3D Simulation of μB due to SC Effects

methods:
- tracking with 3D SC fields
- tracking with periodic 3D SC fields

real shot noise (one macro particle per electron)
no CSR effects, no wakes

bunches:
- 5.8 A, $\varepsilon_n \approx 0.2$ μm, $\sigma_{\mathrm{E0}} \approx 450$ eV
- 18 A, $\varepsilon_n \approx 0.5$ μm, $\sigma_{\mathrm{E0}} \approx 1$ keV

1) laser heater off (but with LH chicane)

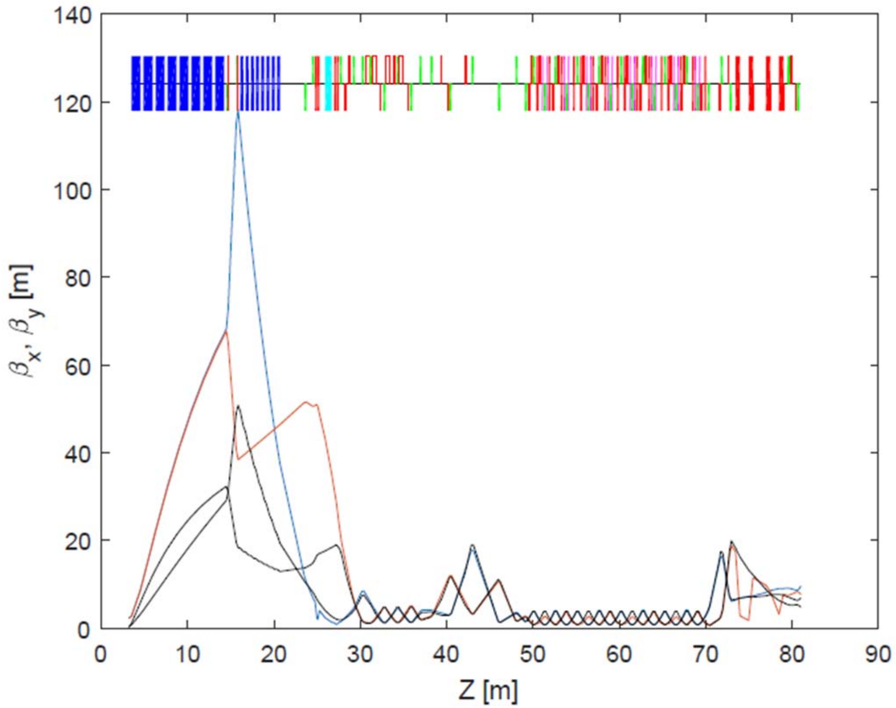
2) increased initial (gaussian) energy spread; LH is still off

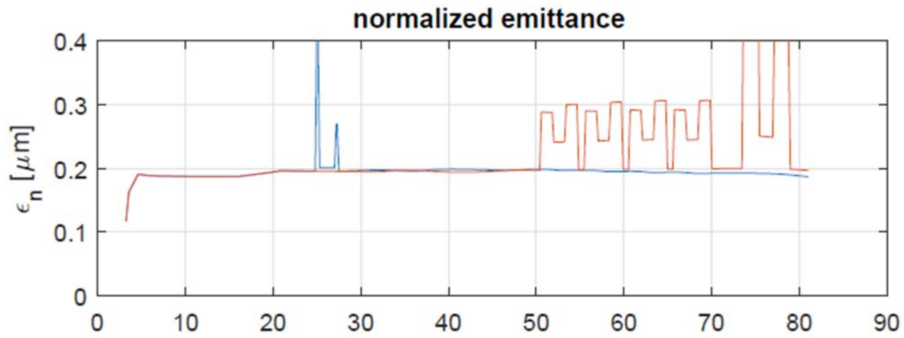
3) increase energy with LH

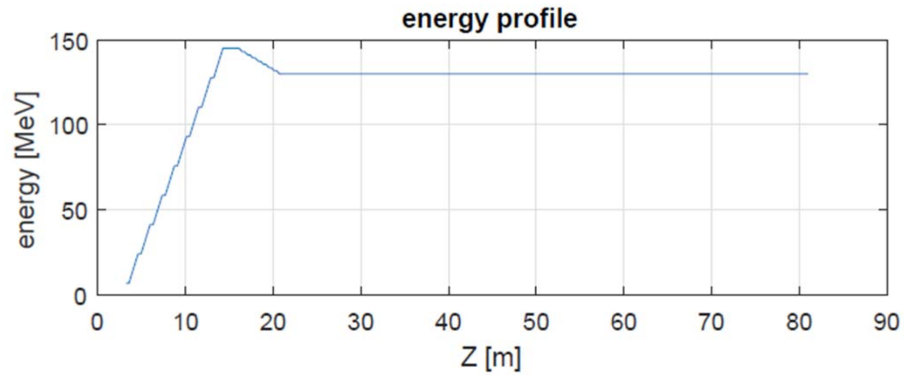
"5.8 A beam"

beam parameters:

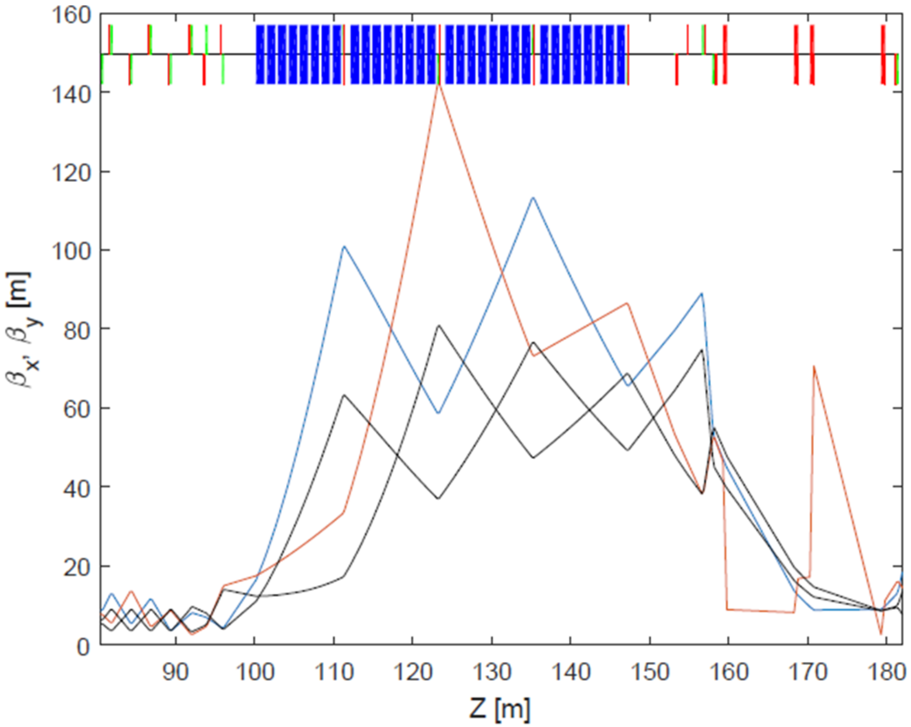
inital beam current 5.8A;
normalized emittance after A1 0.188 μm (in both planes);
initial energy 6.65 MeV;
initial beamline coordinate 3.3 m;
uncorrelated energy spread 450 eV, gaussian;
bunch is generated by random generator; horizontal, vertical and longitudinal phase spaces are decoupled; the initial beam is round, all transverse density functions are gaussian; twiss parameters $\alpha_x = \alpha_y$ and $\beta_x = \beta_y$ are chosen according to a Astra simulation; the emittances are chosen $\varepsilon_x = \varepsilon_y$ to obtain a normalized emittance of about 0.2 μm after A1;
the chirp of A1 is chosen for an compression $C_0 = 3.5$ after bunch compressor BC0;

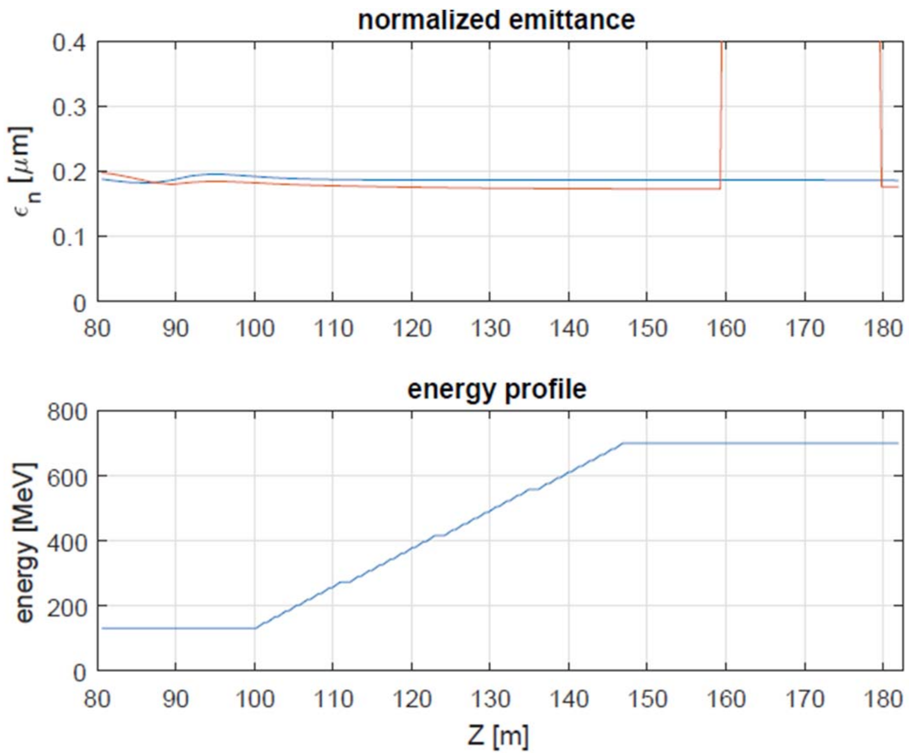


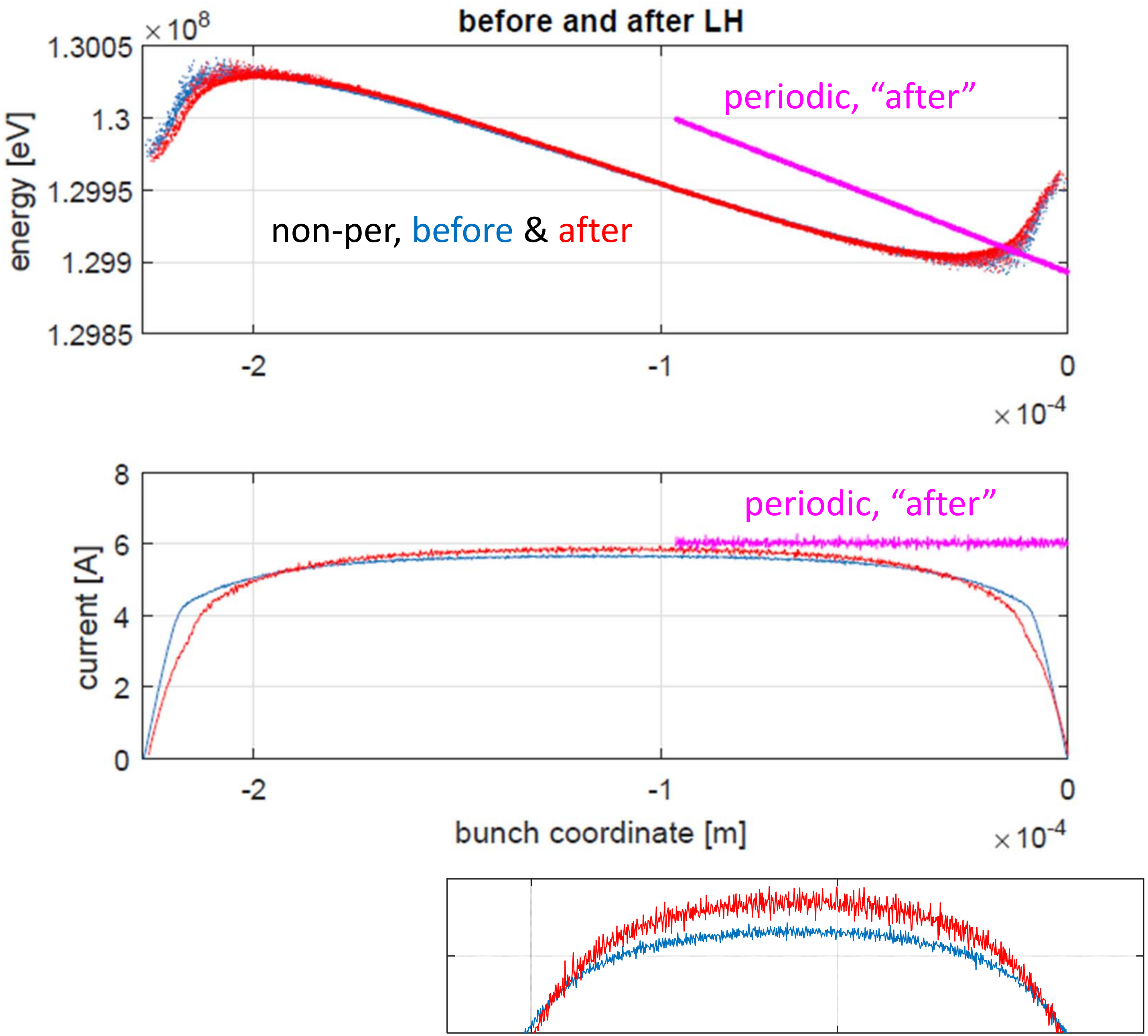




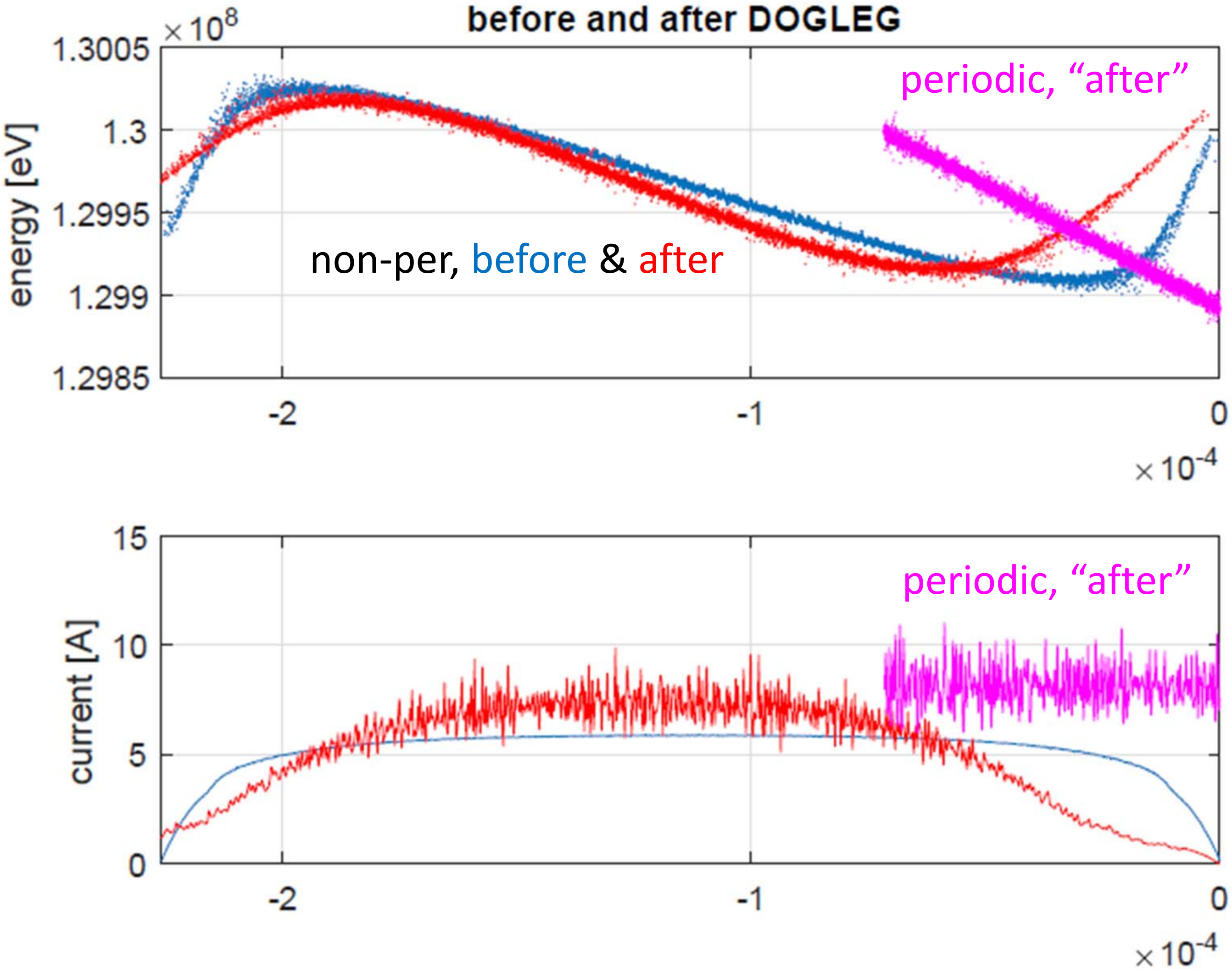
dispersive things and compression:
r56LH/mm=4.7
r56DOGLEG/mm=30.8
r56BC0/mm=54.2
r56BC1/mm=51.7;
beam current after BC0 is 20.3A;
beam current after BC1 is 162A;

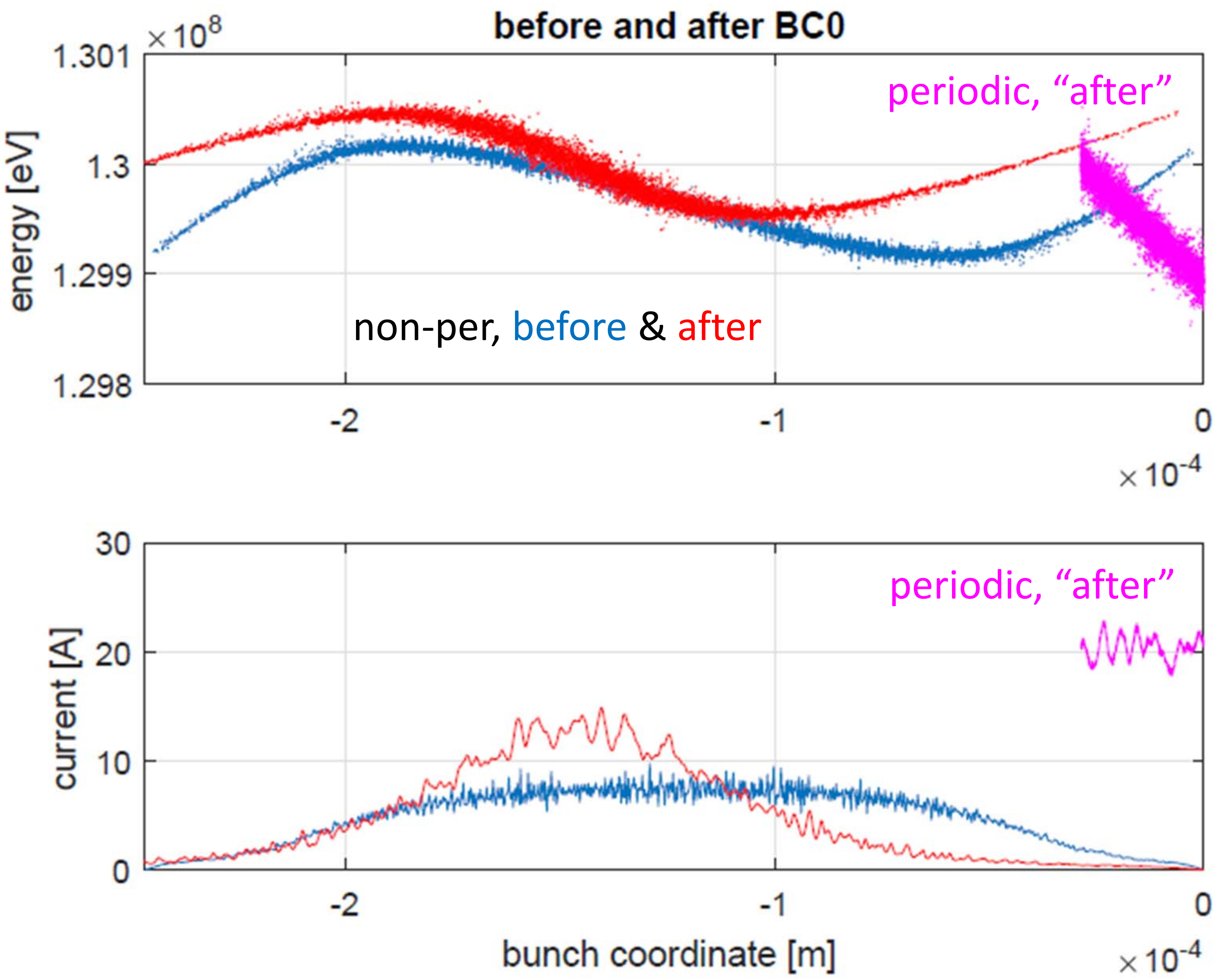






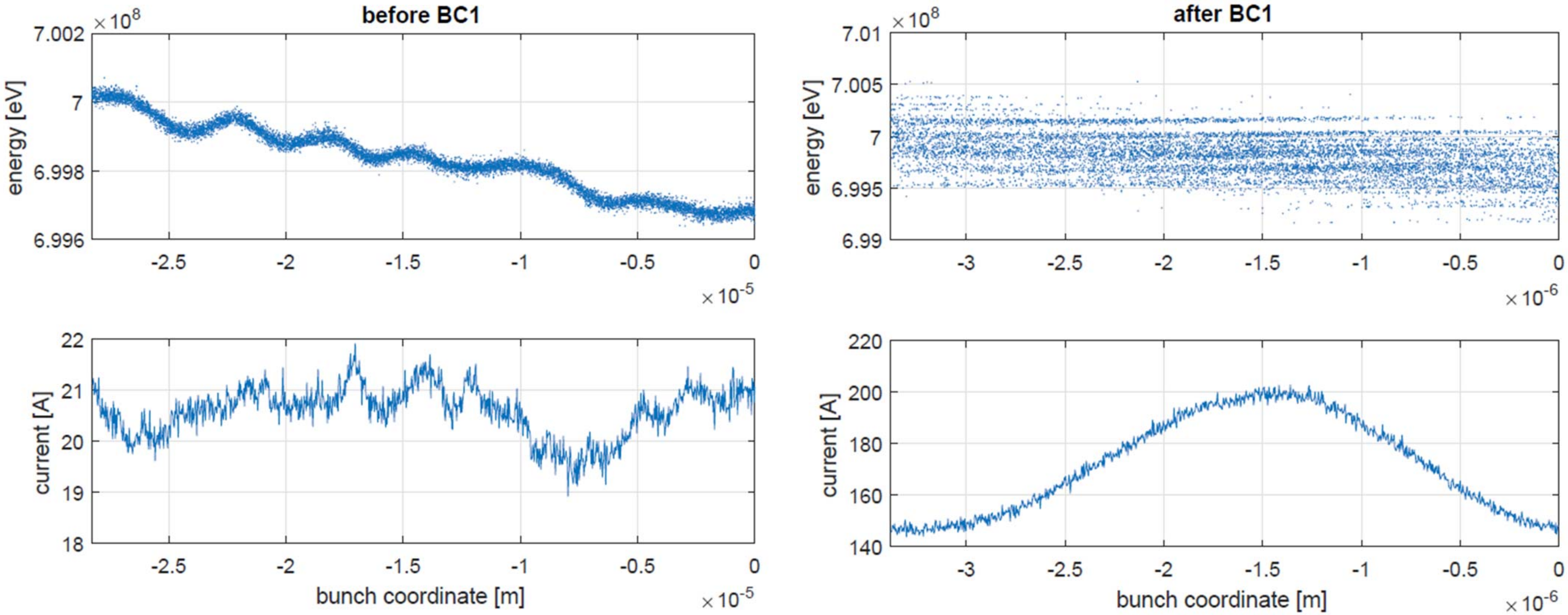
before and after LH
energy [eV]
×10^8
1.3005
1.3
1.2995
1.299
1.2985
periodic, "after"
non-per, before & after
-2
-1
0
×10^-4
current [A]
8
6
4
2
0
periodic, "after"
bunch coordinate [m]
×10^-4


before and after DOGLEG
×10^8
1.3005
1.3
1.2995
1.299
1.2985
energy [eV]
periodic, “after”
non-per, before & after
-2
-1
0
×10^-4
15
10
5
0
current [A]
periodic, “after”
-2
-1
0
×10^-4



before and after BC0
periodic, "after"
non-per, before & after
energy [eV]
×10^8
1.301
1.3
1.299
1.298
-2
-1
0
×10^-4
periodic, "after"
current [A]
30
20
10
0
bunch coordinate [m]

all further simulations with periodic model



lowest wavelength is defined by
period length of simulation!!!

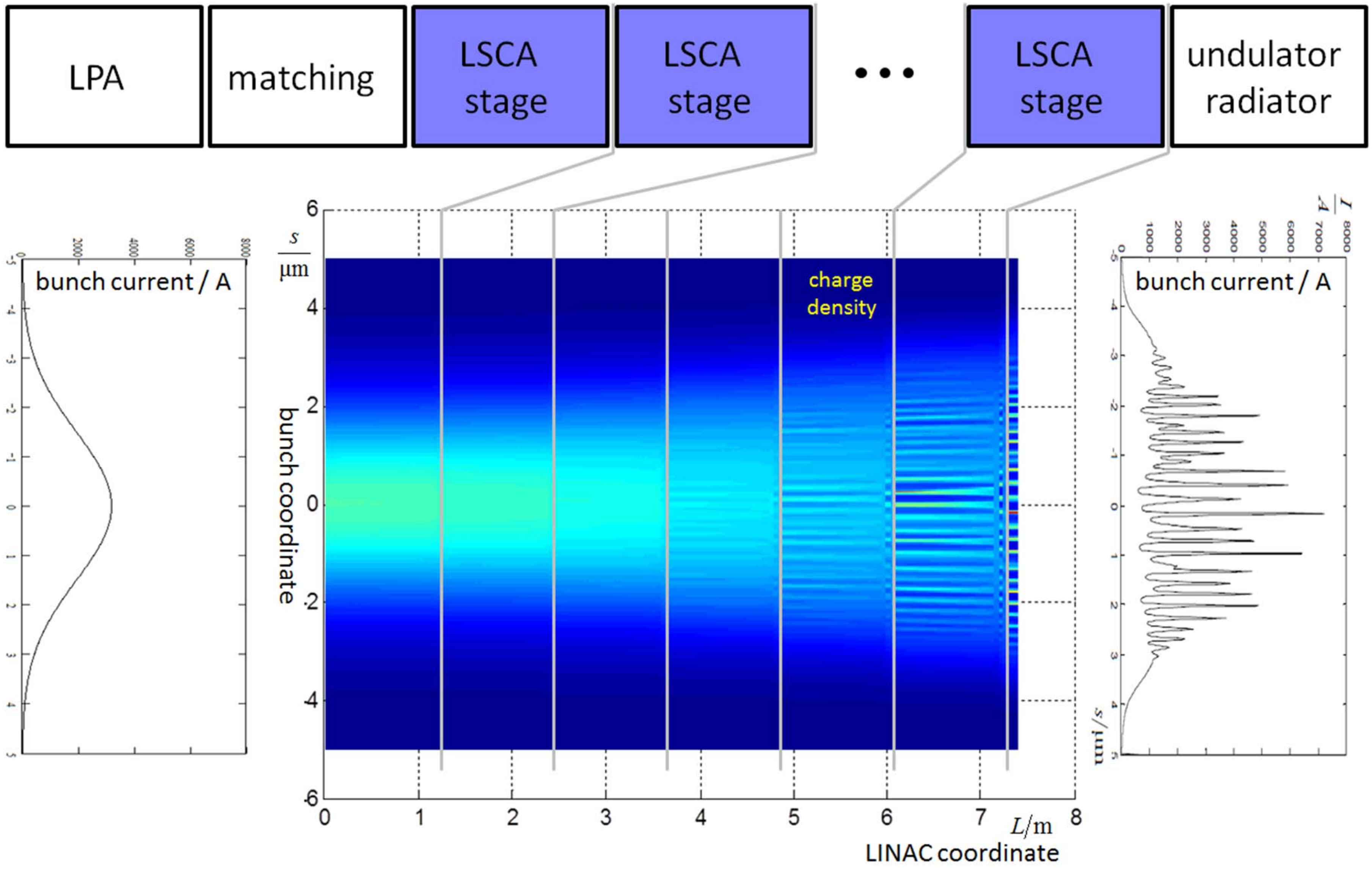
	current (A)	rms noise (A)	σ_E (eV)
before LH	5.8	0.030	560
after LH	6.0	0.063	580
before DOGLEG	6.0	0.024	1340
after DOGLEG	8.1	0.89	2530
before BC0	8.1	0.85	4060
after BC0	20.3	1.05	10350
before BC1	20.6	0.50	22170
after BC1	172	18.8	190E3

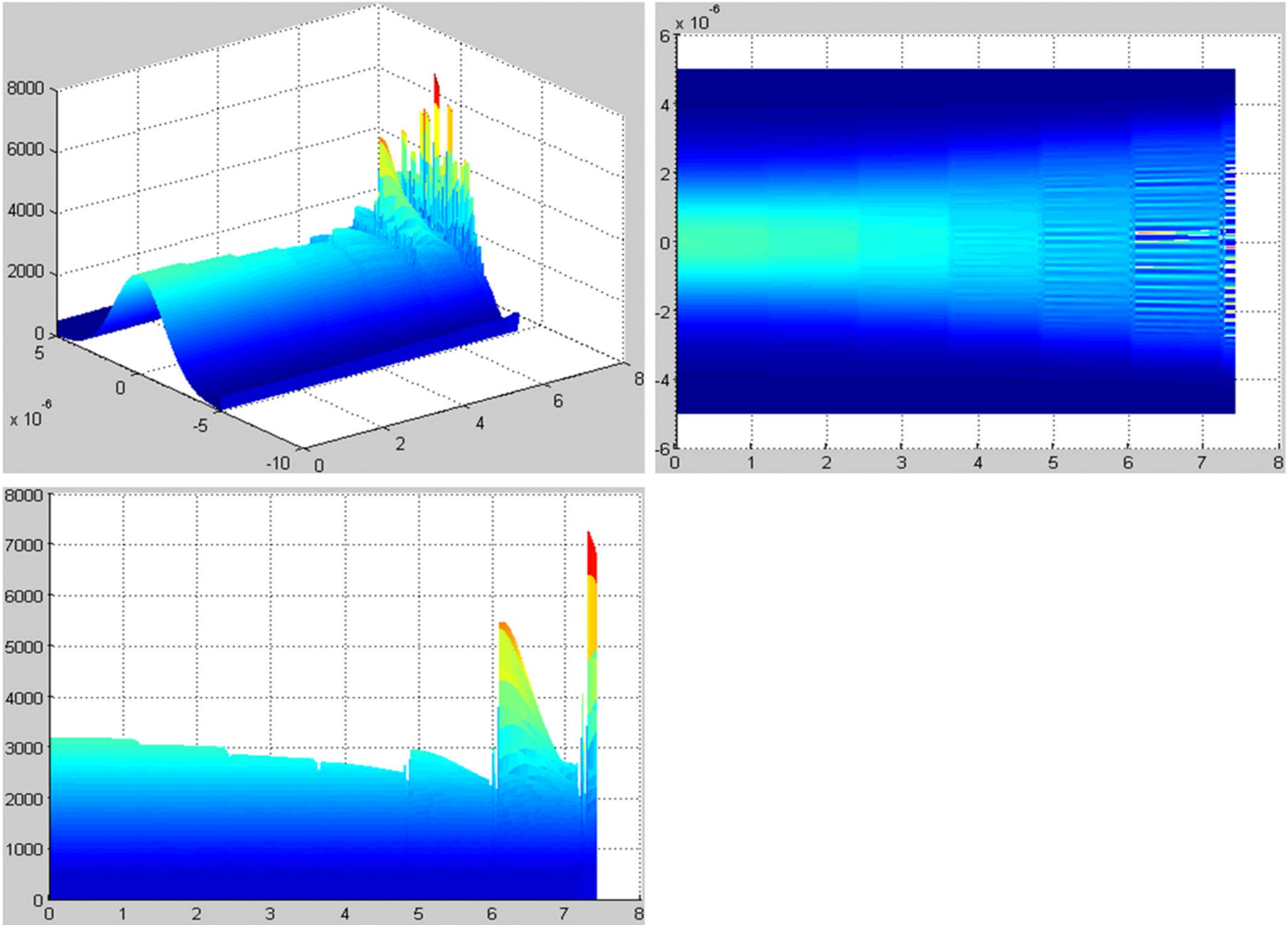
energy spread is always increased

current noise is increased in dispersive sections

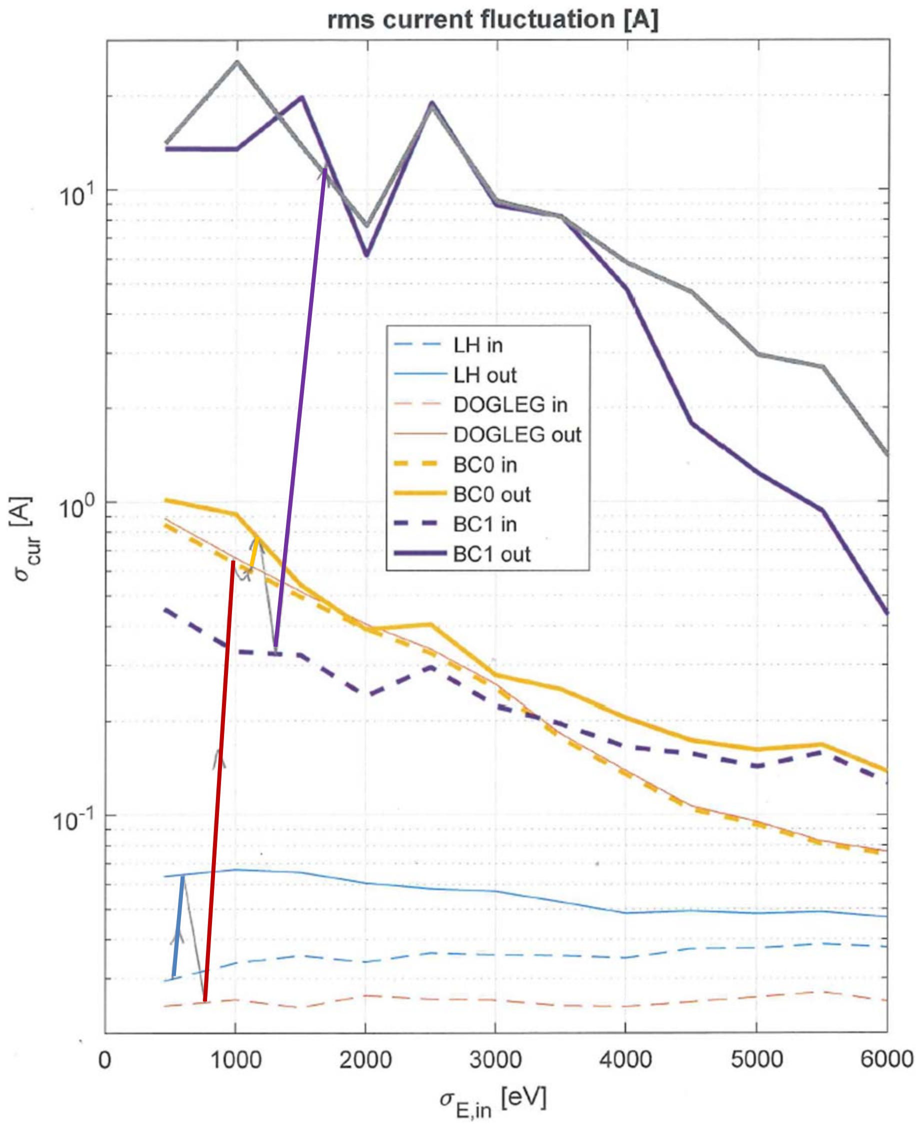
current noise is reduced in non-dispersive sections!

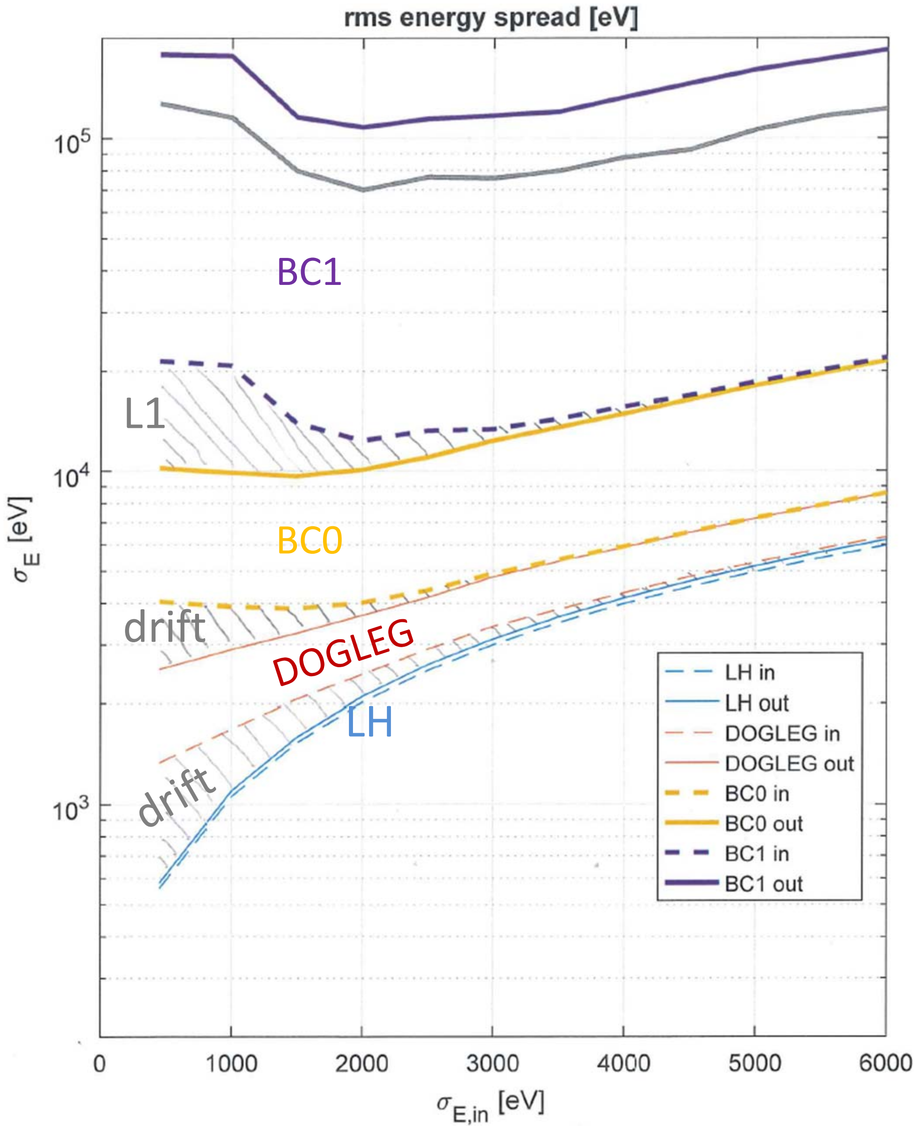
same effect in LSCA stages




8000
6000
4000
2000
0
5
0
x 10-6
-5
-10
0
2
4
6
8
x 10-6
6
4
2
0
-2
-4
-6
0
1
2
3
4
5
6
7
8
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8

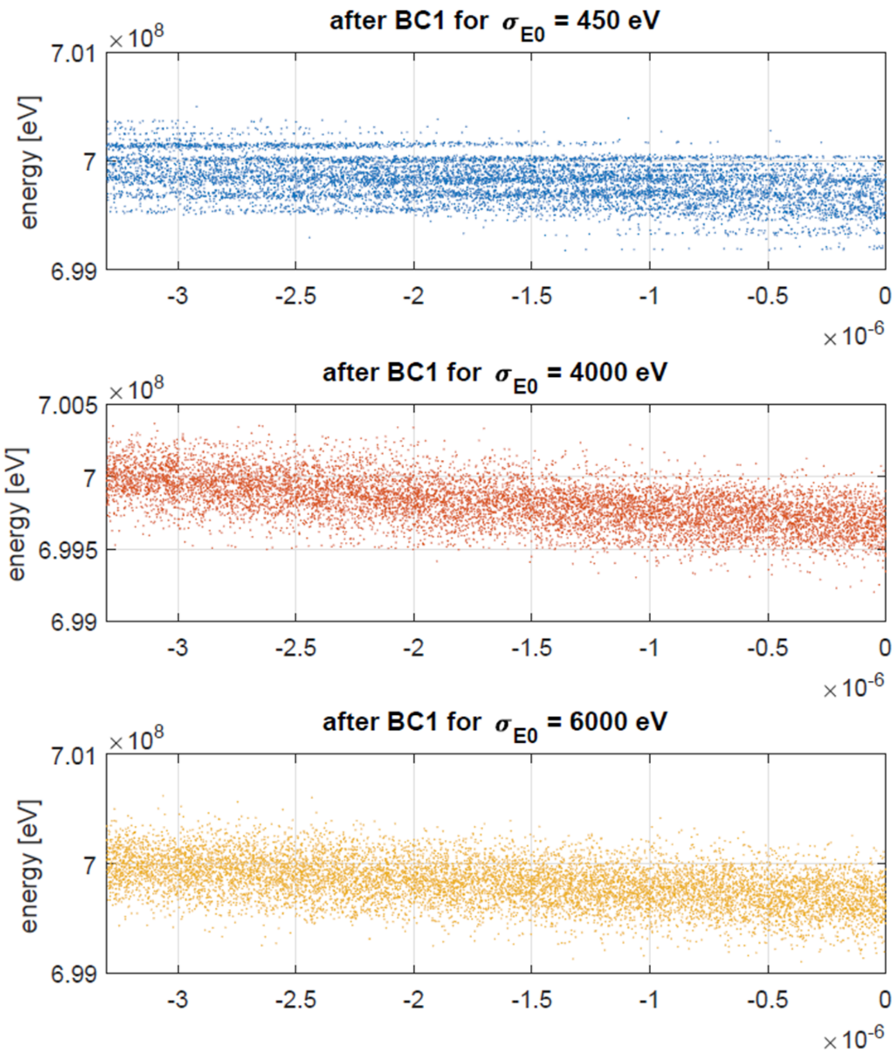
scan: initial energy spread (gaussian!)

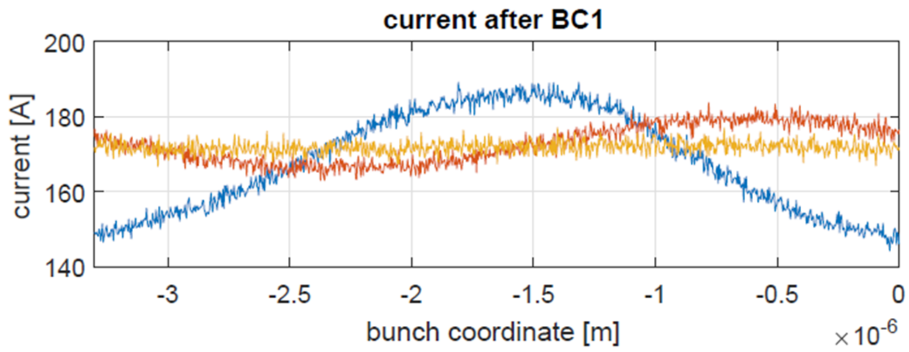




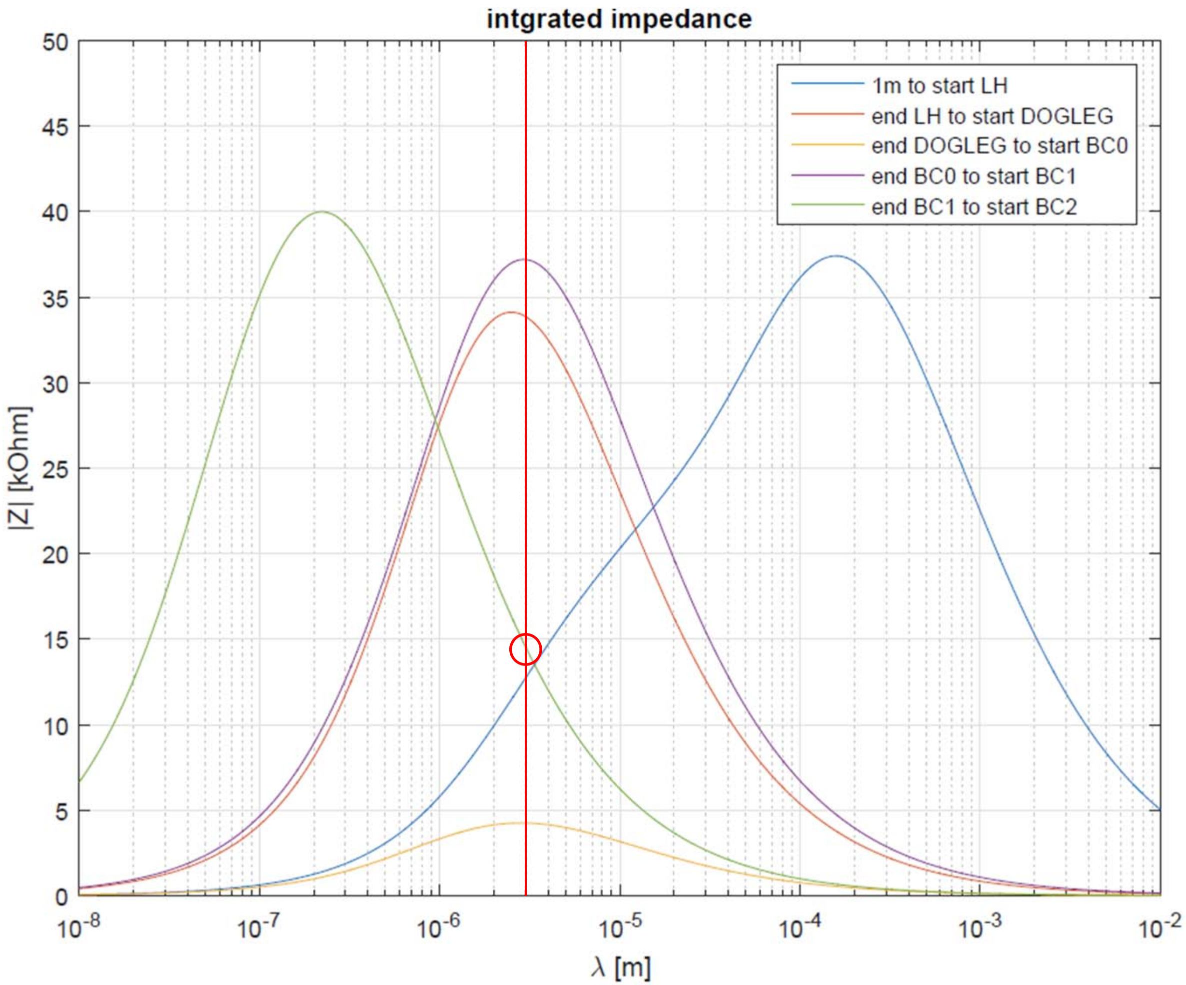
purple C1=8
gray C1=5.5

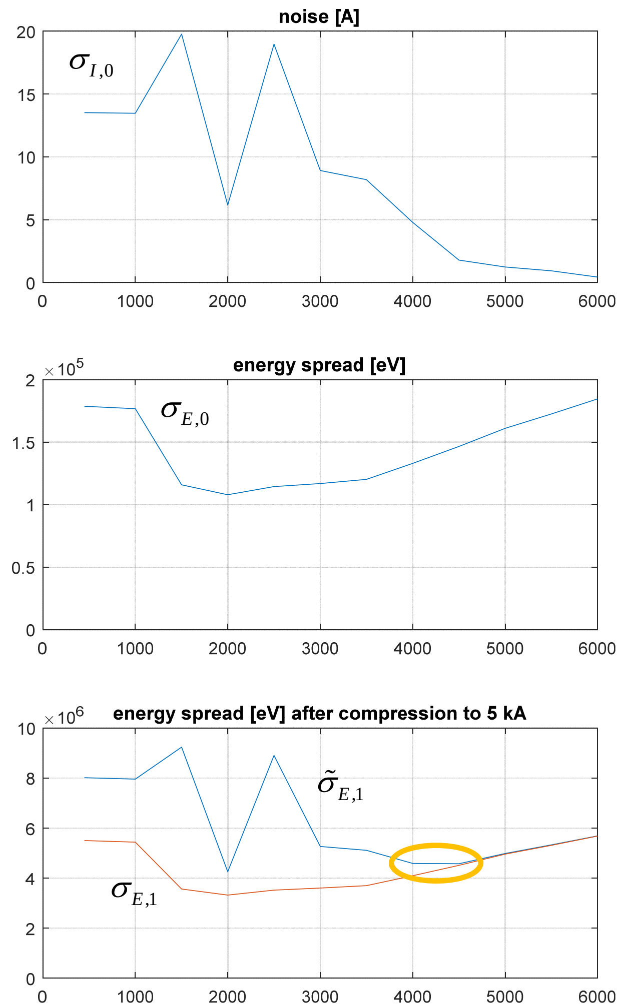
“fast” noise is suppressed after BC1





lowest wavelength is defined by period length of simulation!!!





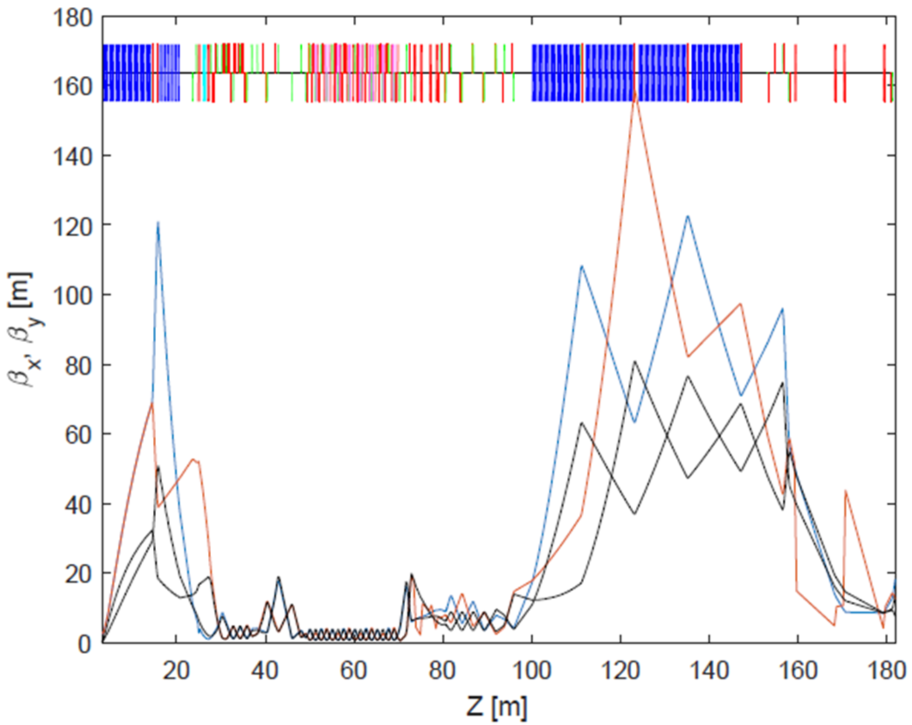
$$\sigma_{E,1} = C\sigma_{E,0}$$

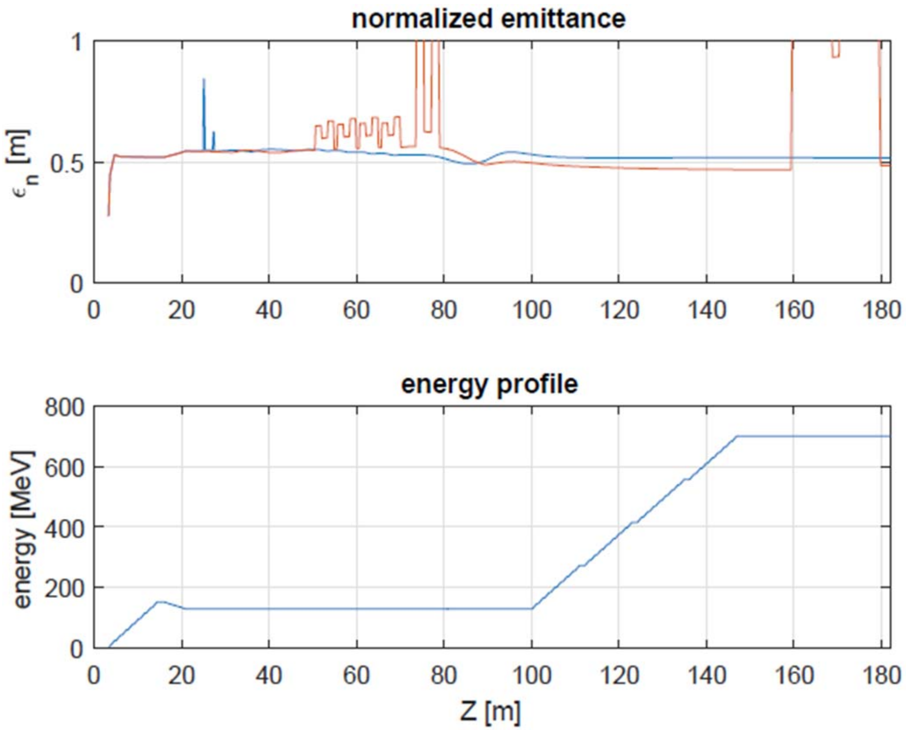
$$\tilde{\sigma}_{E,1} = C\sqrt{(\sigma_{E,0})^2 + |Z\sigma_{I,0}|^2}$$

energy spread for 5kA > 4.5 MeV

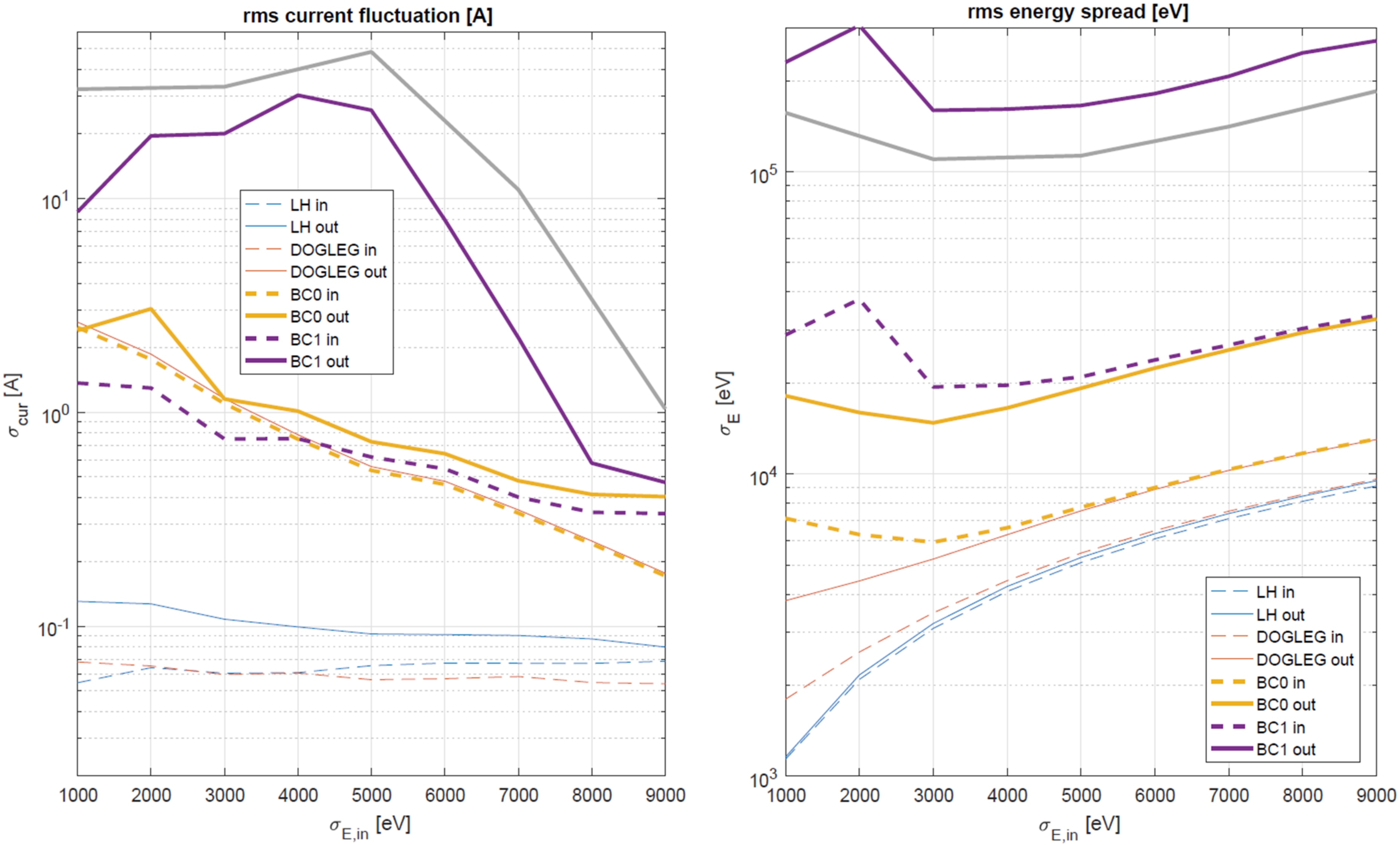
“18 A beam”

a szenario that is closer to the present XFEL operation:
inital beam current 18A;
normalized emittance after A1 is 0.5 μm;
uncorrelated energy spread is 1000 eV, gaussian;
all other parameters are chosen as before;

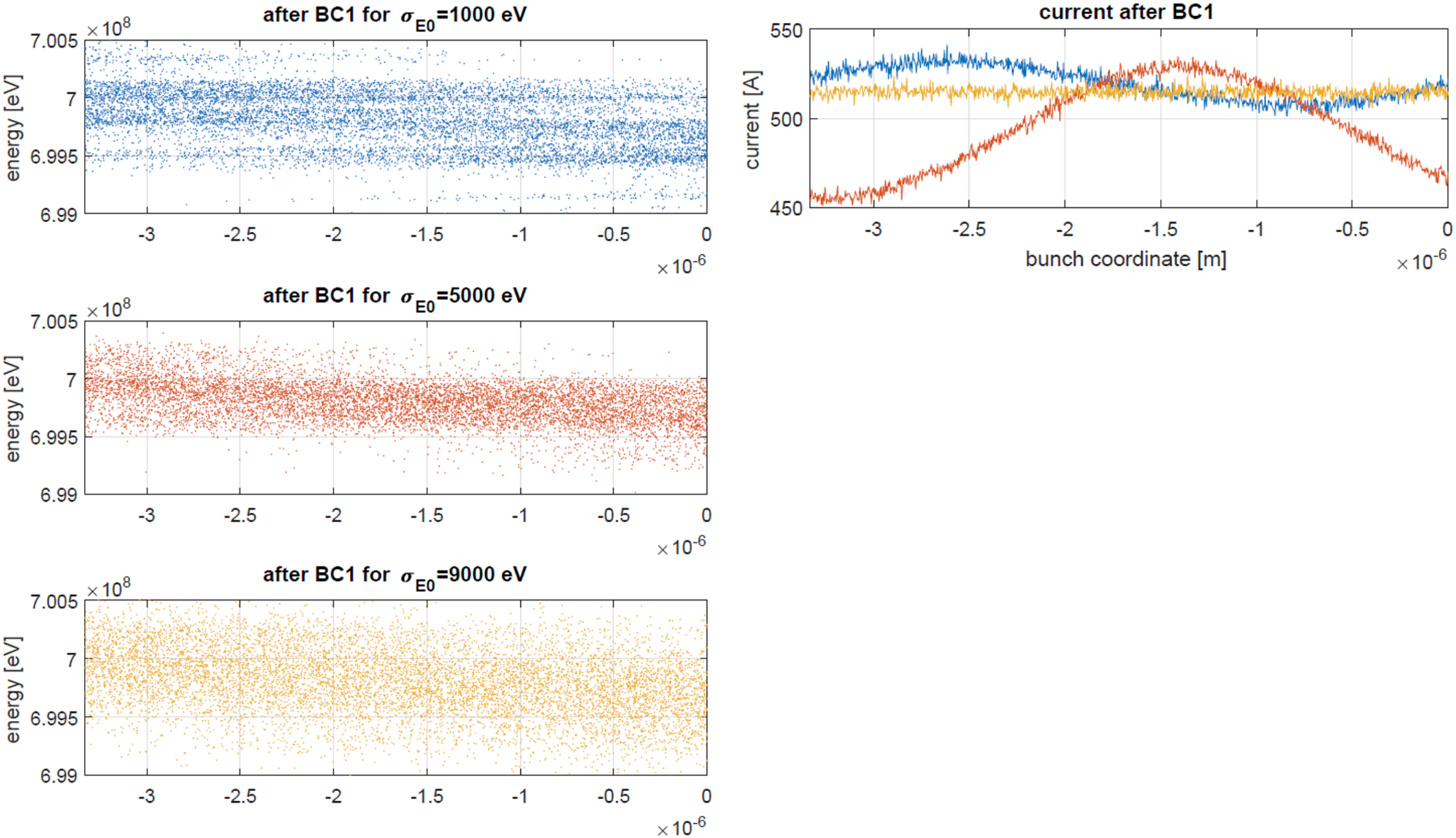


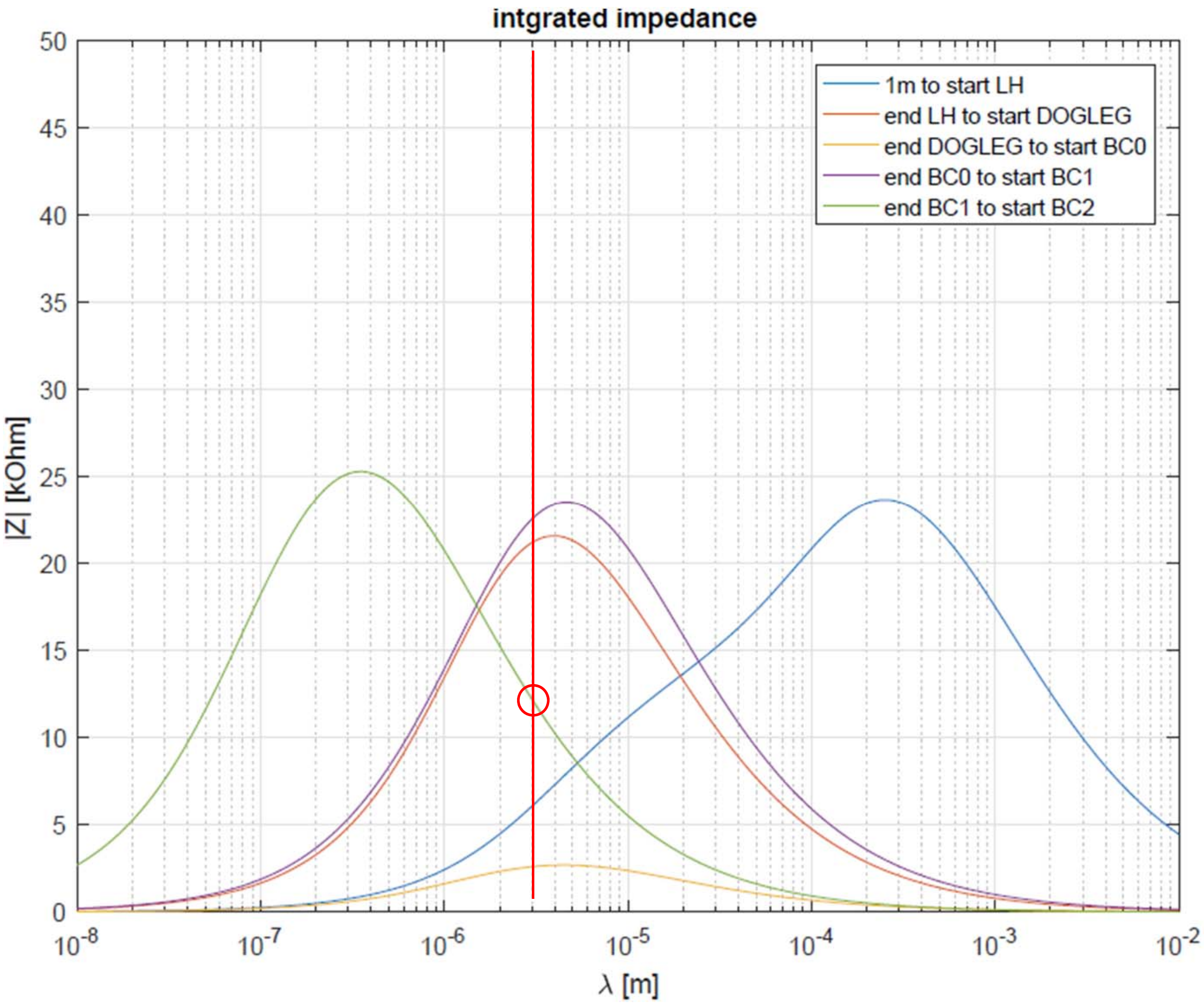


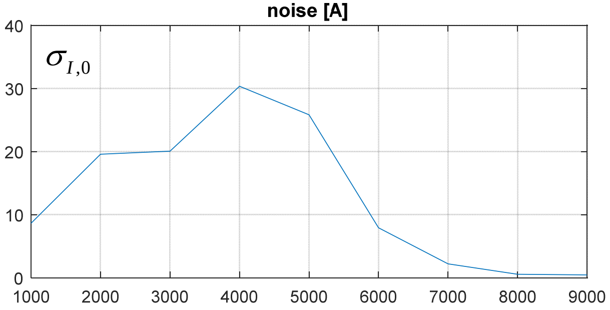
scan: initial energy spread (gaussian!)

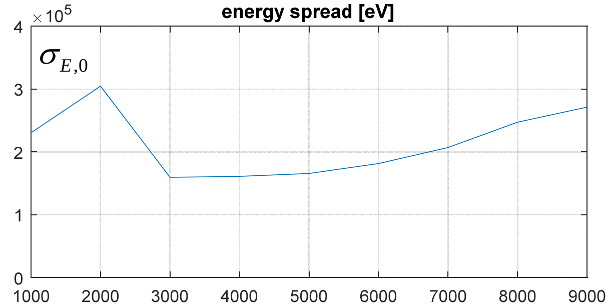


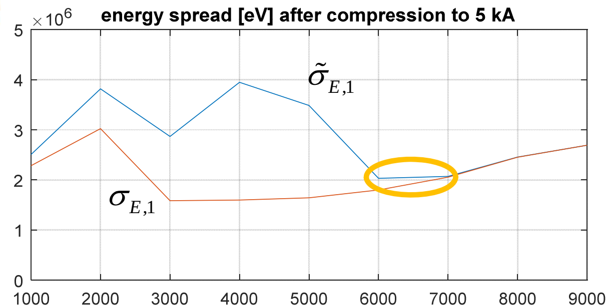
purple C1=8
gray C1=5.5


after BC1 for σ_{E0}=1000 eV
after BC1 for σ_{E0}=5000 eV
after BC1 for σ_{E0}=9000 eV
energy [eV]
$\times 10^8$
7.005
7
6.995
6.99
-3
-2.5
-2
-1.5
-1
-0.5
0
$\times 10^{-6}$
current after BC1
current [A]
550
500
450
bunch coordinate [m]







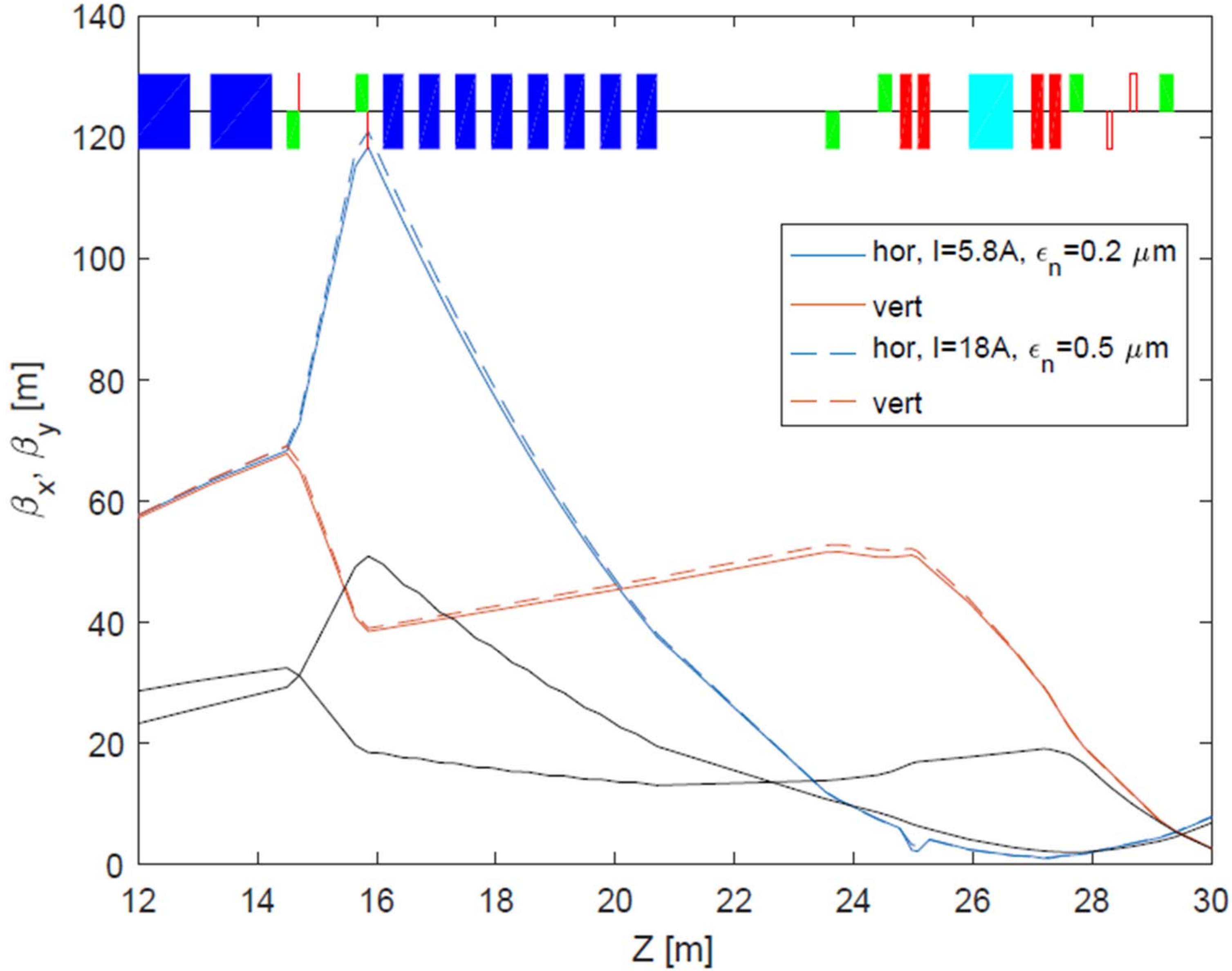


$$\sigma_{E,1} = C\sigma_{E,0}$$

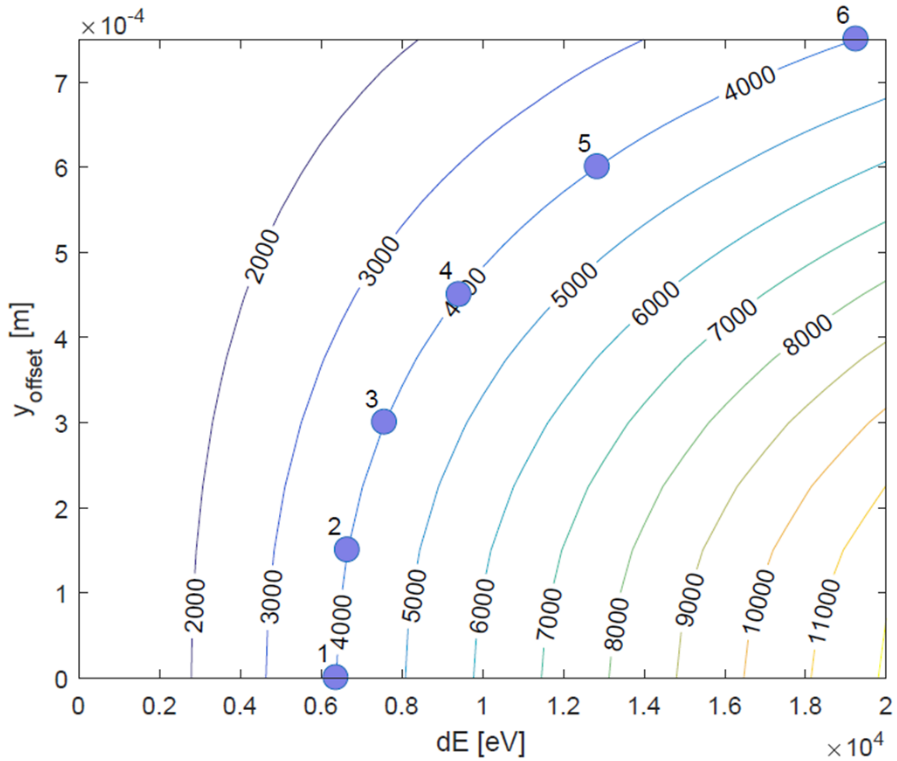
$$\tilde{\sigma}_{E,1} = C\sqrt{\left(\sigma_{E,0}\right)^2 + \left|Z\sigma_{I,0}\right|^2}$$

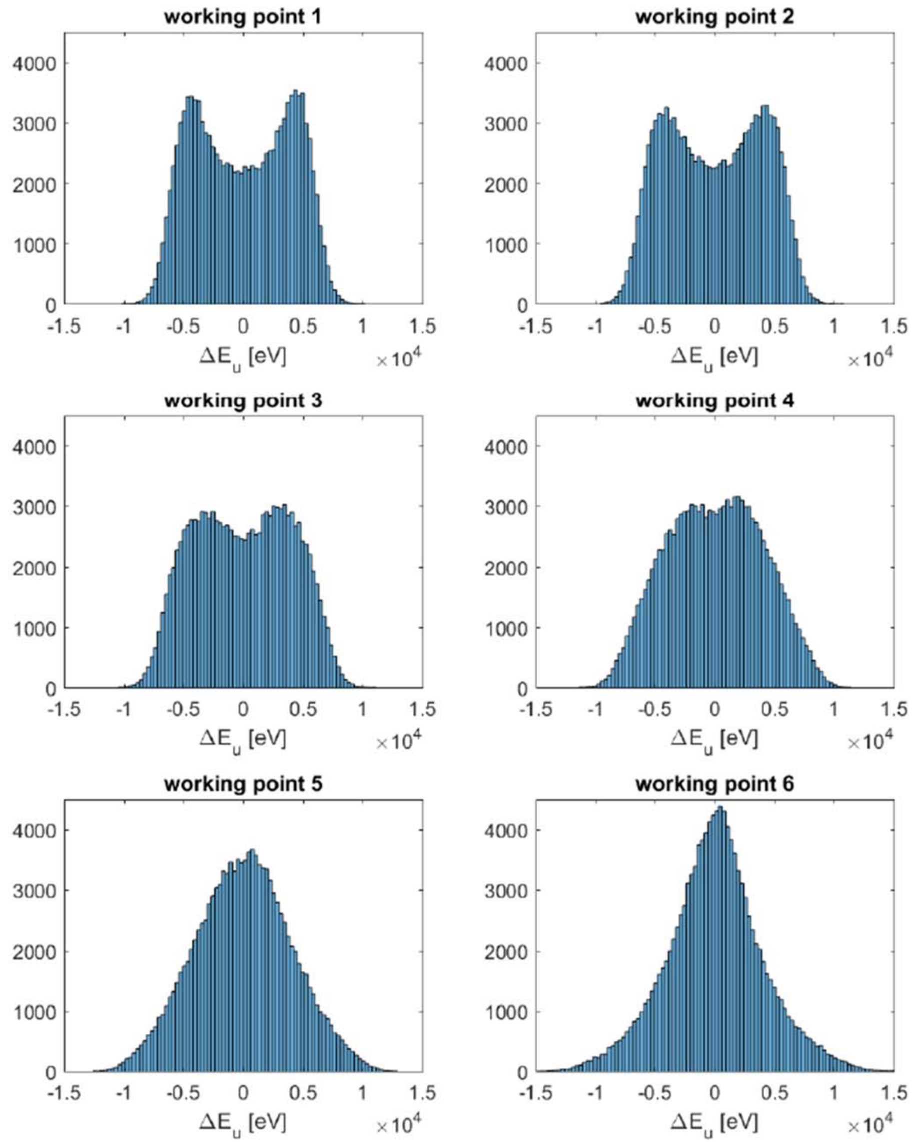
energy spread for 5kA > 2 MeV

heating: LH with laser!

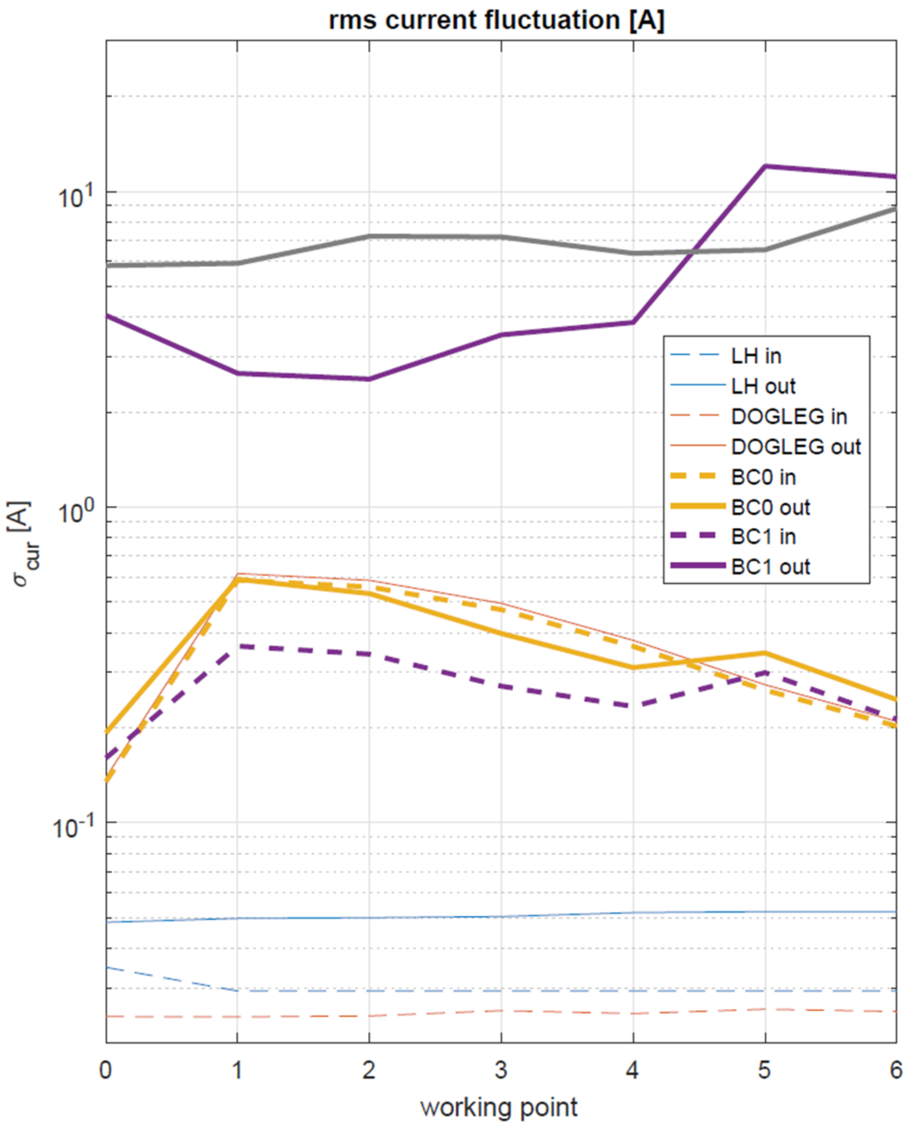


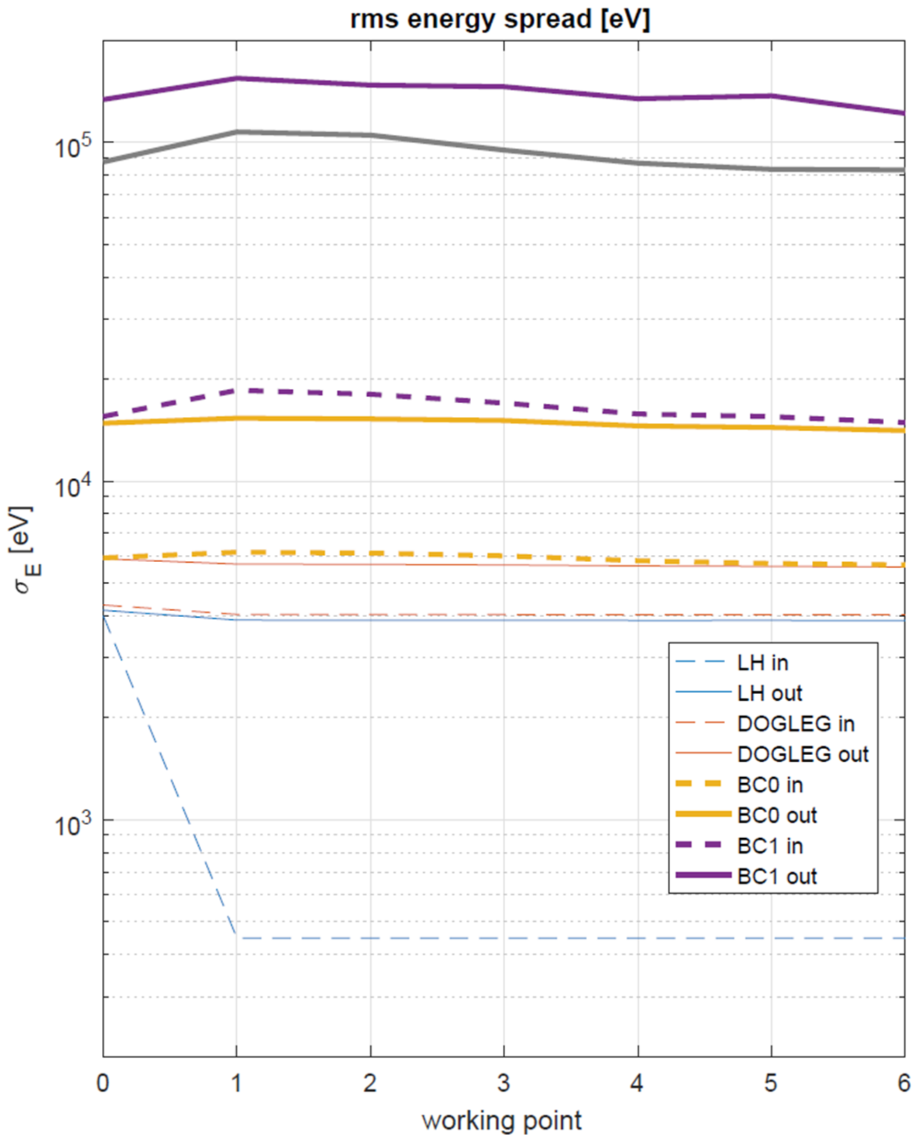
working points for “5.8 A beam” → 4 keV





Gaussian (0) and LH working points (1-6)

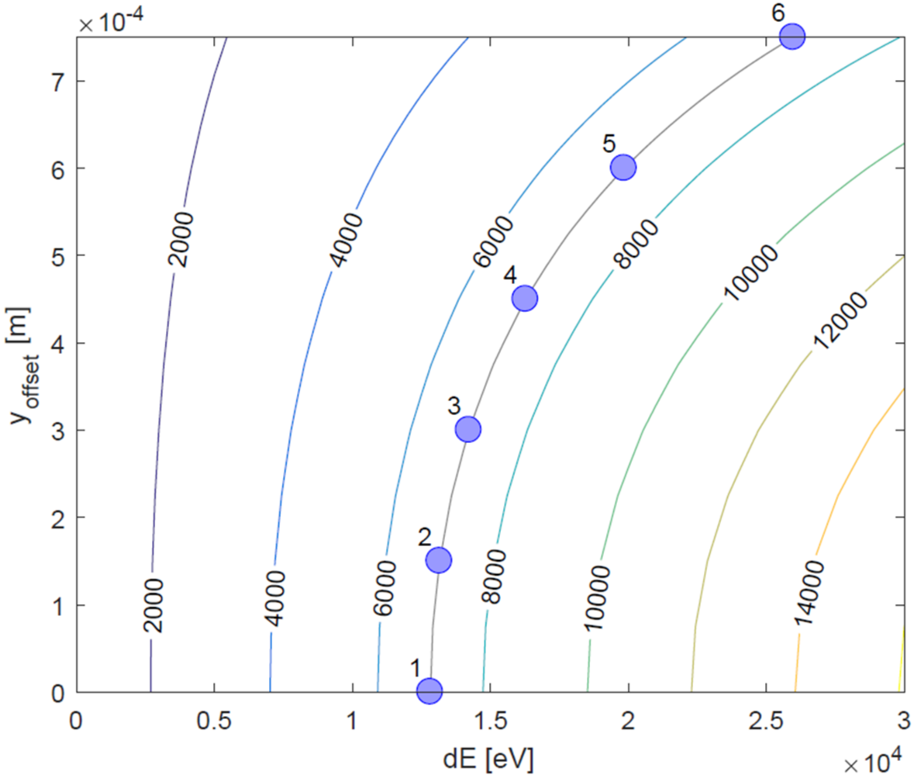


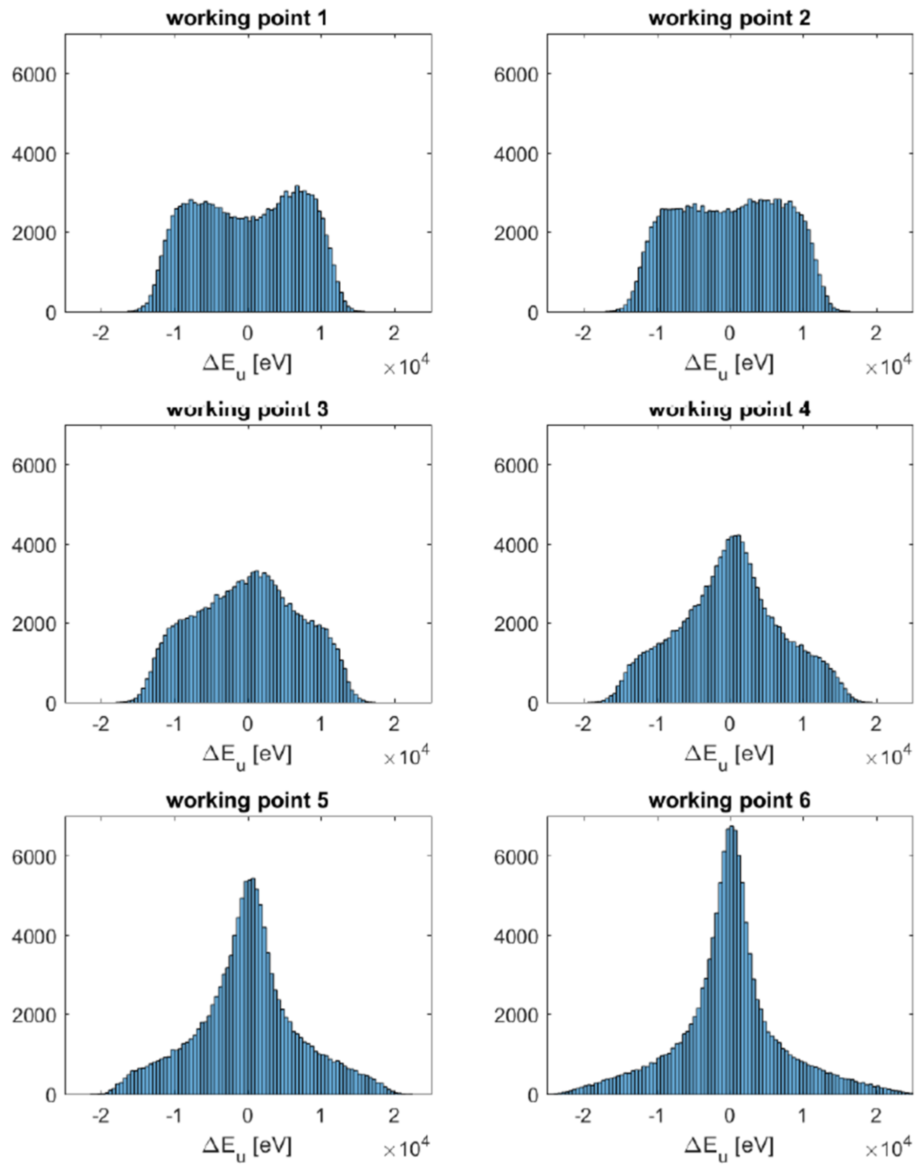


purple C1=8

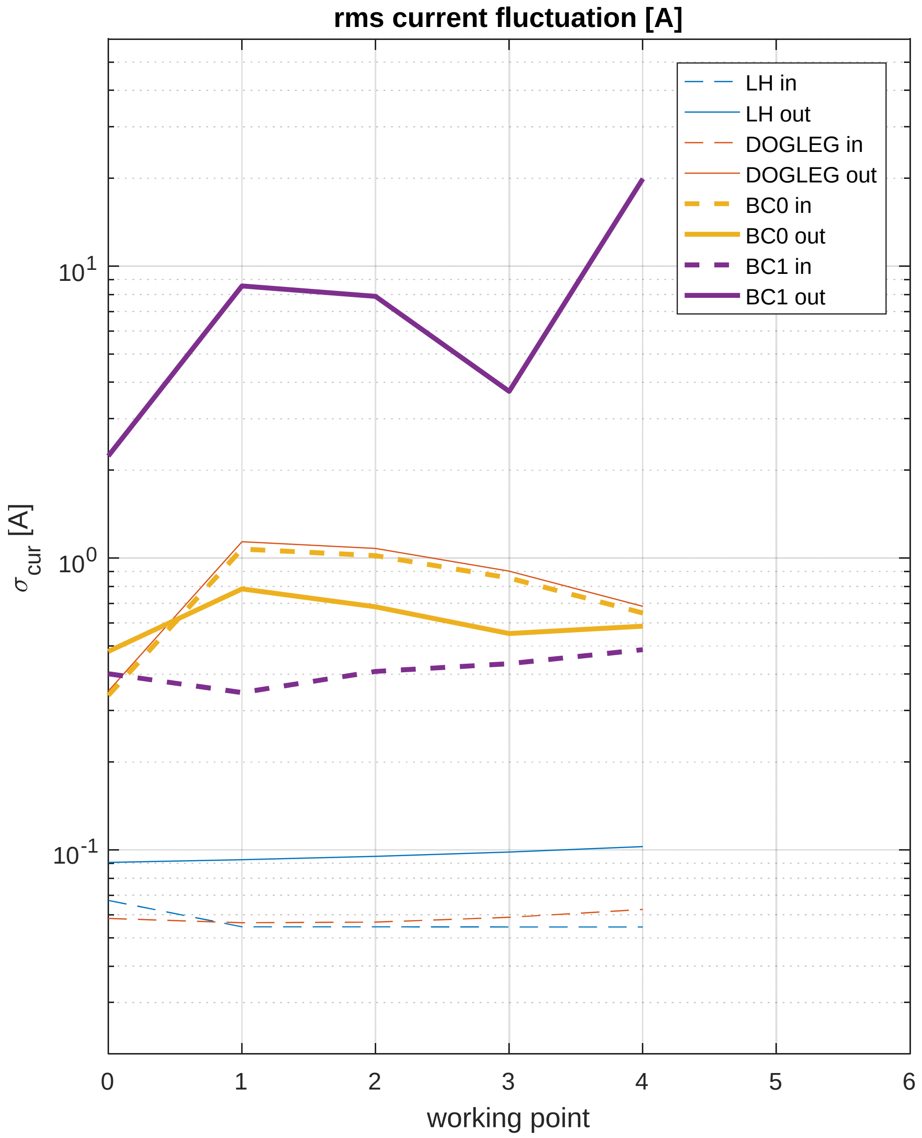
gray C1=5.5

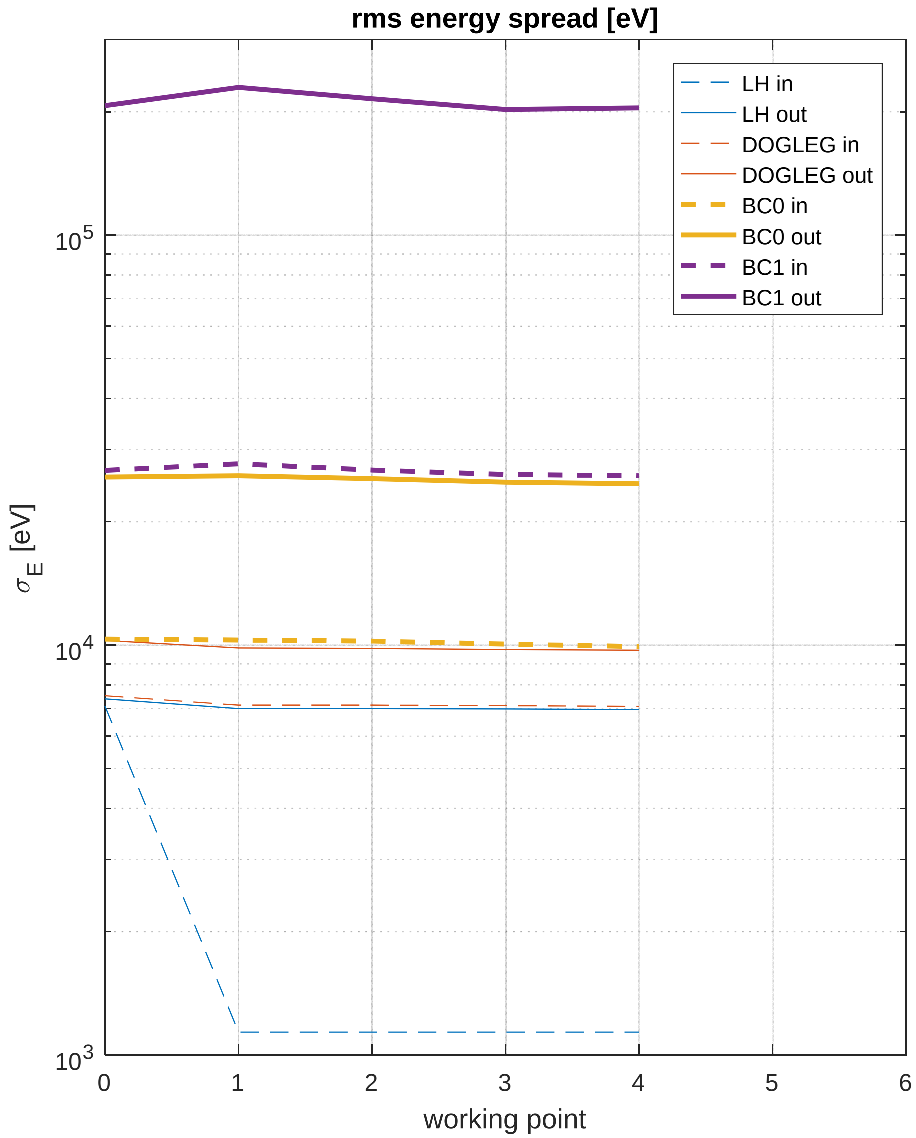
working points for “18 A beam” → 7 keV





Gaussian (0) and LH working points (1-6)

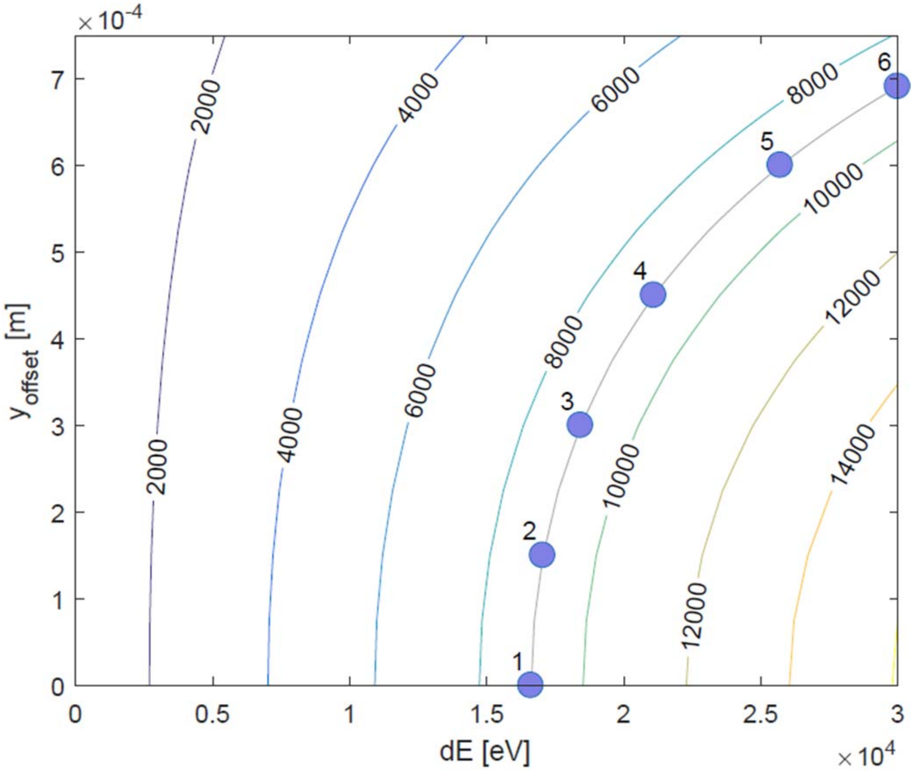


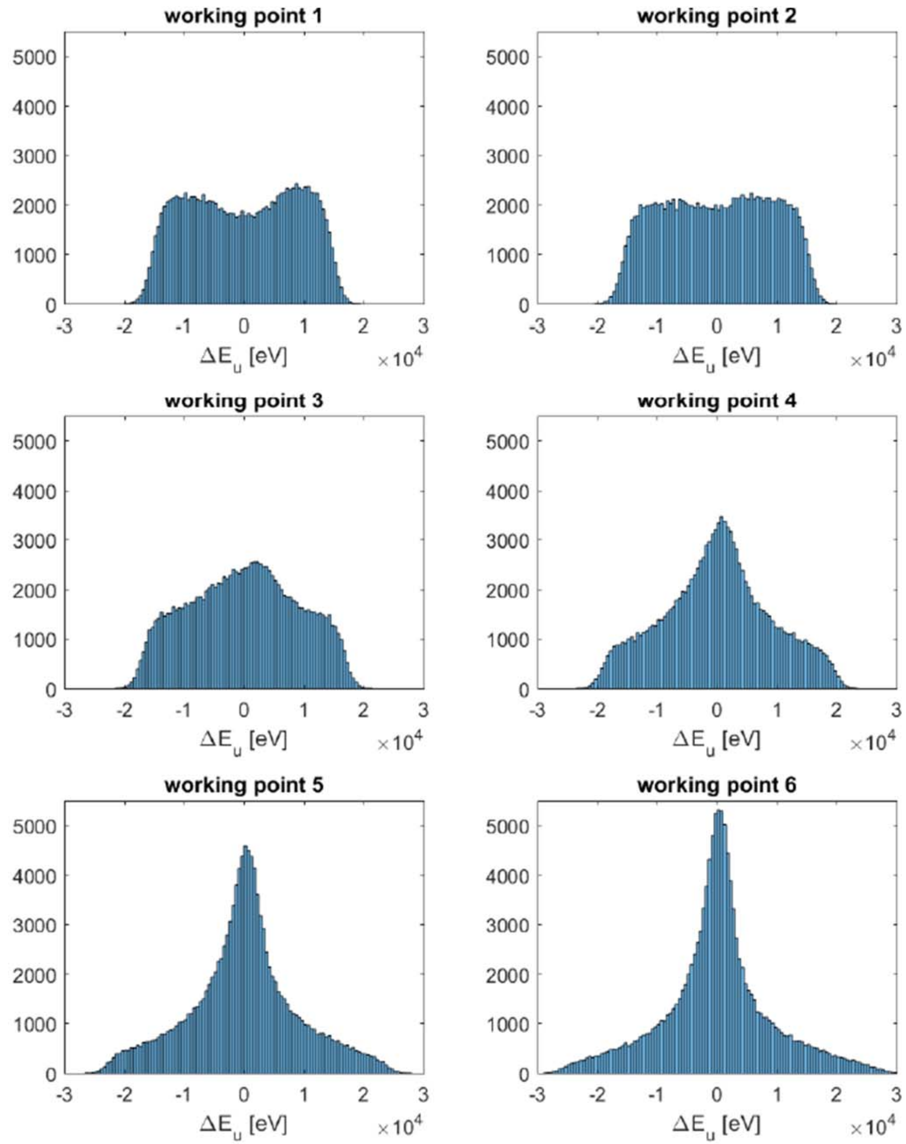


purple C1=8

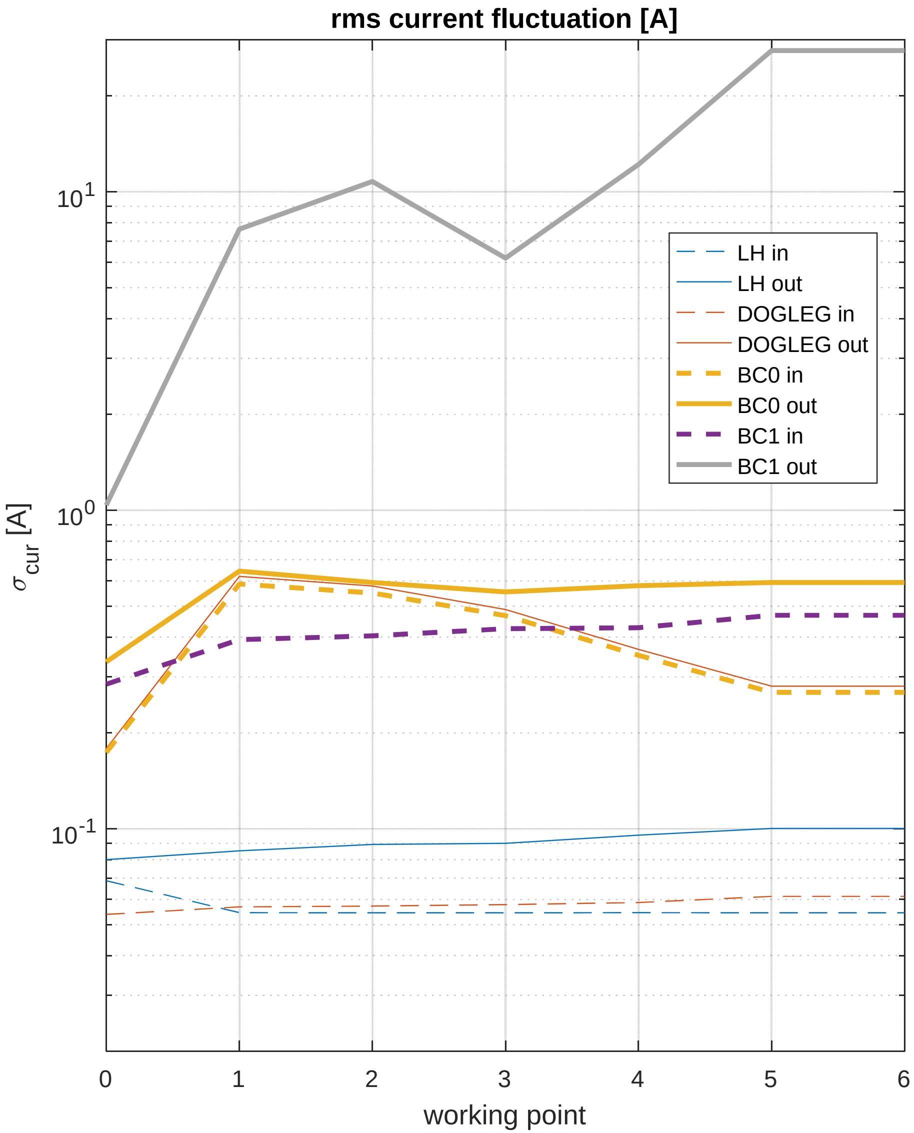
gray C1=5.5

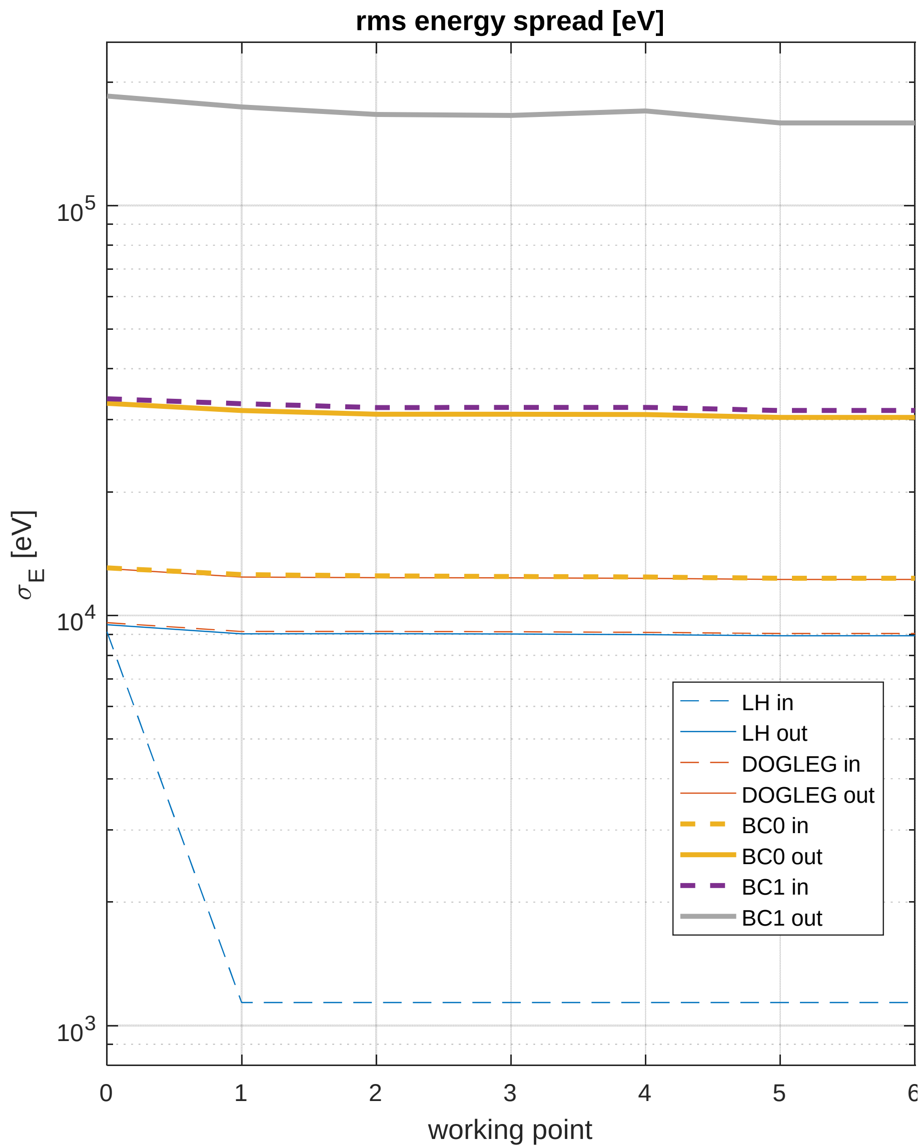
working points for “18 A beam” $\rightarrow$ 9 keV





Gaussian (0) and LH working points (1-6)





purple C1=8

gray C1=5.5

Summary & Outlook

strong μB effects for 5.8 A beam $\rightarrow$ energy spread for 5 kA > 4.5 MeV
(with LH!)

moderate effects for 18 A beam $\rightarrow$ energy spread for 5 kA > 2 MeV
(with LH)

reduction by LH less than 50%
for optimal settings (heating + working point)

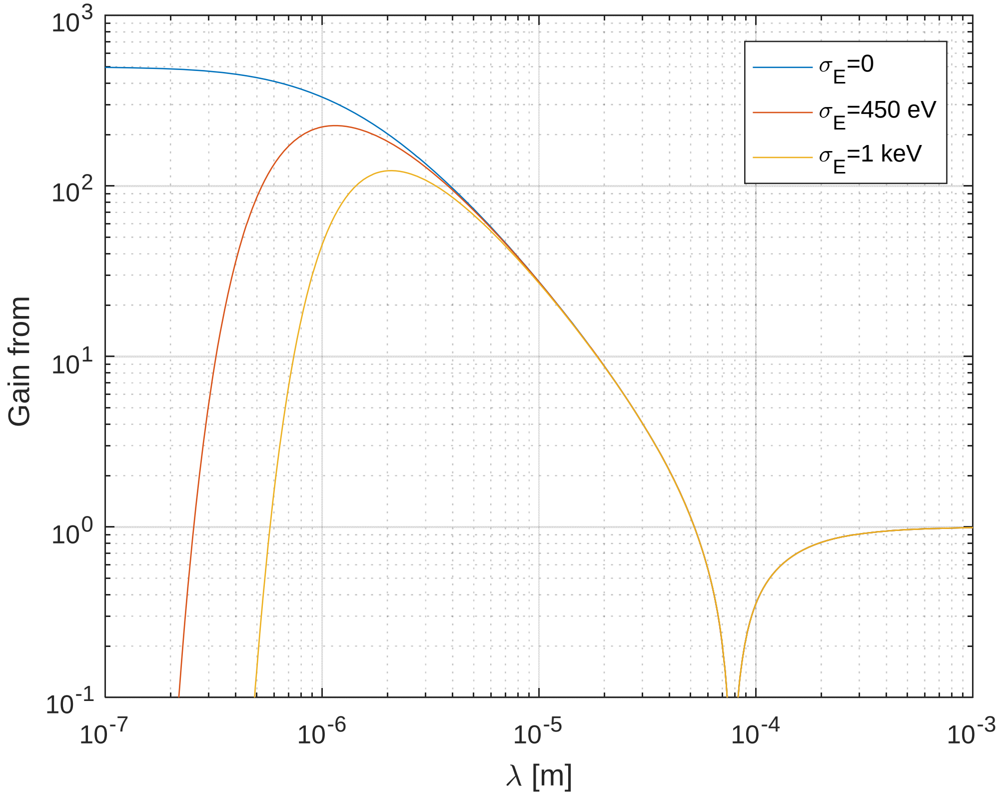
large contribution from DOGLEG even without self effects
(see next slides)

further Investigation for BC2, collimator, …
needs a different method (less macro particles)

1-Stage Model for DOGLEG

$$G = \left(1 - i\frac{Cr_{56}}{\mathcal{E}_{\mathrm{ref}}/e} I_1 k_1 L_{sc} Z'(ck_1)\right) \exp\left(-\frac{(Ck_1 r_{56}\sigma_\delta)^2}{2}\right)$$

with impedance before (!) DOGLEG



$\lambda = 3\ \mu\mathrm{m}$

$\downarrow$

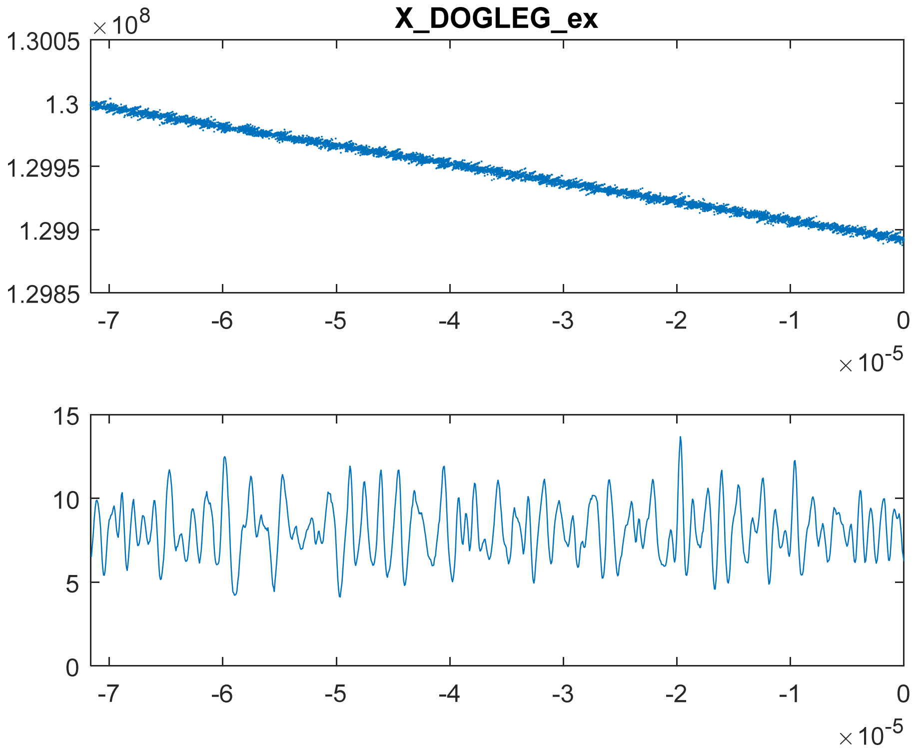
$|Z| \approx 34\ \mathrm{k}\Omega$

$\left|\frac{IZ}{E_{ref}/e}\right| \approx 0.0016$

$Cr_{56}k \approx 84000$

phase space after DOGLEG

SC in DOGLEG off!



SC in DOGLEG on