Rastering vs nonlinear optics for ion irradiation applications

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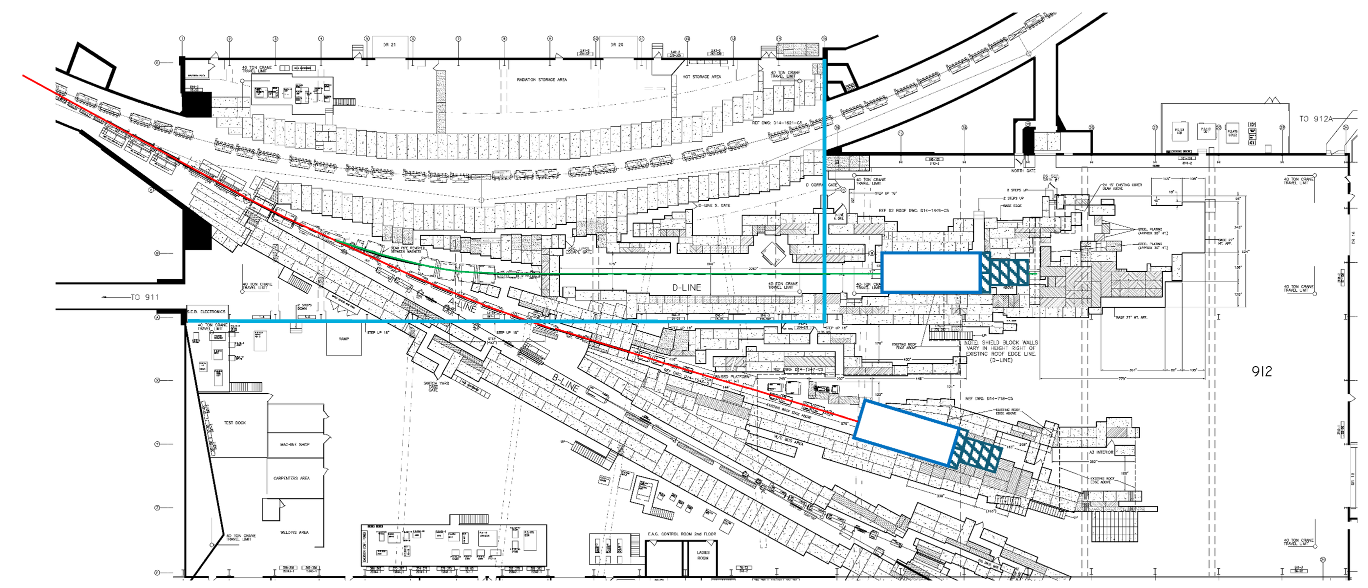
Abstract

Ion beam irradiation of integrated circuits is important for space and aerospace applications. It is important to irradiate specified areas of a target with a well-defined dose. The present state of the art is to transform the transverse ion beam distribution from Gaussian to a uniformly-filled shape that is large enough to fill the slit of a tungsten collimator. Uniform transverse density distributions are also important in spallation applications [1,2]. We will present a comparison of two approaches that can remove the collimator, offering a cleaner, more flexible and more accurate irradiation facility. An approximately uniform particle flux can be achieved over arbitrary rectangular domains by rastering the Gaussian beam in two dimensions. An alternative approach is to use nonlinear optics -- typically placing two octupole magnets (optionally with duodecapole field components) in the beamline [2]. We will present a systematic comparison of these two approaches for a proposed irradiation facility. The possibility of machine learning based automation will be considered.

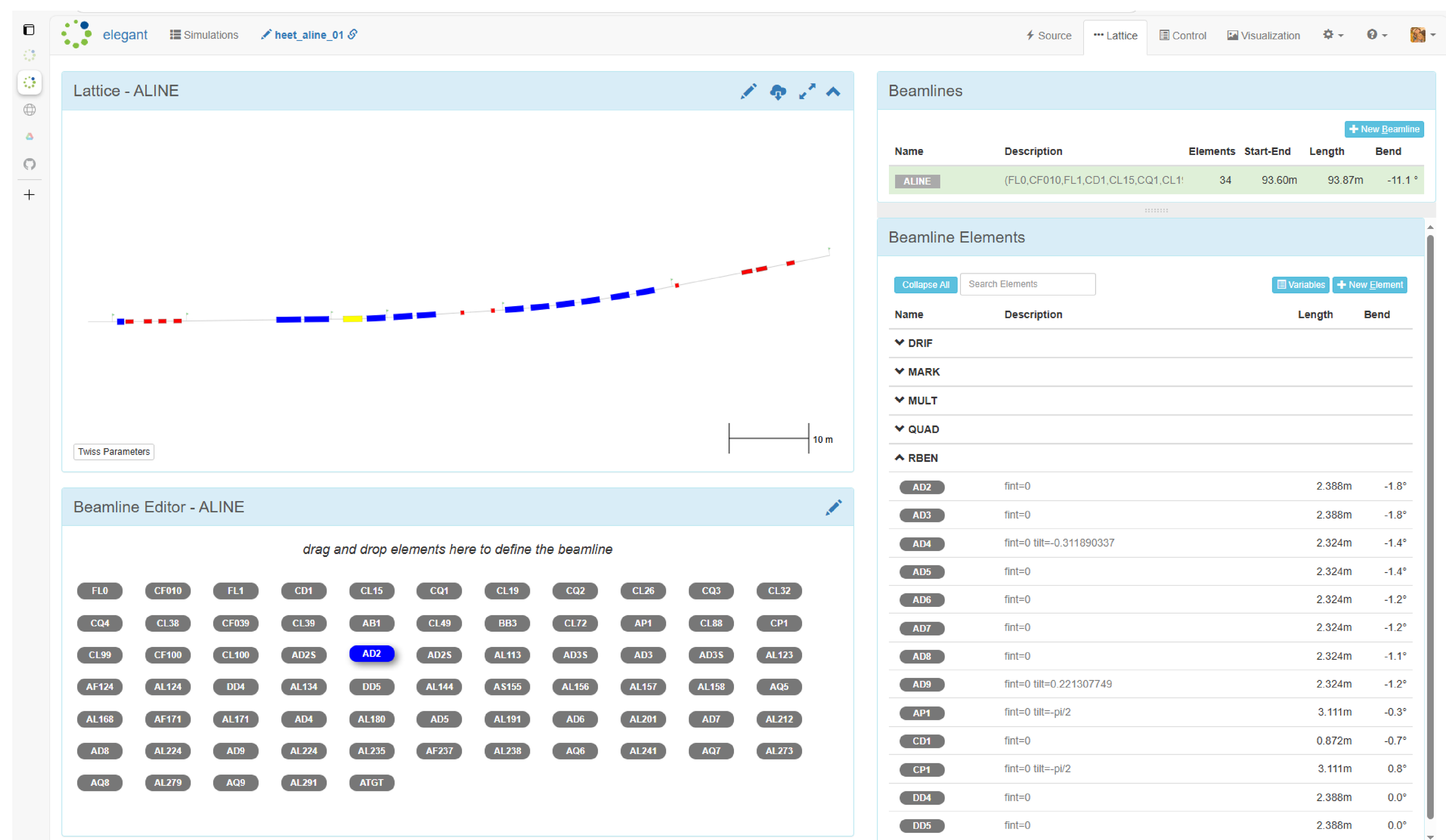
Summary

- Work has recently begun to support the High Energy Effects Test Facility (HEET) Project [3]
- Evaluate the octupole-based approach
  - The linear optics must create a tight horizontal waist and (in a different location) a tight vertical waist.
  - Place an octupole (or a combined-function multipole) at each of these waists:
    - give the y-motion a good 3rd-order kick where the x-motion is only weakly perturbed (i.e. at the horizontal waist)
    - likewise,give x-motion a strong kick at location of the vertical waist
  - Particle tracking can be used to set limits on the Twiss beta values at the two waist locations, for a variety of ion species
    - machine learning can be used to develop a real-time control algorithm
- Evaluate the rastering approach
  - Assume (initially) a Gaussian transverse ion beam profile, and a reasonable repetition rate of ion bunches within a micropulse
  - Place two steering magnets at reasonable places in the beamline
    - simulations will assess deviation of the integrated irradiation intensity from the desired properties: uniformly-filled rectangle
    - machine learning can be used to develop a real-time control algorithm
- Other considerations
  - Use the Aline within the AGS switchyard as our initial working point
  - Minimize chromatic effects
  - Assess failure scenarios for octupole(s) and steering magnet(s)
  - Assess the impact of control errors and/or field errors on the target distribution
    - machine learning can be used to develop a real-time control algorithm

Beamline: the Aline in the AGS switchyard



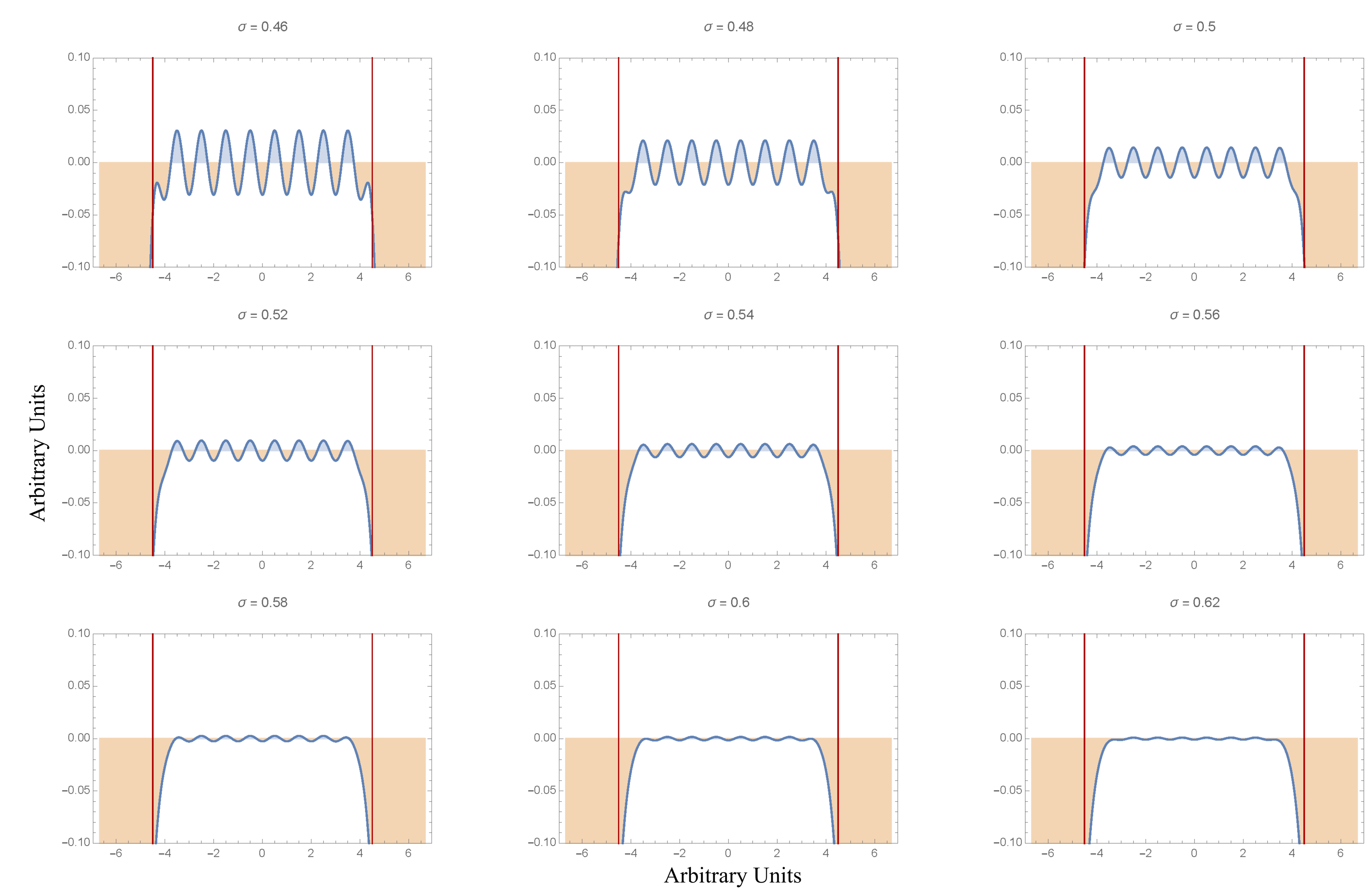
Schematic of the Alternating Gradient Synchrotron (AGS) switchyard at BNL. The Aline is shown in red.



Screenshot of the Sirepo–elegant model for the Aline (part of AGS switchyard at BNL). All details were imported from a MAD-X input file. The same model can be simulated in Sirepo–MAD-X for benchmarking purposes. Models can be shared instantaneously with other Sirepo users. Also, models can be exported for collaborators who work on the command line.

https://sirepo.com

Idealized uniformity of ion beam irradiation via rastering



Schematic overlay of ion beam spots on target, assuming ideal Gaussian profiles. The parameter σ is the ratio of RMS width to spot center separation. The ratio σ = 0.62 (see lower-right figure) is sufficient to obtain a high degree of uniformity, at the cost of a significant rollover on the edges. Extending the uniform region across the full width of the target would require the loss of some electrons in the shoulders of the curve. The ratio σ = 0.48 (see upper-middle figure) limits relative deviations from uniform irradiation to ±5%.

References

[1] Tim Broome, "High Power Targets for Spallation Sources," *Proc. of 1996 European Accelerator Conference*, 267 (1996).

[2] D.L. Bruhwiler and Y.K. Batygin, "Beam Transport for Uniform Irradiation: Nonlinear Space Charge and the Effect of Boundary Conditions," *Proc. Part. Accel. Conf. and Int. Conf. on High-Energy Accel.*, 3254 (1995).

[3] The High Energy Effects Test Facility (HEET) Project, https://www.bnl.gov/heet/

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