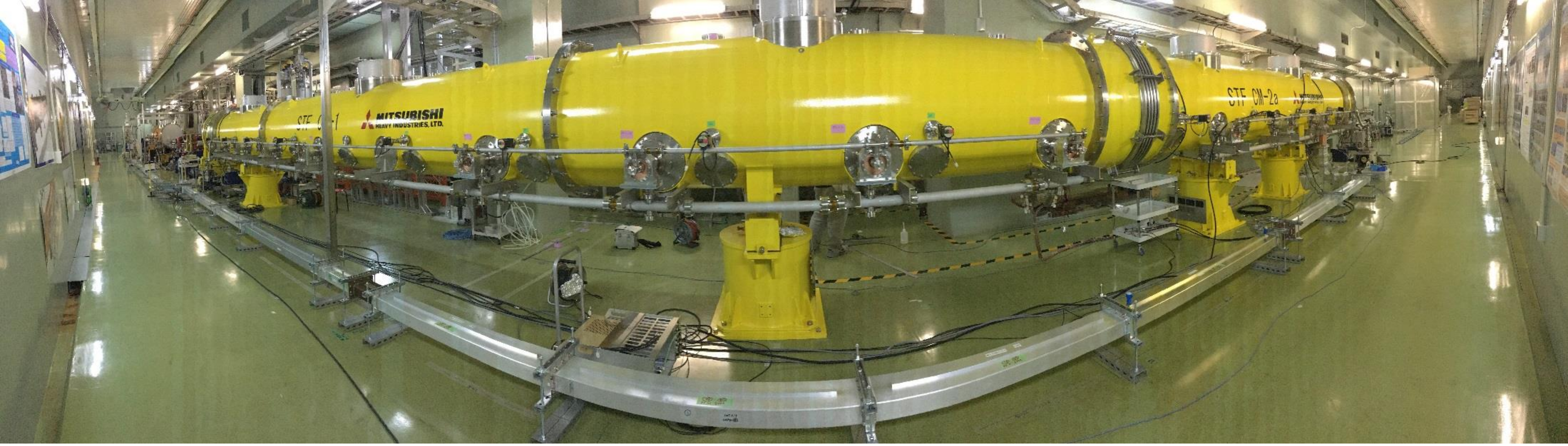


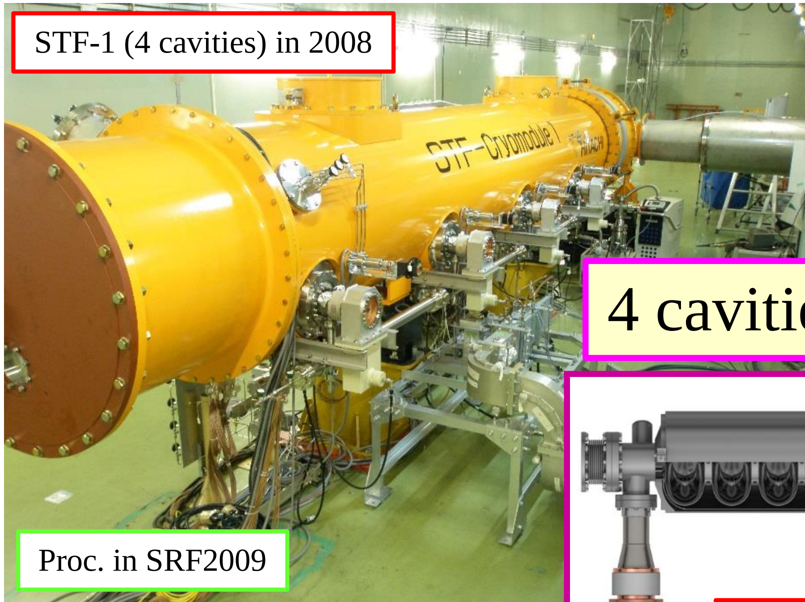
STF-2 Cryomodule Performance and New Input Coupler R&D for ILC

T. Honma, E. Kako, Y. Kojima, T. Matsumoto, S. Michizono, H. Nakai, T. Shishido, A. Yamamoto, Y. Yamamoto (KEK)
E. Montesinos, C. Julie (CERN)

STF Cryomodules

superconducting rf test facility

STF-1 (4 cavities) in 2008

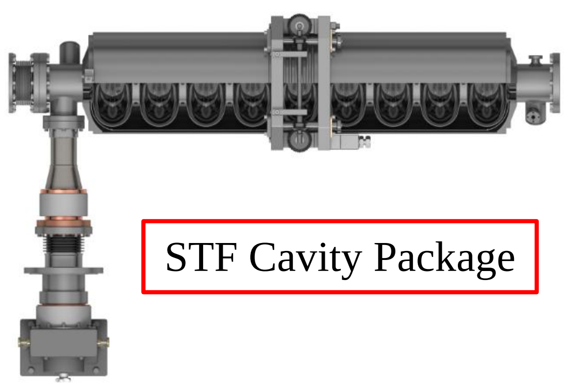


Proc. in SRF2009

S1-Global (4+4 cavities) in 2010

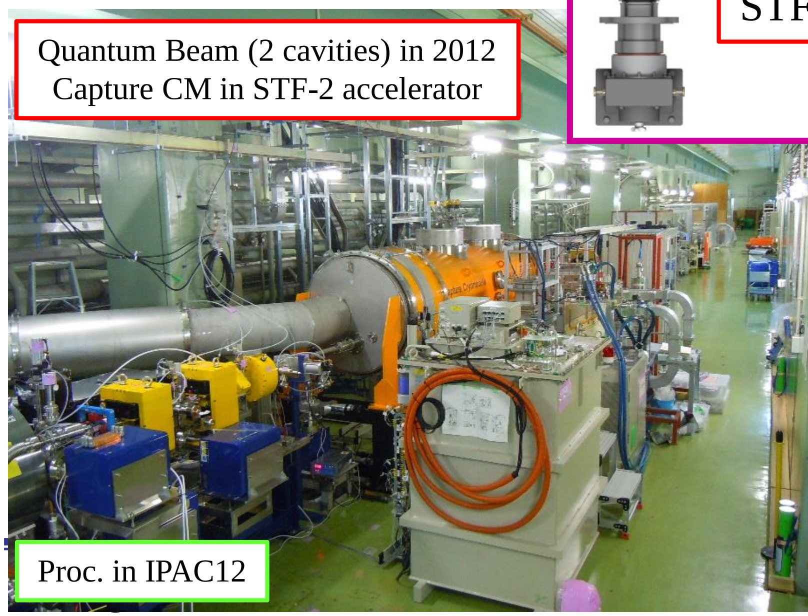
Proc. in SRF2011

4 cavities per batch



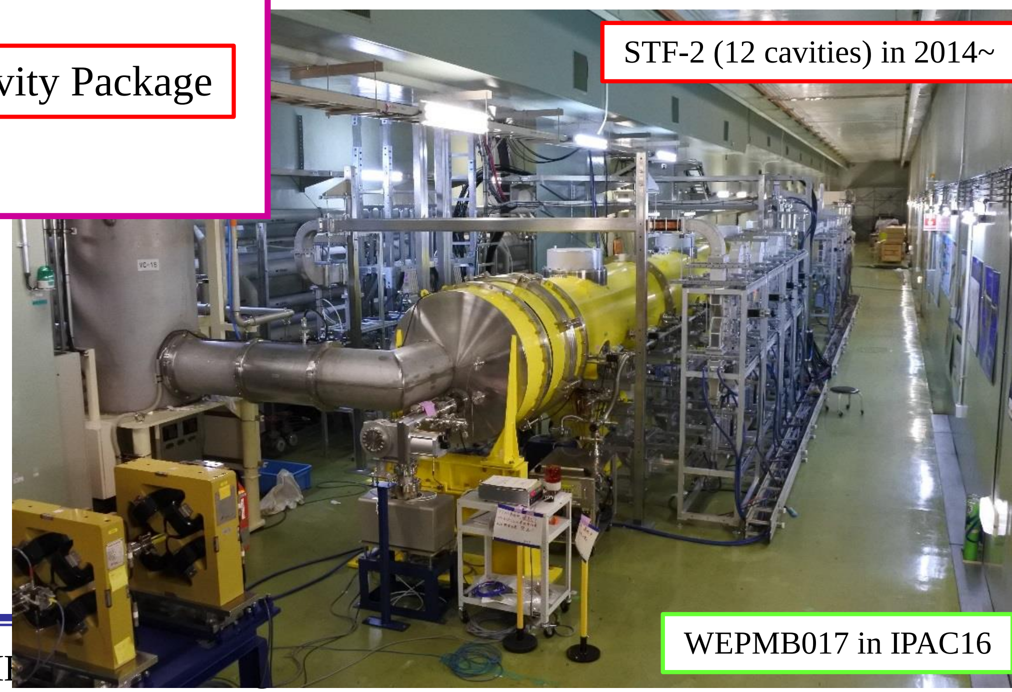
STF Cavity Package

Quantum Beam (2 cavities) in 2012
Capture CM in STF-2 accelerator



Proc. in IPAC12

STF-2 (12 cavities) in 2014~

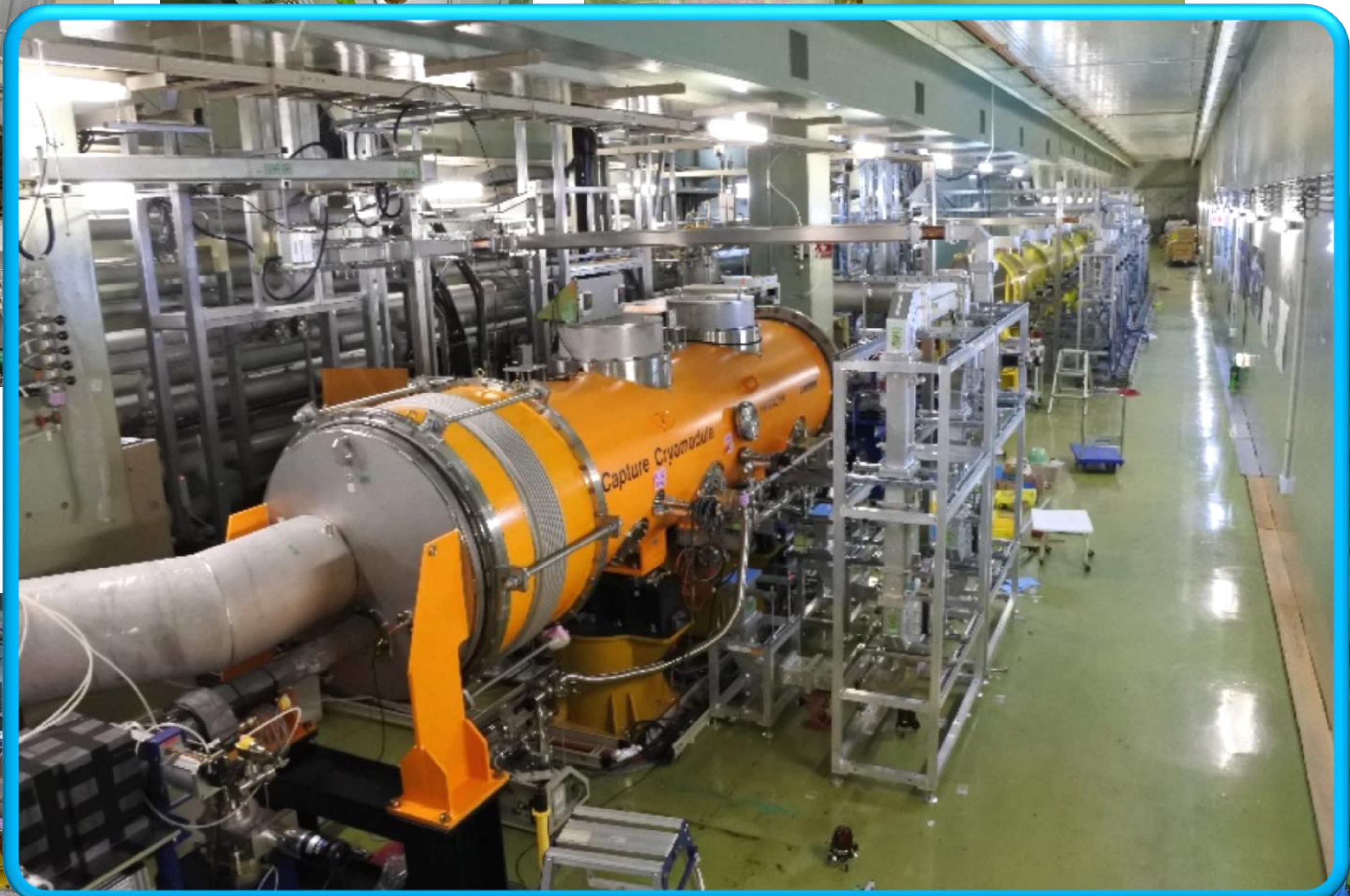


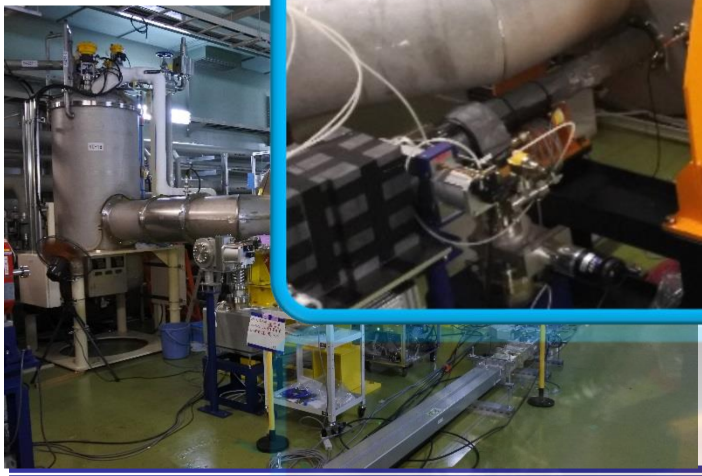
WEPMB017 in IPAC16

STF-2 Cryomodule Performance

Date	Content
2011 ~ 2013	V.T. for 12 cavities
Jun/2013	Cleaning up STF tunnel
Jul/2013 ~ Apr/2014	Cavity string assembly (three times)
Oct/2013 ~ Jan/2014	Module assembly (CM1/CM2a)
Jul/2014	Complete certification for High pressure Gas Code
Oct/2014 ~ Dec/2014	1st cool-down / low power test
Apr/2015 ~ Jul/2015	5MW Klystron / Single waveguide system completed
Jul/2015 ~ Sep/2015	Coupler conditioning at room temperature
Oct/2015 ~ Dec/2015	2nd cool-down / high power test
Jan/2016 ~ Jul/2016	Multi-beam Klystron & Waveguide system completed
Jul/2016 ~ Sep/2016	Coupler conditioning at room temperature
Sep/2016 ~ Dec/2016	3rd cool-down / Q_0 measurement & LLRF study
2017 ~ 2018	Beam operation will start?

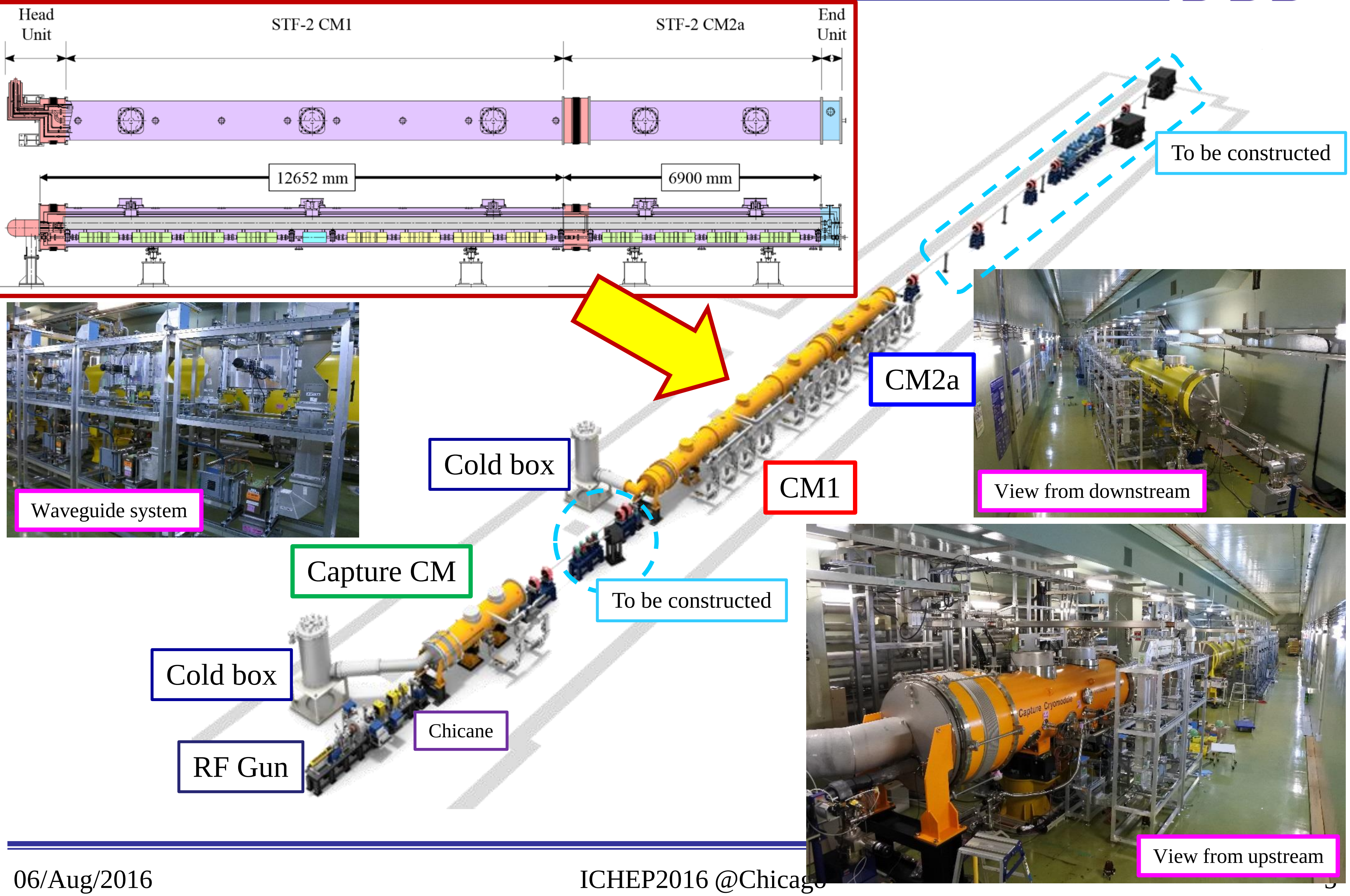
Brief history of STF-2 project





STF-2 Accelerator Layout

superconducting rf test facility

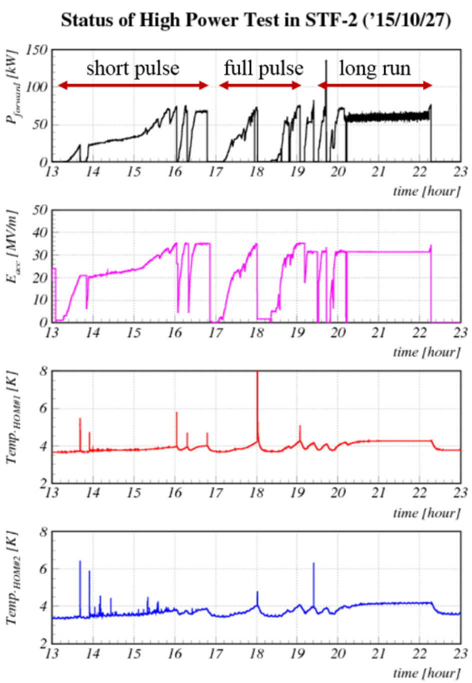


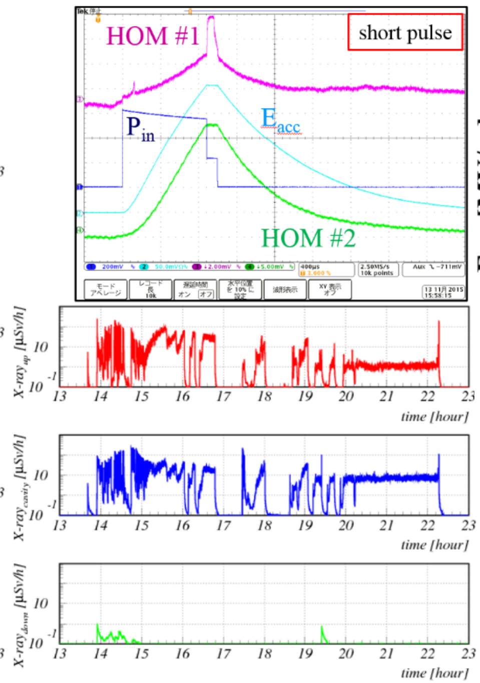
Performance for STF-2 Cryomodule

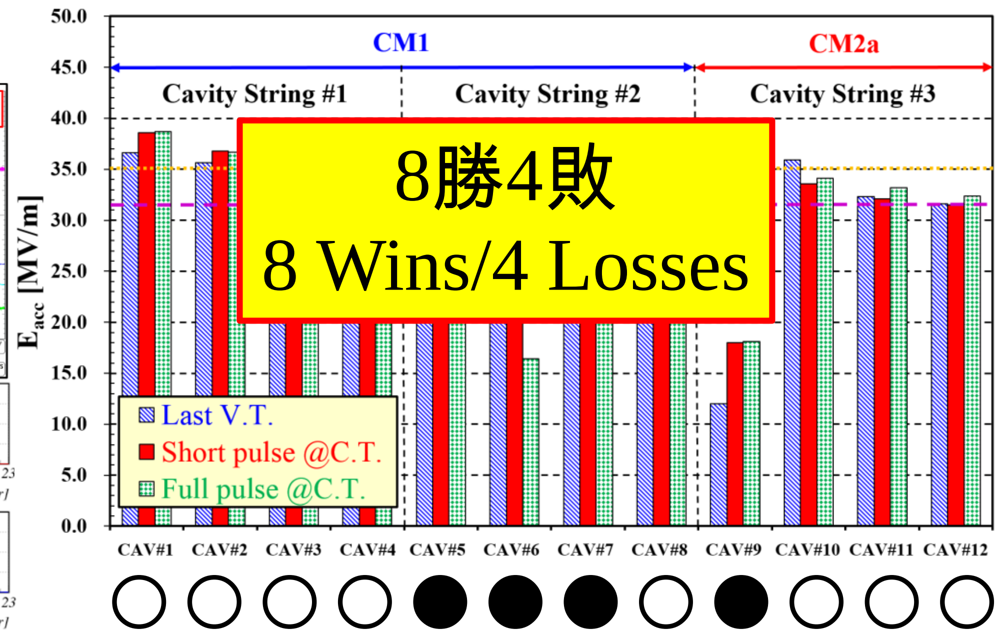
superconducting rf test facility

RF conditioning was done very carefully as monitoring heating at HOM couplers, unusual RF output from HOM couplers, and radiation level.

Short pulse → Full pulse → Long run





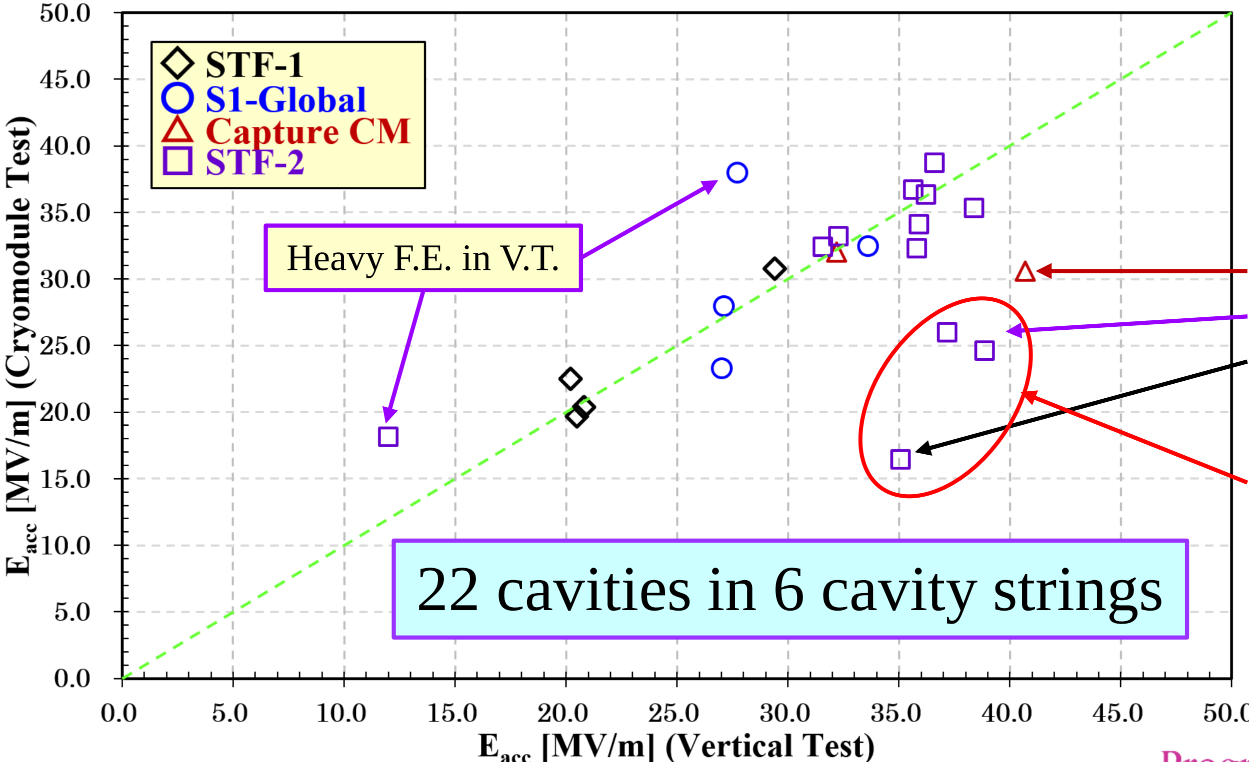


STF-2 RF Parameters

- Q_L : 5.0 x 10^6
- Filling time : 900μsec
- Flat-top : 100μsec (short pulse)
- Flat-top : 800μsec (full pulse)
- Total width : 1700μsec

First and third cavity string achieved "No degradation" in CM test.
(Q_0 measurement will be done from this autumn)
Second had significant trouble (heavy field emission) due to additional (and irregular) clean room work (probably).

Performance Degradation



Statistics for cavity performance;
Above 31.5 MV/m: 11 cavities
Degradation: 4 cavities

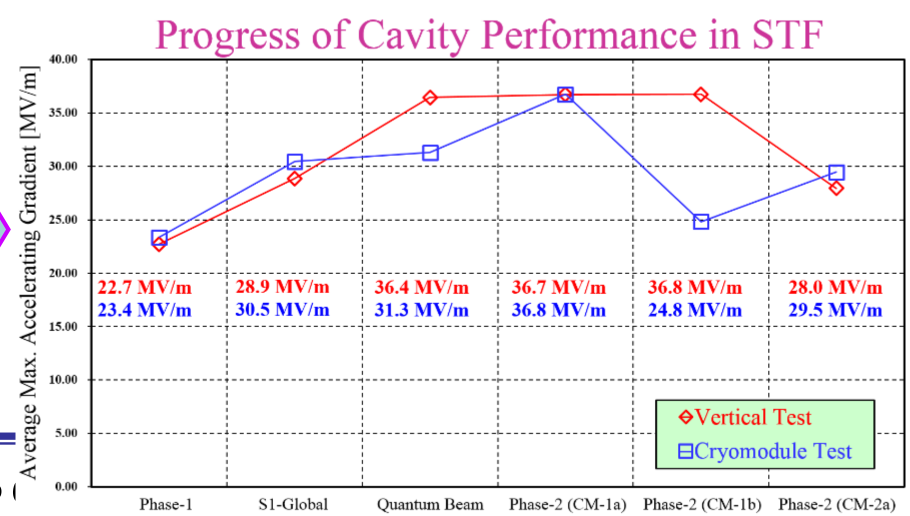
Three types of performance limit;
One cavity: Quench w/o F.E.
Two cavities: F.E. Quench
One cavity: Quench by enormous heat loss

Three degraded cavities in STF-2 are connected in series.
→ Common cause for degradation

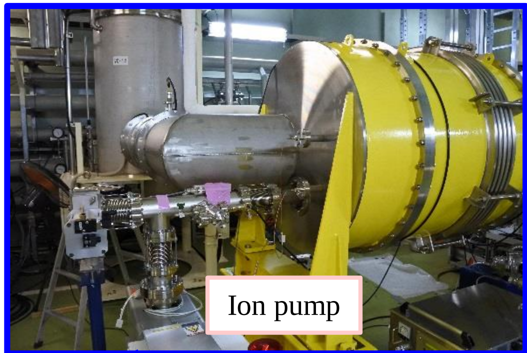
Q_0 measurement is not done yet in STF-2.
It will start from this autumn.

Statistics for cavity string (four cavities per batch);

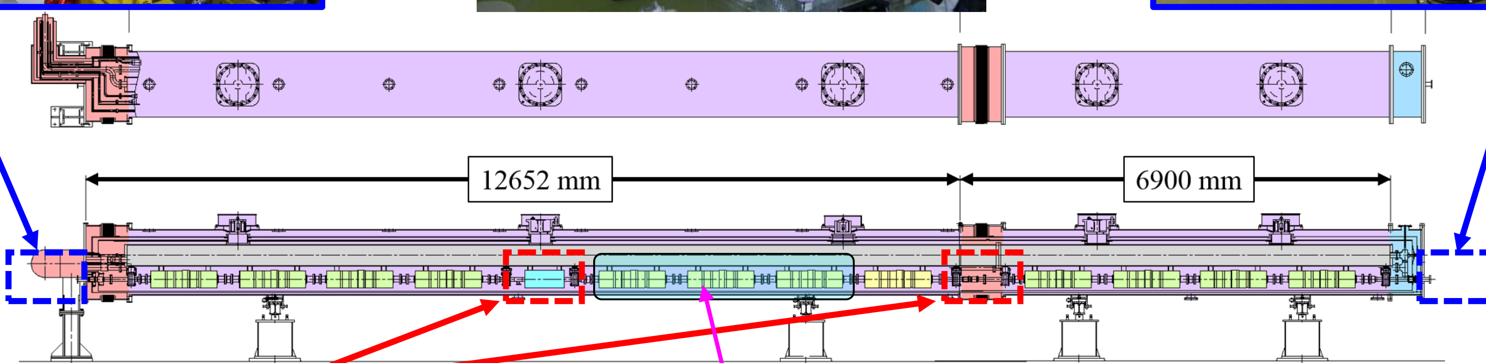
Four cavity strings:	No degradation
Quantum Beam:	Degradation, but around ILC spec.
CM-1b in STF-2:	Significant degradation

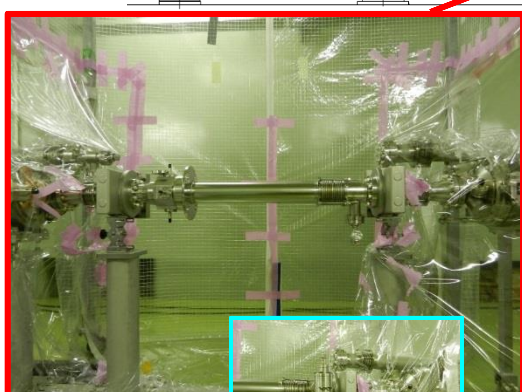


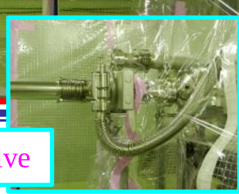
Cavity string/Beam pipe connection in Tunnel



Local clean booth







A little bit bigger metal valve

Three degraded cavities in series

- ✓ Use of simply local clean booth
  - ✓ Local clean booth was used for four beampipe connection parts
- ✓ Exchange of metal valve near cavity string #2
  - ✓ Metal valve was a little bit bigger, disturbed thermal shield attachment
- ✓ Extra Argon gas purging at gate valve opened
  - ✓ Usually, when gate valve opens, both sides should be under vacuum but, we had to do Argon gas purging for the both sides due to complicated process of cryomodule assembly

Improvement of clean room items

superconducting rf test facility

Many experiences in EU-XFEL @DESY

- High quality local clean booth
- Slow pumping system
- High quality particle counter
- Ultrasonic rinsing for ion pump

Will be introduced in 2017(?)

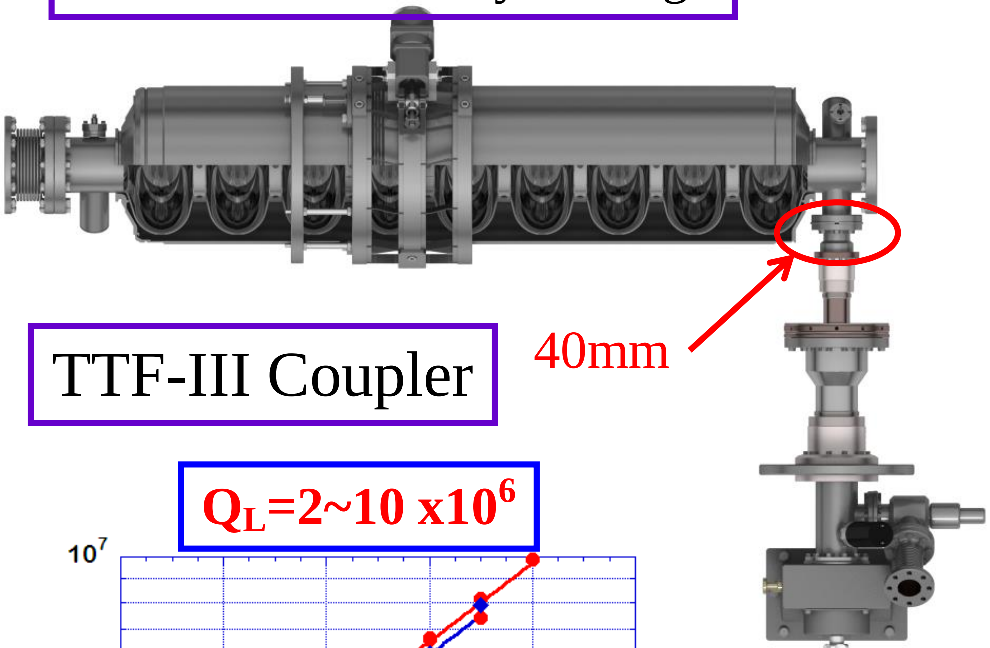
New Input Coupler R&D

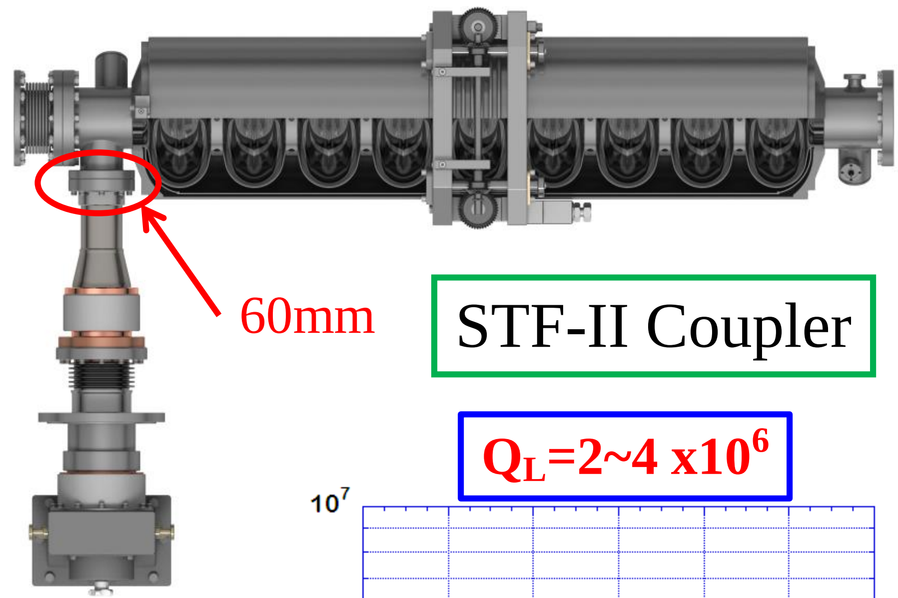
Date	Content
Nov/2013	Recommendation for plug-compatible design from LCC
Feb/2014	Completion of mechanical design
Jun/2014	Completion of RF design by simulation
Nov/2014	Completion of Test Coupler Fabrication
Mar/2015	Incoming inspection in KEK
Dec/2015	Low power test at test bench
Feb/2016	High power test at test bench

Motivation

DESY/FNAL Cavity Package

KEK Cavity Package





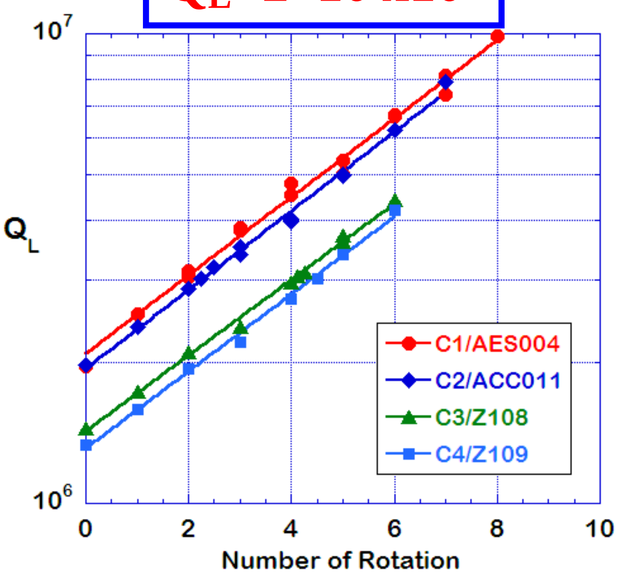
TTF-III Coupler

40mm

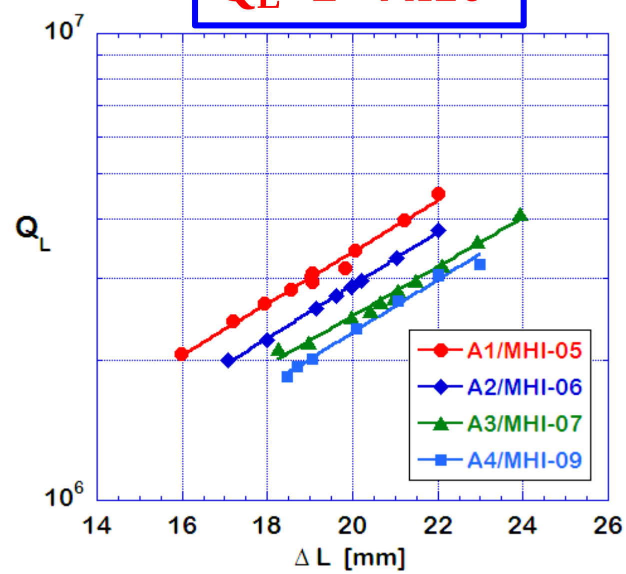
60mm

STF-II Coupler

Q_L=2~10 x10^6



Q_L=2~4 x10^6



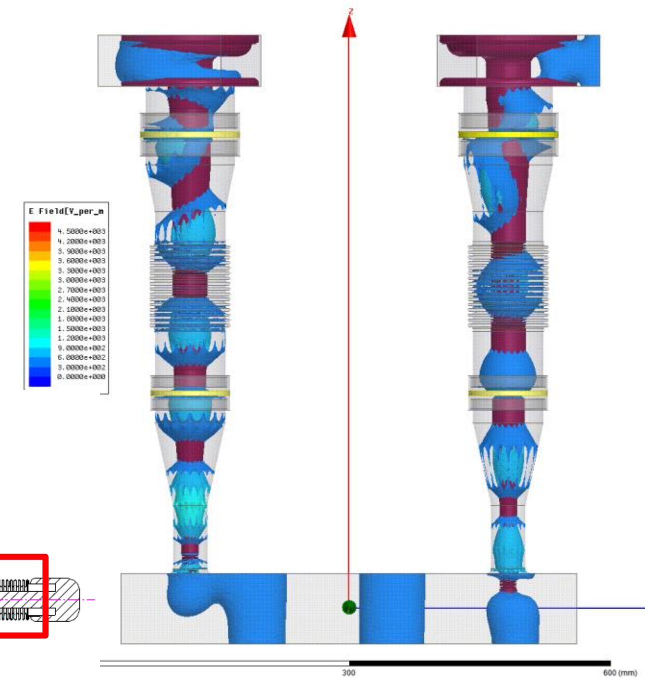
TDR specification

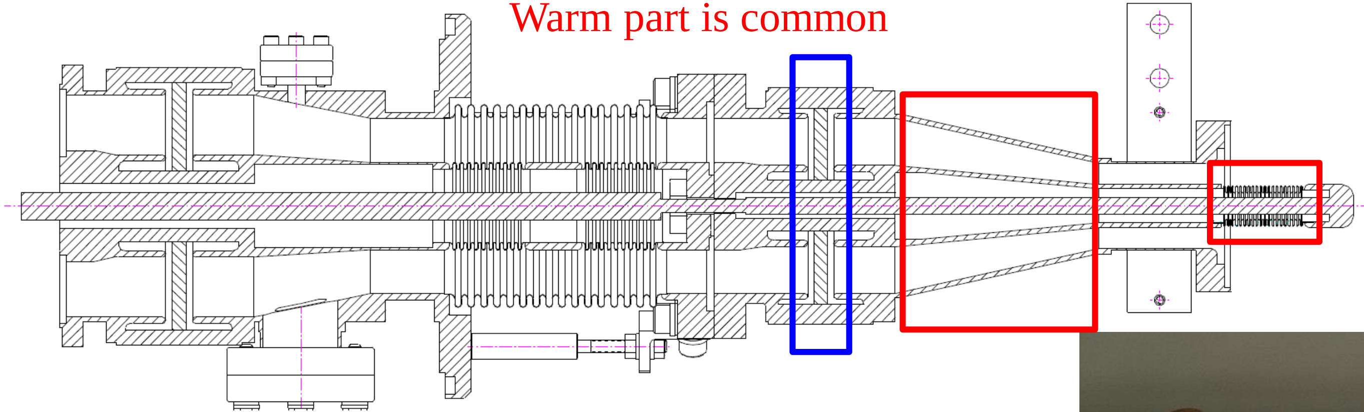
(1) Port dia. : 40mm

(2) Range of Q_L : 10^{6-7}

RF Design & Fabrication

Coupler (TOSHIBA)	Product No.	Serial No.	Ceramic company	Ceramic color	Ceramic coating
Warm #1, #2 (normal)	E42130	14L001 14L002	NGK/NTK	White	TiN
Cold #1, #2 (normal)	E42130	14L001 14L002	NGK/NTK	White	TiN
Cold #3, #4 (new)	E42130	14L003 14L004	KYOCERA	Gray	free





- View point of plug-compatibility
  - Longer tapered pipe for 40mm port
  - Longer bellows for wider range of Q_L
- View point of lower cost study
  - Coating-free ceramic
    - Coating process is dominant in cost

Inspection, assembly, and low power test

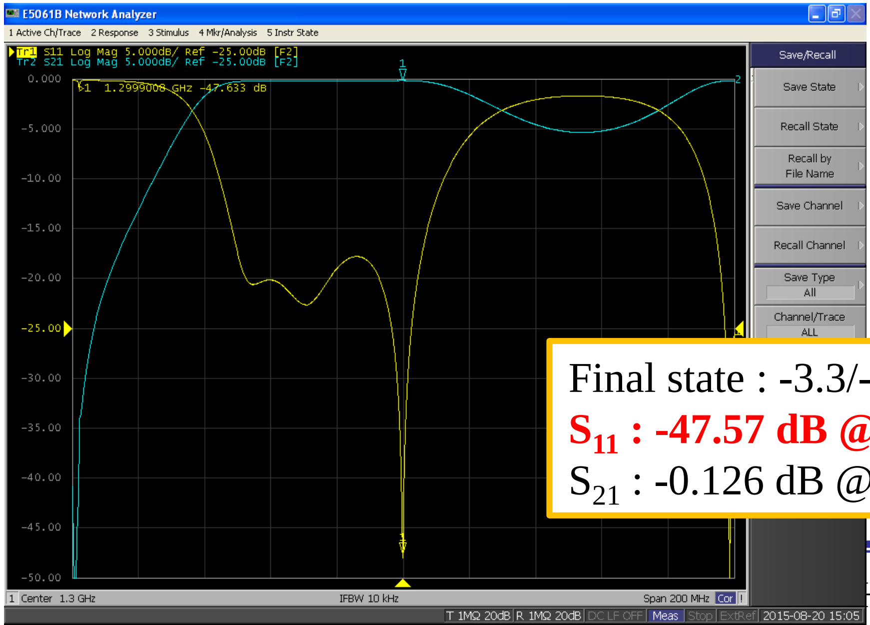
superconducting rf test facility

Head of inner conductor for Cold part #1

Many blisters at head of inner conductor

Ultrapure water rinsing

Assembly in clean room



Final state : -3.3/-4.0mm

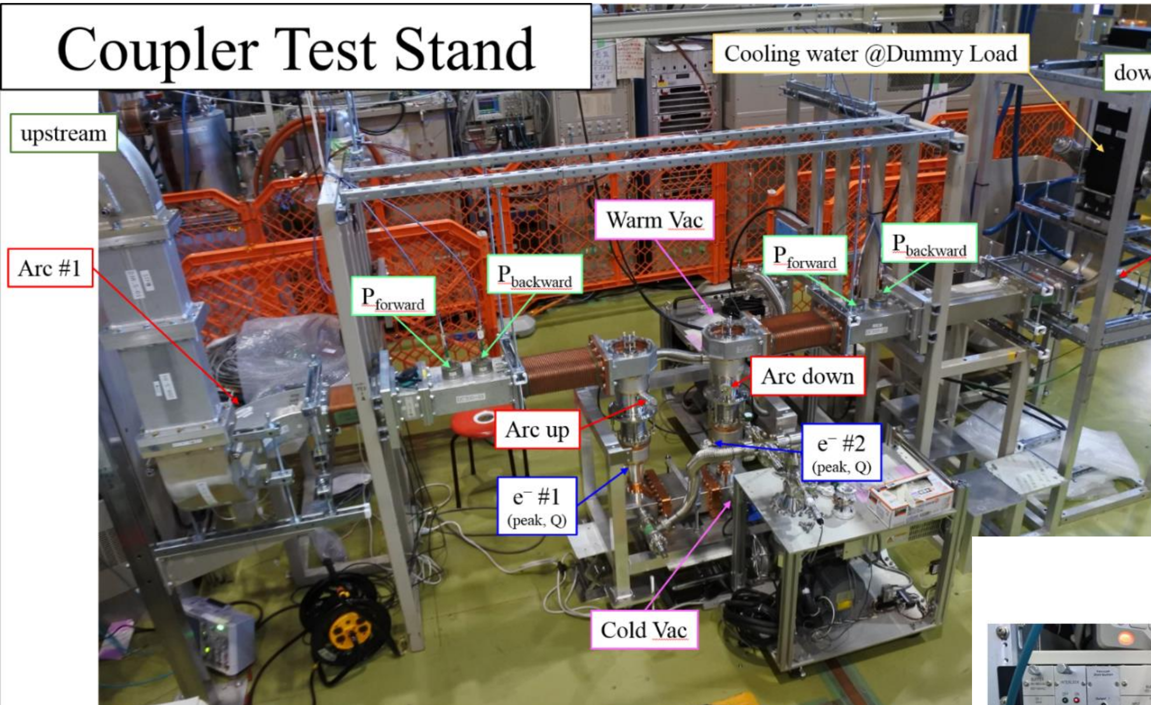
S_{11} : -47.57 dB @1.3GHz

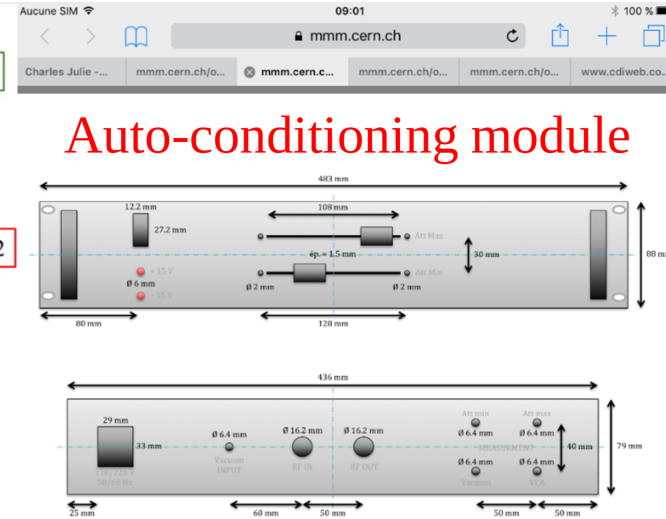
S_{21} : -0.126 dB @1.3GHz

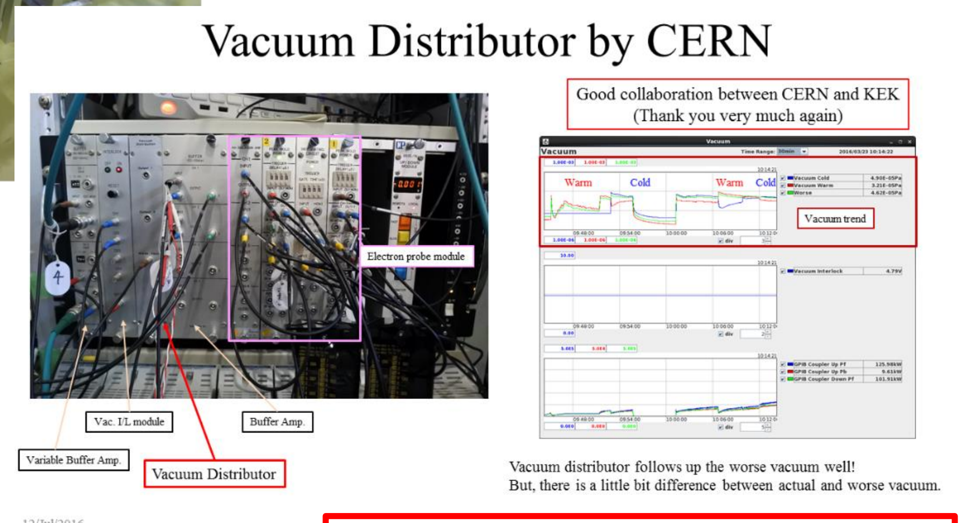
Low power test

High power test at bench

superconducting rf test facility





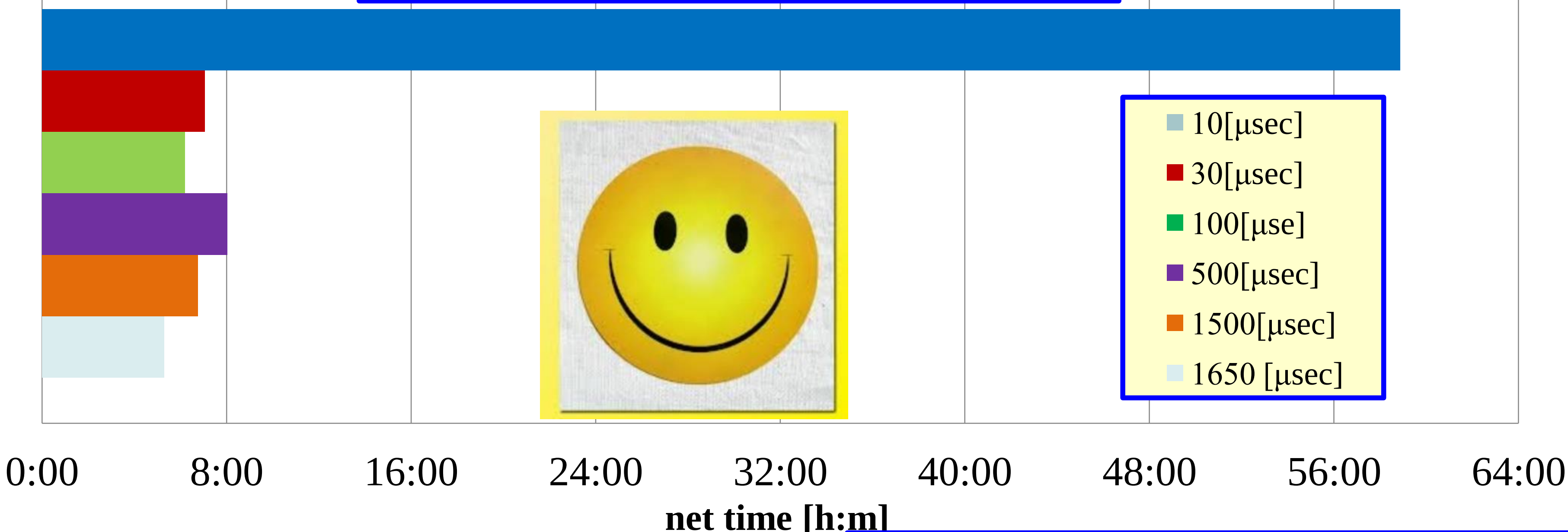


- Warm part is common
- Two kinds of cold parts (TiN coating/free)
- Goal: 1200 kW for <500μs
- Goal: 800 kW for >500μs
- Monitor: Vacuum, Electron, Arc, VSWR
- Devices: Auto-conditioning & Vacuum distributor modules

Good collaboration between CERN and KEK
(Thank you very much)

Result…

Plug-compatible STF coupler with TiN coating ceramic

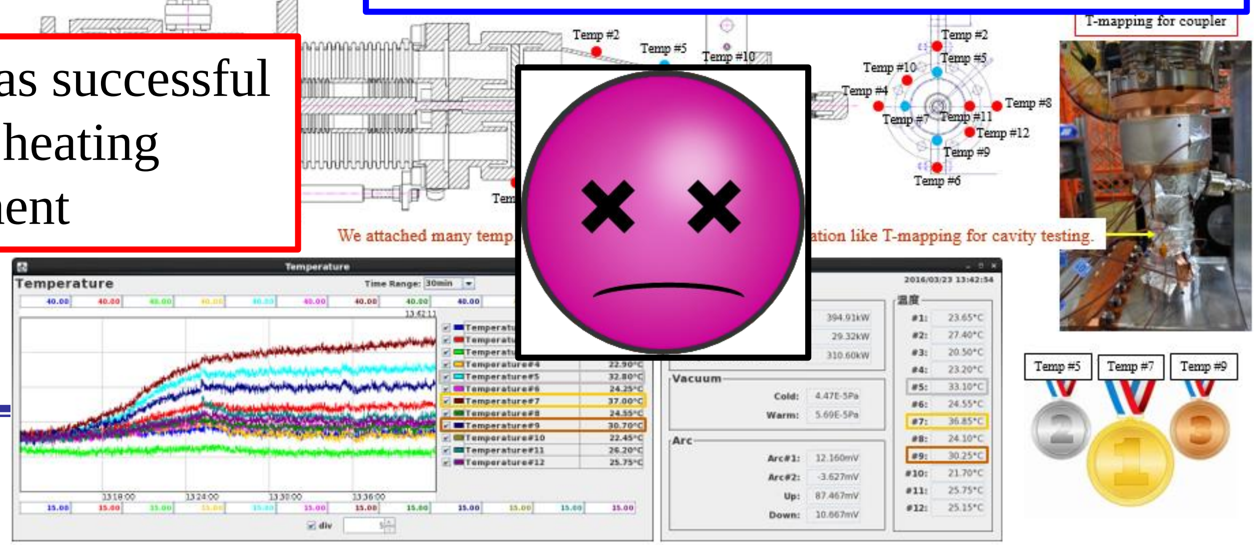


Plug-compatible STF coupler with coating-free ceramic

- Plug-compatible design was successful
- New ceramic had unusual heating due to electron bombardment

1勝1敗
1 Win/1 Loss

○ ●



Summary & Future plan

- ✓ STF-2 cryomodule test have been done twice
  - ✓ Eight cavities achieved above 31.5 MV/m as ILC spec.
  - ✓ Three cavities had significant degradation
  - ✓ One cavity already had heavy F.E. in V.T.
- ✓ New coupler design for plug-compatibility was successful
  - ✓ Longer bellows and narrow coaxial pipe were no problem
- ✓ New ceramic had some problem, and need to improve somethings
  - ✓ Unusual heating at tapered pipe was generated by electron bombardment

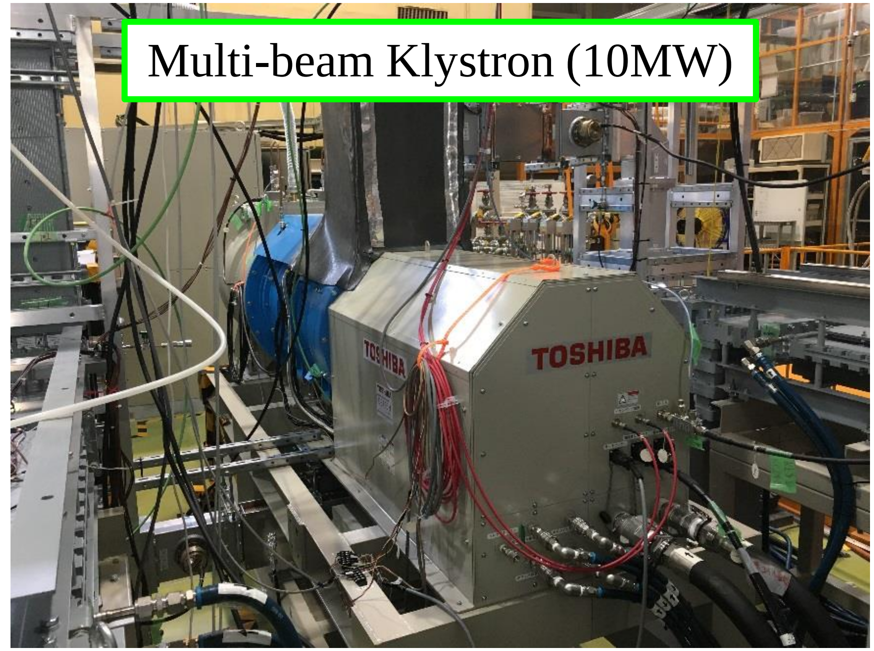
- ✓ 3rd STF-2 cryomodule test will be done from this autumn
  - ✓ Measurement for Q_0 and Lorenz Force Detuning, and LLRF study
  - ✓ Eight cavities operation, additionally injector cryomodule (two cavities)
- ✓ New clean room items will be introduced for beampipe connection
  - ✓ High quality local clean booth, and particle counter, and slow pumping unit
- ✓ More inspection for new ceramic will be done with some vendors
  - ✓ Secondary electron emission coefficient for new ceramic will be measured

Thank you very much for your attention

Back-up slides

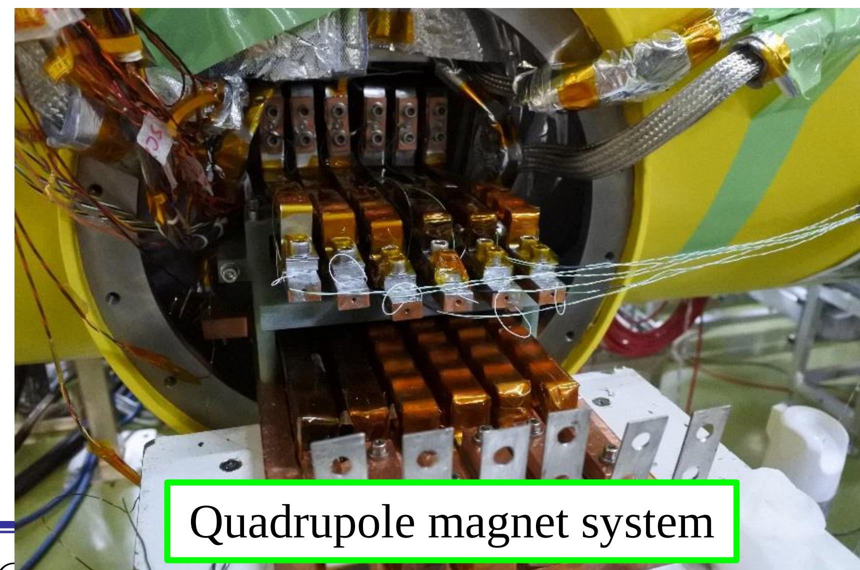
Additional items for beam commissioning


Waveguide system for eight cavities



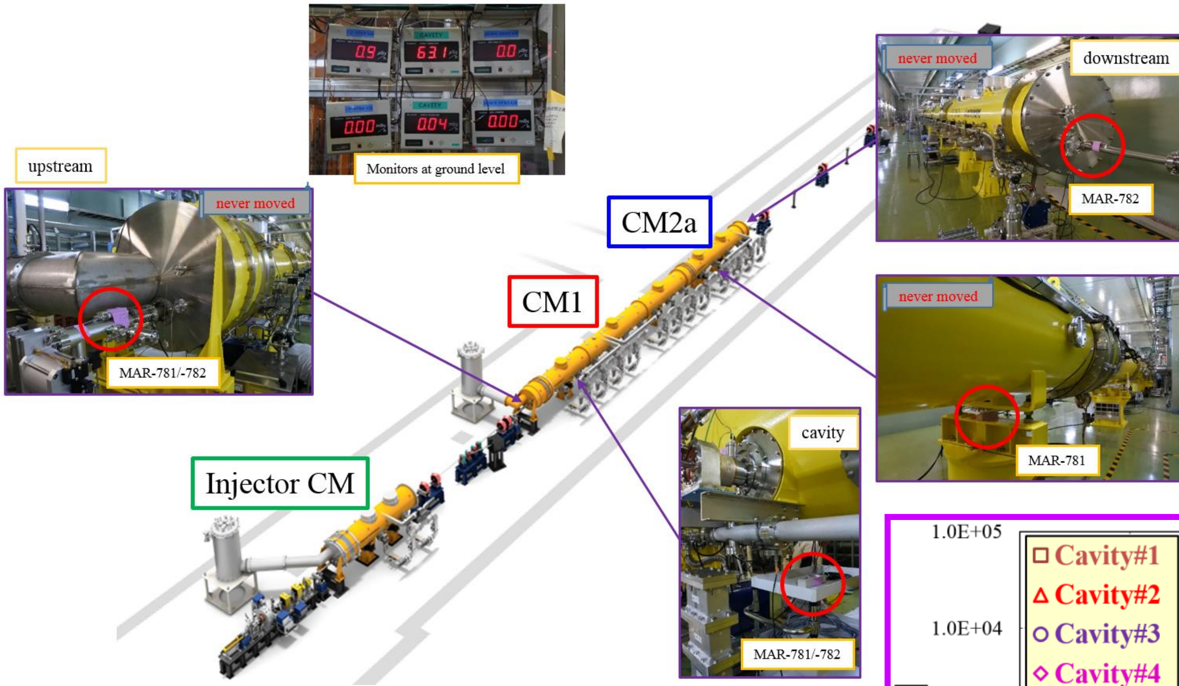
Multi-beam Klystron (10MW)


Pumping unit for 2K liq. helium


Quadrupole magnet system

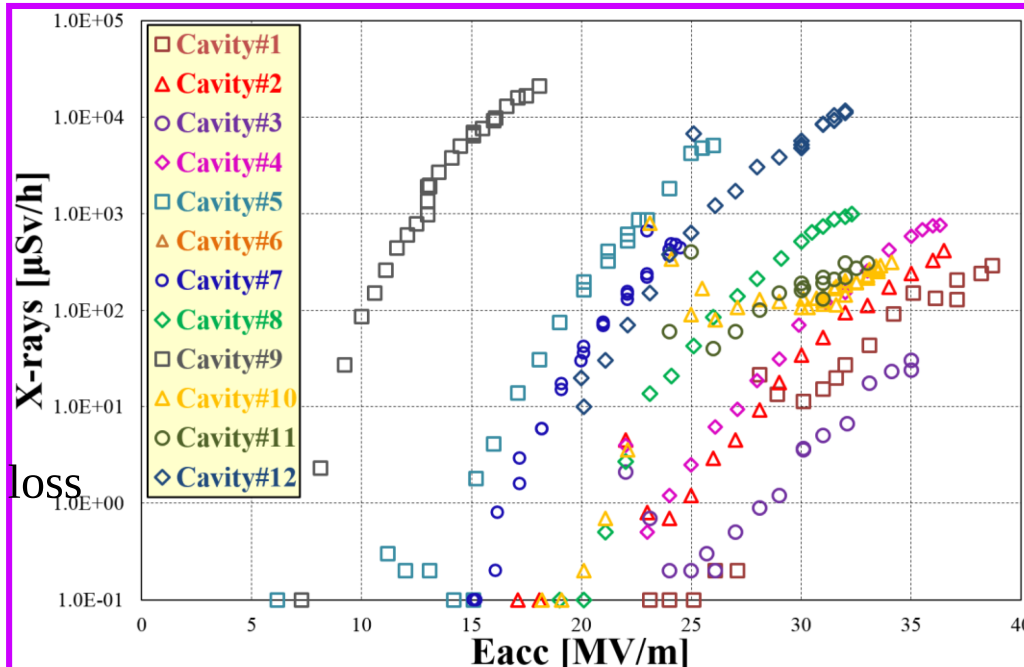
Radiation level near Cryomodule

superconducting rf test facility



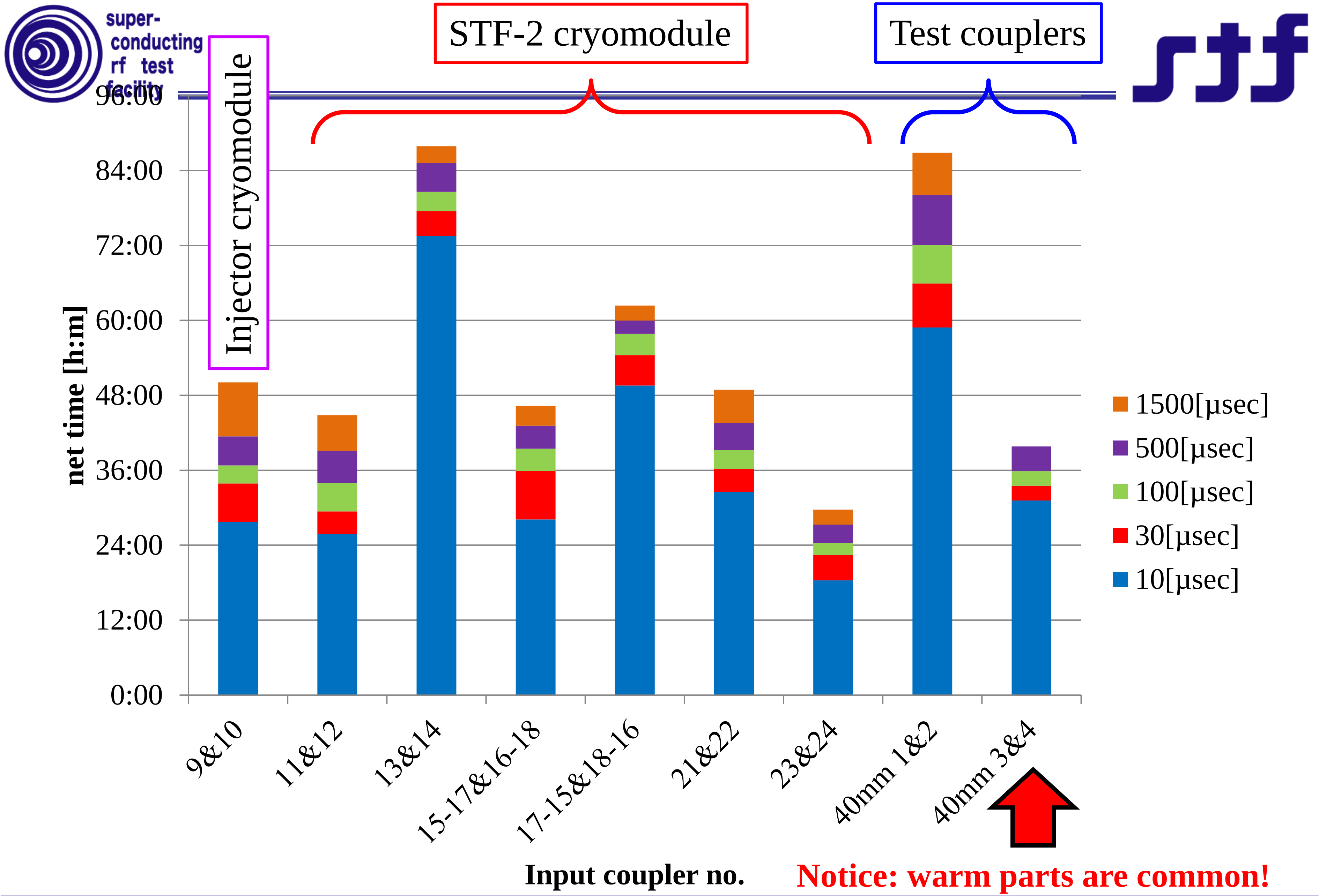
Position of radiation detector:

- ☐ Upstream beampipe
- ☐ Downstream beampipe
- ☐ Below cryomodule (cavity)



Radiation property:

- ◆ Cavity #5 & 7: Heavy F.E.
- ◆ Cavity #6: No x-rays, but enormous heat loss
- ◆ Cavity #9: Heavy F.E. already in V.T.

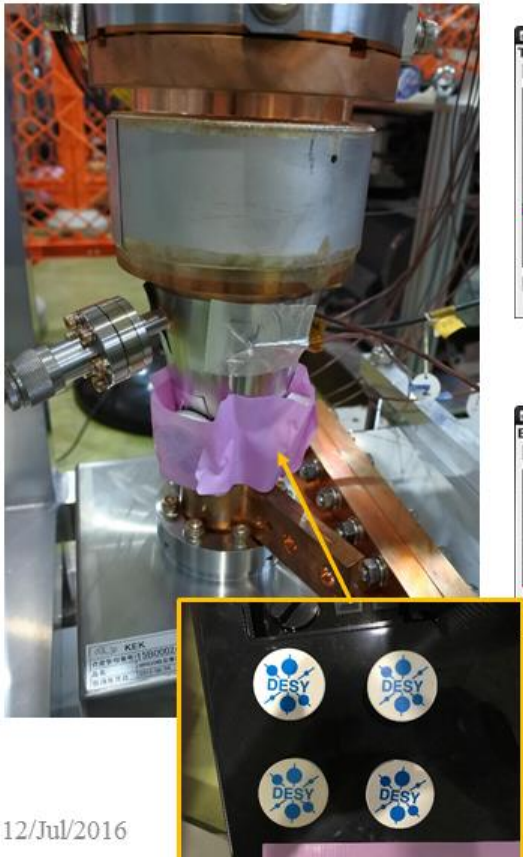


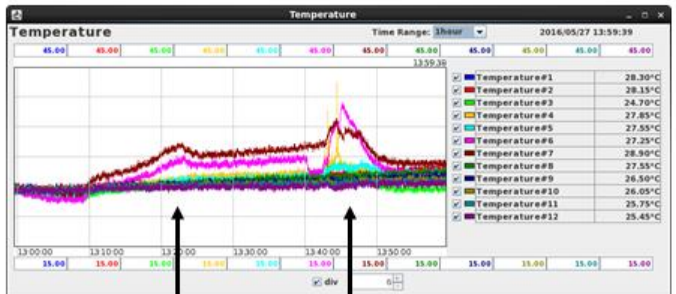
Notice: warm parts are common!

Conditioning time is possibly shorter

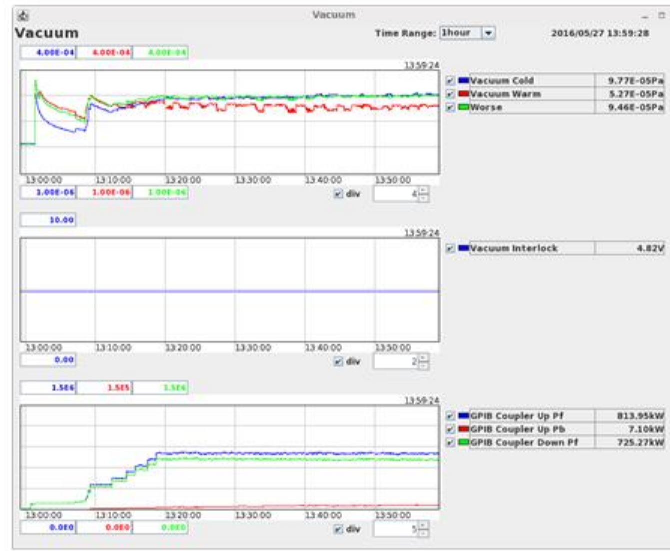
Inspection for unusual heating by DESY magnet

I attached small DESY magnets around tapered pipe.





Only one mag. Four magnets

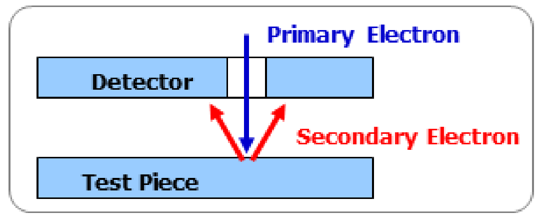


Just after magnets attachment, temperature rise stopped and decreased.
But, when RF pulse width changed from 400 to 500μsec, there was no effect
↓
Many electrons directly hit at tapered pipe! (No thermal conductivity)

12/Jul/2016 103

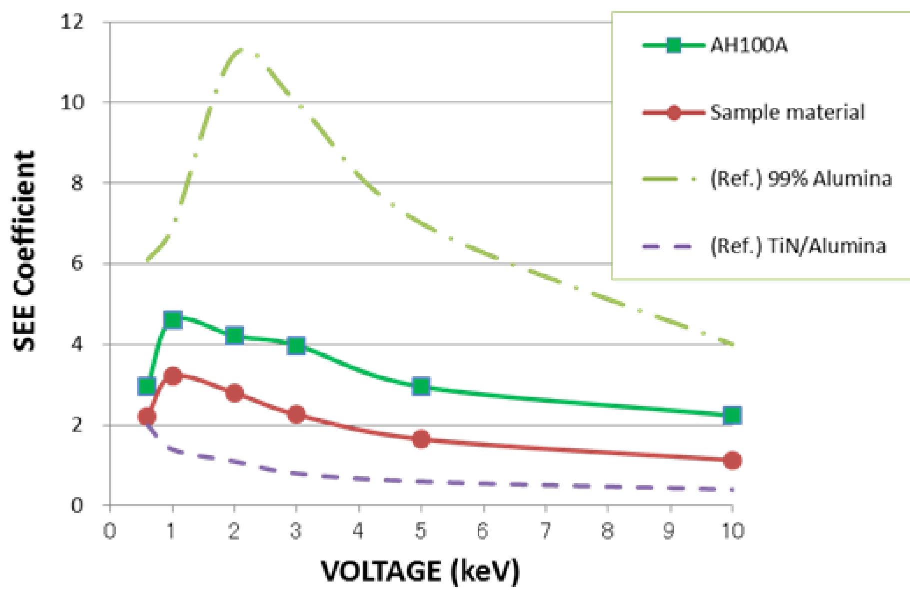
TTC-WG6 2014 No.226KI4K28A

SEE (Secondary Electron Emission) Coefficient Measurement Method



SEE Coefficient Measurement Result

- ✓ AH100A has 1/2 smaller SEE Coefficient than that of 99% alumina.
- ✓ Sample material can make SEE coefficient less than AH100A, however still higher than TiN coated alumina surface.



After Annealing at 1200 degree C

TTC-WG6 2014 No.226KI4K28A

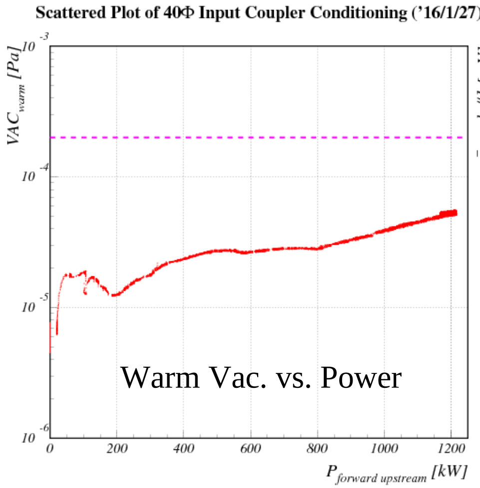
Comparison of Measurement Value for Evaluated Ceramic

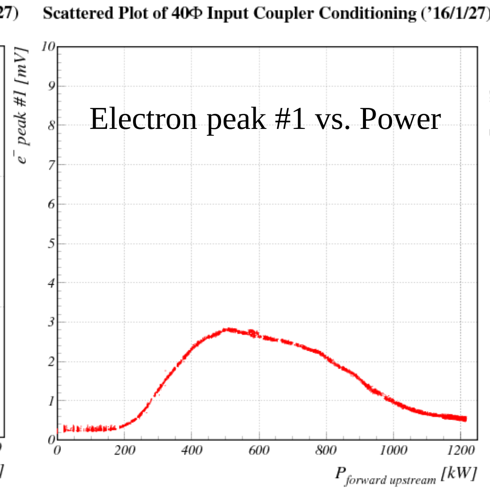
<Ref. Data>

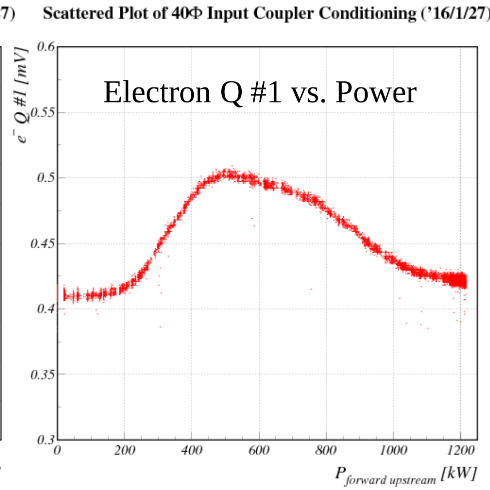
				99.8% Alumina for RF Application (A479B)	AH100A	Sample Material
Electrical Property	Volume Resistivity		ohm・cm	min. 1 X 10^{14}	min. 1 X 10^{14}	-
	Surface Resistivity		ohm/□	8.9 X 10^{14}	7.4 X 10^{15}	1.2 X 10^{14}
	SEE Coefficient		-	11.4	4.6	3.2
	Dielectric Constant	1MHz	-	9.9	10.2	-
		8GHz	-	9.9	10.0	10.0
	Dielectric Loss Angle	1MHz	-	1 X 10^{-4} *1	1 X 10^{-4} *1	-
		8GHz	-	4 X 10^{-5}	1 X 10^{-4}	3 X 10^{-3}
Mechanical Property	Ave. Flexural Strength(RT) ASTM D2442 TYPE3		MPa	300	330	-
	Young's Modulus		GPa	370	380	-
	Poisson Ratio		-	0.23	0.25	-
Thermal Property	Thermal Conductivity (RT)		W/mK	29	24	-
	Coeff. Thermal Expansion	RT-400deg.C	ppm/K	7.0	7.4	-

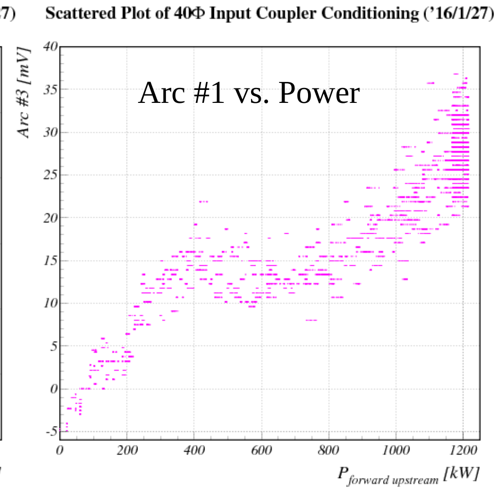
*1:Lower limitation of measurement method

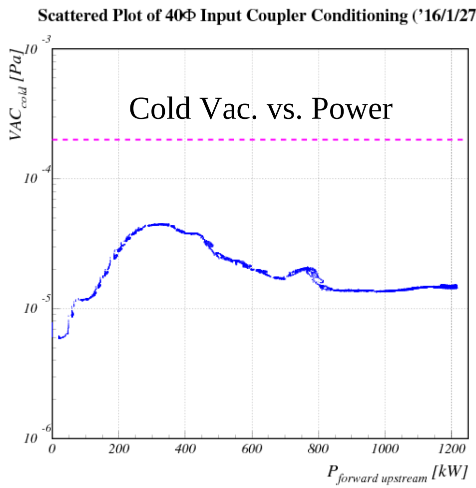
S-band RF Transmission Test Sample

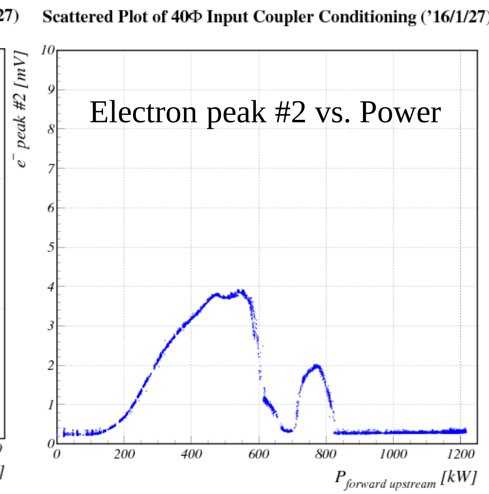

Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Warm Vac. vs. Power
VAC_{warm} [Pa]
$P_{forward\ upstream}$ [kW]

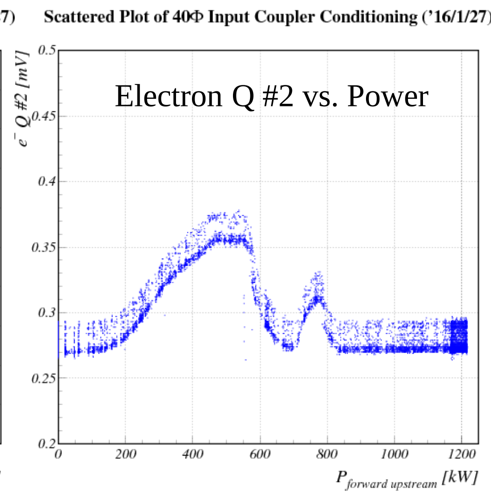

Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Electron peak #1 vs. Power
e^- peak #1 [mV]
$P_{forward\ upstream}$ [kW]

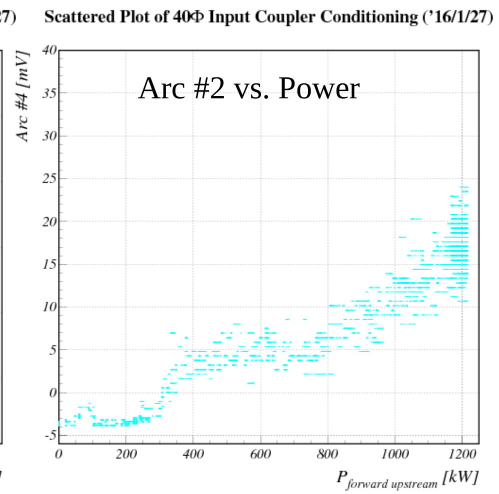

Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Electron Q #1 vs. Power
e^- Q #1 [mV]
$P_{forward\ upstream}$ [kW]


Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Arc #1 vs. Power
Arc #3 [mV]
$P_{forward\ upstream}$ [kW]

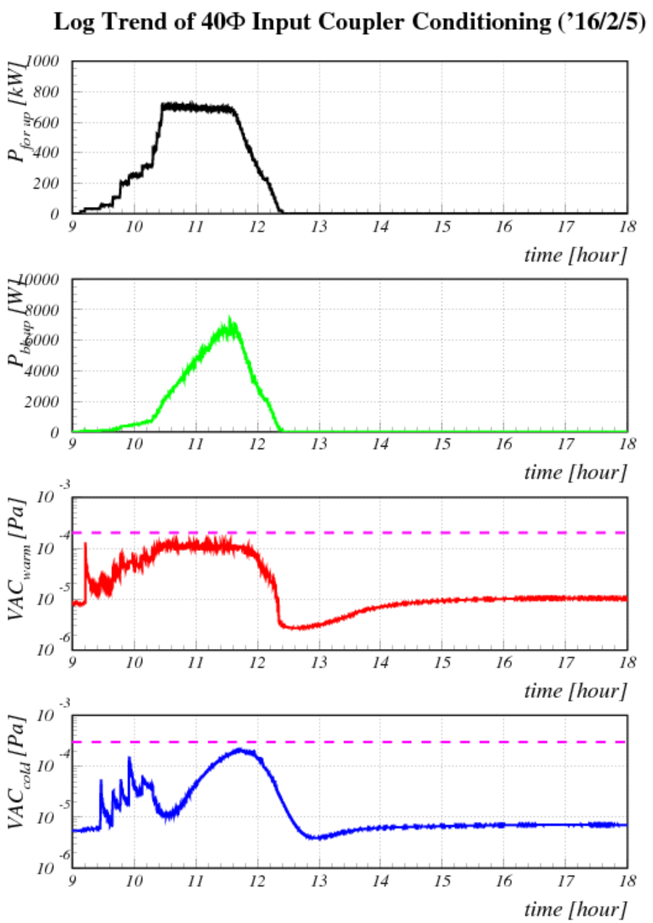

Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Cold Vac. vs. Power
VAC_{cold} [Pa]
$P_{forward\ upstream}$ [kW]


Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Electron peak #2 vs. Power
e^- peak #2 [mV]
$P_{forward\ upstream}$ [kW]

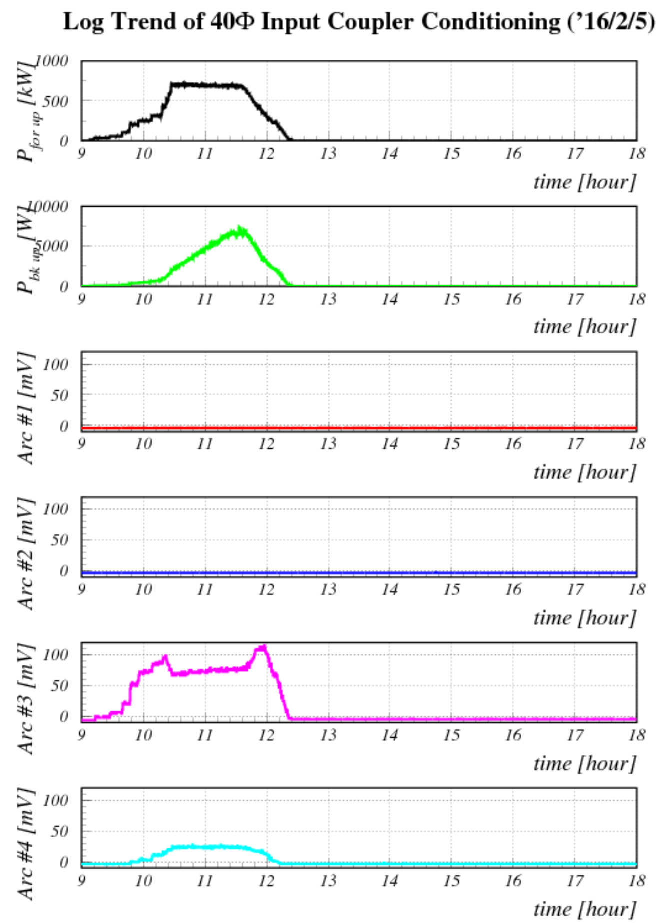

Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Electron Q #2 vs. Power
e^- Q #2 [mV]
$P_{forward\ upstream}$ [kW]


Scattered Plot of 40Φ Input Coupler Conditioning ('16/1/27)
Arc #2 vs. Power
Arc #4 [mV]
$P_{forward\ upstream}$ [kW]

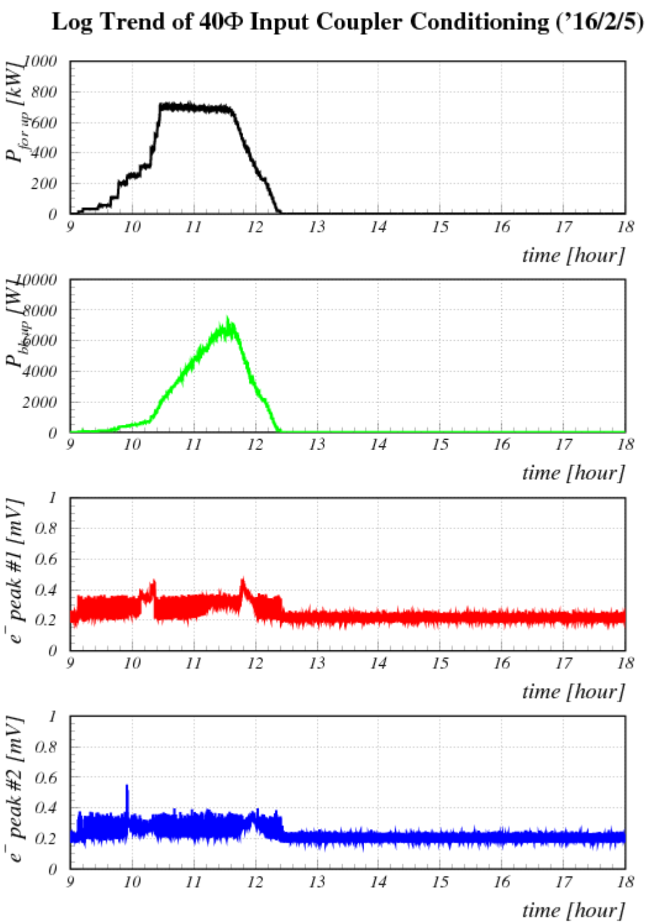
One-day trend graph for coupler conditioning (normal ceramic)



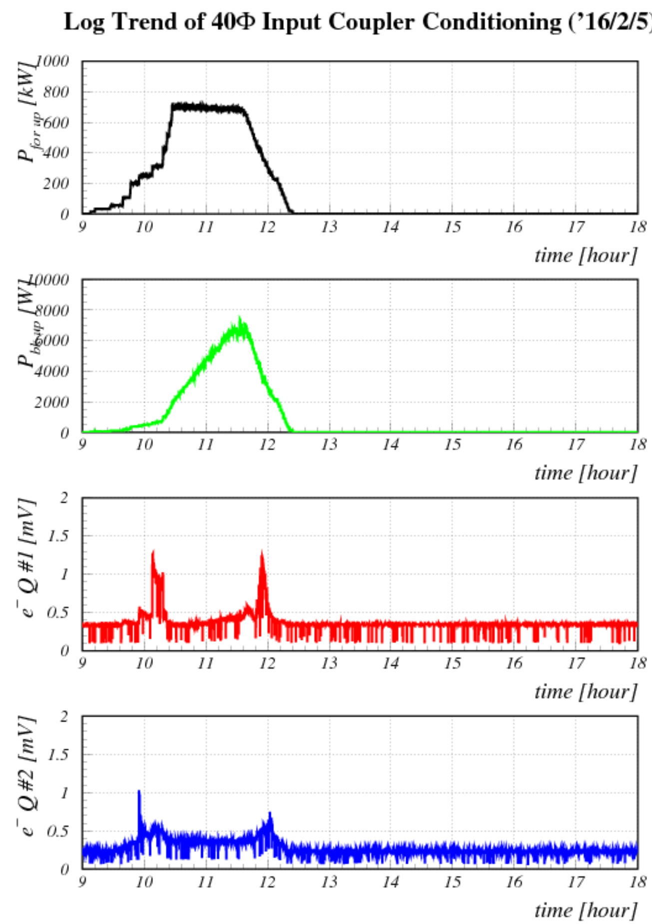
Pulse width : 1650 [μsec]
Rep. frequency : 5 [Hz]

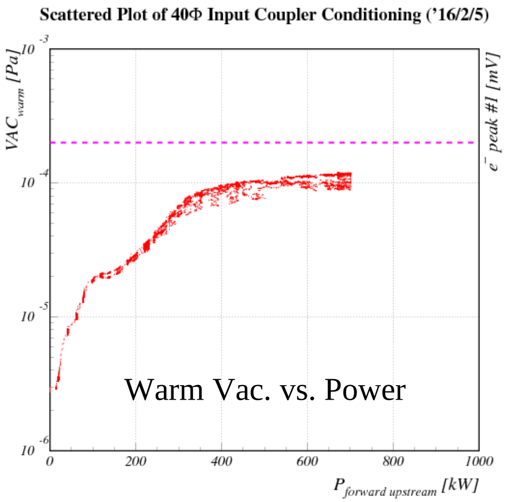


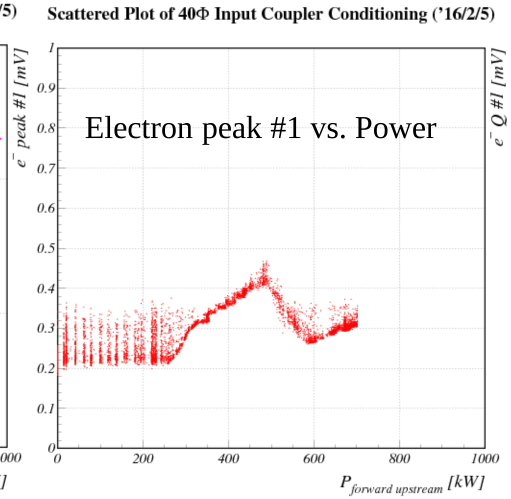
One-day trend graph for coupler conditioning (normal ceramic)

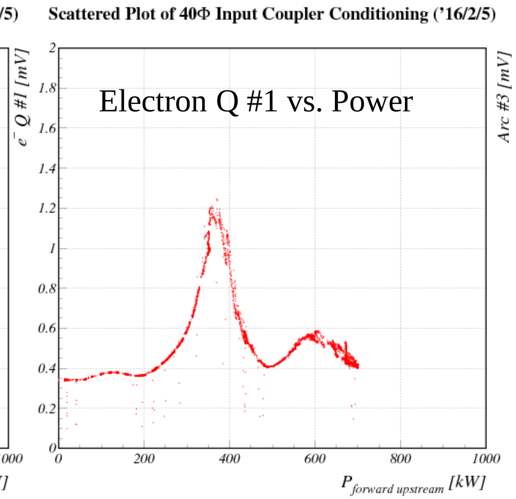


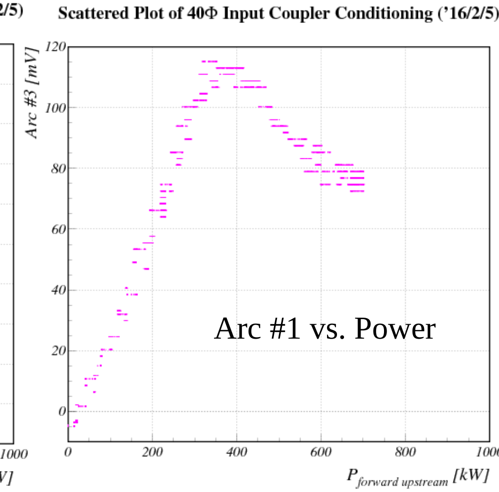
Pulse width : 1650 [μsec]
Rep. frequency : 5 [Hz]

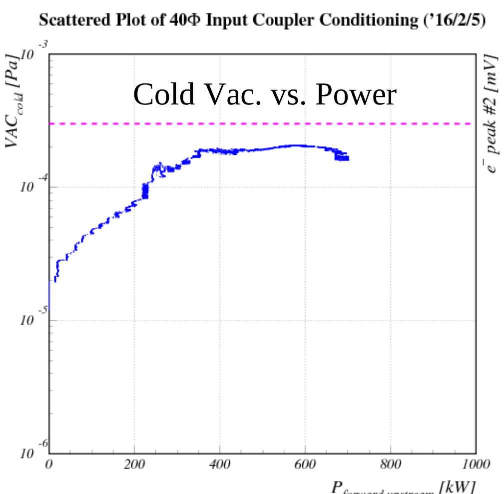


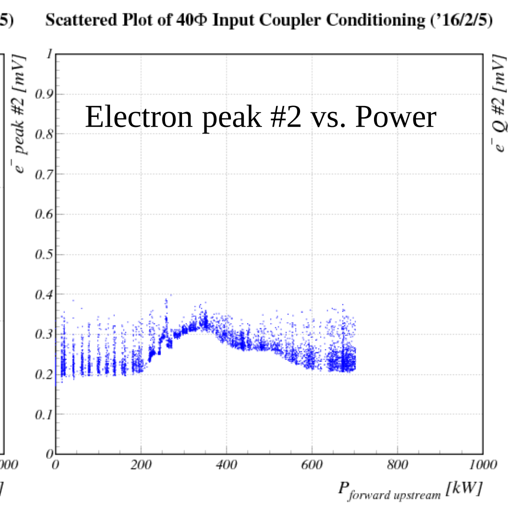

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Warm Vac. vs. Power
VAC_warm [Pa]
P_forward upstream [kW]

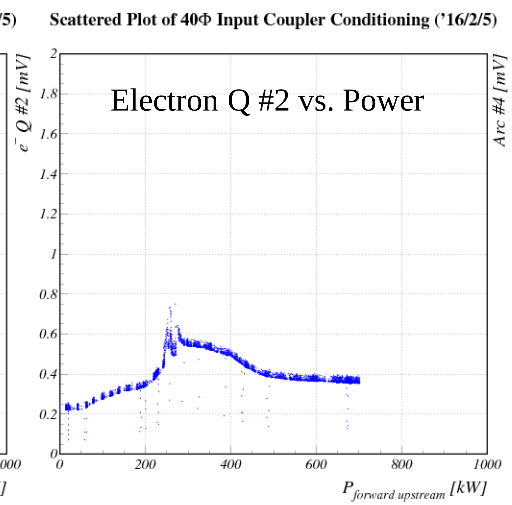

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Electron peak #1 vs. Power
e⁻ peak #1 [mV]
P_forward upstream [kW]

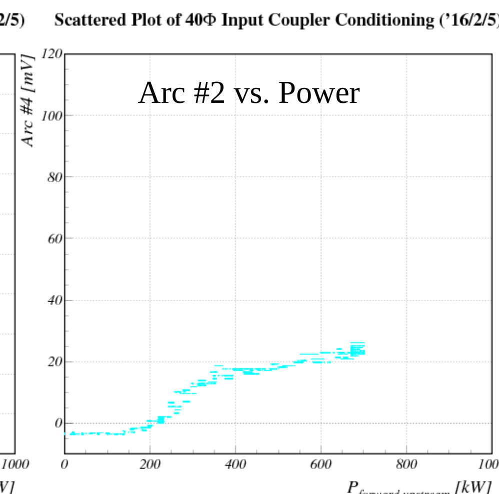

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Electron Q #1 vs. Power
e⁻ Q #1 [mV]
P_forward upstream [kW]


Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Arc #1 vs. Power
Arc #3 [mV]
P_forward upstream [kW]

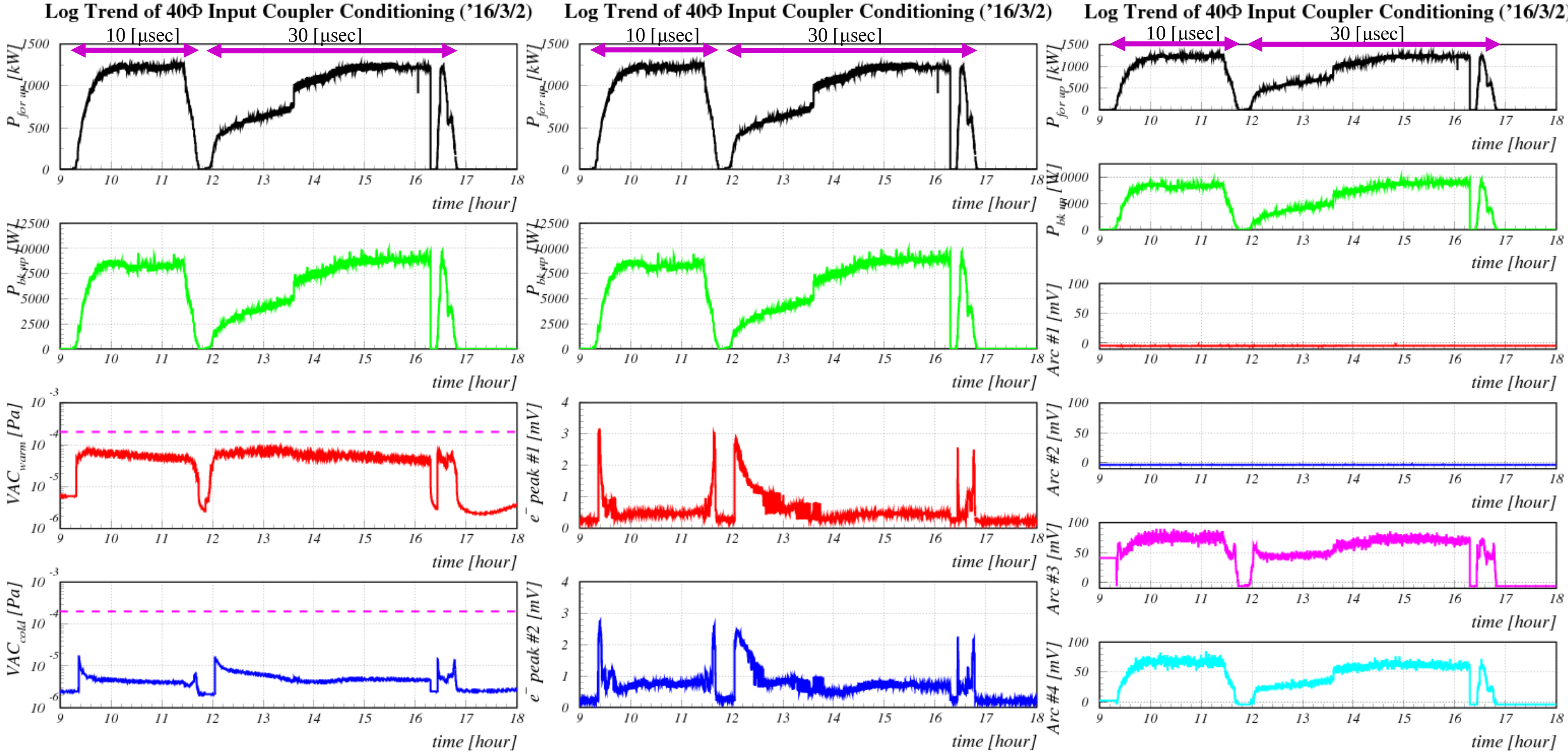

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Cold Vac. vs. Power
VAC_cold [Pa]
P_forward upstream [kW]

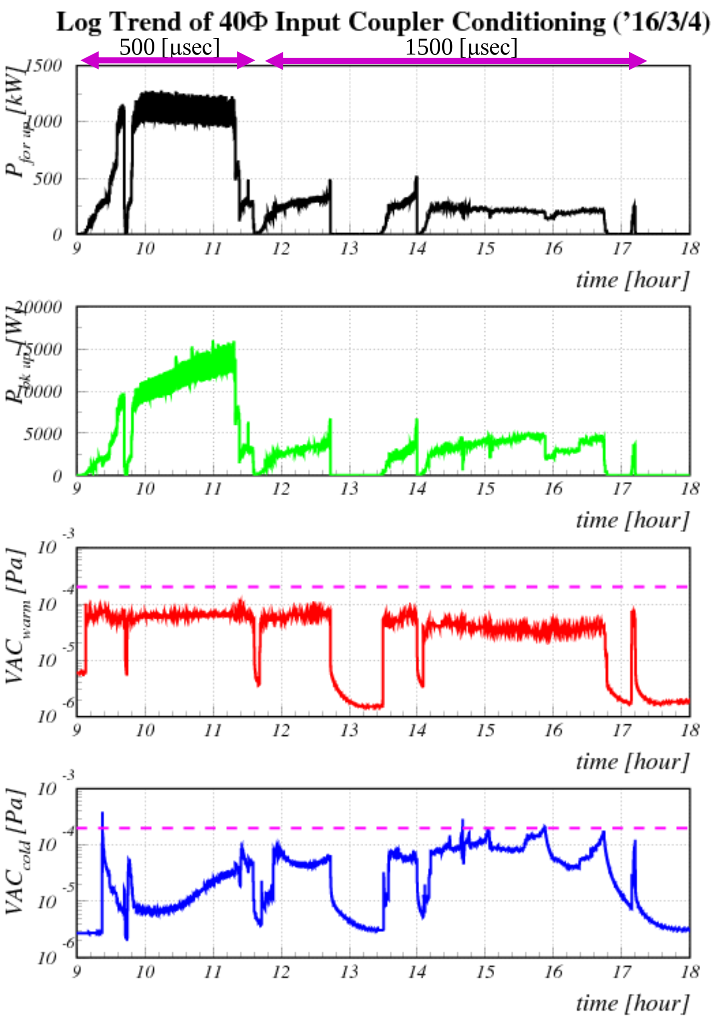

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Electron peak #2 vs. Power
e⁻ peak #2 [mV]
P_forward upstream [kW]

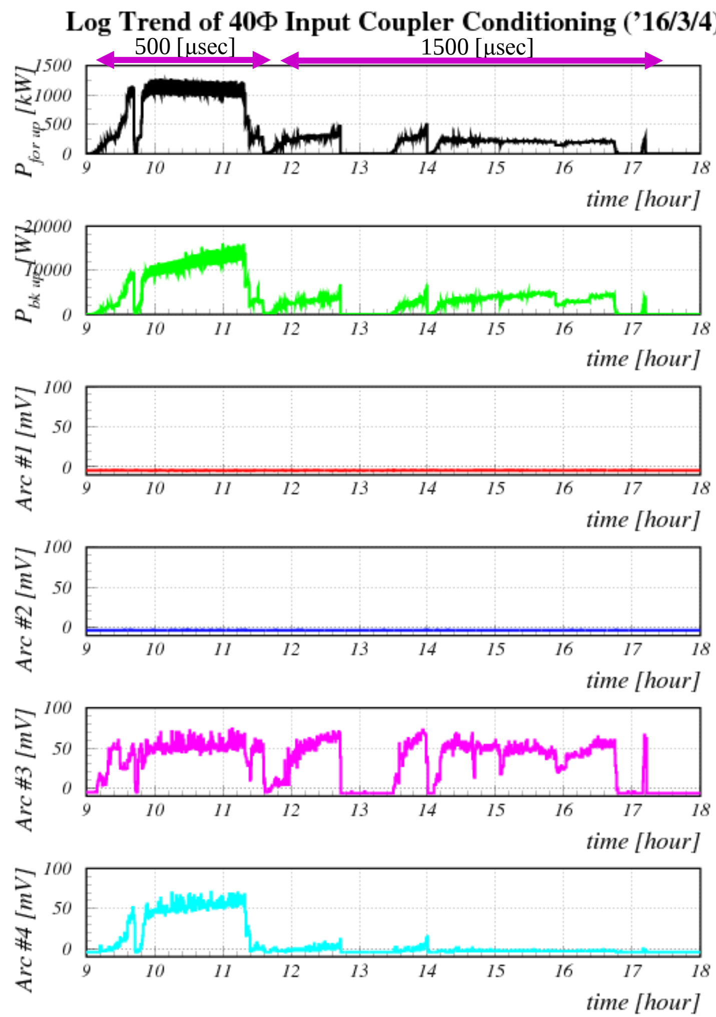

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Electron Q #2 vs. Power
e⁻ Q #2 [mV]
P_forward upstream [kW]

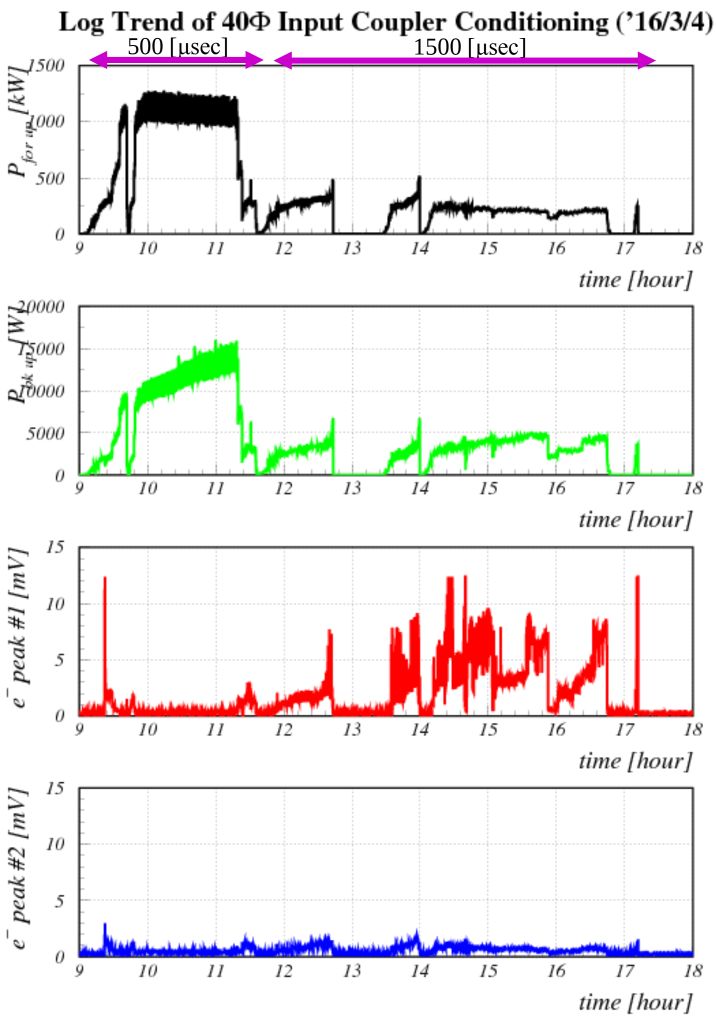

Scattered Plot of 40Φ Input Coupler Conditioning ('16/2/5)
Arc #2 vs. Power
Arc #4 [mV]
P_forward upstream [kW]

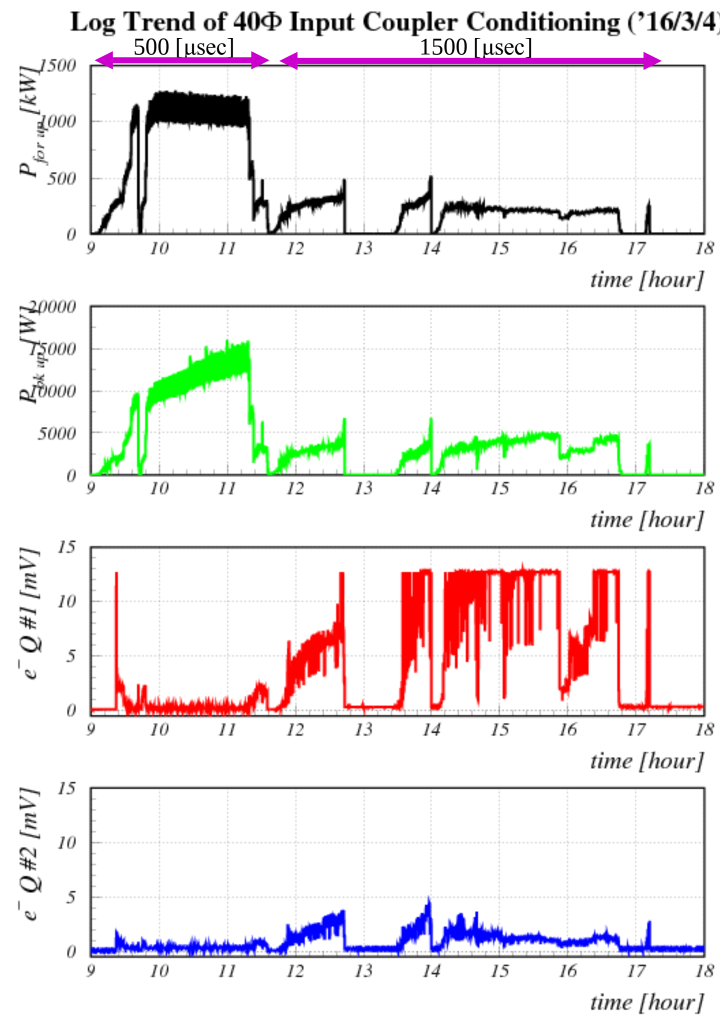
One-day trend graph for coupler conditioning (new ceramic)




Log Trend of 40Φ Input Coupler Conditioning ('16/3/4)
500 [μsec]
1500 [μsec]
P_for up [kW]
P_bk up [W]
VAC_warm [Pa]
VAC_cold [Pa]
time [hour]


Log Trend of 40Φ Input Coupler Conditioning ('16/3/4)
500 [μsec]
1500 [μsec]
P_for up [kW]
P_bk up [W]
Arc #1 [mV]
Arc #2 [mV]
Arc #3 [mV]
Arc #4 [mV]
time [hour]


Log Trend of 40Φ Input Coupler Conditioning ('16/3/4)
500 [µsec]
1500 [µsec]
P_for up [kW]
P_bk up [W]
e⁻ peak #1 [mV]
e⁻ peak #2 [mV]
time [hour]


Log Trend of 40Φ Input Coupler Conditioning ('16/3/4)
500 [µsec]
1500 [µsec]
P_for up [kW]
P_bk up [W]
e⁻ Q #1 [mV]
e⁻ Q #2 [mV]
time [hour]