# High transformer ratio resonant PWFA working point design for EuPRAXIA@SPARC_LAB

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## Summary

We designed and numerically tested an **ideal working point** for **plasma wakefield acceleration beam driven** in **external injection** in the context of the **EuPRAXIA project[1]**.

By means of a 2.4 m plasma module we simulated the acceleration of a **30 pC** electron bunch from the injection energy of **1.2 GeV** up to **5 GeV**.

The acceleration is performed by means of an ideal **train of 4 bunches** (3 drivers and 1 witness).

The working point was designed and optimized to maximize the energy transfer and to preserve the witness quality.

## The EuPRAXIA@SPARC_LAB linac

The working point parameters are compatible with the possibilities of the RF linac of the EuPRAXIA site in Frascati (**EuPRAXIA@SPARC_LAB[2]**) .

The linac itself consists of an S-band photo-injector and an X-band energy booster.

The linac is designed in order to be able to produce trains of bunches with a controlled shape and an energy up to 1.2 GeV.

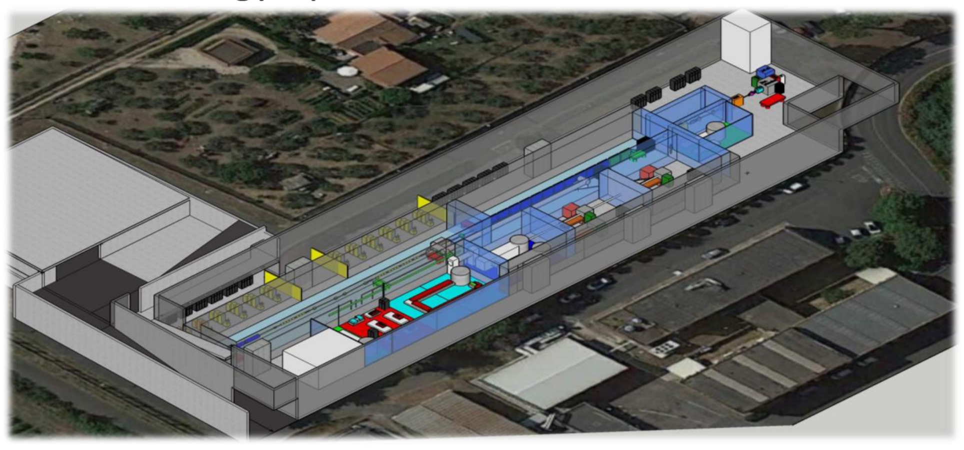

**Fig. 1** Preliminary design of the EuPRAXIA@SPARC_LAB facility

## Simulation code and plasma parameters

The simulations have been performed by means of the hybrid kinetic-fluid code ***Architect*[3]**.

The mesh grid is squared with a dimension of $1\mu m \times 1\mu m$.

The simulated plasma channel consists in a 2.4 m long plateau with a plasma density $\mathbf{n_p = 2.5 \cdot 10^{16}\ cm^{-3}}$ and preceded by a 1 cm long injection ramp.

## Transverse matching

Both drivers and witness were initialized with twiss functions $\beta_{x,y} = 18\ mm$ $\alpha_{x,y} = 1$ in order to achieve the transverse matching condition at the beginning of the plateu

$$\beta_m = \frac{\sqrt{2\gamma}}{k_p}$$

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## Transformer ratio $R_T$ and resonant schemes

In beam driven schemes the **transformer ratio** is a merit factor that describes the energy amount that can be transferred from driver(s) to witness and can be defined as the ratio between the maximum accelerating field acting on the driver(s) and the maximum decelerating field acting on the witness

$$R_T = \frac{|E^{+}_{max}|}{|E^{-}_{max}|}$$

A **train of N bunches[4]**, longitudinally separated by half plasma wavelength $\lambda_p/2$ and with ramped increasing charges can reach a transformer ratio $\mathbf{R_T \approx 2N}$.

**Driving bunches parameters**

- $\gamma = 2348$
- $\varepsilon_{n(x,y)} = 1mm\ mrad$
- $\sigma_z = 33\mu m$
- $Q_{tot} = 40 + 140 + 270pC$

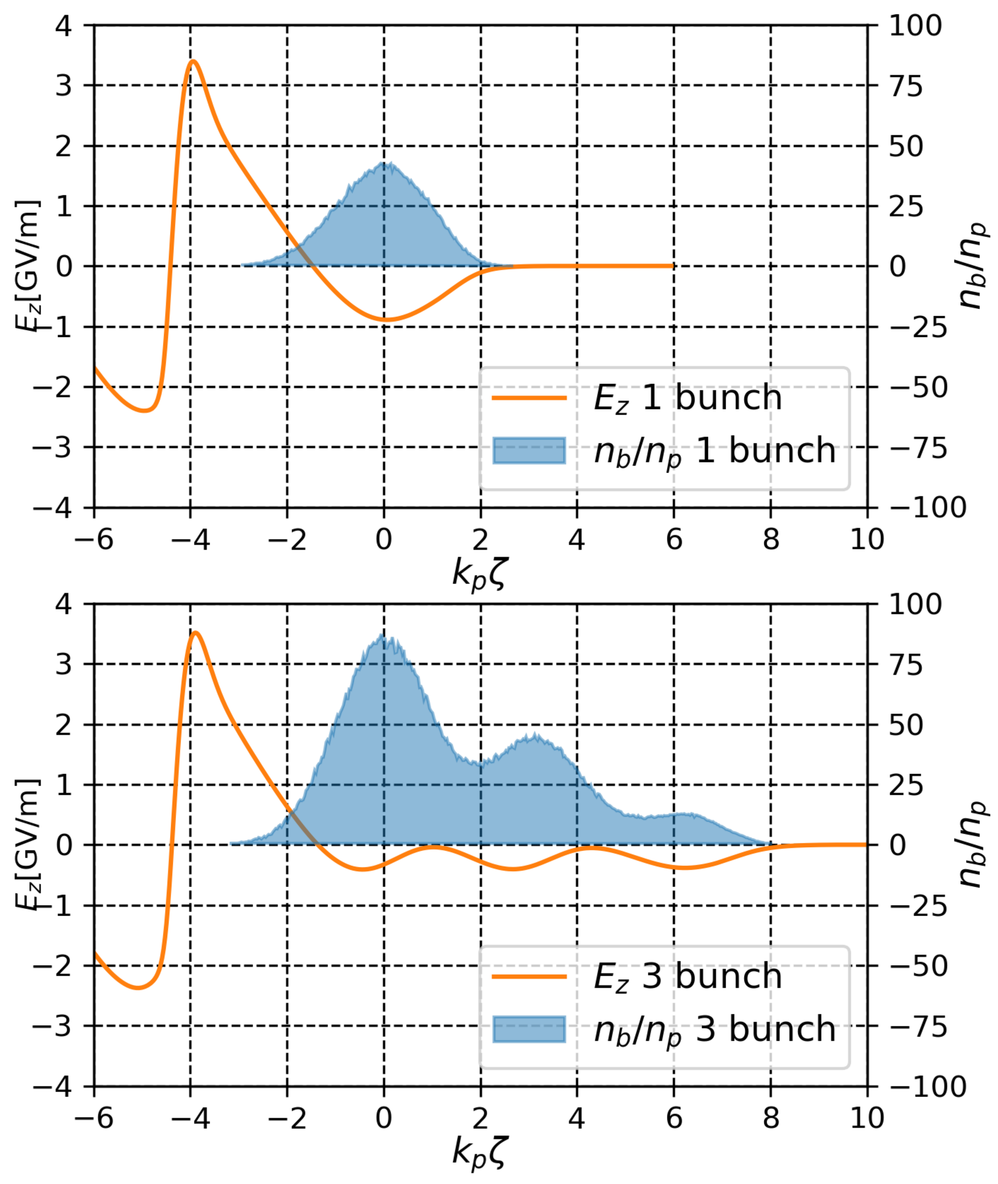


**Fig. 2** Density on axis and relative longitudinal field for 1 driver scheme and 3 drivers scheme.

## Witness acceleration

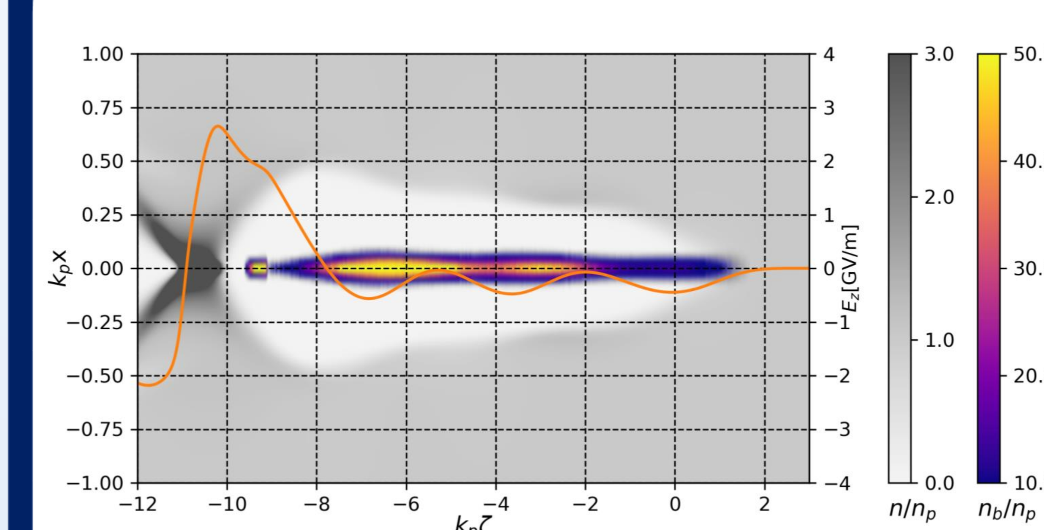


**Fig. 3** Density distribution of bunches and plasma during the acceleration and relative accelerating field.

To preserve the energy spread during the evolution, the witness is injected with **a triangular current shape**.

**Witness bunch parameters**

- $\gamma = 2348$
- $\varepsilon_{n(x,y)} = 0.7mm\ mrad$
- $\sigma_z = 16(3.8\ rms)\mu m$
- $Q = 30pC$

## Witness evolution

$E_z = 1.65GV/m$

$R_T = 3.65$

$\gamma_{fin} = 9800\ (5\ GeV)$

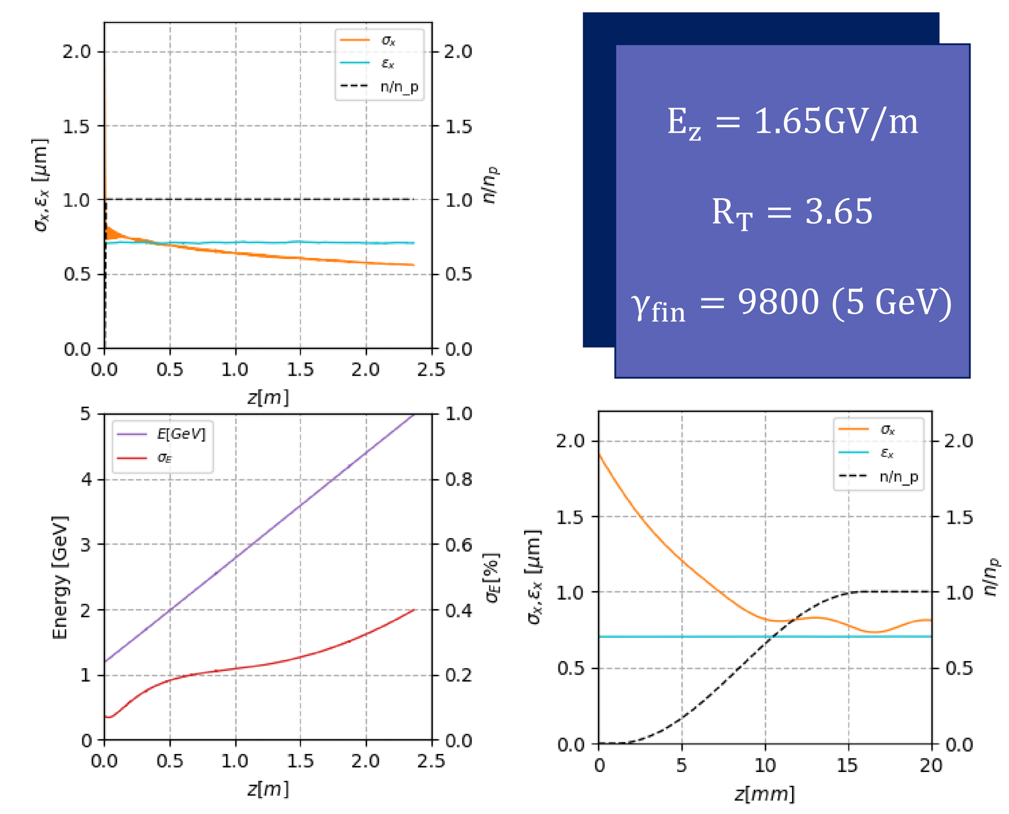


**Fig. 4** Witness macroscopic parameters evolution (on the right) and detail of the witness focusing inside the plasma ramp (on the left)

The witness separation respect to the last driver has been optimized to $\mathbf{\Delta z \approx 0.46\ \lambda_p}$ in order to minimize the energy spread growth.

The beam loading generated by witness dramaticaly decreases the accelerating gradient (3.5 → 1.65 GV/m) and the transformer ratio (7.5 → 3.65). These parameters are still sufficient to accelerate the witness up to 5 GeV In 2.4 m.

The final energy spread is $\mathbf{\sigma_E = 0.4}$ % and the transverse emittance is totally preserved.

## Witness phase space evolution

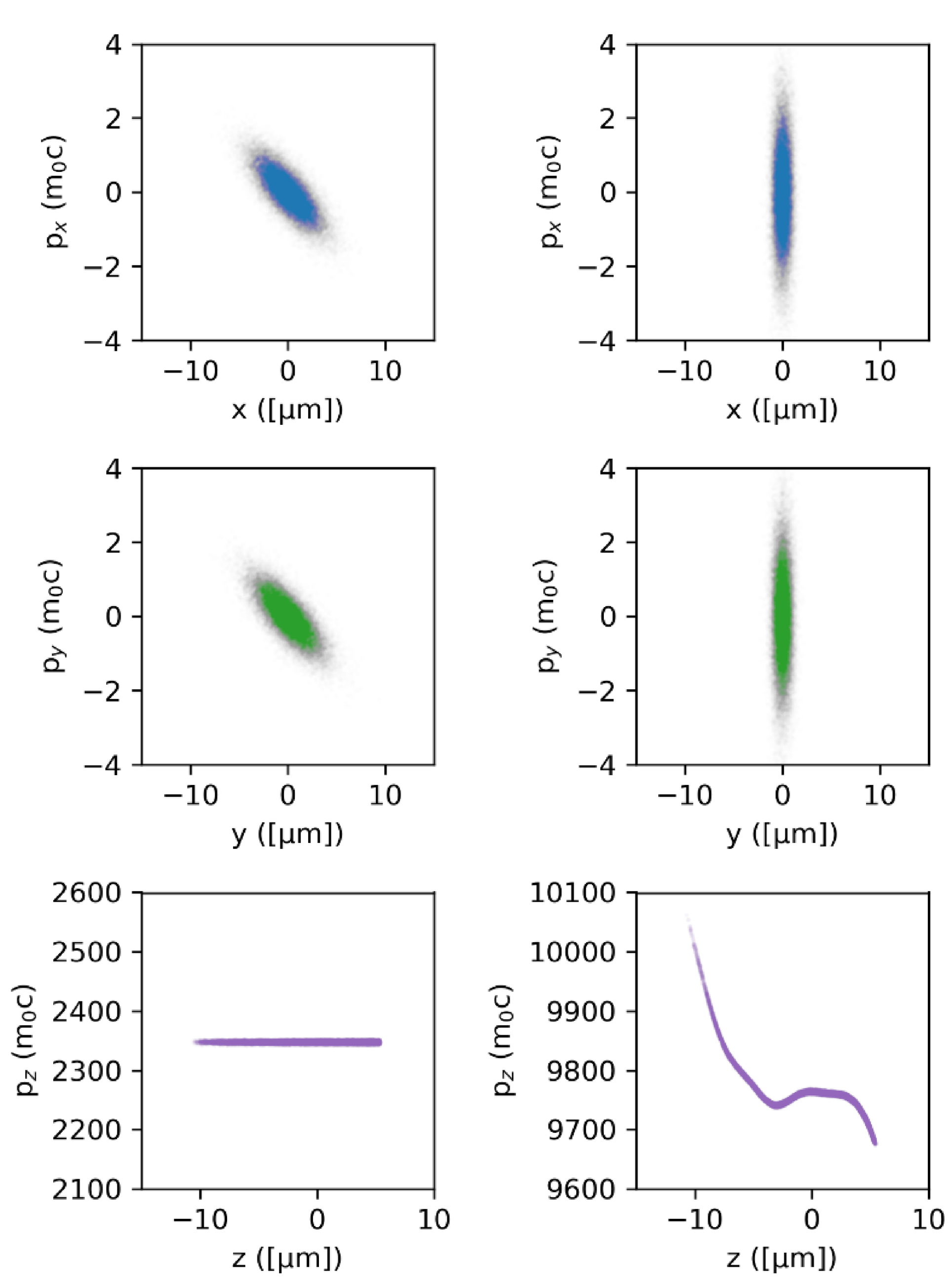


**Fig. 5** Witness phase space at the initialization and at the end of the plasma channel

**List of references**

[1)]**Walker, Paul Andreas, et al.** "Horizon 2020 EuPRAXIA design study." Journal of Physics: Conference Series. Vol. 874. No. 1. IOP Publishing, 2017

[2)]**Giribono, A., et al.** "EuPRAXIA@ SPARC_LAB: The high-brightness RF photo-injector layout proposal." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 909 (2018): 282-285.

[3)]**A. Marocchino et al.**, Efficient modeling of plasma wakefield acceleration inquasi-non-linear-regimes with the hybrid code Architect, Nuclear Instruments and Methods in Physics Research A 829 (2016) 386–391.

[4)]**Tsakanov, V. M.** "On collinear wake field acceleration with high transformer ratio." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 432.2-3 (1999): 202-213.