IPAC 17th International Particle Accelerator Conference
IPAC26

Development Progress of the SHINE Accelerator

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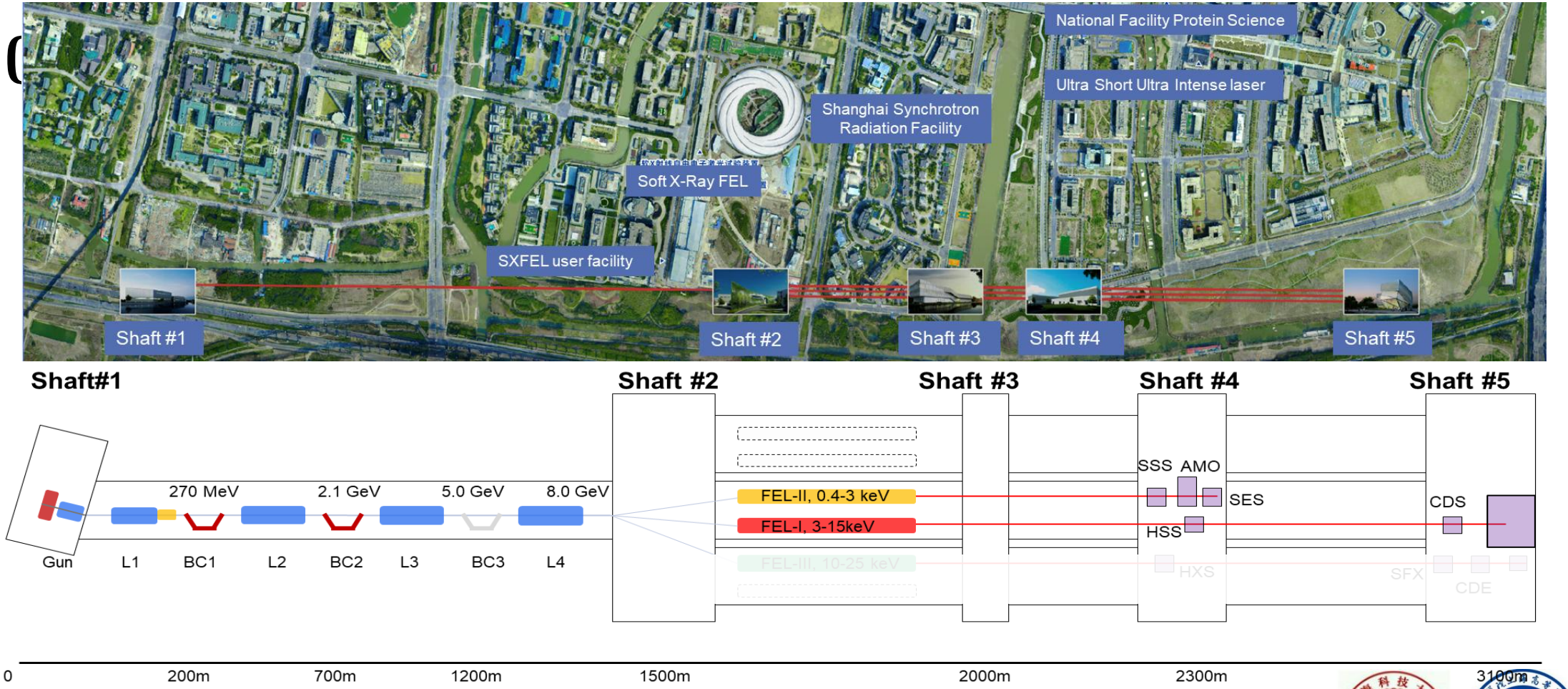
Shanghai Advanced Research Institute, CAS
2026.05.19

2026 May 17 - 22
Deauville | Normandy | France

SHINE: Shanghai Hard X-ray FEL Facility

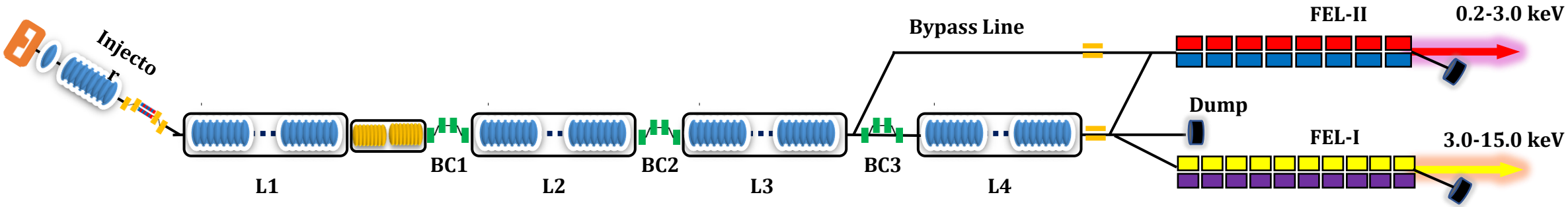
Shanghai HIgh repetitioN rate XFEL and Extreme light facility



Being developed by Shanghai-Tech Univ., SARI and SIOM of CAS.

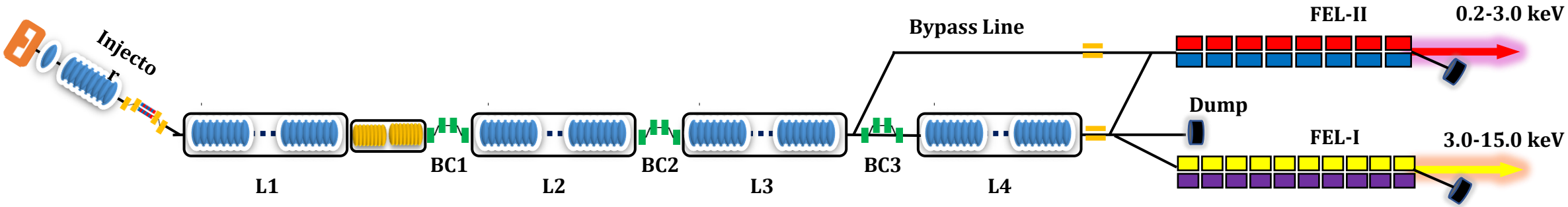
SHINE

Design Modification (2025)



- The maximum energy of main accelerator remains at 8 GeV, employing four-stage acceleration and three-stage bunch compression to achieve a peak current >1.5 kA.
- A new branch/bypass line (after L3, up to 4.5 GeV) is added to directly drive the FEL-II undulator line, expanding the photon energy coverage, improving compatibility with advanced seeding modes.
- The FEL-III line is discontinued; two undulator lines with multiple-period undulators compatible with various operating modes will be constructed in the first phase. FEL-I will cover 3-15 keV photon energy, while FEL-II will cover 0.2-3.0 keV.

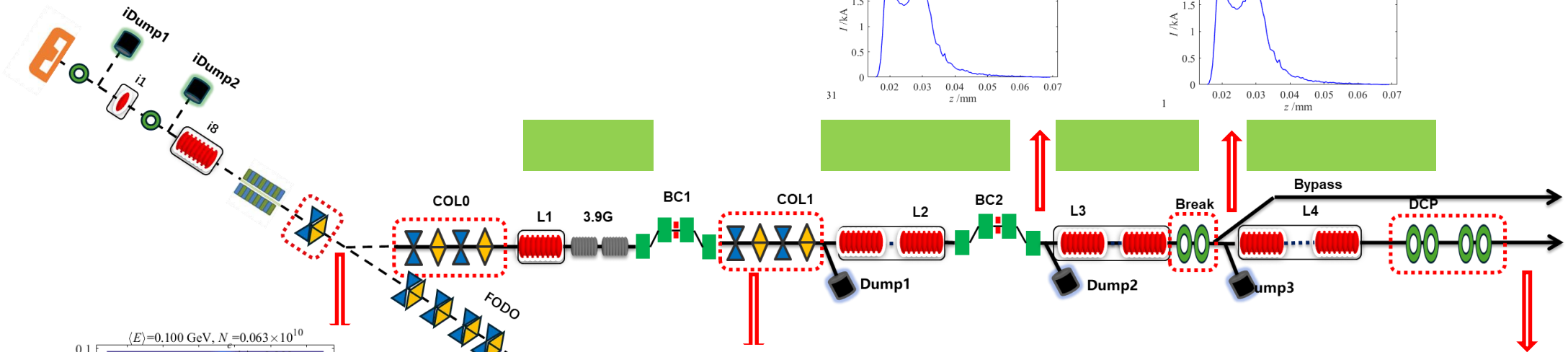
Design Modification (2025)

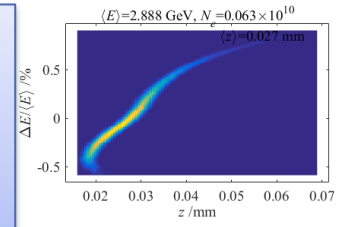


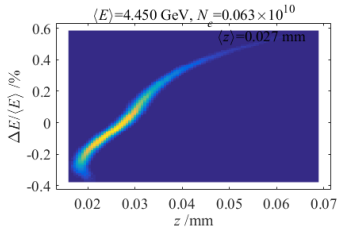
Parameters	Original Design		Modified Design	
	Design Goal	Acceptance	Design Goal	Acceptance
Beam Energy	8GeV	6GeV	8.0GeV	6GeV
Bunch Charge	100pC	50pC	100pC	50pC
Normalized Slice Emittance	0.45mm·mrad	0.5mm·mrad	0.45mm·mrad	0.5mm·mrad
Bunch Rep-rate	1MHz	100kHz	1MHz	100kHz
FEL-I	3-15 keV	5-13 keV, >1E9ph/pulse@5keV	3.0-15.0 keV	3.0-13.0 keV, >1E9ph/pulse@5keV
FEL-II	0.4-3 keV	1-2keV, >1E10ph/pulse@1.24keV	0.2-3.0 keV	0.3-2.0 keV, >1E10ph/pulse@1.24keV
FEL-III	10-25 keV	10-15keV	Cancelled in Phase-I	

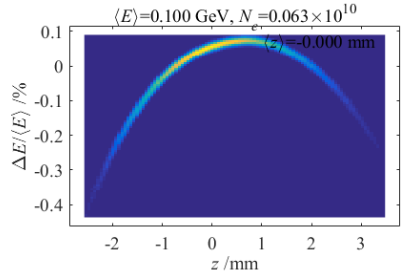
SHINE Accelerator:

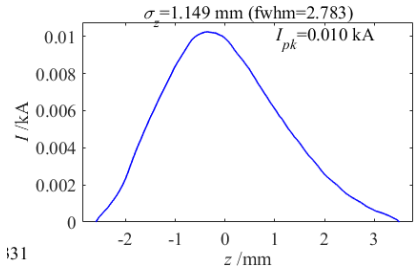
8.0 GeV, with a 4.5 GeV bypass line
54 standard 1.3GHz cryo-modules
20MV/m average gradient (6% as spare)

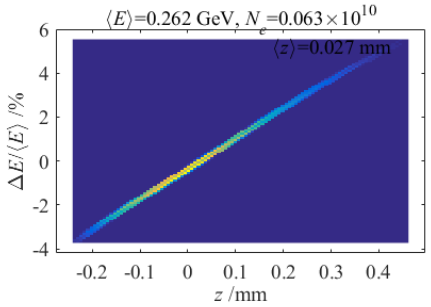


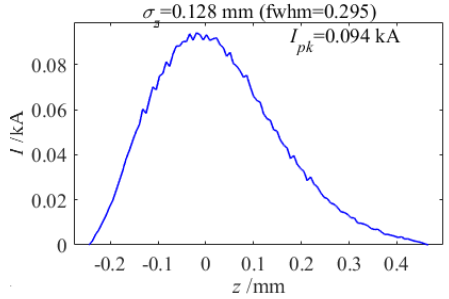


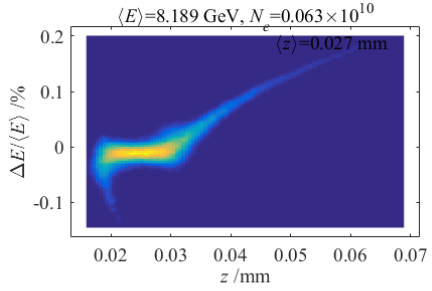


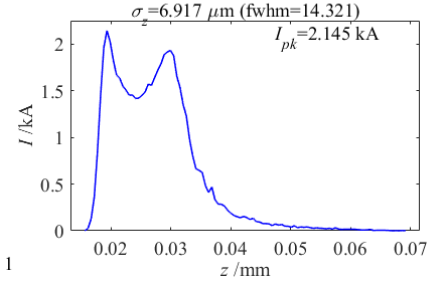






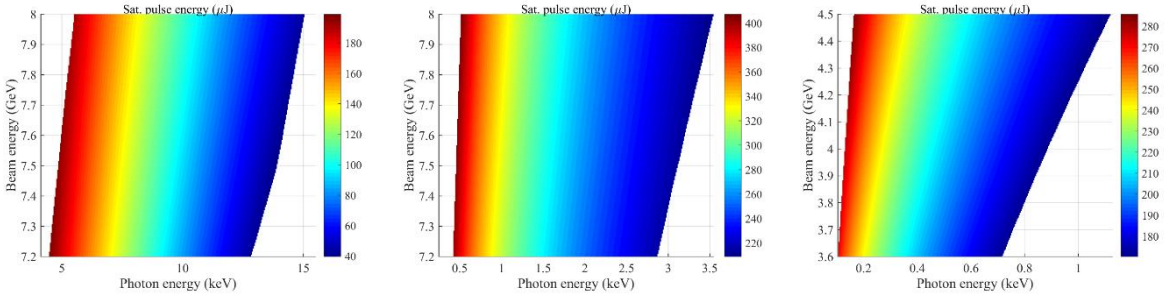




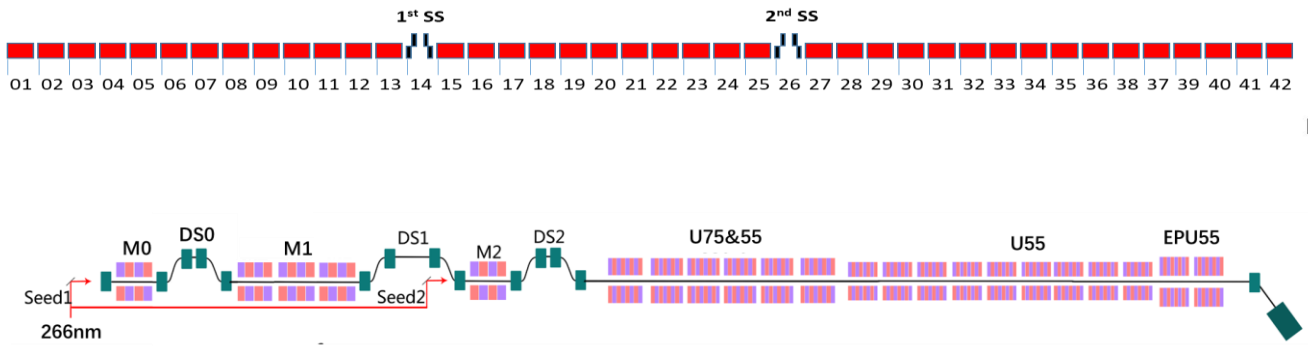


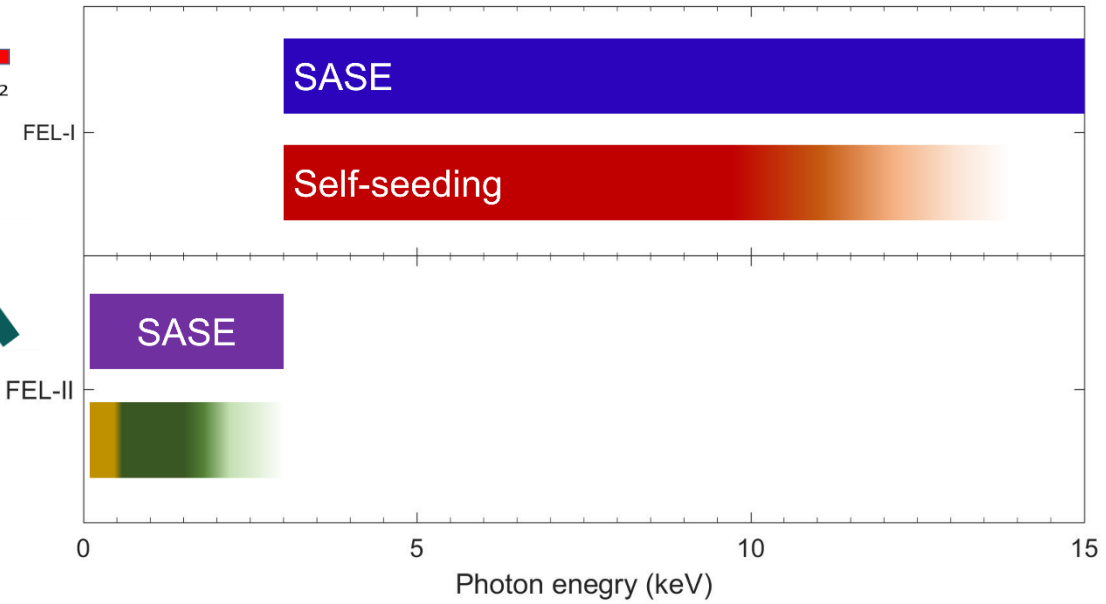
FEL Amplifier (Undulator Lines)

- FEL-I coverage: 3.0-15 keV
- FEL-II coverage: 0.4-3.0 keV @Main linac
- FEL-II coverage: 0.2-1.0 keV @Bypass



FEL-I FEL-II@main linac FEL-II@bypass



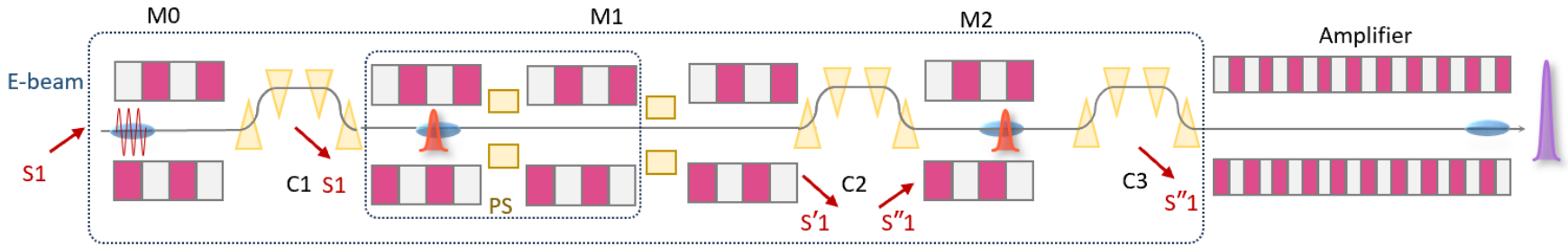


SHINE

Advanced Seeding Schemes @FEL-II

Current layout

More details in TUP2653



- **Baseline design: EEHG, 25-50th, 10-100kHz**
- **Advanced configurations: single weak seed laser + high repetition rate + high harmonics**

Mode	Harmonics	Repetition rate	Type
EEHG harmonic lasing	50 – 100	10 – 100 kHz	Baseline+
EEHG-HGHG cascade	50 – 250	10 – 100 kHz	Baseline+
SM-EEHG （HSM）	20 – 80	1 MHz@60th	Preferred scheme
DE-EEHG	20 – 40	1 MHz@30th	Optimal compatibility
SM-HGHG cascade （HSM）	20 – 80	1 MHz@60th	Alternative scheme

Progress of the SHINE Project

- **Civil Engineering**
- **Accelerator Systems**

  Injector: installation and beam commissioning finished

  Main Accelerator: construction and installation of 1.3GHz and 3.9GHz cryomodules

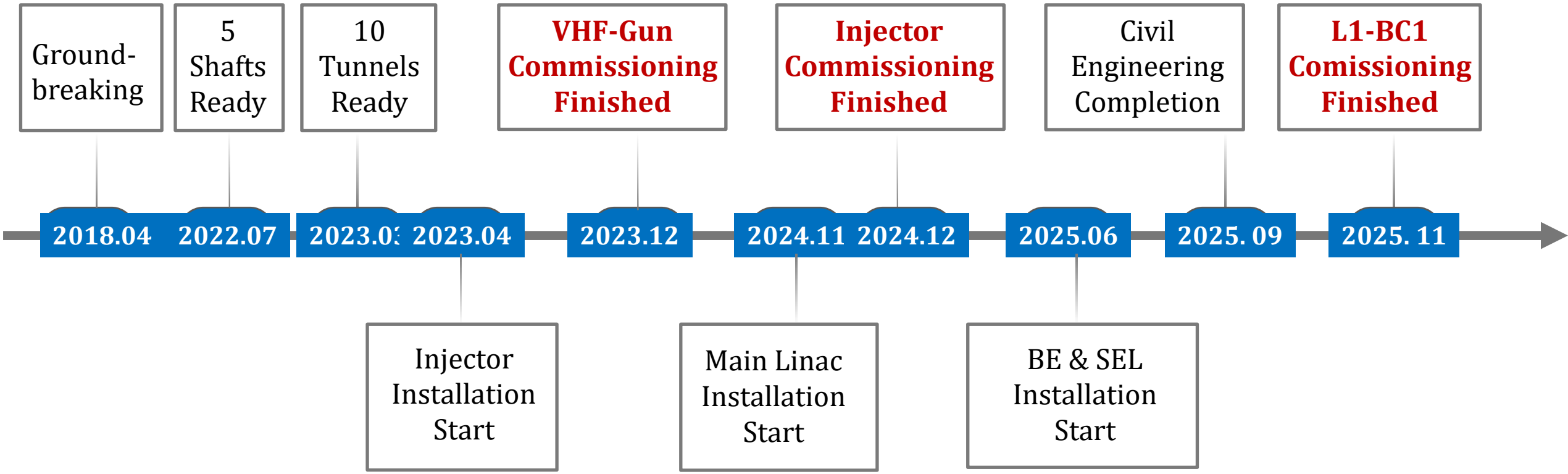
  Undulators: construction and installation of planar U26 and U55/75, EPU…

  Accelerator sub systems: RF power system and LLRF…

  Cryogenic Systems: 1kW@2K plant, 3 * 4kW@2K plants

- **Beamlines and Endstations**
- **High-power Super-intense Laser System**

Milestones


Ground-breaking
5 Shafts Ready
10 Tunnels Ready
VHF-Gun Commissioning Finished
Injector Commissioning Finished
Civil Engineering Completion
L1-BC1 Comissioning Finished
2018.04
2022.07
2023.03
2023.04
2023.12
2024.11
2024.12
2025.06
2025. 09
2025. 11
Injector Installation Start
Main Linac Installation Start
BE & SEL Installation Start

Civil Engineering

Base #1

Base #1

Base #4

SES @ Base #4

Base #2

Base #3

Base #5

Research Building @ #5

Accelerator Systems

- Cryomodules
- RF Power System and LLRF
- Kicker and Septa
- Undulators
- High Power Beam Dumps
- Beam Instrumentation
- Control
- Timing and Synchronization
- Laser
- Photon beam diagnostics
- ……

Construction of the accelerator is underway.

The SHINE Cryomodules

- **The injector cryomodules (a double-feed single-cavity module and an 8-cavity cryomodule)**

  assembled, installed and commissioned with RF and beam.

- **The linearizer cryomodules (two 3.9GHz 8-cavity cryomodules)**

  assembled, installed and commissioned with RF and beam.

- **The main linac cryomodules (fifty-four 1.3GHz cryomodules)**

  More than **30** delivered for tunnel installation.

  Towards finishing all the horizontal tests by the end of Nov. 2026, with the delivery rate of **2-3** modules per month.

☐ The 1.3GHz SRF dressed cavities status

✓ 2+3 suppliers (Nitrogen doping and Mid-T baking)

☐ Couplers, HOM absorbers, tuners, SC magnet and Cold BPM

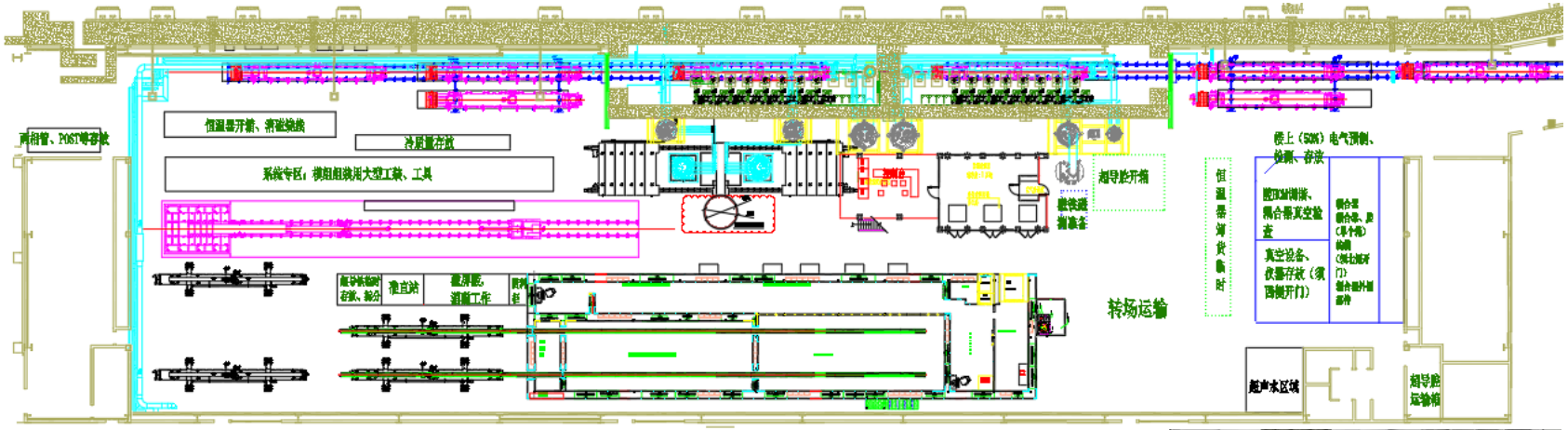
✓ All key components have been technically verified and in batch production for the assembly of the cryomodules.

Cryomodules Development - Infrastructure

Two 3000 m^2 for CM Assembly and Test Halls (ATH1 & ATH2)

Commissioning and gradually put into operation since 2021

More than 40 rounds of CM assembled and tested



Cryomodules Development - SRF Cavities

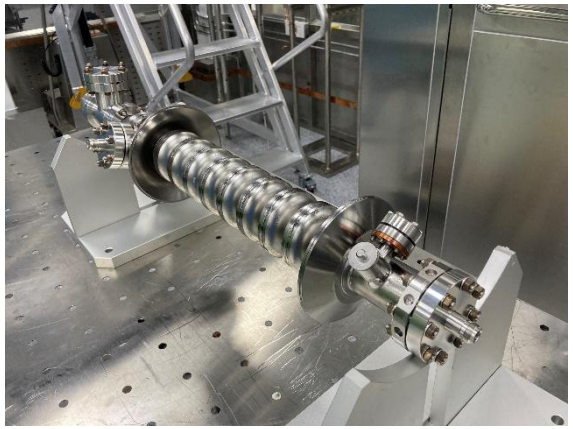
More details in TUP7635

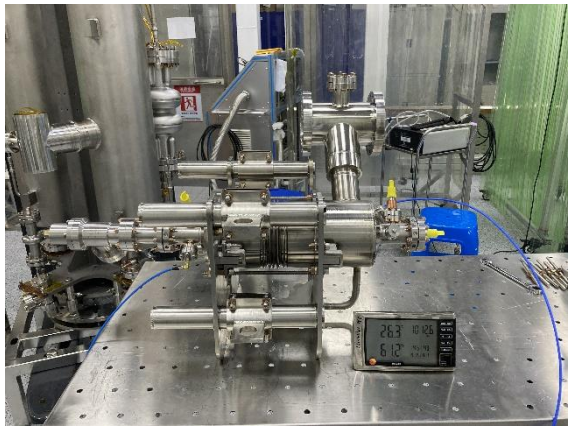
- Required Qualified SRF Cavities: ~500 1.3GHz cavities, 16 3.9GHz cavities

1.3GHz SRF cavity

1.3GHz SRF cavity

Integration of cavities





3.9GHz SRF cavity

Cryomodules Development - SRF Cavities

More details in TUP7635

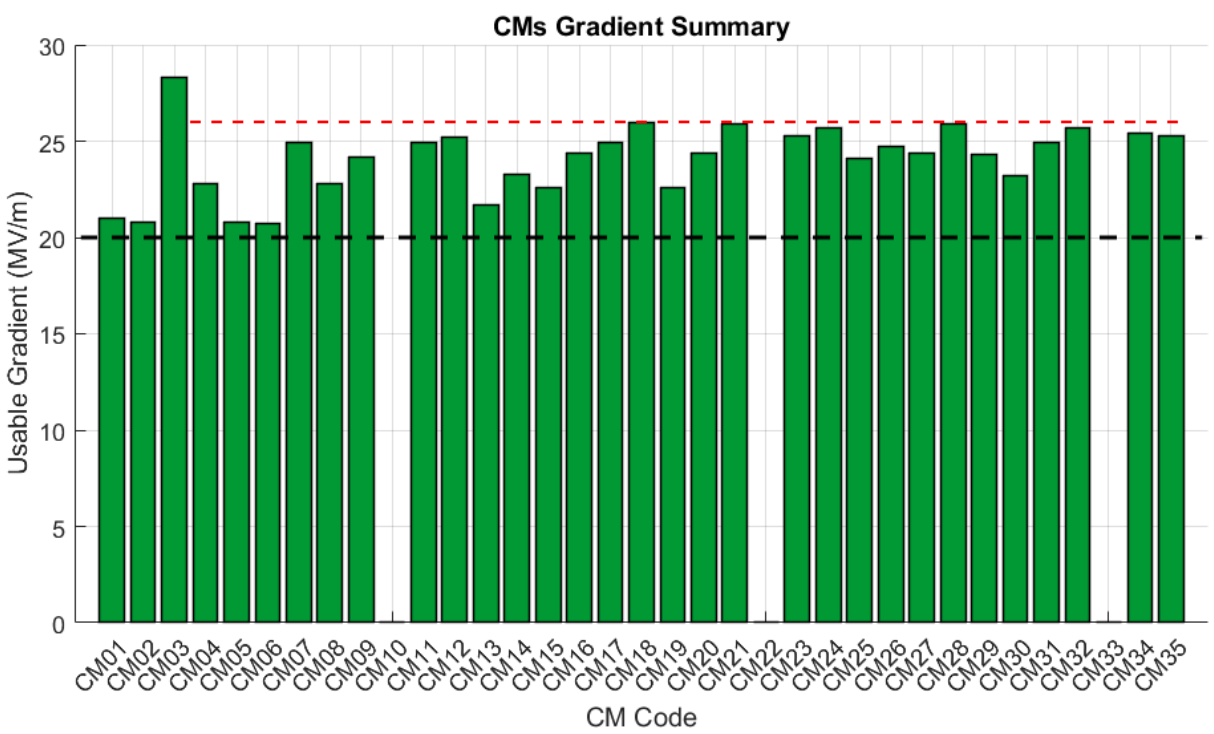
- In total, **5 cavity manufacturers**: three domestic and two international companies
- **Cavities contracted: 530** in three batches, around 3/4 domestic and 1/4 international
- More than **350** dressed cavities have been vertical tested

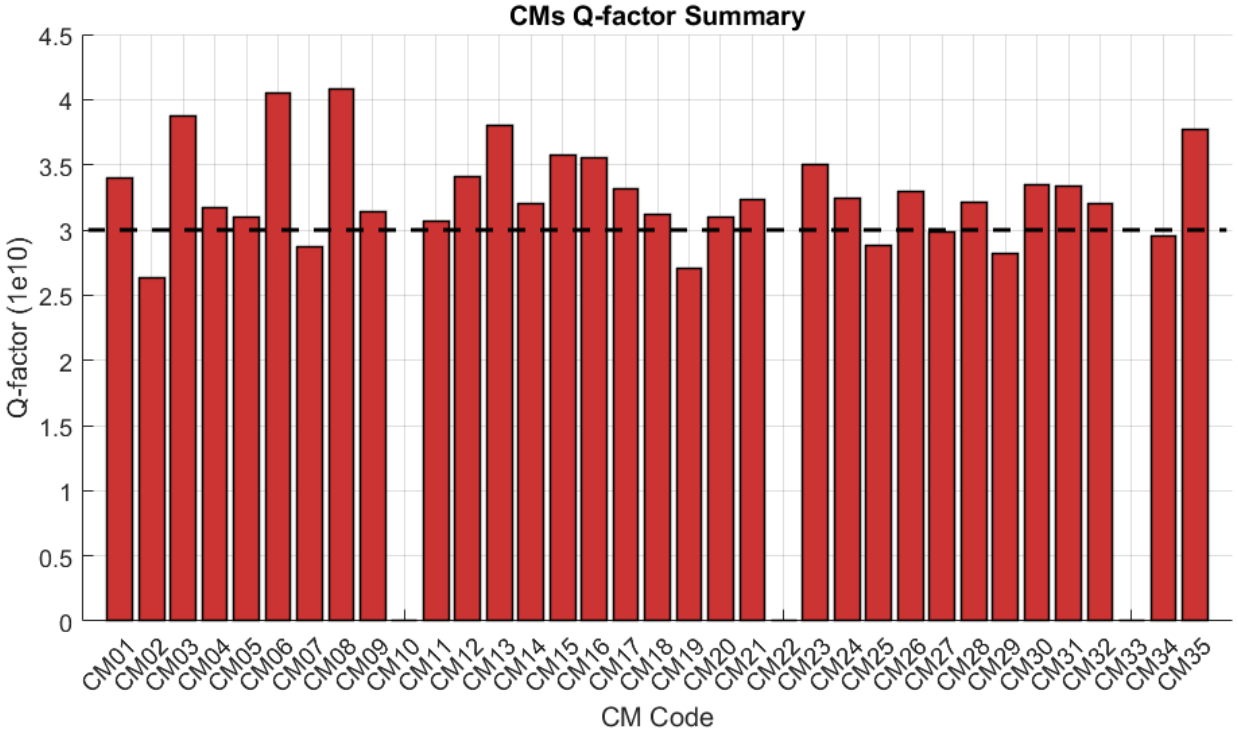
	Domestic			International	
Nb materials	NX/TD	NX/TD	NX/TD	NX	NX
1.3GHz cavity manufacturing	**HERT** (8+72 +64)	**OSTEC** (8+40 +40)	**Shanghai Electric** (2+64+96)	**RI** (8+60)	**ZANON** (8+60)
High-Q recipes	Mid-T baking (300℃/3h)			N-doping (modified 3/60)	
Surface treatment	**SHINE facilities at Wuxi Creative**			**RI**	**ZANON**
VT	SHINE				

Cryomodules Development - 1.3 GHz CMs

More details in TUP7636

32 Cryomodules passed the horizontal test



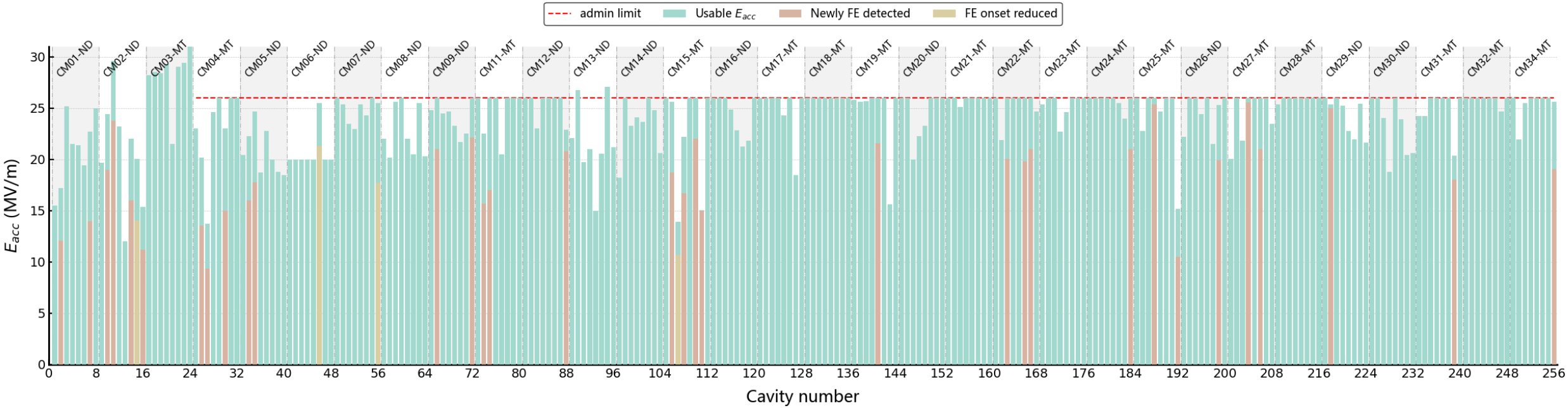


Average Accelarating Gradient: 24.1 MV/m	Average Usable Voltage: 200.1 MV	Average Q_0 @166 MV: 3.3 E+10

Cryomodules Development - 1.3 GHz CMs

More details in TUP7636

32 Cryomodules passed the horizontal test



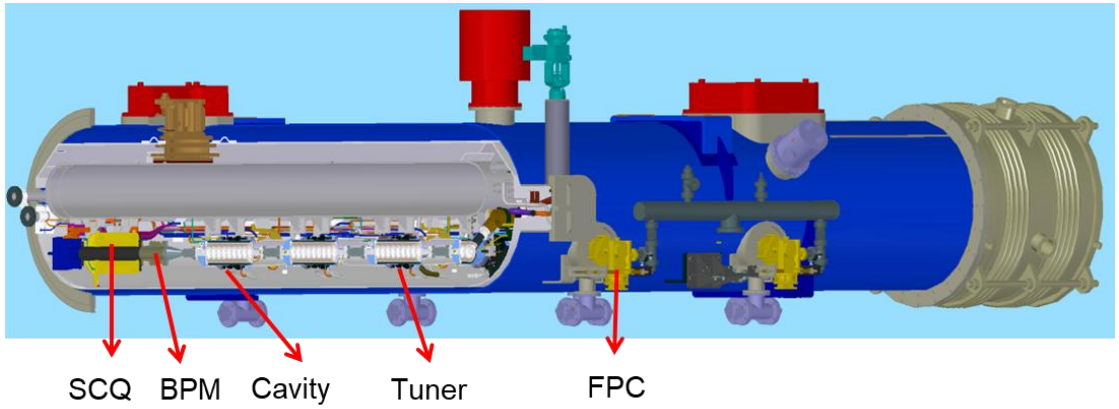
Field Emission (FE) behavior

86% of cavities (219/256) showed no FE degradation from VT to HT (84% FE-free).

14% experienced FE degradation in HT (13% new FE, 1% reduced FE onset). Average FE onset: 18.8 ± 4.4 MV/m.

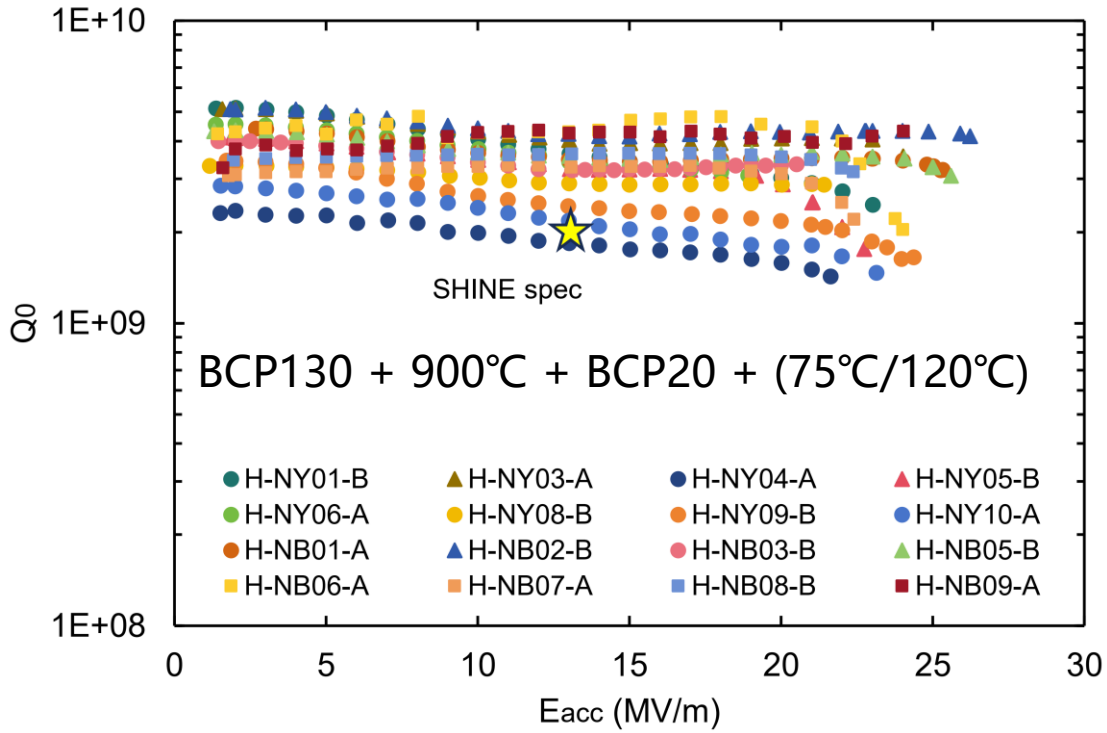
Cryomodules Development - 3.9 GHz CMs

No.	CMs	Specs	V_usable (MV)	<E_{usable}> (MV/m)	Average Q_0 at 15MV/m	Test time
1	**H-CM1**	2E+9 @ 36/41.5MV	63.6	23.0	3.4E+9	Dec. 2024
2	**H-CM2**	Ditto	59.8	21.6	3.4E+9	Jan. 2025

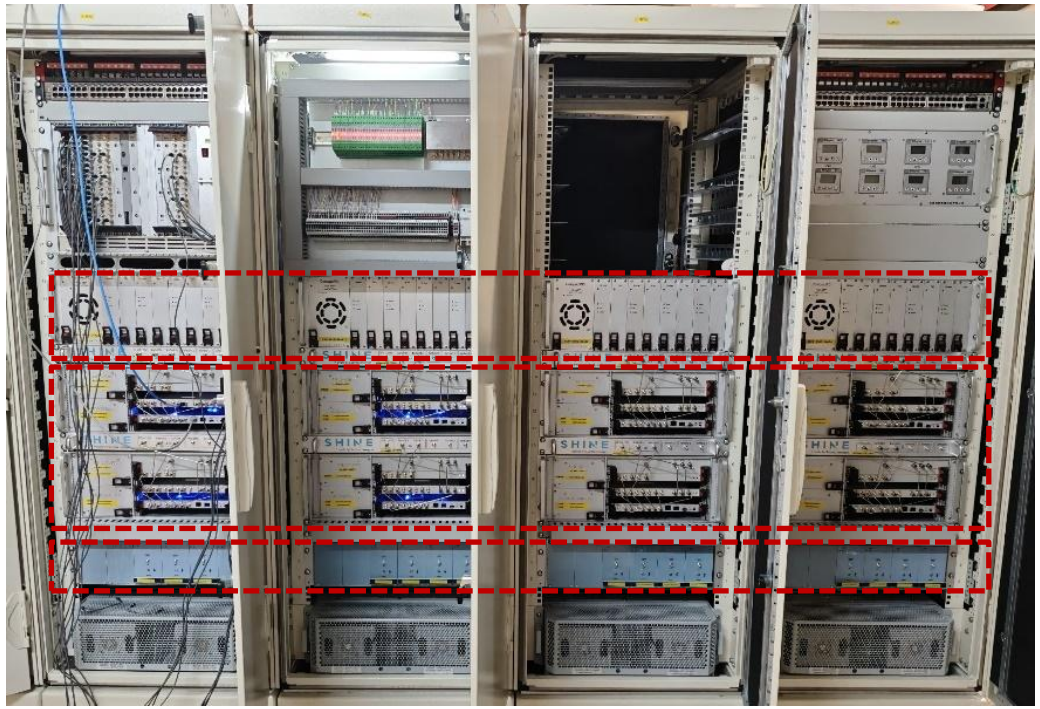


- Nineteen **3.9GHz cavities**, fabricated by OSTEC, surface treated at Wuxi platform, tested in Shanghai

3.9 GHz dressed cavities for the two CMs



LLRF System



All LLRF in L1 section, 2×1.3GHz + 2×3.9GHz, have been successfully installed and commissioned.
Each module contains:
- 8× DSP chassis, 4× motor control chassis
- 4× piezo control chassis, 1× RF interlock chassis

More details in TUP2666

The specifications are fully met.

Amplitude Stability (RMS): 0.006% (<0.01%)

Phase Stability (RMS): 0.009 (<0.01deg)

CM02_STABILITY

	SUM	CAV1	CAV2	CAV3	CAV4	CAV5	CAV6	CAV7	CAV8
amp_rms(%)	0.0025	0.0069	0.0058	0.0068	0.0038	0.0065	0.0046	0.0054	0.0074
pha_rms(deg)	0.0094	0.0276	0.0249	0.0273	0.0249	0.0242	0.0266	0.0287	0.0225

CM03_STABILITY

	SUM	CAV1	CAV2	CAV3	CAV4	CAV5	CAV6	CAV7	CAV8
amp_rms(%)	0.0049	0.0119	0.0095	0.0422	0.0106	0.0141	0.0085	0.0085	0.0036
pha_rms(deg)	0.0099	0.0265	0.0305	0.0519	0.0272	0.0263	0.0272	0.0193	0.0199

HCM01_STABILITY

	SUM	CAV1	CAV2	CAV3	CAV4	CAV5	CAV6	CAV7	CAV8
amp_rms(%)	0.0055	0.0271	0.0172	0.0190	0.0122	0.0028	0.0046	0.0173	0.0103
pha_rms(deg)	0.0075	0.0220	0.0211	0.0227	0.0129	0.0110	0.0264	0.0124	0.0305

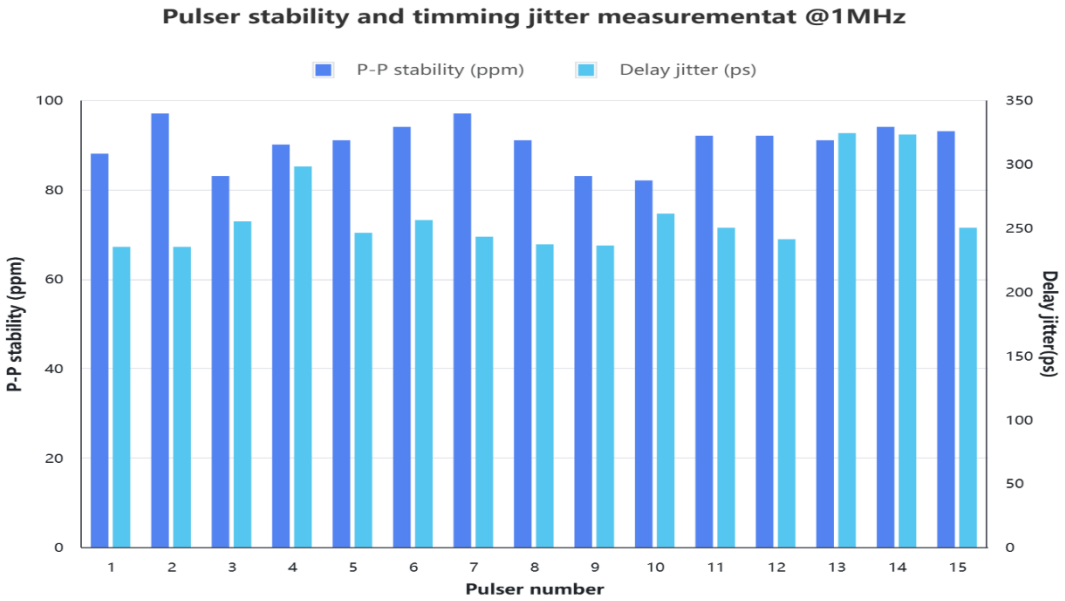
HCM02_STABILITY

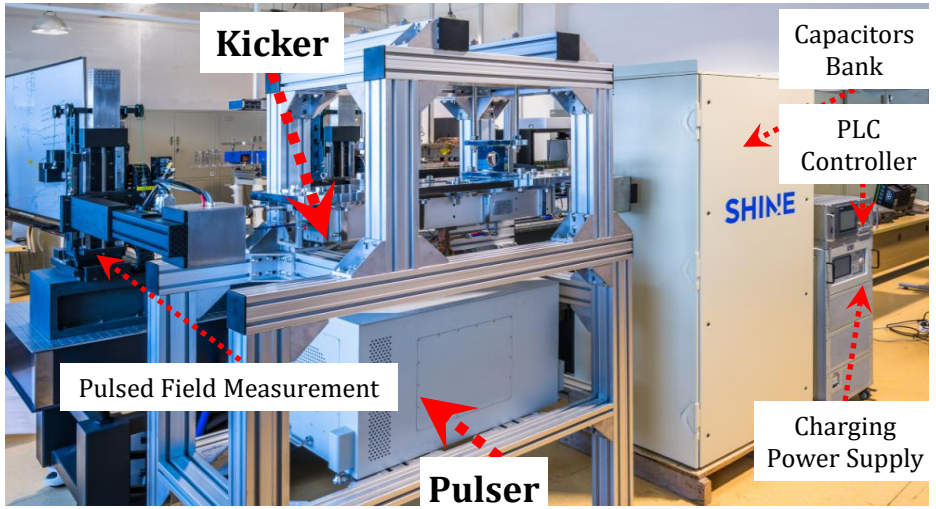
	SUM	CAV1	CAV2	CAV3	CAV4	CAV5	CAV6	CAV7	CAV8
amp_rms(%)	0.0033	0.0089	0.0050	0.0074	0.0154	0.0071	0.0043	0.0097	0.0101
pha_rms(deg)	0.0074	0.0161	0.0173	0.0198	0.0217	0.0200	0.0243	0.0205	0.0213

Amp and phase stability of 1.3GHz and 3.9GHz cavities

Kicker System for Beam Switchyard

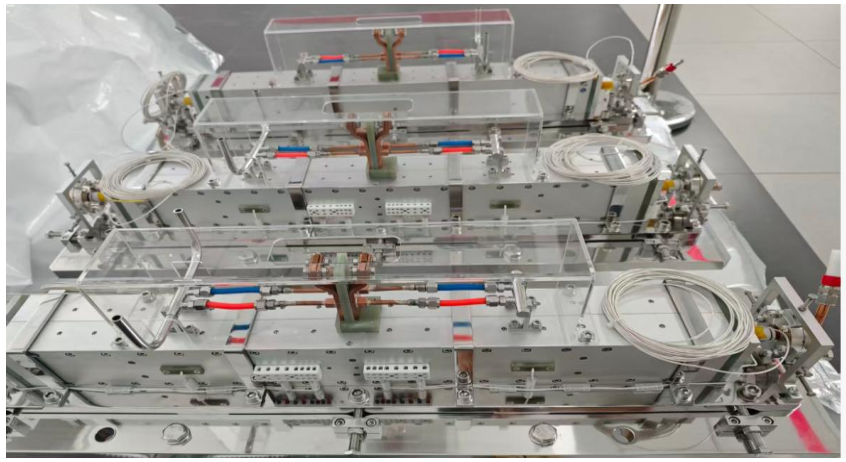
More details in TUP7708





Kicker System Measurement Platform

Kickers already installed



Kickers to be installed

SHINE

FEL-I/II Undulators

More details in TUP7699

78 undulators (FEL-I: 42×U26, FEL-II: 18×U55, 14×U55&U75, 4×EPU55) in total;

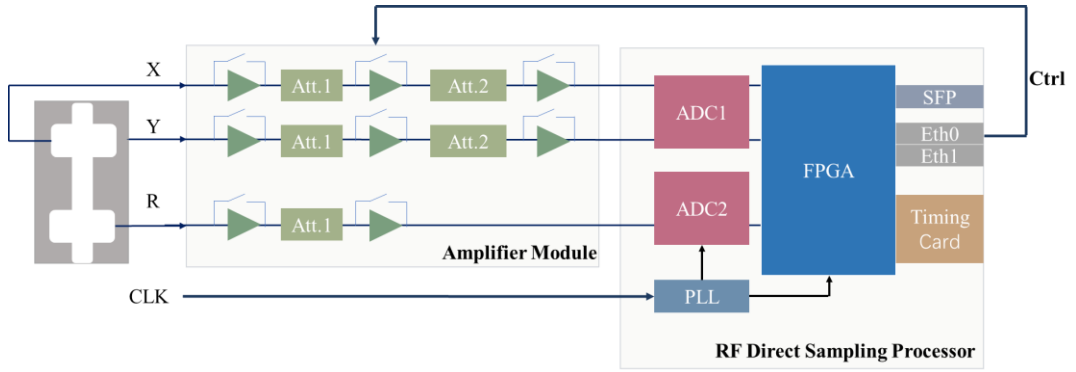
76 phase shifters (FEL-1: 41×PS26, FEL-II: 35×PS55) in total;

Installation of the FEL-II/I undulator-lines will be completed by middle and end of 2026 respectively.

Electronics for Beam Instrumentations

More details in TUP7699

- **~400 units of various electronic produced**
  - 1 GSPS generic beam signal processors
  - 8 channels 1 GSPS beam signal processors
  - 250 MSPS longitudinal beam signal processors
  - Fast orbit feedback & interlock processors
- **Direct RF sampling electronics for CBPM**
  - 9 GHz bandwidth, 2.6 GSPS sampling rate
  - Sampling 5.254 GHz cavity BPM signal directly without RF down-conversion module
  - Real-time digital signal processing, including amplitude and phase extraction, is implemented in FPGA with repetition rates up to 1 MHz.

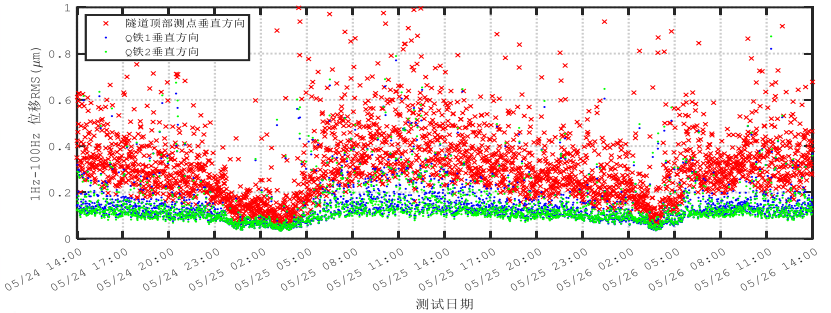


Mechanical System

1.3m-Magnet Support Platform

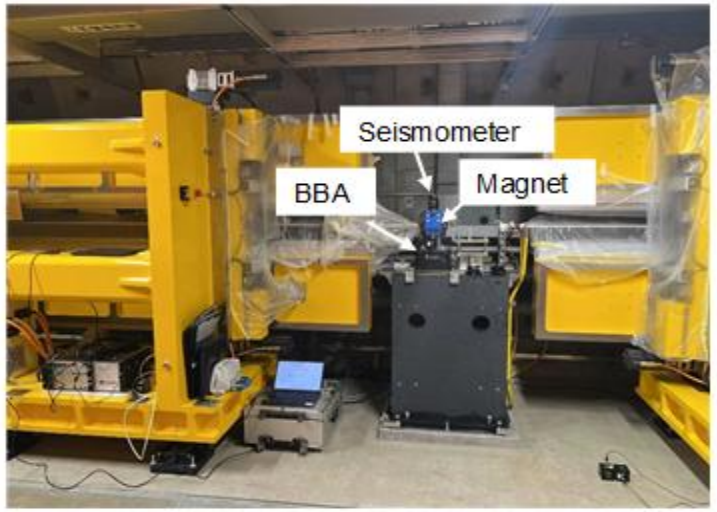
Suspended Support Platform of Cryomodule

Suspended Vibration Induction Platform of Magnet



m-Magnet Support Platform

Mobile Chicane Platform



Mechanical Supports installed in Undulator Segment

Test Items of BBA supporting platform	Acceptance Value	Measured Results
Adjustment range of quadrupole center（H/V）	≥ 0.5mm	≥ 0.75mm
Adjustment step of quadrupole（H/V）	≤0.05μm	≤0.05μm
Positioning accuracy of quadrupole（H/V）	≤ 0.1μm	≤ 0.1μm
Stability of Magnetic Center Vibration of Quadrupole（H/V，RMS，>1Hz）	≤0.20μm(not less than 90% of the time)	≤0.20μm(not less than 98.4% of the time)

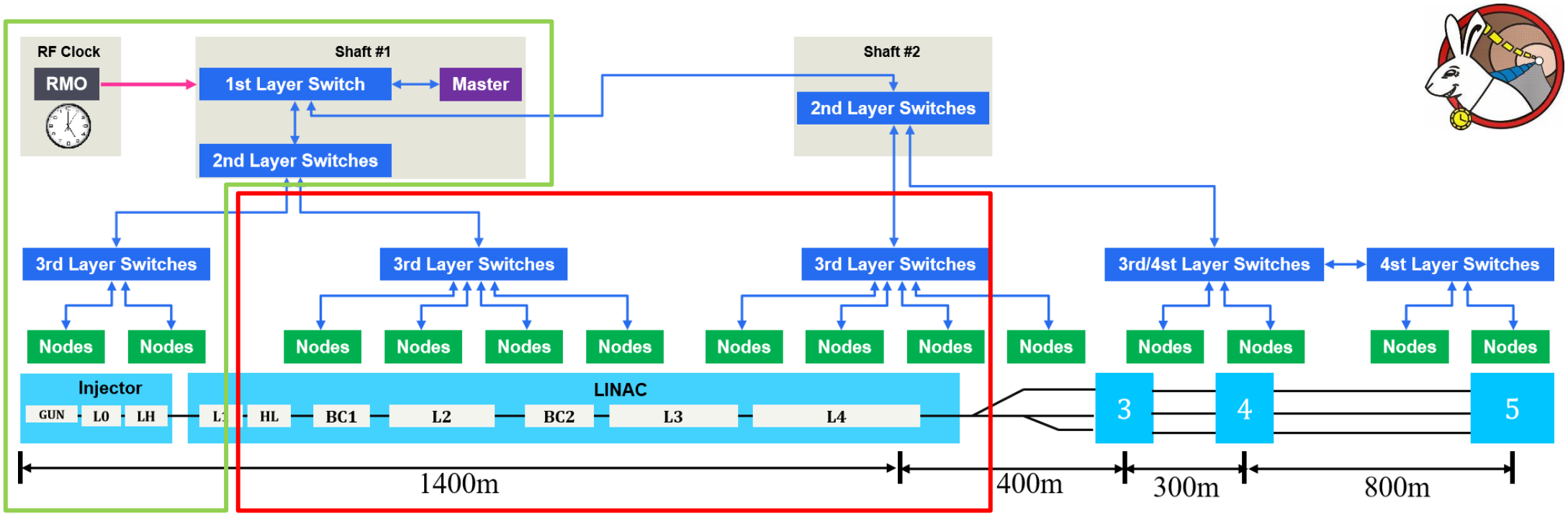
Feedcap Support

Lifting Platform of Analysing Magnet

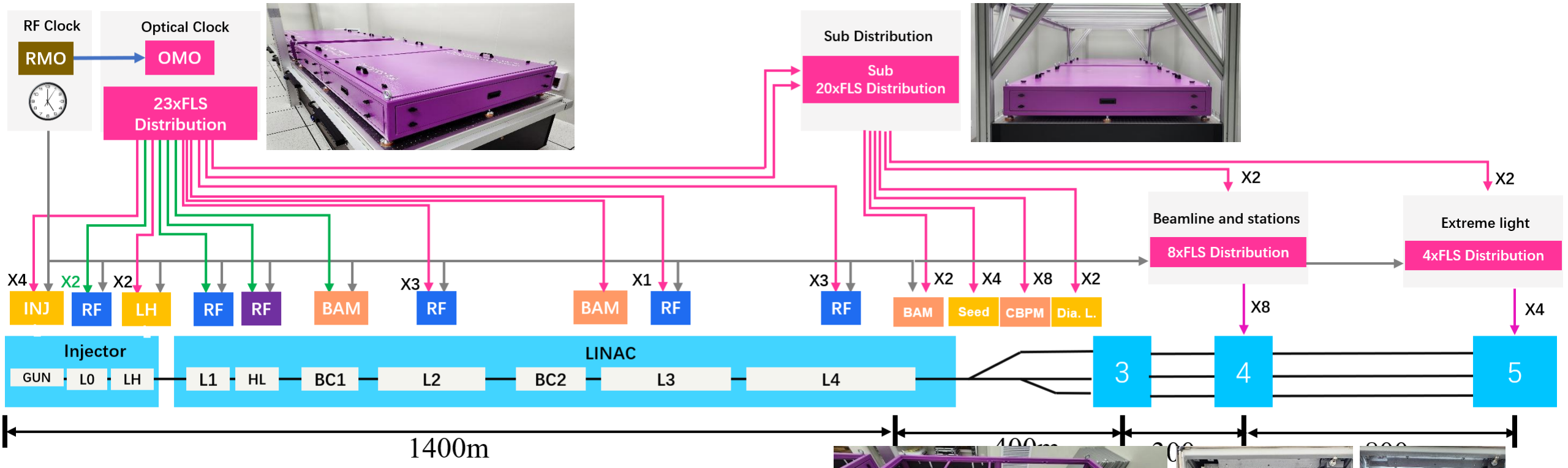
- Many kinds of mechanical supports have been designed and installed in tunnel.
- Vibration compensation platforms have been installed to meet stability requirements of magnets.

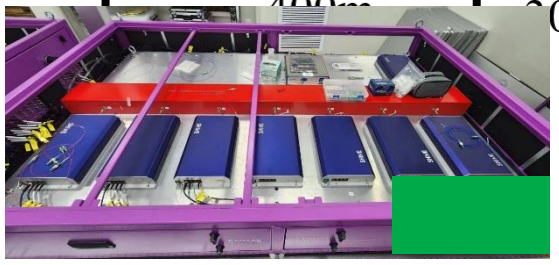
Timing System

- The facility adopts a **White Rabbit-based** timing system, with a repetition rate of **1.0030864 MHz.**
- Installation, commissioning and control interface development of the timing system for the injector, L1 linac and FEL-II undulator sections have been **completed,** while corresponding work for the L2-L3 linac sections is currently **in progress.**



Femtosecond Synchronization System





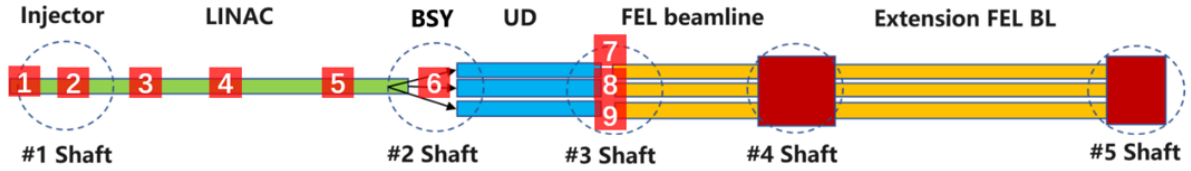
Environmental Control Infrastructure

Completed the installation and commissioning of 4 TSP units (Constant Temperature Platforms) in Shaft #1 and 6 units in Shaft #2; all units are currently in stable operation.

System Deployment & Commissioning

Finalized the delivery of synchronization equipment for the Injector and L1-L3.

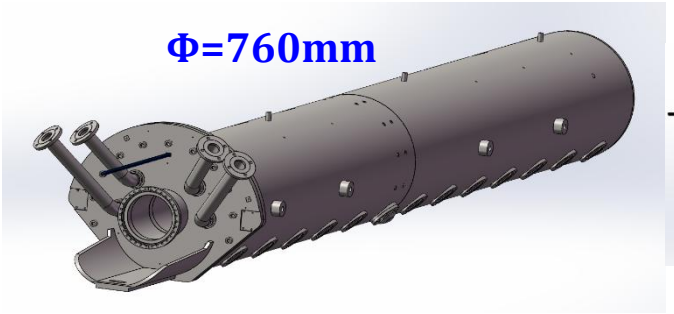
800kW High-Power Dump

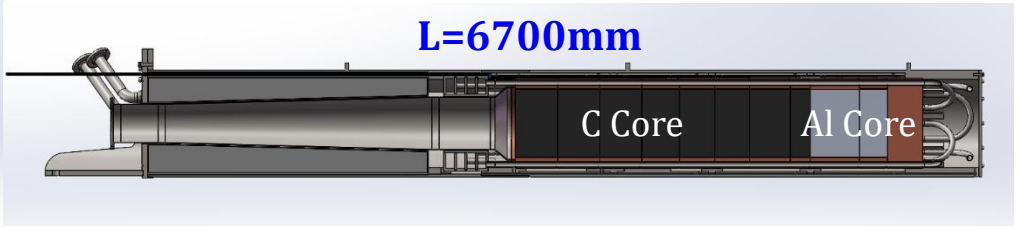


800kW High-Power Beam Dump Distribution

6	800kW@8GeV	Graphite Core	in Progress
7	800kW@8GeV	Graphite Core	DONE
8	800kW@8GeV	Graphite Core	in Progress

800kW Dump @ FEL-II






Single-block absorber in brazing


3m-long absorber in electron beam welding


Absorber in sub-assembly

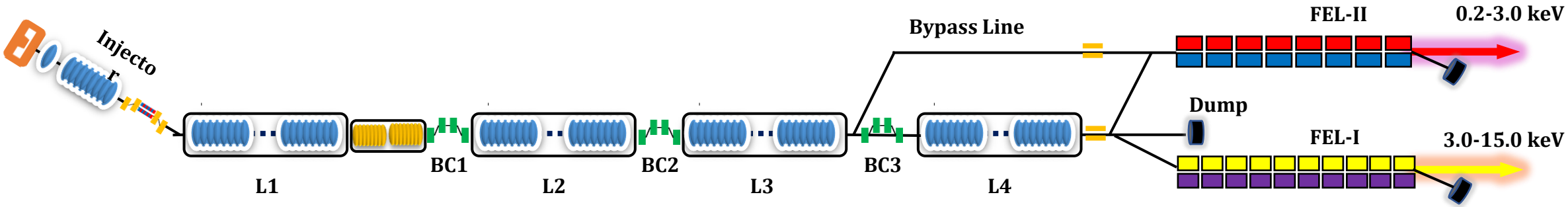

Outer Sleeve assembly


On-site Hoisting

- The first 800kW-Beam-Dump has achieved breakthrough in larger-scale graphite-to-copper welding
- Installation is completed on Nov. 5, 2025

Installation

The SHINE Accelerator and Undulator Lines



- **The SHINE Accelerator and Undulator Lines** consists of

  An injector section: 750kV/217MHz photo cathode VHF gun, a normal-conducting two-cell buncher, a single-cavity CM (TFPC-type) and an eight-cavity CM (ABBA-type);(**completed**)

  A laser heater section; (**completed**)

  Four sections of 1.3GHz standard CMs, and one section of 3.9GHz CMs; Three magnetic bunch compression sections and a dechirper section at the end; (**on-going, L1-L3 almost finished**)

  In addition, a bypass beam transfer line dedicated to FEL-II; (**almost finished**)

  A beam switchyard; (**on-going**)

  Two undulator lines. (**on-going, FEL-II almost finished**)

Installed Sections at a Glance

Presented at IPAC24

VHF Gun

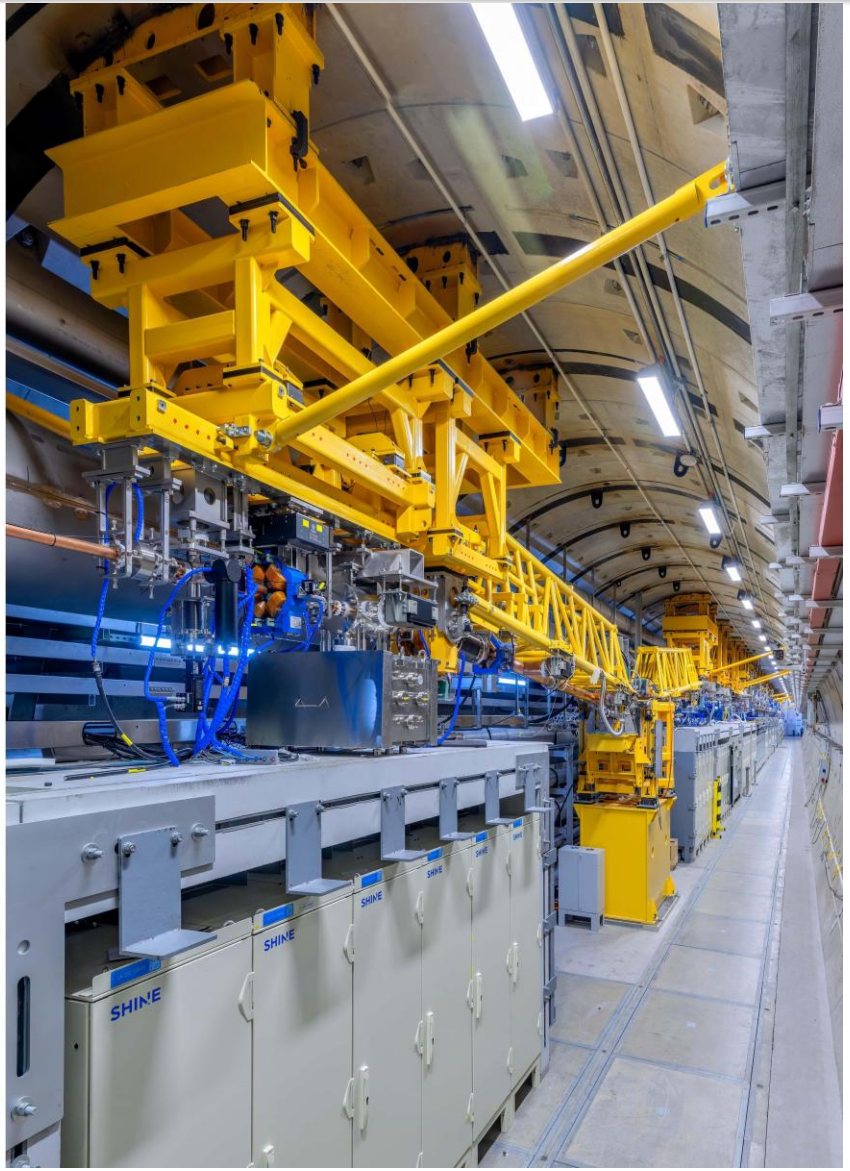
i1CM

i8CM

Laser heater

Installed Sections at a Glance

L1



BC1

L2

BC2

Installed Sections at a Glance

L3

L4 & Bypass

LTD & LTU-II

Drift before FEL-II & FEL-I

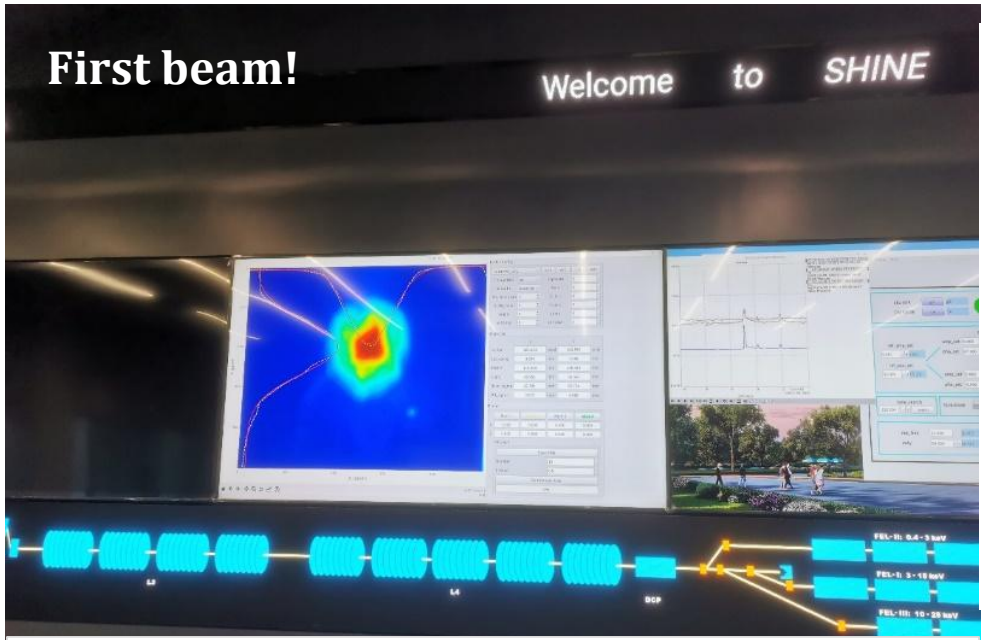
FEL-I & FEL-II Undulator Line

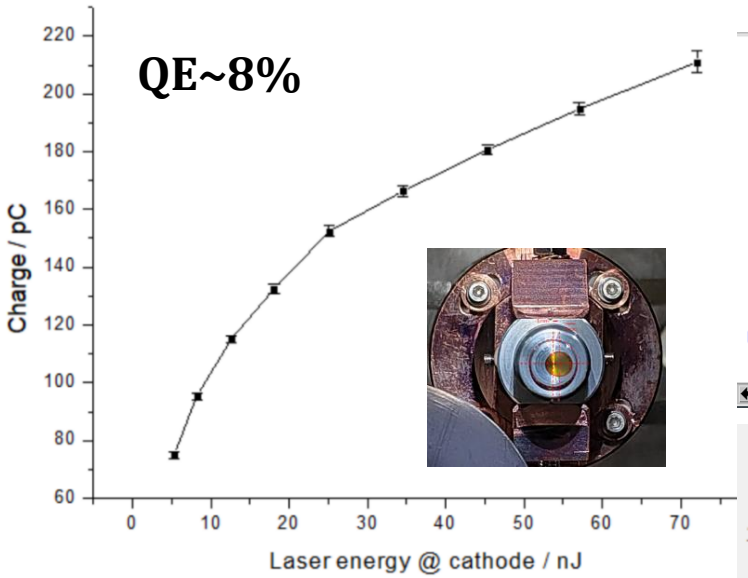
FEL-II Dump Line

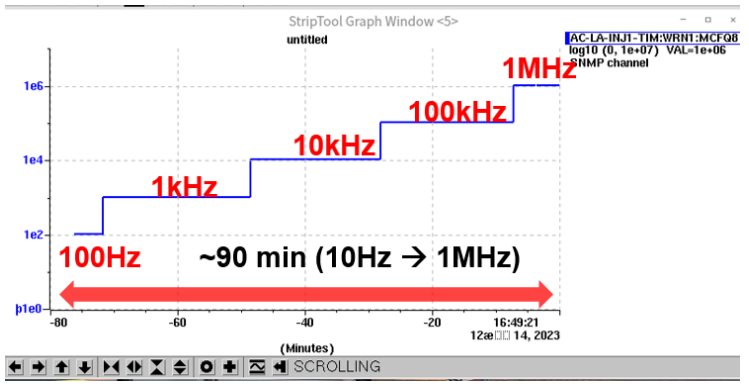
Commissioning

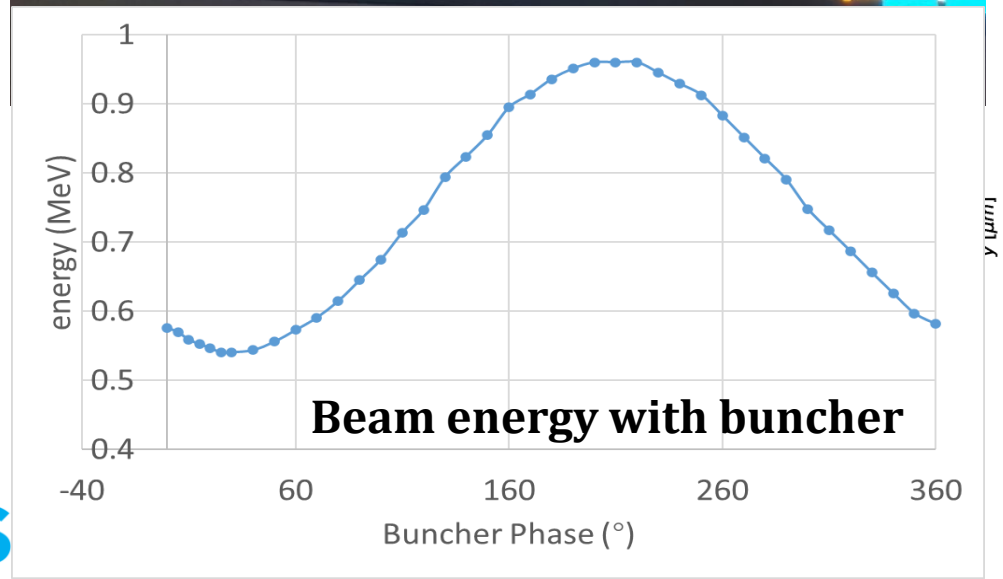
Commissioning: VHF-Gun (2023)

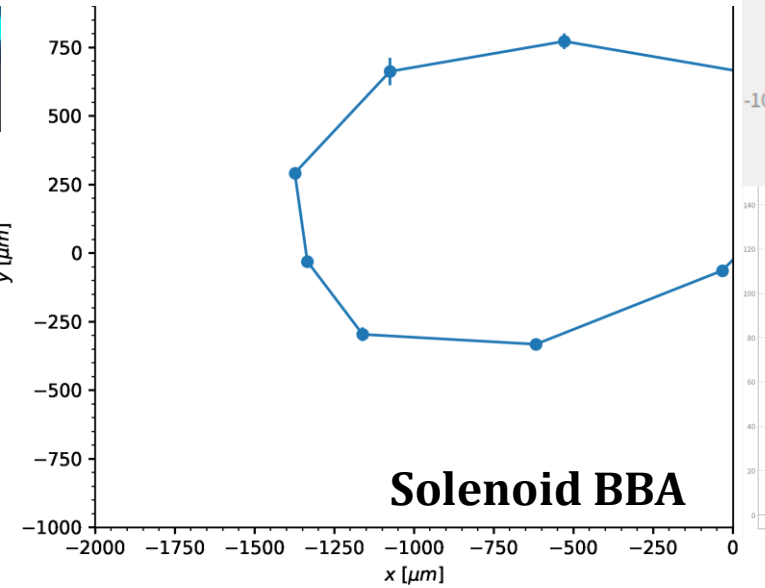
Presented at IPAC24

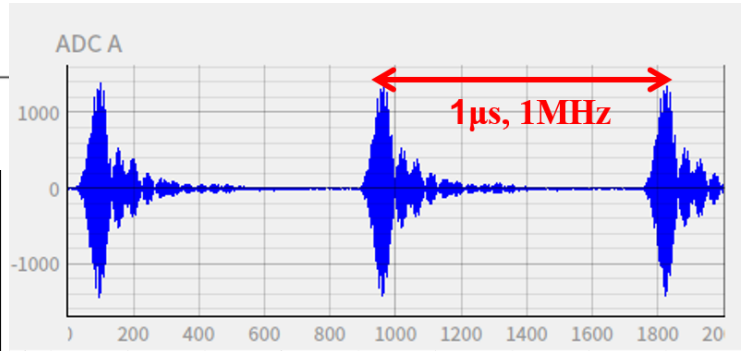


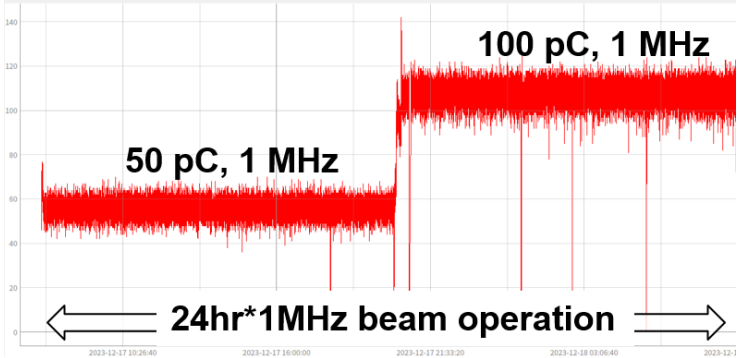










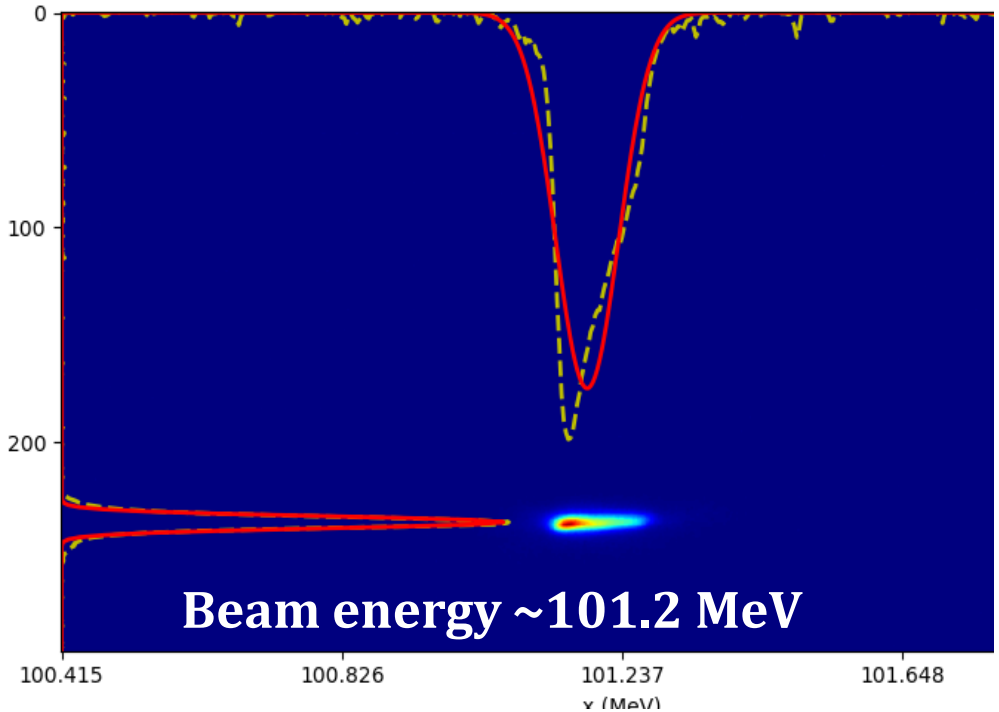


Commissioning: Injector (2024)

IPAC26

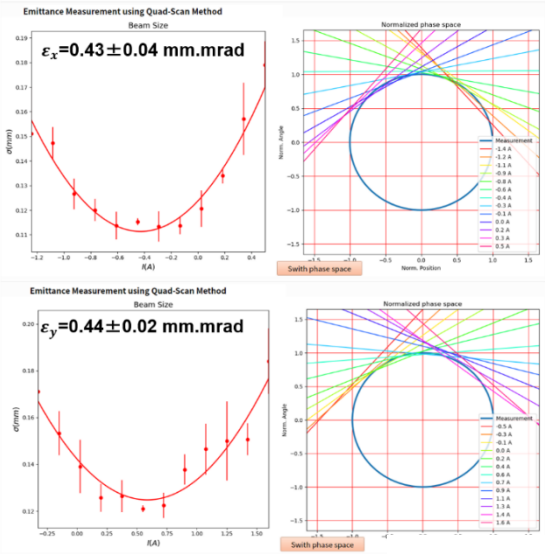
Injector:

More details in TUP2646 &TUP2647



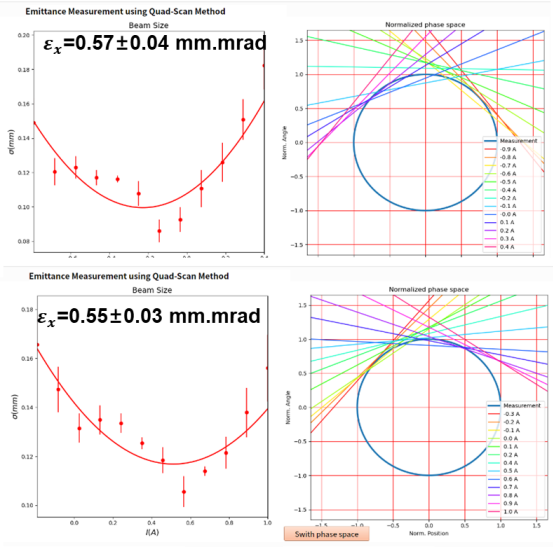
50pC (Long. Gaussian)

$\varepsilon_{slice} = 0.33 \pm 0.06$mm.mrad

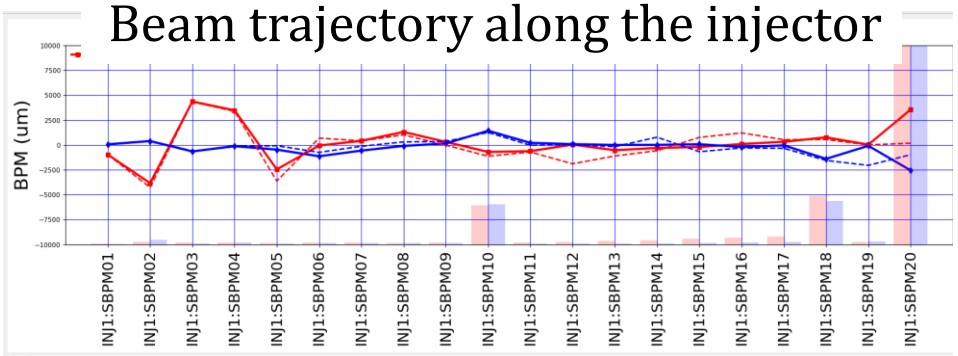


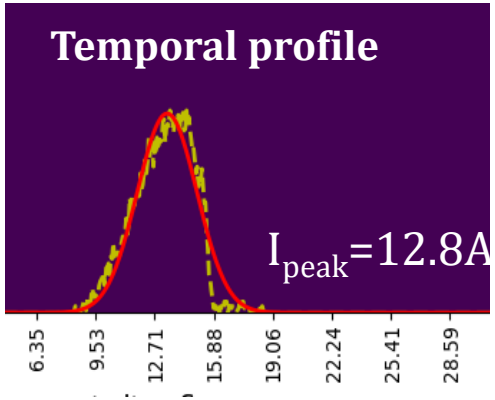
100pC (Long. Gaussian)

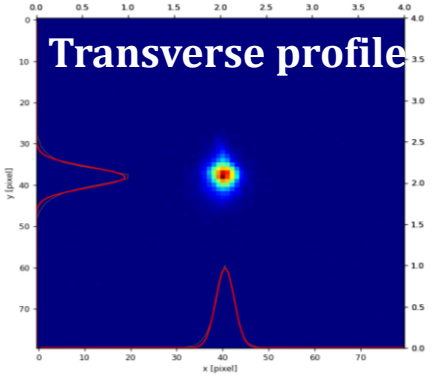
$\varepsilon_{slice} = 0.44 \pm 0.13$mm.mrad



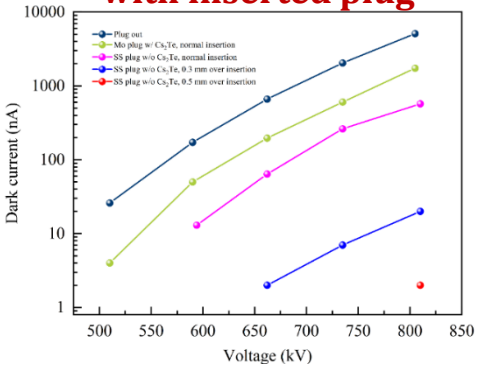
Beam trajectory along the injector







Dark current reduction with inserted plug

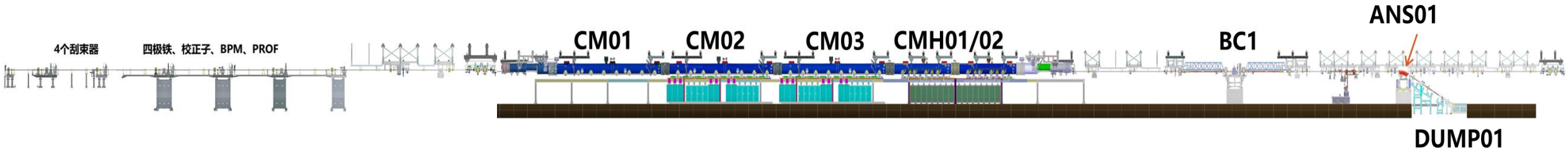


Commissioning: L1 & BC1 (2025)

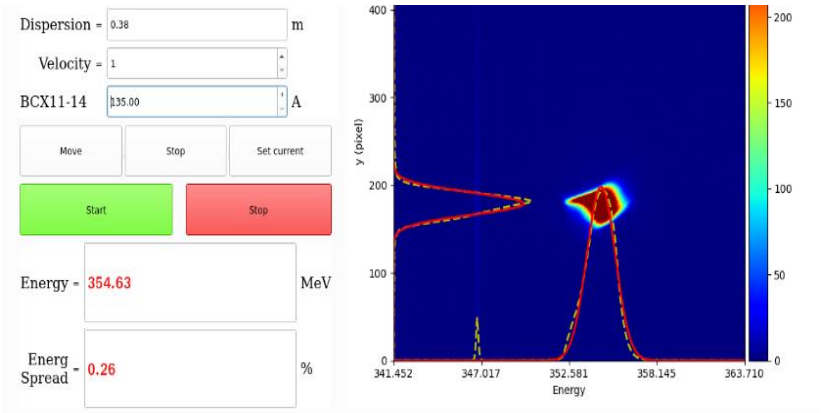
L1 Section:

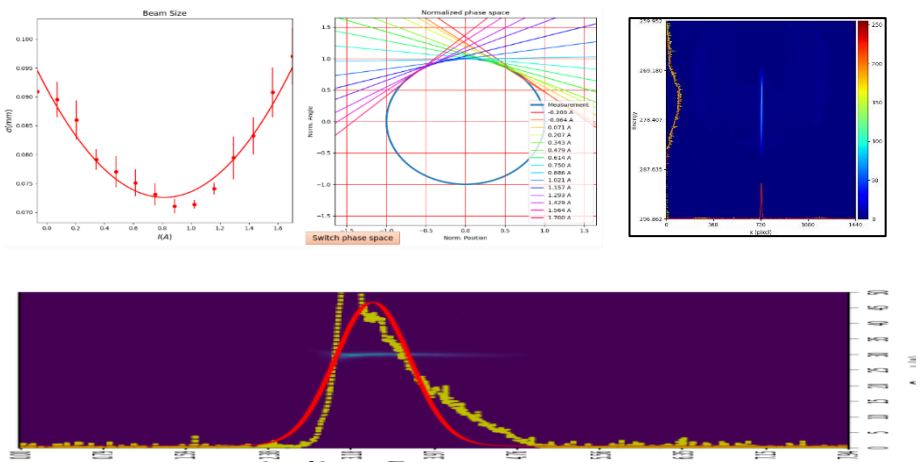
More details in TUP2646 &TUP2647

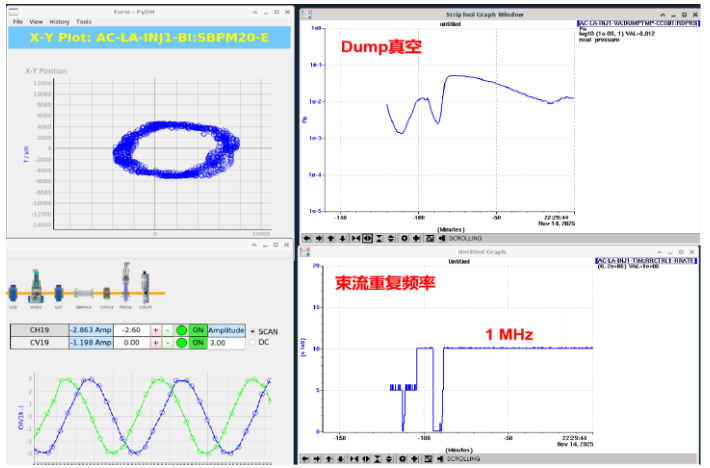
- 1.3GHz Cyromodule * 2, 3.9GHz Cyromodule * 2, Bunch Compressor * 1



COL0~44m | L1~54m | BC1~28m





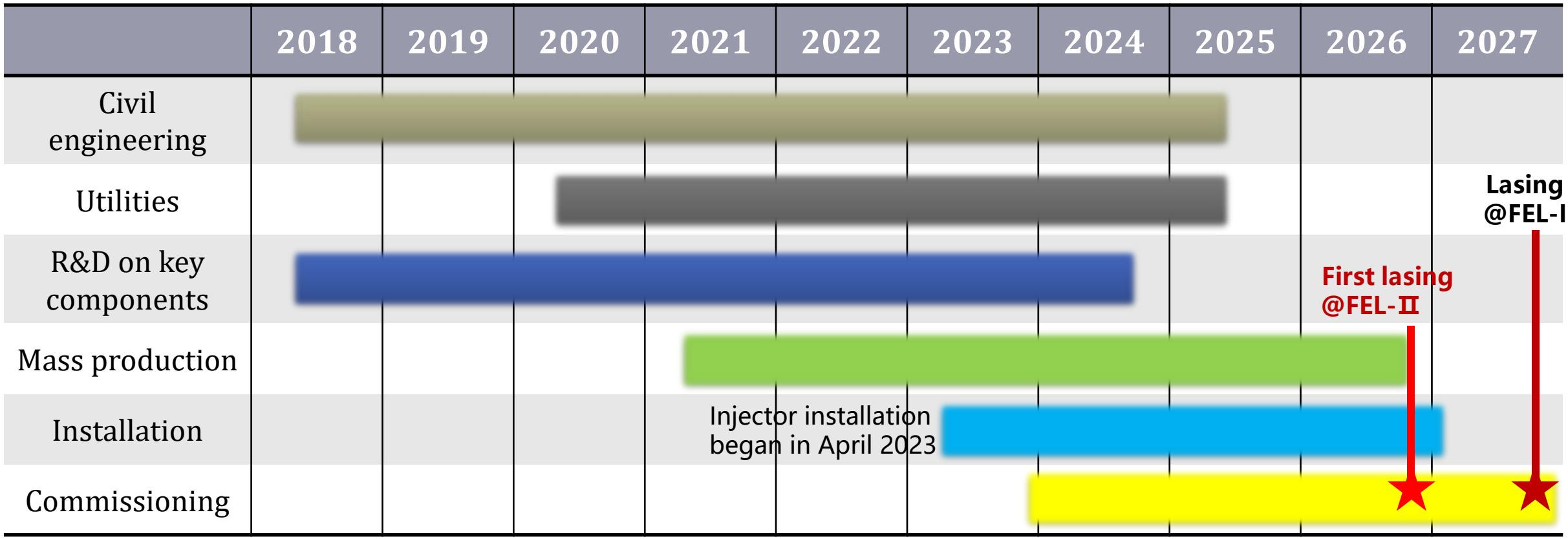


2025.08.18
Beam pass through, 354 MeV

2025.11.03
270MeV / 50pC / 60A / 0.5μm / 1kHz

2025.11.14
Injector: 100MeV / 100pC / 1MHz

Construction Timeline



Groundbreaking was made on April 27, 2018.
First lasing @FEL-II is expected in 2026.

Summary

- Construction of the SHINE main accelerator achieves encouraging progress, and 30 standard 1.3GHz cryomodules for L1-L3 have already been installed into the tunnel. Schedule is extremely tight and it still faces the crucial challenge from the yield rate in the cryomodule production.
- The SHINE injector commissioning was completed with the designed performance at the end of 2024. Commissioning of the L1-BC1 section of the Linac was finished at the end of 2025.
- Great efforts are being made to realize the first lasing of FEL-II in the autumn of 2026 and FEL-I in the autumn of 2027 respectively, towards completing the project at the end of 2027.


Thanks for Your Attention !