Special design considerations of high power input couplers for TEM-type superconducting cavities

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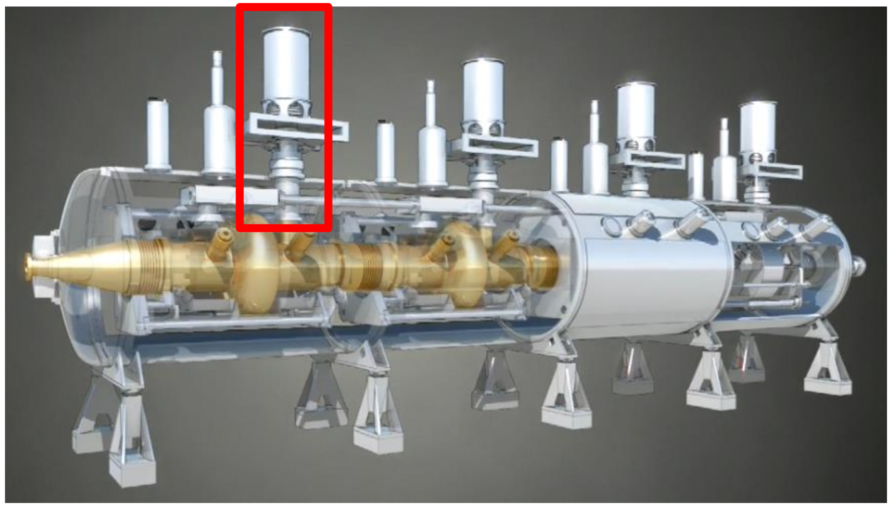
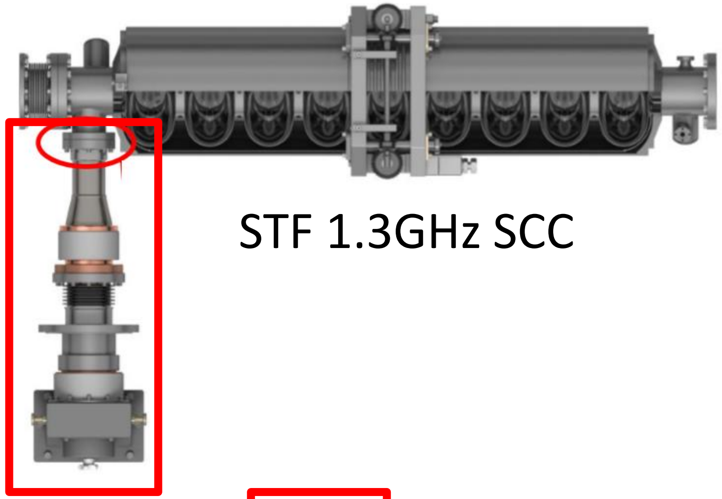
Outline

Introduction

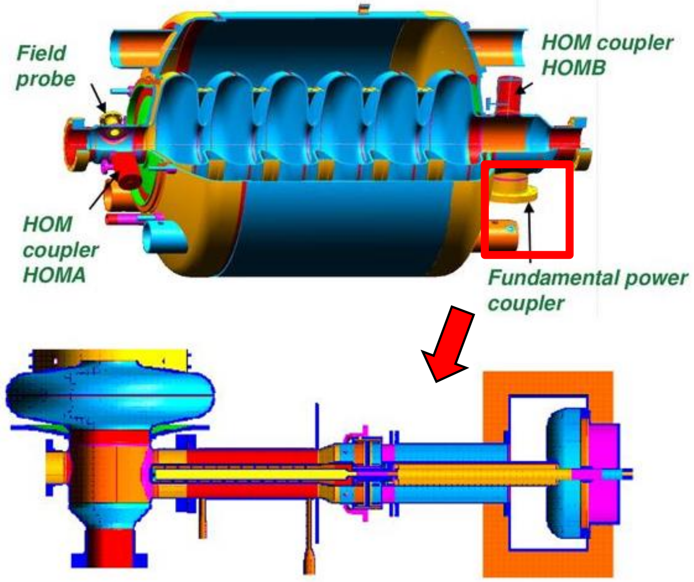
Elliptical type cavity

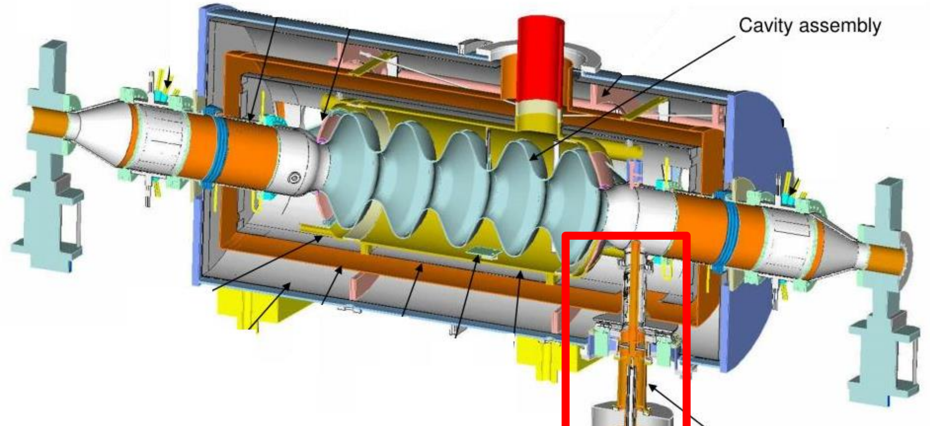


LHC 400MHz SCC

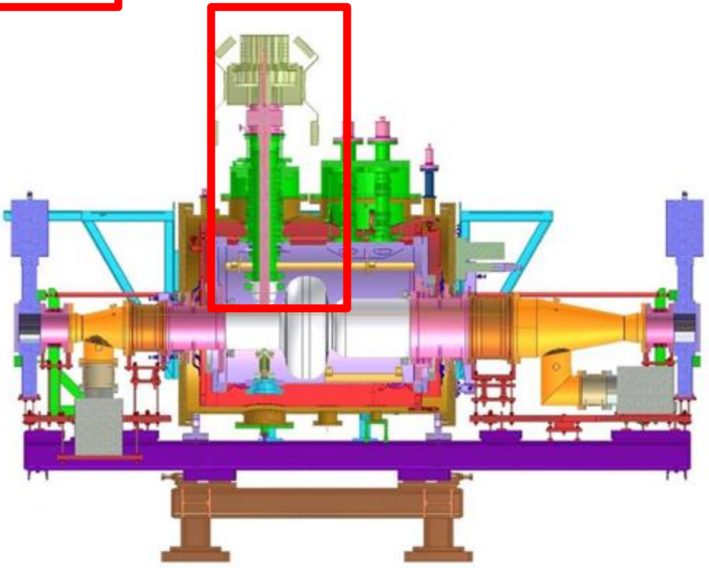


STF 1.3GHz SCC





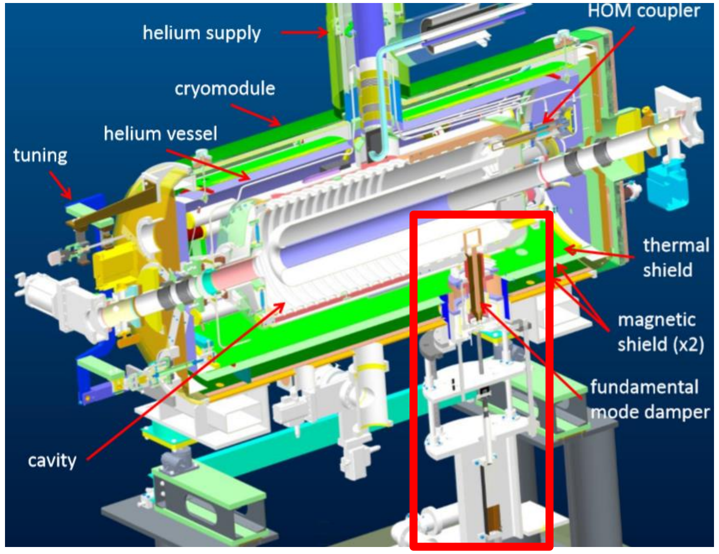
ERL 704MHz SCC



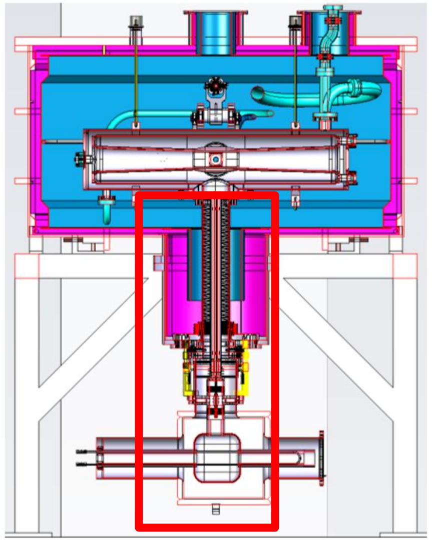
BEPCII 500MHz SCC

For elliptical type cavity, the high power input coupler usually located at the beam pipe.

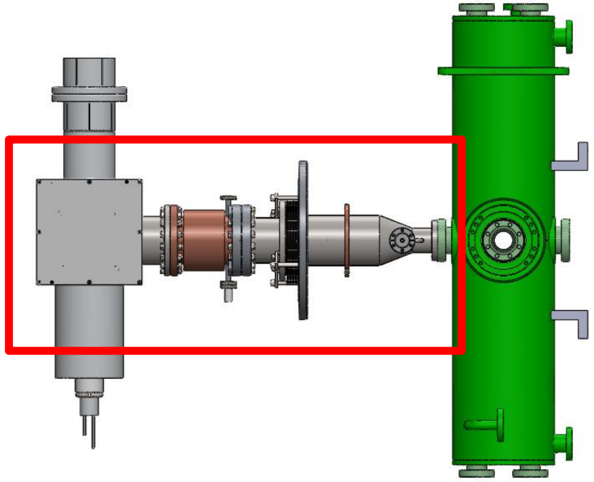
TEM type cavity



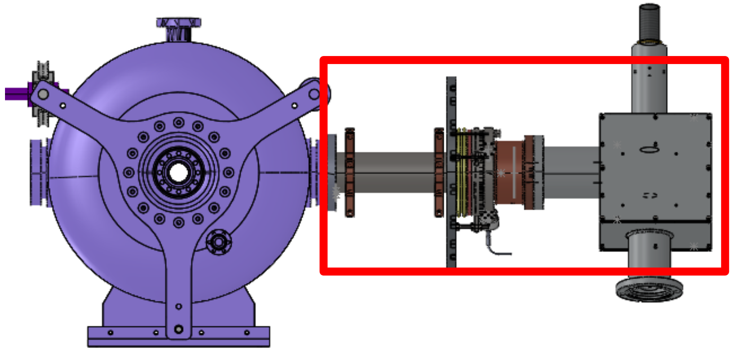
BNL 56MHz QWR SCC



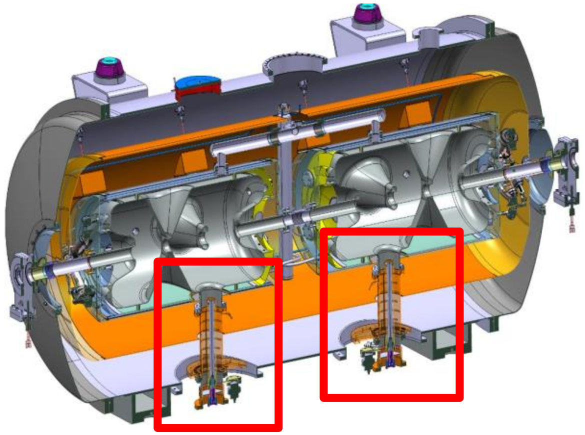
IFMIF 175MHz HWR SCC



CADS 162.5MHz HWR010 SCC



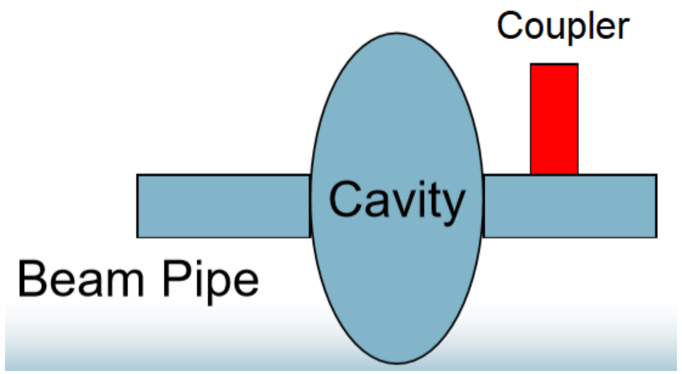
CADS 325MHz Spoke021 SCC

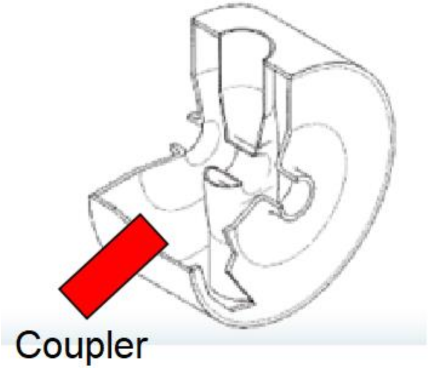


ESS MHz 352MHz Spoke SCC

For TEM type cavity, the high power input coupler usually located at the cavity body instead of beam pipe.

Coupler position considerations





- **Firs choice**
- **Advantages:**
  - Far away from high intensity E-M field
  - No E-M filed enhancement effect
  - Low contamination risk to the cavity

- **Why:**
  - Good accelerating efficiency→ very small beam pipe
  - High intensity beam current→ strong coupling

Coupler has to be arranged at the cavity body (side wall or endplate)

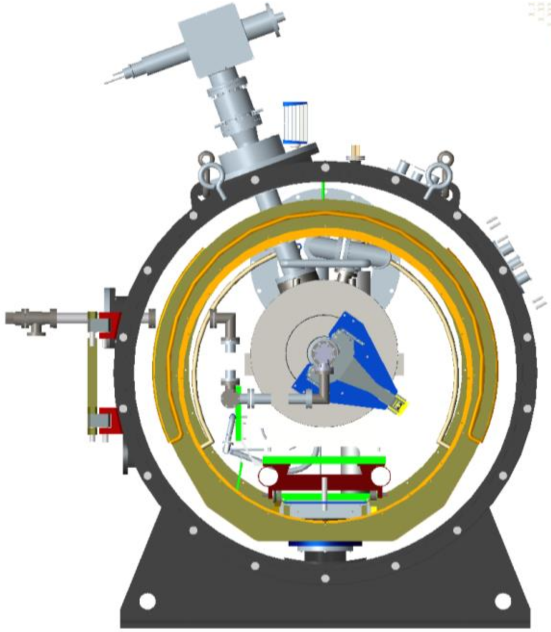
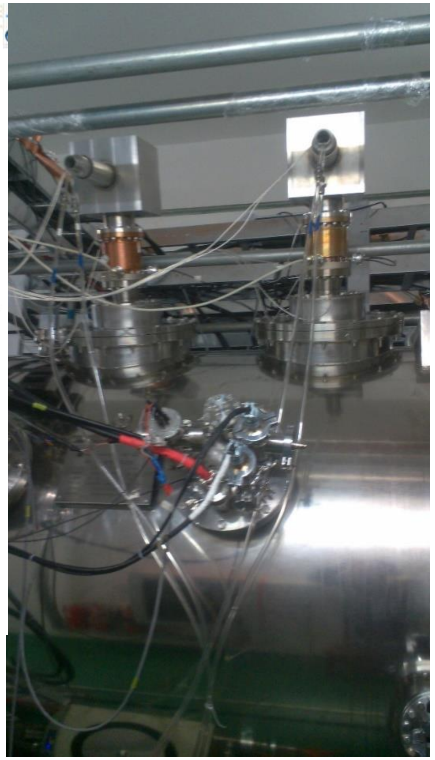
- **Disadvantages:**
  - E-M field enhancement
  - High contamination risk to the cavity

Any other negative effects?

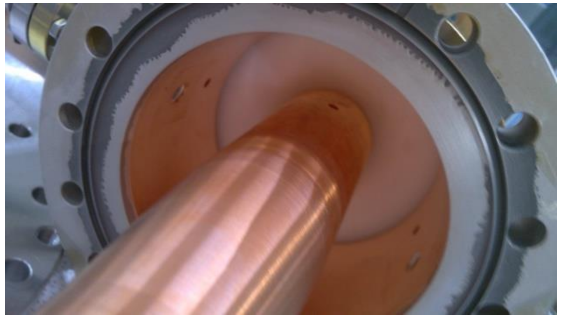
Window damage due to cavity FE

Observations

Two Spoek012 couplers encountered window crack during the rf processing.

In-cryomodule rf processing of Spoke cavities for TCM of C-ADS Injector-I

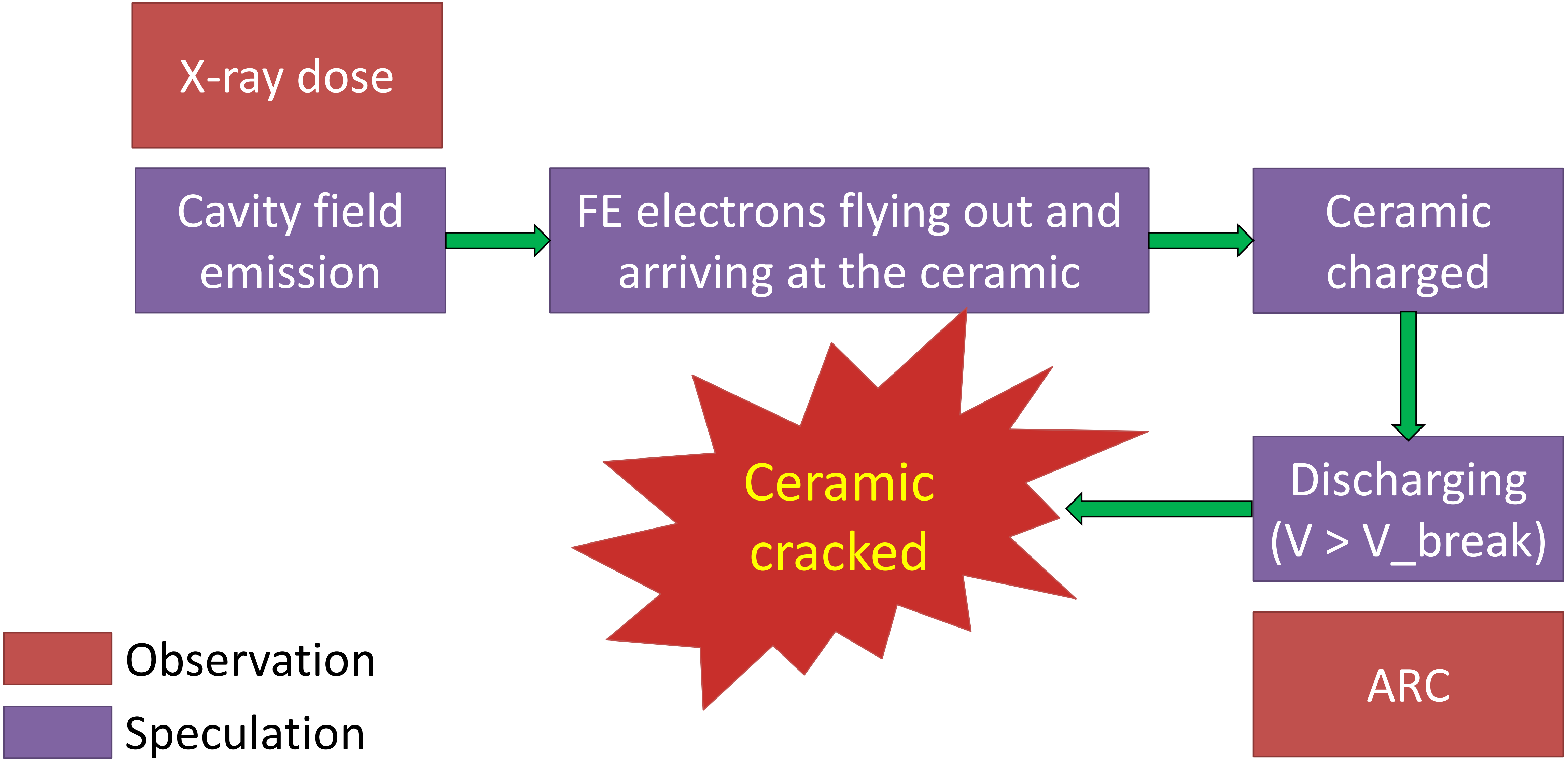


ceramic color:
white → yellow

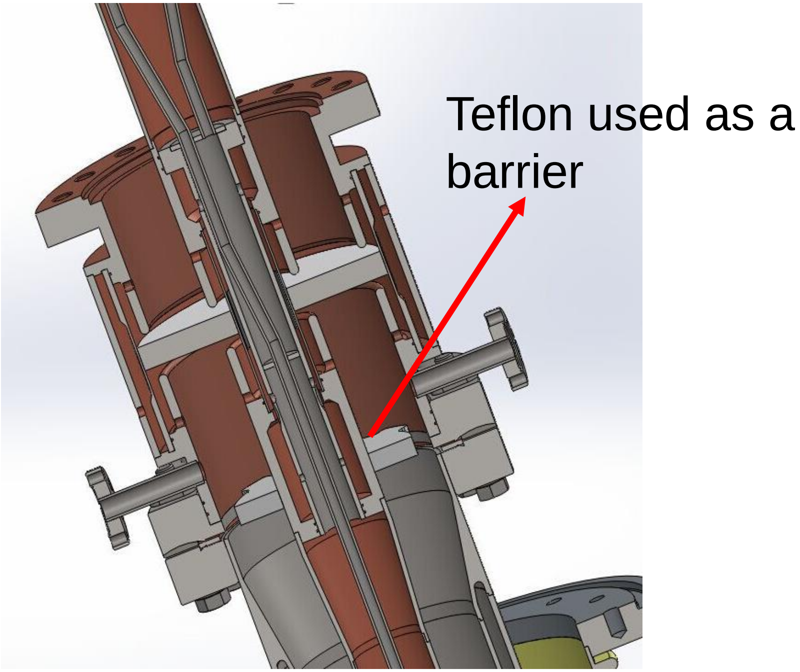

No electron and ion bombarding mark

- Power: < cw 2kW
- No outgasing
- No overheating: Tmax <25°C
- Periodical arc: one time/2~3 min
- After ~10 times arc→ crack
- Only happened at Eacc with large x-ray dose (>3 MV/m)
- Leak rate: 1E-6 mbar.l/s

Speculation



Experimental analysis-1

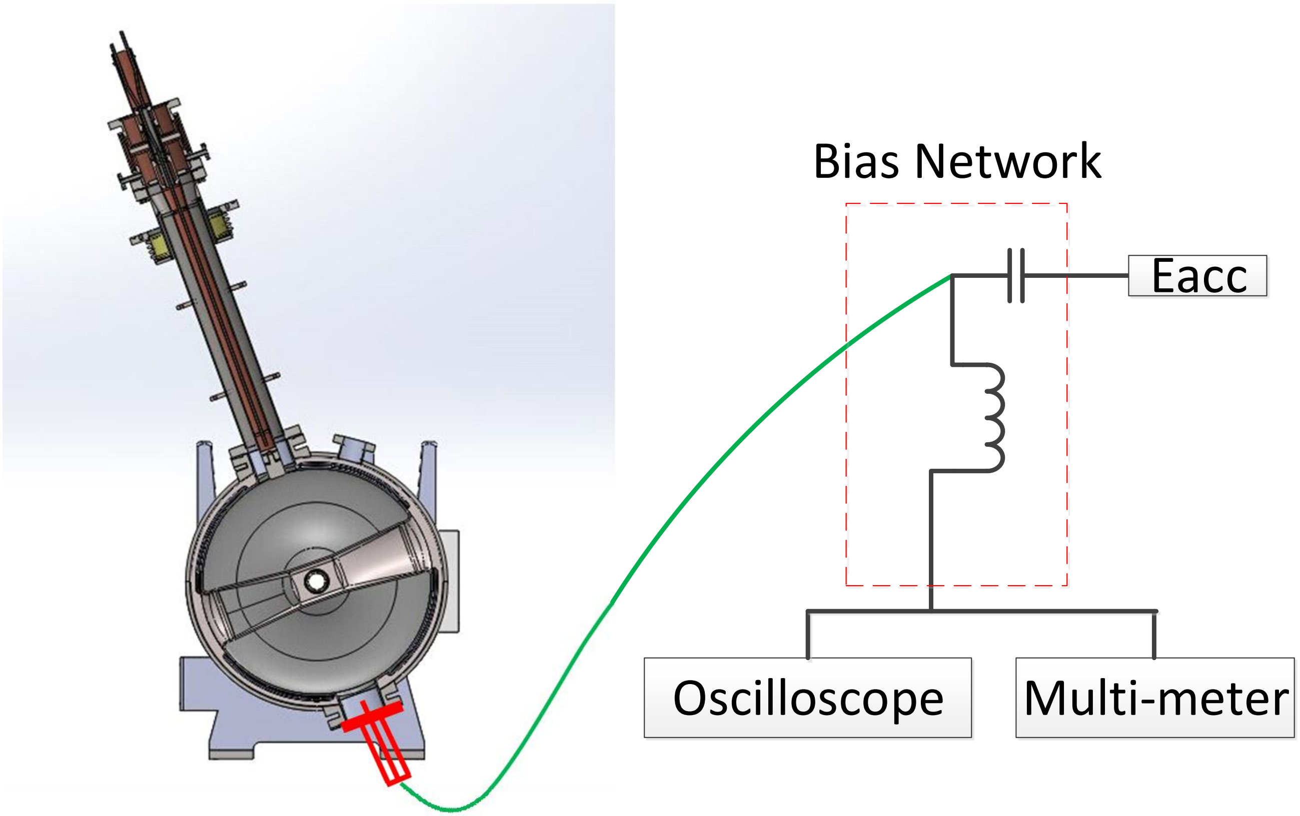


- Something may result in arc and ceramic crack was blocked by the Teflon plate

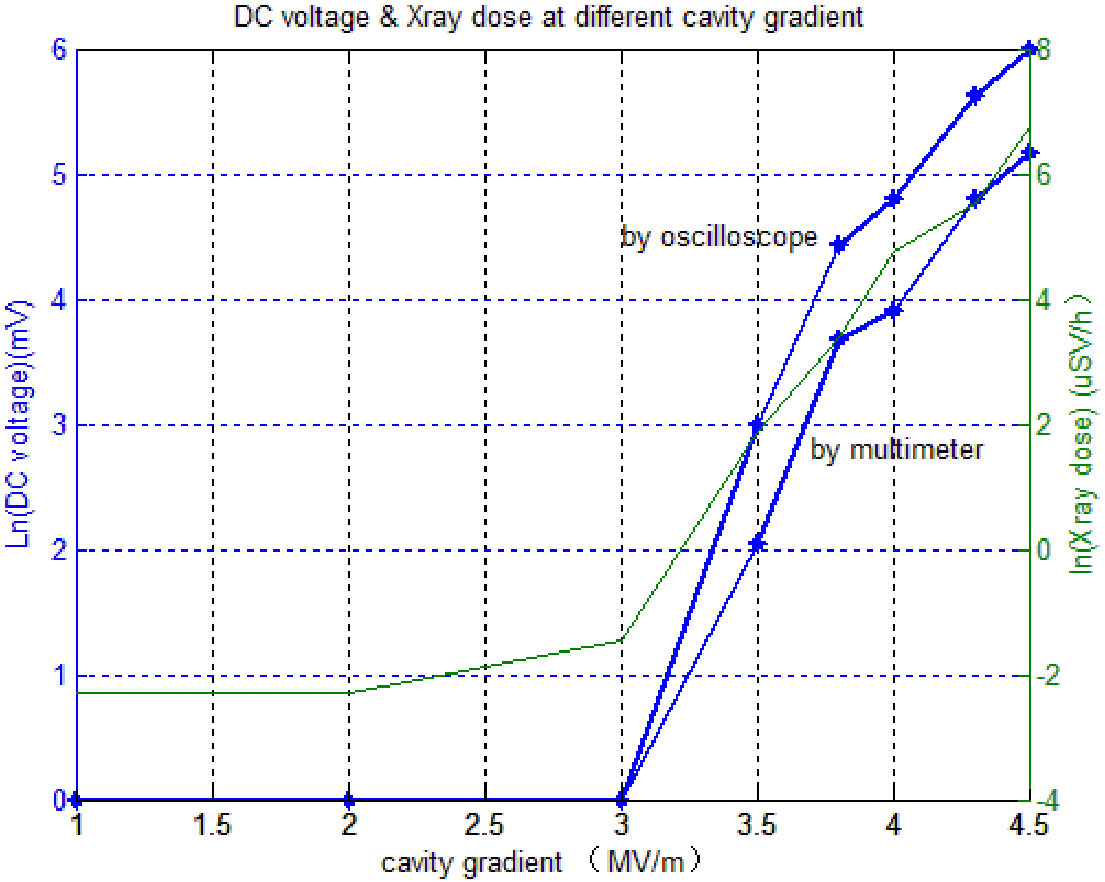
The coupler performance W/O Teflon barrier

	Without Teflon barrier	With Teflon barrier
Eacc	4 MV/m	4 MV/m
Vacuum pressure	~1E-5Pa	~1E-5Pa
X-ray dose	~700 usV/h	~650 usV/h
Arc	One time/2~3 min	Never happened
Window crack	Cracked at 10 times arc triggers	Never cracked after shielding by Teflon plate.

Experimental analysis-2



A"bias network" was connected with the pickup that was geometry symmetry with the coupler port to capture the voltage produced by FE electrons.

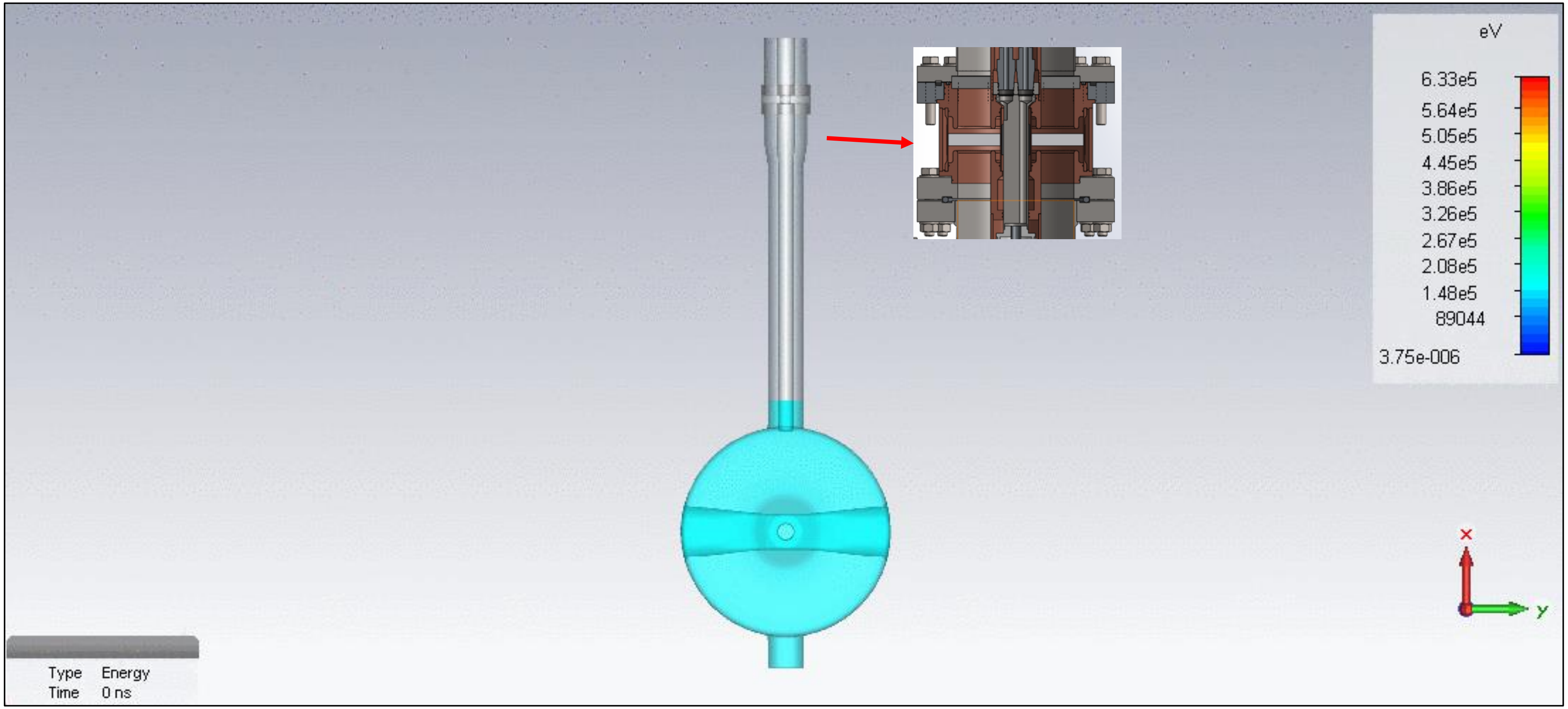


The expected DC voltage was detected accompanying the X-ray dose arising.

Simulation analysis

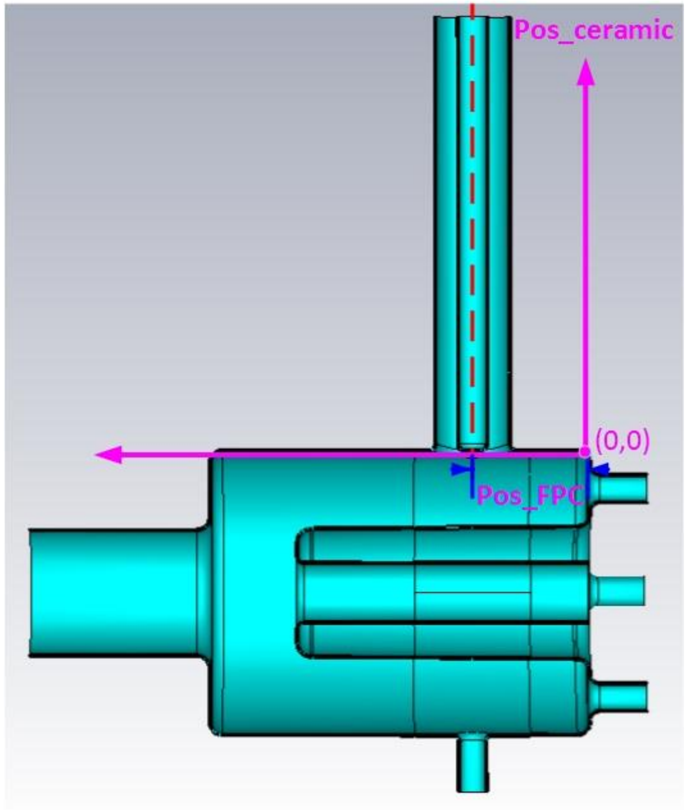
TESLA TECHNOLOGY TTC COLLABORATION

Simulation result shows that the FE induced electrons can fly out from the coupler port and arrive at the ceramic surface due to strong transverse E-field.

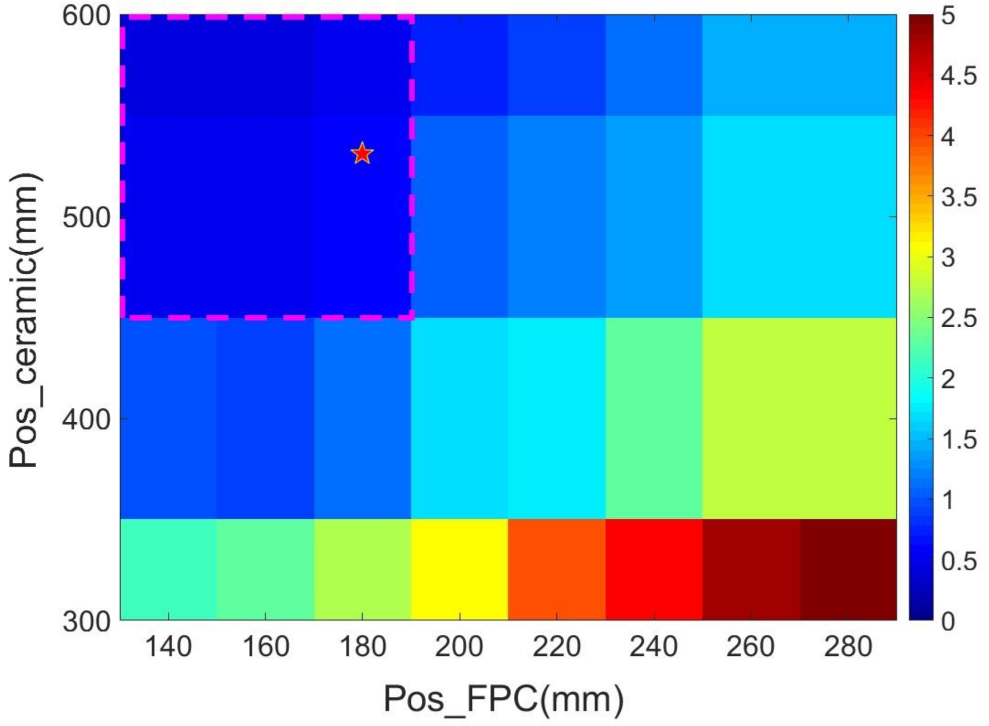


Solutions-1

Optimize the coupler port position(low transverse E-field) and window position (far enough away from cavity body) → FE e- can't arrive at ceramic surface



166.6MHz QWR cavity for HEPS

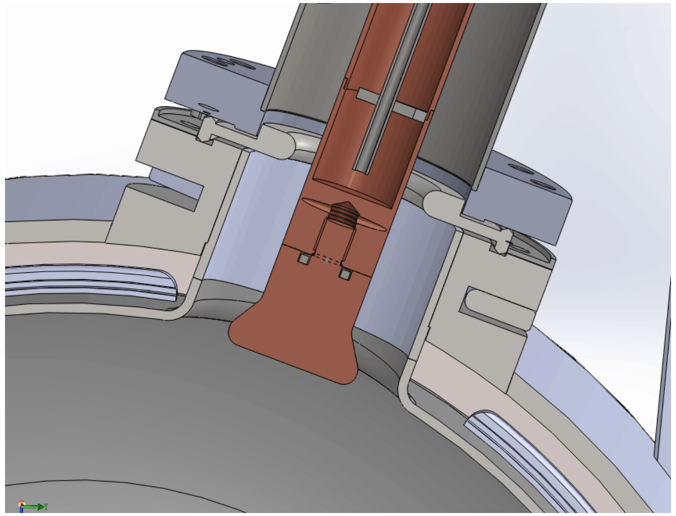


The simulated average number of FE-induced electrons flying into the coupler.

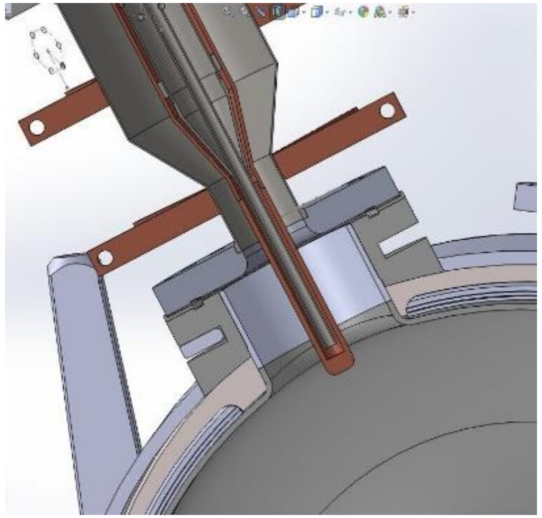
Solutions-2

TESLA TECHNOLOGY TTC COLLABORATION

Design special structures to block the FE electrons

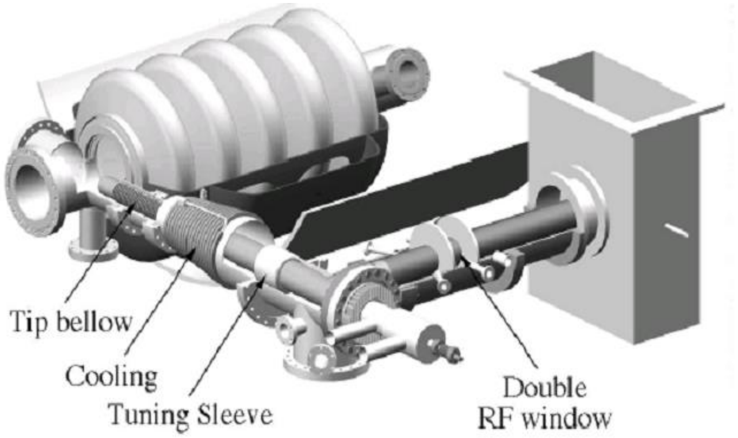


Special gasket or antenna tip for CADS



Reduced size coupler port + tapper structure for CADS

S-shape WG coupler for CEBAF



Window 90 degree bending of APT coupler

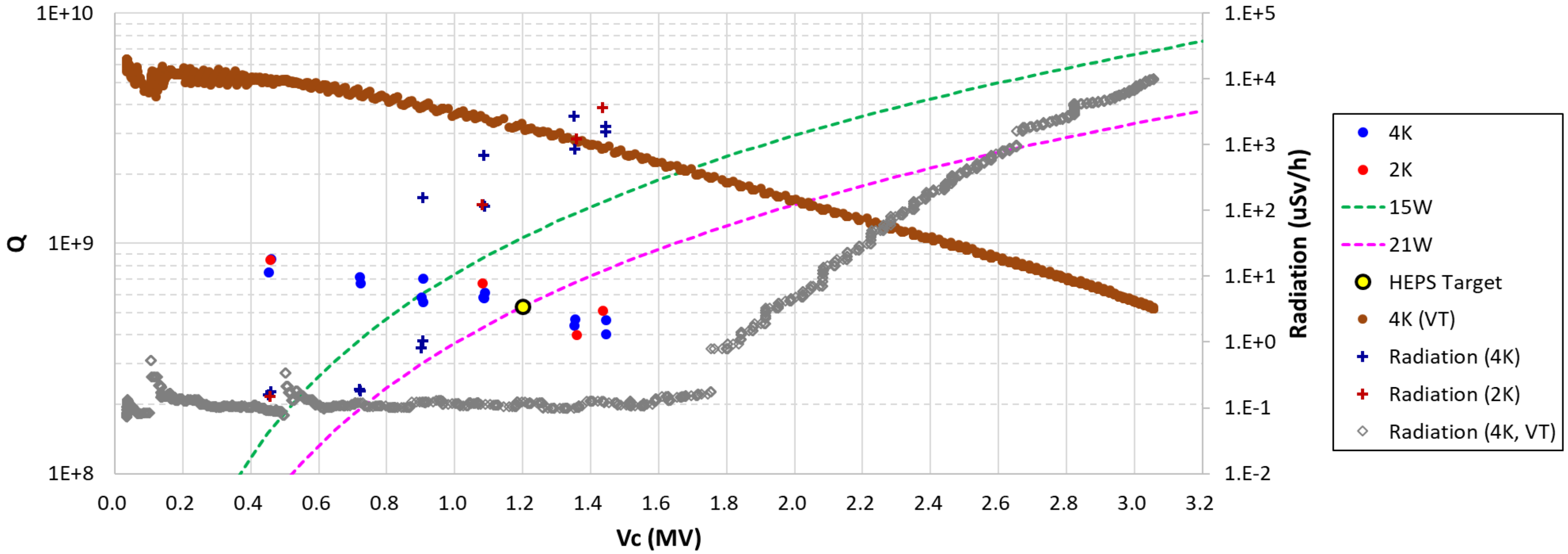
Private opinion: Comparing with disk shape window, cylindrical shape window seems better to hide from FE electrons bombardment?

Overheating due to cavity field leakage

Quality factor degradation

Large Q degradation from vertical test to horizontal test

HT of HEPS 166.6MHz PoP cavity

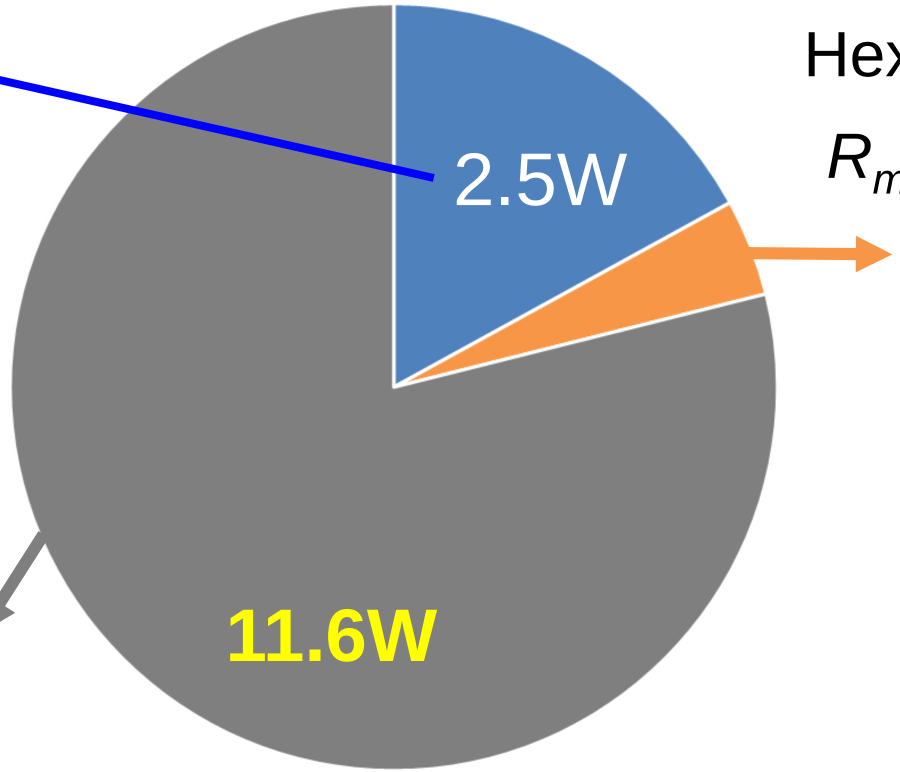


Test results

Unknown load

Vc=1.0MV, 4.2K

- Q0 during VT: 3.5e9 (2.5W)
- Q during HT: 5.9e8 (14.7W)



$$R_{mag} = 0.3(n\Omega) \cdot H_{ext}(mOe) \cdot \sqrt{f(GHz)}$$

Hext = 40mG (close to ports)

R_{mag} = 4.9nΩ

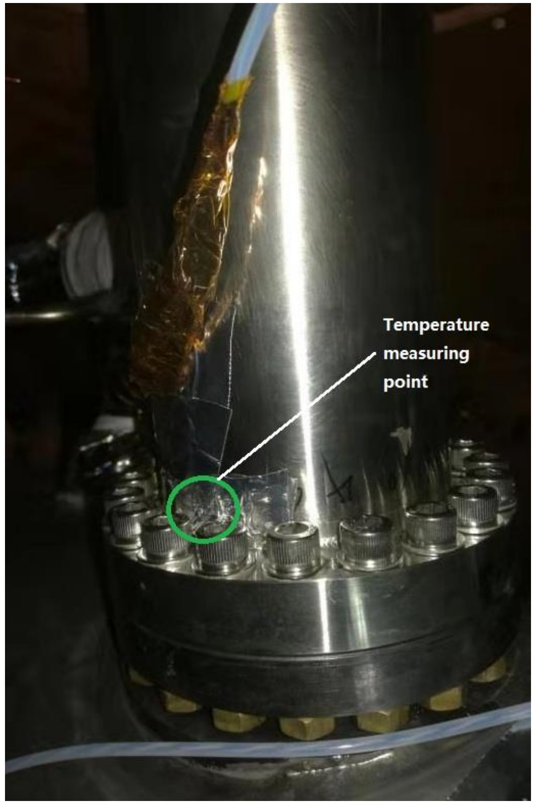
ΔP = 0.6W

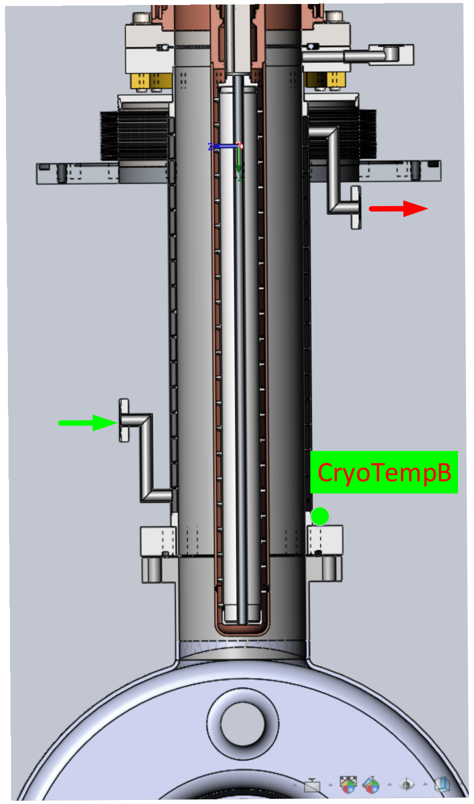
- **Unknown load???**
  - **FPC**
  - **Cavity degradation**

P_unknow= 14.7-2.5-0.6-11.6 (W)

G=55 Ω, R/Q=136 Ω

Overheating on FPC (Observation)





The measured temperature and heat load of the total cavity system

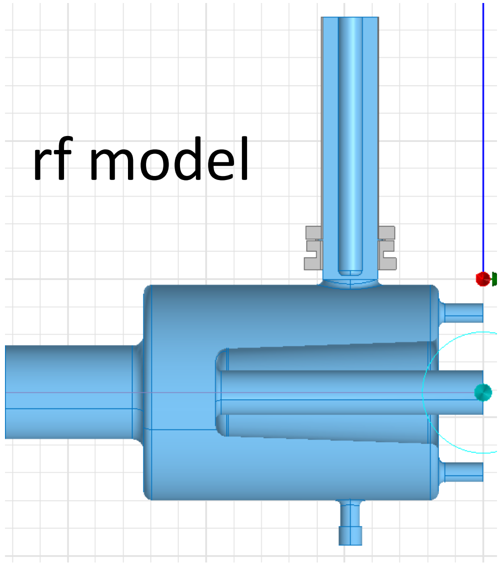
Conditions	Pf (kW)	Vc (MV)	CryoTempB (K)	Heat load (W)
No RF power	0	0	6.5	12.2
Cavity off resonant	13.2	0	**6.5**	**11.8**
Cavity on resonant	13.3	1.0	**36**	**26.4**

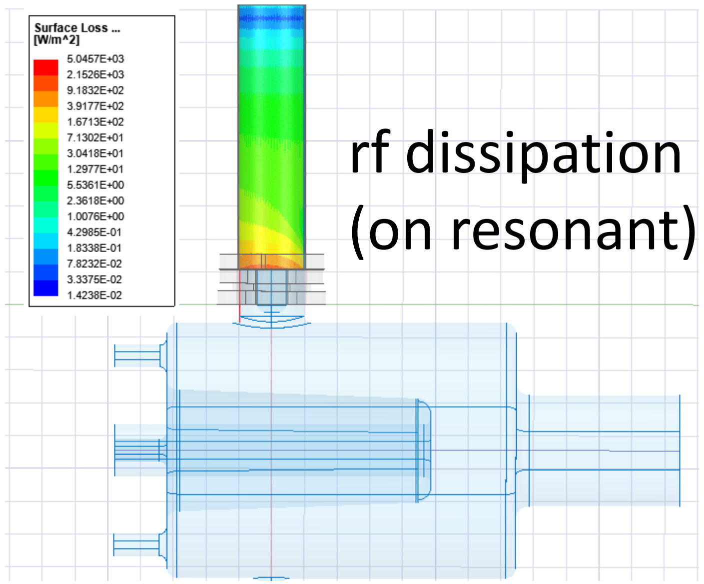
CryoTempB ↑

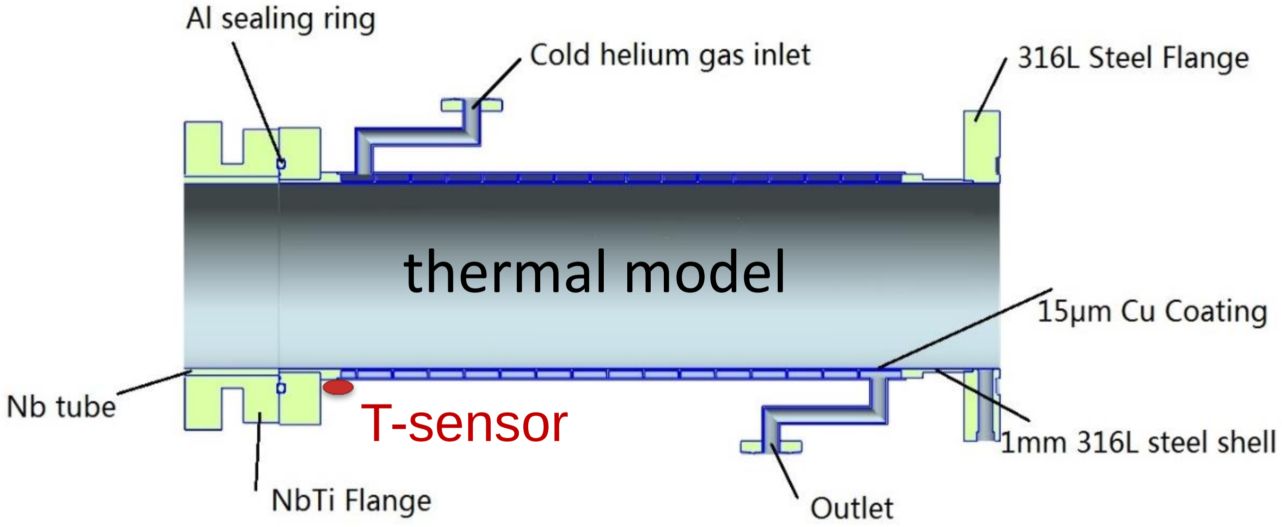
Off resonant → On resonant

Heat load ↑

Overheating on FPC (simulation)







RF-solid-fluid co-simulation ANSYS

Vc: 1.0MV

GHe flow: 14.4 l/min

Initial condition:

Nb and NbTi NC (totally quench)

GHe flow (L/min)	OC temp. (K)		Heat load (W)	
	Simu.	Meas.	Simu. #	Meas.*
4.4	58.6	64	41.8	33.8
8.2	48.5	47	37.3	31
11.2	46.2	41	34.3	29
14.4	38.9	36	30.8	28.3

#: Calculated 4.2K heat load of FPC

*：Measured heat load of whole system

Unknown load analysis

RF-solid-fluid co-simulation ANSYS

Vc: 1.0 MV

GHe flow: 14.4 l/min

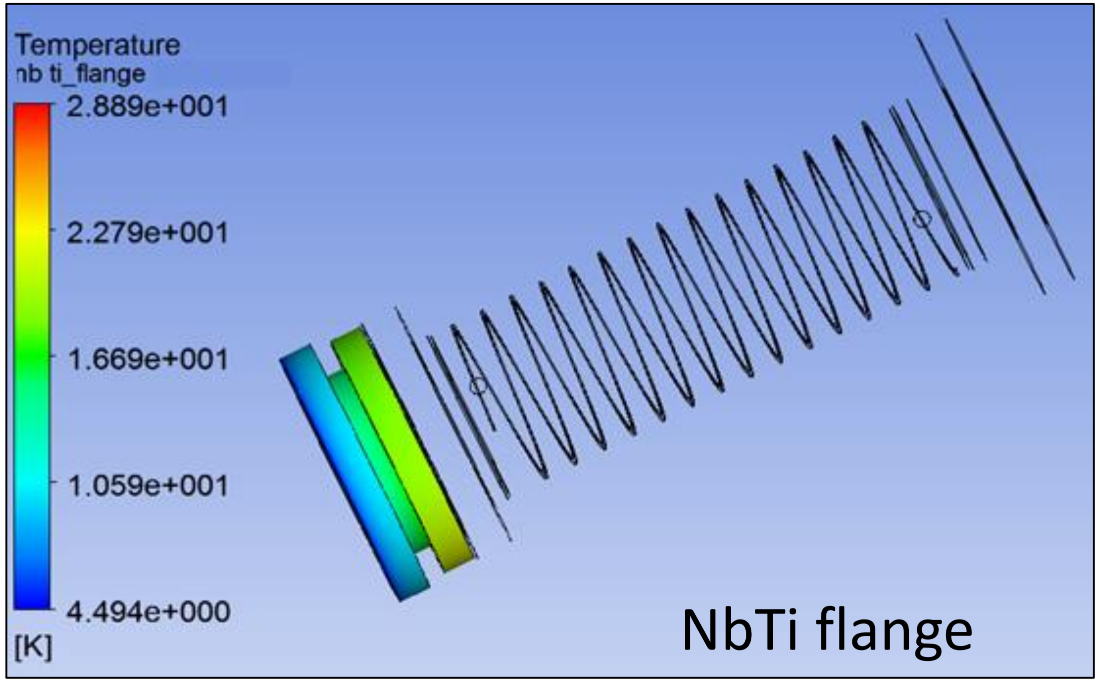
Initial condition of Nb tube and NbTi flange	Calculated 4.2K Heat load of FPC (W)	Unknown loss (W)
SC (not quench)	5.2	11.6
NC (quench totally)	30.8	

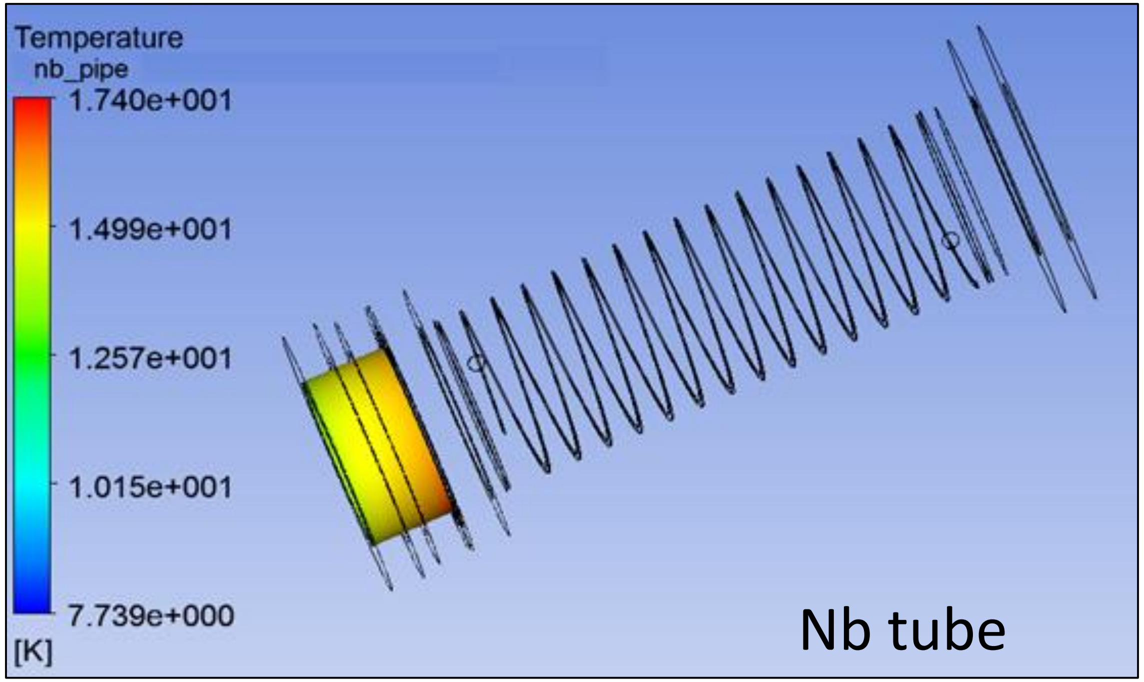
Quench analysis

- Quench was observed at 1.5 MV;
- Simulation indicates both Nb tube and NbTi flange quench.

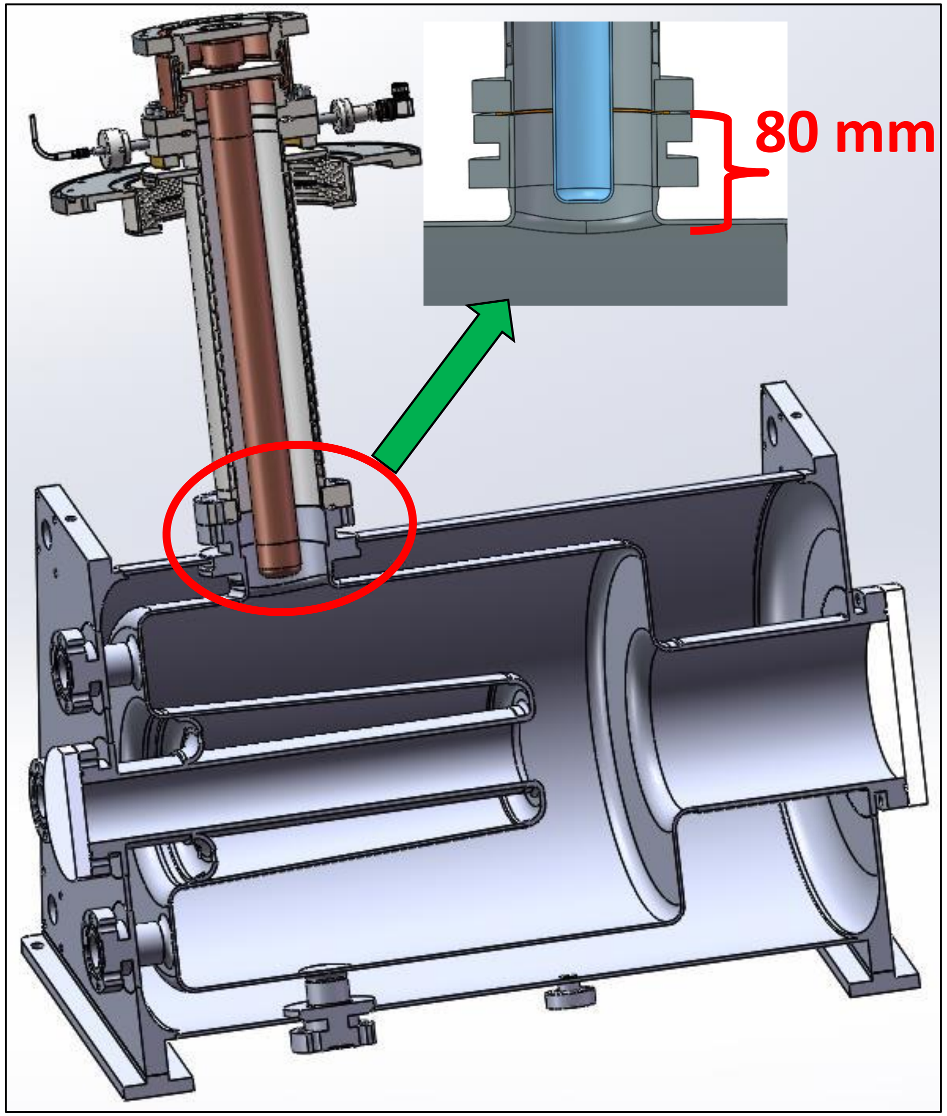
RF-solid-fluid co-simulation ANSYS

Vc=1.5 MV
GHe flow: 86.4 l/min
Initial condition: Nb and NbTi SC





Speculation



Cavity field leakage → Too short Nb tube → Overheating on coupler → Nb and NbTi partly quench → Excessive heat load → Q0 degradation

Solutions

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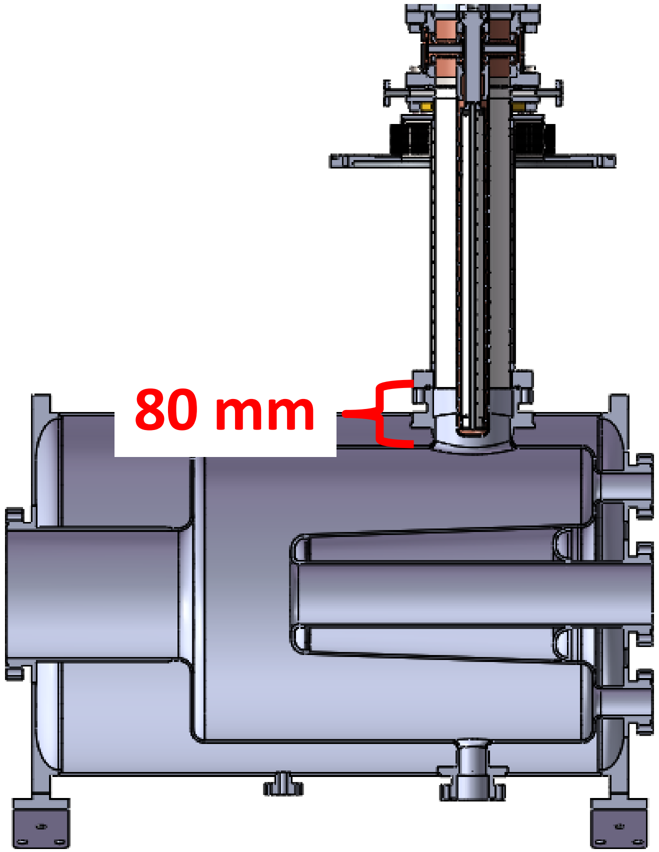
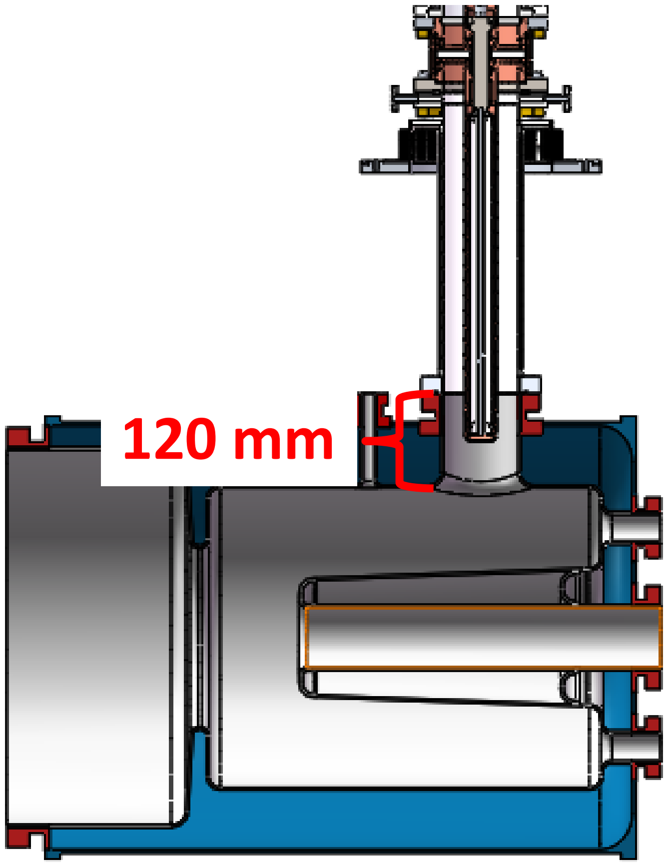
Elongate Nb tube of the FPC port



40mm extension of Nb tube

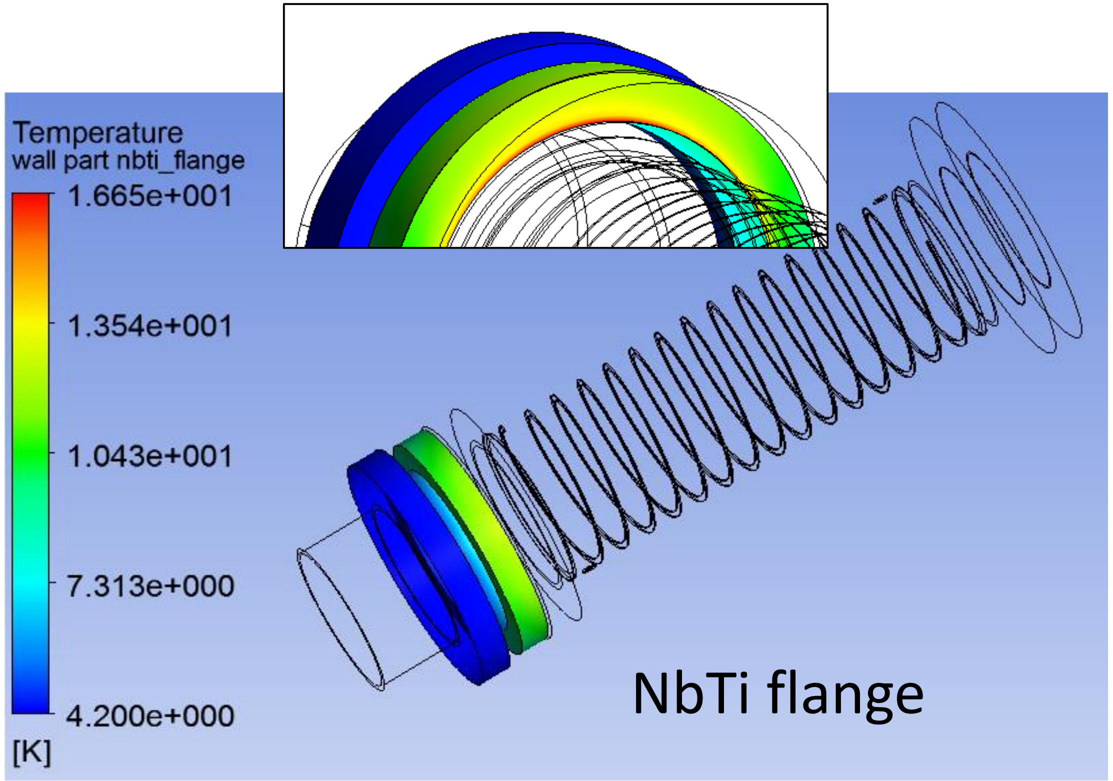


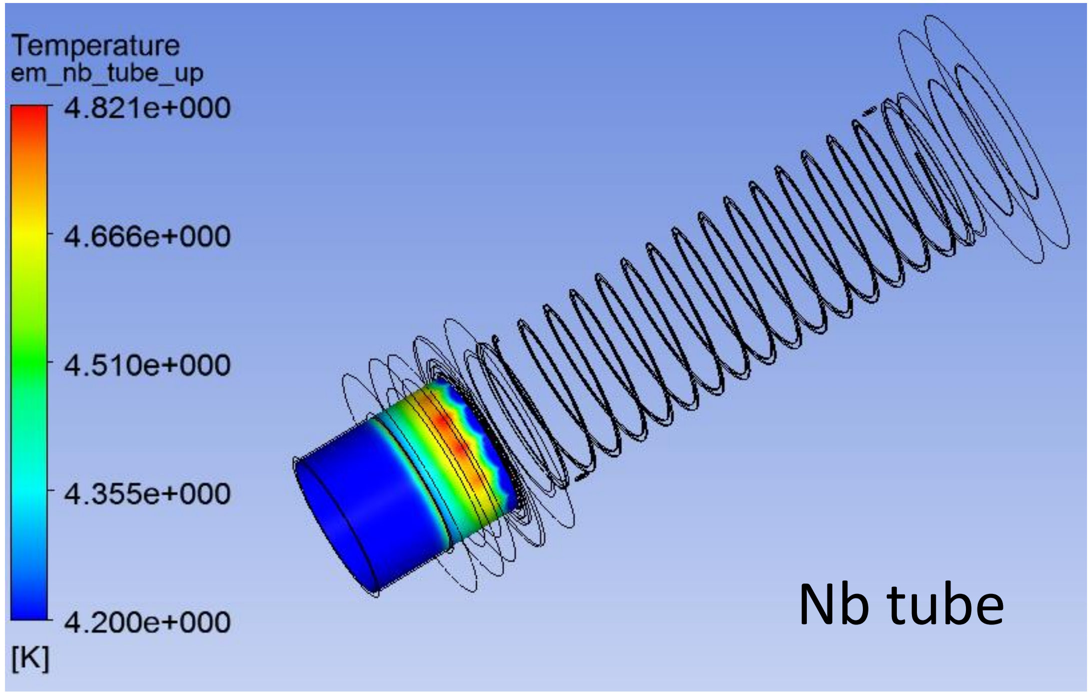
Heat analysis after elongation

- NbTi flange quench partly
- Nb tube Temp < Tc

RF-solid-fluid co-simulation ANSYS

Vc=1.5 MV
GHe flow: 14.4 l/min
Initial condition: Nb and NbTi SC





Comparison

Vc=1.5 MV
GHe flow: 14.4 l/min
Initial condition: Nb and NbTi SC

RF-solid-fluid co-simulation ANSYS

Conditions	Qe	Pf (kW)	GHe (K, l/mim)	OC RF loss (W)	Tmax_Nb (K)	4.2K heat load (W)
PoP (Nb=80mm)	1.4e5	28	7, 14.4	4.4	17.4	9.5
Formal (Nb=120mm)	5e4	83.3	5, 14.4	2.9	4.8	2.3

Summary

- Avoid line-of-light FE induced electrons bombardment on the ceramic window:
  - Optimize window position
  - Design special barrier
- Consider the cavity field leakage to the coupler, when:
  - Optimize the Nb tube length of the coupler port
  - Estimate the cryogenic heat load contributed by the coupler