# VELA (FORMERLY EBTF) SIMULATIONS AND FIRST BEAM COMMISSIONING

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## *Abstract*

VELA (Versatile Electron Linear Accelerator), formerly known as EBTF (Electron Beam Test Facility), at STFC Daresbury Laboratory, is a photoinjector test facility which will provide beam into two user areas for scientific and industrial applications. It is based on a 2.5 cell S-band RF photoinjector driven by a Ti:Sapphire laser. The design is aimed to deliver short bunches at 10-250 pC charge with low transverse emittance to two user areas. We present updated beam dynamics simulations of VELA and show results from first beam commissioning.

## VELA

VELA (Versatile Electron Linear Accelerator), formerly known as EBTF (Electron Beam Test Facility) is a 6 MeV electron accelerator designed to provide low emittance, short pulse beams to two user stations [1]. It will also act as the front end for the proposed FEL test facility CLARA [2]. Fig. 1 shows the layout of VELA. A high quality diagnostics suite allows full 6D characterisation of the beam delivered from the photoinjector. The achievable beam parameters to user areas were previously presented [3] with assumptions made to the photoinjector laser properties. These have since been measured and the beam dynamics re-optimised.

## PHOTOINJECTOR

The electron source for VELA is a 2.5 cell S-band normal conducting RF gun with coaxial coupler originally designed for the ALPHA-X project [4]. A solenoid surrounds the gun cavity with a bucking coil to zero the magnetic field on the cathode plane. The design gradient is 100 MV/m, which equates to a maximum beam energy of 6.5 MeV. For all simulations, an intrinsic transverse emittance from the copper photocathode is included as per LCLS measurements of 0.9 mm mrad per mm rms of a flat-top laser spot [5].

The gun is driven by frequency-tripled Ti:Sapphire laser system with a pulse energy of 2 mJ at 266 nm. For simulations, a laser diameter of 1 mm and a measured Gaussian longitudinal laser profile of 76 fs rms have been used. This short pulse length allows the gun to operate in the so-called "blow-out" regime, where the bunch length expands due to space-charge. A 250 pC bunch expands to 1.3 ps rms during acceleration in the gun and then further expands after the gun as there are no following accelerating sections. VELA will operate at a range of bunch charges up to 250 pC. Beam dynamics simulations were carried out in both ASTRA and GPT to take into account space-charge.

## BEAM DIAGNOSTICS

The front end of VELA has been designed as a photoinjector diagnostics suite to fully characterise the bunches in 6D phasespace. A number of YAG screens and slits will be used to characterise the beam transversely. Characterising the beam longitudinally is more challenging. A dipole and YAG screen can be used as a simple energy spectrometer. Bunch length can be measured using a Transverse Deflecting Cavity (TDC) to streak the longitudinal position of the particles onto the transverse plane, thus making it viewable on the YAG screen. Furthermore, if the streak is performed in the vertical plane, then passing the beam around the horizontal spectrometer dipole will make the longitudinal phase-space directly viewable on the screen. Combining the TDC with the transverse beam diagnostics will allow time-sliced emittance measurements to be made. Details of the cavity design can be found in [6] and beam dynamics through it in [7].

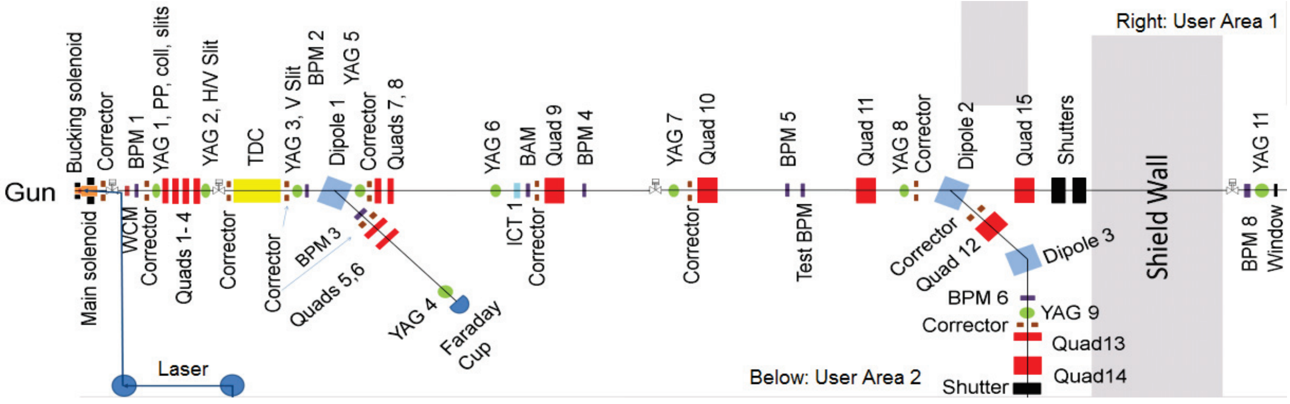

Figure 1: Schematic of VELA.

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## TRANSPORT TO AREA 1

After the diagnostics section, a long straight beamline transports the beam into User Area 1, located at 17 m from the cathode. Initial tracking was done without quadrupoles to set the longitudinal phasespace of the bunch. However, it was found that the solenoid settings have more effect on the final bunch length in VELA than the phase of the RF gun. This was not obvious when looking at the beam straight after the gun or in the diagnostics section, but only when tracking to the user areas, see Fig. 2 and 3 for the 250 pC case.

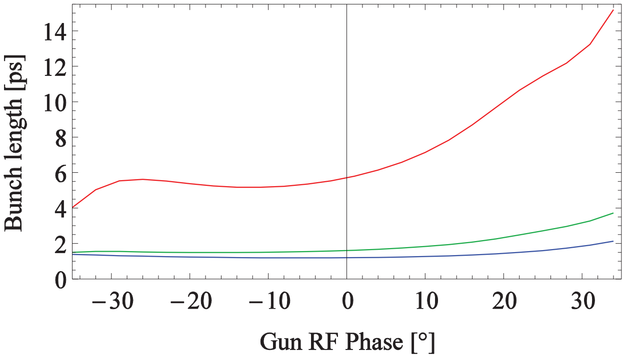

Figure 2: Bunch length as a function of gun phase for a 250 pC beam at distances from the cathode of 1 m (blue), 3 m (green), and 17 m (red).

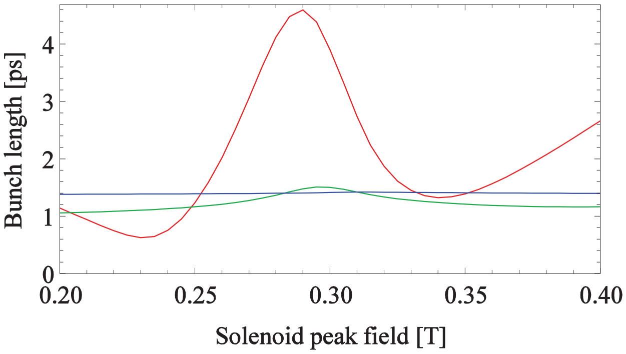

Figure 3: Bunch length as a function of solenoid field for a 250 pC beam at distances from the cathode of 1 m (blue), 3 m (green), and 17 m (red).

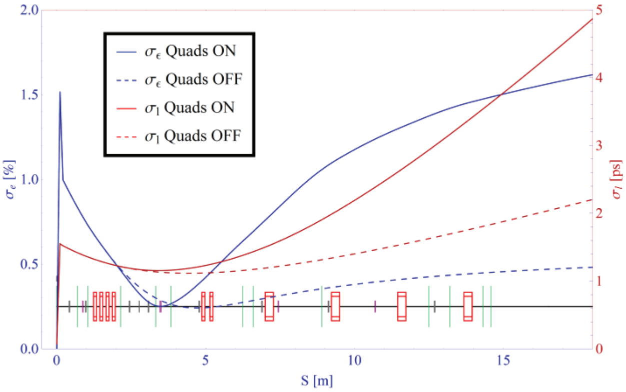

Figure 4: Evolution of bunch length (red) and energy spread (blue), with (solid) and without (dotted) quadrupoles to Area 1.

This indicates that the space charge forces resulting from transversely focussing the beam act to blow up the beam longitudinally, thus the transverse and longitudinal dynamics are not decoupled. Without quadrupoles, the solenoid can be used to control the bunch length in the user area to a similar level as it is in the diagnostics section. However, when quadrupoles are used to control the transverse beam size, the bunch length increases again, see Fig. 4. As such, the quadrupoles have been set to not focus tightly throughout the transport line, as shown in Fig. 5.

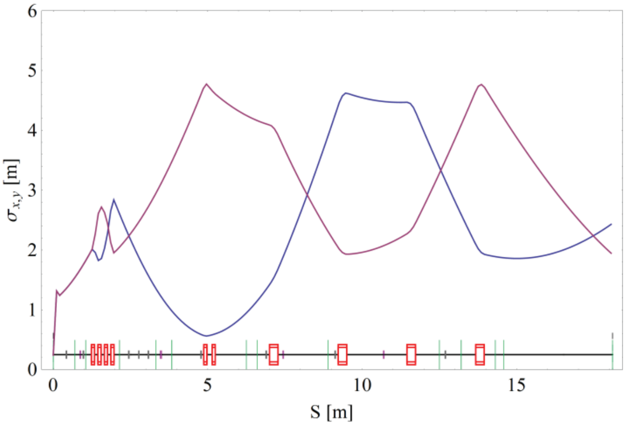

Figure 5: Evolution of transverse rms beam sizes for a 250 pC bunch to Area 1.

Because the beam is space-charge dominated at low energy, the behaviour is completely different at low and high charge operation, and the machine has to be re-tuned for each operating bunch charge. Fig. 6 shows the transverse beamsizes, bunch length and energy spread for a 10 pC bunch. Simulations are shown for a gun field strength of 100 MV/m giving a 6.5 MeV beam.

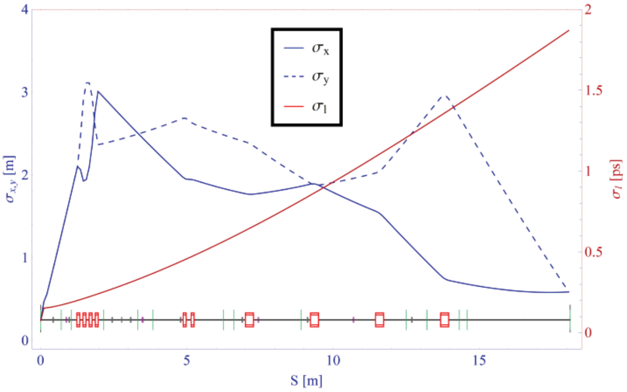

Figure 6: Evolution of transverse rms beam sizes (blue) and bunch length (red) for a 10 pC bunch to Area 1.

## TRANSPORT TO AREA 2

The beam is directed into User Area 2 with a double bend achromat forming a 90° turn. Fig. 7 shows the transverse beam sizes for the 250 pC case with the gun operating at 100 MV/m. This achromat also acts as a longitudinal compression system. For low bunch charges it reduces the bunch length similar to that which it was in the diagnostics section (Fig. 8 shows a 10 pC case), but in the high space-charge regime of 250 pC, (as shown in Fig. 9) the beam still continues to expand after the compression.

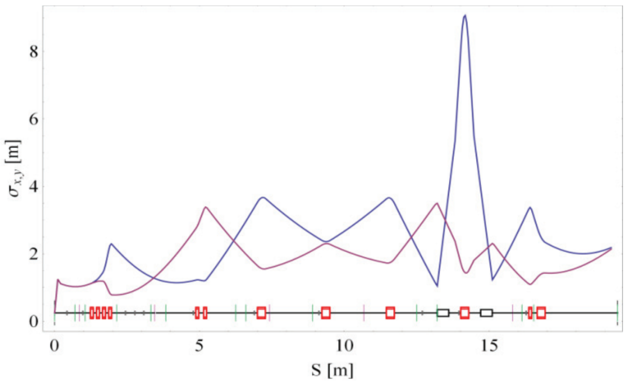

Figure 7: Horizontal (blue) and vertical (purple) rms beamsizes for a 250 pC bunch transported to Area 2.

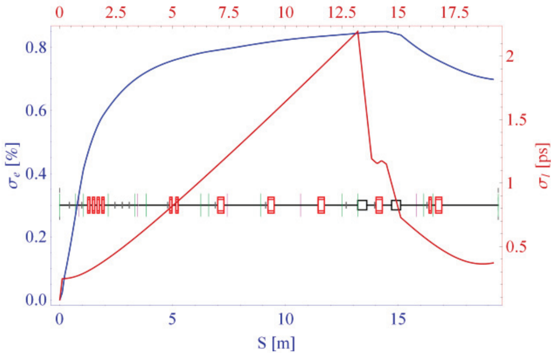

Figure 8: Bunch length (red) and energy spread (blue) for a 10 pC bunch to Area 2.

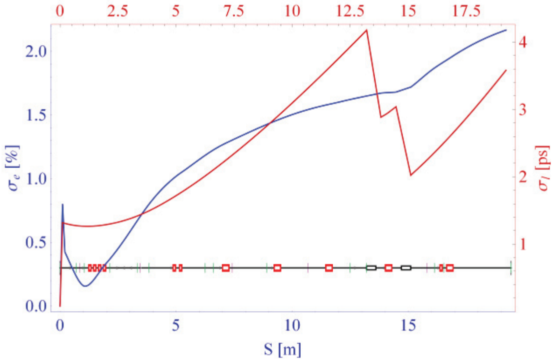

Figure 9: Bunch length (red) and energy spread (blue) for a 250 pC bunch to Area 2.

## FIRST BEAM COMMISIONING

The VELA project was launched in August 2011 with the aim for first electrons to be delivered in December 2012.

Gun RF conditioning took part in two stages, in December 2012, and in early 2013, with breaks to replace faulty RF windows. Full details can be found in [8]. The klystron allows for a peak power of 10 MW. For first beam commissioning, the gun was conditioned up to 5.7 MW of forward power in the cavity, and operated at 5 MW with a 2 μs pulse width. This equates to a field strength in the gun of 70 MV/m and a maximum beam energy of 4.5 MeV.

For first beam commissioning the beamline was terminated with a Faraday cup installed in place of the TDC. Most of the photoinjector laser transport was done in air, however, for full operation the transport will be largely *in vacuo* with beam focussing achieved using mirrors instead of refractive optics.

First beam was demonstrated in early April 2013. Images of the beam on the first YAG screen and Faraday cup trace are shown in Fig. 10. A bunch charge greater than 170 pC was measured on the temporary Faraday cup. This saturated the electronics, which were set for high sensitivity to monitor first beam and dark current.

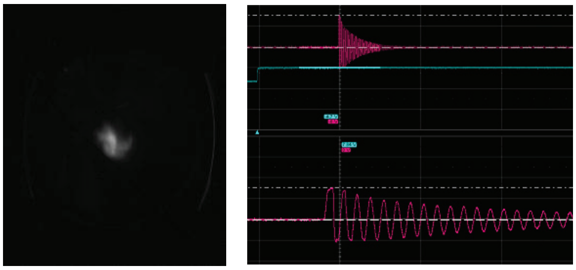

Figure 10: First beam on the YAG screen (left) and Faraday Cup (right).

## CONCLUSIONS

First beam from the VELA photoinjector was achieved from the RF gun in April 2013. VELA will be a photoinjector test facility with an advanced beam diagnostics suite and will provide beam into two user areas for scientific and industrial applications. Example simulations have been presented for beam transport at both 10 and 250 pC to both user areas. Flexibility exists to tune bunch parameters to suit user requirements.

## ACKNOWLEDGMENTS

The authors would like to acknowledge the VELA team, TDC design team, and ALPHA-X collaborators.

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