Simulation of a linear density gradient in the second plasma section

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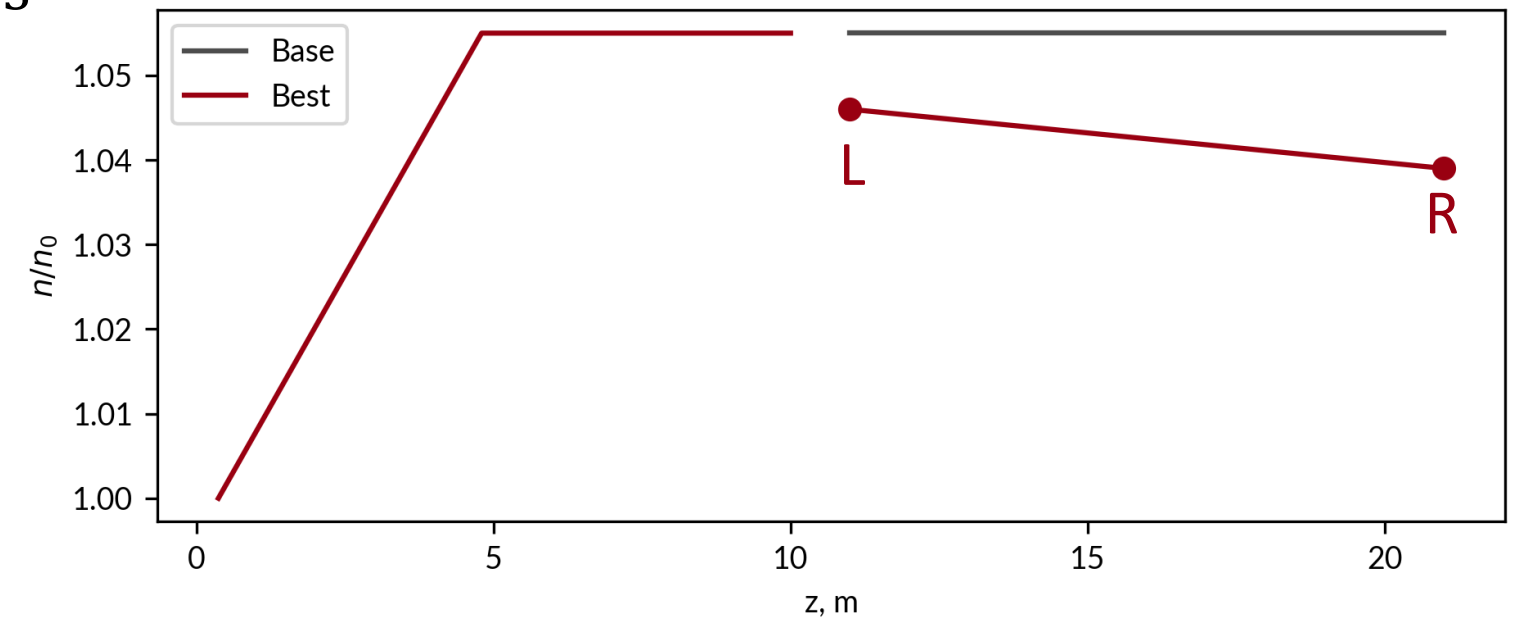
MOTIVATION

- Usually we try to save the driver. Here we try to extract the maximum energy from the driver to get the maximum acceleration after 10 meters
- The negative plasma density gradient in the second section can lead to an increase in the electron energy (why not)
- CM (07.10.22): electron energy is 14% higher
- PEB (27.01.23): electron energy is 35% higher

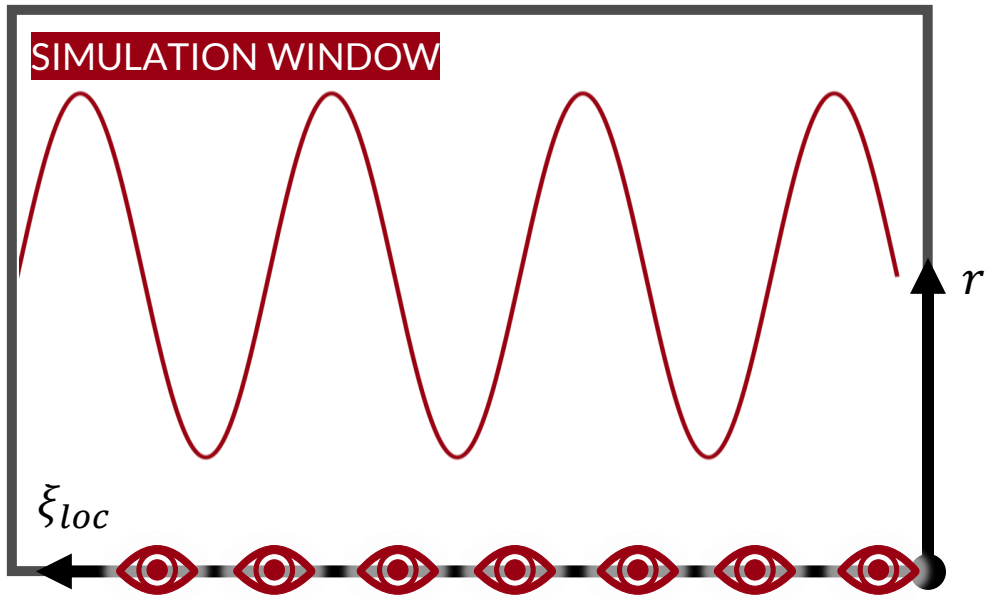
- This work is a PEB repeat with an additional effect

NOTATION

The gradient notation L-R (e.g. “4.6%-3.9%”) means:
n/n_0 at point L is $1 + L/10^2 = 1.046$,
n/n_0 at point R is $1 + R/10^2 = 1.039$,
where $n_0 = 2 \times 10^{14} cm^{-3}$



PREDICTED ELECTRON ACCELERATION



- Viewpoints are distributed uniformly along the ξ axis ($\xi = \mathrm{z} - \mathrm{ct}$)
- The electric field E_z is time integrated at viewpoints
- A viewpoint is eliminated if enters the defocusing phase
- We get the distribution of energies along the ξ axis

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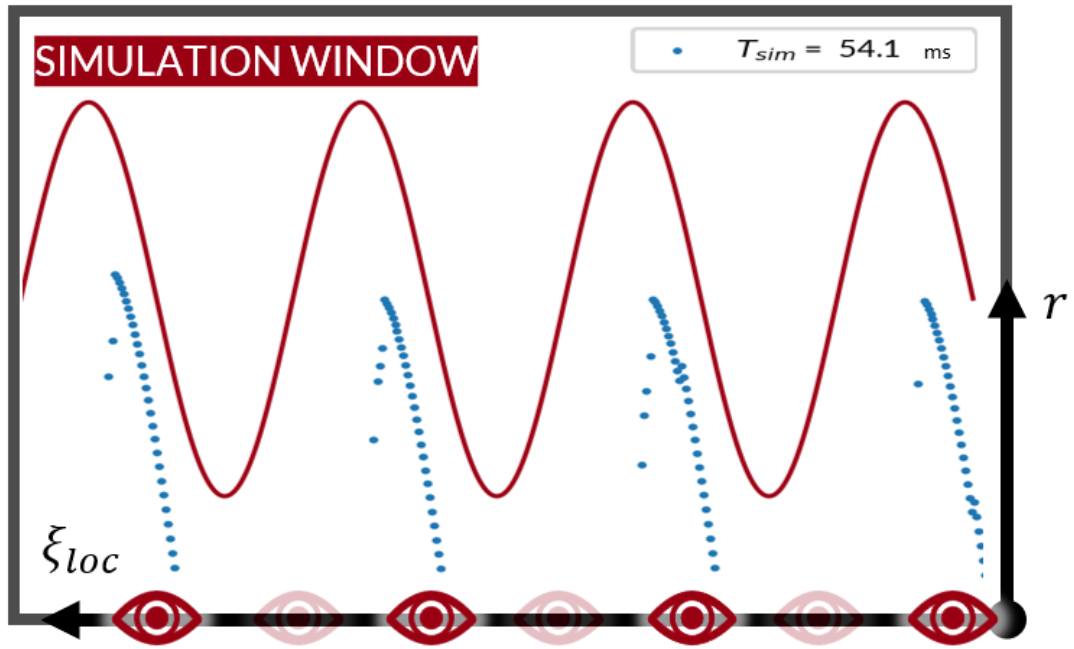

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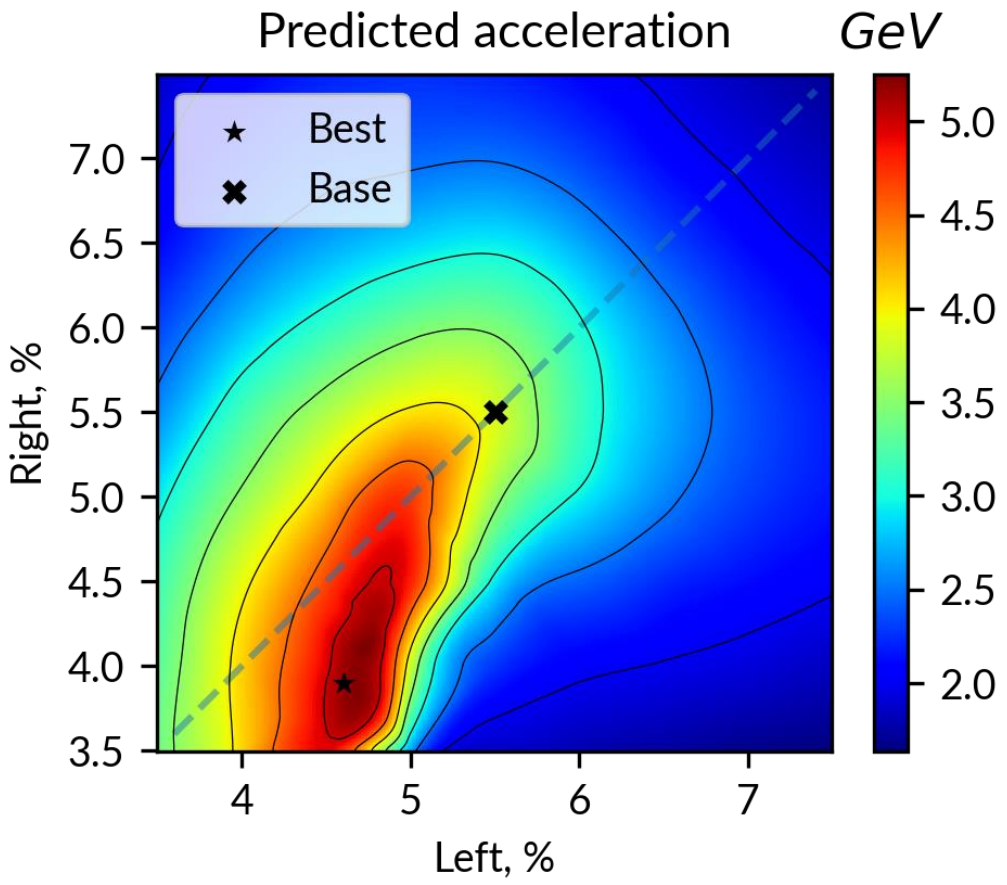

- The best case is 35% better than the base case
- Highest energy region is in the negative gradient region
- 130 points are calculated
  (~13000 CPU hours)

Base — 5.5%-5.5%

Best — 4.6%-3.9%

DRIVER EVOLUTION

We characterize the driver bunches with the effective current

$$I_{eff}(\xi) = A \sum_{\xi_i \in (\xi, \xi+\Delta\xi)} q_i \cdot K_0\,(r_i),$$

where:

q_i — macroparticle charge
r_i — macroparticle radius (dimensionless)
ξ_i — longitudinal coordinate
K_0 — modified Bessel function
A — normalizing factor

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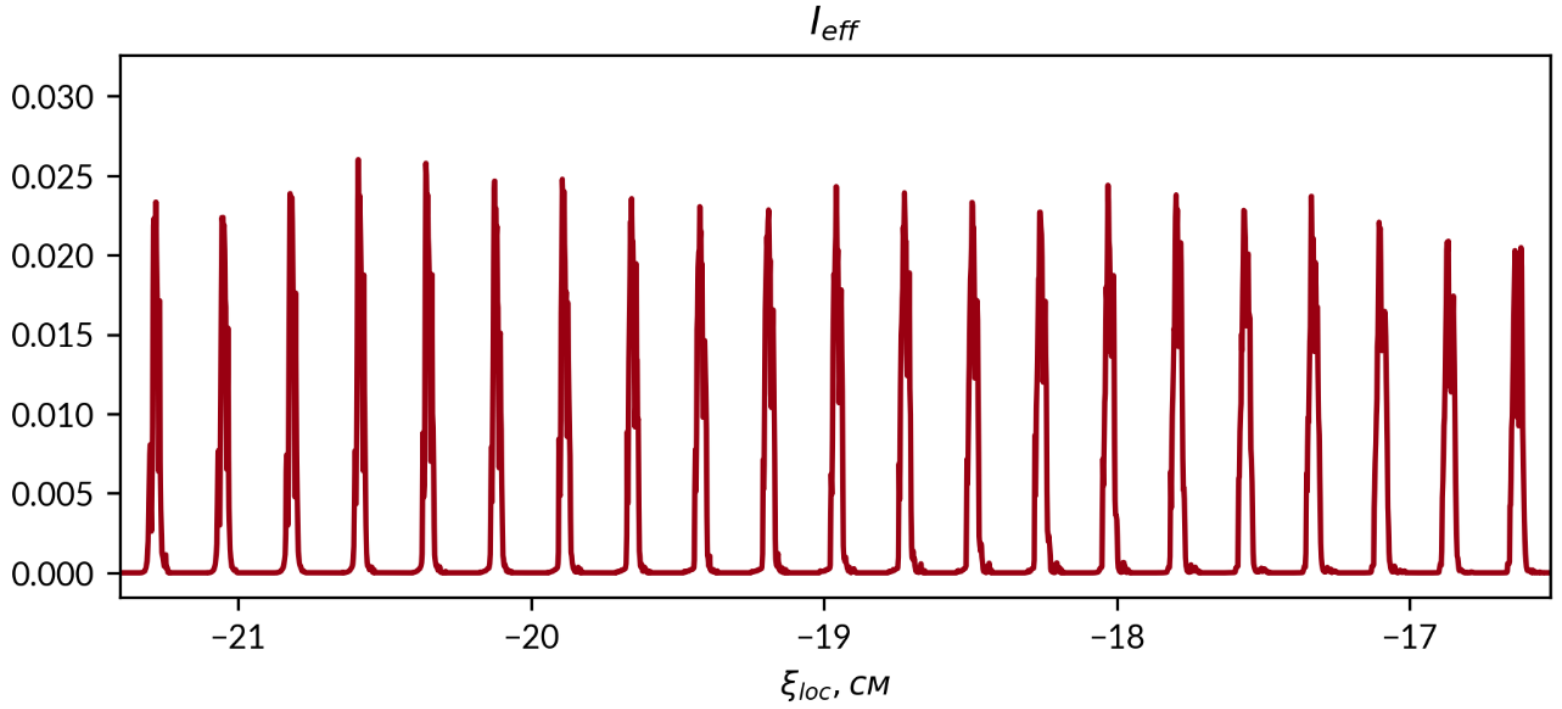
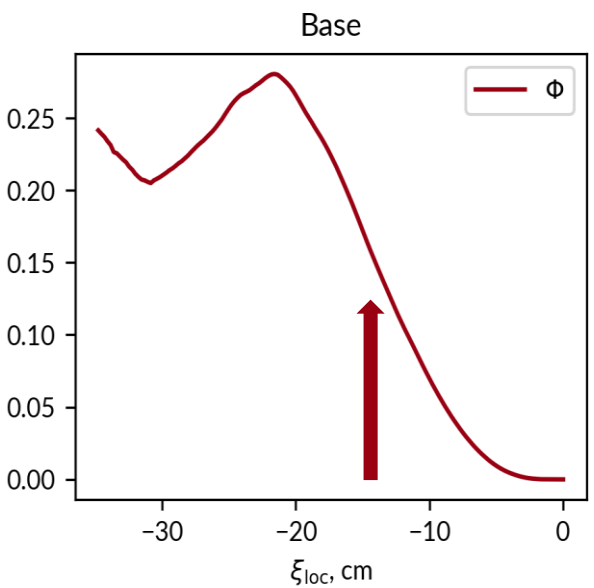
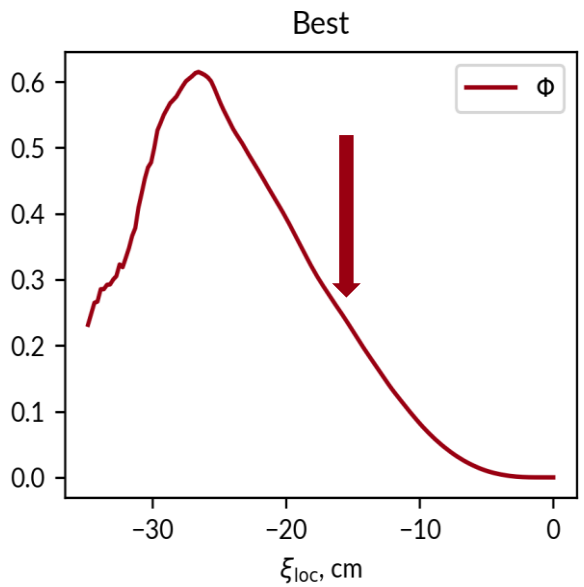


DRIVER EVOLUTION

We look at microbunches located in the region of fastest growth of the wave amplitude ($\xi_{loc} \cong -15cm$)





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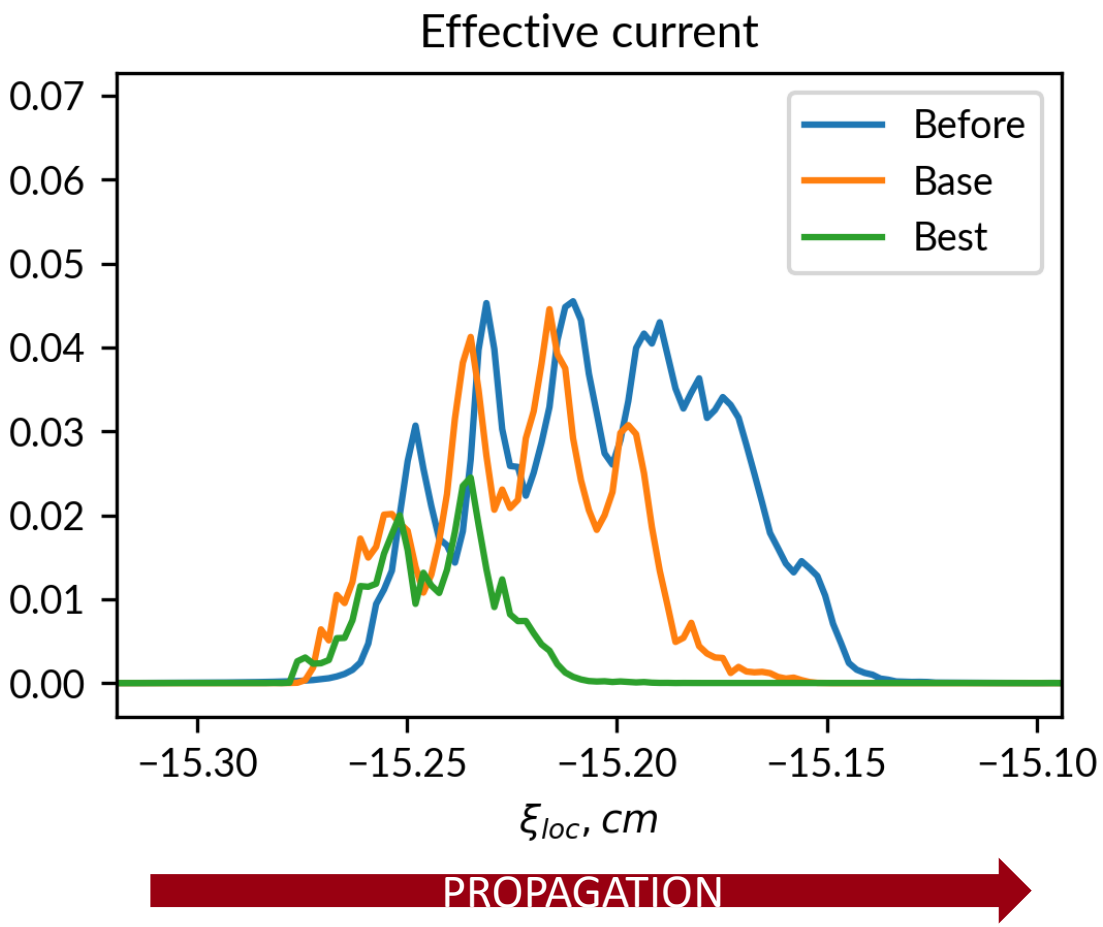
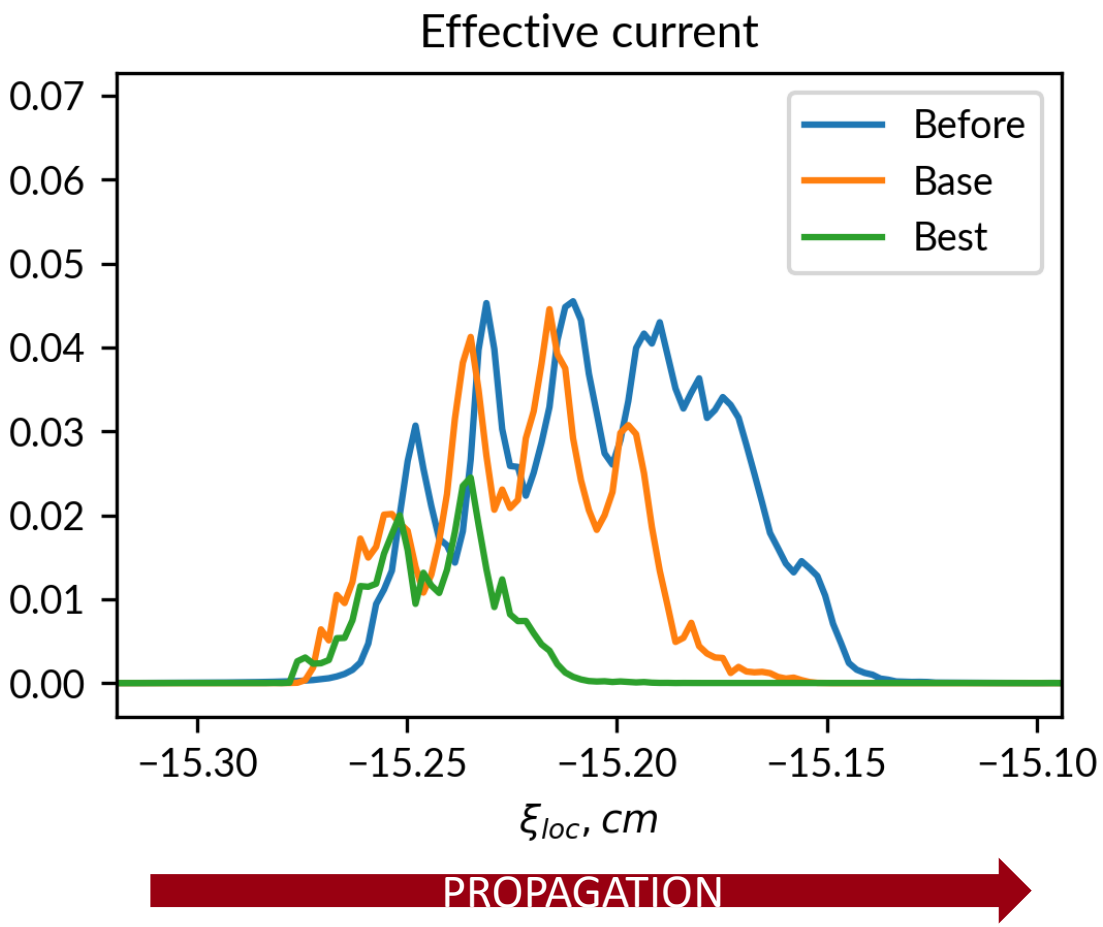


In the best case, driver microbunches are destroyed much stronger

DRIVER EVOLUTION



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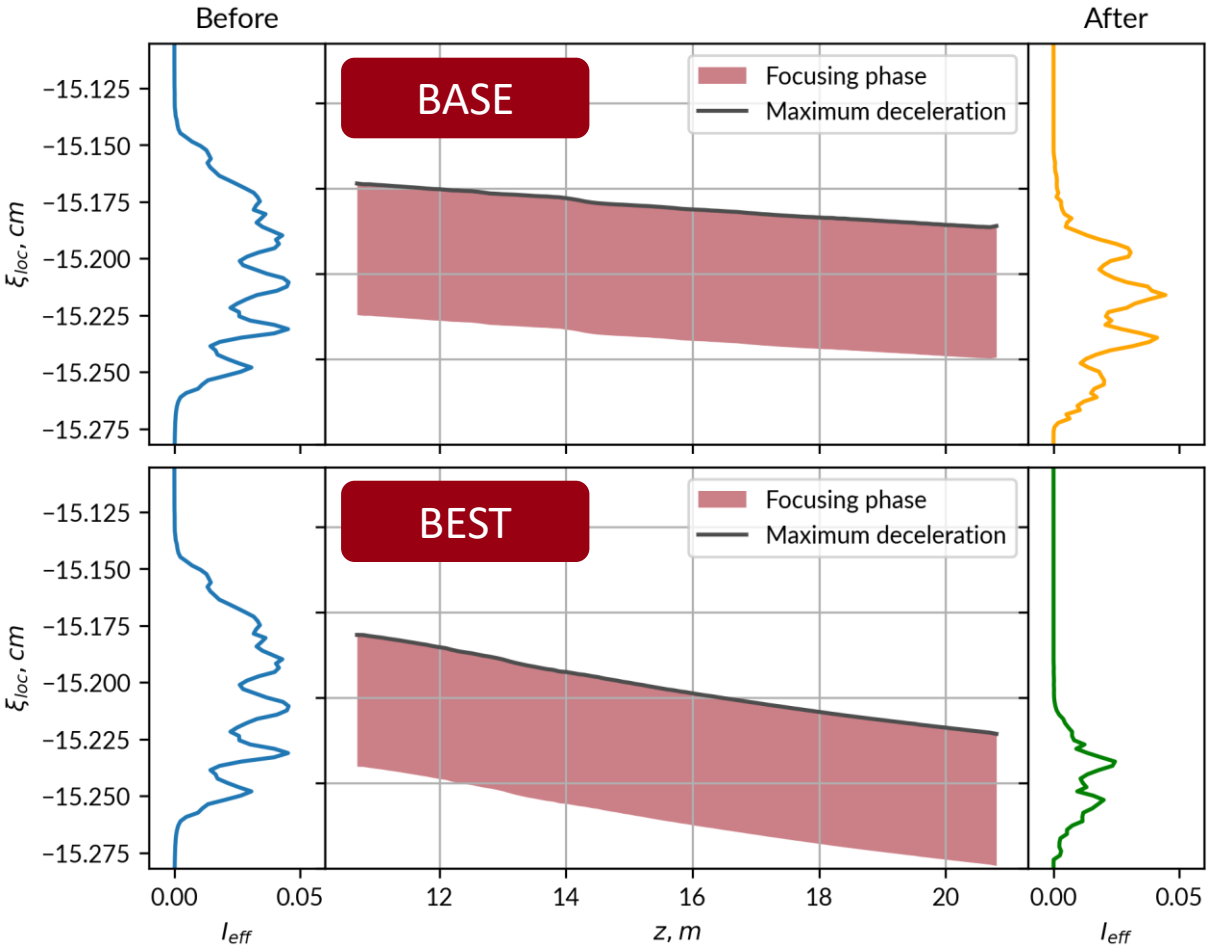
Why?

DRIVER EVOLUTION



In the best case:

- Negative density gradient increases the wakefield period, so the slope is stronger
- The densest part of the bunch falls into the strongest decelerating field
- Larger part of the microbunch falls into the defocusing phase

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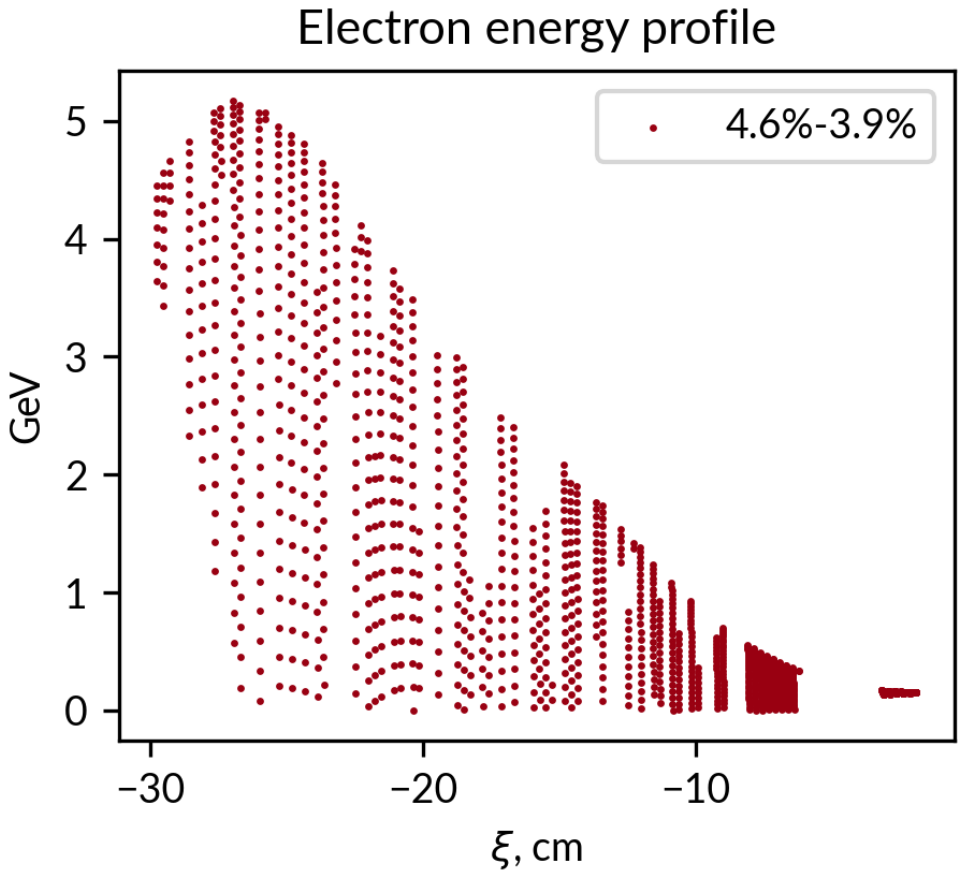
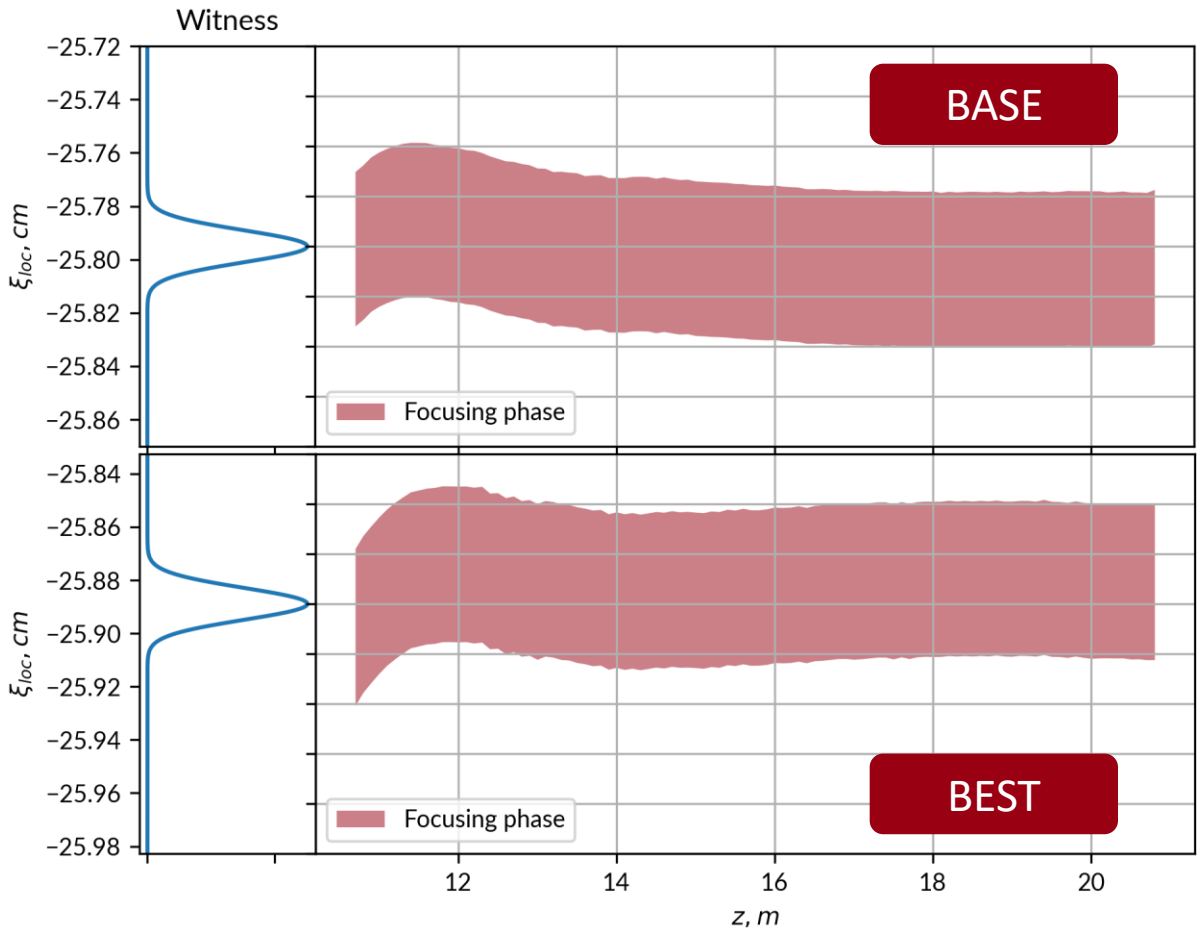
WITNESS



Maximum energy (5.18 GeV) is reached at the end of the simulation window (25 cm)

Let's look at the phase movement in this region

WITNESS



The characteristic size of the witness is depicted

In the best case the focusing phase moves less than in the base case

A possible reason is that the scattered beams stop changing the phase

SUMMARY

- A negative density gradient can increase electron energy by 35%
- The driver excites the wave more efficiently with negative gradients
- Due to the expansion of driver microbunches, the focusing phase is more stable in the witness region

- This trick works for short propagation distances only(10 m), because the driver microbunches are destroyed