High Power Couplers for Higgs Factory

Eiji KAKO
(KEK, Japan)

Acknowledgements

Special thanks are given to

- **Guillaume Devanz (CEA)**
- **Eric Montesinois (CERN)**
- **Wencan Xu (BNL)**
- **Huang Tongming (IHEP)**

for supplying their information on coupler activities.

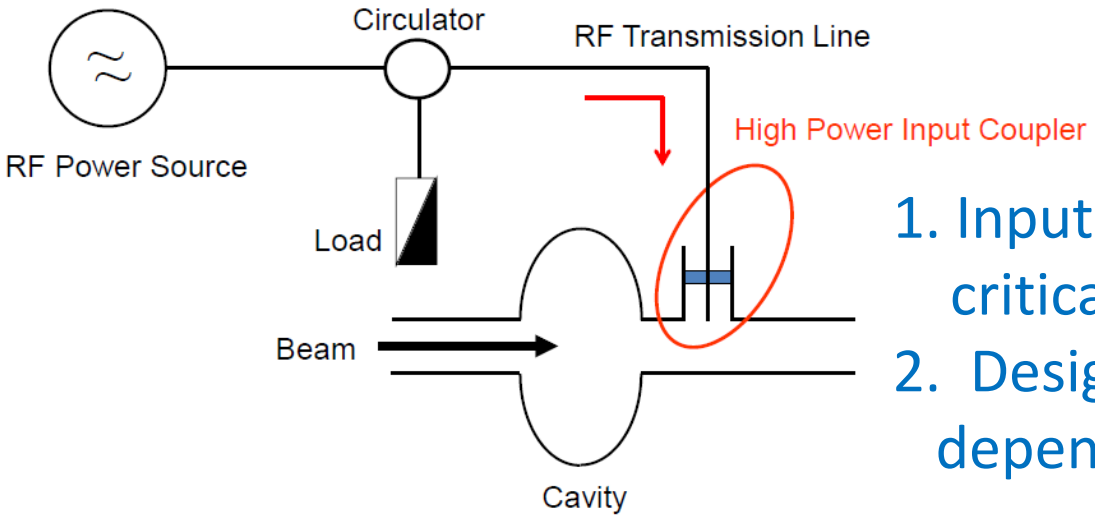
Outline

1. Introduction
2. TRISTAN-type input couplers
3. High power couplers at CEA
4. High power couplers at CERN
5. High power couplers at BNL
6. High power couplers at IHEP
7. Input couplers for Higgs Factory
8. Summary

Coupler Specification for Higgs Factory

Machine Parameters	FCC (TLEP)	CepC
Beam Energy	175 GeV	120 GeV
Beam Current	6.6 mA	16.6 mA
Circumference	100 km	54 km
Total RF Voltage	11 GV	6.9 GV
Coupler Parameters		
RF Frequency	802 MHz	650 MHz
Accelerating Gradient	20 MV/m	15.5 MV/m
Cavity Effective Length	0.93 m (5-cell)	1.15 m (5-cell)
Required RF Power	CW, 125 kW	CW, 260 kW
External Q of Coupler	5.4×10^6	2.4×10^6

Essential Consideration for Input Couplers



1. Input coupler is one of the most critical component of an SRF system.
2. Design of an input coupler strongly depends on a cryomodule structure.

- RF power capability : ($P_{RF} = I_{beam} * V_{acc} * cos\phi$)
- Coupler type : coaxial or waveguide
- Ceramics window type : disk or cylindrical
- Number of windows : single or double
- Coupling with cavity : fixed or adjustable
- Cooling method : air, He-gas, N_2-gas or water
- Bias voltage : useful or needless

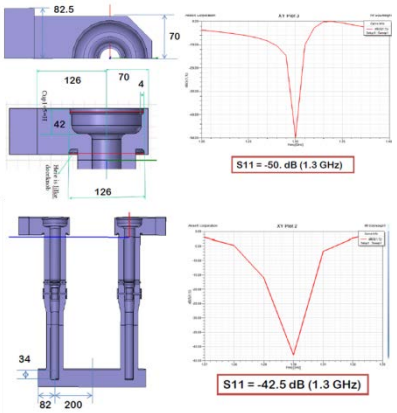
Important Technical Issues for Input Couplers

- Ceramics window : material, purity
- Metalizing of ceramics
- Copper plating : thickness, RRR, adhesion, pits, uniformity
- TiN coating : thickness, uniformity
- Joining by Brazing
- Welding by TIG, Laser, E-beam

- RF properties
- Thermal characteristics
- Mechanical analysis
- Multipacting simulation

- Cleaning procedure
- Assembly in clean room

from Coupler Design to Beam Operation

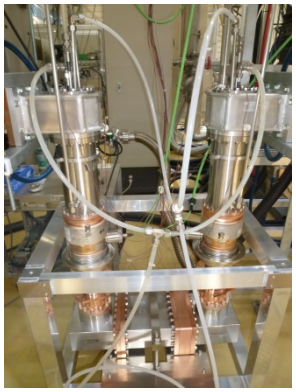


Design/Calculation

Fabrication

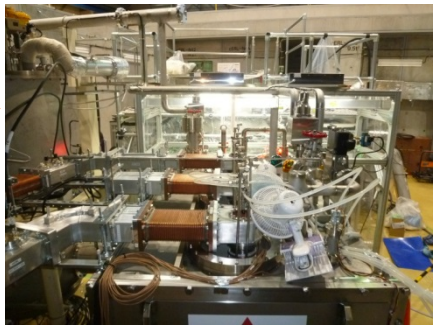
RF measurement

Cleaning/Assembly
Pumping/Baking



Conditioning at
test stand

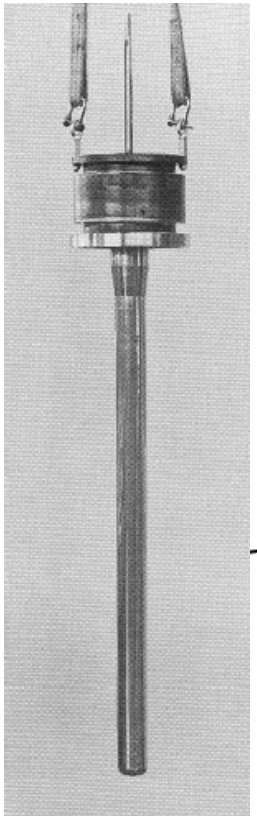
Cavity string assembly

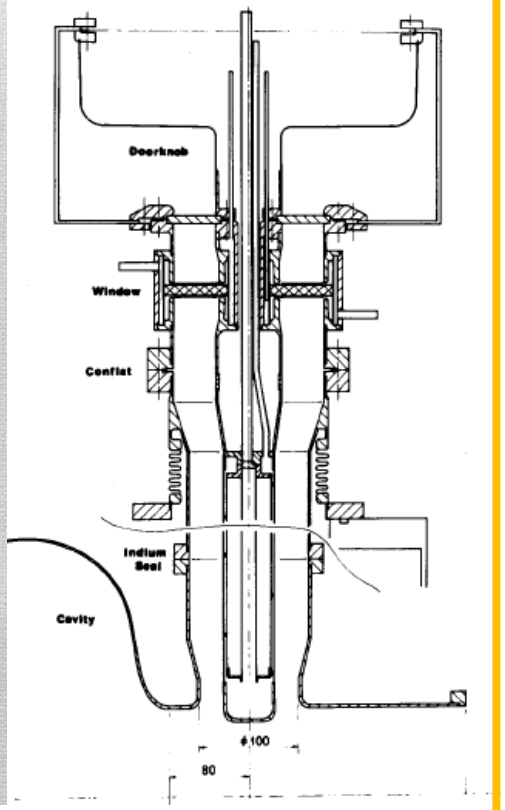


Conditioning at RT
in cryomodule

High power test at LT
and, then
Operation with beam

TRISTAN-type High Power Input Couplers





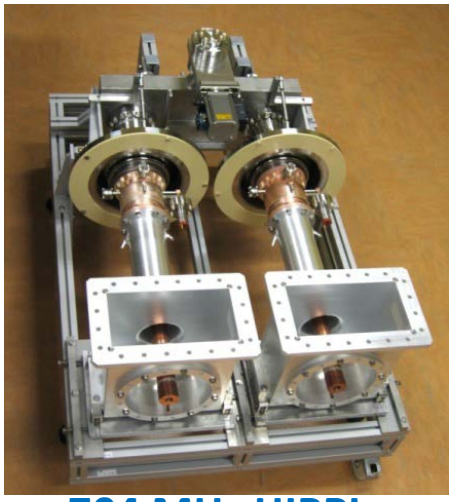
Original design :

508 MHz TRISTAN Input Coupler

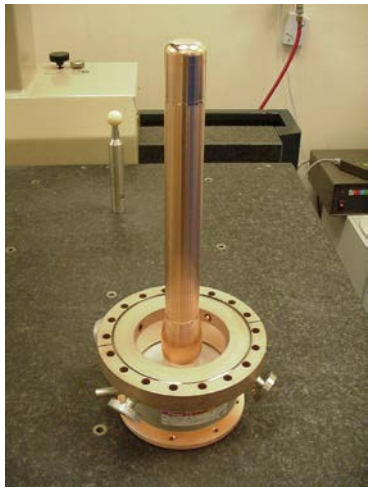
S. Noguchi, E. Kako, K. Kubo

(4th SRF-WS, 1989)

508 MHz KEKB Input Coupler (KEK)



704 MHz HIPPI Input Coupler (CEA)



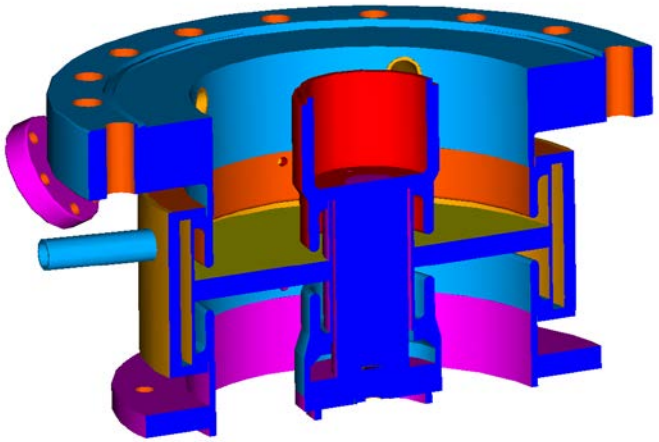
805 MHz SNS Input Coupler (ORNL)

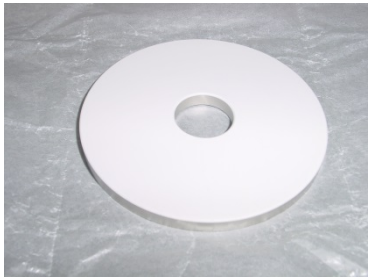
1300 MHz cERL Injector Input Coupler (KEK)

972 MHz ADS Input Coupler (KEK)

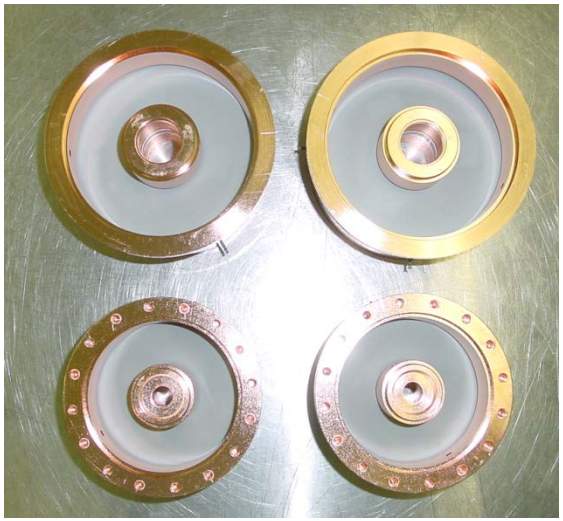
TRISTAN-type RF Window

Tristan-type coaxial disk ceramics RF window with choke structure



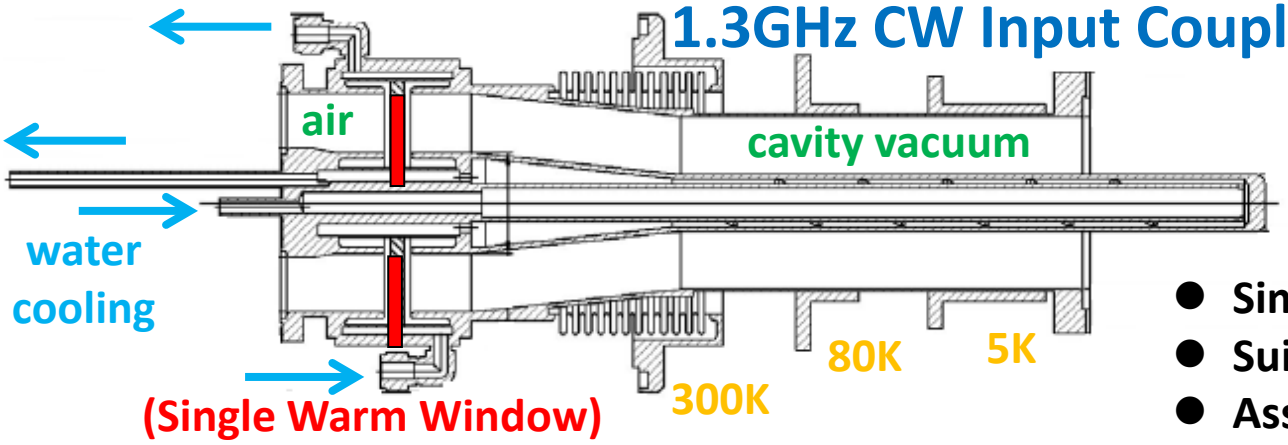


Al_2O_3 ceramics with metalizing



RF windows after 1st brazing

1.3GHz CW Input Coupler for cERL Injector



- Simple structure
- Suitable for cooling
- Assembly with cavity in CR

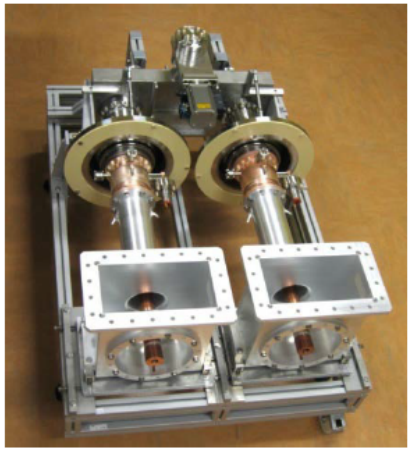
High Power Performance of TRISTAN-type Couplers

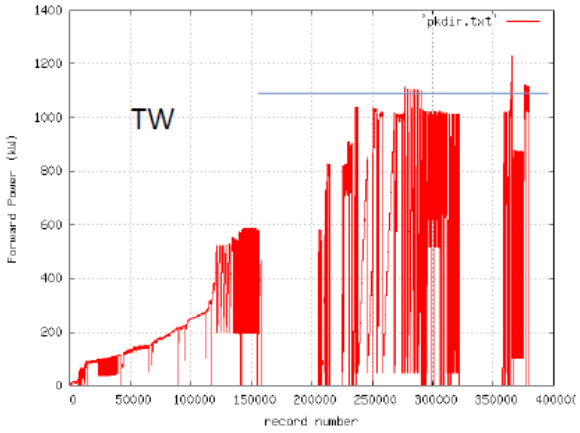
Facility	Frequency	Window type Coupling	Maximum RF Power
TRISTAN /KEK	508 MHz	Coax. Disk Fixed	Test-stand, 200 kW, CW Operation, 70 kW, CW
KEKB /KEK	508 MHz	Coax. Disk Fixed	Test-stand, 800 kW, CW Operation, 380 kW, CW
HIPPI /CEA	704 MHz	Coax. Disk Fixed	Test-stand, 1.2 MW, pulse (10% duty)
SNS /ORNL	805 MHz	Coax. Disk Fixed	Test-stand, 2 MW, pulse Operation, 350 kW, pulse
ADS /KEK-JAERI	972 MHz	Coax. Disk Fixed	Test-stand, 2 MW, pulse Operation, 350 kW, pulse
cERL-Inj. /KEK	1300 MHz	Coax. Disk Fixed	Test-stand, 40 kW, CW Operation, 10 kW, CW

All of these RF windows were fabricated by Toshiba-ED company.

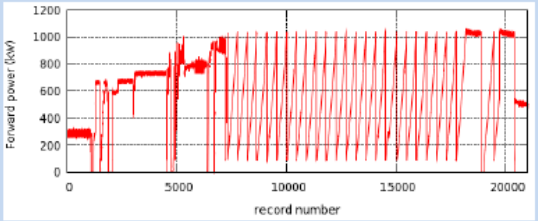
High Power Couplers at CEA-Saclay (1)

704 MHz HIPPI couplers high power tests



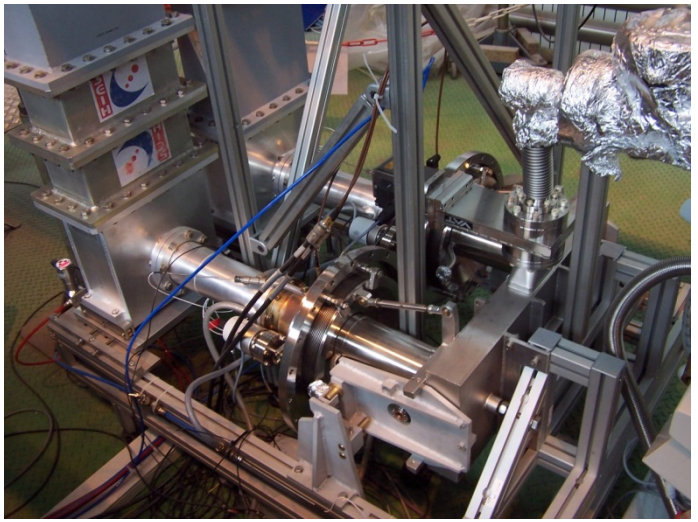


- Tested up to 1.2 MW, 10% duty cycle on room temperature test stand
- Tested up to 1MW full reflection, 10% duty cycle on SRF cavity operating in a horizontal test cryostat



Test of the HIPPI power coupler on the HIPPI cavity at 1.8 K, full reflection

G. Devanz – DESY 06/06/2014



RF Conditioning Results
Pulse mode (2 ms, 50Hz) : 1.2 MW (10% duty)

By G. Devanz (CEA)

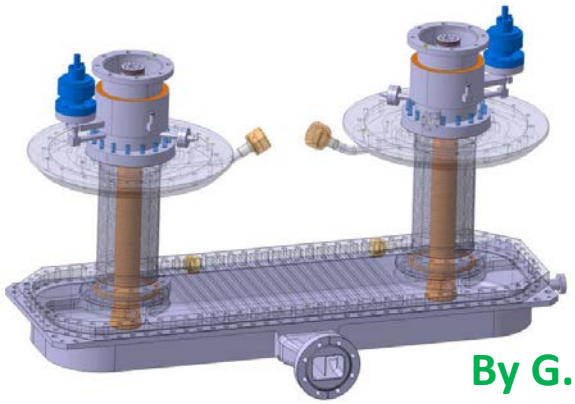
High Power Couplers at CEA-Saclay (2)

ESS 704 MHz power coupler peak power

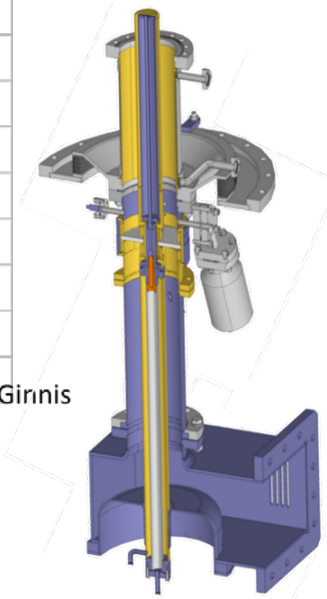
	Optimus	Unit
$E_{acc\ Spoke}$	9	MV/m
V_{Spoke}	5.74 (L = 3 βλ /2)	MV
$P_{coupler\ Spoke}$	330	kW
$N_{Spoke\ modules}$	13	–
$E_{acc\ Mβ}$	16.79	MV/m
$V_{Mβ}$	14.36 (L = 6 β'λ' /2)	MV
$P_{coupler\ Mβ}$	860	kW
$N_{Mβ\ modules}$	9	–
$E_{acc\ Hβ}$	19.94	MV/m
$V_{Hβ}$	18.24 (L = 5 β"λ' /2)	MV
$P_{coupler\ Hβ}$	1100	kW
$N_{Hβ\ modules}$	21	–

Updated for ESS tests :

- Peak power : 1MW (1.2 MW for a short period)
- Repetition rate up to : 25 Hz
- RF pulse length : 3.1 ms



By G. Devanz (CEA)



D. Mc Girnis

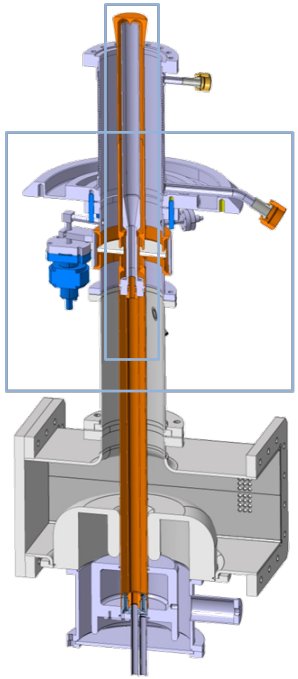
HIPPI coupler

CM integration

- New flange, below is part of vacuum vessel
- Diagnostic ports distribution
- VCRs

Inner conductor

- Conical tip for stronger coupling
- Improved water cooling channels



ESS coupler
HV bias with RF trap

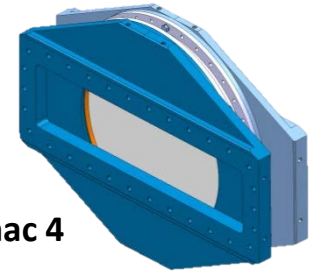
704 MHz ESS coupler
Design Specification :
Pulse 1.2 MW (4.2% duty)

High Power Couplers at CERN (1)

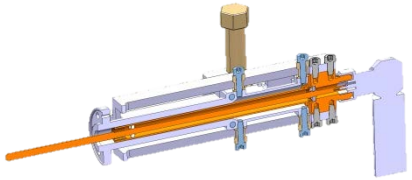
By E. Montesinois (CERN)

2014 FPC results			
	MHz	kW	
SPL disk	704	1000 1000 SW	2 ms – 50 Hz 100 us – 50 Hz
SPL cylindrical	704	1000 500 SW	2 ms – 50 Hz 100 us – 50 Hz
Linac 4	352	750 SW	1 ms – 2 Hz
LHC	400	500 SW	CW
Crab	400	50 SW	CW
SPS800	800	150 SW	CW
SPS200	200	500	CW
ESRF	352	300	CW
SOLEIL	352	300 250 SW	CW CW

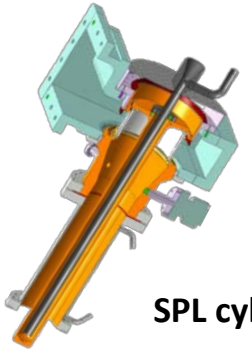
SW = full reflection all phases, successfully tested



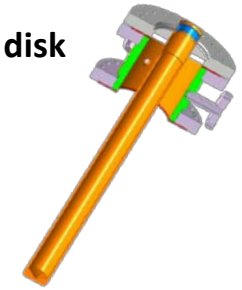
Linac 4



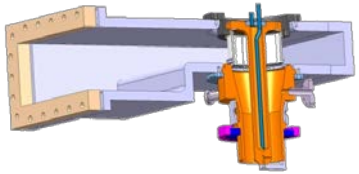
HIE-Isolde



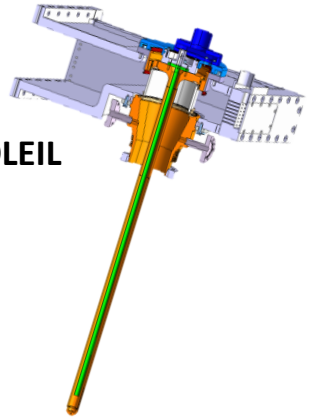
SPL cylindrical



SPL disk



ESRF & APS



SOLEIL

High Power Couplers at CERN (2)

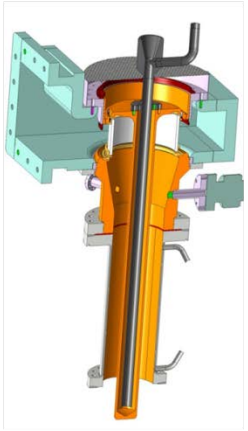
704 MHz SPL Input coupler

By E. Montesinois (CERN)

RF Characteristics	
f_0	704.4 MHz
Power levels	**1000 kW pulsed** 0.4 + 1.2 + 0.4 = 2.0 ms 50 Hz (20 ms) 100 kW average
Cavity design gradient	19-25 MV/m
Q_{ext} of input coupler	1.2×10^6
Input line Ø	100 / 43.5 mm = 50 Ω (from the cavity design)
Waveguides	WR 1150

Technical Choices
Single window coupler
Fixed coupler
With a Double Walled Tube
Mounted in clean room with its double walled tube
Vertically below the cavity and will be a support for the cavity (first time worldwide)
With a HV DC biasing capacitor
Air cooled

SPL Fundamental Power Coupler Project



Cylindrical window Coupler

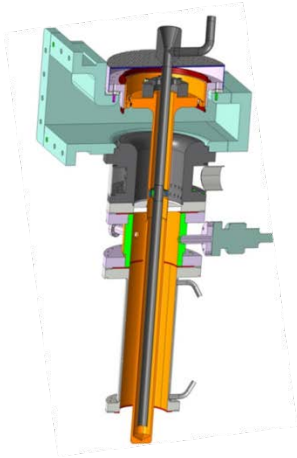
Both designs will have the same

Double walled tube

Matching waveguide without doorknob

Contacts ring including DC capacitor

Interface to cryomodule flange & RF + vacuum gasket



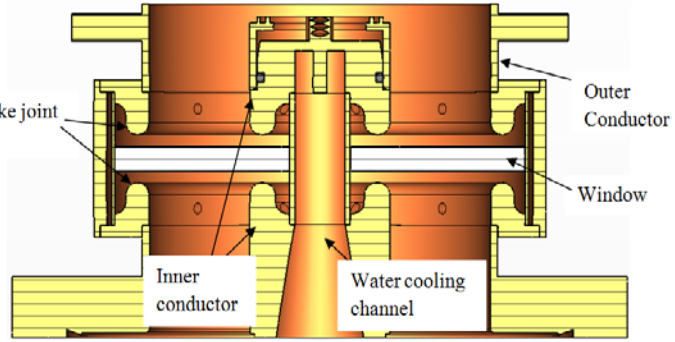
Disk window Coupler

RF Conditioning Results
Pulse mode (2 ms, 50Hz)
TW : 1000 kW
SW : 250 kW

High Power Couplers at BNL

704 MHz Input coupler for BNL SRF-Gun

Design Specification : CW 500 kW



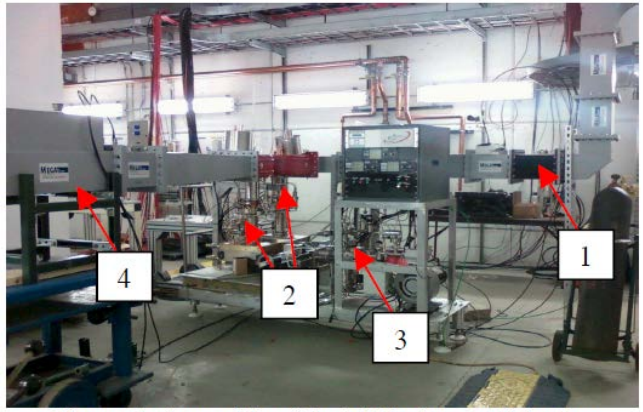
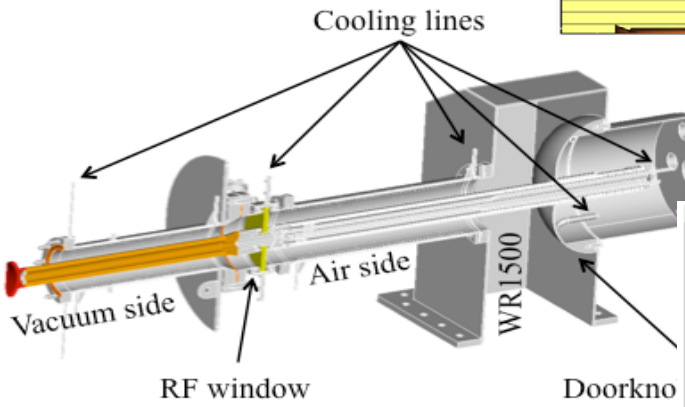


Figure 5: Assembly of the FPCs for conditioning.
1- Waveguide connecting to 1MW klystron
2- Two FPCs
3- FPC conditioning cart
4- Phase shifter and short plate



Cooling : inner conductor, water outer conductor, 5K He gas

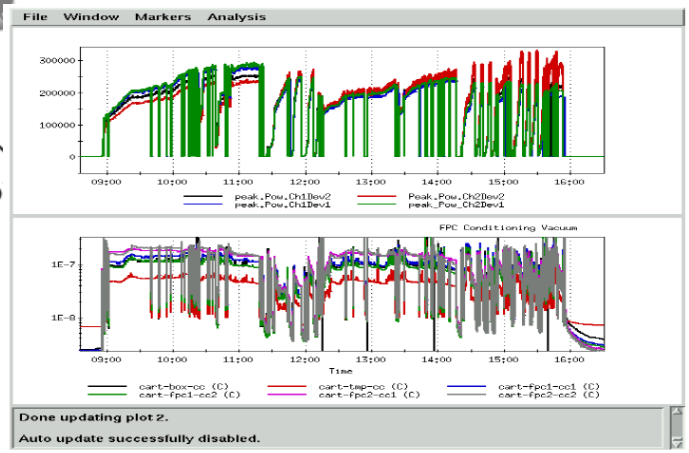


Figure 7: Typical vacuum trip during conditioning.

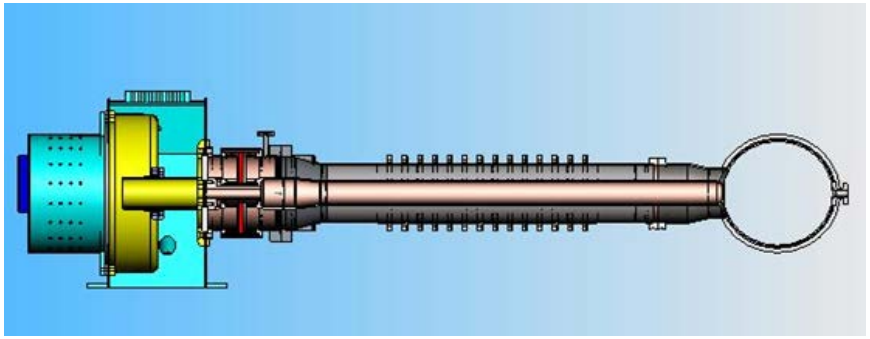
RF Conditioning Results
Pulse mode (100Hz)
0.1 - 2 ms : 250 kW
CW mode : 125 kW

By W. Xu (BNL)

High Power Couplers at IHEP-Beijing

- **Input power coupler of the main ring SRF cavity (650 MHz)**

BEPCII 500MHz SCC coupler is taken as the baseline for CEPC main ring SRF cavity input power coupler

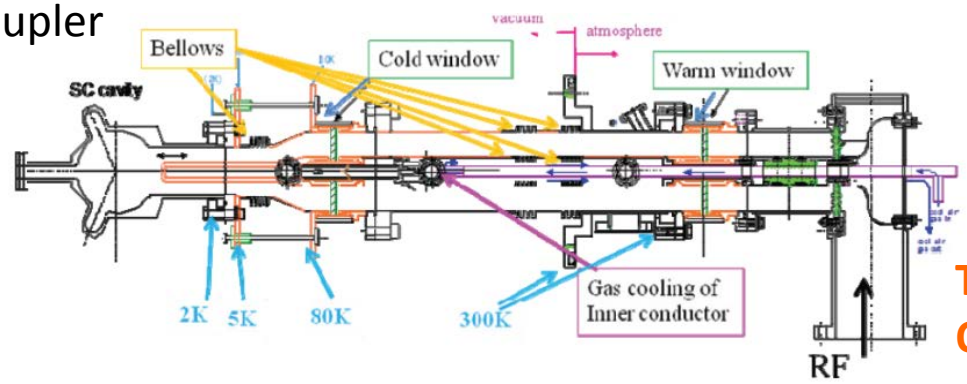


Test-stand,
420 kW, CW

By T. Huang (IHEP)

- **Input power coupler of the booster SRF cavity (1300 MHz)**

KEK cERL main linac power coupler is taken as the baseline of the booster SRF cavity input power coupler



Test-stand, 40 kW, CW
Operation, 15 kW, CW

Consideration of Input Coupler for Higgs Factory (1)

Facility	Frequency	Window, DC-Bias, Coupling, Cooling	Maximum RF Power
CepC /IHEP	**650 MHz**	**Under design**	**Spec., 260 kW, CW**
SRF-Gun /BNL	704 MHz	Coax. Disk, no-Bias Fixed, water & He gas	Test-stand, 125 kW, CW 250 kW, pulse (20% duty)
HIPPI /CEA	704 MHz	Coax. Disk, no-Bias Fixed, water & He gas	Test-stand, 1.2 MW, pulse (10% duty)
SPL /CERN	704 MHz	Disk/Cylind., DC-Bias Fixed, & He gas	Test-stand, 1.0 MW, pulse (10% duty)
ESS /CEA	704 MHz	Coax. Disk, DC-Bias Fixed, water & He gas	Specification, 1.2 MW, pulse (4% duty)
SNS /ORNL	805 MHz	Coax. Disk, DC-Bias Fixed, water & He gas	Test-stand, 2 MW, pulse Operation, 350 kW, pulse
FCC /CERN	**802 MHz**	**Under design**	**Spec., 125 kW, CW**

Consideration of Input Coupler for Higgs Factory (2)

Requirement	FCC (TLEP)	CepC
Frequency	802 MHz	650 MHz
RF power	125 kW, CW	260 kW, CW
Beam current	varied / (fixed)	varied / (fixed)
Operating E_{acc}	varied / (fixed)	varied / (fixed)
Adjustable coupling	yes / (no)	yes / (no)
Range of QL / (Fixed)	- x 10^6 / (5.4 x 10^6)	- x 10^6 / (2.4 x 10^6)
Coupler type	coaxial	coaxial
RF window	single warm window	single warm window
Ceramics window	coaxial disk / cylindrical	coaxial disk
Bias voltage	yes	yes
Cooling method	inner conductor : water outer conductor : He gas	inner conductor : water outer conductor : N_2 gas

Summary

- **Coaxial CW high power input couplers with a single warm RF window have been developing in the frequency range of 500 – 1300 MHz at the power level higher than 100 kW in many laboratories of the world.**

- **Design studies of high power couplers with 802 MHz, 125 kW-CW for FCC and 650 MHz, 260 kW-CW for CepC should be started as soon as possible.**

- **Fabrication of the prototype high power couplers and RF conditioning at a test-stand should be carried out at an early stage.**

Thank you for your attention.