FLASH2020+

Progress Review Meeting

FLASH2020+ Seeding Progress

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With contributions from FLASH2020+ Team

Hamburg, Oct 18th, 2024

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

FLASH2020+ Seeding Progress:

- Seeded FLASH1:
  - Simulations and Diagnostics
- Recap of Start to End EEHG Simulations
- Results of Multi-dimensional Optimization for Operation of FLASH2020+
  - An efficient setup is a stable setup

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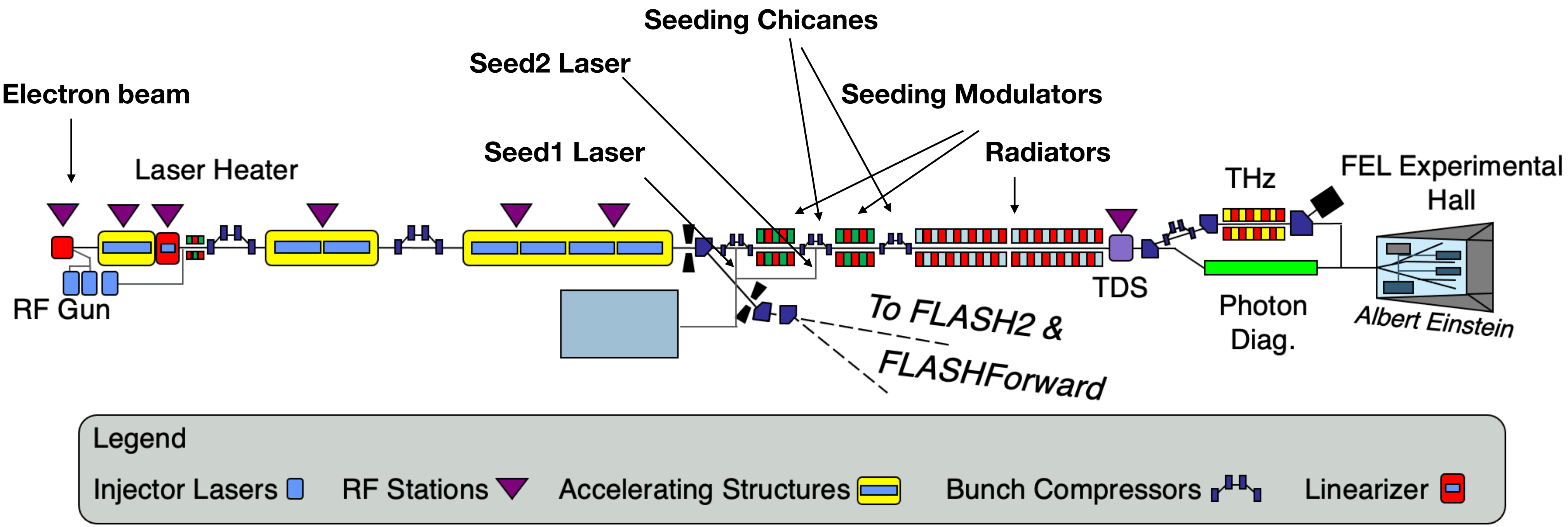
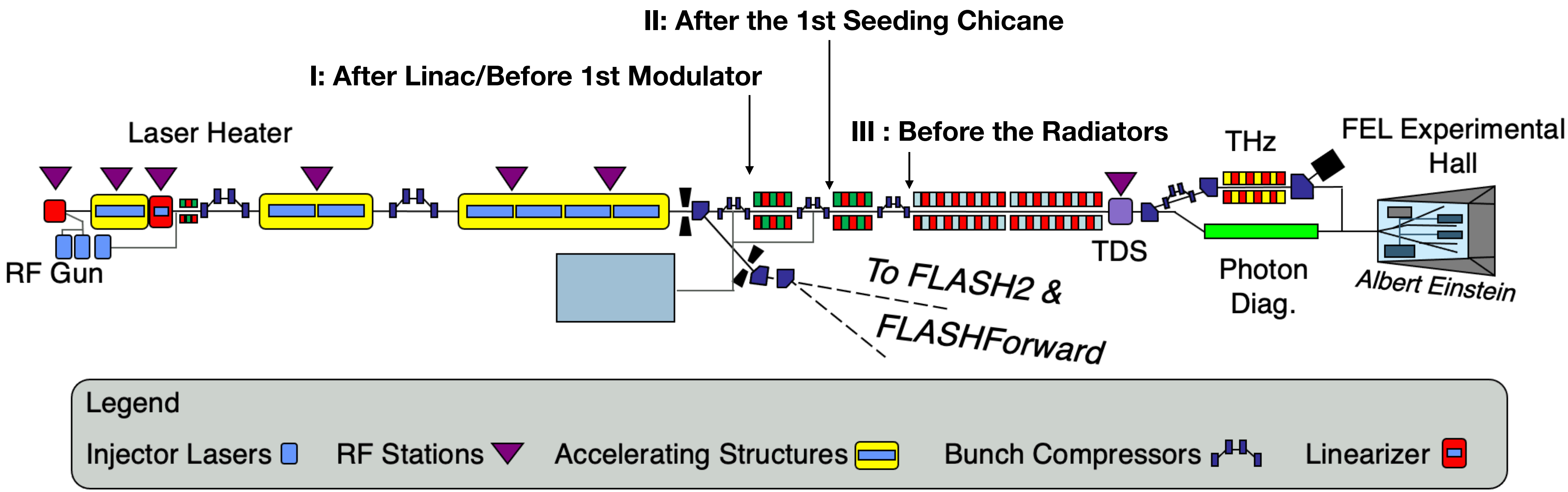
Introduction
Review of FLASH2020+ Upgrade & Main Goal of Simulation Studies

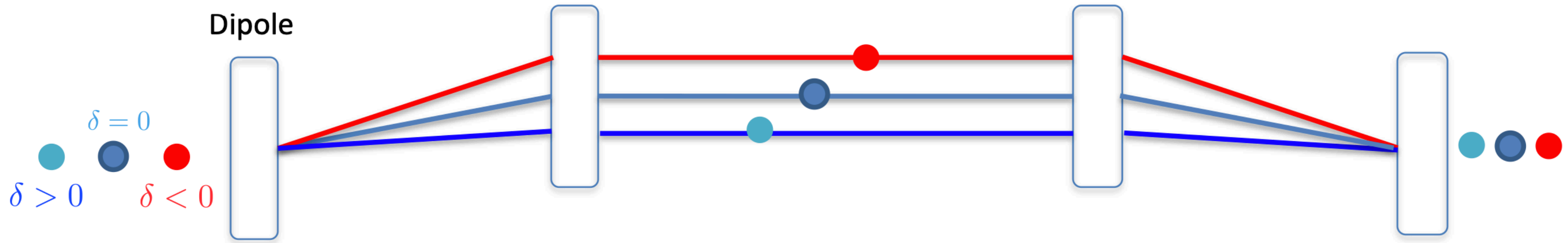


Introduction
The Main Goal of Simulation Studeis is to prepare us for operation of FLASH1 as a seeded FEL



EEHG scheme and FLASH beam

The negative chirp of the beam causes it to compress in a chicane



Nominal Bending Angle:

$$\theta_0 = \frac{l_{dip}}{\rho} = \frac{eB}{p_0} l_{dip}$$

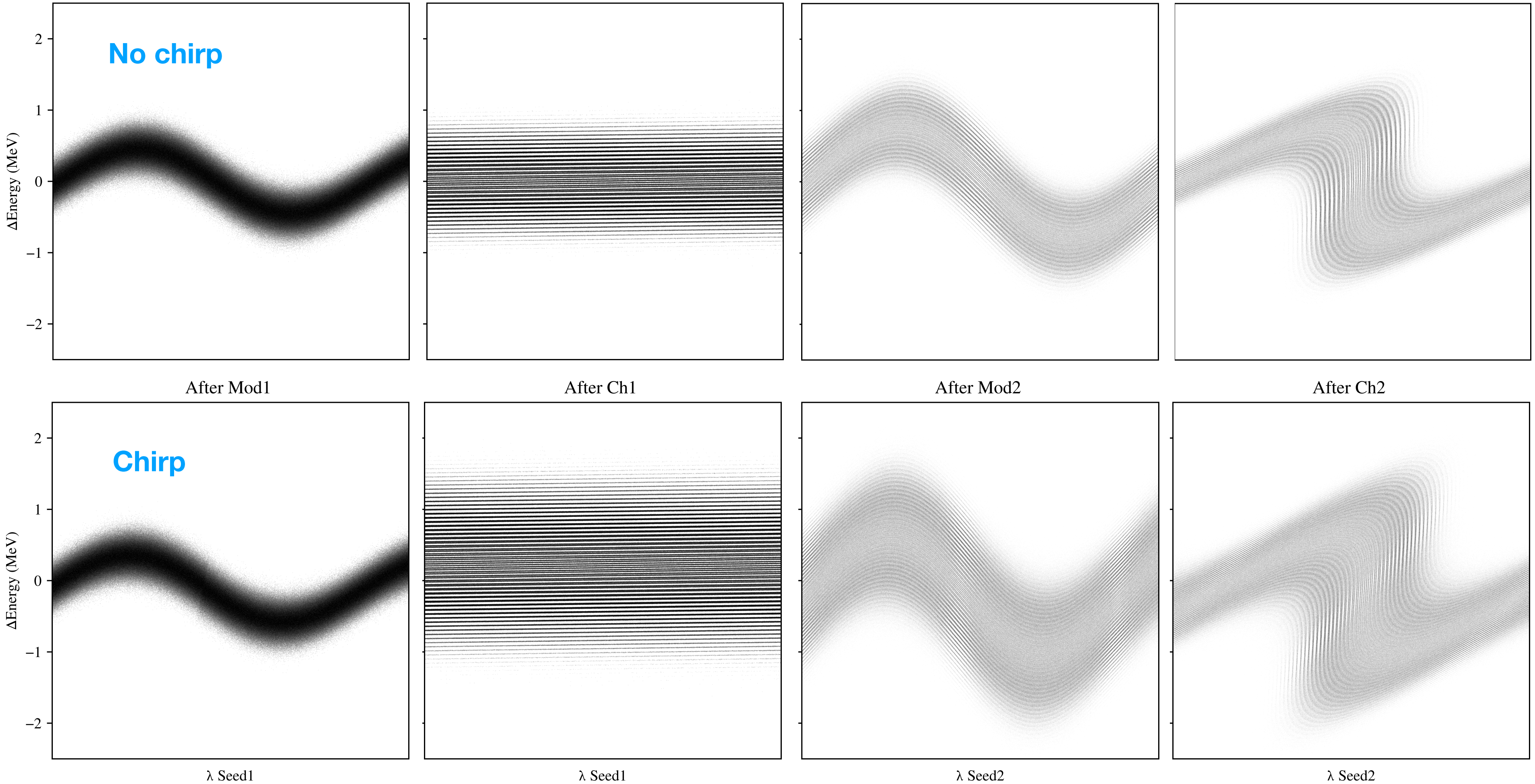
Bending Angle for off-energy particles:

$$\theta(\delta) = \frac{\theta_0}{1+\delta}$$

- Higher-energy particles are bent less
  - they take a shorter path
- Lower-energy particles are bent more
  - they take a longer path
- The high-energy tail shifts forward; the low-energy head shifts back → *Compression*!

D. Bruhwiler – USPAS – January 2018 – Electron Bunch Compression

EEHG scheme and FLASH beam
The negative chirp of the beam causes it to compress in a chicane



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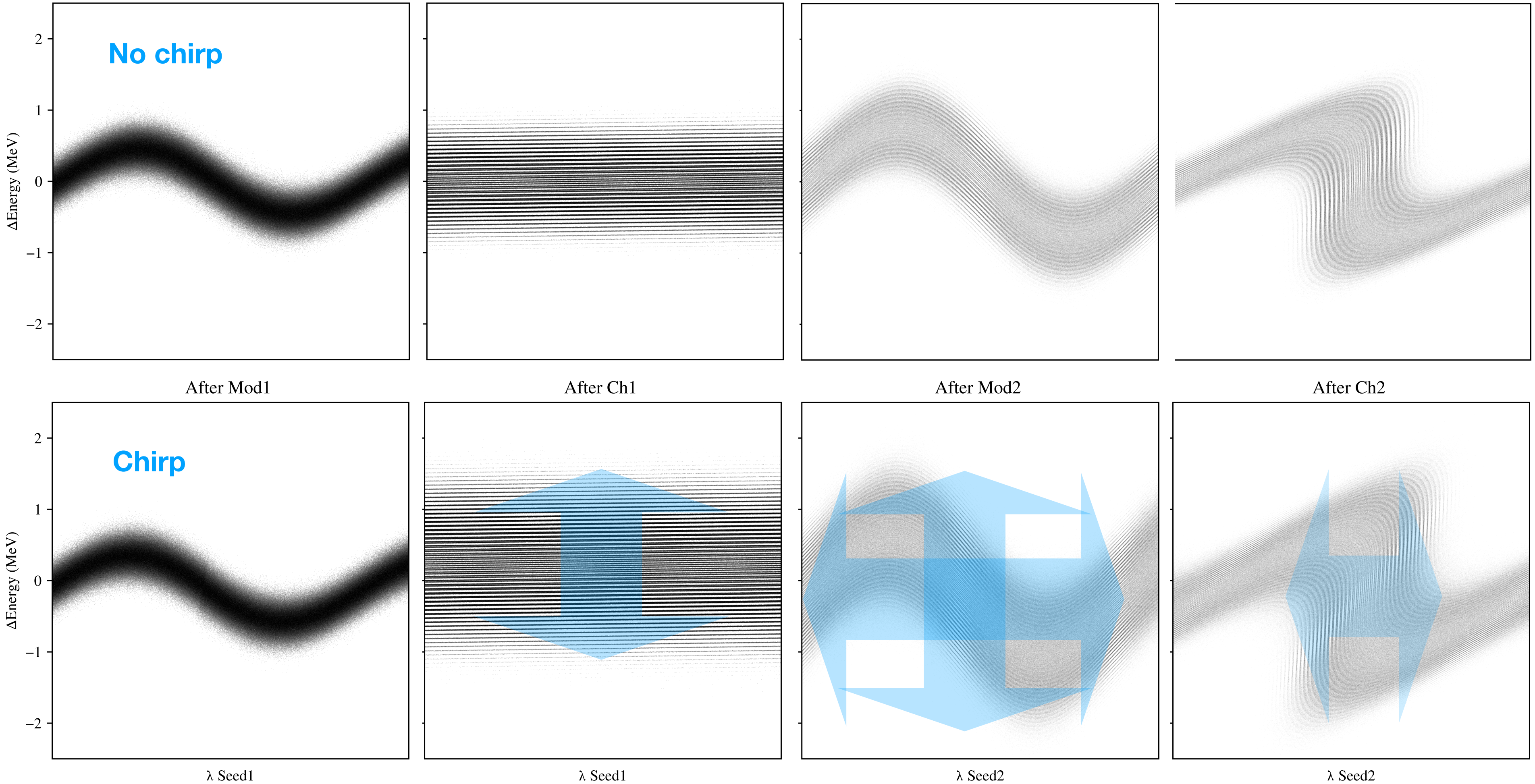


EEHG scheme and FLASH beam
The negative chirp of the beam causes it to compress in a chicane

Increase in slice energy spread

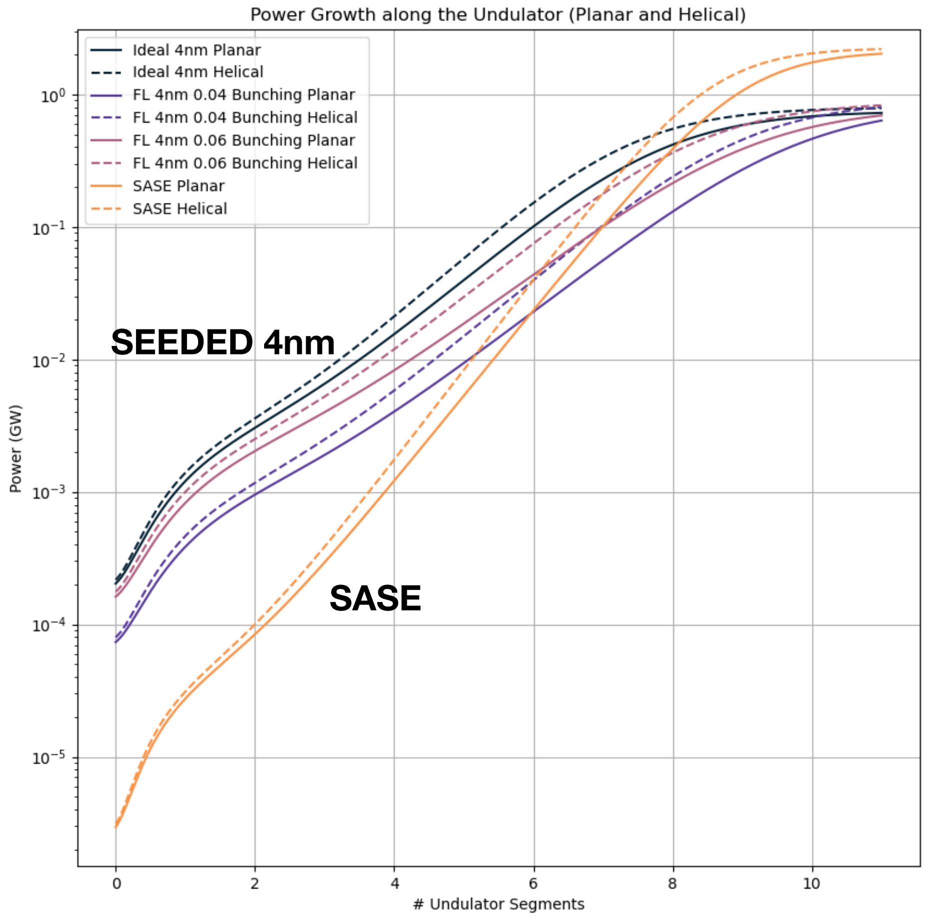
Changes the working point and typically leads to less extractable power

Increased bunching (with higher spectral content)

Can lead to overbunching in the 2nd Chicane

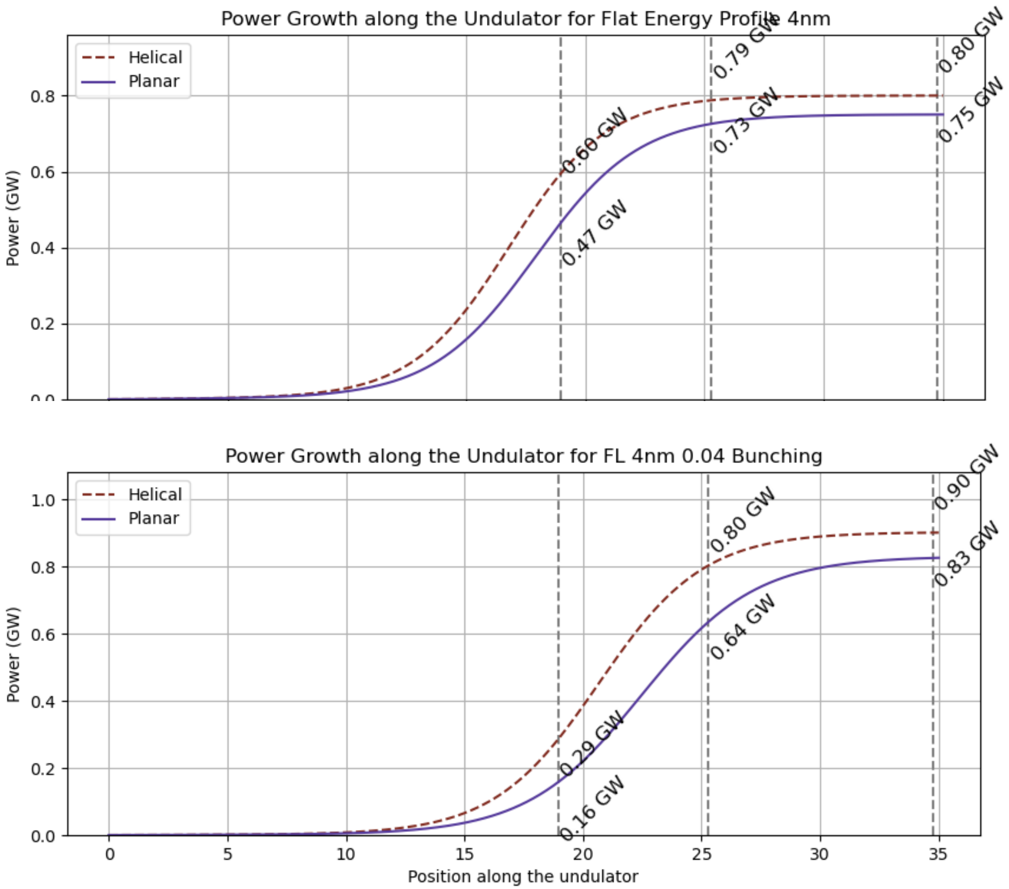
Lead to Increase in Gain length

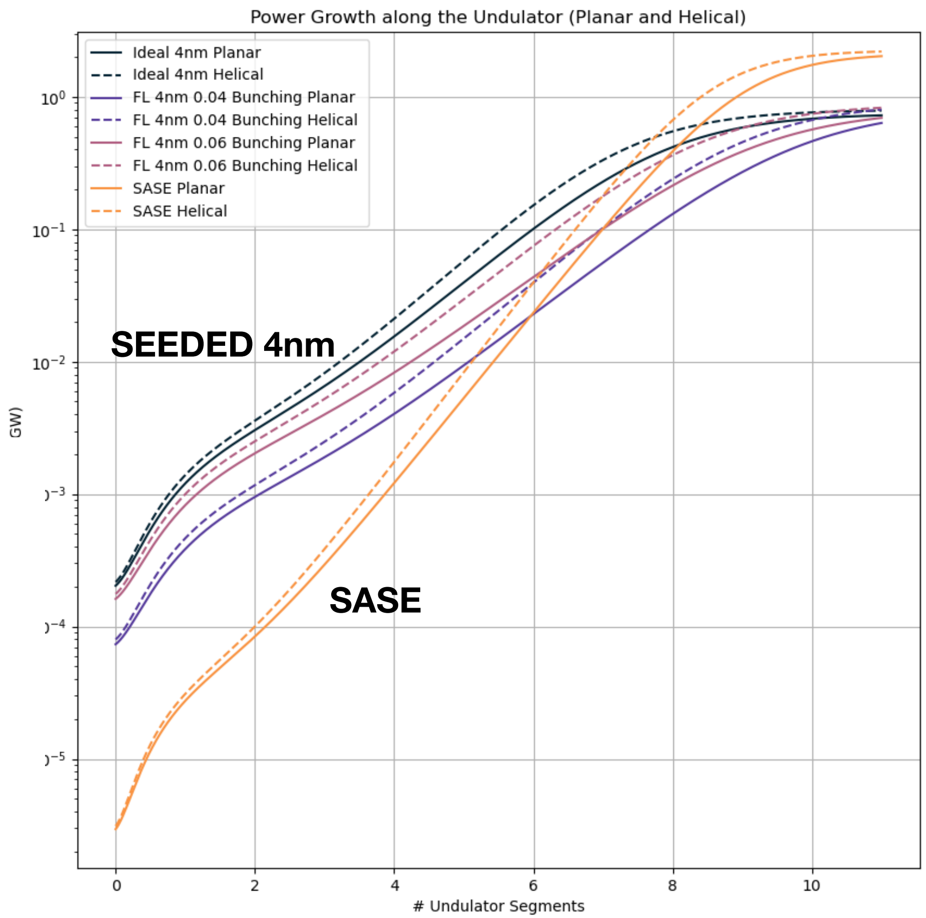
Case	3D gain length (Planar) meter	3D gain length (Helical) meter
Flat Energy Profile 4nm	2.18	2.05
FL 4nm 0.04 Bunching	2.41	2.21
FL 4nm 0.06 Bunching	2.46	2.26
SASE	1.53	1.46



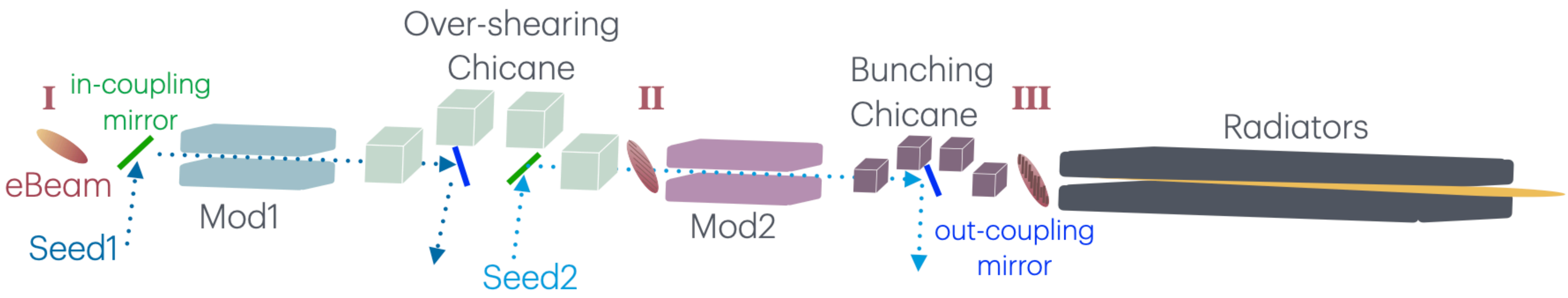
EEHG scheme and FLASH beam

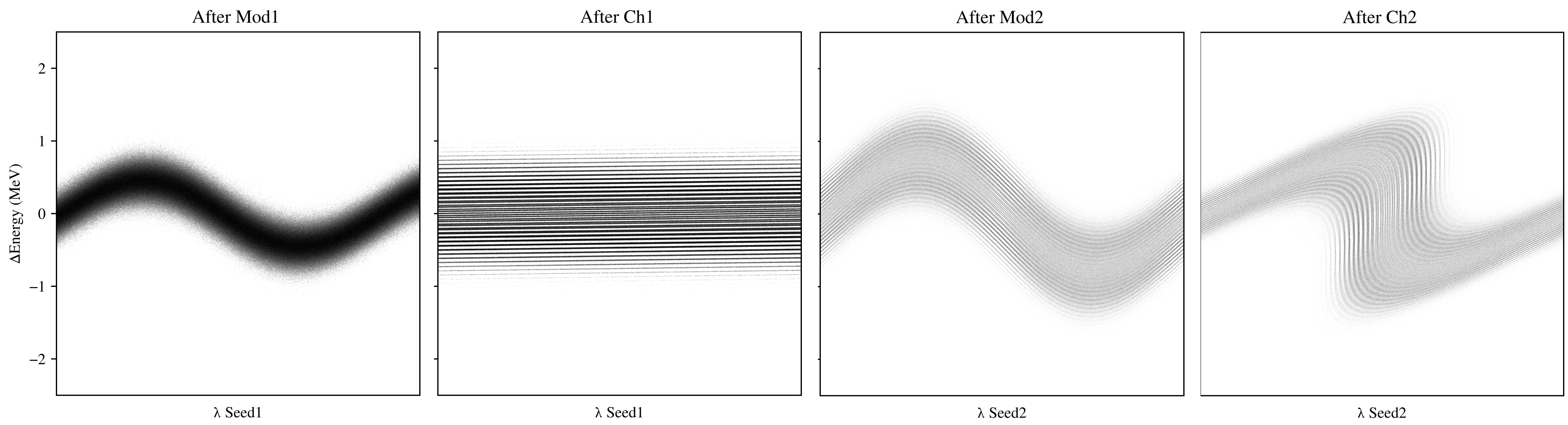
The modified Ming Xie curves already show the effect of negative chirp



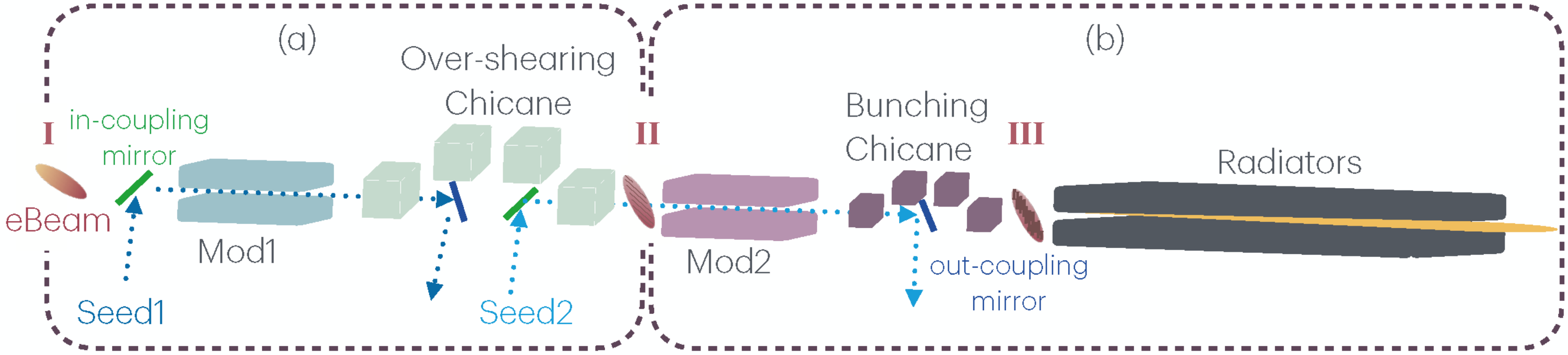


Realistically modeled simulation used as input
Estimating the performace of seeding Setup





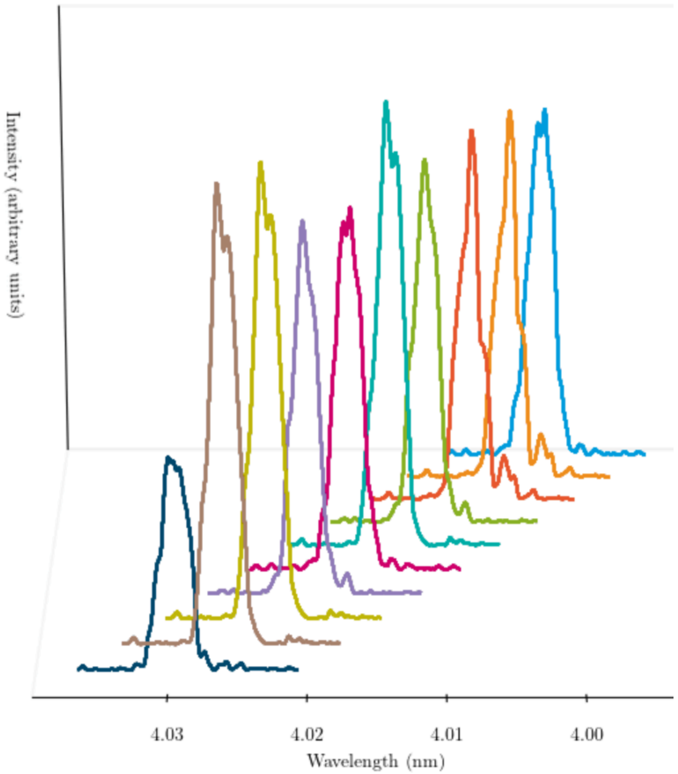
Optimization of EEHG or HGHG setup
Use the eBeam Properties at I, II, III and Modified Ming Xie

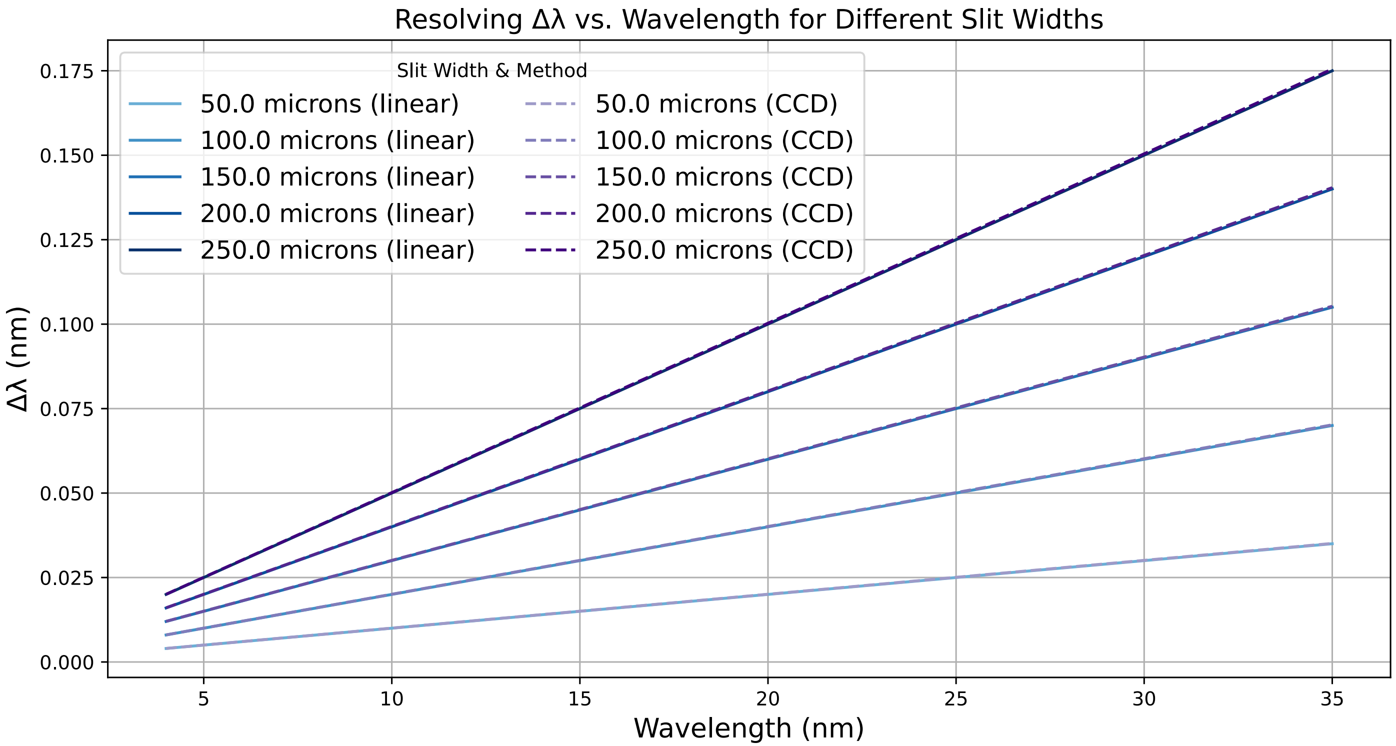


For HGHG we only have one stage of bunching optimization (b)
For EEHG we need two stages of bunching optimization (a+b)

Simulations and Diagnostics
Motivation for Using Realistically Modeled Simulations

Reported resolving power of $\lambda/\Delta\lambda$ = 1000 (for 13-30 nm)





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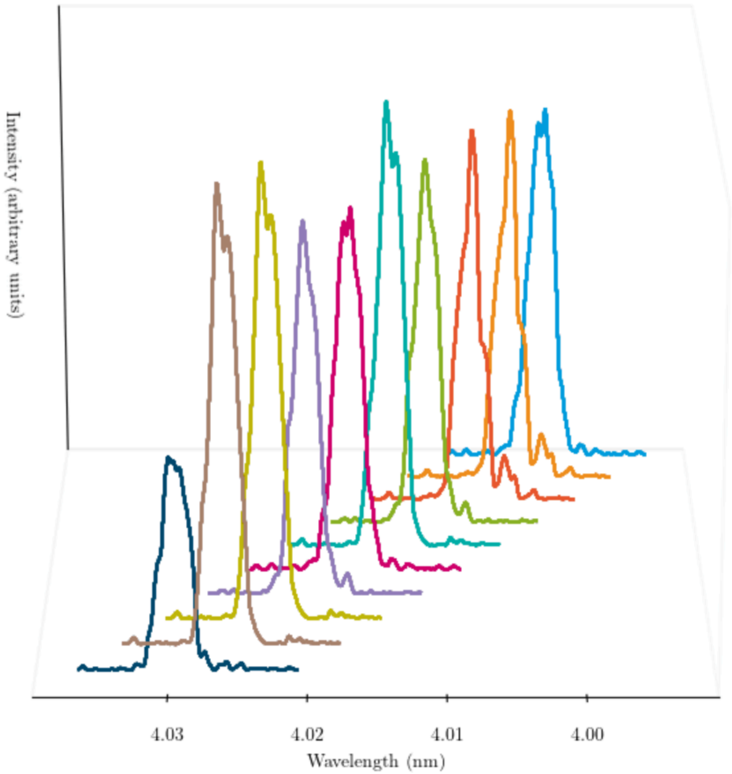

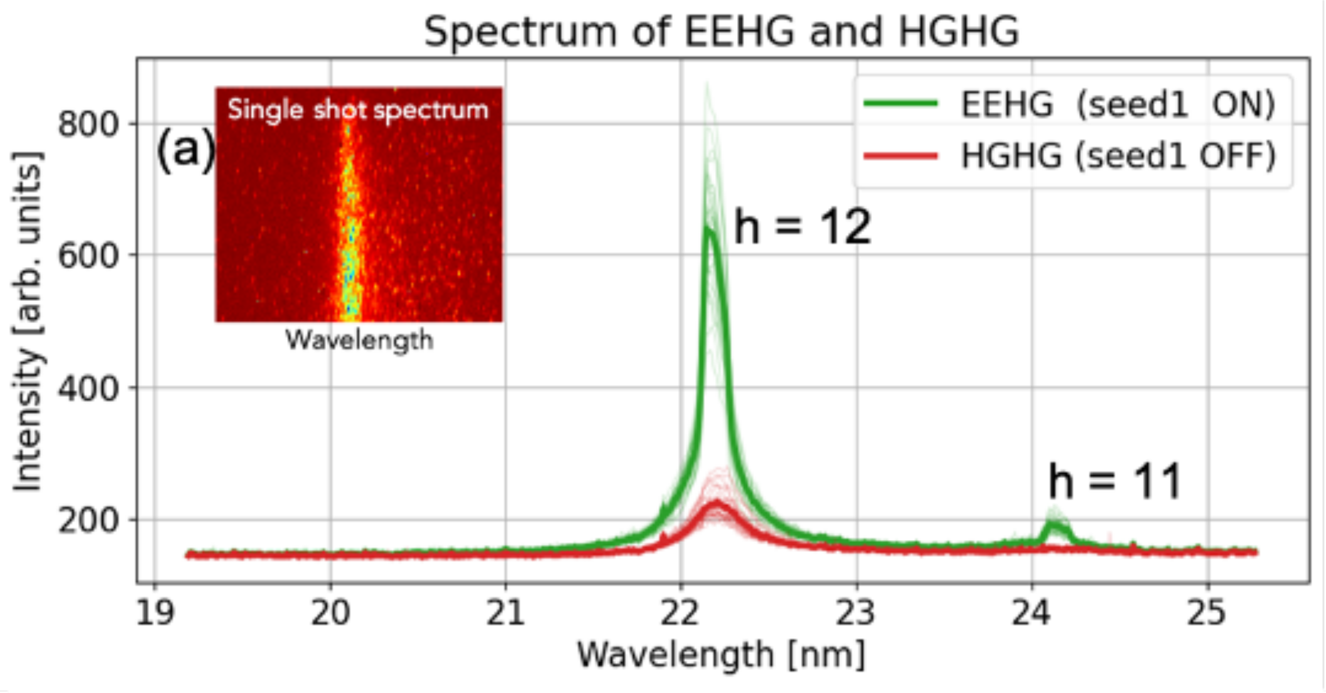

FLASH2020+ Seeding Progress:

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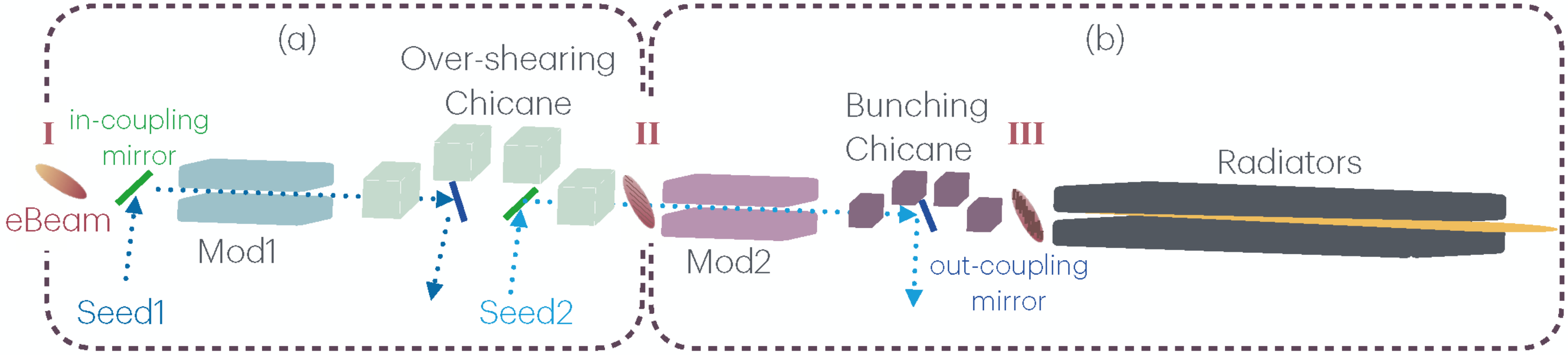

For HGHG we only have one stage of bunching optimization (b)
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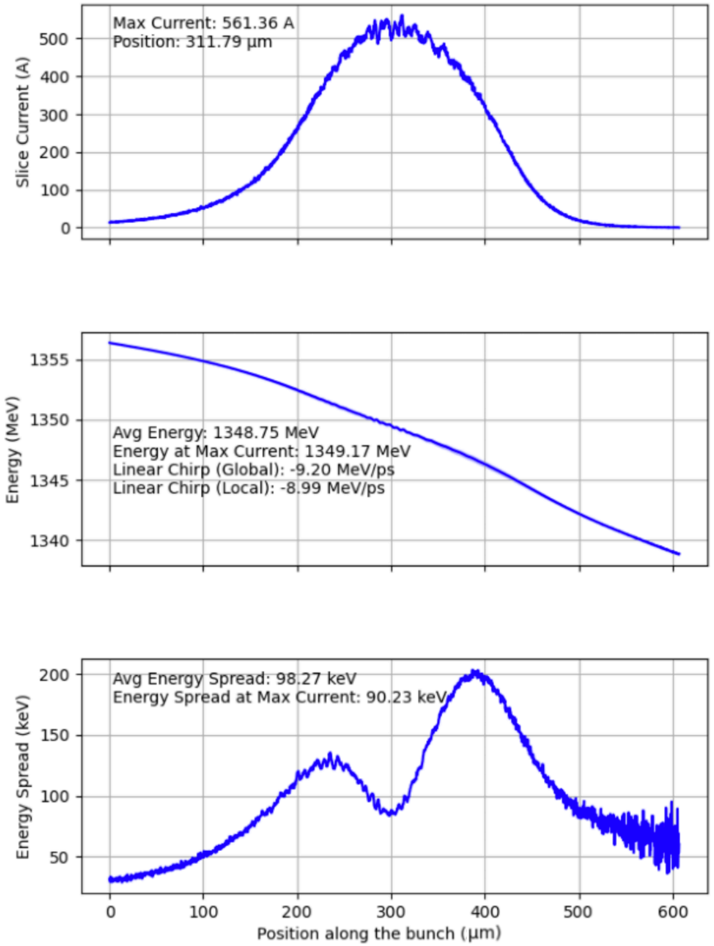
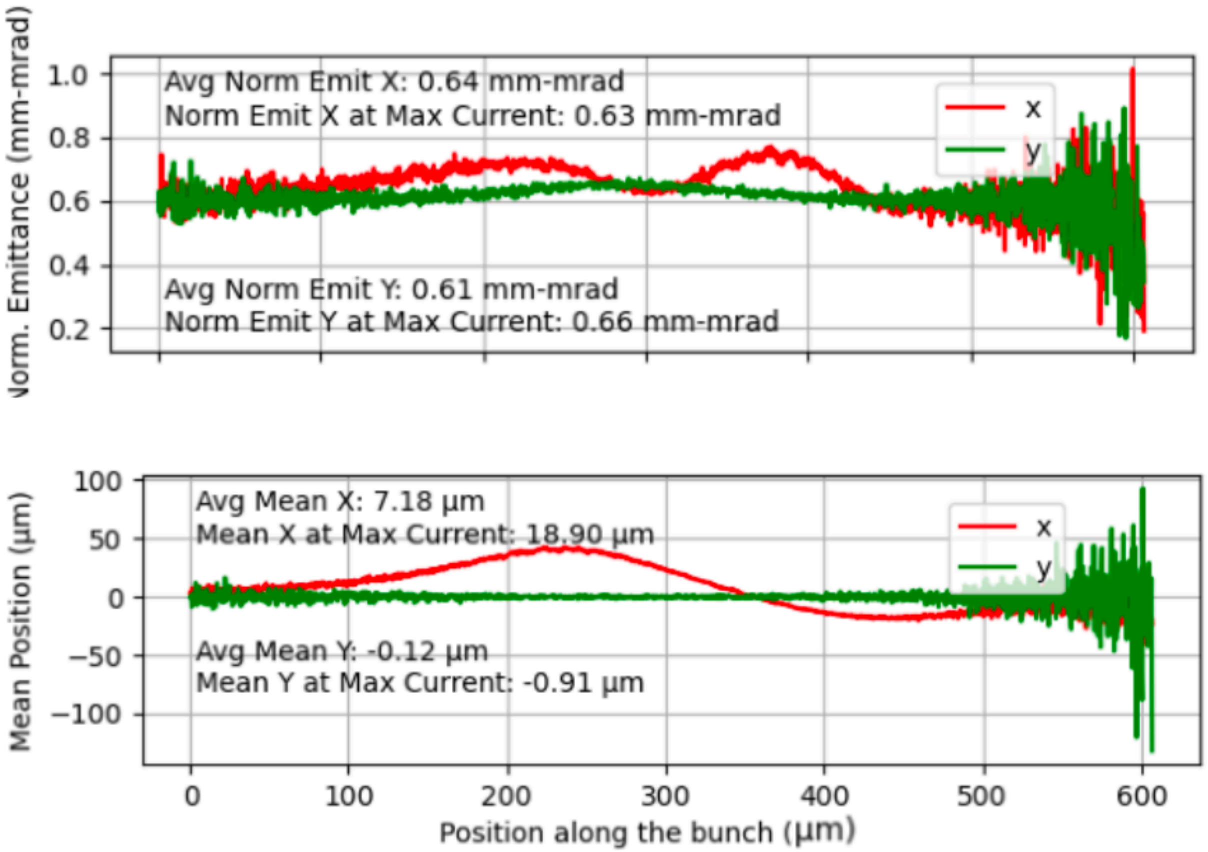
Start to End Simulation
Highlight of Beam (at the End of LINAC) or at I





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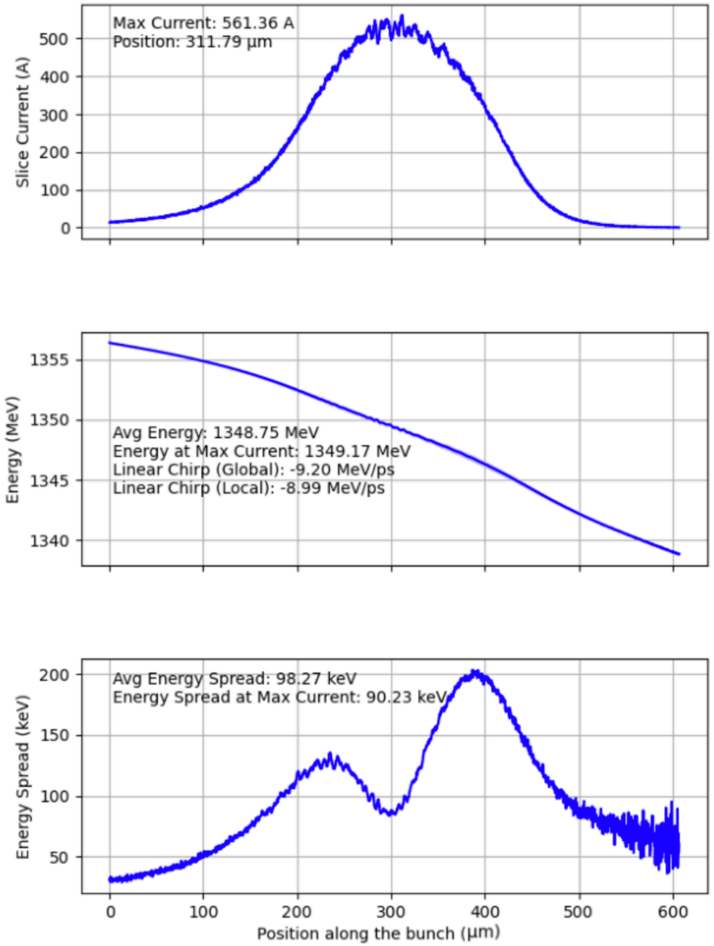

Showes the microbunching and in the region of intrest for seeding

Note: bunch is centered around 300 micron

Start to End Simulation

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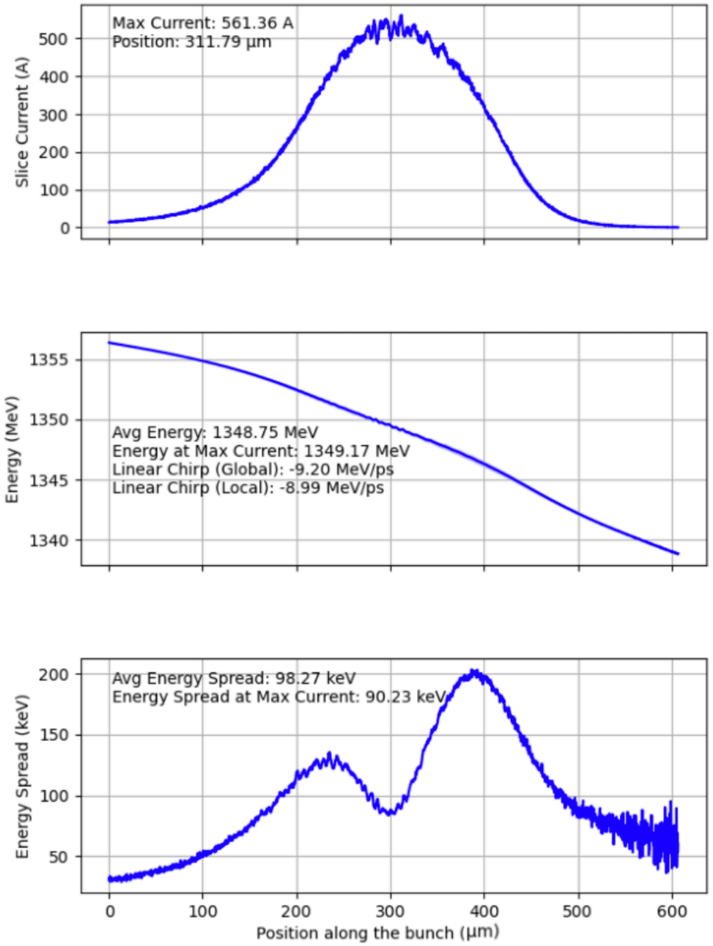

Showes the microbunching and in the region of intrest for seeding

Gives the best case senario for chirp ~9MeV/ps (without dechirper)

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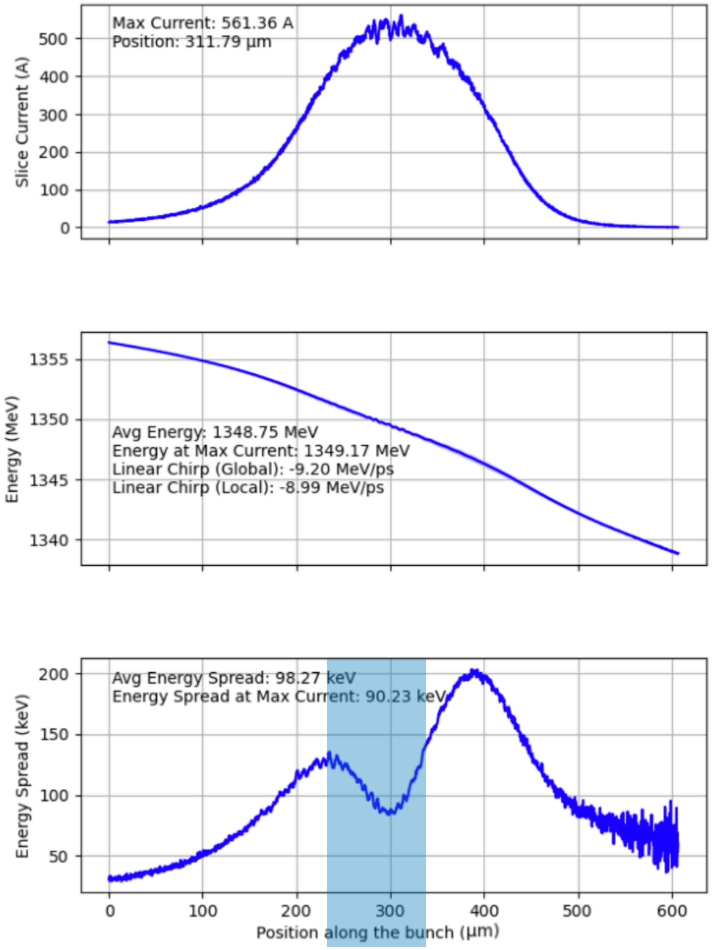

Showes the microbunching and in the region of intrest for seeding

Gives the best case senario for chirp ~9MeV/ps (without dechirper)

Expected variation of energy spread along the Bunch profile we use the 150 keV as worst case scenario

Note: bunch is centered around 300 micron

Start to End Simulation
Highlight of Beam (at the End of LINAC) or at I

Agrees with projected emittance measurments

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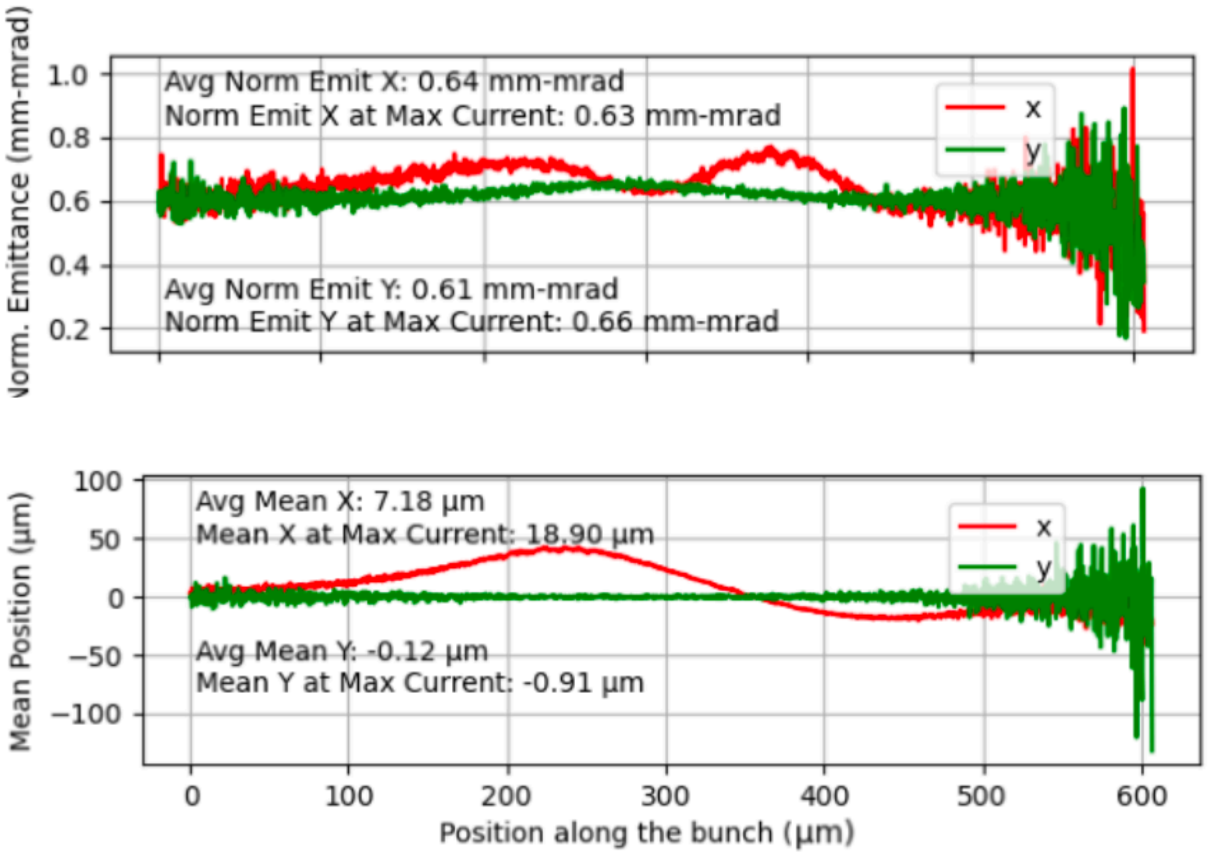

Start to End Simulation
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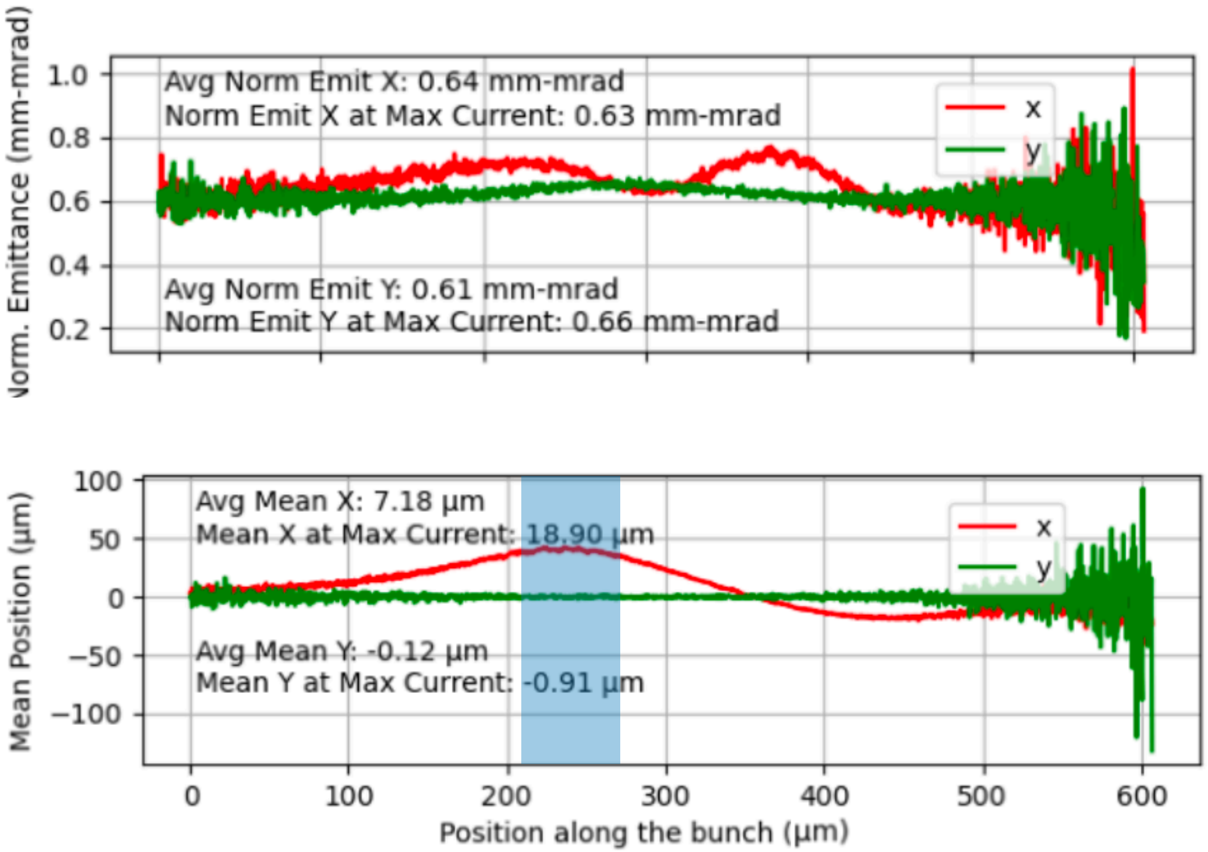
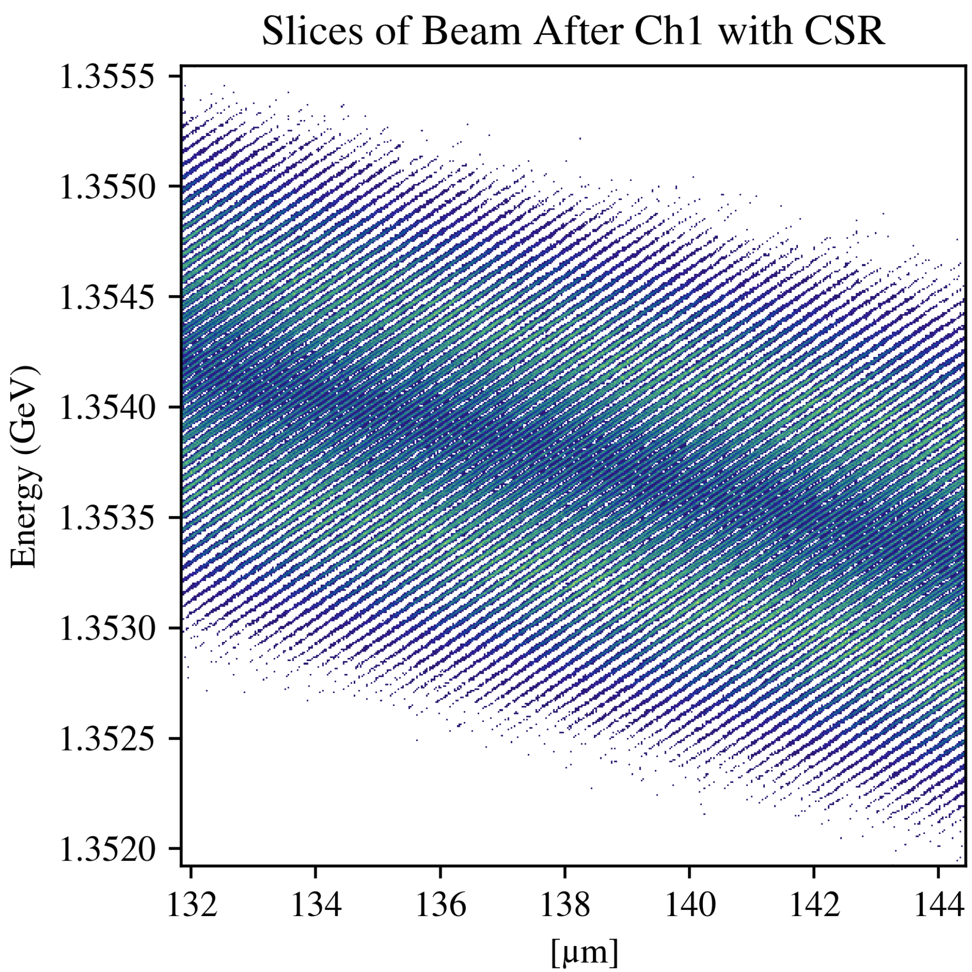
Position jitter that is expected with timing jitter

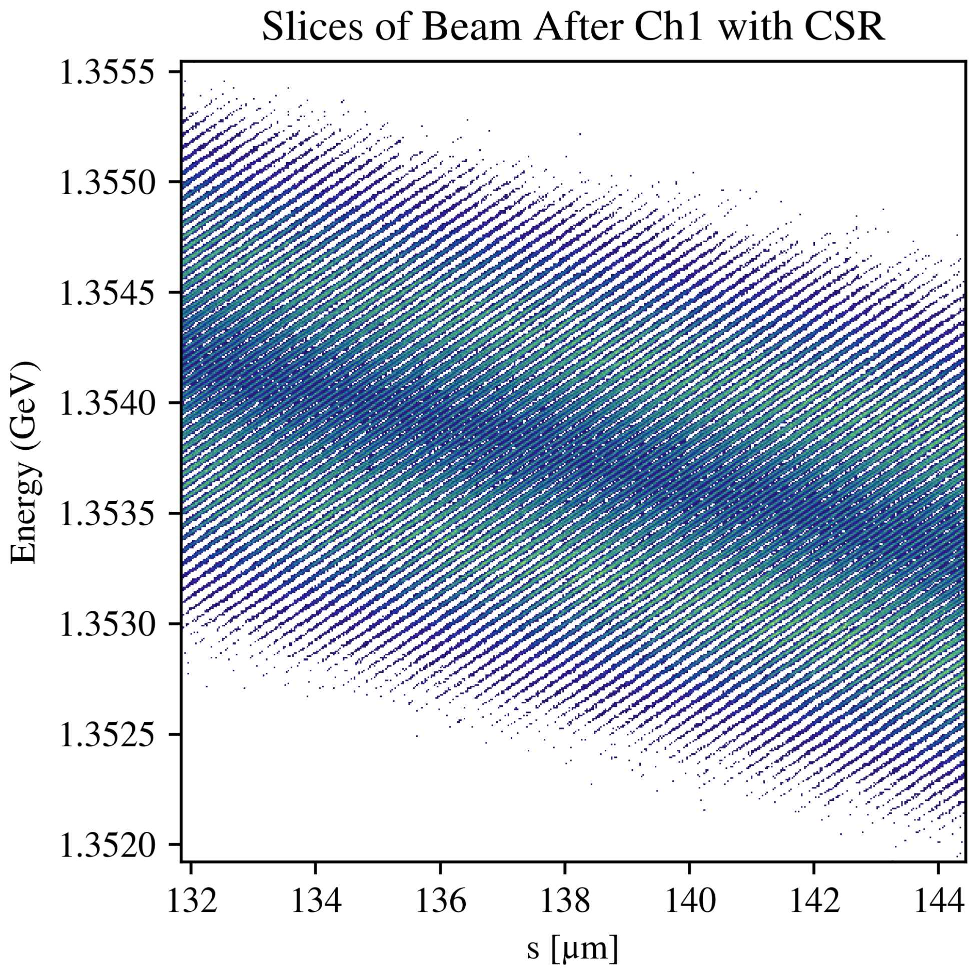


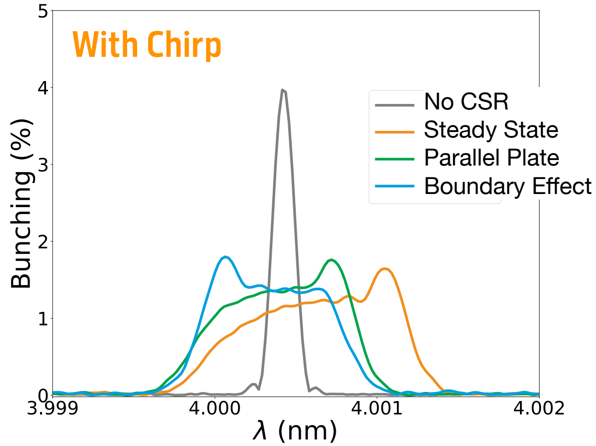
Start to End Simulation
Highlight of Beam (after 1st Modulator-Chicane) or at II



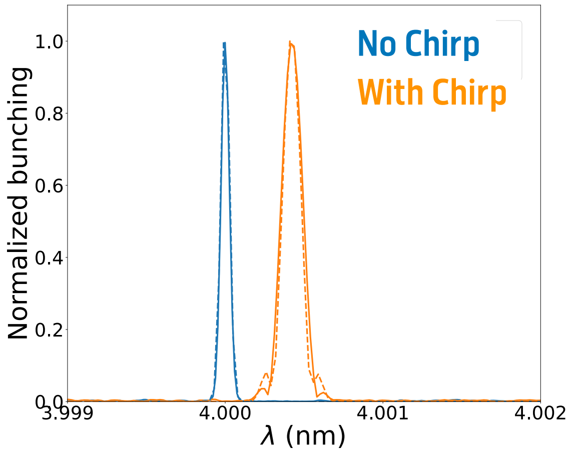
CSR (modeled with transient and shielding effects) to investigate the CSR on the bunching bandwidth in seeding section

Start to End Simulation
Highlight of Beam (after 1st Modulator-Chicane) or at II



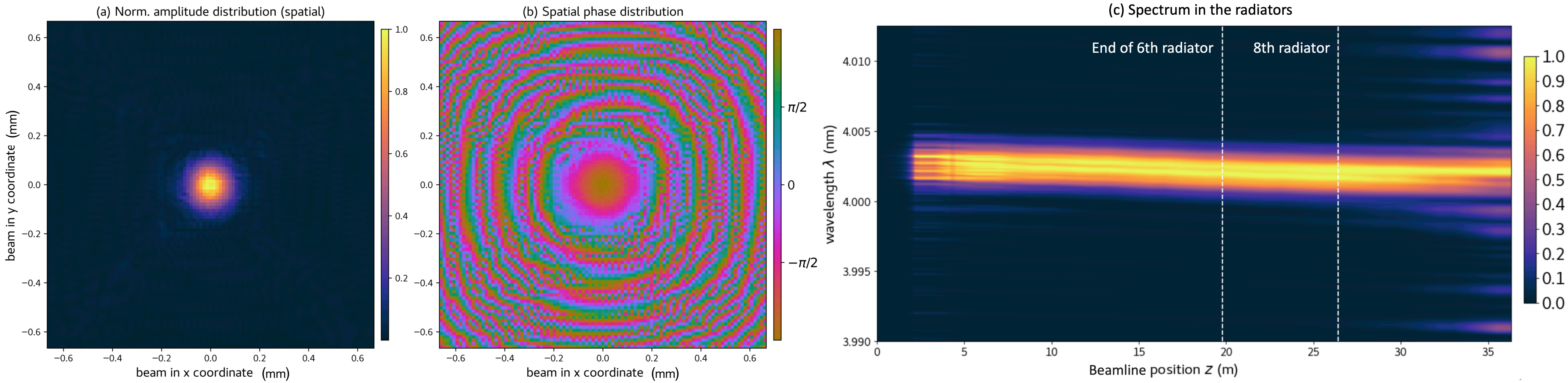


< **BW increase by ~ 0.02 % due to Chirp in EEHG setup in every CSR model**



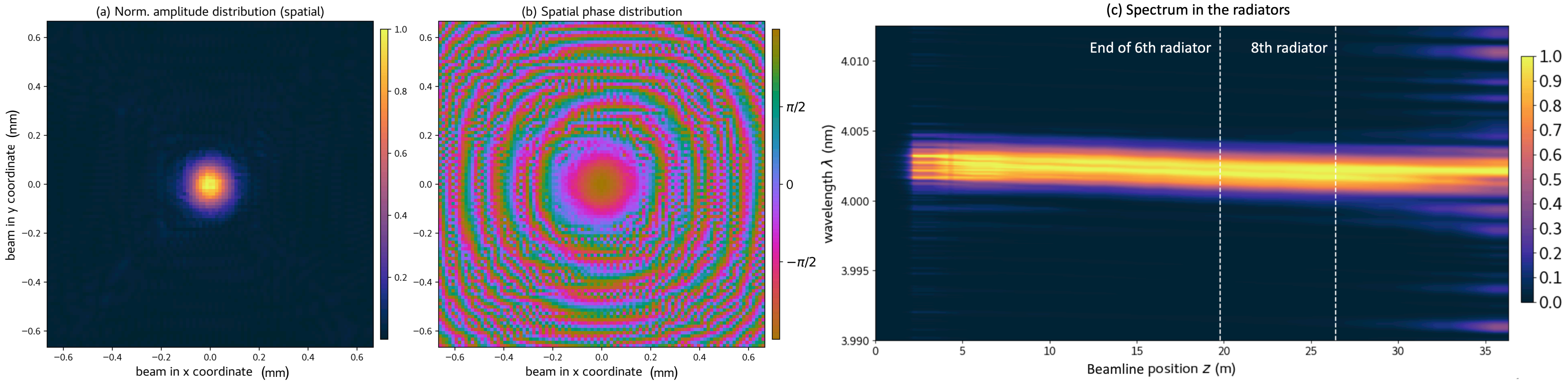
< **Shift by 0.013 % due to Chirp in EEHG setup**

Start to End Simulation (FLASH with chirp and Taper)
Properties of FEL Pulses



- **Despite the energy chirp in the beam, the transverse beam quality did not degrade (maintaining a stable electron trajectory is essential)**
- **Temporal domain: the performance was less optimal longitudinal phase slippage leads temporal smearing of the radiation pulses**
- **The broadened pulses have reduced coherence.**

Start to End Simulation (FLASH with chirp and Taper)
Properties of FEL Pulses



- **Best Optimization results are achieved with multi-dimensional optimization**
- **Allows for balancing trade-off between competing objectives.**

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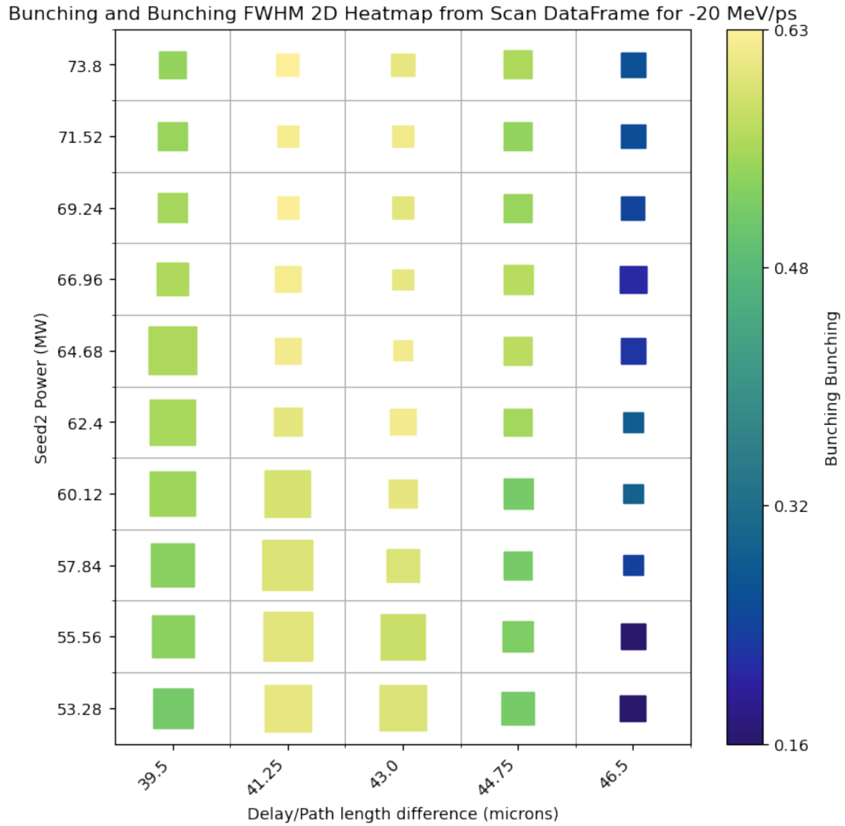
Multi-dimensional Optimization for Operation of FLASH2020+
Visualization tools are crucial for displaying 2D parameter spaces

- **Visualize the results of an optimization or parameter scan**
  - **Each cell's size and color represent some outcome of interest**
  - **There the option look for min or max when looking at size**
  - **Use different color scale for FEL or Electron beam**
- **Results are mapped across two parameter dimensions here (seed power and R56 of bunching Chicane)**



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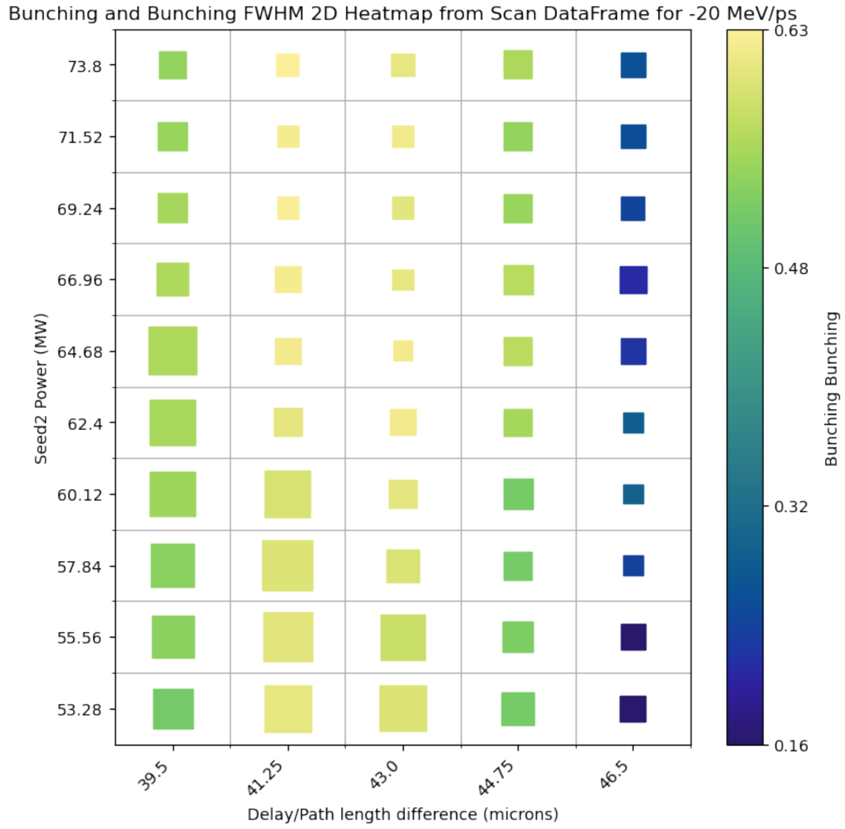
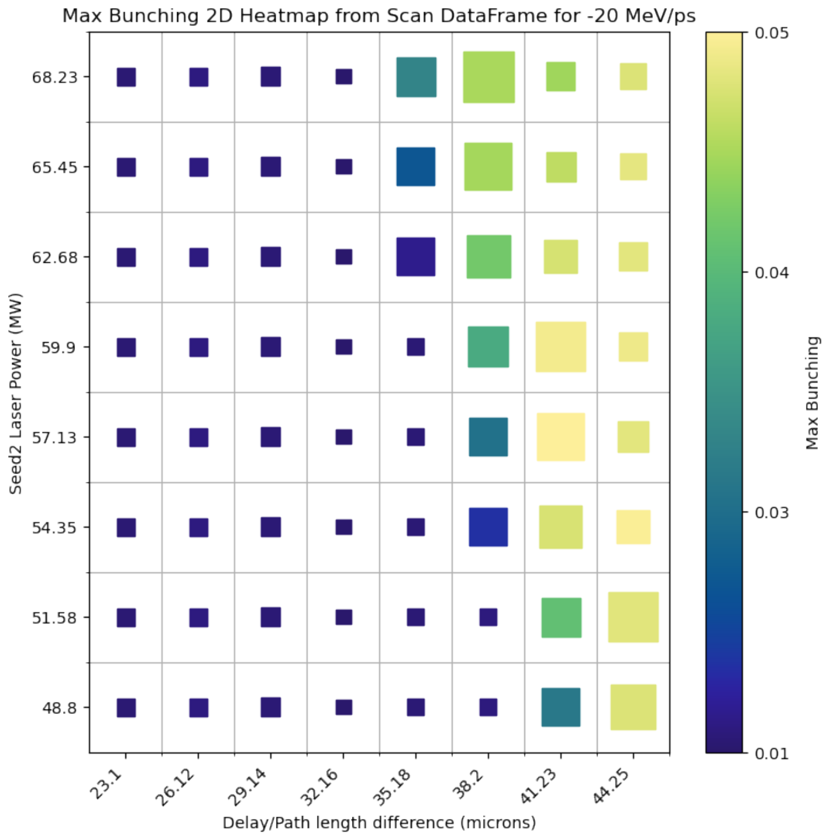
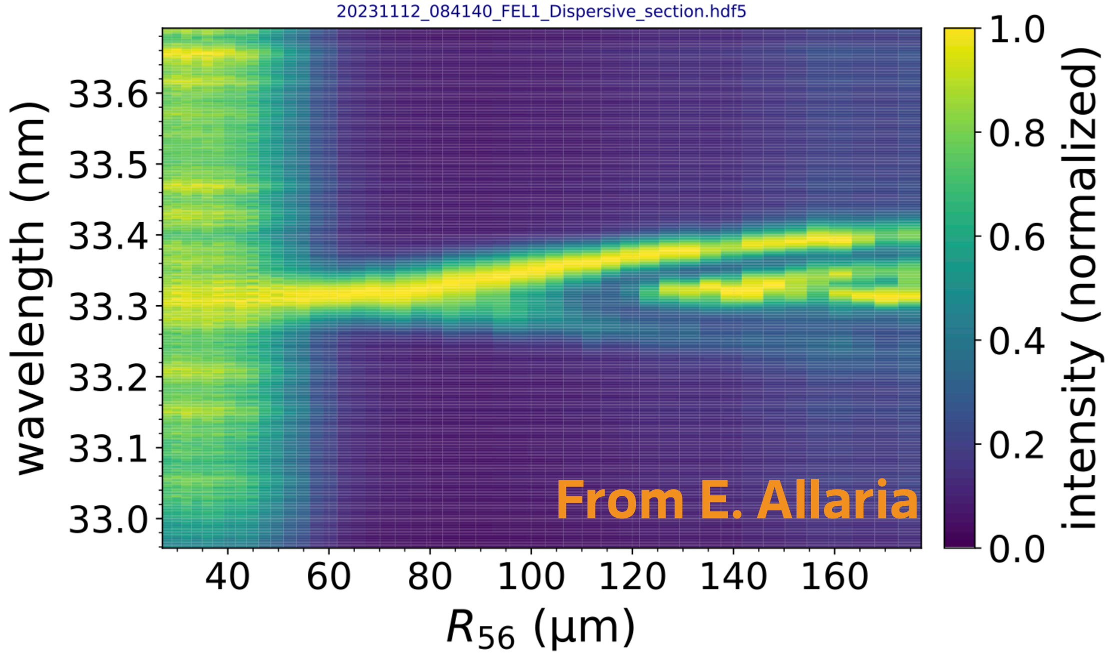


Multi-dimensional Optimization for Operation of FLASH2020+
Focus on scans that can also be done during beamtime

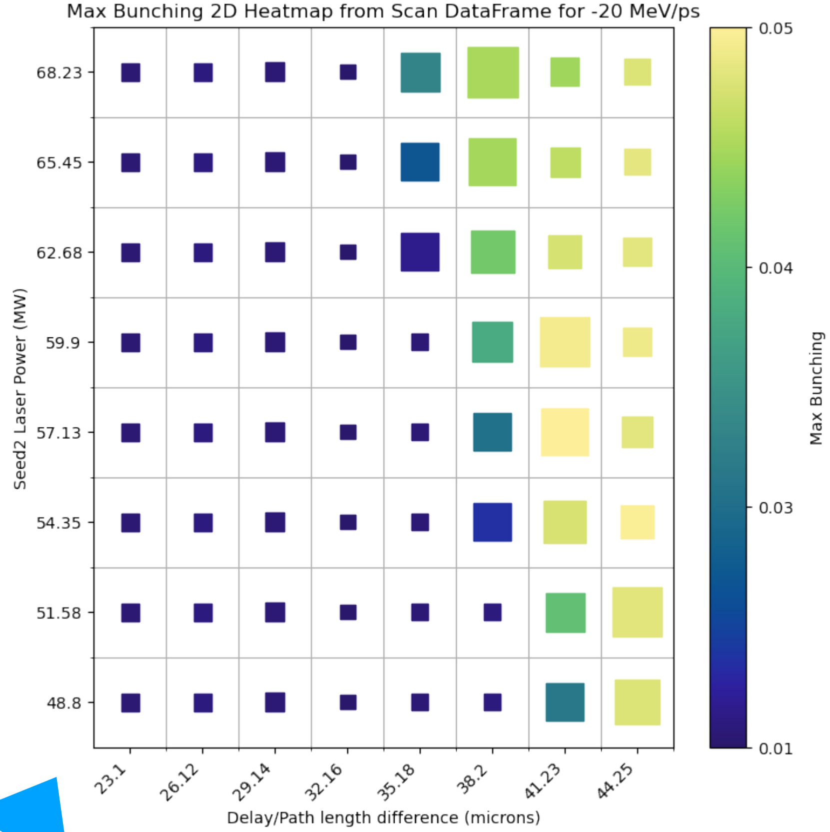


Spectrum from a Dispersion scan at FERMI



Multi-dimensional Optimization for Operation of FLASH2020+
Focus on scans that can also be done during beamtime

If we only close 3 radiators we can look at analogous trends to bunching



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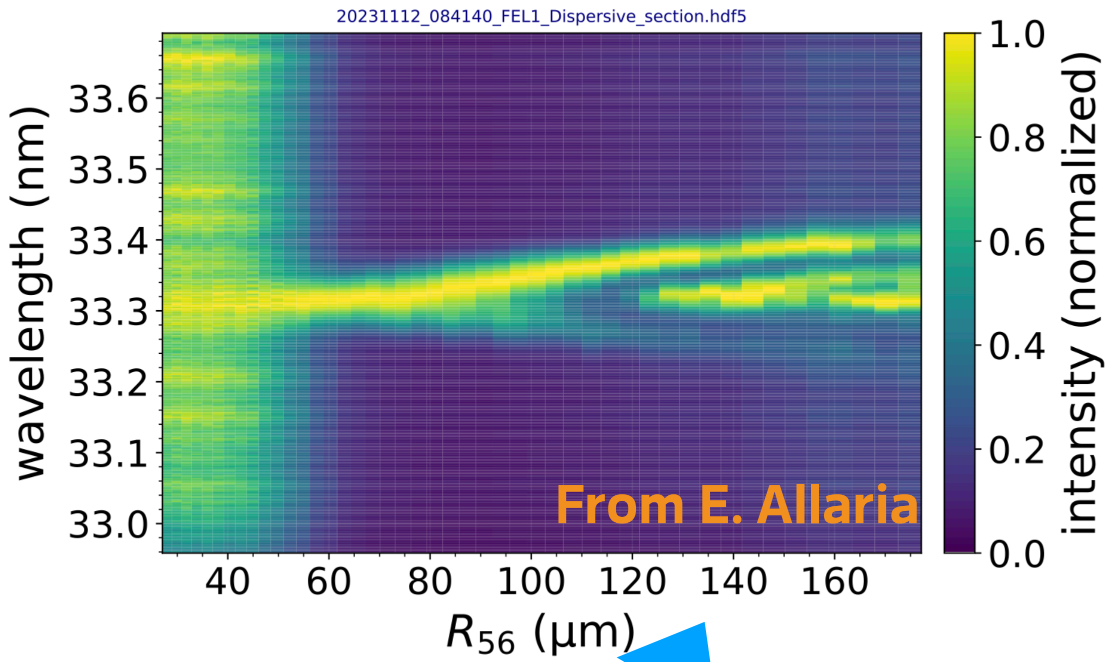

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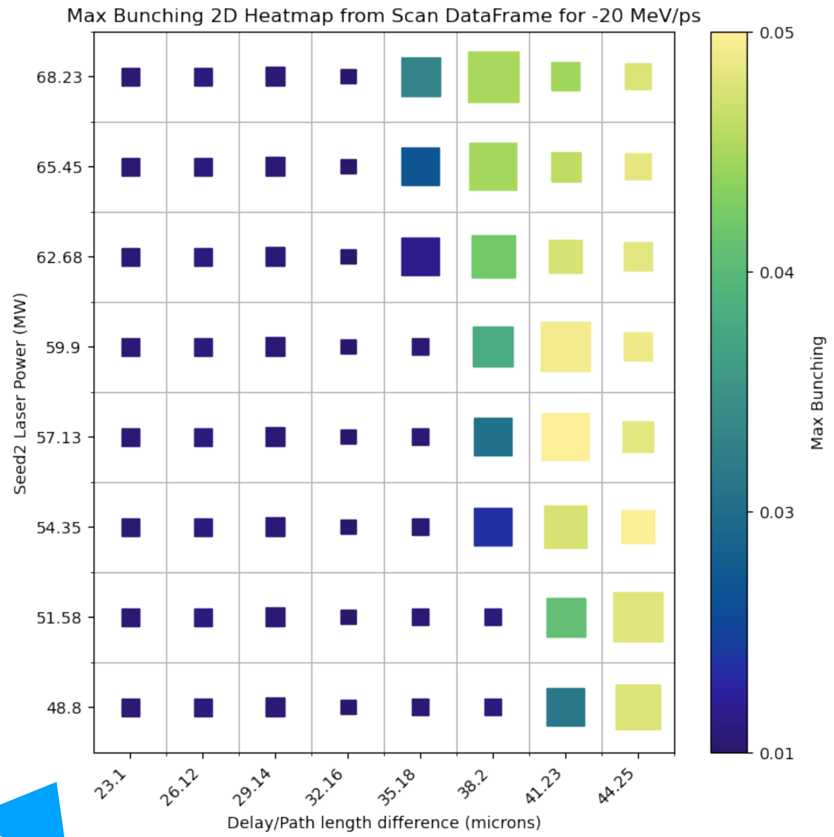
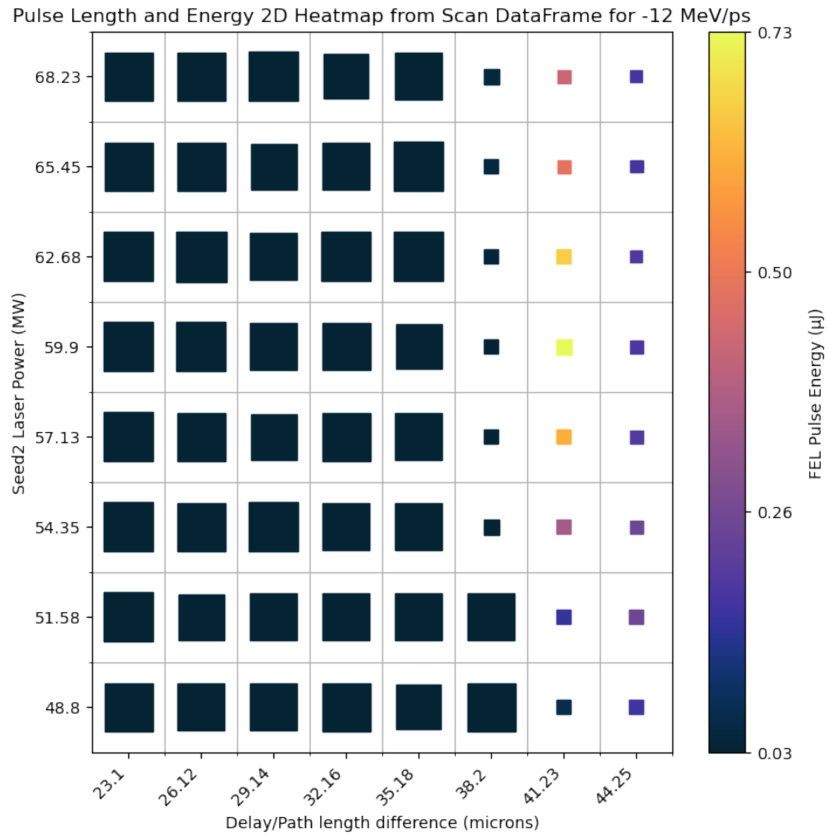


However this is too early for using Pulse length at a metric



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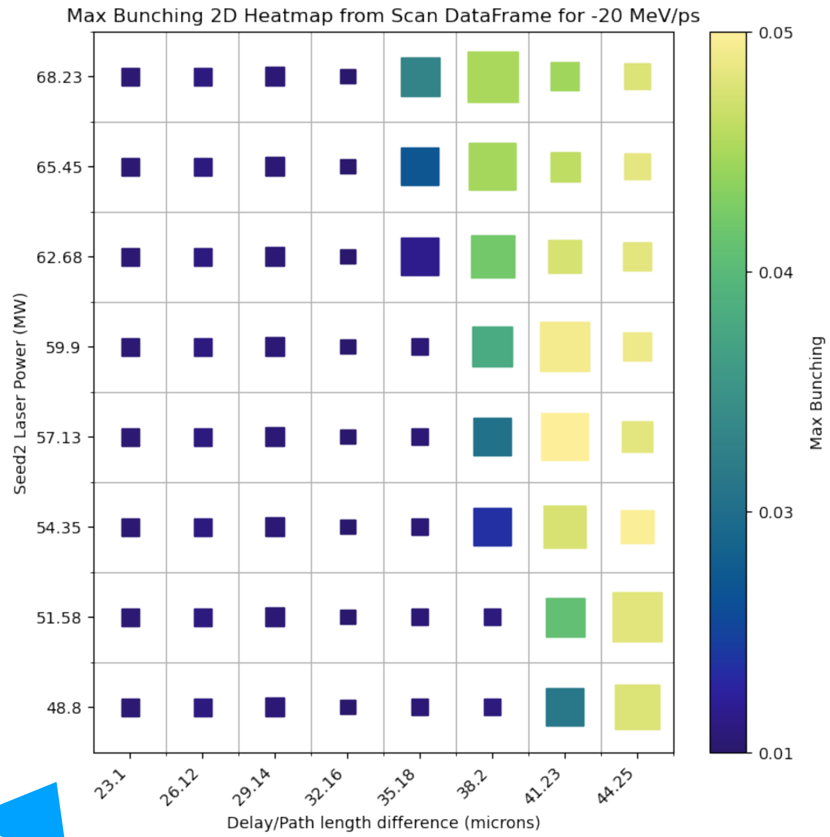

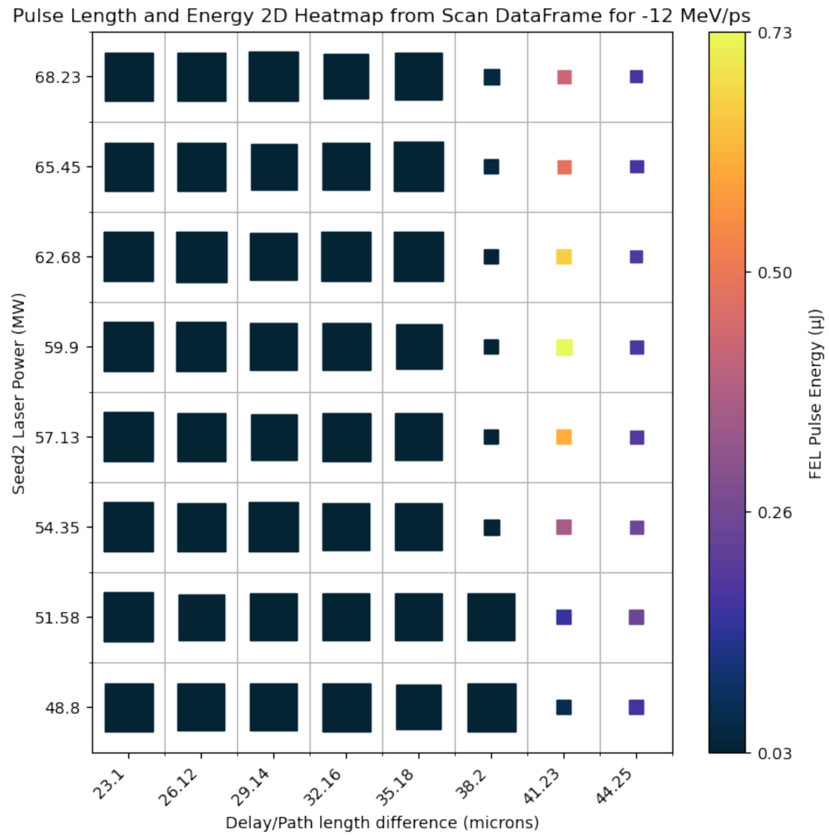

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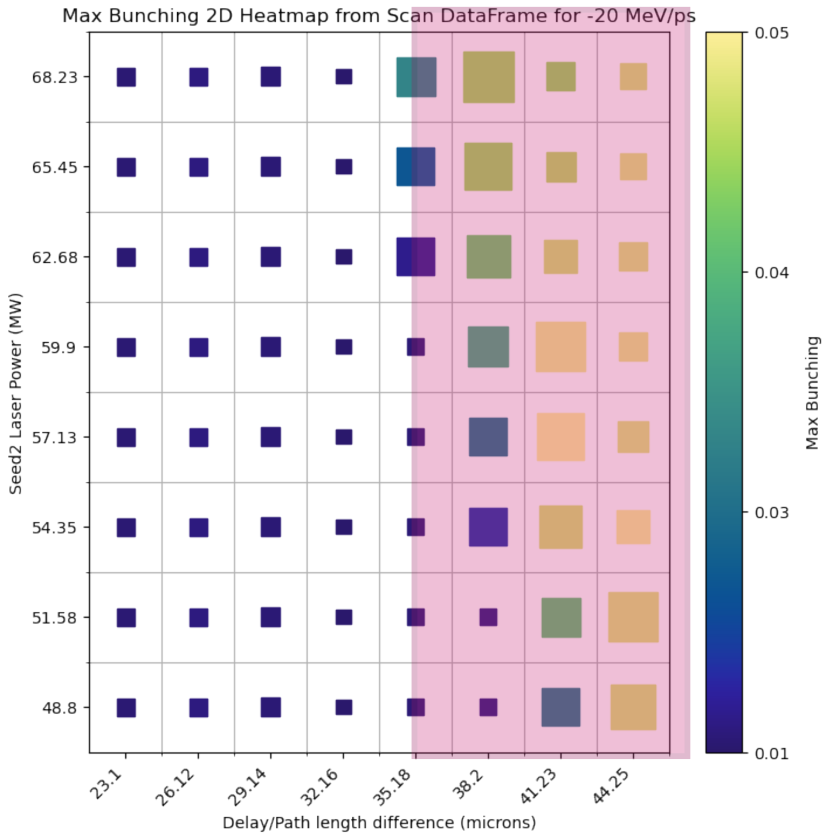

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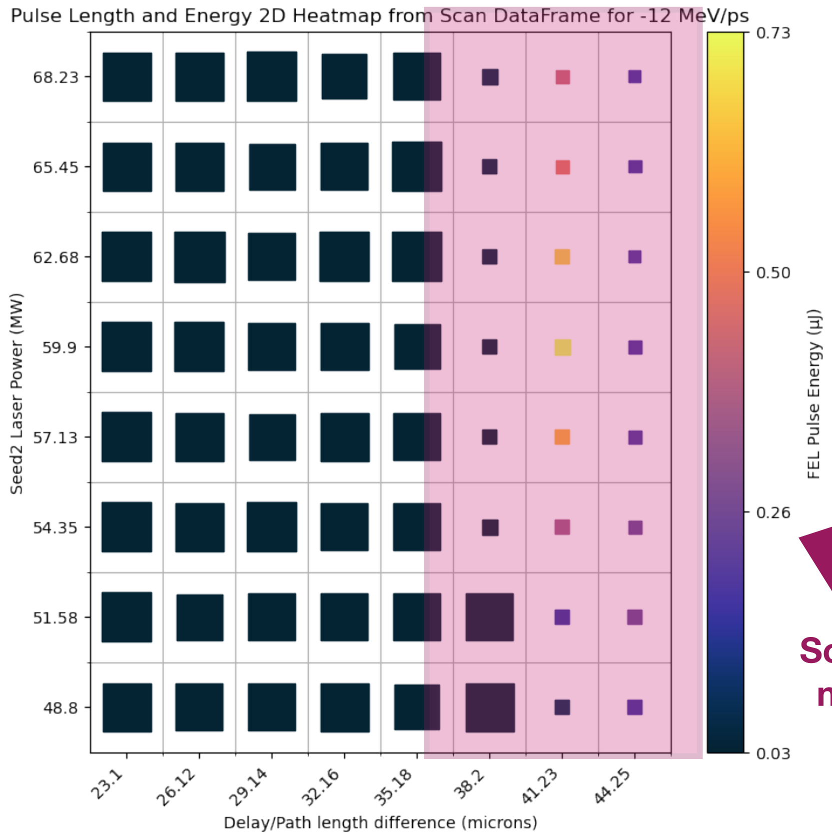
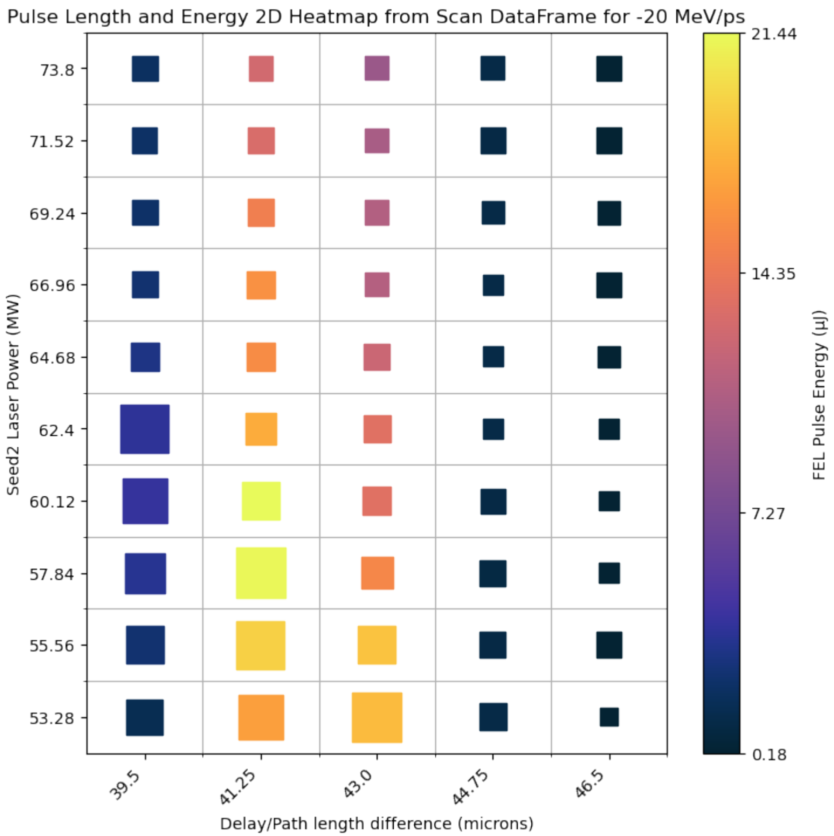


Scans on the next pages

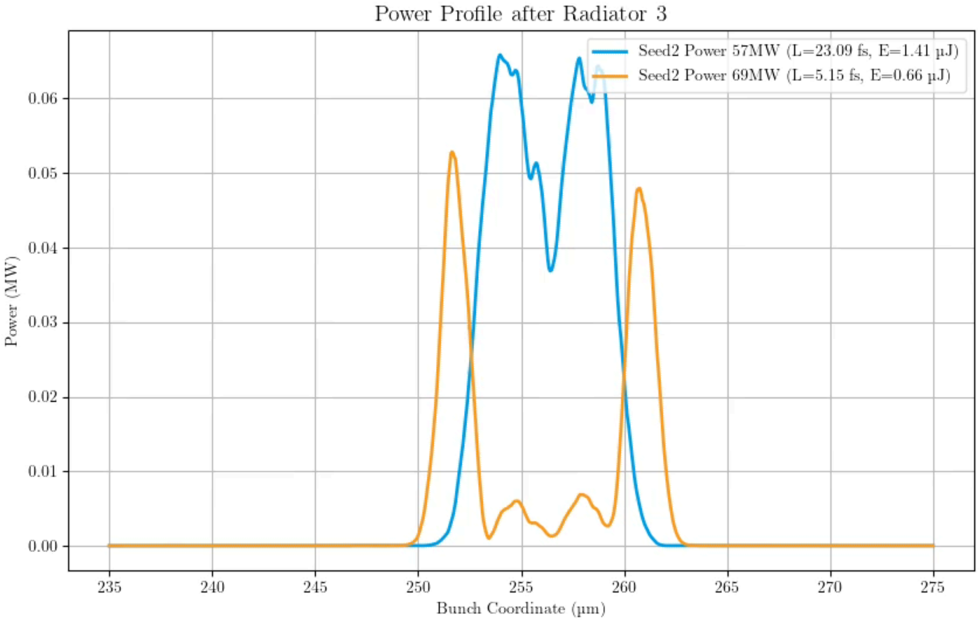
Multi-dimensional Optimization for Operation of FLASH2020+
Focus on scans that can also be done during beamtime

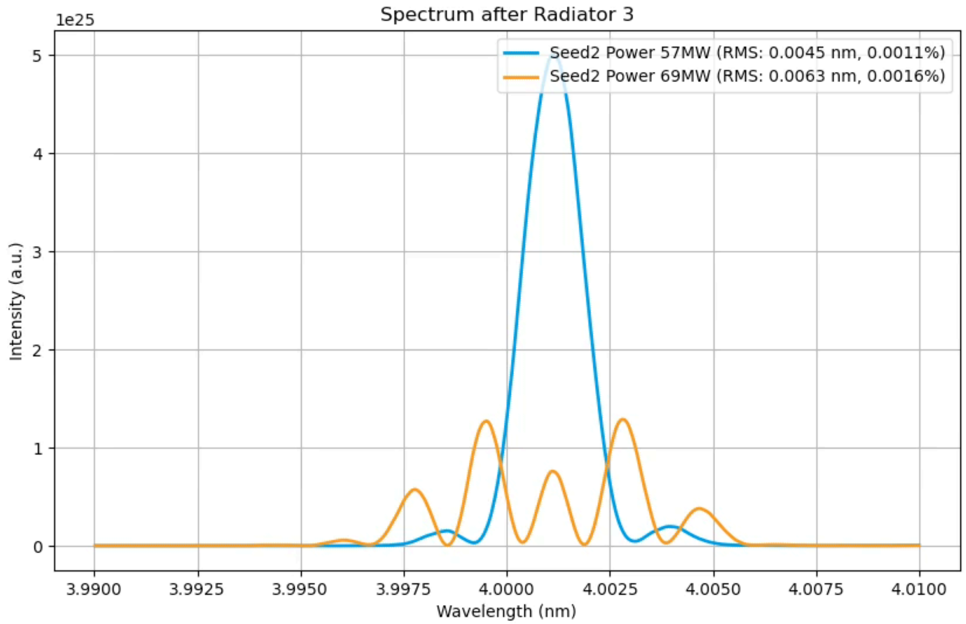
- **Results for optimizing for shortest pulse length (4 fs - 26 fs) and at least 10 uJ FEL pulse energy**

- **We see that for higher chirp we need to go to lower R56 in the bunching chicane**



Realistically modeled simulations (Ex. 1)
Tuning for ~ 10 uJ and short pulses after 6 or 8 Radiators

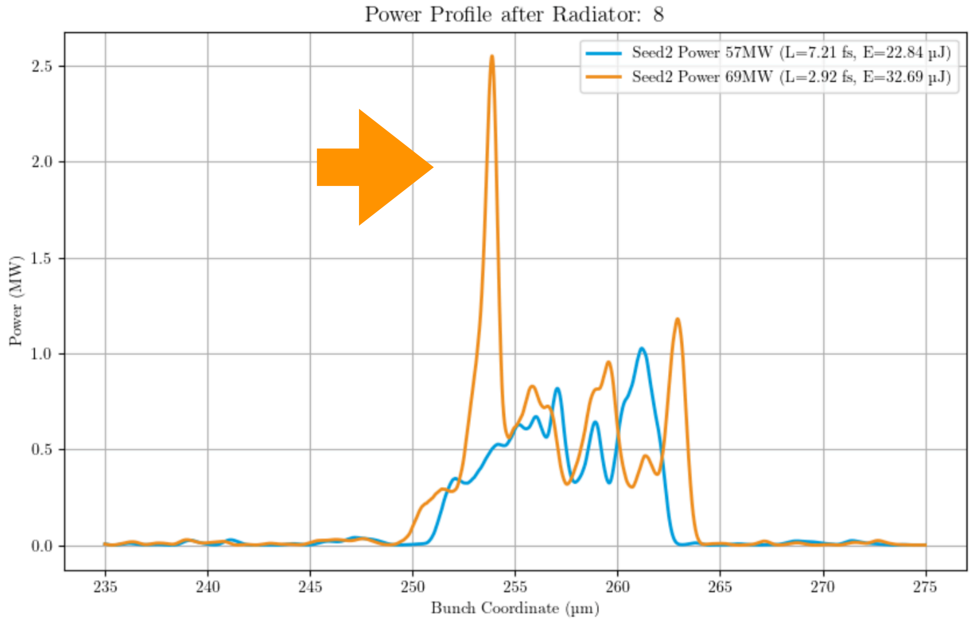


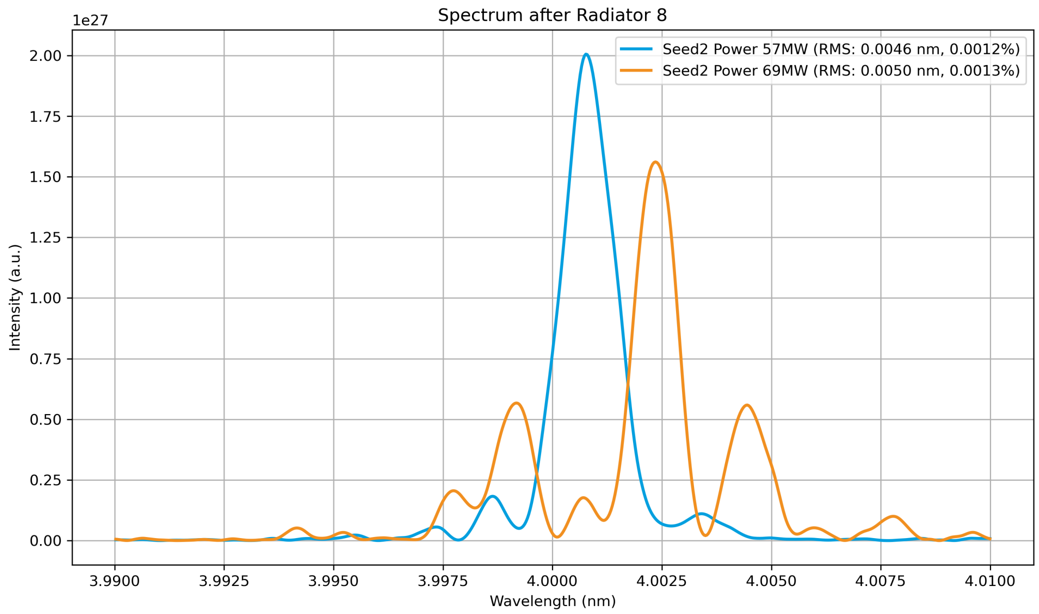


Realistically modeled simulations (Ex. 1)
Tuning for ~ 10 uJ and short pulses after 8 Radiators

Leads to short, intense pulses that are characteristic of sidebands
Expected to have reduced extraction efficiency in SASE or Self seeding.

In EEHG, the coherent microbunching allows for a more efficient interaction between the electrons and the radiation field, mitigating that to some extent.

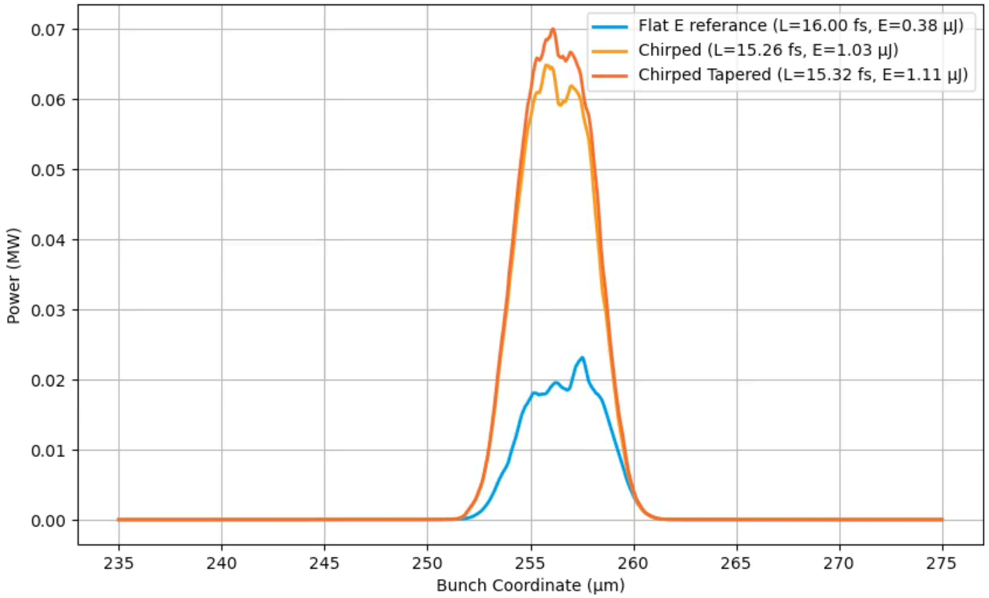


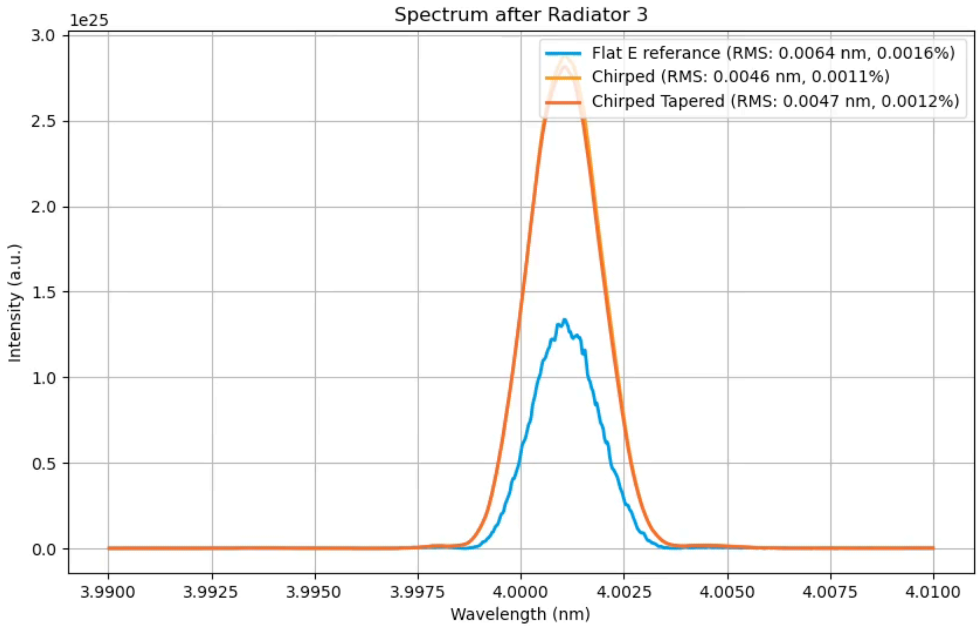


Realistically modeled simulations (Ex. 2)
Using tapering to minimize BW growth and wavelength shift

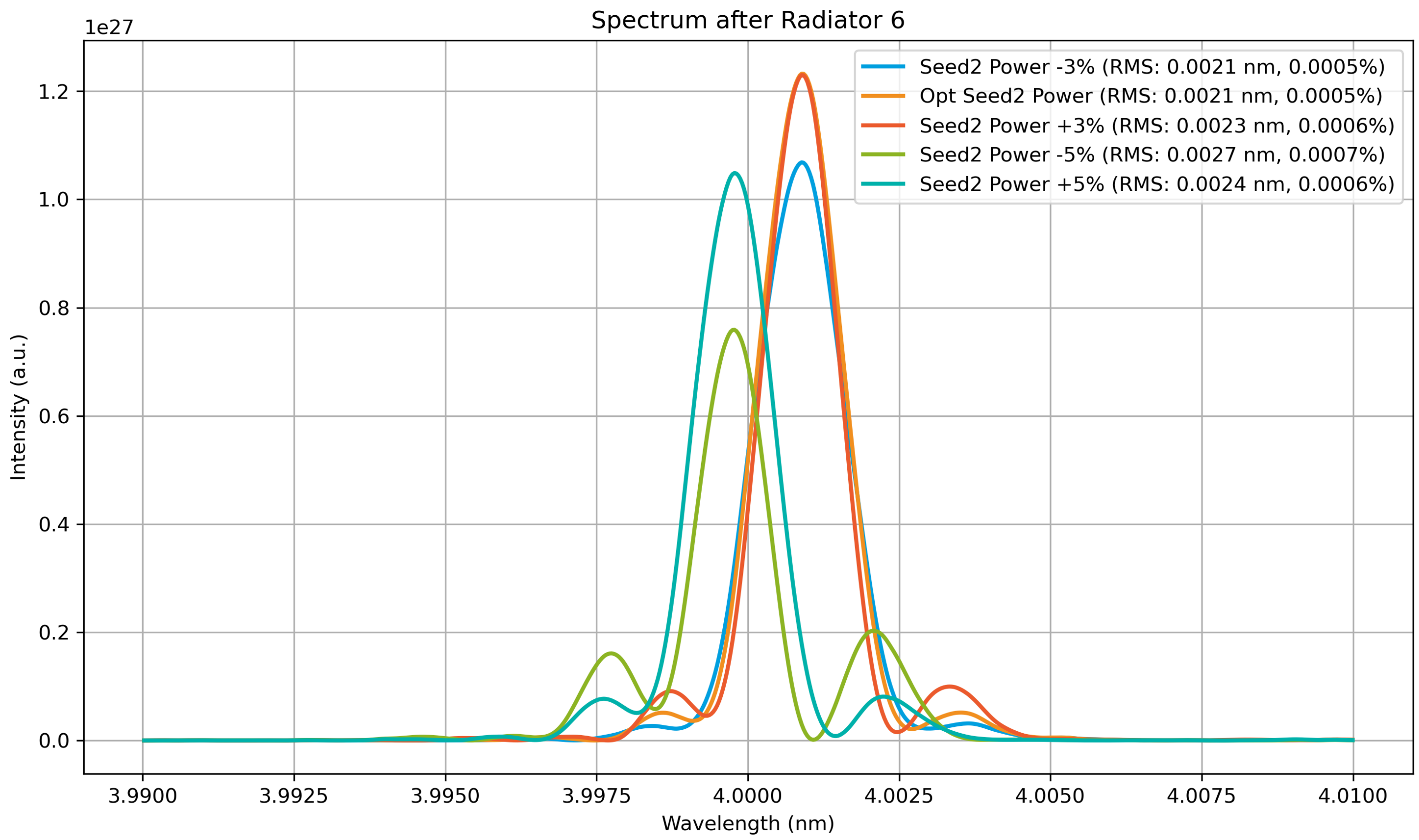
Tapering the undulator (reducing the undulator k) along the length of the undulator compensates for the energy loss in the electron beam.

This maintains the resonance condition, keeping the electron beam more in phase with the radiation and reducing the wavelength shift

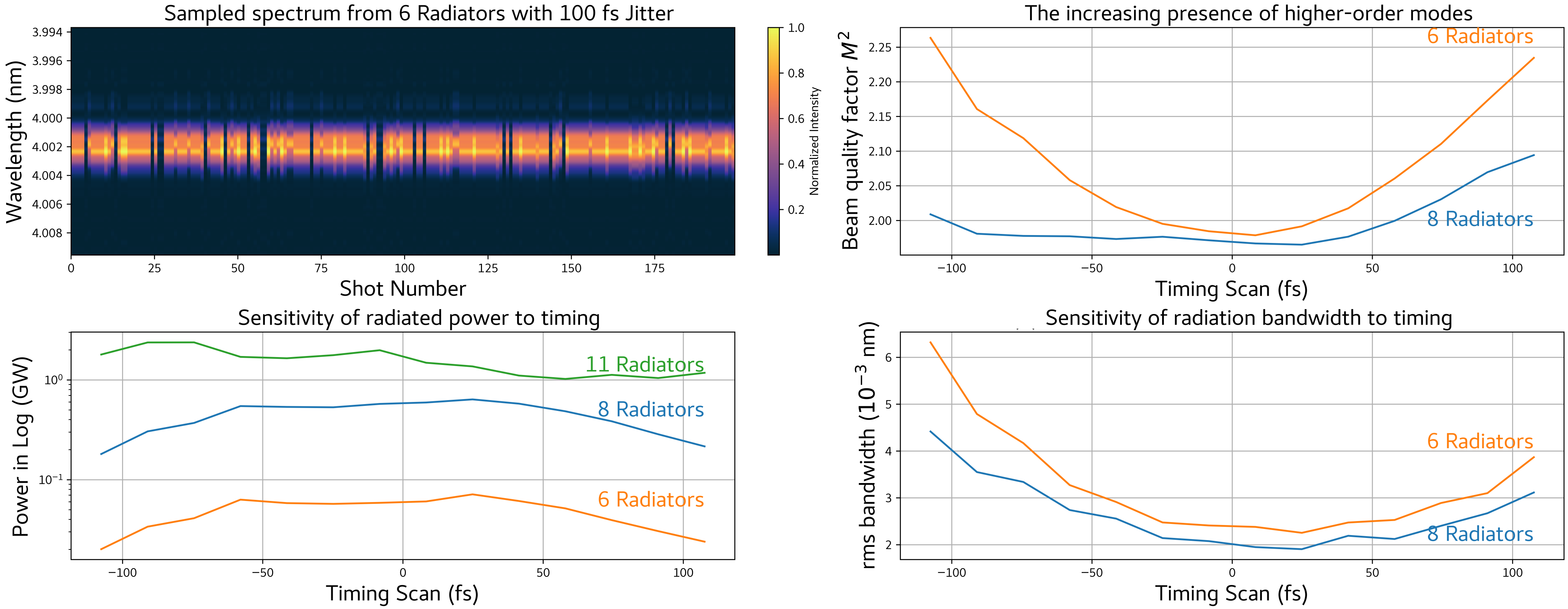




Realistically modeled simulations (Ex. 2)
An efficient setup is a stable setup



Collaboration with SciCat and DAPHNE4NFDI to Save our data and make it easily accessible is in progress



Summary and Future Plans

- Experience gained during the Xseed beam times and the results of the simulation have taught us a lot
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- Achieving optimal performance requires a multi-dimensional optimization approach, especially with complex effects like energy chirp and CSR.

- With this method, we consider both interdependent and coupled parameters, allowing for a balanced trade-off between competing objectives.

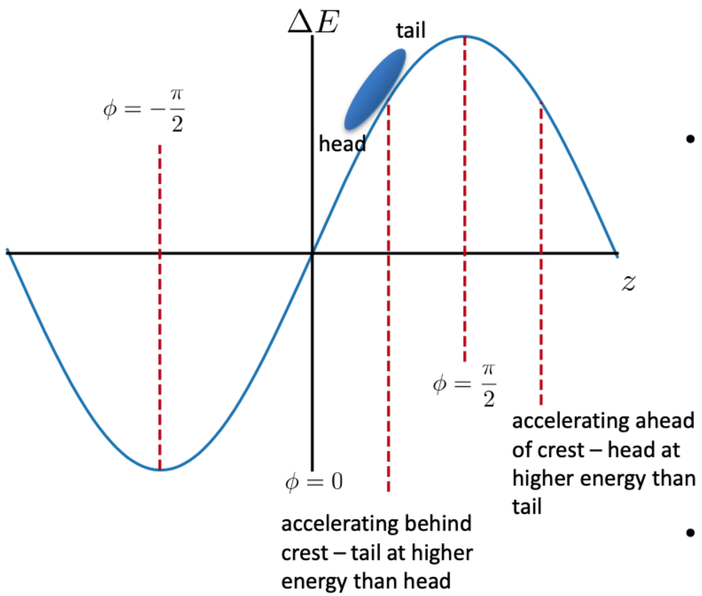
- With the right knowledge and diagnostic tools (software and hardware) and by simultaneously optimizing across multiple dimensions, we can reach optimal working points based on users' requests.

- We plan our studies to support the first user experiment for FLASH2020+, anticipating a productive and exciting initial operation phase.

-

BaCk Up SlIdeS

II. ACC



- Following elegant, use a sine convention for the rf wave

$$E_f(z) = E_0 + eV\,sin(k_{rf} z + \phi)$$

- Energy gain will be determined by voltage V and phase **ϕ**
  - Acceleration

$$0 \leq \phi \leq \pi$$

  - Zero-crossing

$$\phi = 0, \pi$$

  - Deceleration

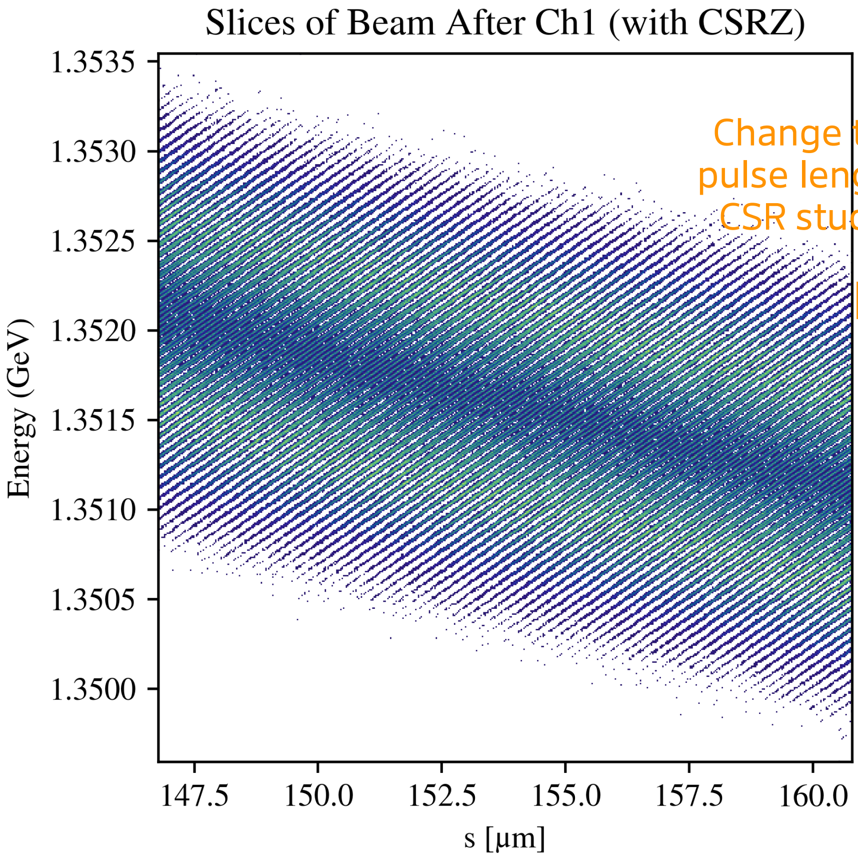
$$-\pi \leq \phi \leq 0$$

- Convention for longitudinal variable z (i.e. t) in elegant:

$$z_{head} < z_{tail}$$

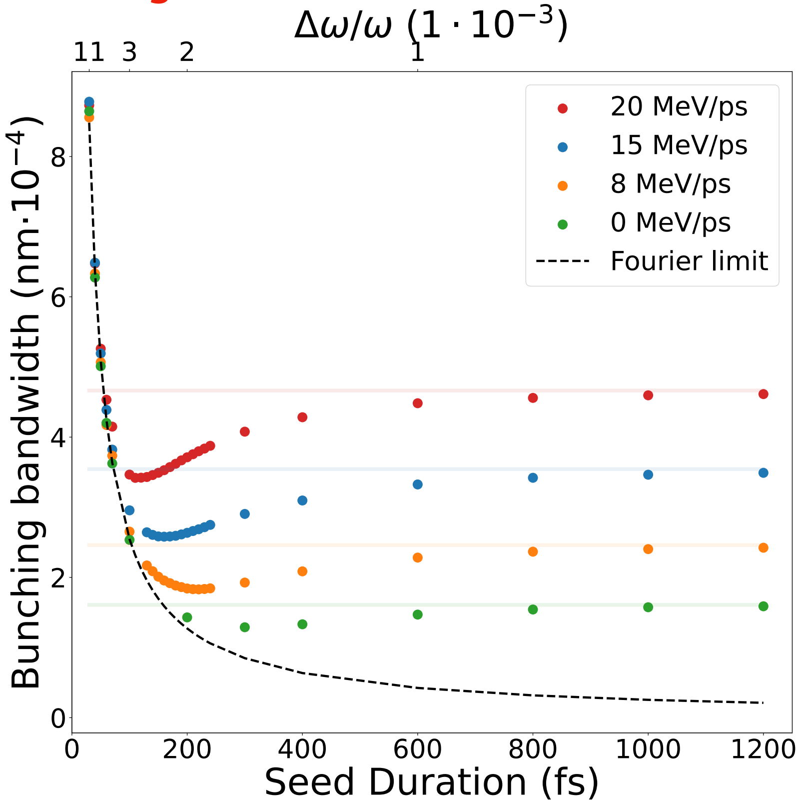
Optimizing Bunching Bandwidth for EEHG scheme

Effect of laser pulse length on the beam with FLASH inherent chirp + CSR induced chirp



Change the laser pulse length in the CSR study setup

Assuming Fourier limited seed2 laser in mod2



D. Samoilenko

Collaboration with SciCat and DAPHNE4NFDI to Save our data and make it easily accessible is in progress

Datasets from simulations are often ~some or some 10s of TB in size.

A FLASH2020P folder will be set up on https://public-data.desy.de/login.

It will have Metadata and Example scripts (or notebooks) for accessing data. Priority goes to data used in papers in review and to be published and data requested by photon science colleagues