ARIES APEC GSI FAIR

High Intensity RFQ meets Reality

the RFQs in IMP

Yuan He

On behalf of Linac Center

Institute of Modern Physics, CAS

Outline

- CW high-intensity RFQs activities in IMP
- Structure and Conditioning of the RFQs
- Problems happened to the RFQs
- How to make a stable RFQ always?

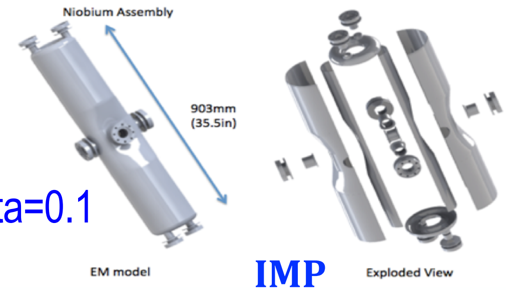
CW RFQs constructed in IMP

	ADS RFQ injector II	CMIF-RFQ	D-RFQ-973	LEAF	SSC-Linac
Project served	CiADS	CMIF	BisoL	HIAF	HIRFL
Freq. (MHz)	162.5	162.5	162.5	81.25	53.67
Type	4-vane	4-vane	4-vane	4-vane	4-rod
Dipole mode	PiMS	PiMS	window	PiMS	-
Species	Proton	Deuteron	Deuteron	HI A/q=7	HI A/q=7
Vane V (kV)	65	65	60	70	70
I (emA)	10	10	50	2	0.5
Inj. E (keV)	35	40	40	98	25
Ex. E (MeV)	2.1	3.0	1	3.5	1
Kp	1.2	1.4	1.68	1.5	-
CW Op. (emA)	11	2.5 (P)	1.8 (H_2^+)	0.5 (HI)	0.2 (HI)
First beam	Jun. 2014	Nov. 2017	Jun. 2018	Feb. 2018	Jan. 2015
Institution	IMP/LBL	IMP	PKU/IMP	IMP	IMP/PKU

Chinese ADS Front-end Demo linac (CAFe)

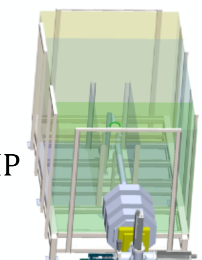
- **Goal: to demonstrate the technology of 10 mA CW beam of superconducting front-end Linac for CiADS.**
- **Design: 25 MeV, 10 mA, CW, 4.5K**
- **IMP collaboration with IHEP 2011 ~ 2017**

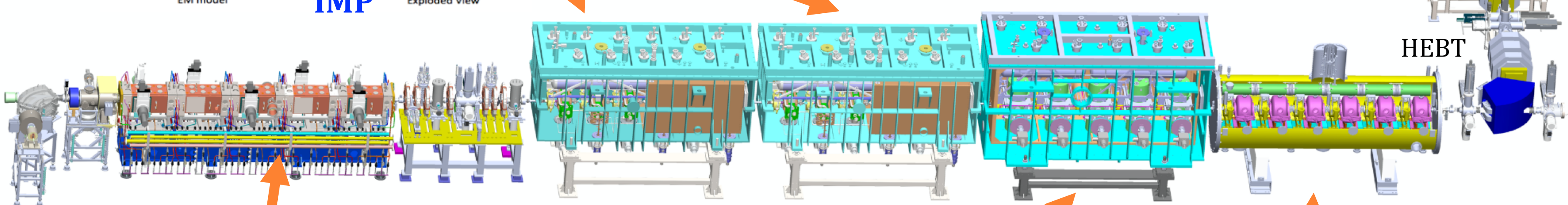
162.5 MHz Half-wave Cavity



Beta=0.1

IMP

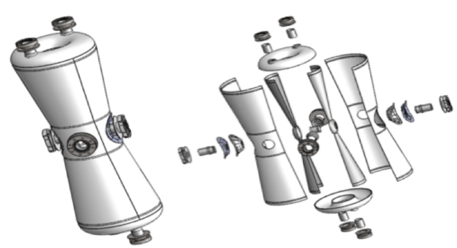




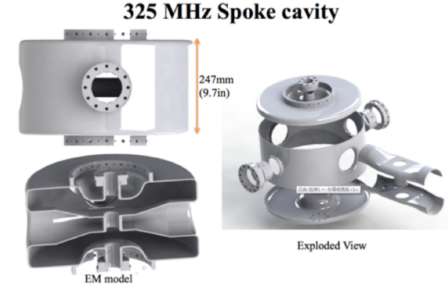
P, He

Beta=0.15 **IMP**

162.5 MHz Taper HWR



325 MHz Spoke cavity



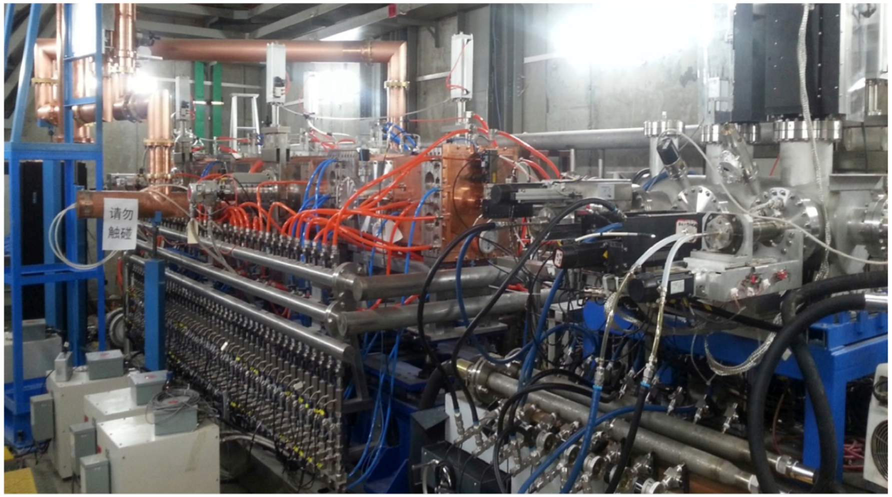
Beta=0.21

IHEP

ADS RFQ : 2014-2017
CMIF RFQ : 2018-

- **Supported by "Strategic Priority Research Program" of the Chinese Academy of Sciences.**

RFQs for CAFe



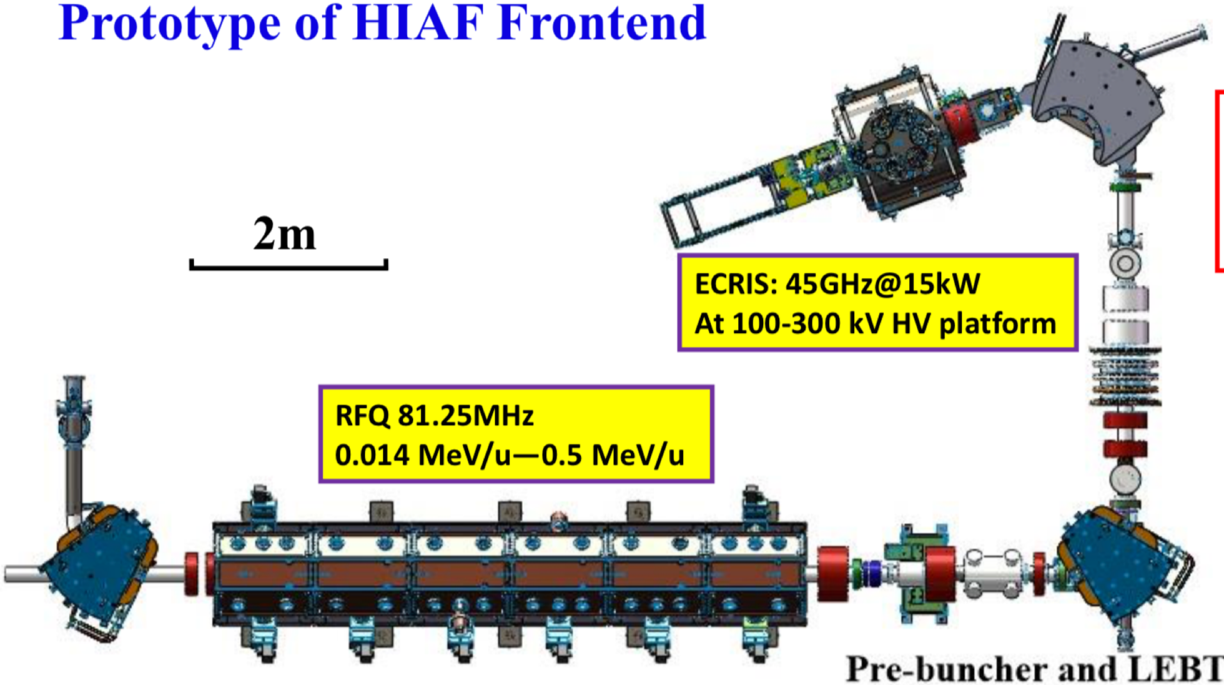
- Apr. 17 to Jun. 6 '14, condition to 90 kW
- **June 6th, 2014， the first beam, 2.16 MeV**
- **June 21st, the first CW beam @ 2 mA**
- **June 30th， 10 mA, CW, 21 kW, 4.5 hours, transmission >97%**
- **CW RF Operation 5904 hours**
- **Offline in Jan. 2018**

- Nov. 2017, short pulse condition to 135 kW
- Online in Oct. 2018
- **Operation from Nov. 2018, RF Operation time, pulse, 312 hours**

- **2017.11.15, H^+, 3.4 mA; H_2^+, 7.8mA**
- **2018.12.17-19, $^4He^{2+}$, 46 hours**

RFQ for LEAF

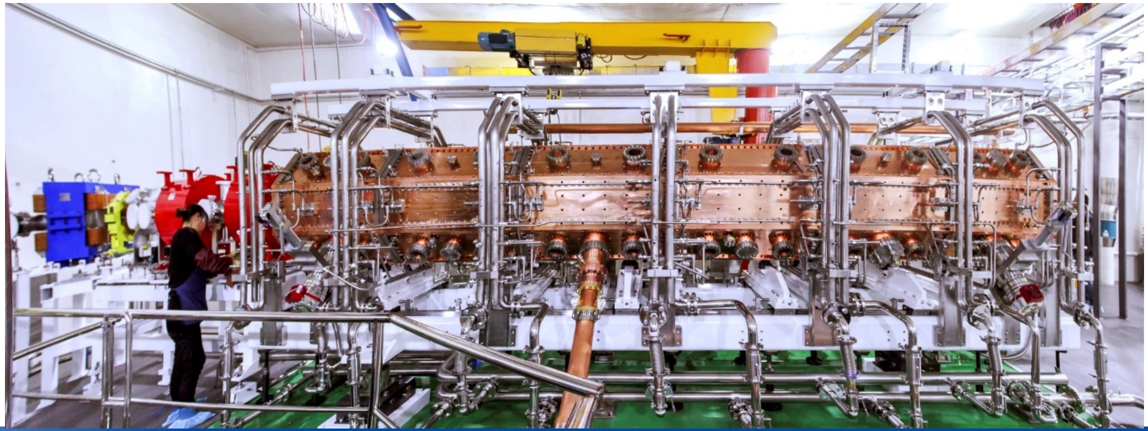
Prototype of HIAF Frontend



- Irradiation material
- Highly charged atomic physics
- Low energy Nuclear astrophysics

Xe^{30+},Bi^{31+},U^{34+}	1.5 emA
$^{129}Xe^{45+}$	30-100 μA
$^{209}Bi^{55+}$	30-100 μA
$^{238}U^{56+}$	30-100 μA

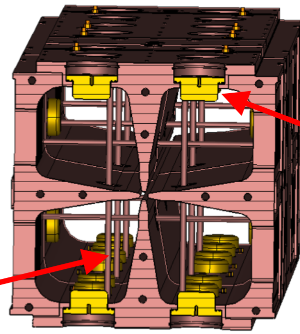
- Feb. 2018, condition to 1.1 nominated power in 44 hours; 200 uA CW $^{4}He^{+}$ beam， 100 uA CW $^{14}N^{2+}$， energy is 0.5 MeV/u
- Operation time, CW, 589 hours



Outline

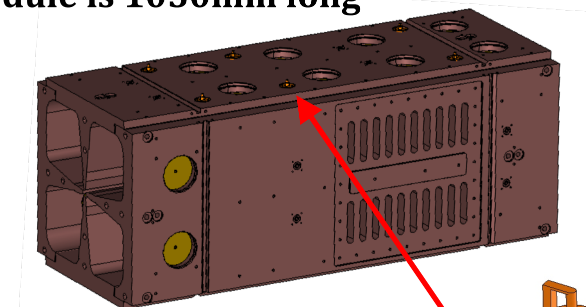
- CW high-intensity RFQs activities in IMP
- Structure and Conditioning of the RFQs
- Problems happened to the RFQs
- How to make a stable RFQ always?

Structure of ADS RFQ



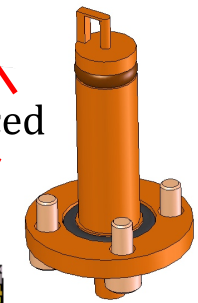
80 Tuners
Equal spaced
20 per module

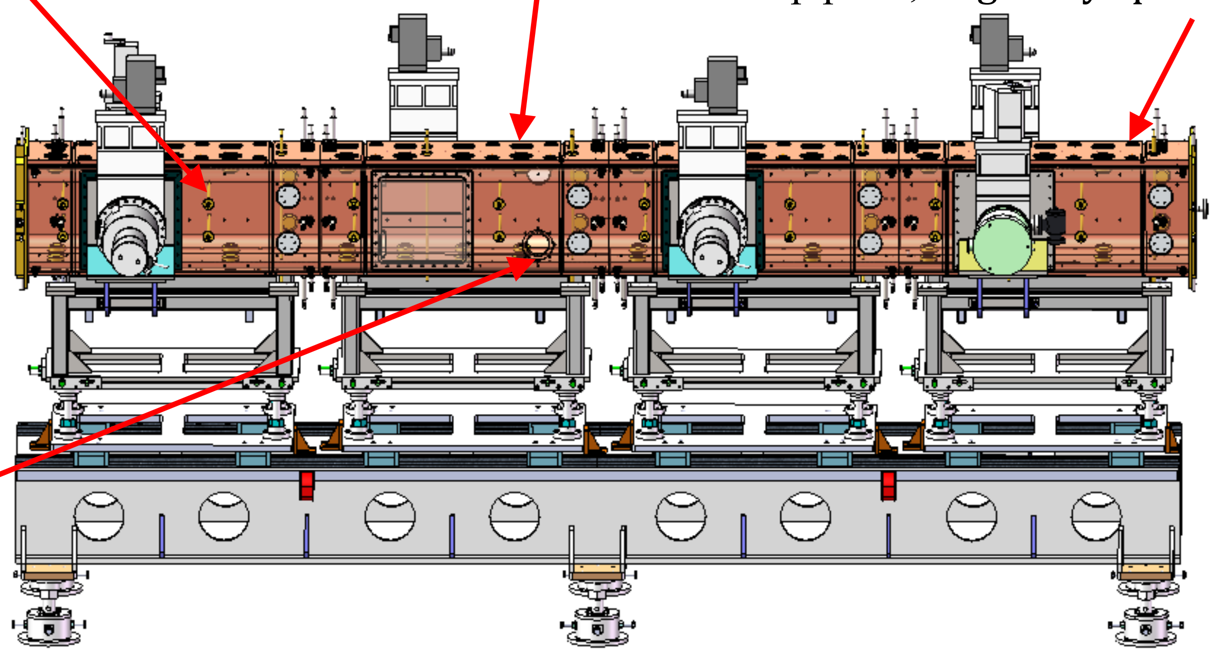
Consists of four modules, each module is 1050mm long



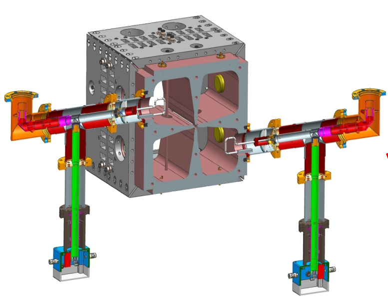
32 Pi-mode Rods
Equal space,
8 per module

48 sensing
loop ports, Regularly spaced

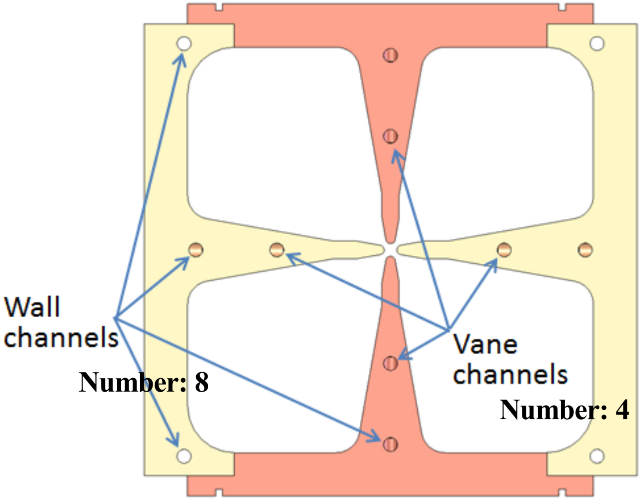




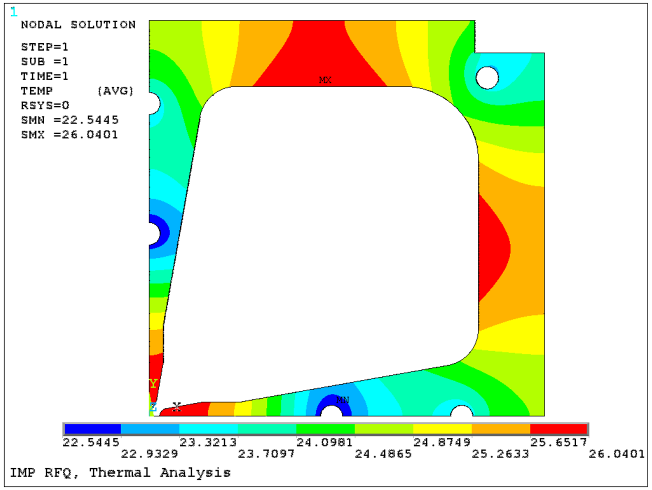
2 RF input ports
Both in Module 2
One near side, one far side



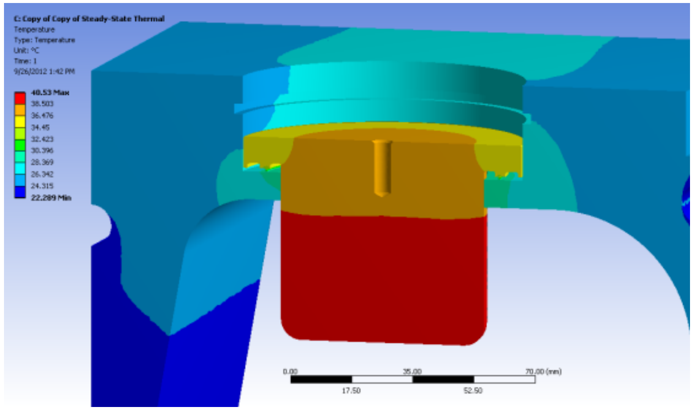
Thermal analysis of the cavity body



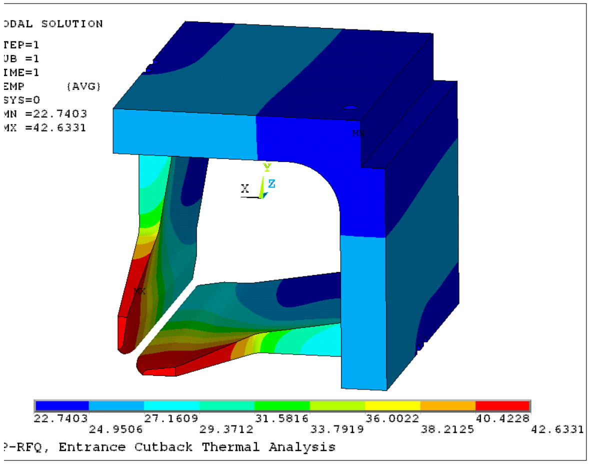
Cooling water 20°C
Velocity < 2.5 m/s



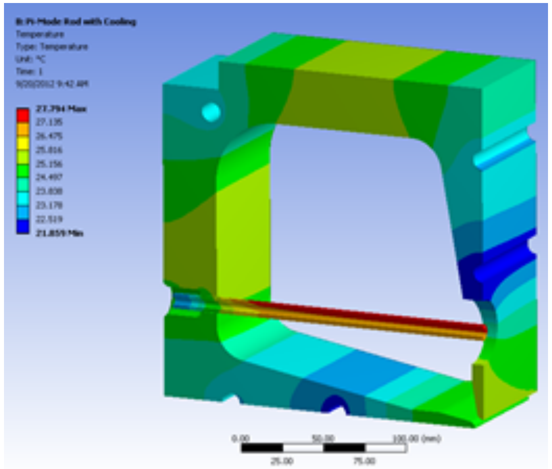
Max. Temp.: 26°C



70~105 W for each
Max. Temp.: 41°C

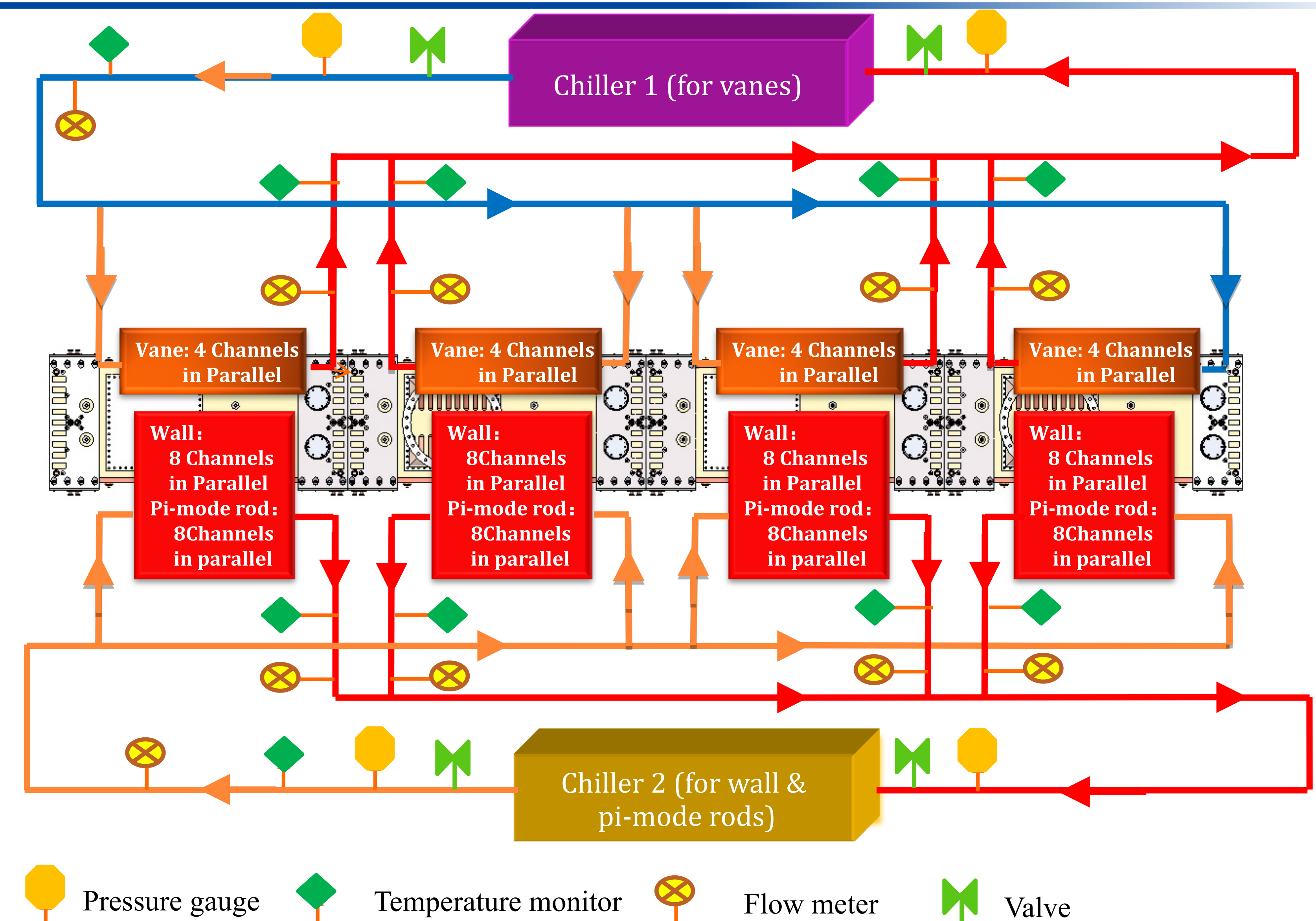


Max heat flux 28.92 W/cm^2;
Max temp of cutbacks 48.0 °C



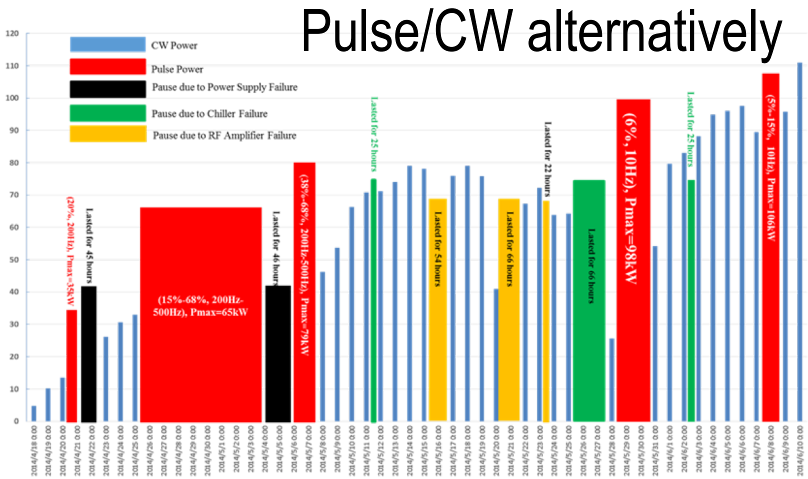
Max. Temp.: 30°C

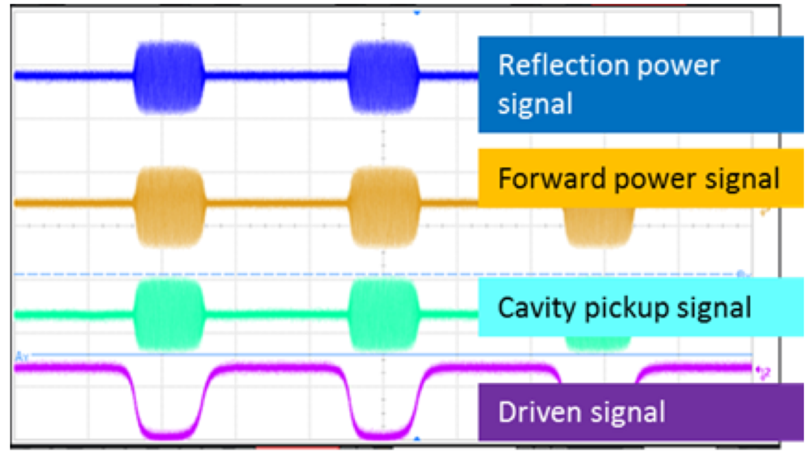
Cooling Water Loops

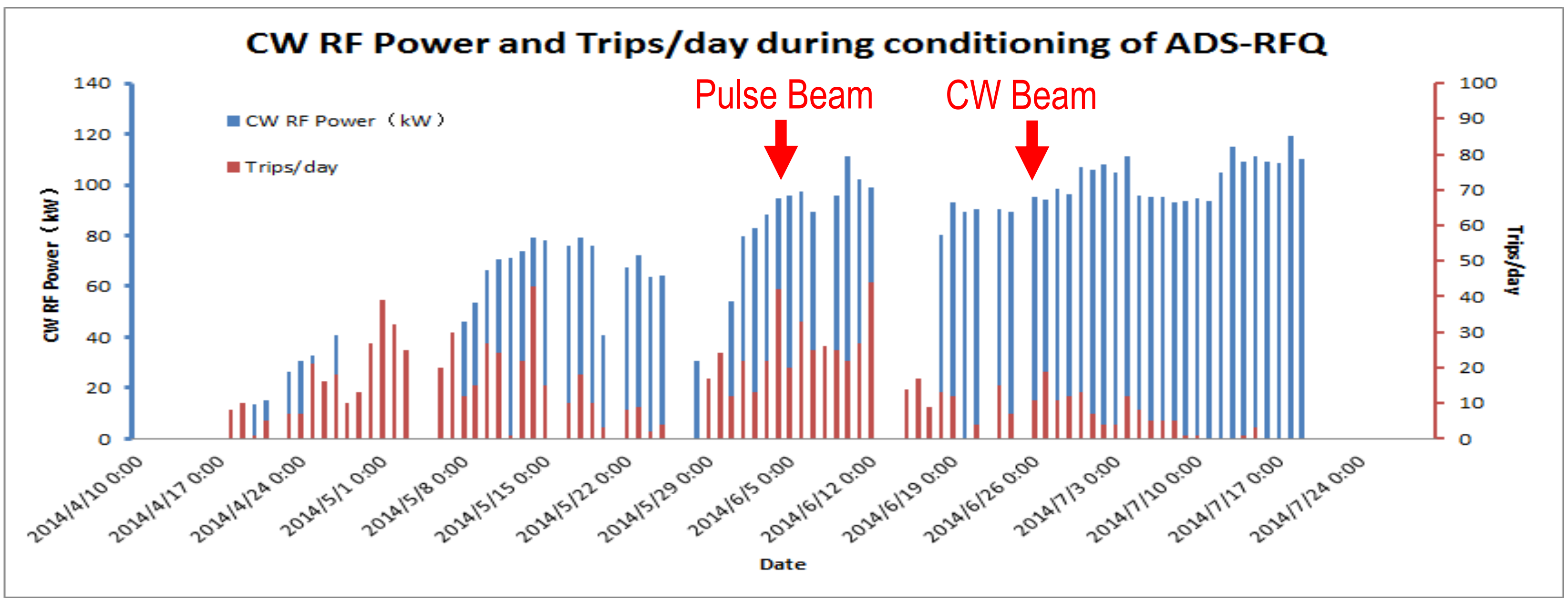


Flow monitor and temperature monitor are required to be installed at the exit of each channel

Conditioning of ADS RFQ



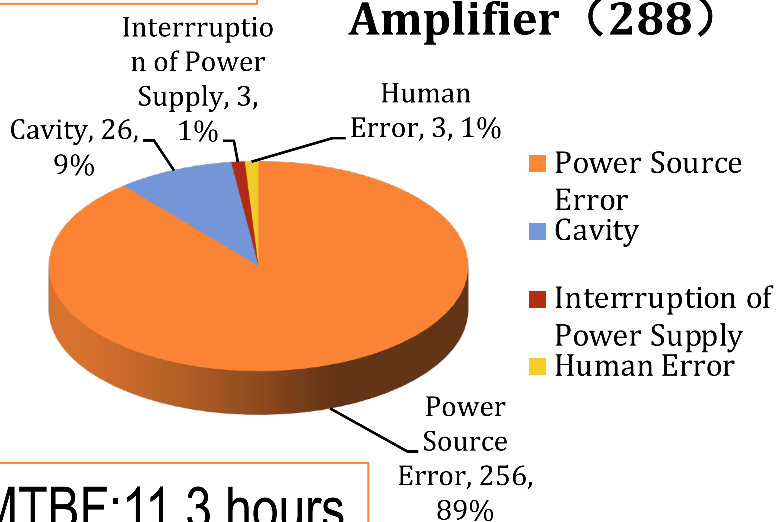




Operation Status

3264 hours

Trips @ Useage of Tetrode Amplifier（288）

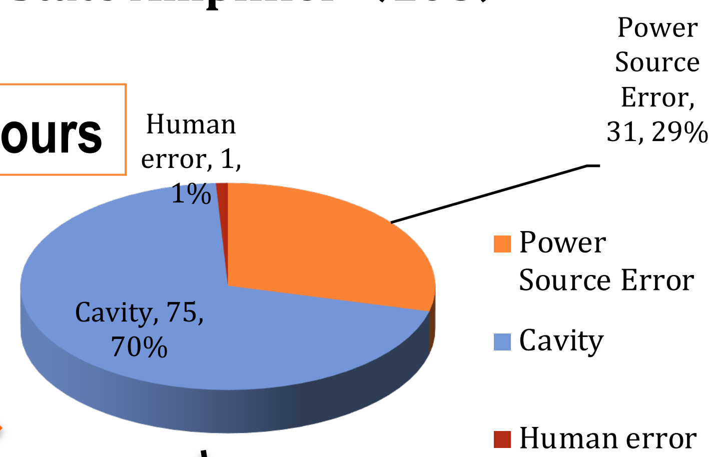


MTBF:11.3 hours

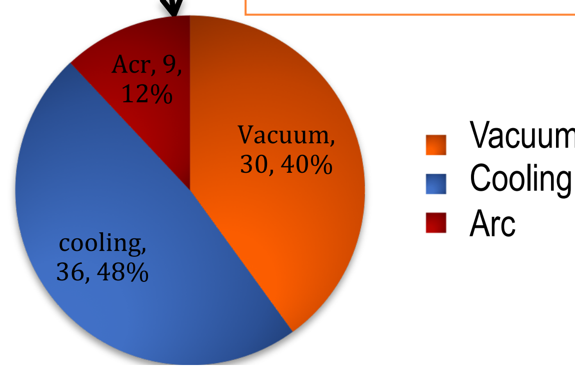
AMP change

Trips @ Usage of Solid-State Amplifier（108）

2638 hours

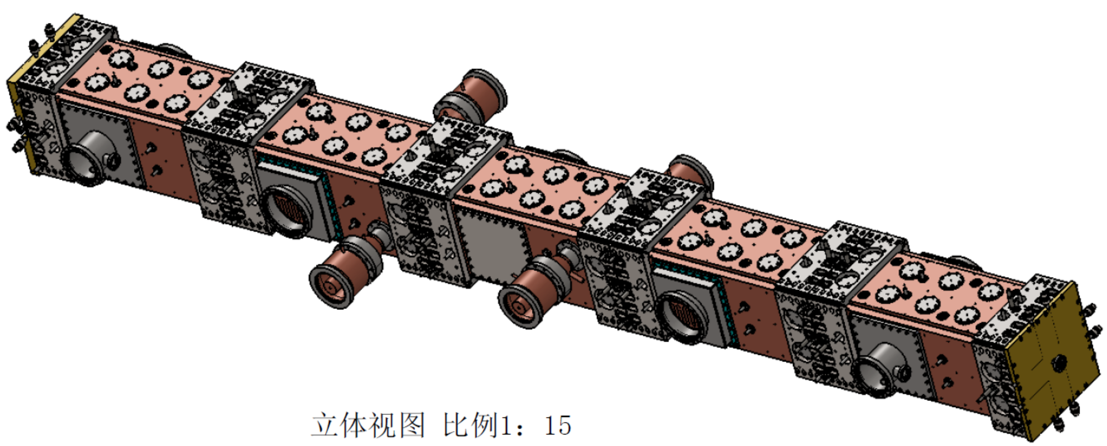


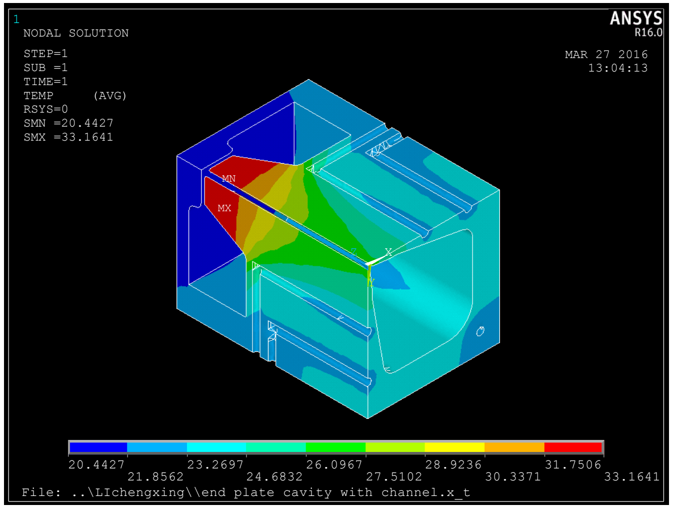
MTBF:24.4 hours



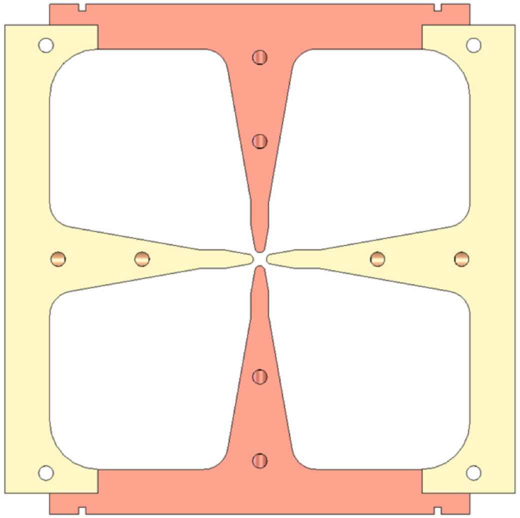
- Alarm of flux meters
- EMC of vacuum gauge
- chiller

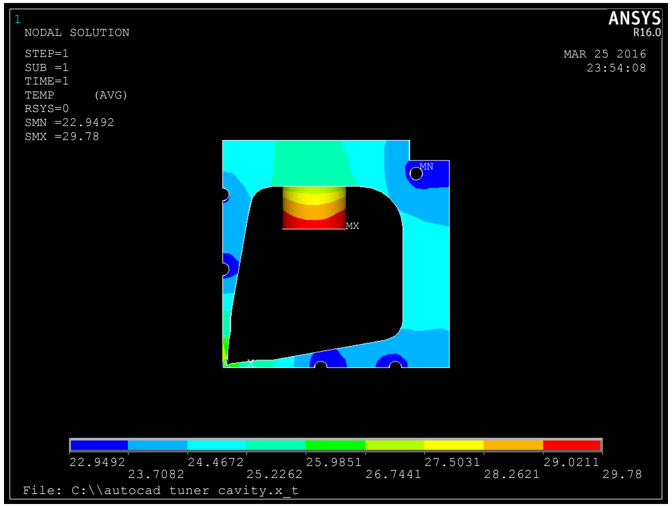
Structure of CMIF RFQ



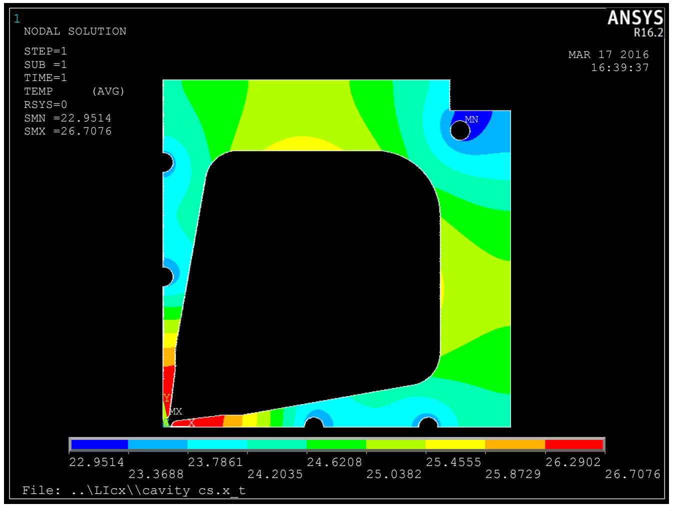


Tmax=33°C



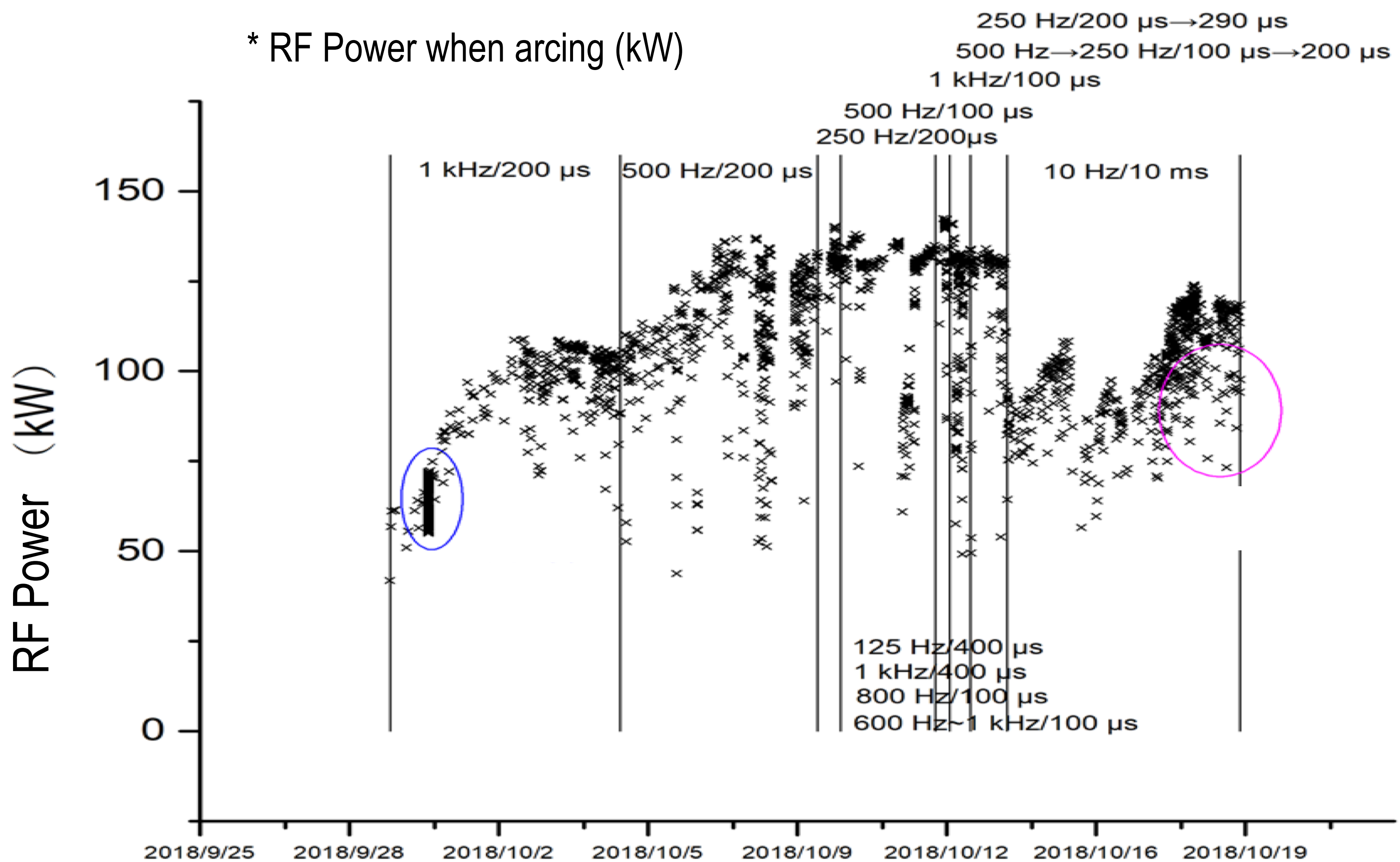


Tmax=30°C

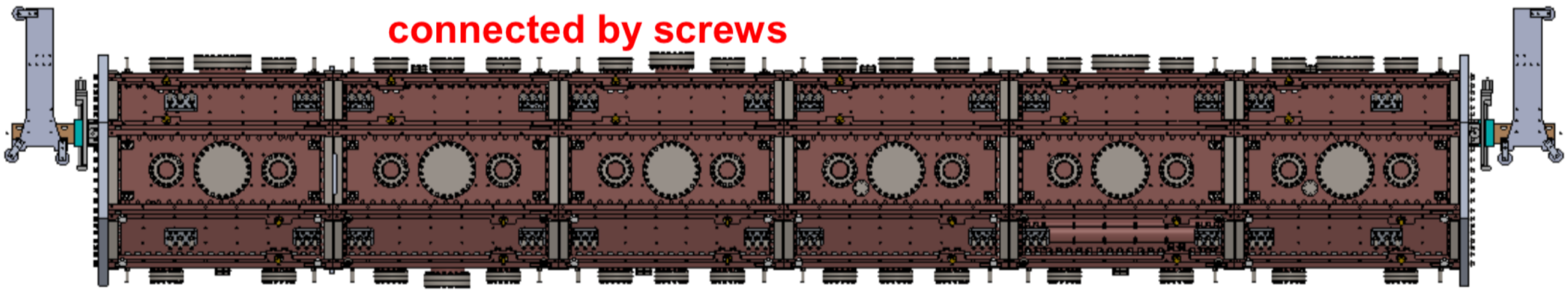


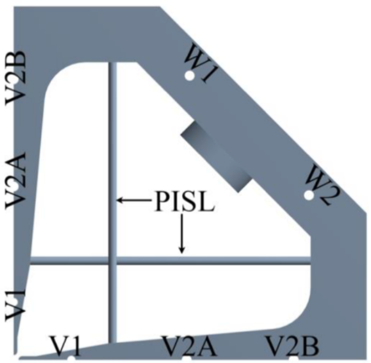
Tmax=26°C

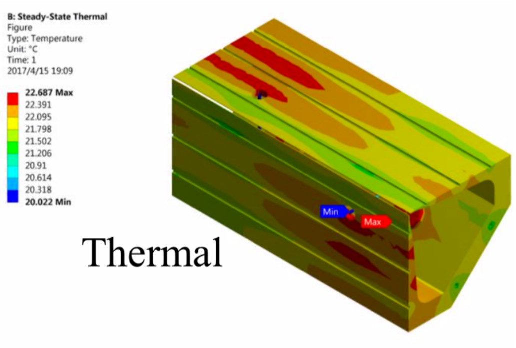
Conditioning of CMIF-RFQ

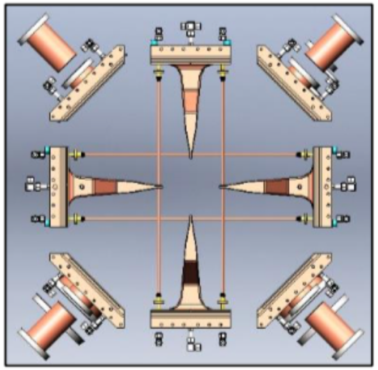


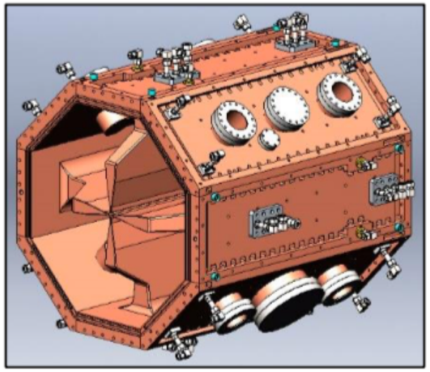
Structure of LEAF RFQ



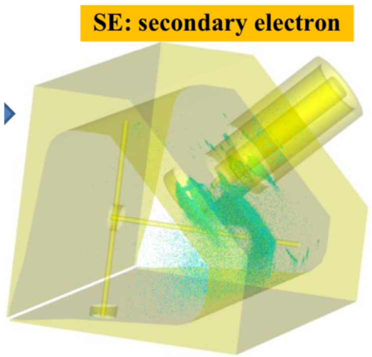


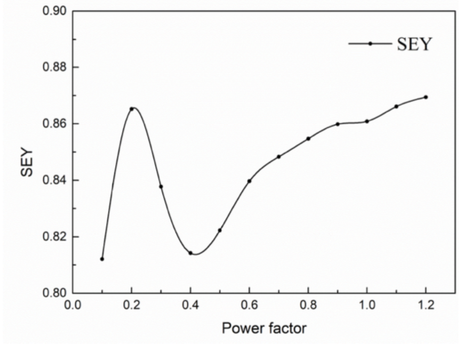




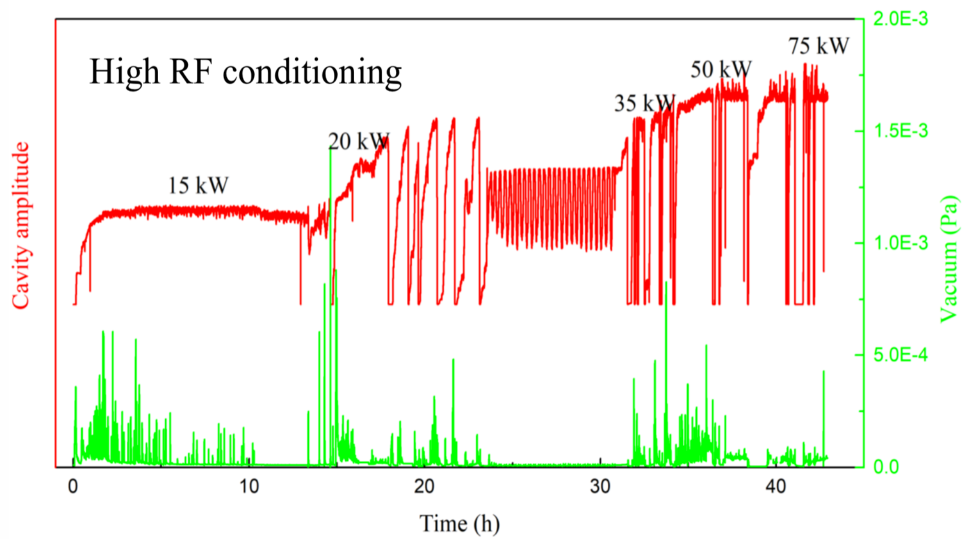


- Max. T: 22.7° C, rised 2.7 ° C
- max deform.: 21.4 μm
- max. stress: 10.99 MPa
- SEY < 1 at coupler

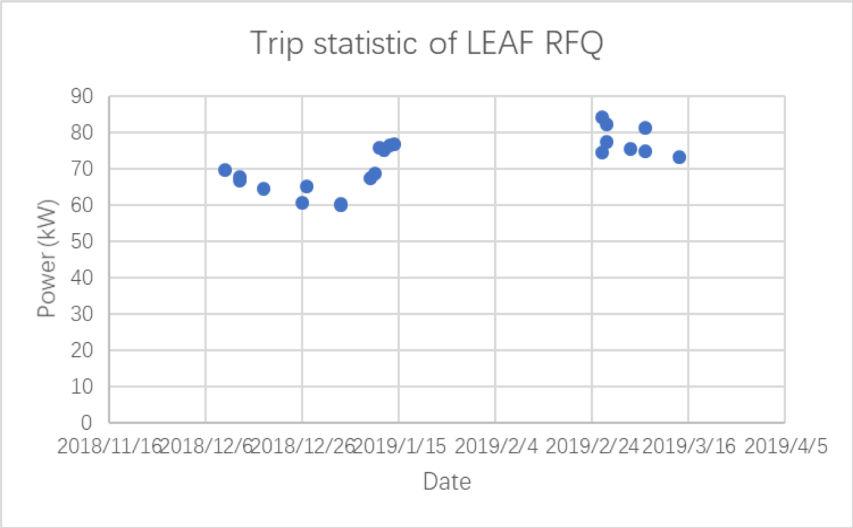


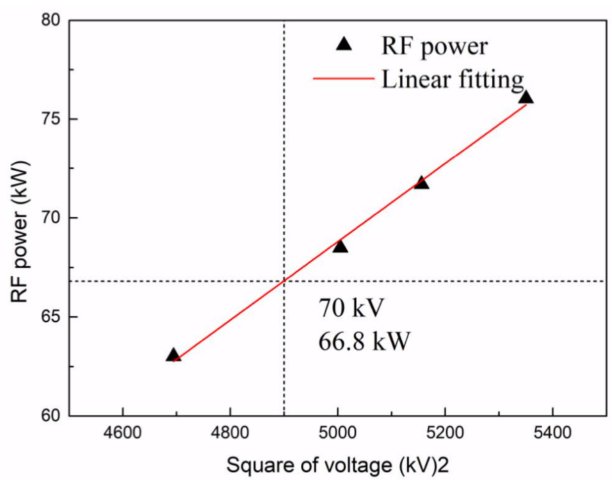


Conditioning of LEAF RFQ



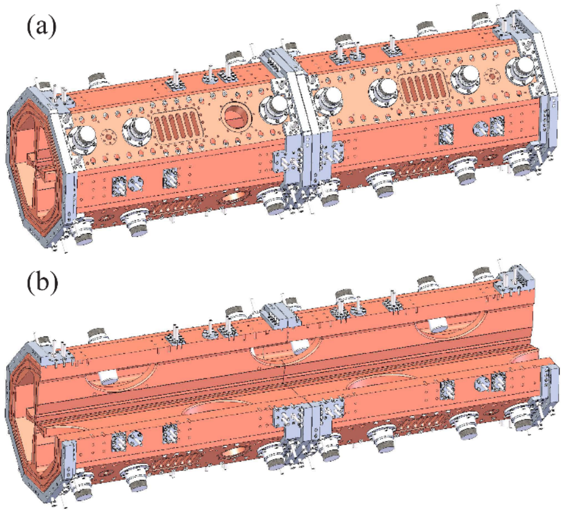
High RF Conditioning process of LEAF RFQ

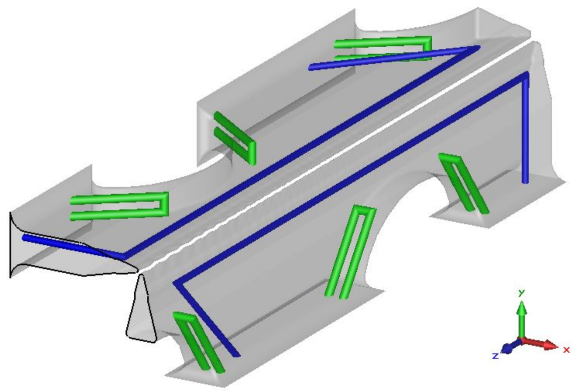




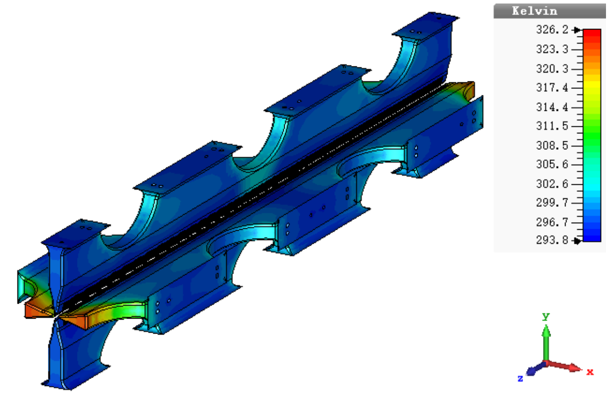
- Keep CW power conditioning
- 44 hours to nominal voltage 70 kV
- Arcing when power was higher than 70 kW

Structure of D-RFQ-973



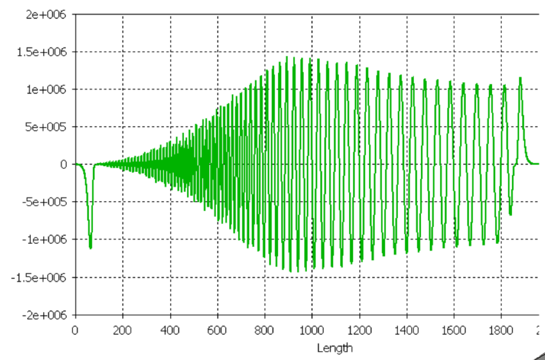


Cooling channel

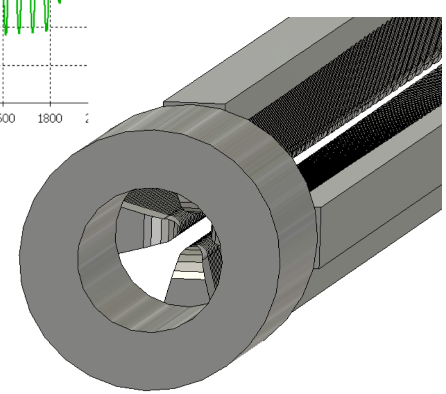


Thermal analysis

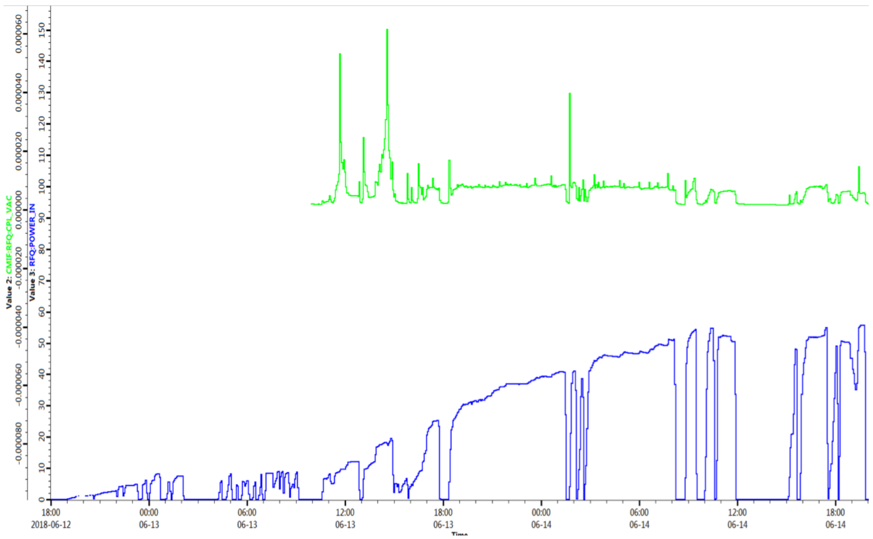
Parameters	CST	ANSYS
Water velocity /m/s	2.3	2.3
Cooling water/°C	18	18
Room /°C	22	22
Power /kW	46.5	52.5
Max dT /°C	31.39	32.56
Max deform/μm	73.27	75.24

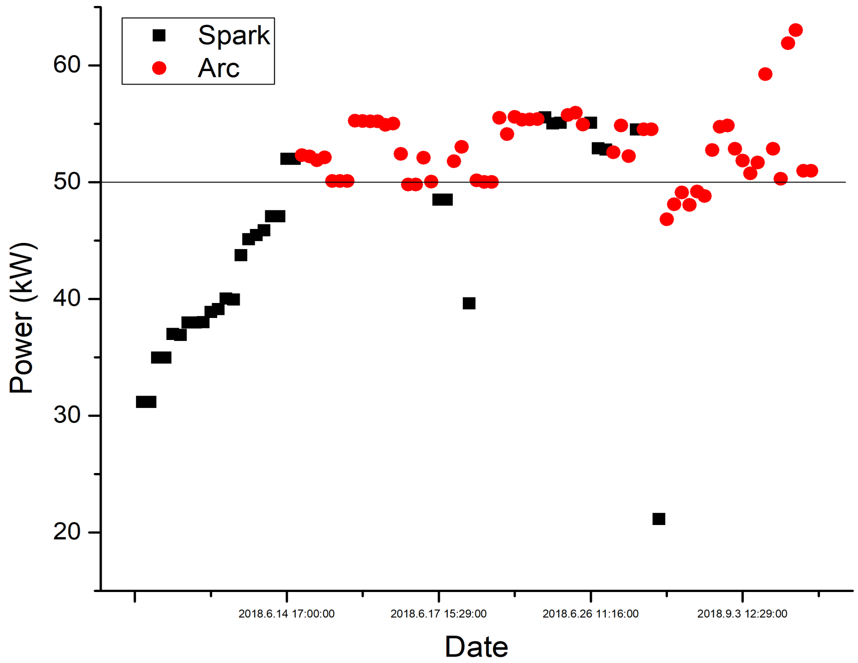


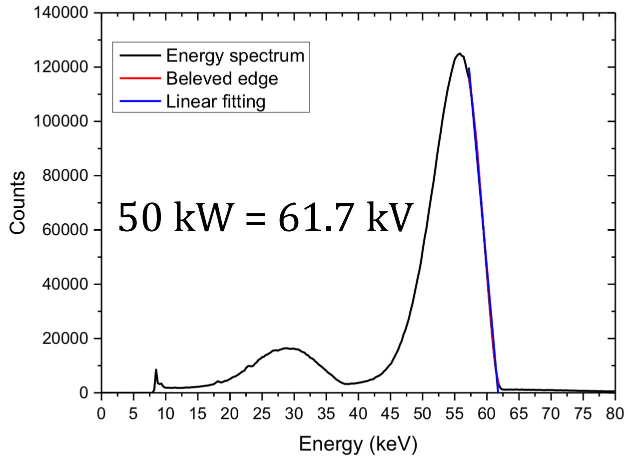
Aperture 40 mm



Conditioning of D-RFQ-973





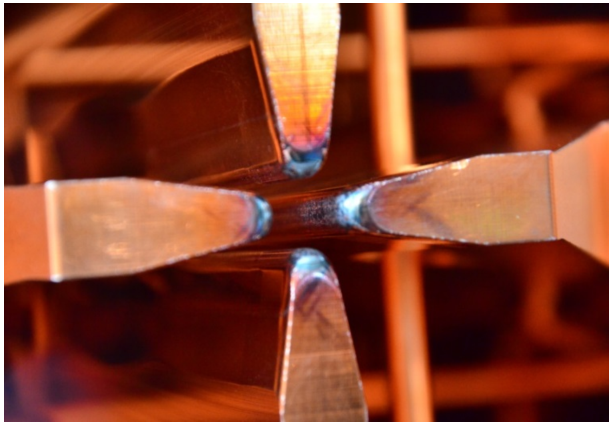


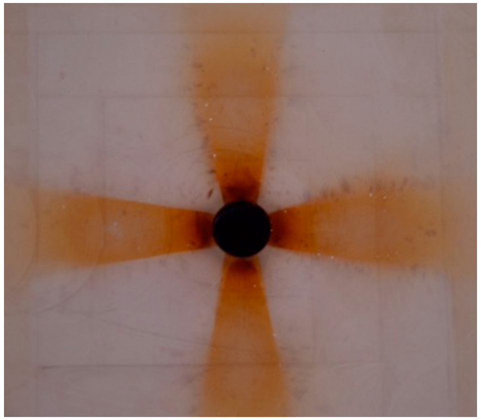
- Jun. 12-14, 2018
- Keep CW power conditioning
- 47 hours to nominal voltage 60 kV
- Arcing when power was higher than 50 kW

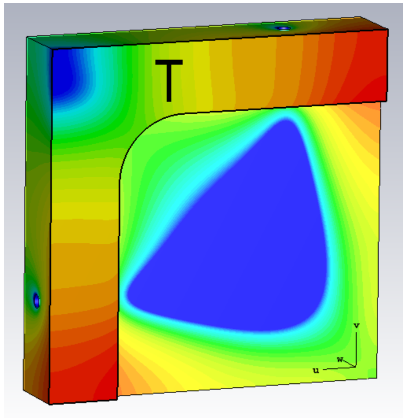
Outline

- CW high-intensity RFQs activities in IMP
- Structure and conditioning of the RFQs
- Problems happened to the RFQs
- How to make a stable RFQ always?

Blue Marks at the Exit of ADS RFQ

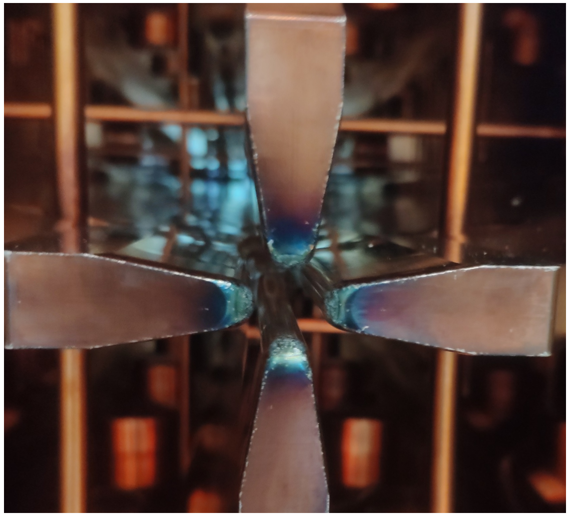


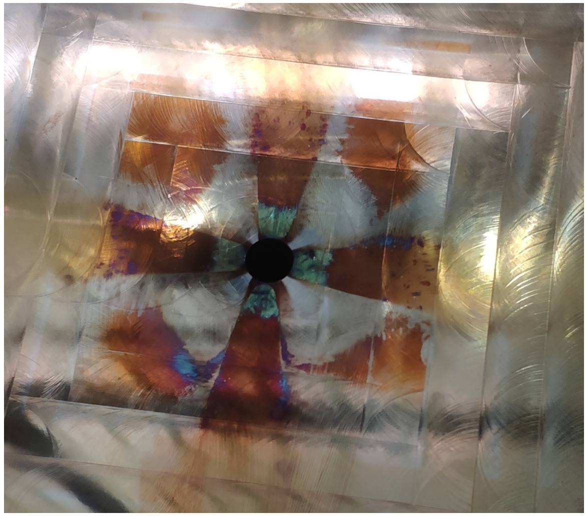


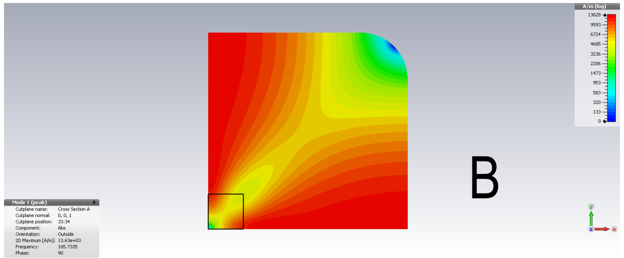


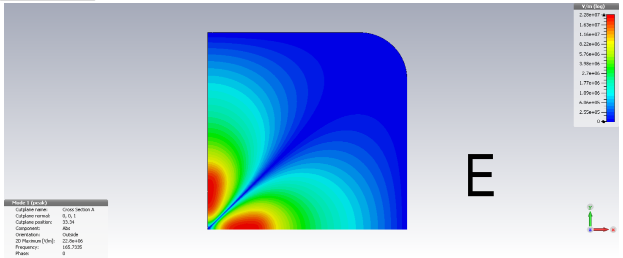
Temp. Max 21 °C

Aug 12, 2014, after conditioning and cw beam commissioning.



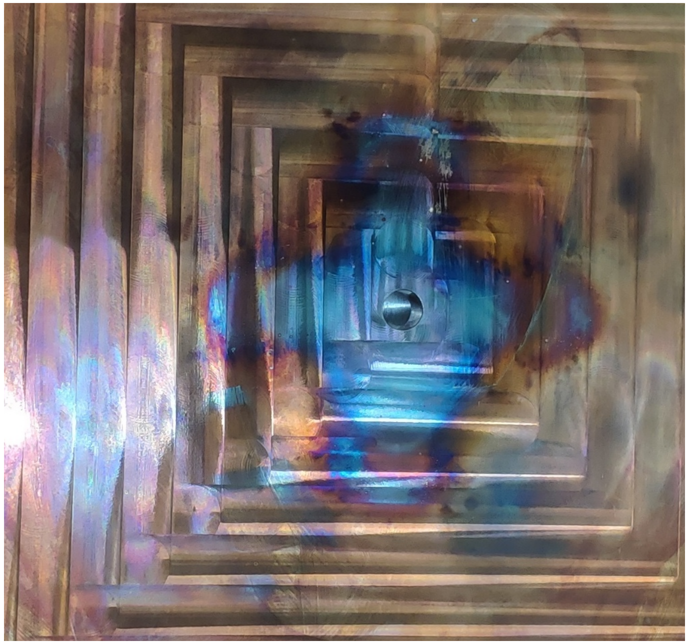


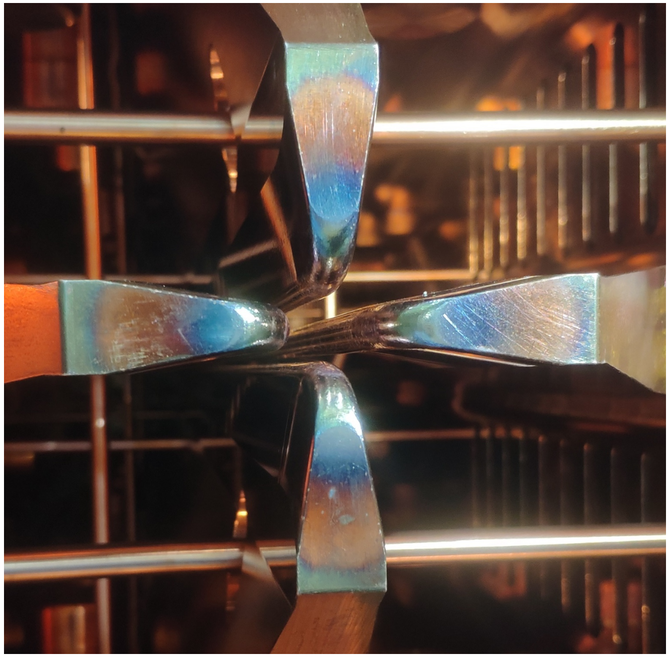




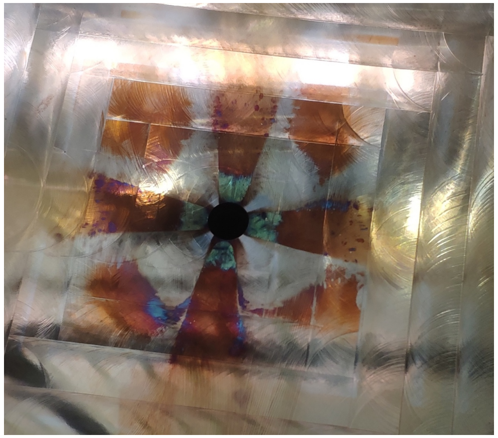
Apr. , 2019, checking after 6000 hours operation.

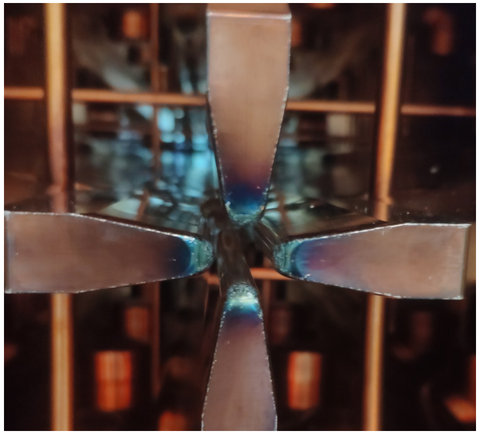
Blue Marks at Entrance of ADS RFQ



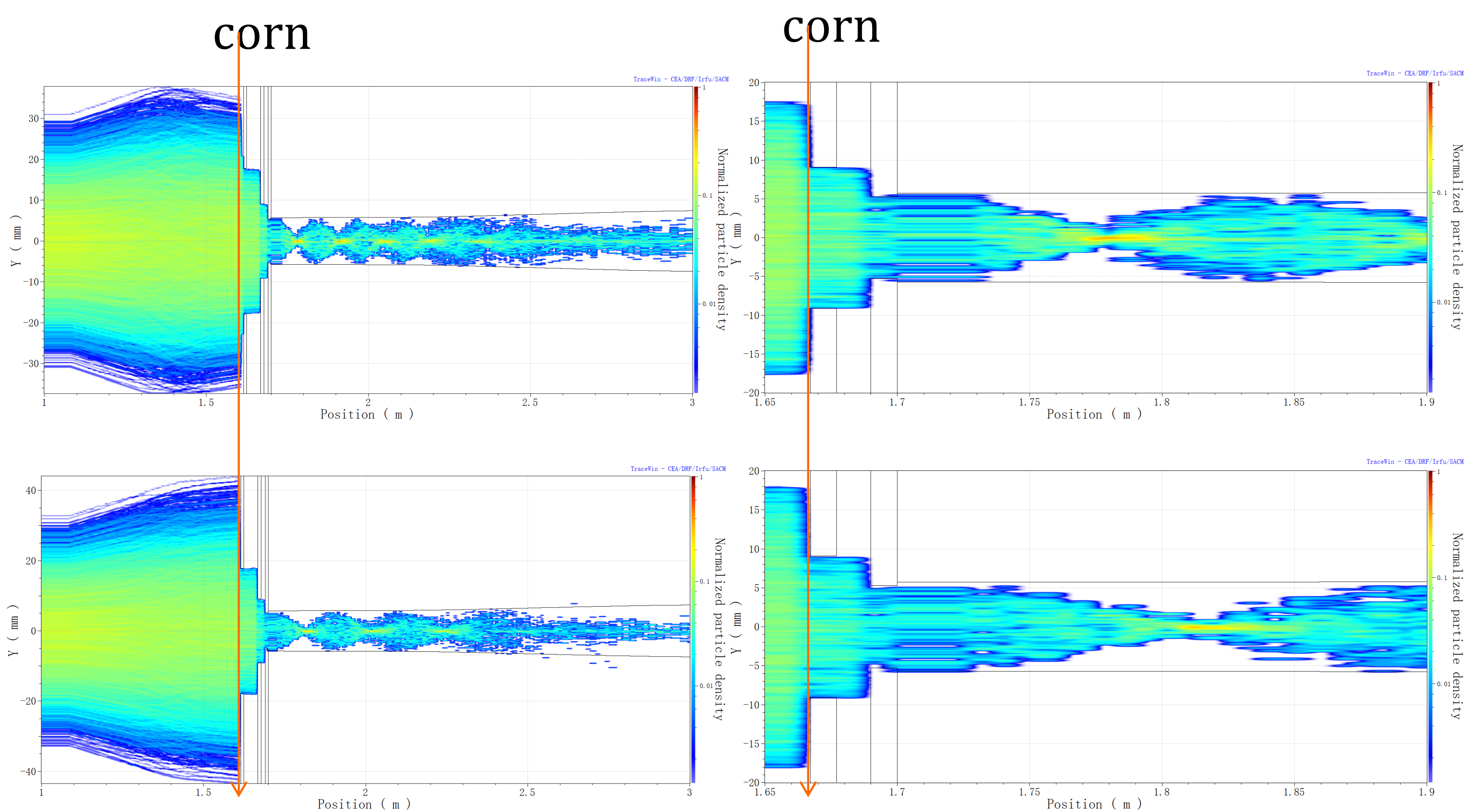


- End-plate of the entrance is near two times farer from electrodes than one of the exit.
- Due to beam loss of H_2^+ and H_3^+, and than gas releasing?
- Due to worse vacuum (1E-4 Pa) at entrance?



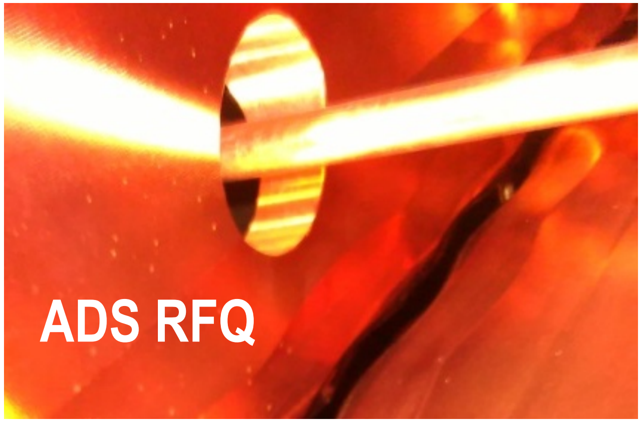


Beam Loss Simulation of H_2^+, H_3^+

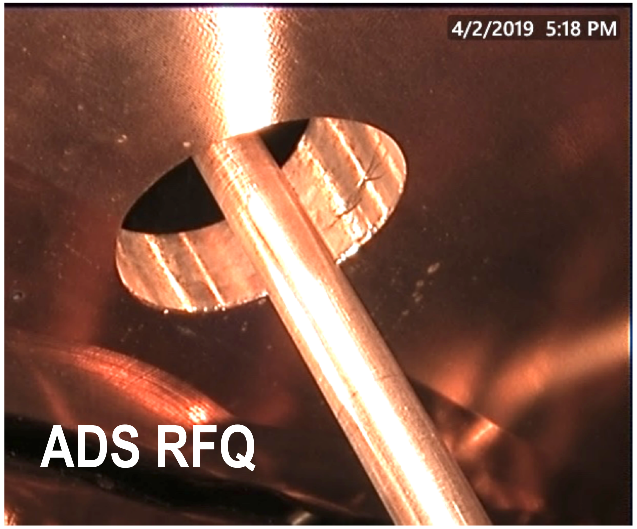


5% of H2+ and H3+ are loss in the entrance of 1.5 m of RFQ, 0.1% is on the tips.

Blue Marks at PiMS of CMIF RFQ



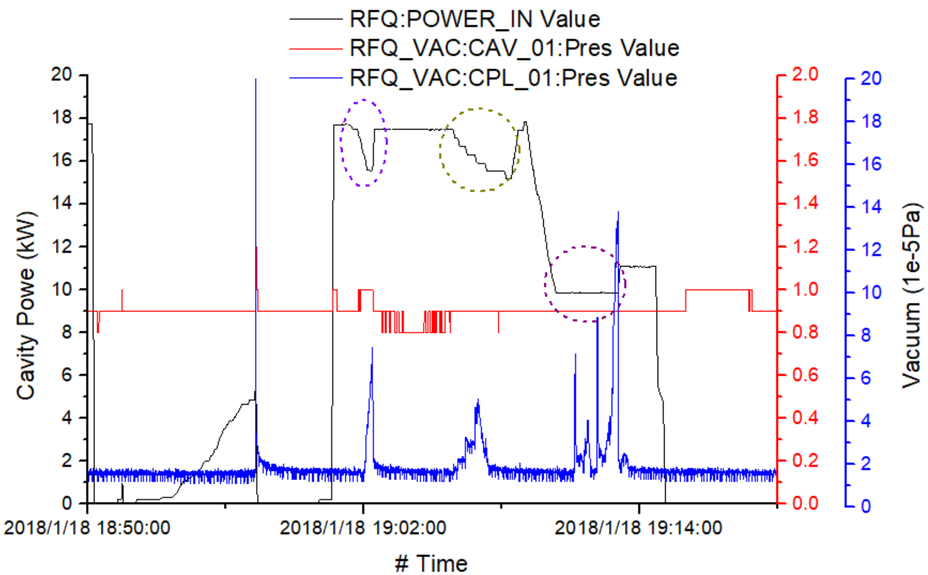
Aug 12, 2014, after conditioning and cw beam.

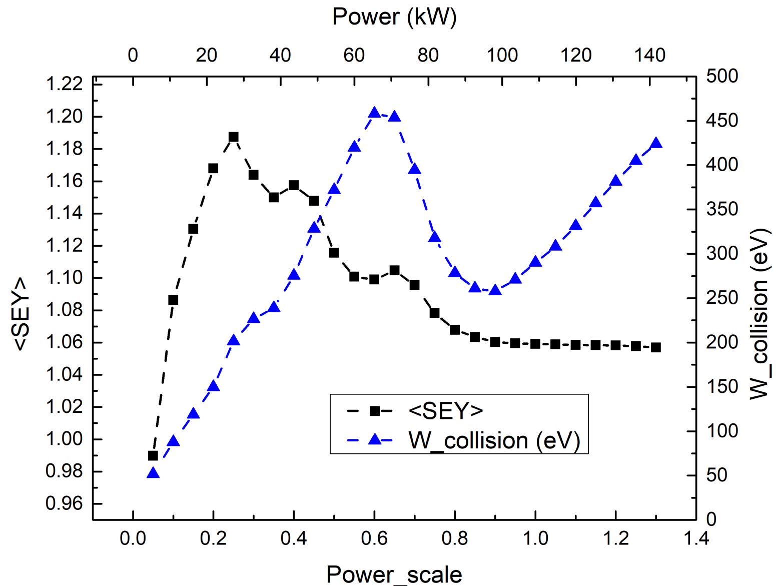


Apr. , 2019, checking after 6000 hours operation.

- Can not achieve nominal field after long term conditioning.
- The max CW power was 110 kW. 100 kW was relatively stable.
- Heavy discharge hapend in PiMS hole.
- Multipactor?

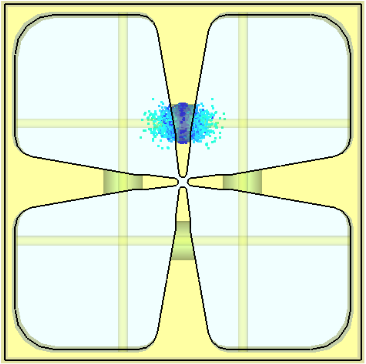
Multipactor in RFQs

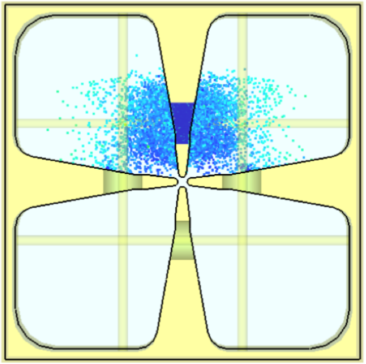


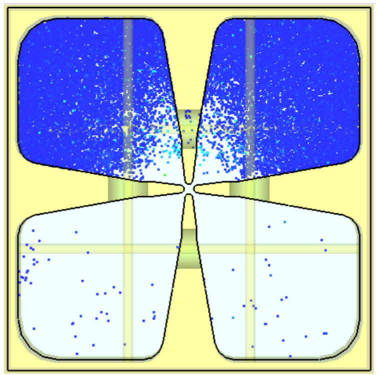


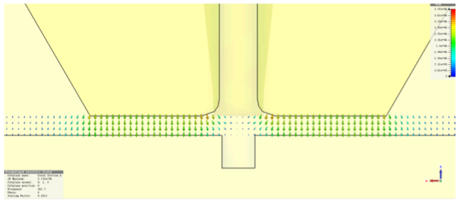
Possible Multipactor in ADS-RFQ

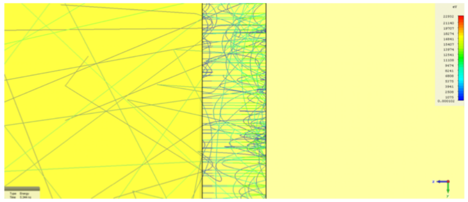
Multipactor simulation in CMIF RFQ


3 ns

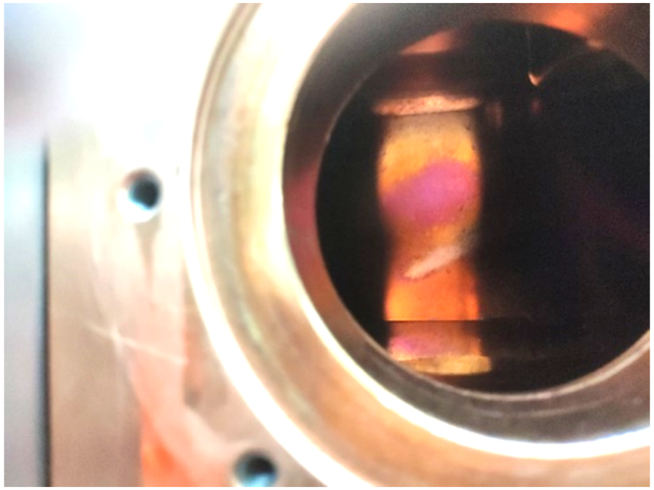

6 ns

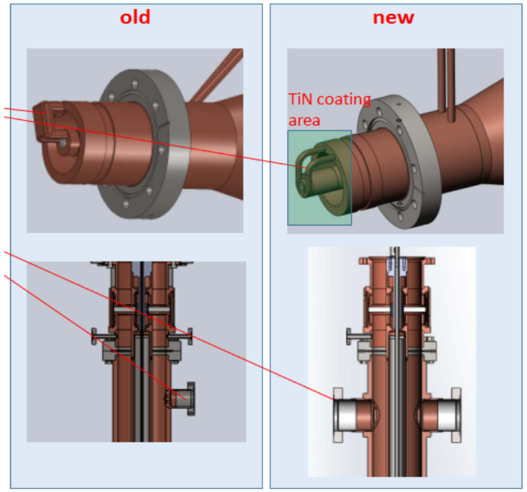

120 ns

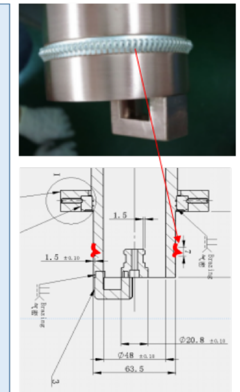




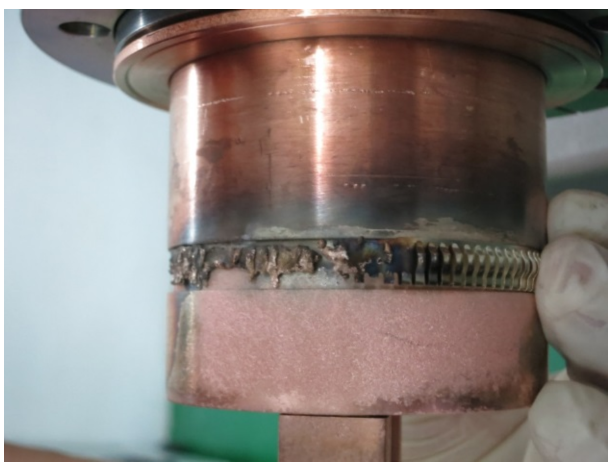
Multipactor of Coupler of ADS RFQ

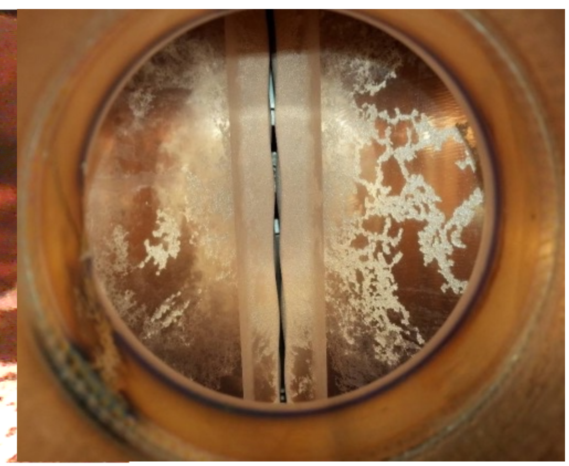




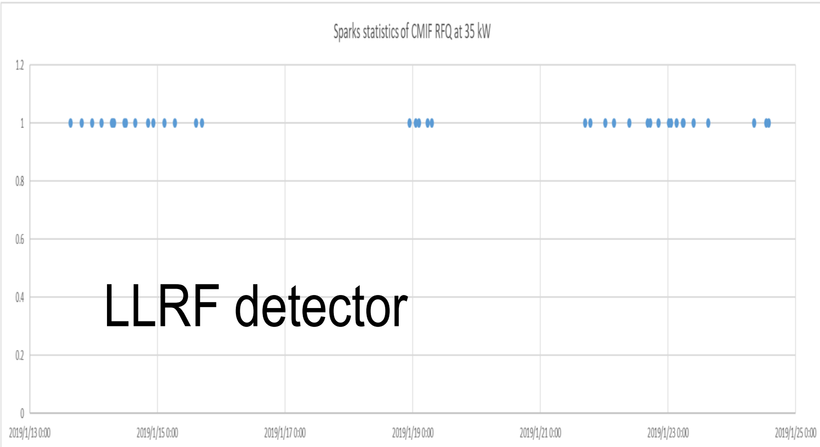


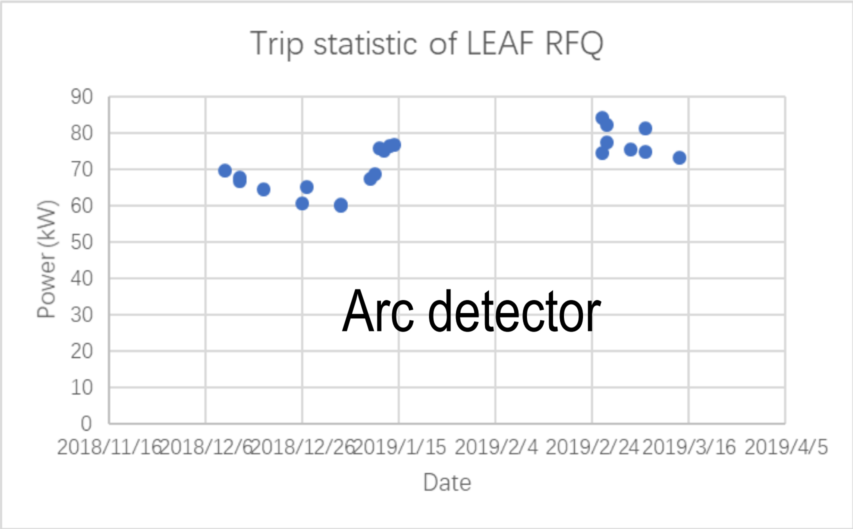
RF contact ring was canceled

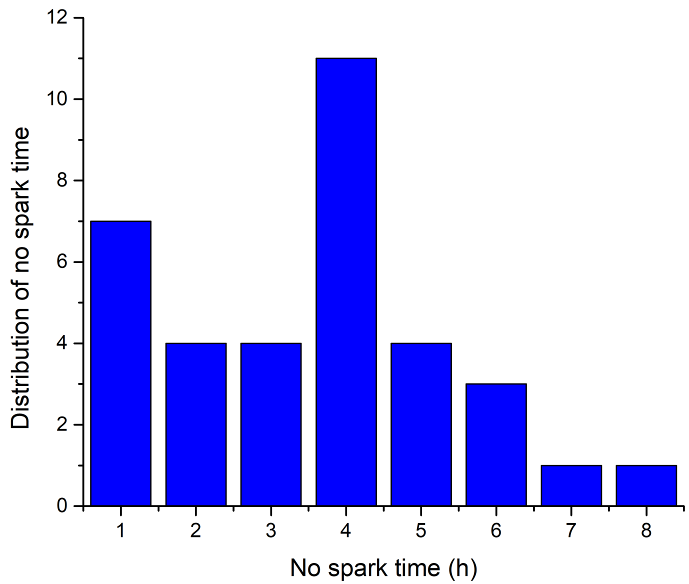


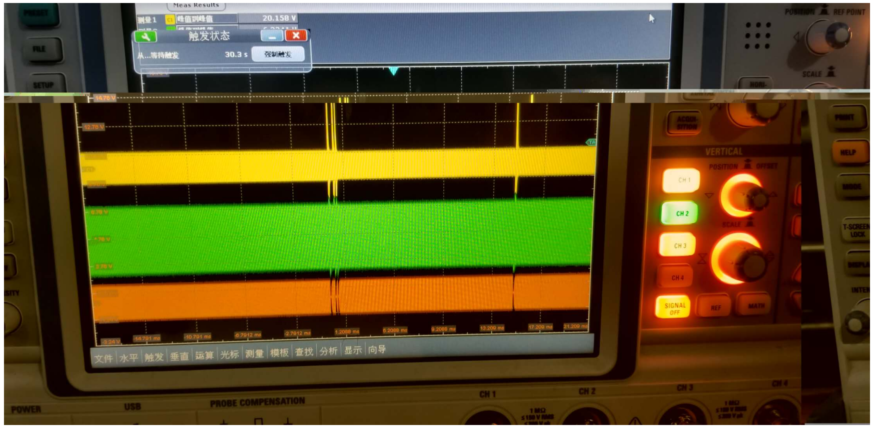


Discharge w/o Arc (spark)







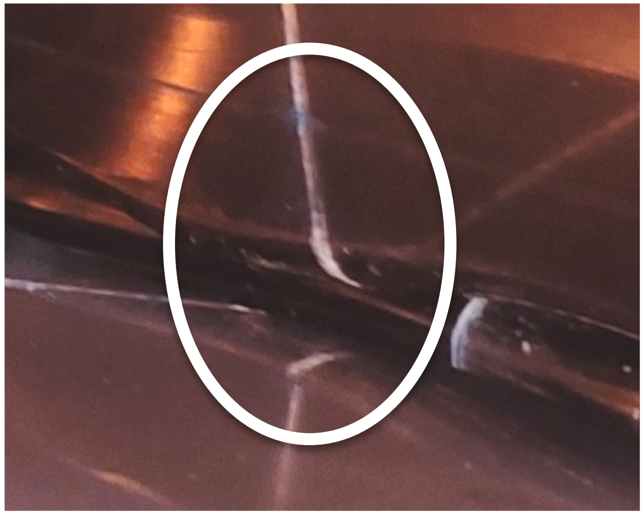


Discharge of LEAF-RFQ（1/2hours，60 kW）

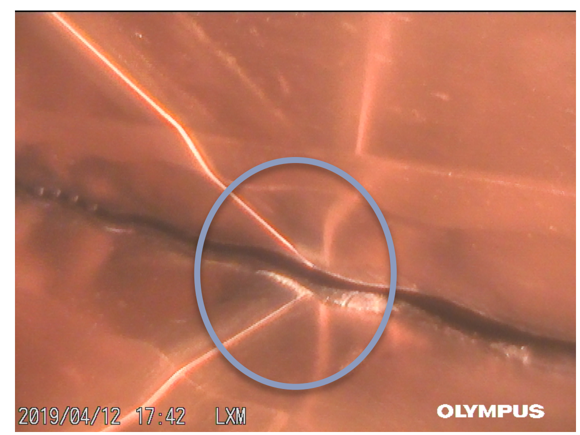
Something Uncertainty

ADS RFQ

Blue mark between sections



D-RFQ-973



Outline

- CW high-intensity RFQs activities in IMP
- Structure and conditioning of the RFQs
- Problems happened to the RFQs
- How to make a stable RFQ always?

A little bit confuse!

	radial matching gap（mm）	fringe-field gap（mm）	**Aperture on end-plates**	voltage（kV）	**vendor**
ADS	10.040	5.987	10/15	65	KJTJ(IMP)
CMIF	9.704	5.295	10/15	65	KJTJ(IMP)
LEAF	11.019	5.579		70	KeLin
973	8.011	7.988	40/40	60	KJTJ(IMP)

	R0（mm）	**a（mm）**	**max m**	**kp**	**vendor**
ADS	5.731	3.16	2.376	1.17	KJTJ(IMP)
CMIF	4.807	2.74	2.279	1.4	KJTJ(IMP)
LEAF	5.805	3.63	2.035	1.55	KeLin
973	3.477-5.971	2.63	1.86	1.68	KJTJ(IMP)

Just thinking……

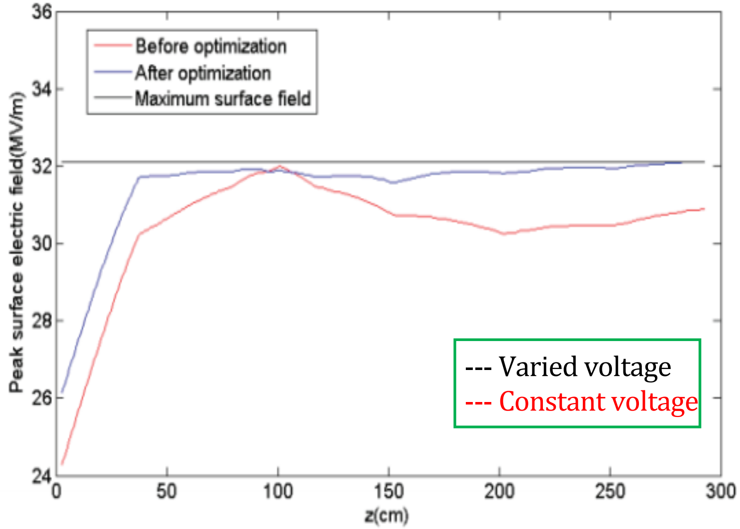
Lessons from the bad experience of ADS and especially CMIF RFQ:

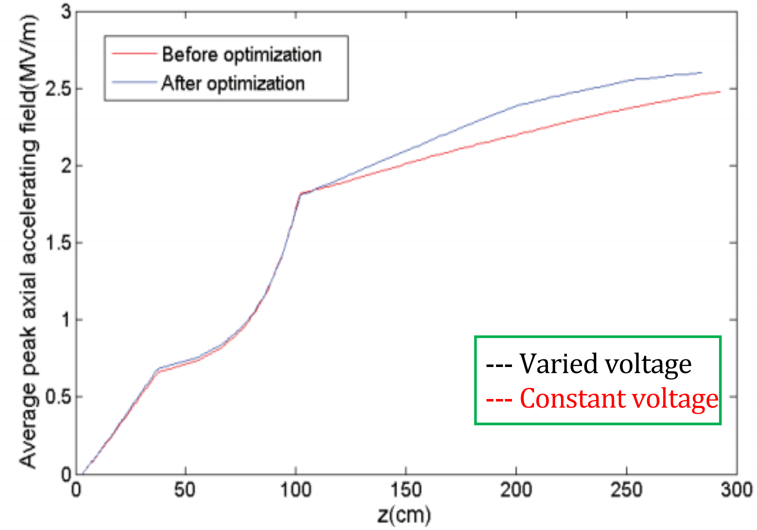
- To optimize Bpeak/V(Eacc), Epeak/V(Eacc), especially at the corner of electrodes and end plates.
- To optimize the multipactor, especially the coupler, PiMS, etc. Try to make SEY < 1.
- To optimize structure of contact. RF fingers or springs will be burned due to bad contact.
- To put "cleanness" on the "first" position. It is not only in the stage of assembly, tuning and installing, but also in the stage of fabrication from acid washing to brazing.
- Any more……?

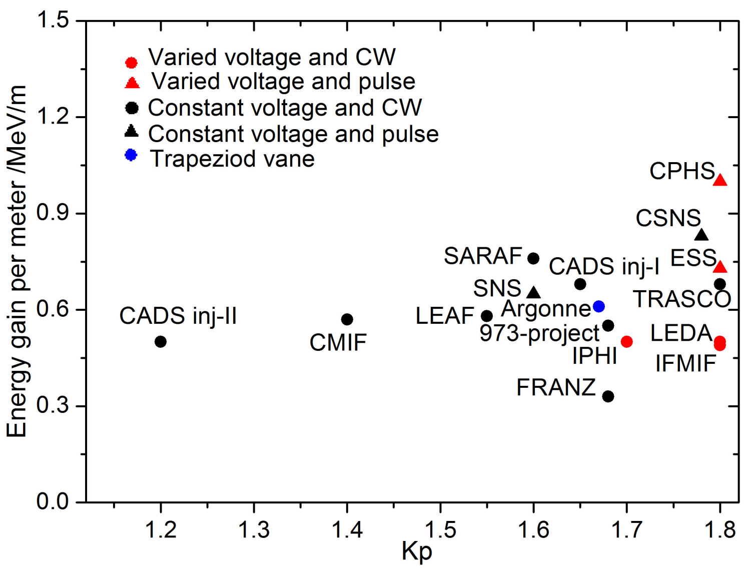
Assembly and tuning in cleanroom

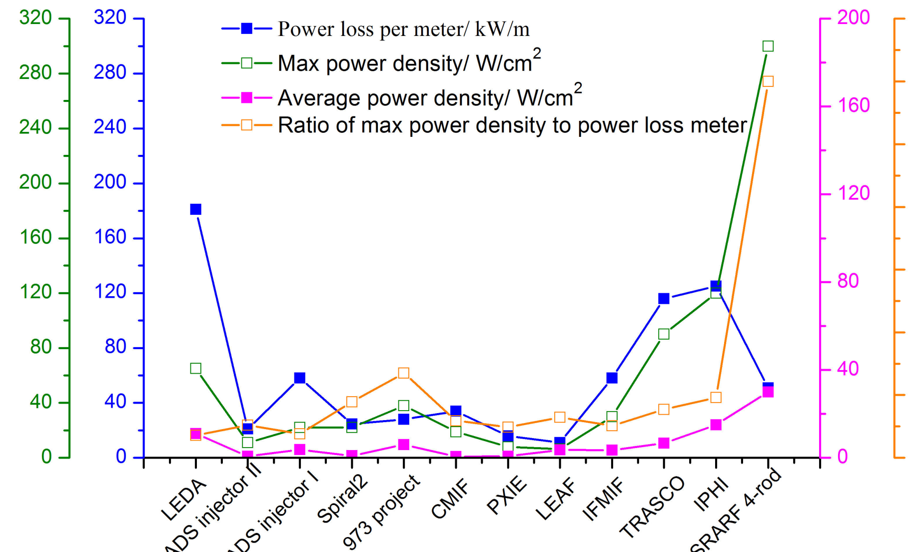
The first ADS RFQ was in dirty surroundings.
CMIF and D-RFQ-973 were in clean room.

Optimize E_{peak} and B_{peak}









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Xiaofeng Jin, Zhijun Wang, Wei Ma

Thanks for your attention