DC-SRF photocathode injector for ERL at Peking University

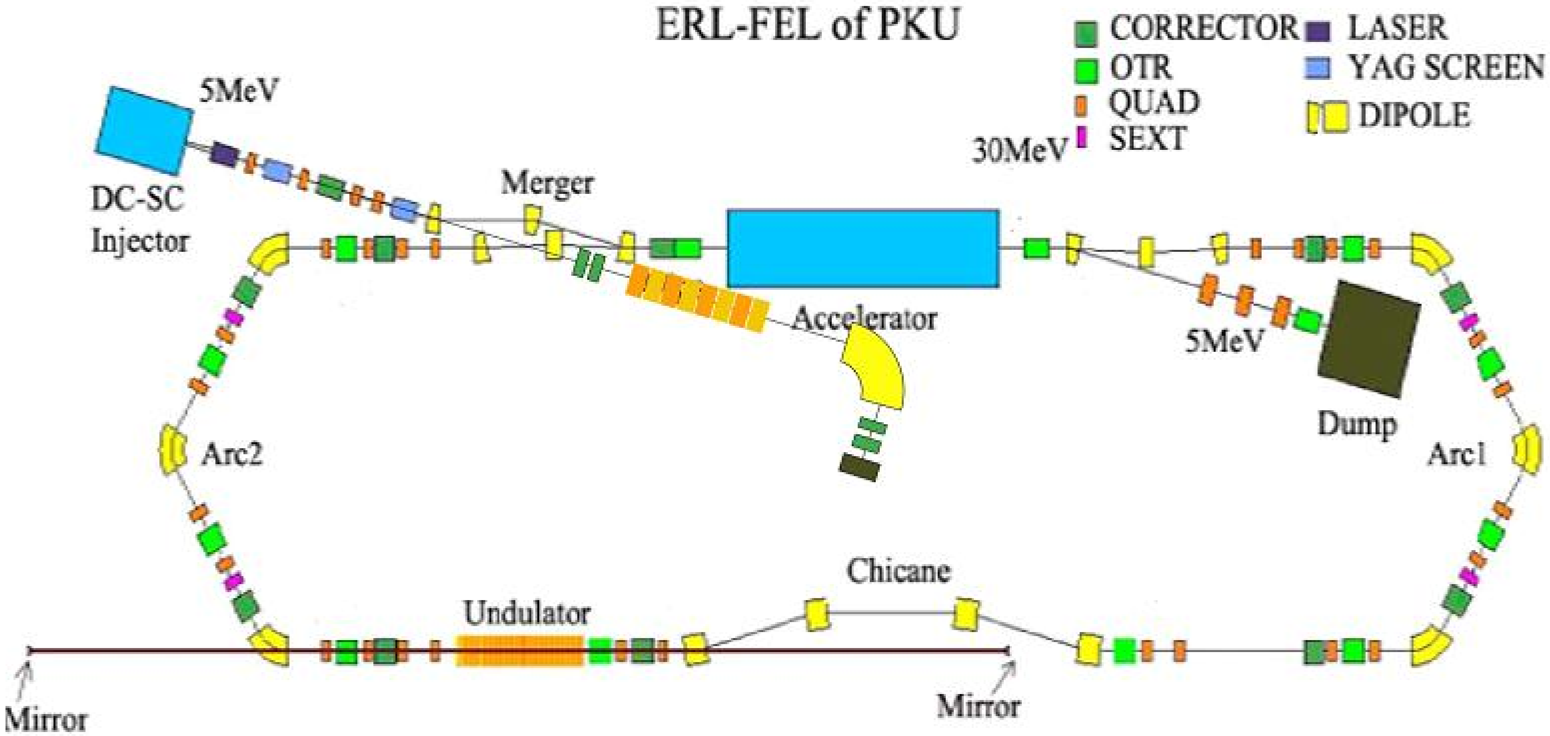
SRF group
Institute of Heavy Ion Physics
Peking University

October 18, 2011

Outline

- ERL project at Peking University
- Design of DC-SRF photocathode injector
- 3.5 cell Injector cryomodule and testing beam line
- Preliminary RF and beam testing of DC-SRF gun
- Summary

ERL project at Peking University

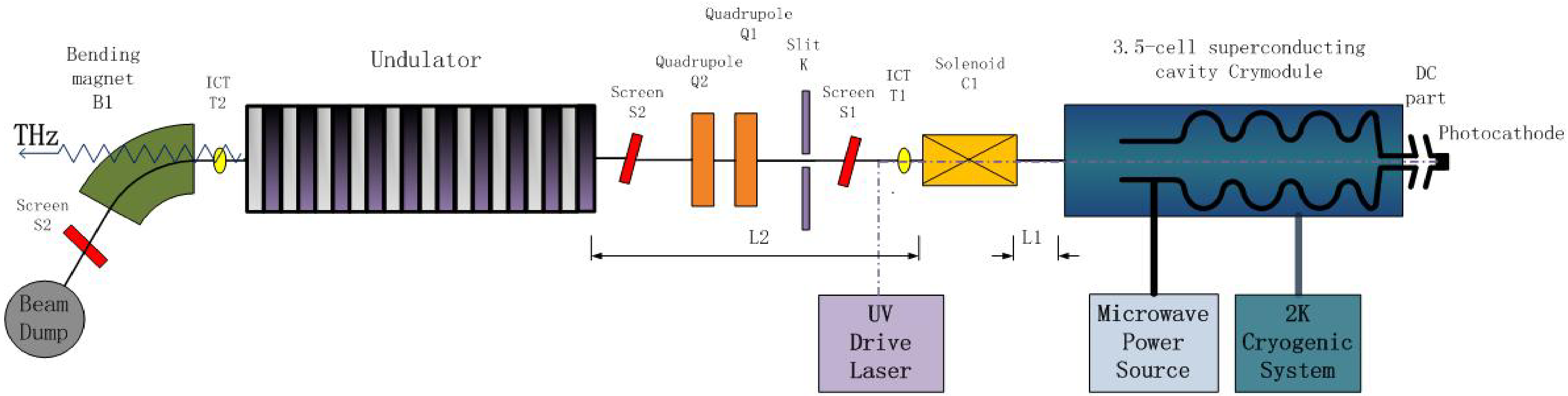


Peking University Superconducting ERL Test Facility (PKU-SETF)

Main parameters of SETF

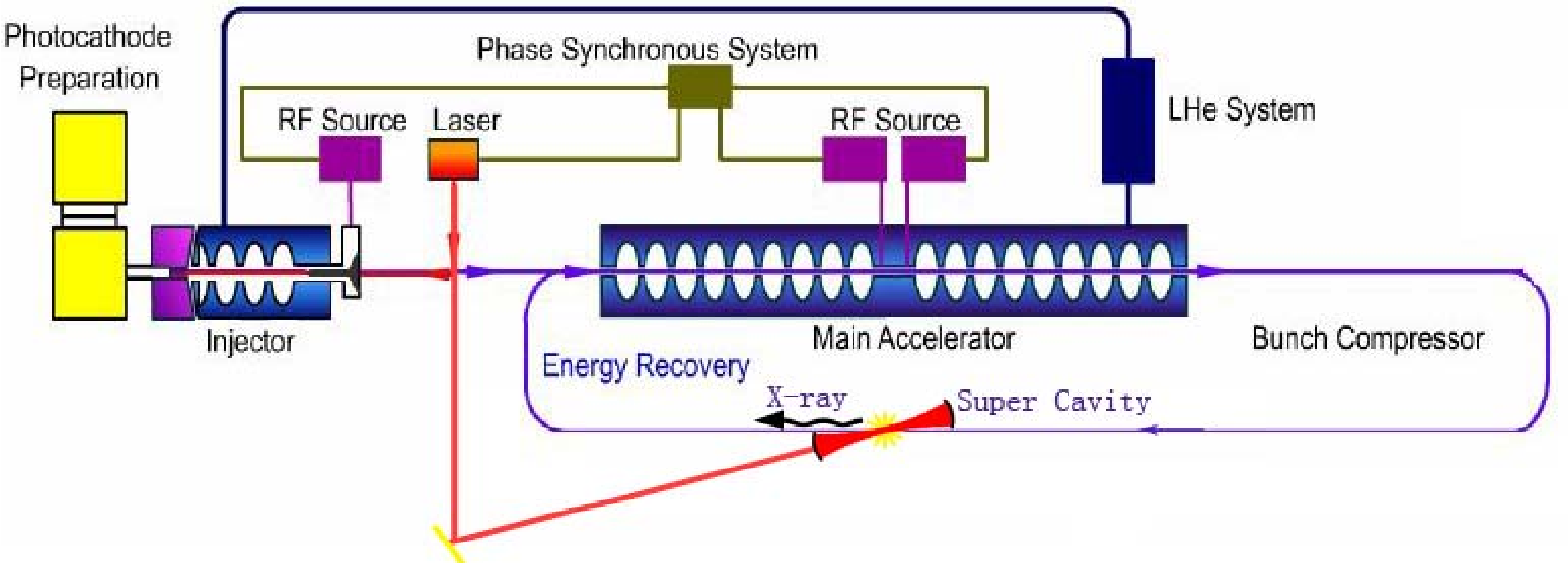
E Beam Parameters		FEL Parameters	
Energy [MeV]	30	Wavelength [um]	10.03 (5.1)
Energy spread, FWHM	0.32%	G0	0.61 (0.21)
Bunch charge [pC]	60	G	0.30 (0.10)
Normalized Emittance [mm.mrad]	4	Out-coupled peak power [MW]	2.12 (0.97)
Bunch length, FWHM [ps]	4	Out-coupled macro pulse avg power [W]	220.7 (101.2)
Micro pulse length [MHz]	26	Out-coupled avg power [W]	4.4 (2.0)
Macro pulse length [ms]	2	Intra-cavity peak power [MW]	26.53 (97.31)
Macro pulse repetition rate [Hz]	10	Intra-cavity avg power [W]	55.2 (202.4)

ERL project at Peking University



Quantity	Value
Wavelength	400μm ~ 1200μm
Radiation Angel	0.04 rad
Bandwidth	5%
Peak Power	~100 kW
Average Power	~1W

ERL project at Peking University



CBS: photon energy ~ 10keV

Flux ~ 10^8 photon/s

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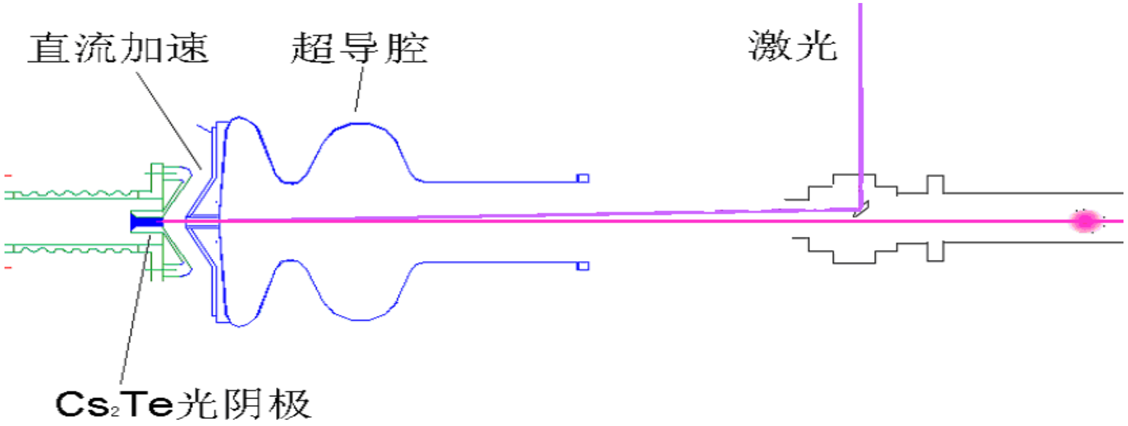
Basic Idea of DC-SRF Photo-injector



Pierce structure + SRF cavity

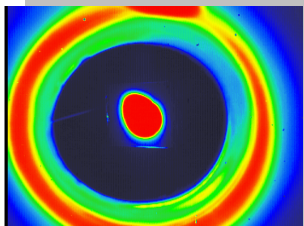
- Compatibility of photocathode and SC cavity
- Compact structure
- Could be operated at CW mode
- Good beam quality

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

Could handle moderate average current (1~10mA)

Feasibility Test at 4K

4.5KW Solid State Power Amplifier



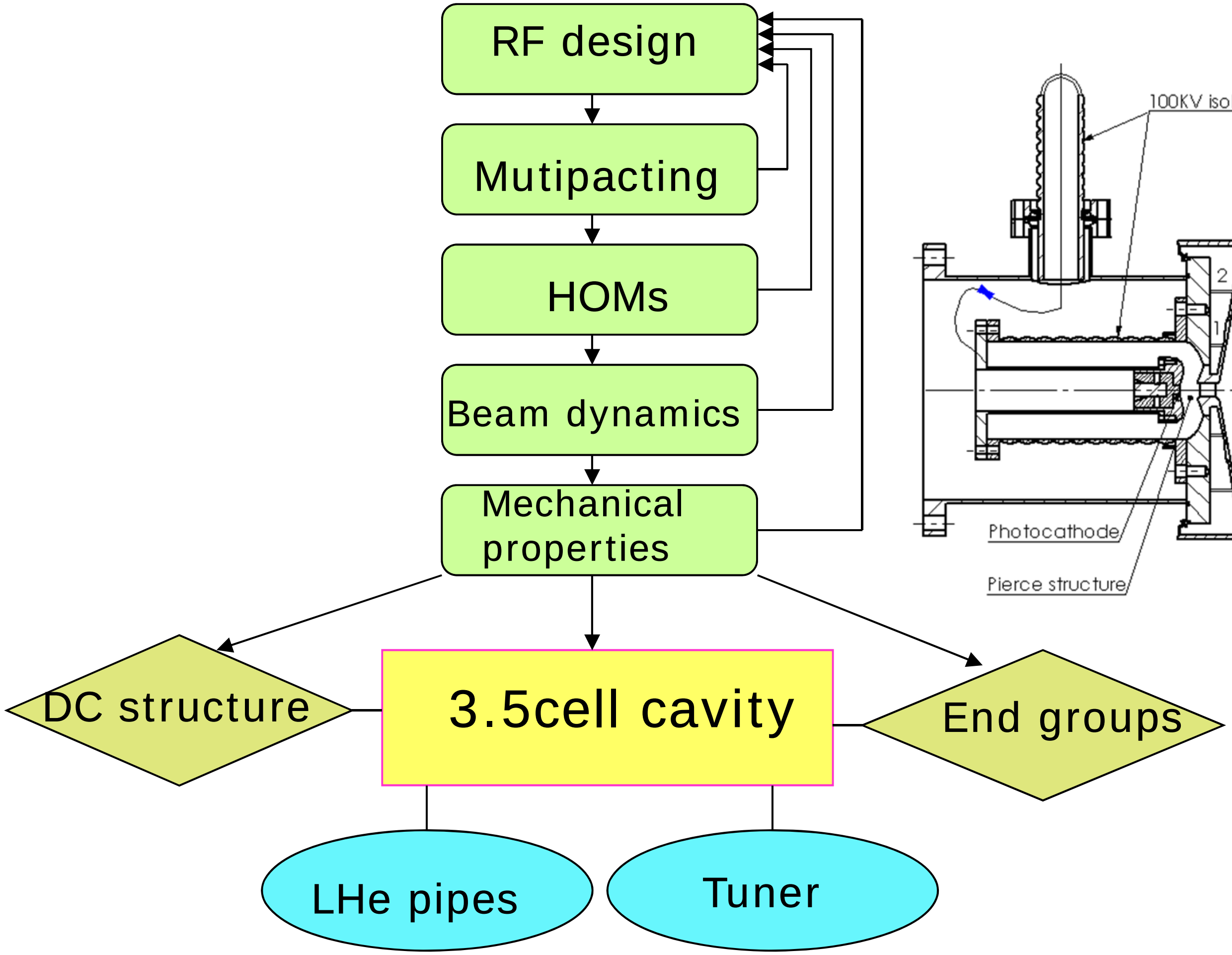
Electron Beam spot after RF acceleration

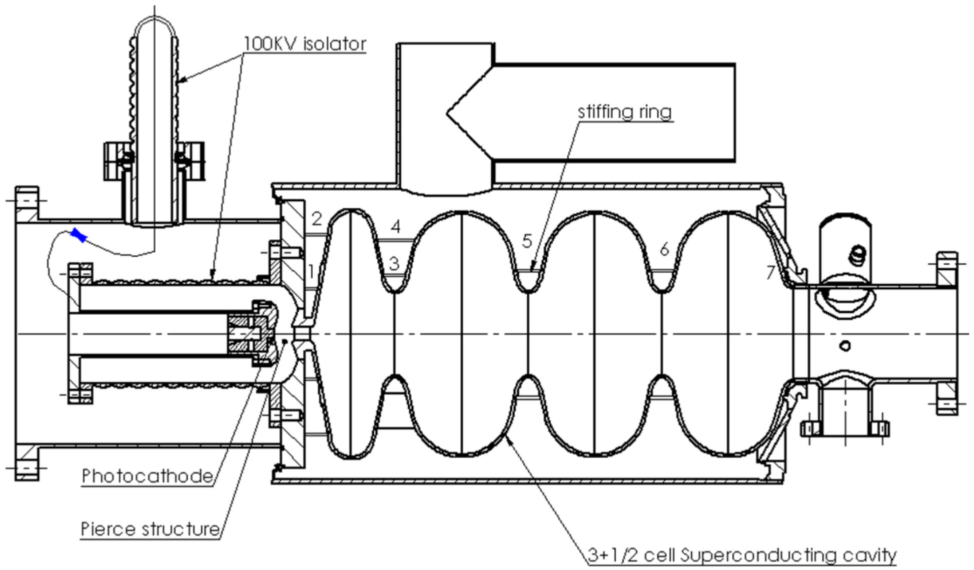
Prototype with a pierce gun and a 1.5cell superconducting cavity succeeded in accelerating electron beams at 4K in 2004

Energy gain ~1MeV, emittance~5μm

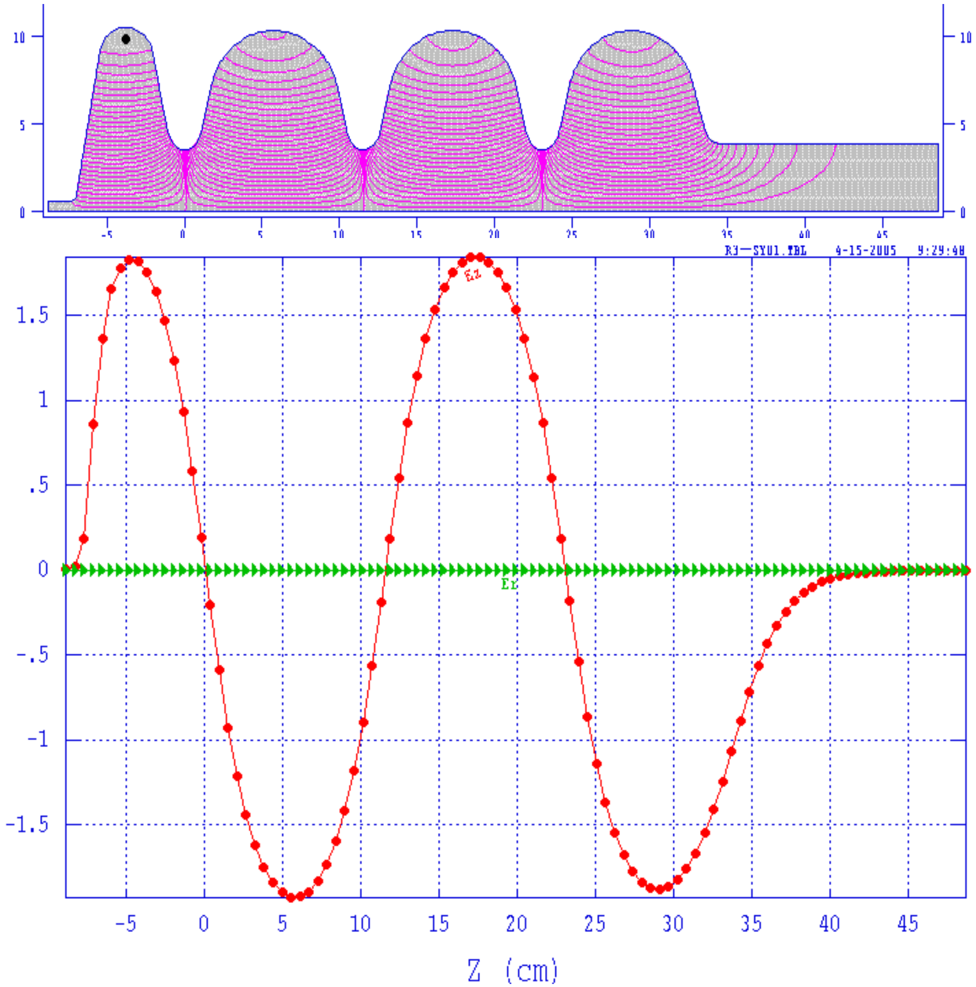
Promoted the design of an upgrade DC-SRF gun with 3.5 cell cavity

Design process of the 3.5cell superconducting cavity



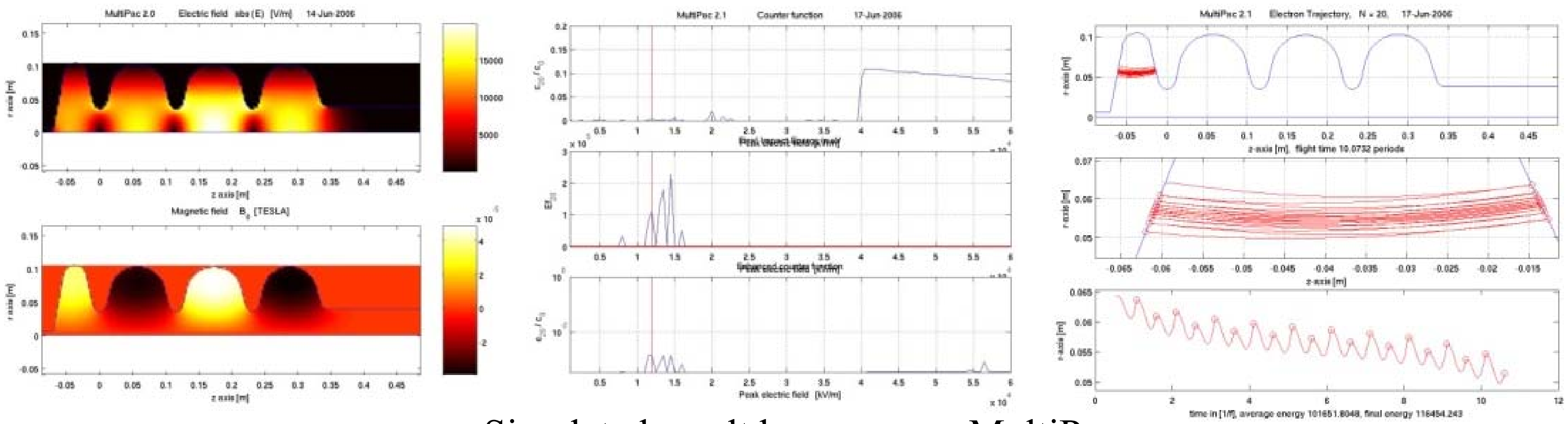


Electric field distribution of the 3.5cell cavity

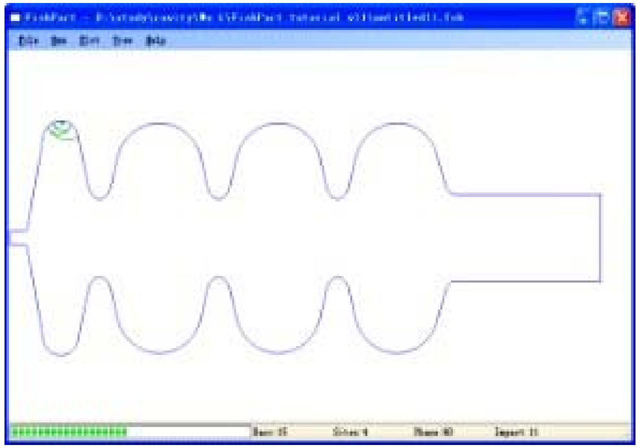


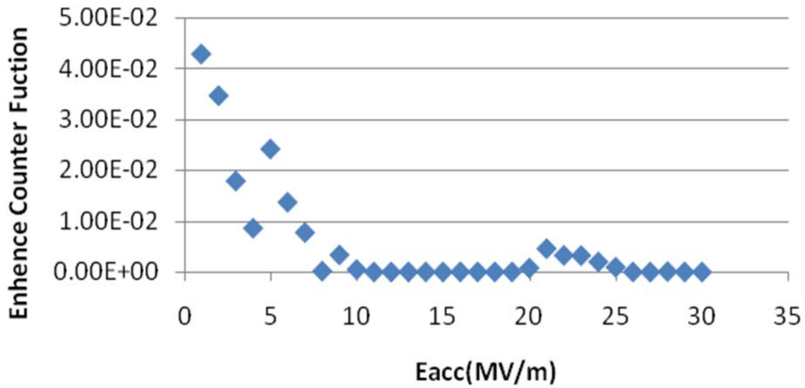
Mode	TM010,π-mode
Working frequency	1300 MHz
Q_0	1×10^{10}
Eacc	13 MV/m
Effective Length	0.417 m
G-factor	242 Ω
Shunt Impedence r/Q	417 Ω
E_{peak}/E_{acc}	2.12
B_{peak}/E_{acc}	4.95 mT/(MV/m)

No serious multipacting with reasonable geometrical parameters



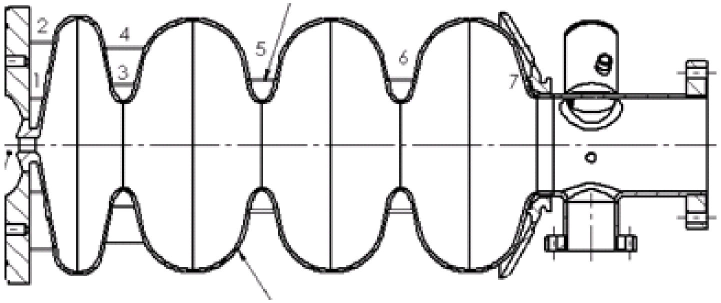
Simulated result by program MultiPac

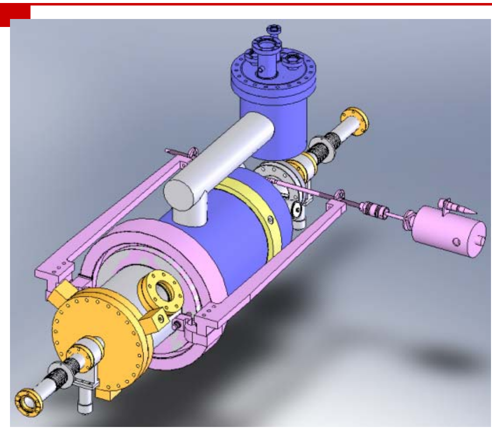




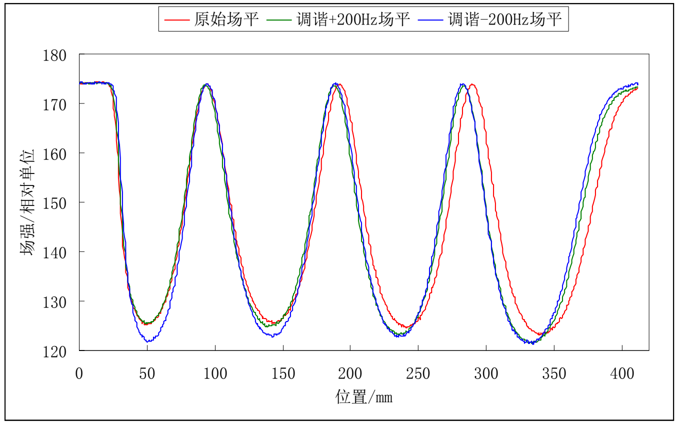
Result from FishPact

Mechanical properties of the 3+1/2 cell cavity





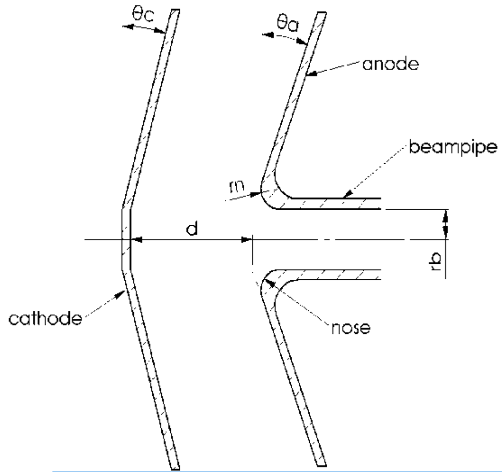
Stiffer ring	Position (distance from the axis) /mm
1	38
2	85
3	50
4	80
5, 6, 7	53.5

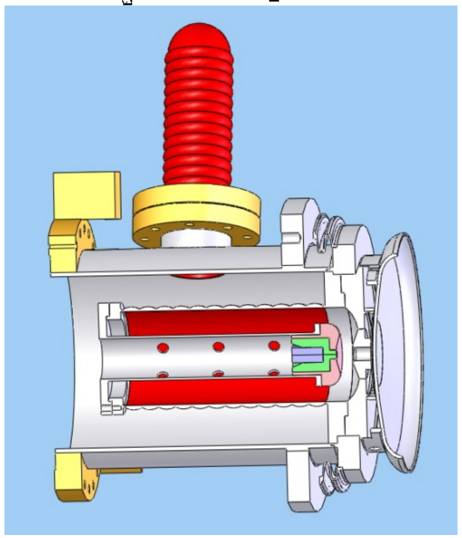


Field flatness

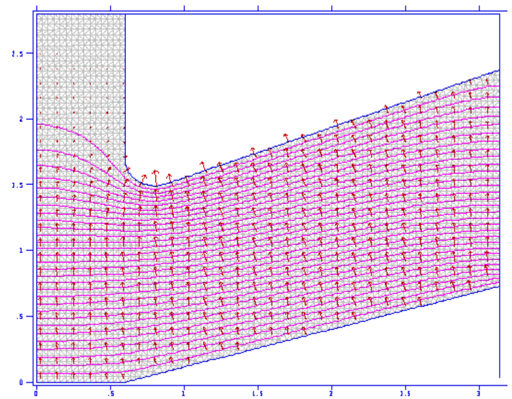
Lorentz force detuning coefficient	tuning range of the cavity	Frequency change by 0.1mm cavity deformation	Force on the cavity with 0.1mm cavity deformation	Flatness change after tuning ±0.4mm
$1.2Hz/(MV/m)^2$	±200kHz	70kHz	1000N	<3%

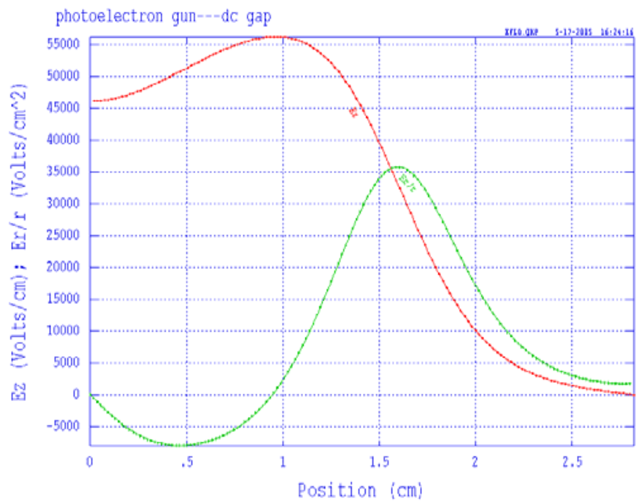
Electric field of DC pierce stucture





structure of DC-gun

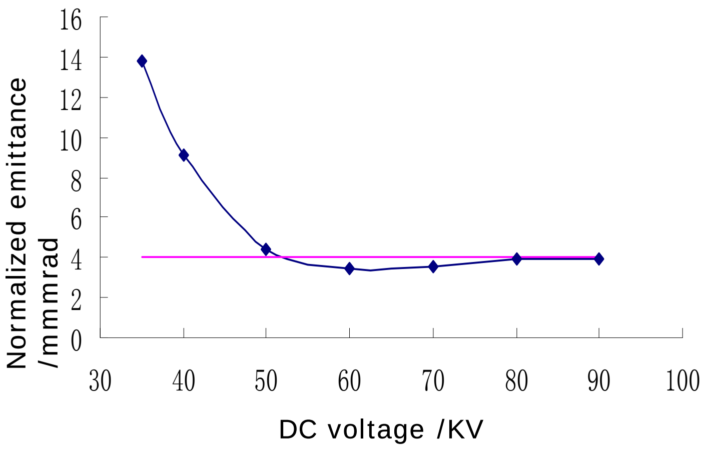




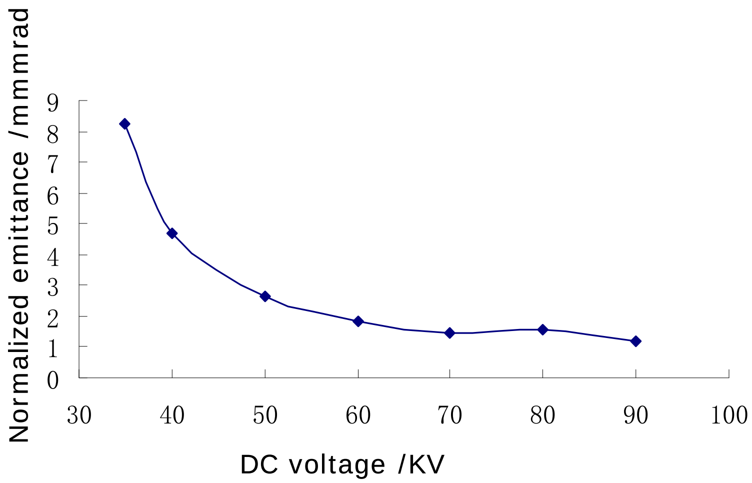
Electric field distribution of the DC-gun

Effect of DC voltage on emittance

Gaussian transverse distribution,
Gaussian longitudinal distribution

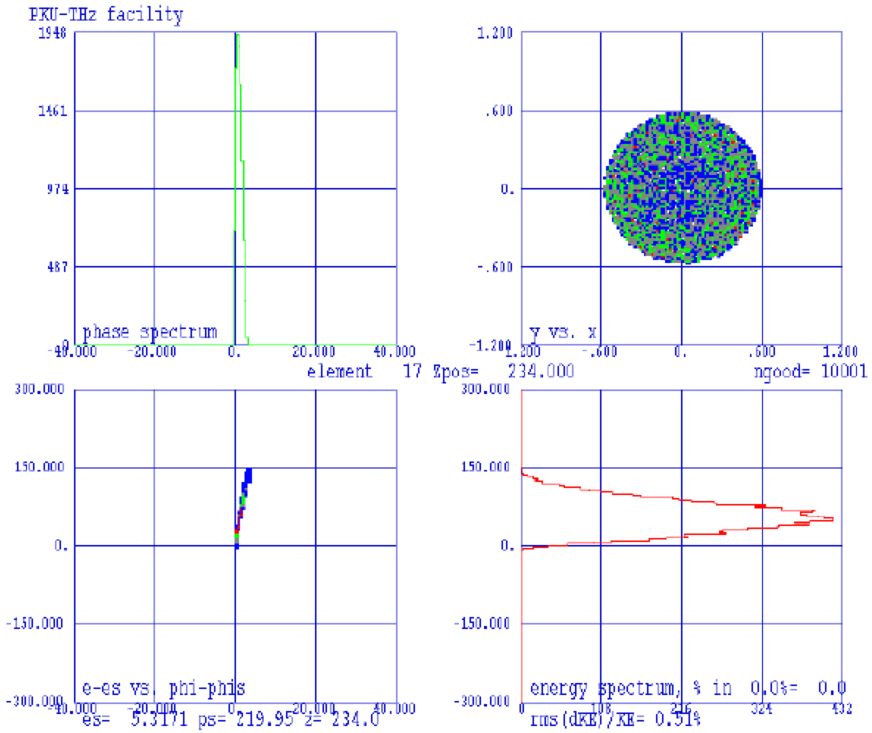


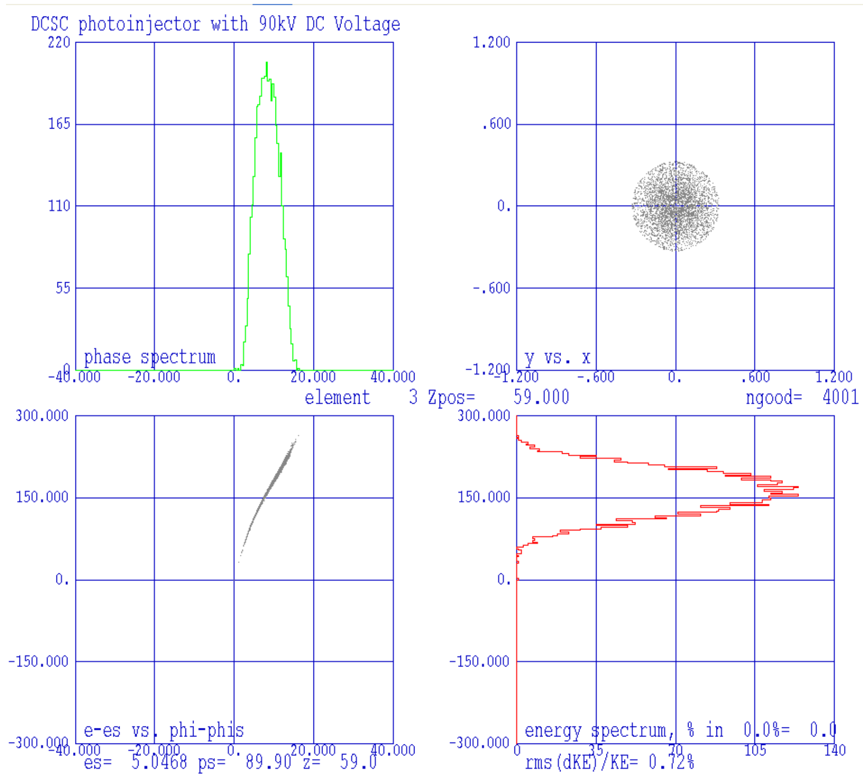
Flattop transverse distribution
Gaussian longitudinal distribution



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

Beam Dynamics simulation at two different operating modes





Pulse shape, beam spot, energy spectrum of the output beam

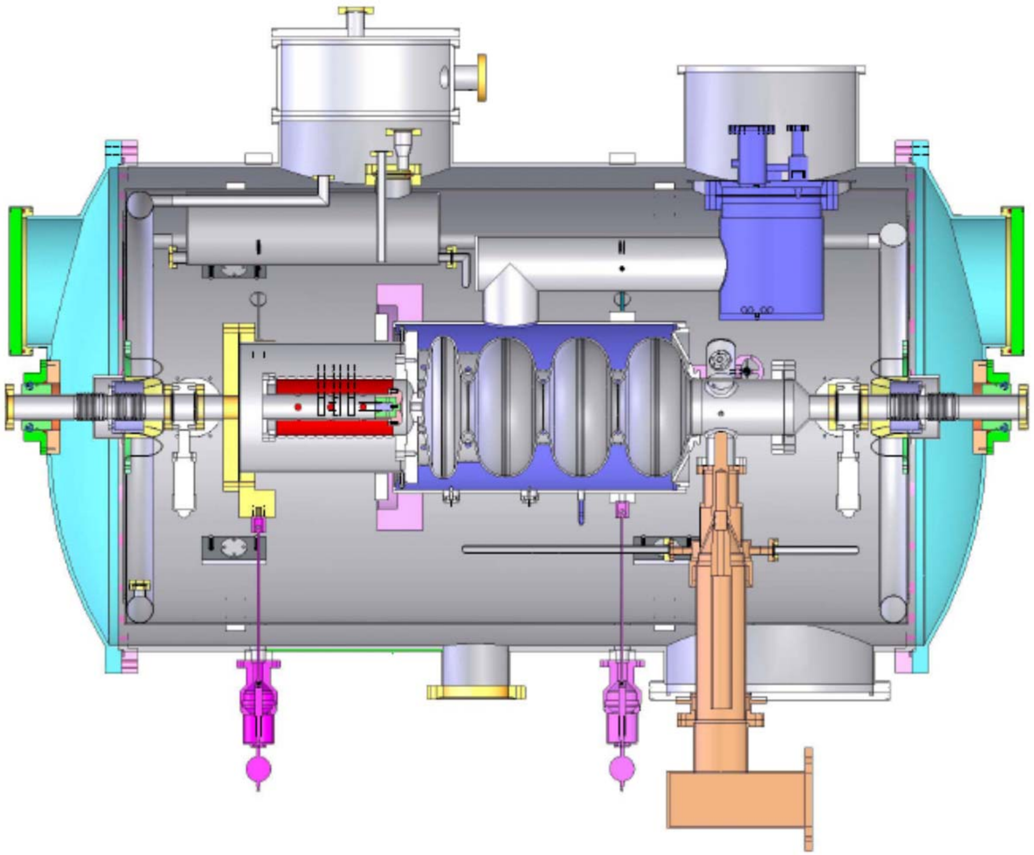
THz mode

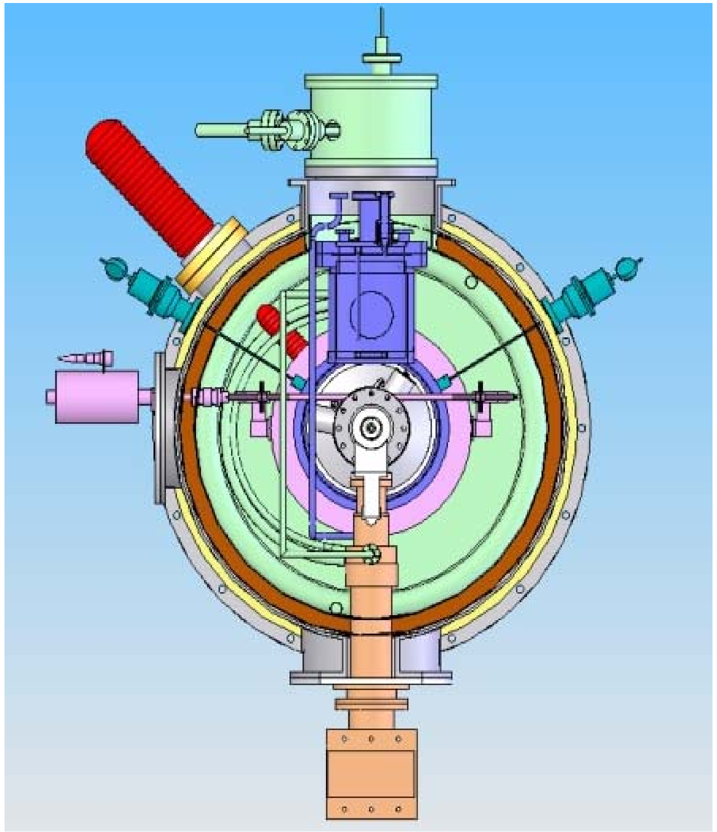
ERL based FEL mode

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%**

Upgrade of DC-SRF injector





- 100 KV Pierce DC gun with Cs_2Te cathode matched with SRF cavity
- Providing 3-5 MeV electron beam with bunch charge of 60 pC and low emmittance

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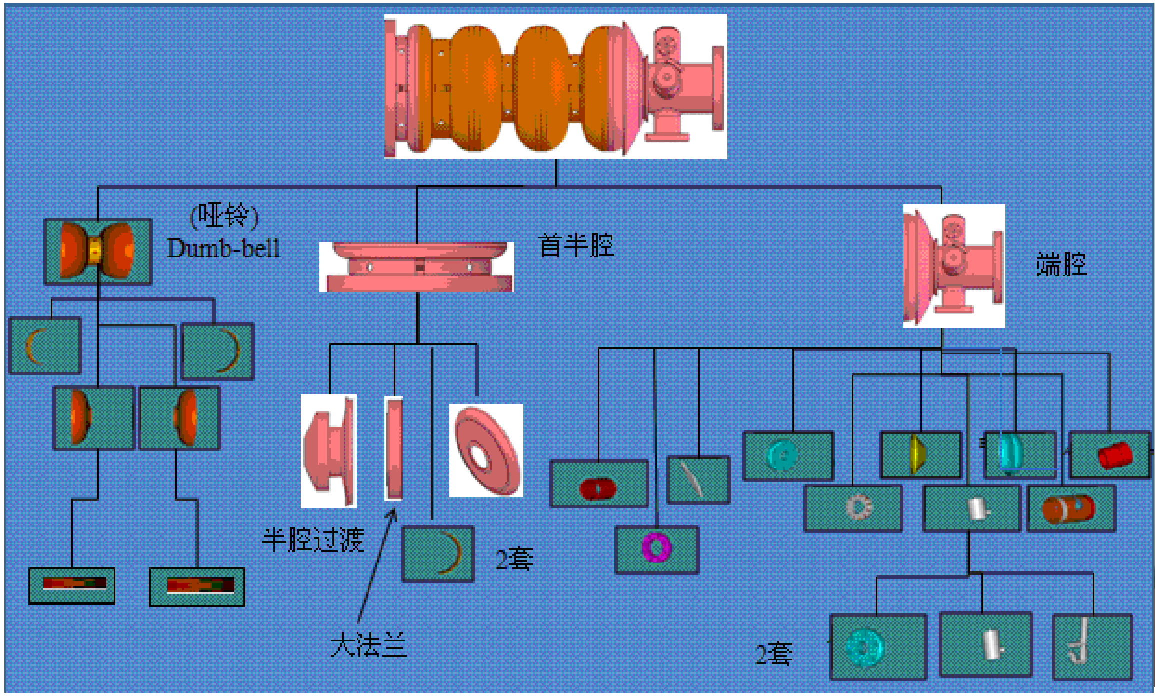
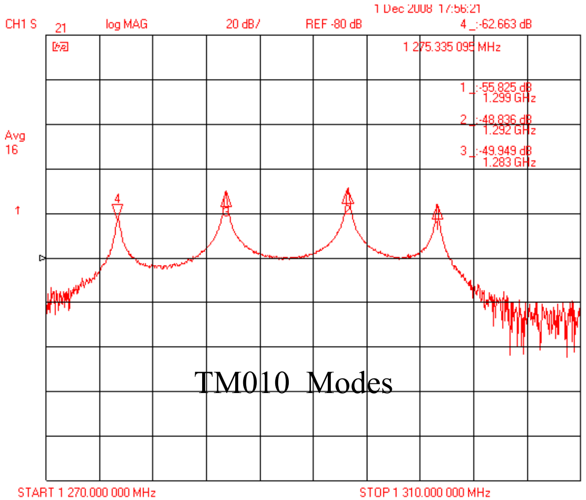
Fabrication and test of 3.5 cell cavity

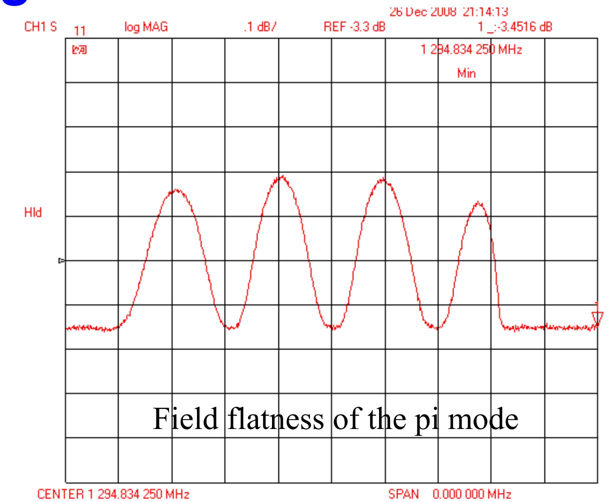


Deep drawn，precise machining，high vacuum electron beam welding

Fabrication and test of 3.5 cell cavity

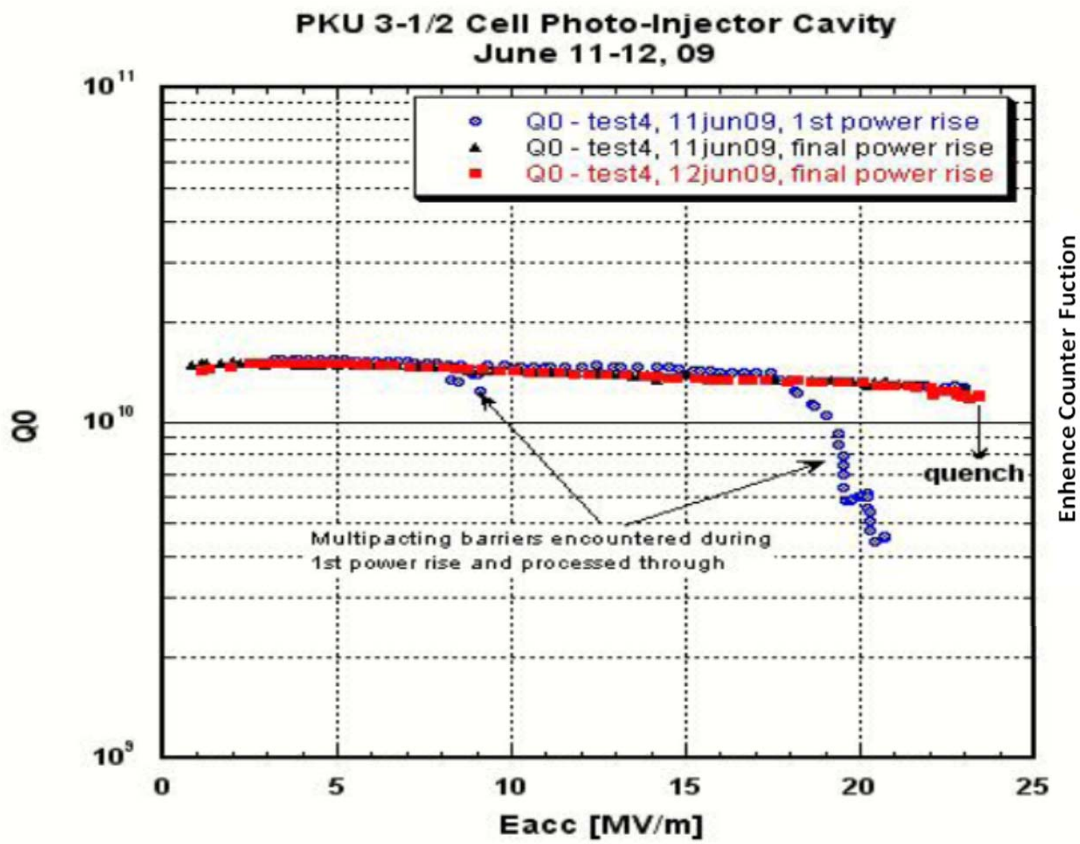
1250C annealing

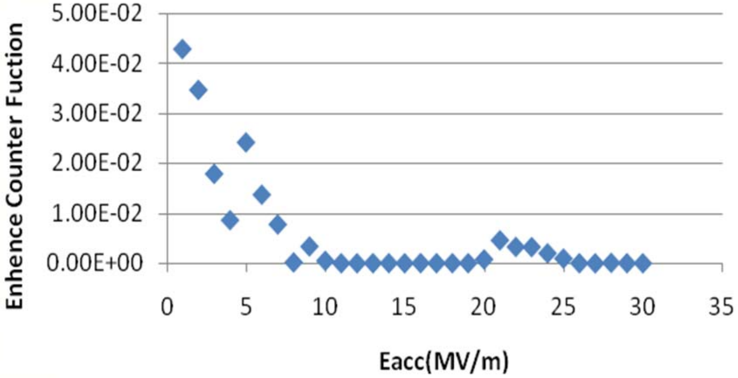




Room temperature RF measurement

Fabrication and test of 3.5 cell cavity

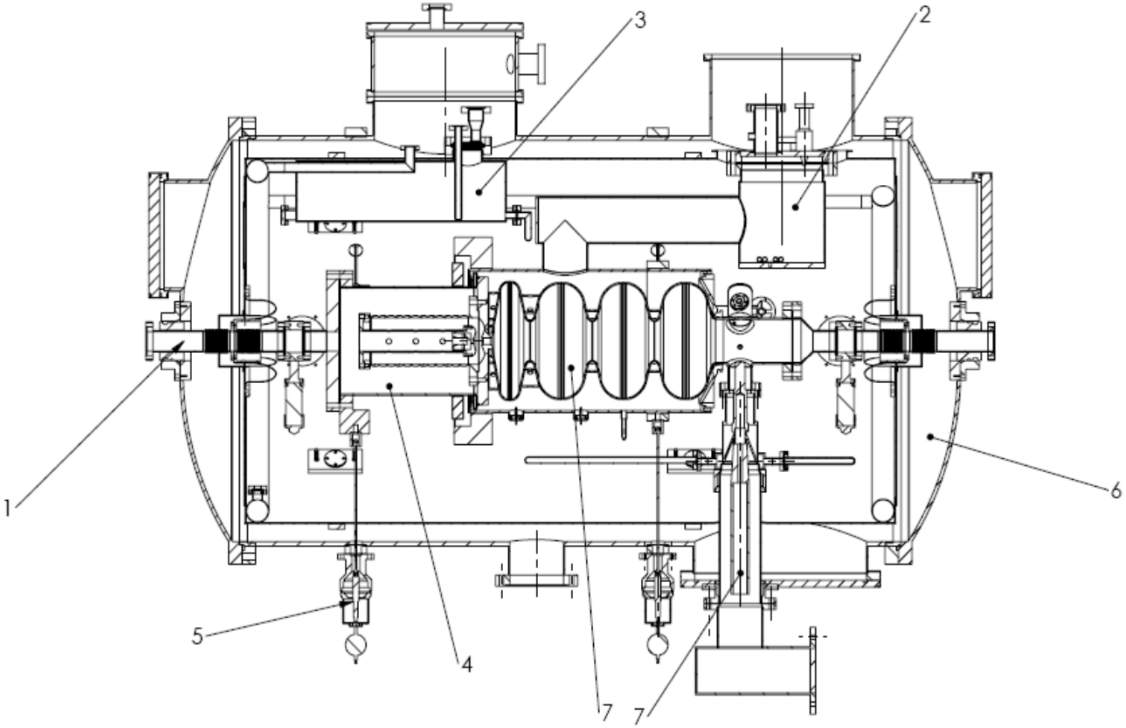


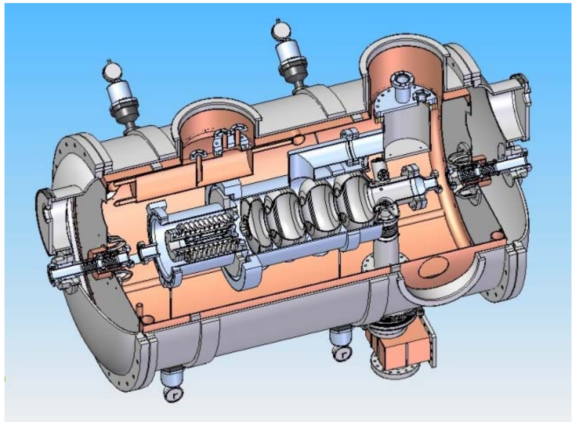


Simulation results on MP

Large grain 3.5 cell Nb cavity of 23.5 MV/m @ Q_0 >1E10 after BCP, HPR and baking 2 hrs at 800^0c by Dr. R. Geng at J-Lab

Meanufacture and assembling of cryomodule

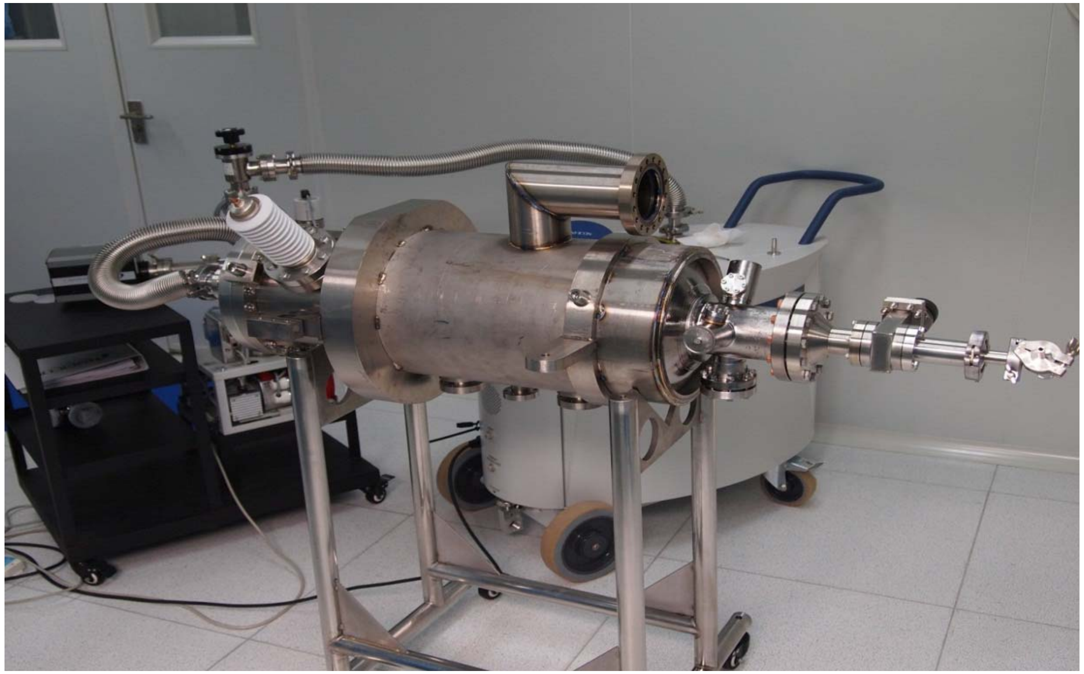




1: photocathode transportation line ； 2：LHe buffer and two phase tube；3：LIN buffer and LIN thermal shield ；4： DC part；5：suspending structure；6：vacuum vessel；7：main coupler and tuner

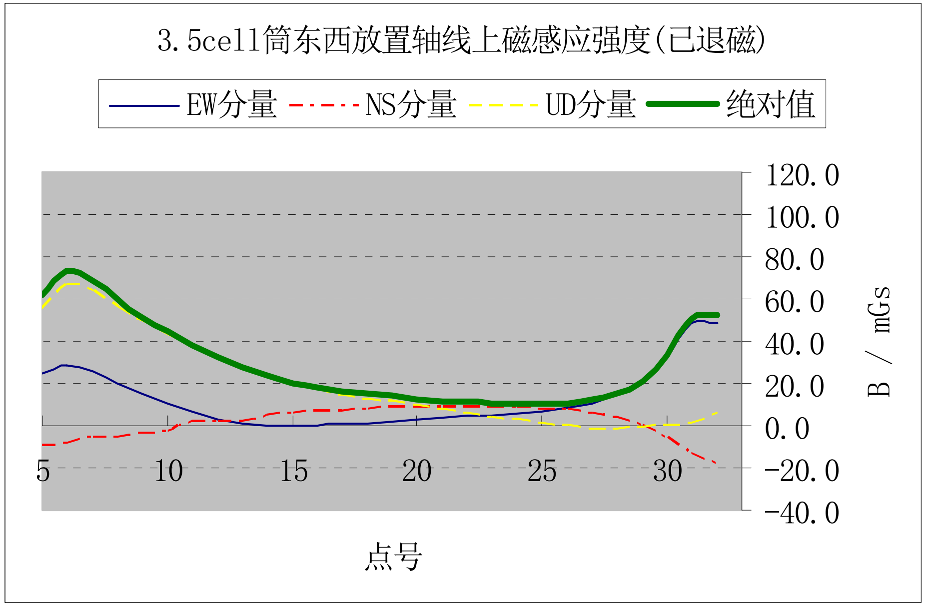
Meanufacture and assembling of cryomodule

HPR in clean room



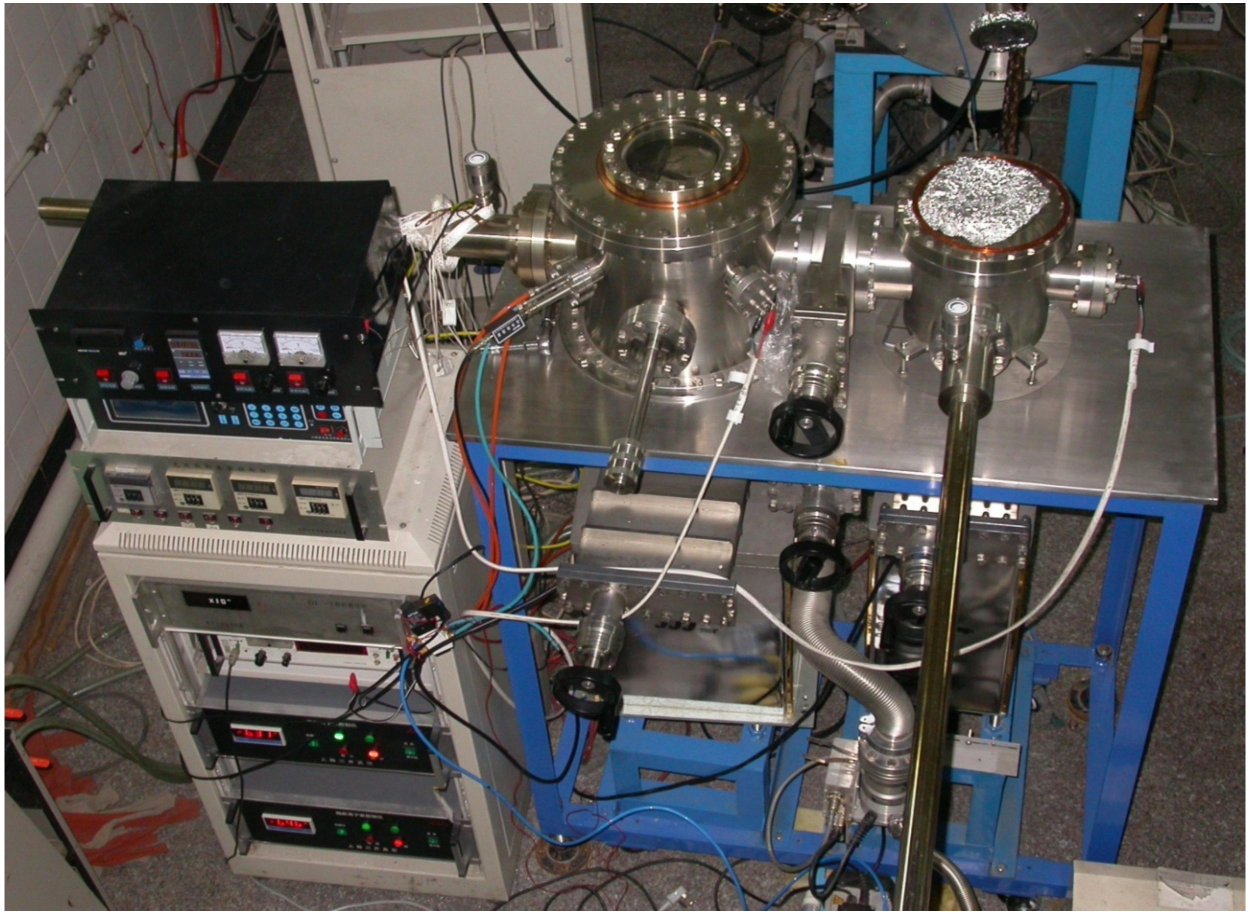
Leak check after assembling of DC high voltage feedthrough and beam pipe

Meanufacture and assembling of cryomodule



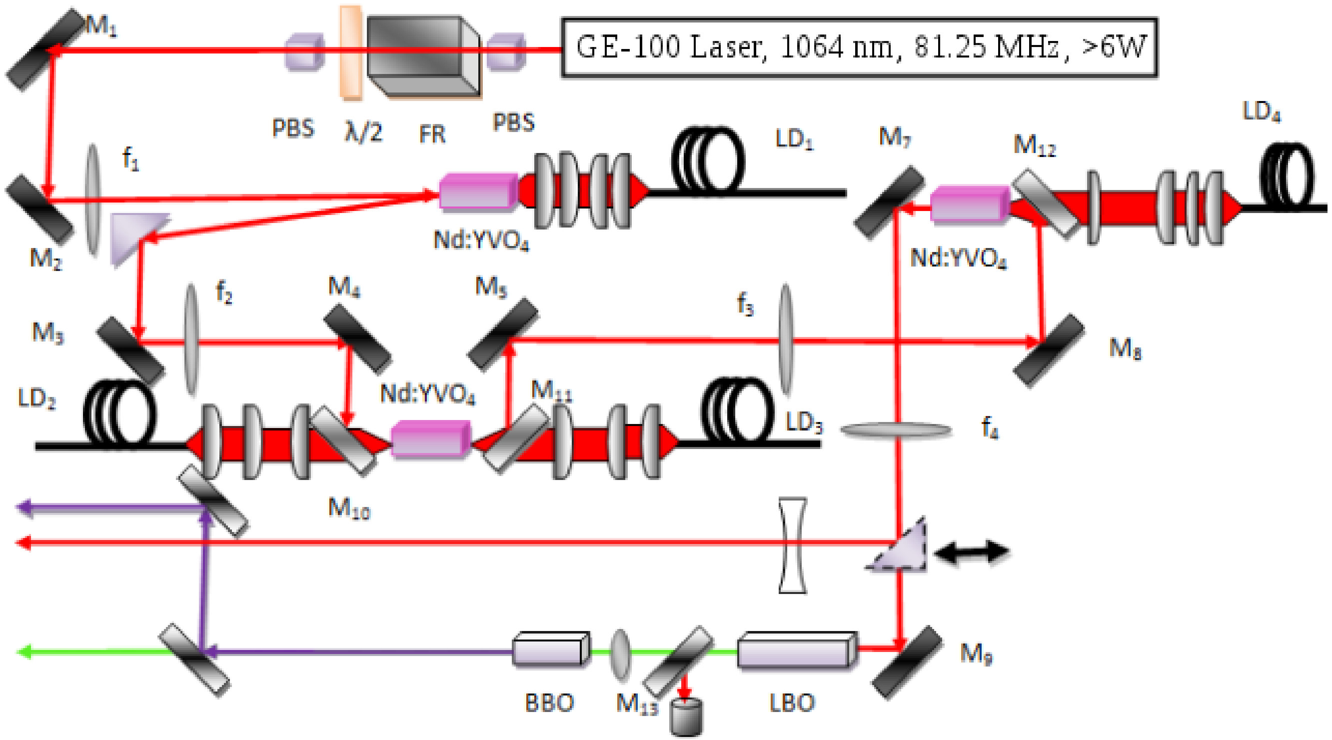
Magnetic field along the axis of the tank

On-line photocathode preparation system



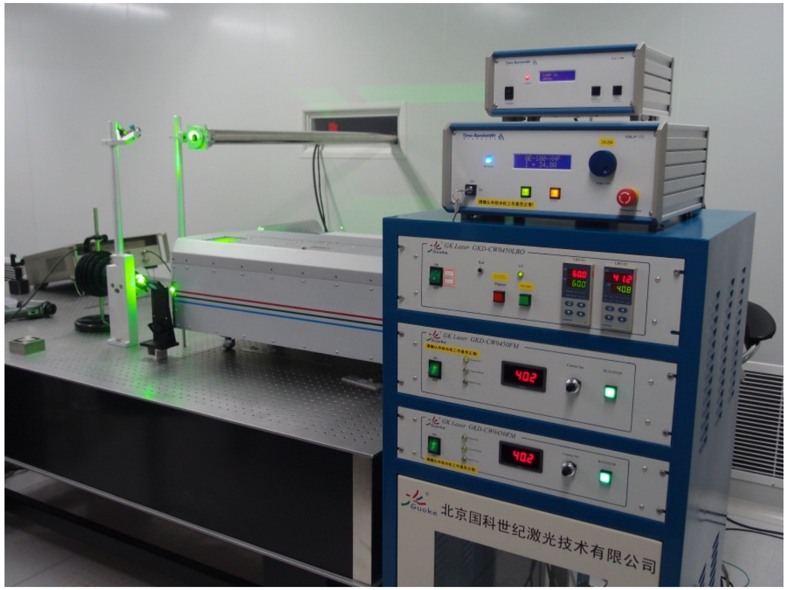
Cs2Te photocathode is prepared on stainless steel substrate,
Substrate is heated to 120°C and the vacuum is ~5×10^{-7} Pa

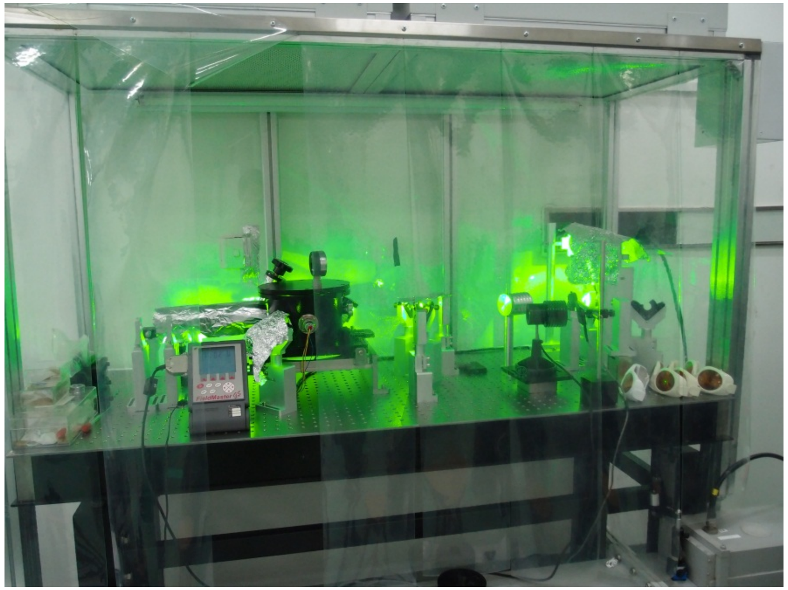
Drive laser system



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

Drive laser system





The laser output power: seed laser（1064nm）5W, after amplified ~40W, green light (532nm) >10W, UV light（266nm）>1W

Repetition rate:81.25MHz

Test beam line of the 3.5cell cavity DC-SRF injector

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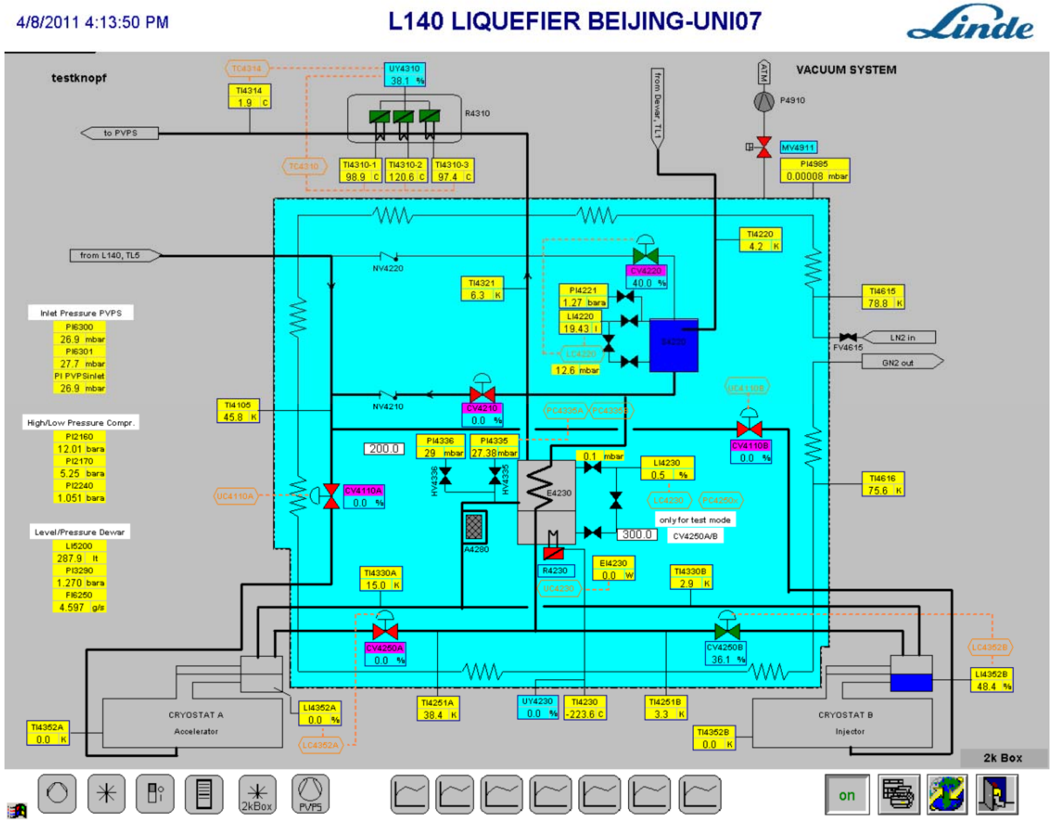
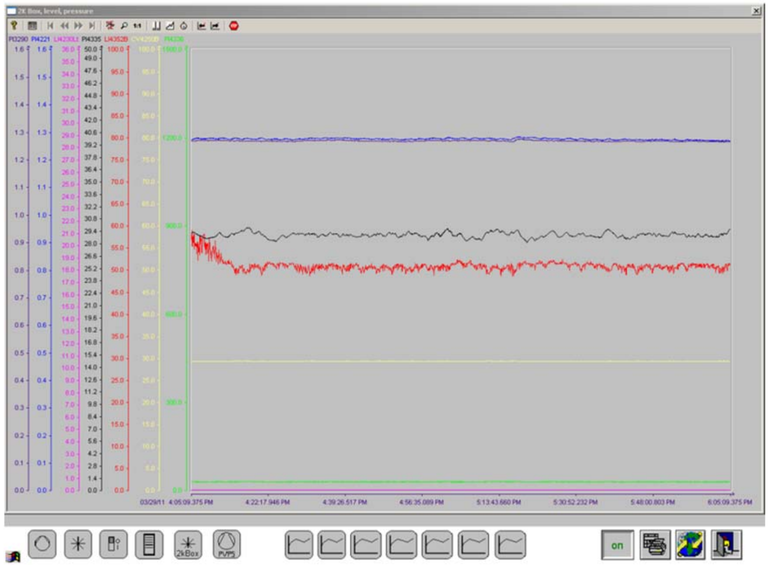
2K cryogenic system at Peking University

Main parts from Linde, transfer lines made in China,
cooling capacity: 58W @2K
Heat load of the 2K transfer lines: <0.5W/m

2K cryogenic system at Peking University

Control diagram of the 2K cryogenic system



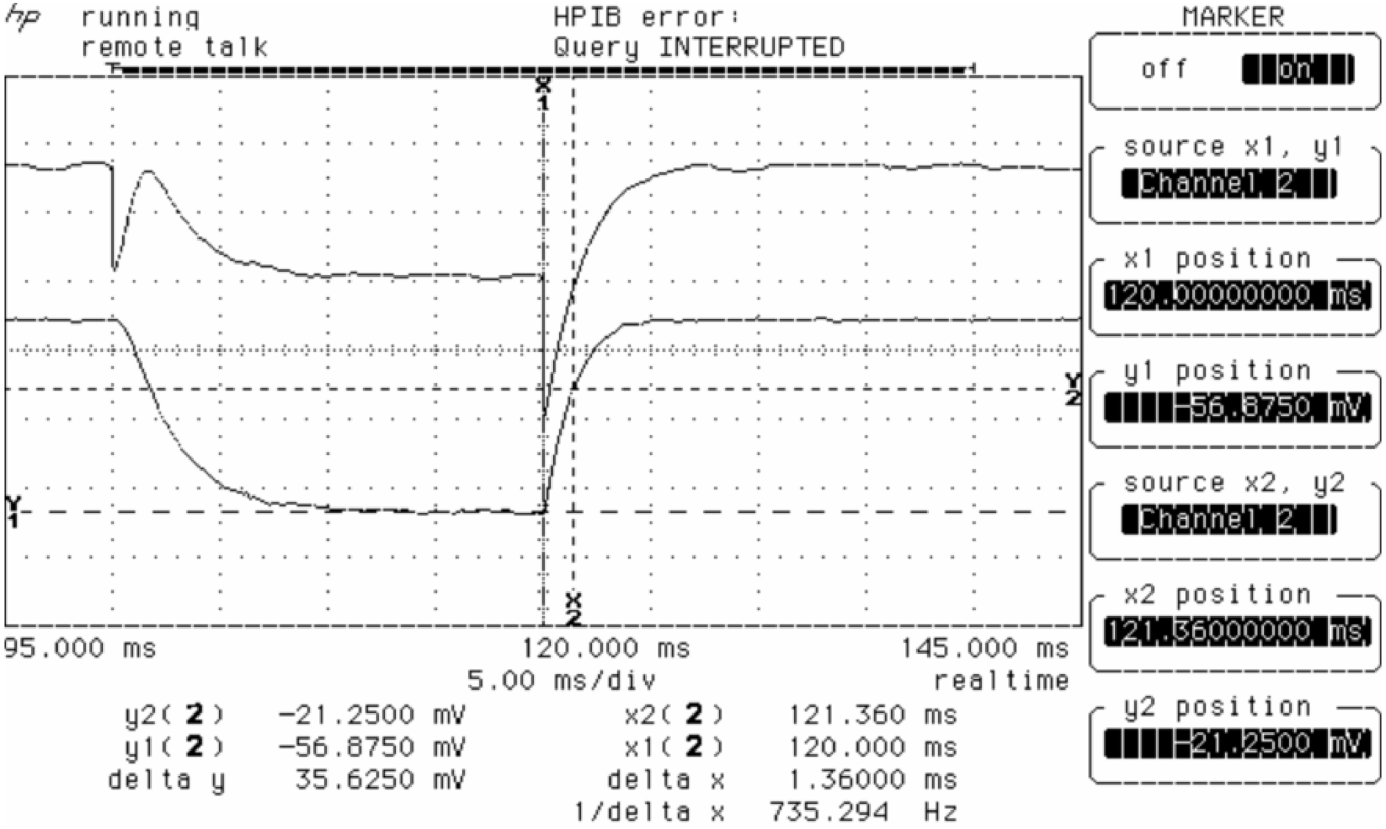


Pressure stability: 30 ± 0.2mbar

October 2010: Successful 2K operation without cryomodule

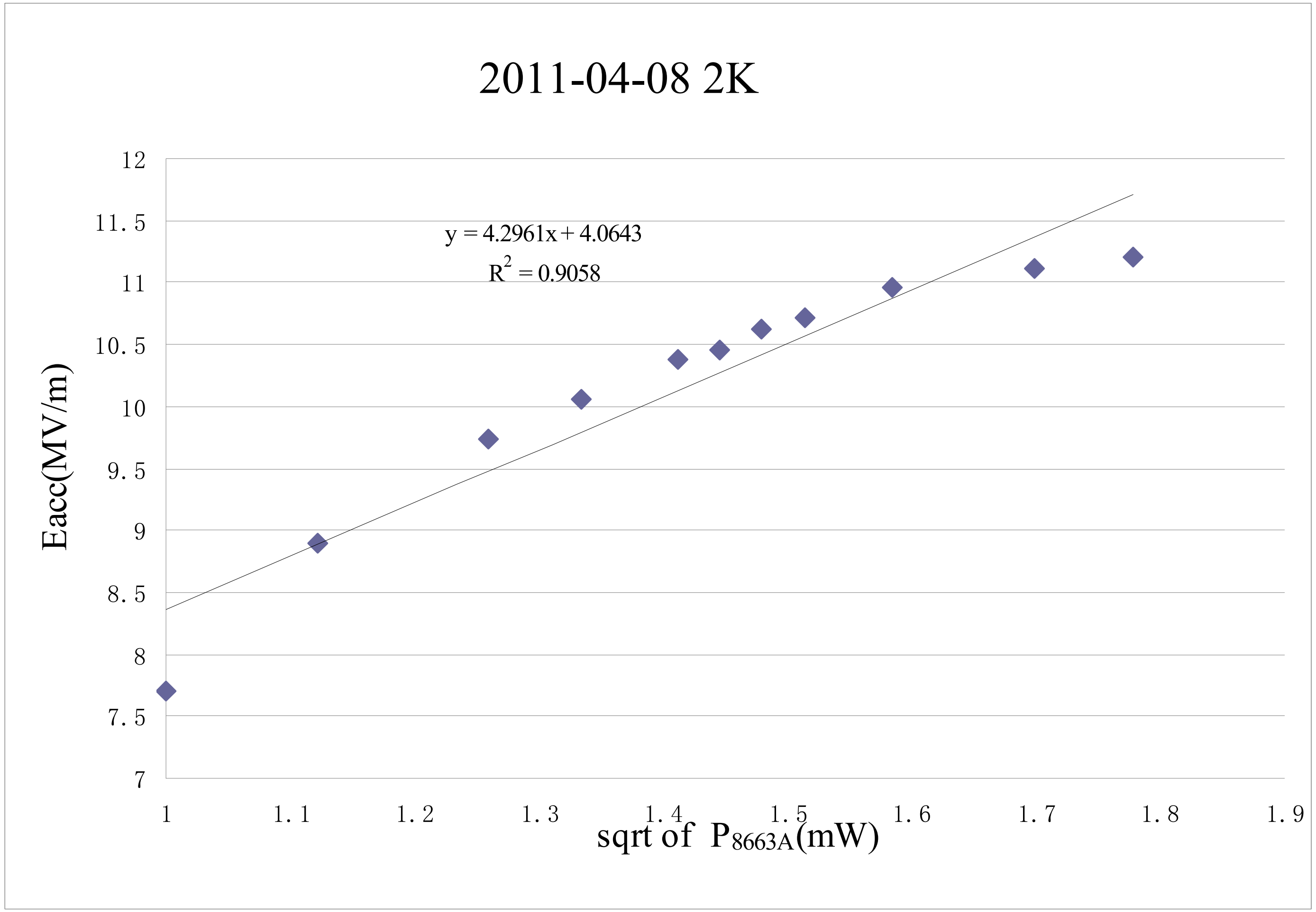
January 2011: Successful 2K operation with cryomodule

RF test of the 3.5cell cavity DC-SRF injector



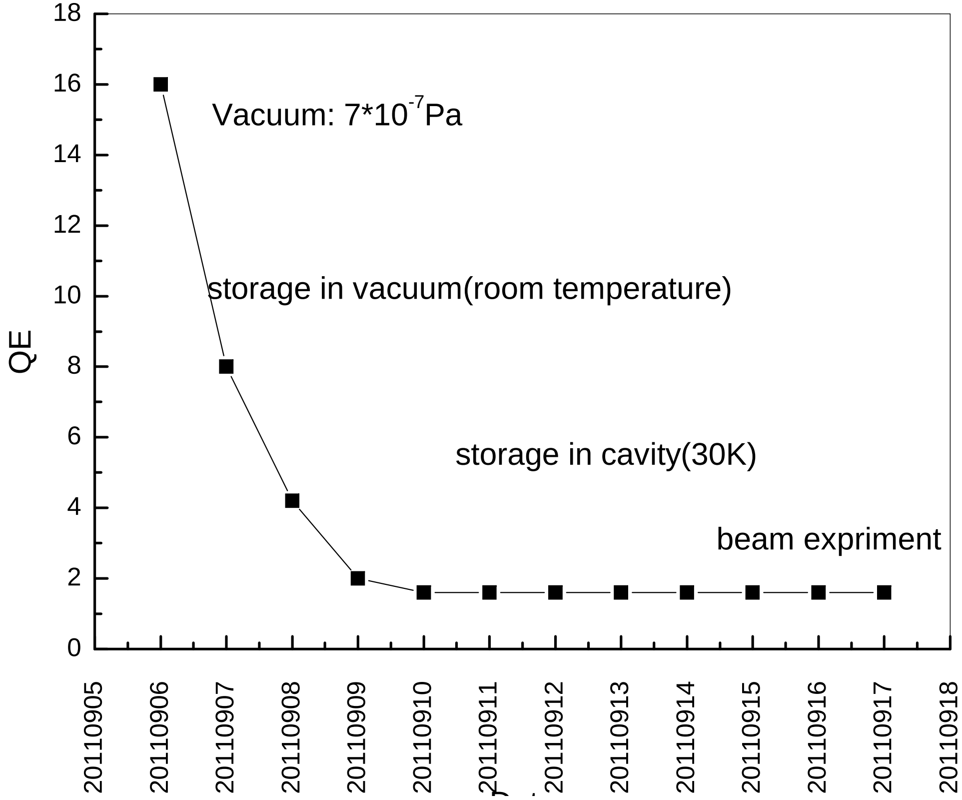
$Qe = 5\times10^6$, $f = 1300.48\text{MHz}$

RF test of the 3.5cell cavity DC-SRF injector



f = 1300.48MHz, Eacc~11MV/m, limited by RF power

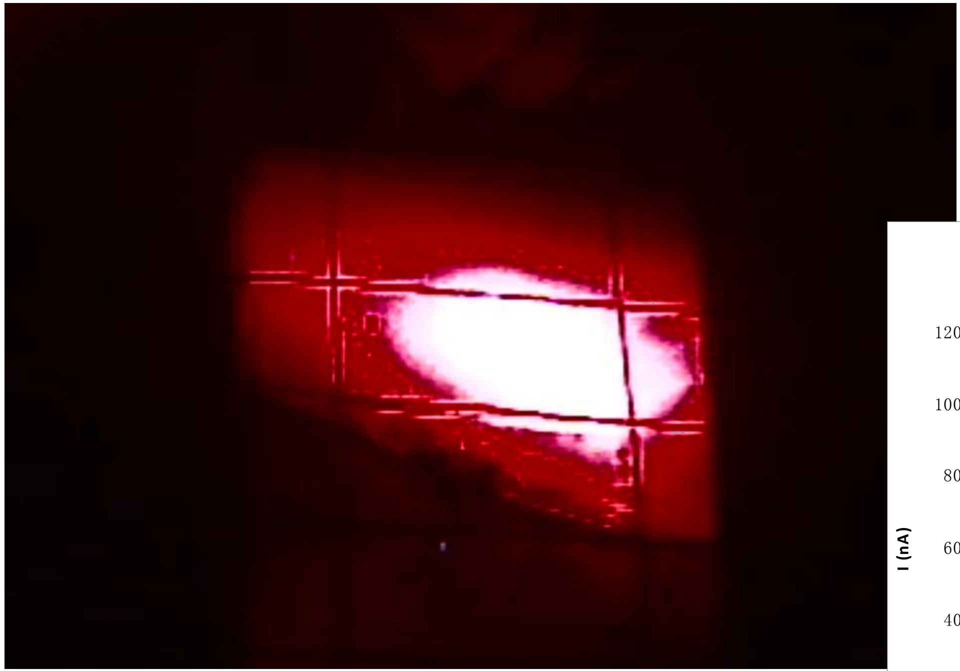
QE of photocathode



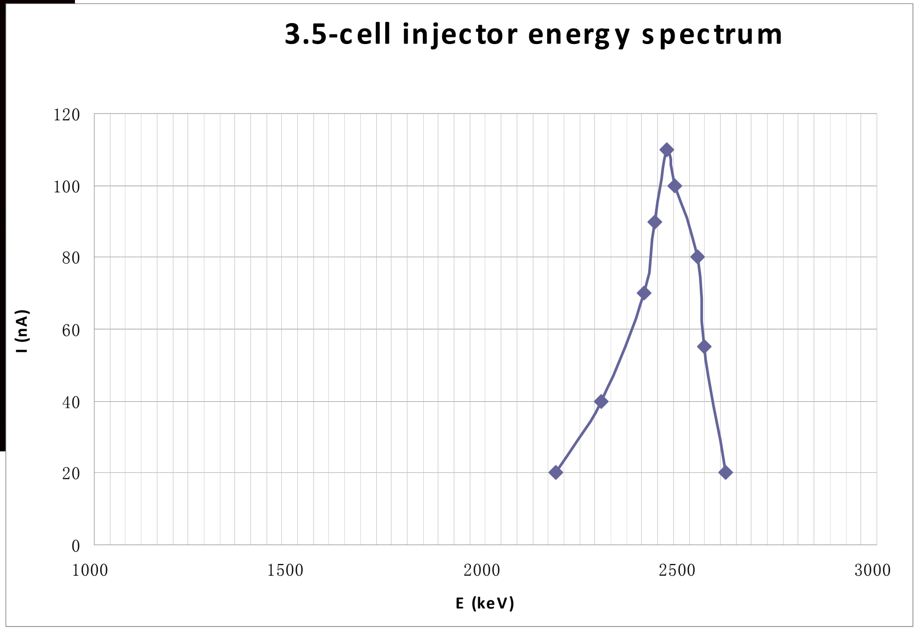
The UV laser power on the surface of the photocathode is about 0.1 W, and the photocurrent is 350 uA

No degradation was found during the two weeks' experiment

Beam test of the 3.5cell cavity DC-SRF injector

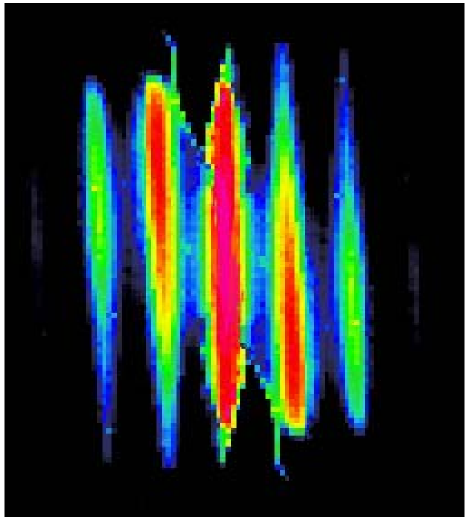


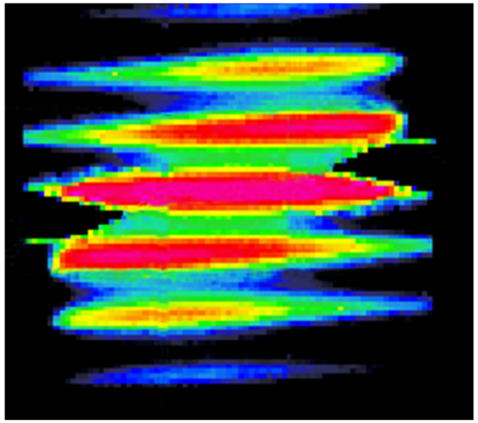
September 8， 2011

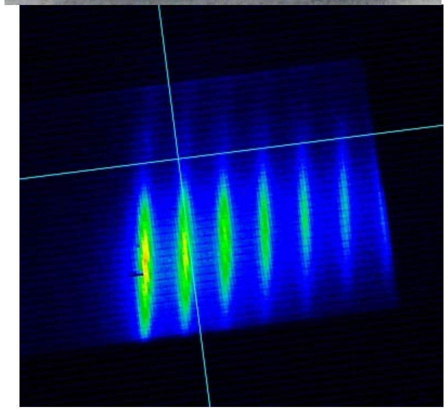


- Eacc~6MV/m
- Beam energy~2.5MeV, current~50μA
- Aperture diaphragm was used to reduce laser power

Beam test of the 3.5cell cavity DC-SRF injector







Slit technique was used for beam emittance measurement

Initial results is 5~7mm-mrad

Summary

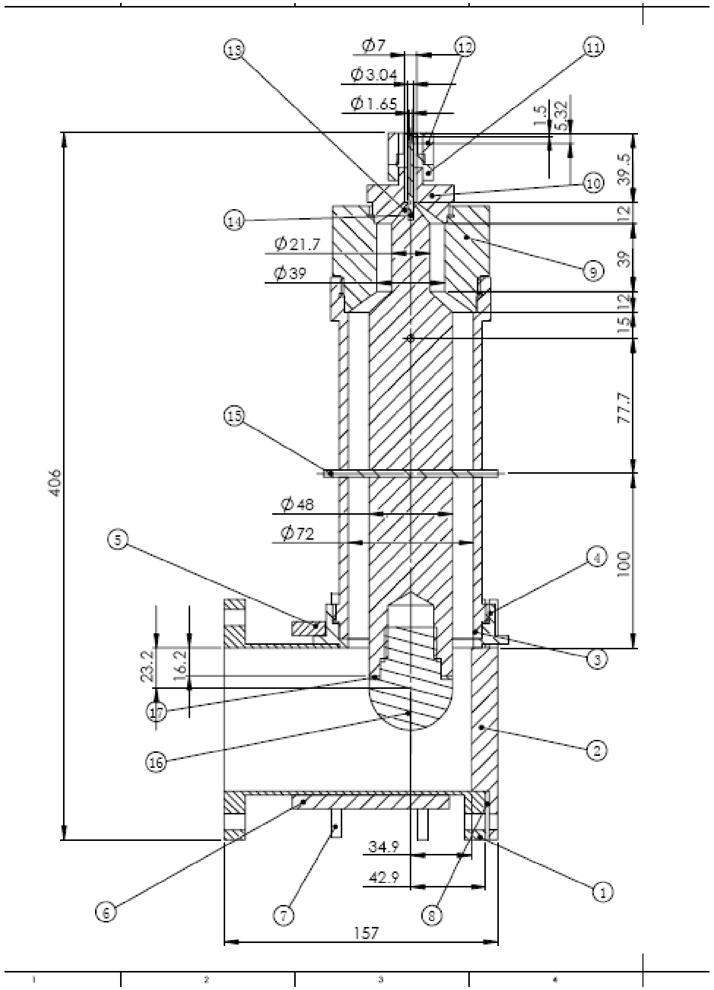
- An upgraded DC-SRF gun was designed, manufactured and installed for SETF at Peking University
- Preliminary RF and beam test show promising result
- Further experiments will be carried out with improved drive laser system, 20kW solid state RF amplifier and modified test beam line

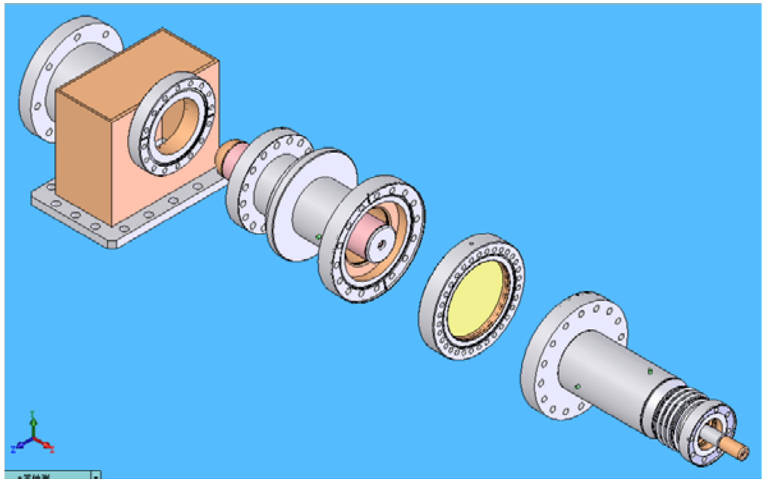
Acknowledgement

- For design of the cryostat of the injector, we would like to thank FZD people and Dr. Proch from DESY for their help
- For cavity vertical RF measurement, we would like to thank Dr. Bob Rimmer, Dr. R.L. Geng and Dr.Peter Kneisel, etc. from JLab

Thank you!

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

characteristics:

1. Simple window structure, easy to fabricate
2. Inner conductor at low temperature, heat load small
3. Stress on ceramic window not strong
4. Convenient for assembly and maintenance