DALI – Key Aspects of the MIR–THz Source

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Outline

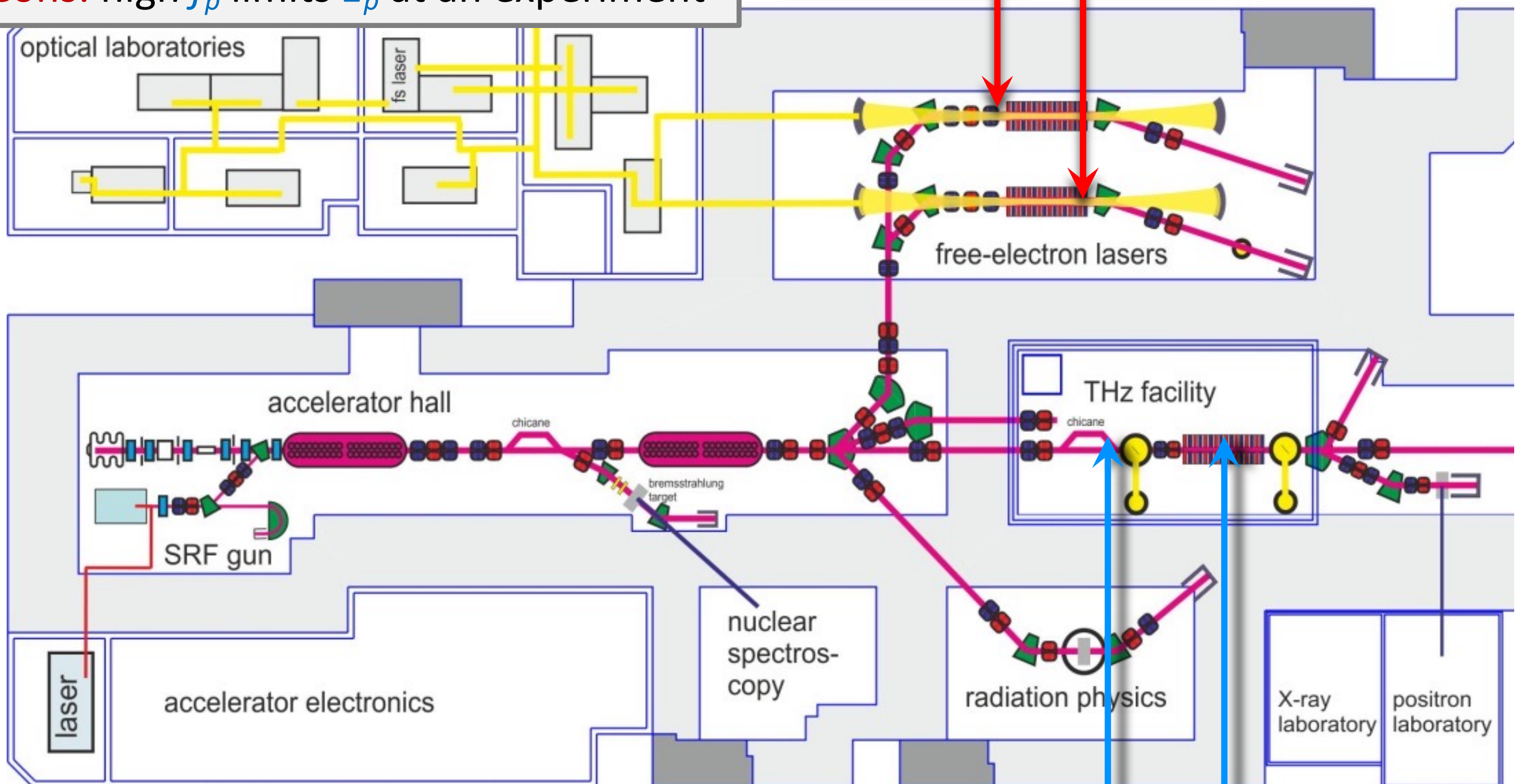
- ELBE ➞ DALI :: requirements
- Overall concept of new sources :: expected performance
- Bunch compression
- Longitudinal emittance growth due to LSC
- 2-Beam Optical-Klystron ➞ modulator ➞ seed generator

ELBE :: IR and THz Sources

Pros: cover 1.2 … 60 THz
Cons: high f_p limits E_p at an experiment

Far-IR FEL

Mid-IR FEL



Pros: E_p is not limited by f_p
Cons: cover 0.3 … 2 THz

Coherent Diffraction Radiator (THz)

Superradiant undulator (THz)

IR-THz User's Requirements

※ Present IR-THz sources operate with pulse energy of a few µJ (at 13 MHz or 100 kHz)

※ New Facility Target Parameters

1. pulse energy: 100 µJ ... 1 mJ *(as high as possible)* E-field of few MV/cm
2. frequency range: 0.1 THz … 30 THz
3. repetition rate: **CW !** 100 kHz … 1 MHz (high flexibility)
4. Bandwidth: ∽ 1 % (multi-cycle) and ∽ 100 % (single-cycle)
5. Synchronization: ∽ 10 fs level
6. Carrier Envelope Phase (CEP) stability

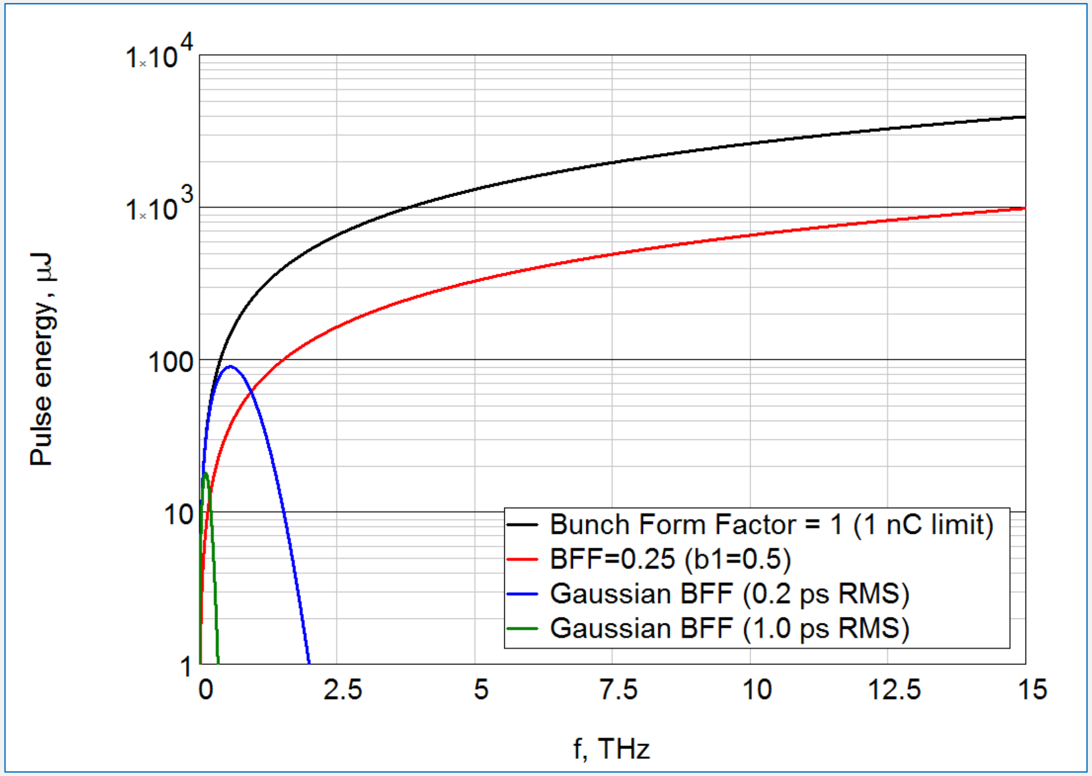
How to increase pulse energy by 10^2 … 10^3 ?

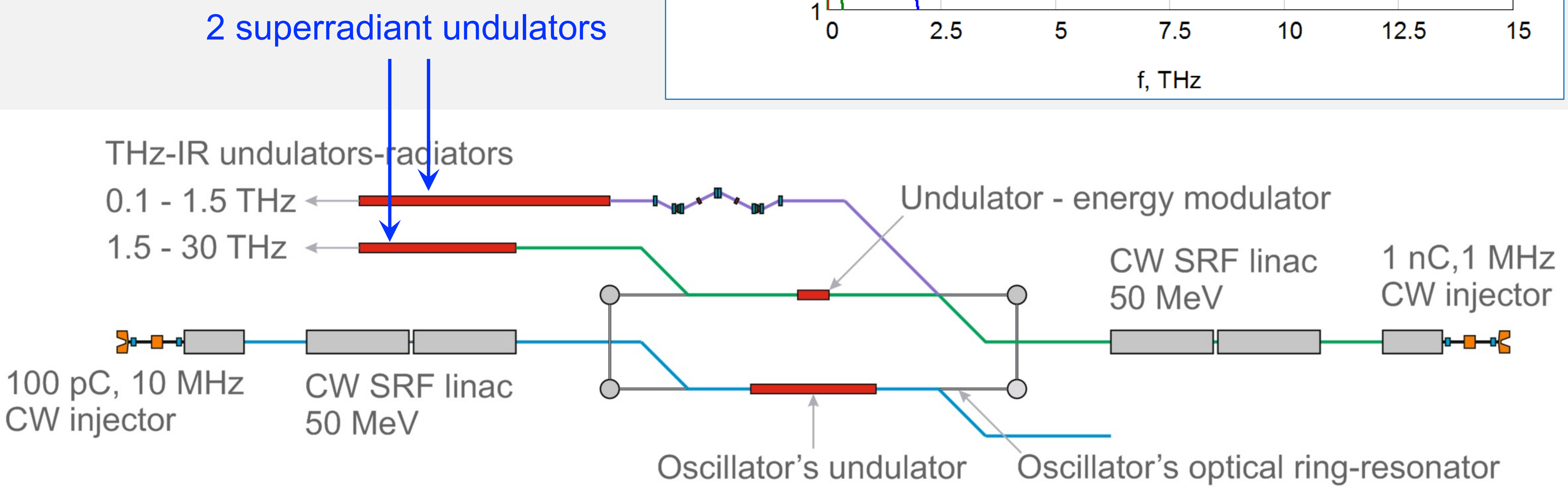
1. Increase bunch charge to ∽ 1 nC
2. Use optimized (2nd order) bunch compression
3. Use longitudinally modulated beams: HGHG @ h=1, (almost Optical Klystron)

Conceptual Source Architecture (SRU)

Set of sources:

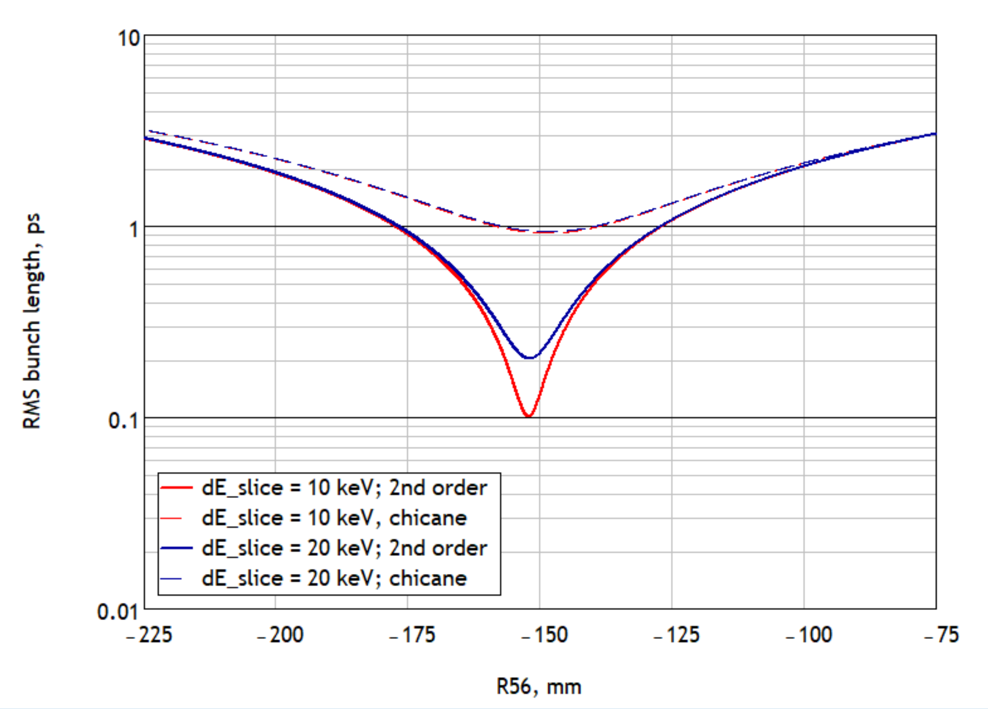
1. SRU driven by short (200 fs) pulses
2. SRU driven by modulated beam
3. FEL oscillator – seeding sources for (2) and standalone source
4. Single-cycle source for each SRU CER / CDR (like TELBE)

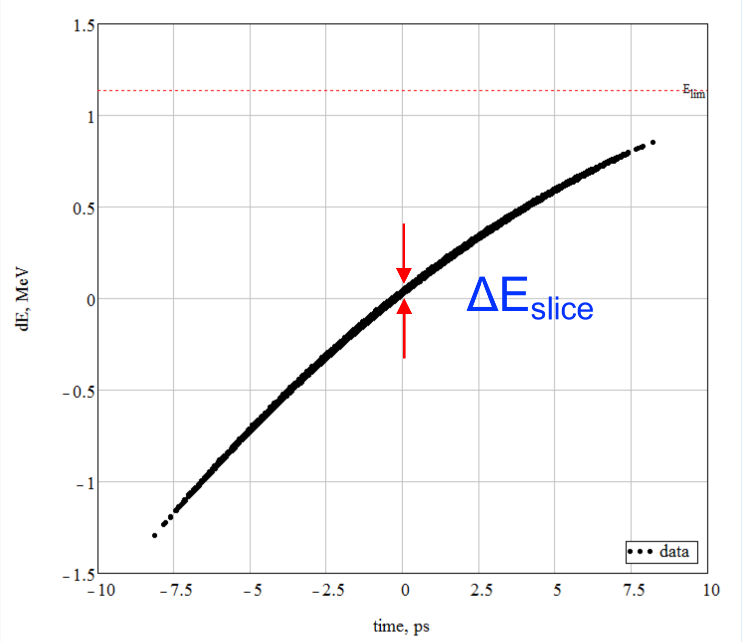




- **Single particle dynamics:**
  a) slice energy spread ΔE_{slice} ultimately limits bunch compression
  b) connects ΔE_{slice}, f_0 (LINAC), $E_{initial}$, E_{final}, $\varphi_{acc.}$ to $\sigma_{t\ final}$
  c) shows required bunch compressor parameters R_{56}, T_{566}
- ΔE_{slice} determined by **(a) injector**, and **(b) by collective effects** longitudinal space charge (LSC)

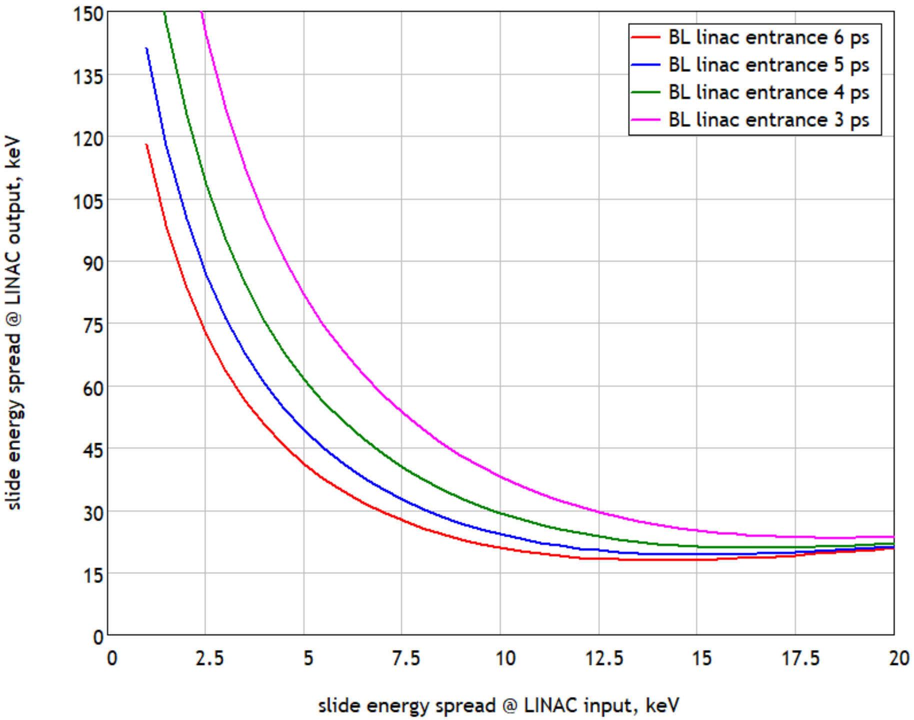
- Longitudinal phase space linearization – large impact on compression (to 2nd order)
- One way to linearize phase space is to use 3rd harmonic (RF) cavity
- Alternative: 2nd-order magnetic compressor (less costly, advantageous for high average I_b)

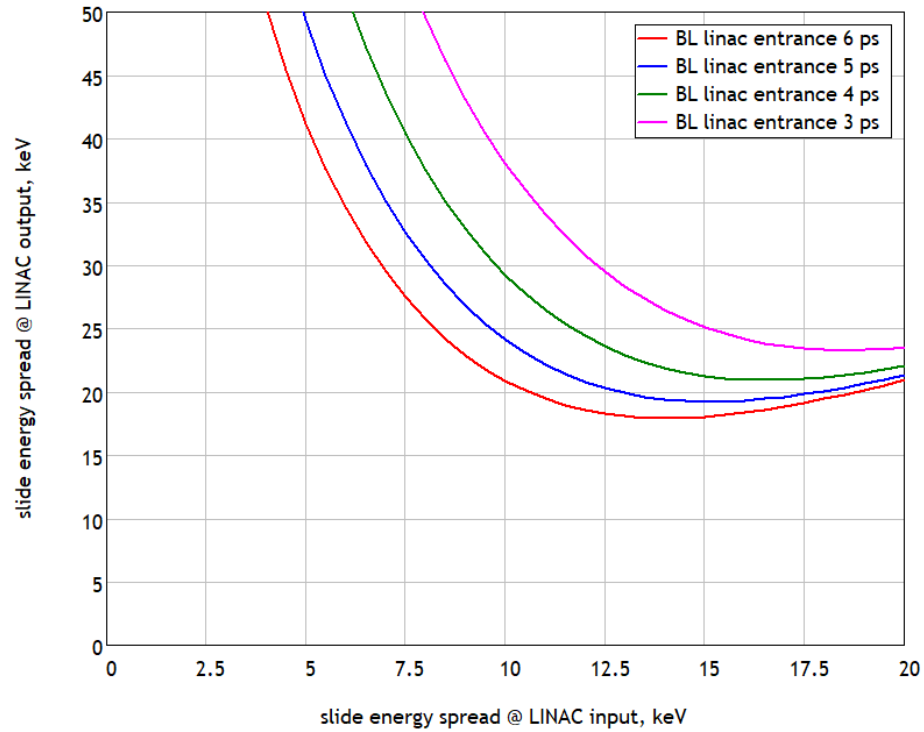




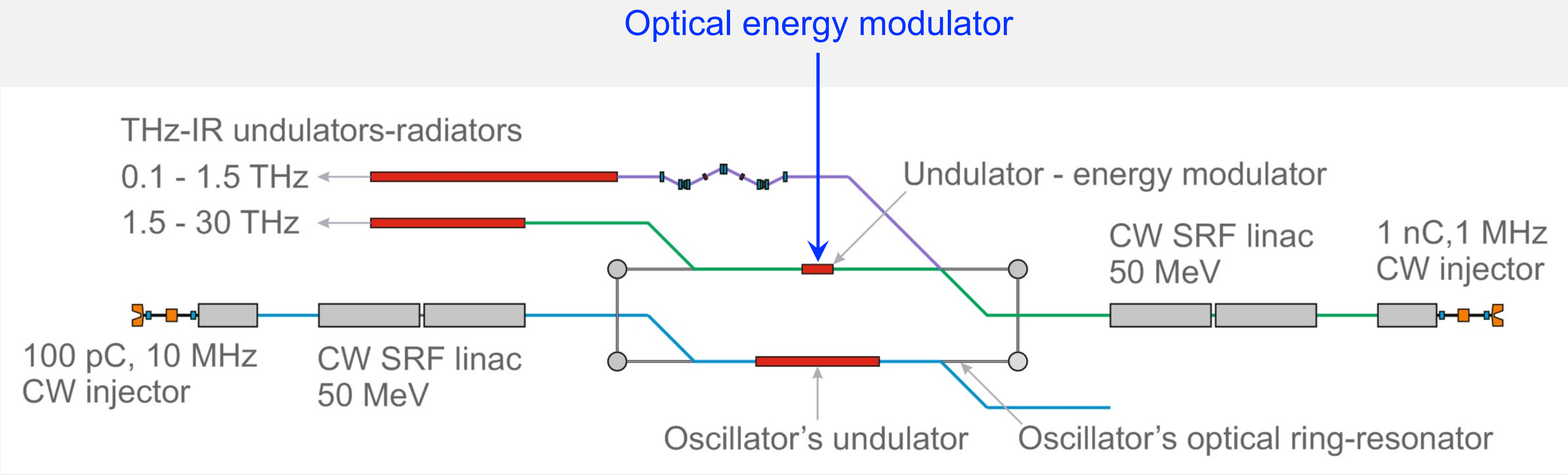
Longitudinal emittance growth (LSC)

- Growth of ΔE_{slice} due to LSC; per 1D, linear µBI theory for 1 nC, $\sigma_{x(y)}$=1 mm, D=50 m

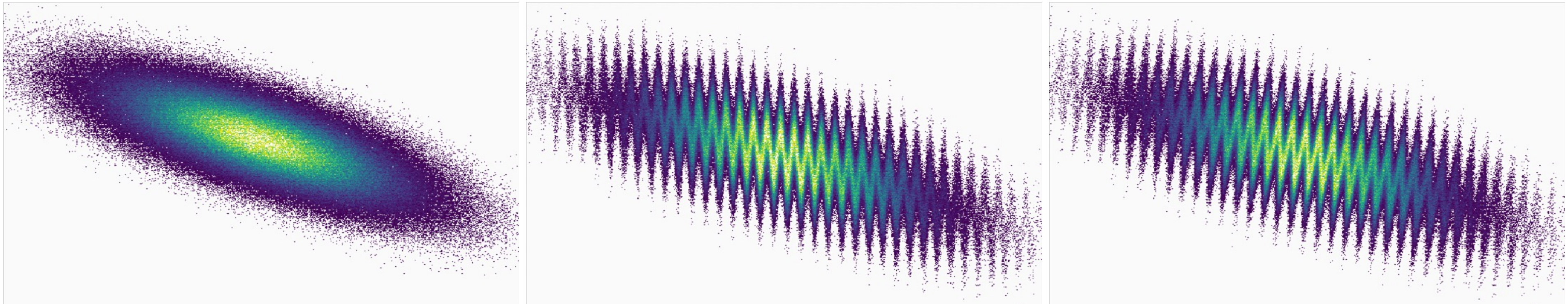




Conceptual Source Architecture (OEM)



Optical Energy Modulation



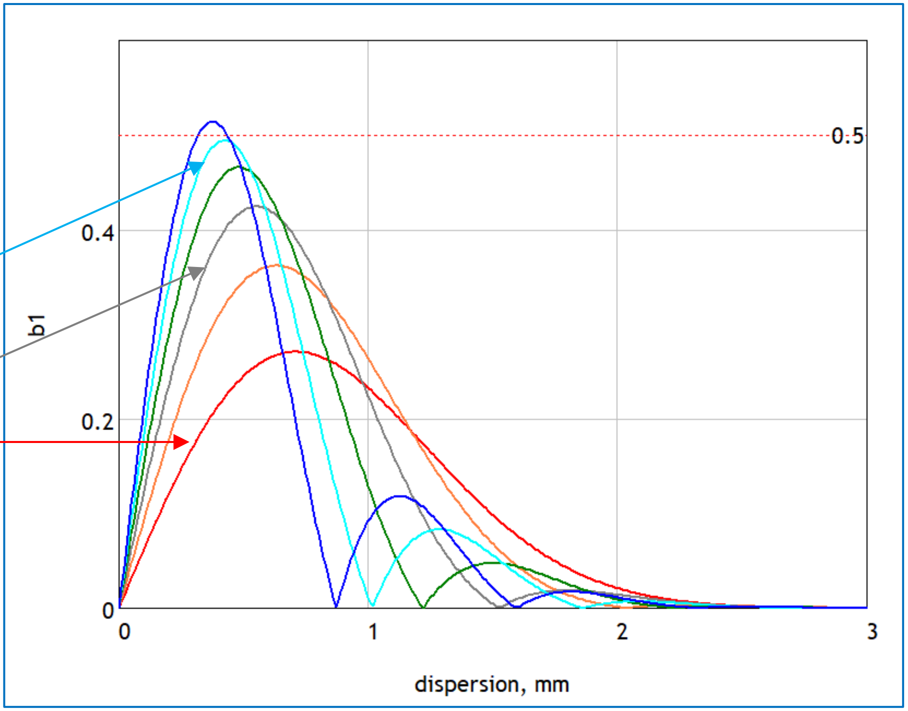
HGHG FEL theory:

$$b_1 = J_1(\delta\gamma_m \cdot k \cdot R_{56}) \exp\left[-\frac{1}{2}(\delta\sigma_E \cdot k \cdot R_{56})^2\right]$$

$\delta\gamma_m = 3 \cdot \delta\sigma_E$

$\delta\gamma_m = 2 \cdot \delta\sigma_E$

$\delta\gamma_m = \delta\sigma_E$



Our design goal is:

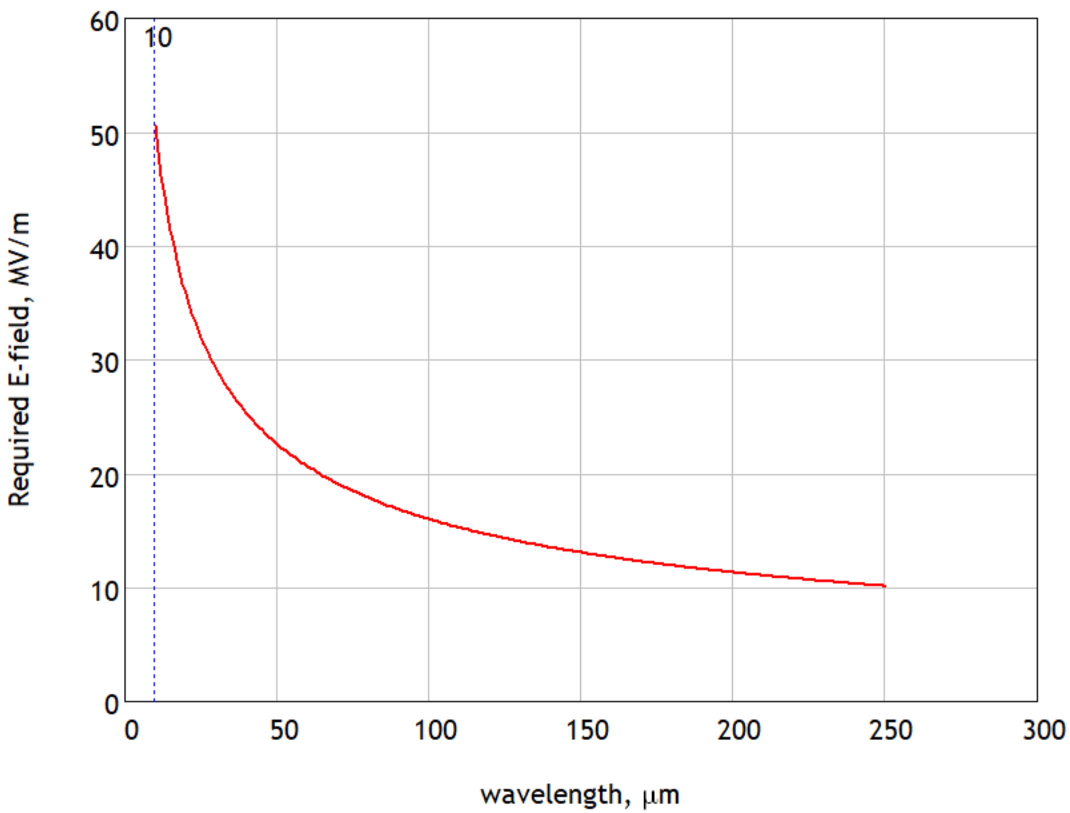
$$\delta\gamma_m = 3 \cdot \delta\sigma_E$$

which leads to

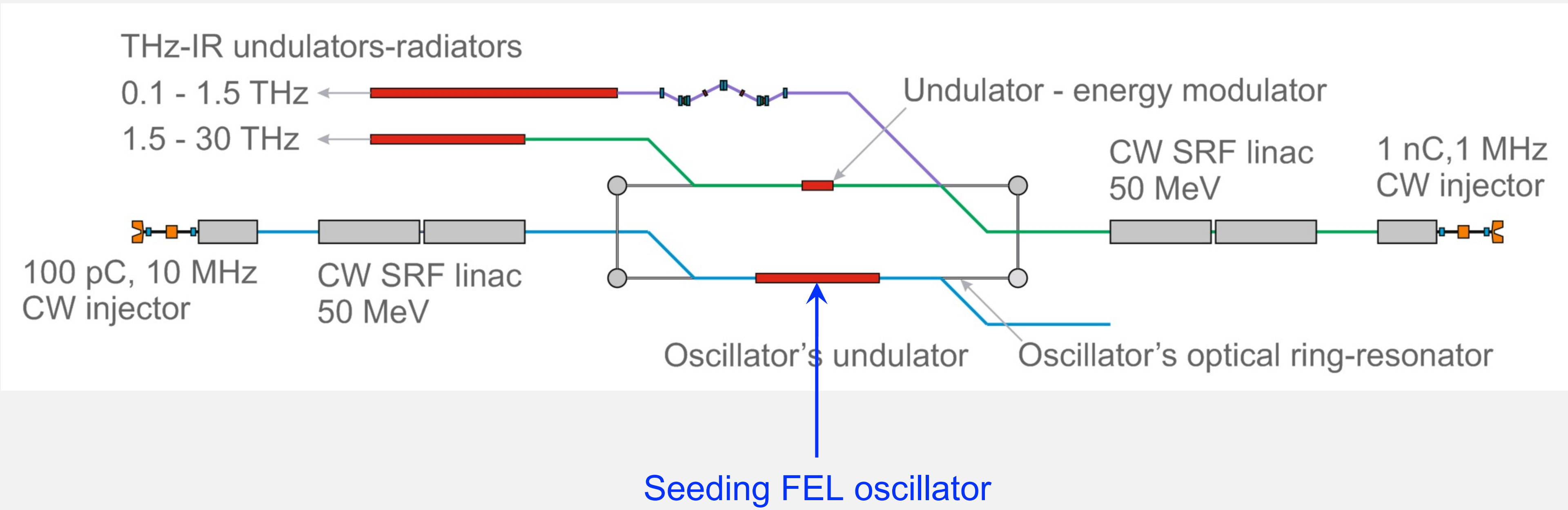
$b_1 = 0.5$, i.e., $|b_1|^2 = 0.25$

OEM :: Required E-field

- LSC (μBI) predicts ~ 40-50 keV SES
- Assume SES = 100 keV (due to other collective effects)
- Modulator 1.17m (130 mm x9) K=1 required following E-field for $\delta\gamma_m = 3 \cdot \delta\sigma_E$



Conceptual Source Architecture (Seed)



FEL oscillator : Intra-cavity mode E-field

- Dattoli – Benson semi-analytical FEL model (well benchmarked by JLab FELs)
- Assuming: Q_b = 80 pC, σ_t = 1 ps, ε_z = 50 keV·ps, R_z = 1 m, δ_{opt} = 4×1.2 %
- Optical model has effective area $[\pi \cdot (3 \cdot r_b)^2]$ with r_b = 0.5 mm