LCLS-II Technical Note

LCLS-II Standard Configuration with a Gaussian-Profile Injector Laser

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Abstract:

In this technical note we list the standard configuration for the LCLS-II SC-linac with bunch charge of 20 pC, 50 pC and 100 pC, respectively. The injector laser has a Gaussian-shape temporal profile. For all the three bunch charges, we optimized the linac settings with fixed BC1 and BC2 R56 values.

1 Introduction

In the previous LCLS-II design studies, the injector laser was based on a flat-top temporal profile and the beam and FEL simulations are summarized in the technical note LCLS-II-TN-17-04 [1]. During Early Injector Commissioning (EIC), a Gaussian shape injector laser was used. Although laser shaping to get a flat-top temporal profile is under development, we are preparing to continue with the Gaussian-profile laser during the linac and FEL commissioning. To investigate the beam and FEL performance with such a laser, optimization with a bunch charge of 100-pC has been performed and summarized in a technote LCLS-II-TN-20-03 [2], and a standard configuration has been discussed there. Recently we performed more studies including 20 pC bunch and corrected the injector settings for the buncher voltage limit (buncher voltage was set higher than achievable for 50 pC in [2]). In this technical note we summarize a "standard" machine configuration which requires minimum changes on the pulse duration of the injector laser and uses the same BC1/BC2 R56 settings at different charges.

2 The injector and linac/chicane settings

After many iterations on the injector optimization with varying the laser pulse duration and iris size, we choose to use 15 ps FWHM Gaussian shape laser for 20 pC and 50 pC bunches, and 20 ps FWHM duration for 100 pC bunch. All thermal emittance values in Astra [3] simulations are set to 0.8 μm/mm (MTE is 330 meV). An example of the Pareto-front curve of emittance versus bunch length for injector optimization is attached in the Appendix Figure 6.

We list the injector settings for the three bunch charges in Tabel-1. Note in the Astra input deck, the peak gradient is used. For the LCLS-II SRF cavity, the peak gradient 32 MV/m is equivalent to an average gradient 16.6 MV/m (the ratio of peak and average gradient is 1.93); the buncher peak gradient 1.8 MV/m is equivalent to a total voltage of 205 kV. The cathode gradient used was 20 MV/m for all the cases. Based on these settings, the 20 pC, 50 pC and 100 pC cases all have an output energy of about 100 MeV at the exit of the first cryomodule. For downstream linac settings, we performed all the

Elegant [4] tracking with scaling the injector output beam energy to be exact 100 MeV, and two examples of the 100 pC case with slightly different final current profile are included. Recently in version R2.0 we updated the 100-pC case using the actual beamline layout as installed in the tunnel (the 20-pC and 50-pC simulation results performed before have already been based on the actual beamline layout).

Table-1: Injector parameter for 20pC/50pC/100pC with a Gaussian shape laser.

	20pC	**50 pC**	**100 pC**
Laser length (fwhm) (ps)	**15**	**15**	**20**
Iris **diameter** (mm)	0.6	0.6	1.0
Injector σ_z (mm)	**0.720**	**0.725**	**1.0**
100% (95%) norm. emittance (um)	0.27(0.18)	0.38(0.27)	0.55(0.36)
Kinetic Energy (MeV)	100.8	99.9	100.1
Gun phase (deg)	-13	8	8.5
Buncher Gradient (peak, MV/m)	1.8	1.8	1.8
Buncher phase (deg)	-50.7	-64	-88.5
Cavity 1-4 **avg**. gradient (MV/m)	6.2, 5.2, 14.0, 5.2	8.8, 7.0, 6.2, 8.3	5.7, 0, 13.47, 10.88
Cavity 1-4 phase (deg)	-8, -25, 20, -7	-40, 10, 20, 15	8, -9, -20, 26
Cavity 5-8 **avg**. gradient (MV/m)	16.6	16.6	16.6
Cavity 5-8 phase	0, 0, 0, 0	0, 0, 0, 0	0, 0, 0, 0
Solenoid peak strengths 1-2 (T)	0.0555, 0.0322	0.0557, 0.0311	0.056, 0.03

The linac and chicane settings are listed in Table-2. For the 100 pC case, we show two possible configurations, one (Setting A) has a better flat time-energy chirp in phase space, while the other one (Setting B) has a more symmetric current profile. For all the cases, the BC1 R56 is fixed at -55 mm, and the BC2 R56 is fixed at -43mm.

Table-2: Linac and chicane settings for 20/50/100pC, using injector output beams from Table-1, respectively.

Parameters	**20 pC**	**50 pC**	**100 pC (A)**	**100 pC (B)**	**unit**
Injector laser	**15**	**15**	**20**	**20**	ps
Inj. beam E	100	100	**100**	**100**	MeV
Inj. beam σ_z	**0.72**	**0.725**	**1.0**	**1.0**	mm
Laser heater	4	6-7	5 - 7	5 - 7	keV
L1 amplitude	235.4	230.3	231	225	MV
L1 phase	-27.4	-25.4	-24.9	-23.8	deg
L1H phase	-170	-170	-172.5	-170	deg
L1H Amp.	60	59	60	57	MV
BC1 Energy	250	250	250	250	MeV
BC1 R56	**-53**	**-53**	**-53**	**-53**	**mm**
L2 amplitude	1329.5	1405	1476	1477	MV
L2 phase	-19.86	-27.2	-32.1	-32.2	deg
BC2 energy	1500	1500	1500	1500	MeV
BC2 R56	**-45**	**-45**	**-45**	**-45**	**mm**
L3 amplitude	2500	2500	2500	2500	MV
L3 phase	0	0	0	0	deg
final energy	4000	4000	4000	4000	MeV

3 Tracking examples for three bunch charges

3.1 Elegant tracking with 20-pC bunch

From the Astra output using the parameters listed in Table 1, we performed Elegant simulations after optimizing the linac/compressor configuration using LiTrack. We show the beam longitudinal phase space and current profile along the beamline in Figure 1.

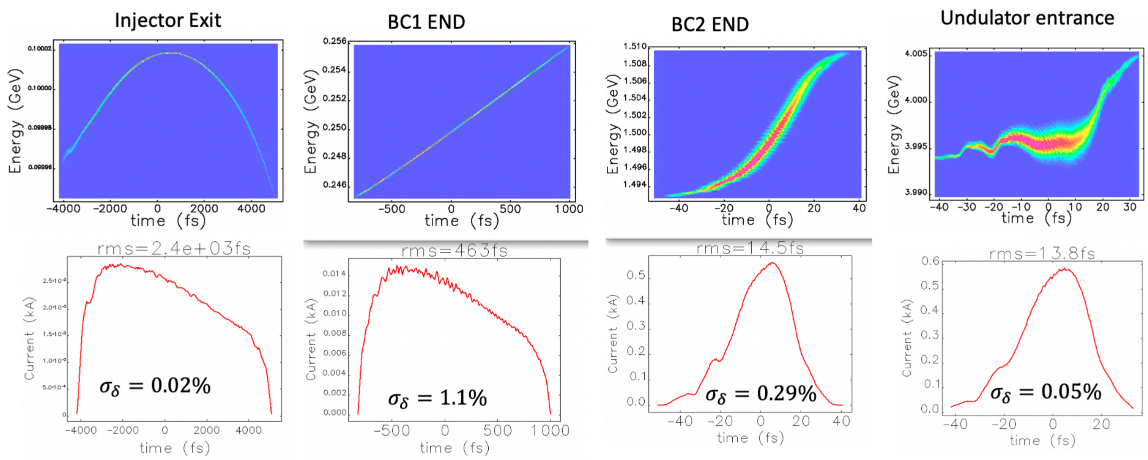

Figure 1: longitudinal phase space and current profile at the injector exit, BC1 exit, BC2 exit, and undulator entrance for bunch charge of 20 pC, using the injector and linac settings shown in Table-1 and Table-2.

3.2 Elegant tracking with 50-pC bunch

The tracking results with 50 pC bunch charge are shown in Figure 2.

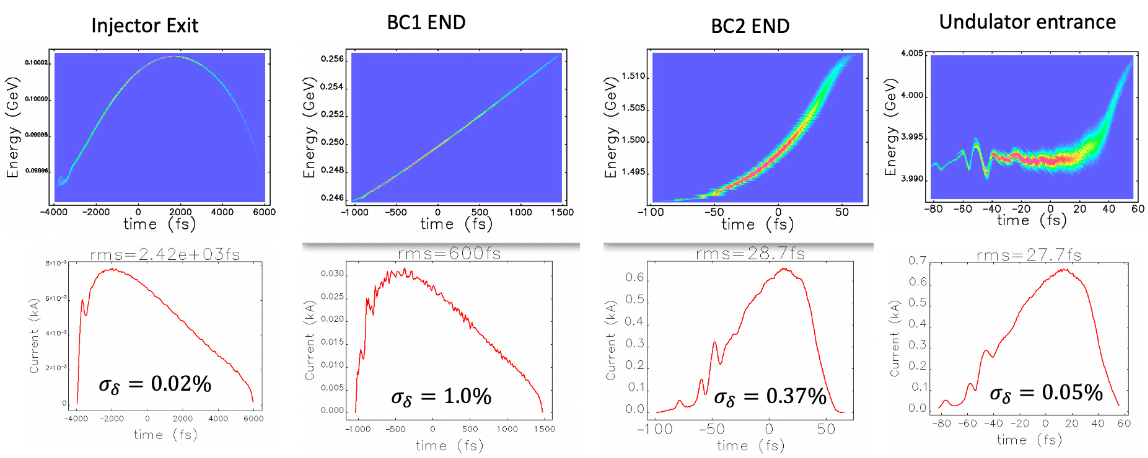

Figure 2: longitudinal phase space and current profile at the injector exit, BC1 exit, BC2 exit, and undulator entrance for bunch charge of 50 pC, using the injector and linac settings shown in Table-1 and Table-2.

3.3 Elegant tracking with 100-pC bunch

For the 100-pC bunch charge, we have two linac settings (A and B) as shown in Table 2. We show the tracking results in Figure 3 (setting A) and 4 (setting B). We can see from Figure 3 that the final current profile is a bit asymmetric with setting A. We keep this current profile to balance with the longitudinal space charge force especially on the bunch head section, so the beam chirp is mostly flat. Then we adjusted the harmonic linearizer and L1 linac as well, the current profile is becoming more symmetric, but the phase space distribution is slightly affected as well.

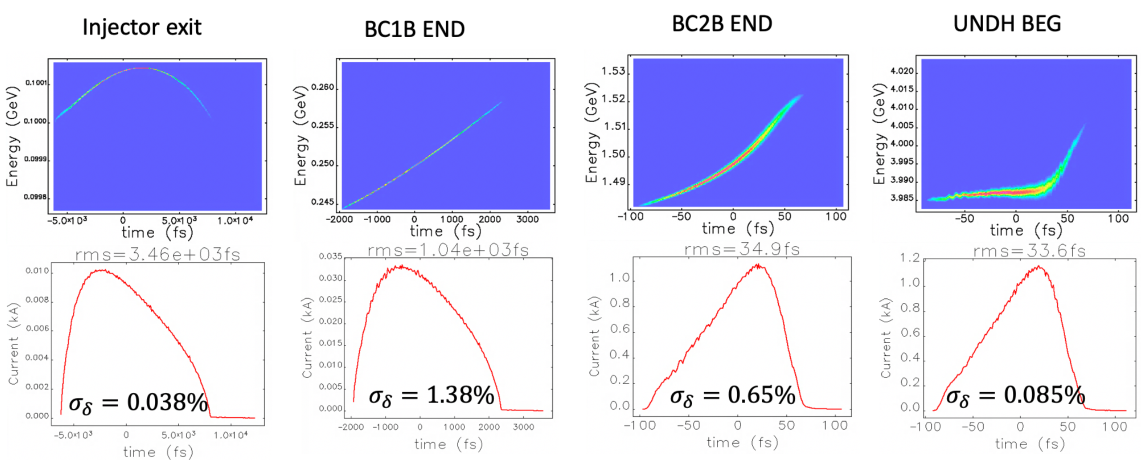

Figure 3: longitudinal phase space and current profile at the injector exit, BC1 exit, BC2 exit, and undulator entrance for bunch charge of 100 pC, using the injector and linac settings shown in Table-1 and Table-2 (100pC A).

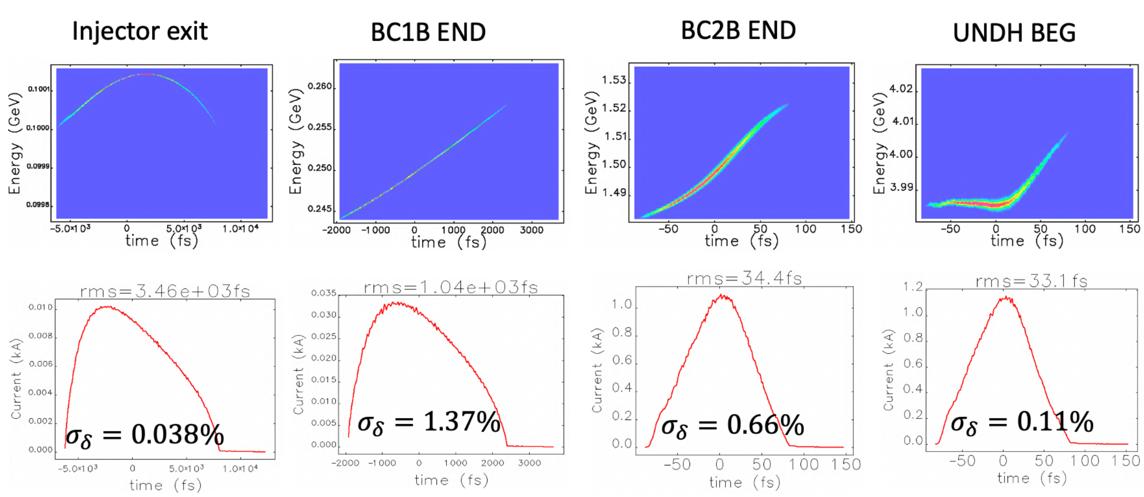

Figure 4: longitudinal phase space and current profile at the injector exit, BC1 exit, BC2 exit, and undulator entrance for bunch charge of 100 pC, using the injector and linac settings shown in Table-1 and Table-2 (100pC B).

4 Summary

We discussed a standard machine setting for 20 pC, 50 pC and 100 pC using a Gaussian shape injector laser, with fixed BC1 and BC2 R56 for all the cases. The tracking shows encouraging results for achieving good beam current profile and phase space at the undulator.

Impact [5, 6] simulations with 3-D space charge could be further used for verification, but the benchmark in [2] using 100 pC bunch shows the Elegant results are reliable in our parameter range.

5 Appendix

5.1 Gaussian laser profile helps suppress the final current horns.

As shown in the previous studies [1], based on a flat-top injector laser, the final beam after compression would typically have current horns especially on the bunch head. In this study, we show that while using a Gaussian shape injector laser, the final current horns after compression will not be formed. This is very interesting, and we further discuss it.

With a copper-structure based linac such as the LCLS, the longitudinal wakefields from the structure will lead to a strong third-order time-energy correlation. This is the main reason that the final beam current profile will have a "double-horn" shape. In the LCLS-II setup, the superconducting linac structure has a larger aperture comparing to the S-band copper linac structure, which would cause less longitudinal wakefields effect. In this condition, the beam high-order time-energy correlation out of the injector (at ~100 MeV) plays an important role affecting the shape of the final current profile.

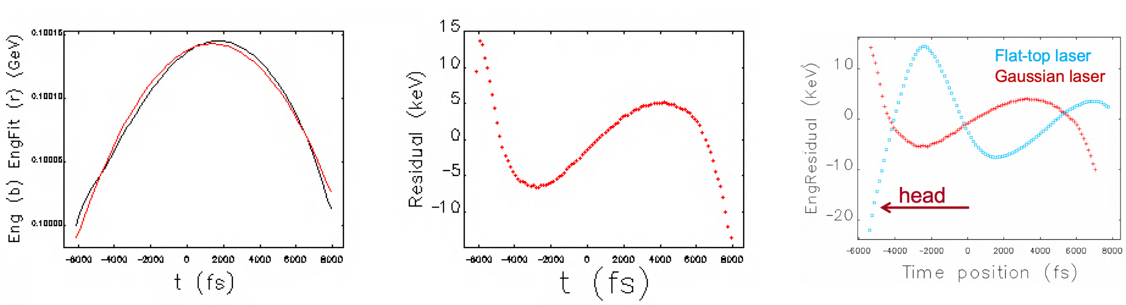

Figure 5: (left) The time-energy phase space (black) at the injector exit from a Gaussian shape injector laser, and the quadratic polynomial fitting (red); (middle) The residual 3rd and higher order time-energy correlation from subtracting the quadratic polynomial fitting as shown in the left plot; (right) The injector beam residual 3rd and higher order time-energy correlation from a flat-top laser (blue), and from a Gaussian laser (red).

We show in Figure 5 the residual 3rd (and higher) order time-energy correlation on the beam from a flat-top injector laser and from a Gaussian laser. A quadratic polynomial fitting has been applied on the time-energy phase space for obtaining the residual energy chirp. We can see from the right plot in Figure 5 that the beam generated from a Gaussian laser has a negative residual chirp on the bunch head, while the beam from a flat-top laser has a positive residual chirp on the bunch head. A positive local chirp at the bunch head for the flat-top laser case would make stronger compression in the downstream bunch compressors and hence form a current spike, while the Gaussian laser generated beam with a negative residual chirp on the bunch head will make less compression and lead to smaller or no local current spikes. This explains how the Gaussian laser helps remove the final current horns as we observed in this technote.

5.2 Injector Beam Optimization

Here we show one example of the injector optimization and where we choose the operating point in this Pareto-front curve. The three circles in the Figure 5 show the three beams we choose to use in Table 1. The flatness in the 20 pC curve is the result of constraining the energy to greater than 100 MeV during optimization. When the energy is constrained to 90 MeV, the curvature of the 20 pC resembles the 100 pC and 50 pC cases.

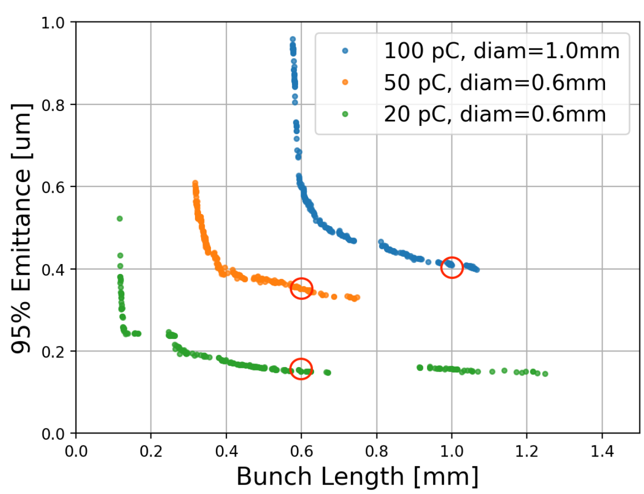

Figure 6: Injector optimization Pareto-front curve with Gaussian laser profile. 20pC and 50 pC used fixed laser pulse duration 15 ps and iris diameter 0.6mm during optimization.

6 Acknowledgements

We thank F. Zhou, C. Mayes, A. Marinelli and P. Emma for helpful discussions.

Reference:

[1] G. Marcus and J. Qiang, LCLS-II technical note LCLS-II-TN-17-04.

[2] N. Neveu et al., LCLS-II technical note LCLS-II-TN-20-03.

[3] K. Floettmann, ASTRA: A Space Charge Tracking Algorithm, https://www.desy.de/~mpyflo/

[4] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced. Photon Source LS-287, September 2000.

[5] J. Qiang, R. D. Ryne, S. Habib, V. Decyk, An object-oriented parallel particle-in-cell code for beam dynamics simulation in linear accelerators, J. Comput. Phys. 163, (2000) p. 434.

[6] J. Qiang, S. Lidia, R. D. Ryne, and C. Limborg-Deprey, A three-dimensional quasi-static model for high brightnees beam dynamics simulation, Phys. Rev. ST Accel. Beams 9, (2006) 044204.