Case 3

Soft X-ray HGHG FEL

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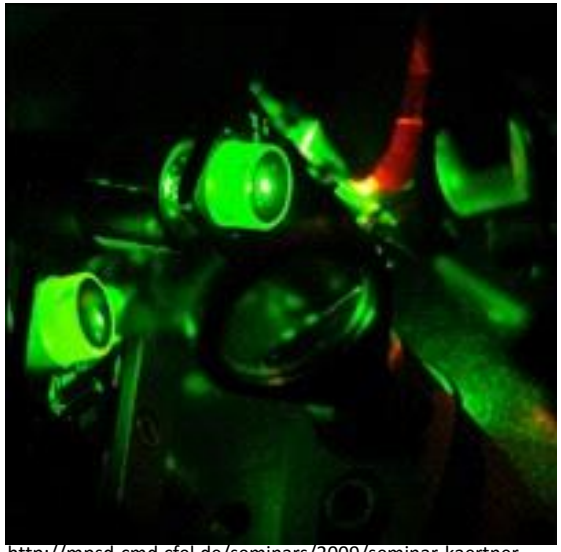
Problem

- 200nm – 1 nm
- 3 stages
- But each max. 9^{th} harmonics

- Two possibilities:
  - laser with small tuning range
    - Range 200 -225 nm
  - few undulator configurations

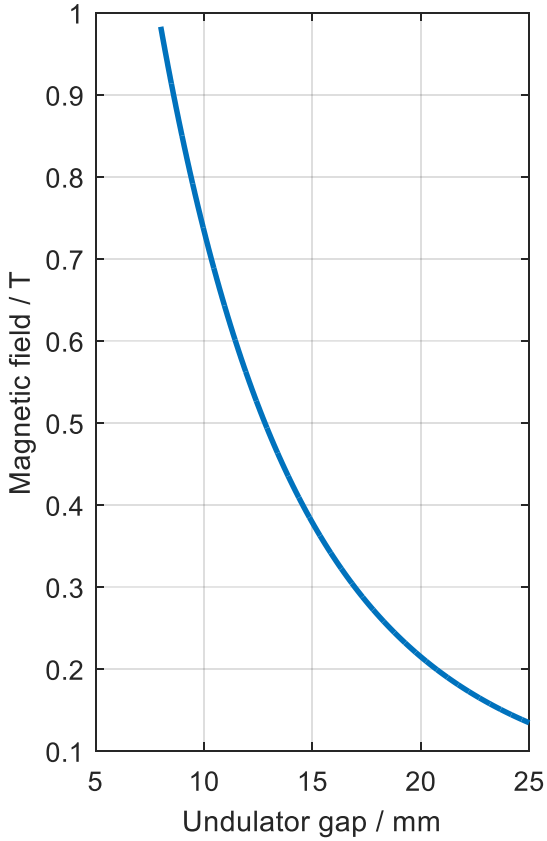


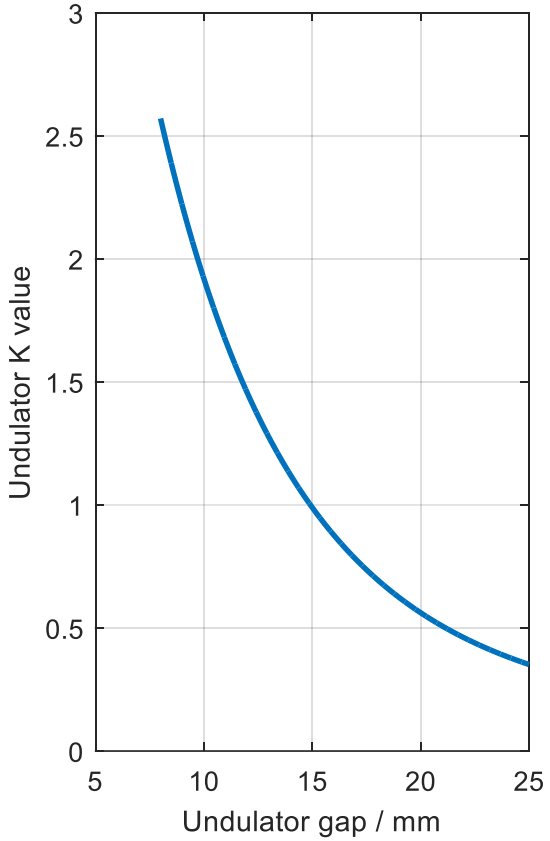
http://mpsd-cmd.cfel.de/seminars/2009/seminar-kaertner-0609_Seite_1_Bild_0004.jpg

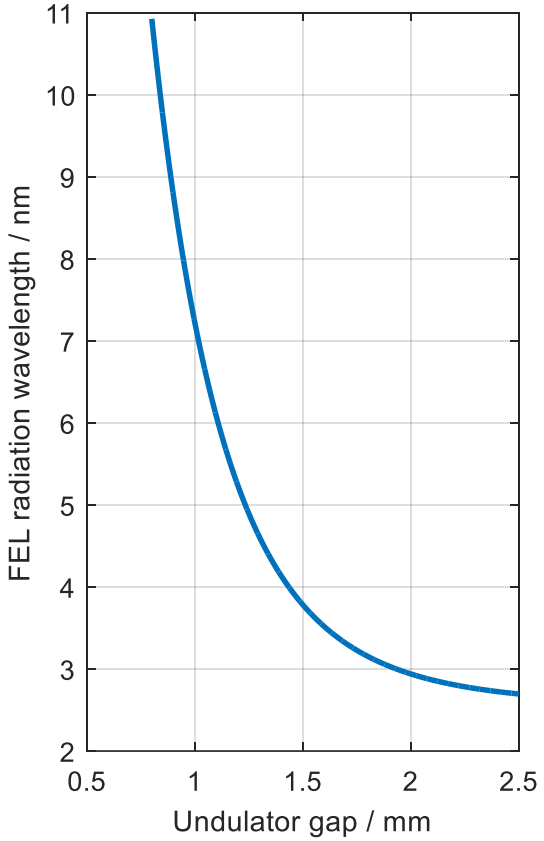
Undulator configurations

λ_0(input) [nm]	Harmonics n1, n2, n3	λ_3(output) [nm]
200 - 190	(200) 5, 5, 8	1 - 1.2
240 - 190	(160) 4, 5, 8	1.18 - 1.5
“	(128) 4, 4, 8	1.48 - 1.87
“	(105) 3, 5, 7	1.18 - 2.29
“	(84) 2, 6, 7	2.26 -2.86
“	(70) 2, 5, 7	2.7 - 3.43
“	(56) 2, 4, 7	3.39 - 4.28
“	(45) 3, 3, 5	4.22 - 5.33
“	(36) 3, 3, 4	5.3 - 6.67
“	(30) 2, 3, 5	6.3 - 8
“	(24) 2, 3, 4	7.29 - 10

Determination of Undulator Parameters







Undulator parameters when changing the gap from 8 mm to 25 mm with bunch energy 1.2 GeV and undulator period 28 mm

Beam parameters

- $E_e = 1.2\ GeV\ - 2\ GeV$
- $Q = 1\ nC$
- $I_{peak} = 1.5\ kA$
- $\mathrm{E}_n = 1.2\ mm\ rad$
- $\sigma_\tau = 60\ \mu m$
- $\sigma_{l,e} = 667\ fs$
- $\beta = 12\ m$
- $\sigma_\gamma = 10^{-4}$
- $\sigma_l = 20\ fs$

Parameters according to STARS – Bessy FEL TDR
https://www.helmholtz-berlin.de/media/media/grossgeraete/beschleunigerphysik/fel/fel_tdr_web.pdf

Undulator parameter

- S. Ming Xie (Web-based calculator by Bart Faatz, DESY http://adweb.desy.de/home/faatz/www/parms/parms.html)
- e.g. 3rd undulator

harmonic conversion

$\sigma_\gamma = 10^{-4}$

1D rho parameter (Bonifacio) :	0.000672	1D gain length [m] :	1.91		
3D rho parameter :	0.000317	**3D gain length [m] :**	**4.061**	**Saturation length [m] :**	**76.81**
Shotnoise power [W]:	23.662	**Saturation power [GW] :**	**0.431**	Power at undulator exit [GW] :	0
Electrons per wavelength:	84594	Effective Energy spread :	0.674	Diffraction parameter :	10.4
Spotsize at exit (FWHM) [mu] :	137.13	Divergence (FWHM) [murad]:	8.71	Bandwidth (FWHM) [%] :	0.07
Pulse duration (FWHM) [fs] :	313.36	Photons per Pulse :	0.02E14	Autocorrelation time [fs] :	8.03
Peak Flux [#/sec] :	0.059E26	Peak Brilliance* :	3.221E30	Pulse Energy [mJ] :	0.144
Average Flux [#/sec] :	0.001E18	Average Brilliance* :	0.404E21		
SR Energy loss [MeV] :	0.0013	SR Energy spread [MeV] :	0.001		

Undulator parameters

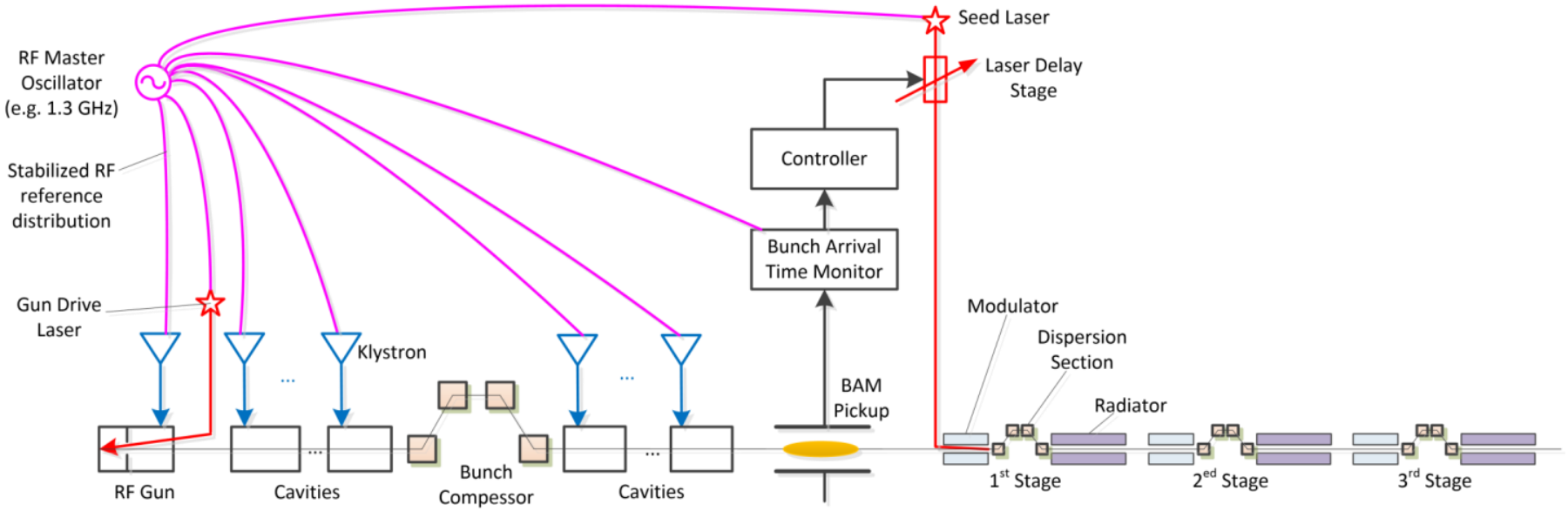
- According to the pendulum equ. and as long as $\mathrm{P}_{\mathrm{seed}} > 500\ \mathrm{MW}$

  $L_{mod} = 1\ m$

  $L_{sat} = L_g \ln \frac{9}{b_0} = 25\ m$

- Total length $\approx 42\ m$

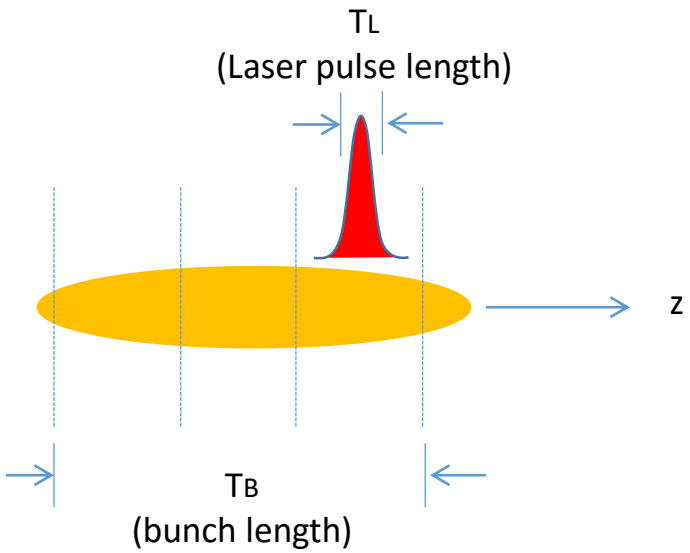
Synchronization Concepts of the Cascaded HGHG FEL Machine



- All synchronized with the same master RF source
- Bunch arrival time monitor
- All systems should be essentially stable

Synchronization Concepts of the Cascaded HGHG FEL Machine

- Bunch arrival time must allow fresh bunches in the HGHG sections.



$$\Delta T_{jit} = \frac{1}{3} T_B - T_L$$

With an electron bunch length of 660 fs, and seed laser pulse length 20 fs, the bunch arrival time jitter WRT the seed laser should be smaller than 200 fs.

Shot noise discussion

- According to Saldin-Yurkov-Schneidmiller

HGHG FEL not possible in lower soft X-ray because of signal to noise ratio

http://cdn.pcwallart.com/images/looney-tunes-thats-all-folks-wallpaper-2.jpg

Why 200- 225 nm

- Relative biggest gap of harmonics with assumption that only 2-9th harmonic / undulator between 21st – 24th harmonic results in a tunability of 12.5% of seed laser

Undulator parameters

- $B = a\, e^{b\frac{g}{\lambda_u} + c\left(\frac{g}{\lambda_u}\right)^2}$
- Paramters a, b, c permanent magnets s. Joachim Pflueger