DC-SRF Photo-cathode Gun at Peking University

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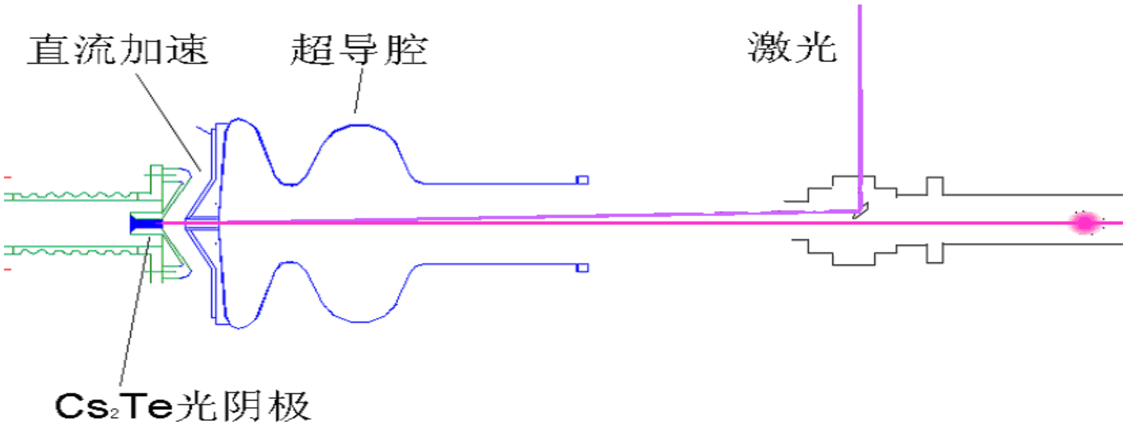
Outline

- Development of DC- SRF injector at PKU
- Experimental facilities
- Experiments and results
- Summary

Concept of DC-SRF Photocathode injector



Pierce structure + SRF cavity

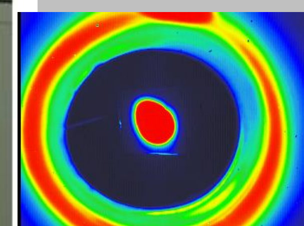
- The concept of DC-SRF was proposed in 2001
- Compatibility of photocathode and SC cavity and compact structure
- Could be operated at CW mode and simulations show good beam quality

  - Electric field on cathode surface could not be high enough
  - Emittance compensation solenoid is far from cathode

Could handle moderate average current (1~10mA)

Feasibility Test at 4K

4.5KW Solid State Power Amplifier



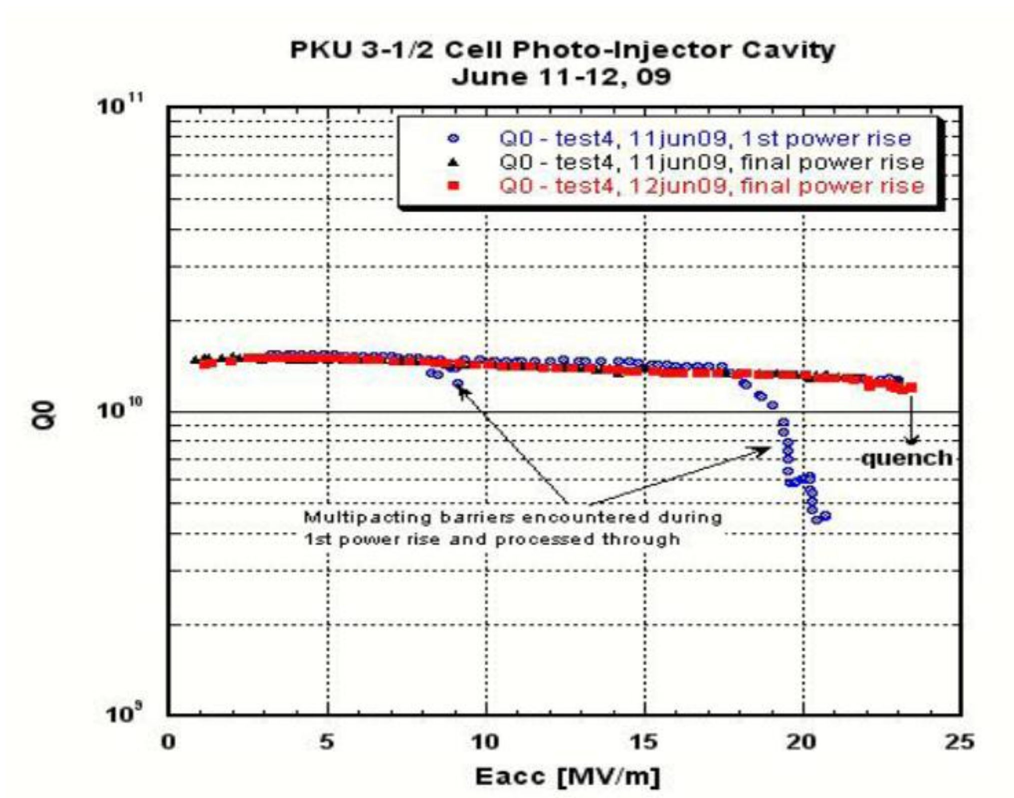
Electron Beam spot after RF acceleration

Prototype with a pierce gun and a 1.5-cell superconducting cavity

Test operation at 4K in 2004 : Gradient ~6MV/m，energy gain ~1MeV，emittance~5μm

Promoted the design of an upgrade DC-SRF gun with 3.5 cell cavity

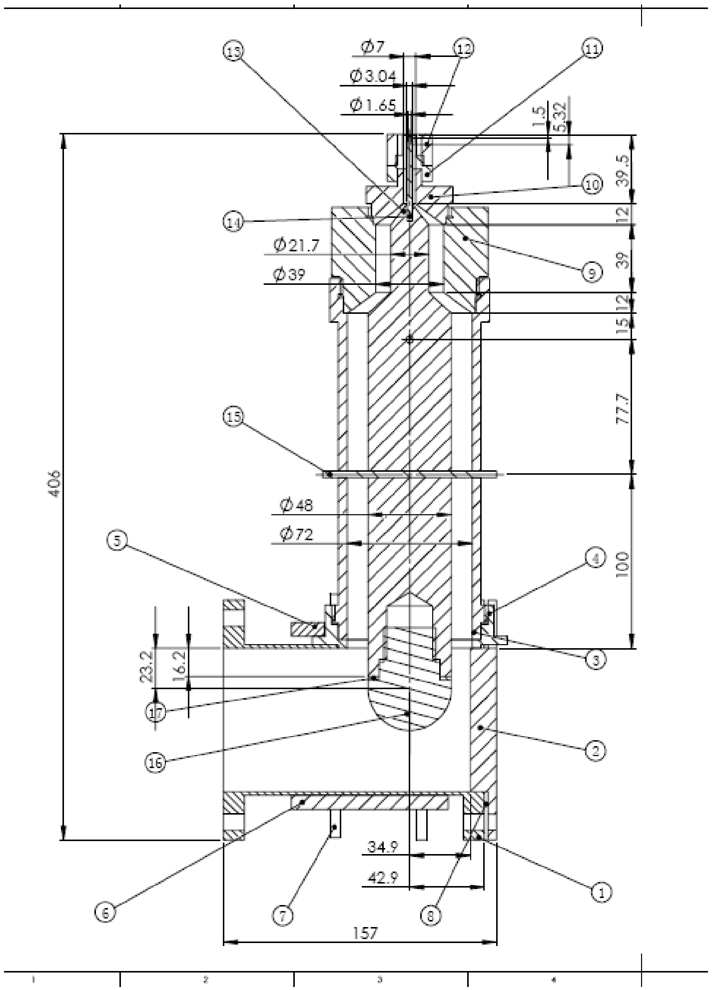
3.5-cell cavity DC-SRF injector

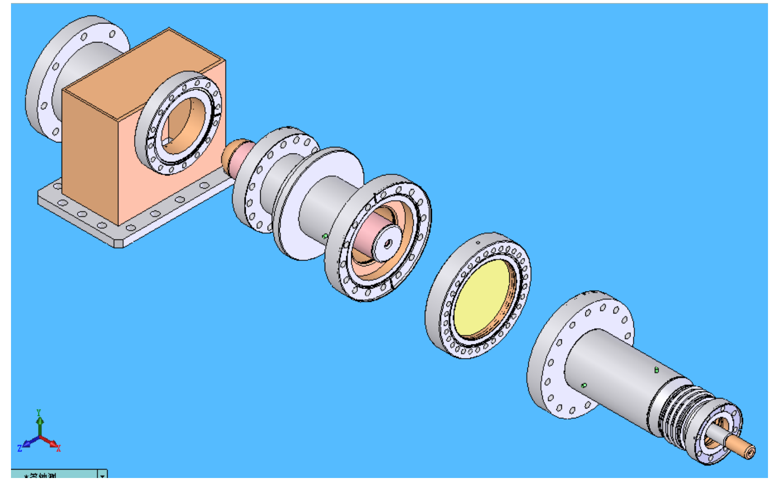


2007 and 2008

- Vertical test of 3.5-cell cavity 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 and .... in 2012

Main coupler

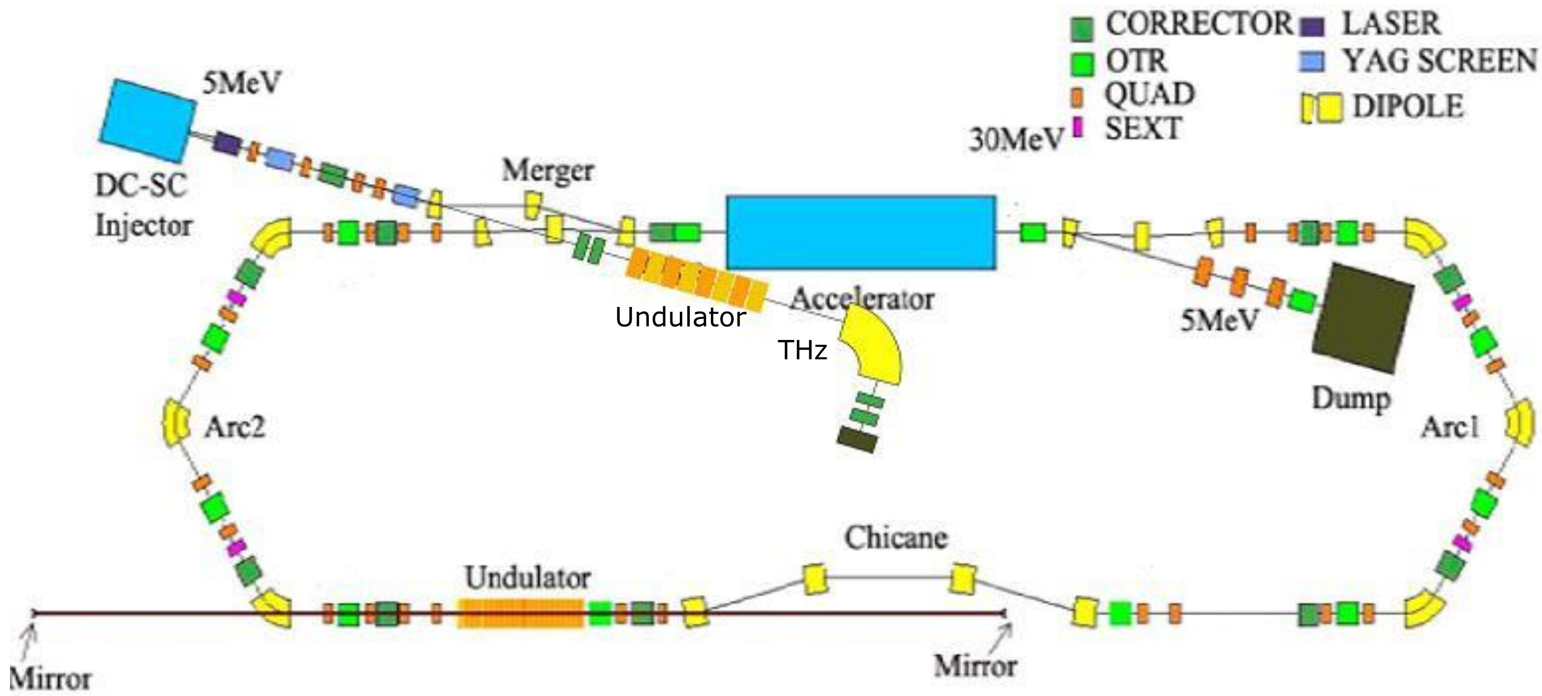




- Capacitive coupling structure referred to KEK proposed coupler structure in 2005
- Four parts connected by flanges
- Disk ceramic window, without contacting inner conductor

- Compact structure, easy for accembling and repare
- Stress on ceramic window is not strong

ERL project at Peking University



Peking University Superconducting ERL Test Facility (PKU-SETF)

First THz with lower bunch charge and then ERL-FEL with higher bunch charge

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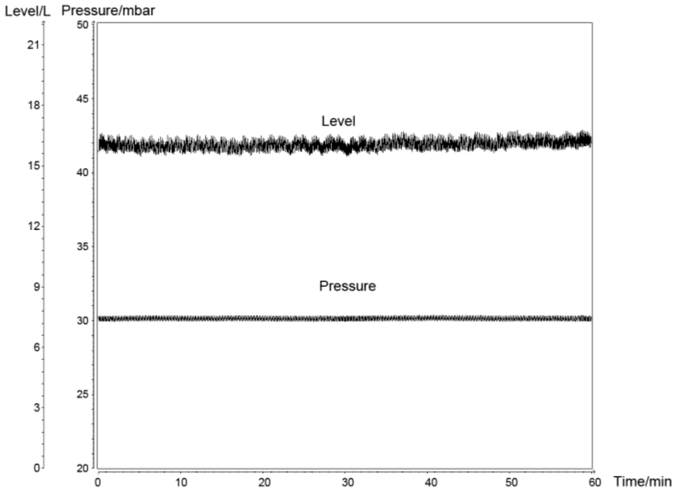
Closed loop 2K cryogenic system at Peking University

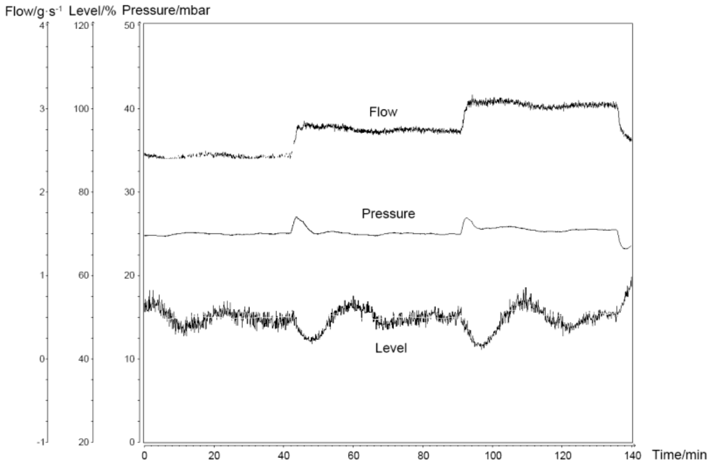
Main parts from Linde, transfer lines made in China,
Designed cooling capacity: 57.5W @2K
Heat load of the 2K transfer lines: <0.5W/m

Stable operation of 2K cryomodule



Commissioning stability of the cryogenic system

- Successive approximation method: the high and low limits of the control valves were preset and finely adjusted to avoid large fluctuation of the helium pressure and level.
- The stability of the helium pressure can be controlled within ±0.1 mbar and the helium level is within ±5%.

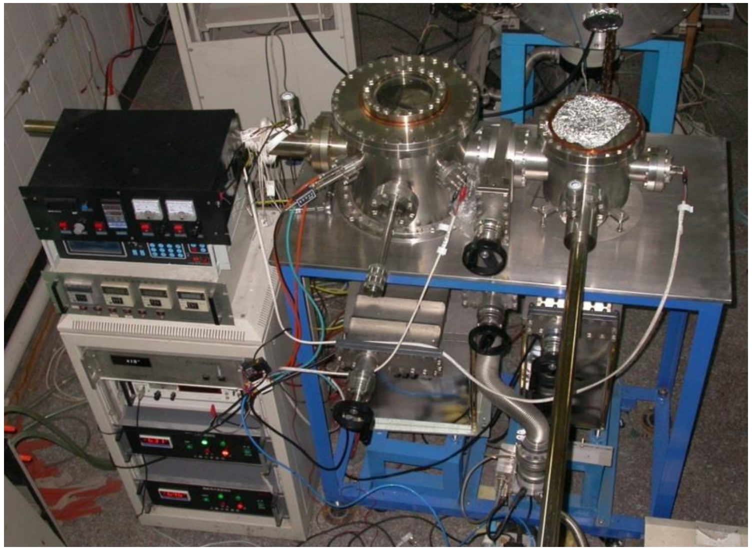


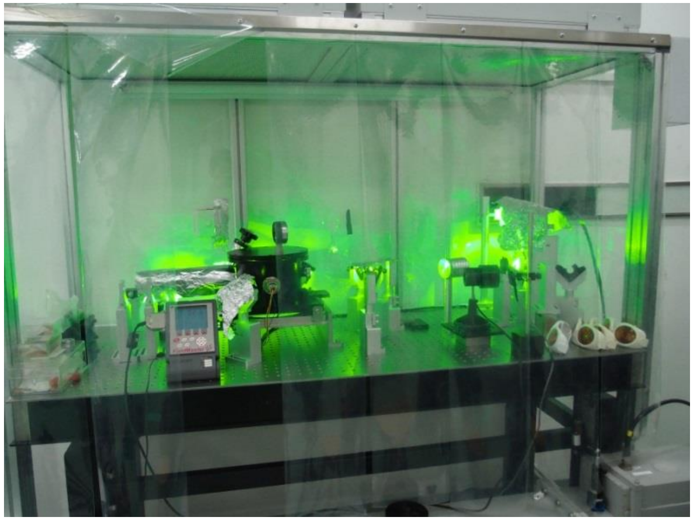
The recovery processes with the jumps of the heat load

- When jump of heat load caused by the change of cavity gradient and the duty factor of RF power.
- 2K cryogenic system could be recovered from the pressure instability and helium level instability within short time.

- **Static heat load: obtained by calibrated helium gas flux measurement, about 20 W in total, transfer line and the cryostat about 15 W.**
- **Dynamic cooling capacity: measured with a heater in the cryostat, stable when the heating power was increased up to 50 W.**
- **Total cooling capacity: more than 65 W at 2.0 K**

On-line Cs_2Te photocathode preparation system





- Vacuum in deposition chamber has been improved to ~10^{-7} Pa with a bigger sputtering ion pump (600L/s).
- A SAES NEG pump (200L/s) has been equipped
- The stainless steel plug polished mechanically, rinsed in ethanol and acetone ultrasonically,heated at 120-150 degree for more than 10 hours

- Seed laser: Timebandwidth GE-100 XHP 5W at 1064nm
- Amplifier: 40W
- SHG: 10W for green light (532nm)
- FHG: 1~2W for UV light (266nm), instability of the UV power <5%.
- Repetition rate : 81.25MHz

QE of fresh Cs_2Te photocathode is around 8%
→stabilized at 3.5% for beam loading tests for ten days,
→dropped to 2% in two weeks, the cathode current was still higher than 2mA

1.3GHz 20kW solid-state power source in 2011

- 1.3 GHz 5kW solid-state RF power supply was replaced with the new one
- Can work in both pulse mode and CW mode.
- Output RF power can achieve 20kW with matched load, and 16kW with total reflection.
- 3dB bandwidth is more than 30MHz. .

LLRF control system

Recent 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 stability of the amplitude and phase: 0.1% and 0.1°

Beam line of the 3.5cell cavity DC-SRF injector

Beam line for preliminary beam test was replaced with a new upgraded one

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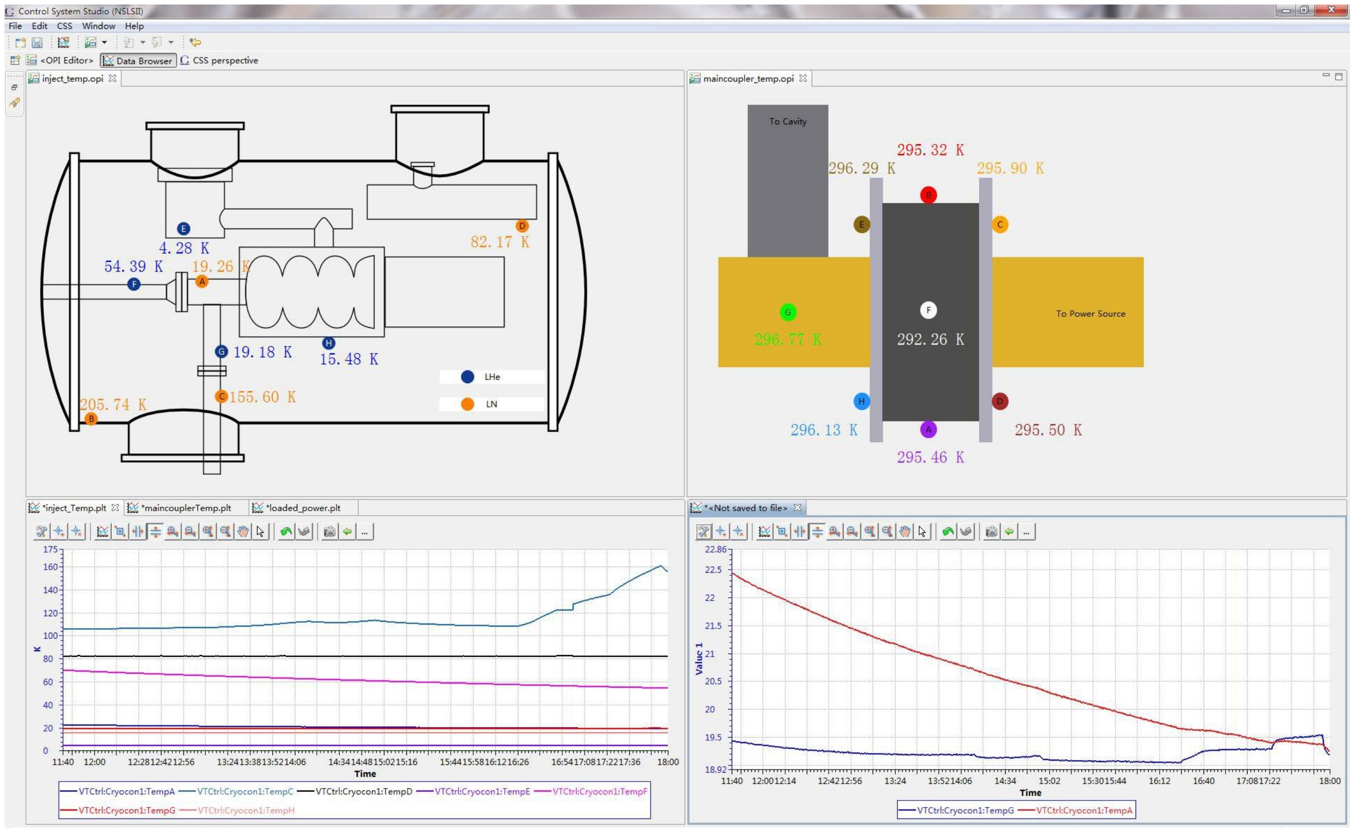
Conditioning of main power coupler



- Temperature at several points inside the coupler was monitored by temperature sensors
- Cavity was non-resonance during the conditioning
- Highest power was 20kW with duty factor of 40%

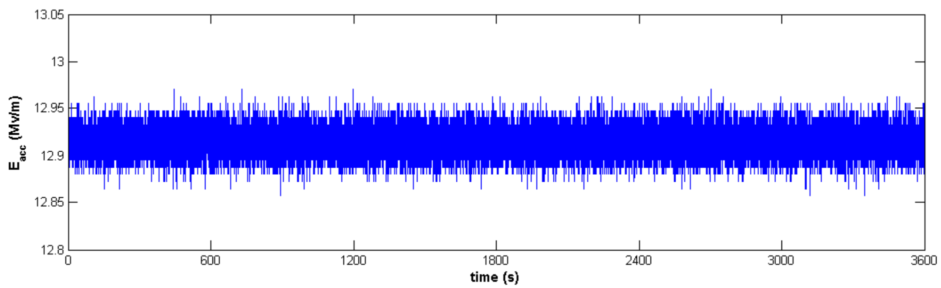
Acceleration gradient (E_{acc})

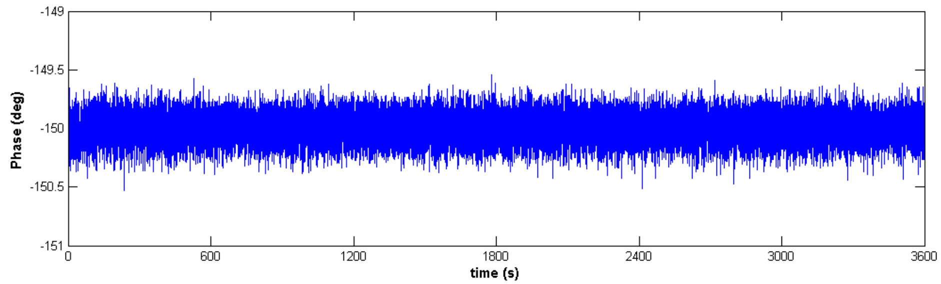
E_{acc} in different conditions have been investigated

Phase-lock: 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

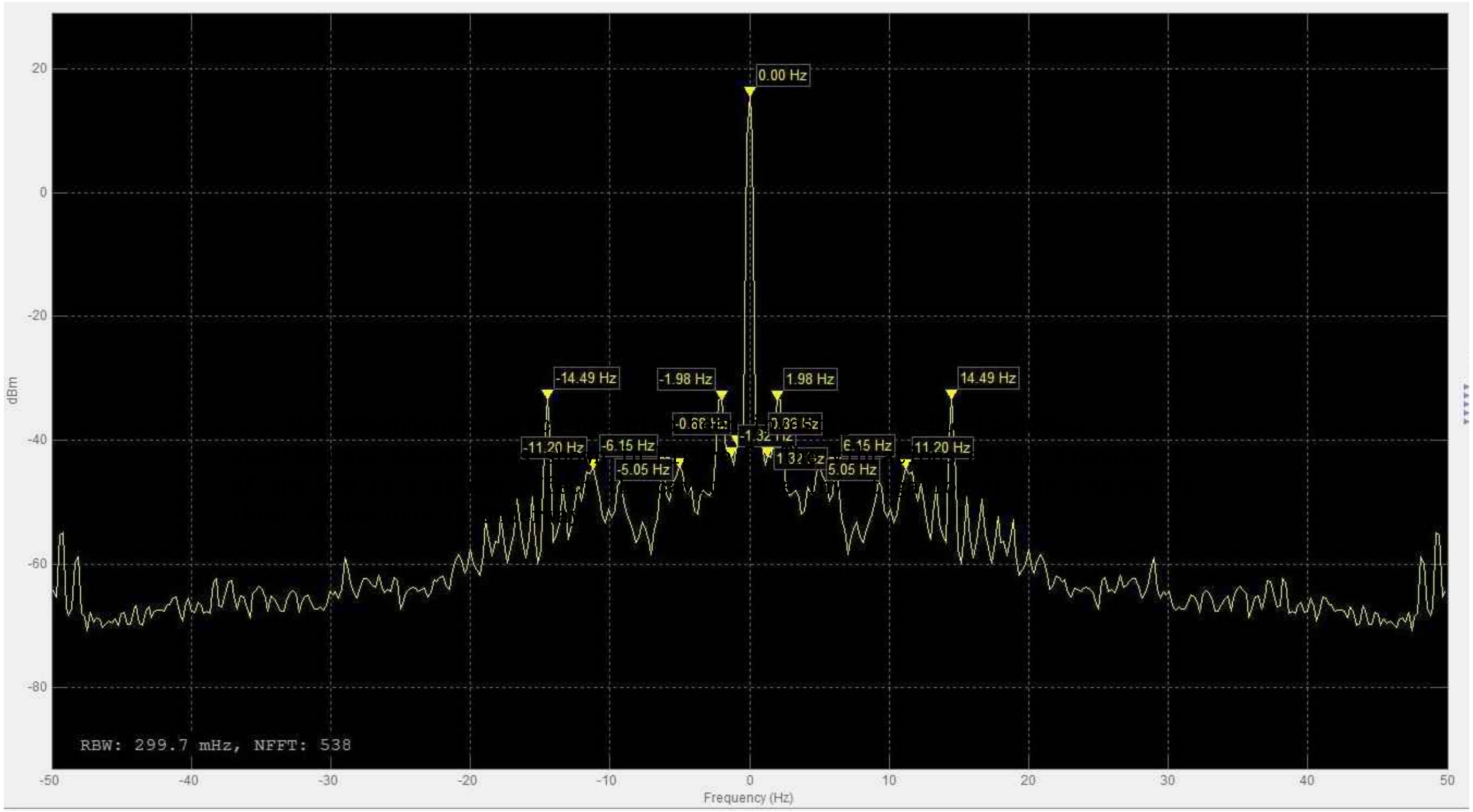
LLRF control: Eacc was 12.9MV/m for a long-term test.





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

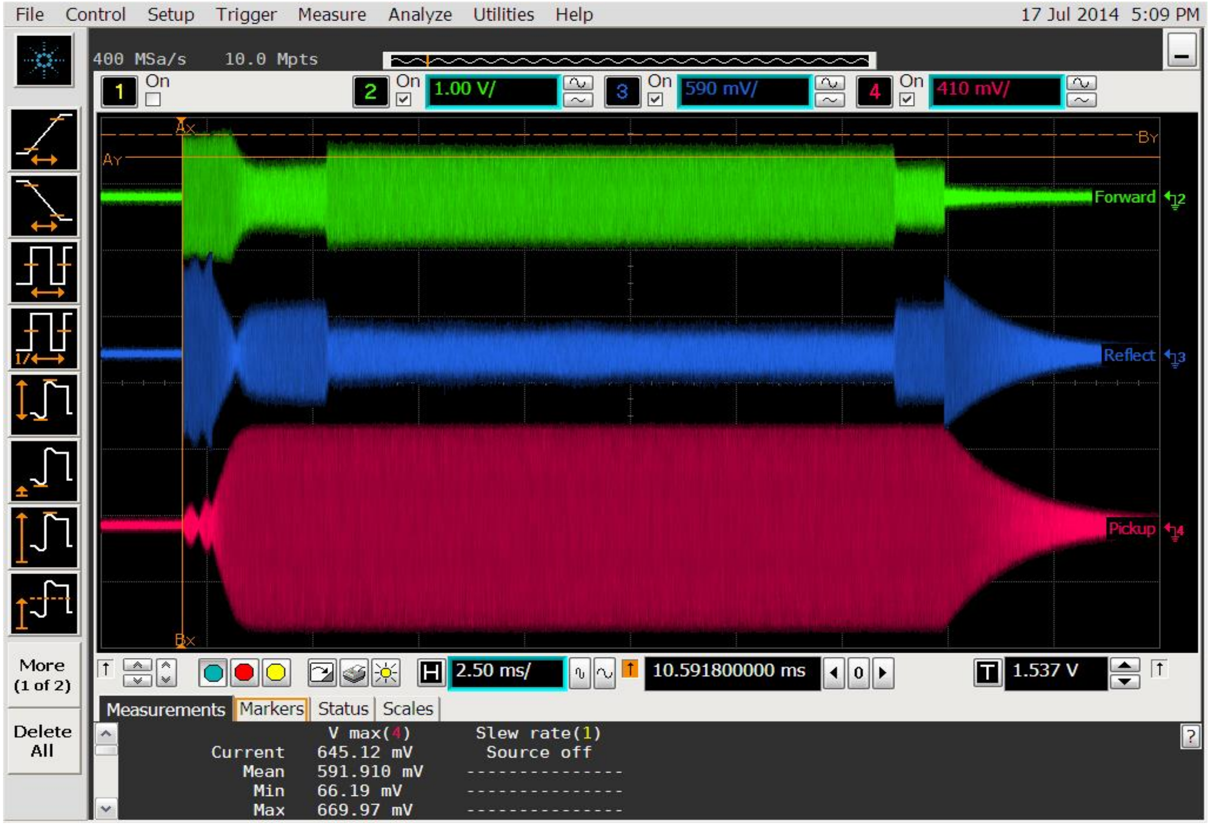
Cavity microphonics



- Real-time measurement of cavity microphonics was done
- The vibrations at the frequency of 2Hz and 14.5 Hz may affect the cavity.
- The investigation of the sources of these vibrations is underway.

Beam experiments

- Beam tuning with a low beam current, reducing the duty factor of laser rather than reducing laser power to keep the same bunch charge for different average current.
- When the duty factor of laser was 1% at 10Hz, the average beam current is about 5μA.
- Degassing of the dump faraday cup became serious with higher beam current

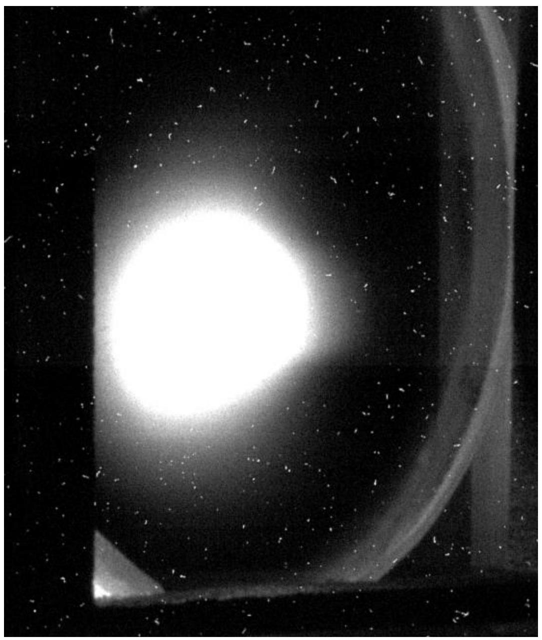


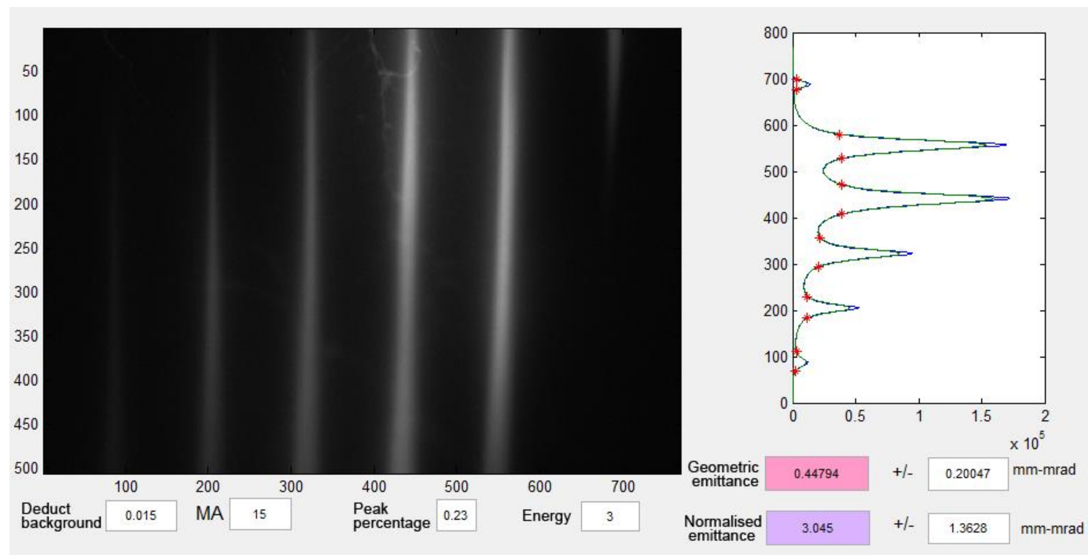
Forward ,Reflected and pickup RF signals with pulsed beam load

- HV=44kV
- E_{acc} was 8.5MV/m during the beam test
- Beam energy is about 3.4 MeV at this accelerating gradient
- Duty factor 7% ，10Hz, average current of the macro pulse 0.55mA
- Long time operation

Transverse emittance measurement by multi-slits method

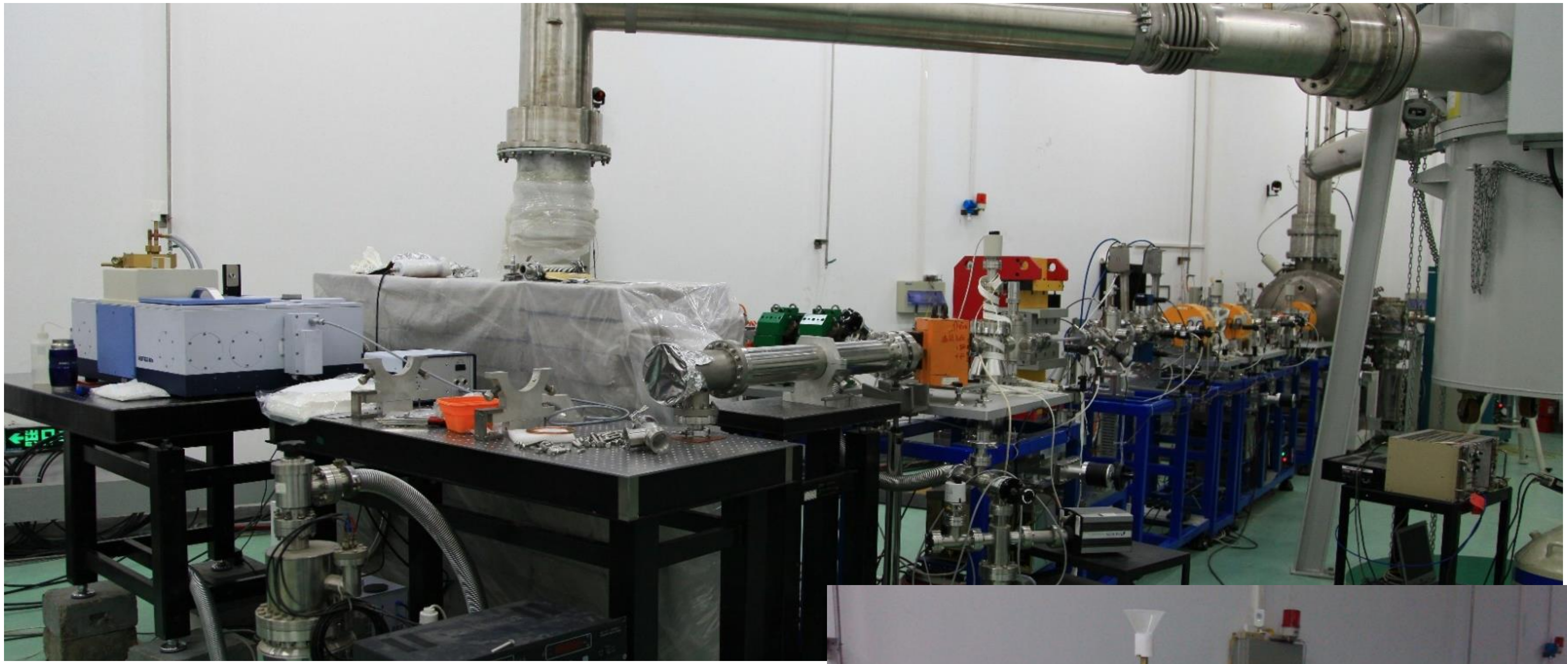
➢Normalized emmittances are all around 3.0 mm·mrad

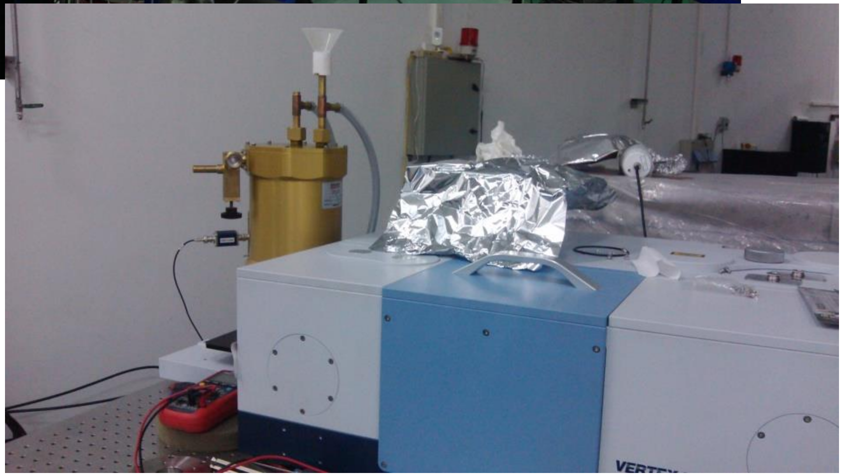




Beam passing through multi-slits (left) and relative intensity (right)

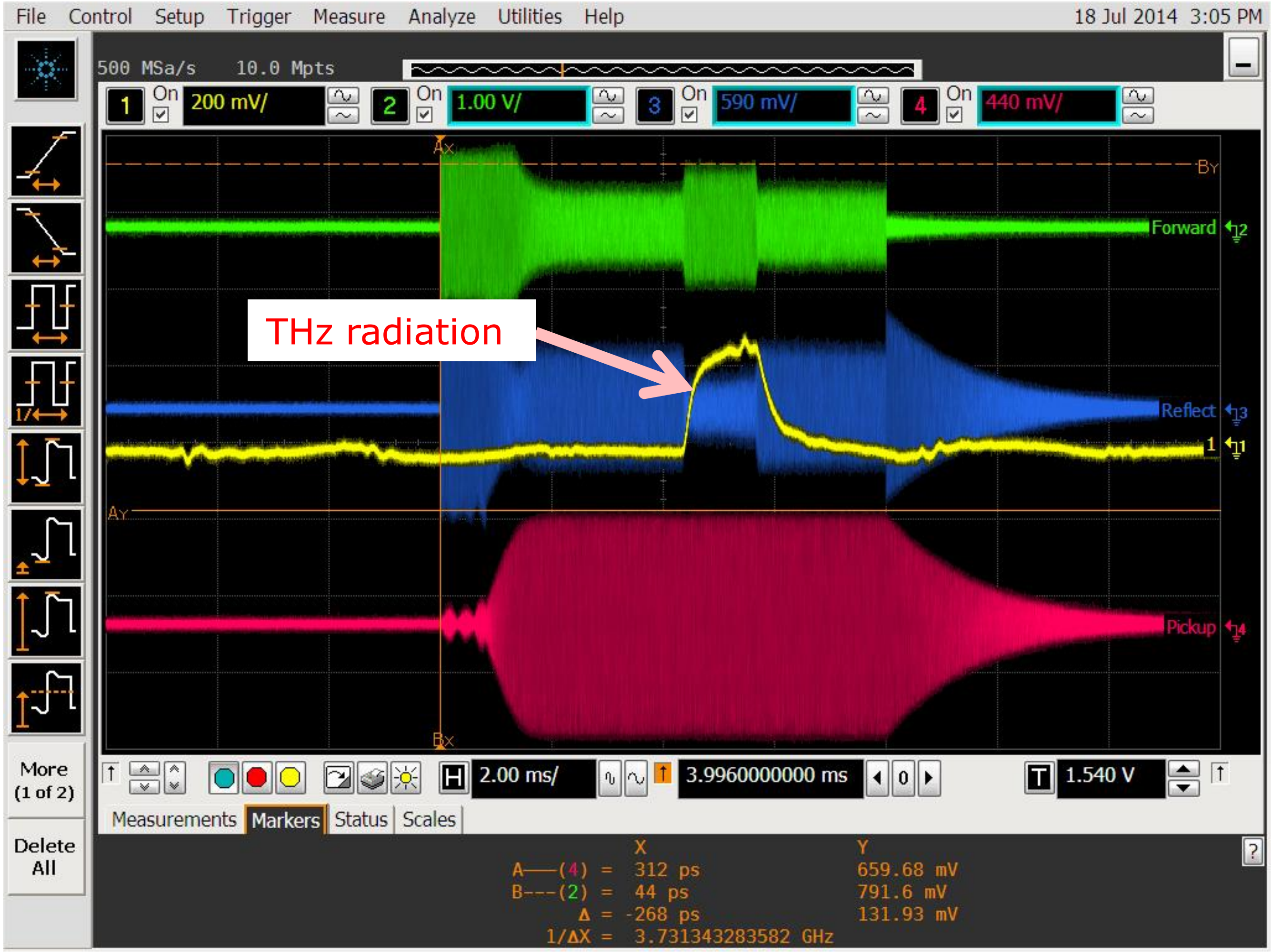
THz radiation experiment based on the DC-SRF injector





- Undulator and spectrometer assembled
- Solenoids, correcting coils, CCD camera and screens added
- The shape and position of the laser spot monitored
- Laser pulse shutter and synchronization control between the laser and RF upgraded

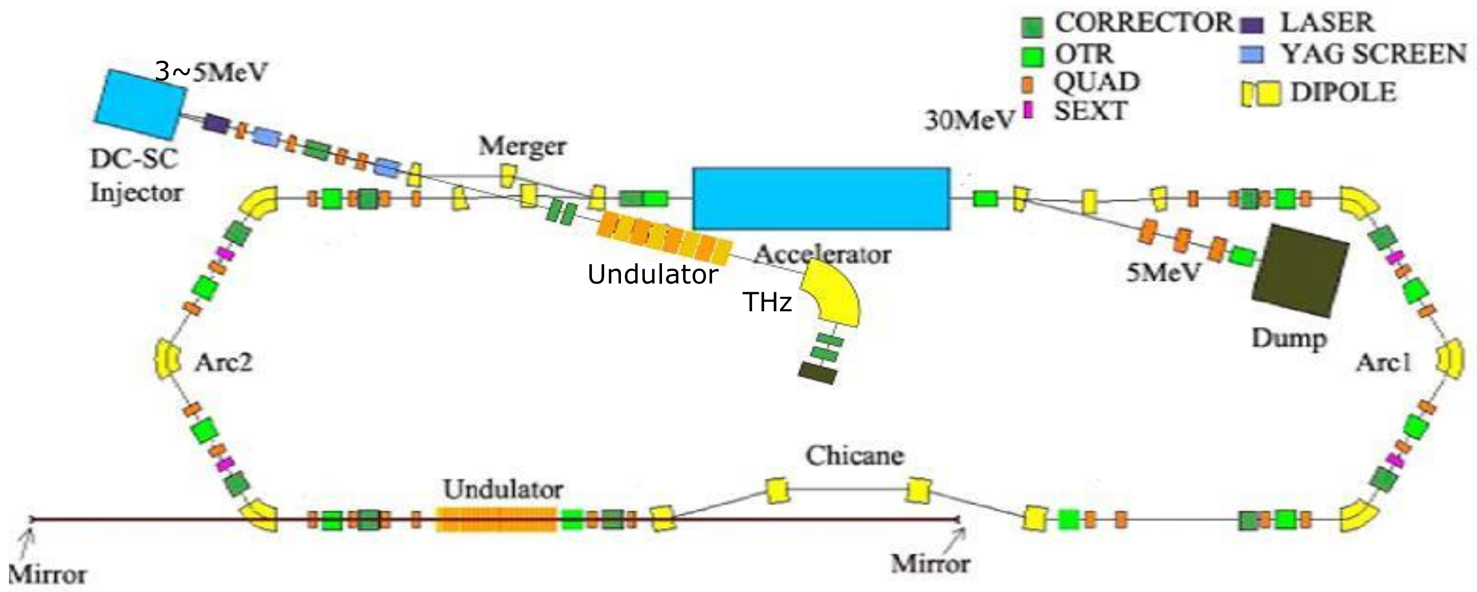
THz radiation experiment based on the DC-SRF injector



Summary and prospect

- RF power supply, photocathode preparation system and beam line are improved
- Progress has been made on the 3.5-cell DC–SRF photocathode injector
- This injector can work both on CW mode and pulsed mode
- 3.4MeV 0.55mA 7% pulsed electron beam has been stably obtained

- limitation of higher current is degassing of dump faraday cup
- 1mA beam is expected with a beryllium window before the dump
- THz radiation has been observed, for the precise measurement of the power and spectrum will be made at the end of this year
- DC-SRF injector will be used for THz radiation and then for ERL-FEL

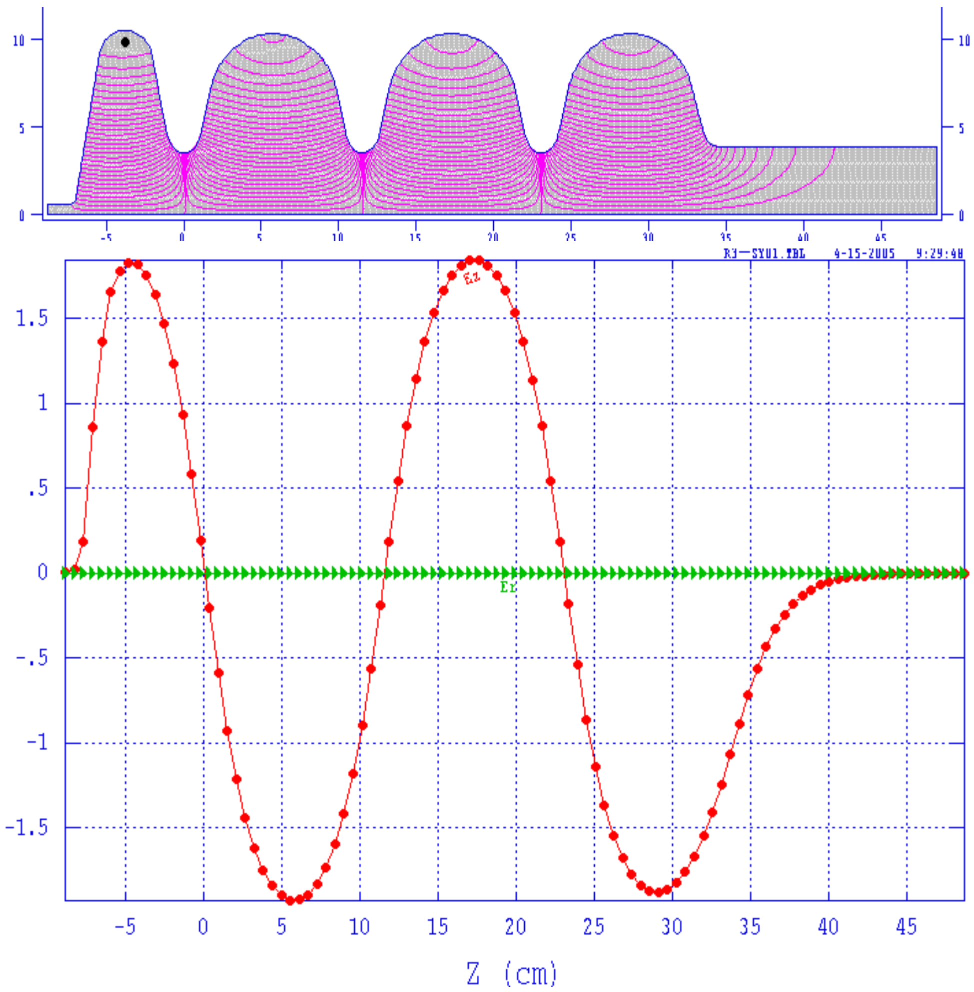


Thank you for your attention !

Design Parameters of the DC-SRF injector（DC voltage 90KV）

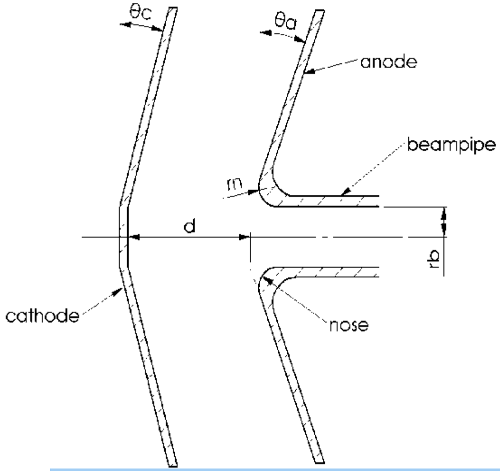
Drive laser		
Pulse length（FWHM）	**10ps**	
laser spot（FWHM）	**3.0mm**	
Repetition rate	**81.25MHz**	
Bunch charge distribution	**transverse uniform , longitudinal Gaussian**	
Injector	**ERL mode**	**THz mode**
gradient	**13 MV/m**	**15MV/m**
Bunch charge	**60~100 pc**	**20pc**
energy	**5MeV**	**<5MeV**
Transverse emittance (rms)	**1.2mm·mrad**	**2.1 mm·mrad**
Longitudinal emittance (rms)	**15 deg—KeV**	**3.0deg—KeV**
Bunch length（rms）	**3ps**	**0.55ps**
Rms beam spot	**0.3mm**	**1.7mm**
Energy spread	**～0.5%**	**0.55%**

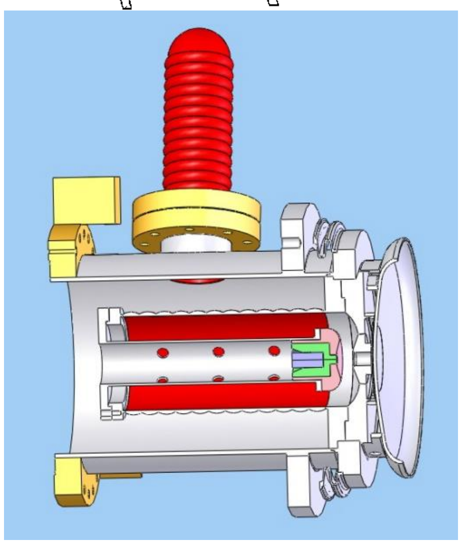
Electric field distribution of the 3.5cell cavity

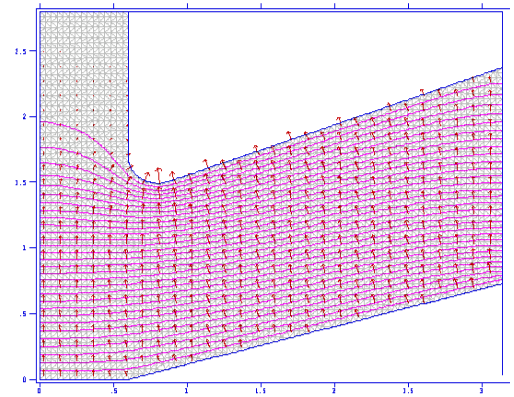


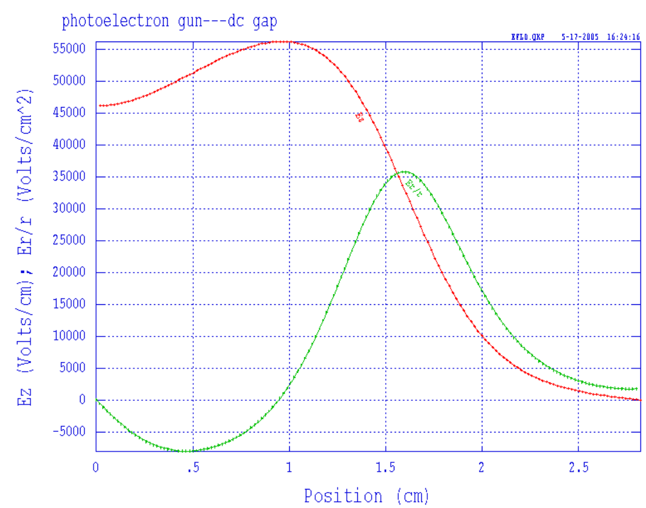
Mode	TM010,π-mode
Working frequency	1300 MHz
Q_0	1×10^{10}
Eacc	13 MV/m
Effective Length	0.417 m
G-factor	242 Ω
Shunt Impedence r/Q	417 Ω
E_{peak}/E_{acc}	2.12
B_{peak}/E_{acc}	4.95 mT/(MV/m)

Electric field of DC pierce stucture







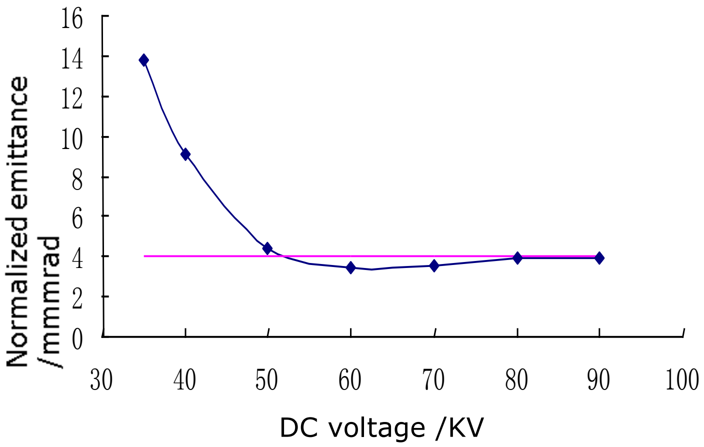


structure of DC-gun

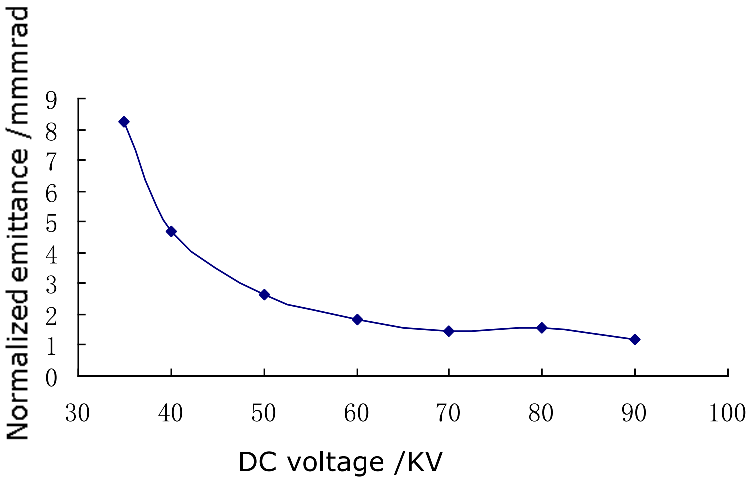
Electric field distribution of the DC-gun

Effect of DC voltage on emittance

Gaussian transverse distribution,
Gaussian longitudinal distribution

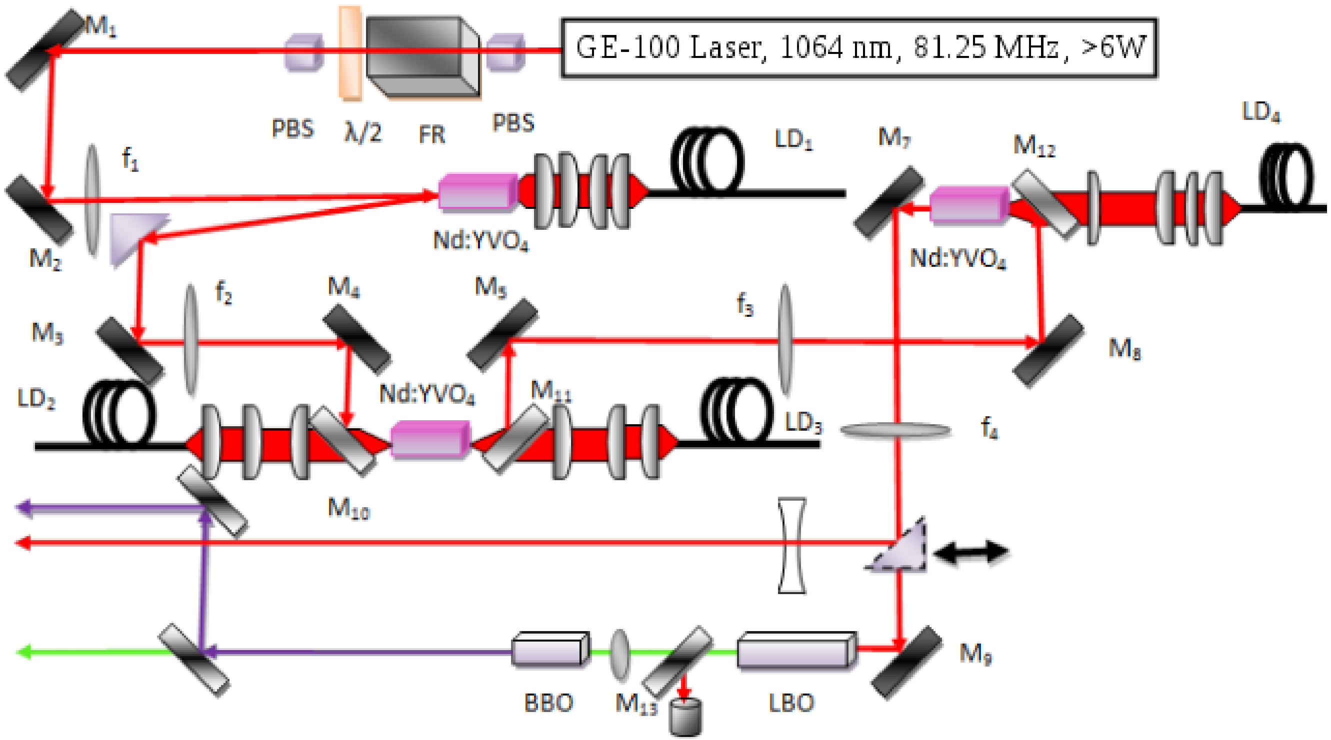


Flattop transverse distribution
Gaussian longitudinal distribution



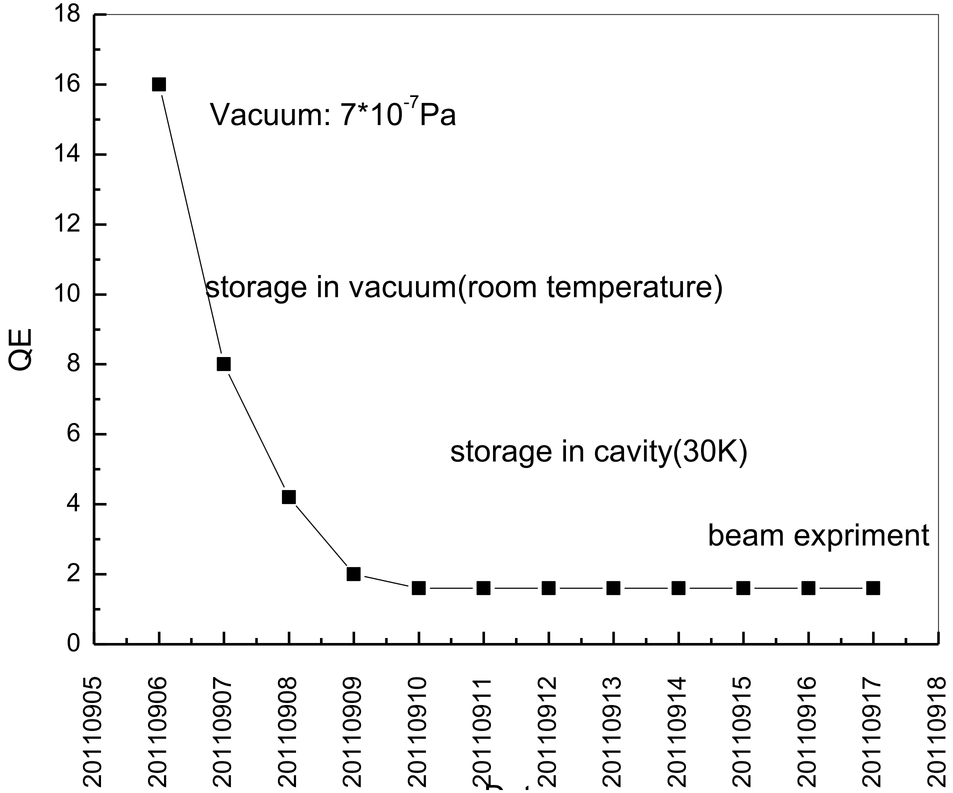
Transverse emittance v.s. DC voltage (100pC, 13MV/m)

Drive laser system



Seed laser is commercial picosecond oscillator (Time-Bandwith GE-100) and was upgraded. Upgraded system compose of amplifier, SHG, FHG, lenses, control system and cooling system

QE of photocathode



The UV laser power on the surface of the photocathode is about 0.1 W, and the photocurrent is 350 uA

No degradation was found during the two weeks' experiment

Fourier Transform Far-Infrared Spectrometer

Spetral range : 8000-10cm^{-1} (1.25μm -1.0mm)

Resolution: better than 0.07cm^{-1}