中國科學院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

Research Activities on Photo Injectors at IHEP

Presented by Jianping Dai

Institute of High Energy Physics, CAS

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jpdai@ihep.ac.cn

Outline

1. **Introduction**
2. **Photocathode RF Gun**
3. **Photocathode DC Gun**
4. **Summary**

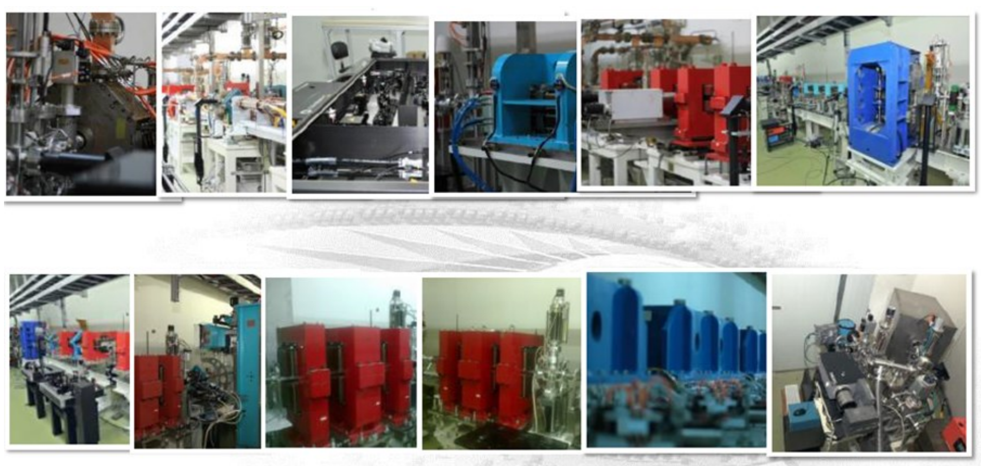
I. A photocathode RF injector was developed successfully for SDUV-FEL in 2008, by the joined group of IHEP/THU/SINAP

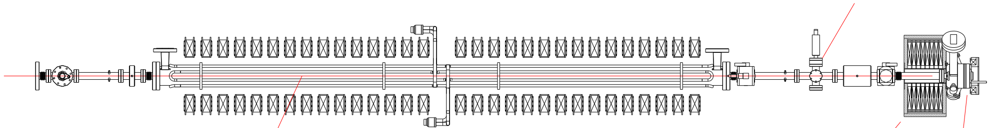
- Shanghai Deep-UltraViolet Free-Electron Laser (SDUV-FEL) started as an 262 nm SASE / 88 nm HGHG FEL test setup around 2000.
- Funding partially supported by
  - Chinese Academy of Sciences / CAS
  - Ministry of Science and Technology of China / MOST
  - National Natural Science Foundation of China / NSFC
- Collaborating between USTC, IHEP, THUB and SINAP
- Be a test bed for the key technologies for XFELs

The photo injector works well, laying a solid foundation for the following FEL experiments

- 2009.04-08: Linac commissioning after energy upgrade
- 2009.09-12: SASE lasing
- 2010.01-03: Seeded FEL Installations
- 2010.05.17: HGHG signal
- 2010.05.22: Echo signal (`double-peak’)
- 2010.12: **HGHG saturation**
- 2011.04: **EEHG-FEL lasing**
- 2011.07-08: Cascaded HGHG experiments begin
- 2011.12: **HGHG tunability**
- 2012.04: Cascaded HGHG signal
- 2013.05-06: Installation for high harmonics EEHG and polarization control
- 2013.08: **EEHG@10th harmonic**
- 2013.11: **Crossed–planar undulator polarization control**

SDV-FEL facility





Parameters	Designed Value	Unit
Energy	30~40	MeV
Emittance（rms）	4~6	mm•mrad
Charge/bunch	1	nC
Bunch Length（FWHM）	8~10	ps
Energy Spread（rms）	<1%	
Repetition Rate	10	Hz

Schematic Diagram and parameters of the photocathode RF injector for SDUV-FEL

II. A photocathode DC injector (Named as PAPS Beam Test System) is being developed at IHEP

Platform of **A**dvanced **P**hoton **S**ource Technology R&D, Huairou Science Park, Huairou, Beijing

HEPS

Construction: 2017.5 – 2020.6
Ground Breaking: May 31, 2017

Cryogenic system

2.5kW@4.5K/300W@2K

800L/h liquidation

- 100W for 3 vertical test stands
- 100W for 2 horizontal module test stands
- 100W for beam test system

X-ray system

- Advanced X-ray related technologies R&D

4500 m^2 SRF lab

Mission: World-leading SRF Lab for future Superconducting Accelerator Projects and SRF Frontier R&D

- Three vertical test stands each with four cavities
- Coupler conditioning stands for eight couplers
- 30 m-long clean room
- 36 m-long module assembly zone
- Two horizontal module test stands (12m module)

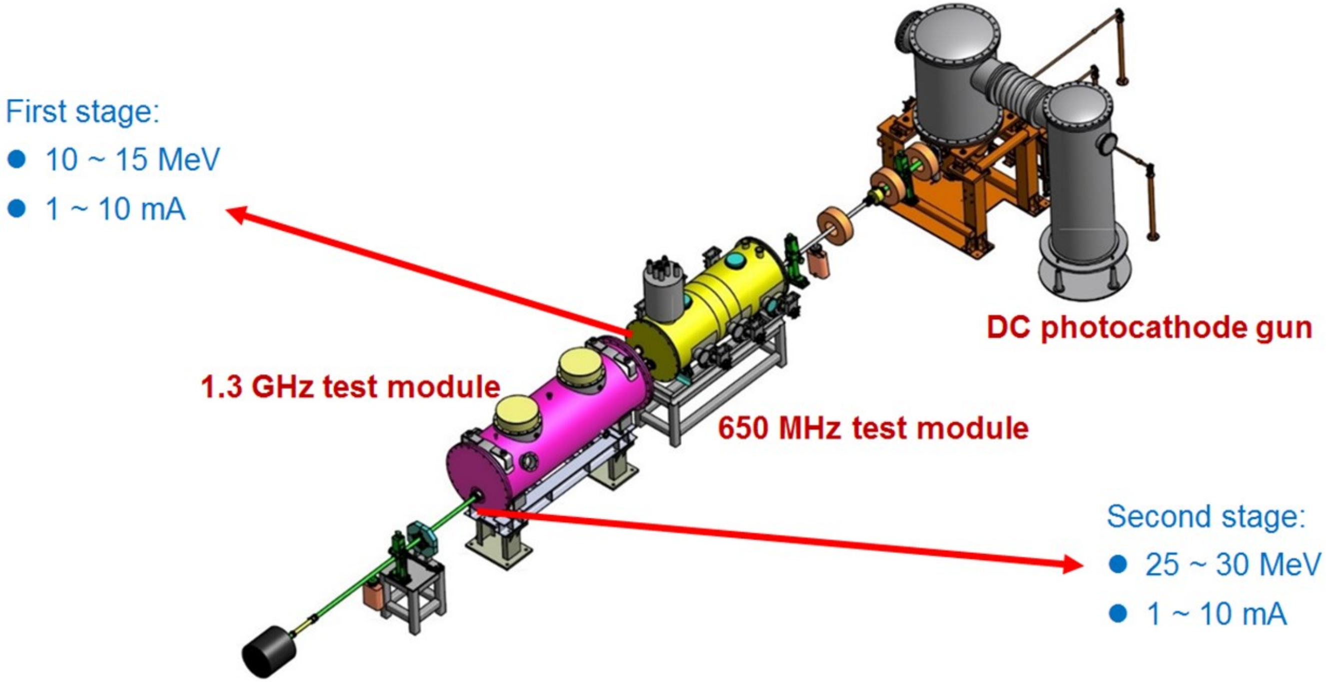
Beam test system

- Beam test based on superconducting module
- High power conditioning (High efficiency klystron)
- High current photoinjector R&D

Magnet system

- Precision machining for HEPS magnets

Photocathode DC Injector (2017~2020)



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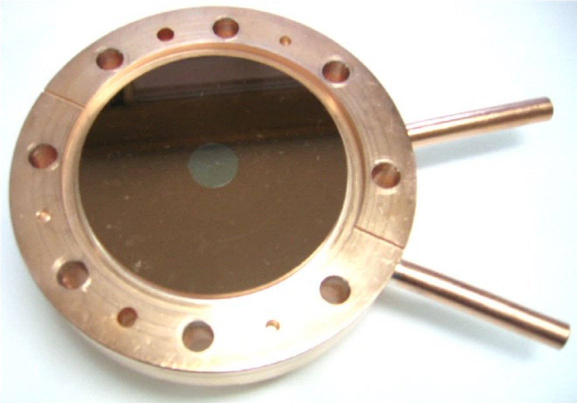
Parameters of the RF Gun

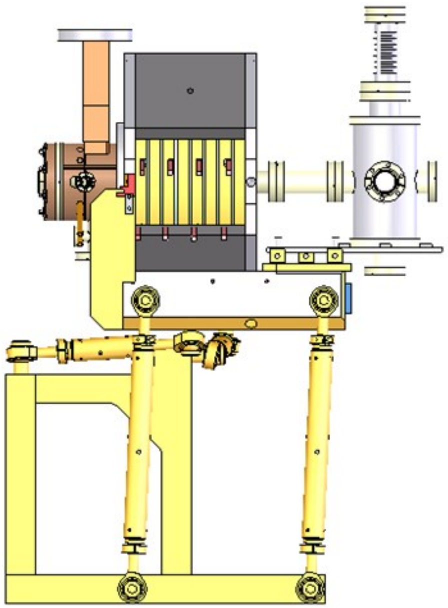
Parameters	Designed Value	Unit
RF Cavity Type	1.6 cell (modified BNL type IV)	
Cathode	Mg (or Cu)	
Radius of the Cathode	6	mm
Surface Field	100~120	MV/m
Q.E. (@262~264nm)	$>2\times10^{-5}$	
Energy	4~6	MeV
Emittance (rms)	3~5	mm•mrad
Bunch Length（FWHM)	8~10	ps
Repetition Rate	10	Hz
RF Power Needed	10~14	MW



Mg cathode

Cu cathode

RF cavity



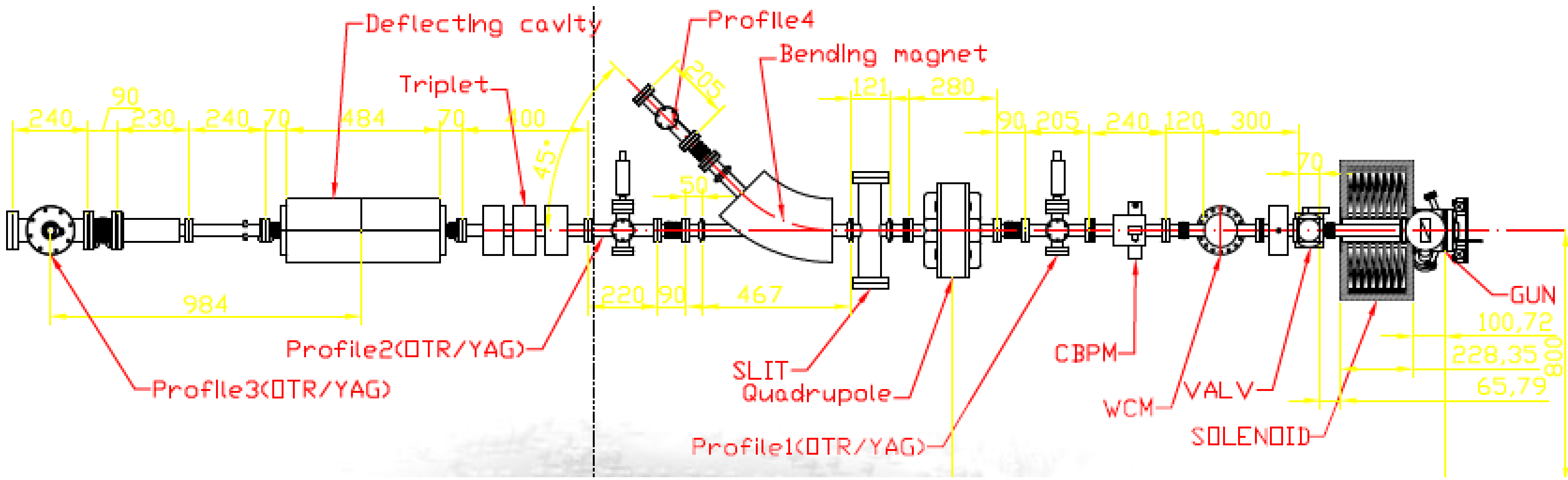
Emittance compensation magnet

Laser system

- **JAGUAR QCW-1000：Time-Bandwidth**
- **Oscillator+Regen-Amplifier+FHG**
- **Nd:YLF（1047nm）**
- **BBO（1047nm→523nm→262nm）**
- **Oscillator:119MHz（for RF 2856MHz, 1/24）**
- **Synchronizer:CLX-1100**

Parameters of laser system

	Design value	Measured value(@10Hz)
Wavelength	260nm-280nm	262nm
Energy	>200μJ	>350μJ
Energy stability(rms)	1％	0.38% @8h rms
Pulse length	～8ps	～8ps
Jitter of beam size and position	<2％rms	<0.15%rms-beam size <0.35%rms beam position
Repetition rate:	0－100Hz	0－100Hz
Synchronization jitter	<1ps	0.12ps(monitored) 0.19ps(measured)



RF gun and the beam monitor system

RF gun commission results

Parameters	Stage I (2008/02~03)	Stage II (2008/05~07)	Stage III (2008/11~12)
Charge (in operation)	/	1.4nC	0.6nC
Charge (max.)	/	2.4 nC	1.1nC
Energy	~3.5	4.3MeV	4.2MeV
Emmittance	/	4mm•mrad	4mm•mrad

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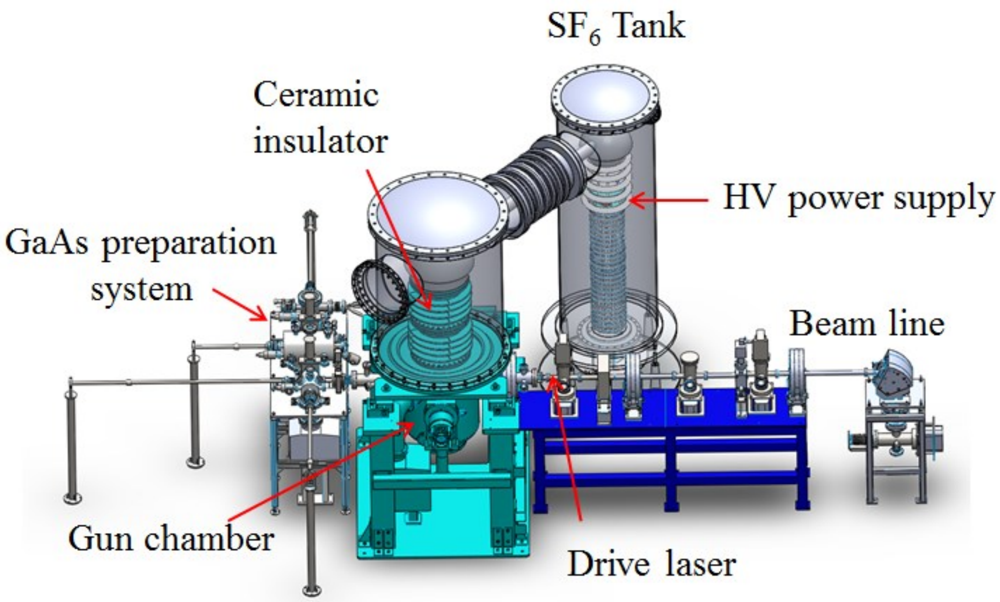
Design and parameters



Layout of Photocathode DC-Gun

Parameter	Value
HV	350 ~ 500 kV
Cathode	GaAs:Cs
QE	5-7%(initial),1%
Driven laser	2.3W， 530nm
Repetition rate	100MHz, 1.3GHz*
Nor. emittance	(1~2)mm.mrad
Bunch length	20ps
Beam current	(1~10) mA

*Two operation modes:

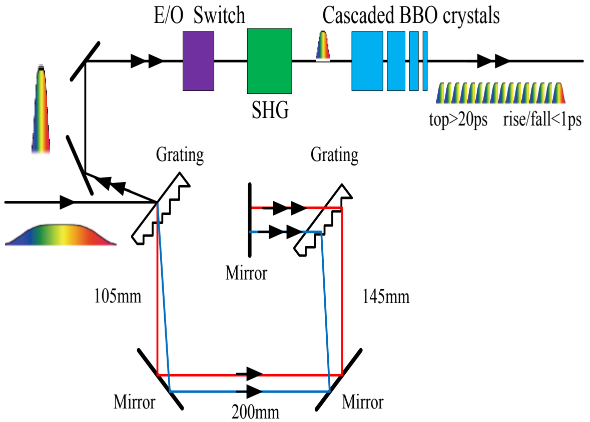
1). 100MHz-7.7mA-77pC,

2)1300MHz-10mA-7.7pC

- # Laser system

1. Two laser oscillators are working at 1.3GHz and 100MHz respectively
2. 100MHz and 1.3GHz oscillators are integrated into one laser system with a 2x2 fiber coupler
3. The green laser output power after SHG crystal is more than 5W
4. A set of four a-BBO crystals is used as longitudinal pulse shaper stacking an input pulse to >20ps

Parameters	Mode 1	Mode 2
Electron bunch charge	77pC	7.7pC
Pulse energy at cathode	18nJ	1.8nJ
Pulse repetition rate	100MHz	1.3GHz
Power at cathode	1.8W	2.3W
Pulse length (flattop)	20-30ps	20-30ps

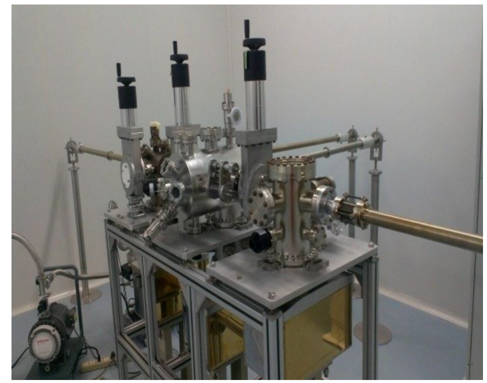
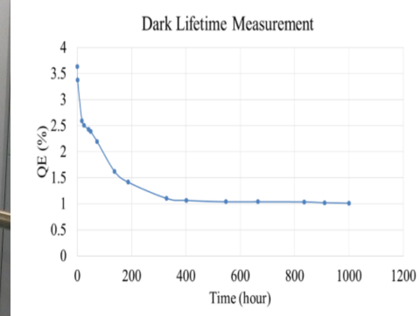


Laser pulse modification and shaping

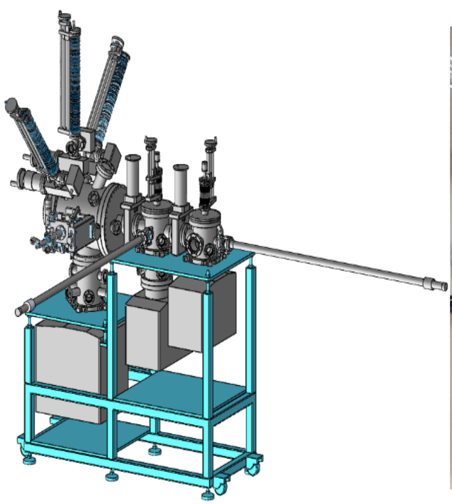
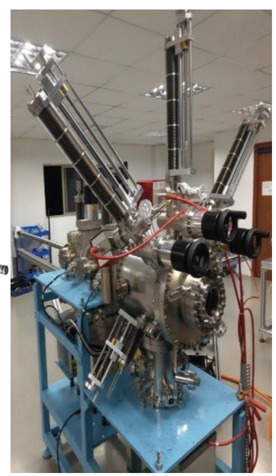

Laser system for photocathode

Photocathode

1. A GaAs photocathode system was built up at first
2. A QE of ~10% after Cs/O activation was obtained
3. Dark lifetime can keep 1000hr with QE≥1%
4. **In recent, a K_2CsSb photocathode system was set up, growth experiment just started**

GaAs photocathode system

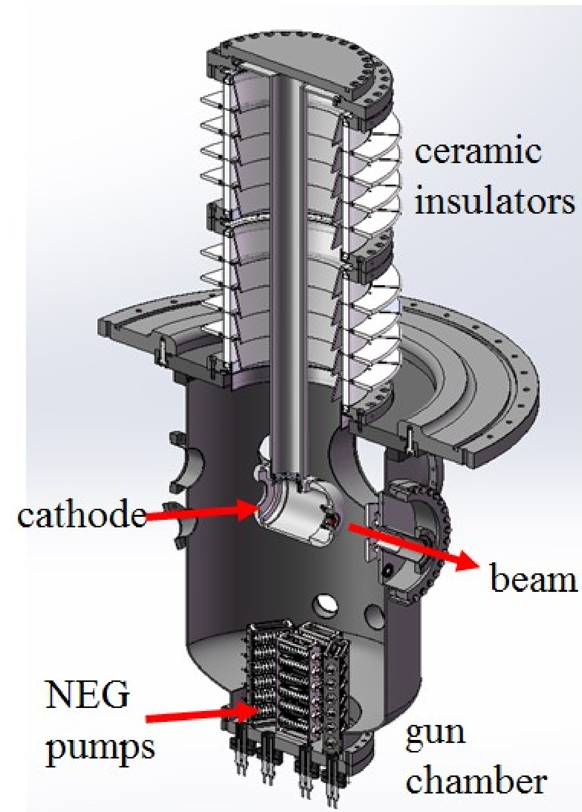




K_2CsSb photocathode system

Mo substrate

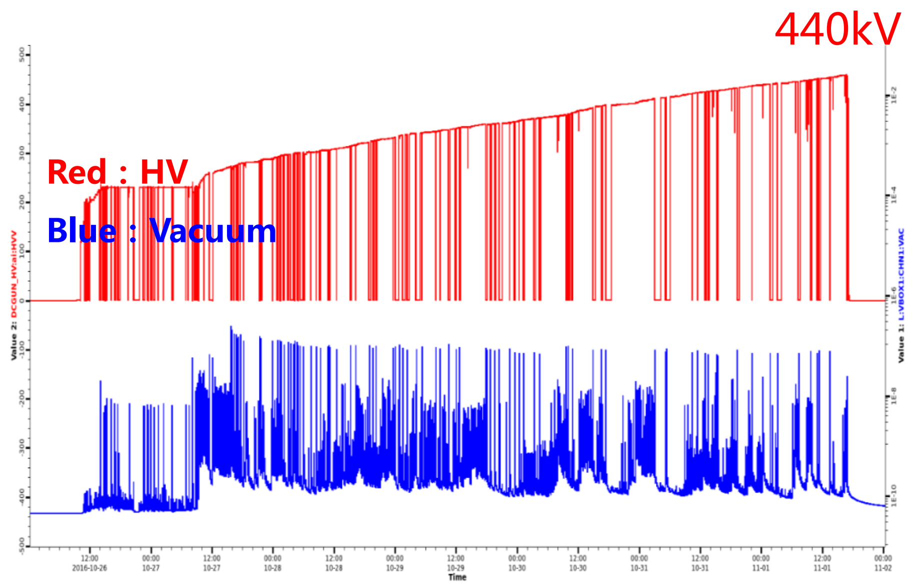
- **Other parts:** **ceramics, gun, power supply, beam line……**

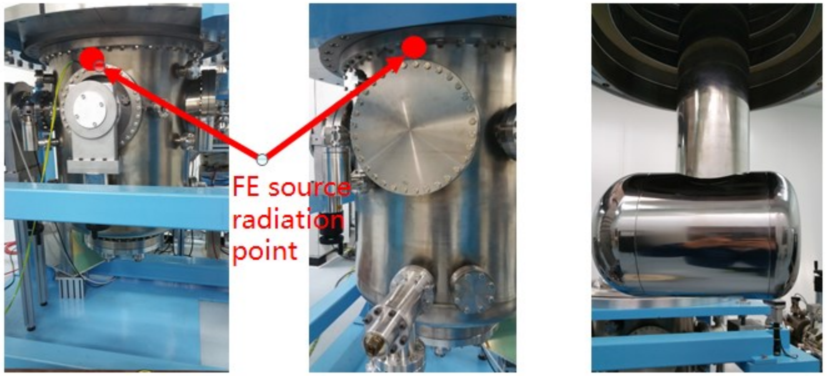
1. Construction of each component is done
2. Vacuum in the gun achieves 6×10^{-10}Pa
3. Pressurized insulating gas: SF_6



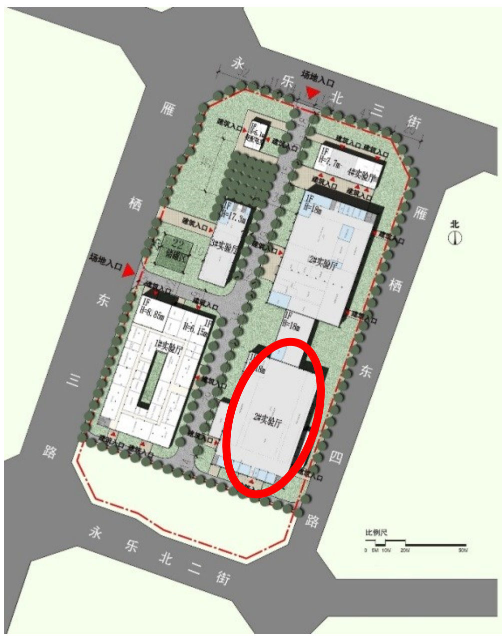
High voltage conditioning

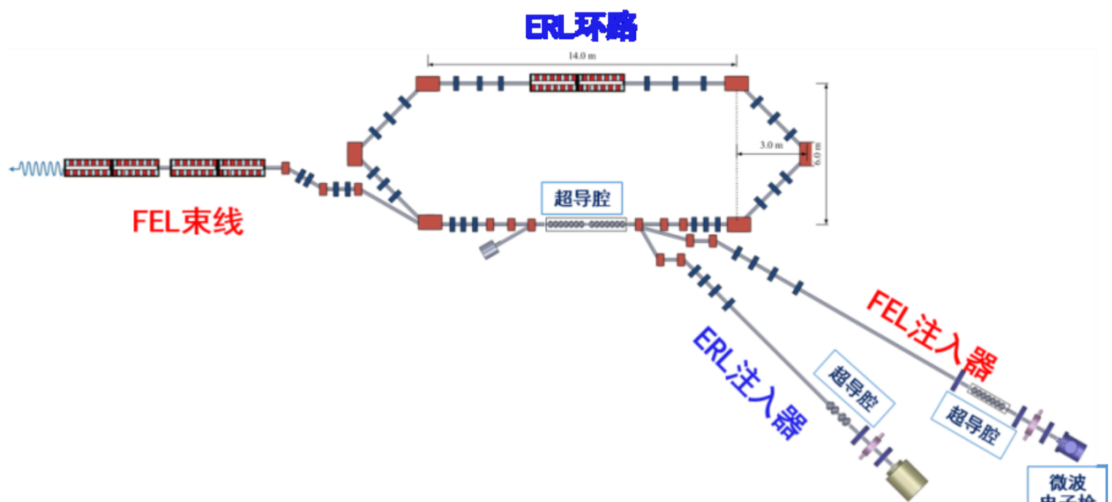
1. The pressure of SF6 in the pressurized tank: 2.5atm
2. The vacuum interlock level is 4×10^{-6}Pa
3. After around 140 hours conditioning, HV reached up to 440kV that means a HV between cathode and anode is around 431kV (5000MΩ/5100MΩ)
4. Then a huge radiation dose caused by field emission was found at one point of gun chamber. There is still a big dose even though reduce the HV to 250kV.
5. Open the gun chamber and re-polish the cathode to remove FE source, then recover the vacuum
6. Re-conditioning up to 370kV (HV between cathode and anode is 362kV) without obvious dose
7. **Next, beam operation @350kV**





Future Plan: After 2020, the hall for Magnet system will be free up. A compact test facility towards one machine, two purposes: using a common SC linac for XFEL and ERL simultaneously now is proposed at IHEP





- Two photo injectors (CW-RF Gun and DC Gun)
- cERL Energy 50MeV
- FEL Energy 35MeV

Summary

- **Two photo injectors have been researched at IHEP**
- **The photo cathode RF injector for SDUC-FEL was developed successfully in 2008 and worked well in the following years.**
- **A photocathode DC injector is being developed now, and good progress has been made**
- **In addition to the DC injector, a photocathode CW RF injector will also be investigated in the near future.**

Thanks!