A 1.3 GHZ CRYOMUDULE WITH 2X9-CELL CAVITY FOR SETF AT PEKING UNIVERSITY

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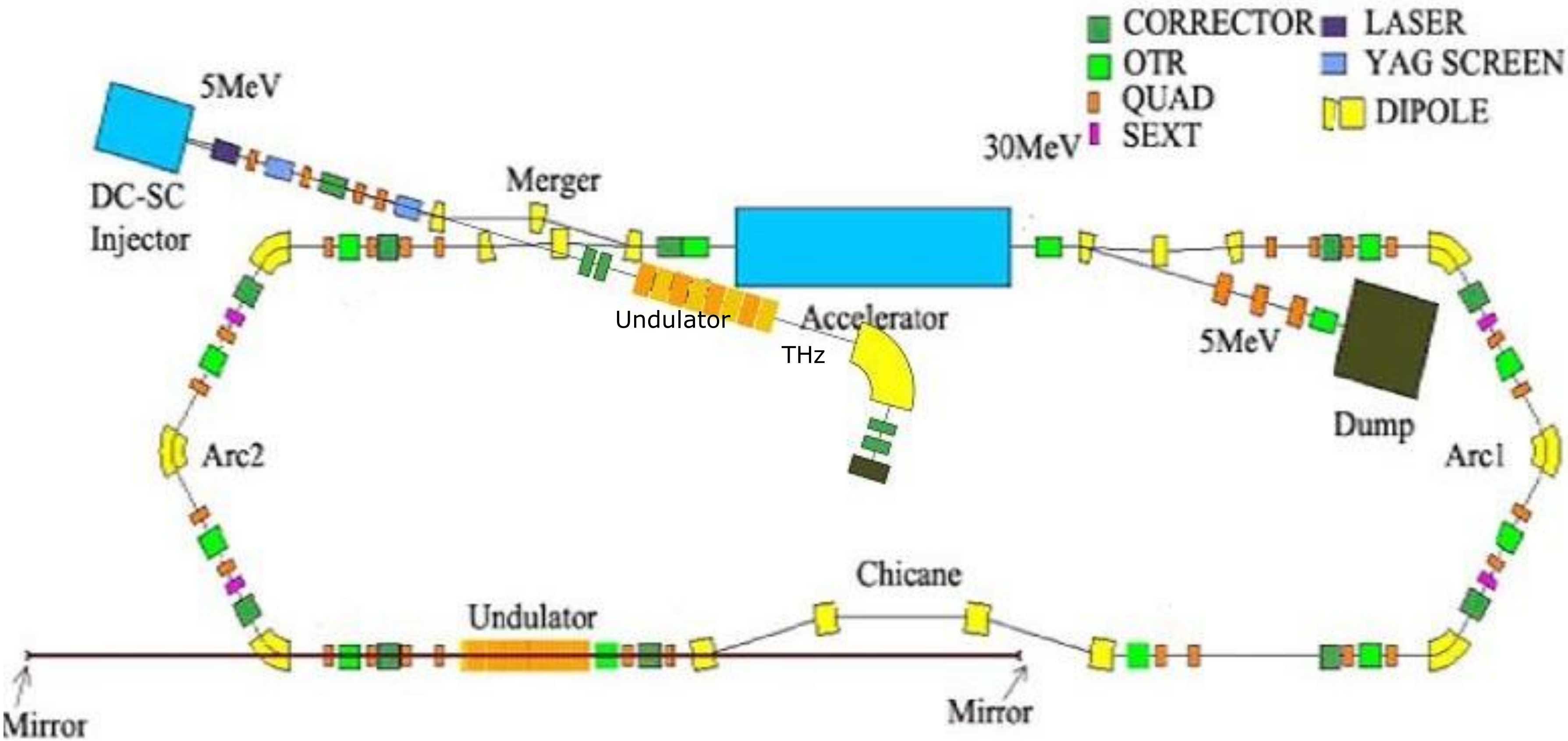
Outline

- SETF at Peking University
- Stable Operation of DC-SRF Photoinjector
- 2×9-cell Cavity Cryomodule
- Summary

Peking University Superconducting ERL Test Facility (PKU-SETF)



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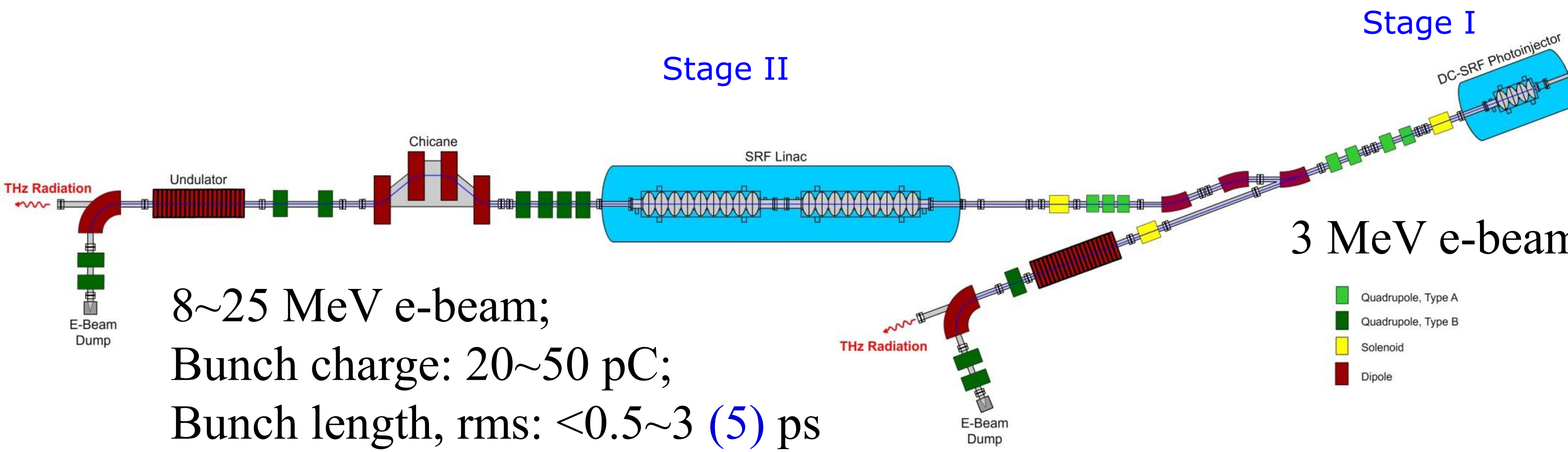


3 MeV e-beam

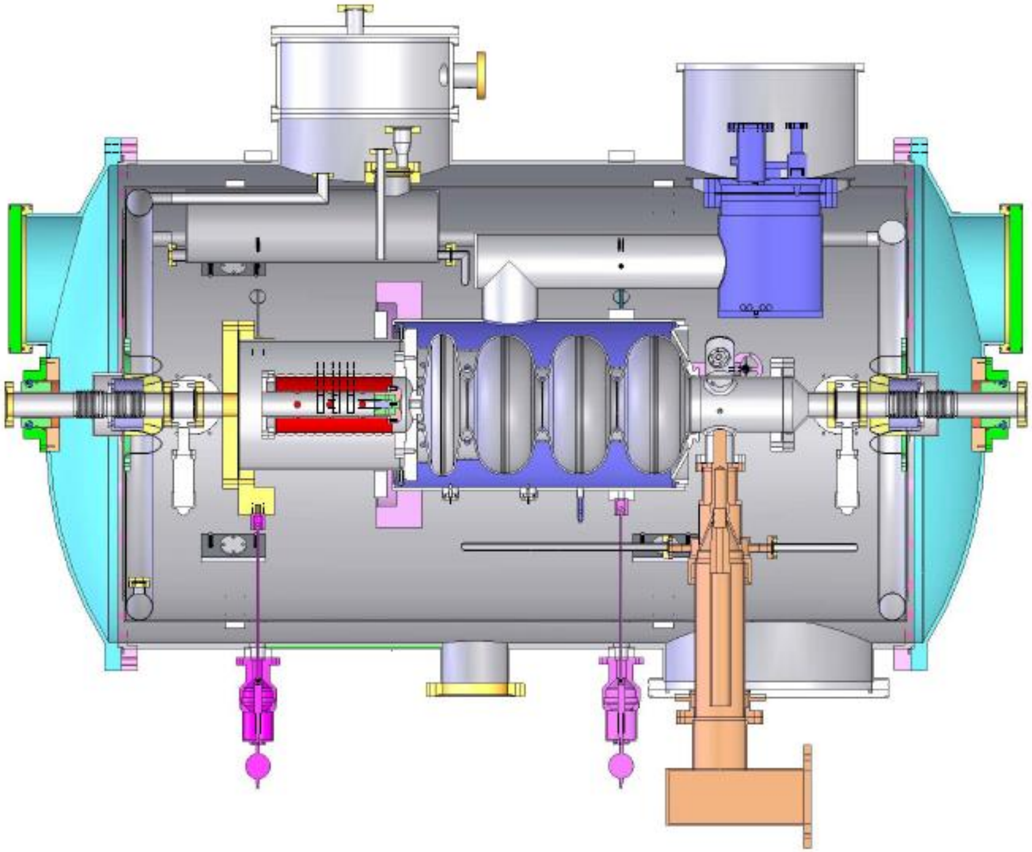
8~25 MeV e-beam;
Bunch charge: 20~50 pC;
Bunch length, rms: <0.5~3 (5) ps

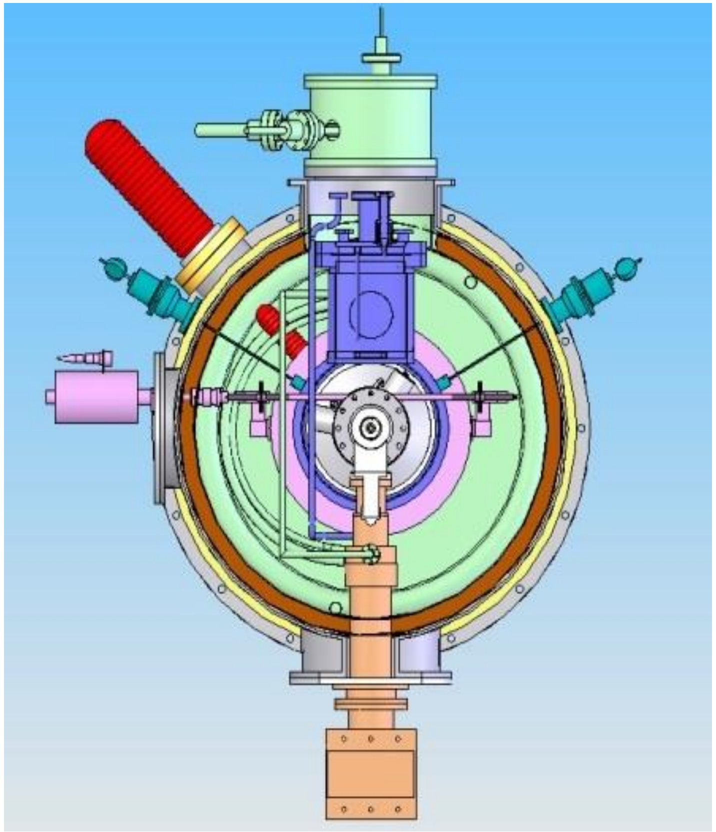
Stable Operation of DC-SRF Photoinjector

DC-SRF Photo-injector

- Developed by PKU SRF group
- Compatibility of normal conducting photocathode and SC cavity
- Compact structure
- Could be operated at CW mode
- Could handle high average current (1~10mA)
- High beam quality

3.5-cell Cavity DC-SRF Injector

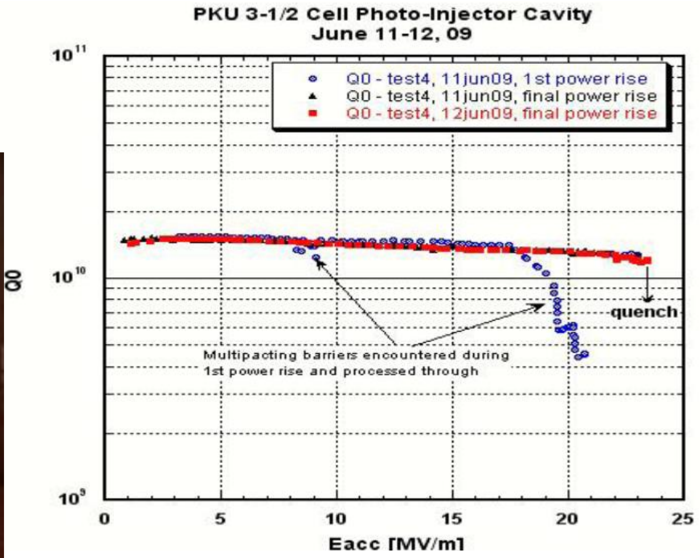




- 90 KV Pierce DC gun with Cs_2Te cathode matched with SRF cavity
- Operating at 2K with tuner and screened LN
- Providing 3-5 MeV superfast pulse beam with low emmittance

DC-SRF Photoinjector

- 3.5-cell large grain cavity has been used
- Vertical test at Jlab: 23.5 MV/m @ Q_0 >1E10
- Assembling and connected to 2K cryogenic system in 2010
- RF test experiments and preliminary beam test in 2011
- Upgrade of RF power supply, beam line since 2012
- Upgrade of drive laser since 2013
- Stable electron beam in 2014



On-line Cs_2Te Photocathode Preparation System

- Vacuum in deposition chamber has been improved to ~10^{-7} Pa with a sputtering ion pump (600L/s) and a SAES NEG pump (200L/s)

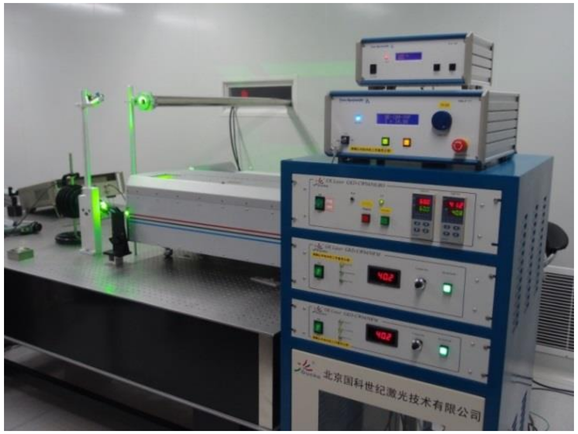
- The stainless steel plug polished mechanically, rinsed in ethanol and acetone ultrasonically, baked at 200°C for more than 10 hours to remove surface residual gases

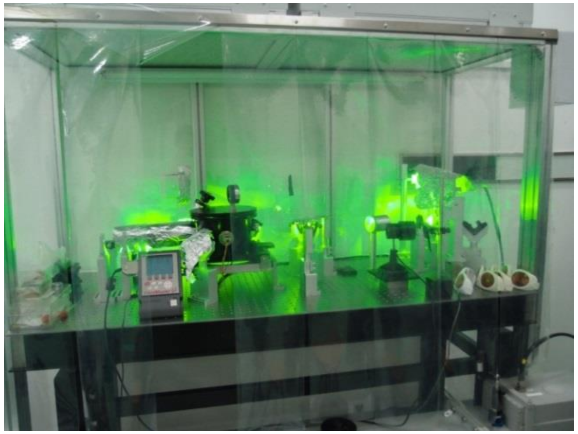
- 7.0 nm tellurium films are deposited and then activated with cesium.

- The photocurrent is monitored during the preparation process by illuminating the surface of the photocathode with a UV light

Drive Laser Upgrade

Seed: Timebandwidth GE-100 XHP, 81.25 MHz, 5W at 1064nm





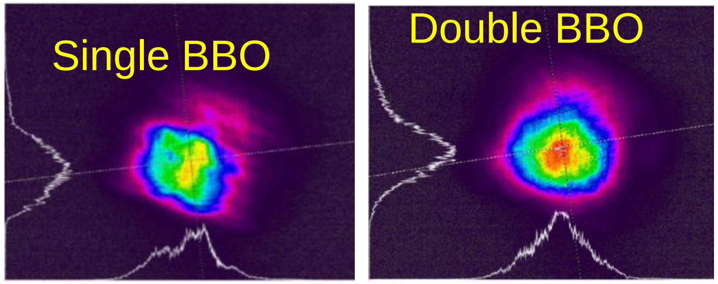
Before upgrade

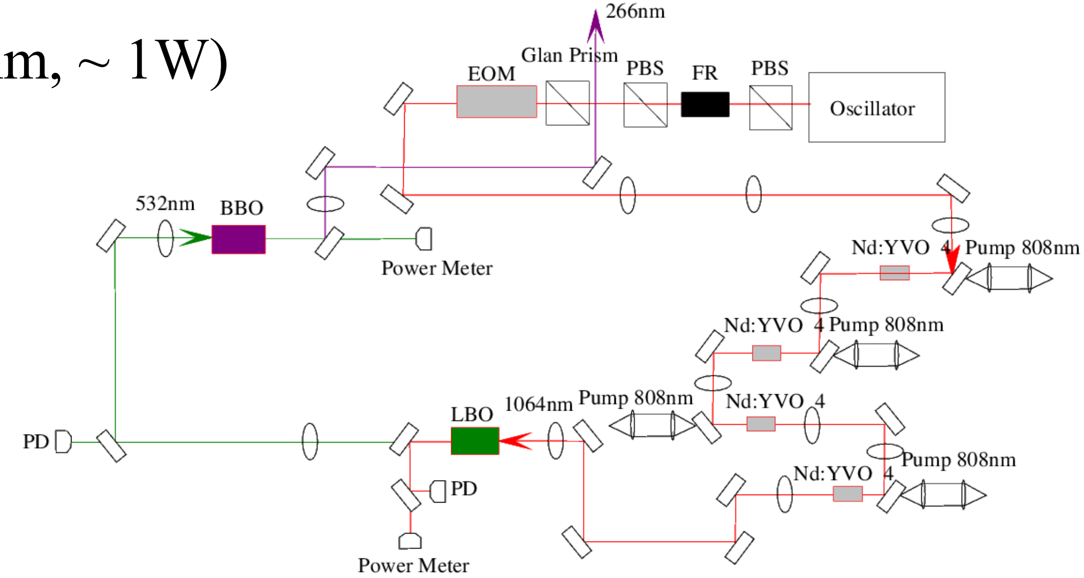
After upgrade

After upgrade, The pointing stability and power stability of the driver laser system has increased

Drive Laser Upgrade

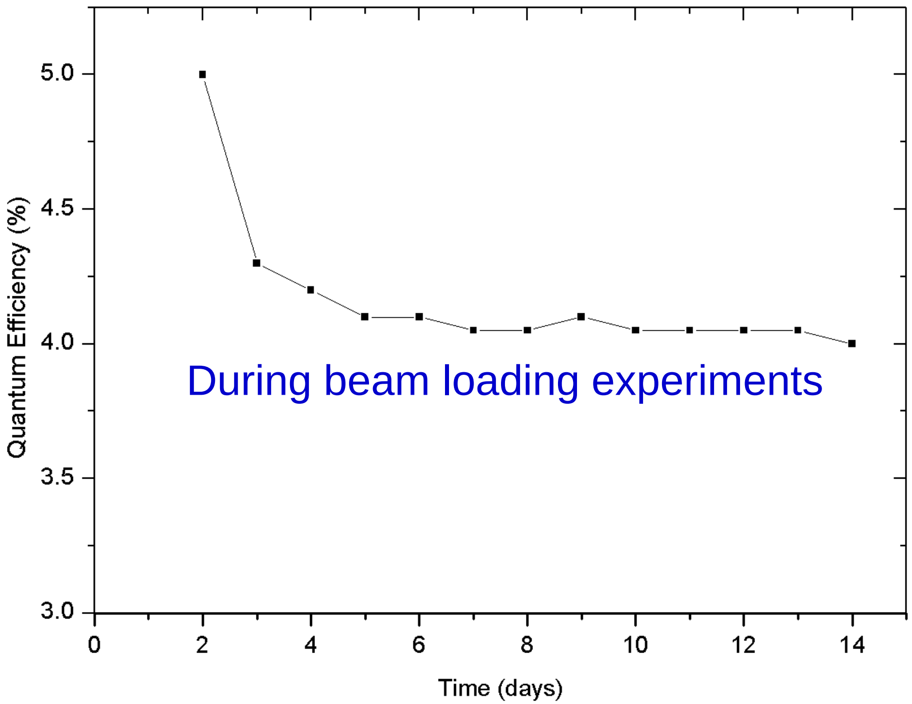
MOPA (1064 nm, 45W)
SHG (532 nm, 10 W)
FHG using double BBO (266 nm, ~ 1W)





- ➢Long terms UV power instability <5%
- ➢EO used for repetition rate adjustment, from 81.25 MHz down to 0.1625 MHz; mechanical shutter used for macro pulse manipulation

Long-term Behavior of Cs_2Te Cathode

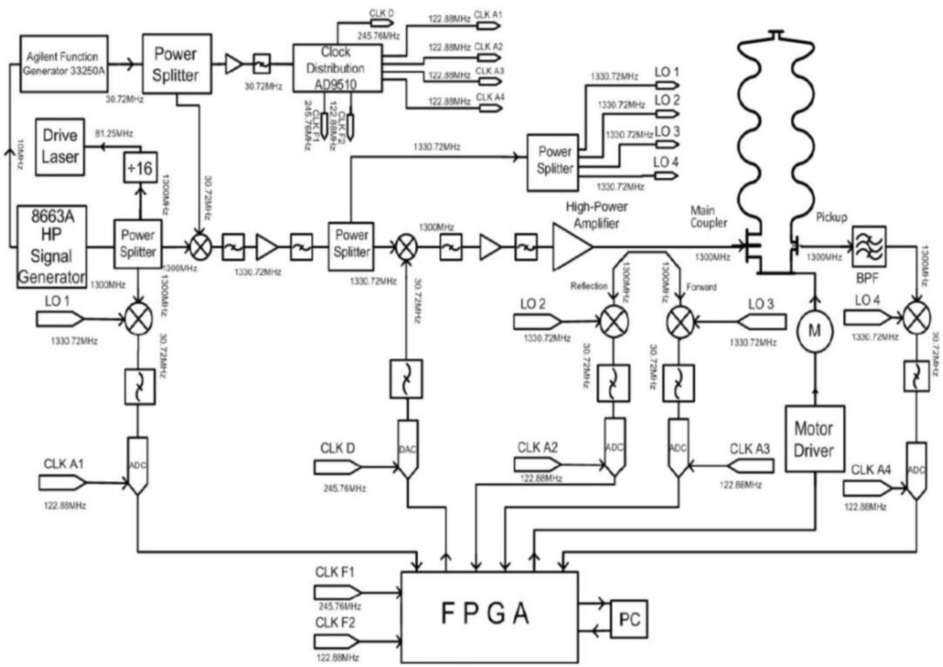


- **A method to increase the QE and to reduce the degradation rate**
- **QE at long term operation ~4%（12 days）**
- **QE~4% : maximum current of 3~4mA electron can be obtained**
- **The life time of this Cs_2Te cathode is at least 150 hours**

A simple and effective method: Just before transferring a Cs_2Te cathode into the injector cryomodule, the cathode is activated again with cesium.

This method promoted QE of Cs_2Te at long-term operation from 1%to 4%

LLRF Control System Improvements



- ➢A DC offset block was added in the FPGA to compensate the DC offset observed in the tests.
- ➢For pulse operation, gate signal was added to the feedback path and the control algorithm was modified to handle lorentz detuning.
- ➢A hardware UDP core was implemented for high speed signal monitoring.
- ➢new control UI offers run-time plotting/modifying for many internal parameters.

Digital Low Level Radio Frequency (LLRF) control:

- Two feedback control loops for amplitude control and phase control.
- PI controller in FPGA adjust output signal to compensate the deviation

LLRF control instability of the amplitude and phase: 0.1% and 0.1° (rms)

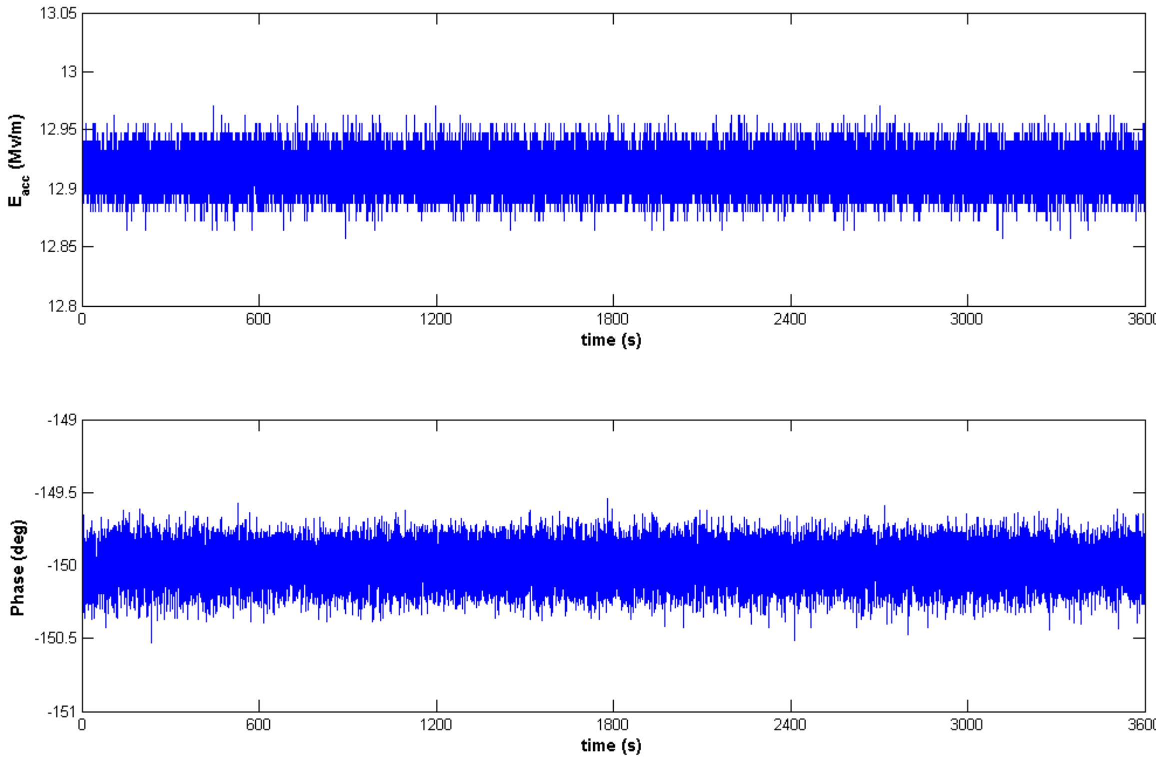
The Beam Experiment Layout of DC-SRF Photoinjector

Acceleration Gradient (E_{acc})

E_{acc} in different conditions have been investigated

➢E_{acc} was increased up to 17.5MV/m in pulsed mode with a duty factor of 10% and a repetition rate of 10 Hz.

➢E_{acc} reached 14.5MV/m for CW mode



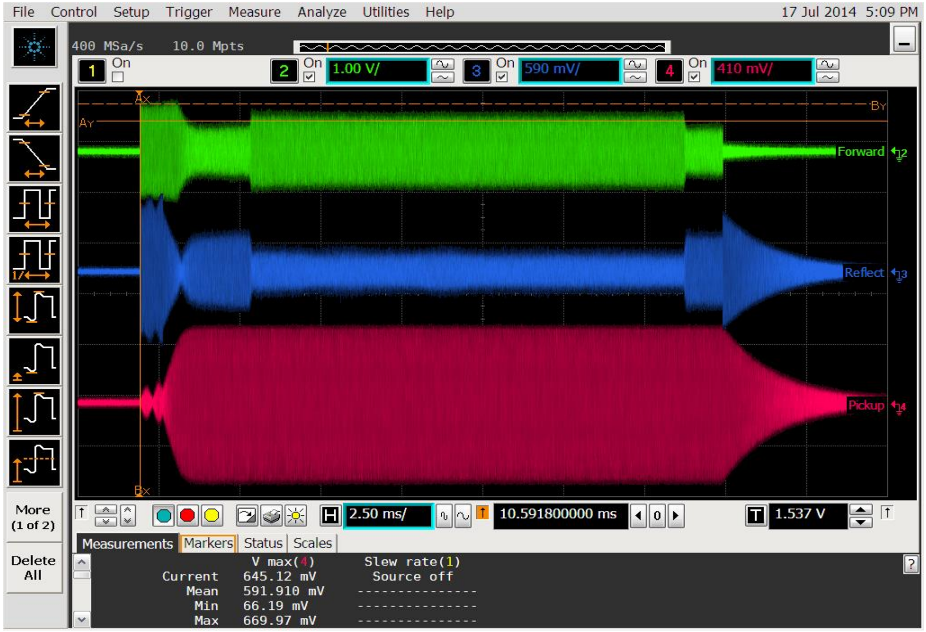
◄ Amplitude (up) and phase (below) signals of 3.5-cell DC-SRF injector at 12.9MV/m without beam load.

Beam Experiment Results

- For commissioning of the DC-SRF injector, we reduce the duty factor and the repetition rate of the drive laser while keep the same bunch charge
- For operation, we increase the duty factor and the repetition rate of the laser to get high average current
- For machine safety, the beam experiments were carried out at an Eacc of 8.5 MV/m and mainly at long pulsed mode.

Operation parameters of DC-SRF photoinjector

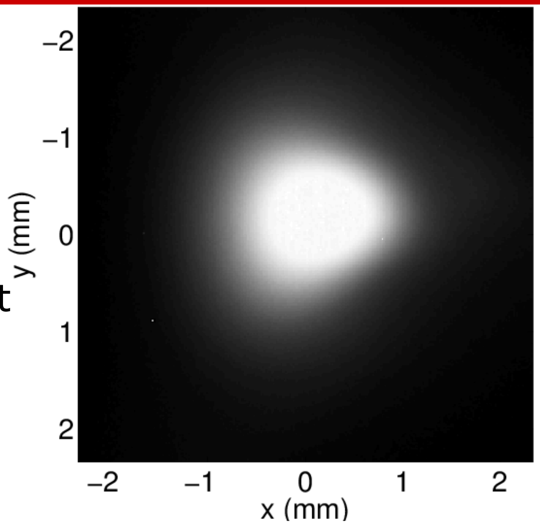
Parameter	Value
DC-SRF photoinjector	
DC voltage	45 kV
E_{acc}	8.5 MV/m
RF frequency	1.3 GHz
RMS pules length of UV laser	~6 ps
Electron beam	
Energy	3.4 MeV
average current	~1mA
Normalized transverse emittance	2.0 mm-mrad
Energy spread	<1%
Bunch repetition rate	81.25MHz
Macropulse duration	7 ms
Macropulse repetition rate	10 Hz

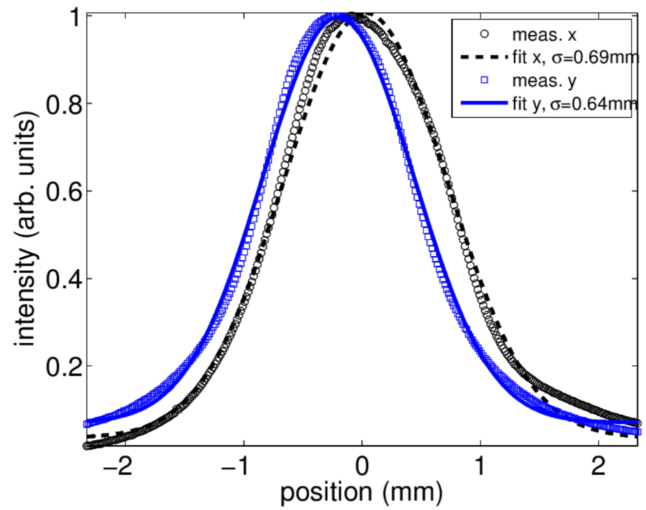


RF signals for beam loading experiment

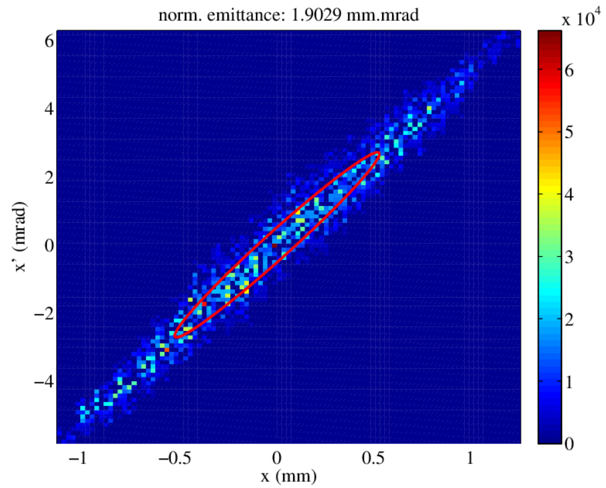
Transverse Electron Beam Profile and Emittance

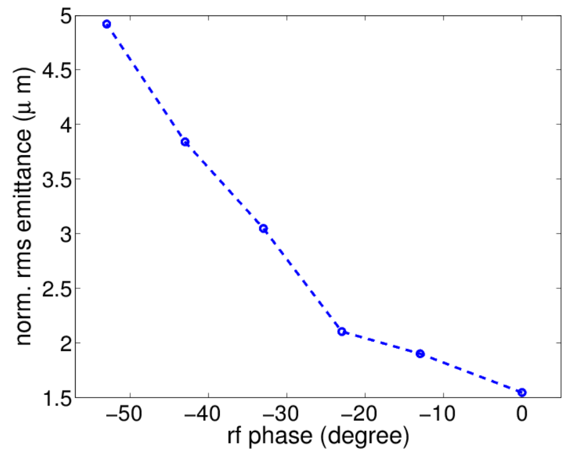
Beam spot





Beam profile

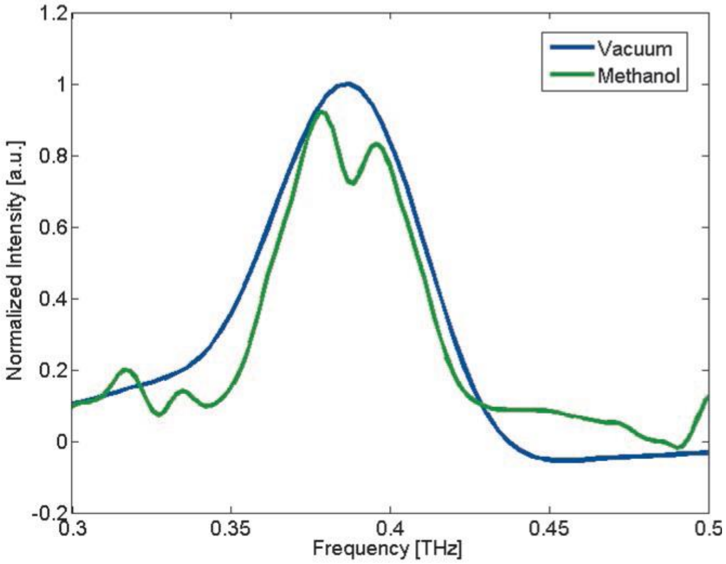




- ✯Single-slit scanning method was used to measure the emittance.
- ✯Emittance was measured as a function of the rf phase.

THz radiation

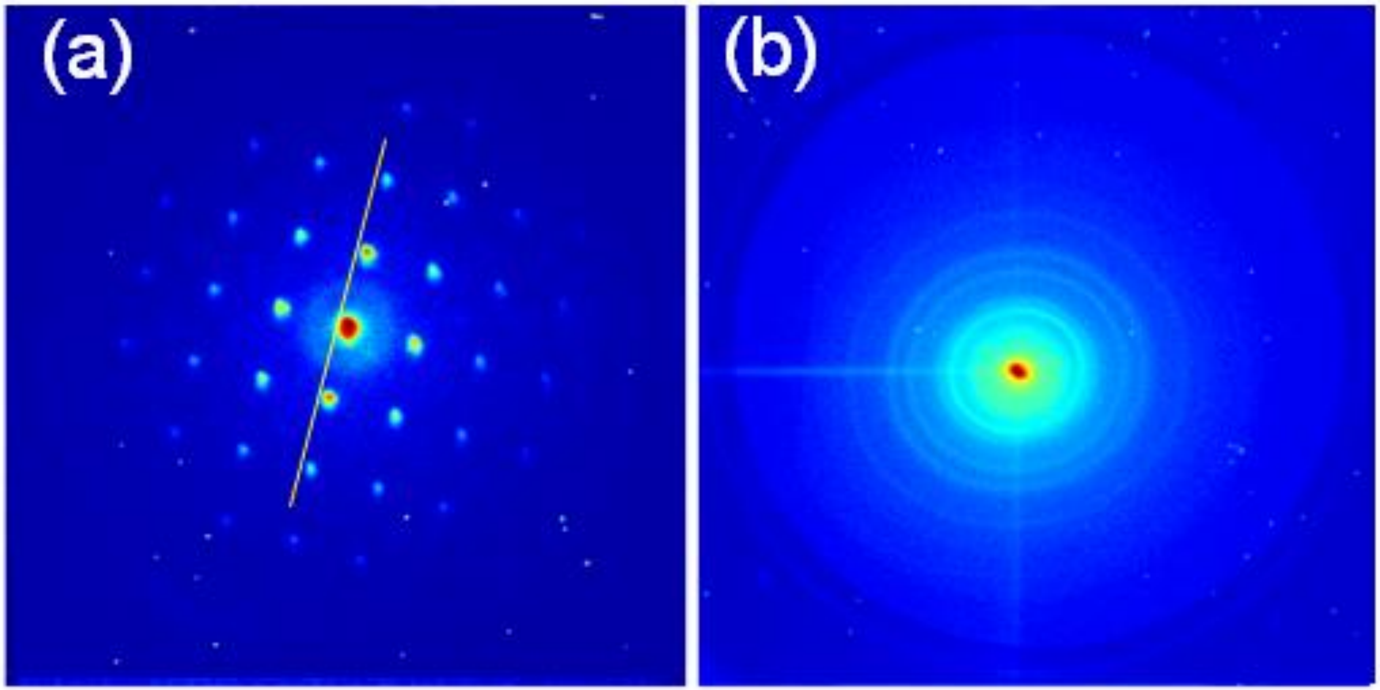
THz radiation



Measured absorption peak of methyl alcohol with the THz radiation

- High repetition rate short pulse THz radiation: average power ~10mW, wavelength adjustable in the rang of 0.7-1.2mm.

Ultrafast Electron Diffraction

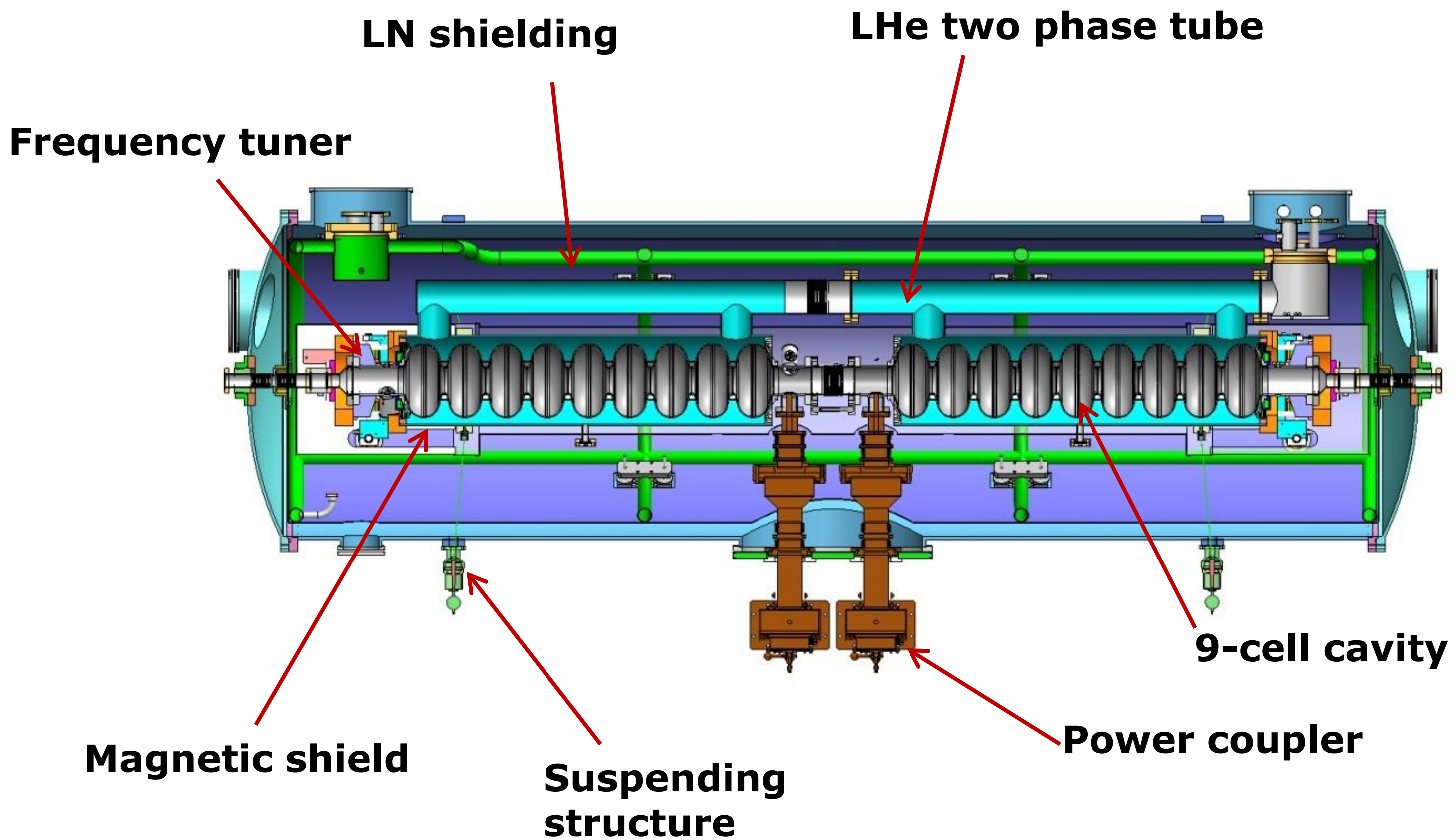


single-crystal Au foil　　a polycrystalline Al foil.

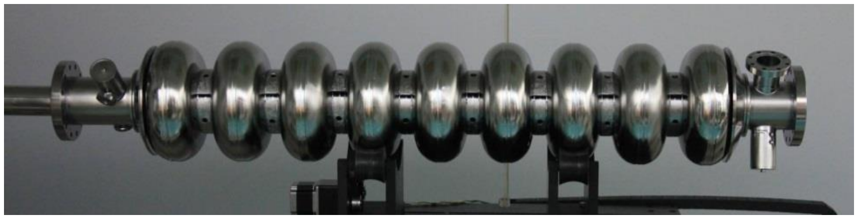
repetition rate:~1MHz,
integrating the signal over 200 ms
The total charge: 33pC
foil thichness: 20nm

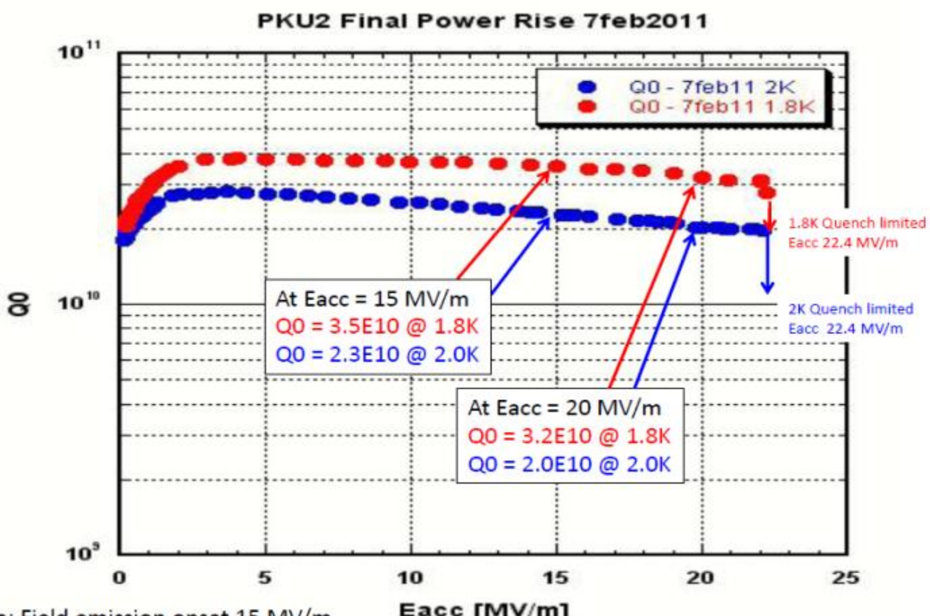
2×9-Cell Cavity Cryomodule

Cryomodule with two 9-cell cavities

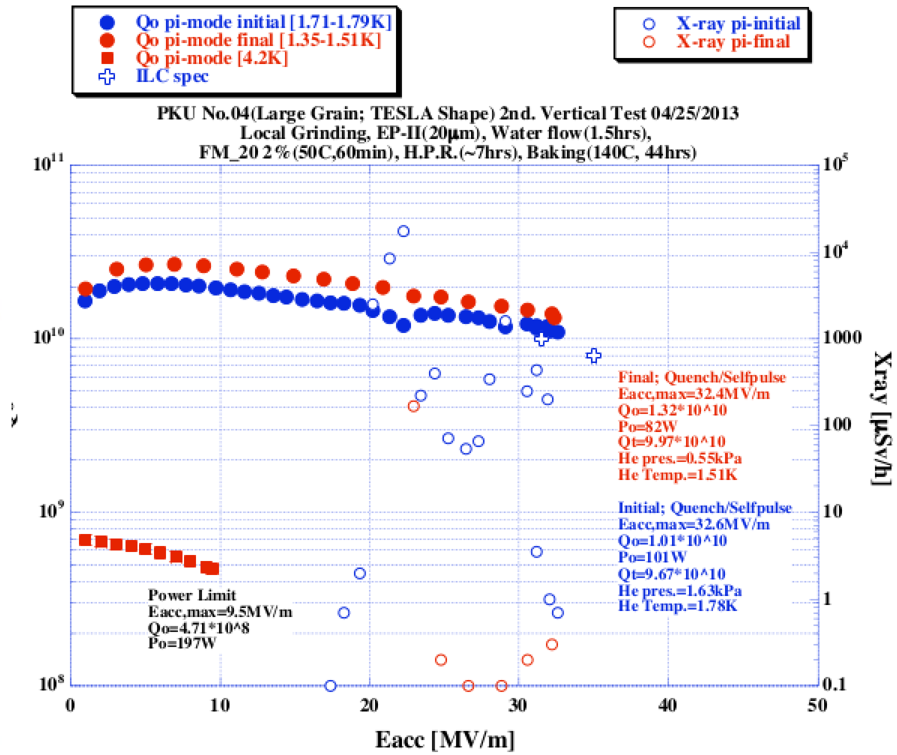


1.3GHz SRF Cavities of Linac





Note: Field emission onset 15 MV/m,
Maximum X-ray dose rate < 100 mR/m. No more mode mixing observed during final power rise.



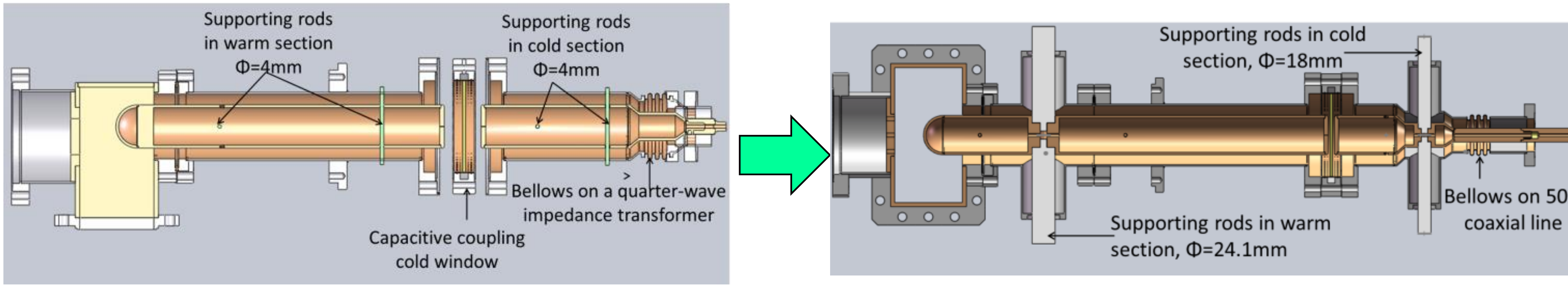
▲ **Post-processed and tested at JLab** ▲ **Post-processed and tested at KEK**

1.3GHz SRF Cavities of Linac

HPR for 9-cell cavity with Helium tank

Assembly of the two 9-cell cavities

Capacitive coupling type RF power coupler
advantage: convinient for assembling

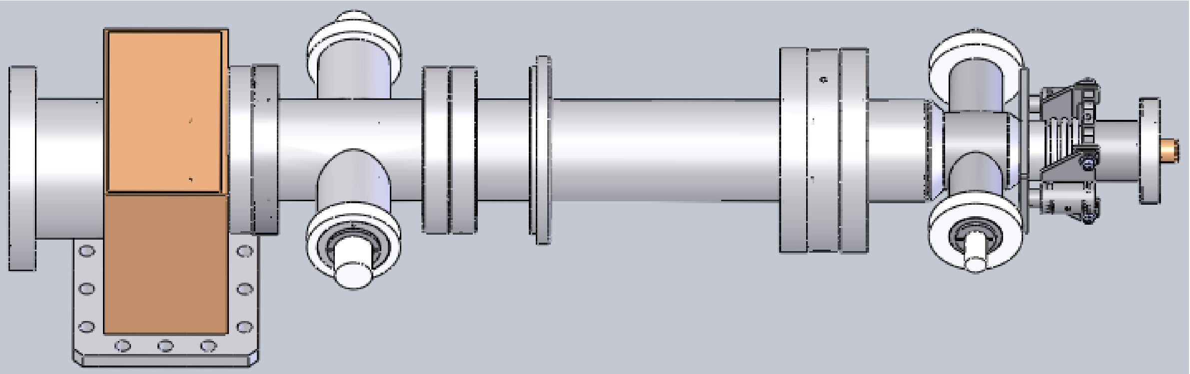


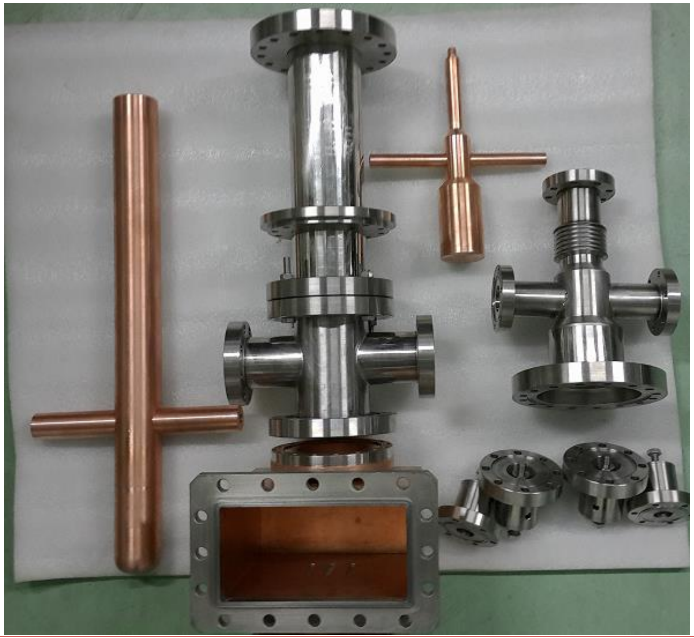
- A obvious temperature increase around supporting rods was observed when the power was over 8 kW.
- During Q_{ext} adjusting, the variation of length of the bellows which is within the quarter-wave transformer will cause RF mismatching.

- Enlarging the supporting rods of inner conductors in order to increase heat conduction
- Moving the bellows from the quarter-wave transformer to the 50 Ohm coaxial line to avoid the mismatch during Q_{ext} adjusting

THPB079

RF Couplers of Linac





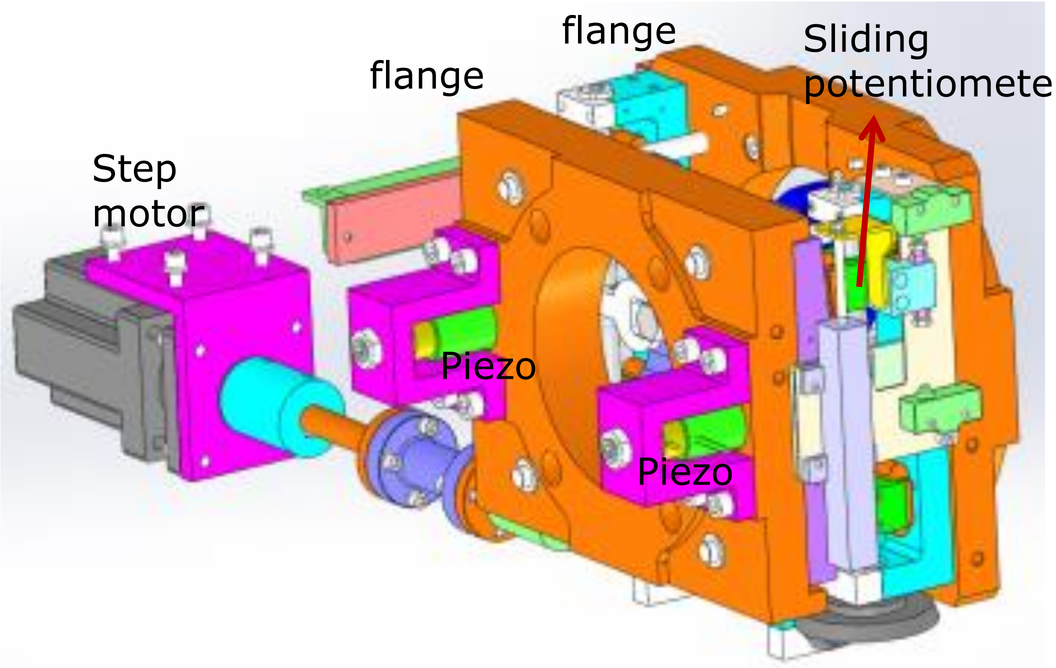
Conditioning of the RF Couplers

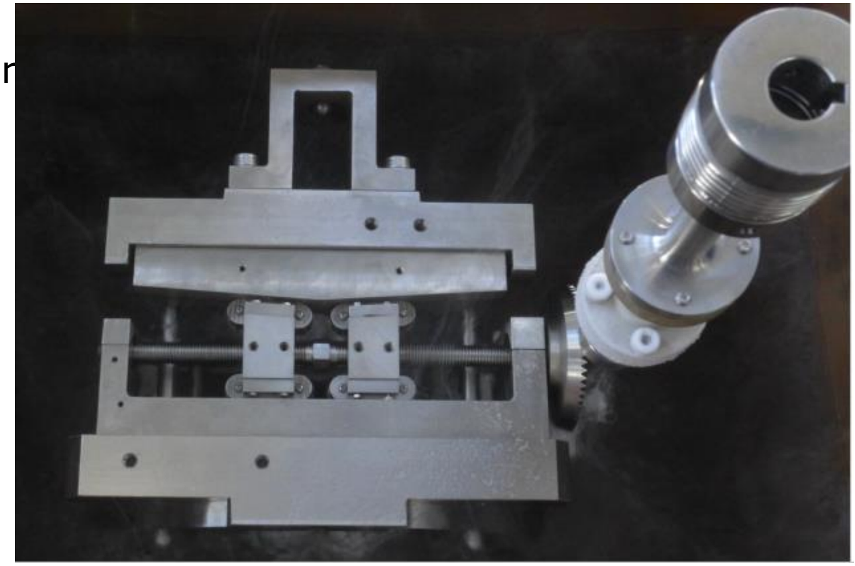
Conditioning test bench for 1.3GHz couplers

Both couplers can transfer 10kW RF power with 10Hz and a duty factor of 30%

Cavity Tuner of Linac

Collaboration between PKU and IHEP, CAS

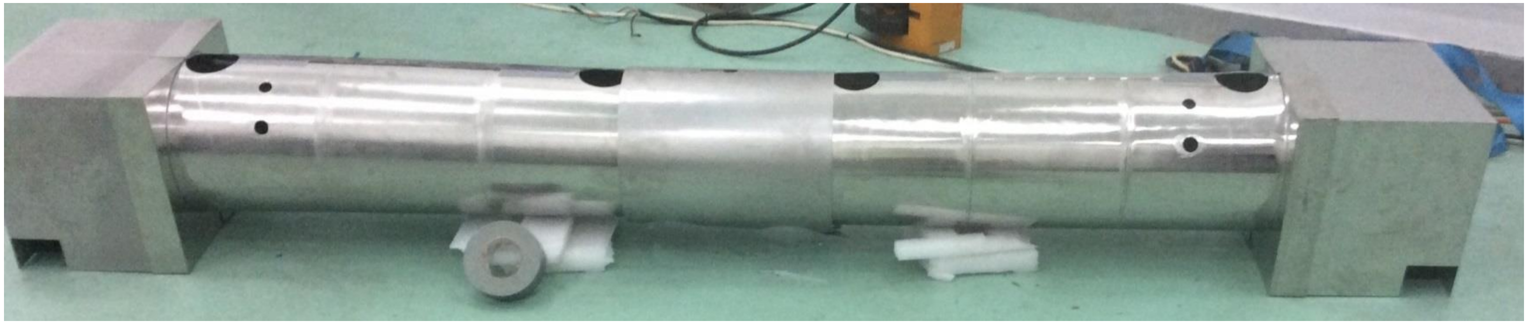




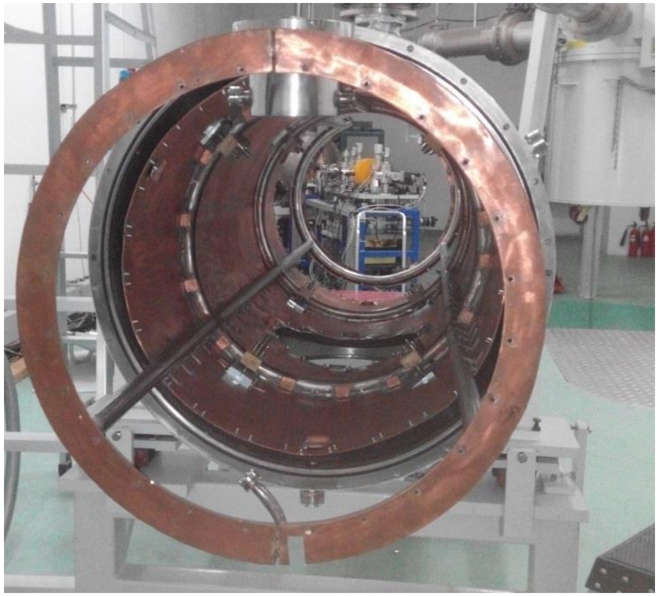
Tuning system includes one step motor and two piezos

The tuning range of motor tuner is about 600 kHz.
The tuning range of piezo tuner is larger than 2 kHz.
Tuning sensitivity: 300kHz/mm
Voltage of piezo: 400V±300V

Cryomodule



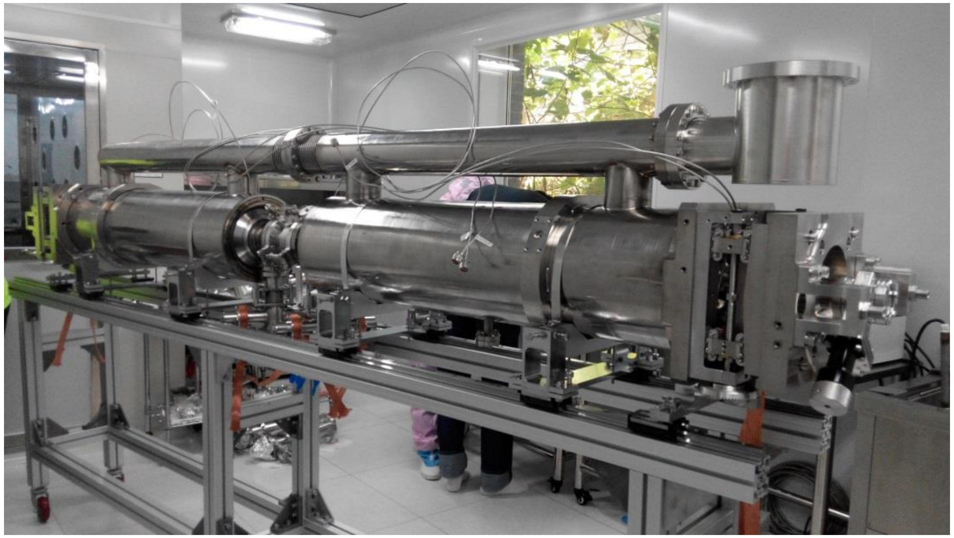
Magnetic shield for 2×9-cell cavity: low temperature permalloy

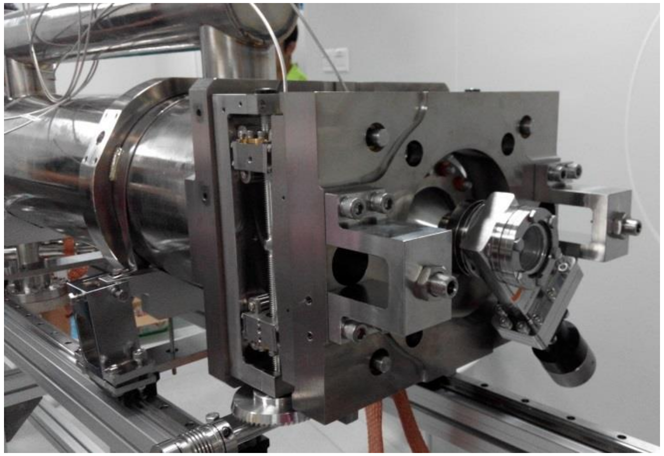


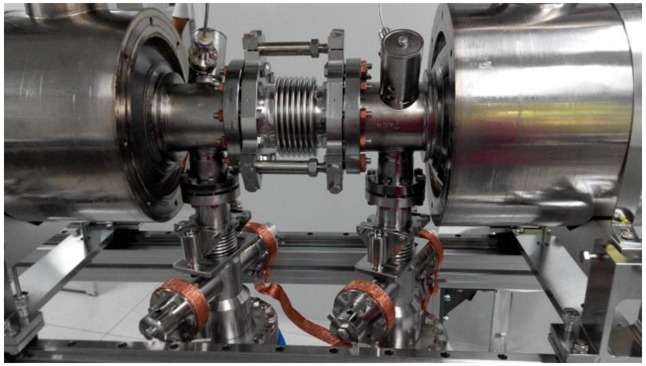
Liquid nitrogen shield

Vaccum vessel of the cryomodule

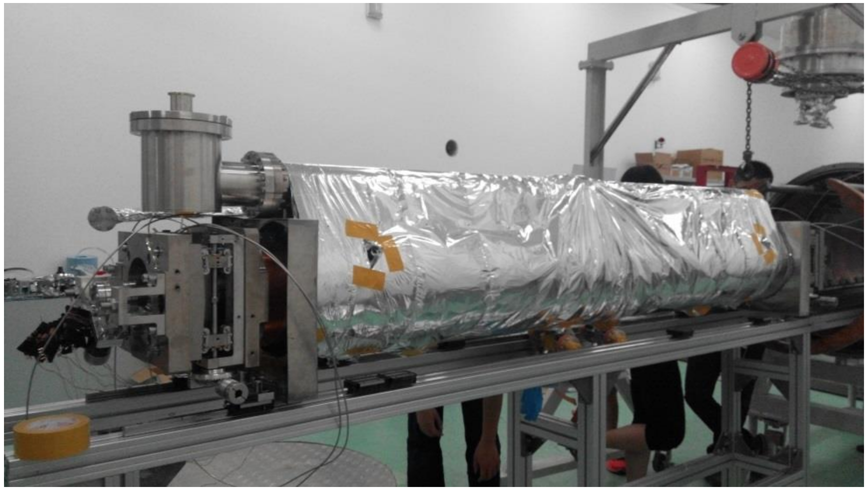
Assembly of the Cryomodule

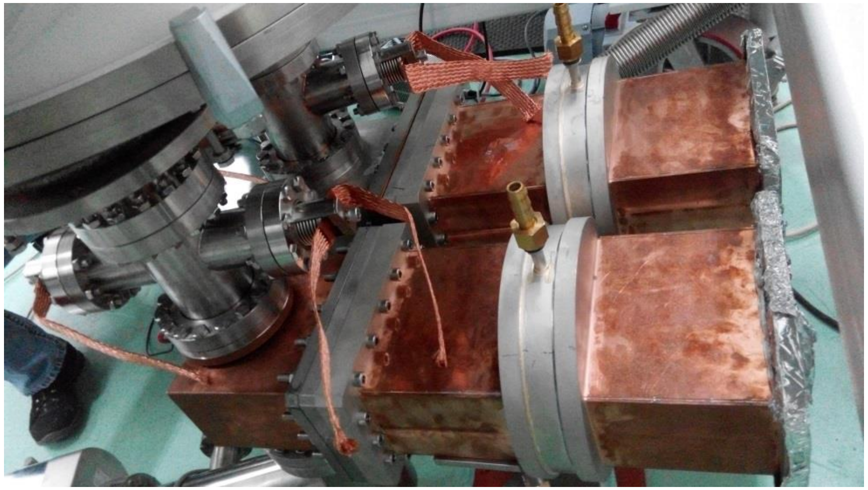
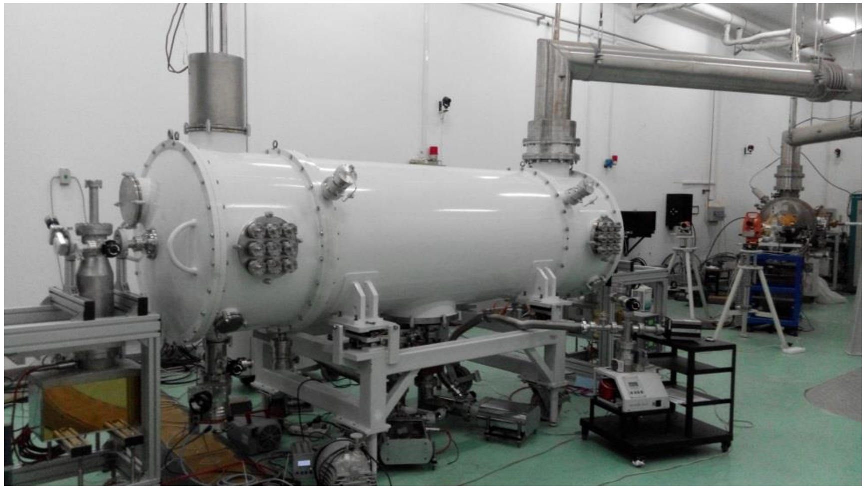






Assembly of the Cryomodule



1.3 GHz Solid-State RF Power Amplifier

Three 10kW 1.3GHz solid-state RF power amplifiers.
For the DC-SRF 3.5-cell cavity and the two 9-cell cavities.

Summary

DC-SRF photoinjector

•Stable operation of DC-SRF photoinjector has been achieved since 2014.

•The electron beam has been successfully used to generate high repetition rate THz superrandiant undulator radiation and ultrafast electron diffraction recently.

2x9-cell cavity cryomodule (straight section)

•Assembling of 2x9-cell cryomodule have been finished.

•The 25 MeV beam line and LLRF control system almost finished.

•RF test and beam loading experiments will be carried out next month.

Acknowledgement

- For cavity vertical RF measurement, we thank Dr. R.L. Geng, Dr. Bob Rimmer, C. Reece and Dr. Peter Kneisel, etc. from JLab and E. Kako, and A. Yamamoto from KEK
- For tuner, we thank Y. Sun and Z. H. Mi from IHEP

Thank you!