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# Preserving beam emittance after plasma acceleration stage

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# The three questions



It is well known: important emittance growth can occur after plasma acceleration stage

But

**1-** Which emittance? (Phase or Trace emittance?)

**2-** In which circumstances? (Drift or Focusing element?)

**3-** Which parameters govern the emittance growth?

→ **How to mitigate emittance growth**

# The two emittances

## Trace Emittance

$$\varepsilon_{tr} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

$$\varepsilon_{tr,n} = \beta_r \gamma_r \varepsilon_{tr}$$

RMS beam size, divergence,
Emittance, Twiss parameters

## Phase Emittance

$$\varepsilon_{ph} = \sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2}$$

$$\varepsilon_{ph,n} = \frac{\epsilon_{ph}}{m_0 c}$$

$x, px$ are conjugate variables

$$\varepsilon_{ph}^2 = \varepsilon_{tr}^2\left(\overline{p_z^2} + \alpha^2\sigma_p^2\right)$$

$$\varepsilon_{ph,n} = \varepsilon_{tr,n} \quad when\ \alpha = 0.$$

➡ Should minimize growth of both emittances

# Emittance evolution through a drift

Through a drift of length $l$, the coordinates change as:

$$\begin{cases} x = x_0 + x_0' l \\ x' = x_0' \end{cases}$$

Role of the plasma acceleration

$$\Rightarrow \quad \varepsilon_{tr}^2 - \varepsilon_{tr0}^2 = 0.$$

$$\varepsilon_{ph}^2 - \varepsilon_{ph0}^2 = \varepsilon_{tr0}^2 \sigma_p^2 \gamma_0 l(\gamma_0 l - 2\alpha_0)$$

Migliorati et al. PRSTAB 2013, Sciscio et al., JAP 2016, etc.:
As $\varepsilon_{tr0}$ and $\sigma_p^2$ are big in plasma acceleration, big emittance growth is unavoidable

**NO! Minimizing $l$ or/and minimizing $\gamma_0$ can help preserving emittance!**

Role of the transfer line

Role of the plasma downramp

When $\alpha_0 = 0$, $\dfrac{\varepsilon_{ph}^2 - \varepsilon_{ph0}^2}{\varepsilon_{ph0}^2} = \dfrac{\sigma_{x_0'}^2}{\sigma_{x_0}^2} \dfrac{\sigma_p^2}{p_z^2} l^2 = \gamma_0^2 l^2 \dfrac{\sigma_p^2}{p_z^2}$

$\Rightarrow$ Chromatic length (R. Conti et al. NIMA 2018)

$$L_c = \frac{\sigma_{x_0}}{\sigma_{x_0'} \frac{\sigma_p}{p_0}} = \frac{1}{\gamma_0 \frac{\sigma_p}{p_0}}$$

# Emittance evolution through a thin lens



Through a thin lens of focusing gradient $K$, the coordinates change as:

$$\begin{cases} x = x_0 \\ x' = Kx_0 + x_0' \end{cases}$$

Role of the plasma acceleration

$$\Rightarrow \quad \frac{\varepsilon_{tr}^2 - \varepsilon_{tr0}^2}{\varepsilon_{tr0}^2} = \beta_0^2 K^2 \left(\frac{\sigma_p}{p_0}\right)^2$$

$$\varepsilon_{ph}^2 - \varepsilon_{ph0}^2 = \overline{x_0^2}^2 \left(\overline{K^2 p_z^2} - \overline{K p_z}^2\right) = 0$$

**Emittance growth is minimized when:**

**- Minimizing $\beta_0 \equiv$ Minimizing $\gamma_0$ in the upstream drift**

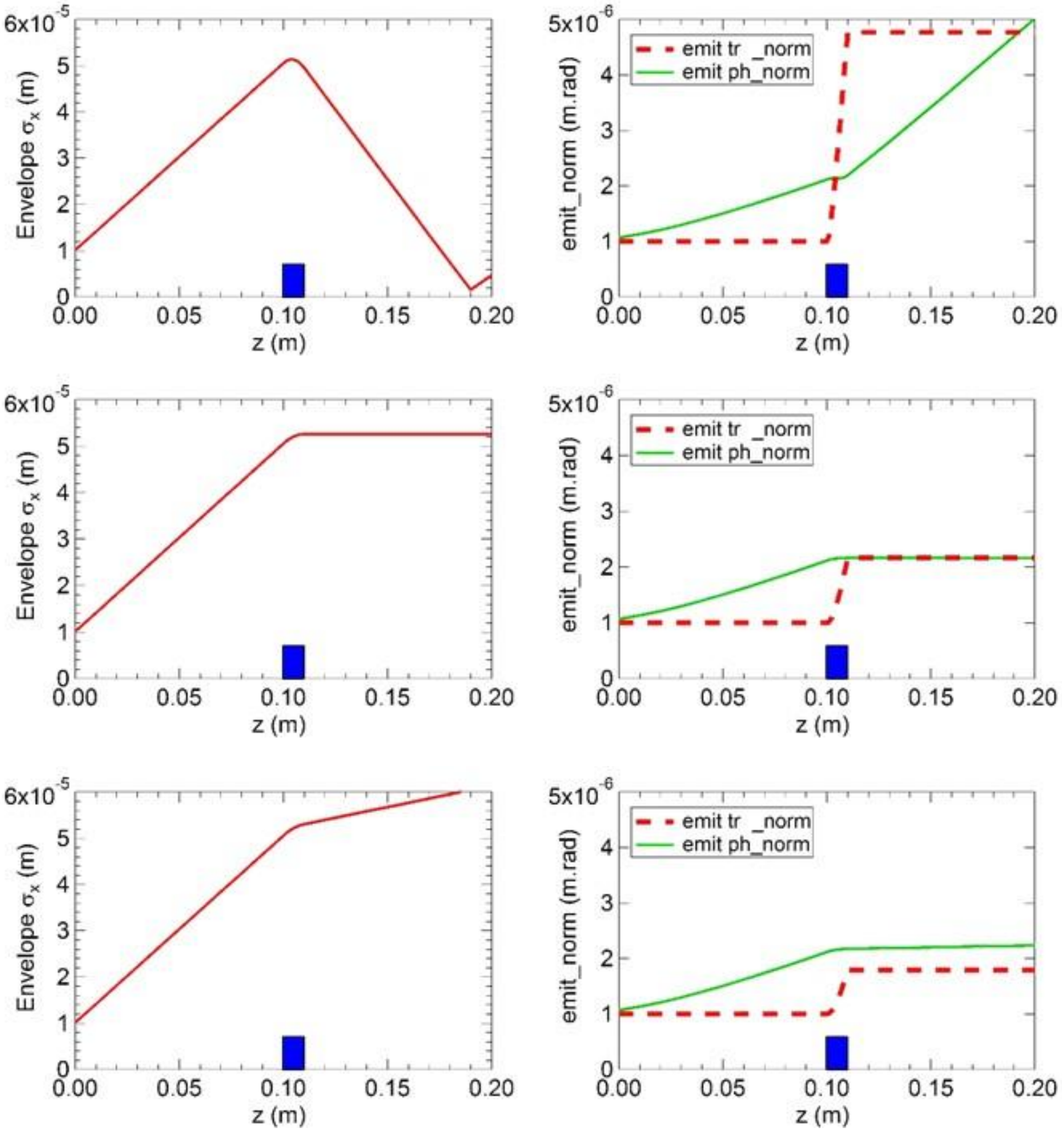
Role of the plasma downramp

**- Minimizing $K_0$**

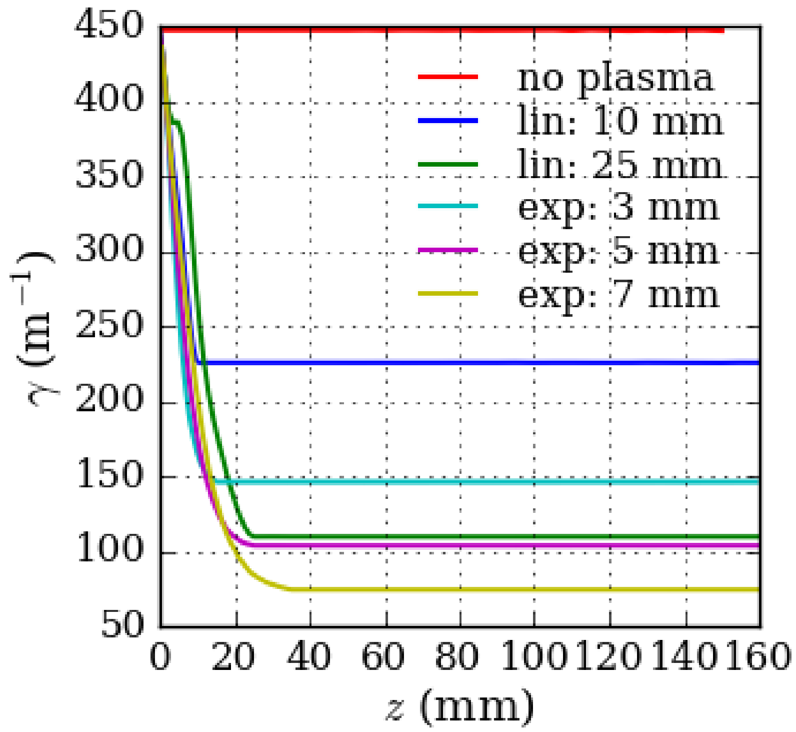
Role of the transfer line

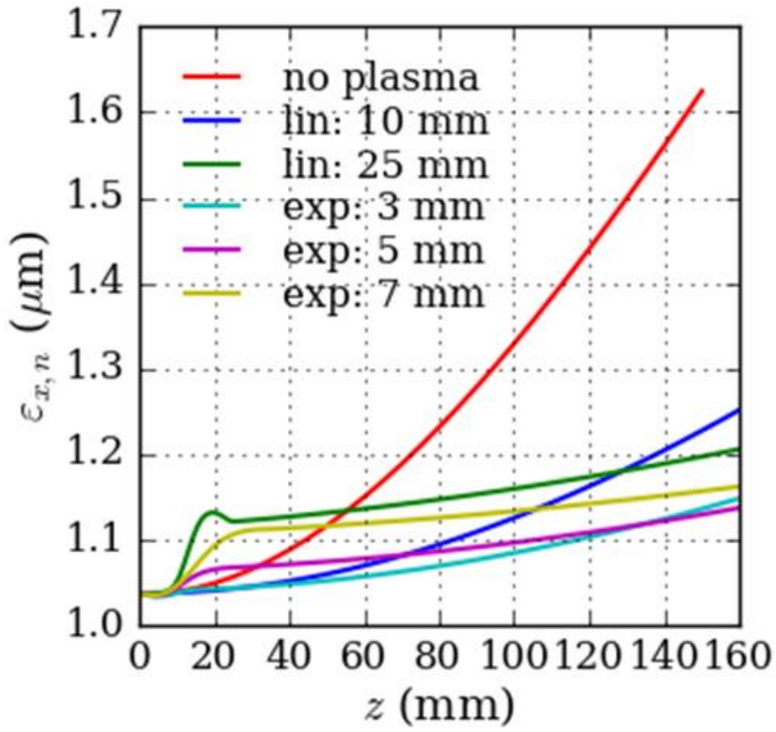
# Particle tracking

TraceWin code (CEA)



# Plasma downramp




**Minimising $\gamma_0$ ⇒ Minimising emittance growth**

# The three key roles



For minimising emittance growth:

1- Plasma acceleration: minimising $\varepsilon_0, \sigma_p/p$

2- Plasma downramp: minimising $\gamma_0$

3- Transfer line: minimising $l, K$