Development of input coupler for cERL main linac

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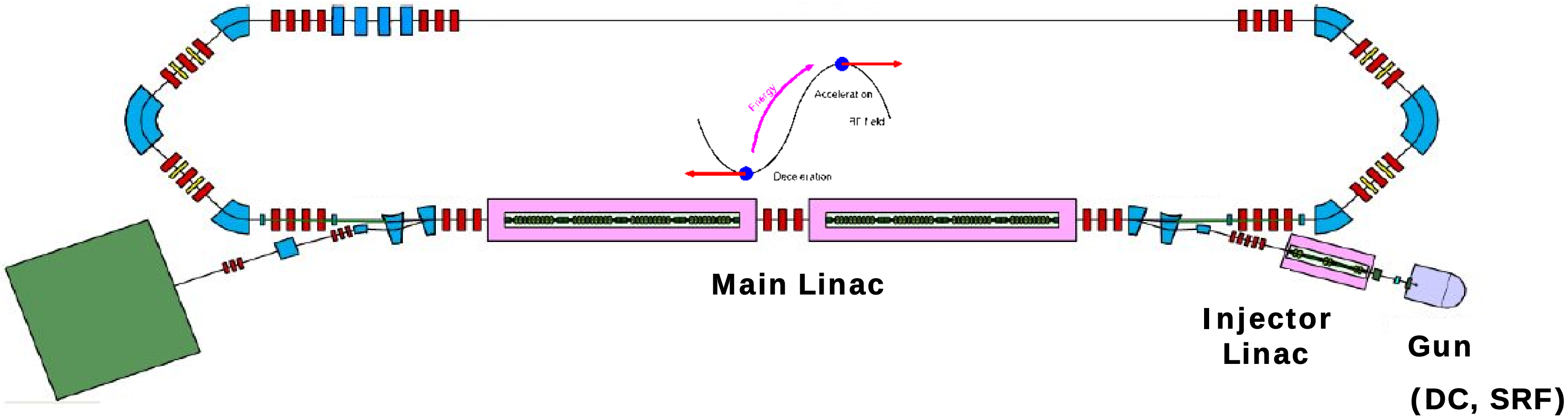
Contents

- Design of input coupler
- High power test of input coupler under LN2.
- Other measurements
- Summary

Coupler requirements & properties for CW-ERL main linac

ERL design based on compact ERL (cERL)



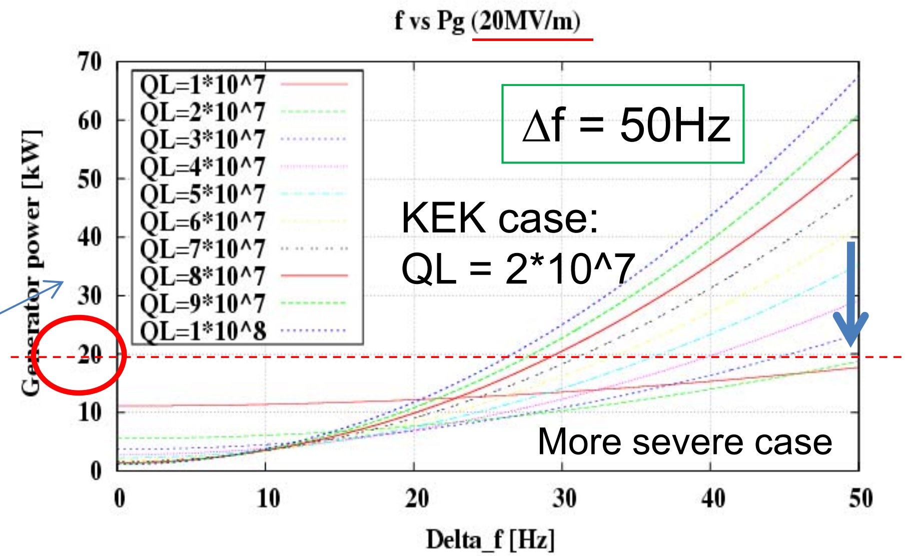
Main linac case (compared with injector)

--Low RF power thanks to Energy Recover
weak coupling (Qext = 1*10^7 – 1*10^8)
which depend on microphonics effect
basically 5-20kW will be needed.

--Reliabilties are another important points
due to fabricate large number of couplers.

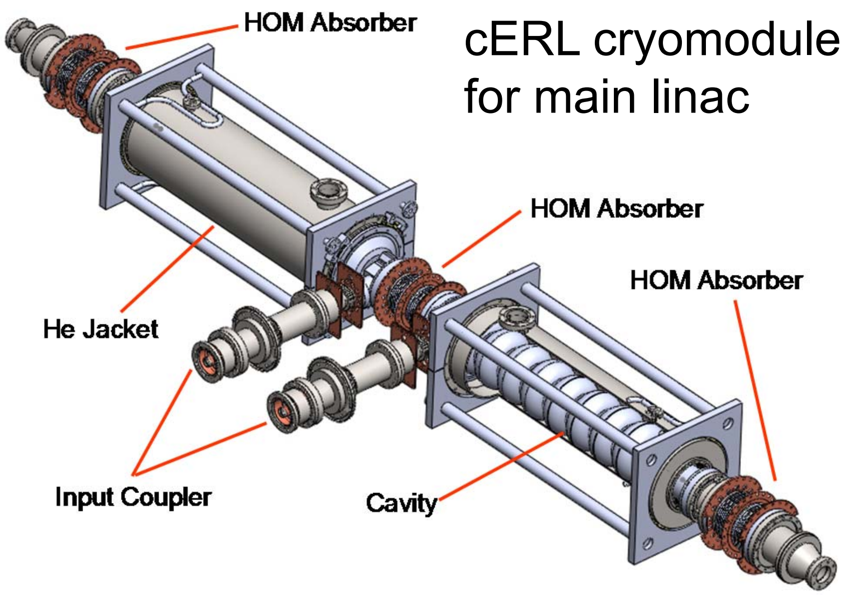
$$P_g = \frac{V_c^2}{4(R/Q)Q_L}\left(1 + 4Q_L^2\left(\frac{\Delta f}{f}\right)^2\right)$$

Calculation of ΔF vs Pg with different QL



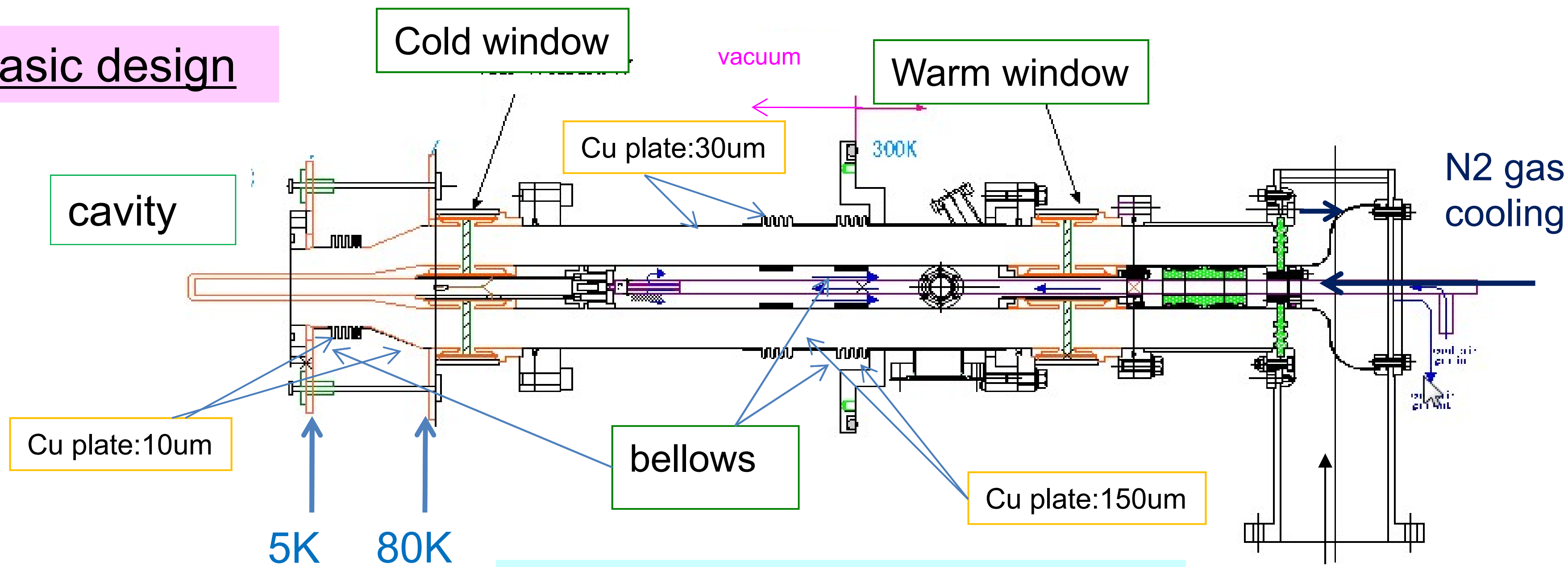
Basic parameters & design of input coupler for main linac at KEK

- Basic parameters
  - frequency : CW, 1.3GHz
  - Accelerating gradient : Max 20MV/m
  - input power : max 20kW , standing wave
  - loaded Q(Q_L) : (1-4) * 10^7 (variable coupling)
- Points (modified from STF-BL coupler for CW)
  - Forced N2 gas cooling of inner conductor
  - Impedance from 50Ω to 60Ω
  - two 99.7% purity of ceramic windows are used.
  - make variable (+-5mm) with cold bellows



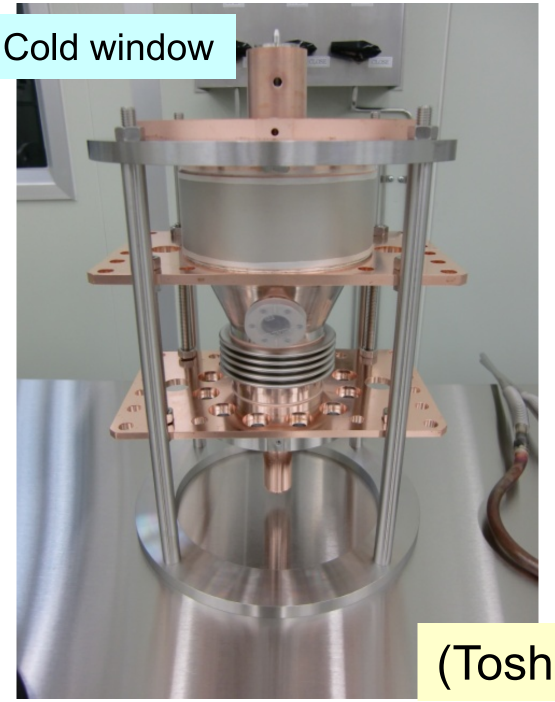
cERL cryomodule for main linac

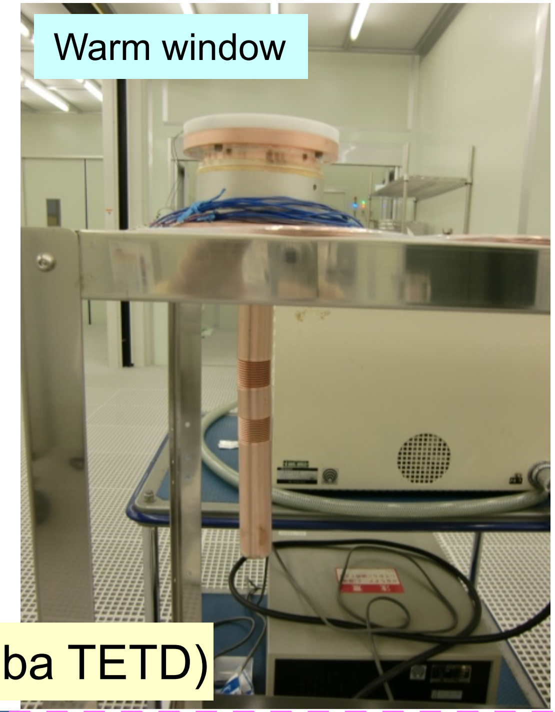
Basic design

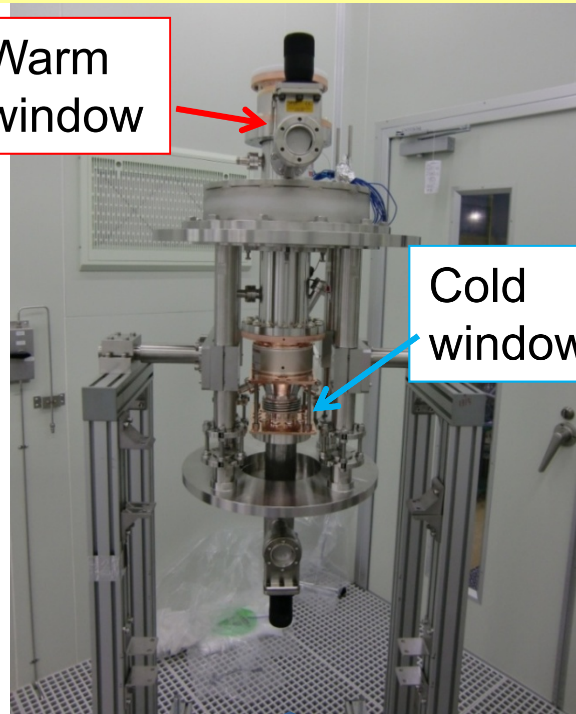


coaxial disk ceramic window was used

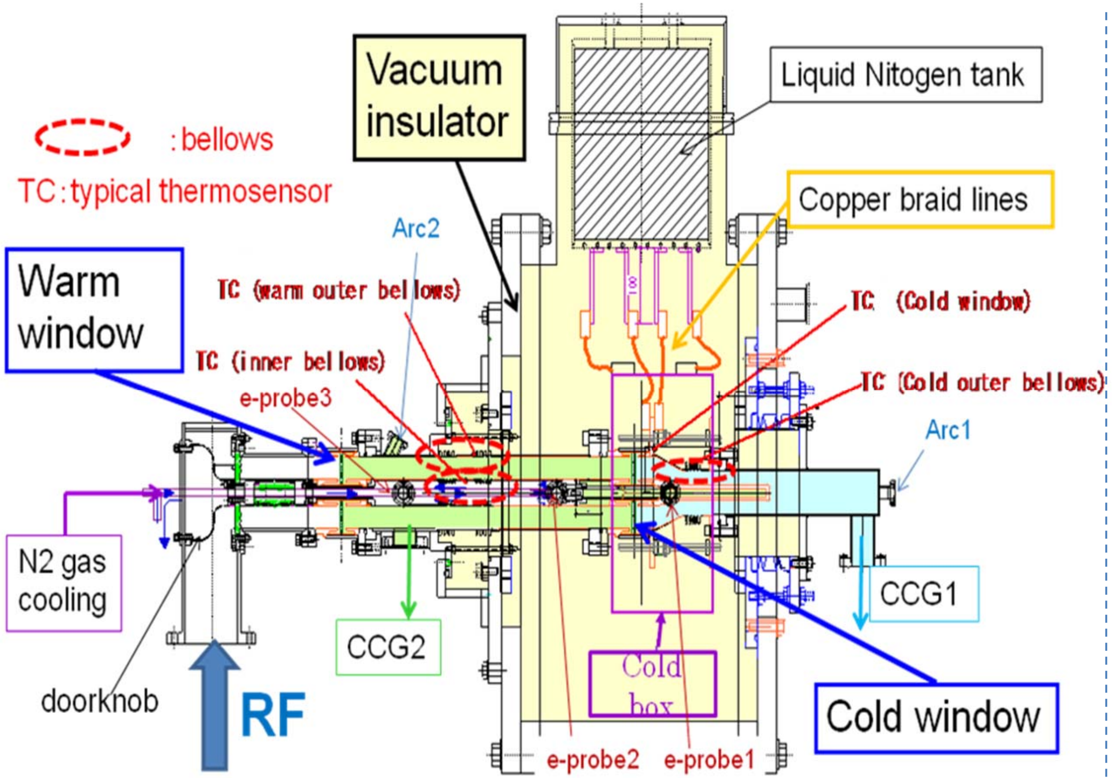
Prototype of input coupler (v1) & assembly in clean room for high power test

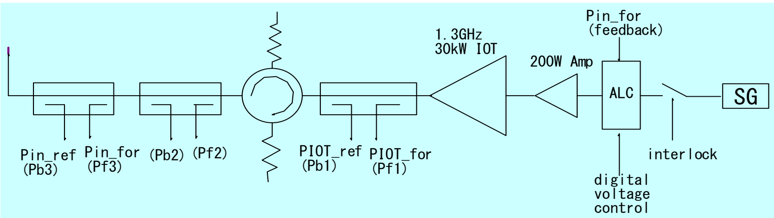


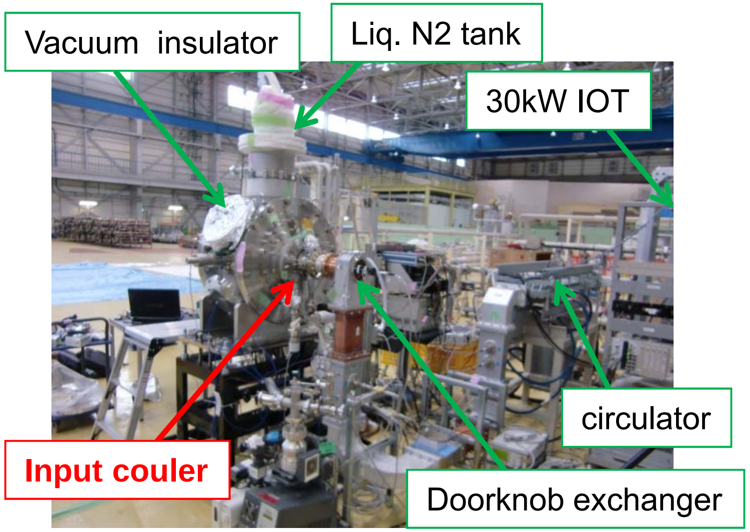


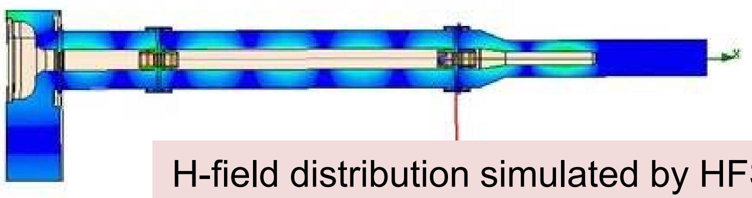


KEK-ERL main linac coupler high power test with liquid Nitrogen





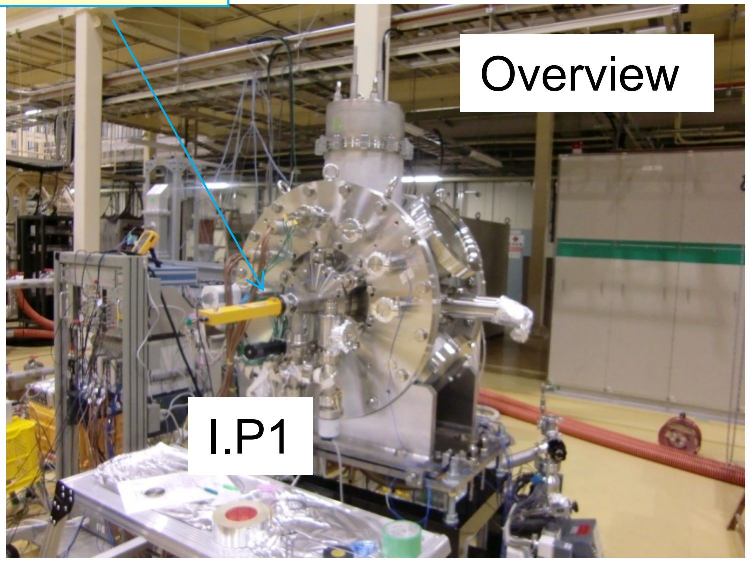


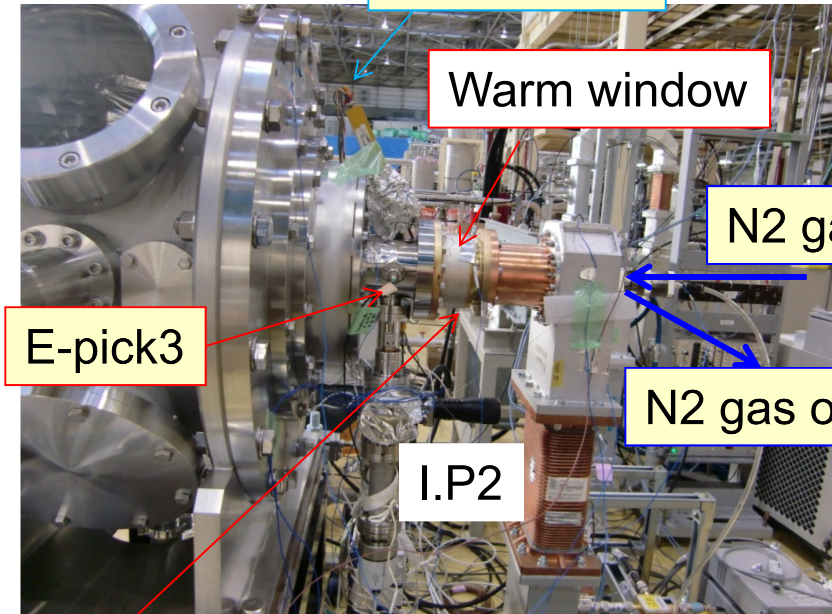


H-field distribution simulated by HFSS

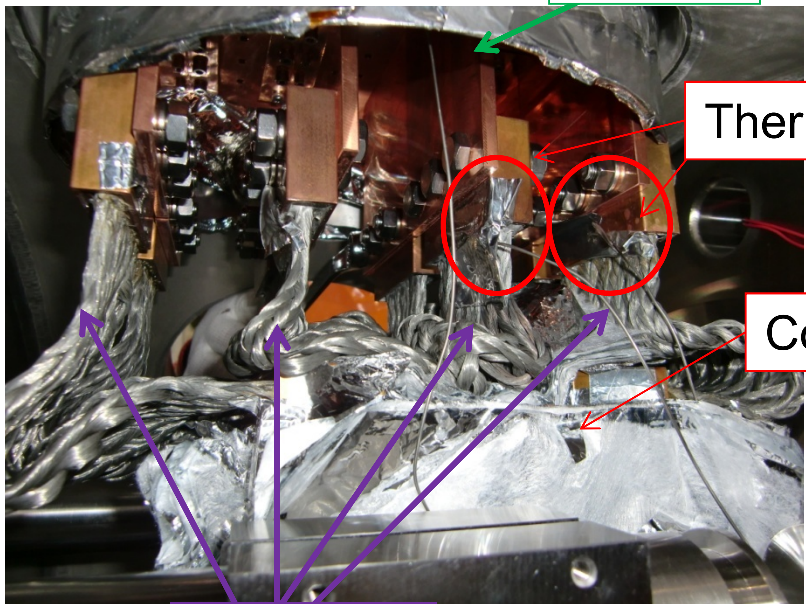
- **High power test of prototype of input coupler under liquid Nitrogen cooling with vacuum insulator to know the real temperature rises under vacuum insulation as same as the cryomodule by feeding the high power .**
- To simulate the same standing wave condition of cryomodule, Bellows and ceramic windows were set not to stand the peak field in high power test.

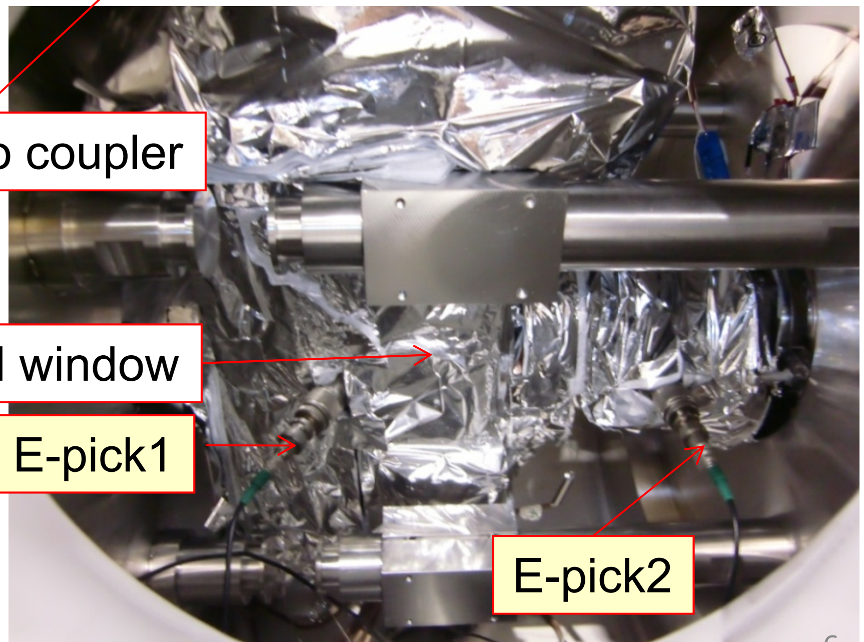
Detail setup of high power test





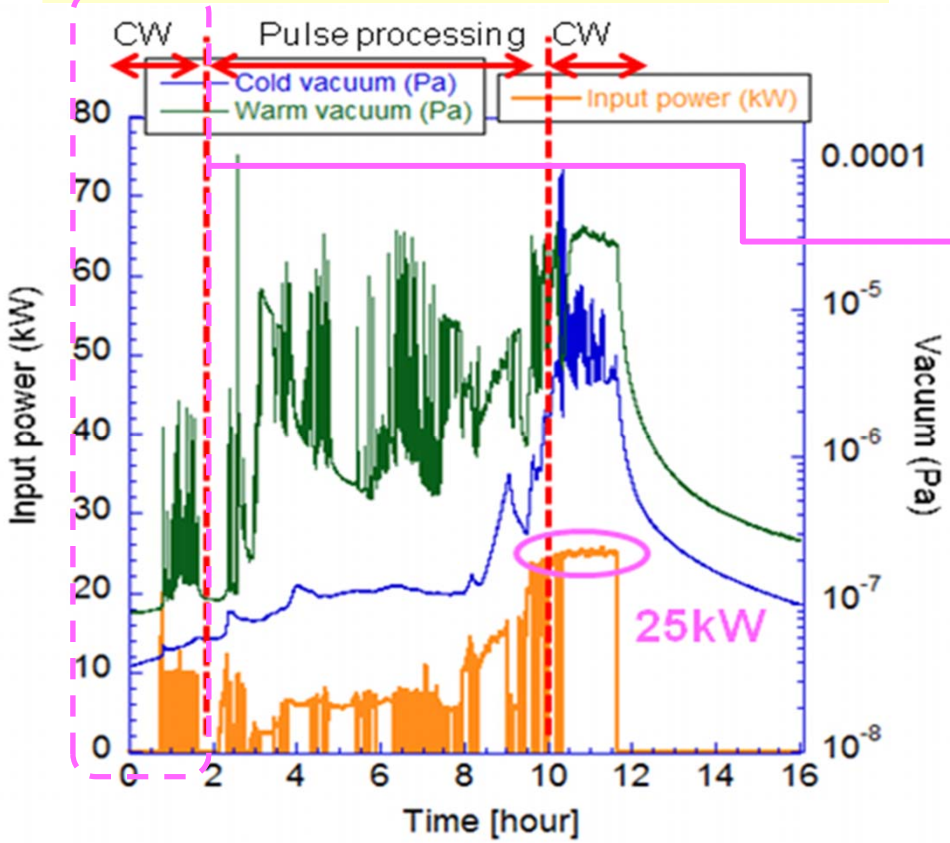
Inside vacuum insulator



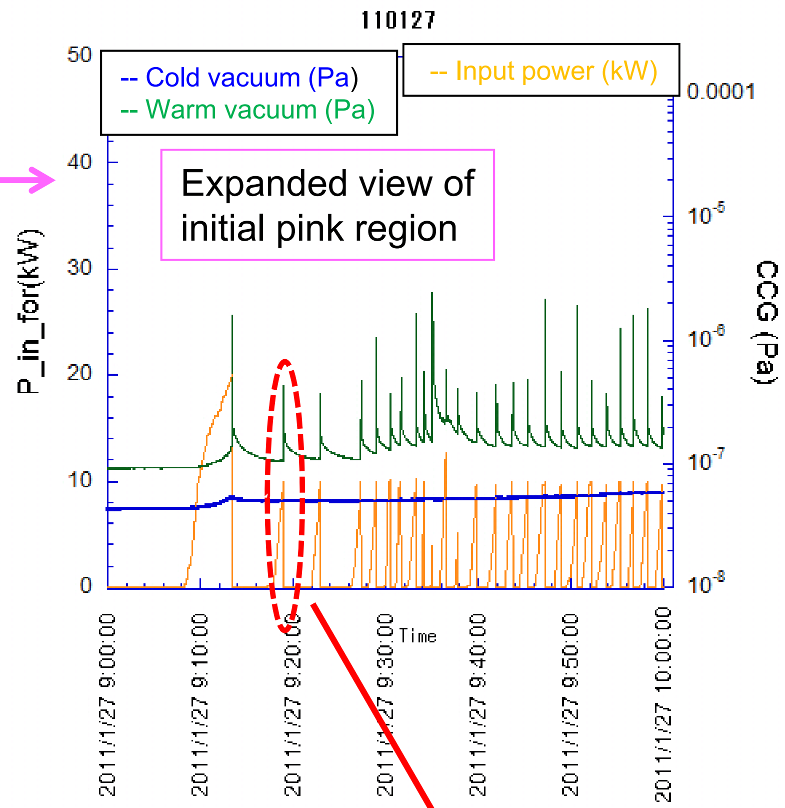


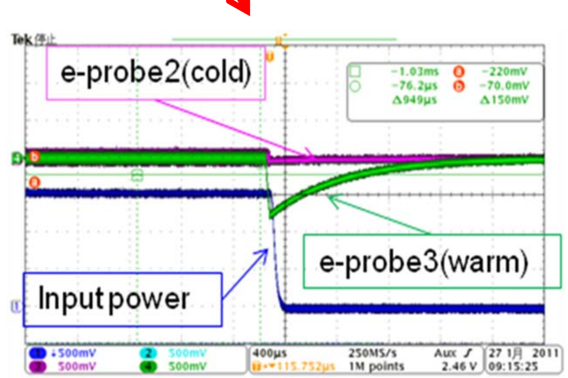
All are surrounded with super insulator

Power history(left) vacuum (right) under processing。



Processing up to 25kW



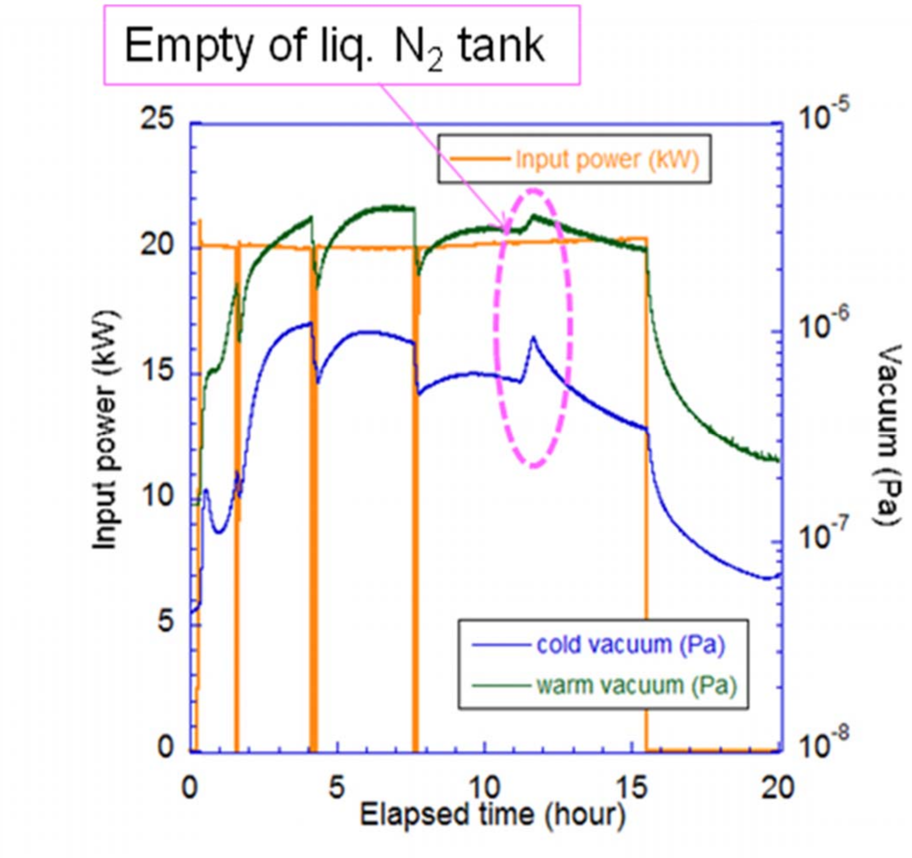


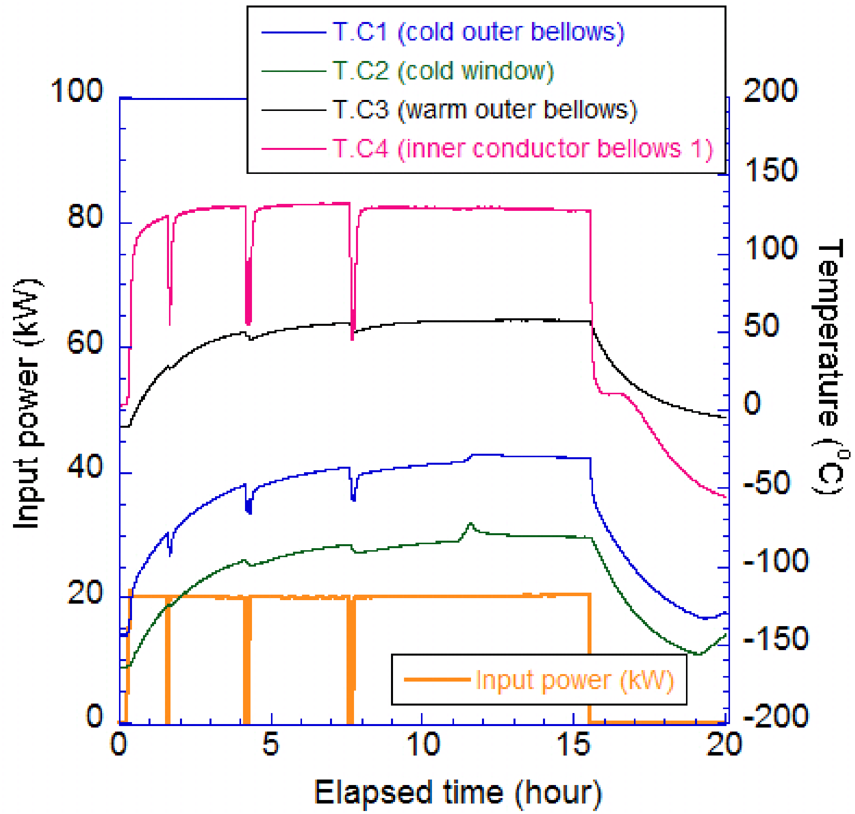
At 20kW, suddenly arc (arc2) and vacuum (CCG2) interlocks worked. feeding power could not overcame 10kW level under CW power feeding.

→Change pulse processing . feeding power gradually increased under keeping the lower vacuum pressure than $1x10^{-4}$ Pa for 8 hours and finally we reached the 25kW power level.

・After changing to the CW power feeding at 25kW,the vacuum pressure of cold window (CCG1) slightly increased and however decreased under keeping the 25kW level**. The processing was smoothly carried out by using the pulse processing**.

20kW keep data (power vs vac & typical temperature)





<u>Can keep 20kW with standing wave for 16hours.</u>

- Vacuum of cold part is near 1*10^-6Pa and decreased while keeping 20kW.
- Temperature of inner conductor with bellows are 130℃ under feeding N2 gas of 116l/min.
- Temperature rise of cold window is 83K,but temperature of cold window is -81℃.
- Temperature rises of bellows of outer conductors of cold window and warm window are about 100K, which is largest point of temperature rise under keeping 20kW standing wave.
- Measured heat load at Cold window was roughly estimated to 53W. This was slightly higher than expected value of 30-40W by calculation.

Details of measured temperatures under 20kW power feeding

Temp.(℃): temperature under 20kW

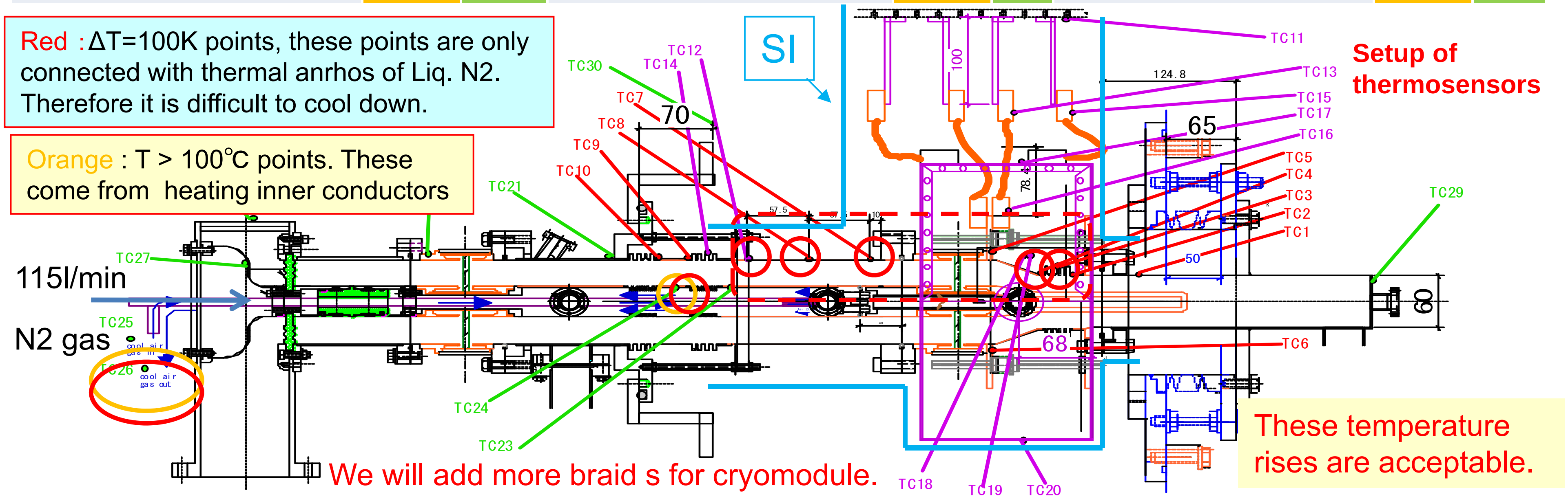
ΔT : difference of temperature between before and after 20kW power feeding

Thermosensors (channel & locations)	Temp. (℃)	ΔT (K)	Thermosensors (channel & locations)	Temp. (℃)	ΔT (K)	Thermosensors (channel & locations)	Temp. (℃)	ΔT (K)
T1-1(cold end plate in vac.)	−11.7	46.1	T2-1(Liq. N2 tank)	−193.1	0.8	T3-1(warm outer outside)	28.2	25.2
T1-2(cold outer bellows down)	−47.7	82.5	T2-2(outer 125mm H-bottom)	32.6	111.8	T3-2(warm window)	78.9	74.7
T1-3(cold outer bellows middle)	−30.5	113.2	T2-3(Blade (3) to Cold window)	−179	10.5	T3-3(inner conductor down)	50.9	47.7
T1-4(cold outer bellows up)	−32.6	117.6	T2-4(outer bellows (middle) cold side)	55.3	99.5	T3-4(inner conductor middle)	127.5	124.1
T1-5(cold window upper)	−81.2	82.7	T2-5(Blade (4) to Cold Box)	−188.2	3.2	T3-5(N2 gas in)	8.8	1.9
T1-6(cold window lower)	−62.9	97	T2-6(Blade (3) at Cold Window)	−93.4	72.6	T3-6(N2 gas out)	108.2	103.7
T1-7(outer 10mm) (H-botoom)	−31.5	106.6	T2-7(Cold Box top)	−108.8	53.4	T3-7(doorknob)	91.7	86.7
T1-8(outer 67.5mm)(H-top)	11.5	117.9	T2-8(Cold Box side 1)	−59	54.9	T3-8(doorknob end plate)	77.7	72.4
T1-9(warm outer bellows middle1)	56.9	67.7	T2-9(Cold Box side2)	−67.3	68.3	T3-9(cold end plate)	7.8	2.9
T1-10(warm outer bellows middle2)	57.9	69.2	T2-10(Cold Box bottom)	−55.8	66	T3-10(room temperature)	5.9	3.9

Red : ΔT=100K points, these points are only connected with thermal anrhos of Liq. N2. Therefore it is difficult to cool down.

Orange : T > 100℃ points. These come from heating inner conductors

Setup of thermosensors

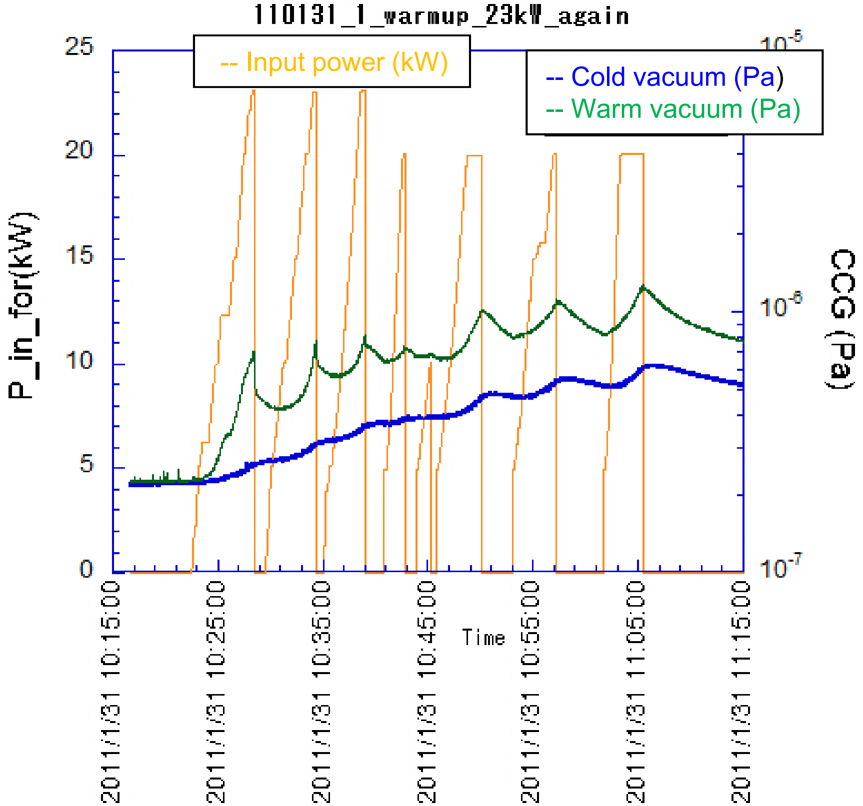


We will add more braid s for cryomodule.

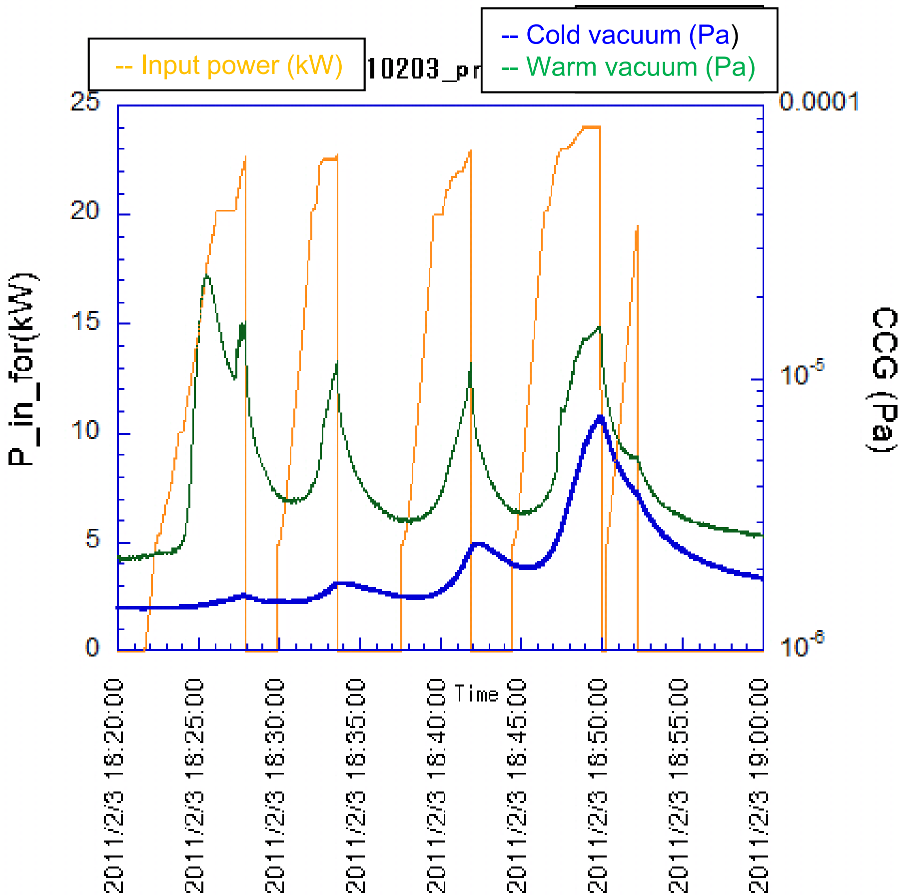
These temperature rises are acceptable.

Processing effect

After warming up

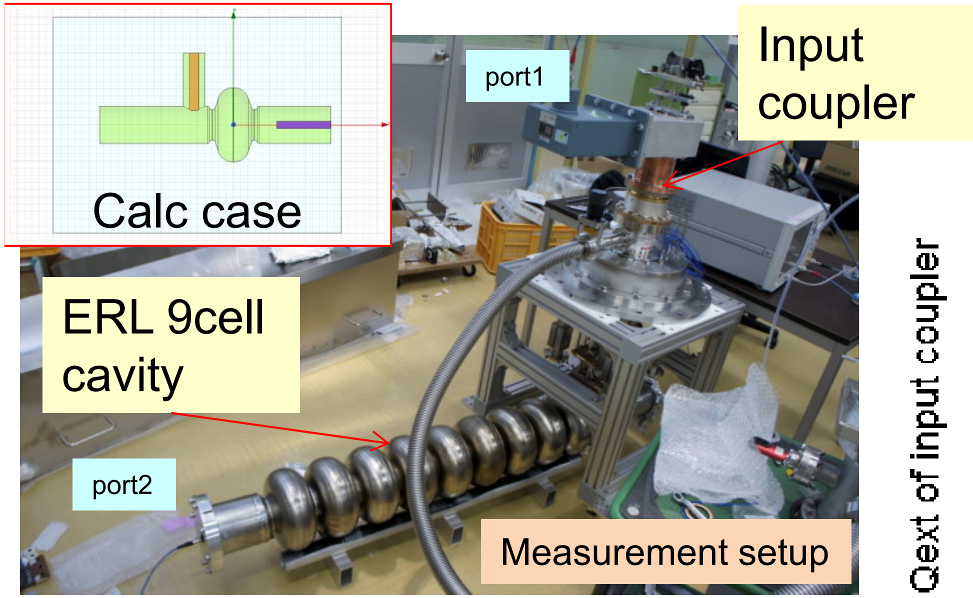


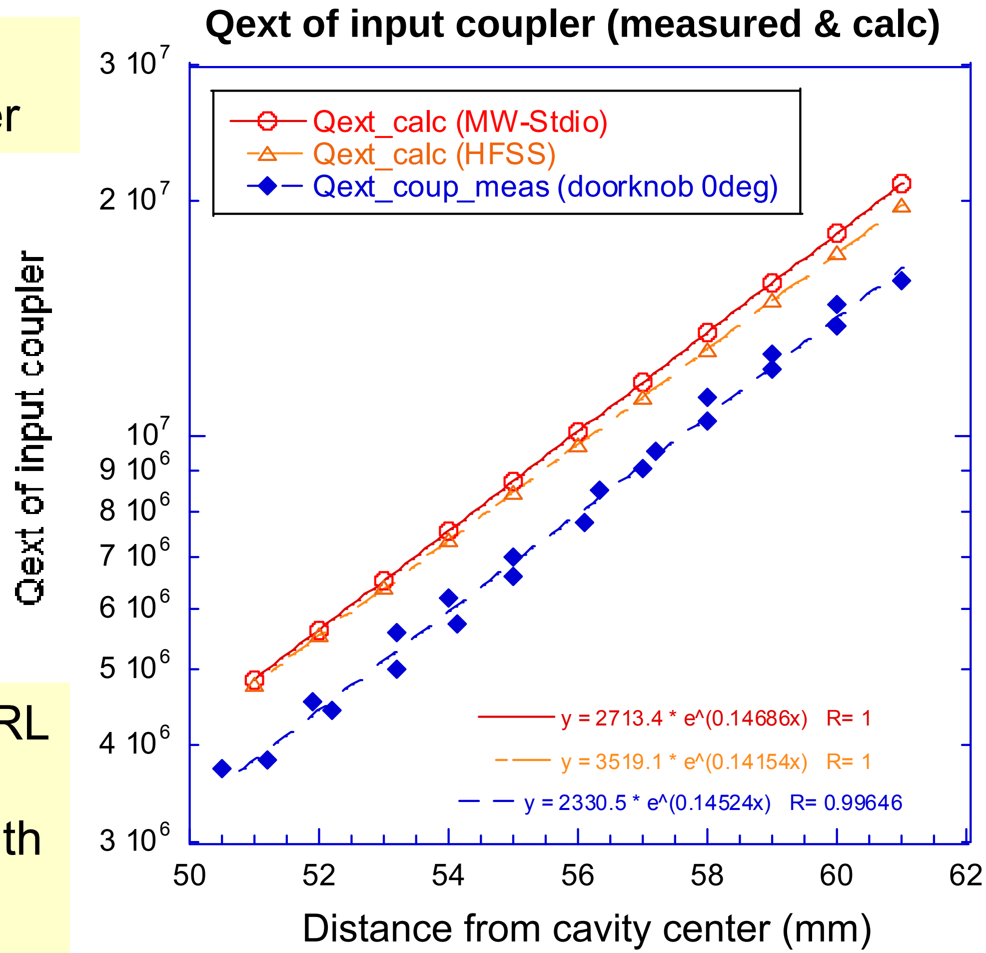
After exposing to air for 4hours



After warming up and exposing to air for 4 hours, the coupler was cooled down to Liq. N2 temperature again and we fed the power . We can feed the power up to 24kW smoothly. Processing effects could keep the coupler .

Coupling measurements





・Connecting the input coupler to 9cell ERL cavity, we measure the coupling directly.
・Slope of Qext change with coupler length agree well with calculation with +-5mm.
・However, the measured value of Qext with doorknob exchanger is 1.3 times higher than calculation

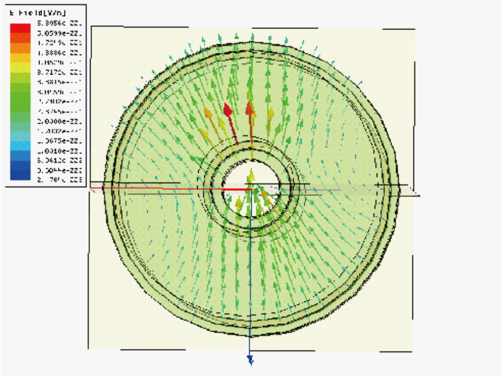
⇩

Change the length of 2mm short for cryomodule from measurement results.

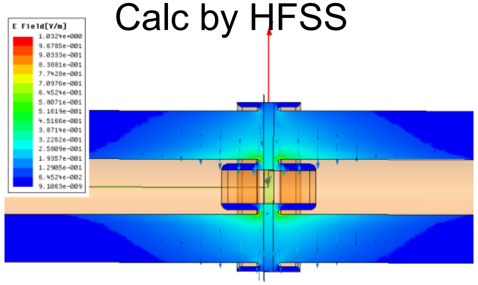
Qext coupler	5.0*10^6	2.0*10^7
Meas 0deg (doorknob)	52.83mm	62.38mm
Calc (MW-Stdio)	51.20mm	60.64mm
Calc (HFSS)	51.09mm	60.88mm

Cautions and learn from previous ceramic window test for ERL about disk ceramic with choke

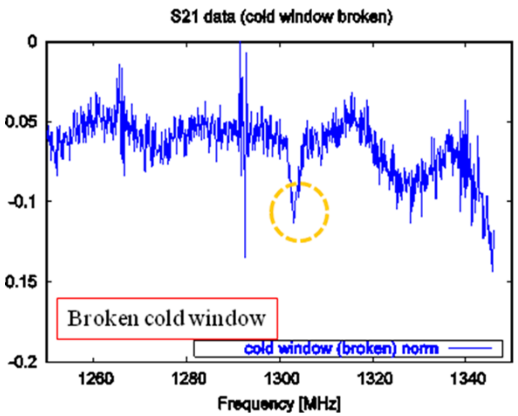
When modify the impedance or diameter from original



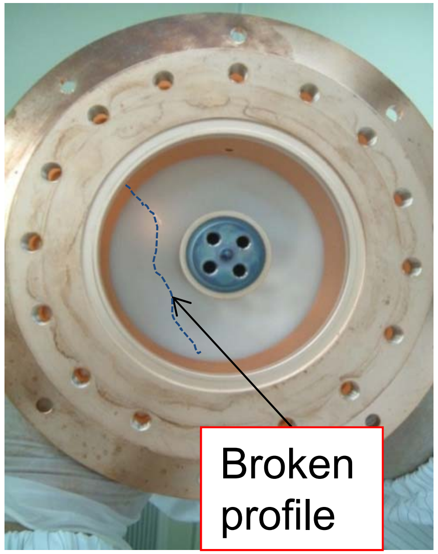
Calc by HFSS



TE mode stands inside



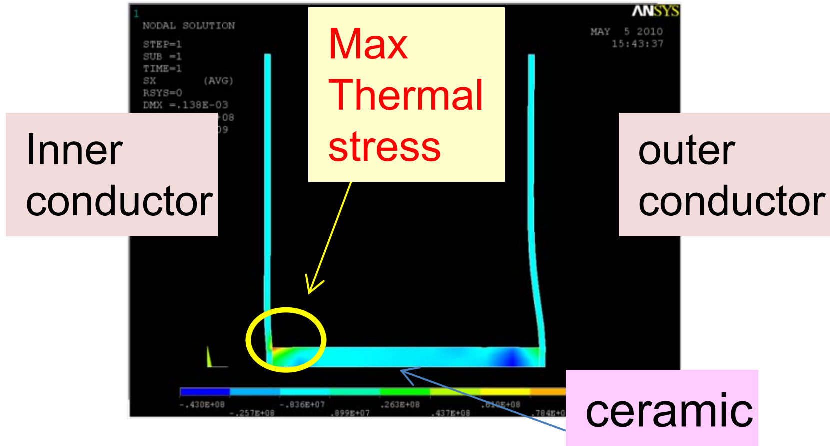
By changing the thickness of window, peak was shifted.



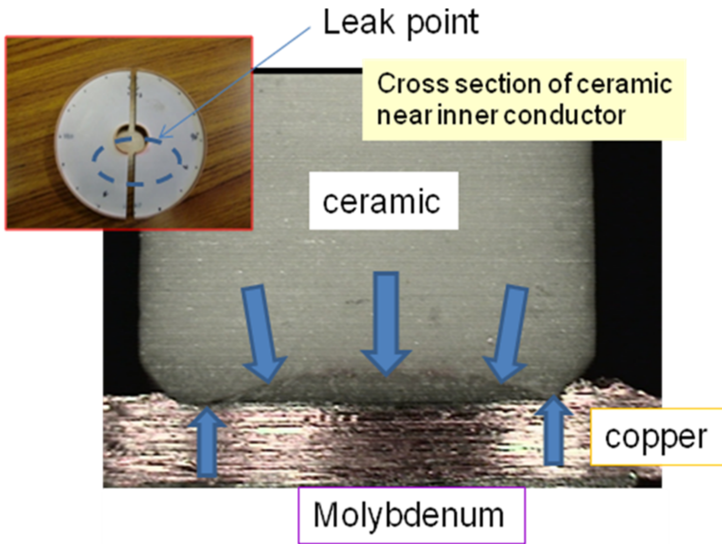
Please calculate not only S-parameter but also eigenmode of disk ceramic itself.

H.Sakai et al., Proc. of 14-th SRF Workshop, Berlin, p684-688, (2009)
K.Umemori et al., Proc. of IPAC10, Kyoto , p2959-2961, (2010)

Caution for using to cold window



After 5th thrmal cycle test between 80K and 300K, old ceramic was broken



modify the blazing conditions → 10 thermal cycle is OK now.

H.Sakai or M.Sato et al, Proc. of 15-th SRF, Chicago (2011)

Summary

- We carried out high power test by using input coupler prototype for cERL main linac. After pulse processing for 8hours, we finally achieved 25kW with standing wave in the high power test and could keep the 20kW SW for 16 hours.
- The maximum temperature rise was measured at the bellows of the inner conductor. However, the temperature rise was suppressed down to 120K by N_2 gas cooling of 115 l/min flow. The temperatures rises of bellows of outer conductors are also high, but these were suppressed by the liq. N2 cooling.
- The vacuum pressure was suppressed at ~10^{-6} Pa under 20kW power feeding.
- We noted that we could smoothly increase up to 24kW power level again after warming up to room temperature and exposing the inside of the input coupler to the air for 4 hours.
- By changing the brazing condition of the cold window, we could stand the thermal cycles up to 10 times and no crack or leak was observed.

・The thermal and RF power tests were successfully done and the basic design of the input coupler has satisfied our requirements by these tests.

・In this year, we will fabricate the two input couplers for the main linac to prepare the compact ERL construction.

Thank you

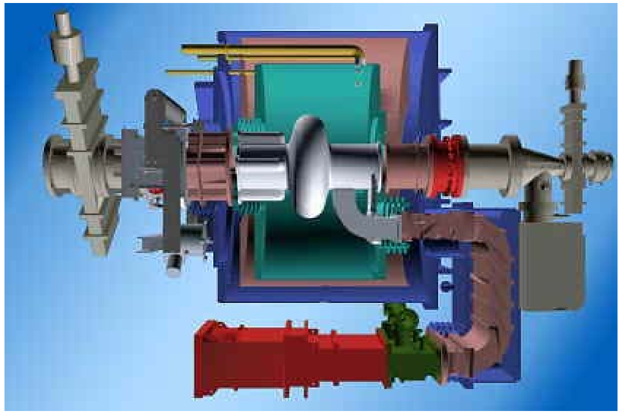
backup

Coupler choices for ERL

Waveguide

- Lower surface electric field
- higher thermal radiation
- No easy tuning

CESR waveguide
- >250kW
- 500 MHz
- WG Bend shields cold window from beam.



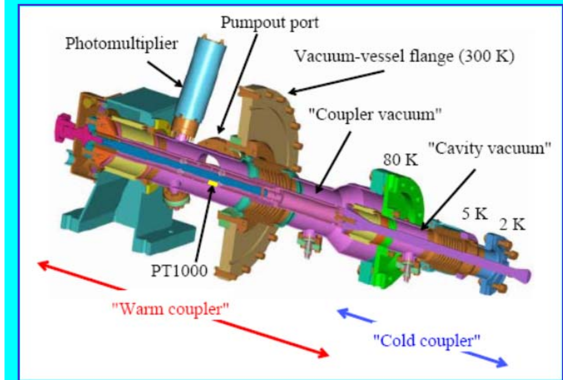
JLAB (CEBAF, JLAB-FEL)

Coaxial

- Smaller heat leak
- Easier to make variable
- Easier to handle multipacting

• Cylinder ceramic (TTF type)

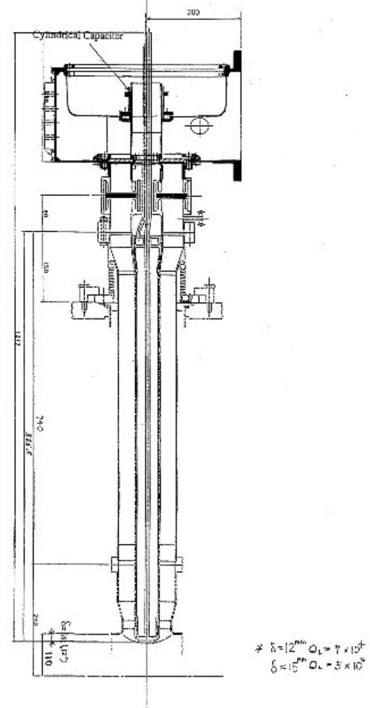
TTF-III
- **1.3GHz**
- **2 Windows**
- **Adjustable Qext**



Cornell, Daresbury,HZB

KEKB coupler
- **>400kW(operation)**
- **509MHz**
- **Disk ceramic with choke**

• Disk ceramic (TRISTAN type)



High Power Input Coupler for KEKB SC Cavity

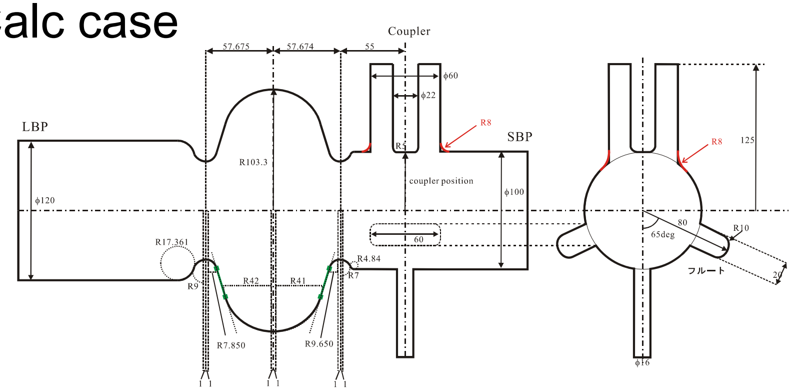
KEK, BNL (SNS), HZB

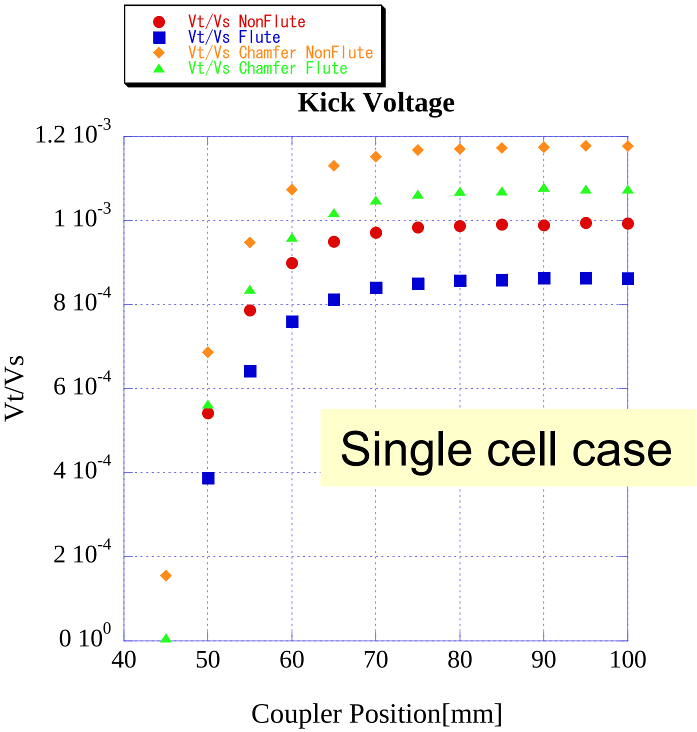
This coaxial disk ceramic window is reliably operated at KEKB applying up to CW 400kW with 1A beam current and STF with high peak power more than 1MW. at 1.3GHz. This is our choice.

Coupler kick & cancelation

By T. Muto

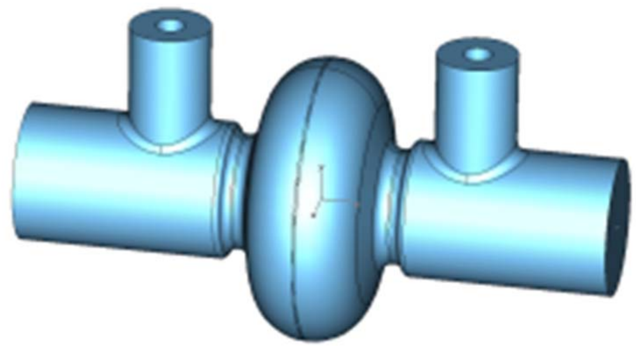
Calc case

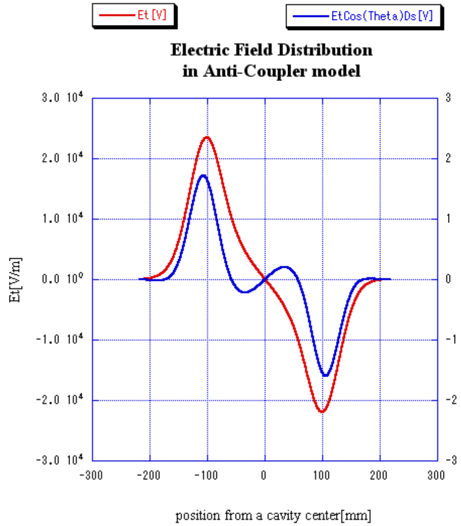




Single cell case

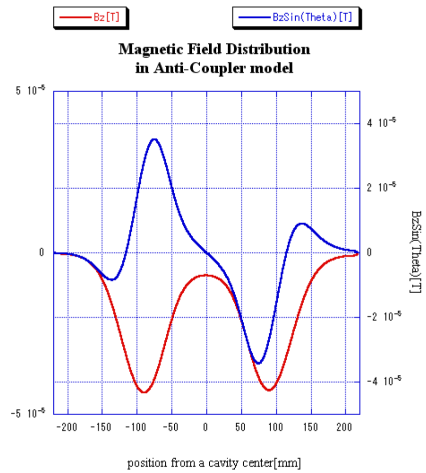
9cell case : Vt/Vs ~ 1*10^-4





E-field

Blue: beam



H-field

Blue: beam

Coupler kick will canceled with setting symmetry with optimum length