Emittance Compensation of Extracted Electron Beam from the AWAKE Plasma Source

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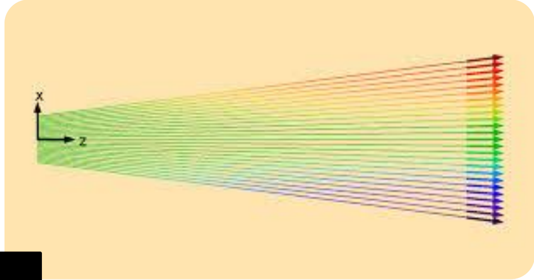
Motivation



In the drift downstream from the plasma accelerating module beam poses

large energy spread (multi percent)

A beam angular divergence around 50 μrad

small betatron function (4 cm for a 10 GeV beam)

$$\varepsilon_n^2 = \langle\gamma\rangle^2(\sigma_E^2\sigma_x^2\sigma_{x'}^2 + \varepsilon^2)$$ → Electron beam emittance growth

A possible way is capturing, control, and transport using strong focusing magnetic fields.

However ,

- Adoption between a plasma accelerator and a coupling device is difficult.
- Focusing gradient in the nonlinear plasma wake is about 30000 T/m.
- Conventional magnets contribute significantly to chromaticity as long as the energy spread is not negligible.

Plasmas

Outline

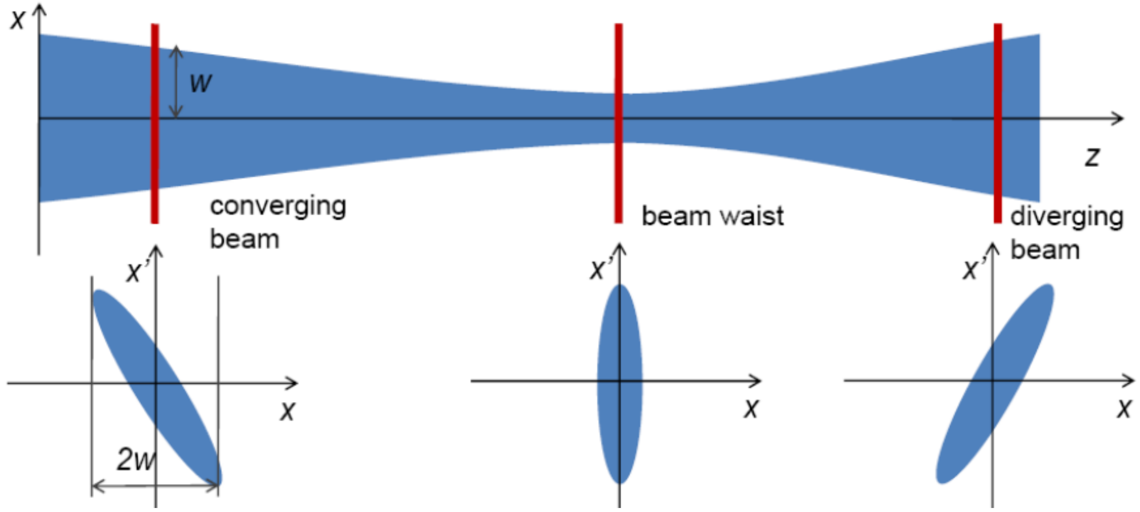
Emittance Variation Equation

Laser plasma lenses as a tool for Emittance Compensation

- z-correlated transverse phase space emittance compensation
- Emittance compensation using generating appropriate EM field

The normalized emittance ϵ_{nx}, is defined as:

$$\epsilon_{nx}^2 = < x^2 >< p_x^2 > - < xp_x >^2$$



Emittance variation along a general EM field:

$$\frac{d\epsilon_{nx}^2}{dz_0} = 2\eta[< x^2 >< p_x E_x > - < xp_x >< xE_x >] + \frac{2\eta c}{p_0}[< xp_x >< xp_z B_y > - < x^2 >< p_x p_z B_y >] \frac{-2p_0}{1+p_0^2}[< xp_x \delta_p >< p_x^2 > - < xp_x >< p_x^2 \delta_p >] \frac{-2\eta c p_0}{1+p_0^2}[< xp_x >< xp_z B_y \delta_p > - < x^2 >< p_x p_z B_y \delta_p >],$$

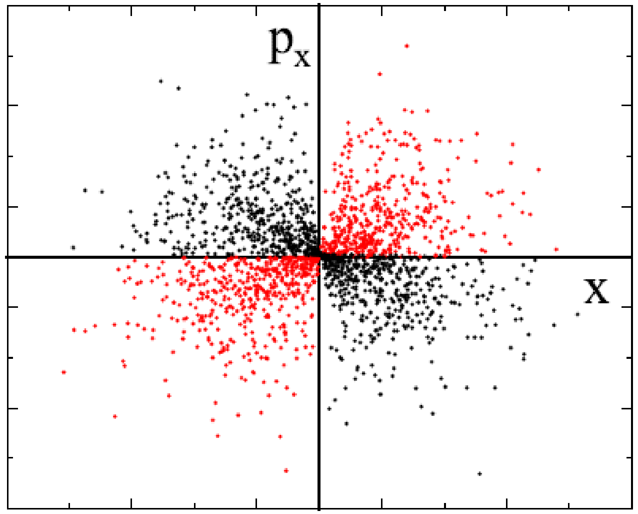
Our study plan

1) We consider EM fields of a plasma Wakefield
2) Then we discus the conditions might have a potential to reduce a beam emittance

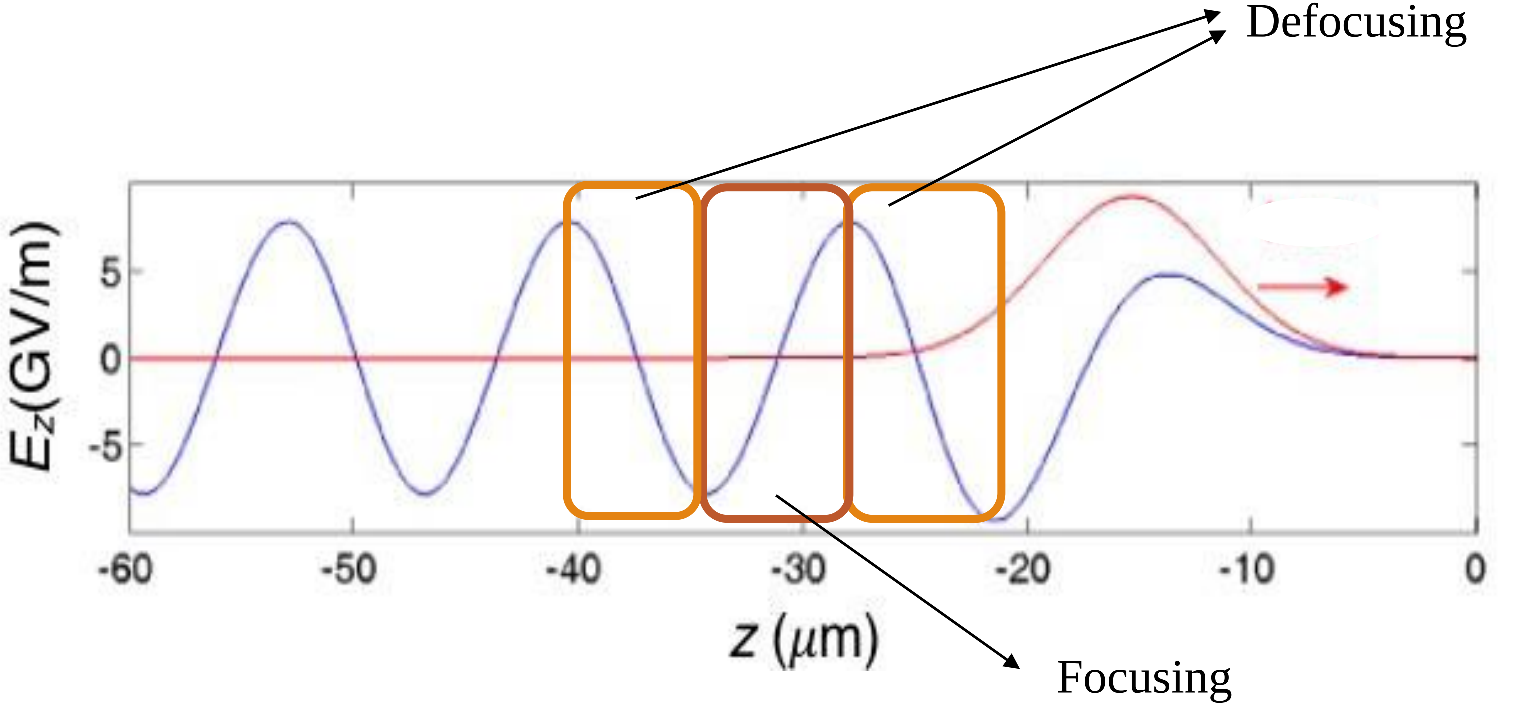
Two scenarios are defined:

- Correlation between bunch length and transverse phase space of beam
- Using appropriate nonlinear fields

Correlation between bunch length and transverse phase space of beam

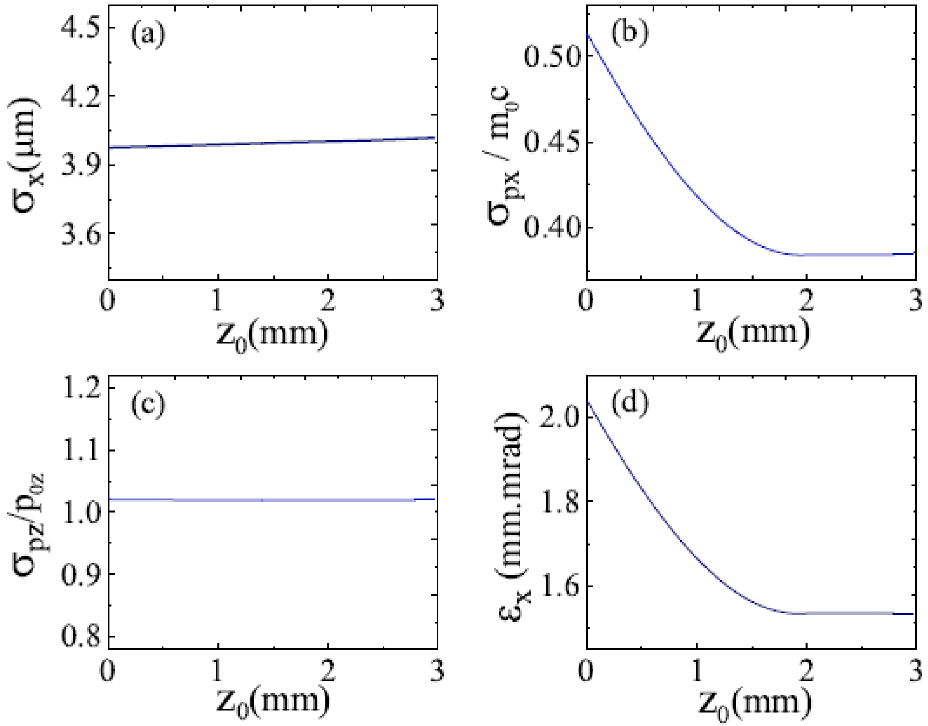


- Front half of the beam
- Back half of the beam

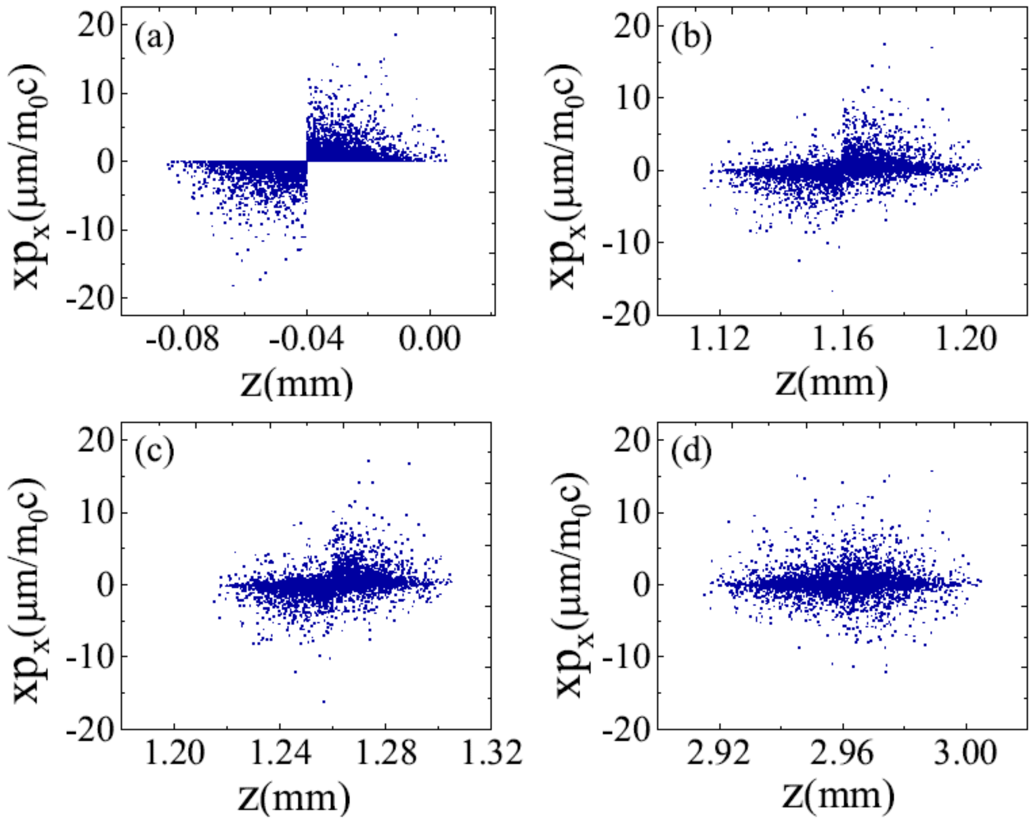


Plasma density = 24.5 × 10^{14} cm^{-3}
Plasm length = 2 mm
e^- beam energy = 10 GeV
ε_x = 2 μm
Energy spread = 1%

Emittance reduction is about 28%



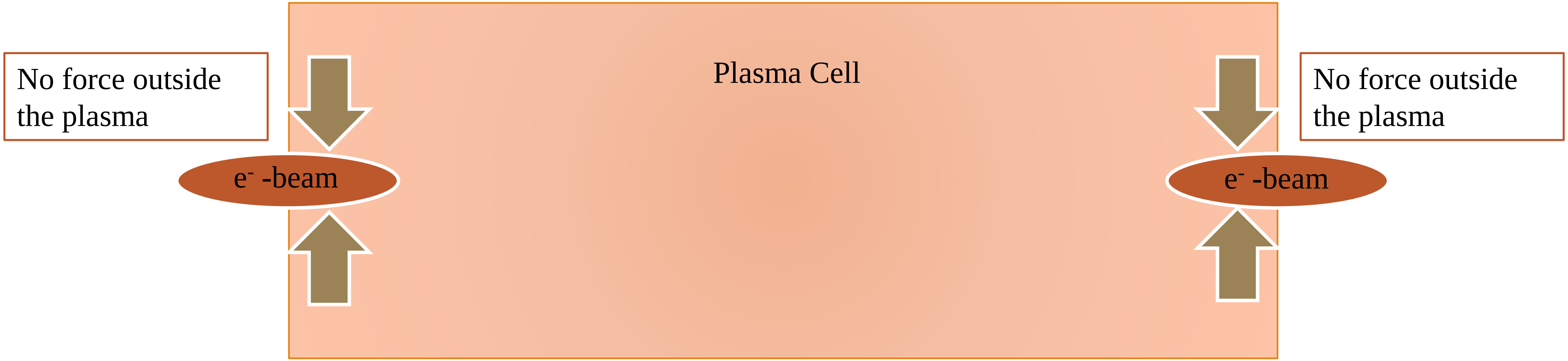
Evolution of beam parameters



Evolution of correlation between beam phase space and z

How this correlation might be generated through a wakefield acceleration process?

If the electron beam is not matched to the plasma different slices of the electron beam feels different forces



Emittance growth of a beam which is produced by z-correlated forces can be compensated using this approach

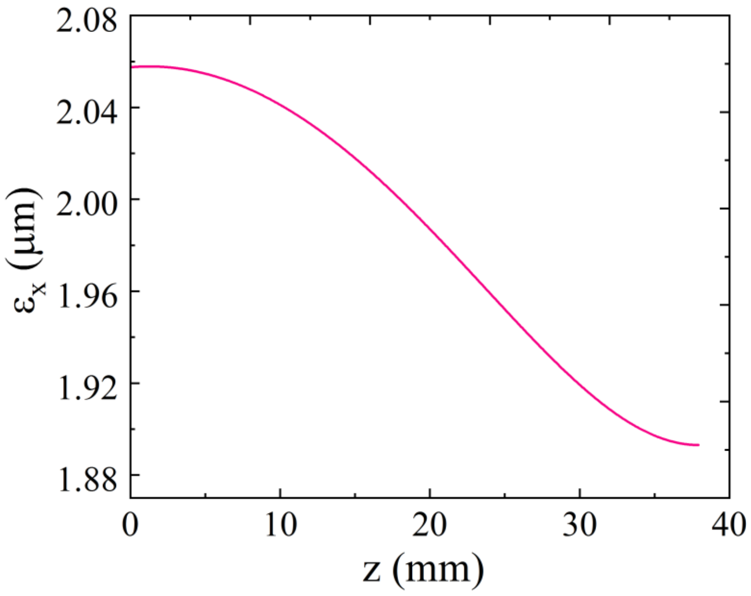
Nonlinear Fields

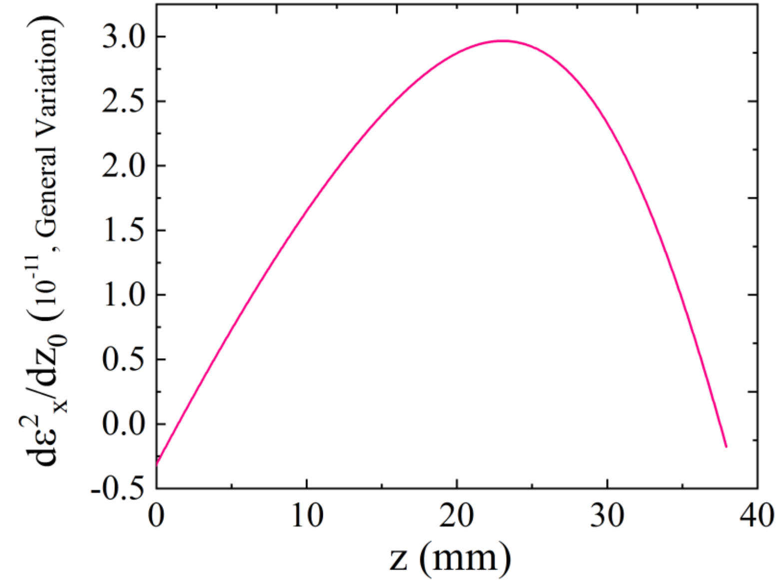
8% of Emittance reduction

$$\frac{d\epsilon_{nx}^2}{dz_0} = 2\eta[<x^2><p_xE_x> - <xp_x><xE_x>] + \frac{2\eta c}{p_0}[<xp_x><xp_zB_y> - <x^2><p_xp_zB_y>] \frac{-2p_0}{1+p_0^2}[<xp_x\delta_p><p_x^2> - <xp_x><p_x^2\delta_p>] \frac{-2\eta c p_0}{1+p_0^2}[<xp_x><xp_zB_y\delta_p> - <x^2><p_xp_zB_y\delta_p>],$$

$$n_p \propto r^2 \ or \ r^5 \ \ then\ plasma\ fields \propto \ r^3\ or\ r^5\ and\ \ if\ <xp_x>\ stay\ close\ to\ zero\ then\ \frac{d\varepsilon^2}{dz_0} \leq 0$$

Plasma density = 7×10^{14} cm^{-3}
Plasm length = 40 mm
e$^-$ beam energy = 10 GeV
ε_x = 2 μm
Energy spread = 2%





Next Plans

- Finding a configuration of fields that may lead to electron beam emittance reduction.
- Finding the optimized field parameters for this purpose .
- Making a plan for implementing the idea of emittance reduction.

Summary

An analytical approach is presented that leads to the evolution of electron beam emittance through an EM field.

A plasma is introduced as a substance that is capable of producing appropriate fields for emittance compensation.

Some of the possibilities that cause the emittance reduction of the electron beams are discussed.It is shown that plasma can provide the appropriate EM fields.

Thank you