Poster 275

Low Energy Buch Compression with Dogleg Chicane

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Introduction

The objective of the ESCULAP project at LAL-Osay is to inject a relativistic electron beam generated by the photo injector PHIL in a plasma wave excited by the 40 TW Laser LASERIX to perform a laser plasma wakefield acceleration (LPWA) experiment (see poster 239). In order to get an efficient acceleration by the plasma wave the electron bunch (10 pC, 10MeV) need to be compressed from 2ps at the exit of PHIL to less than 100fs at the entrance of the plasma (FWHM value is used in bunch length). Here a dogleg scheme is proposed for performing such compression. This scheme has been optimized through numerical simulation including 3D space charge and CSR. Three numerical codes have been used : ASTRA[1] between the PHIL cathode and the dogleg entrance, then ImpactT[2] up to the entrance of the plasma and finally the interaction with the plasma has been described with WakeTraj (study of linear/non-linear approach with WakeTraj is presented in the poster 252).

Dogleg design principle

Longitudinal compression is based on the following principle, when passing through a bend section, electrons of different energy will travel different trajectories. So, the compression means to match the dispersive parameters of dogleg and the correlated energy spread which is introduced by the acceleration section upstream. The whole beam line is shown in the following figure.

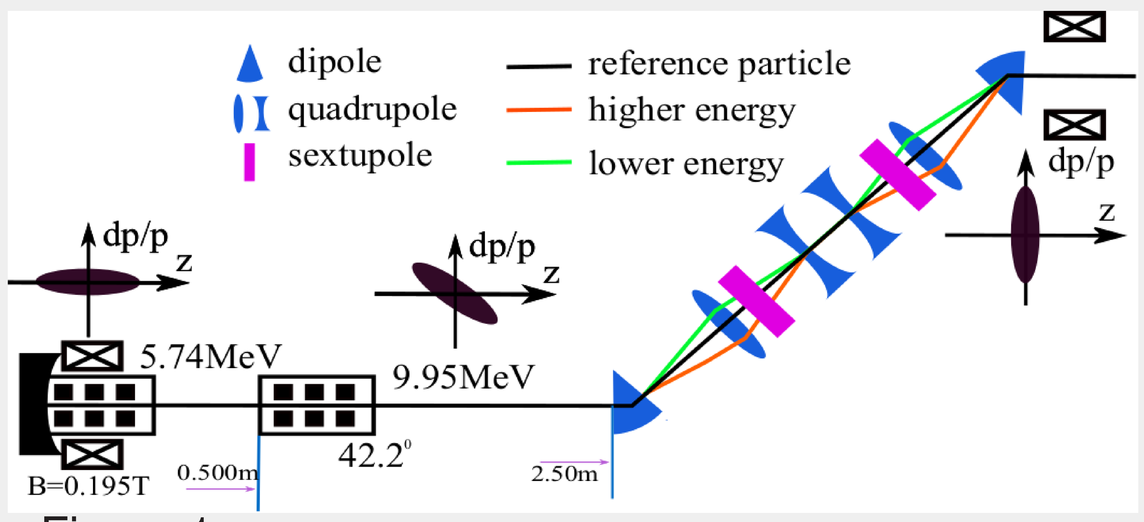

Figure 1: *the schematic of bunch compression line with dogleg*

According to beam optics, final bunch length is related to longitudinal chromatic items and correlated energy spread before injecting into the dogleg. Here only the first two orders are concerned, to fully compress the bunch we need

$$R_{56} = \frac{E_f}{E_f - E_i}\frac{\lambda}{2\pi}cot(\phi_0)$$

$$T_{566} = \frac{1}{2}R_{56}\frac{E_f}{E_f - E_i}\frac{1}{tan\phi_0^2}$$

The correlated energy is introduced by the accelerating section, thus bunch length is sensitive to the acceleration phase jitter, it follows that

$$\frac{\Delta\sigma_{zf}}{\sigma_{zf}} \approx (\frac{\sigma_{zi}}{\sigma_{z_f}} \pm 1)\Delta\phi cot(\phi_0) \qquad (1)$$

Here $\frac{\sigma_{zi}}{\sigma_{z_f}}$ is the compression factor. Consider about the instability we need to make a compromise to choose the compression factor.

Transverse bunch size Control is to match the twiss parameters and control emittance growth. ϵ_x after dogleg fowllows

$$\epsilon_x^2 = det(R_x\epsilon_{x0}R_x^T + \sigma_\delta^2(R_{16}^2 + R_{26}^2) + \langle\delta^4\rangle(T_{166}^2 + T_{266}^2))$$

Dogleg is designed with $R_{16} = R_{26} = 0$, two sextupoles are used to match T_{166}, and T_{566}.

References

[1].http://www.desy.de/ mpyflo/
[2].Qiang J, Lidia S, et al. Physical Review Special Topics-Accelerators and Beams, 2006, 9(4): 044204.

Bunch Compression, Focus and Acceleration

The dogleg configuration is symmetric, as shown in Fig. 2, all magnets have a thickness of 10cm, and for reducing the total size, we set the parameters as $L_1 = 0.45$m, $L_2 = 0.30$m, $L_3 = 0.12$m. For the dipoles, bend angle is $\theta = \pi/4$, bend radius is $\rho = 0.32$m. Quadrupoles strength are $k1 = 38.60/\text{m}^2$, $k2 = -19.70/\text{m}^2$, in order to make $\eta_x = 0.00$m and minimize the maximum β along the dogleg. $ks = 616.1/\text{m}^3$ thus T_{566} can partially cancel the rf curvature effect.

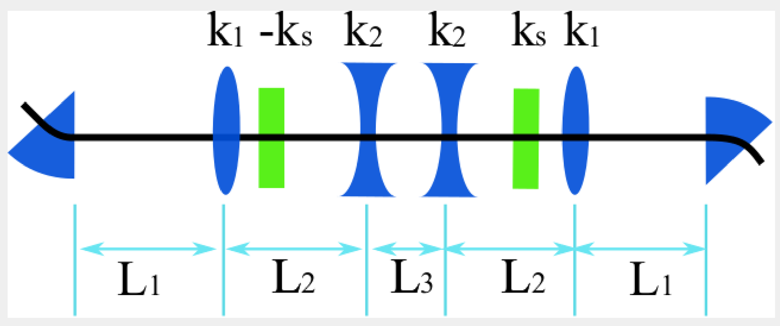

Figure 2: *schematic of dogleg*

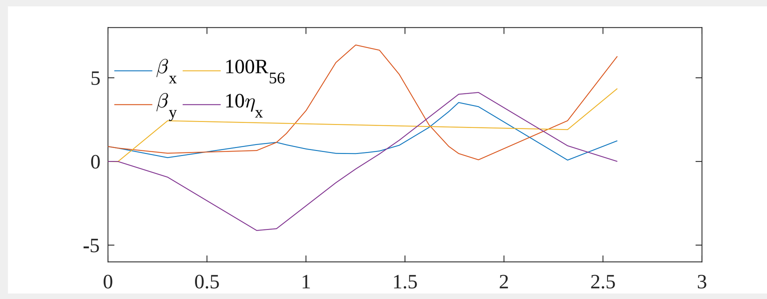

Figure 3: *twiss parameter and R56*

In upstream of dogleg, electron bunch is accelerated off crest, thus an energy chirp $k = 23.19/\text{m}^2$ is introduced to the bunch, the distribution before dogleg is shown in Fig. 4

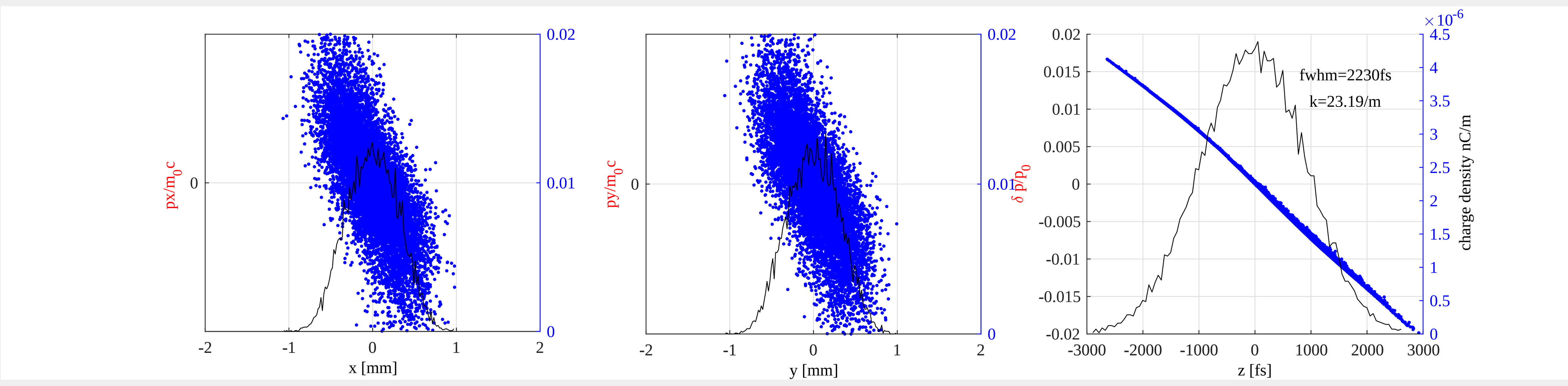

Figure 4: *The phase space of electron bunch before dogleg, energy chirp introduced by off crest acceleration*

This electron bunch is then compressed to 96fs (longitudinal) with dogleg, and finally focused to 0.06mm (transverse) with a solenoid. After dogleg, electron bunch is a little over compressed, this may partially compensate the length growth in focus section. Some parameters are listed in the following table, the unit of emittance is $\text{mm} \cdot \text{mrad}$.

Table I *Emittance and bunch size after compression and focus*

position	ϵ_{nx}	ϵ_{ny}	σ_x(mm)	σ_y(mm)	fwhm length (fs)
bf compression	2.1	2.1	0.31	0.31	2230
af compress@(no space charge,CSR)	2.2	2.5	0.42	0.85	62
af compress@(space charge, CSR)	2.2	2.5	0.43	0.86	96
af focus	4.8	3.8	0.059	0.054	106

According to the table, space charge and CSR have little effect on transvers emittance and size, but lead to 55% growth in longitudinal bunch length. The solenoid can focus the bunch in both x and y plane but may introduce phenomenal emittance growth by disperssive items. Electron bunch before injected into plasma is shown in figure5(a-c), it is tracked in plasma with WakeTraj, plasma density is $2\times10^{17}/\text{cm}^3$, laser density is $1.4\times10^{18}\text{W}/\text{cm}^2$. Longitudinal phase space at the exit of the plasma is shown in Fig. 5d (preliminary results)

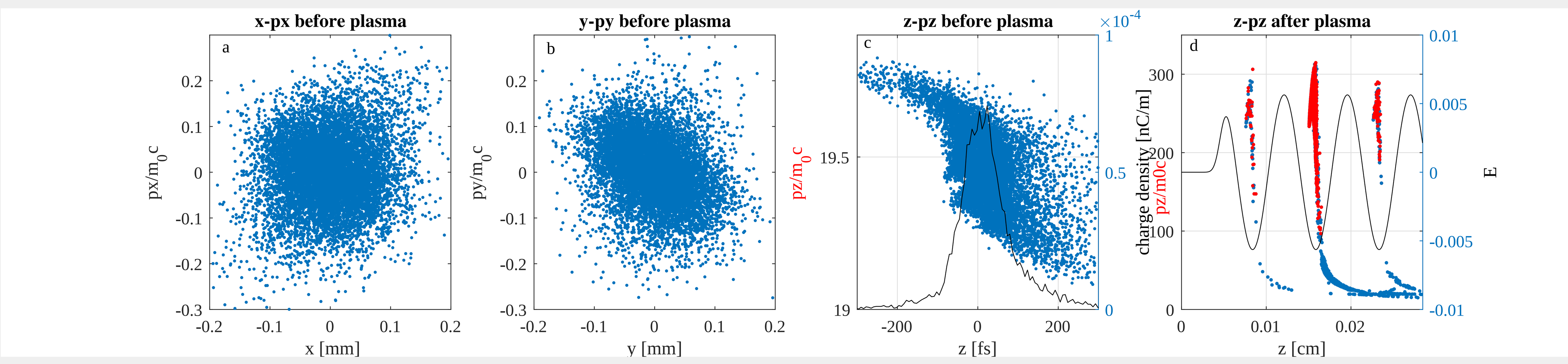

Figure 5: *Electron properties at the entrance (a-c) and at the exit (d) of a 9 cm long plasma cell. In (d) 50% of the injected electrons have a γ larger than 100.*

Conclusion

We have analyzed through numerical simulation the compression of an electron bunch in relation with the ESCULAP project. The results show that, in our conditions, space charge and CSR have significant effects only on the bunch duration. We propose an optimized configuration for which the bunch has been compressed up to 100fs FWHM. At this value the bunch can be efficiently trapped by the plasma wave and accelerated up to energies above 150MeV. Improvement of the experimental configuration is still going on in order to improve the performance of the laser-plasma accelerator and to diagnose the electron beam properties.