Design and Fabrication Issues of High Power- and Higher Order Modes-Coupler for Superconducting Cavities

-A Tutorial-

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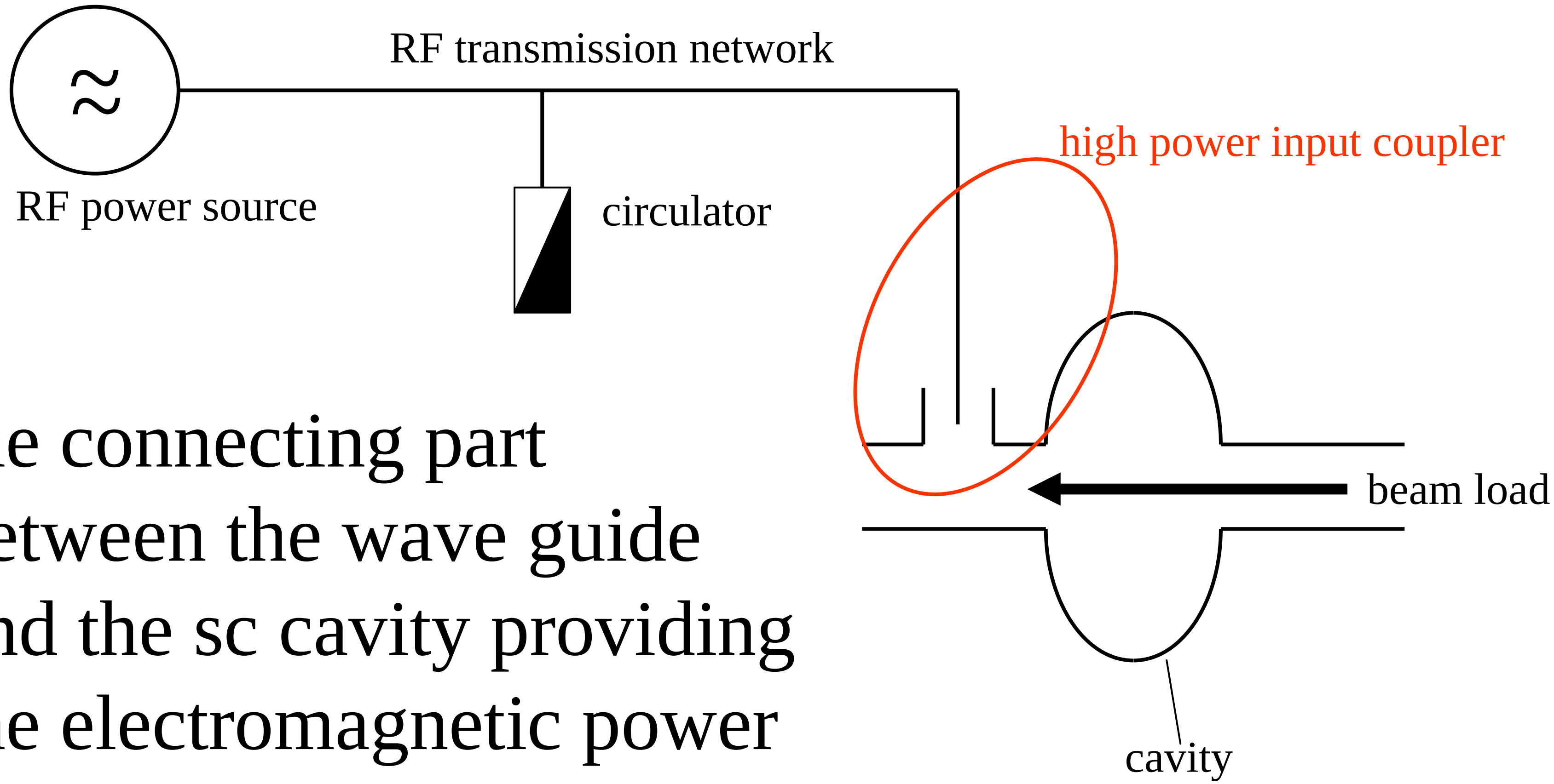
Part I
High Power Input Coupler

- General
- Wave guide vs. coax
- Coupler ports
- PC examples
- Simulations
- Multipacting
- Fabrication issues
- Test and conditioning

What is a high power input coupler?



- the connecting part between the wave guide and the sc cavity providing the electromagnetic power to the cavity and beam

The Power Coupler (PC) is one of the most critical parts of a SC cavity system

- Vacuum failure (cracked window)
  - bad contamination of the very delicate SC cavity surface
  - recovery is time consuming and expensive
- Power limitation (arcing, window heating, multipacting)
  - limits the SC cavity performance
  - may damage the coupler over time and makes it inoperable

worst case

destroyed by excessive power rise with deactivated interlock!!

RF-Functions of the power coupler

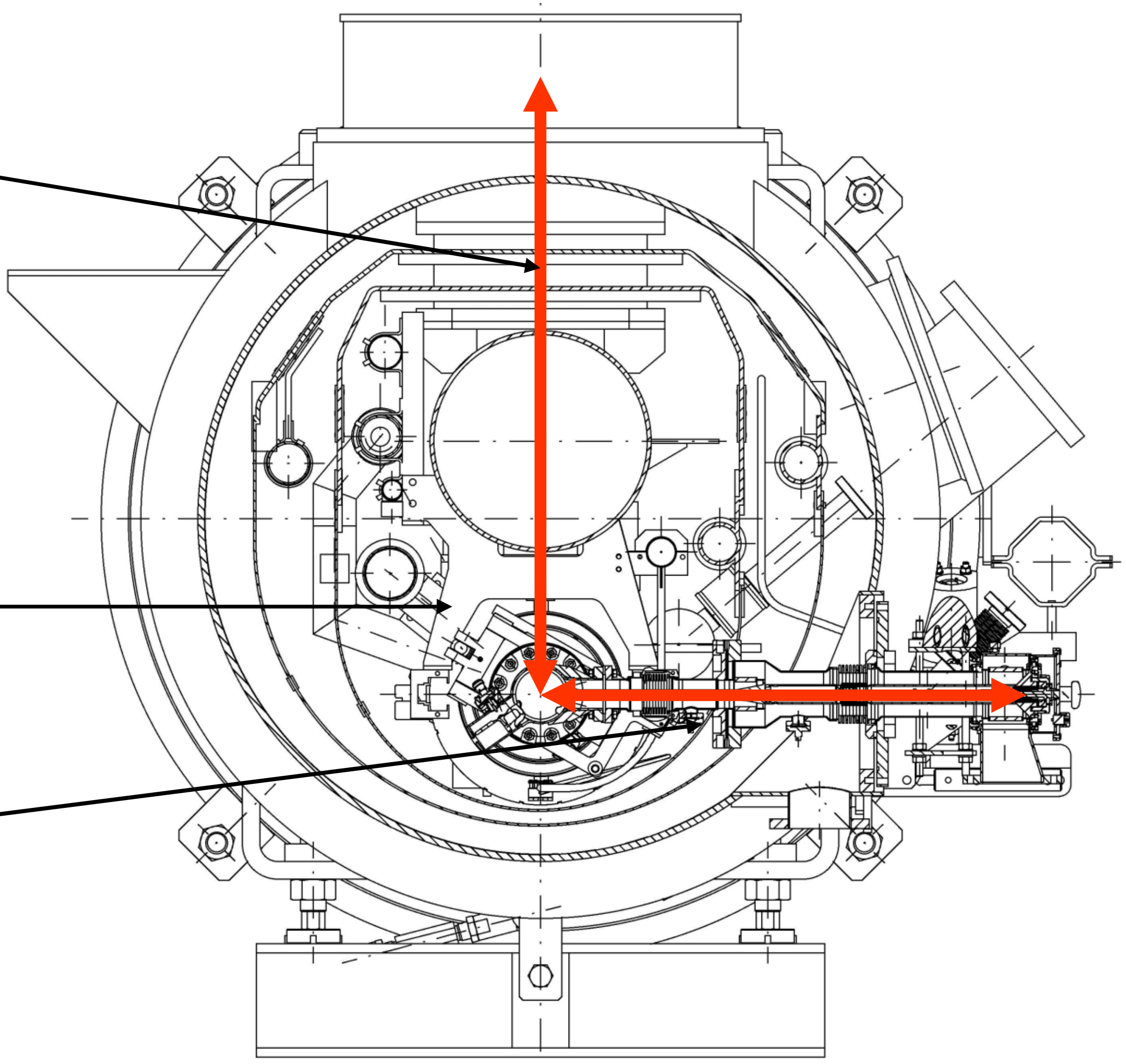
- it has to transfer the power to the cavity field and to the beam at high power levels in pulsed or CW operation
- it has to match the impedance of the klystron to the beam loaded cavity
  - there is a strong mismatch in absence of beam between cavity and generator → full reflection
  - minimize the wasted power
- possibly allow to change the match for different beam conditions
- should have small losses
- dimensions should not allow non –TEM modes

Additional functions of the power coupler

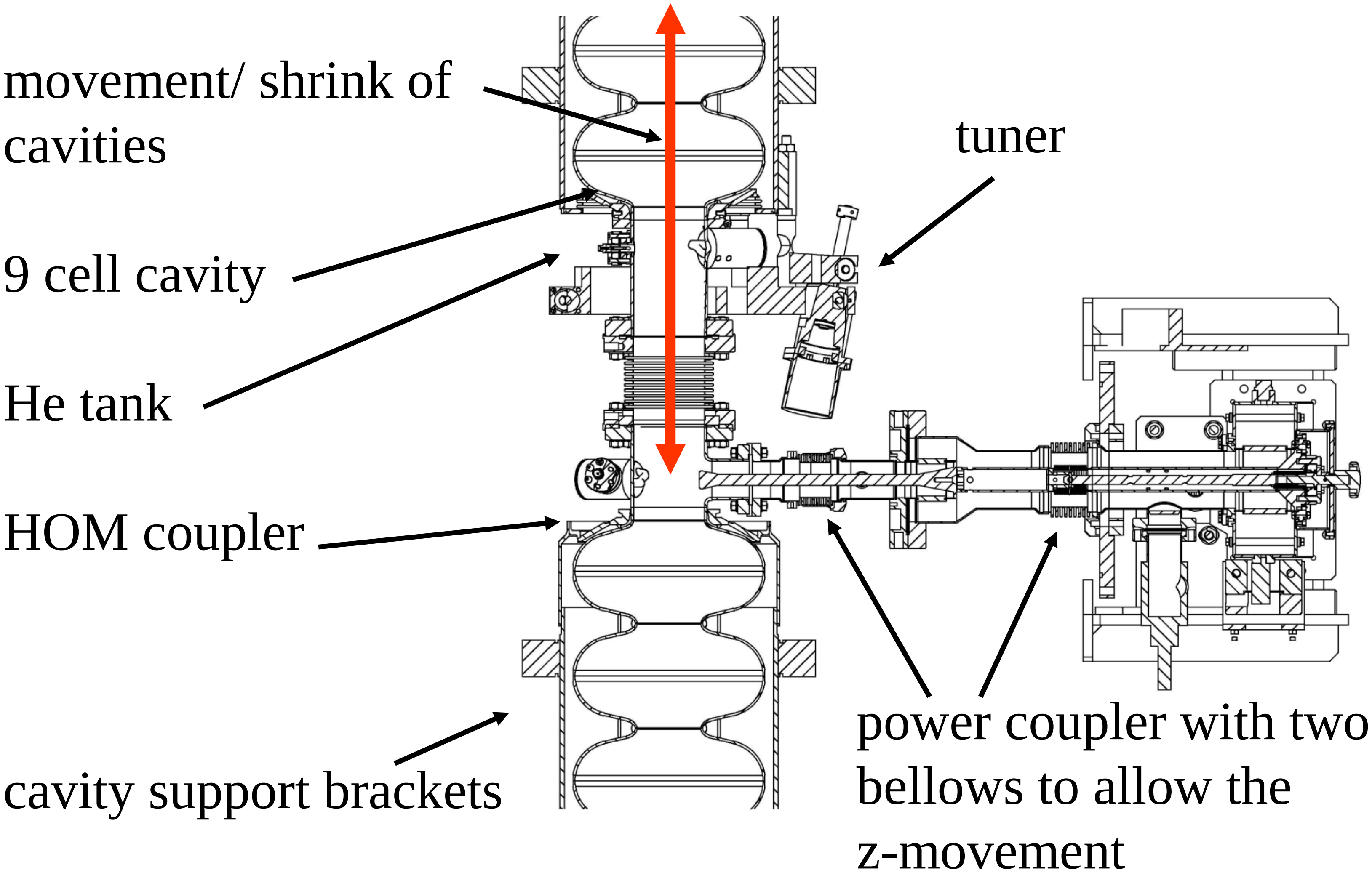
- bridge the gap between room- and cryogenic-temperature
  - mechanic flexibility for the temperature cycles and expansions
  - low thermal losses to the cavity & helium bath (static and dynamic)
- provide a vacuum barrier for the beam vacuum
- not contaminate the sc cavity
  - easy cleaning
  - clean assembly
- Not a function, but important: LOW Costs

e.g. coupler in the TTF module, 1st

- movement of cavity during cool down in vertical direction
- cavities are supported by the SS gas return pipe
- shrinkage of coupler in length



e.g. coupler in the TTF module, 2nd



Wave guide vs. coax coupler

- coax:
  - more compact ✪
  - easy tuning of match, change penetration of antenna ✪
  - circular parts are easy to machine, assemble, seal ✪
  - losses of inner conductor 2/3 to RT or 70K intercept ✪
  - asymmetric fields cause kick to the beam ✯
- wave guide:
  - lower surface electric field (1/4) ✪
  - no easy tuning of the match ✯
  - high thermal radiation ✯
  - machining of big rectangular parts is more extensive ✯

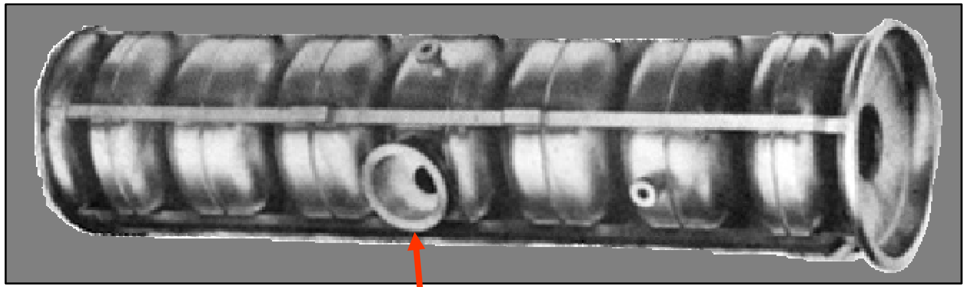
Location of coupler ports

- first SC cavities (HEPL 1977) used to have the coupler ports on the equator (like NC ones)
  - possible enhancement of surface fields H and E
  - multipacting
- modern cavities have the PC and HOMC ports at the beam pipe
  - less cavity limiting effects
  - less filling factor
  - geometric space restrictions

Cavity coupler ports

HEPL cavity 1977

- ports on equator
- limitation by MP



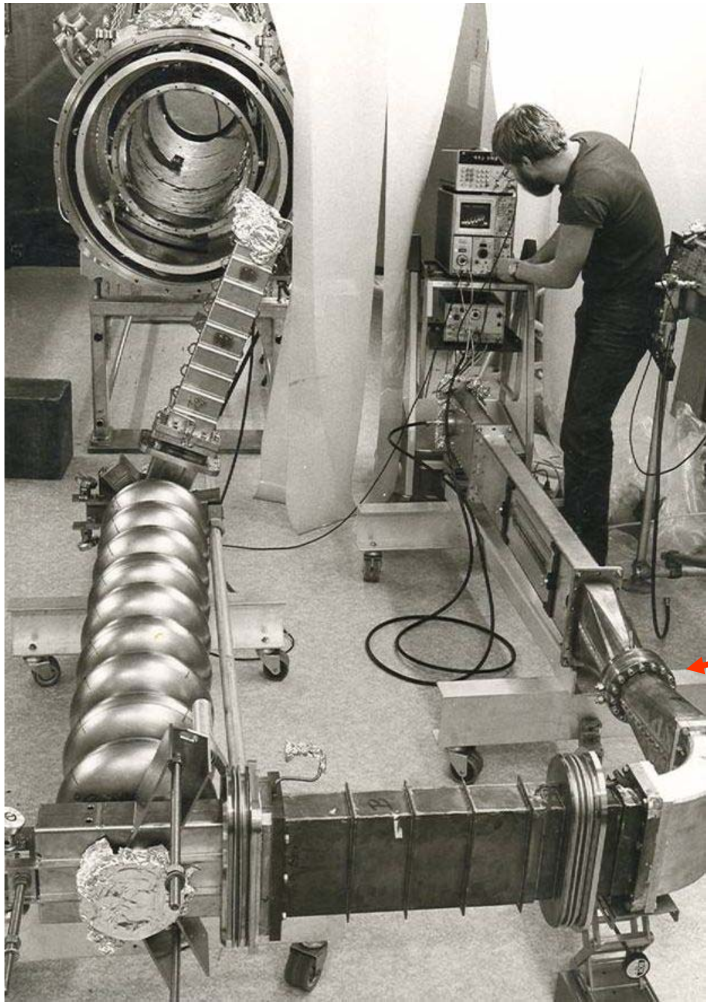
Tesla cavity 1993

- ports on beam line
- longer beam lines and smaller filling factor

Two vs. one window

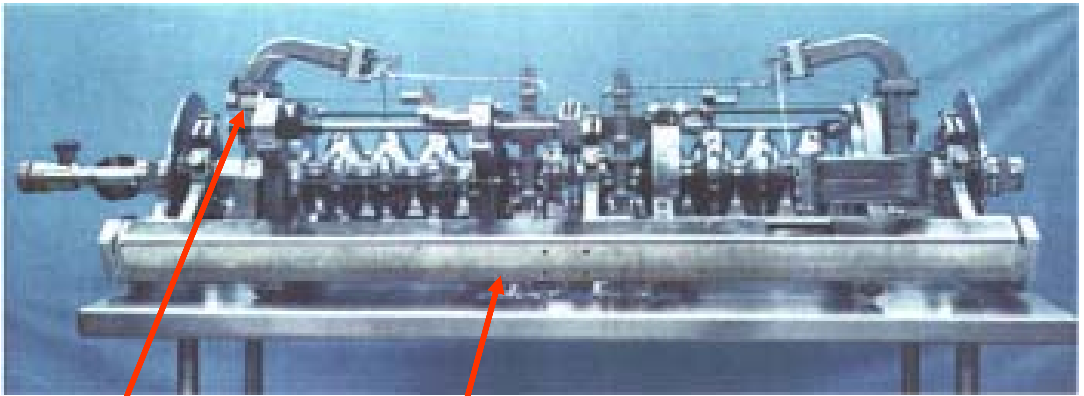
- at low gradient applications (<15 MV/m) one window at RT and PC assembly in presence of the cryogenic environment was used
- for high gradients ($\geqslant$ 20 MV/m)
  - coupler has to be assembled in very clean environment
  - i.e. window has to be close to cavity for later assembly to cryostat
  - i.e. window is at cryogenic temperature and needs a second window at RT
- safety against window failure during operation

Wave guide couplers, 1^{st}

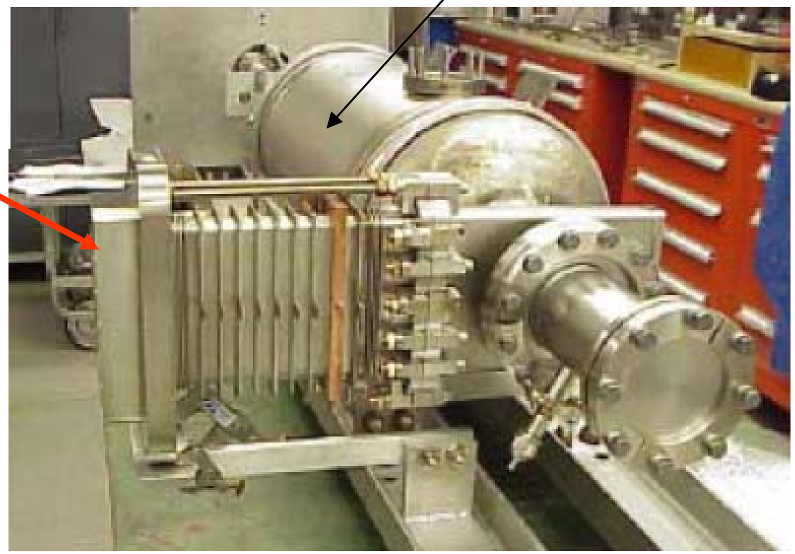


1 GHz Petra test cavity

window

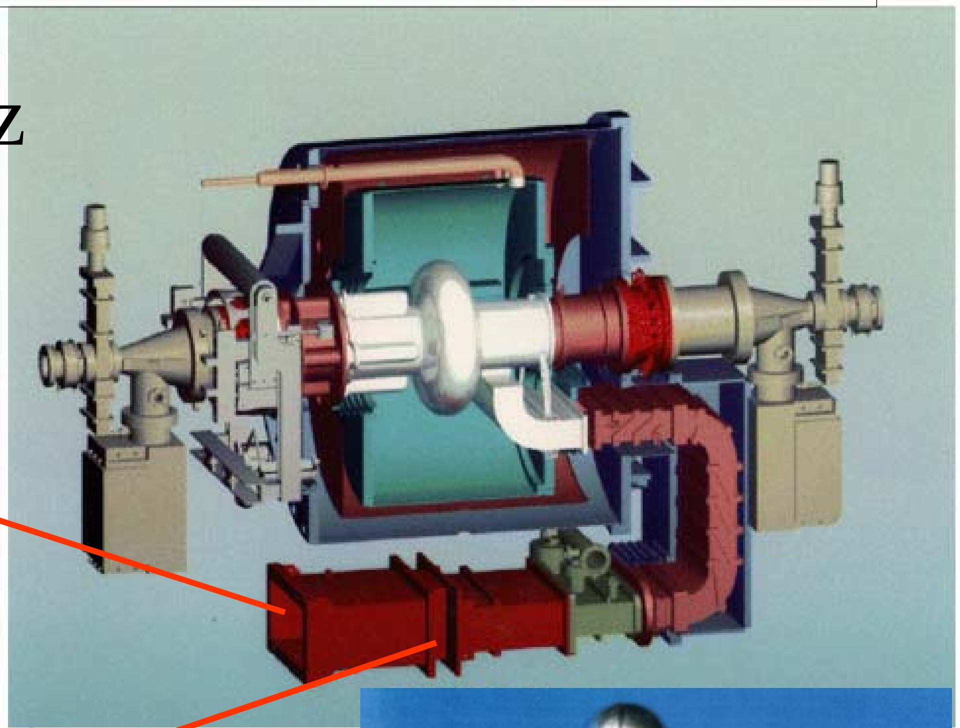


CEBAF cavity pair and new upgrade cavity

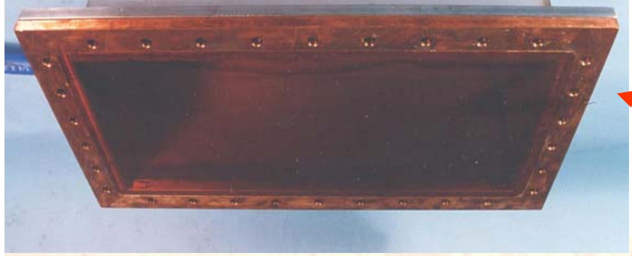


Wave guide couplers, 2^{nd}

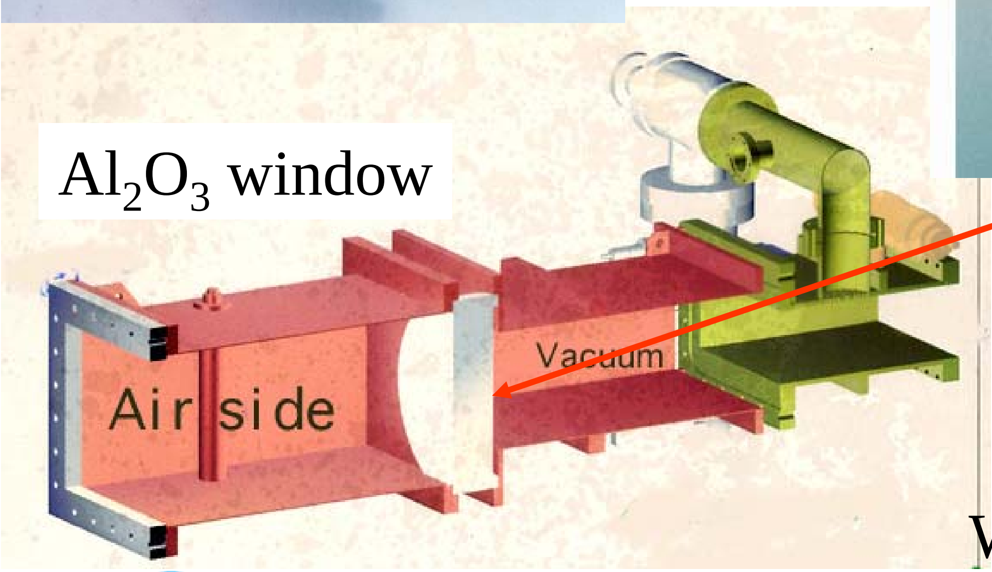
CESR – B cavity, 500 MHz

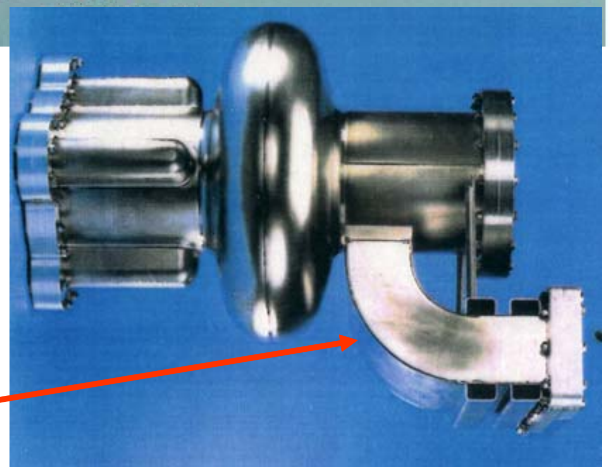


backup Kapton window



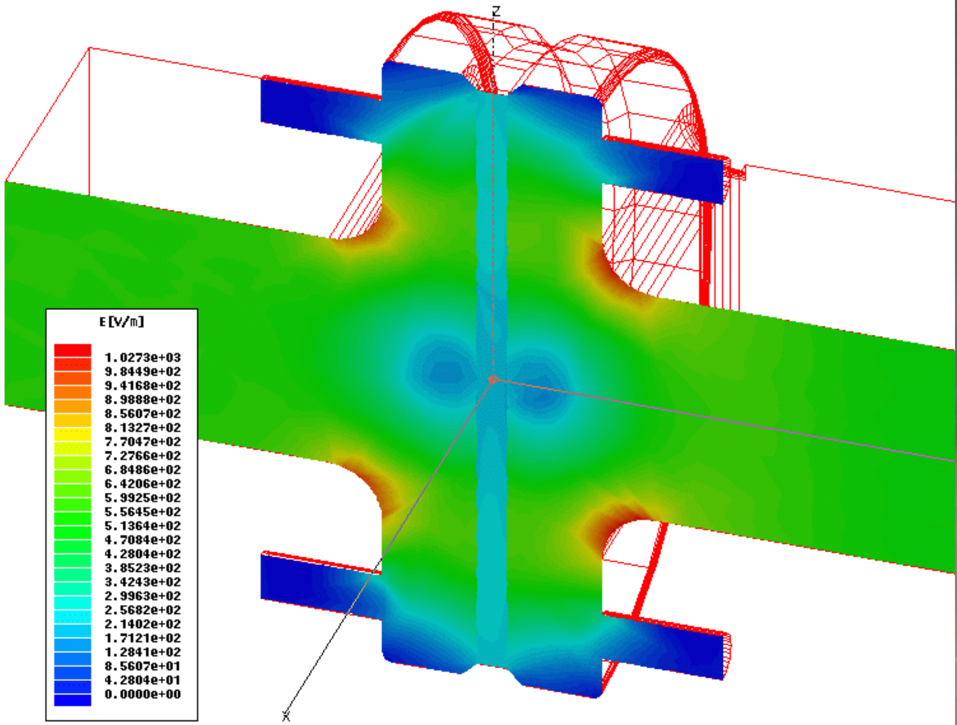
Al_2O_3 window

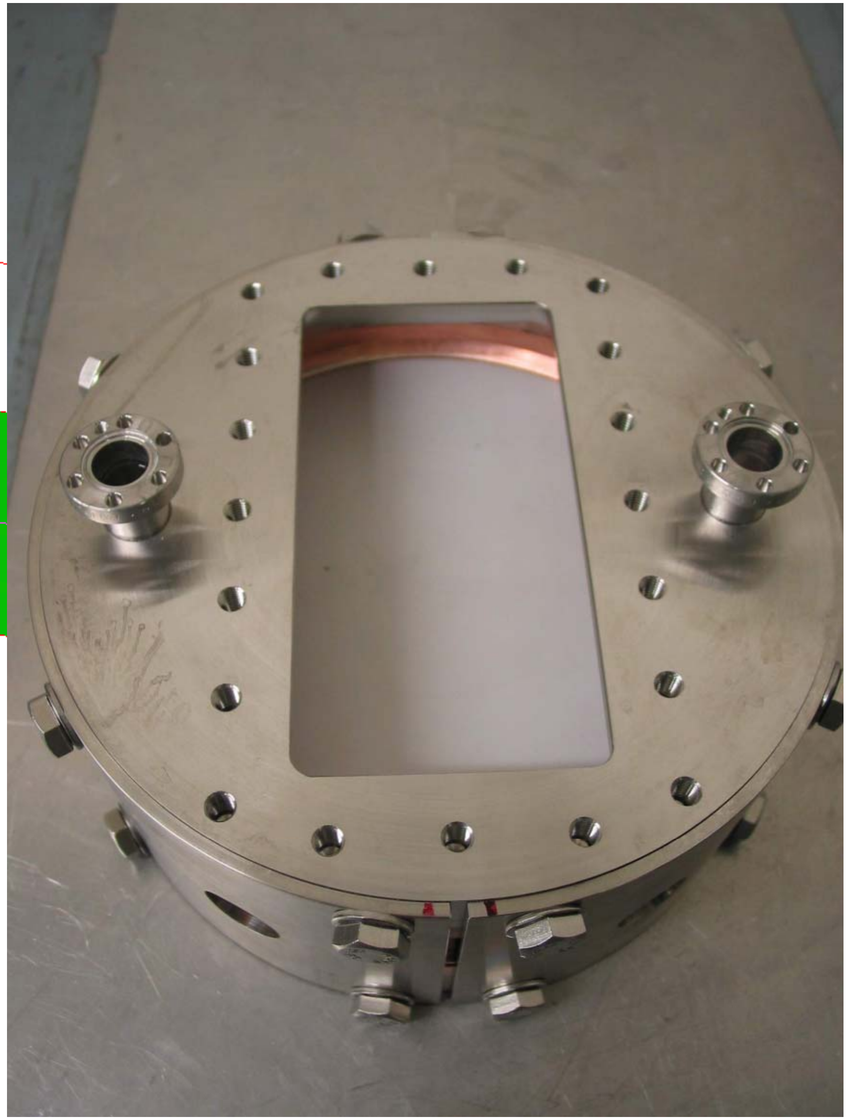




WG coupler

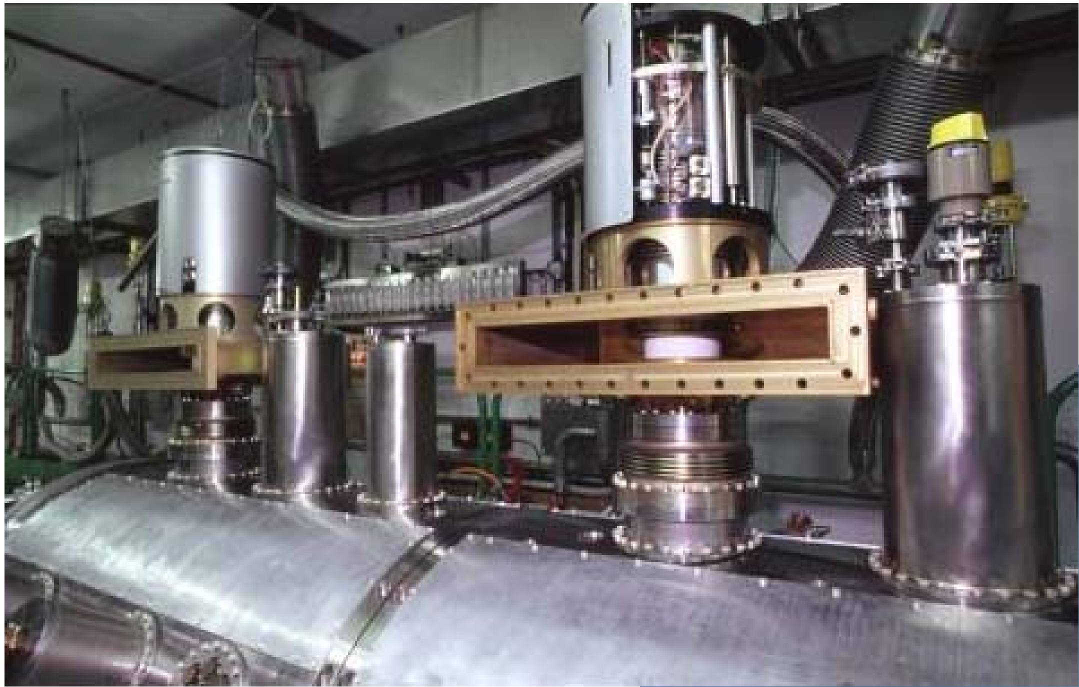
Wave guide window



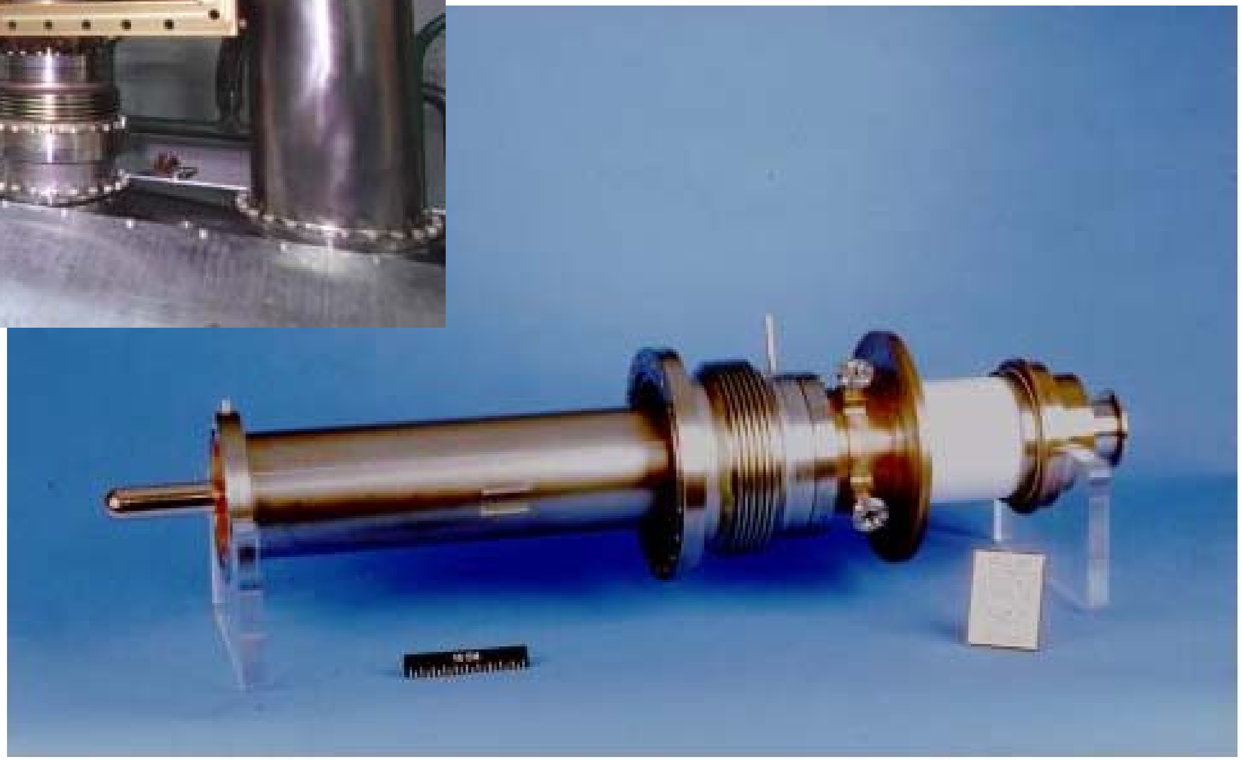


window with diagnostic ports
(TTF 2 coupler)

Coax couplers, one cylindrical window



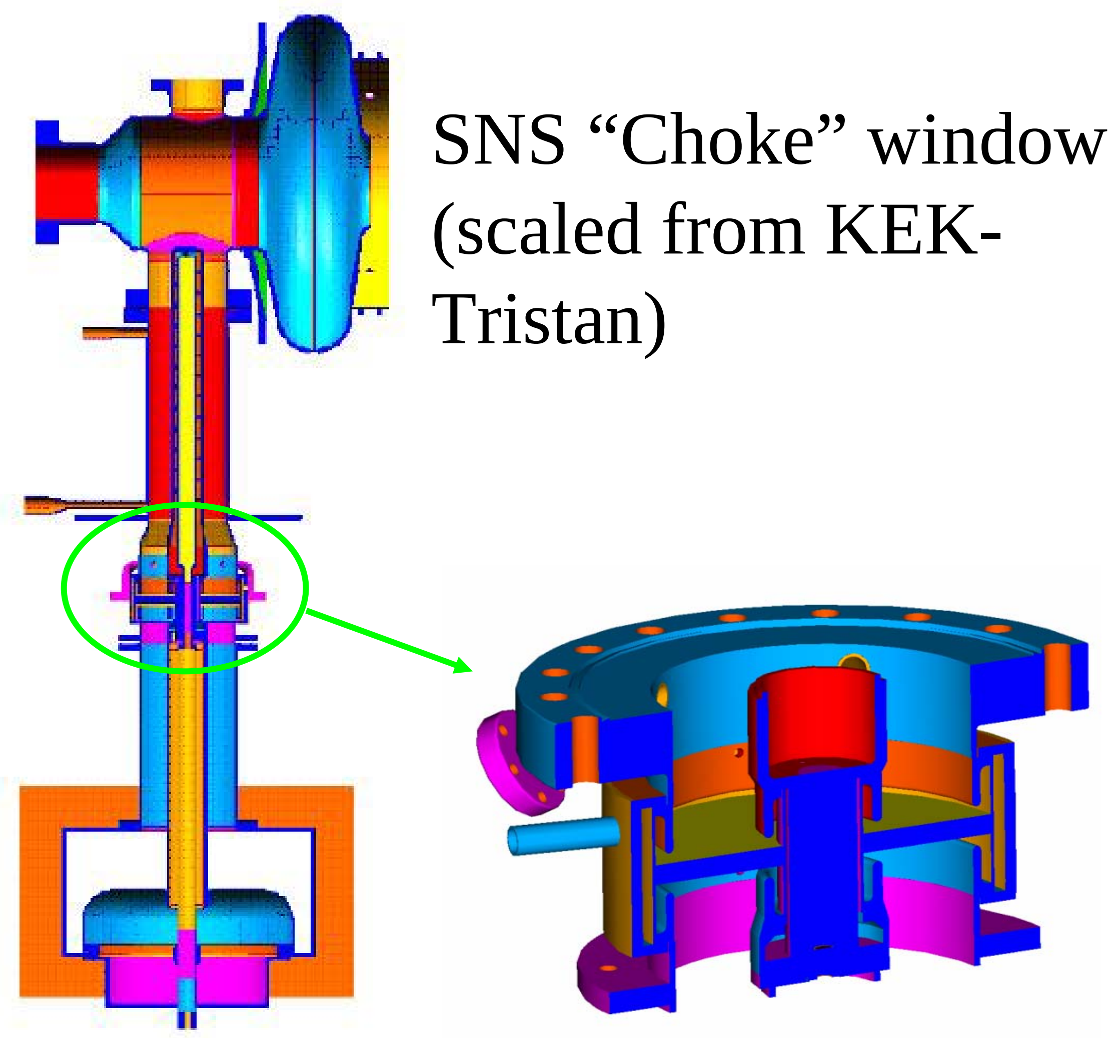
LEP, HERA

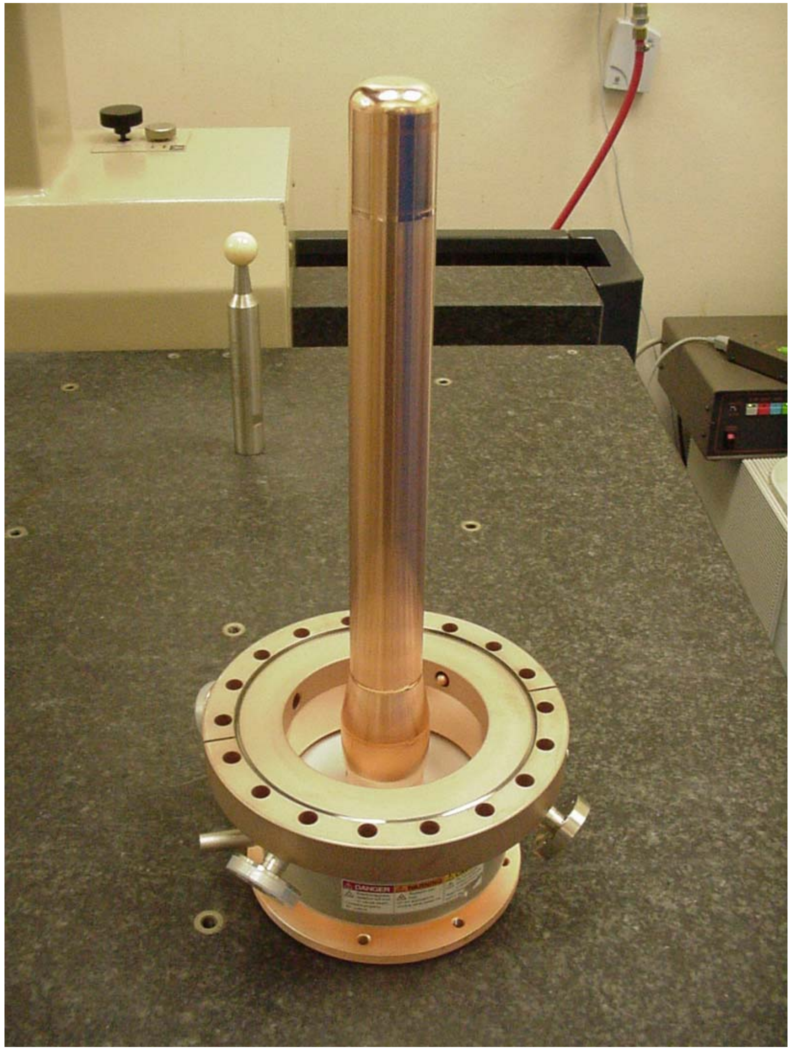


LEP coax to wave guide transition

Coax couplers, flat window

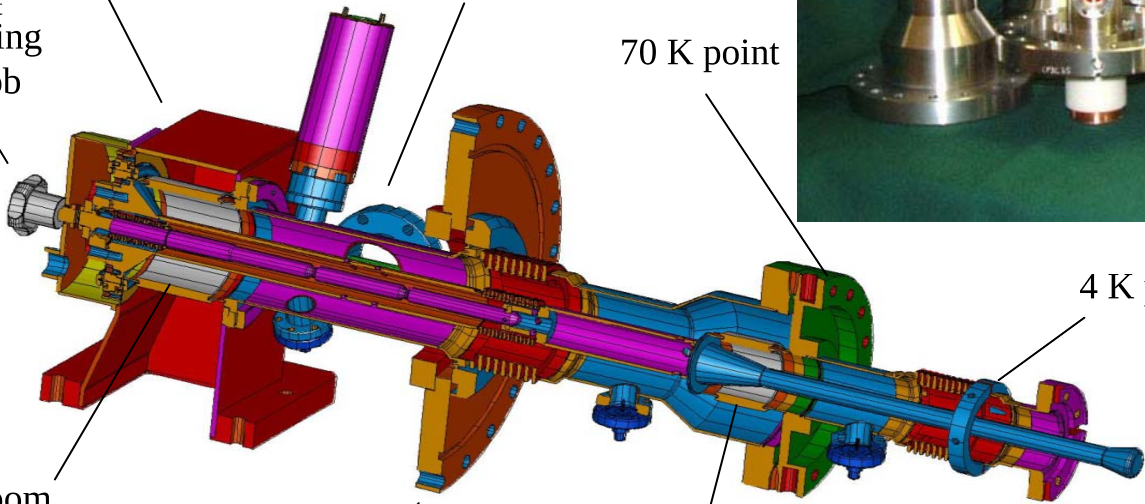
SNS "Choke" window (scaled from KEK-Tristan)



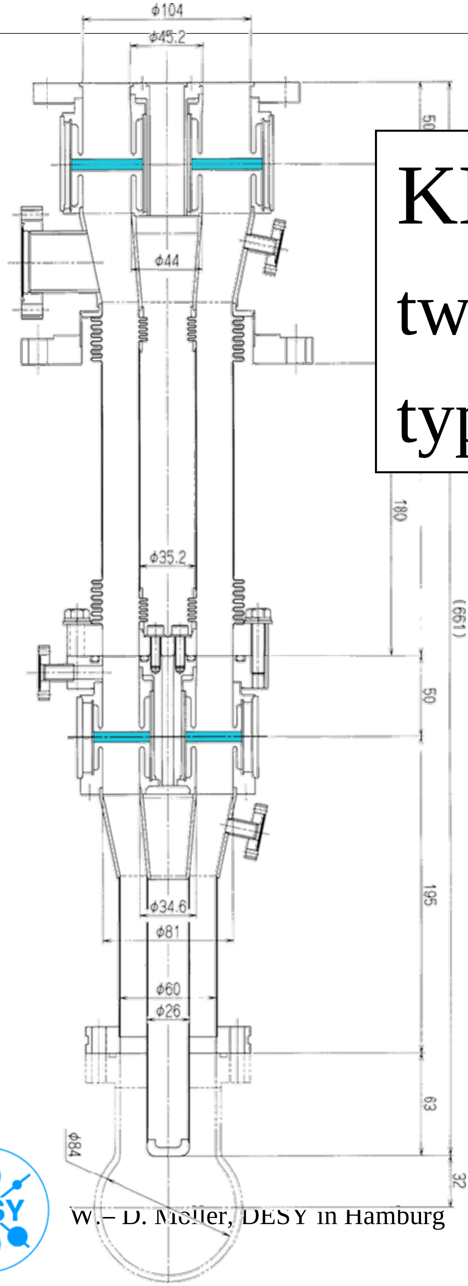


Coax couplers, two cylindrical windows

TESLA Coupler

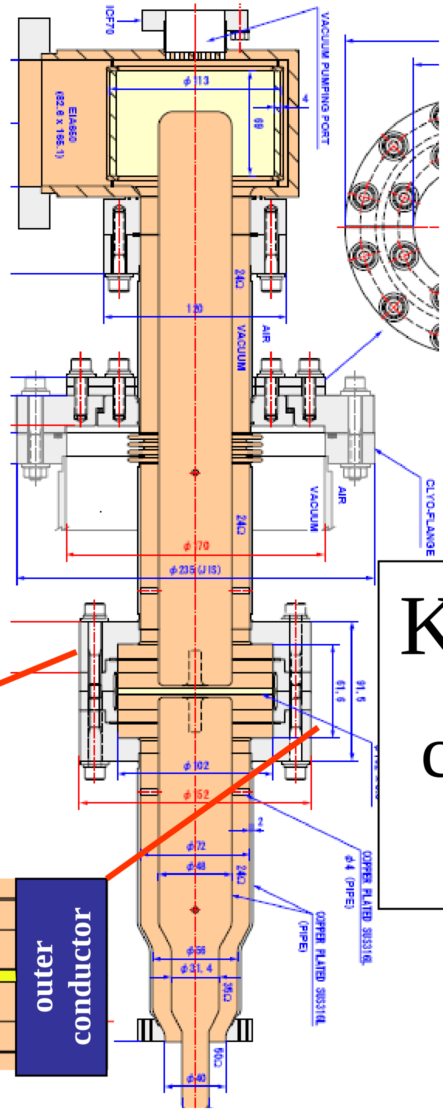


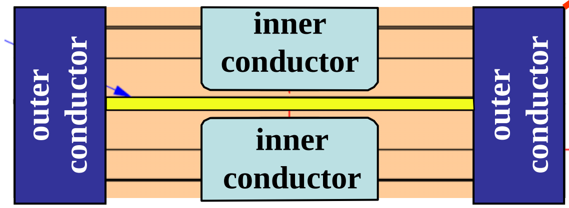
Coax couplers, two flat windows



KEK1:

two TRISTAN type disks





KEK2:

capacitive coupling

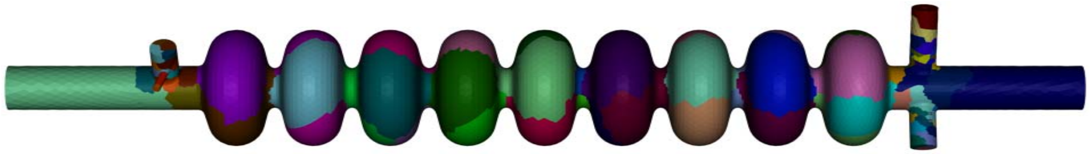
RF simulation codes

- many codes are available:
  - SUPERFISH
  - URMEL
  - **MAFIA™**
  - HFSS™
  - **CST MICROWAVE STUDIO®**
  - …

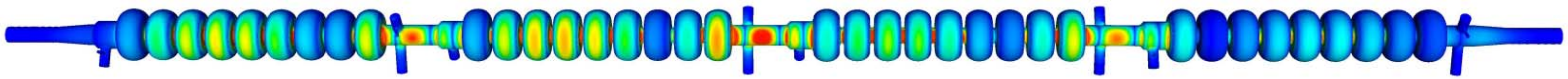
SLAC 3D Parallel FEM EM Codes

Zenghai Li et al., SLAC

- Tetrahedral Mesh with Finite-Element
  - Up to 6th order basis for field accuracy
  - Unstructured grid for modeling geometry with large variation in dimensions
- Parallel implementation (10^2-10^3 processors, 10^2GB memory)
  - Modeling details with great realism



  - Simulating large systems such like multi-cavity cryomodule



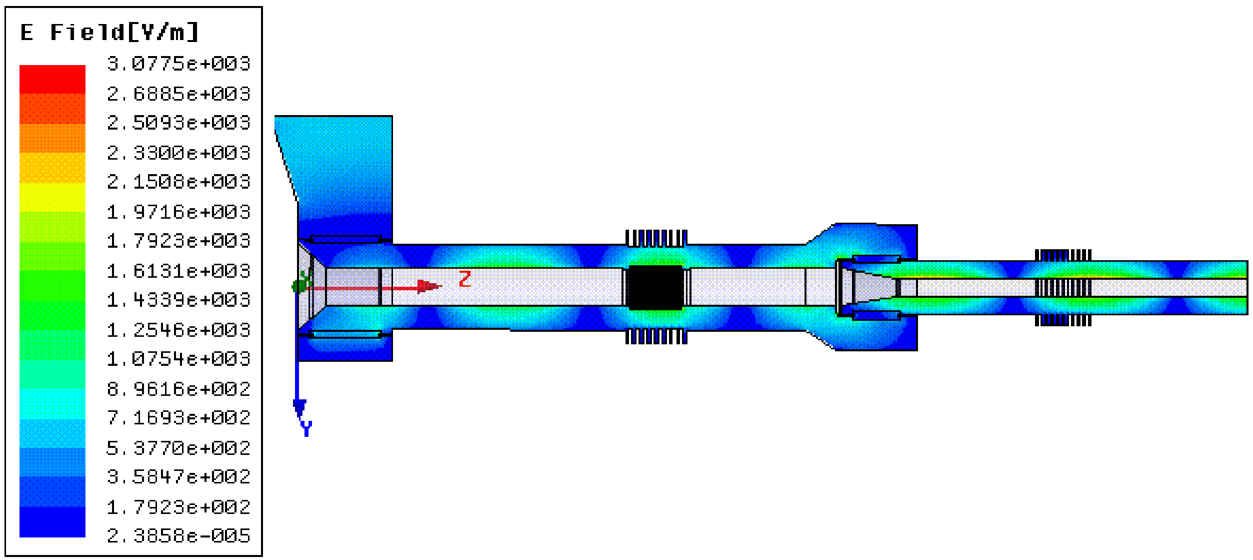
- A suite of solvers including frequency domain and time domain

Omega3P	- Frequency Domain Mode Calculation
S3P	- S-parameter Computation
T3P	- Time Domain With Beam Excitation
Track3P	- Particle Tracking, MP and dark current
V3D	- Visualization

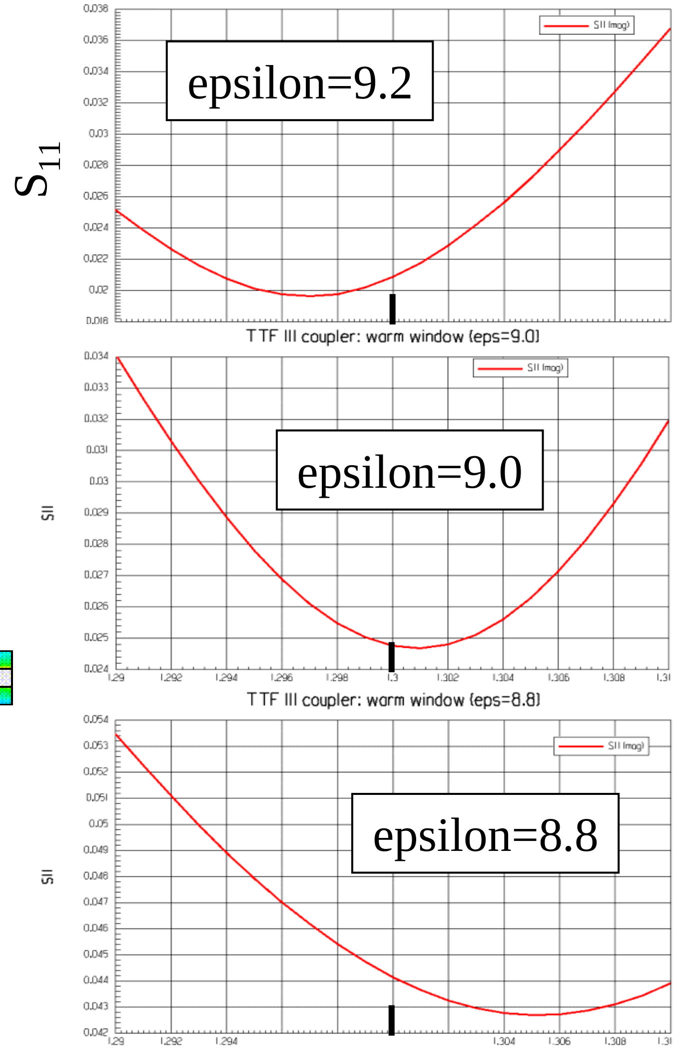
…

RF simulation

- matching of the coupler components
  - here the influence of the ceramic epsilon is shown



TTF3, warm window

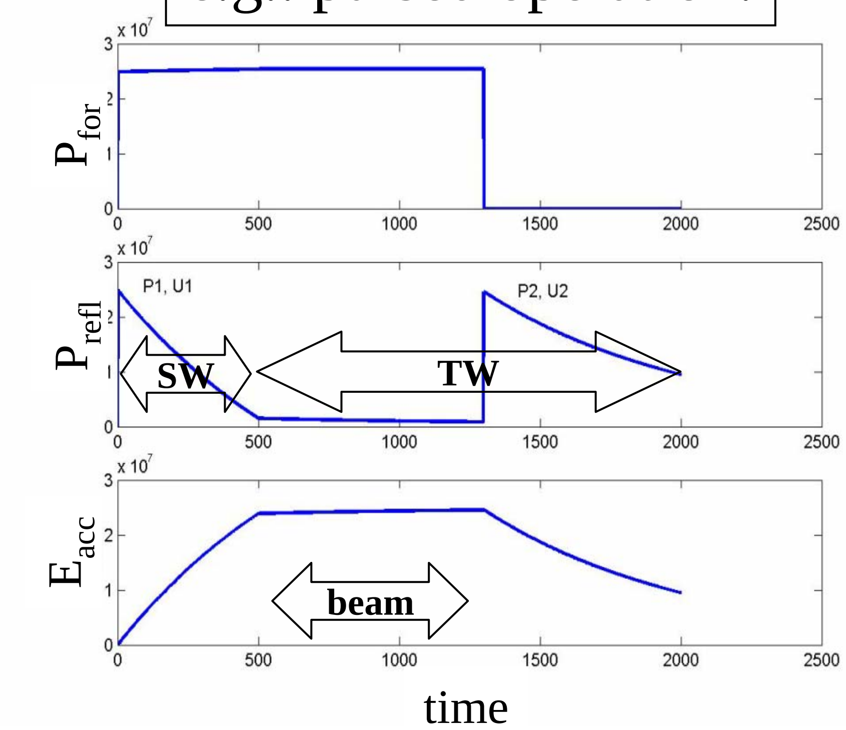


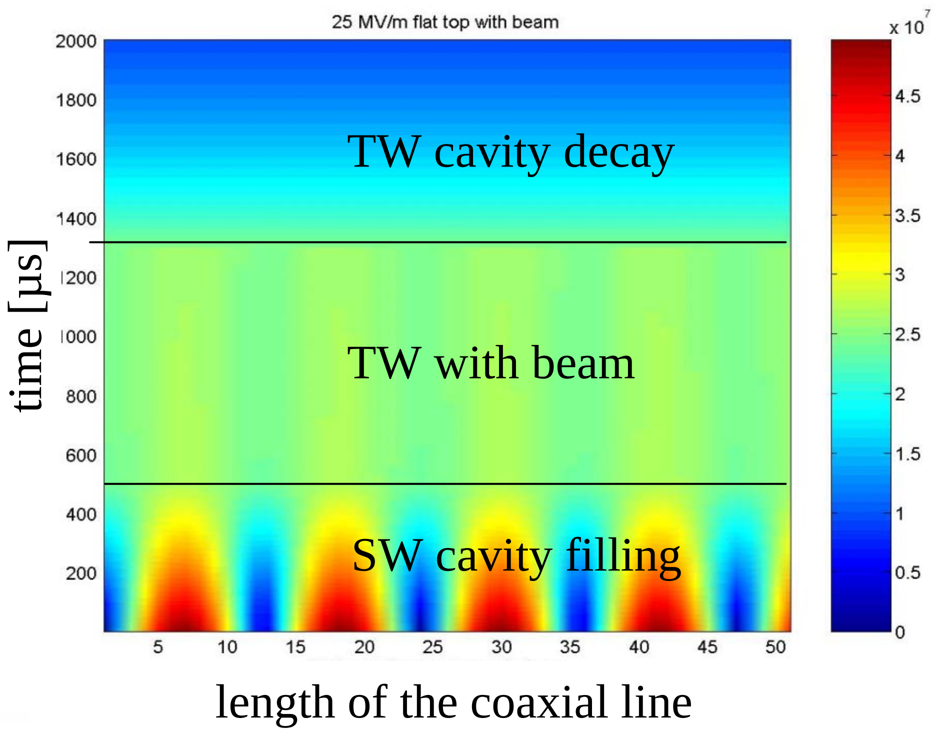
frequency

Standing waves in PC

- during filling time of cavity and at absence of beam: standing waves in coupler

e.g.: pulsed operation:

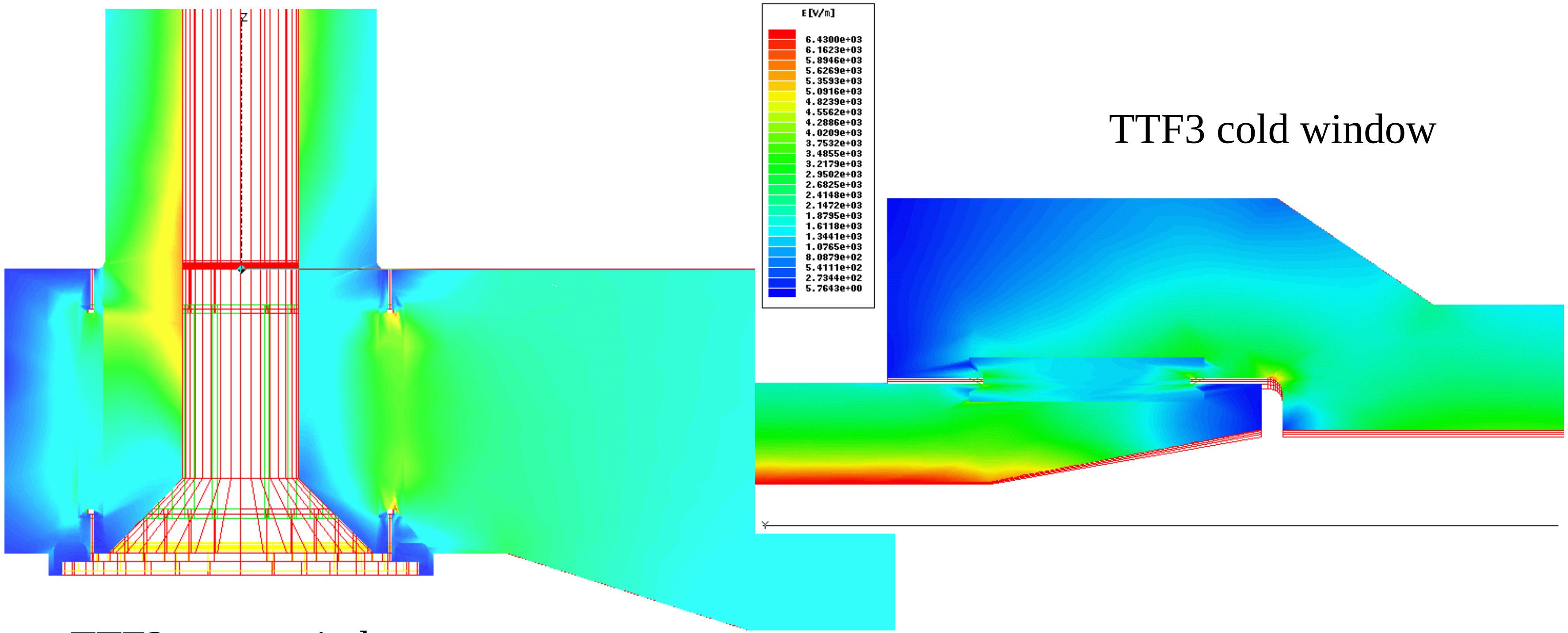




RF simulation, window position

- for pulsed operation: placing the window in the minimum electrical field

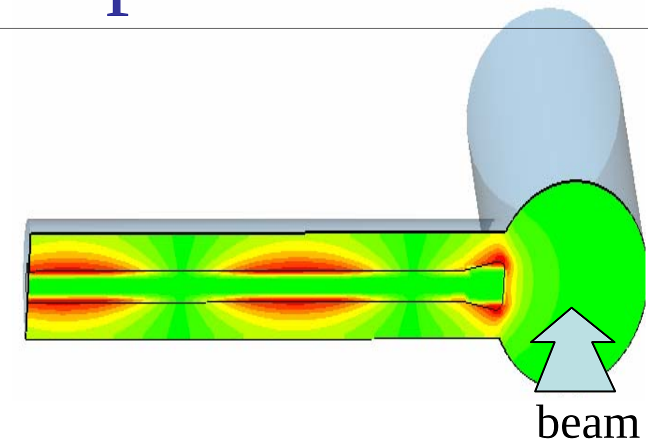
TTF3 cold window



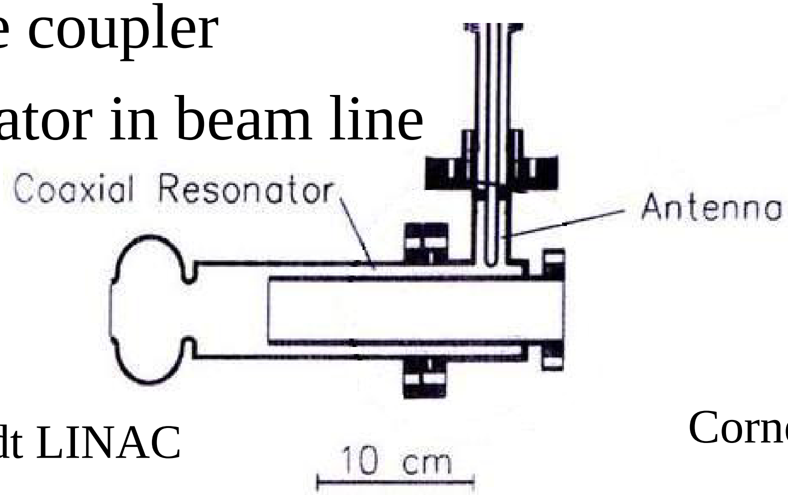
TTF3 warm window

RF simulation, kick to the beam by the RF field of the coupler

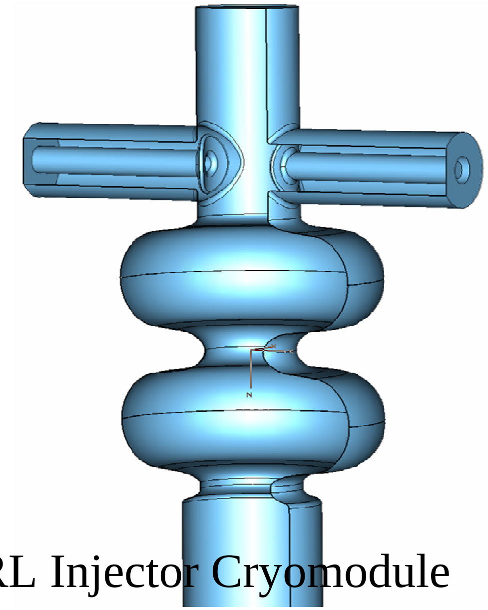
the asymmetric field at the coaxial coupler antenna – beam pipe transition causes an unwanted kick to the beam



- symmetric (2 couplers) or alternating coupler positions
- wave guide coupler
- coax resonator in beam line



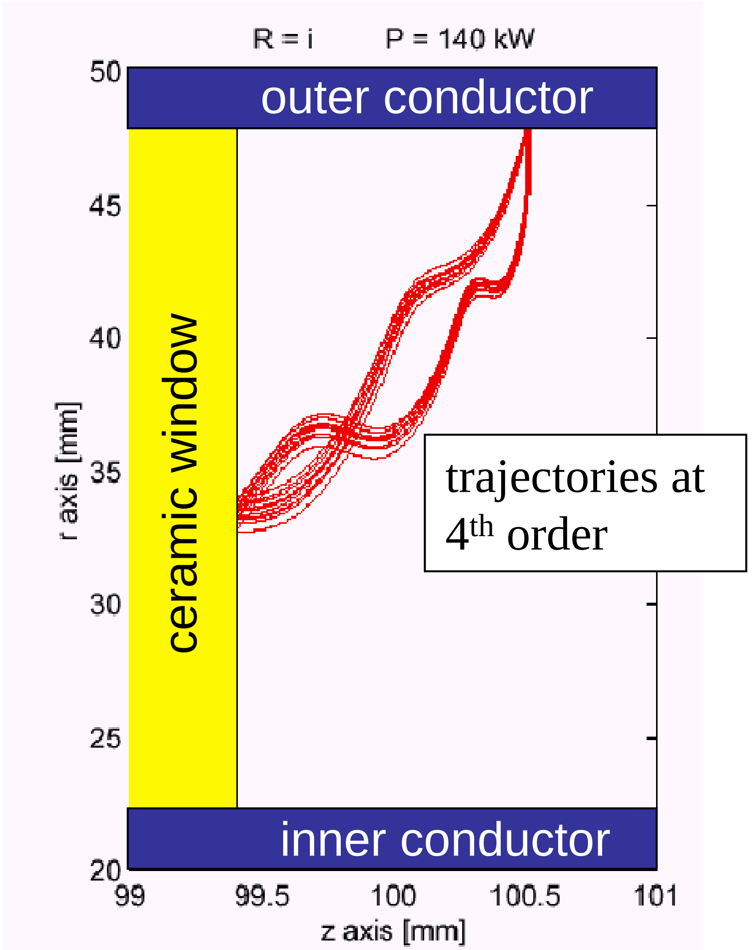
S-Darmstadt LINAC



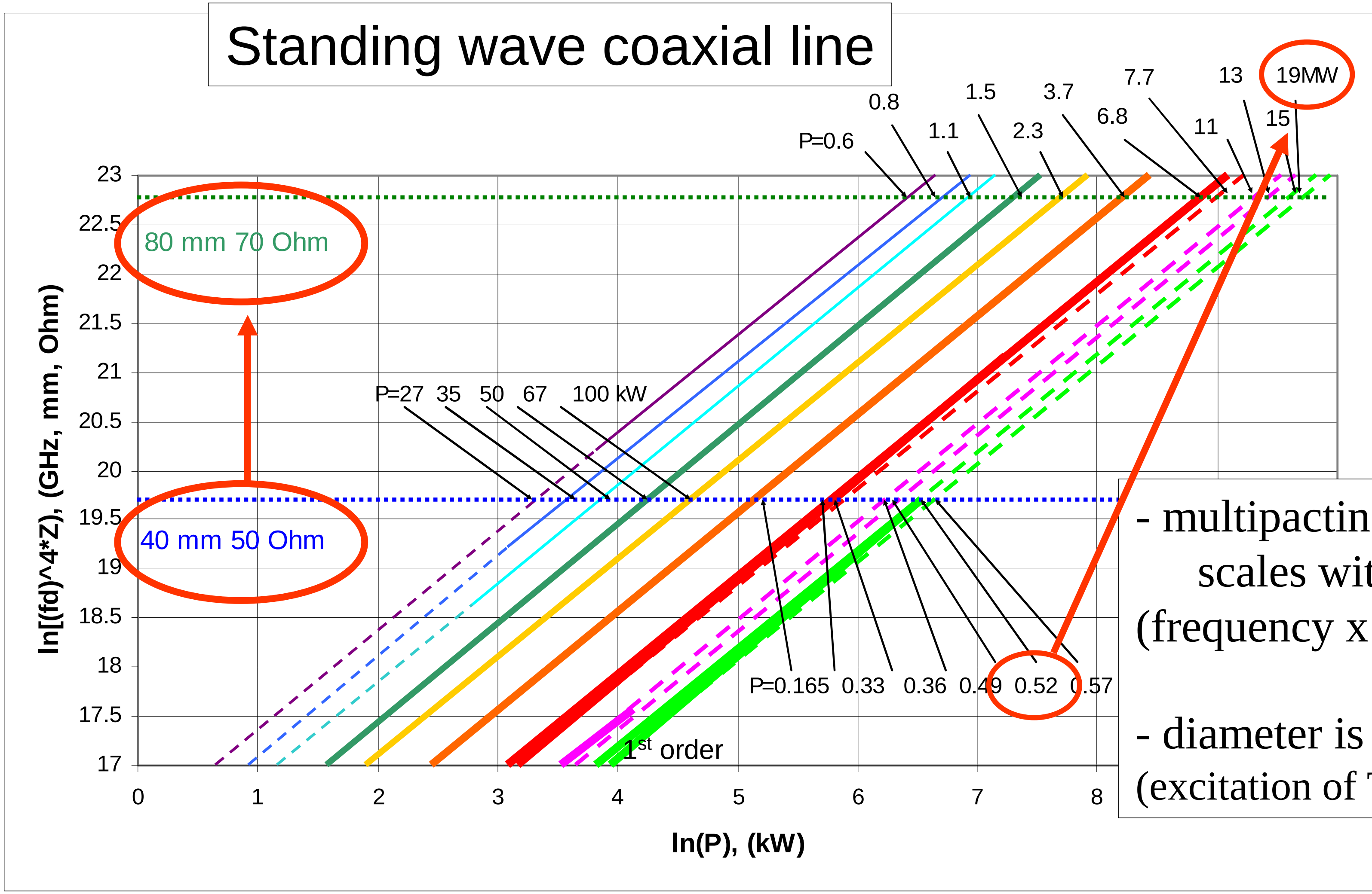
Cornell ERL Injector Cryomodule

Multipacting in the coupler vacuum

- Resonant multiplication of electrons caused by:
  - electron trajectories (1 point or 2 point) determined by RF field and geometry
  - secondary electron emission coefficient (SEC) >1
  - order = traveling time over RF periods, lower order more stable (i.e. more difficult to condition)



Multipacting analytical calculations



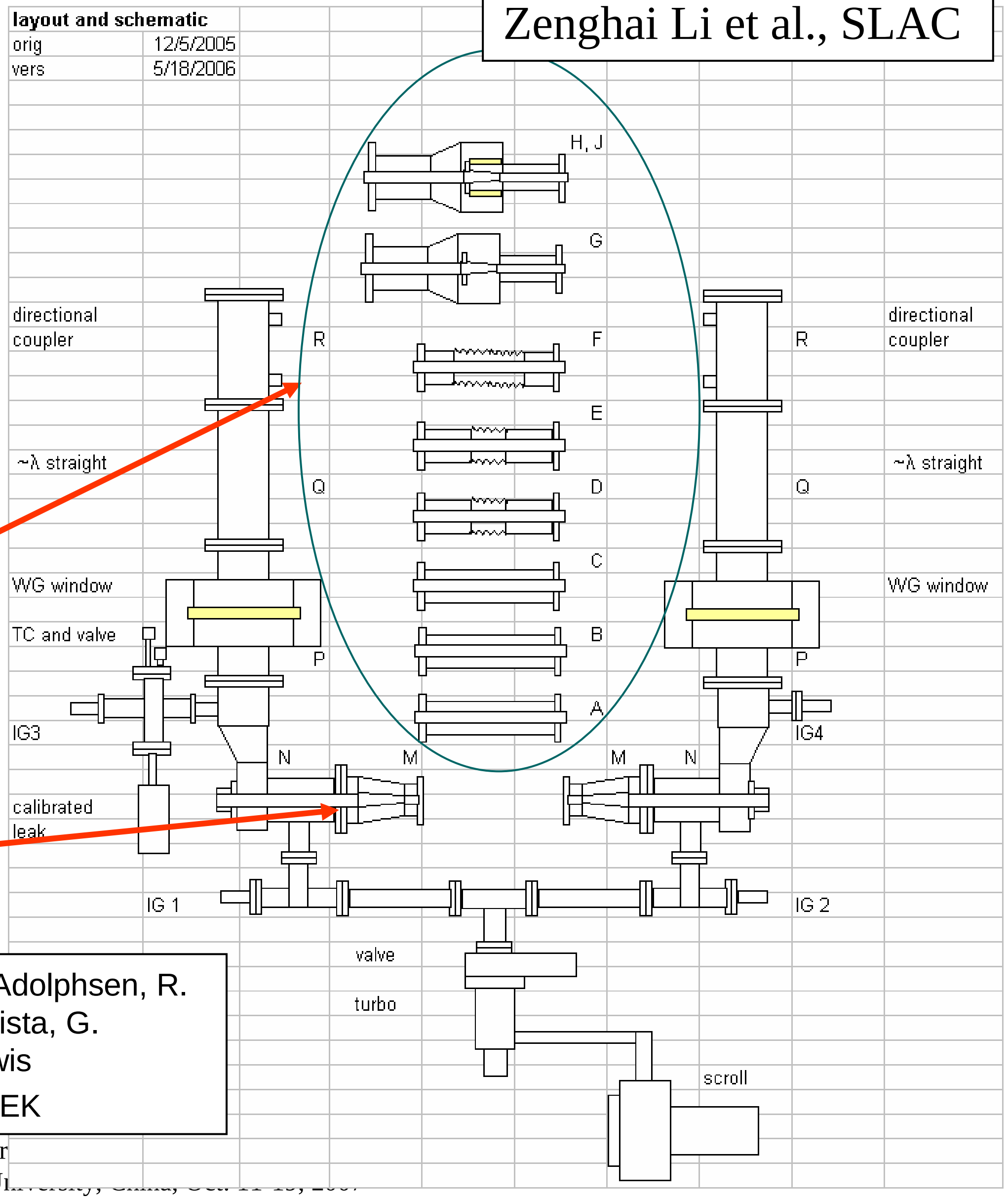
- multipacting power level scales with (frequency x diameter)^4

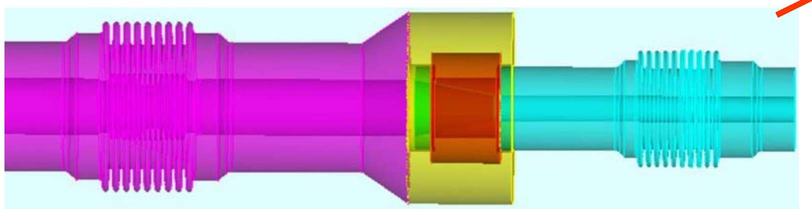
- diameter is limited (excitation of TEM-modes)

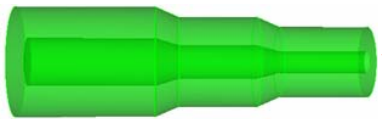
Coupler Test Setup @ SLAC

- Test components of pc
- simulate the MP behavior
- compare with and to help understand the HP test results

Zenghai Li et al., SLAC





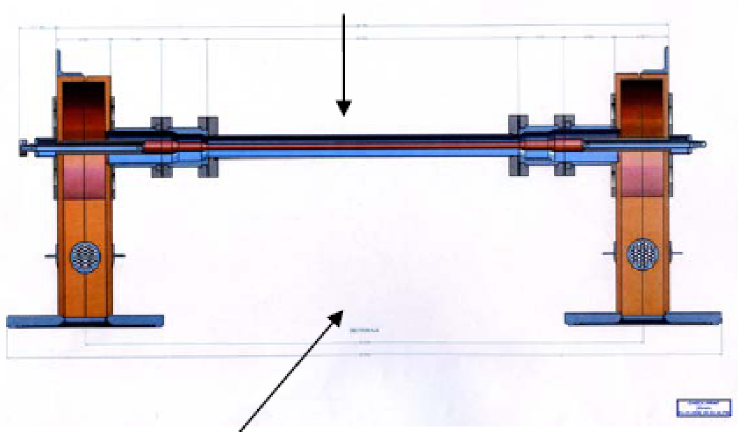


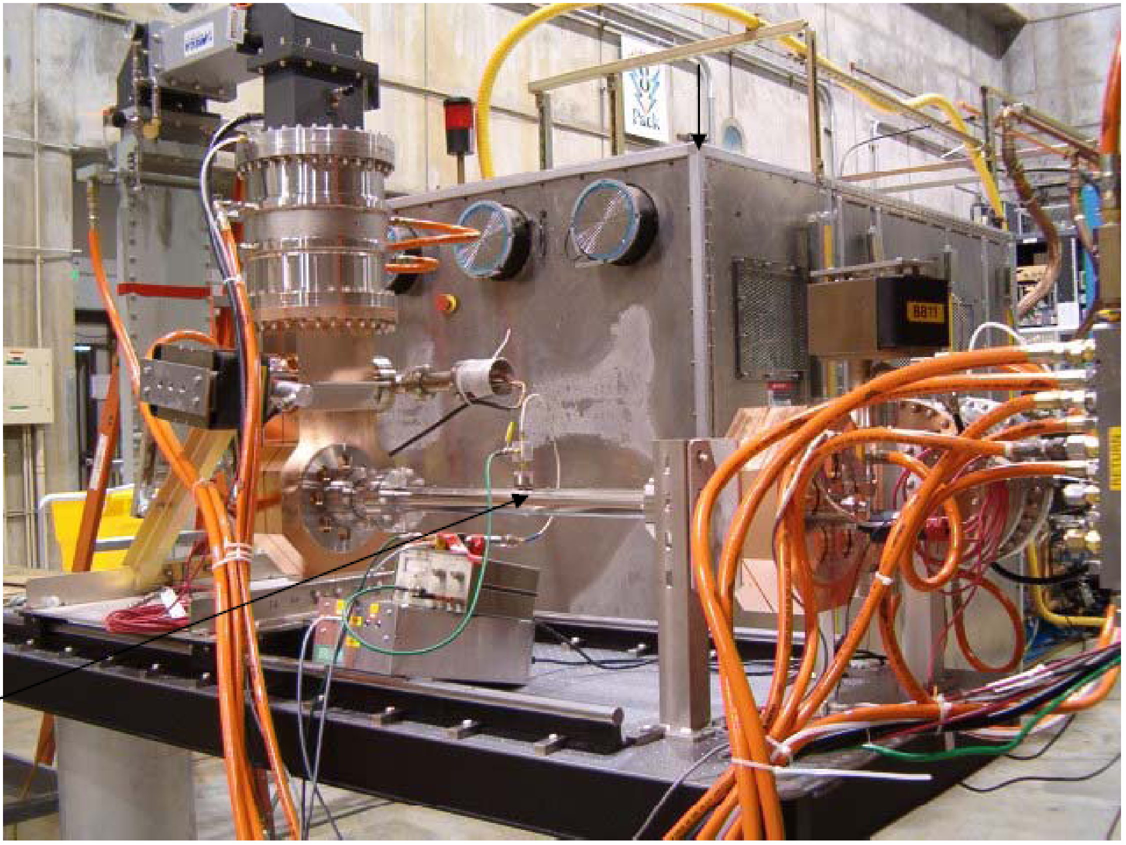
B. Rusnak, C. Adolphsen, R. Swent, C. Nantista, G. Bowden, J. Lewis

TTC meeting KEK

Coupler Test Setup @ SLAC

Component
Under Test



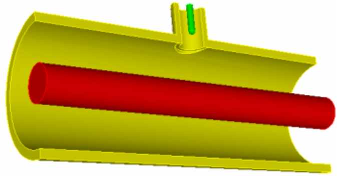


Concept and hardware of test set up for measuring components – first test component is a 40 mm straight tube

Multipacting in Coax of TTFIII Coupler

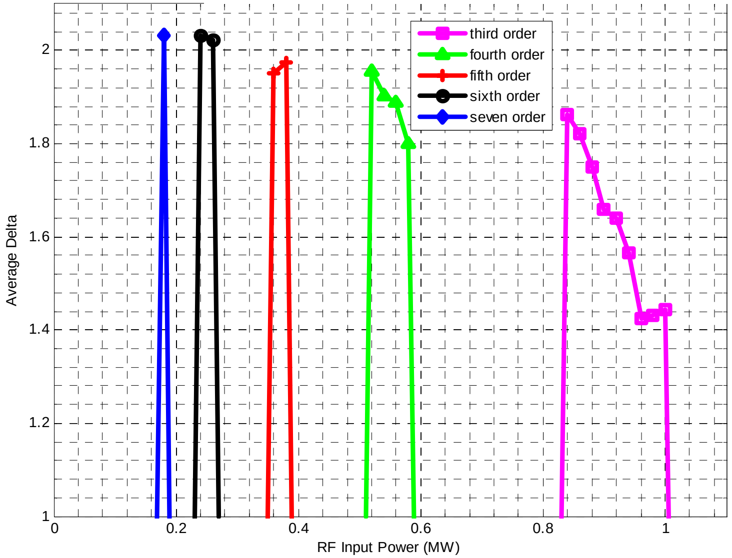
Zenghai Li et al., SLAC

Cold coax, 40mm diameter

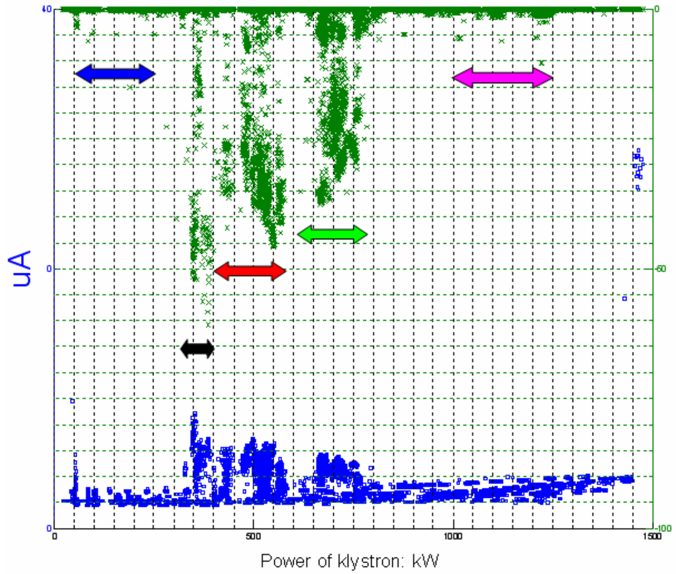


(F. Wang, C. Adolphsen, et al.)

Track3P simulation



Test: After high power processing



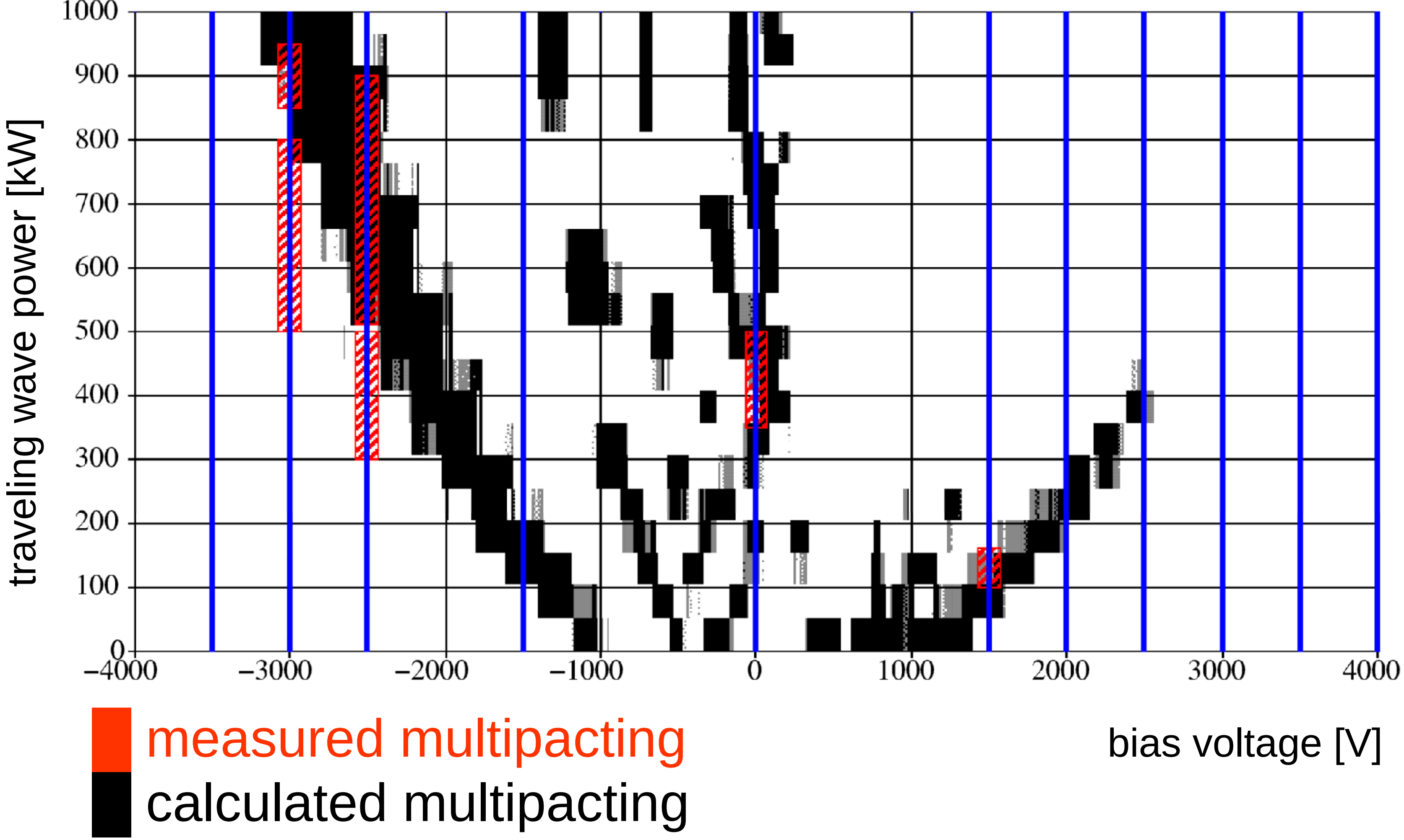
Simulated power (kW)	170~190	230~270	350~390	510~590	830~1000
Power in Coupler (kW)	43~170	280~340	340~490	530~660	850~1020
klystron power (kW)	50~200	330~400	400~580	620~780	1000~1200

More simulations being carried out to understand measurement details

Cures for multipacting

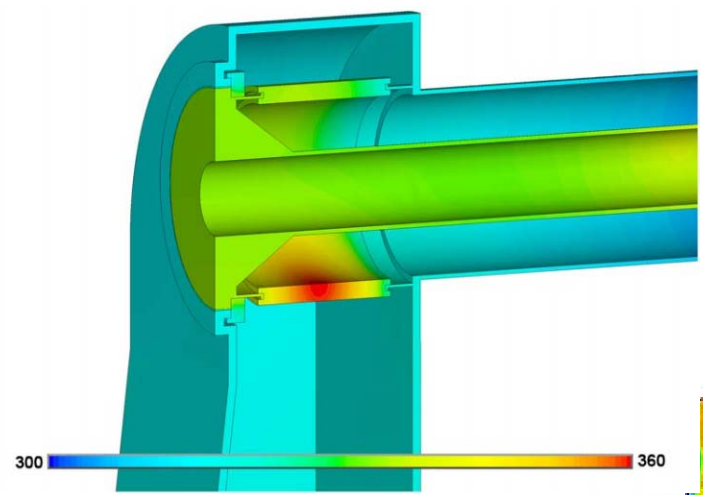
- the right choice of the geometry:
  - bigger coax diameter, higher impedance shift the MP levels to higher power ranges
- reduction of SEC:
  - coating of critical surfaces (e.g. ceramic SEC≈8) with Ti or TiN (SEC≈1)
  - cleaning RF surfaces before or by conditioning
- shift resonant conditions by additional fields:
  - electrical bias on inner coax
  - magnetic bias on wave guide

Multipacting measurements, influence of bias voltage (TTF2 Coupler)

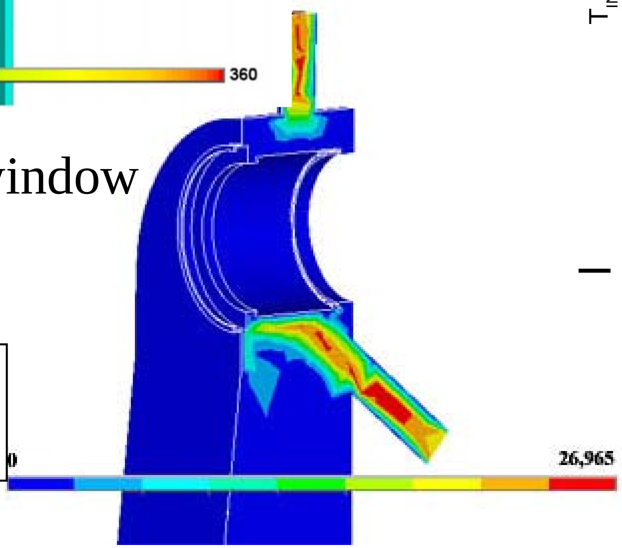


Thermal simulations

75 kW CW Coaxial Input Coupler for Cornell ERL Injector Cryomodule

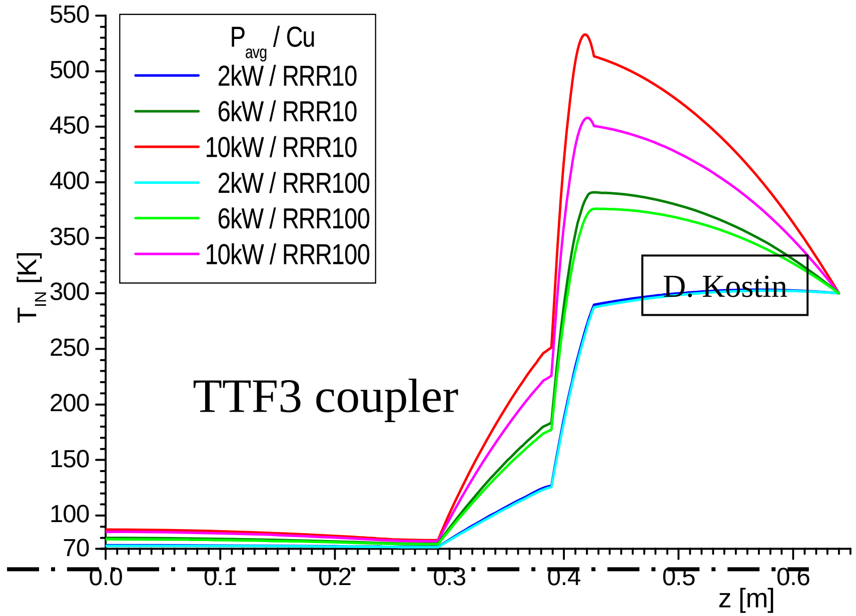


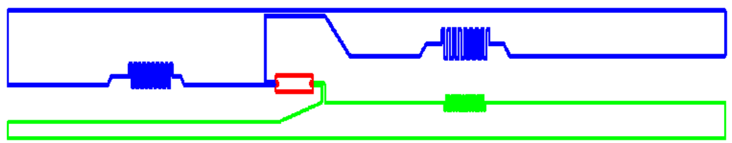
heating of the window and air cooling



Московский инженерно-физический институт and “ИНТРОСКАН”

heating of the inner conductor for different quality of the copper plating





Fabrication issues, general

- a good RF design is a precondition for a reliable working coupler
- to realize a good coupler, the RF design has to consider the fabrication, assembly and costs:
  - use standard material qualities (316LN, Cu-OFHC, Al_2O_3)
  - use standards sizes (tubes, bellows, flanges)
  - use standard fabrication techniques
  - use fabrication techniques according to the abilities of the industries
  - decide on acceptable tolerances
  - clean handling during the fabrication
  - close collaboration with the manufacturer as early as possible and during the fabrication is a must

Fabrication issues, stainless steel

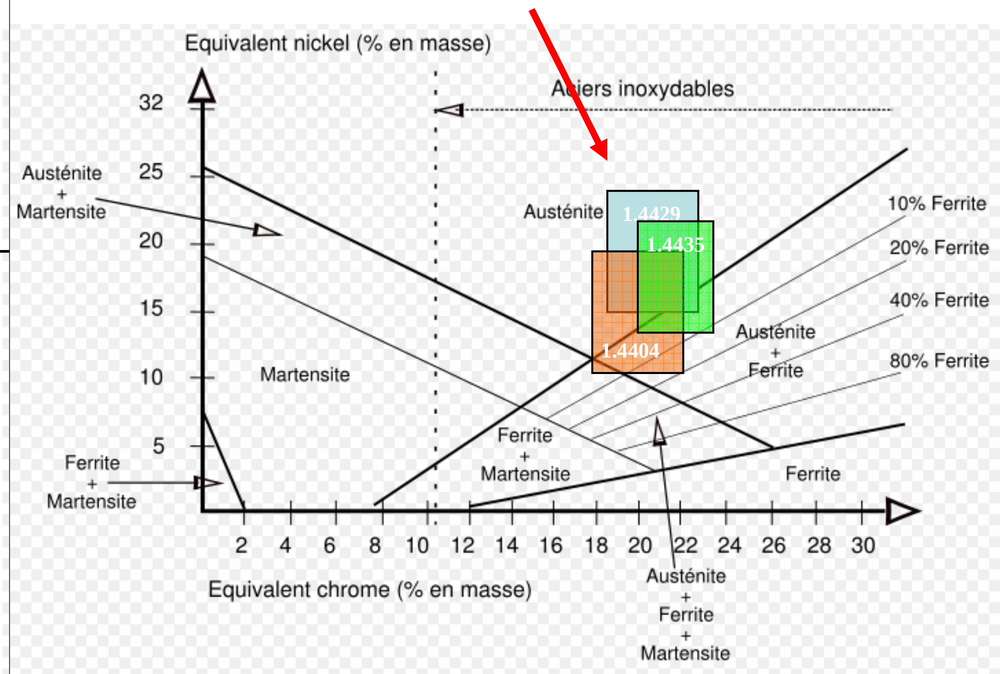
Low permeability (≲1.01) is essential close to SC cavity

S. Prat, LAL, Orsay

EN 1.4404 X2 Cr Ni Mo 17-12-2 (316L) • ferrite number ~ 2 • easy to procure	Tubes, bellows, fixation parts
EN 1.4435 X2 Cr Ni Mo 18-14-3 (316L also) • ferrite number ~ 0 • µ r < 1.01 • less easy to procure	Tubes in cold part
EN 1.4429 X2 Cr Ni Mo 17-13-3 (316LN) • µ r < 1.005 • N2 enriched → Hardness 150 / 190 HB • refined by electro slag process • forged in bars • stands baking 2h at 950° C • difficult to procure	• CF flanges • cavity flange

Verify the real chemical composition !
Standards have a wide range

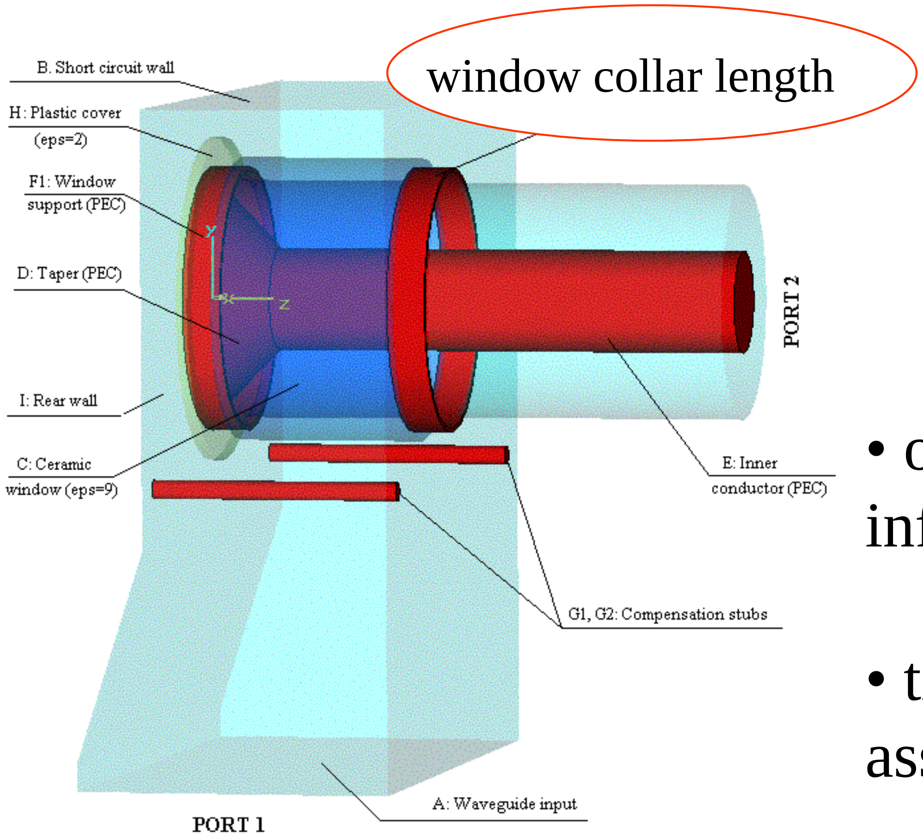
European standard: EN 10088

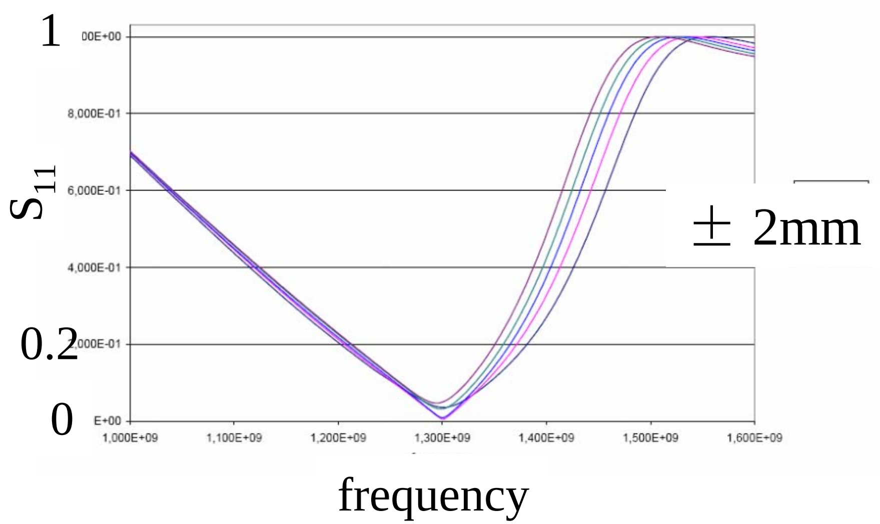


Delong model: Equivalent Chrome : (Cr)eq= (%Cr) + 1,5(%Si) + (%Mo) + 0,5(%Nb)
Equivalent Nickel : (Ni)eq= (%Ni) + 0,5(%Mn) + 30(%C) + 30(%N)

Fabrication issues, mechanical tolerances

TTF3 WG to coax transition





- one detail might not have a big influence, but they might add up

- tight tolerances at welding assemblies requires great care

low tolerances = high costs

A. Labance

Fabrication issues, copper plating

challenges:

- high electrical conductance for low RF losses
- small thickness-low thermal conductance for low static losses
- good uniformity of thickness especially on bellows
- no blisters or stripping
- low surface roughness

Fabricating issues, brazing

- ‘Microwave tube industry prefers to braze fixtures and self- fixtured assemblies’[CPI]
- miscellaneous parts can be brazed at one time
- metalized ceramic must be brazed to joining parts
- but:
  - protect the ceramic from evaporated metal (vacuum brazing)
  - avoid brazes with a high vapor pressure

Fabricating issues, TiN coating

- Al_2O_3 has a high SEC:
  - coating of the surface on the vacuum side is a must
- TiN has a low SEC and is a stable composition
- deposition processes are
  - sputtering
  - evaporating
- ammonia is used to convert the Ti to TiN

Testing and conditioning

- high power coupler tests are needed for
  - acceptance test
  - preconditioning prior to the operation on cavity
- usually test stands of two couplers at RT
- interlock is needed to protect the coupler and investigate the behavior
- coupler parts have to be cleaned up to the SC-cavity standard

What is ‘RF-processing’

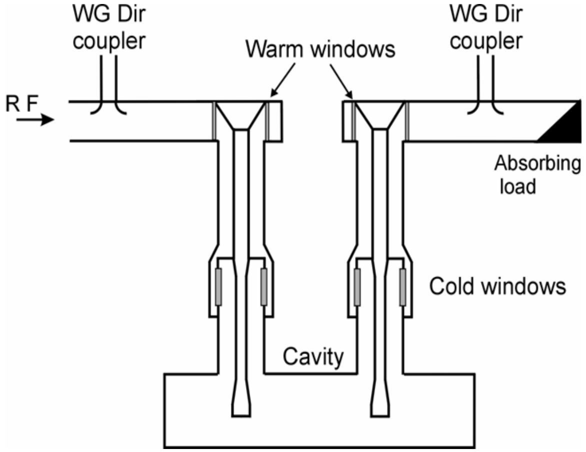
- controlled desorption of absorbed gases by accelerated ions and electrons
- compromise must be found between conditioning speed and sparking risk
- traveling wave cleans all surfaces, at standing waves additional tricks are required
- cold surfaces collect gas after certain period of operation

Interlock

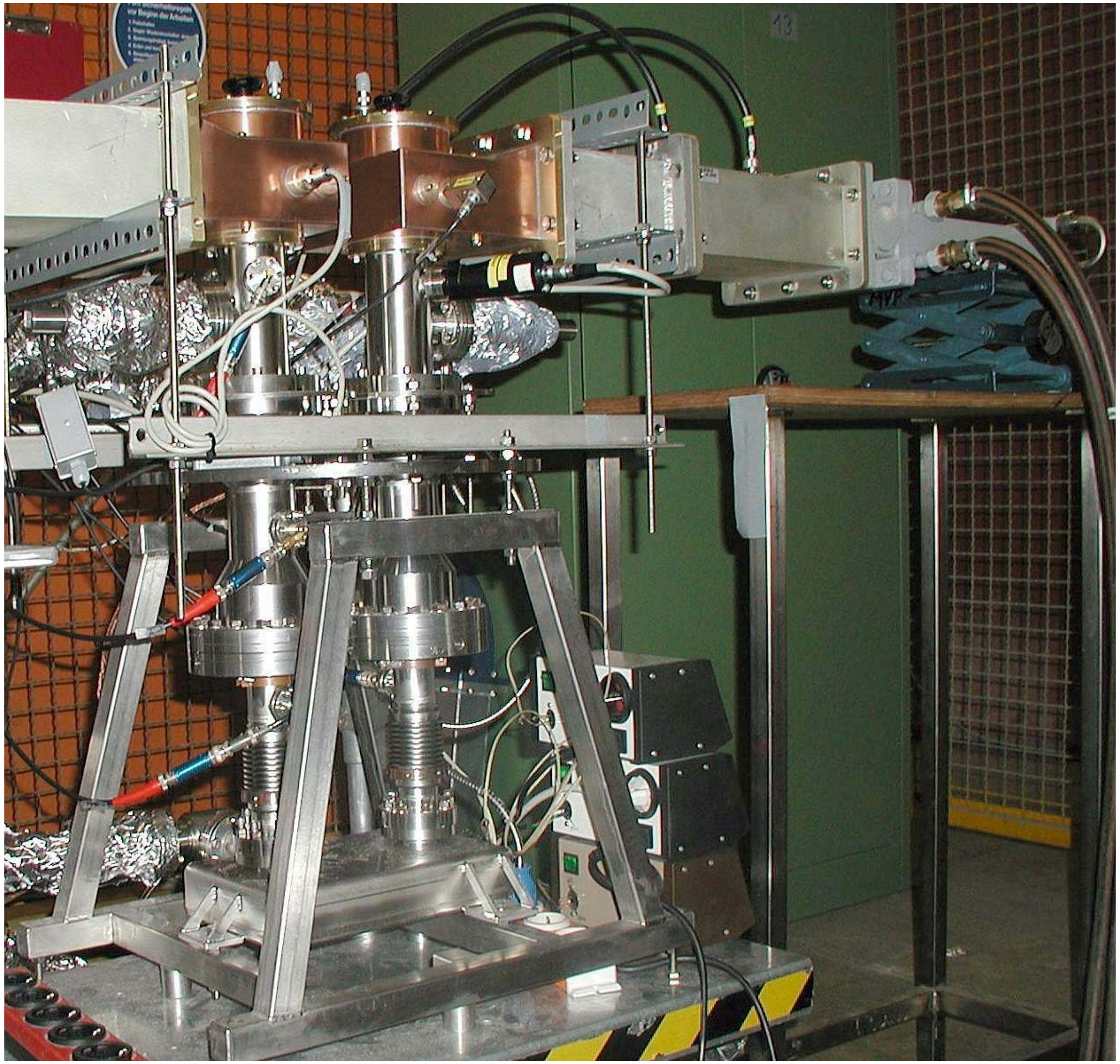
- hardware interlock:
  - vacuum read out
  - e- pick up
  - light detectors in vacuum and on the air side
  - temperature on windows
  - reflected power
- software interlock:
  - all above

TTF 3 Coupler on Test Stand

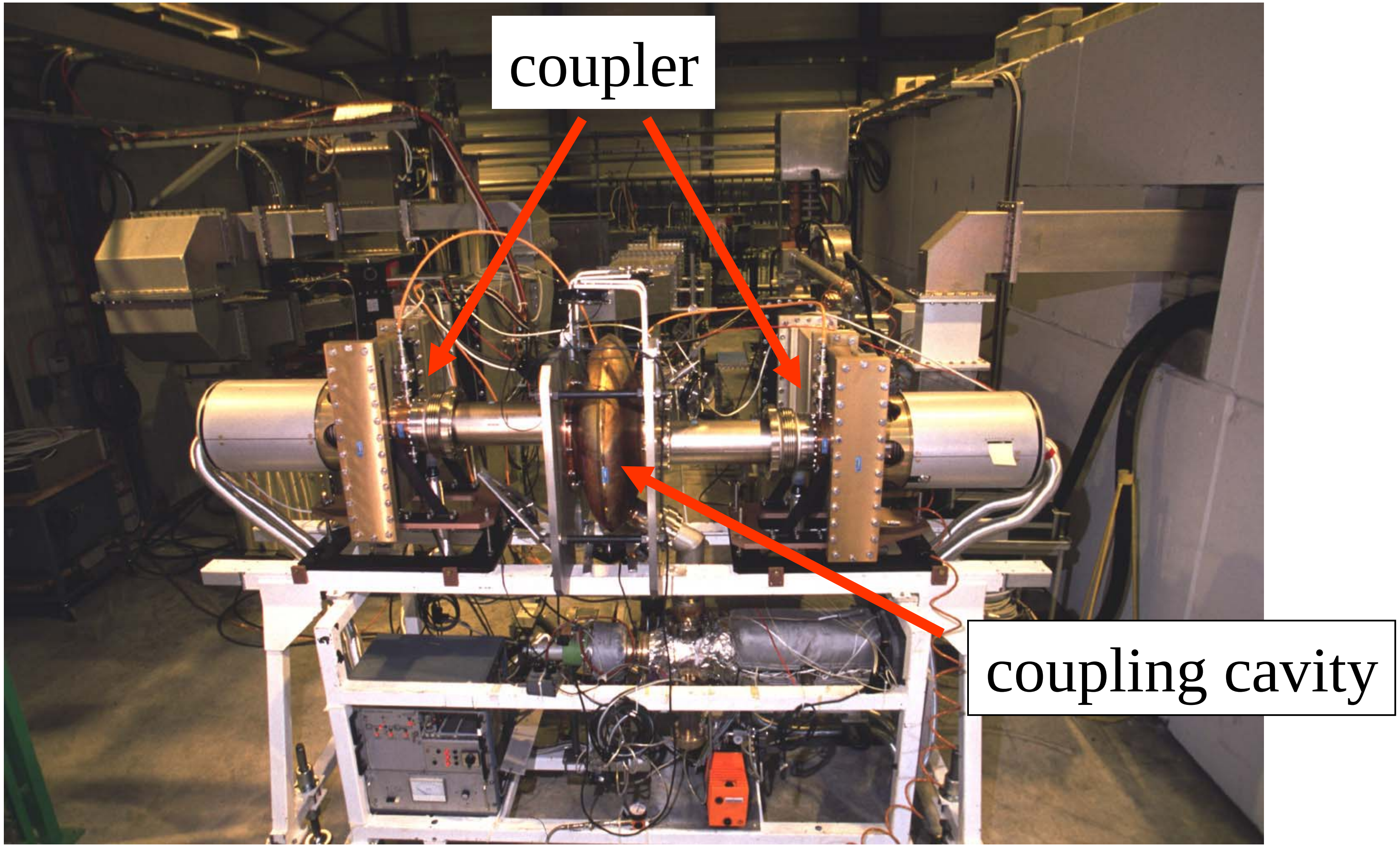
Testsstand



- two coupler
- WG coupled
- traveling wave or standing wave
- room temperature



LHC power coupler test stand



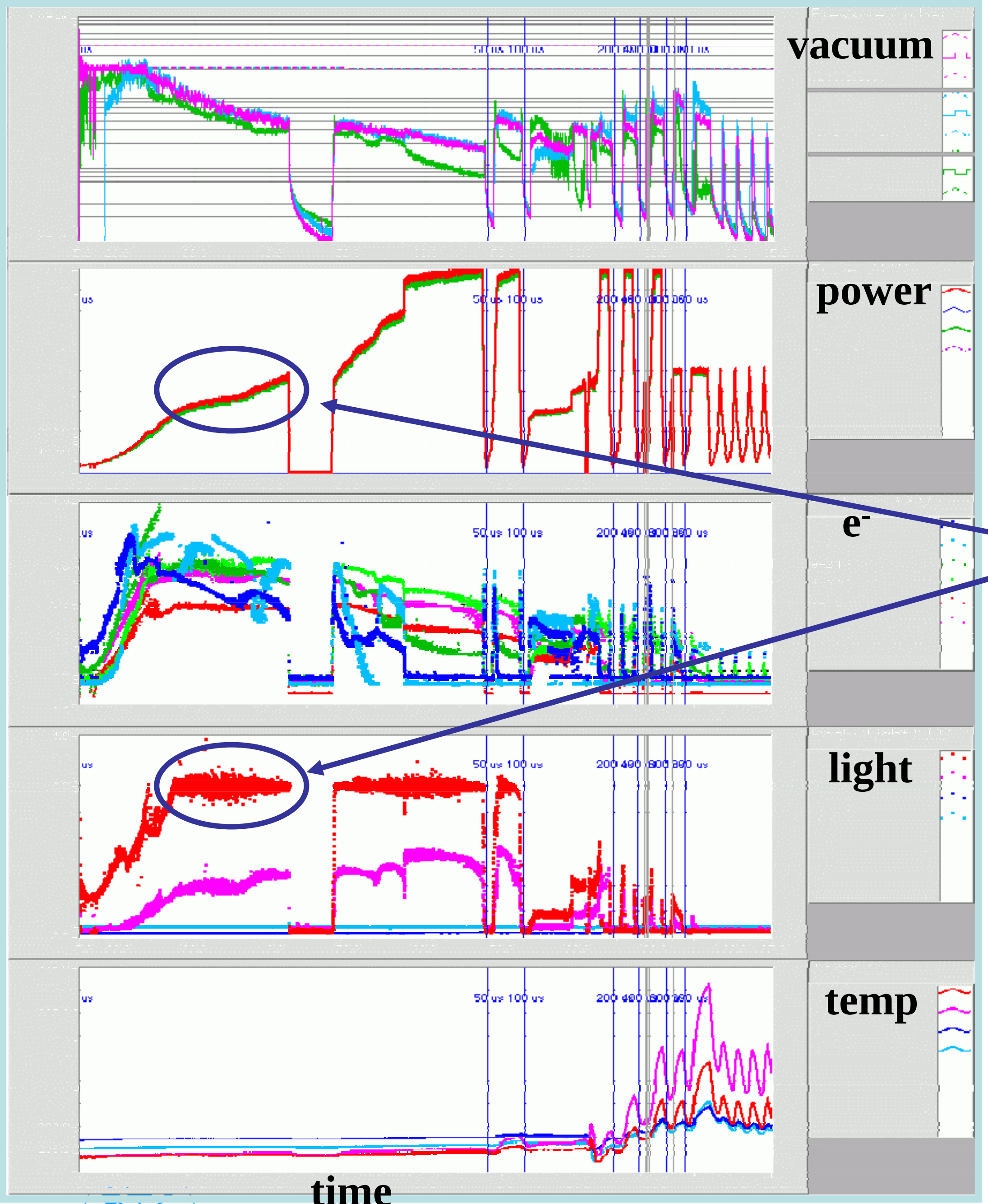
Handling before processing

- storage of all coupler parts always under dry Nitrogen
- cleaning to the sc cavity standard, UP water
- assembly in class 10 clean room
- after assembly baking of the test stand in situ

Testing and processing procedure

- low power to high power
- short to long pulses
- low to high repetition rate
- limitation of power rise by thresholds of vacuum, e-, light
- ‘analog processing’: vacuum feedback loop to keep the power level close to the thresholds developed at CERN

Typical test run for a TTF3 PC



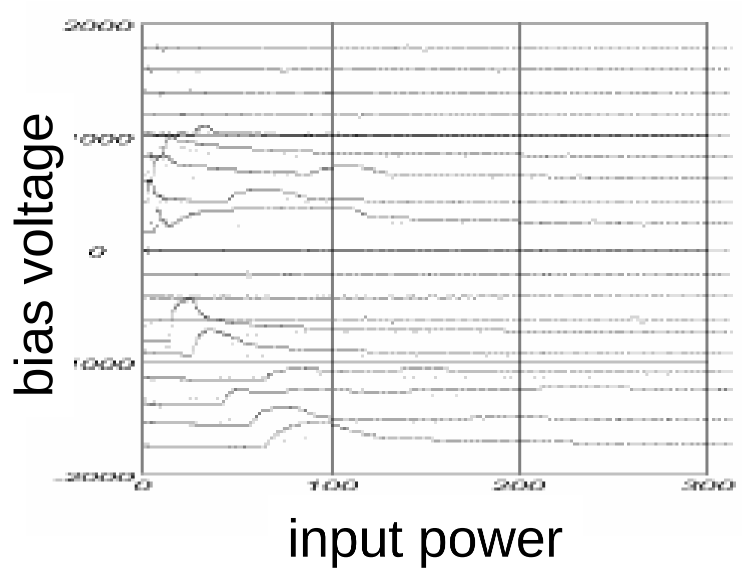
gradient of power rise limited by the light threshold

usually the first power rise (short pulse length) dominates processing time

Other processing ‘tricks’

- at KEK the bias voltage was used to process the multipacting levels at standing wave
- controlled discharge processing with Argon or Helium

pressure increase in coupler at different bias voltage levels



Handling after processing

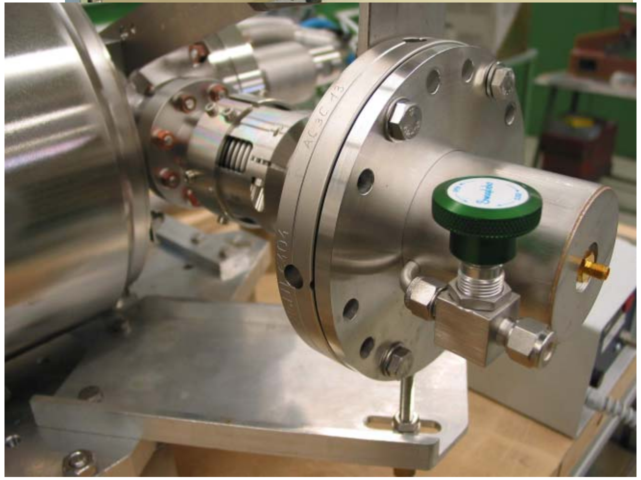
goal is to maintain the processing effect

dry N_2 cabinet

- disassembly from test stand and assembly to the cavity & module under clean conditions

- store always under dry Nitrogen to avoid contamination by water

sealing cap for cold window



Auxiliaries for the coupler

- pumping lines
- cabling and feed through
- wave guide support (takes the strong forces from the WG, caused by thermal movement)
- all has to be x-ray resistant

- assembly tools

TTF3 Coupler on module 5 in FLASH

Part II

Higher Order Modes Coupler

- dangerous modes
- Trapping and propagating of Modes
- HOM couplers
- HOM absorbers

HOM - Dangerous Modes

J. Sekutowicz, DESY, Hamburg

Two kind of phenomena can limit performance of a machine due to the beam induced HOM power:

- *Beam Instabilities and/or dilution of emittance*
- *Additional cryogenic power and/or overheating of HOM couplers output lines*

Beam instabilities and/or dilution of emittance

Transverse modes (dipoles) causing emittance growth+ monopoles causing energy spread
This is mainly problem

***in linacs**: TESLA or ILC, CEBAF, European XFEL, linacs driving FELs.*

Additional cryogenic power and/or overheating of HOM couplers output lines

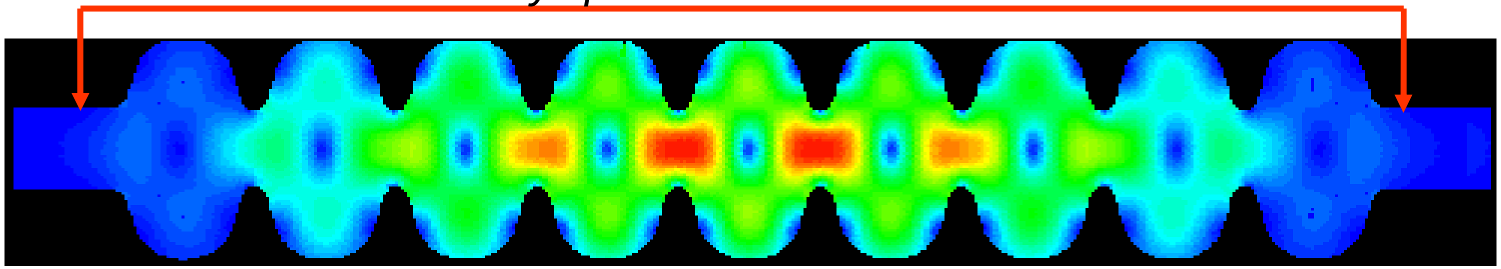
Monopoles having high impedance on axis are excited by the beam and store energy which must be coupled out of cavities, since it causes additional cryogenic load, and induces energy spread.
This is mainly a problem

***in high beam current** machines: B-Factories, Synchrotrons, Electron cooling.*

Trapping of Modes within Cavities, 1st

HOM couplers limit RF-performance of sc cavities when they are placed on cells

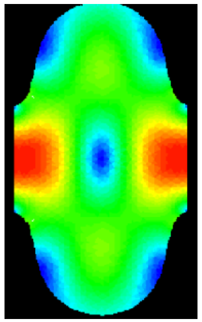
no E-H fields at HOM couplers positions, which are always placed at end beam tubes



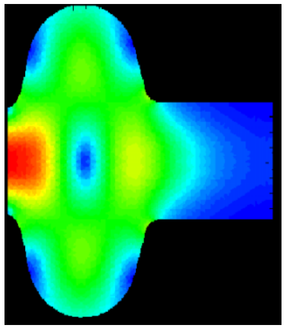
The HOM trapping mechanism is similar to the FM field profile unflatness mechanism:

- *weak coupling HOM cell-to-cell,* $k_{cc,HOM}$
- *difference in HOM frequency of end-cell and inner-cell*

f = 2385 MHz



That is why they hardly resonate together



f = 2415 MHz

J. Sekutowicz, DESY, Hamburg

Trapping of Modes within Cavities, 2nd

1) open both irises of inner cells and end-cells (bigger $\boldsymbol{k_{cc,HOM}}$*) and keep shape of end cells similar*

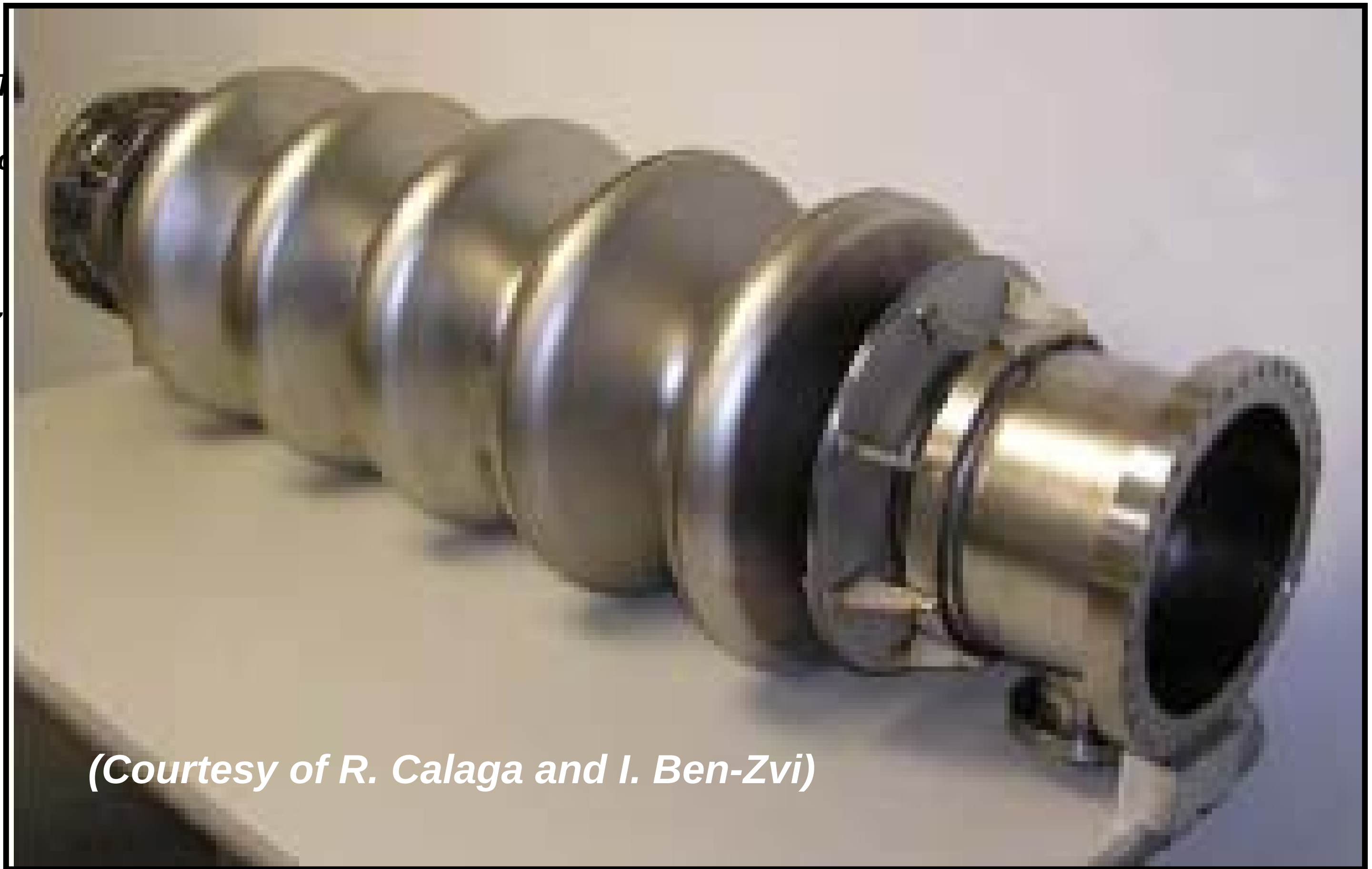
Example:

RHIC 5-cell cavity

Monopole mode $\boldsymbol{k_{c}}$

$\boldsymbol{f_{HOM}}$ *= 1394 MHz*

$\boldsymbol{f_{HOM}}$ *= 1403 MHz*



(Courtesy of R. Calaga and I. Ben-Zvi)

The method causes (R/Q) reduction of fundamental mode, which in this application is less relevant.

J. Sekutowicz, DESY, Hamburg

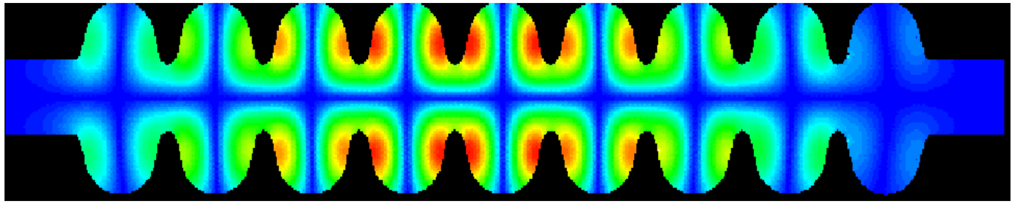
Trapping of Modes within Cavities, 3rd

2) tailor end-cells to equalize HOM frequencies of inner- and end-cells

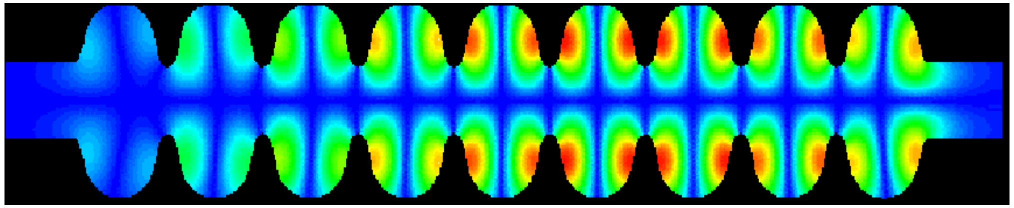
Example:

*TESLA 9-cell cavity, which has **two different end-cells (asymmetric cavity)***

The lowest mode in the passband $\boldsymbol{f_{HOM}}$ = 2382 MHz



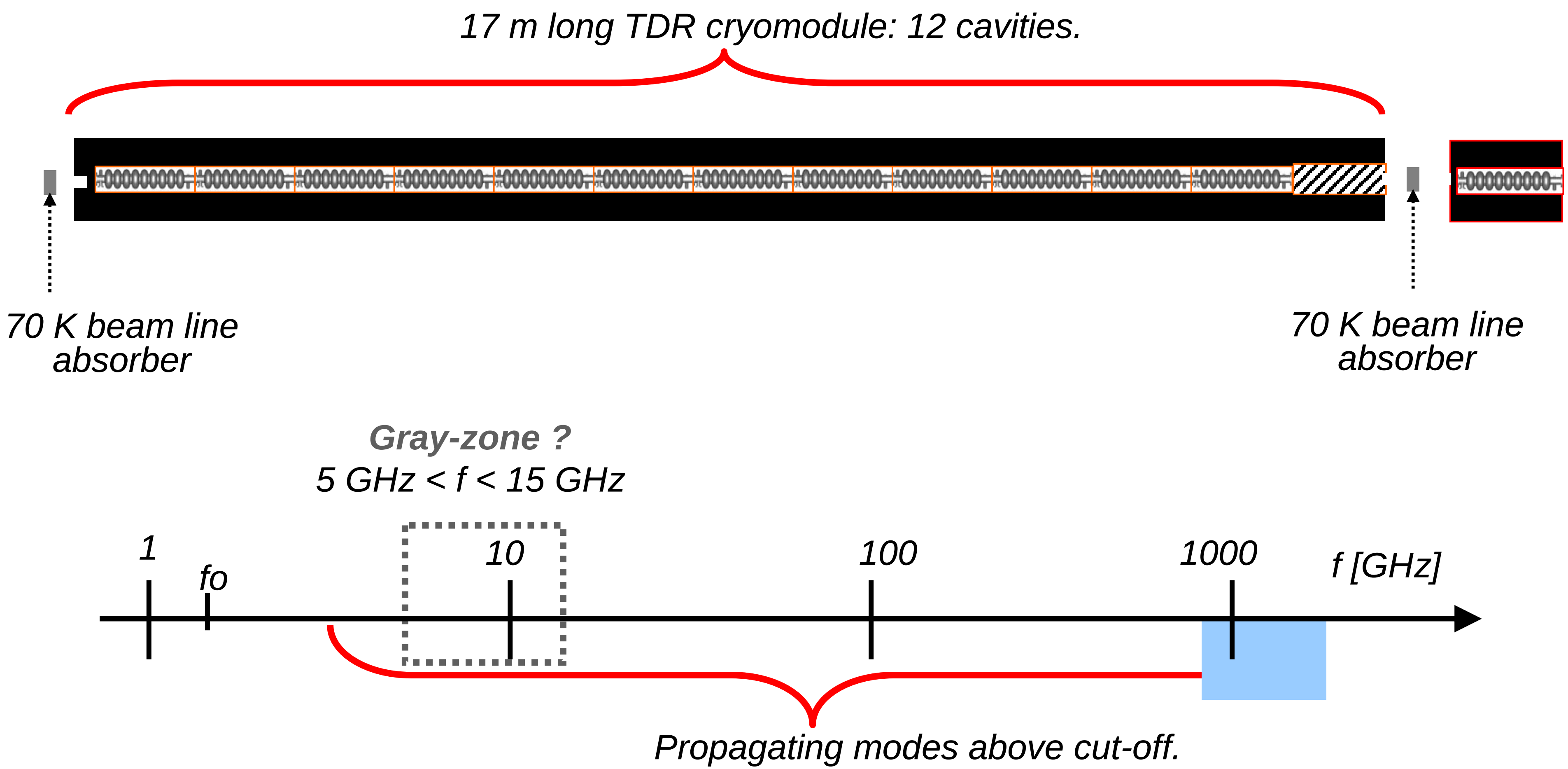
The highest mode in the passband $\boldsymbol{f_{HOM}}$ = 2458 MHz



The method works for very few modes but keeps the (R/Q) value high for the fundamental mode.

J. Sekutowicz, DESY, Hamburg

Propagating Modes and Trapping between Cavities, 1st

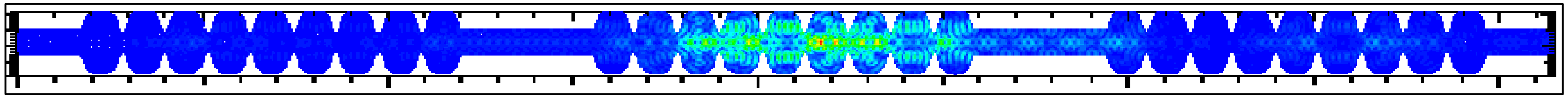


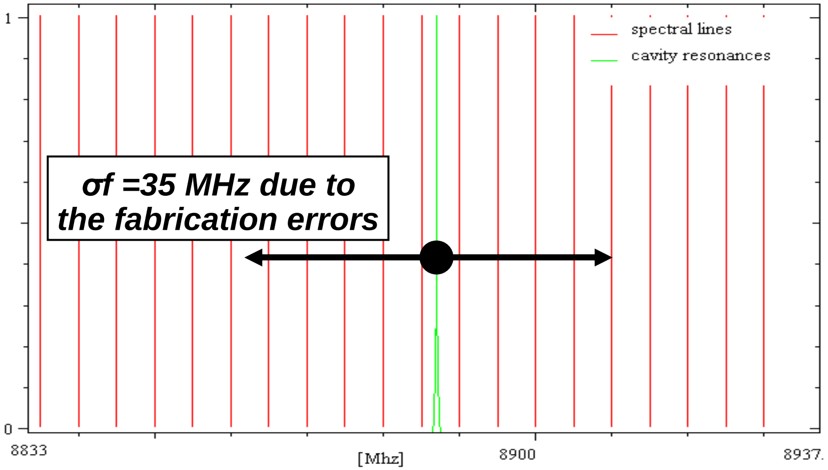
Propagating Modes and Trapping between Cavities, 2nd

Do all these modes propagate towards the absorbers ? => NO

*We look at string of 3 cavities with **$\sigma f/f$ = 4•10^{-3}** HOM frequency spread.*
There are modes trapped due to differences in HOM frequencies of neighboring cavities.

Example: *Monopole mode #794 (R/Q)= 4 **Ω** , **f = 8.878 GHz***
*Intrinsic Q_o is ~ 10^9, **Q_{ext} can be very high, no damping***





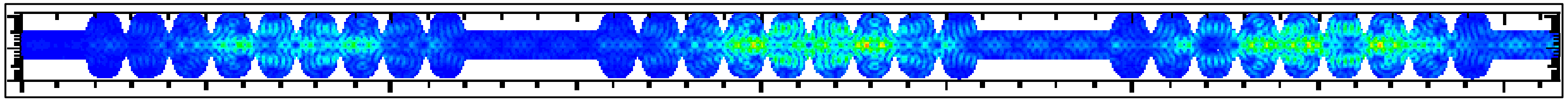
Nominal spectrum and 8.878 GHz mode

~ 1kW** peak power can be extracted from the beam if mode is excited resonantly and **Q_{ext} ~ 10^7.

***1 kW** peak power (2 x dynamic FM loss) can be dissipated at 2 K*

Propagating Modes and Trapping between Cavities, 3rd

These modes propagate when frequencies of neighboring cavities are identical (ideal case).

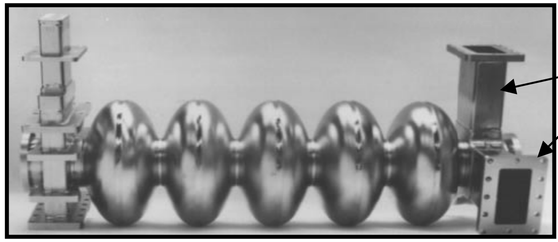


Pre-selection of cavities for each cryomodule matching them for the "gray zone" frequencies might help but identification of modes from the zone is rather difficult.

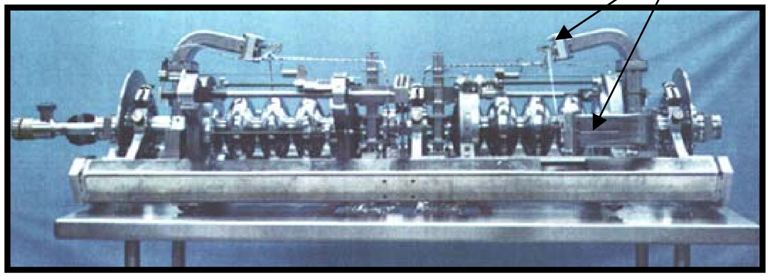
On the other hand we may limit frequency spread by tighter fabrication tolerances, but the beam dynamics experts are not very enthusiastic about it.

Wave guide HOM couplers, 1st

CEBAF/Cornell 1.5 GHz



HOM ports

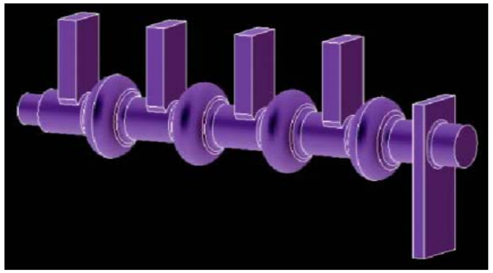


HOM loads

Design (1982) works at present in CEBAF both linacs with

I_{beam} ~ 80µAx4 @ Eacc 7 MV/m

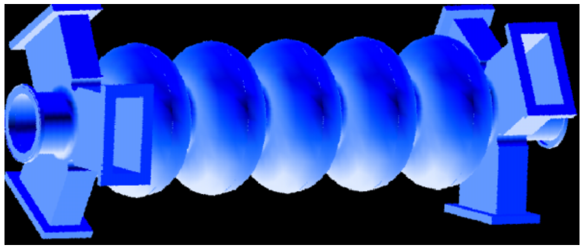
HOM power is very low. It can be dissipated inside cryomodule.



Design proposed by G. Wu (JLab)

1500 MHz for 100 mA class ERLs

LINAC2004



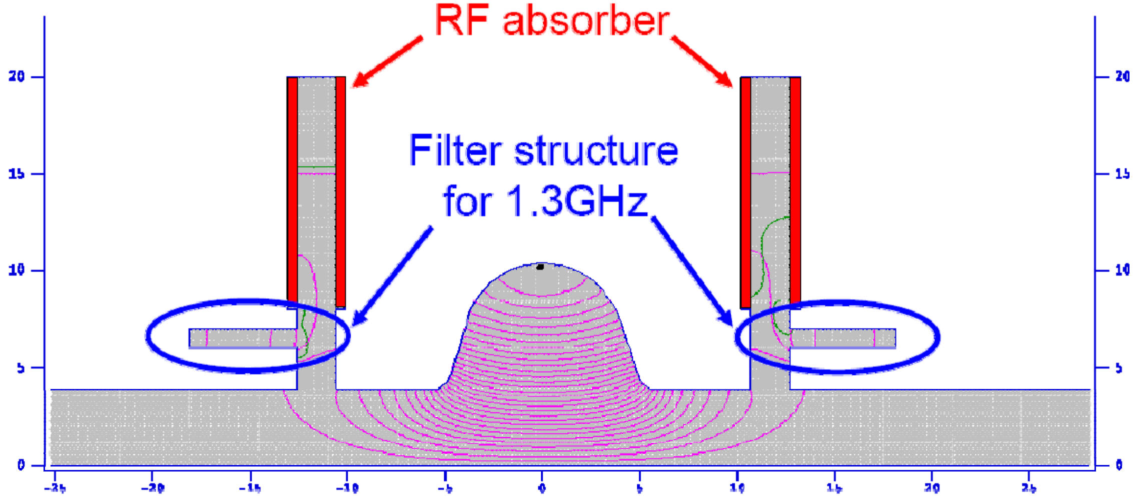
Design proposed by R. Rimmer (JLab)

750 MHz for 1A class ERLs

PAC2005

J. Sekutowicz, DESY, Hamburg

Wave guide HOM couplers, 2nd

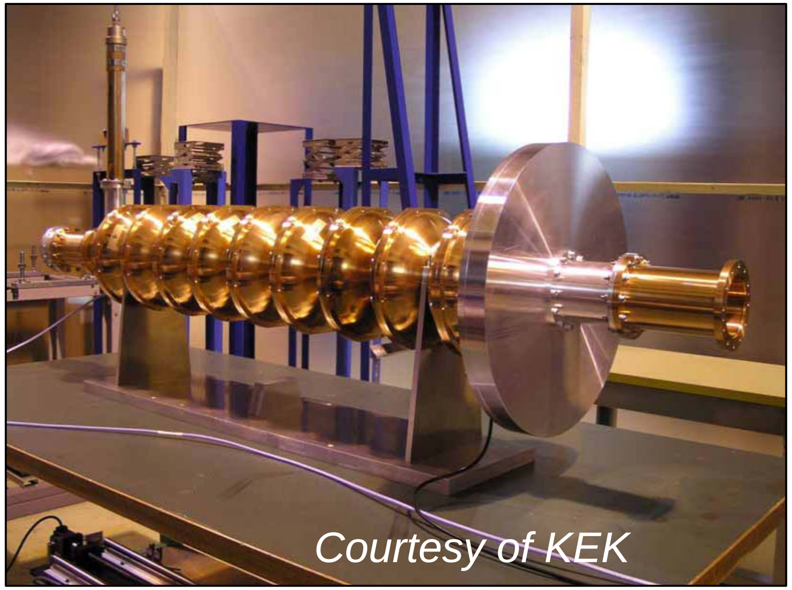


Design proposed by

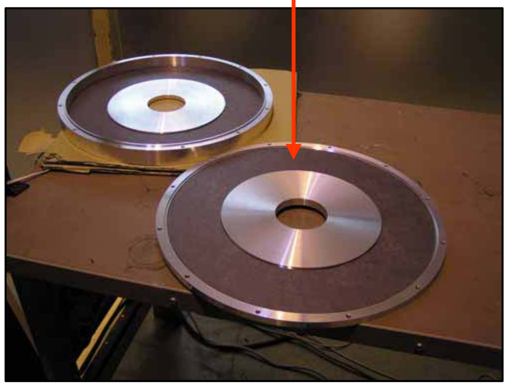
T. Shintake and continued by K. Umemori (KEK)

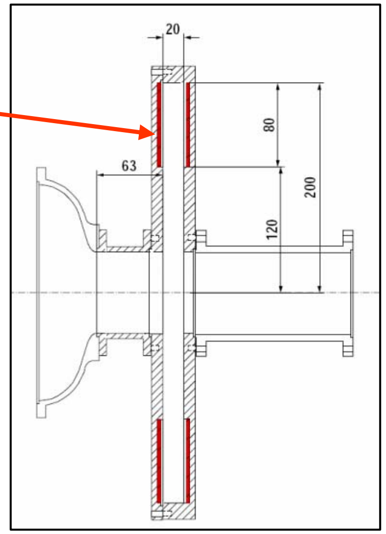
1.3 GHz TESLA cavity, very good damping.

Proceedings ERL2005



RF absorber





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Coaxial line HOM couplers, 1st

HERA 0.5 GHz

3 couplers
P_{HOM} ~ 100W

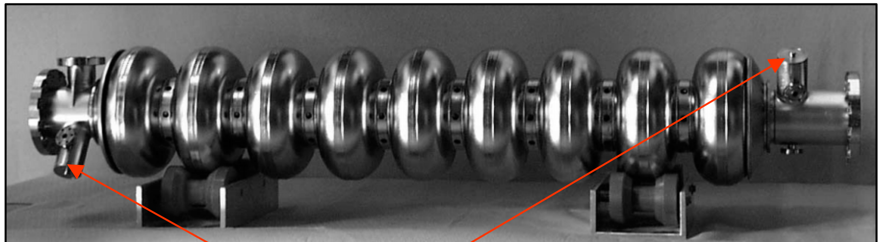
Design (1985/86), 48 work still in HERA e-ring
cw operation I_{beam} ~ 40 mA @ Eacc 2 MV/m

TM011 monopole modes with highest (R/Q)
***damped in 4-cell cavity to Qext < 900** !!*

Couplers are assembled in the LHe vessel

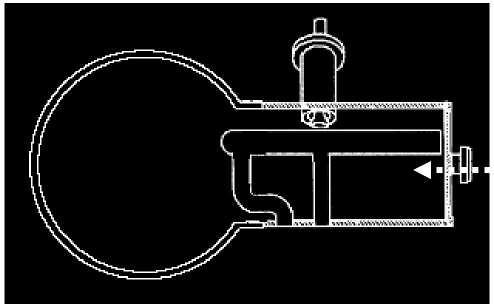
TESLA HOM coupler is a simplified version of HERA HOM couplers for pulse operation with DF of a few percent !!!!!

TESLA 1.3 GHz



2 HOM couplers
<P_{HOM}> ~ few watts

output



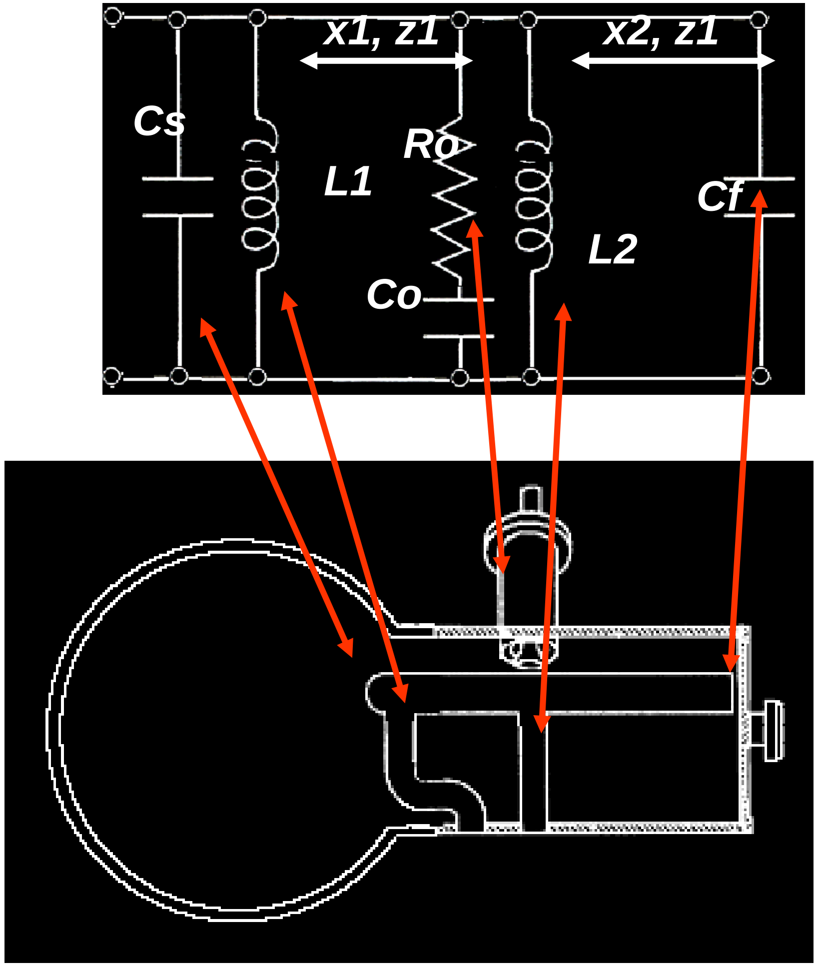
FM rejection filter

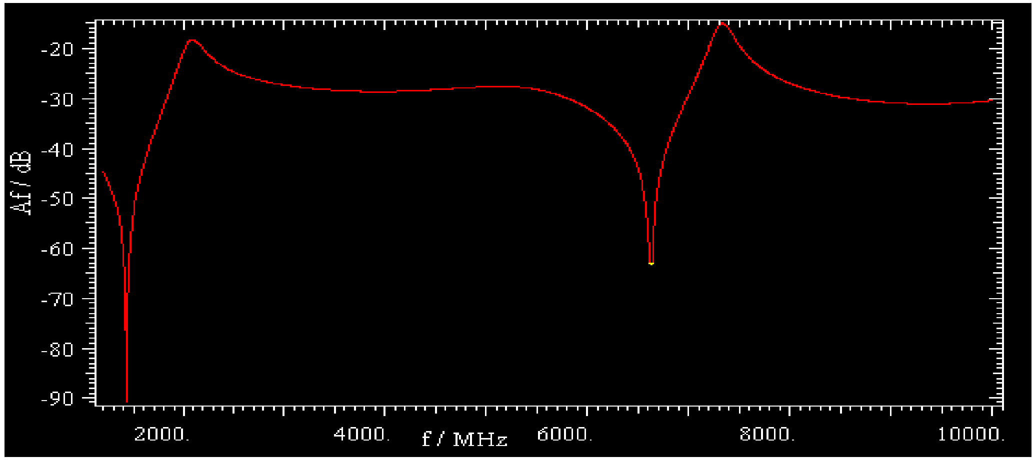
Couplers are assembled outside the LHe vessel !!

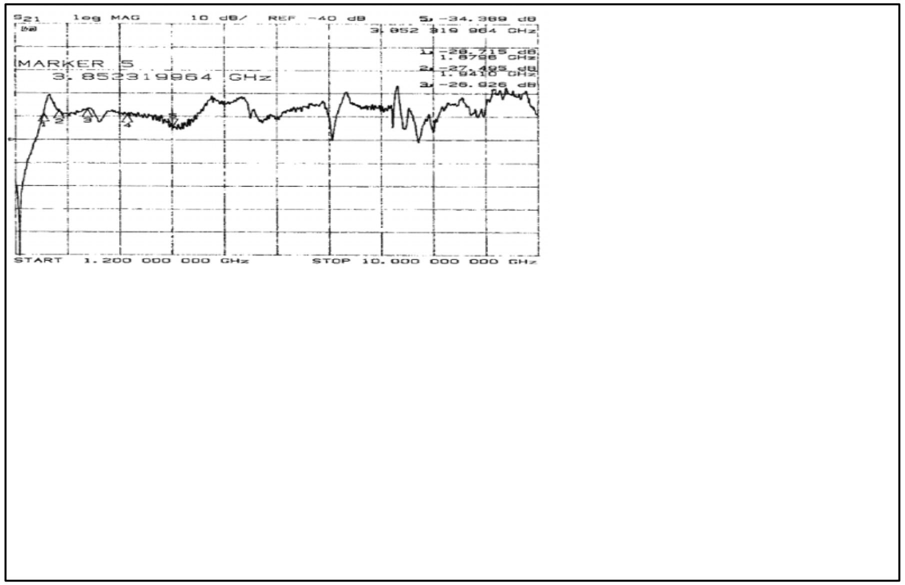
J. Sekutowicz, DESY, Hamburg

Coaxial line HOM couplers, 2nd

The TESLA –like HOM couplers are nowadays designed in frequency range: 0.8-3.9 GHz







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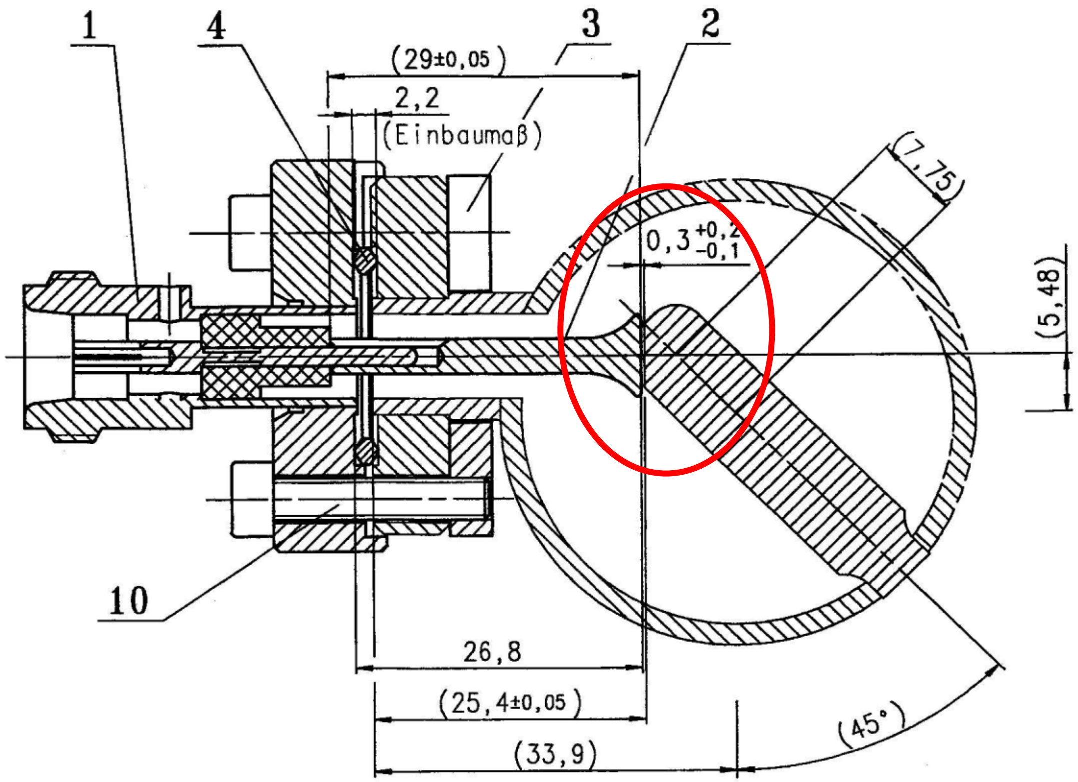
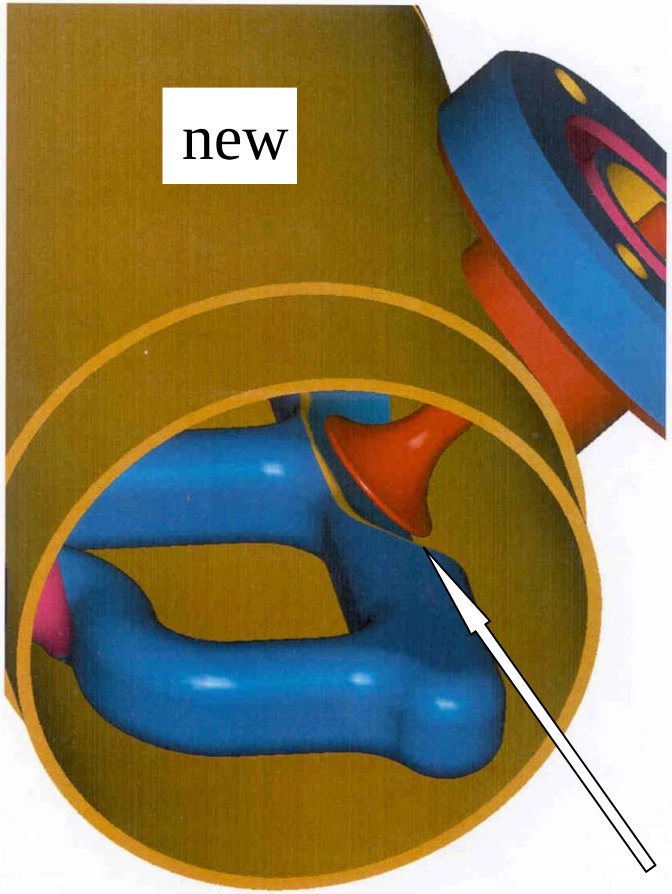
Distance on capacitor, 1st



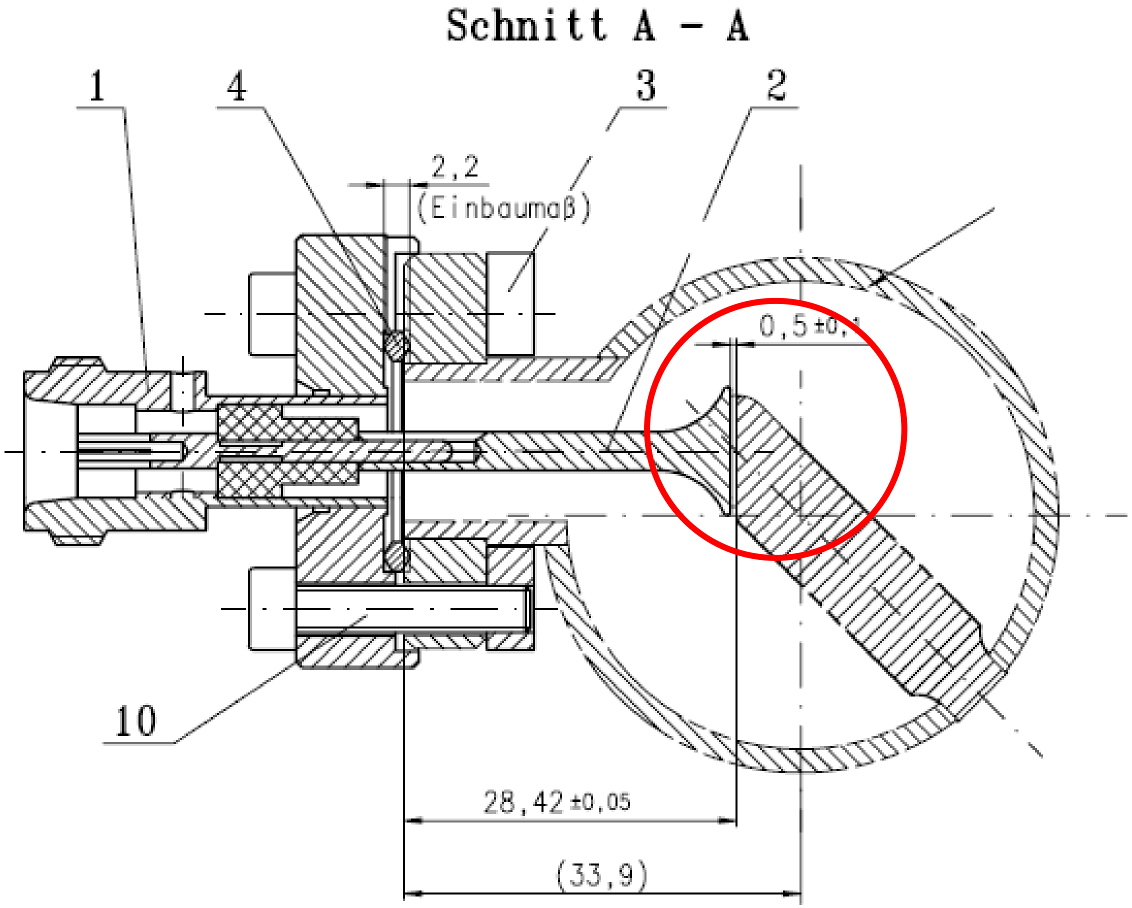
- very small distance: 0.3 mm
- hard to adjust

Distance on capacitor, 2nd



bigger capacitor surface
→ bigger distance

Distance on capacitor, 3rd



changed from

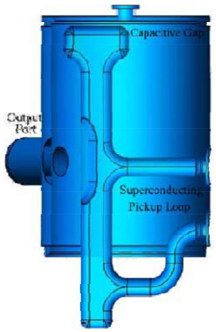
- 0.3mm
  (1st and 2nd cavity production)
- to 0.5mm
  (3rd production)

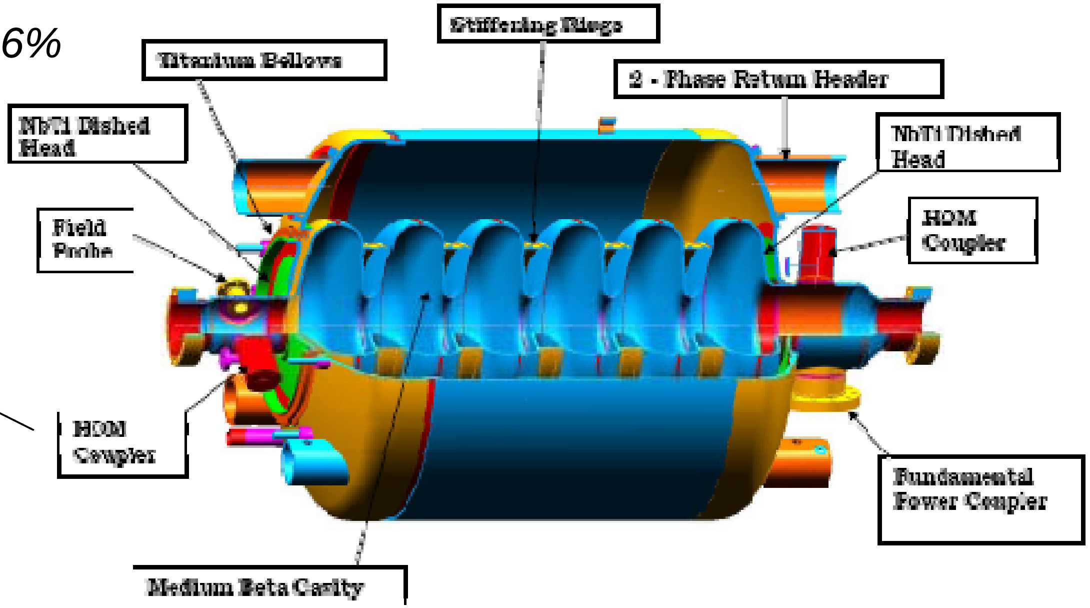
→ easier to adjust

Cooling of HOM coupler, 1st

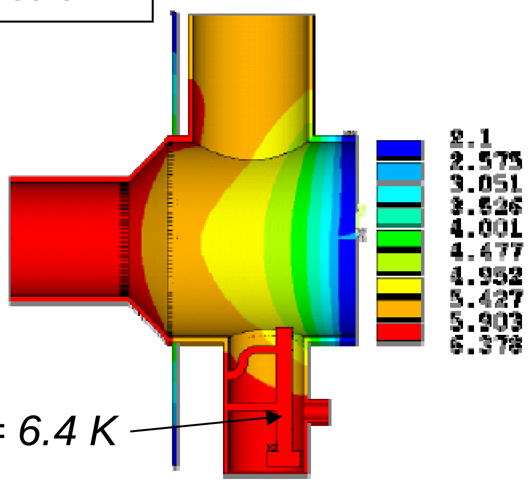
Increasing Duty Factor, one needs to improve cooling of HOM couplers.

SNS cavities: Linac DF = 6%

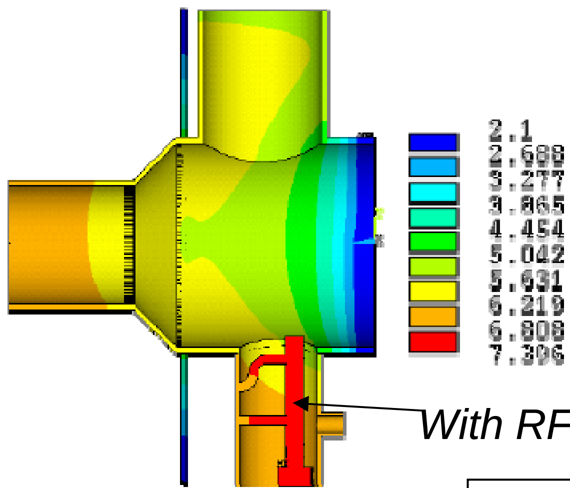




- **HOM coupler outside LHe vessel**
- **cooling by conduction**



No RF Tmax = 6.4 K



With RF Tmax = 7.4 K

(Courtesy of Oak Ridge Group: I. Campisi, Sang-Ho Kim)

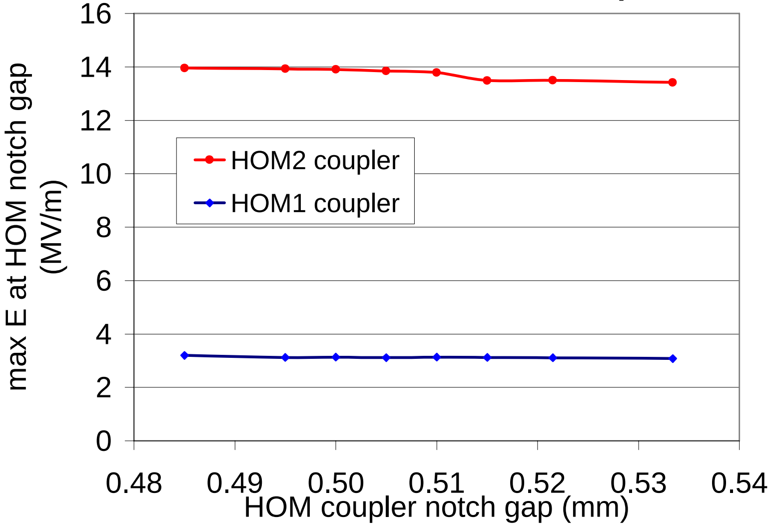
J. Sekutowicz, DESY, Hamburg

Cooling of HOM coupler, 2nd
MP simulation for SNS HOM2

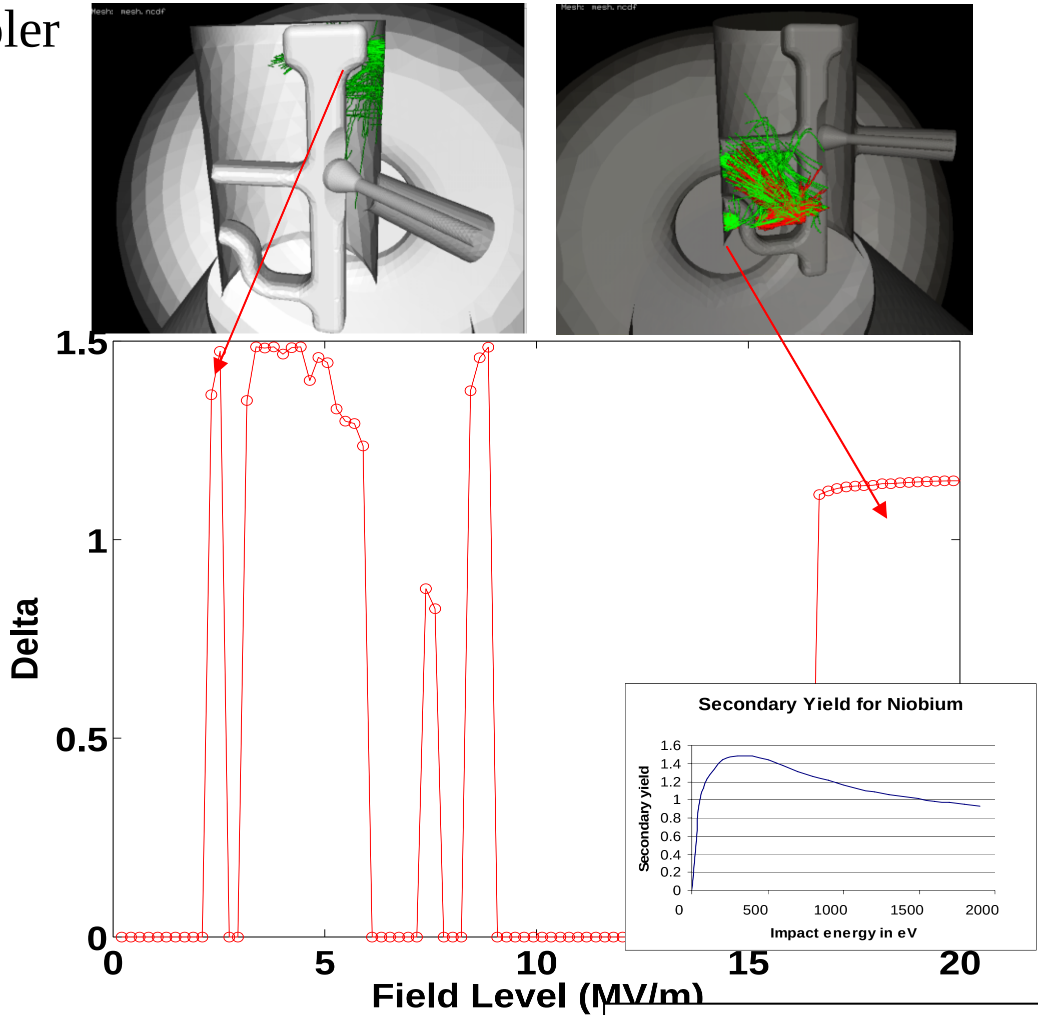
MP can lead to heating of HOM coupler

(Sang-ho Kim and et al, LINAC06-THP081)
- "Abnormal waveforms through HOM feedthrough running RF only without beam (electron loading) at 3.5 MV/m and 6 MV/m"

Field level in HOM couplers



Multipacting in HOM2



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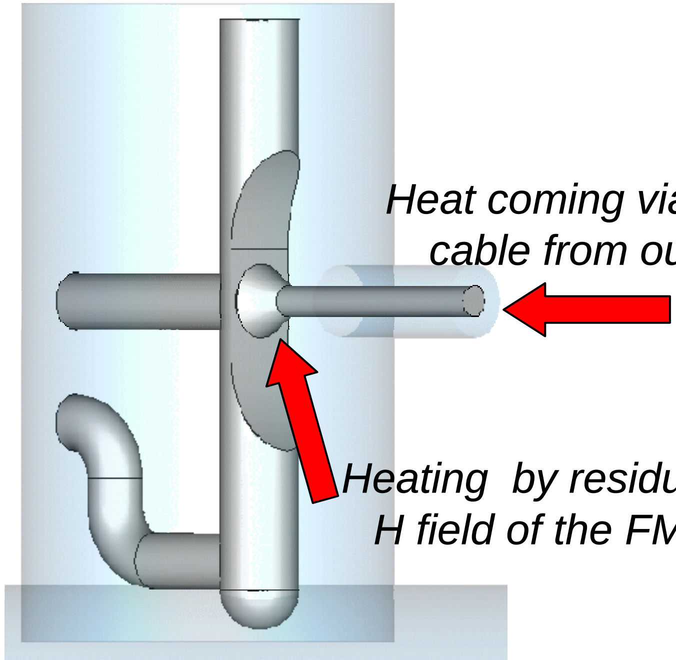
Cooling of HOM coupler, 3rd

The main problem is heating of the output line.



Nb antenna loses superconductivity,

Nb, Cu antennae will warm when the RF on

The problem looks very unimportant but following projects need a solution to it:

12-GeV CEBAF upgrade, 4 GLS Daresbury, Elbe Rossendorf, BESSY Berlin, CW upgrade of European XFEL, ERL Cornell…

Four solutions to that problem are currently under investigation

Cooling of HOM coupler, 3rd
Feed through

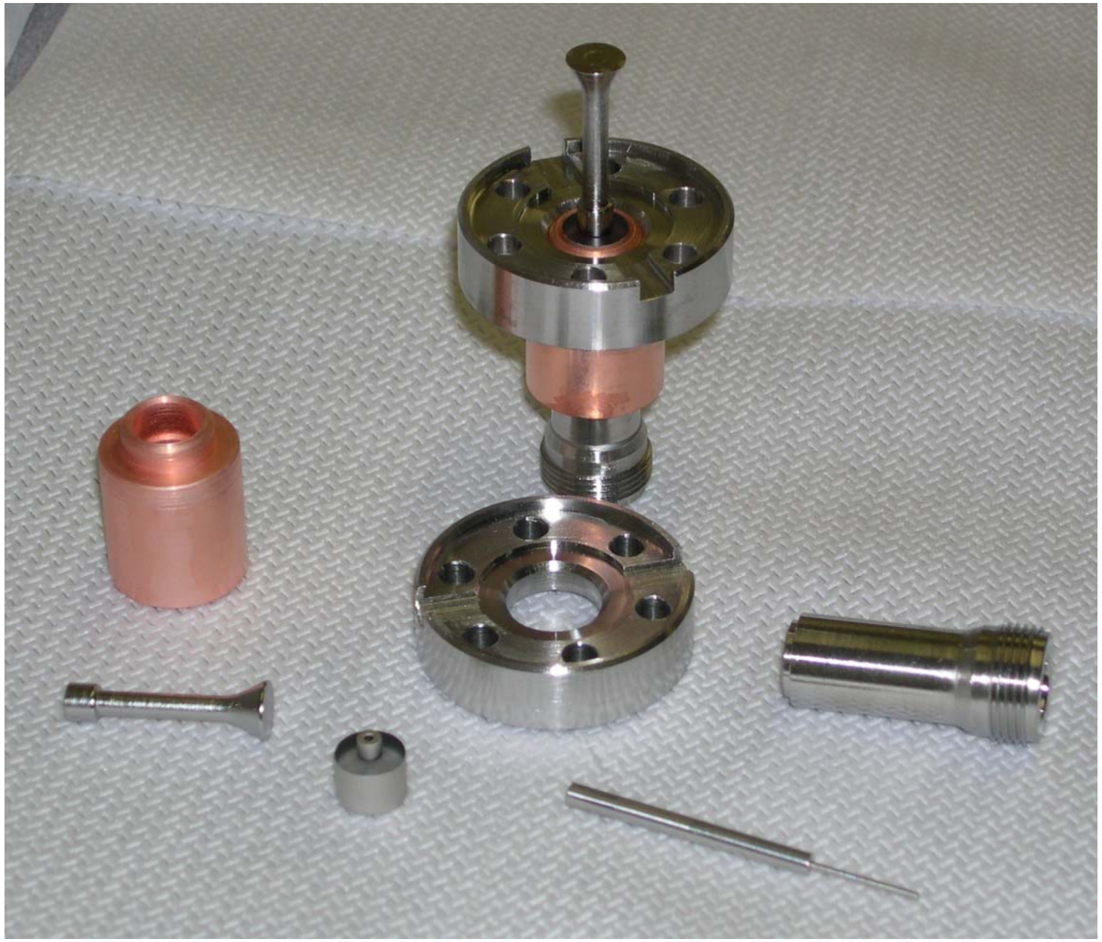
High heat conductivity feedthrough, ensuring thermal stabilization of Nb antenna below the critical temperature (9.2 K) at 20 MV/m for the cw operation.

Jefferson Lab development R&D for the 12-GeV CEBAF upgrade

- Al_2O_3 replaced by single crystal sapphire

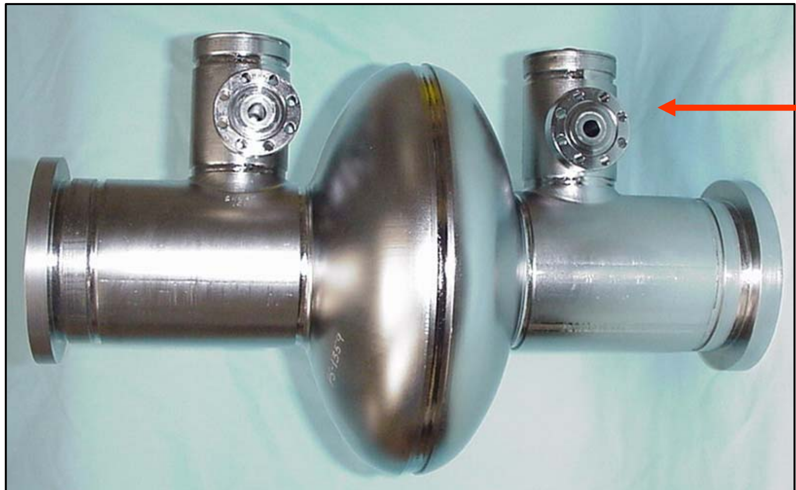
⇒ higher thermal conductivity

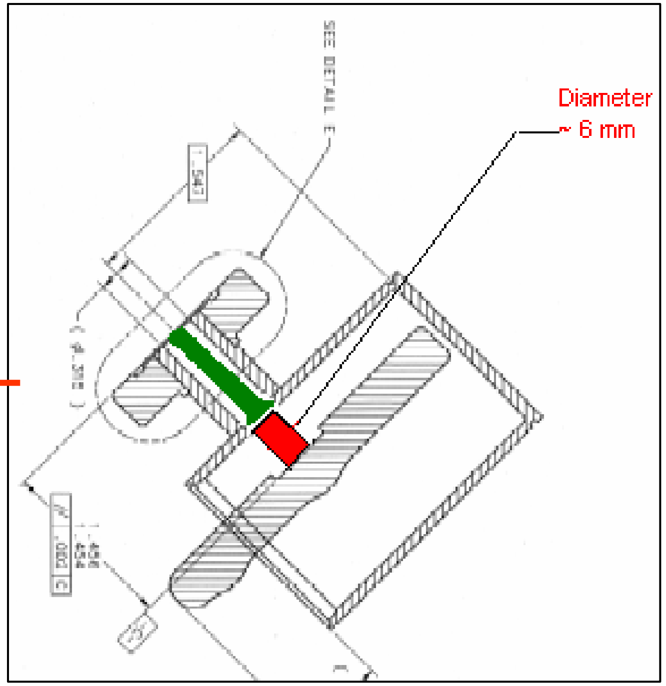
- copper interface for 2K connection



Cooling of HOM coupler, 3rd
Modified HOM Coupler Tests at JLab

- lower H field at the antenna tip
  →less thermal load, tip from Nb3Tin
- in He bath tested: 33 MV/m, cw
- no test in isolation vacuum yet

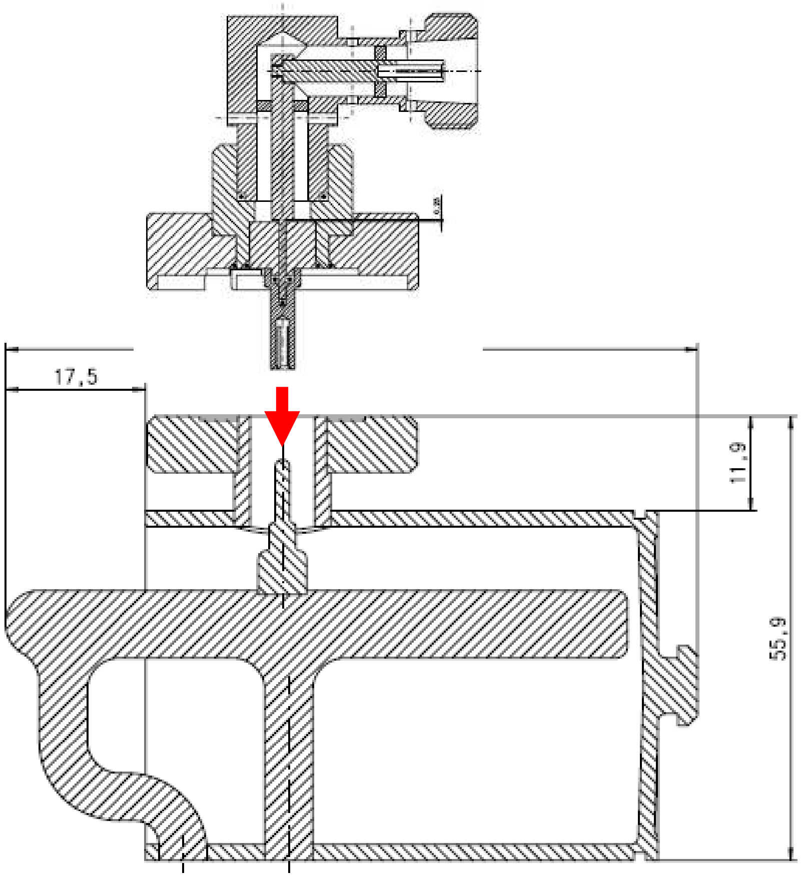




P. Kneisel, J. Sekutowicz

Cooling of HOM coupler, 4th
Modified HOM Coupler Tests at DESY

Elimination of capacitive coupling by straight connection to inner conductor



pro's:

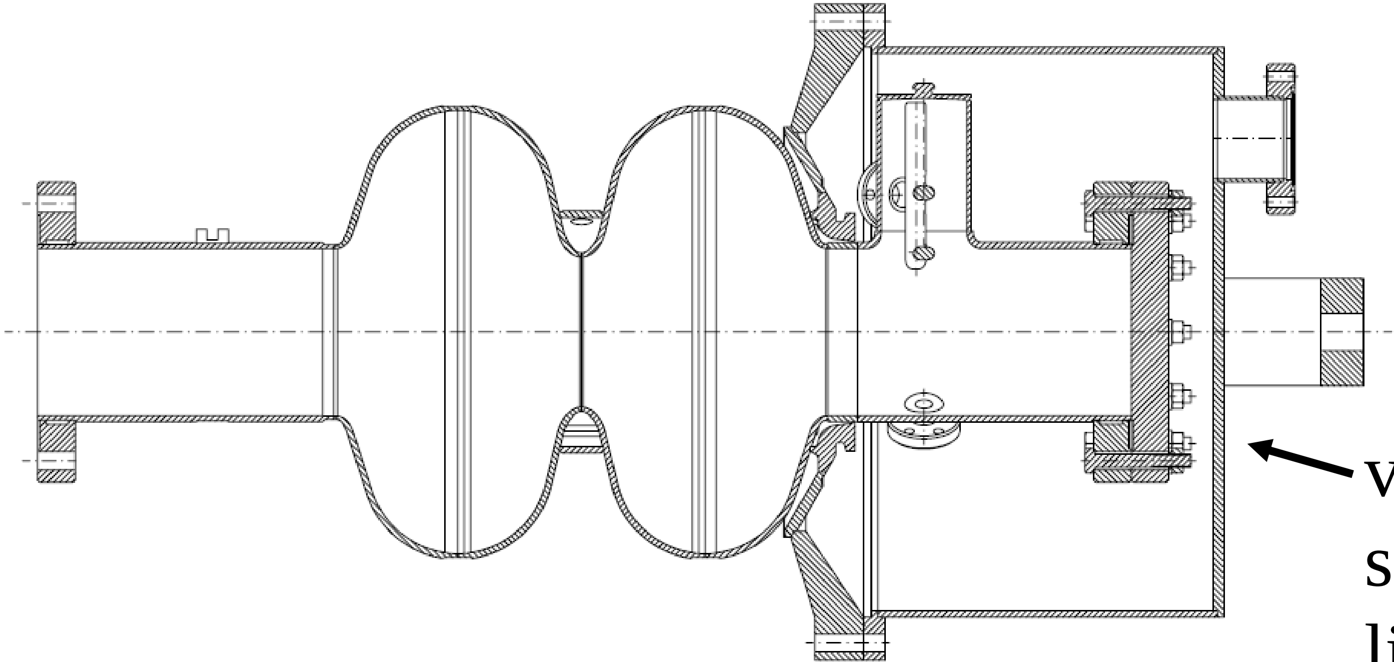
- no heating of the antenna tip
- no adjustment necessary
- simplified fabrication

con's:

- reliable contact necessary
- possible particle source

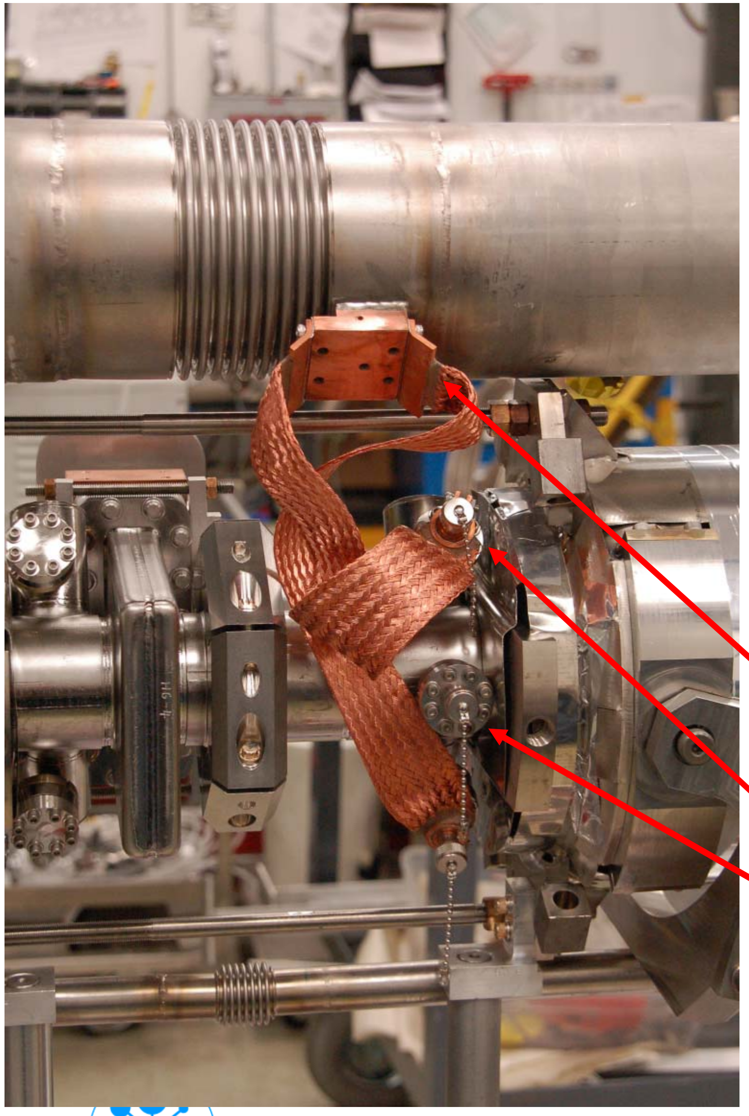
Cooling of HOM coupler, 5th
Modified HOM Coupler Tests at DESY

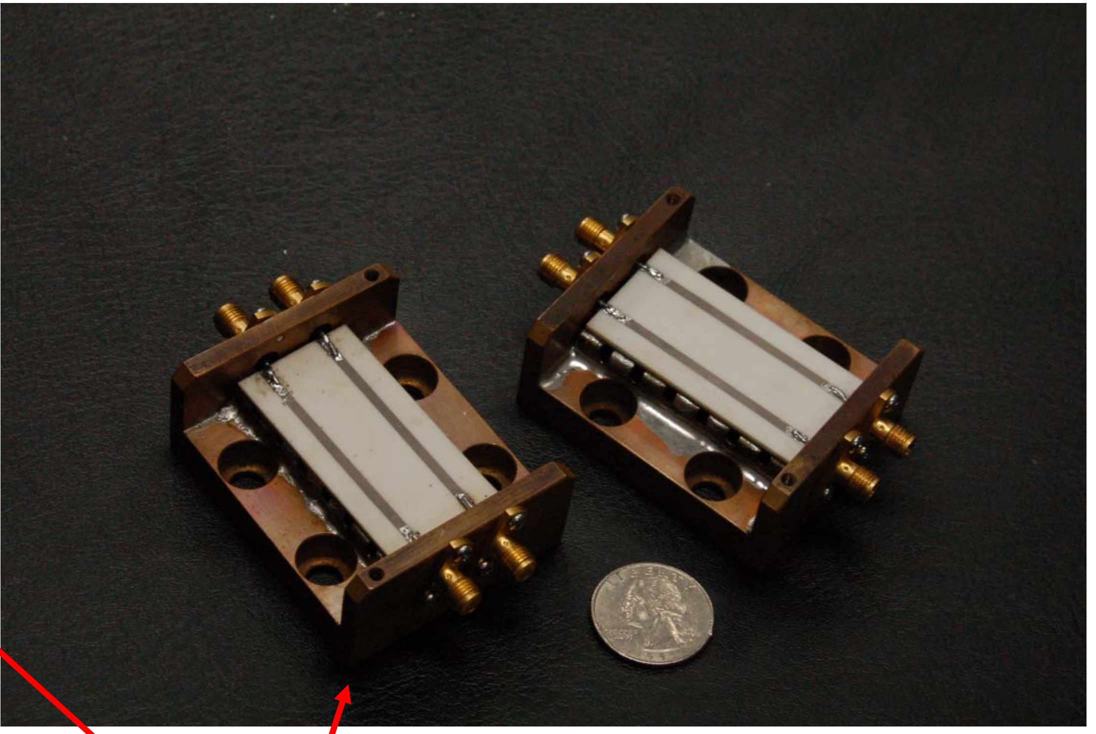
test setup for HOMC test in vertical test stand in LHe bath



vacuum cap for separation of the liquid helium in vert. test

Cooling of HOM coupler, 6st
Heat sink for RF cable



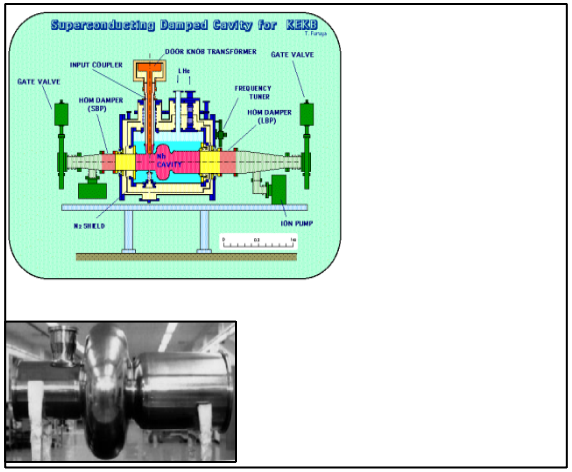


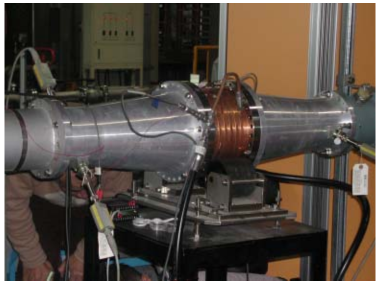
heat sink for the HOM cable at 2K He line

Feedthroughs

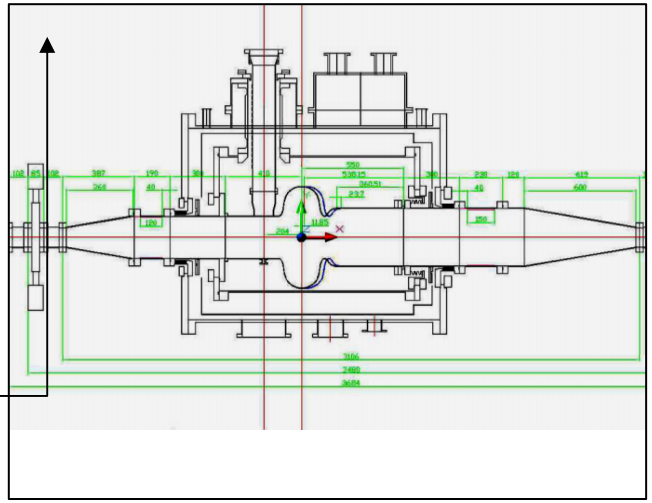
Beam line absorbers: single cell cavities

KEK-B 0.5 GHz

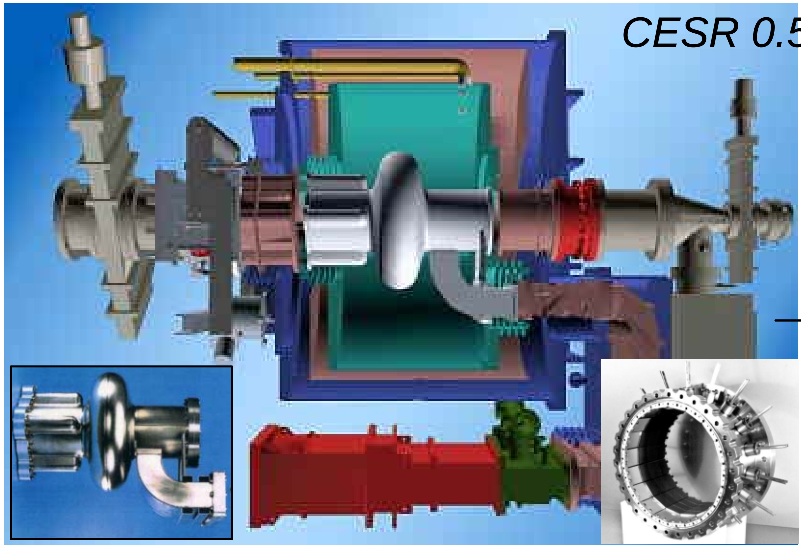




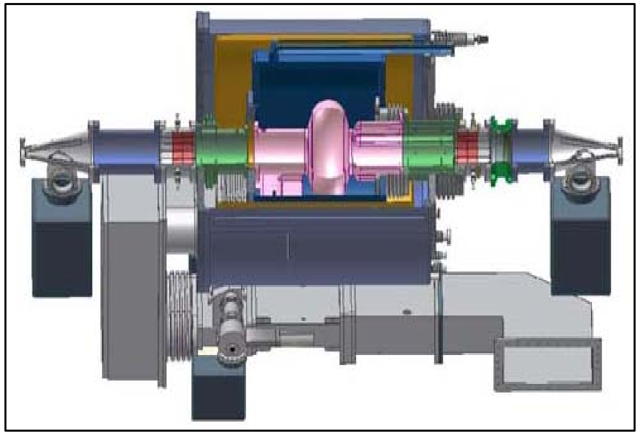
BEP-II Beijing IHEP



CESR 0.5 GHz



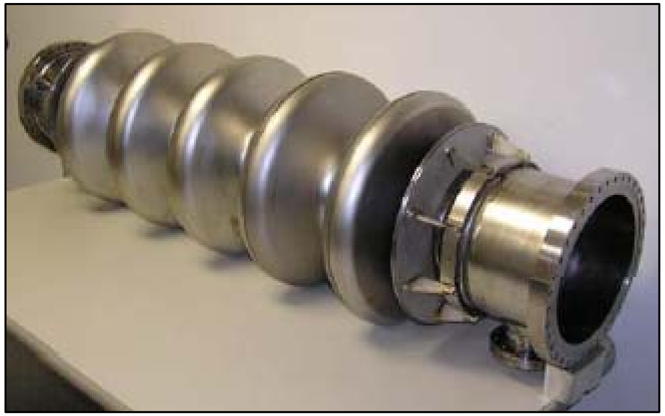
Taiwan Light Source

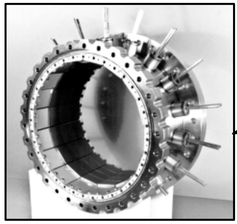


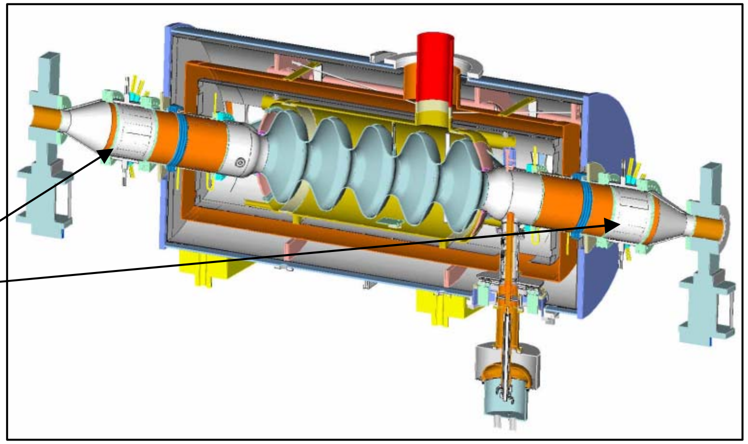
J. Sekutowicz, DESY, Hamburg

Beam line absorbers: multi cell cavities, 1st

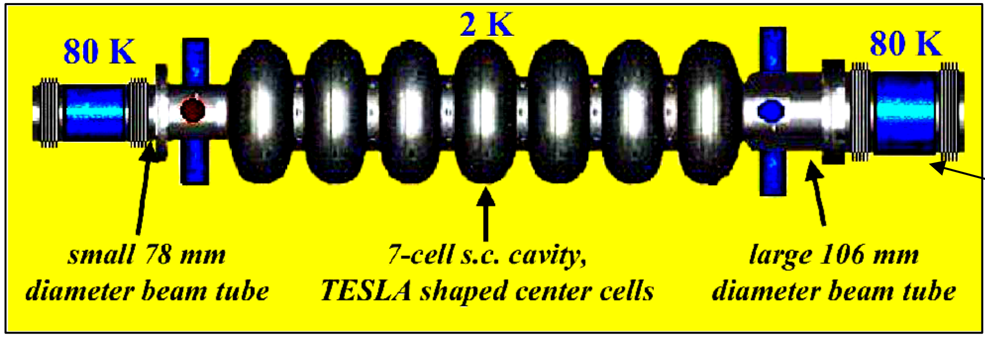
BNL e-cooling for RHIC (four 704 MHz cavities 54 MeV

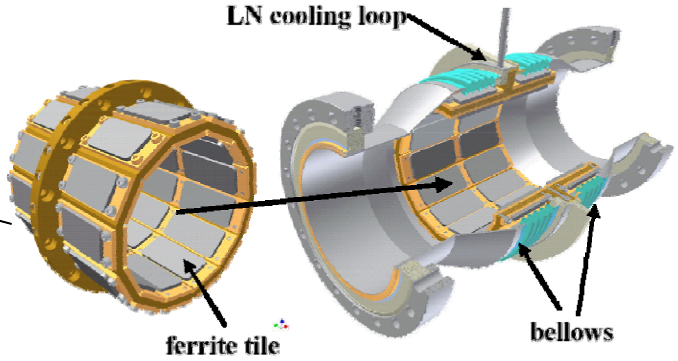






ERL-Cornell, 310 TESLA 1.3 GHz cavities with modified end cells





TESLA 6 HOM couplers/cavity + 2 Beam Line Absorbers

J. Sekutowicz, DESY, Hamburg

Beam line absorbers: multi cell cavities, 2nd

DESY: European XFEL project

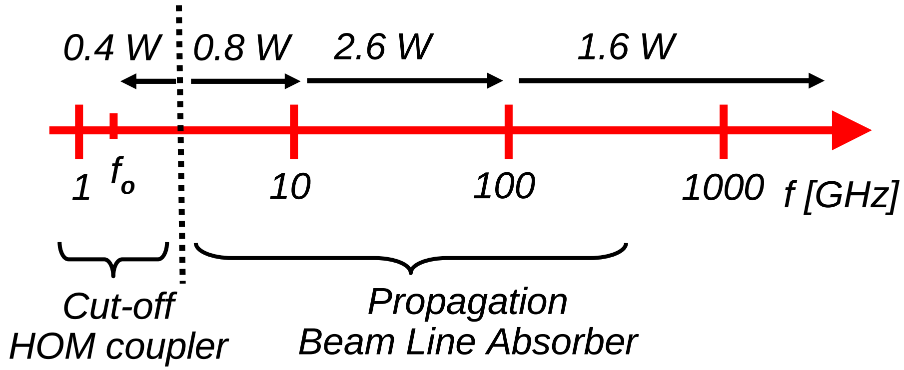
HOM power deposited by the nominal beam

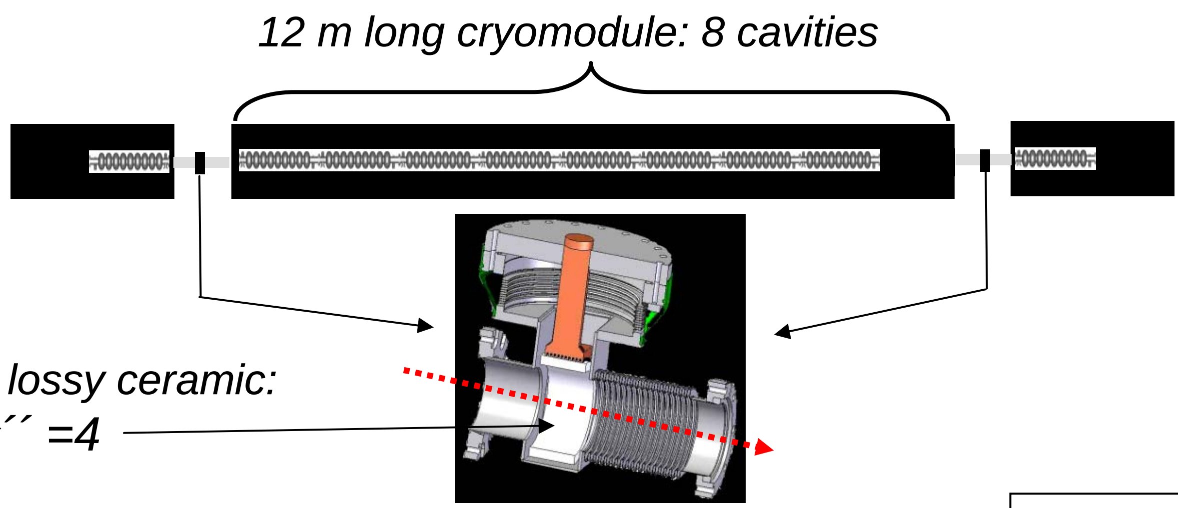
5.4 W/(8-cavity cryomodule, $k_{//}$ =135 V/pC)

Bunch: σ_z = 25 µm (rms) @ 1 nC @ t_b = 200 ns

Spectral lines separation: $\Delta f_{i,i+1}$ = 5 MHz

RF pulse repetition frequency: 10 Hz





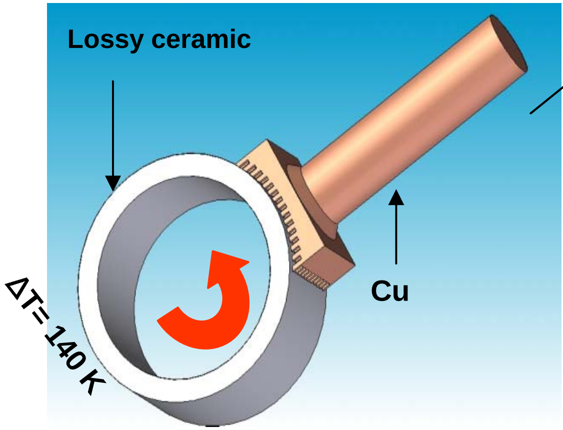
Absorbing ring made of lossy ceramic:
ε´ =15 and ε´´ =4

J. Sekutowicz, DESY, Hamburg

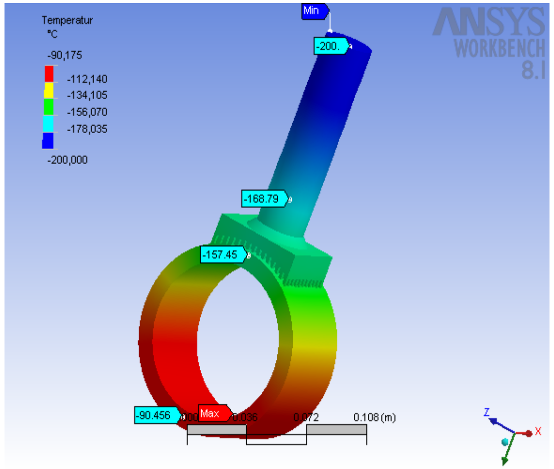
Beam line absorbers: multi cell cavities, 3rd

The thermal capability of DESY beam line absorber is 100W (it takes into account far future upgrade of the XFEL to cw or even energy recovery). For pulse operation dissipation is only 5.4 W.

Modeling:



Heat to 70 K



Performed tests:

✓ *10 x fast cool-down to 70 K*

✓ *140 k ΔT across the ceramic and stub*

✓ *several times cool-down to 4K*

- *Prototype ready in 2005*
- *Beam Test in TTF 2006:*
- *Expected absorption ~80%*

J. Sekutowicz, DESY, Hamburg

Final remark

- new powerful RF simulation codes are very helpful, but tests are still very important
- functions and procedures are well understood
- a good RF design AND a good mechanical design are both essential
- new ideas are in hand and are under investigation

Acknowledgement

Thanks to all colleagues who have contributed to this talk (also without there notice) from the different laboratories and companies:

- ACCEL, CERN, Cornell, CPI, DESY, FNAL, IN2P3/LAL, Jefferson Lab, KEK, Los Alamos, SLAC, SNS, University of Helsinki, Universität Darmstadt and many more…
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