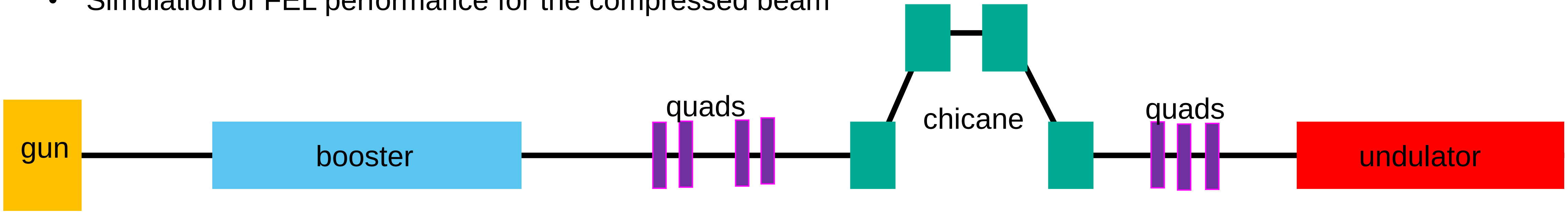
Report on Bunch-Compressor-to-Undulator Simulation Optimized for FEL performance via OCELOT

Implementation and first results

Anusorn Lueangaramwong

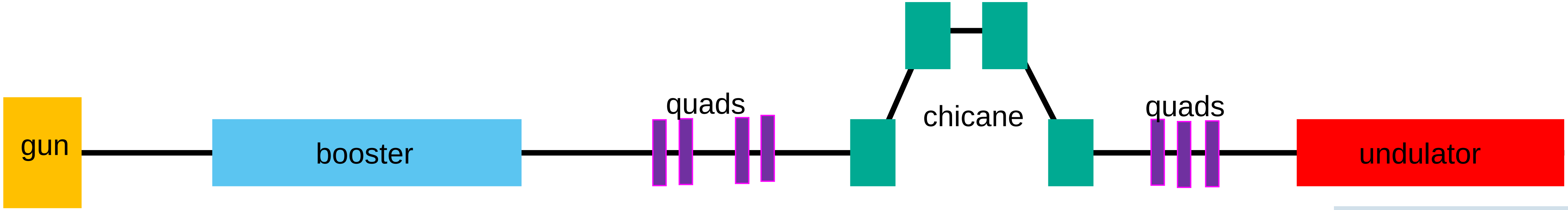
Background

- Complete
  - S2E beam dynamics simulation from gun to bunch compressor via ASTRA+IMPACT-T (CSR effect benchmarked by OCELOT)
  - Measurement of LPS (thereby energy chirp) with benchmarked to ASTRA results
- On-going
  - Simulation of compressed beam transport to undulator
  - Simulation of FEL performance for the compressed beam



- OCELOT is selected to beam downstream booster to undulator, since compressed beam needs beta optimization for FEL during transport from bunch compressor to undulator.

Use of OCELOT



Previously used and developed

Tracking & booster phase scan

Transport

Tracking with CSR effect

red: ASTRA
yellow: OCELOT
green: IMPACT-T

Developing

Tracking & booster phase scan

Optimizing quads for
minimum emittance
with CSR effect

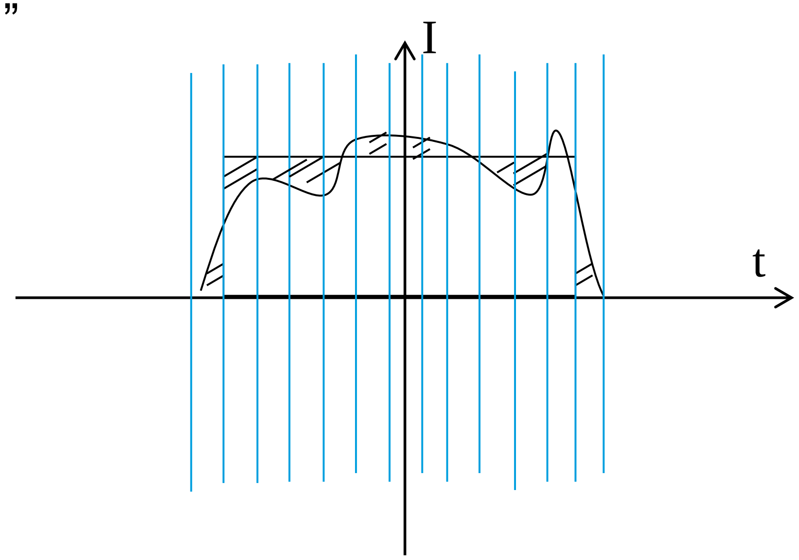
Transport to center of undulator
while optimizing beta
for minimum FEL saturation length
Note: OCELOT's SASE estimator
is a semi-analytical model

OCELOT Features

- 3d particle-in-cell tracking
    - z step size ~ 10 mm
    - mesh 32x32x32
- csrtrack
    - include csr effect
- easy implementation with generic optimizers in Python
    - eg. scipy.fmin
- Job complete by farm within 48 hours for 500k macroparticles
- easy to switch to the GENESIS interface

OCELOT's SASE estimator

- "Knowing the electron beam parameters and the magnetic lattice one can estimate the average SASE power at saturation As the electron beam is typically much longer than the cooperation length, **one can slice it into regions that would never interact with each other** and estimate power growth in each of those regions with MXie (default) M. Xie, "Exact and variational solutions of 3D eigenmodes in high gain FELs," Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 445, no. 1–3, pp. 59–66, 200000114-5) ……."



Reference: https://nbviewer.jupyter.org/github/ocelot-collab/ocelot/blob/master/demos/ipython_tutorials/pfs_5_SASE_Estimator_and_Imitator.ipynb

Ming Xie model

- Semi-analytical method
    - assuming a transversely symmetric electron beam and a constant current profile.
- Ming Xie Input Parameters:
    - Peak Current (Bunch Compression Settings)
    - Slice Energy Spread (vary Laser Heater Power)
    - Transverse Emittance (growth from CSR effect)
    - …..
- Undulator β-function, β-mismatch

Optimization using OCELOT in details

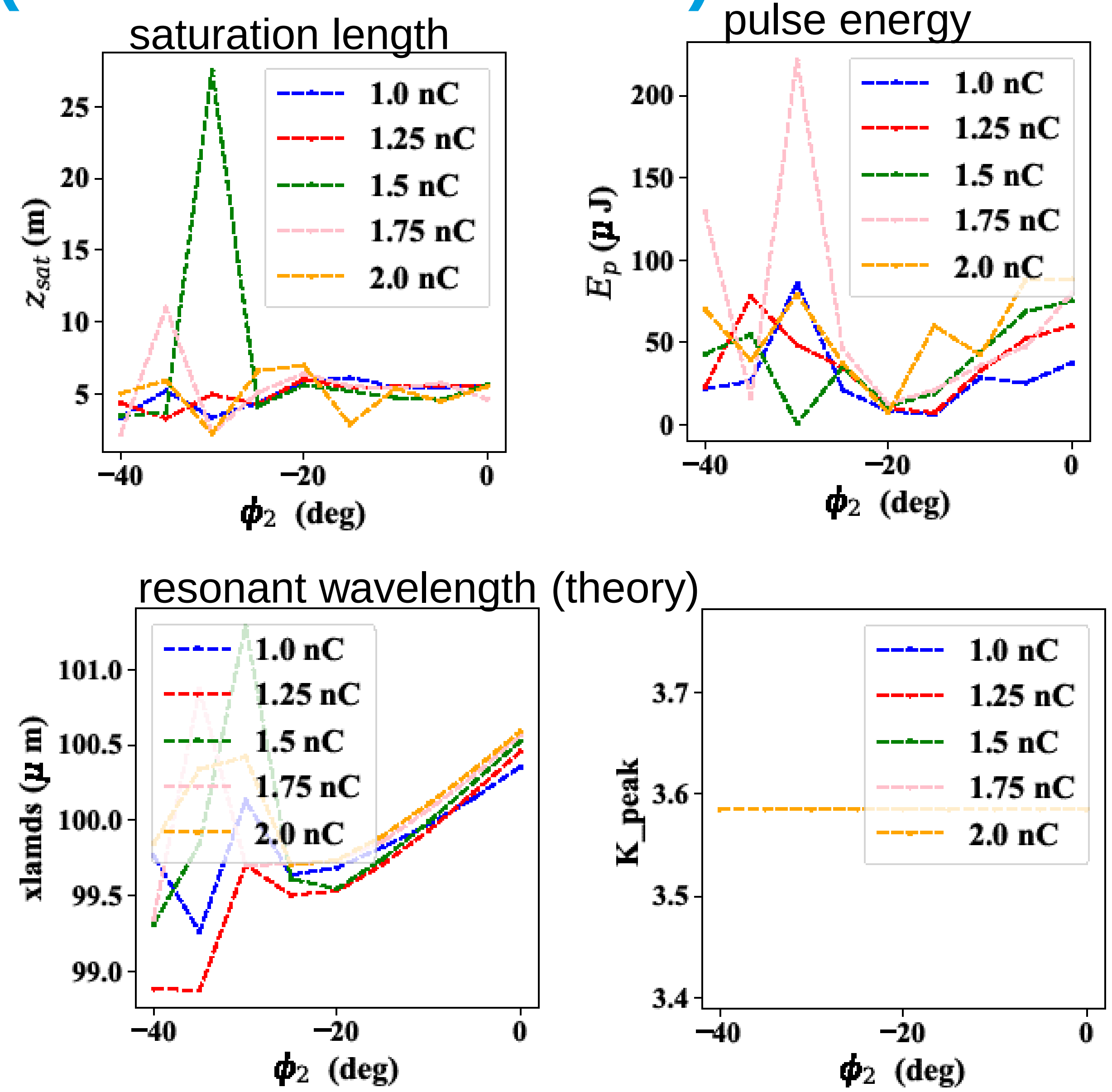
1. ASTRA tracks beam through gun and booster
2. PYTHON (SCIPY) finds optimized H1Q9.k1, H1Q10.k1, H2Q1.k1, H2Q2.k1 for lowest emittance
   - OCELOT (CSRtrack benchmarked with IMPACT-T) for tracking beam through BC with apertures
   - larger z step size in this step for fast calculations
   - small z step size for final optimized H2Q1.k1, H2Q2.k1
3. PYTHON (SCIPY) finds (fast) optimized H3Q1.k1, H3Q2.k1, H3Q3.k1 for FEL saturation length in OCELOT's Ming-Xie
   - larger z step size in this step for fast calculations
   - small z step size for final optimized H3Q3.k1
   - optimized SASE estimator slice width
   - same beta to all slices
   - (optional) head and tail noise removed
4. (optional) OCELOT optimizes single beta for whole beam, so the forced beta gives shorter saturation length

Booster phase scan results (without forced beta)

Fast optimization for Ming-Xie model, no small z step size

- Booster phase range between -40 to -20 gives relatively higher pulse E and shorter saturation length

- This optimization may need smaller step size

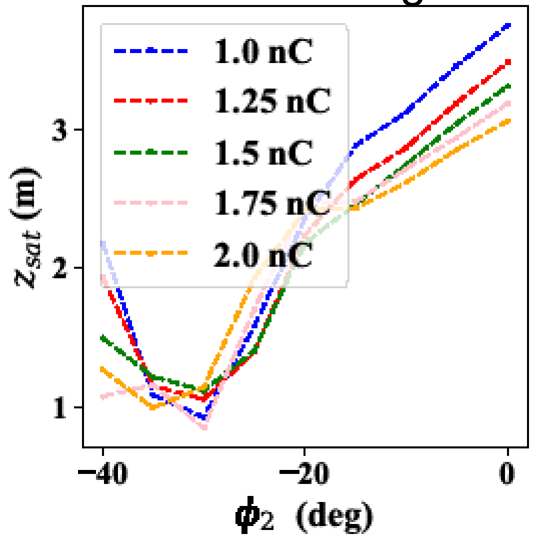


Booster phase scan results (with forced beta)

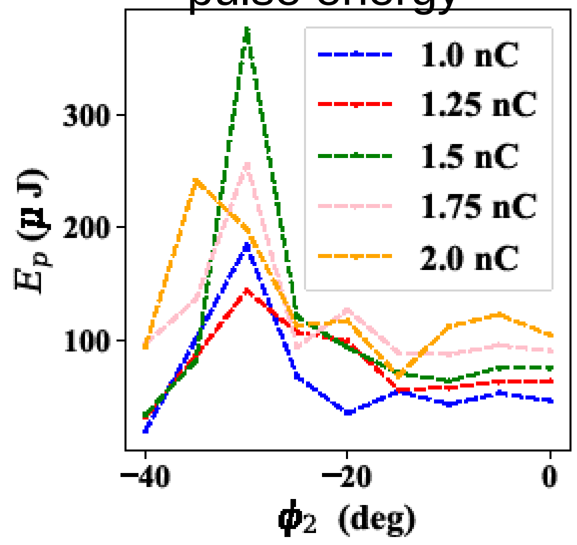
Fast optimization for Ming-Xie model, no small z step size

- The “forced beta” option gives optimistically trends of pulse energy and saturation length
- Note that this beta is not realistic

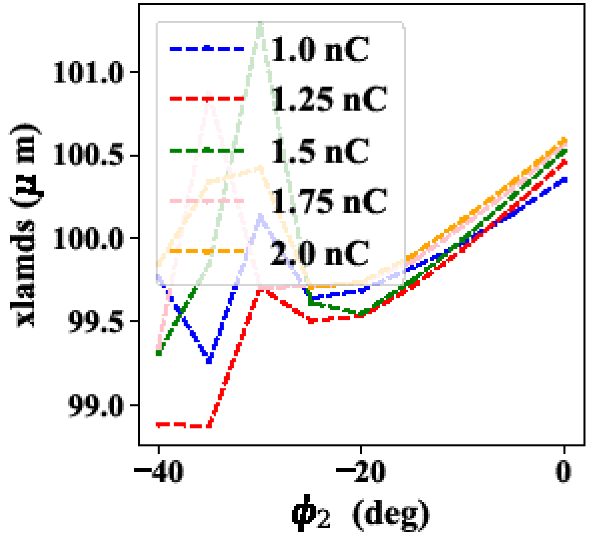
saturation length

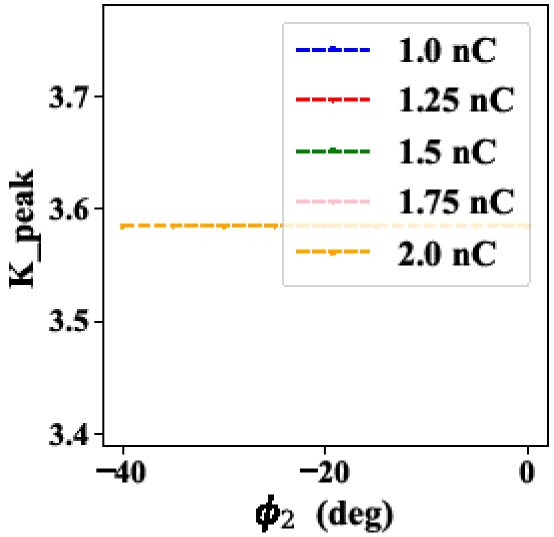


pulse energy



resonant wavelength

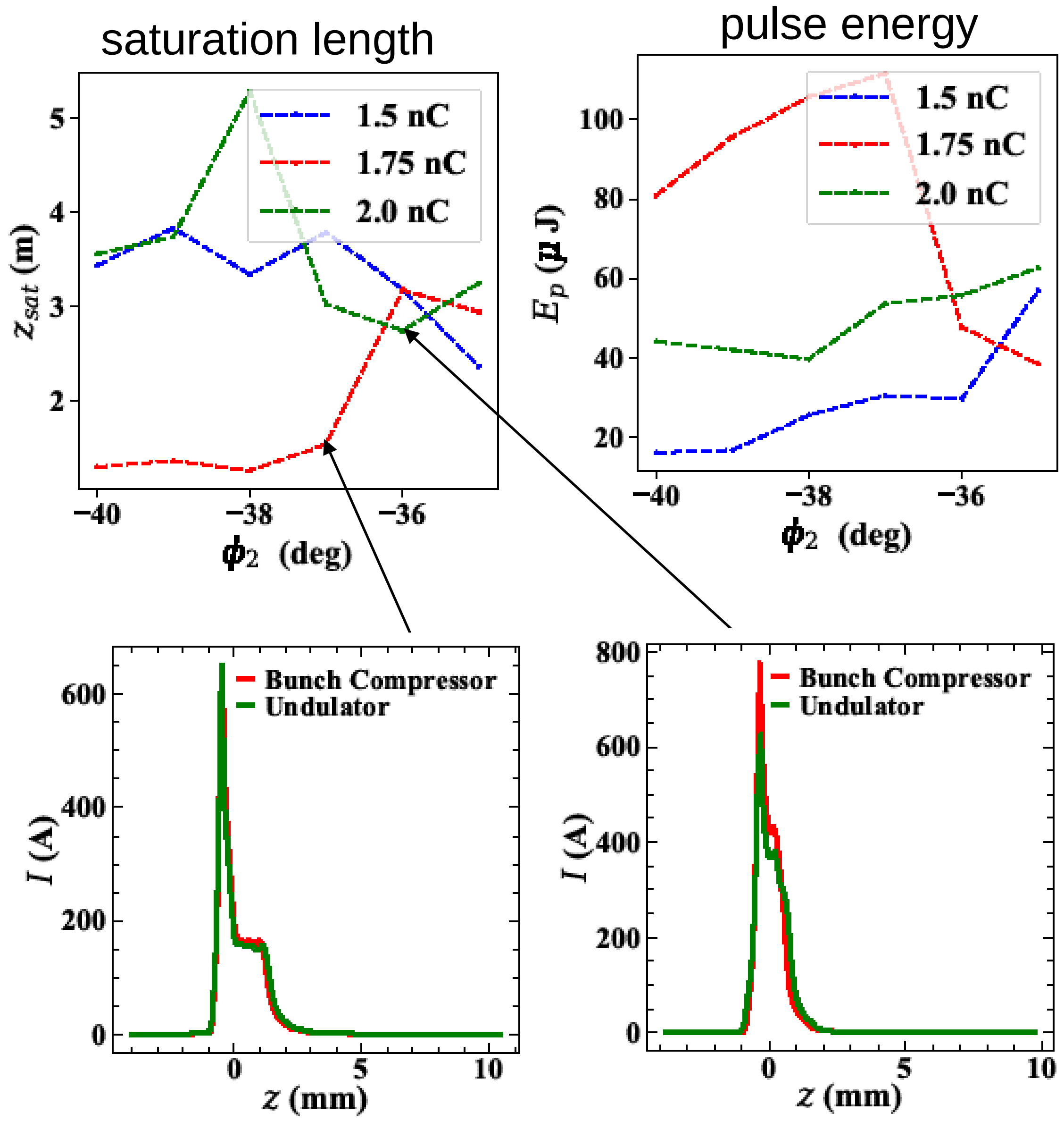




Booster phase scan results

Slow optimization for Ming-Xie model, with small z step size

- Rescan with the suggested scan range

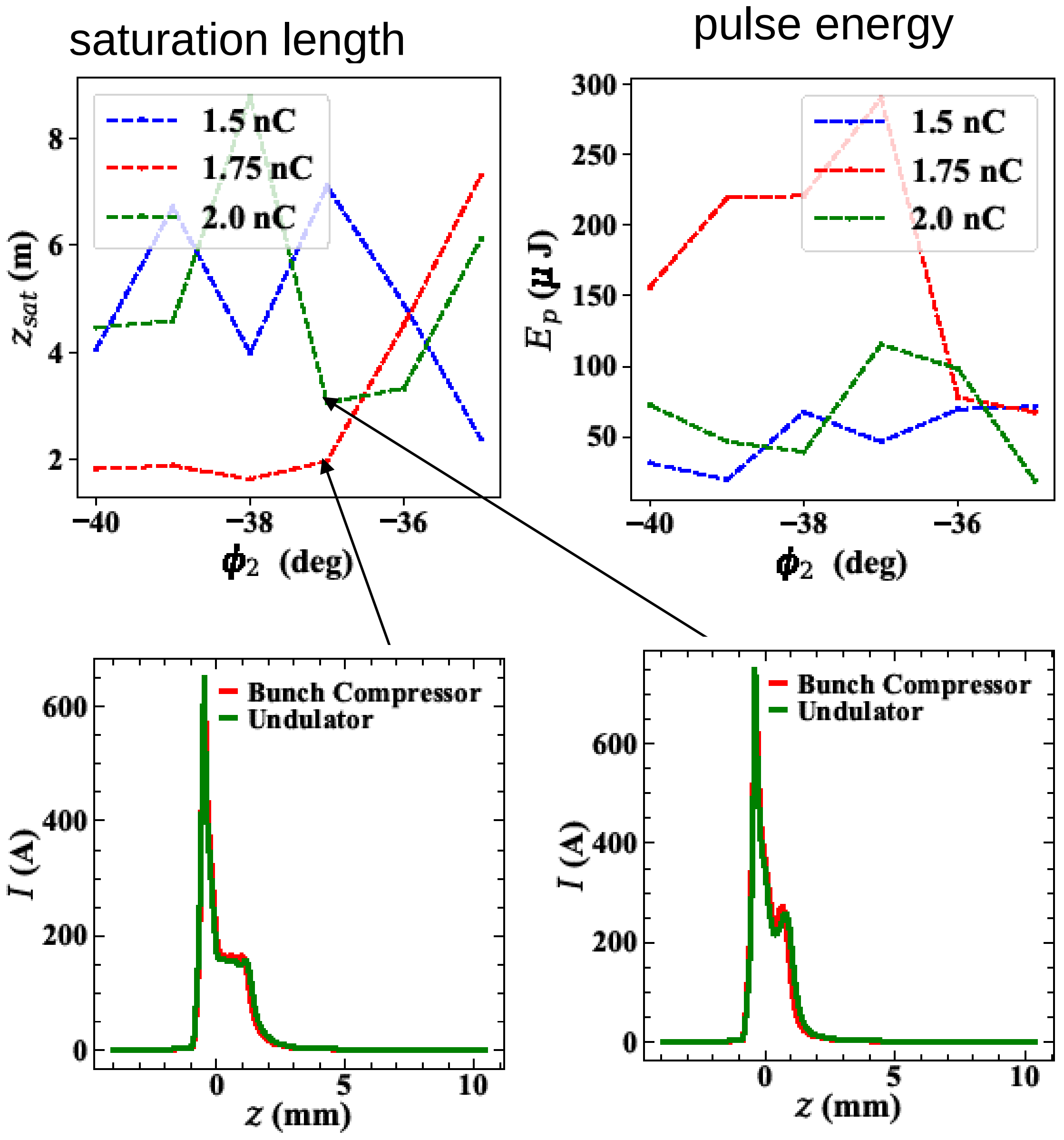


- Current profile changes slightly from BC to Undulator

Booster phase scan results

Slow optimization for Ming-Xie model, with small z step size and head & tail noise cut

- Ming-Xie model in OCELOT may need a proper slicing with head & tail cut



Summary

- S2E optimization from gun to Undulator still has problems and is under development
- The presented optimizer suggests the use of beam with q=1.75nC for FEL radiation with saturation length < 2m and pulse energy ~ 300 uJ

- Next
  - Improve slicing for OCELOT’s SASE estimator
  - Add GENESIS 1.3 version 4 to this optimizer