Beam Dynamics studies for the X-band Linac of the EuPRAXIA @ SPARC_LAB Project

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On behalf of SPARC_LAB collaboration

Outline

- Introduction
- The Linac layout & parameter list
- WP’s details
- BD studies for the nominal cases
- Static and dynamic error studies: first results
- Conclusions

Introduction

In the framework of the Eupraxia Design Study an advanced accelerator facility EUPRAXIA at SPARC_LAB has been proposed to be realized at Frascati (Italy) Laboratories of INFN.

Two advanced acceleration schemes will be applied:

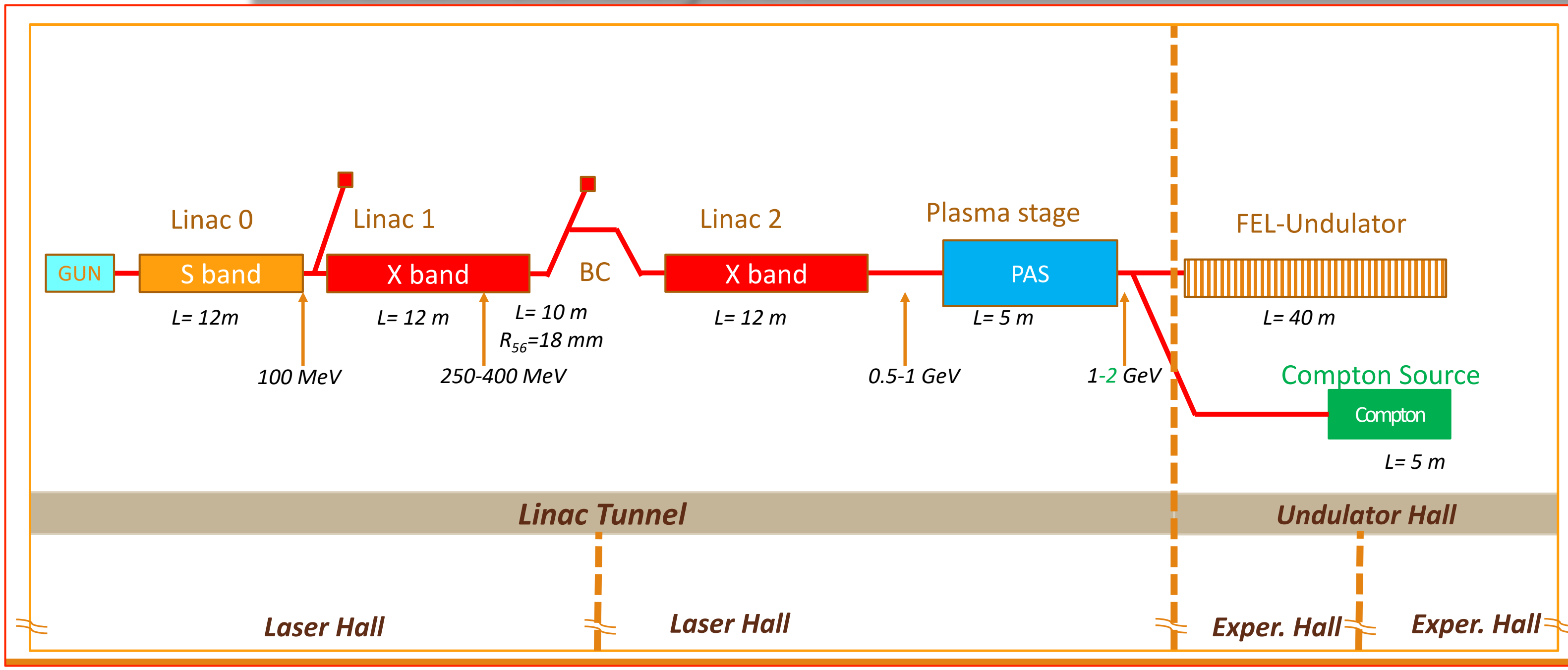
- an ultimate high gradient 1 GeV X-band linac and
- a plasma acceleration stage to provide accelerating gradients of the GeV/m order.

A FEL scheme is foreseen to produce X-ray beams within 3-10 nm range.

A 500-TW Laser system is also foreseen for electron and ion production/acceleration experiments and a Compton backscattering Interaction is planned together with extraction beamlines at intermediate electron beam energy for neutron beams and THz radiation production.

On March 2018 the CDR has been published:
«EuPRAXIA@SPARC_LAB Conceptual Design Report», INFN - 18-03/LNF

The Linac Layout



- S-band photoinjector: Gun+2÷3 acc. structures
- X-band Linac: 32 structures (50 cm)
- Plasma Acceleration Stage
- Magnetic chicane& Transfer Lines

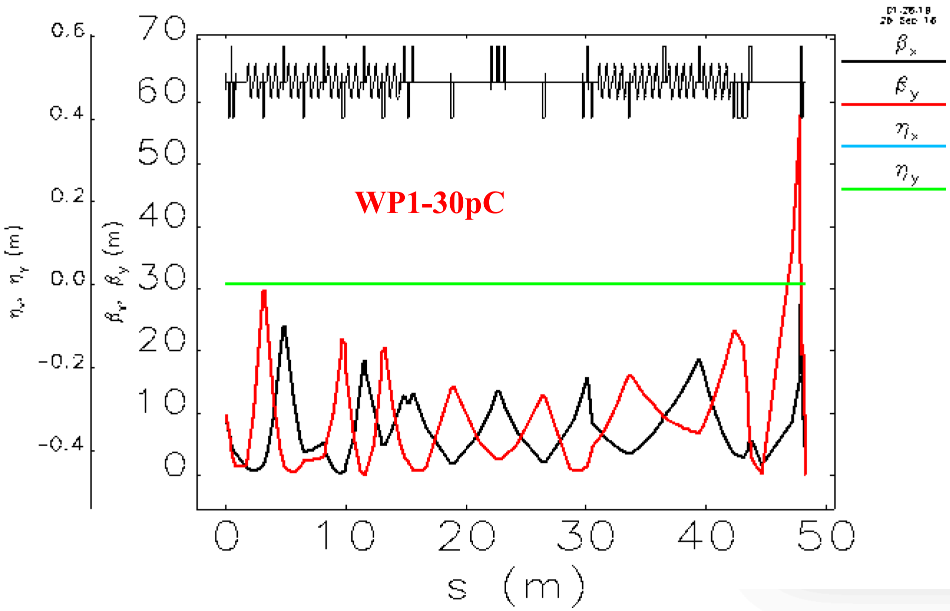
Linac 1 & 2 parameter list for 2 WP's

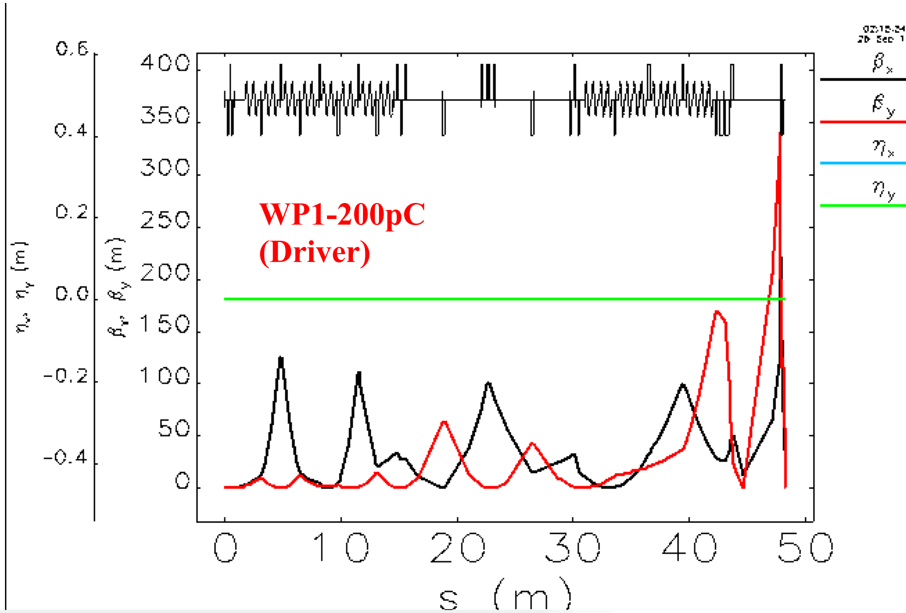
- WP1: Witness (+ Driver) for PWFA: 30 pC-3KA (FWHM) per bunch with only velocity bunching, suitable both for Beam Driven (+ 200 pC Driver) and Laser driven acceleration in Plasma

- WP2: High charge-Low Currrent from Photoinjector: 200 pC-70 A, with and without the longitudinal bunch compression in the magnetic chicane to serve both the SASE-FEL, with peak current Ipk=2kA, and the Compton Source in the high flux operation scheme.

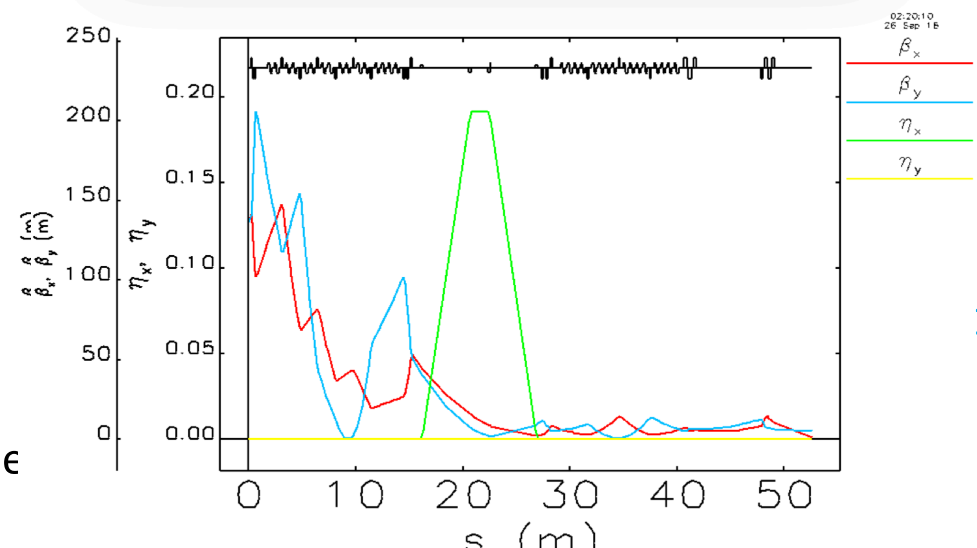
Beam Parameter	Unit	L1		L2	
		WP1	WP2	WP1	WP2
Initial energy	GeV	0.01	0.17	0.260	.600
Final energy	GeV	0.260	.55	.600	1.26
Active Linac length	m	8.0		8.0	
Accelerating Gradient	MV/m	20.0	57.0	36.0	57.0/80
RF phase (crest at 0)	deg	-20.0	-12.0	-19.5	+15.0
Initial rms energy spread	%	0.30	0.67	0.15	0.56
Final rms energy spread	%	0.15	0.56	0.08	0.2
rms bunch length	μm	3	112	3	20

Twiss Parameters for the WP's





WP2-200 pC

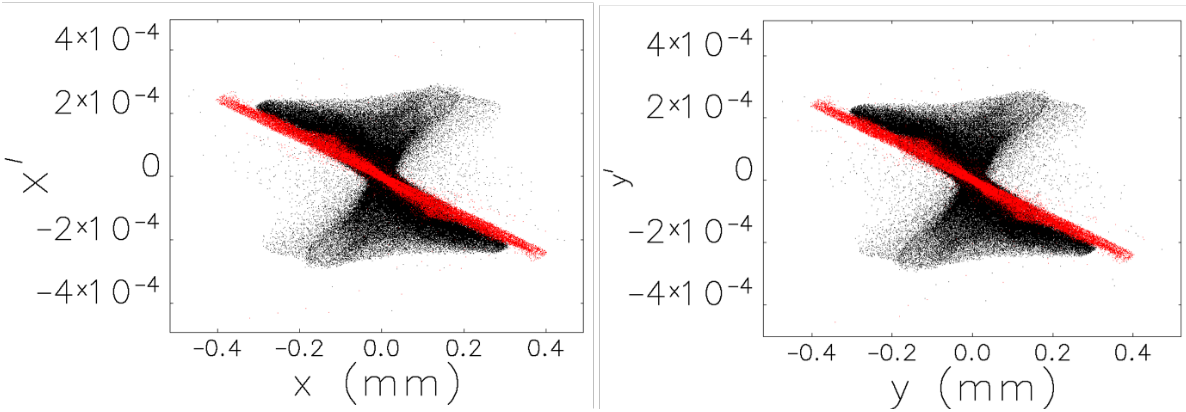


16 mm

30 kp tracked with Elegant code

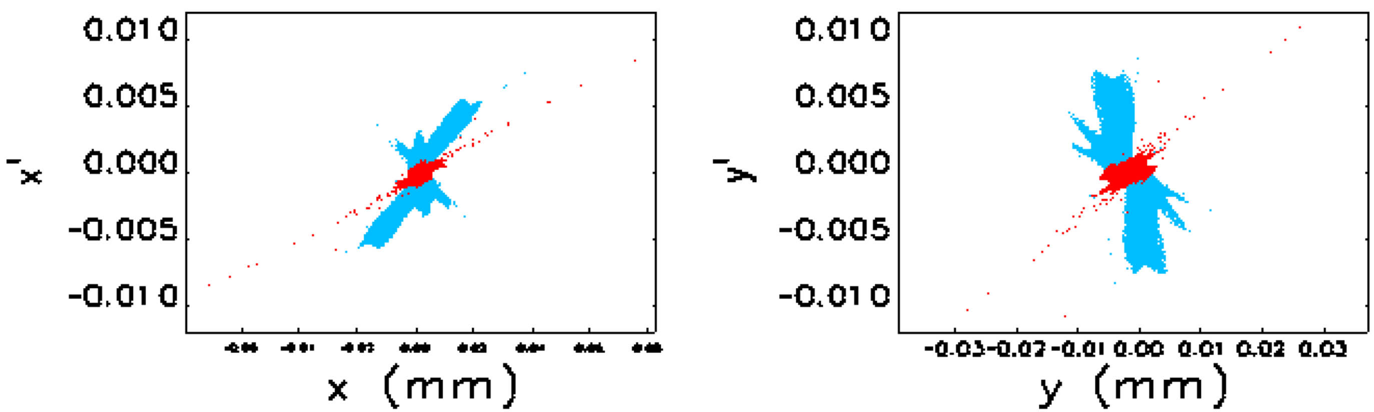
PWFA case: Driver (200 pC) & Witness (30 pC)

Linac entrance
(Photoinjector exit)



Horizontal and vertical phase space distribution of the PWFA driver (black dot) and witness (red dot) beams at the L1 linac entrance

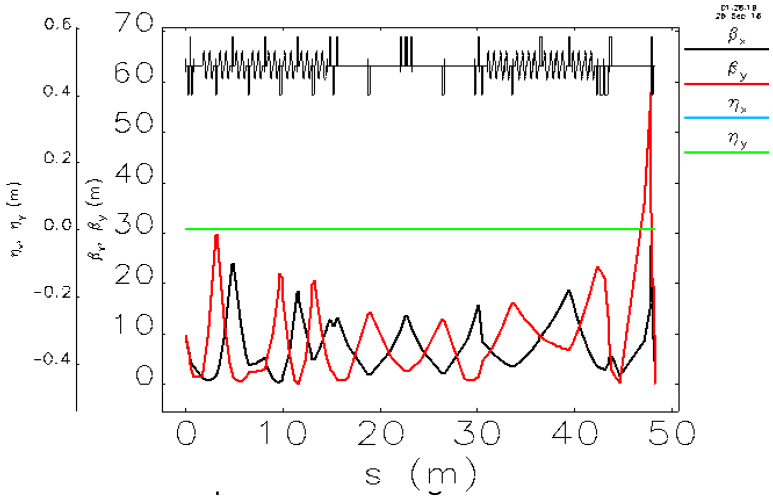
Capillary entrance
(Linac exit)



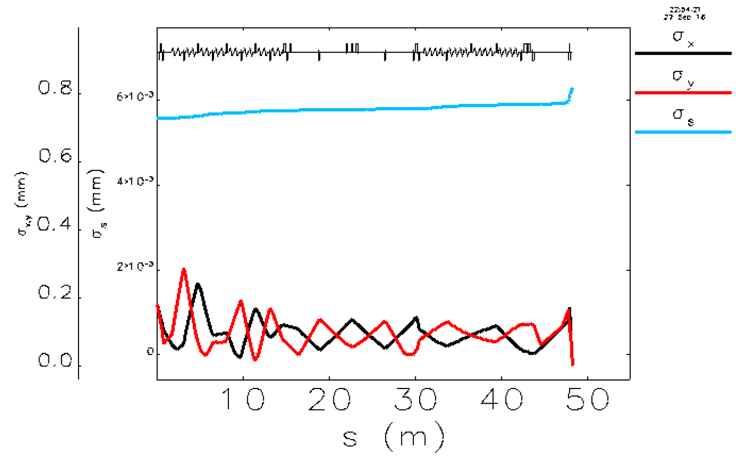
Horizontal and vertical phase space distribution of the PWFA driver (cyan dot) and witness (red dot) beams at the capillary entrance

X-band Linac 32 sections, 50 cm long

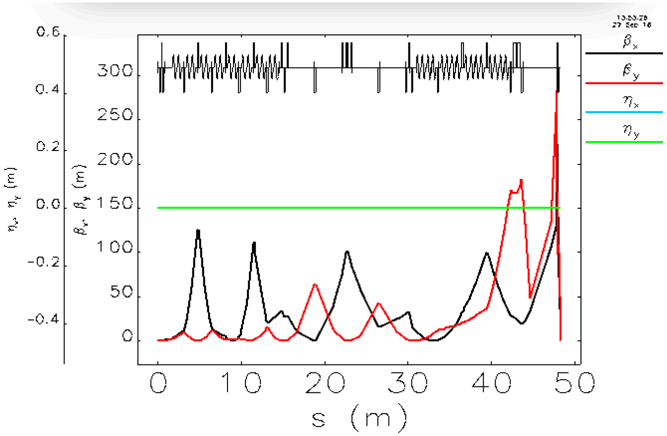
A *gentle* mismatching for Witness + Driver beam has been optimized to control the transverse beam dimensions along the linac and the final strong focusing at the capillary entrance



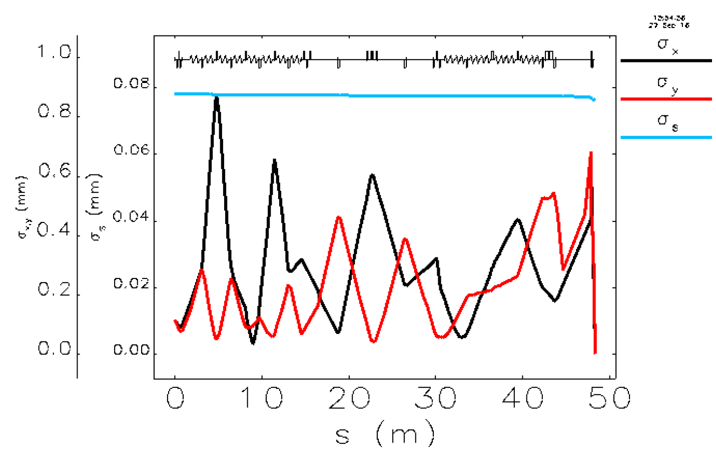
witness



Twiss parameters along the linac

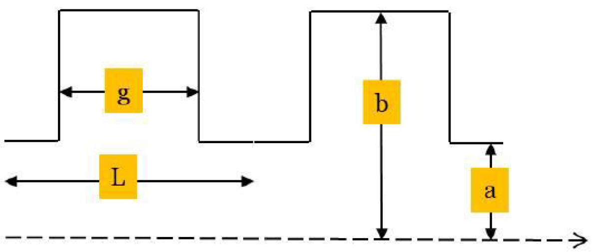


driver

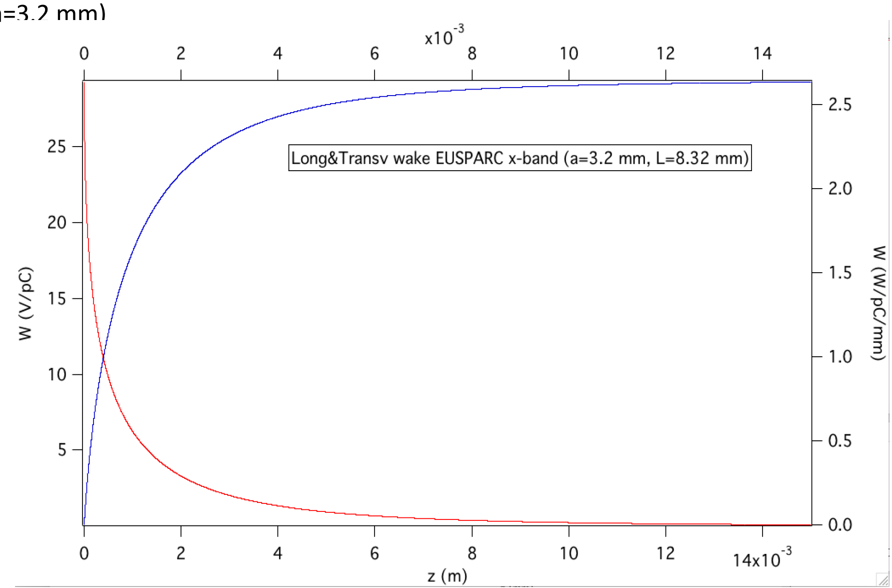


Long & Transv Wake field

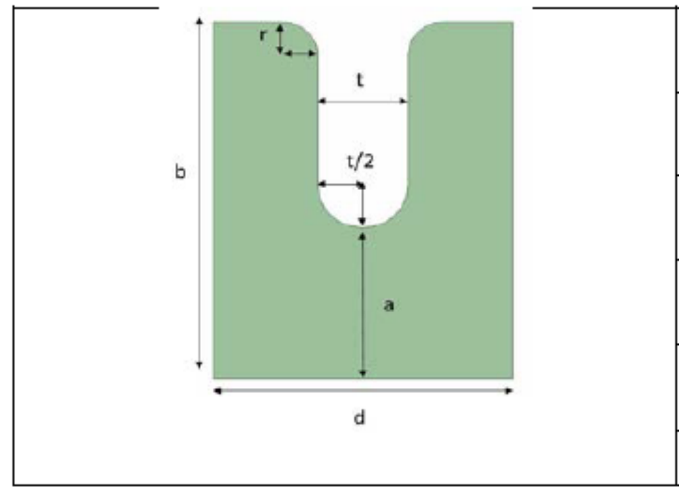
See M.Diomede “Preliminary RF design of an X-Band LINAC for the EuSPARC/EuPRAXIA@SPARC_LAB proposals”



Pill box cavity model considered for the wake feld calculations:
a is the iris radius, L is the cell length. The asymptotic values of the longitudinal and transverse wake functions have been calculated according to K. Bane SLAC{PUB{7862 (Revised) November 1998 with a=3.2 mm)



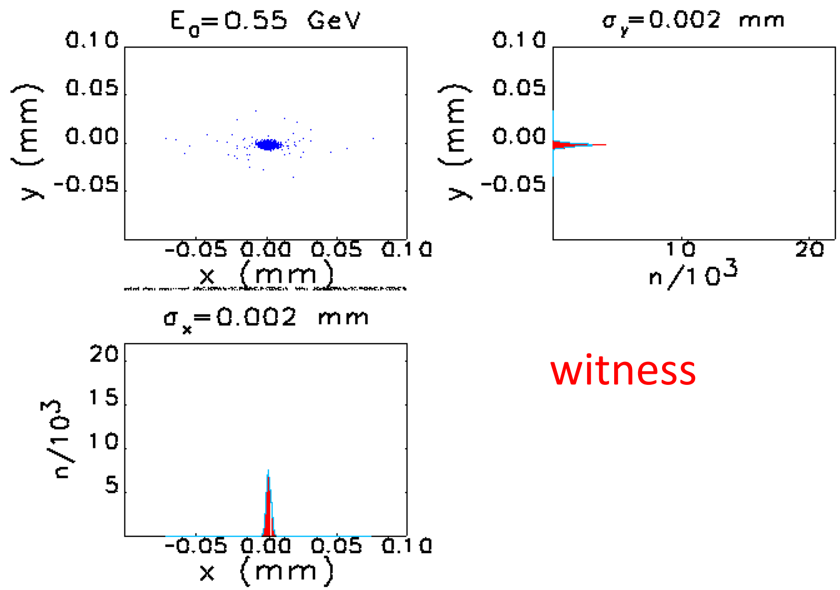
Longitudinal and transverse wakefield calculated for an iris radius of 3.2 mm and a cell length of 8.332 mm.



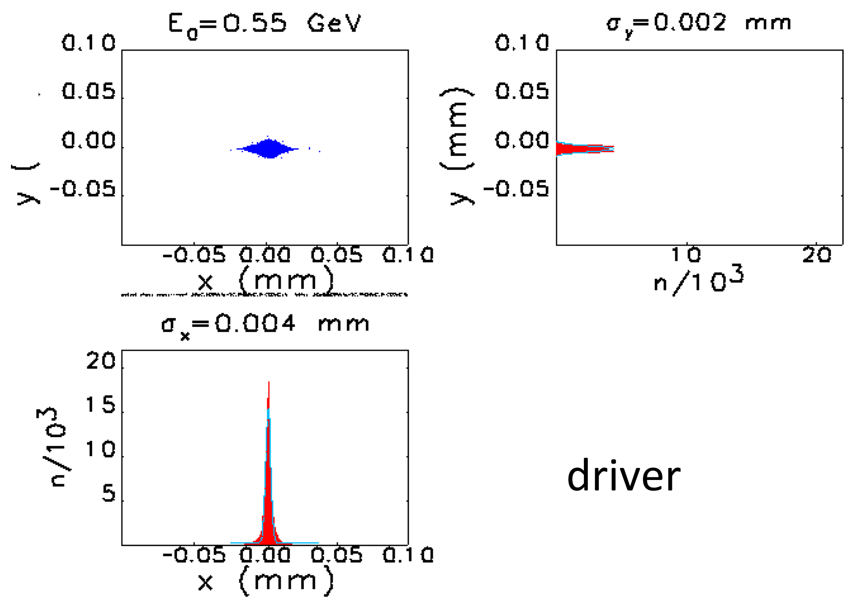
Geometrical parameters	
a[mm]	2 ÷ 5
b [mm]	9.828 ÷ 10.917
d [mm]	8,332 (2π/3 mode)
r [mm]	1
t [mm]	2.5

X-band Linac 32 sections, 50 cm long

Horizontal and vertical distribution of the PWFA witness (left) and driver (below) beams at the capillary entrance.



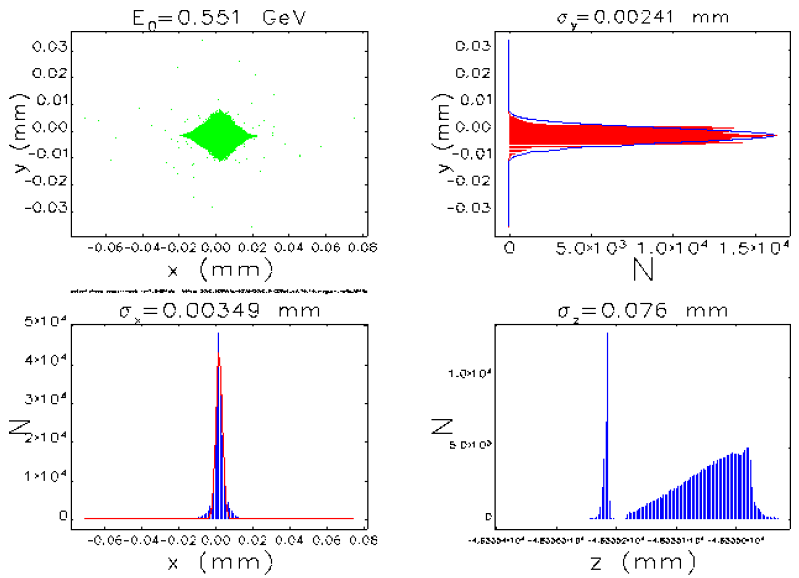
witness



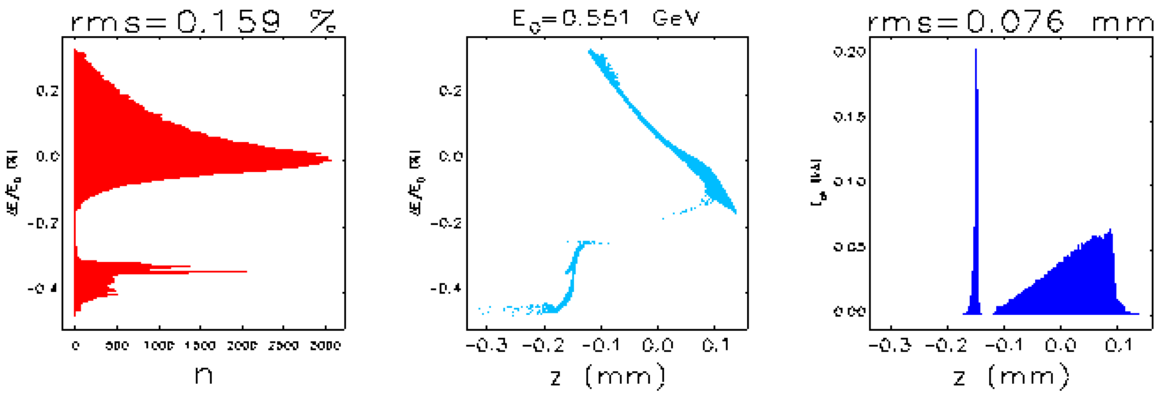
driver

Linac BD results for Driver+Witness

Transverse distribution at the entrance of the plasma capillary.

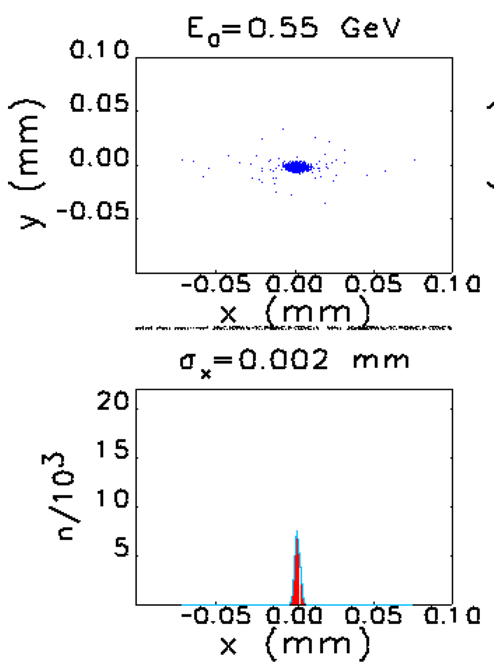


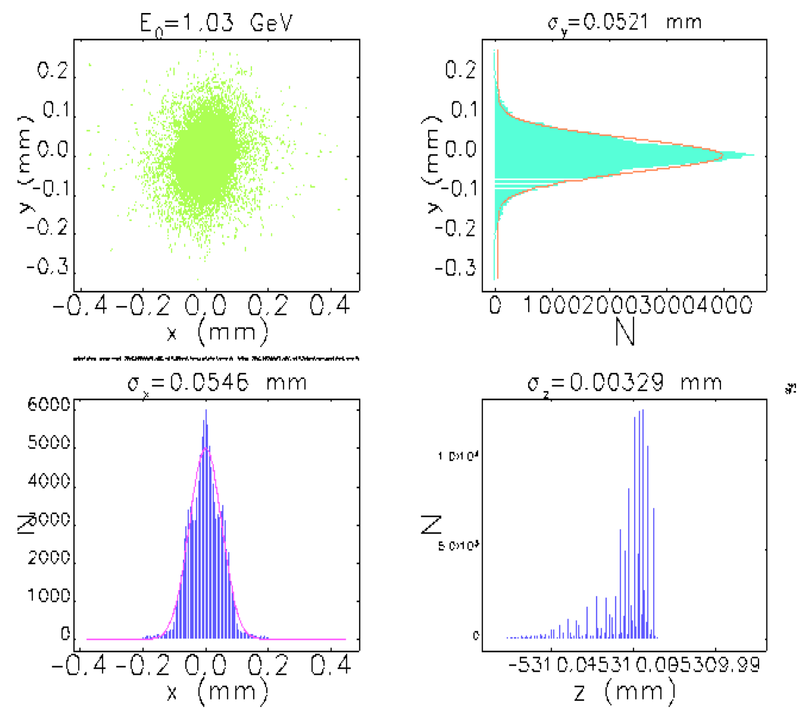
Longitudinal phase at the entrance of the plasma capillary.



WP1 case: Transverse electron beam distribution (witness bunch)

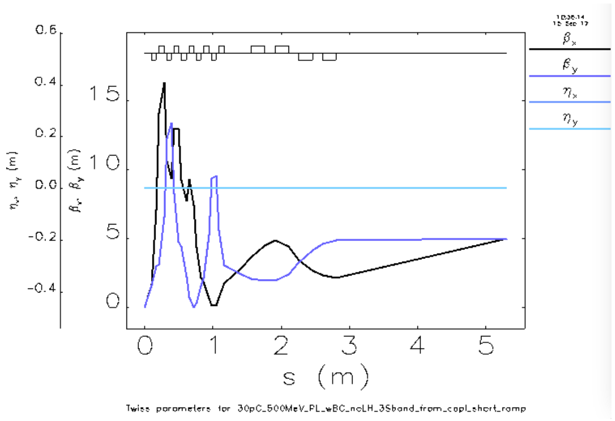
- before the plasma acceleration (capillary entrance)
- undulator entrance

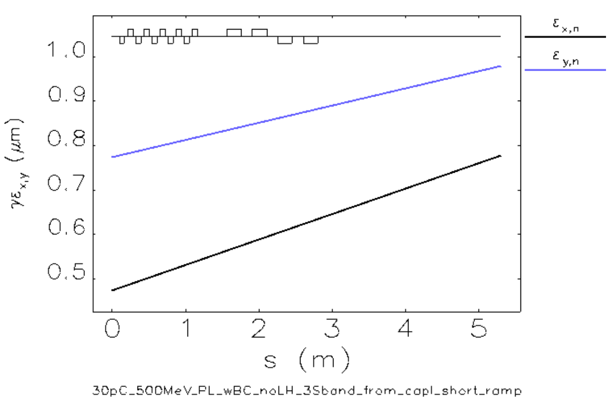




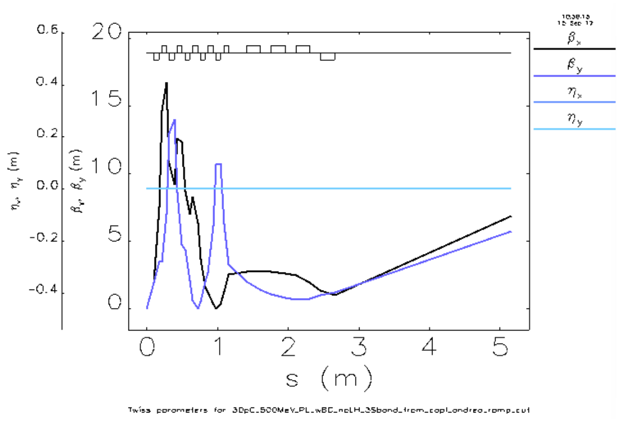
Twiss Parameters & emittance dilution in the Transfer line to undulator (WP1 case)

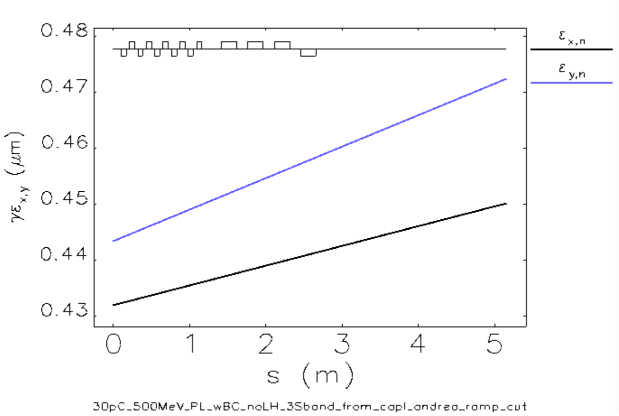
- Beam Driven



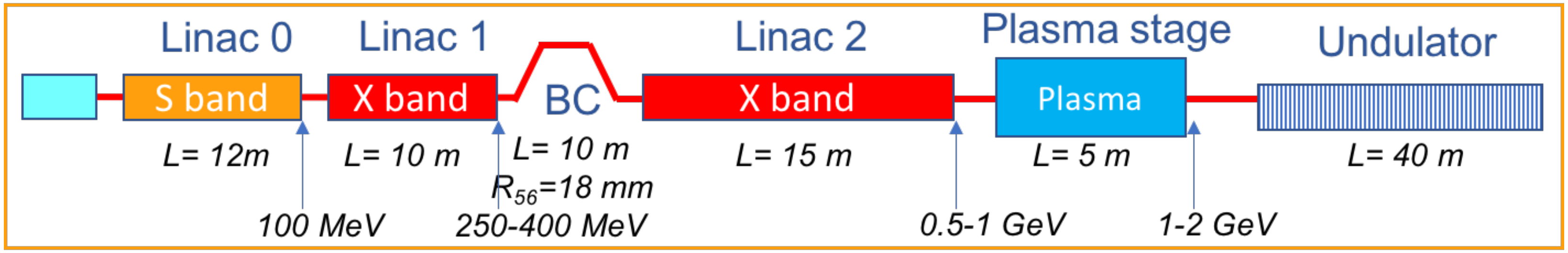


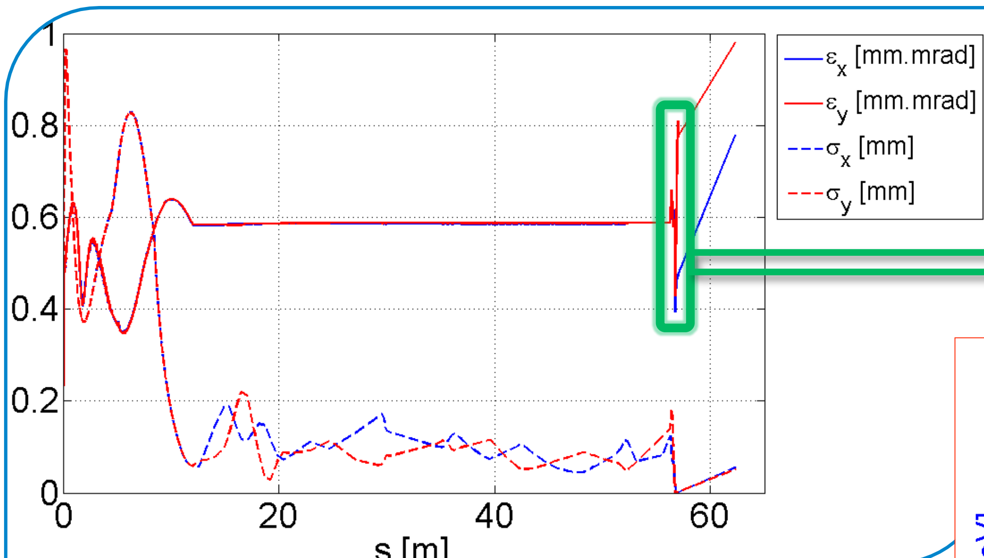
- Laser Driven

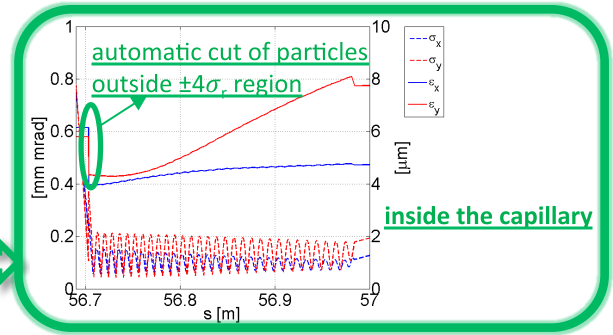


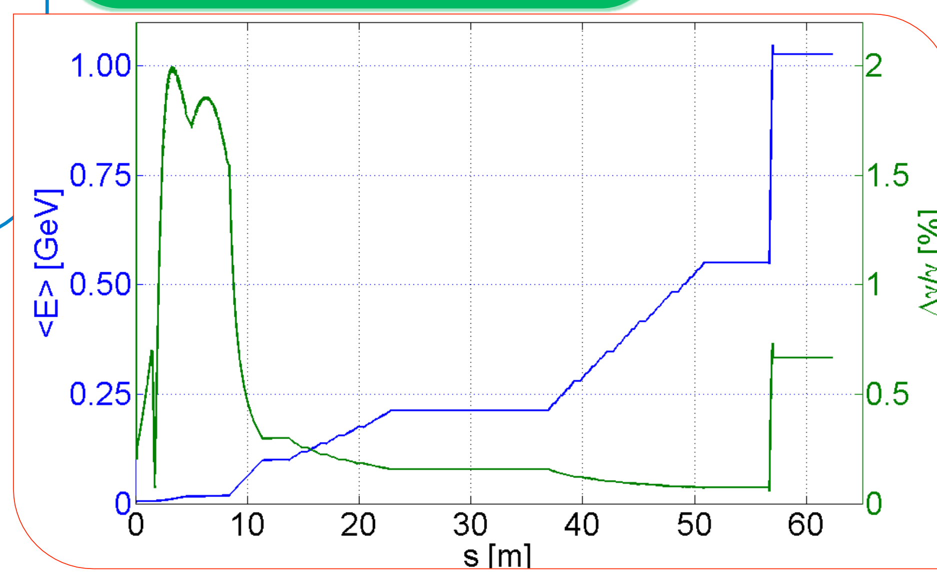


WP1 case: 30 pC beam evolution from Cathode to Undulator

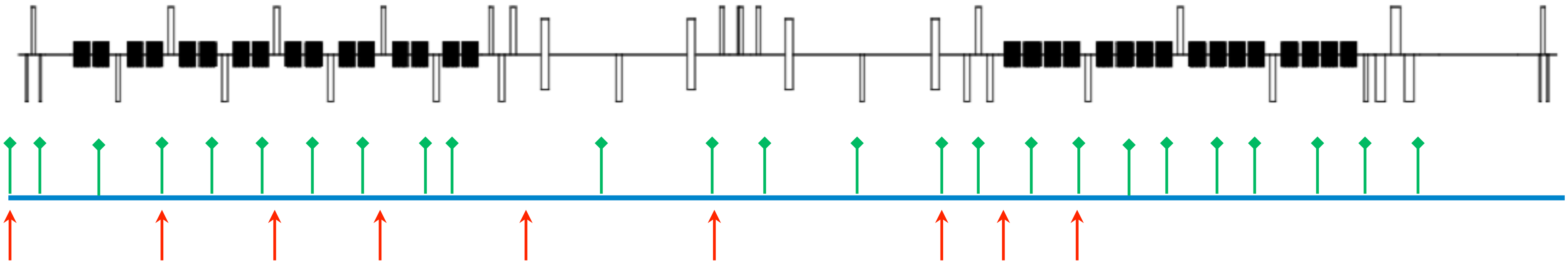








Static and dynamic errors simulation:



Steerer + BPM

Beam error kick (girder to girder)

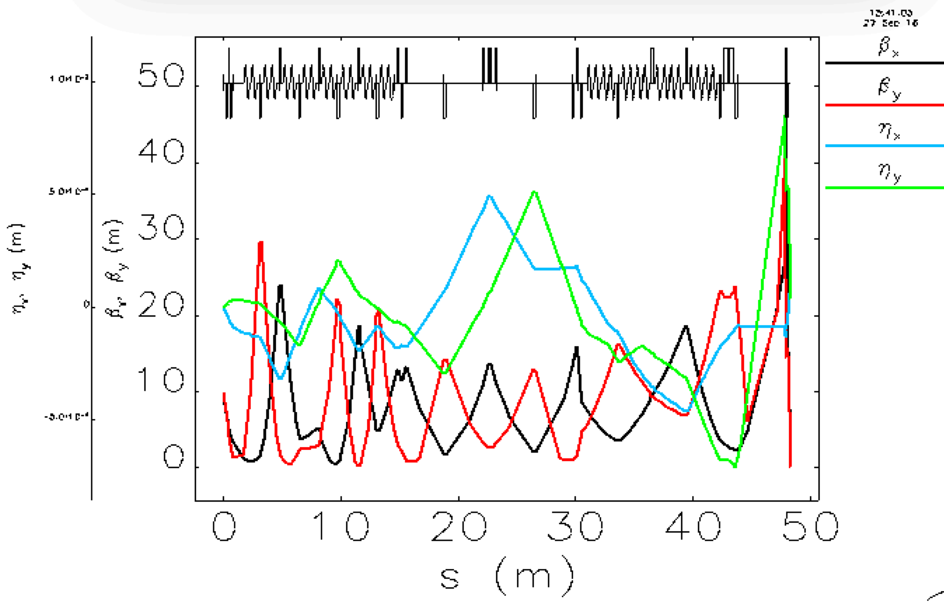
✓ Static errors:
- 100 (20) μm (x ,y) random misalignment on RF's structures and magnetic elements
- 0.05 (0.01) μrad tilt on magnetic elemts
- 100 μm misalignment kick to the beam, ex. girder to girder
- 20 random simulated machines

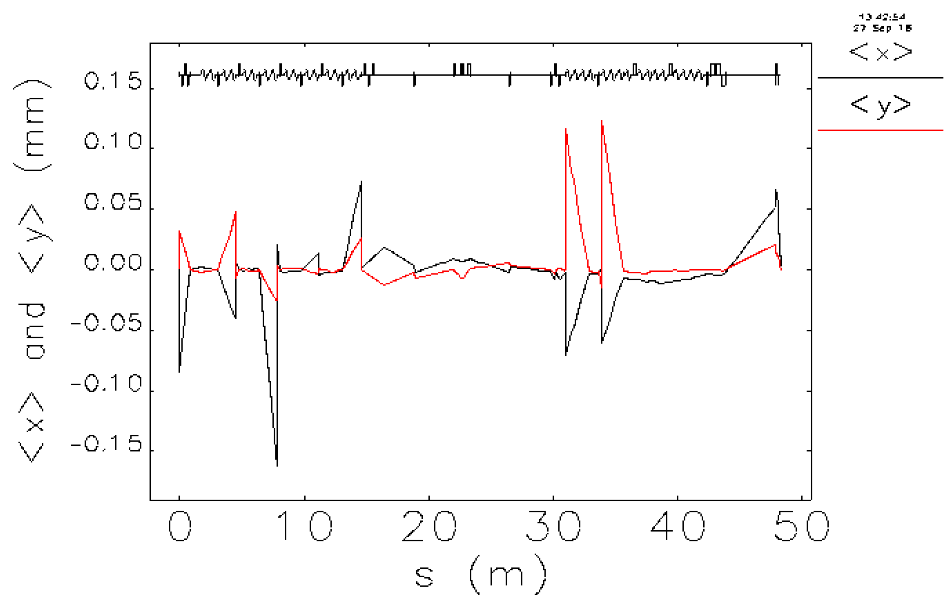
✓ Dynamic errors:
- Quad strength errors 0.1% rms
- Sterer kick errors 0.01% rms (0.4 μrad rms)
- RF Acc Grad 0.1% rms
- RF phase 0.5°
- 40 random machine for each static arrangement

Beam quality parameters:

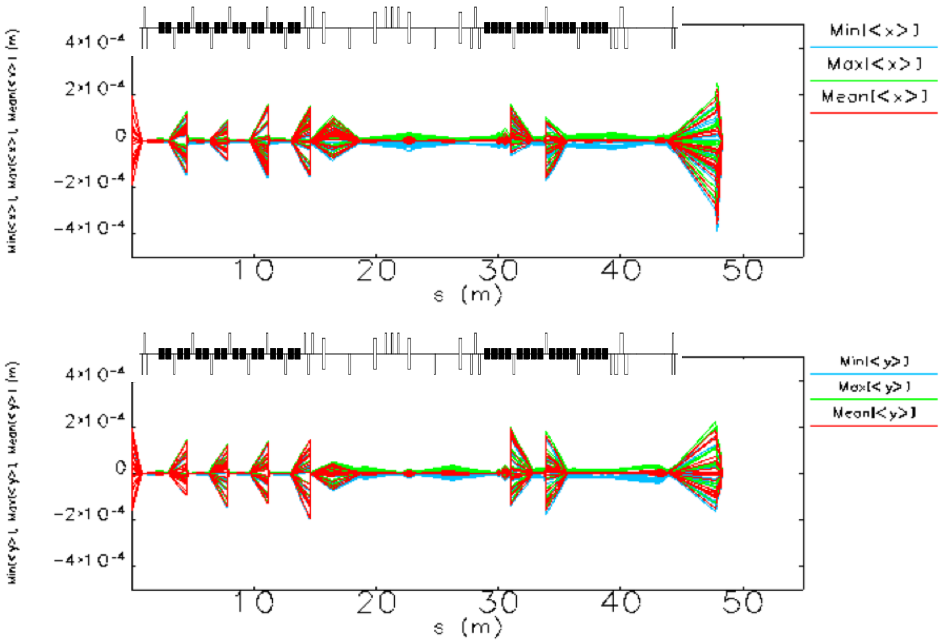
- End of line (capillary/undulator) entrance:
  - Centroid distribution
  - Beam spot size, emittance & energy spread distribution
- Along the linac:
  - Min,Max & Mean : trajectory, beam size, emittance & energy spread

Trajectory steering example wo DSF



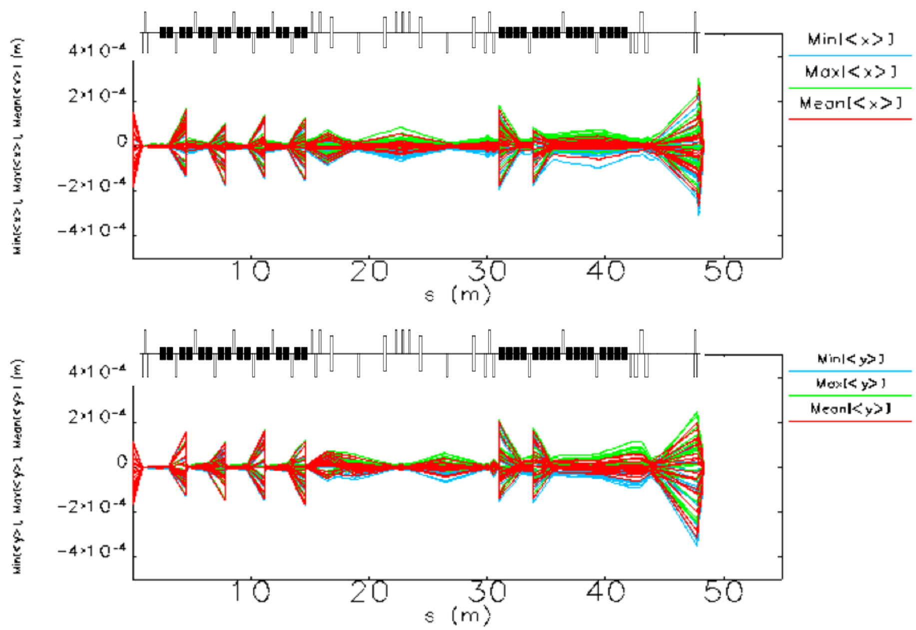


Trajectory envelope: WP1 Witness & Driver

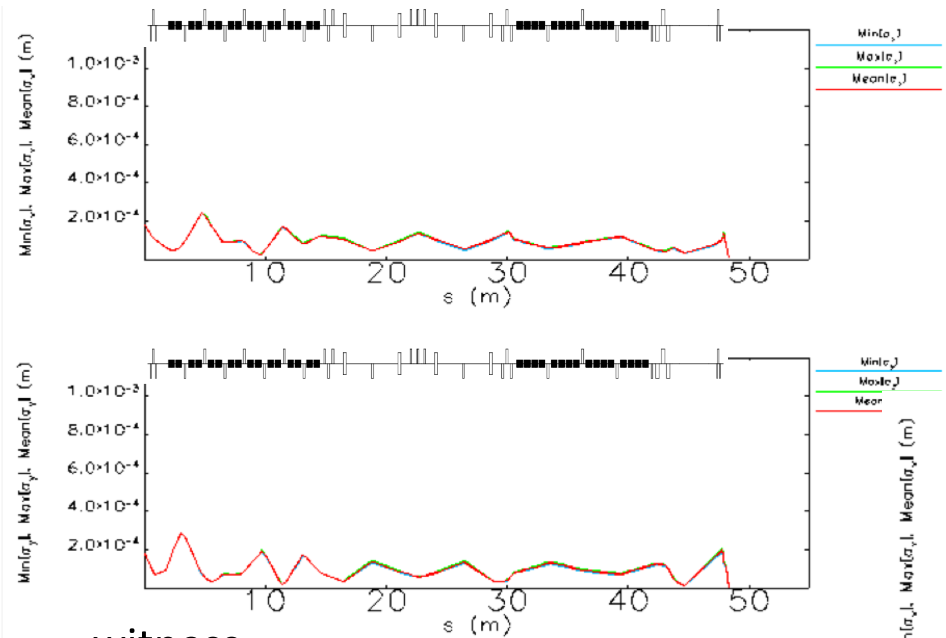


witness

driver

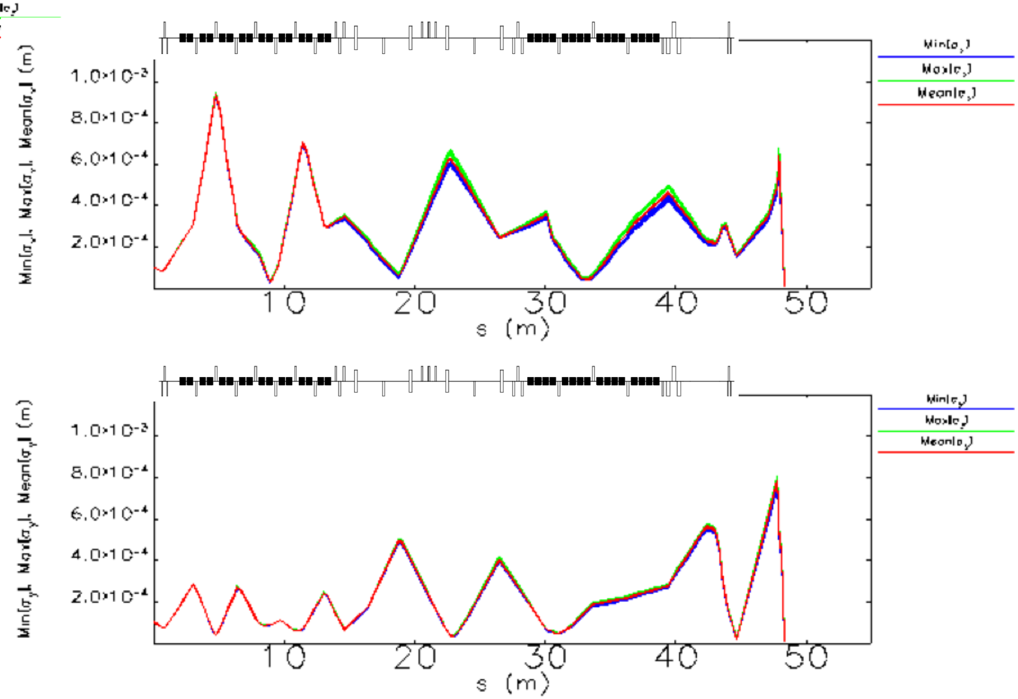


Beam envelope: WP1 Witness & Driver



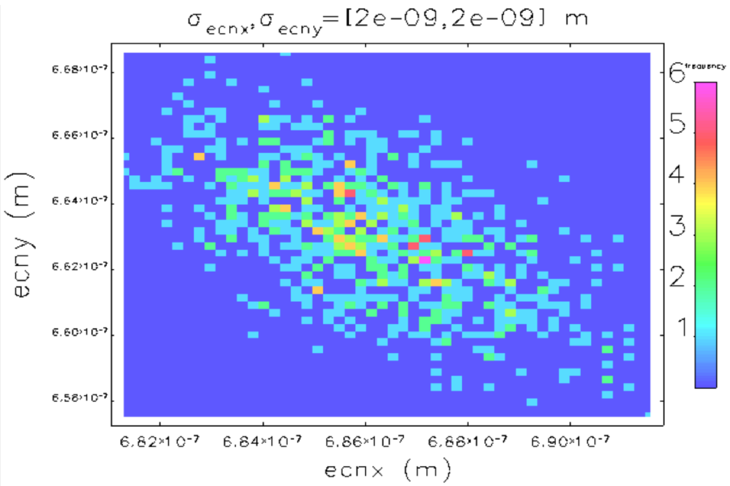
witness

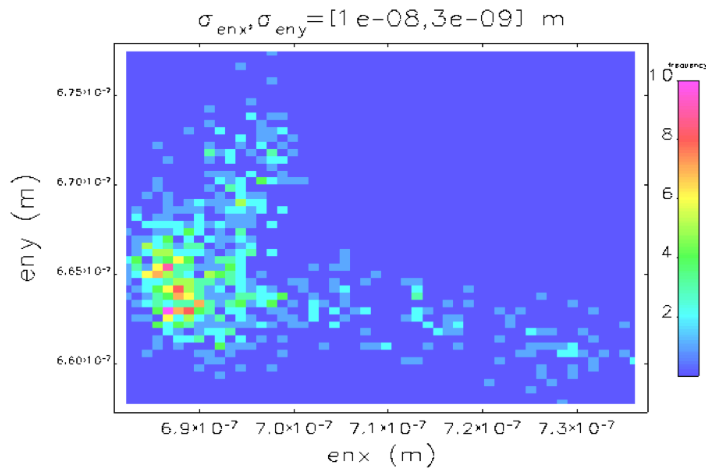
driver



End of line norm. Emittance : WP1 Witness & Driver

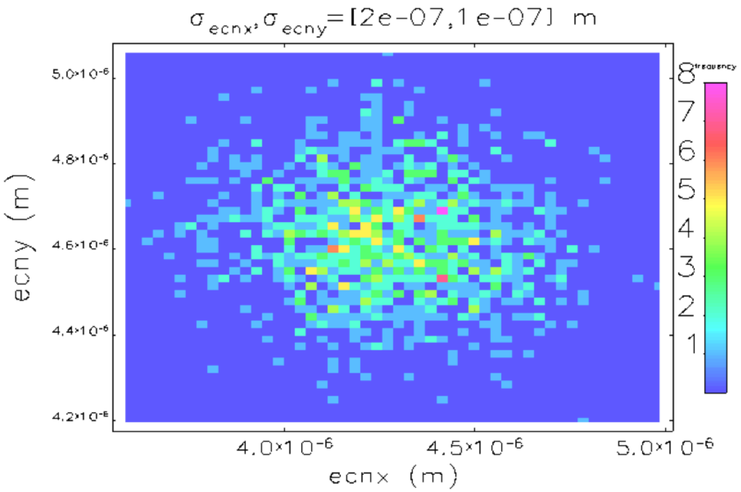
Witness

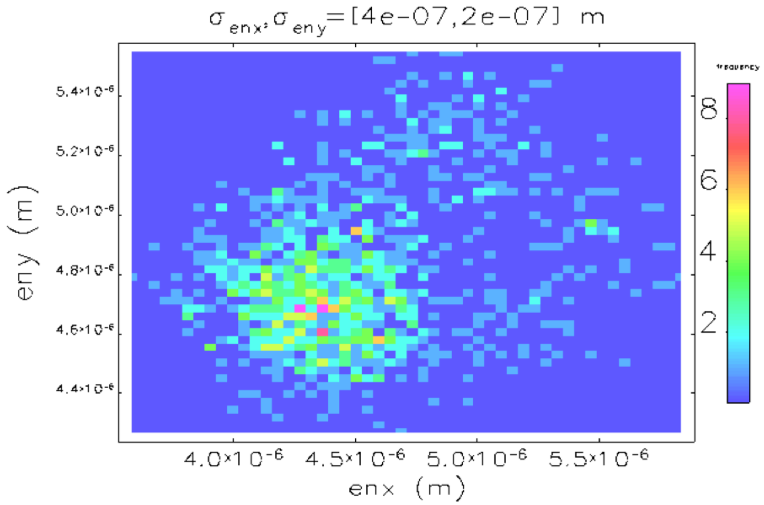




without dispersion contribution

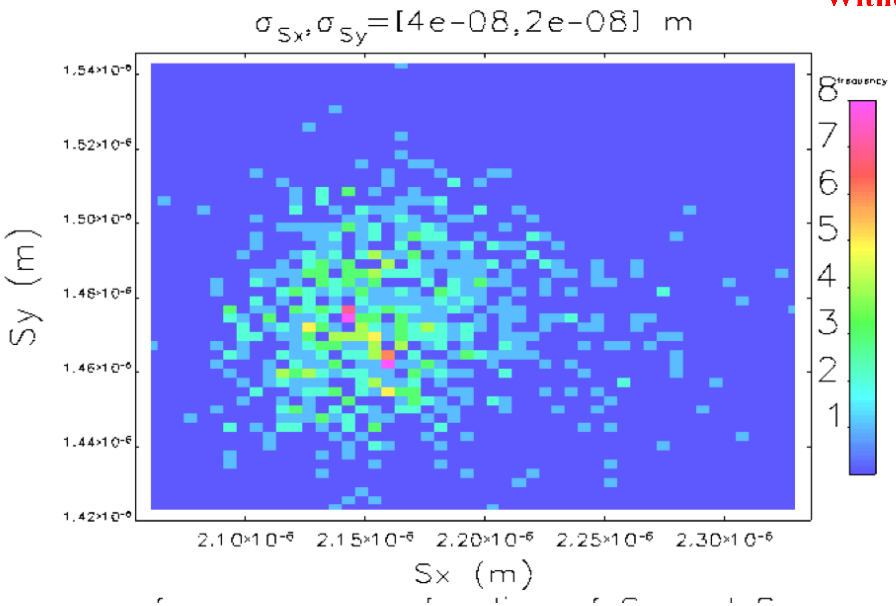
Driver



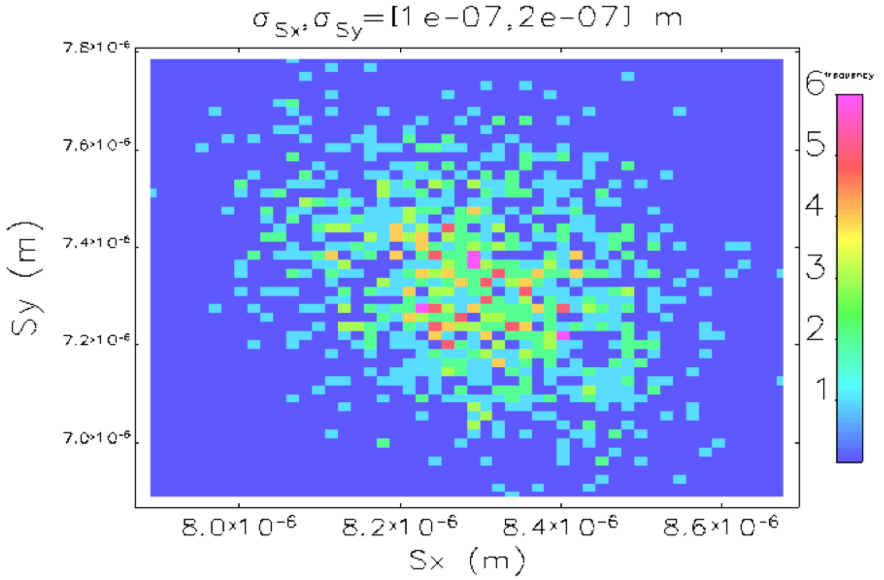


End of line beam size: WP1 Witness & Driver

Witness

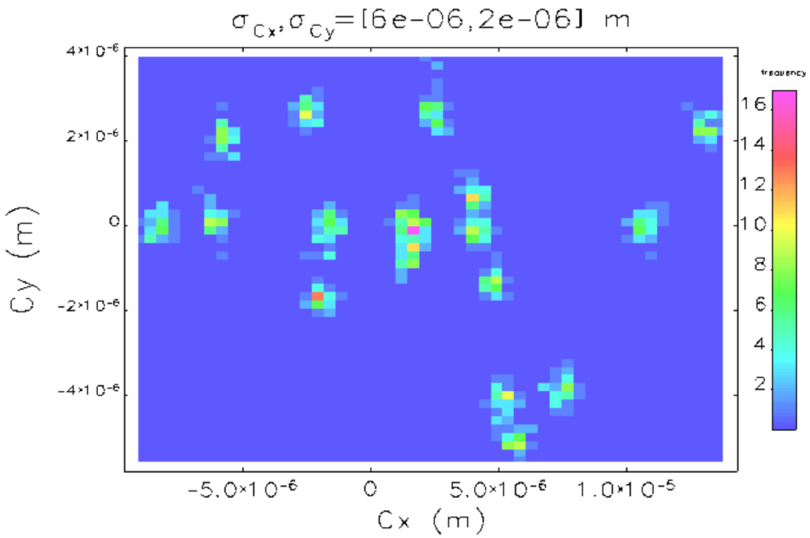


Driver

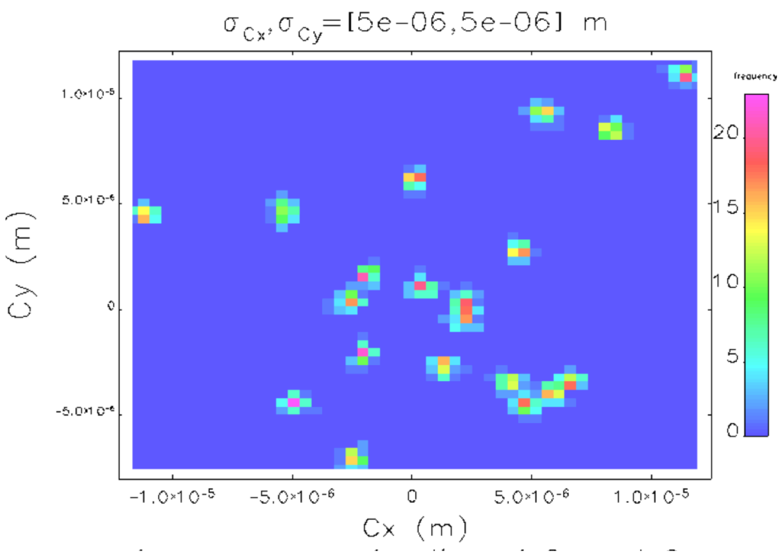


End of line centroid : WP1 Witness & Driver

Witness



Driver



Static plus dynamic errors summary table

	WP1 (@capillary in) witness	WP1(@capillary in) driver	Previous WP3(@undulator in) with no RF jit
Q (pC)	30	30	200
E (GeV)	0.5	0.5	1.0
σ_{Cx} (μm)	6	5	10
σ_{Cy} (μm)	2	5	30
σ_x (μm)	2.1	7	30
StDevσ_x (μm)	0.04	0.1	10
σ_y (μm)	1.6	8	40
StDevσ_y (μm)	0.02	0.2	5
σ_{δ} (%)	0.07	0.2	.14

* No dispersion free steering

Conclusions

- The X-band Linac for the EUPRAXIA@SPARC_LAB is under design
- This stage focuses on two different WP's nominal requirements and is meant to explore the line acceptance and robustness
- BD studies and FEL simulations have been presented for the nominal cases
- As first test bench the active elements (RF & magnetic) misalignments have been considered.
- These first results give an indication on the required tolerances and machine operation scenario (ex. active element and trajectory feedback) .
- Next steps will include Photocathode laser energy and pointing jitters.
- The space charge effects will be also considered.

Twiss parameters of the FODO cell for the L1 and L2 linac