CALIFES Workshop 2016

Emittance preservation in beam-driven plasma accelerators

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October 11, 2016

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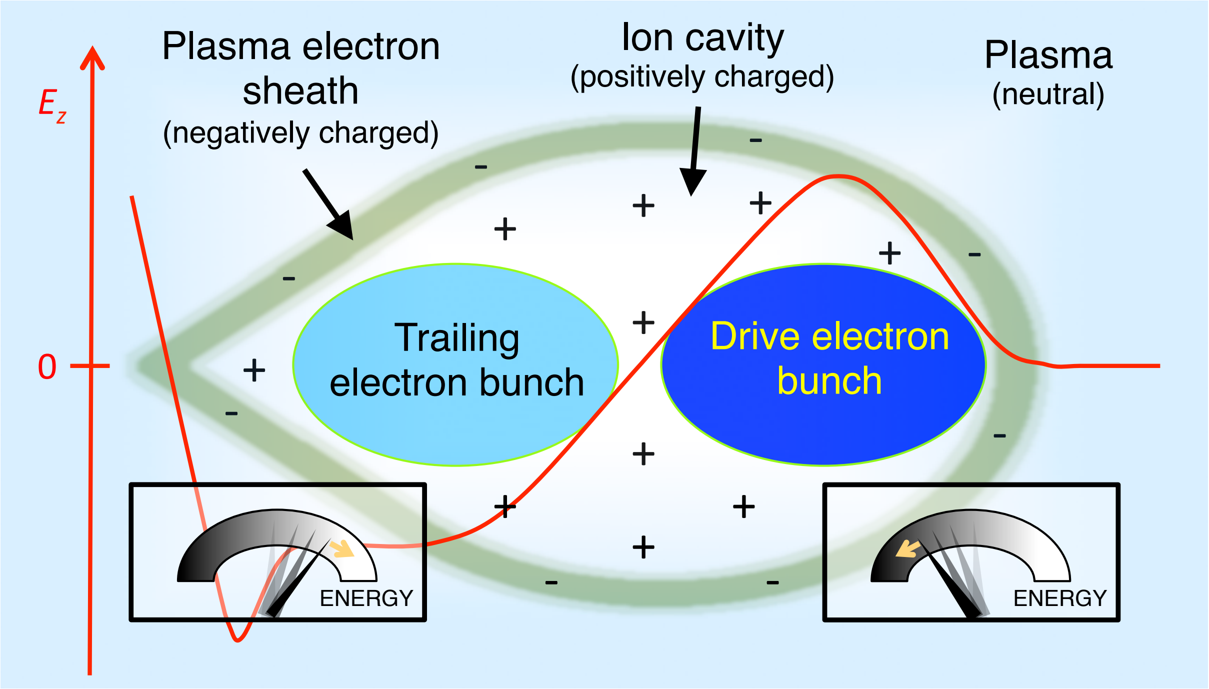
Principle of beam-driven plasma accelerators

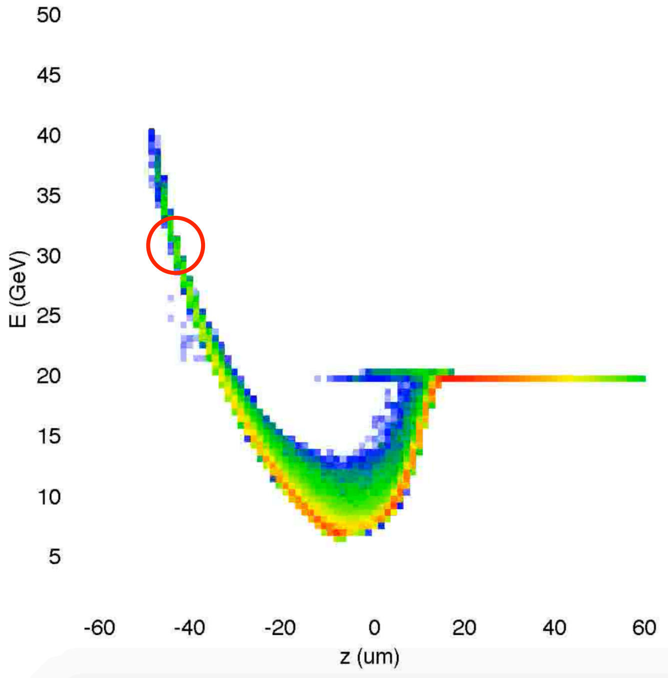


- Recent experimental progress
  - The first beam is driving, exciting the plasma wake
  - The trailing beam is accelerated with high field (> GeV/m) and high efficiency
- What is the next big question?
  - Can a plasma accelerate a beam while preserving its quality?

Emittance preservation studies with a single beam

- With a single beam, the bunch length needs to be long enough so that:
    - The front of the bunch is driving the wake
    - Electrons in the rear of the bunch are accelerated
- Will study the evolution of the emittance of an accelerated slice at the rear

Example of longitudinal phase space of a single bunch after the plasma



CALIFES beam parameters

Beam parameter (end of linac)	Value range
Energy	130 - 220 MeV (down to 60 MeV with upgrade)
Bunch charge	0.01 - 0.5 nC
Normalized emittances	3 um for 0.05 nC per bunch, 20 um for 0.4 nC per bunch (in both planes)
Bunch length	ca. 500 um - 1.2 mm
Relative energy spread	< 0.2 % rms (< 1 MeV FWHM)
Repetition rate	1 - 5 Hz (25 Hz with upgrade)
Number of micro-bunches in train	Selectable between 1 and > 100
Micro-bunch spacing	1.5 GHz

Case 1

$$\sigma_z = 500\ \mu\text{m}$$
$$\beta^* = 10\ \text{cm}$$
$$Q = 50\ \text{pC}$$
$$\epsilon_n = 3\ \mu\text{m}$$

↓

$$\sigma_r = 29\ \mu\text{m}$$
$$n_b = 4.7 \times 10^{13}\ \text{cm}^{-3}$$

Case 2

$$\sigma_z = 500\ \mu\text{m}$$
$$\beta^* = 10\ \text{cm}$$
$$Q = 400\ \text{pC}$$
$$\epsilon_n = 20\ \mu\text{m}$$

↓

$$\sigma_r = 75\ \mu\text{m}$$
$$n_b = 5.6 \times 10^{13}\ \text{cm}^{-3}$$

⟶ Achievable beam density is of the order of 5×10^{13} cm^{-3}.

Beam-driven plasma physics

- To satisfy the blowout requirement ($n_p < n_b$), the target plasma density should be in the range from 1 to 4×10^{13} cm^{-3}. This corresponds to a plasma wavelength ranging from 5 to 10 mm.
- With a bunch length of 500 microns, a non-gaussian profile with a temporal tail at the rear of the bunch is required.
- The electric field is in the 1-10 MeV/m range, so a multi-meter-long plasma can be used.
- The betatron wavelength is in the range from 14 to 28 cm, giving significant phase advance in a 3-m-long plasma (10 to 20 periods).
- Can test emittance growth models based on mismatched or offset beams.

Possible improvements

With a bunch compressor:

- The bunch length can be reduced to 60 microns, almost a factor 10.
- We can use plasma density an order of magnitude higher (1 to 4×10^{14} cm^{-3}), corresponding to plasma wavelength of 1.7-3.4 mm and betatron wavelength of 4.5-9 cm.
- Still needs a non-gaussian temporal profile with a tail at the rear of the bunch.
- Higher fields and higher phase advance (x3.3), but more difficult to match.

With additional focusing (e.g. plasma lens):

- Reach smaller beta functions at the waist and therefore reach matching conditions at higher plasma densities.
- Higher beam density also allows to use higher plasma densities.

With a second 'witness' bunch:

- Do not need tail, can use clean beams.
- Study of the emittance preservation of the entire witness bunch.

Conclusion

- With current CALIFES beam parameters:
  - Plasma experiments on emittance preservation can be conducted in $1\text{-}4\times10^{13}$ cm^{-3} plasma density
  - Need a non-gaussian temporal profile for the bunch with a tail at the rear.

- Several improvements possible:
  - Bunch compression
  - Additional focusing
  - Second bunch to study emittance preservation of an entire beam