BESSY

Berliner Elektronenspeicherring-Gesellschaft
für Synchrotronstrahlung m.b.H.

Experiences with Start to End Simulations and Tolerance Studies for HGHG FEL Cascades

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Leibniz
Gemeinschaft

Outline of the talk

3 simulation examples:

- Bunches of S2E simulations
- Tolerance studies (errors in gun/linac)
- Timing jitter (resulting from above)

Discussion:

- Performance reduction
- Counter measures
- Influence on the layout of HGHG FEL cascades

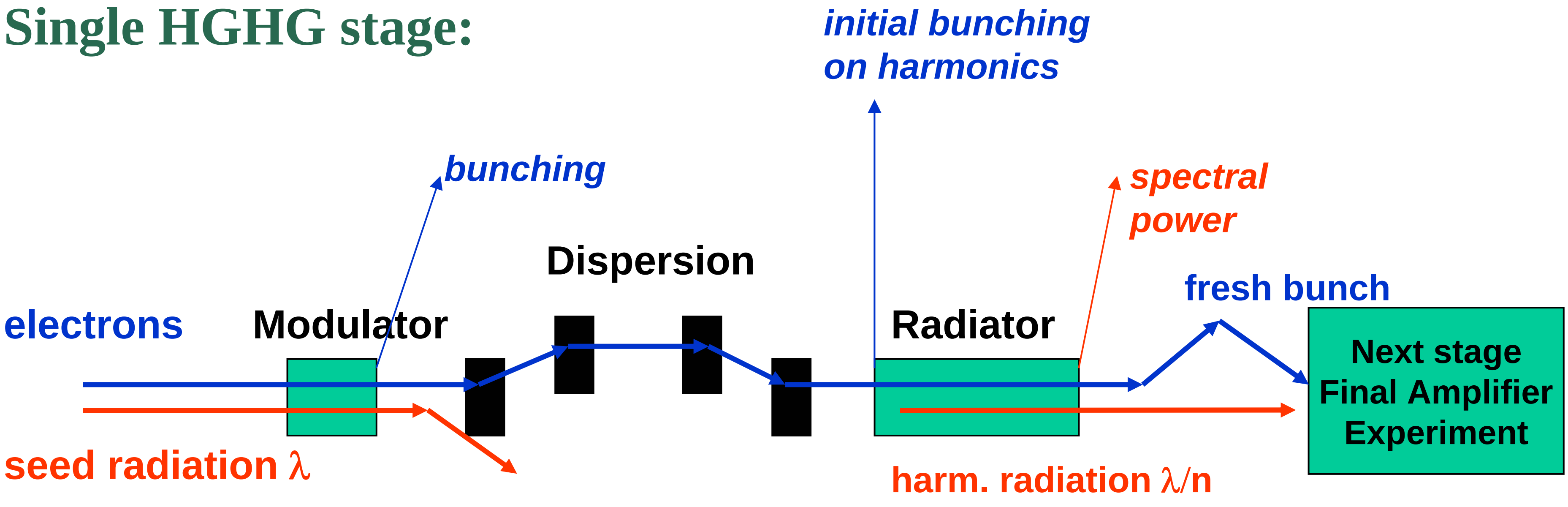
Computational Effort

S2E simulations:

Gun Simulation: Astra	**25000-100000 particles** **3-10 hours of CPU (no. particles/length)**
Linac Simulation: Elegant	**1-2*10^5 particles** **2-6 hours of CPU (no. particles/CSR)**
FEL Simulation: Genesis	**few 10^2 particles/wavelength** **cascading: harmonics used*10^2 particles** **3-4 min / 1000 slices / U-period** **many (!) hours of CPU**

=> Full passage easily takes days
=> Tolerance studies multiply the effort by the number of runs studied

Single HGHG stage:



Modulator:
energy modulation of electrons
resonant to seed wavelength
short undulator (0.5-3m)

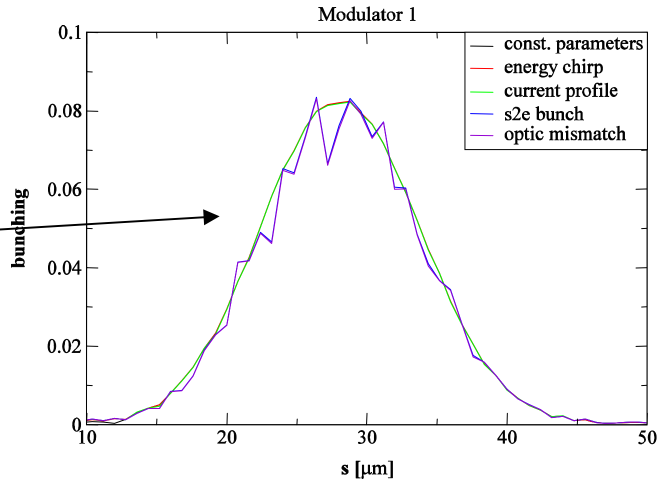
Dispersion:
boost harmonic bunching
4 equal dipoles

Radiator:
harmonic radiation
tuned to harmonics of seed
length 3-20m (enough seed power /
no e-spread in fresh bunch)

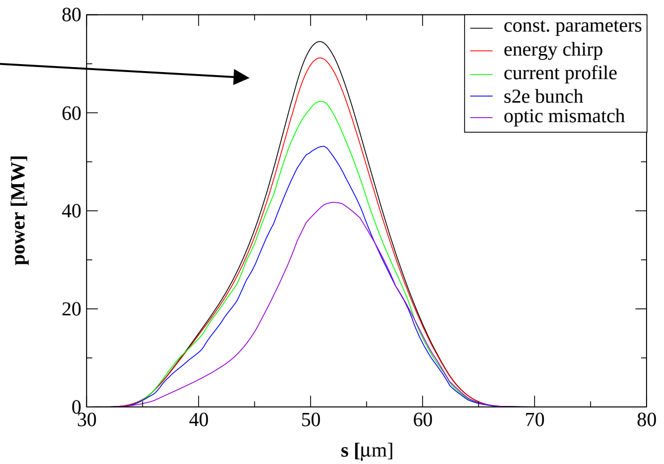
1. Example: Bunches from S2E simulations <=> constant bunch parameters

Single HGHG stage:
- 280 MeV, 200 A

Modulator:
- bunching less smooth for s2e bunch (energy spread)
- no effect for γ-chirp, current

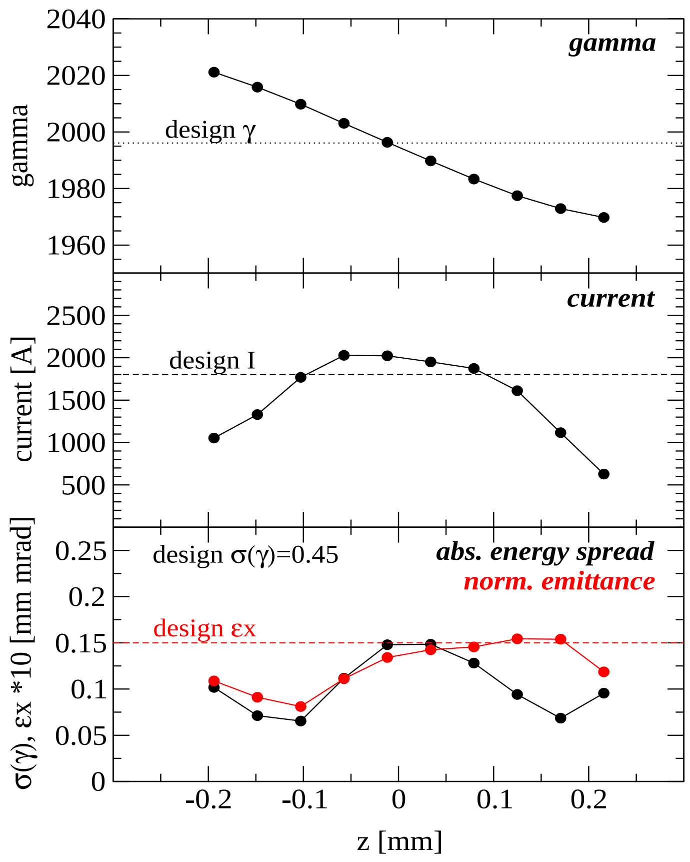


Radiator:
- power loss for every non-constant parameter



Colour code:
- ***bunch with constant parameters***
- ***incl. energy chirp $\Delta\gamma/\gamma$ = 1e-3/100fs***
- ***incl. current profile***
- ***complete s2e bunch***
- ***optics mismatch***

Parameter Profiles in s2e bunches and how to cope with them (BESSY Linac)



Energy Chirp:
- needed for bunch compression
- different γ in each HGHG stage ($\Delta\gamma$ = 0.2%)
- violation of resonance condition

=> use variable gap undulator (< 1% in K)

Current:
- profile created by cathode laser
- determines seeding power for next stage

=> dispersion tuning to adjust bunching

Emittance / Beam Size:
- depend on space charge effects in gun
- mismatch reduces coupling
- quadrupole doublets after each stage
- adjustment of the bunch part used in the next stage

Energy Spread:
- changes modulation depth
- dispersion tuning to adjust bunching

⇒S2E simulations necessary in HGHG cascades to predict local bunch parameters

⇒big effect on the radiator output power

⇒tunable hardware necessary to adjust to varying bunch properties

2. Example: Tolerance Studies

BESSY LE-FEL:

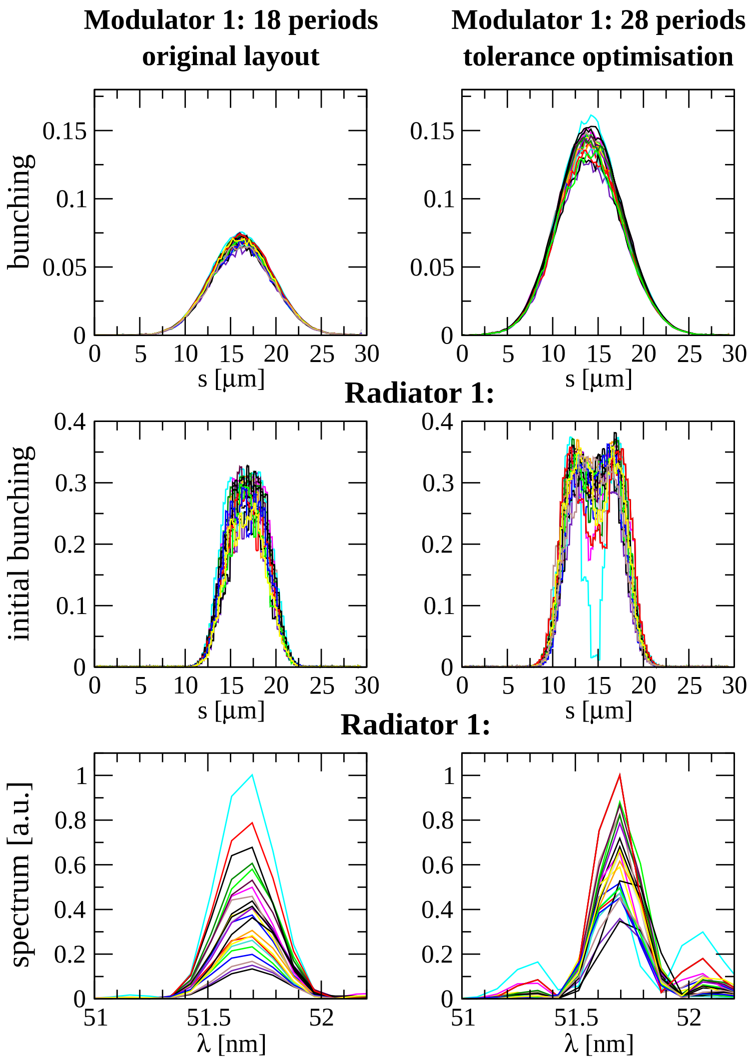
- only first stage
- 1.0 GeV, 2 KA
- 24 s2e bunches
- gun and linac errors

Layout for s2e bunch, no errors:

- 18 period modulator
- 8% bunching @ 258 nm
- ~30% bunching @ 51.5 nm
- spectral power max/min = 10

Modified Layout:

- 28 period modulator
- 15% bunching @ 258 nm
- 30% bunching @ 51.5 nm
- spectral power max/min = 3



=> Tolerance studies directly influence hardware layout

=> Longer devices to make up for reduced coupling of imperfect bunches to radiation

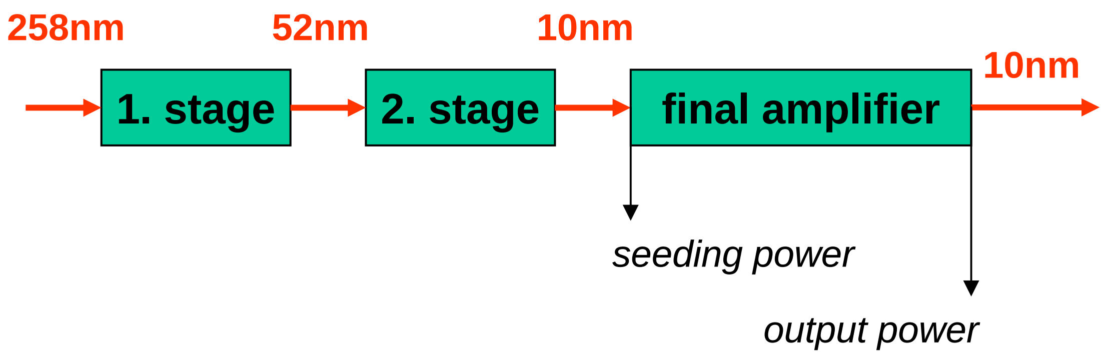
3. Example: Timing jitter – 75 fs rms in BESSY FEL

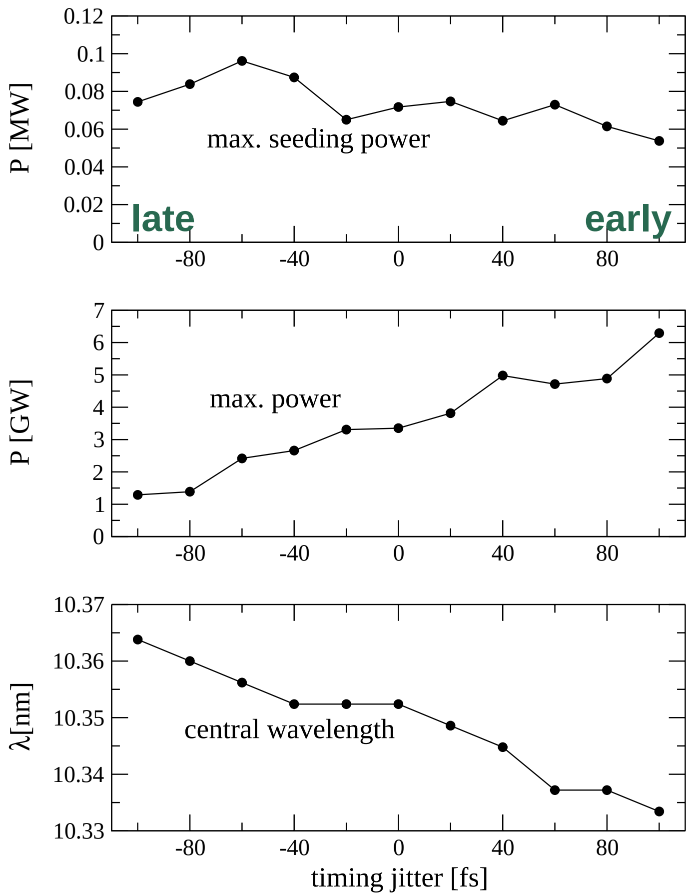
Seeding radiation will interact with different bunch parts

Energy chirp:

earlier arrival ⇔
higher average energy ⇔
lower resonant wavelength

late arrival ⇔
lower average energy ⇔
higher resonant wavelength





Seeding power, output power and central wavelength of the final amplifier as a function of the arrival time

Final amplifier Bessy LE-FEL

- S2E bunch (no errors)
- ontime seed
- simulate different arrival time

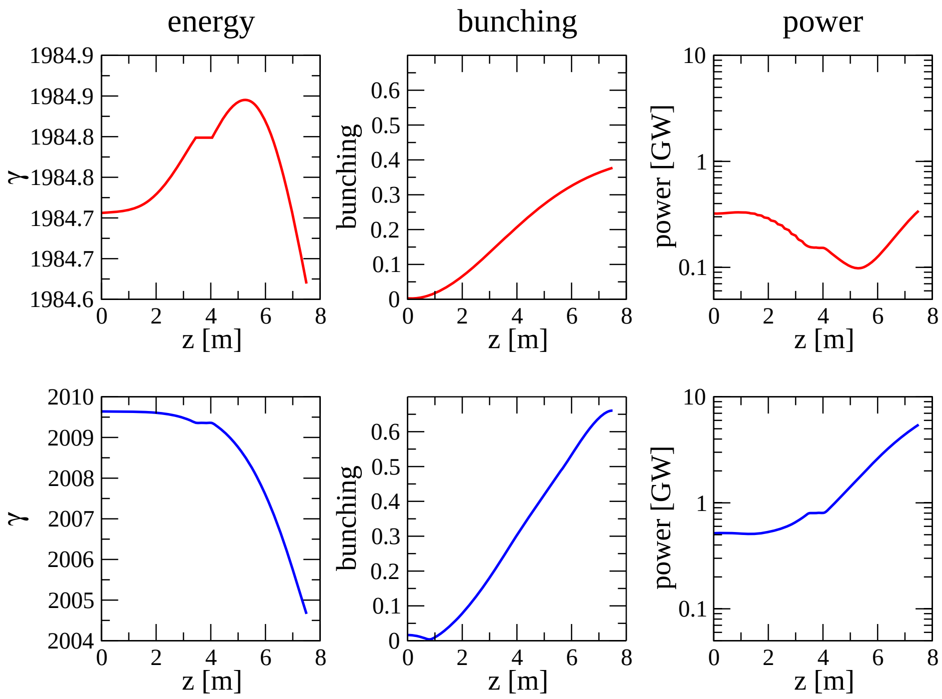
=> asymetric behaviour

For earlier arrivals:

- seeding power decreases
- output power grows
- shorter central wavelength

Development of average slice parameters in the final amplifier

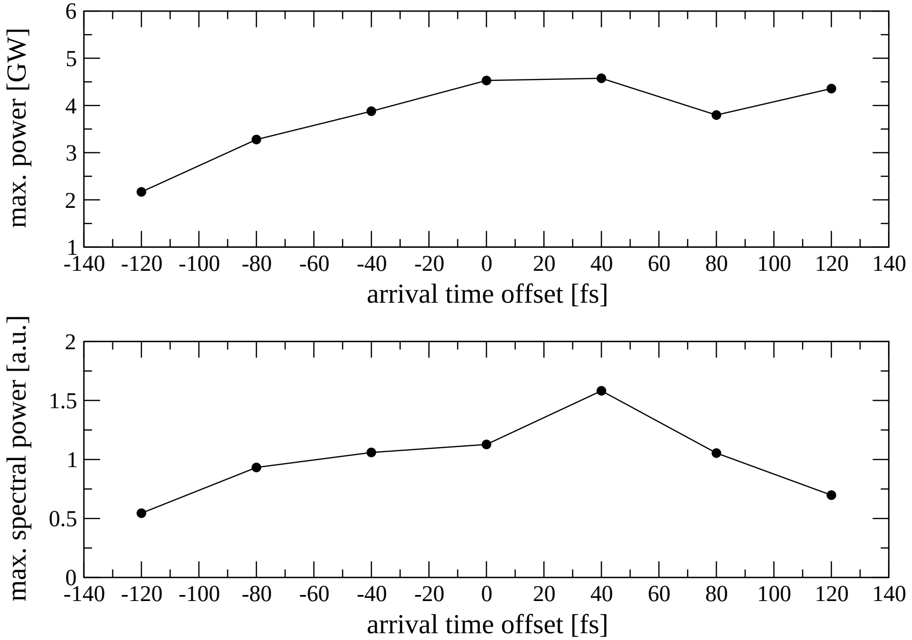
- **identical slice position, +140 fs and - 140 fs**
- **different electron properties**
- **seeding radiation emitted by bunch part ahead**



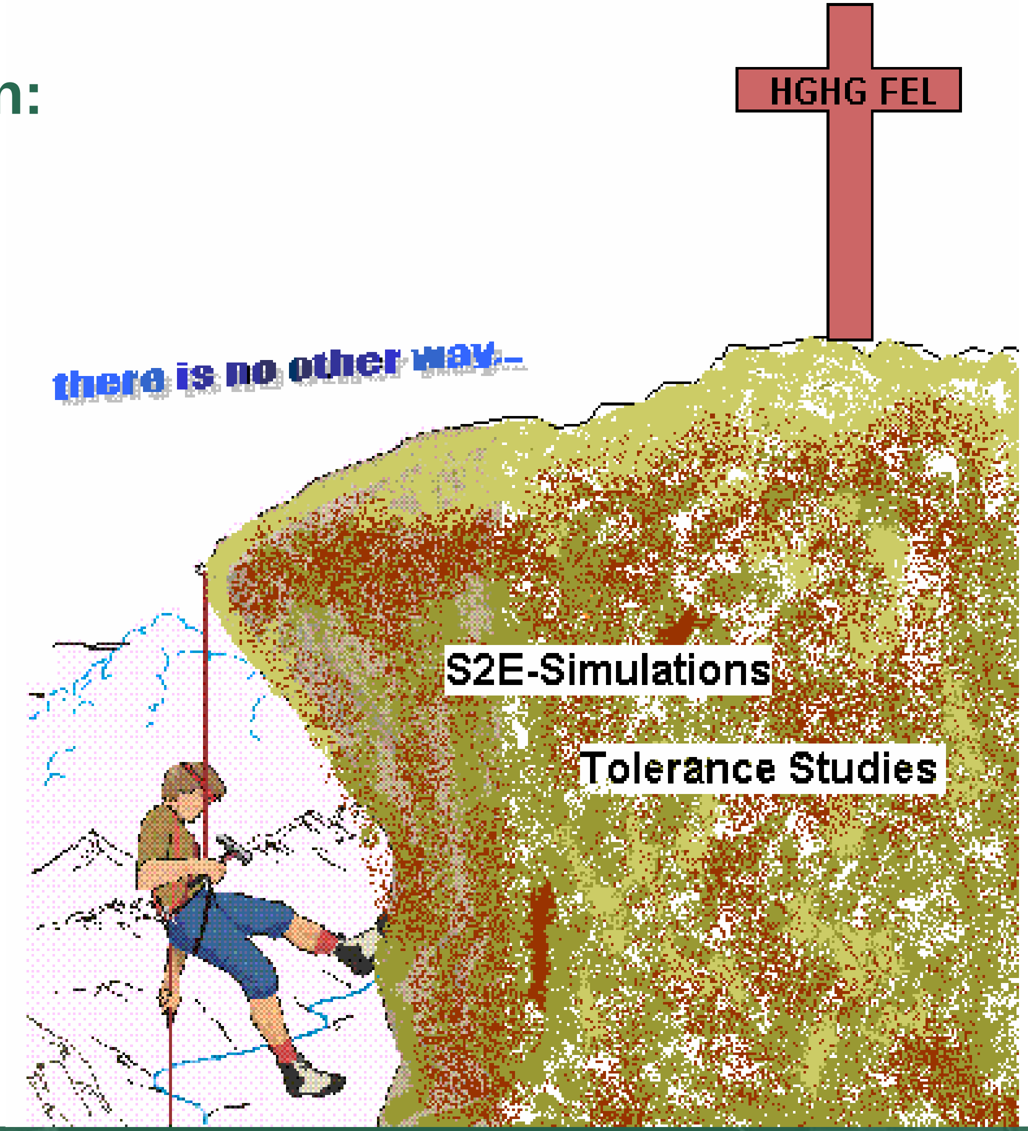
late arrival ⇔
lower than resonant energy ⇔
energy absorbtion ⇔
lower output power

early arrival ⇔
higher than resonant energy ⇔
energy emission ⇔
higher output power

⇒ **Power variation due to timing jitter can be reduced**
⇒ **FA: higher than nominal energy profitable**
⇒ **equivilant to reducing the K-value**



Conclusion:



HGHG FEL
there is no other way...
S2E-Simulations
Tolerance Studies