FLASH II Seeding History and Future

Kirsten Hacker

April 2014

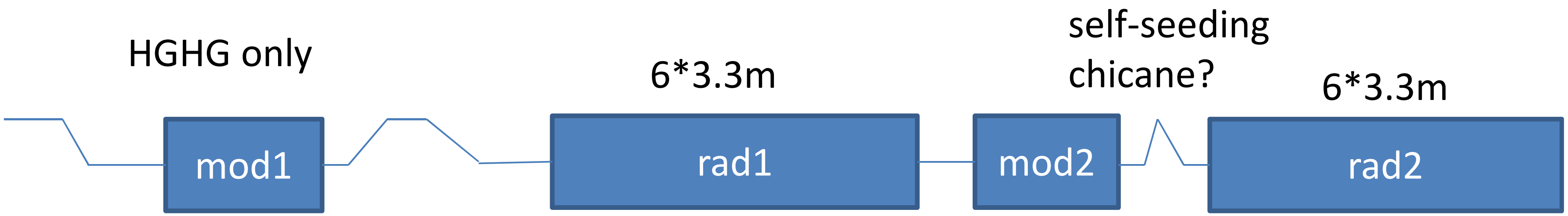
Timeline

- 2011
  - HHG is planned by Tavella & co.
  - HGHG is studied by Ati Mesek (HZB) but energy spread was unrealistic
  - EEHG is studied by SINAP (http://arxiv.org/ftp/arxiv/papers/1103/1103.0112.pdf)
  - I noticed that we could do EEHG in sFLASH, wrote a report on the tolerances, and designed and built the chicane and injection beamline (TESLA FEL reports 2011)
- 2012
  - HHG has trouble demonstrating concept, simulations from Gianessi show that they are on the edge of being able to see anything
  - HGHG/EEHG beamline is commissioned
- 2013
  - HHG demonstrates concept with unacceptable contrast, factor of 10-100 increase in seed power is required
  - HHG gets all of the beamtime, HGHG/EEHG gets very little
  - Directorate requests HGHG design for FLASHII and V. Miltchev makes initial study with a recommendation to put the modulator in the middle of the radiator
  - I decided that the >30 nm performance of HGHG will not be sufficient and write a TESLA FEL report on a more flexible design that has the capability to do research towards the shortest wavelengths.
  - I did 1-D simulations of the effects of LSC on seeded beams
- 2014
  - Martin did 3-D simulations of the effects of LSC on seeded beams and they agree with my previous 1-D results – except for the 3-D effects
  - HGHG/EEHG gets beamtime this year
  - Self-seeding gets a closer look

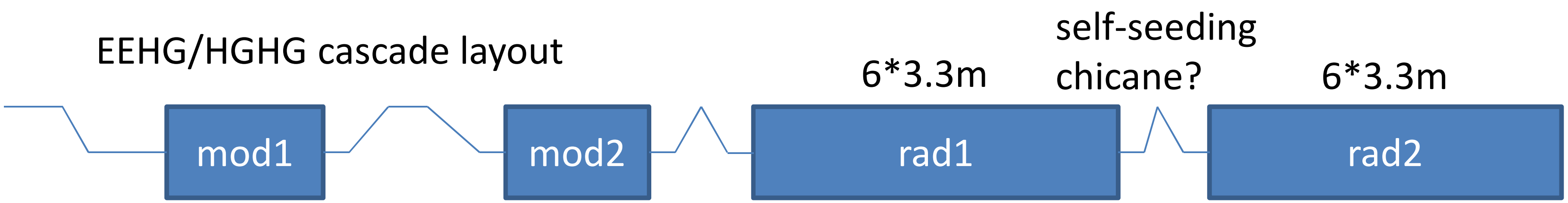
FLASH II Decision Points

- Where to put the HGHG modulator
  - Before the radiator or in the middle of the radiator
- Whether to save space for EEHG modulator and chicane
- Where to put the mid-radiator chicane
  - Should be compatible with self-seeding

Basic Layout

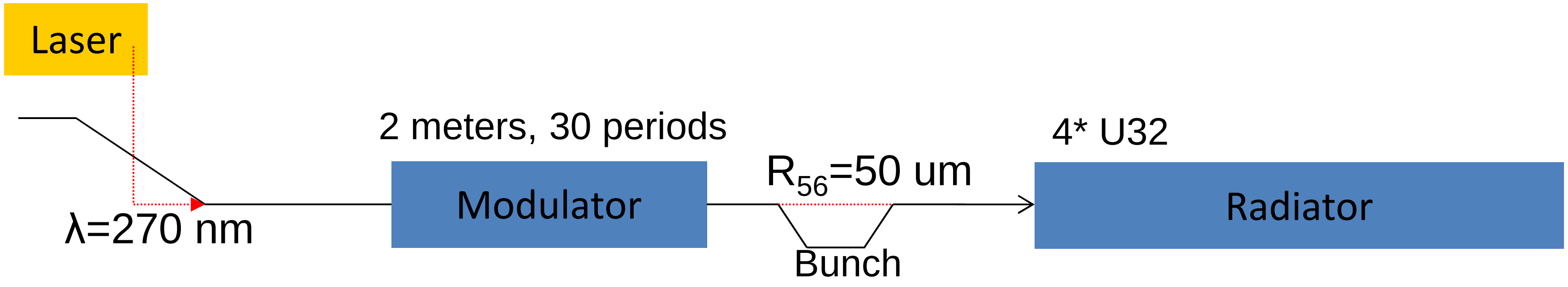


Assumption: energy modulated beam cannot be transported over 20 meters

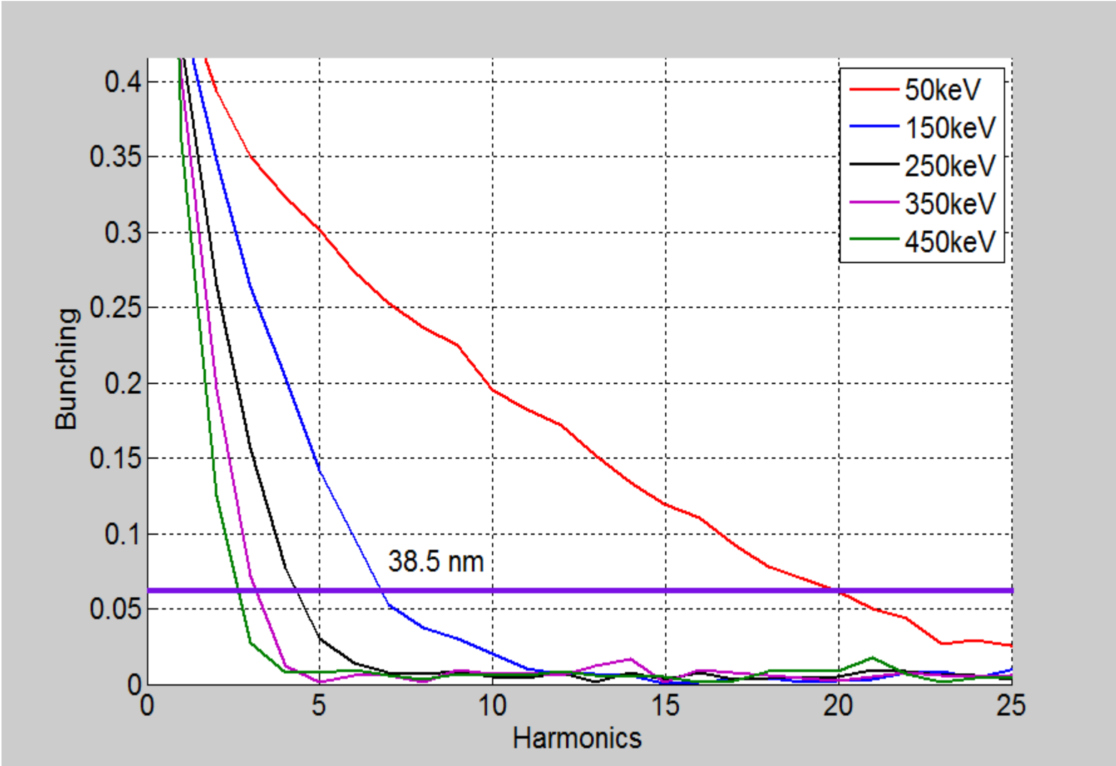


Assumption: the 20 meters is no problem if the beam radius is large (no LSC)

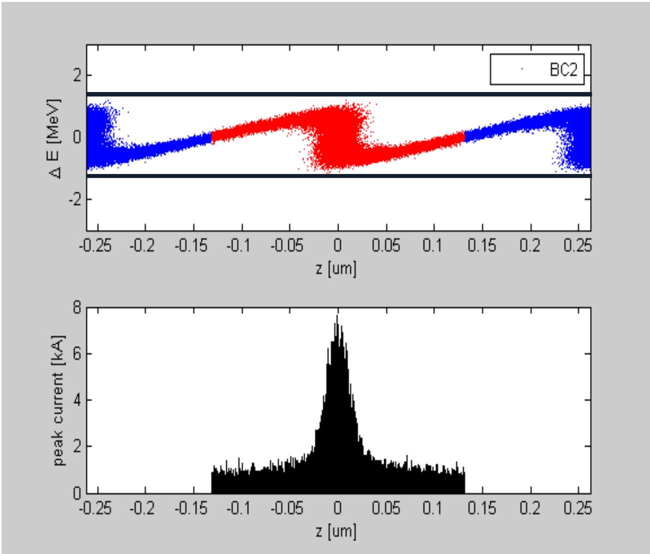
HGHG limit at FLASH2



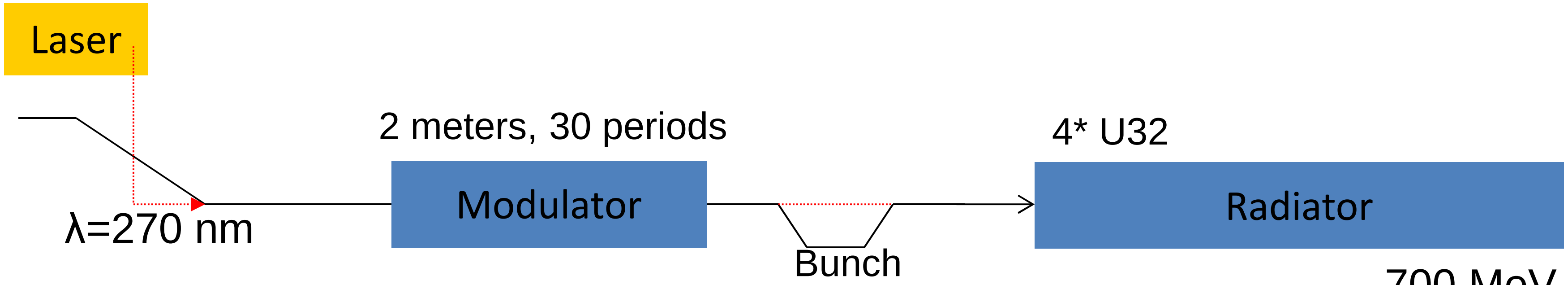
700 MeV
$\Delta E/E<4*10^{-3}$



limit: uncorrelated energy spread of electron beam



HGHG limit at FLASH2



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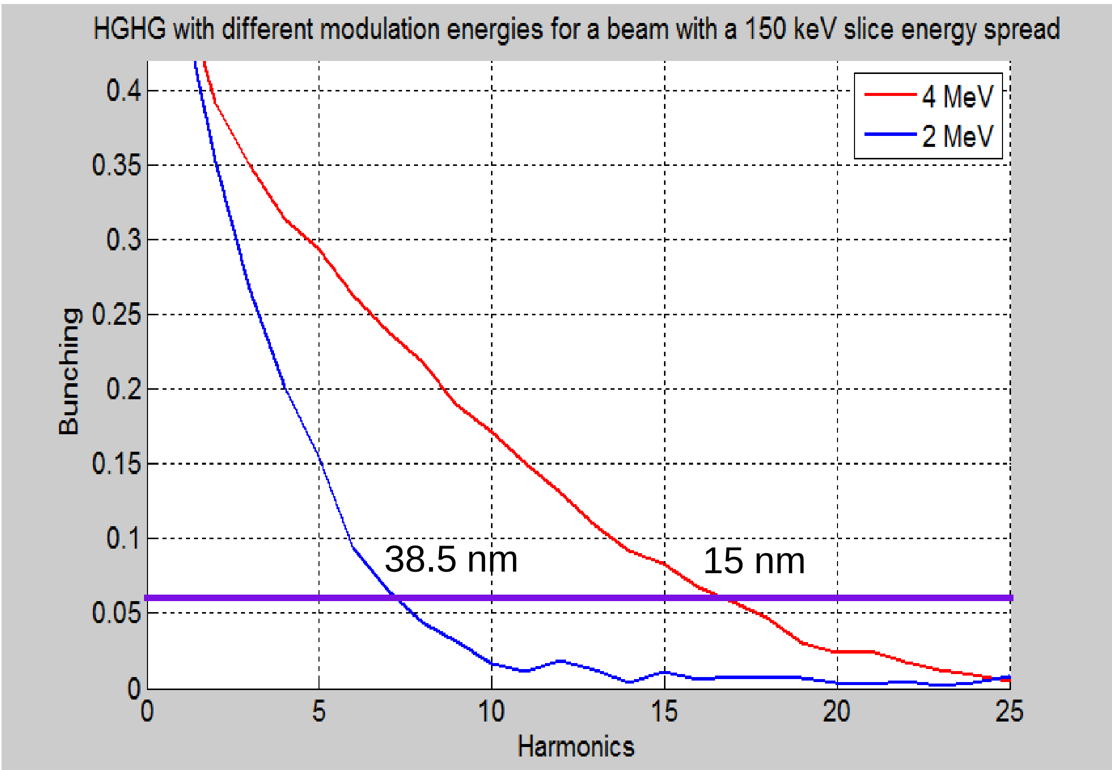
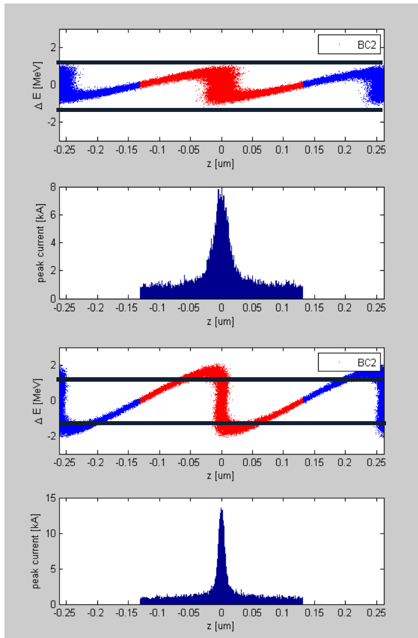


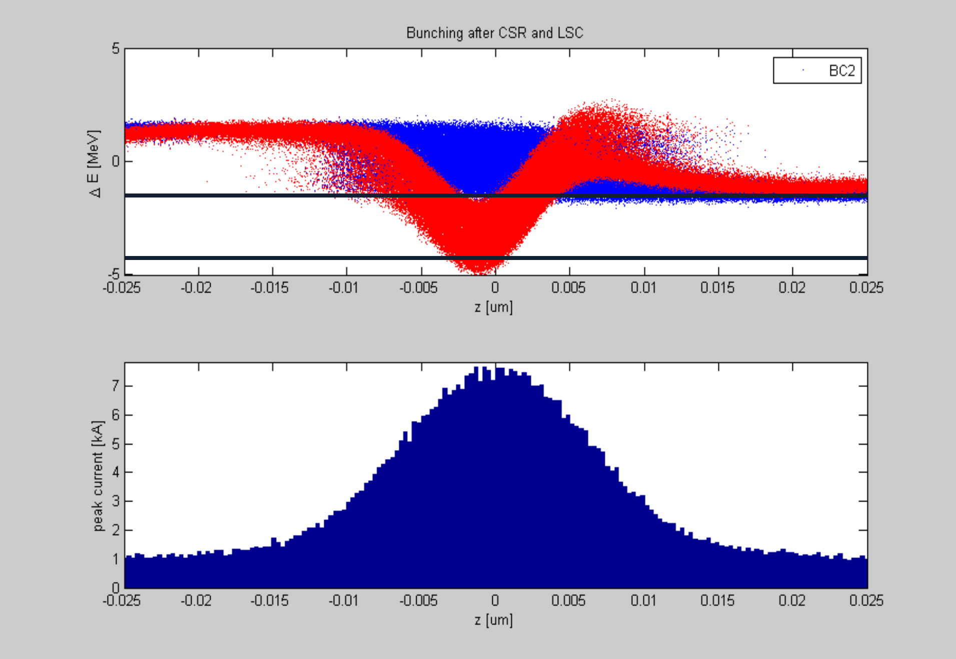
limit: too high peak current

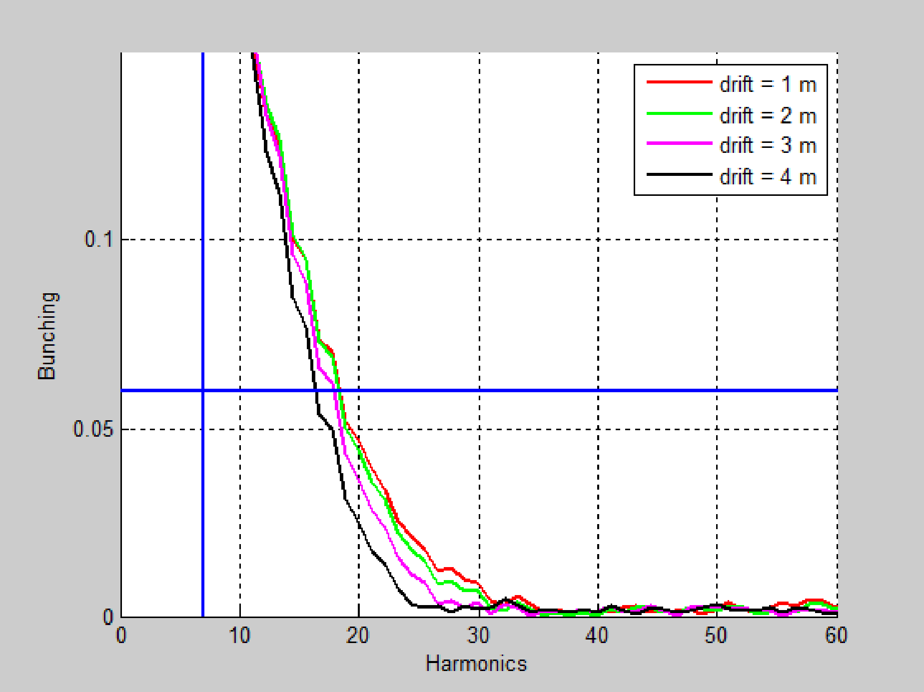


CSR and LSC

4 MeV microbunch after 4 meters

100 μm (rms) beam radius
1kA initial peak current
R_{56} of chicane = 45 μm
700 MeV beam energy



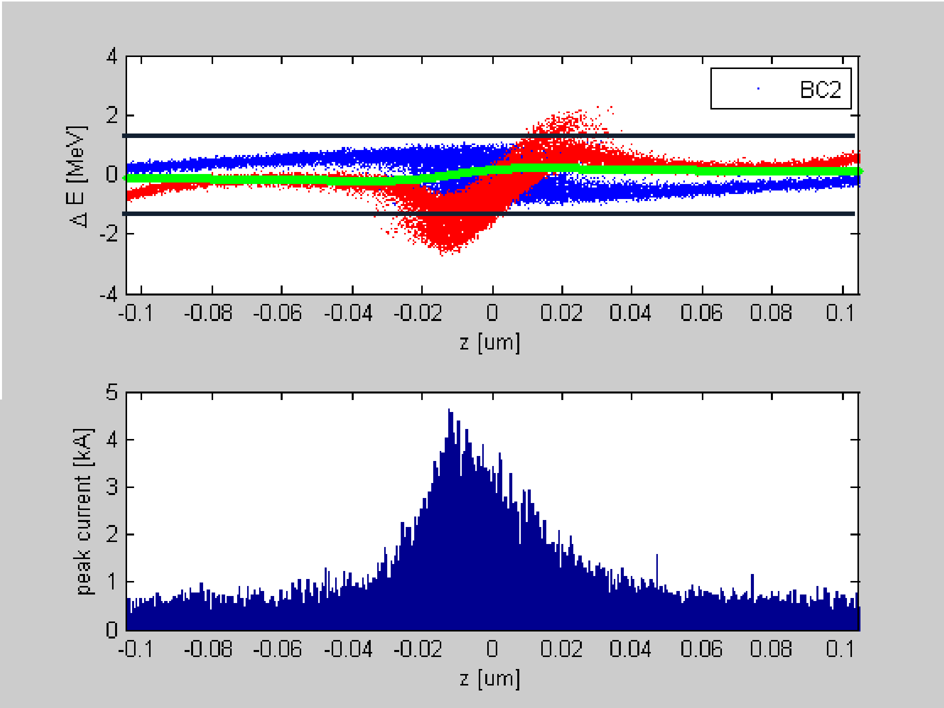


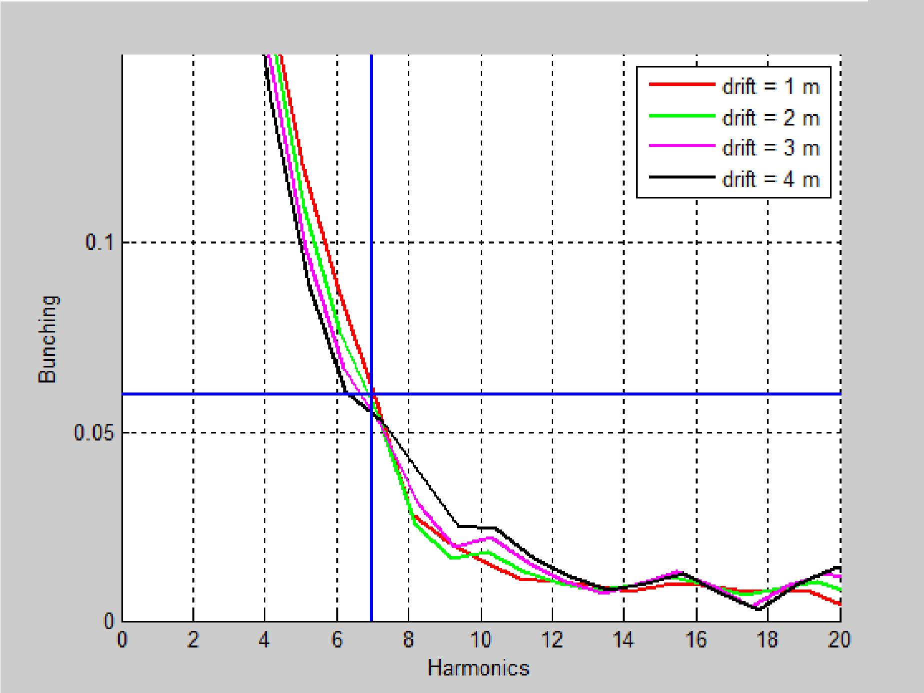
Only small degradation in bunching
But – energy spread is too big

CSR and LSC

2MeV microbunch after 4 meters

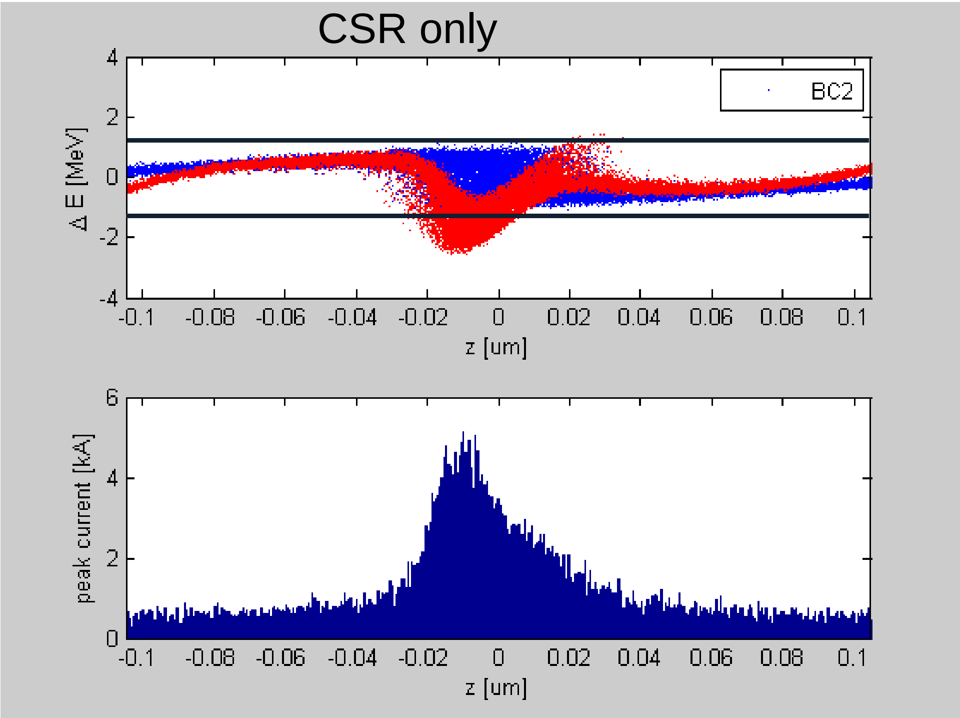
100 μm (rms) beam radius
1kA initial peak current
R_{56} of chicane = 45 μm
700 MeV beam energy



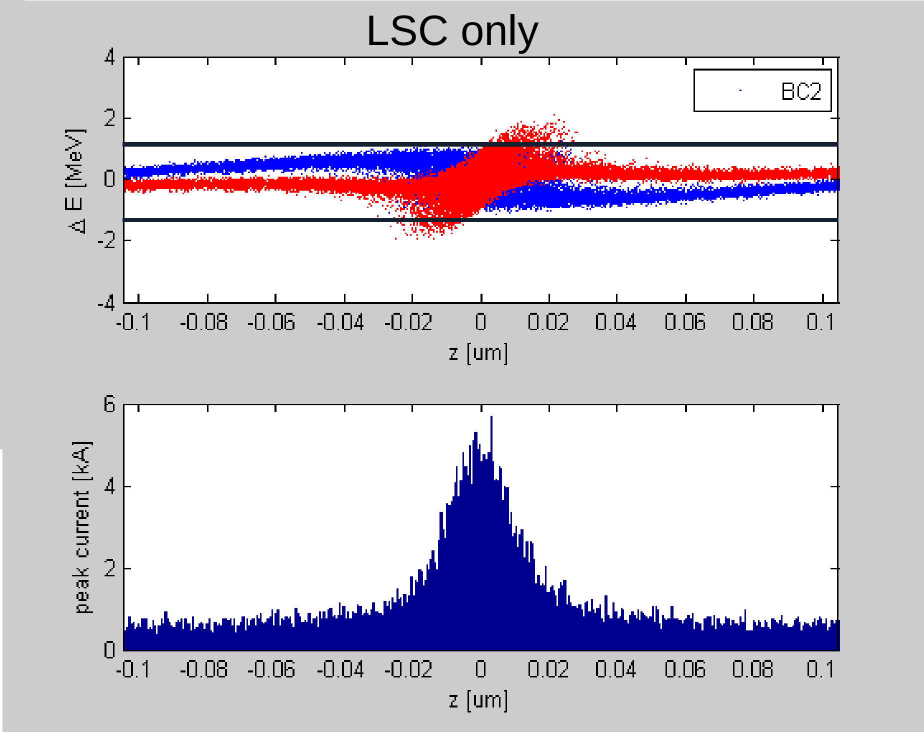


CSR and LSC

2MeV microbunch after 4 meters



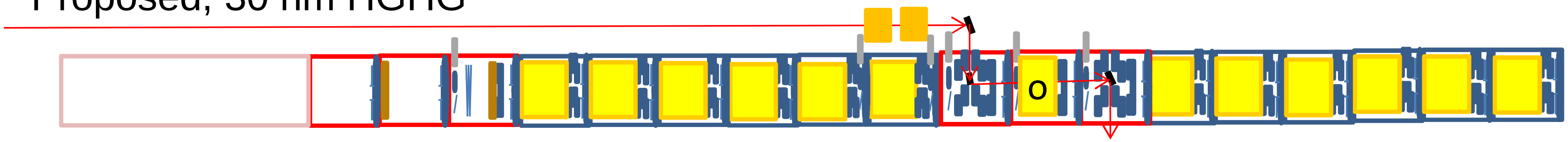
$$Z_{LSC}(k)=\frac{iZ_0}{\pi k r_b^2}\left[1-\frac{kr_b}{\gamma}K\left(\frac{kr_b}{\gamma}\right)\right]$$



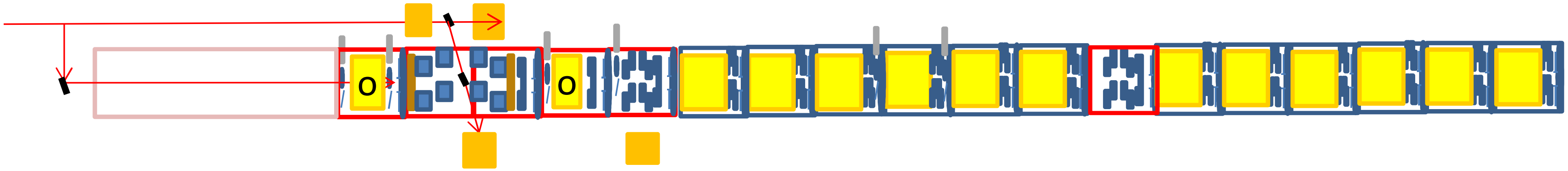
100 μm (rms) beam radius
1kA initial peak current
R_{56} of chicane = 45 μm
700 MeV beam energy

FLASH2 beamline

Proposed, 30 nm HGHG



Alternative, 4-40 nm EEHG/HGHG/HHG/cascade



Caveats:
1). The saturation point has to be at a fixed position in the undulator
2). For long wavelengths, the saturation point has to be at the end
3). Transport the bunched or modulated beam over 30 m
4). Quad misalignments
5). Everything not yet considered.

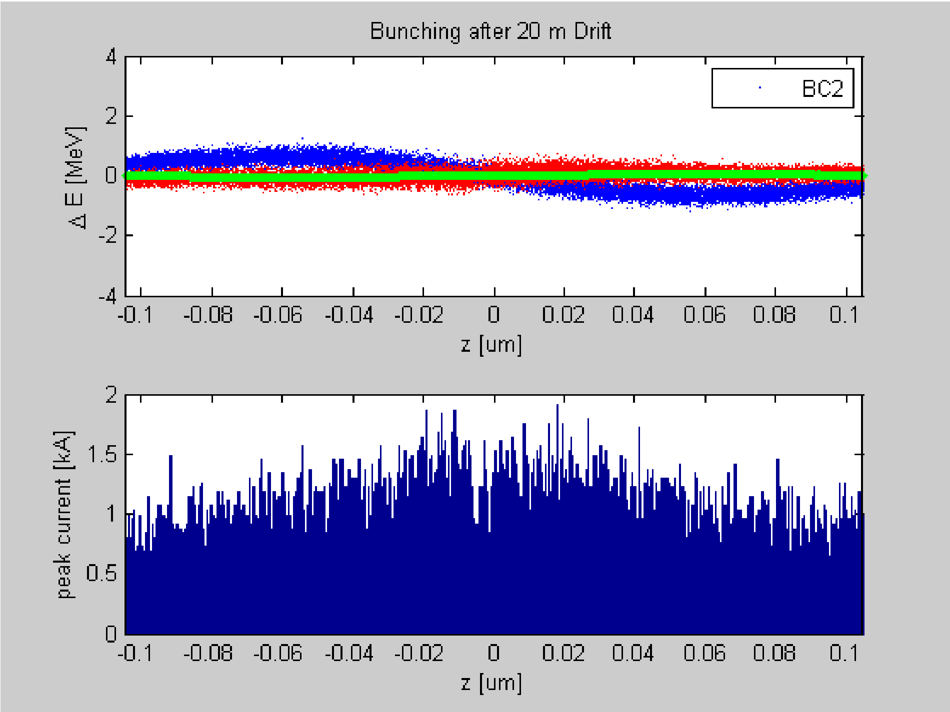
Dispersion in 30 meter Drift

- $R_{56} \sim L_{drift}/\gamma^2 = 15\ \mu m$ @ 700 MeV
- $R_{56} \sim L_{drift}*\theta^2 < 3\ nm$ ~ worst case 100 μm

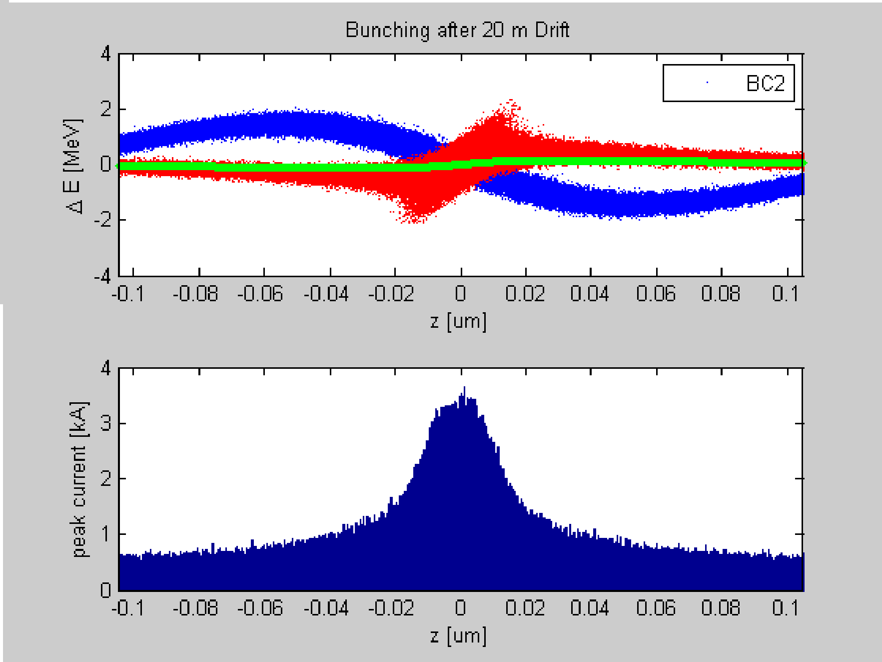
Dispersion required to bunch seeded microbunch is:

20 μm for too-large 4 MeV modulation
50 μm for smaller 2 MeV modulation
>50 μm for smaller modulations

LSC over 20 meters



100 μm (rms) beam radius

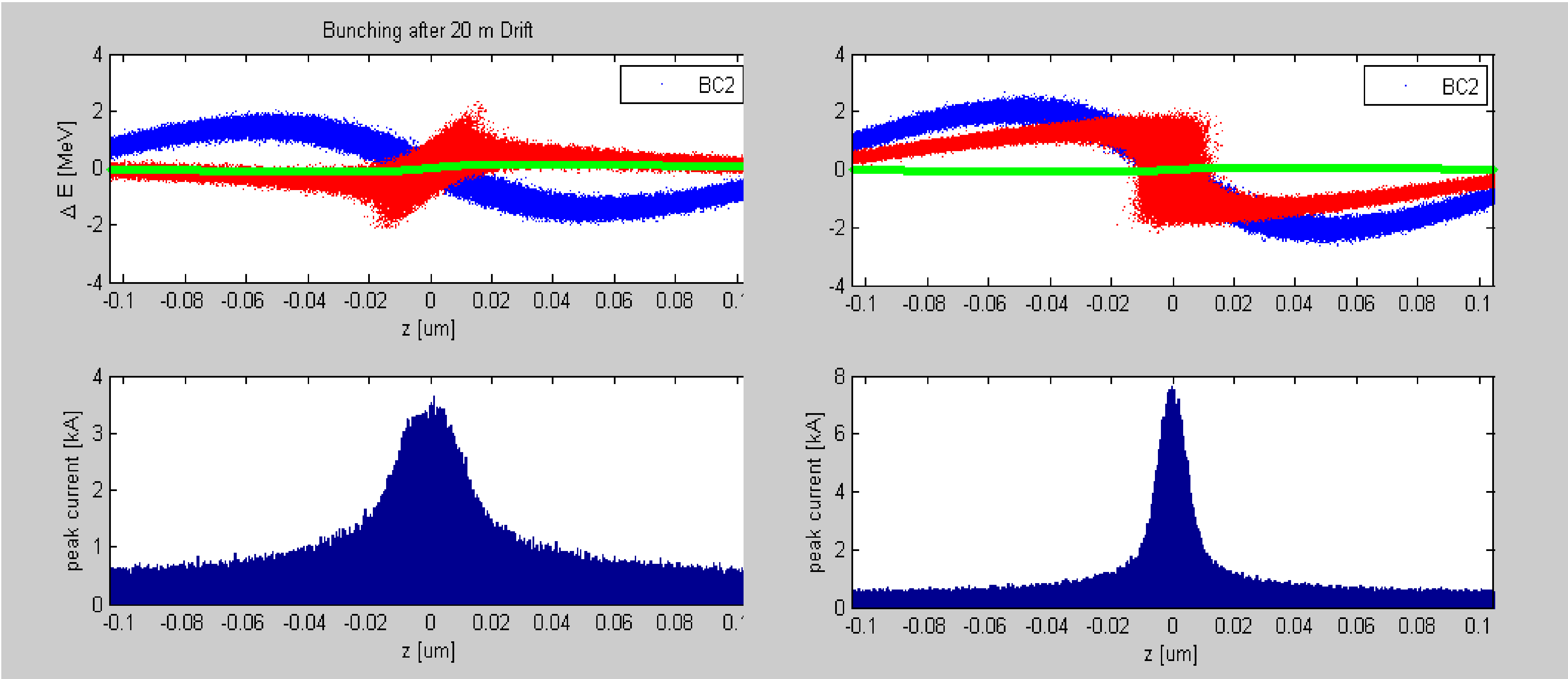


$$Z_{LSC}(k) = \frac{iZ_0}{\pi k r_b^2}\left[1 - \frac{kr_b}{\gamma} K\left(\frac{kr_b}{\gamma}\right)\right]$$

Increase beam diameter to remove LSC problem

100 μm

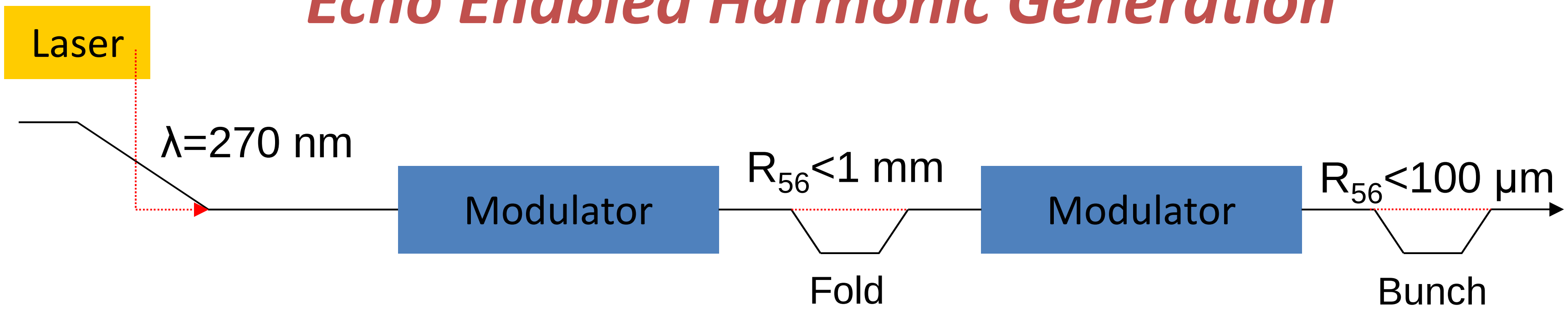
200 μm

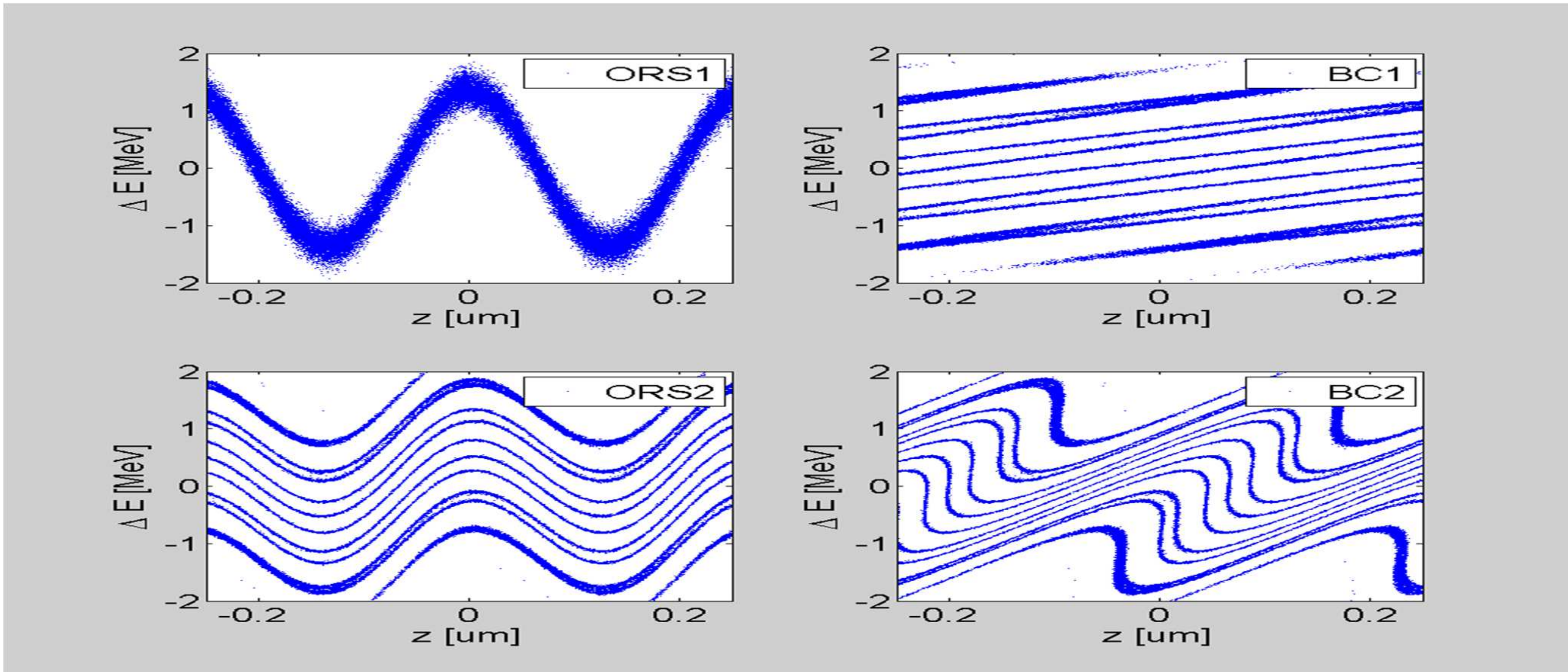


Bonus: no CSR because beam was compressed in drift

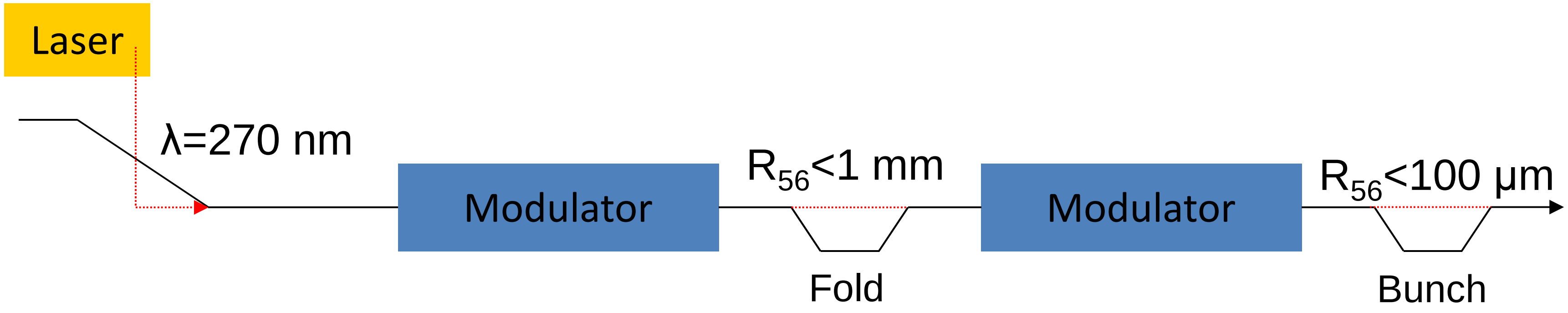
EEHG seeding

Echo Enabled Harmonic Generation

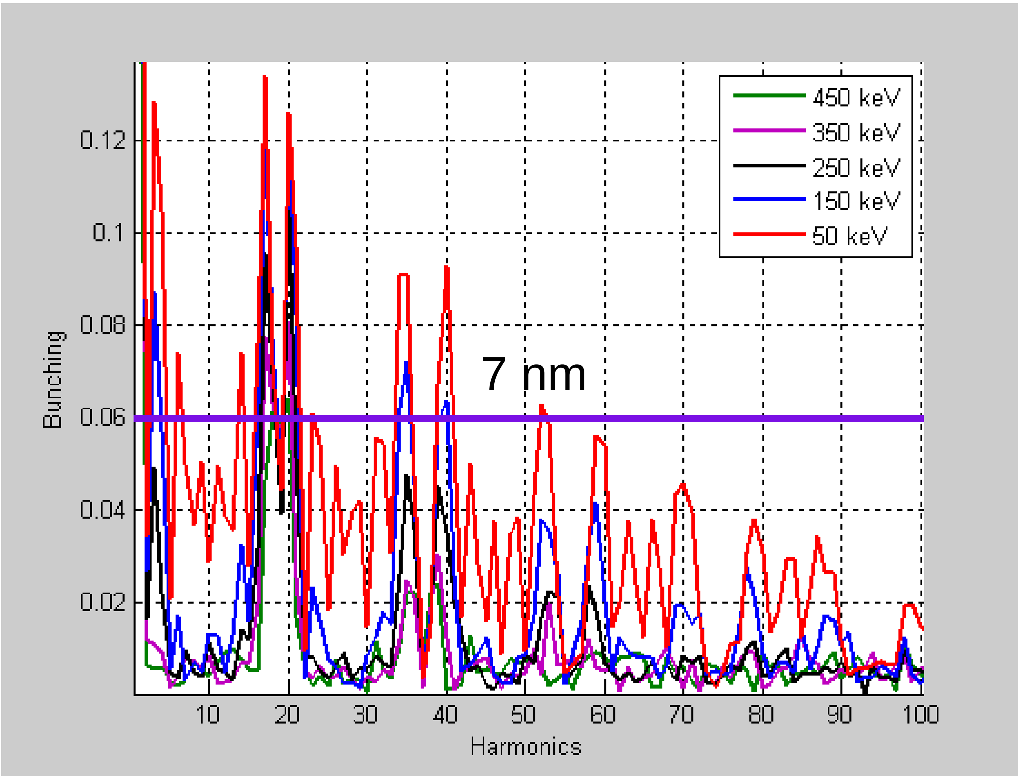


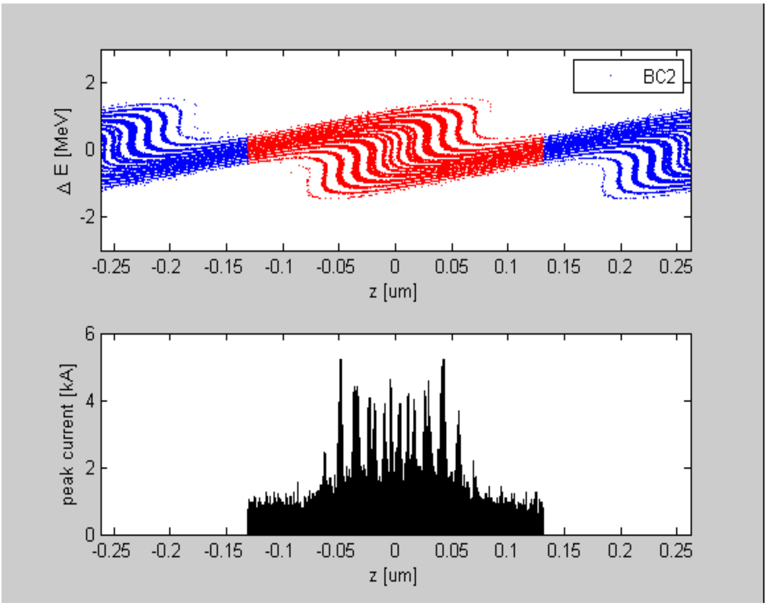


EEHG limit at FLASH2

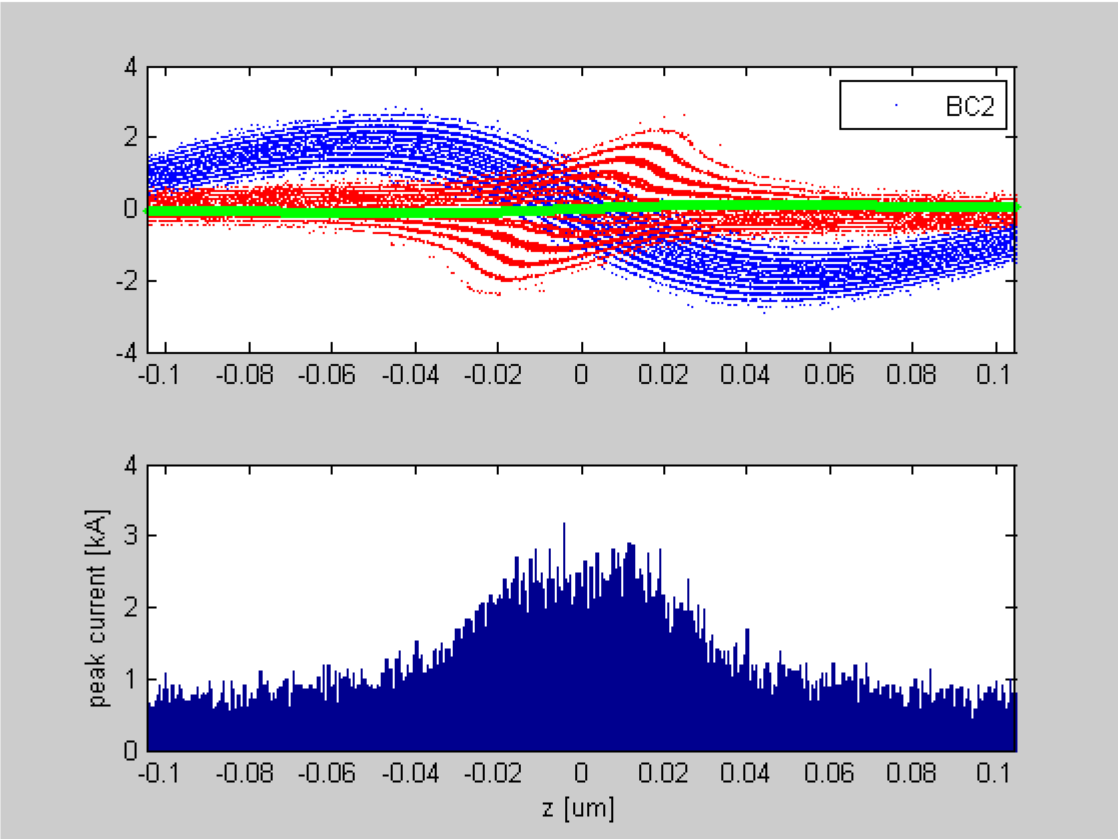


ΔE/E<4*10^{-3}



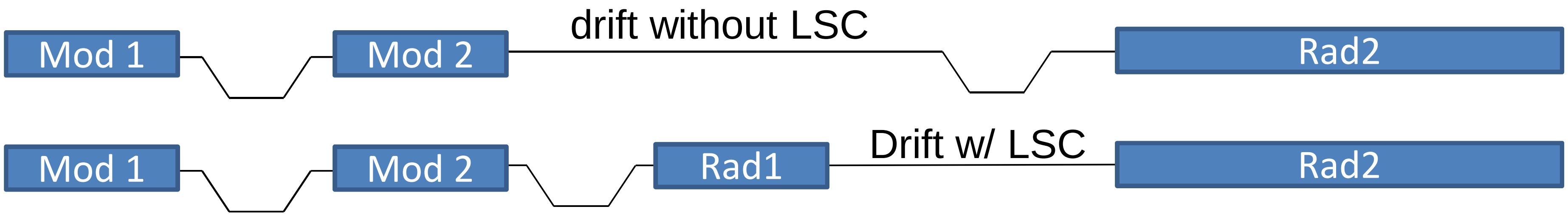


EEHG doesn't tolerate LSC



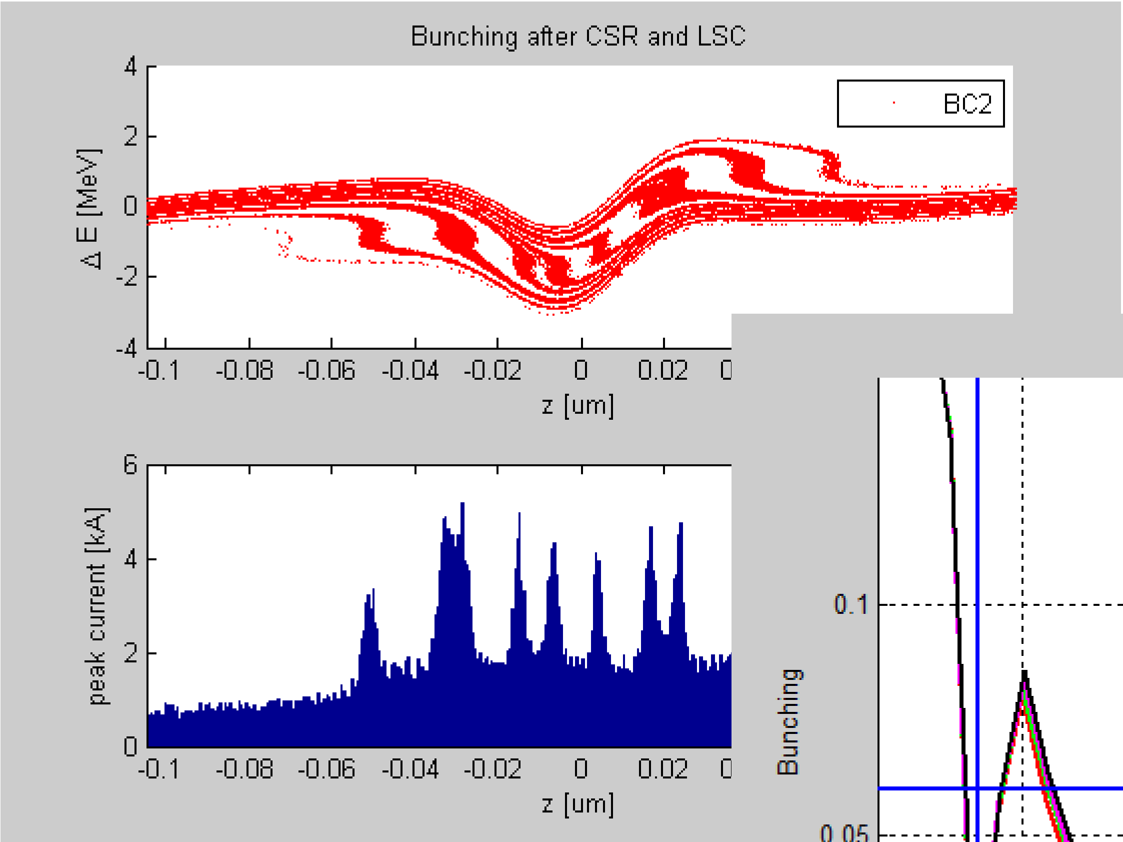
=> Need large beam size and higher energy in drift, and/or split radiator

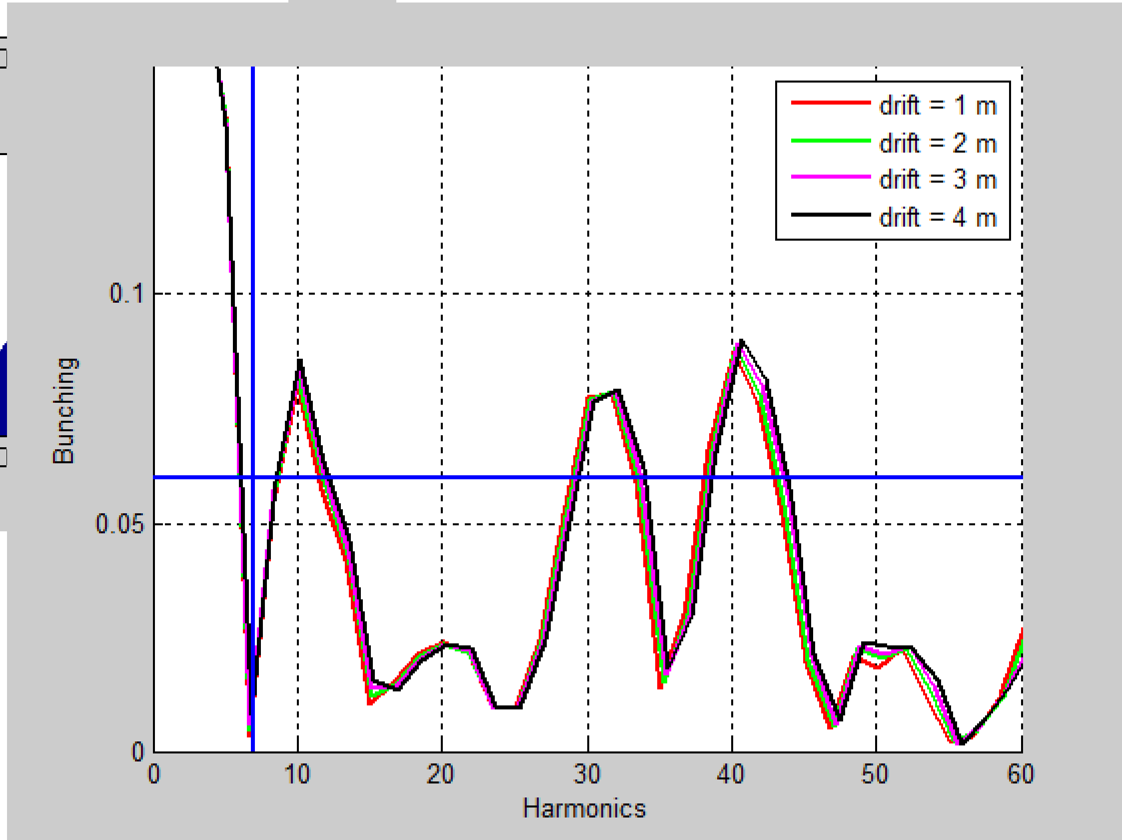
1kA peak current
30 meters of drift
100 um radius



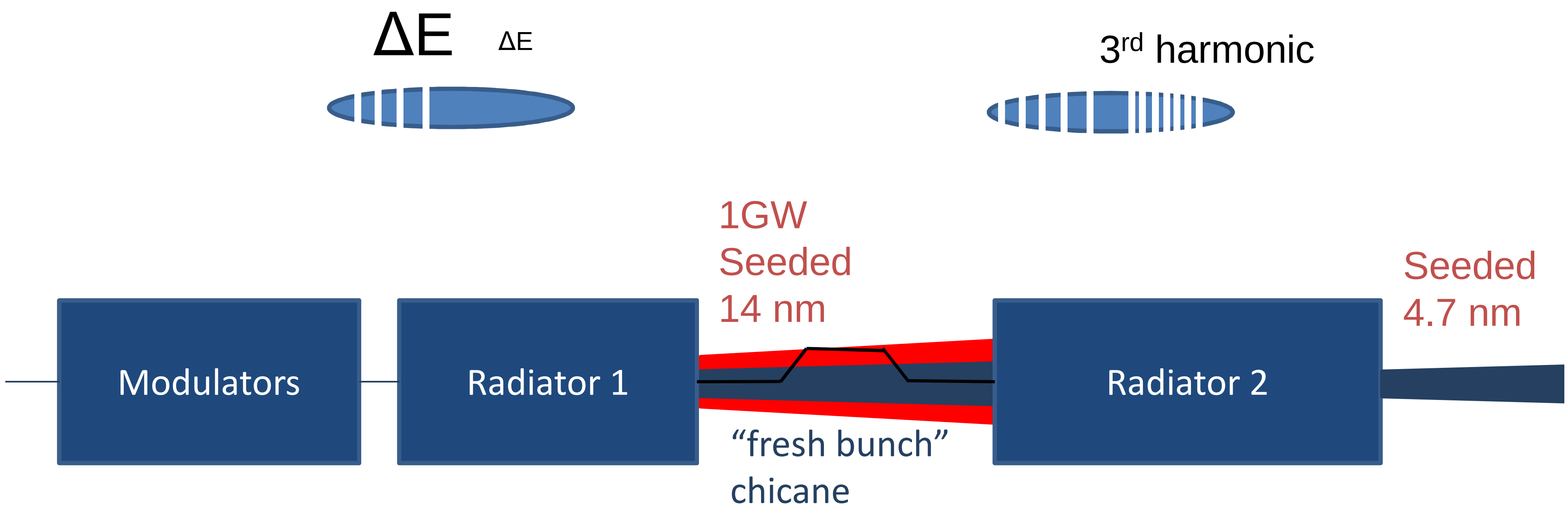
EEHG tolerates CSR

1kA peak current
30 meters of drift
300 um radius (minimizes LSC)
70 um R_{56}



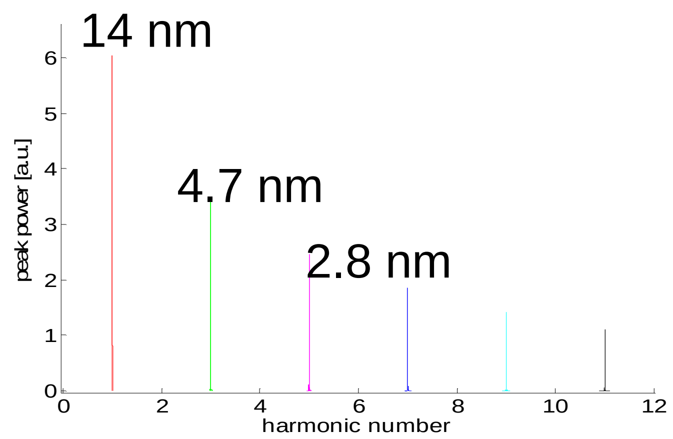


Cascaded seeding at FLASH2

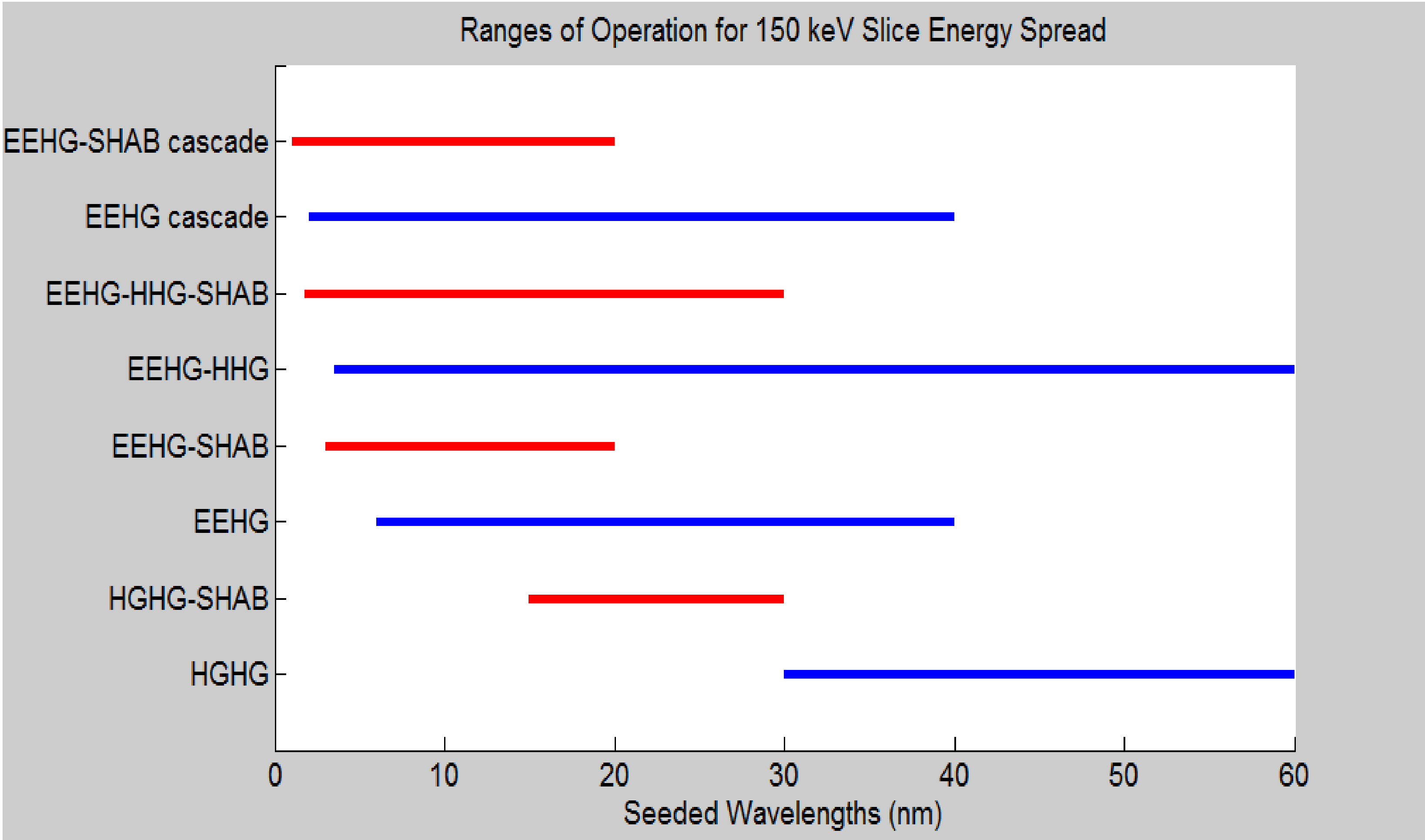


EEHG cascade tolerates 450 keV slice energy spread
12-24 nm -> 3rd harmonic -> seeded 4-8 nm

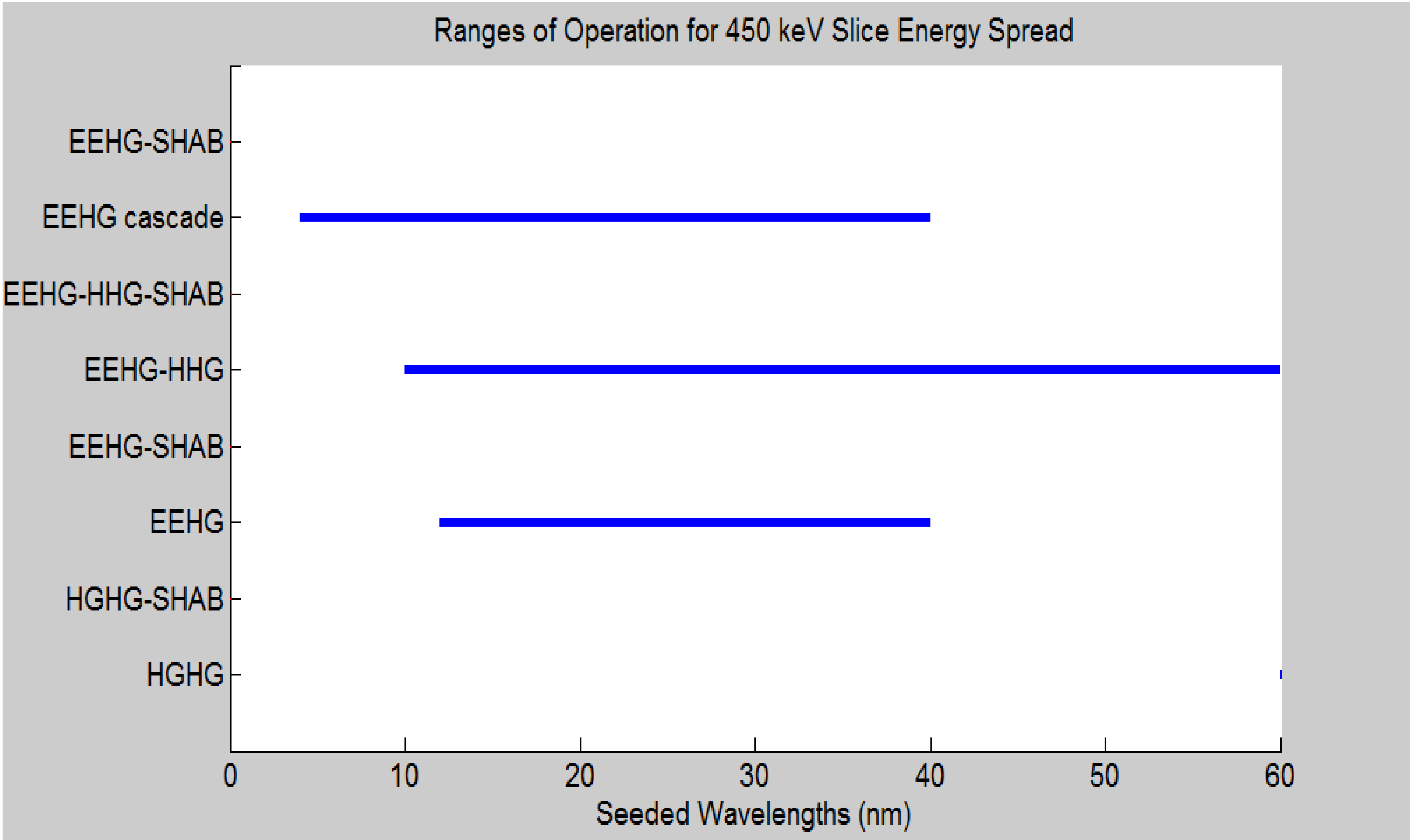
HGHG cascade tolerates 150 keV slice energy spread
24-36 nm ->3rd harmonic -> 8-12 nm



Seeding performance 150 keV energy spread



Seeding performance
150 keV energy spread



Self-seeding (chat with Serkez)

- Success at LCLS with 700 and 1000 eV beams
- <250 eV at FLASH is more challenging because the grating absorbs more energy, making the signal to noise ratio worse
- G-SOLVER is the code required to calculate the grating performance

Combined vs. Dedicated Design

SELF-SEEDING SETUP DESCRIPTION

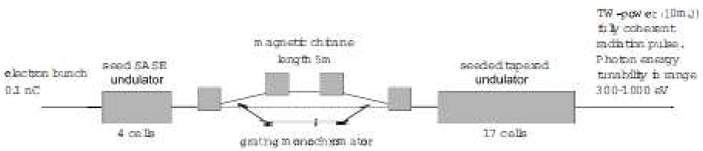


Figure 1: Design of the SASE3 undulator system for TW mode of operation in the soft X-ray range.

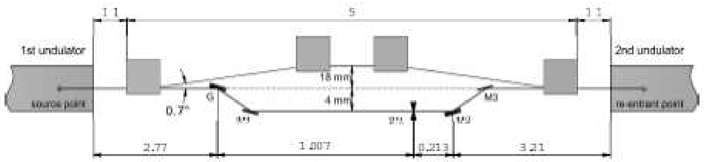


Figure 2: Layout of the SASE3 self-seeding system, to be located in the space freed after removing the undulator segment U5. The compact grating monochromator design relies on a scheme originally proposed at SLAC. G is a toroidal VLS grating. M1 is a rotating plane mirror, M2 is a tangential cylindrical mirror, M3 is a plane mirror used to steer the beam. The deflection of both electron and photon beams is in the horizontal direction.

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6 meter chicane
vs.
3 meter chicane

Steeper angles => more losses

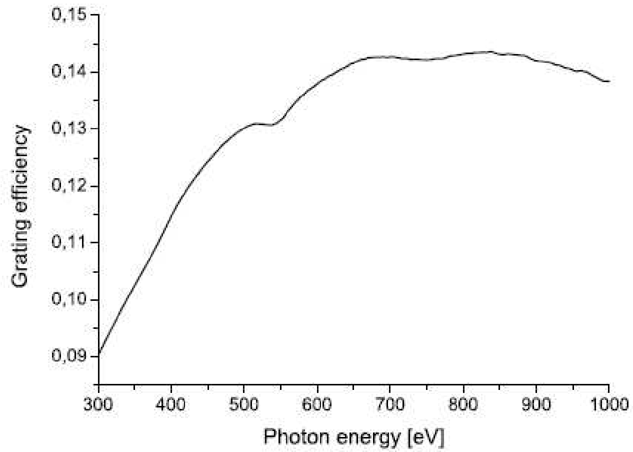
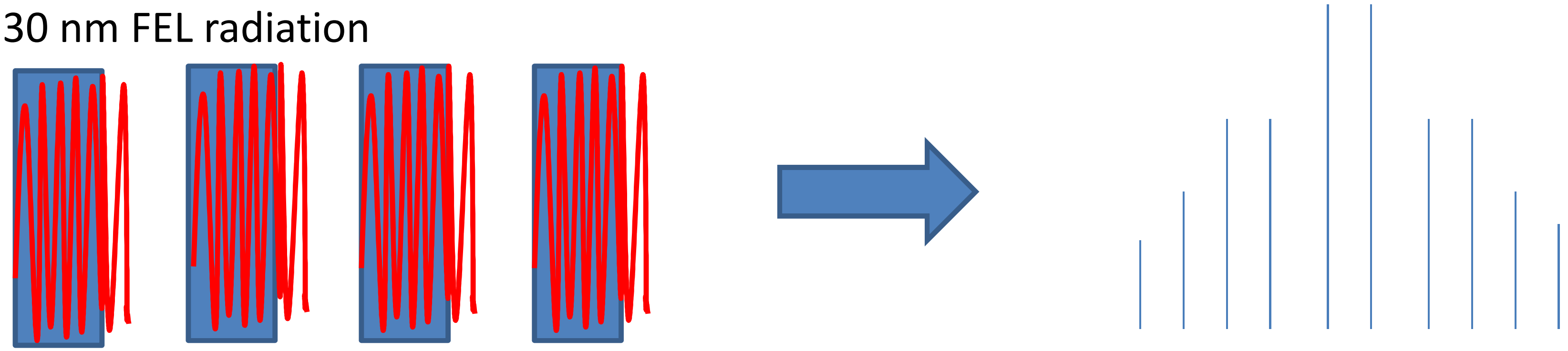


Figure 8: First order efficiency of the blazed groove profile Here the groove density is 1100 lines/mm, Pt coating is assumed, at an incidence angle of 1°. The blaze angle is 1.2°; the anti-blaze angle is 90°.

Advantages of external seeding:

- Tunability
- Synchronization with pump-probe laser
- Frequency combs (B. McNeil)

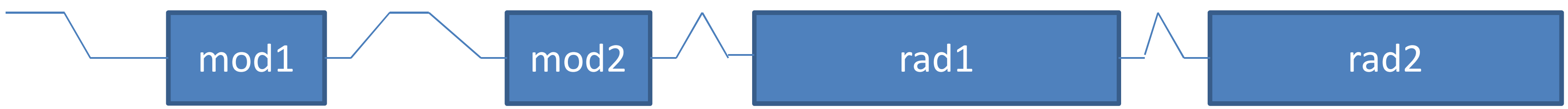
270 nm HGHG microbunches
30 nm FEL radiation



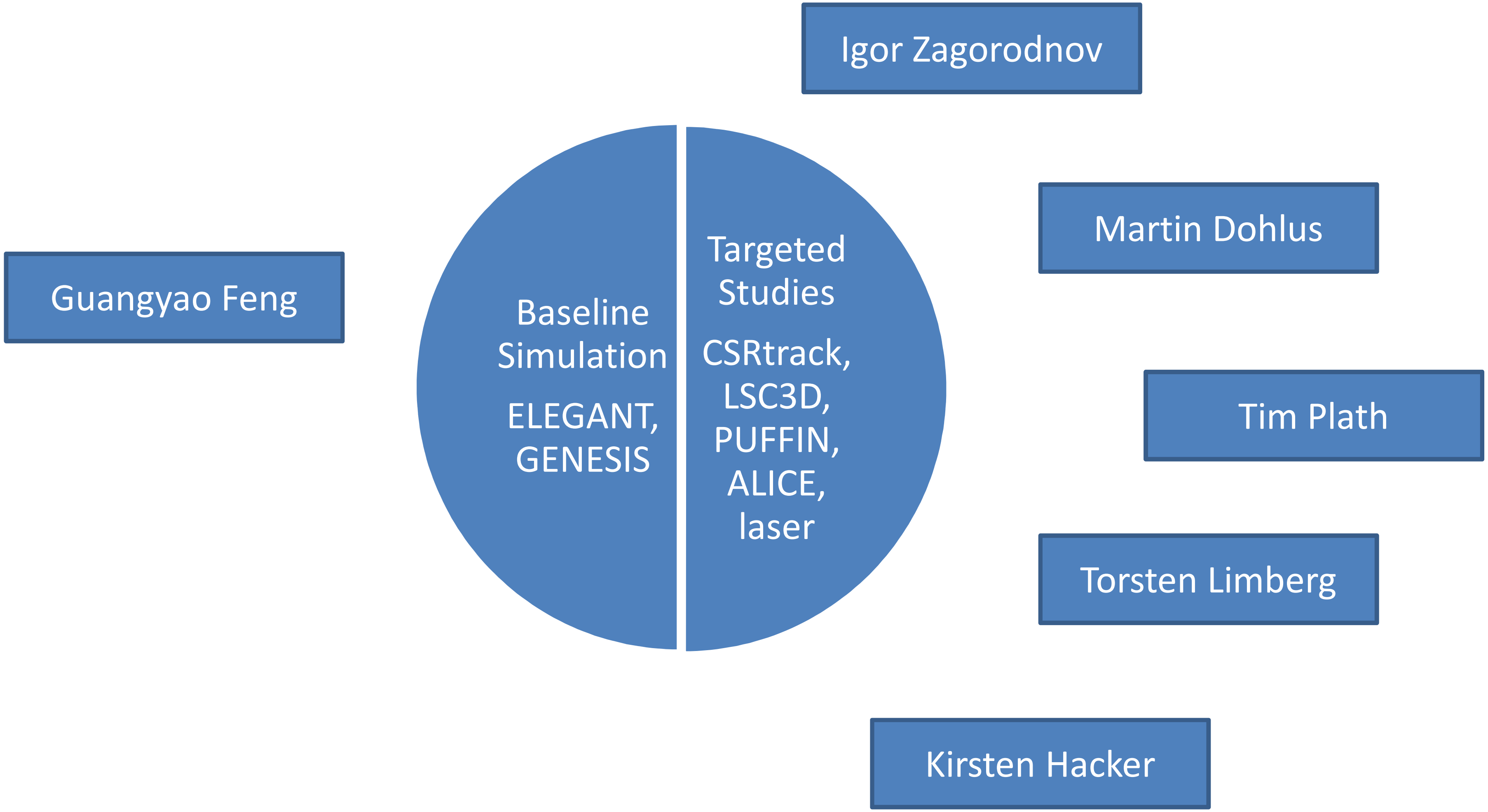
Slippage smears this out
But for a short radiator, it might be preserved

FLASH II Simulation Goals

- Roadmap to present at the end of the summer
  - HGHG is not enough to seed short λ <30 nm
  - Show long-term goals to reach short λ
- MAC in November
- Decision: external seeding or self-seeding
  - Or both with SASE killer as alternative to slotted foil

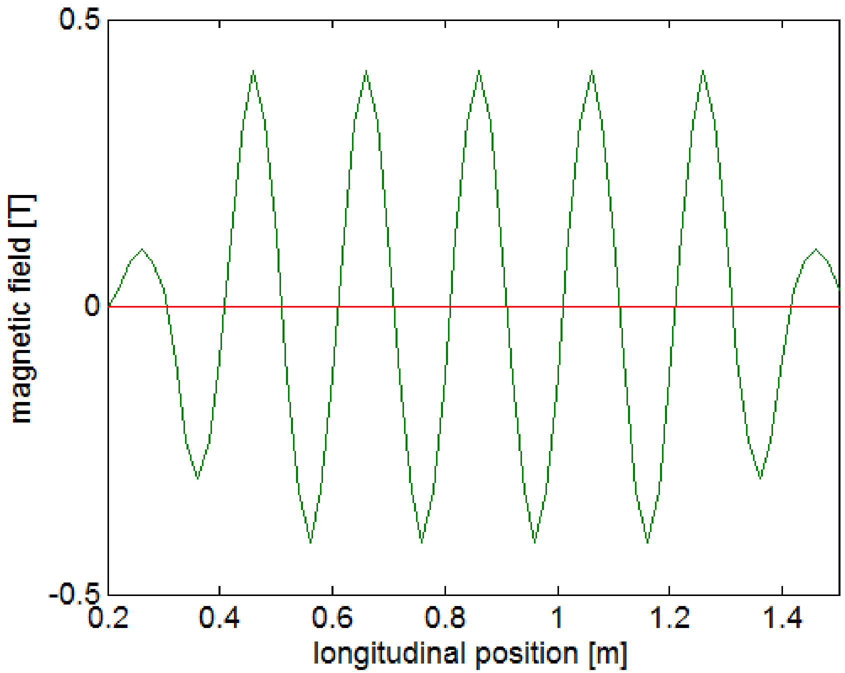


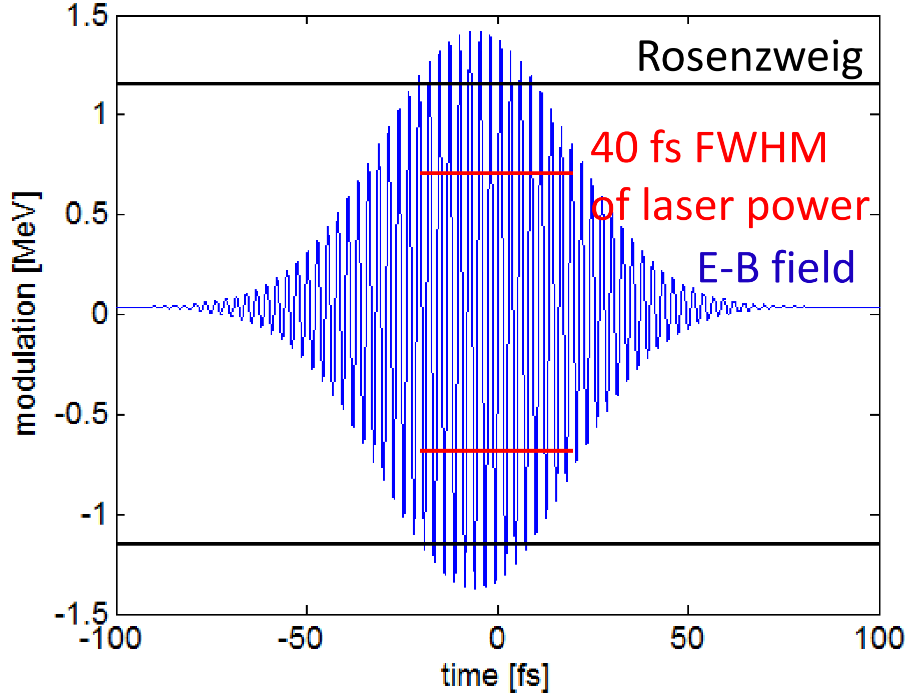
FLASH II Simulation Tactics



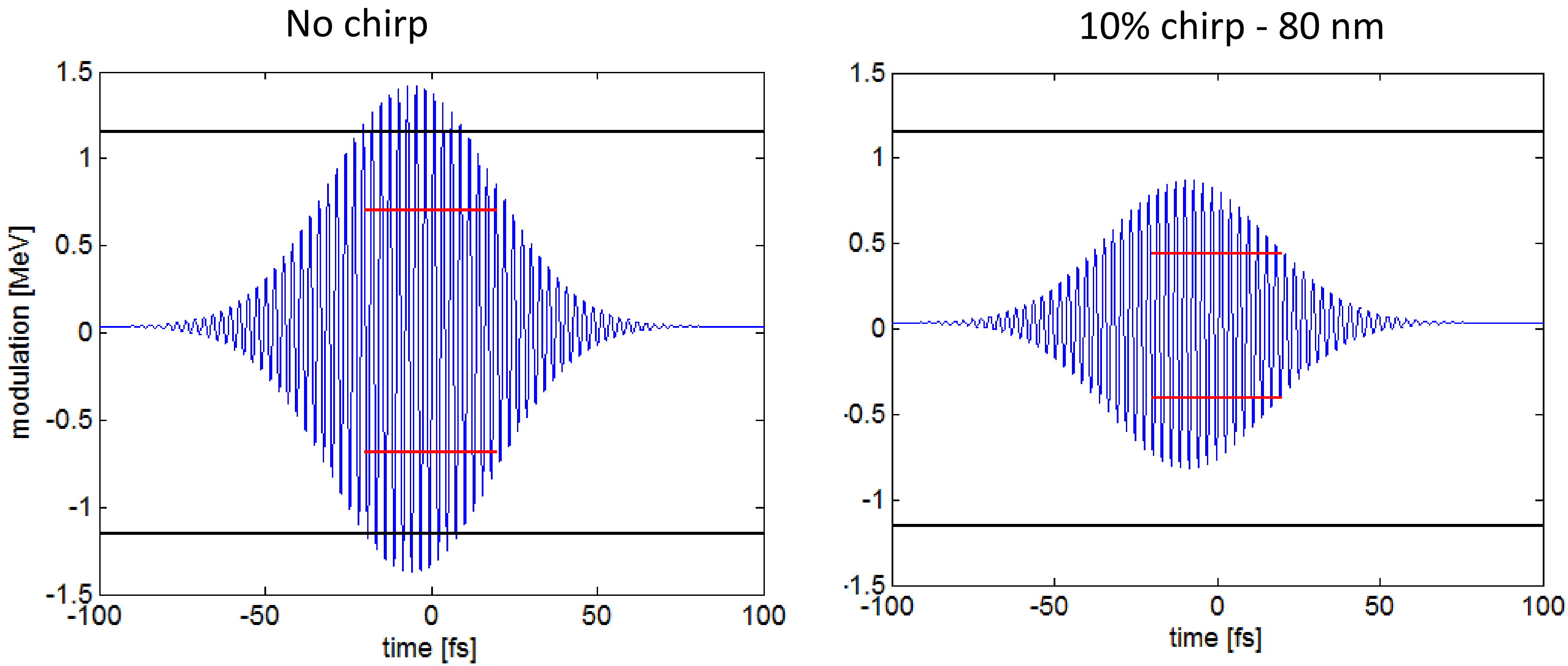
E-B particle tracker slippage

- Full E-B field from Amnon Yariv: "Optical Electronics in Modern Communications", p.66
- Predicts about the same thing as GENESIS and Rosenzweig formula used in Stupakov, Huang papers





Chirp reduces energy transfer



4 GW, 1 mm (FWHM) 6 period ORS undulator

80 nm ~ 0.26 fs/40 fs @ 800 nm