EFFECT OF DC PHOTOINJECTOR GUN VOLTAGE ON BEAM DYNAMICS IN ALICE ERL

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Abstract

The ALICE ERL employs a DC HV photoelectron gun as an electron source. As with other machines in this class, the electron beam is not always of a perfect quality. This is aggravated by the fact the ALICE gun has so far been operated at a lower voltage of 230kV, due to hardware limitations. The “two beams” structure was observed and experimentally investigated and found to be the result of complex processes during the initial stages of beam acceleration. The experimental observations and data are compared with those obtained at 325kV gun voltage. An investigation of the effect of the DC photogun voltage on longitudinal and transverse beam dynamics is presented and discussed.

INTRODUCTION

The electron beam on the ALICE (Accelerators and Lasers in Combined Experiments) energy recovery linac [1] is provided by a DC high-voltage photoelectron gun. The beam is initially focussed, both transversely and longitudinally, using two solenoids and an RF 1.3GHz buncher (Fig.1). The beam is then accelerated in the SC RF booster to 6.5MeV and transported to the main SC RF linac, via the injector beam line. From the linac, the beam emerges at 26.0MeV energy, is transported to the magnetic compression chicane, and then back to the main linac for energy recovery.

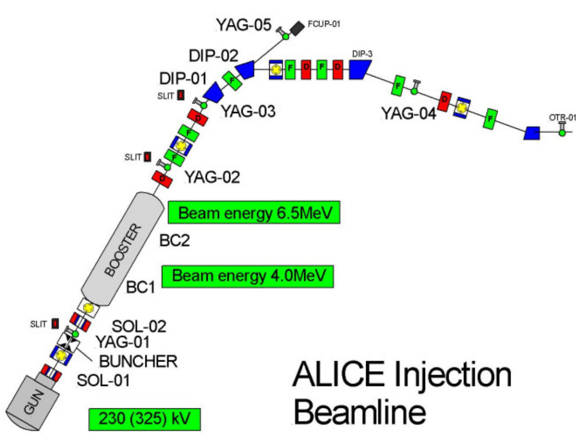

Figure 1: Layout of the ALICE injection line.

As with other machines in this class, the quality of the electron beam is not perfect. From 2007 to 2012, this was aggravated by fact that the ALICE gun was operated at a lower voltage of 230kV, compared to the design value of 350kV, due to hardware limitations. Some transverse beam structure was evident at the exit from the booster (Fig.2,a) and in dispersive sections of the machine (Fig. 2,b). The irregular shape of the beam images post main linac suggests that this structure propagates all around the machine (Fig. 2,c).

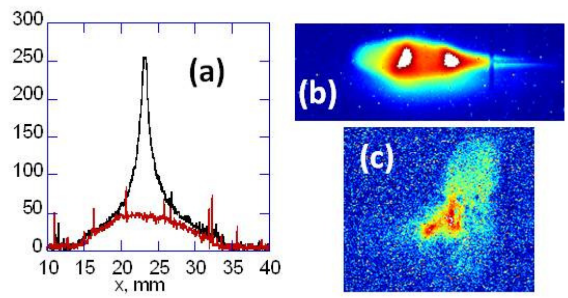

Figure 2: (a) beam single pixel profiles; black – through the centre of the beam image on YAG-02 screen, red – with offset from the centre; (b) beam image in the dispersive section, on YAG-05 screen; (c) beam image on a post linac OTR screen.

In this paper, we present the results of this beam structure investigation, both at the gun voltage of 230kV and 325kV, particularly concentrating on the feature of two distinct charge centres observable in the injector (see Fig 2,b), which shall be referred to as ‘two beams’ here. The higher voltage of 325 kV was achieved after installation of a larger gun HV ceramic and successful gun HV conditioning in March 2012.

EXPERIMENTAL SETUP AND METHODS

The booster cryogenic module consists of two TESLA type superconductive accelerating cavities. In standard injector setups, the first booster cavity (BC1) gradient is set to achieve 4.0MeV beam energy at the exit from BC1. The second cavity, BC2, accelerates the beam further, to 6.5MeV. Computer simulations suggest that, despite relatively low beam energy in the injector, the longitudinal properties of the electron bunch, such as bunch length, are largely determined by BC1 only and BC2 has a much smaller effect, except from controlling the energy chirp of the bunch. This allows the use of BC2 as a diagnostic streaking cavity. The resulting energy spread is observed in the energy spectrometer consisting of DIP-01 and YAG-05 (Fig.1). The experiments were conducted at 50pC bunch charge, BC1 phase set to -10^o and BC2 zero-cross phase set at +90^o (phases quoted are with respect to wave crests and in terms of phase delays applied to the RF wave).

The energy difference between the ‘two beams’ is determined either from a known dispersion of 1.1m on

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YAG-05, or from the DIP-01 current difference, if both beams cannot be seen on a screen simultaneously.

One concern in performing measurements presented here is whether space charge causes the energy spectrum to evolve downstream of BC2. This was evaluated in the following experiment. The beam energy of 4.0MeV was fixed at the exit from BC1. The BC2 gradient was also fixed but the phase was varied around a zero-cross phase ±17° to generate the beam with 3.0, 4.0 and 5.0MeV energy at the exit from BC2. The energy separation between the two beams, clearly identifiable on the energy spectrum (similar to that in Fig.2,b), was not affected by the beam energy variation within ~ 10% of the accuracy of the measurements. The energy spread of individual beams decreases by ~ 20% while the beam energy changes from 3.0 to 5.0MeV. Given the nature of these studies, such a beam evolution does not compromise the major results and conclusions presented here.

BEAM STRUCTURE AT 230KV GUN VOLTAGE

The energy separation between "two beams" depends strongly on various parameters of the injector, most notably the buncher power (Fig.3). Note also a dependence on the second solenoid, SOL-02, strength that indicates the role of space charge effects in formation of the bunch structure.

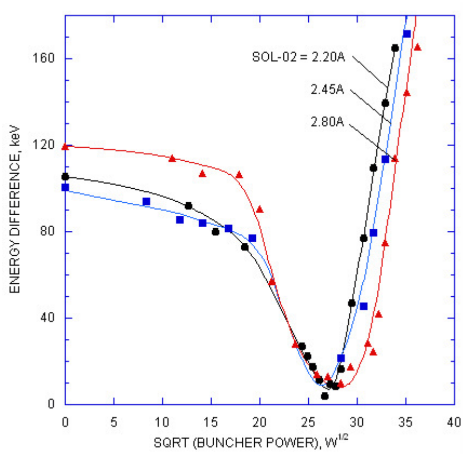

Figure 3: Energy difference between two peaks in the beam energy spectra as a function of the buncher power and the solenoid field. BC2 phase here is set to +40deg.

When BC2 is set to the zero-cross phase, it introduces an additional energy spread proportional to the BC2 voltage and the bunch length thus rotating the bunch in longitudinal phase space. Such dependence is shown in Fig.4 at two levels of buncher power, 0.8 and 1.0kW. From the slopes of the straight lines, the longitudinal separation between peaks is deduced to be 3.3mm at buncher power P_b=0.8kW and 9.0mm at 1.0kW. Extrapolation to zero BC2 voltage can also give an estimate of the initial energy separation between beams at the exit from BC1: ~200keV and ~530keV respectively. The minimal post-booster energy spread condition, when both beams have approximately equal energy after exiting BC2, is achieved at a BC2 voltage of ~ 2.3MV.

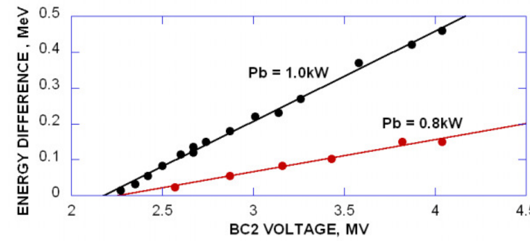

Figure 4: Energy difference between two peaks in the beam energy spectra as a function of the BC2 voltage. The BC2 phase is set to zero-cross.

The above measurements suggest that the electron bunch at the exit from the booster has a structure that includes two well defined beams, one at the head and the other at the tail of the bunch, separated longitudinally by a distance approximately equal to the full bunch length.

The ALICE photoinjector laser system employs a laser pulse stacker that combines four 7ps pulses into one of 28ps FWHM. The resulting pulse may not be necessarily uniformly flat, as was demonstrated by measurements with a streak camera [2], and thus could be the cause for the resulting longitudinal structure of the electron bunch. However, an experiment with a fundamental Gaussian 7ps long laser pulse (pulse stacker removed) clearly showed the same bunch structure as seen with the pulse stacker, suggesting the cause of the two beams is in the low energy beam dynamics.

The "two beams" structure remains present in energy spectra with a wide range of bunch charges, from 20 to 120pC. The energy difference between the peaks does depend on bunch charge, but this is likely to be the result of variations in bunch length and energy chirp, as both are space charge dependent.

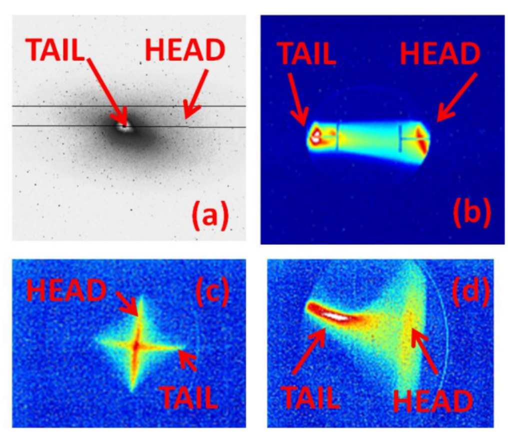

Figure 5: Beam images on screens: (a) screen YAG-02, horizontal lines show the position of beam profiles showed in Fig.2,a; (b) screen YAG-05 in dispersive region; (c) screen YAG-04 at P_b=1.0kW; (c) the same but BC2 is set to zero-cross.

A combination of techniques, including the use of slit assemblies on motorised stages to block beams progressively and setting some parameters deliberately

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non-optimally, were used to accentuate the beam structure, and thus to investigate the relation between the transverse and longitudinal properties of the beam (Fig.5). It was concluded that the longitudinal structure observed in dispersive sections of the machine correlates clearly with a transverse structure, and that the two beams have different Twiss parameters at the exit from the booster.

BEAM STRUCTURE AT 325KV GUN VOLTAGE

At the higher gun voltage of 325 kV the beam structure cannot be observed as easily as at 230kV. However , the two-beam bunch structure in the energy spectrum could be induced by setting the injector to non-optimal parameters, most notably the buncher power, see Fig.6. Transversely, no beam structure could be distinguished.

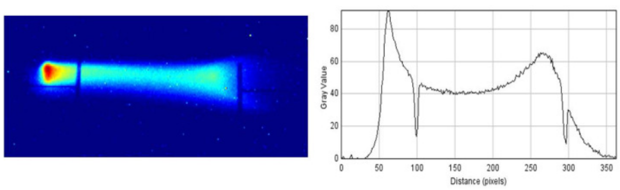

Figure 6: "Two beam" structure on YAG-05 screen at significantly reduced buncher power of 0.4kW.

Measurements similar to those presented in Fig. 4 were repeated at the higher 325kV gun voltage, with the difference that the FWHM widths of the energy spectra were recorded, instead of the energy separation between the beams at the head and the tail of the bunch, see Fig.7. Fitting the experimental data with the analytical formula $\Delta E = \sqrt{\Delta E_0^2 + \left[\left(\frac{dE}{dz}\right)_1 - \frac{dE_2}{dz}\right]^2 \Delta z^2}$, where ΔE_0 is a non-correlated energy spread, $(dE/dz)_1$ is the energy chirp of the bunch at the exit from BC1, and Δz is the bunch length, allows evaluation of the three parameters, summarised in Table 1.

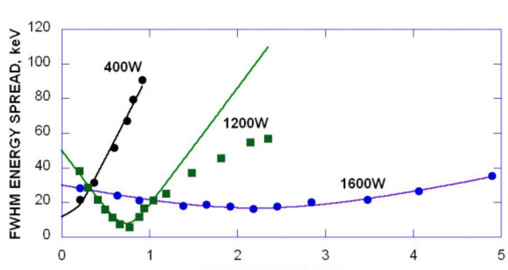

Figure 7: FWHM energy spread as a function of the BC2 voltage. The BC2 phase is set to zero-cross.

In measurements presented in Fig. 7, the bunch structure was clearly observed at a low buncher power P_b=400W, can hardly be seen at the approximately nominal P_b for this gun voltage, P_b=1200W, and cannot be distinguished at all at a slightly higher P_b=1600W. The latter is probably due to the fact that the bunch length is extremely small at this buncher power. This also leads to a higher uncorrelated energy spread (Table 1).

Table 1: Bunch Parameters at 325kV Gun Voltage

Buncher Power, W	Uncorrelated energy spread, keV	Energy chirp from BC1, keV/mm	Bunch length, mm
400	10	1.6	3.7
1200	5	20	2.5
1600	16.5	60	0.42

SUMMARY AND CONCLUSIONS

The results presented here suggest that the "two beams" substructure develops due to the low energy dynamics of the injector before the second booster cavity. The structure is characterised by the existence of two well defined beams, at the head and the tail of the bunch. These beams also have different transverse properties, and this is likely to be the reason for the irregular beam shapes seen on different screens around the machine.

At increased gun voltage (325kV compared to 230kV), the beam structure is much less pronounced, and could be identified only at non-optimal injector settings. This does not necessarily mean that the irregular beam structure ceases to exist completely at higher gun voltages.

Preliminary results from ASTRA simulations confirm that, at certain conditions, the "two beam" structure can develop within the bunch (Fig. 8). It is clearly seen at higher than nominal buncher powers, where two distinct peaks in the longitudinal bunch profiles are formed.

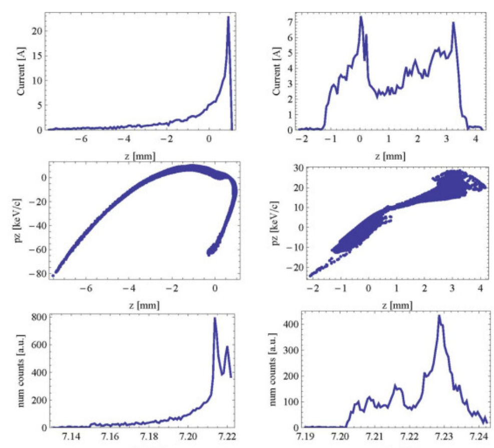

Figure 8: Simulated (ASTRA) longitudinal bunch profile (top), longitudinal phase space (middle) and energy spectra (bottom) at buncher powers of 400W (left column) and 1100W (right column). Gun voltage 230kV.

In conclusion, the bunch structure, described here, is likely to be a feature of all electron beam injectors with relatively low energy electron guns (HV DC photoguns in particular). This can be alleviated by increasing the gun voltage to as high a level as practically possible.

REFERENCES

[1] F. Jackson et al, IPAC'11, pp.934-936.
[2] Y. M. Saveliev et al, EPAC'08, pp. 211-213.

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