Seeding FLASH between 4 and 40 nm

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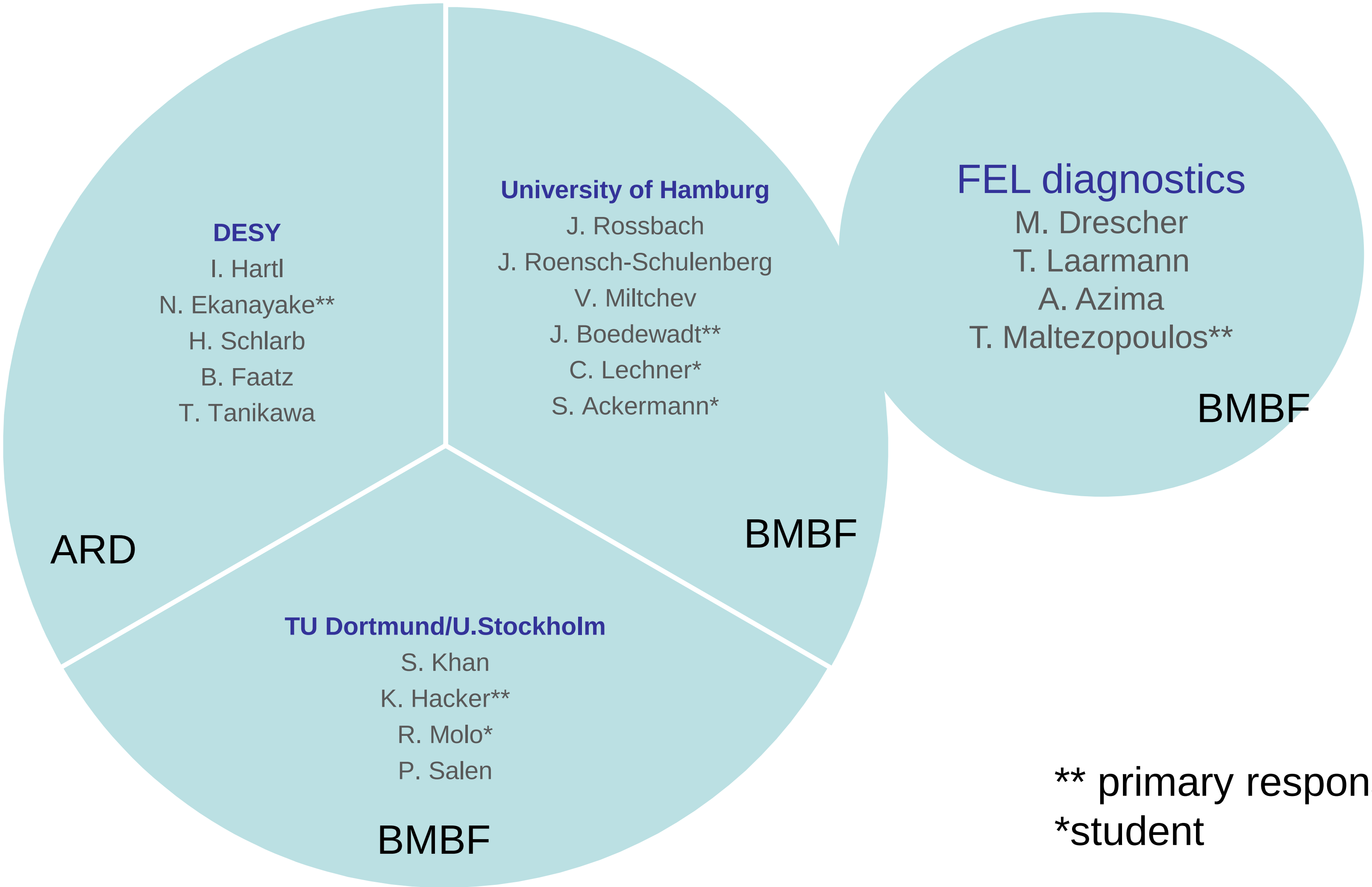
FLASH1 Seeding Collaboration



** primary responsibility
*student

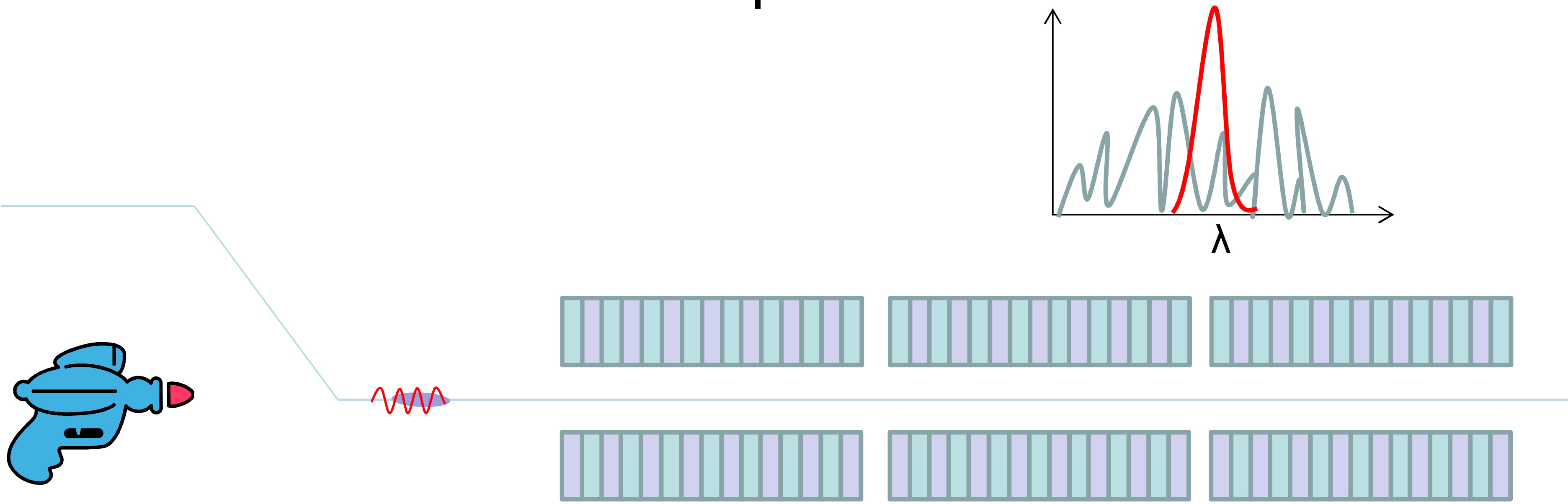
Outline

- HGHG seeding limits at FLASH
- EEHG seeding limits at FLASH
- Cascaded seeding limits at FLASH
- Seeding at other labs
- A proposed layout for FLASH2
- Conclusion

All simulations are 1-D
3-D effects are estimated

Seeded FEL

- More intense and monochromatic radiation
- Shorter undulator required

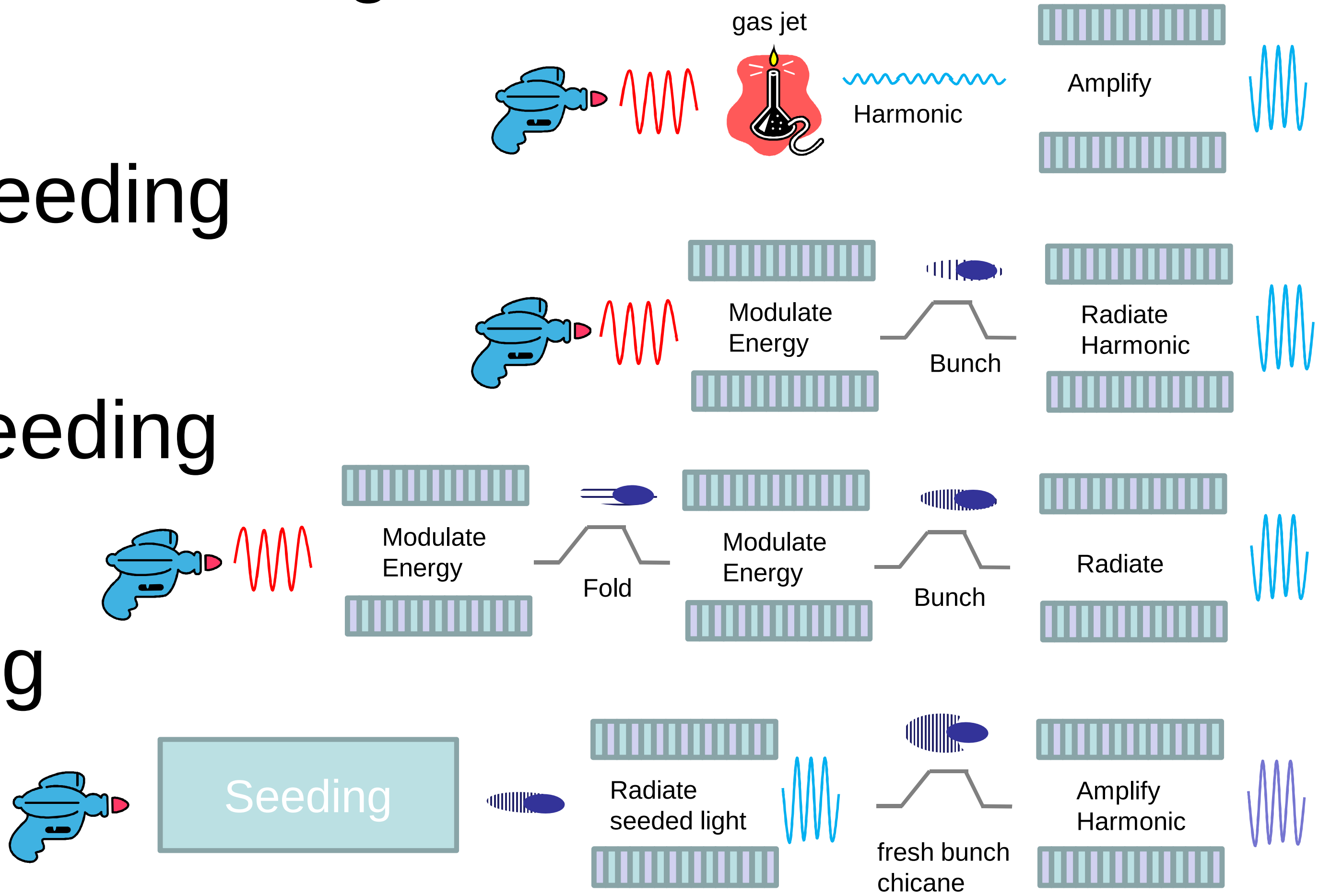


Seeded FEL

- Convenient for pump-probe experiments

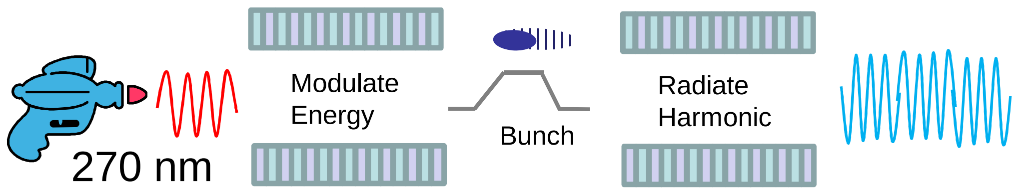
Types of external seeding

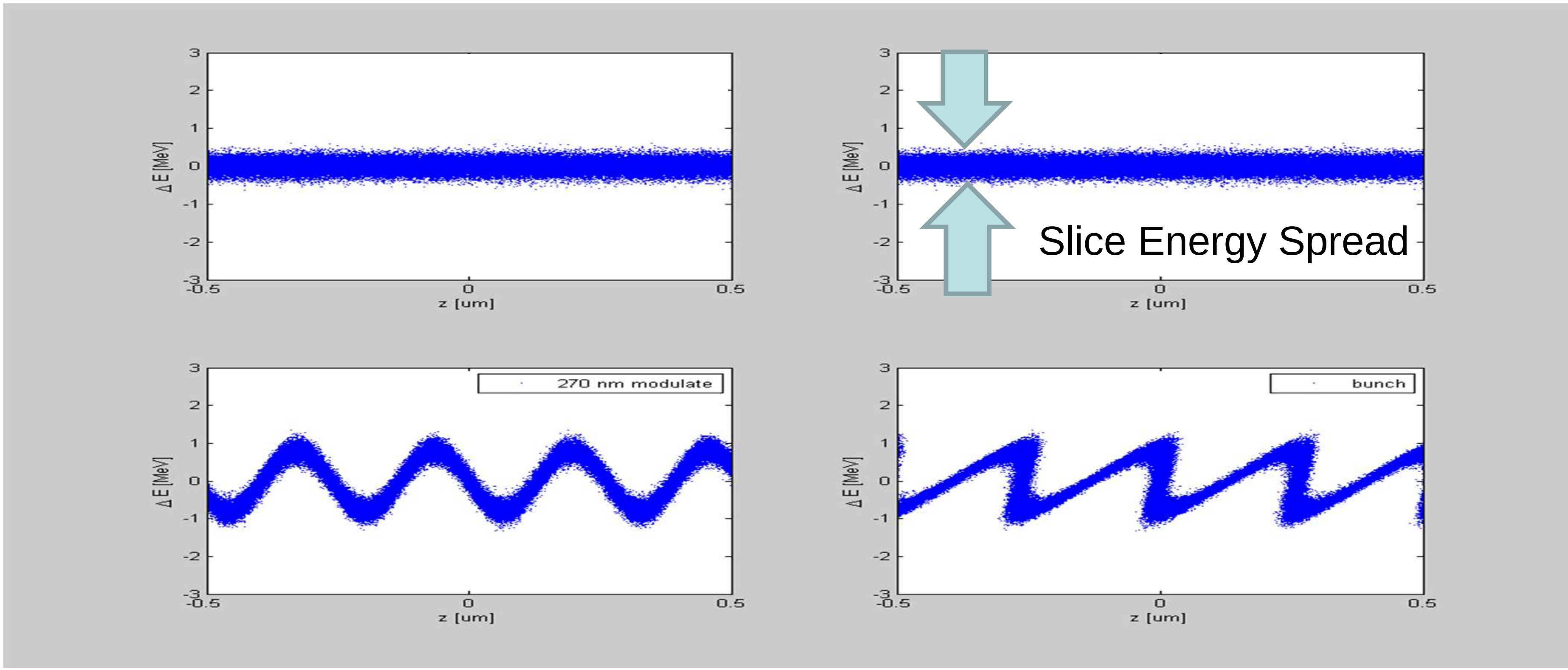
- HHG direct seeding
- HGHG seeding
- EEHG seeding
- cascading



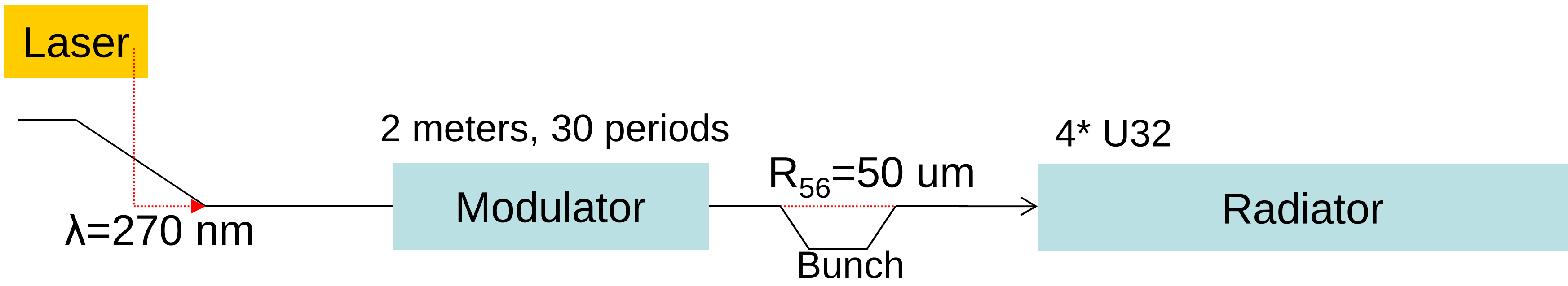
HGHG seeding

High Gain Harmonic Generation

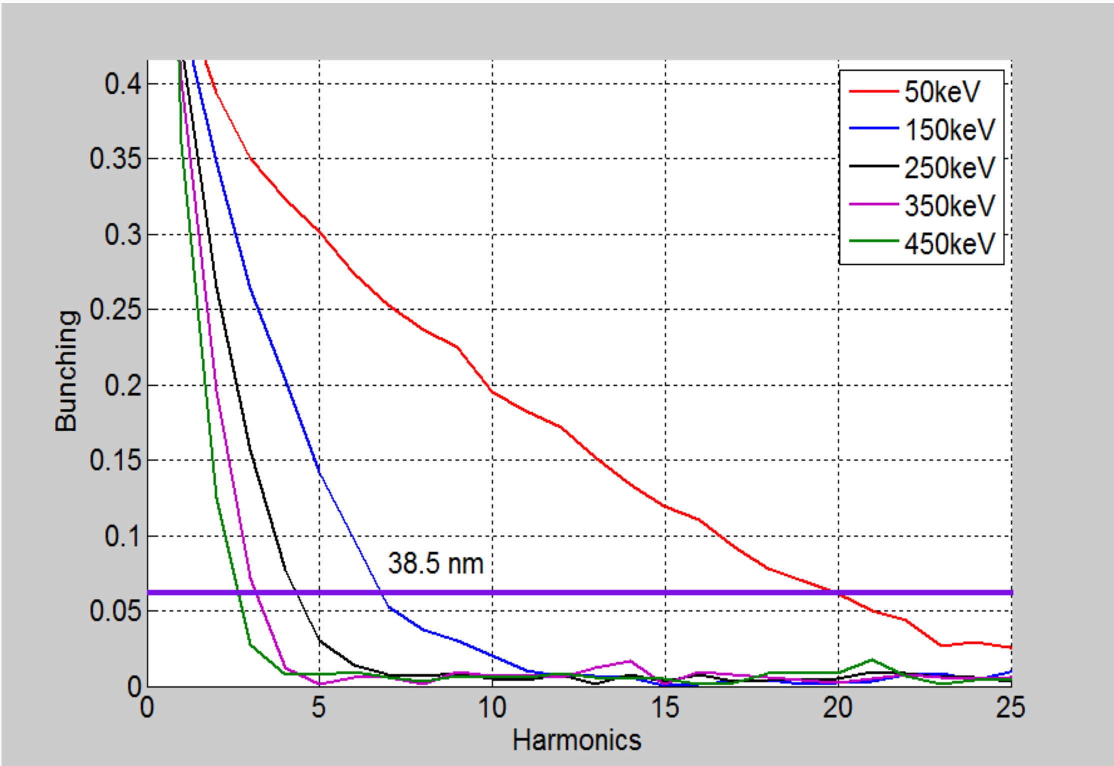




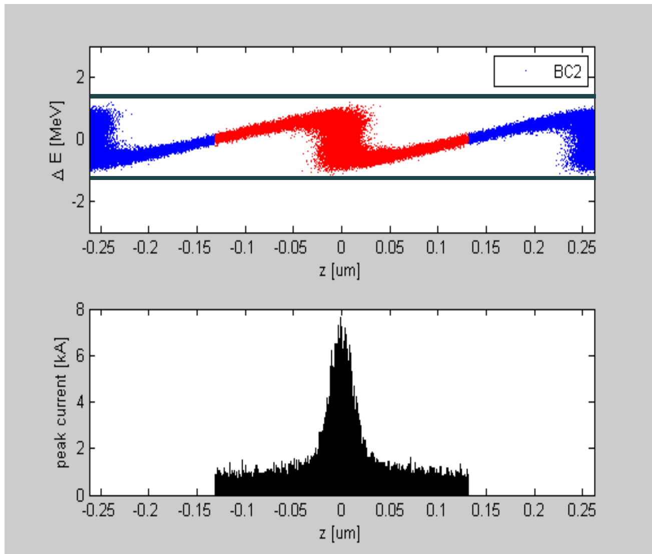
HGHG limit at FLASH2



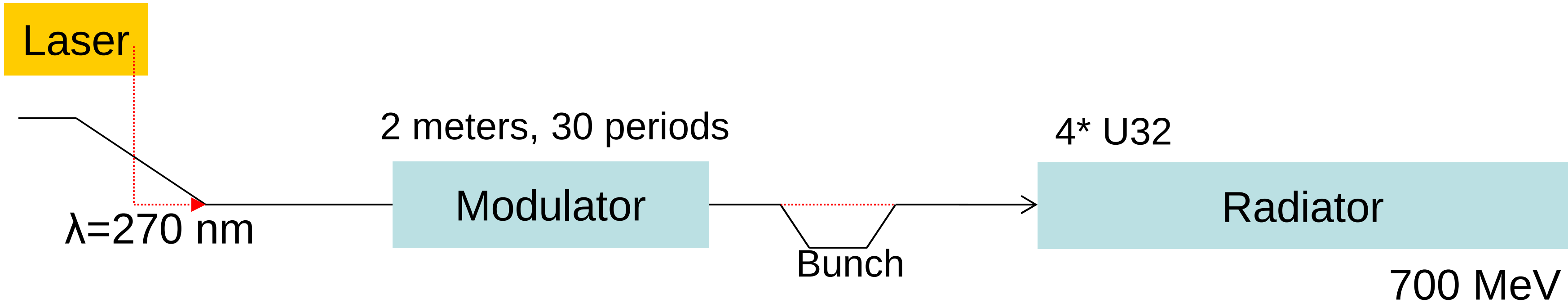
700 MeV
$\Delta E/E<4*10^{-3}$



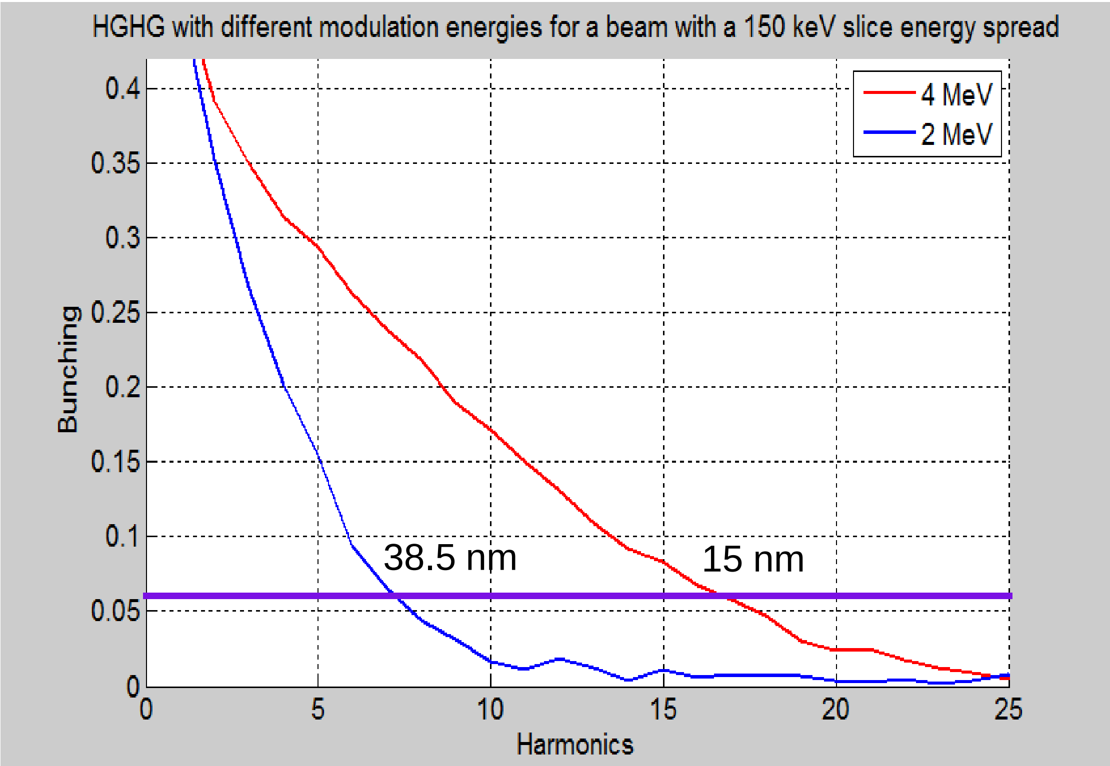
limit: uncorrelated energy spread of electron beam



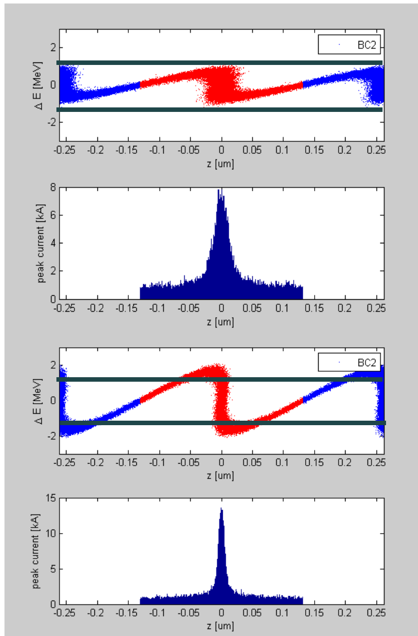
HGHG limit at FLASH2



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



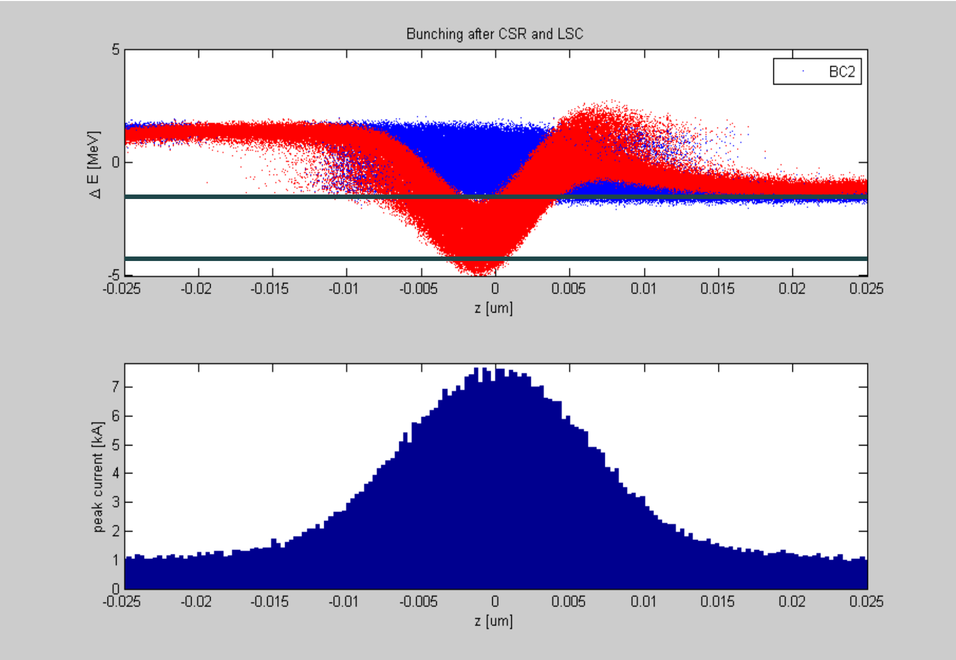
limit: too high peak current

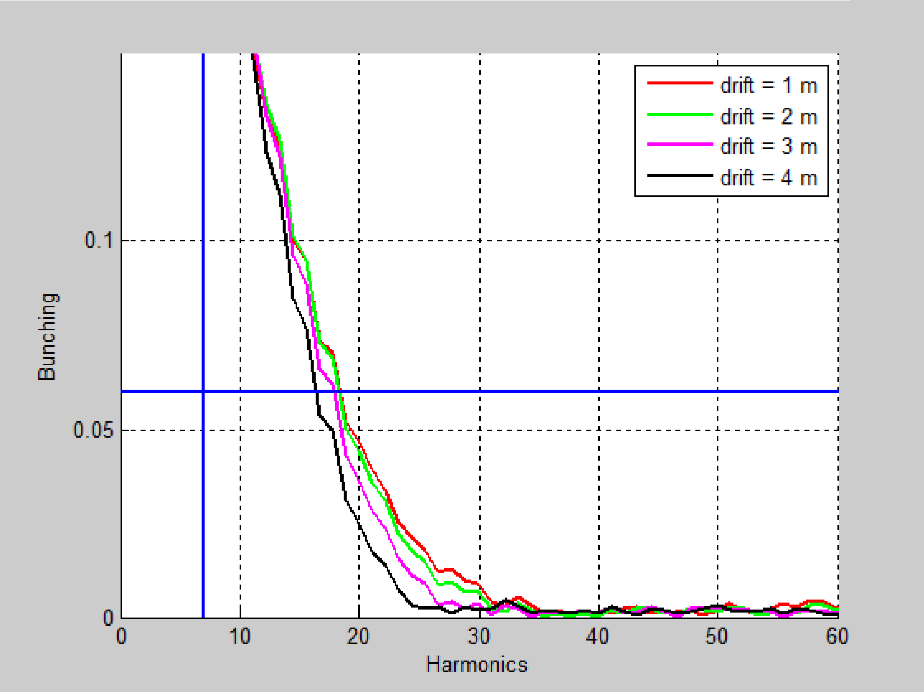


CSR and LSC

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



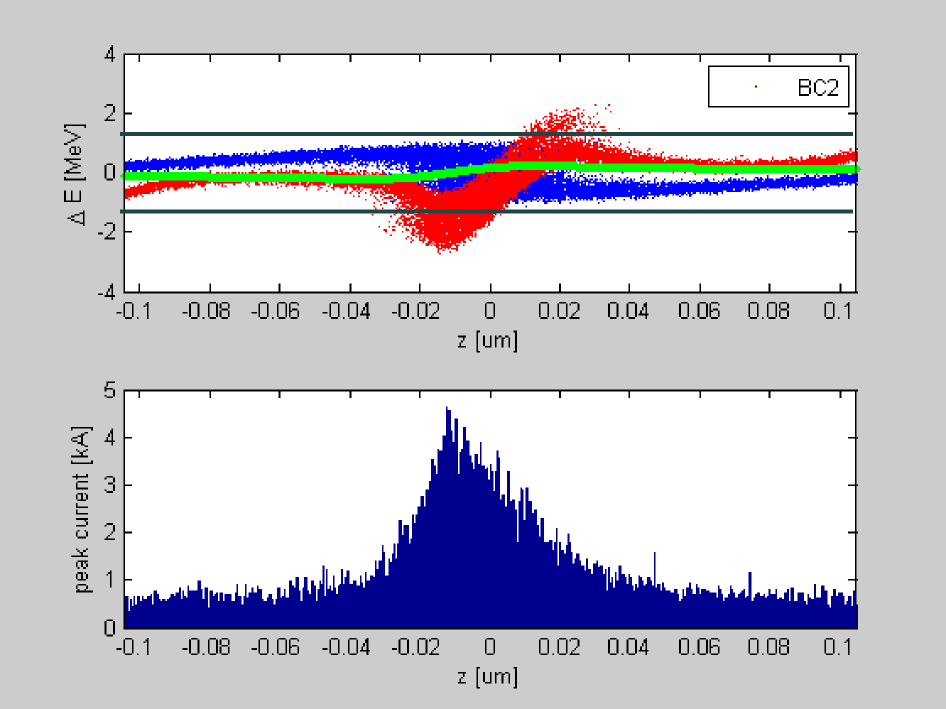


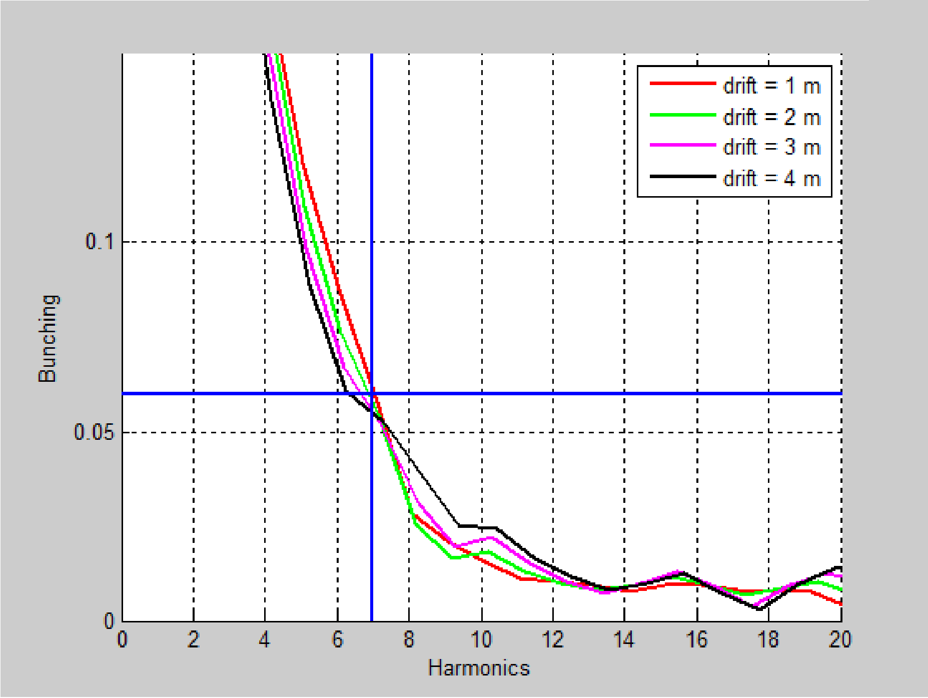
Only small degradation in bunching
But – energy spread is too big

CSR and LSC

2MeV microbunch after 4 meters

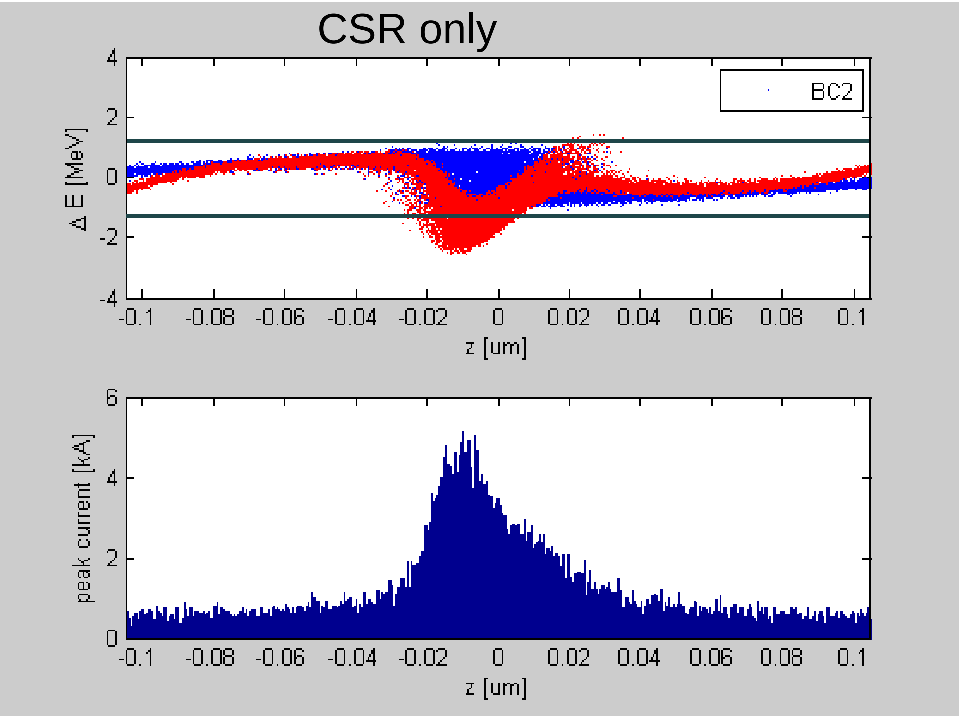
100 μm (rms) beam radius
1kA initial peak current
R_{56} of chicane = 45 μm
700 MeV beam energy



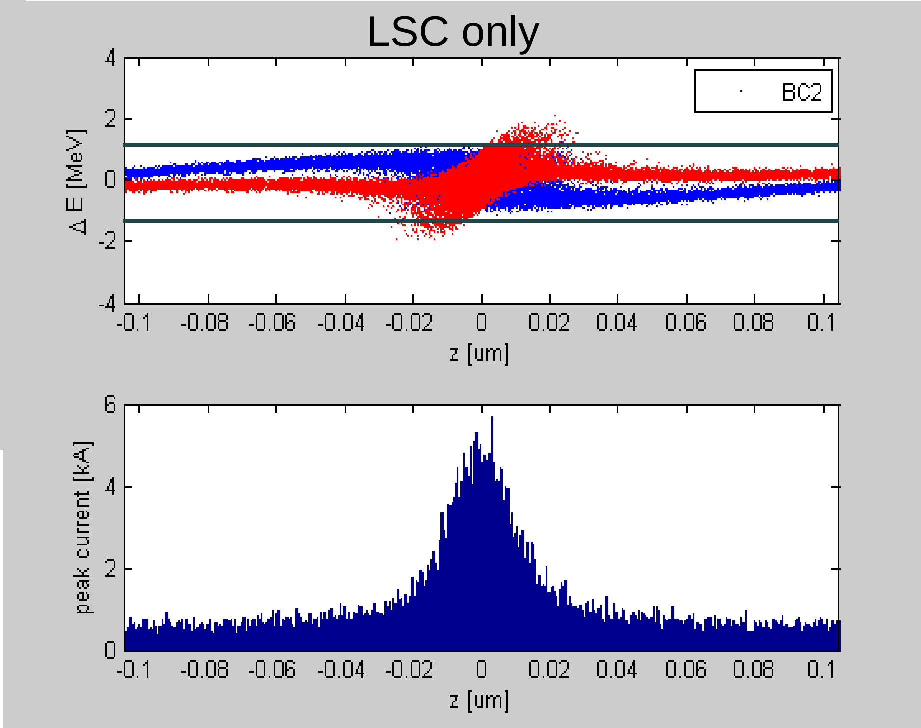


CSR and LSC

2MeV microbunch after 4 meters



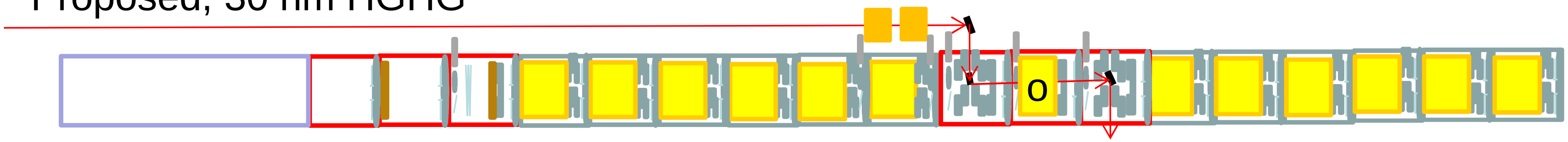
$$Z_{LSC}(k) = \frac{iZ_0}{\pi k r_b^2}\left[1 - \frac{kr_b}{\gamma} K\left(\frac{kr_b}{\gamma}\right)\right]$$



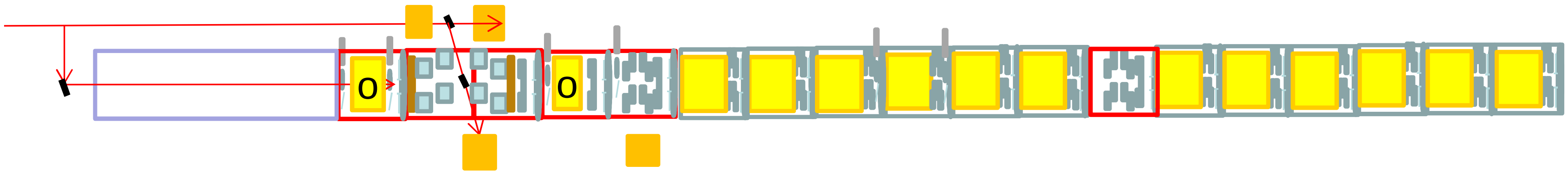
100 μm (rms) beam radius
1kA initial peak current
R_{56} of chicane = 45 μm
700 MeV beam energy

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 focusing might reduce the bunching due to T_{126} effects.

5). Everything not yet considered.

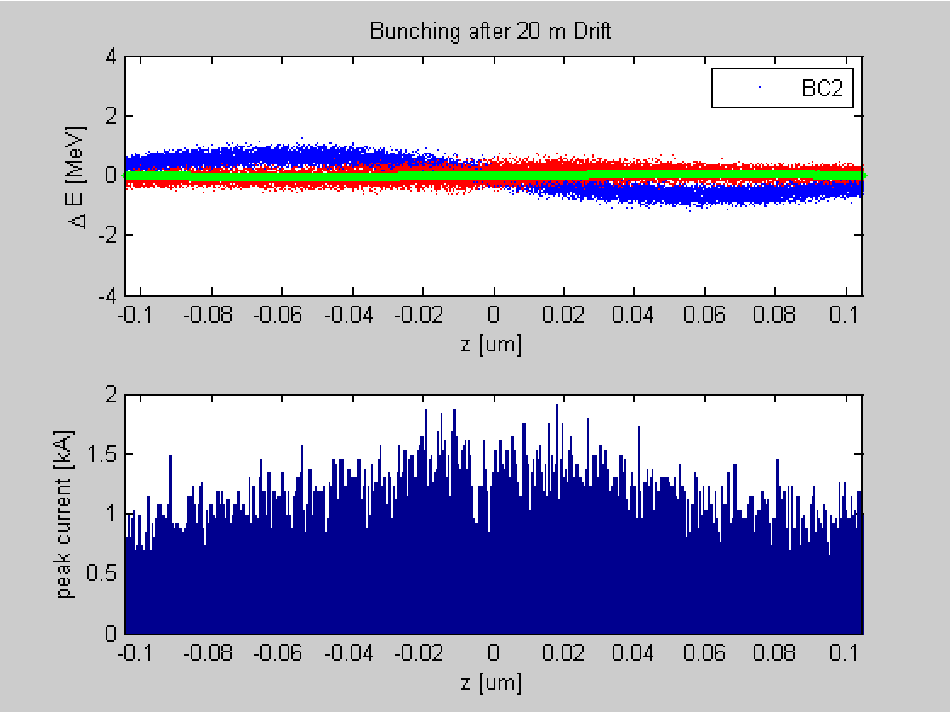
Dispersion in 30 meter Drift

- $R_{56} \sim L_{drift}/\gamma^2 = 15$ μm ~ 700 MeV
- $R_{56} \sim L_{drift}{*}\theta^2 < 3$ nm ~ worst case 100 μm
- $T_{126} \sim l_{bend}$ (sextupole moment)
  - $R_{11} \sim \cos\theta=1$
  - $R_{12} \sim \theta/l_{bend} \sin(\theta/l_{bend})=0$
  - $R_{16} \sim 2{*}R_{56}{*}\theta=0$

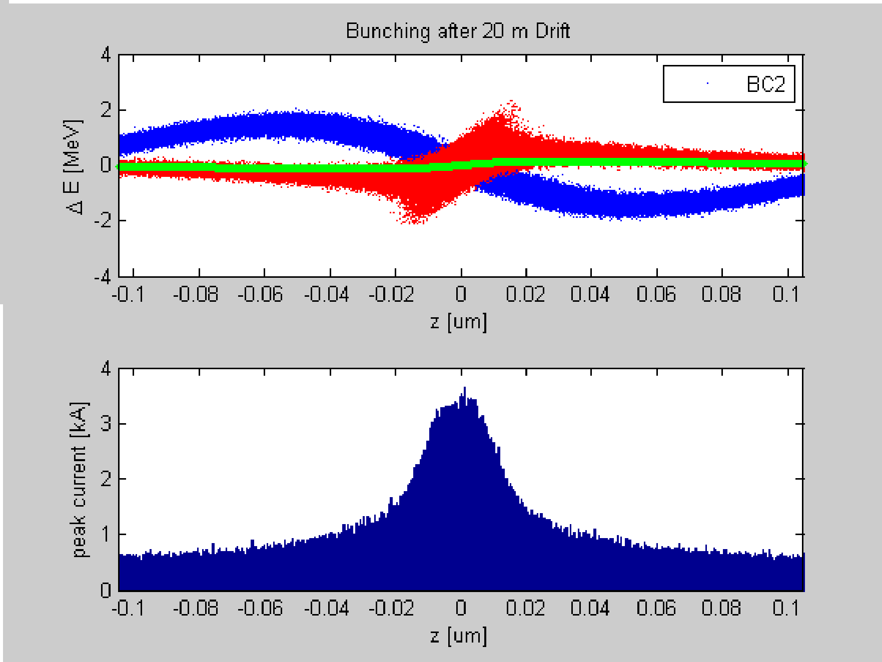
Dispersion required to bunch seeded microbunch is:

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

LSC over 20 meters



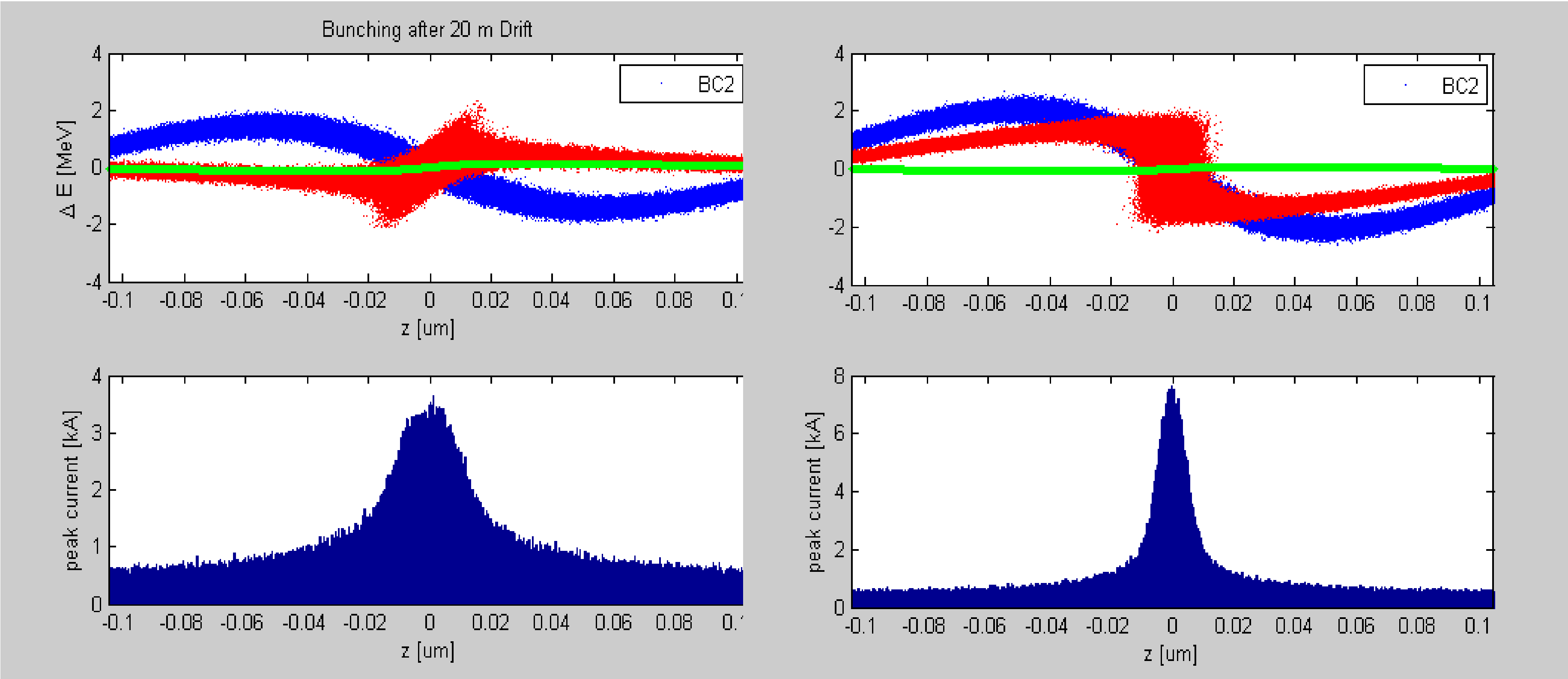
100 μm (rms) beam radius



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

Increase beam diameter to remove LSC problem

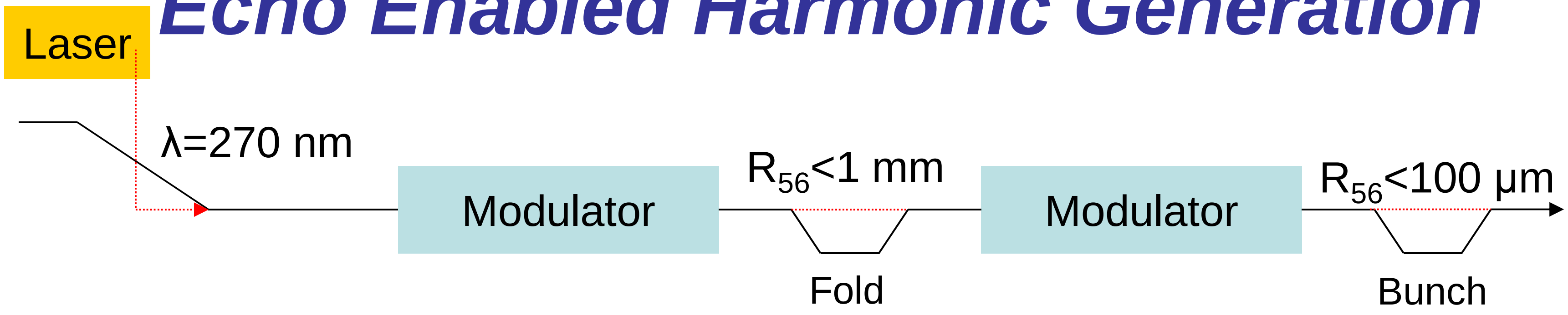
100 µm 200 µm

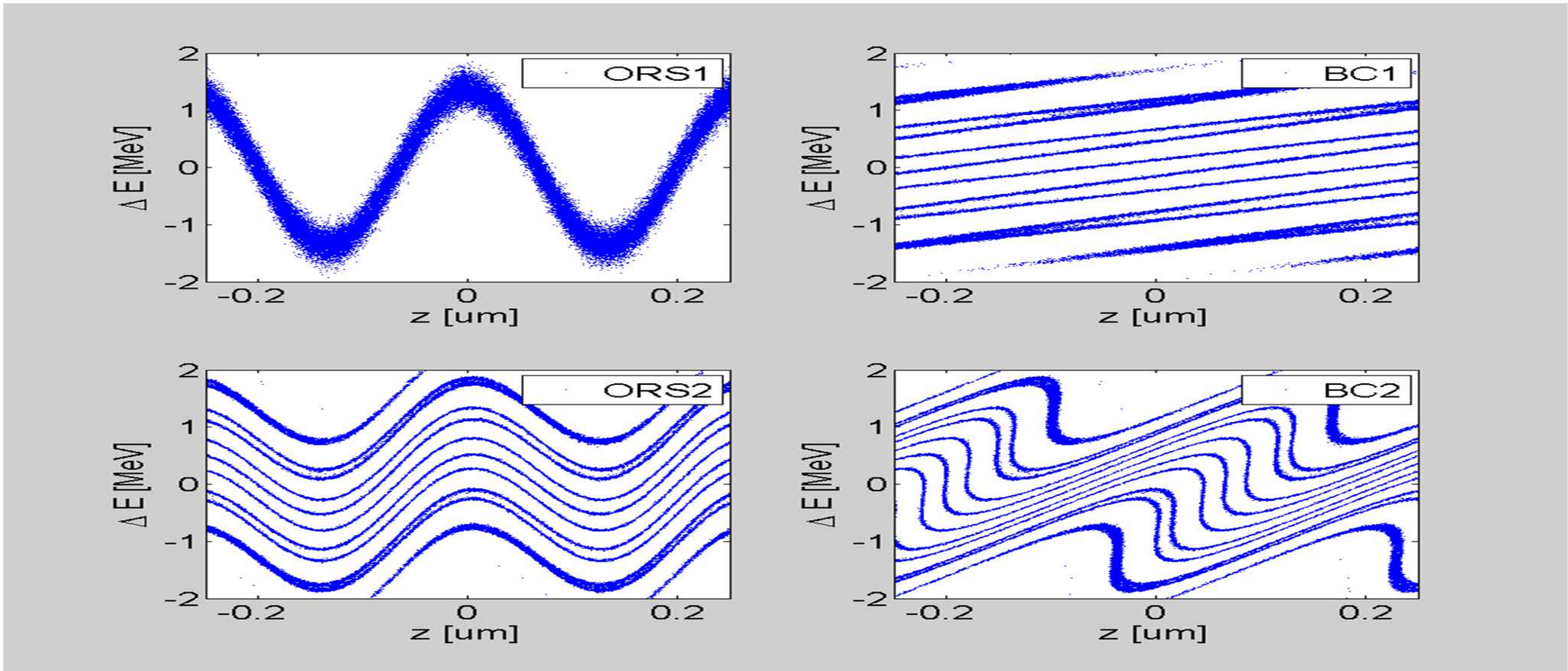


Bonus: no CSR because beam was compressed in drift

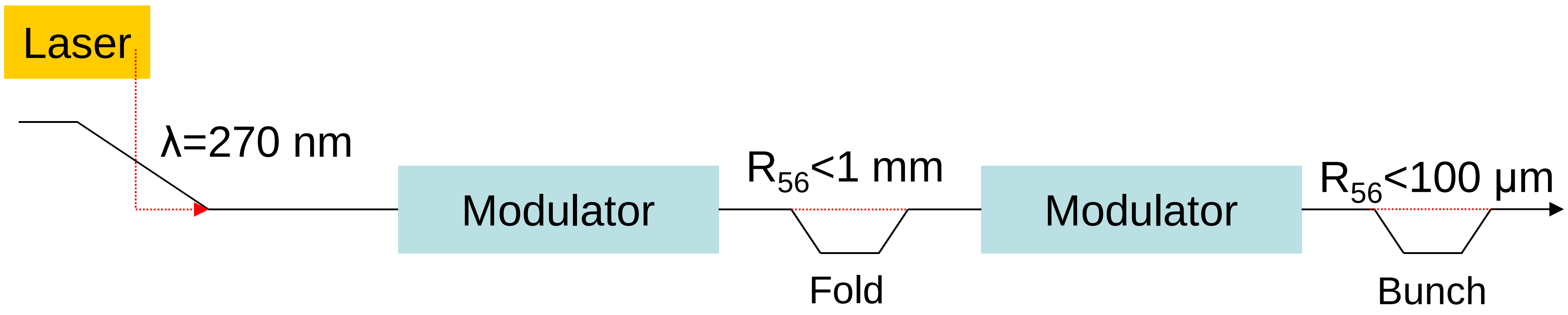
EEHG seeding

Echo Enabled Harmonic Generation

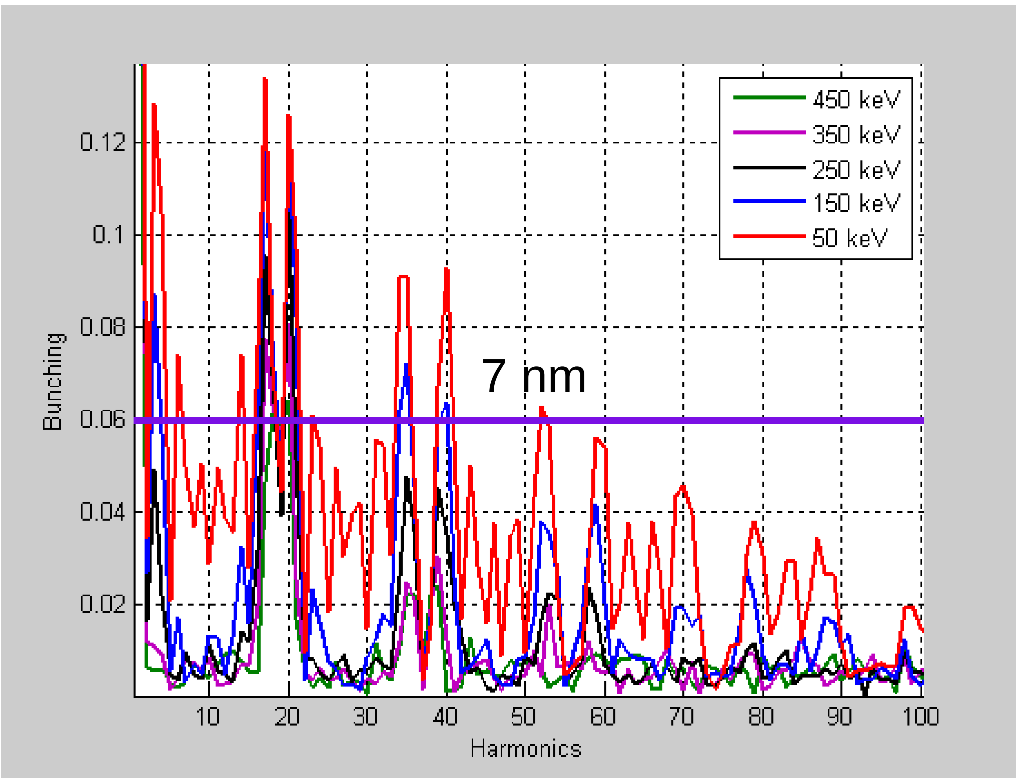


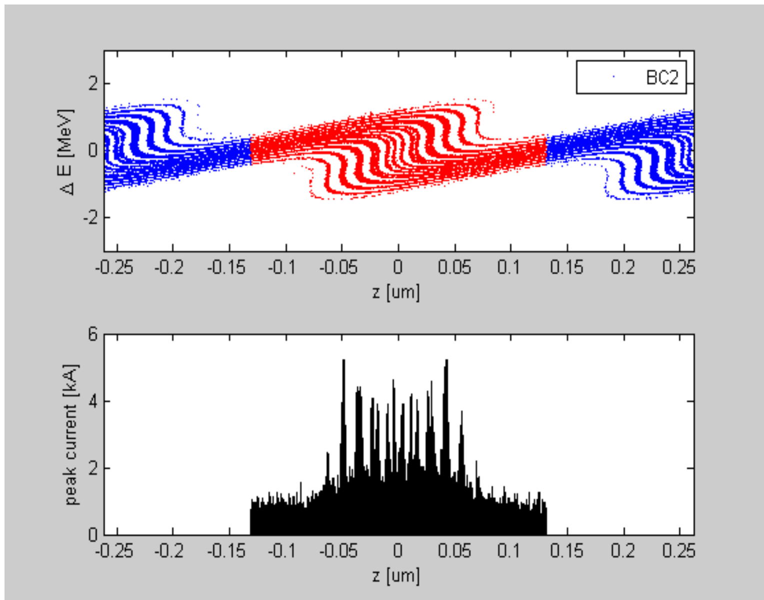


EEHG limit at FLASH2

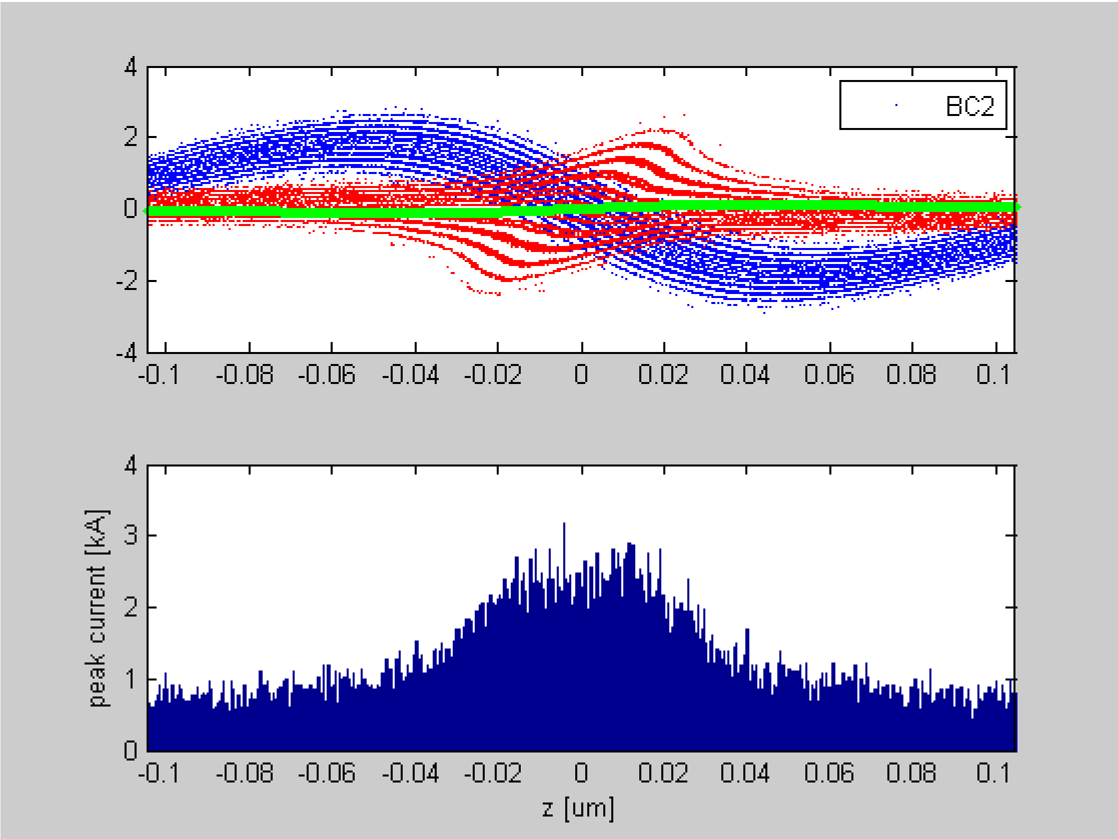


$\Delta E/E < 4 * 10^{-3}$



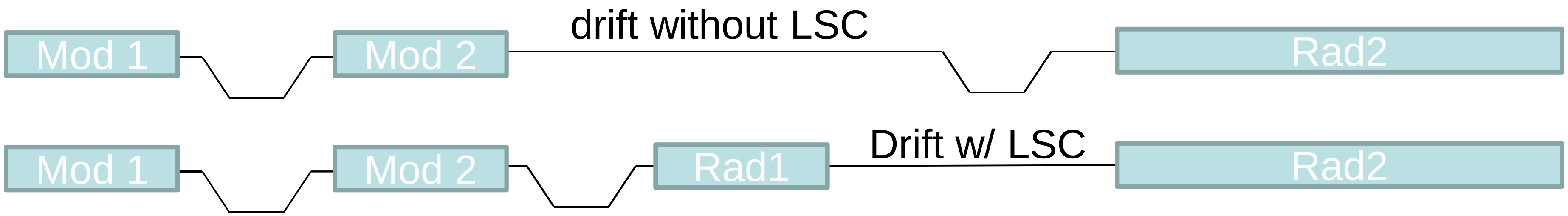


EEHG doesn't tolerate LSC



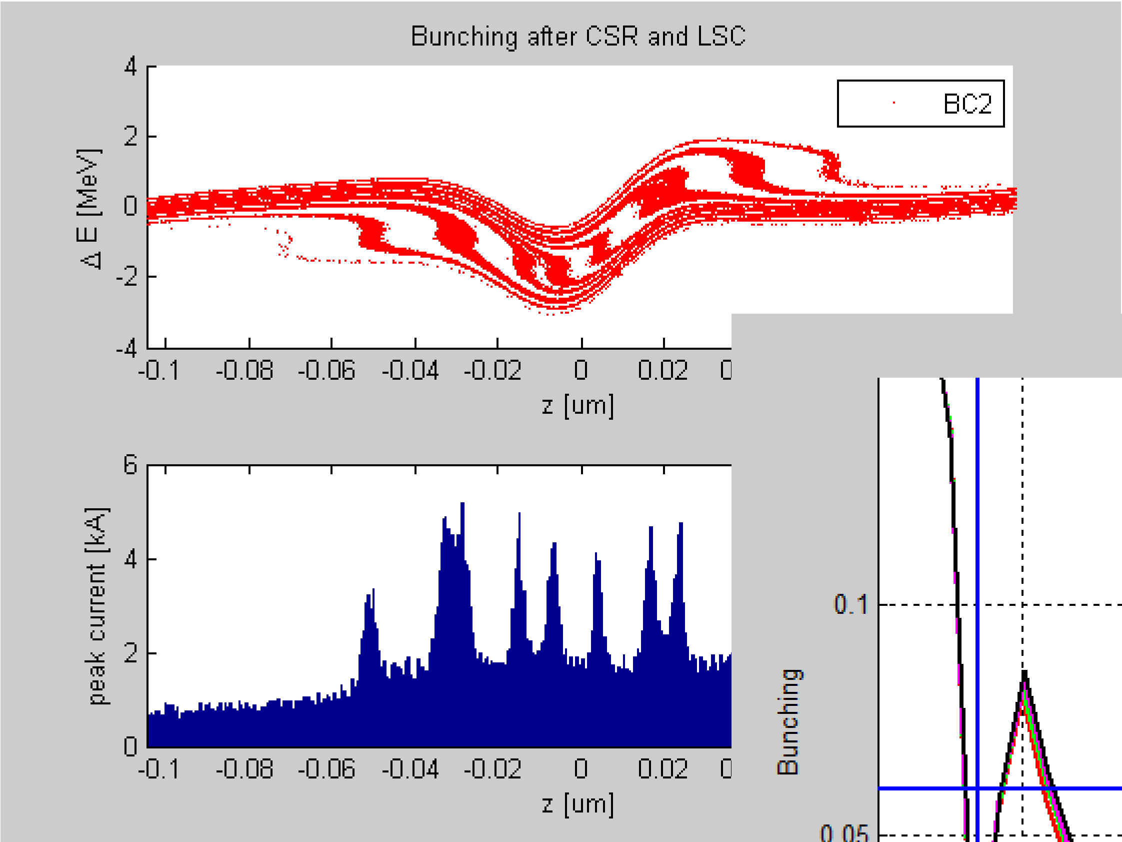
=> Need large beam size and higher energy in drift, and/or split radiator

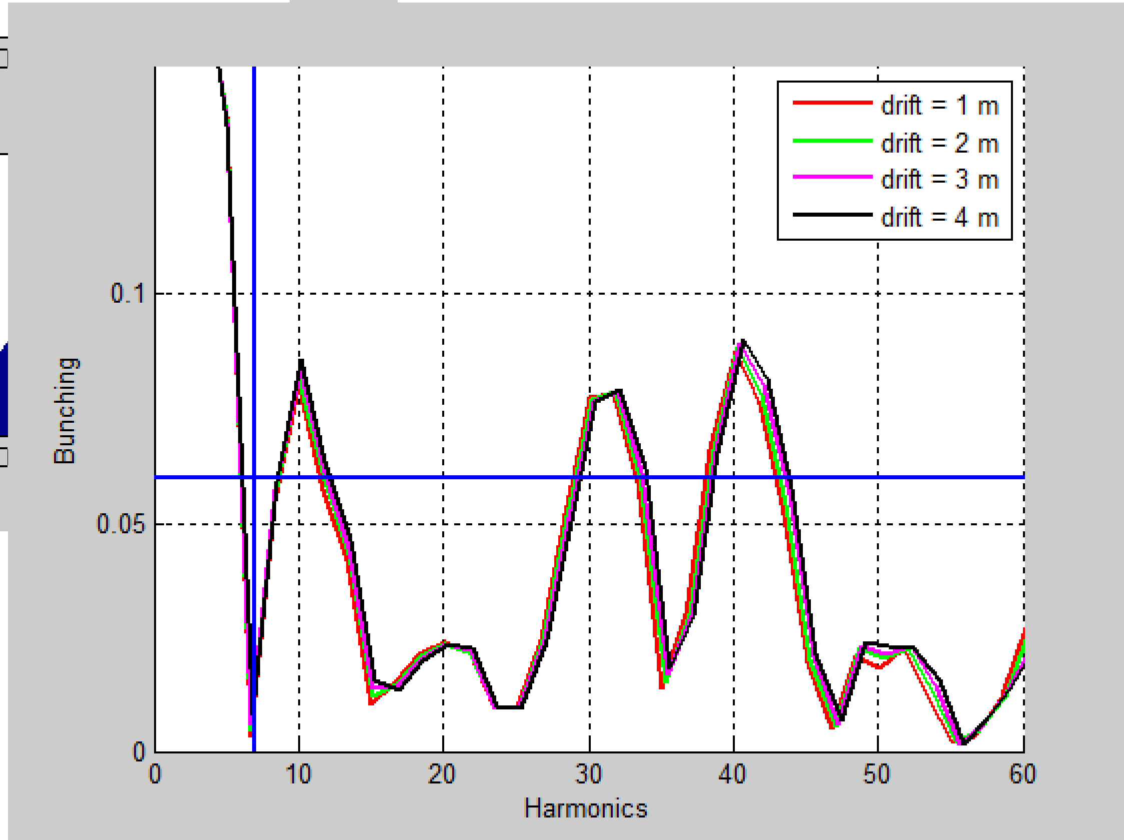
1kA peak current
30 meters of drift
100 um radius



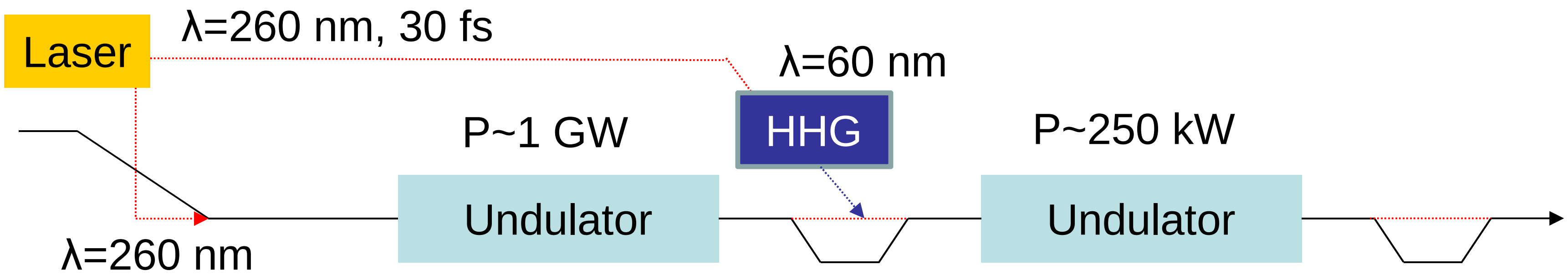
EEHG tolerates CSR

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

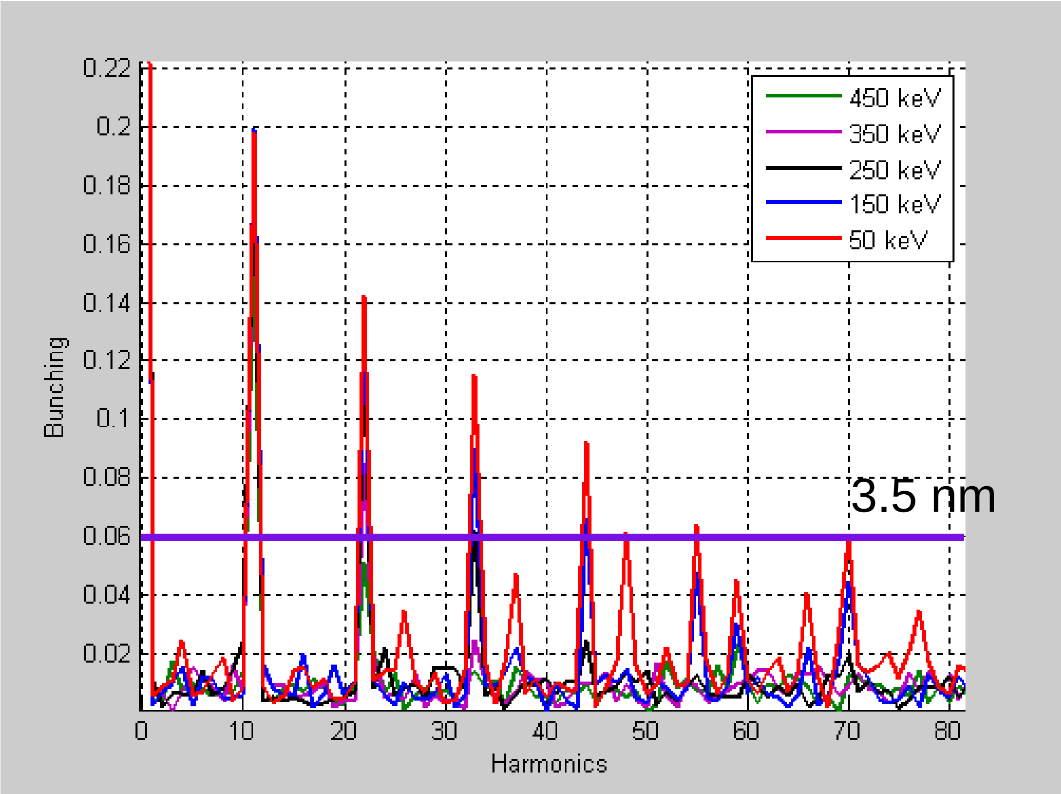




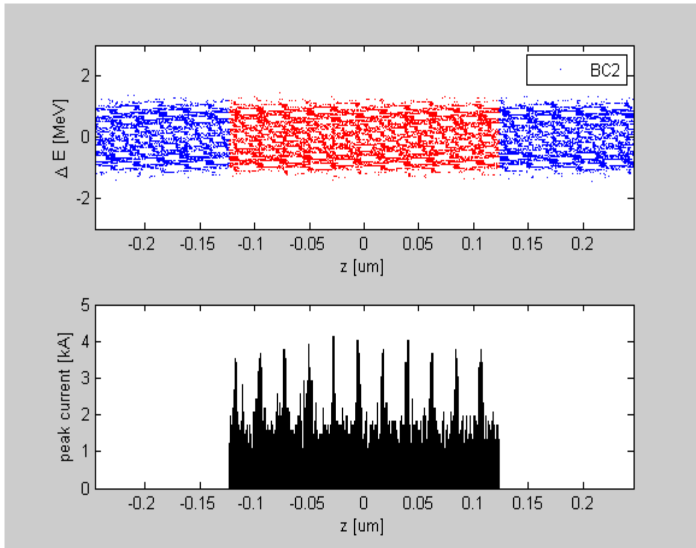
EEHG-HHG limit at FLASH2



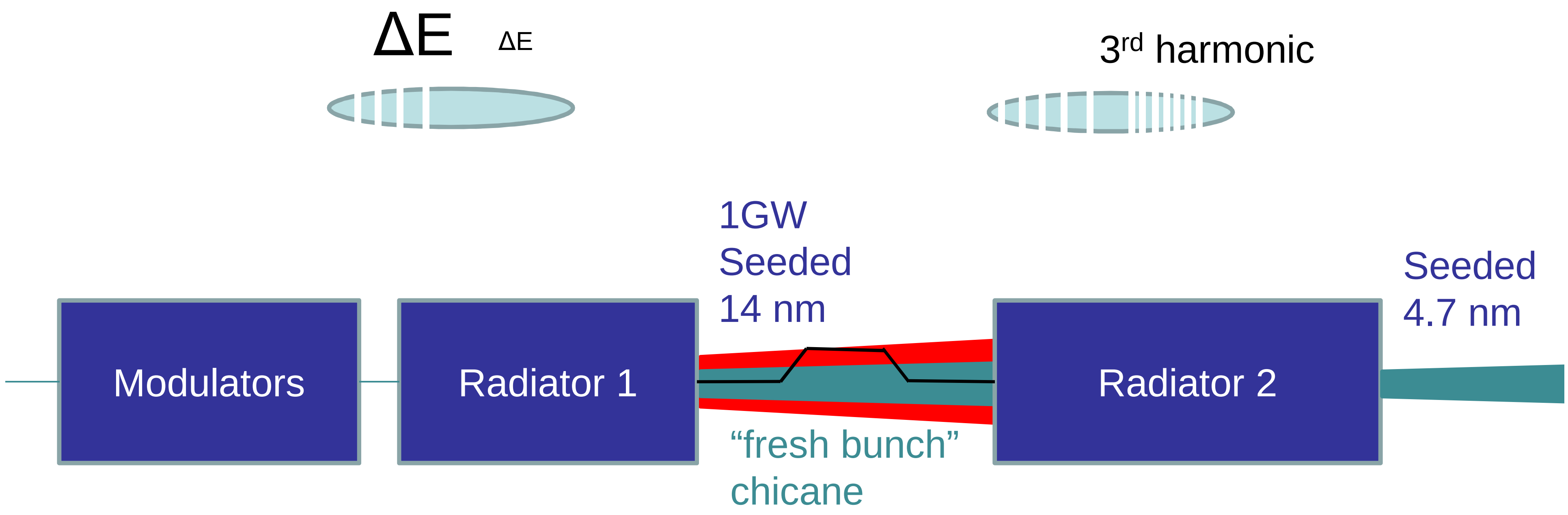
ΔE/E<4*10^{-3}



Flatter current distribution
is better for LSC and CSR



Cascaded seeding at FLASH2

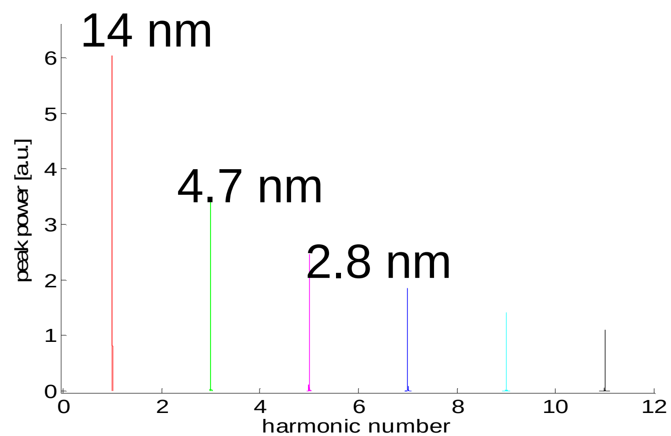


EEHG cascade tolerates 450 keV slice energy spread

12-24 nm -> 3rd harmonic -> seeded 4-8 nm

HGHG cascade tolerates 150 keV slice energy spread

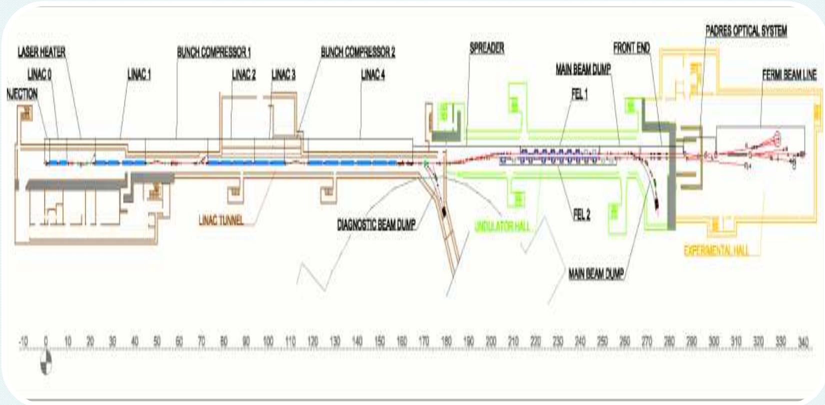
24-36 nm ->3rd harmonic -> 8-12 nm

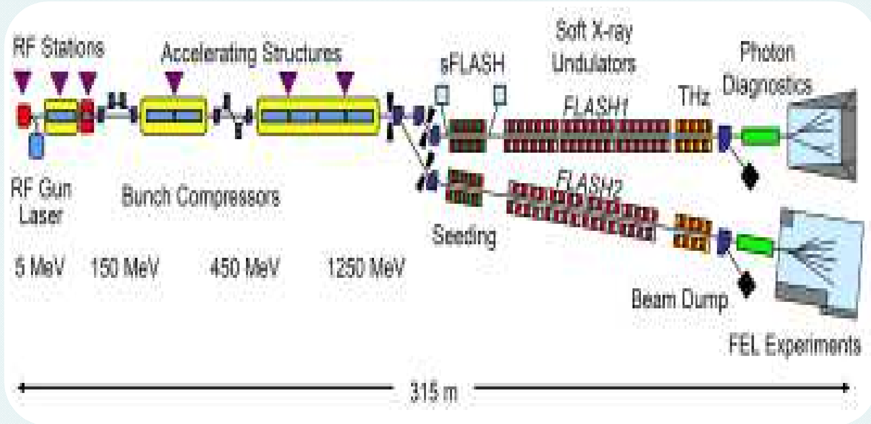


Seeding at other labs

- SINAP
  - EEHG at 300 nm, but moving very fast
- SLAC (NLCTA)
  - EEHG at 170 nm (14^{th} harmonic)
- ELLETRA (FERMI)
  - HGHG down to 19 nm
  - HGHG cascade down to 4 nm

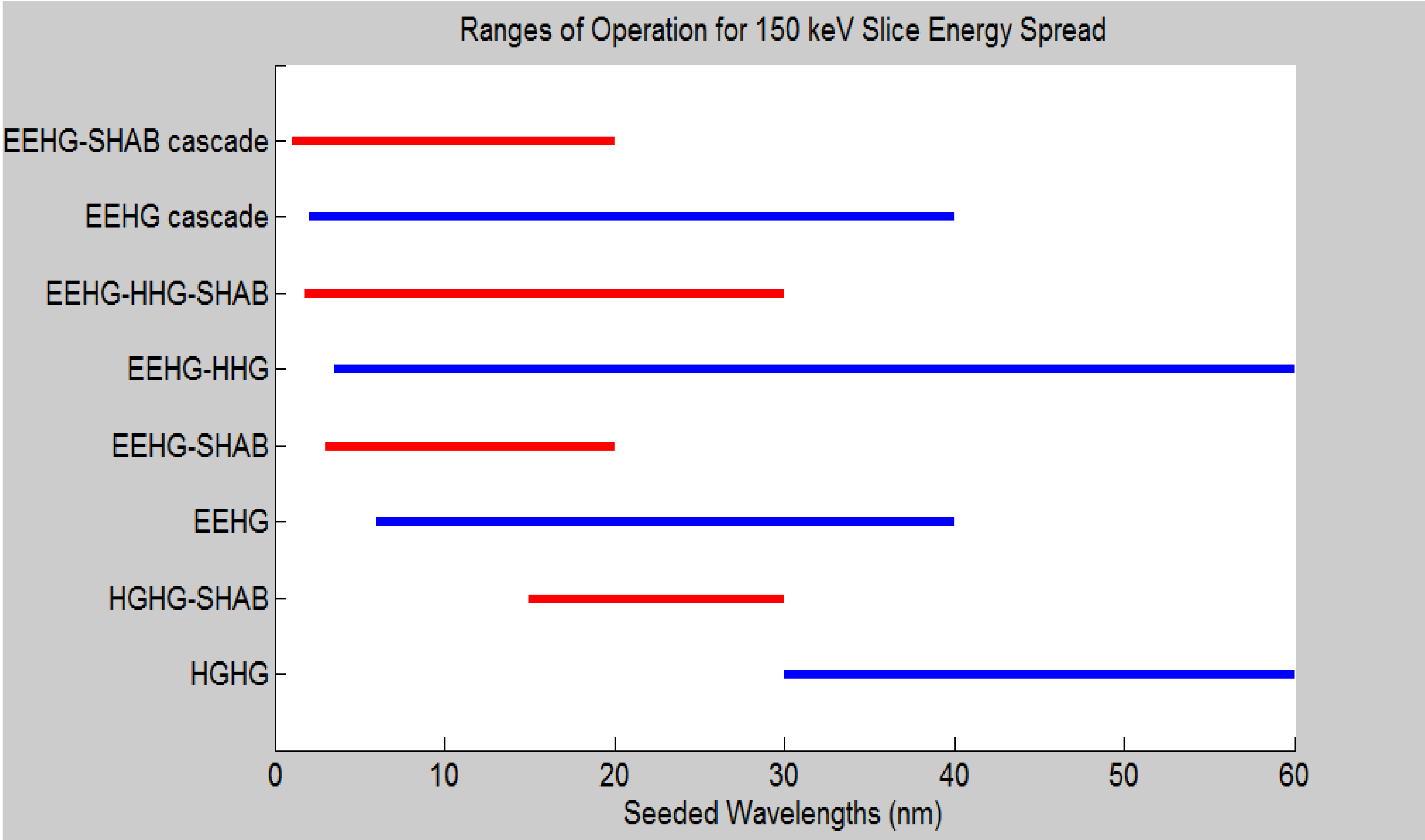
Why not copy FERMI?



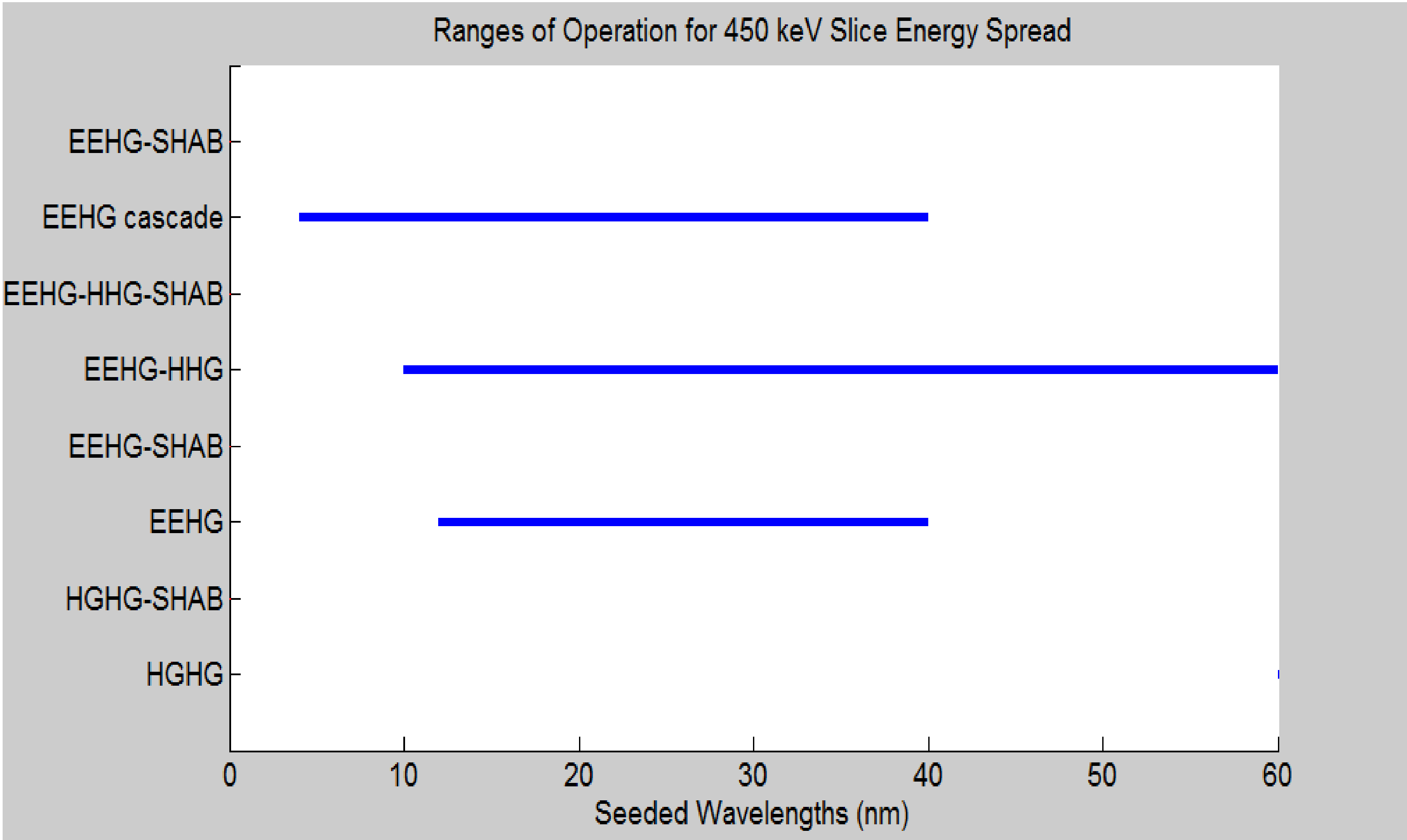


Low peak current	High peak current
Low charge	High charge
Low energy spread	Big energy spread
No SASE	SASE
Less pulse energy	More pulse energy
Low rep-rate	High rep-rate
Laser heater	No laser heater
Radiator for cascade	Radiator for SASE

Seeding performance 150 keV energy spread



Seeding performance
150 keV energy spread



Conclusions

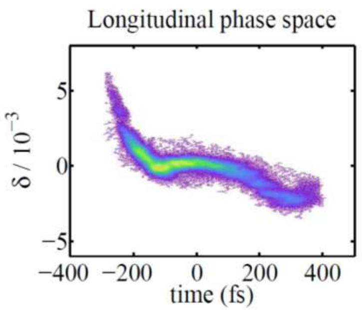
- EEHG has the highest tolerance of a bad slice energy spread

- The HGHG-only FLASH2 design is limited in performance to 150 keV energy spreads and 30 nm minimum wavelengths

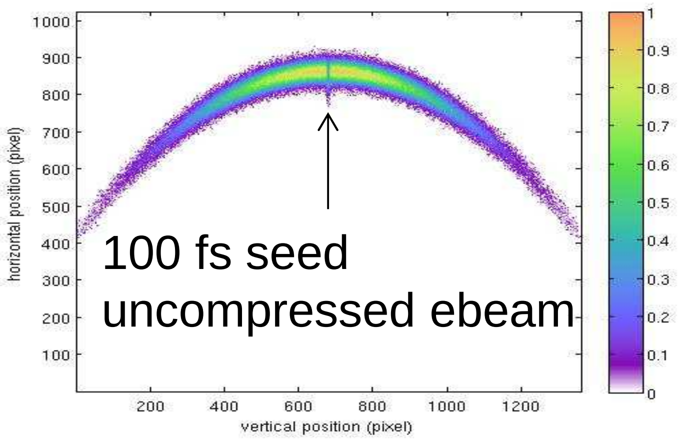
- The more flexible design for FLASH2 offers more ways to seed from 4-40 nm and with a larger tolerance of the slice energy spread

X-Band Transverse Deflecting Structure for FLASH2

(addendum)



- giving users information about the longitudinal profile of the FEL pulse for each bunch train
- R&D for LAOLA ultra-short bunch diagnostics
- commissioning the FLASH II extraction line
- operating any seeding experiments
  - energy modulation diagnostic



Images from C. Behrens

Thank you for your time