HEPS vibration issues

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1. Introduction of HEPS project

Location at Beijing China ： Huairou District

SR & booster Energy ： 6 GeV / 500MeV

Designed natural emittance: 34.82 pm.rad

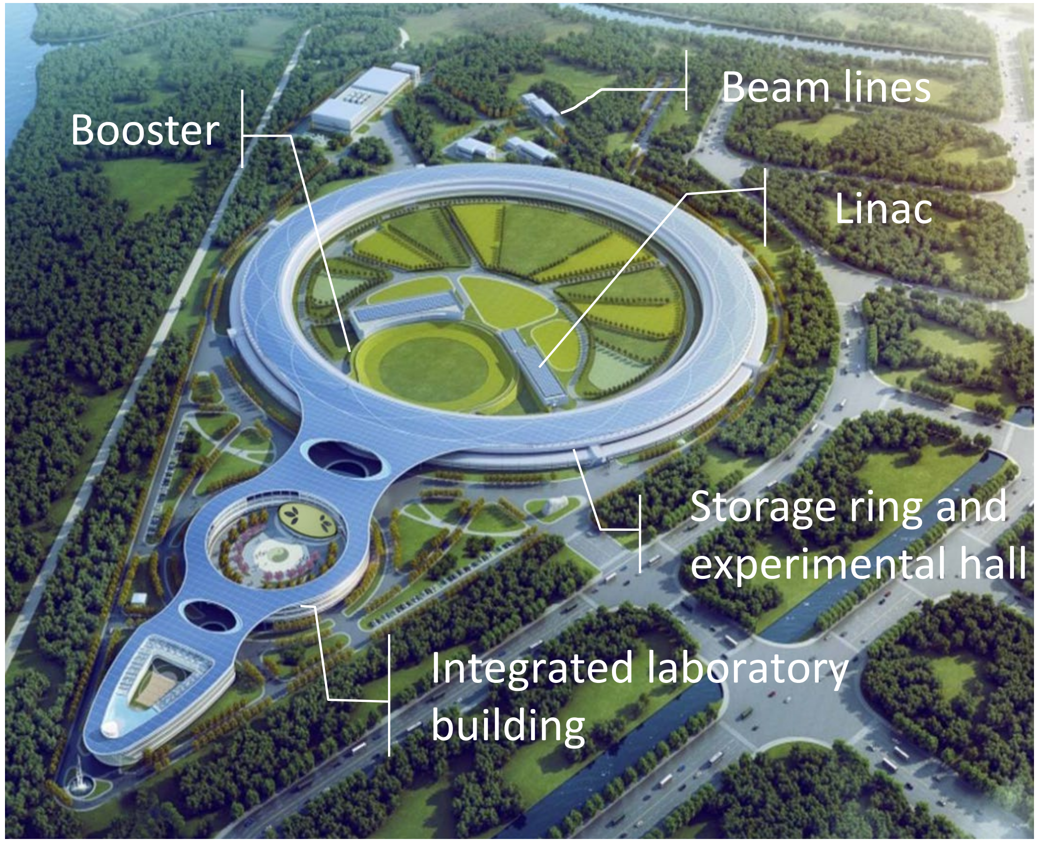
Circumference ： 1360.4 m

Beam current ： 200 mA

Lattice design ： 48 hybrid 7BAs

Phase I beam line number ： 14

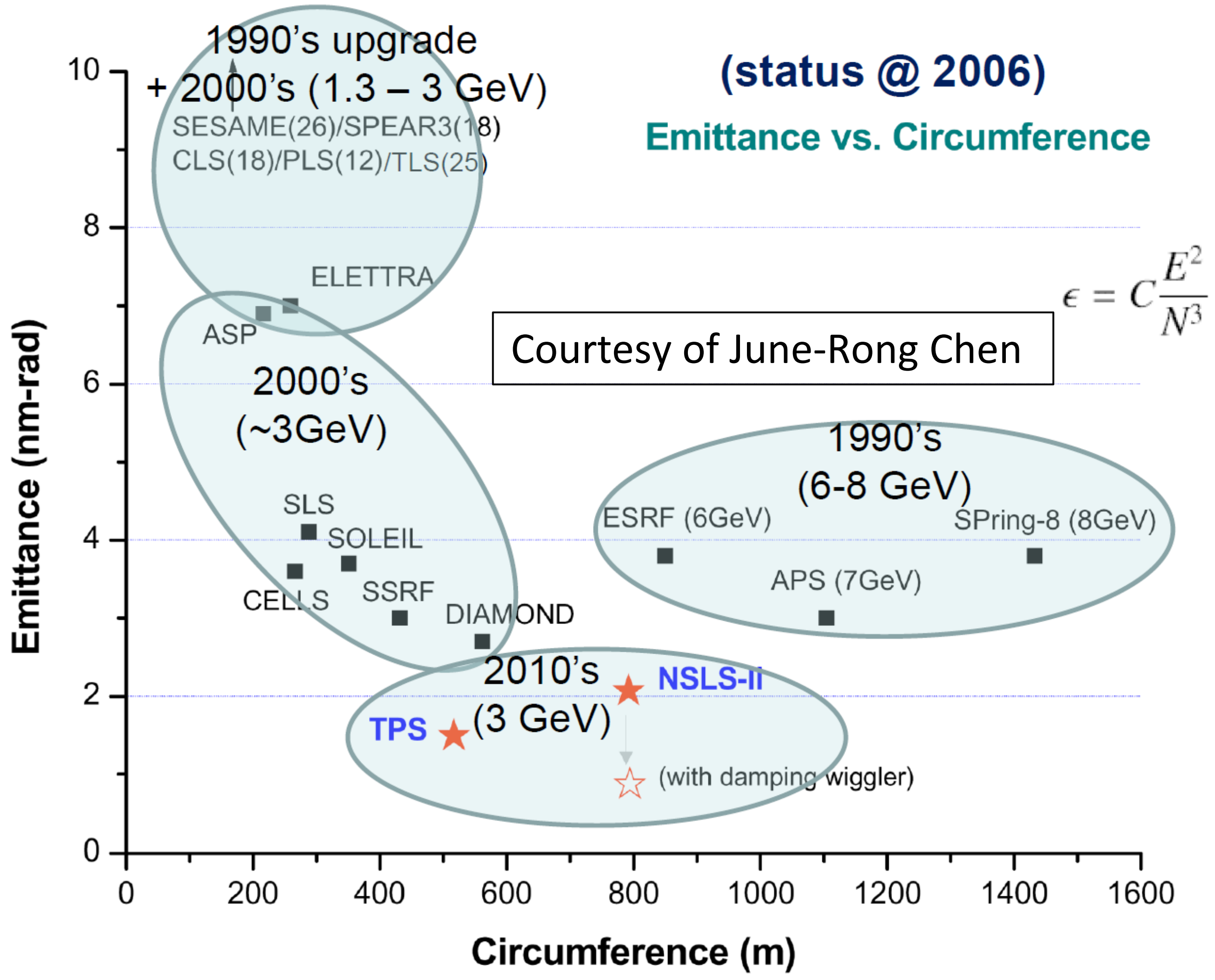
Max beam lines number: ： 90



Duration： 6.5 years （2019/7-2025/12: the SR commissioning started at July. 23th , 2024）

Luminosity： >1×10^{22} photos/s/mm^2/mrad^2/0.1%BW

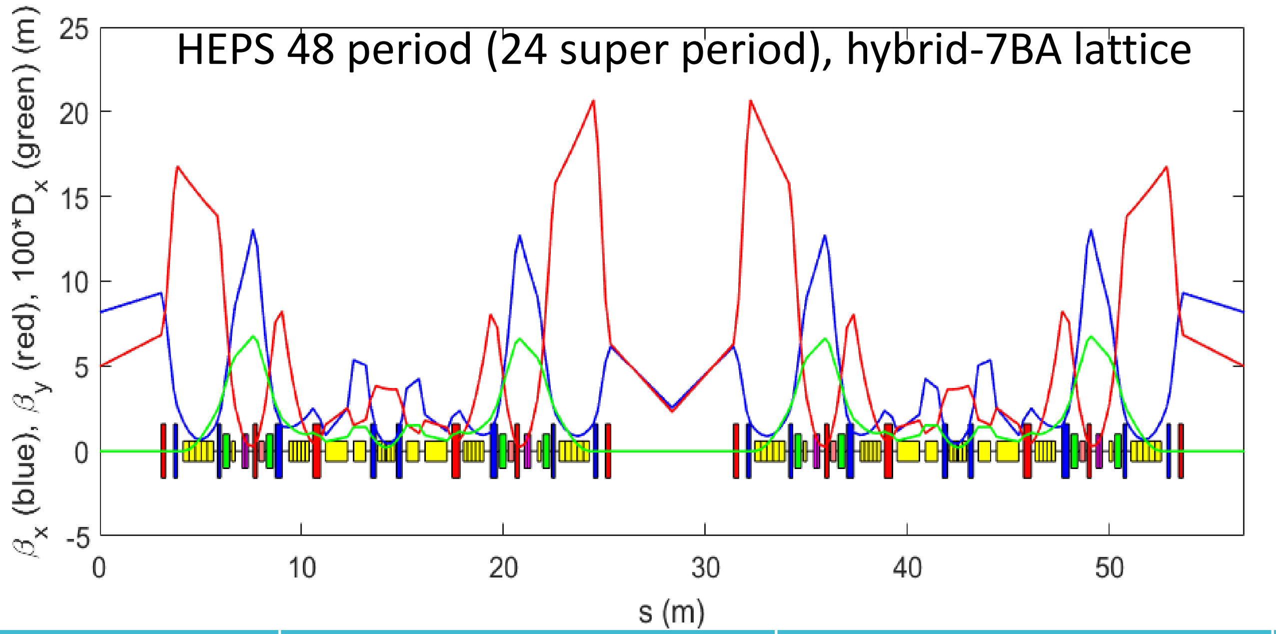
1. Introduction of HEPS project



Partial list of light sources since 2006:

Facility	Energy (GeV)	Emittance (pm.rad)
PETRA III	6	1300
MAX-IV	3	200~330
SIRIUS	3	280
SLS2.0	2.7	131-158
ESRF-EBS	6	120
Spring-8-II	6	108
HALF	2.2	86
APS-U	6	42
HEPS	6	35
NSLS-IIU	3	~25
PETRA-IV	6	20

1. Introduction of HEPS project

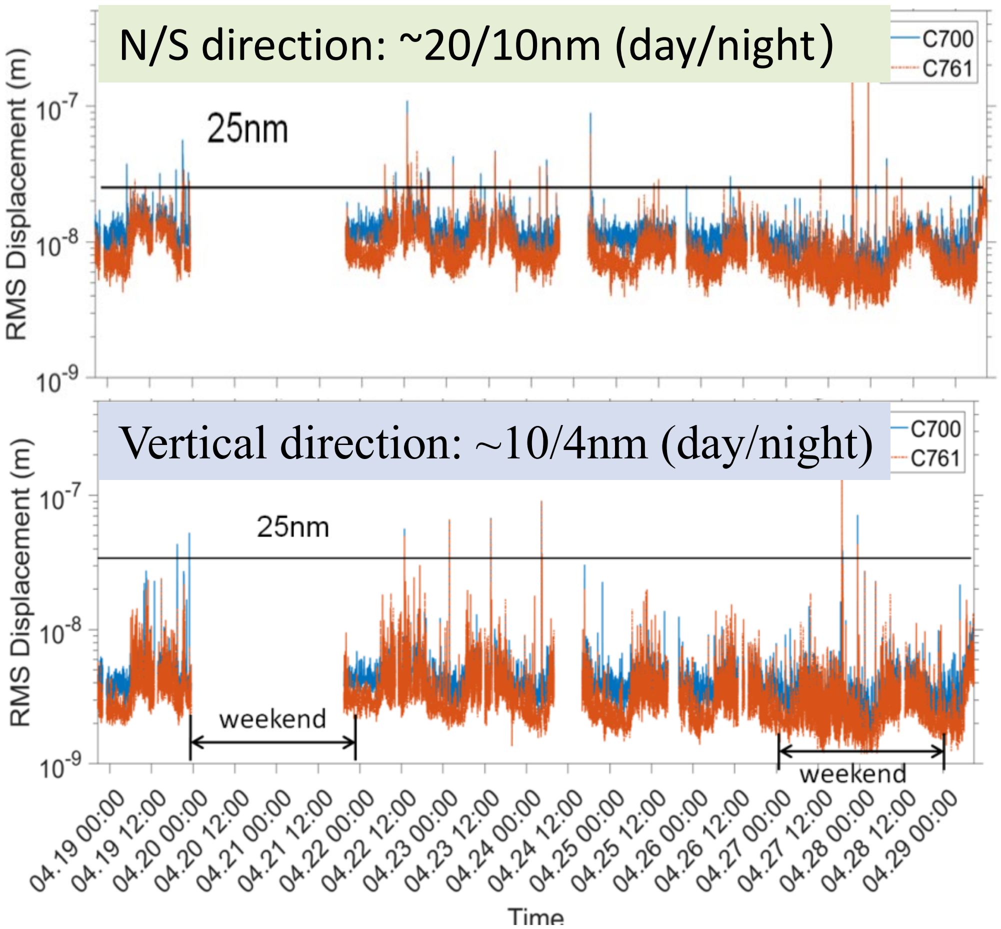


RMS beam size at ID positions	σ_x (μm)		σ_{px} (μrad)		σ_y (μm)		σ_{py} (μrad)	
	H-beta straight	L-beta straight	H-beta straight	L-beta straight	H-beta straight	L-beta straight	H-beta straight	L-beta straight
Storage ring	17	9.4	2.0	3.7	4.5	3.0	0.9	1.3

Basing on the 10% stability requirement of the beam, the beam orbit fluctuation limit:

$\sigma_{\triangle x} < 0.9\mu m$ $\sigma_{\triangle px} < 0.2\mu rad$ $\sigma_{\triangle y} < 0.3\mu m$ $\sigma_{\triangle py} < 0.1\mu rad$

2. Ground motion levels and vibration specifications



Ground motion shows clearly day and night shift.

The HEPS green field vibrations are below 25 nm in all three directions.

Vibration tolerance for slab motion: 25 nm

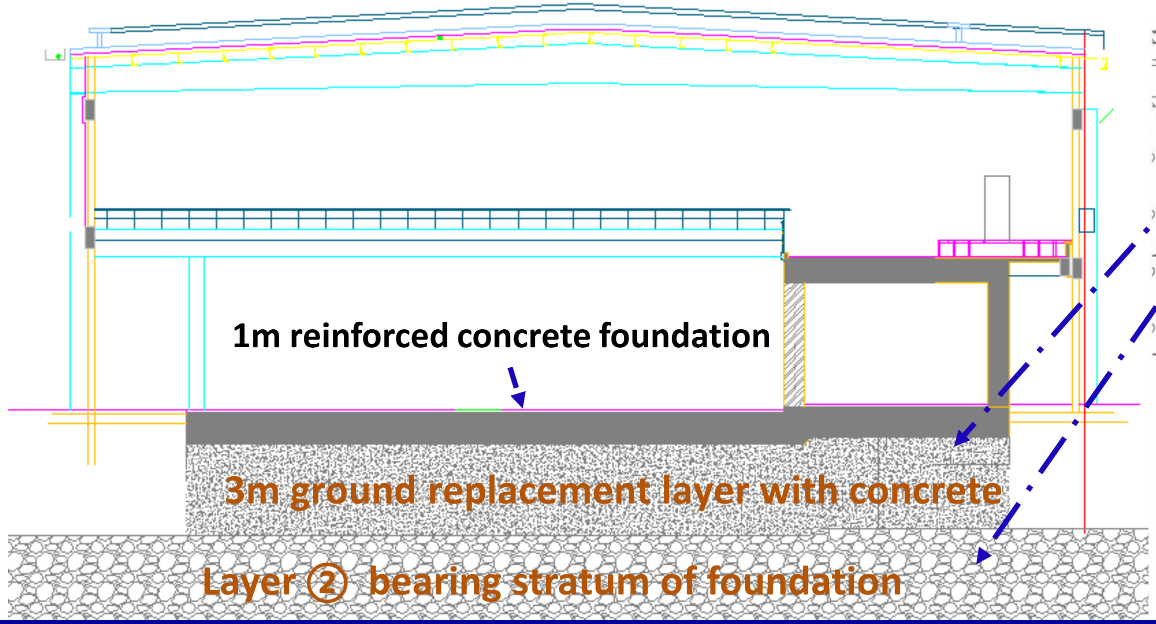
RMS displacement, integrated over 1-100 Hz

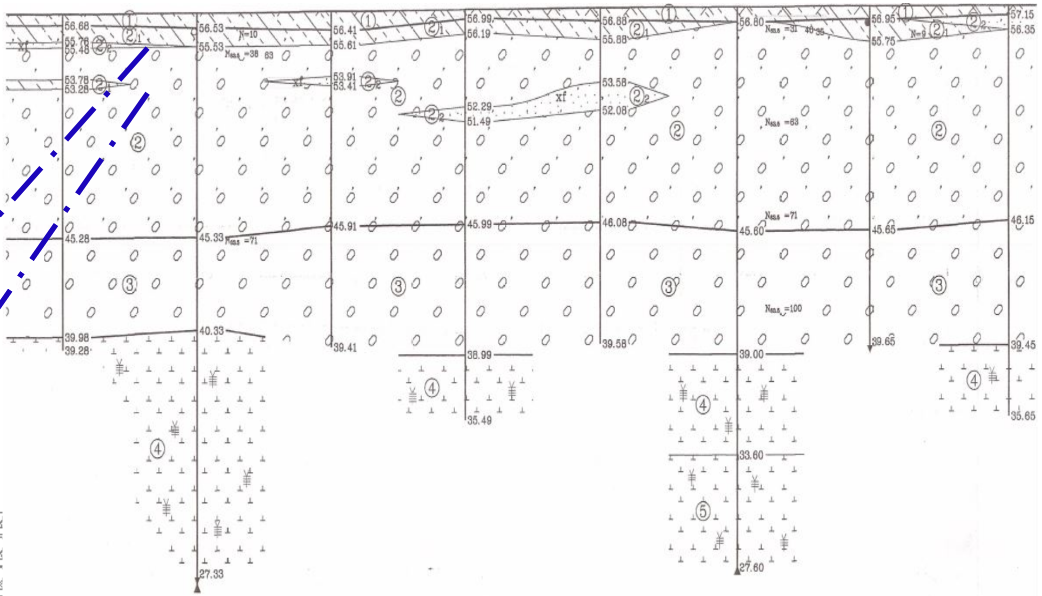
Decomposed Specifications:

Component	Requirement
Support-girder-magnet	Natural freq. **> 54 Hz**, no amplification
BPM girder	Natural freq. **> 54 Hz**, no amplification
SR Slab	No vibration amplification
Vibration sources	Influence on SR slab < 1nm

3. Vibration control performance of the SR slab

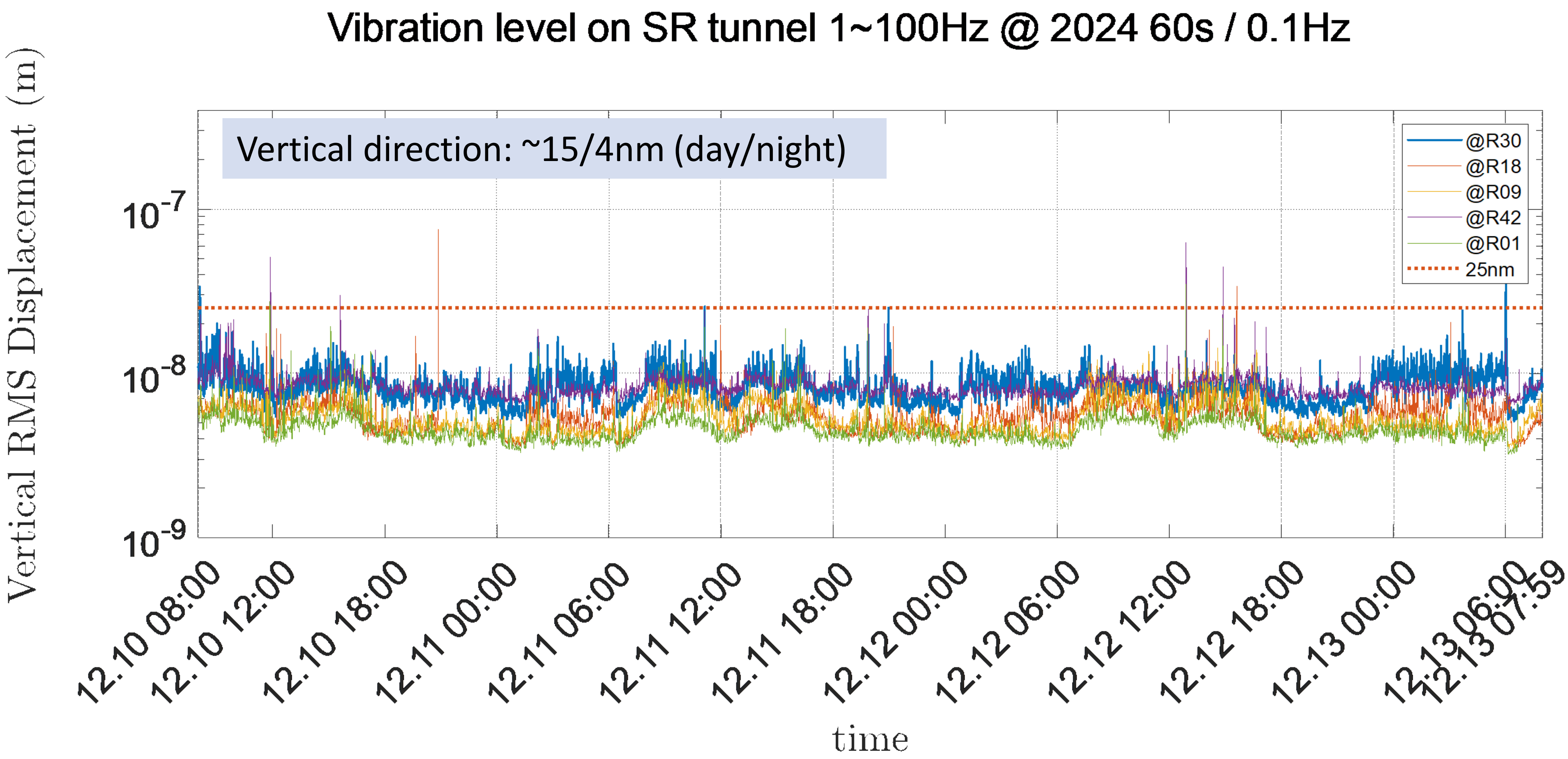
- The foundation-slab design for the SR and experimental hall is an 1m reinforced concrete slab & 3m replacement layer underneath using plain concrete.
- The artificial layer ①， the first cobble layer $②_1$ and part of the newly deposit cobble layer $②_2$ (totally 4m) have been dug out and refilled.



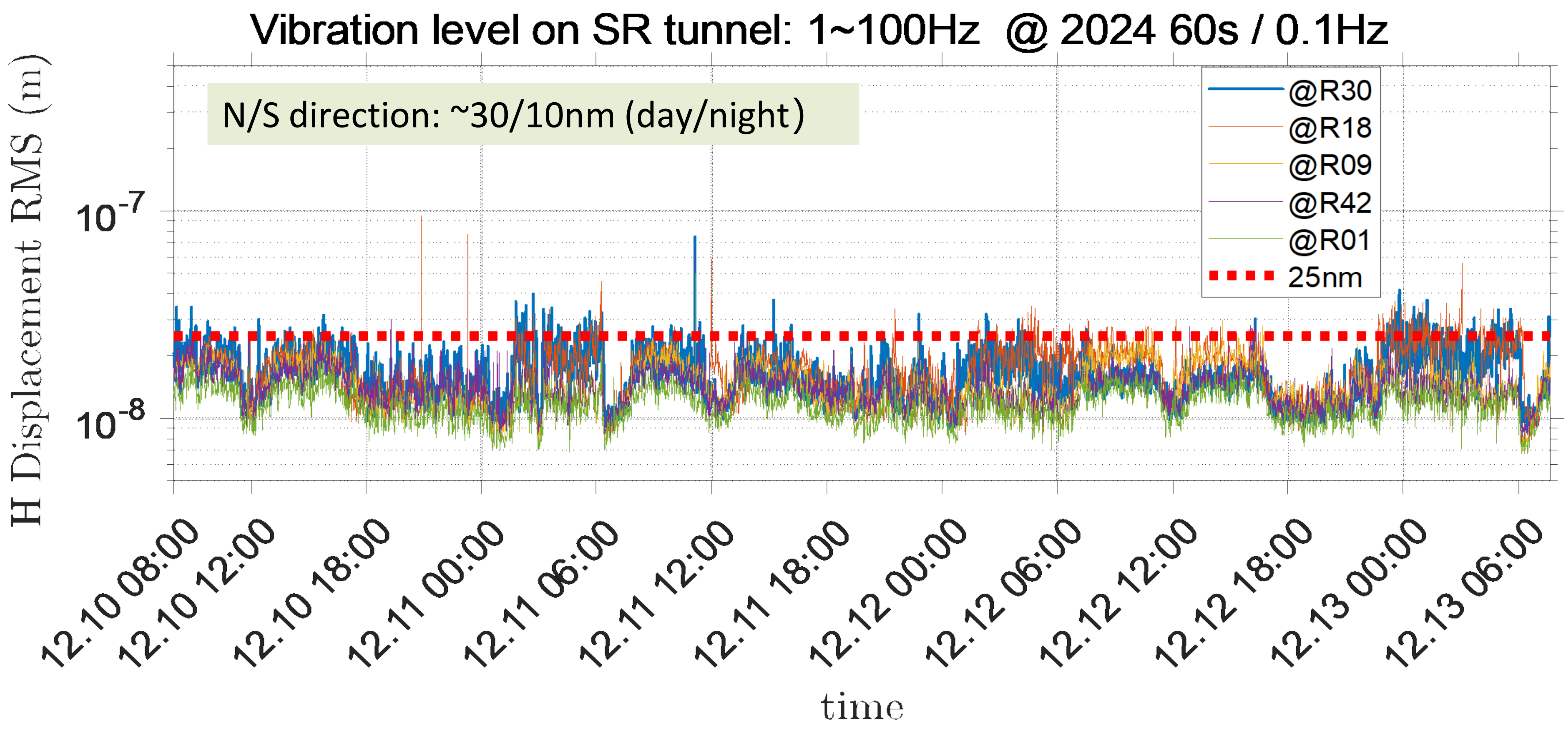


① Artificial fill
$②_1$ Cobble layer
$②_2$ Newly deposit cobble layer
③ Quaternary deposit cobble layer
④ Cobble layer
$⑤_1$ Completely weathered bedrock
$⑤_2$ Strongly weathered bedrock 36.1-45m
⑤ Moderately weathered bedrock

3. Vibration control performance of the SR slab



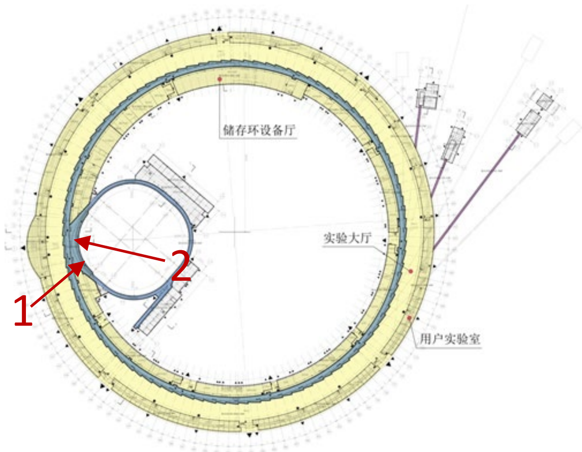
3. Vibration control performance of the SR slab

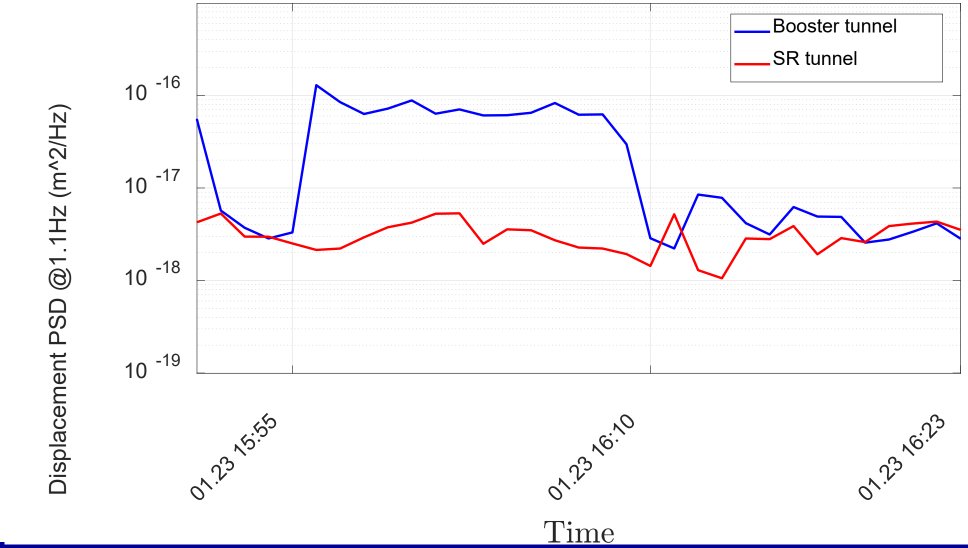


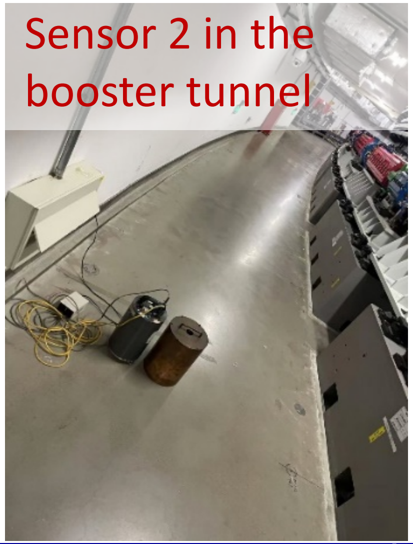
3. Vibration control performance of the SR slab

Detached foundation design between the booster and the SR slab

- Measurement has been done in the HEPS SR and booster tunnel during booster commissioning during year of 2024.
- A 1.1Hz peak appears in booster tunnel but not in SR tunnel;
- The detached foundation design is proved effective.







4. Amplification control performance of Quads/BPM supports

High stability low expansion BPM support

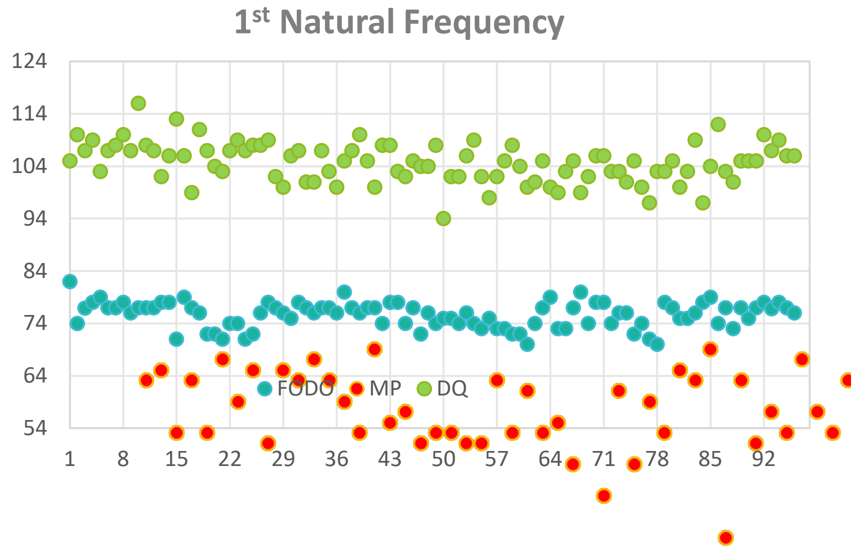
- Carbon fibre (upper half) and invar alloy (lower half) bounded by expoxy-resin & fixed with rivet to give better magnet permeability.
- Grouting at the bottom.
- BPM girder: eigen frequency ≥66Hz, magnification factor ≤1.05
- Thermal stability： **±20nm；** magnet permeability **μ < 1.02** （No magnetic field within 670mm of the beam）

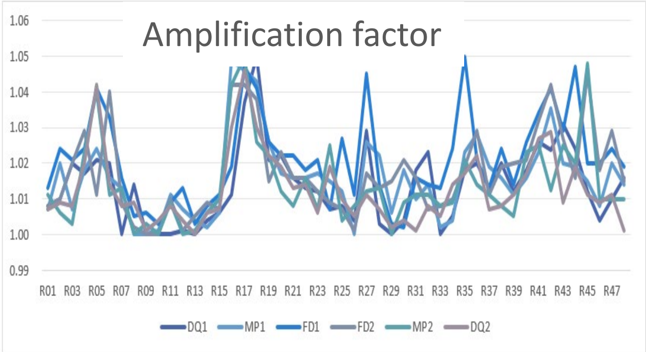
	1st-order freq. （Hz）	2nd-order freq. (Hz）	Horizontal vibration amplification factor	Vertial vibration amplification factor
BPM girder	**66.23**	**88.75**	**1.05**	**1.03**

Courtesy of Sui Yanfeng of IHEP

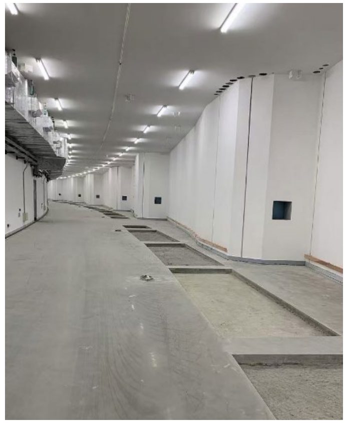
4. Amplification control performance of Quads/BPM supports

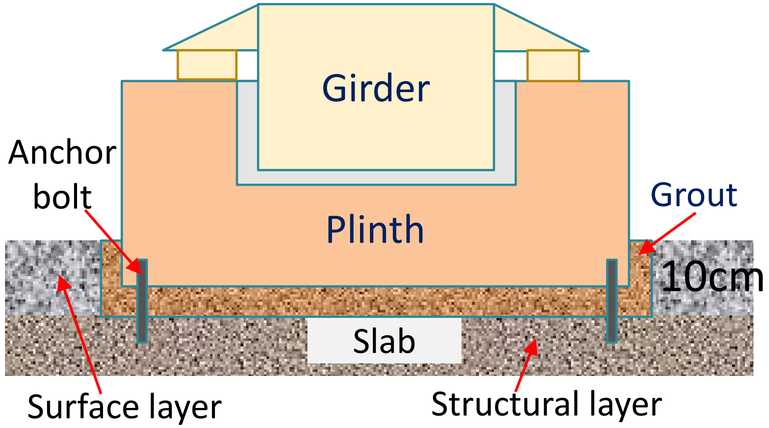
- All 288 support modules have been tested after the alignment in the tunnel, and all meet the requirements.
  - Eigen frequency： ≥70 Hz
  - Transmissibility: ≤1.05

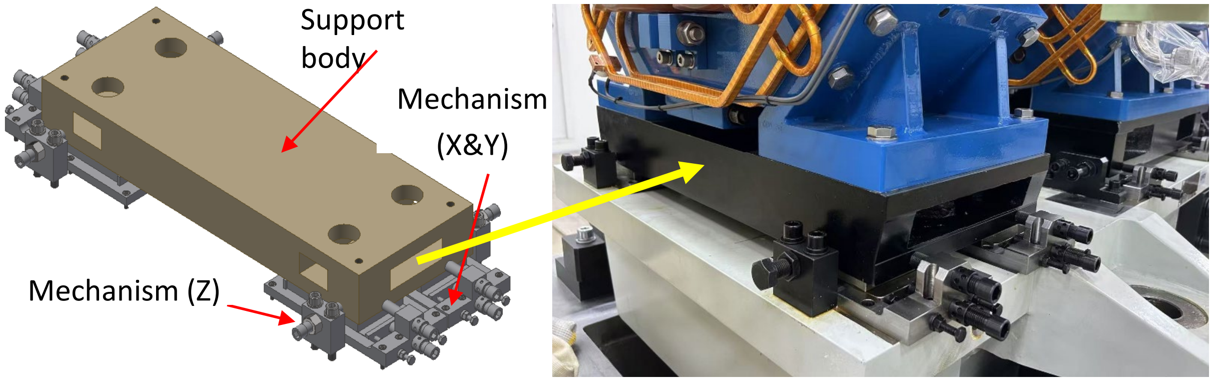




	FD	MP	DQ
Min	70	88	94
Max	82	106	116
Avg	76	100	105







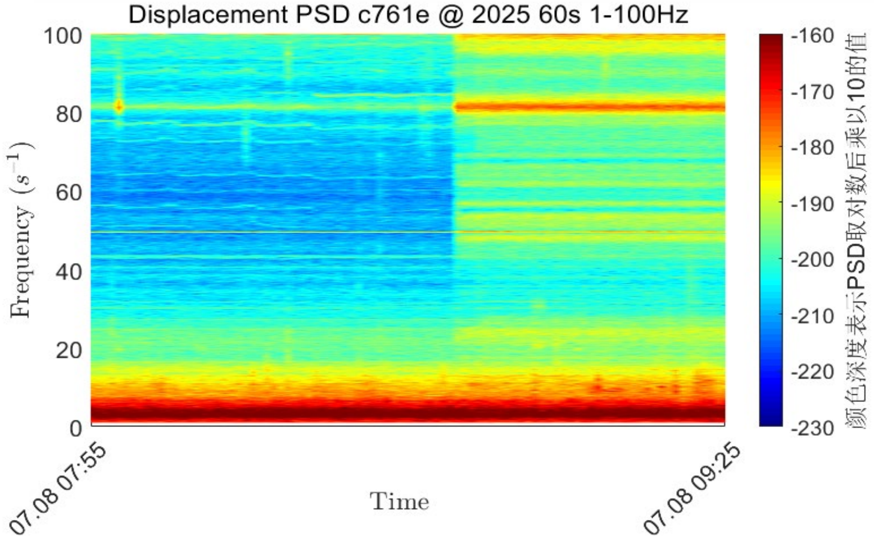
Courtesy of LI Chunhua of IHEP

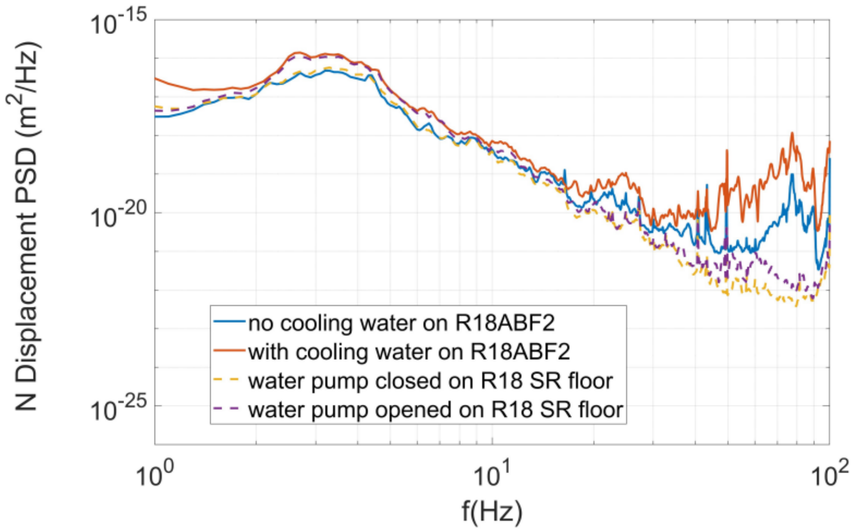
5.Cooling-water vibration control performance in Quads

During a maintenance shutdown, the transfer functions of **all quadrupoles within one lattice period** were measured. The entire process involving **water-flow and no-flow conditions**.

The flow excites broadband vibrations across the 1-100 Hz frequency band.

The magnet spectrum exhibits a natural frequency of 80 Hz and it is enhanced during pump activation.





5.Cooling-water vibration control performance in Quads

Table 1. The magnification factor of quadrupole magnet and FC vibration relative to ground motions and the BPM vibrations relative to girder motions. Ratios are evaluated from RMS vibration displacement integrated over 1–100 Hz.

Sensor position	Horizontal w/o WC (nm)	Amp. F	w/ WC (nm)	Amp. F	Vertical w/o WC (nm)	Amp. F	w/ WC (nm)	Amp. F
R18QD1	20	1.2	21	1.2	6.7	1.0	7.2	1.1
R18QD2	19	1.1	20	1.1	7.3	1.1	7.9	1.2
R18QD3	20	1.2	21	1.2	7.4	1.1	8.0	1.2
R18QD4	19	1.1	20	1.1	6.9	1.0	7.5	1.1
R18QD5	18	1.1	19	1.1	6.6	1.0	7.1	1.1
R18QD6	18	1.1	19	1.1	6.6	1.0	7.2	1.1
R18QD7	18	1.1	19	1.1	6.6	1.0	7.2	1.1
R18QD8	18	1.1	19	1.1	6.6	1.0	7.3	1.1
R18QF1	20	1.2	21	1.2	7.4	1.1	8.0	1.2
R18QF2	20	1.2	22	1.2	7.3	1.1	8.0	1.2
R18QF3	19	1.1	20	1.1	7.1	1.0	7.7	1.2
R18QF4	18	1.1	19	1.1	6.7	1.0	7.3	1.1
R18QF5	-	-	10*	1.0	-	-	5.0*	1.3
R18QF6	-	-	11*	1.1	-	-	5.0*	1.3
R18BD1	19	1.1	20	1.1	7.0	1.0	7.6	1.2
R18BD2	16	1.0	20	1.1	6.6	1.0	8.0	1.2
R18ABF1	19	1.1	22	1.2	7.0	1.0	7.7	1.2
R18ABF2	19	1.1	21	1.2	6.6	1.0	7.7	1.2
R18ABF3	17	1.0	20	1.1	7.2	1.0	8.1	1.2
R18ABF4	19	1.1	20	1.1	7.1	1.0	7.6	1.2
R18FC2	19	1.1	20	1.1				
R18BPM01	-	1.1	-	1.2	-	-	-	-
On slab	17	-	18	-	5.9	-	6.6	on Day one
On slab	-	-	10*	-	-	-	3.9*	on Day two*

*Noted:The data marked with stars were collected on Day two, whereas the remaining data were obtained on Day one.

Magnification factors under magnet water-cooled operating conditions

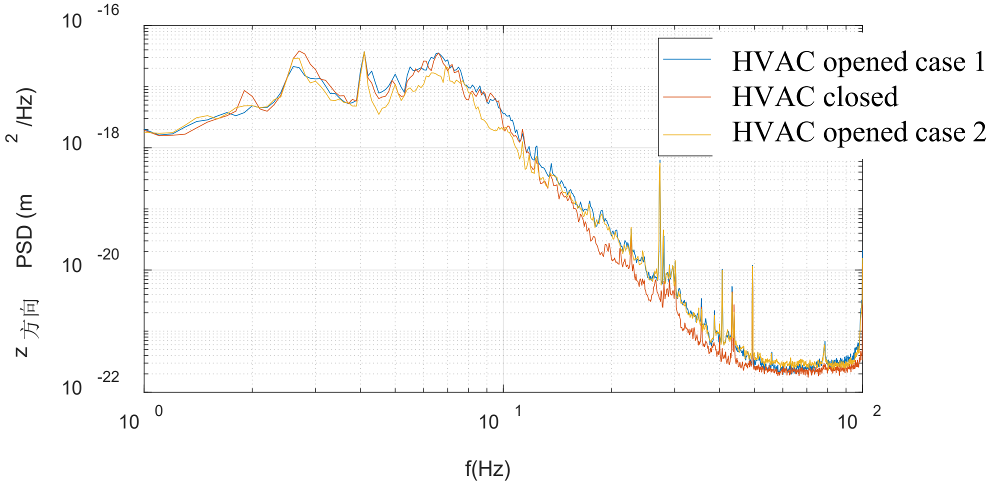
- The vibration level increases after the cooling water is circulated.
- The corresponding magnification factors ranging from **1.0~1.3**.

For **quadrupole** magnets operated **without cooling water**, the vibration magnification factors (relative to ground motion) along the horizontal and vertical axes remain consistently within the range of **1.0 to 1.2**.

6. Vibration control performance against internal & external sources

Vibration impact of the utilities in HEPS

HVAC room	Sensor position (in SR tunnel)	f (Hz)		RMS
4#	Blow SR BMag.	15-100Hz	z	0.7nm
			n	0.4nm
6#	Close to SR wall	8-100Hz	z	1.4nm
			n	0.6nm
7#	Close to SR wall	12-100Hz	z	0.9nm
			n	0.6nm
8#	Close to SR wall	11-100Hz	z	1.1nm
			n	0.6nm
9#	Blow SR BMag.	10-100Hz	z	0.8nm
			n	0.6nm
10#	Blow SR BMag.	12-100Hz	z	1.0nm
			n	0.4nm

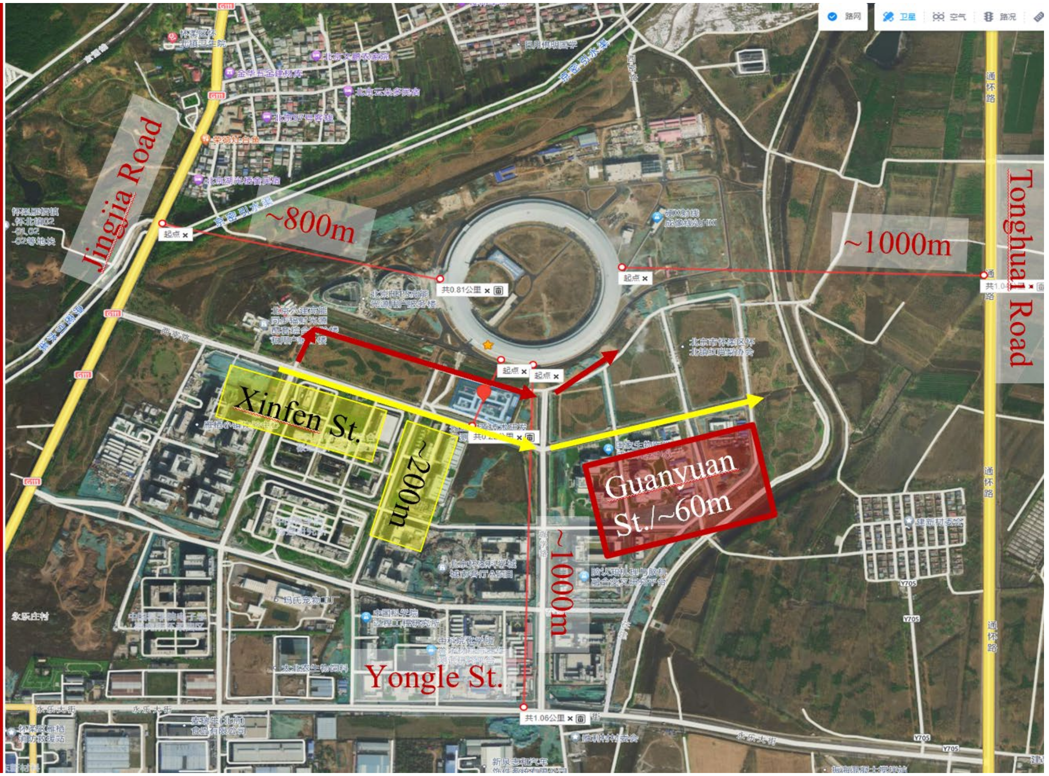


WC Pump room	Sensor position (in SR tunnel)	f (Hz)		RMS
2#	Blow SR BMag.	10-100	n	1.2nm
2#	Blow SR BMag.	10-100	z	2.1nm
6#	Blow SR BMag.	13-100	z	1.0nm
			n	0.8nm
7#	On girder of SRR42ABF3	8-100	z	4.4nm
			n	4.0nm

6. Vibration control performance against internal & external sources

- There are 3 major road around HEPS campus, which is 800-1000 meters away;
- The closest is Guanyuan (GY) St., which is ~60m away;
- Xinfen St. is further than GY St. which is about 200m away

HEPS surrounding transportation



Traffic Regulations (approval process is under way)

No trucks (≥ 4.5 t) on Guangyuan St.

No trucks (≥ 4.5 t) on Xinfen St. starting from the intersection of Guangyuan St.

⚠ **Key Observation:**

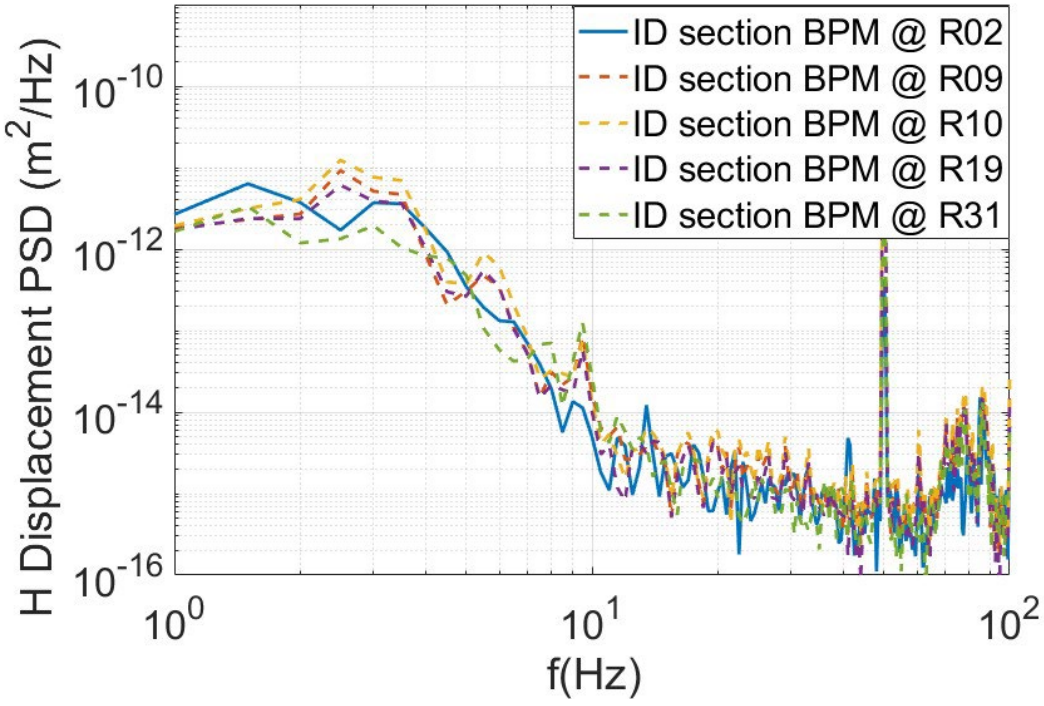
The vibration level still increased compared with the bare ground test results before construction.

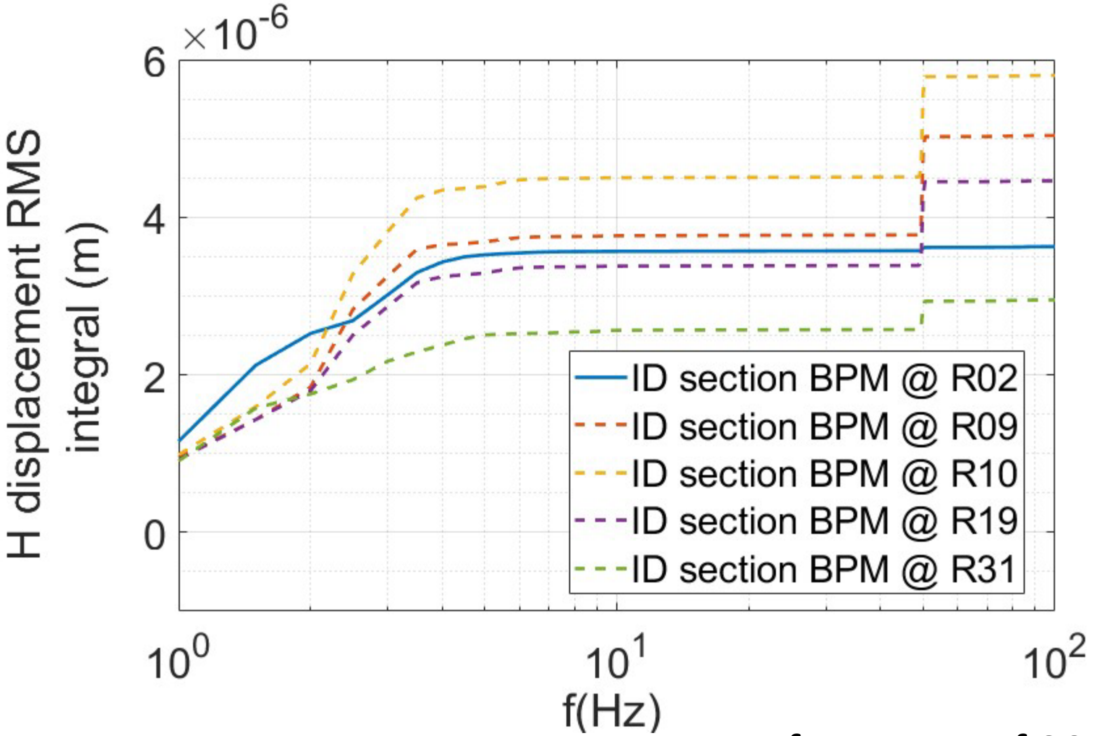
Surrounding culture noises are the major contribution.

Over the past six years, extensive construction of buildings and infrastructure for neighbouring institutions has emerged in the vicinity of the HEPS site.

7. Beam instability mitigation and stability performance

During the commissioning phase of the HEPS storage ring, low-frequency electron beam fluctuations were observed from BPMs with RMS integral of few micrometers starting from 1Hz up to 4Hz.

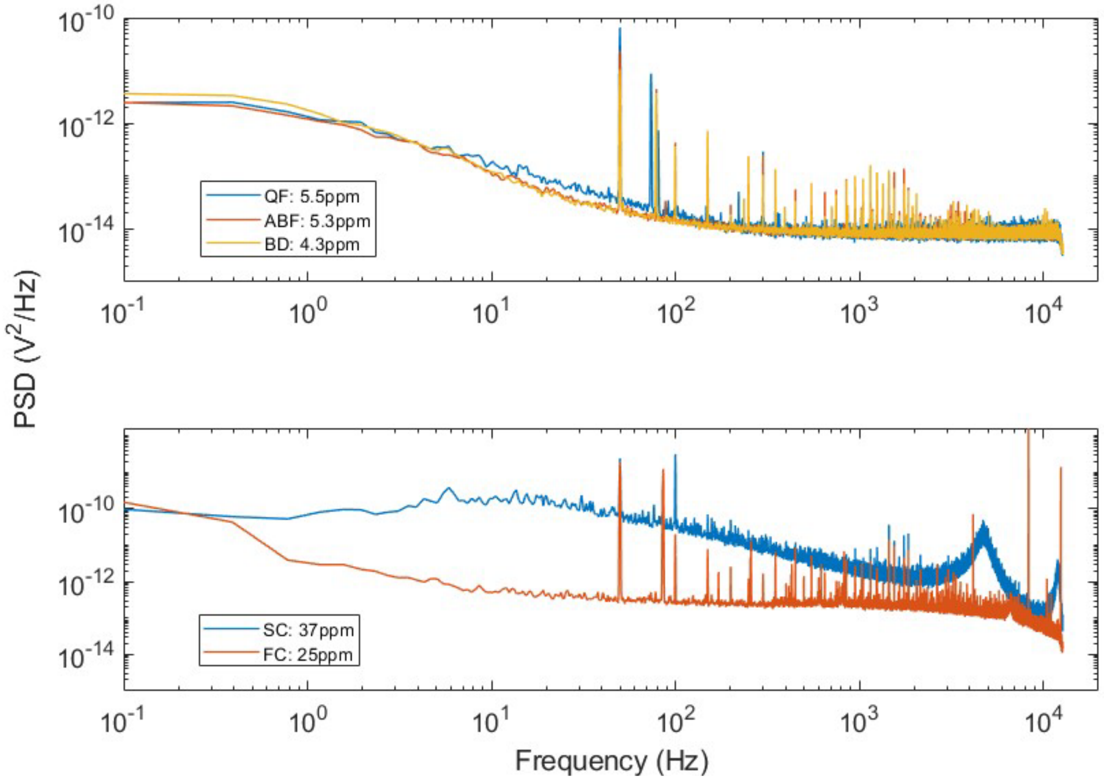




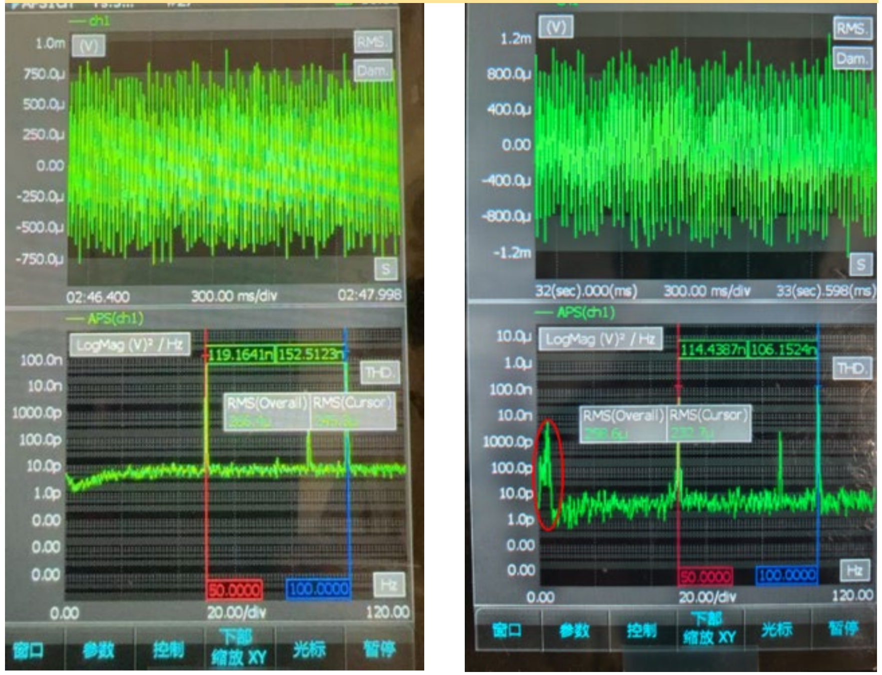
Data from May of 2025

7. Beam instability mitigation and stability performance

- To identify the source, a series of vibration measurements were performed which traced the disturbance back to the ripple noise of the slow corrector (SC) PS.
- A PWM frequency detuning strategy was adopted, which effectively suppresses low-frequency noise.
- Within a single cell, the PWM frequencies of the second and subsequent correctors along the beam direction are sequentially adjusted following an arithmetic sequence with a common difference of -20 Hz.



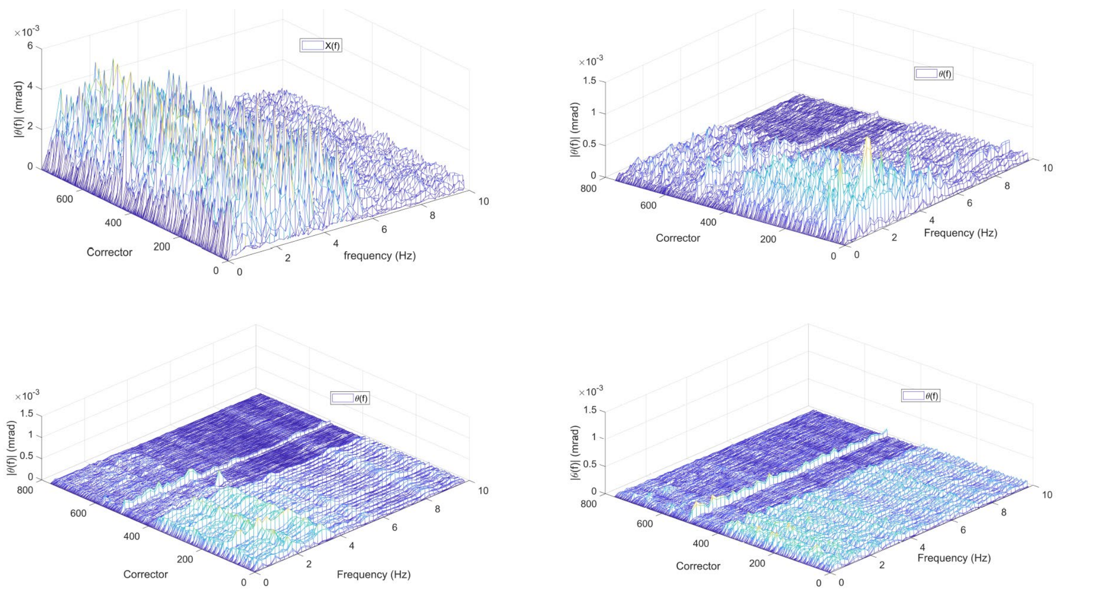
Power supply ripple of one SC with and without PWM frequency tunning

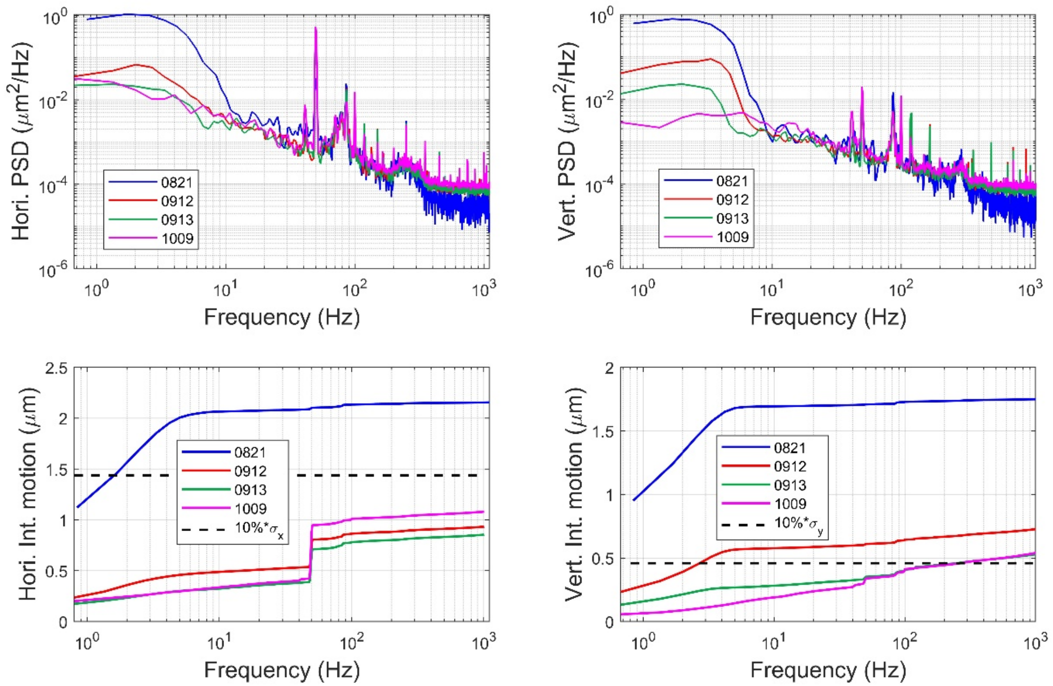


A paper has been submitted to NIM-A (under review) presents the logic, methodology, and experimental results of the troubleshooting.

7. Beam instability mitigation and stability performance

- Low-frequency power supply ripple of correctors at different stages: initial beam commissioning stage (top left), simple modification (top right) , more targeted modifications to SD2V/3V/4V (bottom left) , after complete optimization (bottom right) .
- After eliminating these ripples, beam stability improved significantly: horizontal orbit fluctuation decreased from approximately 3-4 μm to 0.5 μm, and vertical orbit fluctuation from 1-2 μm to below 0.5 μm.





7. Beam instability mitigation and stability performance

Slow Corrector Optimization

Courtesy of CUI Xiaohao. IAC 2026 report

The Breakthrough (August 2025)

The SC corrector PWM frequency was systematically adjusted and optimized .

This change dramatically suppressed the low-frequency orbit oscillation.

Technical Details

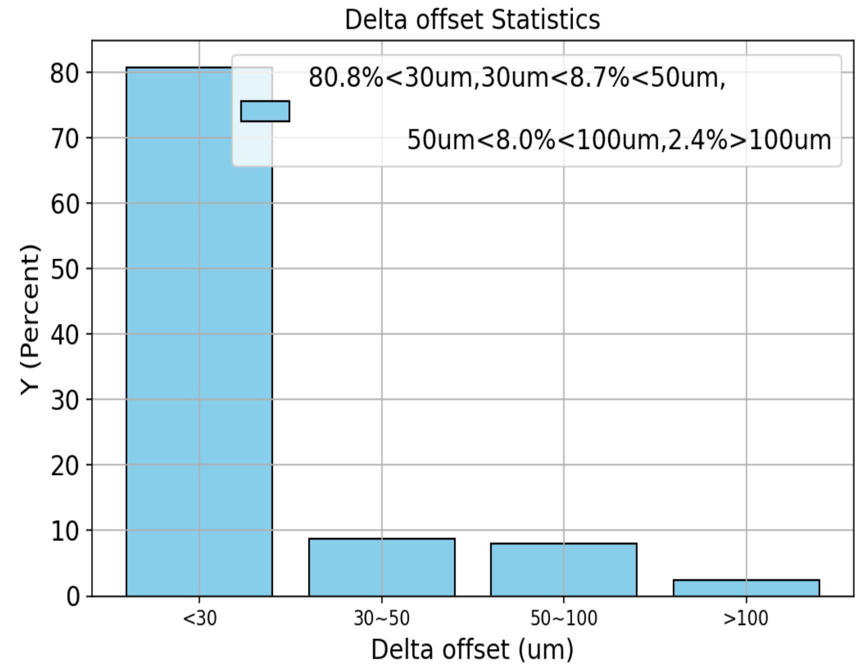
The PWM frequency adjustment shifted the power supply's noise spectrum away from the sensitive low-frequency band.

Result: 10x reduction in orbit drift amplitude.

Impact on BBA

Improved orbit stability directly translated to dramatically improved BBA repeatability .

Post-optimization measurements showed significantly higher consistency.

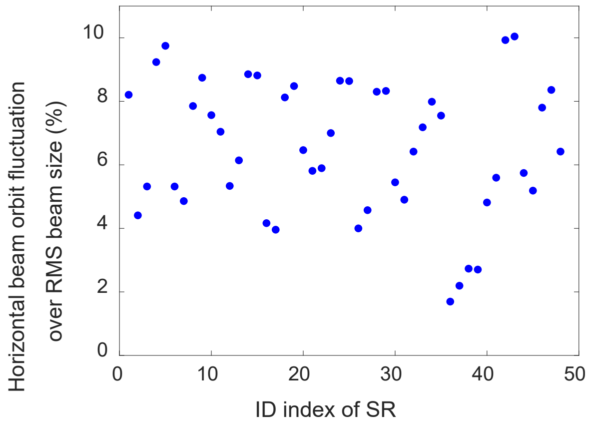


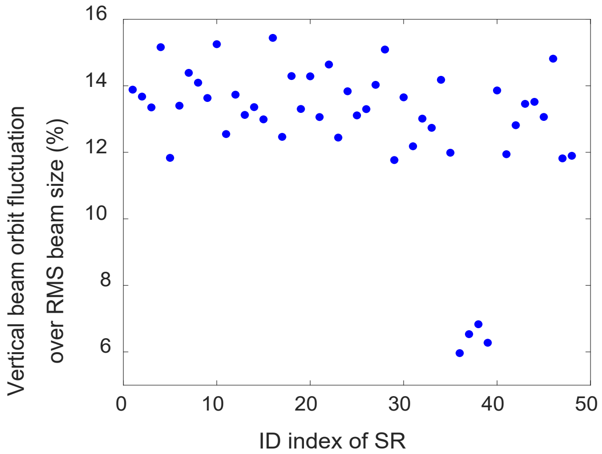
Achievement

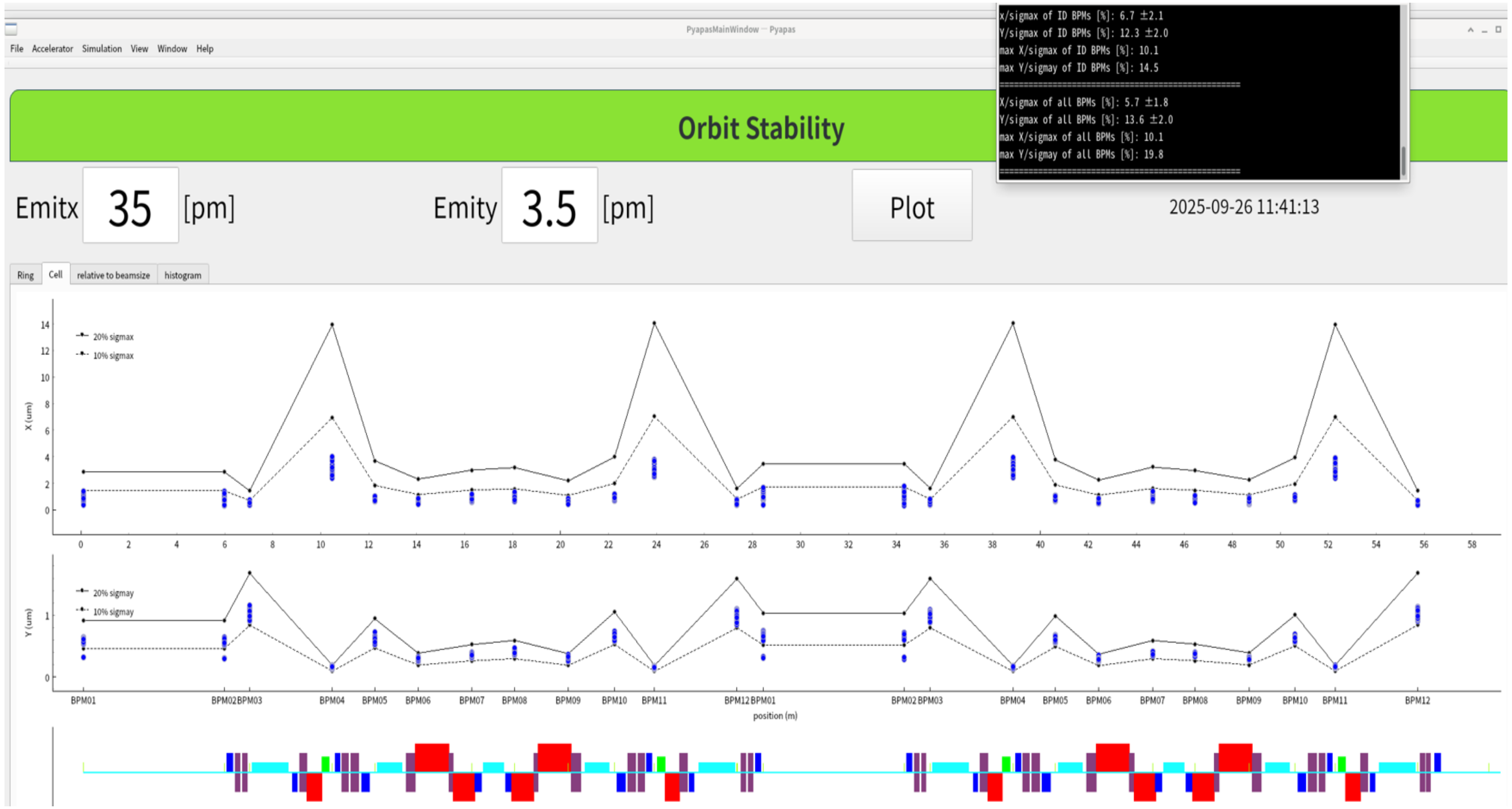
Precision <30μm	**>80%**
Repeatability	**Excellent**

7. Beam instability mitigation and stability performance

HEPS successfully passed its on-site key performance tests on last Sep. At the insertion device (ID) positions, the measured beam stabilities are maintained below 14.5% vertically and 10.1% horizontally over a 0.1-500Hz bandwidth without any orbit feedback on basis of a 10-second BPM data samples.







8. Summary

Achievements

- HEPS is a **4th generation** light source with designed natural emittance of **35 pm·rad.**
- The vibration specification is set to be **25 nm** with decomposed requests to the SR slab, girder-magnet assembly, BPM girder (>54 Hz, no amplification). Additionally, internal and external vibration perturbations imposed on the SR slab shall not exceed 1 nm.
- Vibration disturbances induced by utility systems on the storage ring slab are mostly kept below 1 nm. No truck with load higher than 4.5 tons are permitted on adjacent St.
- All other decomposed specifications have been fully satisfied.
- SC power supply ripple optimization achieved **ten times of stability improvement.**
- Key performance tests **passed** in September 2025 with beam stability <20% without any orbit feedback (vertically below 14.5% and horizontally below 10.1% at the ID positions).

Remaining Challenges

- Vibration level still **increased** comparing with the bare ground test results before construction. **Surrounding culture noises are** the major contribution.

Thanks for your attention!