Overview of CW input coupler for ERL

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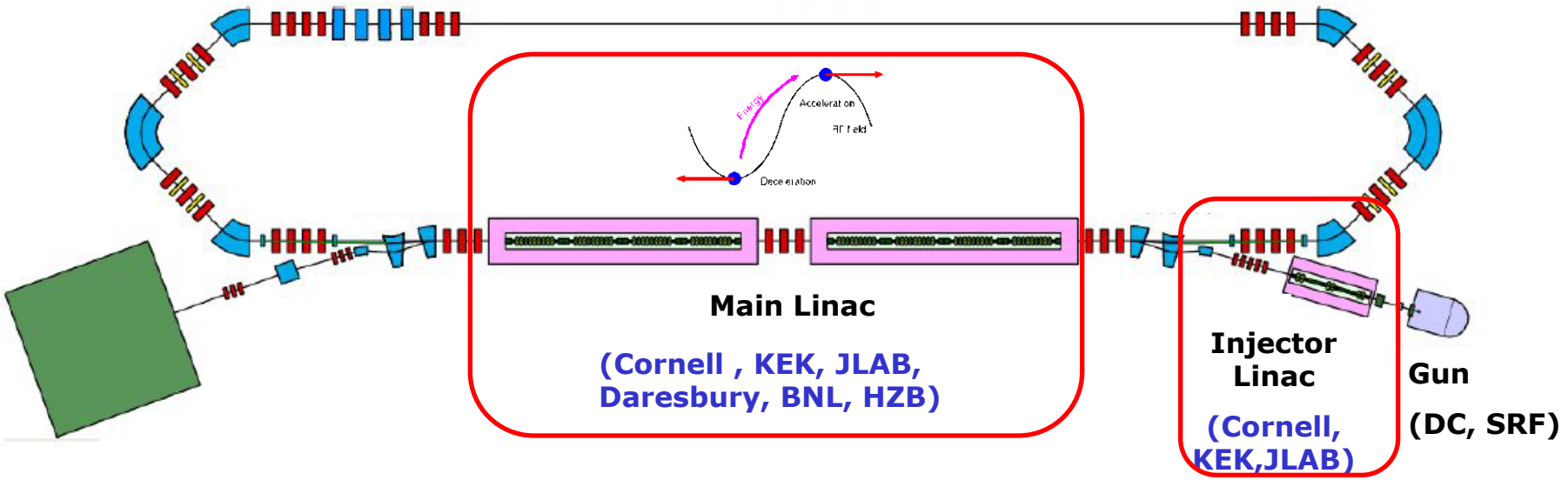
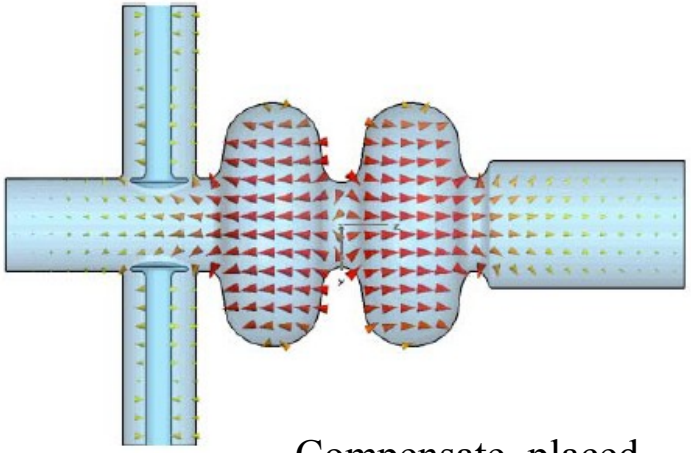
Coupler roles & requirements for CW-ERL

ERL design



- **Passive device able to transfer Power from Source to beam loaded cavity with optimised reflection**
  - **Injector – High Powers and Strong Coupling (TW)**
  - **Linac – Low Powers Weak Coupling (SW) due to Energy Recovery**
- **Separate between atmosphere and vacuum by window. Assembly of Cold windows are seen as important to hermetically seal a smaller cold mass in the clean room.**
  - **We should be optimized position of ceramic window and number of window.**
- **Connect room and cryogenic temperatures not to leak the heat load to cryomodule.**
- **Provide appropriate coupling for different operating modes (different beam current)**

Specified for ERL operation



Compensate placed symmetrically

- # Injector

--High beam current, low beam energy.

--That leads to high RF power, strong coupling and requirements of minimal field perturbations due to couplers.

--High RF power delivered to the beam is **the most challenging** factor. (More than 50kW TW)

--For minimizing perturbation of beam motion, couplers should be placed symmetrically (in pairs) or compensating stubs should be used.

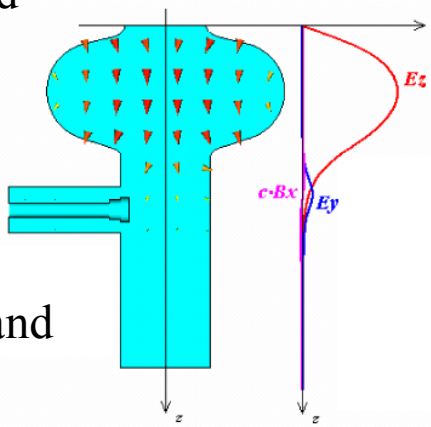
- # Main linac

--High beam energy. But low RF power thanks to Energy Recover

--That leads to low RF power, weak coupling (Qext = 1*10^7 – 1*10^8) and weak restrictions on field perturbations due to couplers.

--Verifying microphonics effect is one of the most important issues.

--Reliabity & Cost factor are another important issues due to fabricate large number of couplers.



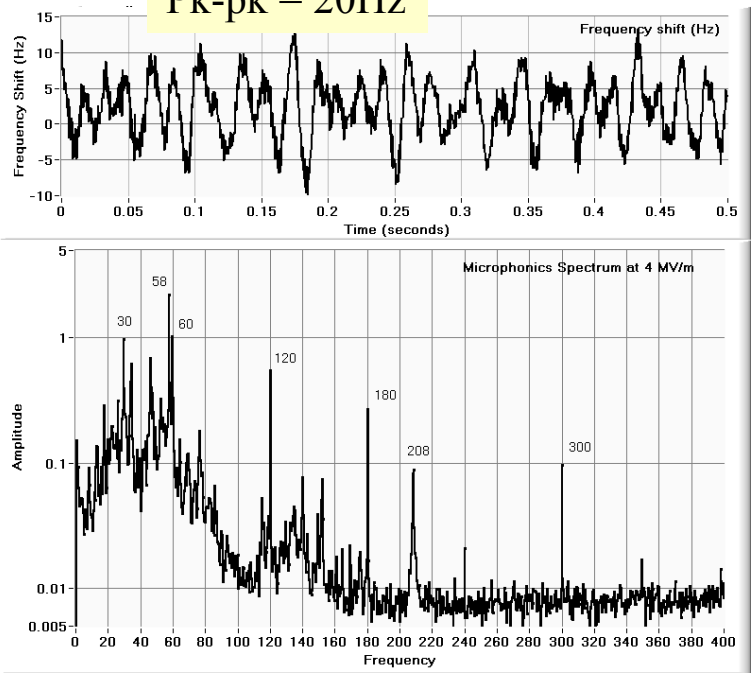
Coupler kick

Microphonics vs RF power

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

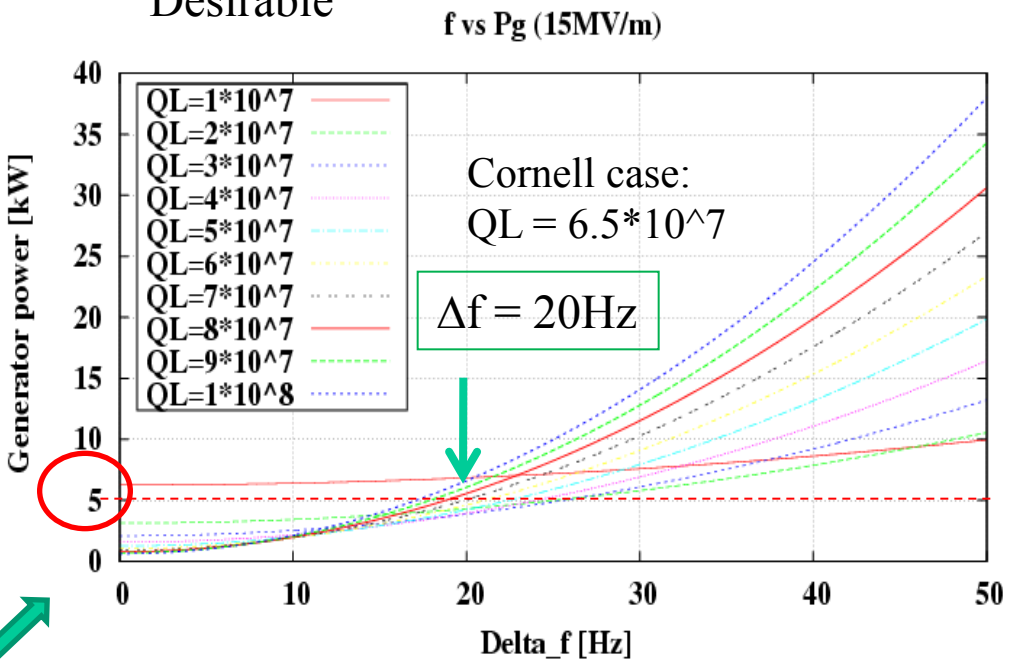
For main linac, no beam power & RF power requirements are determined by microphonics (+ possible beam loss, beam return time errors, etc.) To keep stable operation, Sophisticated Feedback control is needed .→ Challenging issue

Pk-pk = 20Hz

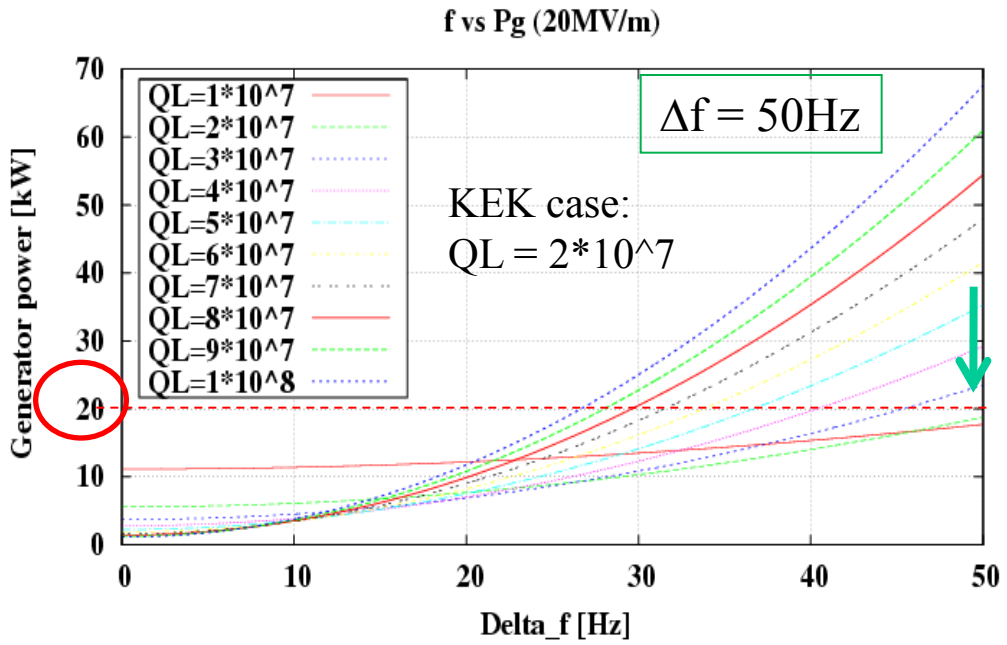


Michrophonics of CEBAF 5cell cavity

Desirable



More severe case



Coupler Design Options 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.

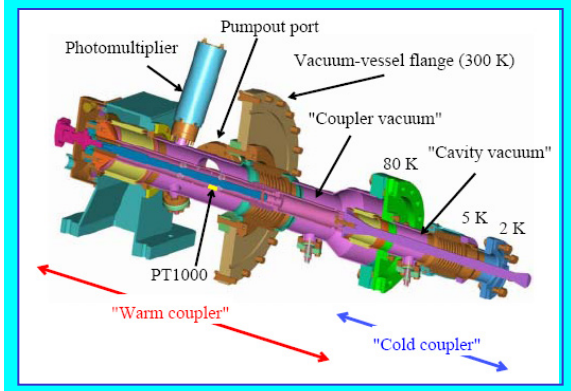
JLAB (CEBAF, JLAB-FEL)

Coaxial

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

●Cylinder ceramic (TTF type)

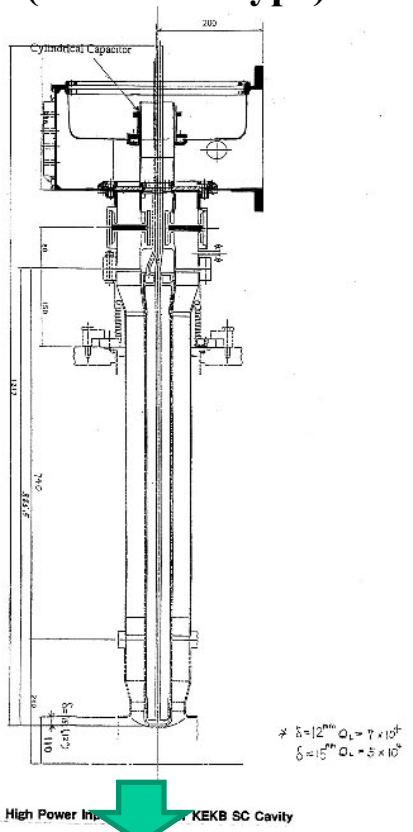
TTF-III
- 1.3GHz
- 2 Windows
- Adjustable Qext



Cornell, Daresbury,

●Disk ceramic (TRISTAN type)

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



KEK, BNL (SNS), HZB

JLAB

From CEBAF operation

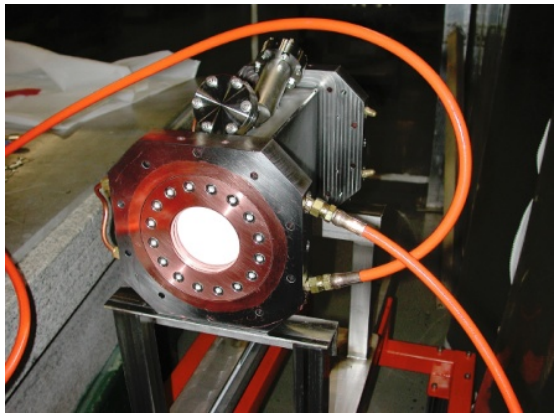
CEBAF waveguide

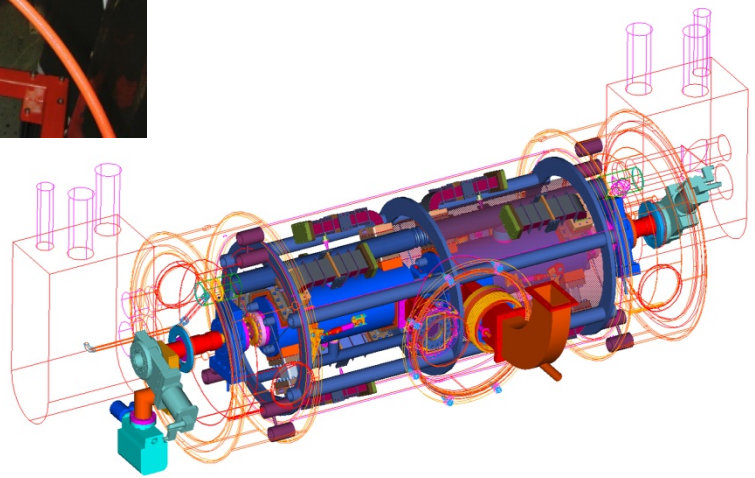
- **Peak power up to 6 kW CW → upgrade 13kW**
- **2K → 300 K windows**
- **Dogleg shields cold window is used for sealing from beam.**

JLab High-Power WG Coupler for FEL

- **Frequency: 1.497GHz**
- **FWD RF power: 50 kW CW (100 kW max)**
  Prototype tested to 60kW CW
  (limited by available klystron)
- **300 K window**
- **Cooling:**
  Window: water

MOIOA03





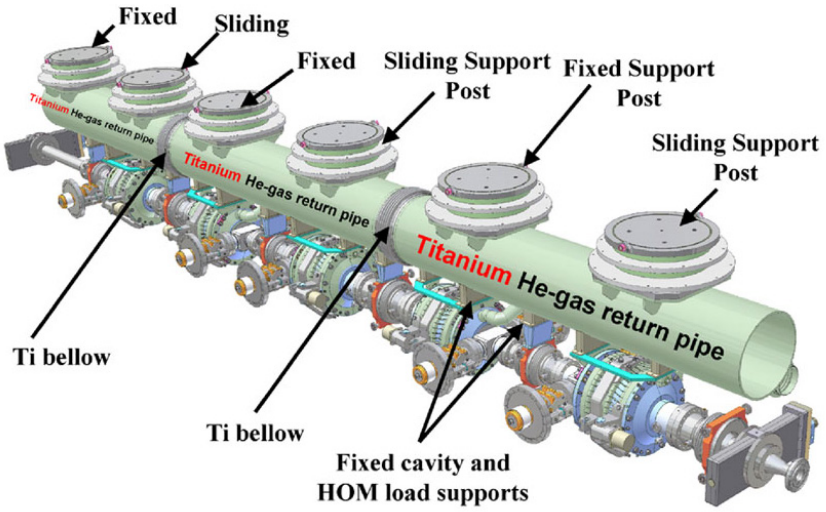
By George Neil, Bob Rimmer

Cornell injector Input coupler

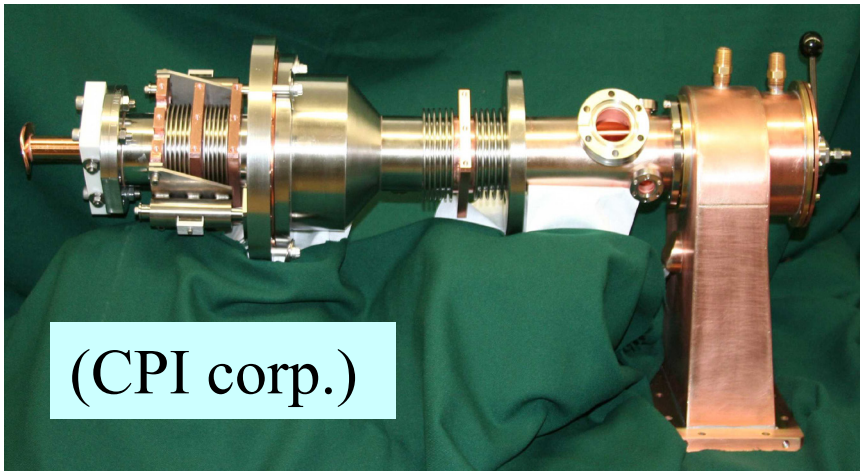
MOIOA03

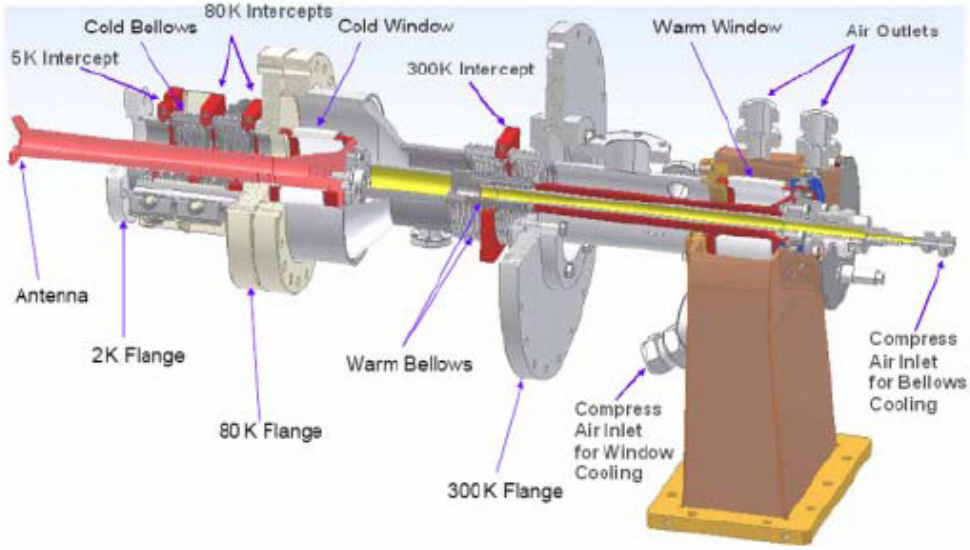
- Modified TTF-III Design for CW operation
  a. Many thermal anchors are set in bellows
  b. Forced air cooling of inner conductor.
  c. Make strong coupling by enlarging antenı
  d. Change impedance from 70 Ω to 60 Ω.

2cell 5cavity + 10 coupler accelerate up tp 5MeV



- **Frequency : 1.3 GHz**
- **Beam current : max 100mA**
- **Input power : 50 kW CW**
- **Q_{ext} : 4.3×10^4 -1×10^6(variable)**

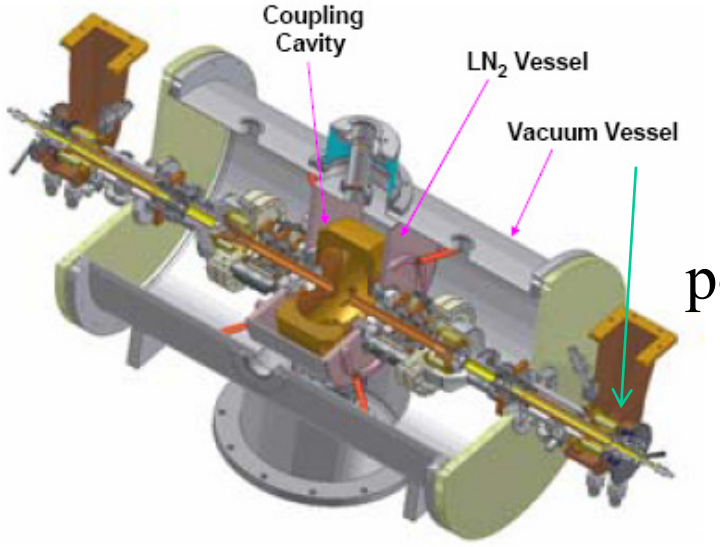




By Vadim Veshcherevich

Cornell injector Input coupler high power test

By Vadim Veshcherevich



Nitrogen cryostat with coupling cavity for high power coupler tests

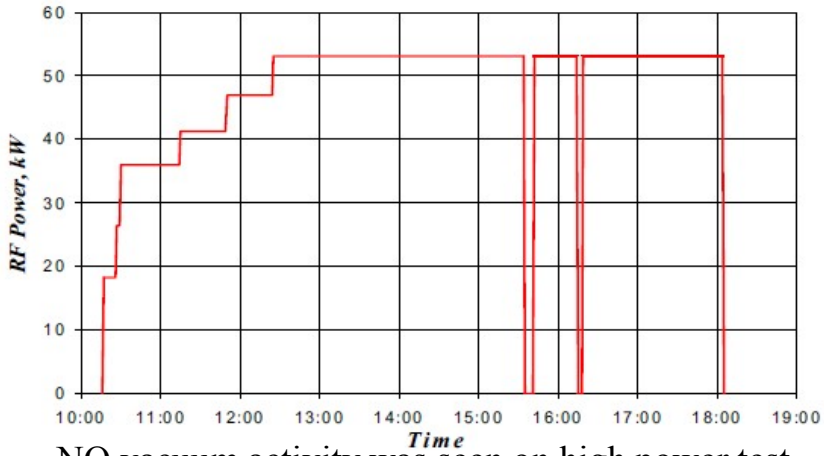
High Power Test Setup at 77 K

Two coupler were faced by coupling cavity cooled at 77K.

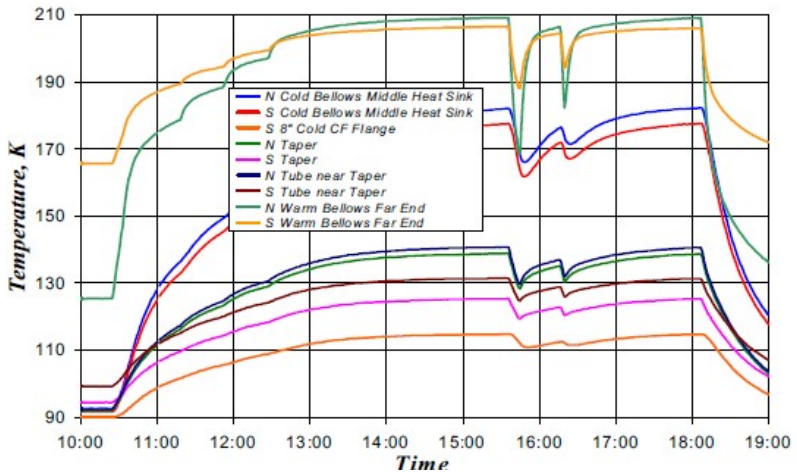
Finally achieve the 61kW power feeding with TW.

power

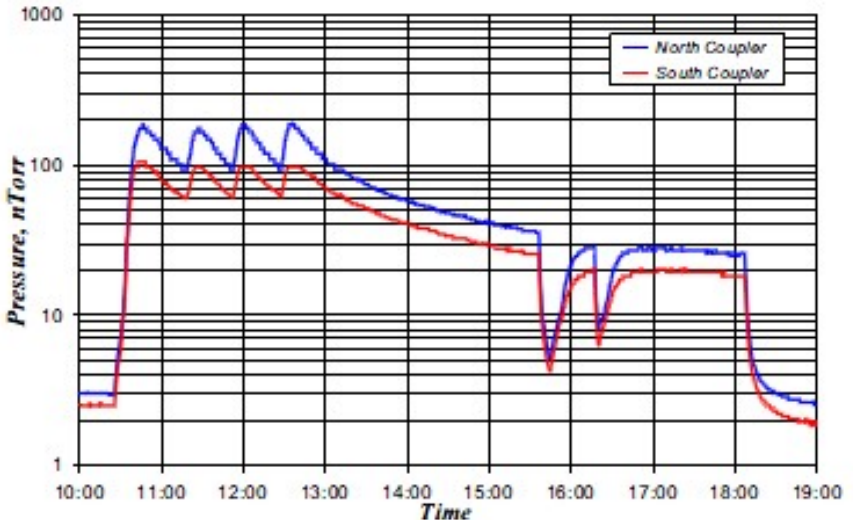
Could keep power 53kW(TW) for 6 hours



Temperature rise at cold portion
In cold bellows, max temperature rise is 100K.
In warm portion, cooled by air.

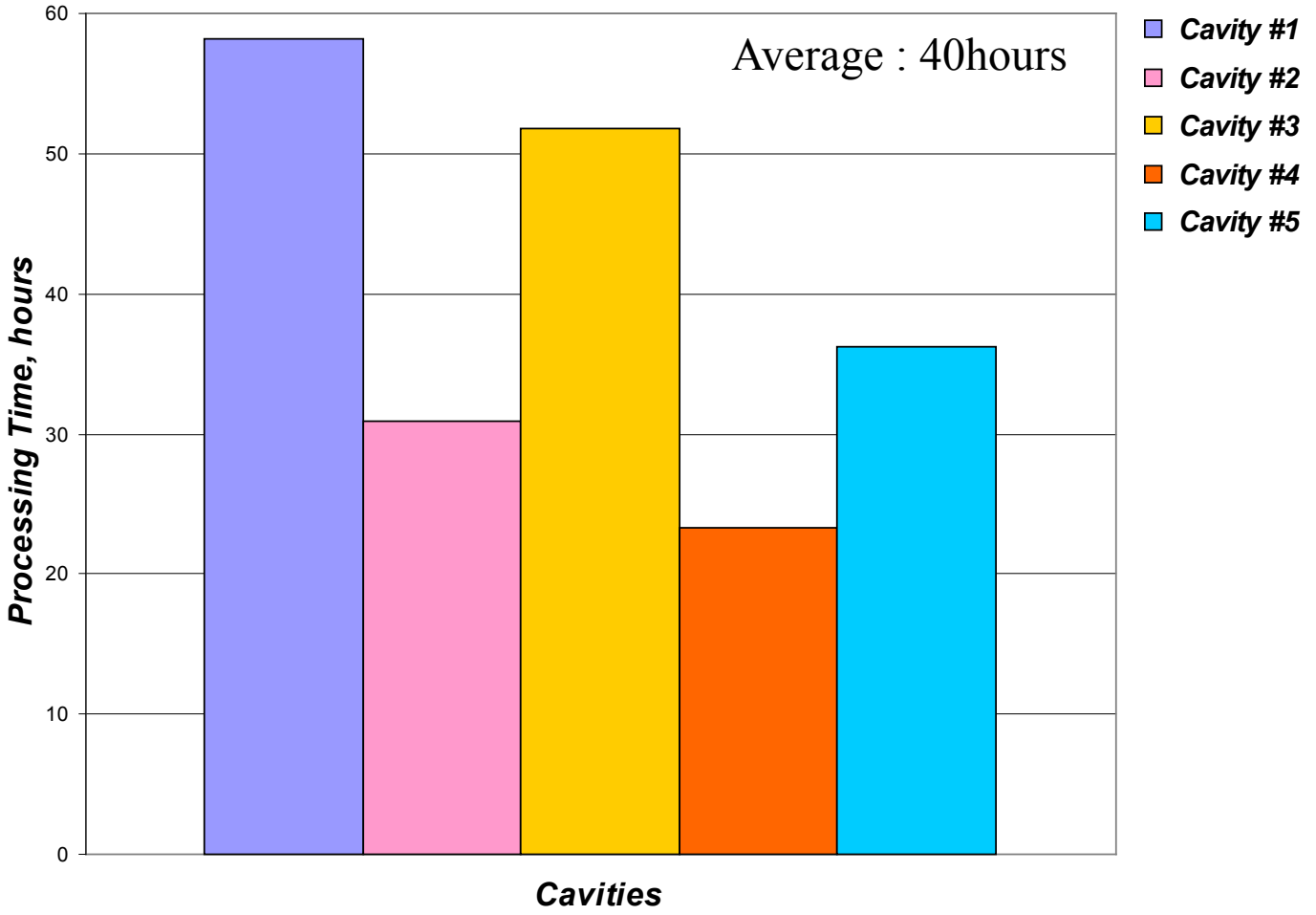


NO vacuum activity was seen on high power test



Coupler Conditioning & beam operation status

Processing Time for Couplers of Cornell ERL Injector Cavities (up to 25 kW SW per two Couplers):



Coupler bake helps to shorten the processing time. And pulse processing is also help conditioning

Now 10 couplers were set in test beam line and operate up to 25mA beam current.

→ This coupler also transfers to Daresbury CW cryomodule test. TUPO013

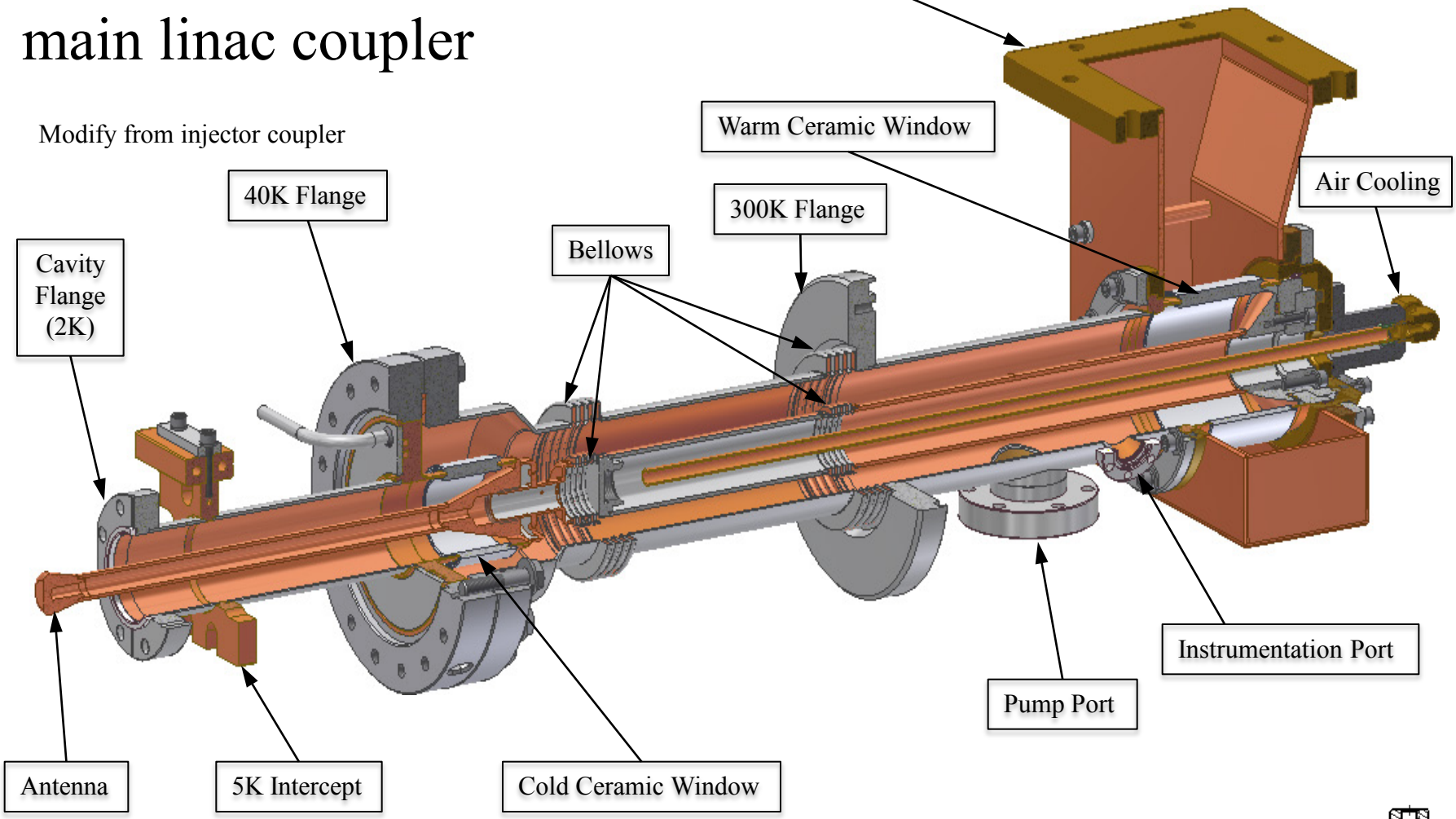
By Vadim Veshcherevich

Cornell ERL main linac coupler

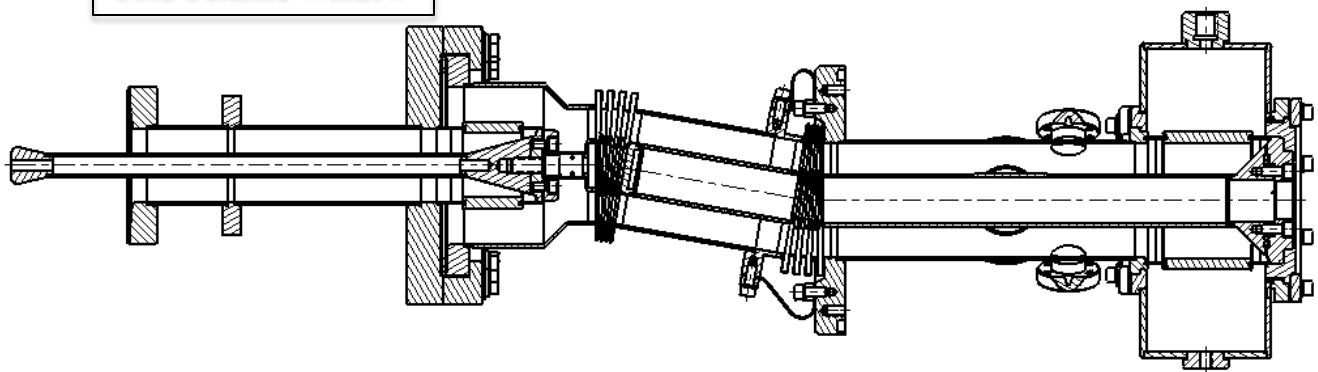
MOPO016

By Vadim Veshcherevich

Modify from injector coupler

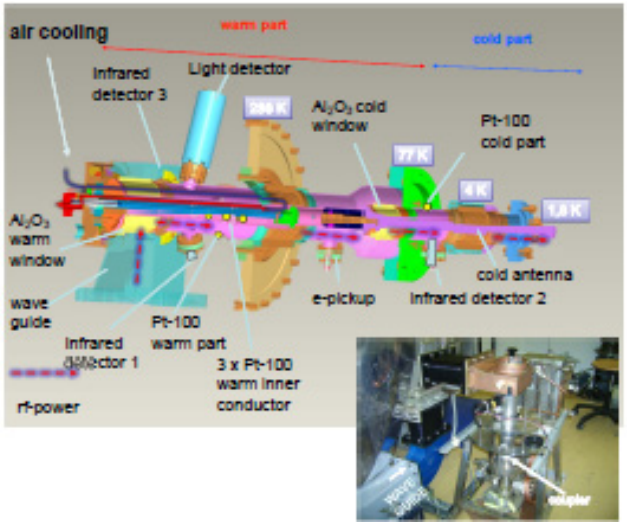


- **Frequency : 1.3 GHz**
- **Input power : 5 kW CW**
- **Q_{ext} : 6.5×10^7**
- **Gas cooling of inner conductor**

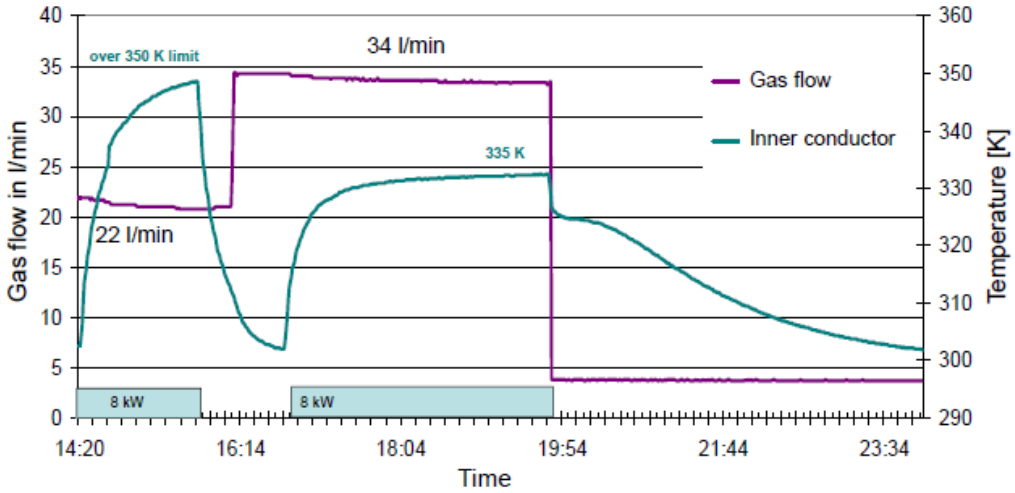


BESSY(HZB) ERL MAIN LINAC COUPLER DEVELOPMENT

- **Solution for coupler: BESSY coupler operable up to 10 kW of modifled TTF-III coupler**

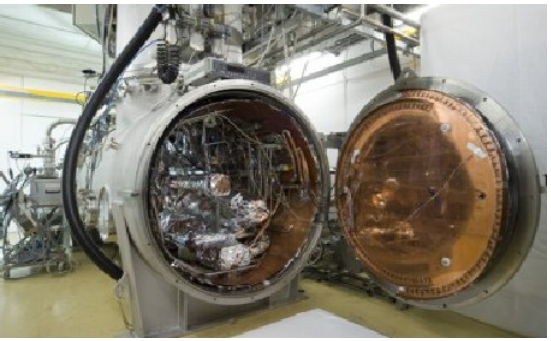


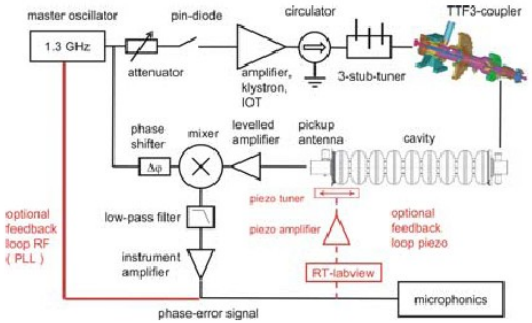
Main modification is inner gas cooling for TTF-III coupler

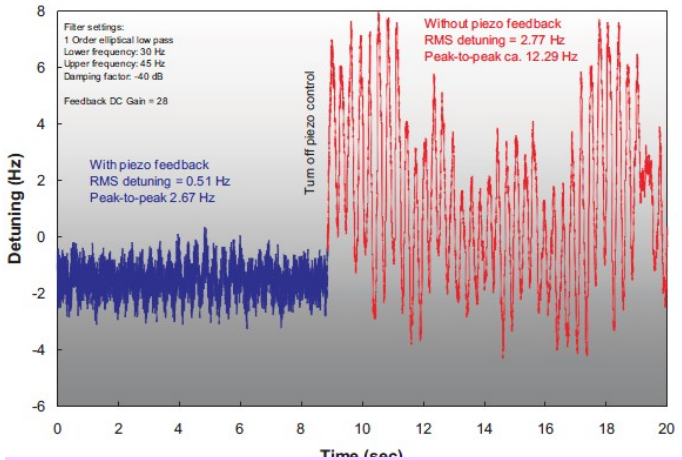


Temperature of the inner conductor at 8 kW

Microphinics suppression by horizontal test at HoBiCaT







MOPO067

Pk-Pk 12Hz → 3Hz of michrophoinics by using Feed back and feedforward

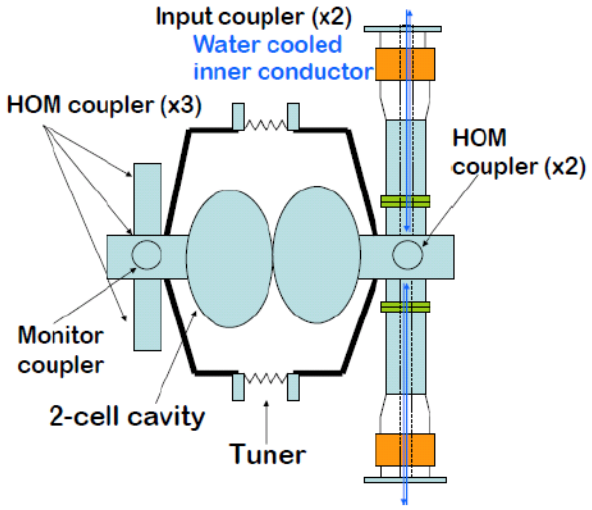
Can lead more higher Qext > **1×10^8**
And lower power source < 1kW

b y Wolfgang Anders

Solid state power source can be applied for power feeding

KEK-ERL injector input coupler

+ Scheme of three 2-cell cavities with 5 HOM couplers
  2 input couplers are faced for compasating coupler kick

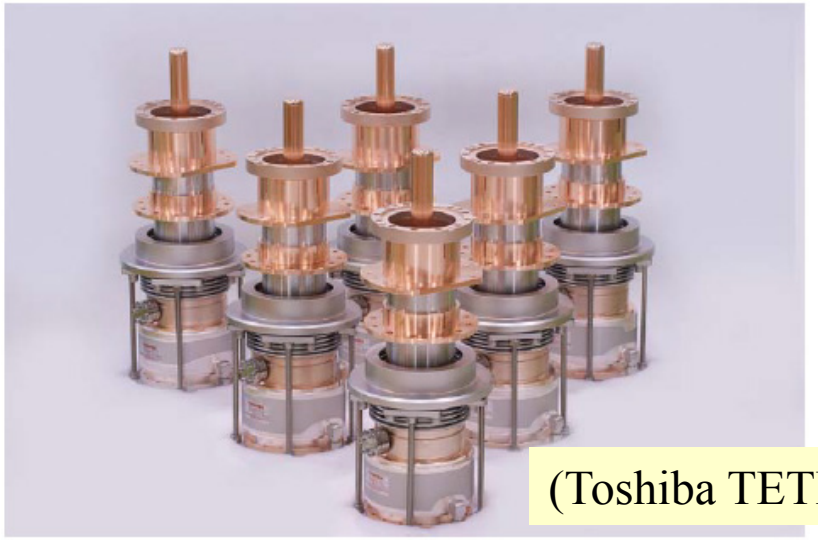


- **Frequency : 1.3 GHz**
- **Input power : 170 kW CW (100mA)**
- **Coupling : $Q_{ext} = 1.7\times10^5$**
- **No cold window**
- **Water cooling of inner conductor**

	V_{acc} [MV]	P_{rf} [kW]
Cavity-1	1.5	10
Cavity-2	2.5	25
Cavity-3	2.5	25

(I_{beam} = 10 mA, P_{rf} /coupler)

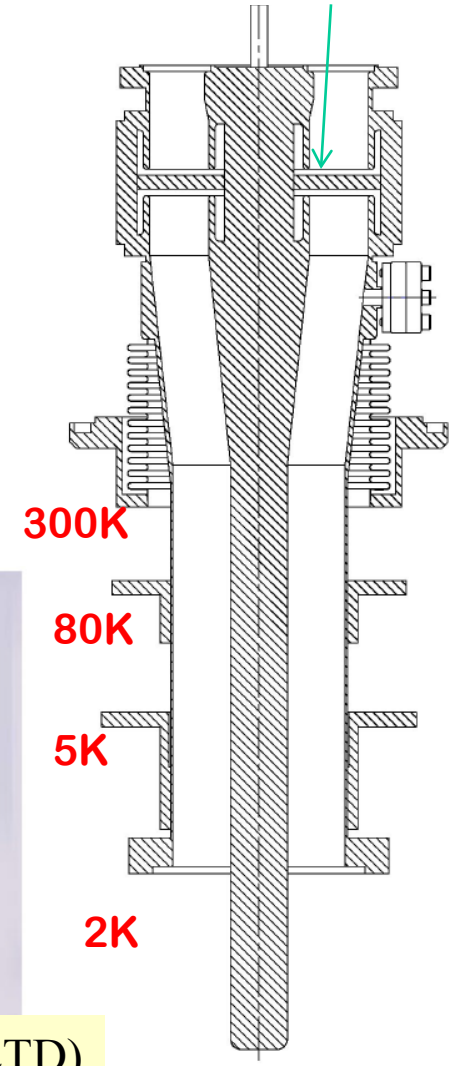
For cERL initlal 10mA



(Toshiba TETD)

Six cw input couplers

Tristan-type
Ceramic
Window

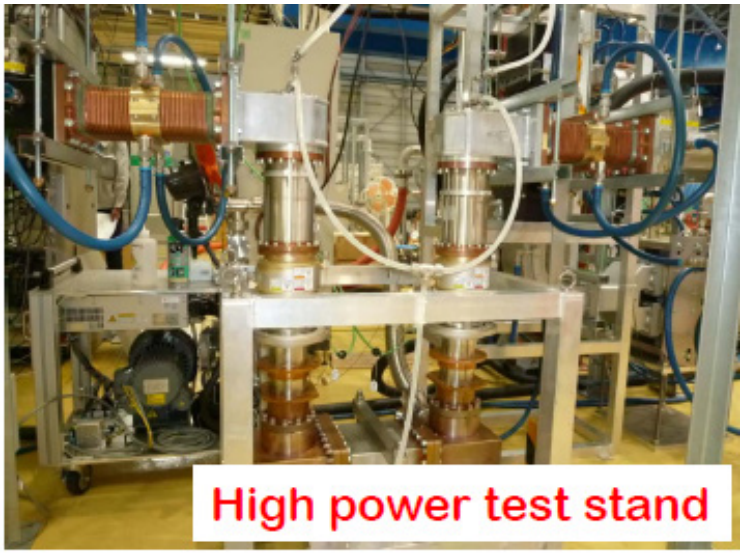


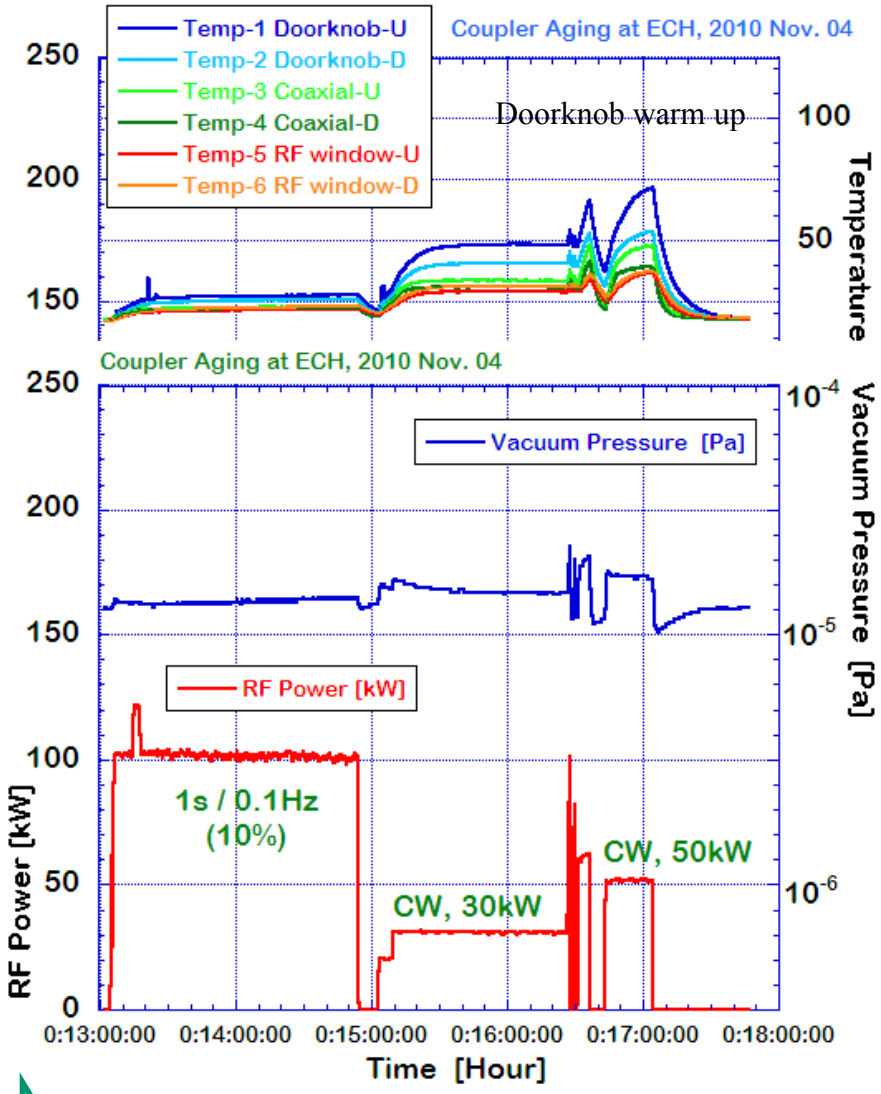
FRIOA06

By Eiji Kako (KEK)

High power test of KEK-ERL prototype injector coupler

By Eiji Kako (KEK)





Results of conditioning

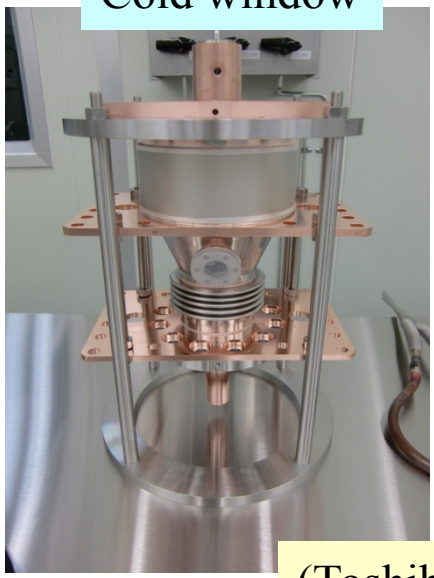
- pulse(1 sec, 0.1 Hz), 100 kW (2hours)
- CW 30 kW (1.5hours)
- CW 50 kW (0.5hours) partially temperature increased
- CW 100 kW (1min) (warm up inner conductor)

Modify inner conductor cooling
for cERL injector coupler up to 100mA operation

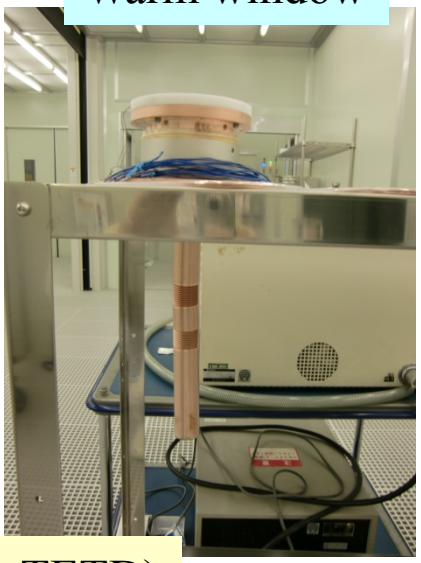
Development of input coupler for main linac at KEK

- Basic parameters
  - frequency : CW, 1.3GHz
  - Accelerating gradient : Max 20MV/m
  - input power：max 20kW , standing wave (50Hz)
  - 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
  - 99.7% pulity of ceramic window are used.
  - make variable and ad cold bellows

Cold window

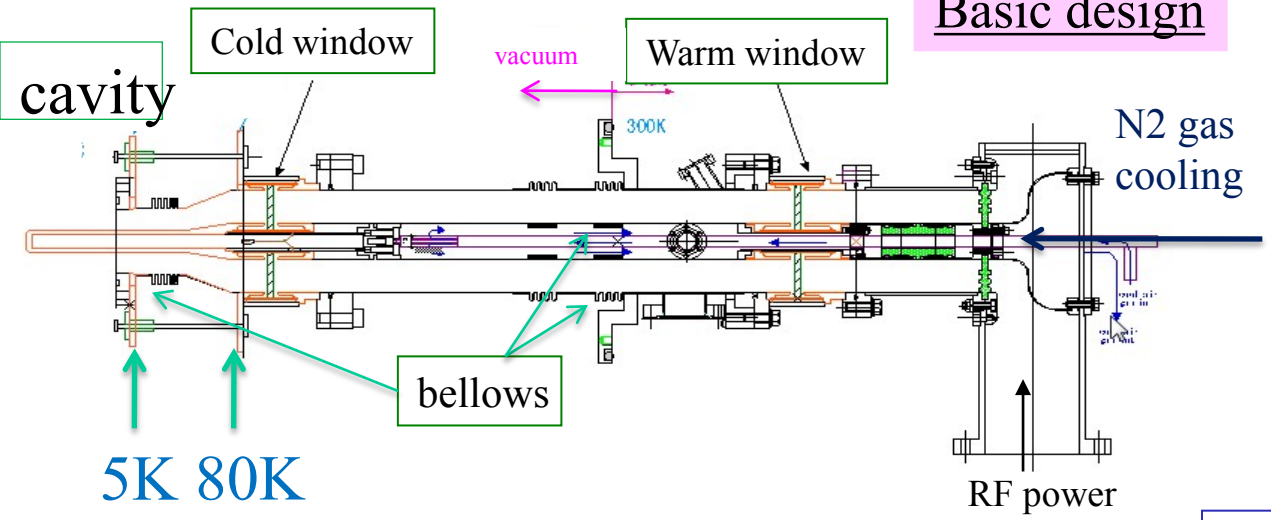


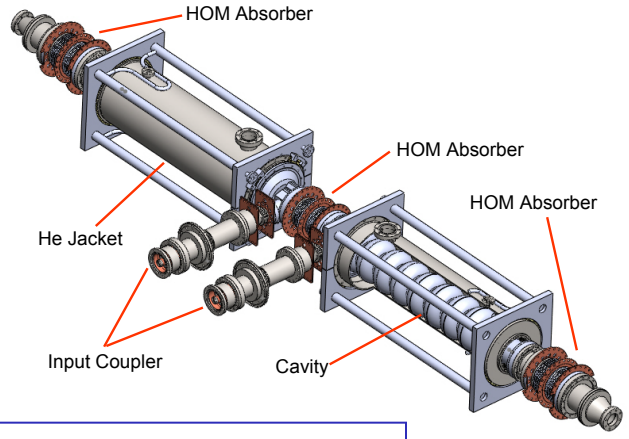
Warm window



(Toshiba TETD)

Basic design





FRIOA06, TUPO005

KEK-ERL main linac coupler high power test

TUPO005

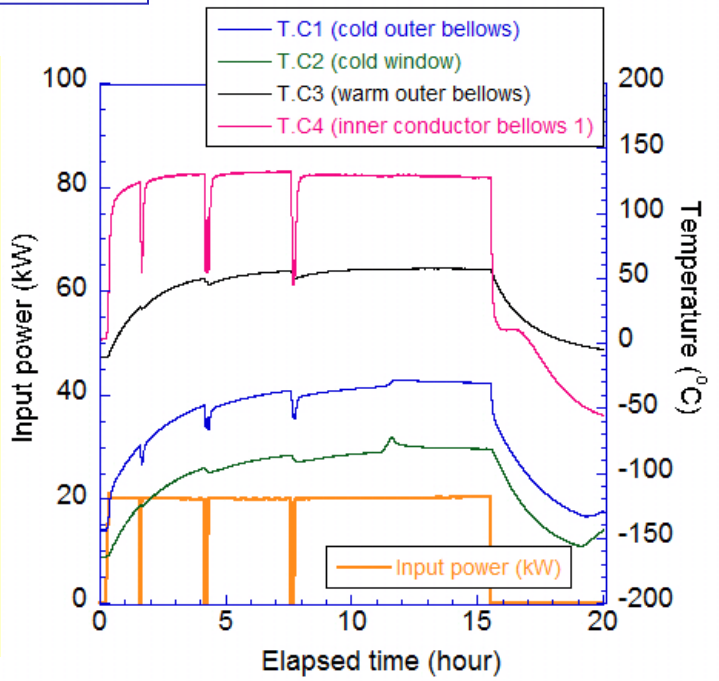
- **High power test of prototype of input coupler under liquid Nitrogen cooling with vacuum insulator**

Add pulse processing for 8hours, (easy to process)
Finally achieve 25kW power feeding with standing wave.

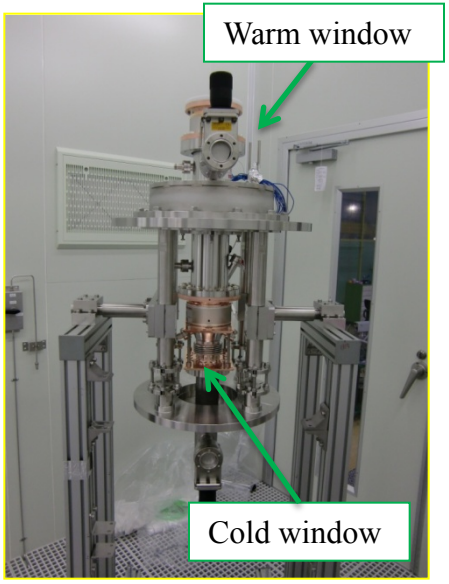
Can keep 20kW power for 16hours with standing wave.
Temperature of inner conductor is 120 °C.
Temperature rise of cold bellows is 100K

works well and fabricate 2 more coupler for cERL.

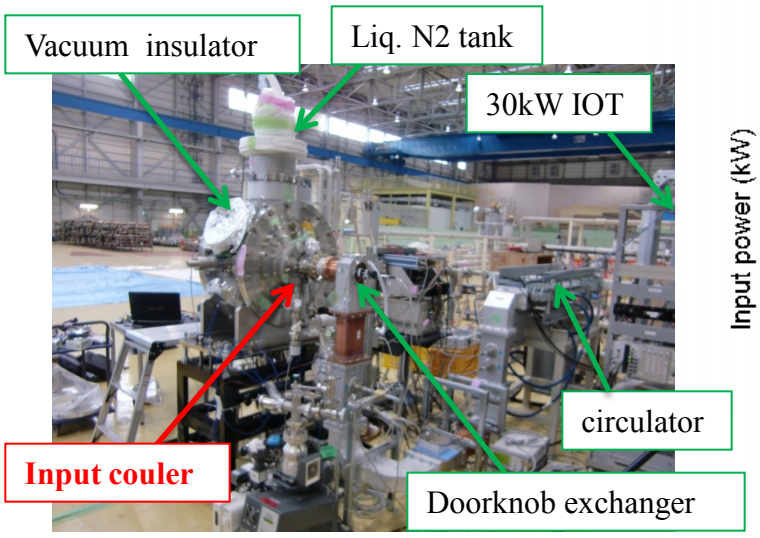
Results of keeping 20kW

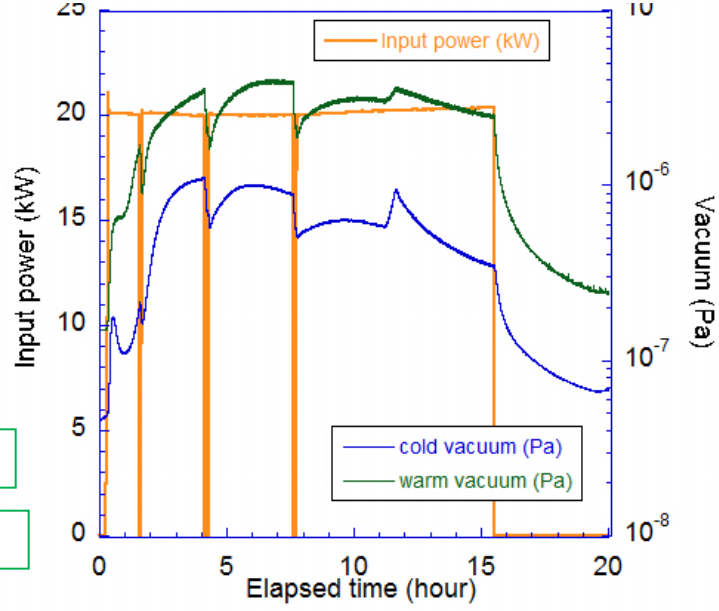


Prototype of input coupler



High power test setup with liquid Nitrogen





Sudden power down is mainly caused by noise of arc sensor.

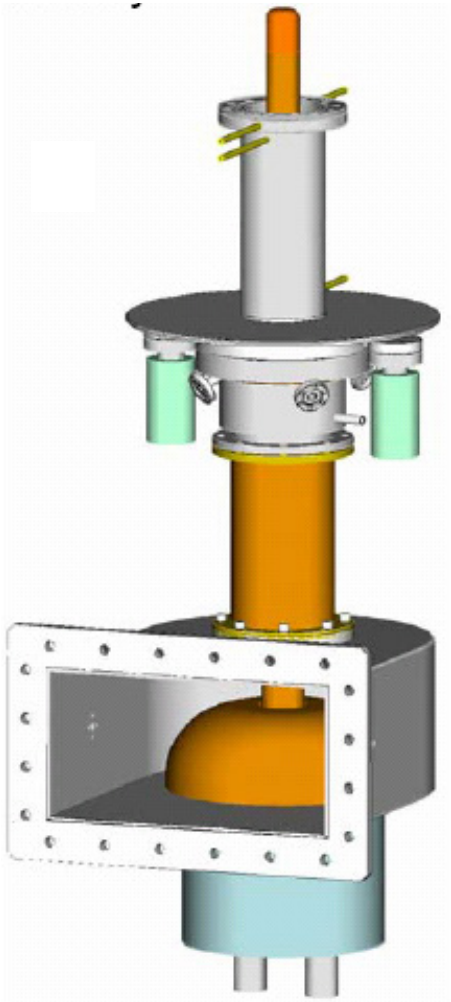
BNL ERL Coupler

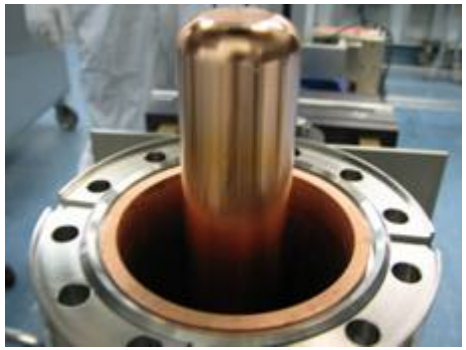
SNS coupler is used. SNS coupler is based on TRYSTAN type coupler design.

- **Frequency: 704 MHz**
- **Average Power: 50 kW achieved**
- **300 K window**
- **Cooling:**

Inner conductor extension: water

Outer conductor: GHe flow



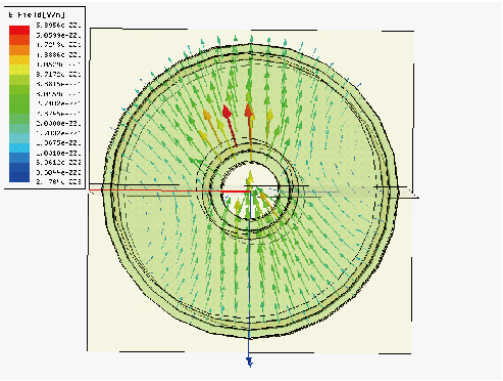


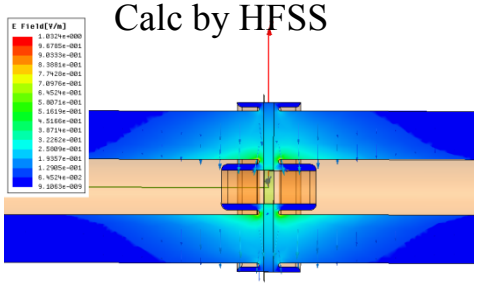
Now 500kW (!) CW power coupler are developed for CW SRF gun at BNL.

TUPO010

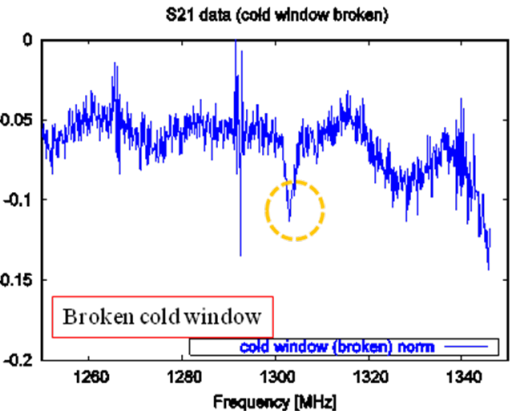
Cautions about disk ceramic with choke (about TRISTAN type coupler)

When modify the impedance or diameter from original

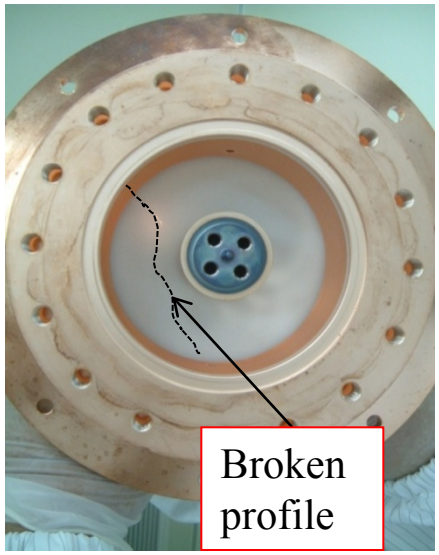




TE mode stands inside



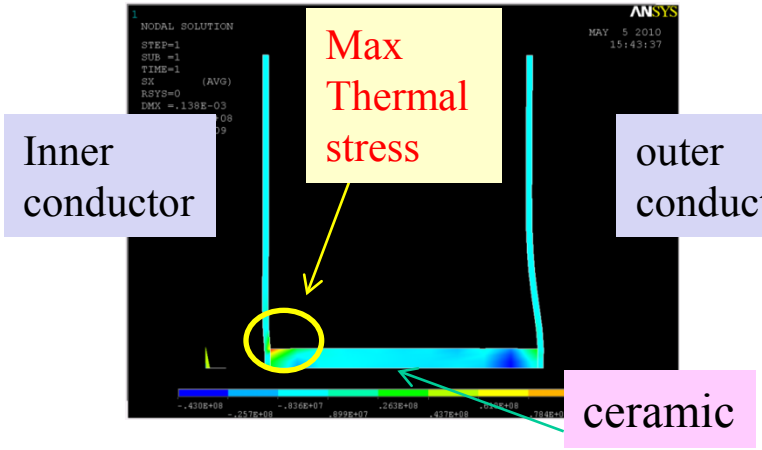
By changing the thickness of window, peak was shifted.



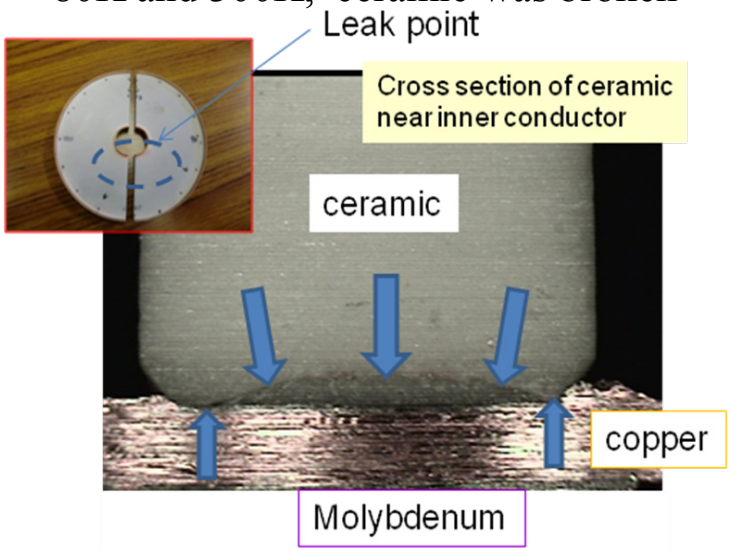
Please calculate not only S-parameter but also eigenmode of disk ceramic itself.

By using for cold window

TUPO005,TUPO007



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



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

Summary

- **Many couplers have been designed for different ERL cryomodules.**
- **Many coupler designs were based on successful existing designs (TTF-III, TRISTAN coupler, waveguide) though often with necessary upgrades or modifications.**
- **Requirements for injector couplers are challenging due to high power that has to be delivered to the beam. More than 50kW couplers were developed up to now.**
- **Couplers design for main linacs are determined by microphinics. This effect leads to achieve more smaller power source and cost efficient. By using sophisticated feedback system, Qext > 1×10^{8} was achieved and the power source was reduced to 1kW.**

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