Possibility of obtaining high charge beams using RF guns

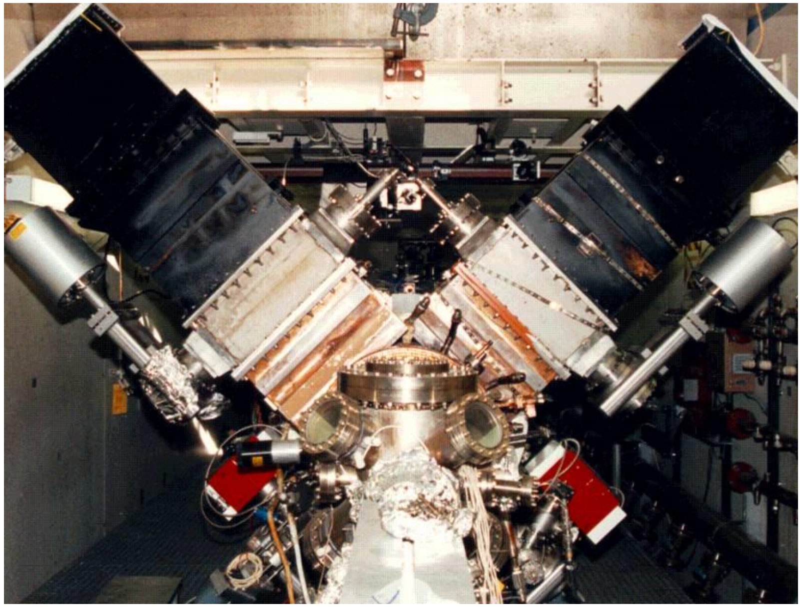
Outline

- Boeing/LANL 433 MHz gun
- The PITZ RF gun
- Injector SKEKB
- RF gun for SKEKB
- Photocathode resume
- FCC RF Gun Design strategy

Boeing/LANL 433 MHz gun

This gun was fabricated in 1988-1989, and tested at high average power from 1990-1992 up to 5 MeV beam energy

Photocathode Performance:	
Photosensitive Material:	K_2CsSb Multialkali
Quantum Efficiency:	5% to 12%
Peak Current:	45 to 132 amperes
Cathode Lifetime:	1 to 10 hours
Angle of Incidence:	near normal incidence
Gun Parameters:	
Cathode Gradient:	26 MV/meter
Cavity Type:	Water-cooled copper
Number of cells:	4
RF Frequency:	433 $x10^6$ Hertz
Final Energy:	5 MeV(4-cells)
RF Power:	600 $x10^3$ Watts
Duty Factor:	25%, 30 Hertz and 8.3 ms
Laser Parameters:	
Micropulse Length:	53 ps, FWHM
Micropulse Frequency:	27 $x10^6$ Hertz
Macropulse Length:	10 ms
Macropulse frequency:	30 Hertz
Wavelength:	527 nm
Cathode Spot Size:	3-5 mm FWHM
Temporal and Transverse Distribution:	gaussian, gaussian
Micropulse Energy:	0.47 microjoule
Energy Stability:	1% to 5%
Pulse-to-pulse separation:	37 ns
Micropulse Frequency:	27 $x10^6$ Hertz
Gun Performance:	
Emittance (microns, RMS):	5 to 10 for 1 to 7 nCoulomb
Charge:	1 to 7 nCoulomb
Energy:	5 MeV
Energy Spread:	100 to 150 keV



The PITZ RF gun

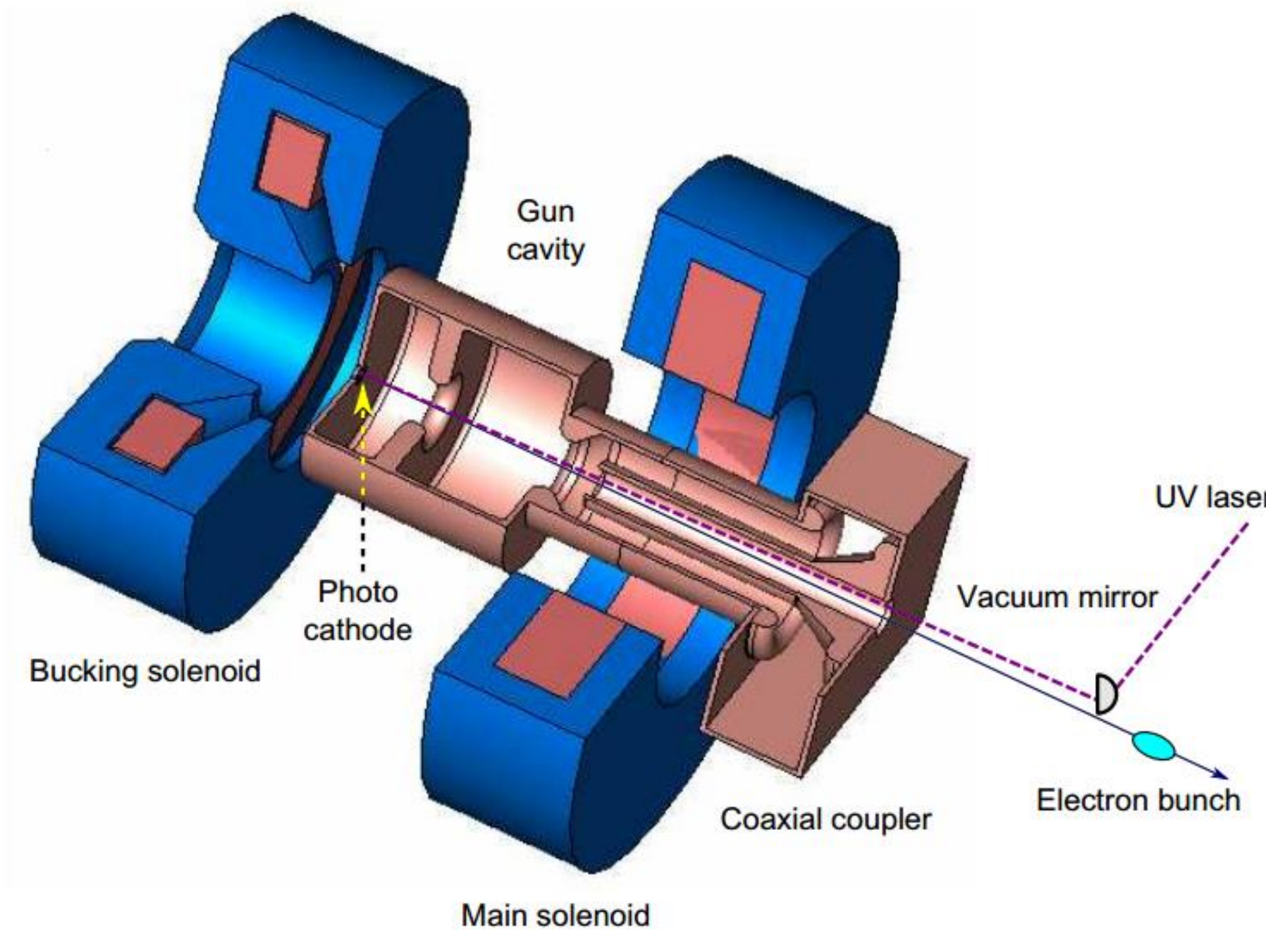


Figure 3.4: Electron gun cavity at PITZ

Semiconductor cathode Cs2Te

M. Haenel, F. Stephan and et. al. INVESTIGATIONS ON THE INCREASED LIFETIME OF PHOTOCATHODES AT FLASH AND PITZ. Proceedings of PAC09, Vancouver, BC, Canada

Wavelength(λ)	263 nm
QE	13 % (263 nm)
Lifetime	for > 1.5% T > 500 h
Vacuum condition	10^{-11} torr
Response time	>3 ps
Acceleration gradient	до 120 MV/m

Operation condition: frequency 1.3 GHz, RF pulse duration 800 us, acceleration gradient 60 MV/m (3.8 MW), laser wavelength 257/262 nm, vacuum <10^-10 mbar, average QE 8.5%.

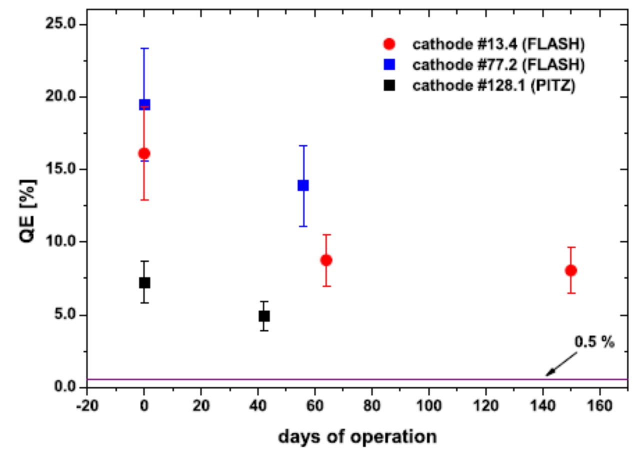


Figure 1: QE vs. operation time for cathodes #13.4 and #77.2 (both used at FLASH), and cathode #128.1 operated at PITZ.

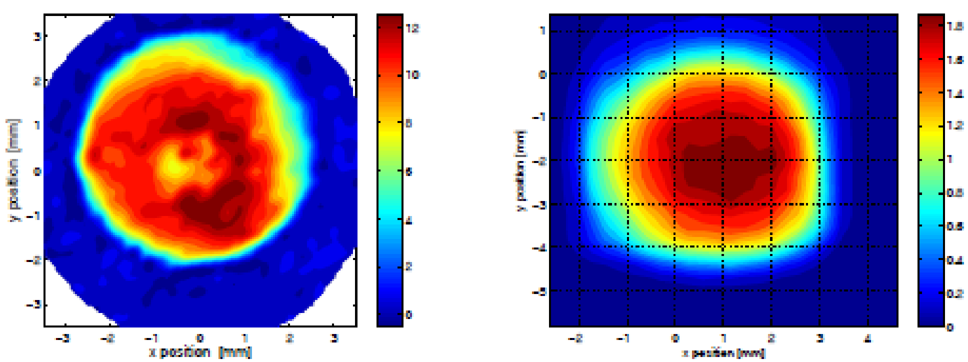


Figure 4: QE-maps of cathode #128.1 used at PITZ (left), and cathode #13.4 operated at FLASH (right).

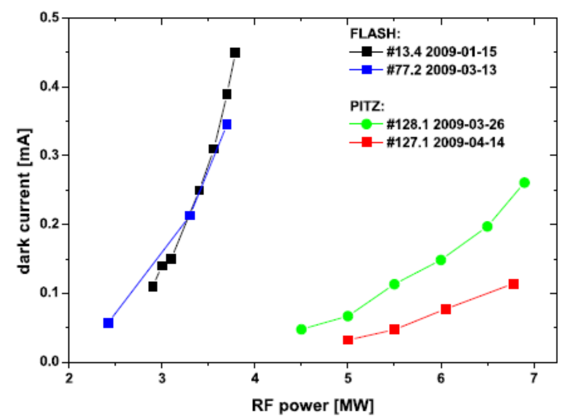
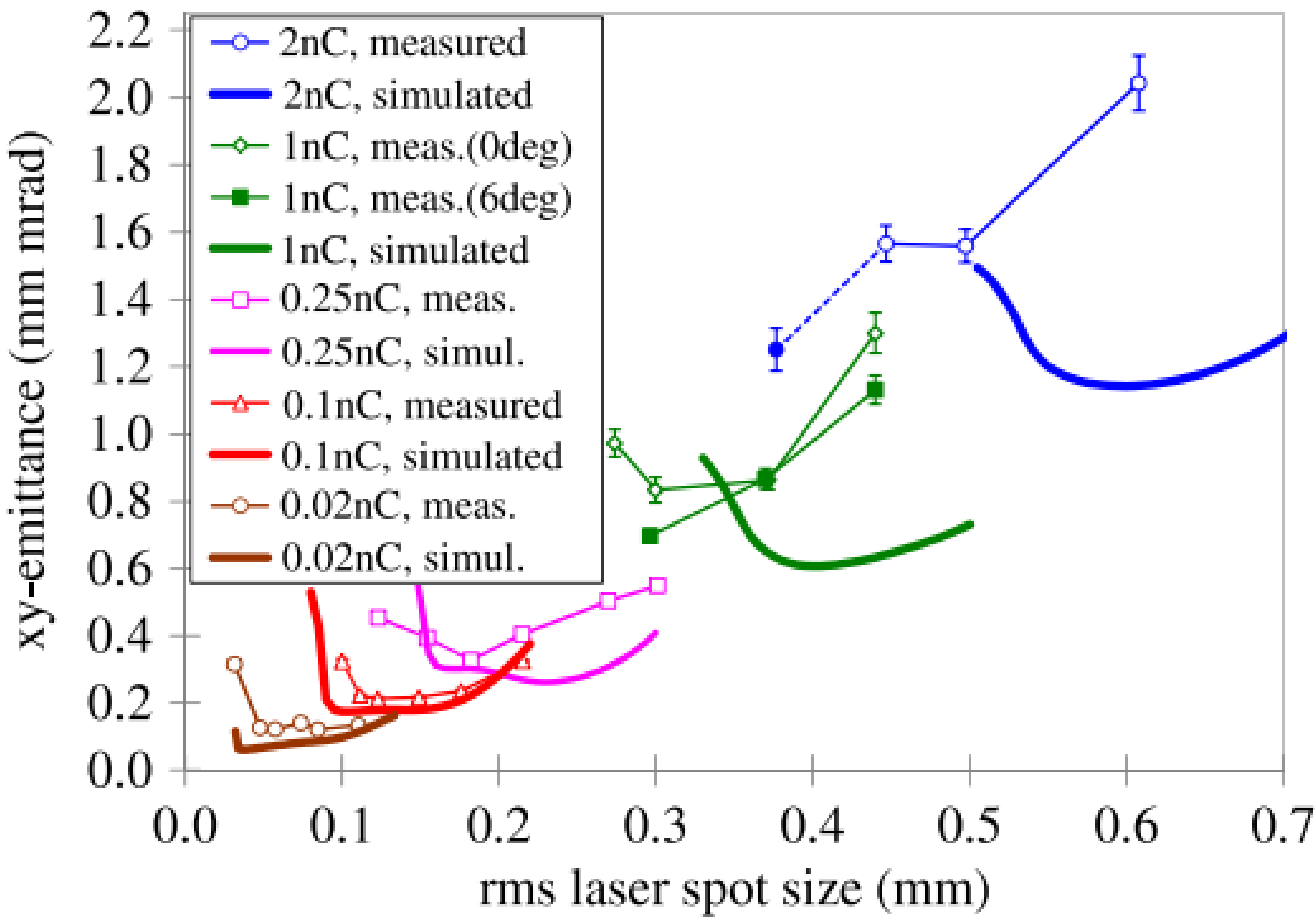


Figure 5: Dark current as function of RF-power for different cathodes measured at FLASH and PITZ.

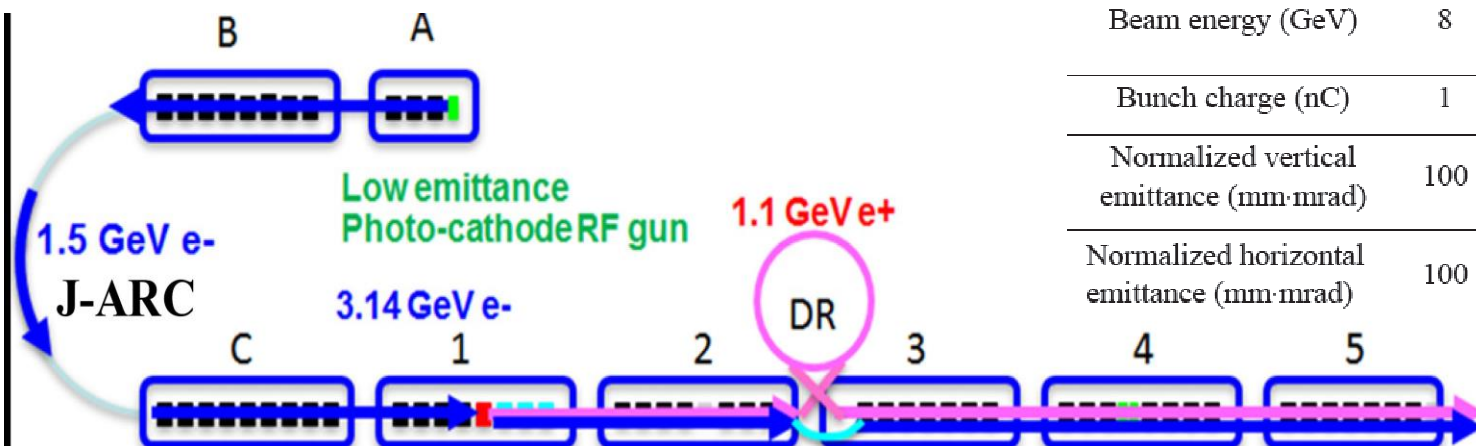
PITZ emittance measurement

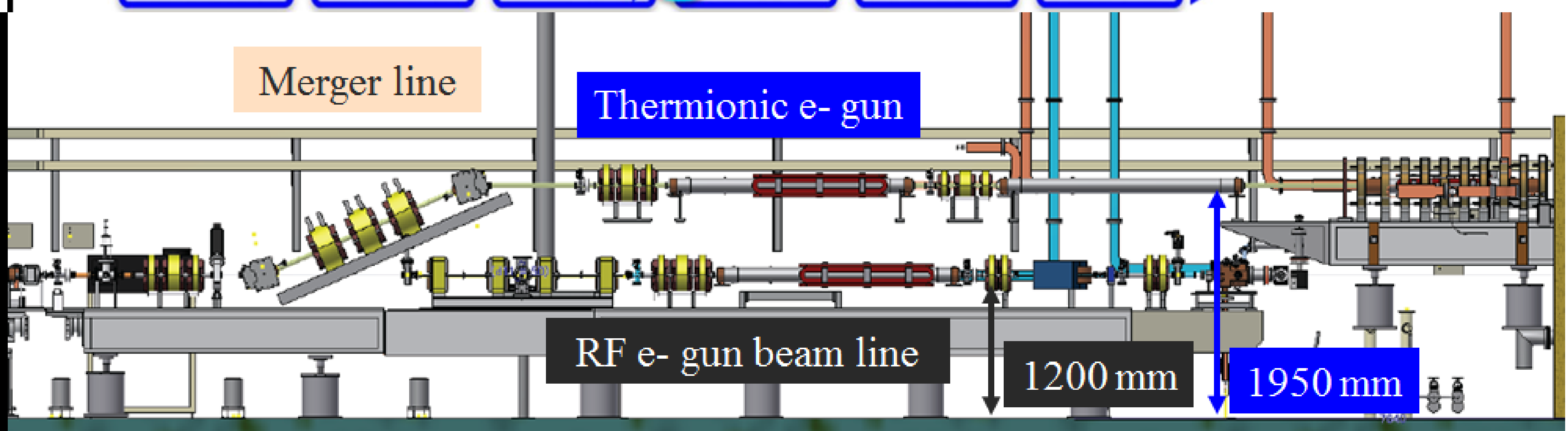


Injector SKEKB

Table 1: Main Parameters of SuperKEKB Injector Linac

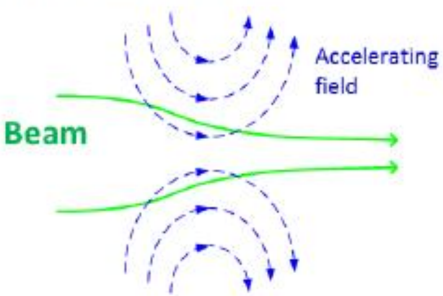
	KEKB		SuperKEKB (Phase III)	
	e-	e+	e-	e+
Beam energy (GeV)	8	3.5	7	4
Bunch charge (nC)	1	1 (10*)	5	4 (10*)
Normalized vertical emittance (mm·mrad)	100	2100	20	20
Normalized horizontal emittance (mm·mrad)	100	2100	50	100





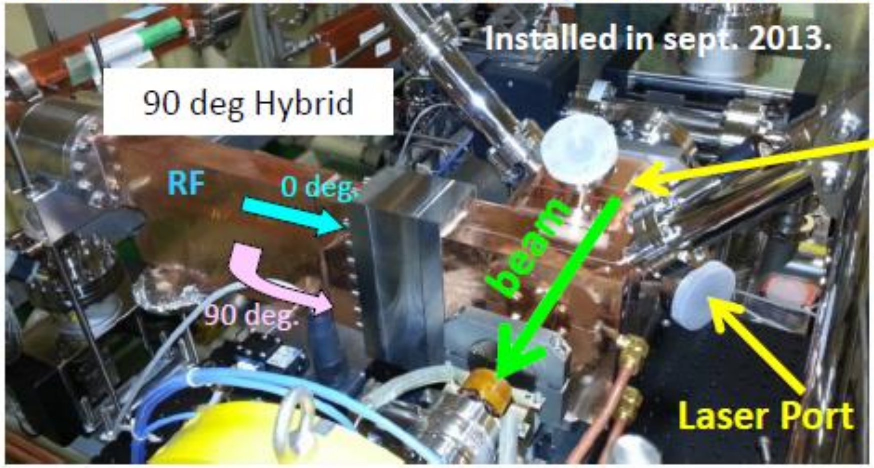
RF gun for SKEKB

Strong focusing force using accelerating field



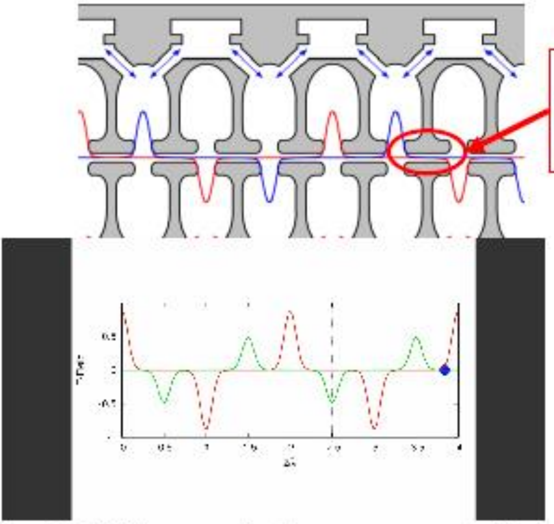
=> Strong focus

Quasi traveling wave (QTW) side couple RF gun



QE=1×10^{-4} @266nm
Long lifetime

Incident angle: 60deg to the cathode surface.

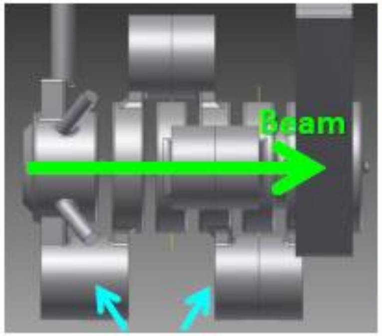


QTW type is adopted to make drift space short.

Drift space = no focus field

7 cell, 13.5 MeV@design
Norm. ε: 5.5 mm-mrad @5 nC (by simulation)
This RF gun can generate e- up to 10 nC

QTW is made by two standing waves with 90deg phase difference.



coupling cavities

T.Natsui, M.Yoshida

YAG laser 258 nm up to 5 mJ, operating regime ~1 mJ, 25 J

IrCe photocathode

D. Satoh and et. al. DEVELOPMENT OF BETTER QUANTUM EFFICIENCY AND LONG LIFETIME IRIDIUM CERIUM PHOTOCATHODE FOR HIGH CHARGE ELECTRON RF GUN. Proceedings of IPAC2013, Shanghai, China

We have been developing a new photocathode material as an electron source for the SuperKEKB electron linac. This injector is required to obtain a low emittance and high charge electron beams in order to achieve the highest luminosity all over the world. The required properties of a new photocathode are reasonably high quantum efficiency (**QE > 10-4**) and high laser durability to achieve a **longterm (> 1 year)** accelerator operation. We succeeded in developing an iridium cerium (**Ir5Ce**) **photocathode** which has a reasonably high QE **(~ 9.1×10-4 @213nm at room temperature**) and long **lifetime** (> **LaB6**). Furthermore, the QE of Ir5Ce photocathode was increased to a maximum value of **2.70×10-3 by heating at 1006 °C**. These great advantages of Ir5Ce photocathode led to generate the electron beams with a maximum charge of **4.4 nC/bunch using a new-type RF gun** at a test bench of KEK electron linac.

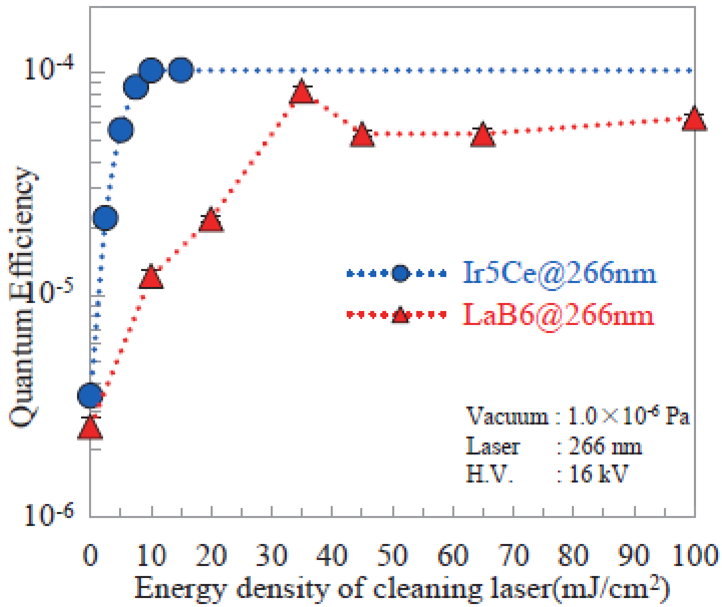


Figure 2: The QE as functions of the scanned energy density of cleaning laser.

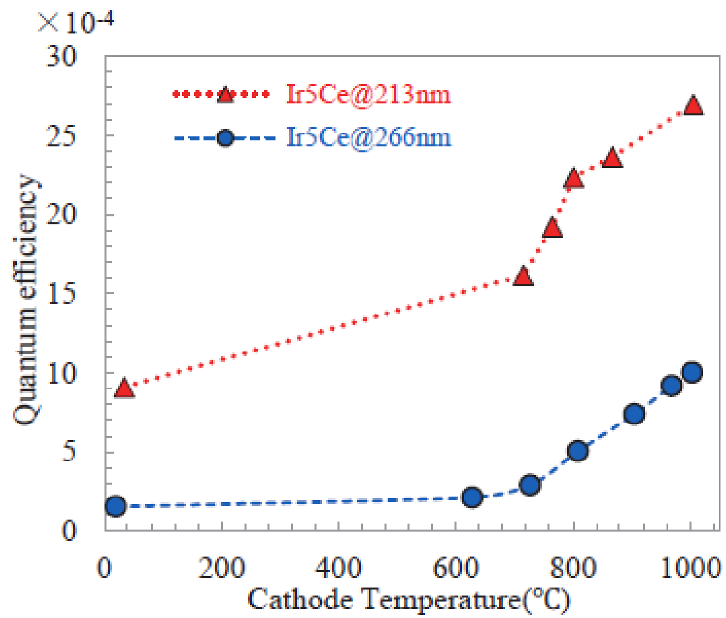


Figure 4: The QE of the Ir_5Ce photocathode as functions of the surface temperatures.

IrCe photocathode

D. Satoh and et. al. DEVELOPMENT OF BETTER QUANTUM EFFICIENCY AND LONG LIFETIME IRIDIUM CERIUM PHOTOCATHODE FOR HIGH CHARGE ELECTRON RF GUN. Proceedings of IPAC2013, Shanghai, China

Takuya Natsui and et. al. QUASI-TRAVELING WAVE RF GUN AND BEAM COMMISSIONING FOR SUPERKEKB. Proceedings of IPAC2015, Richmond, VA, USA

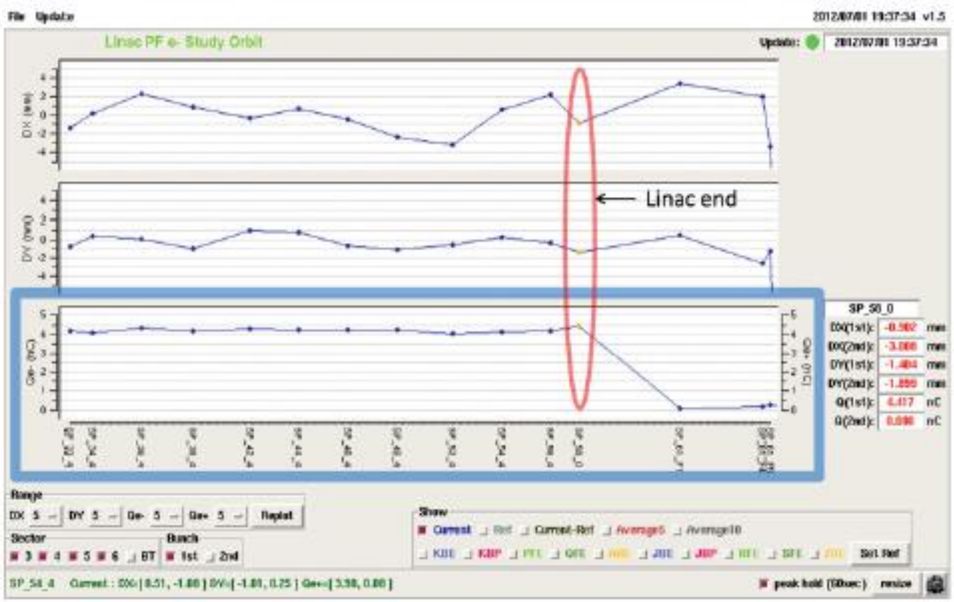


Figure 7: The result of a beam study at July 2012.

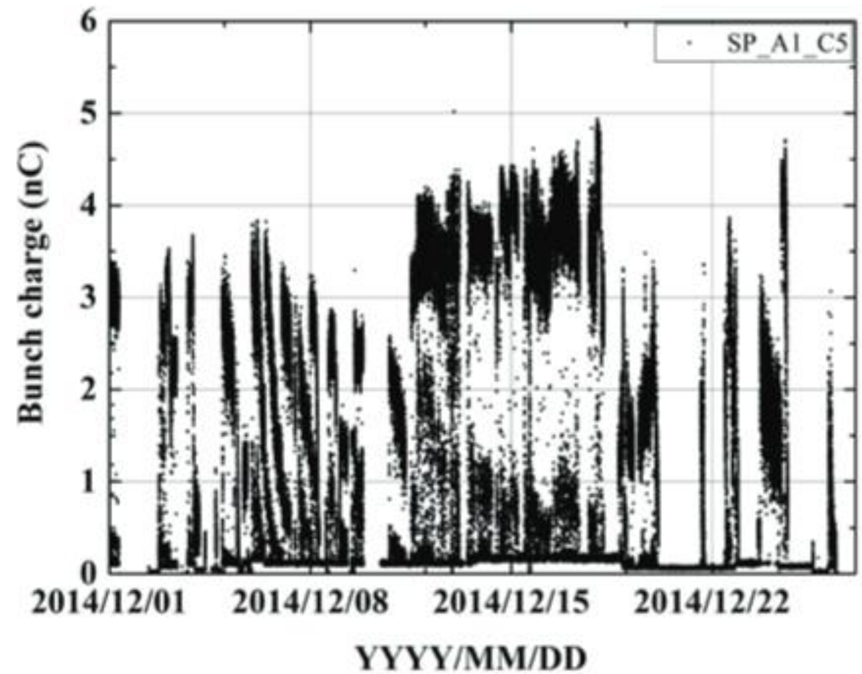


Figure 6: Beam charge of RF gun.

In the SuperKEKB injector linac, **beam commissioning by using the RF gun is in progress**. However, **instability of laser power is one of big problem**. The laser system was upgraded to 25 Hz from 5 Hz operation. 25 Hz operation has thermal conductance issue. **RF conditioning progress is one of the problems**. Cathode cell had a risk of breakdown. **The cavity was redesigned**. The new RF gun has choke structure for RF cutoff. **This RF gun was already constructed**. **RF conditioning will be started in this summer. RF gun commissioning will be carried out with new RF gun and stable laser system**.

Measured emittance for 3 nC: Enx=49.2 mm mrad, Eny=26.2 mm mrad

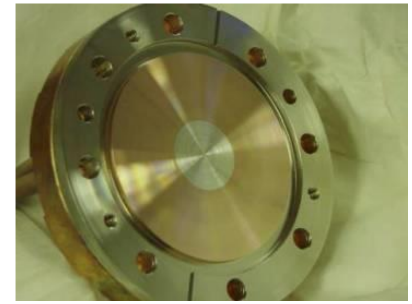
Metal cathode Mg

Terunobu NAKAJYO and et. al. Quantum Efficiencies of Mg Photocathode under Illumination with 3rd and 4th Harmonics Nd: LiYF4 Laser Light in RF Gun (Sumitomo Heavy Industries). Jpn. J. Appl. Phys. Vol. 42 (2003) Pt. 1, No. 3

X.J. Wang, M. Babzien and et.al. MG CATHODE AND ITS THERMAL EMITTANCE (NSLS, BNL). Proc. of LINAC2002, Gyeongju, Korea

Mg cathode been **operating routinely at a field of 100 MV/m** with quantum efficiency (QE) **of 0.2 to 0.3%.**

The vacuum pressure after rf conditioning was measured to be 6.0*10^-7 Pa (6.0*10^-9 mbar) when the rf was off **and 3.0*10^-6 Pa (3.0*10^-8 mbar)** when the rf was on.



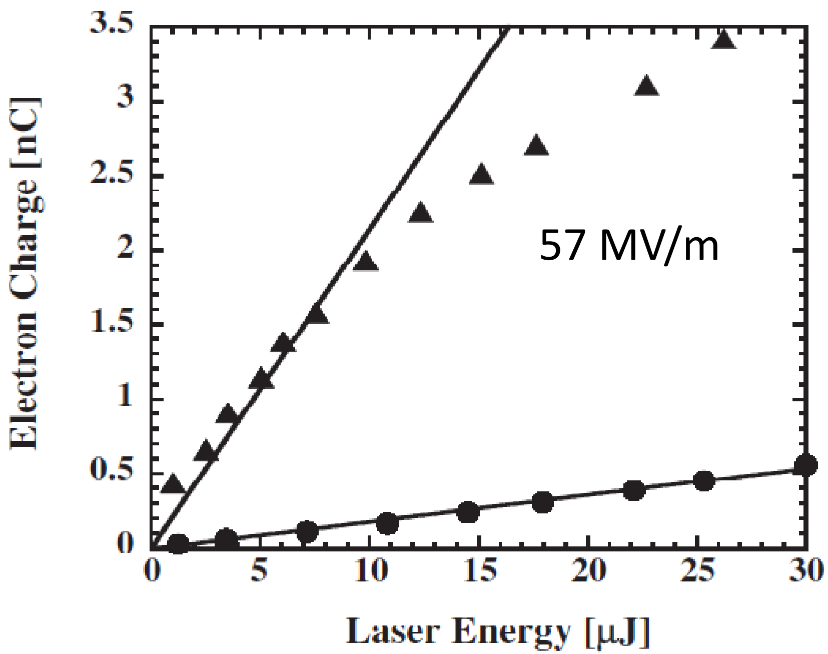


Fig. 4. Emitted electron charge from the Mg cathode as a function of the laser (262 nm) energy before (●) and after (▲) laser cleaning. The lines represent the best fit of the data at <2.0 nC by eq. (2).

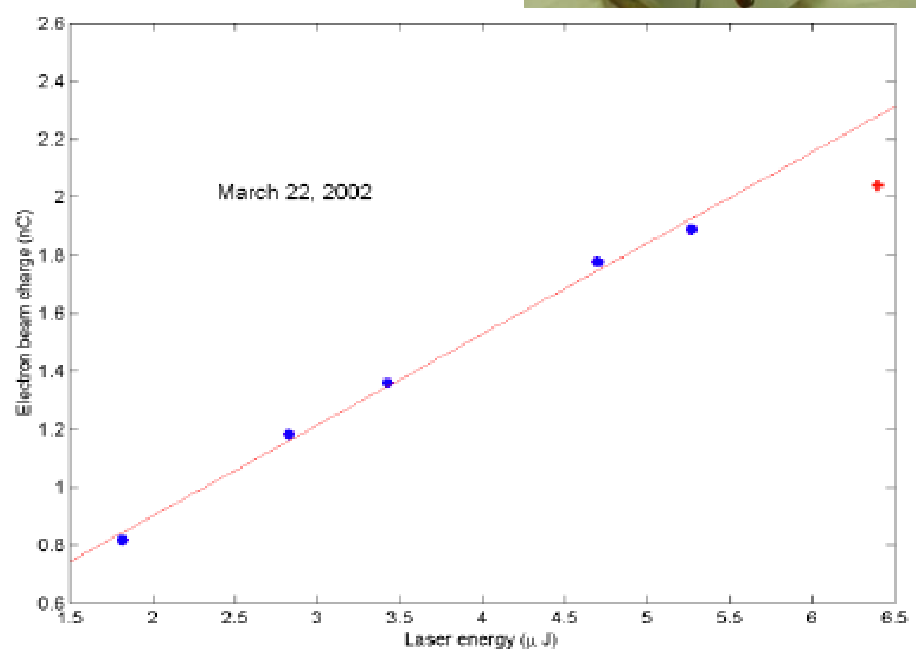


Figure 2: QE (0.2%) measurement for Mg cathode at the field of 90 MV/m.

Photocathode resume

Cathode type	Quantum efficiency	Vacuum	Advantages	Disadvantages
Cs2Te	20%-0.5%	10^-11 Torr (>1000Hrs)	Good QE and life time. Available for high acceleration gradient. High charge production	Very sensitive to vacuum conditions. Complicate installation.
Ir5Ce	5*10^-5	10^-9 Torr		
	4*10^-3 (after heating for 800 deg)	10^-9 Torr	Acceptable QE and very good life time. Available for high acceleration gradient. High charge production. Not so sensitive to vacuum conditions, it does not require something special equipment.	Ir evaporation -> decrease in breakdown threshold??
Mg	0,1%	10^-9 Torr	Very good QE for metal photocathode. Not so sensitive to vacuum conditions, it does not require something special equipment.	Apparently sensitive to very high acceleration gradients. (need to investigate)

Injector LINAK of SKEKB: preinjector

S. Ohsawa, A. Enomoto, K. Furukawa and et.al. PRE-INJECTOR OF THE KEKB LINAC. Proceedings of EPAC 2000

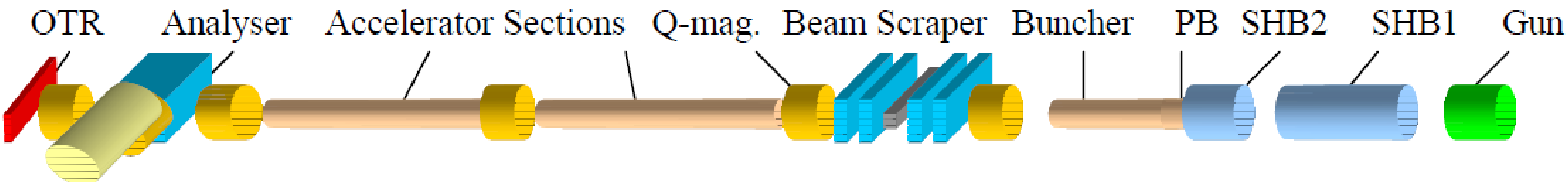


Figure 1: Schematic layout of the pre-injector. ORT is the optical-transition-radiation monitor for measuring bunches.

Table 1: Operation parameters

Element	Frequency	(Power)
Gun	50 Hz	200kV
SHB1 (standing wave)	114 MHz	11 kW
SHB2 (standing wave)	571 MHz	7 kW
Prebuncher(travelling wave)	2856 MHz	1 MW
Buncher (travelling wave)	2856MHz	23 MW
Accelerating sections (travelling wave)	2856MHz	12 MW x 2

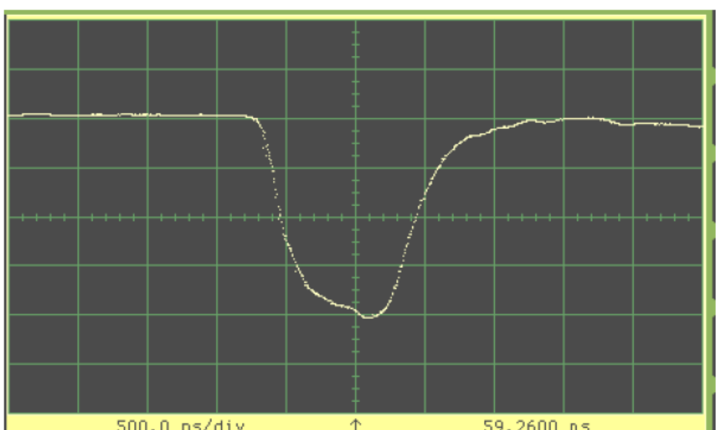


Figure 2: Pulse shape of the new grid pulser. A typical timing jitter (σ) is about 4 ps. The h-axis is 500ps/division.

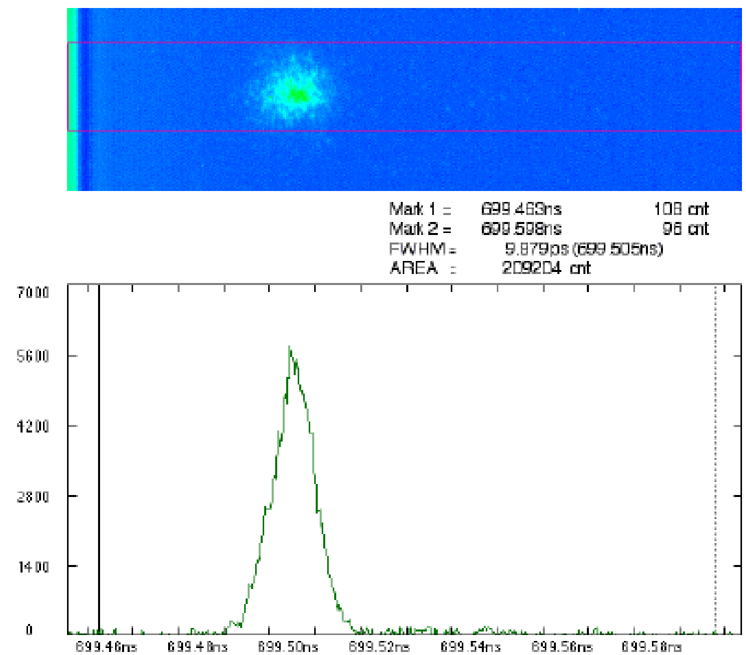
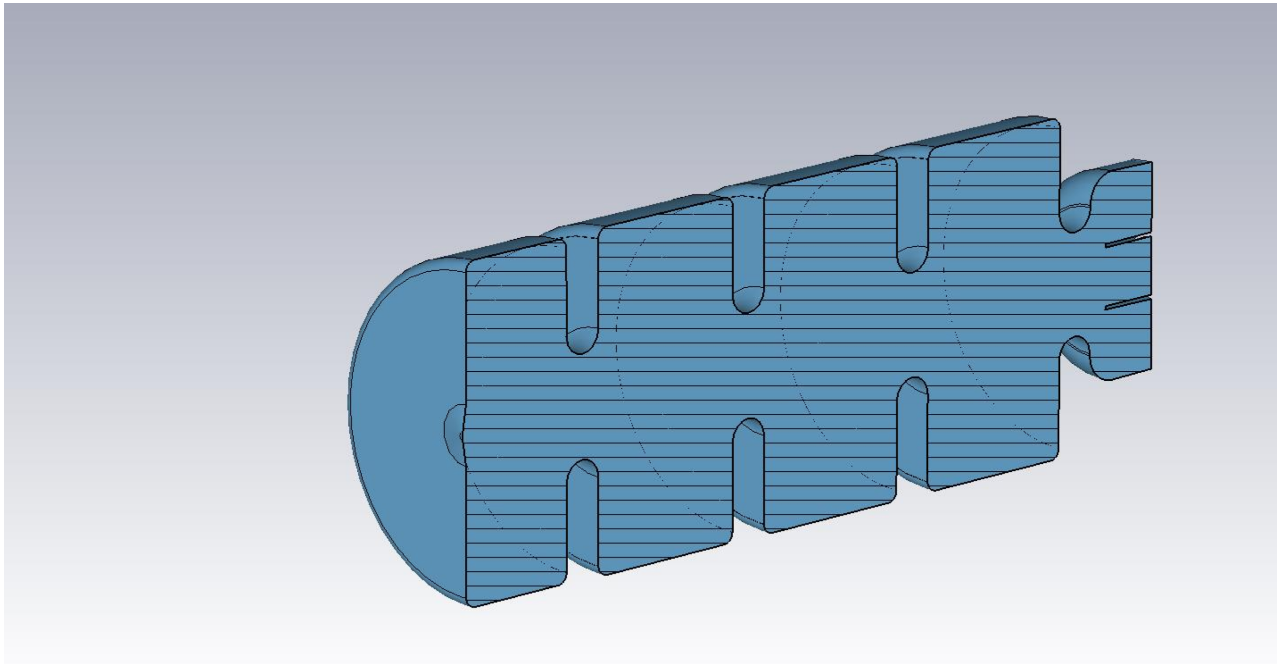


Figure 4: The 10-nC electron bunch of 10ps width.

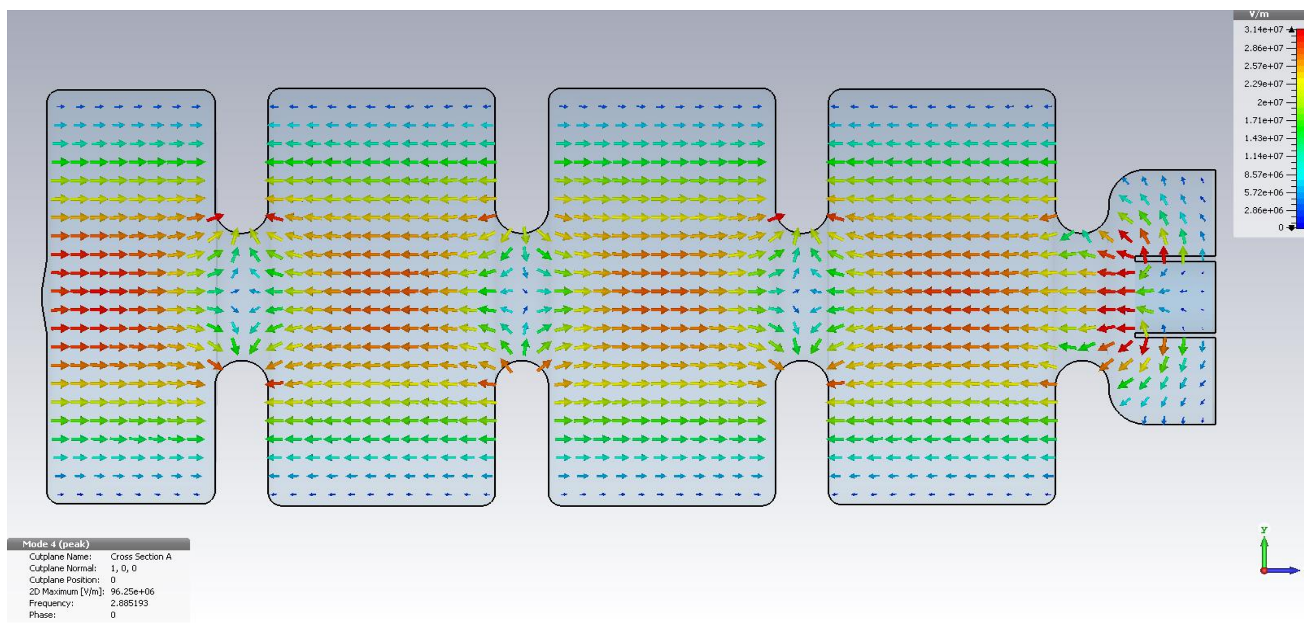
As a result the beams are stably accelerated to the target or the end of the linac with transmission efficiencies of greater than 90%.

FCC RF Gun Design

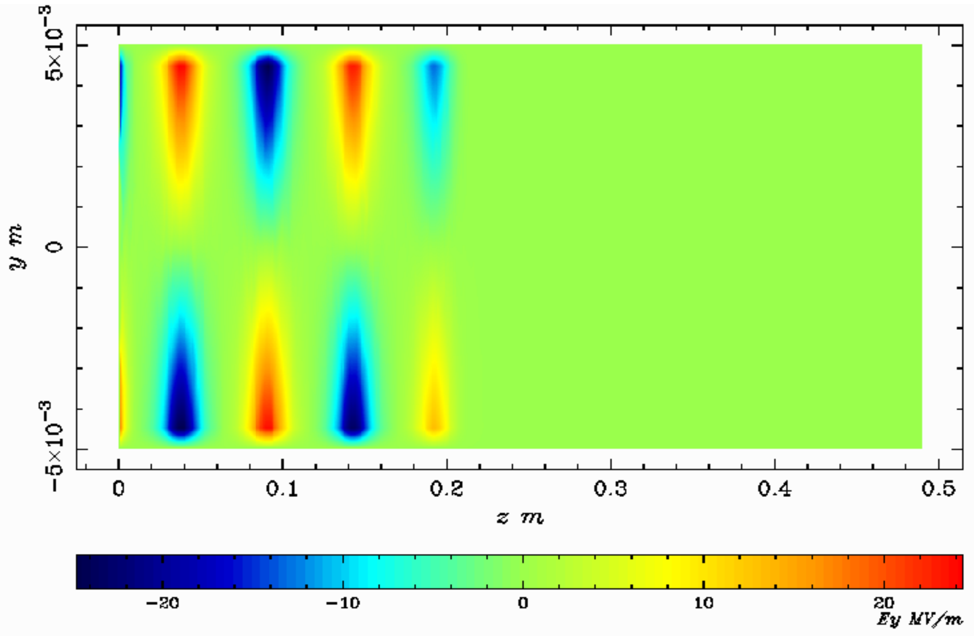


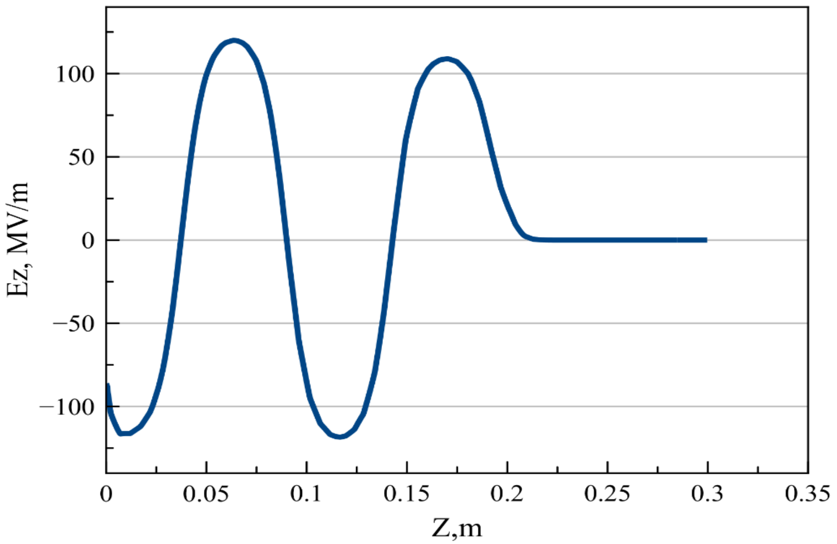
3+1/2 cavity cells with coaxial type feeder for power supplying

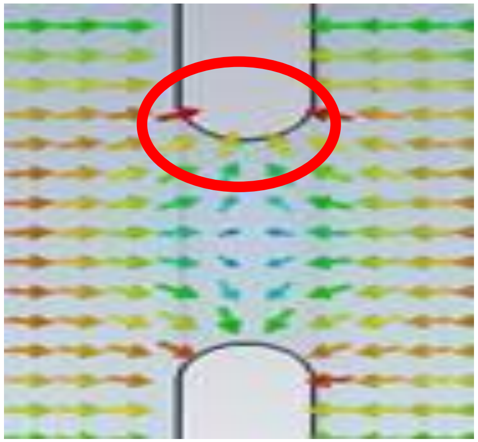
The phase shifting of oscillating mode is π

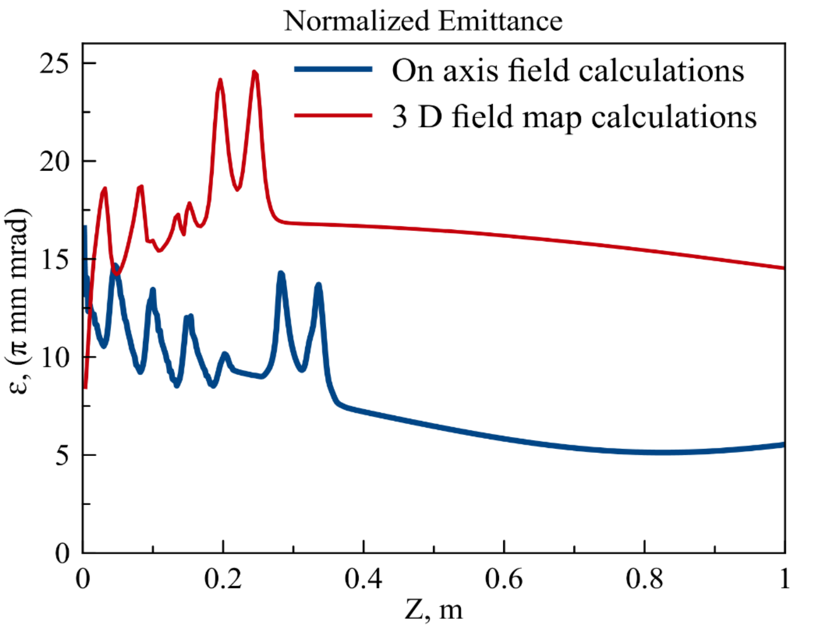


Emittance growth due to edge effects









RF gun design resume (plans)

- The charge of 6.5 nC is possible obtained with semiconductor cathode, but the design of the gun is significant more complex. The high vacuum is needed.
- With metallic cathode the charge of 4-5 nC is most likely can be achieved too, but of 6.5 nC is under the question.
- Using the gun with thermionic cathode the high charge can be achieved without problem, but in this case the beam length should be not more 1 ns to compress it in the following bunching system. In order to obtain such length the control grid is needed, therefore, the emittance of the charge will be significant higher than necessary.
- The RF gun with thermionic cathode can produce the “train” of the bunches with long tails and high energy spread. To produce one beam the additional control grid is most likely also necessary. Anyway the length of such beam will be longer than for RF gun with photocathode.
- In our opinion the RF gun with photocathode has to be used, but the following investigation concerning the cathode is needed. But in this case the design of the gun should provide low nonlinear fields, high shunt impedance. Such gun is under researched in our team. Also L-band RF gun can be interested, because, it provides small beam with high gun aperture (paraxial dynamics mode), but the duty cycle of beam injection is under the question.

Thank you for attention