CHARACTERISATION OF ELECTRON BUNCHES FROM ALICE (ERLP) DC PHOTOINJECTOR GUN AT TWO DIFFERENT LASER PULSE LENGTHS

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Abstract

In high-voltage DC photoinjector guns, the drive laser pulse duration affects the electron bunch characteristics and is therefore an important subject for experimental investigation in order to optimise performance of the gun. Initial experimental studies into this effect have been carried out on ALICE (formerly the Energy Recovery Linac Prototype) photoinjector. During the commissioning of its DC photoinjector gun, electron bunch parameters were measured at two laser pulse durations, ~7 ps and ~28 ps FWHM. The shorter laser pulse is the intrinsic output pulse length of the laser, while the longer pulse was synthesised using a pulse stacker. The electron bunch parameters that were measured included transverse emittance, correlated and tilt compensated energy spectra and bunch length. The experimental results and their comparison with computer simulations are presented and discussed.

INTRODUCTION

Photoinjector guns, both RF and DC, are the obvious choice for generation of high-brightness electron beams. However, preservation of the low transverse emittance which is an intrinsic characteristic of photocathode sources is not a trivial task and relies on the understanding and optimisation of many parameters. Amongst these are the longitudinal and transverse profiles of the driving laser beam used for the generation of photoelectrons. The laser pulse length is known to affect major bunch parameters including the transverse emittance, bunch length and energy spread through the effects of space charge, and while there are several reports on beam characterisation from RF photoguns with various laser pulse shapes (for example, see [1]), data on beam characteristics of DC photoguns is scarce.

We present experimental results for the characterisation of electron bunches generated by the ALICE DC photoinjector gun using two different laser pulse lengths of 28 and 7 ps, and the comparison of these results with ASTRA simulations to facilitate data interpretation. This work was part of the gun commissioning programme, the results of which are presented in these Proceedings [2].

EXPERIMENT AND COMPUTER MODEL

The experiments were conducted with the ALICE DC photocathode gun which is essentially a copy of the 500 kV Jefferson Lab gun [3]. The gun was operated at nominal 350 kV, and was able to generate electron bunch charges Q in excess of 100 pC from the activated GaAs photocathode. However, the bunch charge was kept at 16 pC in the experiments reported here. The electron bunches were characterised using a dedicated diagnostic beamline, detailed in [2]. The beamline consisted of two solenoids which provided transverse beam focusing and emittance compensation, a 1.3 GHz RF buncher cavity for longitudinal bunch compression, a 1.3 GHz RF transverse kicker cavity for longitudinal bunch profile measurements, an energy spectrometer, plus horizontal and vertical slits for transverse emittance measurements. Beam or slit images were observed on five YAG screens.

The fundamental from a Nd:YVO_4 mode-locked laser was frequency-doubled to yield 532 nm green beam whose transverse beam size on the photocathode was 4.1 mm FWHM. The laser pulses were Gaussian in profile with a 7 ps FWHM length. Longer pulses were generated with the use of a vanadate pulse stacker, which yielded 28 ps FWHM pulses. The pulse shape was not perfectly flat-topped, however, and a representative laser pulse profile is shown in Fig. 1 below.

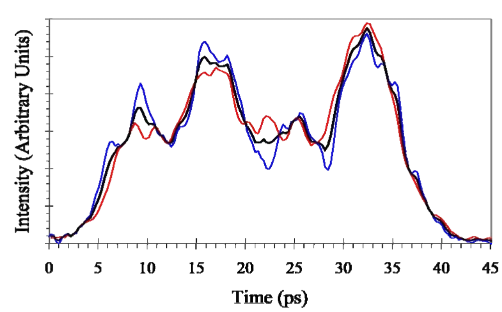

Fig. 1: Longitudinal profile of the 'stacked' 28 ps laser pulse measured with a streak camera. The red and blue traces each show the average of ten data sets, and the black trace the average of these.

The geometrical transverse emittance was measured in terms of its RMS values from slit scans. The bunch length Δz and the energy spread ΔE_{tot} were measured at 10% of the peak level.

Operating the buncher at zero-cross phase can compensate a correlated energy tilt and this was done by varying the buncher RF power until the width of the image on the energy spectrometer screen is minimised. This compensated energy spread is denoted by ΔE_{comp}. The bunch charge of 16 pC and the solenoid fields were kept identical at both 28 and 7 ps laser pulse lengths.

ASTRA computer simulations were carried out with three different laser profiles which simulated the

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experimental laser beam conditions, i.e. (i) 'single' Gaussian 7 ps FWHM pulse, (ii) 'flat top' pulse of 28 ps width, and (iii) 'two pulse' profile consisting of two Gaussian 7 ps pulses with their leading edges separated by 21 ps to simulate a wide 28 ps pulse. The same total bunch charge of 16 pC was used for all three profiles. The 'two pulse' profile was chosen to represent the actual profile as it does not have a purely flat top.

EXPERIMENTAL RESULTS

Measured and theoretical results are summarised in Table 1, with geometric RMS emittance given for both the experiment and the model. The bunch length and the energy spread are given at 10% of their peak levels. Correlated energy tilt was determined as $\Delta E_{tot}/\Delta z$, which could be compensated by applying buncher RF power giving the energy kick of $dV_b / dz = 2\pi V_0 / \beta\lambda$ where V_0 is the buncher voltage at given RF power and λ is the RF wavelength.

Table 1: Summary of experimental results

	Experiment		ASTRA model		
	28 ps	7 ps	flat top	two pulse	single
ε_x, µm	1.95	1.91	0.56	0.80	0.49
ε_y, µm	1.43	1.47	0.56	0.80	0.49
Δz, mm	19.1	18.6	23.8	23.5	25.5
ΔE_{tot}, keV	24.4	29.7	22.5	23	28
ΔE_{comp}, keV	5.1	2.8	6.0	7.2	1.3
$\Delta E_{tot}/\Delta z$, keV/mm	1.28	1.60	0.95	0.98	1.10
dV_b/dz, kV/mm	1.23	1.67	-	-	-

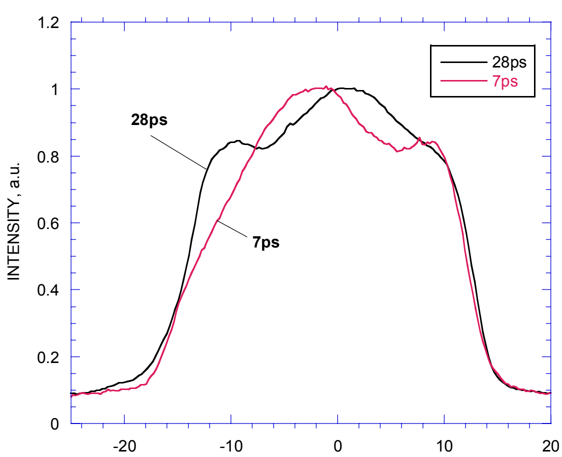

Fig. 2: Longitudinal intensity profiles for electron bunches generated by 28 ps and 7 ps laser pulses. These profiles include an emittance-related contribution which widens the total measured bunch length by ~15 mm.

The measured emittance values are significantly higher than those predicted by the model, but the overall behaviour was confirmed. In the experiment, no difference in emittance was noticed between 28 and 7 ps laser pulses. The model shows a slight decrease of ~10% for the 'single' profile, but a somewhat higher emittance for the 'two pulse' profile. However, we note that in the model, the emittance is appreciably higher for a 7 ps pulse if the bunch charge is increased to 80 pC. The apparent insensitivity of emittance to the laser pulse length could be explained if space charge is not the dominant factor at Q = 16 pC, but rather other factors such as the initial thermal emittance at the cathode which could be estimated to be as high as ~0.5 µm [4], or the non-uniformity of the quantum efficiency map over the cathode area illuminated by the laser. The latter factor could cause significant deterioration in emittance, as has been shown in [5]. Since the ASTRA model did not include these factors, this may explain the large differences observed in emittance between the experimental measurements and simulation predictions.

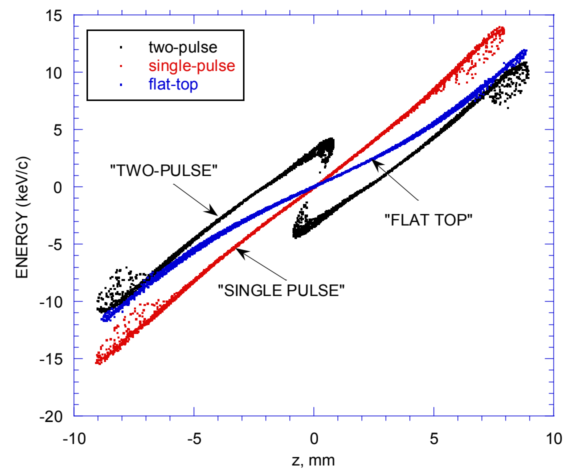

Fig. 3: ASTRA simulations showing longitudinal phase space for three different laser pulse profiles: 'flat top', 'single pulse' and 'two pulse'. The total bunch charge in all cases is 16 pC.

No significant change in the bunch length Δz was observed in experiment between 28 ps and 7 ps pulses as shown in Fig. 2. The longitudinal bunch profiles were largely symmetric, lacking the long tail normally associated with a GaAs photocathode [6]. As in the experiment, the model predicted nearly identical bunch lengths at 28 and 7 ps (only ~10% longer in the latter case, becoming even smaller for Q = 80 pC). Similarly, there is no difference in the bunch length between 'flat top' and 'two pulse' laser profiles, but the longitudinal bunch profile exhibits distinctive peaks in the latter case.

Absolute values of the total energy spread determined by experiment correlate very well with those gained from the model. This observation also applies to the increase in ΔE_{tot} by ~20% when the laser pulse length changed from 28 ps to 7 ps. There is no appreciable difference predicted in ΔE_{tot} between the 'flat top' and 'two pulse' profiles, as shown in Fig. 3, and the energy spectra measured for both laser pulse lengths are shown in Fig. 4. Both the experimental measurements and the model predictions demonstrate a large decrease in tilt-compensated energy spread when the laser pulse was reduced from 28 to 7 ps, as shown in Fig. 5.

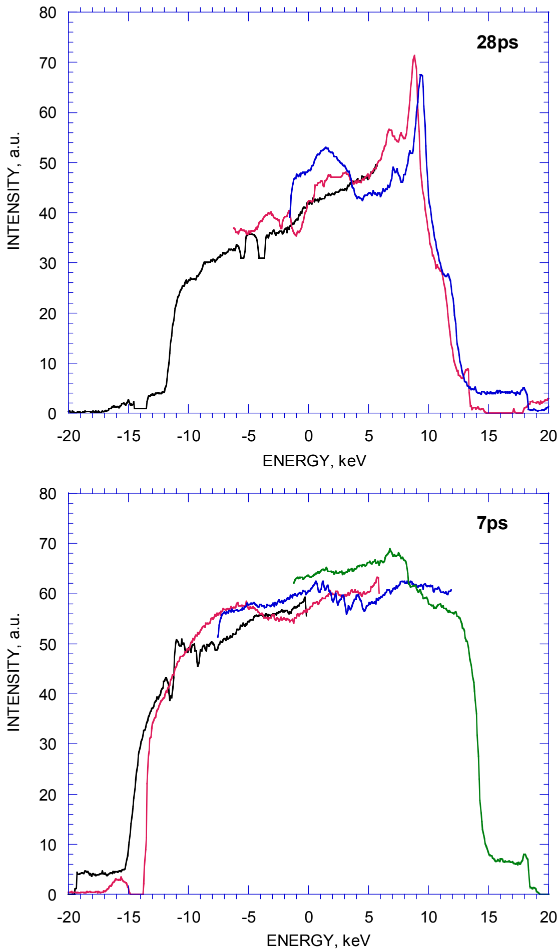

Fig. 4: Total energy spectra for bunches generated by 28 ps (top) and 7 ps (bottom) laser pulses. Note: the imaging screen was not wide enough to accommodate the whole spectrum, and several images at different dipole settings were taken to permit reconstruction of the full spectrum.

Comparison between the energy tilt determined as $\Delta E_{tot}/\Delta z$ with the required compensating buncher cavity 'kick' shows excellent agreement between the two, with an accuracy of better than 5%. This also corroborates measurements of the energy tilt $\Delta E_{tot}/\Delta z$ being larger in the case of the 7 ps laser pulse.

DISCUSSION

It may be concluded from our experimental and modelling results that the use of 28 and 7 ps laser pulse profiles at a modest bunch charge of 16 pC generate electron bunches of similar quality. Optimisation of the beamline settings for each laser profile may potentially lead to a lower transverse emittance for longer laser pulses, the benefits of which will be more pronounced at higher bunch charges in the 0.1 nC range. However, this observation only applies to a perfectly flat-top pulse, and if this is not the case, transverse emittance can be severely compromised.

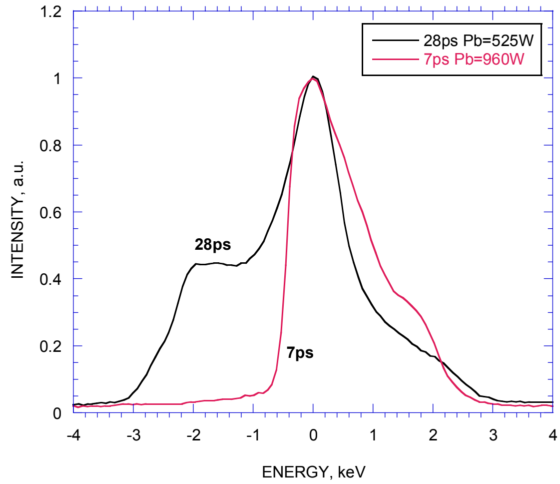

Fig. 5: Tilt-compensated energy spectra for 28 ps and 7 ps laser pulses.

Electron bunch length appears unaffected by the initial laser pulse length. This is a consequence of increased space charge in the initially shorter bunches. Once the bunch generated by the 7 ps pulse has become as long as that from the 28 ps pulse, further longitudinal expansion should be similar for both with energy tilt continuing to act as a de-bunching force, though this effect is more pronounced for the shorter laser pulses.

The ASTRA model correctly describes trends observed in the experimental work, and accurately predicts absolute values for various bunch characteristics, except the transverse emittance. This can, however, be improved by the introduction of more sophisticated models for electron generation in the photocathode.

In conclusion, longer laser pulses used for generation of modest bunch charges below ~20 pC do not offer significant advantages over shorter ones in terms of bunch length and energy spectra. However, they can offer a measurable improvement in transverse emittance, but this can be easily compromised if the longitudinal profile of the drive laser pulse is not sufficiently smooth.

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