High Brightness Beam Generation by Ultrafast Field Emission Gating

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Introduction

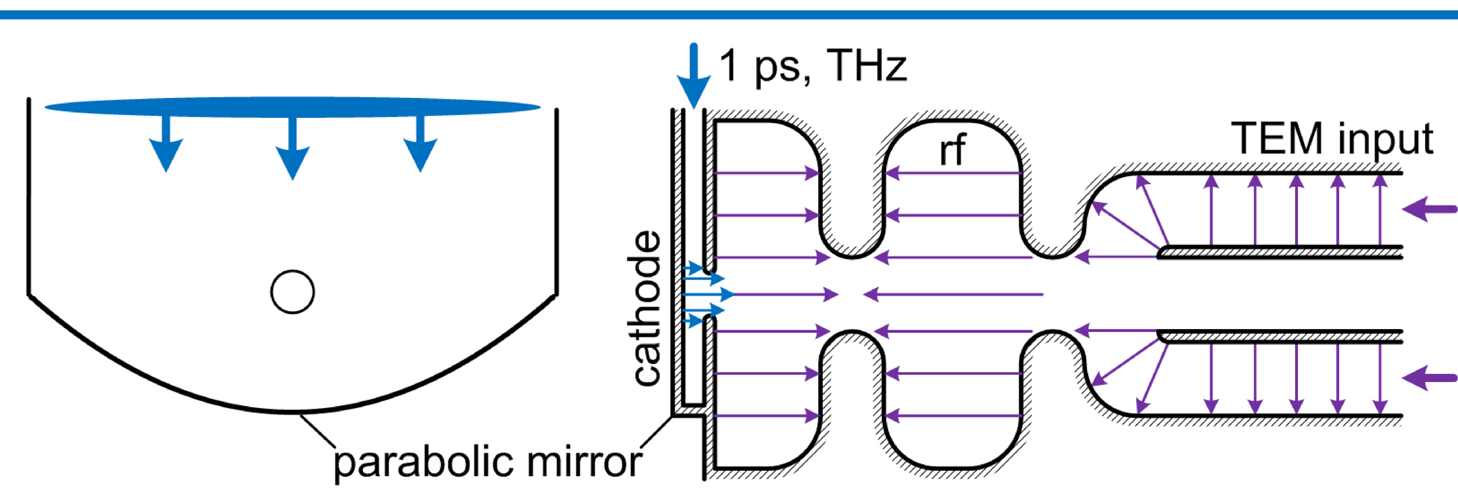
In the quest for high brightness beams, the source technology of choice is based on the use of high gradient electron guns. In order to achieve high brightness, the beam generated at the cathode needs to be accelerated to a higher energy before space-charge effects lengthen the bunch. Euclid TechLabs LLC, in collaboration with the Northern Illinois Center for Accelerator and Detector Development, proposes to build a high brightness gun based on a gated picosecond flat field-emission cathode. Laser-based single-cycle THz pulse production by optical rectification and semiconductor switching yields high intensity, ~ 1 ps long THz pulses. The 1 GV/m field strength of the THz pulse, combined with the RF gun accelerating field of ~100 MV/m, results in the emission of a short current pulse from the cathode. Compared to a standard photocathode, the beam brightness is increased due to the high additional accelerating field provided by the THz pulse. This allows considering the possibility of creating electron bunches with a brightness of 10^{16} A/m^2×rad^2 with bunch charges at the 100 pC level.

The highest gradients might be obtained by means of phase-locked millijoule, single-cycle THz pulses produced by the rectification of laser radiation in large size organic crystals. In the reported experiments, conversion efficiency of 1–3% and 1–100 MV/cm field levels at the focal point have been shown.

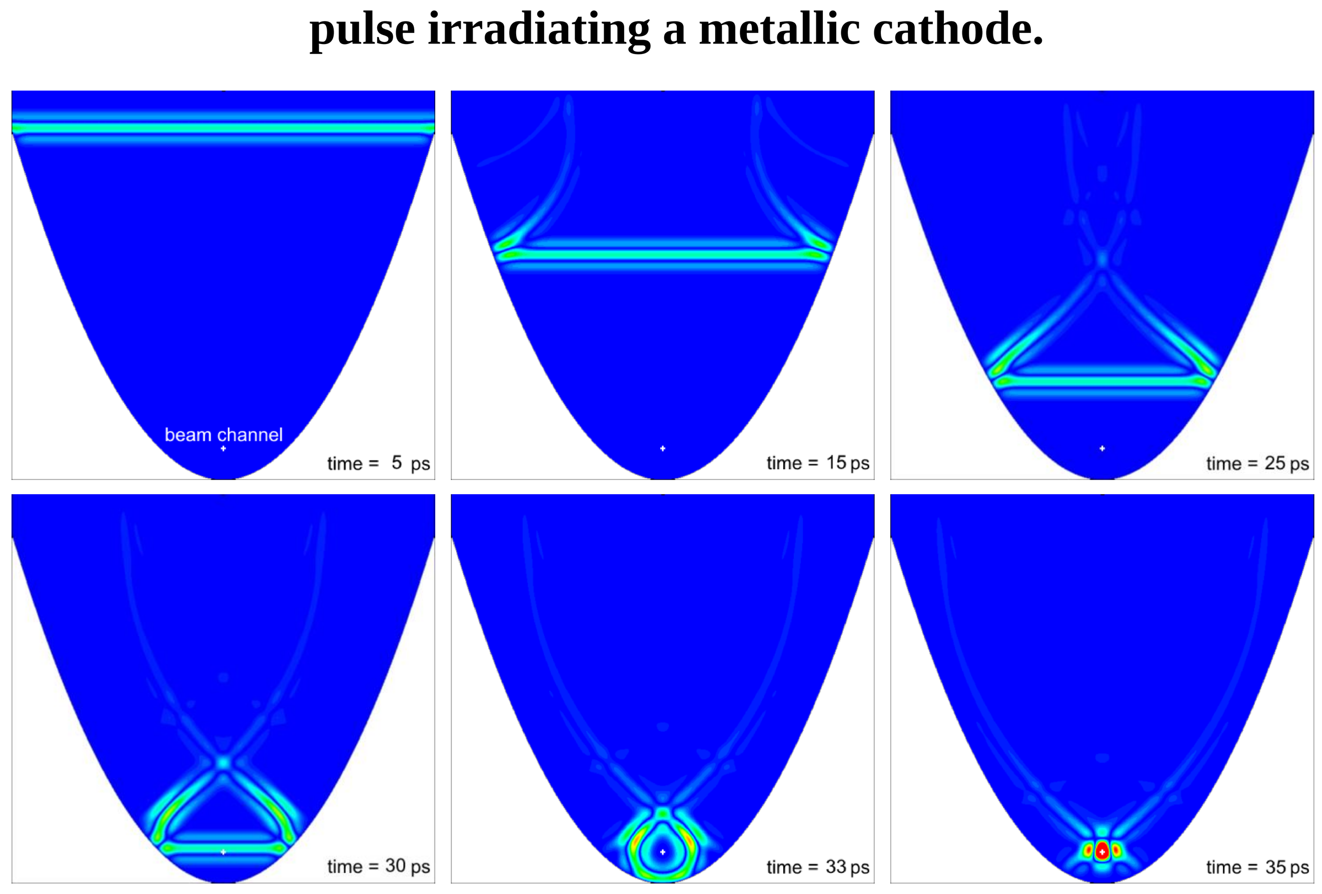
As it was recently shown, the higher the injection cathode rf field in a gun, the smaller the emittance and energy spread that can be obtained. From this point of view, an rf gun might be improved by means of cathode field enhancement, which is implied to be safe with respect to breakdown. For this purpose, a high-power, single-cycle THz radiation of the picosecond duration seems an ideal mean as a synergetic addition to main rf field. In this rf gun an incident rf power comes in two-cell accelerating resonator on π-mode. The THz pulse is focused at cathode by parabolic mirror. Electron emission occurs at the instant in time when the THz radiation is focused at the cathode region, and provides the maximum surface field on the metal surface, and the emitted electrons begin to be accelerated towards the first cavity iris. The emission of electrons from a metal is described by the Fowler-Nordheim (FN) law.

A new gun design can be based on a long set of waveguides with different adjusted lengths, in which the synchronism of accelerated particles with transversely propagating THz pulses is to be sustained. A proper mirror shape allows one to accelerate particles injected with near zero initial velocity.

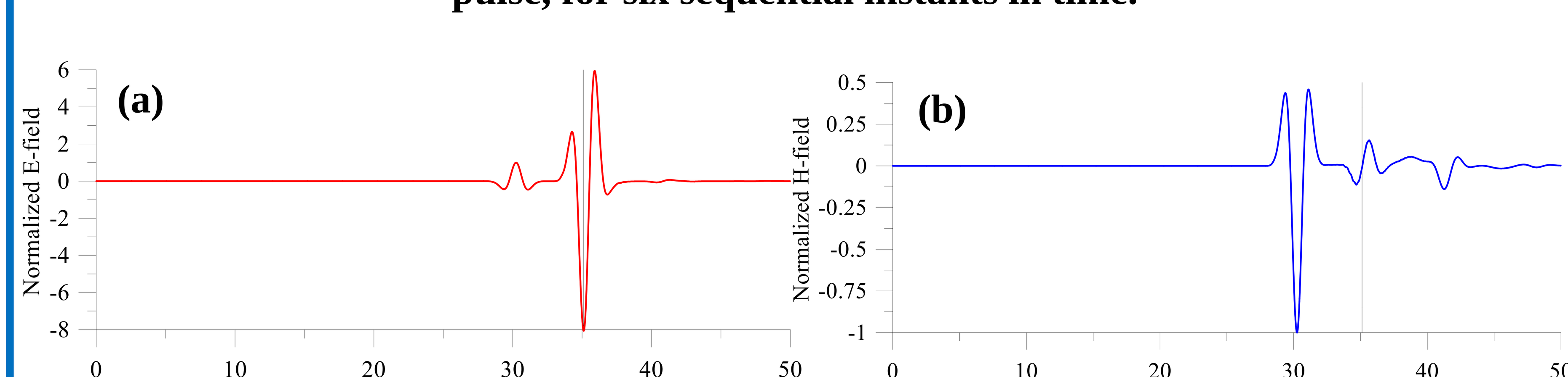
A Rf Gun with Electron Emission Controlled by Picosecond THz Pulse



RF gun wherein electron emission is controlled by a picosecond THz pulse irradiating a metallic cathode.

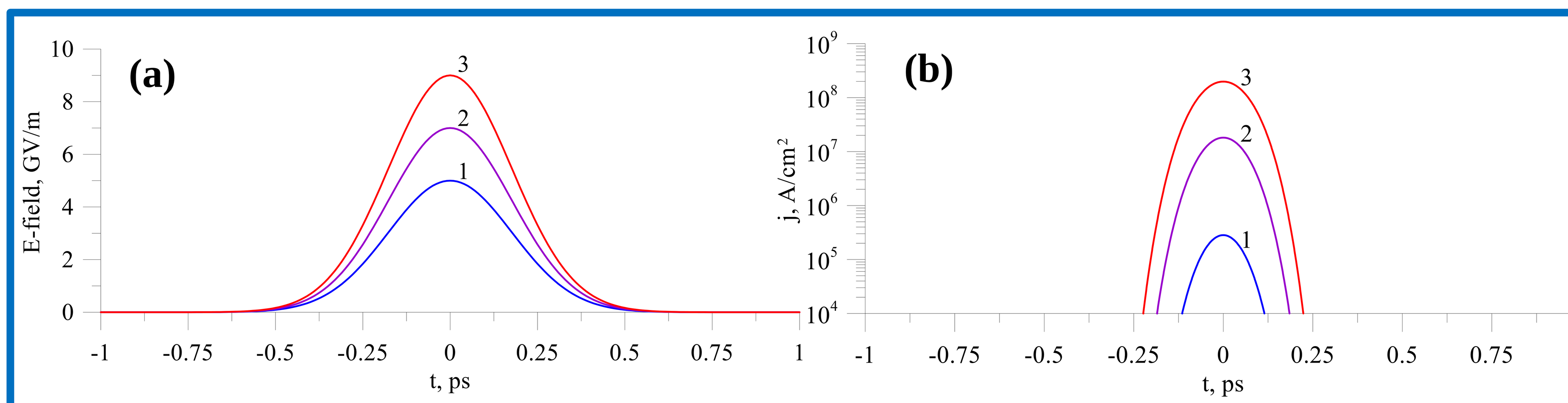


Field distributions at the parabolic mirror while focusing the short THz pulse, for six sequential instants in time.

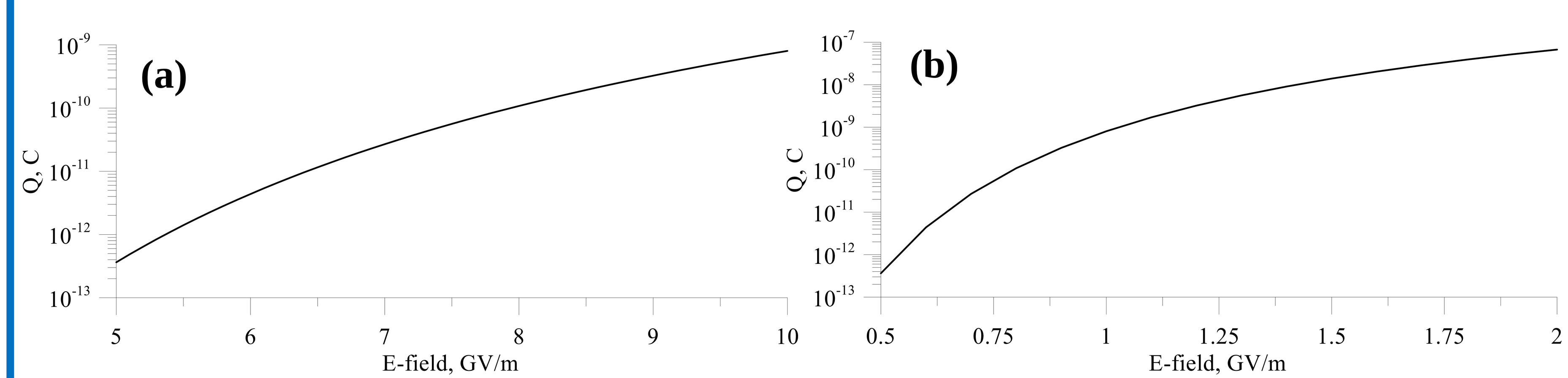


Electric (a) and magnetic (b) field components at the focus of the parabolic mirror.

Simulation of THz field emission



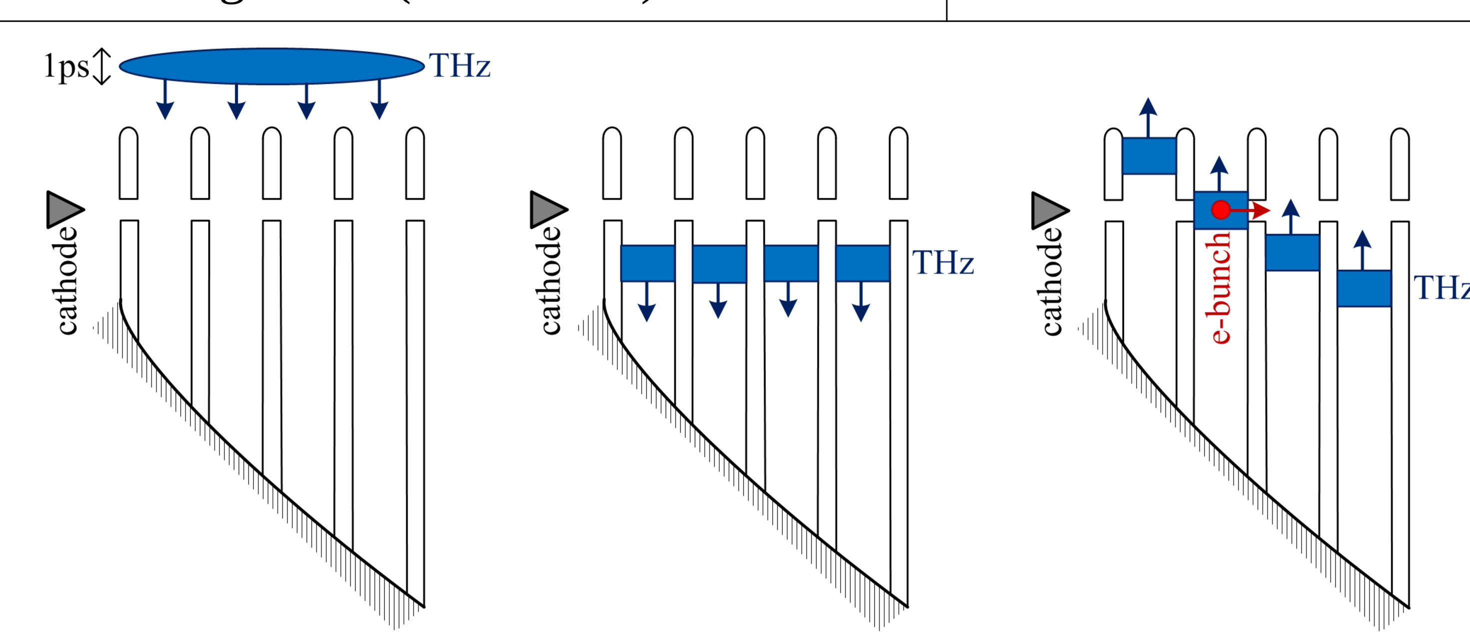
(a) Temporal profile of THz pulses and (b) the currents induced by these pulses for β=1.



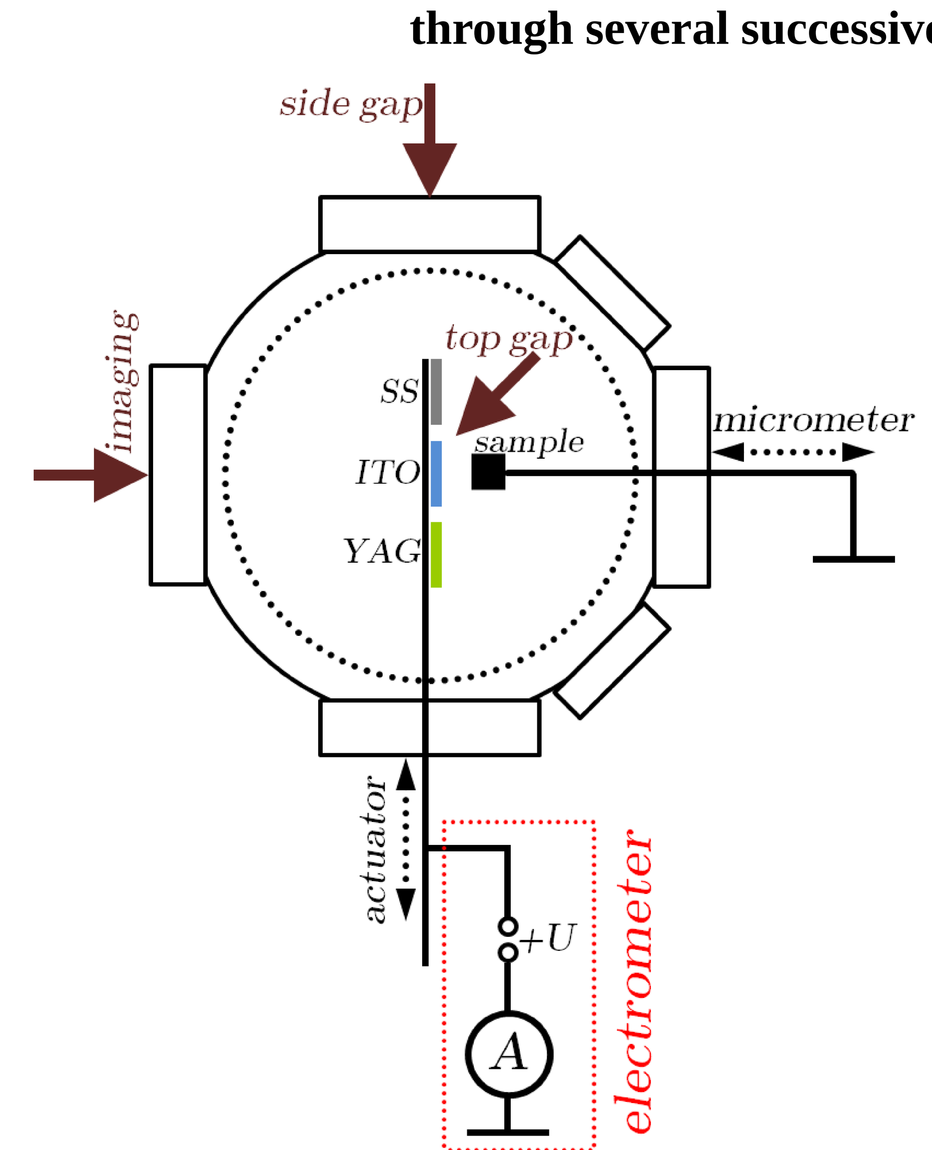
Charges emitted from the metallic surfaces for (a) field enhancment β=1 and (b) β=10.

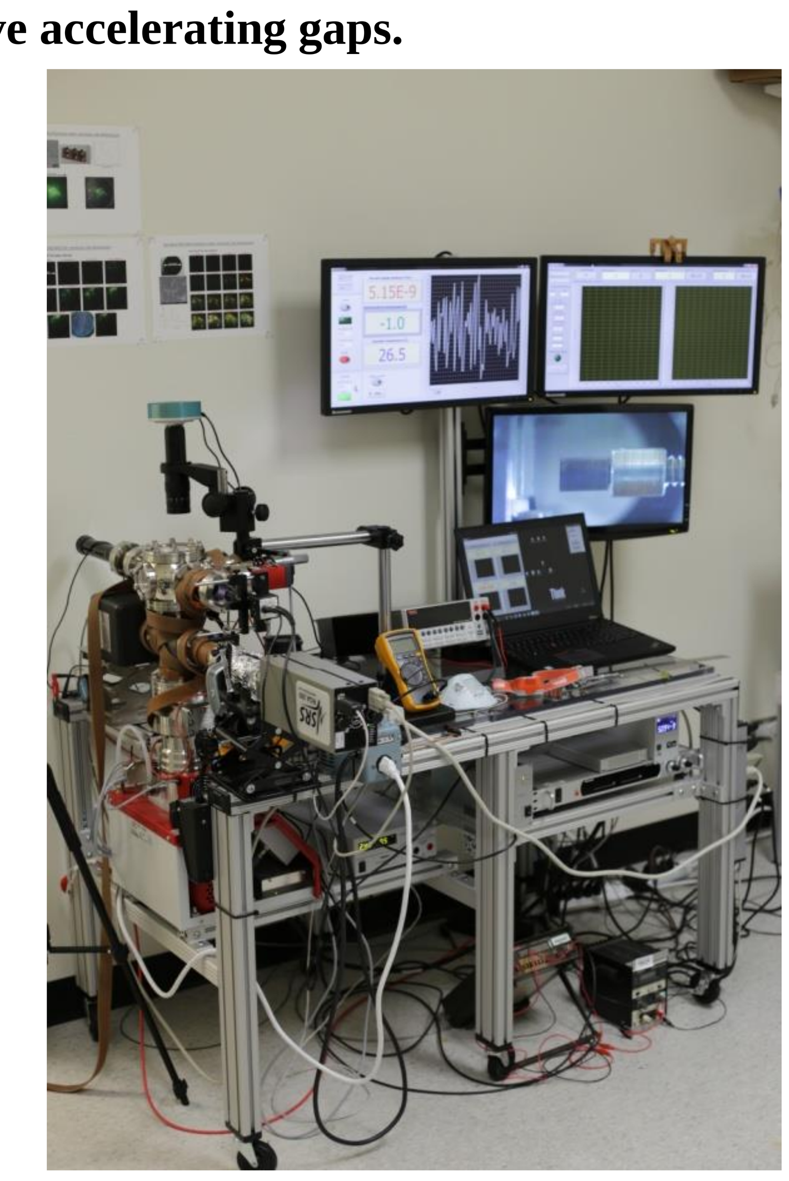
Anticipated parameters of the targeted THz-gated injector:

Maximum electric field on cathode (GV/m)	8
Effective bunch length (ps)	0.13
Effective cathode radius (mm)	8×10^{-3}
Bunch charge (pC)	25
ε_{th} (mm×mrad)	9×10^{-4}
ε_{sc} (mm×mrad)	0.13
ε_{RF} (mm×mrad)	7×10^{-3}
Brightness (A/m^2×rad^2)	2.2×10^{16}



Concept for particle acceleration by a single picosecond THz pulse through several successive accelerating gaps.





A schematic of the electron emission imager. Solid arrows represent the 3 cameras: two cameras are used to monitor parallelism between the cathode and anode surfaces, upon installation, and to measure the interelectrode gap during field emission measurements, and the third camera is used to detect light either from anode screen luminescence or light originating from the cathode surface itself, or both. The right picture shows the actual test stand at Euclid.