中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

TESLA TECHNOLOGY
T T C
COLLABORATION

Progress and first beam operation of 1.3GHz 9-cell twin-FPC cryomodule for SHINE

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09th April, TTC'2025, Daejeon, Korea

SHINE

Content

Introduction

SHINE: Shanghai Hard X-ray FEL Facility

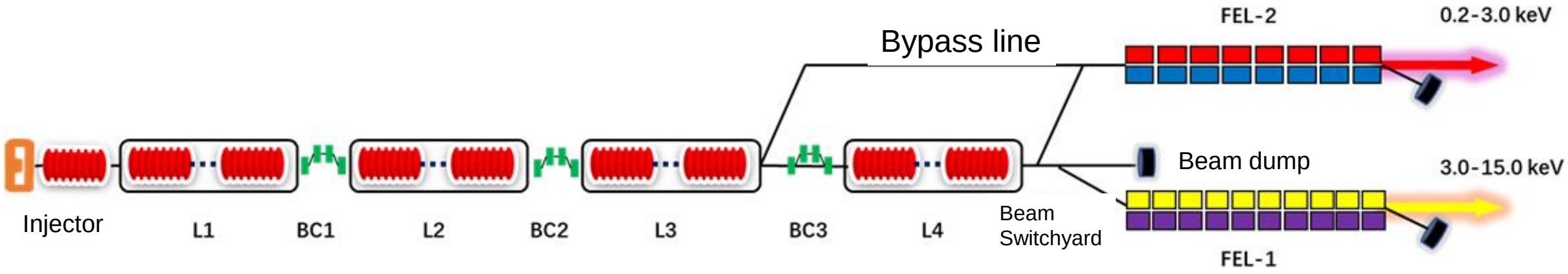
Shanghai HIgh repetitioN rate XFEL and Extreme light facility (SHINE)

- SHINE is an 8 GeV CW SCRF linac based high rep-rate XFEL facility, it will be installed in a 3.1 km long tunnel underground at Zhangjiang High-Tech Park, across the SSRF campus to the southwest corner of ShanghaiTech University;
- This XFEL facility, assisting with a 100 PW super-intense laser facility, has 3 undulator lines, 3 beamlines and 10 experimental stations in phase-I, and it can provide the XFEL radiation in the photon energy range of 0.4-25 keV.
- This project was launched by the central government in April 2017, and its groundbreaking was made in April 2018, aiming at the first lasing at the beginning of 2026.

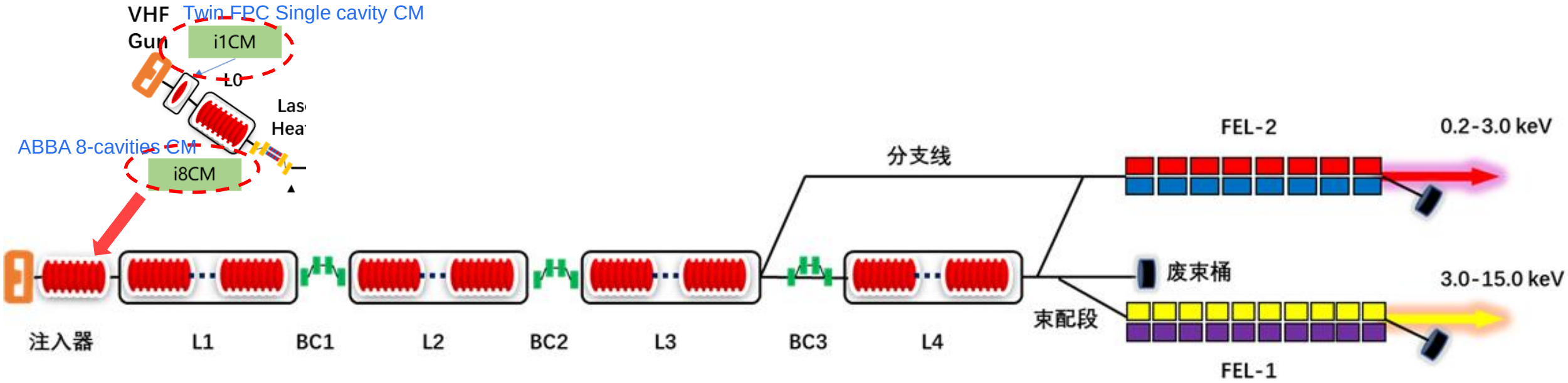
This facility is being developed by Shanghai-Tech Univ., SARI and SIOM of CAS.

The SHINE Linear Accelerator

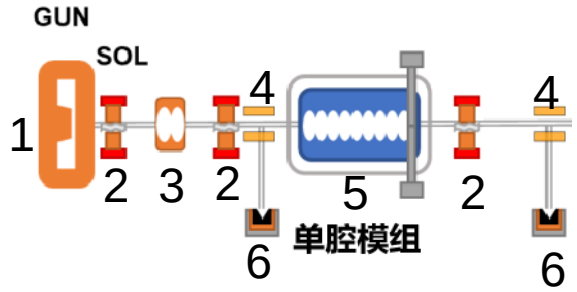
- **The SHINE Accelerator** consists of
  - An injector section: 750kV/217MHz photo cathode VHF gun, a two-cell buncher, a single-cavity CM and an eight-cavity CM;
  - A laser heater section;
  - Four sections of 1.3GHz standard SRF CMs, and one section of 3.9GHz SRF CMs;
  - Three magnetic bunch compression sections;
  - A dechirper section at the end;
  - In addition, a bypass line dedicated to FEL-II.



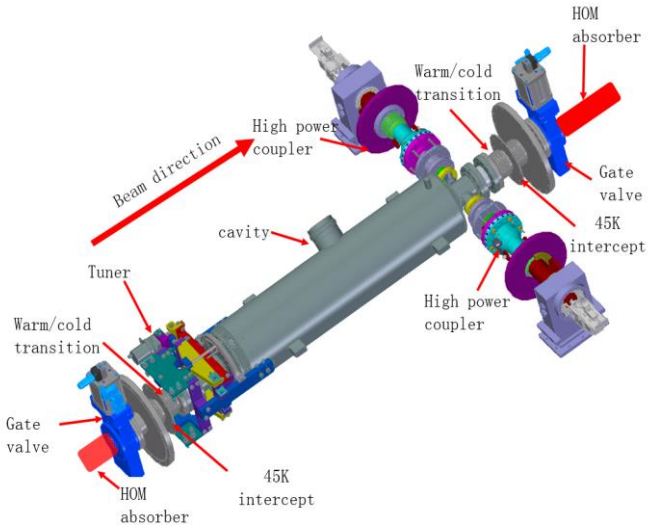
Layout of SHINE SRF Accelerator



1 GUN 2 Solenoid 3 Buncher 4 Bend 5 cavity with twin FPC 6 Dump



- ✓ **Reduce RF kick**
- ✓ **Suppression the influence on Emittance**



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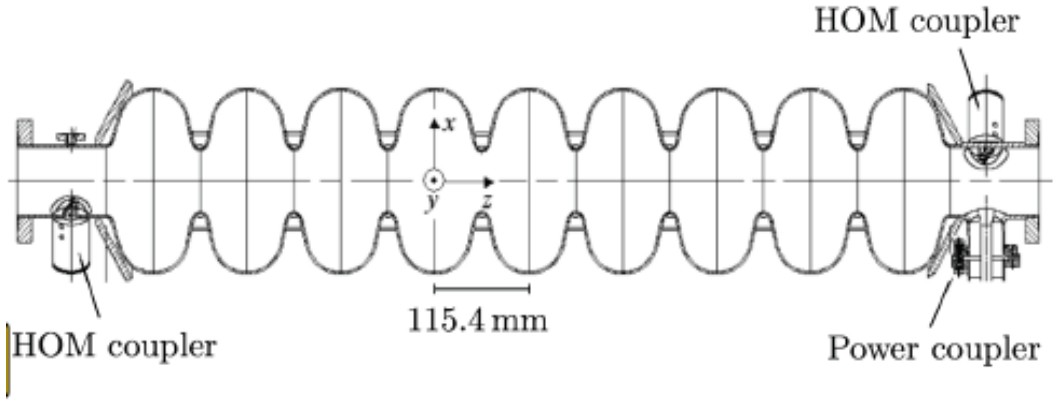
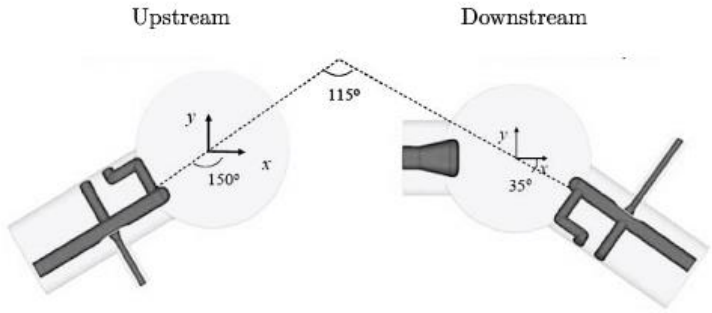
Influence of TESLA type cavity





Beam

Asymmetric increase beam emittance

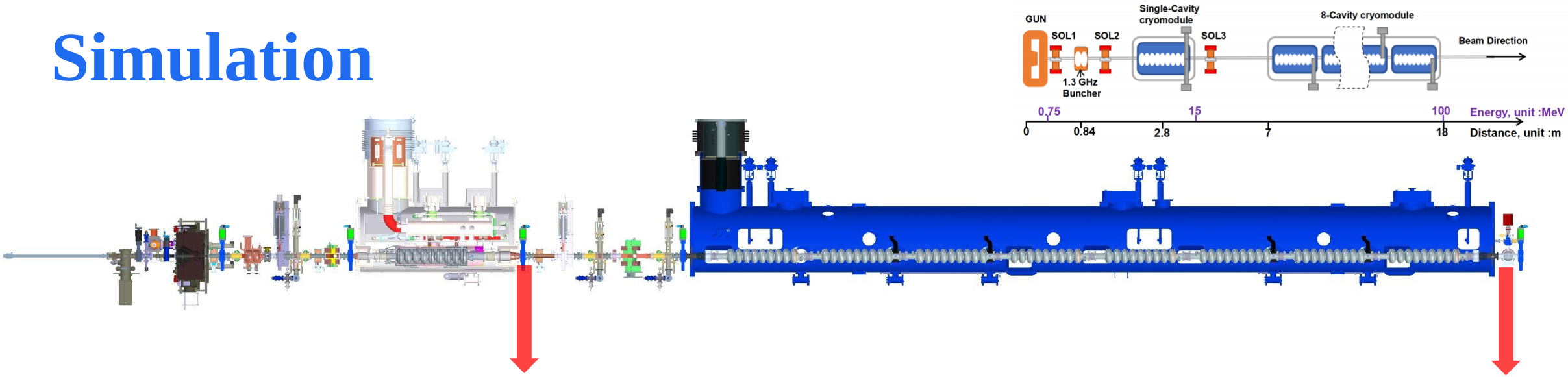
- **RF kick from FPC**
- **Perturbation from upstream HOM coupler**
- **Simulation shows emittance will increase about 24%, if using standard TESLA cavity**

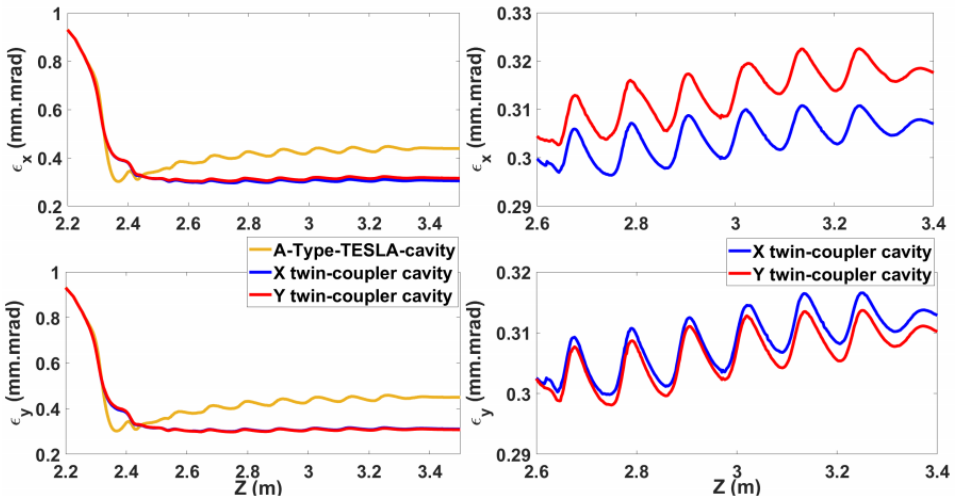
Cavity with twin FPCs

- **Axial symmetry cavity**
- **Enlarged beam pipe at downstream for HOM propagation**
- **Eliminate HOM couplers**
- **Twin FPC located downstream**

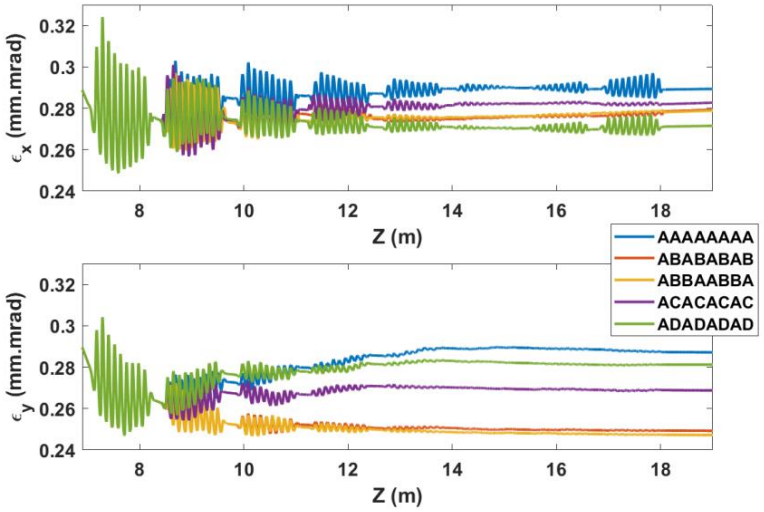
[1] Junjie Guo et al 2024 JINST **19** P02029, "Coupler RF kick and emittance optimization of the SHINE injector"

Simulation





- The emittance growth of the symmetrical twin-coupler cavity is much lower than that of TESLA cavity



- Both ϵ_x and ϵ_y are smaller than 0.3 after twin-FPC cavity CM and ABBA CM

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Worldwide cavities with Twin-FPC

Cornell ERL injector

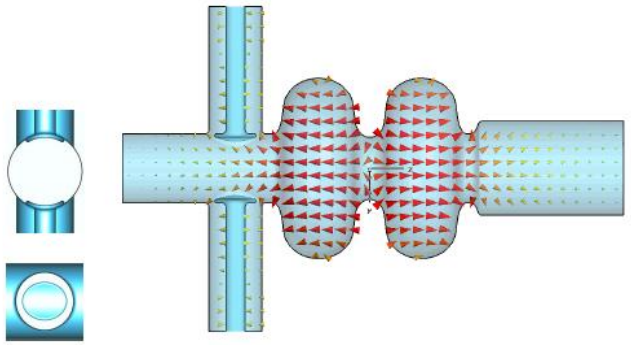
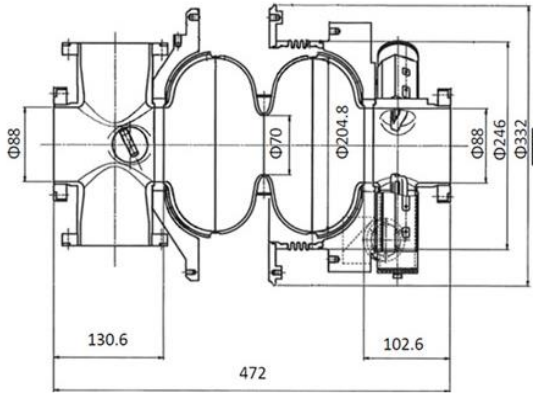
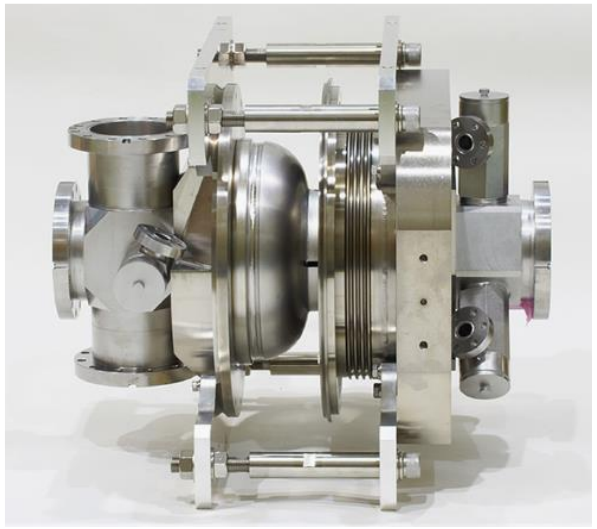


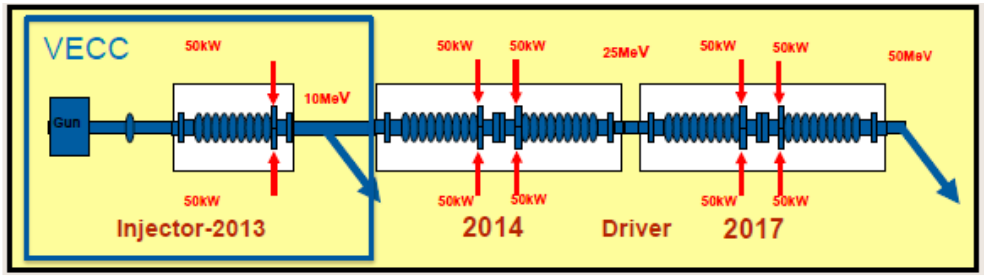
Figure 1: Input coupler in the injector cavity.

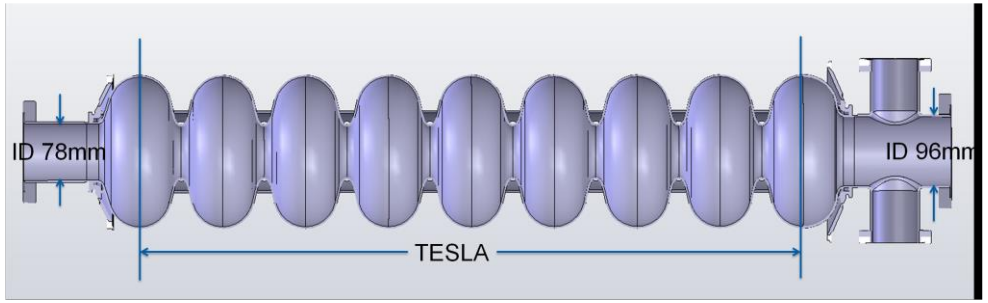
KEK cERL injector





Triumph e-linac





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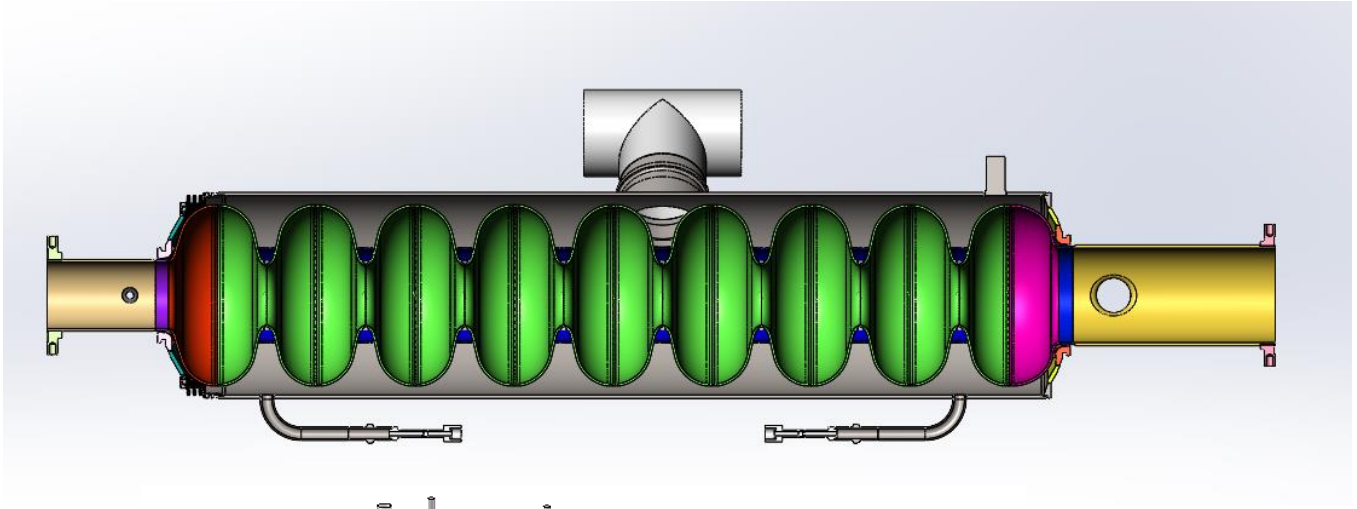
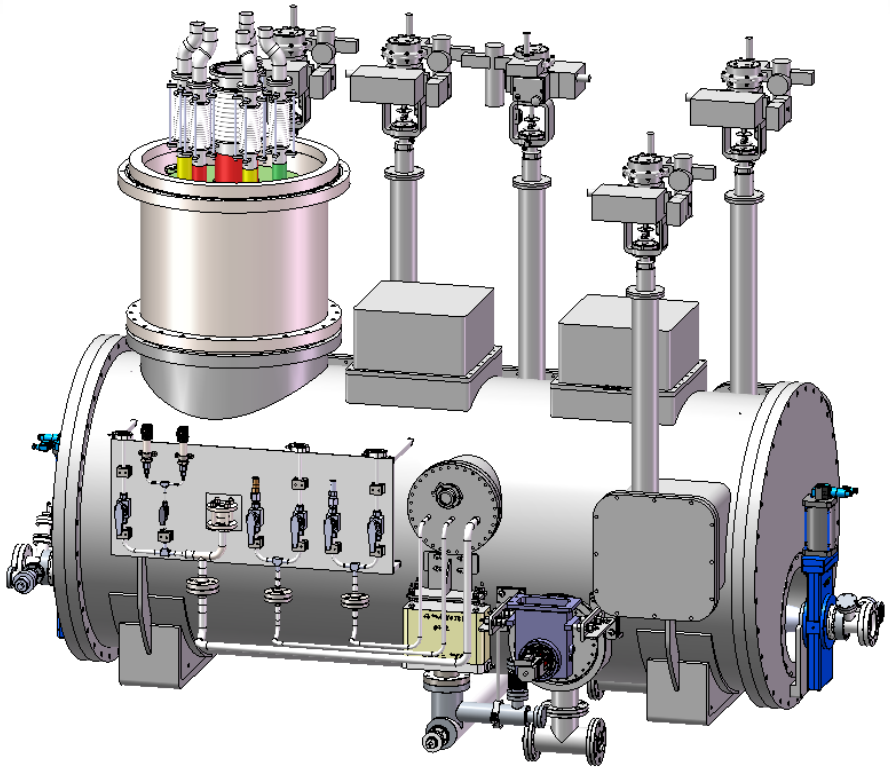
Development of Cavity and CM

Design of the cavity

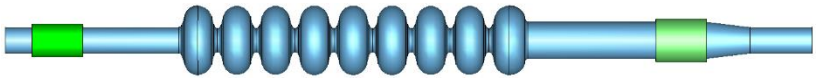
- Axial symmetry cavity
- Enlarged beam pipe at downstream for HOM propagation
- Eliminate HOM couplers
- Twin FPC located downstream
- Using CST、Mutipac、Ansys
- Beam pipe HOM absorber

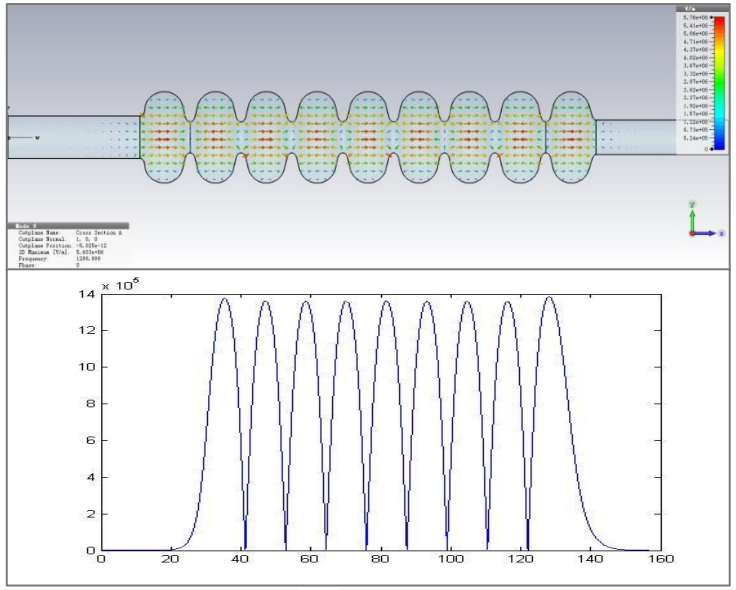


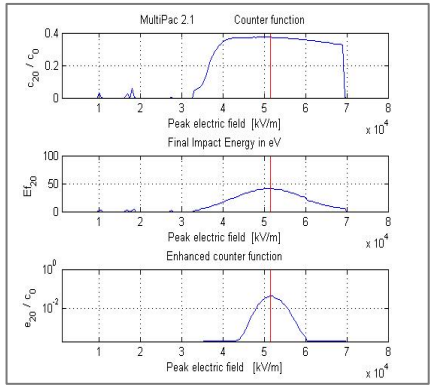


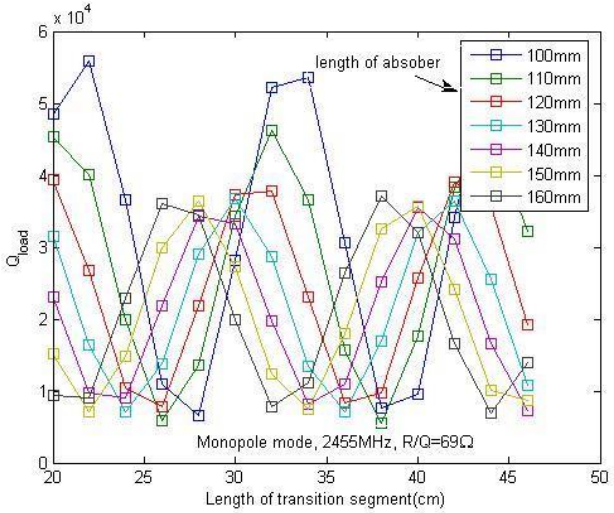
Simulation Results

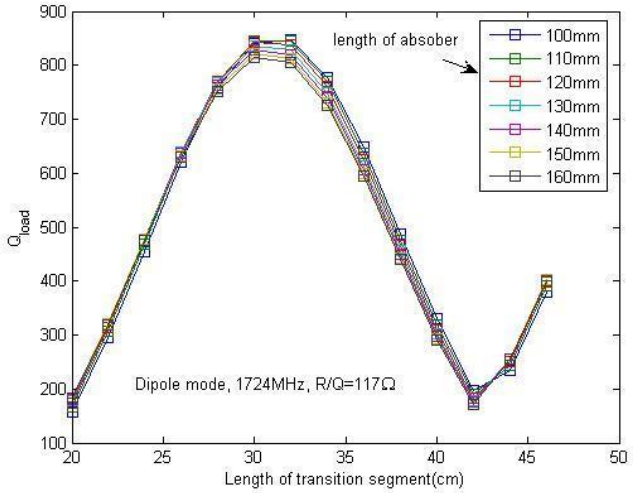
Epeak/Eacc	Bpeak/Eacc (mT/(MV/m))	R/Q (Ω)	G (Ω)	f (MHz)	flatness
2.0	4.2	983.4	273.6	1300.0001	98.3%

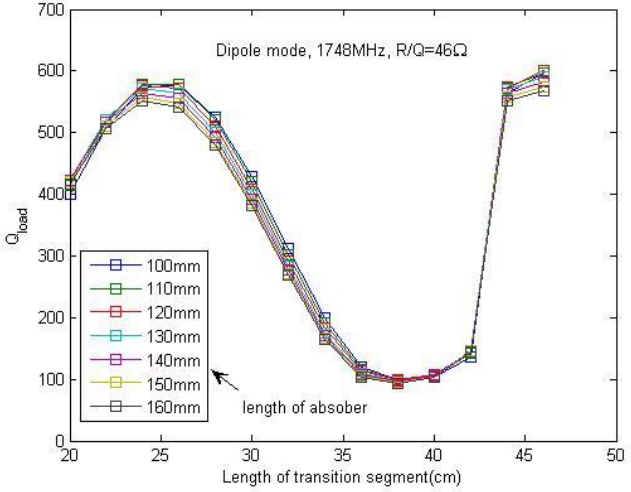


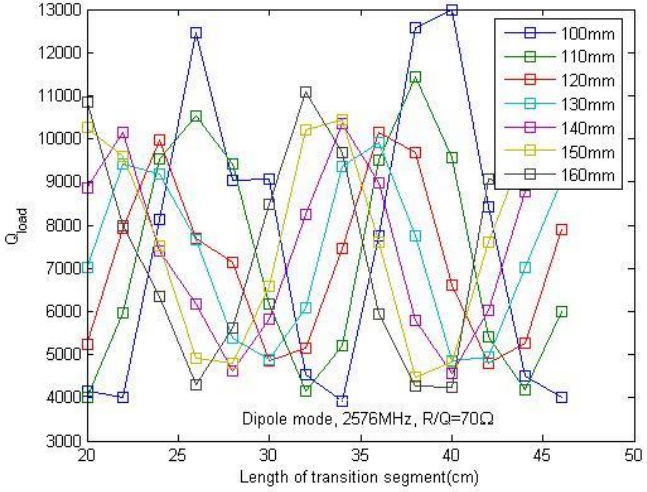












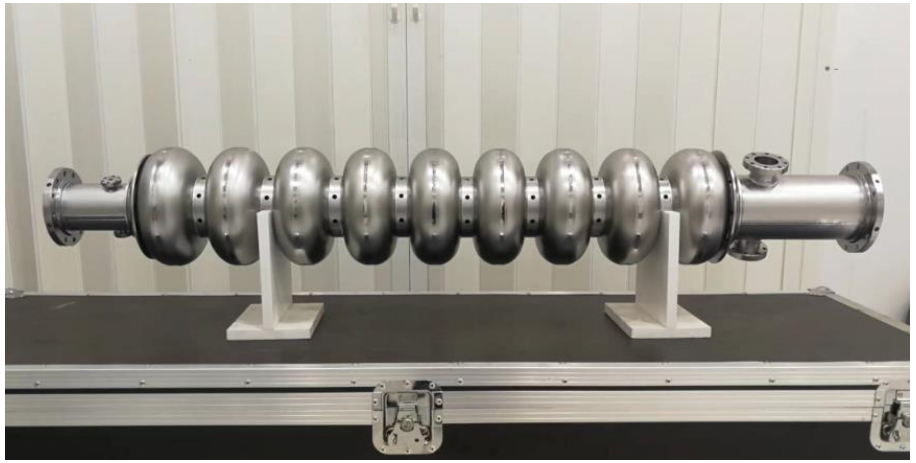
Ql of monopole and dipole modes with different HOM absorber locations

Fabrication

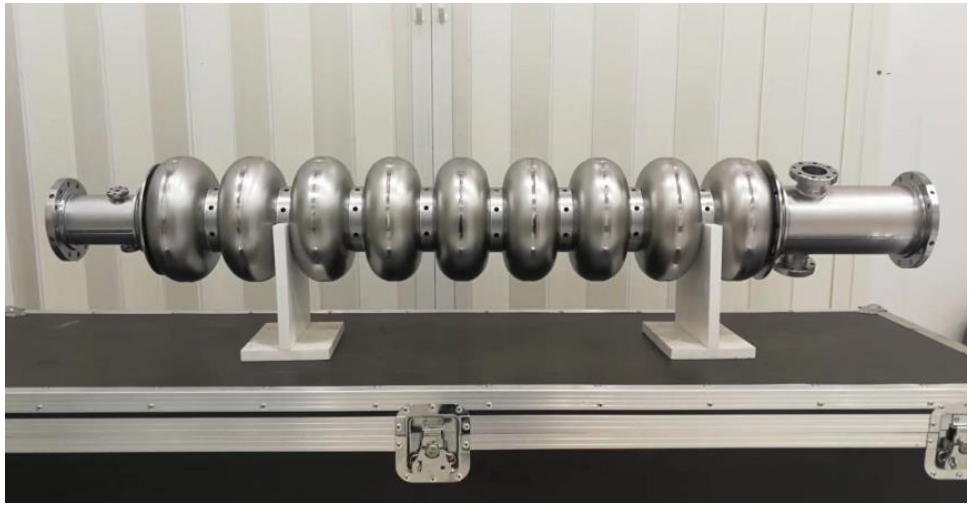
- High purity Nb material
- Deep drawing
- Electron beam welding
- BCP treatment
- Helium vessel welding
- Vertical test

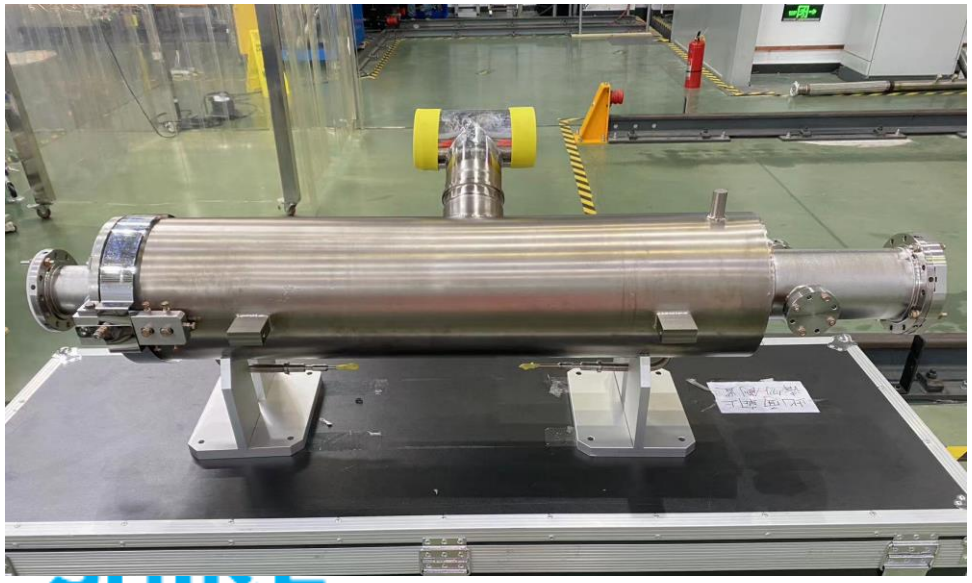
Specification

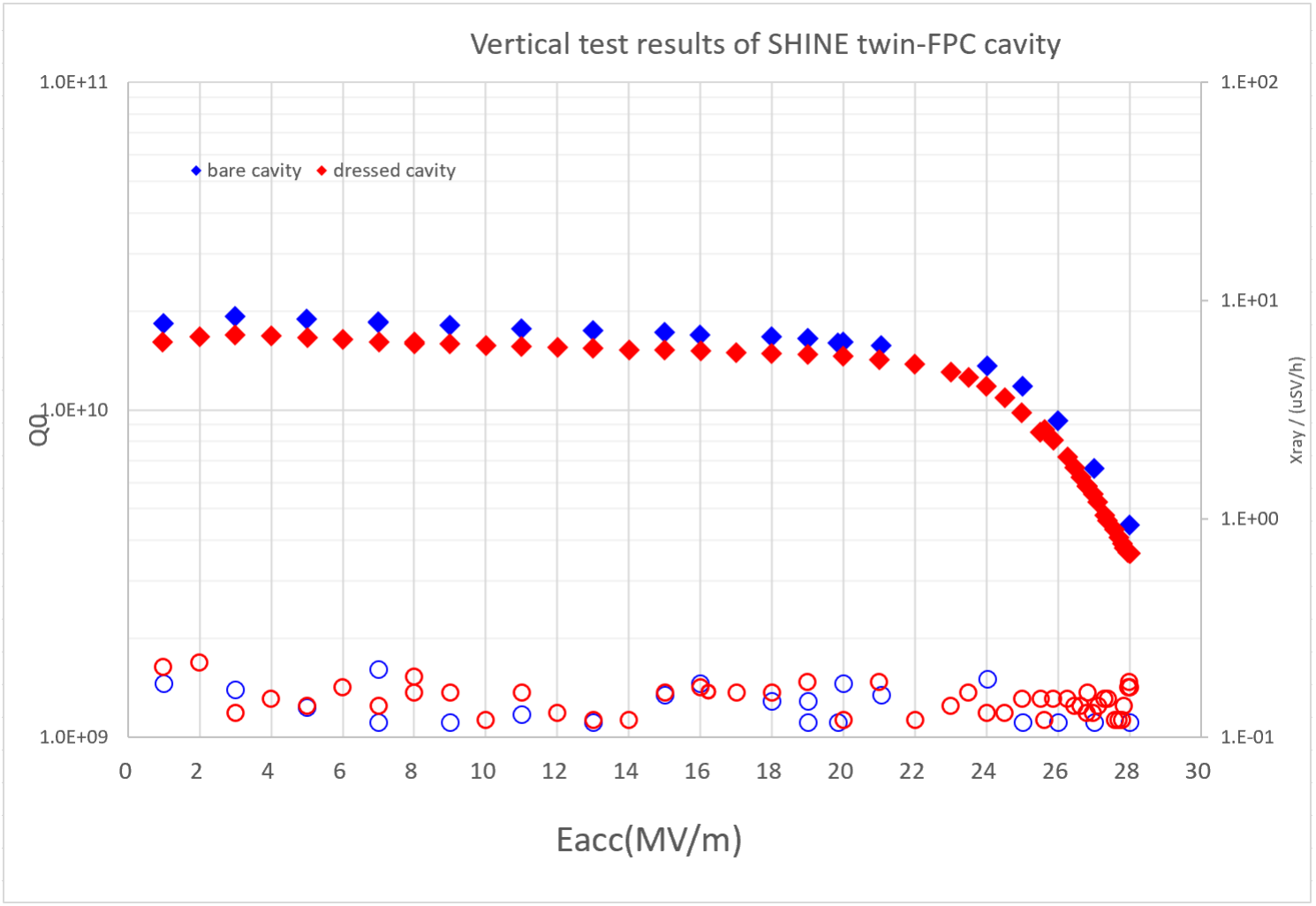
- Frequency：1300.2+/- 0.1 MHz @ 2.0 K， field flatness ≥ 90%（dressed cavity）
- Q0> 1.5 e10 @ Eacc=12 MV/m，Eacc_max ≥ 19MV/m
- Low QL of HOM modes with high r/Q： QL < 1e6
- straightness ≤0.4 mm，length ≤+/- 3.0 mm，shape accuracy ≤+/- 0.5 mm
- Leakrate ≤ 1e-10 mbar l/s
- Pressure test of dressed cavity: 0.23 MPa



Vertical test results: f=1300.146 MHz @ 2K, Q_0> 1.5 e10 @ E_{acc}=12 MV/m， E_{acc_max} ~28MV/m







Coupler

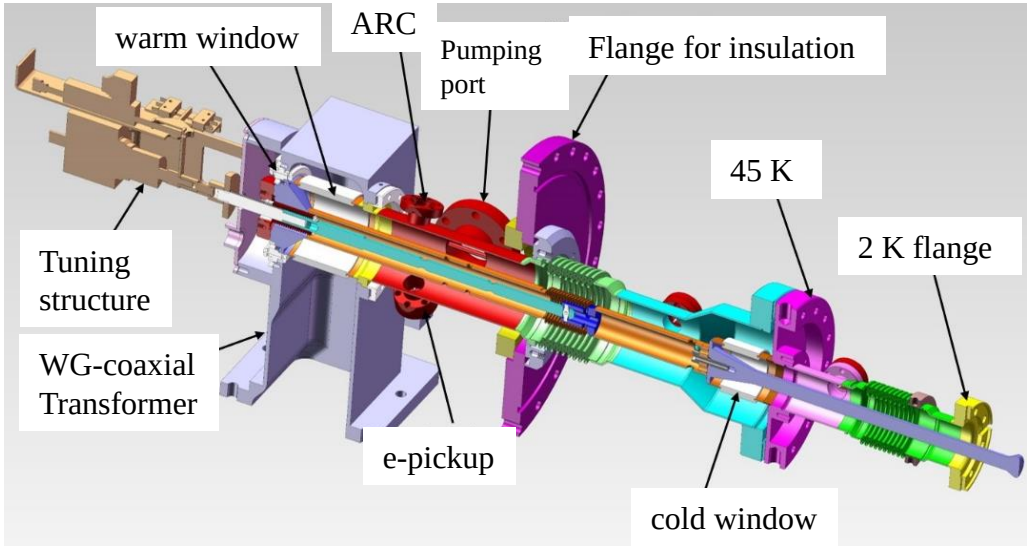
E_{acc}=12MV/m、Q_0=1.5×10^{10}，Q_e=3.53×10^7，assuming frequency detuning by microphonics δf=10 Hz，with 15% power loss

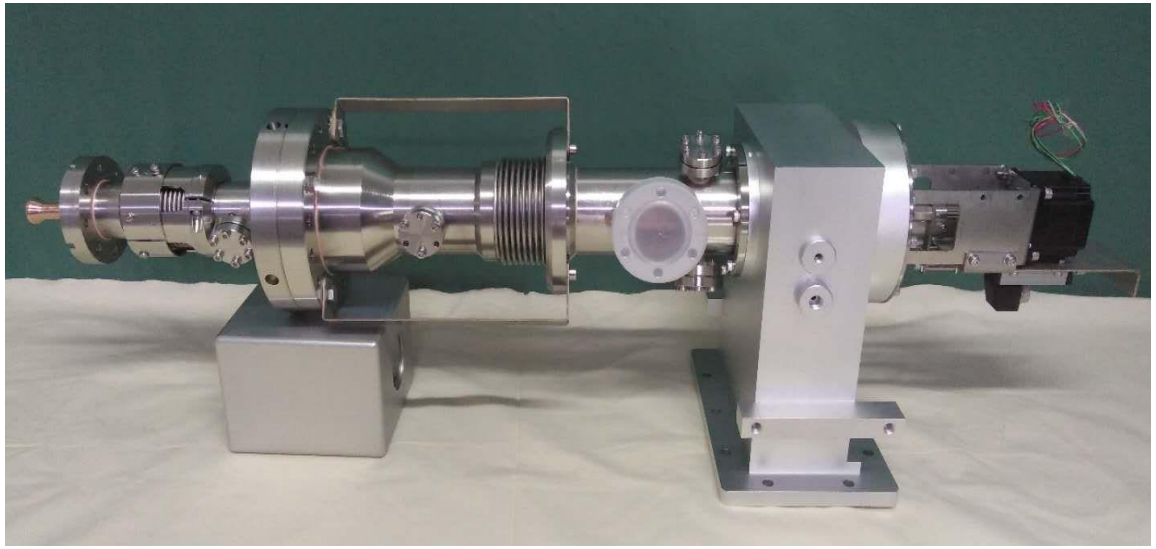
$$P_f = \frac{V^2}{4(R/Q)Q_l} * \left[\left(1 + \frac{I * (R/Q) * Q_l}{V} * \cos(\emptyset)\right)^2 + \left(2 * Q_l \frac{\Delta f}{f} + \frac{I * (R/Q) * Q_l}{V} * \sin(\emptyset)\right)^2\right]$$

Ib/mA	Pf/kW	Pb/kW	Pr/kW	Pf/KW (single FPC)
0	1.66	0	1.66	0.83
0.05	2.05	0.62	1.43	1.025
0.1	2.48	1.25	1.23	1.24
0.15	2.96	1.87	1.09	1.48
0.2	3.5	2.49	1.01	1.75
0.25	4.08	3.11	0.97	2.04
0.3	4.71	3.74	0.97	2.355

Coupler

Parameters	Spec.
Operation Power	1.24 kW（0.1mA）
Max. Power	2.40 kW（0.3mA）
Qext	7.0×10^{7}
Qext_range	$3.0\times10^{7}\sim1.0\times10^{8}$





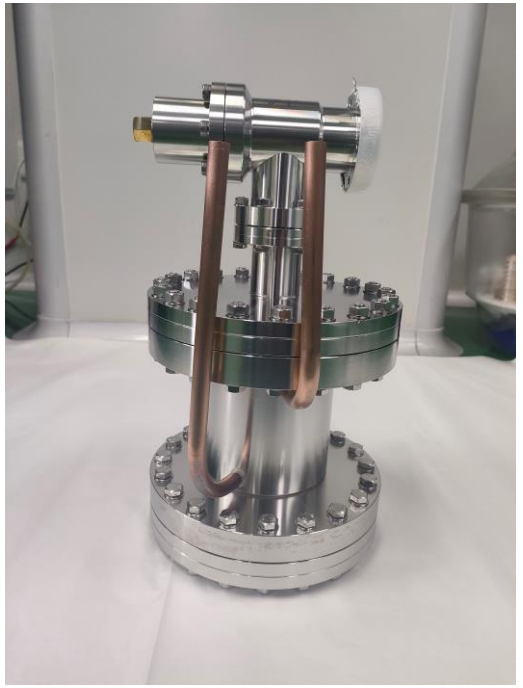
SHINE

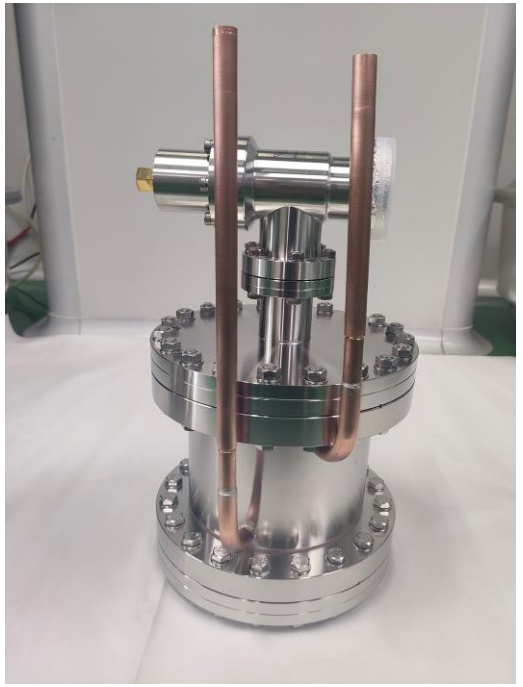
Length of inner connector is 23.5 mm shorter compared to standard one

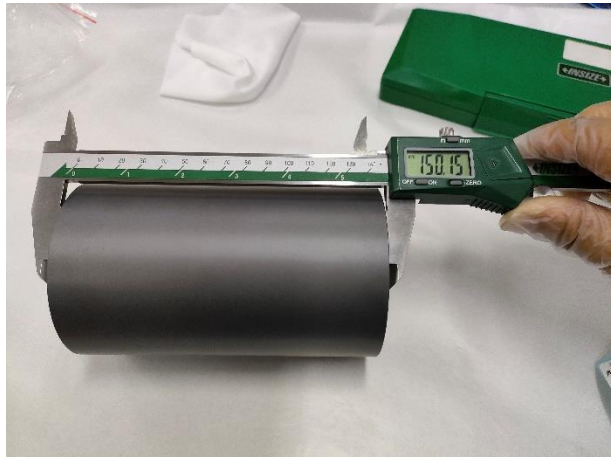
HOM absorber

- Beam line type
- SiC Material
- Shrinkage method
- PU side: ID80 *OD90*L=150mm
- FPC side: ID110

  *OD130*L=150mm

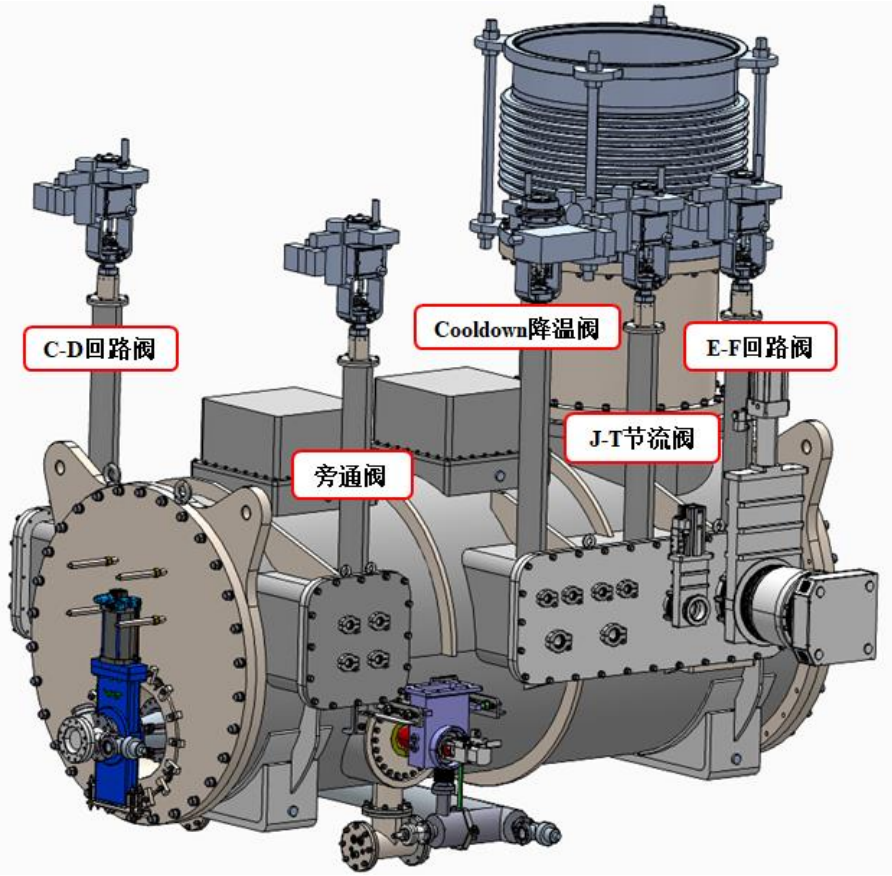






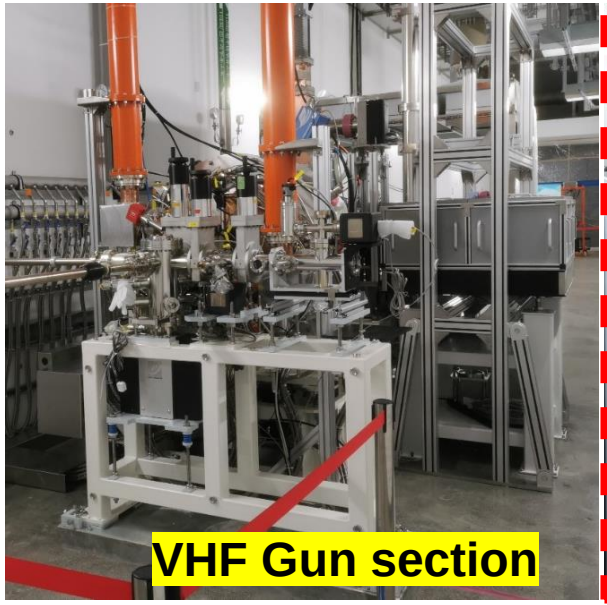
Cryostat

- Vacuum vessel, thermal shielding, magnetic shielding……
- No 5K shielding



Installation and Commissioning

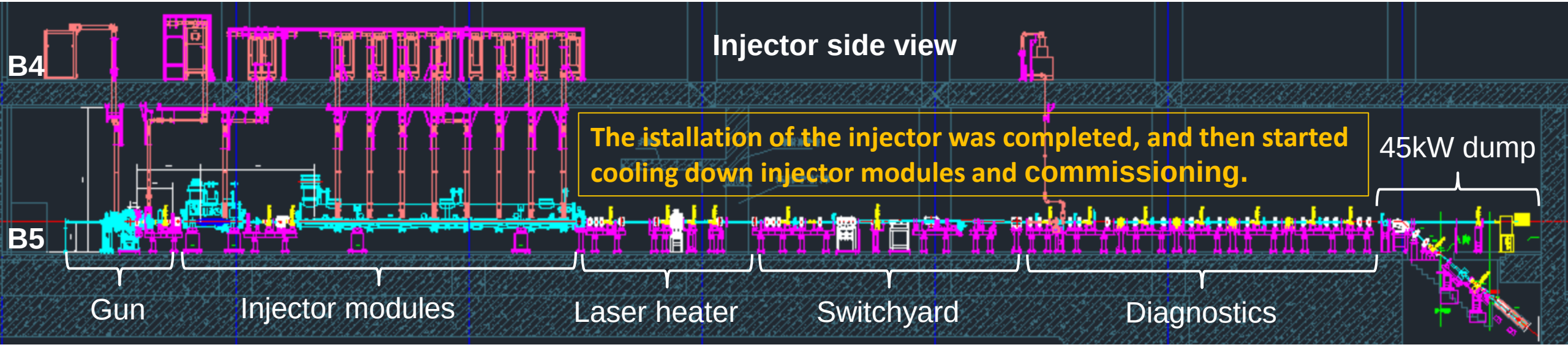
Injector: Installation and Beam commissioning


VHF Gun section


i1CM section


i8CM section

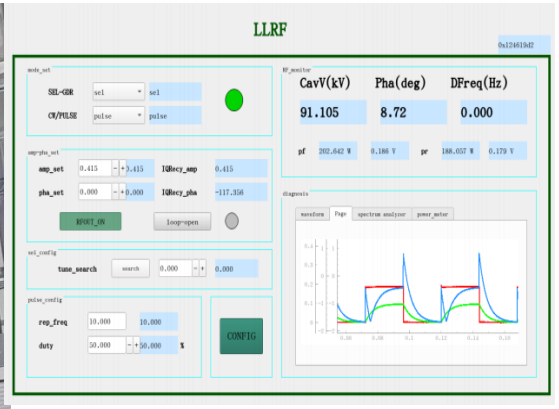

Laser heater



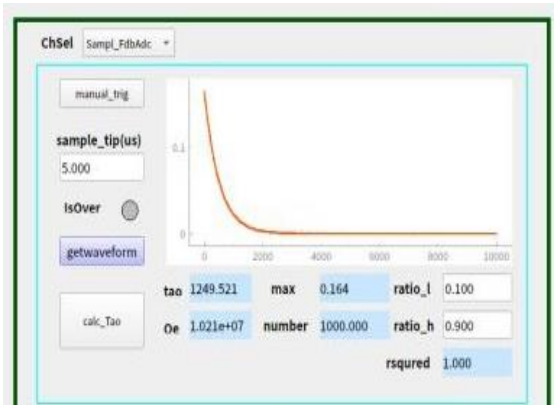
1.3GHz i1CM LLRF commissioning

i1CM=twin FPC CM

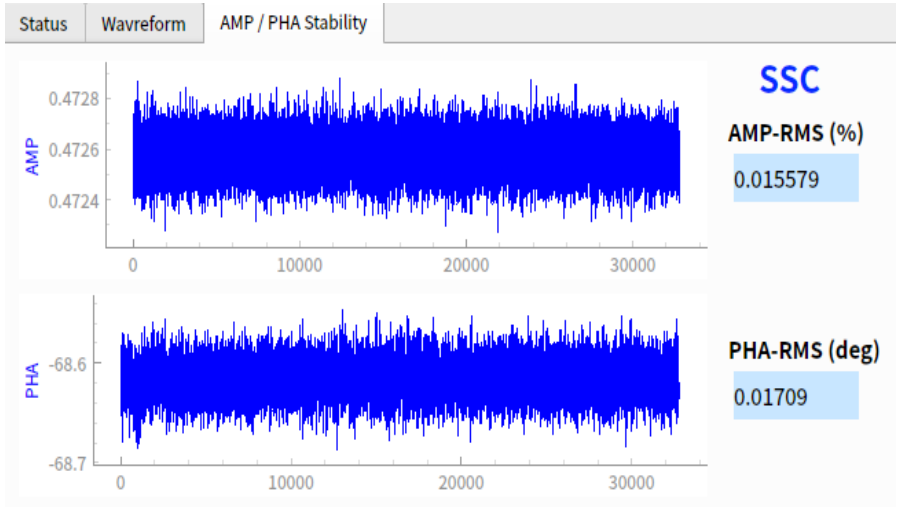
Waveguides mounting in injector section

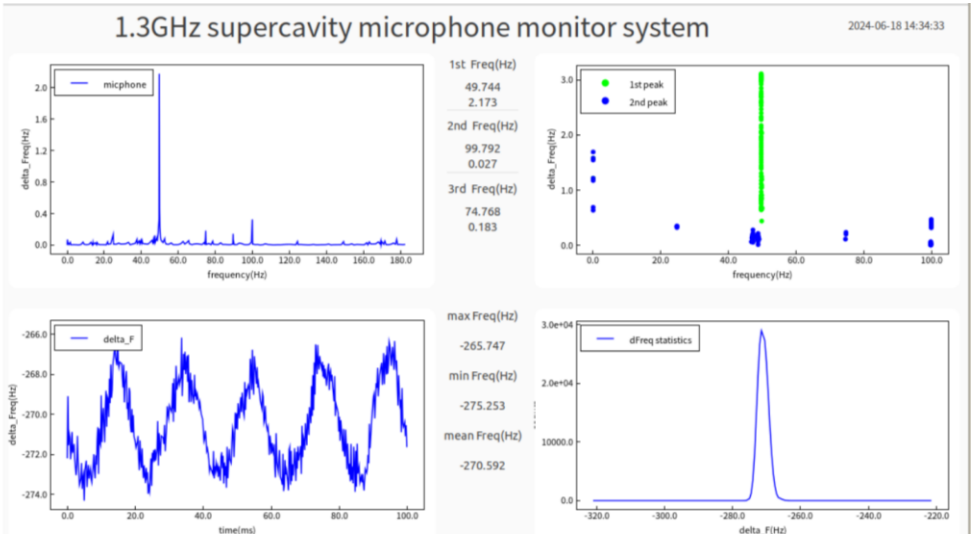


Operation GUI



Qe measurement GUI





Real-time microphonics monitor based on DMA

Dual-fed cryo-module	Required	Measured
Amplitude Stability (RMS, %)	0.02	0.016
Phase Stability(RMS, deg)	0.02	0.017

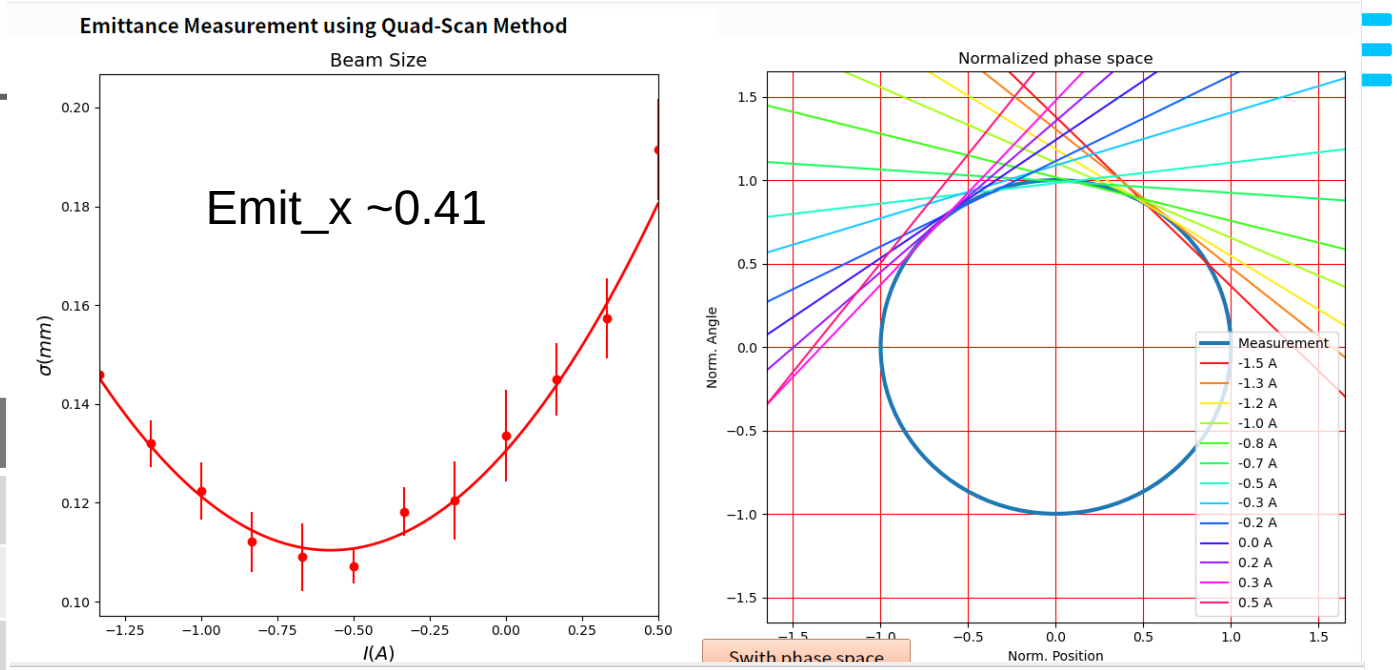
Several tools, including microphonics monitor, Qe measurement, microphonics suppression, have been integrated.

[3] Houjun Qian, 3rd SHINE Machine Advisory Committee Meeting

Emittance scan

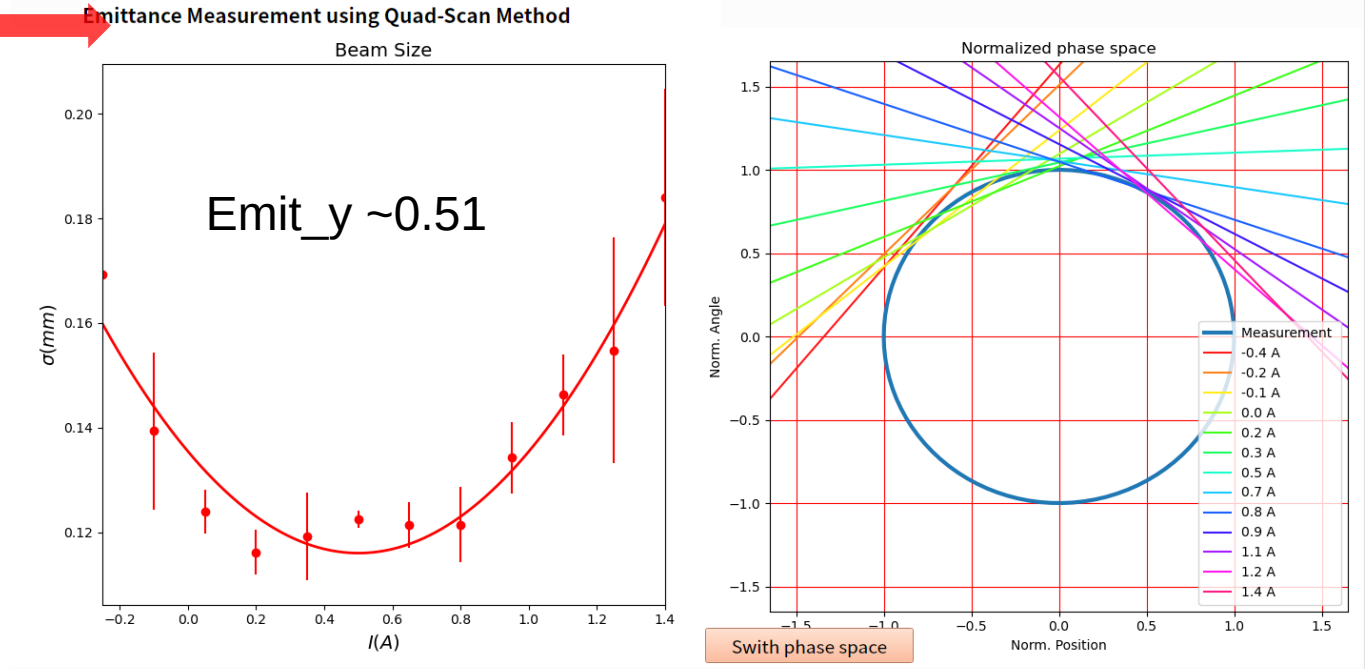
- 50 pC results

50pC/12.5A	1	2	3	average	Unit
X	0.40	0.40	0.44	**0.41±0.03**	mm mrad
Y	0.50	0.51	0.52	**0.51±0.01**	mm mrad
Slice	0.328	0.268	0.384	**0.33±0.06**	mm mrad



- 100 pC results

100pC/10A	1	2	3	average	Unit
X	0.62	0.53	0.57	**0.57±0.04**	mm mrad
Y	0.55	0.56	0.55	**0.55±0.01**	mm mrad
Slice	0.38	0.48	0.46	**0.44±0.13**	mm mrad



SHINE

[3] Houjun Qian, 3rd SHINE Machine Advisory Committee Meeting

Summary

Summary

- One twin-FPC CM has been developed for SHINE injector to decrease the influence on emittance
- SC cavity, HOM absorber and cryostat are fabricated by domestic company
- Injector beam commissioning succeeded in 2024