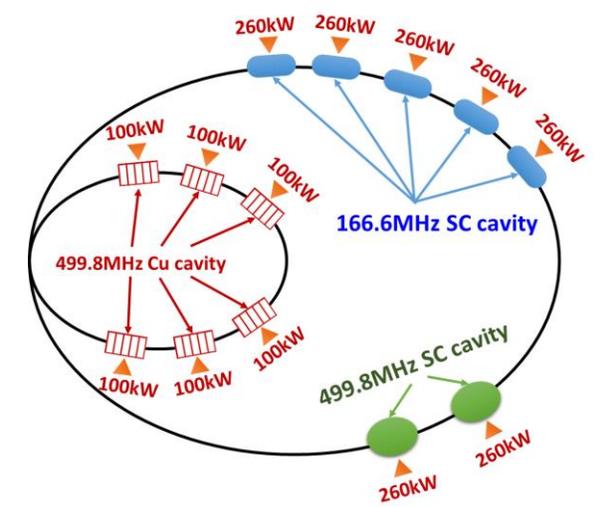
[2] Y. Jiao, *RDTM* 4, 399 (2020).

[3] H. Xu *et al.*, *RDTM* 7, 279–287 (2023).

# High Energy Photon Source (HEPS)

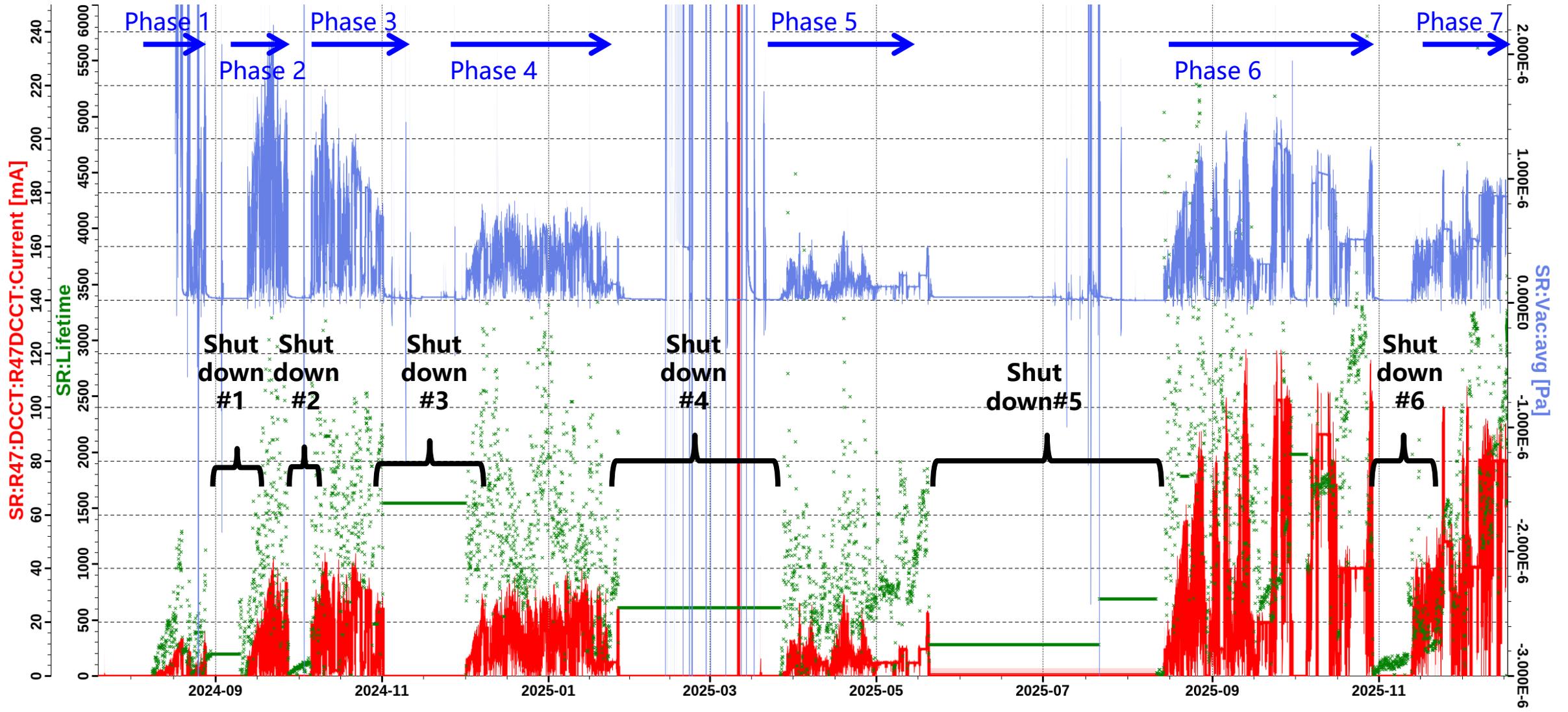


- 1700+** Magnets
- 19** IDs
- ~1300** vacuum chambers
- 500+** BPMs
- 288** Girders
- 5** 166MHz SRF
- 2** 500MHz SRF

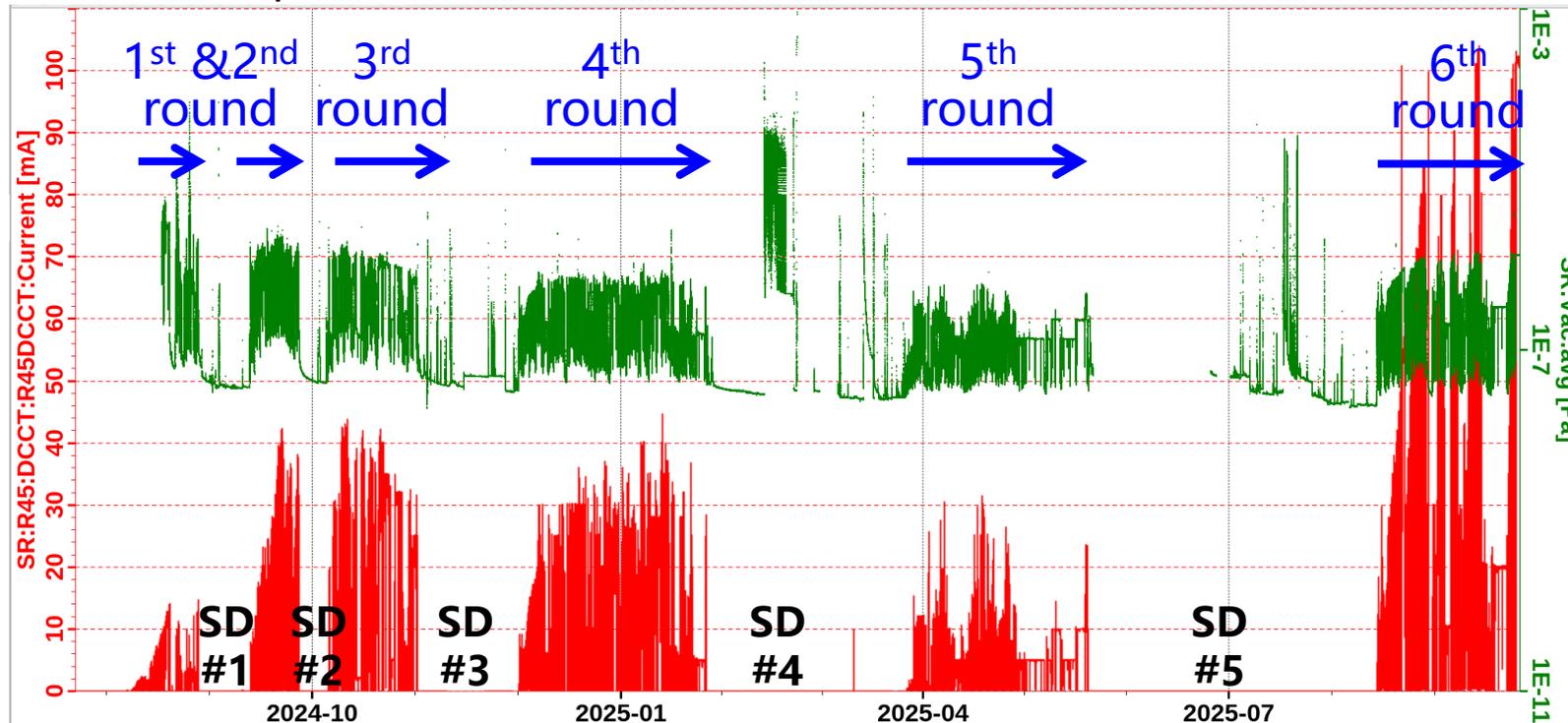


[1] Y. Jiao *et al.*, *J. Synchrotron Rad.* 25, 1611–1618 (2018).  
 [2] Y. Jiao, *RDTM* 4, 399 (2020).  
 [3] H. Xu *et al.*, *RDTM* 7, 279–287 (2023).

# HEPS storage ring commissioning



- Not all hardware systems were ready at Day One
- The commissioning was paused a few times mainly for installation
- Staged commissioning
  - injection: slotted-pipe kicker -> stripline kicker
  - **RF: 500MHz RF -> 166 MHz RF + 500 MHz (3<sup>rd</sup> harmonic)**
  - ID: backup vacuum chamber -> In-air IDs -> In-vacuum IDs



**SD#1:**

- 1, replace injection kickers & pulsers
- 2, replace R20VC14 vacuum chamber

**SD#2:**

- 1, replace vacuum chambers of ID21/42/46;

**SD#3:**

- 1, install ID09;
- 2, replace vacuum chambers of ID08 & ID30;
- 3, install 3 collimators;
- 4, replace 500MHz SCC;

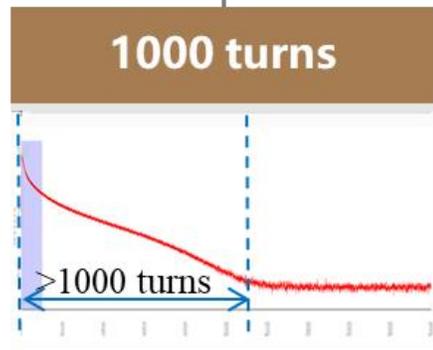
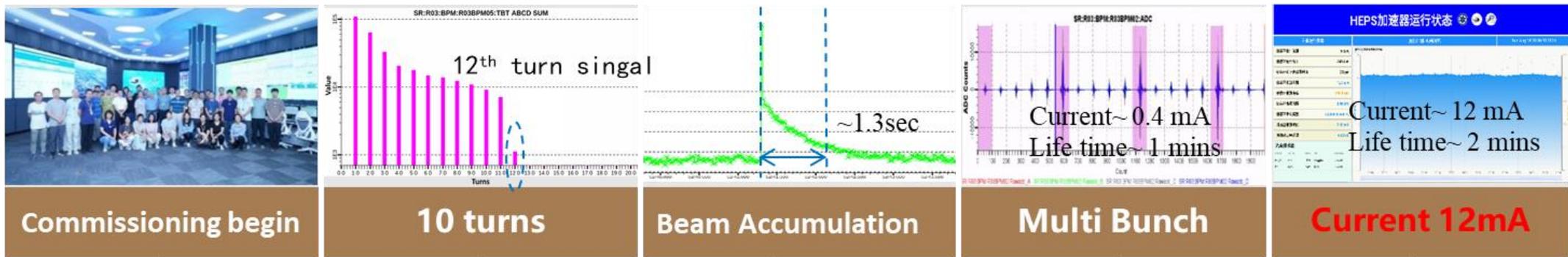
**SD#4:**

- 1, install most IDs;
- 2, fine global alignment;
- 3, install beam dump kicker;

**SD#5:**

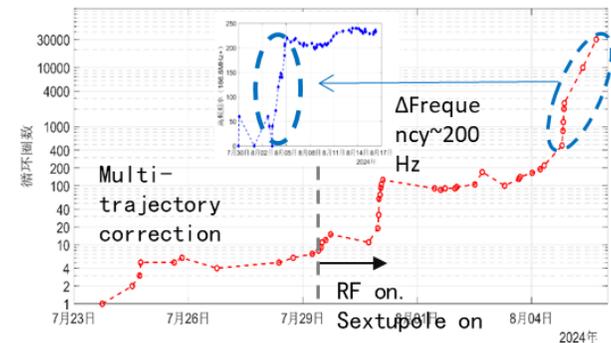
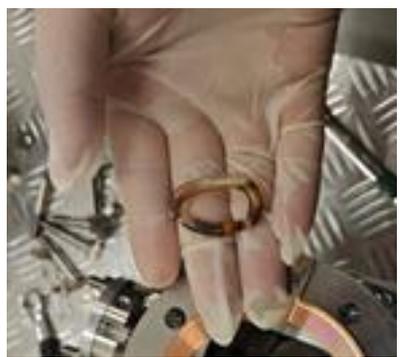
- 1, **install 166MHz & 500MHz SCCs;**
- 2, install 4th collimator;
- 3, fine alignment of booster;
- 4, install remaining IDs

# Phase 1: Achieved beam storage with current >10 mA.(7.23-8.27)

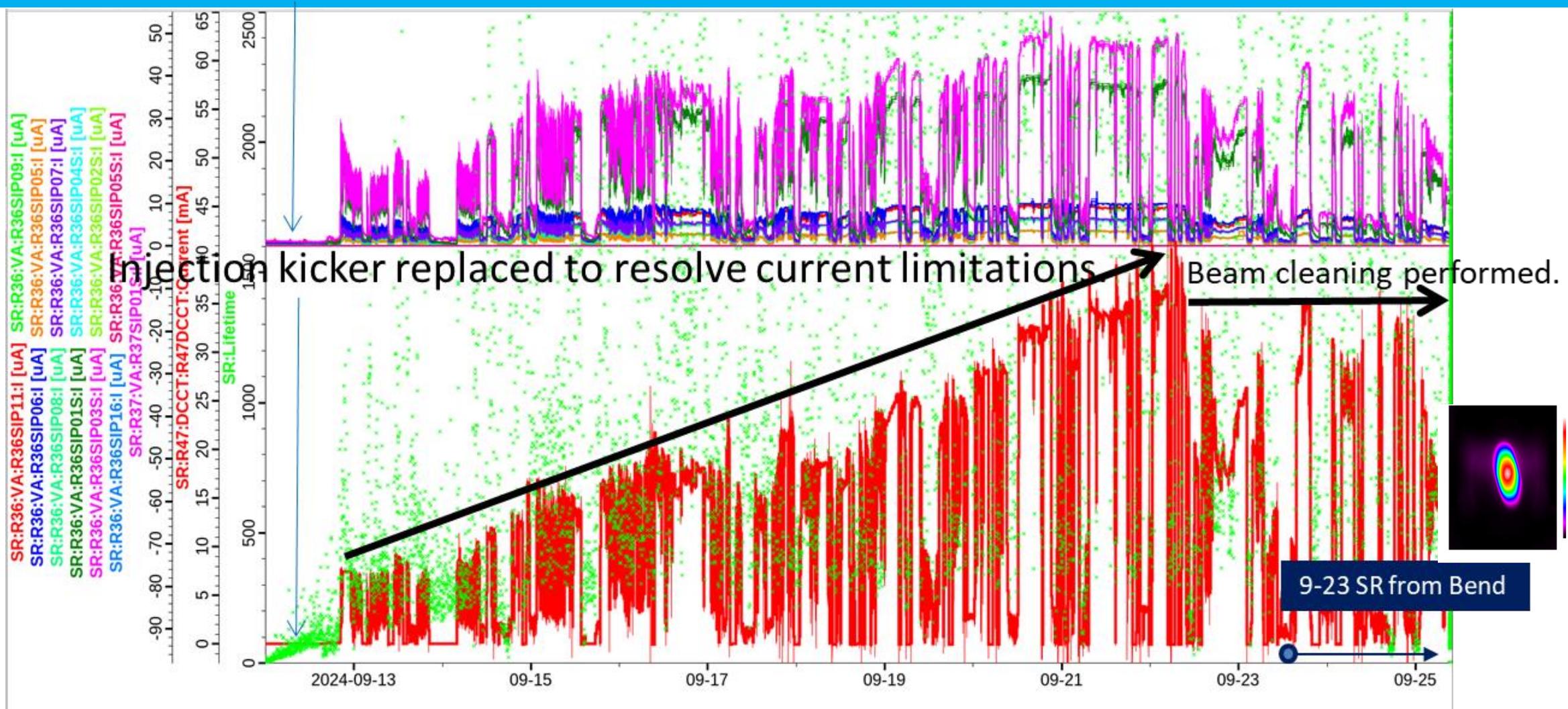


## Shut down #1:

- Replace injection kicker and power supply;
- Replace R20VC14 vacuum chamber.

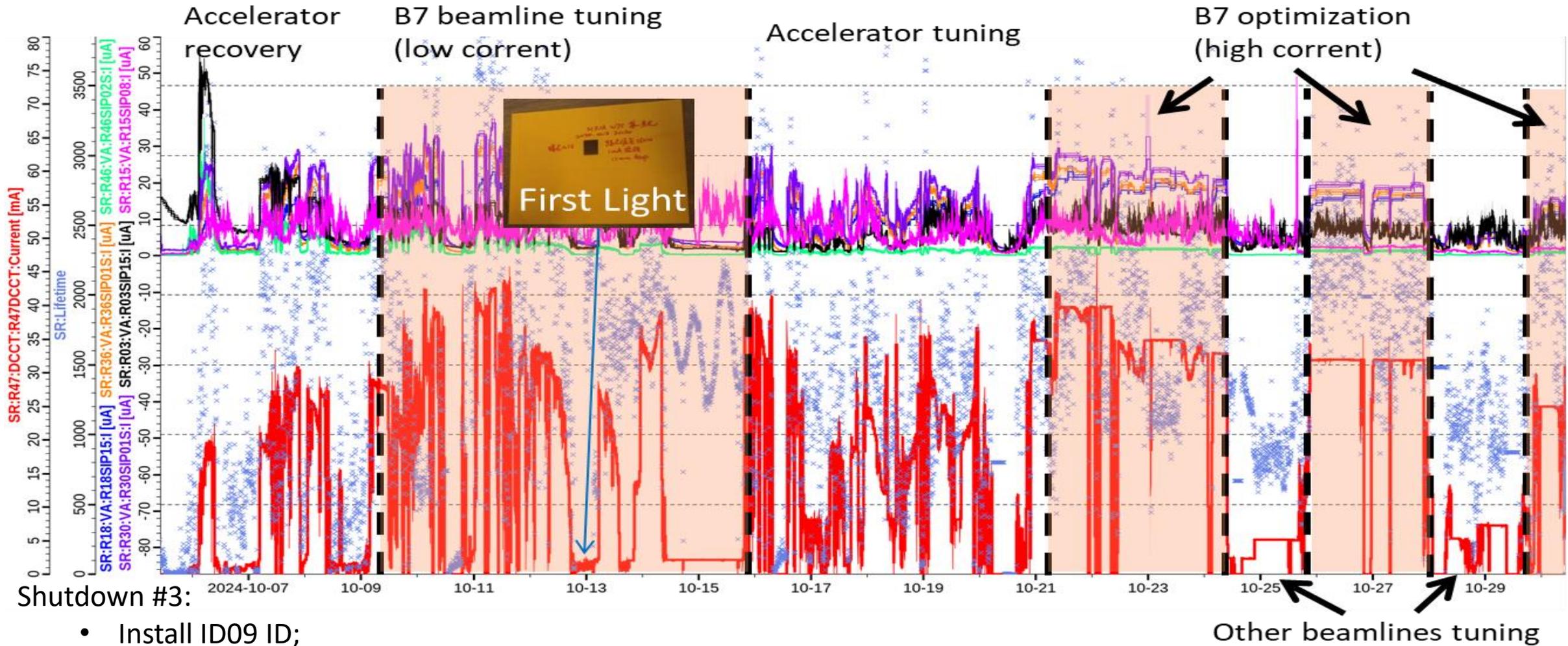


# Phase 2: Current increased to ~40 mA. (9.12-9.26)



Shutdown #2:  
Replace ID21/42/46 vacuum chambers.

# Phase 3: First light, beamline experiments. (10.5-11.1)



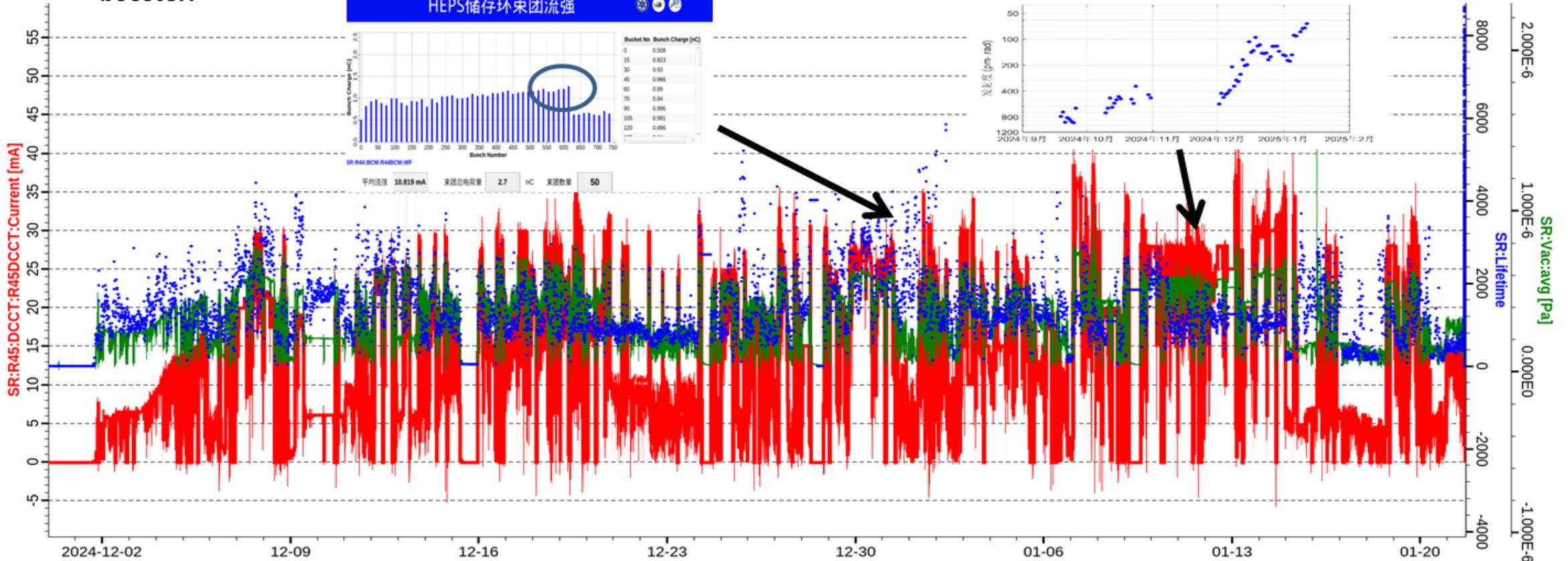
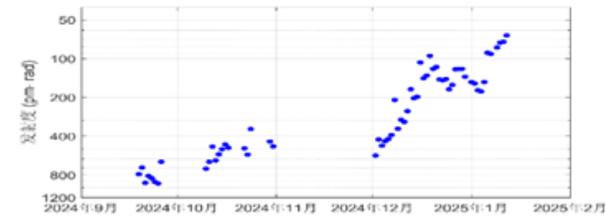
- Install ID09 ID;
- Replace ID08 and ID30 vacuum chambers;
- Install three collimators;
- Replace superconducting cavity.

# Phase 4: Preliminary beam dynamics optimization completed.(11.30-1.26)

Verified swap-out injection with high-energy accumulation in the booster.



Beam emittance reduced to <100 pm·rad at 27 mA.

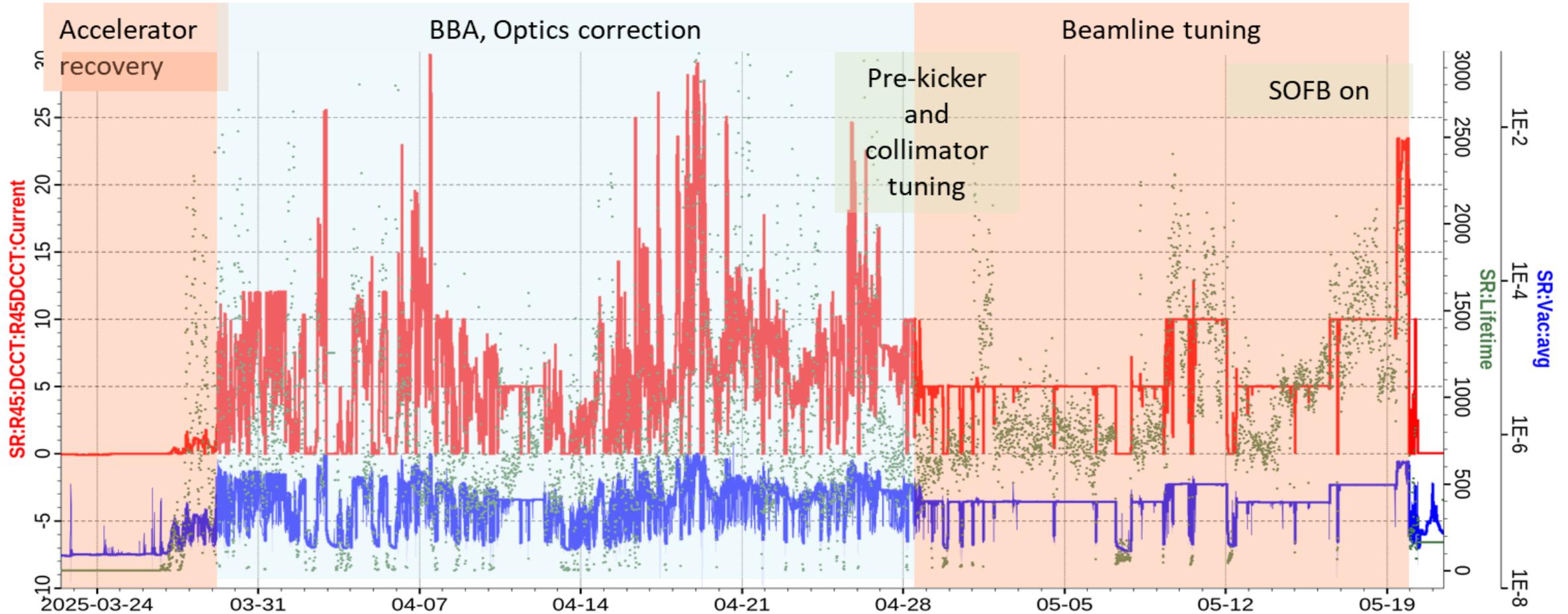


Shutdown #4:

- Install most ID;
- Perform full-ring precise alignment;
- Install pre-kicker.

- COD(rms): ~100/100  $\mu\text{m}$ .
- Beta beating (rms): ~3%/3%.
- Dispersion deviation (std): ~4/3 mm.

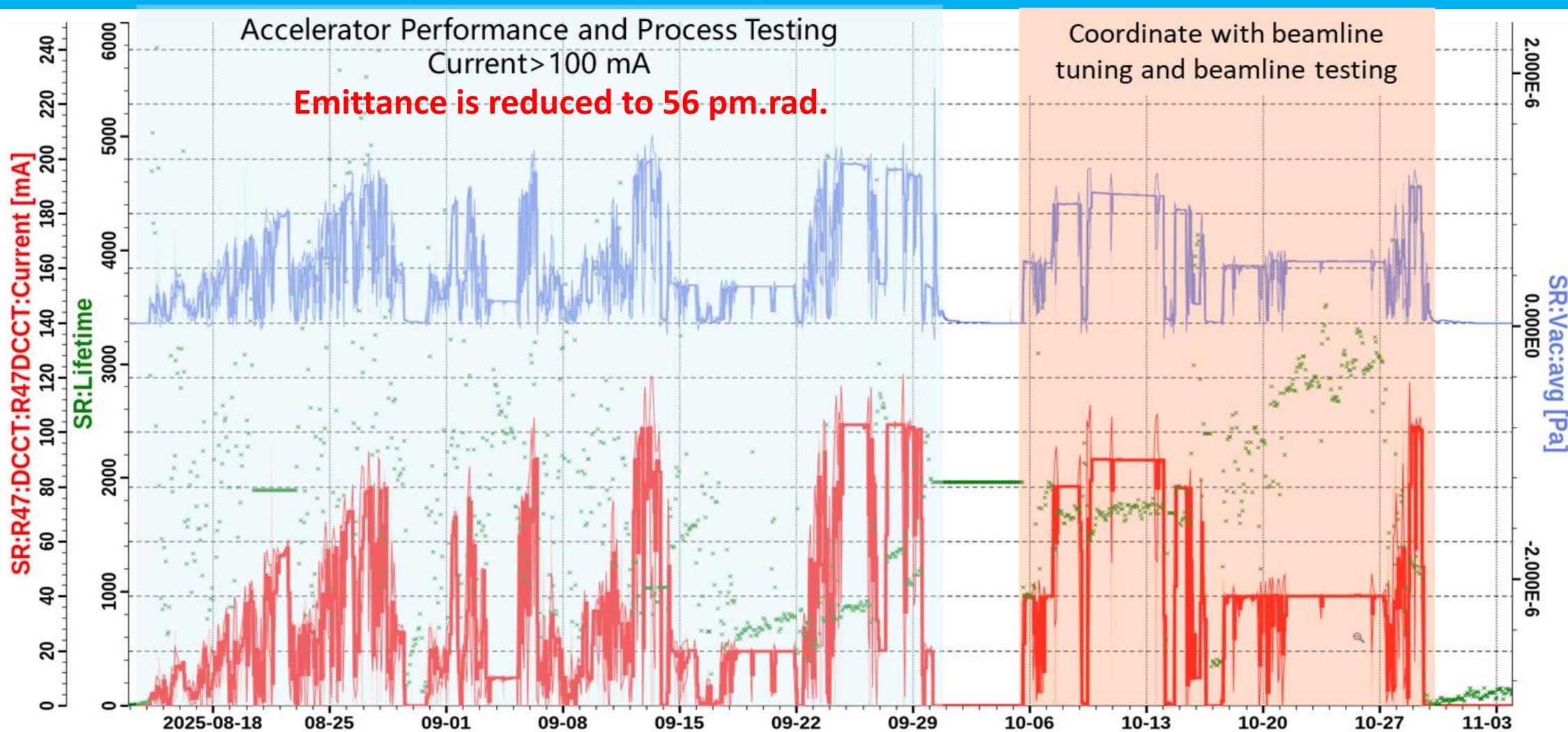
# Phase 5: Optimization of storage ring current, lifetime, and vacuum. (3.23-5.20)



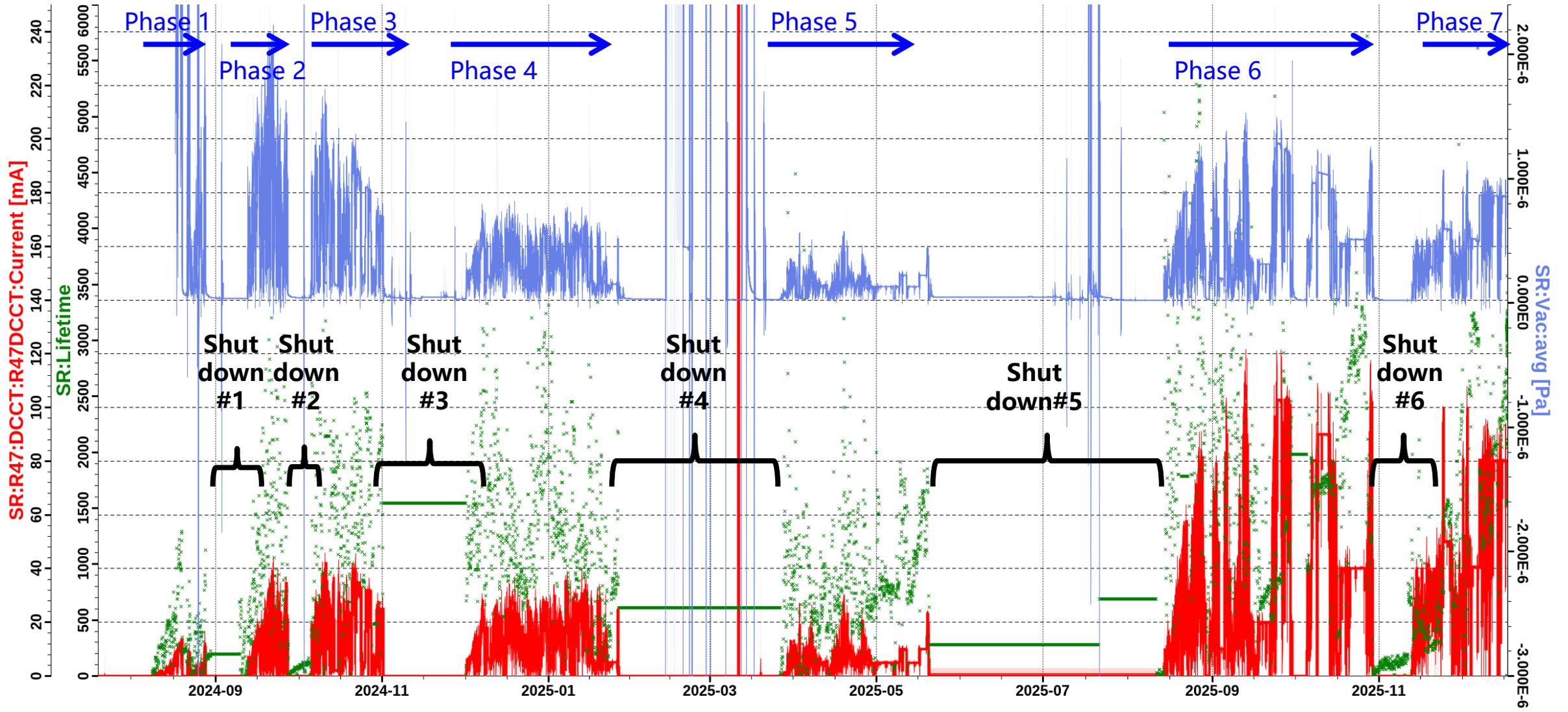
Shutdown #5 (5.20-8.10):

- Install all 166 MHz cavity;
- Replace collimator.

# Phase 6: Complete performance process test and process acceptance (8.12 - 10.29)

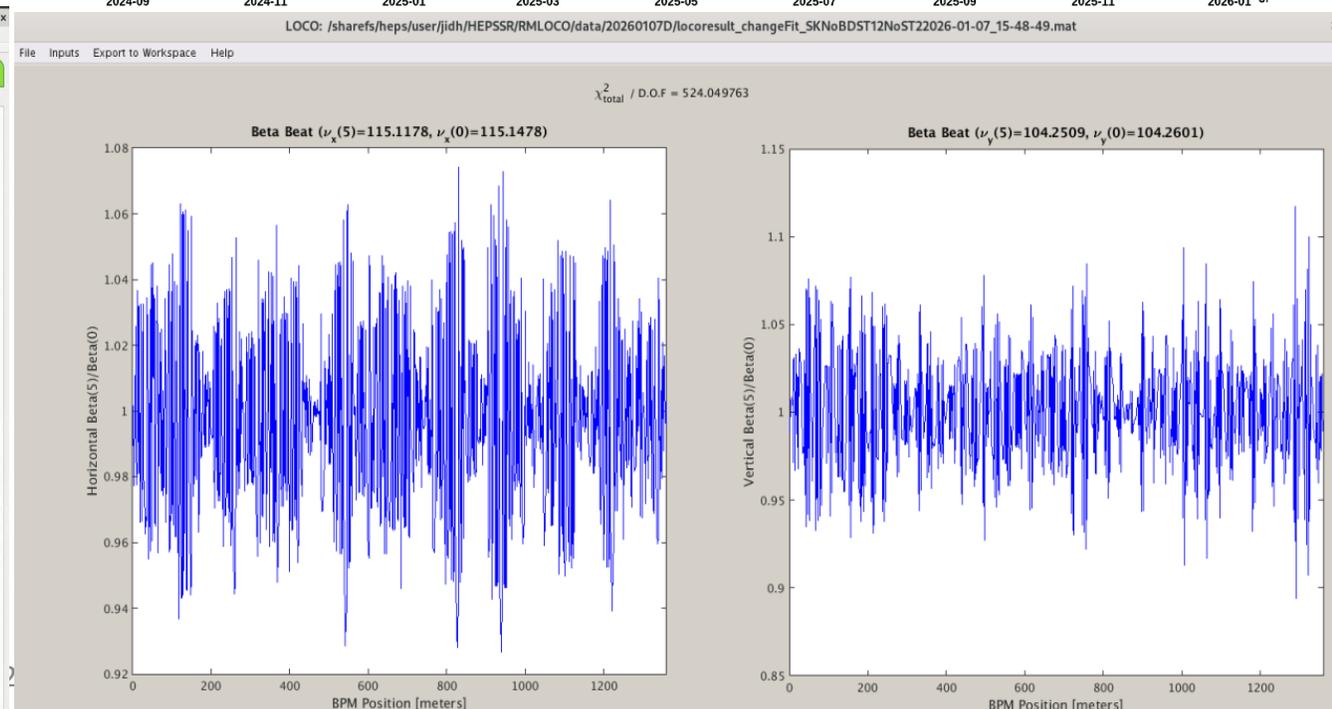
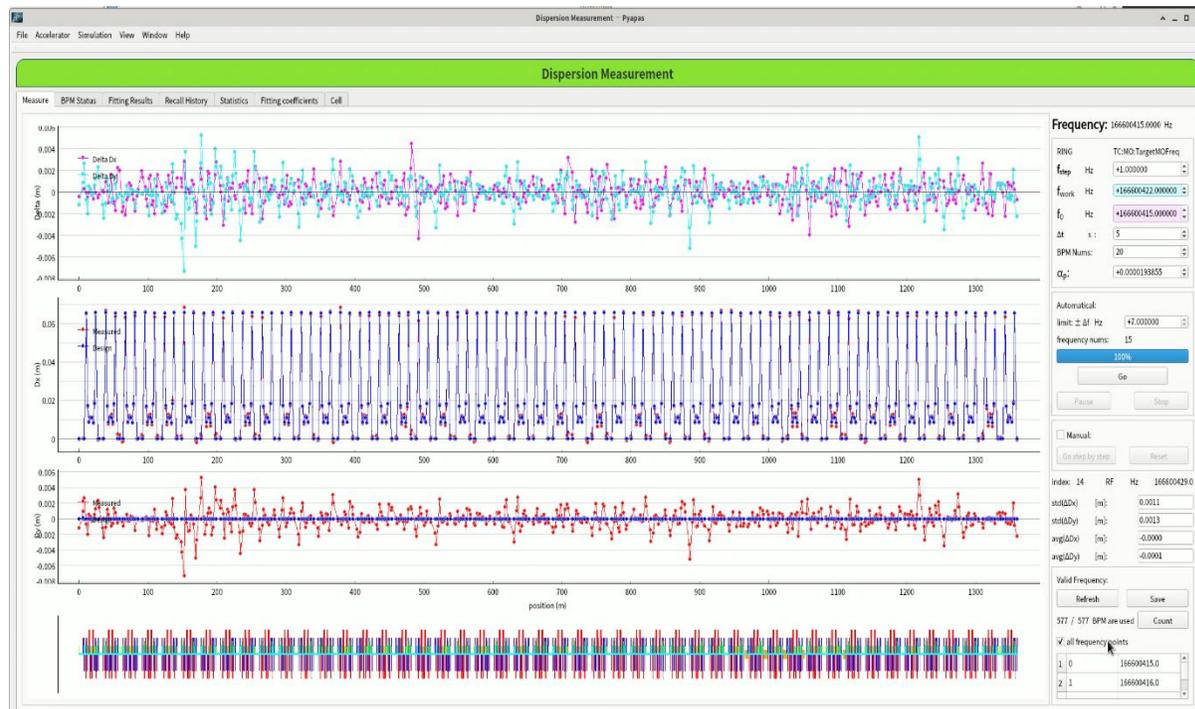
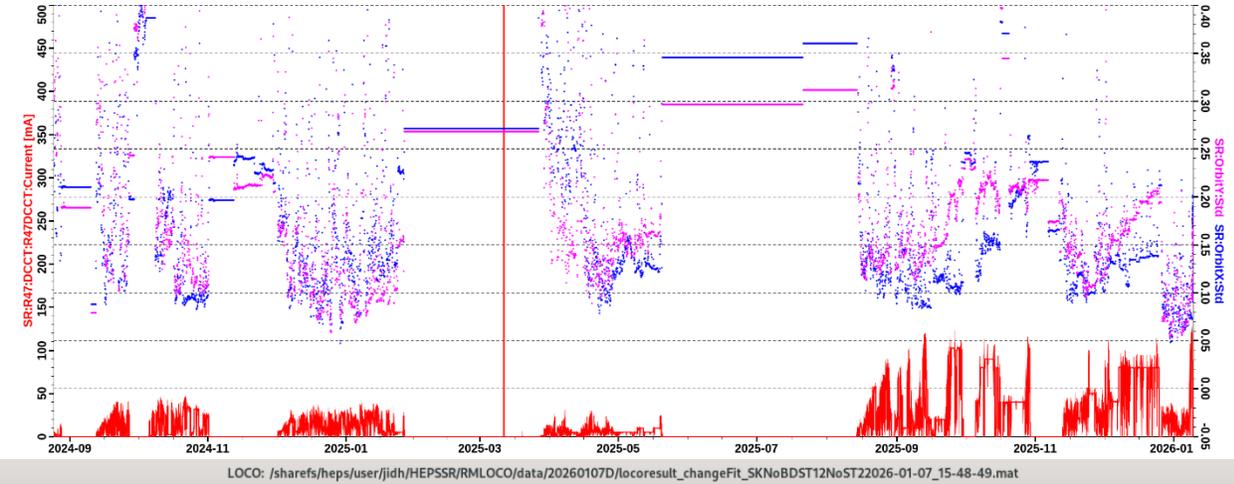


# HEPS Storage Ring Commissioning



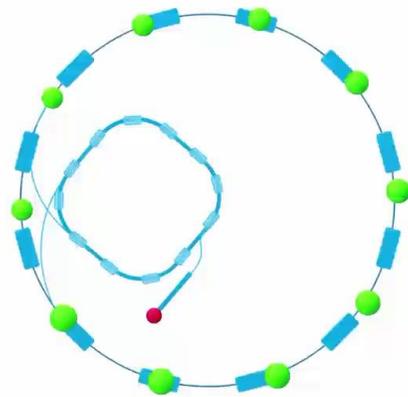
# Orbit, optics, dispersion optimization

- COD(rms):  $\sim 60/60$   $\mu\text{m}$ .
- Beta beating (rms):  $\sim 2\%/2\%$ .
- Dispersion deviation (std):  $\sim 1.5$  mm.
- Coupling  $< 10\%$
- Optics corrected by sextupole mover

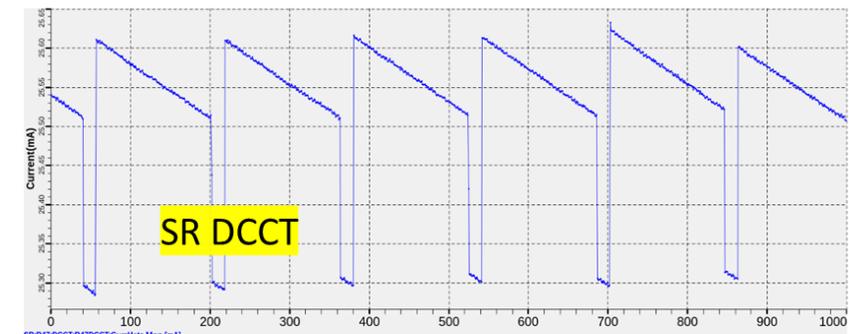
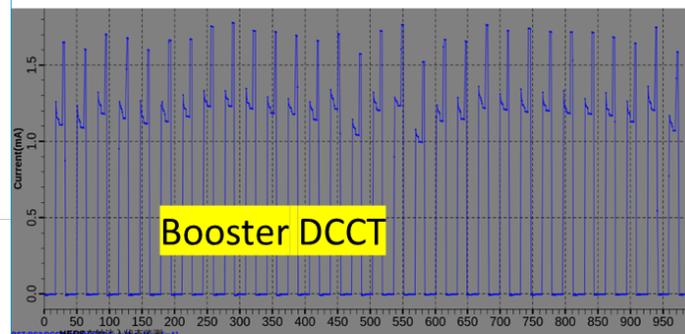
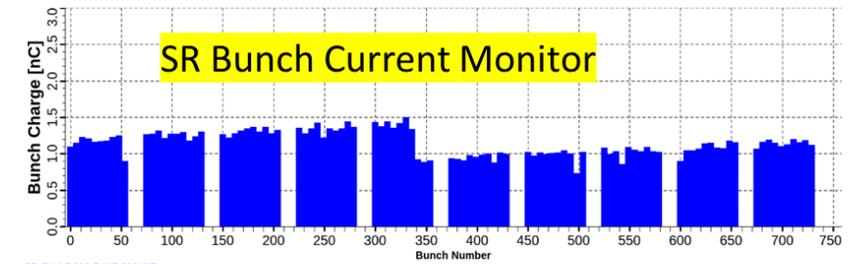
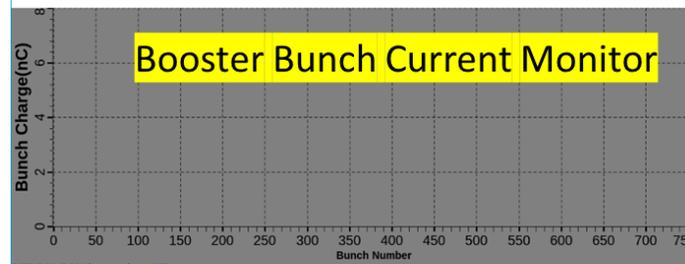


# Top-up injection based on high-energy accumulation in the booster (2025.01)

- 2025.01.02, achieved the world's first successful commissioning and was officially put into operation.
- 2025.09.12, the single-bunch charge of the storage ring exceeded 5nC, meeting the requirements for relevant beamline testing and acceptance.



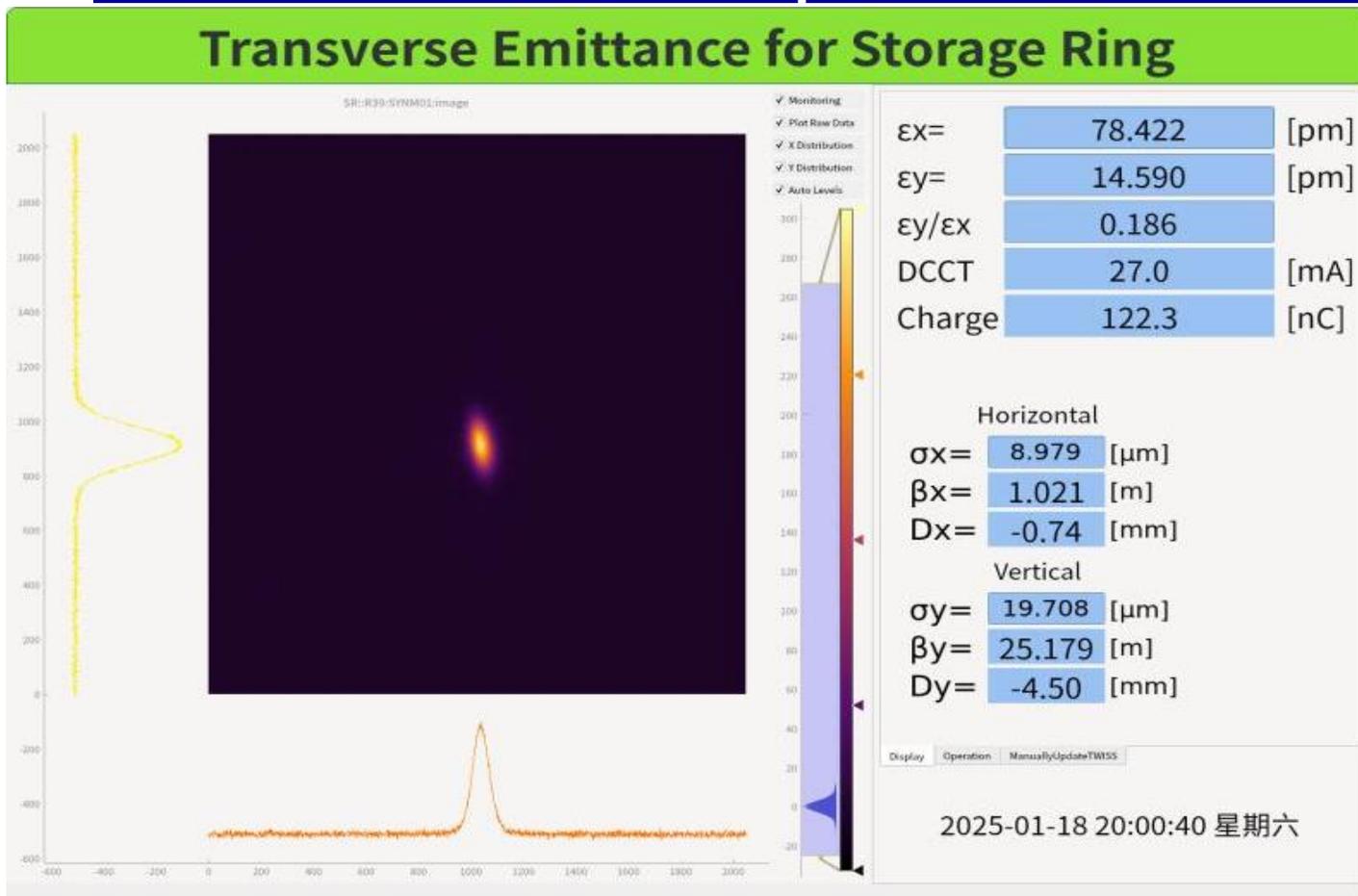
## HEPS Swap-out injection status monitor



Note: transmission efficiency yet to be fully optimized.

# The beam emittance self-test passed the review (2025.03)

The expert panel confirmed that the HEPS storage ring achieved a beam emittance of less than 100 pm·rad at 27 mA and 6 GeV.



国家重大科技基础设施—高能同步辐射光源

## 储存环束流发射度阶段自测试评审意见

2025年3月18日，中国科学院高能物理研究所高能同步辐射光源工程指挥部组织专家（名单附后）在北京怀柔对国家重大科技基础设施“高能同步辐射光源”进行了储存环束流发射度阶段自测试评审。与会专家听取并审阅了高能同步辐射光源储存环发射度阶段自测试测试大纲和测试报告。经过认真讨论、质询，形成意见如下：

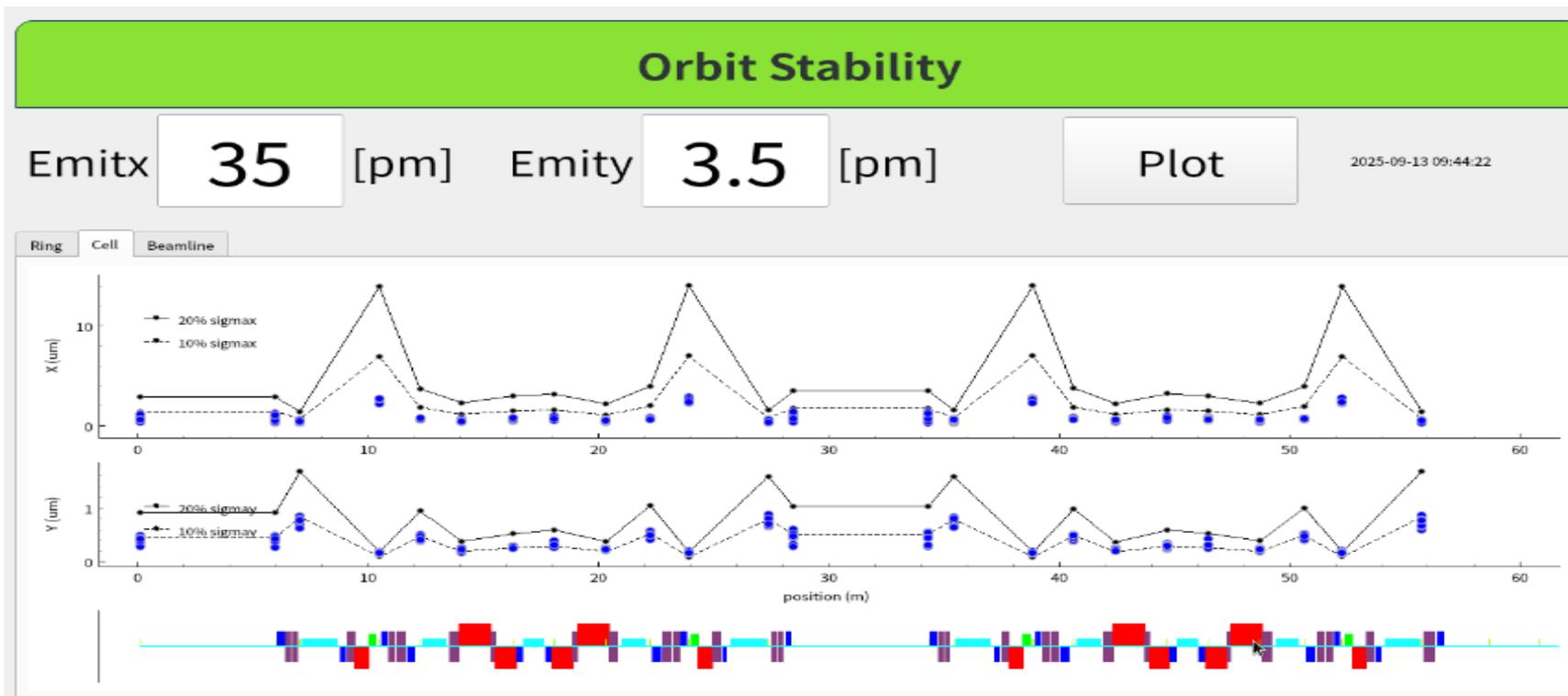
高能同步辐射光源储存环束流发射度阶段自测试方法合理，测试结果真实有效。专家组一致认可 HEPS 储存环在 27mA@6GeV 实现束流发射度小于 100 pm·rad。

专家组组长：

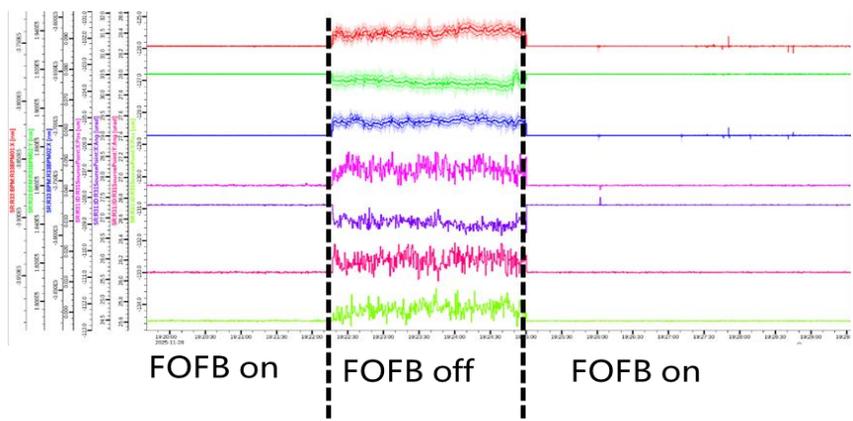
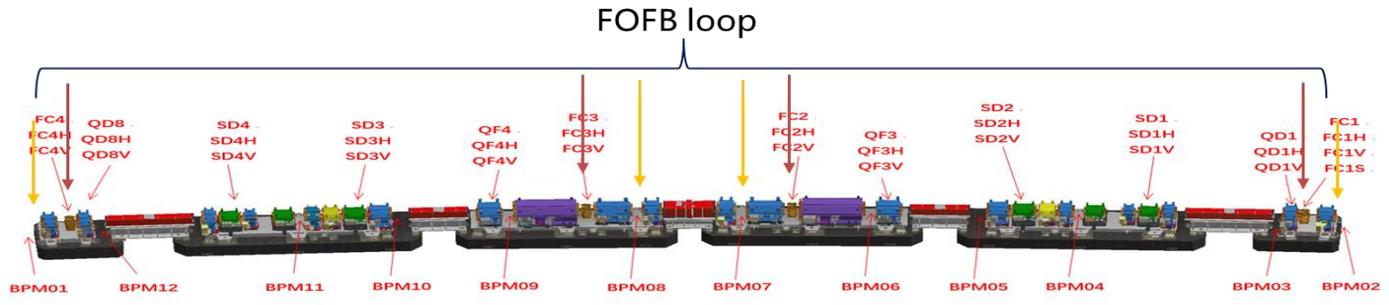
2025年3月18日

# The beam orbit stability of the storage ring improved

- A series of hardware and software optimizations were implemented to improve the beam orbit stability.
- **2025.09:** Achieved at 100 mA
  - Horizontal orbit stability of less than 10% of the bunch size
  - Vertical orbit stability of less than 20% of the bunch size



# FOFB Commissioning and Operation

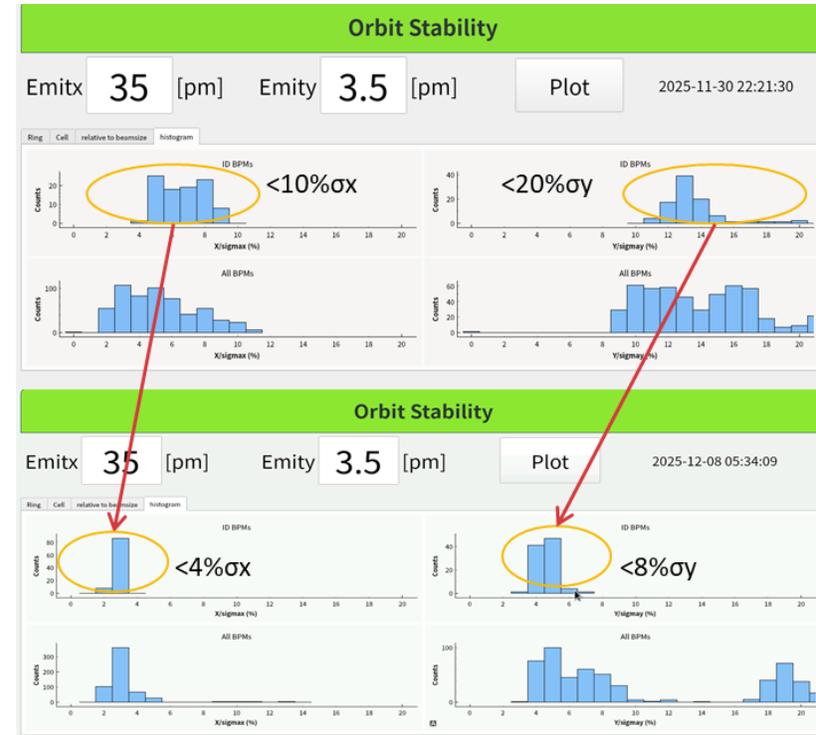


BPM

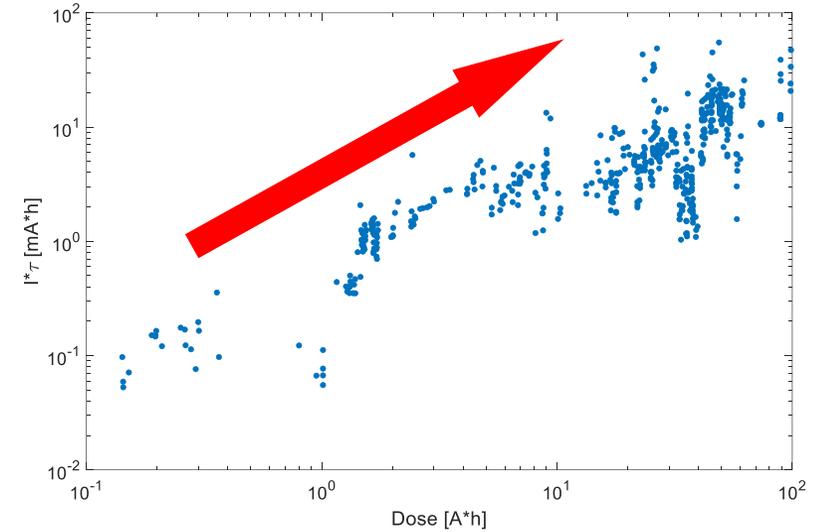
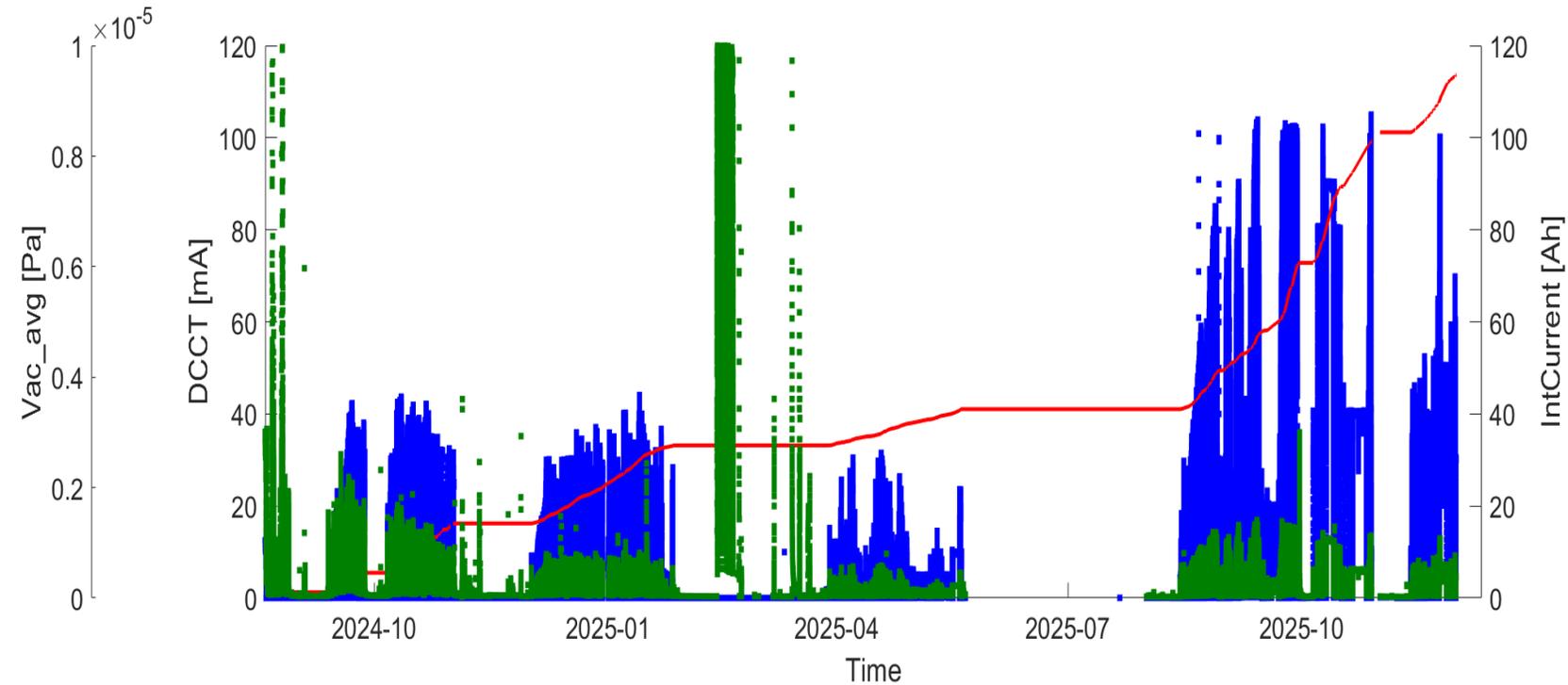
Source Point Orbit and Angle

FOFB off

FOFB on



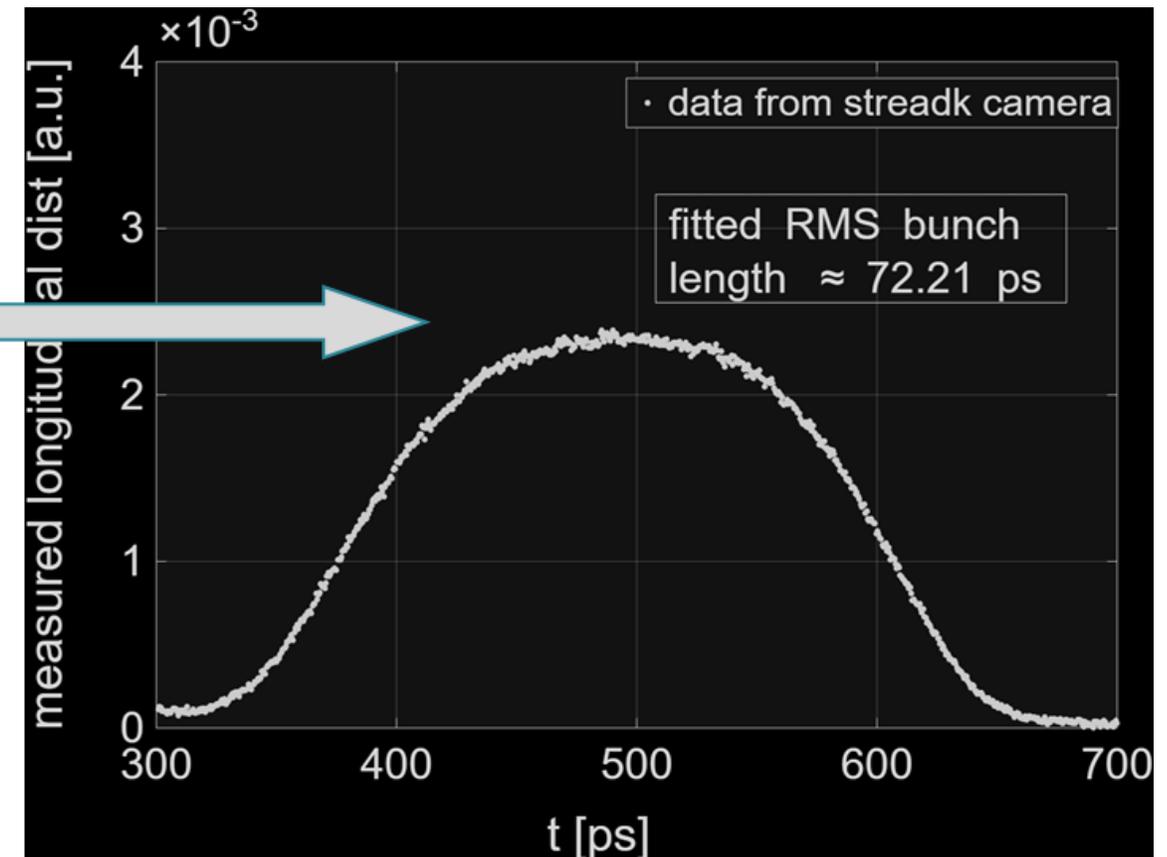
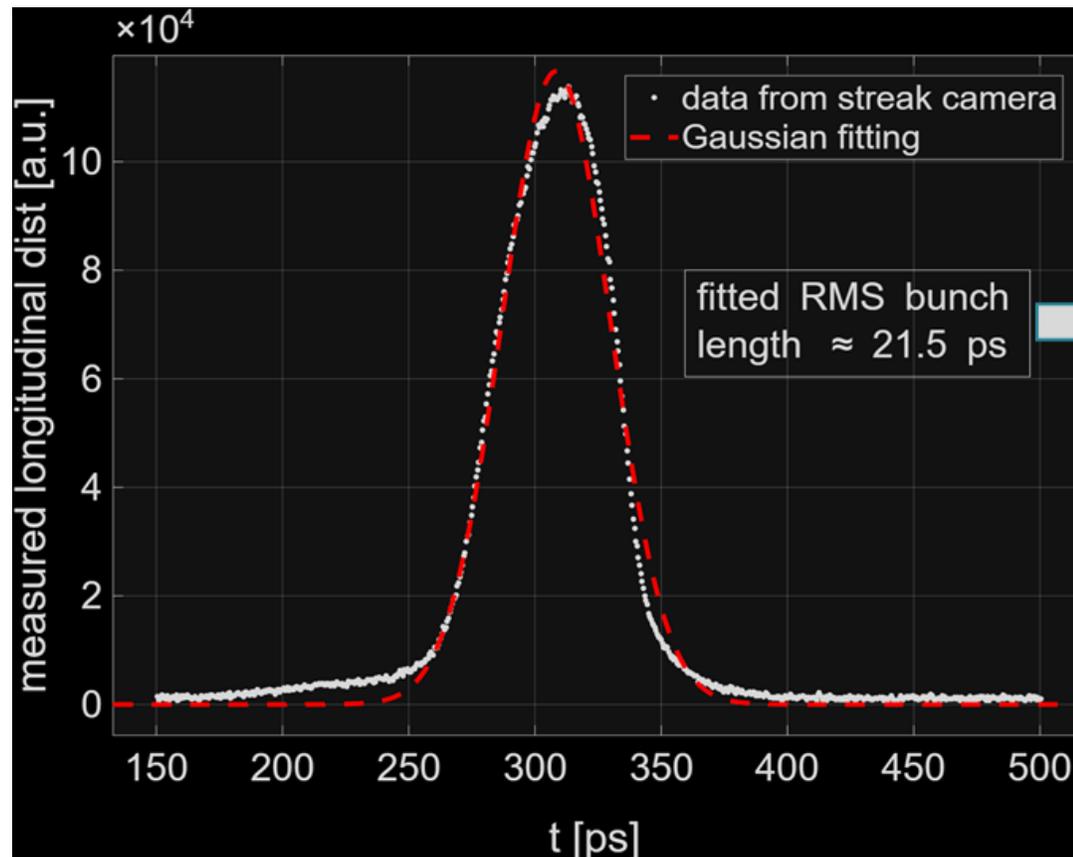
# The vacuum cleaning has exceeded 100 A-h



Normalized total beam lifetime  $I^*_{\tau}$ (mA\*h)

# Commissioning of the third harmonic cavity for beam length stretching

- 08.18, Approximately 3.4-fold beam length stretching was achieved



# Next Beam Tuning – Target: Design Specifications

- Continue optimizing BBA and optics correction;
- Optimize harmonic cavity settings and control strategies to enhance longitudinal stability;
- Increase beam current;
- Improve orbit stability (e.g., SOFB and FOFB operation);
- Perform vacuum cleaning.

- Thanks to BEPCII-U & HEPS Commissioning Team

# Thank you !