3D Modeling of the ALICE Photoinjector Upgrade

J.W. McKenzie, B.L. Militsyn, Y.M. Saveliev

STFC Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom

Abstract. The injector for the ALICE machine (Accelerators and Lasers In Combined Experiments) at Daresbury Laboratory is based around a 350 kV DC photocathode electron gun. An upgrade is proposed to introduce a load-lock GaAs photocathode preparation facility to allow rapid transfer of photocathodes to the gun without breaking the vacuum system. In the current design this requires side-loading of the photocathodes into the cathode ball. An alternative is to relocate the ceramic insulator vertically which will allow back-loading and also back-illumination of the photocathodes. 3D electrostatic simulations of the gun chamber are presented for both options along with 3D beam dynamic simulations for an off-axis photocathode, introduced to increase photocathode lifetime by reducing damage by ion back-bombardment. Beam dynamic simulations are also presented for the entire injector beamline as well as for a proposed extension to the injector beamline to include a diagnostic section.

Keywords: Electron sources; linear accelerators; electron and positron beams
PACS: 29.25.Bx; 29.20.Ej; 41.75.Fr

INTRODUCTION

ALICE is a 35 MeV energy recovery linac undergoing commissioning at Daresbury Laboratory [1]. The injector is based around a 350 kV DC photocathode gun which is a modified version of the gun developed for the Jefferson Laboratory Infra-Red FEL [2]. Electron bunches with charge 80 pC are produced from a GaAs photocathode illuminated by laser pulses of wavelength 532 nm. Currently the photocathodes are activated *in situ* in the gun chamber by means of a Cs and NF_3 or O_2 "yo-yo" procedure. Replacing the photocathode takes weeks due to the requirement to break the vacuum, replace the photocathode, and then restore the vacuum to the operational level of 10^{-11} mbar. An upgrade is planned to introduce an external load-lock photocathode preparation facility to reduce changeover downtime to a matter of hours [3]. Details of this three-chamber design can be found in [4]. This facility will use new GaAs photocathodes currently under development [5], with a reduction in diameter from 25 mm, as currently used in ALICE, to 10 mm.

SIDE-LOADING GUN OPTION

It is proposed that the photocathodes are loaded from the preparation chamber into the side of the gun, in order to avoid disruption to the existing ALICE infrastructure. This involves a re-design of the cathode ball from the present rear-loading mechanism. The ball requires a slot in the side for loading of the photocathode. This has been positioned on the cylindrical part of the ball surface to keep the field distortion low. The photocathode then has to be moved forward into position, requiring a second slot further back in the cathode ball for insertion of a magnetic screwdriver to drive the winding mechanism. A third slot, perpendicular to the loading slot, might be required as a viewport to ensure the photocathode is loaded properly. Figure 1 shows the electric fields at 350 kV on the cathode ball surface, modelled in CST Studio [6]. The electric field has been kept lower than 10 MV/ on the curved surface of the ball and also around the edges of the slots. A focussing electrode has been added and optimised by performing beam dynamic simulations in ASTRA [7]. Figure 2 shows that the transverse beam properties for the new gun design compared to the existing gun which lacks the focussing electrode.

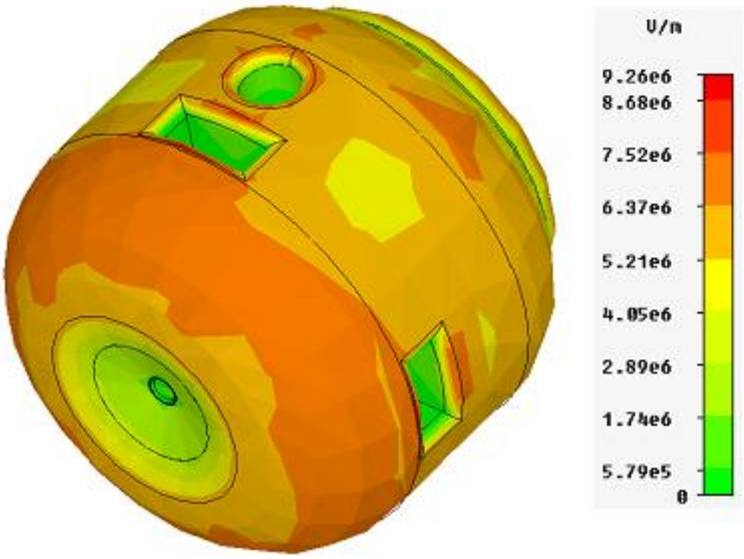

FIGURE 1. The cathode ball with slots and focusing electrode showing electric fields.

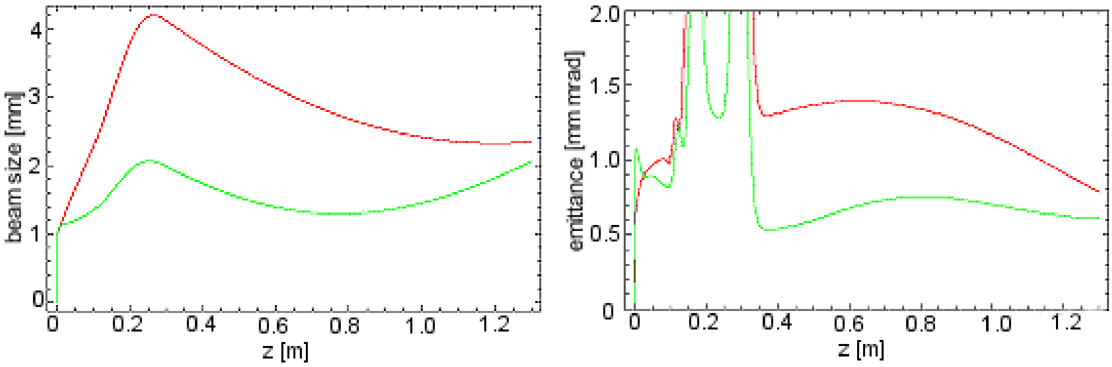

FIGURE 2. RMS beam size (left) and transverse emittance (right) for the new gun design (green) compared to the current gun (red) including a 330 G solenoid at 0.25 m.

VERTICAL CERAMIC GUN OPTION

As an alternative to the side-loading design, the ceramic insulator can be relocated vertically to allow back-loading of the photocathodes. This would also allow back-illumination of transmission-mode photocathodes and should be more mechanically stable. However, this requires relocation of the gun power supply and ancillary equipment. Electrostatic simulations have been performed using CST Studio, shown in figure 3. The cathode stem introduces a vertical component of electric field along the electron beam trajectory, peaking at 1.5 kV/m. This is small compared to the peak of the longitudinal electric field of 5 MV/m. 3D fieldmaps were extracted and used in GPT [8] to perform particle tracking simulations with space charge. These show that the vertical field displaces the beam by an almost negligible amount.

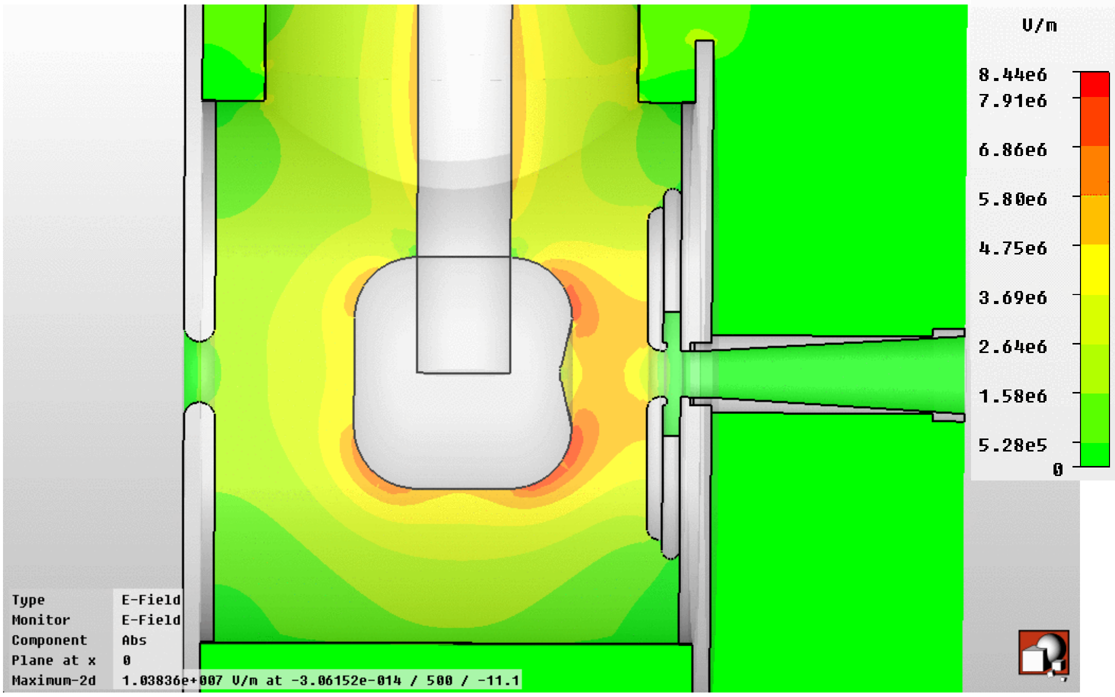

FIGURE 3. Electric fields in the gun chamber for the vertical ceramic design at 350 kV.

OFF-AXIS BEAM TRANSPORT

The lifetime of photocathodes is a major issue for regular operation of photoelectron guns. The principle cause of photocathode degradation is ion back-bombardment. When the gun is in operation, ions are produced by collision of the electron beam with residual gases and accelerated directly back towards the cathode. These ions acquire a large acceleration but little transverse displacement. Therefore, citing the photocathode off-centre should result in fewer ions striking the photocathode surface, thus increasing the photocathode lifetime. One method currently in use is to direct the drive laser off-centre on the photocathode [9]. When designing a new gun, two further options present themselves - situating the photocathode off-centre on the cathode ball, or situating the whole cathode ball off-axis. Previous GPT simulations [10] show that for the offset ball, the electron beam still moves parallel to the optical axis, thus ion damage should remain the same, whereas the off-centre photocathode produces a beam which moves directly away from the photocathode. Both horizontal and vertical steering coils are placed around the beampipe at the same position as the solenoid and simulations in GPT show that these can be used to steer the beam parallel to the beampipe whilst retaining an emittance of 1 π mm mrad, as can be seen in figure 4.

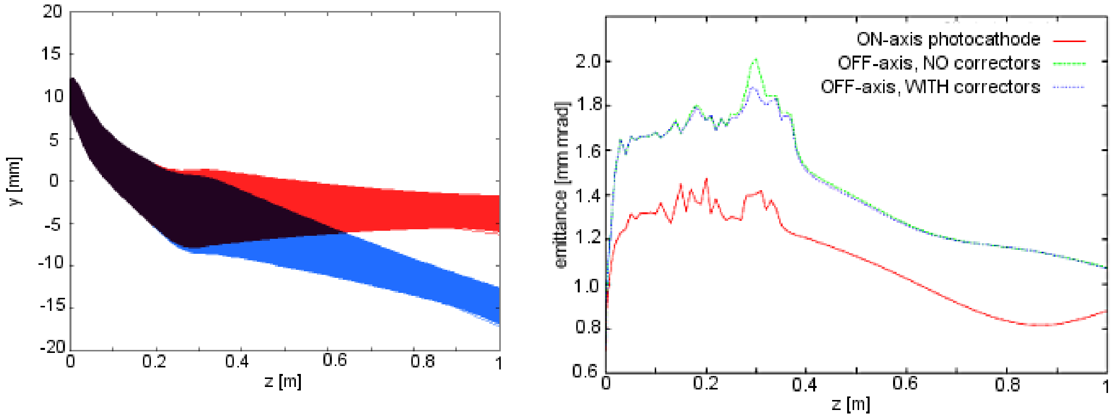

FIGURE 4. (a) Particle trajectories for a 10 mm off-centre photocathode including a 300 G solenoid both with (blue) and without (red) steering coils. **(b)** Transverse emittance for the off-centre photocathode compared to the on-axis version.

GUN BEAMLINE UPGRADE

During the ALICE gun commissioning phase a dedicated diagnostic beamline was used to characterize the beam. For the commissioning and operation of the full ALICE machine, this was removed, leaving just two focusing solenoids, three sets of steering coils, a buncher cavity, and a single YAG screen before the superconducting booster cavity. An extension to the current gun beamline is proposed to reinstate some diagnostics. The layout is shown in figure 5.

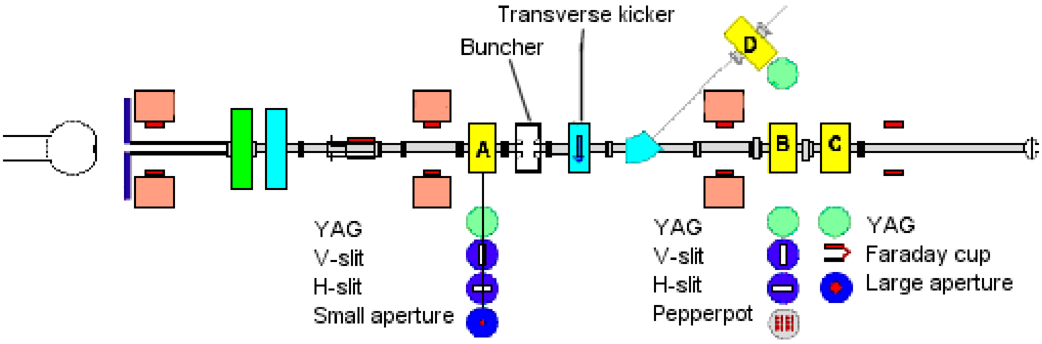

FIGURE 5. Schematic of the gun beamline upgrade showing components in each diagnostic unit.

A RF transverse kicker and dipole leading to a YAG screen orientated above the gun beamline will allow for longitudinal profile, energy, and bunch length measurements. A pair of horizontal and vertical slits plus a pepperpot provide the ability for emittance measurements and an insertable Faraday cup will be used for measuring the bunch charge. Two apertures are included: one small (~1 mm) to give the option of operating ALICE at low bunch charges without having to reset the setup of the photocathode gun; and one larger aperture to cut off any halo that may be produced along with the core beam. The positions of the first diagnostic unit, buncher and second solenoid have been reversed from the initial gun beamline in order to perform measurements with the solenoid switched on. An additional solenoid and set of steering coils are needed to provide good beam transport into the booster module for this extended beamline. The total additional length of the beamline is 1.2 m which involves moving the entire gun and power supply systems backwards. The extra length of this beamline means that there is a smaller range of parameters for good beam transport. Figure 6 shows the results of beam dynamics simulations performed using ASTRA, compared to the existing injector design. They show that although there is an increase in transverse emittance, there is a decrease in both bunch length and longitudinal emittance which combined with the benefit of the added diagnostics, will improve the operation of the ALICE facility.

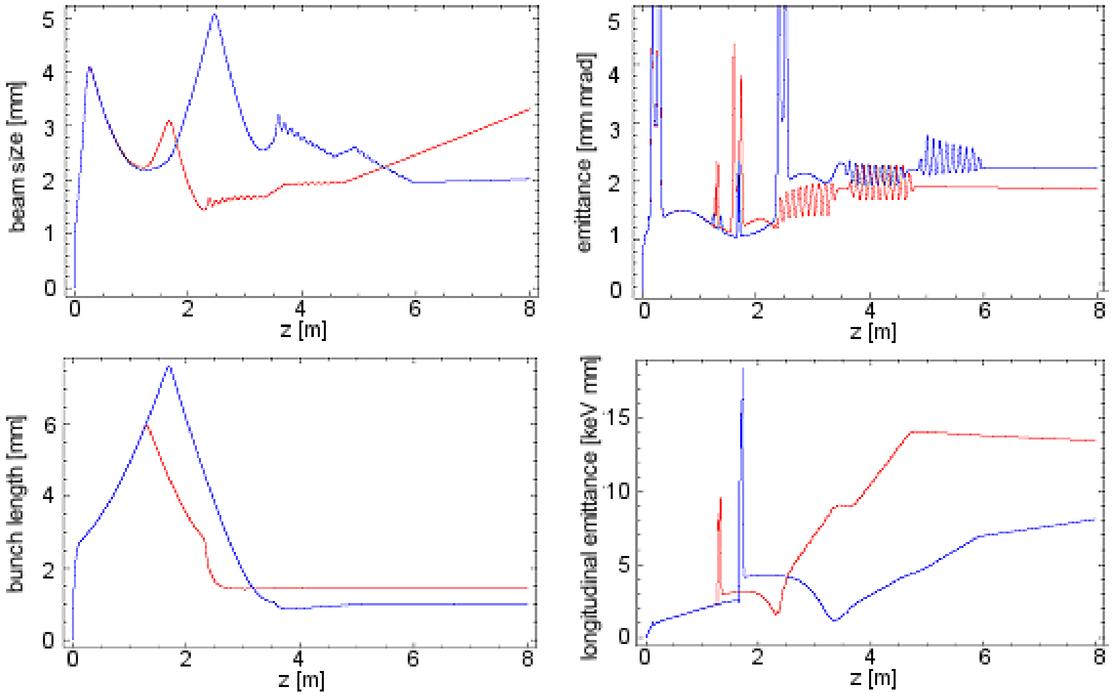

FIGURE 6. Beam dynamic simulations comparing the current gun beamline (red) with the upgraded beamline design (blue).

REFERENCES

1. L.B. Jones et al., *"Status of the ALICE Energy Recovery Linac"*, these proceedings
2. T. Siggins *et al.*, *"Performance of a DC GaAs photocathode gun for the Jefferson lab FEL"*, NIM A 475 (2001) 549-553
3. B.L Militsyn et al., *"Design of an upgrade to the ALICE photocathode electron gun",* Proceedings of EPAC 2008
4. K.J. Middleman et al., *"Photocathode preparation system for the ALICE photoinjector"*, these proceedings
5. L.B. Jones et al., "*Cooled transmission–mode NEA–photocathode with a band–graded active layer for high brightness electron source"*, these proceedings
6. CST Studio Suite, http://www.cst.de
7. K. Flöttmann, ASTRA, http://www.desy.de/~mpyflo
8. M.J. de Loos and S.B. van der Geer, General Particle Tracer, http://www.pulsar.nl/gpt
9. C. Hernandez-Garcia et al., *"A high average current DC GaAs photocathode gun for ERLs and FELs"*, Proceedings of PAC 2005
10. J.W. McKenzie and B.L. Militsyn, *"3D simulations of a non-axisymmetric high average current DC photocathode electron gun"*, Proceedings of EPAC 2008