S2E simulation for XFEL

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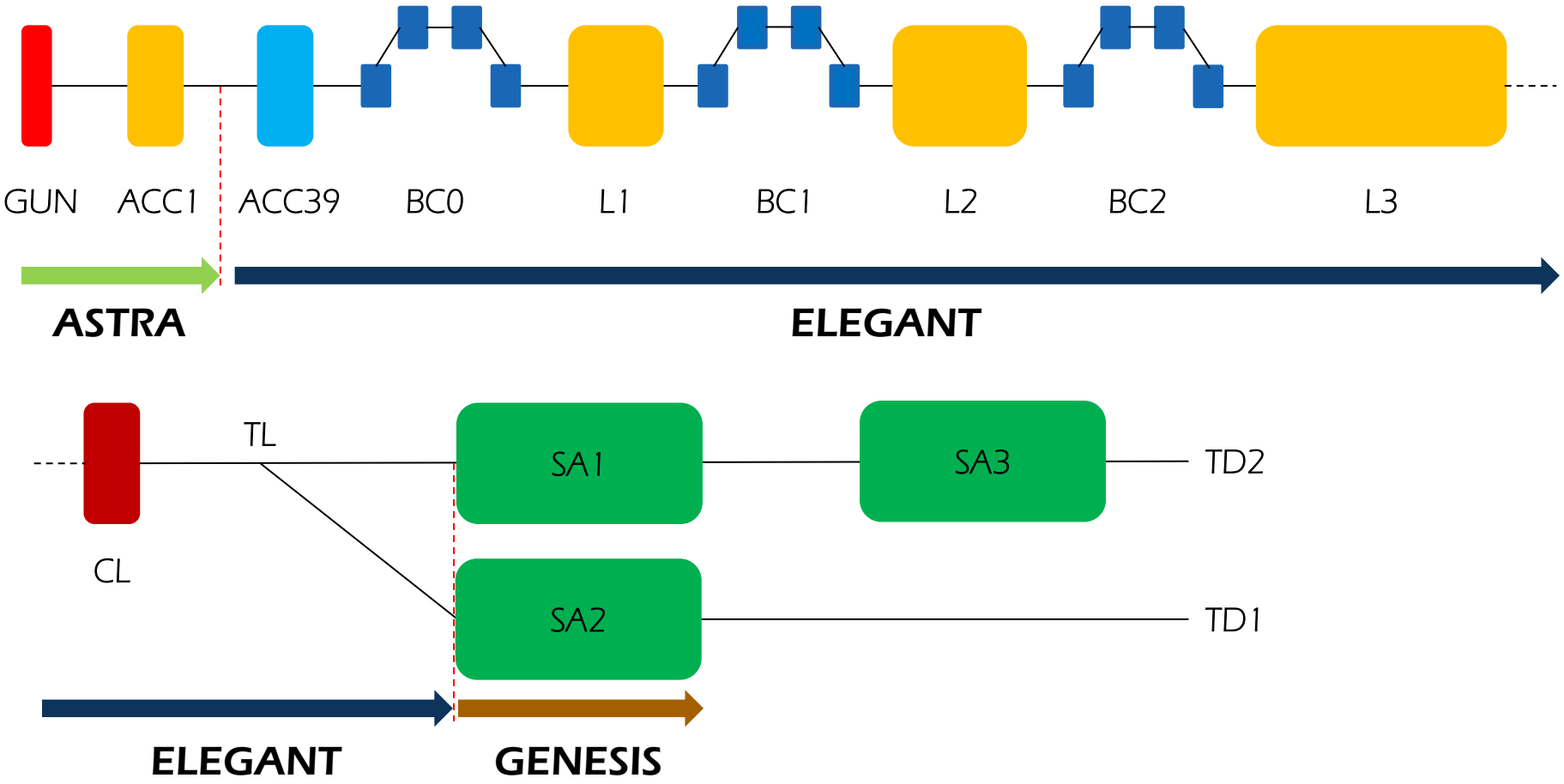
DESY

Plan

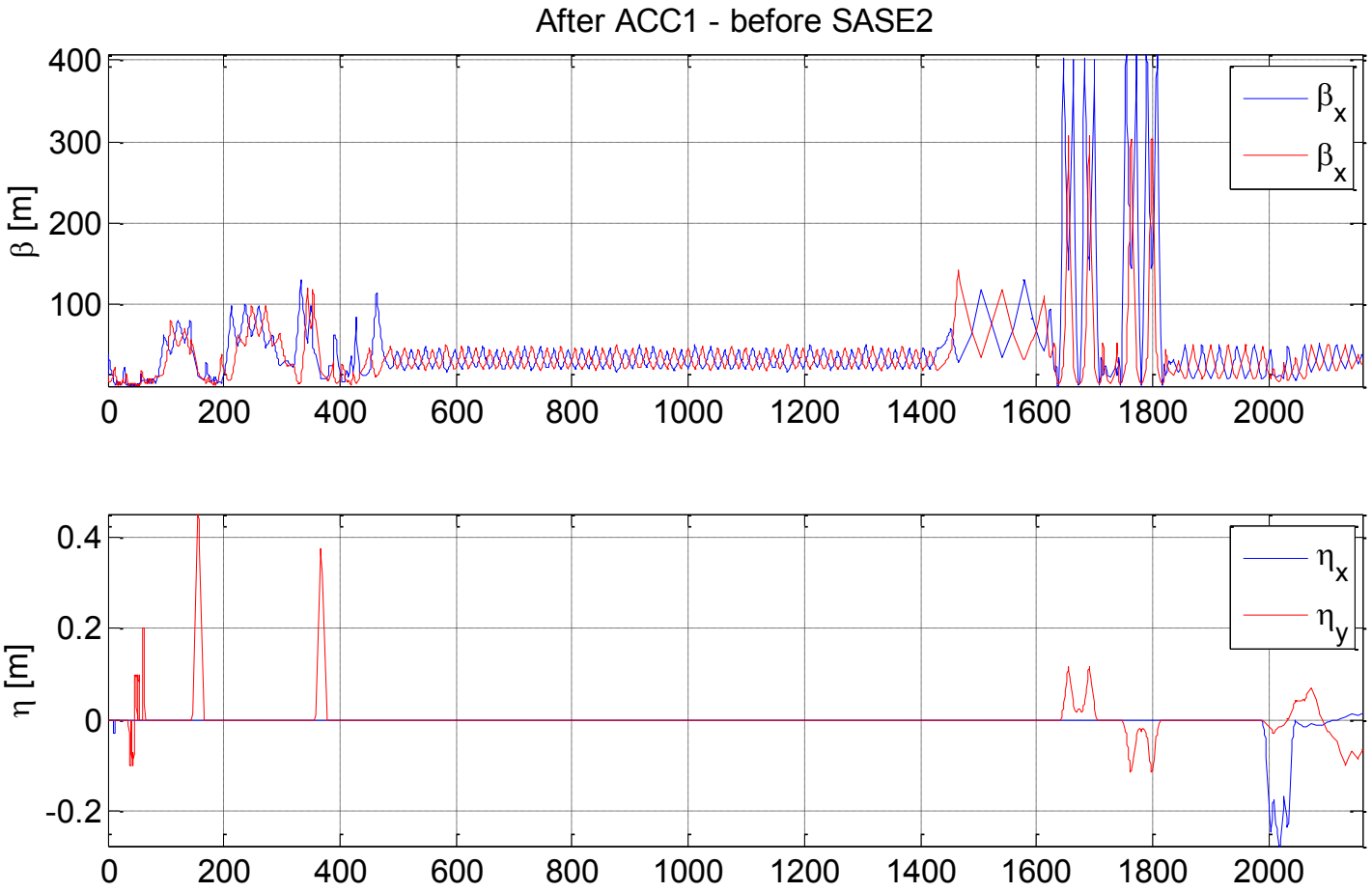
- Start-to-end(S2E) simulations with ASTRA, ELEGANT, and GENESIS for XFEL.
- Collective effects are included:
  - CSR + LSC + WAKE (RF cavities)
- Several beam charges are tested:
  - 1.0, 0.5, 0.25, 0.1, and 0.02 nC
- Obtained results are compared with the results of ASTRA + CSRtrack (G. Feng).

S2E simulations

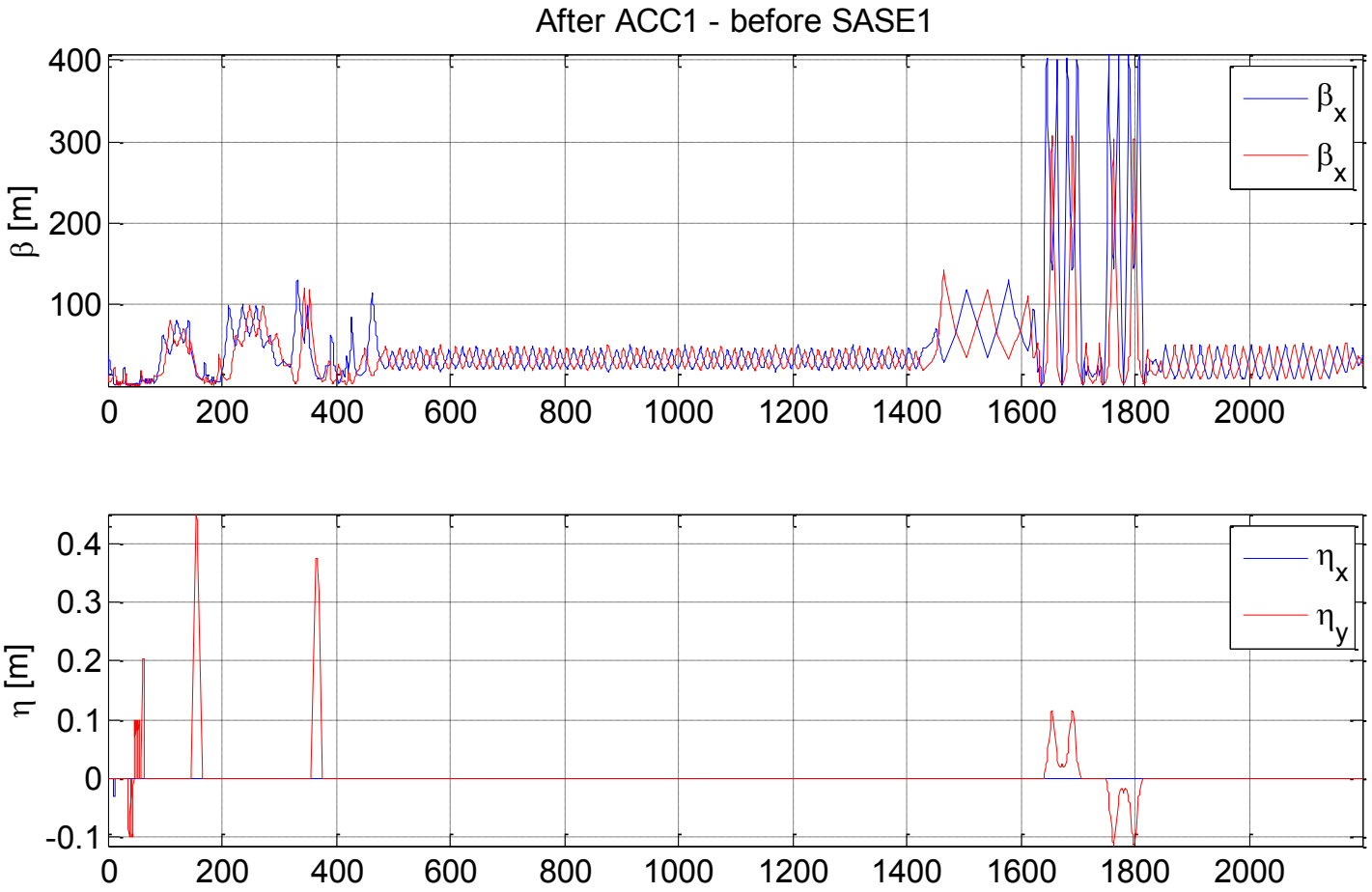


- Particles : 200k
- Collective effects : CSR + LSC + WAKE (RF cavities)

Twiss parameters (TD1)



Twiss parameters (TD2)

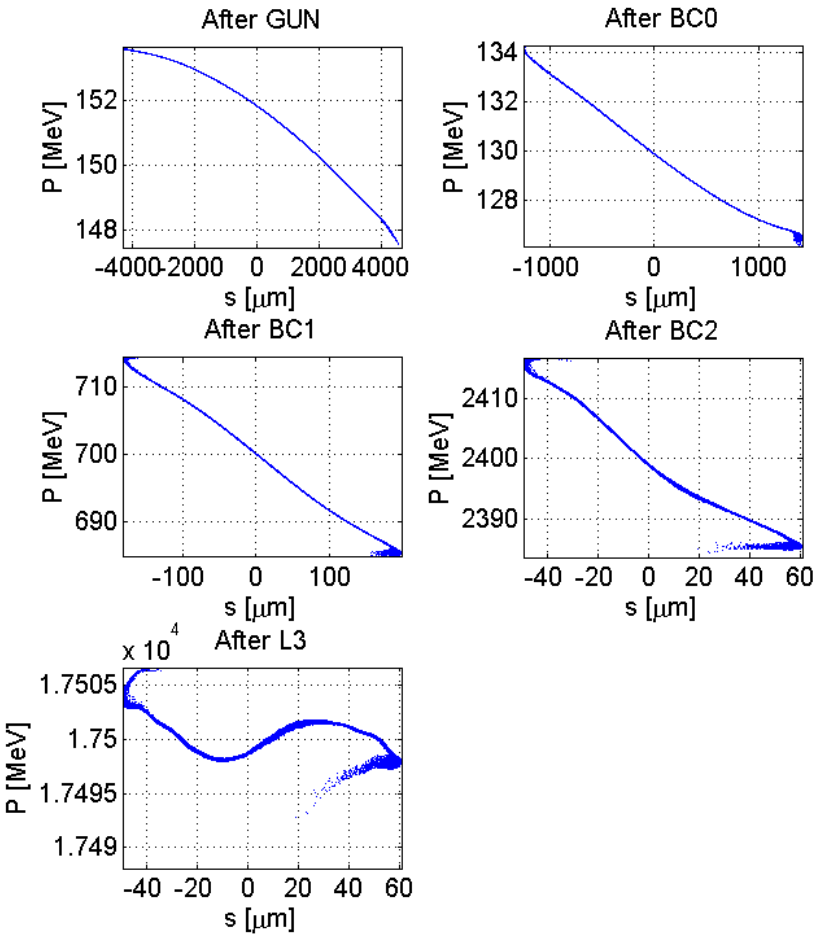


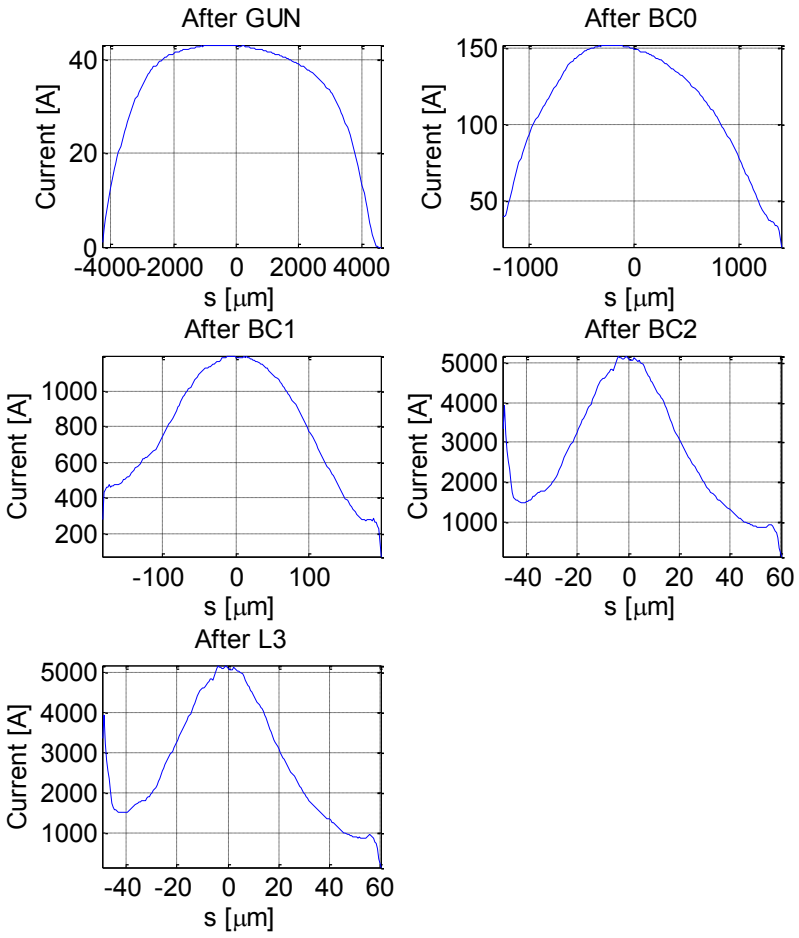
Machine parameters & RF settings in cavities

Charge [nC]	R56 in BC0 [mm]	Comp. In BC0 C1	R56 in BC1 [mm]	Comp. In BC1 C1	R56 BC2 [mm]	Total comp. C
1.0	-62.2	3.5	-54.0	8.0	-20.0	121.0
0.5	-55.0	3.5	-50.0	8.0	-20.0	217.0
0.25	-48.2	3.5	-50.0	8.0	-20.0	385.0
0.1	-43.9	3.5	-50.0	8.0	-20.0	870.0
0.02	-41.4	3.5	-50.0	8.0	-20.0	4237.0

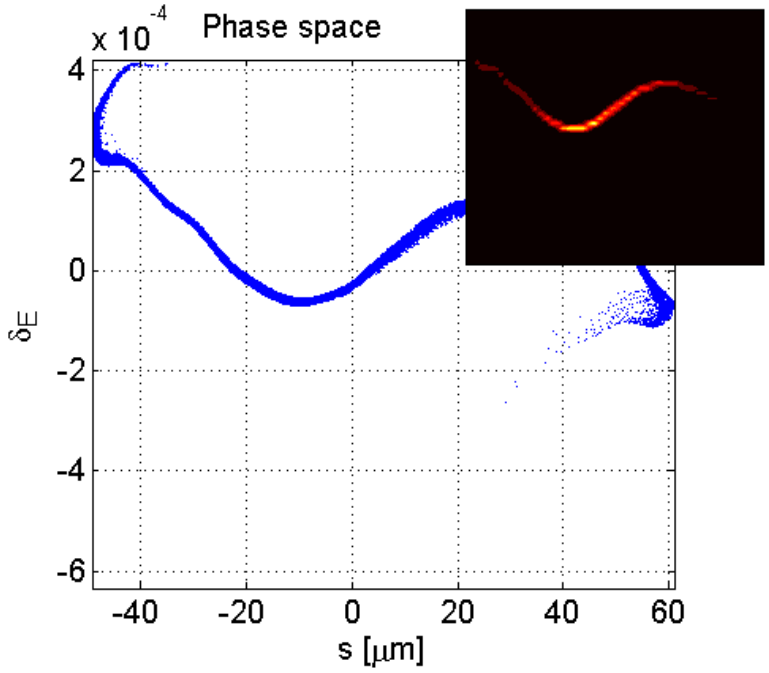
Charge [nC]	V11 [MV]	f11 [deg]	V13 [MV]	f13 [deg]	V2 [MV]	f2 [deg]	V3 [MV]	f3 [deg]
1.0	147.4	9.5	22.0	171.2	649.4	28.5	1838.4	22.1
0.5	153.8	16.9	23.8	186.0	657.4	29.8	1810.5	20.0
0.25	160.7	22.9	25.7	196.8	650.0	28.7	1844.1	22.6
0.1	164.2	25.0	27.1	199.4	644.6	27.8	1865.5	24.2
0.02	163.4	23.9	27.3	195.9	641.4	27.3	1888. 5	25.7

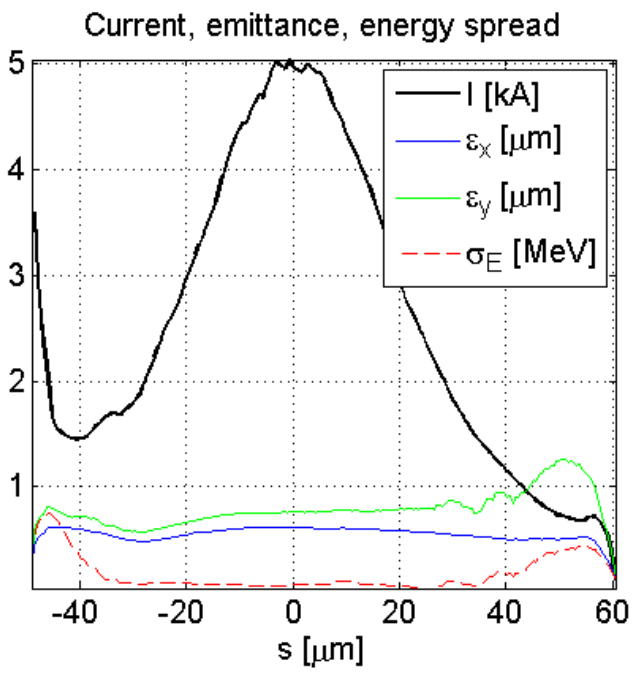
Longitudinal phase space & beam current – 1 nC





Beam profile after L3 – 1 nC





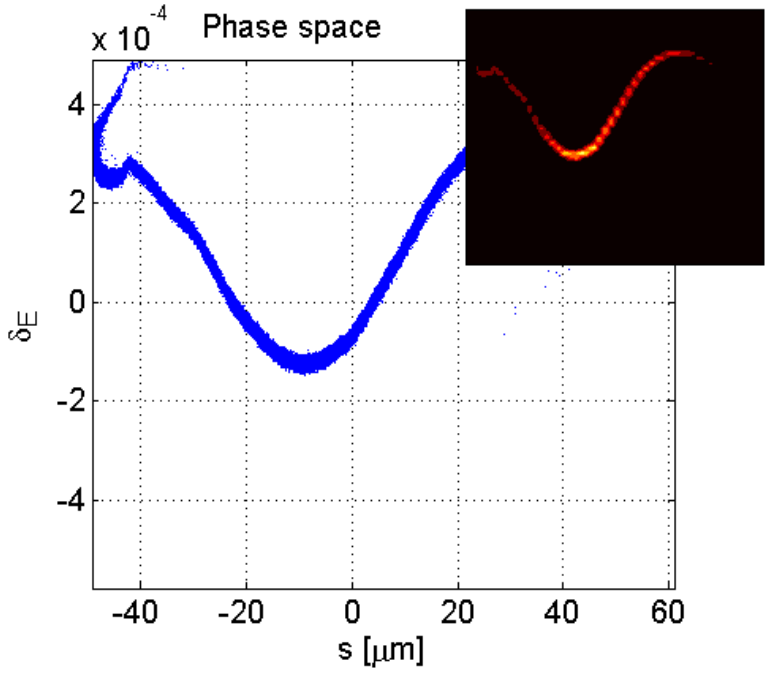
Remove about 6% bad particles in the analysis

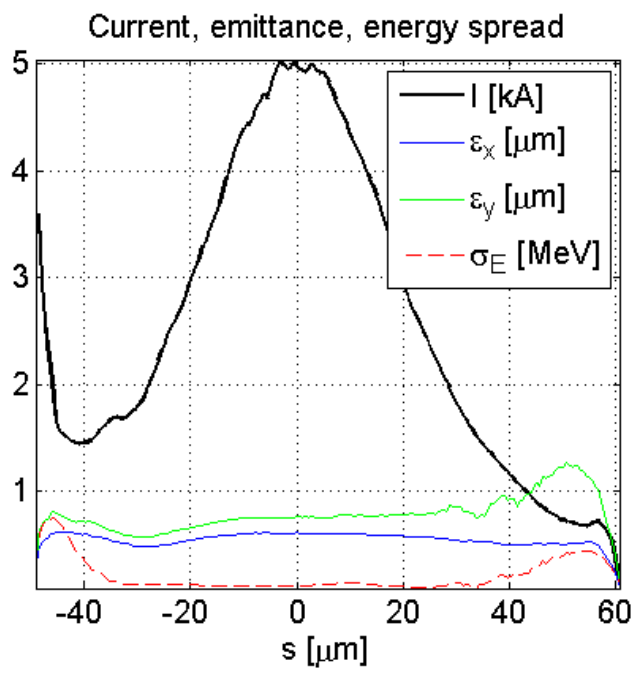
$\varepsilon_{proj,x}$ = 0.7 μm

$\varepsilon_{proj,y}$ = 1.6 μm

FWHM = 152 fs

Beam profile before SASE1 (TD2) – 1 nC





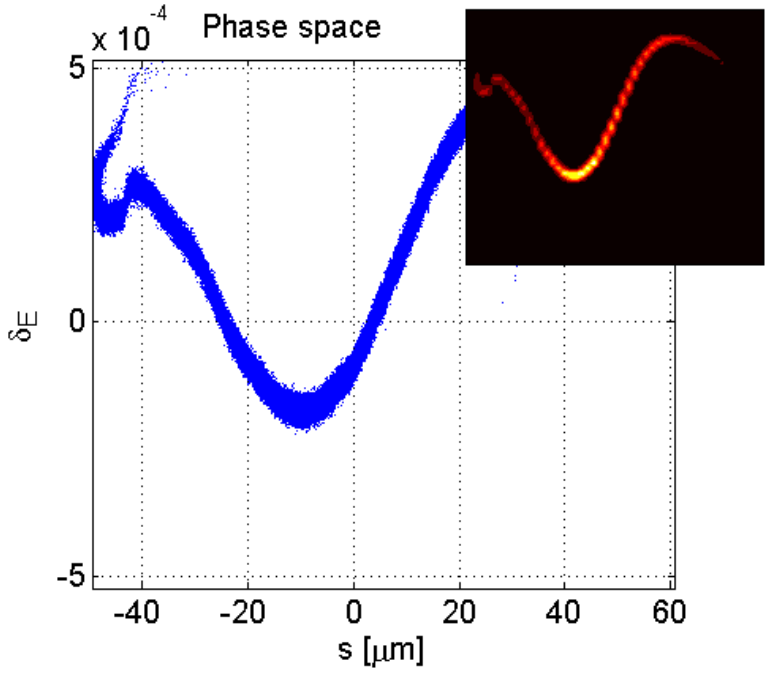
Remove about 6% bad particles in the analysis

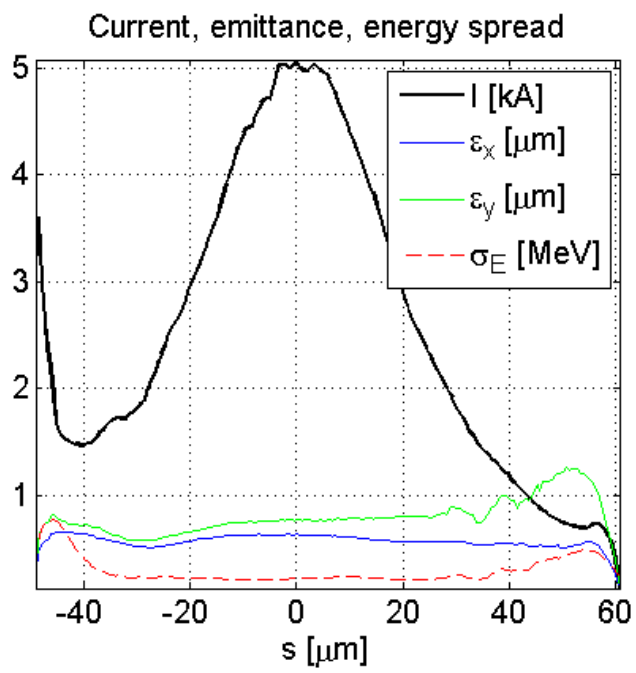
$\varepsilon_{proj,x}$ = 0.7 μm

$\varepsilon_{proj,y}$ = 1.6 μm

FWHM = 152 fs

Beam profile before SASE2 (TD1) – 1 nC





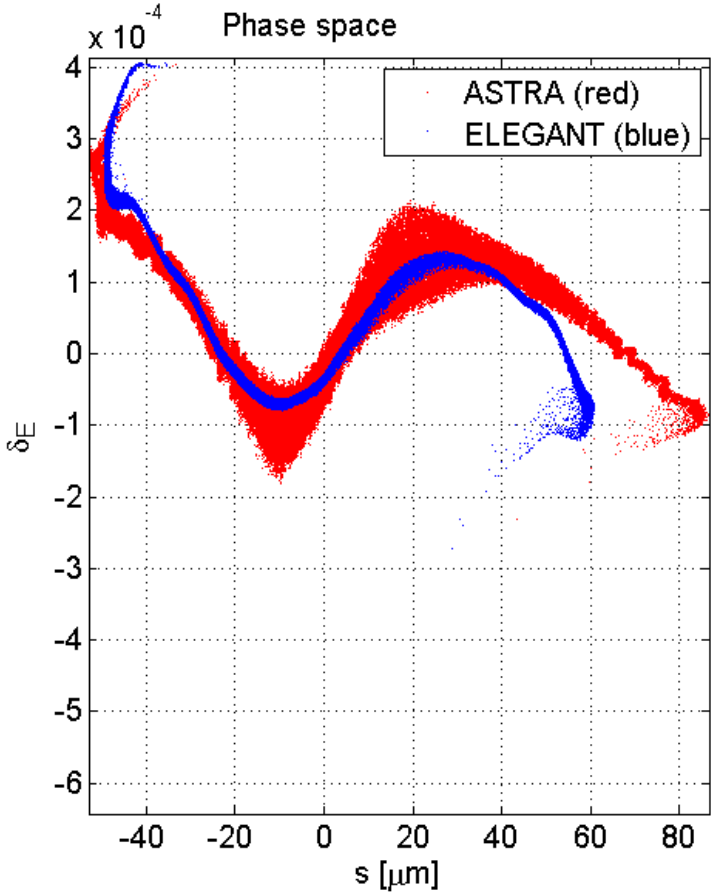
Remove about 6% bad particles in the analysis

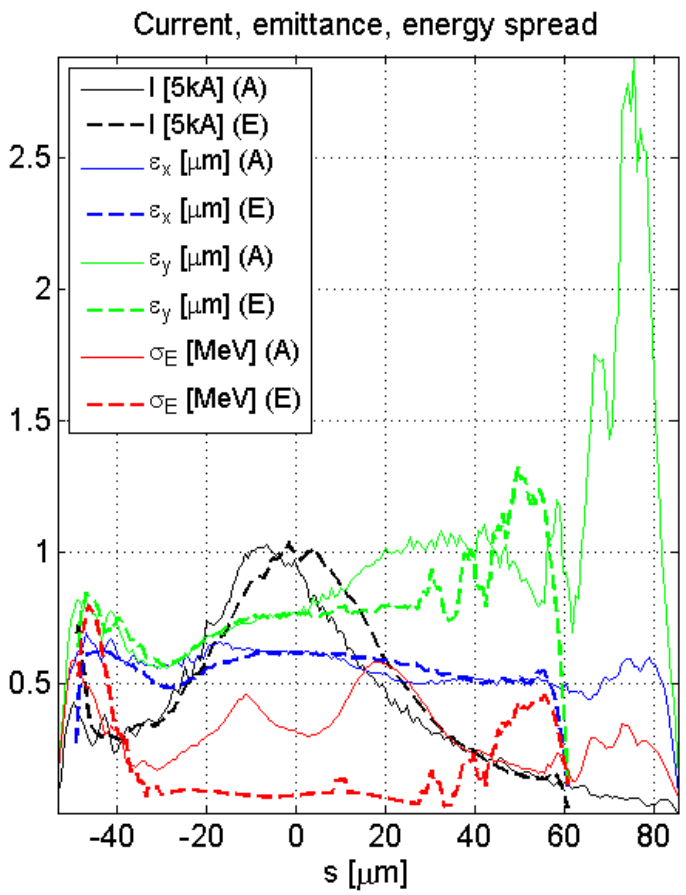
$\varepsilon_{proj,x}$ = 0.8 μm

$\varepsilon_{proj,y}$ = 1.8 μm

FWHM = 147 fs

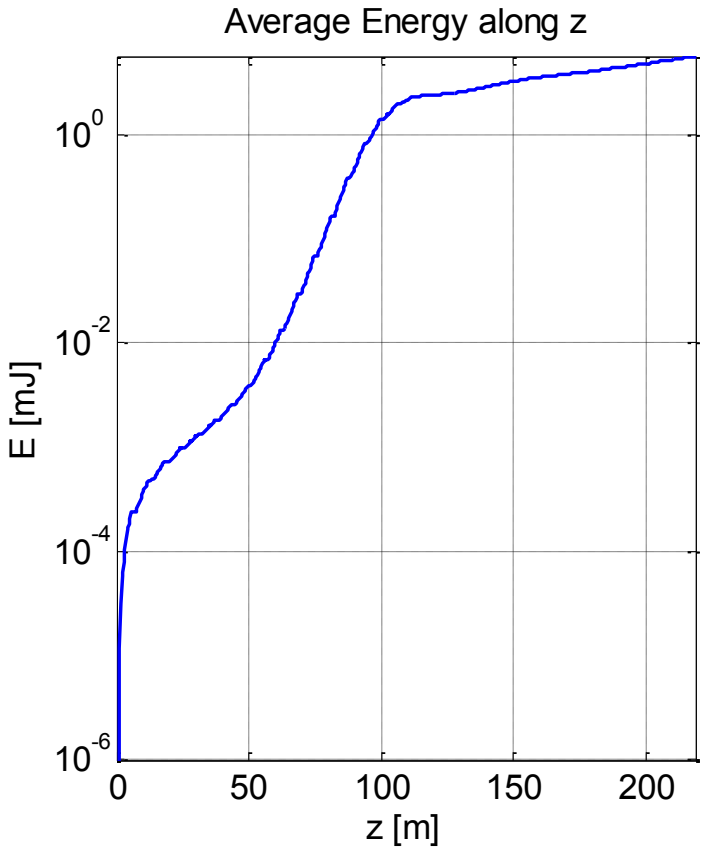
Comparison of beam profiles between ELEGANT and ASTRA+CSRtrack after L3 – 1 nC

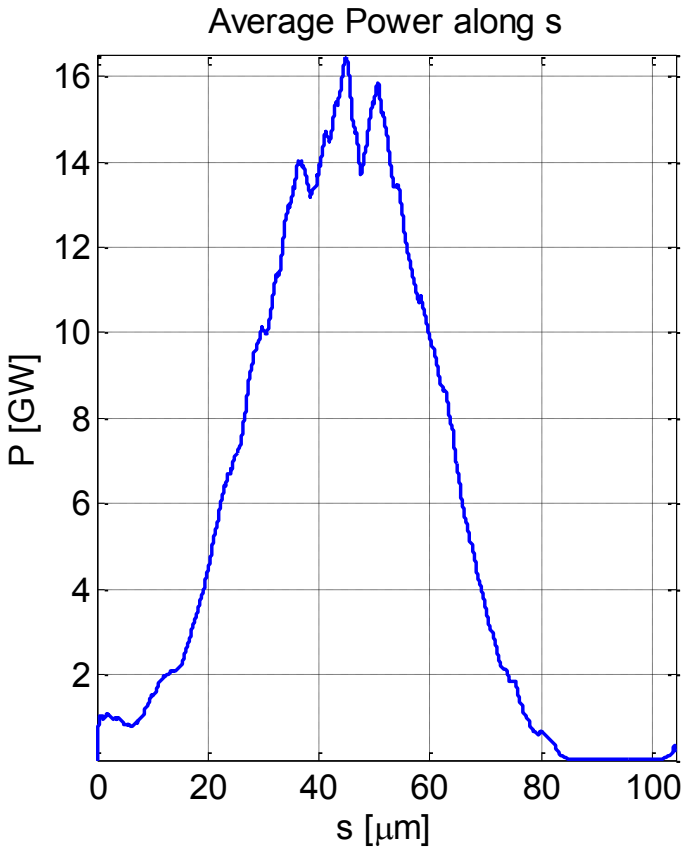




	V11 [MV]	f11 [deg]	V13 [MV]	f13 [deg]	V2 [MV]	f2 [deg]	V3 [MV]	f3 [deg]
Jin (AST+ELE)	147.4	9.5	22.0	171.2	649.4	28.5	1838.4	22.1
Feng (AST+CSR)	144.6	7.7	24.5	148.7	643.8	27.5	1837.4	22.0

Average radiation energy & power at SASE1 – 1 nC

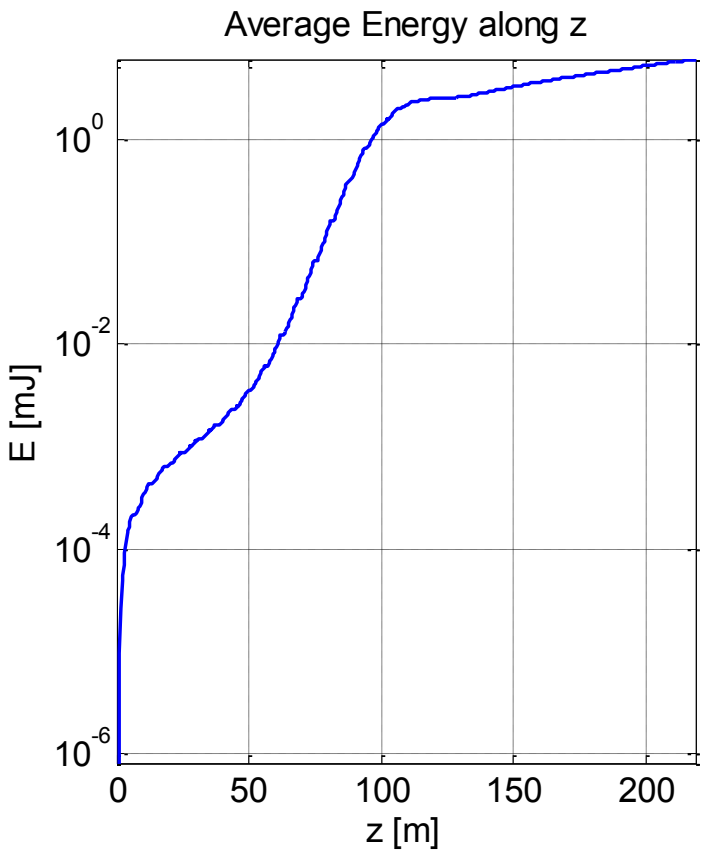


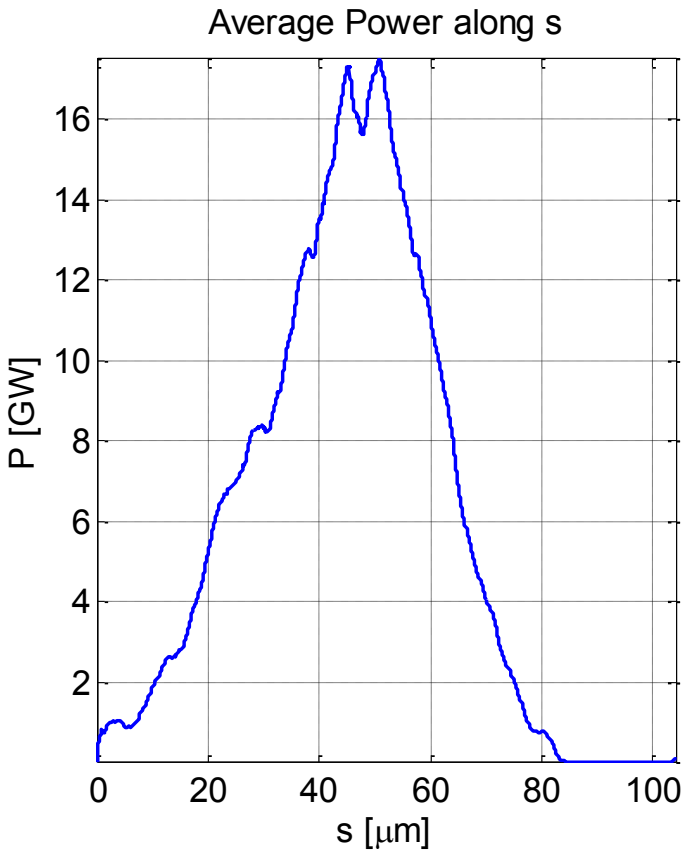


Averaged through 7310 slices
5 random seeds

FWHM = 117 fs

Average radiation energy & power at SASE2 – 1 nC

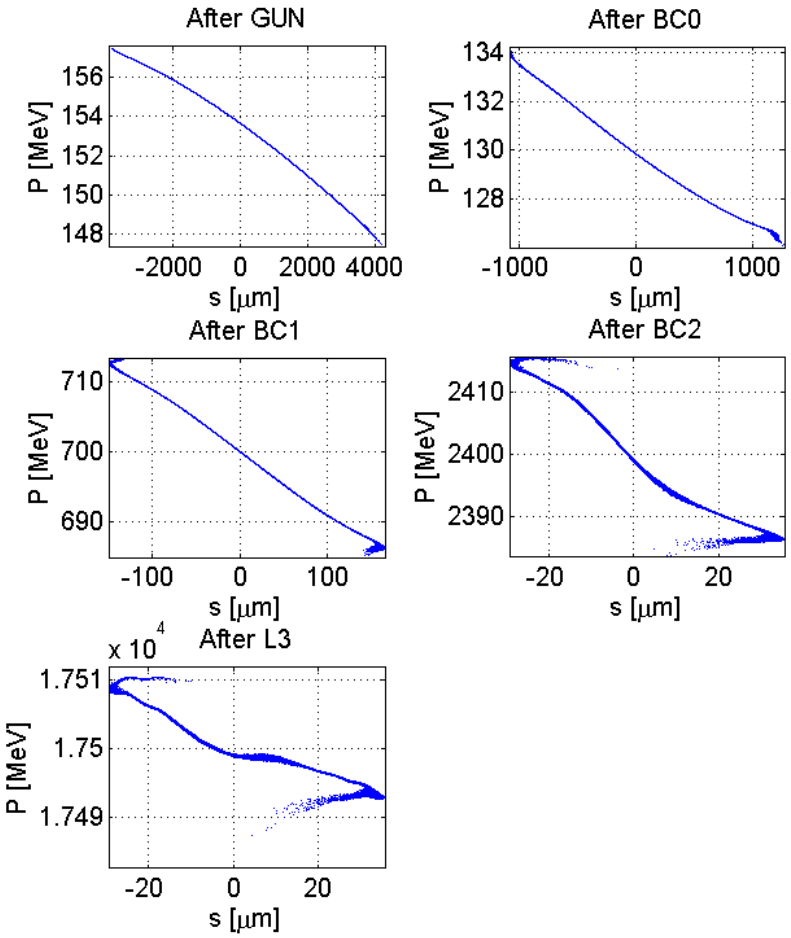


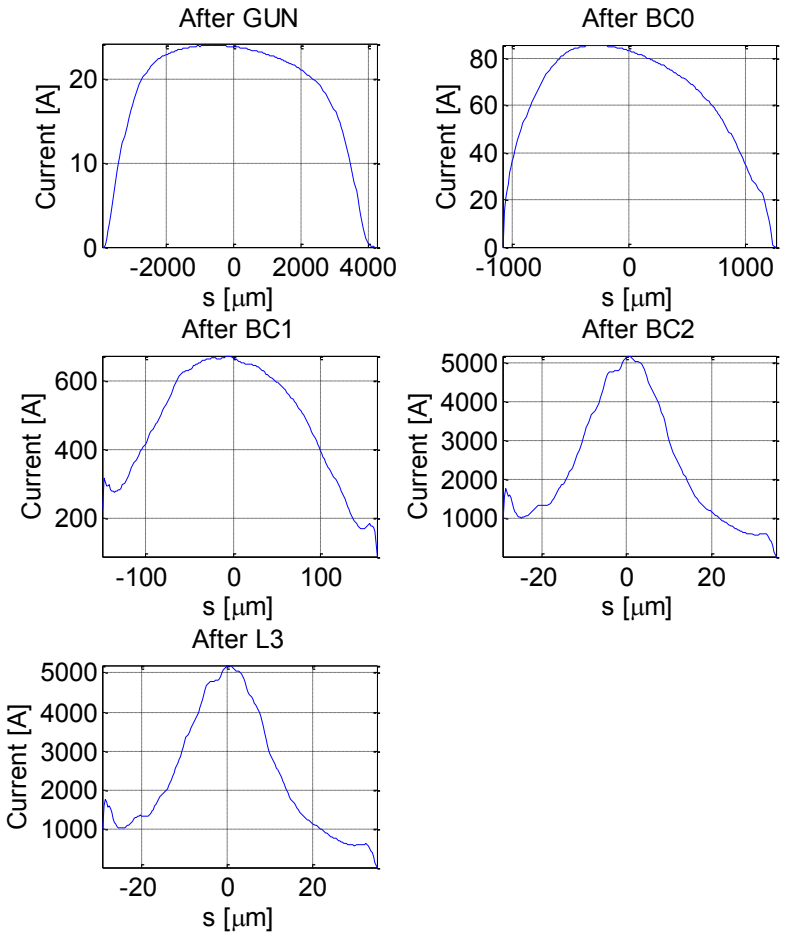


Averaged through 7303 slices
5 random seeds

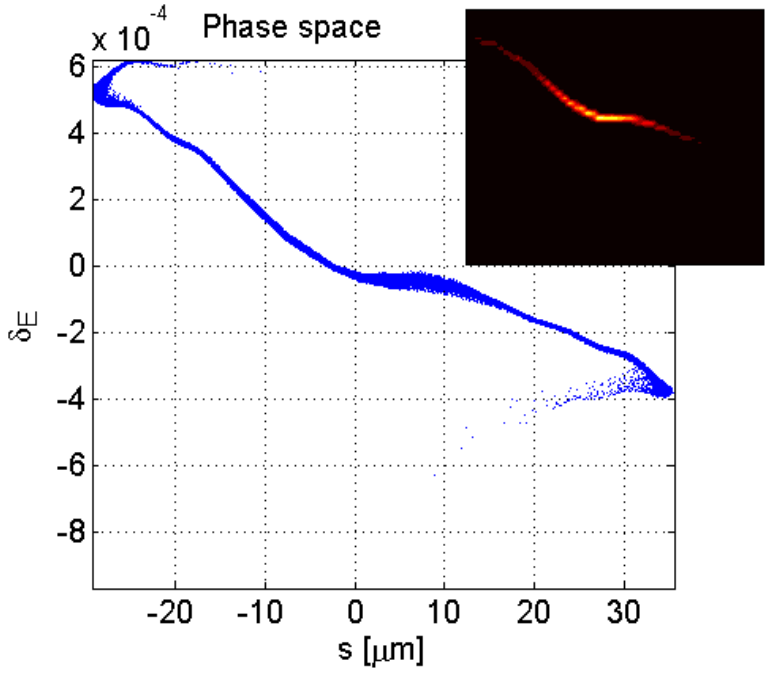
FWHM = 86 fs

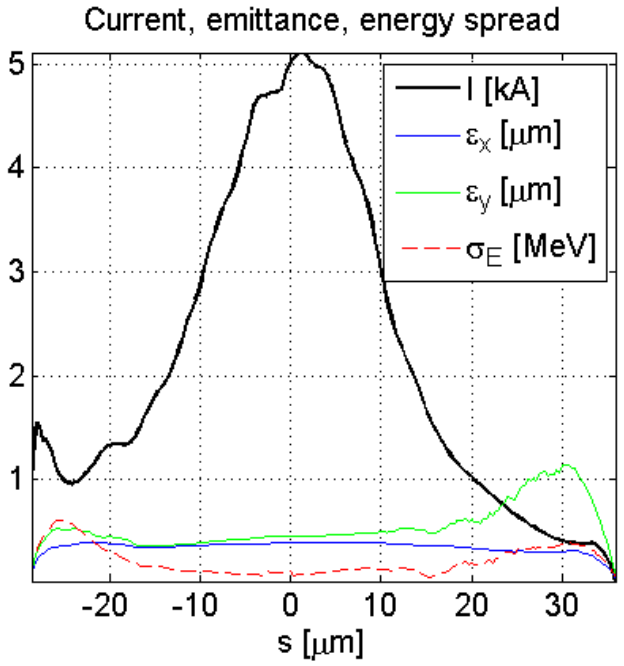
Longitudinal phase space & beam current – 0.5 nC





Beam profile after L3 – 0.5 nC





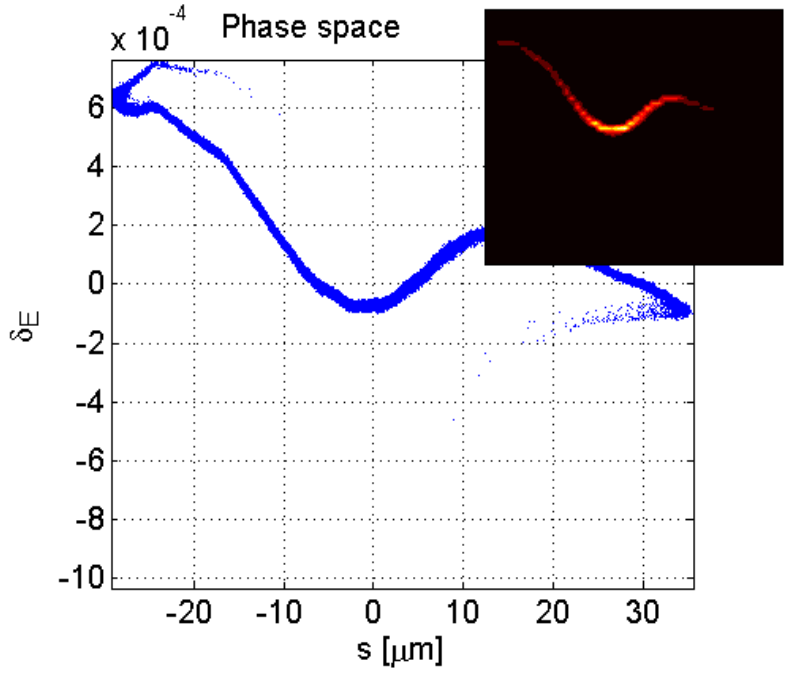
Remove about 6% bad particles in the analysis

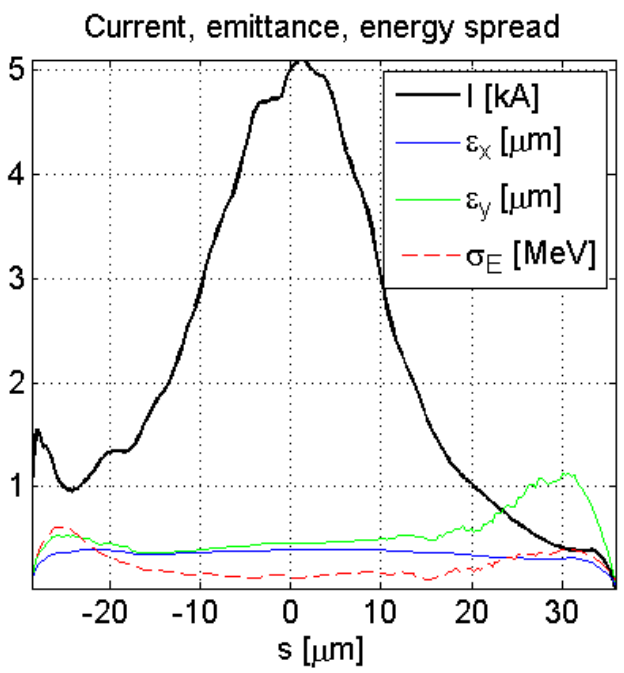
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.3 μm

FWHM = 71 fs

Beam profile before SASE1 (TD2) – 0.5 nC





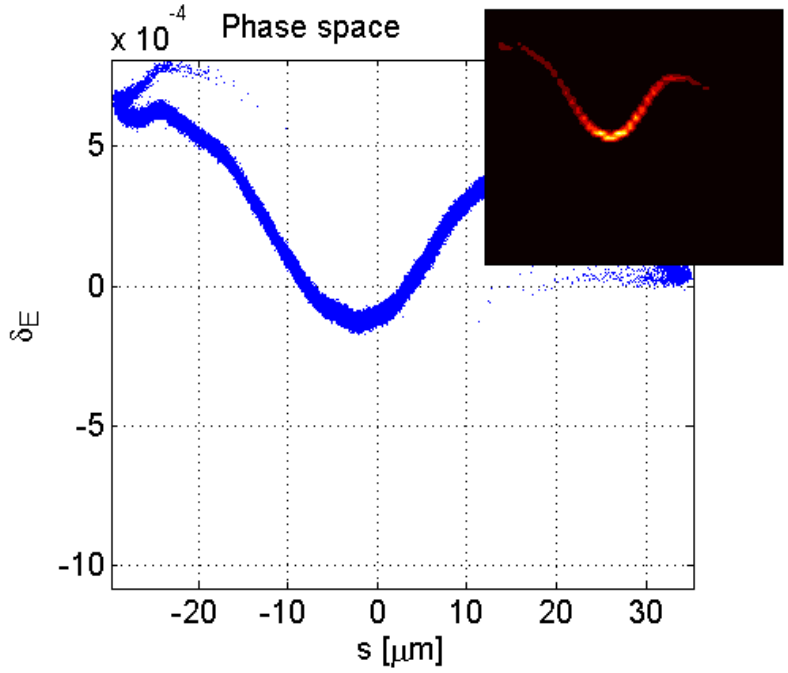
Remove about 6% bad particles in the analysis

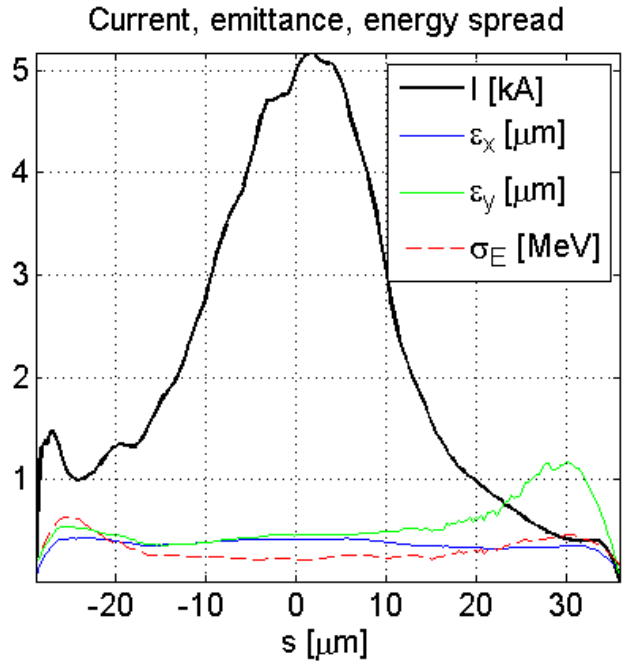
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.3 μm

FWHM = 69 fs

Beam profile before SASE2 (TD1) – 0.5 nC





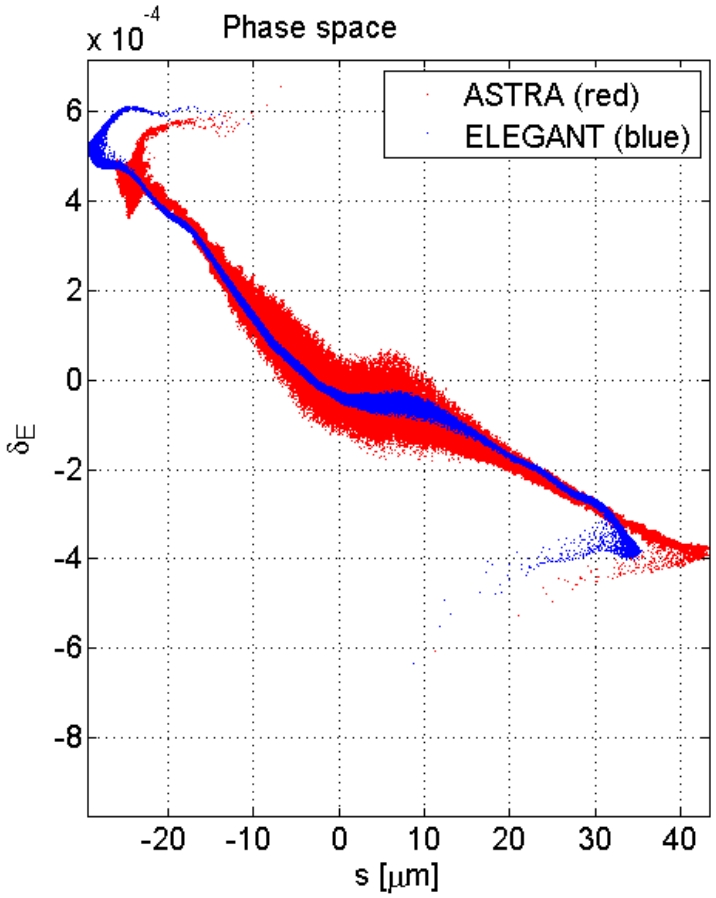
Remove about 6% bad particles in the analysis

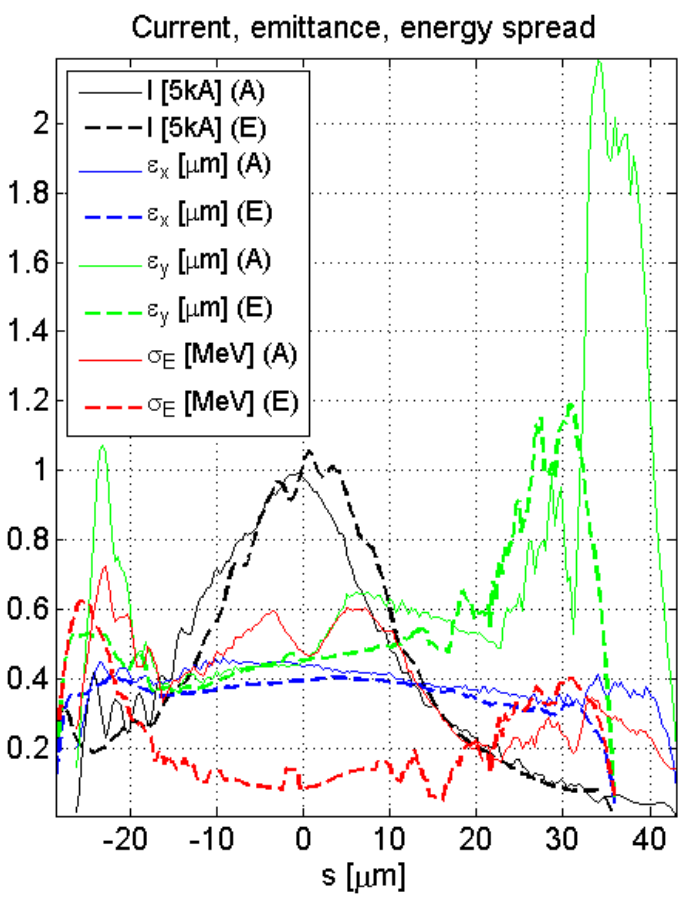
$\varepsilon_{proj,x}$ = 0.7 μm

$\varepsilon_{proj,y}$ = 1.4 μm

FWHM = 68 fs

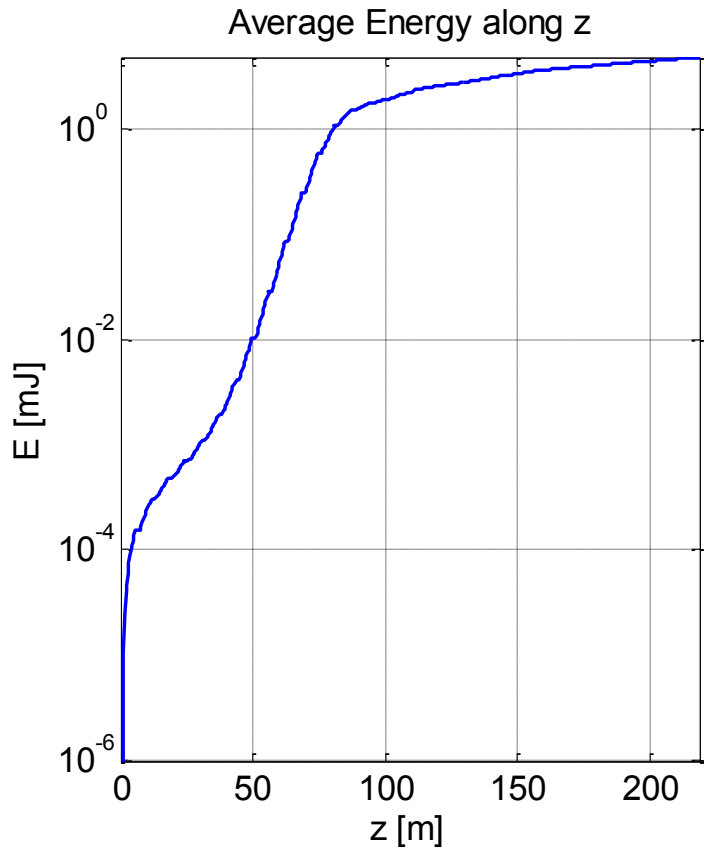
Comparison of beam profiles between ELEGANT and ASTRA+CSRtrack after L3 – 0.5 nC

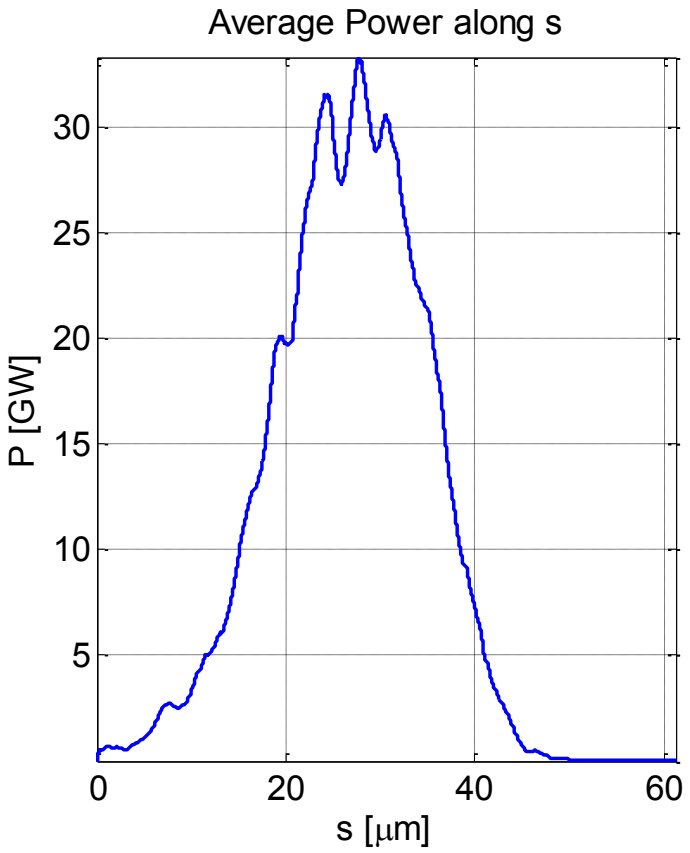




	V11 [MV]	f11 [deg]	V13 [MV]	f13 [deg]	V2 [MV]	f2 [deg]	V3 [MV]	f3 [deg]
Jin (AST+ELE)	153.8	16.9	23.8	186.0	657.4	29.8	1810.5	20.0
Feng (AST+CSR)	153.5	16.7	23.5	184.5	651.9	29.0	1864.7	24.0

Average radiation energy & power at SASE1 – 0.5 nC

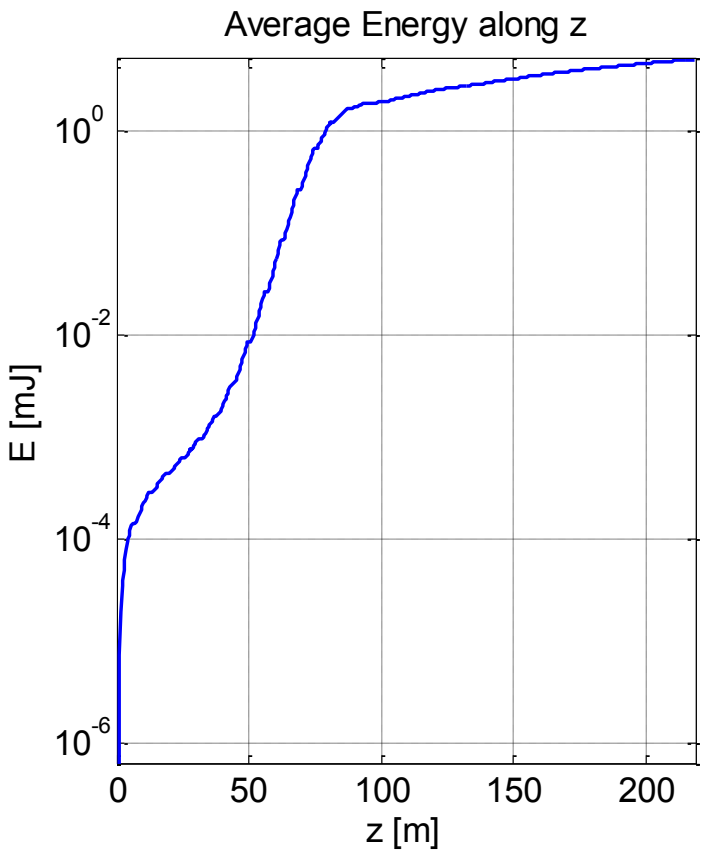


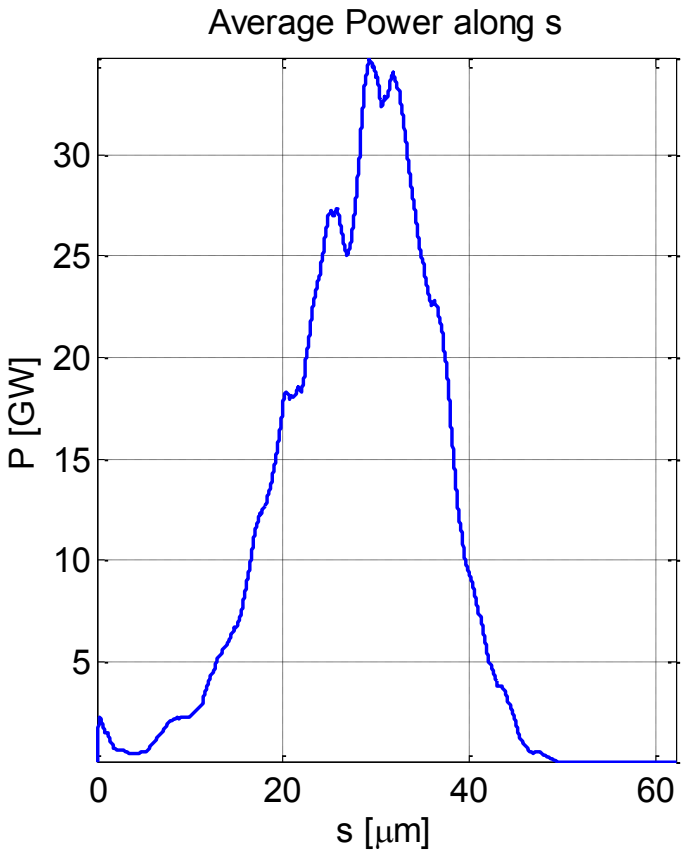


Averaged through 4296 slices
5 random seeds

FWHM = 58 fs

Average radiation energy & power at SASE1 – 0.5 nC

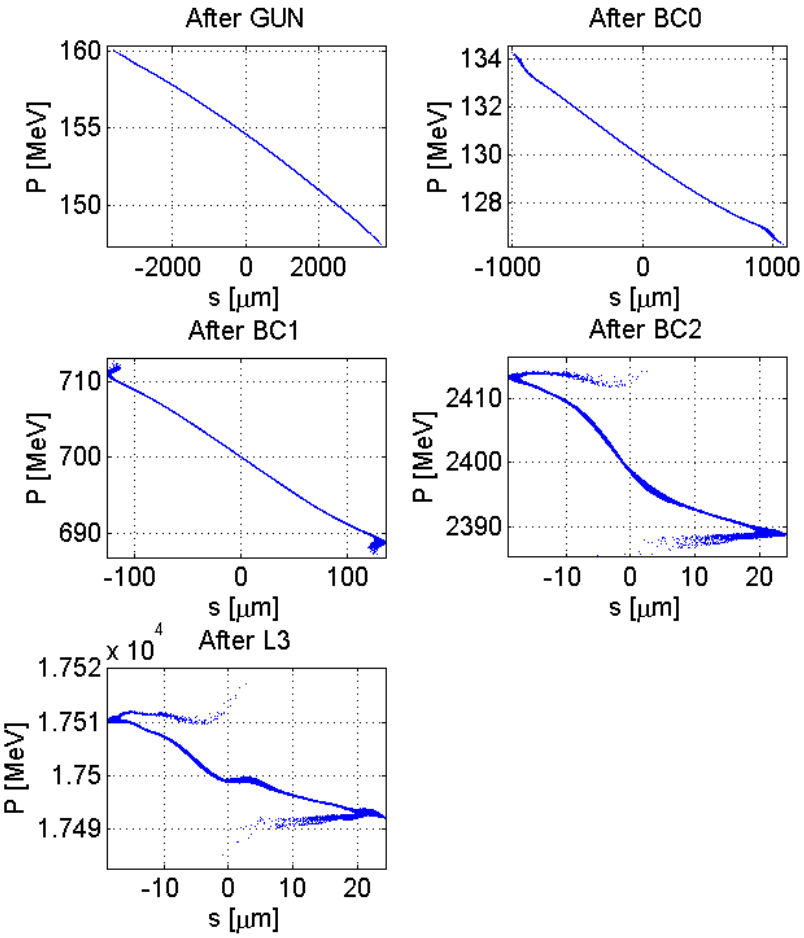


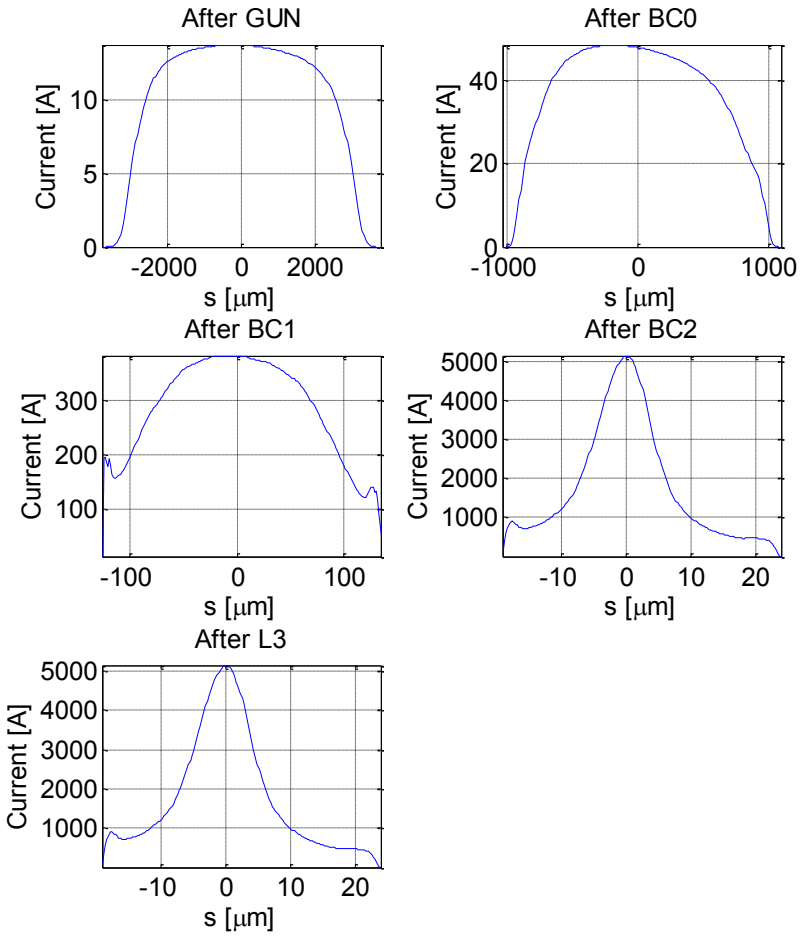


Averaged through 4359 slices
5 random seed

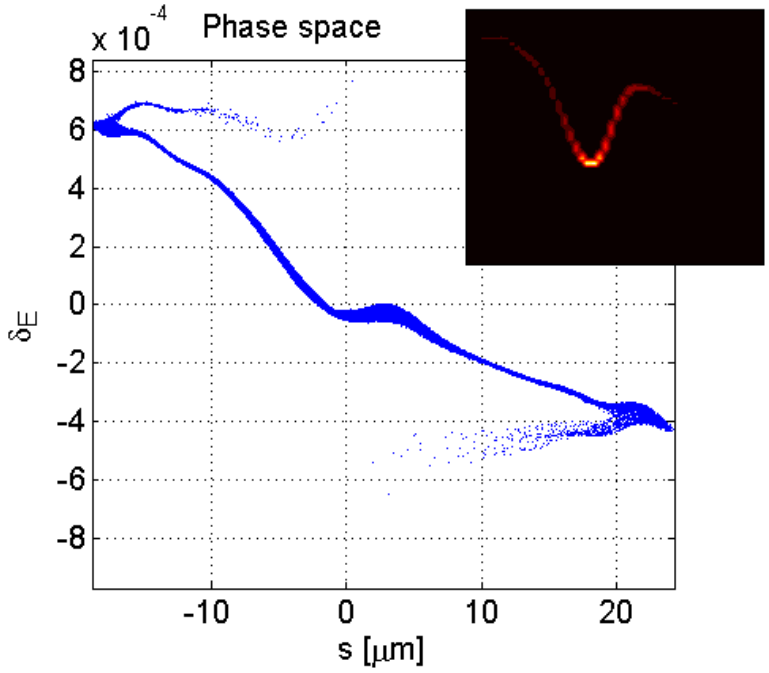
FWHM = 56 fs

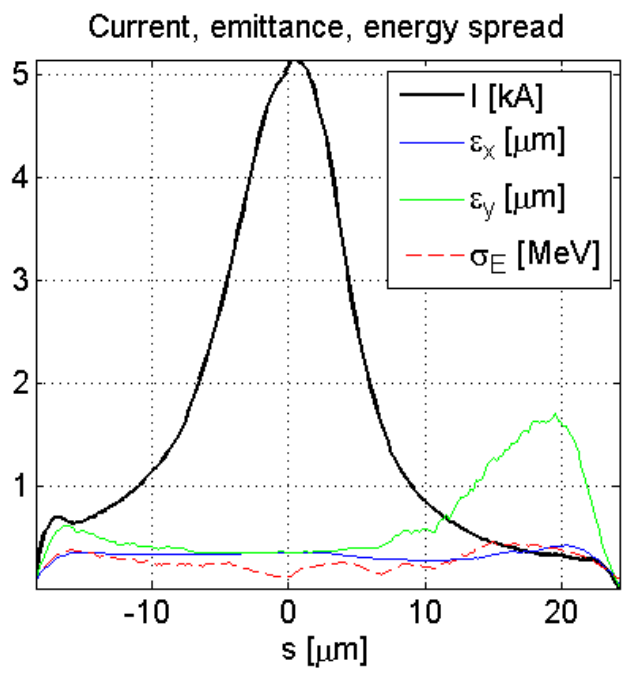
Longitudinal phase space & beam current – 0.25 nC





Beam profile after L3 – 0.25 nC





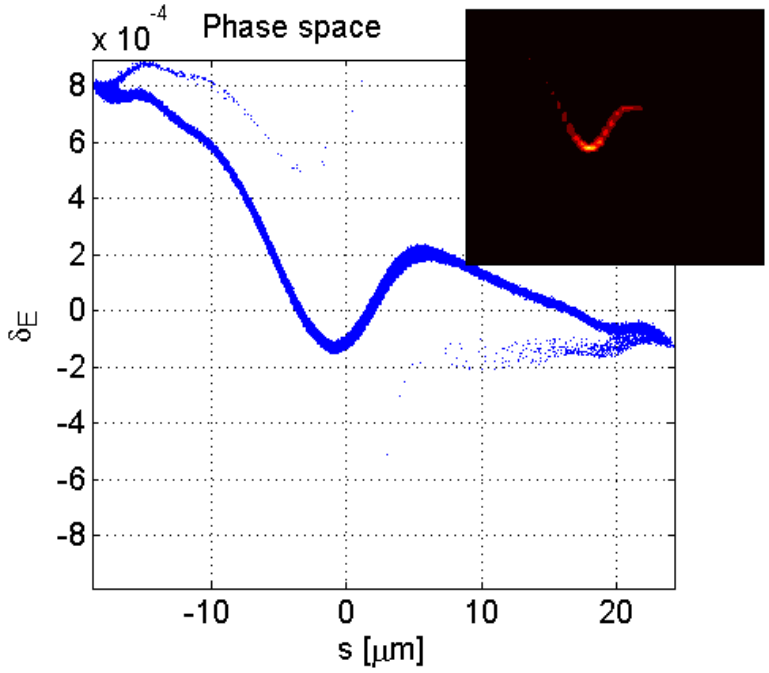
Remove about 6% bad particles in the analysis

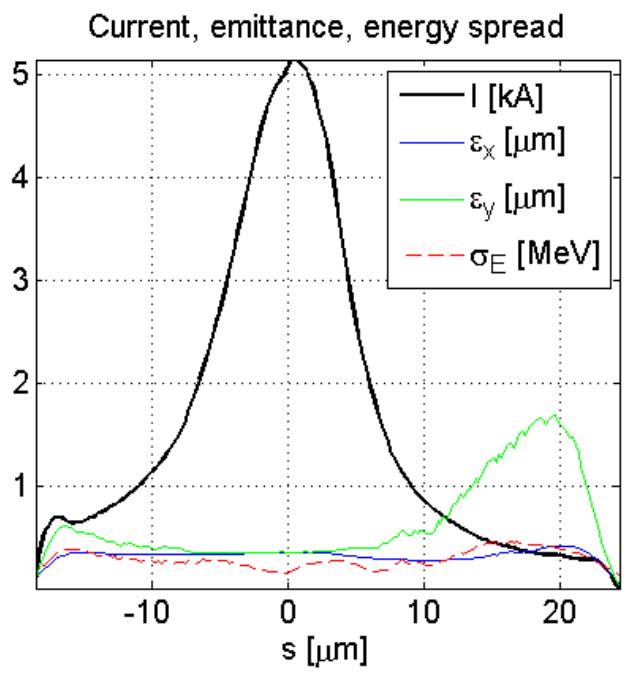
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.4 μm

FWHM = 32 fs

Beam profile before SASE1 (TD2) – 0.25 nC





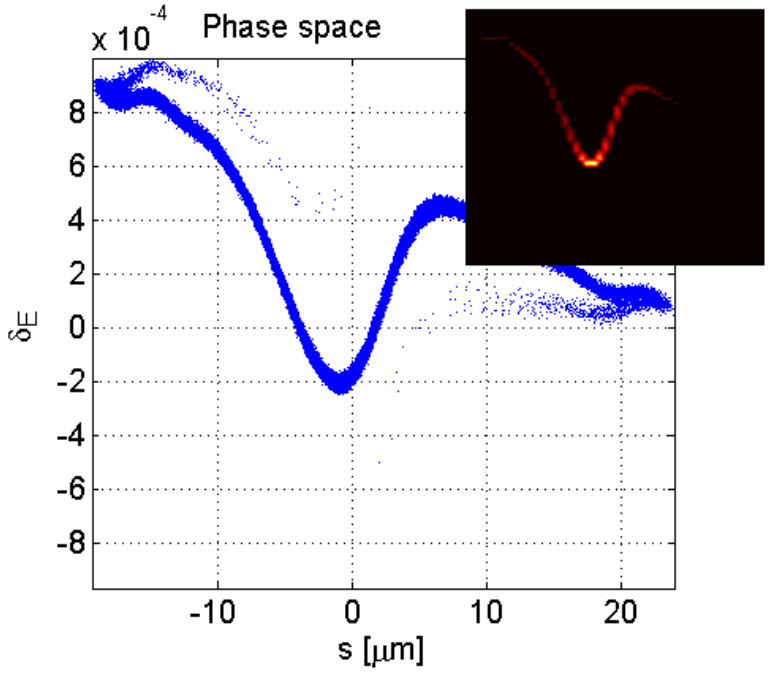
Remove about 6% bad particles in the analysis

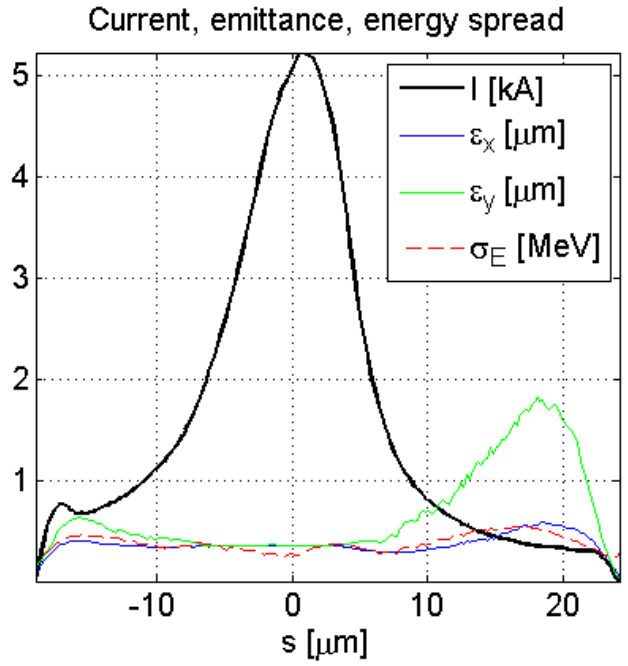
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.4 μm

FWHM = 32 fs

Beam profile before SASE2 (TD1) – 0.25 nC





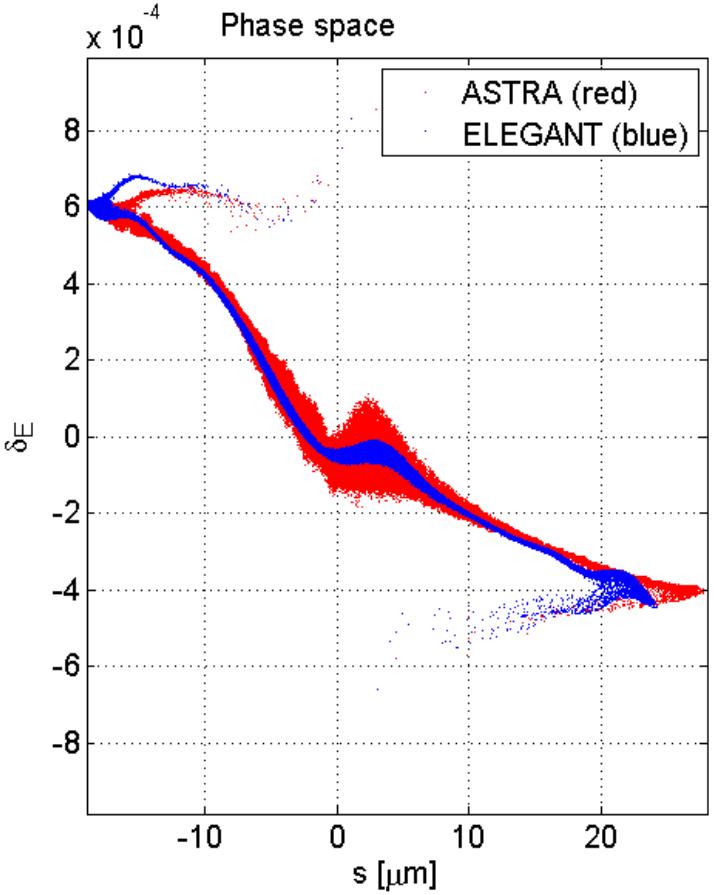
Remove about 6% bad particles in the analysis

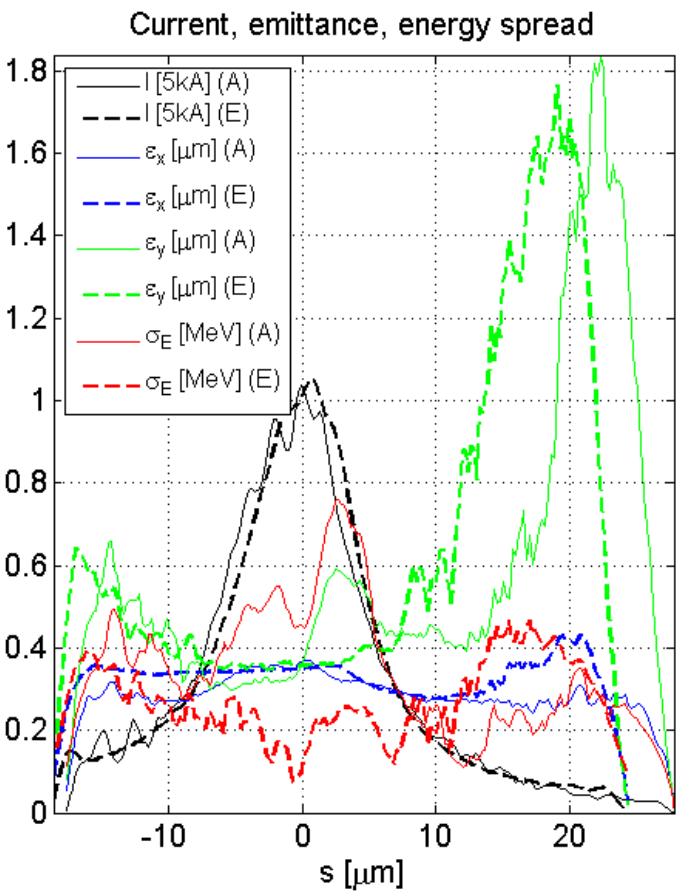
$\varepsilon_{proj,x}$ = 0.8 μm

$\varepsilon_{proj,y}$ = 1.5 μm

FWHM = 31 fs

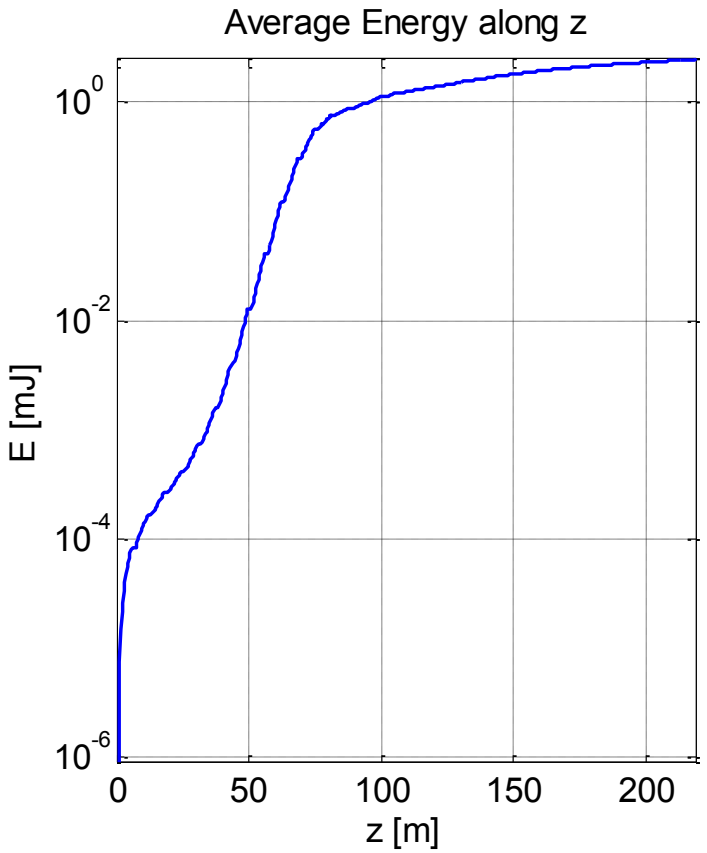
Comparison of beam profiles between ELEGANT and ASTRA+CSRtrack after L3 – 0.25 nC

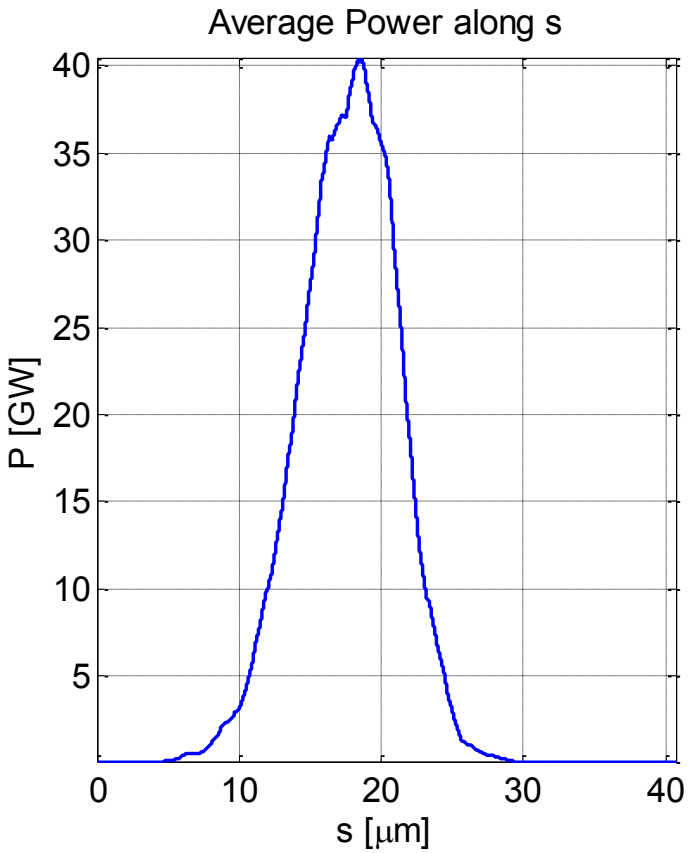




	V11 [MV]	f11 [deg]	V13 [MV]	f13 [deg]	V2 [MV]	f2 [deg]	V3 [MV]	f3 [deg]
Jin (AST+ELE)	160.7	22.9	25.7	196.8	650.0	28.7	1844.1	22.6
Feng (AST+CSR)	156.2	18.7	24.6	187.1	646.7	28.1	1812.6	20.0

Average radiation energy & power at SASE1 – 0.25 nC

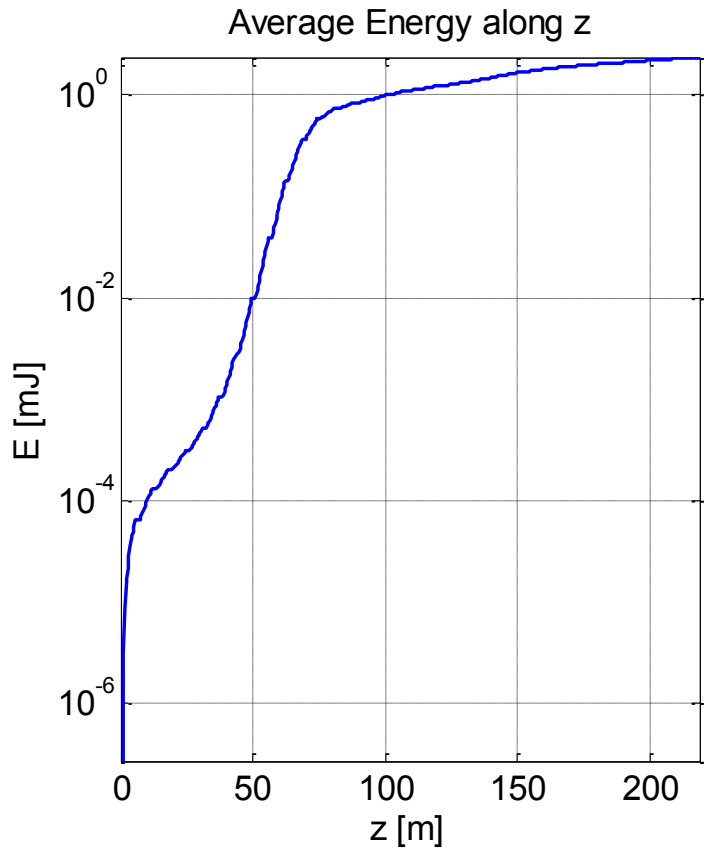


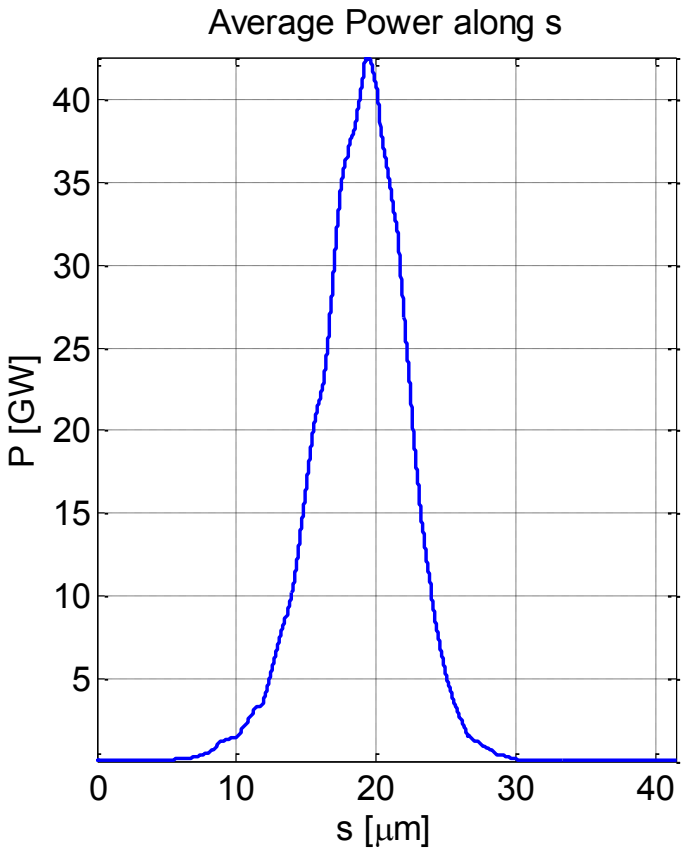


Averaged through 2859 slices
5 random seeds

FWHM = 25 fs

Average radiation energy & power at SASE2 – 0.25 nC

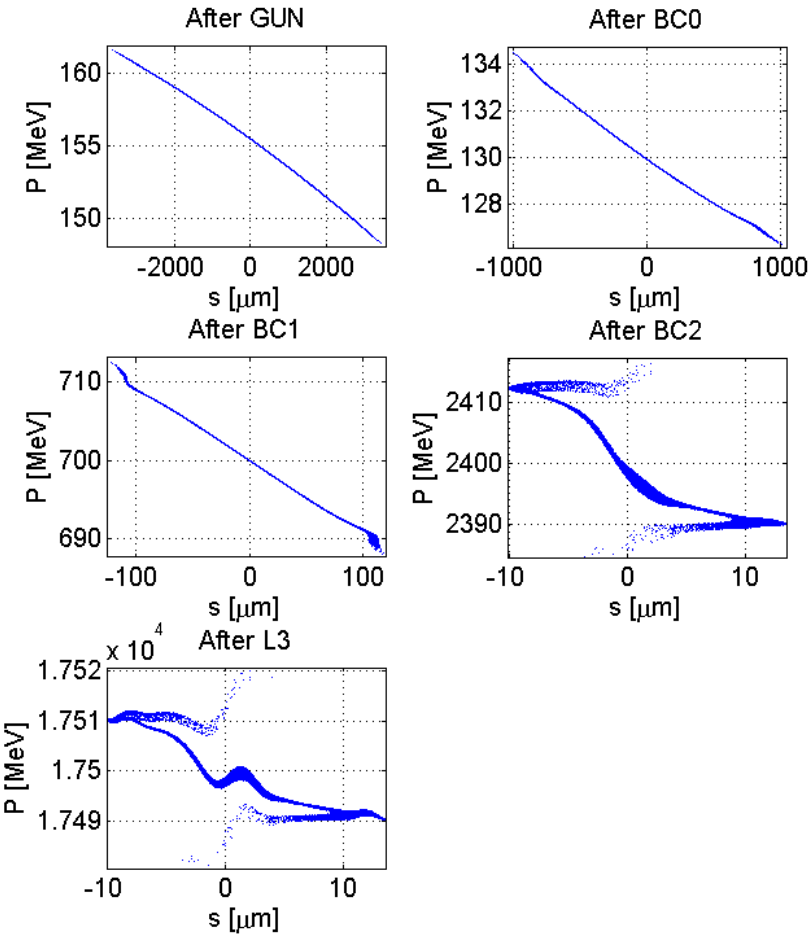


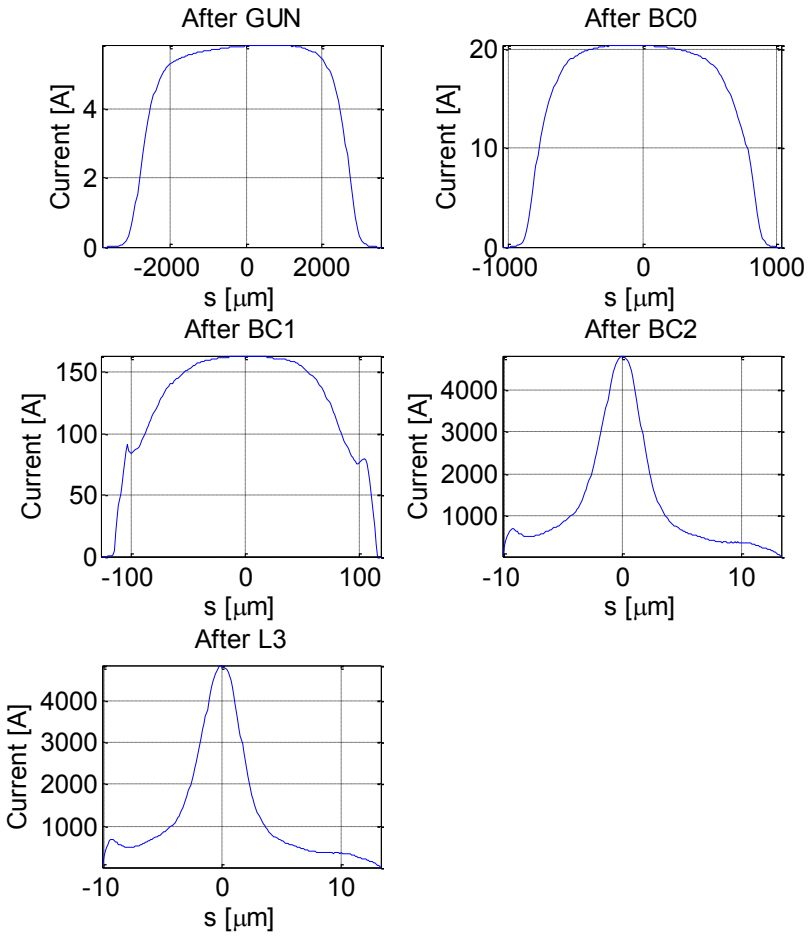


Averaged through 2906 slices
5 random seeds

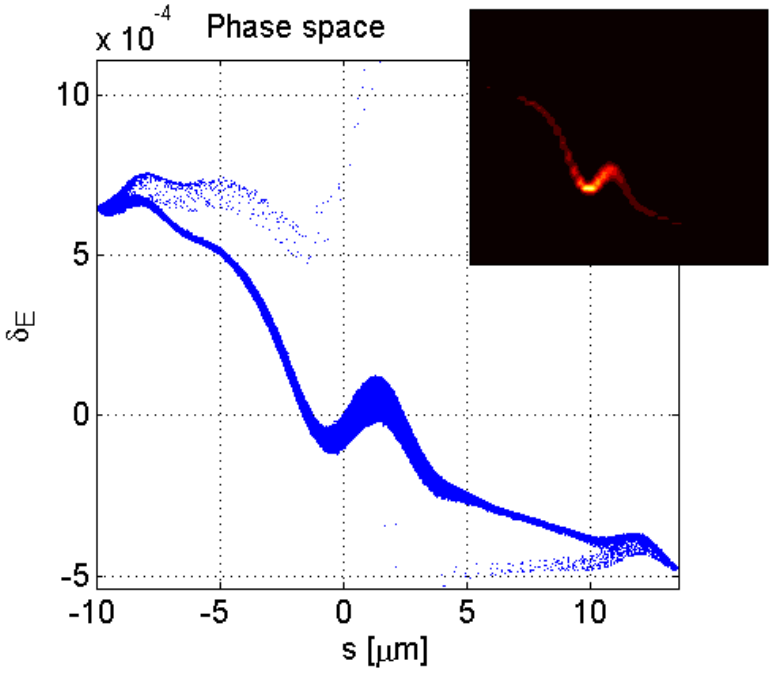
FWHM = 19 fs

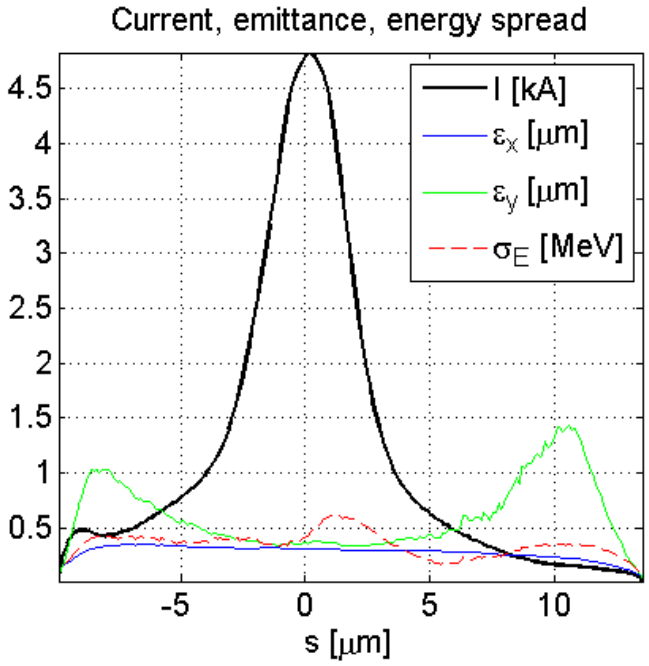
Longitudinal phase space & beam current – 0.1 nC





Beam profile after L3 – 0.1 nC





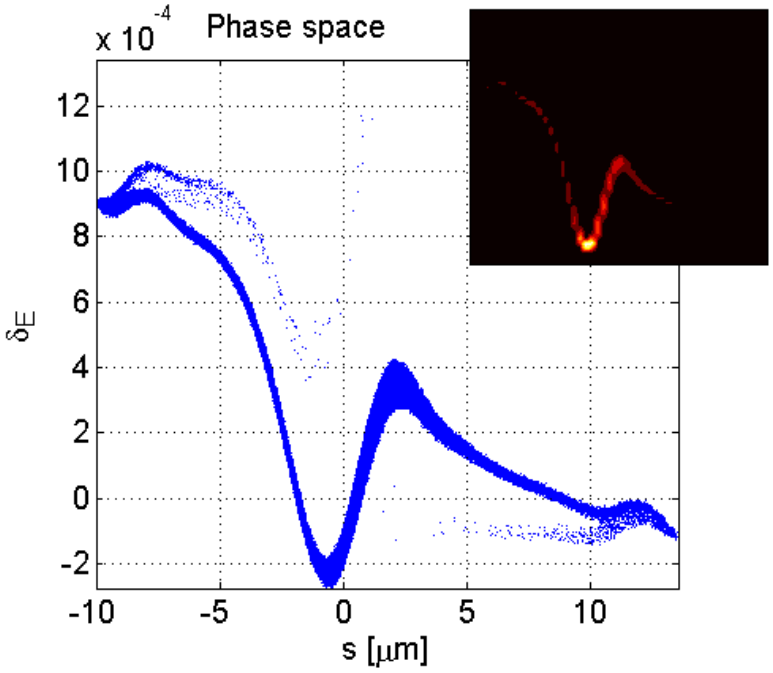
Remove about 6% bad particles in the analysis

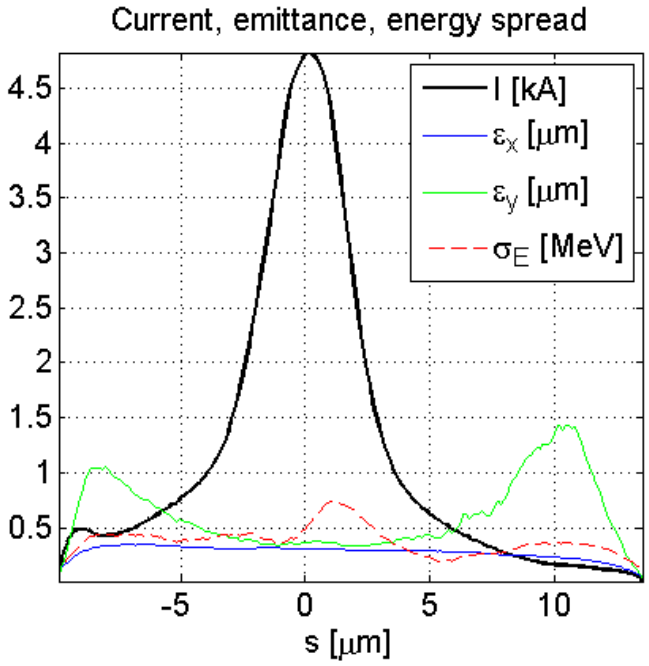
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.5 μm

FWHM = 13.3 fs

Beam profile before SASE1 (TD2) – 0.1 nC





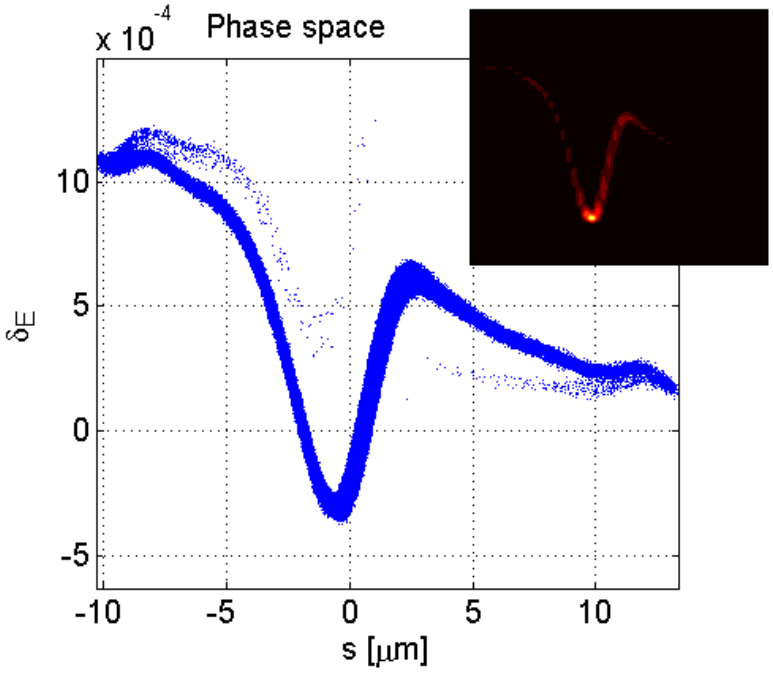
Remove about 6% bad particles in the analysis

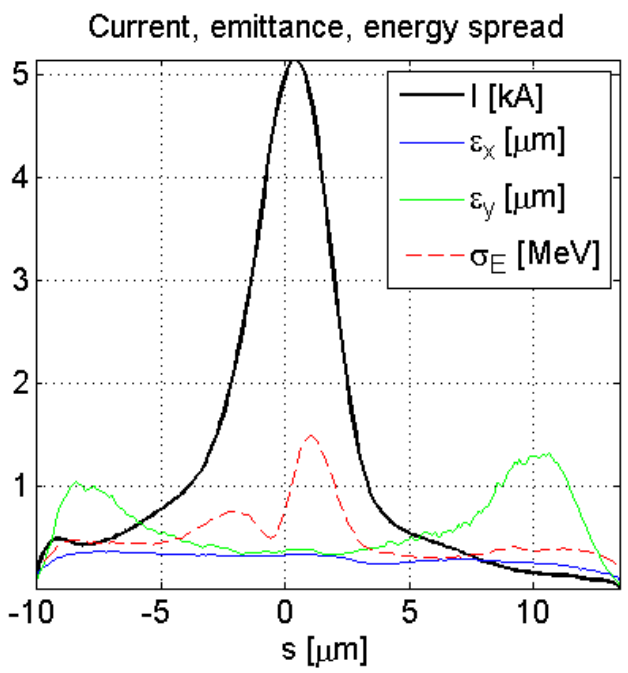
$\varepsilon_{proj,x}$ = 0.5 μm

$\varepsilon_{proj,y}$ = 1.5 μm

FWHM = 13.4 fs

Beam profile before SASE2 (TD1) – 0.1 nC





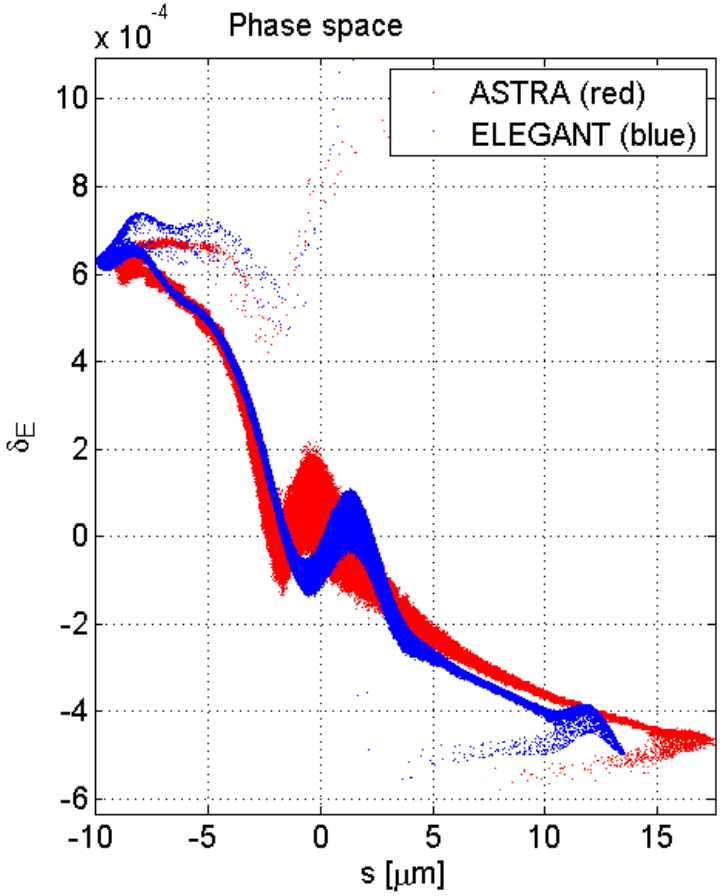
Remove about 6% bad particles in the analysis

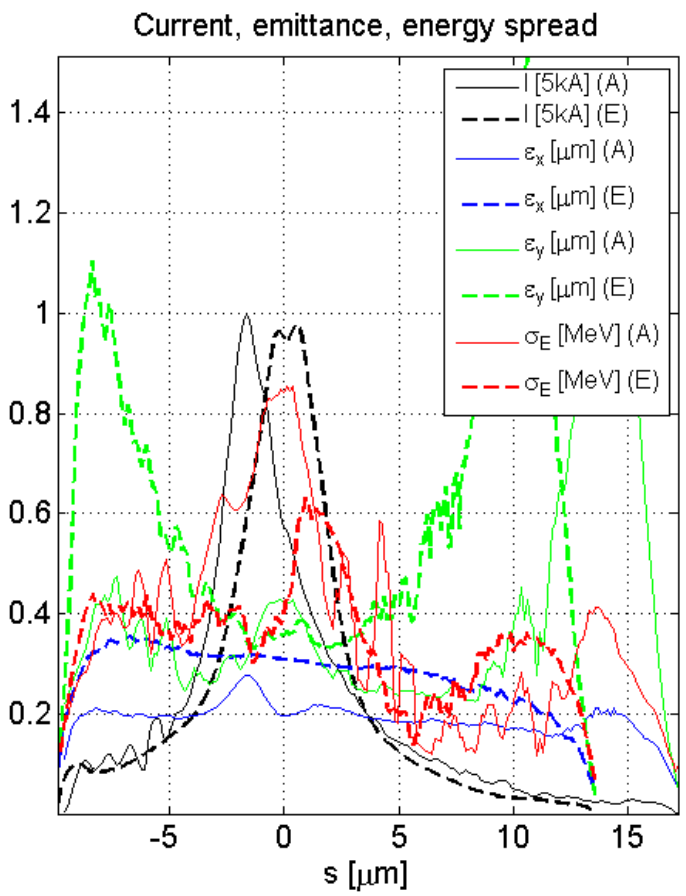
$\varepsilon_{proj,x}$ = 1 μm

$\varepsilon_{proj,y}$ = 2.2 μm

FWHM = 12.1 fs

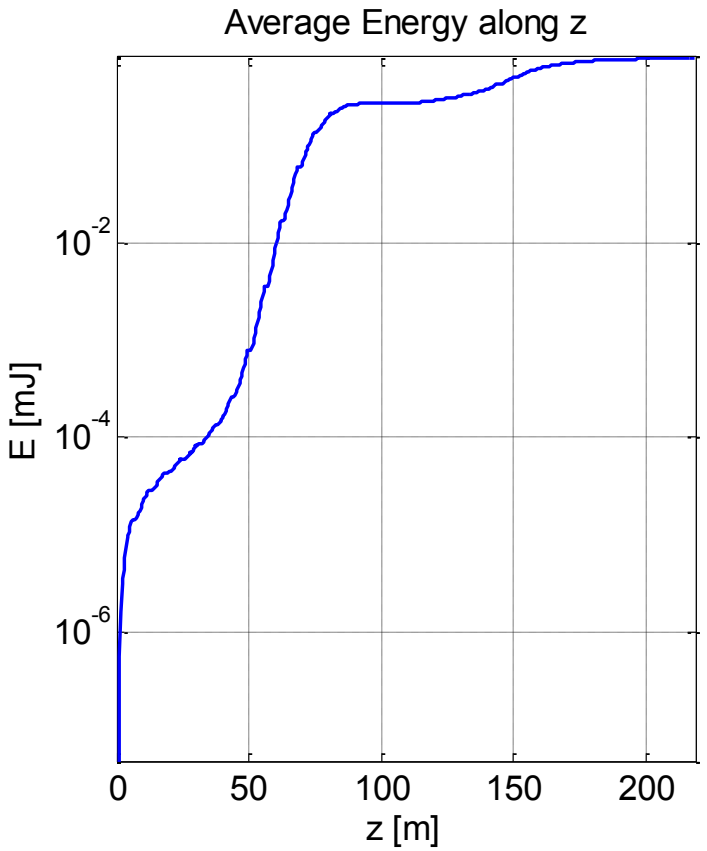
Comparison of beam profiles between ELEGANT and ASTRA+CSRtrack after L3 – 0.1 nC

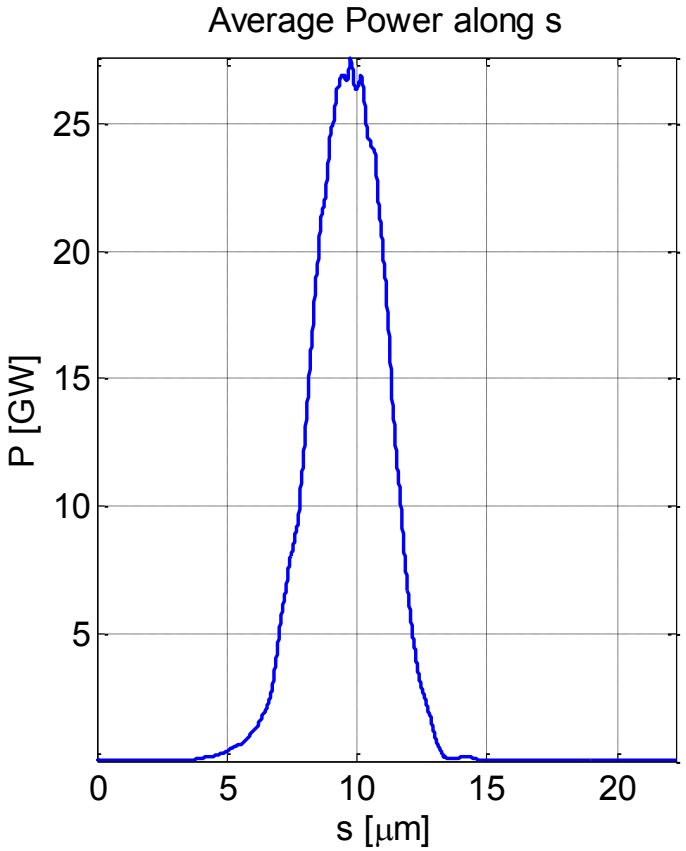




	V11 [MV]	f11 [deg]	V13 [MV]	f13 [deg]	V2 [MV]	f2 [deg]	V3 [MV]	f3 [deg]
Jin (AST+ELE)	164.2	25.0	27.1	199.4	644.6	27.8	1865.5	24.2
Feng (AST+CSR)	156.7	18.0	25.6	184.1	639.6	27.2	1831.2	21.5

Average radiation energy & power at SASE1 – 0.1 nC

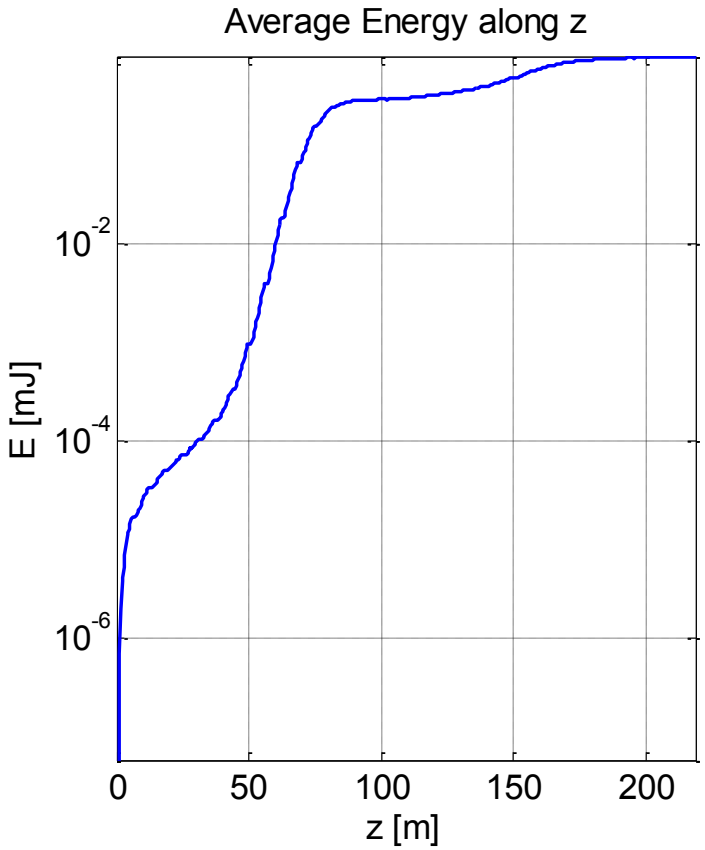


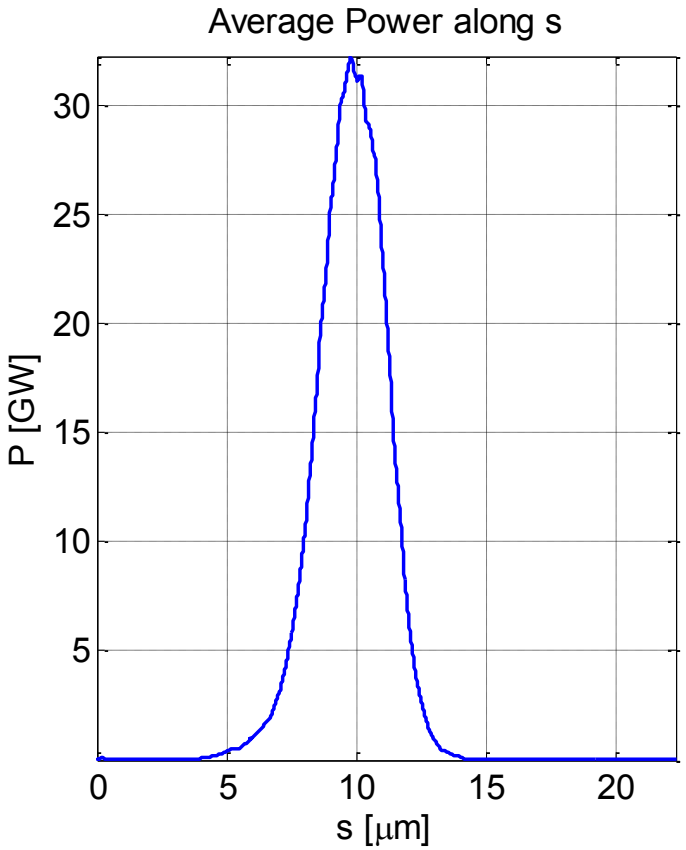


Averaged through 1563 slices
5 random seeds

FWHM = 10 fs

Average radiation energy & power at SASE2 – 0.1 nC

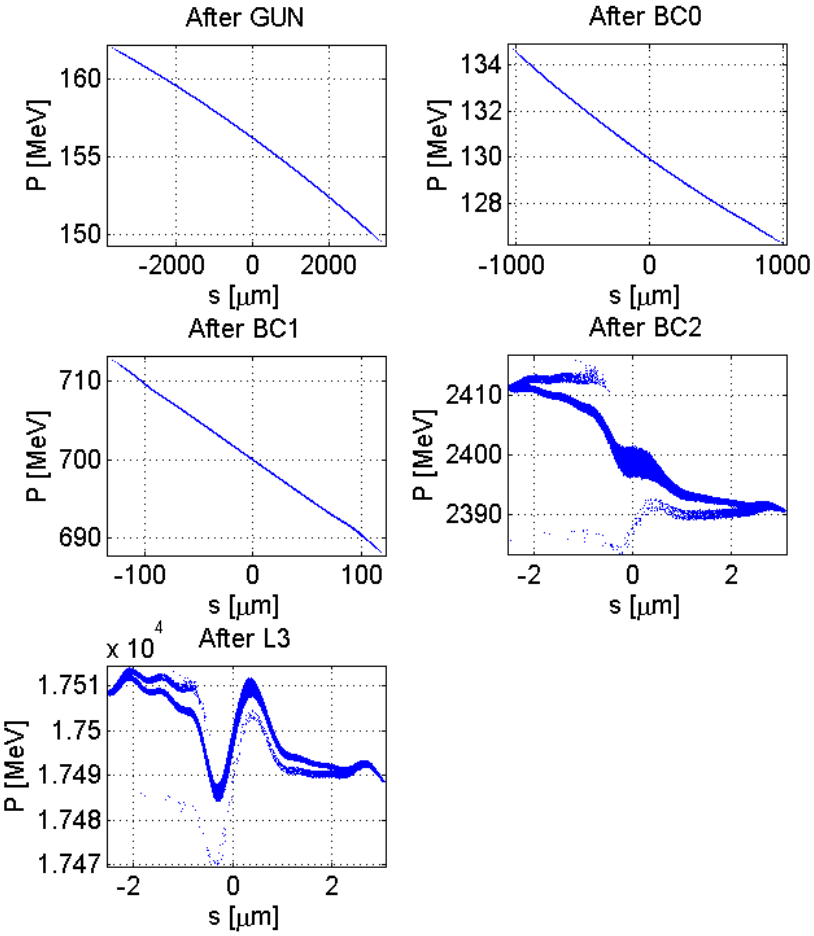


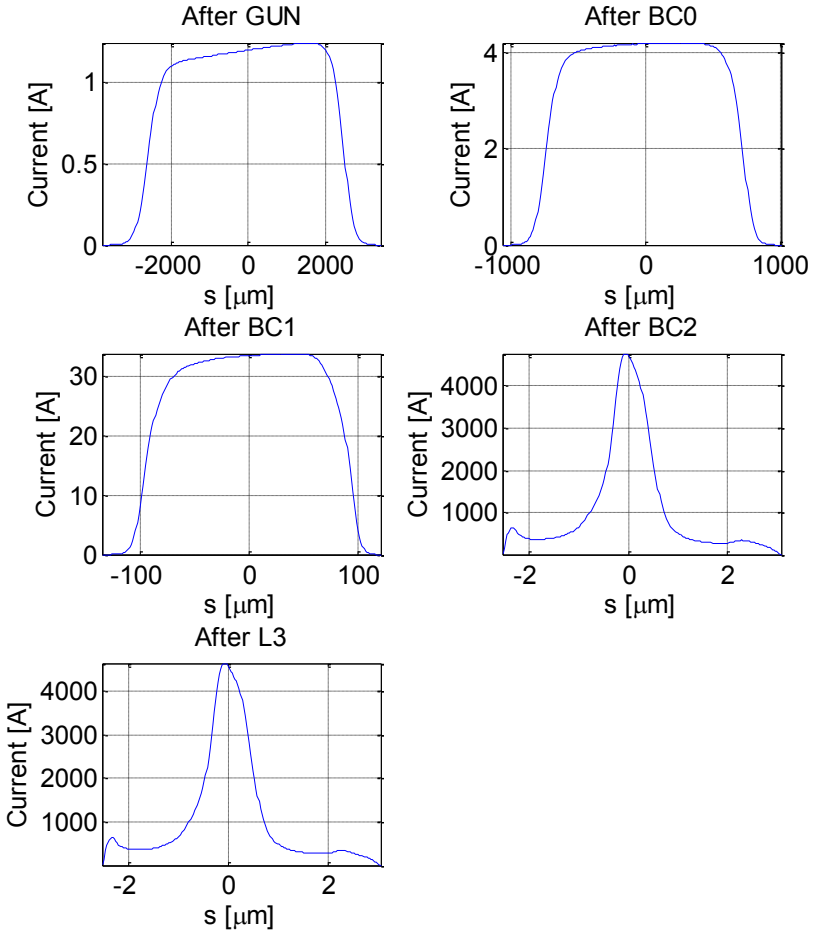


Averaged through 1565 slices
5 random seeds

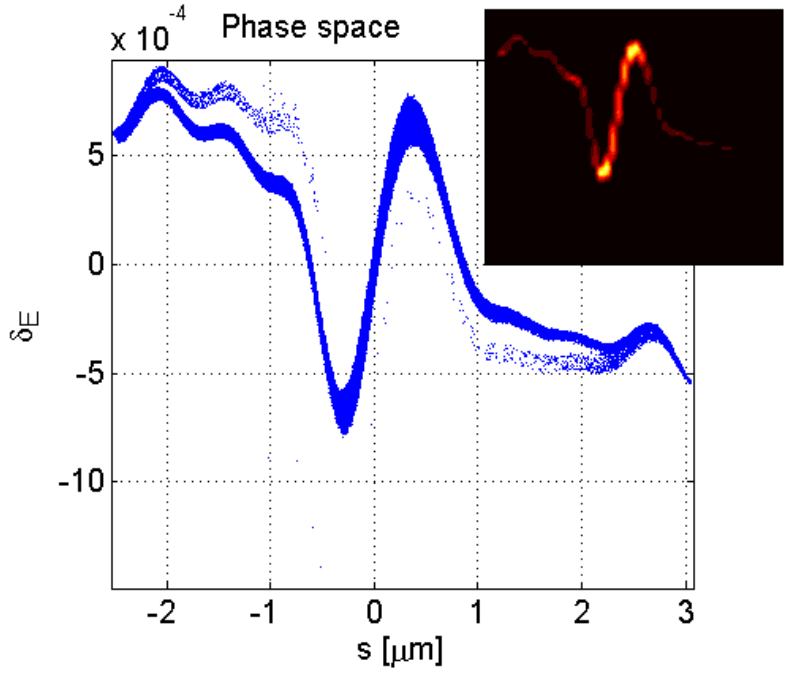
FWHM = 9 fs

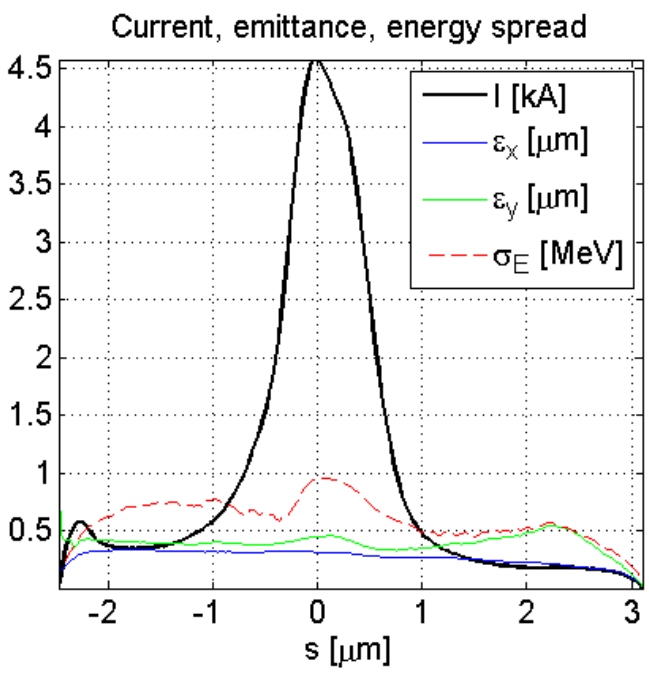
Longitudinal phase space & beam current – 0.2 nC





Beam profile after L3 - 0.02 nC





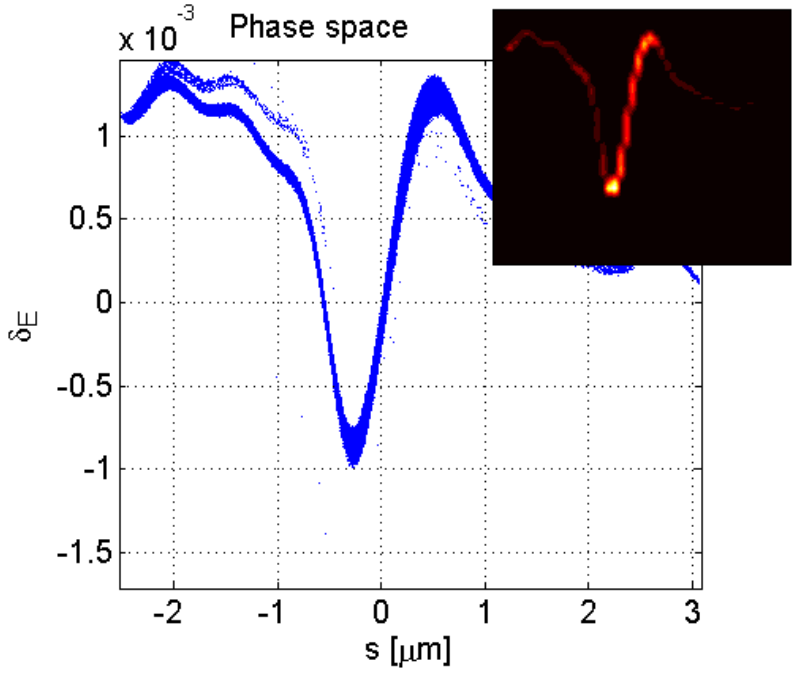
Remove about 6% bad particles in the analysis

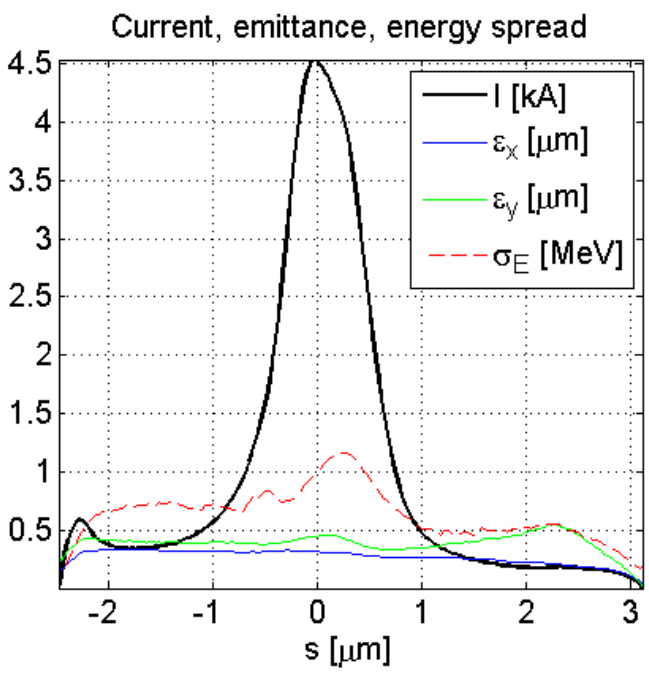
$\varepsilon_{proj,x}$ = 0.3 μm

$\varepsilon_{proj,y}$ = 0.7 μm

FWHM = 2.8 fs

Beam profile before SASE1 (TD2) – 0.02 nC





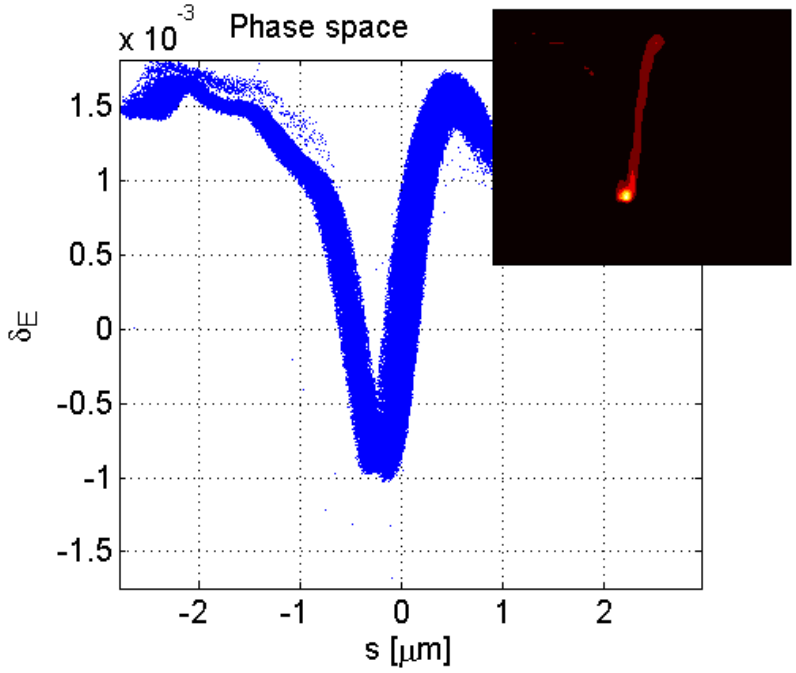
Remove about 6% bad particles in the analysis

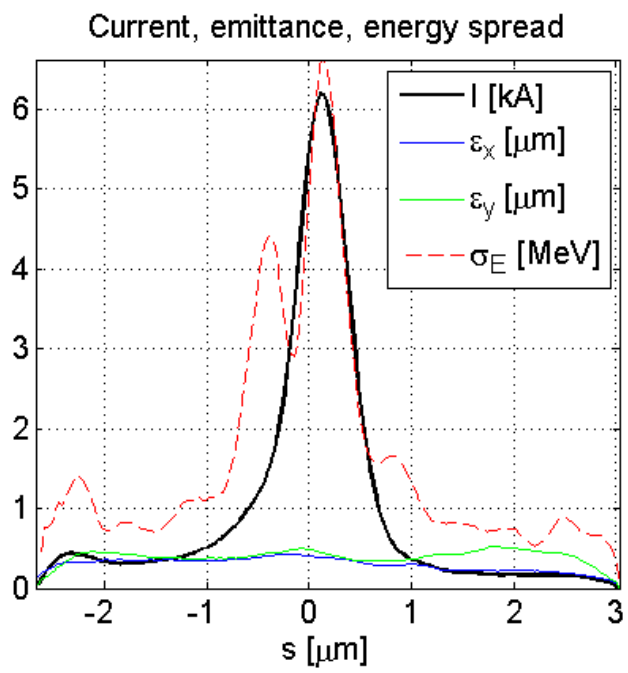
$\varepsilon_{proj,x}$ = 0.3 μm

$\varepsilon_{proj,y}$ = 0.7 μm

FWHM = 2.8 fs

Beam profile before SASE2 (TD1) – 0.02 nC





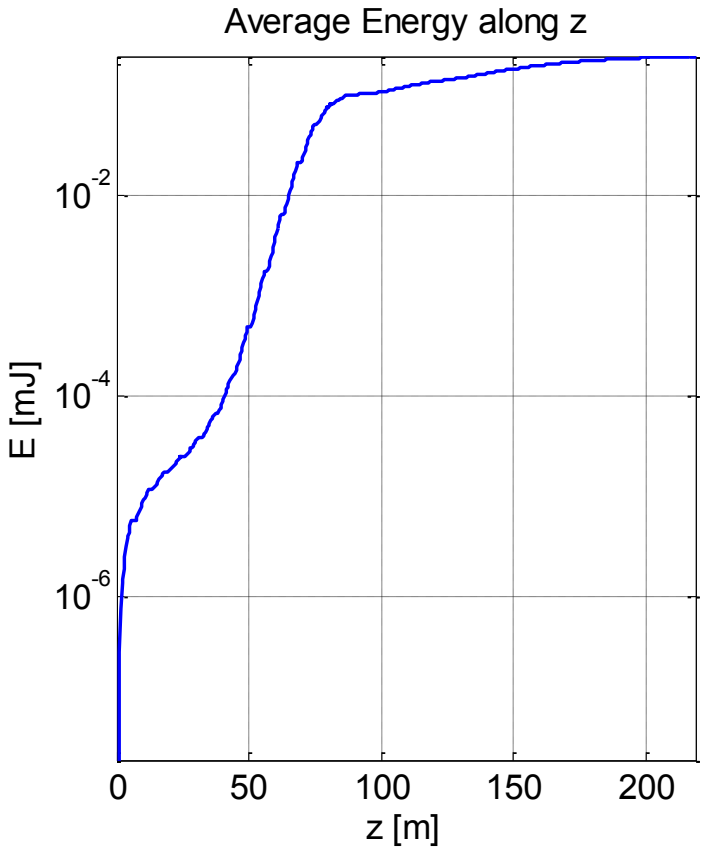
Remove about 6% bad particles in the analysis

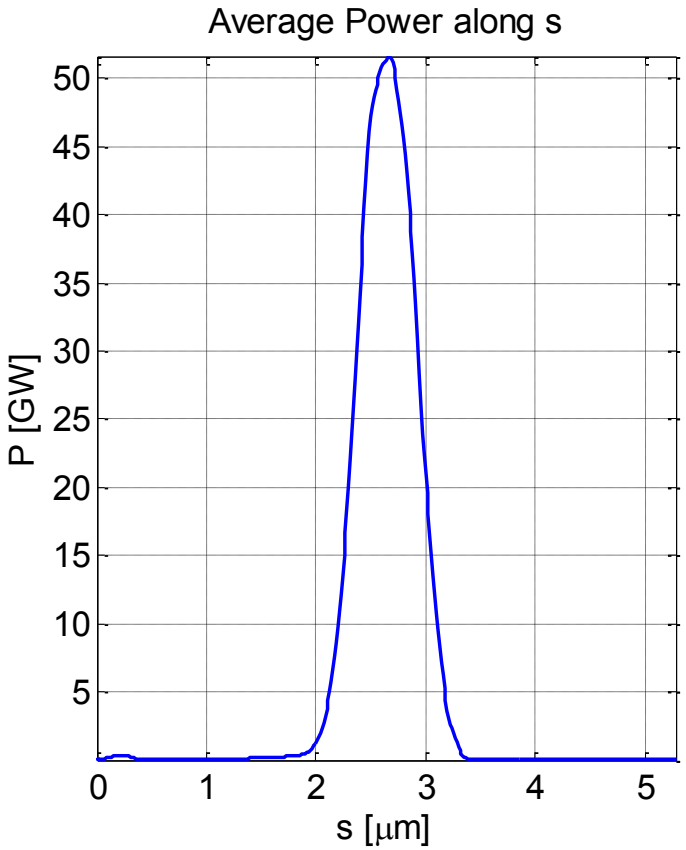
$\varepsilon_{proj,x}$ = 0.9 μm

$\varepsilon_{proj,y}$ = 2.3 μm

FWHM = 1.9 fs

Average radiation energy & power at SASE1 – 0.02 nC

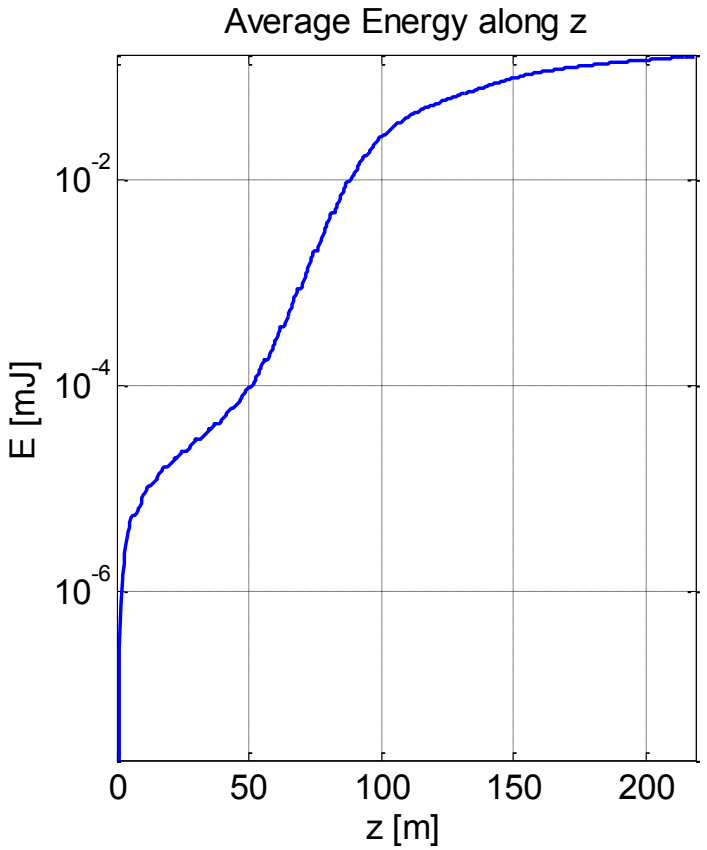


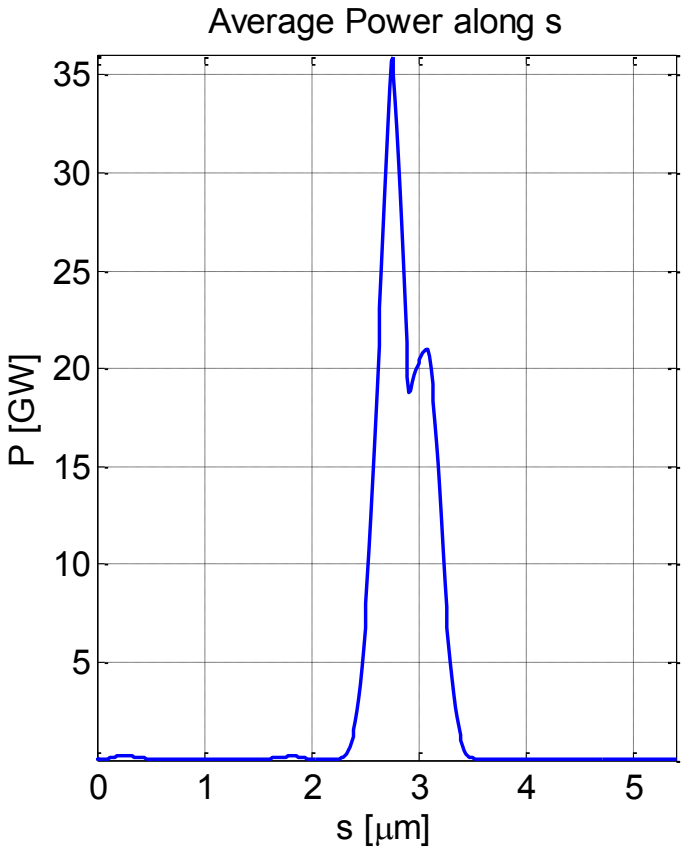


Averaged through 371 slices
5 random seeds

FWHM = 2 fs

Average radiation energy & power at SASE2 – 0.02 nC

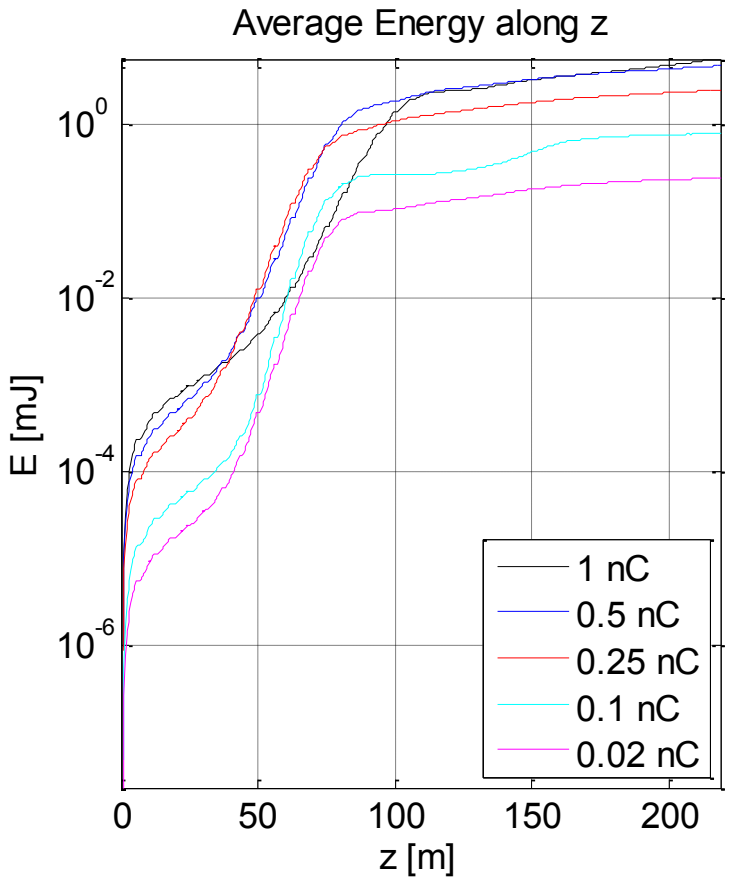


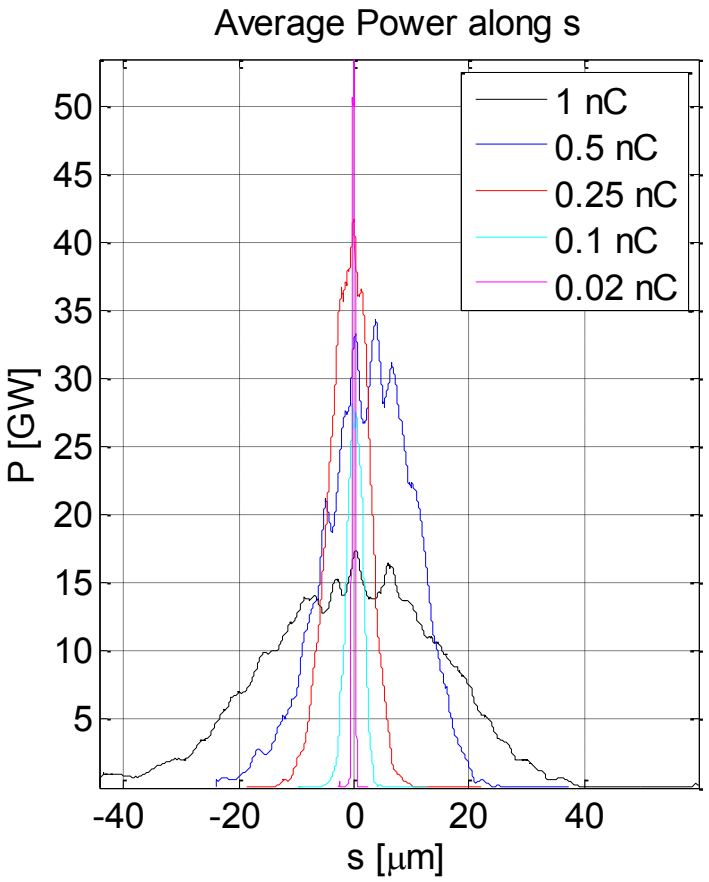


Averaged through 379 slices
5 random seeds

FWHM = 2 fs

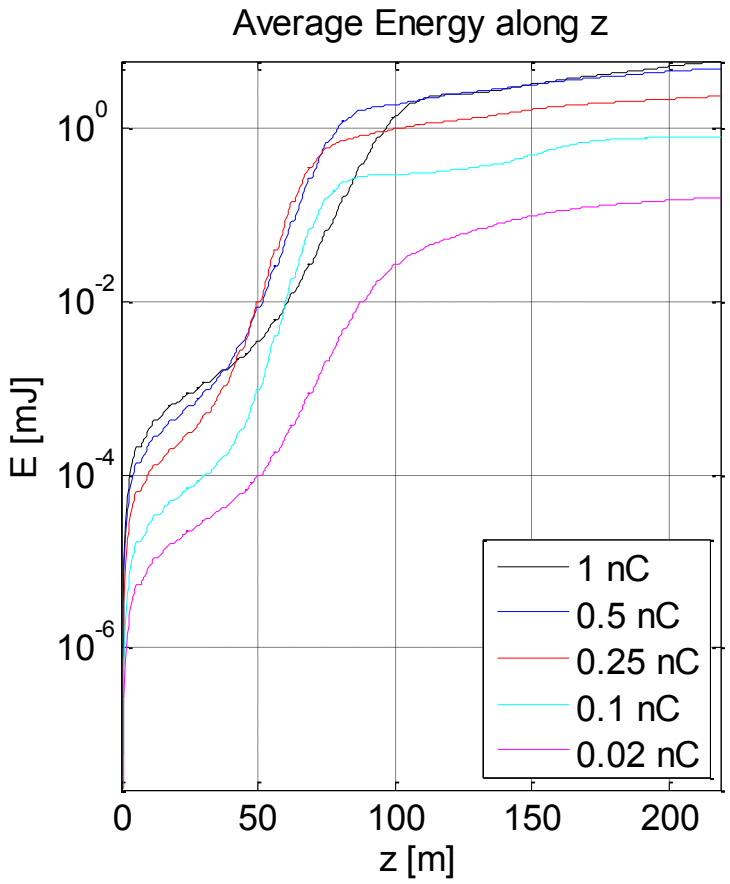
Average radiation energy & power at SASE1

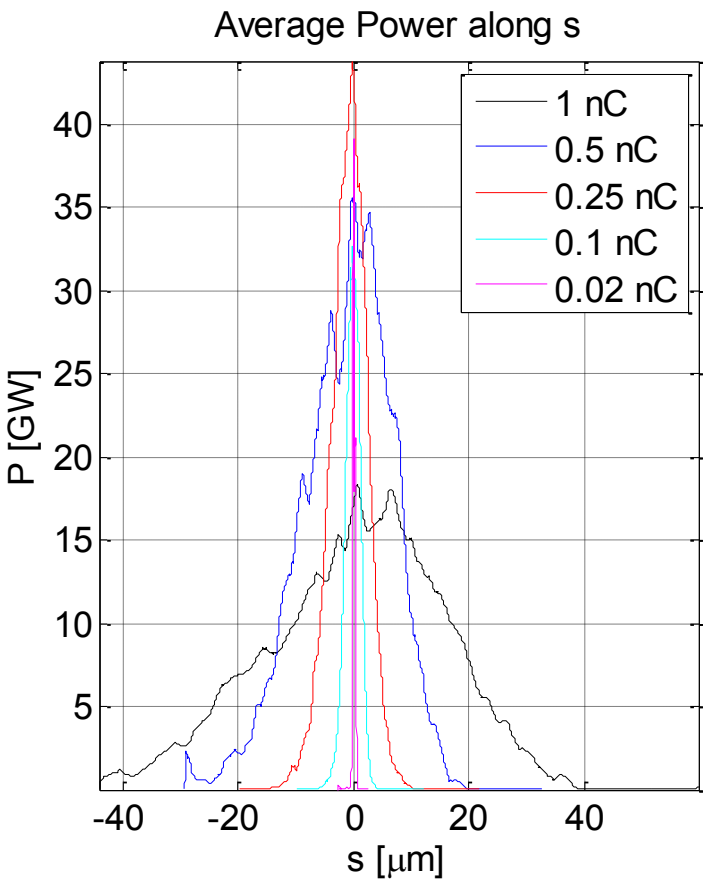




5 random seeds

Average radiation energy & power at SASE2





5 random seeds

Summary

		1 nC	0.5 nC	0.25 nC	0.1 nC	0.02 nC
Total compression		121	217	385	870	4237
Peak current before SASE1/SASE2	kA	5.4/5.6	5.6/5.6	5.5/5.6	5.0/5.4	4.8/6.5
Bunch length, FWHM before SASE1/SASE2	fs	152/147	69.1/67.5	31.9/30.8	13.4/12.1	2.8/1.9
Slice emittance before SASE1 (H/V)	μm	0.59/0.74	0.39/0.45	0.35/0.36	0.31/0.35	0.31/0.42
Slice emittance before SASE2 (H/V)	μm	0.60/0.75	0.41/0.45	0.35/0.36	0.33/0.37	0.39/0.45
Projected emittance before SASE1 (H/V)	μm	0.73/1.62	0.49/1.27	0.53/1.37	0.51/1.55	0.34/0.73
Projected emittance before SASE2 (H/V)	μm	0.84/1.80	0.69/1.39	0.80/1.54	1.07/2.25	0.87/2.31
Slice energy spread before SASE1/SASE2	MeV	0.12/0.22	0.15/0.24	0.22/0.32	0.54/0.99	0.99/4.97
Peak average radiation power (SASE1/SASE2)	GW	21/23	40/43	46/50	33/37	55/42
Radiation pulse duration, FWHM (SASE1/SASE2)	fs	117/86	58/56	25/19	10/9	2/2