Electron sources at ATF/LUCX facility of KEK

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Two lectures about the electron source

The Cs_2Te RF gun developed at KEK will be delivered IUAC in 2015 for the FEL project.

I would like to focus my lectures on developments and experiences of the Cs_2Te RF gun at KEK.

Part-I

- Development of Cs_2Te RF gun

Part-II (afternoon)

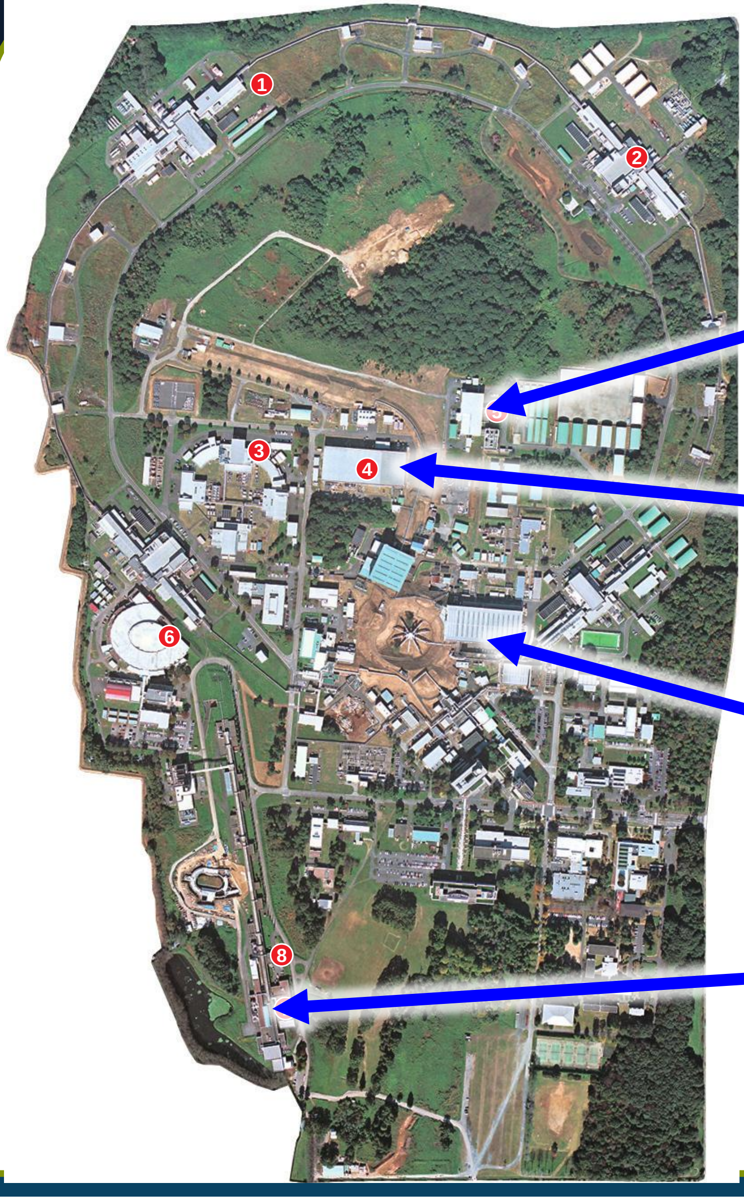
- Experiences of Cs_2Te photocathode at KEK

Part-I

Development of
Cs_2Te photocathode RF gun

- Introduction; KEK electron accelerators and gun
- Development of the Cs_2Te RF gun
- Experiences of the Cs_2Te photocathode under beam operation

Electron sources of the KEK Accelerators



Cs_2Te photocathode RF gun

- well established
- compact and long lifetime

STF

L-band 1.3 GHz

ATF and LUCX

S-band 2.8 GHz

cERL (500kV DC gun for CW beam)

GaAs photocathode

KEKB

Thermionic Gun

SuperKEKB

Quasi traveling wave side coupled cavity gun

advanced, still being developed

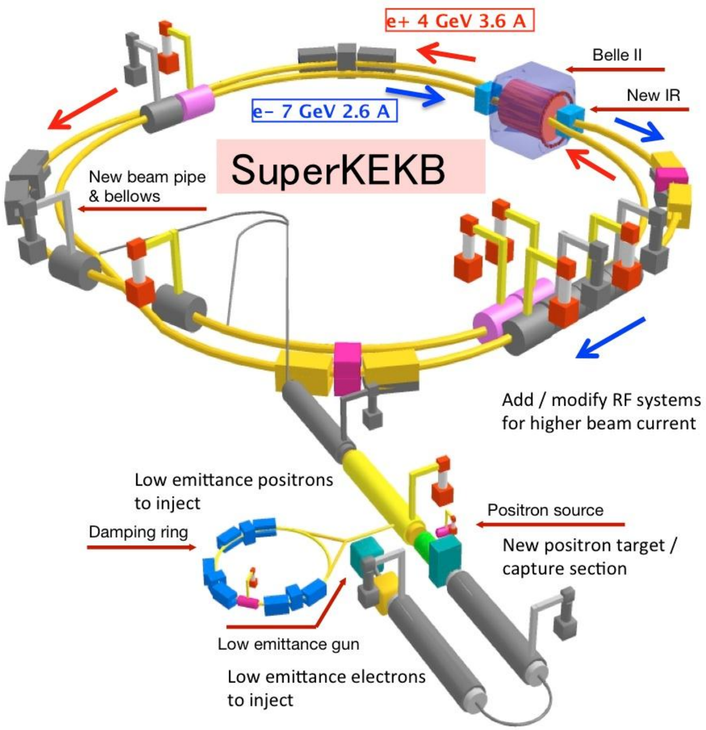
Electron sources at KEK

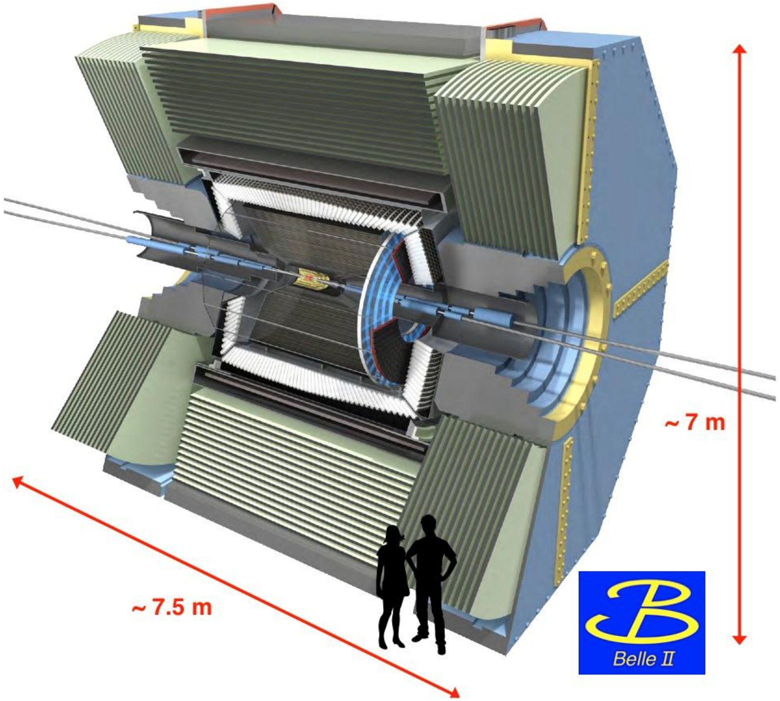
Two specials electron guns (not Cs_2Te)

- SuperKEKB
- cERL (Compact Energy Recovery Linac)

SuperKEKB: electron-positron collider for High Energy Physics

- CP violation, flavor physics, …
- SuperKEKB is an upgrade of KEKB to increase the luminosity (x40), to 8 x 10 ^{35} cm $^{-2}$ s $^{-1}$. The construction started in 2010 and will have the first beam in 2016 or so.





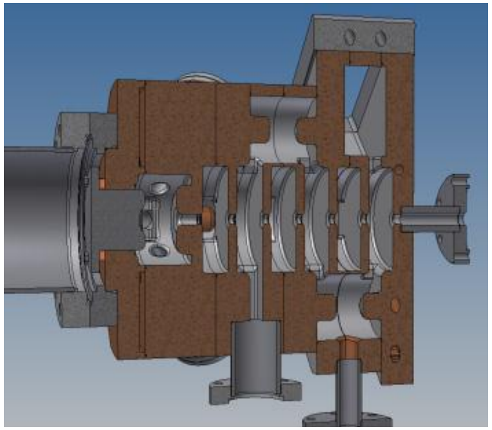
Electron source of SuperKEKB

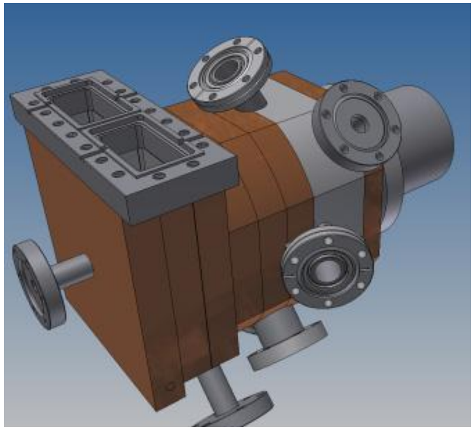
High charge low emittance electron and positron beams are required for SuperKEKB.

Aiming to generate 7.0 GeV electron beam at 5 nC 20 mm-mrad

Table 1 : e- and e+ beam parameter

	KEKB (e+/e-)	SuperKEKB (e+/e-)
charge [nC]	1 / 1	4 / 5
Emittance [mm-mrad]	2100 / 300	6 / 20





T. Natsui et al., proceedings of IPAC 2013, TUOCB103

Advanced S-band RF gun for high charge low emittance electron beam

- **Disk and Washer (DAW) type RF gun was tested.**
- **another new RF gun is under developing and testing.**

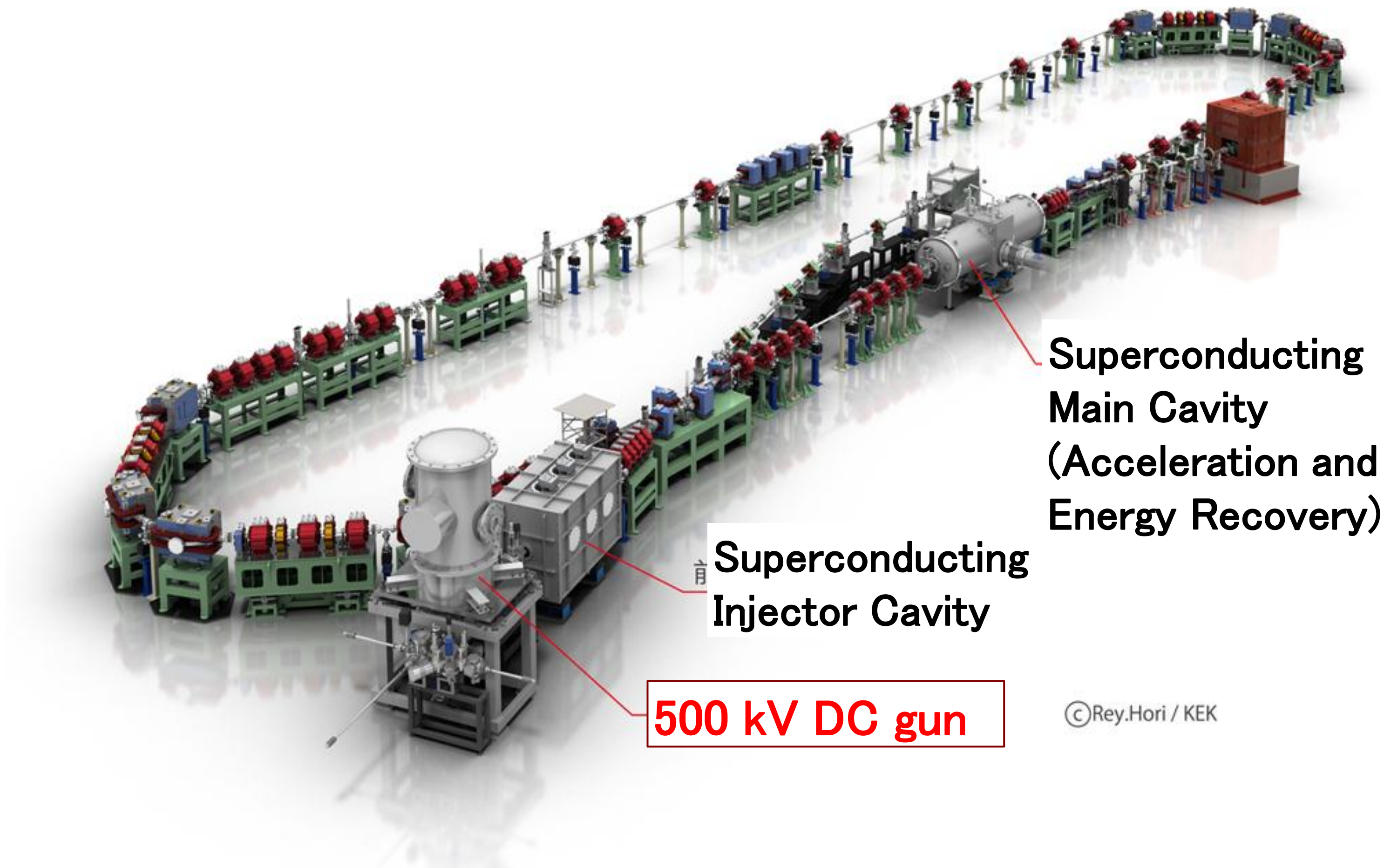
quasi traveling wave side couple RF gun

- **a strong focusing field at the cathode**
- acceleration field distribution also has a focusing effect.
- Cathode: Ir_5Ce

Compact Energy Recovery Linac (cERL)

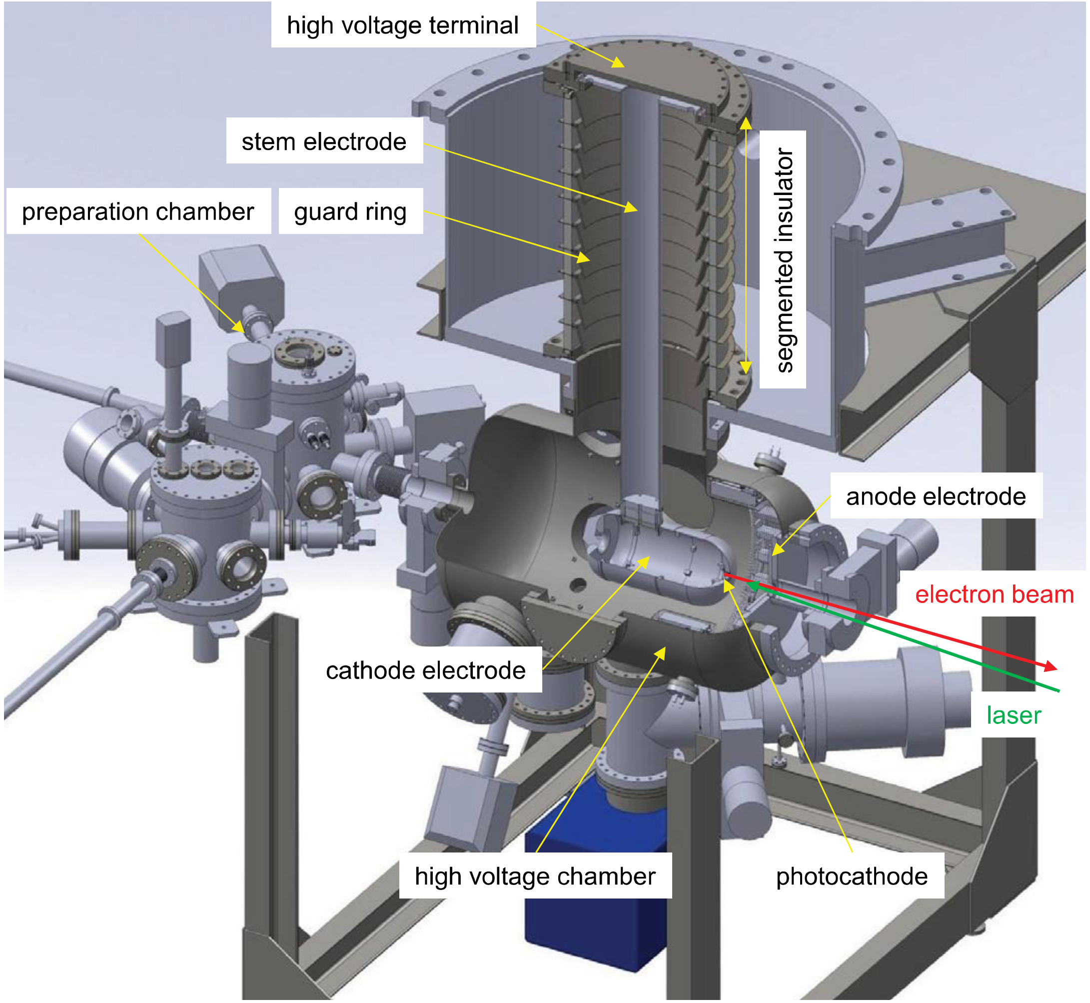
R&D accelerator for the future 3 GeV ERL

Target: 35 MeV, 10 mA (100 mA in future?)



Electron source of cERL

500 kV DC Gun (by JAEA)



N. Nishimori et al., Applied Physics Letters 102, 2341103 (2013)

Aiming to develop **High-brightness, high-current electron beam** for ERL

CW operation → DC gun

500 keV e^- beam

- reduce space-charge induced emittance growth

GaAs photocathode

- Lifetime is an issue.
- R&D for multi-alkaline cathode

Beam achieved:

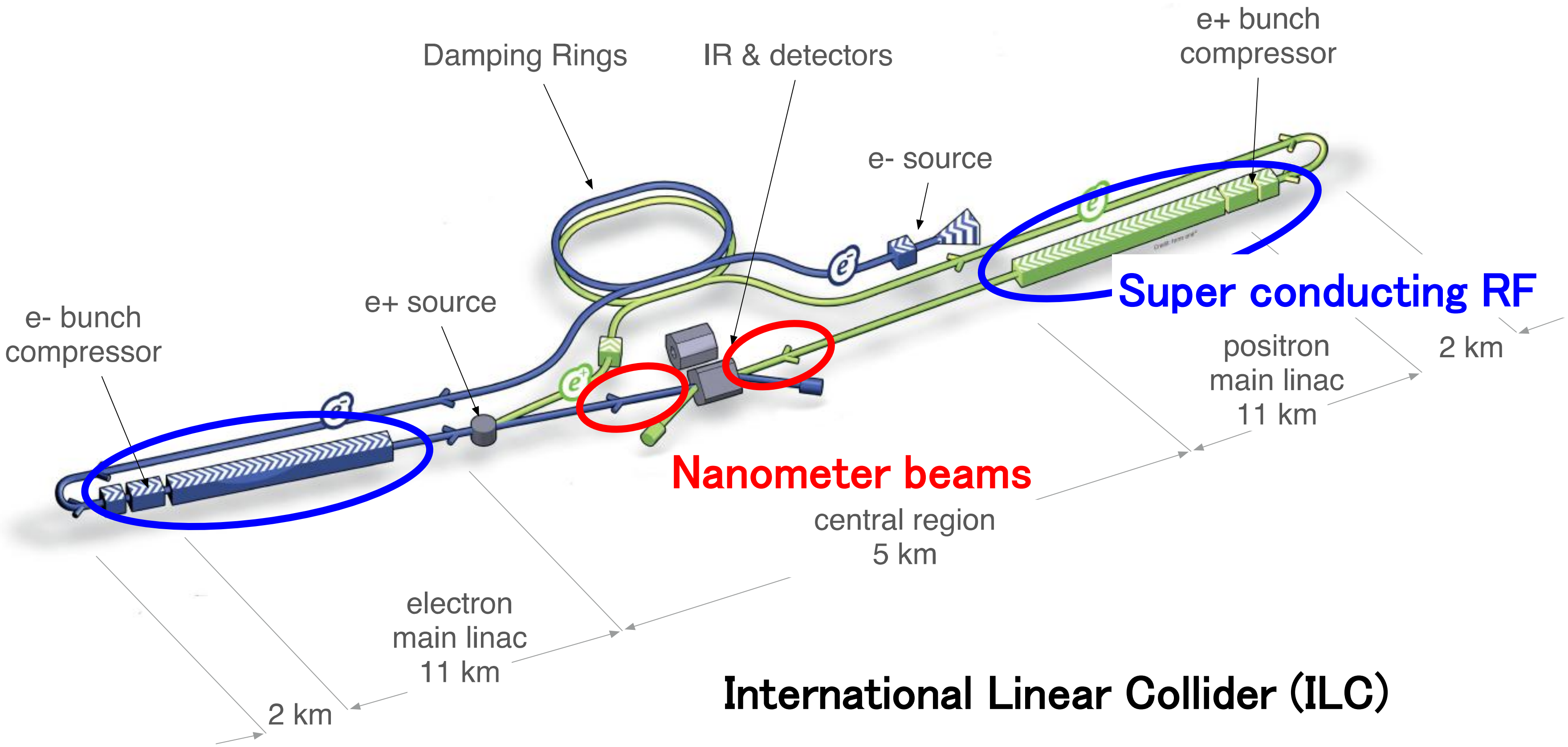
- 1.8 mA, 500 keV
- 10 mA, 180 keV

KEK accelerators with Cs_2Te photocathode RF gun

- STF
- ATF
- LUCX

What are the ATF and STF?

They are Accelerator Test Facilities aim to develop and establish the technologies for ILC



International Linear Collider (ILC)

STF: Superconducting RF Test Facility

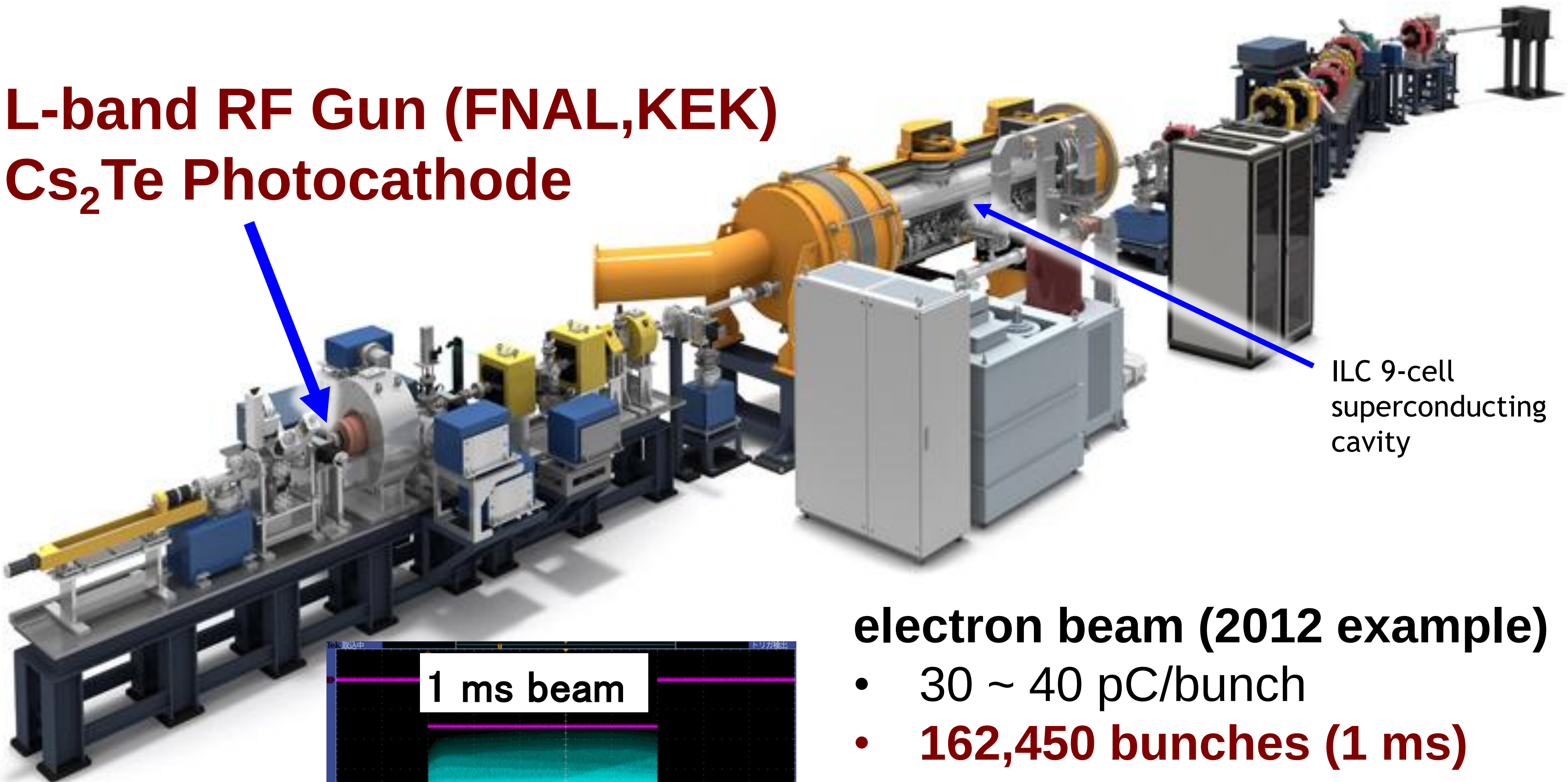
Aiming at establishment and industrialization of a superconducting acceleration system that is indispensable for the ILC (International Linear Collider).

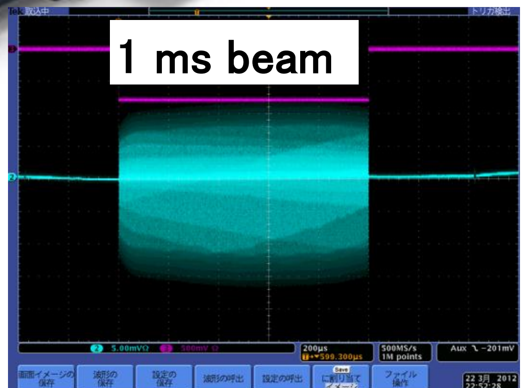
9-cell Nd superconducting cavity

Electron source of STF

STF: Superconducting RF Test Facility

L-band RF Gun (FNAL,KEK)
Cs_2Te Photocathode



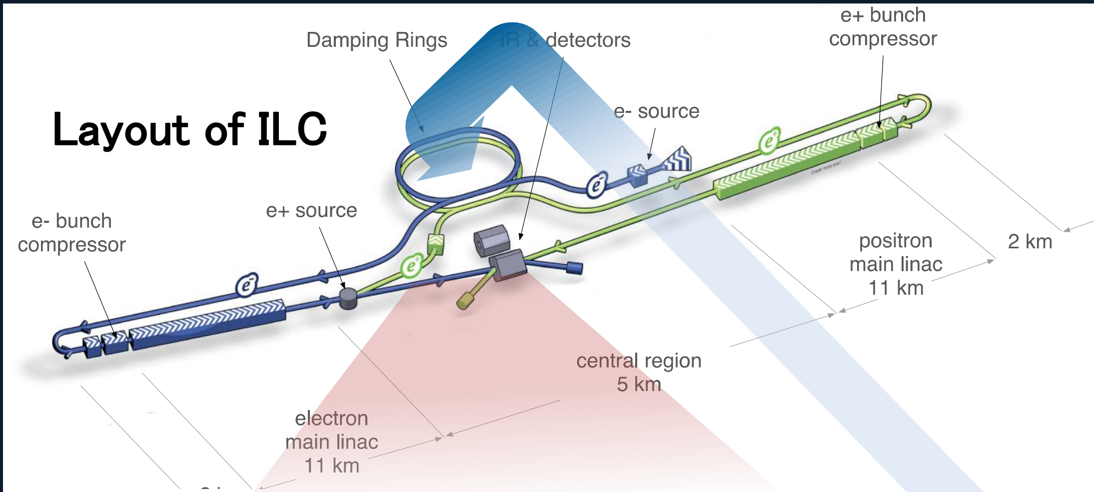


electron beam (2012 example)

- 30 ~ 40 pC/bunch
- **162,450 bunches (1 ms)**
- 3.5 MeV
- RF power 2.6 MW
  (37.5 MV/m on cathode)

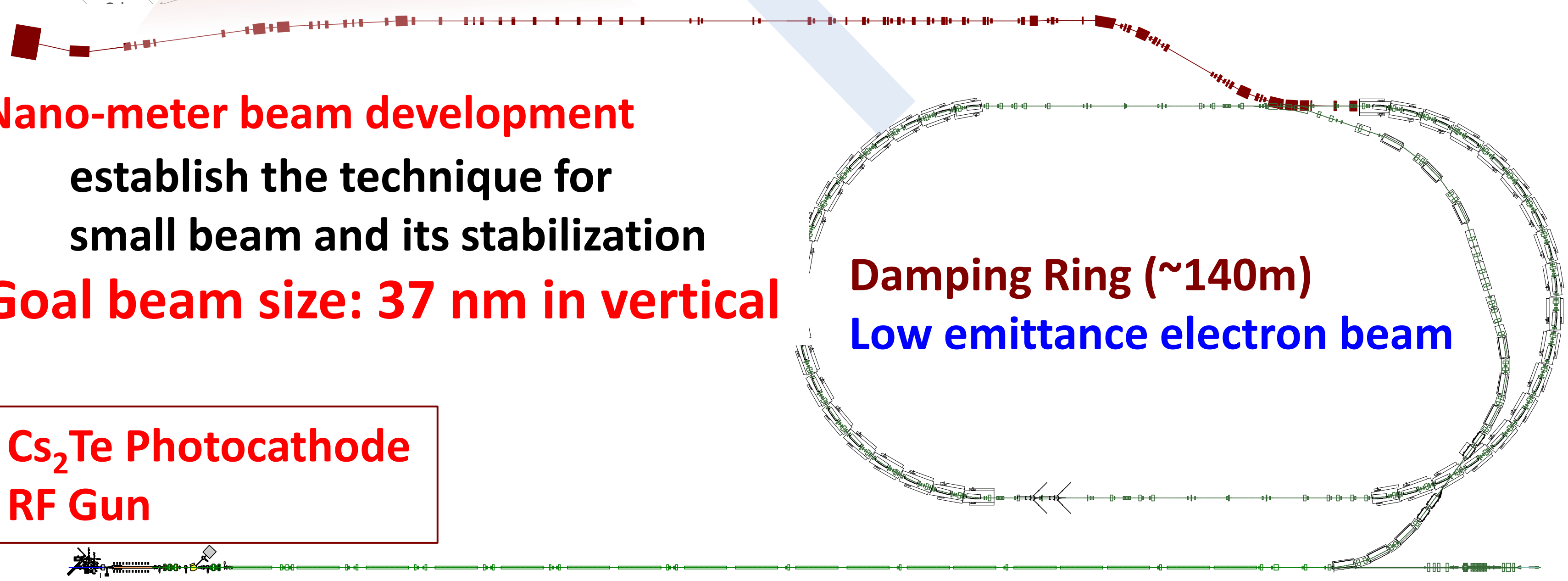
ATF: Accelerator Test Facility

Layout of ILC



Develop the nanometer beam technologies for ILC

6 nm beam at IP



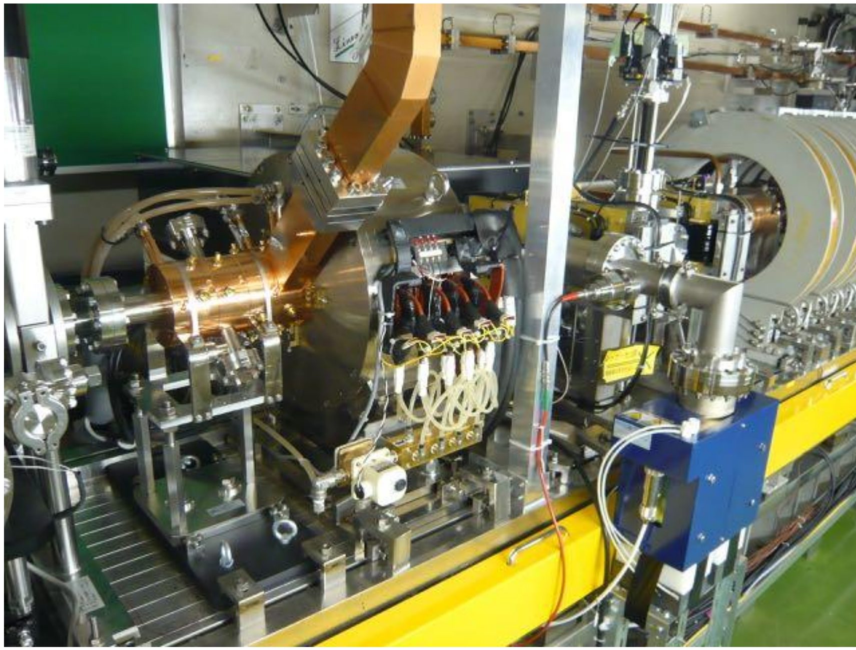
Nano-meter beam development

establish the technique for small beam and its stabilization

Goal beam size: 37 nm in vertical

Cs_2Te Photocathode RF Gun

Electron source of ATF



RF gun: S-band 3.6 cell

Typical operation for ATF

- **5 MeV** (limited by available RF power)
- **$1\text{x}10^{10}$ electrons/bunch**
- 1~20 bunch/pulse (2.8 ns spacing)
- 3 Hz repetition

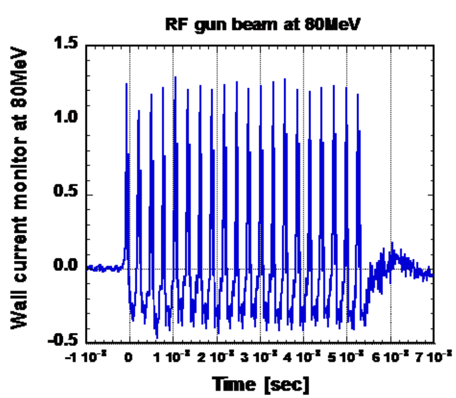
Laser

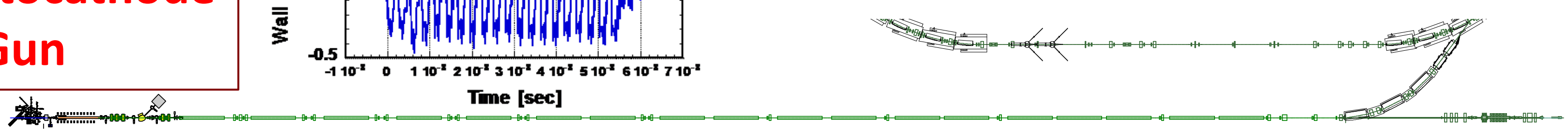
- $Nd:YVO_4$: 1024 → 266 nm
- 357 MHz
- 2 uJ/bunch
- 1~20 bunch by pockels cell

Cathode

- **Cs_2Te: QE ~1%**

Cs_2Te Photocathode RF Gun

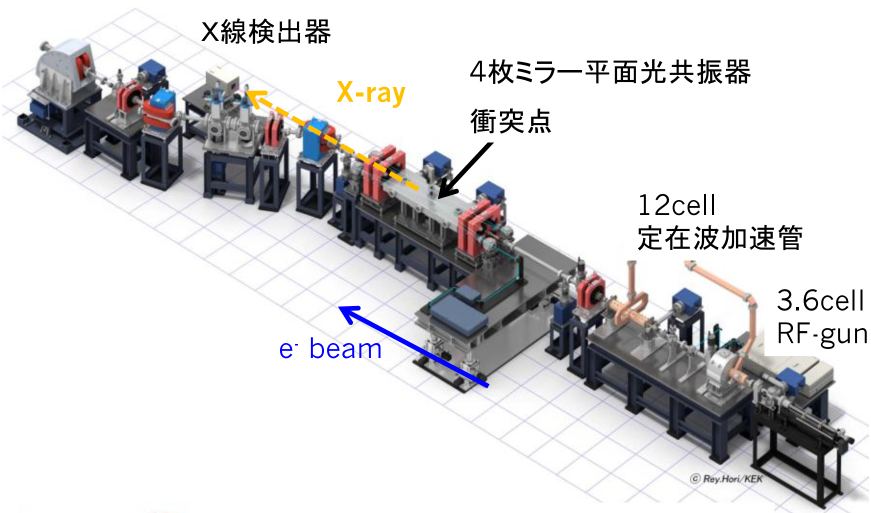


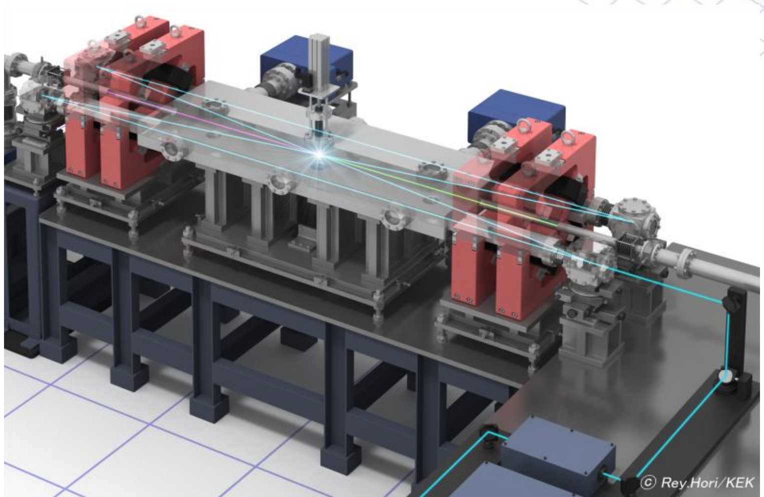


1.3 GeV S-band Electron LINAC (~70m)

One more Test Facility

LUCX: Laser Undulator Compact X-ray source





Constructed in ATF building, KEK.

Aim to develop the technologies for the compact X-ray source and imaging.

Develop an usable intense X-ray source (10~100keV) in a room scale by using **Inverse Compton scattering (ICS)**; i.e., laser and electrons.

GeV ring + Undulator

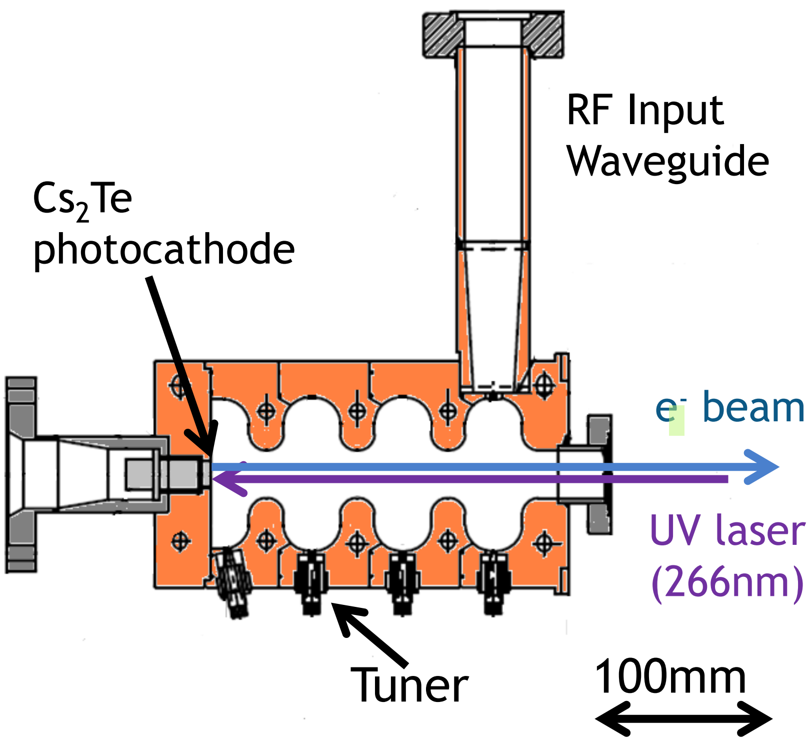
- High intensity, High quality
- Huge and Expensive

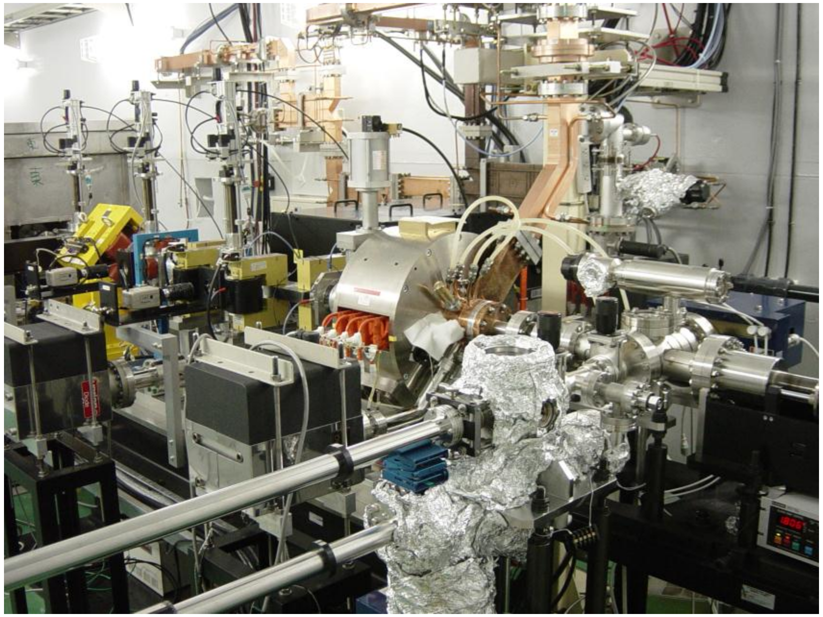
Inverse Compton scattering (ICS)

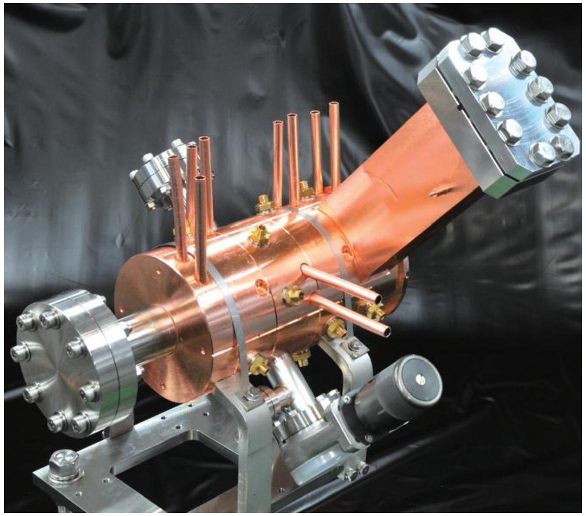
- Compact, Inexpensive

LUCX and ATF electron source: 3.6-cell RF gun

Frequency (π-mode)	2856 MHz
Qvalue	15000
Coupling β	0.99
R/Q	395Ω
Mode separation (π-2π/3)	2.8 MHz



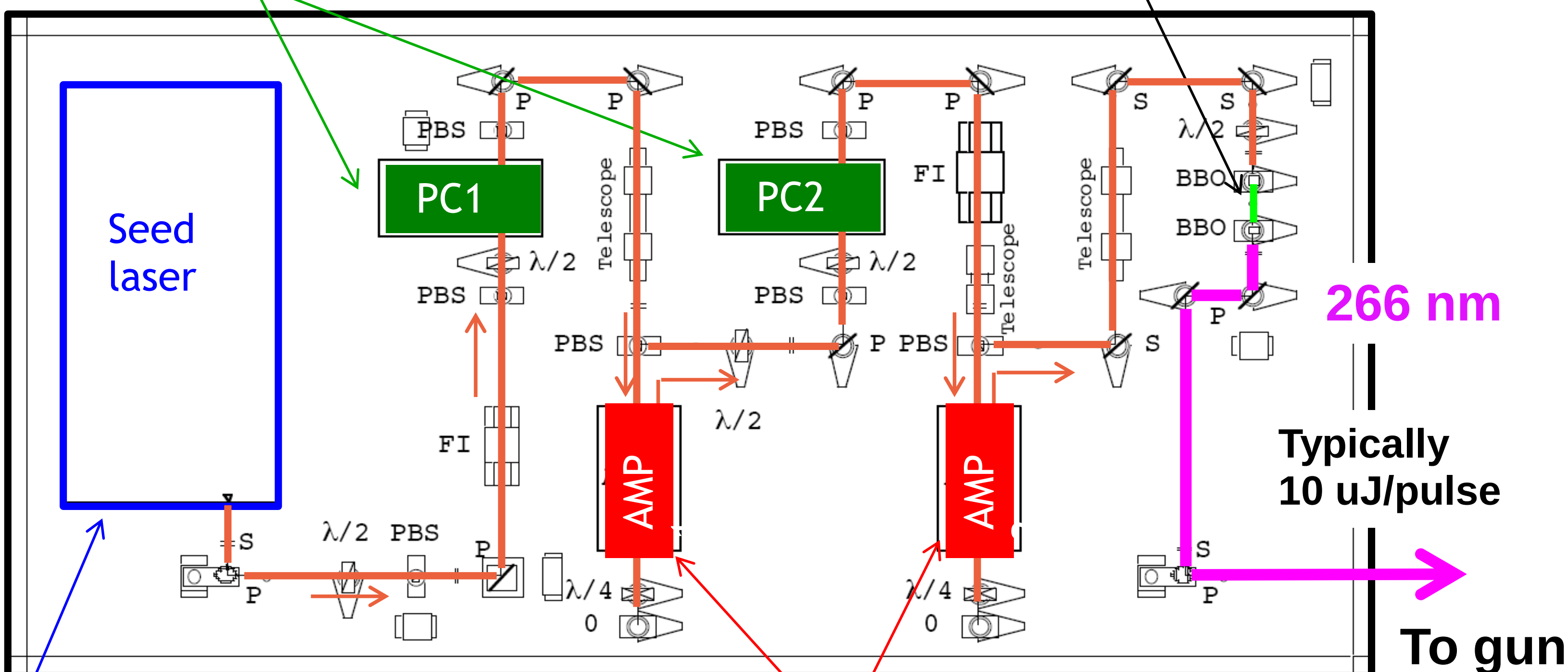




LUCX Laser for Cs_2Te photocathode

Pockels cell(BBO):
Pulse width ≦ 280ns (100bunches)

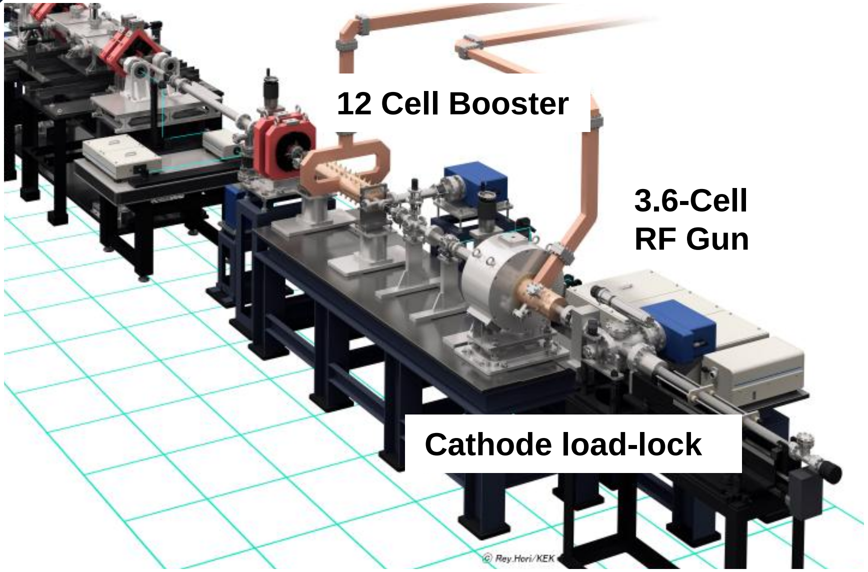
Fourth Harmonic Generation: Two BBOs,
Conversion efficiency ~ 25% (IR -> UV)

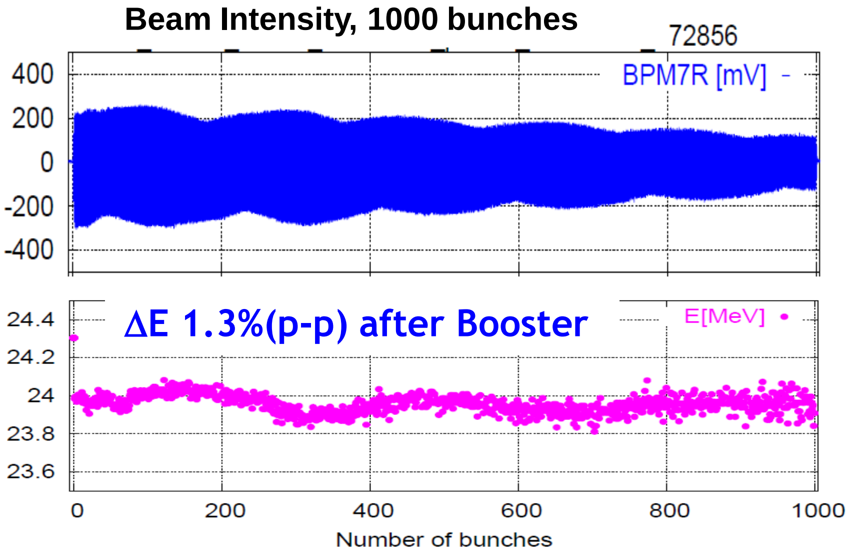


TBP, 357MHz mode-locked pulse laser
$Nd:YVO_4$ (λ:1064 nm, FWHM:9 ps)

Two amplifier heads
(Continuum, rod: Nd:YAG)
Double pass configuration
Gain ~ 2000

Example; Performance of LUCX RF gun





RF gun: S-band 3.6 cell

- **RF input: 12 MW**
- **beam energy: 10 MeV**
- **600 nC/pulse, 1000 bunch/pulse**
- **380 nC/pulse, 300 bunch/pulse**

Laser

- Nd:YVO_4: 266 nm, 357 MHz
- 10 uJ/bunch
- 100 ~ 1000 bunch/pulse by pockels cell, 3 Hz laser pulse

Cathode

- **Cs_2Te: QE ~0.3%**

Development of Cs_2Te RF gun at KEK

- Motivation of Cs_2Te RF gun for ATF
- Configuration of RF gun and laser in the ATF Injector system

Motivation of Cs_2Te RF gun for ATF

ATF had been started the Damping Ring for the R&D of multi-bunch beam for LC since 1996.

The beam intensity was limited ~ 1/10 because of the beam loss of the injected beam.

required: $2x10^{10}$ e^-/bunch, realized: $2x10^{9}$ e^-/bunch

ATF Injector: Thermionic gun and bunchers

Large tail, energy jitter, … → beam loss at LINAC to Damping Ring

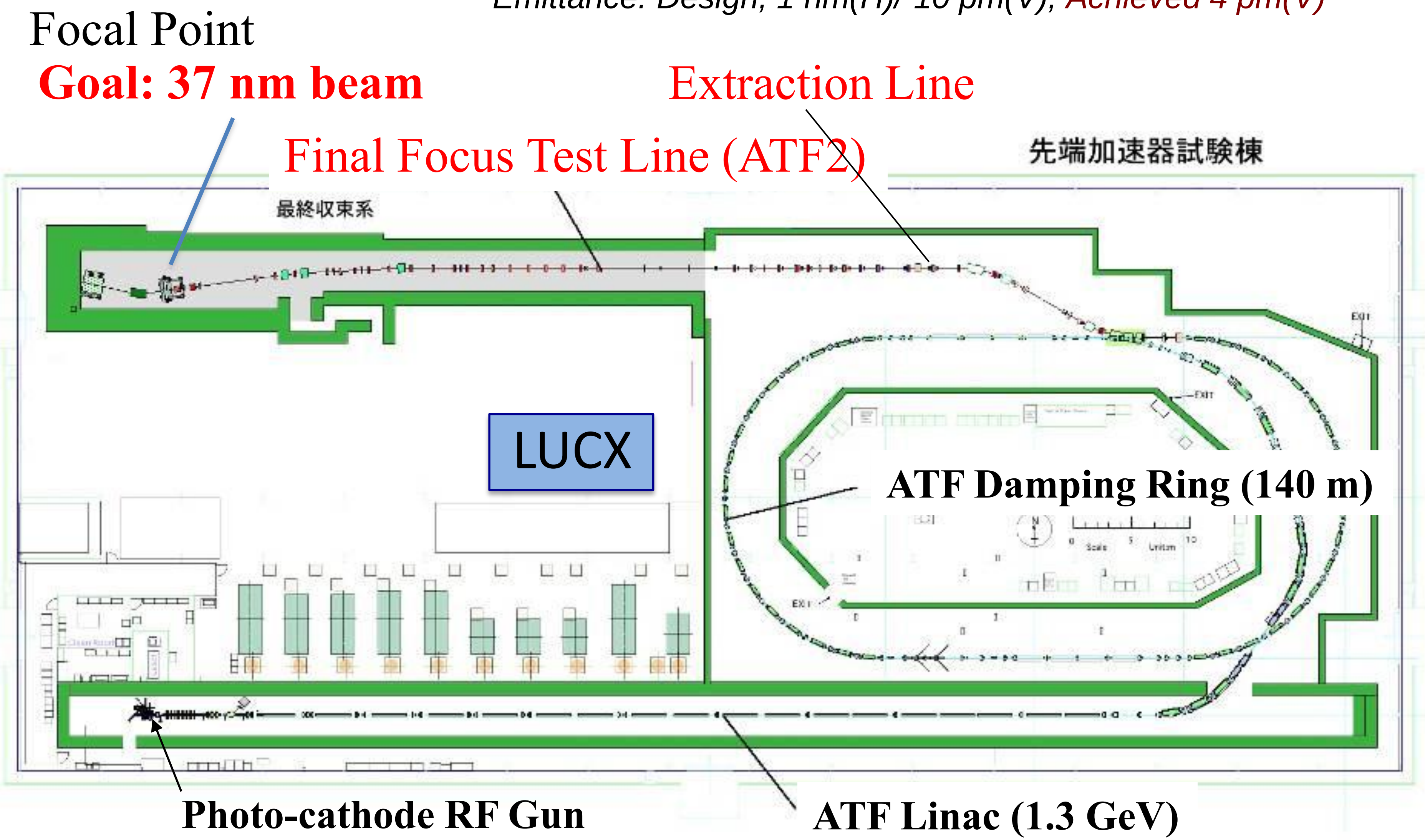
Improve the beam quality: thermionic gun → RF gun.
required intensity: Cs2Te

$1x10^{10}$ e^- ~ 1%(Q.E.) x 1mJ(Laser)

Higher QE photocathode ~1% → Cs_2Te

KEK Accelerator Test Facility (ATF and LUCX)

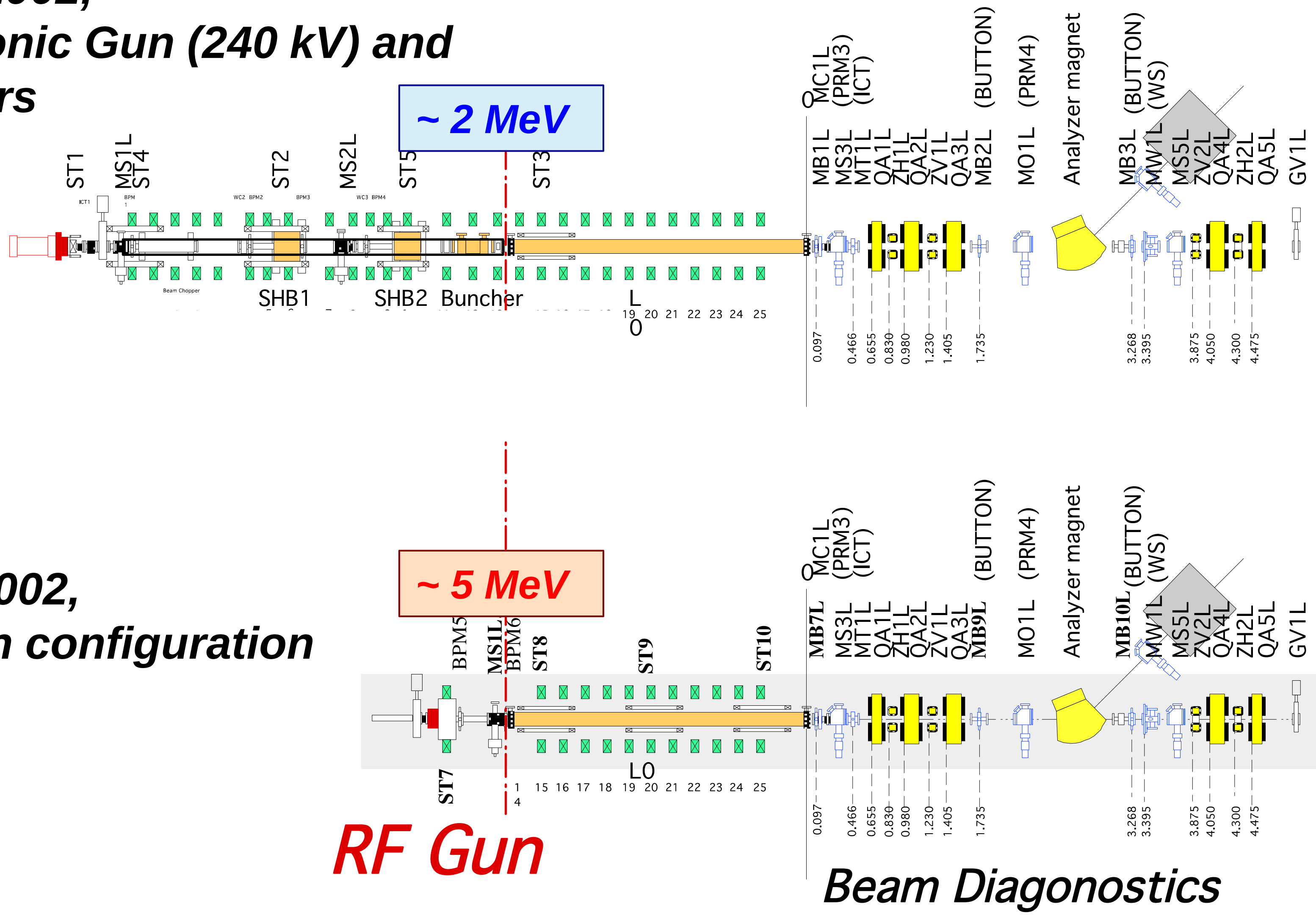
Energy: 1.3 GeV, Repetition: 1.56 Hz
Intensity: 1x10^{10} e-/bunch (max. 2x10^{10}), 1~20 bunches/pulse
Emittance: Design, 1 nm(H)/ 10 pm(V), Achieved 4 pm(V)



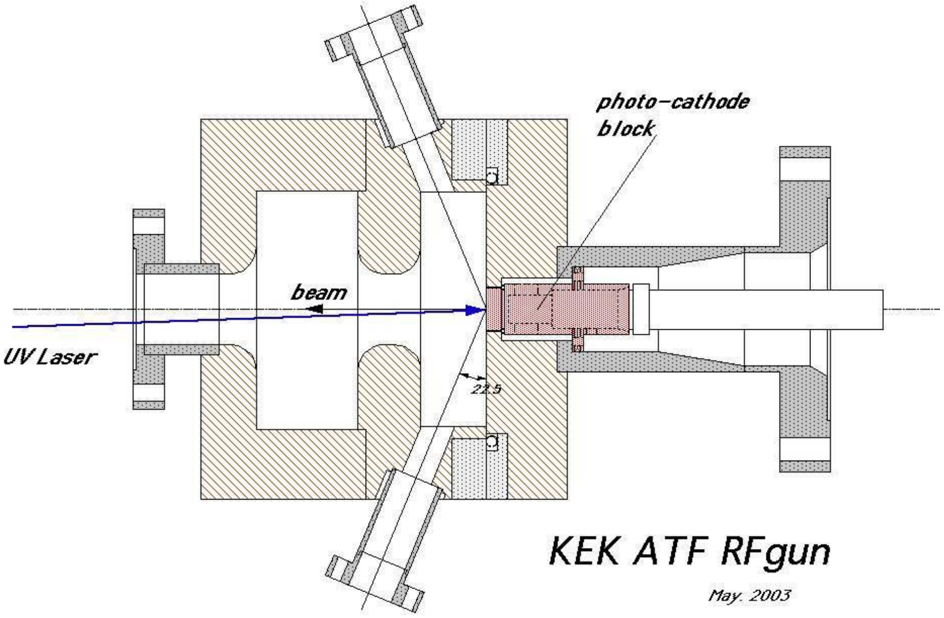
Installation of RF gun at ATF Injector in 2002

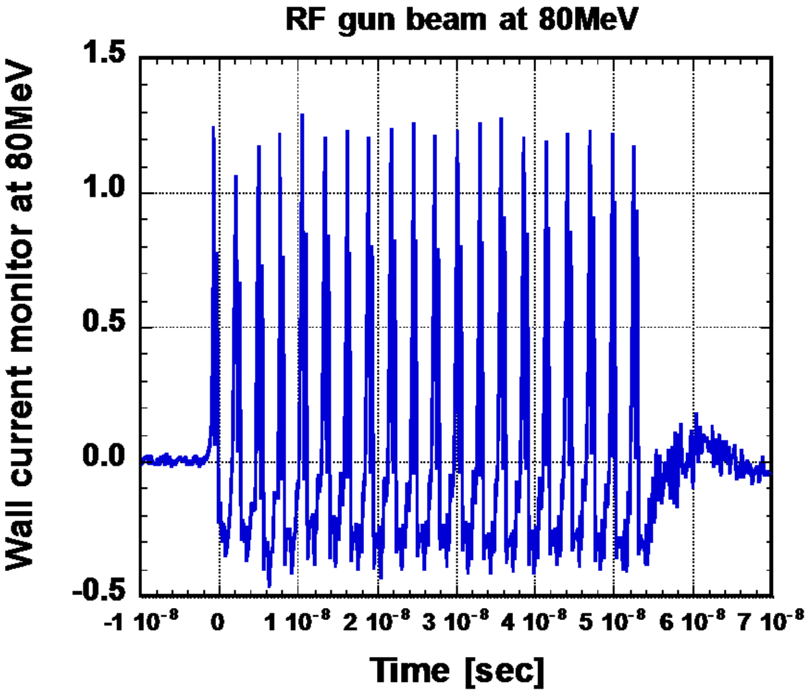
1996 ~ 2002, Thermionic Gun (240 kV) and Bunchers

After 2002, RF Gun configuration



Result of RF gun application to ATF





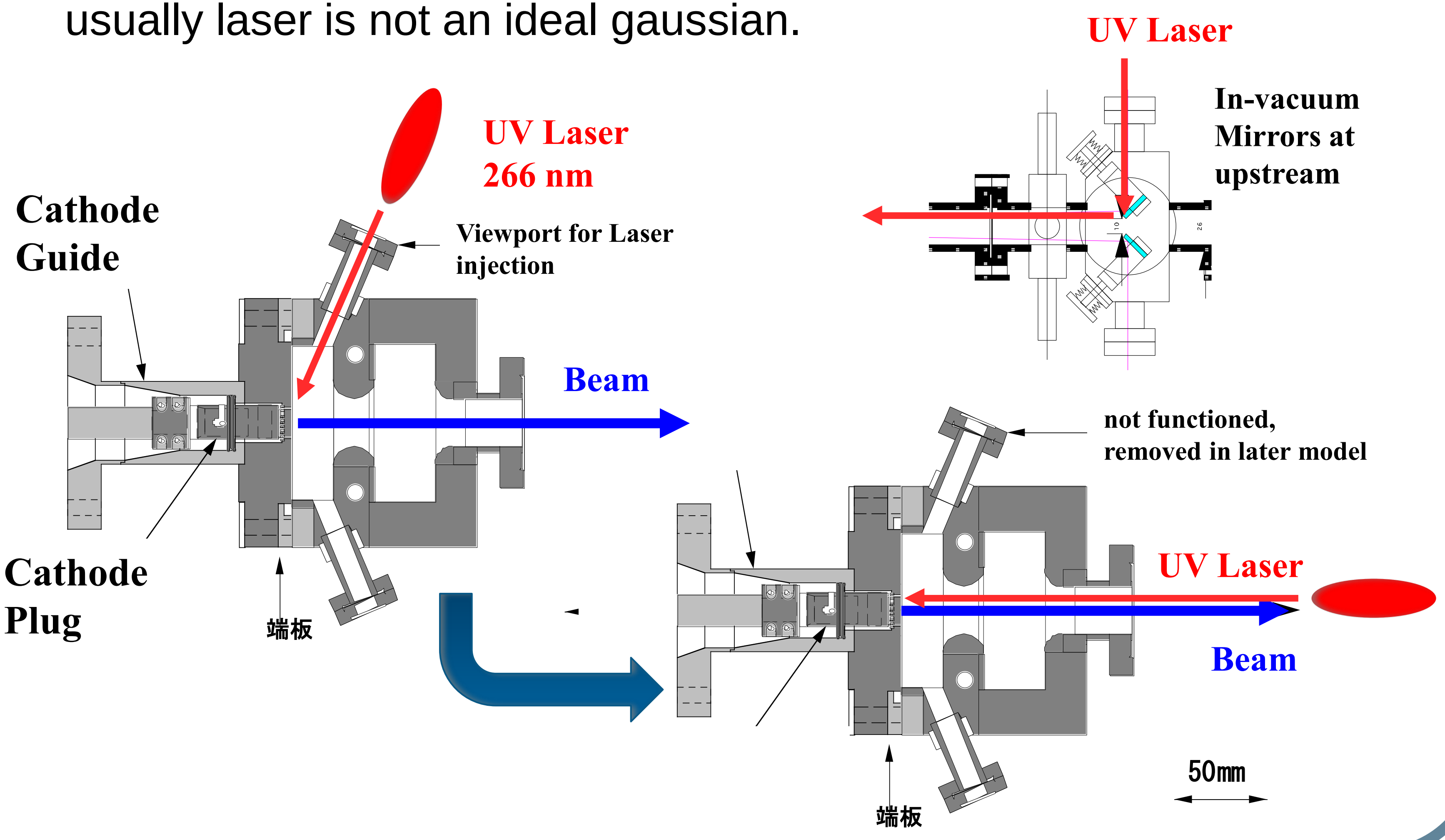
Generated electron beam

- ***1.56 Hz***
- ***1 ~ 20 bunches/pulse(train) with 2.8ns spacing***
- ***~ 2 x 10^{10} electrons / bunch***

Injection efficiency from Linac to DR: 60 % → ~100 %

Change of the laser injection angle, in 2003

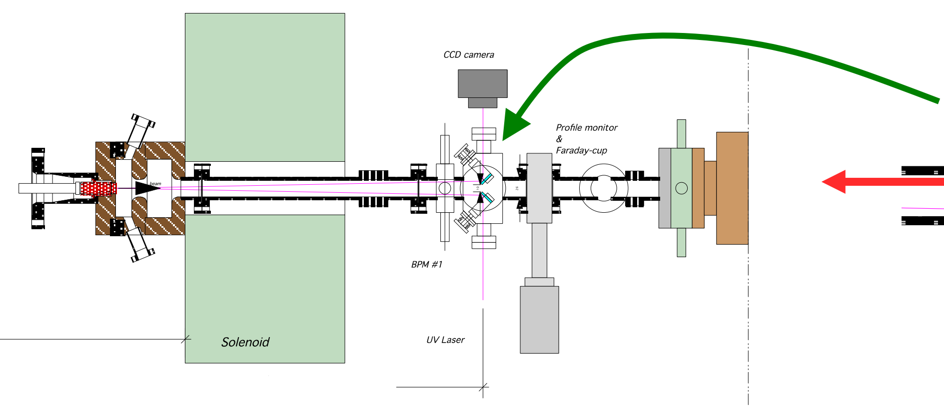
Aim to improve the emittance due to the non-uniform space charge effect by sliced transverse laser-profile on the cathode; usually laser is not an ideal gaussian.

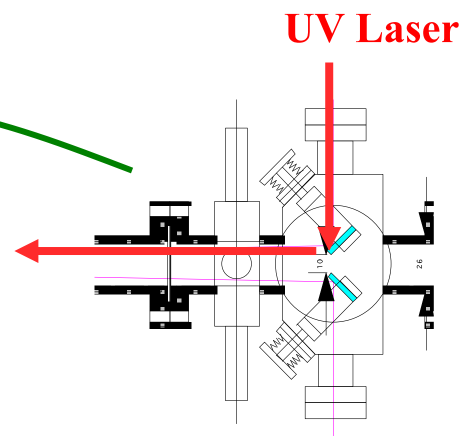


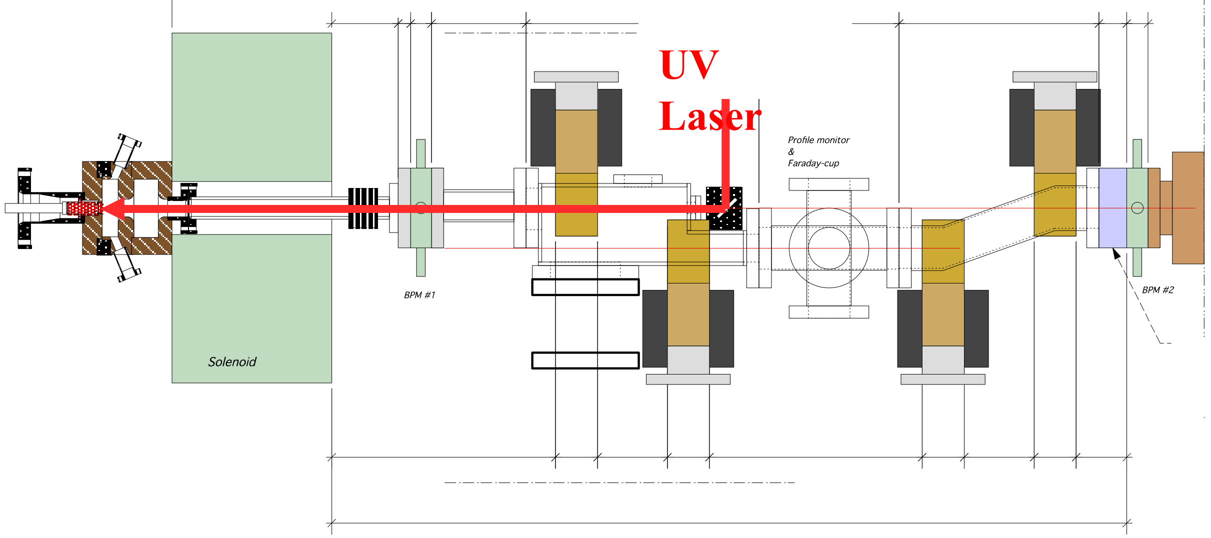
Install Chicane for Laser Injection in 2007

In-vacuum mirrors

- narrow aperture for e- beam (gap 10 mm)
- alignment of laser





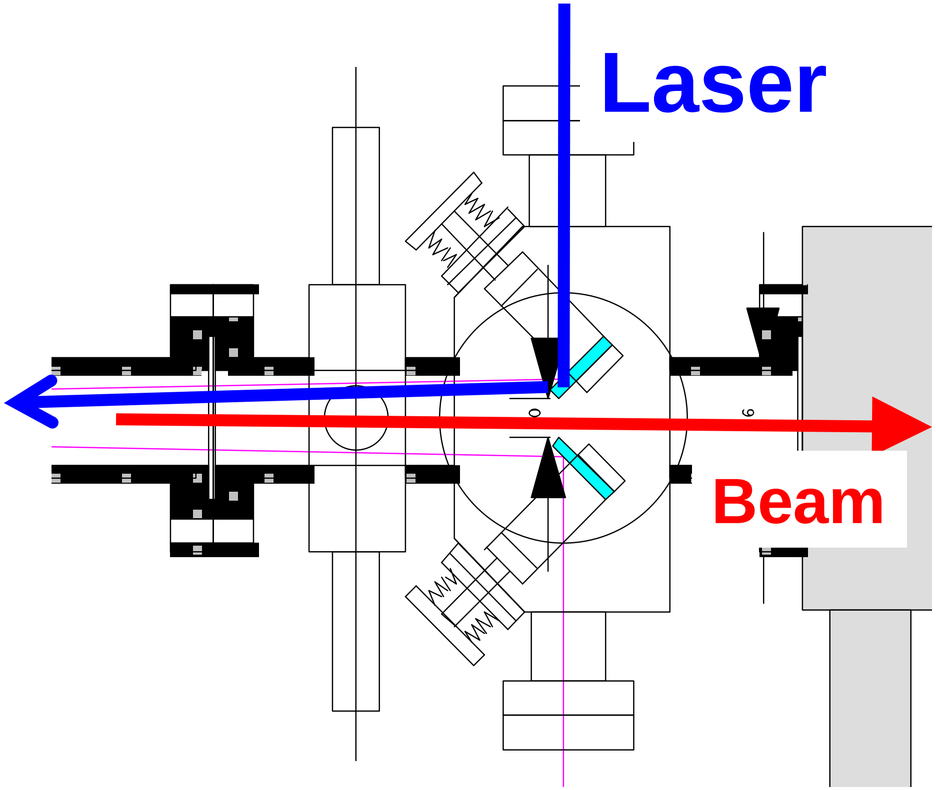


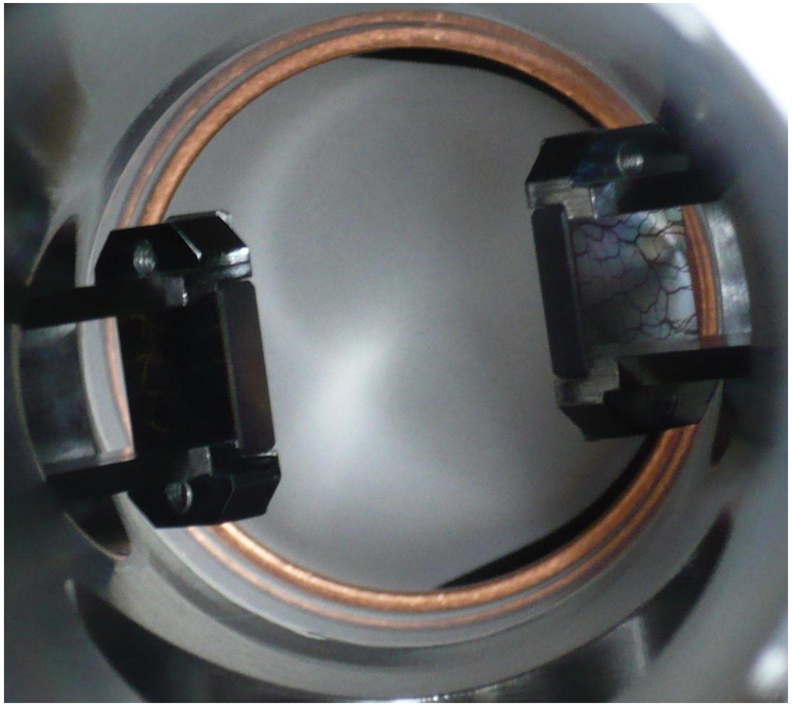
Chicane:

- **normal laser injection**
- dark current scraping

- increased aperture
- easy laser alignment

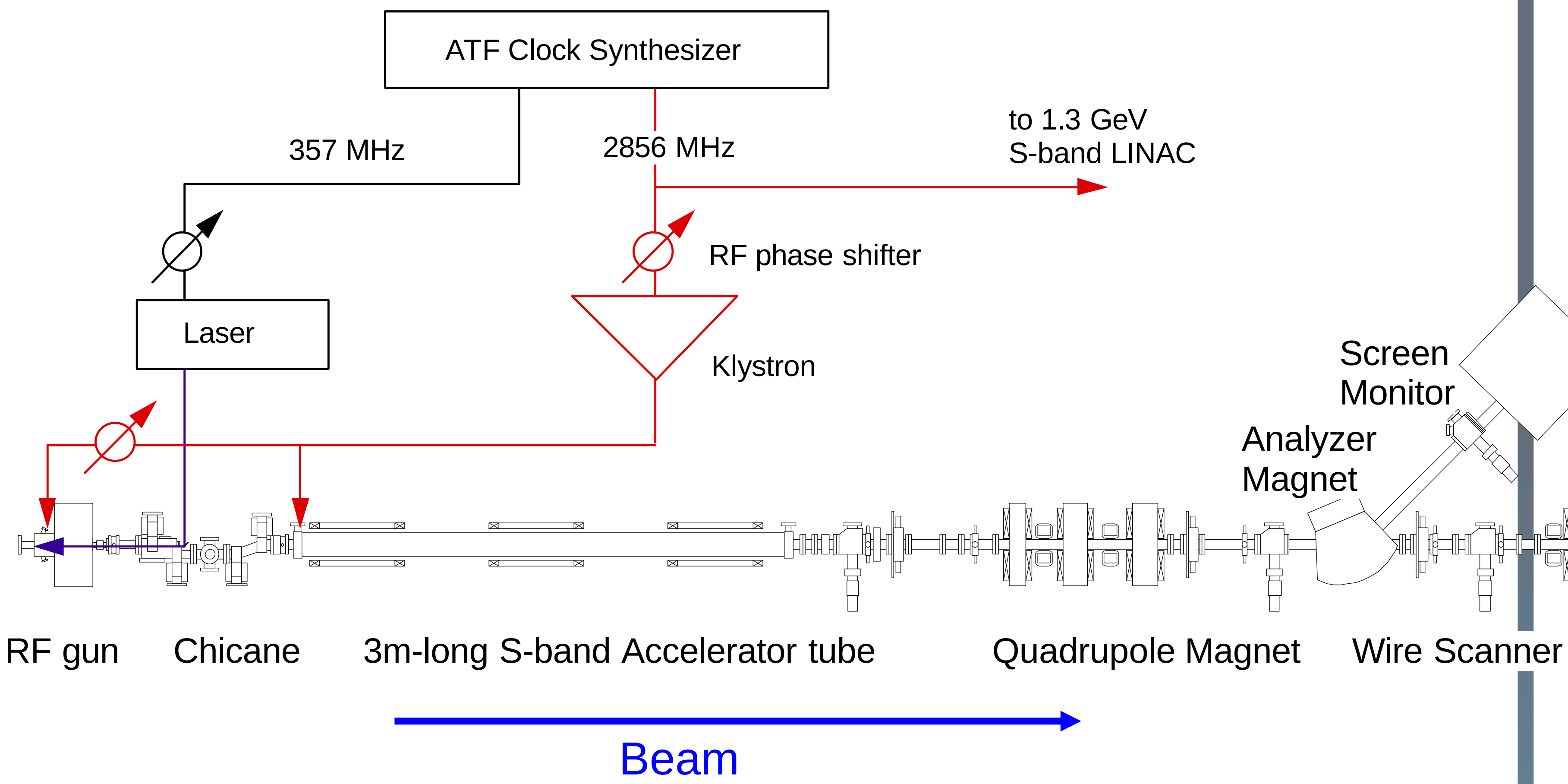
Damage of mirrors was found during the chicane installation in 2007



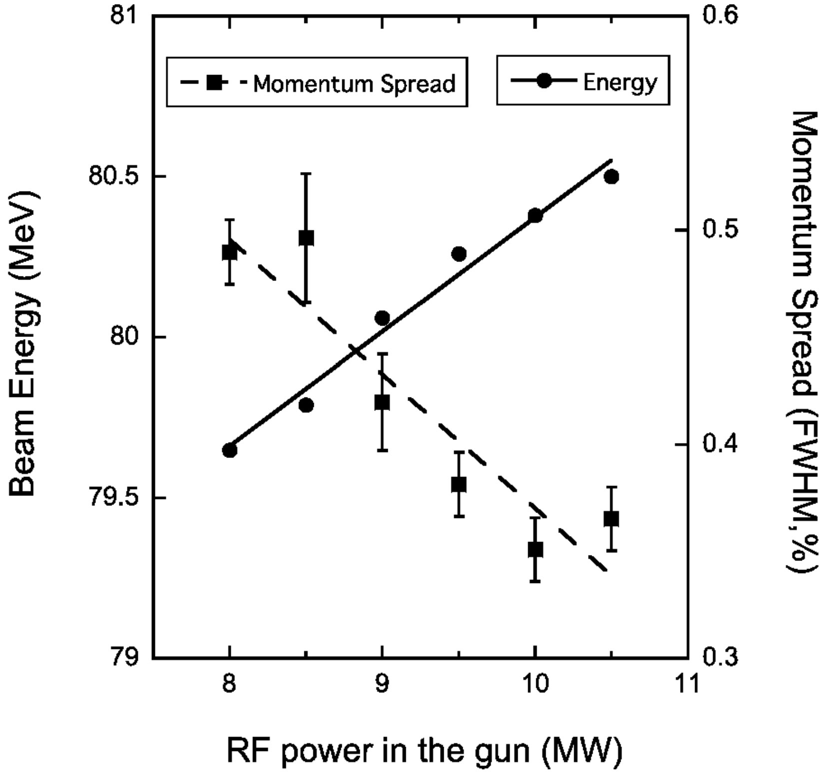


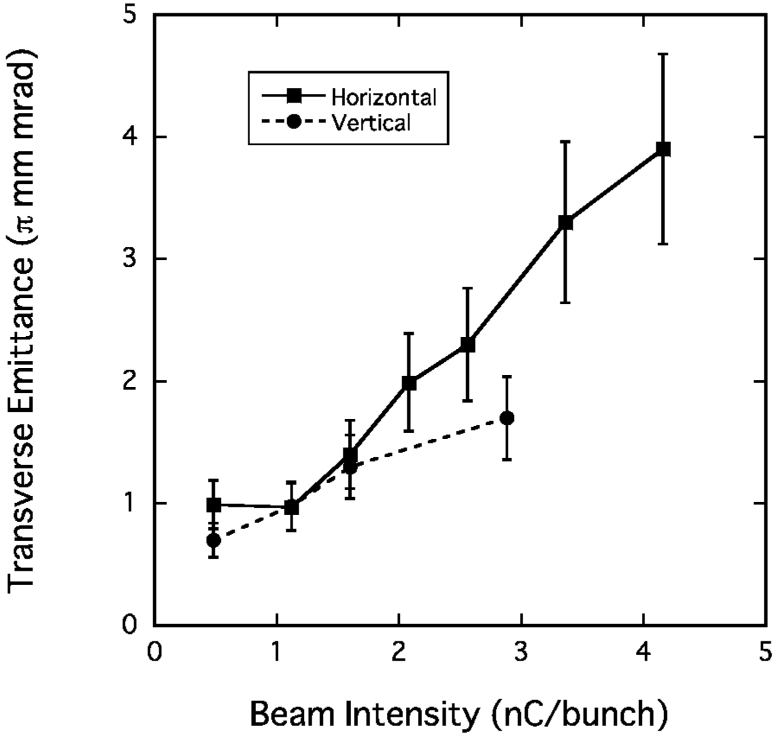
Mirrors: (10mm gap)
for the laser injection and the monitoring of hit position on surface
Damage: charge or heat by miss-steered beams, dark current.

Configuration of the ATF 80 MeV Injector



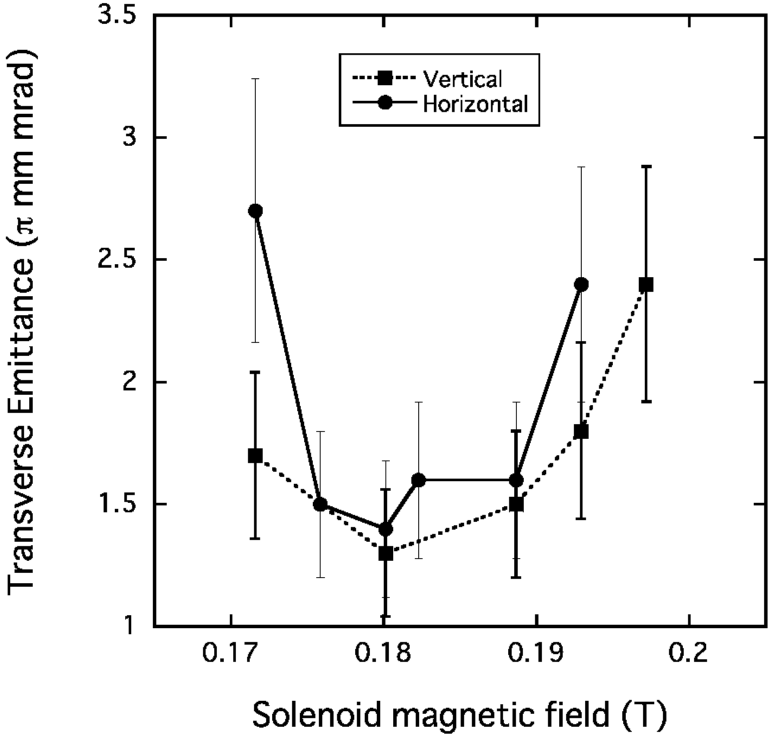
Example: Performance of Cs2Te RF gun at 80 MeV ATF Injector

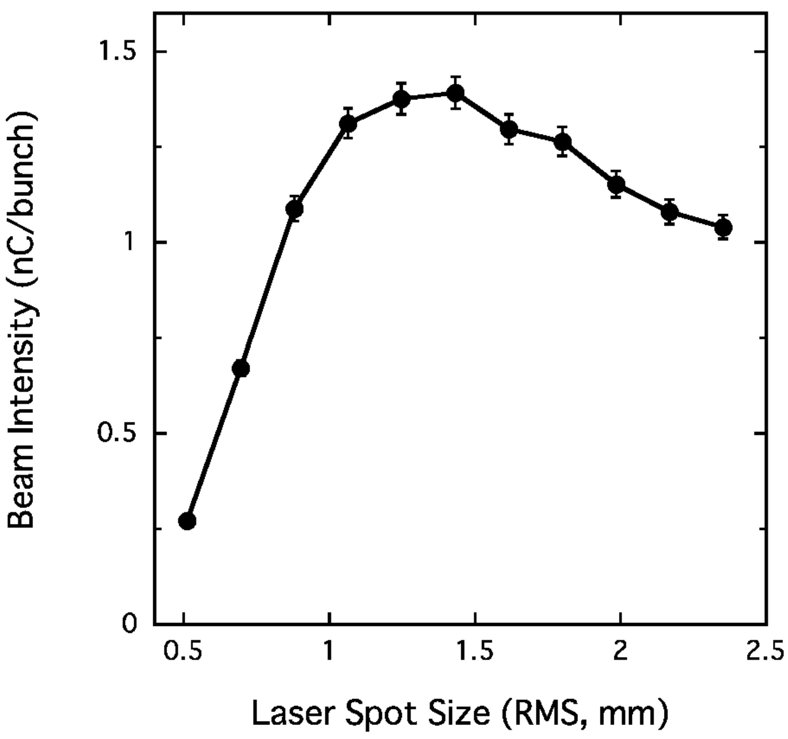




1.6 Cell S-band RF Gun, ATF, 2009

Example: Performance of Cs2Te RF gun at 80 MeV ATF Injector





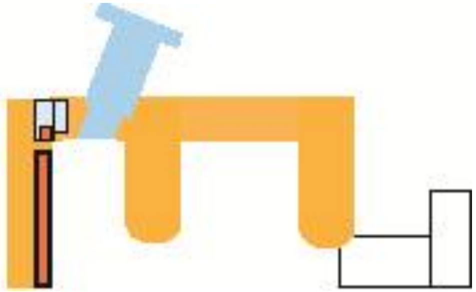
1.6 Cell S-band RF Gun, ATF, 2009

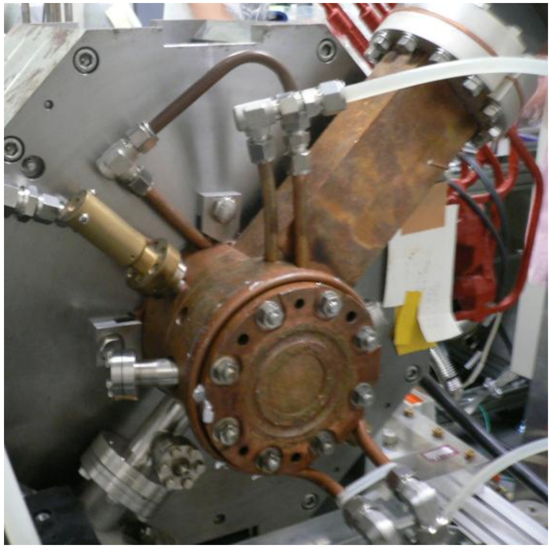
Development of Cs_2Te RF gun at KEK

- Improvements over 10 years

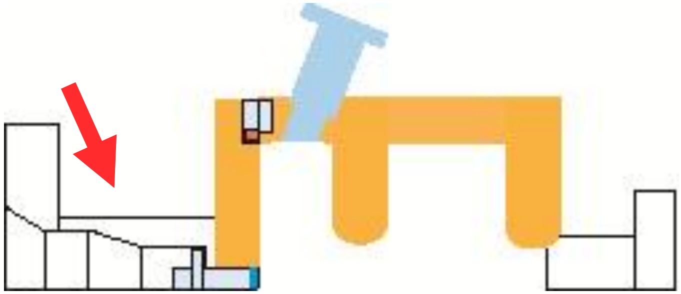
(1) Y2002: Plugged photocathode in vacuum

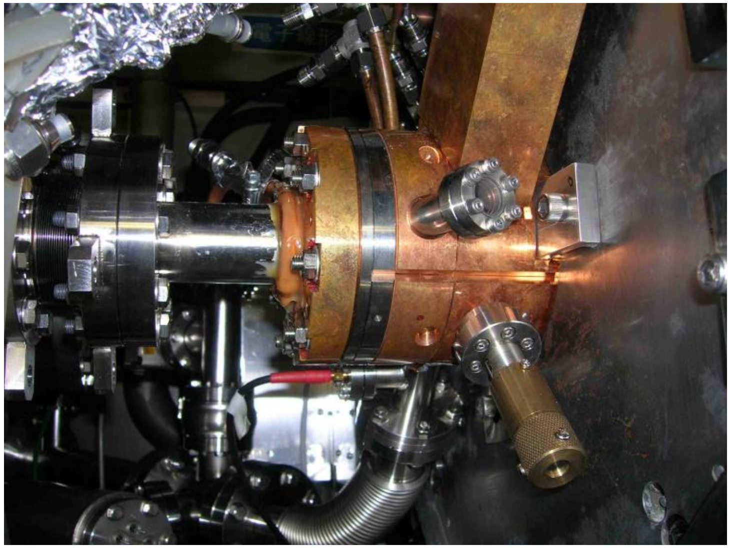
Original Gun (BNL type4)
- endplate is a cathode
- re-mountable as a flange





Modified Gun for Cs2Te
- cathode load-lock mechanism in vacuum

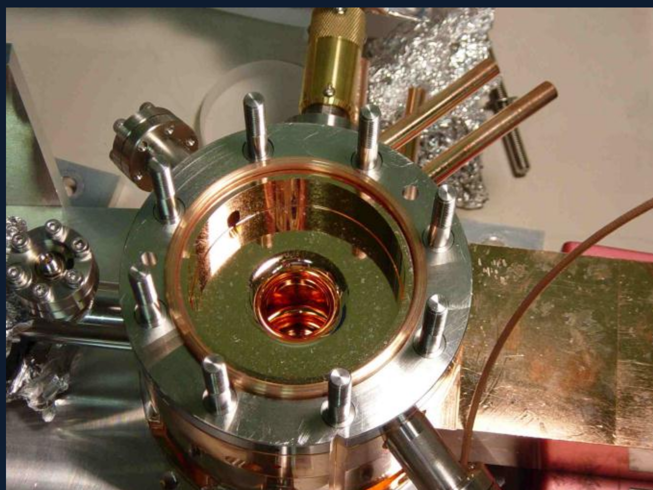


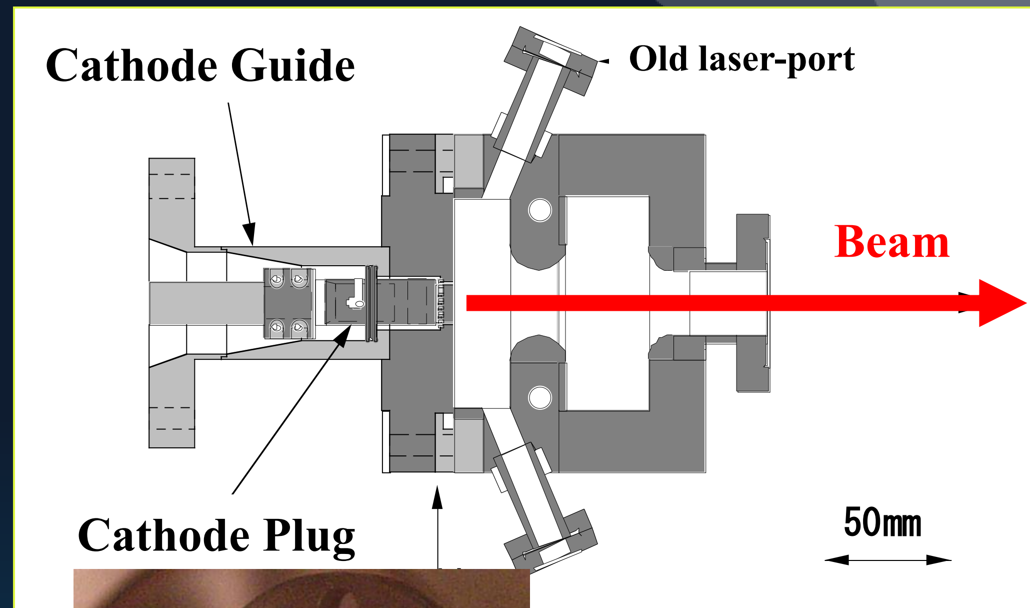


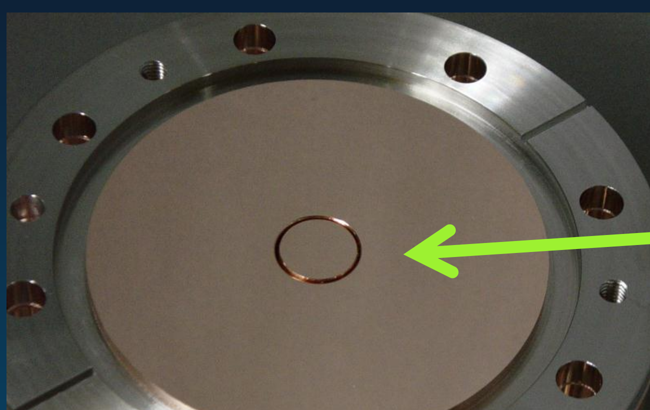
How the photocathode attached on the RF gun?

Example: First Cs_2Te RF Gun at KEK

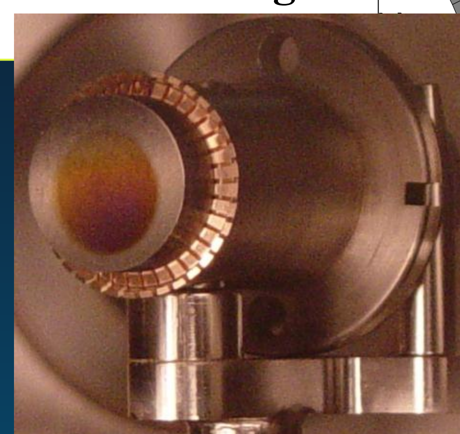
Modified BNL type IV: 1.6 cell, 2856 MHz





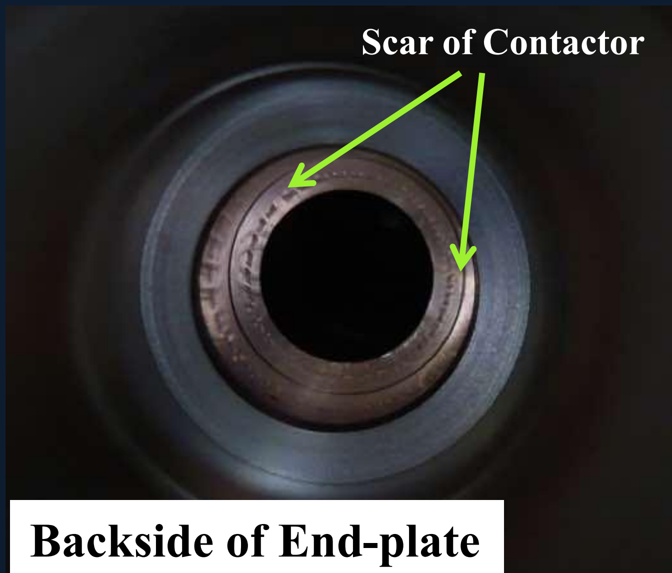


End-plate with Cathode plug

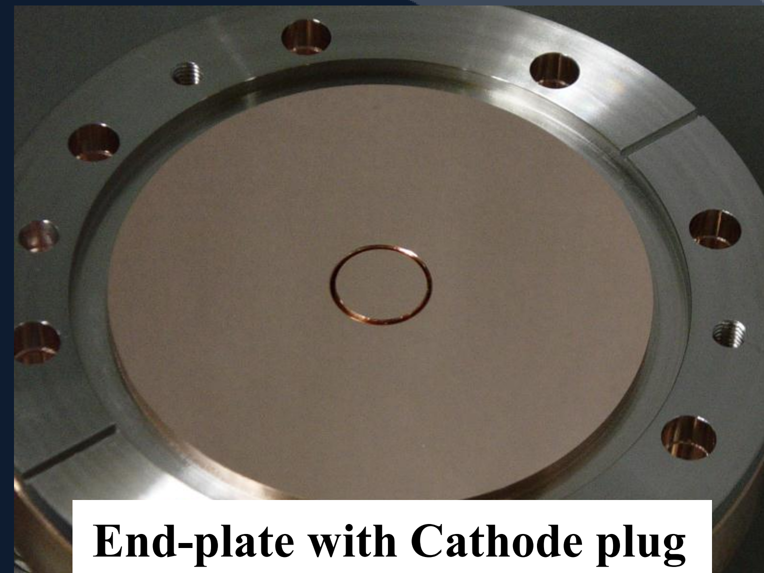


Spring Contactor

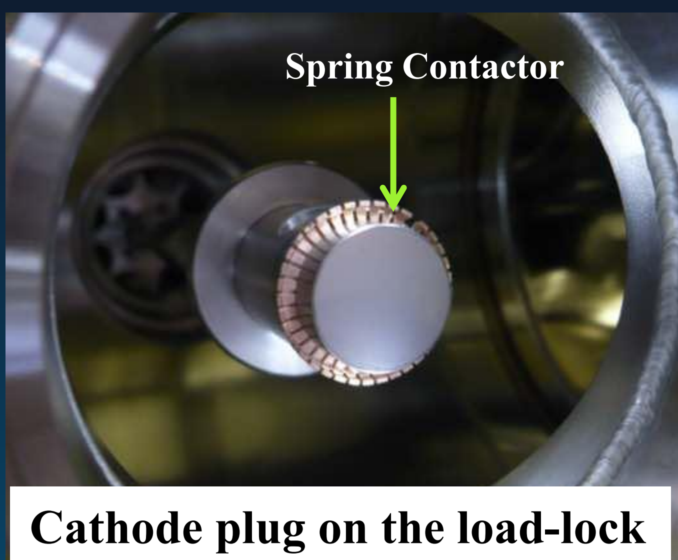
How the photocathode attached on the RF gun?



Backside of End-plate



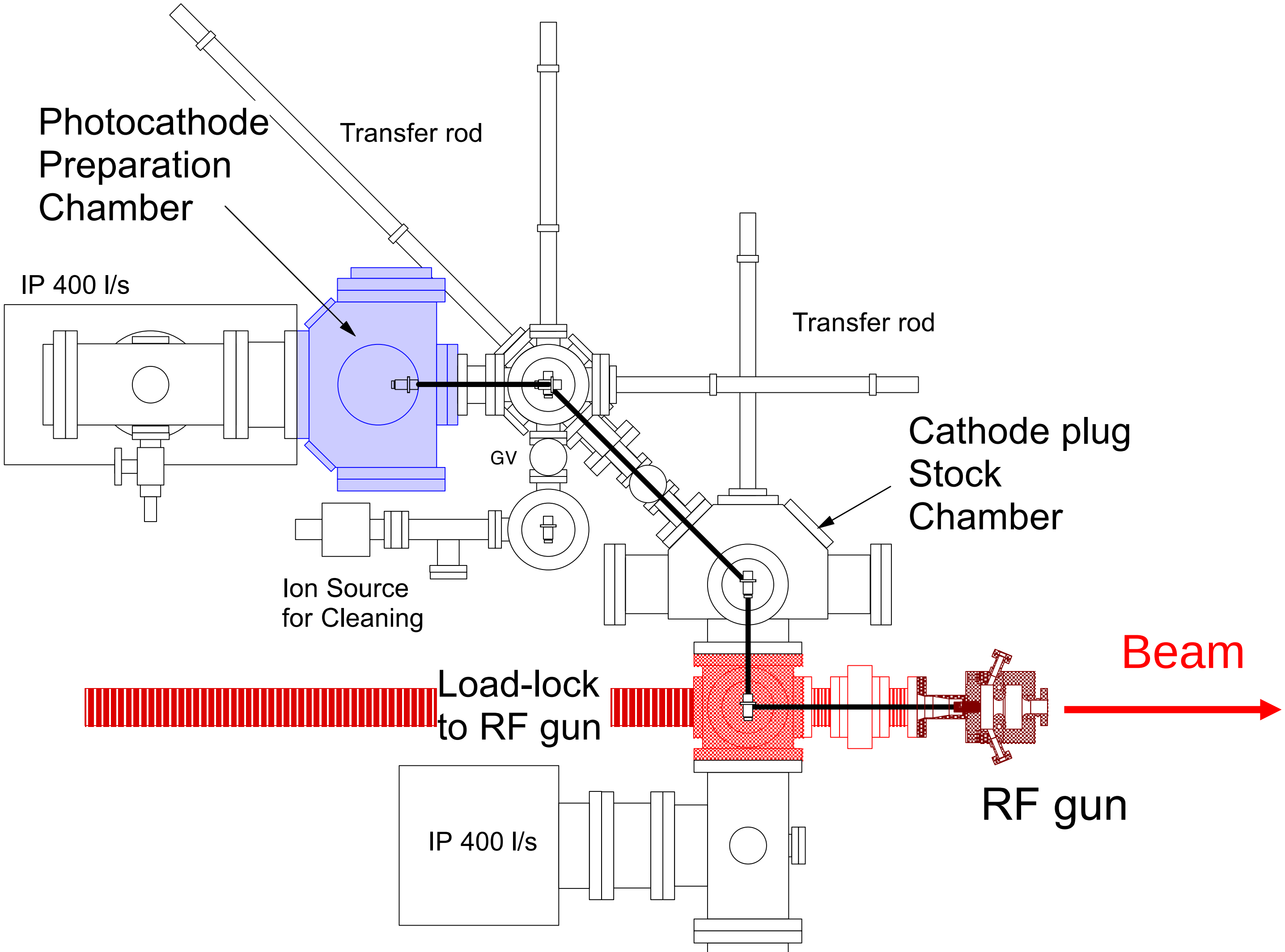
End-plate with Cathode plug



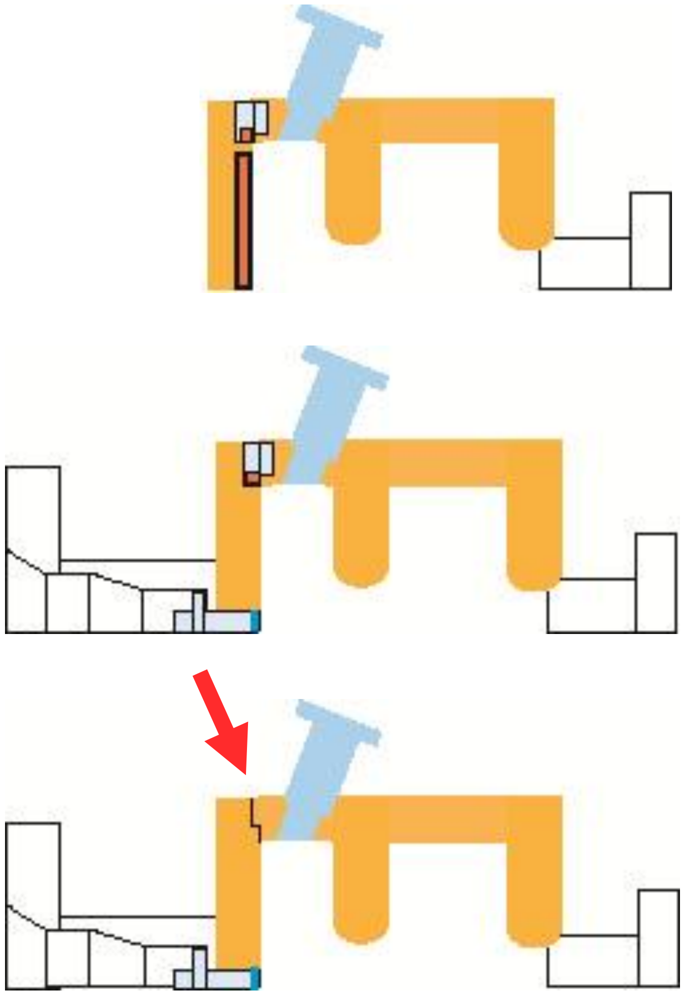
Cathode plug on the load-lock

Cathode plug on the load-lock, GV removed

ATF Cs2Te photocathode preparation and load-lock system



(2) Y2007: Braze the half-cell endplate

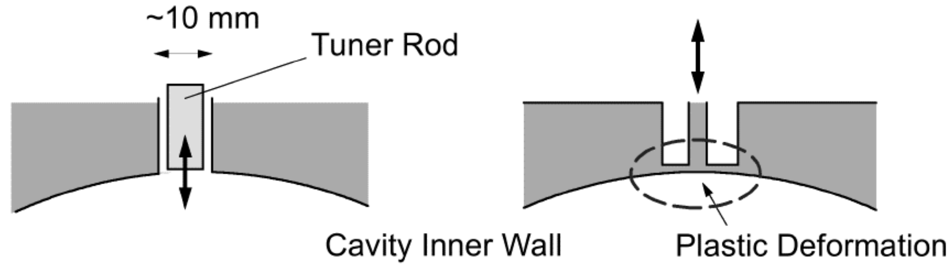


Original Gun (BNL type4)
- endplate is a cathode
- re-mountable as a helicoflex flange
- fastening vs., tune control

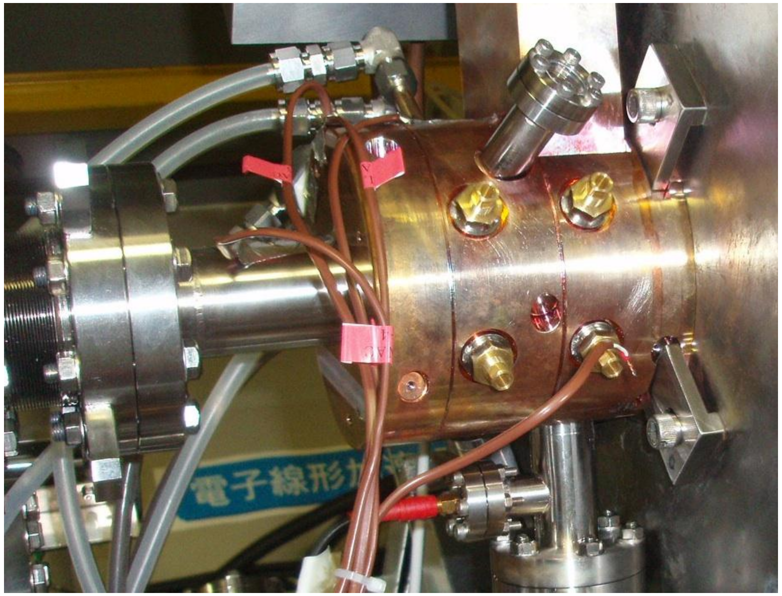
Modified Gun for Cs2Te
- no needs to remount the endplate
- cathode load-lock mechanism

Brazing the endplate
- **reduce the risk of a field emission at corner**
- expect an increase of Q

(3) Y2007: No-gap tuner for freq. adjustment



(a) Conventional Tuner (b) New Compact Tuner



Conventional Tuner

- gap between rod and cavity wall
- suspected to be a source of discharge

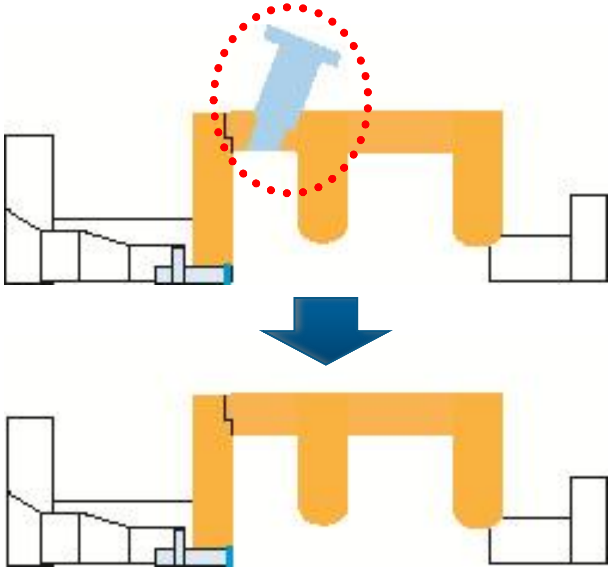
New Compact Tuner

- **No gap**
- **Plastic deformation of the cavity wall**
- expect an increase of Q
- 220 kHz/tuner, 4 tuner x 2 cells

(4) Y2008: RF gun for normal laser injection

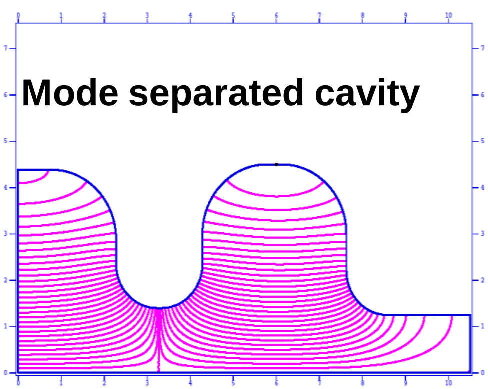
Remove the ports on the half cell for slant laser injection

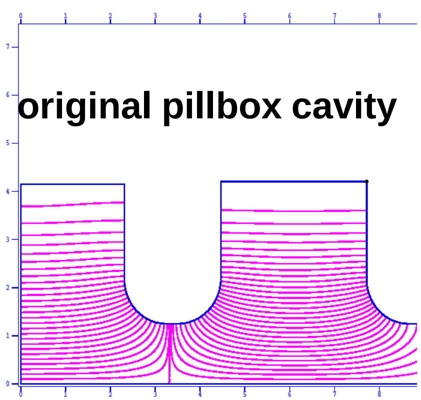
- **only accept the normal incidence of a laser on the cathode**
- simplified half-cell cavity
- expect an increase of Q

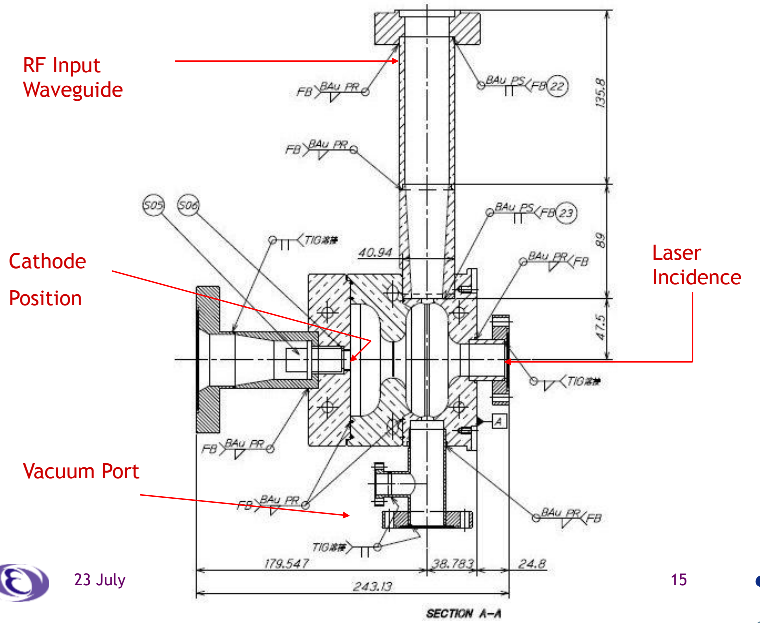


(5) Y2009: Mode Separated RF gun

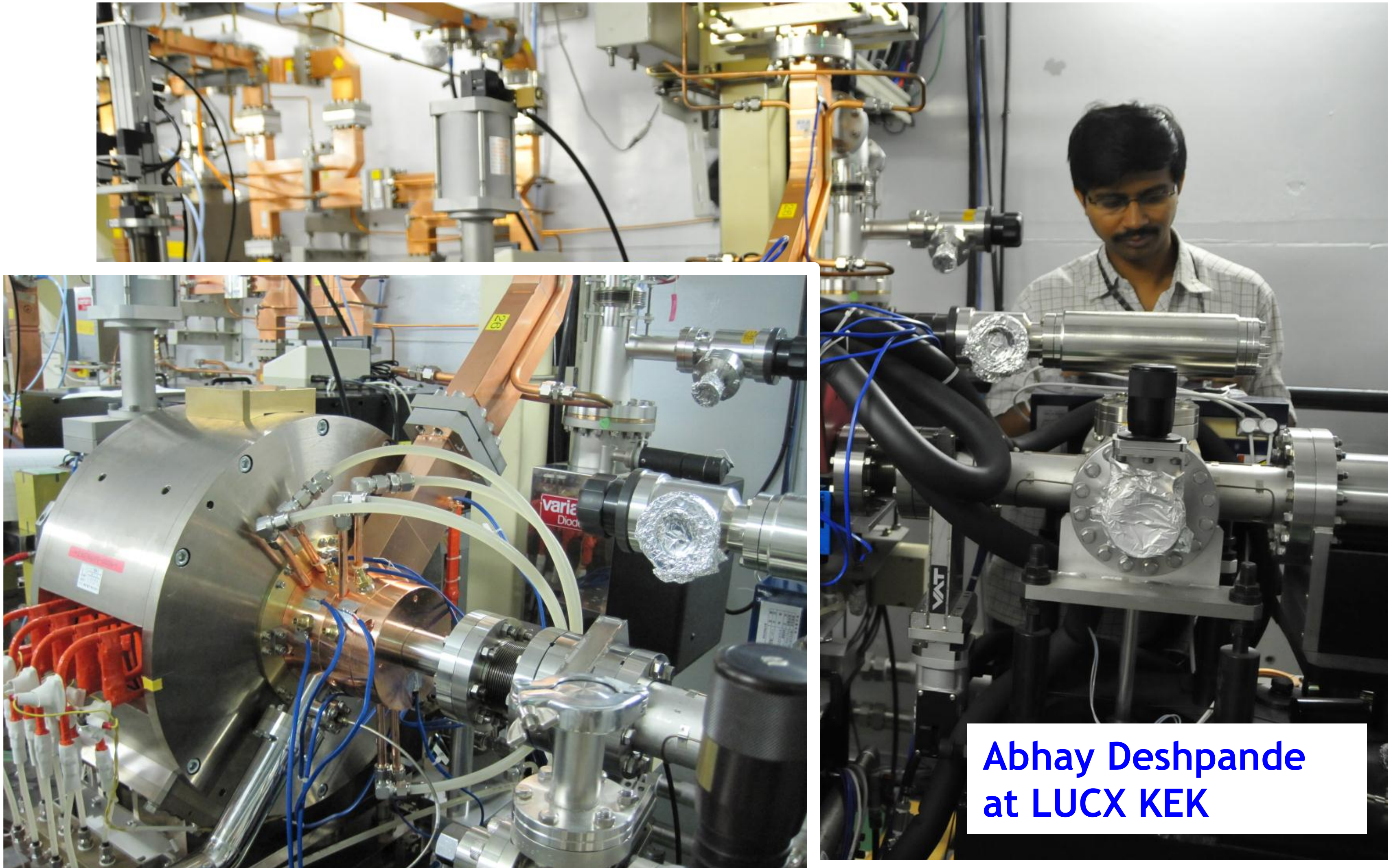
- **RF gun for high charge, low emittance multi-bunch beam is demanded for LUCX experiments.**
- **Mode separated RF gun for LUCX, have been developed with a separation of 8.6 MHz as against 3.5 MHz of original cavity.**
- By increasing the separation, the minimum of emittance and energy spread is more stable over phase variations.
- LCLS (SLAC) changed the mode separation from 4 MHz to 15 MHz and LLNL also shifted to 12 MHz.
- **Ph.D thesis of Abhay Dashpande, SOKENDAI, Japan (2010)**







Mode Separated RF gun - continued -



Abhay Deshpande
at LUCX KEK

(6) Y2010: Mode separated 3.6-cell RF gun

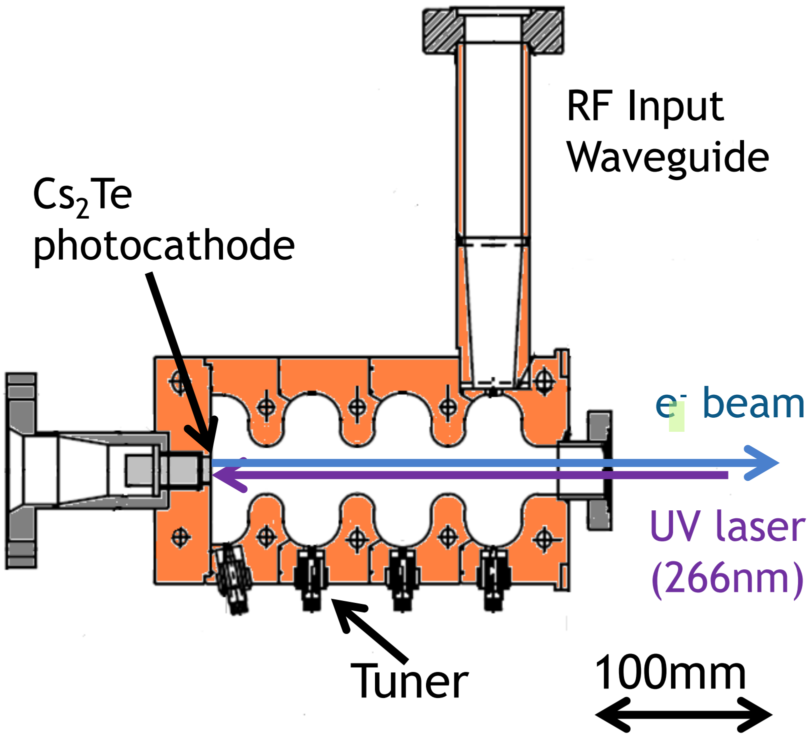
Frequency (π-mode)	2856 MHz
Qvalue	15000
Coupling β	0.99
R/Q	395Ω
Mode separation (π-2π/3)	2.8 MHz

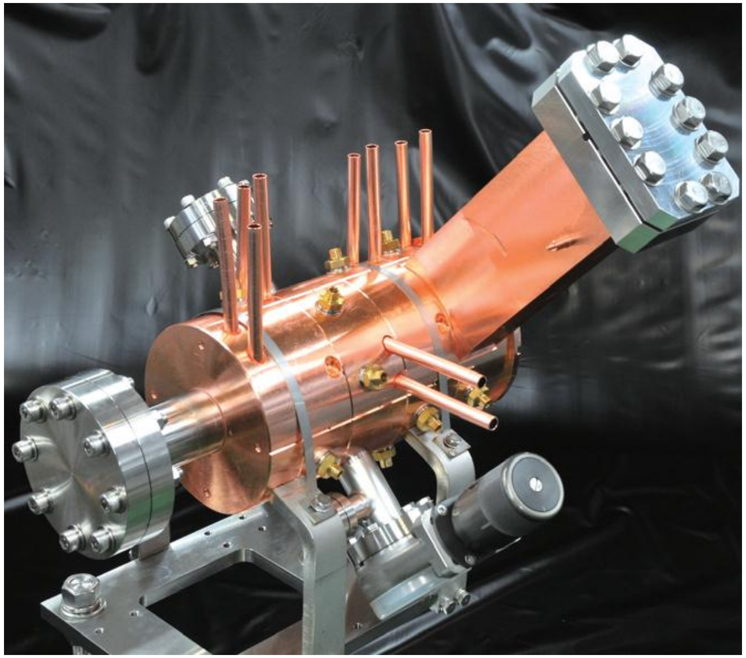
1.6-cell mode separated

↓

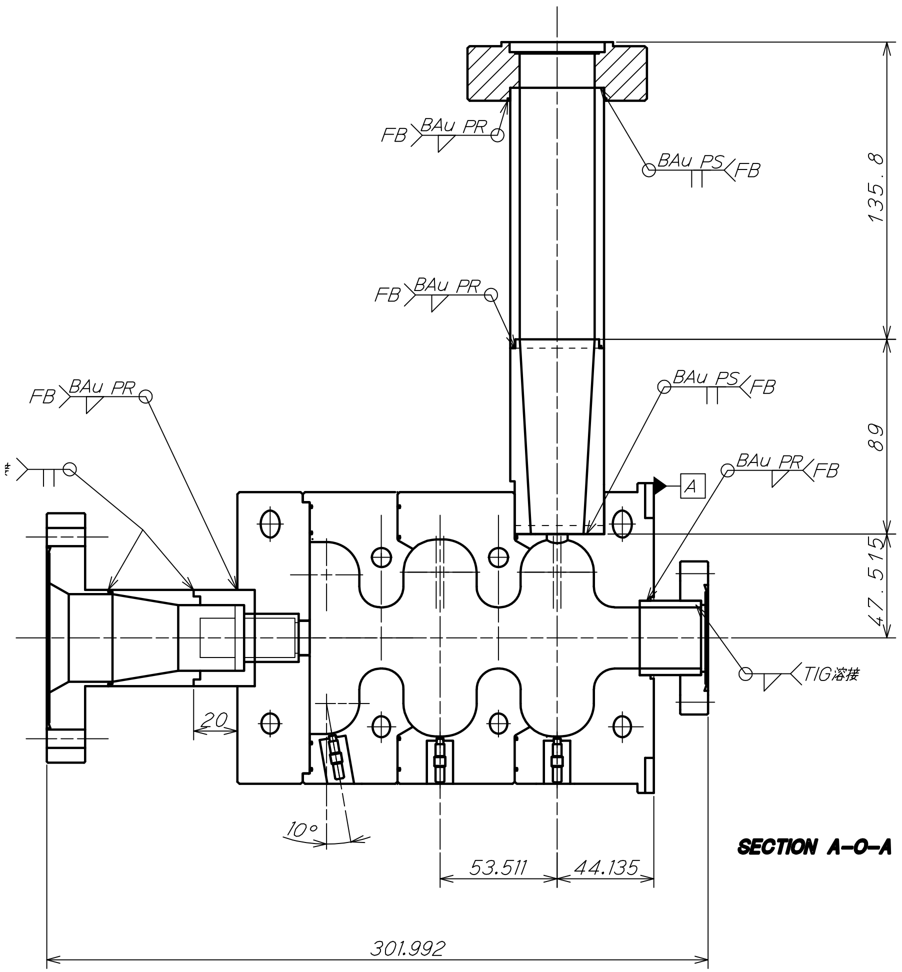
3.6-cell mode separated

This gun generates the electron beam with the energy of **10MeV**.





Newest design: 2.6-cell RF gun for IUAC



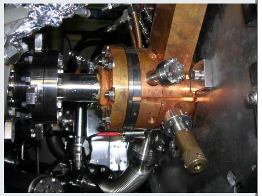
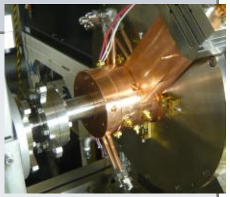
3.6-cell mode separated RF gun

- aimed to get 12 MeV e- beam
- RF breakdown limit the input power
- low field on cathode
- 9 MeV e- beam was achieved

2.6-cell mode separated

- much better field gradient at cathode
- expect better beam quality,
- …

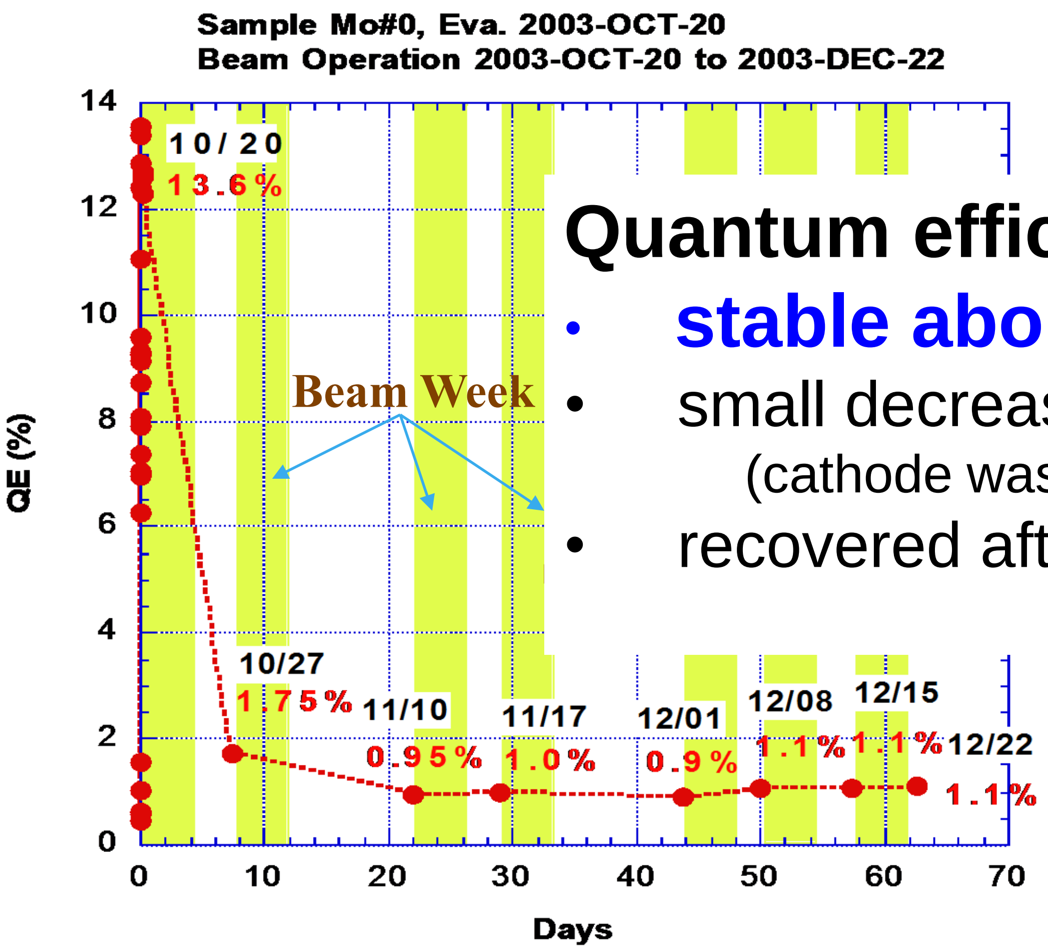
History of Cs_2Te RF guns by KEK

Improvements	Results	ATF	LUCX	prepared for …
(Demonstration of BNL type-IV at ATF)	low intensity by Cu cathode	(2001)		
Cs2Te cathode plug attachment	Q ~7,900 RF 9 MW 3 nC/bunch	**2002**	2004	
Half-cell brazing, Screw tunner	Q ~12,200 RF ~12 MW			2007 Waseda Univ.
Removed Laser Ports	Q ~13,500	2008		2007 Kyoto 2008 Osaka 2009 AIST 
Mode separated 3.5 → 8.6 MHz	Q ~14,700		2009	
1.6 Cell → 3.6 Cell	10 MeV	2010	2011	
(2.6 Cell)				(2015 IUAC)

Some results of Cs_2Te photocathode by beam operation

Details are not shown here but in Part-II

Two months history of the quantum efficiency under the ATF operation



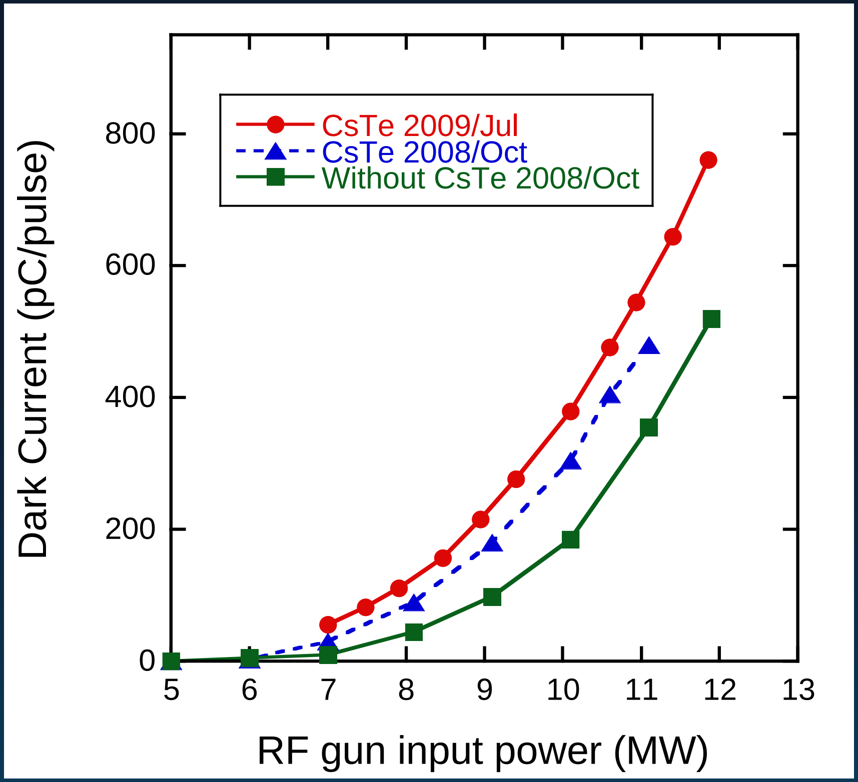
Quantum efficiency was …

- **stable about 1%.**
- small decrease in the shutdown week?
  (cathode was kept in the RF gun. 5×10^{-7} Pa)
- recovered after the beam generation?

Cathode surface after long-term operation

- A lot of small spots were observed.
- They were scattered over the plug surface.
- somehow much on the Cs_2Te area (??)
- **~1% of QE was confirmed with these spots**
- We are not sure that spots are due to Cs_2Te because we have no long-term sample without Cs_2Te.

Dark Current with Cs_2Te photocathode



- Dark current was increased 30% with Cs_2Te.
  (when the Cs_2Te was prepared)
- 8 months later, more dark current was observed; i.e., 60% of without Cs_2Te,
- but it was not clear due to Cs_2Te. Gun itself?
- Gun operated (4 months)
  - 12.5 Hz, 9 MW
  - RF pulse 2.5 usec
  - 1.1 nC/bunch

Summary

- RF guns with Cs_2Te photocathode are used at ATF, LUCX and STF accelerators.
- Well established with more than 10 years experiences.
- Cs2Te worked well with a long-enough lifetime.

Details about the Cs_2Te photocathode will be shown in next session