EXTENDED ALICE INJECTOR

J.W. McKenzie*, B.D. Muratori, Y.M. Saveliev, STFC Daresbury Laboratory, WA4 4AD, UK

Abstract

Results of designing of the extended ALICE injector with the aim to include a special dedicated diagnostic line are presented. The purpose of the diagnostic line is to characterise the low energy beam, before it enters the booster, as much as possible. A key component of the ALICE is the high brightness injector. The ALICE injector consists of a DC photocathode gun generating ~ 80 pC electron bunches at 350 keV. These bunches are then matched into a booster cavity which accelerates them to an energy of 8.35 MeV. In order to do this, three solenoids and a single-cell buncher cavity are used, together with the off-crest of the first booster cavity where the beam is still far from being relativistic. The performance of the injector has been studied using the particle tracking code ASTRA.

INTRODUCTION

ALICE is a 35 MeV energy recovery linac at Daresbury Laboratory based on 1.3 GHz superconducting RF technology [1]. The injector is based around a 350 keV DC photoelectron gun which is a modified version of that designed for the Jefferson Laboratory Infra-Red FEL [2]. This is a 350 kV DC gun using GaAs photocathodes. These are currently activated *in-situ* in the gun chamber with Cs and O_2 or NF_3 in a “yo-yo” procedure. The photocathodes are illuminated by a mode locked $Nd:YVO_4$ laser frequency doubled to 532 nm [3]. This provides 7 ps FWHM pulses at a repetition rate of 81.25 MHz. A pulse stacker is used to generate 28 ps pulses. The pulse train length can be varied from a single bunch up to 100 μs with a train repetition rate of 20 Hz. The nominal bunch charge is 80 pC with a corresponding average train current of 6.5 mA.

INJECTOR LAYOUT

The layout of the current injector beamline is shown in the top of Figure 1 (with the booster line replacing the diagnostics). Directly following the gun is a solenoid and a pair of steering coils. A second pair of steering coils precedes a normal conducting 1.3 GHz single cell buncher cavity. There is then a single YAG screen to view the beam before a second solenoid with steering coils focuses the beam into the superconducting booster linac. This consists of two 9-cell tesla-type cavities, operated at 1.3 GHz, which accelerate the beam up to 8.35 MeV.

During the ALICE gun commissioning phase, a dedicated diagnostic beamline [4] was used to characterise the beam, with the results presented in [5]. This beamline included an RF transverse kicker as well as three further diagnostic units including YAG screens, slits, a pepperpot and also a Faraday cup. For the commissioning and operation of the full ALICE machine, this diagnostic beamline had to be removed to allow room for the booster cavity at the position marked in Figure 1.

During full ALICE commissioning it was found that the injector to be the most difficult section of the machine to set up. Reinstating some diagnostics should increase

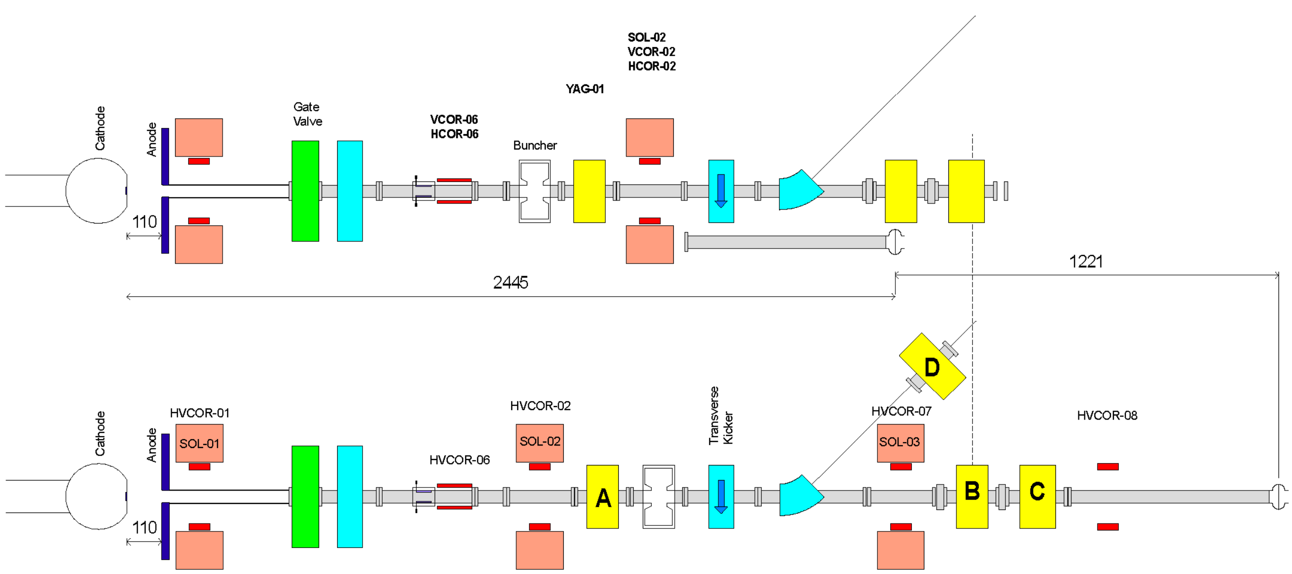

Figure 1: Schematic of the ALICE gun commissioning beamline (top) marking the position where diagnostic sections were removed and the booster linac added. The bottom shows the schematic of the extended ALICE injector up to the entrance of the first cell of the booster.

*julian.mckenzie@stfc.ac.uk

the speed of tuning the injector and increase the beam quality achieved. The extra diagnostics will also be beneficial in the commissioning of the proposed gun upgrade [6] and testing different photocathodes.

DIAGNOSTICS

A proposed extended gun beamline is shown compared to the current and gun commissioning beamlines in Figure 1. The yellow rectangles indicate diagnostic units with YAG screens and components explained below. An RF transverse kicker and dipole lead to unit D, orientated above the gun beamline, which will allow for longitudinal profile, energy, and bunch length measurements. A pair of horizontal and vertical slits plus a pepperpot, in units A and B, provide the ability for emittance measurements.

An insertable Faraday cup in unit C will be used for measuring the bunch charge. This will be especially useful for configuring ALICE to operate at different bunch charges as currently the charge can only be measured much further downstream of the booster via a Faraday cup located after a dipole used for energy measurements.

A small (~ 1 mm) aperture is included in unit A to enable preliminary setup of the injector at low bunch charge whilst operating the electron gun at full charge, thereby reducing the risks associated with losing the beam. A second, larger, aperture is included in unit C to cut off any halo that may be produced along with the core beam.

The positions of the first diagnostic unit, buncher cavity 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. A large number of steering coils have been included because of the presence of Earth and stray fields which, if left uncorrected, can missteer this low energy beam by up to 20 mm.

The total additional length of the pre-booster beamline is ~ 1.2 m. The entire gun and power supply systems will have to be moved backwards and the photocathode laser transport system adjusted accordingly.

SIMULATION RESULTS

Preliminary beam dynamic simulations have been performed using ASTRA [7] to compare the performance of the extended and existing beamlines (based on [8]) up to the exit of the booster cavities, with the beam at a final energy of 8.35 MeV. Optimisation was performed with the aid of a multi-objective genetic algorithm based on a non-dominating sorting technique. Care was taken to ensure a small beam size at the buncher cavity as this has the smallest aperture of the gun beamline. This constraint results in increasing the strength of the first solenoid and having the second solenoid set at a comparatively low field strength.

The extra length of the beamline results in a smaller range of parameters for good beam transport and results in a larger transverse emittance. No thermal emittance has been included in the simulation results shown. Estimates of the initial energy spread based on [6] show that this could be as large as 0.72 eV, giving an initial thermal emittance of just under 1.2 mm mrad. However, including this into ASTRA simulations show only a small increase of the final emittance and leaves all other beam parameters unaffected.

To keep the transverse beam size to a reasonable level, the phases of the booster cavities have been increased from ± 10° off-crest as per the current baseline design, to ± 15° in order to control the transverse beam size and divergence at the exit of the booster. This increase still results in a larger beam size but with identical divergence. The beam size downstream should be controllable by quadrupoles positioned at the exit of the booster.

Figures 2 – 6 show the evolution of beam parameters along both the existing and extended injector beamlines and Table 1 summarises the injector settings used. Table 2 summarises the beam parameters at the position of the first quadrupole after the booster linac.

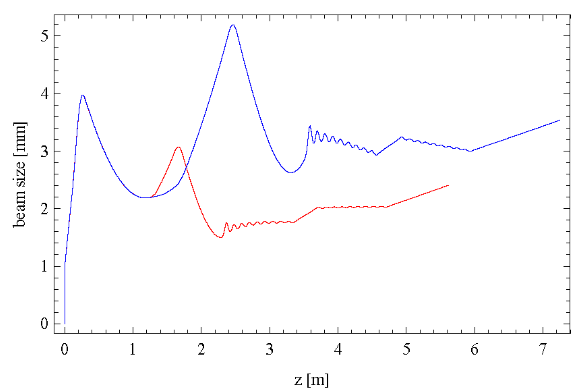

Figure 2: Transverse beam size (rms) along the existing (red) and extended (blue) injector beamlines.

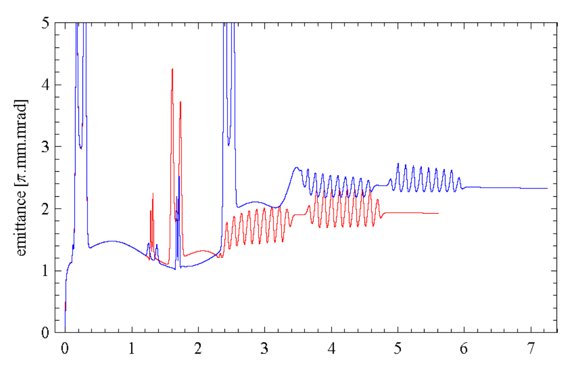

Figure 3: Normalised transverse emittance (rms) along the existing (red) and extended (blue) injector beamlines.

Table 1: Existing and extended injector beamline settings.

Parameter	Current	Extended
Laser spot diameter [mm]	4.0	4.0
Laser pulse length [ps]	28	28
Gun voltage [keV]	350	350
1st Solenoid peak field strength [G]	330	330
2nd Solenoid peak field strength [G]	230	65
3rd Solenoid peak field strength [G]	n/a	195
Buncher gradient [MV/m]	2.20	2.08
1st Cavity gradient [MV/m]	9.0	9.0
2nd Cavity gradient [MV/m]	7.0	7.0
1st Cavity phase [deg.]	+10	+15
2nd Cavity phase [deg.]	-10	-15

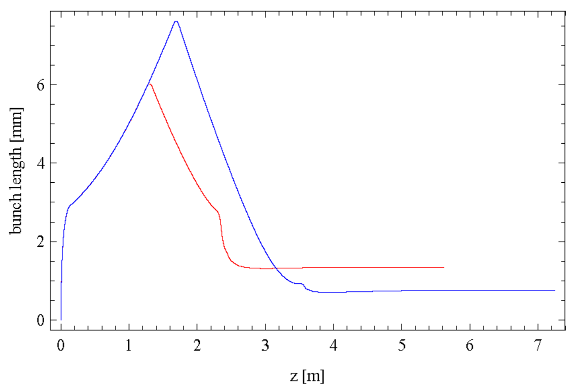

Figure 4: Bunch length (rms) along the existing (red) and extended (blue) injector beamlines.

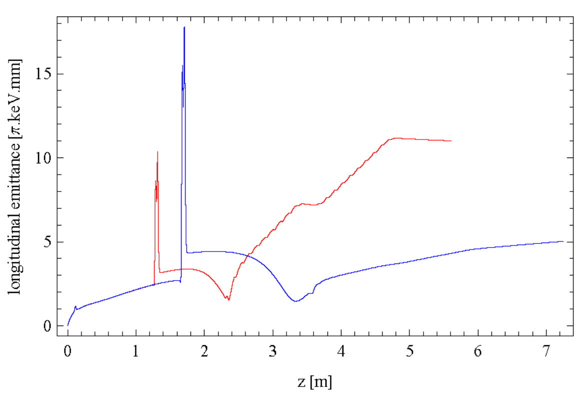

Figure 5: Longitudinal emittance (rms) along the existing (red) and extended (blue) injector beamlines.

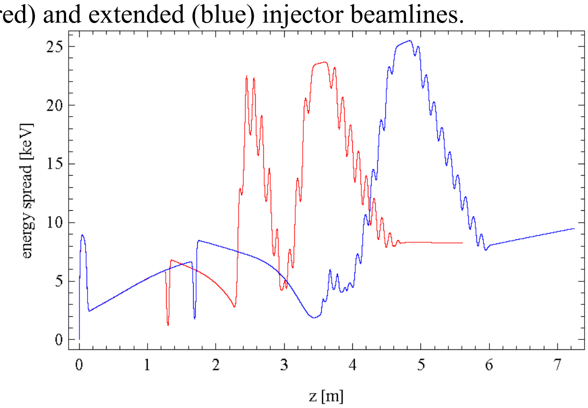

Figure 6: Energy spread (rms) along the existing (red) and extended (blue) injector beamlines.

Table 2: Beam parameters (rms) at the position of the first quadrupole after the booster for the existing and the extended injector beamlines.

Parameter	Current	Extended
Transverse beam size [mm]	2.41	3.54
Transverse divergence [mrad]	0.42	0.42
Transverse emittance [mm mrad]	1.93	2.32
Bunch length [mm]	1.35	0.76
Energy spread [keV]	8.26	9.49
Longitudinal emittance [keV mm]	11.0	5.03

CONCLUSIONS

The extension of the ALICE gun beamline by ~ 1.2 m would lead to a smaller range of parameters for a low energy beam transport. It may be concluded from the results of ASTRA simulations that although there may be an increase in the normalised transverse emittance, a decrease in both bunch length and longitudinal emittance could be achieved. Given the fact that the transverse emittance is strongly affected by numerous factors (steering, beam size in certain beamline components, RF phases etc) and that the extended beamline offers a much better control over the beam focussing and transport from the gun to the booster, this may result in comparable, or even lower, transverse emittance with the extended beamline. Combined with the benefit of the added diagnostics, this will significantly improve the operation of the ALICE and its flexibility as an R&D facility. .

REFERENCES

[1] S.L. Smith et al., *"Progress on the commissioning of ALICE, the energy recovery linac based light source at Daresbury Laboratory"*, these proceedings.

[2] T. Siggins et al., "*Performance of a DC GaAs photocathode gun for the Jefferson lab FEL"*, NIM A475 (2001) 549-553.

[3] L.B. Jones, *"Status of the ERLP photoinjector drive laser"*, proceedings of ERL 2007.

[4] D.J. Holder et al., *"ERLP gun commissioning beamline design"*, proceedings of LINAC 2004.

[5] Y.M. Saveliev et al., *"Results from ALICE (ERLP) DC photoinjector gun commissioning"*, proceedings of EPAC 2008.

[6] B.L. Militsyn et al., *"Design of an upgrade to the ALICE photocathode electron gun"*, proceedings of EPAC 2008.

[7] K. Flötmann, ASTRA homepage http://www.desy.de/~mpyflo

[8] B.D. Muratori & Y.M. Saveliev, *"ALICE (ERLP) Injector Design"*, proceedings of EPAC 2008.