RESULTS FROM ALICE (ERLP) DC PHOTOINJECTOR GUN COMMISSIONING

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Abstract

The ALICE (formerly ERLP) DC photoinjector gun has been commissioned and the beam characteristics measured. The gun has demonstrated the nominal ALICE parameters of 350keV electron energy, 80pC bunch charge and ~130ps bunch length (at 10% level). The bunch parameters were measured at different bunch charges from 1pC up to 80pC. Special attention was given to measurements of the beam transverse emittance (using a movable slit), correlated and uncorrelated energy spread (using an energy spectrometer) and bunch length (using a transverse RF kicker) at each bunch charge. The effect of the 1.3GHz RF buncher on the bunch length was also investigated. The experimental results are then compared with ASTRA simulations.

INTRODUCTION

The ALICE (Accelerators and Lasers in Combined Experiments) experimental facility (known formerly as ERLP [1]) is being commissioned at present. This includes an energy recovery linac and a high voltage DC photoemission electron gun. The gun is a replica of the Jefferson Lab design [2] and operates at a nominal voltage of 350kV and a nominal bunch charge of 80pC. Electrons are generated from the NEA GaAs cathode by green light from a Nd:YVO$_4$ mode-locked laser, frequency-doubled to generate a 532nm beam.

Despite there being a few similar guns in operation or under construction, very limited experimental data is available on beam characteristics from this type of DC photoinjector. Our gun has been recently commissioned and the beam was fully characterised at various bunch charges. The results of this experimental investigation are presented here.

EXPERIMENTS

Electron bunch properties from the ALICE DC photogun were investigated with a dedicated diagnostic beamline shown schematically in Fig. 1. It includes two solenoids used for transverse beam focusing and emittance compensation and an RF buncher operating at a fundamental frequency of 1.3GHz. A 1.3GHz transverse RF kicker allows the investigation of the longitudinal profiles of the electron bunches and measurement of the bunch length Δz. The energy spectrometer, apart from measuring energy spectra, was also used for buncher characterisation, calibration and phase setting and for bunch length measurements using "energy mapping" and "zero-crossing" methods described below in more detail. For both bunch length and energy spectrum measurements, the vertical slit "A" was always inserted and solenoid 2 was switched off.

The transverse RMS emittance was measured by slit scans at positions "A" and "B". All measurements were made with the laser beam size on the cathode of 4.1mm FWHM. The intrinsic laser pulse was of a Gaussian profile with a 7ps length but, in these experiments, longer pulses were generated with the use of a pulse stacker resulting in 28ps FWHM pulses. Experimental data were compared with an ASTRA computer model.

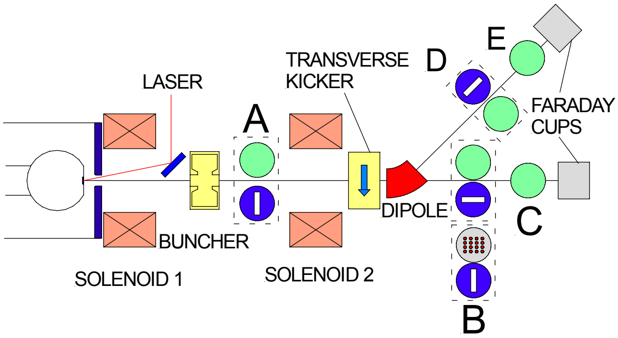

Figure 1: Schematic diagram of the diagnostic beamline (not to scale) Green circles represent YAG screens and blue circles slits.

EXPERIMENTAL RESULTS

The gun is routinely high-voltage conditioned to 450kV after a bakeout to operate at a nominal 350kV for electron beam generation. Immediately after the bakeout, the vacuum was in the low 10^{-11}mbar range but increased to ~10^{-10} mbar following the HV gun conditioning. The quantum efficiency of a freshly activated GaAs photocathode was normally above 3%, allowing the generation of electron bunches with charges (Q) well above 100pC. The nominal bunch charge for ALICE operation is 80pC and this was set as the maximum bunch charge in these experiments.

The cathode lifetime was limited due to the non-ideal vacuum in the gun (ideally it should be in the range of 10^{-12}-10^{-11} mbar) and the presence of a field emission spot on the GaAs wafer. The field emission current was prevented from entering the diagnostic beamline by choosing specific positions of the laser spot on the photocathode and by choosing appropriate settings for solenoid 1. Higher than optimum solenoid fields were normally required to achieve this, leading to a reduced operational range for beam optimisation, especially at lower bunch charges.

RMS values of the beam's transverse emittance are presented in Fig. 2. As expected the emittance increases

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with increase of the bunch charge. However the data exhibits a large experimental scatter and the absolute values are significantly larger than those predicted by the ASTRA model, in which the emittance is below 1π mm-mrad even at 80pC bunch charge. This could be due to the fact that the emittance compensation process employed, with two solenoids, is quite complicated and ideally, would require optimisation of the solenoid fields for each bunch charge. This was not always possible due to the presence of the field emission and was especially true for $Q<20$pC when, the beam always exhibited a transverse crossover upstream of the point of measurement. The model also did not take into account several factors, including the initial thermal emittance of the GaAs photocathode (estimated to be as high as ~0.5μm [3]) and non-uniformity of the quantum efficiency across the cathode area illuminated by the laser. The latter could significantly degrade the emittance, as shown in [4]. The laser pulse in these experiments was not perfectly flat topped, which could also contribute to the emittance growth [5].

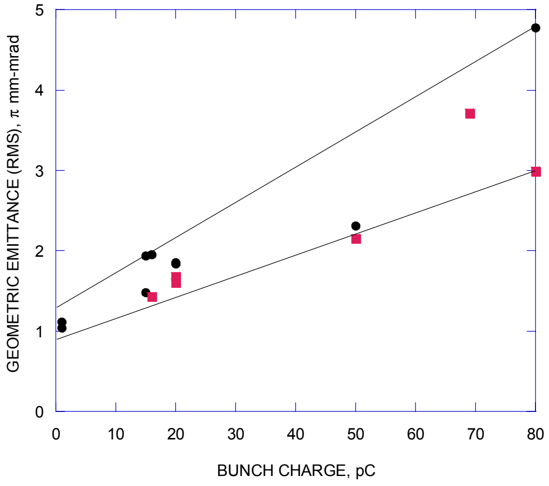

Figure 2: Horizontal (circles) and vertical (squares) RMS geometric emittance as a function of the bunch charge. The straight lines indicate boundaries within which all measured values are contained.

The bunch length Δz was measured with three different methods; the results are shown in Fig. 3. We used measurements of Δz at 10% of the peak value because usual RMS or FWHM values are not particularly representative in the case of complex profiles. When using the transverse kicker, the bunch length was determined as the difference between slit "A" images on screens "B" or "C" with the kicker on and off thus eliminating the emittance-dominated image widening.

The bunch length was also measured by the "energy mapping" method when the buncher was set to a zero-cross phase, thus introducing an electron energy variation depending linearly on the electron position within the bunch. The resulting spectra at several levels of the buncher RF power were then analysed with the energy spectrometer and, using the known voltage function of the buncher, the bunch length could then be determined. Note that this method allows the determination of the intrinsic energy tilt of the bunch. Finally, the bunch length was measured using a zero-crossing method similar to that reported in [6] with the buncher as an RF cavity.

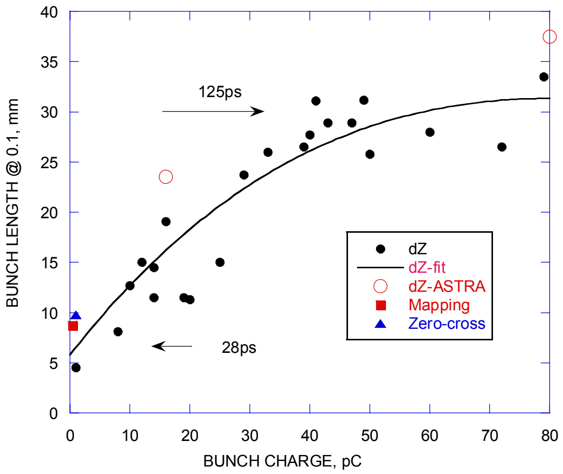

Figure 3: Bunch length at 10% of the peak value as a function of bunch charge. Data were obtained with the RF transverse kicker (full circles), "energy mapping method" (square) and zero-crossing method (triangle). Open circles are the results from the ASTRA model.

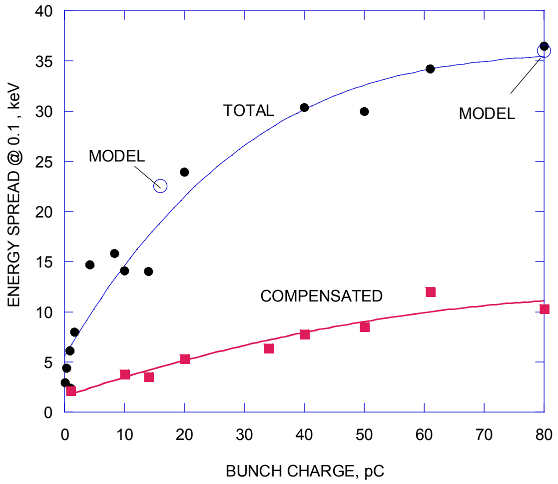

Figure 4: Total and tilt-compensated energy spread as a function of the bunch charge. Open circles indicate the results from the ASTRA model.

The bunch length increases with Q but "saturates" at the level of ~30mm above ~40pC. At a low bunch charge of ~1pC, the bunch length measured with the kicker appears to be lower than the initial laser pulse length of 28ps FWHM. We note however that the accuracy of Δz measurements at low Q (<20pC) was poor because of the limited RF power available for the kicker operation. Somewhat tedious but more accurate measurements using the "energy mapping" and "zero-crossing" methods produce a bunch length of ~40ps at Q~1pC, consistent with the laser pulse length. Experimental values of Δz are slightly lower than those predicted by the ASTRA model but the overall trend is correct.

The energy spread was measured as the total energy spread ΔE_{tot} and the compensated energy spread ΔE_{comp}. The latter is when the correlated energy tilt within the bunch is nullified by varying the RF power to the buncher (set at a zero-cross bunching phase) until the image width on the energy spectrometer screen is minimised.

All the experimental data on the total and compensated energy spreads are presented in Fig. 4. Note the ASTRA model predicts accurately ΔE_{tot} values and their behaviour with changing bunch charge. The dependence of the voltage tilt $\Delta V/dz$ required from the buncher to compensate the correlated energy tilt on the bunch charge is shown in Fig. 5. The remarkable feature is that above ~20pC the bunch energy tilt depends weakly, if at all, on the bunch charge. This is corroborated by the independence of the ΔE_{tot} / Δz ratio on the bunch charge and by the ASTRA simulation results, both also shown in the Figure.

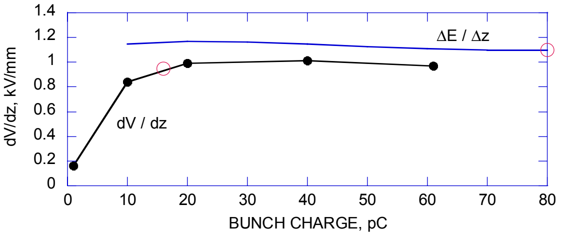

Figure 5: Voltage tilt $\Delta V/dz$ required from the buncher to compensate the correlated energy spread (tilt) as a function of the bunch charge. Also shown is the ratio ΔE_{tot} / Δz where the total energy spread and the bunch length are taken from curves fitted to the experimental data in Figs. 3 and 4. Open circles indicate the results from the ASTRA model.

The longitudinal bunch compression was studied at different bunch charges and the results are shown in Fig.6, where the bunch length at the position of the kicker is given as a function of the voltage tilt dV/dt introduced by the buncher. It is instructive to compare this data with the analytical expression for the bunching length that can be re-written as

$$\frac{dV}{dz} = \frac{m_0 c^2 \beta^2 \gamma^3}{eL_b} + \left(\frac{dE}{dz}\right)_0$$

where L_b is the distance between the buncher and the longitudinal bunch waist and $(dE/dz)_0$ is the initial correlated energy tilt of the bunch longitudinal phase space that can be estimated from data in Fig. 5. At higher bunch charges, above ~40pC, the experimental data match the above analytical expression with an accuracy better than 10%. At Q<10pC, the difference is larger and this can be ascribed, as noted earlier, to insufficient accuracy of the bunch length measurements at low bunch charges.

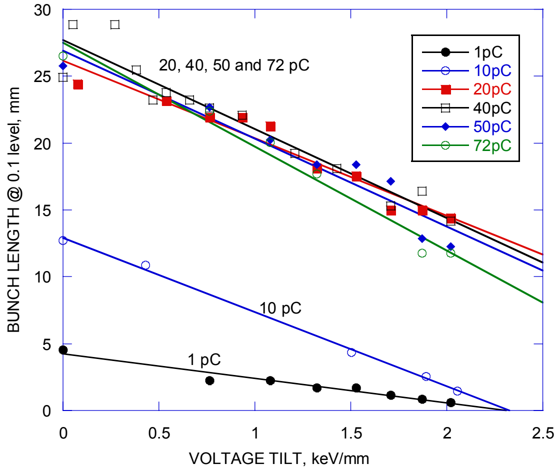

Figure 6: Bunch length at the position of the transverse kicker as a function of the voltage (energy) tilt introduced by the buncher.

In conclusion, we have commissioned the ALICE DC photogun and fully characterised the generated electron bunches. We found that there is a good agreement between the experimental data and the ASTRA model in terms of the bunch length and the energy spread but the transverse emittance was found to be significantly larger than the model predicted. This could be due to the fact that the model did not take several factors into account (e.g. the initial thermal emittance) and due to non-ideal experimental conditions (presence of field emission, sub-optimal magnetic field settings, non-uniform quantum efficiency map). In the future ALICE operation, we expect a sizeable decrease of the transverse emittance once these adverse factors are eliminated.

ACKNOWLEDGEMENTS

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