Optimization of the longitudinal phase space distribution of a 20 pC e-bunch at the RF-gun exit for quasi single spike operation at the European XFEL

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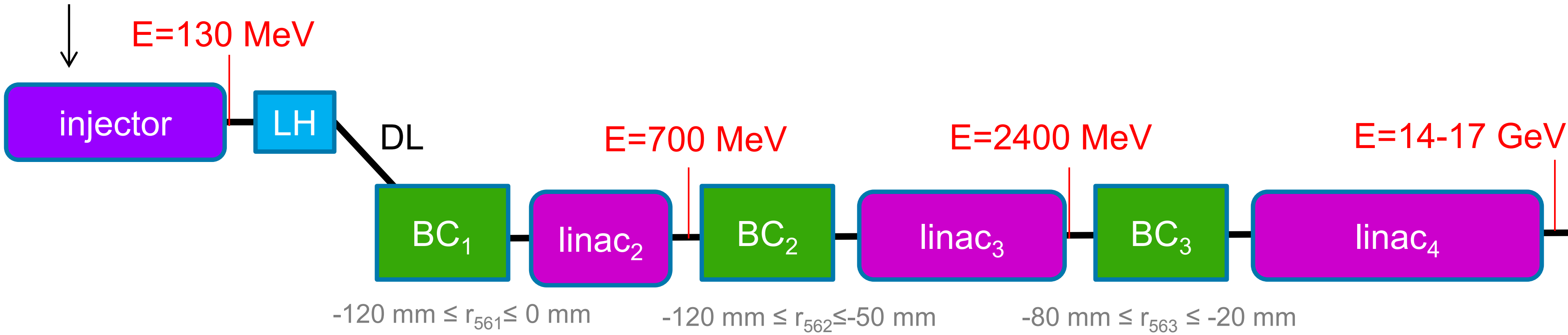
European XFEL layout

- Photocathode RF gun, 1.6 cell L-band normal conducting having 60 MV/m peak E_{field} at the Cs_2Te cathode
- TESLA accelerating cavity, 1.3 GHz
- TESLA 3.9 GHz cavity



XFEL working points:

I. I. Zagorodnov, M. Dohlus, Phys. Rev. ST Accel. Beams 14, 014403 (2011).

II. I. Zagorodnov, Beam Dynamics Simulations for XFEL (Jan. 2011) , http://www.desy.de/fel-beam/s2e/index.html

Laser longitudinal profile: flat-top 20 ps long -> e-bunch emittance has been optimized

Short radiation pulses operation

$$L_b \leq 2\pi L_c \rightarrow \text{single spike regime}$$

L_b = bunch length

L_c = cooperation length

In order to fulfill this requirement or get as close as possible to it:

- The charge of the e-bunch must be small (20 pC or less)
- It is necessary to work at the maximum compression point (or very close to it)

Short pulses operation and choice of the laser parameters

- When working with low charges (e.g. 20 pC) and at maximum compression, we may decide to optimize the e-bunch production and compression w.r.t. RF-stability and shortest achievable bunch length.
- The use of short bunches at the gun exit (by using a shorter laser pulse length) allows a better stability for the e-bunch compression.
- The correction of the non-linearity in the longitudinal phase space is a critical point: in order to achieve the shortest bunch length at maximum compression the non-linearity present in the longitudinal phase space of the e-bunch at the gun exit must be precisely known.

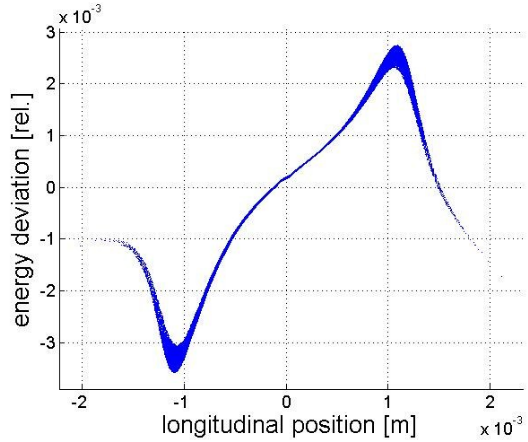
Energy of the particle at position s

Non-linear terms

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

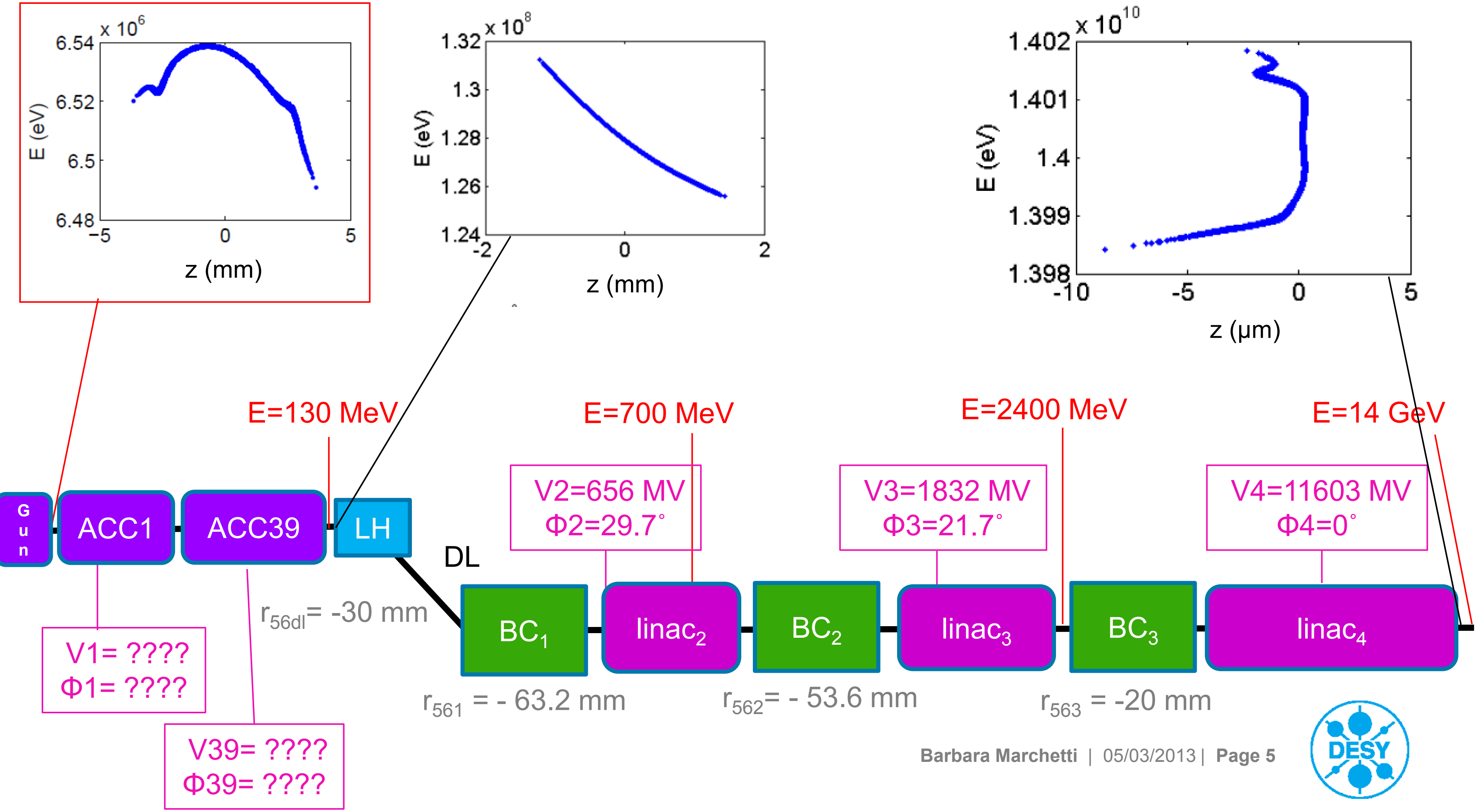
Energy deviation at position s

Energy of the reference particle



Why the longitudinal phase space distribution at the gun exit must be precisely known.

- The setup of the main linac has been fixed
- The aim is to eliminate the second and third order non-linear terms in the longitudinal phase space distribution having the maximum compression at the linac exit.



Simulations

> The study has been restricted to 2 longitudinal laser shapes:
  - 2.1 ps FWHM gaussian
  - 5.4 ps FWHM flat-top having 2ps rise/fall time

> The setup of the main linac is fixed.

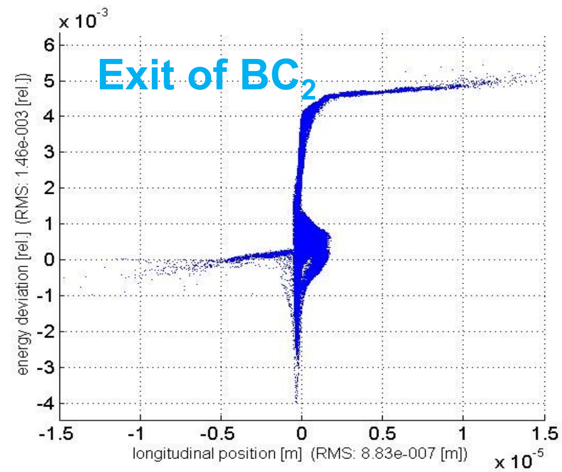
> The injector setup is different for each input distribution.

> I have used a fast, partially 3D, transport (see the list of codes below).

Used codes:

- **ASTRA (tracking with 3d space charge, DESY, K. Flötmann) in the injector;**
- **CSRtrack (tracking through dipoles, DESY, M. Dohlus, T. Limberg) in the LH, DL and BCs**
- **Linear transport matrices multiplication in the linac sections;**
- **RF-wakefields and longitudinal space charge along the linac sections have been added analytically (I. Zagorodnov, M. Dohlus, Phys. Rev. ST Accel. Beams 14, 014403 (2011)).**

Flat top laser pulse 2/5.4\2 ps, transverse rms 0.11 mm

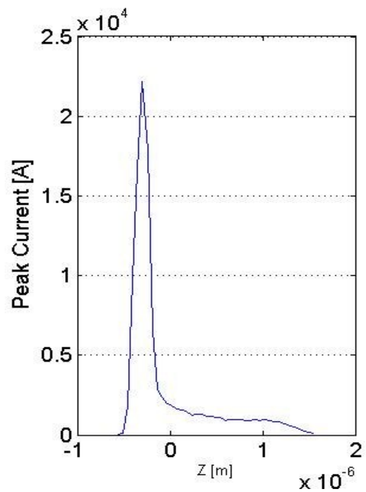


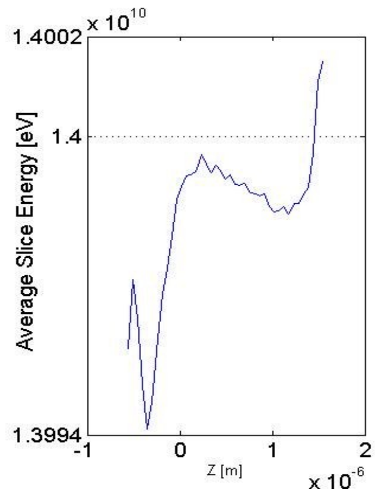
Track through the undulator

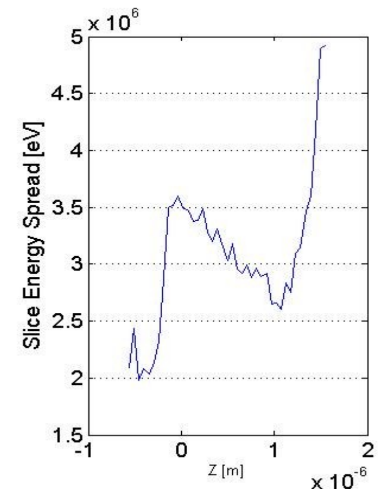
Input beam for Genesis code:

Beam at the linac exit

E= 14 GeV
$\Delta E/E$= 2.53*10^{-4}
ε_x=0.16 mm*mrad
ε_y=1.11 mm*mrad
FWHM= 0.74 fs (0.22 μm)

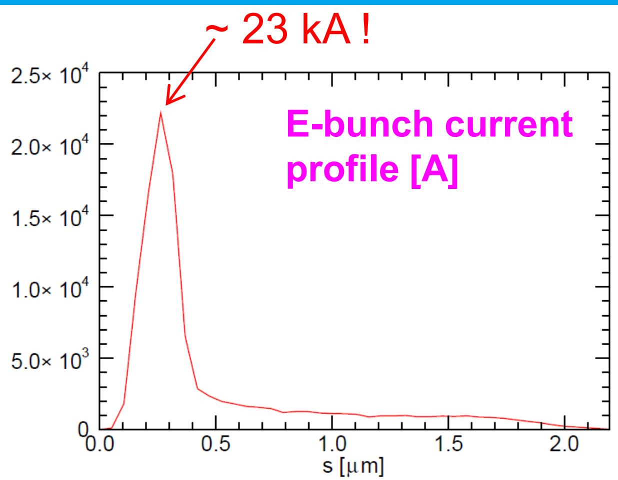




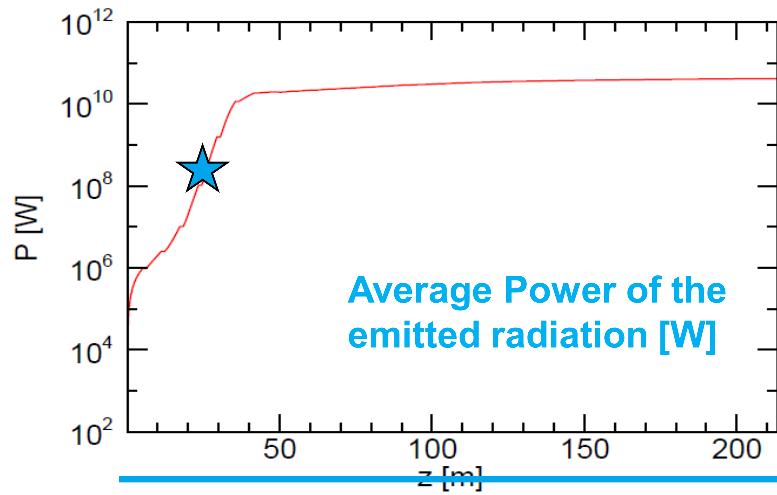


DESY

Radiation production (λ=0.26 nm)



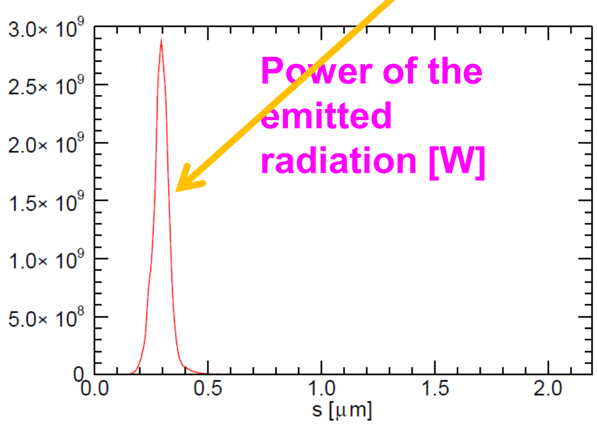
Longitudinal coordinate along the e-bunch



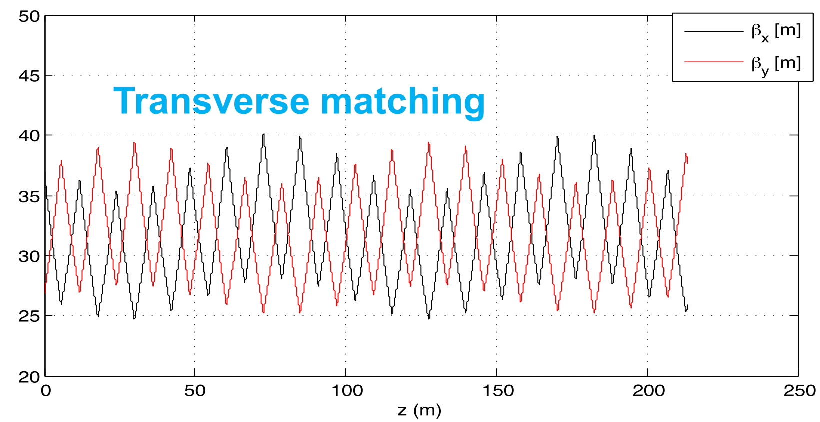
Coordinate along the undulator [m]

z = 24 m

FWHM~0.08μm = 0.27fs!

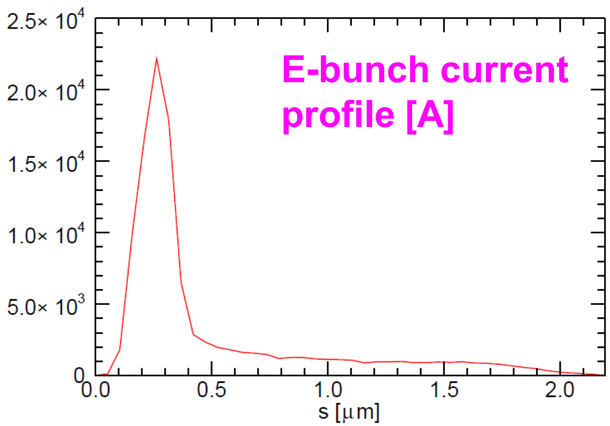


Single spike

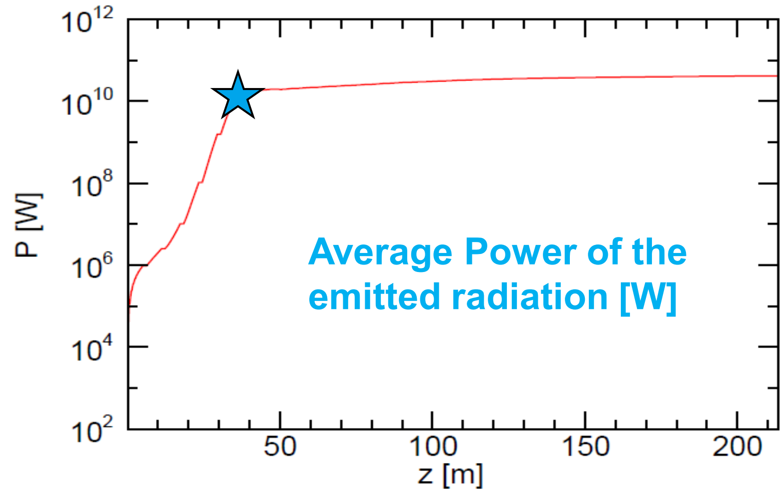


DESY

Radiation production



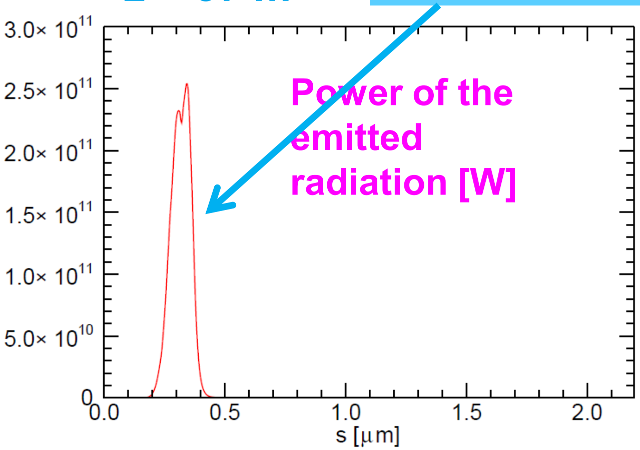
Longitudinal coordinate along the e-bunch



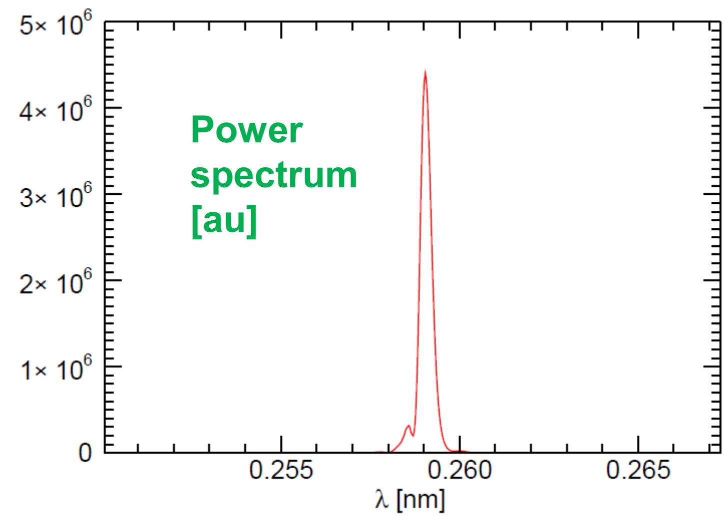
Coordinate along the undulator [m]

z = 37 m

FWHM~0.12μm = 0.4fs

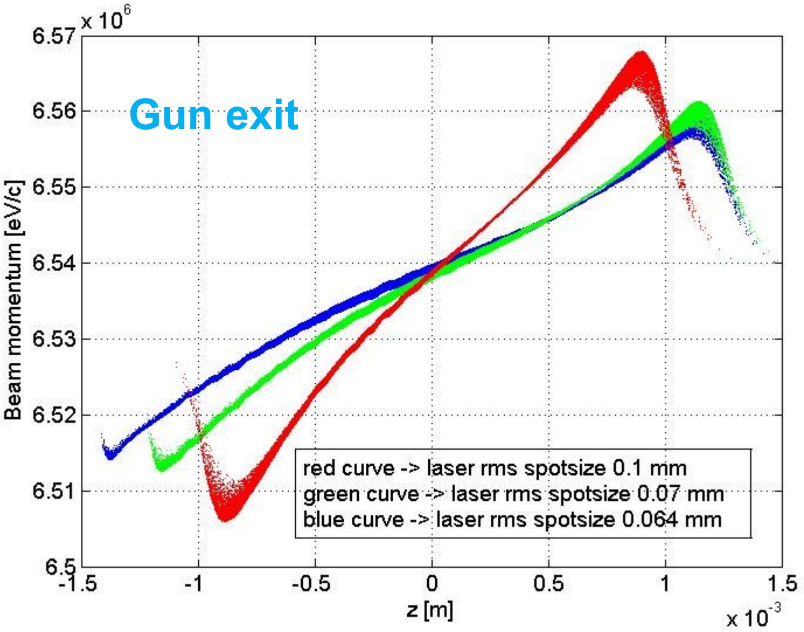


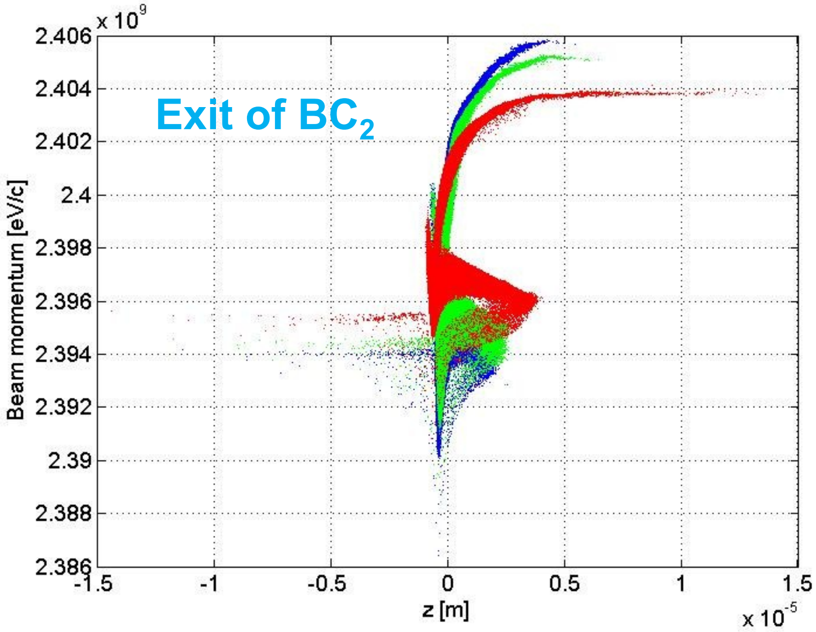
Two spikes



Wavelength [nm]

Studies using the gaussian longitudinal laser profile having 2.1 ps FWHM length

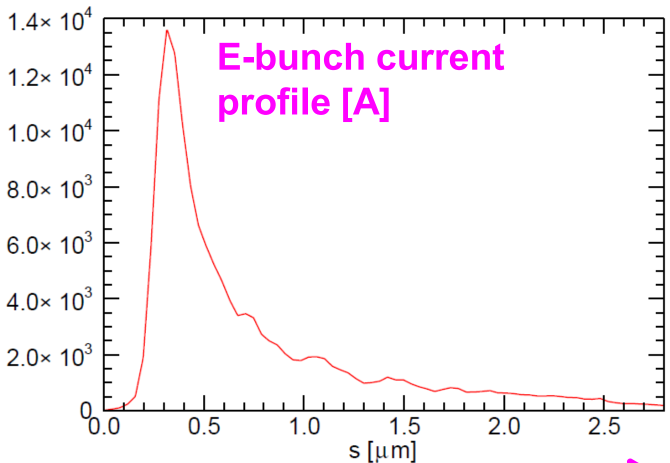




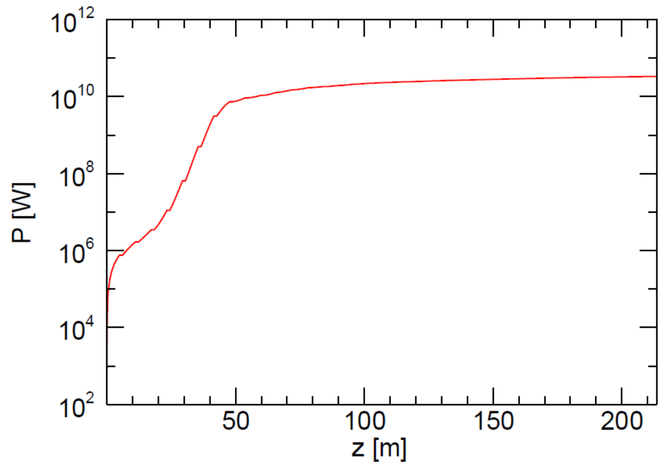
Beam parameters at the exit of the linac:

Laser rms spotsize (mm)	ε_x (mm*mrad)	ε_y (mm*mrad)	Energy spread (relative)	FWHM (μm)	FWHM (fs)
0.064	0.224	0.964	2.67*10^(-4)	0.28	0.934
0.07	0.21	0.92	2.33*10^(-4)	0.341	1.14
0.1	0.19	0.804	1.44*10^(-4)	0.432	1.44

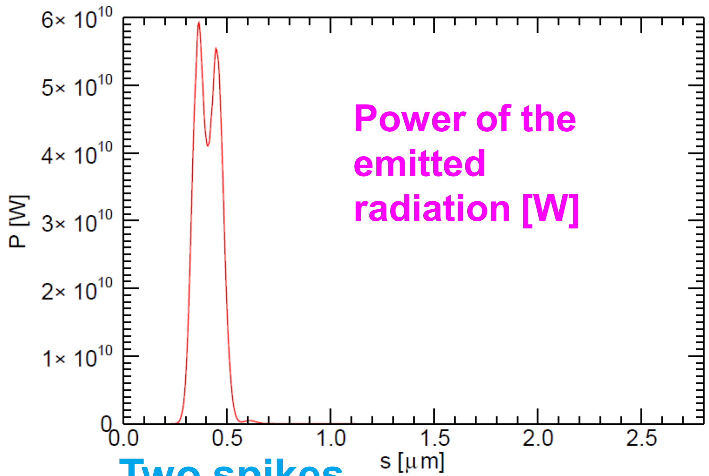
Radiation production for the 0.064 mm rms spotsize



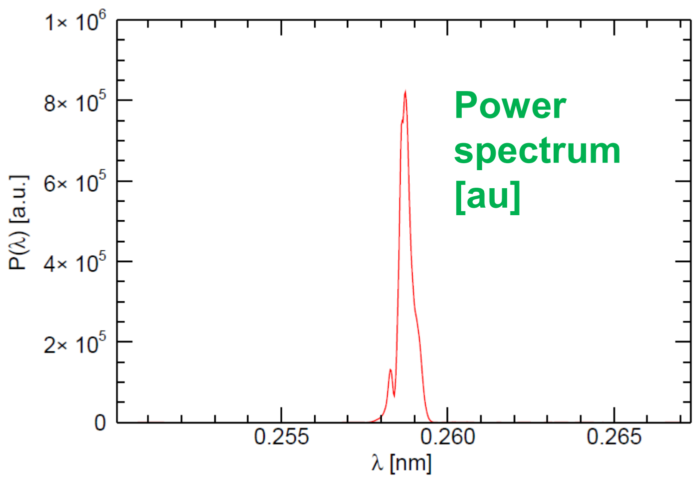
Longitudinal coordinate along the e-bunch



z = 42 m



Two spikes



Known limits of the presented simulations

- The wakefields and the SC in the undulator are not included. Due to the high peak current the impact of these wakefields is expected to be non-negligible.
- The transport line between the exit of the main linac and the entrance of the first undulator has not been taken into account.
- The impact of the RF jitter on the bunch length has not been quantitatively investigated (even though we expect to have a fluctuation of about 20% of the peak current with a jitter of the phase of ACC1 of 0.001 deg).
- The track along the linac was done only for the longitudinal phase space. A precise study requires instead the use of Astra or Elegant.

Conclusion & outlook

- A laser configuration delivering a single spike radiation pulse at 0.26 nm wavelength has been discussed using fast S2E simulations.
- This configuration use a short flat-top at the cathode in order to relax RF tolerances, despite the increase in emittance.
- In order to tune the machine settings the knowledge of the longitudinal phase space of the e-bunch at the gun exit is crucial.
- Experimental measurements to characterize the e-bunch properties at the exit of the gun are feasible at PITZ.

Thank you for the attention !

I would like to thank J. Roensch-Schulenburg, M. Rehders and in general the group of "Ultra-short pulses at FLASH" for profitable discussions.