Progress of RFQs for China ADS

Yuan He

On behalf of

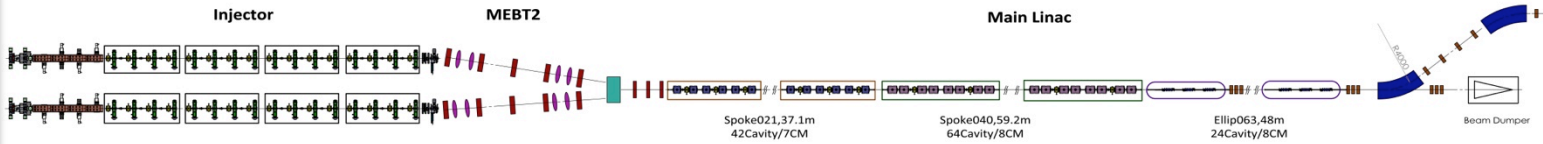
Accelerator Team of China ADS

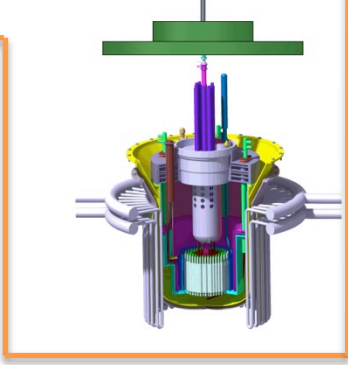
Outline

- General introduction of superconducting linac for China ADS
- 325 MHz RFQ for injector-I
- 162.5 MHz RFQ for injector-II
- Summary

Layout of Accelerator for China ADS

The 13th 5-year plan, Research facility, 250 MeV accelerator





Injector II

ECR | LEBT | RFQ 162.5MHz | MEBT1 | SC-HWR SC-CH 162.5MHz

35 keV — 2.1 MeV

Local compensation

Hot stand-by

MEBT2 10MeV

Spoke021 325MHz 28 cavities | Spoke040 325MHz 72 cavities | Elliptical 063 650MHz 28 cavities | Elliptical 082 650 MHz 85 cavities | HEBT | Target

34 MeV — 178 MeV — 367 MeV — 1500 MeV

Main Linac

CW @ 10 mA

ECR | LEBT | RFQ 325.0MHz | MEBT1 | Spoke 325MHz

35 keV — 3.2 MeV

Injector I

Tasks of IMP

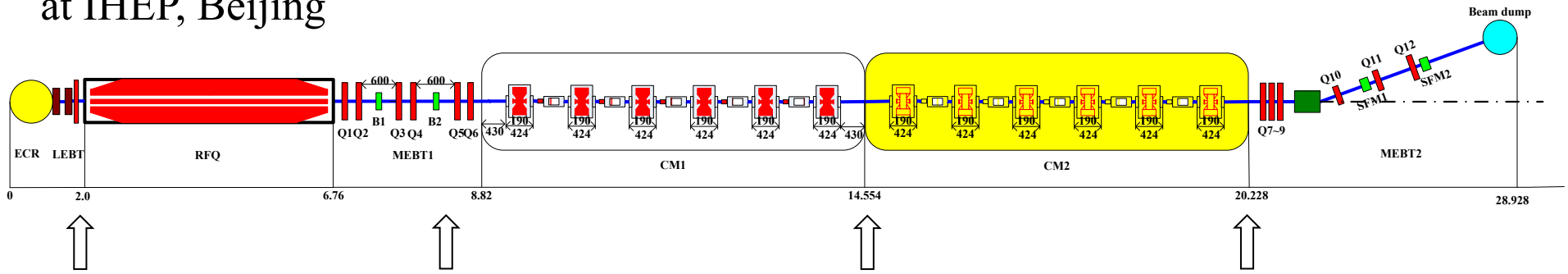
Tasks of IHEP

"strategic Priority Research Program" of the Chinese Academy of Sciences

Two options of 10-MeV injectors

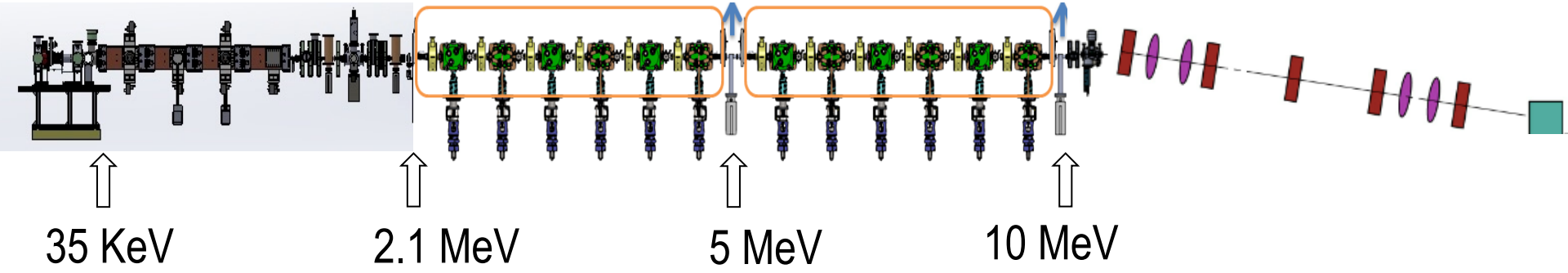
Injector I
at IHEP, Beijing

Base on 325 MHz and Superconducting Spoke cavity



Injector II
at IMP, Lanzhou

Base on 162.5 MHz and Superconducting HWR cavity



Outline

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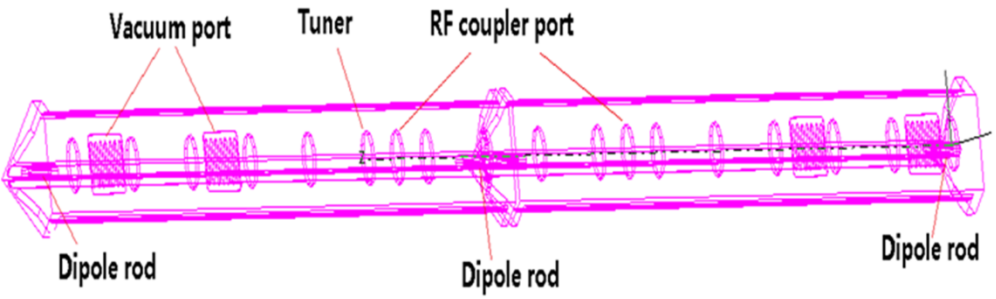
Specifications

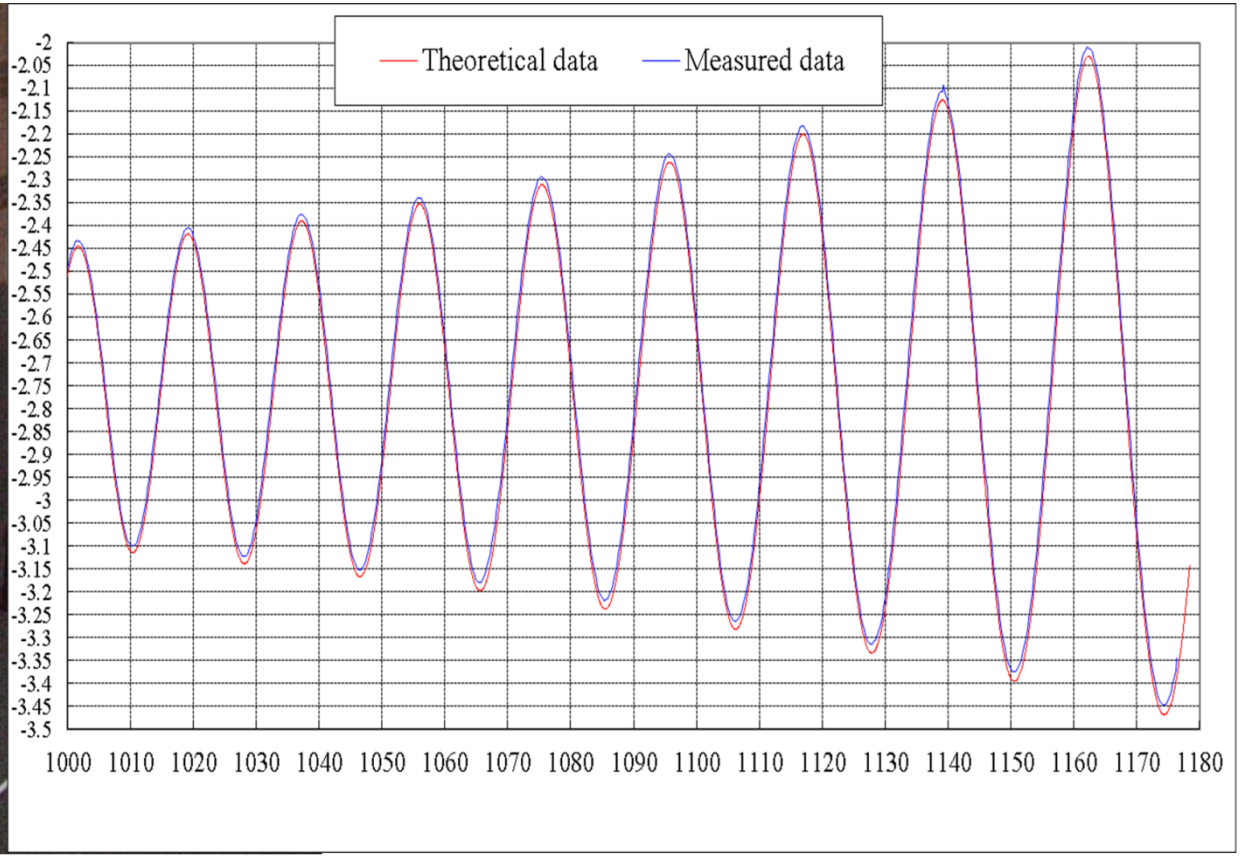
4 technical modules, 64 tuners, 4 RF power couplers, 4 dipole rods on each plate .



3D design drawing for RFQ simulation

Parameters	Value
Frequency (MHz)	325
Injection energy (keV)	35
Output energy (MeV)	3.2128
Pulsed beam current (mA)	15
Beam duty factor	100%
Inter-vane voltage V (kV)	55
Beam transmission	98.7%
Average bore radius r_0 (mm)	2.775
Vane tip curvature (mm)	2.775
Maximum surface field (MV/m)	28.88 (1.62Kilp.)
Input norm. rms emittance (x,y,z)(πmm.mrad)	0.2/0.2/0
Output norm. rms emittance(x/y/z) (πmm.mrad/MeV-deg)	0.2/0.2/0.0612
Vane length (cm)	467.75 6
Accelerator length (cm)	469.95

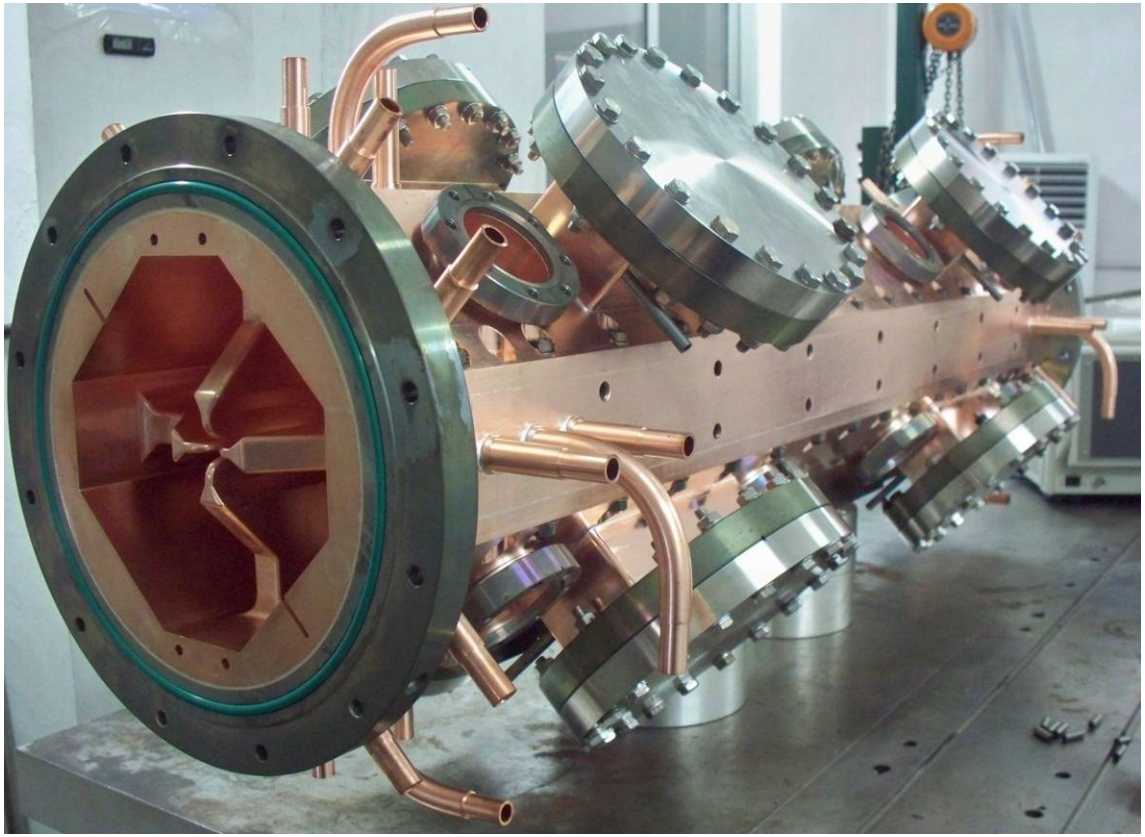
Manufacture tolerance

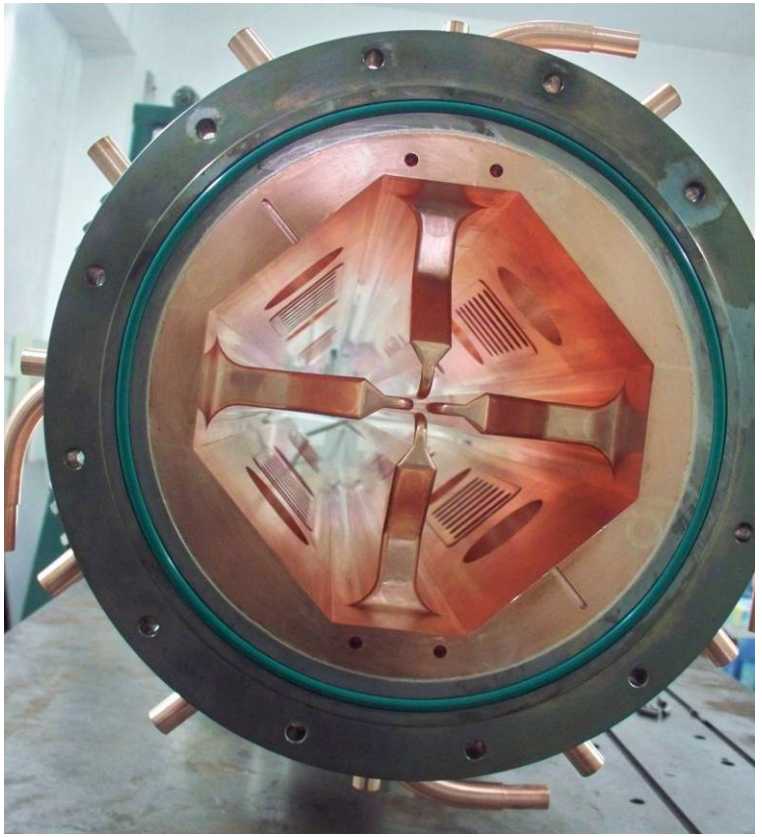


The manufacture errors of the vane-electrode are smaller than 20um

Brazing module

The end flanges, the tuner flanges, the vacuum bodies and water-cooling pipes are brazed together with the cavity.





RF measurement for the first module

After brazing, the resonant frequency (the designed value 323.7MHz), the field distribution and the Q value change better.

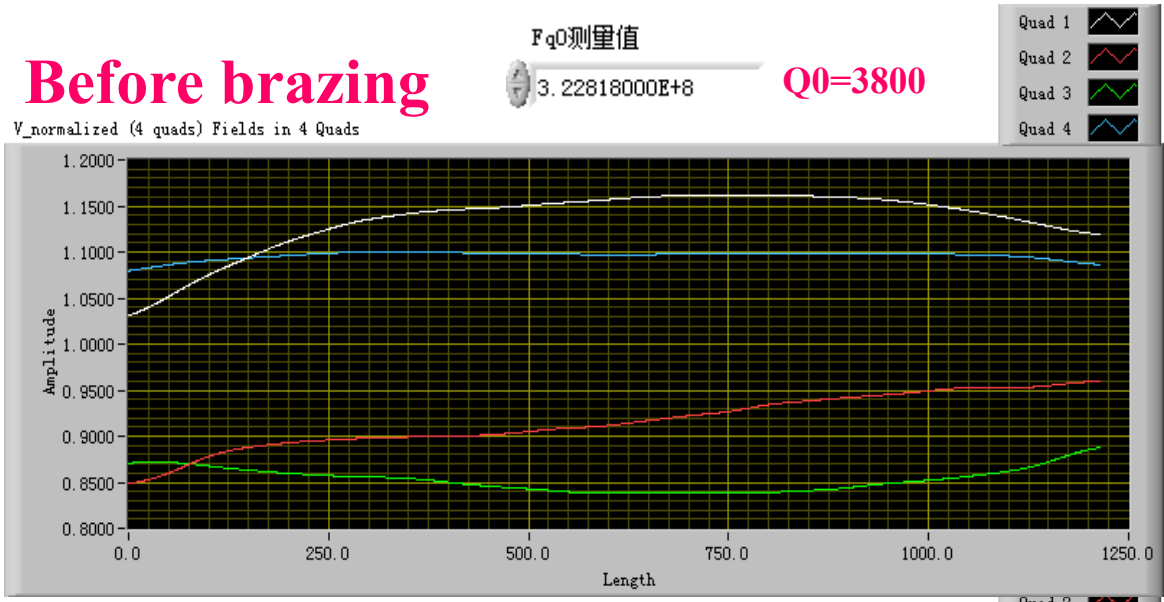
Q0=3800 → Q0=4350

FqO测里值: 3.22818000E+8 → FqO测里值 2: 3.23097001E+8

Before brazing

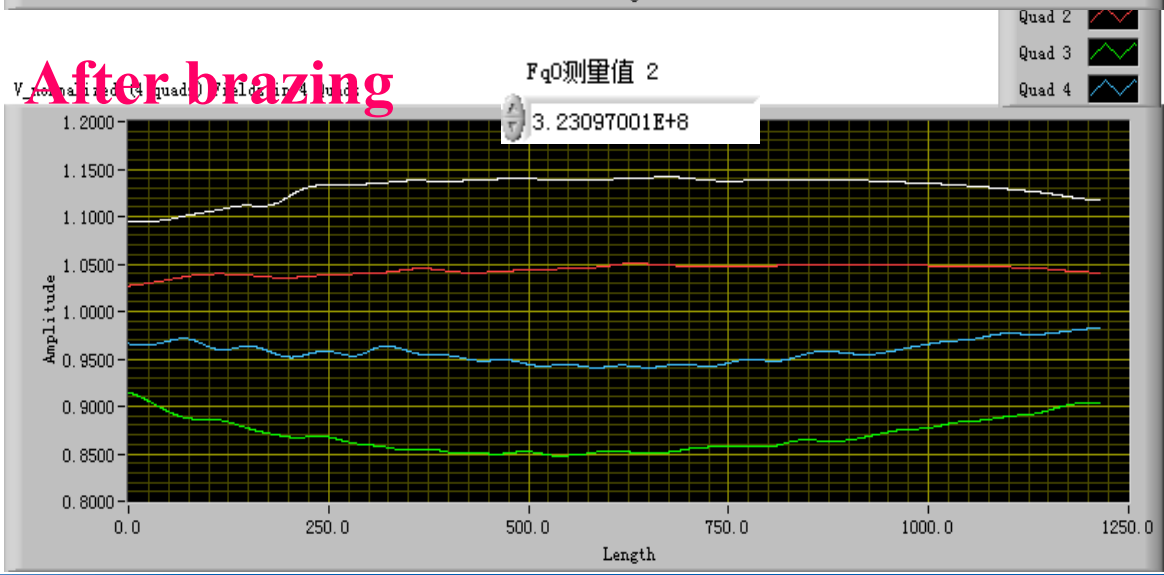
FqO测里值: 3.22818000E+8

Q0=3800

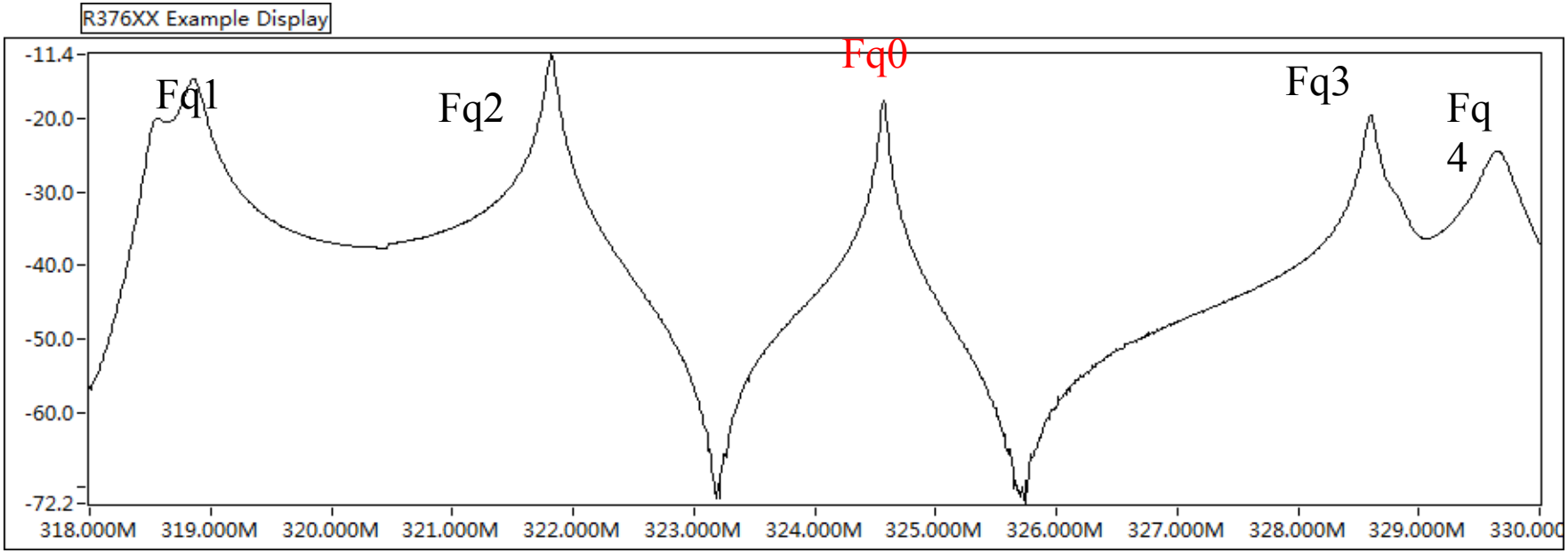


After brazing

FqO测里值 2: 3.23097001E+8



Frequency and Q Measurement



F1=318.86MHz

F2=322.16MHz

Running Mode Fq0=324.796MHZ (a theoretic one is 324.905)

F3=328.66MHz

F4=329.67MHz

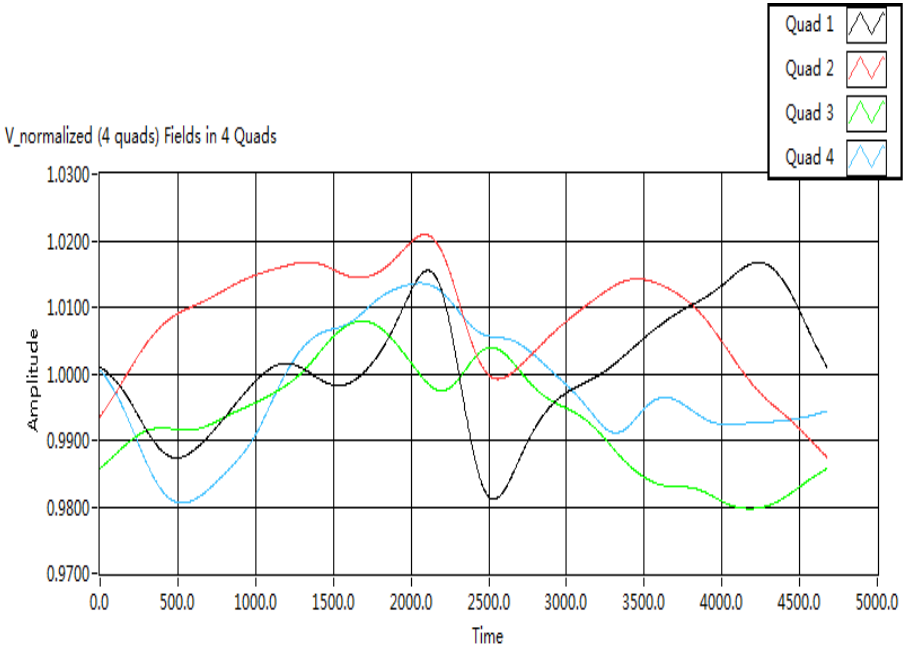
Q value after installations of 64 tunners for vacuum obtain

Q0=ql/(1+1/swr1+1/swr2)

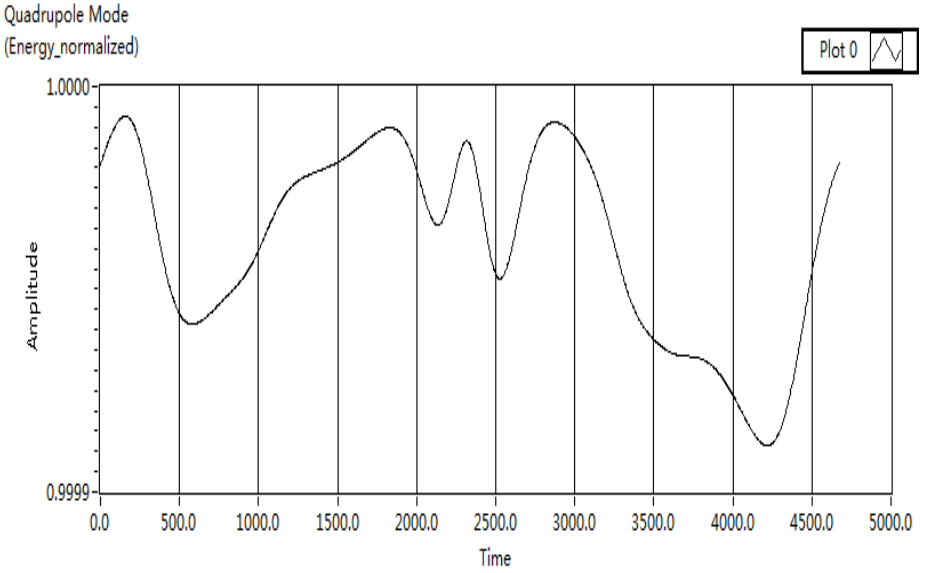
Measuring results, Ql=6421， swr1=8.05， swr2=12.02

Q0=6421/(1+1/8.05+1/12.02)=7752.8

Tuning of whole cavity



RF field distribution along the longitudinal direction of RFQ



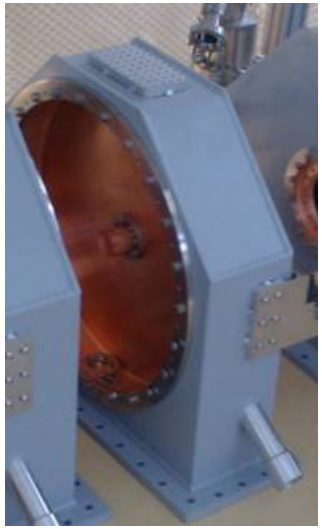
Quadrant component distribution along the longitudinal direction of RFQ

The couplers for RFQ-I

Five **RFQ couplers** have been fabricated; and coupler windows had been conditioned up to 100 kW with CW RF power.

The outer conductor assembly

The window assembly

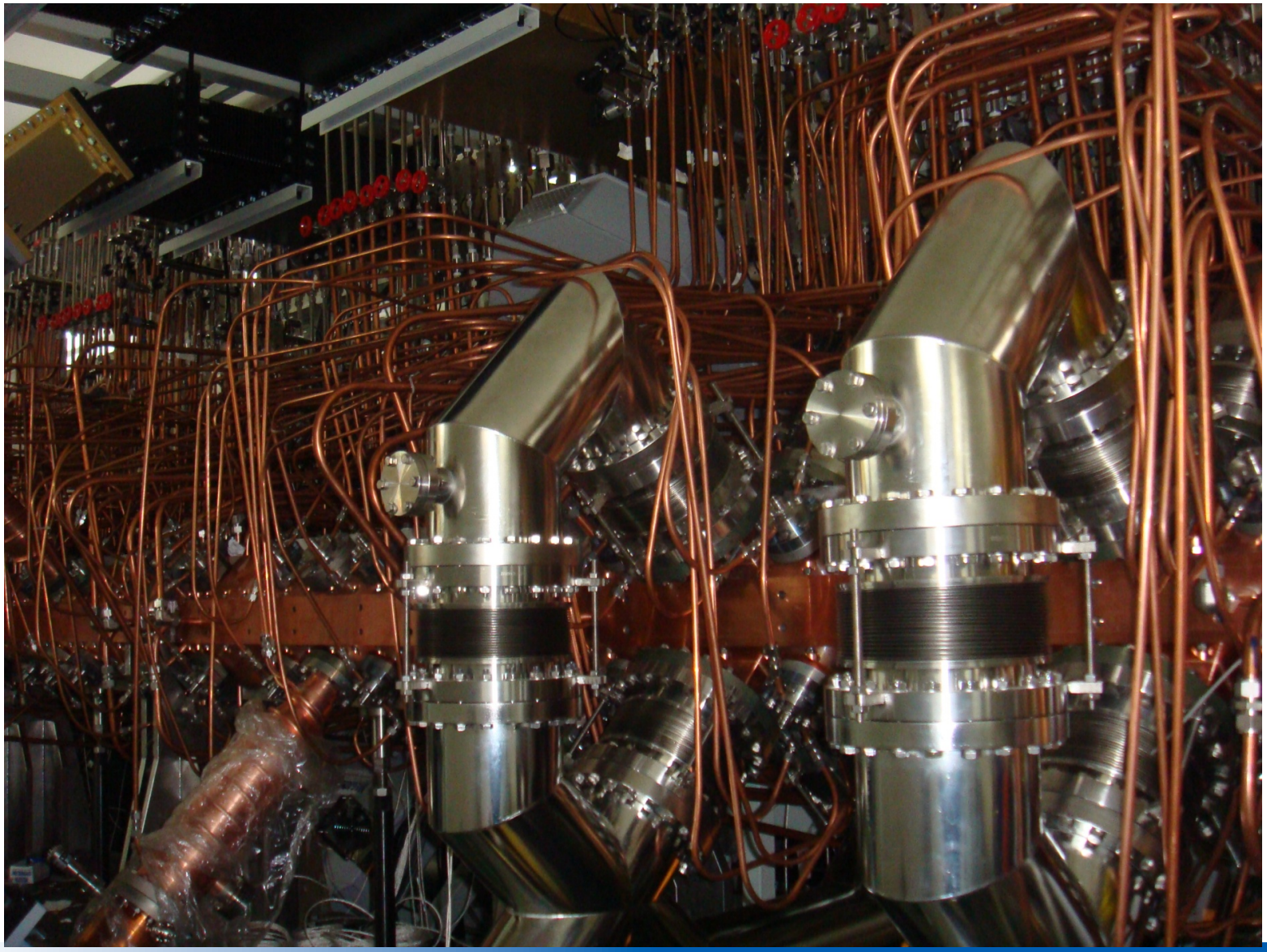


The doorknob assembly

Window assembly high power test result: 100 kW, CW,TW

Coupler installation on RFQ

Assembly are finished onsite



Outline

- General introduction of superconducting linac for China ADS
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- 162.5 MHz RFQ for injector-II
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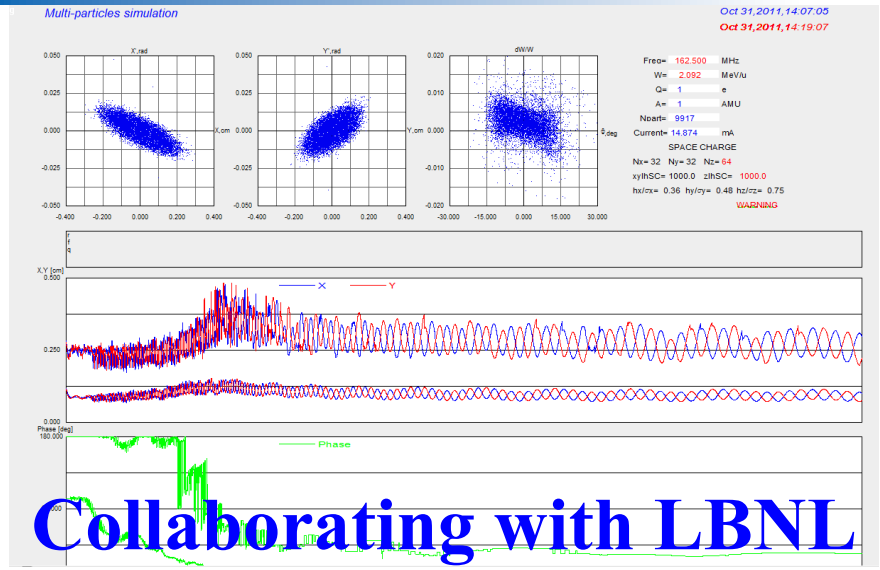
General specifications and consideration

Frequency	162.5	MHz
Intensity	15	mA (protons)
Operation mode	CW	
Inject energy	35	keV
Output energy	2.1	MeV
Transmission efficiency	~ 95%	
Normalized input emittance	0.3	π.mm.mrad (rms)
emittance growth	< 10%	
Output longitudinal emittance	< 1	10^{-6} eV-s
Alpha of TWISS parameters for Input and output beam	< 1.5	

- 162.5 MHz is the half frequency of the downstream frequency of the China ADS, lower frequency reduces the thermal management challenge for CW RFQ
- 15 mA will guarantee the 10 mA beam at the final energy.
- 35 keV helps beam dynamics manipulation and shorten the length of RFQ.
- 2.1 MeV is to reduce the radiation (neutron production) caused by beam loss at MEBT.
- Emittance and TWISS specifications are for up/down stream matching and SC. segment.
- To reduce power consumption and inter-vane voltage for CW machine.

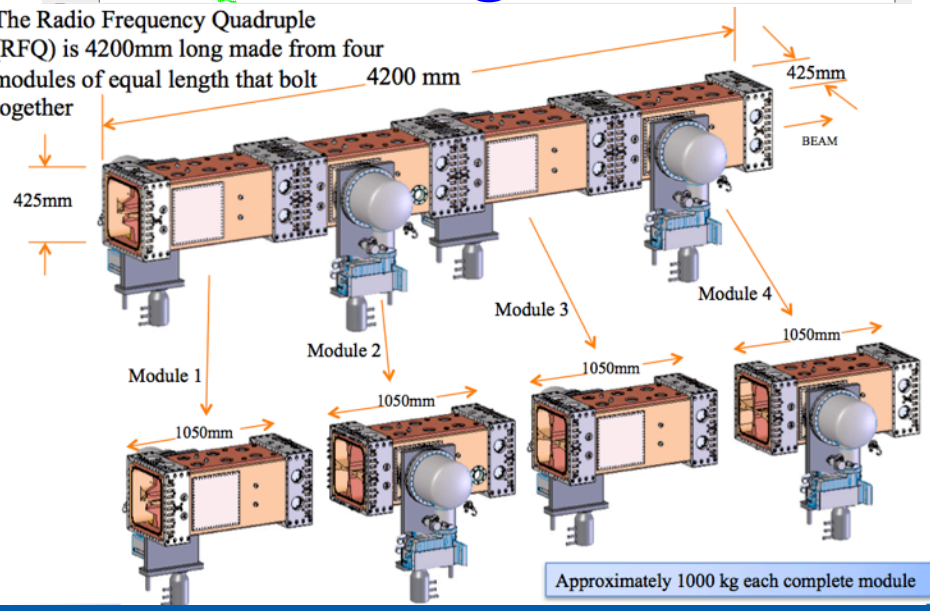
Dynamic and Structure Design

Parameter	Value
Ion species	Proton
frequency [MHz]	162.5
Inter-vane voltage V (kV)	65
Average bore radius r_0 (cm)	0.5731
Vane tip curvature (cm)	0.4298
ρ / r_0	0.75
Vane length / Total length (cm)	419.2 / 420.8
m_{max}	2.38
Number of cells	192 (including 2 T cell)
Maximum surface field (MV/m)	15.7791
Synchronous phase	From -90° to -22.7°
a_{min} (cm)	0.3158
Transverse acceptance (RMS, x/y, πmm.mrad)	0.3/0.3
Input norm. RMS emittance (x/y, πmm.mrad)	0.3/0.3
Output norm. RMS emittance (x/y/z, πmm.mrad, keV.ns)	0.31/0.31/0.92
Overall beam transmission @ 0 /15 mA	99.7% / 99.6%

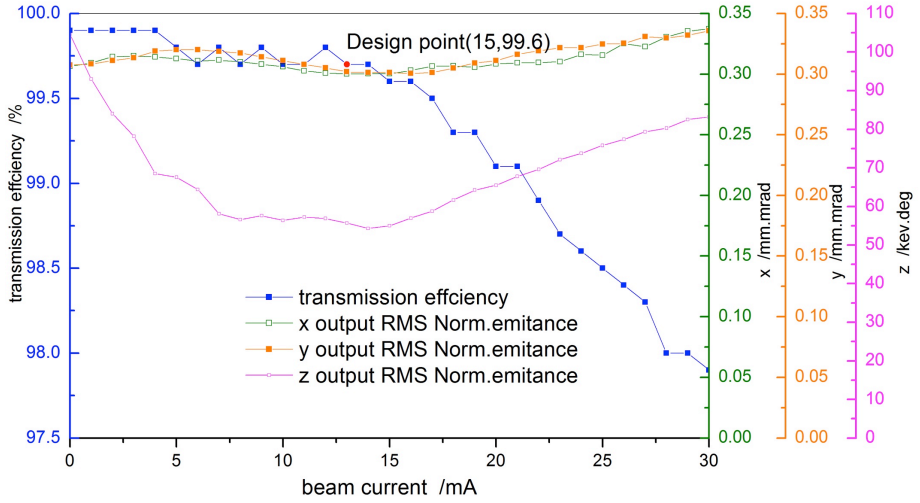


Collaborating with LBNL

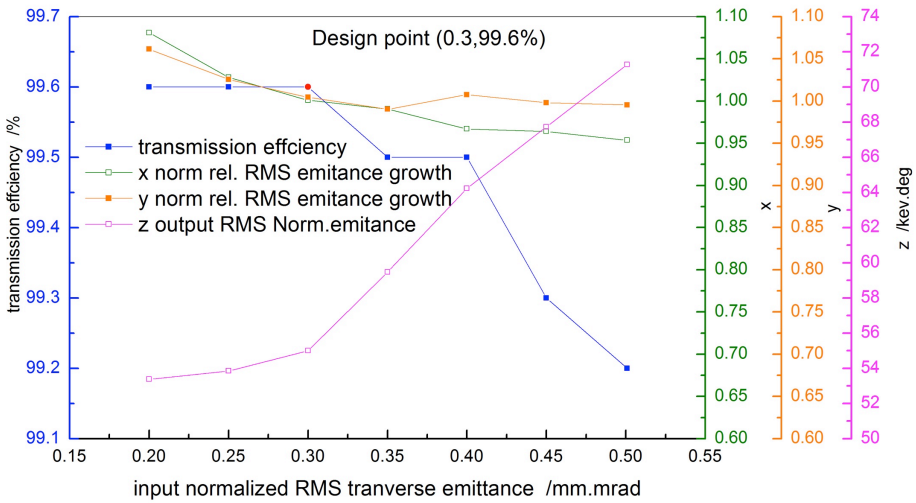
The Radio Frequency Quadruple (RFQ) is 4200mm long made from four modules of equal length that bolt together



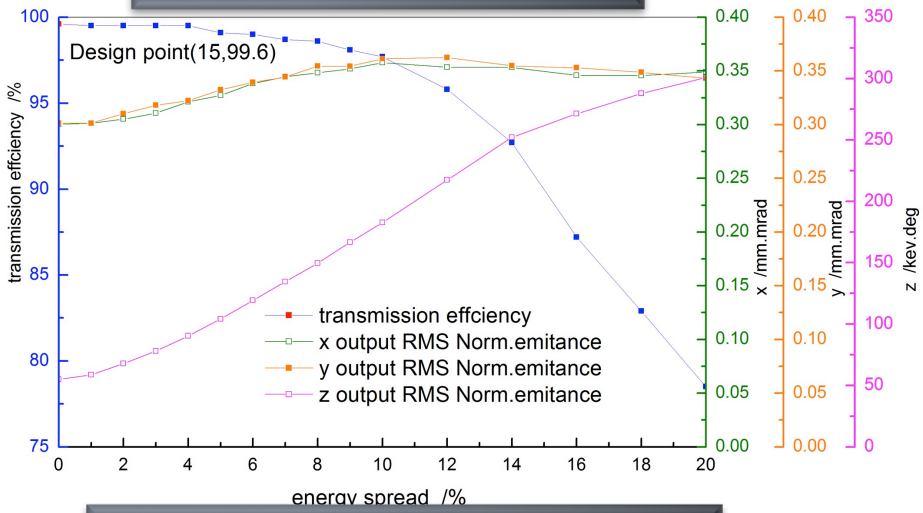
Analysis of tolerance



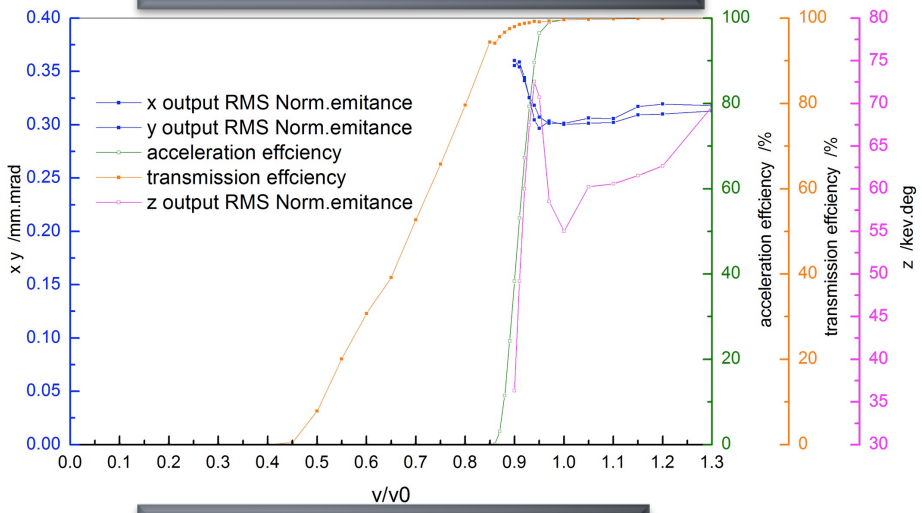
Transmission vs current



Transmission vs emittance

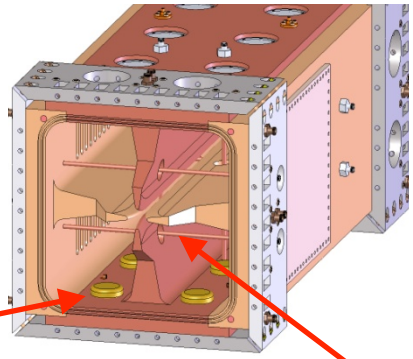


Transmission vs energy spread

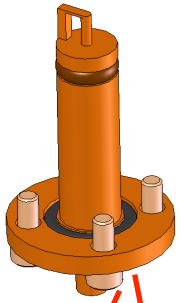


Transmission vs voltage

General Mechanical Structure

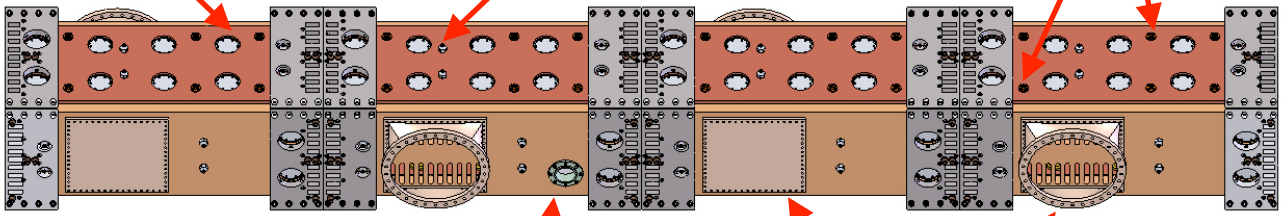


80 Tuners
Equal spaced
20 per module

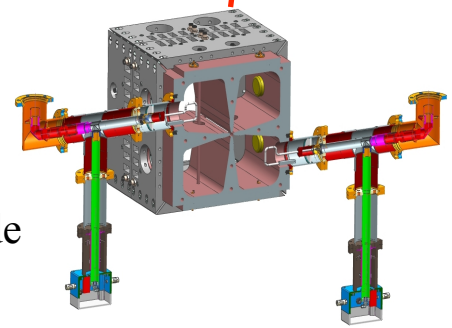


48 sensing
loop ports,
Regularly spaced

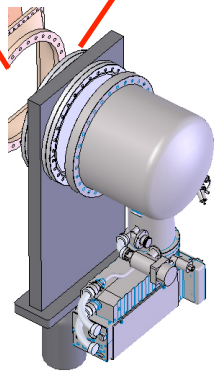
32 Pi-mode Rods
Equal space, 8 per module



Consists of four modules, each
module is 1050mm long

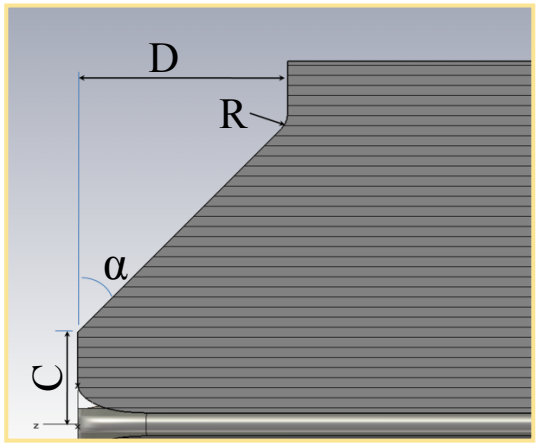


2 RF input ports
Both in Module 2
One near side, one far side

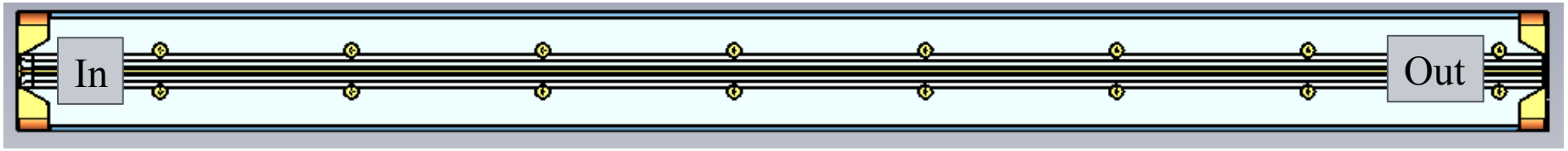


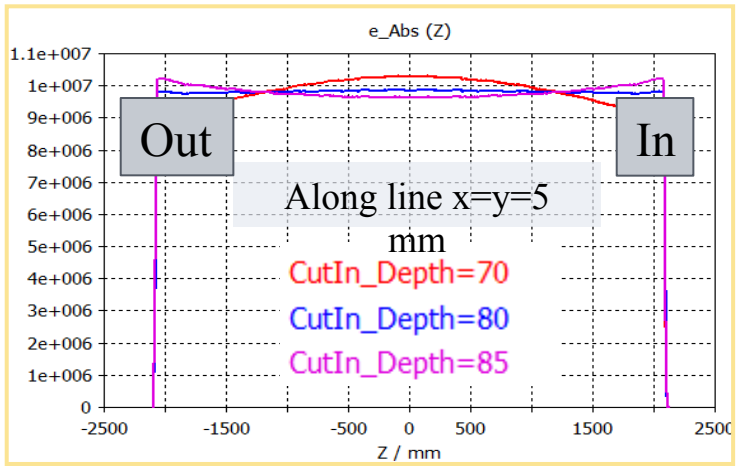
8 vacuum ports
Not all are used

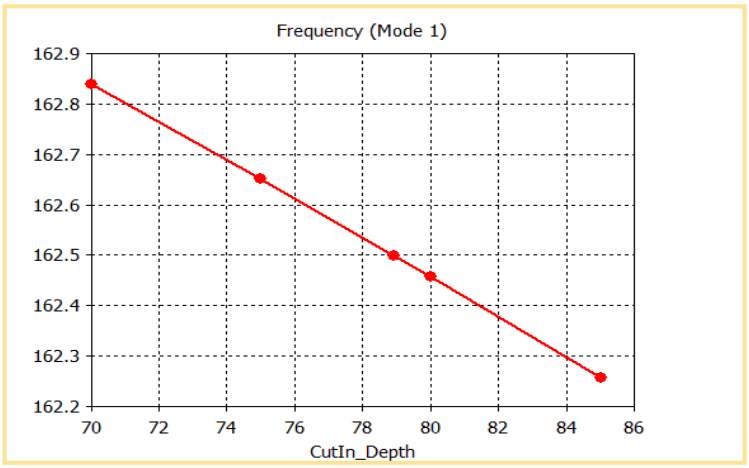
Undercut



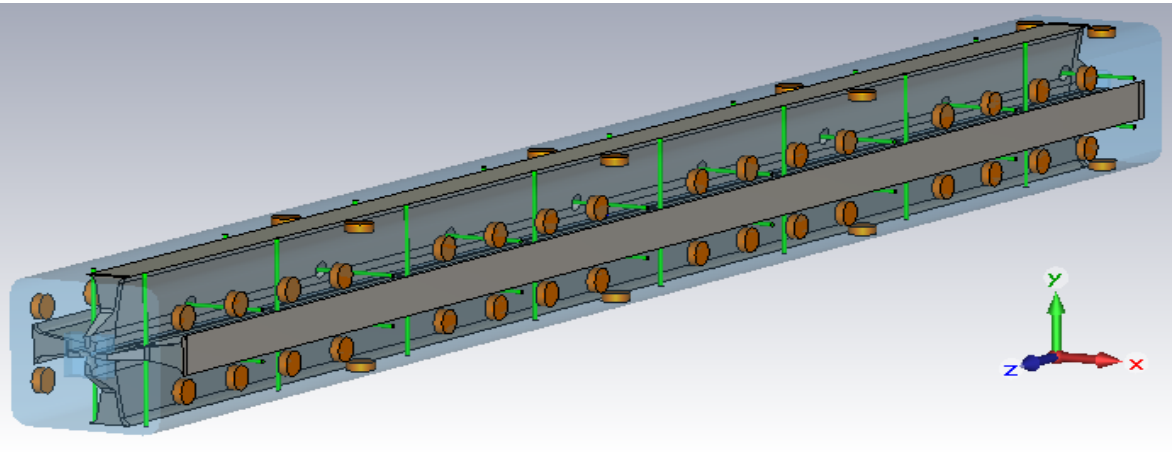
Parameters	Value	
	In	Out
D, mm	80.2	76
R, mm	10	10
α, degrees	30	30
C, mm	45	45

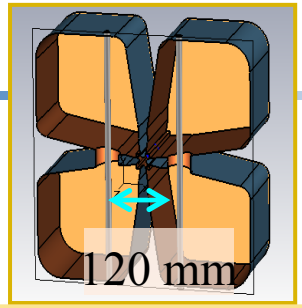


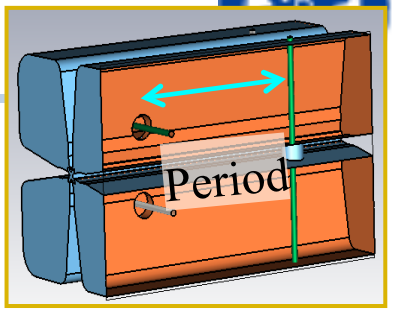


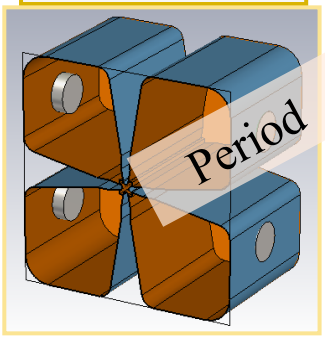


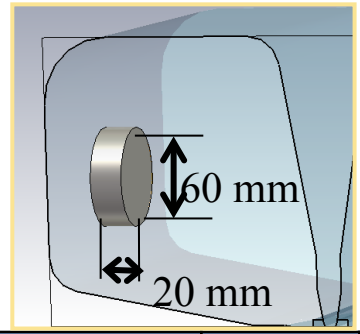
Whole model simulation







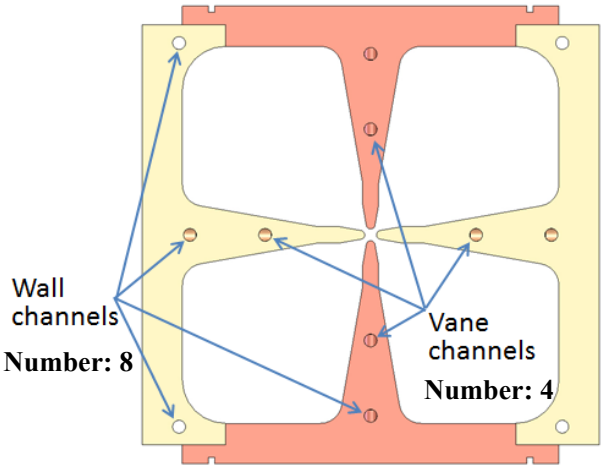




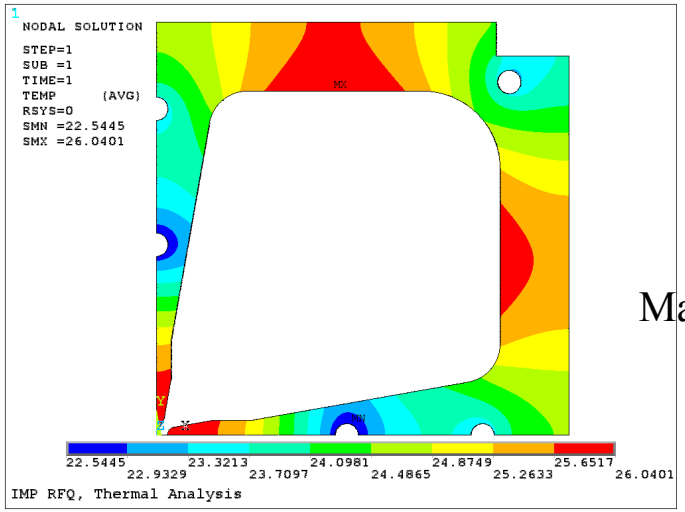
Parameters	Value
Operational frequency, MHz	162.4016
Quadrupole frequency 2, MHz	165.9422
Quadrupole frequency 3, MHz	176.0886
Dipole Frequency, MHz	191.7119
Q factor	14388.72
Side length, mm	346.06
Peak electric field, MV/m	15.26
Tuning coef. of one tuner kHz/ mm	0.91

Part	Total, kW	%
Walls	33	39.5
Vanes, 4 units	34.4	41.2
Input cut-backs, 4 units	1.73	2.07
Output cut-backs, 4 units	1.84	2.2
Pi-mode rods, 32 units	6.67	7.99
Tuners, 80 units	5.83	6.98
Total	83.5	
Max. power density, W/cm^2	28.95 (on cutback)	

Thermal analysis of the cavity body



Layout of cooling passage



Max. Temp.: 26°C

Temp. distribution of the cavity body

Parameters of passage and water

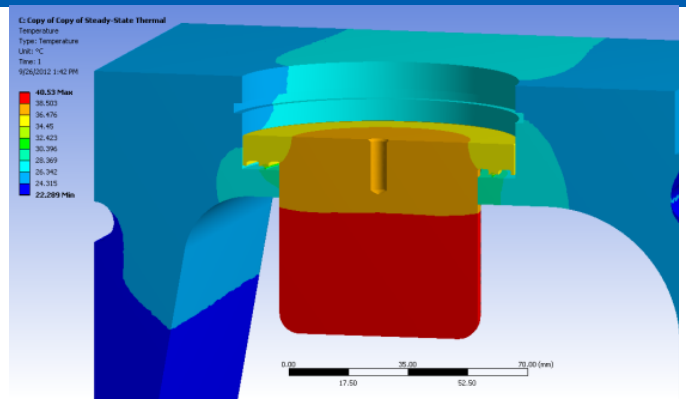
Items	Values
Wall channel diameter [mm]	12
Vane channel diameter [mm]	12
Pi-rod diameter [mm]	10
Water velocity [m/s]	2.29
Water working temperature [^{0}C]	20

Frequency shift vs water temperature

Frequency Shift (2D)	Average
Vane (kHz/°C)	-16.00
Wall (kHz/°C)	13.20
Sum of Vane & Wall (kHz/°C)	-2.80

The actual temperature sensitivity of resonant frequency for each water path shall be measured

Thermal analysis of tuner, pi-rod and cutback

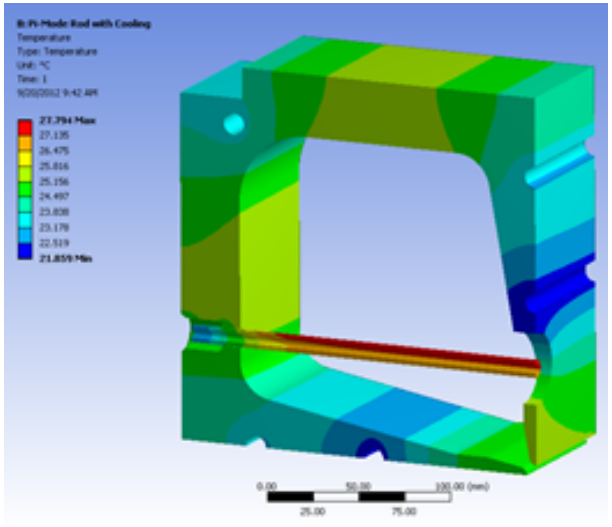


Temp. distribution of tuner

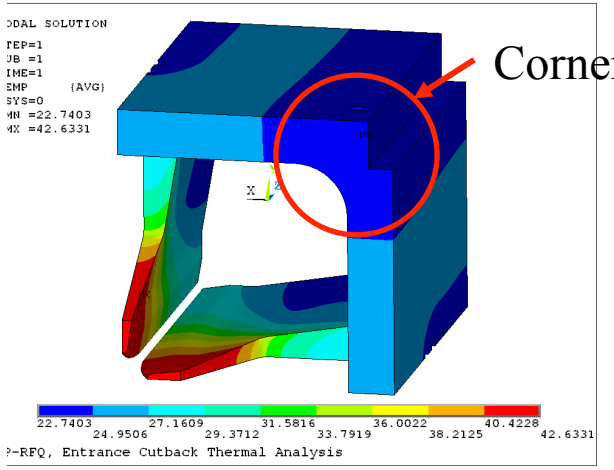
Maximum temperature of tuner is below 35°C, heat flow is 70W for insertion of 20mm;

Maximum temperature of tuner is below 41°C, heat flow is 104W for insertion of 40mm;

Maximum temperature of Pi-rods is ~28 °C; Maximum stress is ~4.7MPa; Deflection at the center of it is very small -> submicron range; Monitoring of cooling water is required.



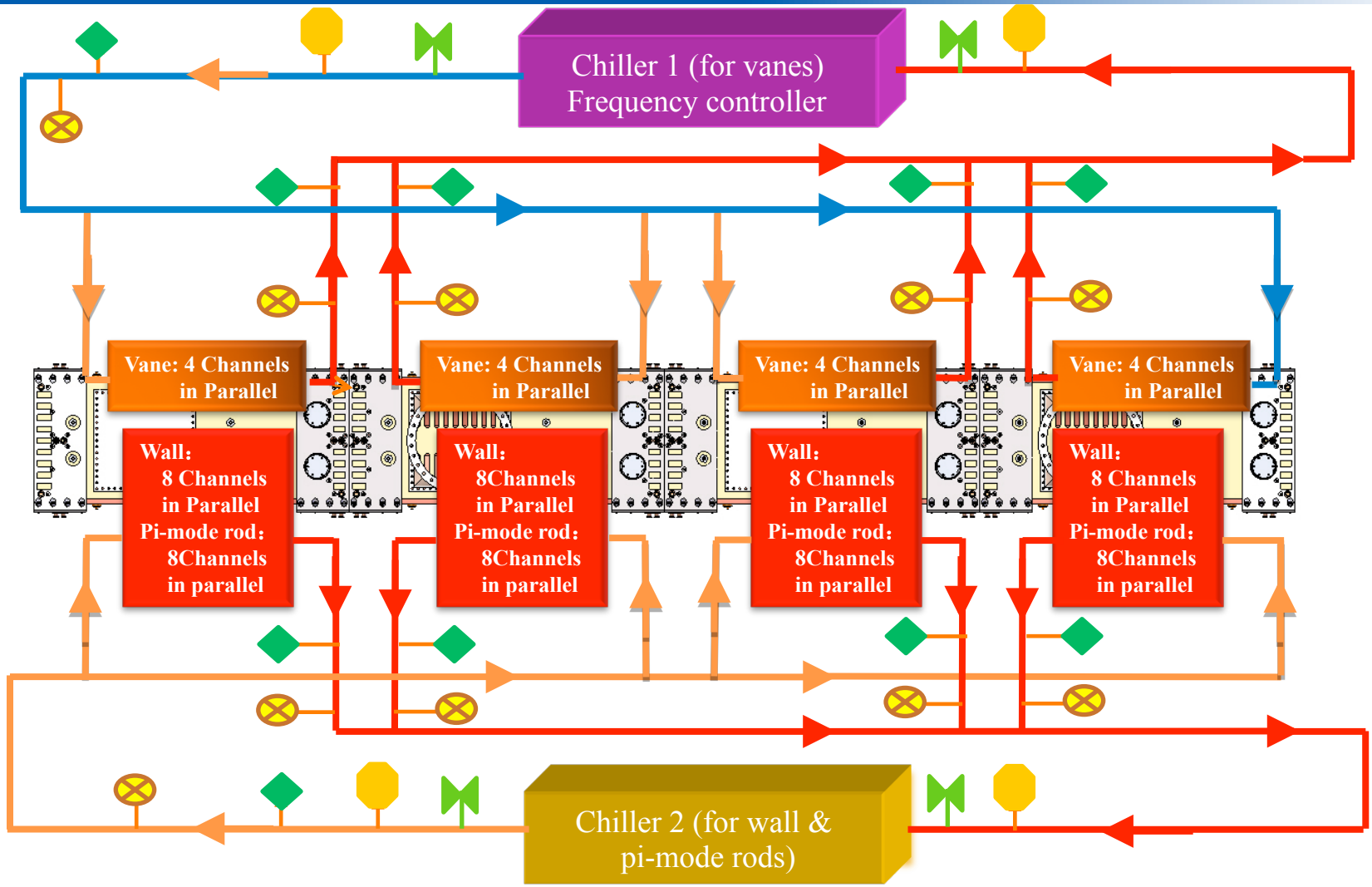
Temp. distribution of pi-rod



Temp. distribution of cutback

Maximum heat flux is 28.92 W/cm^2; Max temp of cutbacks is ~48.0 °C at the exit, the deformation is about 160um at the far corner.

Water Cooling System



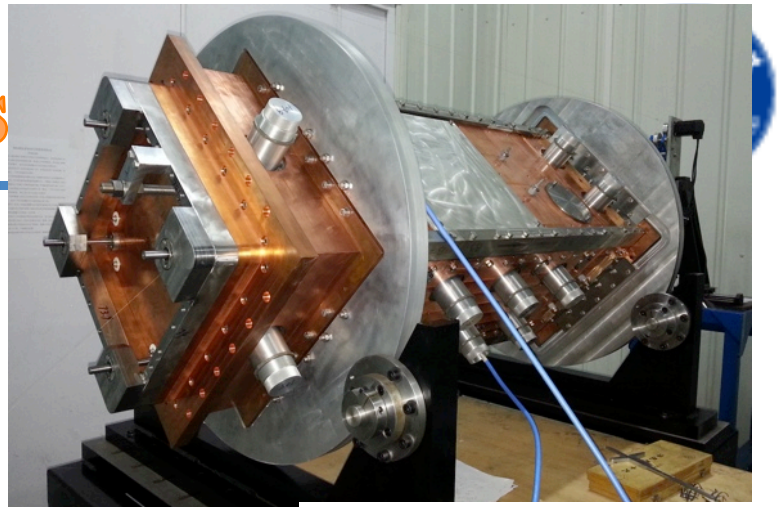
Flow monitor and temperature monitor are required to be installed at the exit of each channel

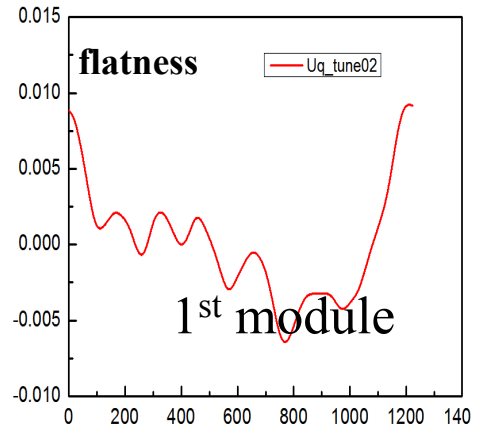
Pressure gauge Temperature monitor Flow meter Valve

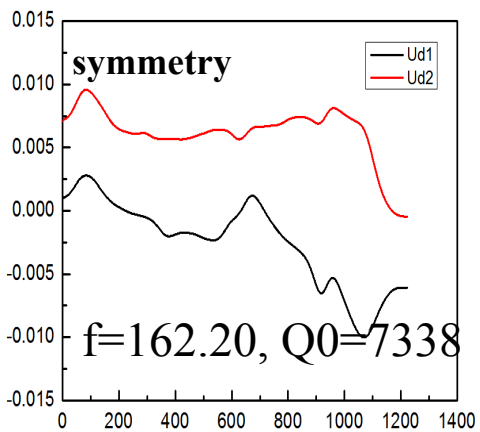
Modules Measurements

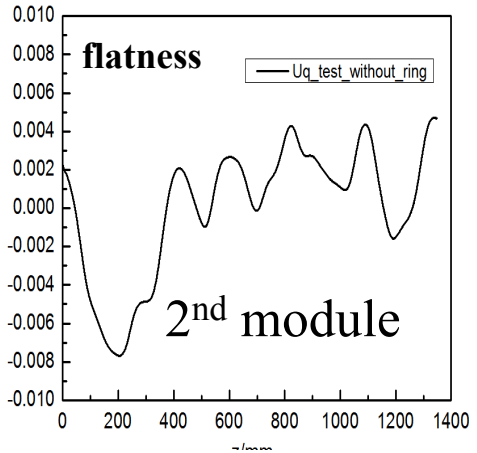
The RFQ was manufactured and brazed in the workshop of IMP.

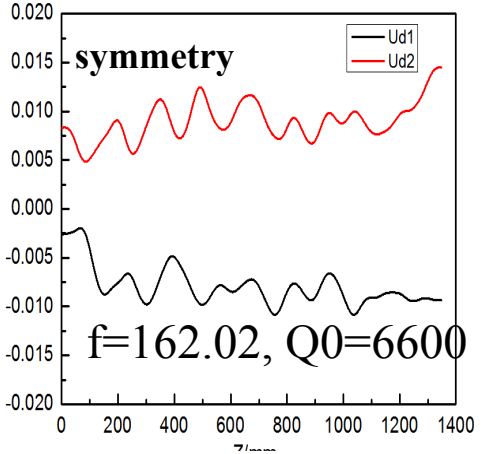
The flatness is ±1%, and symmetry is ±1.5% with all tuners in the initial positions for all modules.

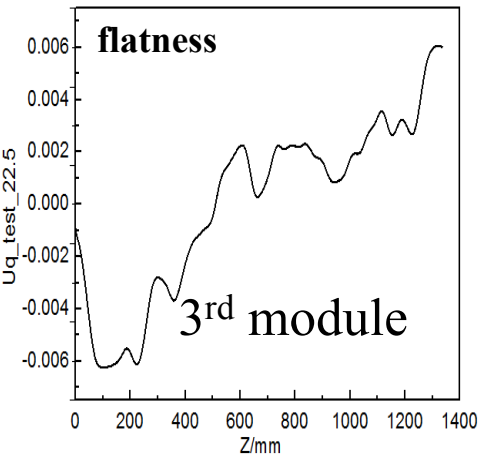


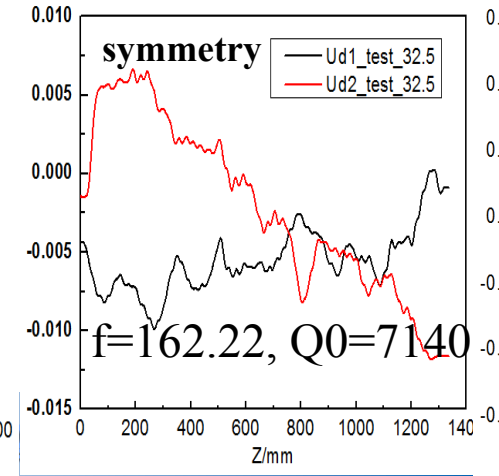


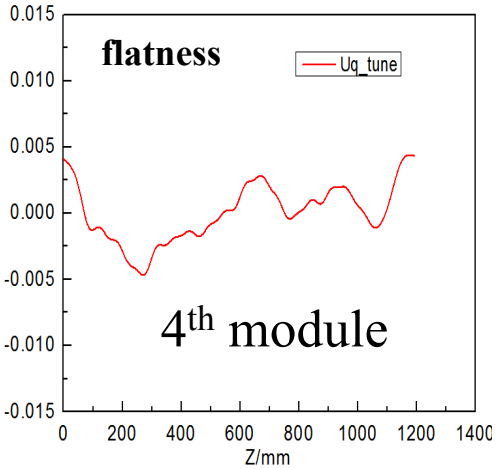


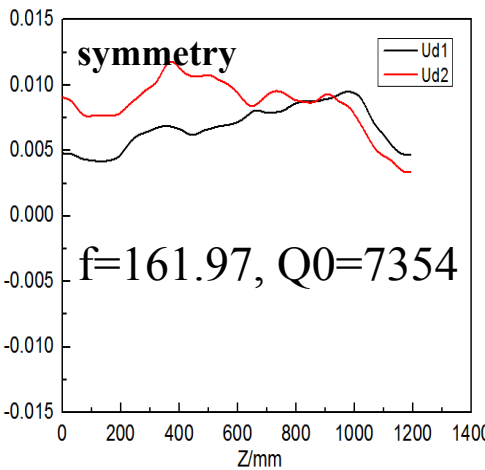




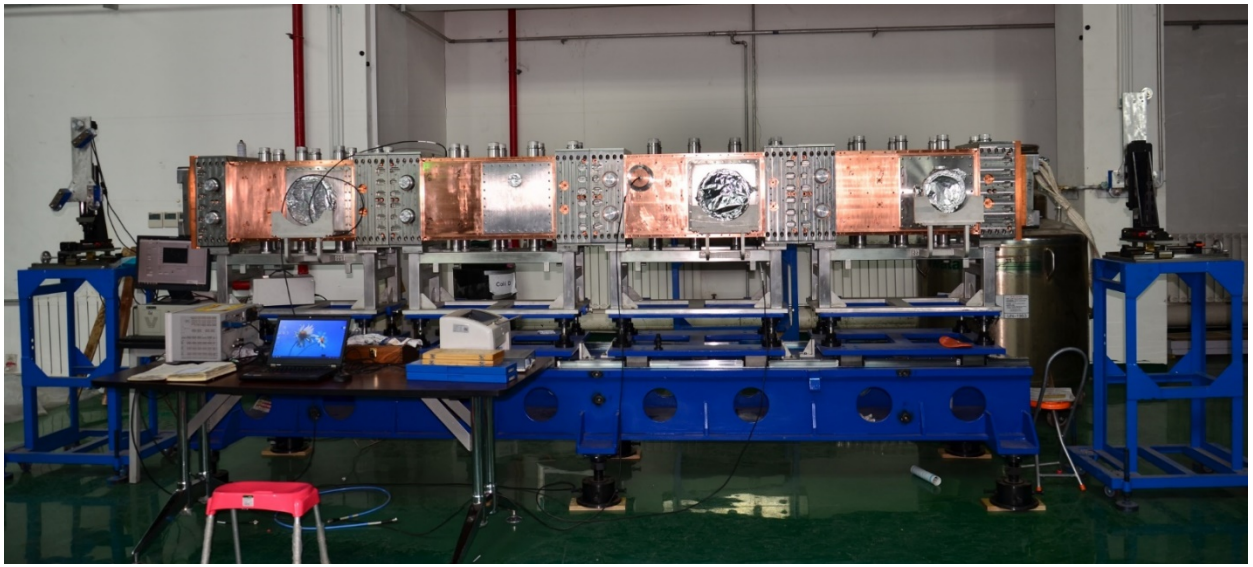


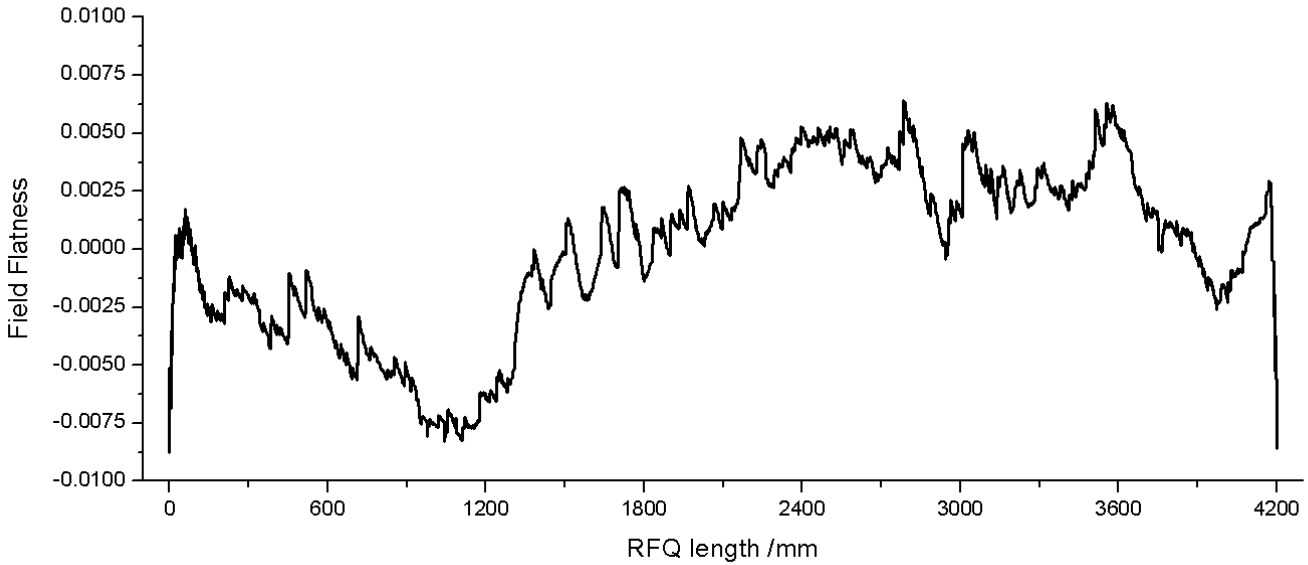






Flatness of Field after Tuning



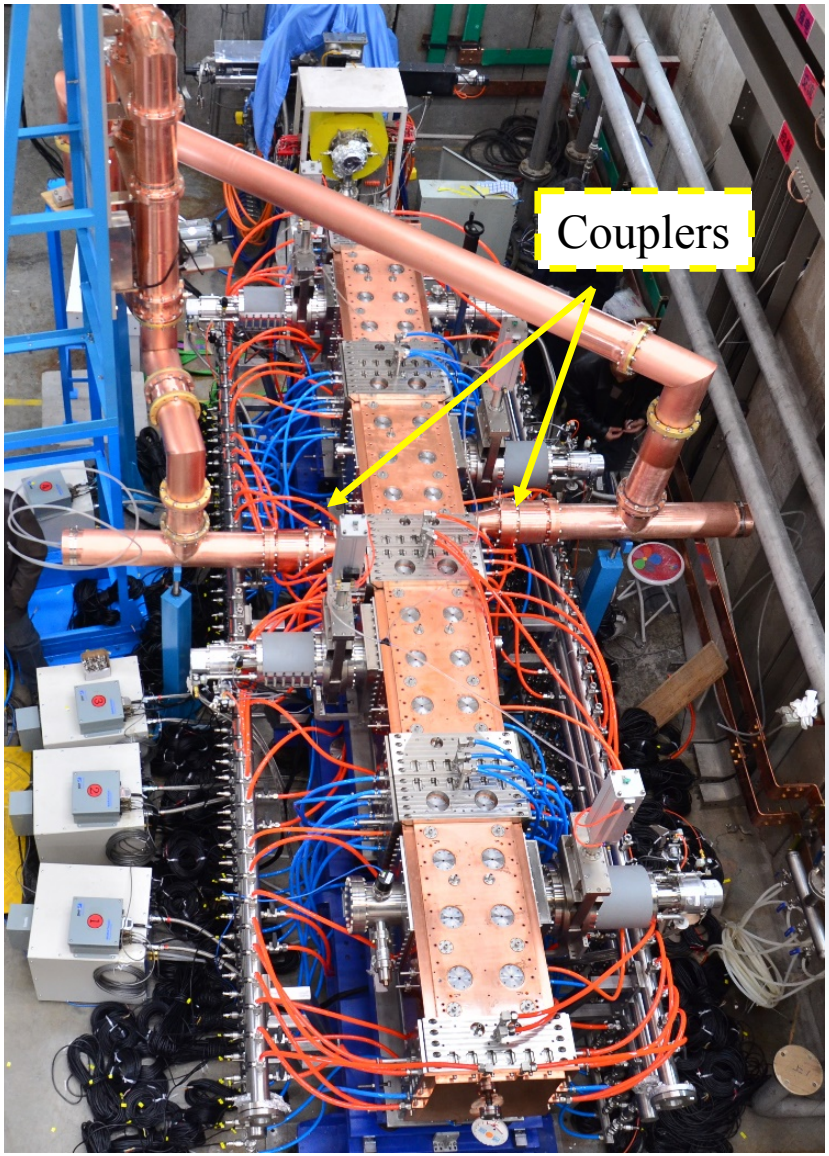


Cavity frequency and Q_0 after tuning :

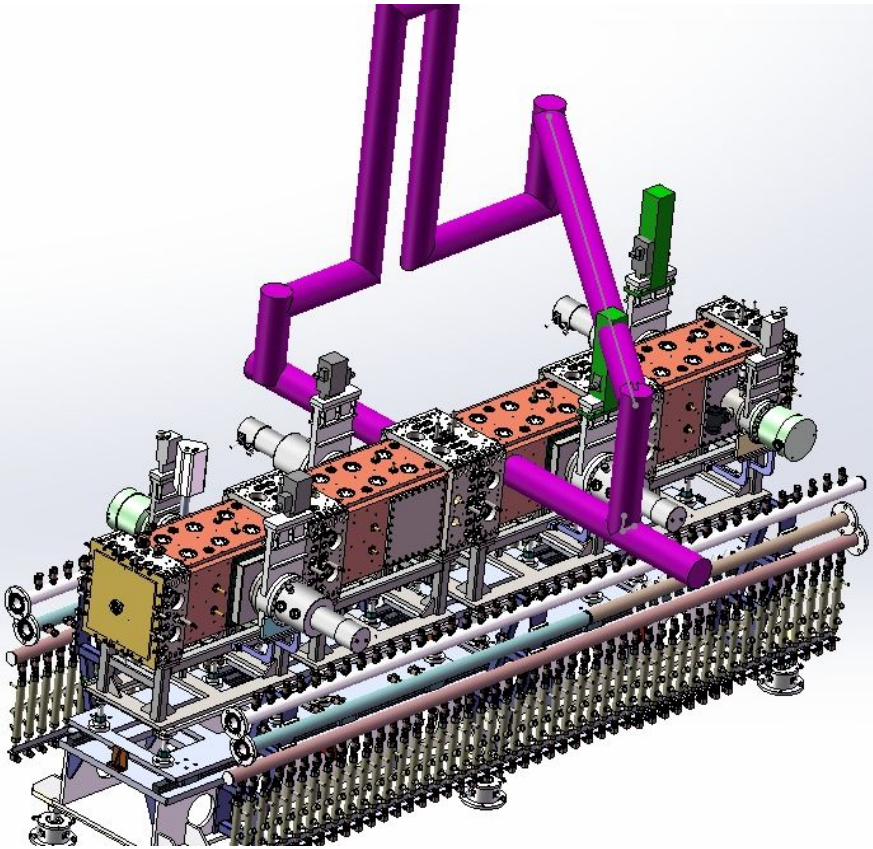
Fq=162.46MHz
Fd=183.4MHz
Q_0=12600

Field flatness after tuning is within $\pm 1\%$

RFQ installation



Two couplers are installed. The total coupling strength is 1.324 for acceleration for 15mA proton beams, so the coupling strength of each coupler is 0.662.



RF conditioning of the cavity

Conditioning goal: 93kW

Low power conditioning in CW mode
(Maximum power:30kW)

⇩

HIgh power conditioning in pulse mode
(Duty factor: ~36%; repetition rate: 200Hz)

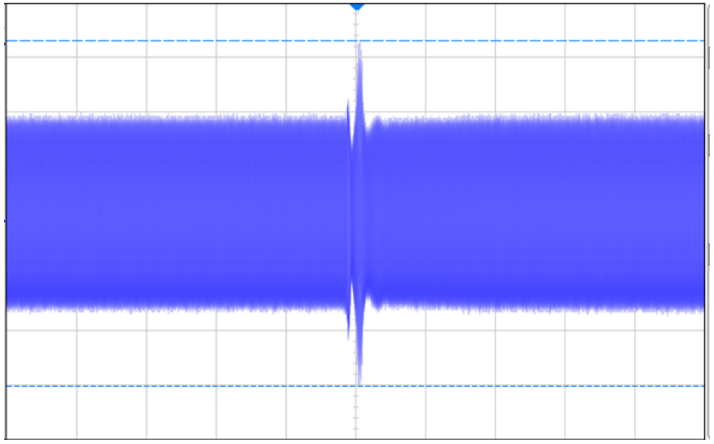
⇩

High power conditioning in CW mode
(Maximum power:93kW)

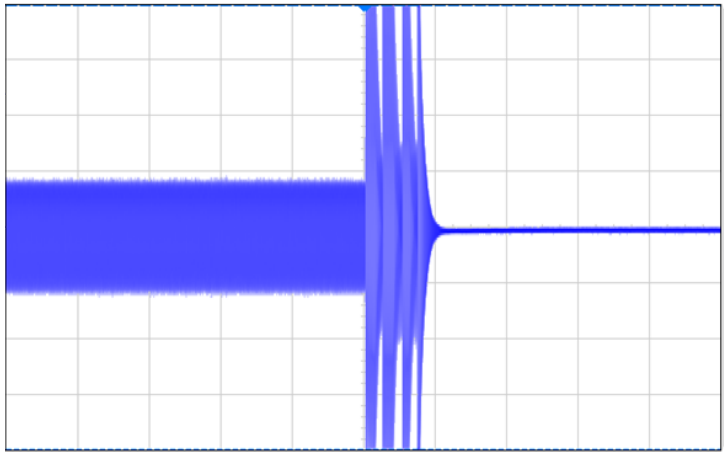
Vacuum is kept below 1.5×10^{-5}Pa and the ration of reflection power and forward power is less than 5% during the conditioning process.

Status: 60% to the full power; and 70 kW in CW

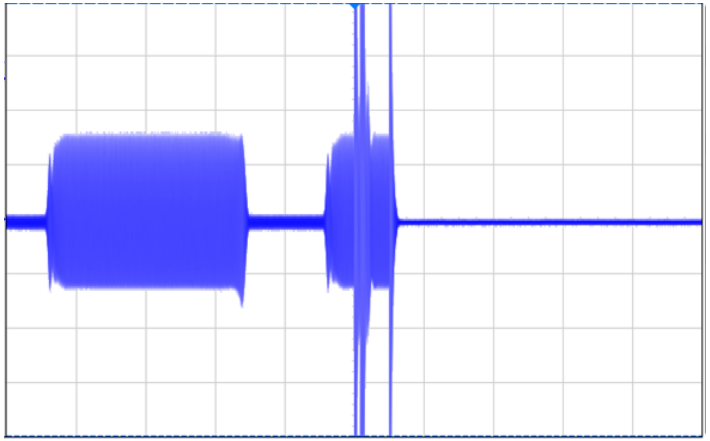
Arcs during the conditioning



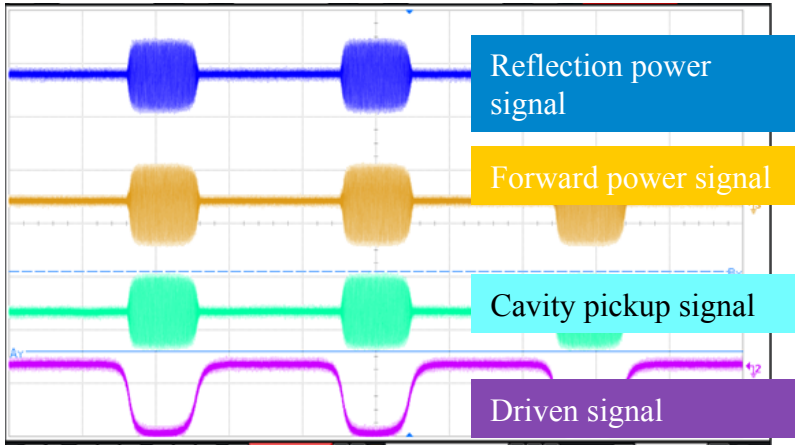
Reflection power shape in CW mode with arc but without interlock



Reflection power shape in CW mode on the case of fast interlock of arc



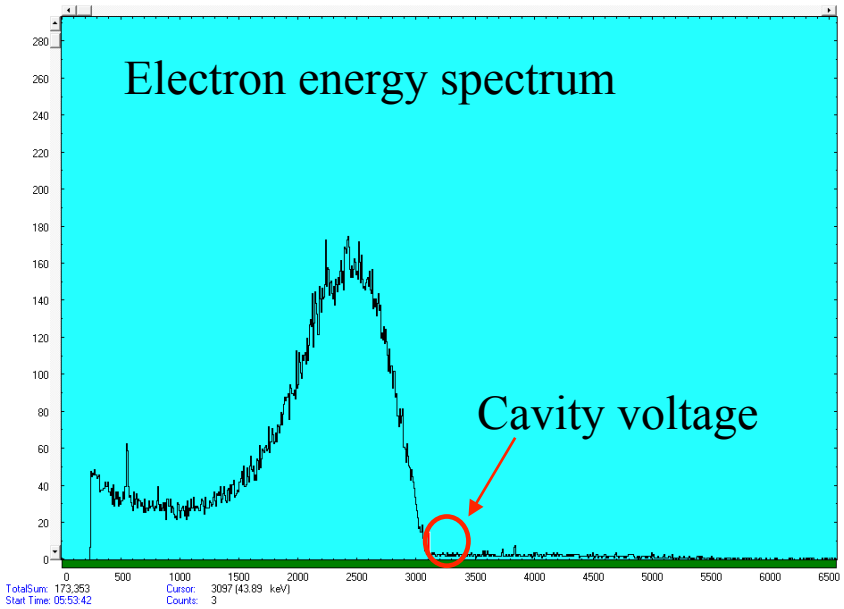
Reflection power shape in pulse mode on the case of fast interlock of arc

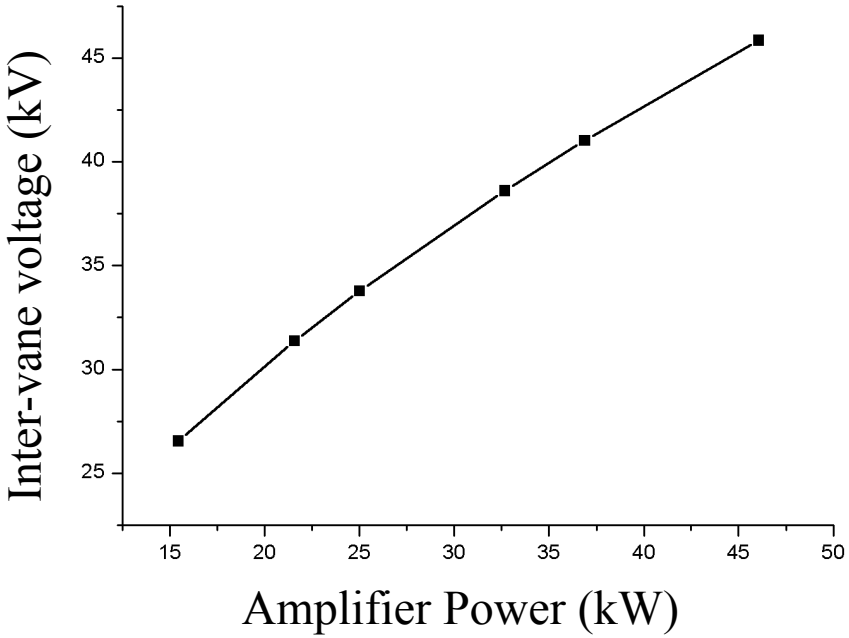


Customized pulse shape to eliminate reflection during the pulse

Measurement of inter-vane voltage

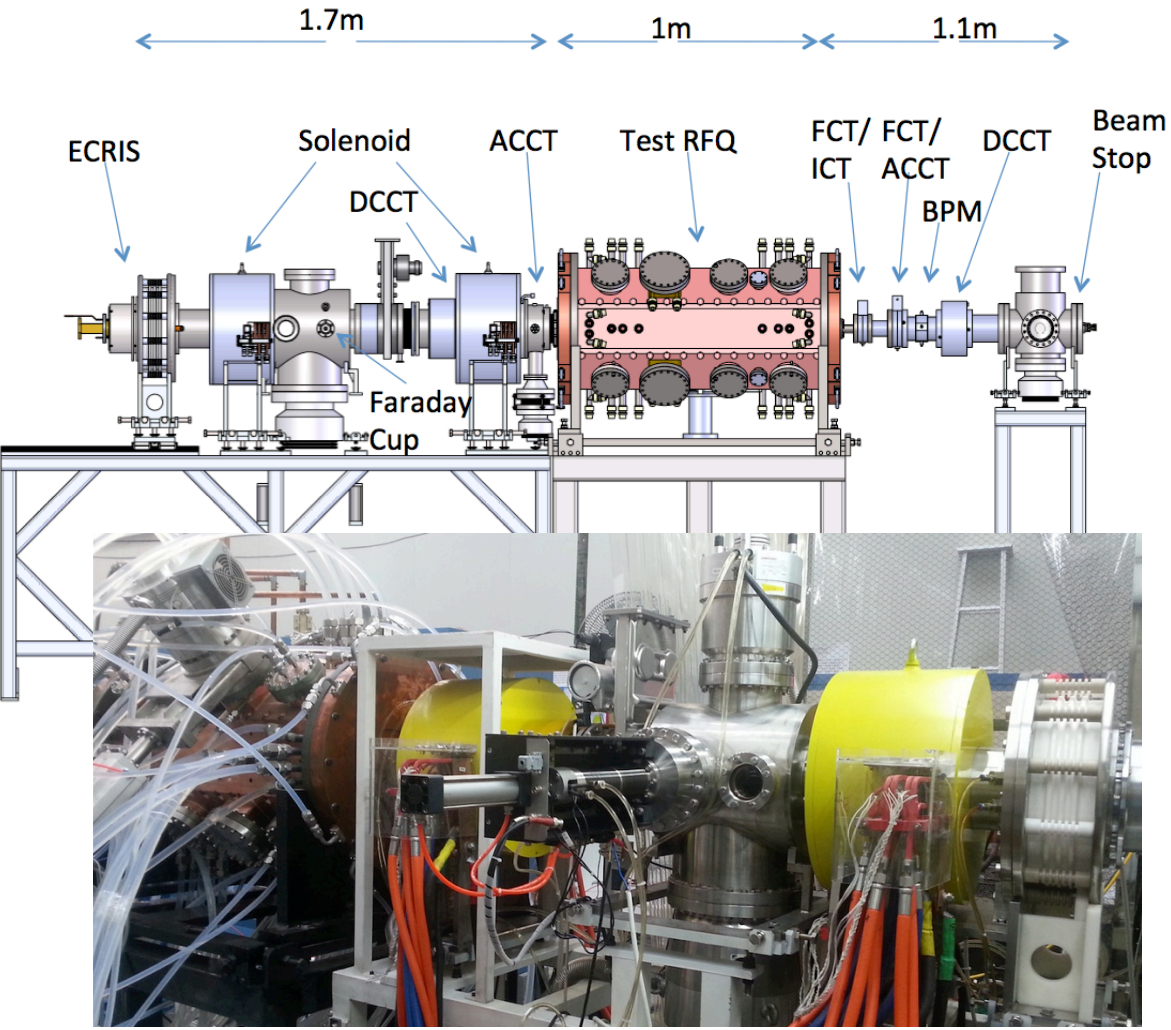
X-ray end point method was used to measure the inter-vane voltage.

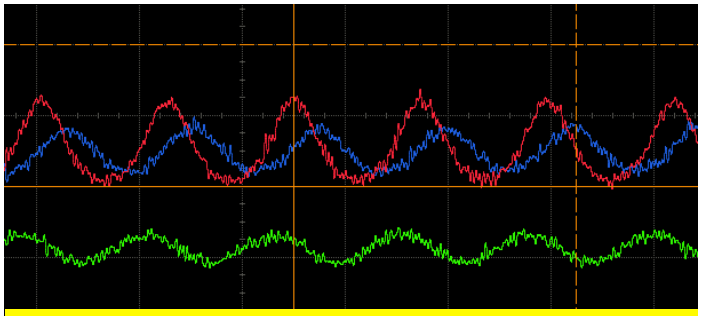




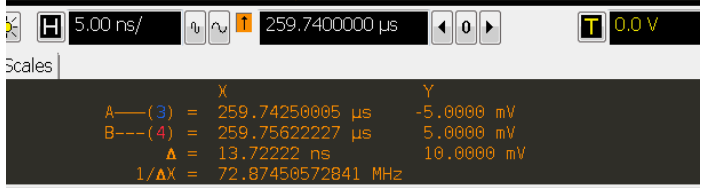
Based on the measured data, the inter-vane voltage is 65kV when the amplifier power reaches 93 kW.

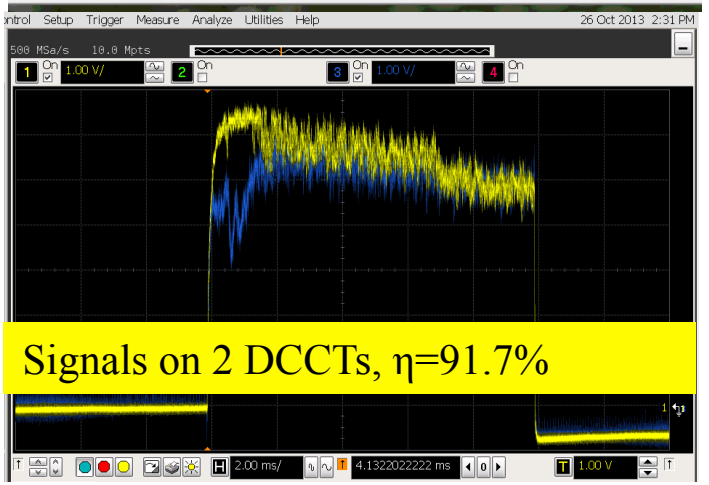
Commissioning of 560keV-RFQ Demo





Signals on 2 FCTs, E=558keV





Signals on 2 DCCTs, η=91.7%

Worked on CW mode weeks ago for 3 days. 10.5 mA proton from RFQ, transmission is better than 90%, finally.

Outline

- General introduction of superconducting linac for China ADS
- 325 MHz RFQ for injector-I
- 162.5 MHz RFQ for injector-II
- Summary

Summary

- Two kinds of RFQs have been developed for China ADS. One is based on the frequency of 325 MHz and the other is based on 162.5 MHz.
- Both of the RFQs have been tuned and installed onsite.
- The RFQ of 162.5 MHz is in high power conditioning, and has been conditioned to 70 kW in Continue Wave. Beam commissioning will be in June.
- The RFQ of 325 MHz will be conditioned in June and beam commissioning will be in August.
- A demo a 162.5 MHz RFQ with 560 keV has been commissioned last year. 10-mA, CW beam was transferred with 90% efficiency.

Thanks for your attention and welcome to collaboration