Considerations on the longitudinal phase space at the gun exit for short pulses operation at the XFEL. Discussion on possible measurements at Pitz.

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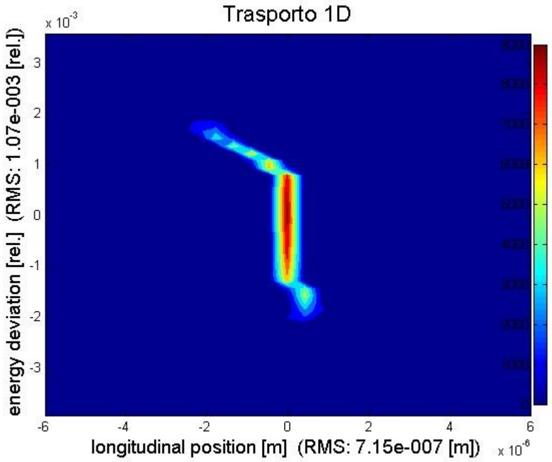
Motivation

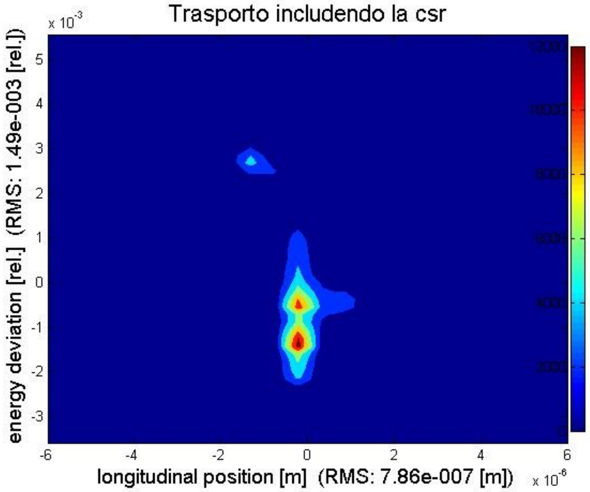
Simulation for XFEL presented at the ICAP: max compression for 20 pC bunch.

Longitudinal phase space at the exit of the 3rd compressor:

ASTRA injector + 1D compression



ASTRA injector + 2D compression using CSRtrack (CSR included)



What is limiting the peak current:

1 – The CSR that makes the bunch profile thicker

2 – The presence of the tails which come from non-linearity in the longitudinal phase space

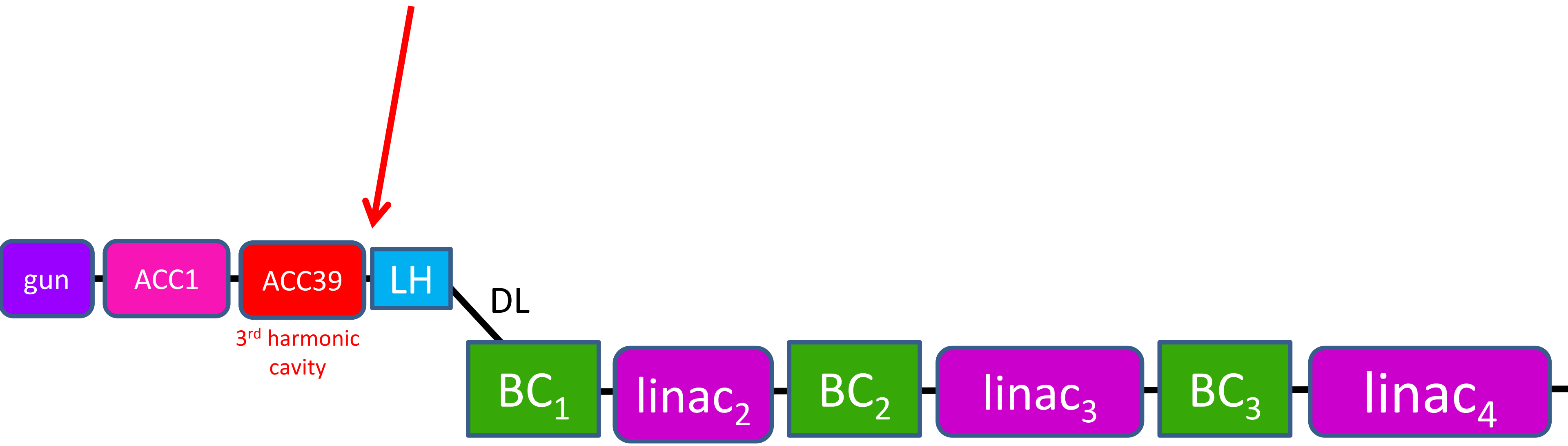
… The second factor can be improved!

Non-linearity in the phase space comes from…

- Longitudinal space charge in the gun region
- RF curvature along all the accelerator
- Non-linear terms in magnetic bunch compressors (T_{566}, U_{5666})

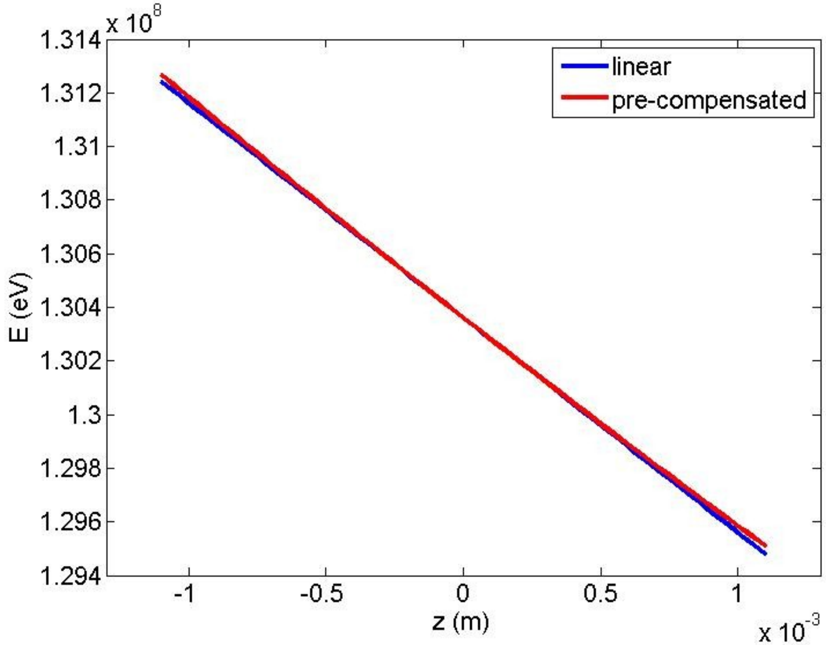
Compensation using the 3rd harmonic cavity

- In principle: by setting appropriate (V_1, ϕ_1) and (V_{39} , ϕ_{39}) a particular phase space distribution can be realized at the exit of ACC39 that pre-compensates all non-linearity in the compression in order to achieve a linear phase space in the end.

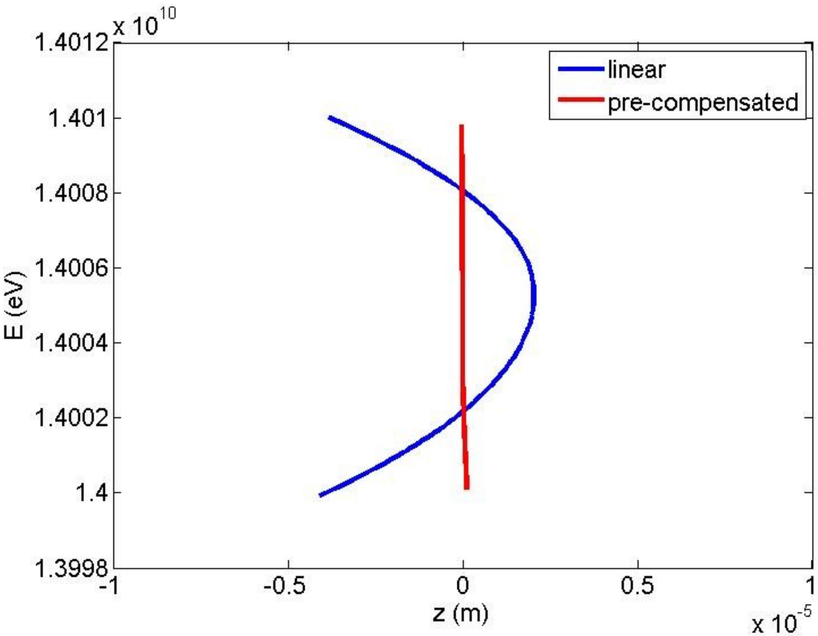


Example of compensation

Longitudinal phase space at the exit of the 3rd harmonic section



Longitudinal phase space at the exit of the accelerator



Compensation using the 3rd harmonic cavity

- Practically: due to the maximum power achievable in the first accelerating cavity and in the 3rd harmonic cavity, not all the non-linearity can be compensated.

Longitudinal phase space distribution expression (neglecting the uncorrelated energy spread):

Energy of the particle at position s

Non-linear terms

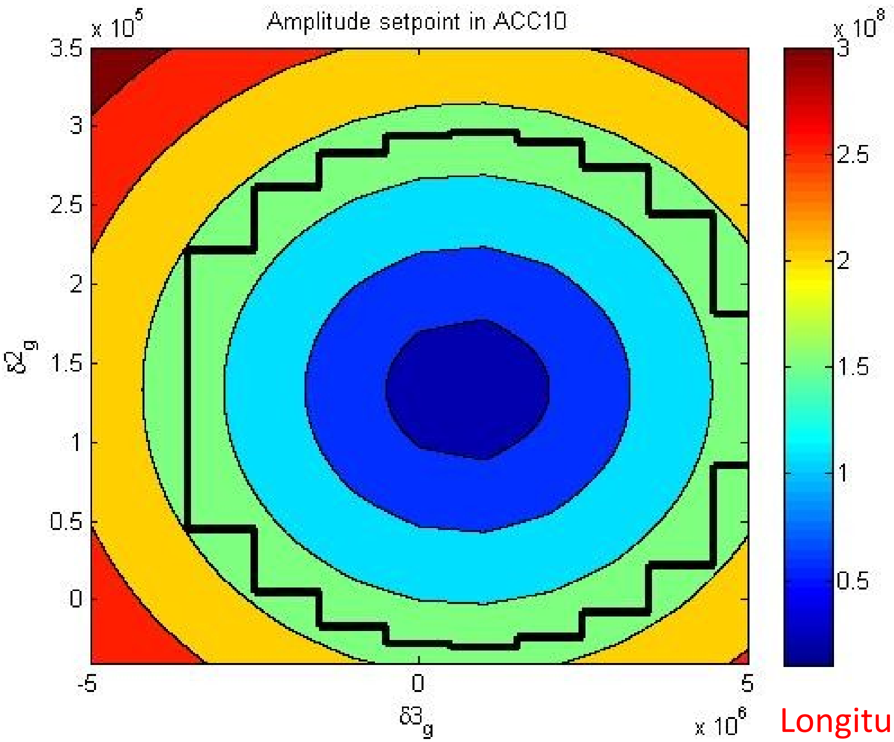
$$\delta(s) \equiv \frac{E_0(s) - E_0^0}{E_0^0} \approx \delta'(0)s + \frac{\delta''(0)}{2}s^2 + \frac{\delta'''(0)}{6}s^2$$

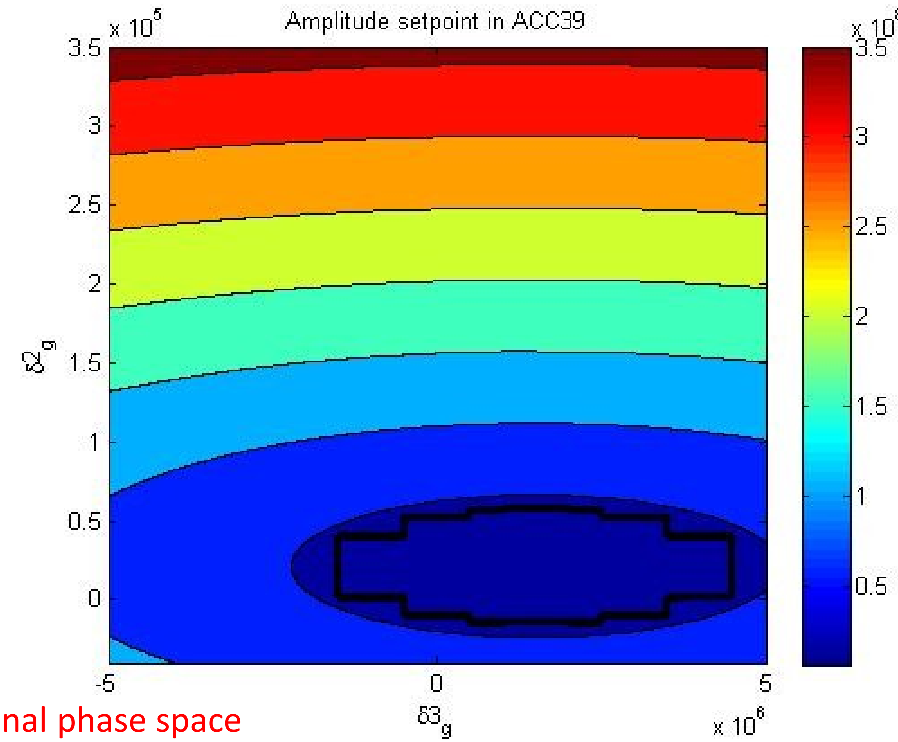
Normalized energy coordinate at position s

Energy of the reference particle

Amplitude setpoint requested in ACC1 and ACC39 in order to achieve a particular "pre-compensated-distribution" at the exit of ACC39 starting from longitudinal phase space distributions at the gun having non-linear contributes named $\delta 2_g$ and $\delta 3_g$

(the black line states the technical limit: 180 MV for ACC1 and 40 MV for ACC39)





$$X_{1,n} + iY_{1,n} = V_{1,n} e^{i\varphi_{1,n}}, \quad X_{1,1} + iY_{1,1} = V_{1,1} e^{i\varphi_{1,1}}$$

$$X_{1,1} = \frac{F_3 + F_1 (kn)^2}{k^2 (n^2 - 1)}, \quad Y_{1,1} = -\frac{F_4 + F_2 (kn)^2}{k^3 (n^2 - 1)}$$

$$X_{1,n} = -\frac{F_3 + F_1 k^2}{k^2 (n^2 - 1)}, \quad Y_{1,n} = \frac{F_4 + F_2 k^2}{k^3 n (n^2 - 1)},$$

Longitudinal phase space at the exit of ACC39 value (fixed in these plots)

$$F_1 = E_1^0 - E_0^0, \quad F_i = E_1^0 \alpha_{i-1} - E_0^0 \frac{\partial^{i-1} \delta_0}{\partial s^{i-1}}(0), \quad i = 2, 3, 4$$

Longitudinal phase space at the gun exit

A Semi-Analytical Modelling of Multistage Bunch Compression with Collective Effects

Igor Zagorodnov* and Martin Dohlus

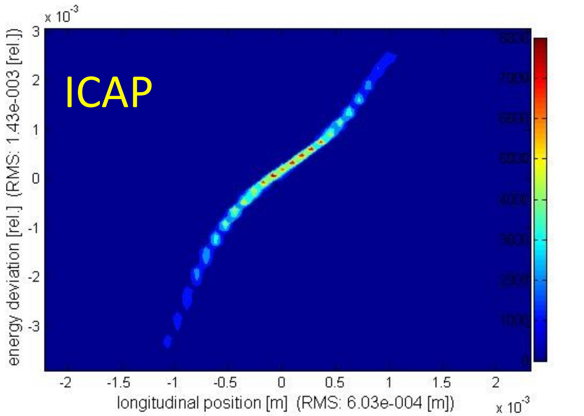
Impact of the non-linearity in the longitudinal phase space at the exit of the gun on the slice peak current at maximum compression

- I have chosen a set of different longitudinal phase space distributions at the gun exit (correspondent to different laser settings);
- I have fixed the machine setup after ACC39 and calculated the longitudinal phase space distribution at the exit of ACC39 needed to compensate non-linear effects;
- For each initial phase space distribution (at the gun exit) I have calculated the settings of the injector parameters (V_1, ϕ_1, V_{39} , ϕ_{39}) needed to reach the desired phase space distribution at the exit of ACC39 (… or a distribution as close as possible to the desired one, considering the limit in the maximum power in the cavities);
- I have run the 1D simulation of bunch compression and acceleration including RFwakes but neglecting space charge and CSR;
- I have compared the longitudinal current profiles obtained after compression for the different e-bunches (NB: the maximum compression point has been finely tuned using an additional small linear term in bunch compression)

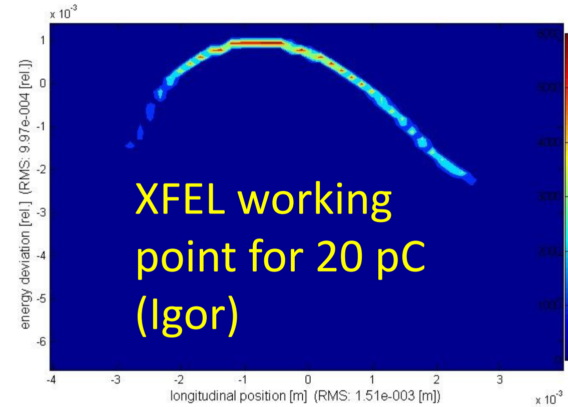
Phase space distributions at the gun exit

(most interesting cases)

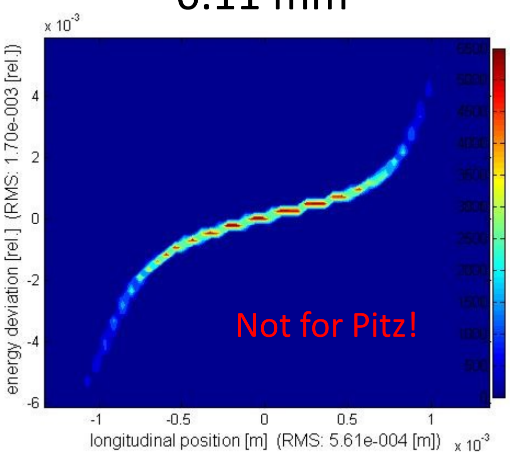
Length → **2/5.4\2 ps, 0.11 mm** ← Spot size



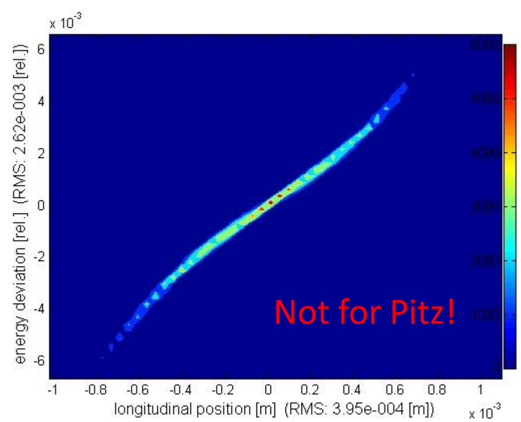
2/20\2 ps, 0.075 mm



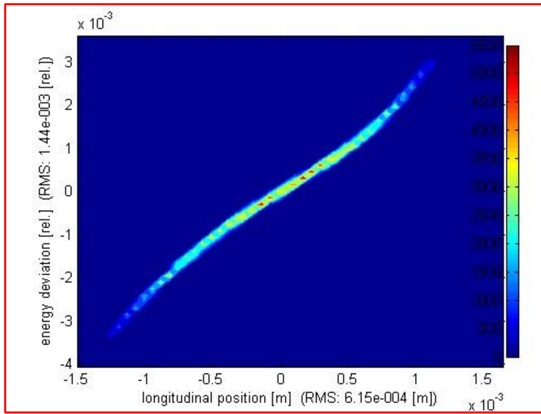
0.54/5.4\0.54 ps, 0.11 mm



Gaussian rms 0.6 ps, 0.11 mm



Gaussian rms 0.85 ps, 0.064 mm



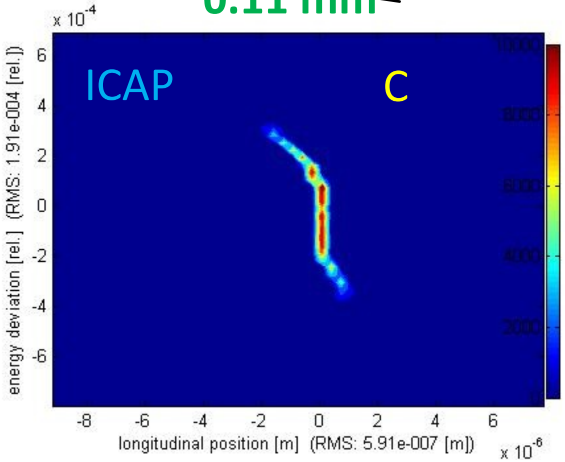
Correspondent phase space distributions after compression

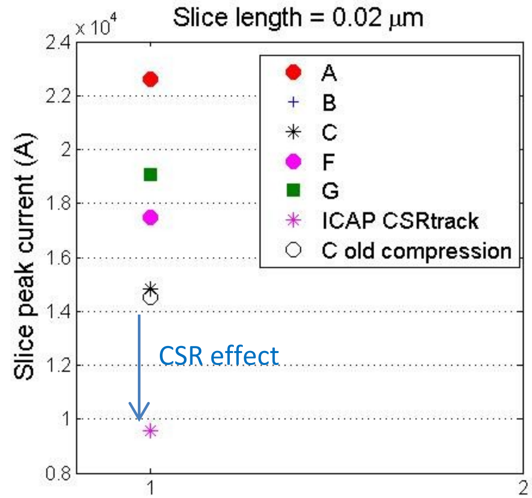
Length

2/5.4\2 ps,

0.11 mm

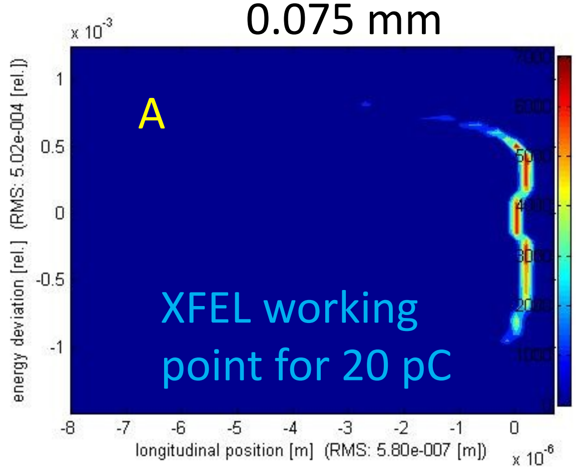
Spot size





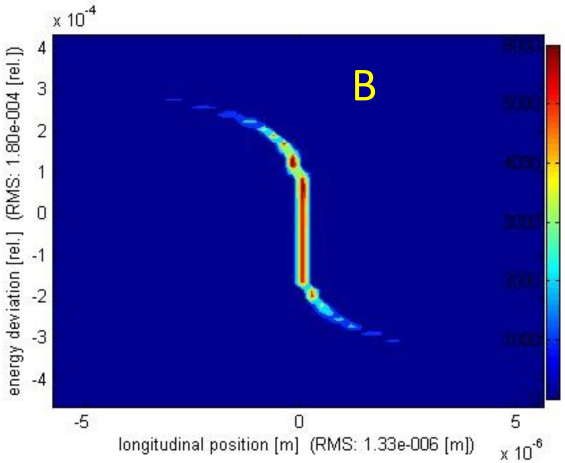
2/20\2 ps,

0.075 mm



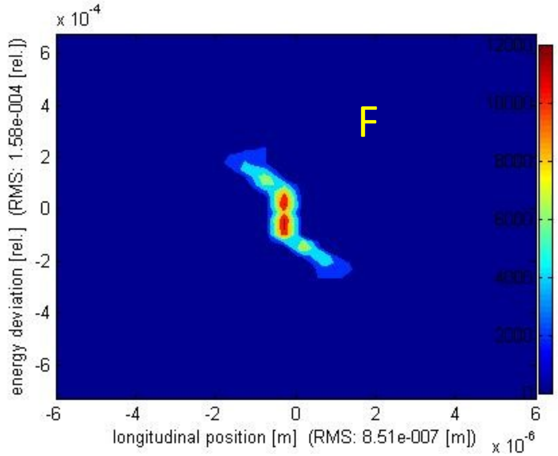
0.54/5.4\0.54 ps,

0.11 mm



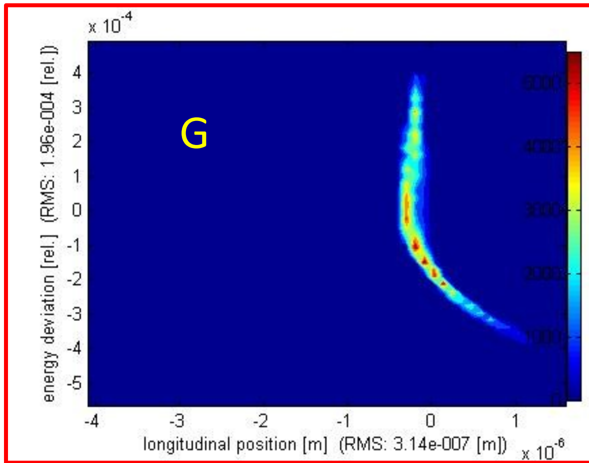
Gaussian rms 0.6 ps,

0.11 mm

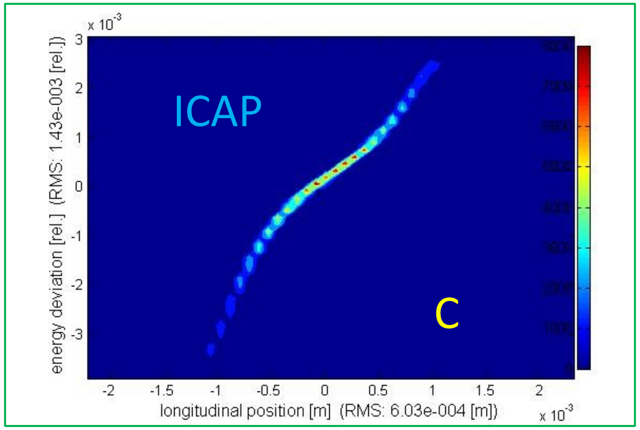


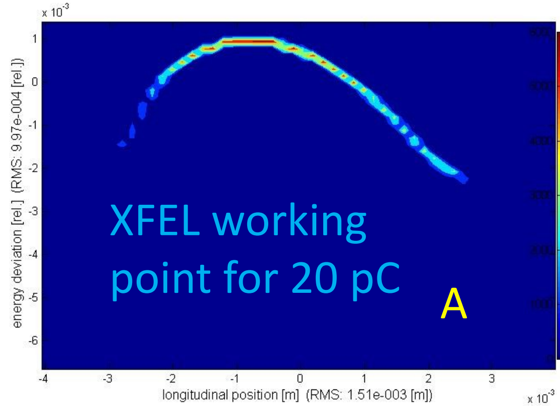
Gaussian rms 0.85 ps,

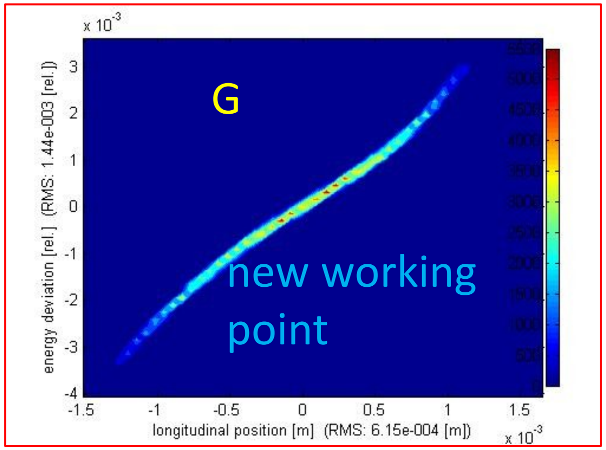
0.064 mm

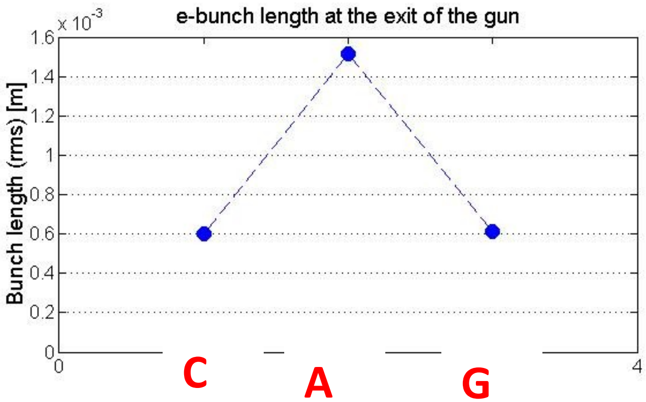


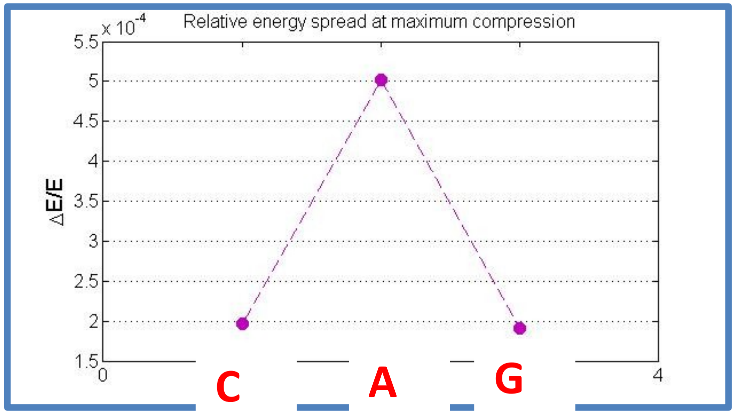
Bunch length and energy spread working at maximum compression

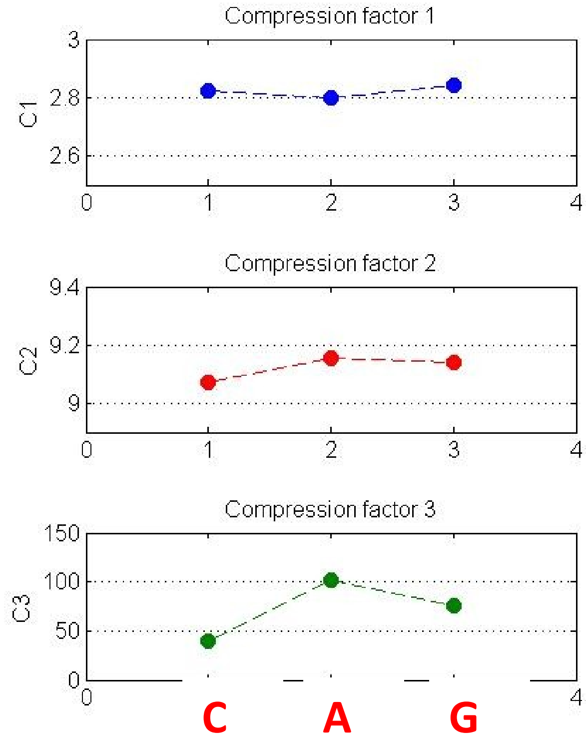






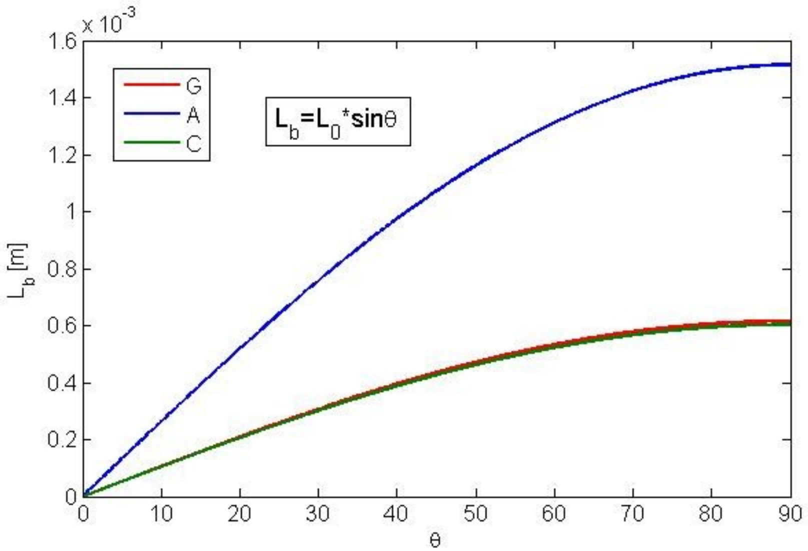


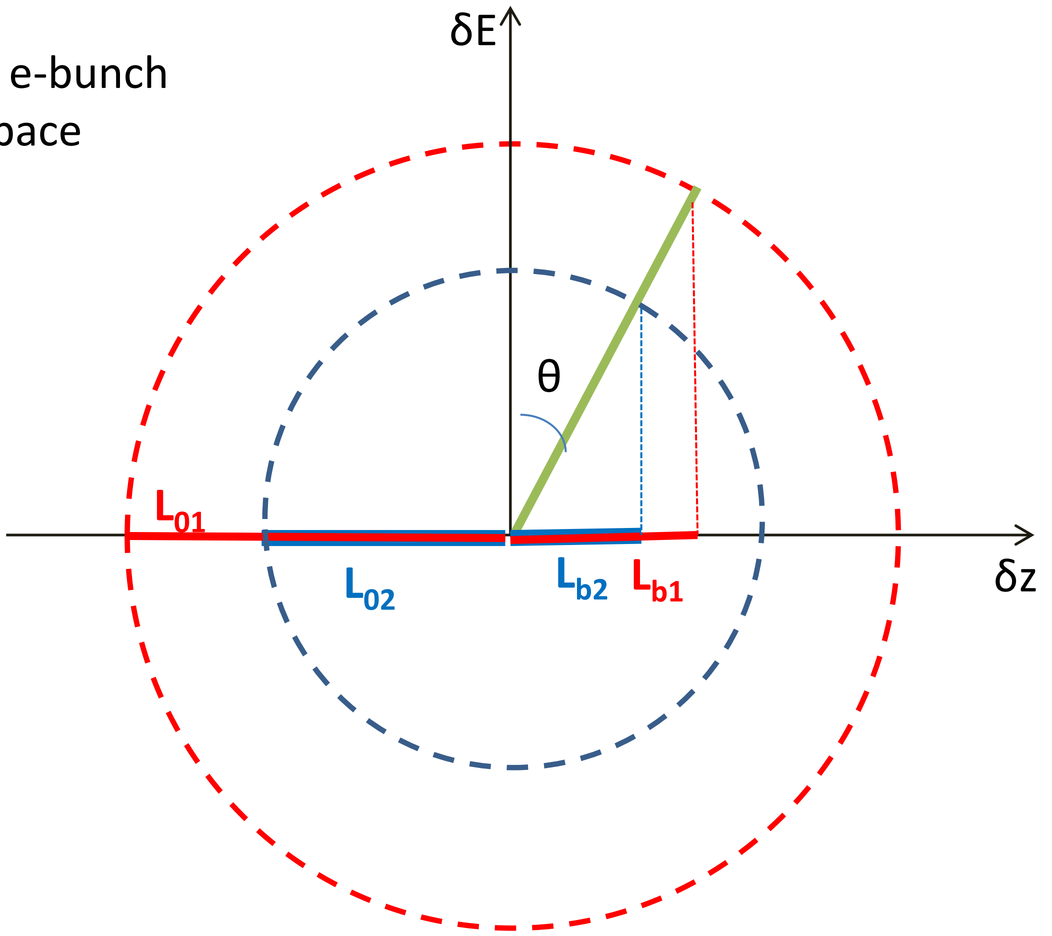




Bunch length and tolerances working at maximum compression

The green line is the e-bunch longitudinal phase space distribution.





Let's ignore the uncorrelated energy spread of the e-bunch.
Fixed the machine setup and the jitter (i.e. fixed θ), the final bunch length stability L_b is directly proportional to L_0.

Θ=0 is the maximum compression point.
Due to RF jitter, Θ will be jittering around Θ=0.

Work in progress …

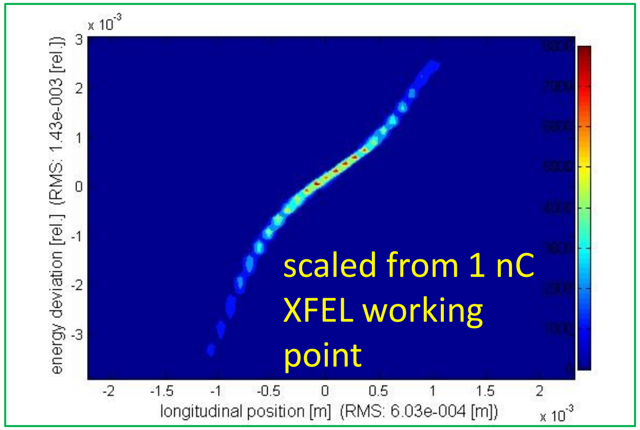
- Add CSR effect
- Try different setups of the magnetic bunch compressors

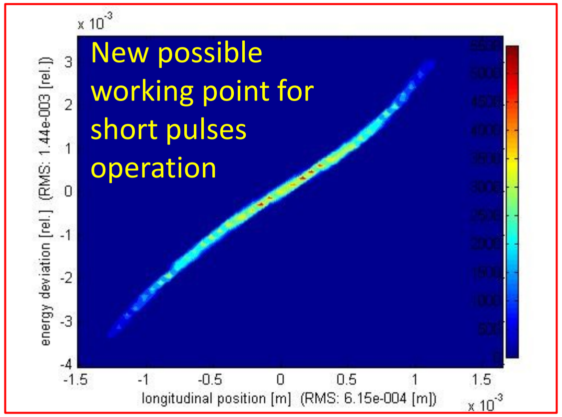
Proposal for PITZ:

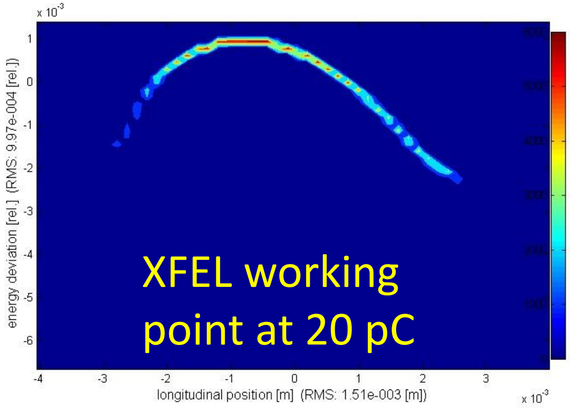
The simulations encourage to look for a/some **alternative working point/s** for short pulses SASE lasing at XFEL **having the following characteristics**:

- Short e-bunch length at the gun exit -> better RF tolerances + lower final energy spread
- Short laser pulse length and tuned laser spot size -> optimize longitudinal phase space linearity
- Good emittance -> already checked that emittance of 0.2 mm*mrad is achievable with optimized solenoid

Requirement: we need to be able to distinguish (for example) these three longitudinal phase space distributions after the gun







Experimental issues:

- Streak camera and/or RF deflector?
- Do we have enough resolution?
- Space charge effect -> slit issue (see PRSTAB **12**, 070704 (2009))
- Booster on/off?
- Fine correction of systematical errors caused by RFdeflector is needed

… A detailed study of the measurement is needed!