STATUS OF SINGLE SPIKE SIMULATIONS FOR XFEL

Barbara Marchetti

NB: Many routines has been provided by I. Zagorodnov and beam dynamics group in Hamburg.

THE UNDULATOR SIDE:

RADIATION SPECTRUM FOR DIFFERENT INPUTS (BUNCH LENGTH, EMITTANCE AND CHARGE)

SINGLE SPIKE CONDITION

$$\rho = \sqrt[3]{\frac{1}{16} \cdot \frac{I}{I_A} \cdot \frac{{k_0}^2 \cdot JJ(arg)^2}{\gamma^3 \cdot \sigma^2 \cdot {k_u}^2}}$$

$$\lambda_r = \frac{\lambda_u \cdot (1 + {a_w}^2)}{2 \cdot \gamma^2}$$

$$L_g = \frac{\lambda_u}{\lambda_r \cdot L_c}$$

$$JJ(arg) = J_0(arg) - J_1(arg)$$

$$arg = \frac{{a_w}^2}{2 \cdot (1 + {a_w}^2)}$$

$$k_0 = \sqrt{2} \cdot a_w$$

$$a_w = \frac{\lambda_u[cm] \cdot B_u[kG]}{10.71}$$

$$L_c = \frac{\lambda_r}{4 \cdot \pi \cdot \sqrt{3} \cdot \rho}$$

L_b = bunch length
L_c = cooperation length (length spanned by the radiation in one undulator passage, in its slippage over the e- bunch-> radiation emitted by one slice of the bunch having this length is coherent)

$L_b \leq 2\pi L_c$ → single spike regime

(neglecting radiation diffraction, transverse emittance and energy spread influence !!)

I have assumed Bu = 1.14 T and λu = 40 mm

LCLS RESULT

SPARC-BD-07/004
10 October 2007

Generation of Ultra-Short, High Brightness Electron Beams for Single Spike SASE FEL Operation

J. B. Rosenzweig, G. Andonian, M. Dunning, A. Fukusawa, E. Hemsing, P. Musumeci, B.O'Shea, C. Pellegrini, S. Reiche
UCLA Department of Physics and Astronomy
L. Faillace, A. Marinelli, L. Palumbo
Università di Roma "La Sapienza" and INFN-LNF, Frascati
D. Alesini, M. Ferrario, M. Boscolo, B. Spataro, C. Vaccarezza
INFN-LNF, Frascati
V. Petrillo
Universita' di Milano and INFN-MI, Milano
L. Giannessi, C. Ronsivalle
ENEA, Frascati

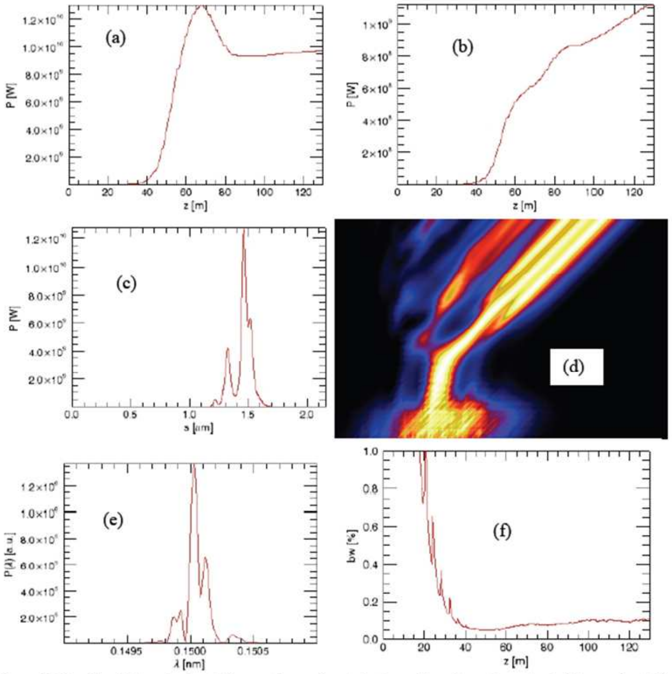


Figure 7. Results of Genesis simulations, using as input electrons taken form the output of beam simulations, concerning the performance of the LCLS FEL. (a) power vs. distance along the undulator z, (b) average power in simulation window vs. z, showing lack of saturation due to radiation after initial lasing, (c) power as a function of ζ at undulator exit, (d) power profile as a function of z (vertical) and ζ, illustrating growth of secondary spikes due to super-radiance (e) power spectrum at undulator exit (f) relative bandwidth vs. z.

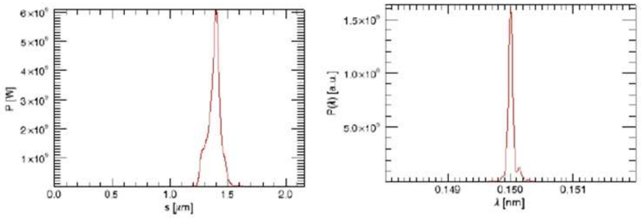


Figure 8. Results obtained from Genesis simulations of the LCLS FEL, as in Figs. 7, but quantities examined just previous to saturation: (left) power vs. ζ current profile as a function of ζ; (right) at undulator exit.

Table 3. Parameters for Genesis simulation of LCLS system with ultra-short beam.

Undulator wavelength λ_u	3.0 cm
Undulator strength K_{rms}	2.2
Resonant wavelength λ_r	1.5 Å
Focusing β-function	25 m
Dimensionless gain parameter ρ_{1D}	2.0×10^{-3}

Charge 1pC
σz= 0.16 μm (530 as)
E=14.5 GeV
ΔE= 1*10^(-4)
Lb=sqrt(2*pi)σz= 401 nm
I=Q*c/Lb=747.5 A

Lg=0.69 m
Lc=3.45 nm

PROCEDURE

- Goal: understand what are the required length and emittance of the beam for different charges.
- Starting from the 1pC case, I have increased the charge and to obtain Single Spike lasering for bunches more accessible to beam diagnostics.
- In the following simulations I have assumed Gaussian longitudinal bunch shape.

CONSTRAINTS & CHOSEN PARAMETERS

Integration step must be much shorter than gain length:

$zsep \ll \frac{1}{4\pi\rho}$=79 Zsep must be at least ¼ of this limit… I have chosen zsep=10

For long bunches, simulated bunch has to be longer than slippage length:

$Nslice > \frac{nwig*nsec}{zsep} = 534$

For short bunches, simulated region has to be longer than the bunch itself:

$Nslice > \frac{Lbunch}{\lambda rad*zsep} = 98$ (Considering 6*σ as bunch length)

Frequency resolution constraint (to resolve the gain curve with at least 4 points):

$Nslice > \frac{2}{\rho*zsep} = 200$ … I have chosen Nslice=600

Other parameters:

Npart=8192
ncar=151
Rmax0=9
Prad0= 0e-99

Zsep= 10
Shotnoise= 1
Nslice=600
I0tail=1

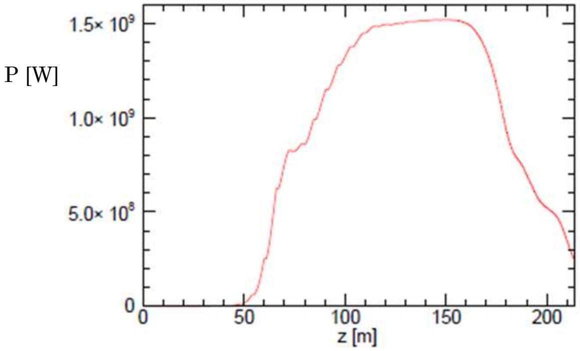
Delz has been evaluated through specific tries…

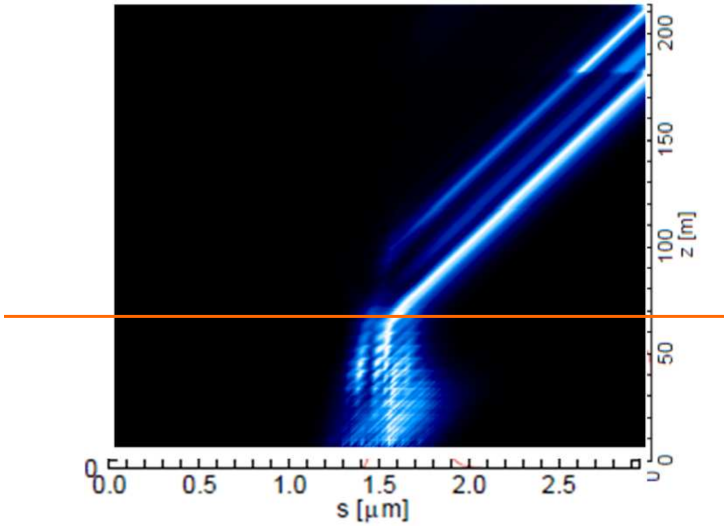
1 PC (I = 600A)

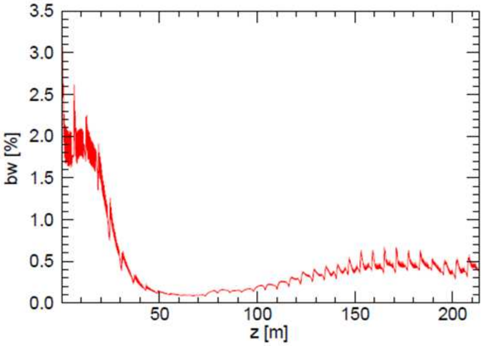
UNDULATOR:
Lambdau= 4 cm
Krms=4.27351
(maximum value)
λr= 4.91 Å
β lattice=31 m

EMISSION:
ρ=0.001
Lg=1.7773 m
Lc=0.022 μm
2*π*Lc=0.138 μm

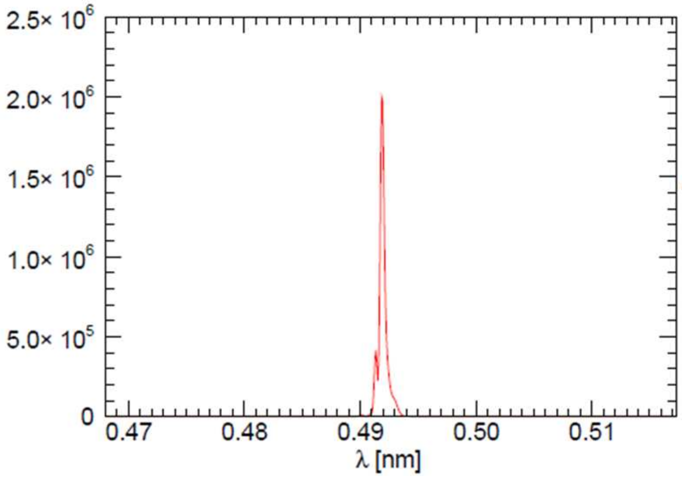
E-BUNCH:
σz=0.2 μm
DeltaE=0.0001
I=600 A
Normalized emittance
0.06*10^(-6)m*rad

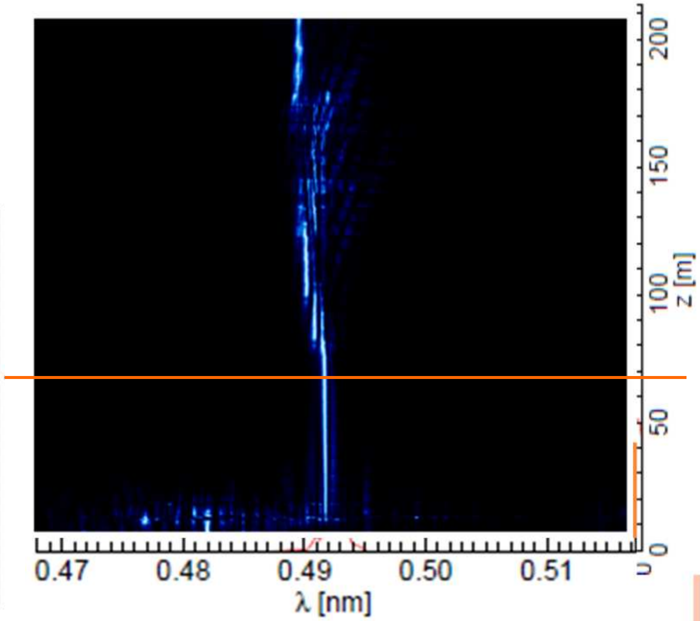






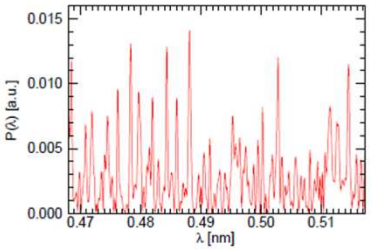
Z=70 m



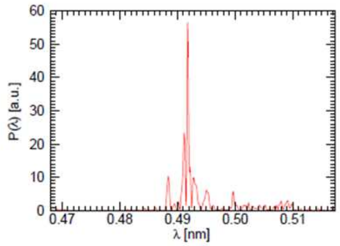


SPECTRUM ALONG UNDULATOR

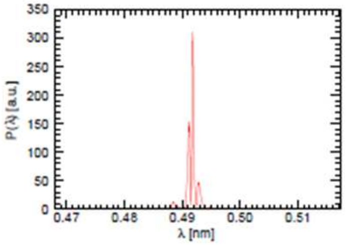
Z=0.04 m



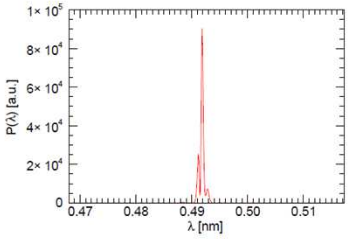
Z=20 m



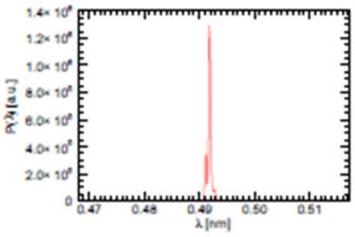
Z=30 m



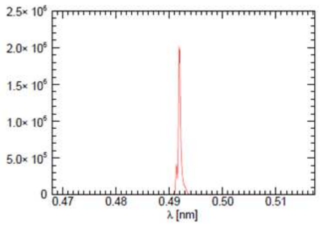
Z=50 m



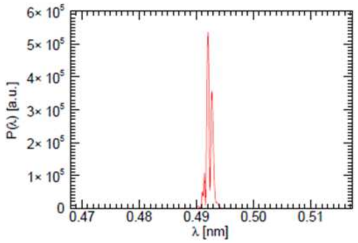
Z=60 m



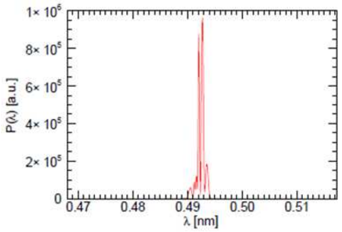
Z=70 m



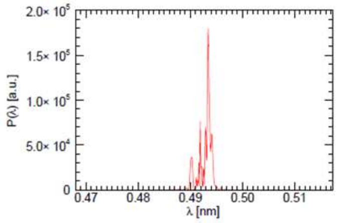
Z=80 m



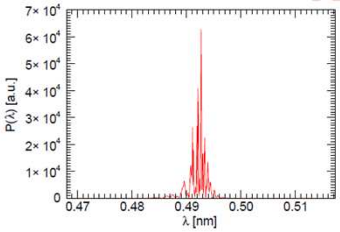
Z=90 m



Z=120 m



Z=150 m



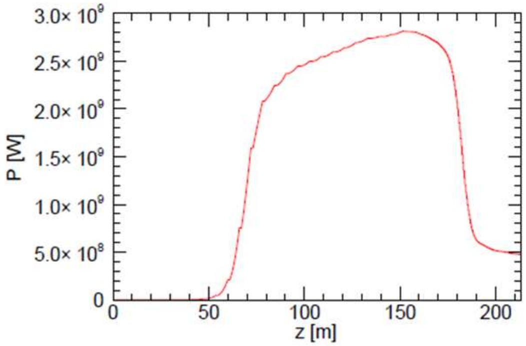
Single spike lasering happens only around saturation region. The better the single spike conditions are fulfilled (Lc is big compared to bunch length → short bunch, high transverse emittance), the longer the radiation spectrum maintains the single spike.

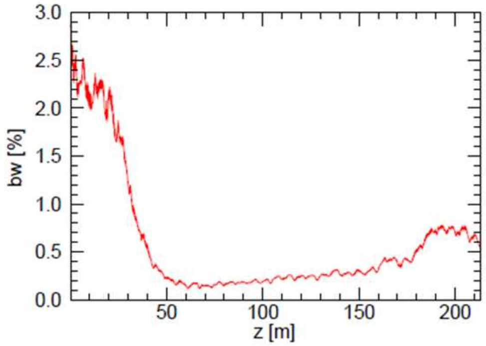
The knob of emittance increase cannot be used too much because it has two contra-indications:
1- incresing emittance, radiation power at saturation decreases,
2- due to coupling between transverse and longitudinal plane during electron acceleration and compression, it becomes difficult to increase transverse emittance without making the bunch longer.

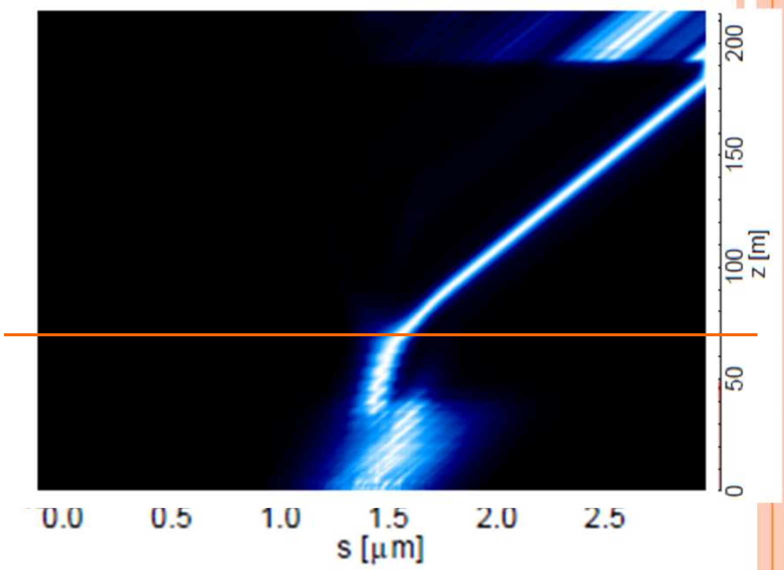
5 pC (I=2998 A)

- ρ=0.00075
- Lg=2.4646 m
- Lc=0.03 μm
- 2*π*Lc=0.188 μm

- σz=0.2 μm
- DeltaE=0.0001
- I=2998 A
- Normalized emittance 0.8*10^(-6)m*rad

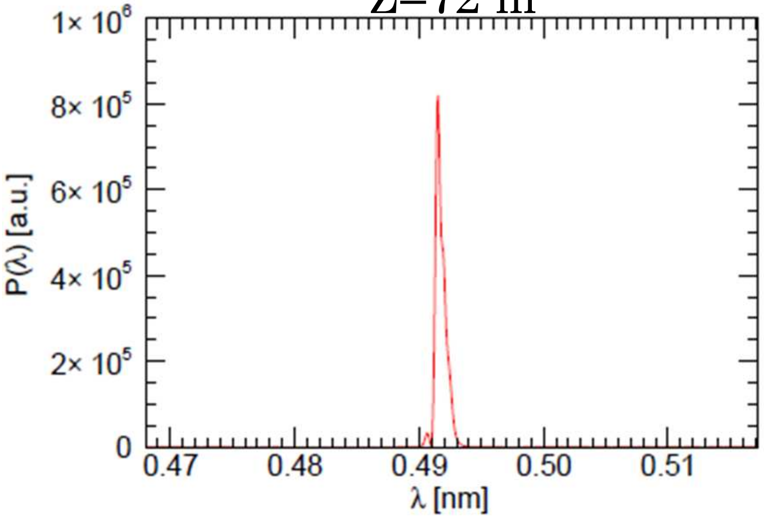


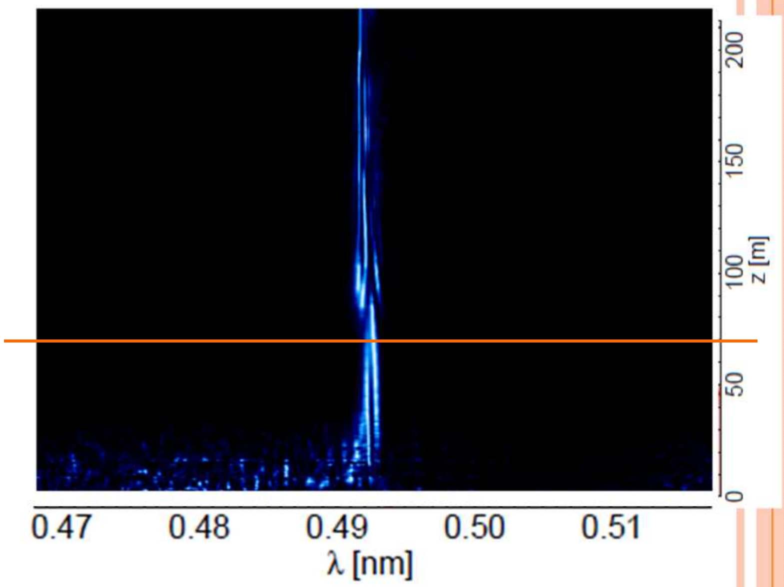




NB: I have significantly increased bunch length (for 1pC σz was 0.08 μm) and the single spike is hardly obtained.

Z=72 m

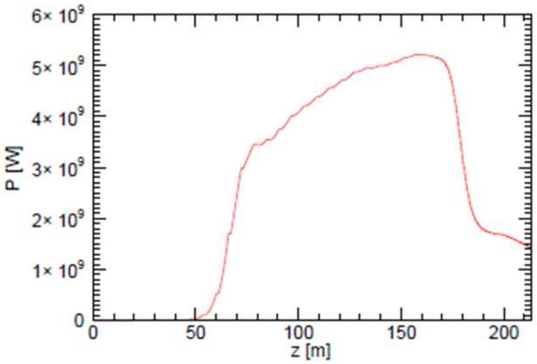


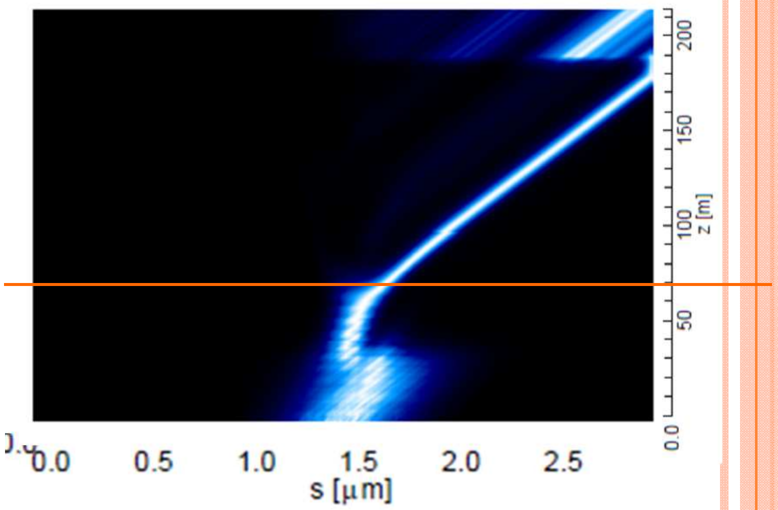


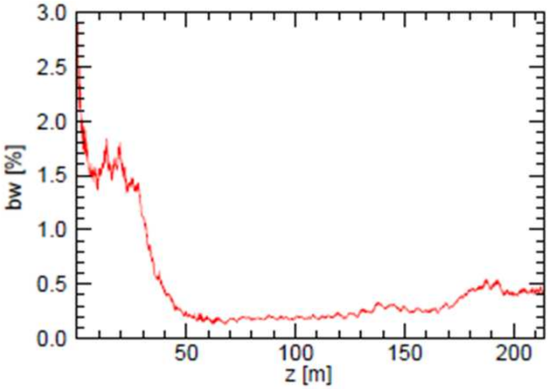
10 PC (I=5996 A)

- ρ=0.00076
- Lg=2.4121 m
- Lc=0.0296 μm
- 2*π*Lc=0.188 μm

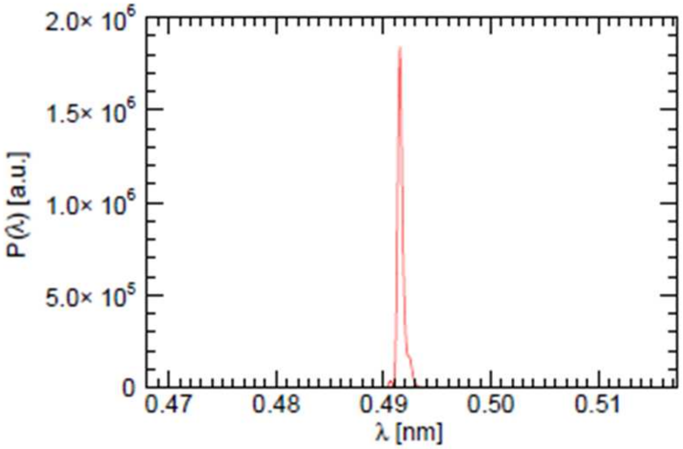
- σz=0.2 μm
- DeltaE=0.0001
- I=5996 A
- Normalized emittance 1.5*10^(-6)m*rad

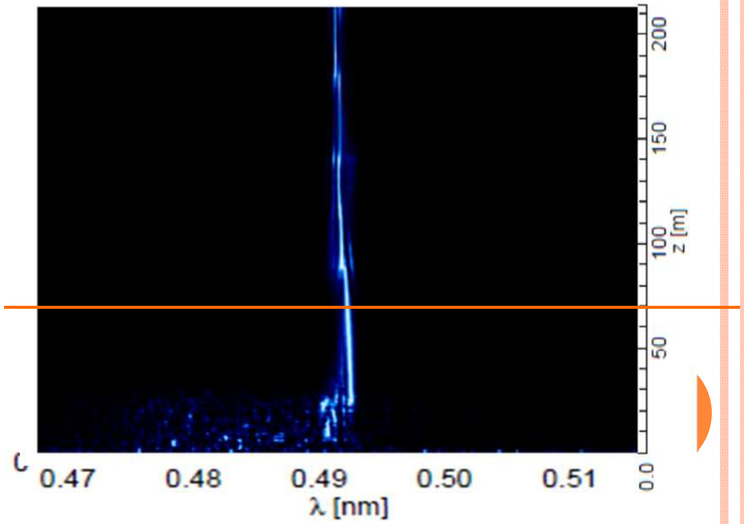






Z=70 m

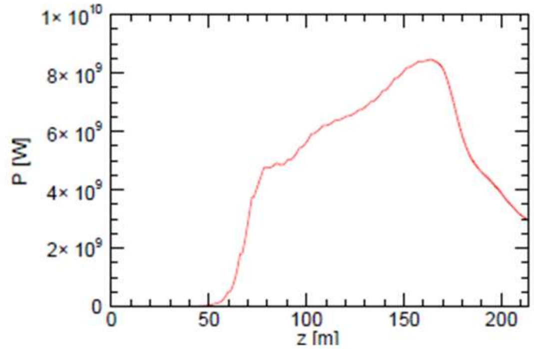


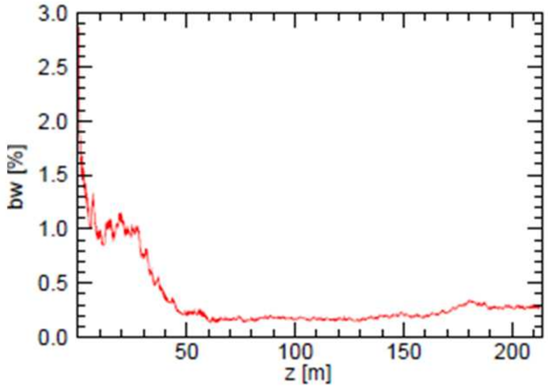


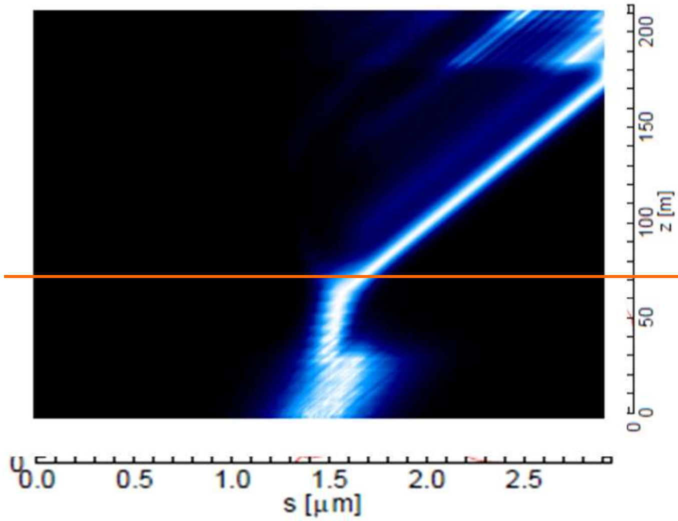
20 PC (I= 11992 A)

- ρ=0.0011
- Lg=1.6148 m
- Lc=0.0198 μm
- 2*π*Lc=0.126 μm

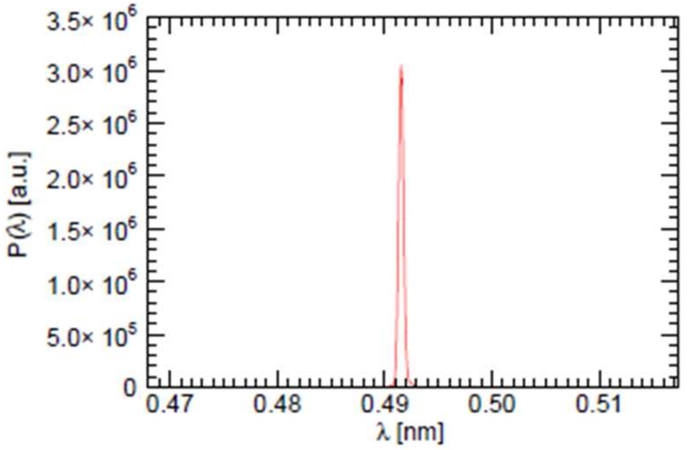
- σz=0.2 μm
- DeltaE=0.0001
- I=11992 A
- Normalized emittance 3*10^(-6)m*rad

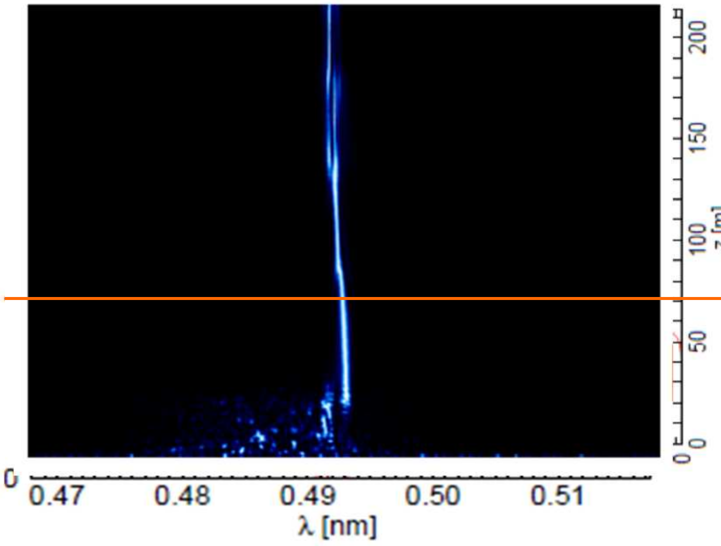






Z=70 m

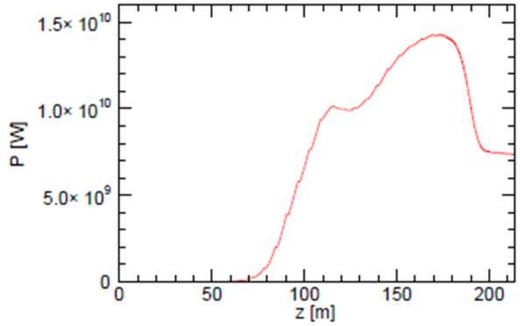


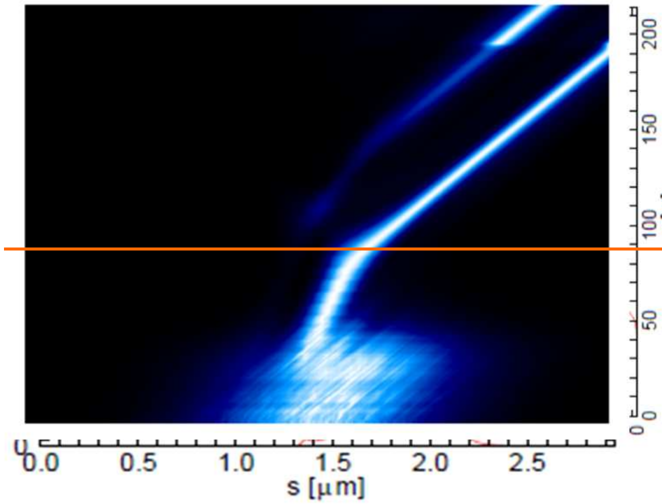


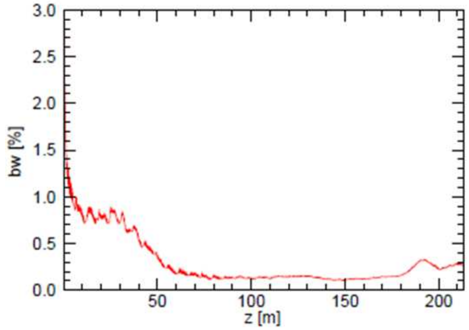
50 pC (I= 14990 A)

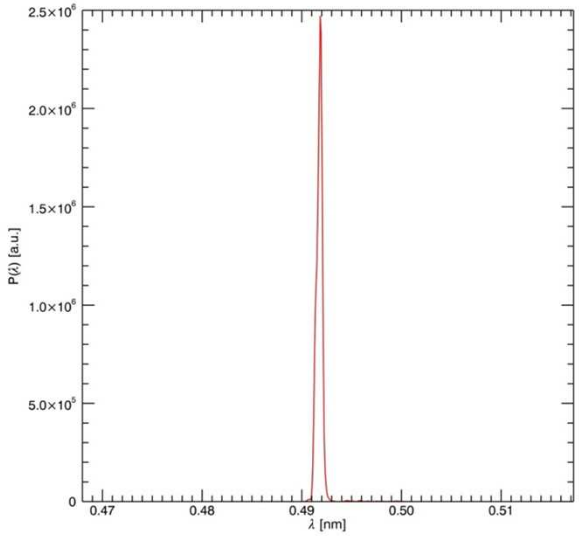
ρ=0.0094
Lg=1.9561 m
Lc=0.024 µm

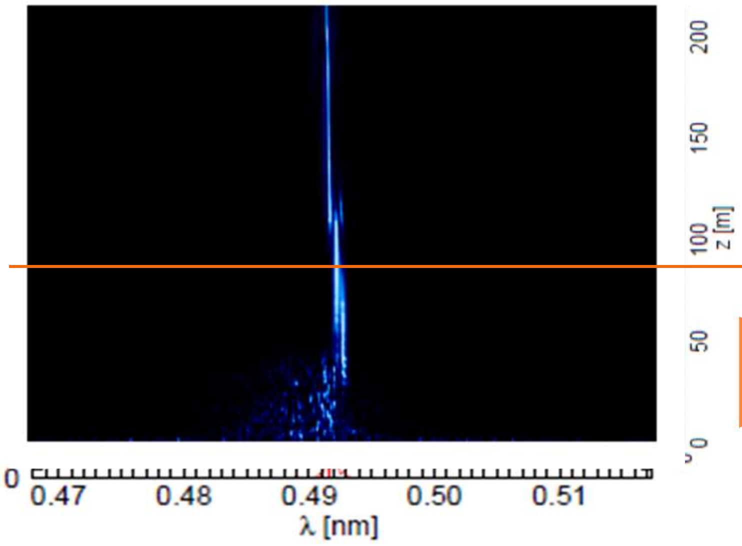
σz=0.400 µm
DeltaE=0.0001
I=14990 A
Normalized emittance
6*10^(-6)m*rad











LINAC SIDE: CHARGE SCALING OF NOMINAL XFEL PARAMETERS

LONG TERM PROGRAM

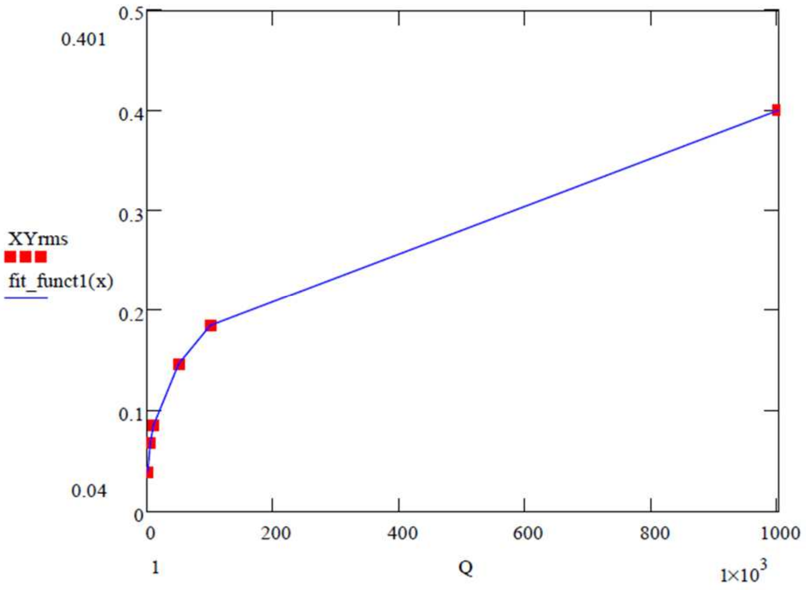
- Choose the bunch charges for which the transport has to be optimized.
- Change laser and RF parameters to optimize the compression for each charge set point.
- S2E simulations with ASTRA + CSRtrack+Genesis for best sets of machine and bunch parameters.

SHORT TERM PROGRAM

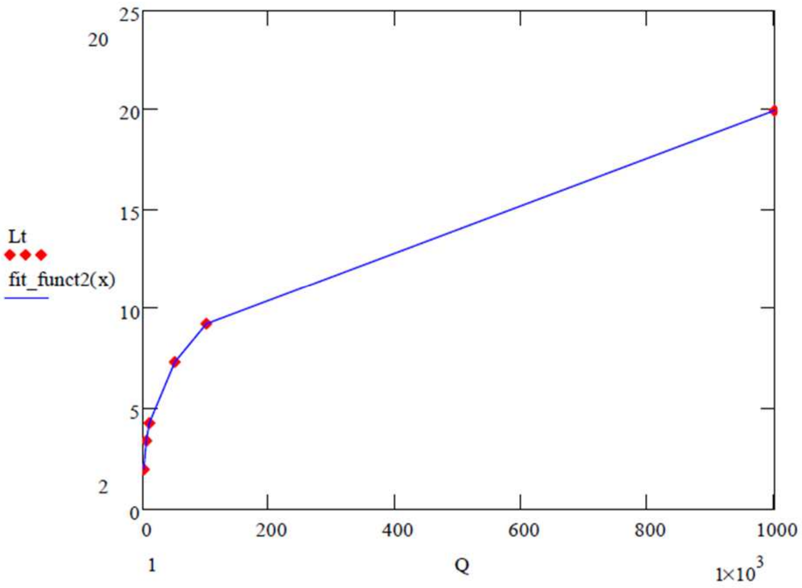
- Understand through a rough, fast, preliminary calculation, which charges seem to have access to Single Spike lasering (minimum achievable bunch length is the critical parameter). In this first calculation machine parameters are frozen to the nominal setup (optimized 1nC charge, 20ps flat top). Laser characteristics are scaled with charge.
- The injector is out of this game: for it I will continue to use ASTRA (it takes not too much time).

LASER SCALING @ CATHODE

- Reference point: Q=1 nC, XYrms=0.4 mm, Lt=2/20\2 mm



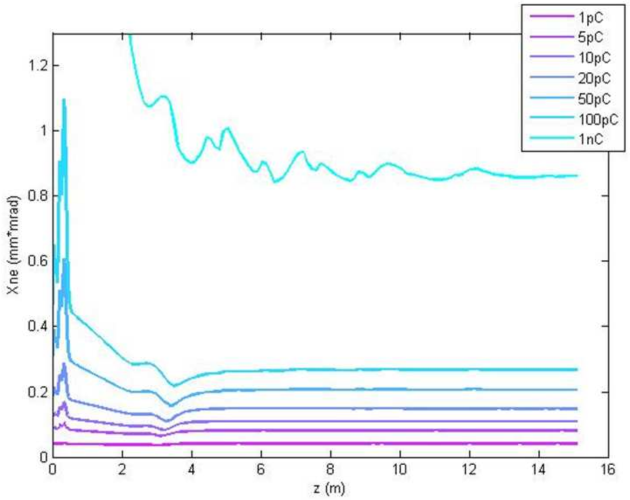
Xyrms=0.04*$Q^{1/3}$

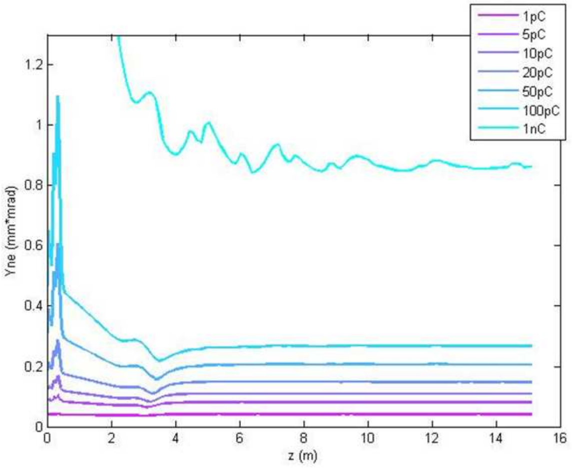


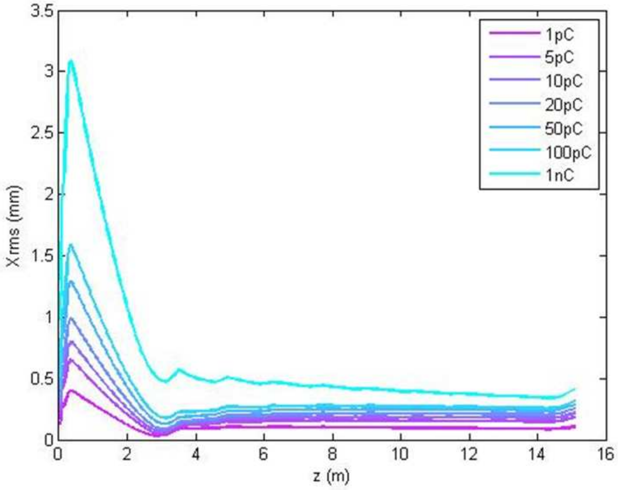
Lt=2*$Q^{1/3}$

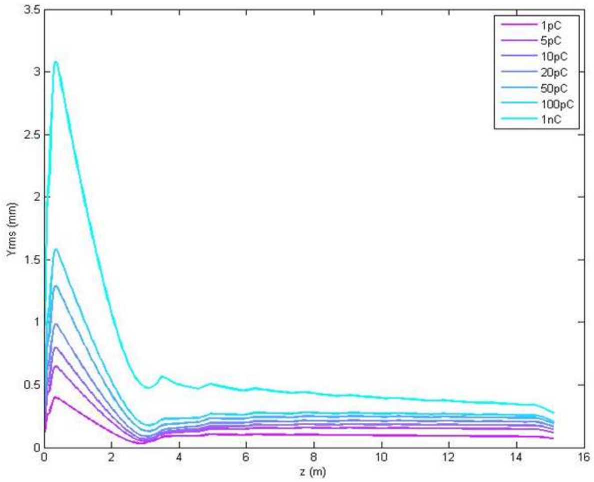
Charges: 1pC, 5pC, 10pC, 50 pC, 100 pC, 1nC

EMITTANCE & ENVELOPE @ INJECTOR (ASTRA SIMULATIONS INCLUDING SPACE CHARGE & WAKEFIELDS)

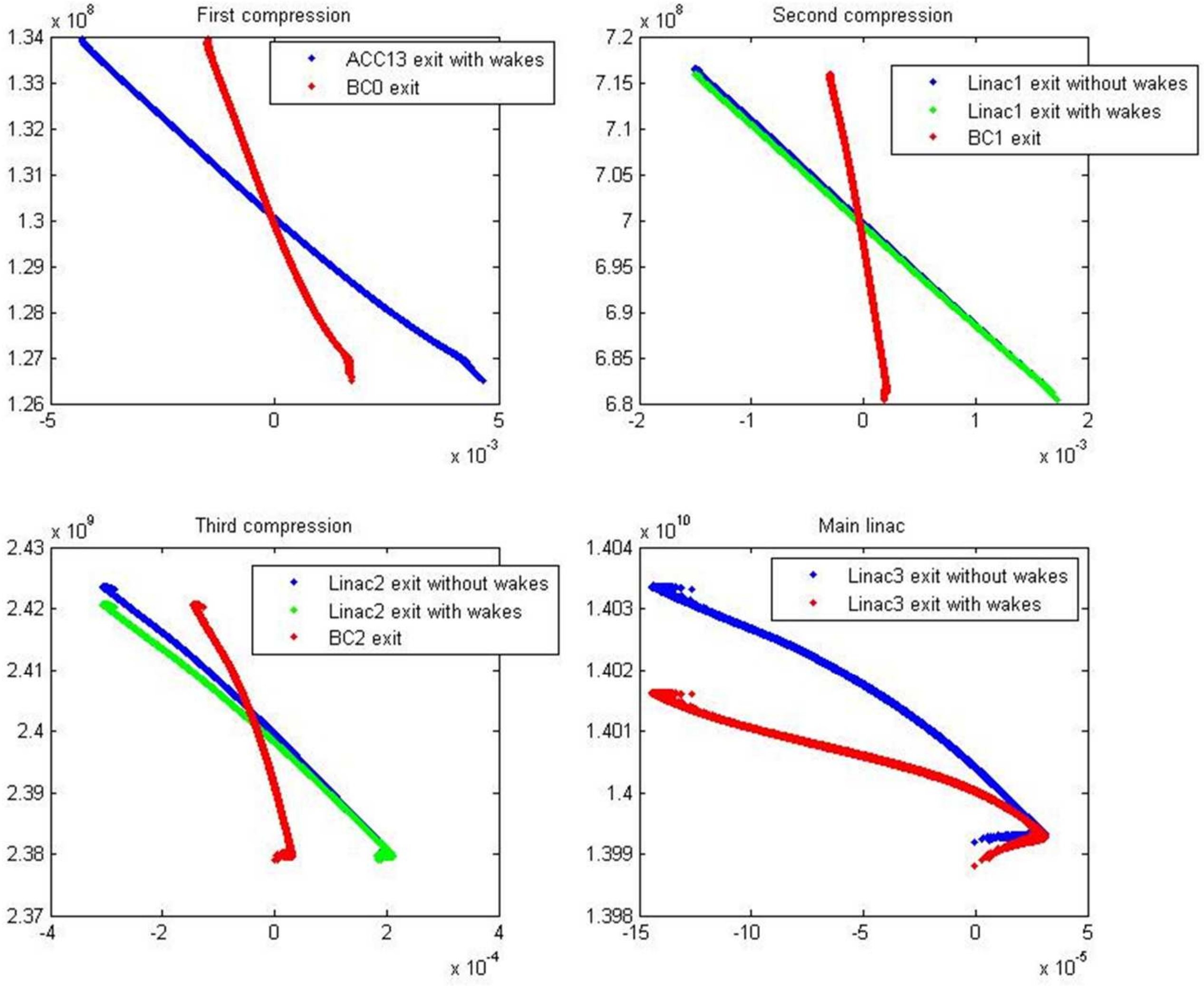




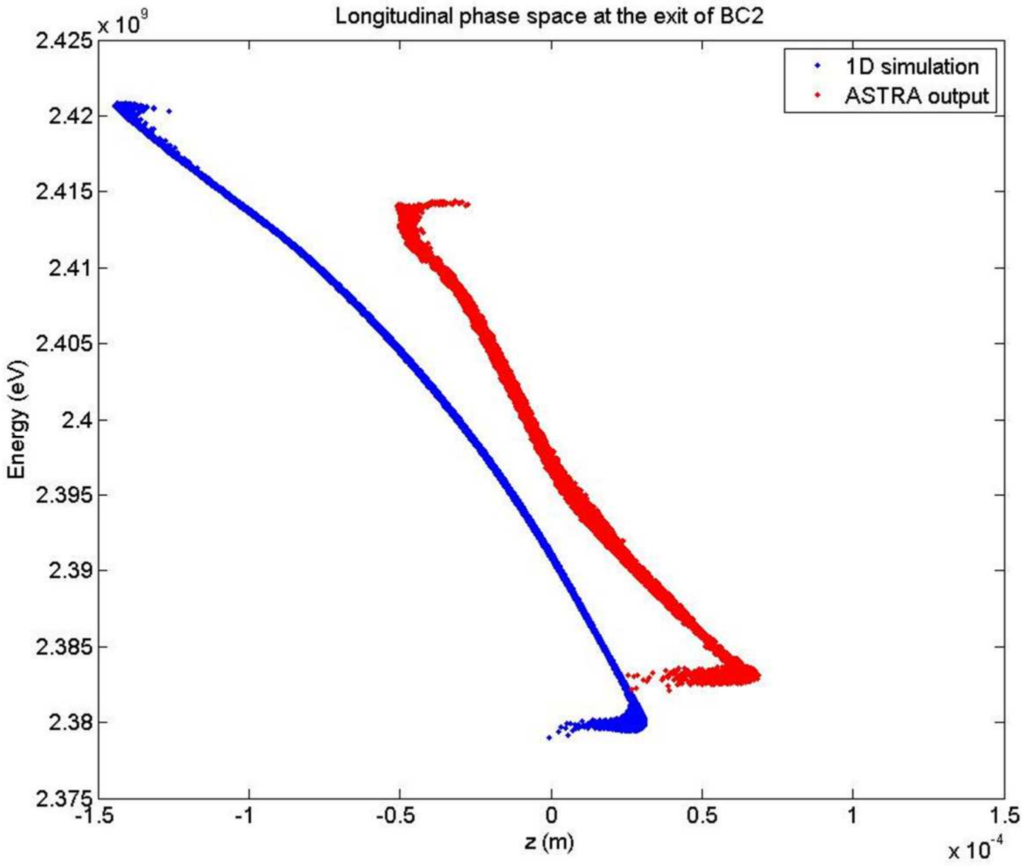




1NC TRANSPORT USING MATRIX TRANSPORT, INCLUDING WAKEFIEDS (SC INCLUDED ONLY UP TO INJECTOR EXIT)

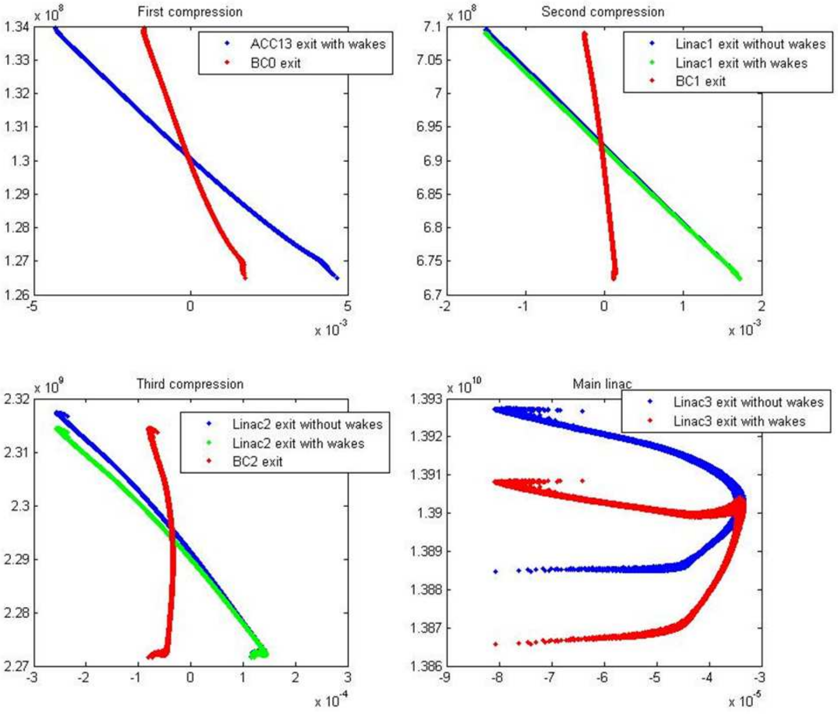


COMPARISON WITH ASTRA OUTPUT AT THE EXIT OF BC2



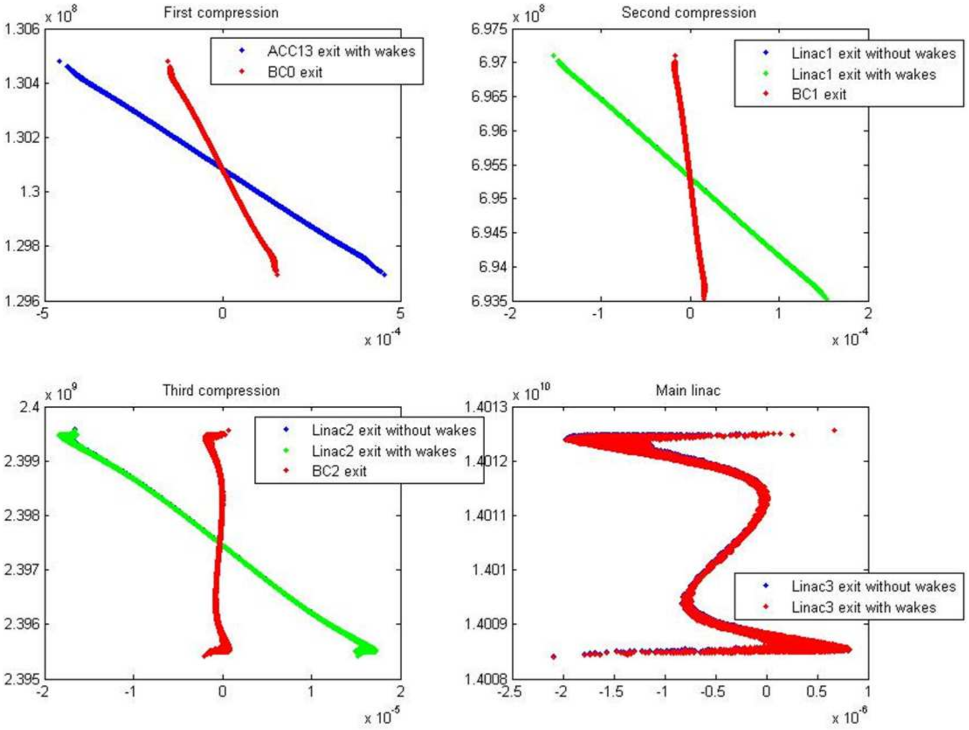
ESTIMATION OF BUNCH LENGTH AT MAXIMUM COMPRESSION

Examples

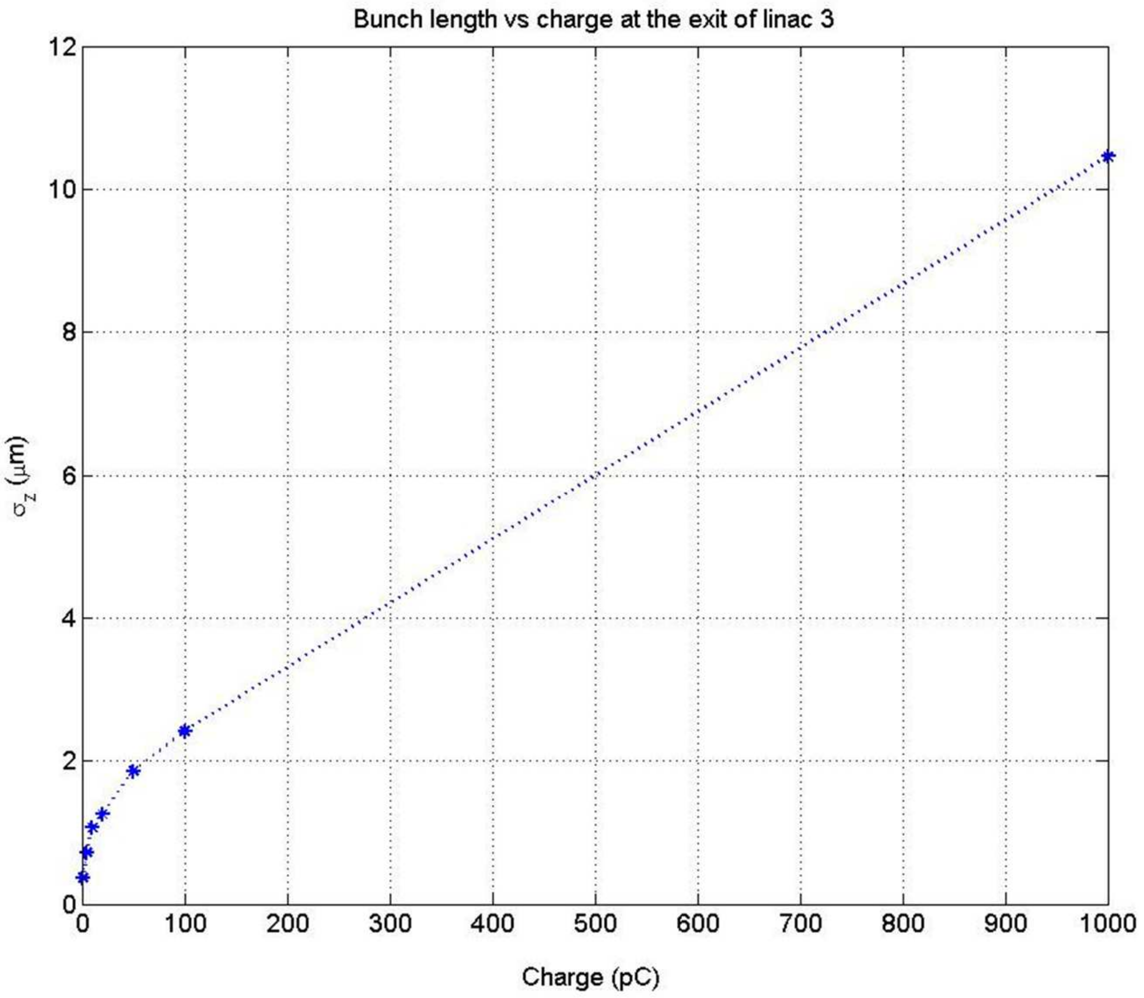


1nC

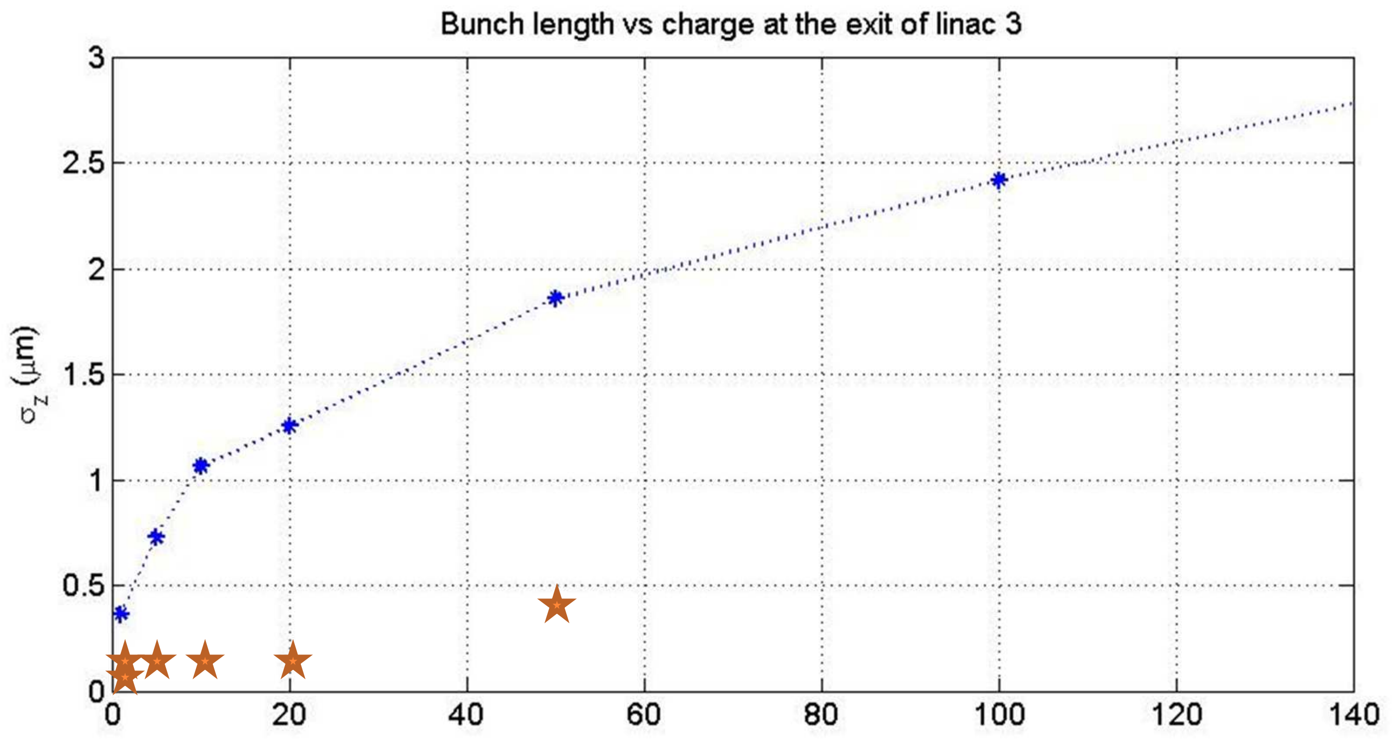
1pC



ESTIMATION OF BUNCH LENGTH AT MAXIMUM COMPRESSION

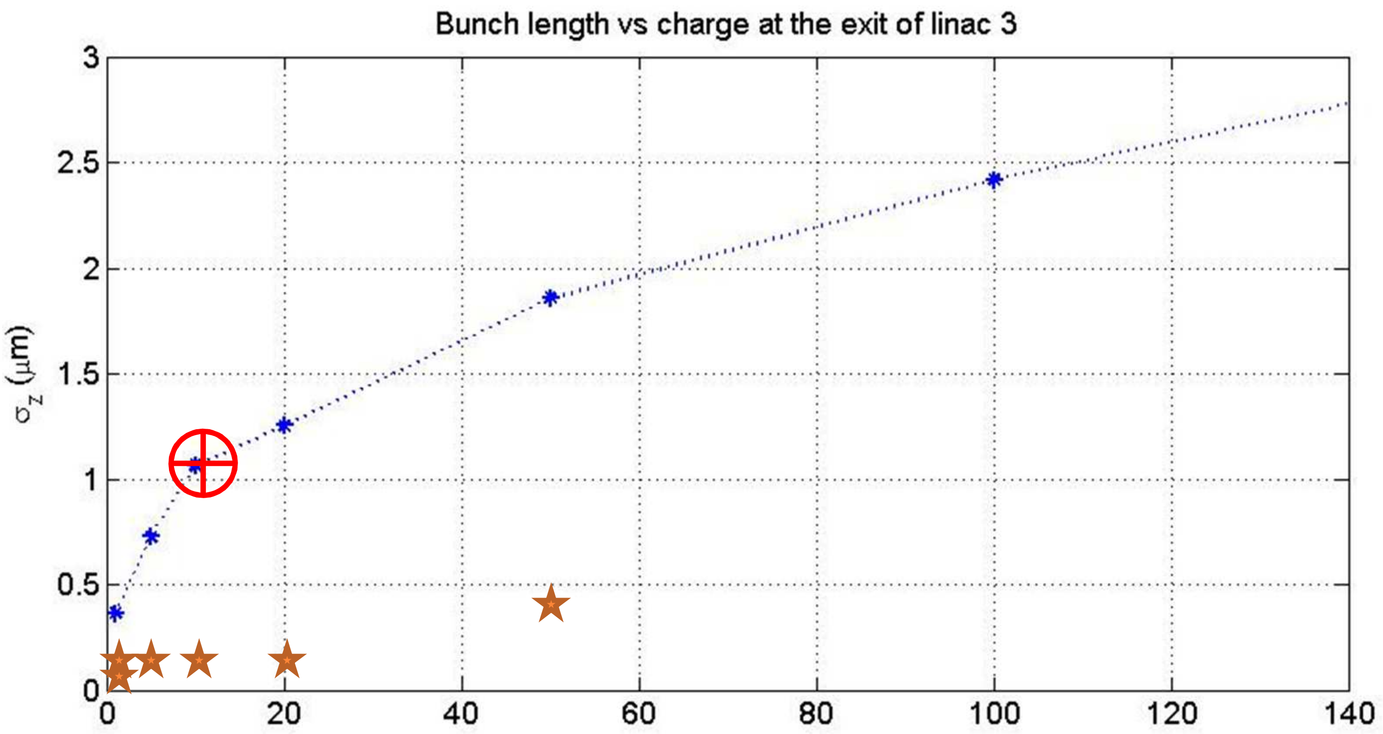


ESTIMATION OF BUNCH LENGTH AT MAXIMUM COMPRESSION



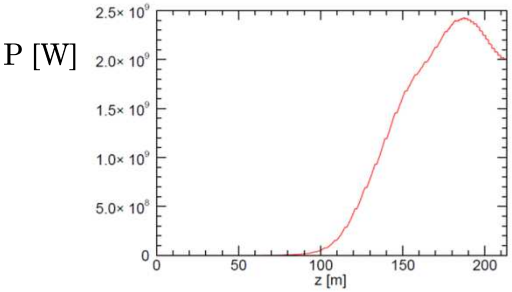
★= length used in Genesis simulations
NB: Gaussian shape assumed!

ESTIMATION OF BUNCH LENGTH AT MAXIMUM COMPRESSION



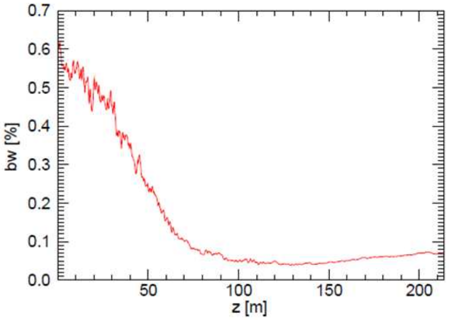
★= length used in Genesis simulations
NB: Gaussian shape assumed!

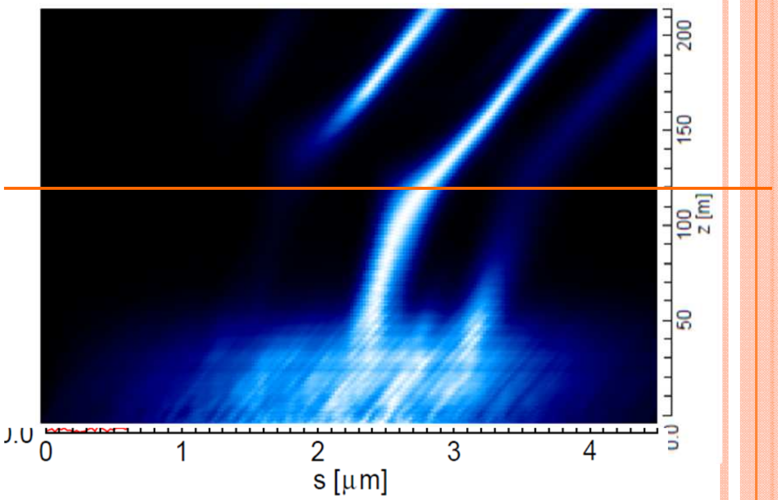
10 PC (I=1086 A)



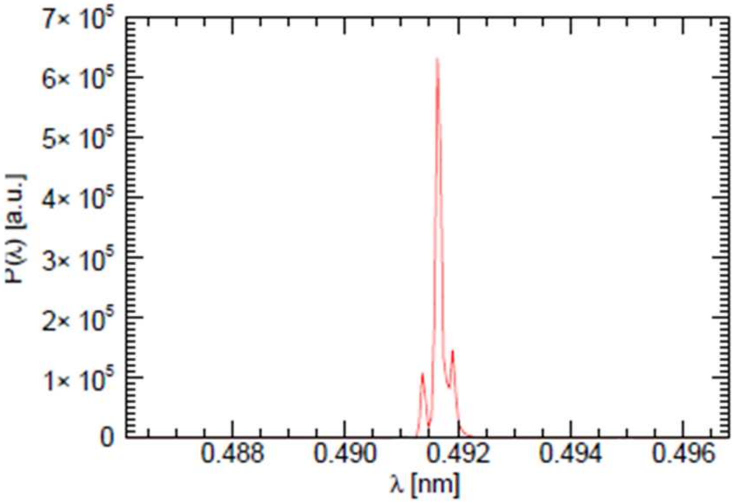
- ρ=0.00043
- Lg=4.2630 m
- Lc=0.0524 μm
- 2*π*Lc=0.329 μm

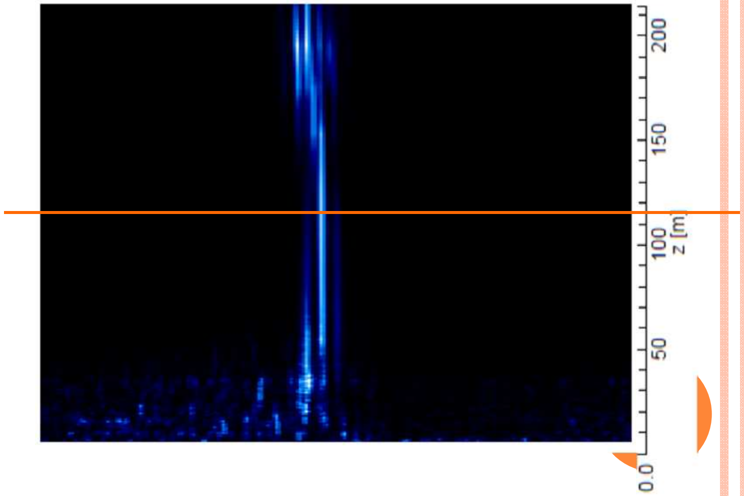
- σz=1.1 μm
- DeltaE=0.0001
- I=1086 A
- Normalized emittance 1.5*10^(-6)m*rad





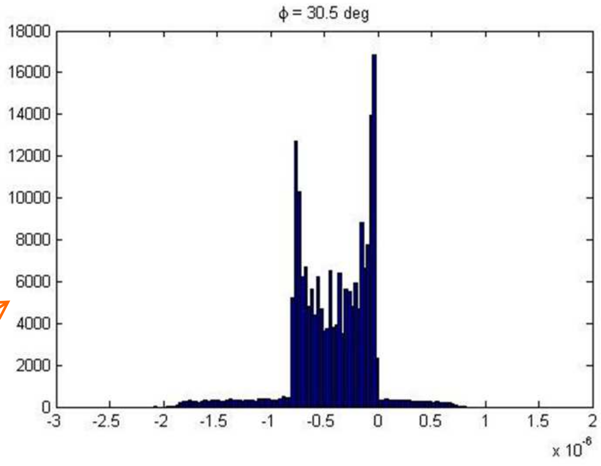
Z= 120 m

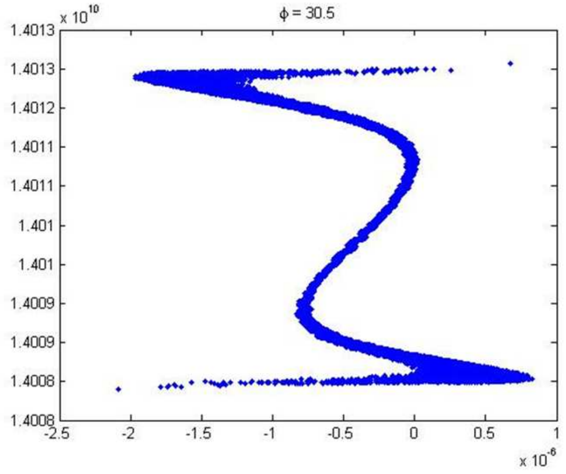


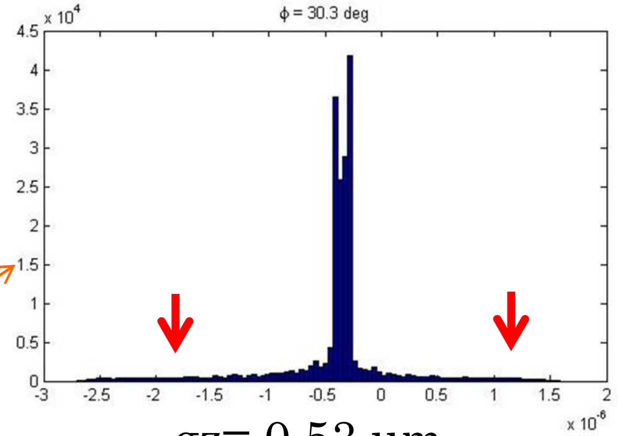


COMMENTS ABOUT REAL PROFILES (1 PC CASE)

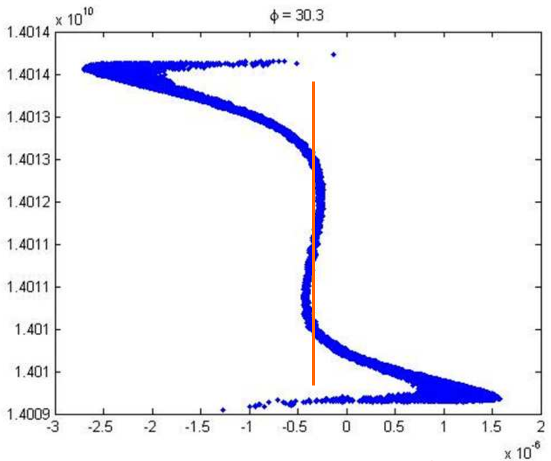
Smallest σz= 0.37 μm →







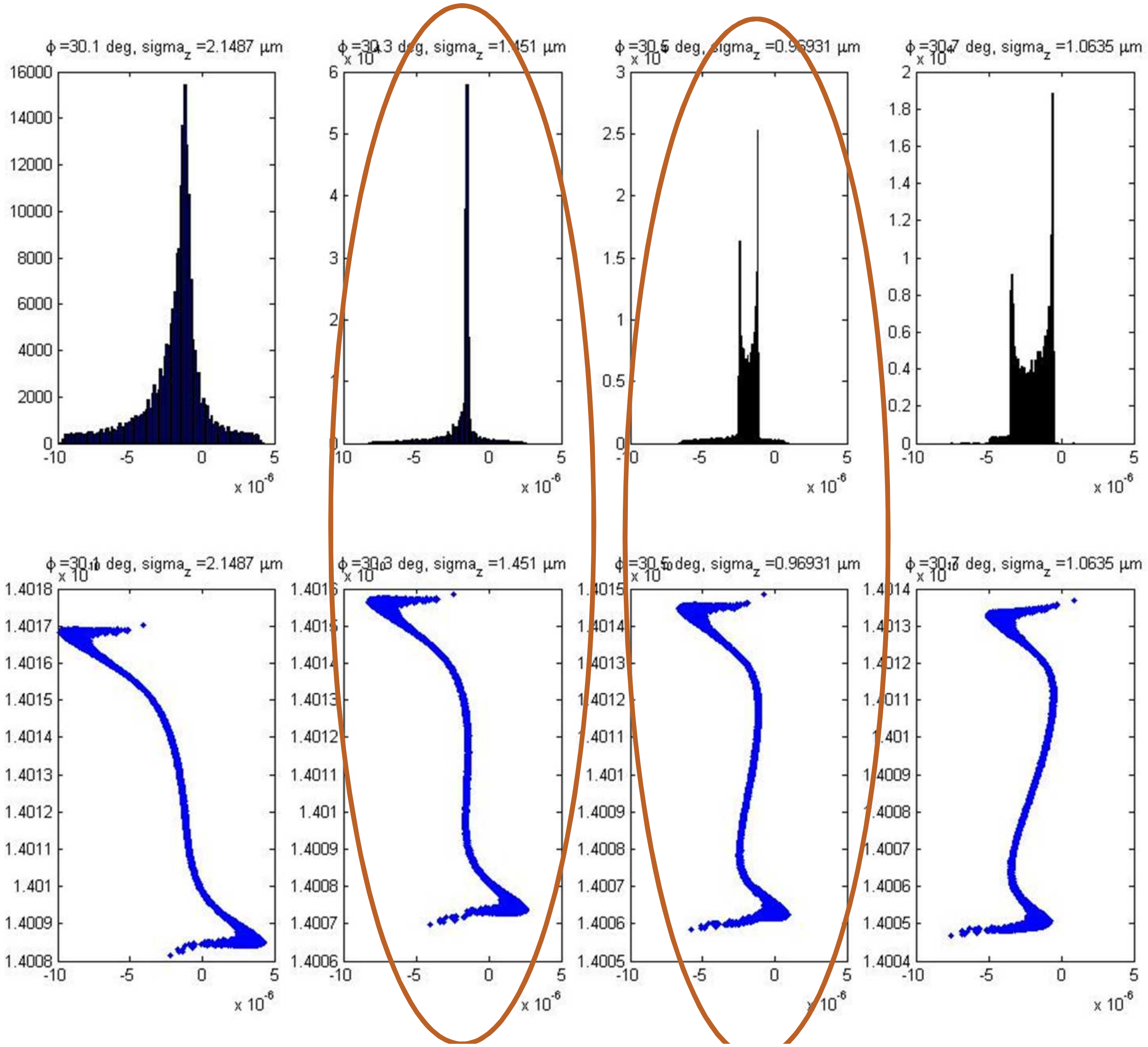
σz= 0.53 μm



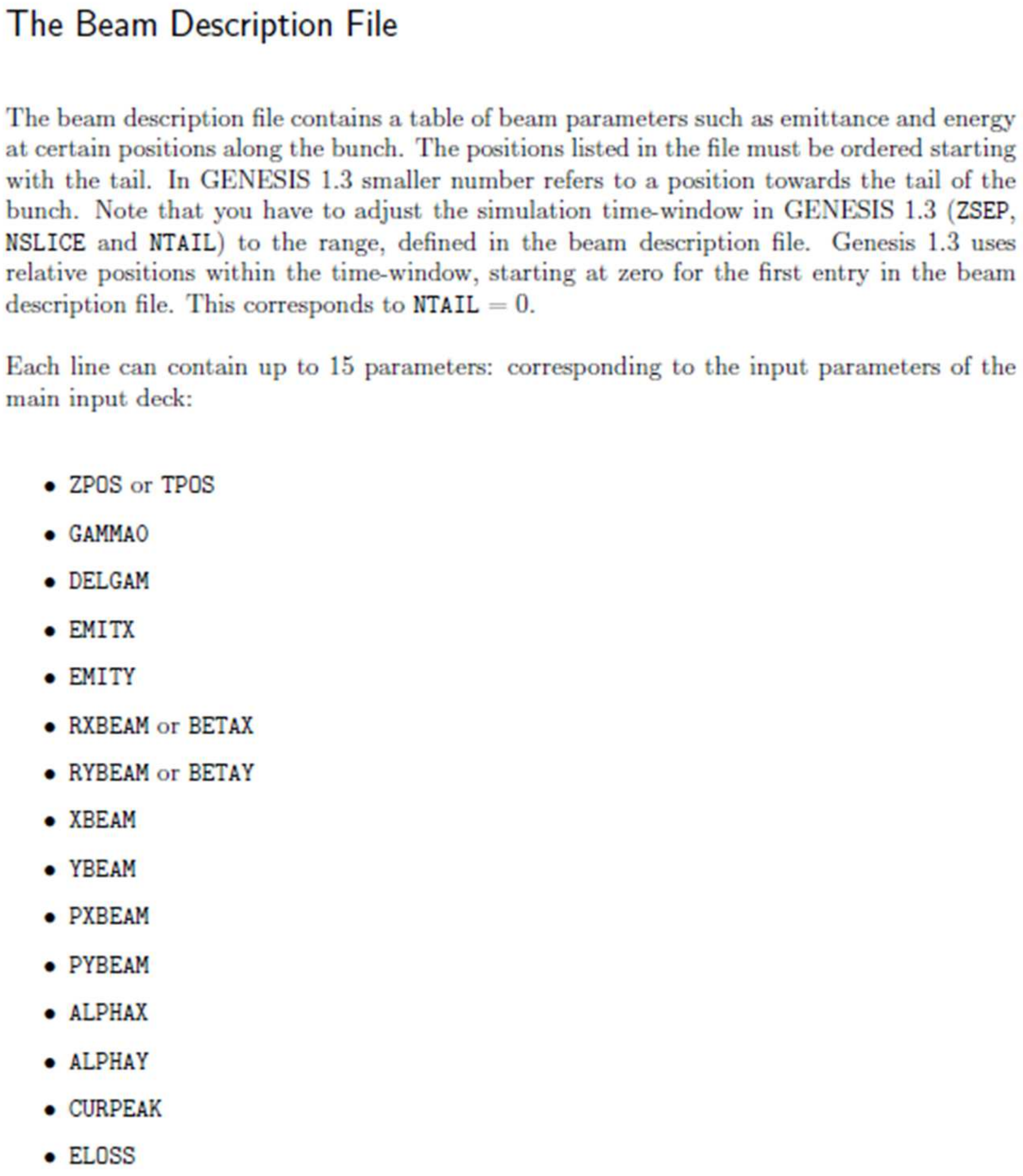
Since the longitudinal bunch profiles are not Gaussian, I should include profiles from bunch compression simulations in Genesis.

10 pC compression for
different linac 2 phases

WHAT I AM DOING NOW



It is possible to implement in Genesis the real longitudinal profile:
CURPEAK vs ZPOS



The Beam Description File

The beam description file contains a table of beam parameters such as emittance and energy at certain positions along the bunch. The positions listed in the file must be ordered starting with the tail. In GENESIS 1.3 smaller number refers to a position towards the tail of the bunch. Note that you have to adjust the simulation time-window in GENESIS 1.3 (`ZSEP`, `NSLICE` and `NTAIL`) to the range, defined in the beam description file. Genesis 1.3 uses relative positions within the time-window, starting at zero for the first entry in the beam description file. This corresponds to `NTAIL` = 0.

Each line can contain up to 15 parameters: corresponding to the input parameters of the main input deck:

- `ZPOS` or `TPOS`
- `GAMMA0`
- `DELGAM`
- `EMITX`
- `EMITY`
- `RXBEAM` or `BETAX`
- `RYBEAM` or `BETAY`
- `XBEAM`
- `YBEAM`
- `PXBEAM`
- `PYBEAM`
- `ALPHAX`
- `ALPHAY`
- `CURPEAK`
- `ELOSS`

TO DO SOON

- Go on with Genesis simulations using longitudinal distributions from 1D study.
- 6D bunch compression using: ASTRA (injector) + matrices (linac) + CSRtrack (dogleg, compressors). This will produce input particles for Genesis.
- Genesis simulations using 6D particles coordinates as input.
- What else?

QUESTIONS

- Check by Hamburg (e.g. undulator parameters)?
- Poster ICAP? What to include? (soon abstract submission)
- Problem of run main linac.