The Development of the DC-SRF Photoinjector at Peking University

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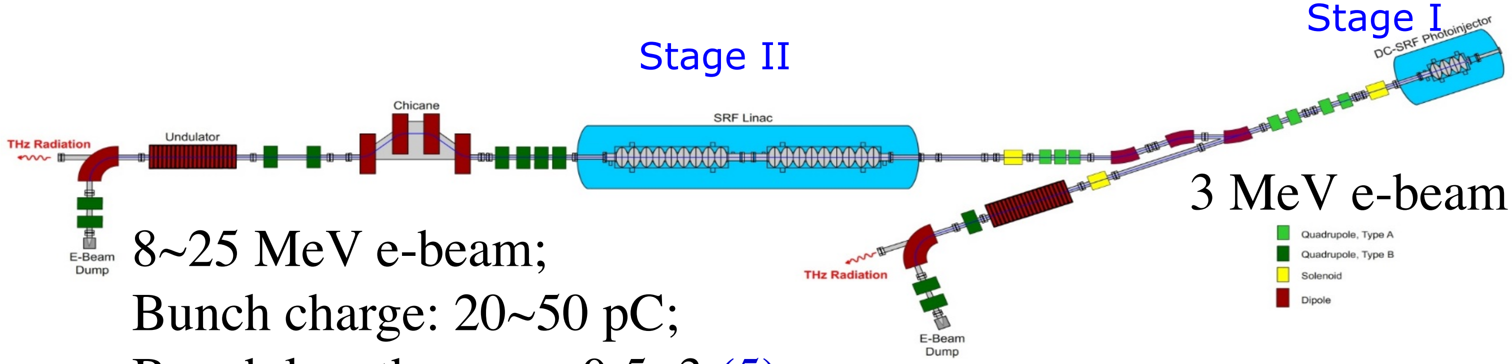
Outline

- Stable Operation of DC-SRF Photoinjector
- Lower emittance of the DC-SRF injector
- New Photoinjector design
- Summary

Peking University Superconducting ERL Test Facility (PKU-SETF)

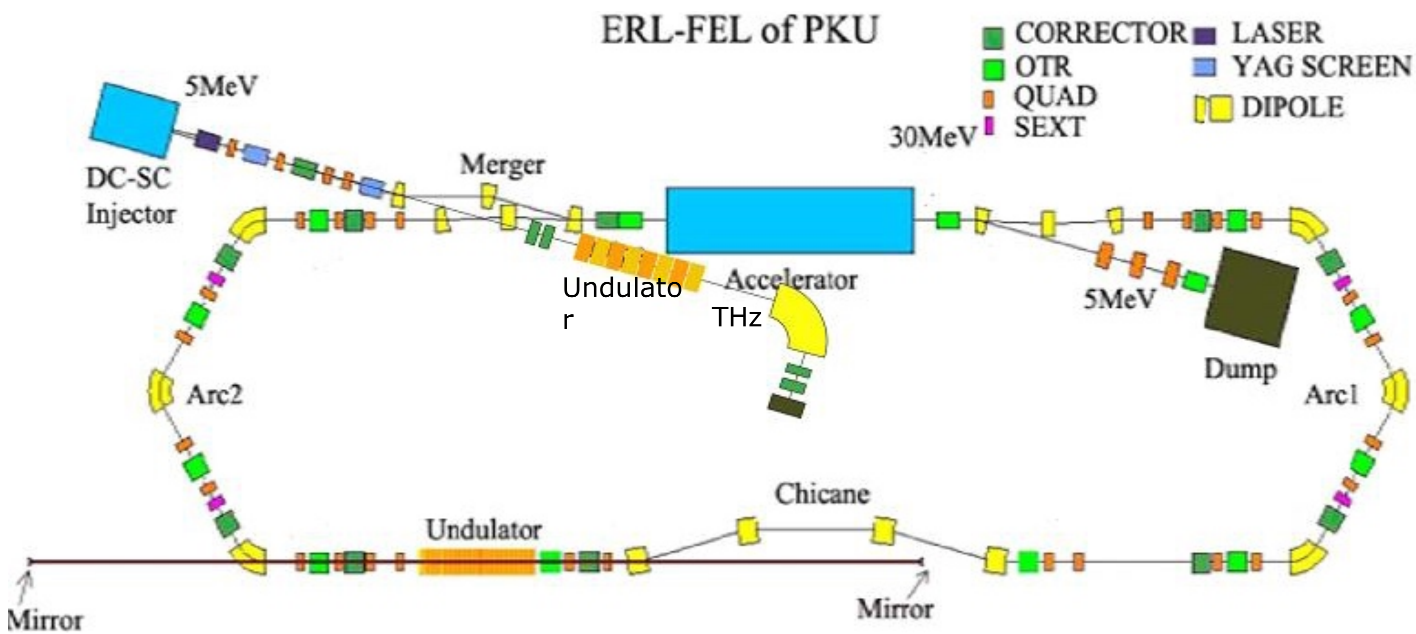
Stage II

Stage I

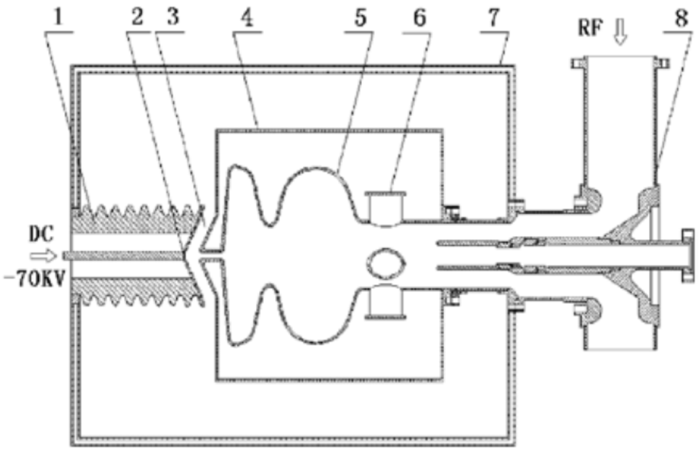


3 MeV e-beam

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

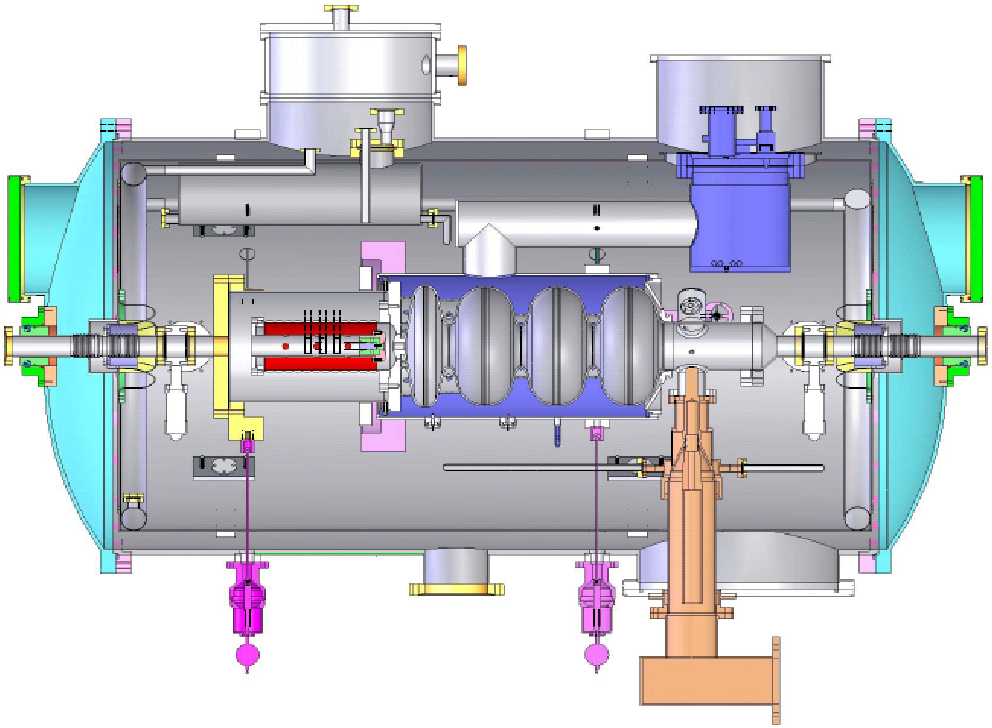


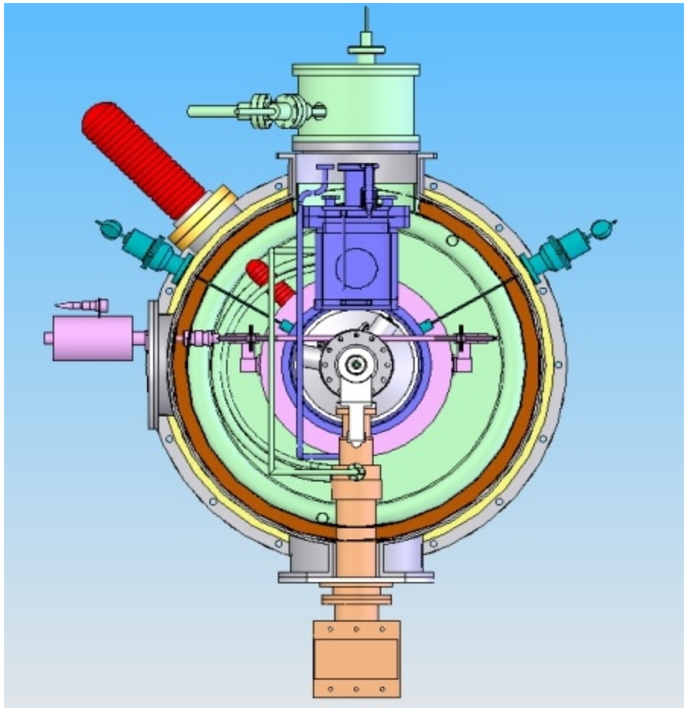
Development of DC-SRF injector



1) The photocathode is installed out of the superconducting cavity, Q degradation caused by the contamination from the cathode material would therefore be avoided and dark current from the photocathode could also be reduced. As a result, the accelerating field of the cavity could be kept at a high value.
2) Possibility of quenches caused by photoemission on the inner wall would be reduced due to the narrow beam channel between the Pierce electrodes and the superconducting cavity.
3) The structure is **compact** and **the short distance of electron drift is helpful to suppress the emittance increase** due to space charge effect

Development of DC-SRF injector

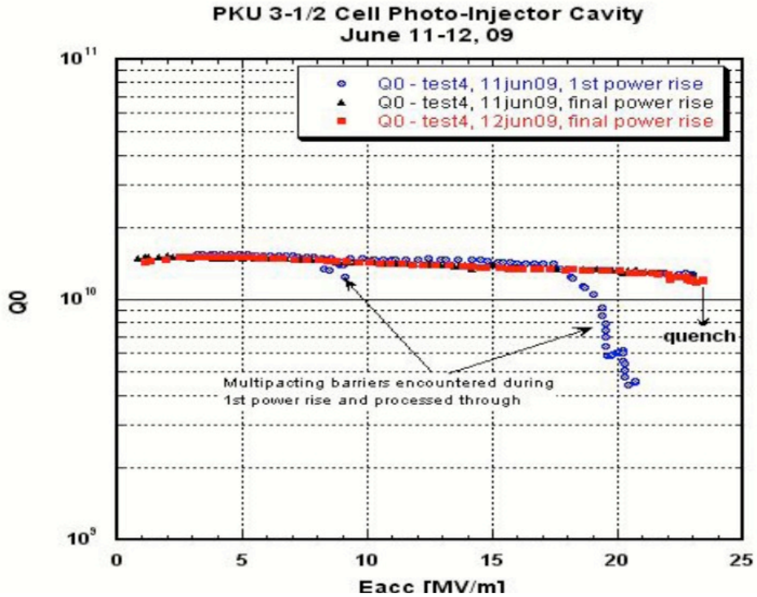




Designed in 2007, Commissioned in 2014

3.5 cell DC-SRF Injector

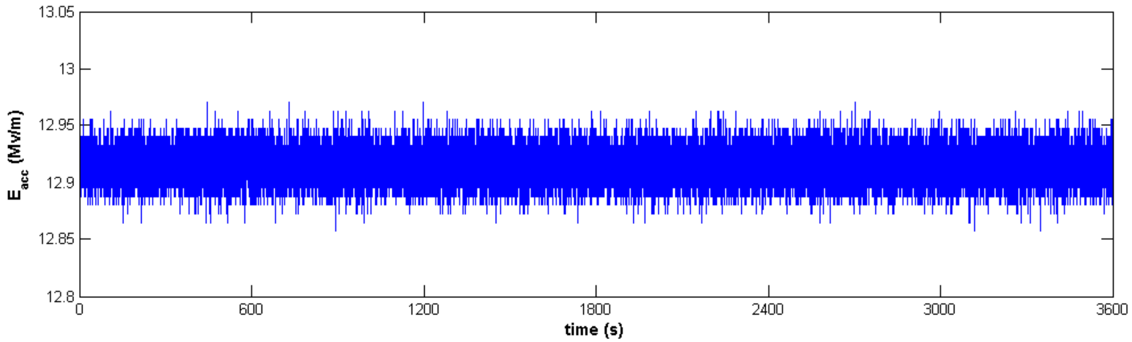
- 3.5-cell large grain cavity has been used
- Vertical test at Jlab: 23.5 MV/m @ Q_0 >1E10
- Assembling and connected to 2K cryogenic system in 2010
- RF test experiments and preliminary beam test in 2011
- Upgrade of RF power supply, beam line since 2012
- Upgrade of drive laser since 2013
- Stable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

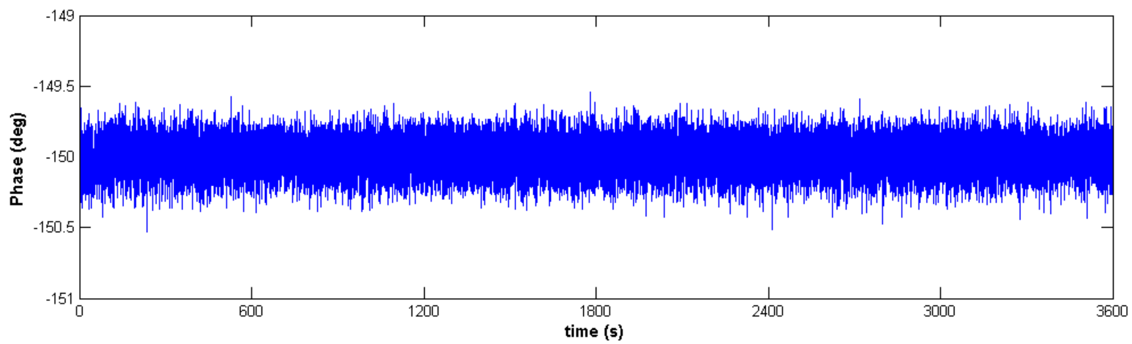


Acceleration Gradient (Eacc)

E_{acc} in different conditions have been investigated

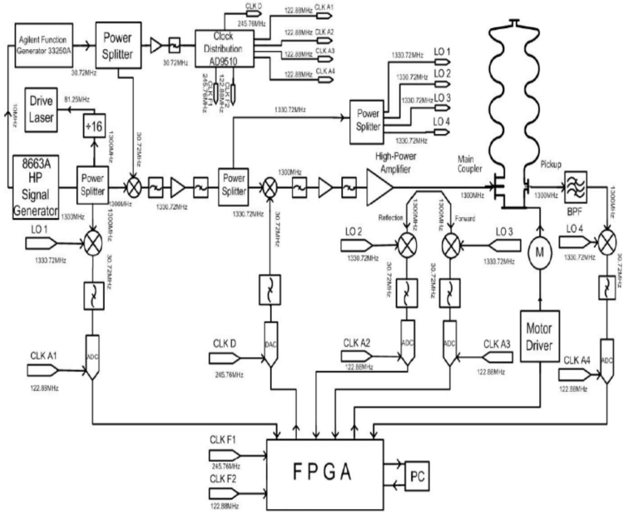
- E_{acc} was increased up to 17.5 MV/m in pulsed mode with a duty factor of 10% and a repetition rate of 10 Hz.
- E_{acc} reached 14.5 MV/m for CW mode





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

Associated auxiliary systems



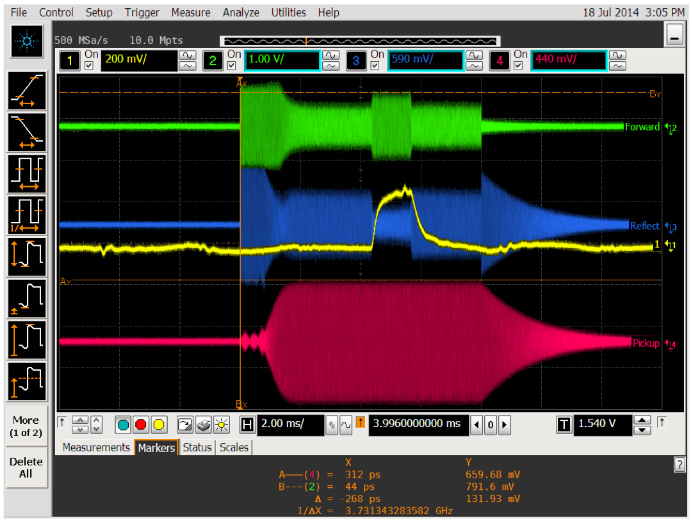
Beam Line

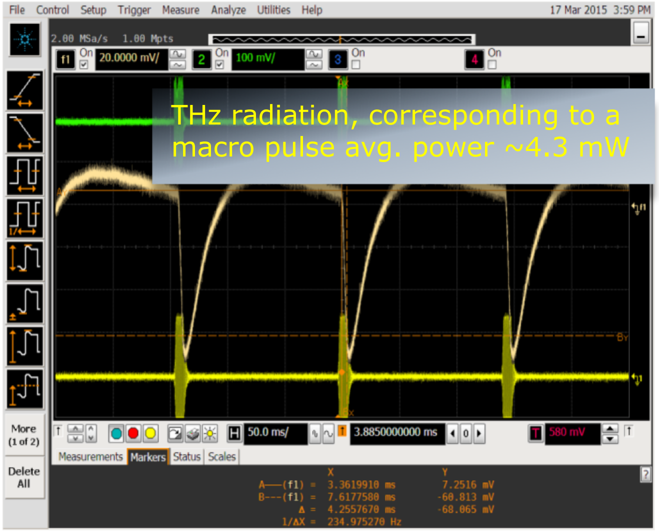
Beam experiment results

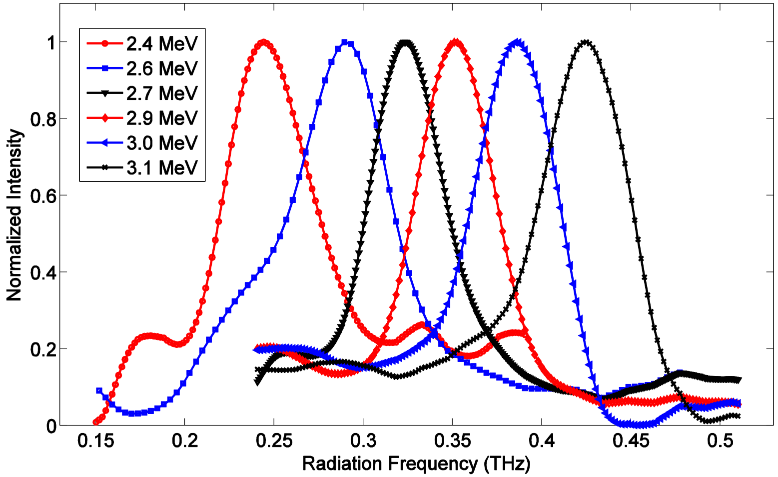
Operation parameters of the DC-SRF injector

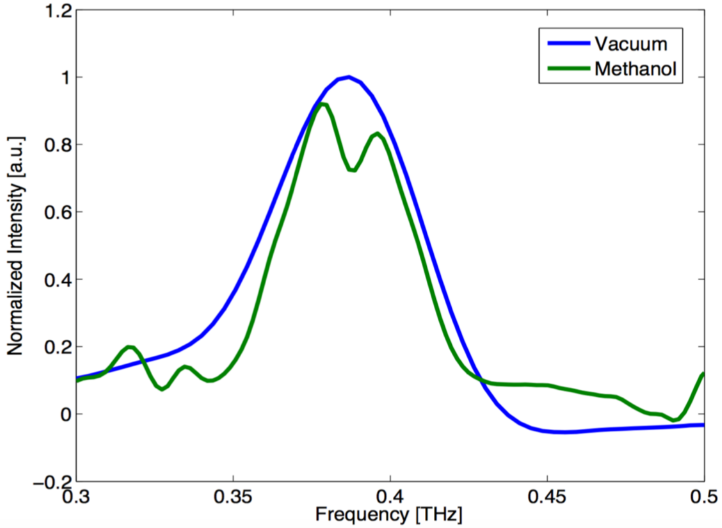
Parameter	Value	Unit
Eacc	14.5	MV/m
DC voltage	50	kV
Beam Energy	3.4	MeV
Beam current	~1.0	mA
Bunch length(FWHM)	~5	ps
RF amplitude instability	<0.1	%
RF phase instability	<0.02	degree
Dark current	<1.0	nA
Beam emittance	1.5	mm.mrad

THz by the DC-SRF injector

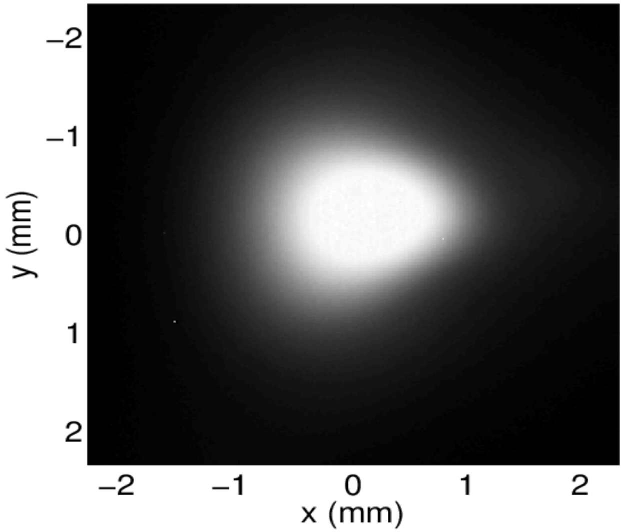


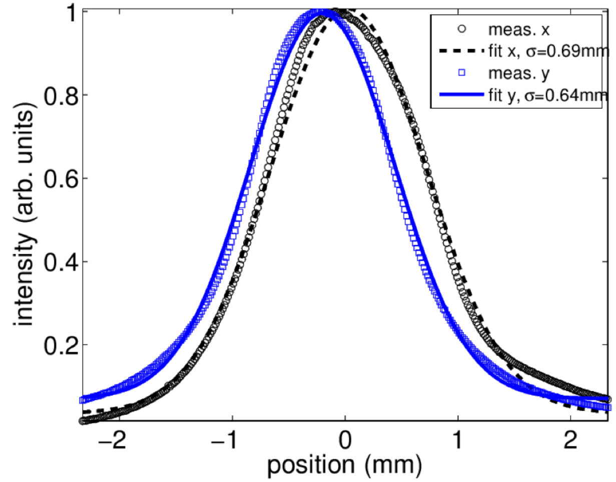


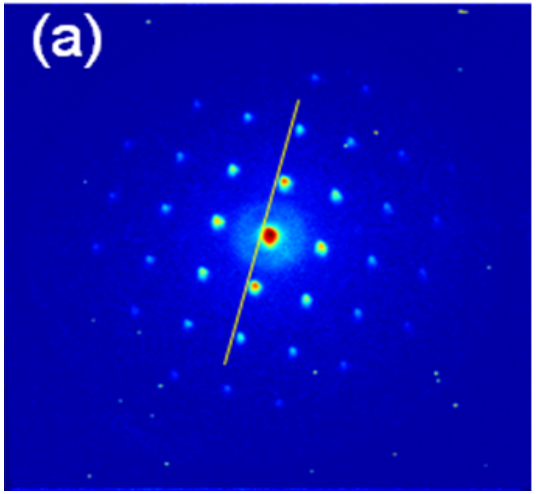


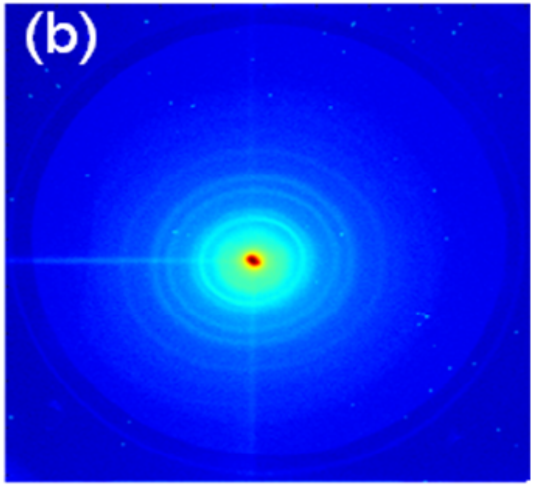


Beam experiment and UED

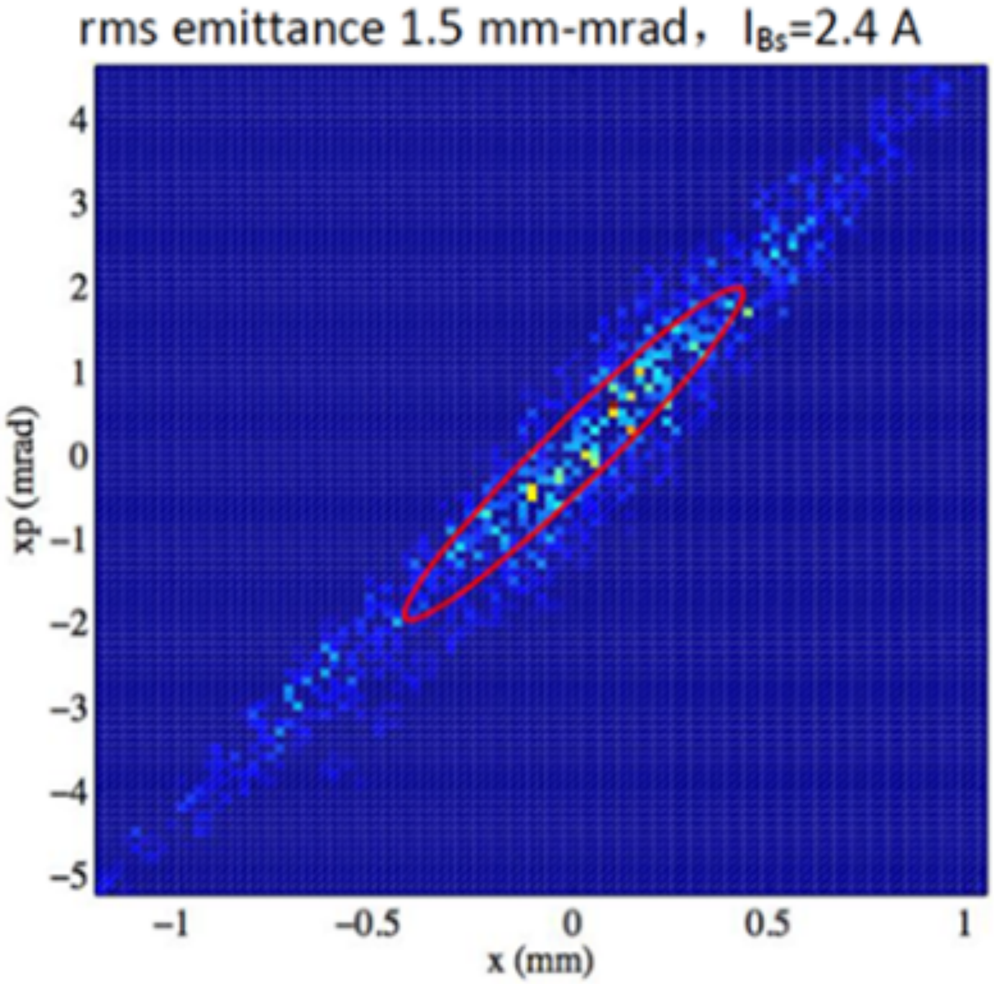




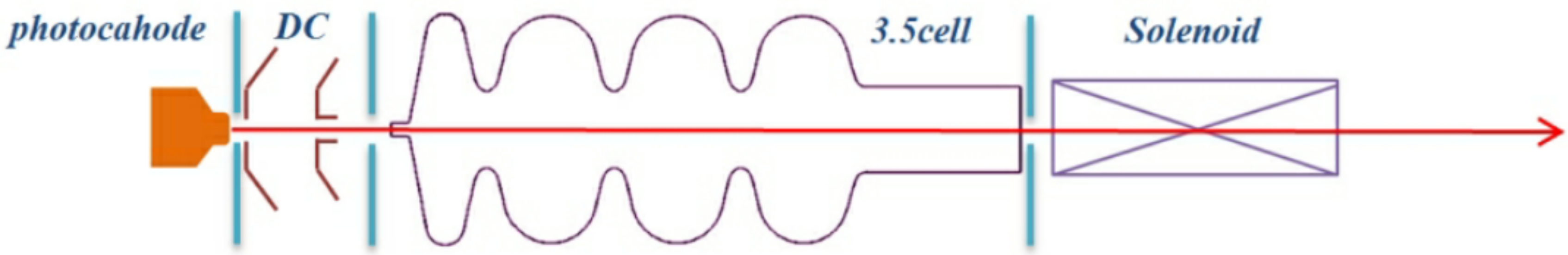




Beam emittance of DC-SRF injector



Optimization for lower emittance



- DC + 3.5 (1.5) cell SRF + Solenoid
- Drive laser: Transversely truncated Gaussian
  Longitudinally uniform
- Bunch charge: 100 pC
- Cs_2Te cathode / K_2CsSb cathode

Genetic algorithm (GA)

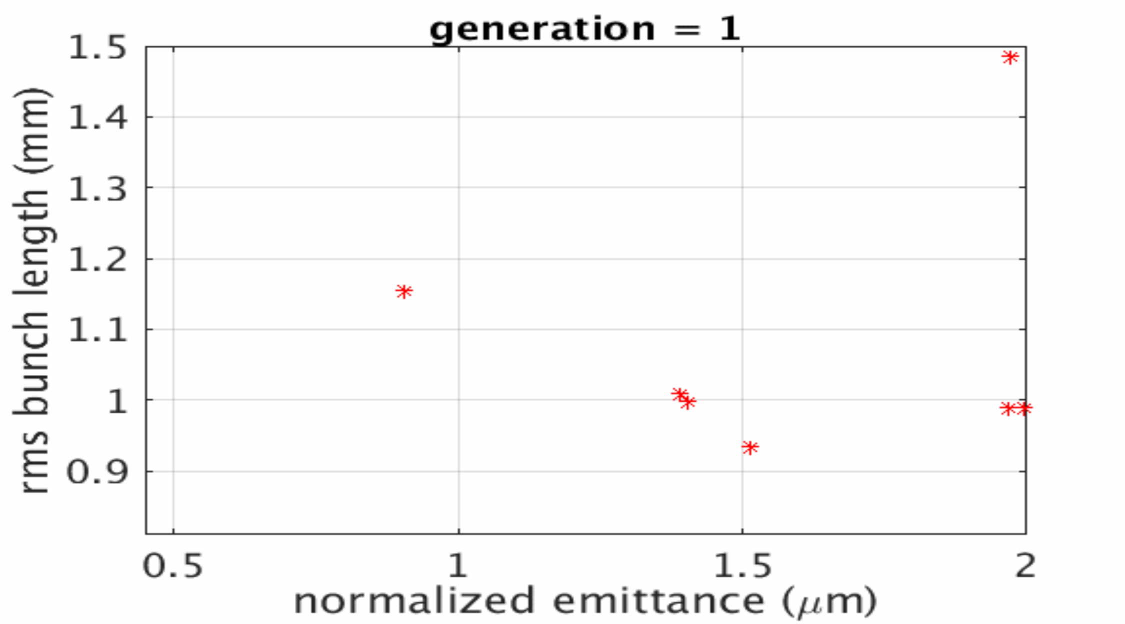
$$\mathrm{Cs_2Te}: \varepsilon_{th}[\mathrm{mm}\ mrad] = 0.4788 * 0.847 * \sigma_r$$

$$\mathrm{K_2CsSb}: \varepsilon_{th}[\mathrm{mm}\ mrad] = 0.4788 * 0.56 * \sigma_r$$

Astra

Parameters and Results

Variables	Min	Max	Units
Laser pulse length	5	15*	ps
Laser rms size	0.5*	2	mm
3.5 cell Ez,max	12	25*	MV/m
3.5 cell phase	-30	30	degree
Solenoid Bz,max	200	1500	Gs
Solenoid position	1*	2	m



DC High voltage @ 100 kV

Photocathode: K_2CsSb

Result: $\boldsymbol{\epsilon_{nx} = 0.44\mu m}$

Laser pulse length@ 11.3 ps

Laser size: 1.13 mm

$E_{z,max}$ @ 23MV/m

RF phase @ -17 deg

Solenoid field: @ 840 Gs

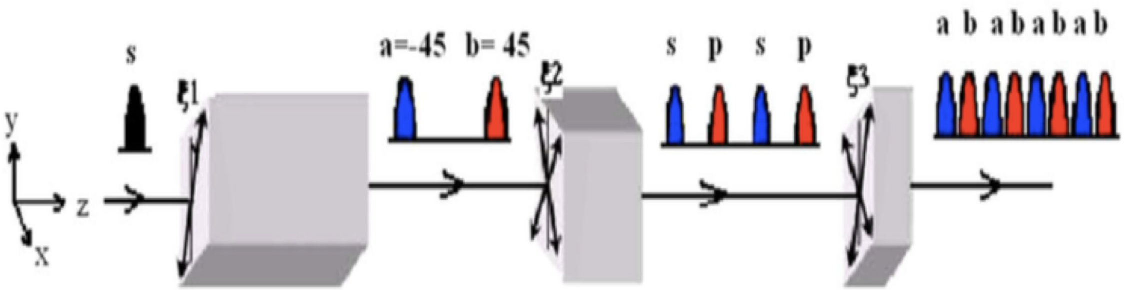
Solenoid position:@ 1.25m

$$\frac{\epsilon_{thermal}}{\epsilon} = 69\%$$

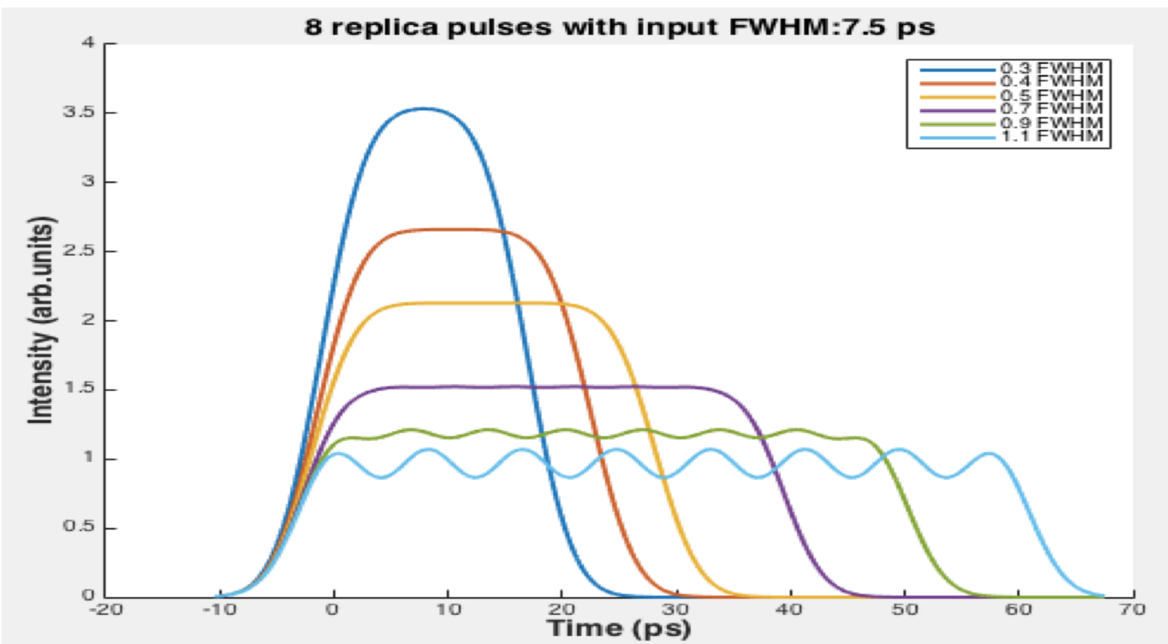
New Photoinjector Design

- Upgrade/optimization of the DC-SRF photoinjecter to lower emittance(< 1 mm.mrad @100 pC)
- Improved drive laser system
- New designed photo-cathode preparation system
- New design of DC part for higher DC voltage
- New cryomudule for lower heat loss

Temporal(longitudinal) shaping



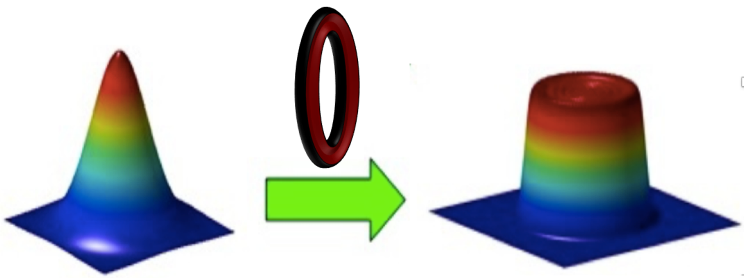
YVO_4 crystals for 532nm laser

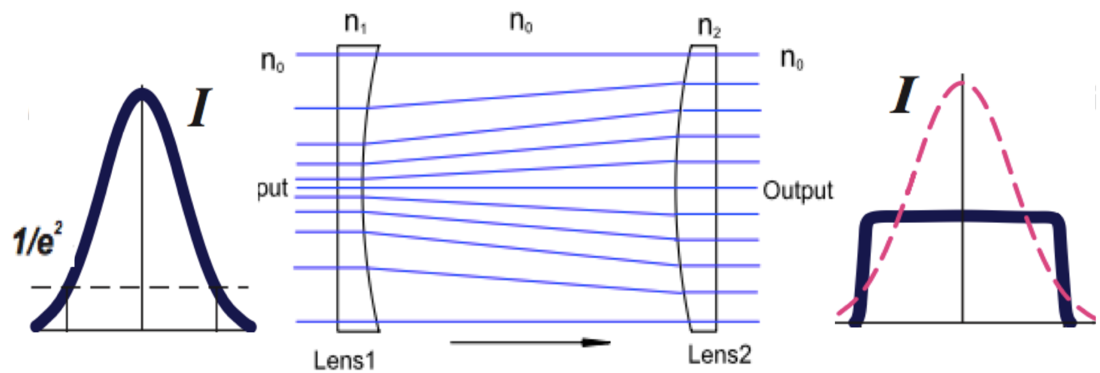


Pulse stacking——birefringent crystals

- Generate delayed pulses along the ordinary and extraordinary axes of birefringent crystals
- Time separation depends on the crystal length and on Δn
- The rise and fall time and the ripples depend on the input pulse
- Interference between pulses is reduced by cross polarization
- Though with limited parametric flexibility，it is relatively simple and robust

Spatial(transverse) shaping





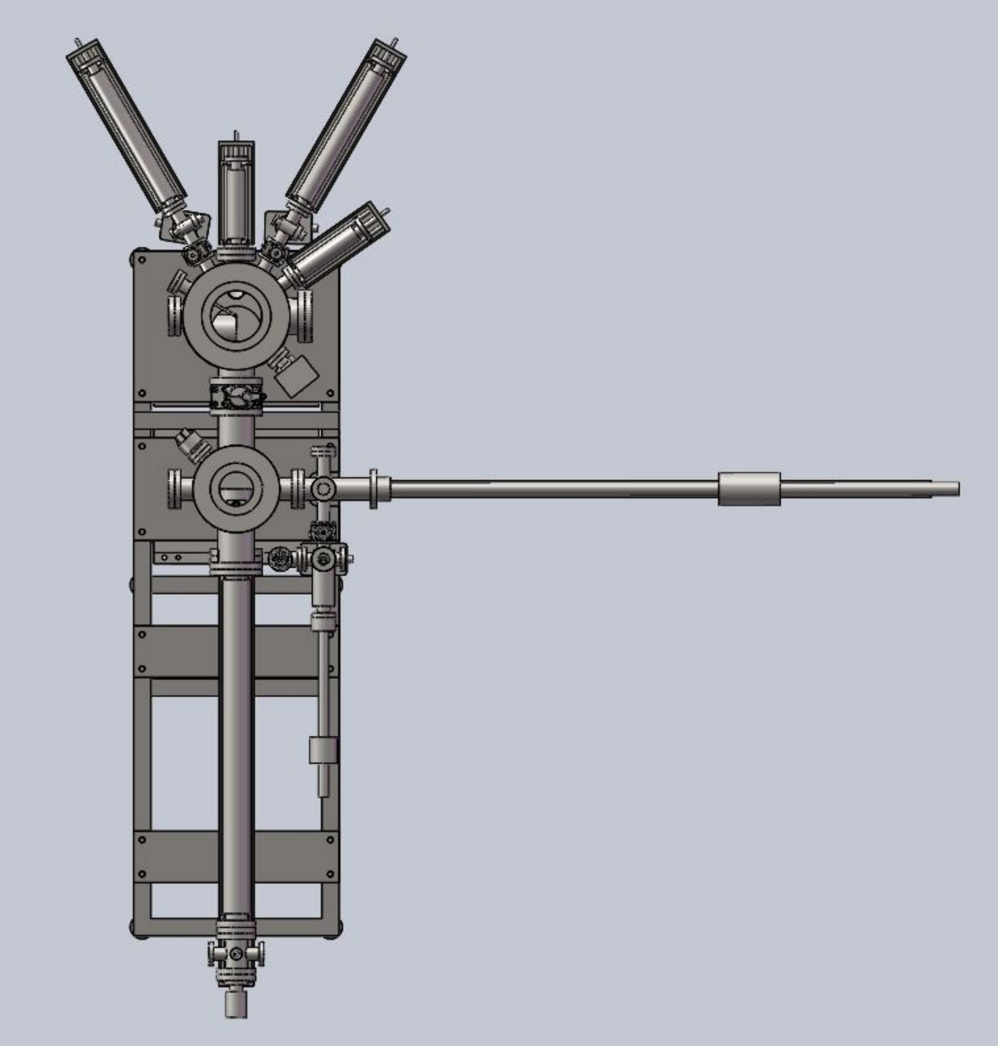
Clipped with aperture

- Overfilled iris cuts out the inner flat part of laser beam
- Loss is large but simple
- Widespread for photoinjector application

Aspheric optics

- High transmission (90%), commercial available Systems
- High-precision fabrication process is needed
- Sensitive to input laser parameters: shape, size and collimation

New Photocathode deposition system



- Vacuum in deposition chamber and transport chamber can reach up to low 10^{-9} Pa with a sputtering ion pump (400L/s) and a SAES NEG pump (3500 L/s and 2000L/s)
- SAES alkali sources and effusion sources can both be used in the system.
- The temperature of the substrate puck can be controlled from 4 K to 800 K .
- Alkali based photocathode, Cs_2Te, K_2CsSb, K_2NaSb, GaAs etc can be grown on this system.

Conclusion

- Stable operation of the DC-SRF injector(1.3 GHz) has achieved. The compatibility between cathode material and superconducting cavity can be solved by using the DC-SRF structure

- Simulation shows that with bialkali photocathode (K_2CsSb), Laser shaping, Higher DC voltage(100 kV), etc. Electron beam with emittance ~0.5 μm @100 pC can be achieved with present the DC-SRF injector(1.3 GHz).

- A new photoinjector is being designed for lower emittance

- Thanks for the useful discussion on the new photocathode deposition system from Dr. Erdong Wang, Dr. Triveni, Dr. Ilan Ben-Zvi, Dr. Shukui Zhang etc.

Thank you !