High brightness, plasma boosted beams for driving a Free Electron Laser

Andrea R. Rossi*
INFN - Milan

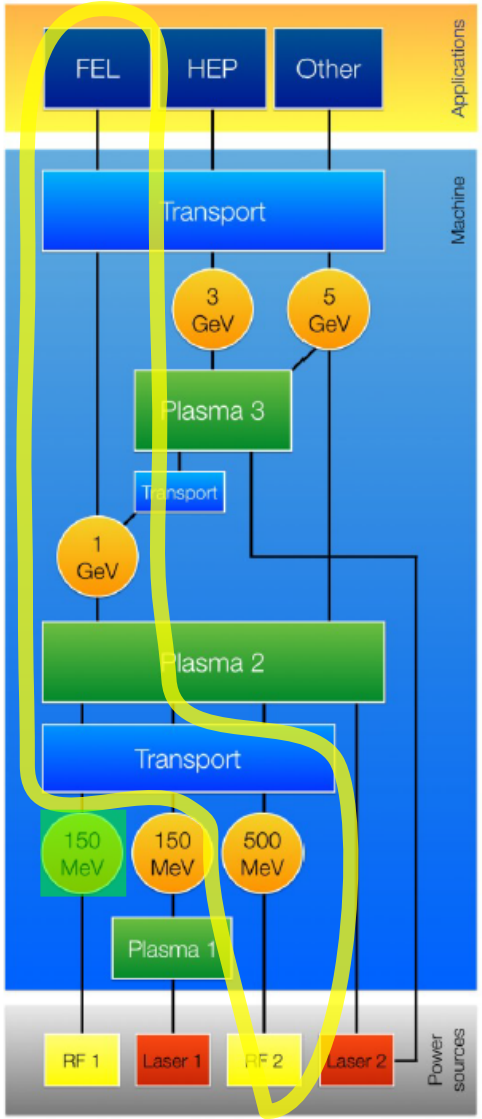
INFN
Istituto Nazionale
di Fisica Nucleare

* andrea.rossi@mi.infn.it

SPARC LAB

Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

EuPRAXIA framework



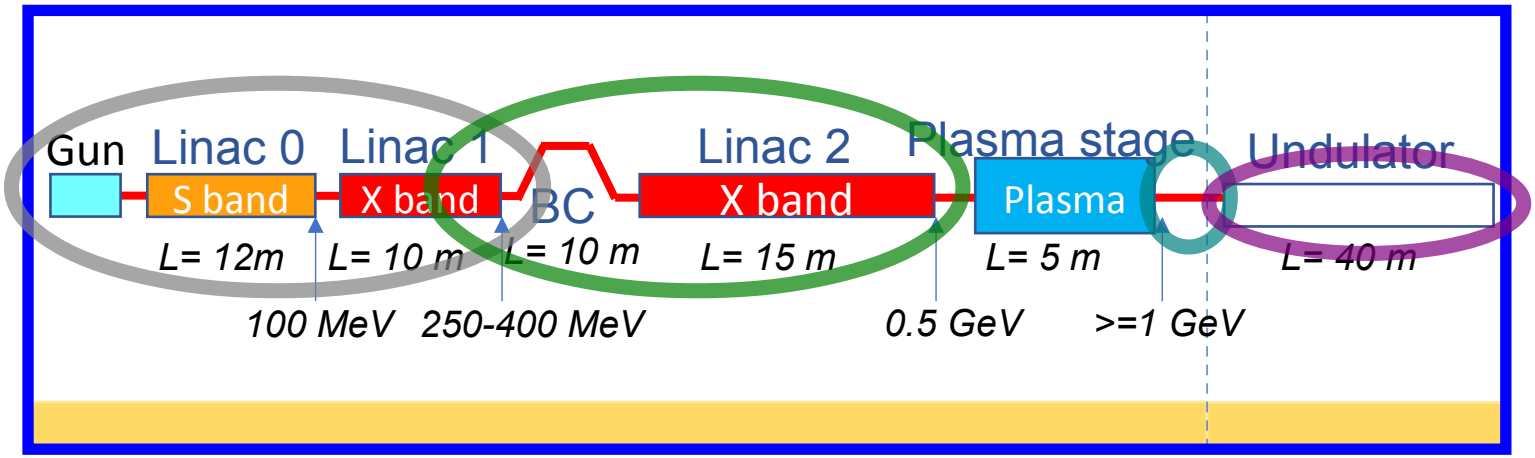
Quantity	Symbol	Baseline value	Range of exploration	
			Lower limit	Upper limit
RF injector beam: at the photo-injector exit				
Energy	E	152.2 MeV	100 MeV	200 MeV
Charge	Q	50 pC	10 pC	50 pC
Bunch length (RMS)	τ	29 fs	3 fs	30 fs
Current	I	0.5 kA *	1 - 10 kA	
Shaped profile	-	Gaussean	triangular	
Total energy spread (RMS)	σ_E/E	0.3 %	0.3 %	
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	0.4 mm mrad	0.4 mm mrad	
Transverse norm. slice emittance	$\varepsilon_{N,x,S}$, $\varepsilon_{N,y,S}$	tbd	tbd	
Slice length	z_s	tbd	tbd	
Jitter, beam to global reference (RMS)	$\sigma_{\Delta t}$	10 fs	10 fs	
* Further compression is mandatory to fulfill the current requirement of 3 kA at the undulator entrance.				

FEL beam requirements at entrance of undulator				
Particle type	-	e-	e-	
Energy	E	1 GeV	1 GeV	
Charge	Q	30 pC	15 pC	100 pC
Bunch length (FWHM)	τ	10 fs	3 fs	30 fs
Peak current	I	3 kA	3-5 kA	
Repetition rate	f	10 Hz	1 Hz	100 Hz
Number of bunches	N	1	1	
Total energy spread (RMS)	σ_E/E	1%	1%	
Slice energy spread (RMS)	$\sigma_{E,S}/E$	0.1 %	0.1 %	
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	1 mm mrad	1 mm mrad	
Transverse norm. slice emittance	$\varepsilon_{N,x,S}$, $\varepsilon_{N,y,S}$	tbd	tbd	

- Case 2A: Laser Wakefield Acceleration with external injection from a RF accelerator, and acceleration to 1 GeV and staging to 5 GeV
- Case 3A: Laser Wakefield Acceleration with external injection from a laser plasma injector, and acceleration to 1 GeV and staging to 5 GeV

EuPRAXIA @ SPARC_LAB framework

Wednesday, 27 September 2017, WG1 - WG8 Joint Session
18:00 EuPRAXIA@SPARC_LAB: design study towards a new compact FEL facility at LNF
Massimo Ferrario



Monday, 25 September 2017, WG3
17:10 RF injector design studies for the witness beam for a plasma-based user facility.
Anna Giribono

Wednesday, 27 September 2017, WG4
16:45 EUPRAXIA at SPARC_LAB: Beam Dynamics studies for the X-band Linac
Cristina Vaccarezza

Monday, 25 September 2017, Poster Session
ELECTRON BEAM TRANFER LINE DESIGN FOR PLASMA DRIVEN FREE ELECTRON LASER
Marcello Rossetti Conti

Wednesday, 27 September 2017, WG4
18:45 FEL performances of plasma accelerated electron beams
Vittoria Petrillo

Design guidelines

- Require minimal parameters for laser, allowing for staging.

σ_{tr} [μm]	35
τ_{FWHM} [fs]	112
E [J]	6,13
a_0	1,15

- Require minimal capillary length for plasma stage (plasma channel).

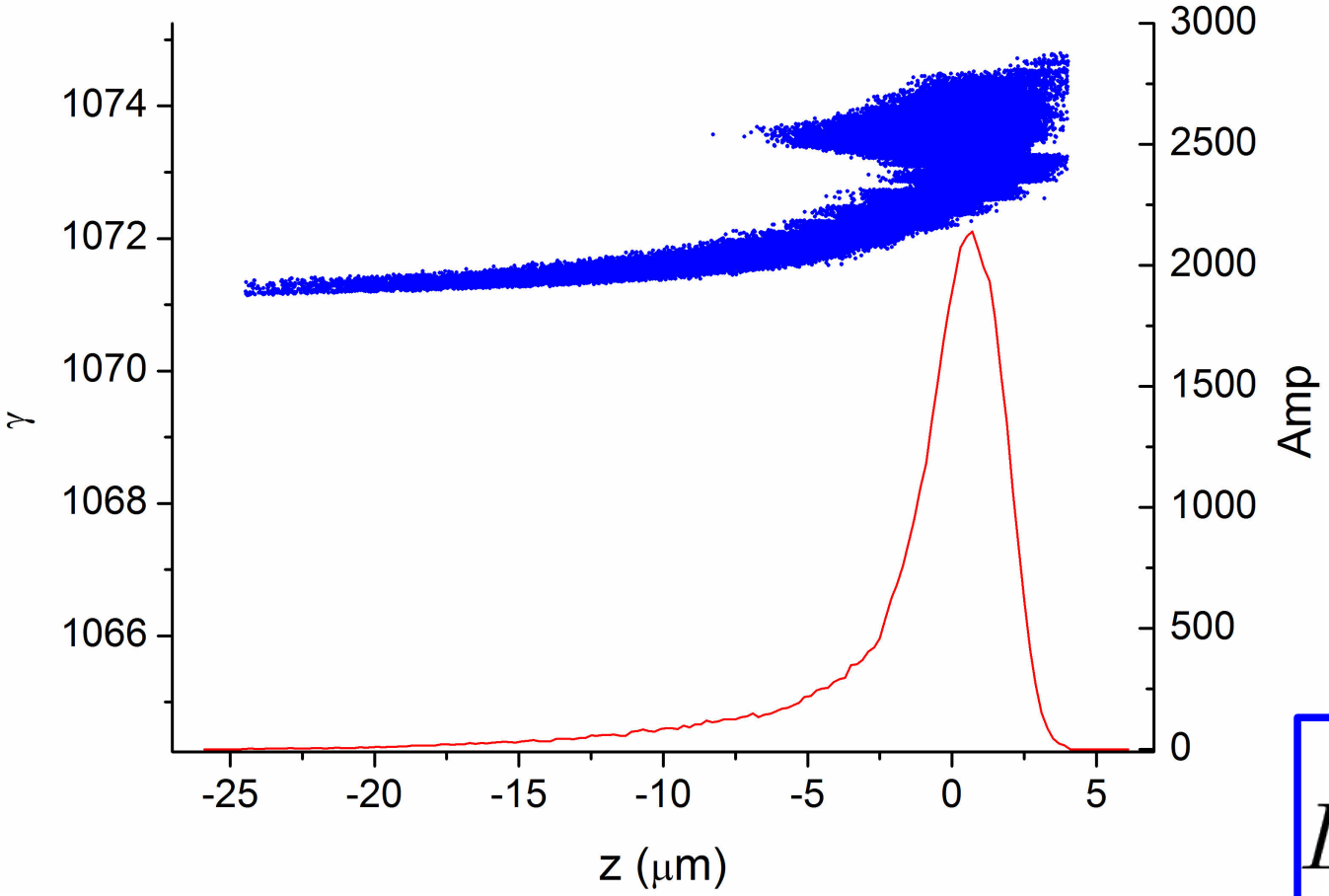
n_0 [cm^{-3}]	10^{17}
L [cm]	6

- Allow for higher target energies.

$$L_d \sim L_{pd} \sim \text{tens of cm}$$

Input beam

A. Giribono and C. Vaccarezza



E [MeV]	536,5
σ_{tr} [μm]	3
σ_z [fs]	12,4
L_{FWHM} [fs]	4,3
Q [pC]	30
dE/E	$6.1\ 10^{-4}$
ε_n [μm]	0,44
L_c [m]	36

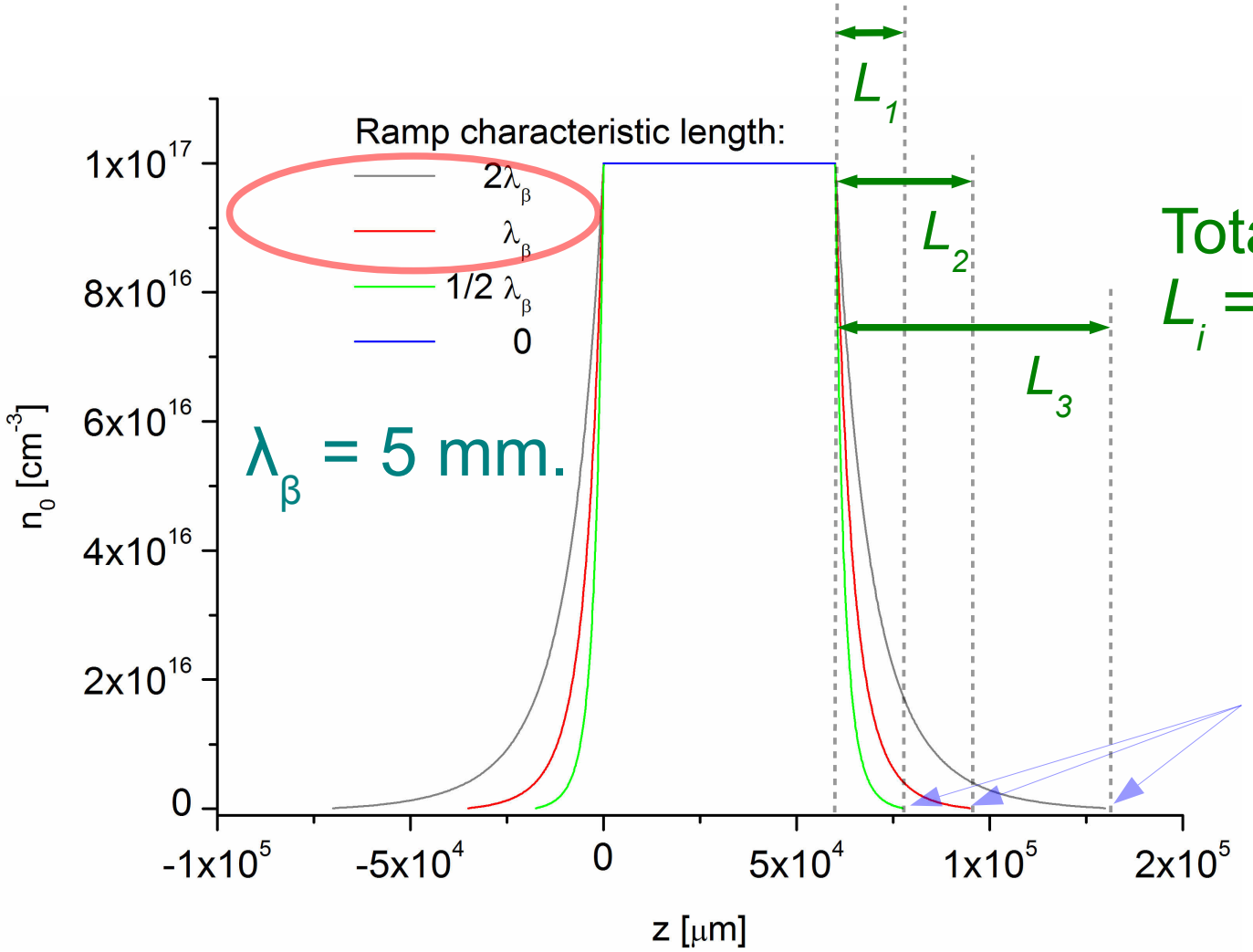
$$L_c = \frac{\gamma\,\sigma_x^2}{(\delta\gamma/\gamma)\varepsilon_n}$$

Wednesday, 27 September 2017 WG3
17:10 extreme high brightness electron beam generation in a space charge regime
Luca Serafini

Plasma profile

- Ideal setting has sharp edges plasma channel.
- More realistic settings have exponential ramps with char. length l_r.

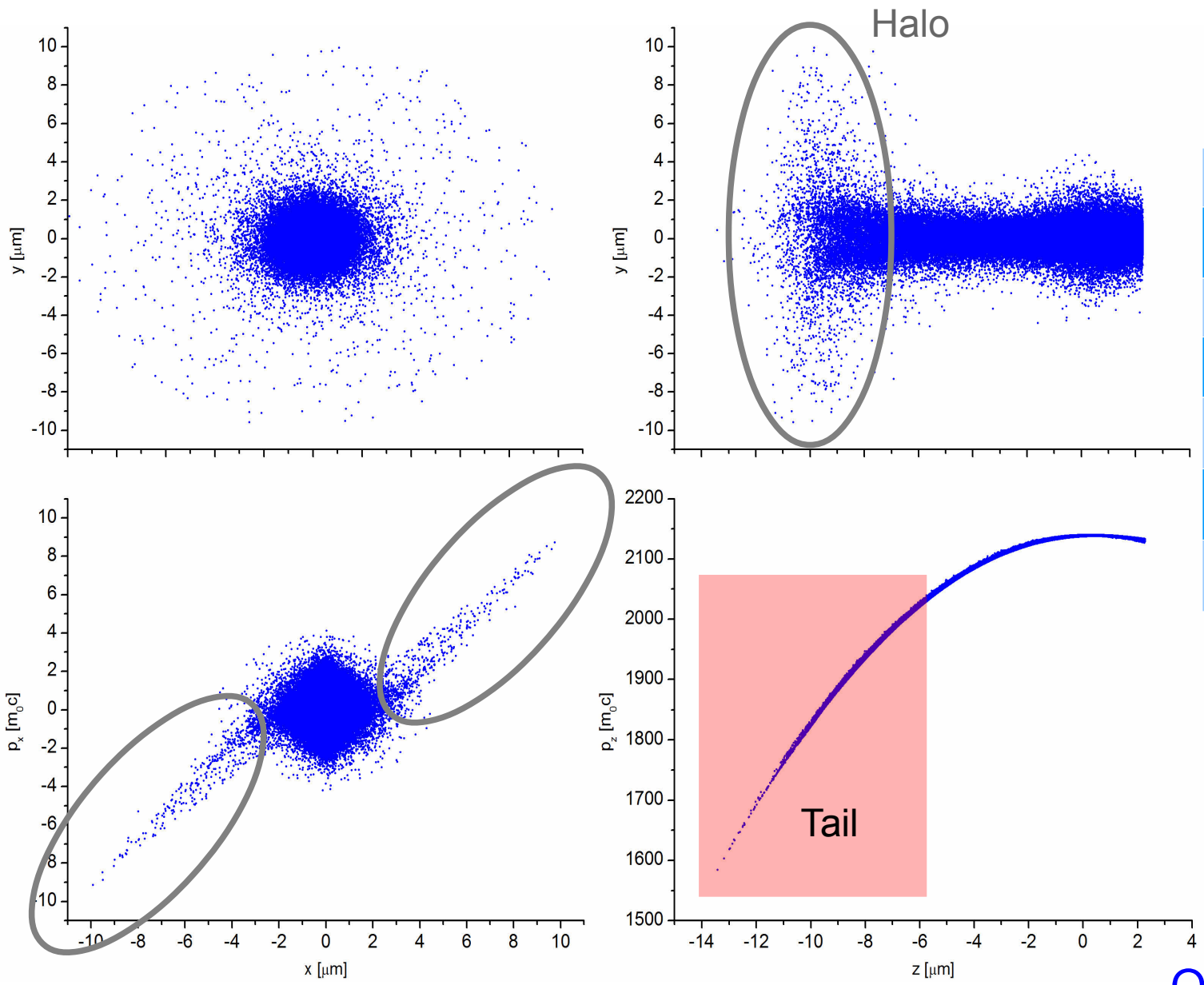
Work in progress



Total ramp length is
$L_i = 7\ l_r$

$n_f = 10^{14}\ \mathrm{cm}^{-3} = n_i$

Ideal setting: final beam



Removing halo and tail:

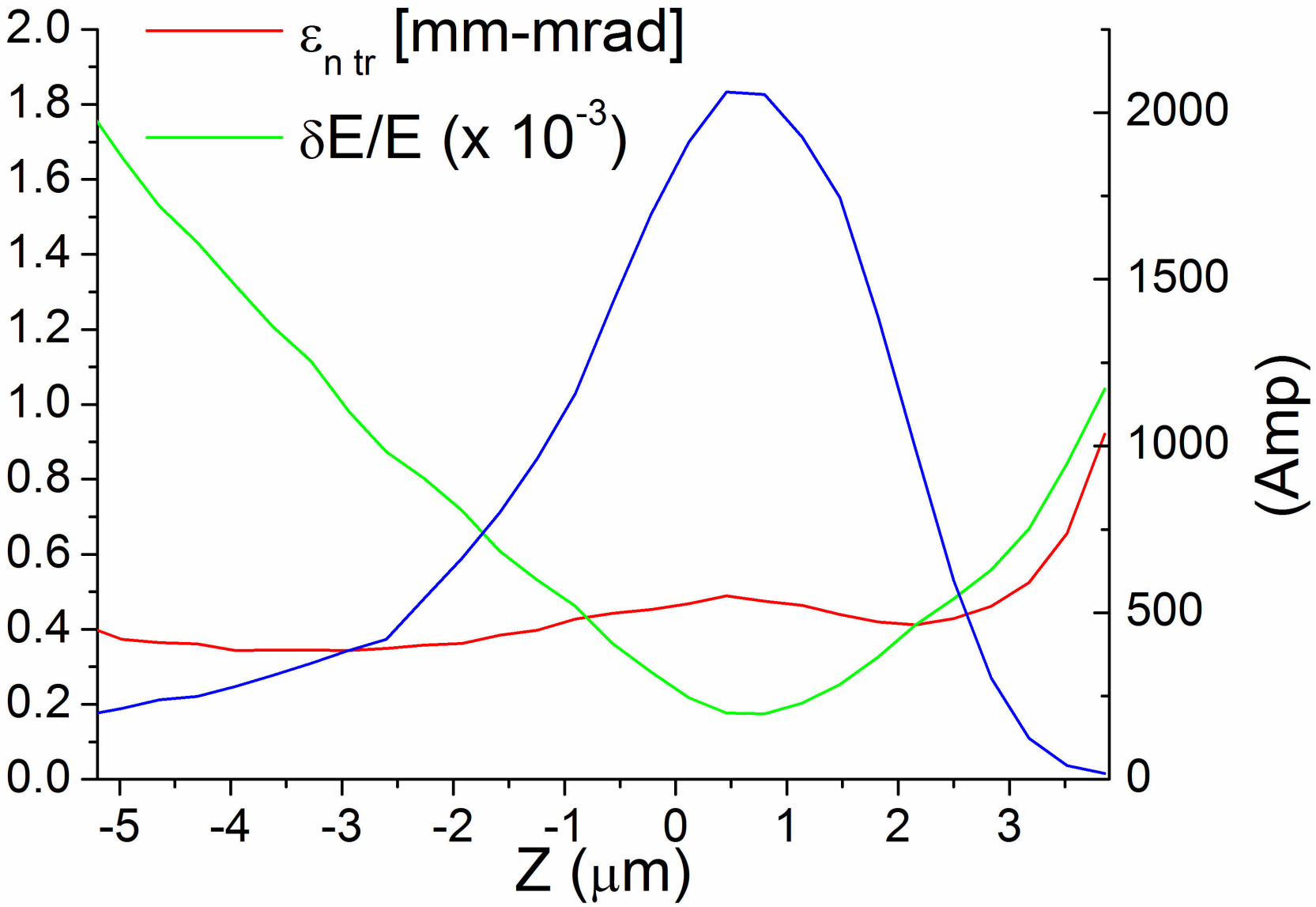
E [MeV]	1065
L_{FWHM} [fs]	4,3
Q [pC]	26,5
dE/E	$1.2\ 10^{-2}$
dE/E_{slice}	$7\ 10^{-4}$
ε_n [μm]	0,44
L_c [m]	0,06

Best beam after scan over injection size and phase

QFluid[1] simulations

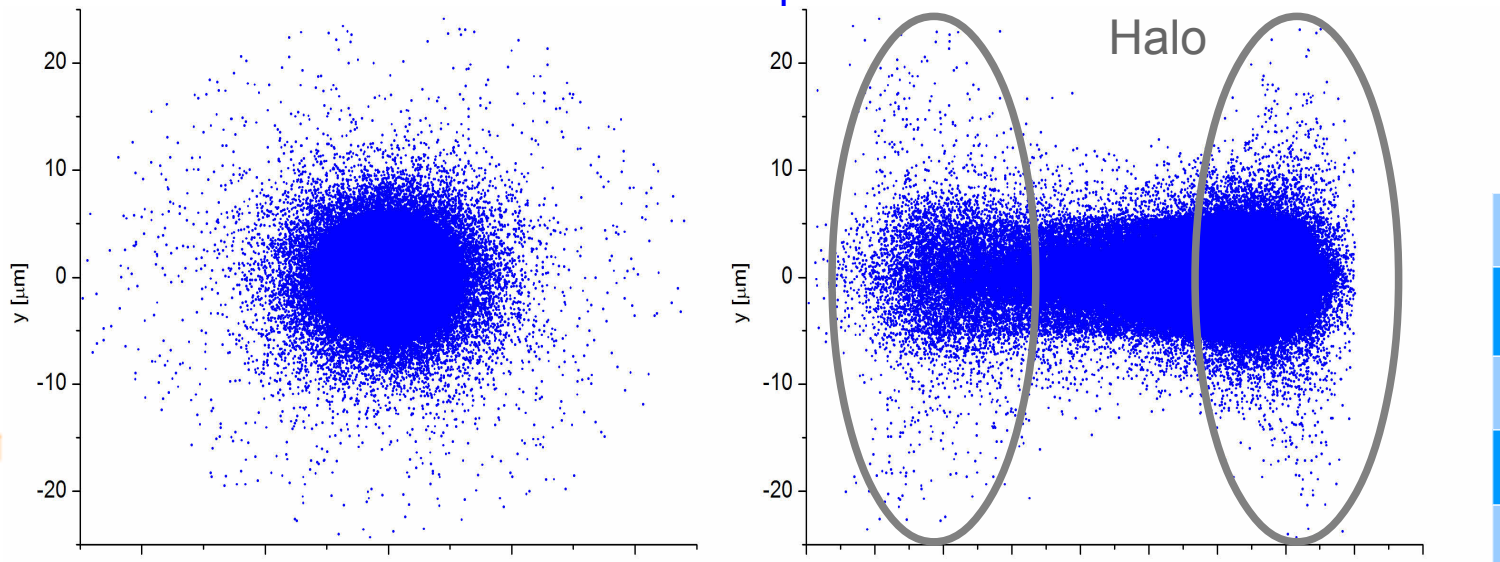
1. P. Tomassini and A.R. Rossi, Plas. Phys. Cont. Fus. 58, 034001 (2016)

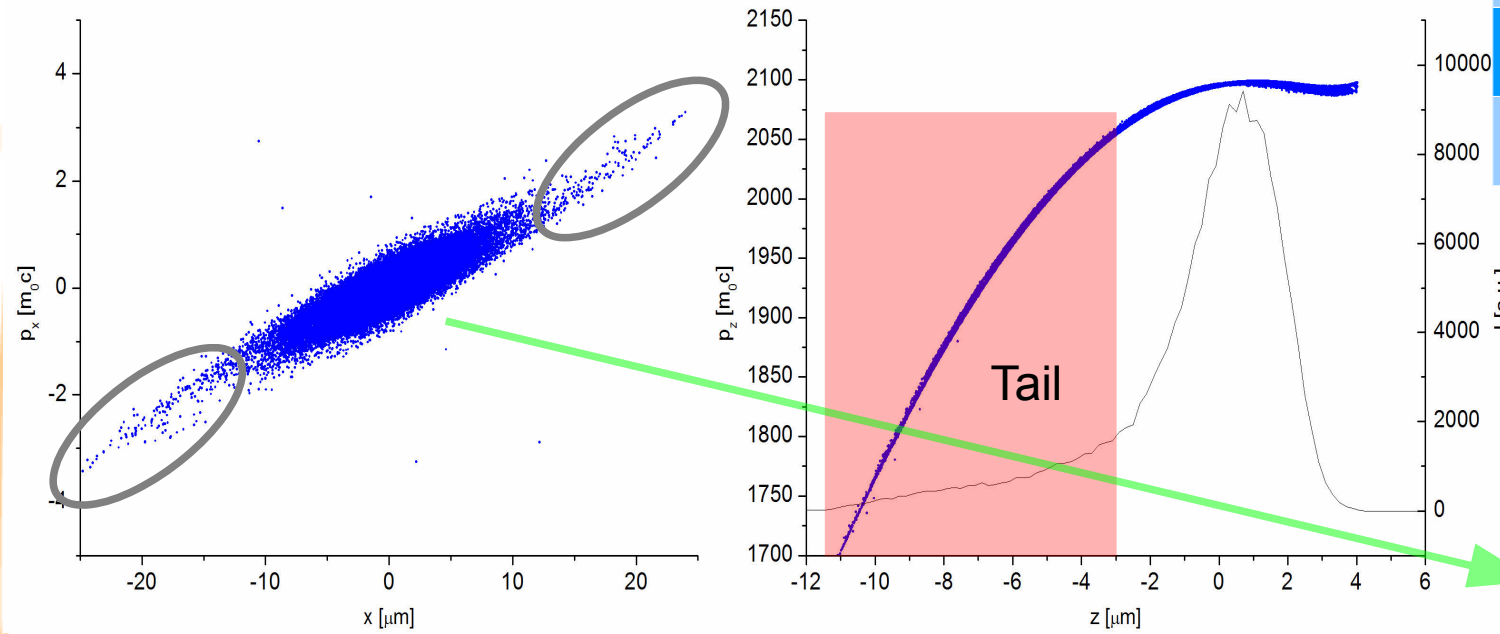
Ideal setting: final beam slice analysis



Around current peak, beam properties preserved!

$l_r = 0.5\lambda_\beta$ setting: final beam





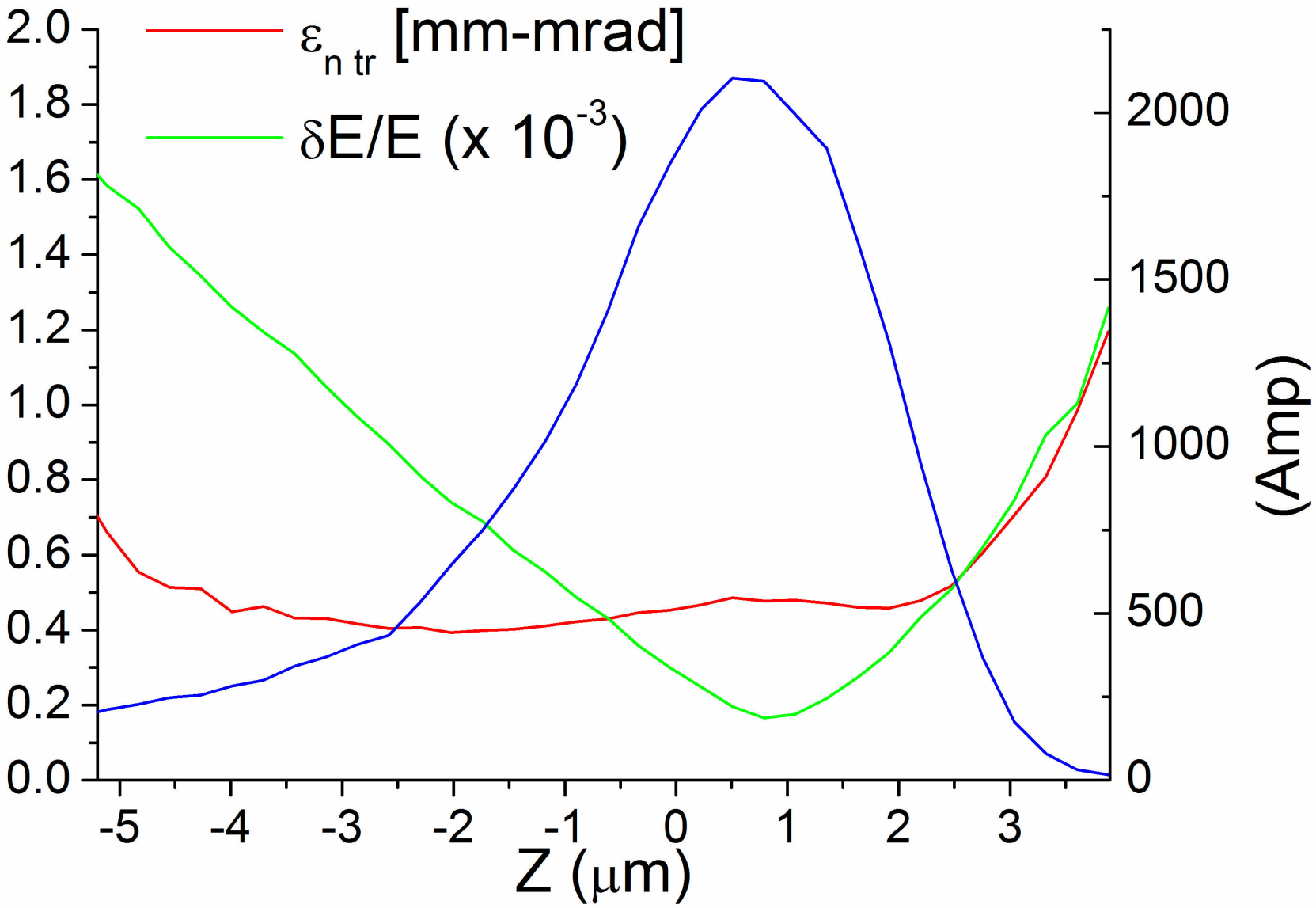
Removing halo and tail:

E [MeV]	1044
L_{FWHM} [fs]	4,3
Q [pC]	26,5
dE/E	$2.3\ 10^{-2}$
dE/E_{slice}	$3\ 10^{-4}$
ε_n [μm]	0,45
L_c [m]	0,27

Best beam after scan over injection size and phase

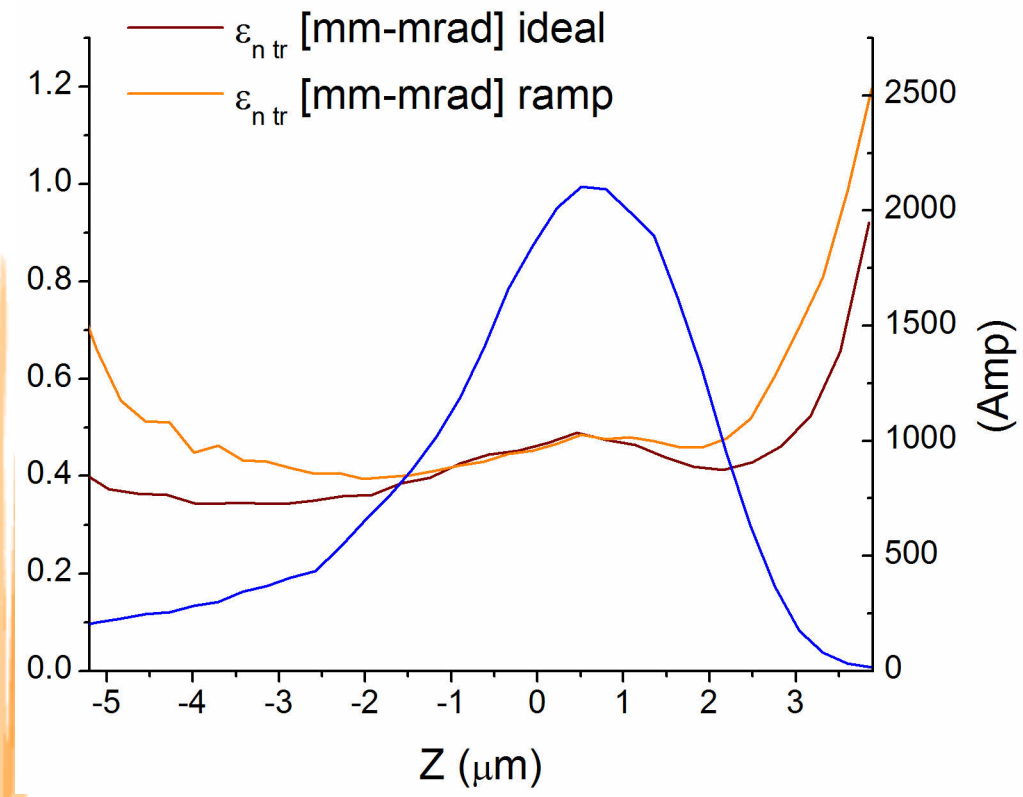
$\alpha_{Twiss} = -2$ adiabatic defocusing!

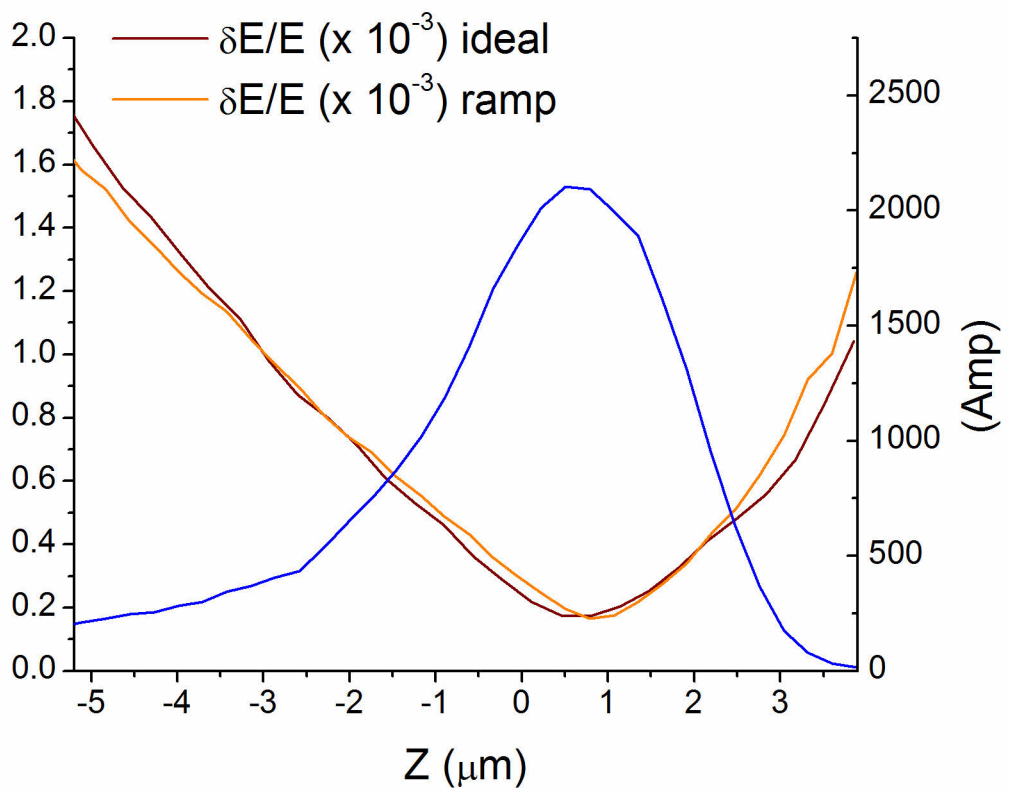
$l_r = 0.5\lambda_\beta$ setting: final beam slice analysis



Around current peak beams properties preserved with ramp!

Ideal and $l_r = 0.5\lambda_\beta$ settings comparison

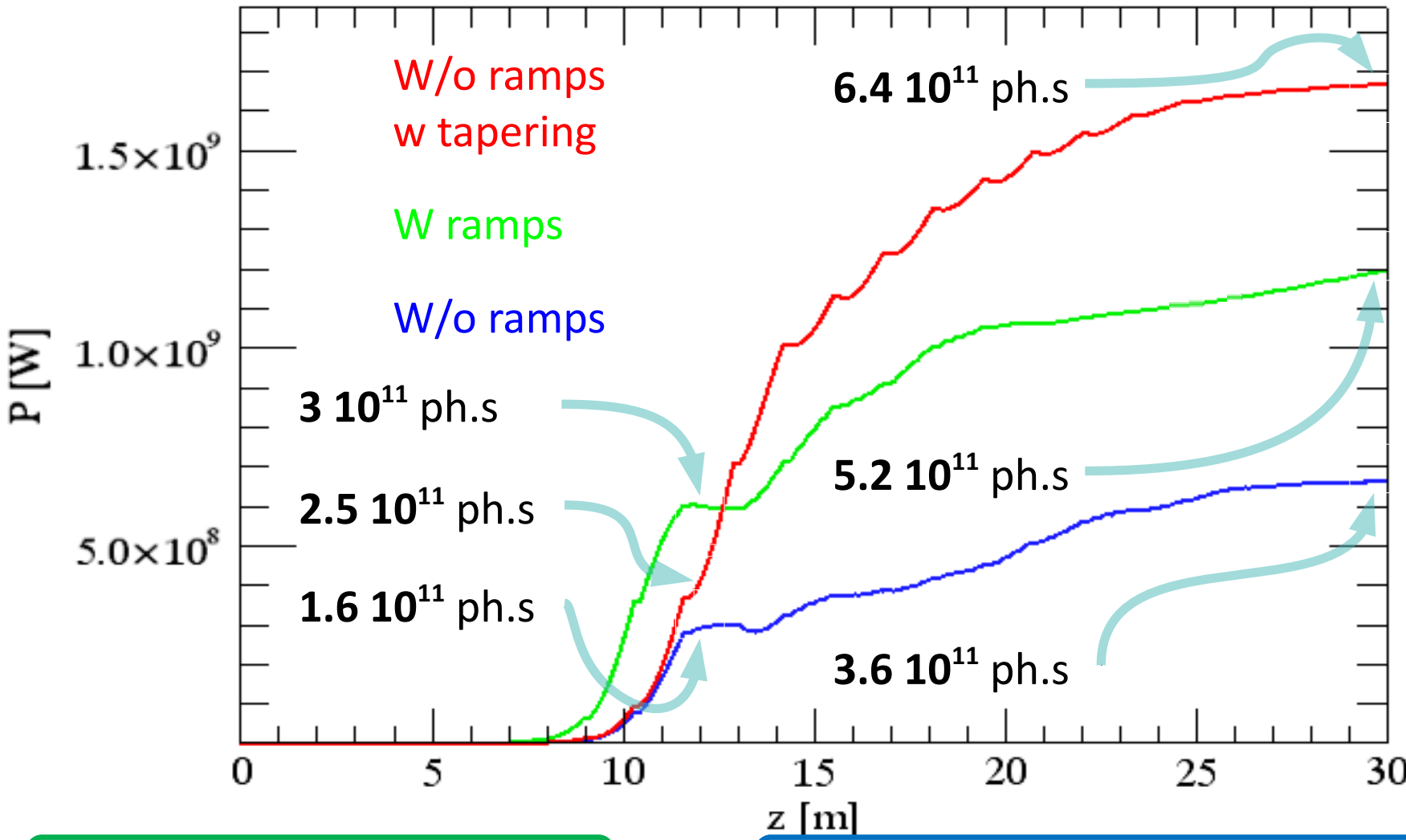




No significant differences on current peak

FEL performances

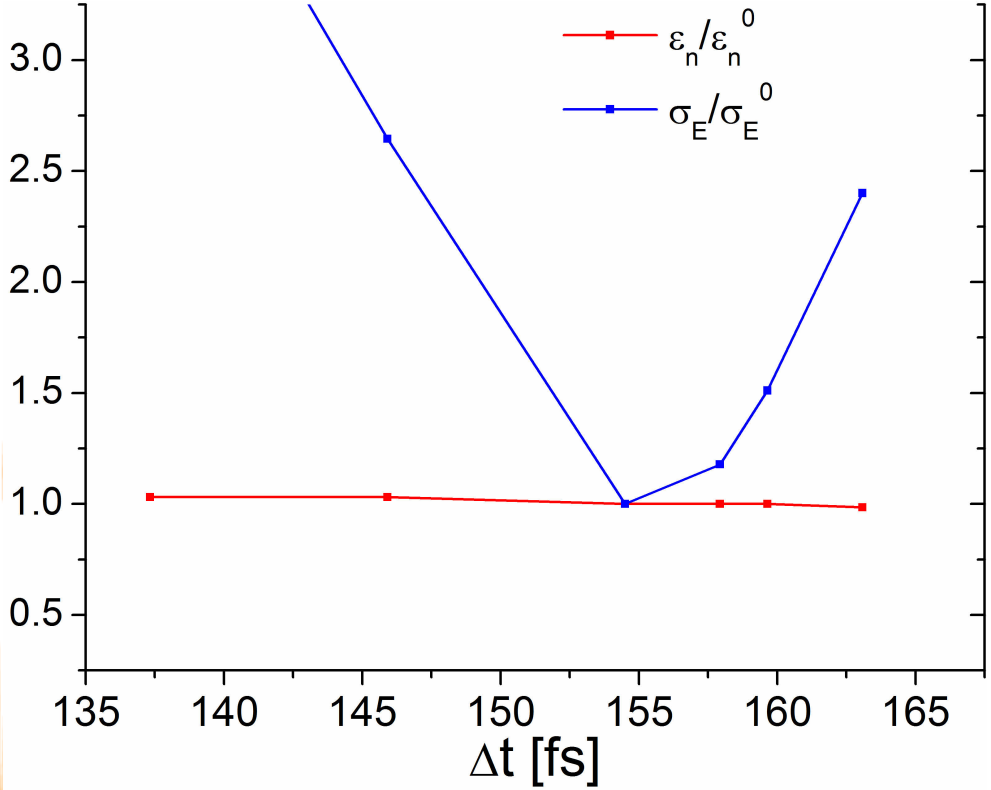
Growth of the radiation along the undulator



Undulator λu=1.5 cm, a_w=0.8

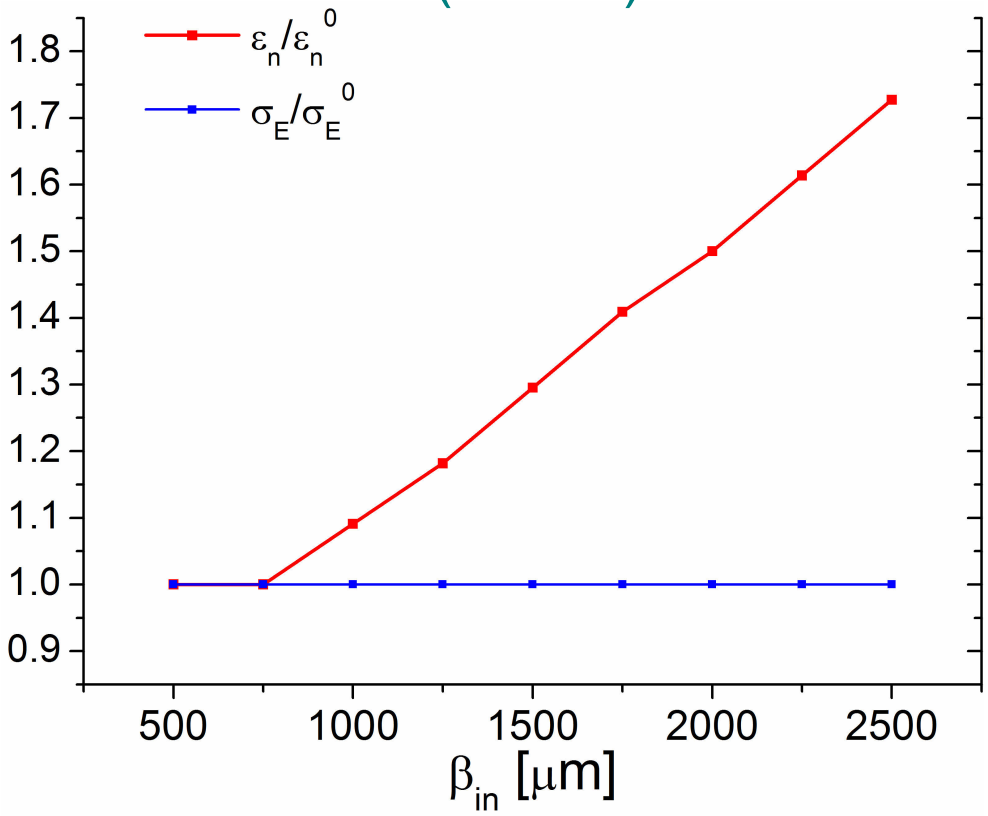
Radiation: λ=2.7 nm, E_{ph}=0.45 keV

Working point stability

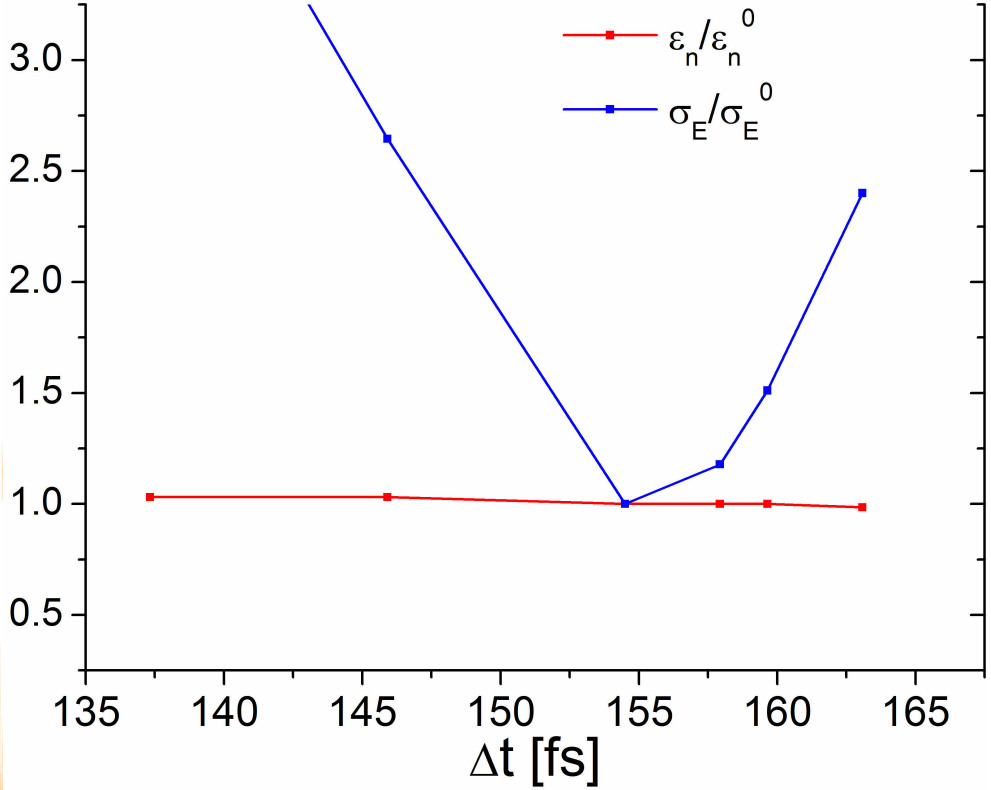


Fixed β_{in} = 2.0 mm
(IDEAL)

Fixed Δt = 155 fs
(IDEAL)

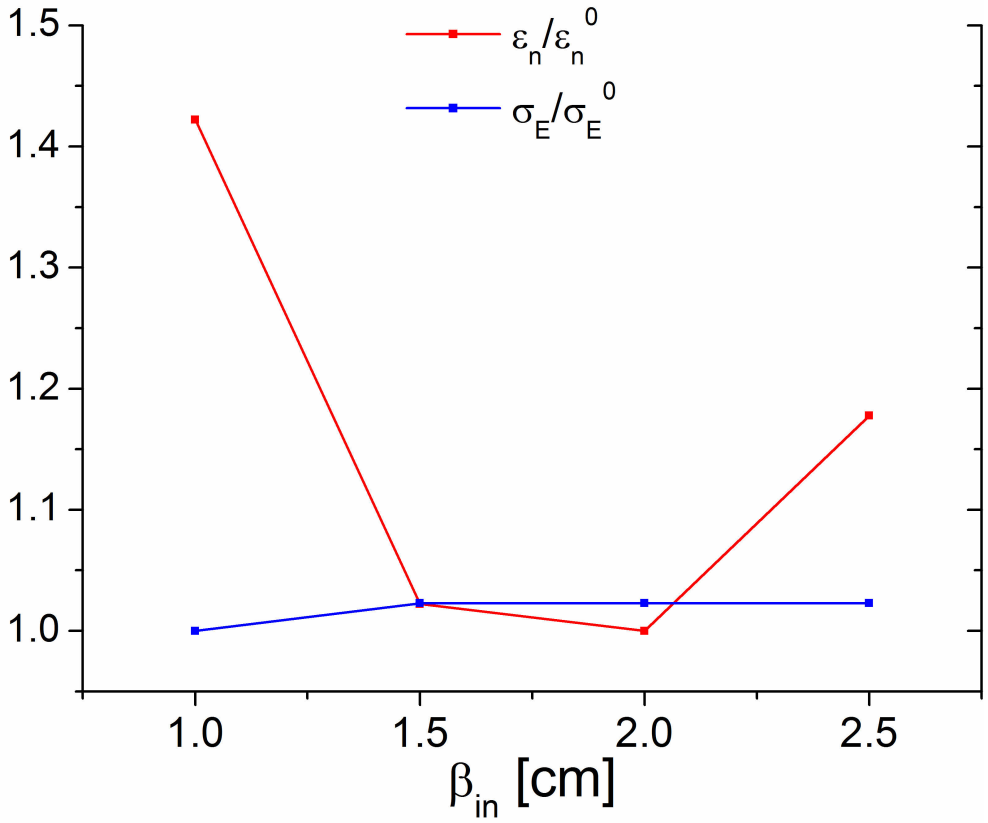


Working point stability



Fixed β_{in} = 2.0 mm
(IDEAL)

Fixed Δt = 140 fs
(RAMP)



Conclusions

- Preliminary simulations for EuPRAXIA and EuPRAXIA@SPARC_LAB 1GeV LWFA stage with External Injection are ongoing.
- They are yielding promising results in terms of beam brightness.
- Ideal setting and a configuration with short ramps produce bunches able to drive an FEL.
- A rough estimate for stability vs jiters in injection phase and beam size has been presented.
- To do: conclude longer ramps study and extend to 5 GeV target energy.