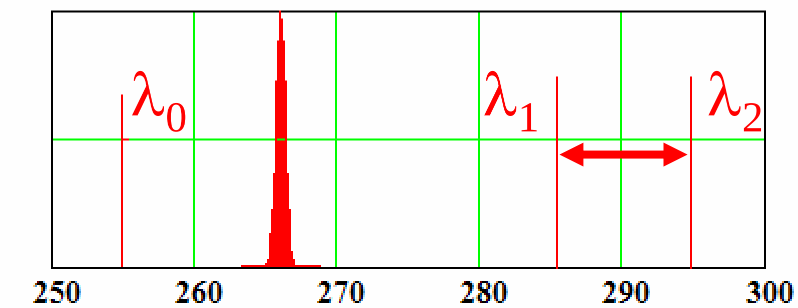
HGHG with variable wavelength

Timur Shaftan
for DUVFEL team



DUV FEL team

E. Johnson, S. Krinsky, H. Loos,
J.B. Murphy, G. Rakowsky, J. Rose,
T. Shaftan, B. Sheehy, J. Skaritka,
X.J. Wang, Z.Wu, L.H. Yu,

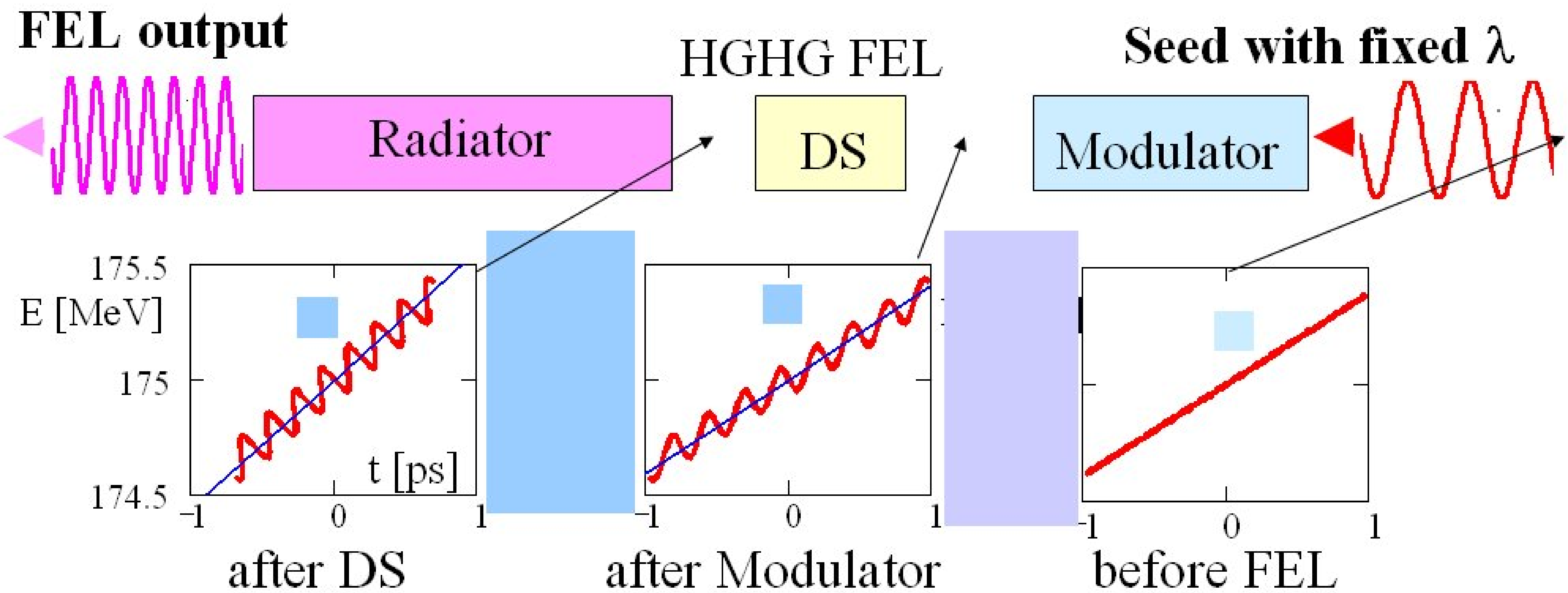
NSLS, BNL, Upton, NY 11973, USA

Motivation

- As in any seeded scheme, in HGHG the central wavelength is predetermined by a seed laser
- Seed laser must be tunable (8 % for Ti:Sa, 10 % for GaAs diode-pumped, ~35 % using OPA)
- In general, tuning wavelength of the seed is time- and effort-consuming procedure
- If the same laser is used as RF-gun driver →

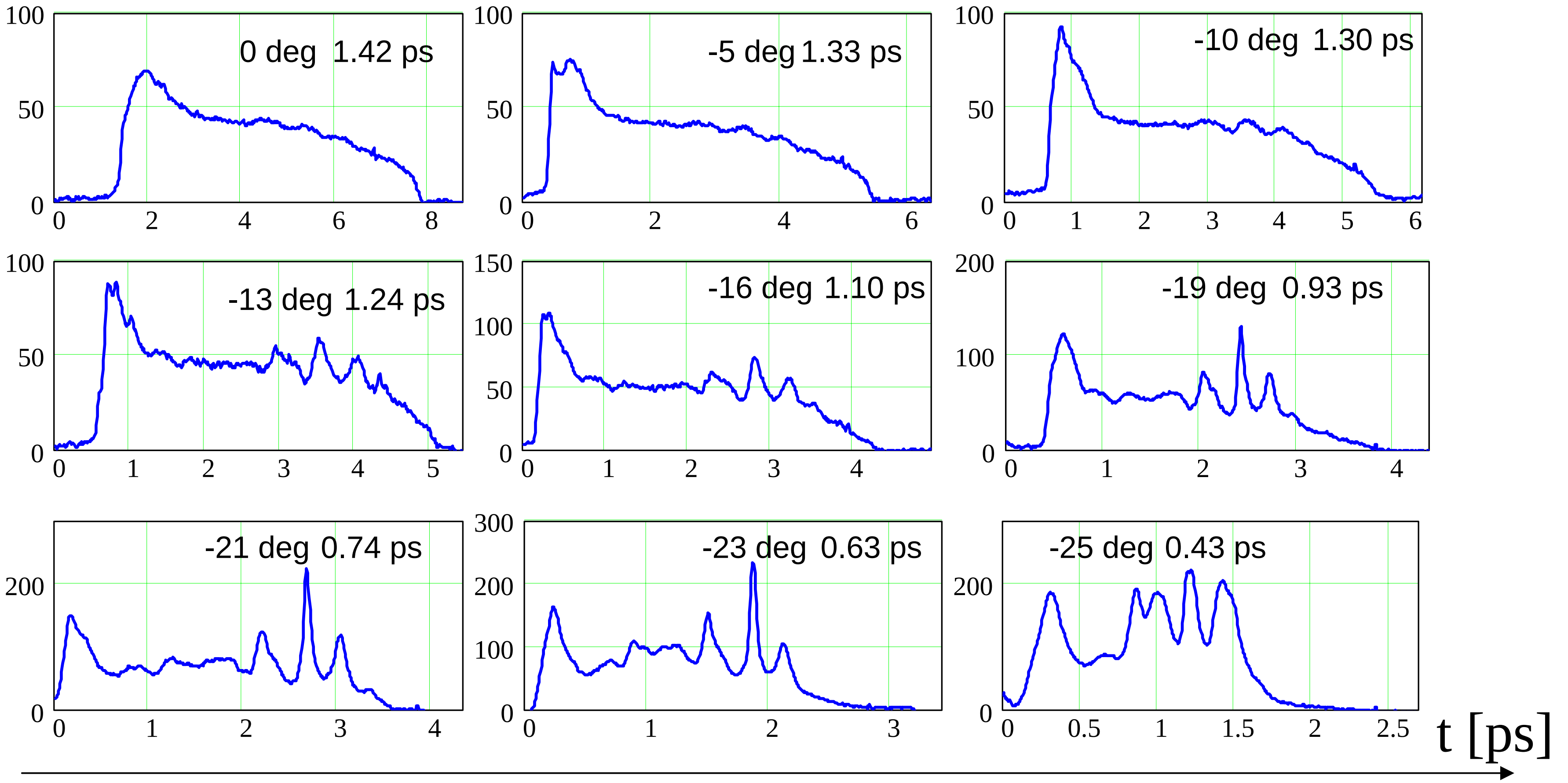
  change in λ => change in ε_{ph} => change in Q.E.
- Electron and seed laser beam must be overlapped in modulator with a high accuracy. Change in λ => change in timing (dispersive optics), change in the laser beam size/traj. (chromatic optics) => misalignment + mismatch
- Etc.

Alternative method



- Compression in DS using initially chirped beam
- DS does conversion of energy modulation (EM) into bunching
- DS does compression of EM wavelength
- Using seed laser power we can control EM amplitude

Illustration



Our recent studies of space-charge induced modulation: λ of structure gets compressed with the same bunch compression ratio (~350 %). For FEL we would be happy to have a few %.

DUV-FEL parameters

FEL wavelength, nm	266
Beam energy, MeV	175
Seed laser wavelength, nm	800
Seed laser Raleigh range, m	2.4
Seed laser power, MW	< 30
Seed laser pulse length, ps (FWHM)	6
Modulator length, m	0.8
Modulator period, m	0.08
Electron bunch length, ps (FWHM)	1
Sliced energy spread[1]	$3 \cdot 10^{-5}$

[1] f.e., M. Hüning and H. Schlarb, Proc. of PAC-2003, Portland, p. 2074.

Compression ratio

- Compression ratio: $C = \frac{\sigma_{out}}{\sigma_{in}} \approx 1 - R_{56}h,$ where

$$h = \frac{1}{E}\frac{\partial E}{\partial z}$$ Energy chirp

$$R_{56} = \frac{\gamma}{k_n}\frac{\partial \psi}{\partial \gamma}$$ DS strength, n – harmonic number

- Wavelength tuning range: $\frac{\Delta\lambda}{\lambda} = \frac{\lambda_C - \lambda_0}{\lambda_0} = R_{56} \cdot h,$

- h and R_{56} are functions of γ (and $\gamma_C = \gamma_0 / \sqrt{C}$)

In order to stretch HGHG tuning range one should maximize DS strength and chirp

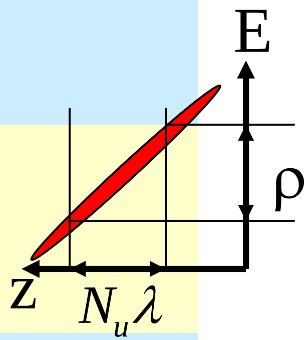
Limitations

- DS strength is limited by sliced energy spread

$$\left(\frac{\partial\psi}{\partial\gamma}\right)_{\max} \approx \frac{1}{\sigma_\gamma}$$

- Chirp is limited by resonance condition $h_{\max} < \frac{\rho_{FEL}}{N_u\lambda}$

  $N_u\lambda$ - slippage length in the radiator



- Large *h* →Broadening of FEL output $\frac{\Delta\lambda}{\lambda} \approx 2h\sigma_z,$

  σ_z – bunch length

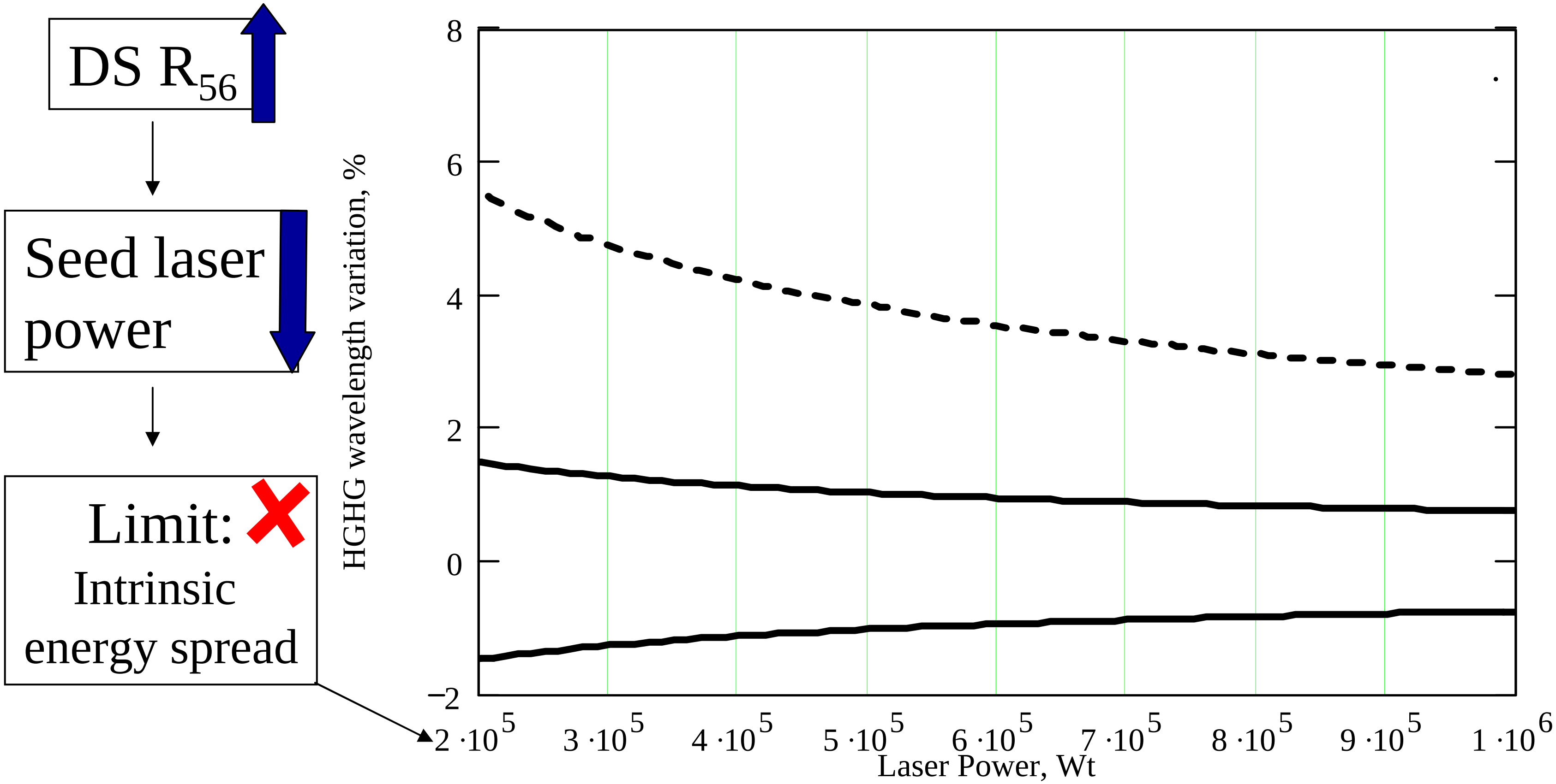
- Large *h* → large projected energy spread → problems with beam transport
- Large *h* requires RF system to provide more than nominal value of energy
- Modulator bandwidth for large compression ratio

Dispersive section

- DS strength $$R_{56} \approx \frac{4}{3}\frac{B_0^2 d^3}{(B\rho)^2}$$
- Present max DS strength R_{56}=0.35 mm or $\frac{\partial \psi}{\partial \gamma} = 23$
- OK-4 DS from Duke University, max R_{56}=3.9 mm

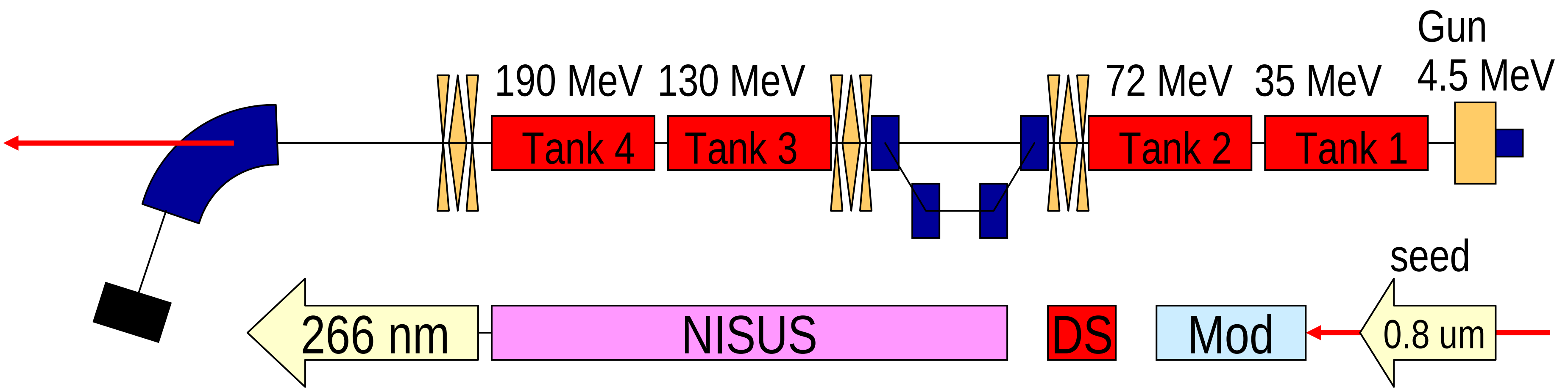
OK-4 Dispersive section (built at Budker Institute of nuclear physics, Novosibirsk)

Wavelength tuning range

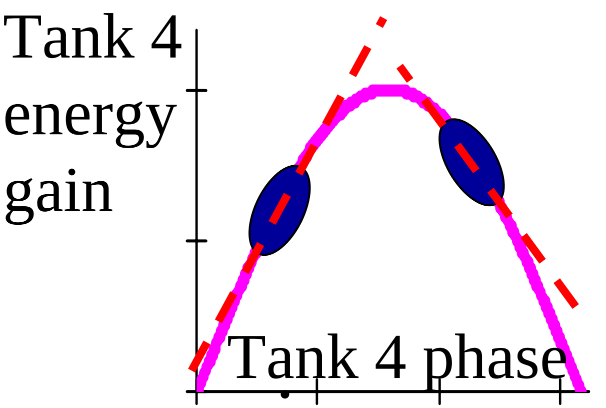


- Currently tuning range (weak DS): ~1%
- OK-4 DS: tuning range is constrained by s.e.s. and RF → ~3%
- OK4 DS+Maximum chirp (#2 on slide 8) → ±5%

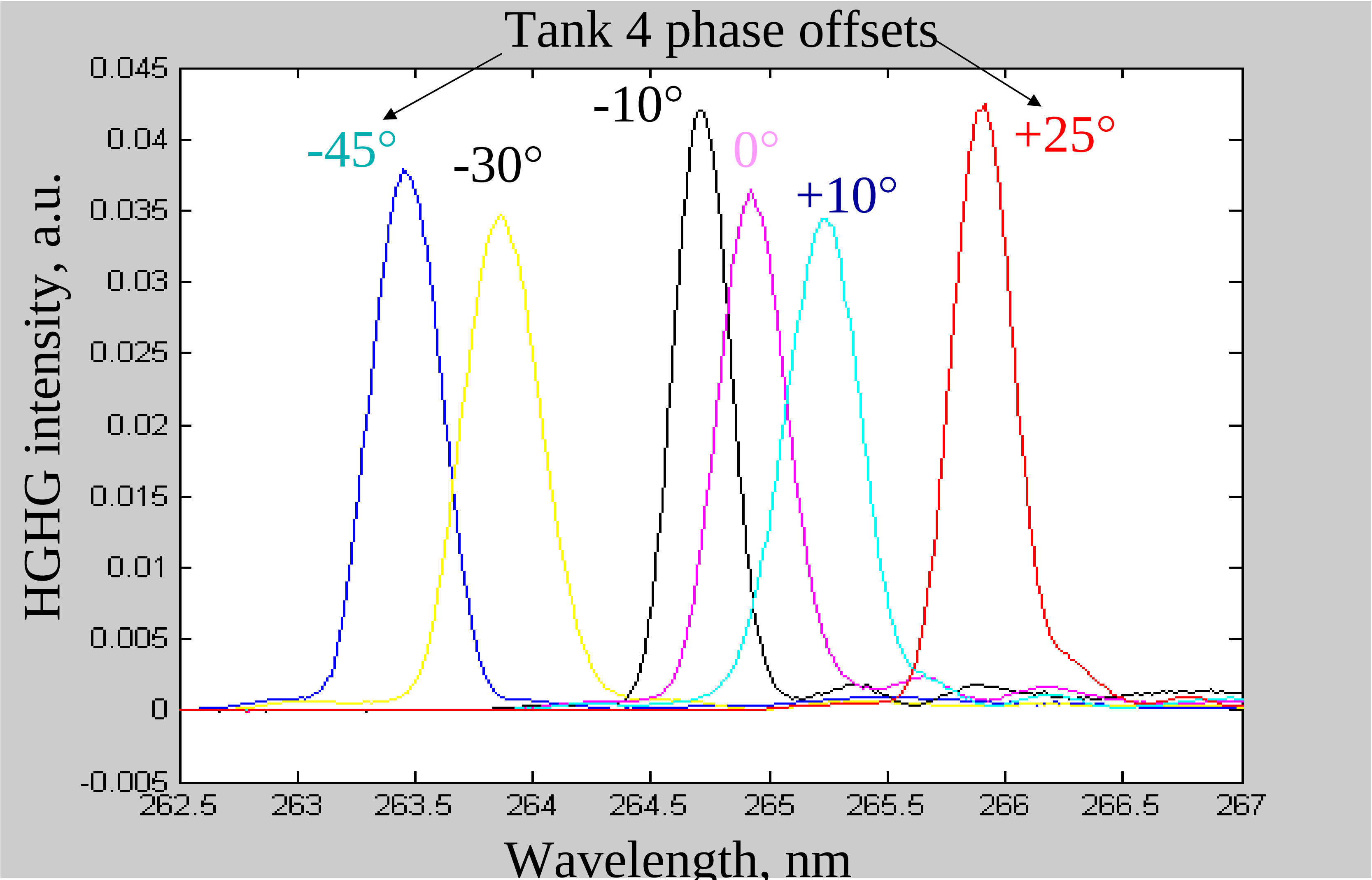
Experiment



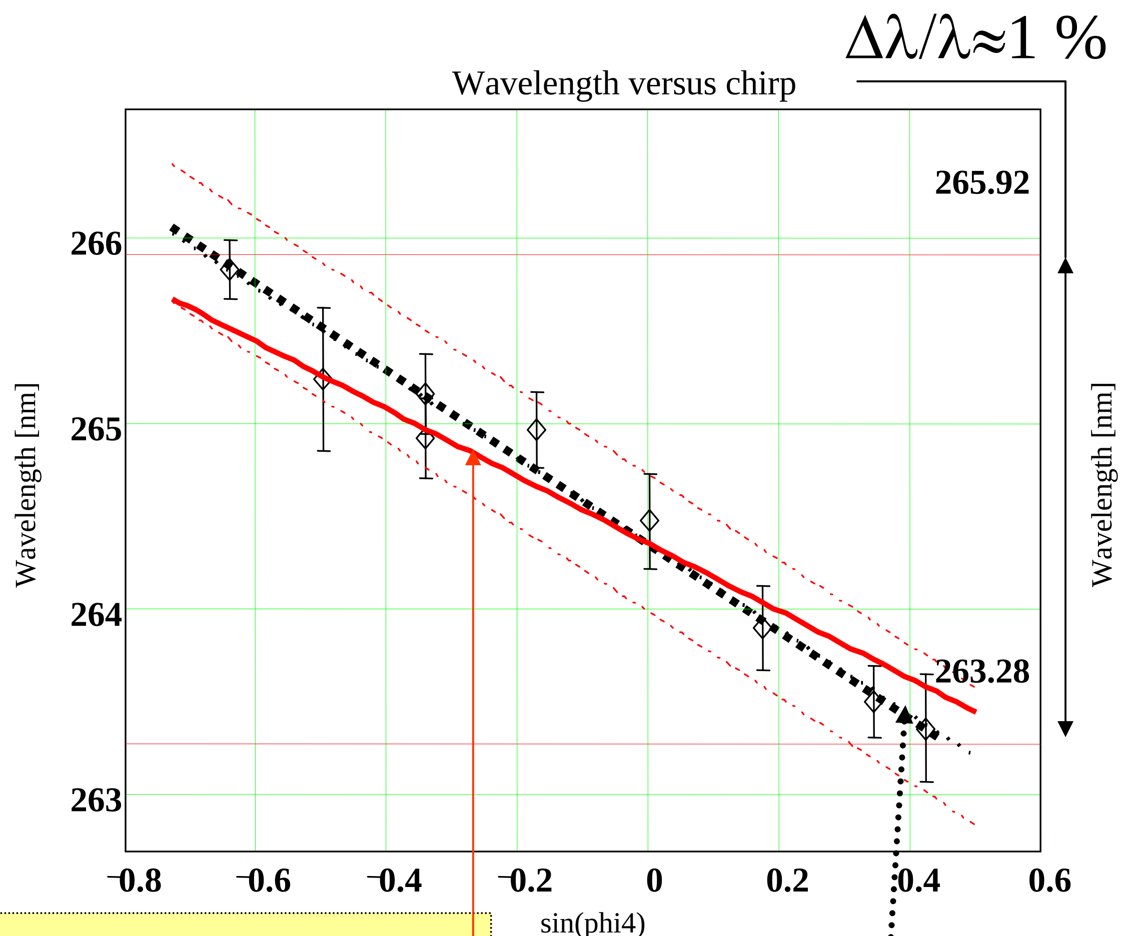
- Chirp is provided by shifting beam off-crest in tank 4 (E_{max} = 58 MeV)
- Tank 4 phase shift: from +25° to -45°
- DS is set to maximum current (200 A)
- Nothing else was changed !
- Spectrum of HGHG is measured for different amounts of chirp

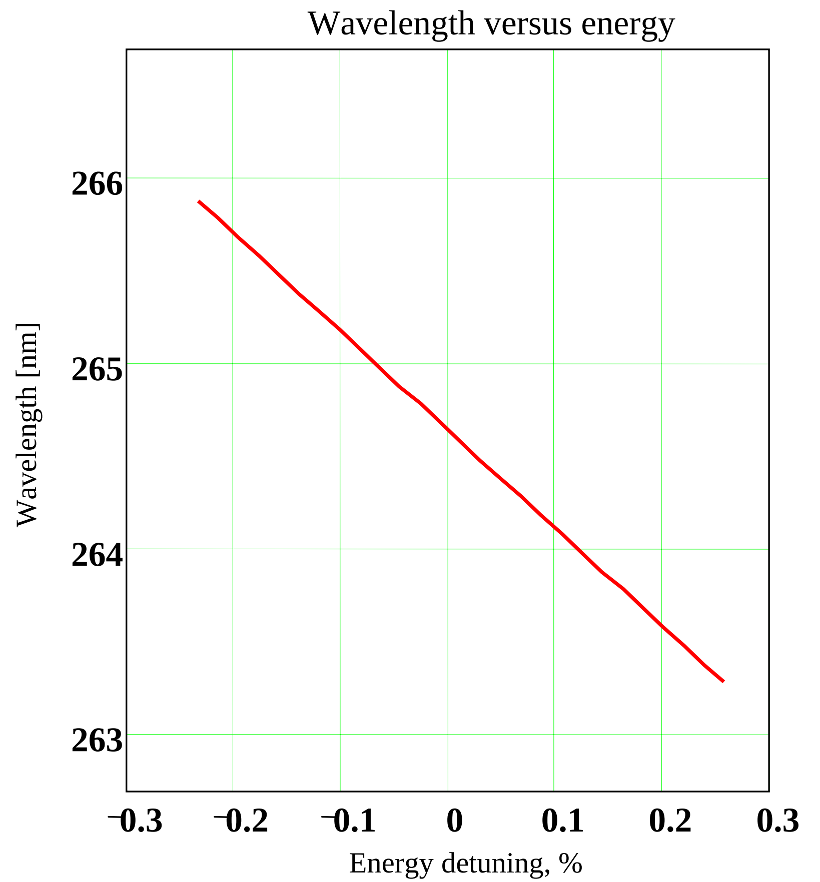


Measured single-shot spectra versus chirp
(B. Sheehy)



Measured tuning range



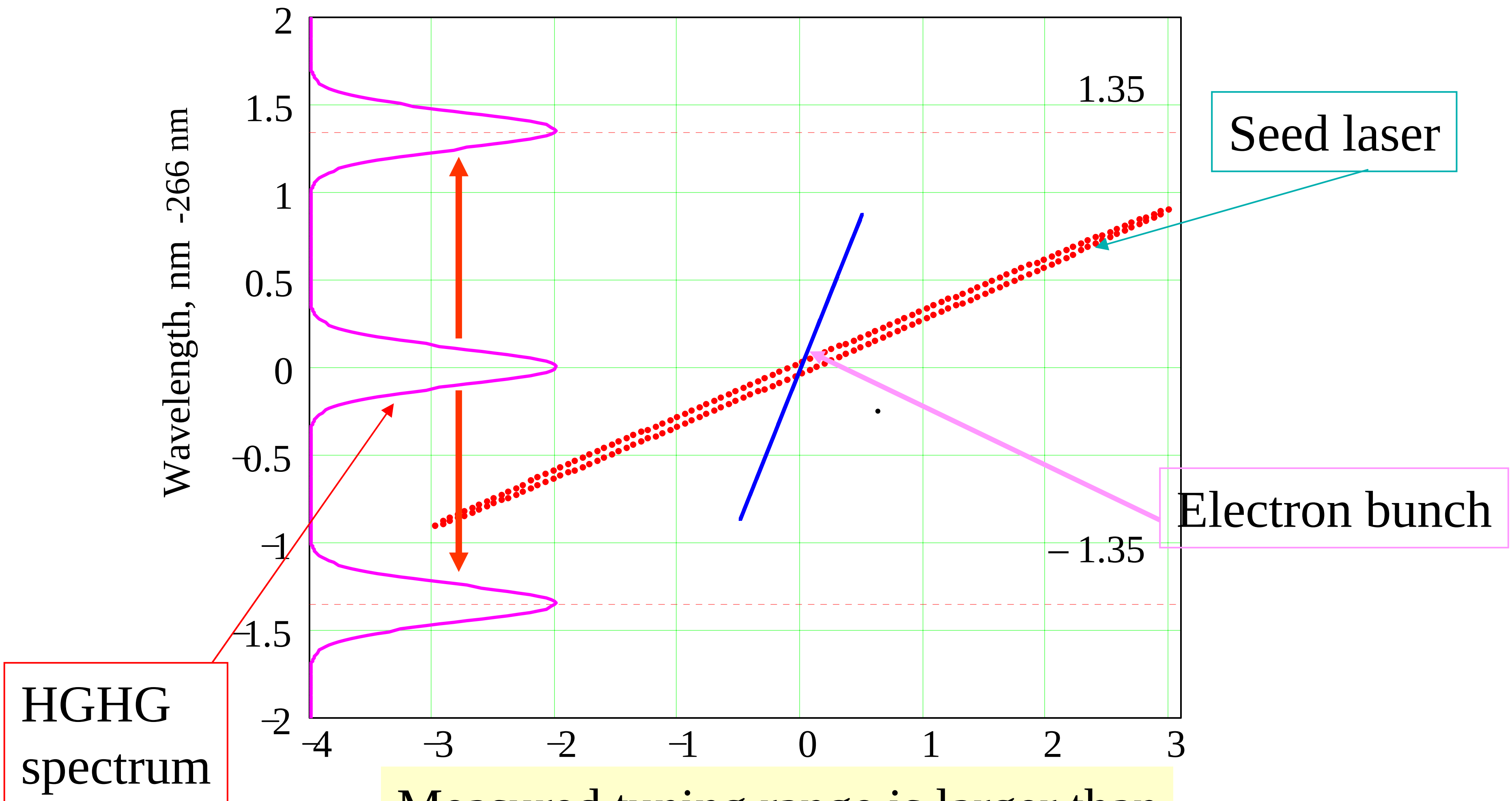


Fit, based on R_{56}(DS)=0.34 mm

Fit including R_{56} of DS and radiator

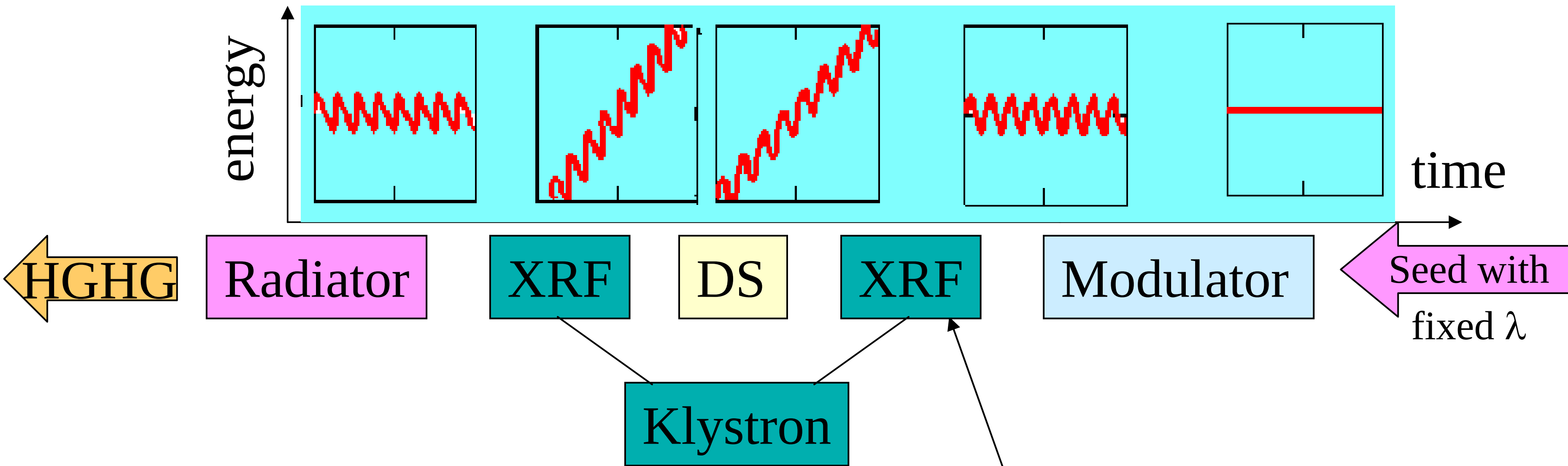
Additional compression in the radiator

Electron and seed laser beams in phase space



Measured tuning range is larger than the seed laser bandwidth

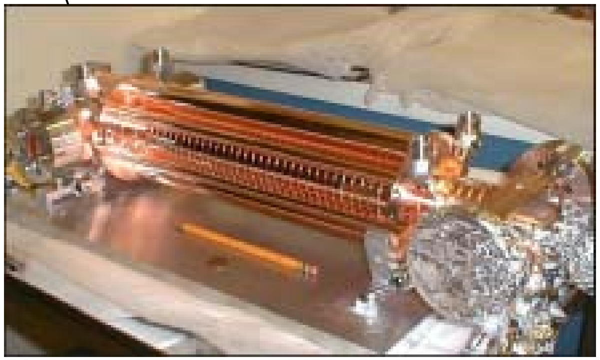
Optimized scheme



- Short and high-frequency RF
- Chirp is provided only locally →

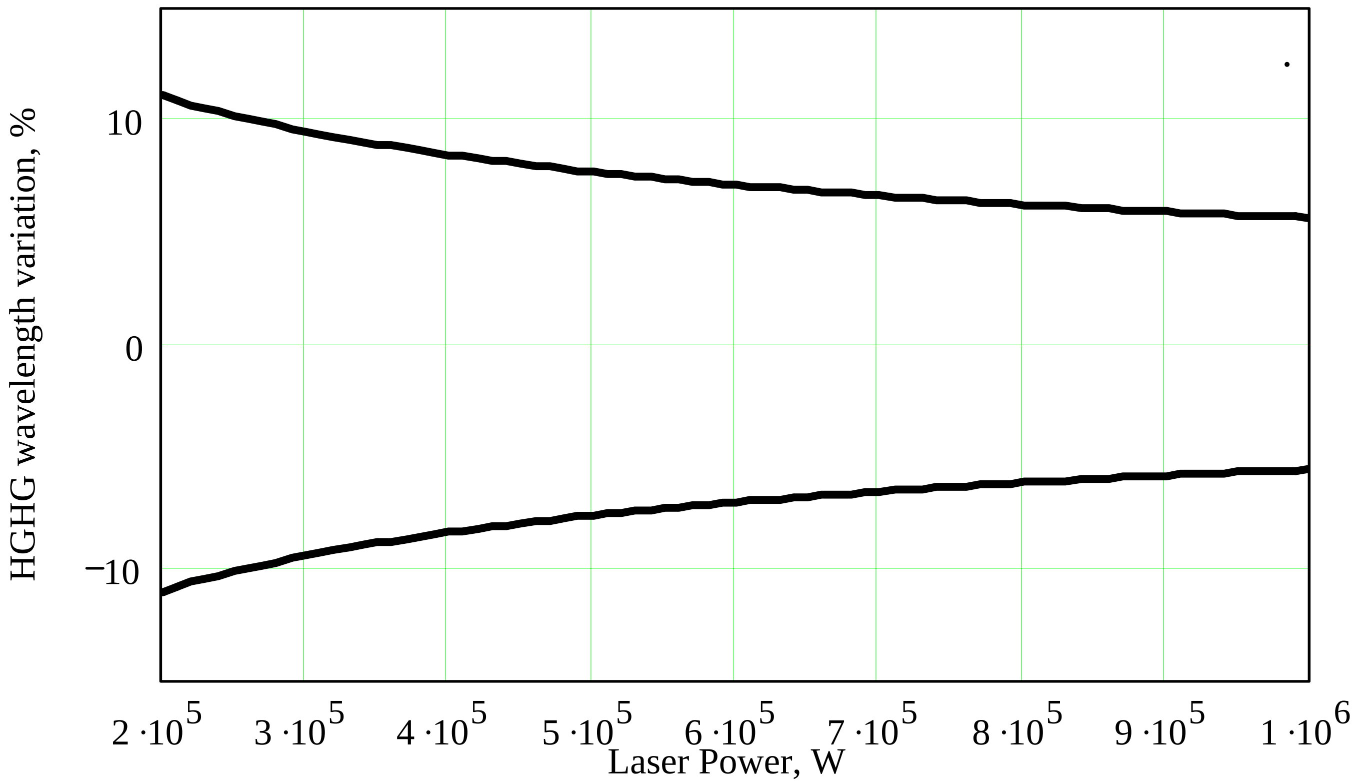
→Most limitations due to chirp are gone

- XRF amplitude jitter → jitter in λ: Assuming realistic jitter of ~10^{-4} → jitter in λ is: $\Delta\lambda/\lambda = hR_{56}\ 10^{-4} = 10^{-5}$



Example: SLAC X-band RF section
11.4 GHz, 50-100 MeV/m, 0.5 m
or CLIC RF: 30 GHz

Wavelength tuning range



- Assuming energy gain of 60 MeV at 11.4 GHz → tuning range is ±10% for positive and negative chirps

Conclusions

- Alternative method of tunable HGHG
- Experiment data are in a good agreement with expectations
- Dedicated scheme can provide tuneability of ~20%

- If we utilize different harmonics (3rd, 4th) we can cover a large spectral range: 3rd =266 nm, 4th =200 nm → $\Delta = 25\%$. Use this method around each harmonic.
- Even if tuning range is not sufficient: coarse shift of $\lambda_{\text{seed laser}}$ and then use this method to adjust λ_{HGHG} with high accuracy (better than HGHG bandwidth)