# SLAC MEMORANDUM-E163

**DATE:** September 8, 2004

**TO:** Heinz Vincke

**FROM:** Eric Colby

**SUBJECT:** **Explosive Electron Emission (EEE) Loss Calculations for E163**

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This memo describes a calculation of beam power losses that result from "Explosive Electron Emission" (EEE) from the photocathode of the ORION/E163 rf gun. EEE can result when a plasma is formed in response to an over-focused laser striking the photocathode. In addition to producing large amount of beam current and radiation, this form of emission generally results in permanent damage to the cathode surface and must be assiduously avoided.

Prior estimates for the LCLS gun apply[1] to the ORION/E163 gun, as the microwave design, maximum gradient and manner of laser illumination are similar. Estimates for the beam transmission through the booster linac, however, differ substantially owing to significant differences between the LCLS and NLCTA accelerator beamlines. We will assume, as in reference [1], that the charge per rf bucket is space-charge limited, which for 120 MV/m gradient in the gun, and the design E163 spot size of 2.5 mm means:

$$q = E_o \pi r_o^2 \varepsilon_o = (120MV/m)\pi(2.5mm)^2(8.854\times10^{-12}F/m) = 20.8nC \qquad (1)$$

is the approximate charge emitted in each rf bucket. At this emission rate, the beam (initially) extracts energy at a rate of 20.8 nC*2.856 GHz*6 MeV~360 MW and the rf stored energy in the gun is depleted very rapidly, causing the electric fields to diminish rapidly to levels that no longer sustain the EEE mode. Experiments show the integrated charge emitted over a single rf pulse from a similar s-band rf gun at Brookhaven approaches 1 μC[2]. Beam is emitted at rapidly diminishing energy (and hence in rapidly diminishing charge bunches) due to the stored energy depletion. For (conservative) estimation purposes here, the entire charge of 1 μC will be assumed to be emitted at full energy (6 MeV) in 20.8 nC bunches, and the beam loss power deposition profile calculated using Parmela (a tracking code that includes rf and space charge effects).

Equation (1) with $E_o \rightarrow E_o \sin(\omega_{rf} t)$ is used to derive the temporal bunch shape. This gives a significantly longer electron bunch (and consequently larger energy spread and emittance) than Fowler-Nordheim emission, the mechanism thought primarily responsible for dark current emission.

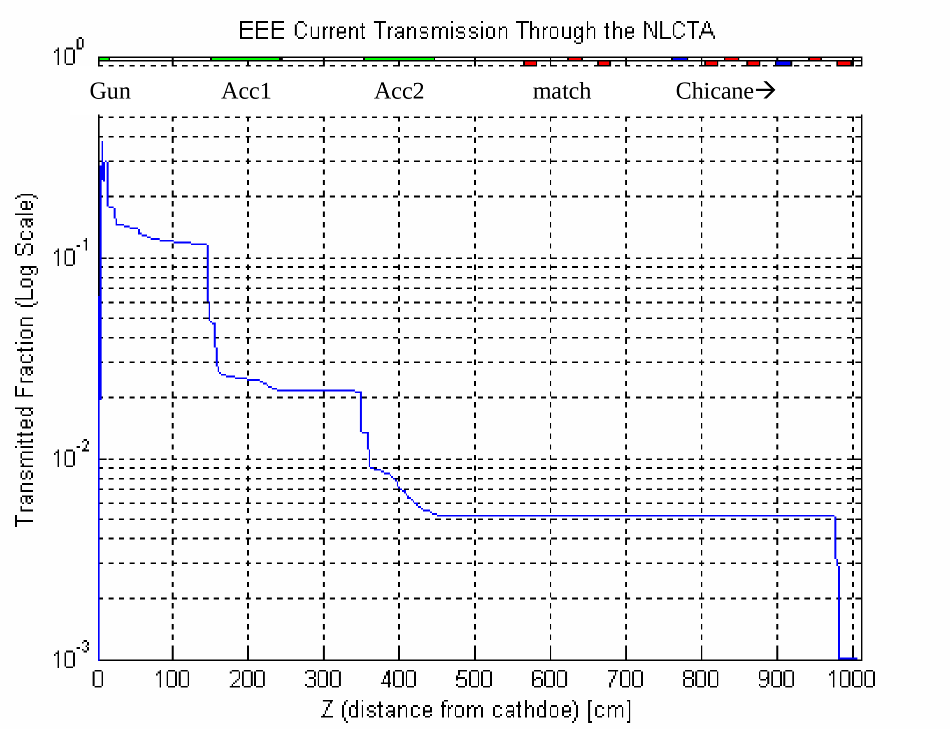


Figure 1. Transmitted fraction of EEE charge on a logarithmic scale.

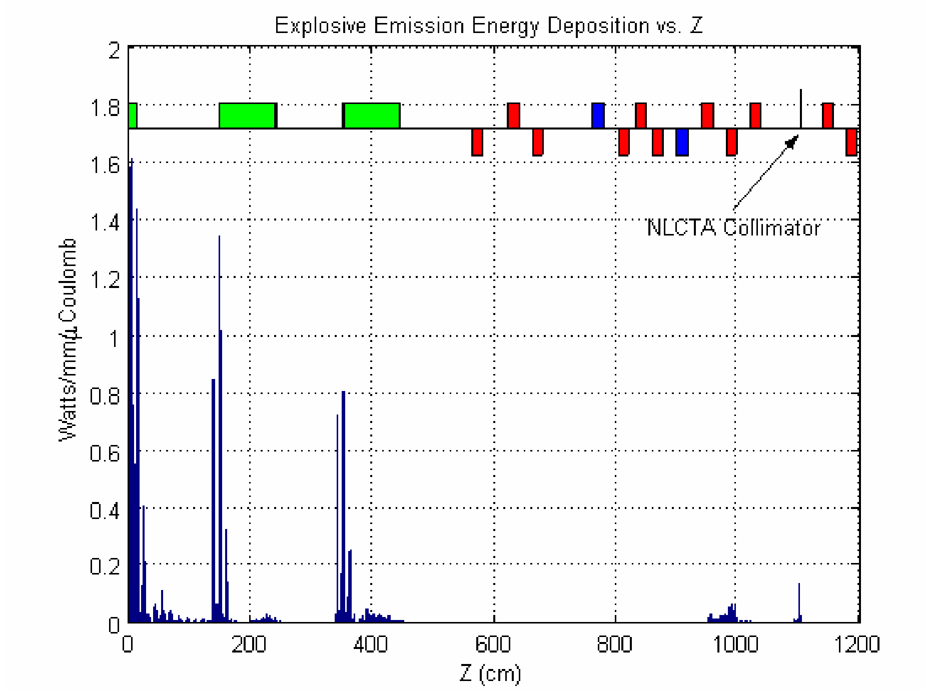


Figure 2. Deposited power along beamline. It is assumed that 1 μC total charge is emitted from the cathode surface each rf pulse at 10 Hz and that all emitted bunches experience the maximum gun field of 120 MV/m.

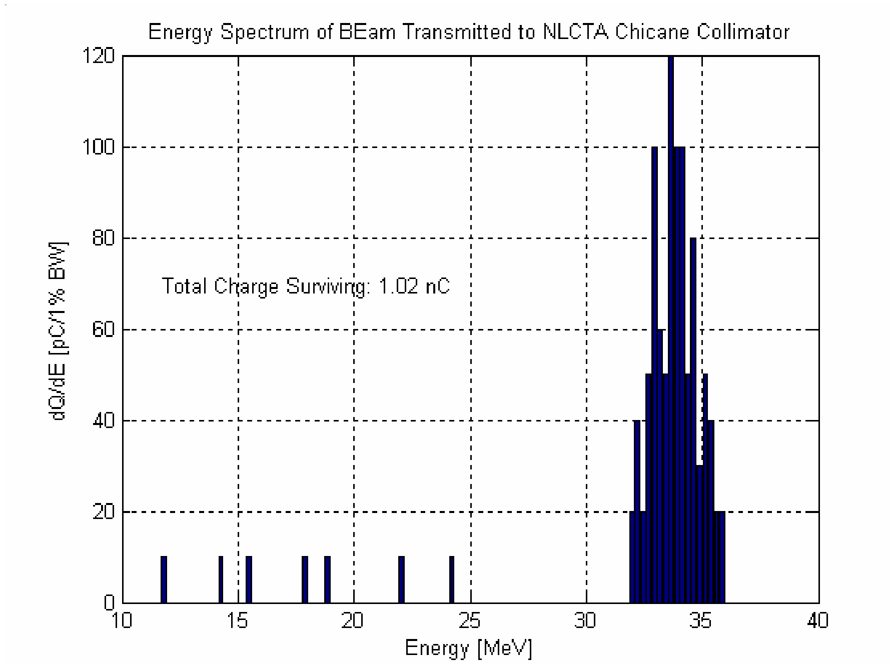


Figure 3. Energy spectrum of surviving EEE charge at the position of the NLCTA chicane collimator. The NLCTA chicane collimator will be set to a fairly narrow slit that passes ~60 MeV particles under both E163 and NLCTA HGRF testing circumstances.

From figure 1 it is clear that more than 99% of all the EEE charge produced will be intercepted in the x-band accelerators of the NLCTA injector. Figure 2 shows where the deposited power falls, with a few watts average intercepted in the first few cells of each rf structure.

From figure 3 it is clear that most of the remaining particles that are not scraped off in the accelerators have energies low enough to be lost in the NLCTA chicane, either after the first bend or two, or at the NLCTA collimator. As the NLCTA chicane and E163 dogleg have regions of substantial dispersion (0.3m and 0.7m, respectively) the large energy deviation of the transmitted bunch (~34 MeV) from the lattice setting of ~60 MeV means that the EEE beam will be far off-orbit and intercept the walls of the chicane beam pipe long before reaching the E163 extraction point.

**Conclusion**

The EEE process leads to long, large energy spread, large emittance bunches with high charge that are rapidly lost in the injector x-band accelerators and chicane. From the transmission calculations, it is anticipated that negligible EEE beam power (of the same order as the E163 photocurrent, tens of mW) will exit the NLCTA enclosure under any circumstances.

References

[1] J. Clendenin, *et al*, “LCLS Maximum Credible Beam Power”, LCLS-TN-01-2, March (2001).
[2] X.-J. Wang, *et al*, J. Appl. Phys., **72**, p. 888ff, (1992).