Growth of RF Superconductivity In China

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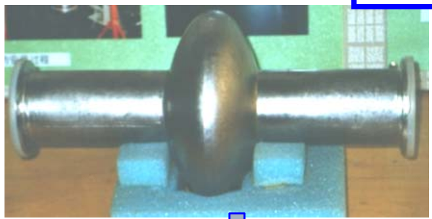
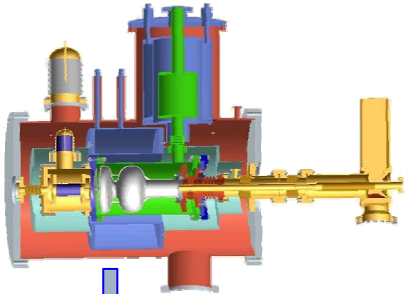
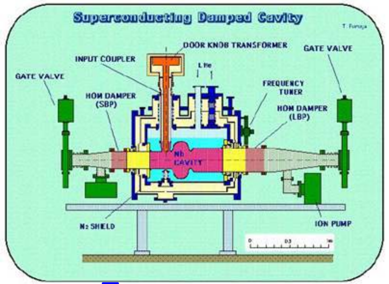
Milestones of SRF in China

Beijing SRF Center
(PKU-IHEP)



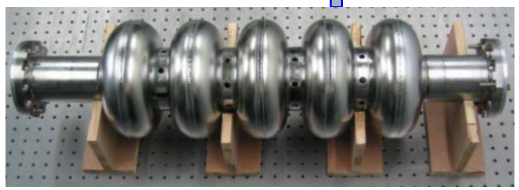




1988 1994 2000 2001 2002 2004 2005 2006 2007

PKU SRF
Lab founded

SRF based FEL
approved by MOST

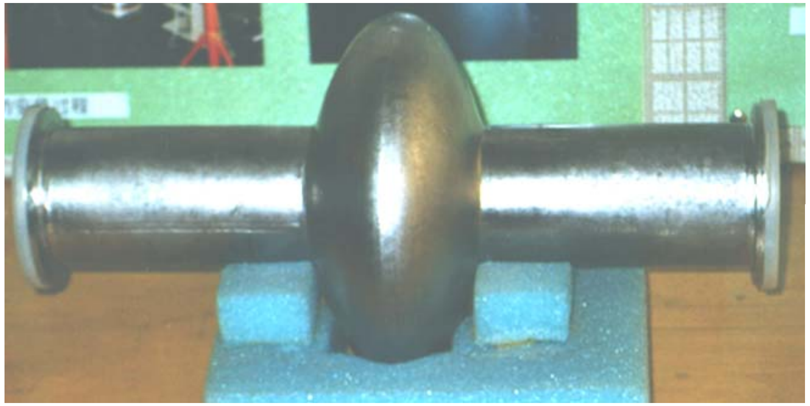


I. Starting Phase of RF Superconductivity at IHIP, Peking University

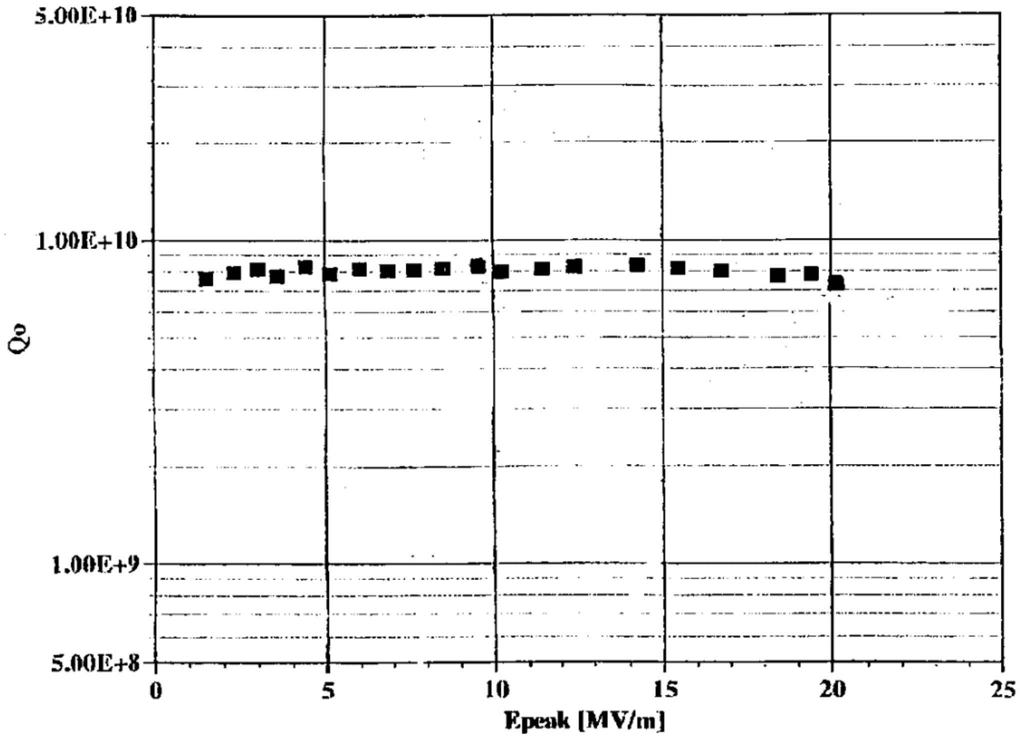
R&D on fabrication of SC CAVITIES

- Single-cell SC cavities
- Cu-Nb Sputtering QWR

RF Superconducting Cavities



RRR ~ 50 $\xrightarrow[1400\ C]{}$ 470



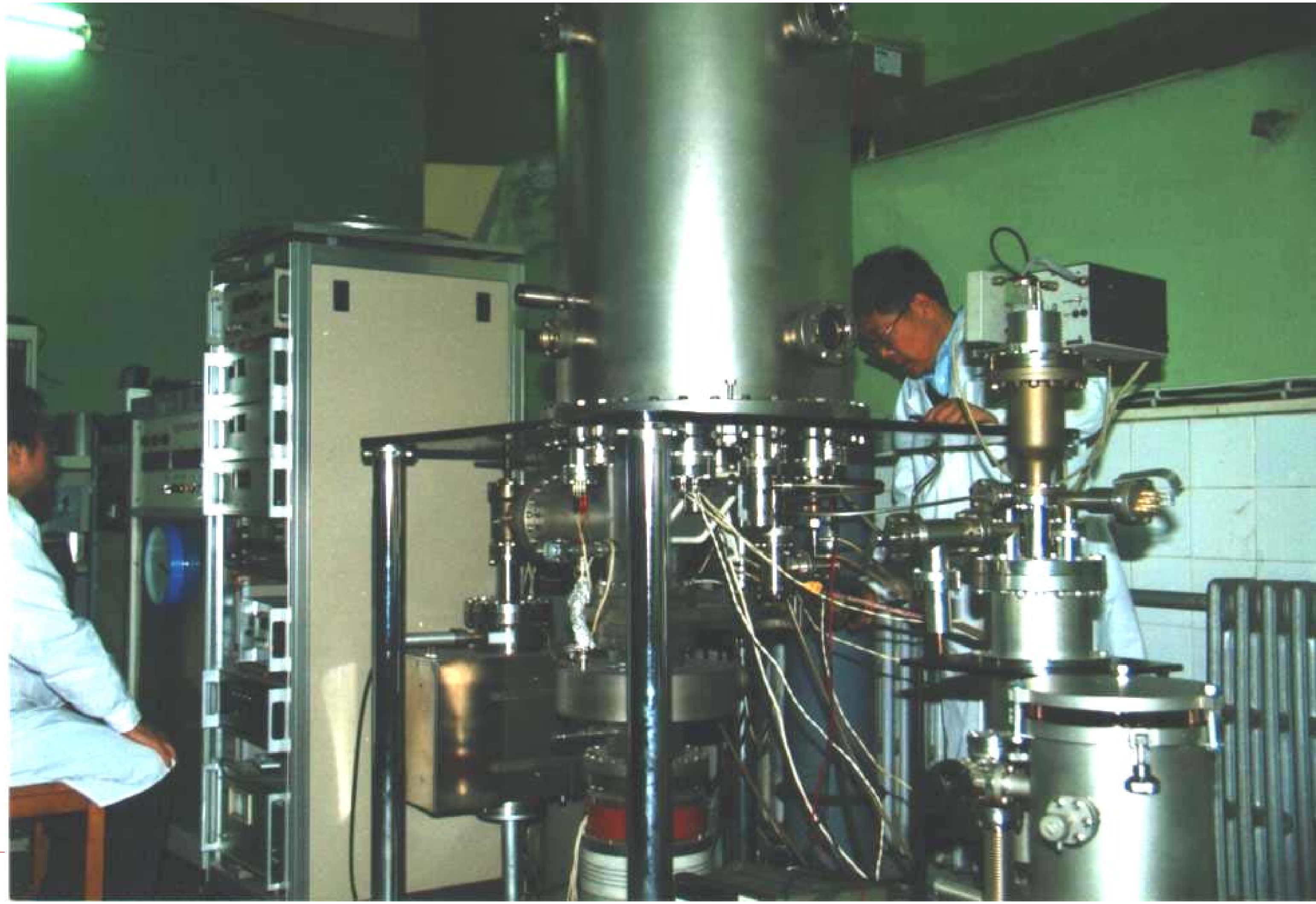
- 1st Single Cell Cavity with China made Nb (1994)
- RRR> 270

1.3 GHz Single cell cavity beam test at CAEP

Input Energy	3.45 MeV
Energy Gain	0.58 MeV
Pulse Intensity	o.1 A
Micro width Macro	10 ps 1 μs

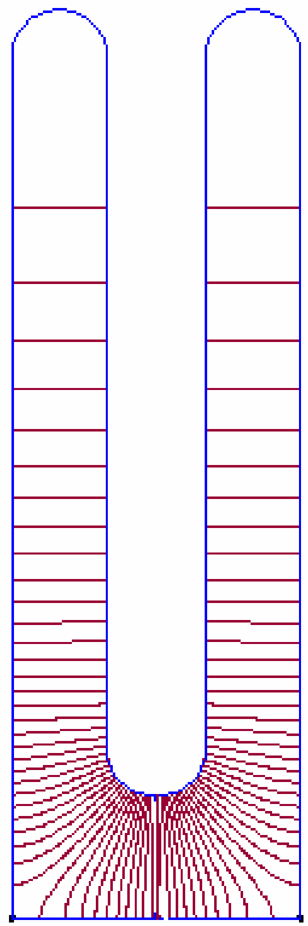
Cavity, cryostat and main coupler processed by PKU

Nb Sputtering System at PKU

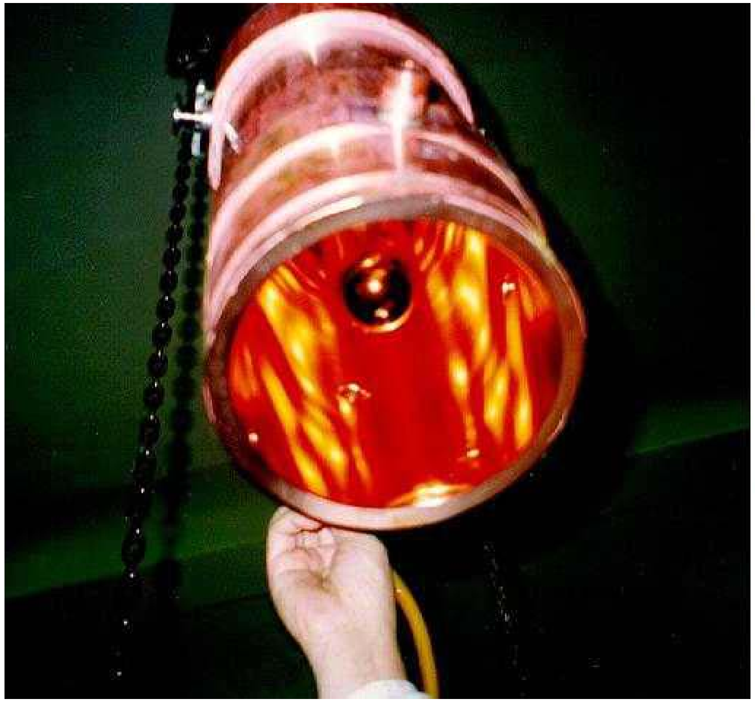


Geometry of the SRF QWR

F_0	143.2	MHz
β	0.11	
U_0/E_a^2	0.0411	$J/(MV/m)^2$
R_s	3.12	mΩ
Z_{sh}	18.2	MΩ/m
$R_{s*}Q$	26.2	Ω
H_p/E_a	6318	(A/m)/ (MV/m)
E_p/E_a	3.65	

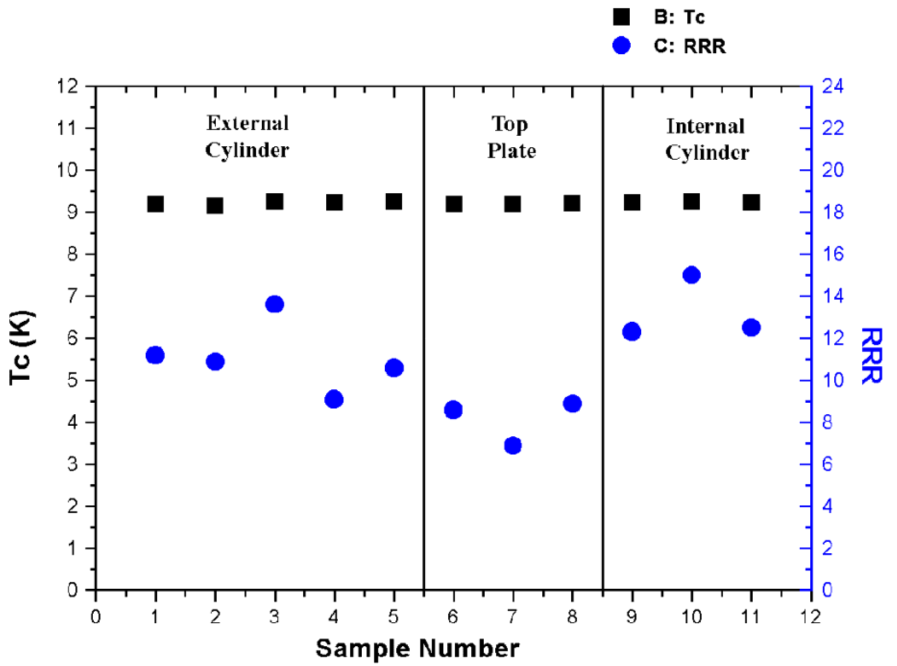


□ Sputtered Nb-Cu SRF QWR

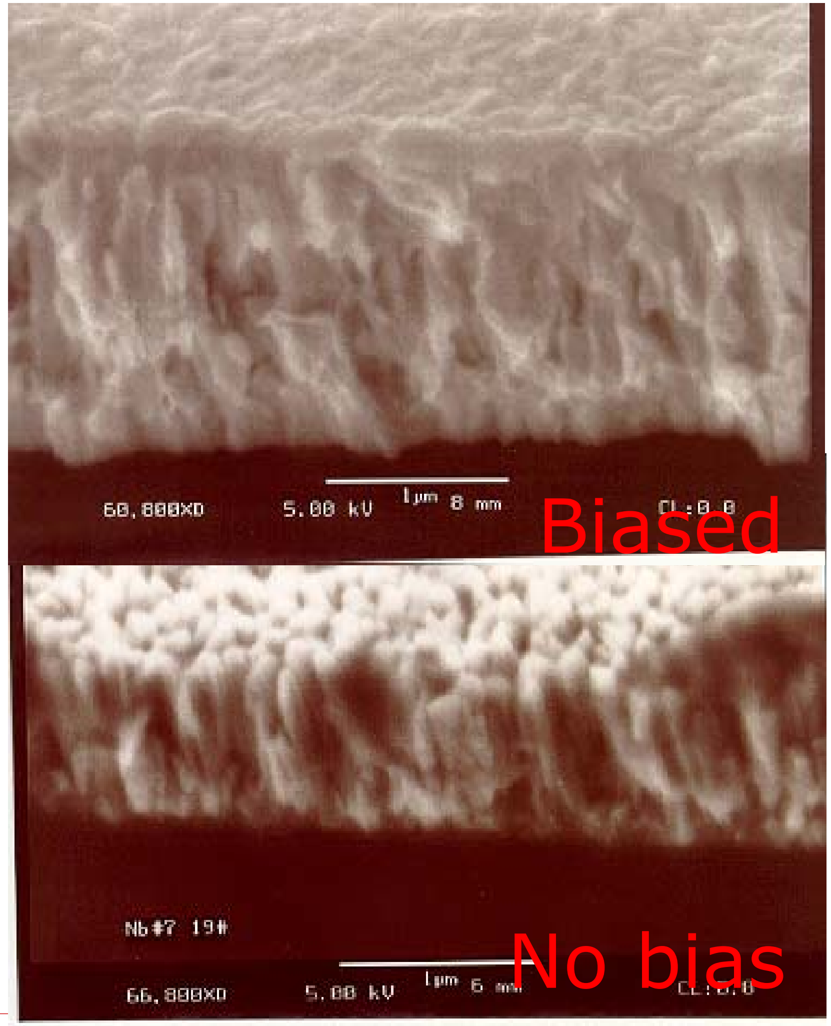

Before Sputtering


After Sputtering

Structure & quality of Nb film



Tc and RRR of niobium films



❖ Tc & RRR of Nb Film at various Position

Beam Loading Test in 2001

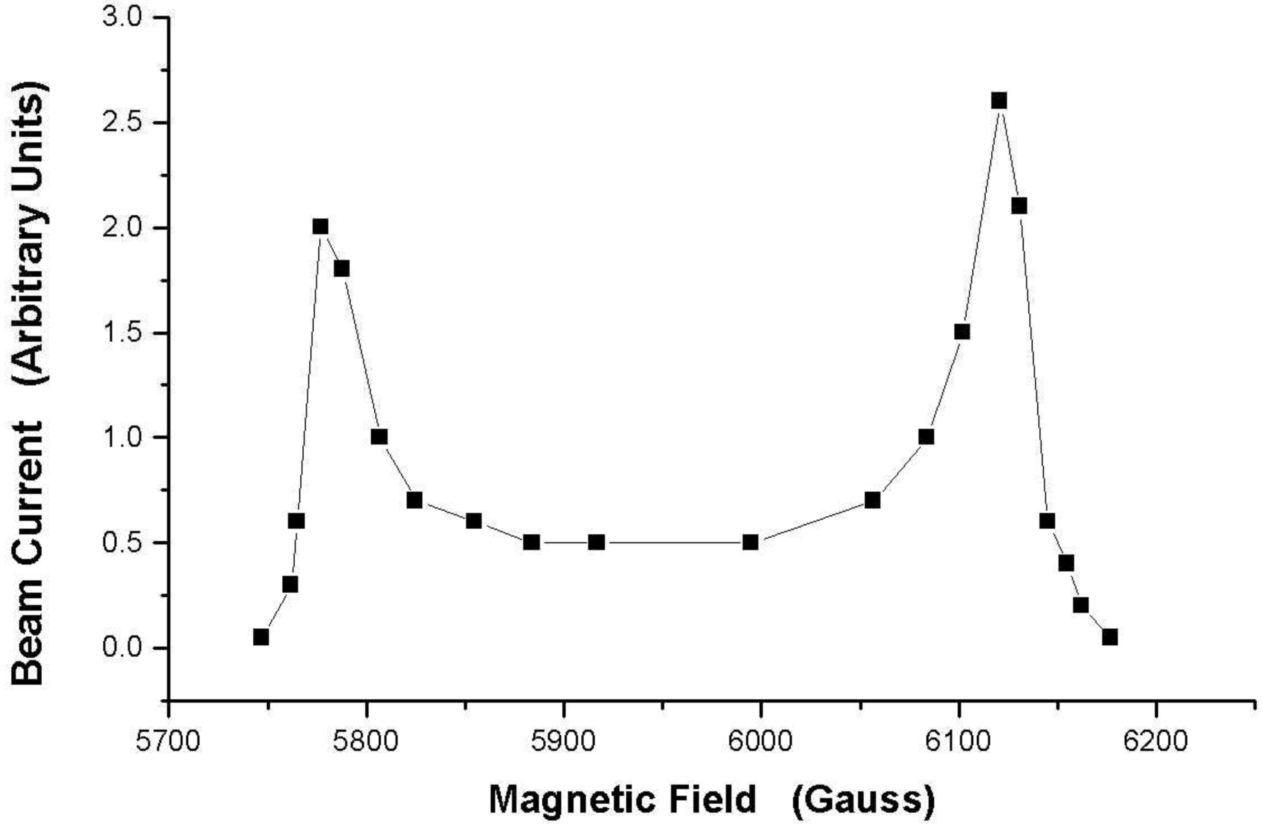
Energy Spectrum of Protons After QWR

- Input energy

  6.8 MeV
- RF power

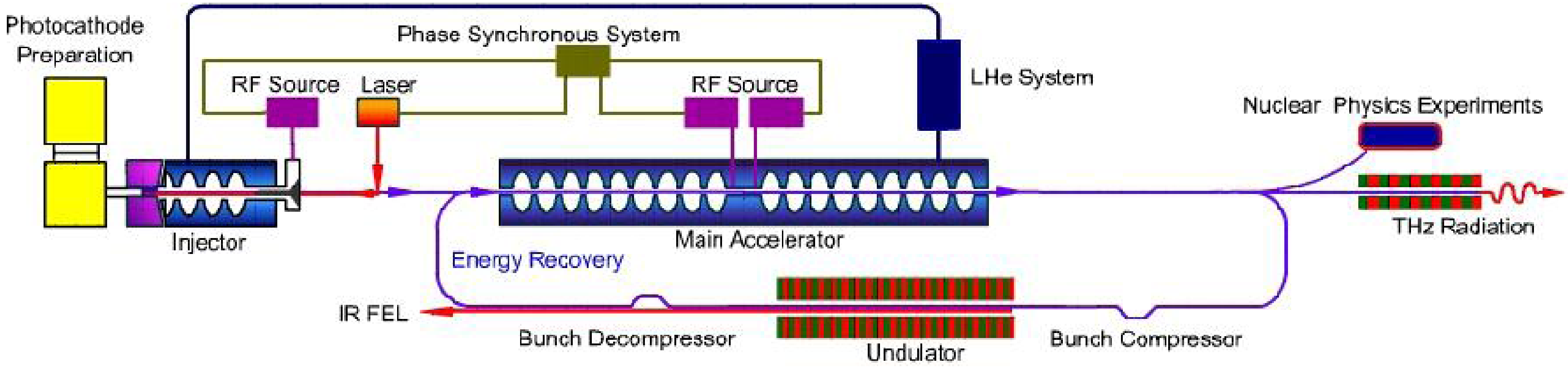
  6 Watts
- Energy gain

  500 keV
- E_{acc} ~3MV/m



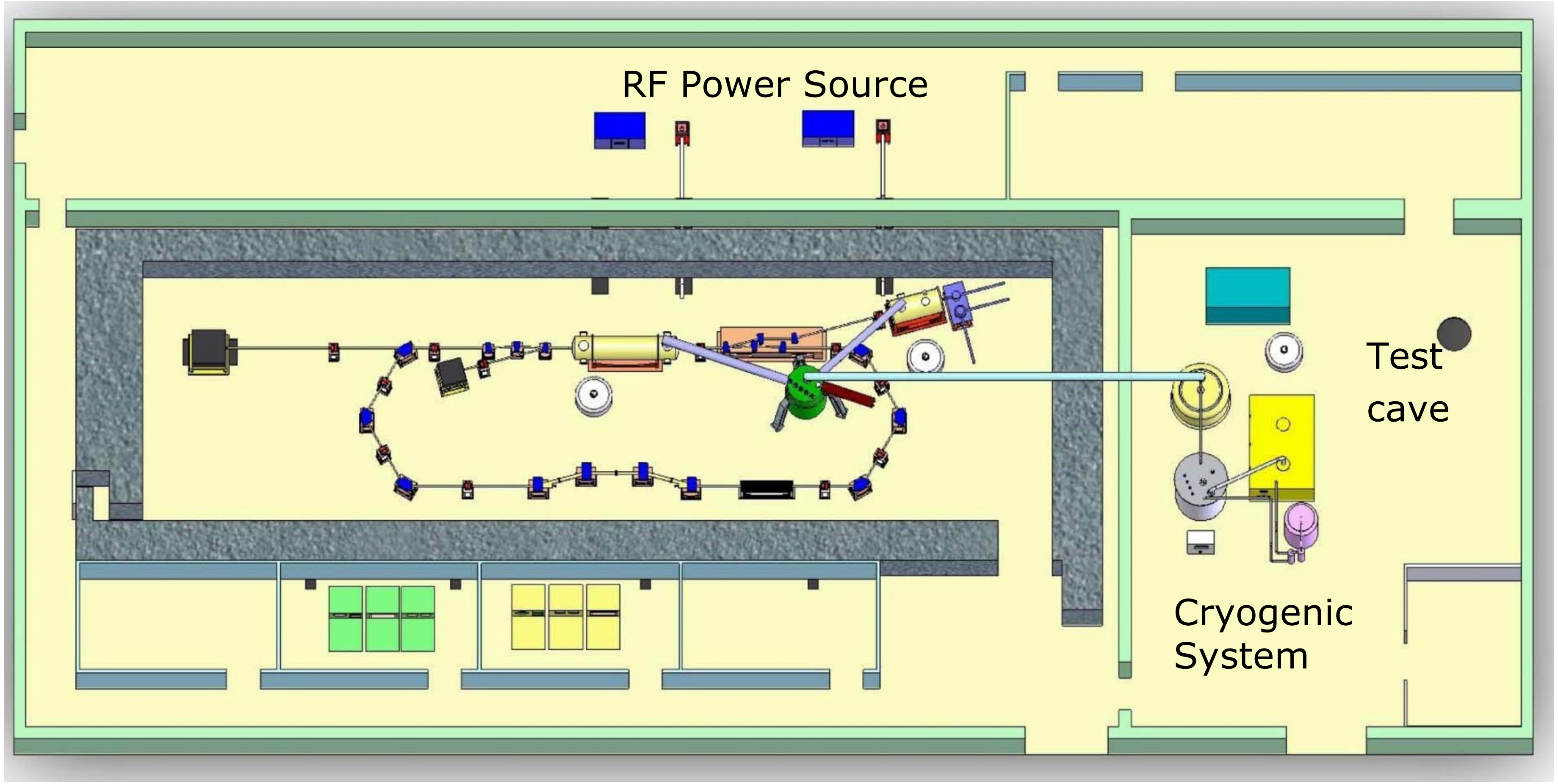
II. Progress on SRF Accelerator based FEL Facility at PKU

PKU Superconducting Accelerator Based FEL Facility proposed in 2001

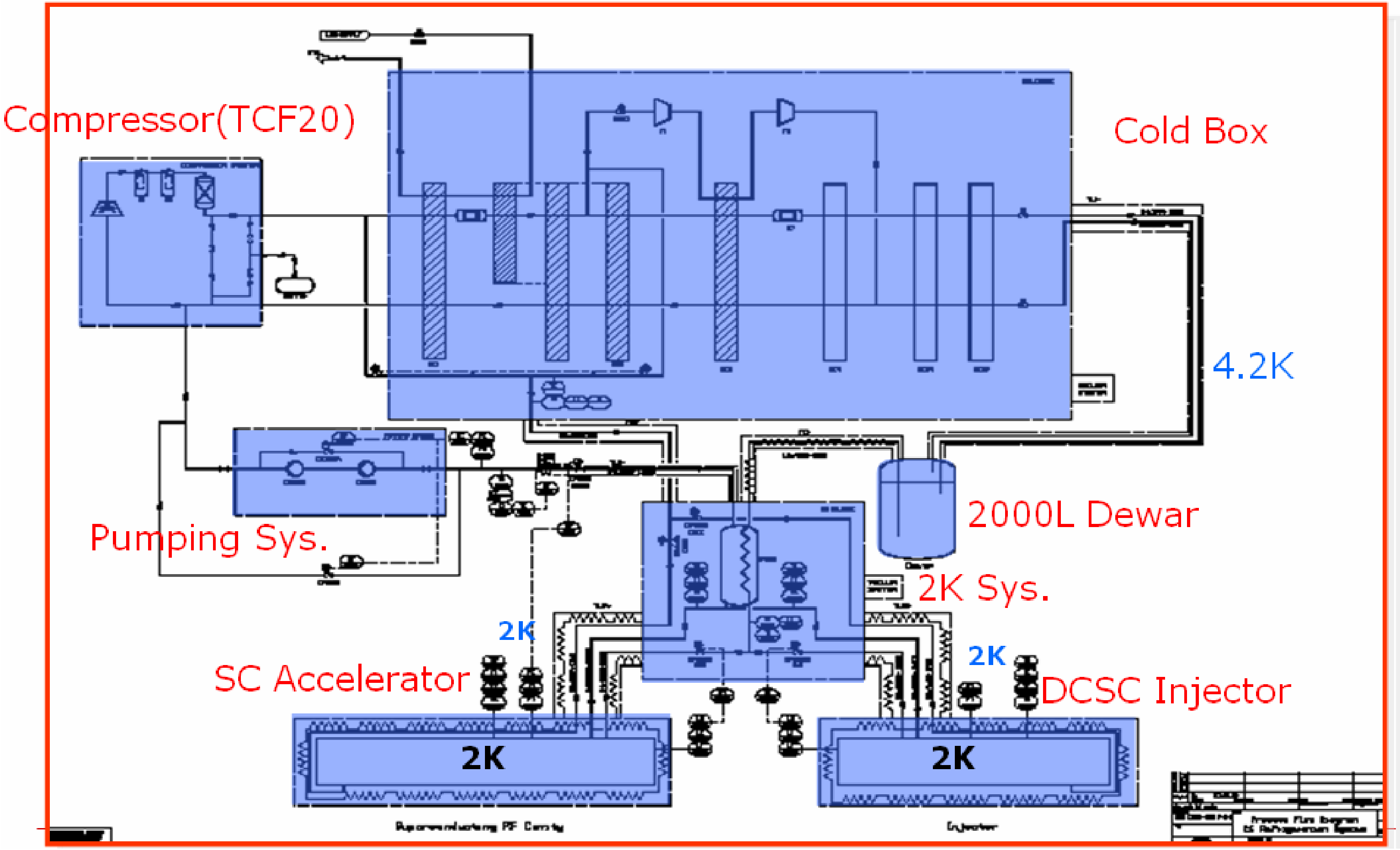


- Laser driven DC-SC injector
- Main accelerator cryomodule
- Bunch compressors and undulators

Planned PKU-ERL-FEL Laboratory

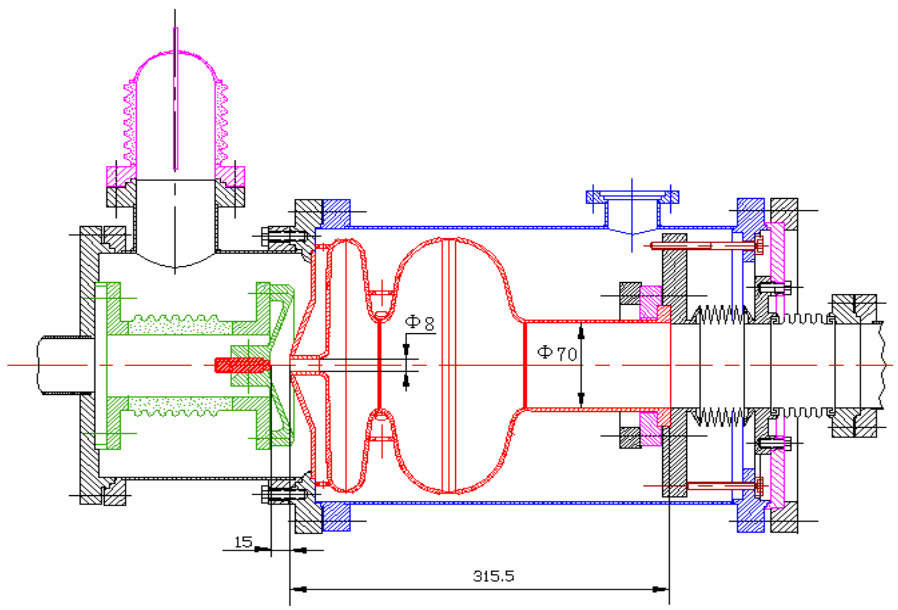


The cryogenic system for 2k



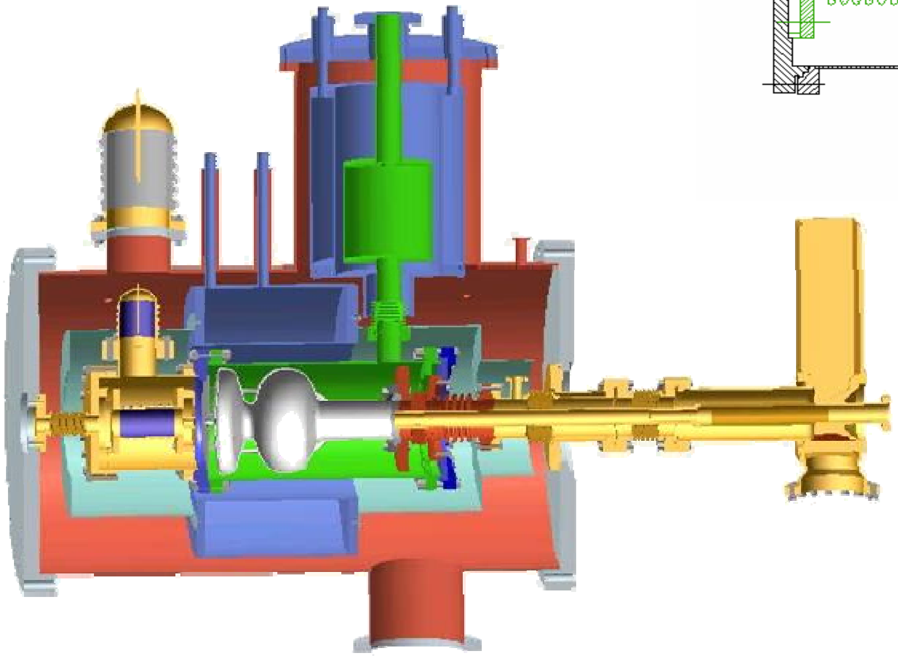
Productivity of Liquid He 122 l/hr

Laser Driven DC-SC Injector



Core Elements

Cryomodule



Numerical Simulations of DC-SC Injector

Initial conditions			Simulation results	
Electron bunch	Radius	3.0 mm	Anode inclination	65°
	Length	10 ps	Synchronous phase	-50°
	Charge	60 pC	Energy	2.43 MeV
	Emittance	0 mm-rad	Radius	2.8 mm
SC cavity	Average gradient	15 MV/m	$\Delta E_k/E_k$ (rms)	2.63%
Pierce gun	Distance between cathode & anode	15 mm	Bunch Length	7.8 ps
			ε_x (90%, n)	8.249 πmm-mrad
	Cathode voltage	-70 kV	ε_y (90%, n)	8.832 πmm-mrad
	Anode voltage	0 kV	ε_z (90%, n)	55.223 keV-Deg

1+1/2-Cell Cavity

Nb cavity, RRR>250.   Flanges, Alloy of Nb and Ti.

Test Bench of DC-SC Photoinjector

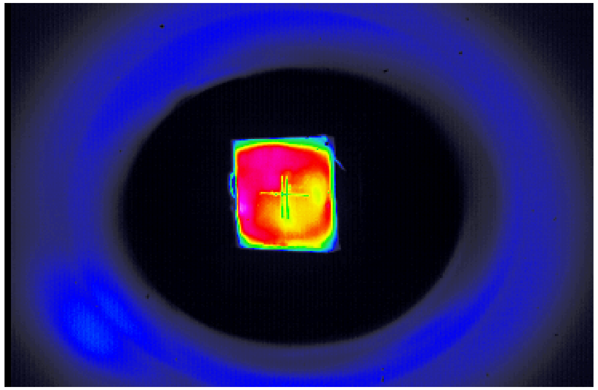
Up: 4.5KW Solid State Power Amplifier

Left: Electron Beam Diagnostic System

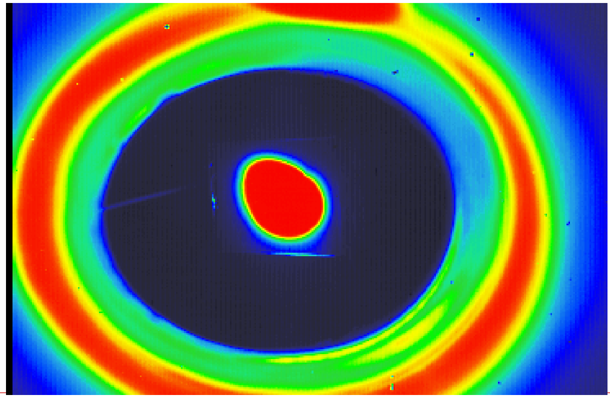
Photo-cathode Preparation Chamber with magnetic carriage for Cs_2Te and Cs_3Sb Photo-cathode

Beam loading Test at 4.2K (Aug. 2004)

- Progress of DC Gun
  - Average I: 400μA @ 100mW laser power
  - Lifetime of Cs_2Te: 10 hours @ 100μA, CW
- Progress of RF SC Cavity (Static Test)
  - $Q_0 \sim 2\times10^8$ @ 4.2K, Eacc ~ 4MV/m
- Progress of DC-SC Injector (Beam Test)
  - Beam spot at target 2 m apart from cathode

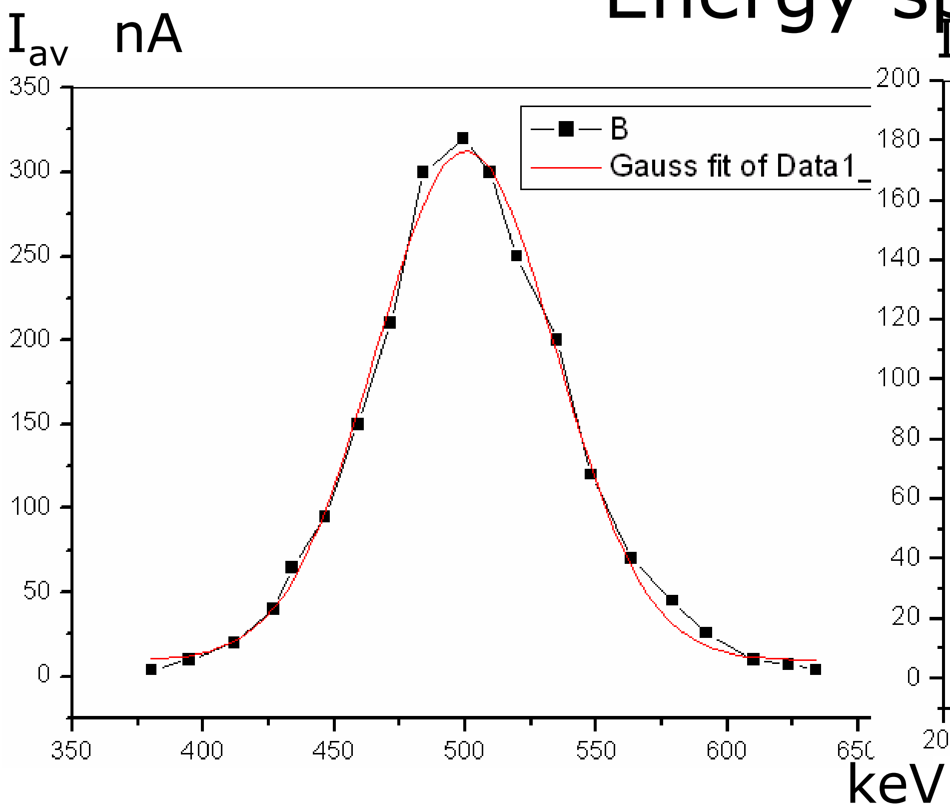


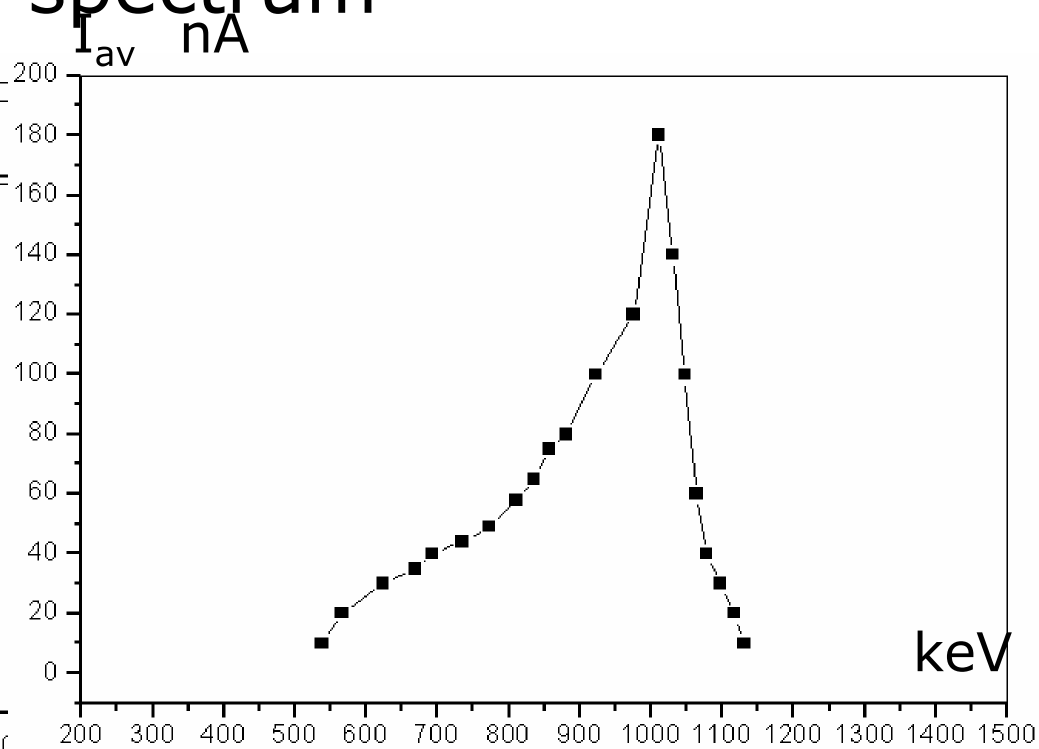
DC acceleration



DC＋SRF acceleration

Energy spectrum



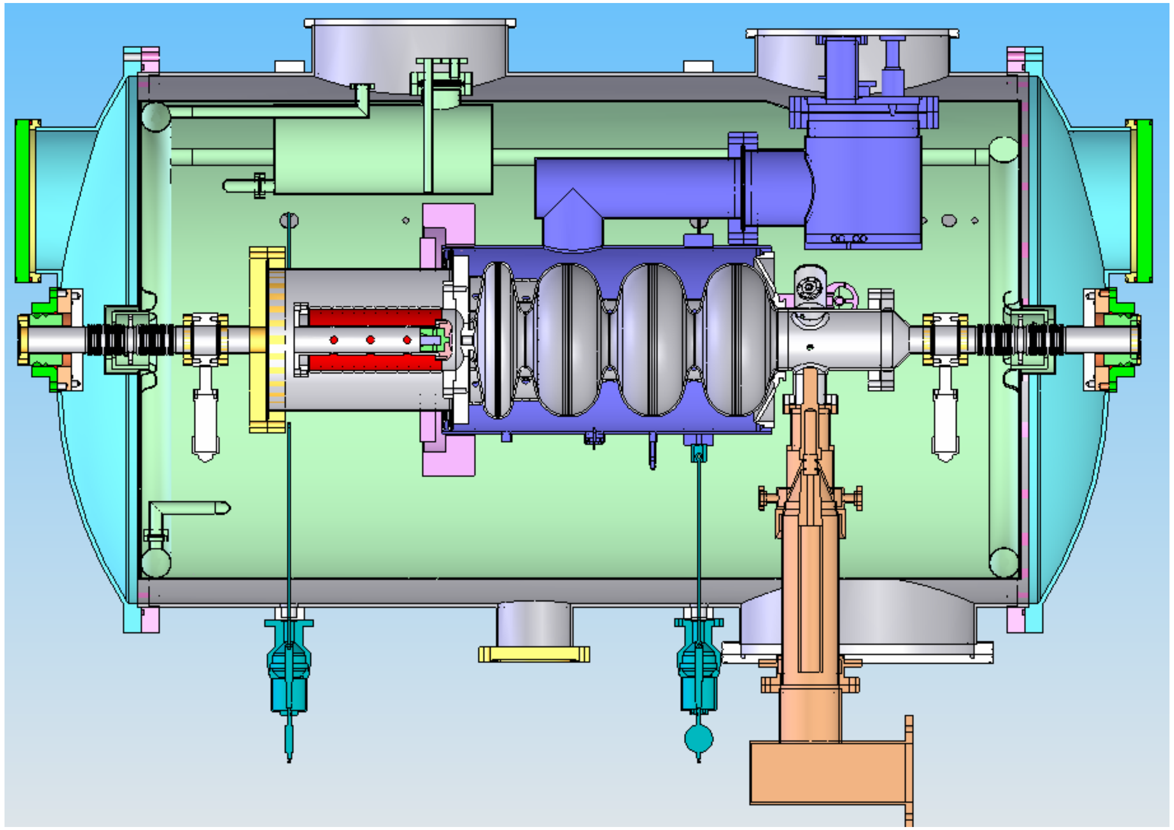


E_p =0.5MeV

ε_{rms}=5.4 mm.mrad

E_{pmax}=1.1 Mev

Upgrade of DC-SC Injector



DC pierce structure

3+1/2 cell cavity

LN shield

Main Coupler

HOM coupler

Suspending system

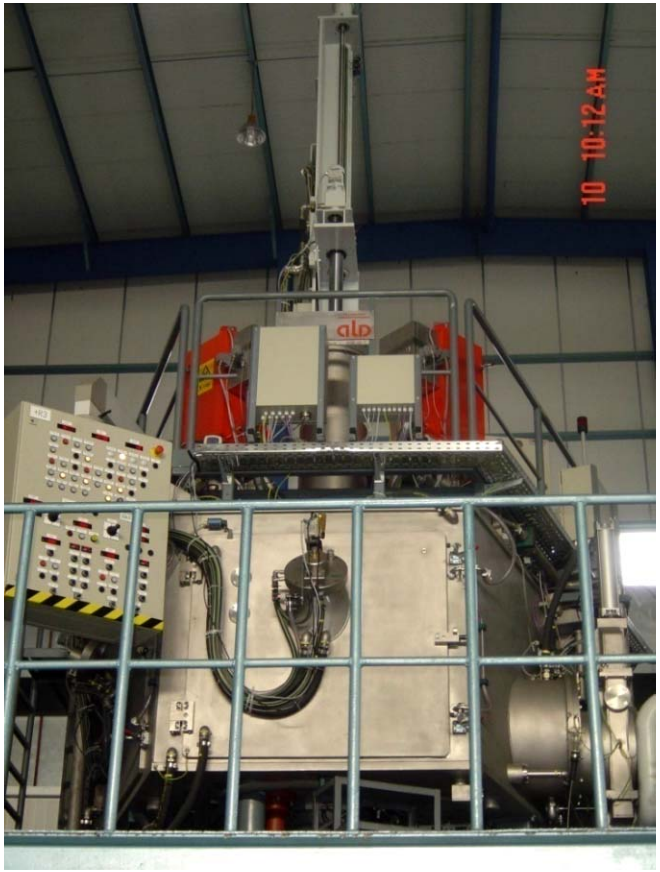
Parameters of 3+1/2 DC-SC Photoinjector

Frequency	1.3 GHz
Peak field at cathode	6 MV/m
Charge per bunch	100 pC
rms norm. emittance (at which energy?)	3.6 mm-mrad @ 5 MeV
Peak current	15 A
Average current	1~5 mA
Cathode Material and QE	Ce2Te, 1~5%
Laser wavelength	266 nm
Laser pulse shape	Gaussian

Collaboration for multi-cell cavity

- Peking University
- Ningxia OTIC
- Harbin Institute of Technology

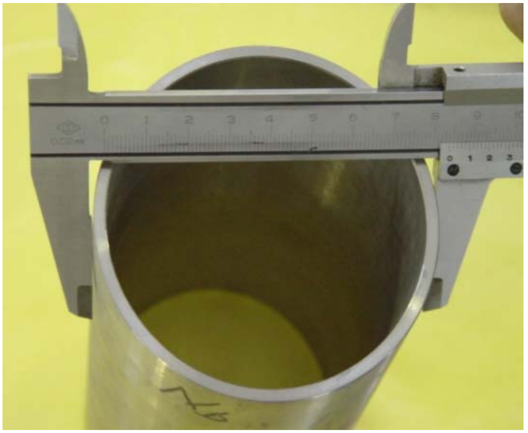
Development of Nb materials at Ningxia OTIC with support of PKU



600KW EB furnace

Nb Sheets

RRR > 350-400



Weldless
Nb Tube

EBW studies: collaboration between HIT (Harbin Institute of Technology) and PKU

1 EBW machine

2 sample welding

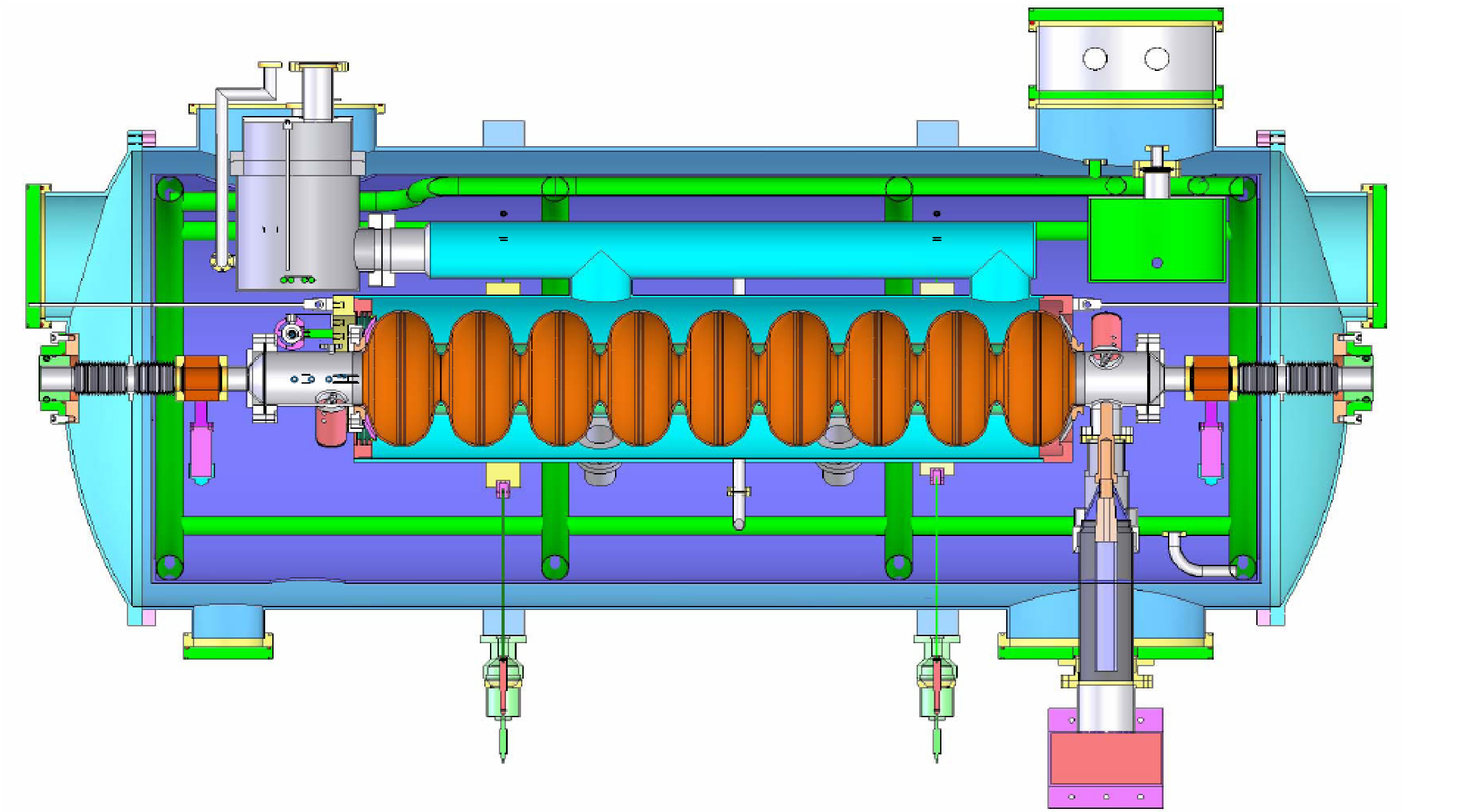
3 dumbbell welding

4 cavity welding

266×1.7(mm)

RRR measurement shows weld is qualified

Main cryomodule with a 9-cell cavity



Designed Performance of Main Accelerator

RF frequency (cavity at 2.0 K)	1.3 GHz
Accelerating voltage	17 MV/m guaranteed, goal is $\geqslant$ 20 MV/m
Q_0 @20 MV/m	1×10^{10}
Electron Beam Peak Current	20~50 A
Bunch Charge	About 20~50 pC
Electron Beam Average Current	1.6~4.0 mA
External Q of Power Coupler	$2\times10^{6}\sim1\times10^{7}$
Cryogenic losses (stand-by)	12W at 2K

Working plan for multi-cell cavity

- 9-cell copper cavity
  - Qualification of dies of deep drawing
  - Cups trimming technology
  - Test of EBW tools
  - Cavity measurement and pre-tuning
- 5 cell Nb cavity
  - Modification of EBW tools if needed
  - EBW technology of multi-cell Nb cavity
  - BCP polishing, HPR, etc.
- 9-cell Nb cavity
  - EBW technology of 9-cell Nb cavity
  - BCP polishing, HPR, etc.

Deep drawing of half cells

EB welding of dumbbells for 5-cell cavity

Dumbbells for 5-cell cavity

5-cell Nb cavity

Post Processing of cups and dumbbells

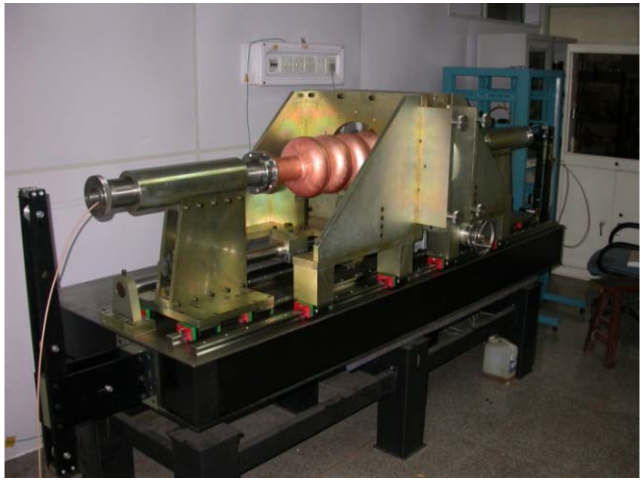
- BCP treatment of cups and dumbbells before welding
- Ultra pure HP water rinsing

Clean room

Ultra pure HP water system

RF measurement and Tuning

for half cell

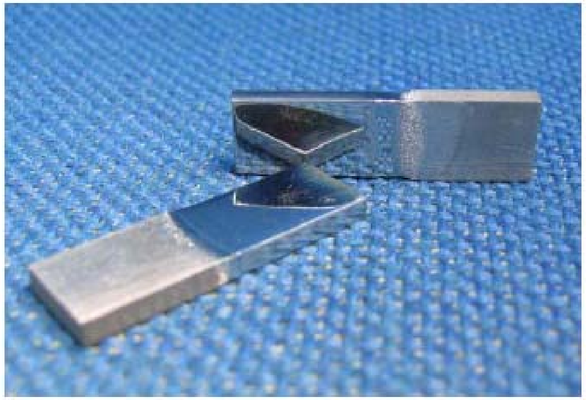


for dumbbell

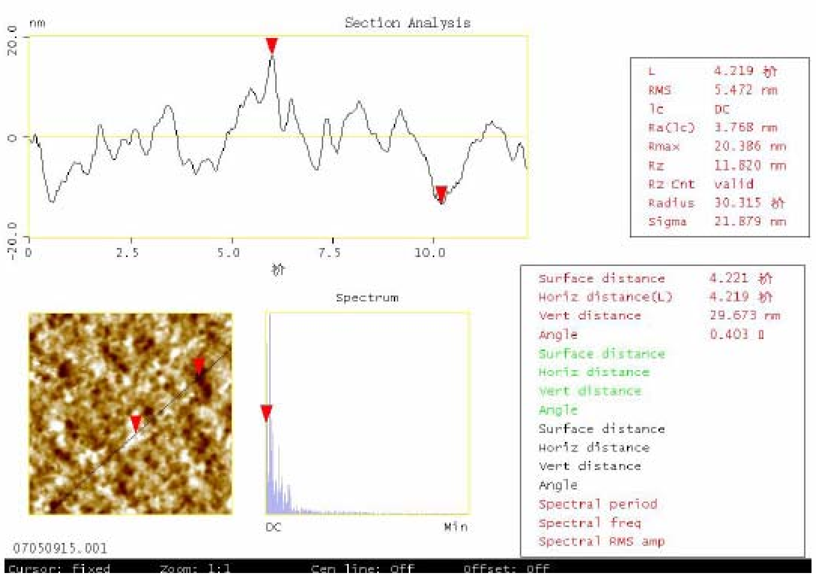
Tuning system of multi-cell cavity

Electrical Polishing (EP) Studies

The electrolyte of EP is consisted of hydrofluoric, sulfuric and lactic acids.



EP of small samples

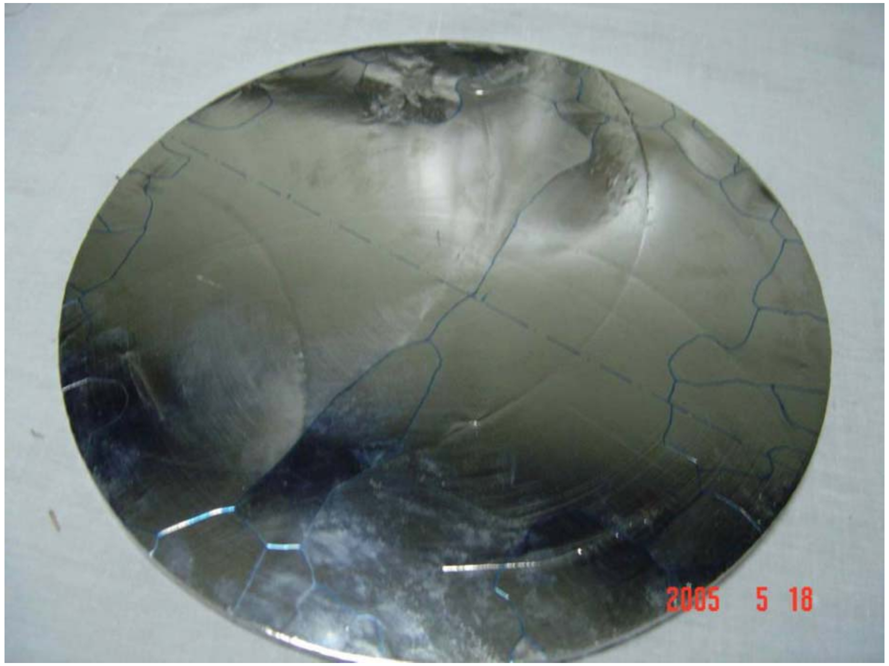


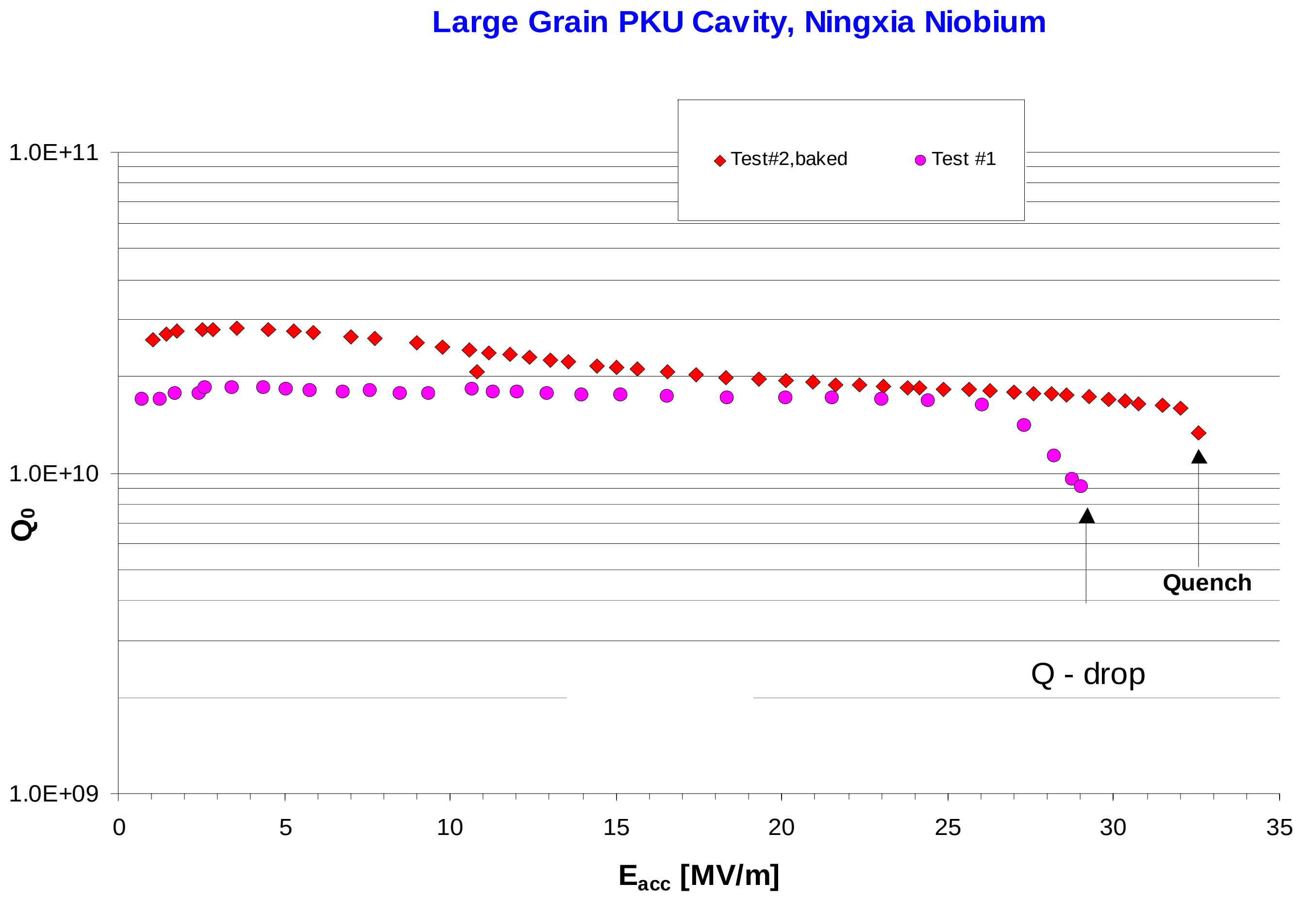
EP sample surface analysis by AFM, Ra<4nm

EP of dumbbell

- Development of SRF Cavities with Large Grain Nb Sheets

Development of single cell cavity with large grain Nb since 2005



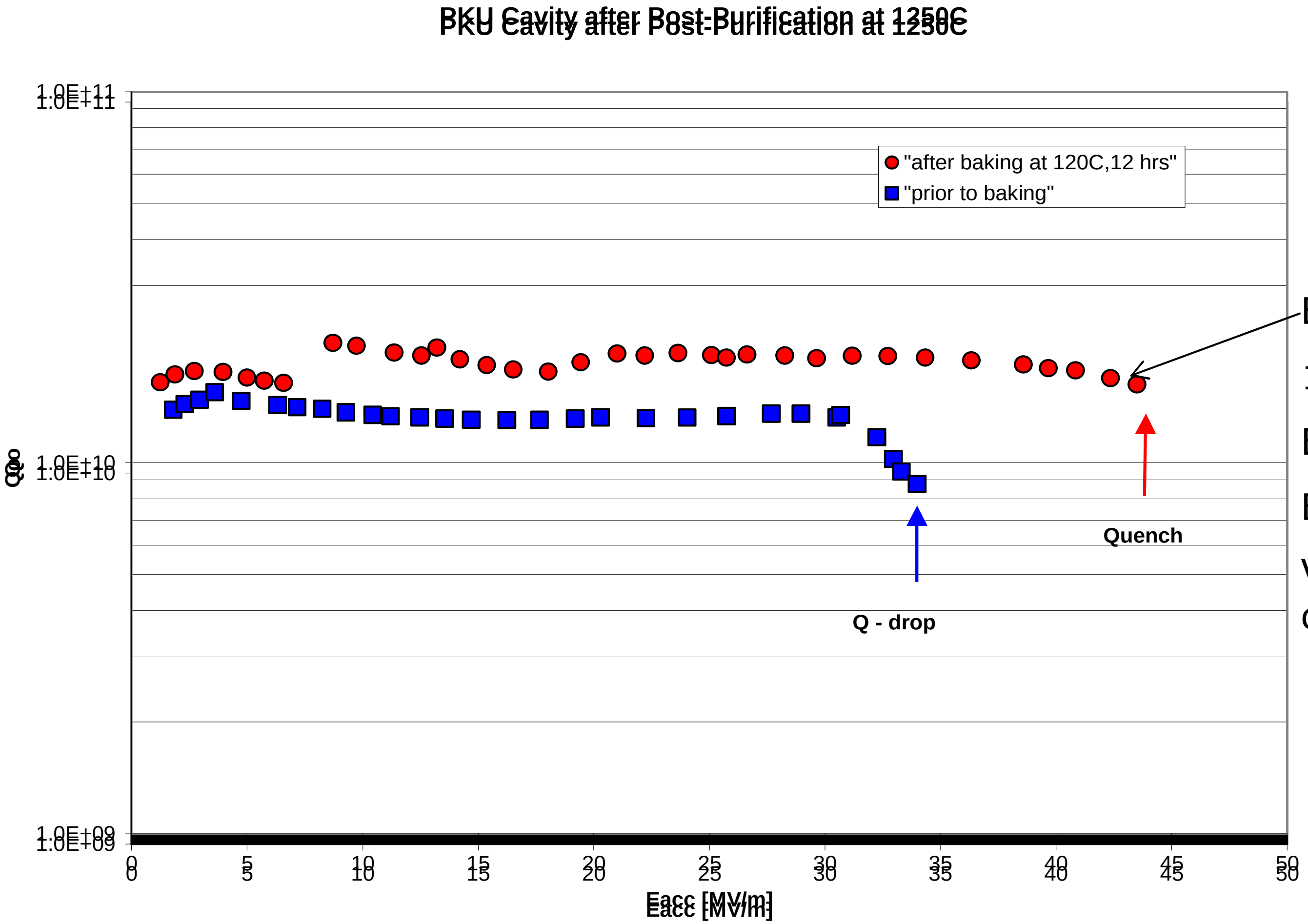


Result of first cryogenic tests

Vertical tests of the single cell large grain Nb cavity

Test #	BCP[μm]	HPR	Gasket	Eacc[MV/m]	Bpeak[mT]	Q[Bpeak]	Baking
1		R&D	AlMg	29	124 [QD]	9×10^{9}	
1a				32.5	139 [Q]	1.4×10^{10}	12 hrs
2	57	R&D	Indium	~ 8 (MP)		9×10^{9}	
3		R&D	Indium	~ 15 (FE)		6.4×10^{9}	
4	41	Prod.	AlMg	~ 11 (FE)		6×10^{9}	
5	24	R&D	AlMg	34	145 [QD]	8.8×10^{9}	
5a		Prod.	AlMg	**43.5**	**183**	$\mathbf{1.6 \times 10^{10}}$	12 hrs
6		Prod	AlMg	42.2	180	1.4×10^{10}	

Treatment and Test by Dr. P. Kneisel at Jlab



Baking 120 C

12 hrs

Eacc=43.5MV/m

Bp=185mT

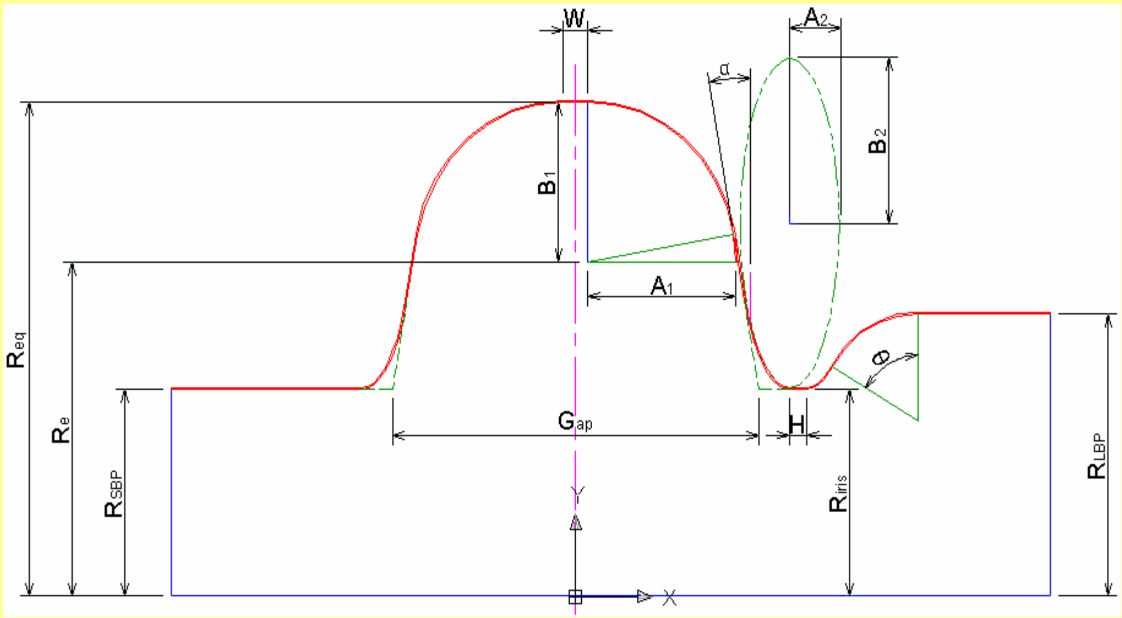
Very close to Bc of Nb at 2K

Treatment and Test by Dr. P. Kneisel at Jlab

III. SRF Activities at IHEP

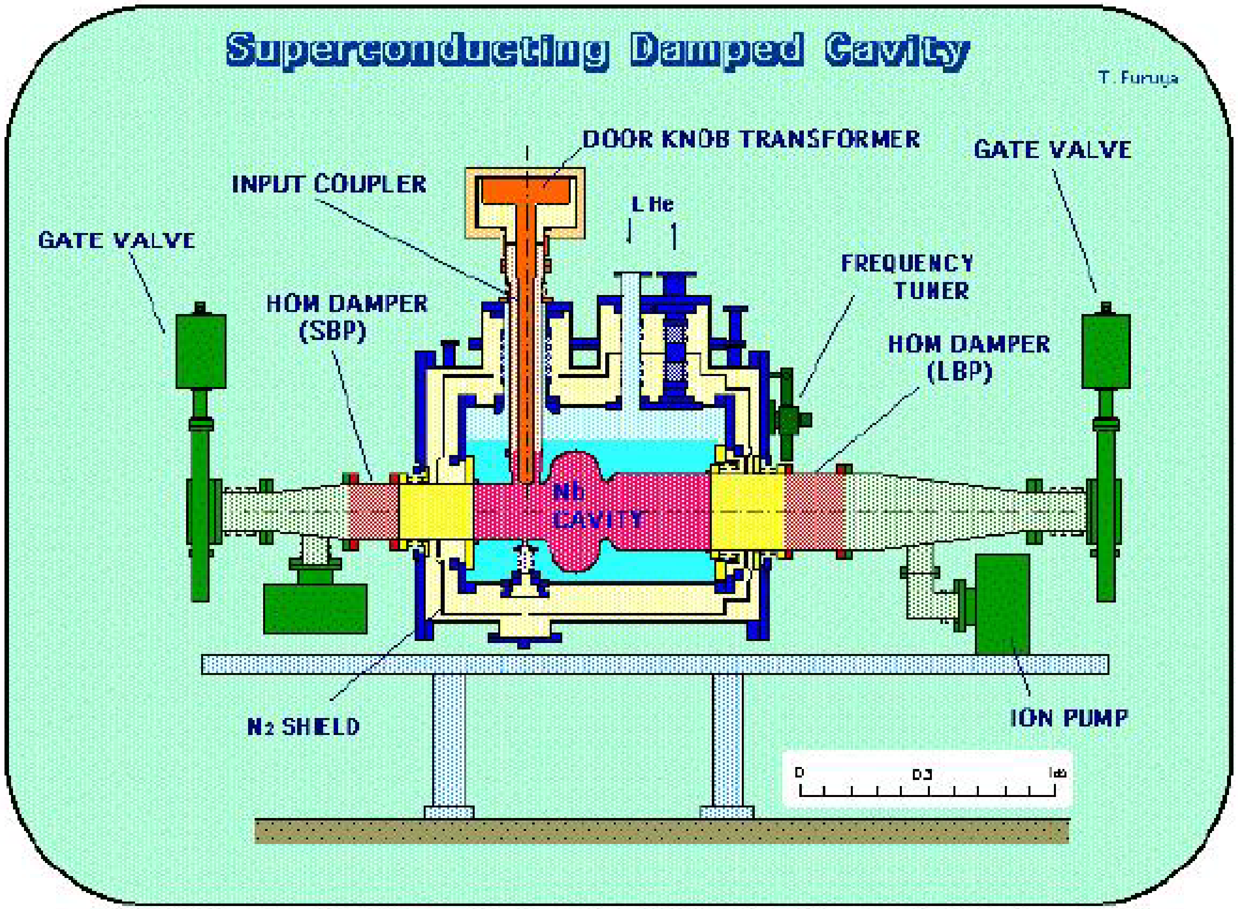
Joint efforts of IHEP & KEK

- Two 499.8MHz SC cavities of BEPCII were designed on the base of KEKB's cavity of 508.887 MHz. With the joint efforts, finally a minimum modification scheme was chosen:



- The cell equator length ***W*** is elongated from 13mm to 36.5mm to satisfy the only frequency change, beam duct radii of both side $\boldsymbol{R_{SBP}}$ **and** $\boldsymbol{R_{LB}}$ remained as it was.

❑ Final design of 500MHz SC cavity for BEPC II



Beam current:~1A

RF input: 380kW

HOM:10kW/cavity at 1.1A

Vertical assembly and test at KEK

1. A temperature mapping device

2. Prepare to vertical test

3. Cold-down test

4. Coupler high power test

5. Damper

6. Cell and cryostat assembly

	Specification	IHEP-#1	IHEP-#2 First test	IHEP #2 Second test
Measurement Date		'04/12/08	'04/12/27	'05/01/26
Frequency [MHz]		499.344255	499.176495	499.135505
Initial Q_0		3.42E+09	3.57E+09	3.35E+09
Vc max [MV]	**2.0**	**>3.59**	**2.05**	**2.90**
Field limitation		not limited	Thermal	Thermal
Q_0 at 2MV	**1.0E+09**	**1.10E+09**	**0.67E+09**	**0.88E+09**
Q_0 at 10 MV/m		1.59E+09	Not reach	1.20E+09
Qext (pickup port)		1.15E+11	1.36E+11	1.09E+11
Qext (transmitted port)		Failure for poor cable connection	3.12E+11	2.94E+11

Vertical test results at KEK--- summarized by Prof. T. Furuya

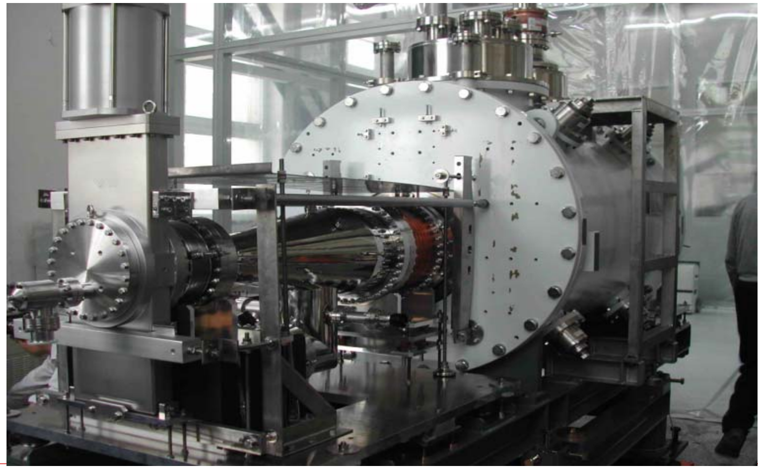
Final assembly and horizontal test in IHEP

1. Assemble the damper with the beam taper

2. Mount the damper on the cryostat

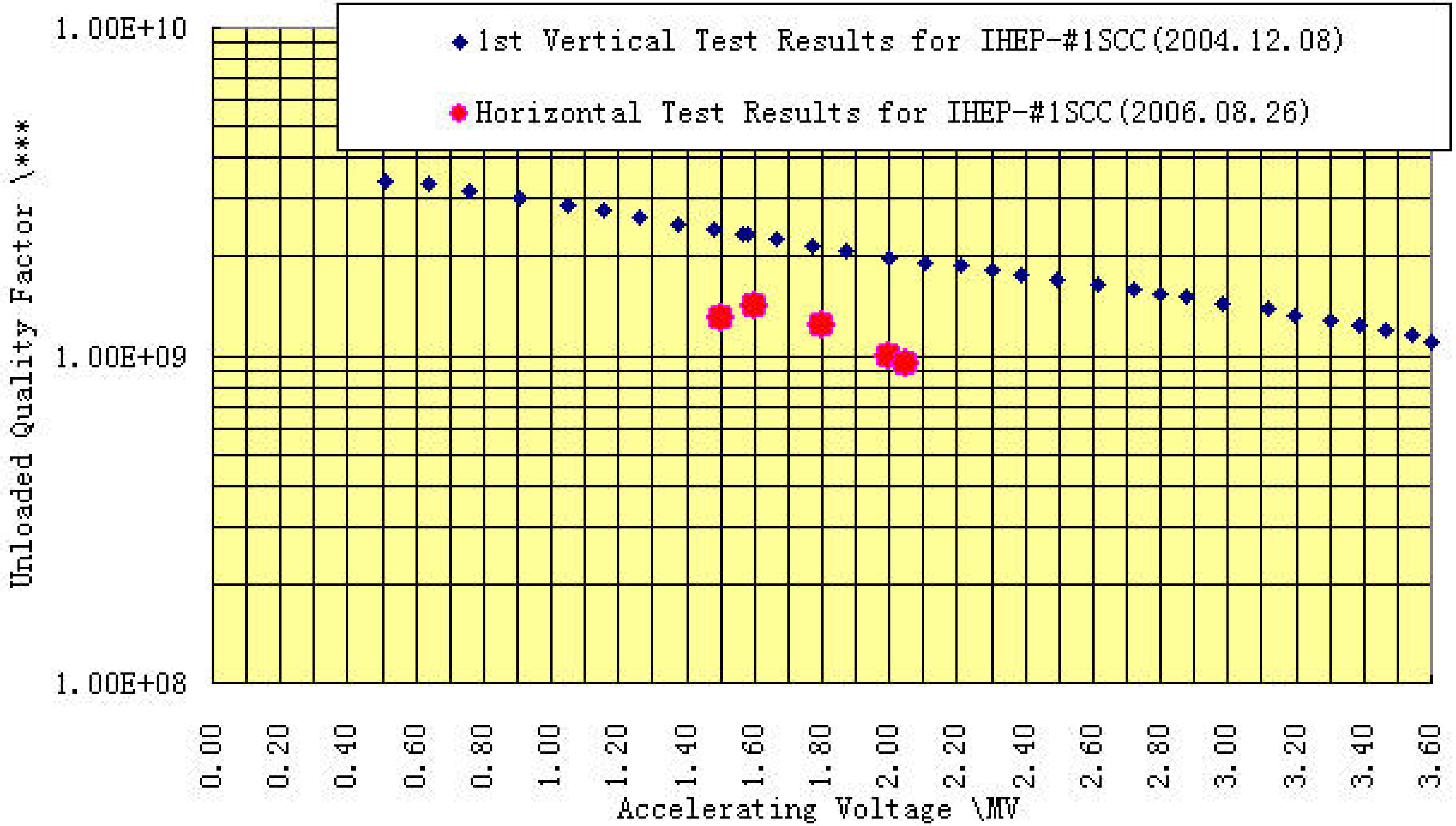
3. Mount the coupler on the cryostat

4. Install the doorknob on the coupler

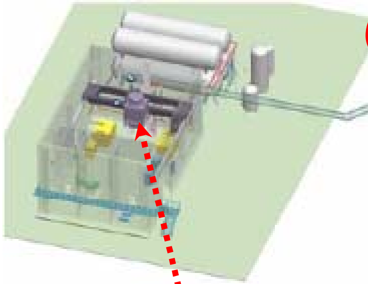


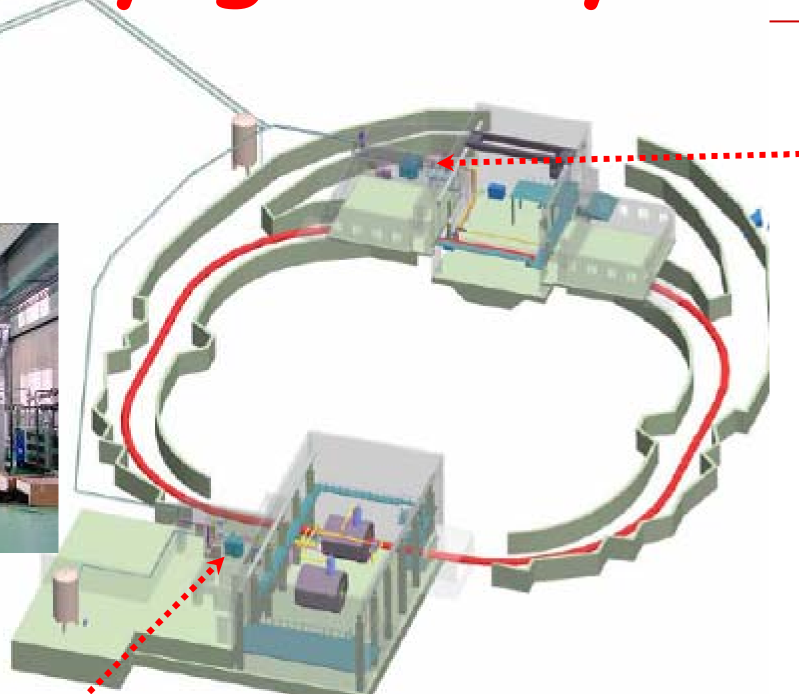
5. Ready for horizontal test at test stand

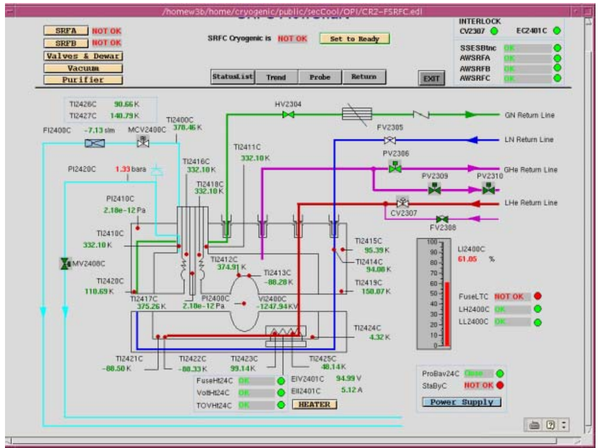
Performance of vertical and horizontal test of IHEP-#1SCC

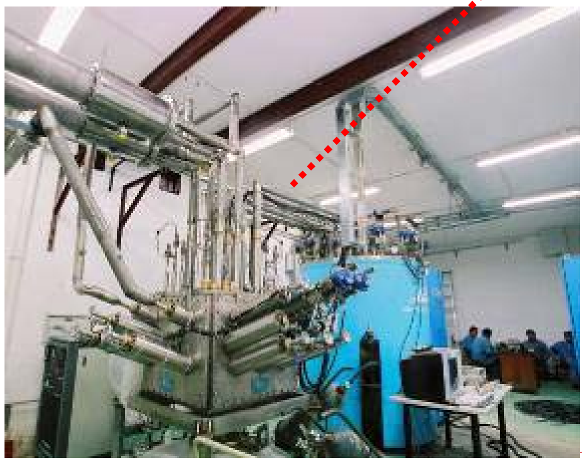


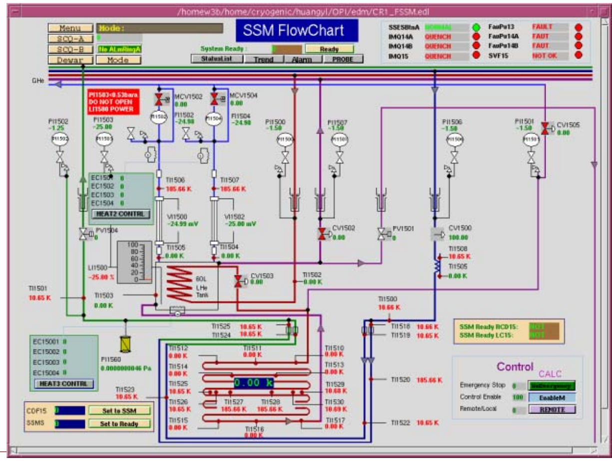
Cryogenic System

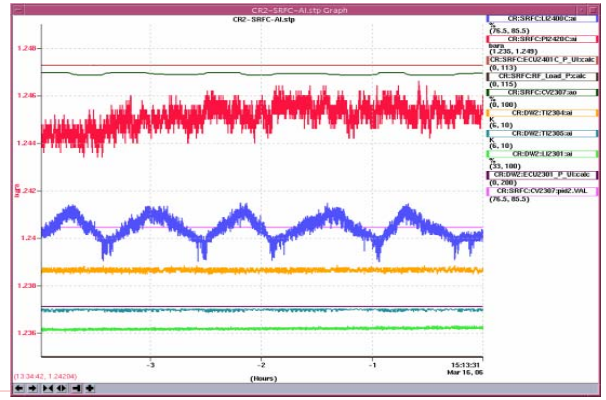












R&D on SC Cavities in IHEP

Clean assembling and rinsing room

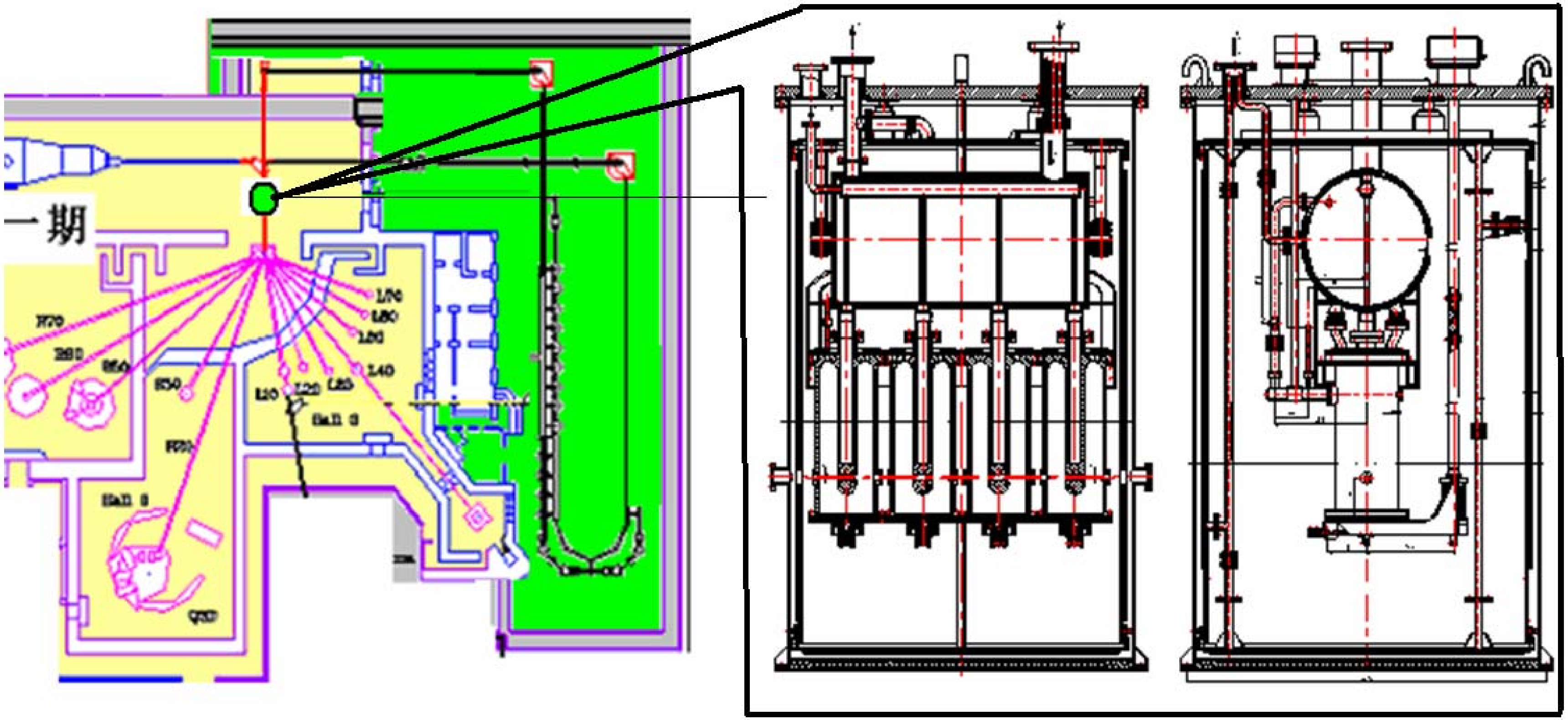
SRF Experiment building
With 230 m^2 user's area

1.3 GHz Cryostat & Test Frame, IHEP

Half cell after trimming

R&D on 1.3 GHz single cell cavity for CSNS

IV. Progress of Nb-Cu QWR at CIAE

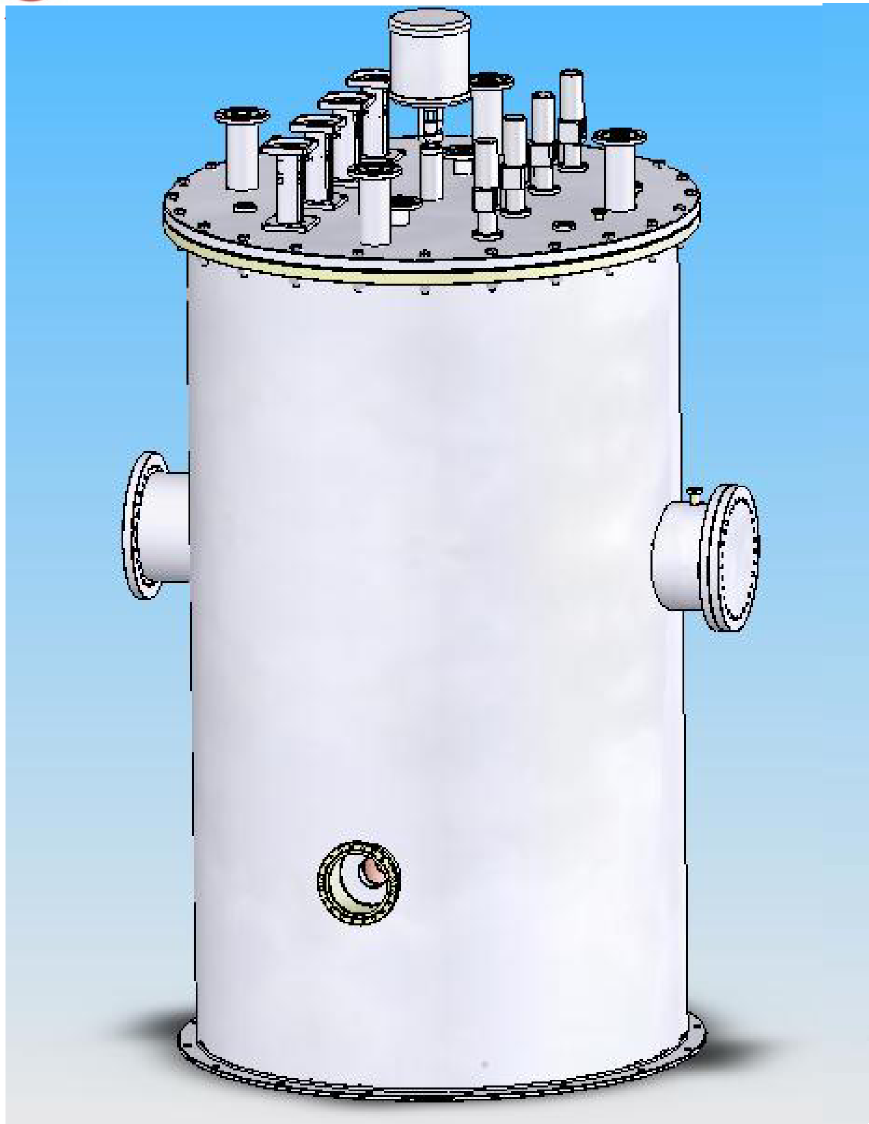


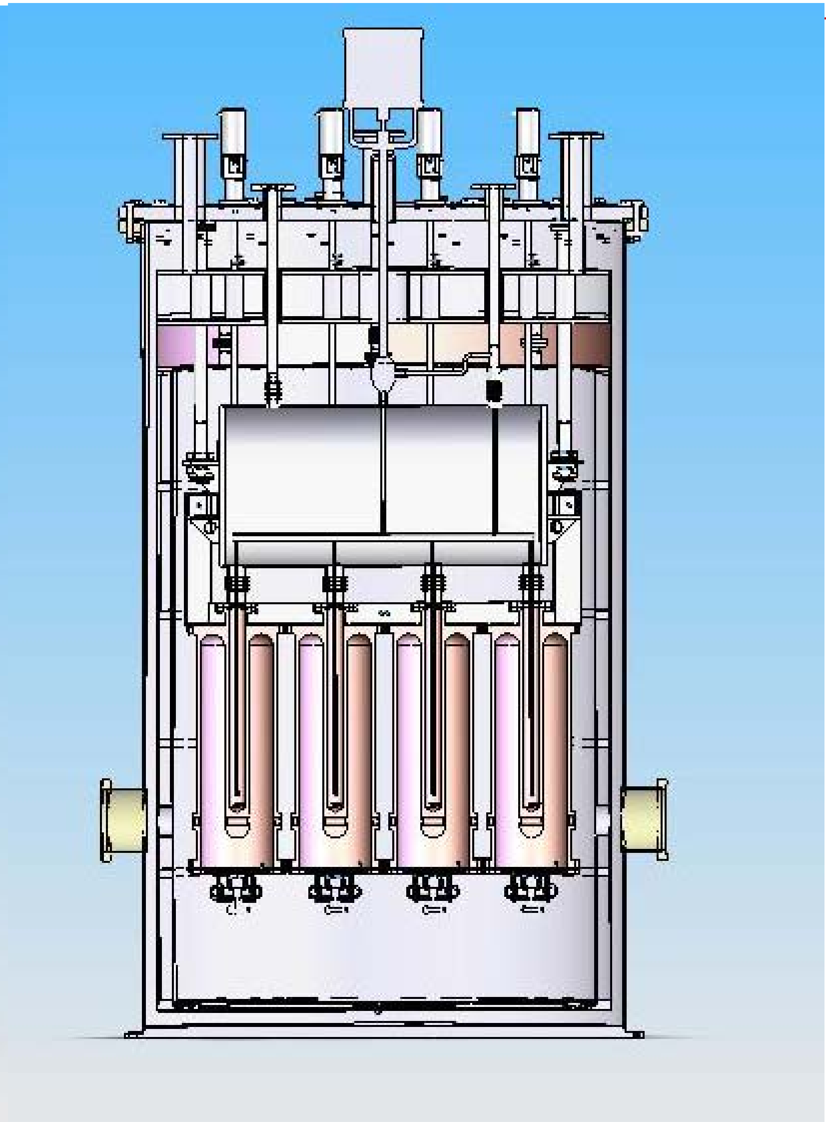
Superconducting QWR cryogenic module developed at CIAE for Beijing Radioactive Ion Beam Facility (50 M$)

The CIAE Booster Linac

- The design goal of the booster is to have an energy gain of 2 MeV/q
- The cryogenic module consists of four cylindrical coaxial quarter wave resonators
- The diameter of the cryostat is 1.2meter
- The QWR frequency for β =0.10 is 150.4 MHz with a geometry factor of 26.7 Ω.

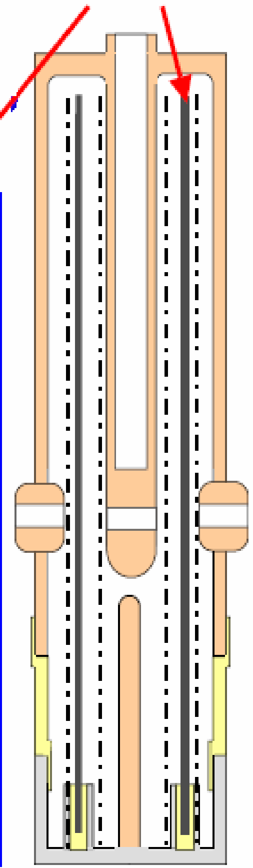
IHIP, Peking University





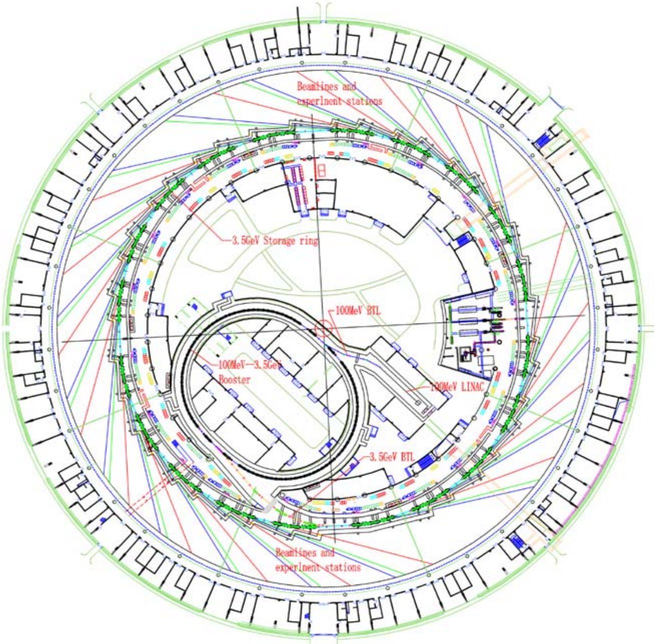
Nb-Cu Sputtering Facility under construction

- Sputtering Chamber
- Mechanical finishing
- Electro-polishing
- Chemical polishing
- HPWR processing
- Drying and storage

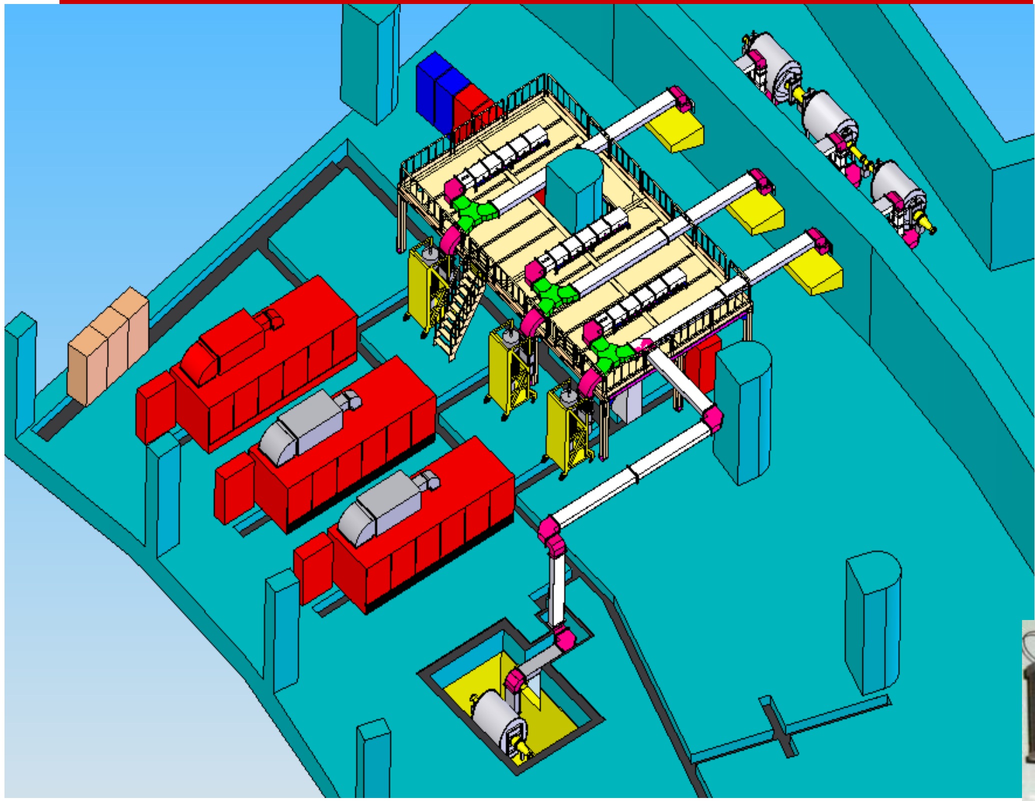


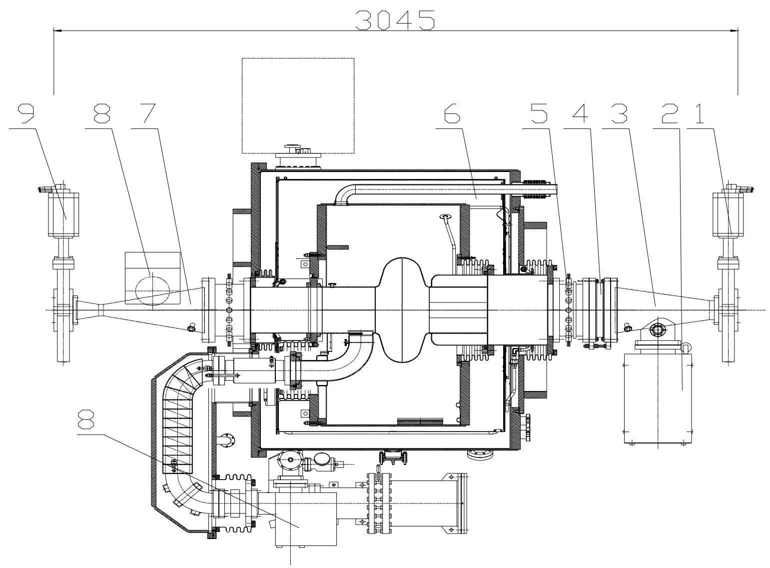
V SRF Project at SSRF
SIAP

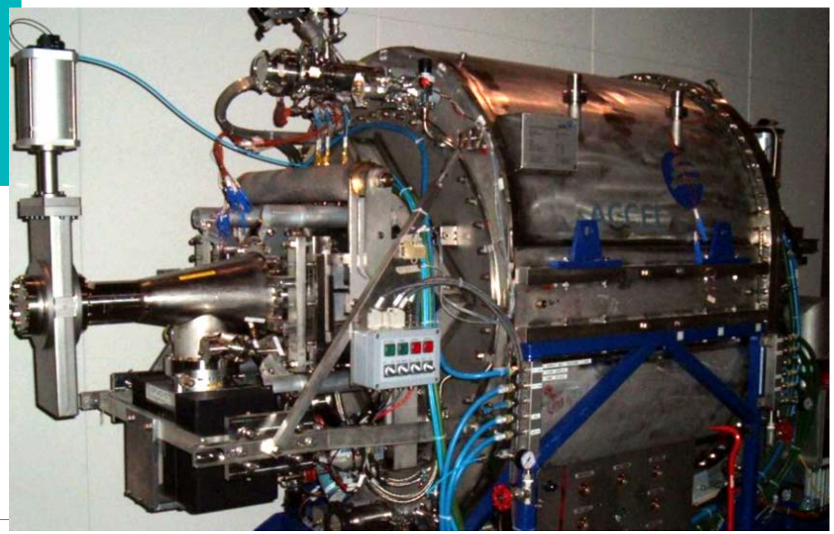
Layout of the SSRF Complex & Campus



- 150 MeV Electron Linac and 3.5GeV Booster & Storage Ring
- User operation scheduled on Spring 2009







The layout of cryomodules consisting of 3 CESR type cavities on the SSRF ring

The Main SSRF SRF Cavity System

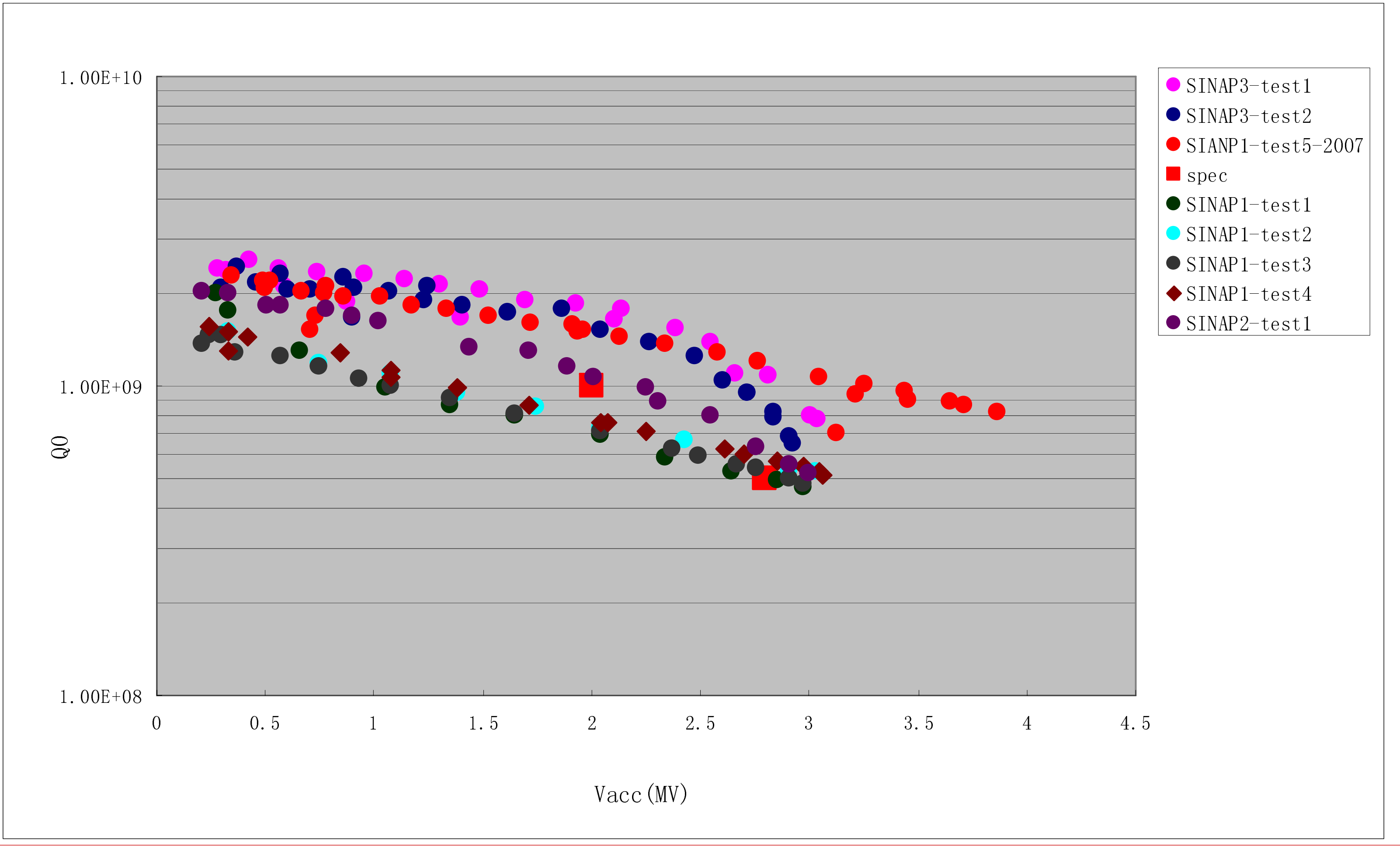
- RF Voltage > 4MV, Beam Power >600kW
- Stability: Amplitude <±1%, Phase <$\pm 1^0$

- Three single cell SRF cavities (CESR type/ACCEL)
- Three 310kW Klystron RF power amplifiers (THALES)
- One 650W Helium refrigerator (Air-Liquid)
- Digital LLRF system

Parameters of the SRF Module

Frequency	499.654 MHz
Tuning range	$\pm$200 kHz
Tuning resolution	10 Hz
Operating temperature	4.2 K
V_{acc}	>2.4 MV
Q_0 @2MV	1×10^9
Standby losses (RF off)	< 35 W
Dynamic heat load at 2MV	< 65W
Q_{ext} of input coupler	$1.8 \times 10^5 \pm 0.2 \times 10^5$
Power transferable to beam	>250 kW

Vertical test results



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The SSRF 3rd Harmonic Cavity System

- Manipulation of bunch length in storage ring;
  - Bunch lengthening for increasing Tousheck lifetime;
  - Bunch shortening;
- Suppression of beam instabilities
  - Providing Landau damping;
  - Suppressing longitudinal multi-bunch instability;

The SSRF 3rd Harmonic Cavity System

- The SSRF 3rd harmonic cavity
  - A CW passive SRF cavity system with frequency of 1498.962MHz ($3xf_{RF}$)
  - RF voltage about 1.8~2.0MV
  - A heavily HOMs damped cavity
- Cavity structure of the 3rd harmonic cavity
  - Cavity geometry optimization
  - 2- cell or multi-cell super structure
  - Beam pipe HOMs damper

- Single cell cavity Developing technology

- Copper and niobium cavities;

R&D of 3rd Harmonic Cavity

- Infrastructure
- Cavity processing lab
- RF cavity cold test setups;
- Vertical test setups;
- Refrigerator system

Conclusion

- SRF is well developed in China over last 20 years
- Great efforts have been made by PKU on SRF capability building in the starting stage
- A number of large projects like BEPCII, BRIBF, SSRF & CSNS involved in SRF in recent years
- International cooperation promotes the progress of SRF in China
- A growing phase of SRF is emerging in China

ACKNOWLEGEMENT

- Many thanks to Dr. Zhang Chuang, Dr. Wang Guang Wei & Dr. Lu Hui-hua of IHEP; Dr. Guan Xia Ling of CIAE and Dr. Zhao Zhen Tang of SIAP for their important contribution

- Many thanks to Prof. D. Proch, Prof. H. Padamsee, Dr. P. Kneisel, Dr. G. Neil, Dr. Saito and Dr. Furuya for their long lasting help and encouragement to our work from the very early days.

Thank you for your attention!