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Institute of High Energy Physics
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Status of the CEPC HOM Coupler Development

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Contents

- Damping requirements & scheme
- HOM coupler R&D
- Cryogenic test
- Summary

HOM Challenges for CEPC

- The obvious impact on SRF system is the cavity HOM power, HOM CBI, especially for Z.
- CDR Z-pole (460 mA, 12.8 nC)
  - 2 kW estimated average HOM power per cavity.
  - Assume all the power go through HOM coupler (impossible), 500 W power each.
  - Actually much less power through HOM coupler (below cut-off only 25 W each).
  - HOM coupler design power 1 kW is much more than enough.
- Simulation and experiment on HOM power generation and propagation through multi-cavity string and HOM couplers and absorbers. Cold components heating. Give input to practical HOM damping scheme and cryomodule design for **HL Z**.
- Optimize HOM damping of most dangerous mode to the CBI growth time that longitudinal bunch-by-bunch feedback system can deal with. Cavity shape and asymmetry, beam pipe diameter, HOM coupler shape and orientation, (artificial enlarged) HOM frequency spread.

Parameters of the CEPC Main Ring (CDR)

Parameter	Higgs	W	Z
nus	0.065	0.04	0.028
Nux/nuy	363.10 / 365.22		
Energy（GeV）	120	80	45.5
alphp	1.11E-5		
Rising time（ms）	51.6	19.6	2.3
Natural damping time(ms)	46.5	156.4	850
Revolution time（ms）	0.33		
Bunch number	242	1524	12000
Bunch space（ns）	680	210	25
Current（mA）	17.4	88	461
Cavity number	240	120	120

- Z is the most dangerous mode which need feedback system.
- Fast beam ion instability is dominant.
- Damping time requirement for transverse feedback : <2.3ms

HOM CBI Threshold

- For CDR design, the designed Qe is 1E4
- The CBI for Z mode is a problem

Modes	*f* (GHz)	*R*/*Q* (monopole Ω, dipole Ω/m)	Q_e designed	CBI Growth Time (ms)		
				H (240 cavity)	W (120 cavity)	Z (120 cavity)
TM011	1165.574	65.2	1E4	440.55	142.08	**10.95**
TM020	1383.898	1.3	1E4	18754	6048.29	466.29
TE111	844.738	279.8	1E4	228.37	120.82	13.10
TM110	907.592	420.1	1E4	152.13	80.49	**8.73**

Design Considerations of HOM Coupler

Requirements / Specification

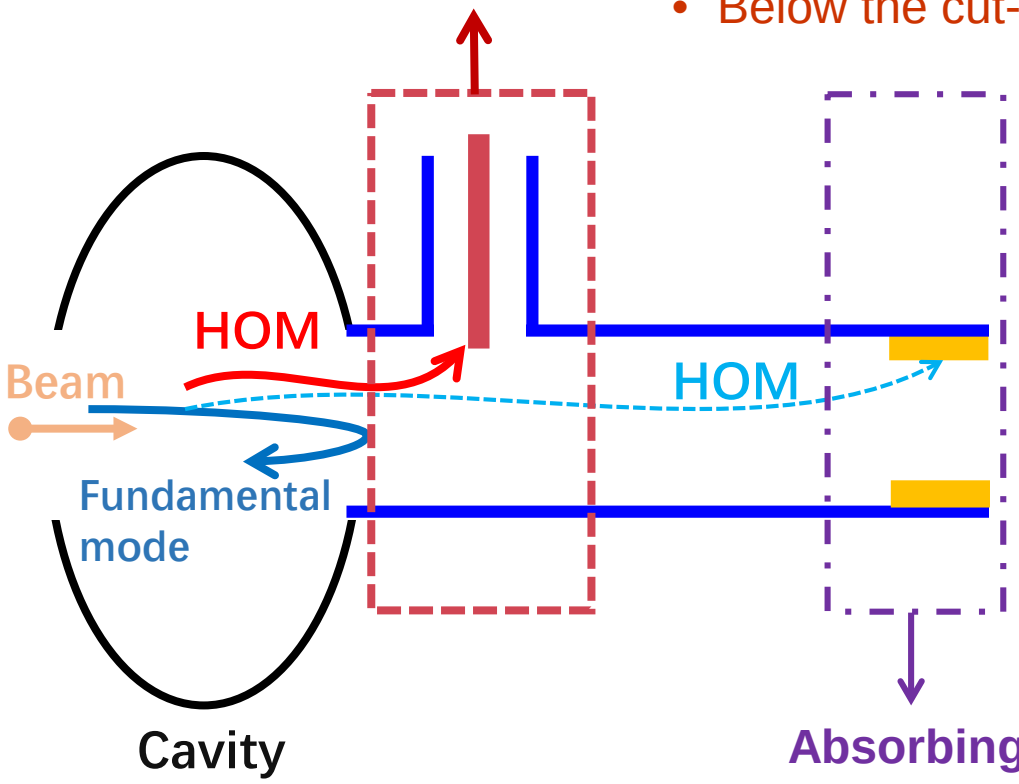
- Frequency
- Damping
- Maximum Power
- Operation Mode
- Heat Load

Choice

- Type: Coaxial or Waveguide
- Position: Cell or Beam Pipe
- Welded or Flange
- Number of Couplers
- Cooling
- Position of Loads

Hybrid damping

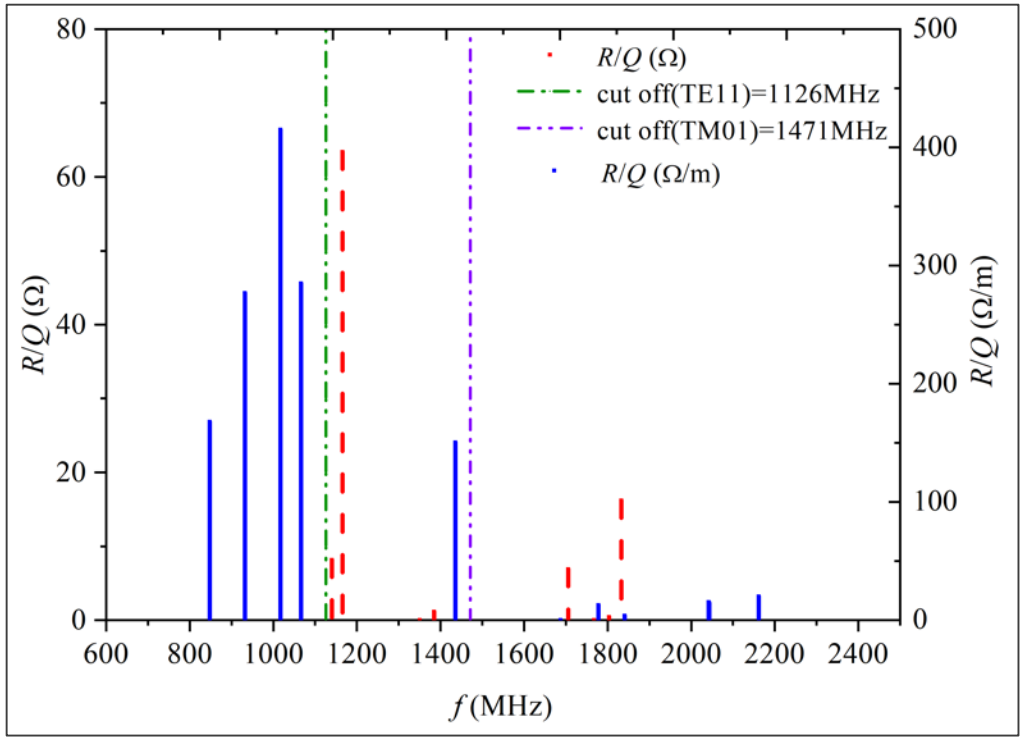
- E-field coupling or H-field coupling
- Below the cut-off frequency

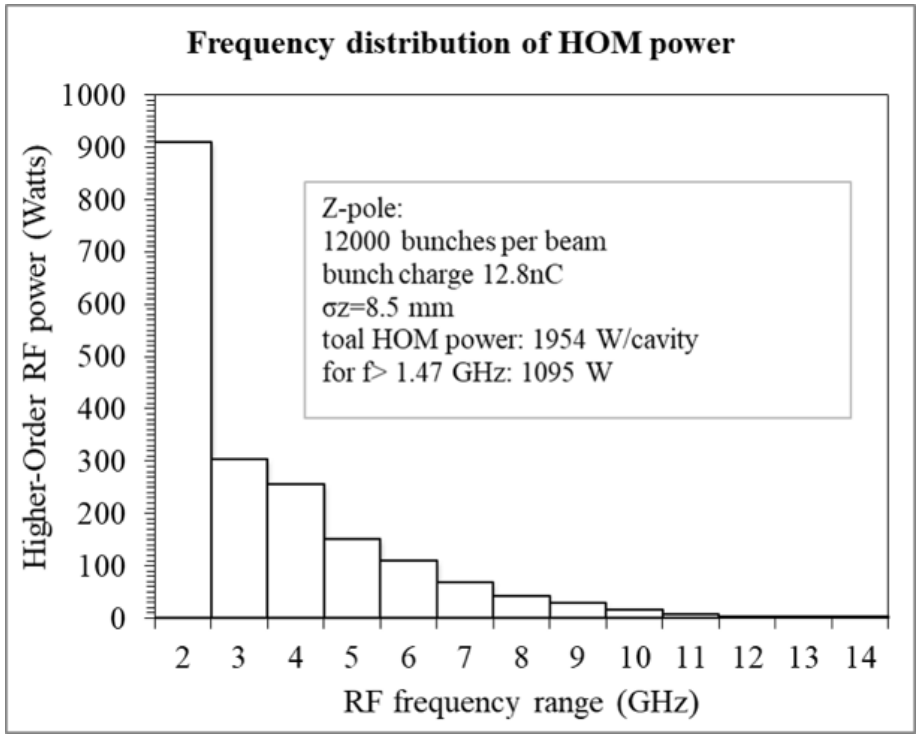


Absorbing material:

- Broadband
- Above the cut-off frequency

Cavity spectrum and HOM power



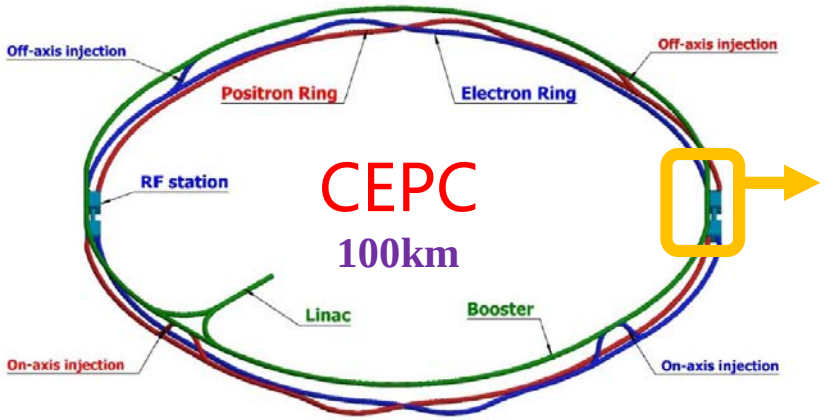


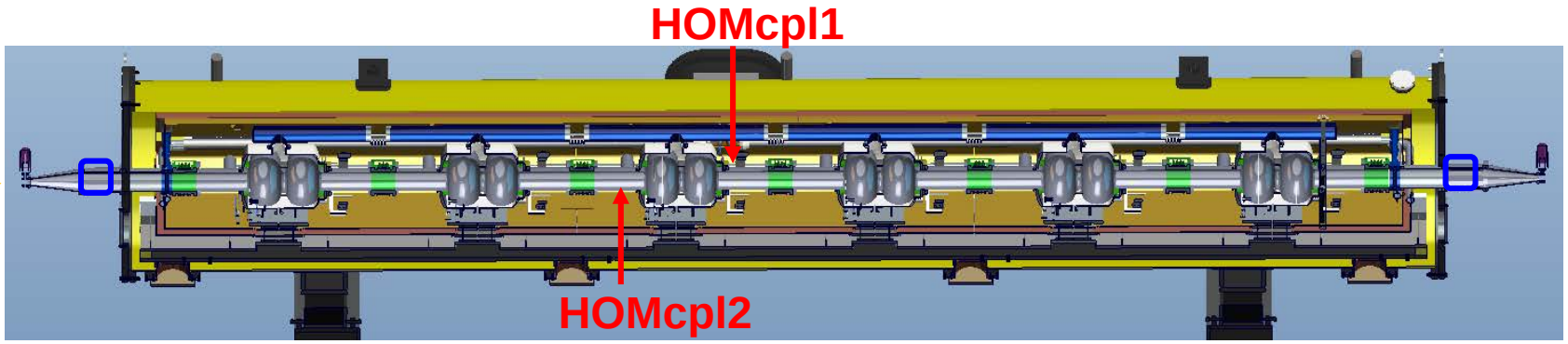
- ✓ Dangerous monople: ~1200MHz
- ✓ Dangerous diople: 800MHz ~ 900MHz, ~1200MHz

- ✓ **HOM coupler range: 800~1400 MHz**
- ✓ Beam pipe absorber range: 1.4 ~ 20 GHz

HOM coupler design

- Design scheme of HOM coupler: double-notch, coaxial LC filter
  - ✓ Wide bandwidth for fudamental mode
  - ✓ No need tuning for fudamental mode in actual
- Damping requirement for fundamental mode (TM010): Qe **>1×10^{11}**

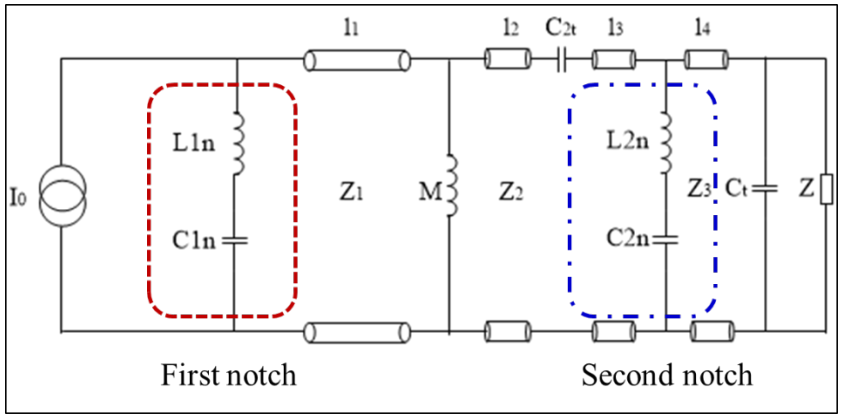


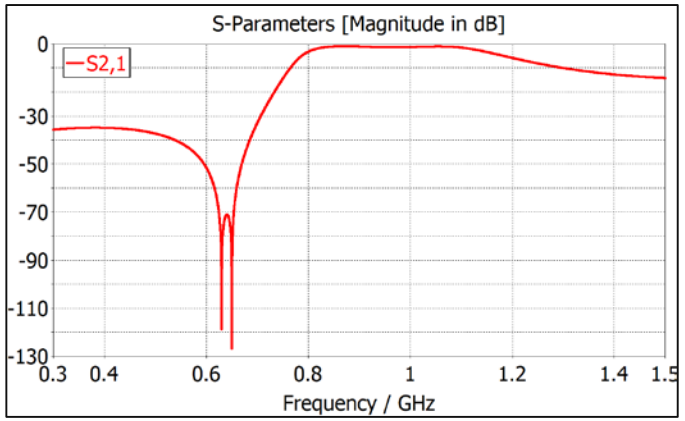


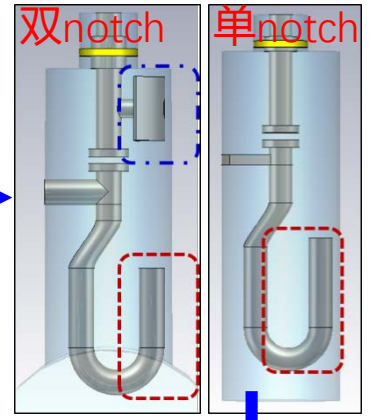
Collider 650 MHz Cryomodule (6x2-cell, 10 m)

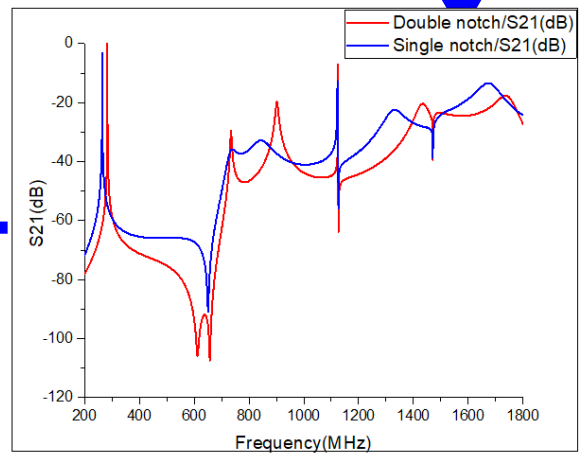
HOM coupler design approach

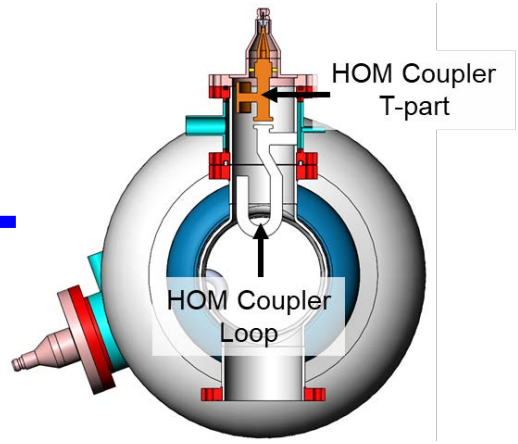
- Equivalent circuit (transmission line model) → Optimize each part according to S21 curve ↔ 3D structure ↔ Electromagnetic optimization design

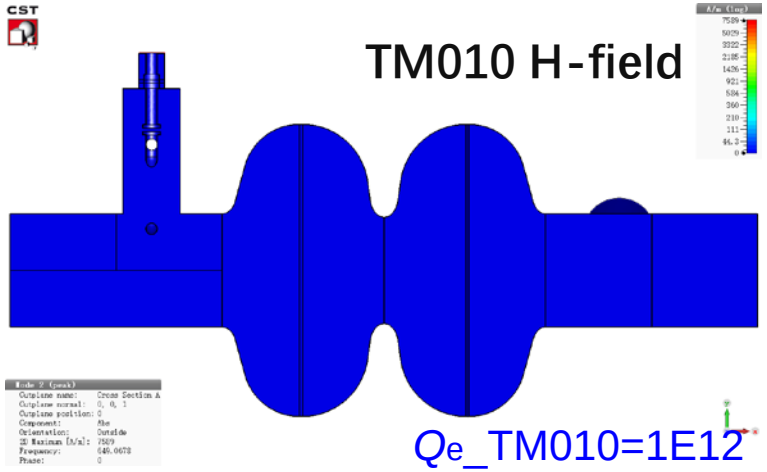






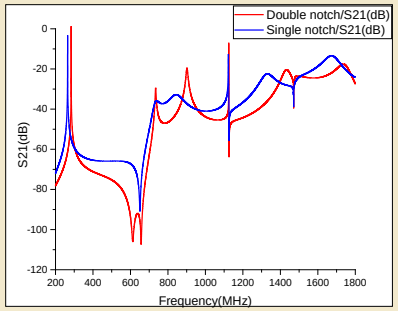




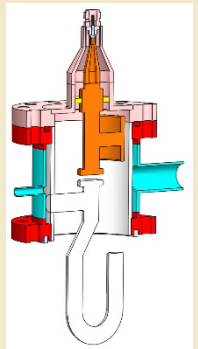


HOM coupler design contents

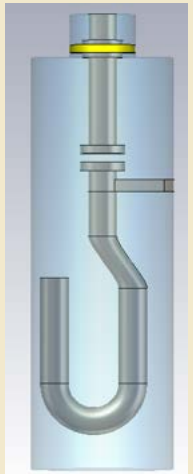
RF design

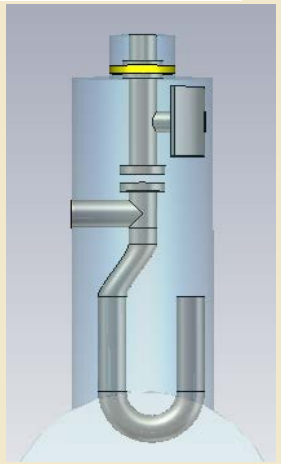


Mechanical designs



Design schemes for HOM coupler





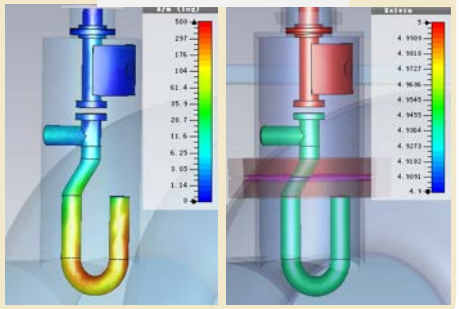
Single notch coupler

double notch coupler

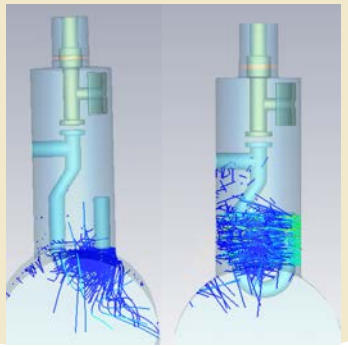
~ 1 kW power

2 kW/cavity, each direction 1 kW, assume 50 % coupled by the HOM coupler (0.5 kW).

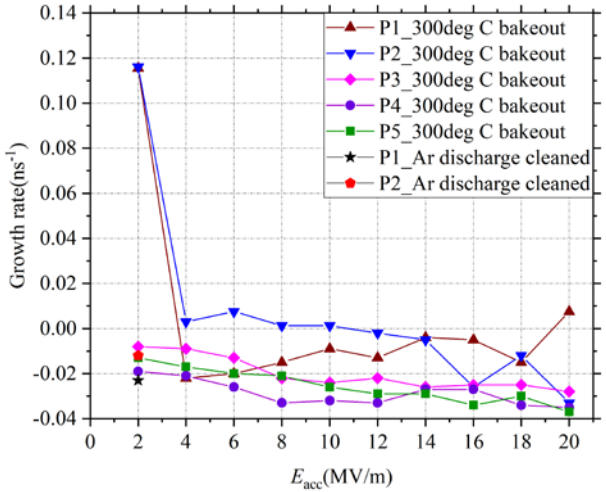
Heat loss



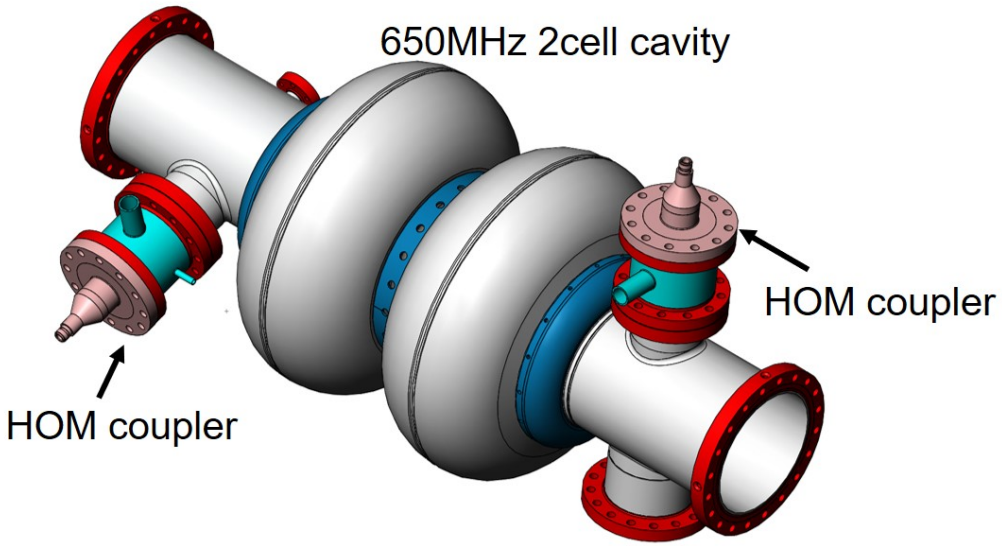
Multipacting analysis



- The power dissipation caused by the fundamental mode and 1 kW HOM was in the range of milli-watts.
- A helium tank is needed outside the HOM coupler.

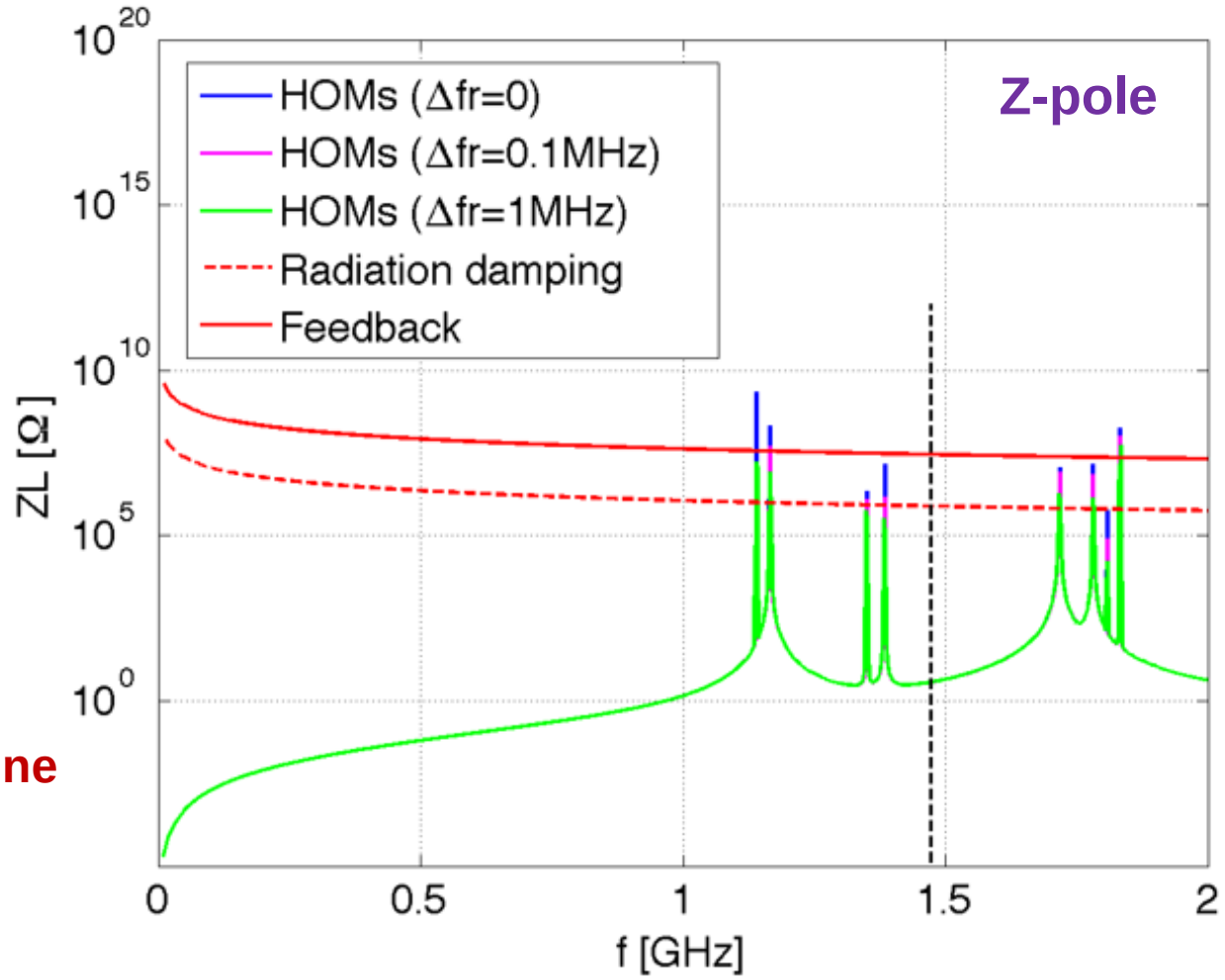


Damping results: longitudinal impedance

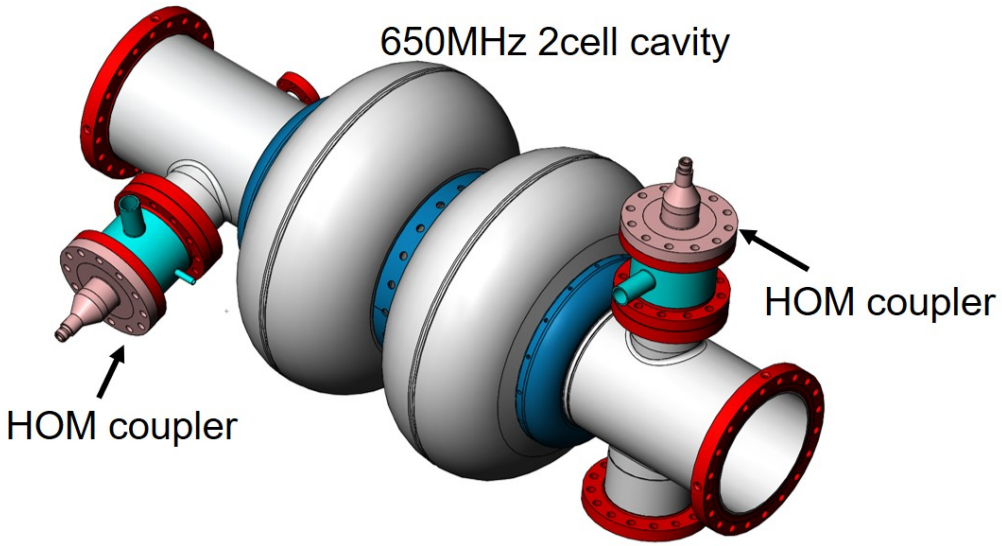


CEPC Z-pole (CDR)

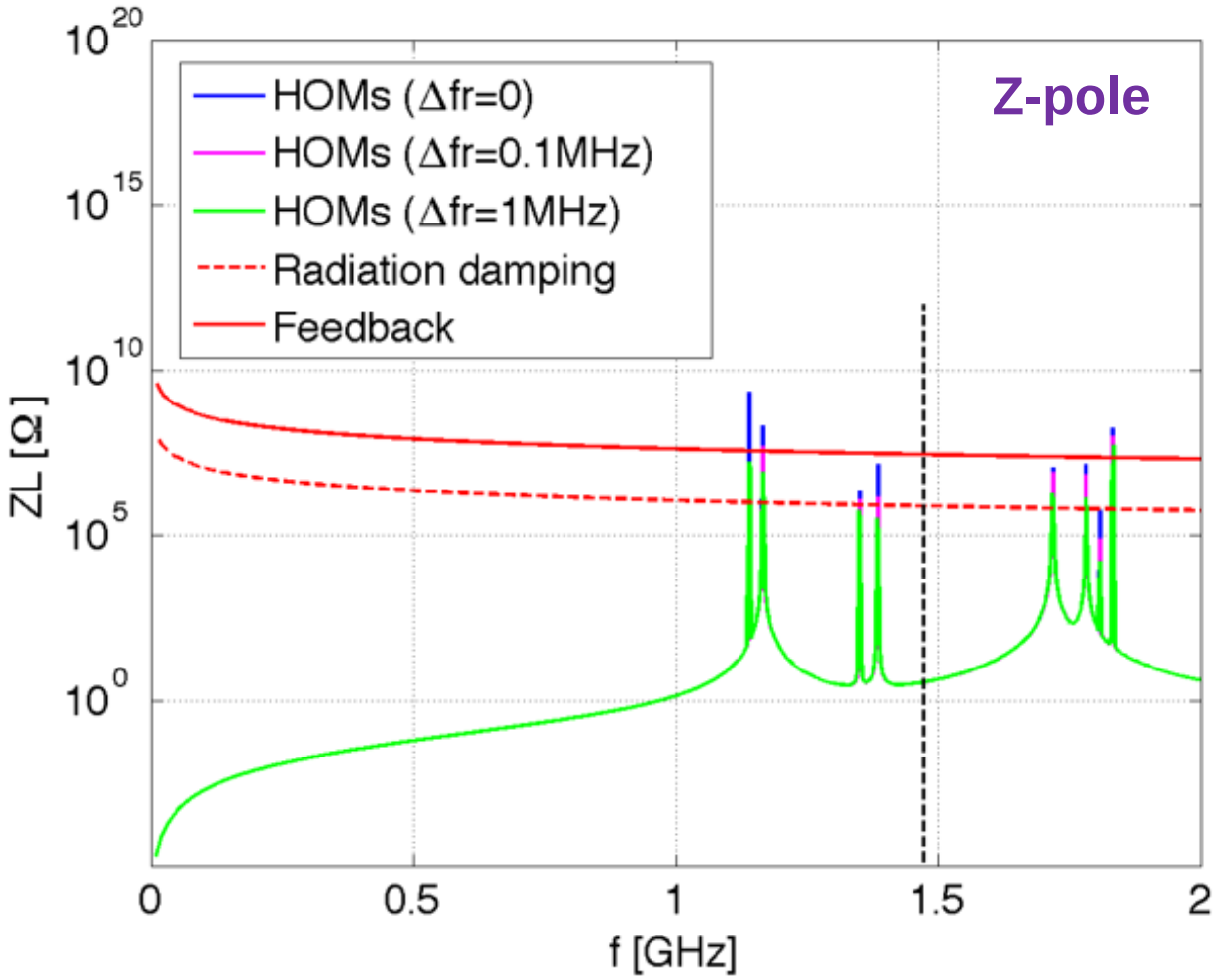
- Current~460mA, bunch charge~12.8nC
- **Same cavity design with Higgs, all cavity online**
- Limitation of luminorsity: HOM CBI
- **Strong damping requirements**
- Need longitudinal feedback
- Qe<1E4



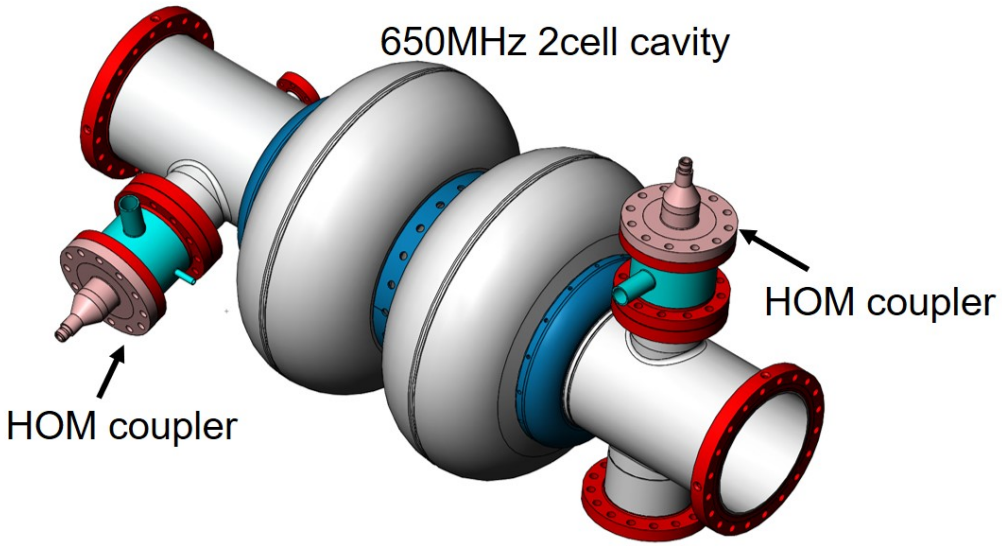
Damping results: longitudinal impedance



- Frequency spread ~1 MHz
- **All can meet the beam stability requirements if the feedback consider.**
- **HOMs propagate in multi-cavities is not considered.**



Damping results: transverse impedance



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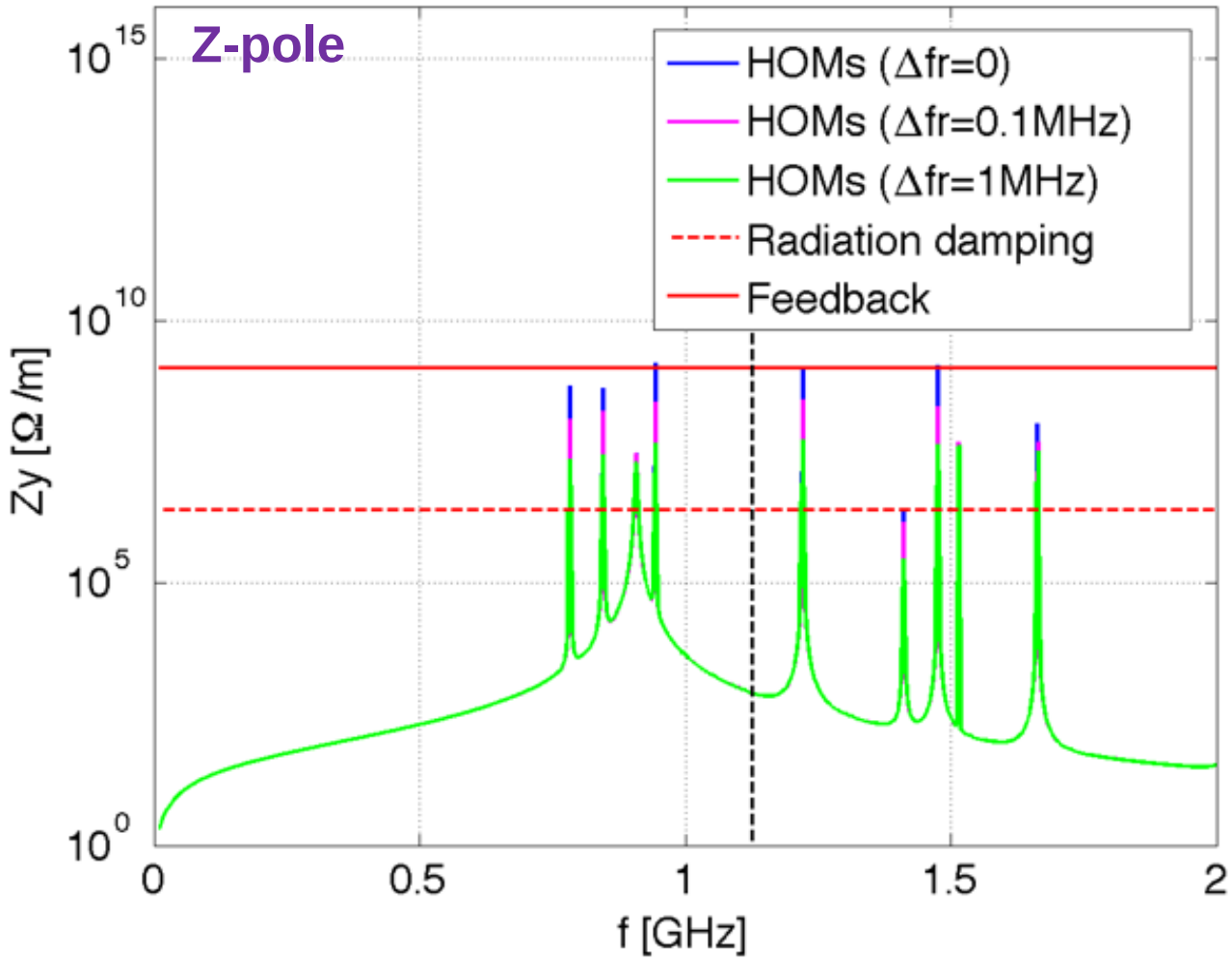
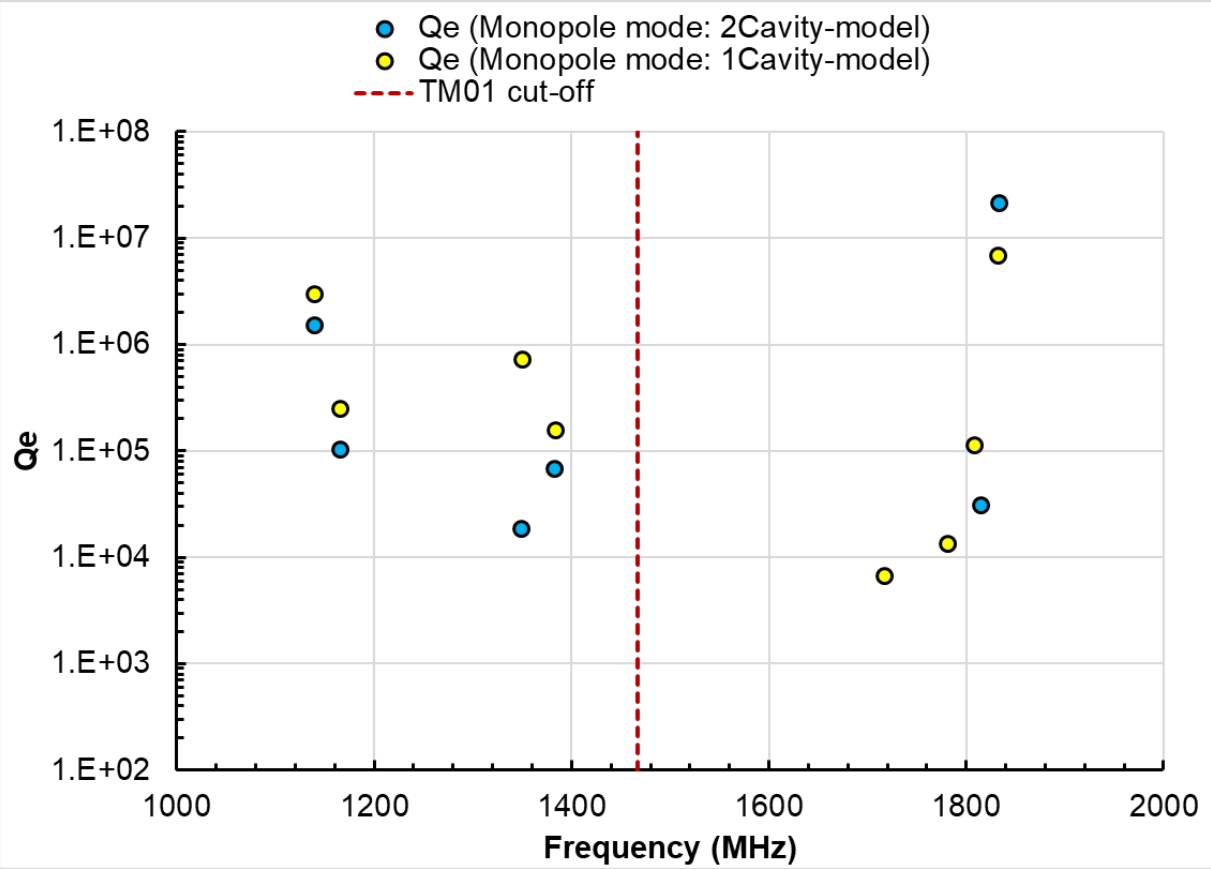
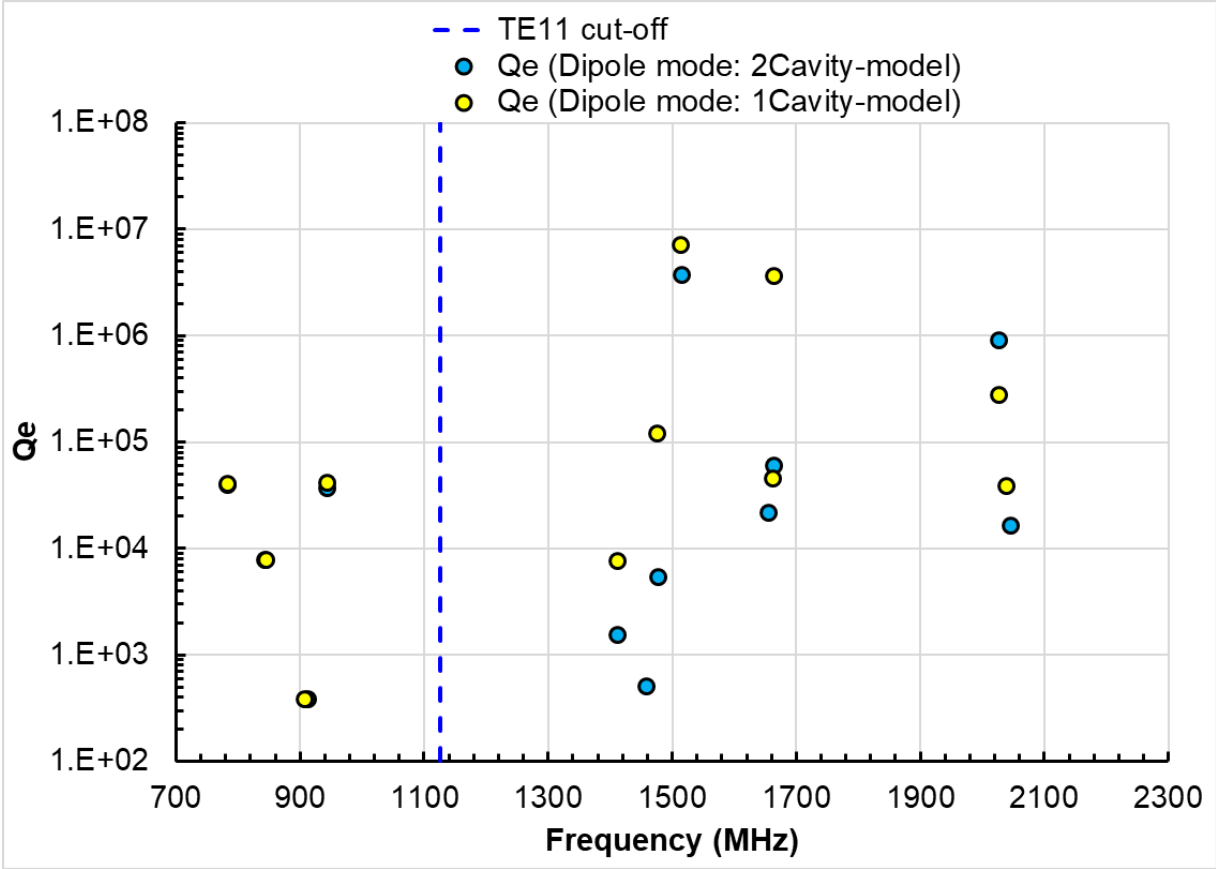


HOMs propagate in multi-cavities





Monopole modes:

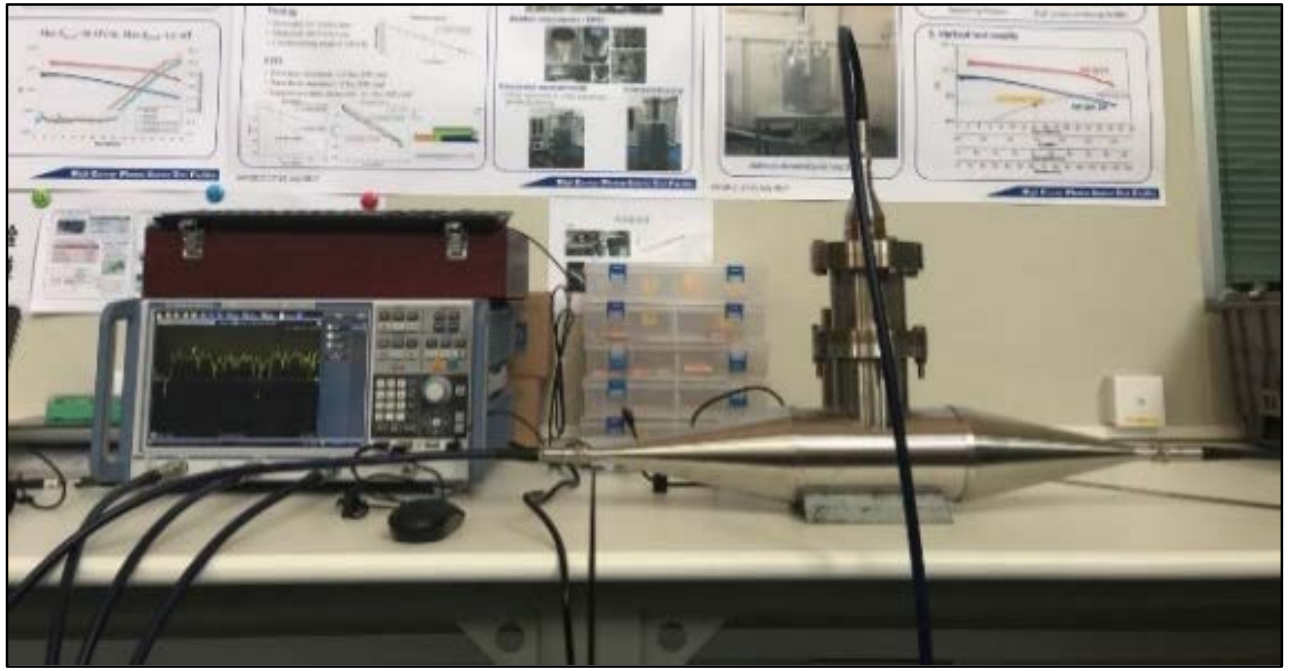
- Qe is much smaller when two cavity model used for modes below the cut-off frequency.
- The boundary conditions affect the results.

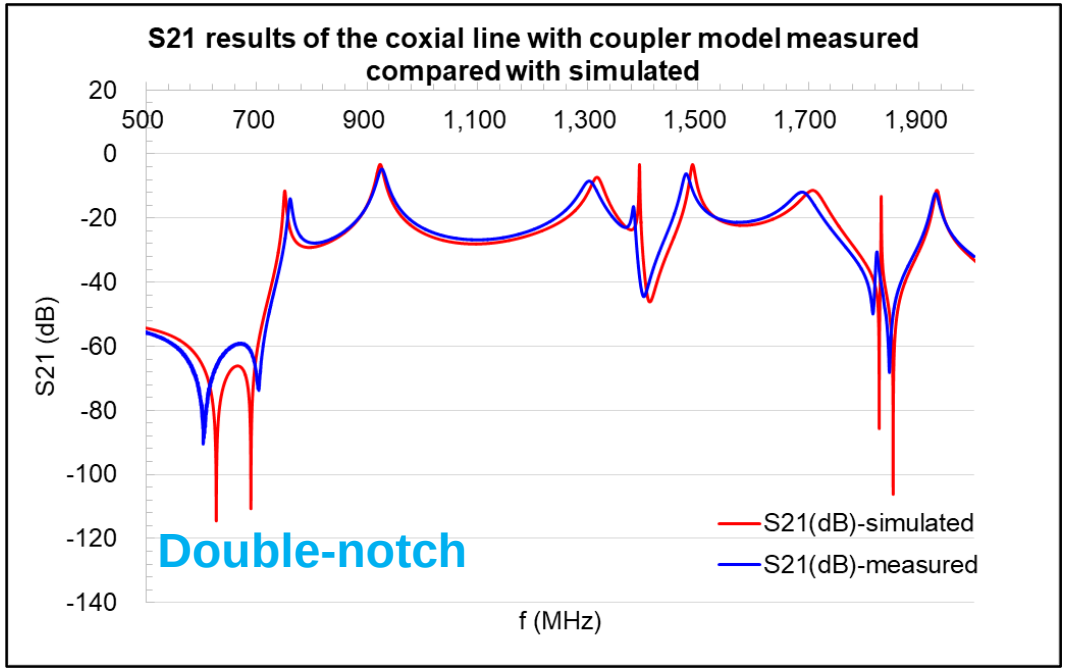
Dipole modes:

- Qe is much smaller when two cavity model used for modes above the cut-off frequency.
- The boundary conditions affect the results for modes above the cut-off frequency.

Test results of the prototype

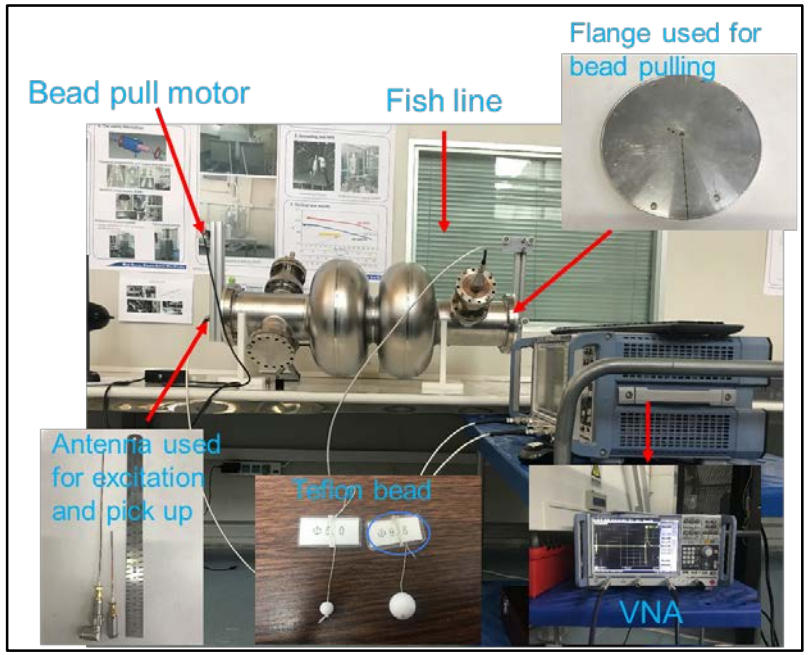
- Detachable HOM coupler design, adding installation fixture to ensure installation accuracy.
- The test results are in good agreement with the design.
- Double-notch works good.

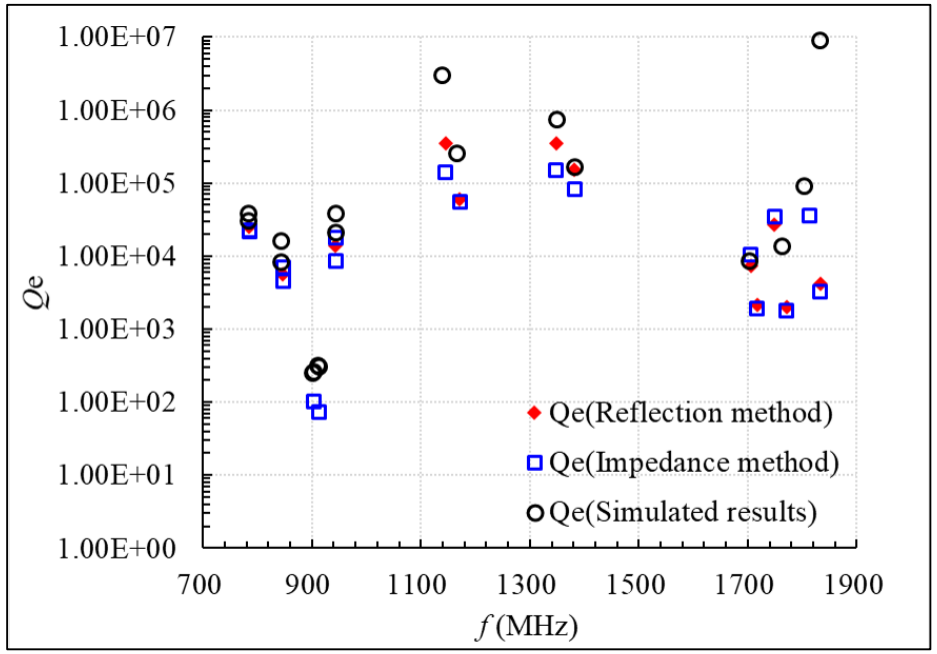




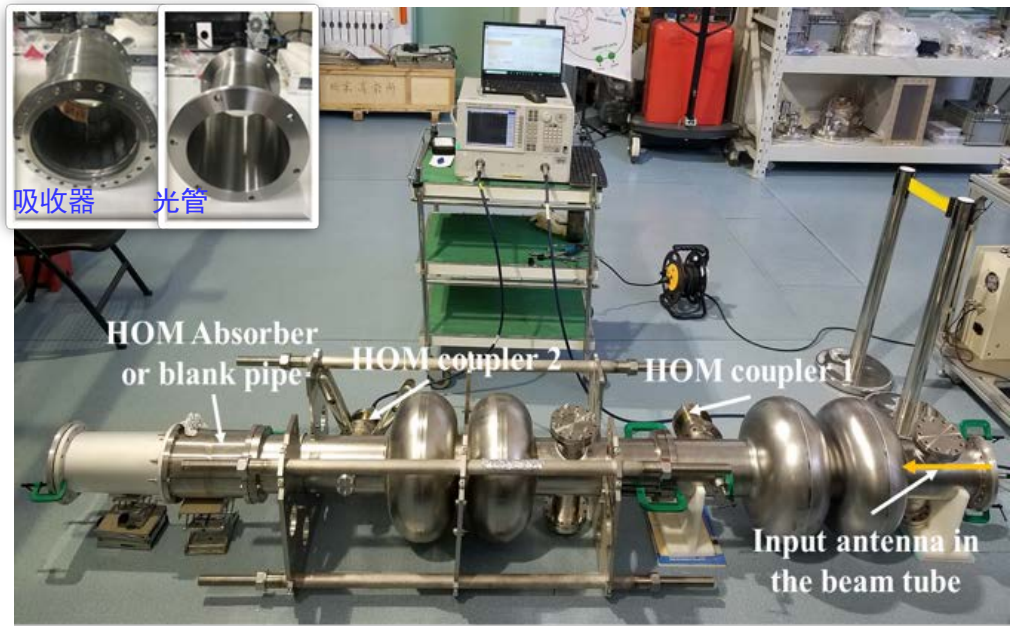
Test results of the prototype

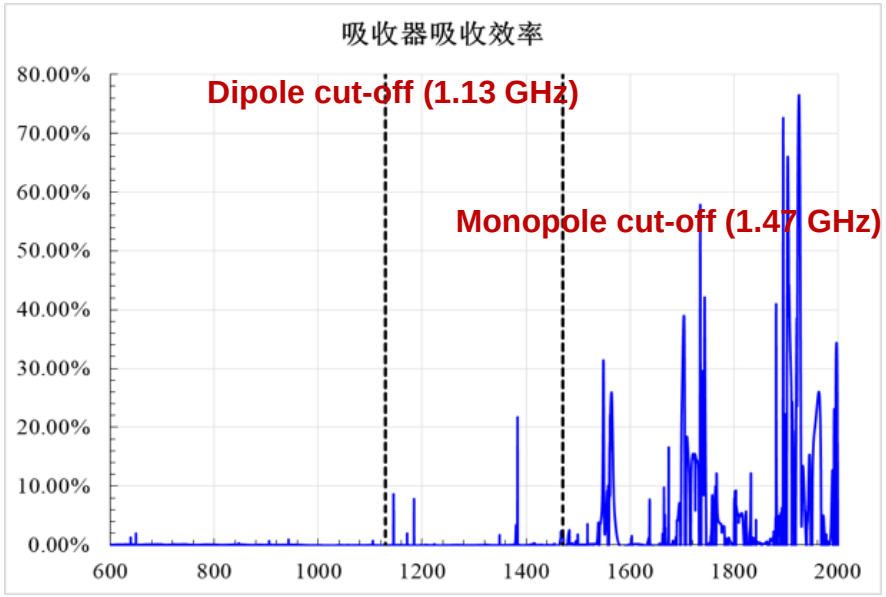
- Two HOM coupler installed on 650MHz 2-cell cavity.
- The measured Qe results by two different methods are in good agreement.
- The measured Qe results of the two ports for the fundamental mode are 1.4E11 and 1.3E10, respectively. Q0 of the cavity is 1.5E10.

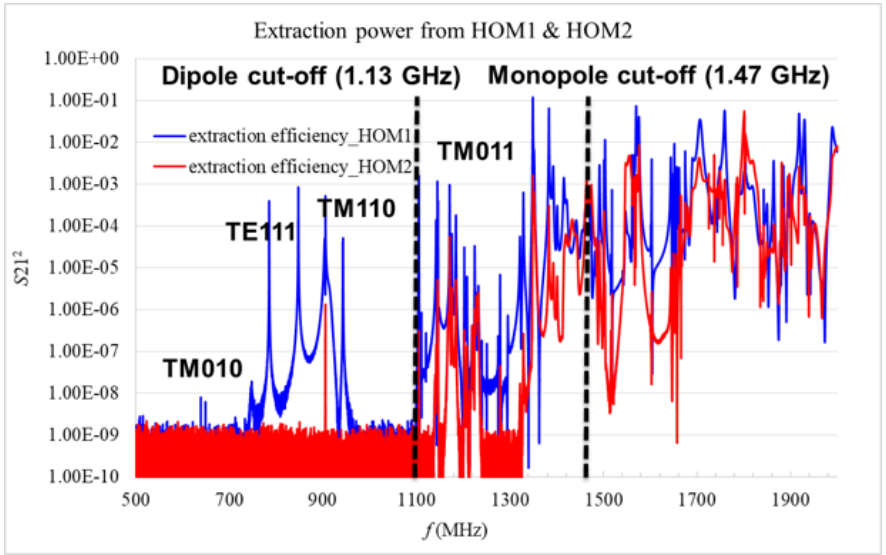




HOM Propagation through Two 2-cell Cavities



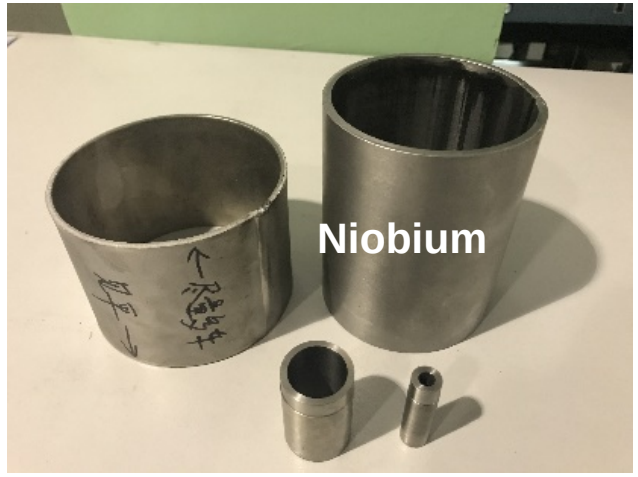


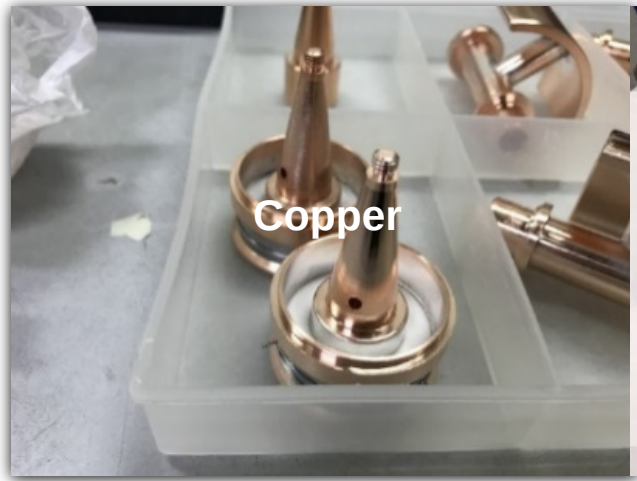


- The cavity wall loss was subtracted by replacing the absorber with a blank flange.
- In general, the power extracted through the HOM coupler port is a small percentage, no greater than 10%.
- The maximum absorption efficiency for absorber is up to 80% at high frequencies.

650 MHz HOM Coupler Fabrication

- Four HOM couplers have been finished fabrication, post-processing, which have been assembled in the test cryomodule in the Platform of Advanced Photon Source Technology R&D (PAPS).
- Compact structure design, control machining accuracy





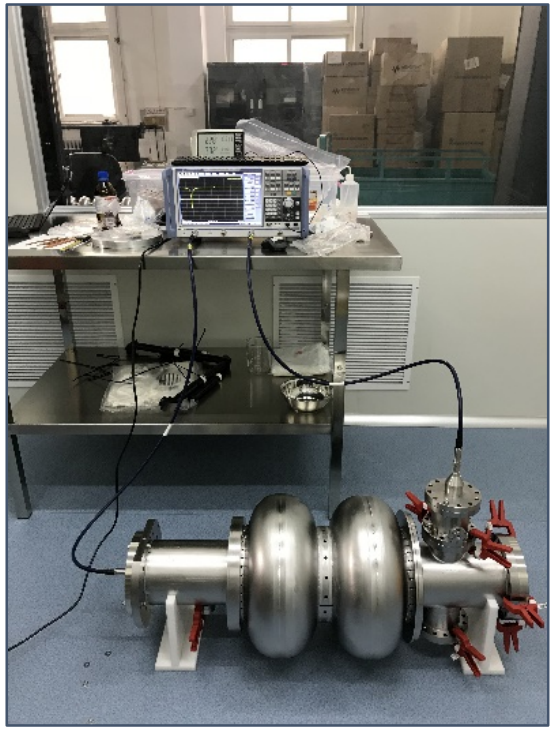
HOM coupler post-processing

- Degreasing with ultrasonic bath
- Heavy BCP of 80 μm
- 700 ◦C heat treatment for 3 h
- Light BCP of 20 μm
- Final HPR

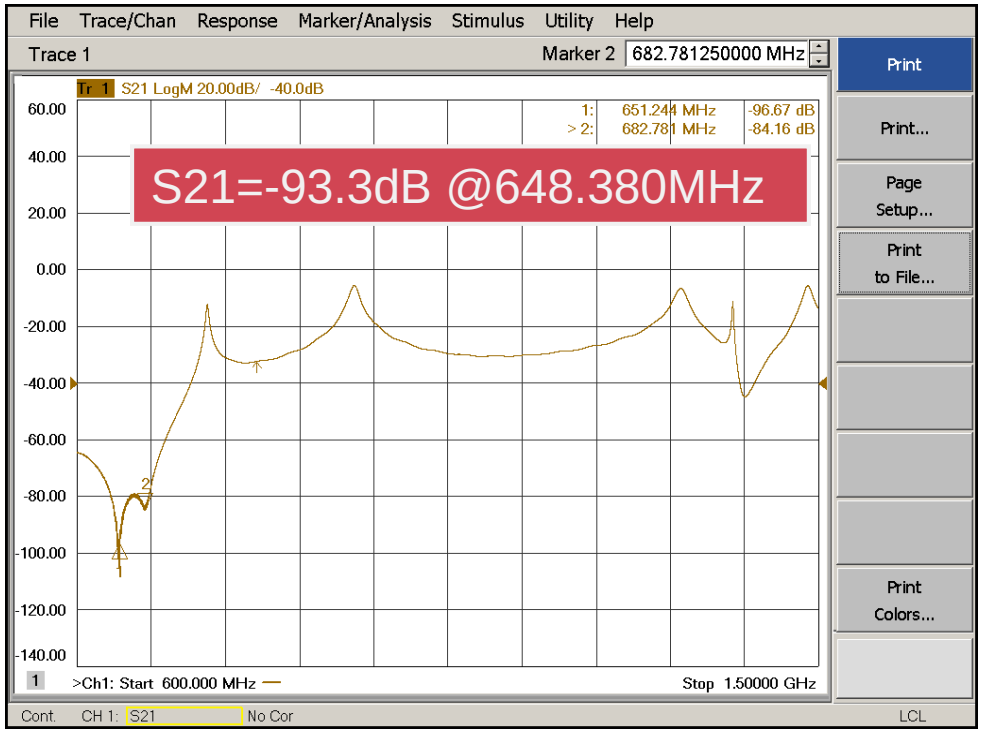
- Rough grinding
- Polished by a mixed acid and gloss treatment fluid
- Degreasing with ultrasonic bath

Qe Measurement for TM010

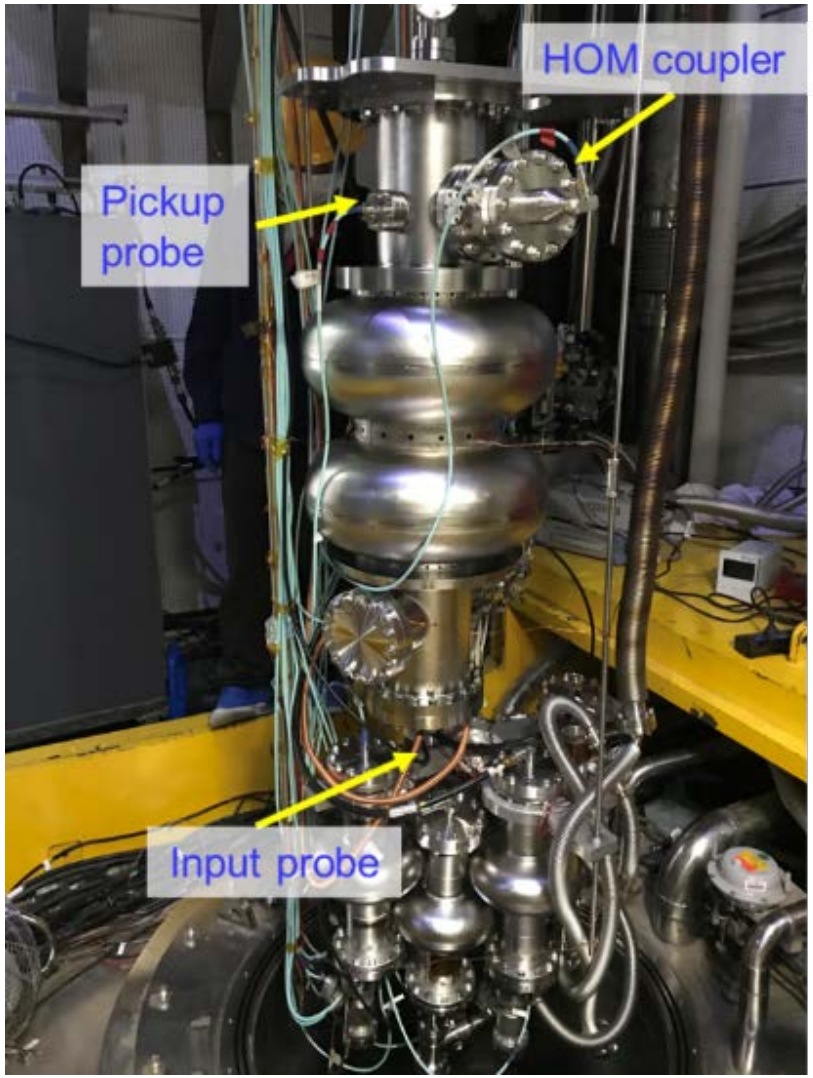
- Control the installation error
- **The double-notch works well.**
- Damping for TM010 meets the requirements, Q_e>1E11.

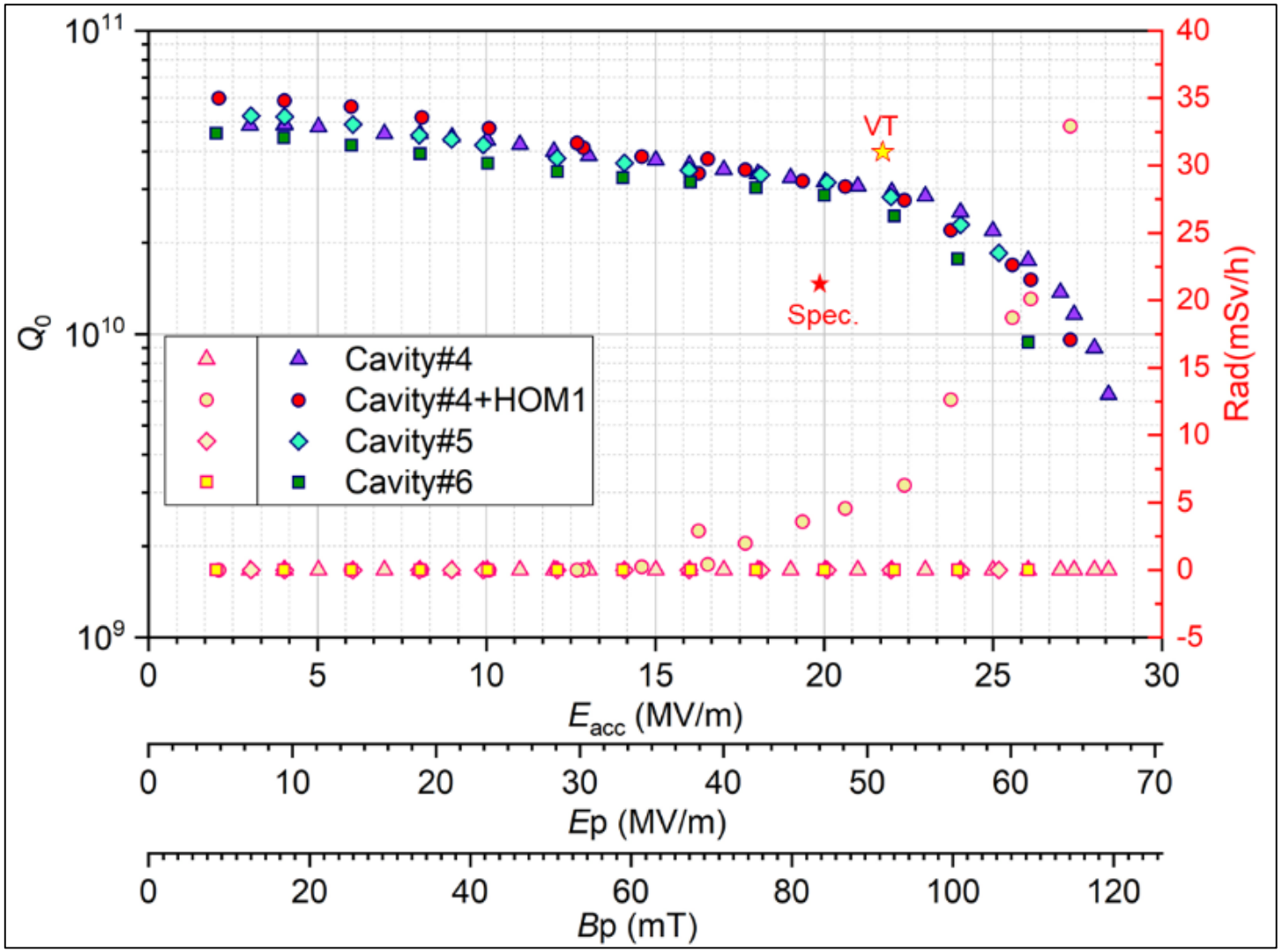


No.	Q_e (TM010)
#1	4.0E+12
#2	1.7E+14
#3	3.3E+11
#4	3.7E+13



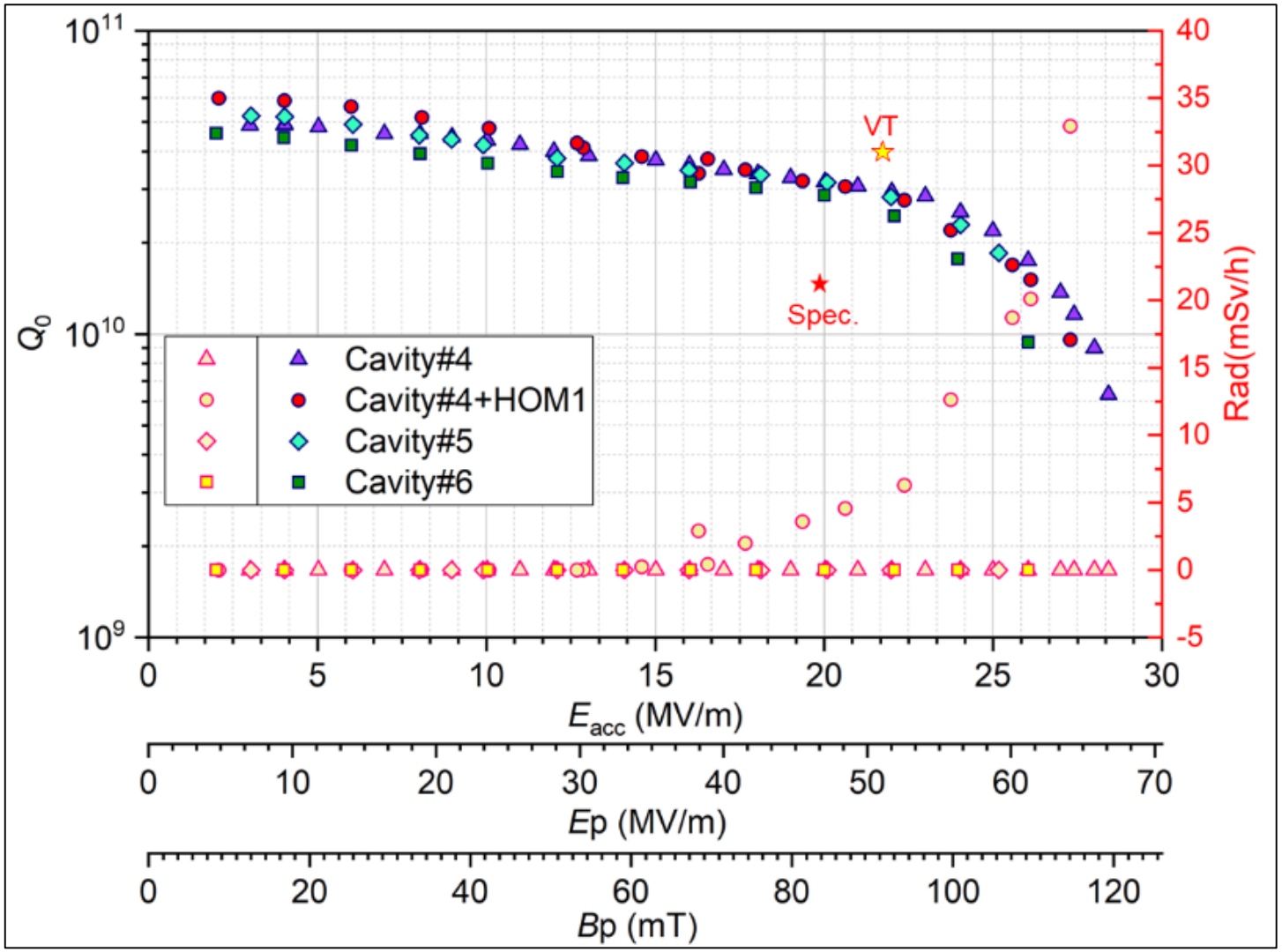
Cavity vertical test with HOM coupler





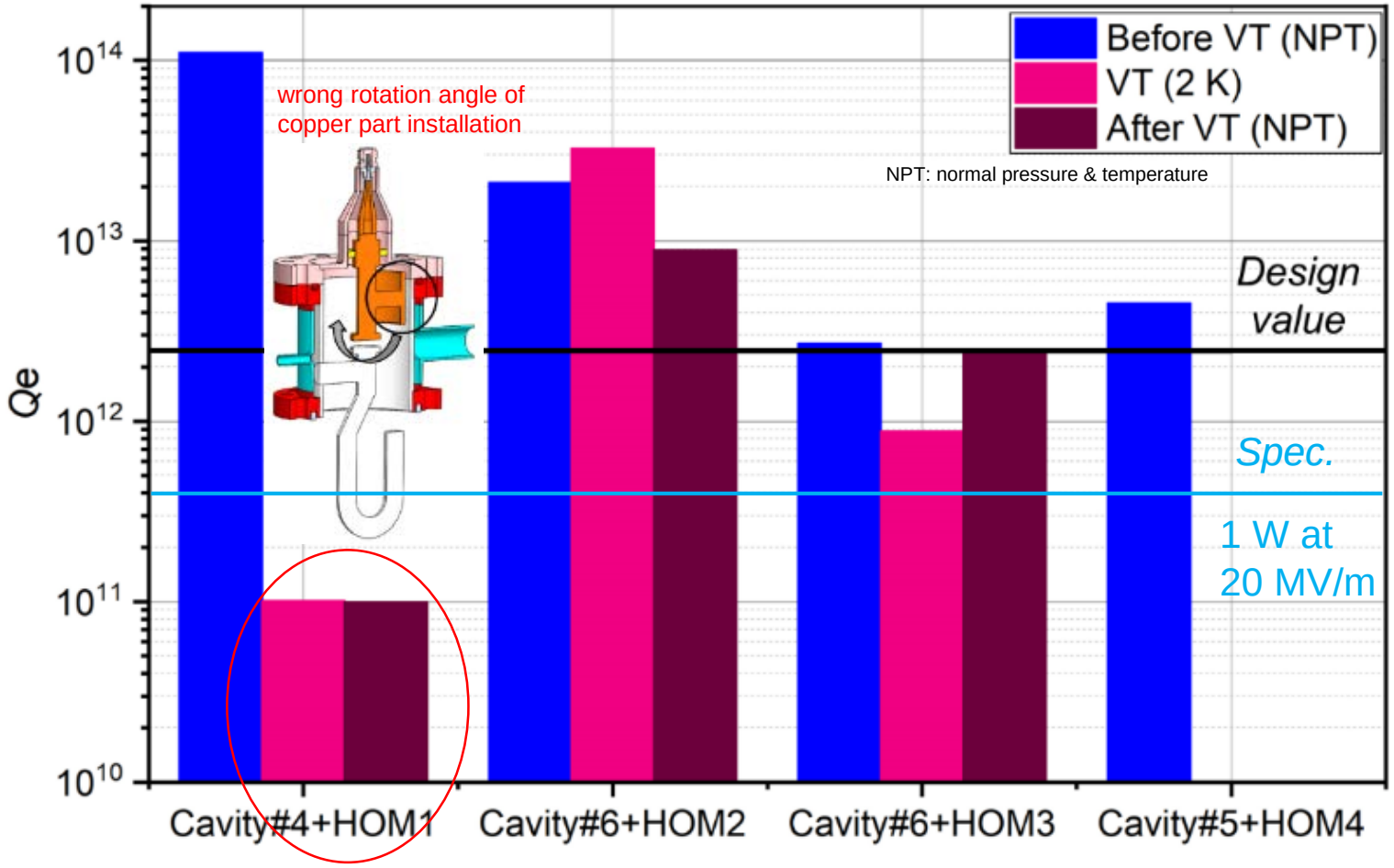
Cavity vertical with HOM coupler

- **650 MHz 2-cell cavity**:
  - ✓ BCP
  - ✓ 2.8E10@22 MV/m
  - ✓ VT spec: 4E10@22 MV/m
- The performance of superconducting cavity is not affected after installing HOM coupler.
- To improve the Q0 of the cavity, EP/Mid-T will be adopted next.



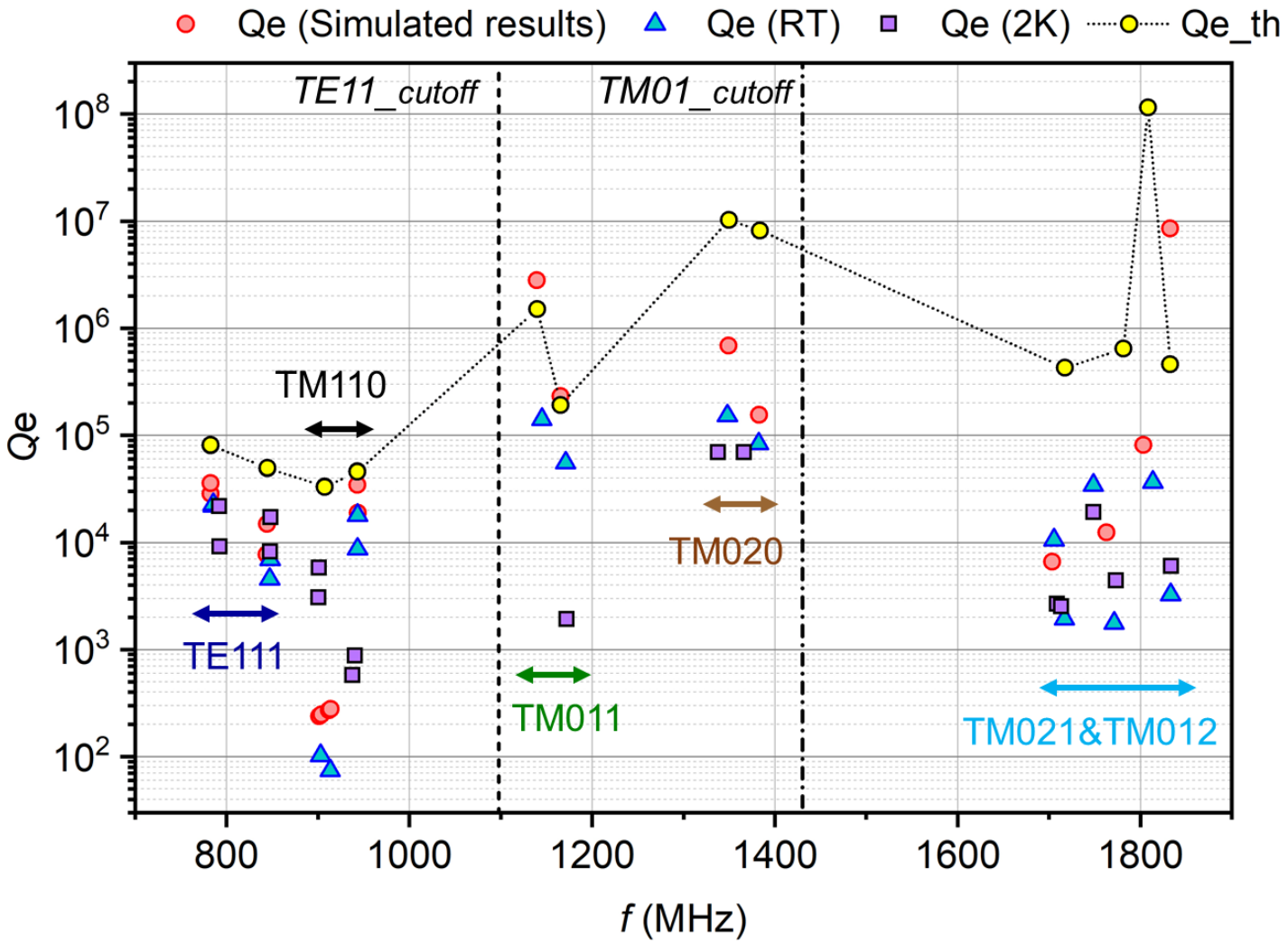
RF performance for the fundamental mode

- **Qe for TM010:**
  - ✓ At 2 K, $Qe \geq 1\times10^{12}$
  - ✓ The suppression of HOM couplers for TM010 at 2 K is not much different between the designed and measured values, if the installation tolerance is well controlled.
  - ✓ No tuning is required at 2 K.
  - ✓ The design can satisfy the damping requirement at cryogenic temperature.

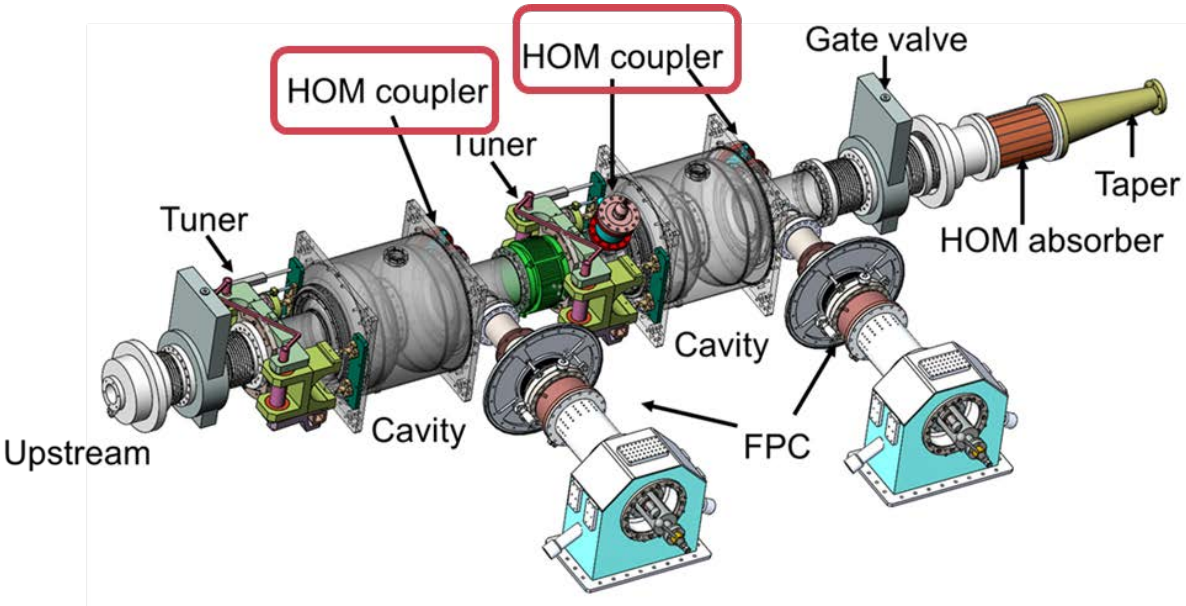


RF performance for the HOMs

- **Damping for HOMs:**
  - ✓ Measured Qe for TE111 and TM020 modes at 2 K are not much different from those of measured at room temperature.
  - ✓ Measured results of the other modes at 2 K are different from those at room temperature.
  - ✓ The damping results for HOMs becomes better under 2 K.
  - ✓ Satisfy the damping requirements for Higgs.
  - ✓ Need feedback for Z-pole.
  - ✓ Further optimization design is needed.



CEPC 650 MHz Test Cryomodule



- Modul installation in beamline, 2 K cool down test in May to July.
- Three HOM coupler installed on the cavity string.
- Qe for TM010 measured at 2K: 6.8E13, 1.9E13, 2.1E12
- No vacuum leakage occurred.

Summary

- Four 650 MHz HOM coupler have been finished fabrication and done vertical test with cavity. The damping results for fundamental mode were good. The damping results for HOMs can meet the requirements if consider the feedback and frequency spread between cavities.
- Two 650 MHz 2-cell cavities with HOM couplers have been assembled in the test cryomodule in beamline. 2 K cool down test has been successfully completed. The tests of cavity dressed with HOM couplers proved that the double-notch design was very stable and effective in damping the fundamental mode and HOMs.
- The application of HOMs in beam diagnosis is scheduled at the beamline in the Platform of Advanced Photon Source Technology (PAPS).

Thank you for your attention!