SACLA's thermionic low-emittance gun and the future perspective

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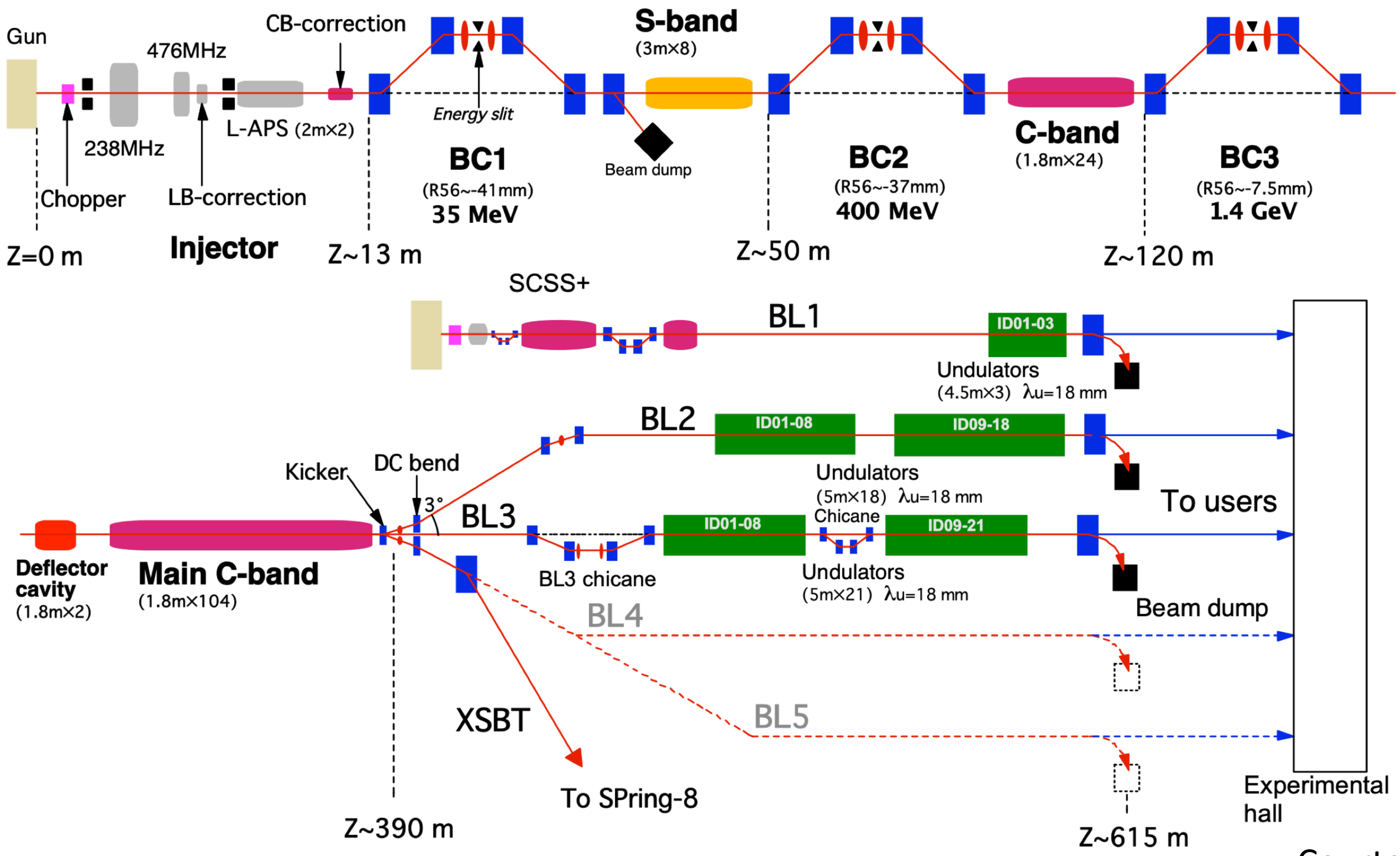
Outline

- Overview of the x-ray free-electron laser facility, SACLA
- CeB_6 thermionic gun
- A problem and a solution of the SACLA’s CeB_6 gun
- Future perspective

Overview of the x-ray free-electron laser facility SACLA

X-ray free-electron laser facility, SACLA

SACLA accelerator layout



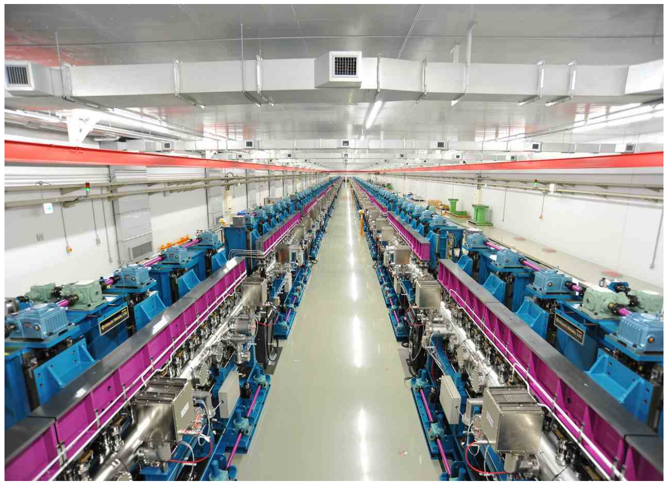
Courtesy of T. Hara

SACLA accelerator main components

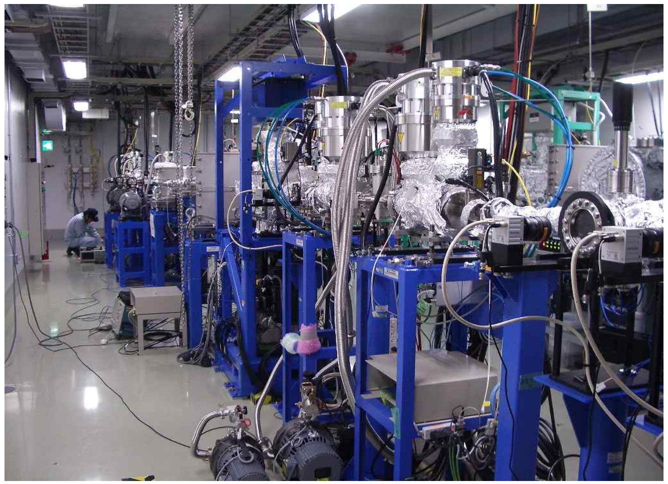
Electron injector

C-band accelerator

In-vacuum undulator



Photon beamline

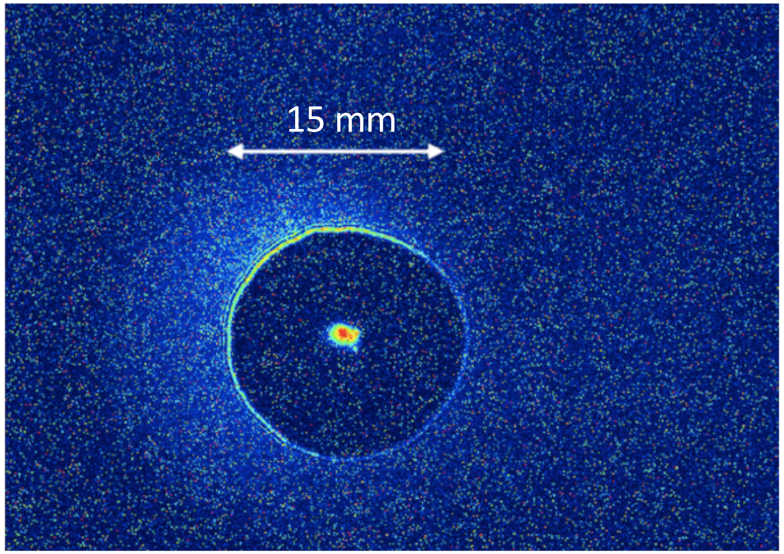


SACLA beam specifications

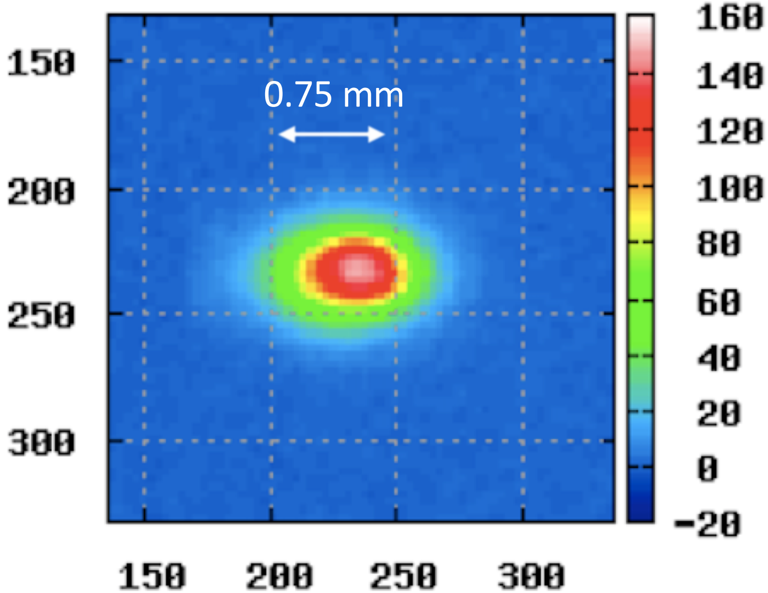
	BL3 / BL2	**BL1**
Electron beam energy	8.5 GeV (max.)	800 MeV (max.)
Bunch charge	0.2 – 0.3 nC	0.2 – 0.3 nC
Peak current	>10 kA	>300 A
Pulse repetition rate	60 Hz (max.)	60 Hz (max.)
Photon energy	4 – 15 keV (0.08 – 0.3 nm)	20 – 150 eV (8 – 60 nm)
FEL pulse energy	~0.5 mJ @10 keV	~100 μJ @100 eV
Pulse width	<10 fs	<1 ps
Spectrum band width	0.5 %	3%

SACLA beam performances

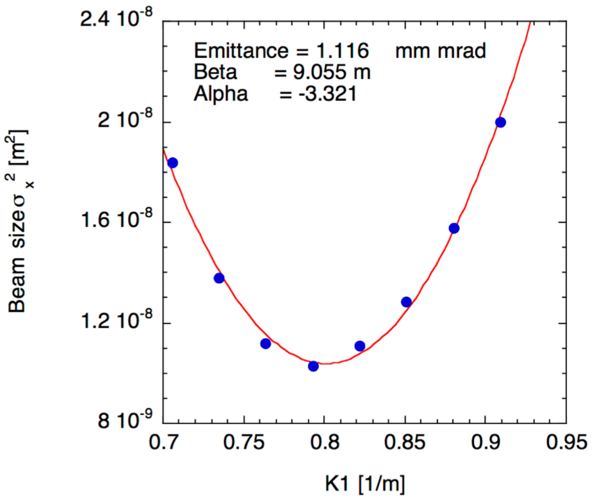
Electron beam profile



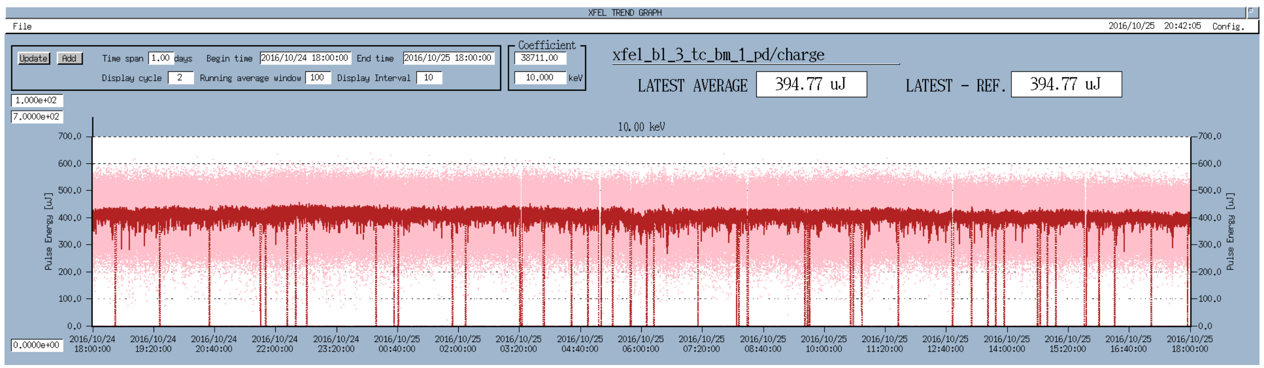
XFEL beam profile



Emittance



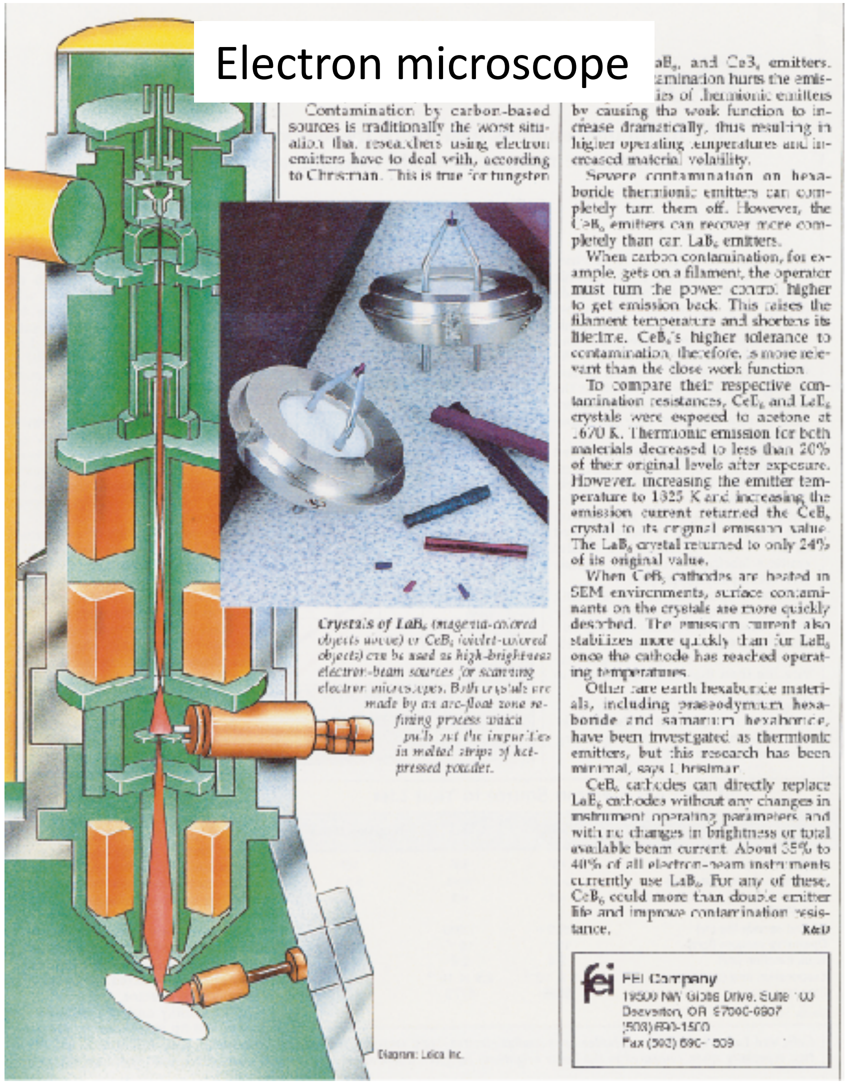
Output trend



CeB_6 thermionic gun

Cerium hexaboride cathode

Electron microscope



- Properties
  - Very flat surface by self evaporation (surface roughness <1 μm)
  - Low work function (~2.4 eV)
  - Long lifetime (>10,000 hours)
  - Rapid recovery from contamination

- Design Parameter (Ideal Case)
  - Thermal Emittance

$$\varepsilon_{n,rms} = \frac{r_c}{2}\sqrt{\frac{k_B T}{m_e c^2}} \quad = 0.4 \text{ mm mrad}$$

$$r_c = 1.5\,mm \qquad T = 1450°C\,(1723K)$$

  - Emission Density

$$J_c = 120.4T^2 \exp\left(-\frac{\phi'}{k_B T}\right) \quad > 42 \text{ A/cm}^2$$

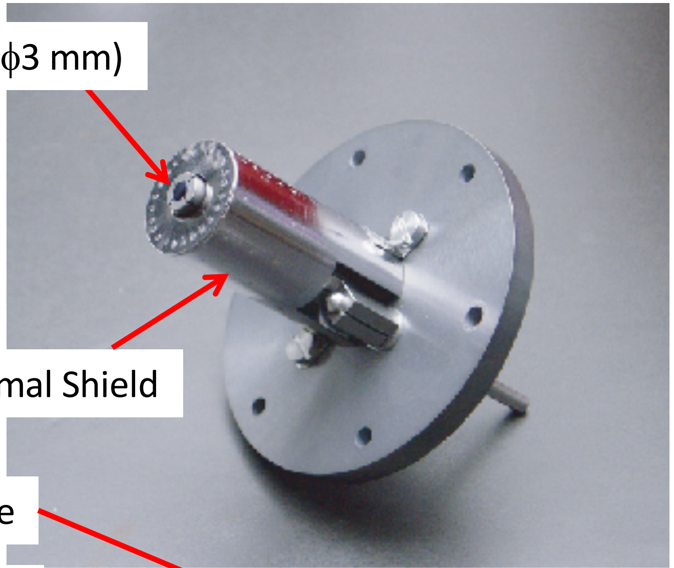
$$k_B = 8.617\times10^{-5}\,(eV/K)$$

$$\phi' = \phi - \frac{e}{2}\sqrt{\frac{eE}{\pi\varepsilon_0}} \sim 2.3\,(eV)$$

CeB_6 cathode assembly

CeB_6 Cathode (ϕ3 mm)

Tantalum Thermal Shield

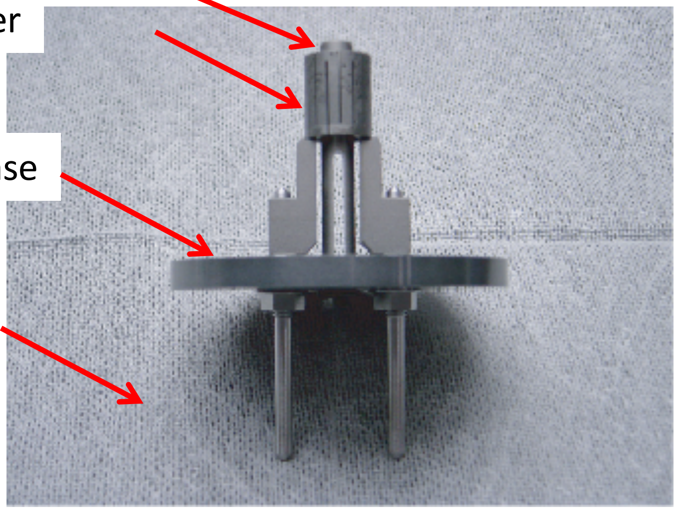


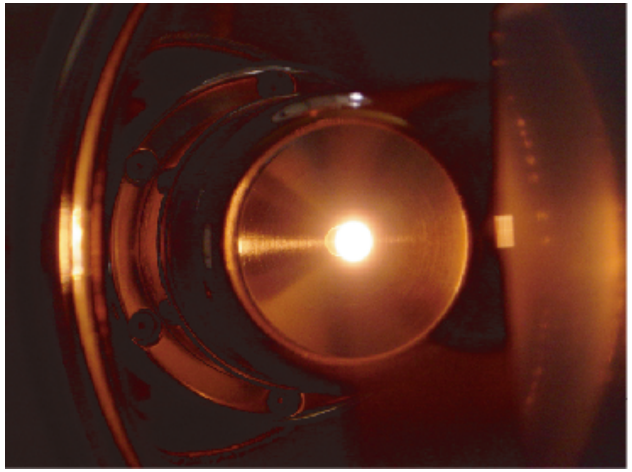
Graphite Sleeve

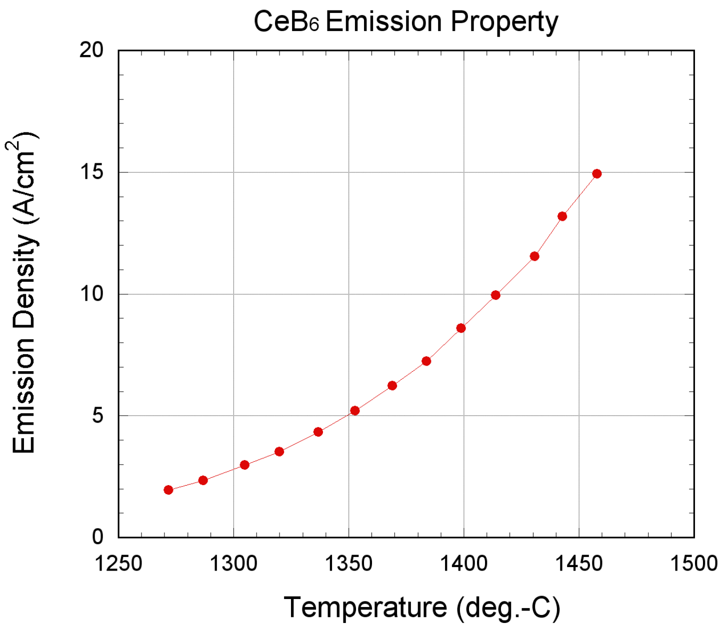
Graphite Heater

SiN Ceramic Base

Molybdenum
Current Lead







500-kV electron gun test stand (2003)

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CeB_6 electron gun for low-emittance injector

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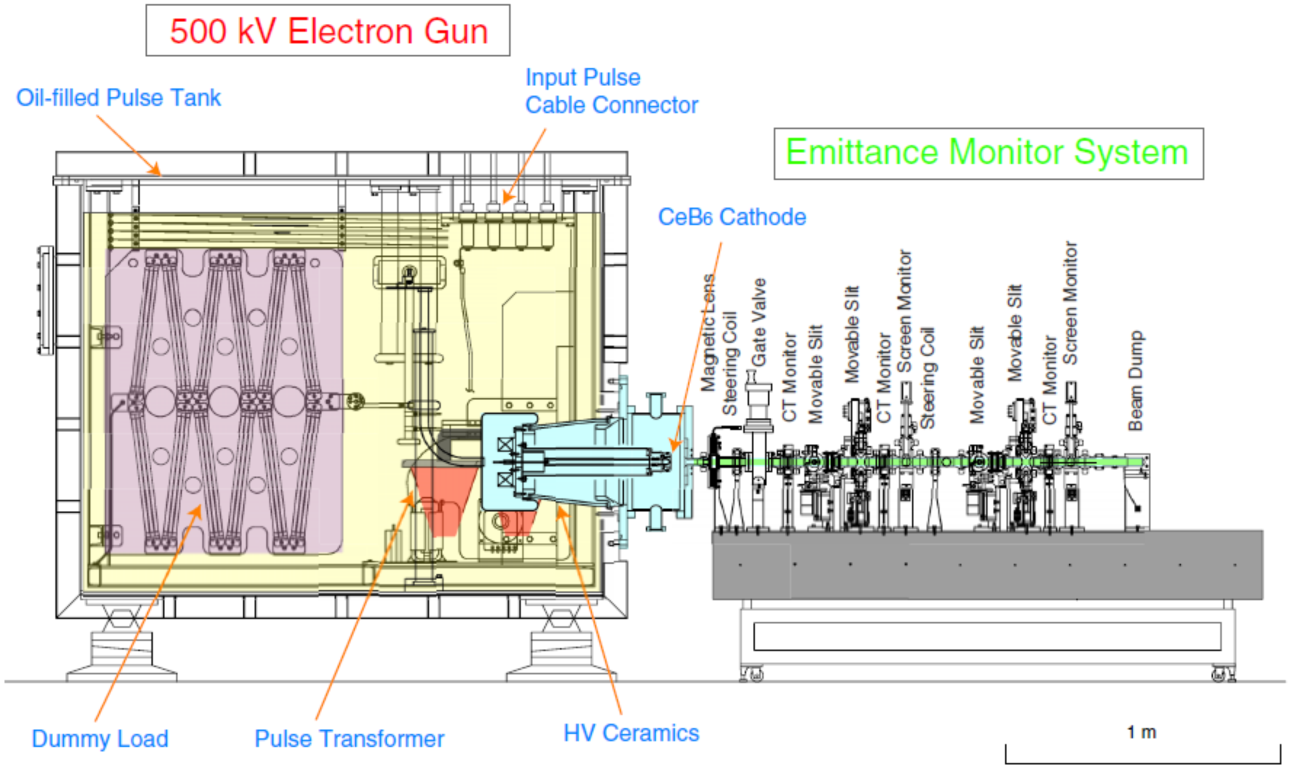
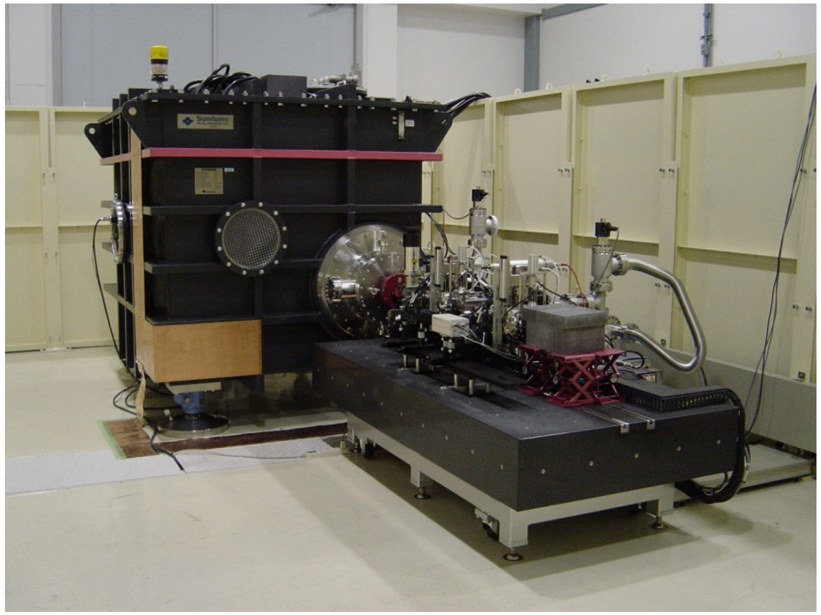
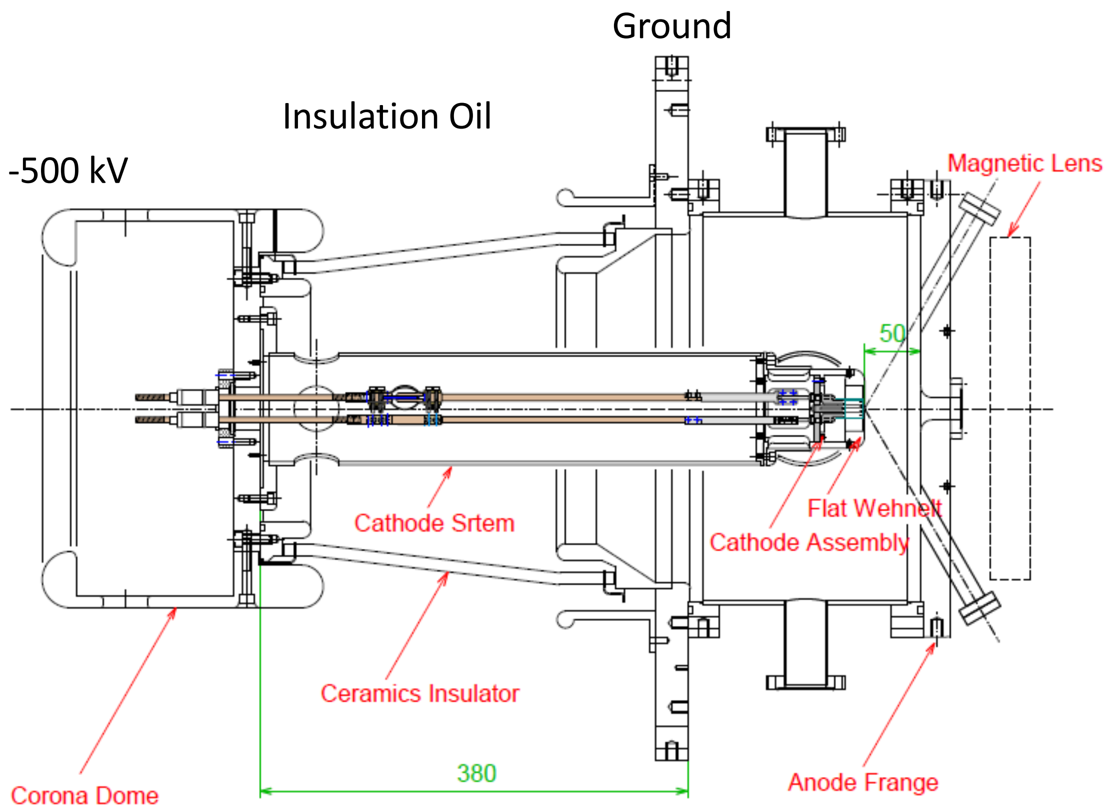




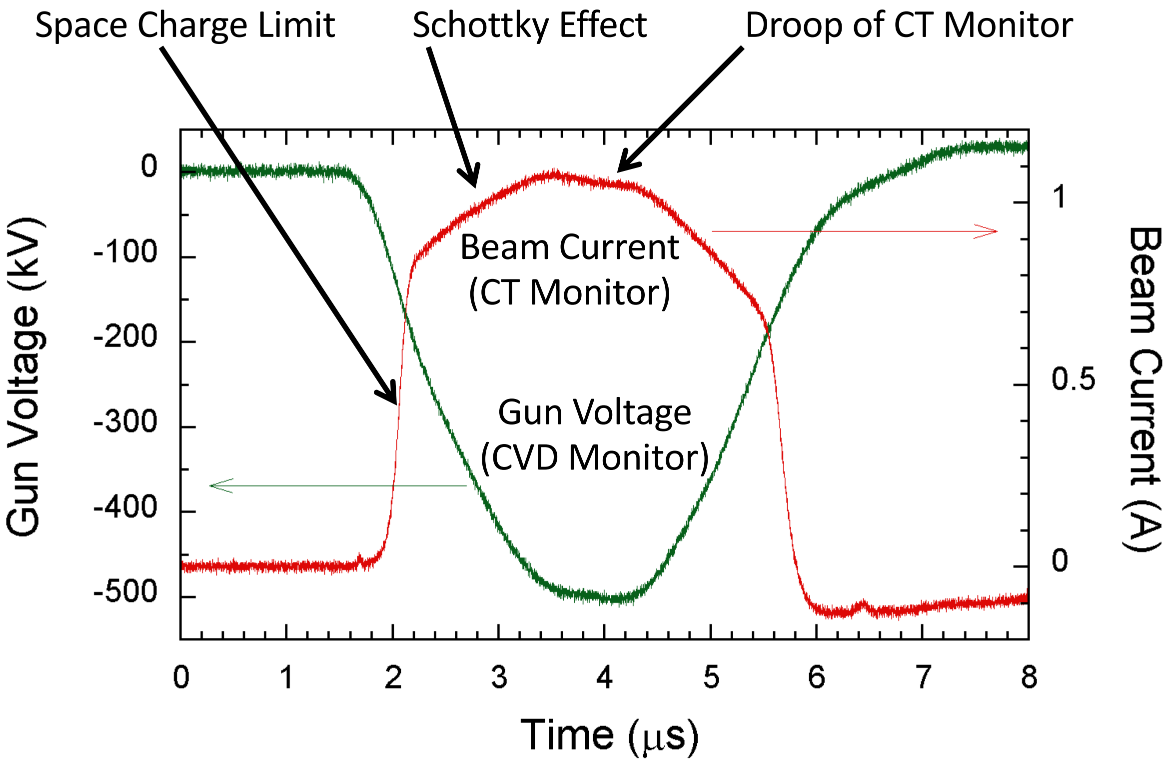
Electron gun chamber



- High-voltage Wehnelt
  Material : Super-clean SUS316L
  Surface : Chemical etching+
  Ultra-pure water rinsing
- Vacuum
  Pressure : <3x10^{-7} Pa
  Baking is not needed.

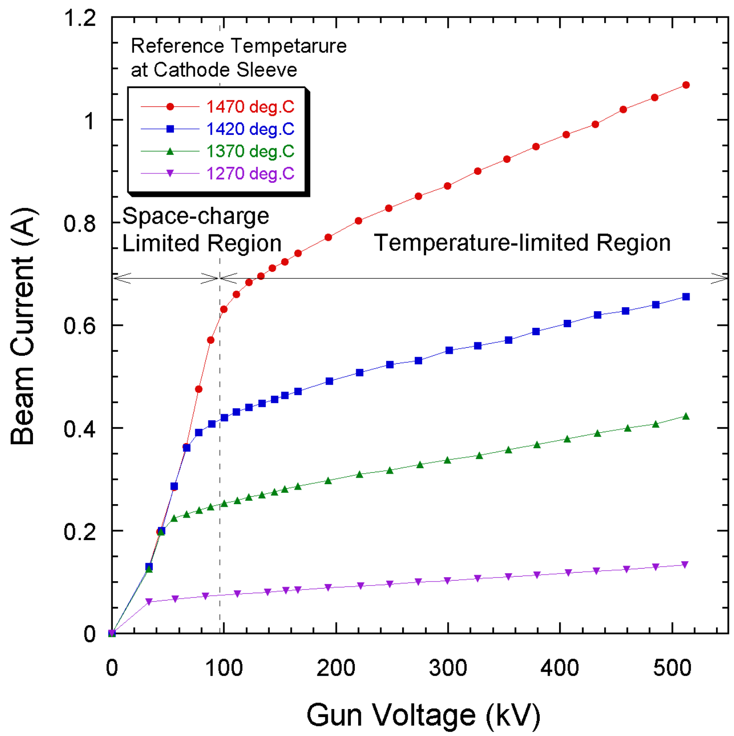
500-kV beam performance

Beam Waveform



- ~1 ns part is cut out from the flattop by a beam chopper.

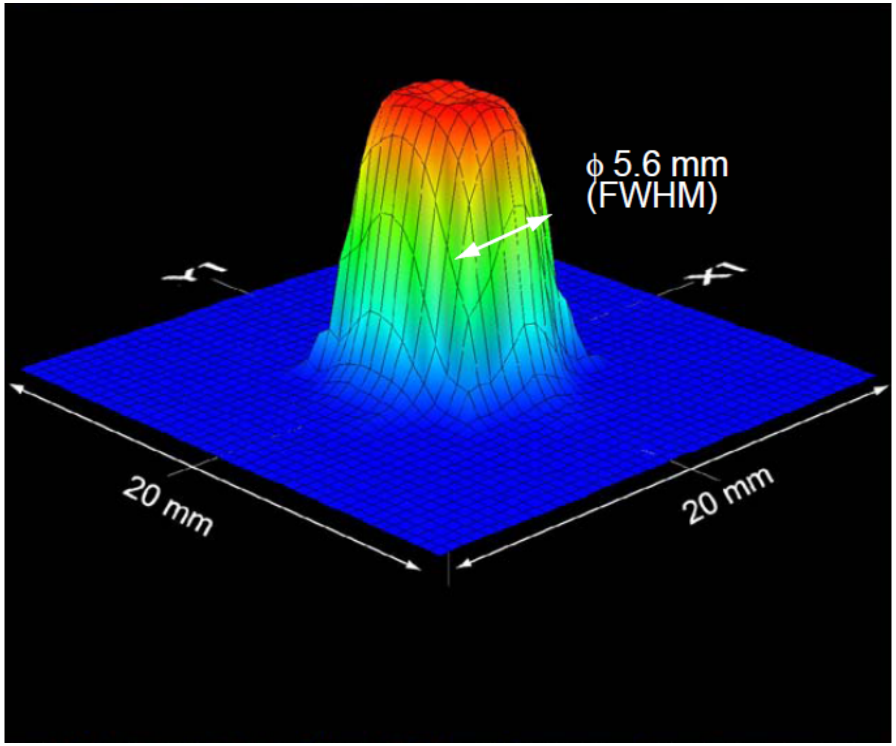
I-V Curve



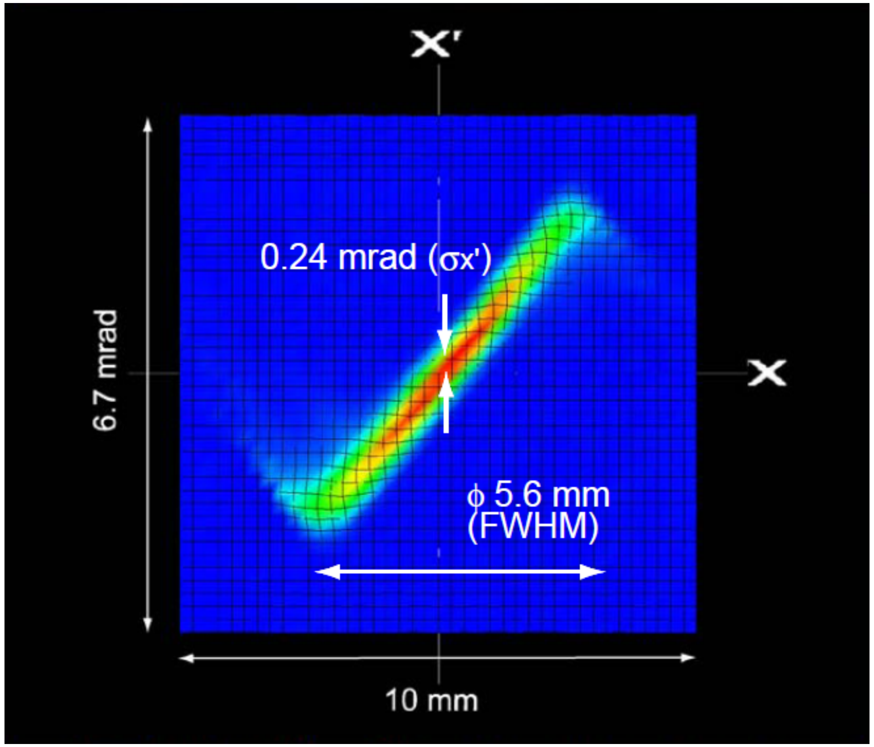
- The gun operates in temperature limited region to reduce emittance growth due to space charge.

Emittance measurement

Transverse Beam Profile



Phase Space Distribution

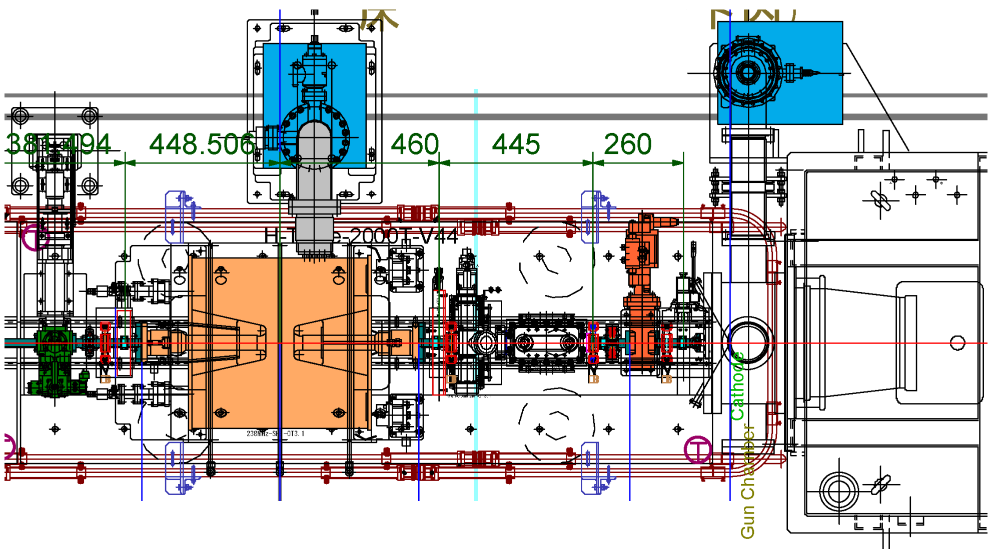


- Beam Energy : 500 keV
- Peak Current : 1.0 A
- Pulse Width : 3 μs (FWHM)

- Normalized rms Emittance
  : 1.1 mm mrad (full particles)
  : 0.6 mm mrad (90% core)

Clear beam at the SACLA injector

Beam



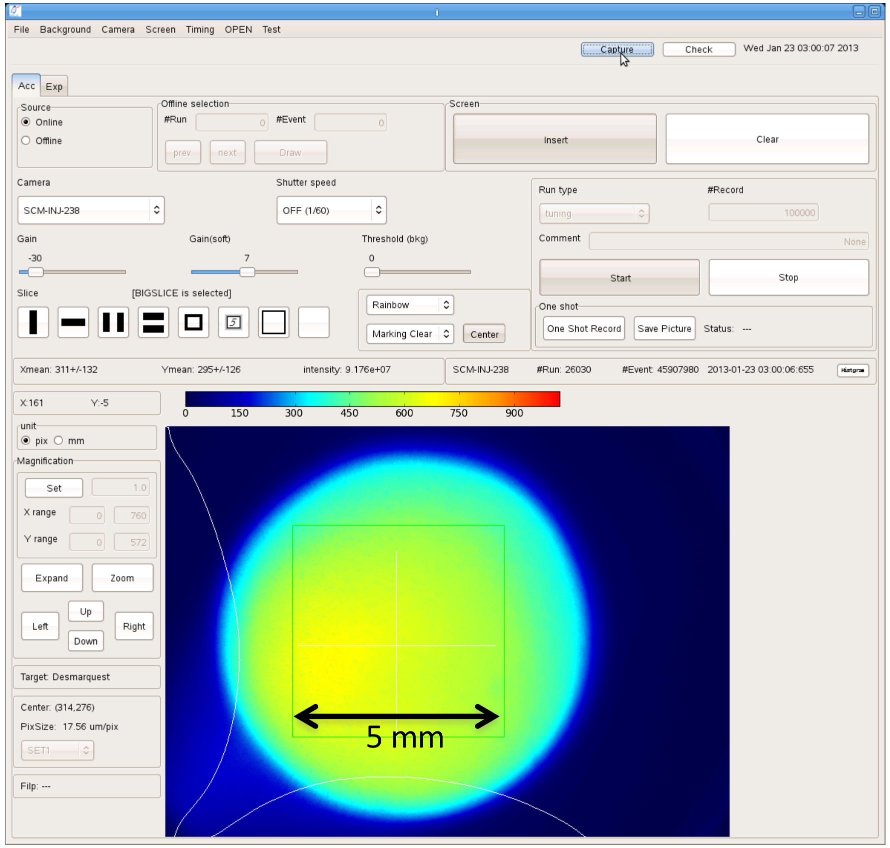
Buncher

CeB_6 Cathode

Beam Chopper

Screen Monitor
(Alumina Ceramics)

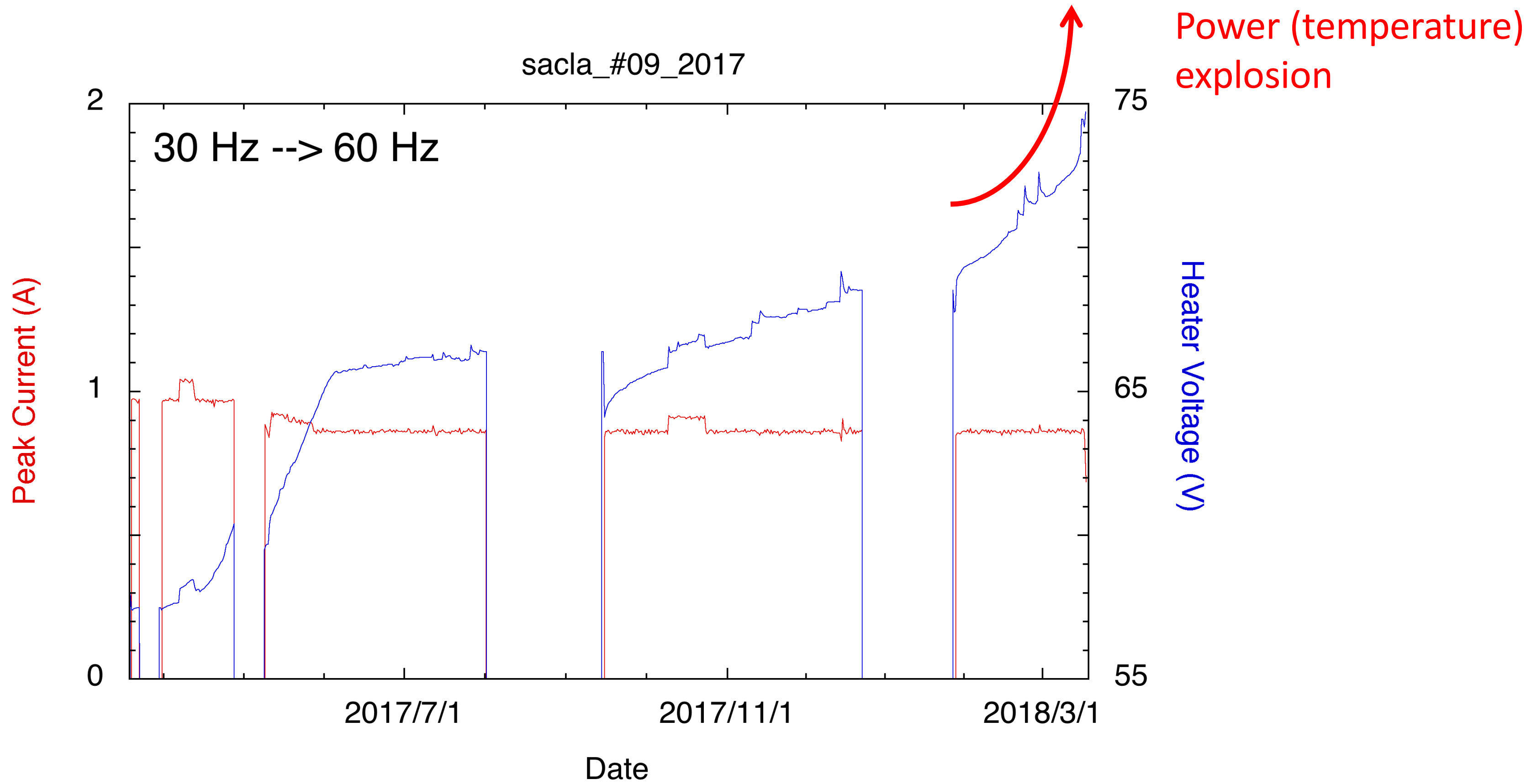
Circular Collimator
(ϕ4 mm typical)



- Hard edge and good uniformity is realized.
- Low slice emittance ~0.4 mm mrad should be achieved.

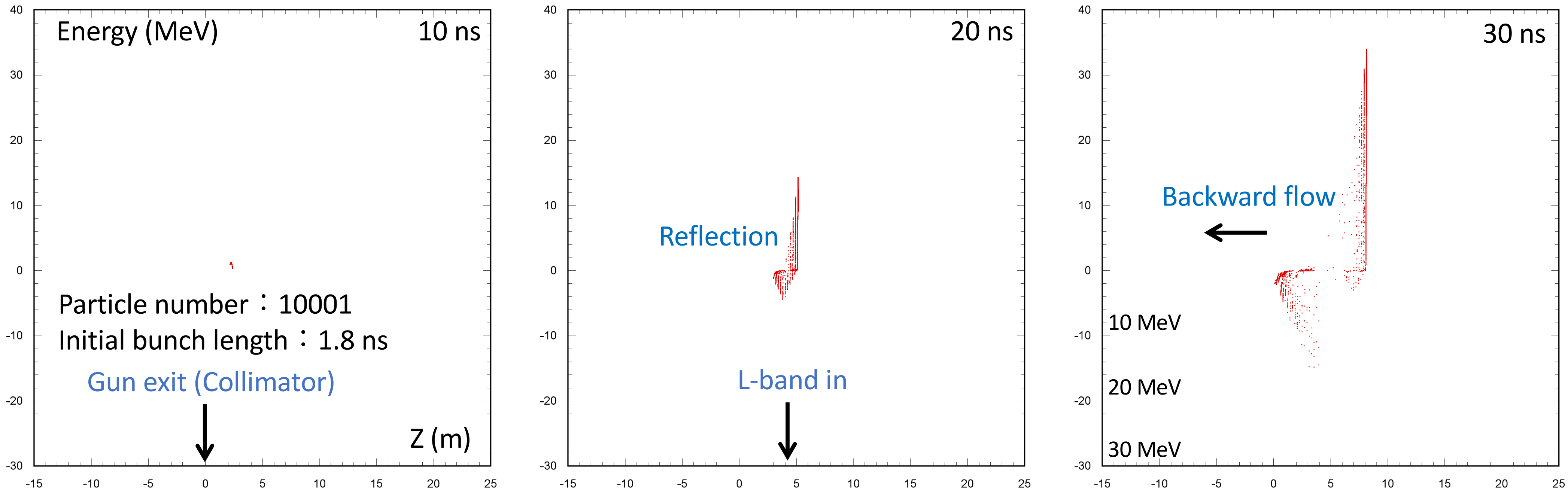
A problem and a solution of the SACLA's CeB_6 gun

Cathode lifetime problem at SACLA

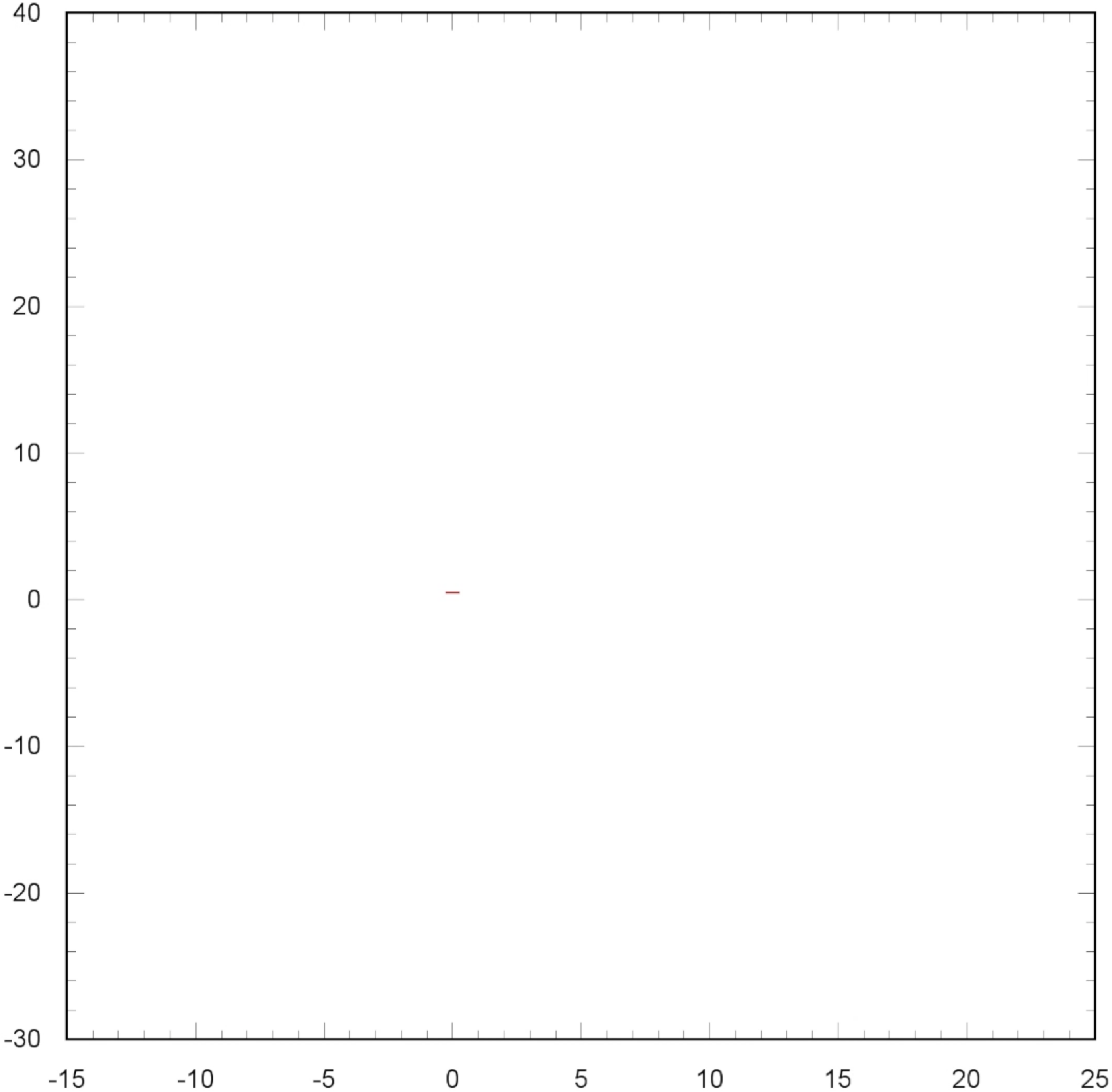


- Cathode emission lifetime is restricted to 1-year at SACLA in spite of 2 or 3 years lifetime at the prototype accelerator SCSS.
- Backward flow of the electrons from the L-band accelerator may be a source of the short lifetime.

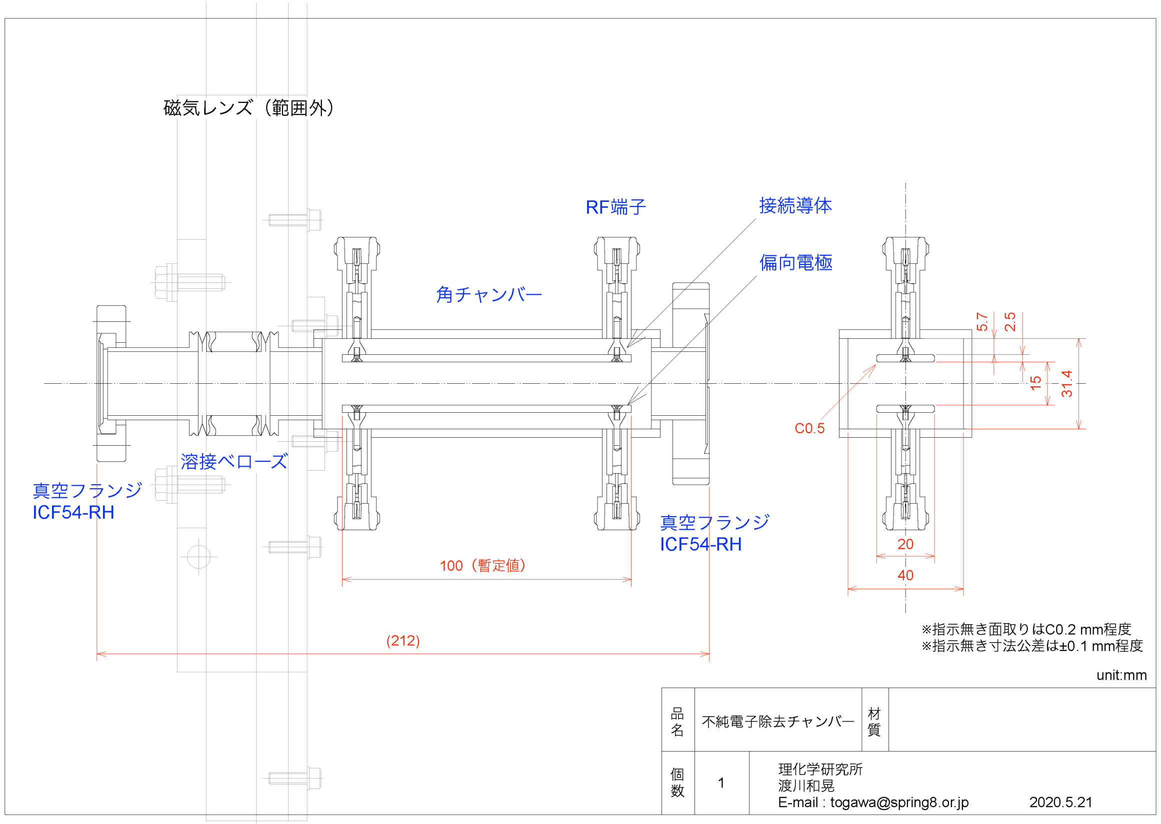
1D particle simulation of the SACLA injector

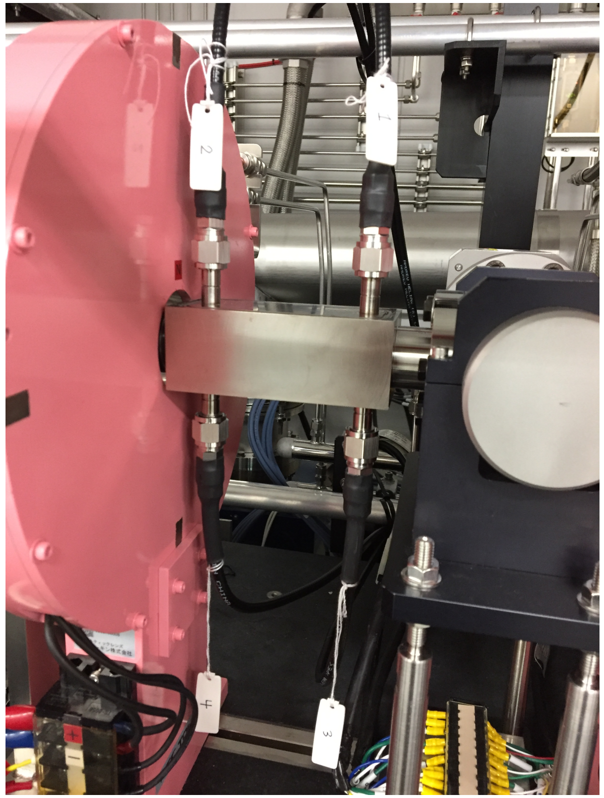


- 1-dimensional particle simulation without space charge.
- High-energy electrons can flow backward and cause damage to the cathode.
- Beam kicker installed in front of the L-band accelerator will remove the backward electrons.


40
30
20
10
0
-10
-20
-30
-15
-10
-5
0
5
10
15
20
25

Impure bunch sweeper





- An impure bunch sweeper was installed in front of the L-band injector linac to sweep out the unwanted bunch tail in this summer.
- This was introduced to remove electron contaminations that mix in empty buckets in the storage ring.
- The sweeper will work as a backward electron kicker.

Future perspective

Future perspective

- Future XFELs require extremely small emittance ($\leq 0.1\ \mu m$).
- Emittance relation: $\varepsilon_n = \frac{r_c}{2}\sqrt{\frac{k_B T}{m_e c^2}}$ r_c: *cathode radius,* T: *tempetature*
- Lowering the operation temperature is not effective to achieve a lower emittance due to square root function.
- Making the cathode size smaller is important.
- In return for the small cathode size, extremely high-density of thermionic emission is required ($\geq 100\ A/cm^2$).
- CeB_6 cathode has a possibility to produce such a high-density low-emittance beam, if a higher-gradient electric field is applied on the cathode surface.
- Search for new-type thermionic cathodes is also important.

Summary

- CeB_6 thermionic gun has been derivering low-emittance high-intensity electron beams for SACLA for 10 years.
- Cathode lifetime problem may be solved by removing or reducing the backward high-energy electrons from the injector linac.
- Reducing an emittance of the cathode is essential to increase an XFEL output. The CeB_6 gun should have a possibility.