Fundamental power couplers for superconducting cavities in ERL's

Isidoro E. Campisi

SNS/ORNL

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Purpose of couplers for SC cavities

- The main purpose of couplers is to provide means of transferring power from a generator to a superconducting cavity

REAL tasks of couplers

- DO NOT compromise the performance of the cavities they are connected to
- DO NOT negatively affect the beam

- The above are the first criteria for designing couplers

Coupler features

- Electromagnetic: provide appropriate transmission line/cavity field interface
- Thermal: sustain large thermal gradients without transferring large amounts of heat to the cryogenic environment
- Vacuum: provide one or more vacuum barriers to atmospheric pressure (windows are a critical component which are part of the coupler) and guarantee low pressure increases under the influence of electromagnetic fields, multipacting electrons, local heat dissipation etc.
- Do not exhibit negative features (e.g. multipacting)

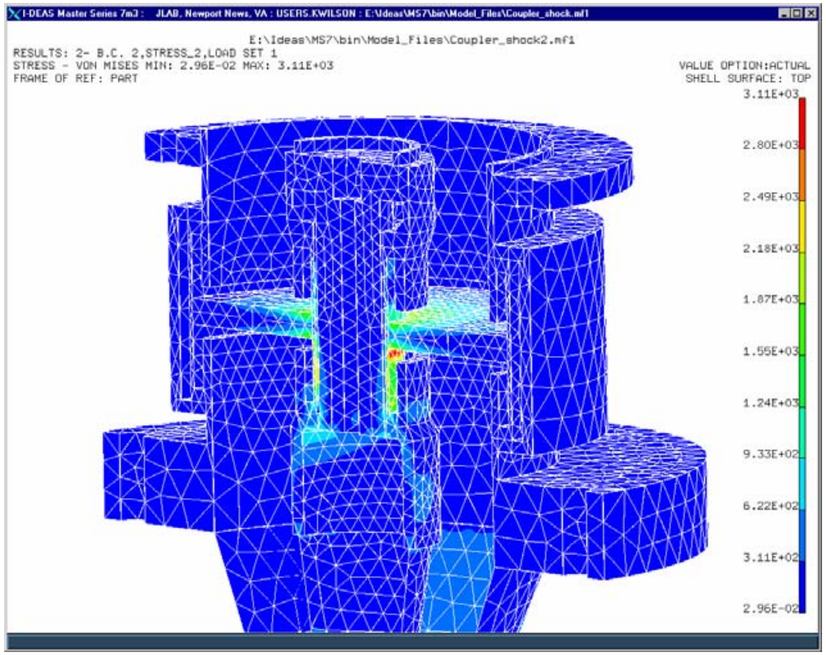
Simulations

- Simulations have become one of the most important tools in predicting complex behaviors of couplers/cavity systems and have enormously improved reliability and shortened the time necessary to achieve successful design solutions.

Mechanical stress simulations

Mechanical:

Structural interface with cavity and cryomodule and stability under predictable accelerations

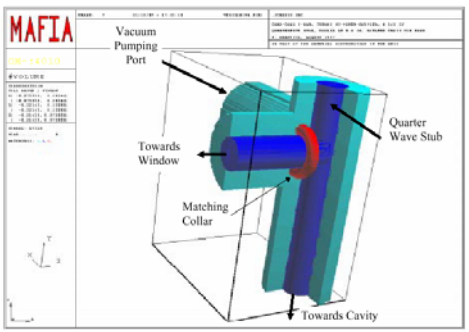


Stresses at SNS ceramic window

Electromagnetic simulations

Electromagnetic:

- •Field configuration and interaction between field in the transmission line and in the cavity
- •Predict matching and coupling coefficients
- •Predict field asymmetries



APT window

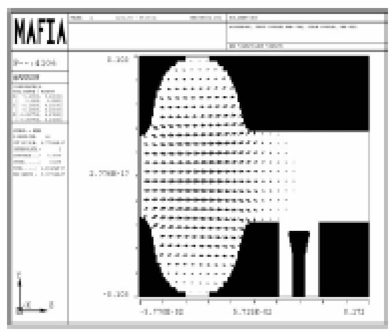


Figure 3: The undisturbed RF field of the last cavity cell

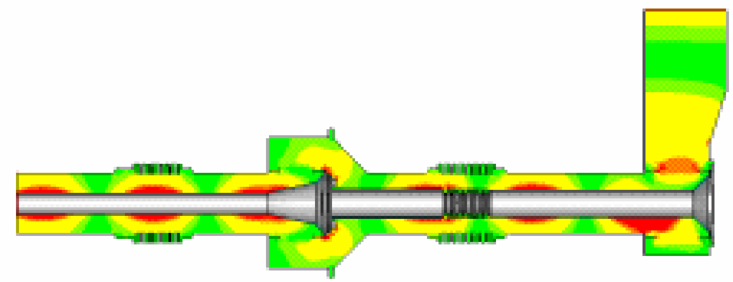


Figure 5: Electric fields in the coupler.

Rossendorf injector

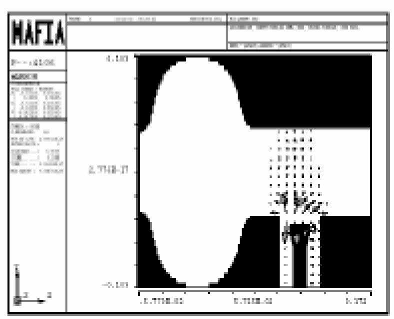


Figure 4: The field perturbation caused by the RF coupler

Cornell ERL injector

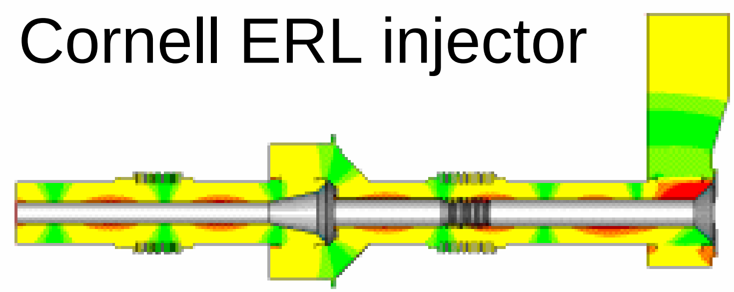
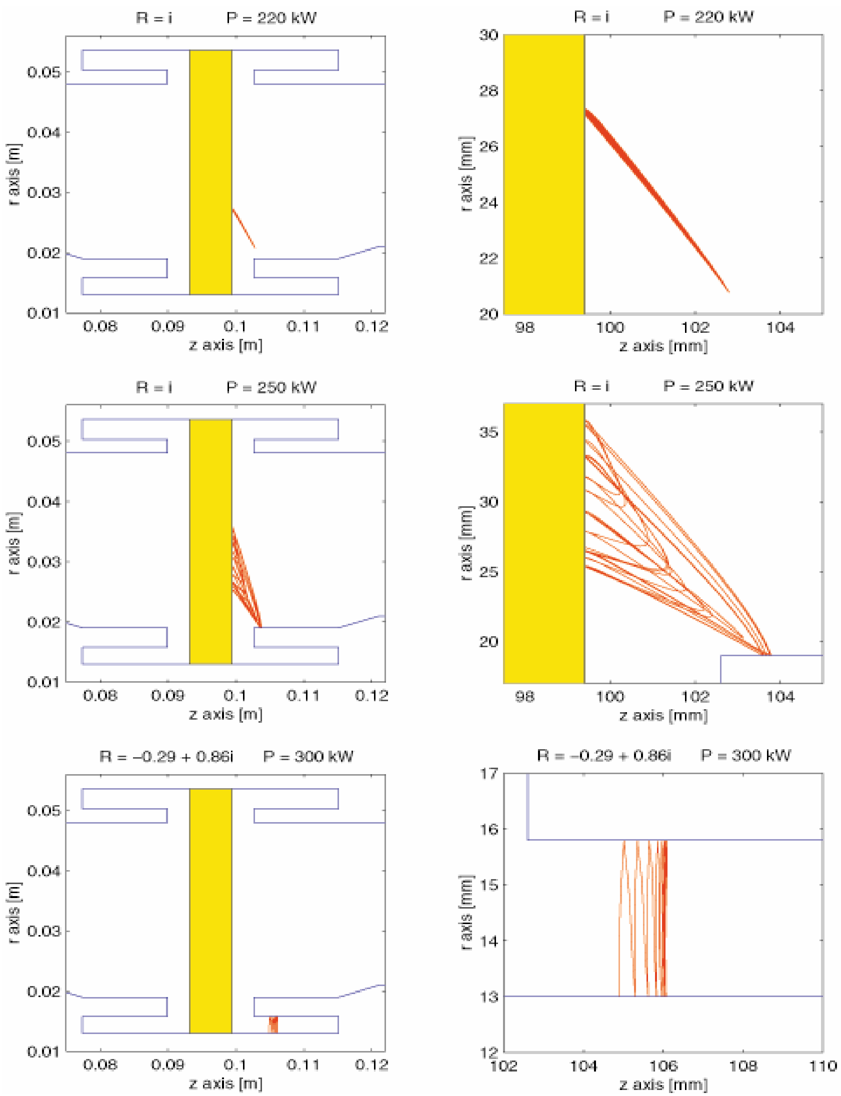


Figure 6: Magnetic fields in the coupler.

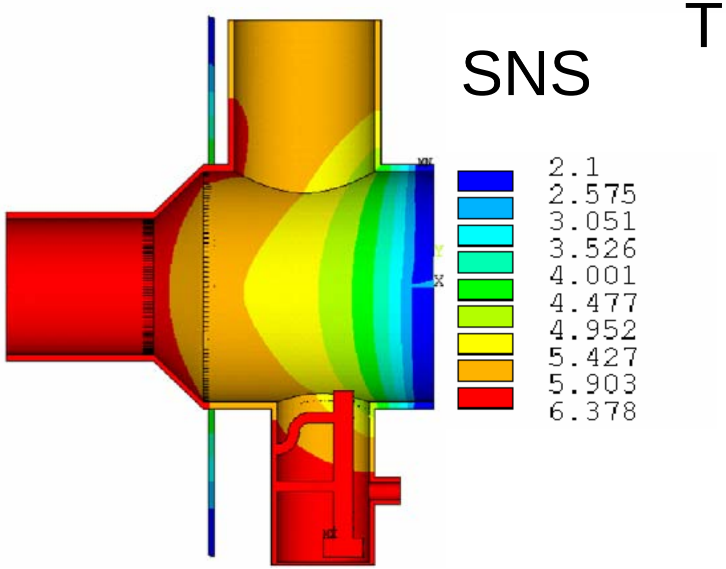
Multipacting simulations



SNS couplers

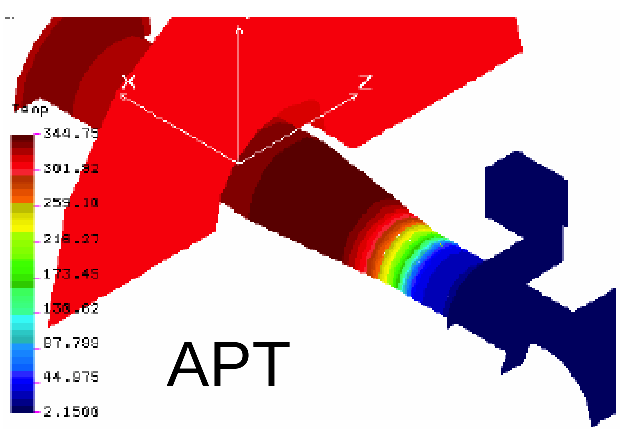
Thermal simulations

SNS

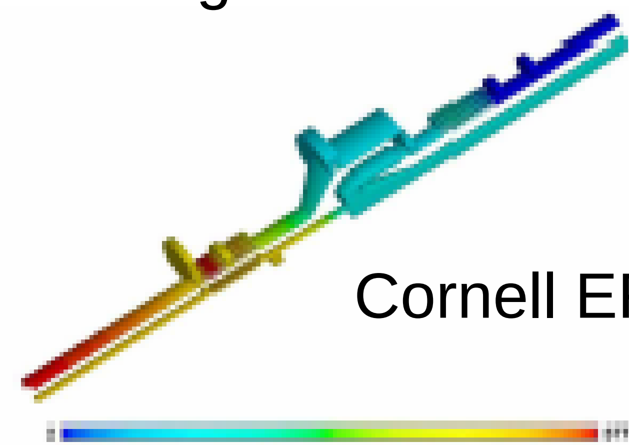


Thermal:

- Evaluate heat leaks into cryogenic sink
- Determine radiative and conductive losses which could disrupt the superconducting state



APT



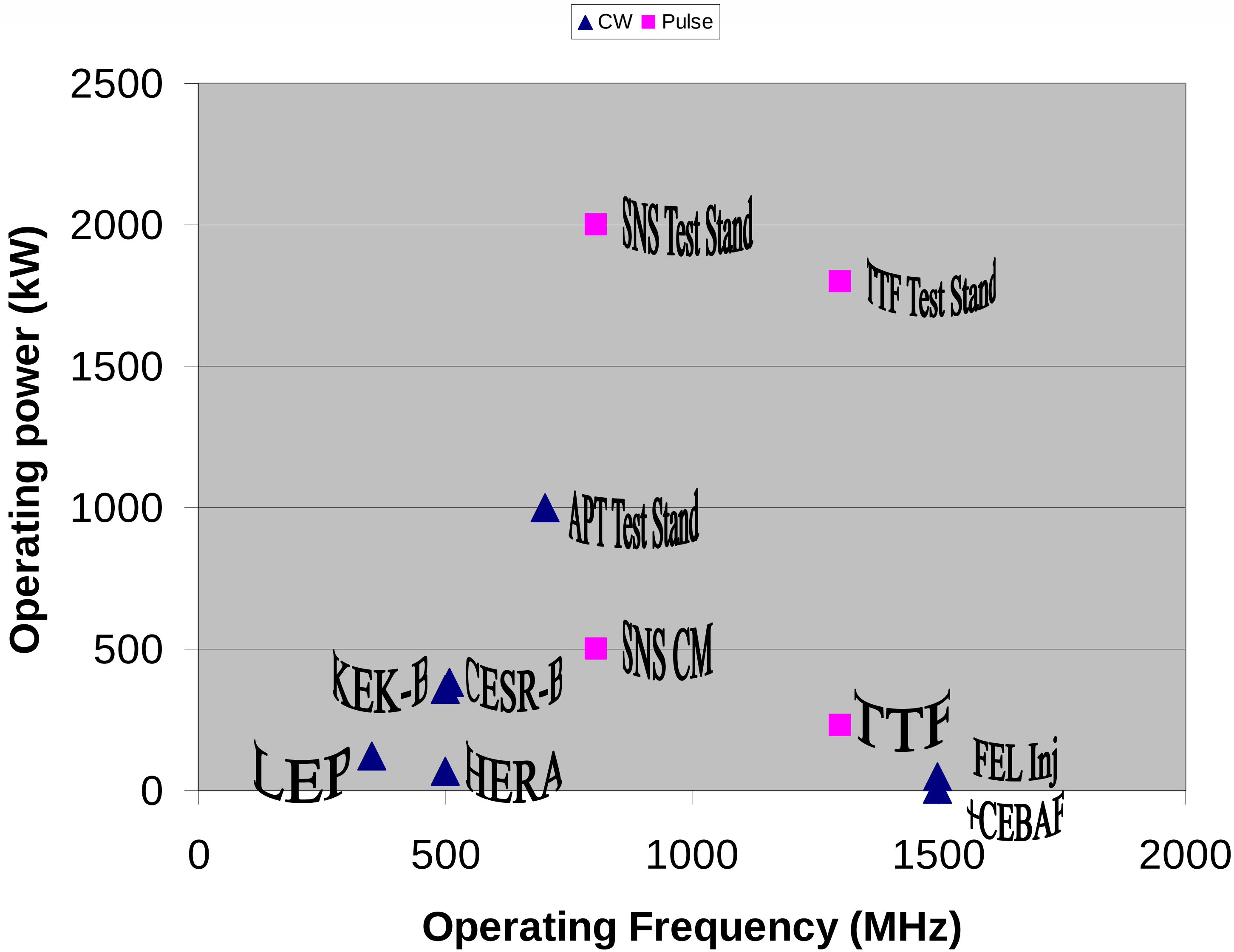
Cornell ERL

Figure 7: Temperature map of the coaxial part.

Table 4: Heat flow at coupler components.

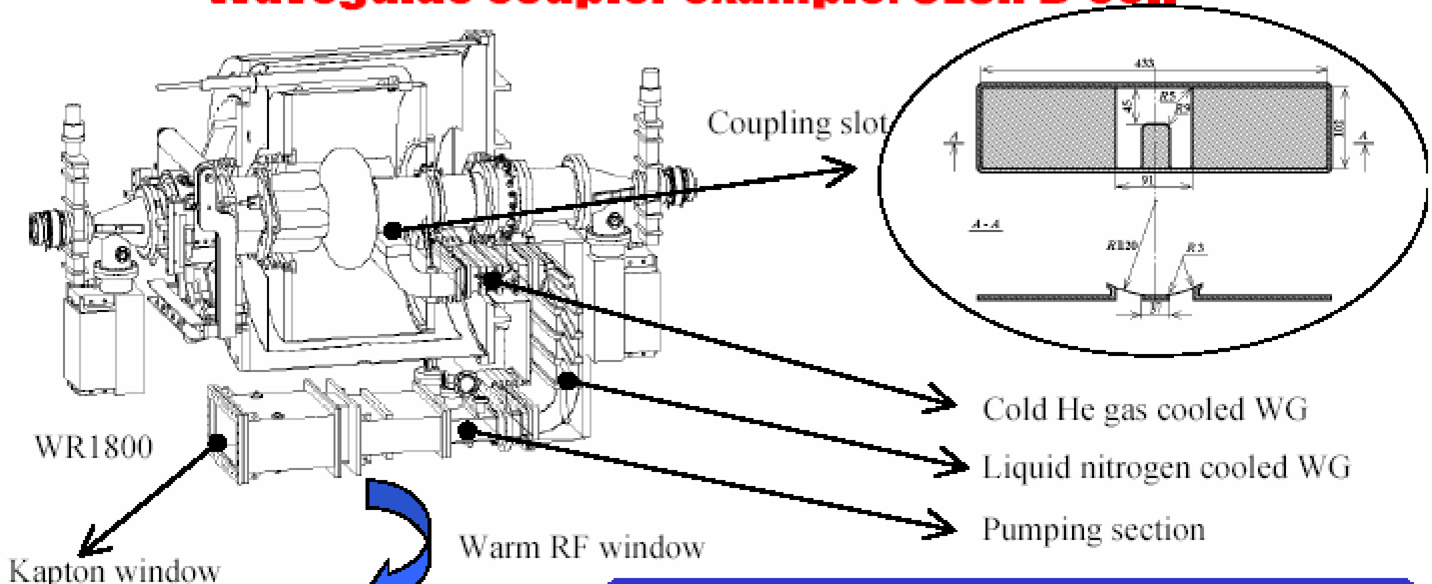
Flange 2 K	0.17 W
Heat sink 5 K	3.53 W
Total loss at 80 K	70.6 W

Couplers for superconducting cavities

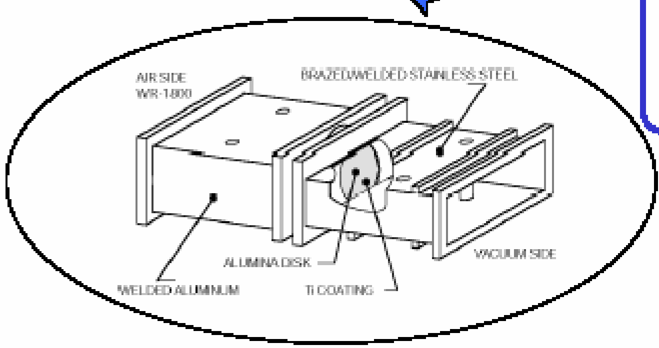


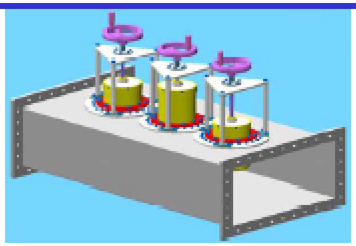
Successful CW coupler: waveguide

Waveguide coupler example: CESR B-cell



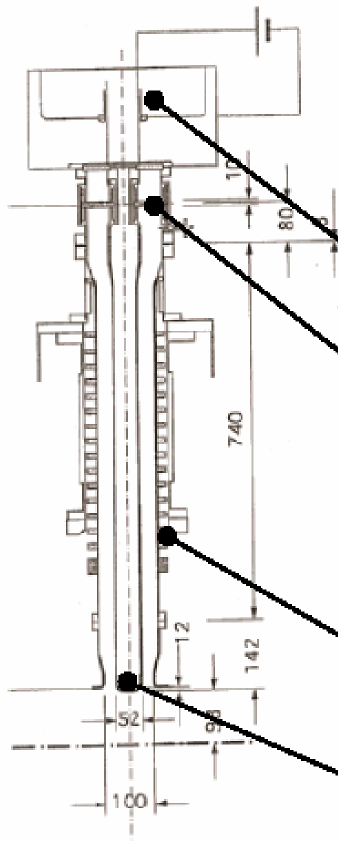
- Fixed coupling @ $Q_{ext} = 2\times10^5$
- Magnetic bias of the WG to suppress multipacting
- Adjustability is provided via a 3-stub WG transformer





Successful CW coupler: coaxial

Coaxial coupler example: KEKB



- Based on the long-term operation of 32 SC cavity couplers in TRISTAN
- 50 Ohm coaxial line
- Fixed coupling @ $Q_{ext} = 7\times10^4$
- Improved monitoring, cooling, choke structure around window

Biased doorknob (±2 kV)

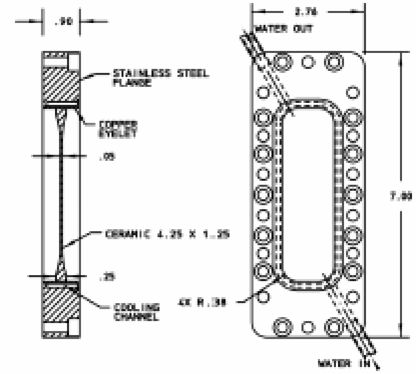
Alumina (99.5%) coaxial disk window, coated with 100 Å of TiN_xO_{1-x}, air cooled outside

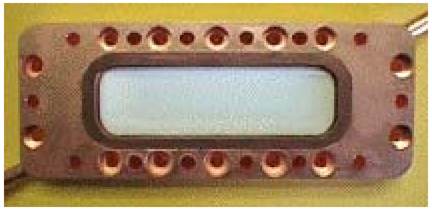
Copper plated SS,
4 K He gas cooling at 8 l/min

Water cooled inner conductor,
electropolished copper

JLab FEL Injector warm window

Run to 50 kW in test stand
Operated to 30 kW in ¼ cryomodule





Design still maintains the CEBAF double window configuration

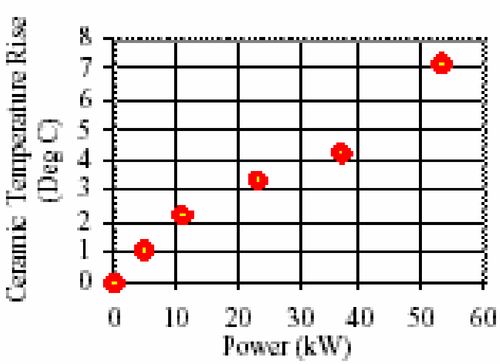
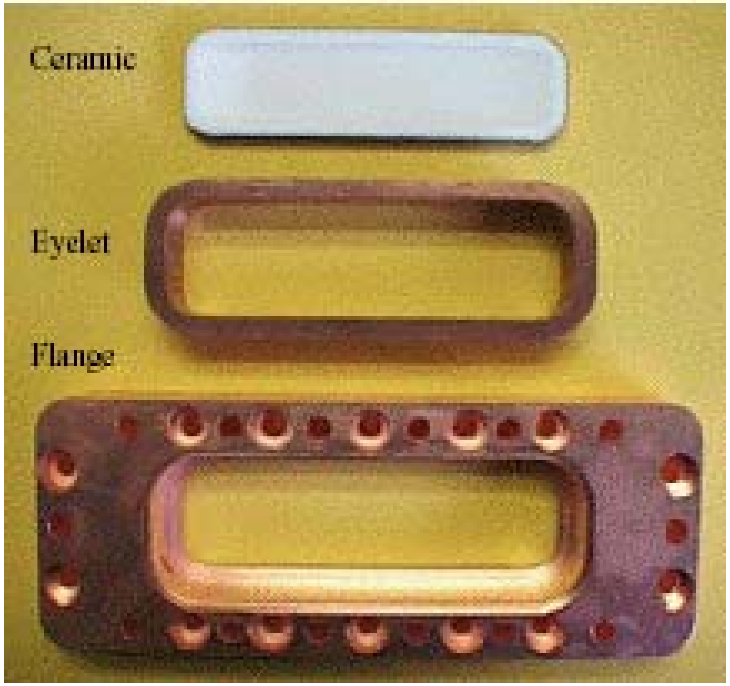
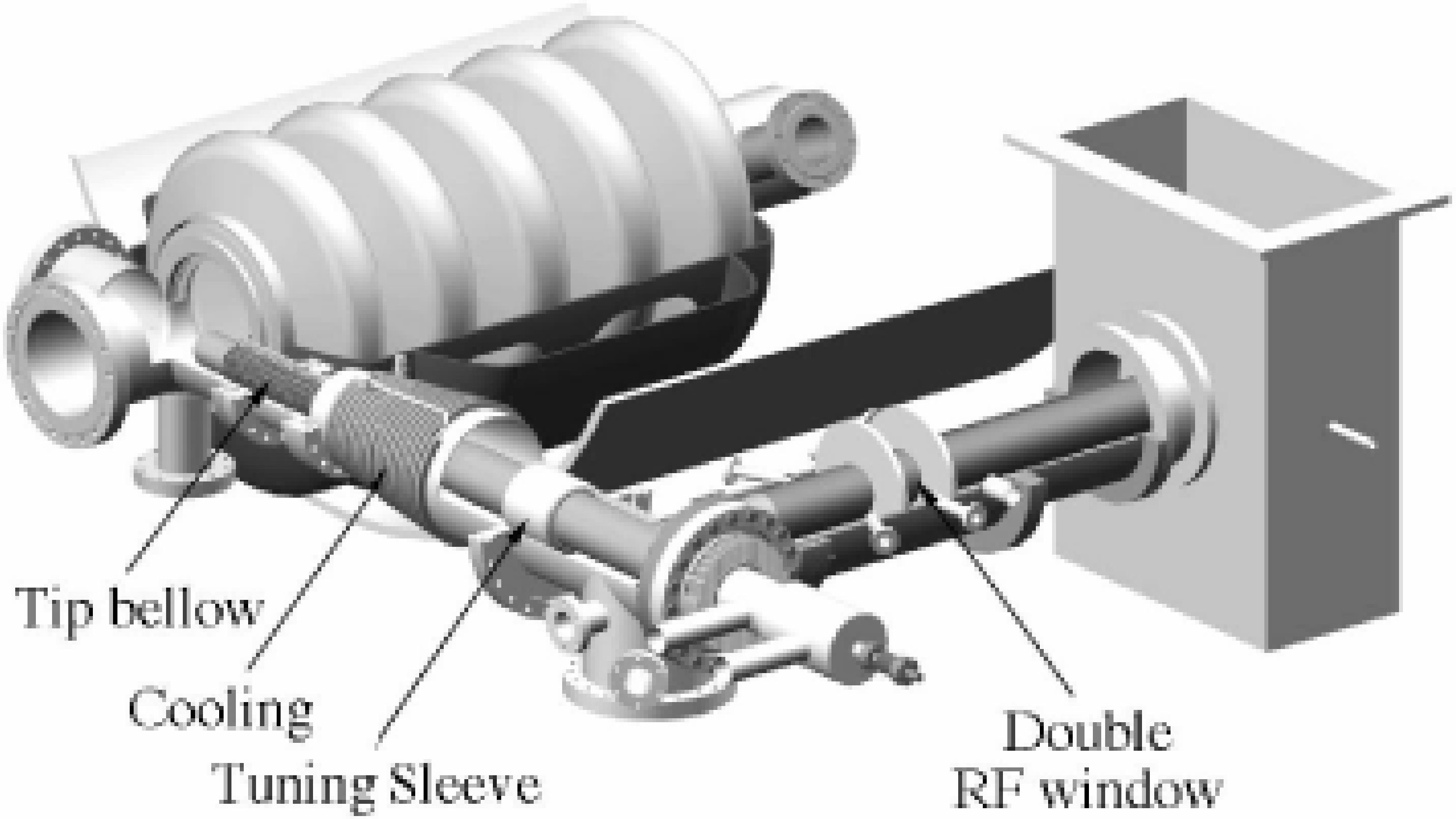


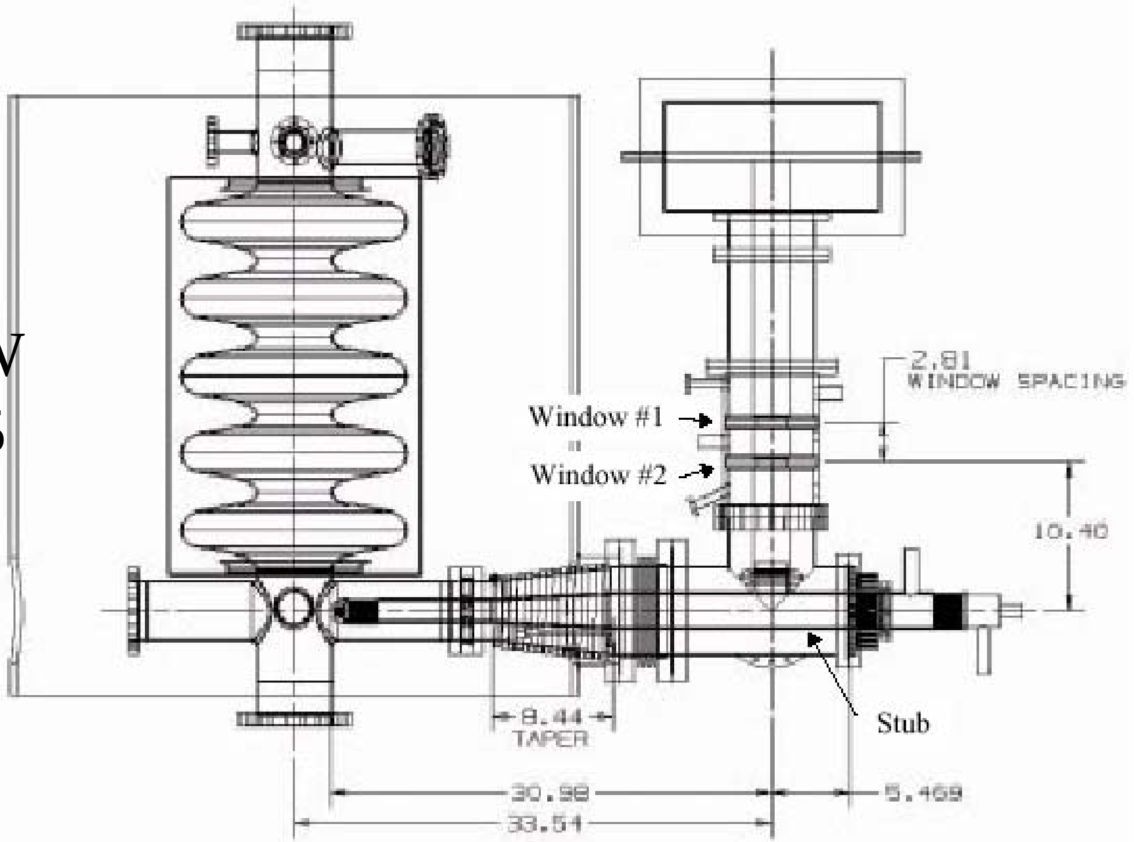
Figure 5. Ceramic temperature rise vs power



APT coupler configuration



APT Coupler details



High Power: > 400 kW CW
Variable coupling: 2 - 6 E5
High-speed pumping
Double window
Tested on CW stand to
•1 MW TW
•850 kW SW

APT test stand and conditioning effects

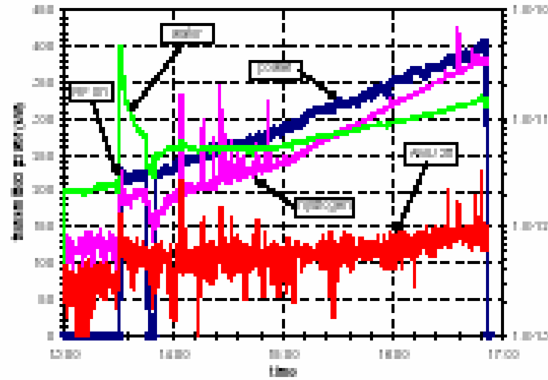
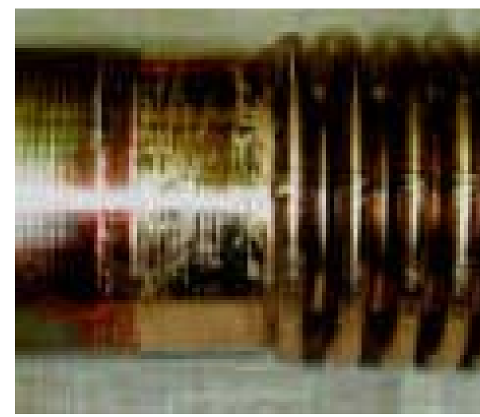


Figure 4: Residual gas magnitude (right axis) and power level (left axis) versus time during a room temperature power level sweep to look for multipacting power levels.



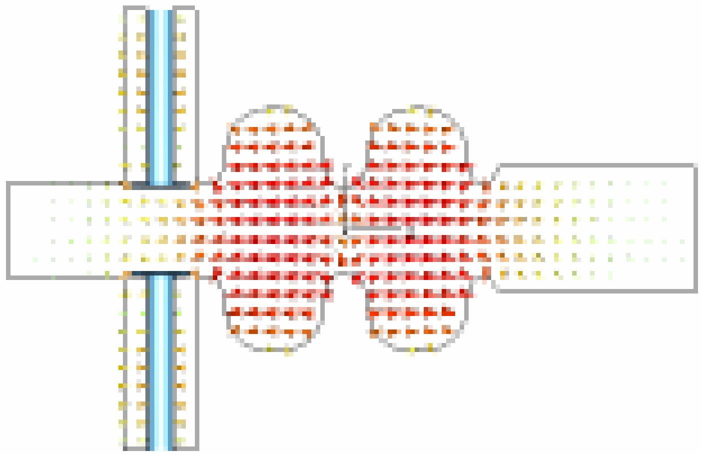
Bellows are the weak area

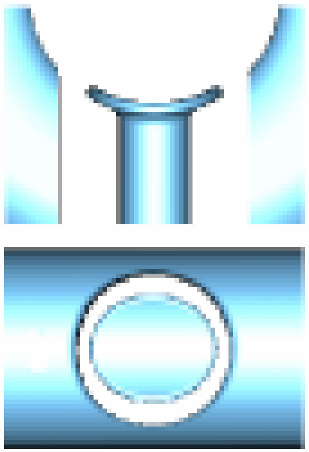
Cornell ERL operating parameters

Table 1: RF parameters of ERL cavities.

	Buncher cavity	Injector cavity	Linac cavity
Frequency, MHz	1300	1300	1300
Energy of particles, MeV	0.5	0.5 to 5 (15)	5 (15) to 100
Number of cells per cavity	1	2	9
R/Q, Ohm	210.5	218.4	1036
Q_0	2×10^4	$\geq 5\times10^9$	$\geq 10^{10}$
Q_{ext} nominal	2×10^4	4.6×10^4	2.6×10^7
Q_{ext} range	–	4.6×10^4 to 4.1×10^5	8×10^5 to 4×10^7
Cavity gap voltage, MV	0.12	1 (3)	20.8
Installed RF power per cavity, kW	20	150	20

Cornell ERL coupling scheme





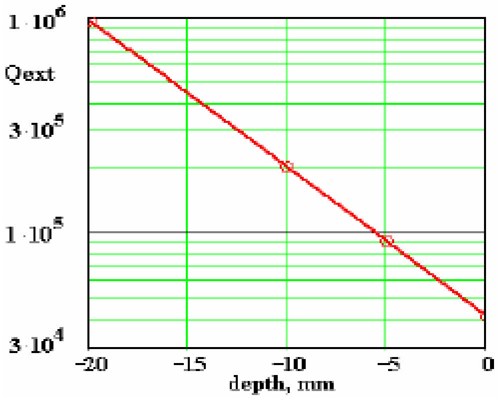
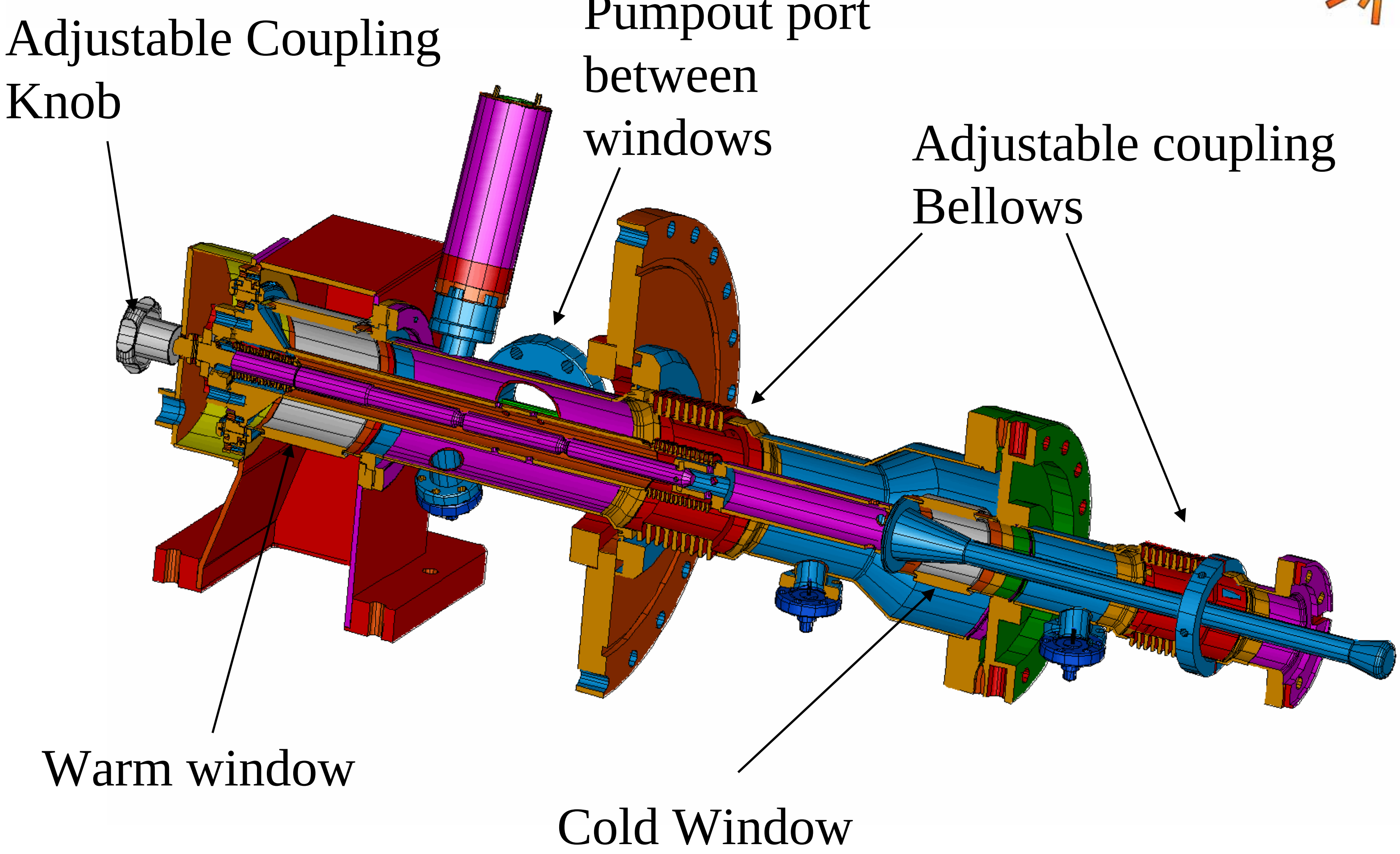


Fig. 3. Dependence of Q_{ext} on the depth of antenna penetration measured relative to the inner cavity iris.

Fundamental π-mode frequency	1300 MHz
E_{pk}/E_{acc}	1.94
H_{pk}/E_{acc}	42.8 Oe/(MV/m)
Coupling cell to cell	0.7 %
R/Q , fundamental mode (FM)	218 Ohm
Q_{ext} , FM, required range	$4.6\times10^4 \ldots 4.1\times10^5$
Q_{ext} , FM, penetration *depth* of the antenna = 0…-15 mm	$4.1\times10^4 \ldots 4.6\times10^5$
$Q_{ext,p}$, dipole mode, parallel	250
$Q_{ext,t}$, dipole mode, transverse	1000

TTF 3 coupler



Modified TTF3 Coupler for Cornell Injector

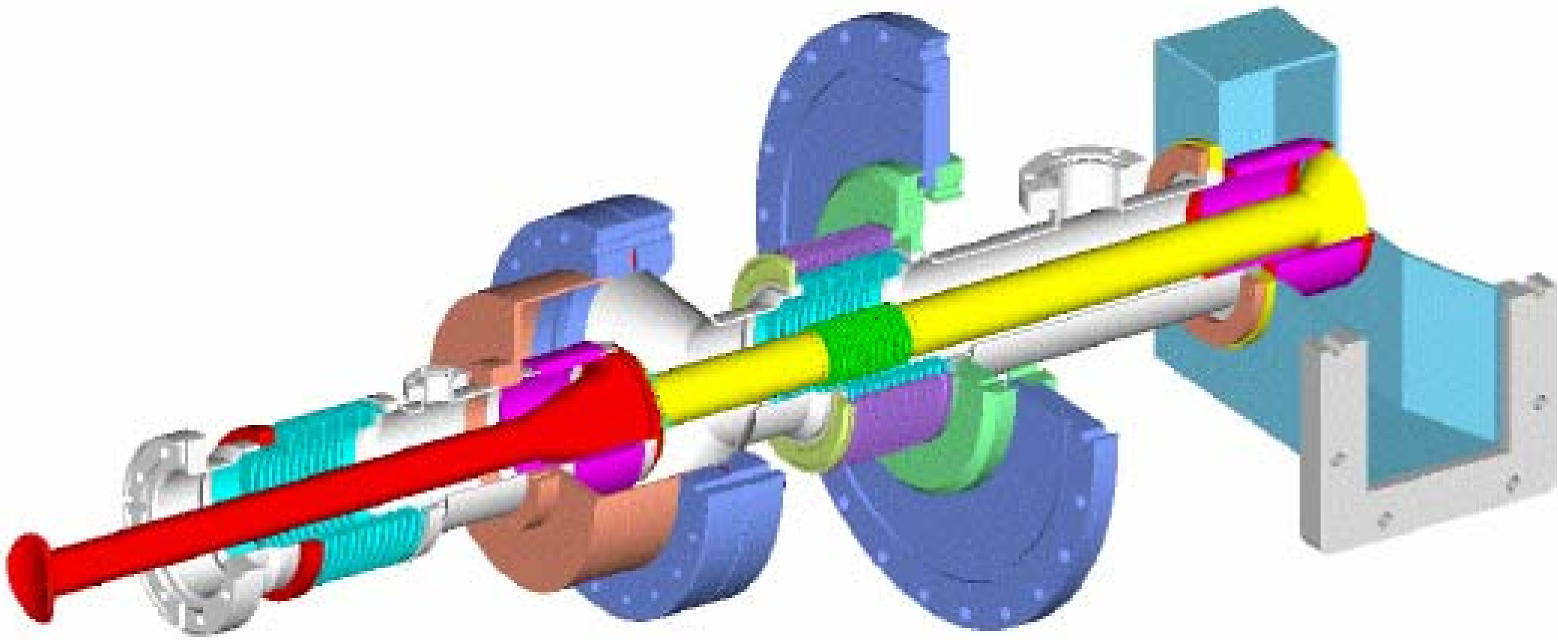
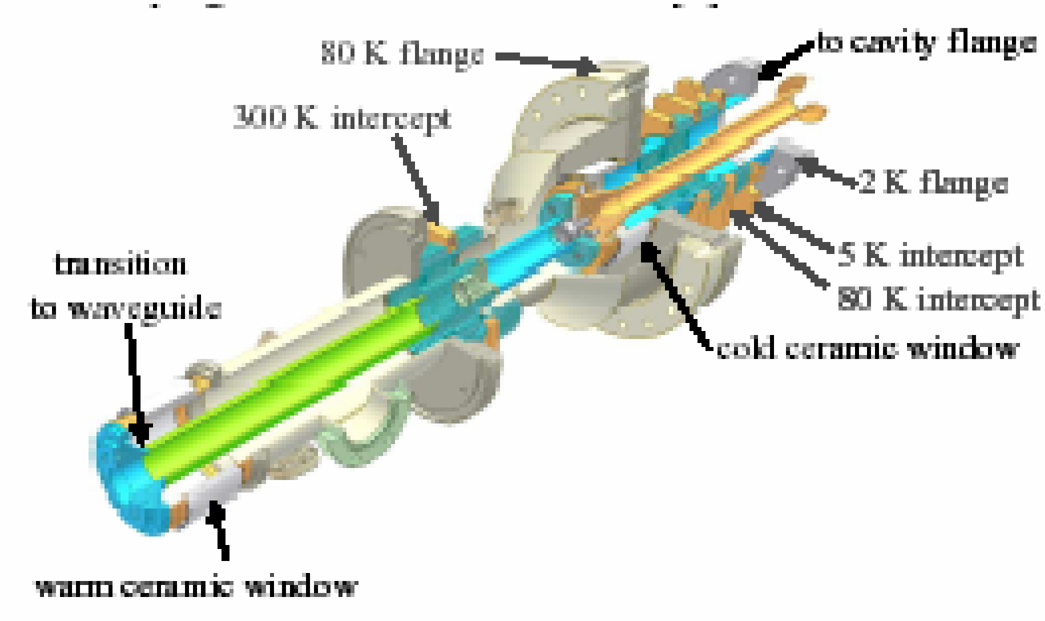
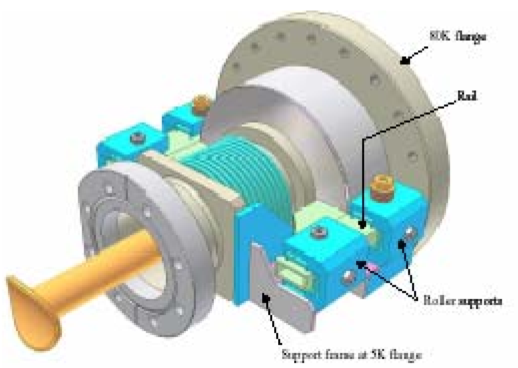
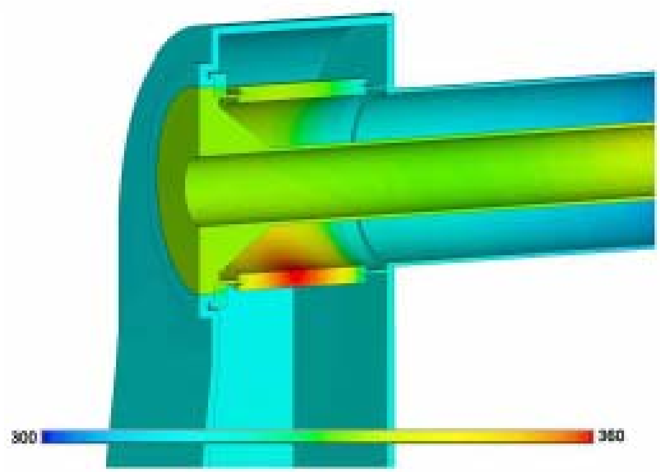


Figure 3: 3D view of the injector cavity coupler.

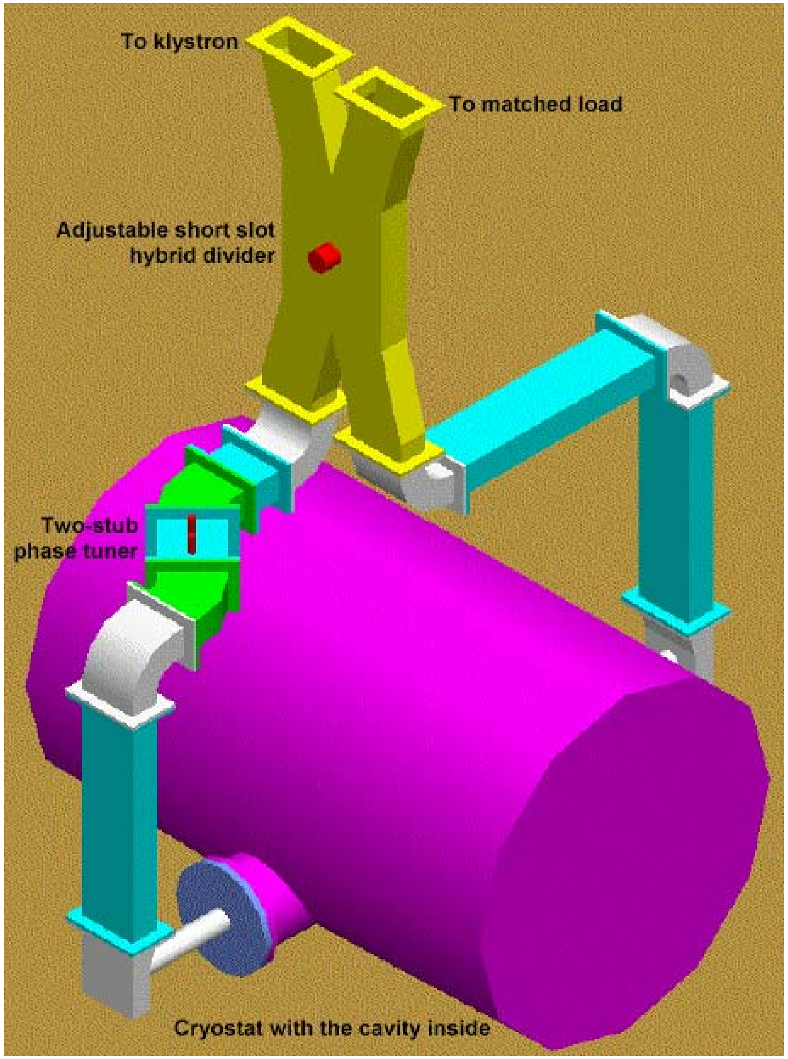
Cornell ERL thermal and mechanical study







Cornell symmetric coupler configuration



Cornell coupler testing configuration

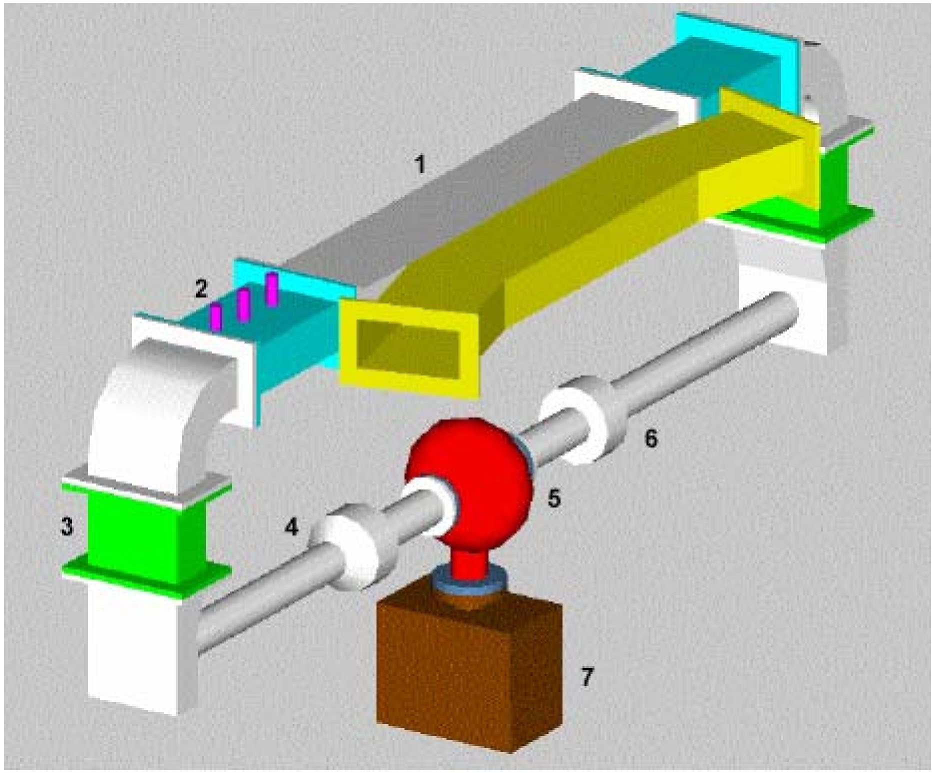
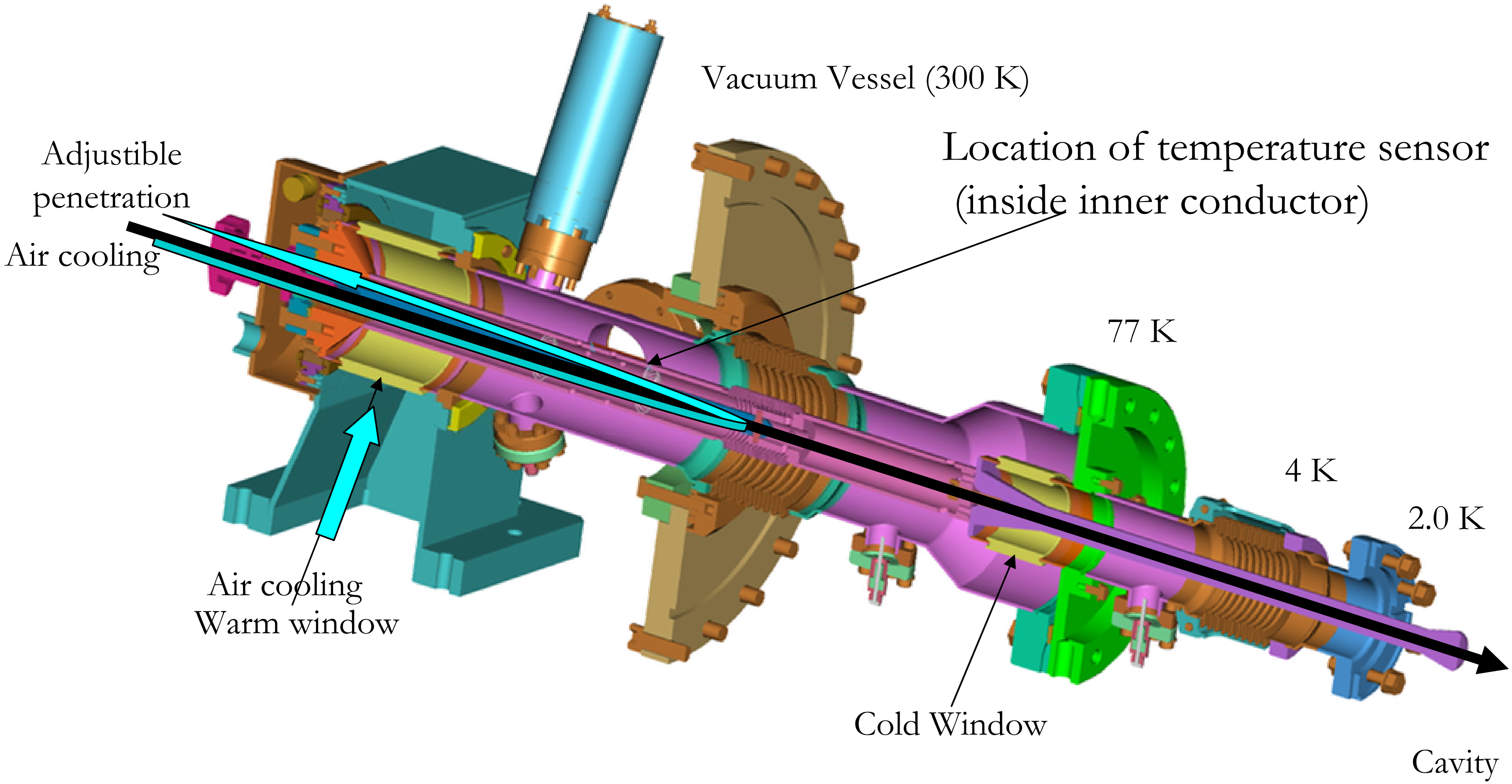


Figure 22: 3D view of resonant ring for coupler tests. 1: main directional coupler; 2: 3-stub transformer; 3: instrumentation directional coupler; 4, 6: couplers under test; 5: coupling cavity; 7: vacuum pump.

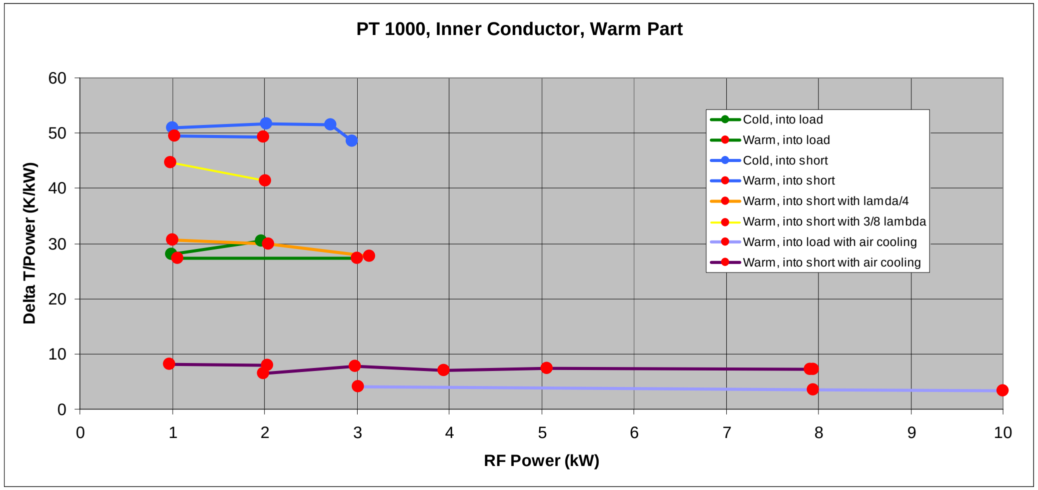
BESSY Test configuration

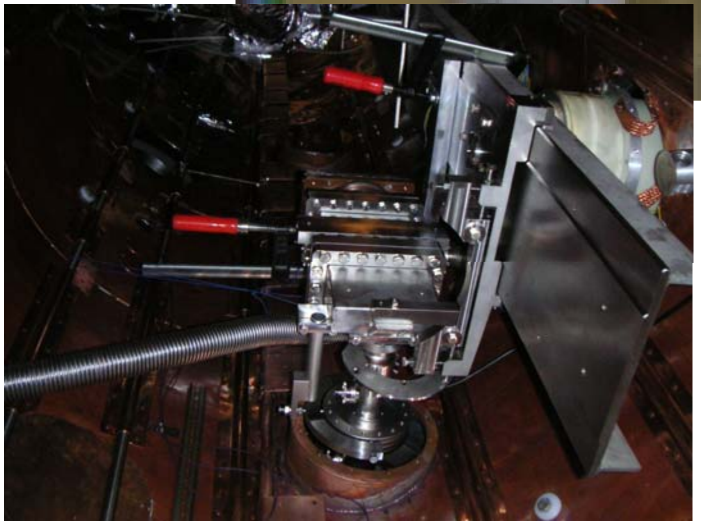


CW tests of TTF3 coupler

Rossendorf: CW test of TTFIII coupler to 4 kW at room temperature

BESSY: test in HoBiCaT at 10 kW





CW limitations: a personal view

- Bellows: geometry changes, field enhancement, difficult to clean, source of multipacting, difficult to cool, typically made out of materials difficult to work with
- Window cooling: need simple, symmetrical geometries that distribute the losses uniformly and remove the heat effectively. Need improved dielectric materials
- Coaxial tip cooling: Stefan will get you!
- Complicated geometries: difficult to predict multipacting, difficult to clean…..
- ………discussion…..