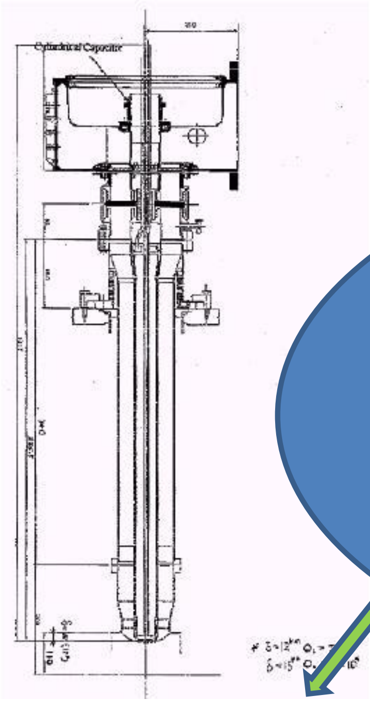
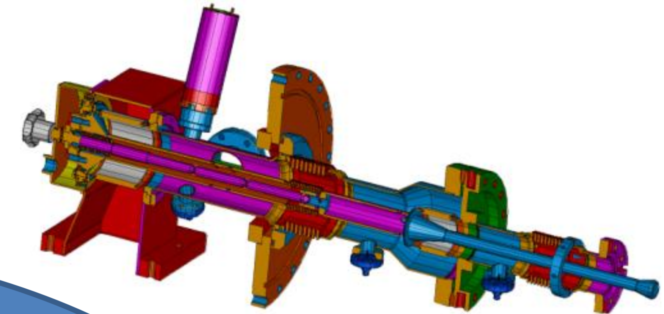
Power coupler development for high intensity superconducting linacs

G. Devanz
CEA-Saclay

The archetypes and offsprings





Tristan coupler

KEK-B coupler
508 MHz
350 kW CW to beam
10 yrs+ beam operation

TTF 1.3 GHz
250 kW peak power
0.5 kW average power
10 yrs+ beam operation

Pulsed couplers

- KEK Compact ERL 1.3 GHz
- J-Parc 972 MHz
- SNS 805 MHz
- CEA-Saclay 704 MHz

CW couplers

- BNL 704 MHz
- IPN Orsay 704 MHz

Pulsed couplers

- XFEL
- ILC

CW couplers

- Cornell ERL injector
- Cornell ERL main linac
- Daresbury ALICE

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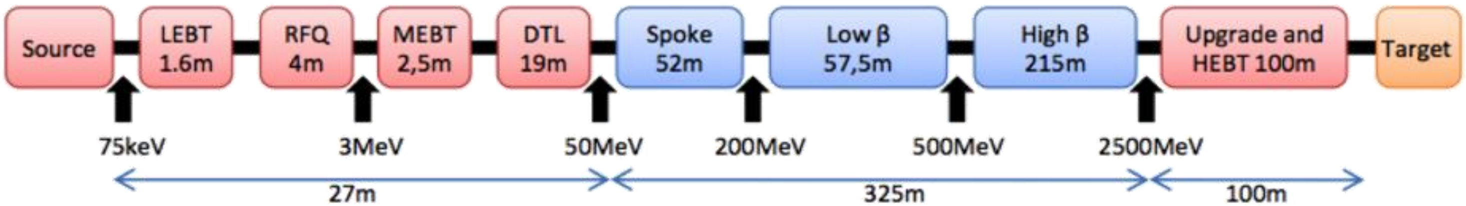
Power needs in SC H+/H- pulsed linacs

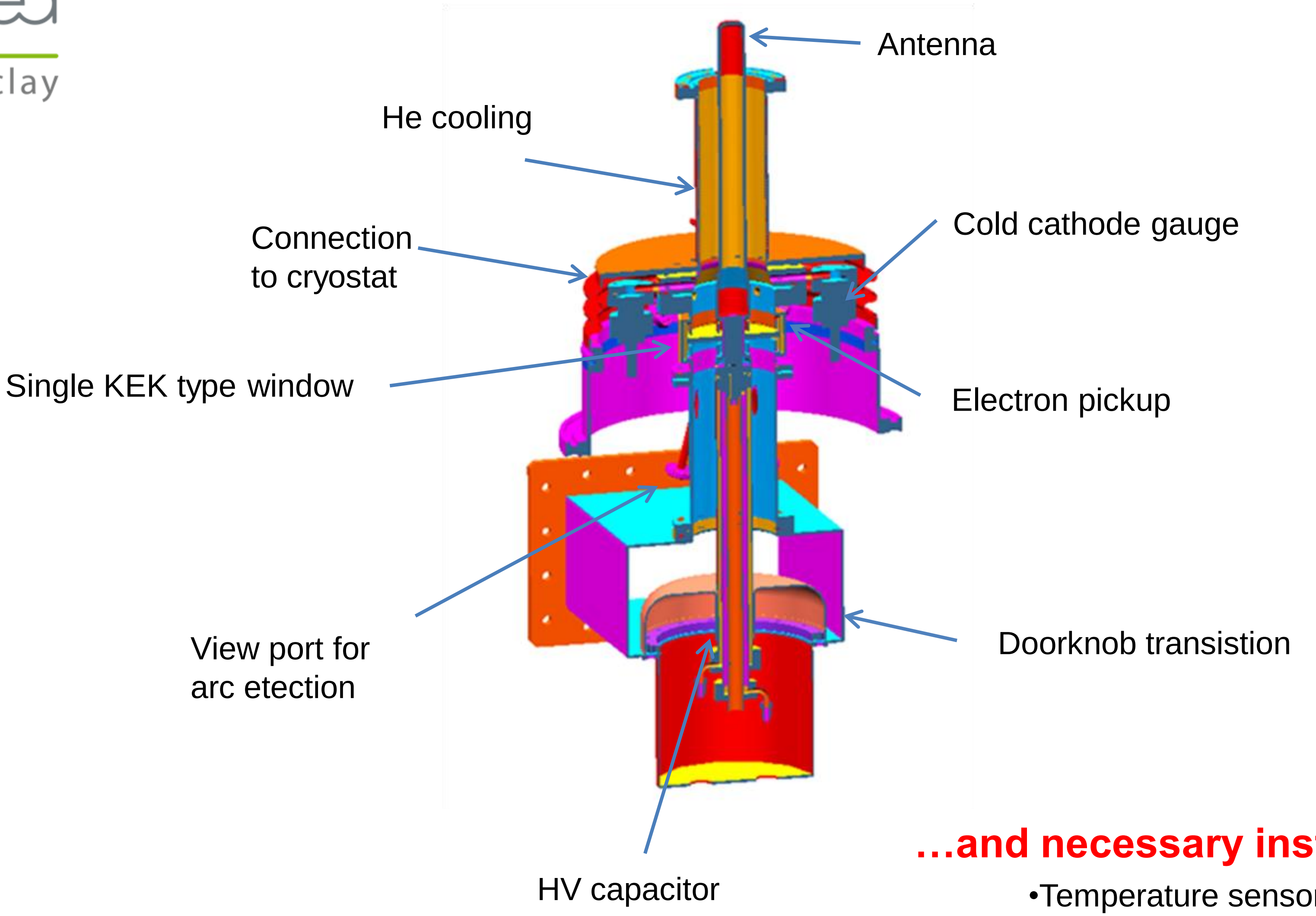


: ESS baseline

	SPL	ESS	SNS	SNS upgrade
RF frequency	352/704	352/704	402/805	402/805
Beam current (mA)	40	50 (75)	38	59
Repetition frequency (Hz)	50	20	60	60
RF Pulse length (ms)	0.6 – 2	2	1.3	1.3
High β Elliptical cavities (MV/m)	20 - 25 5-cell	15 - 20 5-cell	13 - 15 6-cell	15 - 18? 6-cell
Peak Power delivered (kW)	1000	900	550 design 300 beam	600 ? (depends on Eacc reached in cavities)

Q_{ext} of the order of 10^6
Power margin for RF control

SNS couplers



…and necessary instrumentation

- Temperature sensors
- Flow meters

Courtesy M. Stirbet

Irfu
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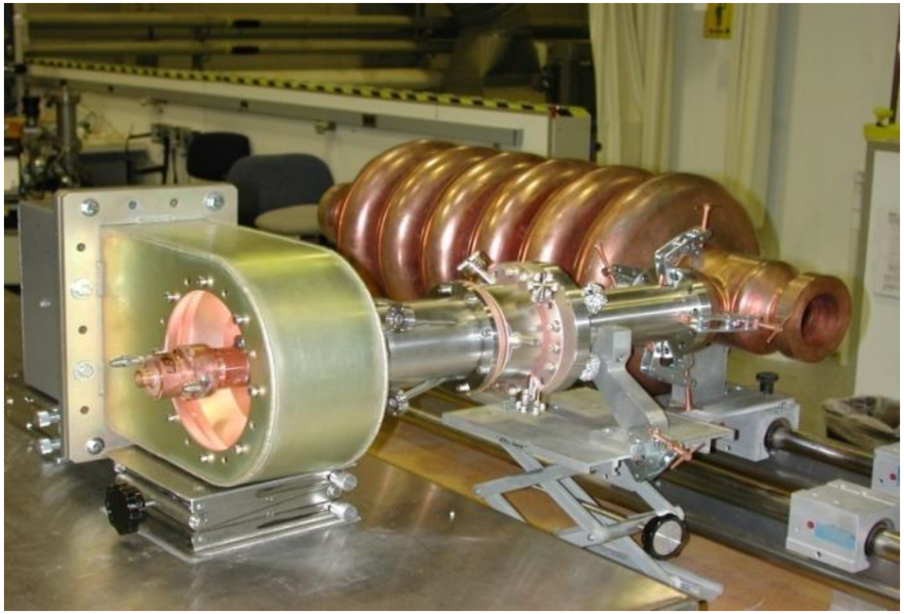
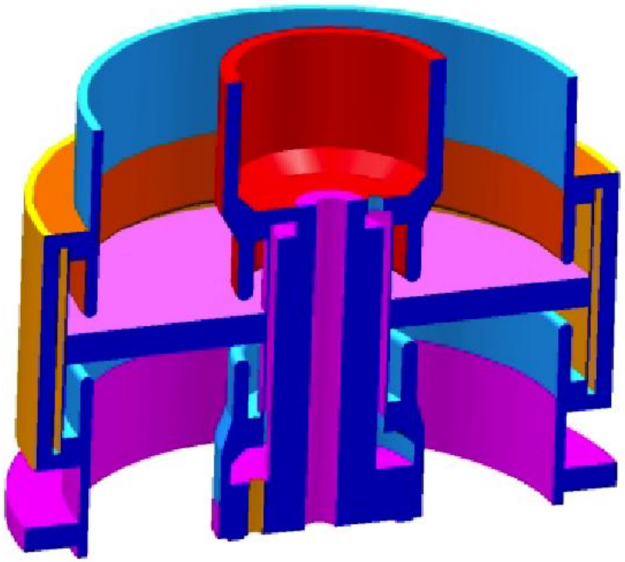
SNS couplers





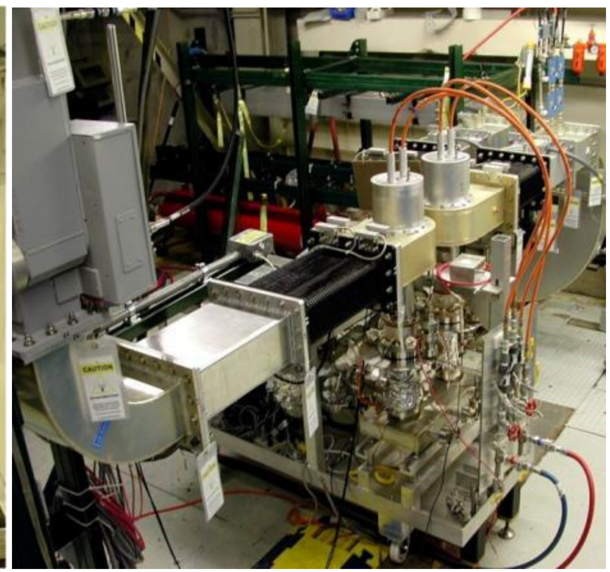
RF window

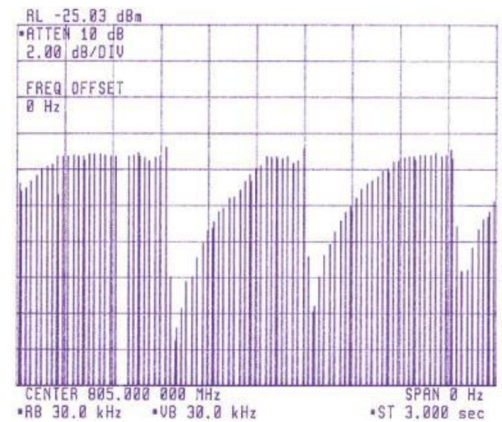
- 50 Ω coaxial line
- VSWR <1.1 at 805 MHz
- required Q_{ext} : $5 \times 10^5 \pm 20\%$
- power ratings: 400 kW at 7% duty cycle, design 550 kW
- operating pressure: $< 5\ 10^{-9}$ mbar
- ± 5 kV Bias Voltage
- He gas cooling on the outer conductor (0.3 g/s, 3 atm, inlet 5K exit 300 K)
- Water cooling on inner conductor extension (300 K)
- Possibility to water cool the ceramic outer diameter

Courtesy M. Stirbet

SNS couplers tests and operation statistics

	Design	Conditioning	Machine operation
Peak power (kW) in TW	550	650 - 1000 at Oak Ridge 1000 at Jlab	300
Peak power (kW) in SW	550	600	300





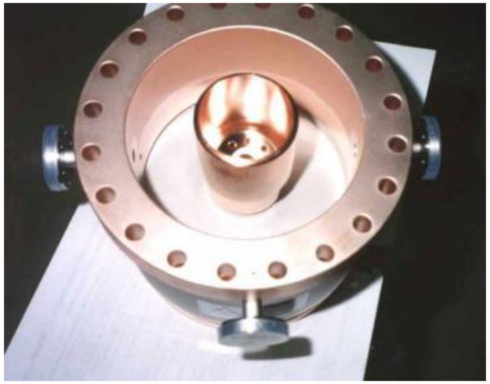
84 couplers were conditioned
81 running on the SNS
0 coupler failed

For the SNS upgrade

- The 650 kW – 1 MW range the couplers have been tested is sufficient
- Cold cathode Pressure gauge replaced
- Reduce thermal leak (end group are from Low RRR, quench observed)
    - Remote control of the He flow valves, discrepancies among couplers
    - Improve antenna cooling to reduce radiative losses

Courtesy M. Stirbet
See poster THP051

J-Parc 972 MHz coupler



	Design
Frequency (MHz)	972
Impedance (Ω)	50
Diameter (mm)	80
Qext	$5\ 10^5$
Peak power (kW)	300
Pulse length (ms)	3
Repetition rate (Hz)	25

E. Kako et al. PAC03

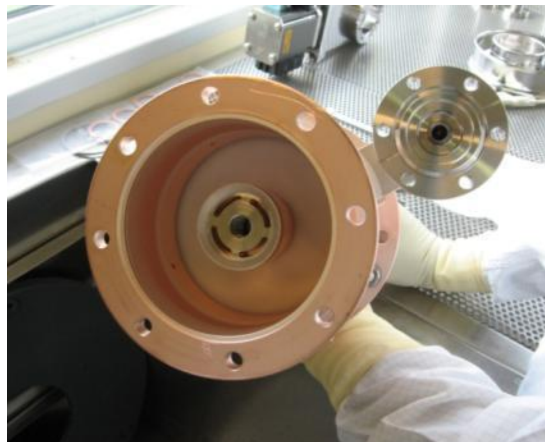
Test	Pulsed operation	Max. rf power
1. Initial Tests:		
	0.1msec, 10Hz	300kW
	2.45msec, 25Hz	350kW
2. Exposure to N_2 gas:		
	0.1msec, 10Hz	300kW
	2.45msec, 25Hz	350kW
	0.6msec, 25Hz	1100kW
3. Kept for one month without pumping:		
	0.1msec, 25Hz	1700kW
	0.6msec, 25Hz	2200kW
	Standing Wave	650-800kW
4. Exposure to air:		
	0.1msec, 25Hz	360kW
	3.0msec, 25Hz	370kW
	Standing Wave	370kW

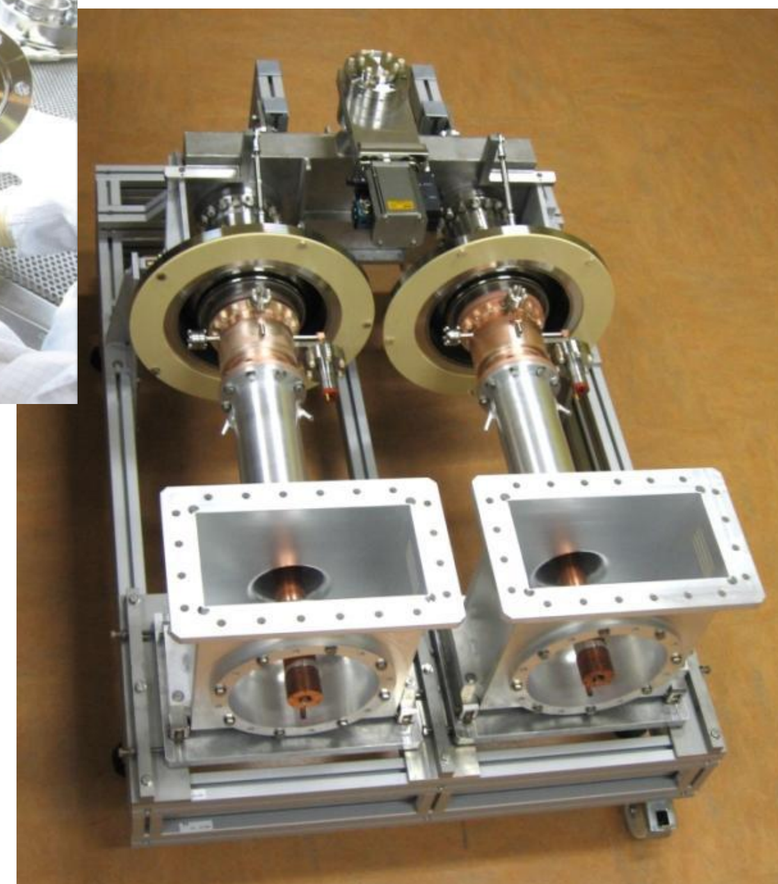
- Max. average power on the test stand 21 kW, limited by klystron power available
- turning off the water cooling of the inner conductor, antenna tip temperature increased by 100K
- Couplers tested on the prototype cryomodule connected to cavities at 2K

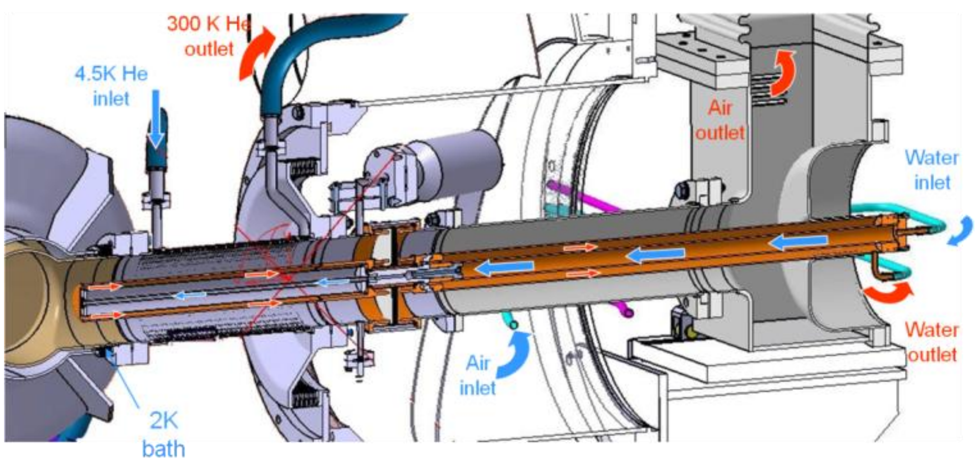
CEA-Saclay 704 MHz coupler

	Design
Frequency (MHz)	704
Impedance (Ω)	50
Diameter (mm)	100
Qext	$1.8\ 10^6$
Peak power (kW)	1000
Pulse length (ms)	2
Repetition rate (Hz)	50

- KEK type warm window matched at 704 MHz
- Water cooling of the inner conductor
- Cold part : double wall with He gas. Cu deposited by magnetron sputtering at CERN
- DC bias

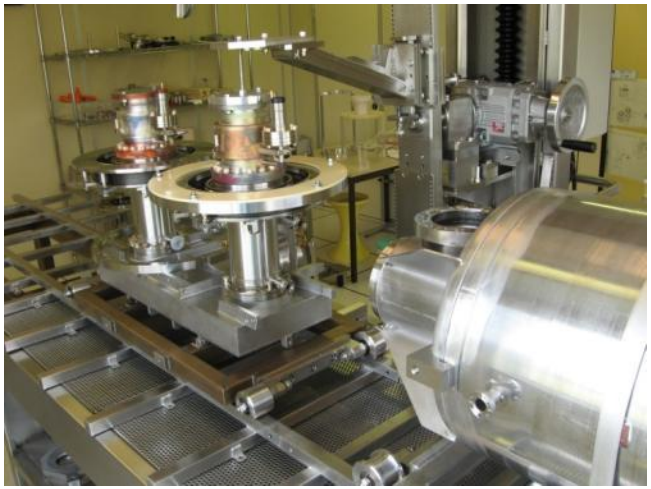




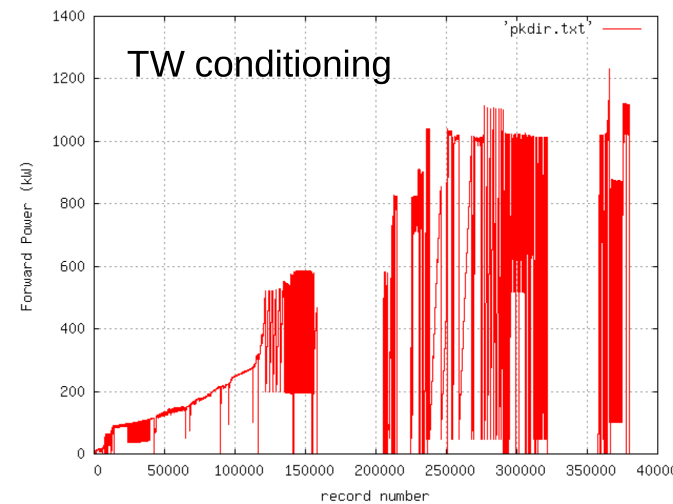


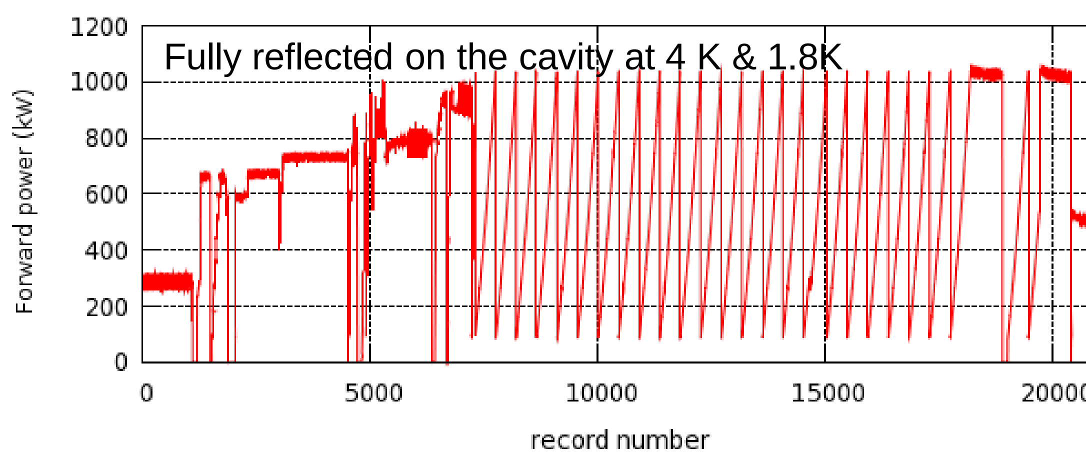
CEA-Saclay 704 MHz coupler

	Design	Conditioning	Cavity 1.8 K Cryholab (β=0.47)
Peak power (kW) in TW	1000	1200, 2 ms 50 Hz	-
Peak power (kW) in SW	1000	940, 1 ms, 0.31 Hz	1000, 2 ms 50 Hz, cavity off resonance

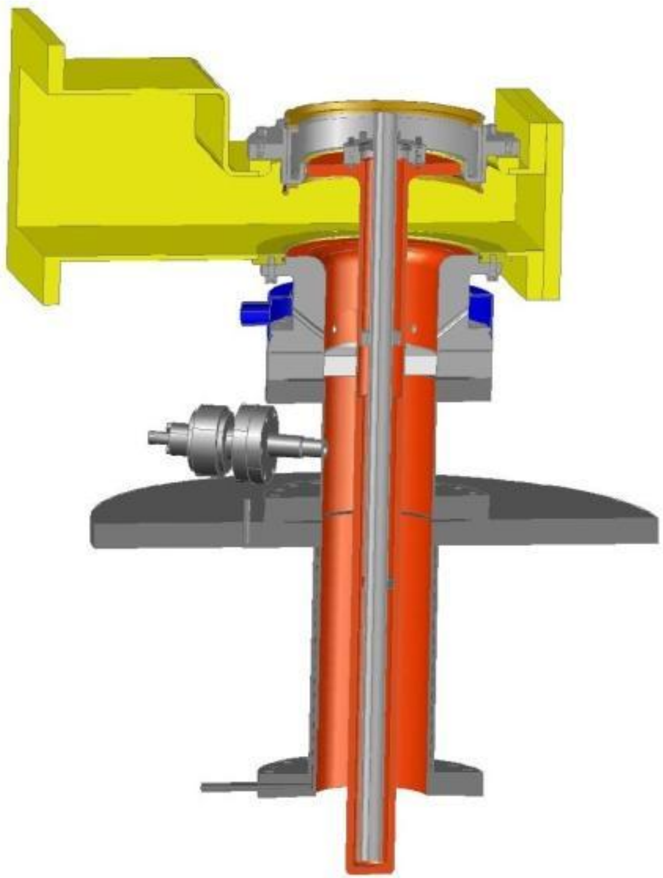


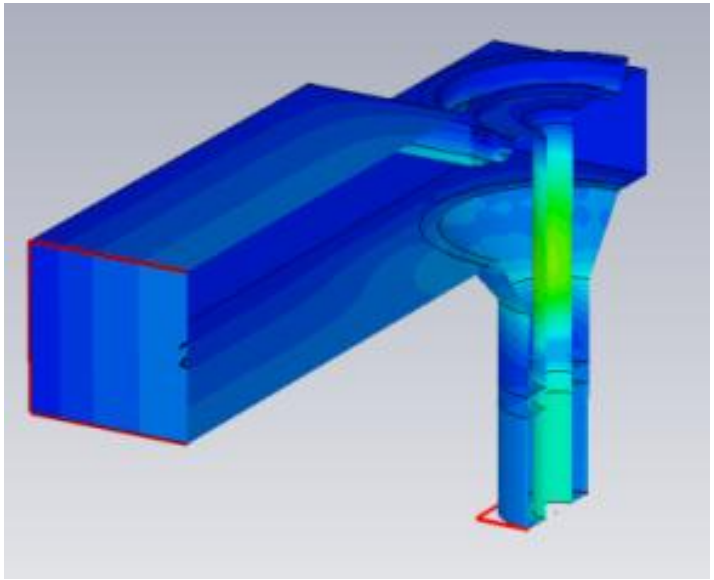
It is foreseen to test the coupler in CW on the cavity at 1.8 K to evaluate the dynamic losses





CERN SPL 704 MHz couplers



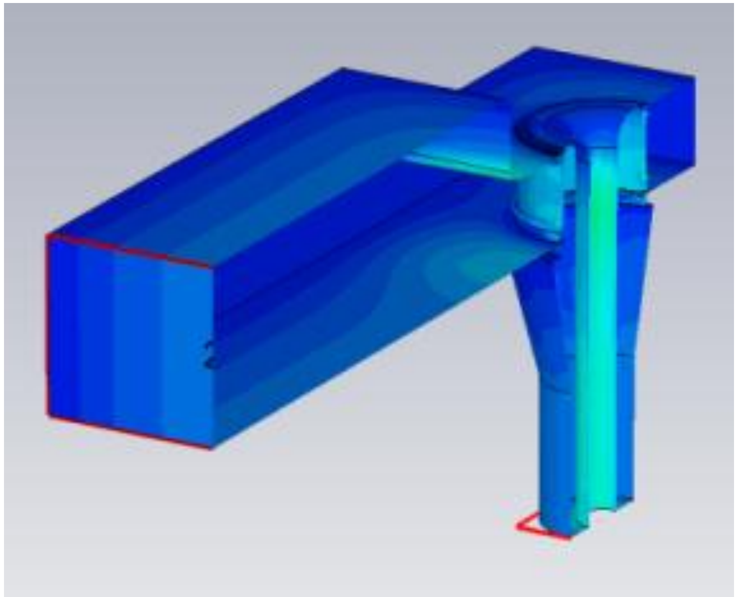


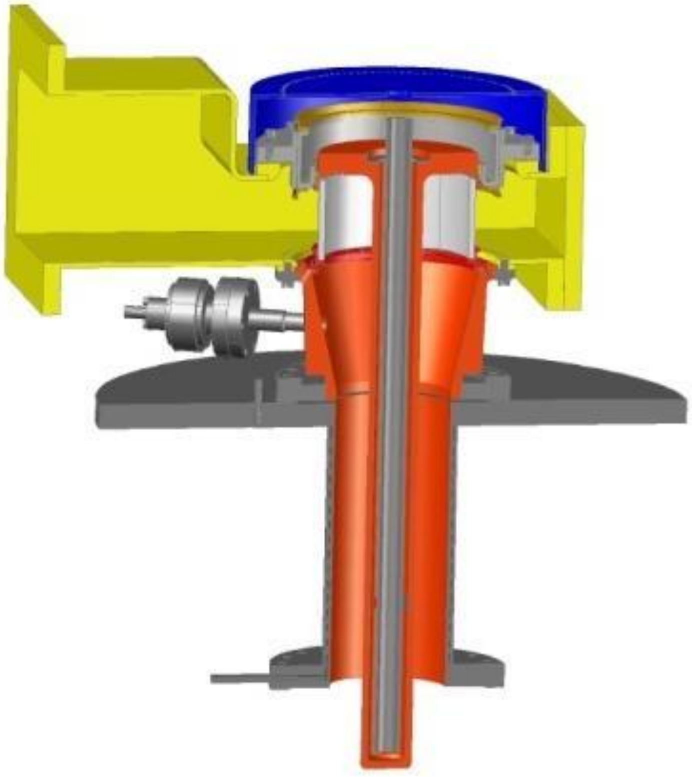
- 50 Ω
- SPS type window, RF matching using the waveguide transition
- DC bias
- Air cooled antenna
- LHC type double wall for He cooling

Prototypes are currently manufactured. Test is foreseen in 2011 at Saclay

Courtesy E. Montesinos

CERN SPL 704 MHz couplers



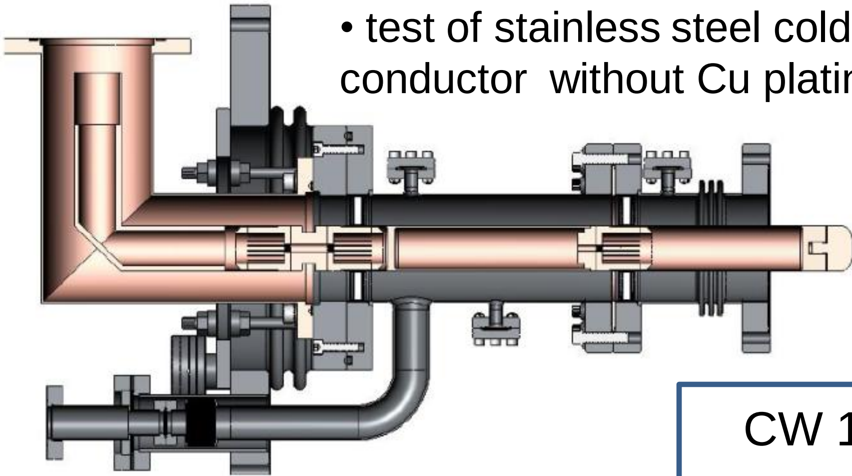


Same caracteristics but with LHC type cylindrical window

Window of first prototype after brazing

Courtesy E. Montesinos

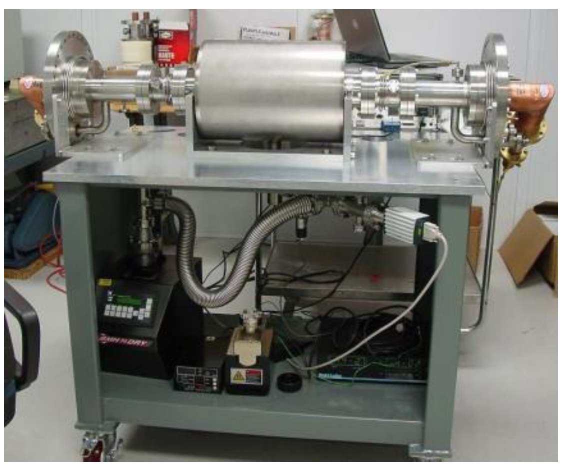
Projetc-X & HINS couplers



- solid copper antenna
- test of stainless steel cold outer conductor without Cu plating

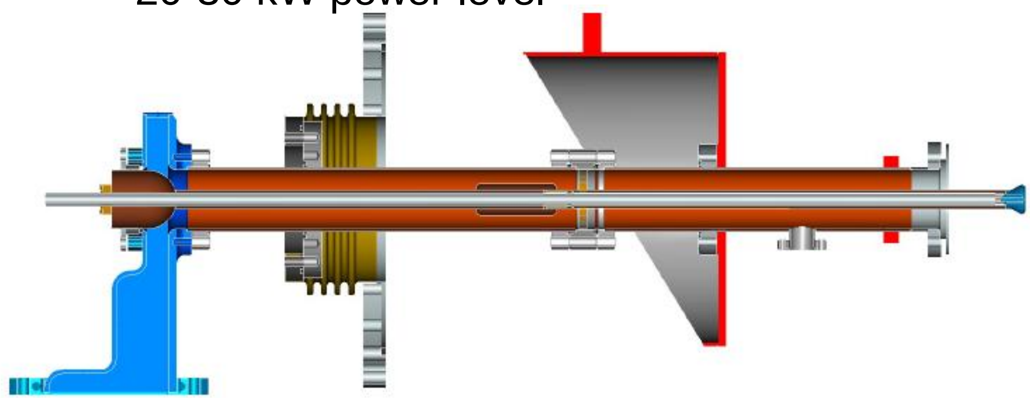
	Design
Frequency (MHz)	325
Impedance (Ω)	50
Diameter (mm)	78
Peak power (kW)	250

In 25 hrs conditioning obtained 700 kW, 3 ms 2 Hz



CW 1.3 GHz coupler concept

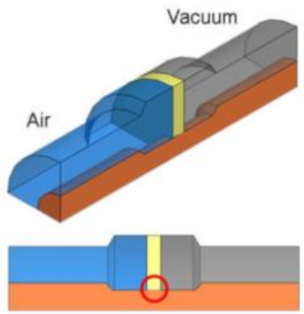
- fits in place of a ILC module
- single window
- fixed coupling
- 20-30 kW power level

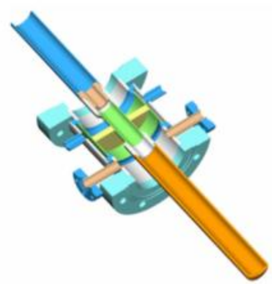


V. Yakovlev, S. Kazakov

SRF ion CW linacs

IPN-Orsay Eurisol Spoke coupler

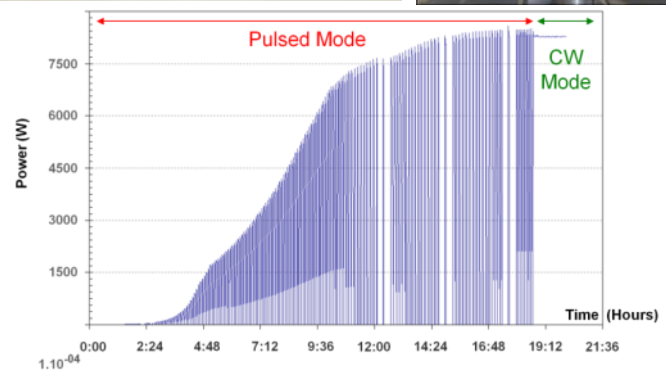




β = 0.15 spoke

	Design
Frequency (MHz)	352
Impedance (Ω)	50
Diameter (mm)	56
Qext	10^6
Max power (kW)	20

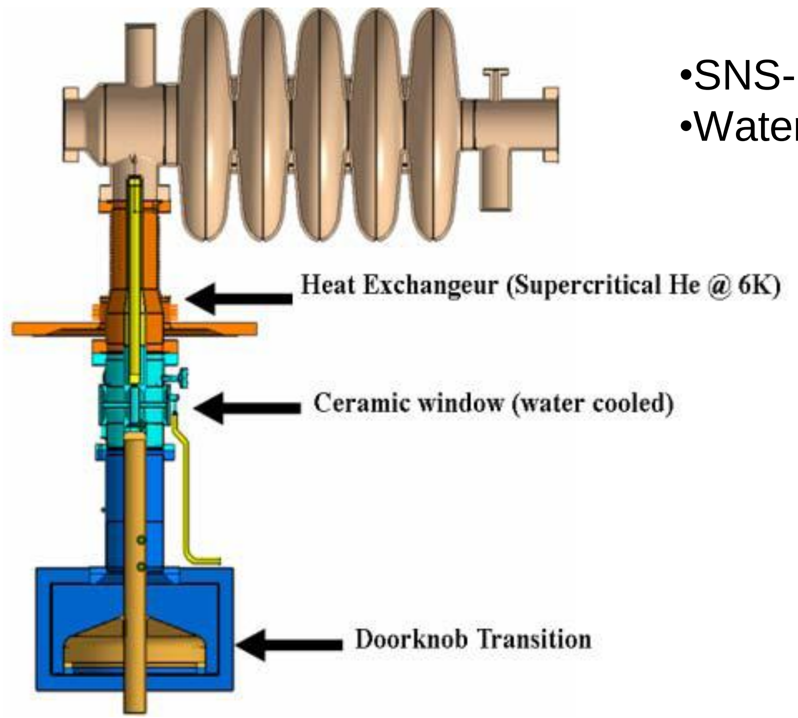
- window outer diameter cooling channel
- supercritical He heat exchanger (3 atm, 6 K)
- Test in the horizontal cryostat with the cavity done at 4.5 K and 2 K



	Design	Conditioning	Cryomodule test
Max. power (kW) in TW	20	8.8 (max. available)	-
Max. power (kW) in SW		-	4

Courtesy E. Rampnoux

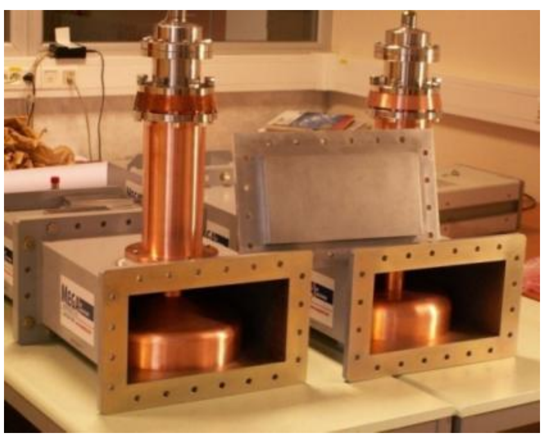
IPN-Orsay Eurotrans coupler



- SNS-like window
- Water cooled antenna

	Design
Frequency (MHz)	704
Impedance (Ω)	50
Diameter (mm)	80
Qext	10^7
Max. Power (kW)	150

All components are fabricated
Will be conditioned using a 80 kW IOT

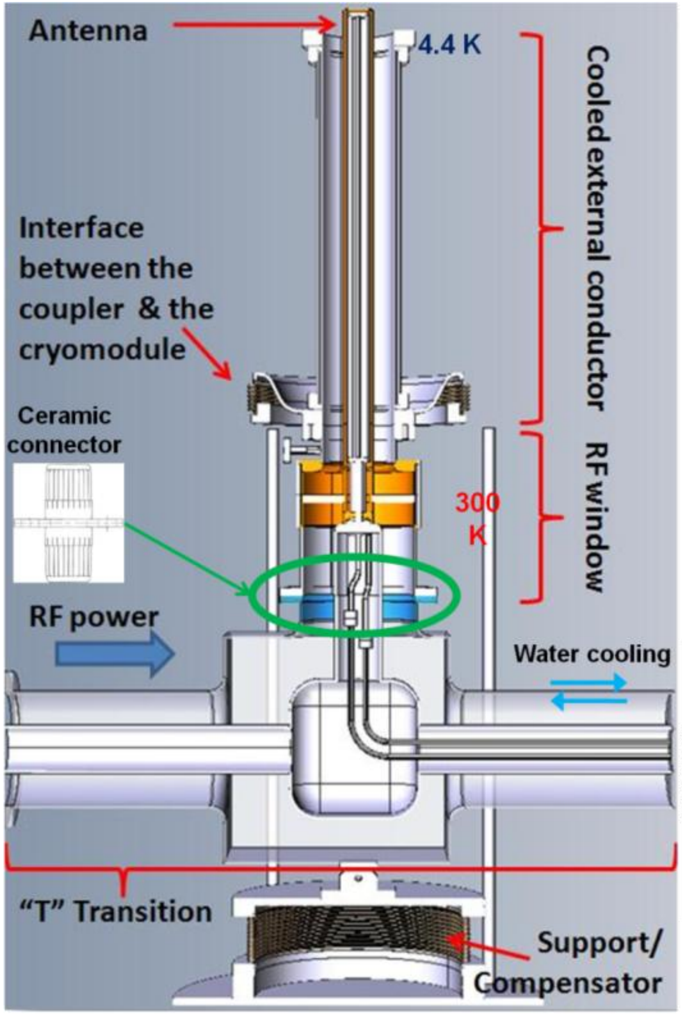


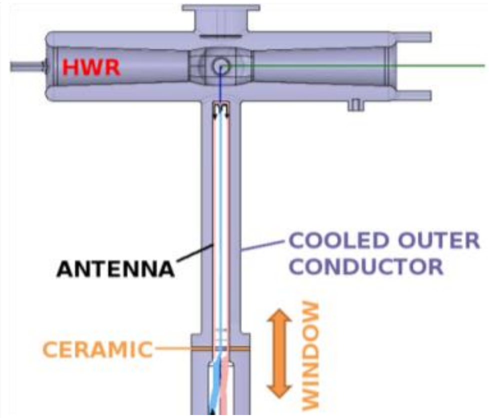
Doorknob transitions

Coupling cavity for tests

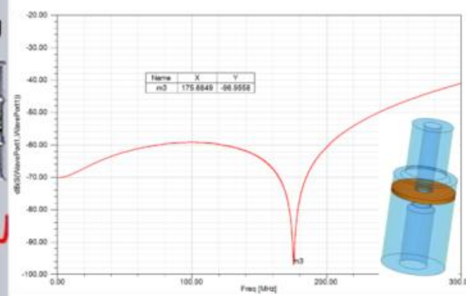
Courtesy E. Rampnoux

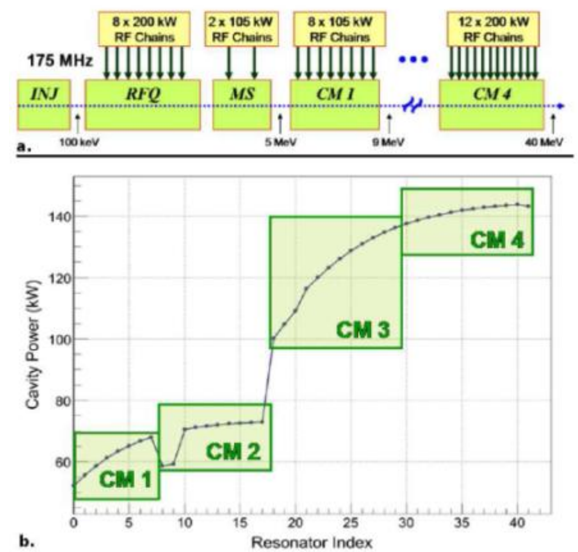
IFMIF-Eveda coupler – CEA-Saclay





	Eveda	IFMIF
Frequency (MHz)	175	175
Beam current (mA)	125	125
Qext	6.5 10^4	
Max. Power per coupler (kW)	70	200
Impedance (Ω)	50	
Diameter (mm)	98/152	





Prototypes have been ordered

Power needs for SRF ERLs

ERL injectors :

large CW beam current, moderate Eacc : high power

ERL main linacs:

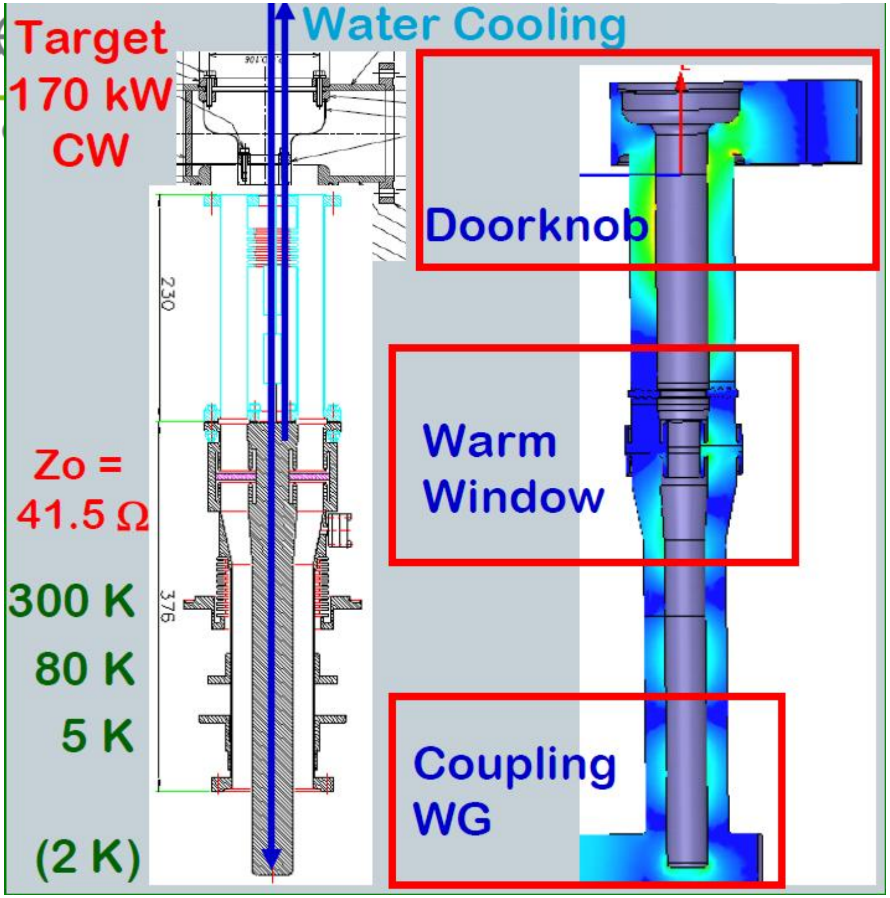
ERL mechanism, losses and microphonics to compensate : low power in SW

	BNL	Cornell	KEK
Frequency (MHz)	703.75	1300	1300
Beam current (mA)	500	100	50 (100)
Max. Power per coupler Injector (kW)	500	50	58 (167)
Max. Power main linac (kW) SW	-	5	20

At 1.3 GHz the TTF-3 coupler needs cooling to sustain more than 5 kW CW in standing wave (tested at BESSY in Hobicat)

2 couplers per cavity to preserve field symmetry

KEK ERL injector



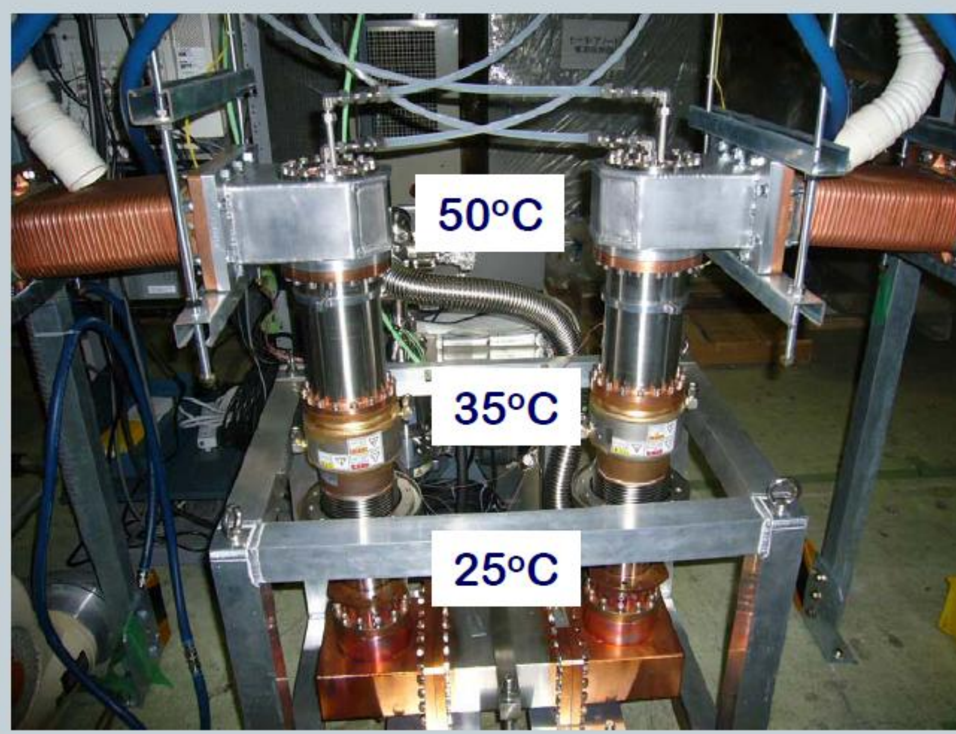
	Injector
Frequency (MHz)	1300
Beam current (mA)	50 (100)
Qext	4.5 (3.3) 10^5
Max. Power per coupler (kW)	58 (167)

2-cell ERL cavity

Courtesy E. Kako

KEK ERL injector - conditioning

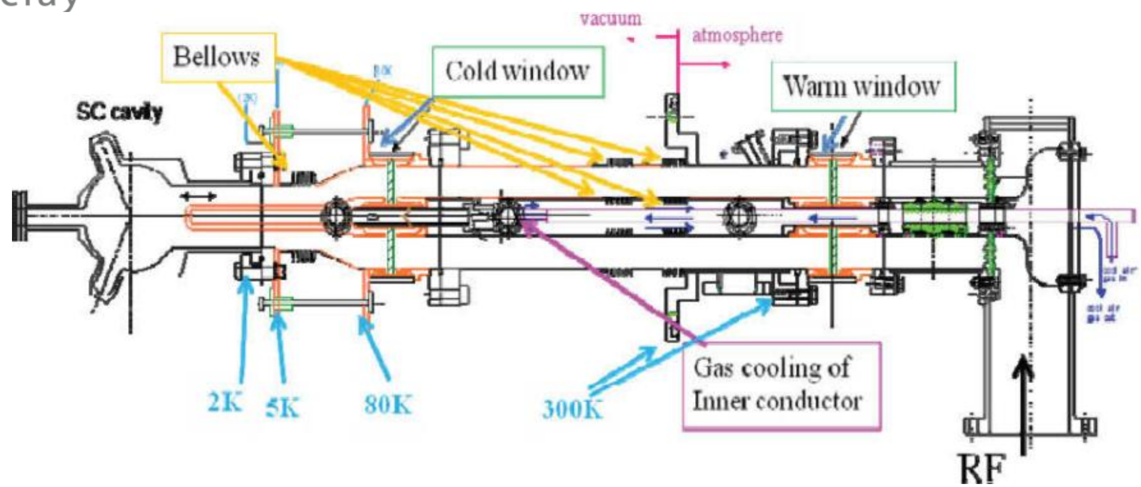
Conditioning	Goal	Done
Max. power TW (kW)	300 CW	100 CW, paused resuming in october 2010



1.3 GHz
300 kW
CW

Courtesy E. Kako

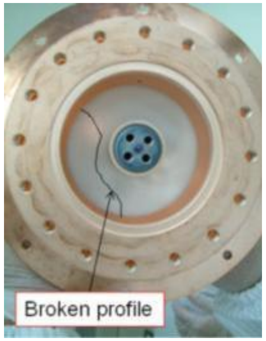
KEK ERL main linac



	Main linac
Frequency (MHz)	1300
Beam current (mA)	50 (100)
Qext	$5\ 10^6$ - $2\ 10^7$
Max. Power per coupler (kW)	20 SW

- Adjustable coupling
- Warm and cold window
- Air cooled antenna

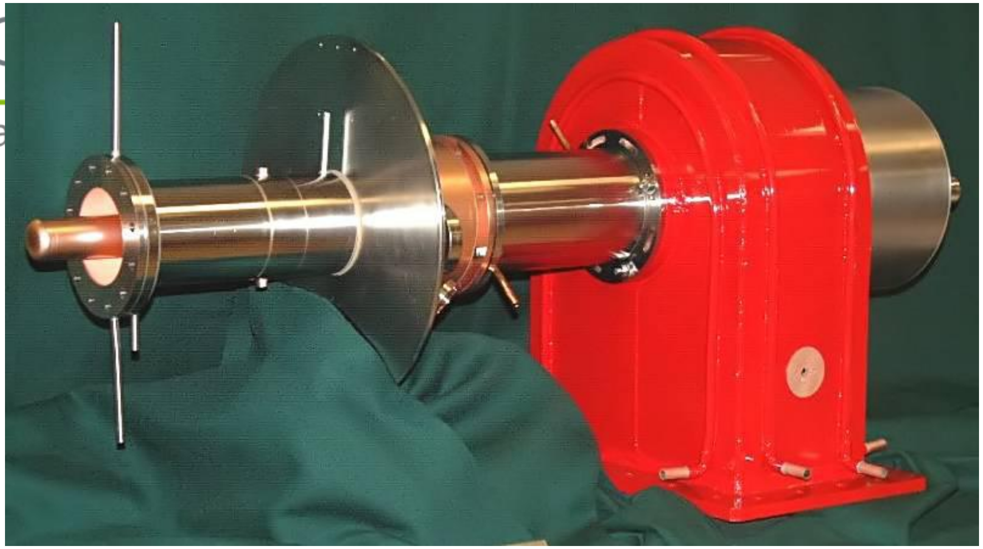
Conditioning	Goal	Done
Max. power SW (kW)	20 CW	27 CW



First design: resonant dipole mode in the ceramic disk very close to the operating frequency (1305 MHz) damaged the window
Disk thickness was modified : mode shifted to 1335 MHz, safe conditioning

K. Umemori

BNL ERL injector

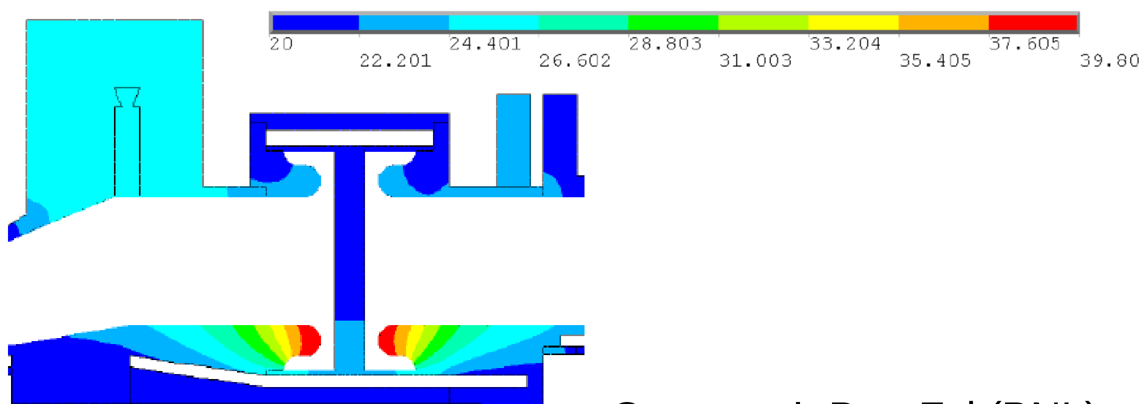


	Injector
Frequency (MHz)	703.75
Beam current (mA)	500
Qext	$3.7\ 10^4$
Max. Power per coupler (kW)	500

½ cell SRF gun

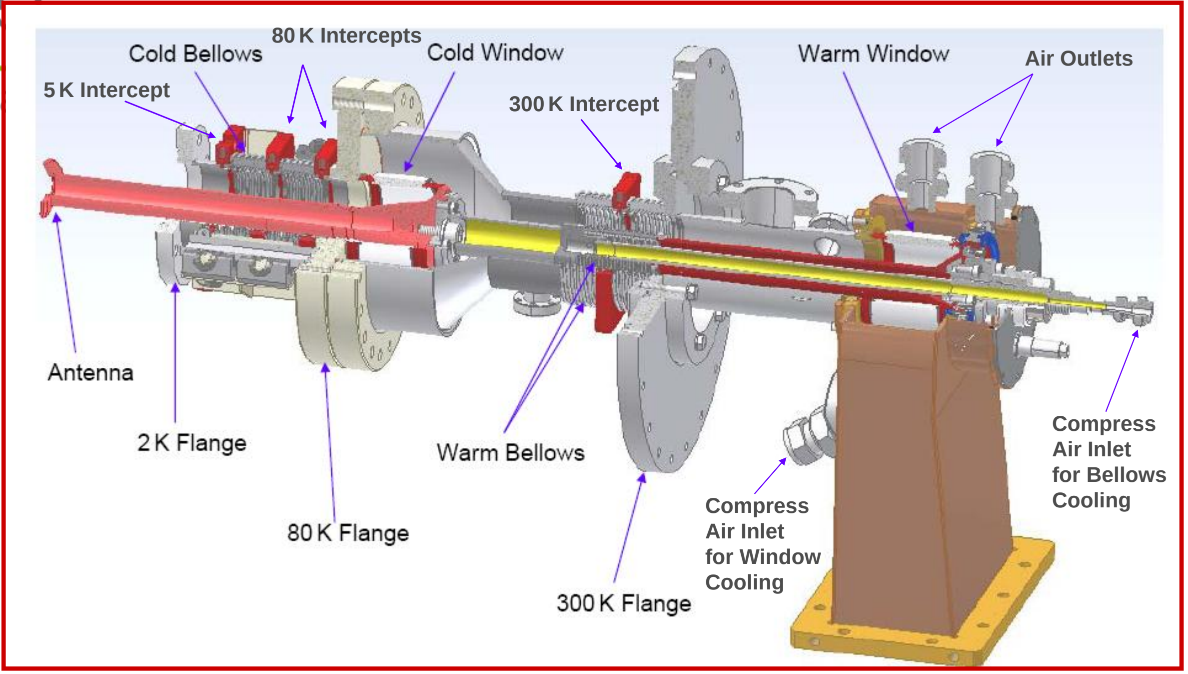
- Water cooling for all parts but the double wall
- A new WG transition is designed without water cooling
- 6 couplers build, one test to 1MW CW foreseen

Temperature Contours FPC

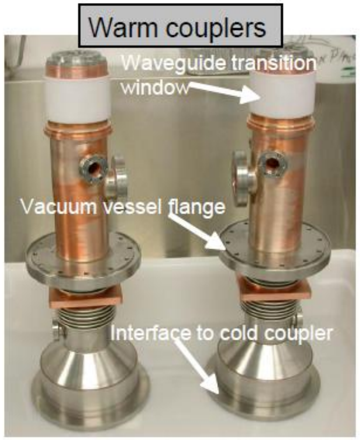


Courtesy I. Ben-Zvi (BNL) & M. Cole (AES)

Cornell ERL injector



	Injector
Frequency (MHz)	1300
Beam current (mA)	100
Qext	$9.2\ 10^{4}$ - $8.2\ 10^{5}$
Max. Power per coupler (kW)	50

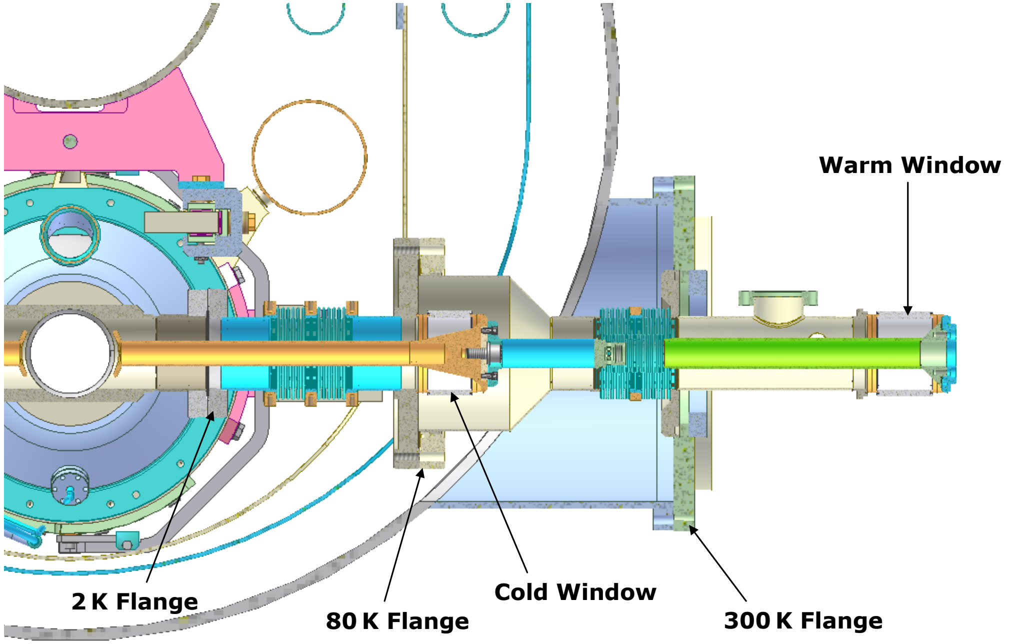


Courtesy S. Belomestnykh

Cornell ERL injector

- Design derived from the TTF-III coupler
- The cold part was completely redesigned using a 62 mm, 60 Ohm coaxial line for stronger coupling, better power handling and avoiding multipacting
- Antenna tip was enlarged and shaped for stronger coupling
- “Cold” window was enlarged to the size of “warm” window
- Outer conductor bellows design was improved for better cooling (added heat intercepts)
- Air cooling of the warm inner conductor bellows was added

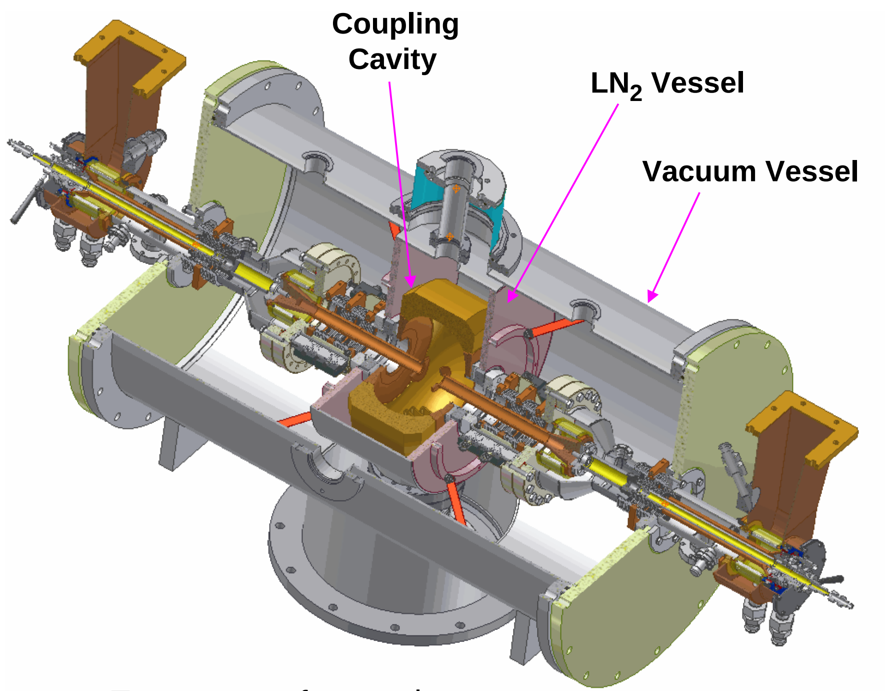
Frequency	1300 MHz
Bandwidth	±10 MHz
Max. power transfer to matched load	75 kW
Number of ceramic windows	2
Cold coax. line impedance	60 Ohm
Warm coax. line impedance	46 Ohm
Coax. line OD	62 mm
Q_{ext} range	$9.2 \cdot 10^4$ to $8.2 \cdot 10^5$
Antenna stroke	> 15 mm
Heat leak to 2 K	< 0.2 W
Heat leak to 5 K	< 3 W
Heat leak to 80 K	< 75 W



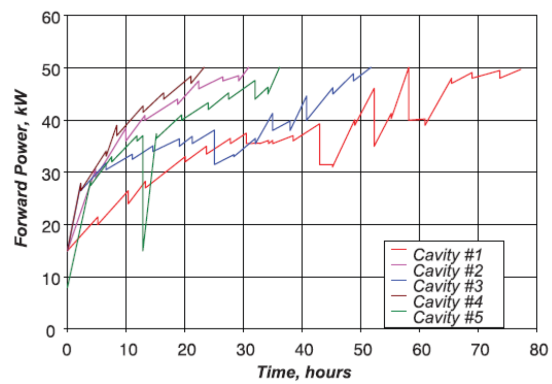
Courtesy S. Belomestnykh

Cornell ERL injector coupler tests

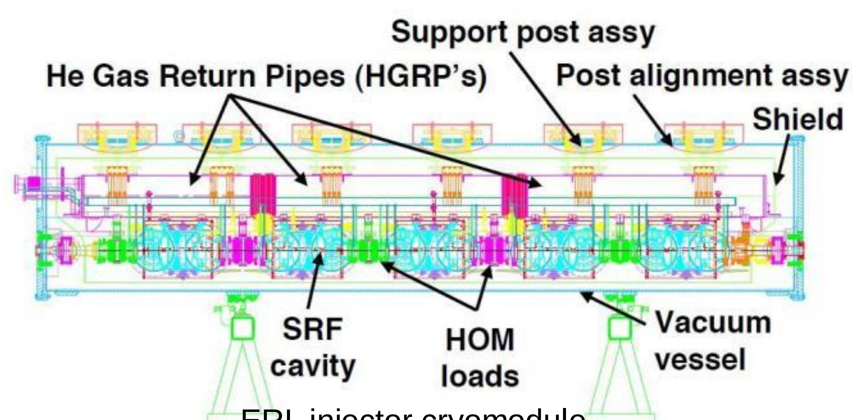
Conditioning	Goal	Done
Max. power TW (kW)	75 CW	61 CW 85 kW pulsed for production couplers
Max. power SW (kW)		25 kW full reflection in the cryomodule



Test cryostat for couplers



Pulse processing 2 ms 50 Hz (data for twin couplers)

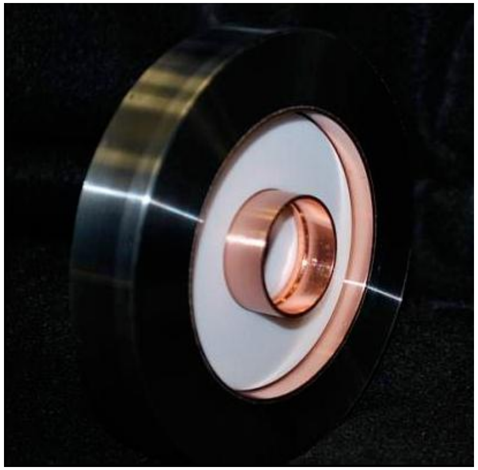


ERL injector cryomodule

Courtesy S. Belomestnykh

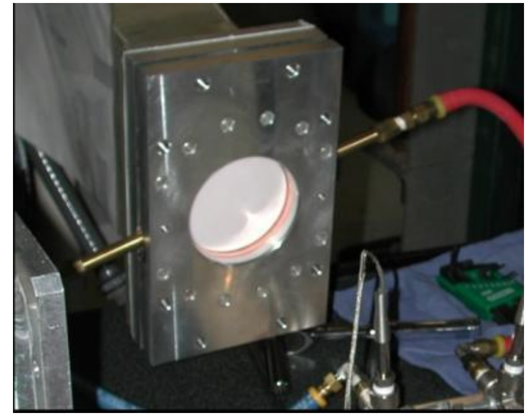
Jlab developments

Coaxial pre-stressed window

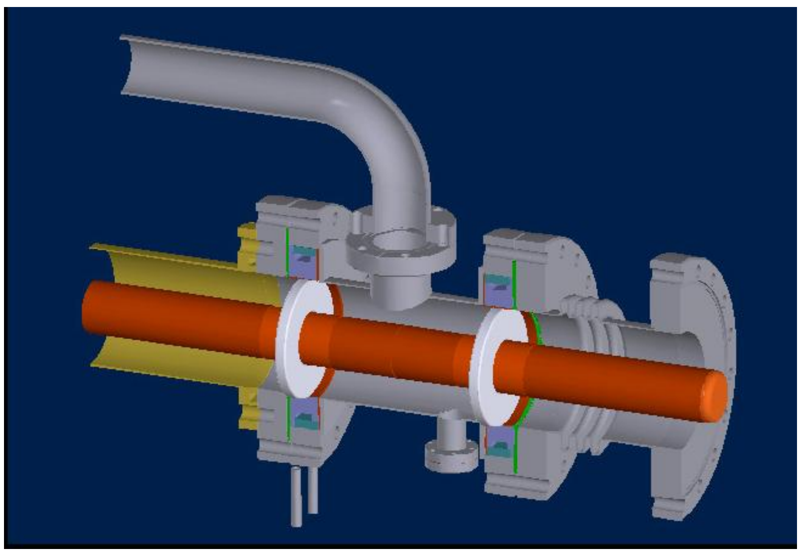


2 technologies :

- Brazing
- Compression bonding



WR 650 pre-stressed brazed window used a gas barrier, water cooled (1.5 GHz)



Double window coupler concept
- No matching element required
- 2 disks spaced by ~$\lambda/2$
- can be applied to wide range of frequencies

Tests	Goal	Done
Max. power TW (kW)	50	60 in CW
Max. power SW (kW)	50	30 in CW all phases

R. Rimmer, M. Stirbet

Conclusion

• With current developments and first results, we can be optimistic about the availability of couplers that match the needs of high intensity linac projects

•Only two examples of couplers on SRF linacs with good statistics, TTF and SNS.

• All couplers which pass the test of room temperature conditioning with strict criteria on vacuum behavior and electronic activity are assembled on the linac. The difficult choice is : up to which power level ?

  • XFEL : 1 MW in test for 150 kW nominal
  • SNS : 650 kW or 1 MW in test for 550 kW nominal

• The fact is : once on the linac, they don't fail during the lifetime of the machine, but their instrumentation do (procedures, QC).

• This may explain why most of the couplers for high intensity linacs derive from the TTF and KEK model

• Coupler tests are often limited by the available RF power source, therefore it is difficult to define margins in terms of peak power for a coupler

•Few examples of aggressive development (BNL), although 1MW CW was demonstrated by APT (LANL) couplers.

Some history

THE INPUT COUPLER FOR THE KEKB ARES CAVITY

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Abstract

We have developed the input coupler for the ARES cavity and carried out the high-power test of the coupler by using the coupler test stand. The couplers have succeeded in transmitting the rf-power of about 1 MW (508 MHz, CW).

1. Introduction

For the KEK B-factory, the Accelerator Resonantly coupled with Energy Storage (ARES) cavity has been developed. The ARES cavity requires the rf-power of about 400 kW per cavity with the full beam loading of the B-factory. [1]

In order to feed the rf power to the ARES cavity, we have developed the new input coupler. [2] The target rf power to be transmitted by the coupler is set to 800 kW (CW) which is twice the required value.

It is well known that the performance of the coupler strongly depends on the ceramic window structure. The most powerful coupler in KEK is the output coupler of the UHF (508 MHz) klystron developed for the rf cavities of the TRISTAN. It can transmit the 1.2 MW (CW) rf power. [3] The klystron output coupler has the disk-type coaxial ceramic window. Thus the klystron output coupler is the good standard for the coupler of the ARES. However the vacuum condition of the input coupler of an accelerating cavity is much worse than that of klystron output coupler. Thus total performance of the input coupler is probably lower than that of the klystron output coupler.

the choke structure for the impedance matching of the window.

The surface of the window in vacuum side has the TiN coating of about 1 nm in thickness in order to reduce the coefficient of the secondary electron emission.

The coaxial wave guide of the coupler and the door knob transformer are made of copper and the rectangular wave guide is made of aluminum. The total weight of the coupler is about 50 kg.

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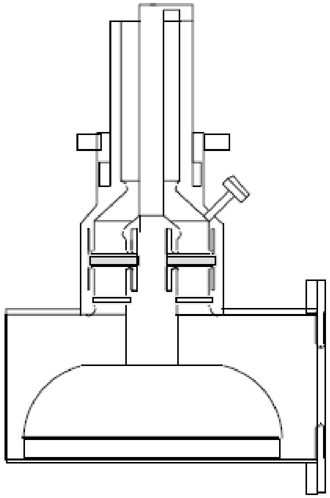

Figure 1. Schematic view of the coupler with the choke structure

This was for a room temperature structure

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