High Power Input Couplers for Superconducting Cavities -A Tutorial-

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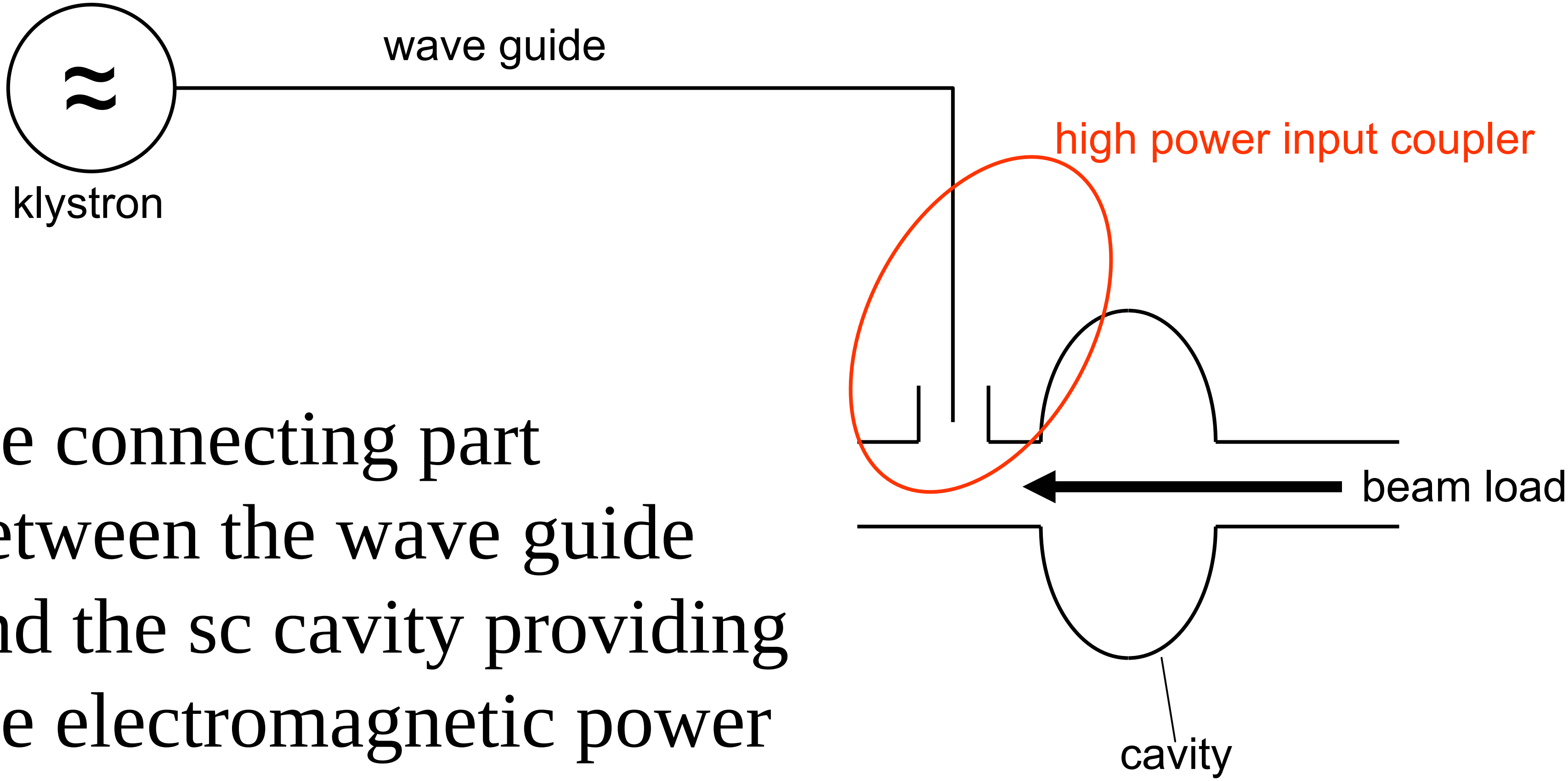
12th International workshop on RF Superconductivity

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

RF-Functions of the power coupler

- it has to transfer the power to the beam and to the cavity field at high power levels in pulsed or CW operation
- it has to match the impedance of the klystron to the beam loaded cavity
- possibly allow to change the match for different beam conditions

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 cavity
  - easy cleaning
  - clean assembly

The power coupler 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!!

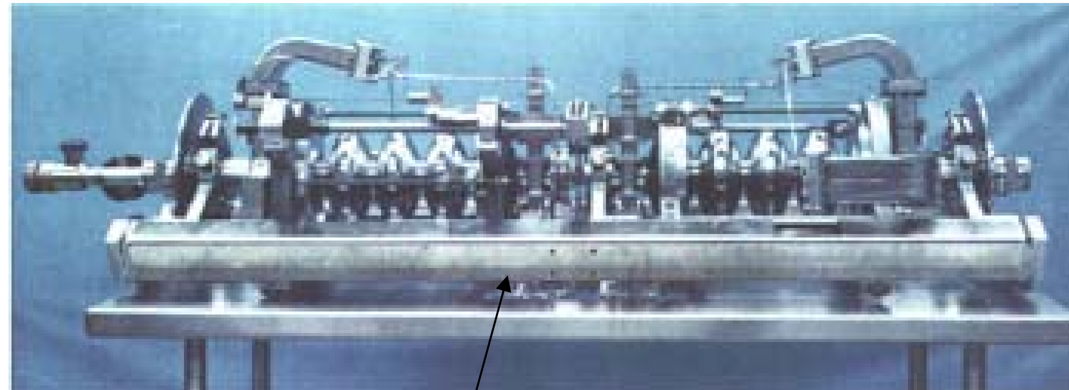
Design criteria for a power coupler

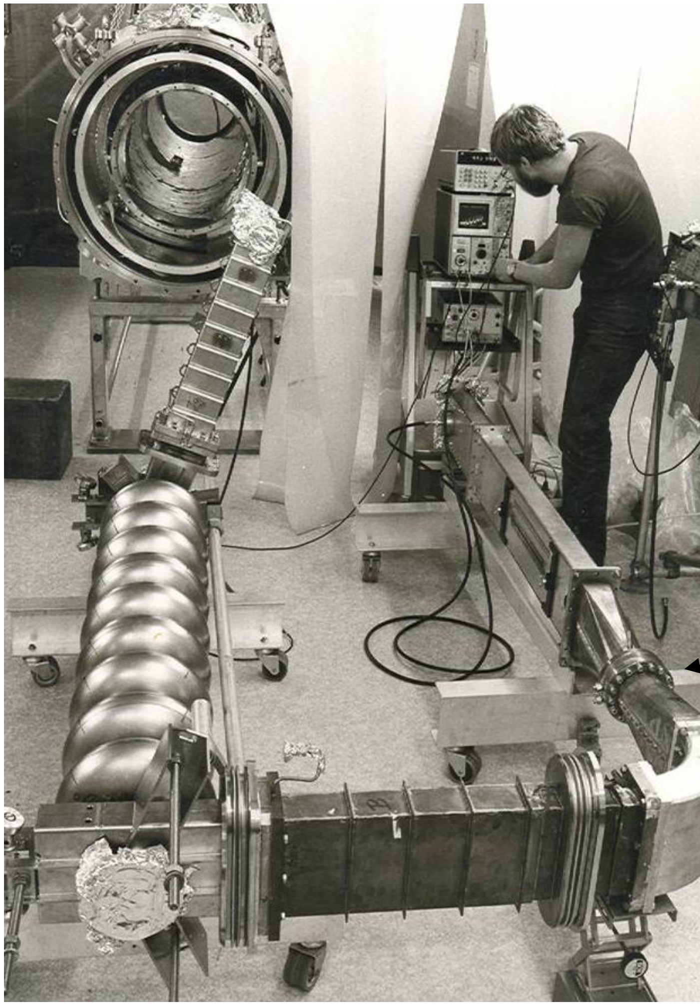
- good matching to prevent standing waves (increased voltage)
- prevent multipacting at operating power level
- prevent field emission and breakdowns
- fast processing time
- safe operation
- interlock system to secure coupler & cavity

Wave Guide vs. Coax Coupler

- coax:
  - more compact
  - easy tuning of match, change penetration of antenna
  - circular parts are easy to machine, assemble, seal
  - asymmetric fields cause kick to the beam
- wave guide:
  - lower surface electric field
  - no easy tuning of the match
  - high thermal radiation
  - machining of rectangular parts is more extensive

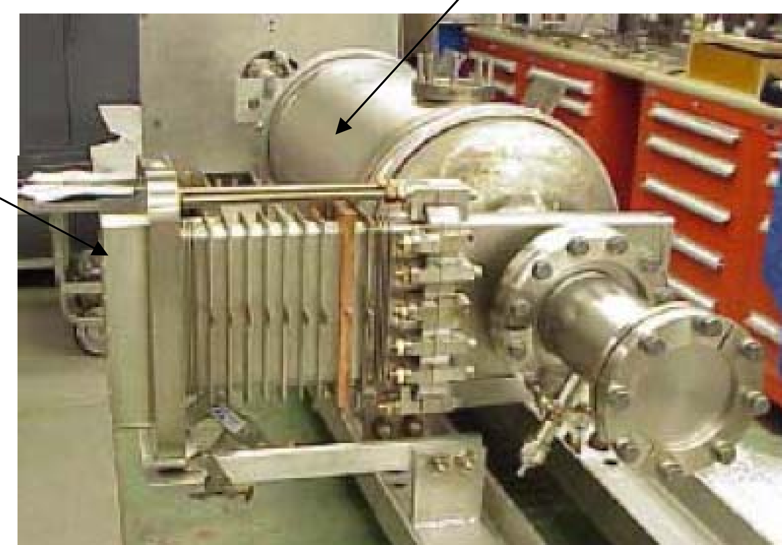
Wave guide couplers





CEBAF cavity pair and new upgrade cavity

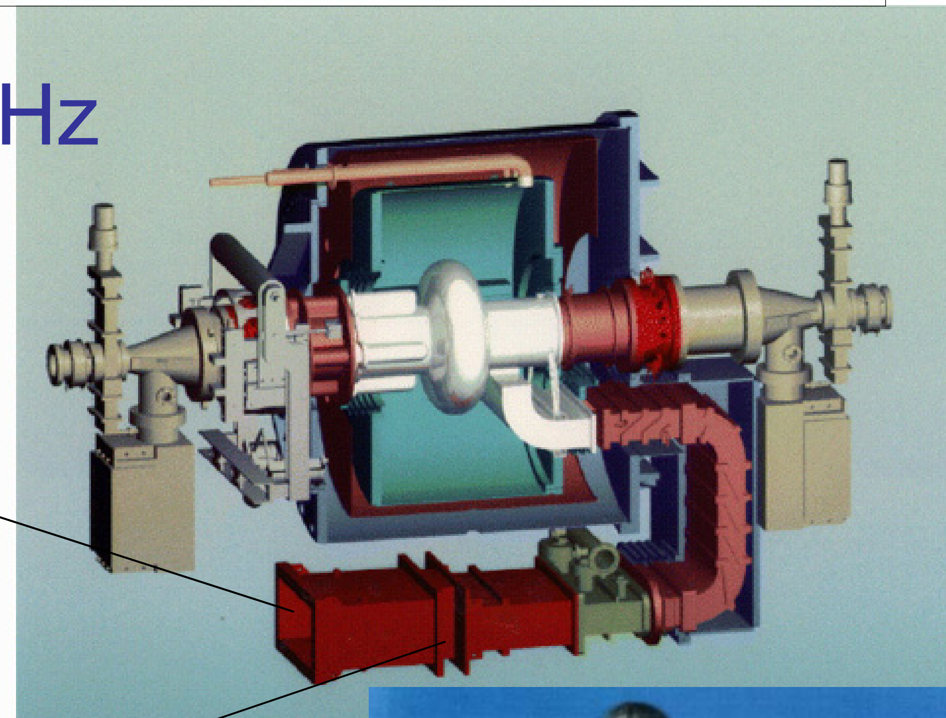
window



1 GHz Petra test cavity

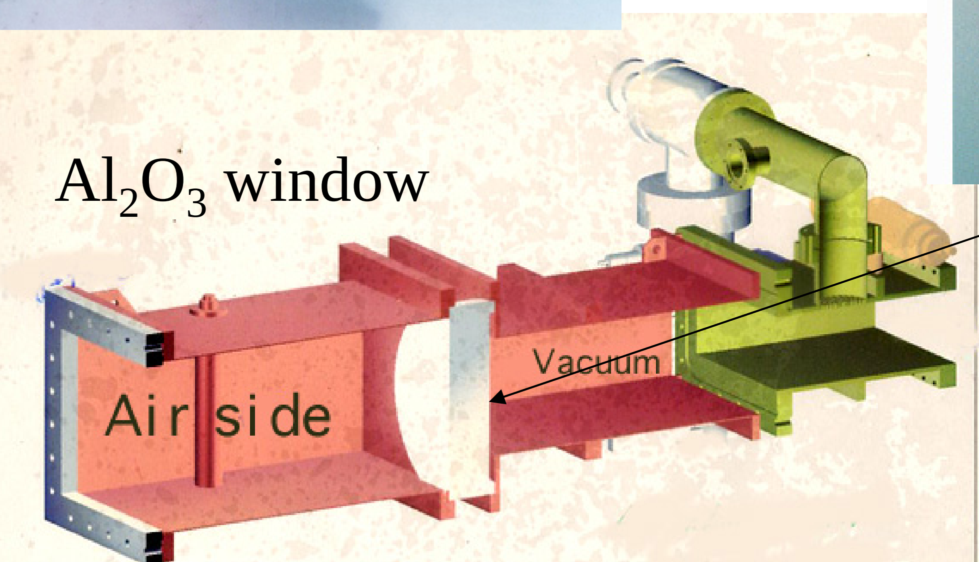
Wave guide couplers, cont.

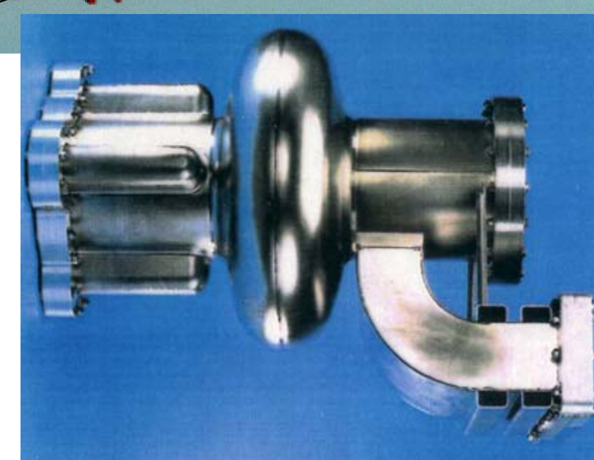
CESR – B cavity, 500 MHz



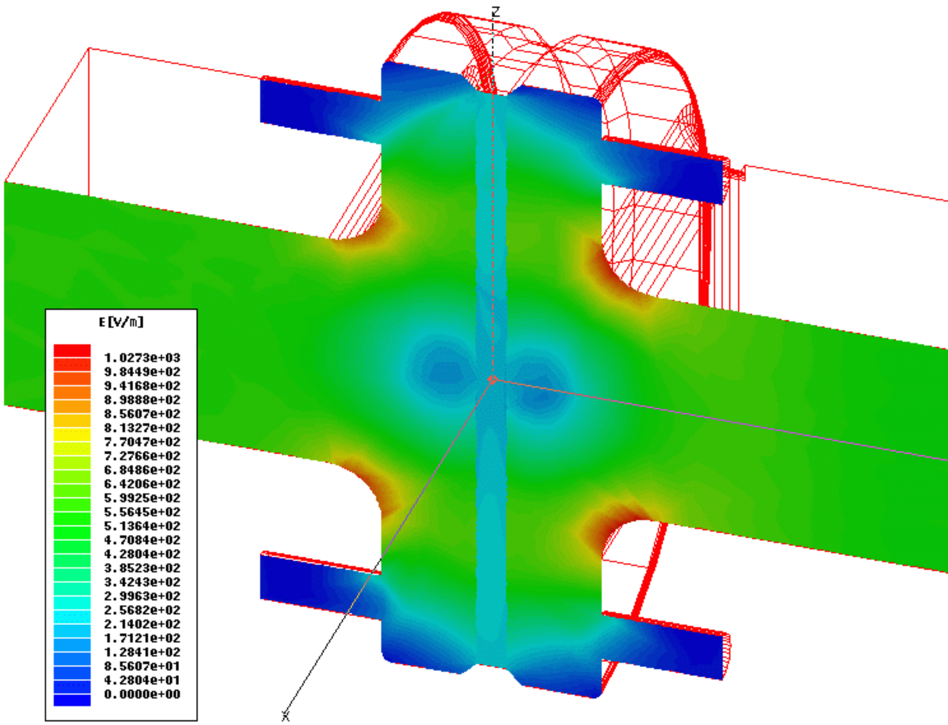
backup Kapton window

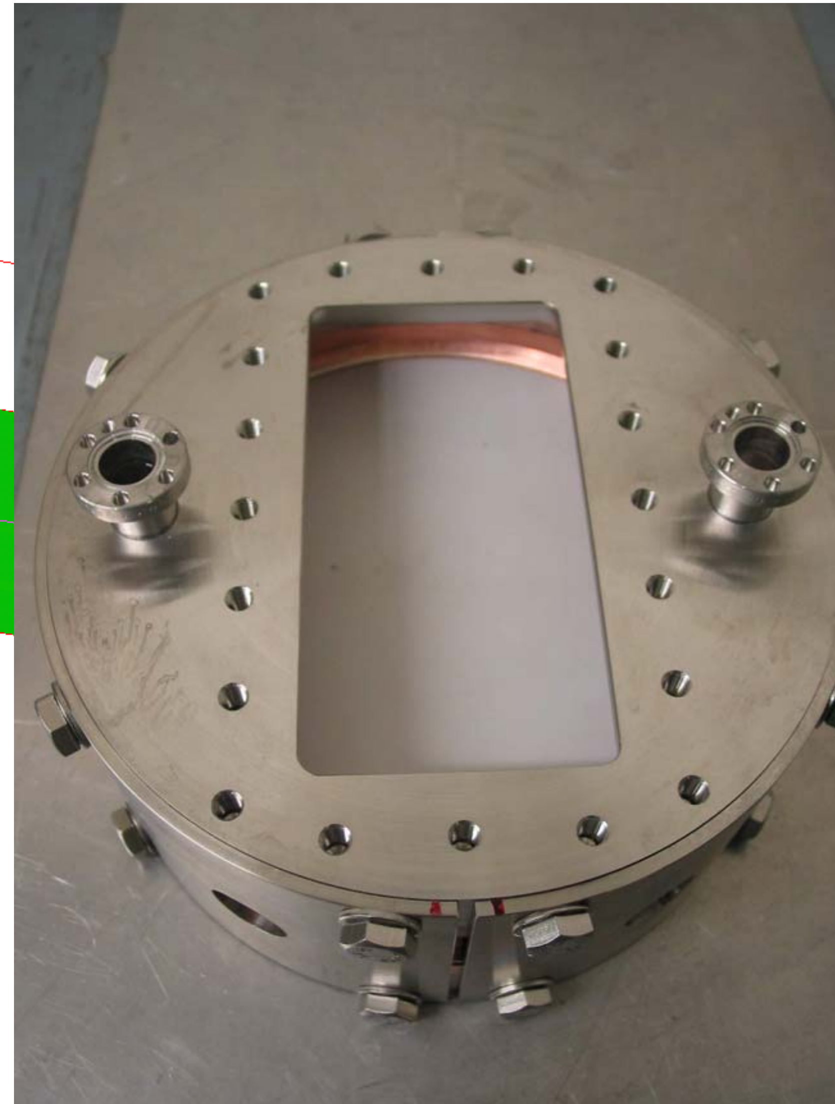
Al_2O_3 window





Wave guide window





window with diagnostic ports (TTF2 coupler)

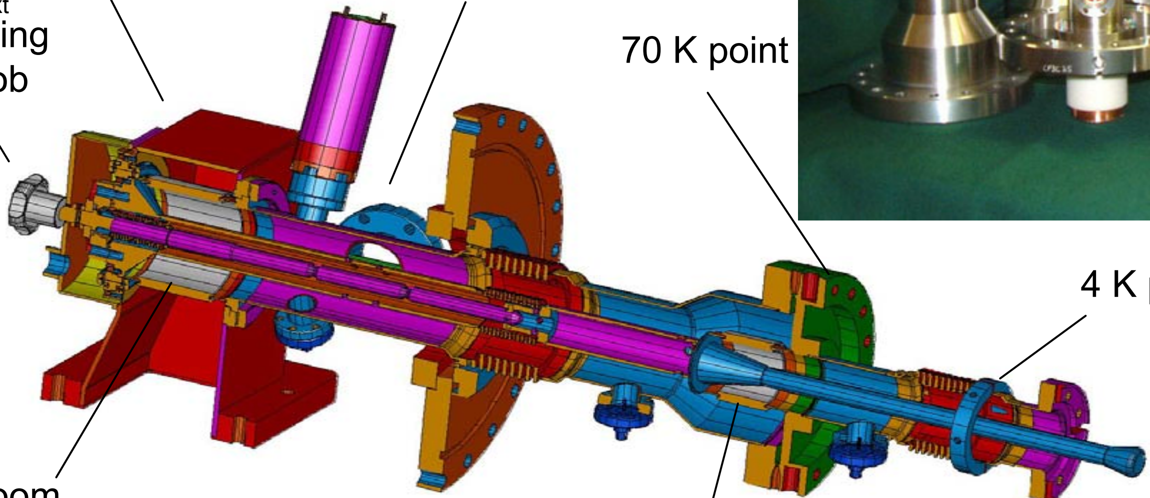
Coax couplers, one cylindrical window

LEP (HERA)

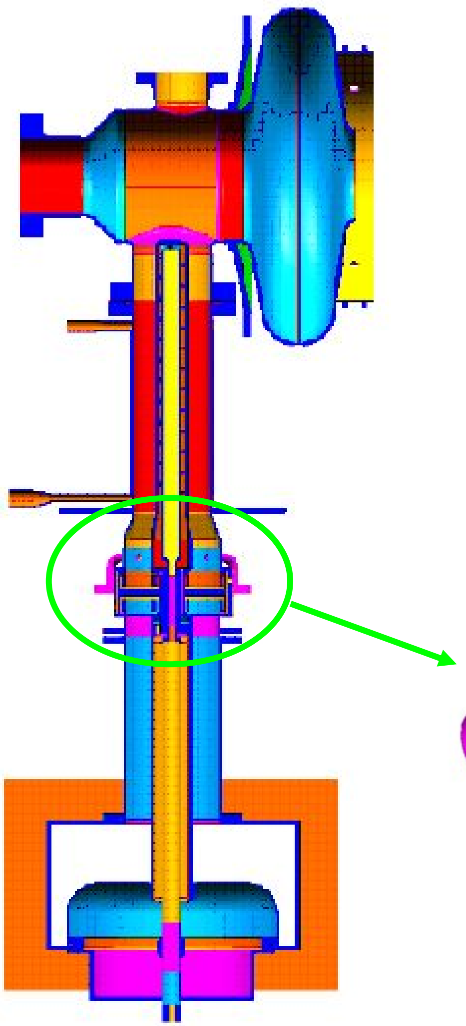
LEP coax to wave guide transition

Coax couplers, two cylindrical windows

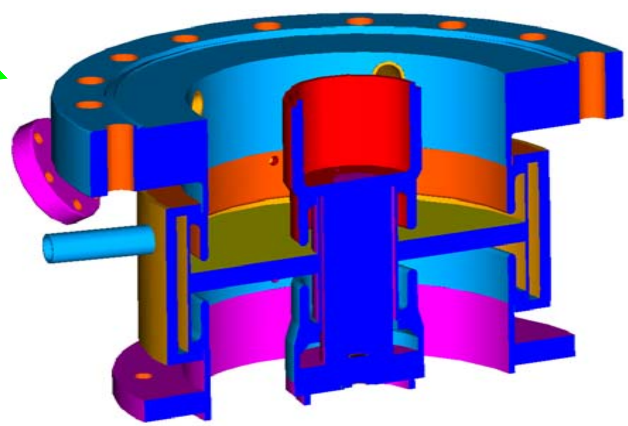
TESLA Coupler

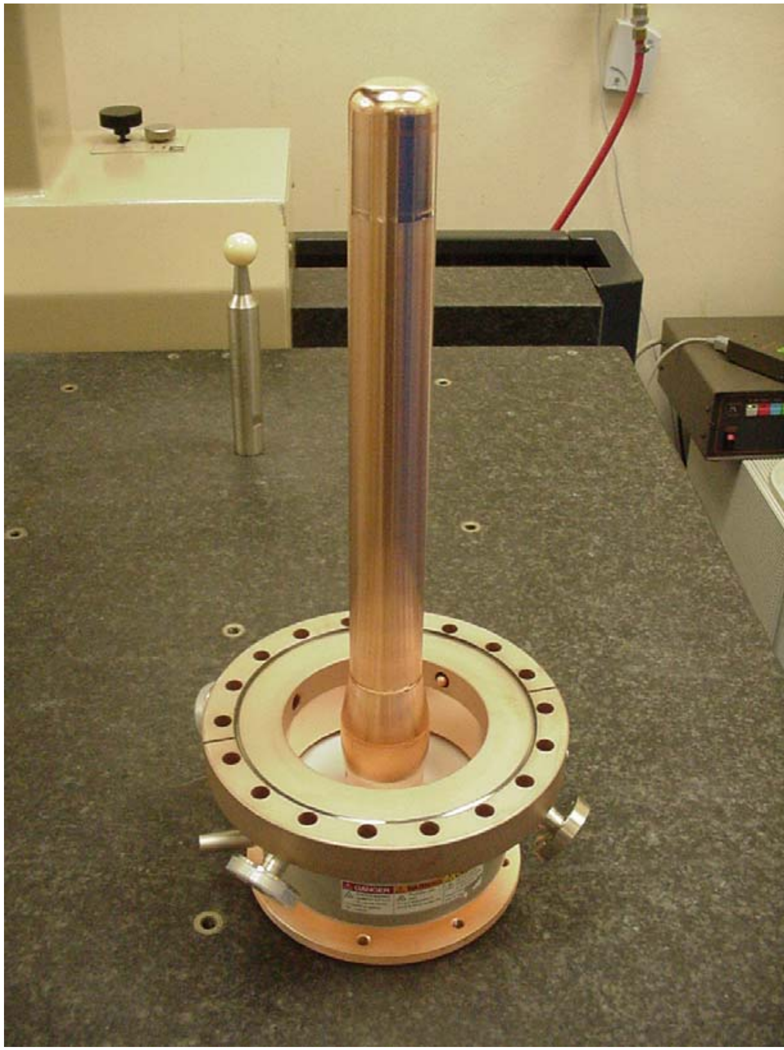


Coax couplers, flat window



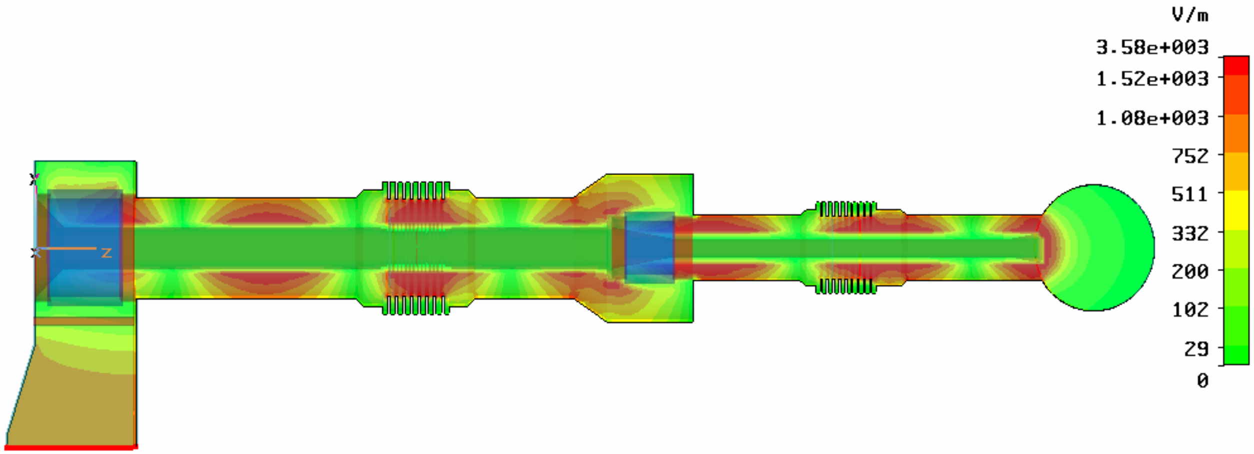
SNS “Choke” window (scaled from KEK-B)

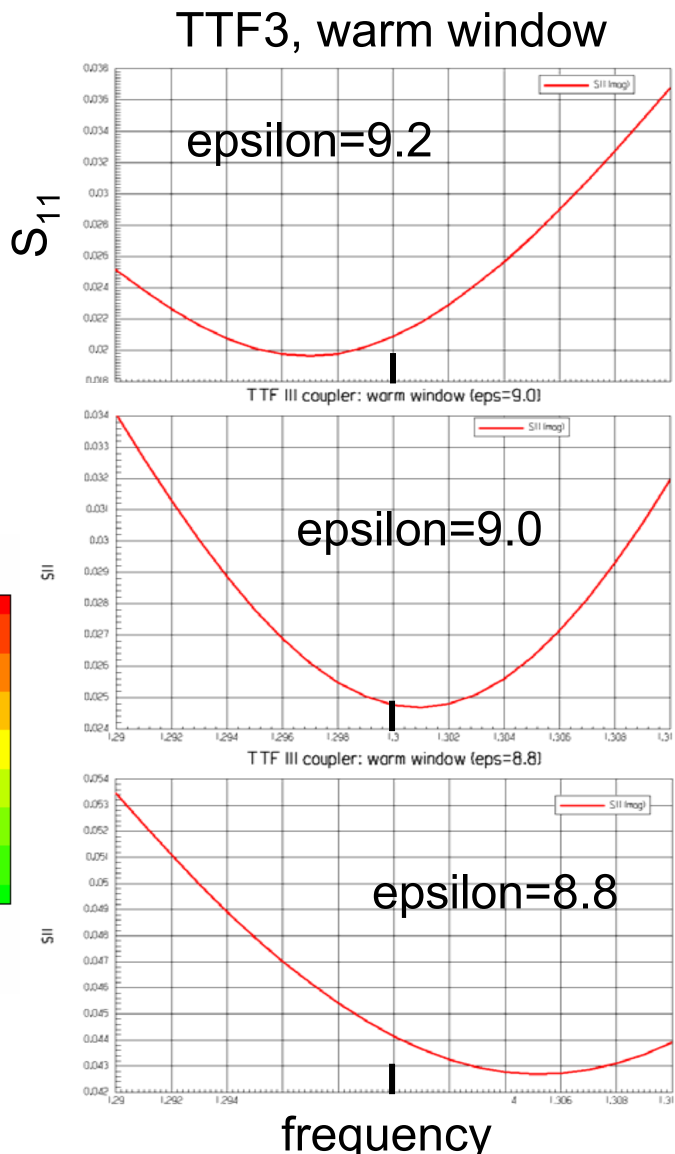




RF simulation

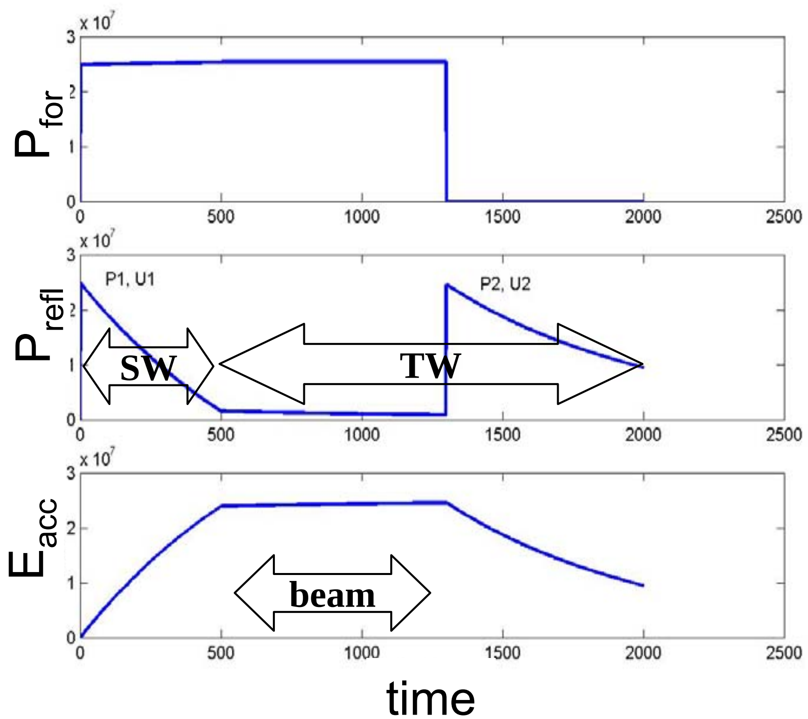
- matching of the coupler components
  - here the influence of the ceramic epsilon is shown

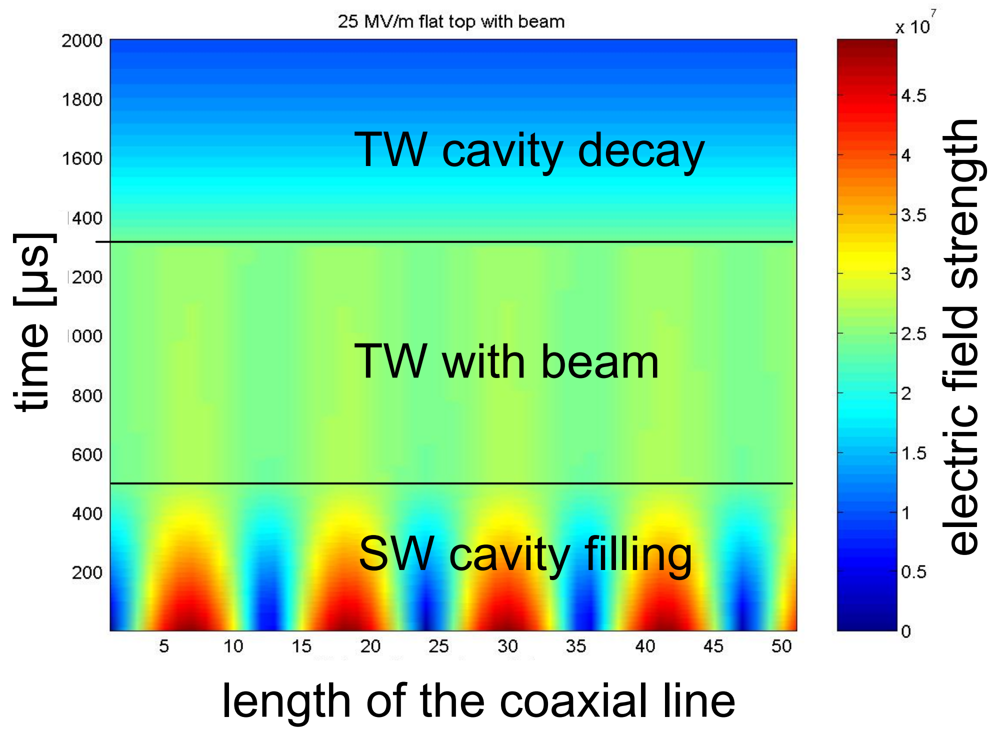




Standing waves at pulsed operation

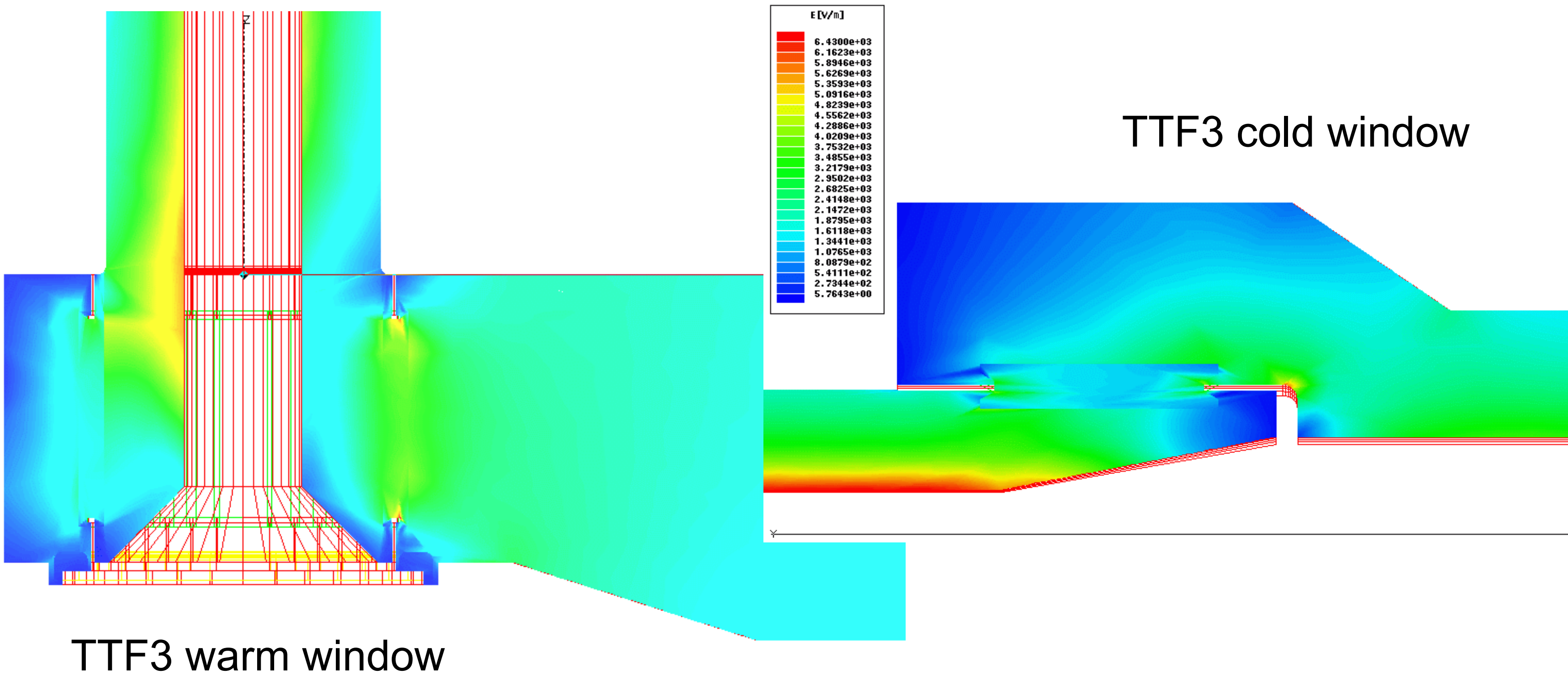
- during filling time of cavity: standing waves





RF simulation, window position

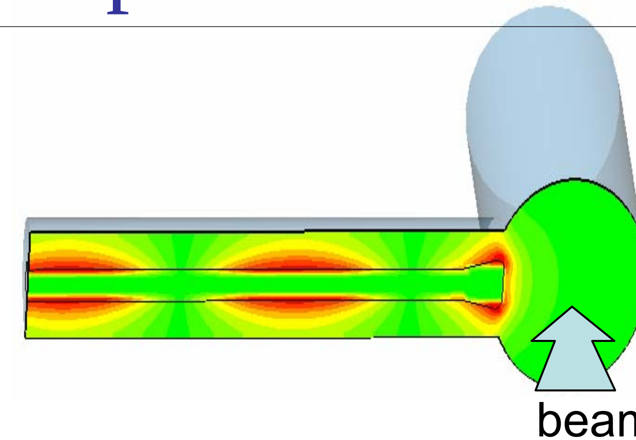
- for pulsed operation: placing the window in the minimum electrical field

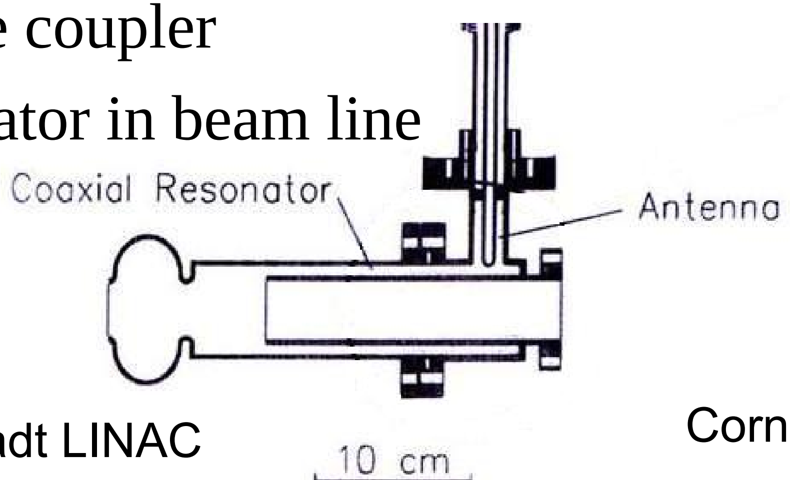


RF simulation, kick to the beam by the RF field of the coupler

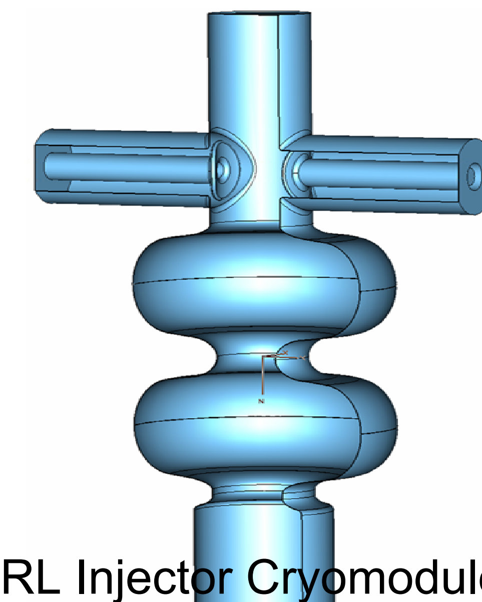
the asymmetric field at the coaxial coupler antenna – beam pipe transition causes an unwanted kick to the beam

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





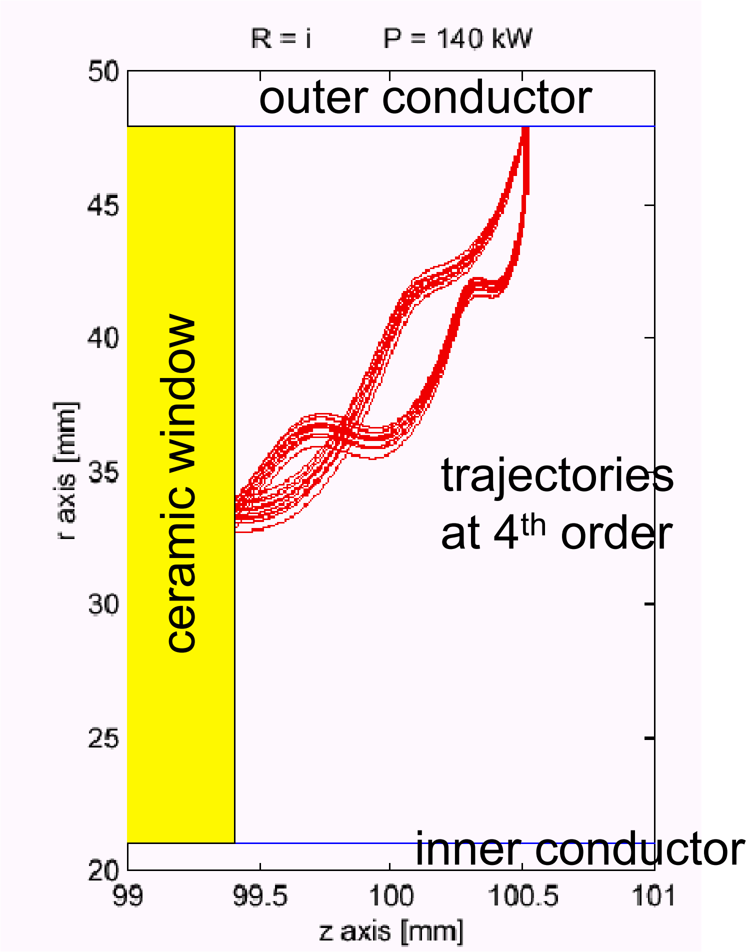
S-Darmstadt LINAC



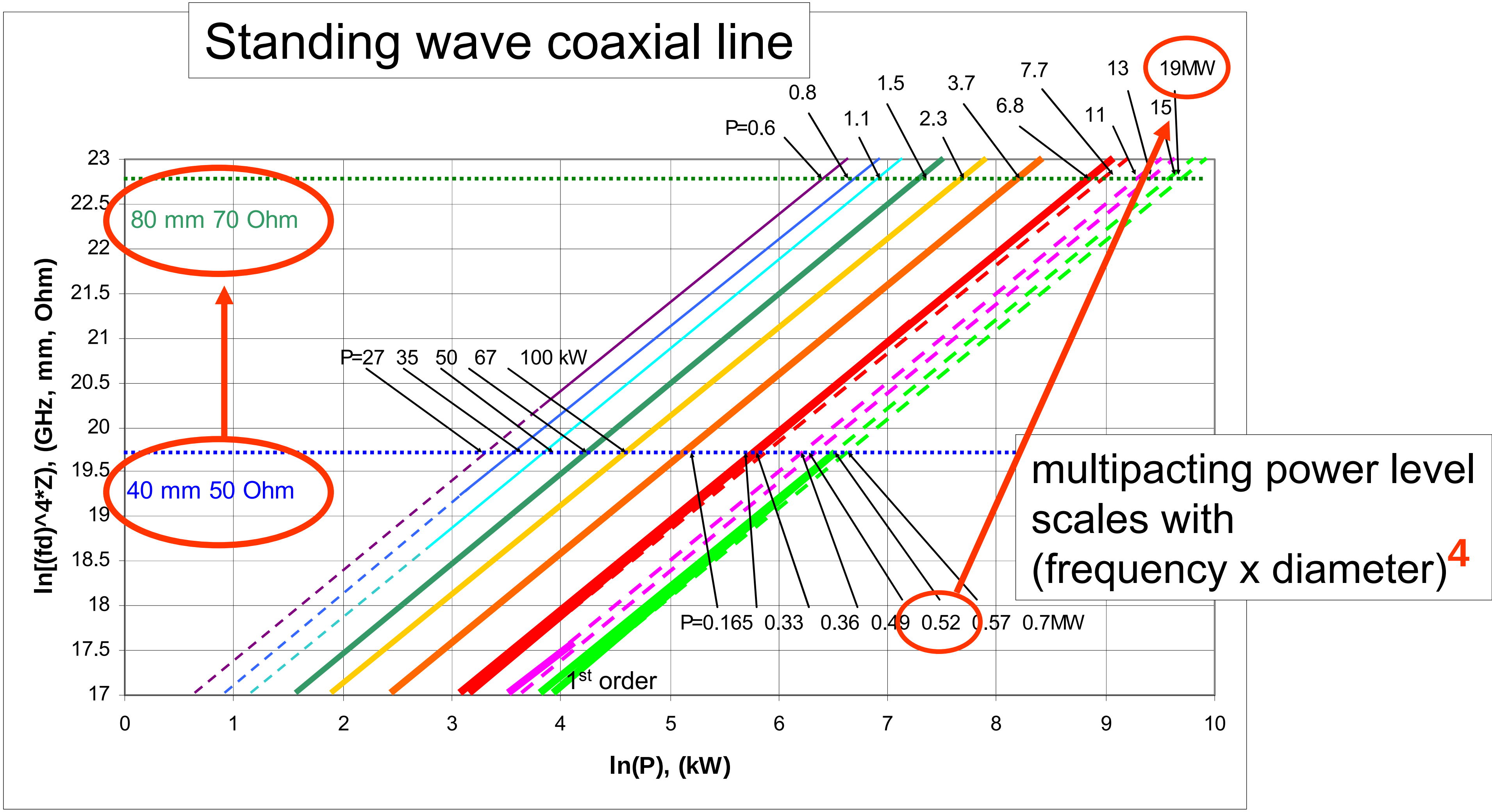
Cornell ERL Injector Cryomodule

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)



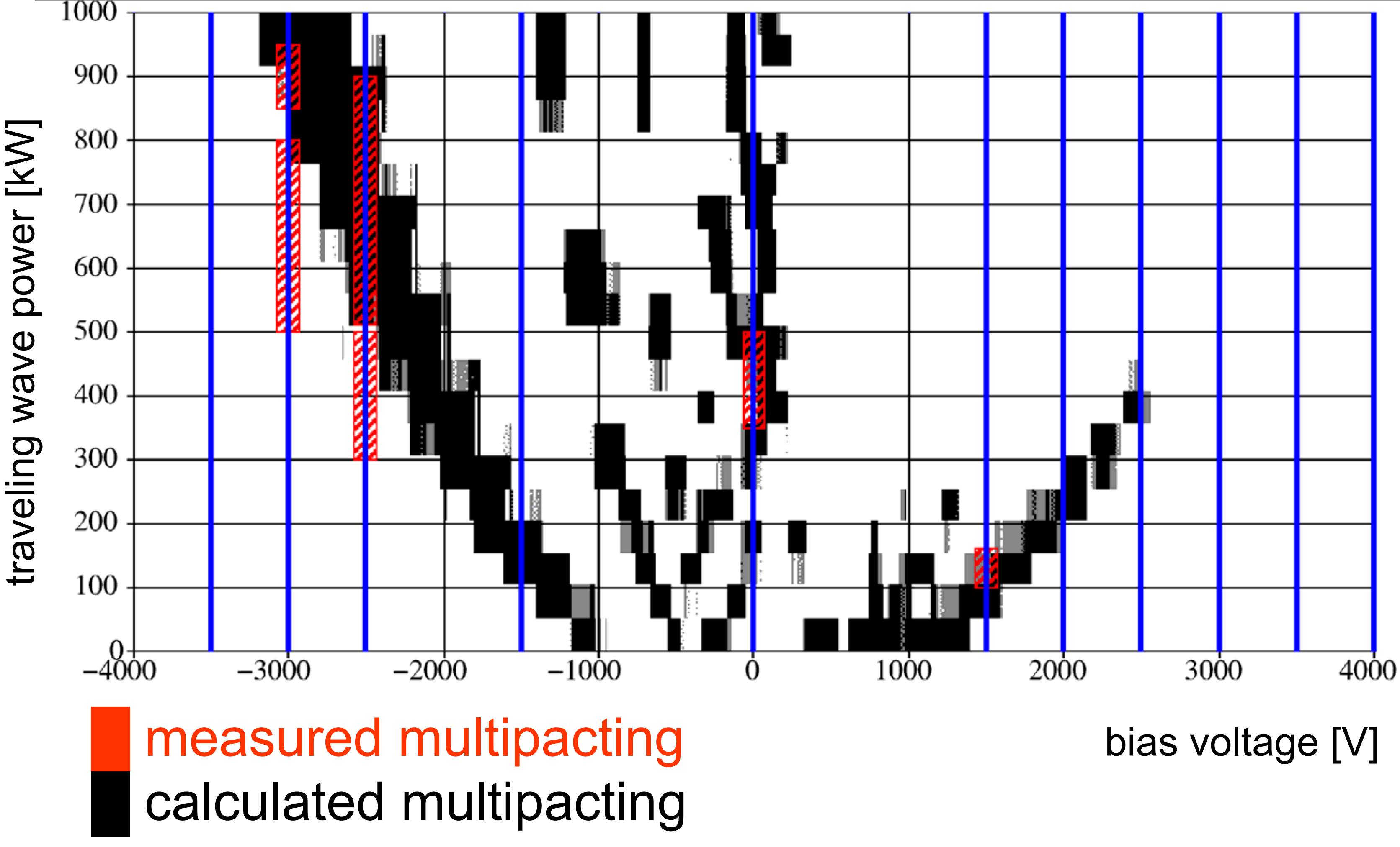
Multipacting analytical calculations



Cures for multipacting

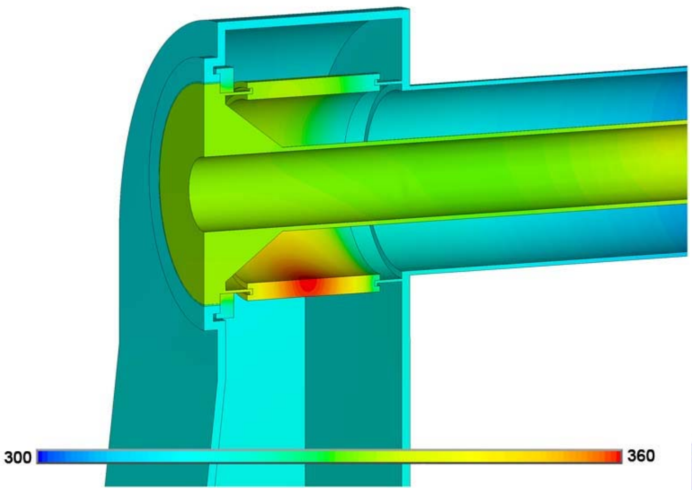
- the right choice of the geometry:
  - bigger coax diameter, higher impedance
- reduction of SEC:
  - coating of critical surfaces (e.g. ceramic SEC≈8) with Ti or TiN (SEC≈1)
  - cleaning RF surfaces before or by conditioning
- shift resonant conditions by additional fields:
  - electrical bias on inner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

Multipacting measurements, influence of bias voltage (TTF2)



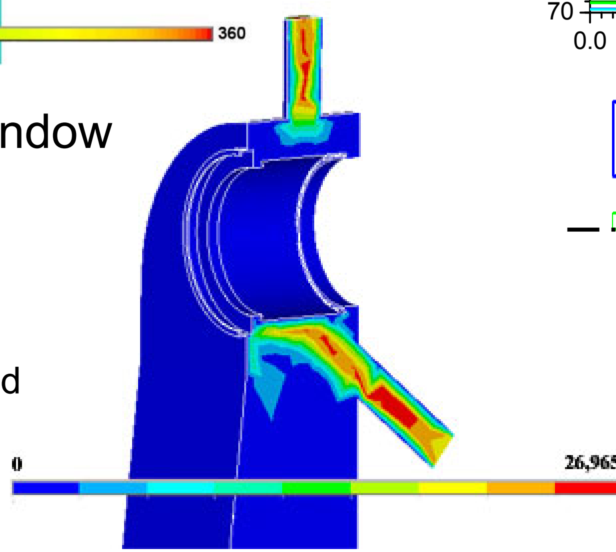
Thermal simulations

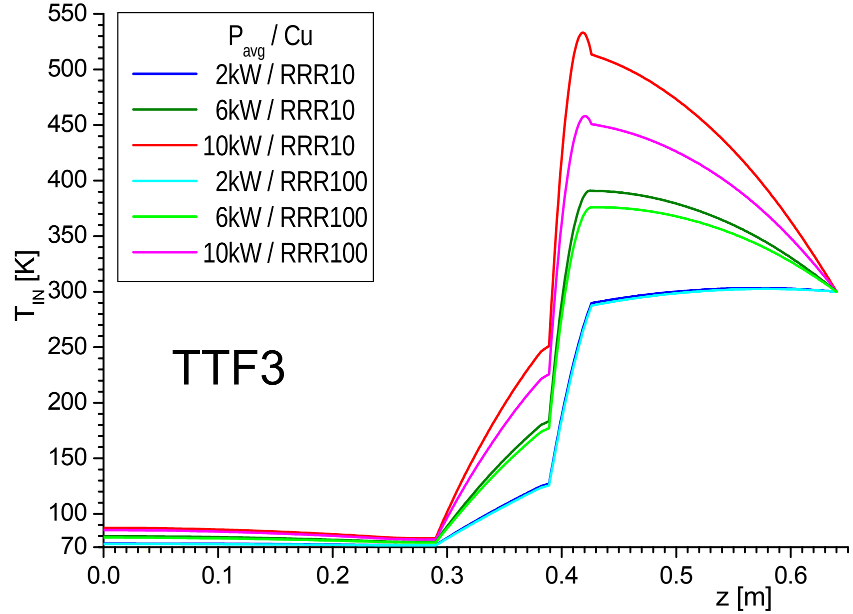
75 kW CW Coaxial Input Coupler for Cornell ERL Injector Cryomodule

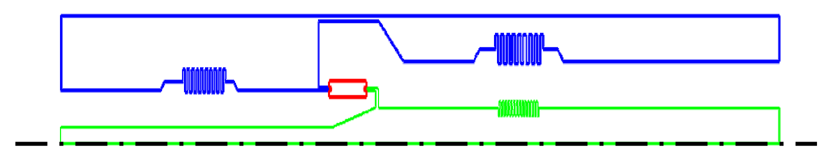


heating of the window and air cooling

Московский инженерно-физический институт and “ИНТРОСКАН”







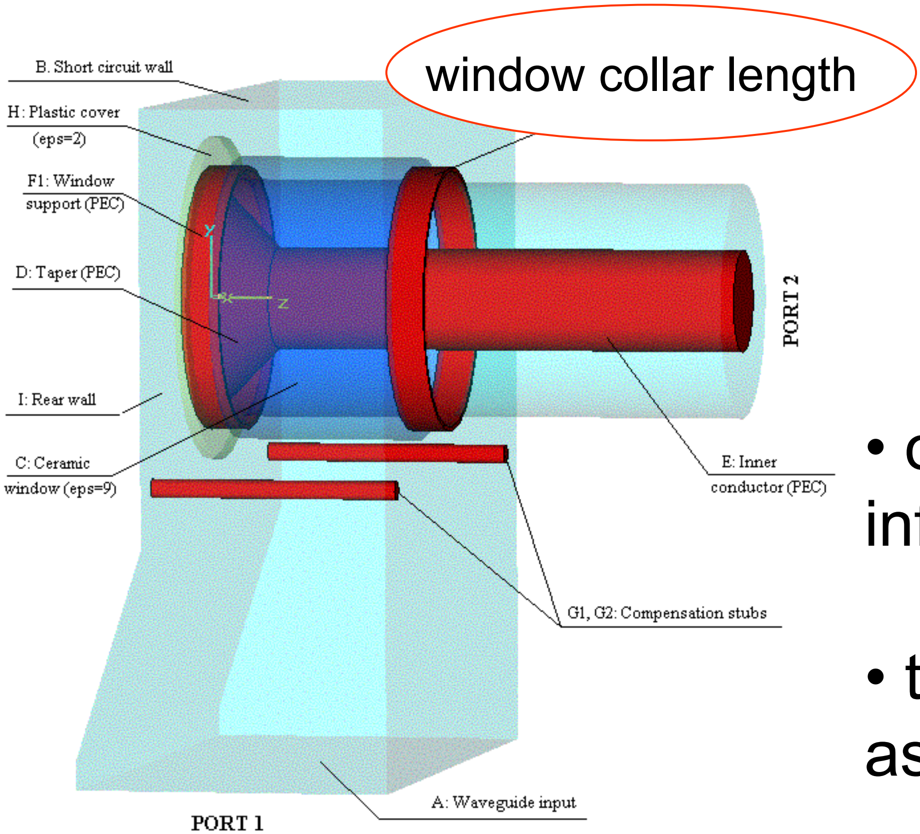
heating of the inner conductor for different quality of the copper plating

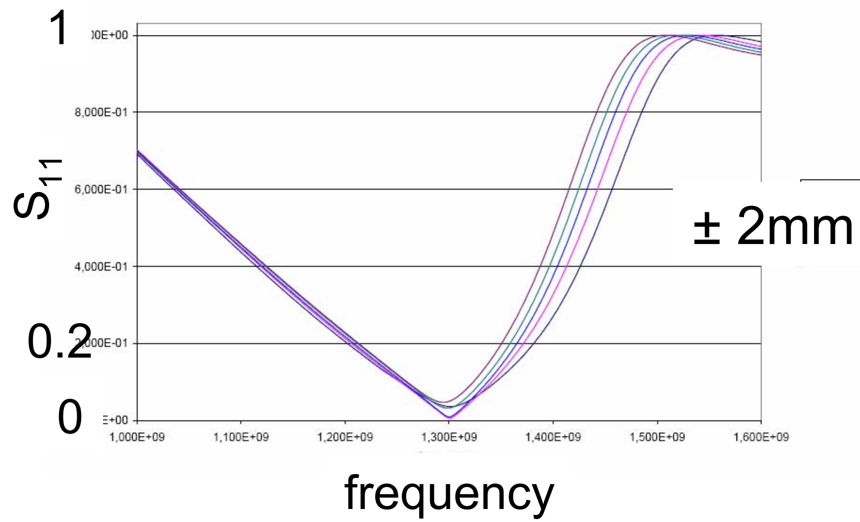
Fabrication issues, general

- 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
  - 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, mechanical tolerances

TTF3 WG to coax transition





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

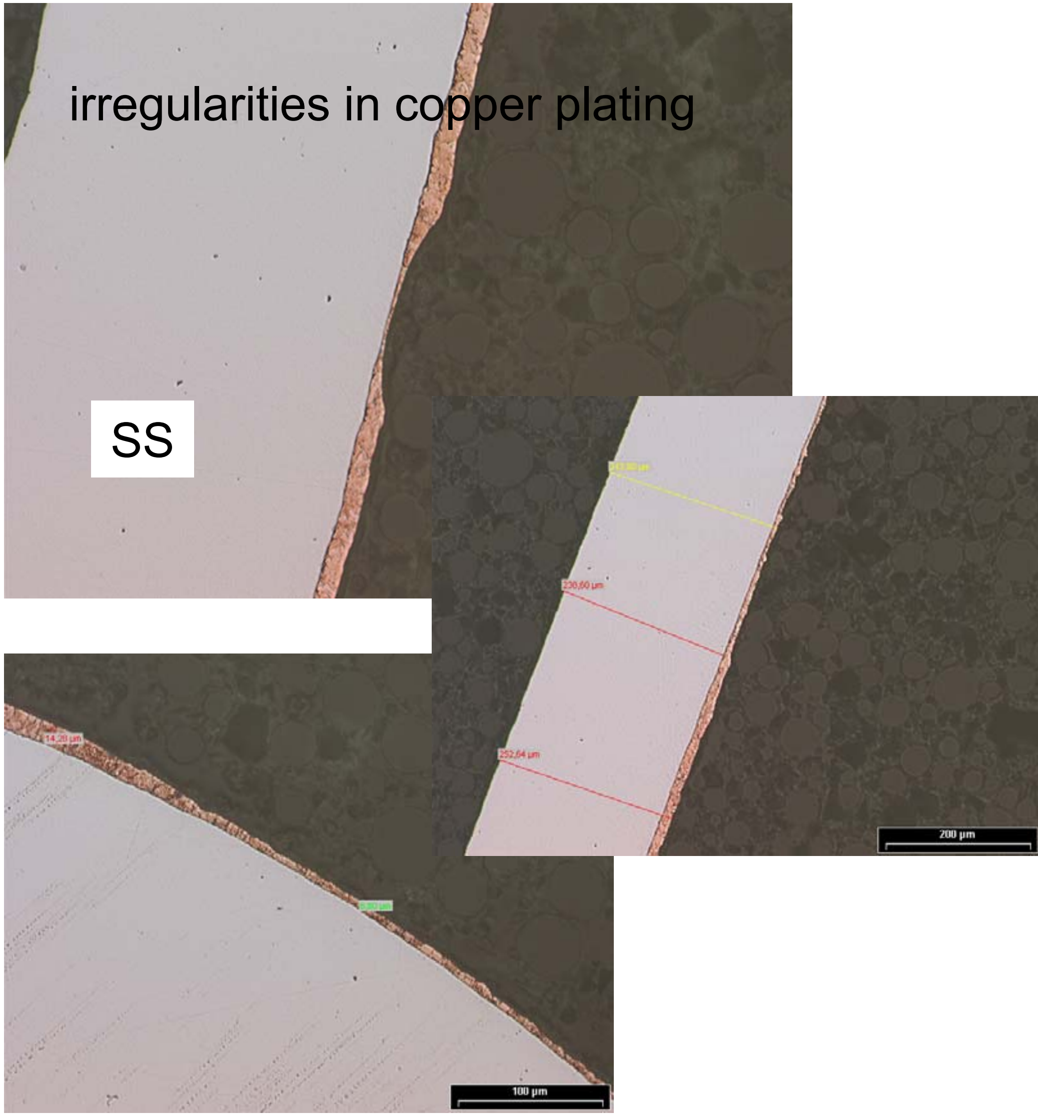
- tight tolerances at welding assemblies requires great care

low tolerances = high costs

Fabrication issues, copper plating

challenges:

- high electrical conductance for low losses
- good uniformity of thickness especially on bellows
- small thickness-low thermal conductance
- 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

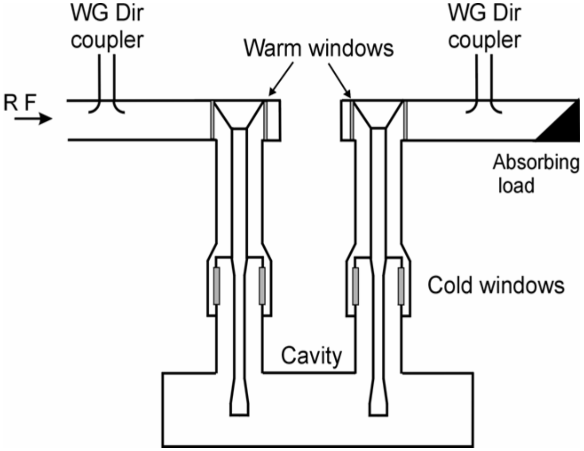
- high power coupler tests are needed for
  - acceptance test
  - preconditioning prior to the operation on cavity
- usually test stands of two couplers at RT
- interlock is needed to protect the coupler and investigate the behavior
- coupler parts have to be cleaned up to the SC-cavity standard

What is ‘RF-processing’

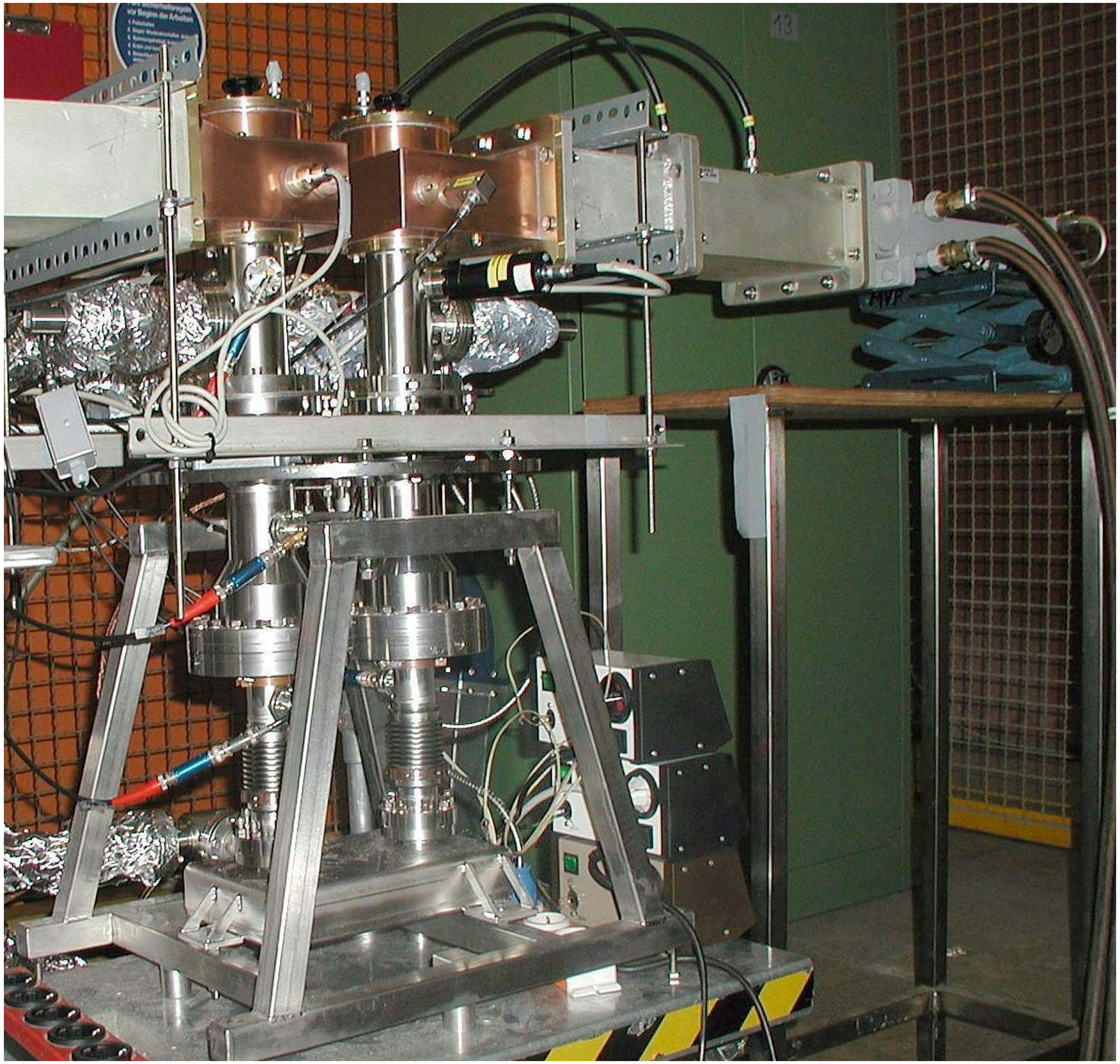
- controlled desorption of absorbed gases by accelerated ions and electrons
- compromise must be found between conditioning speed and sparking risk
- traveling wave cleans all surfaces, at standing waves additional tricks are required
- cold surfaces collect gas after certain period of operation

TTF 3 Coupler on Test Stand

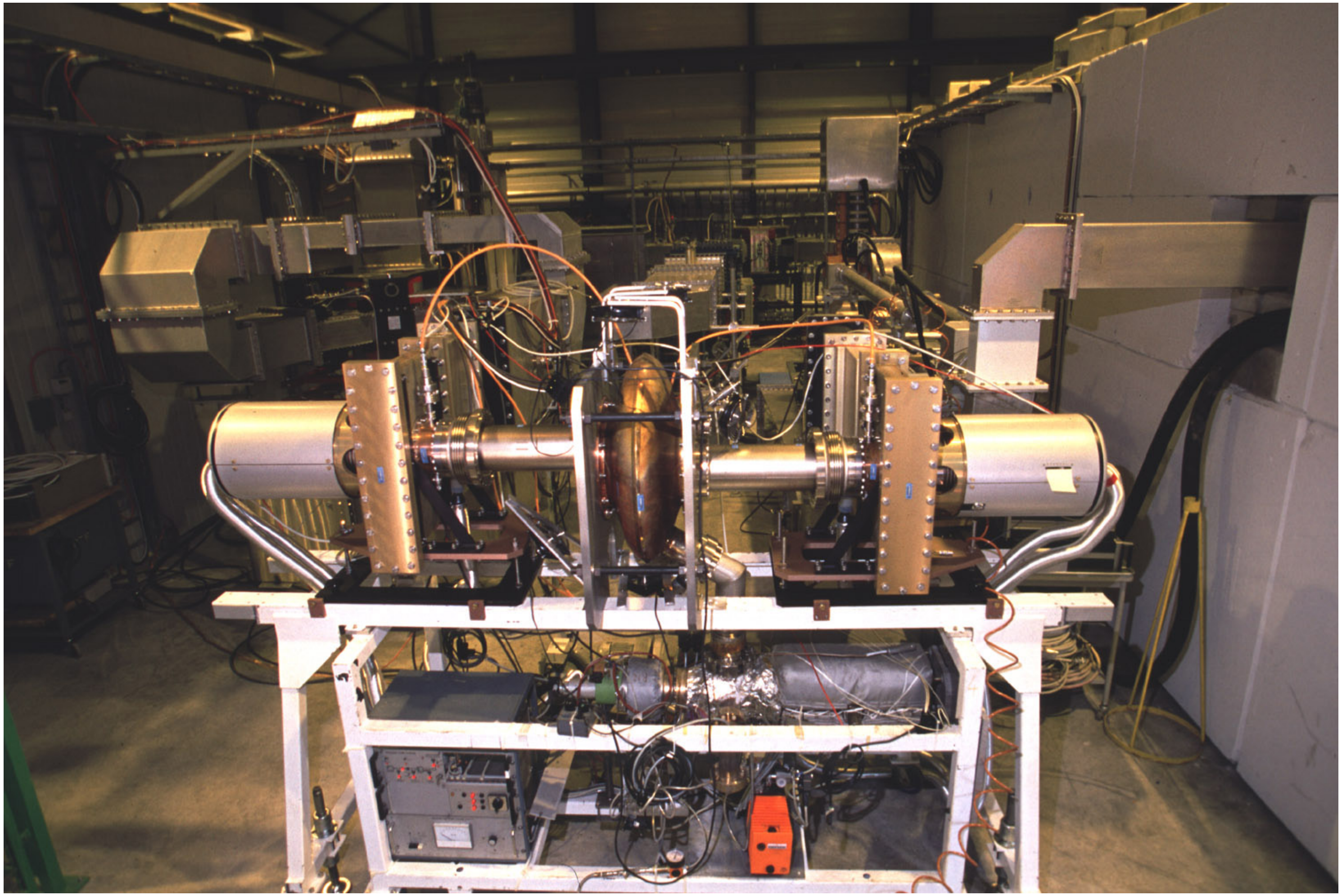
Teststand



- 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

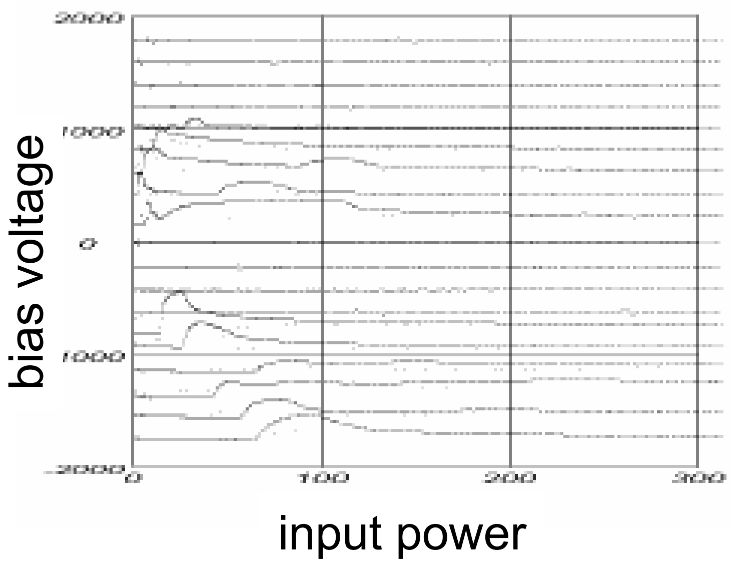
Testing and processing procedure

- 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

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



Interlock

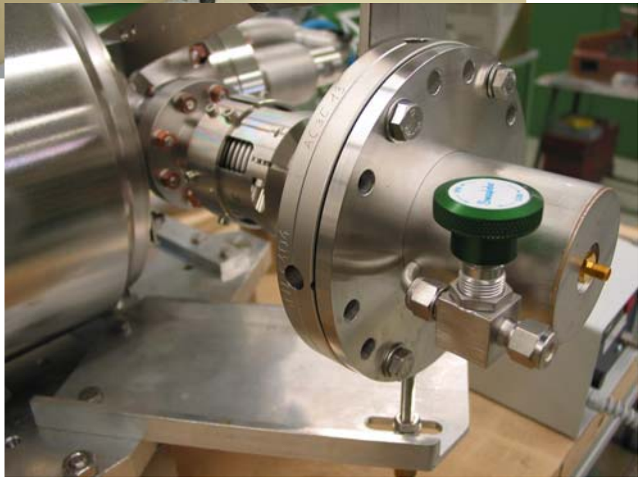
- hardware interlock:
  - vacuum read out
  - e- pick up
  - light detectors in vacuum and on the air side
  - temperature on windows
  - reflected power
- software interlock:
  - all above

Handling after processing

goal is to maintain the processing effect

– 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

TTF3 Coupler on Module 5 in the VUVFEL

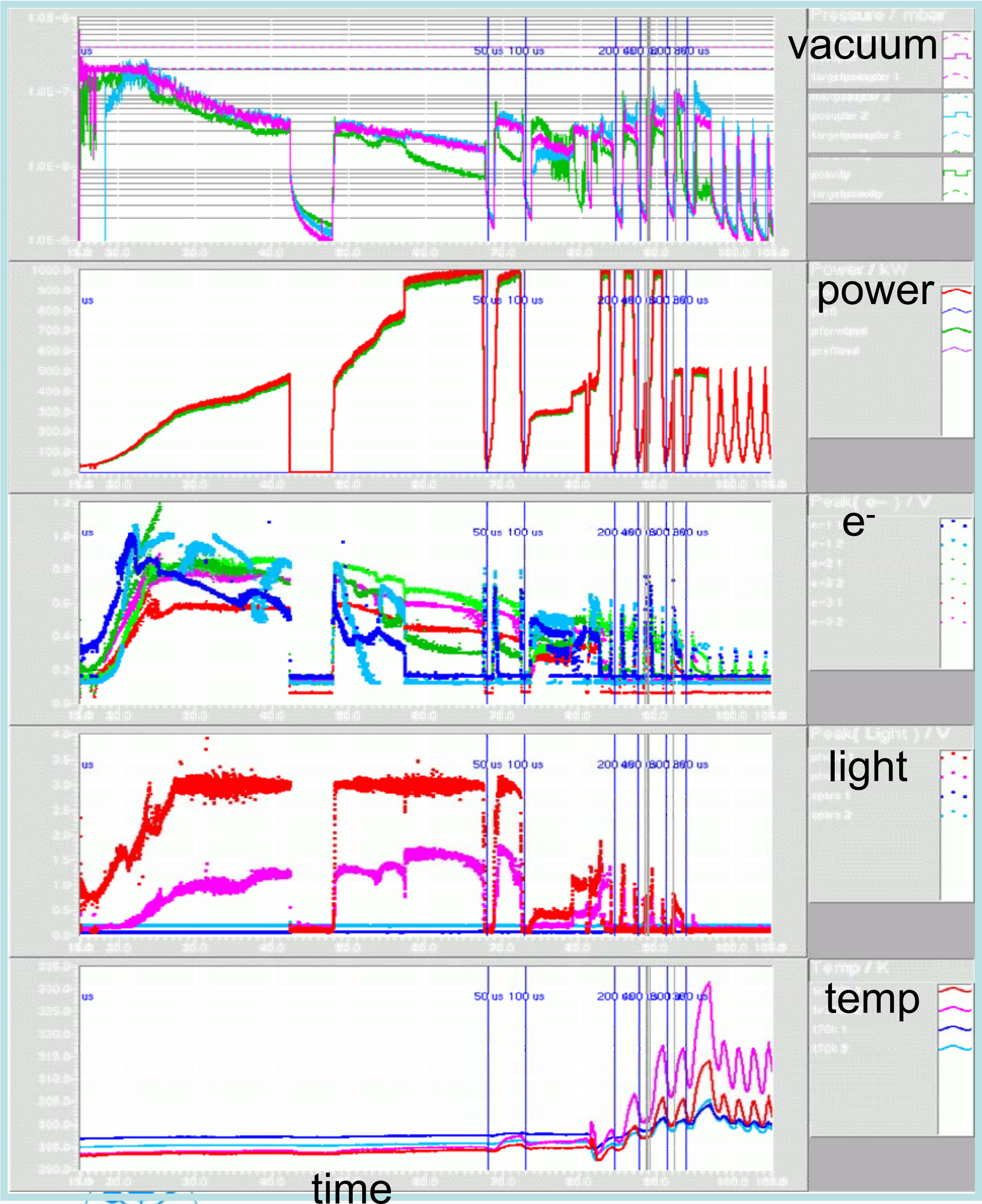
Acknowledgement

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

A very good collection of references can be found in:

I. E. Campisi ‘Fundamental Power Couplers For Superconducting Cavities’ EPAC2002



Typical test run for a TTF3 Coupler