DESIGN OF A COLLIMATION SYSTEM FOR THE NEXT GENERATION LIGHT SOURCE AT LBNL*

C. Steier†, P. Emma, H. Nishimura, C. Papadopoulos,
H. Qian, F. Sannibale, C. Sun, LBNL, Berkeley, CA 94720, USA

Abstract

The planned Next Generation Light Source at LBNL is designed to deliver MHz repetition rate electron beams to an array of free electron lasers. Because of the high beam power approaching one MW in such a facility, effective beam collimation is extremely important to minimize radiation damage, prevent quenches of superconducting cavities, limit dose rates outside of the accelerator tunnel and prevent equipment damage. We describe the conceptual design of a collimation system, including detailed simulations to verify its effectiveness.

INTRODUCTION

A collimation system is necessary to safely contain the beam halo in high power cw accelerators. The beam halo can be produced by many sources, including dark current from the RF gun or from the accelerating modules, scattering off of residual gas particles, Touschek scattering within the bunches, and several other smaller effects. If not collimated safely, this beam halo can damage undulators, cause Bremsstrahlung co-axial with the photon beams, cause quenches in superconducting cavities and can activate the components of the facility. Collimating the beam halo at the lowest possible beam energy, which means as near as possible to the various sources, is important as this reduces the overall radiation levels in the machine. In addition to the continuous removal of the beam halo, the collimation system must also provide protection against missteered beam or element failure scenarios without being damaged itself.

Collimation Strategy and System Layout

The plan for the NGLS is to make use of a distributed collimation system, roughly similar to the approach that has been used successfully at FLASH [1]. In the injector, in addition to collimation of large transverse amplitude particles, a dark current kicker will remove most of the dark current bunches. The next stage consists of multiple (energy) collimators in the middle of each of the bunch compressors as well as the laser heater chicane to achieve collimation at the lowest beam energy feasible. The post-linac collimation removes the beam halo particles in a transverse collimation section with approximately 90 degree phase advance between each set of horizontal and vertical collimators (two of each). Finally there is another energy collimation section that makes use of the dispersion at the beginning of each of the spreader arcs. The geometry of the spreader allows to keep any particle showers after the collimators away from the photon production sections, similar to top-off collimation at 3rd generation light sources [2]. Figure 1 shows the conceptual collimator layout for the NGLS.

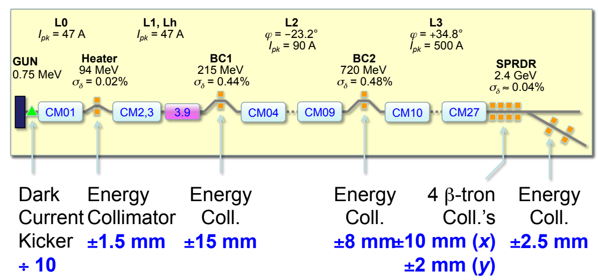

Figure 1: Schematic layout of NGLS injector, linac, bunch compressors, and undulators with collimator locations and settings.

DARK CURRENT TRANSPORT

Dark current from the gun usually is the major source of beam halo. This is expected to be true at NGLS, since gradients for the s/c cavities are relatively low (15 MV/m), where dark-current-free cavities have been demonstrated. To study the effectiveness of the conceptual NGLS collimation system, simulation techniques similar to FLASH, XFEL [1] and LCLS [3] have been employed. The dark current model has been calibrated with data from the APEX test facility. It is expected that APEX dark current will be improved over time, so this is a conservative starting point for the collimation design. The dark current emission is then simulated in ASTRA [4].

The distribution has a very large energy spread and some of the particles spill into subsequent linac buckets. We simulate about 250,000 macroparticles at the cathode, of which about 50,000 survive to the end of the injector at about 90 MeV. The predicted loss rates (compare Fig. 2) in the injector cryomodule for the most conservative dark current model appear to have little safety margin compared to conservative quench thresholds for superconducting cavities without a dark current kicker. So the kicker is now considered part of the baseline.

Dark Current Deflector

The dark current produced at the gun is quasi continuous with the rf-frequency of the gun as repetition rate

* This work is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
† CSteier@lbl.gov

ISBN 978-3-95450-126-7

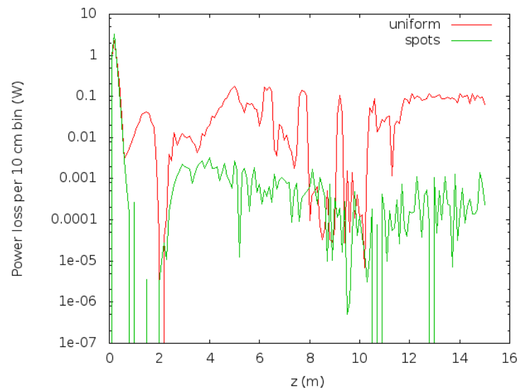

Figure 2: Predicted dark current losses in the injector up to 90 MeV beam energy for two different, assumed spatial emission distributions. Measured distributions are close to the one that results to the much smaller losses in the injector cryo-module in these simulations.

(187 MHz). The beam used to drive the FEL has a nominal repetition rate of up to 1 MHz. Therefore it is possible to reduce the dark current significantly by kicking any dark current in between nominal bunches into a dump or collimator. Such a system has been employed at FLASH and reduces the dark current intensity downstream by a significant factor. A similar system is planned at NGLS as well and will be tested at APEX (see Fig. 3). It is based on a scaled design of a fast kicker that is installed for a different purpose in the ALS [5]. The NGLS system will work at a beam energy of less than one MeV, meaning a scaled version of the ALS design, that has a wide enough good field region for the at this point fairly large nominal beam, provides sufficient deflection using the same pulser.

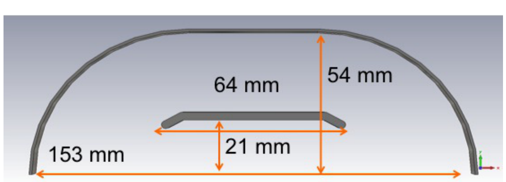

Figure 3: Cross section dimensions of stripline kicker scaled up from the ALS design.

Linac, Spreader, Undulator Section

To study the dark current transport at higher beam energies, standard codes have been used to track the remaining dark current particles throughout the machine lattice. We used both AT [6] (upgraded to treat linacs) and elegant [7]. The tracking codes allow to determine loss locations along the complete machine. The draft collimator layout described above is effective in localizing losses of dark current particles avoiding the undulator sections as well as most other parts of the accelerator (see Fig. 4). The loss power on the first collimators could reach 100 W, without taking credit for the dark current kicker. With the expected reduction of a factor of more than ten with the kicker, these loss levels appear acceptable when compared to FLASH and are used as basis for the tunnel shielding design.

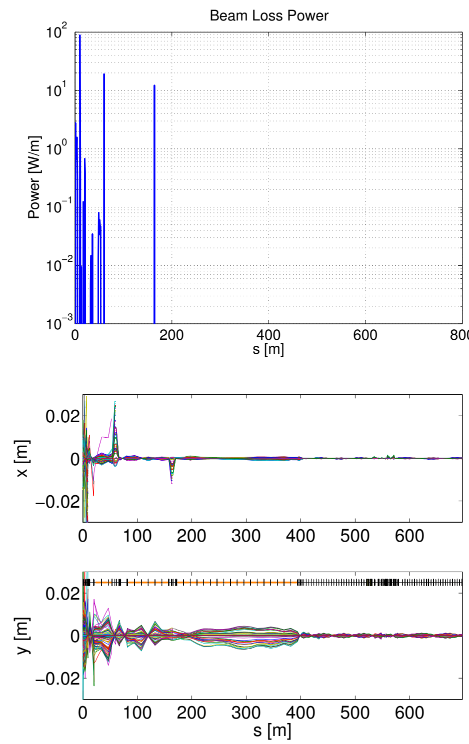

Figure 4: Top: Loss location histogram for NGLS for conservative gun dark current assumptions without crediting the dark current kicker. Bottom: Calculated trajectories of dark current particles the NGLS.

Error sensitivity studies were performed by putting gradient and dipole errors on magnets as well as phase errors on acceleration sections and positioning errors on collimators (see Fig. 5). The collimator layout performed robustly for dark current collimation and reasonable error seeds with the first collimator in the laser heater being the most critical one.

Additional simulations were carried out to evaluate, whether smaller undulator gaps would be possible from the standpoint of halo control. While the nominal magnetic gap of the superconducting undulators right now is 7.5 mm, with a clear beam aperture of 5.5 mm, magnetic gaps as small as 5 mm were considered. The studies did not reveal any fundamental show stoppers. However, the energy collimators in the spreader section as well as the vertical betatron collimators would need to be set much closer resulting in high energy beam losses in the range of more than 100 W per collimator, which is possibly too high.

Other Sources of Beam Halo

Measurements at FLASH and LCLS indicate that background radiation in the undulator sections cannot be fully explained with just dark current production. This will likely be true for NGLS as well. Tracking studies were

ISBN 978-3-95450-126-7

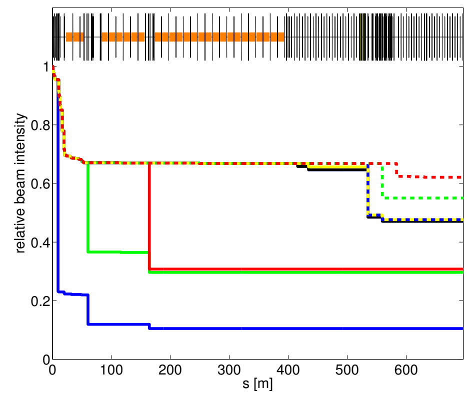

Figure 5: Ratio of remaining gun dark current along the NGLS when opening upstream collimators. The undulator section as well as the linac structures are well protected for most reasonable collimator errors.

carried out to evaluate the effectiveness of the collimator layout for Touschek and gas scattering. In addition, analytical calculations were carried out to calculate the loss rates on each collimator for typical gas pressures. The loss rates were found to be small. Finally, losses due to Touschek scattering were estimated using analytical formulas based on the Piwinski theory [8]. One first calculates the momentum acceptance along the NGLS (see Fig. 6). Using the result one can then calculate loss rates analytically. For standard NGLS beam parameters and aggressive collimator settings, the beam loss on the worst collimator of the order of 1 W, much smaller than the dark current losses.

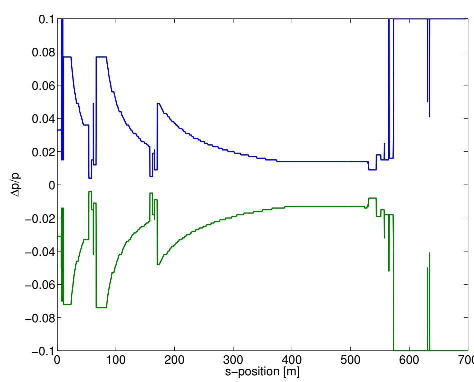

Figure 6: Calculated momentum aperture of the NGLS lattice with collimators. This corresponds to about 1 W losses on the worst collimator for typical beam parameters.

Tails produced by collective effects in the main bunch could also be relevant and will be included later.

COLLIMATOR DESIGN

The machine protection issues at NGLS include the collimation system itself, which of course is designed to prevent damage to other parts of the facility. Potential damage sources for the collimators could be synchrotron radiation, wakefields, as well as beam losses. The largest concern are beam losses of the full 1 MW beam in case of equipment failure. The collimator design has to withstand those until the machine protection system can shut down the beam. Because NGLS uses (almost) equal spacing between bunches, at any moment, only a few bunches are present. So the latency/integration time of the machine protection system is the determining factor. The system is planned to react in well under 1 ms, which limits the worst case deposited energy to acceptable levels for properly designed collimators, similar in magnitude to beam dumps in 3rd generation light sources [2].

Another important consideration is the impedance of the collimators. In LCLS the short range wakes were minimized by using a thin Titanium-Nitrite coating of the collimator jaws. Similar coating techniques are envisioned for NGLS, but in addition efforts will be undertaken to minimize geometric impedance and long range wakes. Whenever possible the adjustable collimators will be double sided to allow to center the beam and minimize impedance induced dipole kicks.

SUMMARY

A conceptual design for a collimation system for the NGLS has been completed. Using a conservative dark current model for the gun, start to end tracking simulations of dark current particles have been completed. Results conclude that a standard set of energy collimators can effectively protect most of the linac and the undulator region with lost beam power at the collimators well within the limits of simple water-cooled designs. A fast dark current kicker right after the gun is planned to reduce losses in the very first superconducting linac module. The design has also been evaluated with regards to gas and Touschek scattered particles, and it was found to be effective and expected power deposition due to those effects are comparatively small. Error sensitivity studies have started, and showed the design to be robust. Work that remains for the future includes the detailed collimator design including impedance considerations, as well as a detailed treatment of secondary particles after the collimators.

REFERENCES

[1] L. Froehlich, DESY-THESIS-2009-012
[2] H.Nishimura, et al. - ALS Topoff, NIM A (2009)
[3] P. Emma, et al., LCLS collimation, EPAC 2008
[4] K. Floettmann. ASTRA: A space charge tracking algorithm.
[5] S. Kwiatkowski, et al. Camshaft bunch kicker, EPAC 2006
[6] A. Terebilo AT Accelerator Toolbox, SLAC Note
[7] M. Borland, Elegant, APS LS-287, (2000).
[8] A. Xiao, M. Borland, Touschek Calculations, PAC 2007

ISBN 978-3-95450-126-7