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External Injection with Sub-Femtosecond Timing Jitter

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EuPRAXIA 1st Collaboration Week - WP2 meeting

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Outlook

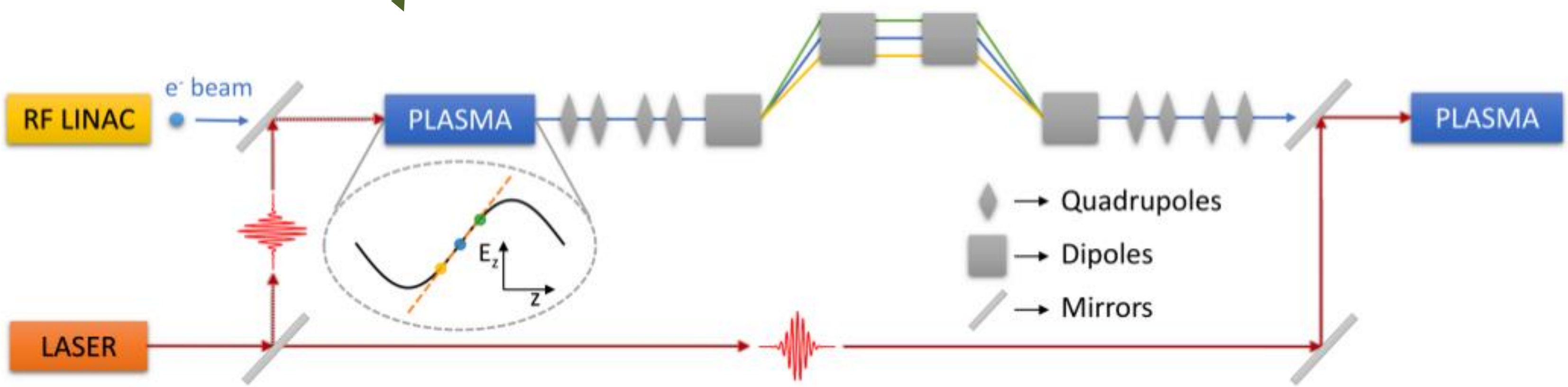
- Main idea.
- Linear model.
- Simulation setup and results.
- Some concerns.
- Conclusion.

Overview of the Scheme

Horizon 2020

Chicane corrects the initial jitter

Plasma correlates arrival time jitter and beam energy



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

A. Ferran Pousa, R. Assmann, R. Brinkmann, A. Martinez de la Ossa, "*External Injection with Sub-Femtosecond Timing Jitter*", Proc. IPAC 17.

Linear Model

- R_{56} required at the chicane:

$$R_{56} = -\frac{E_0}{eE_z{}'L_p}$$

E_0 - reference energy of the beam.
E_z' - Slope of the accelerating field.
L_p - length of plasma stage.

- Assuming plasma in the linear regime:

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

Typically < 1 mm!

- If the laser spot size is matched to the plasma ($\sigma_z k_p = 1$):

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

Simulation Setup

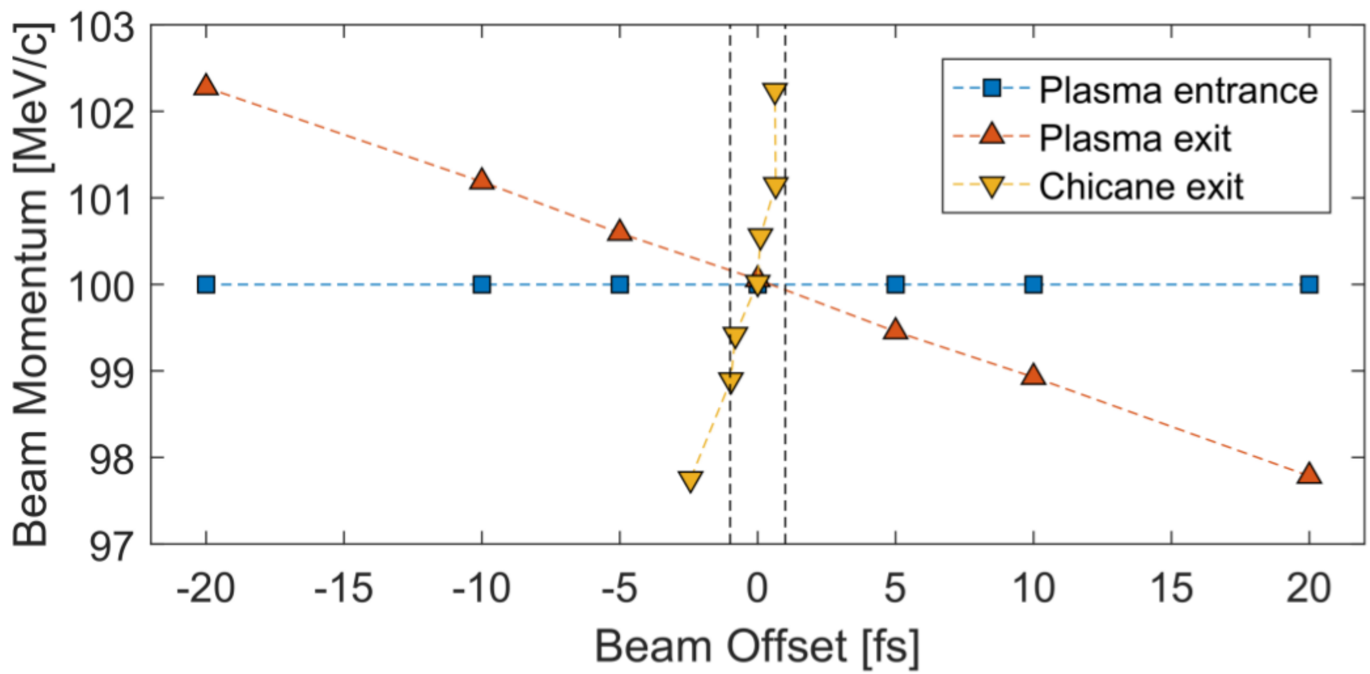
Laser (weak pulse)	
λ	800 nm
Energy	3.5 J
a_0	0.6
Peak Power	35 TW
w_0	54 μm
L_{FWHM}	93 fs (in intensity)
First Plasma Stage	
Density	10^{17} cm^{-3}
Length	2 mm
Electron Beam	
Charge	0.1 pC
Energy (spread)	100 MeV (0.1%)
Norm. emitt.	0.3 mm mrad
$\sigma_{x,y}$	1.3 μm
σ_z	1 fs
Quadrupoles	
Length	1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

- Laser with roughly 3% of the EuPRAXIA pulse energy.
- Electron beam parameters chosen similar to ARES linac for SINBAD. Charge chosen not to have significant beam loading.
- Relatively high plasma density and laser power to allow for a shorter plasma stage (and save computational time).
- Beamline after plasma incudes CSR effects but no space charge.

Osiris dev + ELEGANT

Simulation Results

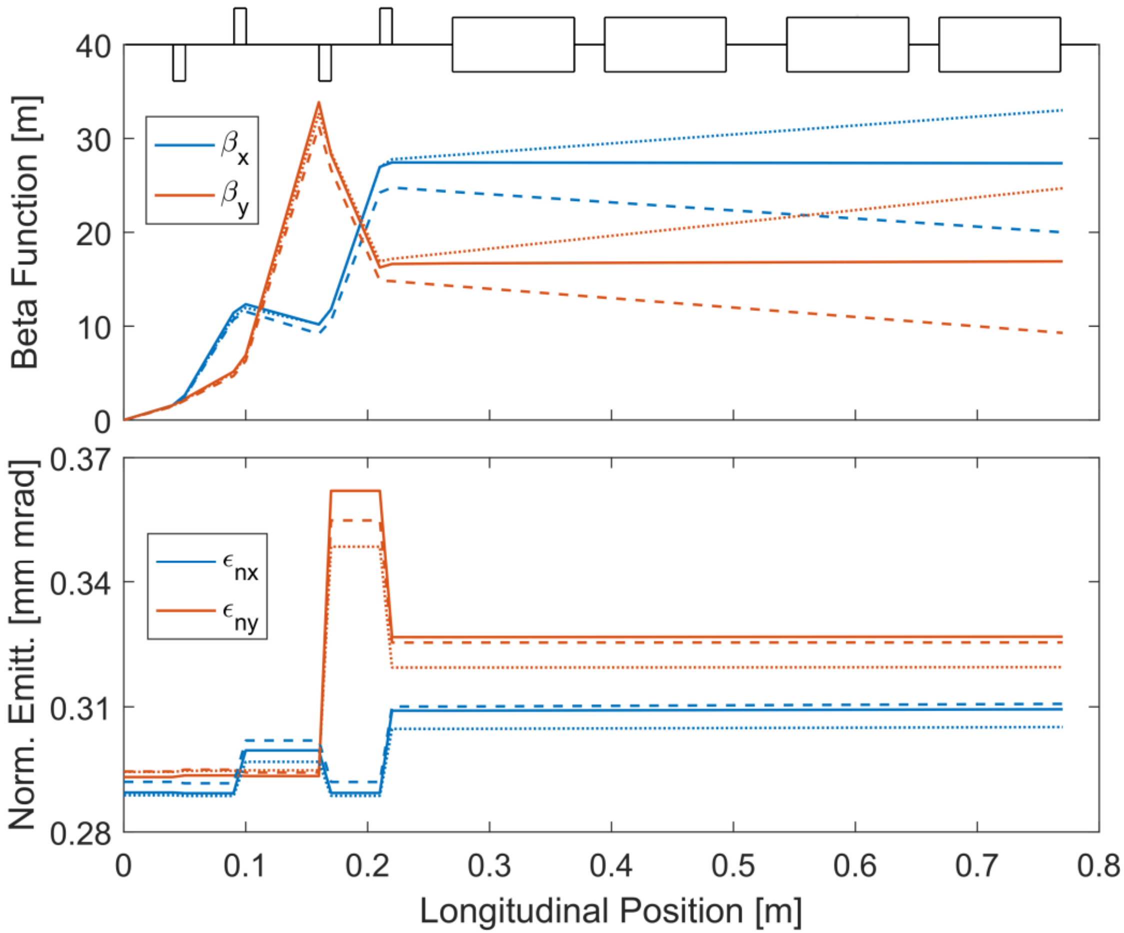
> Arrival time jitter correction:



Initial jitter of 10 fs reduced to sub-fs level

Simulation Results

- Beam evolution:

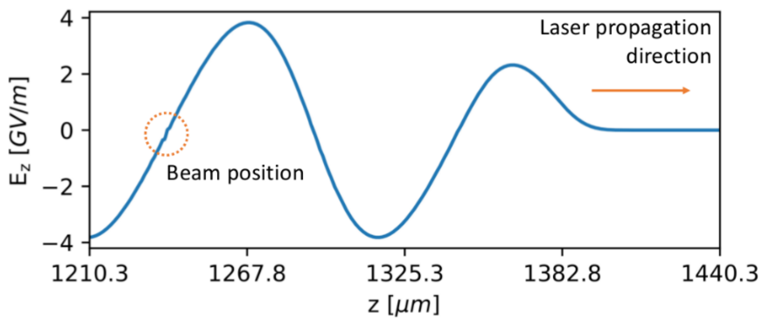


No offset
-20 fs offset
20 fs offset

- 10-20% Emittance increase.
- Chromatic effects at the quadrupoles.

Some Concerns

- Energy kick given to the beam should be significantly higher than its initial energy spread.
- Strong beam loading should be avoided (limit on charge). If significant, it has to be taken into account to calculate the R_{56}.



- R_{56} of the drift space should be taken into account.

Conclusions

- Timing jitter of 10 fs can be reduced to sub-fs level.
- Higher jitter can be corrected with lower plasma densities.
- More beam charge can be accepted by going to higher density or laser power.
- Some way of correcting chromatic effects is needed.
- Study stability and tolerances.