# DESIGN OF A VHF PHOTOINJECTOR OPTION FOR THE UK'S NEW LIGHT SOURCE PROJECT

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### *Abstract*

The injector for the UK's New Light Source project is required to deliver low emittance 200 pC electron bunches at a repetition rate of up to 1 MHz. A possible solution to these requirements is an injector based around a normal conducting VHF RF gun. The injector design and results of beam dynamics simulations are presented for cases with and without an independent buncher cavity.

## INTRODUCTION

Low emittance electron beams delivered at a high repetition rate are desired for several future FEL-based light source projects including the UK's New Light Source (NLS) [1]. Currently operational linac-based FELs such as LCLS [2] and FLASH [3] use 1½ cell pulsed normal conducting RF guns operating at the frequency of the main linac but only in single or train pulsed modes. The LCLS S-band gun has experimentally demonstrated beams with emittance values down to 0.3 mm mrad [2], however is limited in repetition rate due to cavity heating. The first stage of NLS will use an L-band RF photoinjector utilising a modified PITZ gun [1] which, according to simulations, is able deliver the beams with emittance in the range of 0.3 mm mrad. However, this gun is also unable to operate at 1 MHz CW as desired by the science case for the project.

Four injector options were considered as potentials to deliver 1 MHz CW. Thermionic cathode based injectors were ruled out despite recent advances at SCSS [4], they have so far been unable to provide short bunches, low emittance, and high repetition rate simultaneously. High voltage DC photocathode guns were ruled out because they are unable to deliver the low emittance required since the maximum achievable field strength on the photocathode is limited to less than 5 MV/m, due to parasitic field emission from high voltage electrodes. The two remaining options were an L-band superconducting RF gun, as described elsewhere [5] and a low frequency, normal-conducting RF gun based injector, as described here.

## VHF GUN

A design of a high repetition rate normal conducting VHF gun has been proposed by LBNL [6]. A normal conducting copper cavity is driven with a frequency of 187 MHz that allows the gun to deliver bunches over a broad range of repetition rates, varying from a few Hertz to the driving frequency. The cavity is based on mature normal conducting technology but demands a dedicated RF power supply. The total RF power required for acceleration of the beam to 750 keV is about 100 kW. This corresponds to a maximum field strength on the cathode of 20 MV/m. Operation at relatively low frequencies allows reduction of the power density dissipated in the cavity walls to 10 W/cm$^2$, which significantly simplifies the cooling system.

The gun can use a broad range of photocathodes ranging from metal and $Cs_2Te$, to $K_2CsSb$ or similar alkali-antimonide structures. Use of antimonide based photocathodes, which operate at a wavelength of 532 nm, require extra high vacuum, provided by a combined pumping system which comprises of an ion pump and an array of NEG strips installed on the periphery of the gun cavity. Use of $Cs_2Te$ photocathodes operating at 266 nm is also under consideration but its performance is restricted by the maximum average laser power of 1 W available at present.

## INJECTOR DESIGN WITH BUNCHER

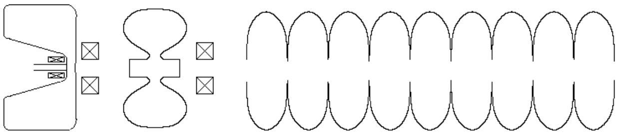

Figure 1: Schematic of the injector featuring a dedicated buncher cavity and second solenoid. The first of eight linac cavities is shown.

A design of a VHF gun based injector for NLS is shown in Fig. 1. A solenoid after the gun is required for emittance compensation and transverse focusing, and a bucking coil is needed to zero the magnetic field on the cathode. Since the emitted bunch is expanding longitudinally after the gun because of low cathode field strength, a dedicated buncher cavity can be used to reduce the bunch length. A second focusing solenoid is then needed to match the beam into the main linac. This arrangement is similar to that of DC gun based photoinjectors - the low frequency of the gun RF means that the beam essentially sees a high gradient DC field.

The beamline shown in Fig. 1 was simulated in ASTRA [7] with 100,000 macroparticles up to the end of the first linac module. The evolution of beam parameters shown in Fig. 3 and the final profiles of the 200 pC bunch shown in Fig. 4. A single-cell normal conducting buncher cavity operating at 1.3 GHz was used. Previous simulations [8] show no difference in using a subharmonic, such as 650 MHz, buncher. These simulations use a laser pulse with a 2 mm diameter flat-top transverse profile and a 90 ps flat-top temporal profile with rise and fall times of 2 ps. Initial thermal energy of 0.7 eV was included in the simulation, which corresponds

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to that of $Cs_2Te$ photocathodes, as this type of photocathode is able to deliver the 200 µA average current required for NLS and very likely will be used in the photoinjector. Previous simulations [8] have shown the effect of differing thermal emittance of final projected emittance. The long laser pulse length was chosen in order to keep the slice emittance low, with an average of 0.64 mm mrad. The beam has been bunched from the initial 90 ps down to just under 33 ps full width, however, the temporal current profile is far from flat, with an rms of 7.8 ps. The beam energy after the first linac module is 124 MeV with the gradients and phases in the first of eight TESLA cavities of the accelerating module chosen to minimise emittance whilst keeping a short bunch length. The first cavity thus operates at 10 MV/m with a phase of -20°. The remaining cavities are set to provide an average accelerating gradient of 15 MV/m and to leave no residual energy chirp.

## NO BUNCHER INJECTOR DESIGN

As an alternative to using a buncher cavity, the beam from the gun can be directly injected into the first cavity of main linac, following a solenoid, as shown in Fig. 2. Due to the lack of buncher cavity, the laser pulse duration was reduced to a 30 ps flat top (with 2 ps rise and fall times). Because the beam is not fully relativistic after the gun, the bunch length is still expanding. In order to compensate this lengthening, the first cavity of the linac is operated off-crest to restore the bunch length to the original 32 ps but with an rms of 7.9 ps due to a non-flat temporal profile. A phase of -40° is used in this simulation to keep the bunch length to that of the laser pulse. Operating even further from crest would cause the emittance to increase and the current profile to become highly peaked towards the head of the bunch. The slice emittance is higher than in the case with a buncher cavity, at an average of 0.74 mm mrad. The rest of the bunch properties look similar, with a smoother current profile. Fig. 4 shows the final distribution of the 200 pC bunch after being accelerated to 120 MeV, from an ASTRA simulation of 100,000 macroparticles and Fig. 3 shows how the beam parameters evolve along the beamline. The removal of the buncher and second solenoid remove elements introducing significant jitter and since the beam properties and time of flight are very sensitive to the buncher settings, the no buncher scheme is preferable, despite the increased emittance.

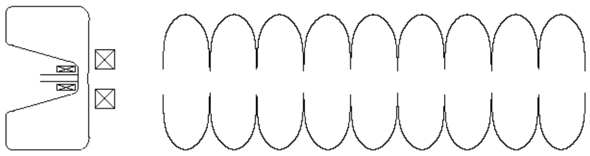

Figure 2: Schematic of the injector without a buncher cavity. The first of eight linac cavities is shown.

## SIMULATION RESULTS

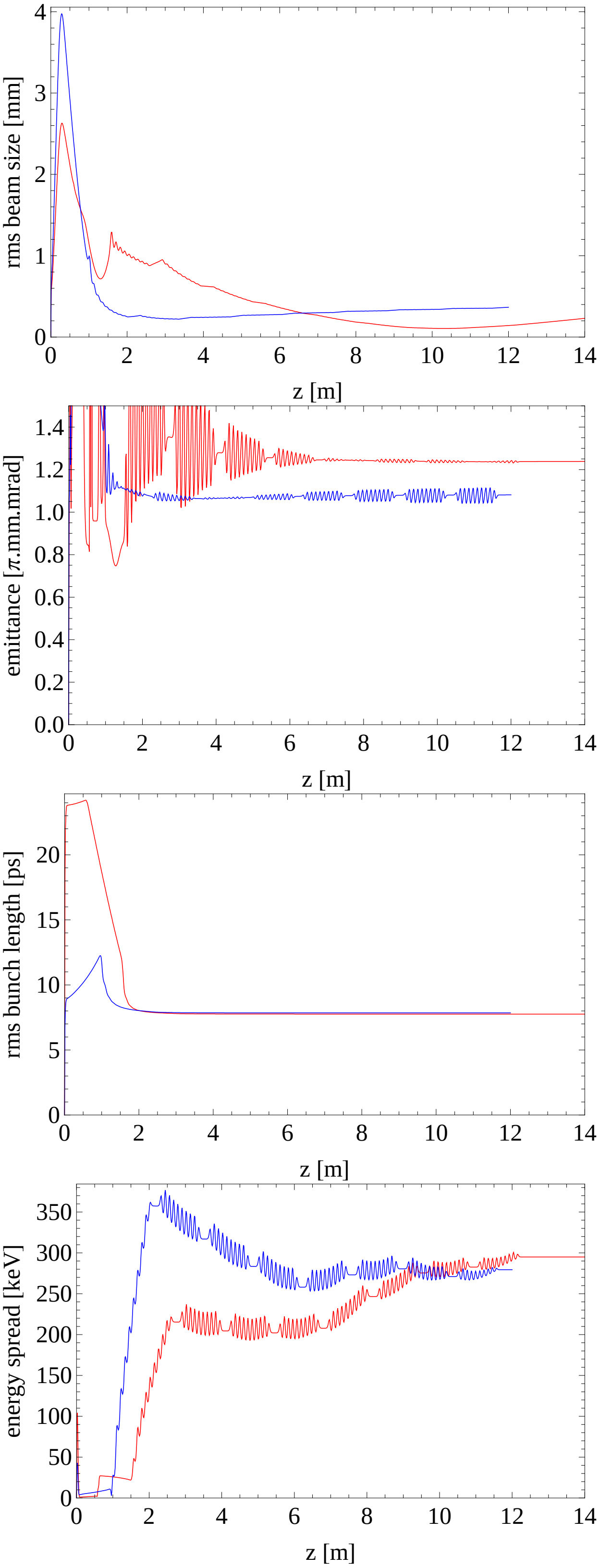

Figure 3: Evolution of beam parameters for the buncher (red) and no buncher (blue) schemes.

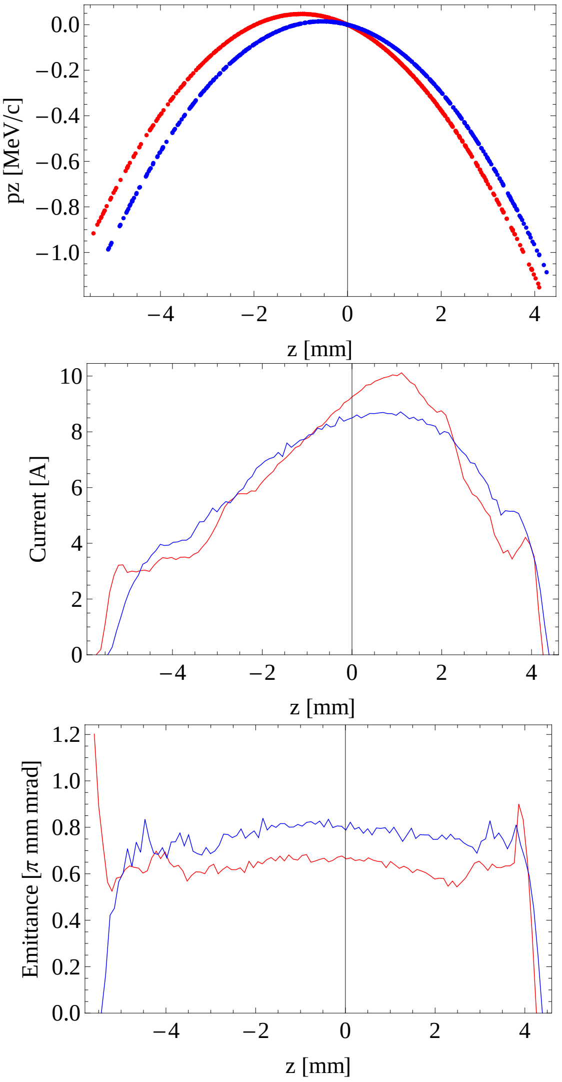

Figure 4: Evolution of beam parameters for the no buncher scheme.

## SUMMARY

A normal-conducting VHF gun based injector is possible to achieve high repetition rates, however, because of relatively low cathode field strength, cannot deliver the low slice emittance of S- and L-band guns, either normal or superconducting, which is down to 0.3 mm mrad. Starting with a long laser pulse and with subsequent reduction in bunch length down to 7.8 ps rms with a dedicated buncher cavity, slice emittance of 0.64 mm mrad is achievable. However, this buncher cavity adds complication to machine setup and operations and introduces significant jitter. A scheme where the VHF gun injects directly into the main TESLA linac modules is viable with only slightly increased bunch length of 7.9 ps rms and increased slice emittance of 0.74 mm mrad. Table 1 summarises the simulated final properties of the electron beam produced by both schemes.

Table 1: Beam parameters at the exit of the injector with (A) and without (B) a dedicated buncher cavity.

| Parameter | Units | A | B |
|---|---|---|---|
| RMS projected emit. | mm mrad | 1.239 | 1.081 |
| Average slice emit. | mm mrad | 0.642 | 0.736 |
| Full bunch length | ps | 32.86 | 32.45 |
| RMS bunch length | ps | 7.80 | 7.87 |
| RMS longitudinal emit. | keV mm | 662 | 651 |
| RMS energy spread | keV | 295 | 278 |
| Average kinetic energy | MeV | 124.1 | 123.1 |

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] "NLS Project: Science Case & Outline Facility Design", available at http://www.newlightsource.org.
[2] P. Emma, "First lasing of the LCLS X-Ray FEL at 1.5 Å", proceedings of PAC 2009.
[3] K. Honkavaara et al., "Status of FLASH", proceedings of FEL 2008.
[4] K. Togawa et al., "Emittance measurement on the CeB6 electron gun for the Spring-8 compact SASE source", proceedings of FEL 2004.
[5] J.W. McKenzie & B.L. Militsyn, "Initial design of a superconducting RF photoinjector option for the UK's New Light Source project", these proceedings
[6] F. Sannibale et al., "Status and plans for the LBNL normal-conducting CW VHF photo-injector", proceedings of FEL 2009
[7] K. Flötmann, ASTRA homepage, http://www.desy.de/~mpyflo.
[8] J.W. McKenzie & B.L. Militsyn, "VHF high repetition rate photoinjector design for the NLS project", proceedings of FEL 2009.