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BENCHMARKING THE LCLS-II PHOTOINJECTOR

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Abstract

Commissioning of the LCLS-II photoinjector started in late 2018. Efforts to accurately model the gun and laser profiles are ongoing. Simulations of the photoinjector and solenoid are performed using IMPACT-T, OPAL-T, and ASTRA. This work includes efforts to use the laser profile at the virtual cathode as the initial transverse beam distribution, and effects of 2D and 3D field maps. Beam size results are compared to experimental measurements taken at the YAG screen located after the gun.

EARLY INJECTOR COMMISSIONING

Construction of a high repetition rate superconducting (SC) Free Electron Laser (FEL) at SLAC has begun. This beam line will deliver X-ray energies up to 25 keV at a rate of 1 MHz. Once completed, the normal conducting Linac (original LCLS), and the SC Linac will operate simultaneously and provide X-rays to multiple users.

The LCLS-II Early Injector Commissioning (EIC) area consists of a 187 MHz quarter cell gun cavity followed by solenoids, a 1.3 GHz two cell buncher, a YAG screen, correctors, BPMs, and current monitors; see Fig. 1 for detailed layout. This gun is based on the APEX gun work done at LBNL [1]. Some commissioning goals include dark current characterization, production of electron beams with a CsTe cathode, beam based alignments, radiation safety surveys, and continued testing of beam measurement GUIs.

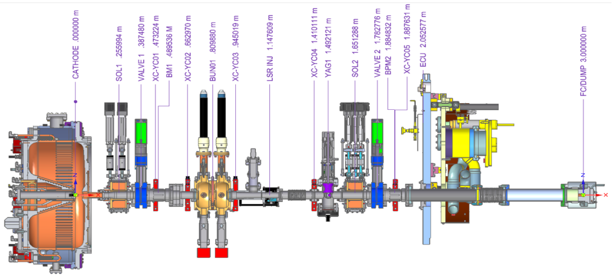

Figure 1: EIC layout, which includes the gun, buncher solenoids and diagnostics.

All simulations and measurements hereafter were preformed with the EIC area as the model. While the buncher has been successfully operated, recent runs have kept the buncher turned off. Therefore the buncher is also off in the following simulations.

SIMULATIONS

Several particle-in-cell codes are freely available and able to simulate the physics present in photoinjectors. While they do not share exactly the same features, typical beam dynamics of interest are included. In this fashion, LCLS-II beam lines are simulated in a variety of codes. For the injector, IMPACT-T [2], ASTRA [3], and OPAL [4] are used. For higher energies or X-ray generation, codes such as Bmad [5], ELEGANT [6], Genesis 1.3 [7], and SRW [8] are used. Often times it is desirable to switch between codes, or use output from one code as input to another. This is usually difficult to accomplish, as each code can have a unique convention.

Table 1: Simulation Inputs for Code Comparison

Parameter	Value
Charge	20 pC
Laser radius	0.5 mm
Laser FWHM	20 ps
Gun phase	Max energy gain
Field on the cathode	20 MV/m
Buncher	Off
Solenoid Strength	0.06 T

The Lightsource Unified Modeling Environment (LUME) is an effort to reduce the start up time associated with using various simulations codes. In addition, emphasis is placed in forming standards for saving simulation data, with the goal of simplifying hand off from one code to another. This work comes in the form of Python 3 wrappers, of which three are currently being developed on GitHub: lume-astra [9], lume-impact [10], and lume-genesis [11]. Lume-astra was used heavily for this work.

Code Comparison

As a quick check to ensure the EIC area was being simulated correctly, two codes were used and results compared. The transverse laser profile was set to a circular and a uniform distribution. The longitudinal profile was Gaussian. Typical EIC commissioning gradient and solenoid strength values were used. Simulation parameters can be found in Table 1. For these settings, good agreement is shown between OPAL and ASTRA in Figs. 2 and 3. This confirms some understanding of how to simulate the gun. Future work will include IMPACT-T in comparisons.

3D Field Maps

It is commonplace for most accelerator design work and optimization to use 1D or 2D field maps at the start of a project. This reduces the time to simulation, and allows for analysis of results quickly. Often the accuracy is adequate depending on the project goals. Such maps were used for the simulations in the previous section (Fig. 3), with no asymmetries in the traverse fields assumed.

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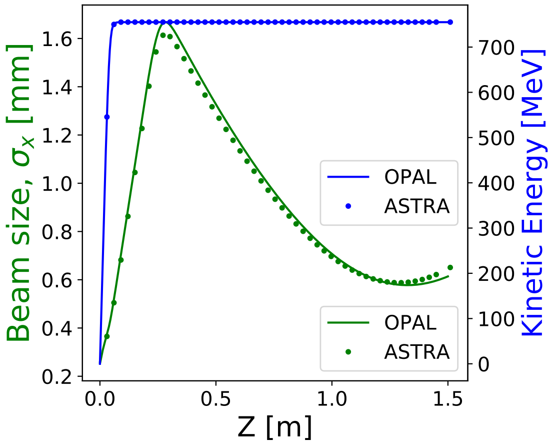

Figure 2: Comparison of beam size and energy out of the LCLS-II gun. The codes OPAL and ASTRA were used.

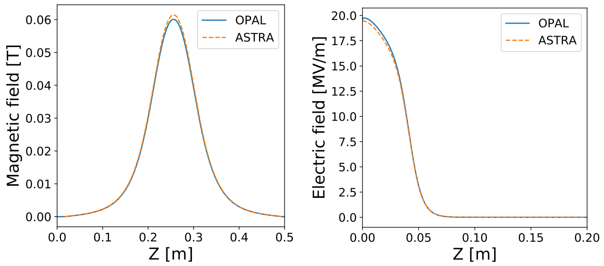

Figure 3: Comparison of electric and magnetic fields used in ASTRA and OPAL. Perfect symmetry is assumed.

The LCLS-II gun has been simulated in ACE3P [12] and 3D field maps are now available, see the electric fields in Fig. 4. The beam dynamics showing in Fig. 2, will be re-simulated with the 3D rf fields shown in Fig. 4, and if no substantial difference in beam parameters are seen, this will serve as a confirmation that the relevant physics parameters are captured by the 1D or 2D maps. Or, if some differences are observed, this can be taken into account for future simulations.

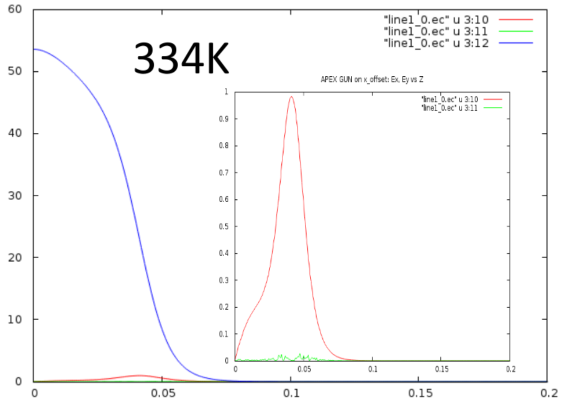

Figure 4: Plot of 3D electric fields in the LCLS-II gun, courtesy L. Xiao.

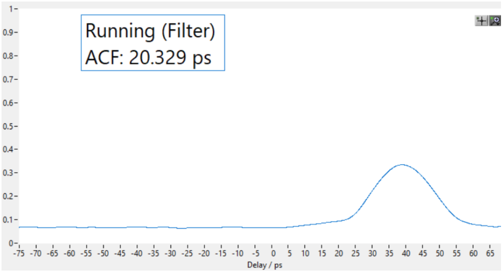

Figure 5: Longitudinal laser profile, as measured by the cross-correlator in the laser room, courtesy S. Droste.

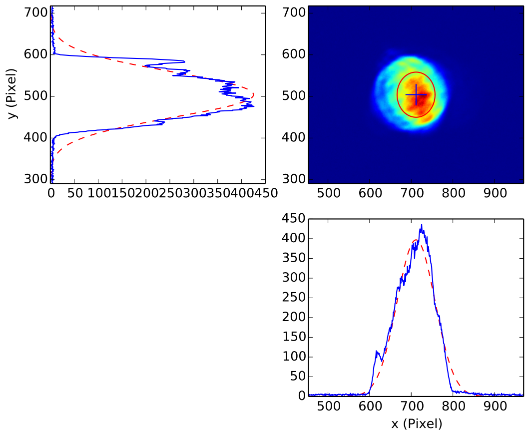

Figure 6: Recorded VCC image. This is the transverse laser profile distribution that will hit the cathode. This image was used in the OPAL-T simulation shown in this section.

LASER PROFILE

The LCLS-II laser system is described in [13]. Current set up of the laser produces a Gaussian longitudinal profile with a FWHM of about 20 ps as shown in Fig. 5. This configuration was replicated in all simulations shown here. The transverse distribution is controlled by an iris wheel on a laser table in the bunker. The typical radius for EIC operations is 0.5 mm.

Using Virtual Cathode Images

When the laser is running, a small portion of the light is imaged to the Virtual Cathode Camera (VCC). Images taken here closely resemble the laser image on the cathode. During EIC operations, VCC images were recorded as the gun was running. An example from these images is shown in Fig. 6.

Figure 6 indicates the transverse laser profile is not smooth. The effects of this non-uniformity in the laser distribution on the beam dynamics is not clear, so it is desired to study what effect this distribution has on the beam. There are two options available to carry out the study: A) generate an initial particle distribution based on the vcc image, then provide this distribution to simulation codes, or B) provide the laser image to a code to use when generating the particle distribution.

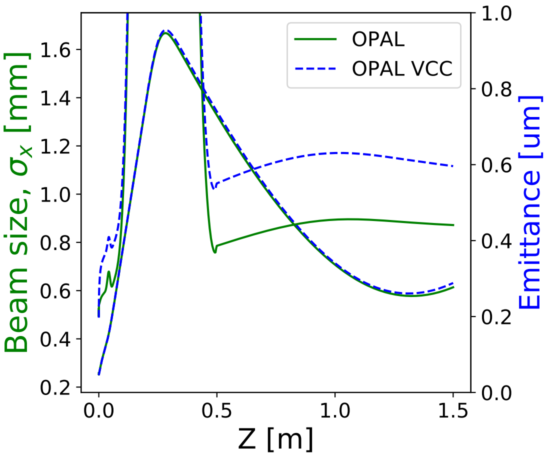

Figure 7: Comparison of beam dynamics using a uniform and vcc image as the transverse beam distribution.

The later method in combination with the image in Fig. 6 was used to simulate the transverse laser distribution on the cathode in OPAL. The results were compared to the nominal uniform distribution case from above. Again, the parameters in Table 1 were used for both simulations, and the results are shown in Fig. 7. The emittance is slightly larger in the VCC case. If the non-uniformity causes a hot spot, i.e. an area with more elections, this emittance growth may be a result of stronger space charge forces in localized areas. In a future study, simulating a range of charges should answer this definitively.

MEASUREMENTS

A combination of MATLAB and Python GUI's are used to take beam measurements on LCLS. This will continue to be the case for LCLS-II.

Beam size

During the last EIC run time, some beam size measurements were recorded with the `ProfMon` MATLAB GUI [14]. During these measurements the gun phase was set for max energy, and the buncher was turned off, and the charge was about 4 pC. The solenoid was scanned through a small range of strength settings. Note, the error bars represent the standard deviation of the data taken. However, due to time limitations, the same number of samples was not taken for each setting. This artificially creates smaller error bars on some points.

Figure 8 shows the comparison between simulation and measured data. While the simulation follows the same trend as the data, they do not match in magnitude. There are several possible reasons that will be investigated. One likely contributor to this error is beam alignment on the cathode and in the solenoid. A careful beam based alignment in the solenoid is scheduled as part of EIC activities, but had not been performed yet at the time this data was taken.

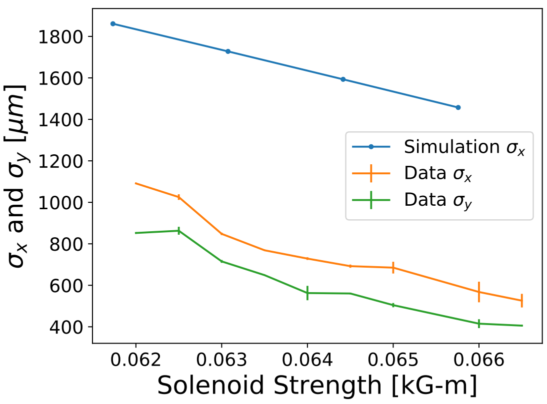

Figure 8: Beam size measurements compared to Astra simulations. All settings were kept constant while the solenoid was scanned.

Emittance GUI

The current emittance measurement GUI is written in MATLAB, and has been used during LCLS operations routinely. Several updates were made to extend use to LCLS-II. This included updating device names to include LCLS-II areas. This allows the GUI to talk to new hardware. Other updates include adjustments of assumptions made in physics code. Calculations that assumed relativistic beam energies were modified to account for low energies out of the gun. The equations were made more general, so that the GUI can work at all energies. An attempt to make an emittance measurement was done. However, the solenoid range was not large enough to capture the beam waist. Due to limited time, the measurement has not been repeated yet. This measurement is scheduled again for the next run time.

CONCLUSION

The as built LCLS-II gun has been simulated in several codes. Work to build out the rest of the beam line is well underway. The longitudinal laser profile is Gaussian, and the transverse is non-uniform. Using the VCC image for the transverse profile showed a slightly larger emittance in simulation. In future work, 3D field maps generated by ACE3P will be used to confirm that off axis fields are not effecting the beam dynamics. The emittance measurement MATLAB GUI was updated to be more general, i.e. handle non-relativistic beams. Emittance measurements will take place during future EIC run time.

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REFERENCES

[1] F. Sannibale *et al.*, "Advanced photoinjector experiment photogun commissioning results," *Phys. Rev. ST Accel. Beams*, vol. 15, p. 103501, Oct 2012.

[2] J. Qiang, R. D. Ryne, S. Habib, and V. Decyk, "An object-oriented parallel particle-in-cell code for beam dynamics simulation in linear accelerators," *J. Comput. Phys.*, vol. 163, no. 2, pp. 434 – 451, 2000.

[3] K. Floettmann, "ASTRA: A Space Charge Tracking Algorithm," 1997-2017.

[4] A. Adelmann *et al.*, "The OPAL (Object Oriented Parallel Accelerator Library) Framework," Tech. Rep. PSI-PR-08-02, Paul Scherrer Institut, 2008-2019.

[5] D. Sagan, "Bmad: A relativistic charged particle simulation library," *Nucl. Instrum. Meth.*, vol. A558, pp. 356–359, 2006.

[6] M. Borland, "Elegant: A flexible sdds-compliant code for accelerator simulation," Tech. Rep. LS-287, Argonne National Laboratory, 2000-2018.

[7] S. Reiche, "Genesis 1.3." `https://github.com/svenreiche/Genesis-1.3-Version2`, 2019.

[8] O. Chubar and P. Elleaume, "Accurate and efficient computation of synchrotron radiation in the near field region," *Conf. Proc.*, vol. C980622, pp. 1177–1179, 1998.

[9] C. Mayes, "lume-astra." `https://github.com/ChristopherMayes/lume-astra`, 2019.

[10] C. Mayes, "lume-impact." `https://github.com/ChristopherMayes/lume-impact`, 2019.

[11] C. Mayes, "lume-genesis." `https://github.com/slaclab/lume-genesis`, 2019.

[12] O. Kononenko, L. Ge, K. Ko, Z. Li, C.-K. Ng, and L. Xiao, "Advances in massively parallel electromagnetic simulation suite ACE3P," in *Proc. ICAP'15*, p. FRAJI3, 2016.

[13] S. Alverson, D. Anderson, and S. Gilevich, "LCLS-II Injector Laser System," in *Proc. ICALEPCS'17*, p. THPHA025, 2018.

[14] C. Zimmer, F. Zhou, and T. Maxwell, "LCLS-II Injector Commissioning Beam Based Measurements," in *Proceedings, North American Particle Accel. Conf.*, p. MOPLM24, 2019.