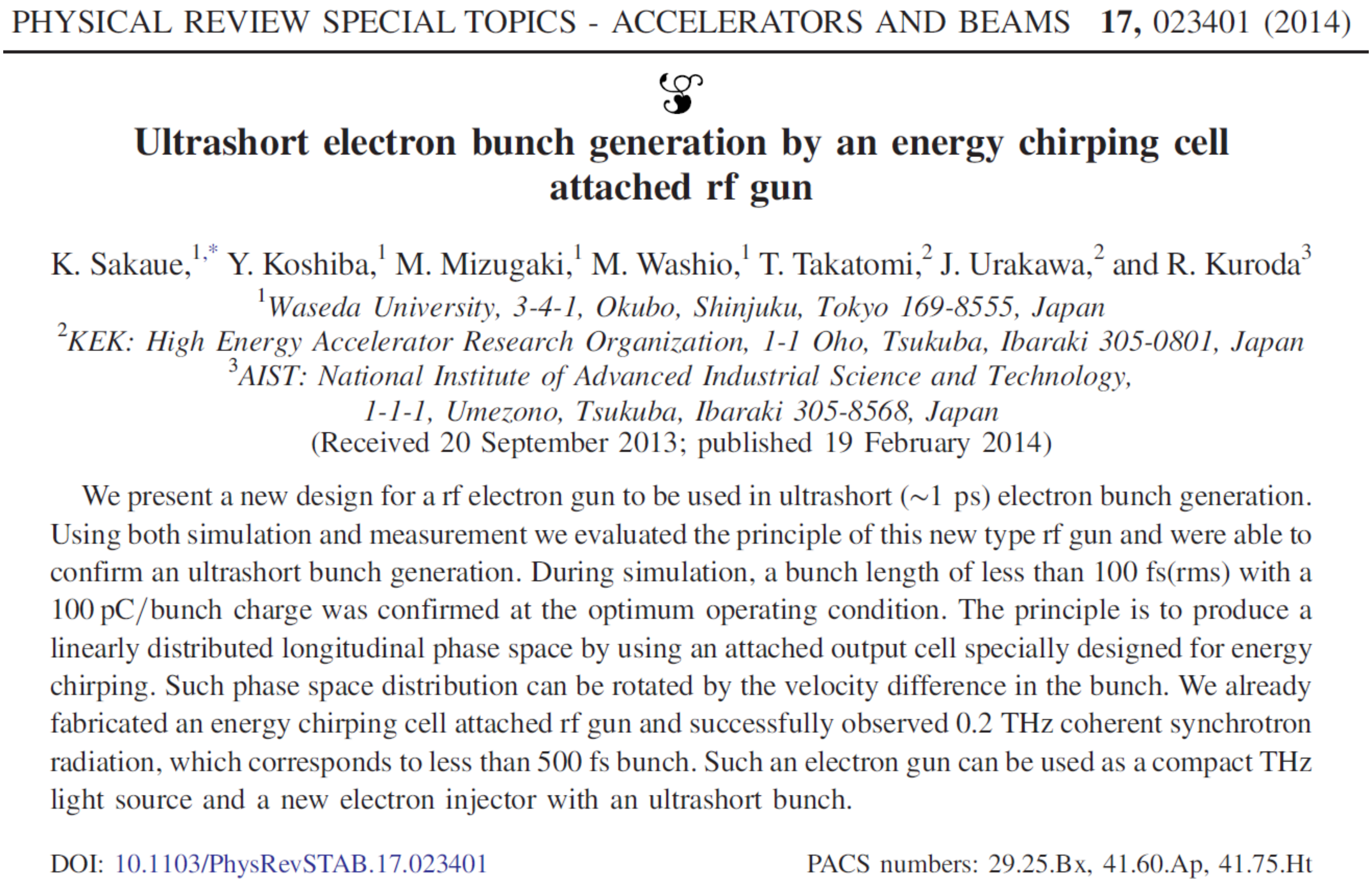
Frank Stephan → Report about:



PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 023401 (2014)

Ultrashort electron bunch generation by an energy chirping cell attached rf gun

K. Sakaue,[1,*] Y. Koshiba,[1] M. Mizugaki,[1] M. Washio,[1] T. Takatomi,[2] J. Urakawa,[2] and R. Kuroda[3]
[1]*Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan*
[2]*KEK: High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*
[3]*AIST: National Institute of Advanced Industrial Science and Technology, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8568, Japan*

(Received 20 September 2013; published 19 February 2014)

We present a new design for a rf electron gun to be used in ultrashort (~1 ps) electron bunch generation. Using both simulation and measurement we evaluated the principle of this new type rf gun and were able to confirm an ultrashort bunch generation. During simulation, a bunch length of less than 100 fs(rms) with a 100 pC/bunch charge was confirmed at the optimum operating condition. The principle is to produce a linearly distributed longitudinal phase space by using an attached output cell specially designed for energy chirping. Such phase space distribution can be rotated by the velocity difference in the bunch. We already fabricated an energy chirping cell attached rf gun and successfully observed 0.2 THz coherent synchrotron radiation, which corresponds to less than 500 fs bunch. Such an electron gun can be used as a compact THz light source and a new electron injector with an ultrashort bunch.

DOI: 10.1103/PhysRevSTAB.17.023401 PACS numbers: 29.25.Bx, 41.60.Ap, 41.75.Ht

→ paper not written perfectly, but VERY interesting idea and nice realization !

The idea

- Cut normal RF gun in two parts:
  - one for generating electron bunch and acceleration
  - One for providing energy chirp for ballistic bunching

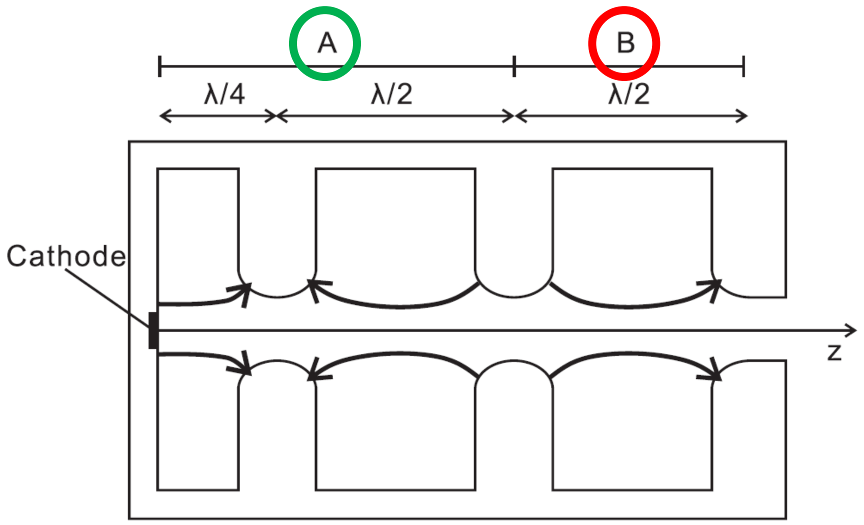


FIG. 1. Schematic of rf electron gun.

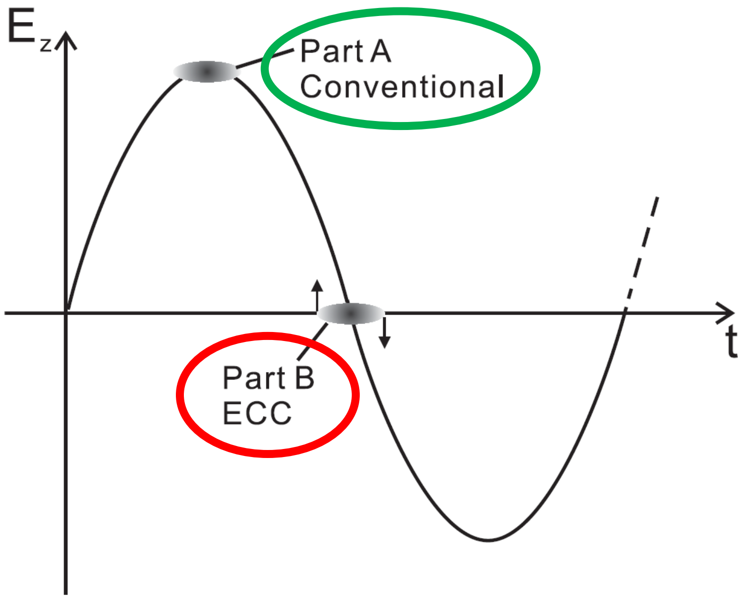


FIG. 2. Bunch acceleration by rf electric field.

“energy chirping cell attached rf gun” → “**ECC-rf gun**”

Analytical estimated based on Kwang Je Kims Theory:

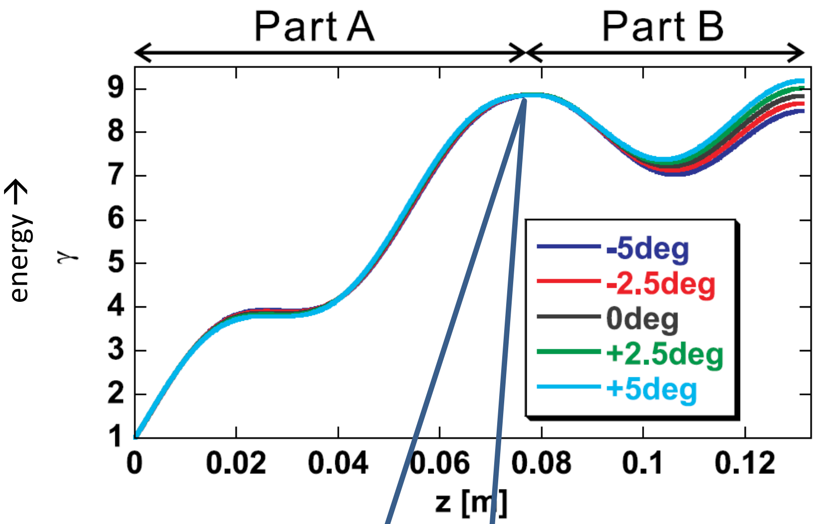


FIG. 3 (color online). Evolution of γ in the rf gun for the cases of ϕ_0, ±2.5°, and ±5°.

at the end of part A the beam has almost the same energy for all 5 cases of injection phases

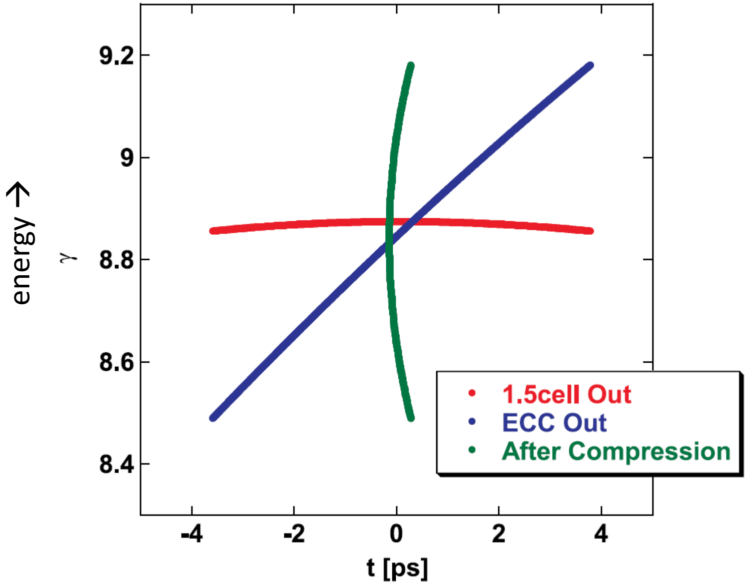


FIG. 4 (color online). Phase space distribution at the end of part A (red), end of part B (blue), and at 2.33 m away from the cathode.

➔

- Energy spread is small at end of part A
- almost linear chirp is provided by part B
- strong compression with 2.33 m drift

Design with Superfish ….

- usual RF gun
- new design:

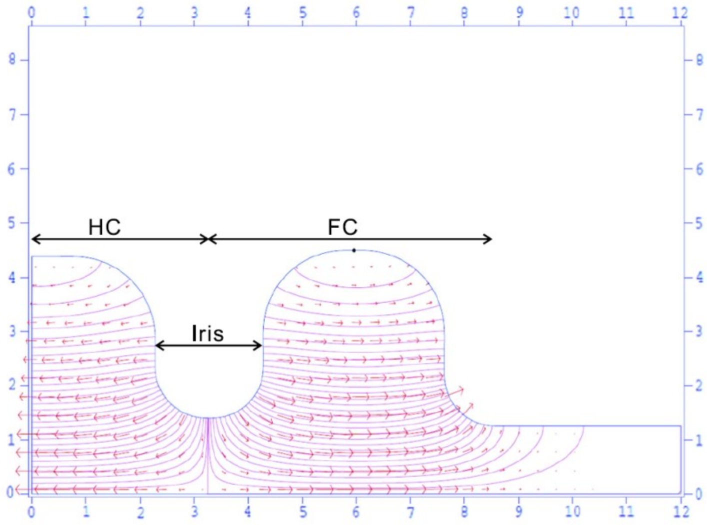


FIG. 5 (color online). Profile of a conventional 1.6-cell rf gun. Designed to obtain a minimum energy spread.

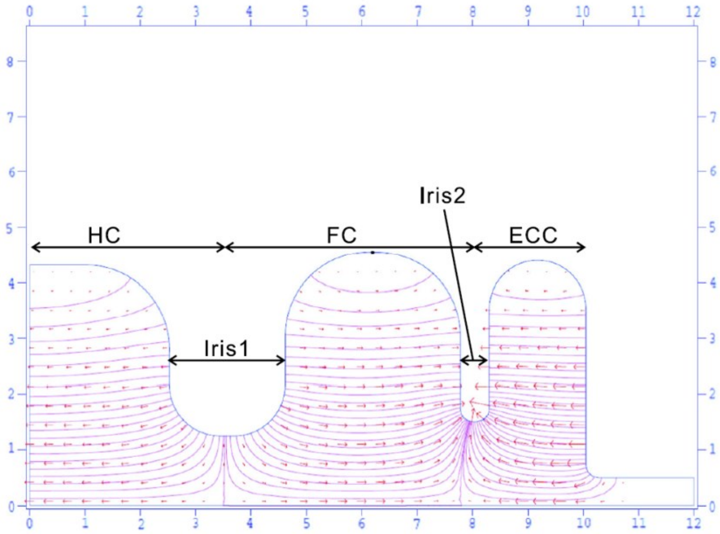


FIG. 6 (color online). Profile of an ECC-rf gun. ECC is added to a conventional rf gun shape. The parts, half cell (HC), full cell (FC), ECC, iris 1, and iris 2, are described.

TABLE I. Design parameters of ECC-rf gun cavity.

Parameter	Q value	E_h	E_f	E_e
Value	13290	1	1	1.5

… and GPT for the new design

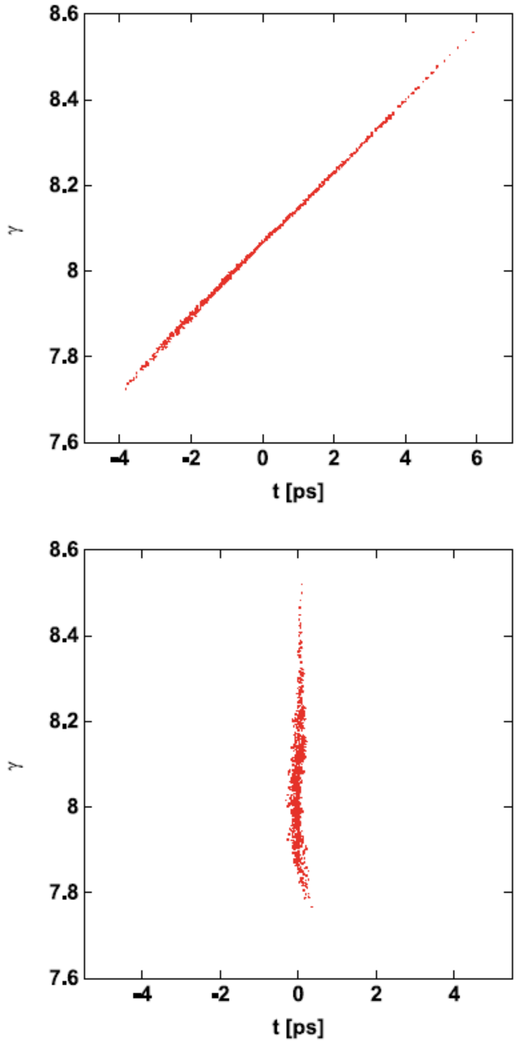


FIG. 7 (color online). Phase space distribution at the output of ECC-rf gun (top) and most compressed point (bottom) calculated by GPT.

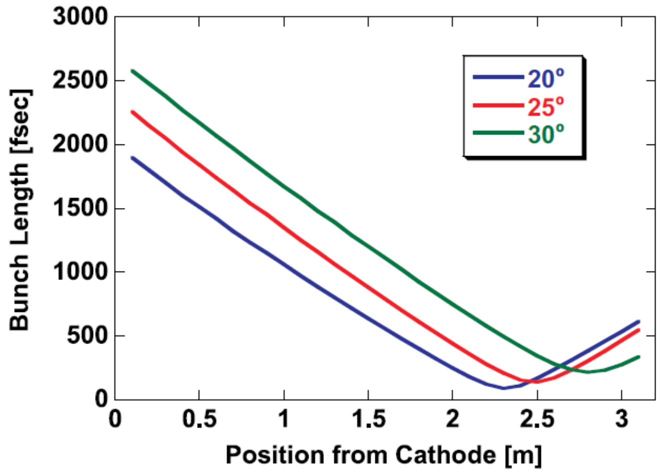


FIG. 8 (color online). Evolution of the bunch length by GPT. Three of laser injection rf phase are shown. The optimum phase was 20°, and a 88.4 fs (rms) ultrashort bunch was achieved at $z = 2.3$ m.

TABLE II. Simulation parameters.

Parameter	Value
Charge	100 pC/bunch
E_z at cathode	100 MV/m
Injection phase	20°
Initial bunch length	4.3 ps (rms)
Initial beam size	400 μm (rms)
Solenoid field	1050 G

TABLE III. Results of ECC-rf gun simulation by GPT and PARMELA.

	GPT	PARMELA
Energy	4.24 MeV	4.34 MeV
Minmum bunch length	88.4 fs (rms)	85.9 fs (rms)
Most compressed distance	2.30 m	2.36 m
Normalized emittance	4.39 π mm mrad	4.27 π mm mrad

Realization

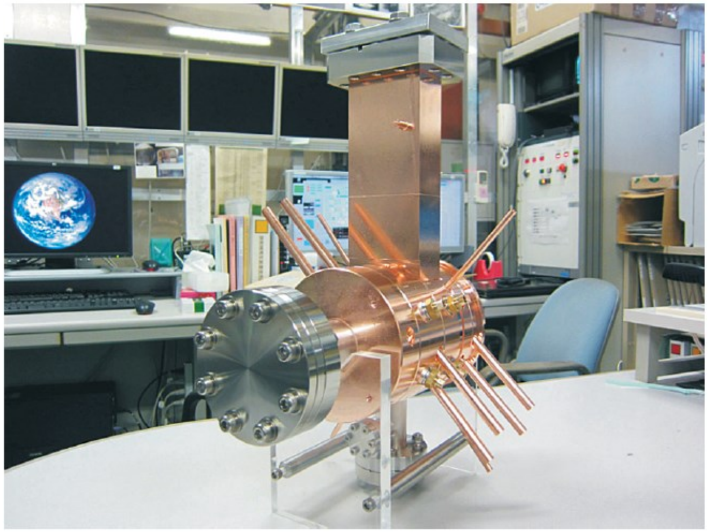
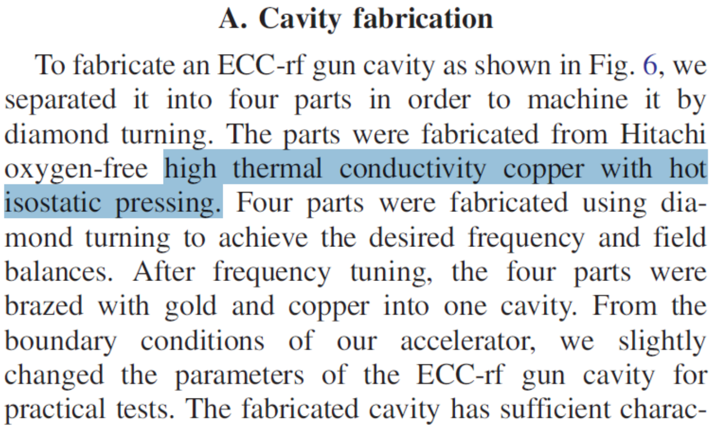


FIG. 9 (color online). Photograph of ECC-rf gun cavity. Cathode insertion port (near side), beam port (far side), rf waveguide (top), and vacuum pumping port (bottom). Water cooling pipes and rf tuners can be seen around the cavity.



A. Cavity fabrication

To fabricate an ECC-rf gun cavity as shown in Fig. 6, we separated it into four parts in order to machine it by diamond turning. The parts were fabricated from Hitachi oxygen-free high thermal conductivity copper with hot isostatic pressing. Four parts were fabricated using diamond turning to achieve the desired frequency and field balances. After frequency tuning, the four parts were brazed with gold and copper into one cavity. From the boundary conditions of our accelerator, we slightly changed the parameters of the ECC-rf gun cavity for practical tests. The fabricated cavity has sufficient charac-

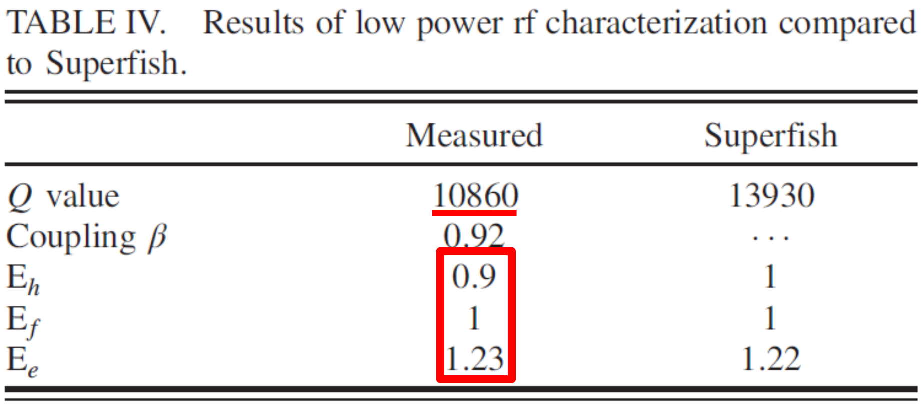


TABLE IV. Results of low power rf characterization compared to Superfish.

	Measured	Superfish
Q value	10860	13930
Coupling β	0.92	...
E_h	0.9	1
E_f	1	1
E_e	1.23	1.22

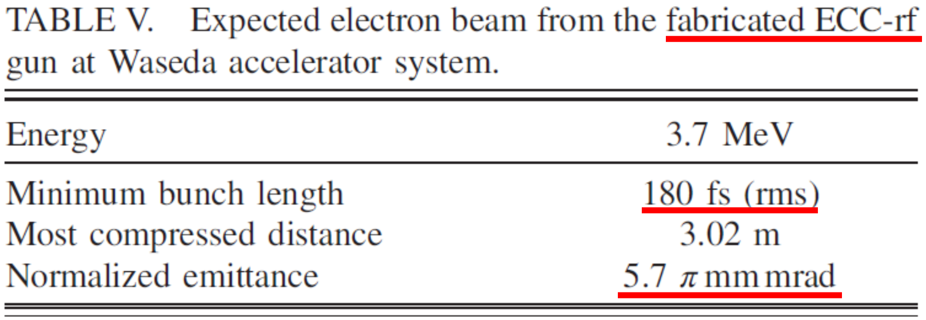


TABLE V. Expected electron beam from the fabricated ECC-rf gun at Waseda accelerator system.

Energy	3.7 MeV
Minimum bunch length	180 fs (rms)
Most compressed distance	3.02 m
Normalized emittance	5.7 π mm mrad

Simulation, Setup and Measurement

Simulation of charge and bunch length

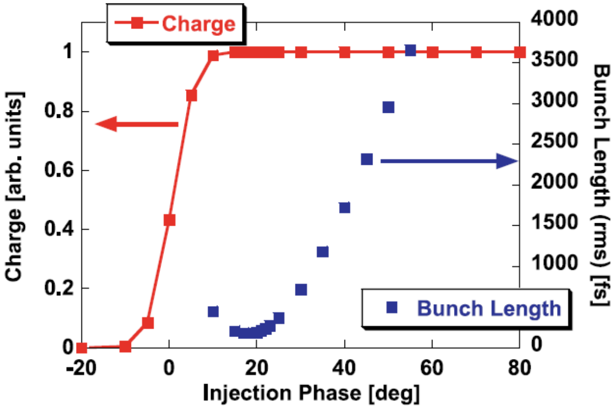


FIG. 10 (color online). Expected bunch length as a function of injection phase at $z = 3.0$ m. The shortest bunch was 180 fs (rms) at the phase of 19°.

Measurement of charge and energy

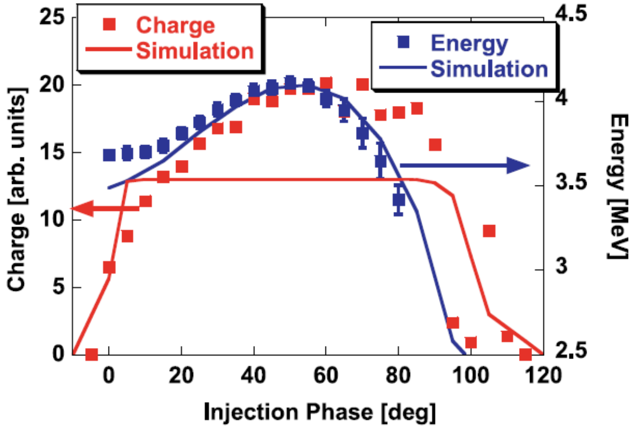
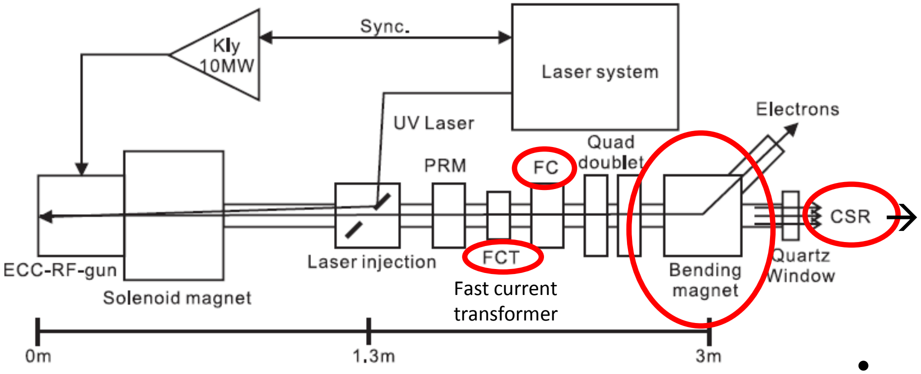


FIG. 12 (color online). Results of charge and energy measurement as a function of injection phase. The dots and lines show measurement results and simulation results, respectively. Measurement and simulation show good agreement.

simulation, the charge profile was a top-hat shape because the charge calculation does not include the Schottky effect from the rf electric field. It is clear that the ECC-rf gun works correctly as in the design simulation. We consider that this plot provides a proof of the ECC-rf gun concept.



→ spectroscopy

FIG. 11. Experimental setup for the ECC-rf gun.

- RF: 2856 MHz, up to 25 Hz, 4 µs, single bunch
- Laser: 262 nm, 10 ps FWHM on Cs2Te

Estimate of bunch length

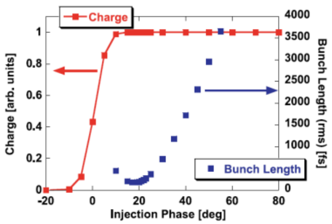


FIG. 10 (color online). Expected bunch length as a function of injection phase at $z = 3.0$ m. The shortest bunch was 180 fs (rms) at the phase of 19°.

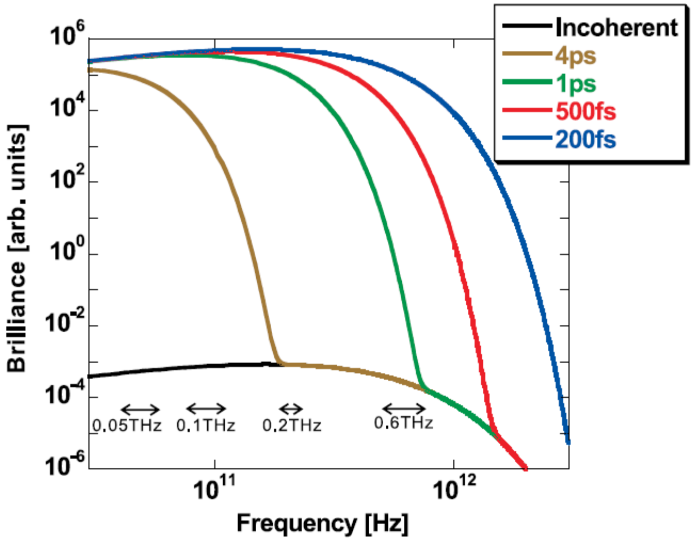


FIG. 13 (color online). Calculated synchrotron radiation spectrum by a 3.7 MeV electron bent by a 0.14 T magnetic field. Coherent enhancement of various bunch lengths are plotted on the incoherent spectrum.

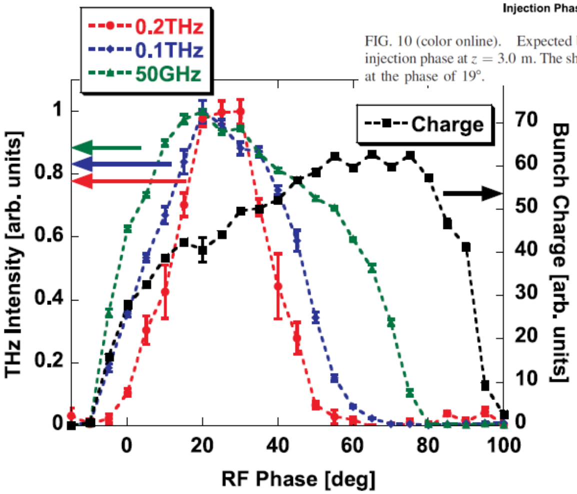


FIG. 16 (color online). CSR intensity as a function of the injection phase detected by 0.05 THz SBD (green), 0.1 THz SBD (blue), and 0.2 THz BPF + SBD (red). Bunch charge is also plotted as a reference. The peak of THz intensity was around 20° and the profile became narrower as the radiation frequency grew higher.

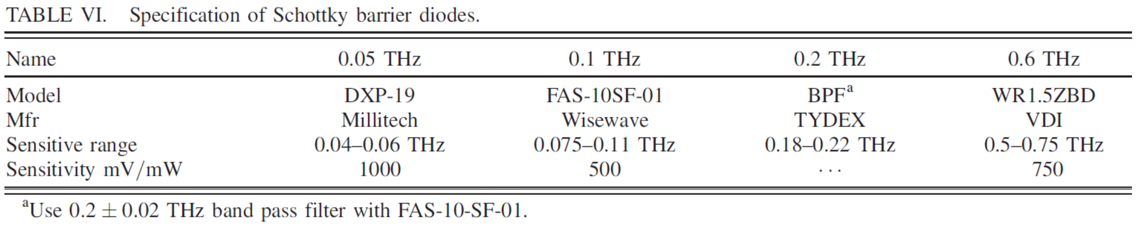
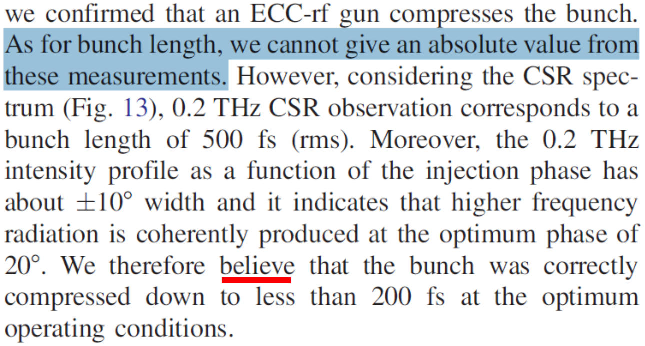


TABLE VI. Specification of Schottky barrier diodes.

Name	0.05 THz	0.1 THz	0.2 THz	0.6 THz
Model	DXP-19	FAS-10SF-01	BPF[a]	WR1.5ZBD
Mfr	Millitech	Wisewave	TYDEX	VDI
Sensitive range	0.04–0.06 THz	0.075–0.11 THz	0.18–0.22 THz	0.5–0.75 THz
Sensitivity mV/mW	1000	500	...	750

[a] Use 0.2 ± 0.02 THz band pass filter with FAS-10-SF-01.



we confirmed that an ECC-rf gun compresses the bunch. As for bunch length, we cannot give an absolute value from these measurements. However, considering the CSR spectrum (Fig. 13), 0.2 THz CSR observation corresponds to a bunch length of 500 fs (rms). Moreover, the 0.2 THz intensity profile as a function of the injection phase has about ±10° width and it indicates that higher frequency radiation is coherently produced at the optimum phase of 20°. We therefore believe that the bunch was correctly compressed down to less than 200 fs at the optimum operating conditions.

- Next step: use transverse deflecting cavity to measure bunch length