HOM couplers at DESY

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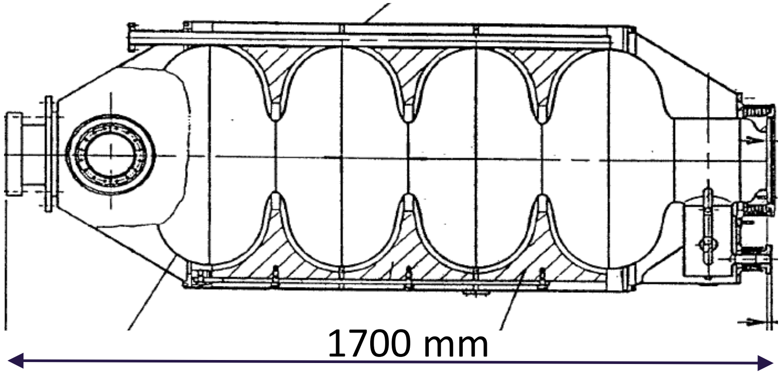
Outline

- HOM Couplers
  - HERA and TESLA cavities
  - Acceptance Test vs. Nominal Operation
  - Pulse Acceptance Test
  - Modification of HOM Loop Couplers for cw
- Final Remarks

HERA and TESLA cavities

Designing the TESLA cavity we benefited from our experience with the sc cavities for HERA (collider operating 1992-2007). For example, TESLA HOM couplers are based on the HERA HOM couplers, which were designed in 1985.



- 16 HERA sc cavities operated cw with I_{beam} up to 42 mA, spec was 60 mA.
- Each 4-cell, 500 MHz cavity had 3 HOM loop couplers, one was for TM011 and TM012.
- Very dense beam spectrum (47 kHz between lines) generated 100+ W / cavity.
- Cavities were tested up to E_{acc} = 8 MV/m.

Why I am mentioning that "old" DESY design?

The spec and performance of HERA cavities (60 mA, 8 MV/m) differ less than factor of 2 from what is nowadays proposed for the cw operating 100 mA-class machines.

HERA and TESLA cavities

- TESLA cavity was designed in 1992 at DESY, with Saclay contribution to the shape of inner cell.
- The cavity was design for **small duty factor of 0.8 %.**
- Nowadays TESLA cavities are made of high RRR niobium (300+), which has very good heat conduction. This is why they can operate at much higher duty factors.
- Two HOM loop couplers provide sufficient damping for linacs up to I_{beam} ~ 10 mA.
- It is asymmetric structure with two different end cells, to damp TE121, which was trapped in 4-cell LEP structures.

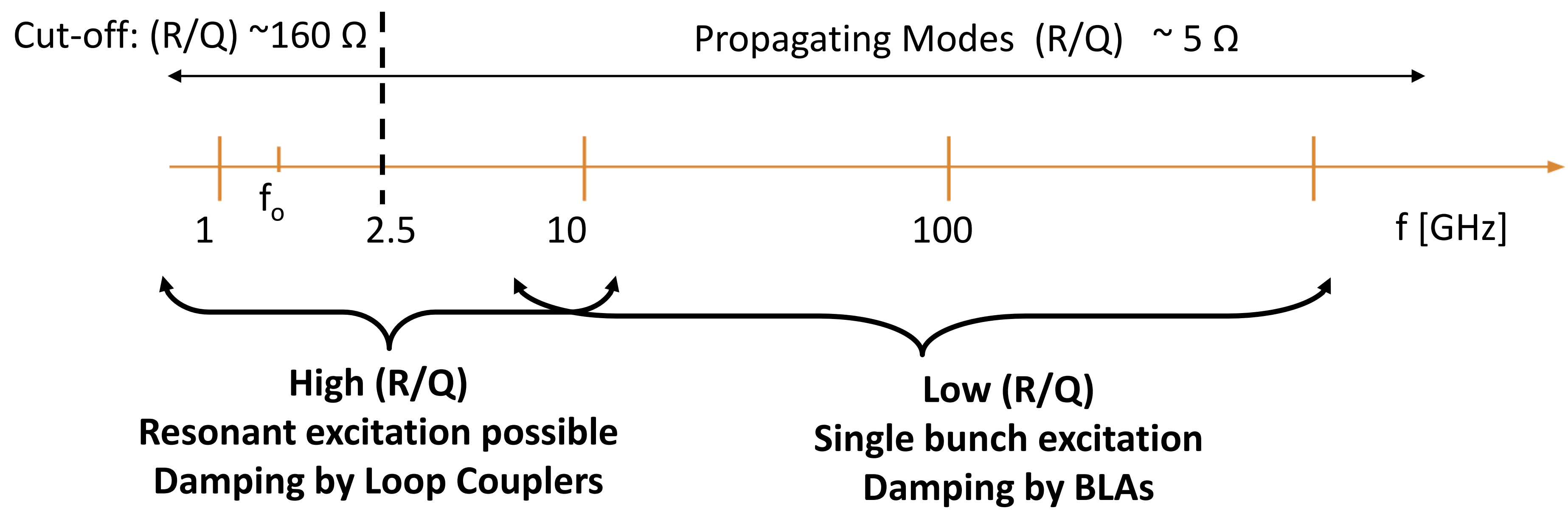
HERA and TESLA cavities

TESLA cavities will be used for:

European XFEL (beam: 27000 bunches/s, σ_z = 25 µm, 1 nC), non-resonant **P_{HOM} = ~ 0.5 W/cav**.

TESLA / ILC (beam: 14000 bunches/s, σ_z = 300 µm, 3.2 nC), non-resonant **P_{HOM} = ~ 2 W/cav.**

TESLA cavity mode spectrum



Acceptance Test vs. Nominal Operation

All XFEL cavities will undergo the acceptance test. **For the cost production** reason, they will be equipped with the HOM feedthroughs **priory to the acceptance test**.

The cw test of XFEL cavities would be in that different from the cw tests for non-equipped FLASH / TESLA / ILC cavities, performed over last 18 years.

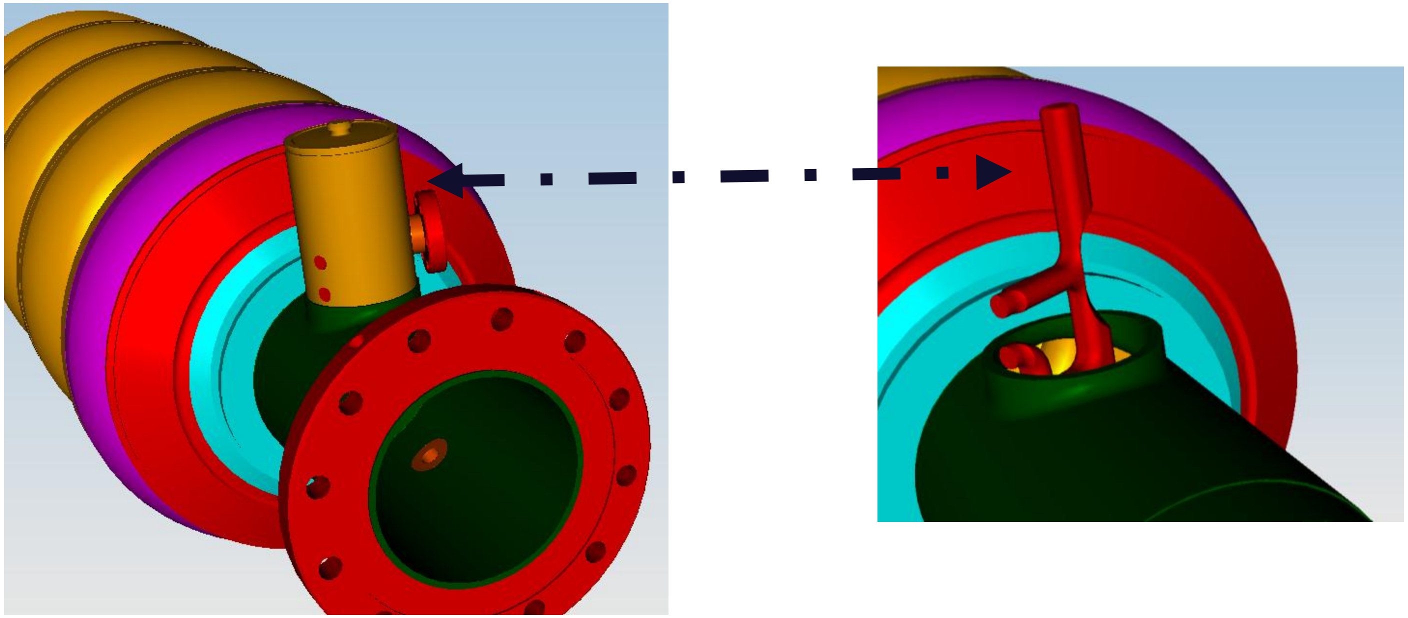
The heat load of the HOM output lines during the cw acceptance test would be very high, even much higher than for the future cw and near-cw operations of XFEL.

	Nominal operation	Far future cw operation	Far future near-cw operation	cw acceptance test for the production
Maximum E_{acc}	24 MV/m	7.5 MV/m	24 MV/m	24 MV/m
Maximum DF	0.01	1	0.1	1
Maximum Heat Load	**If the nominal load = 1**	**x 10**	**x 10**	**x 100**

Acceptance Test vs. Nominal Operation

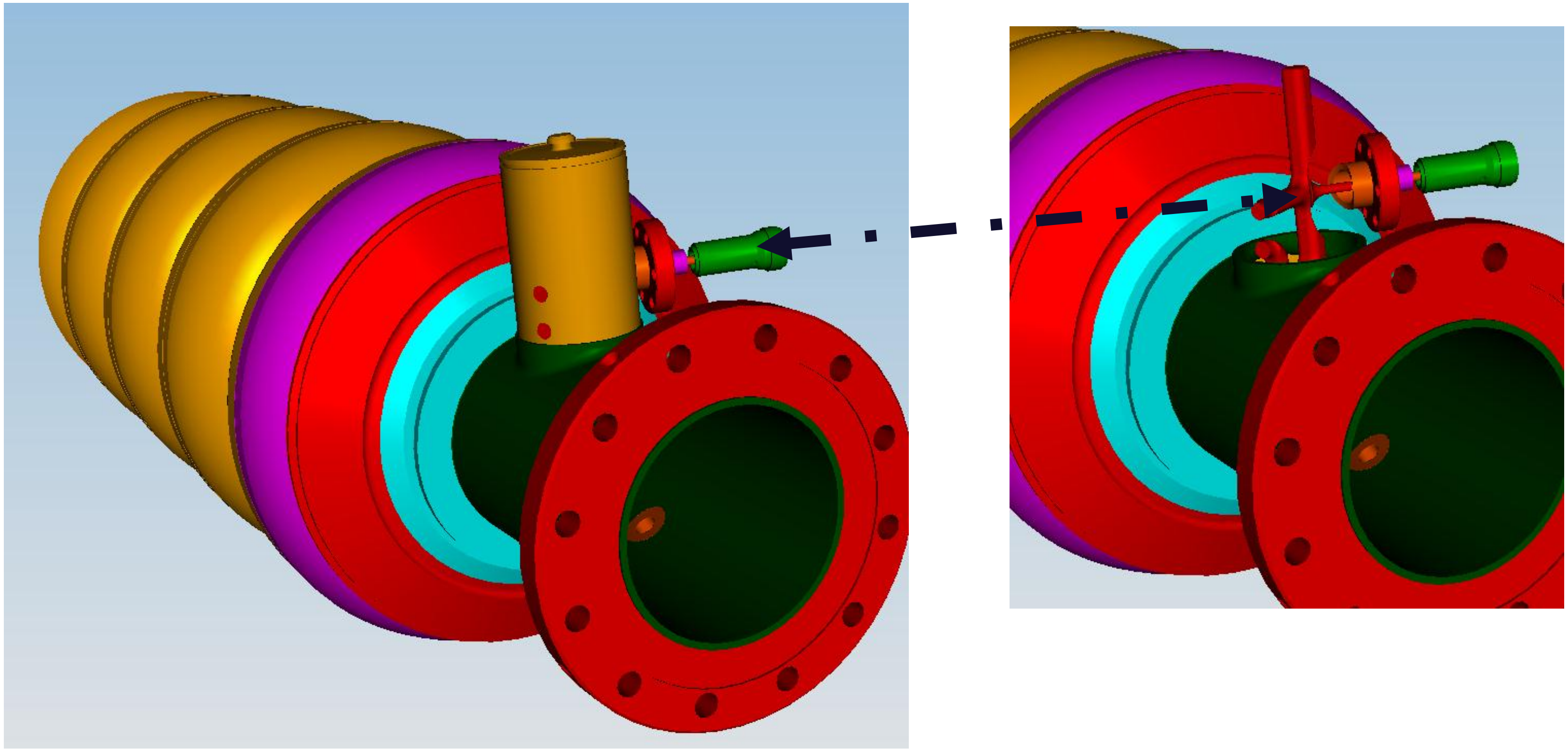
Testing the cavities, which have attached HOM feedthroughs, we observed often heating in the HOM couplers. We do not observed that in cavities operating at the nominal short pulse conditions in the FLASH (TTFI and TTFII) linac.

We have learned in last 18 years that the welded F-parts and cans of HOM couplers pass the cw vertical acceptance tests at gradients higher than 35 MV/m, showing neither heating nor multipacting if these parts were properly cleaned.

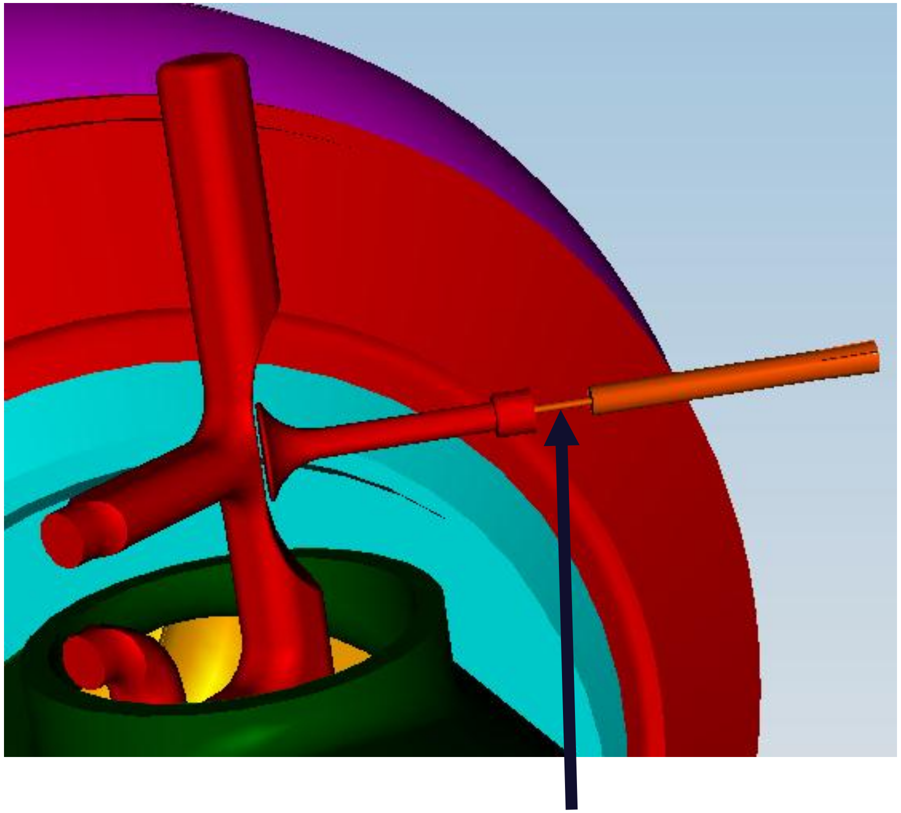


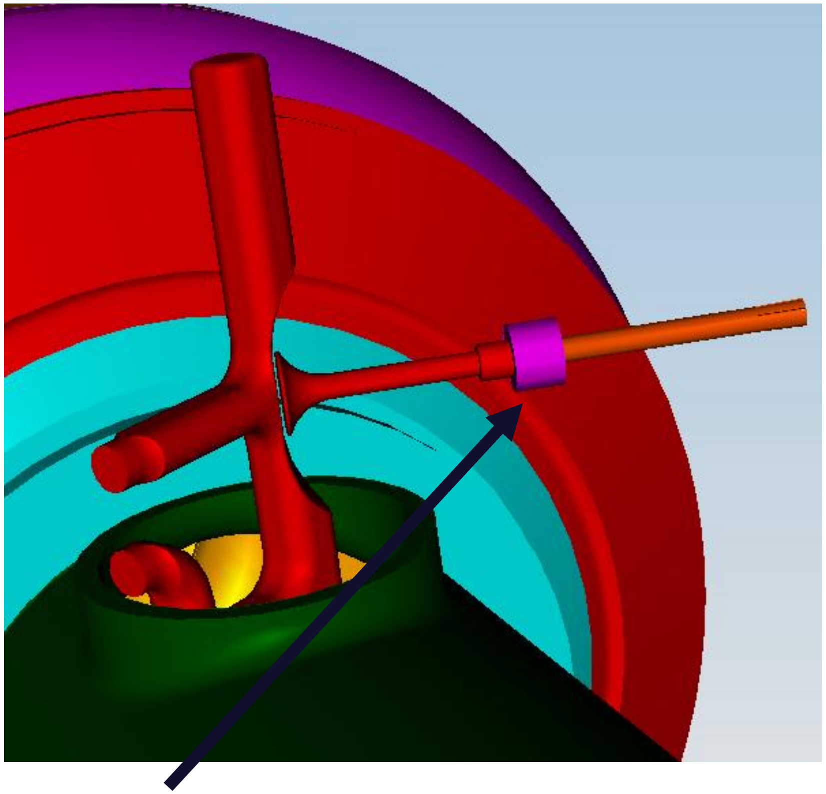
Acceptance Test vs. Nominal Operation

An insufficient heat conduction of the HOM feedthroughs, even after the alumina window has been replaced with sapphire window, caused heating of the Nb antennae above the Tc.



Acceptance Test vs. Nominal Operation



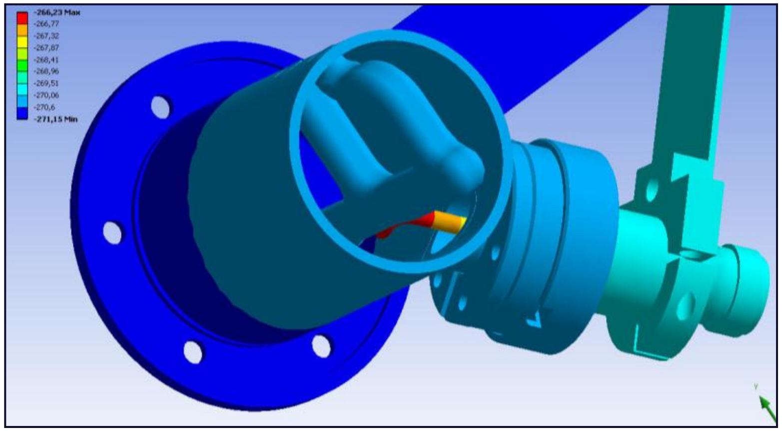


The molybdenum wire and the sapphire window do not “keep” the Nb antenna below 9.2K, when for example micron-size impurities on it get hot.

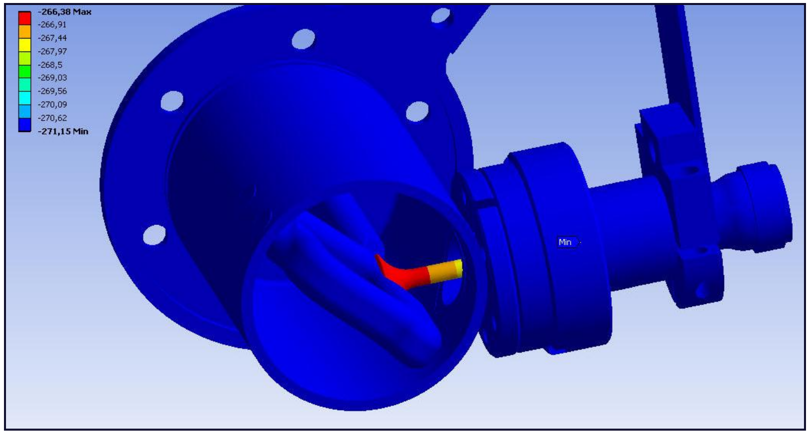
Acceptance Test vs. Nominal Operation

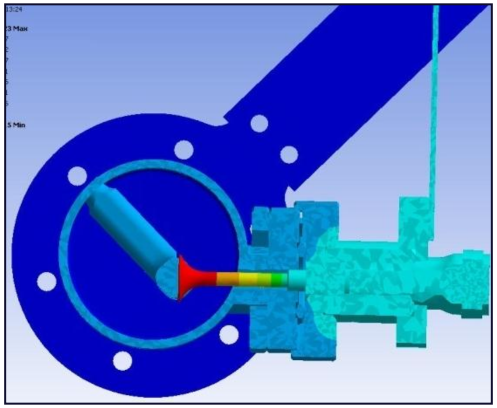
Thermal modeling (*T. Ramm*): $T_{antenna}$ vs. Heat

In cryomodule (vacuum)

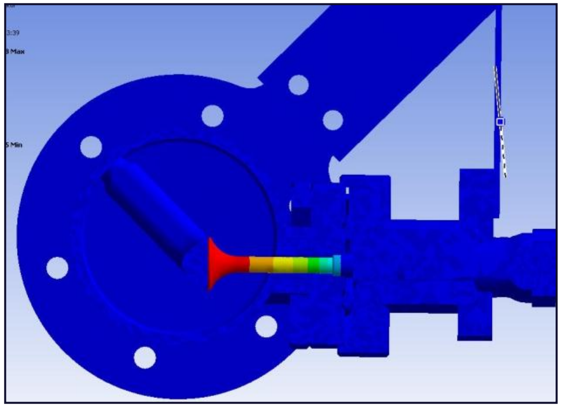


In vertical cryostat (LHe)



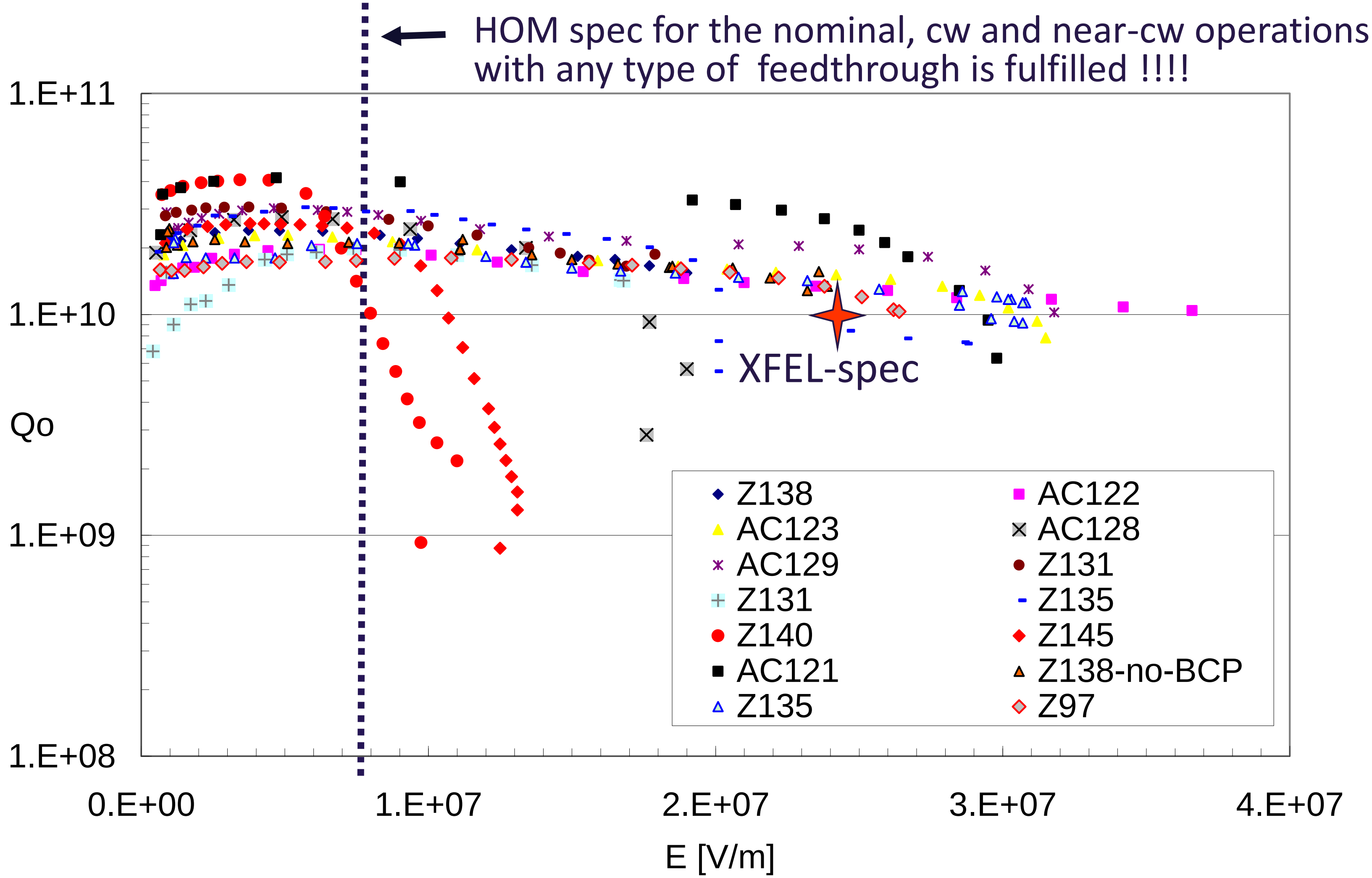


Heat	T_{ant} (V)	T_{ant} (LHe)
[mW]	[K]	[K]
20	7.0	6.8
5	4.6	4.5
4	4.2	4.2
3	4.0	3.9
2	3.6	3.5
1	3.1	3.0



Acceptance Test vs. Nominal Operation

Statistics for the cw acceptance test

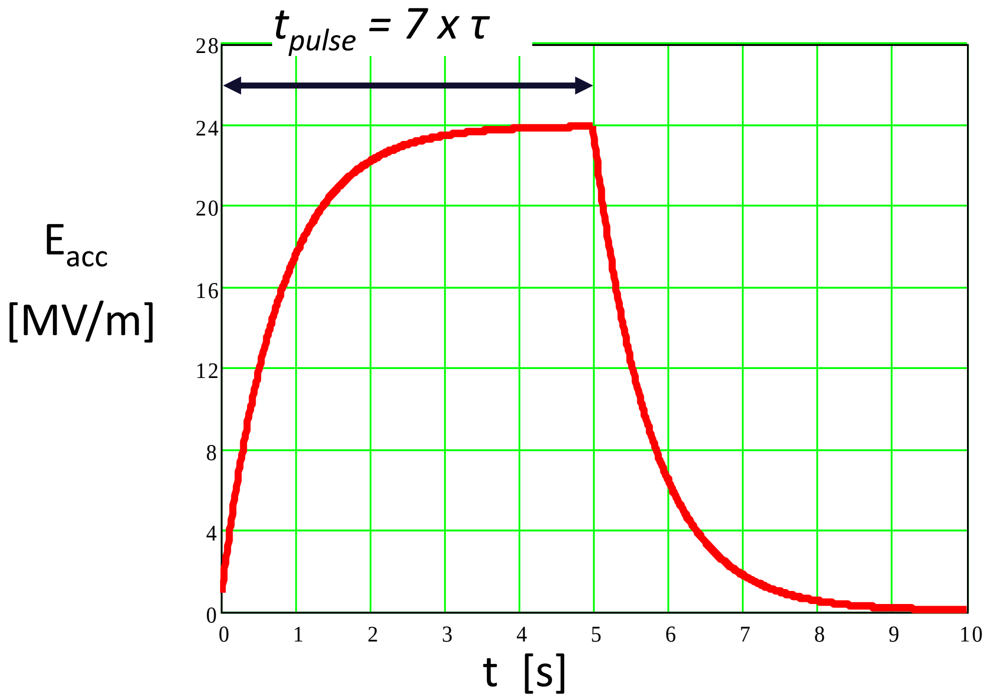


Pulse acceptance test

Recently, it was proposed and the decision was made to test the XFEL cavities in less demanding way, with the heat load higher "only" 10 times than the nominal one.

Pulse acceptance test:

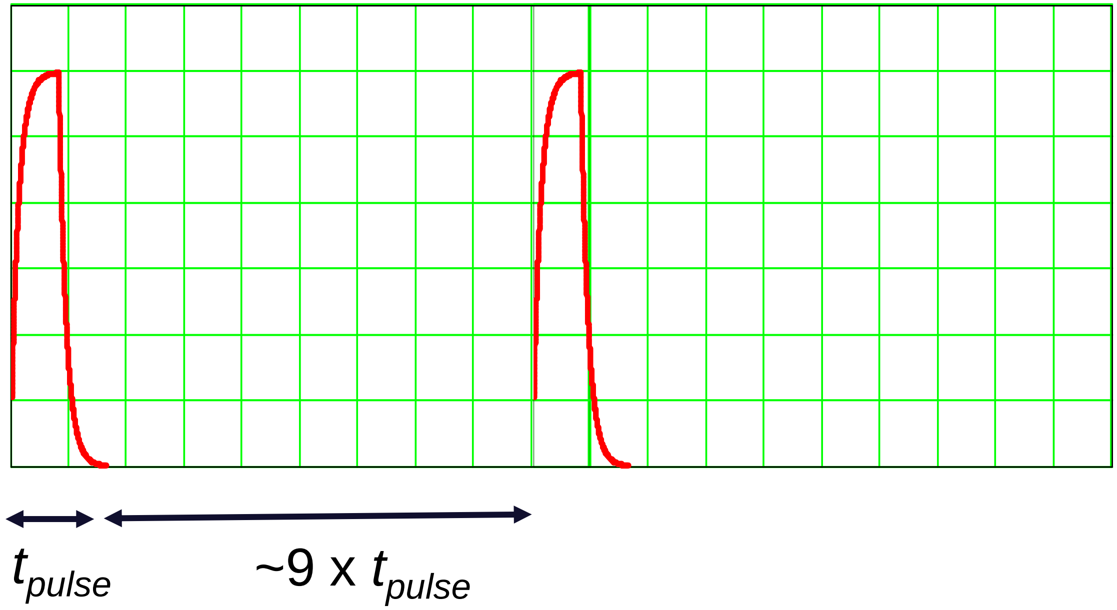
- DF = 0.1
- Fixed antenna Q_{ext} = 1E+10
- For Qo ~ 1.7E+10 → Q_L = 6.3E+9 and the filling time is τ = 0.77s



Pulse acceptance test

Pulse acceptance test: repetition frequency

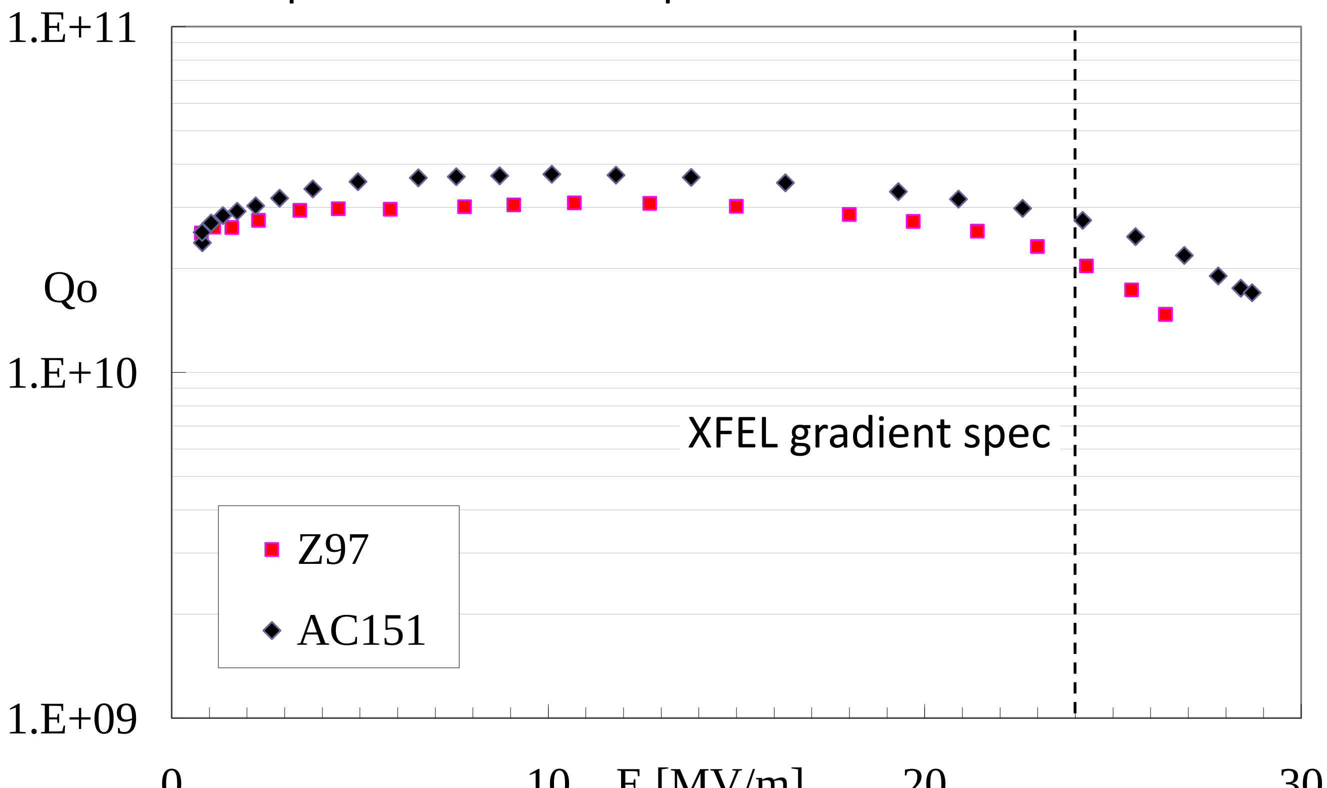
- DF ~ 0.1



Pulse acceptance test

15 cavities were tested (22 tests) in the pulse mode in last several months. No excessive heating was observed and all types of feedthroughs passed the tests. The temperature of small diameter antennae (8 mm) and large diameter antennae (11 mm) increase by 0.2-0.3 K and 0.4-0.5 K respectively at maximum gradients.

Example of test result in pulse mode at 1.8 K.



Pulse acceptance test

Conclusions from the pulse tests:

- Cavity with HOM feedthroughs demonstrated in VC the same performance as without feedthroughs.
- The production sequence of XFEL cavities can be kept less expensive.

- **The TESLA cavity and loop HOM couplers, as designed in 1992, can operate at DF at least of 10% at high gradients.**

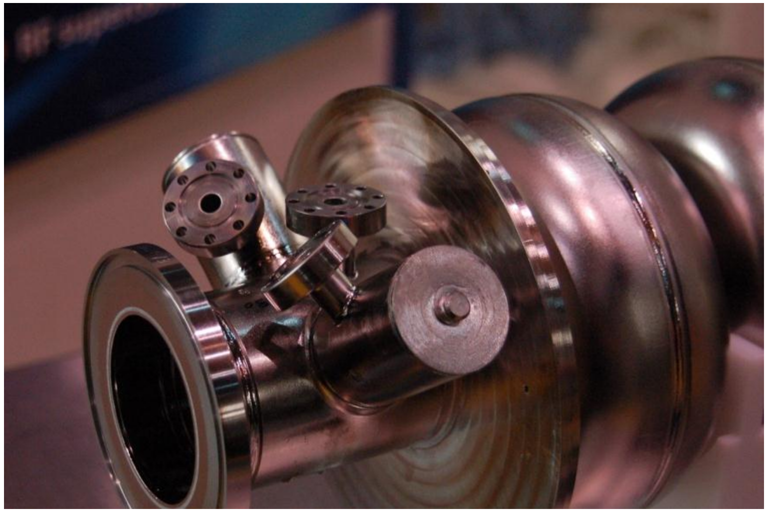
- We will increase the DF in coming tests to find out what is the limit.

Modification of HOM Loop Couplers for cw

Three presented in following modifications are towards reduction of heat on the output antenna or better cooling of the antenna.

1. CEBAF 12 GeV upgrade solutions: works when less HOM dumping is required (Q >10^7):

- High heat conduction feedthrough
- HOM couplers located further from the end-cells
- Antenna has diameter of 6.3 mm, which minimize the surface exposed to the residual B.



Courtesy C. Reece

Several cavities have reached gradients of 33+ MV/m in the cw mode

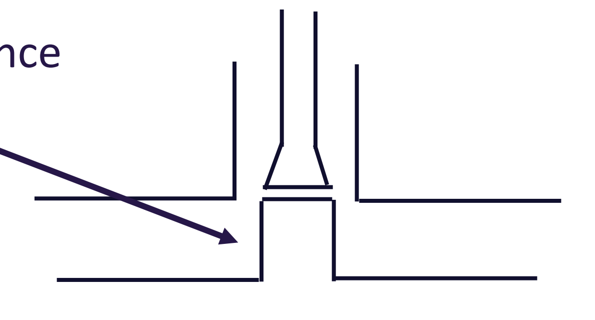
The HOM couplers for the 12 GeV CEBAF upgrade are based on the TESLA HOM coupler. All modifications mentioned above have been proposed by JLab Colleagues.

Modification of HOM Loop Couplers for cw

2. DESY/JLab solutions (PAC05, Linac06): based on the additional third inductance.

- High heat conduction feedthrough
- Antenna has diameter of 8 mm
- Antenna is “hidden” in the output tube

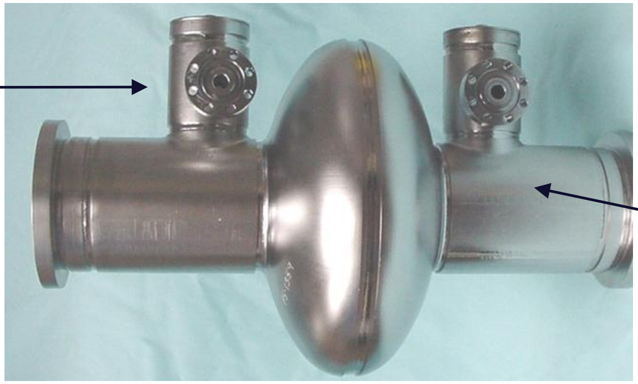
F-part with third inductance



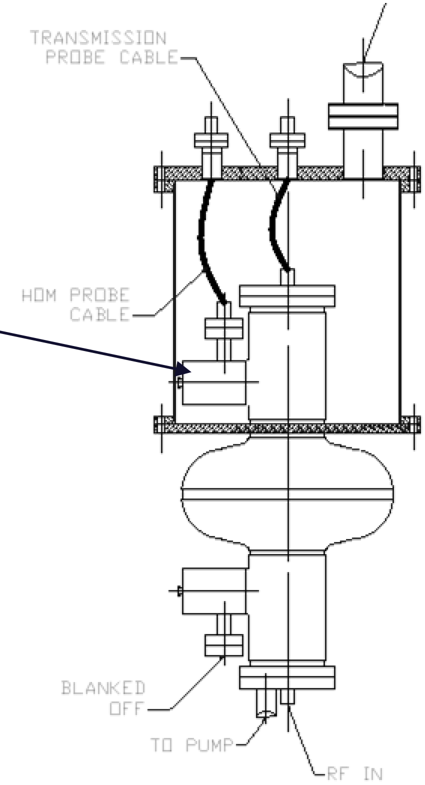
Courtesy P. Kneisel

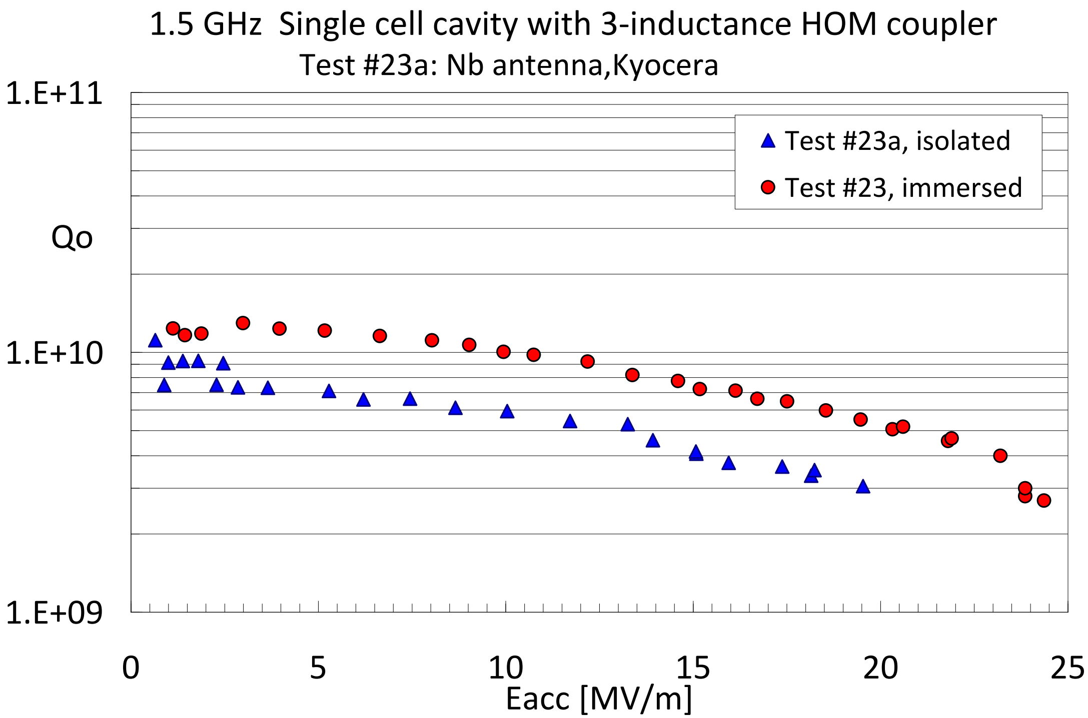
Modification of HOM Loop Couplers for cw

2- inductance standard coupler



3- inductance new coupler

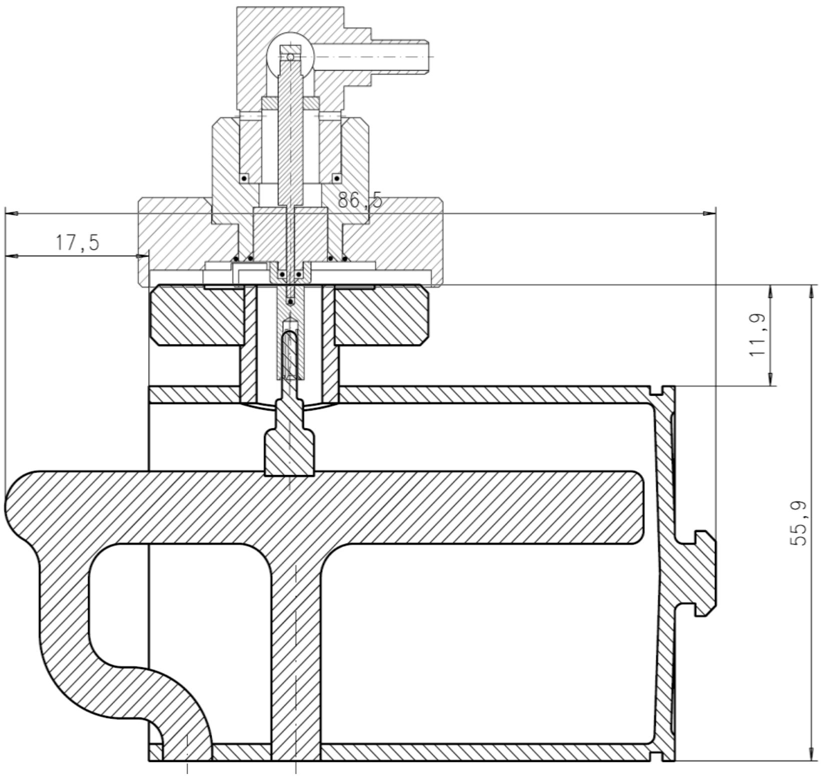




Modification of HOM Loop Couplers for cw

3. DESY: Galvanic connection between the antenna and F-part

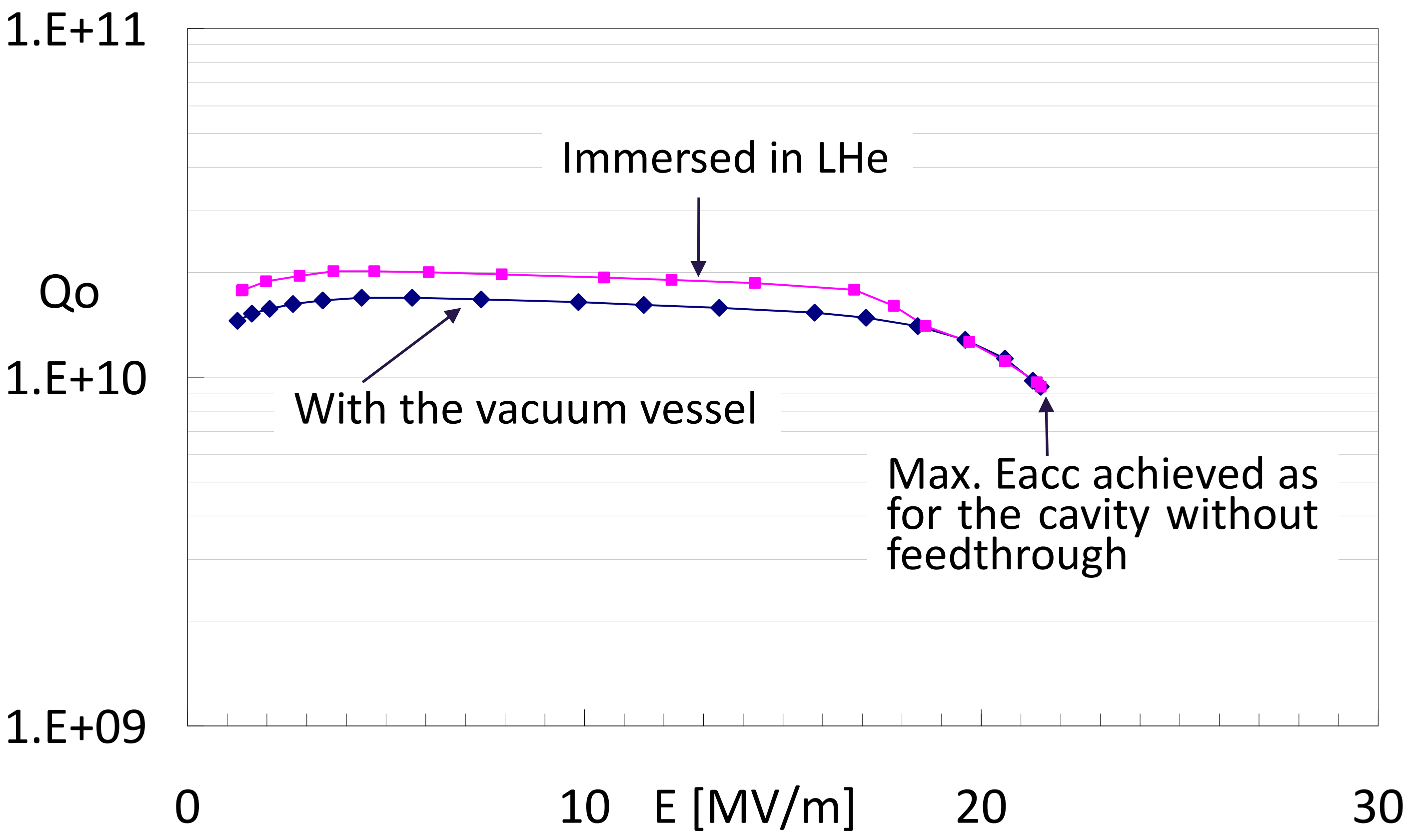
- Coupler has been attached to the 2-cell cavity
- Antenna of 8 mm diameter
- Kyocera standard feedthrough (alumina window)



Courtesy W.-D. Möller

Modification of HOM Loop Couplers for cw

π-mode test results with and without vacuum vessel. Standard Kyocera feedthrough has been used in that experiment. The cavity with vacuum vessel was kept for 4 h at max. gradient of 21.5 MV/m and no change in Qo was observed.



Final Remarks

- 48 HOM couplers for HERA (500 MHz) operated reliably with beams up to 42 mA.
- ~100 TESLA HOM couplers operate many years in TTF-I & II with beams up to 9 mA.
- Pulse acceptance tests of TESLA cavities proved that TESLA HOM couplers, as designed can operate at least with DF ~ 10%. The DF limit is not known yet.
- The modified HOM TESLA couplers have been tested cw at 33+ MV/m, 20 MV/m and 21.5 MV/m for the JLab, DESY/JLab and DESY version respectively.

Acknowledgements

DESY

- W.-D. Möller
- A. Gössel
- K. Twarowski
- C. Müller

JLab

- P. Kneisel
- L. Turllington

Thank you

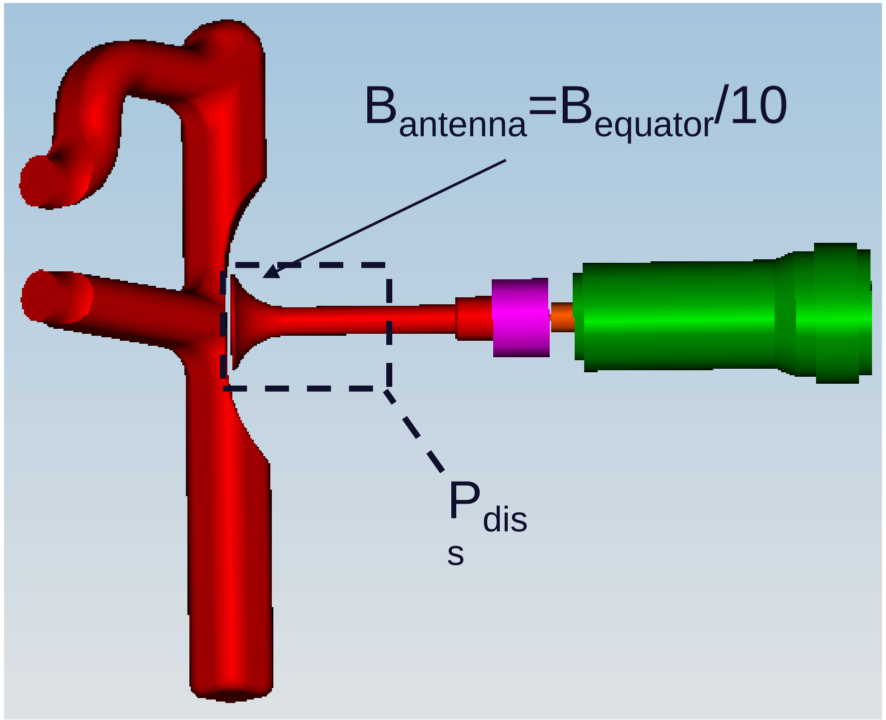
Additional Transparencies

HOM and Pickup Feedthroughs

Acceptance Test vs. Nominal Operation

Losses in the antenna vs. $T_{antenna}$:

at 24 MV/m and 7.5 MV/m for the cw mode



$T_{antenna}$	R_r+R_{bcs}	P_{diss} at 7.5 [MV/m]	P_{diss} at 24 [MV/m]
[K]	[nΩ]	[mW]	[mW]
7	14+3117	6.5	67
6	14+1873	3.9	40
5	14+1067	2.25	23
4	14+500	1.07	11
3	14+152	0.34	3.5
2	14+8	0.05	0.47

HOM and Pickup Feedthroughs

Acceptance Test vs. Nominal Operation

Statistics of the performed cw vertical tests till February 2010.

Cavity	HOM type	Eacc [MV/m]	Qo at max Eacc	comment
AC121	**Kyocera old**	**28.9**	6.3E09	
Z138	**Kyocera old**	**20.0**	3.0E09	**cw;21 MV/m** without HOMs
AC123	**Kyocera old**	**31.5**	7.8E09	
Z131	**Kyocera old**	**15.0**	2.0E09	**cw;18 MV/m** without HOMs
Z132	**Kyocera old**	**16.8**	1.4E10	**cw;** No test without HOMs
AC122	**Kyocera old**	**38.9**	1.0E10	
AC129	**OM25/26**	**30.2**	8.2E09	
Z135	**OM27/28**	**28.9**	7.7E09	
AC128	**OM30/29**	**17.5**	5.7E09	**cw;33 MV/m** without HOMs
Z145	**Kyocera new**	**13.5**	1.3E09	**cw;29 MV/m** without HOMs
Z140	**OM29**	**11.0**	8.9E08	**cw;22 MV/m** without HOMs
Z138	**OM-Ø 11mm**	**24/34**	1.6E10/1E10	cw / pulse; no BCP
Z135	**Kyocera old**	**30.4**	9.2E9	Pulse; cw 28 MV/m
Z97	**OM-Ø 8mm**	**26.7 / 26.7**	1E10 / 1.5E10	Pulse; 2K /1.8K