Physics of transverse dynamics in a laser-plasma accelerator

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PLASMA STAGE/TRANSPORT LINE COUPLING

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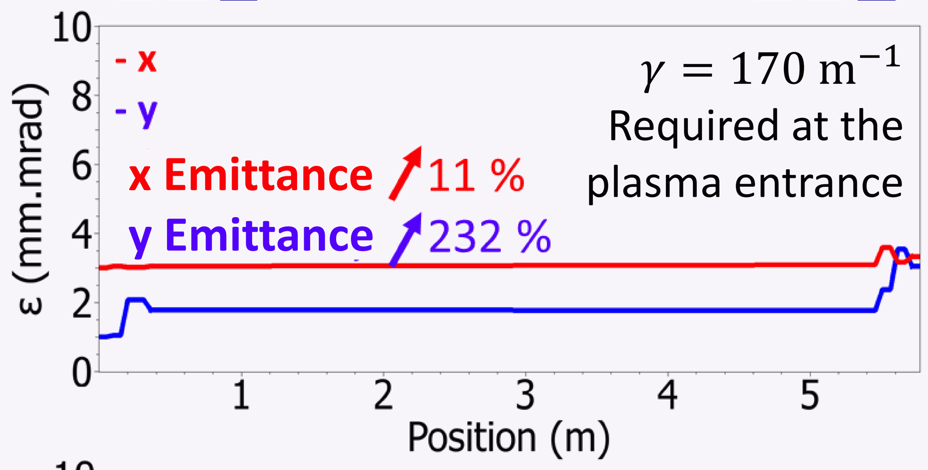
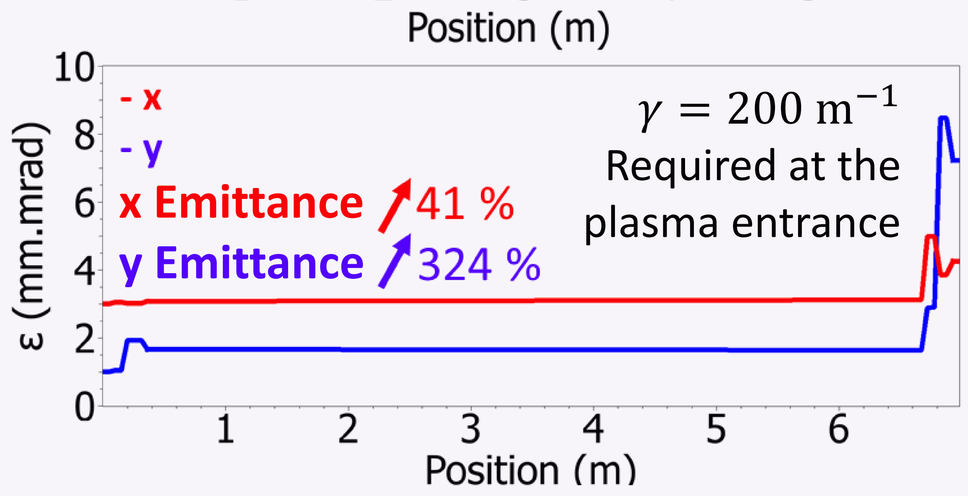
Goal : Preserving electrons beam transverse emittance through a succession of transport lines and plasma stages.

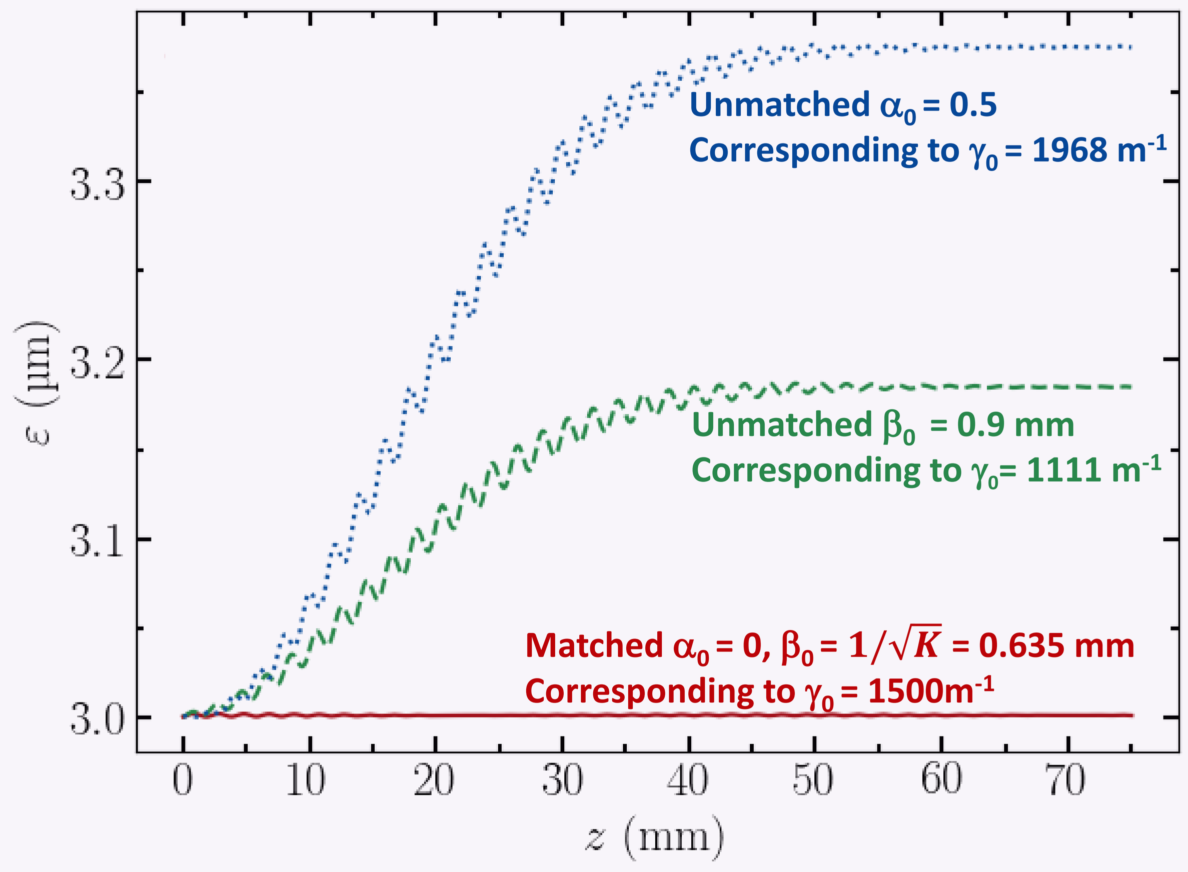
Transport line upstream



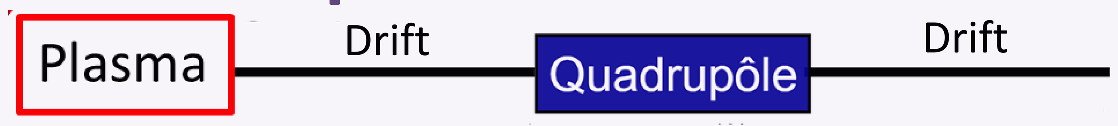


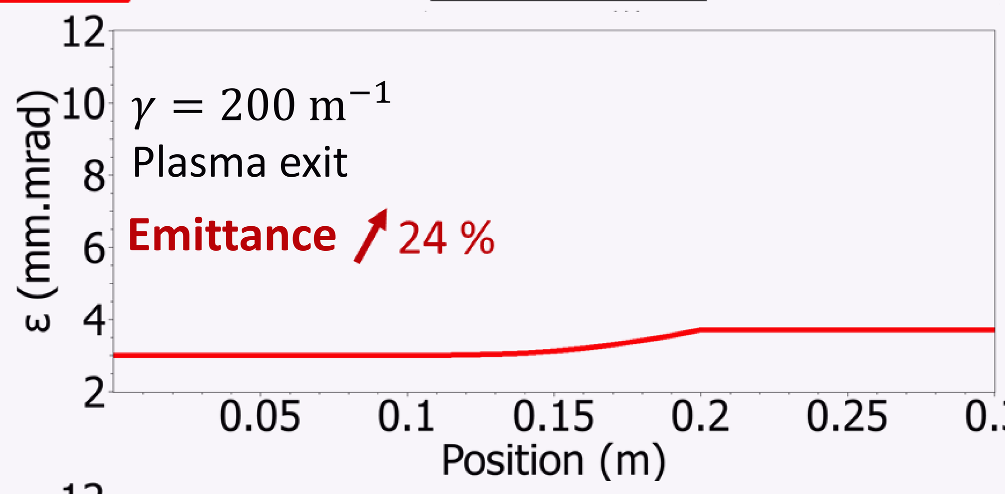
Plasma Plateau

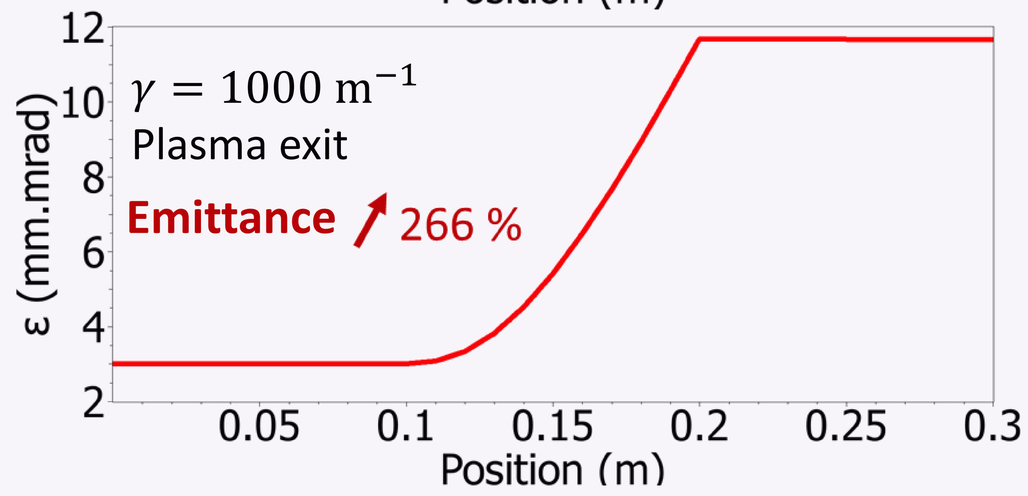
Plasma



Transport line downstream



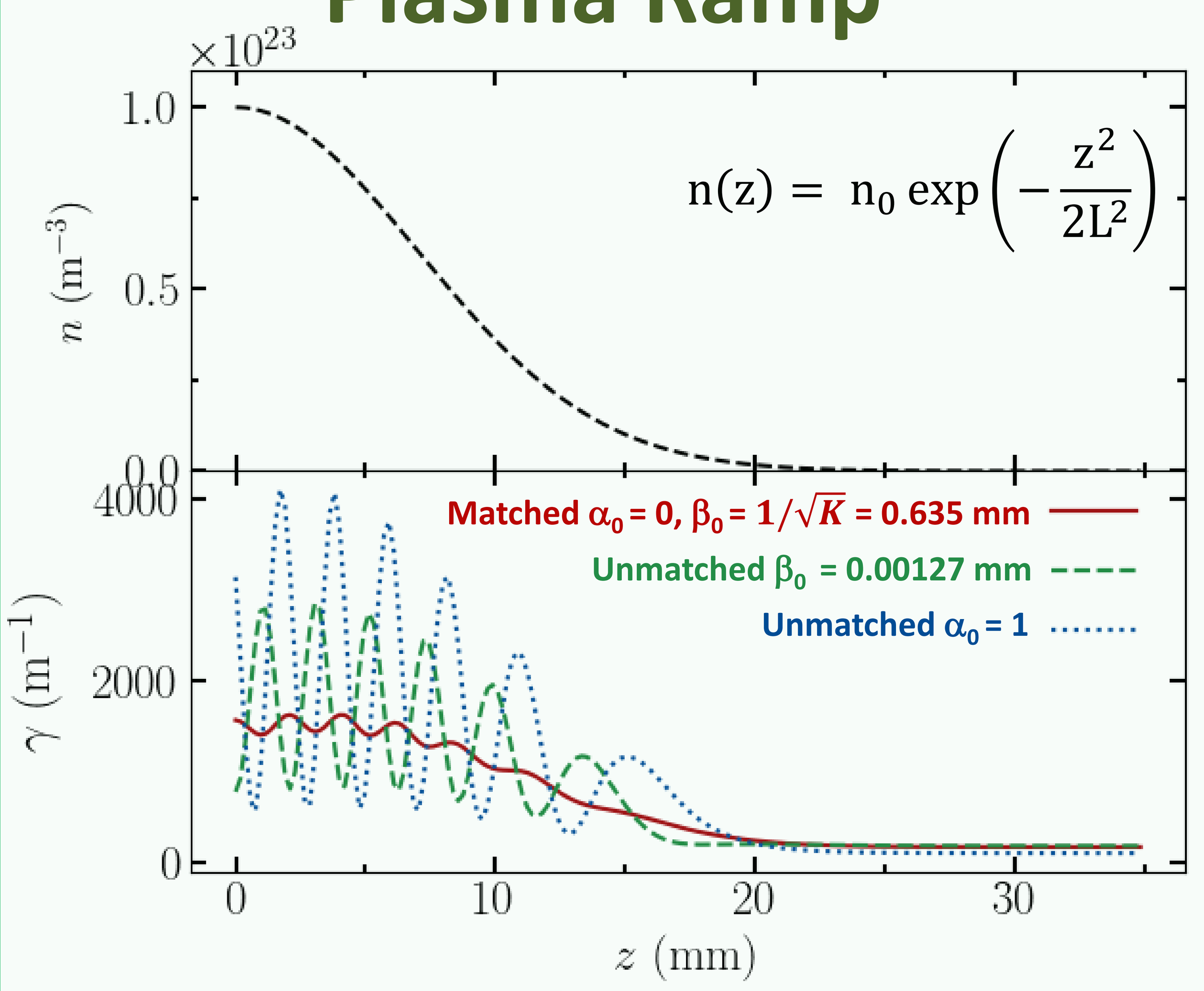


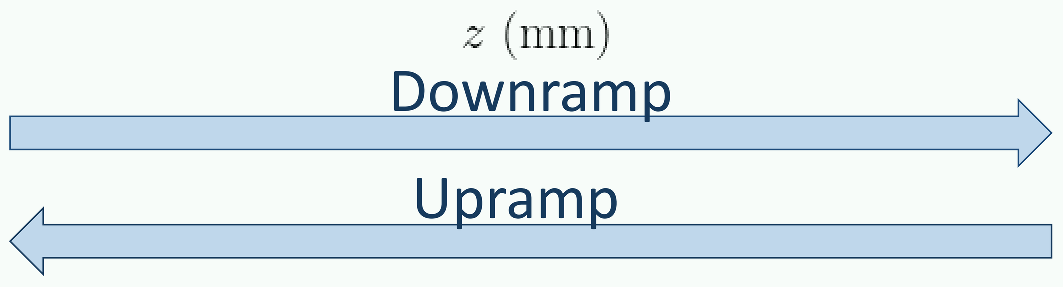


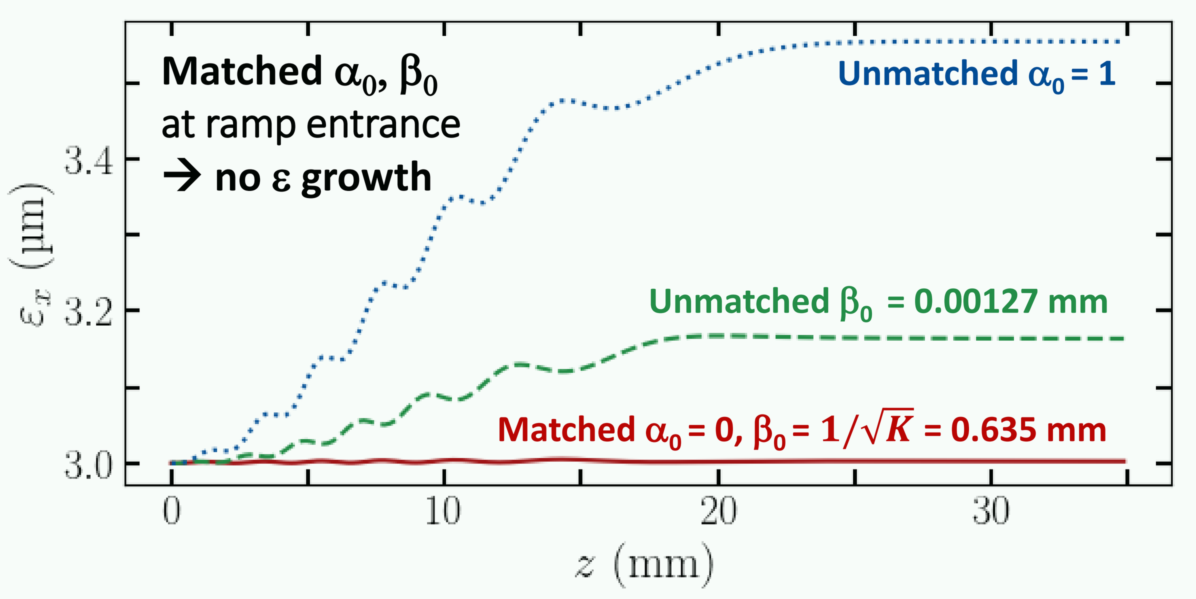
If $\gamma < 200\ m^{-1}$ then lower Δε — Matched beam requires $\gamma > 1000\ m^{-1}$ — If $\gamma < 200\ m^{-1}$ then lower Δε

⇒ Without plasma ramp : incompatible required γ → Emittance growth in the plasma or in transport lines

Plasma Ramp







Twiss γ

The key parameter

$$\gamma = \frac{1+\alpha^2}{\beta} = \frac{\langle u'^2\rangle}{\varepsilon}$$

Parameters used for the study

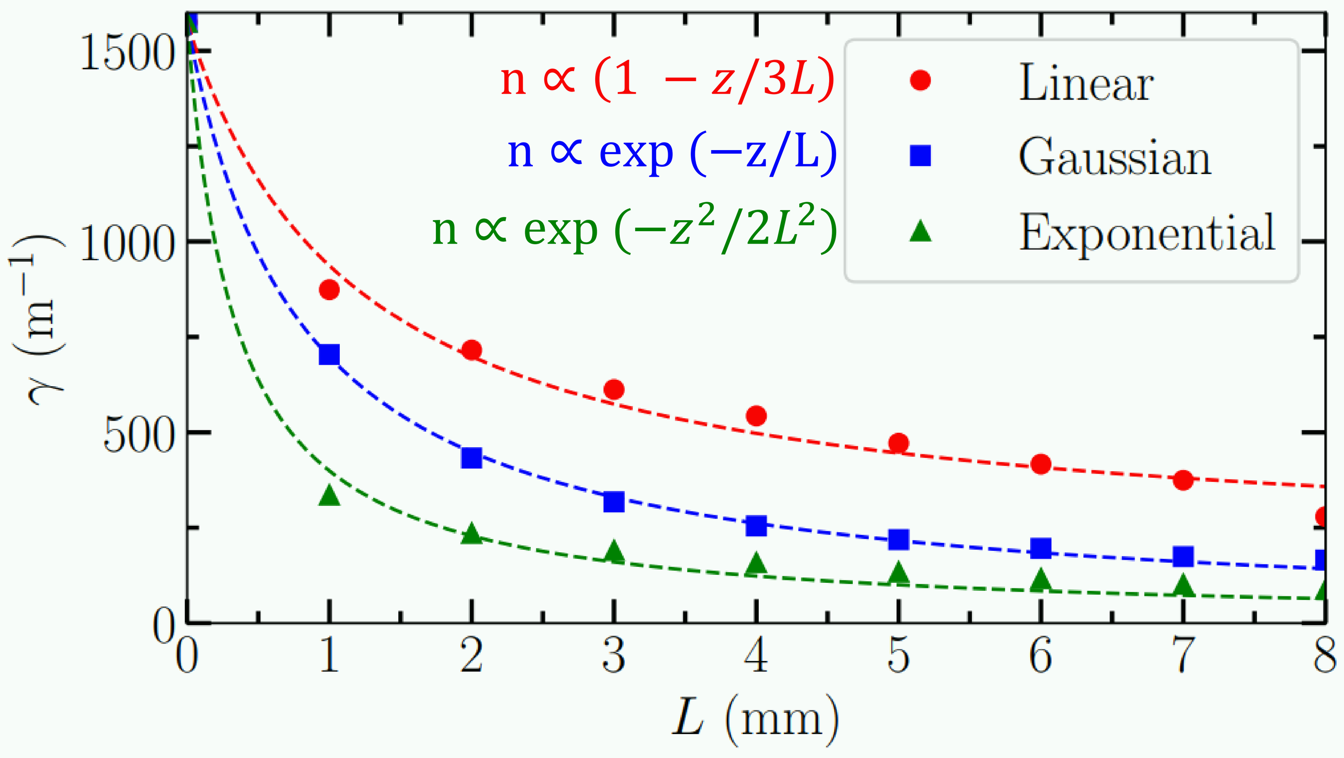
Laser	
Strength a_0	2
Pulse waist w_0	50 μm
Pulse duration (field) τ_0	50 fs
Plasma	
Density n_0	10^{23} m^{-3}
Plateau length	up to 45 mm
Injected electron beam	
Mean energy E	200 MeV
Energy spread σ_E/E	3%
Normalized emittance ε_{xN}	3 mm mrad
Normalized emittance ε_{yN}	1 mm mrad
Beam length σ_z	3 μm
Laser-electron bunch distance ξ	50 μm

Studies with:

- Analytical calculations
- TraceWin transport code
- FBPIC PIC code
- Wake-T fast-tracking code

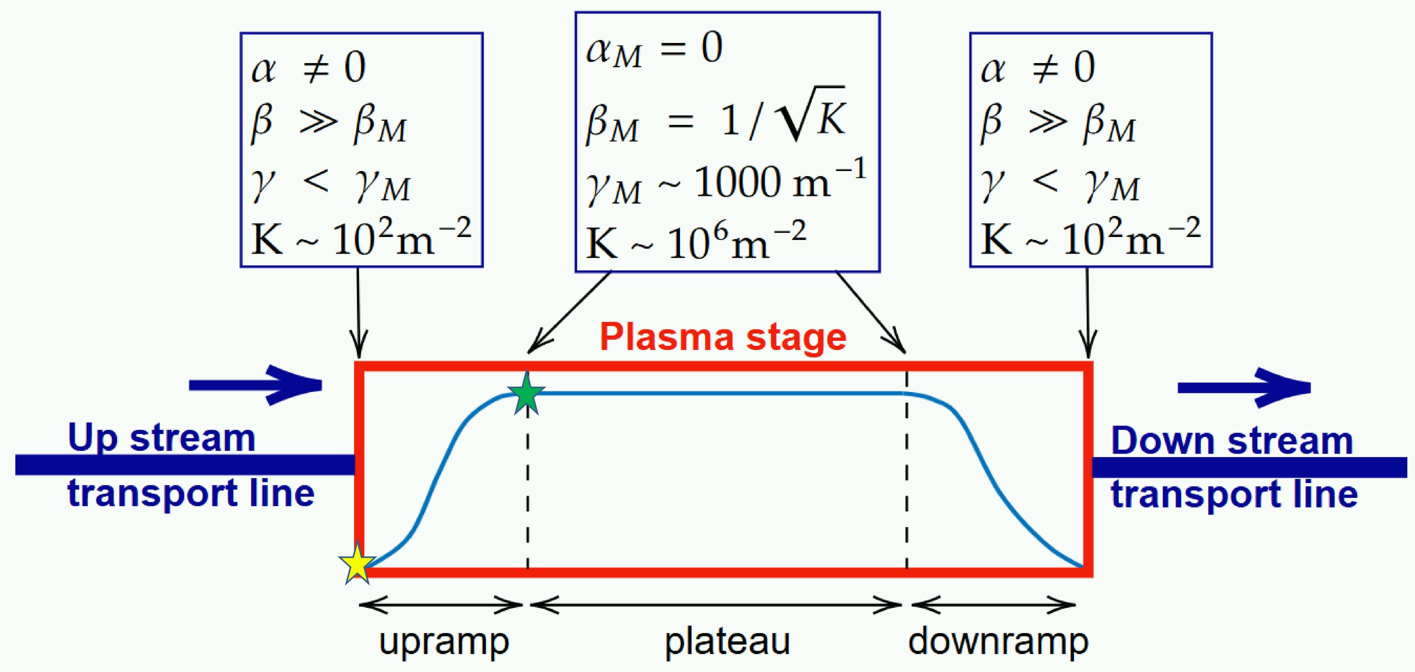
See oral presentation (25/09/25, 17h) and publication in PR (submitted)

Plasma Ramp



What ever the ramp shape
increasing the ramp length ⇒ decreasing γ

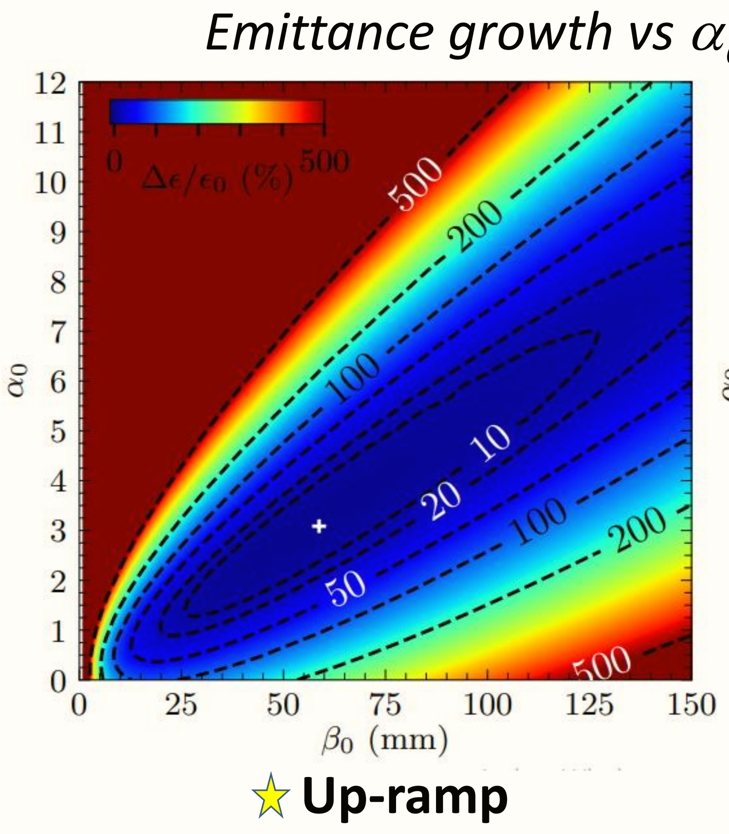
Role of the ramps: decreasing γ



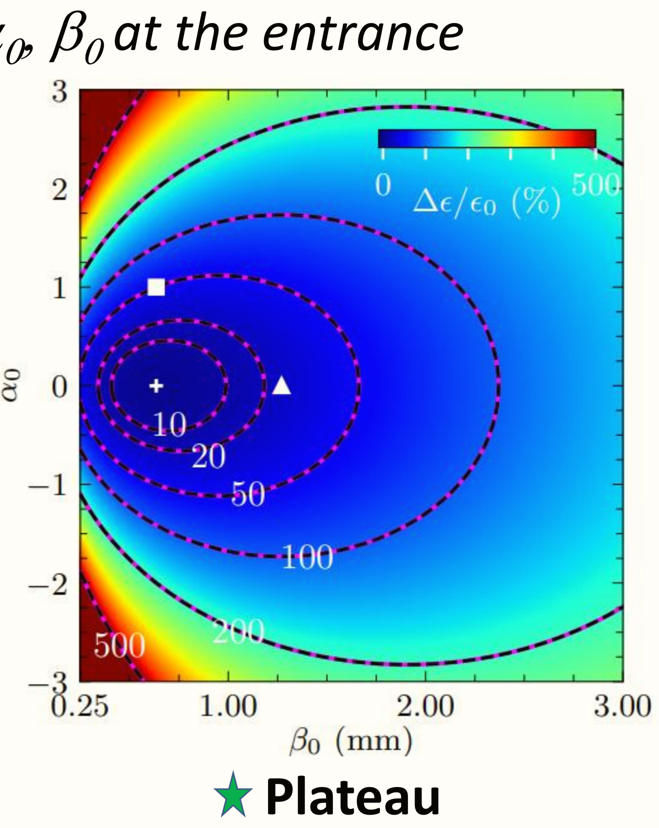
Example of coupling

Transport line/2nd plasma stage

Emittance growth vs α_0, β_0 at the entrance

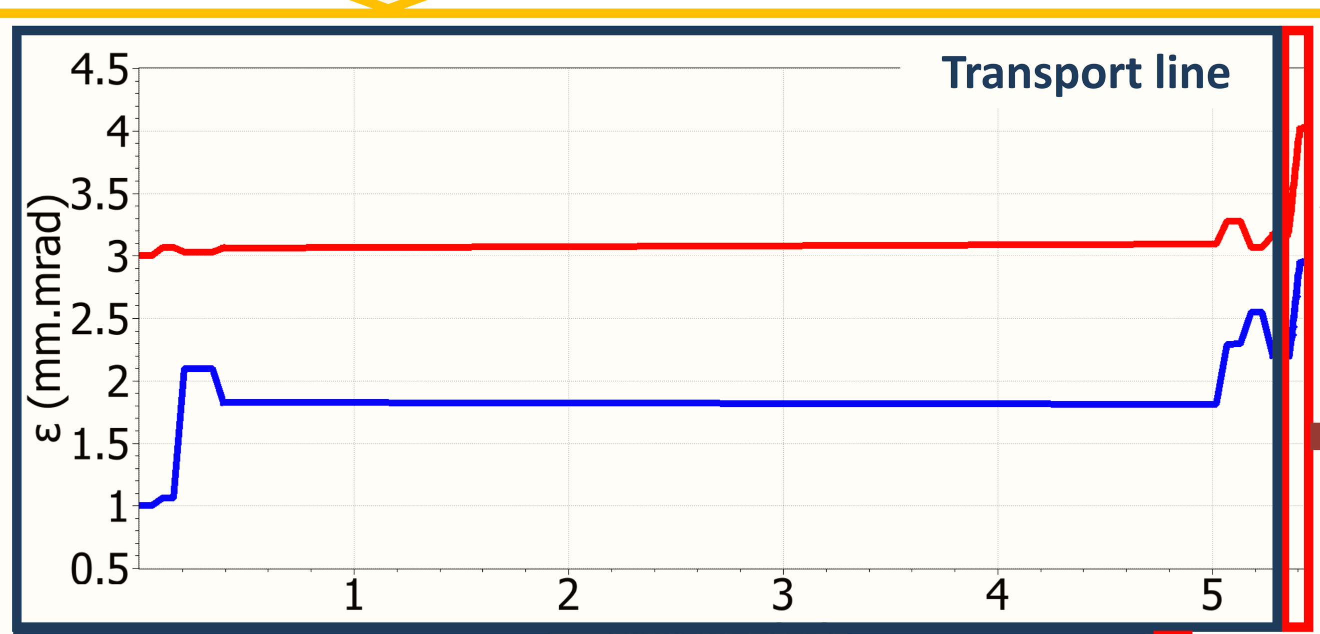


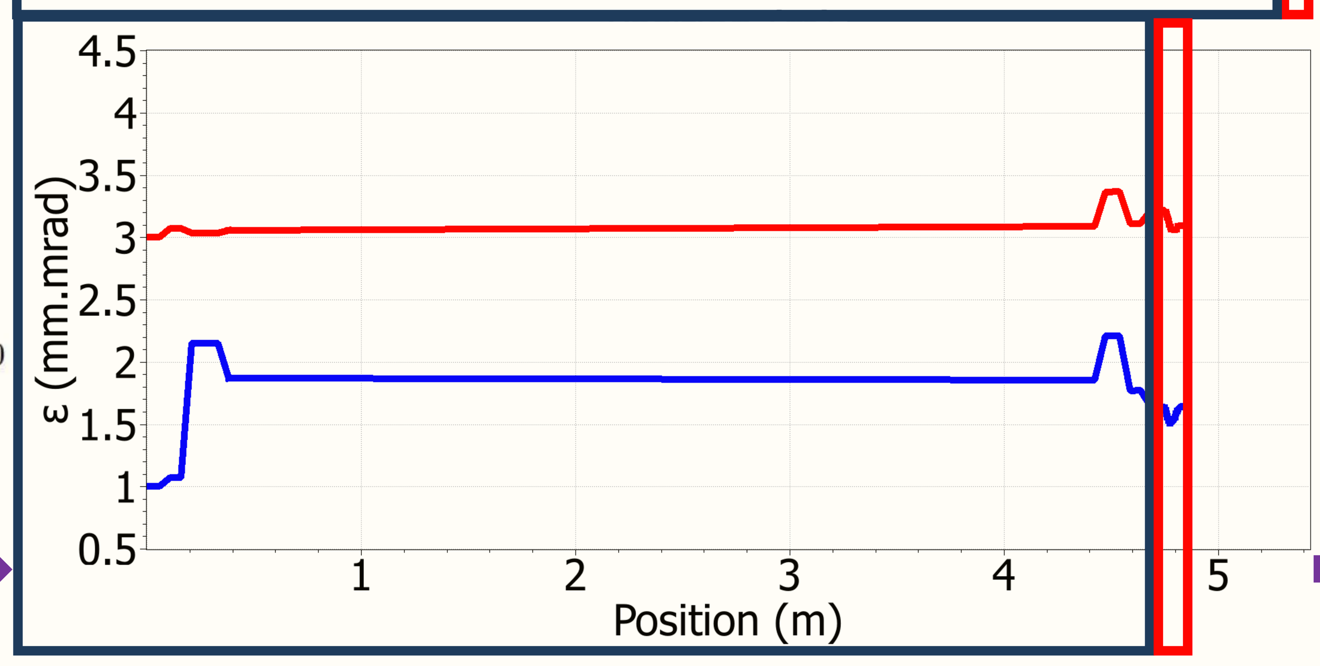
☆ Up-ramp



★ Plateau

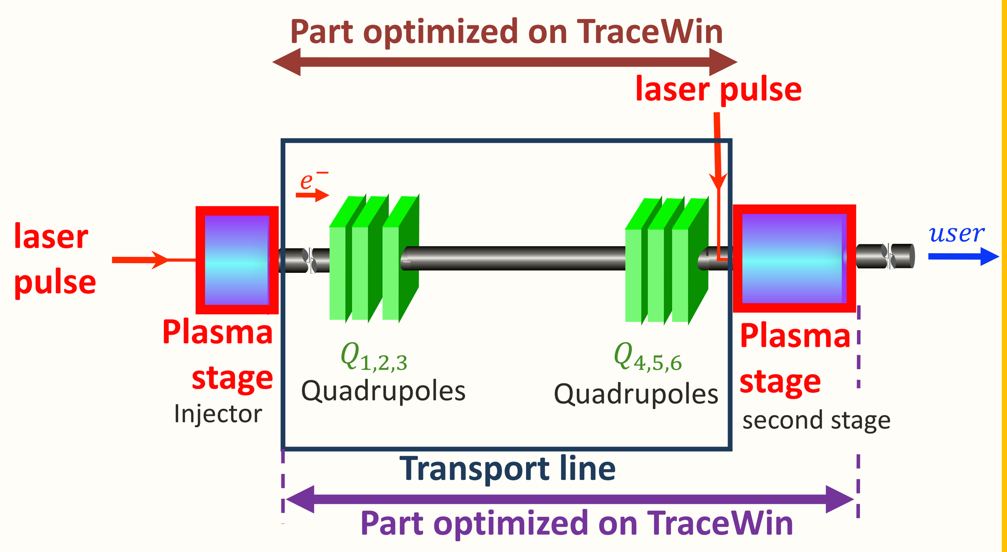
Output emittance from the first stage :
ε_x = 3 mm.mrad
ε_y = 1 mm.mrad





Allow compromises between emittance growthwithin the plasma stage and within the transport line

Output emittance after the second stage :
ε_x = 4.0 mm.mrad
ε_y = 2.9 mm.mrad



Output emittance after the second stage :
ε_x = 3.1 mm.mrad
ε_y = 1.6 mm.mrad