Simulations on Chirp Evolution of the Longitudinal Phase Space of a 250pC Bunch during Transport through EuXFEL

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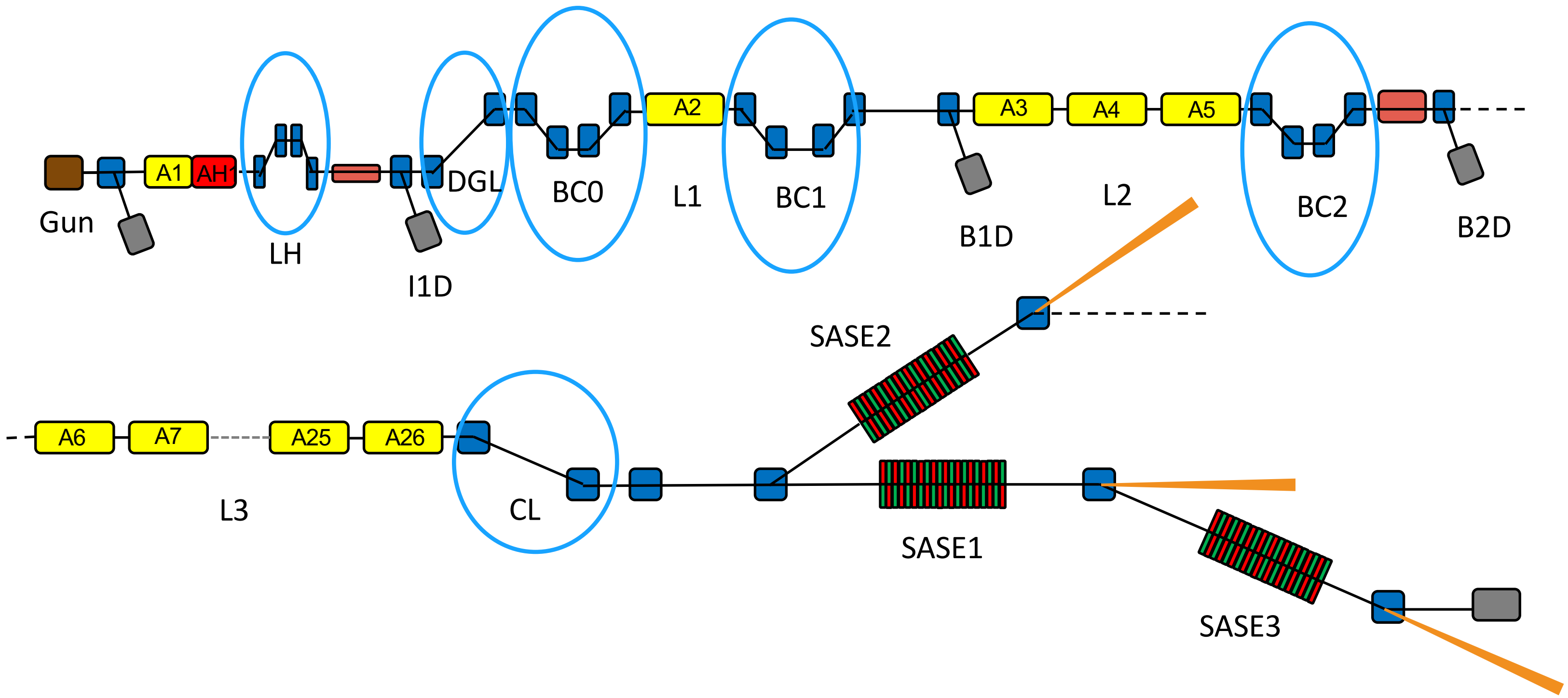
Hamburg, 01.06.2021

Longitudinal Phase Space

Actors to take into account

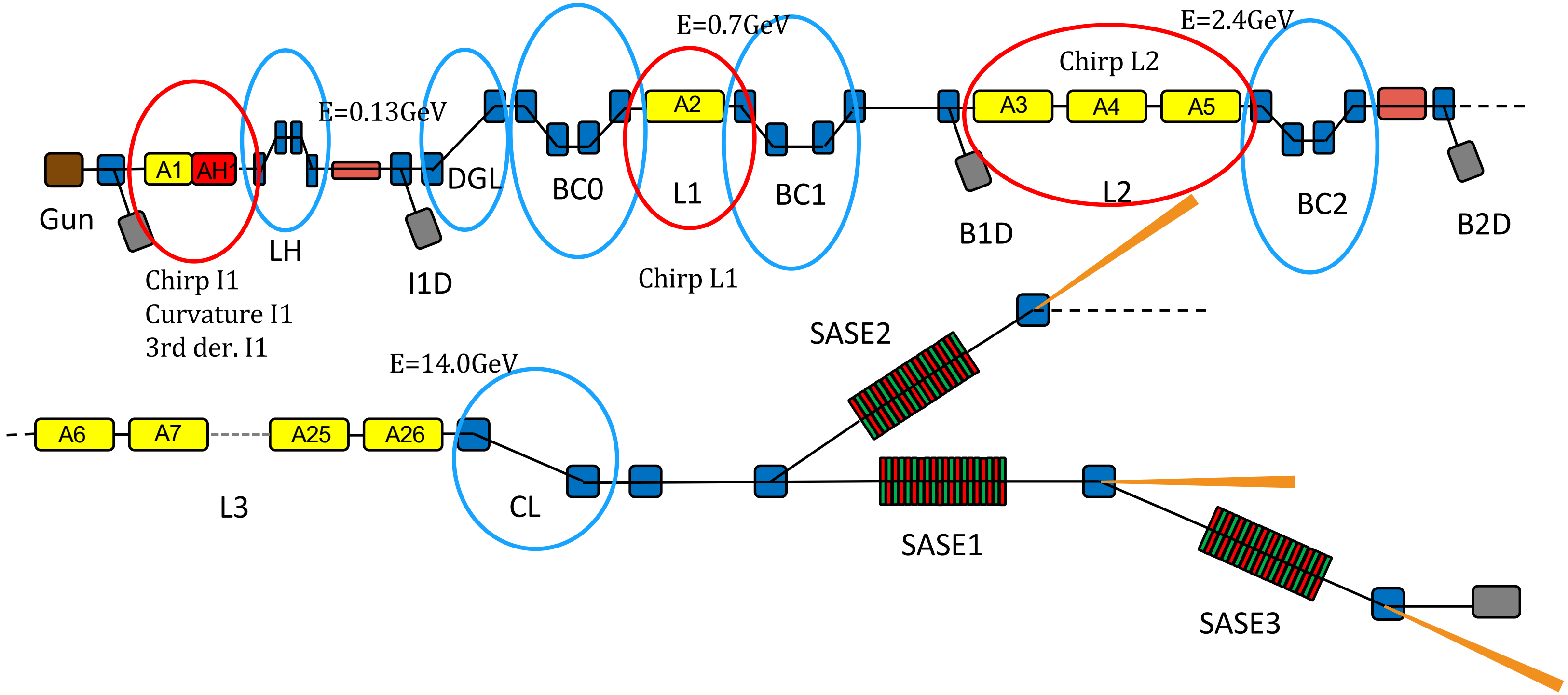


Dispersive regions to establish compression:
3 stage BC scheme BC0-BC1-BC2 + Laser Heater Chicane (LH)
+ Dogleg (DGL)+ Collimation (CL)

- *I. Zagorodnov, M. Dohlus „Semianalytical modeling of multistage bunch compression with collective effects“ Phys. Rev. – Accelerator and Beams* ***14****, 014403 (2011)*
- *XFEL Lattice Definition component_list_9.1 Version 9.0.5 – 28.01.2019*

Longitudinal Phase Space

Actors to take into account



- Dispersive regions to establish compression:
  3 stage BC scheme BC0-BC1-BC2 + Laser Heater Chicane (LH)
  + Dogleg (DGL)+ Collimation (CL)

- RF parameters for energy, chirp, curvature and 3rd derivative

chirp, curvature, 3rd derivative in I1

definitions

Typically:

$$\Delta E = U_1 \cos(\omega t + \varphi_1) + U_{39} \cos(3\omega t + \varphi_{39})$$

$$Chirp = \frac{1}{E}\frac{d\Delta E}{ds} = -\frac{\omega U_1}{cE}\sin(\omega t + \varphi_1) - \frac{3\omega U_{39}}{cE}\sin(3\omega t + \varphi_{39})$$ ~-10

$$Curvature = \frac{1}{E}\frac{d^2\Delta E}{d^2 s} = -\frac{\omega^2 U_1}{c^2 E}\cos(\omega t + \varphi_1) - \frac{9\omega^2 U_{39}}{c^2 E}\cos(3\omega t + \varphi_{39})$$ $\sim \pm\ 10^2$

$$3rd\ der. = \frac{1}{E}\frac{d^3\Delta E}{d^3 s} = \frac{\omega^3 U_1}{c^3 E}\sin(\omega t + \varphi_1) + \frac{27\omega^3 U_{39}}{c^3 E}\sin(3\omega t + \varphi_{39})$$ $\sim \pm\ 10^5$

$$\omega = 2\pi \cdot 1.9E + 9$$

Functions of time → functions of the position within the bunch

chirp, curvature, 3rd derivative in L1 and L2

definitions

Typically:

$$\Delta E = U_1 \cos(\omega t + \varphi_1) + U_{39} \cos(3\omega t + \varphi_{39})$$

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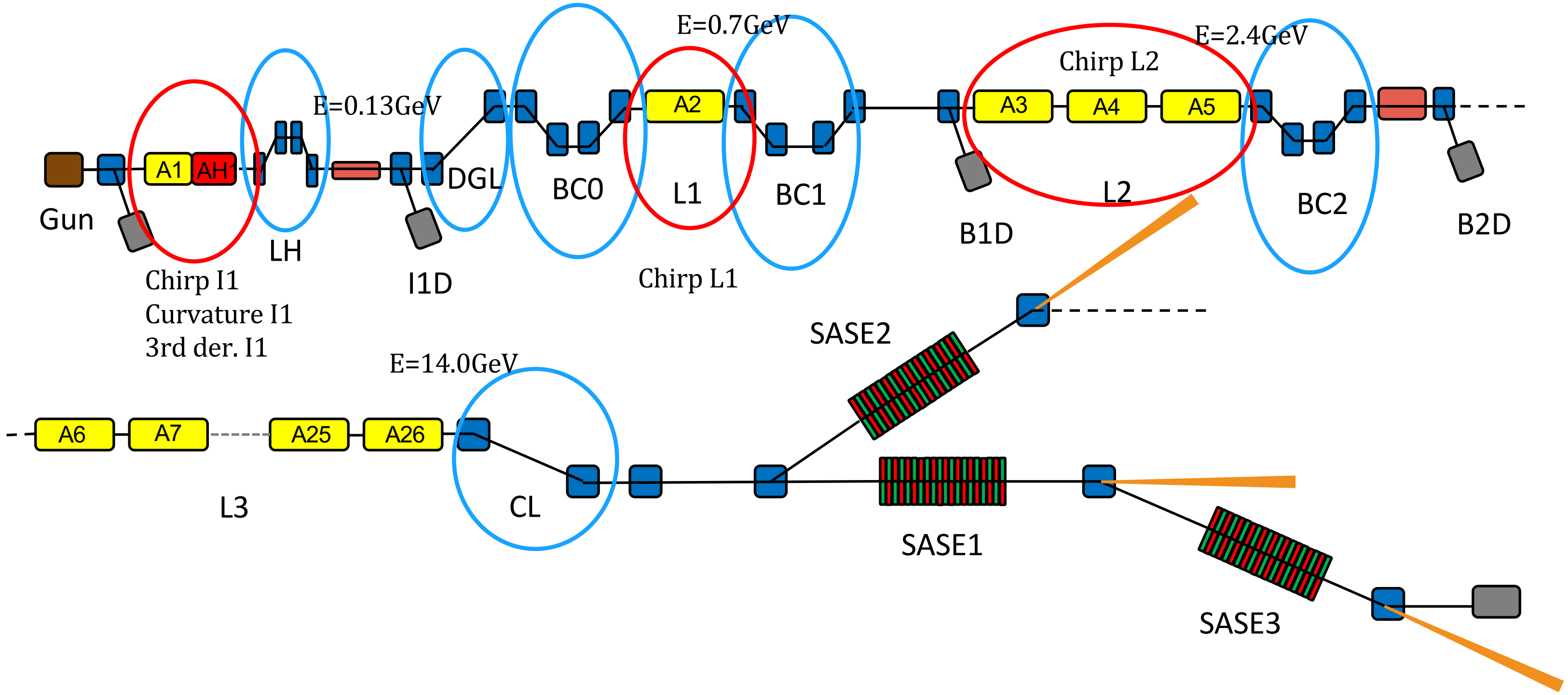
$$\omega = 2\pi \cdot 1.9E + 9$$

L1 and L2: without curvature and 3rd der., and without second term

Longitudinal Phase Space

Actors to take into account



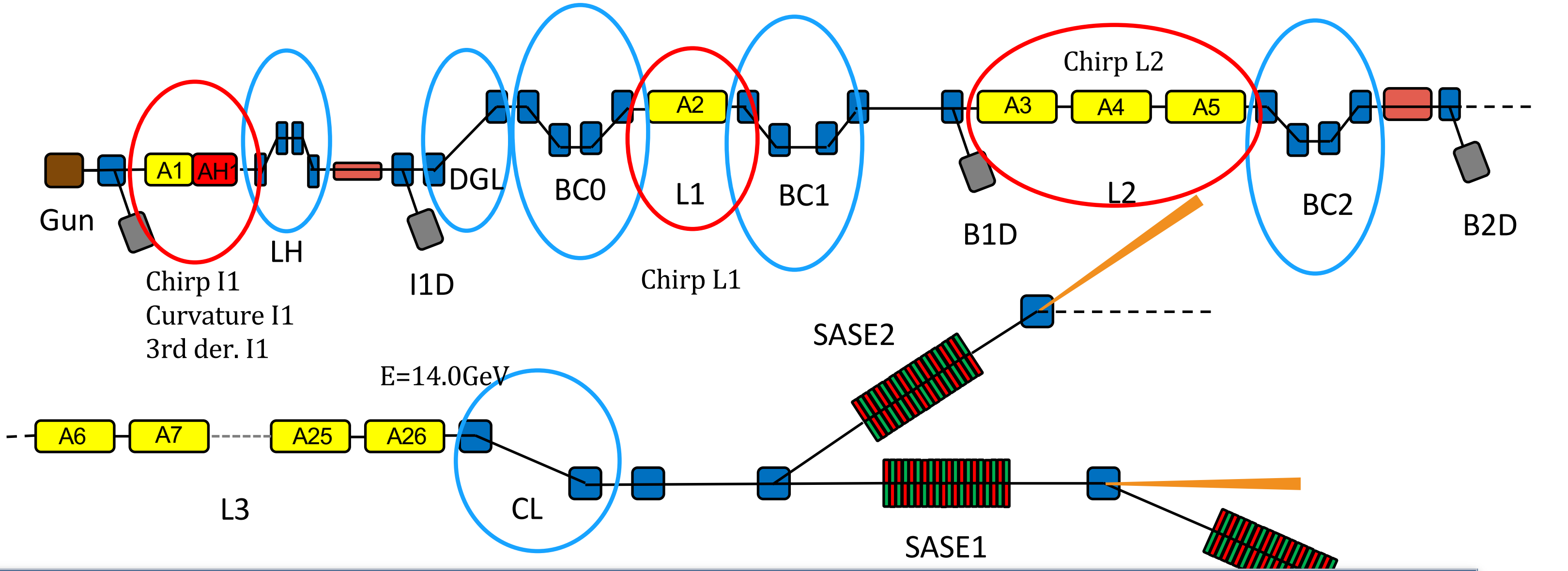
- Dispersive regions to establish compression:
  3 stage BC scheme BC0-BC1-BC2 + Laser Heater Chicane (LH)
  + Dogleg (DGL)+ Collimation (CL)

- RF parameters for energy, chirp, curvature and 3rd derivative

- Wakes, CSR ...

Simulations Setup

Goal: examine bunch chirp at SA1 for different scenarios



Dispersive Sections	RF settings			
acc. to design		Injector	L1	L2
	chirp	~ -8.9	-9.7894	-11.4677
	curvature	0-60-180-320		
	3rd der.	20332		

Parameters changed in the simulations: curvature in I1

Chirp in I1 adjusted to keep peak current at SA1 constant at 4.4kA

Simulations Setup: Krack und Xtrack

Krack

RF-Gun

E_{cath}= 56.88MV/m
ϕ_{cath} = - 3 deg w.r. to MMMG phase

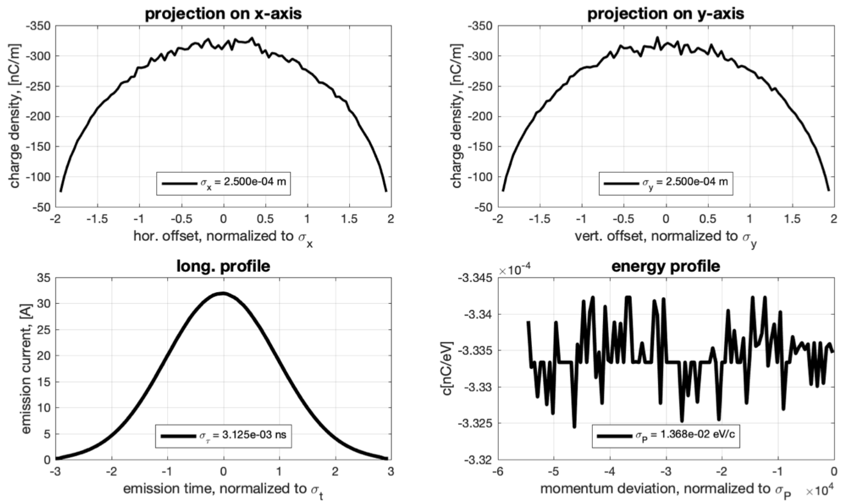
B_{main} = 0.2195 T

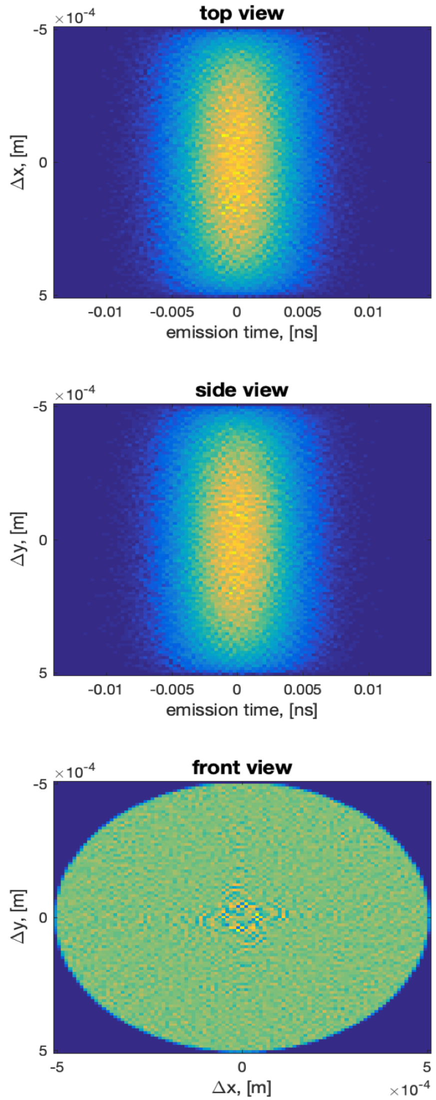
Field Balance = 1.04

Cathode Laser

Temporal Profile:
Gauss 3.125ps rms
(FWHM: 7.34ps)

Transverse:
radial homogeneous
BSA = 1mm





Xtrack

- starts at 2.063m

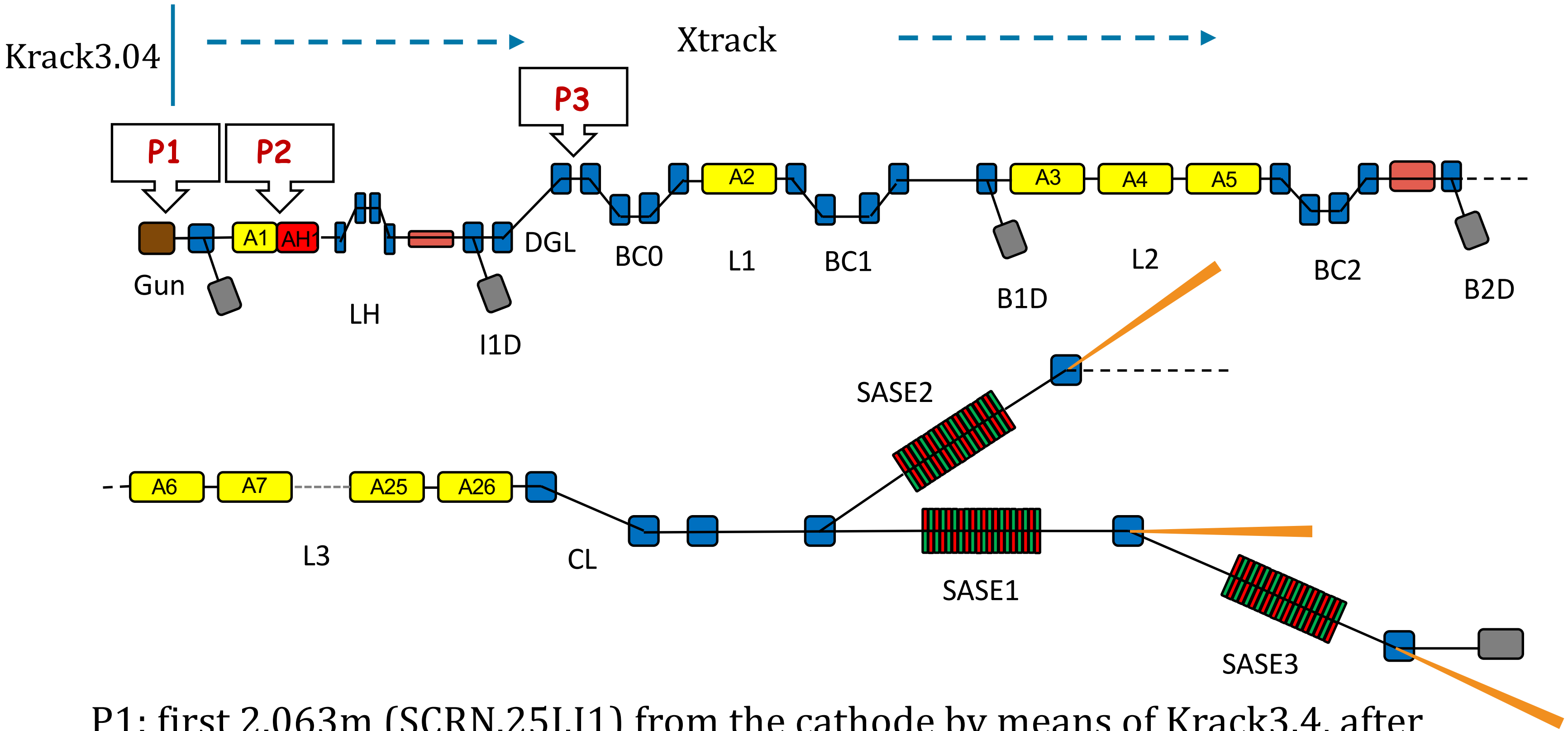
1M particles with
- wakes
- coupler kicks
- CSR
- Space charge till 362m (L2 included)

- Matched in the injector matching section for curvature = 60.5

Variated Parameters:
- RF curvature in I1

Simulations Setup

fixed observation points in the Injector



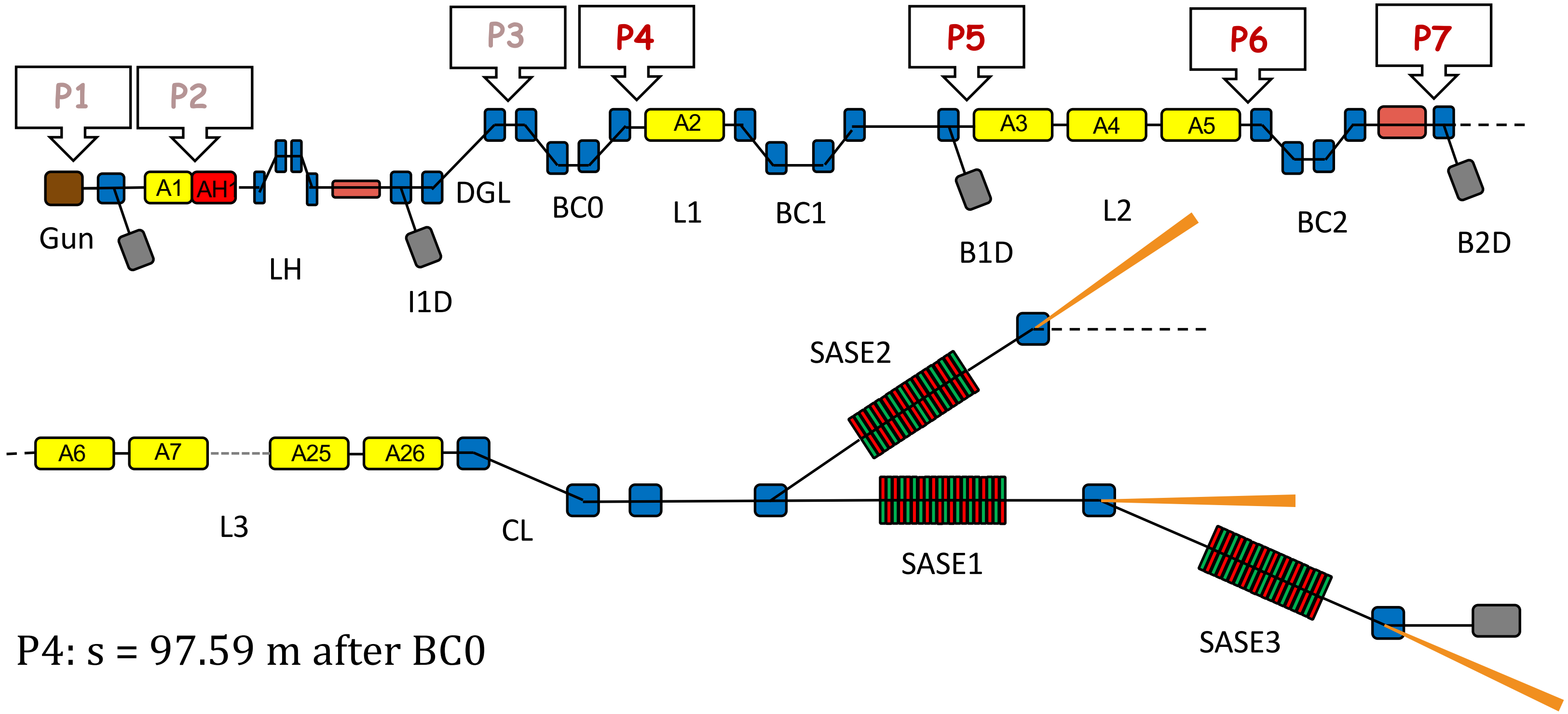
P1: first 2.063m (SCRN.25I.I1) from the cathode by means of Krack3.4, after P1 with Xtrack

P2: s=14.4484m, Start of the matching section

P3: s=73.21m to control Matching and Injector

Simulations Setup

Fixed observation points in L1 – B2



P4: s = 97.59 m after BC0

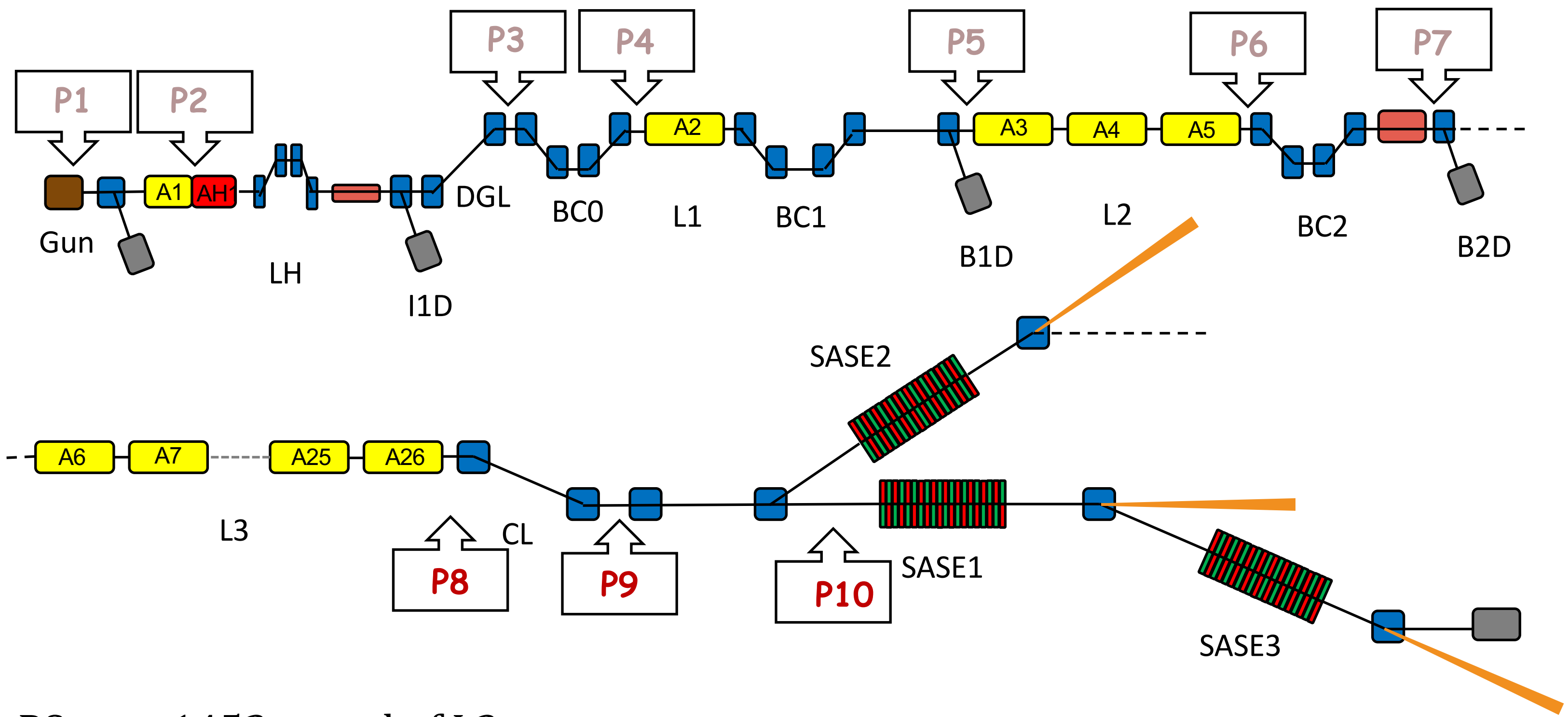
P5: s = 212.59 m after BC1

P6: s = 362 m after L2

P7: s = 422.59 m after BC2 (MATCH.446.B2 / OTRA.446.B2)

Simulations Setup

Fixed observation points L3 – SA1



P8: s = 1452 m end of L3

P9: s = 1831 m end of CL

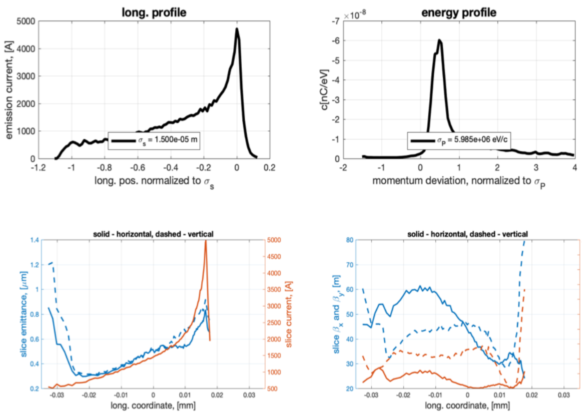
P10: s = 2213 m entrance into SASE1

Slices, Mismatch, Current Profile at SA1 (P10)

Curvature = 0 – 60 – 180 - 320

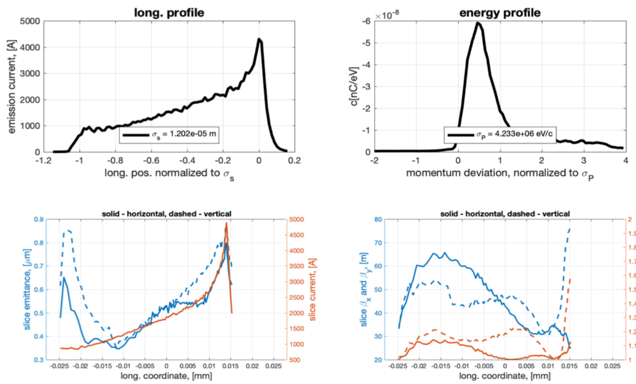
Curvature = 0.5

Q, pC	250
σ_s µm	15.0
σ_E MeV	5.99
ε_x	0.58
ε_y	0.97
I_p kA	4.71



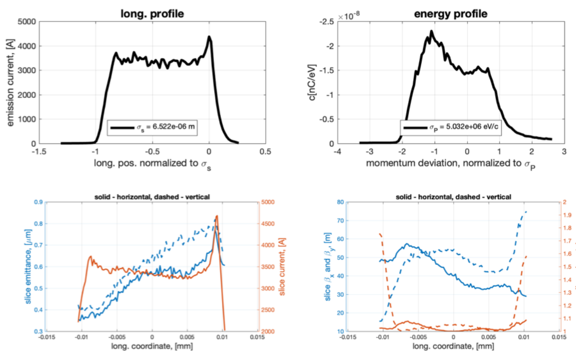
Curvature = 60.5

Q, pC	250
σ_s µm	12.0
σ_E MeV	4.23
ε_x	0.58
ε_y	0.91
I_p kA	4.31



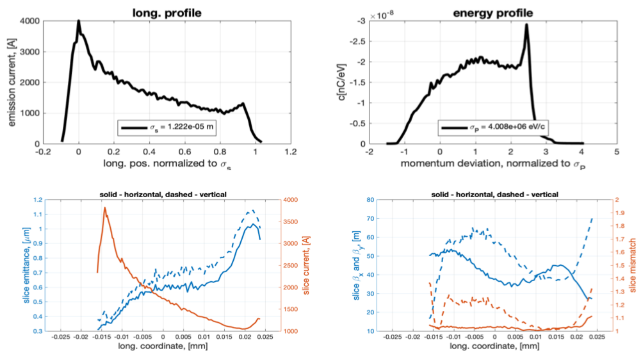
Curvature = 180.5

Q, pC	250
σ_s µm	6.52
σ_E MeV	5.03
ε_x	0.58
ε_y	0.82
I_p kA	4.37



Curvature = 320.5

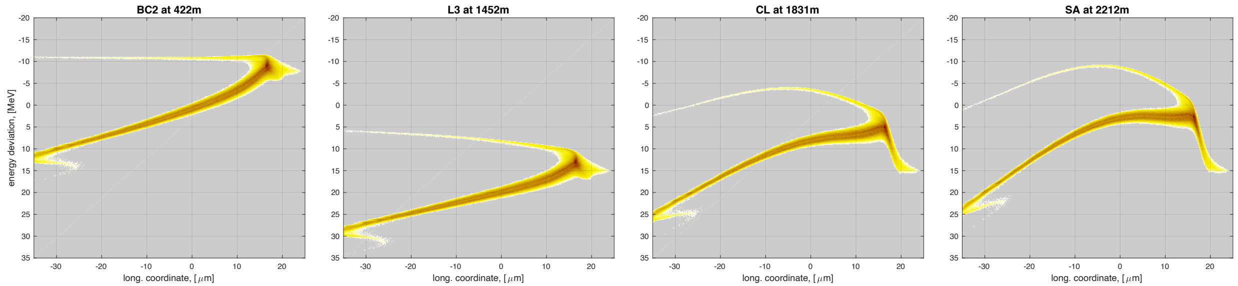
Q, pC	250
σ_s µm	12.2
σ_E MeV	4.01
ε_x	0.60
ε_y	1.04
I_p kA	4.00



Longitudinal Phase Space

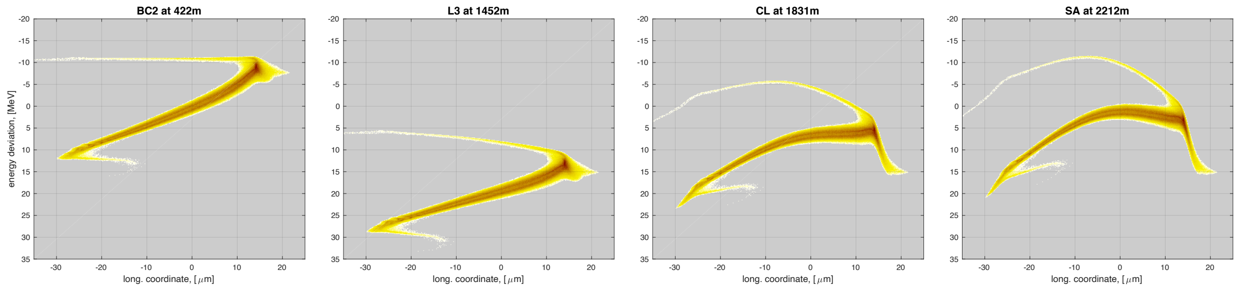
Curvature = 0.5

not flipped



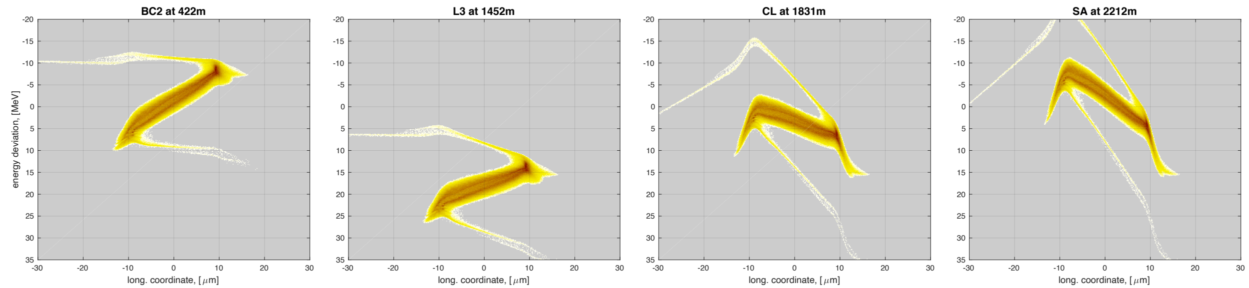
Curvature = 60.5

„zero“chirp



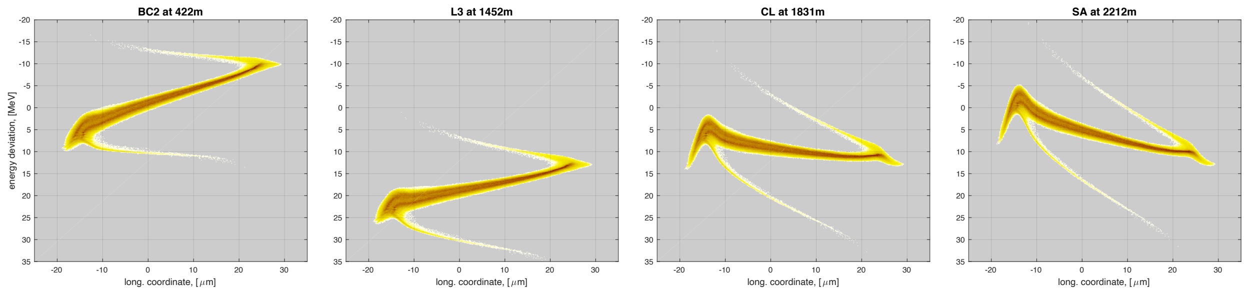
Curvature = 180.5

flipped longitudinal
phase space distribution



Curvature = 320.5

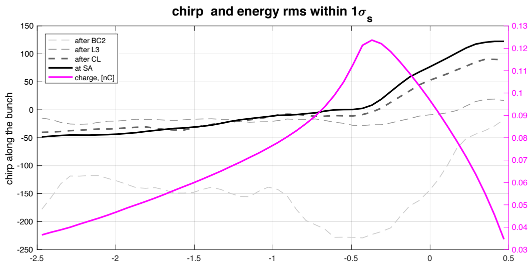
flipped, but impact of
wakes seems to be weaker

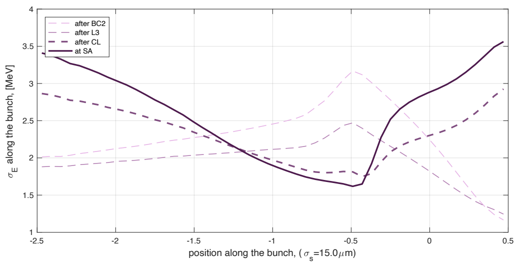


Chirp at SA1 for 1σ_s part of the bunch

Curvature = 0.5

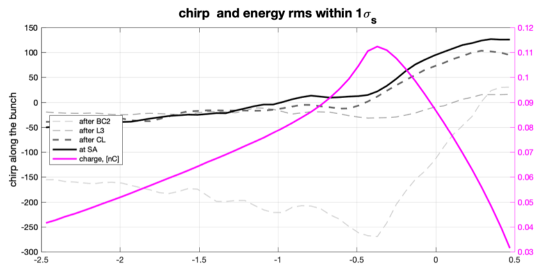
Param. at peak	
Q, pC	124
σ_s µm	15.0
σ_E MeV	2.10
chirp	8.2

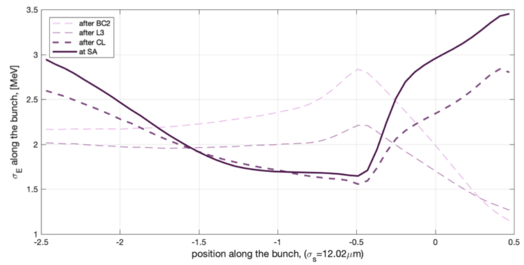




Curvature = 60.5

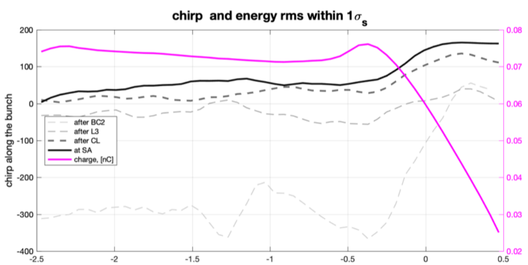
Param. at peak	
Q, pC	112
σ_s µm	12.0
σ_E MeV	1.95
chirp	11.8

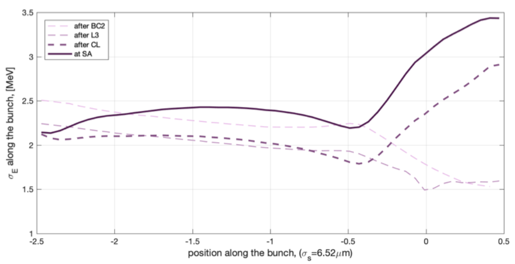




Curvature = 180.5

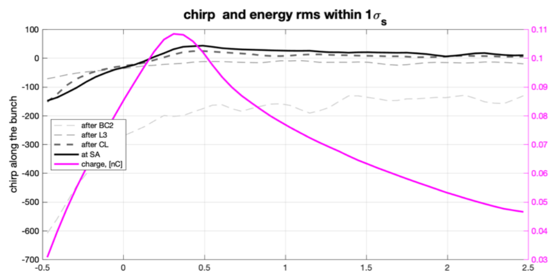
Param. at peak	
Q, pC	76
σ_s µm	6.52
σ_E MeV	2.27
chirp	57.6

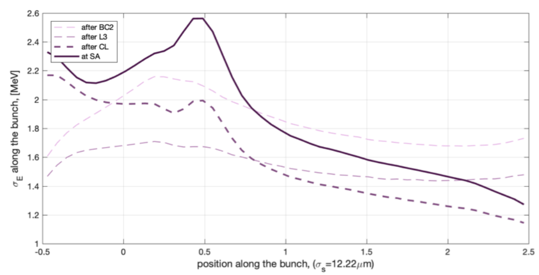




Curvature = 320.5

Param. at peak	
Q, pC	108
σ_s µm	12.2
σ_E MeV	2.38
chirp	29.1

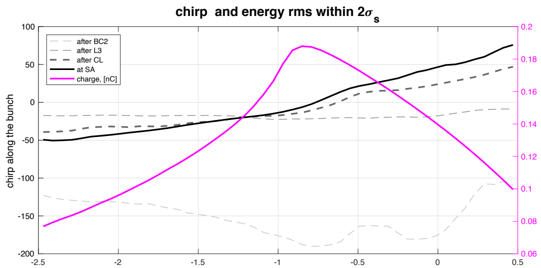


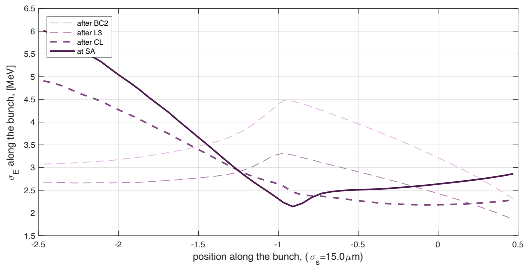


Chirp at SA1 for 2σ_s part of the bunch

Curvature = 0.5

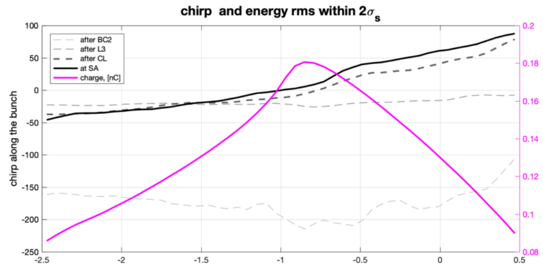
Param. at peak	
Q, pC	188
σ_s μm	15.0
σ_E MeV	2.28
chirp	-6.3

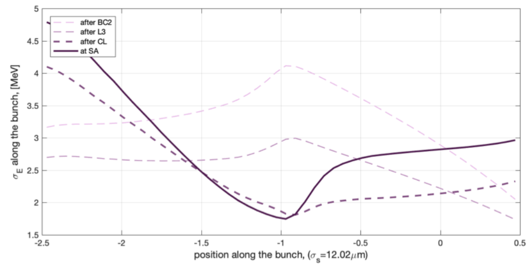




Curvature = 60.5

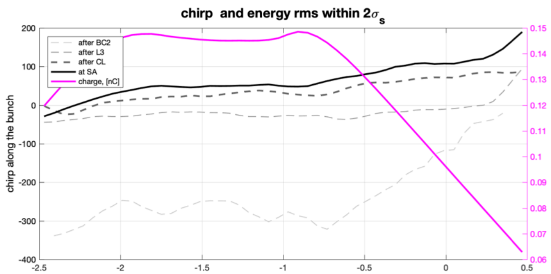
Param. at peak	
Q, pC	181
σ_s μm	12.0
σ_E MeV	2.00
chirp	4.1

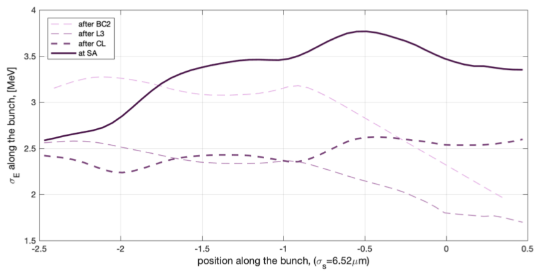




Curvature = 180.5

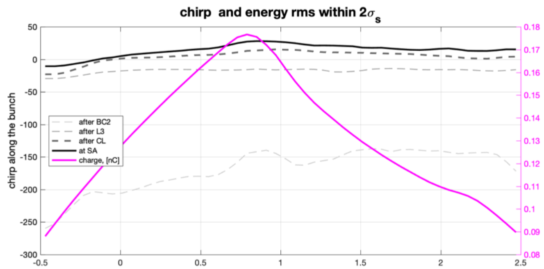
Param. at peak	
Q, pC	148
σ_s μm	6.52
σ_E MeV	3.12
chirp	55.7

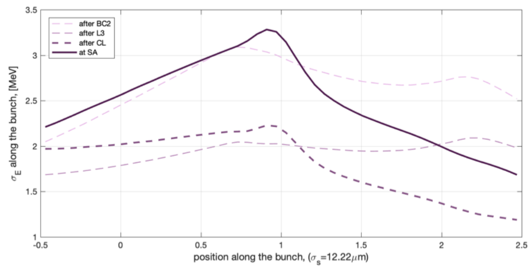




Curvature = 320.5

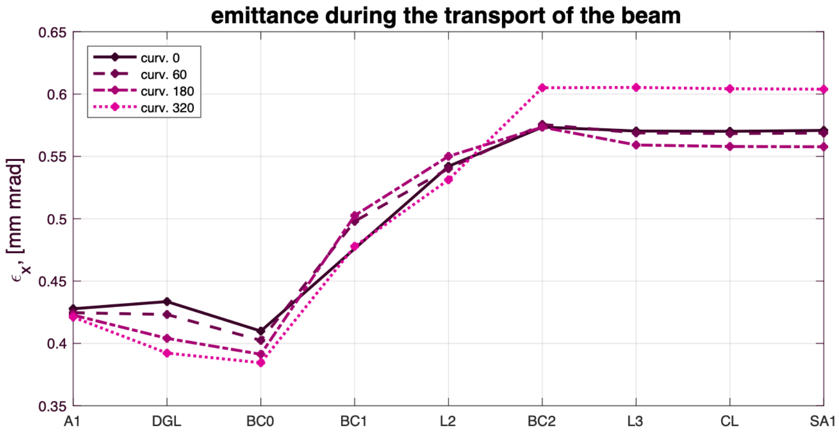
Param. at peak	
Q, pC	177
σ_s μm	12.2
σ_E MeV	3.15
chirp	30.5

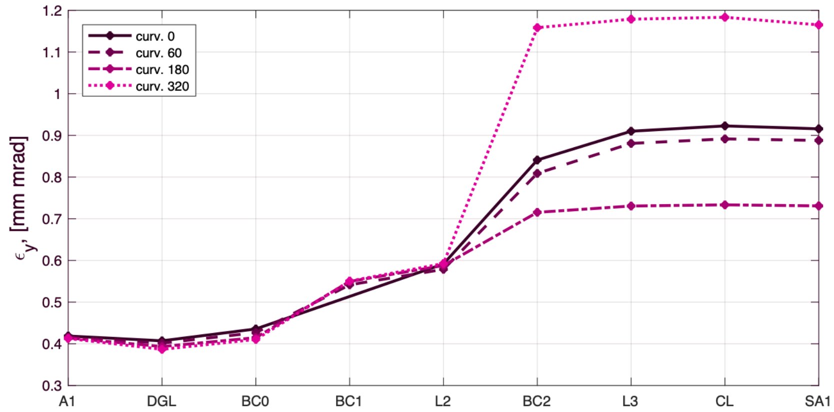




Projected emittance during bunch transport

5% of bad particles (with large temporal deviation) are cutted away



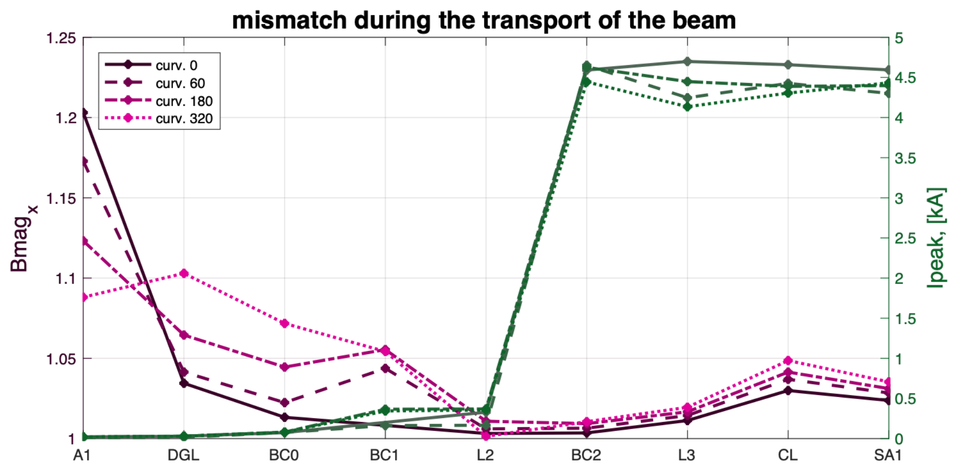


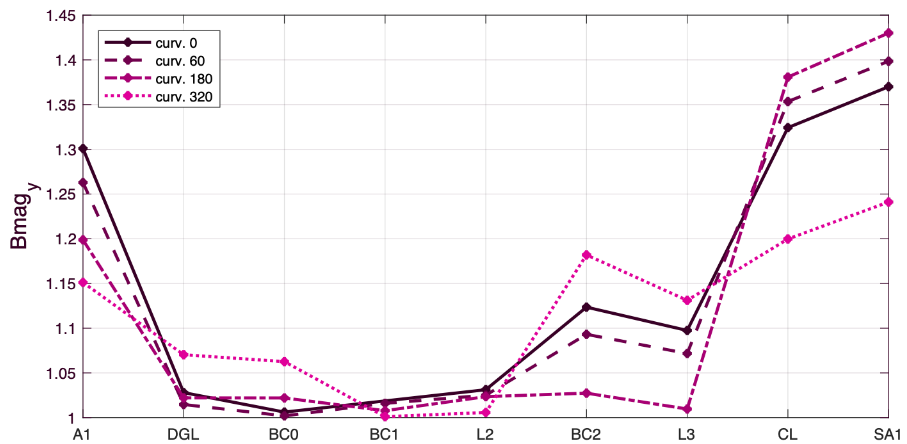
Curv.	0	60	180	320
ε_x	0.580	0.575	0.580	0.603
ε_y	0.939	0.911	0.819	1.167
I_p [kA]	4.58	4.31	4.37	4.34
σ_s [μm]	15.0	12.0	6.52	12.2

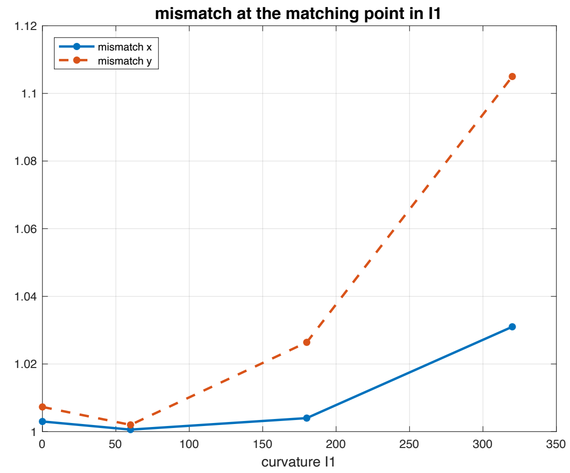
Influence of the RF curvature in I1 on the emittance:

- emittance follows bunch length
- up to 5% incease horizontally
- up to 42% increase vertically

Matching issues







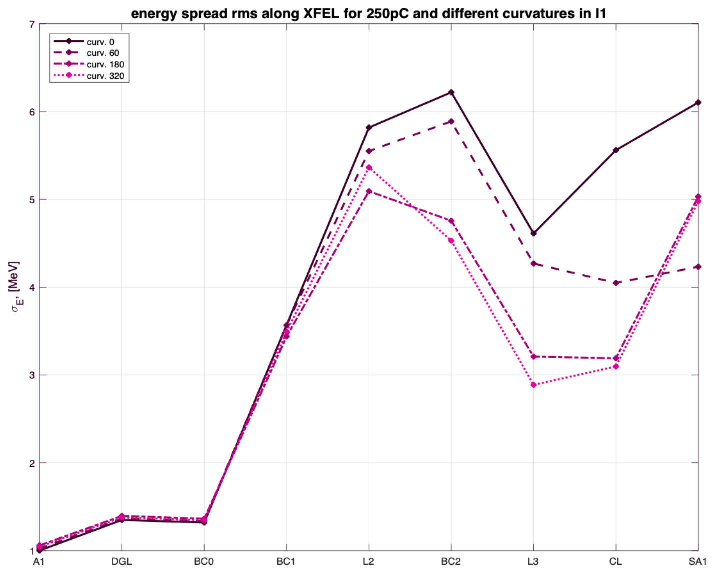
curv.	0.5	60.5	180.5	320.5
Ip, [kA]	4.71	4.31	4.37	4.00
σ_f/σ_i	82	102	188	100

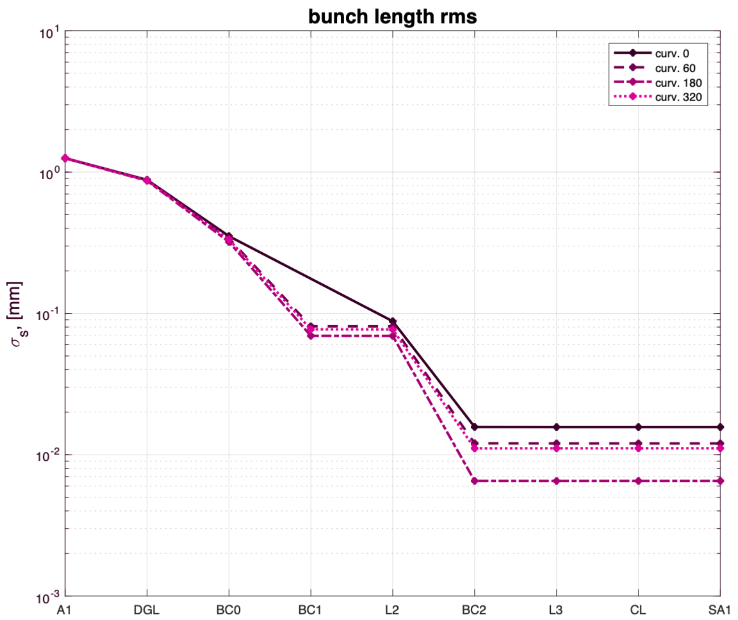
Beam was matched with MADX only once for curvature = 60

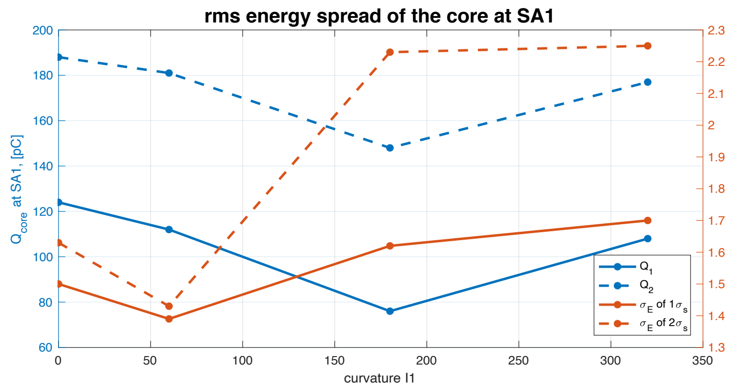
Final mismatch is dominated by the compression and peak current

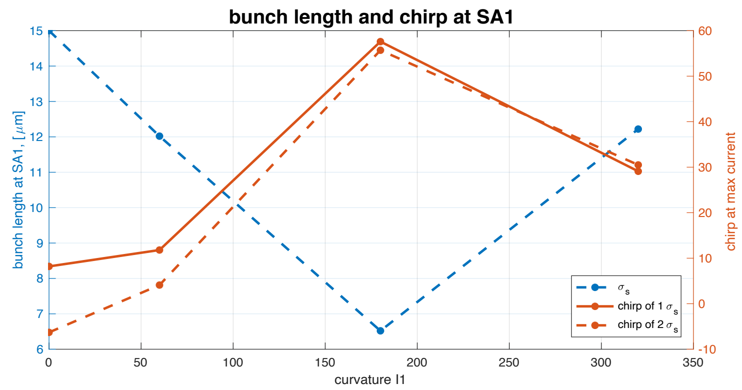
Energy spread rms and chirp of the bunch core

Curvatures = 0 – 60 – 180 – 320









- Effect of the curvature on longitudinal phase space at I1:

- bunch length
- charge of the 1 or 2σ core
- Minimum of the bunch length and of the energy rms at different values
- „zero" chirp of the core in the region 0 -60 expected
- Maximum chirp for 180
- Higher curvature → longer bunch → less impact from wakes for flipping

Summary

- Simulations for 4.4kA peak current, 250pC beam has been carried out with 1M particles by means of Krack and Xtrack from the Cathode to SASE1. Four cases of the curvature 0 – 60 -180 -320 have been investigated.
- Prominent minimum of the bunch length rms and maximum of the chirp at the curvature of 180
- Minimum energy spread rms for SASE1 at curvature 60, but for CL at curvatures 180-320
- Significant increase of the transverse emittance for high curvature of 320
- Beam optical mismatch is dominated by the peak current. Matching can be performed once for one particular curvature
- Manipulation of the position of the peak current by means of the curvature: low curvature --> peak current in the head, high curvature → in the tail
- Minimum slice emittance in the tail for all cases

Thank you