A Laser Heater for CompactLight FEL

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Funded by the European Union

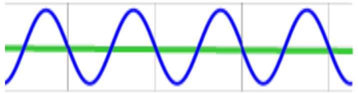
The problem

Compact

Peak at $\frac{r_b k}{\gamma} \simeq 1$

$\lambda \sim 1 - 10\ \mu m$

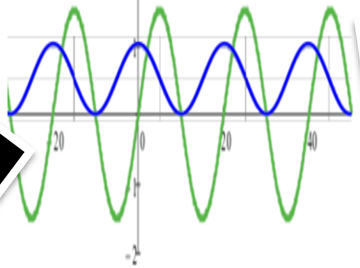
density mod.



LSC

linac

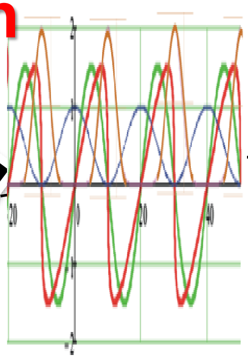
energy mod.



R_{56}, CSR

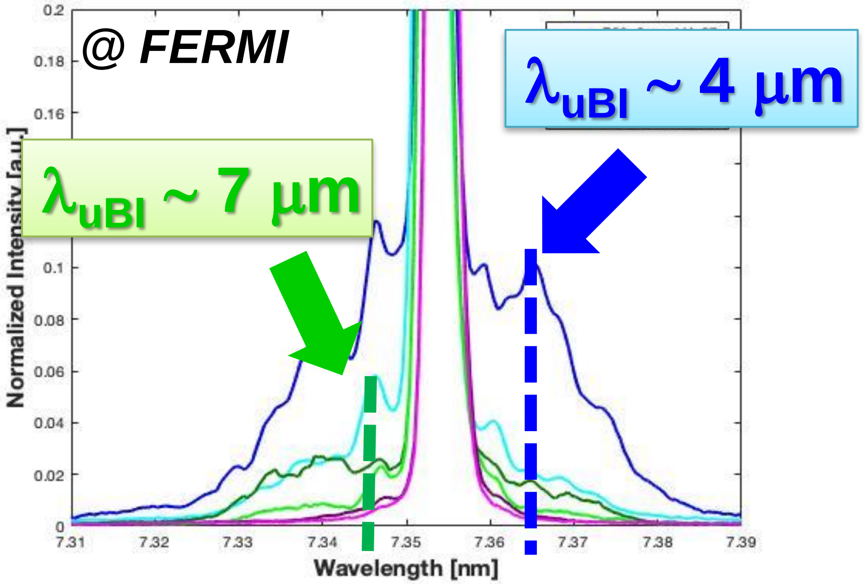
magnetic compressor

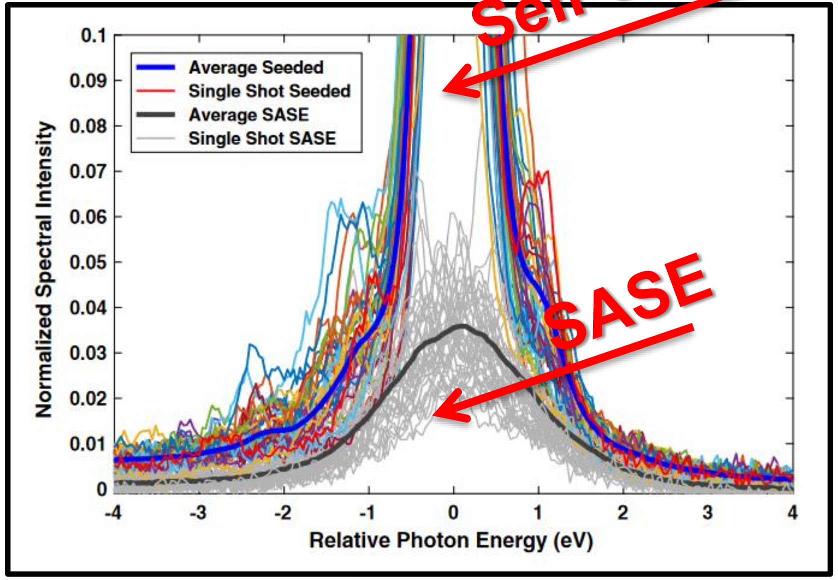
compression & amplification



- ❑ $\sigma_{\delta,slice} > \rho_{FEL}$,
  Lower FEL intensity
- ❑ $\lambda_{MBI} \approx \lambda_{coh}$,
  Larger FEL bandwidth

$k_{FEL} = h k_{seed} \pm m k_{ubi}$





G. Marcus et al., PRAB 22 (2019)

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A solution

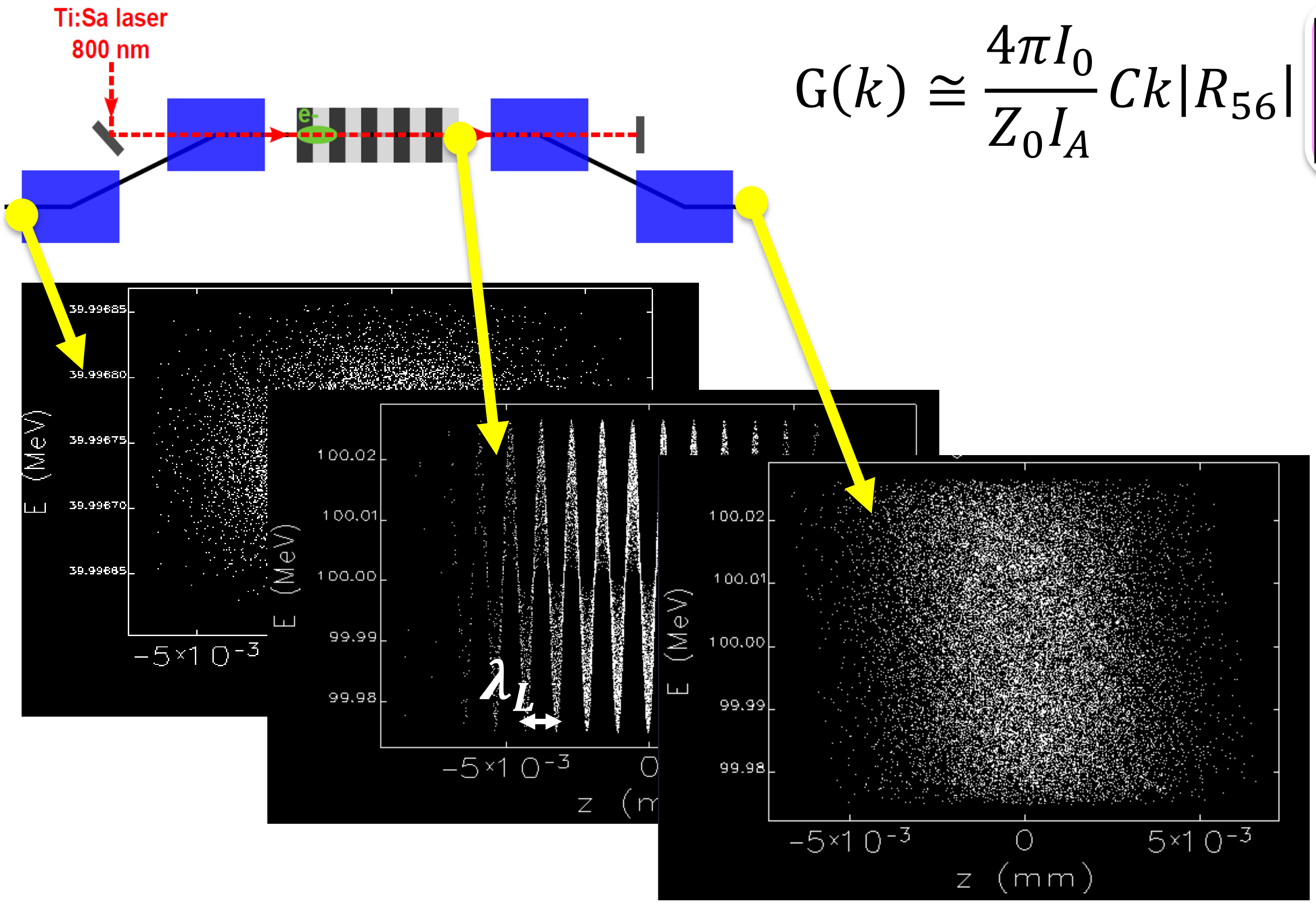
Compact

A tool to increase the initial beam uncorrelated energy spread, σ_δ

Gain = amplification of modulations

$$G(k) \cong \frac{4\pi I_0}{Z_0 I_A} C k |R_{56}| \left| \int d\,s \frac{Z_{LSC}(k;s)}{\gamma(s)} \right| exp\left[-\frac{1}{2}(C k R_{56} \sigma_\delta)^2\right]$$

amplification **damping**



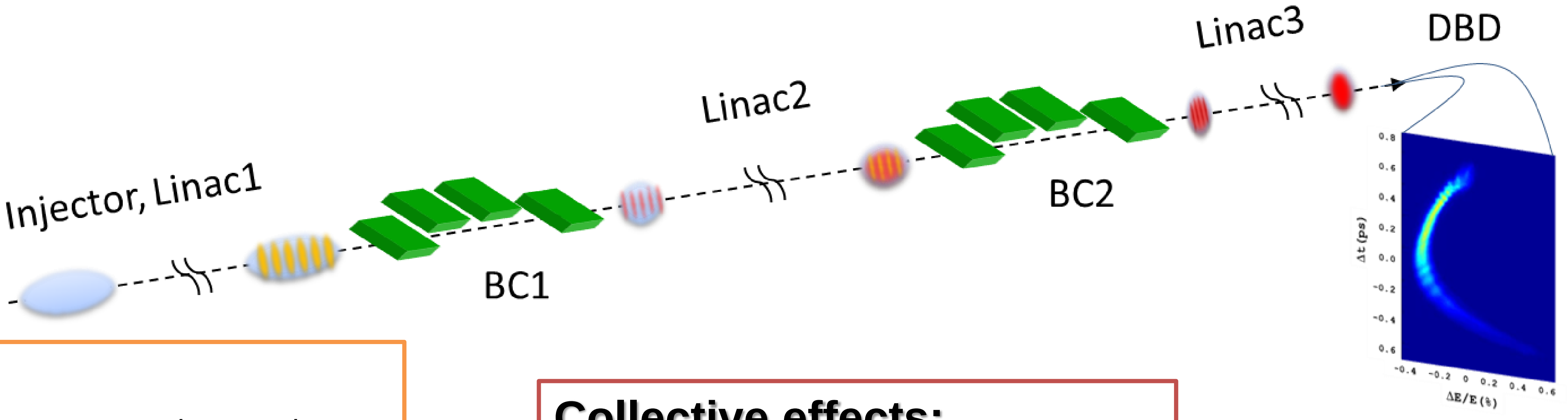
Why in a chicane ?

- To wash out the laser modulation,

$$|R_{52}|\sigma_{x'} \gg \lambda_L/2\pi$$

- For laser injection collinear to the e-beam, and extraction.

Modelling the microbunching instability



Input:

- beam parameters at ~100 MeV;
- initial SES from tracking runs (2 keV @ 75 pC);
- Linac gradients;
- Compression factors (bunch core);
- Emittance and average betatron functions.

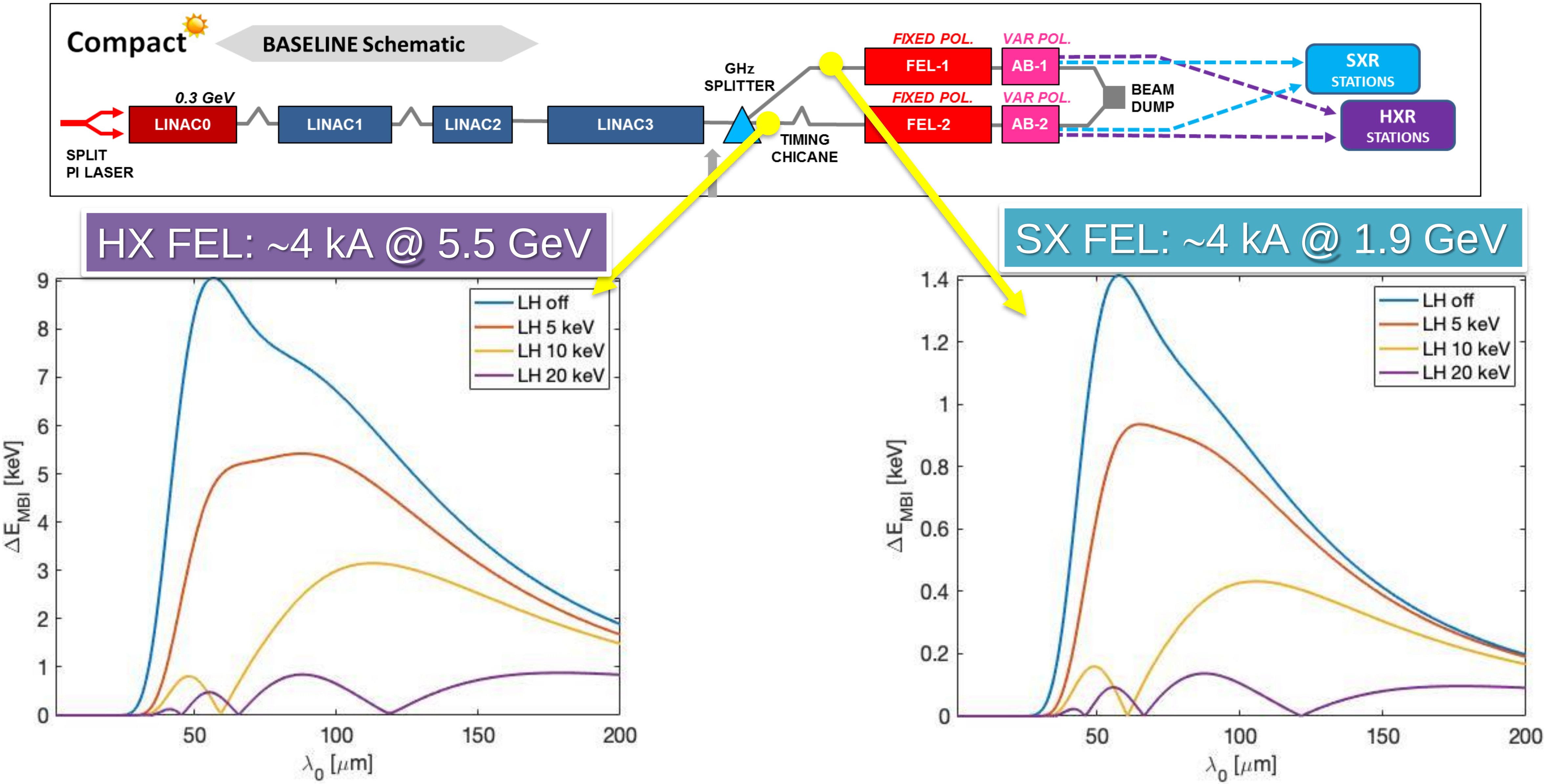
Collective effects:

- 1.5-D LSC and CSR impedance;
- 2-D laser heater;
- Intrabeam scattering;
- transverse and longitudinal Landau damping.

Output:

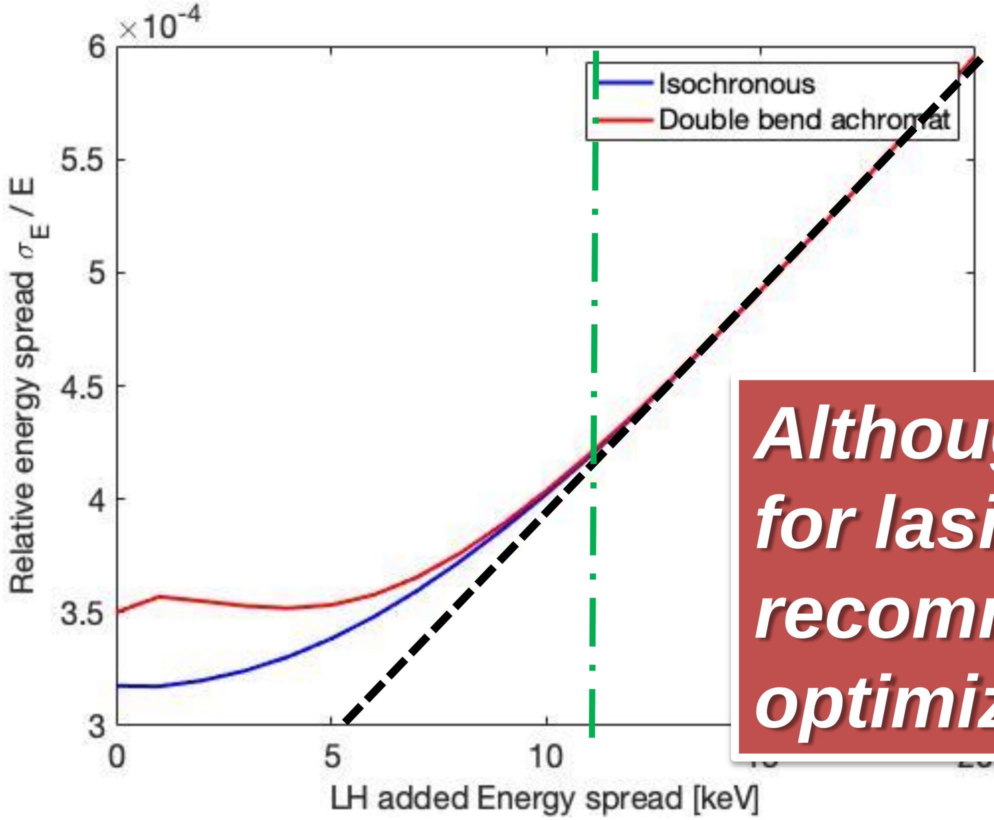
- spectral gain;
- energy modulation;
- SES (equivalent)

Do we really need a LH ?

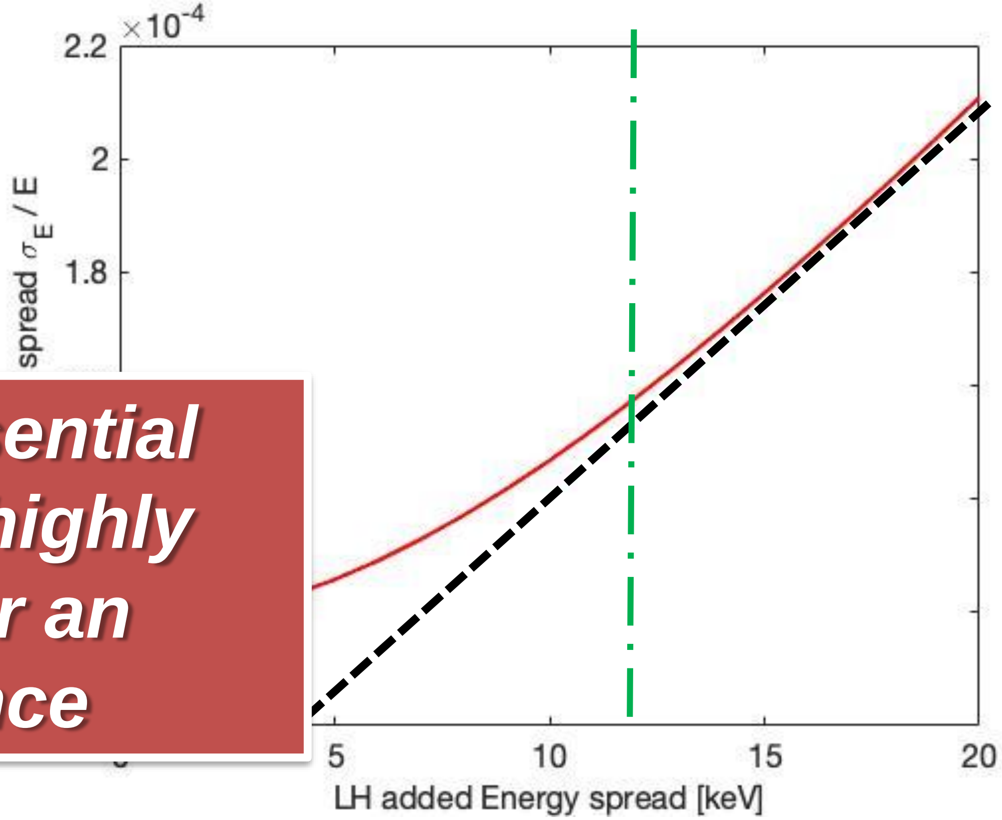


A closer look to the energy spread

SX FEL: SES vs. LH at the spreader end



HX FEL: SES vs. LH at the linac end



Although not essential for lasing, LH is highly recommended for an optimized brilliance

The linear trend (**---**) corresponds to MBI fully damped.
Deviation from it (**-.-.-**) sets the minimum LH level for damping.

Guidelines to LH design

Beam energy:

- at as *low energy* as possible since damping ~ $\Delta E_{LH}/E_0$ (< 200 MeV or so)
- better control if *out of* the beam space charge regime (> 80 MeV or so)

Laser:

- short lambda for more efficient smearing of the laser modulation (1 or 0.5 micron)
- must tolerate 1 kHz rep. rate (expected ~10 mW average power)

Chicane:

- bending angle is a compromise between length, laser injection, smearing and CSR-induced emittance growth (typically < 6 deg)
- Should include 2 view screens and 2 BPMs

Undulator:

- undulator period has to match the beam energy (typically, few cm)
- the number of periods is a compromise between max. heating and coupling to the laser bandwidth (~10 periods are usually enough)

Design – educated assumptions

Educated assumption: **N_{und}=8, B_{und} = 0.4 T**
(depends on gap and period length)

On the shelf: **Yb laser** @ 1064 nm. Spill **2nd harmonic** from the PIL

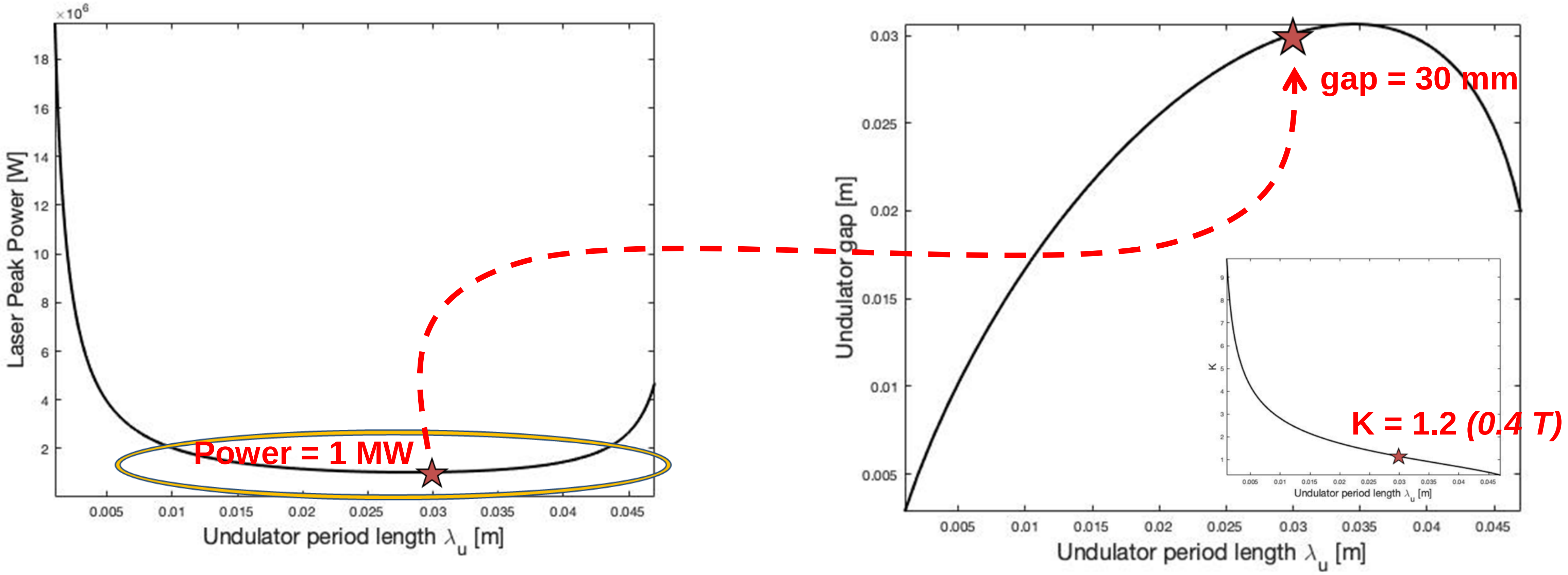
From instability model:
$\sigma_{E,LH} \leq$ 30 keV
(larger values from higher laser energies)

From simulations:
$\sigma^{e}_{x,y}$ = 70 μm, E=110 MeV @ und
(still ok up to 130 μm, 150 MeV)

Design – optimization

- With assumptions in the previous slide, the laser power only depends on the undulator period:

$$P_L(\lambda_u) = 2P_0\left(\frac{\gamma\sigma_E\sigma_{wl}}{K(\lambda_u)[JJ(\lambda_u)]N_u\lambda_u I_x(\lambda_u)I_y(\lambda_u)}\right)^2$$



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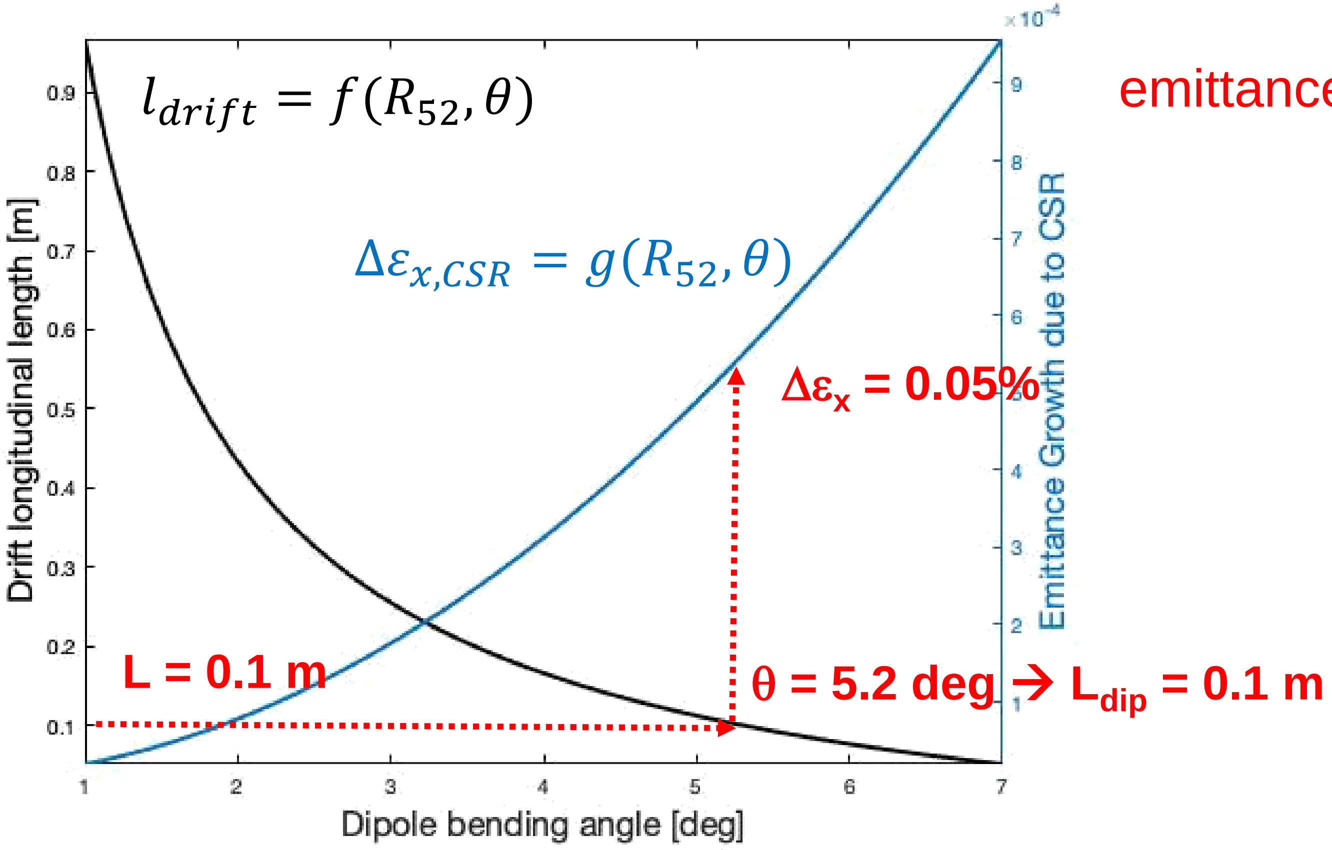
Design – chicane

Compact

For large smearing of the laser modulation, we impose: $R_{52} \approx 3 \times \frac{\lambda_{\text{laser}}}{2\pi\sigma'_x} \approx 18$ mm.

$$\frac{\Delta\epsilon_x}{\epsilon_x} \simeq \frac{1}{2}\left(\frac{R_{52}\sigma_E}{\sigma_x E}\right)^2 < 0.3\%$$

emittance growth from laser interaction in a dispersive region



emittance growth CSR in a chicane

- ***Total LH length including diagnostics is ≤ 1.5 m***
- ***Does not need dedicated matching quads***
- ***At least 30 keV added***

Conclusions

1. Microbunching instability in CompactLight is not expected to be a show stopper.

2. A laser heater is highly recommended to maximize the FEL brilliance, especially for seeded schemes.

3. Tens' of keV energy spread at 1 kHz are guaranteed in a 1.5 m-long insertion.

Thank you for Your kind attention – questions are very welcome