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COMPRESSION OF AN ELECTRON-BUNCH BY MEANS OF VELOCITY BUNCHING AT ARES

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Abstract

ARES is a planned linear accelerator for research and development in the field of production of ultra-short electron bunches. The goal of ARES is to produce low charge (0.2 - 50 pC), ultra-short (from few fs to sub-fs) bunches, with improved arrival time stability (less than 10 fs) for various applications, such as external injection for Laser Plasma Wake-Field acceleration. The ARES layout will allow to perform and compare different kind of conventional e-bunch compression techniques, such as pure velocity bunching, hybrid velocity bunching (i.e. velocity bunching plus magnetic compression) and pure magnetic compression with the slit insertion. This flexibility will allow to directly compare the different methods in terms of arrival time stability and local peak current. In this paper we present simulation results for the compression of an electron bunch with 0.5 pC charge. We compare the case of pure velocity bunching compression to the one of a hybrid compression using velocity bunching plus a magnetic compressor.

INTRODUCTION

Ultra-short electron bunches, having a RMS length below 1 fs, are of great interest for various applications. First of all they can be used for ultrafast science, for example to generate ultra-short radiation pulses or to run electron diffraction experiments. Moreover they are expected to allow superior performances when injected into novel compact accelerating structures (e.g. based on Plasma Wake-Fields Acceleration) [1]. Besides studying novel acceleration techniques aiming to produce high brightness short bunches, the ARD group at DESY is working on the design of a conventional RF accelerator that will be hosted at SINBAD (Short and INnovative Bunches and Accelerators at Desy) [2]. ARES (Accelerator Research Experiment at Sinbad) [3] will allow the production of such ultra-short bunches and at a later stage it will be used to inject ultra-short electron bunches into laser driven Plasma Wake-field Accelerator.

One of the characteristics of this accelerator is that it will allow the direct experimental comparison of the performance achievable by using different bunch length compression techniques. In this paper we will focus on the pure velocity bunching and hybrid compression techniques, while we refer the reader to references [4] and [5] for more information about the working points using the magnetic compression and the study of the arrival time stability of the beam.

SIMULATIONS

The elements of ARES which are relevant for the simulations presented in this paper are shown in Fig. 1. In particular we select 4 locations that will be important in the following plots:

- Z1, located at 12.9m and corresponding to the exit of the linac in the baseline layout;
- Z2, located at 18.3m and corresponding to the entrance of the section that matches the beam to the dogleg;
- Z3, located at 21.2m, i.e. the dogleg entrance;
- Z4, located at 30.2m, i.e. the dogleg exit.

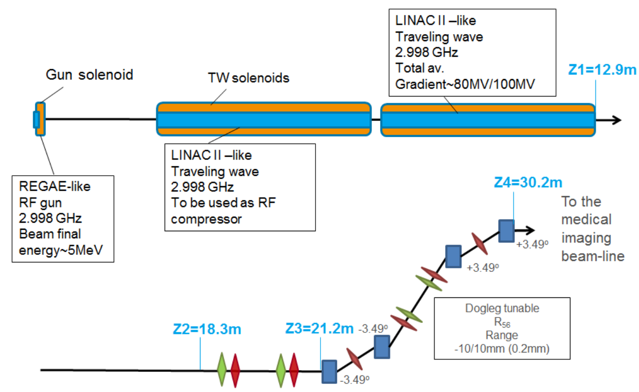

Figure 1: Elements of the ARES beam-line, which are relevant for the simulations described in this paper.

Pure Velocity Bunching

Injecting a not ultra relativistic electron bunch into a RF cavity close to the 0 phase of the electric field, where the head of the bunch sees a lower field amplitude than the tail, the beam is compressed because of the induced velocity chirp. Since the average velocity of the bunch is less than the velocity of the RF field, the first slips along the second, moving towards the crest. In this way it is possible to compress and accelerate an electron bunch at the same time.

In 2010 it has been firstly experimentally shown that it is possible to compress a beam with this technique while controlling the transverse emittance oscillations, through the so-called emittance compensation method [6].

The transverse dynamics of a beam accelerated along a constant focusing channel is described by the envelope equation [7]. Any mismatch between the space charge correlated forces and the external focusing leads to slice envelope oscillations that cause oscillations of the transverse normalized emittance. By properly matching the beam with the focusing channel surrounding the RF compressor it is possible to get close to the invariant envelope beam solution of the envelope equation, that minimizes the transverse emittance growth [8].

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In the velocity bunching compression the transverse and longitudinal evolution of the beam are coupled through the space charge effect. In order to obtain ultra-short bunches it is critical to control the bunch density versus the bunch energy gain [9].

Table 1: Low Charge Working Points at Z1

Parameter	**WP1**	**WP2**	**WP3**
Charge [pC]	0.5	0.5	0.5
FWHM [fs]	2.1	2.7	4
E [MeV]	109	111	111
$\Delta E/E[\%]$	0.1	0.1	0.3
$\sigma_{x,y}[mm]$	0.6	0.15	0.009
$n\epsilon_{x,y}[\mu m]$	0.07	0.05	0.05
I_p (in 1 FWHM) [A]	133	115	87

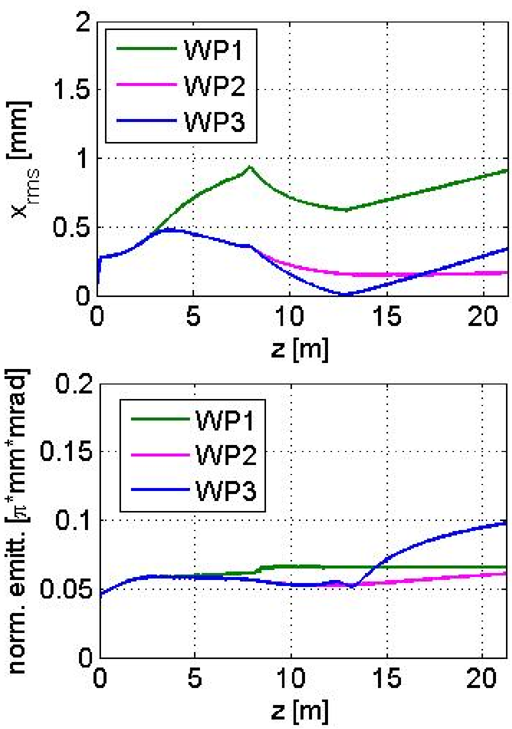

Figure 2: Evolution of the transverse spot-size and normalized transverse emittance of the beam along the line.

The goal of ARES is to produce ultra-short bunches having $FWHM \sim 1fs$. For the applications like external injection into a plasma chamber [1], not only the bunch length but also its transverse size must be extremely small ($\sim \mu m$ or sub-μm).

In Table 1 we have summarized three possible working points which deliver different transverse focusing of the beam at Z1, where, in the baseline stage of the project, the diagnostics line will be located. The simulations for the extraction, compression and transport of these beams have been done using the well known ASTRA code [10].

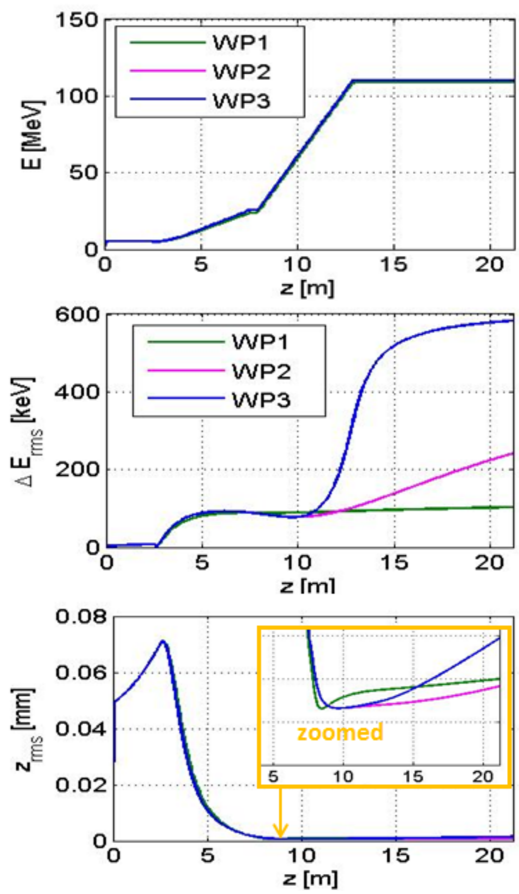

Figure 3: Evolution of the energy, energy spread and bunch length along the line.

The laser spot-size used was assumed transversely flat-top shaped (with $RMS_{x,y} = 40\ \mu m$) and longitudinally Gaussian (with duration $\sigma_t = 124$ fs).

Figures 2 and 3 show the evolution of the transverse and longitudinal beam parameters along the entire line, up to the entrance of the dogleg.

While WP1 and WP3 deliver only locally optimized beam parameters (the best bunch length and best transverse spot-size at Z1 respectively), WP2 represents a stable solution, which keeps a fairly constant small transverse emittance and spot-size up to the entrance of the dogleg, without the need for any additional optics.

Hybrid Compression

Figure 4 shows the longitudinal phase space distributions for WP2 at 2 different locations: Z1 and Z3. In this simulation the quadrupoles installed between the two locations have been kept off and the phase space of the bunch becomes longer only because of the space charge effect along the drift, which is not totally frozen. The phase space of the beam at the entrance of the dogleg (Z3) has a thinner core than the one at the linac exit (Z1). Moreover it exhibits a fairly linear energy correlation that can be used to re-compress it just in

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front of a second experimental area, located at the dogleg exit.

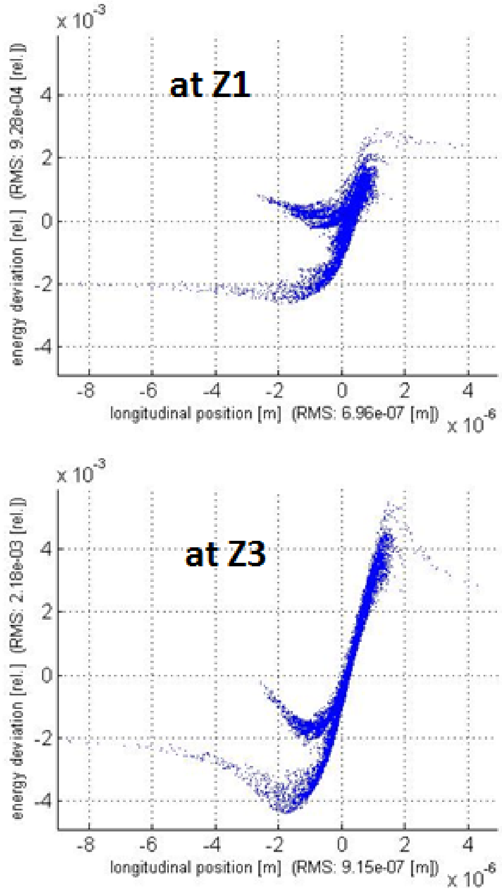

Figure 4: Longitudinal phase space of WP2 at Z1 and at Z3.

We have used the Elegant code [11] to track the beam along the dogleg including the Coherent Synchrotron Radiation (CSR) effect. The phase space of the beam at Z4 is shown in Fig. 5. The chirp provided by the space charge can be tuned by changing for example the solenoid strength around the second travelling wave cavity. However the compensation of the non-linear terms generated by the space charge or by the transit in the dogleg is negligible with respect to the CSR effect.

It is interesting to note that a higher peak current and a shorter bunch duration has been obtained with this method with respect to the presented working points for the velocity bunching case. Anyway we do not exclude that a further optimization of the velocity bunching scheme can bring to better results.

CONCLUSION

We have presented the status of the simulations done for the velocity bunching and hybrid compression schemes foreseen at ARES. By compressing beams of 0.5 pC total charge, a peak current of the order of hundred A is expected, together with 1-2 fs FWHM e-bunch duration.

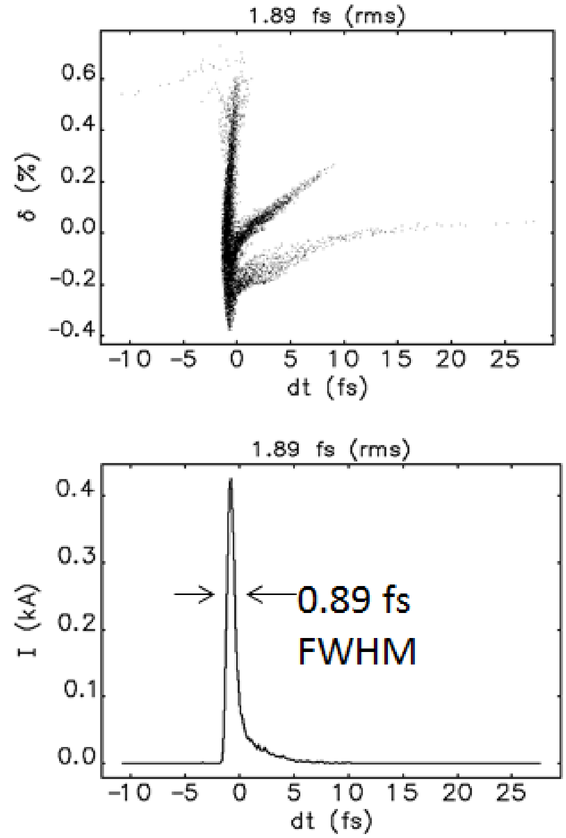

Figure 5: Longitudinal phase space of WP2 at Z4. Linear and quadratic momentum compaction terms of the dogleg in the simulation: R_{56}= 0.5 mm, T_{566}= 14.2 mm. The normalized transverse emittance value at this location is 0.06 mm*mrad in both planes, while the spot-size is not round (σ_x= 9 μm, σ_y= 66 μm)

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