External Injection Into a Laser-Driven Plasma Accelerator With Sub-Femtosecond Timing Jitter.

A. Ferran Pousa[1,2], R. Assmann[1], R. Brinkmann[1], A. Martinez de la Ossa[1,2].

[1] Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg, Germany.

[2] Universität Hamburg, 22761 Hamburg, Germany.

Laser-Driven Plasma Wakefield Acceleration (LWFA)

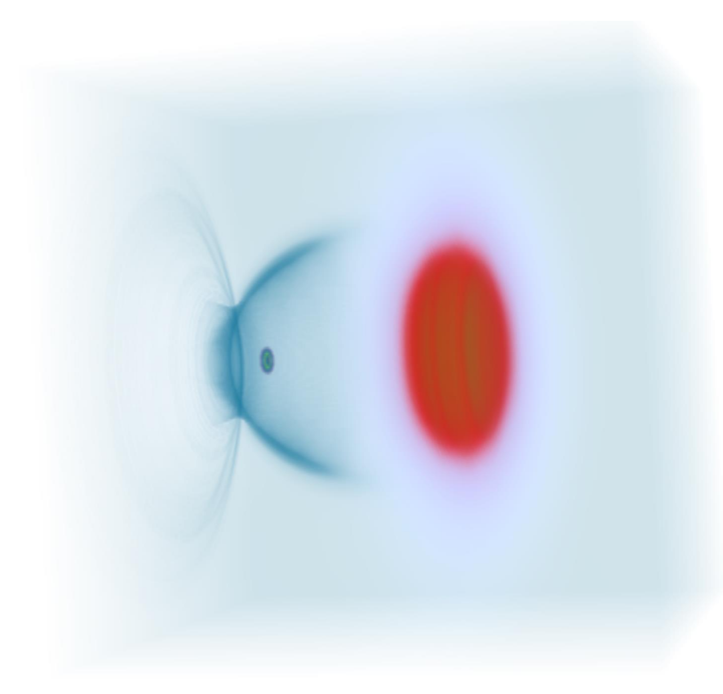


Figure 1. 3D visualization of an OSIRIS [1] LWFA simulation, the 3D render was made with VisualPIC [2].

- LWFA offers accelerating gradients on the **hundreds of GV/m,** but the **beam quality is not yet on par** with standard RF accelerators**.**
- **External injection** allows better control over beam parameters, which can be tuned to **minimize emittance and energy spread growth** in the plasma.
- However, **extremely low timing jitter** between laser driver and electron beam is required.

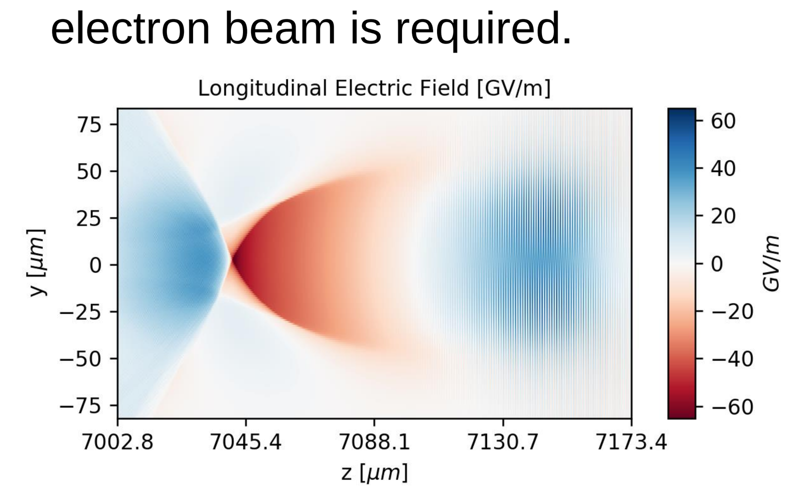


Figure 2. 2D cut of the accelerating field inside the bucket.

External injection **requires extremely low timing jitter.**

A Scheme for Timing Jitter Compensation

First Plasma Stage

A first plasma stage can be used to **correlate arrival time and beam energy.**

$$E_z' = \frac{mc^2}{e}\sqrt{\frac{\pi}{2}}a_0^2 k_p^3 \sigma_z e^{-\frac{k_p^2\sigma_z^2}{2}}$$

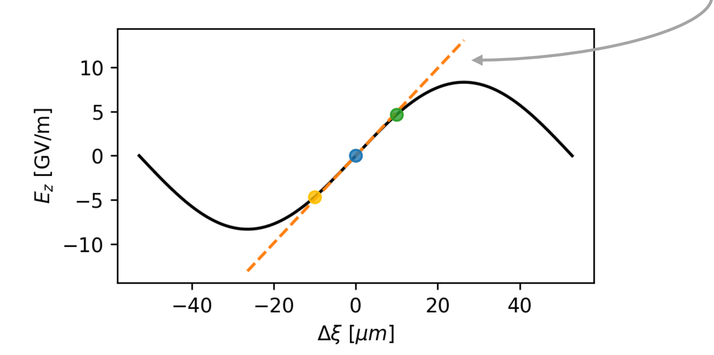


Figure 3. Accelerating field inside the first plasma stage.

Chicane

This correlation can then be used by a chicane in order to **remove the initial arrival time jitter.**

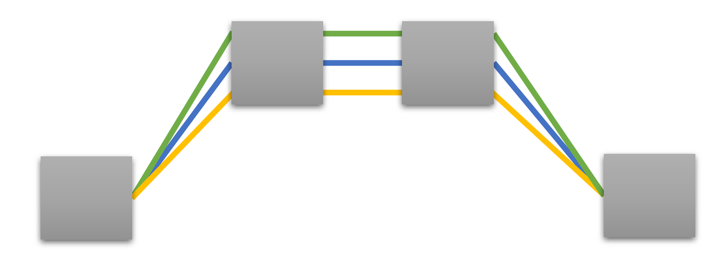


Figure 4. Illustration of the energy-dependent trajectories in the chicane.

In the chicane, beams will experience **different path length depending on their mean energy**.

A **chicane** coupled to a plasma stage **can reduce the timing jitter**.

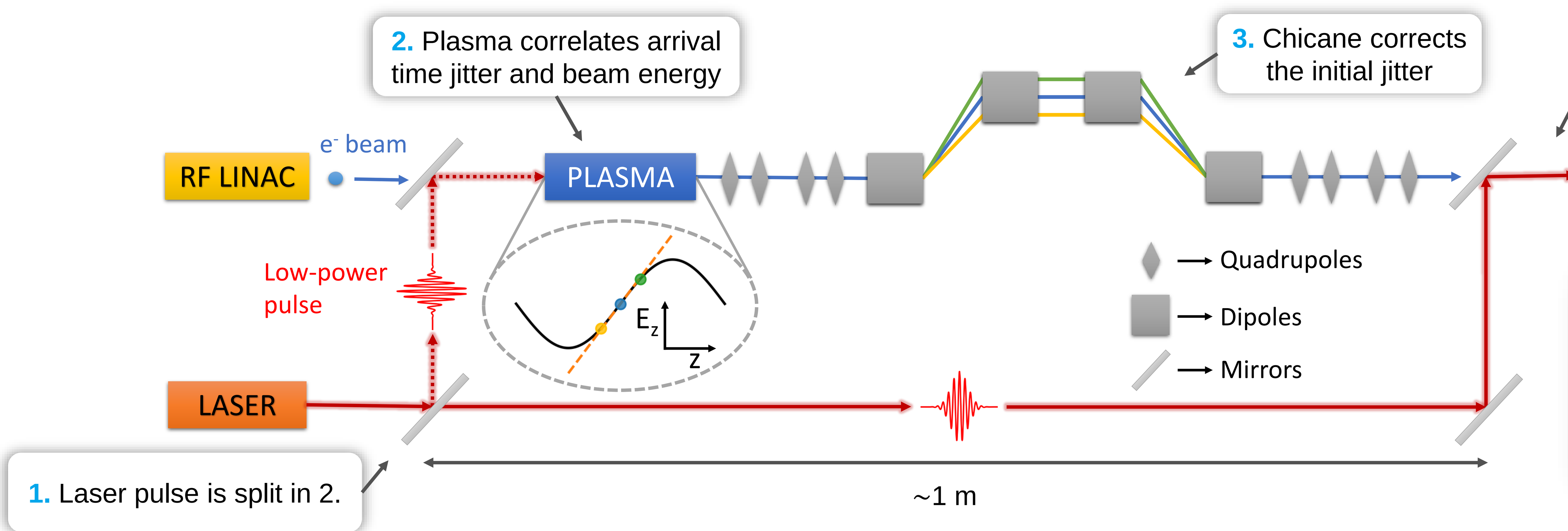
Linear Model

For a linear plasma wake, the R_{56} at the chicane can be approximated as:

$$R_{56} = -\sqrt{\frac{2}{\pi}}\frac{E_0}{mc^2 a_0^2 k_p^3 \sigma_z L_p} e^{\frac{k_p^2\sigma_z^2}{2}}$$

If the laser length satisfies the resonant condition ($\sigma_z k_p = 1$):

$$R_{56}[\mathrm{mm}] = -7.27\times 10^{13}\frac{E_0[\mathrm{MeV}]}{a_0^2 n_p[\mathrm{cm}^{-3}] L_p[\mathrm{mm}]}$$



Objective

Reduce an initial jitter of 10 fs down to sub-fs level.

Start-to-end Simulations (until end of chicane).

Laser (weak pulse)	
λ	800 nm
Energy	3.5 J
a_0	0.6
Peak Power	35 TW
w_0	54 µm
L_{FWHM}	93 fs (in intensity)
First Plasma Stage	
Density	10^{17} cm^{-3}
Length	2 mm
Electron Beam	
Charge	0.1 pC
Energy (spread)	100 MeV (0.1%)
Norm. emitt.	0.3 mm mrad
$\sigma_{x,y}$	1.3 µm
σ_z	1 fs
Quadrupoles	
Length	1 cm
K	-878, 1406, -1497, 823 m^{-2}
Dipoles	
Length	10 cm
Bending angle	2.19 °

Table 1. Simulation parameters.

- Beam offsets between -20 and 20 fs have been tested.
- The simulation codes used were: OSIRIS (plasma stage), WinAGILE [3] and MAD-X [4] (lattice optimization) and ELEGANT [5] (beam tracking).

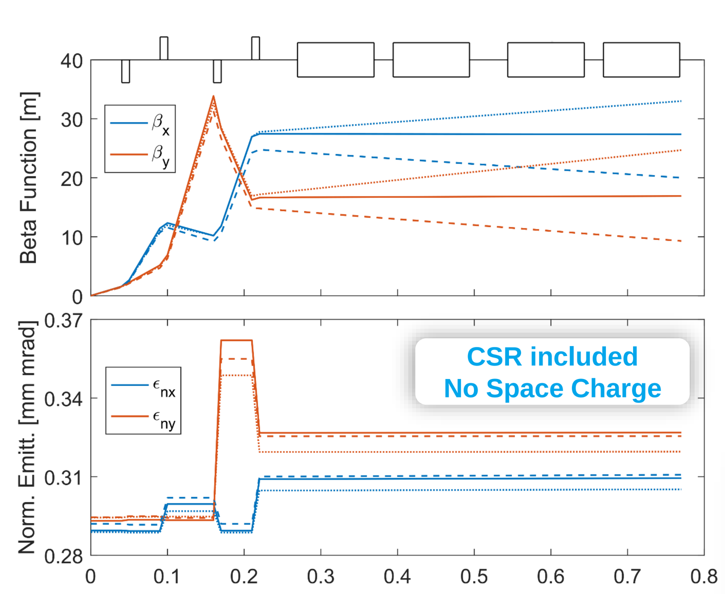


Figure 5. Beam evolution after first plasma stage.

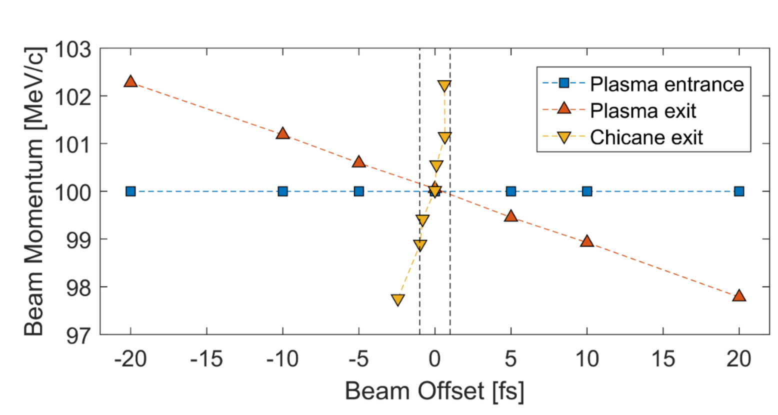


Figure 6. Jitter correction thanks to plasma stage and chicane. The vertical lines delimit a 1 fs jitter.

Simulation Results

- All **beam offsets between ±10 fs have been reduced to sub-fs level**, showcasing the potential of this method.

Timing jitter can be **reduced to sub-fs level** with **minimal loss of beam quality.**

Conclusion

- Simulation results show that **this scheme can provide sub-fs timing jitter**.
- Further studies are required to **determine the stability and tolerances** of the setup and the influence of space charge effects.
- Also, although only ultrashort beams have been tested, it is possible that for longer beams **this scheme could be used both for beam synchronization and compression**.

References

A Ferran Pousa *et al* 2017 *J. Phys.: Conf. Ser.* 874 012032.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 653782.