DEVELOPMENT OF A 1.5+0.5 CELL PHOTOINJECTOR*

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Abstract

We present the development and status of a traditional UCLA/BNL/SLAC style 1.5 cell photoinjector with an additional half cell downstream to aid in longitudinal pulse compression. The work presented includes radio frequency design via SuperFish and HFSS as well as beam dynamics simulation using PARMELA. We investigate longitudinal compression of an electron beam in this extra downstream half cell and show shorter final beam lengths at the cost of transverse beam quality, when compared with traditional 1.6 cell systems.

INTRODUCTION

The use of ultrafast electron pulses to stroboscopically image a target to obtain a "movie" of it's evolution [1, 2, 3] is a subject of great interest to physical chemists, physicists and others examining the time evolution of systems on the sub-picosecond scale. Since the time resolution of the images is ultimately limited by the length of the probing electron beam [4, 5], it is important to produce beams as short as possible. To this end several strategies have been used to compress beams including α-magnets and RF cavities [4, 6]. For the most part experiment is centered around electrons in the keV range, but recent work has been done in expanding into the MeV energy range [5, 7], the impetus for such work being the reduction of space charge forces in highly relativistic beams.

Resolution of fast processes via diffraction is split between x-rays and electrons, with electron diffraction having the distinct advantage of lower energy deposited per useful scattering event. The difference between the two methods being upwards of 1000 times less energy deposited in the case of 80-500 keV electrons when compared with 1.5 Å x-rays [8]. Energy deposition is of concern to those utilizing the pump-probe scheme of excite then examine in experiments to prevent excitation of the specimen beyond states produced by the pump laser.

The work presented here is the result of radio frequency design and beam dynamics simulation of a SLAC/BNL/UCLA style 1.6 cell gun with additional downstream half cell, the so called "guncher", named for the longitudinal bunching which occurs in the extra half cell. The beam dynamics simulation of the guncher and traditional 1.6 cell guns are compared and show that the guncher produces shorter beams at the cost of transverse beam quality.

* Work supported by Office of Naval Research grant N00014-08-1-0463 (20081884).
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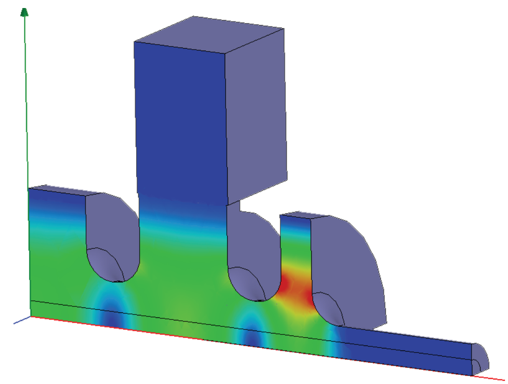

Figure 1: (Color online) HFSS plot of the electric field showing the enhanced field in the downstream half cell.

Additionally simulations were run in which the injector was characterized in the "blowout" regime, where an ultra-thin sheet of charge is allowed to expand into a uniform 3D ellipsoid [9, 10]. Results show the longitudinal focusing in the bunching cell are insufficient to reverse the natural chirp of the expanding ellipsoidal beam produced via this method. Results show insufficient beam length, for this frequency of operation, to affect significant change in the momentum spread $\frac{\delta p}{p}$.

RF DESIGN

Design began with SuperFish [11] for initial cavity shape and mode balance and proceeded to HFSS [12] for full simulation including input coupling, see Figure 1. The cavity was designed to run in the π-mode at 2.856 GHz. The input coupler was designed using a z-coupler similar to the LCLS photoinjector as opposed to the θ-coupling typical of previous UCLA designs.

The guncher offers unique challenges in that the additional half cell must be 0.5λ / 2 in field length so the physical pillbox cavity is much shorter, due to the field extending down the beam pipe. HFSS simulations show the max on iris electric field, for this particular design, is given by $\sim 10^5 \sqrt{P}$, where P is the input power. Using 100 MV/m as a maximum value of macroscopic field strength before breakdown, this results in a theoretical peak on axis field of 50 MV/m[14].

BEAM DYNAMICS

Notwithstanding the difficulties in producing a physical structure to provide 100 MV/m on axis peak field, guncher simulations were conducted at this voltage for comparison

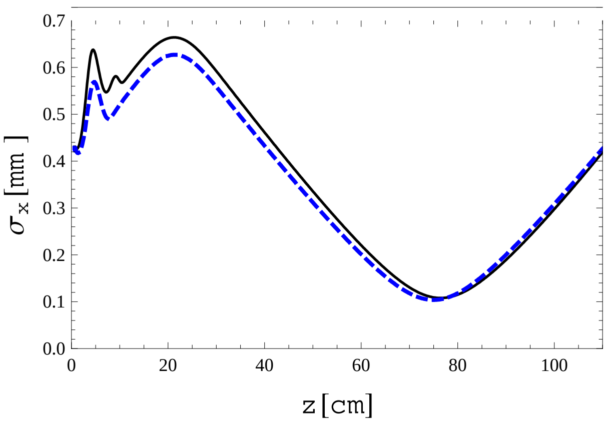

Figure 2: Evolution of the rms beam size σ_x for the guncher (black, solid line) and a traditional 1.6 cell photoinjector (blue, dashed line), from PARMELA.

with previously modeled 1.6 cell structures running at 100 MV/m.

The initial beam distribution was generated outside of PARMELA using Mathematica [13] to create a half-circle profile in r (azimuthal symmetry) [9],

$$\sigma(r) = \sigma_\circ \sqrt{1 - (\frac{r}{A})^2}, \qquad (1)$$

a Hammersley Sequence (Hammersley Point Set) in angle ϕ with respect to the x-axis and a Gaussian distribution in the z direction.

PARMELA simulations were conducted using a 10 picocoulomb, 500 femtosecond RMS, two millimeter diameter initial beam profile of 50,000 macro-particles. The beam was placed behind a virtual cathode wall and allowed to advance out where at the cathode surface a temperature of 0.46 eV was added. In both cases the beams were launched 55° before crest, with a bimodal solenoid of on axis peak field B_z=2000 G.

As shown in Fig. 2 and 5 the transverse beam size σ_x and the normalized emittance $\epsilon_{x,n}$ behave similarly, with simulation showing a small difference in emittance at the beam waist. The RMS beam length σ_z evolution, Fig. 4, shows longitudinal compression due to the momentum kick applied in the guncher's additional half cell. Results indicate that the momentum kick imparted to ellipsoidal beams, which are generated through self expansion, is insufficient to over come the natural chirp created during expansion. At the beam waist, slice energy spread σ_E ranges from .1-5 keV while the longitudinal phase space resembles the "swan" shape typical of 1.6 cell photoinjectors.

CONCLUSIONS

The guncher shows promise as a source producing beams shorter than the present standard photoinjector. By appropriate selection of the initial conditions it is possible to produce beams on the order of 50 fs RMS at the longitudinal waist [5]. It is not feasable to compress self shaped

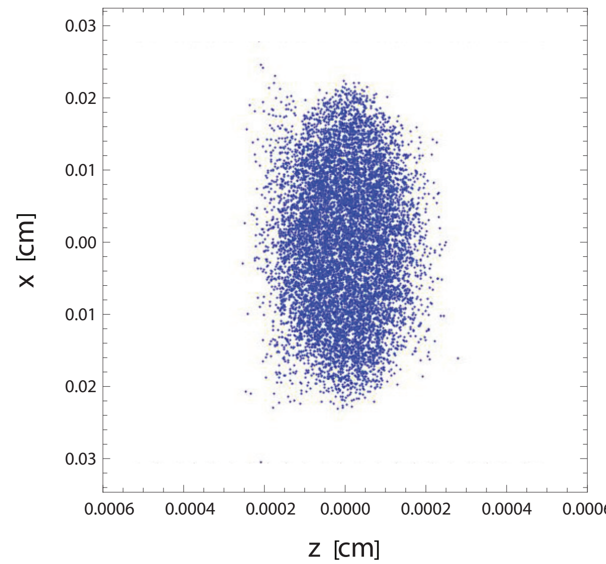

Figure 3: The Z-X beam profile at the beam waist.

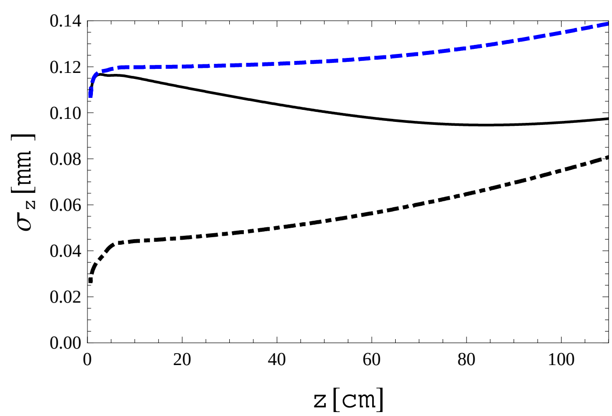

Figure 4: RMS bunch length σ_z progression in the guncher (black, solid line) and a 1.5 cell photoinjector (blue, dashed line). Simulation shows the guncher's additional half cell imparts a momentum kick which focuses the beam downstream. The dot-dashed line represents σ_z evolution for an ellipsoidal beam of initial σ_t =35fs. Results from PARMELA.

ellipsoidal beams using the guncher due to the length of the beam as it enters the final half cell, the beam is too short for adequate bunching. The ability to compress such short beams will require investigation into higher frequency devices, or an independent bunching cell.

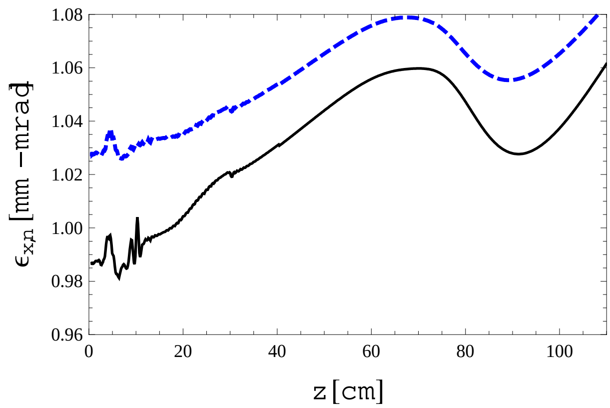

Figure 5: Transverse normalized emittance $\epsilon_{x,n}$ in the guncher (black, solid line) and a 1.6 cell gun (blue, dashed line). Results from PARMELA.

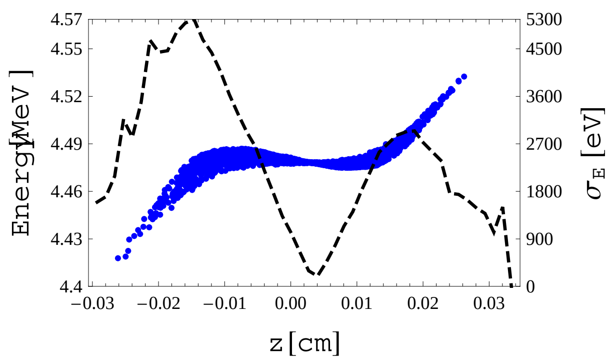

Figure 6: Representation of the longitudinal phase space of the beam at the waist near z=75 cm. Overlying the longitudinal phase space is the slice energy spread σ_E(50 slices). Results from PARMELA.

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