Z-dependent Spectral Measurements of SASE FEL Radiation at APS

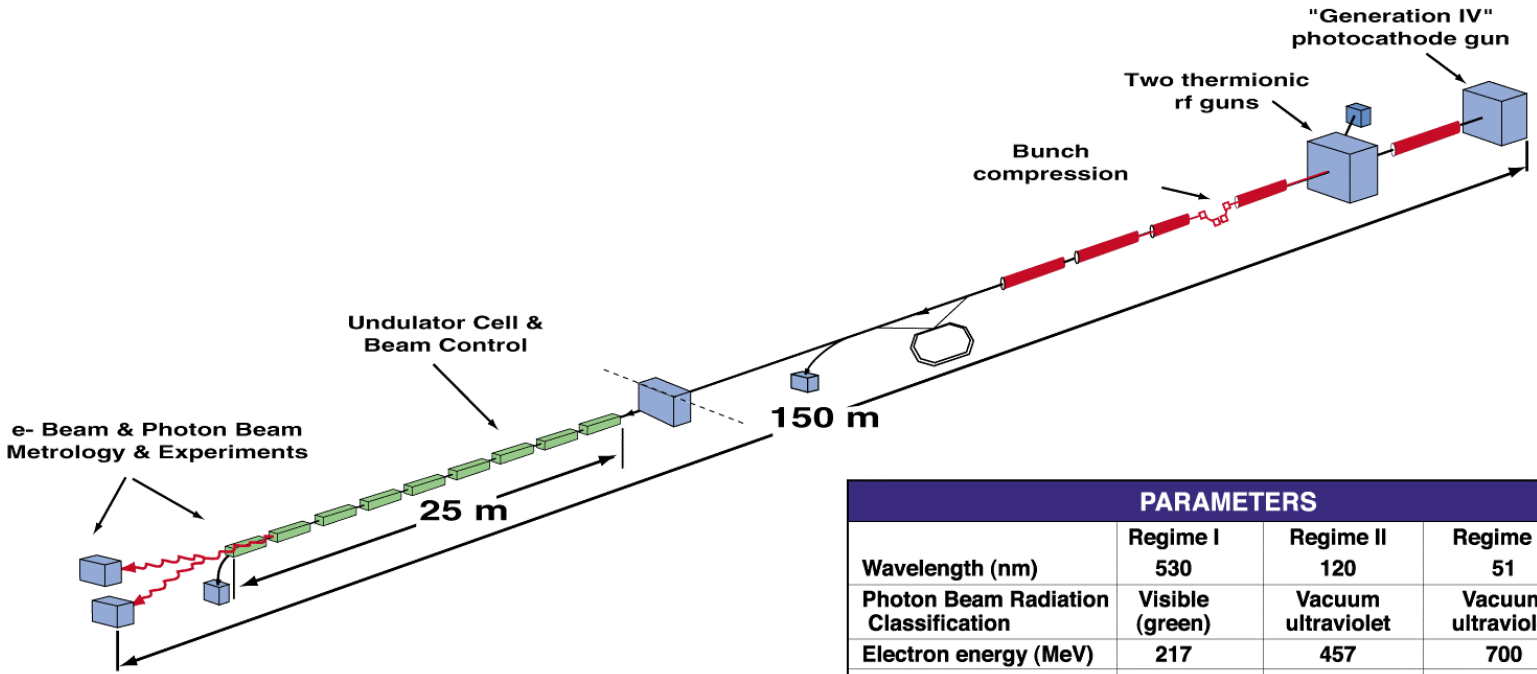
Vadim Sajaev

Z. Huang, S. G. Biedron, P. K. Den Hartog, E. Gluskin, K.-J. Kim,
J. W. Lewellen, Y. Li, O. Makarov, S. V. Milton, E. R. Moog

Advanced Photon Source, ANL

FEL XXIII, Fr-O-05, 24 August 2001

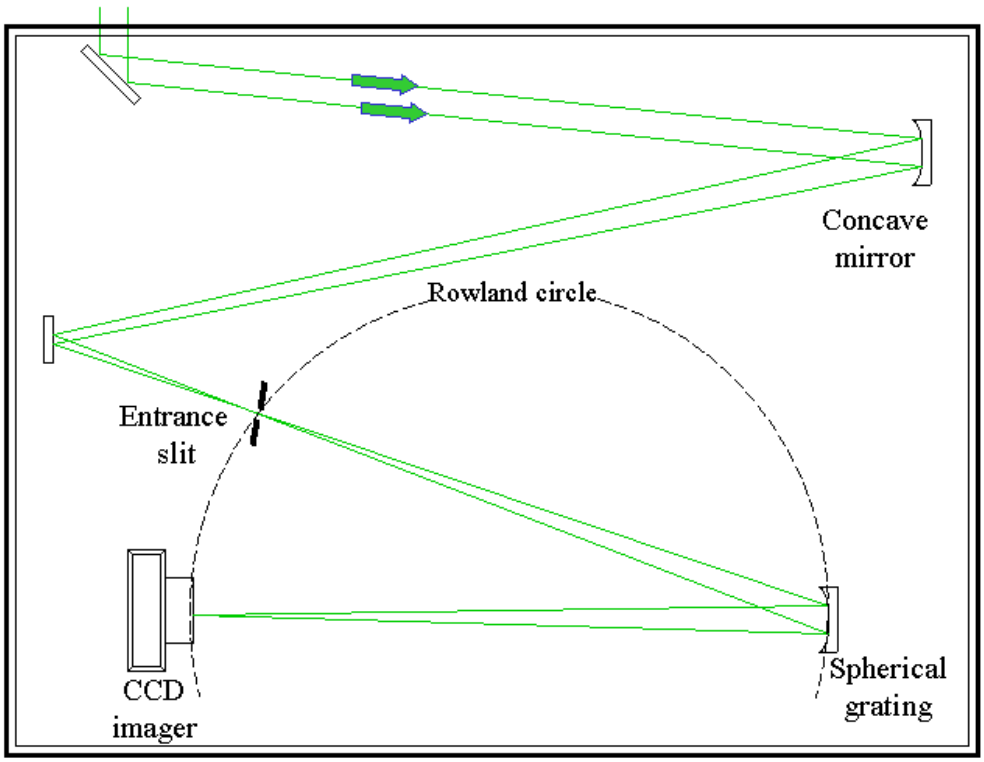
The APS SASE-FEL



PARAMETERS			
	Regime I	Regime II	Regime III
Wavelength (nm)	530	120	51
Photon Beam Radiation Classification	Visible (green)	Vacuum ultraviolet	Vacuum ultraviolet
Electron energy (MeV)	217	457	700
Normalized emittance (mm mrad)	5π	3π	3π
Energy spread (%)	0.1	0.1	0.1
Peak current (A)	100	300	500
Undulator period (mm)	33	33	33
Magnetic field (T)	1.0	1.0	1.0
Undulator gap (mm)	9.3	9.3	9.3
Cell length (m)	2.73	2.73	2.73
Gain length (m)	0.81	0.72	1.2
Undulator length (m)	9 x 2.4	9 x 2.4	10 x 2.4

Spectrometer

- The spectrometer utilizes a Paschen-Runge mount.
- It provides independence on the angle of the incoming light
- It can be tuned for wide range of wavelengths
- It is flexible and easy to modify

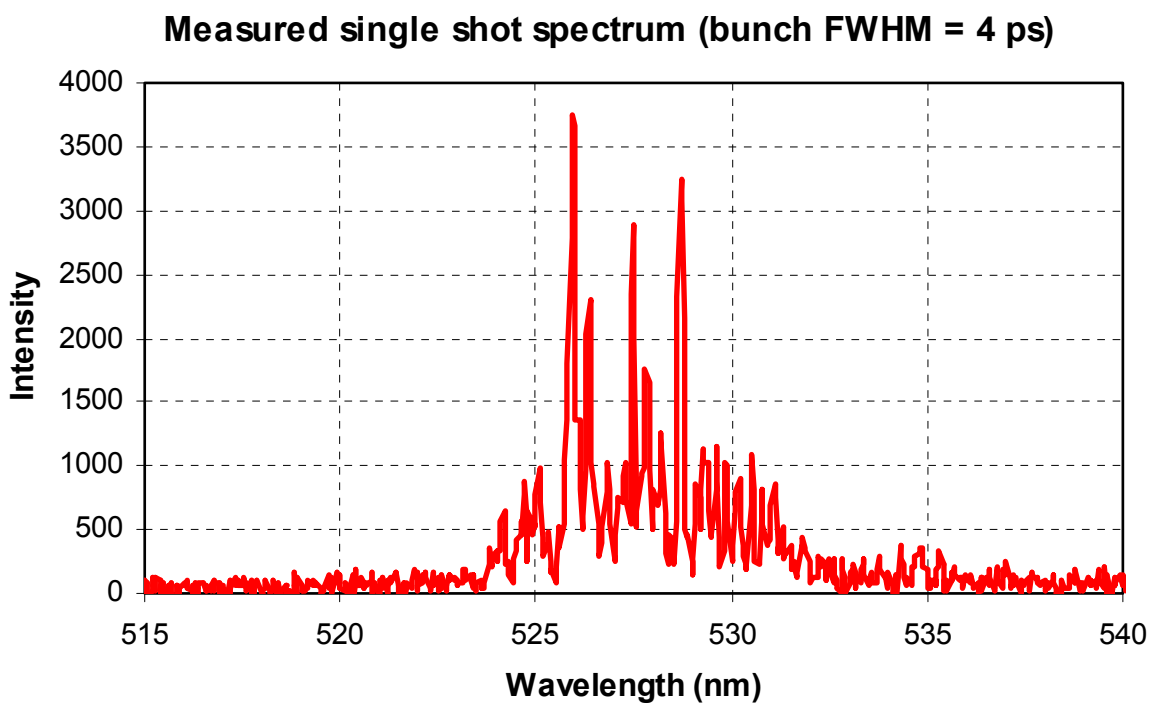


Main parameters

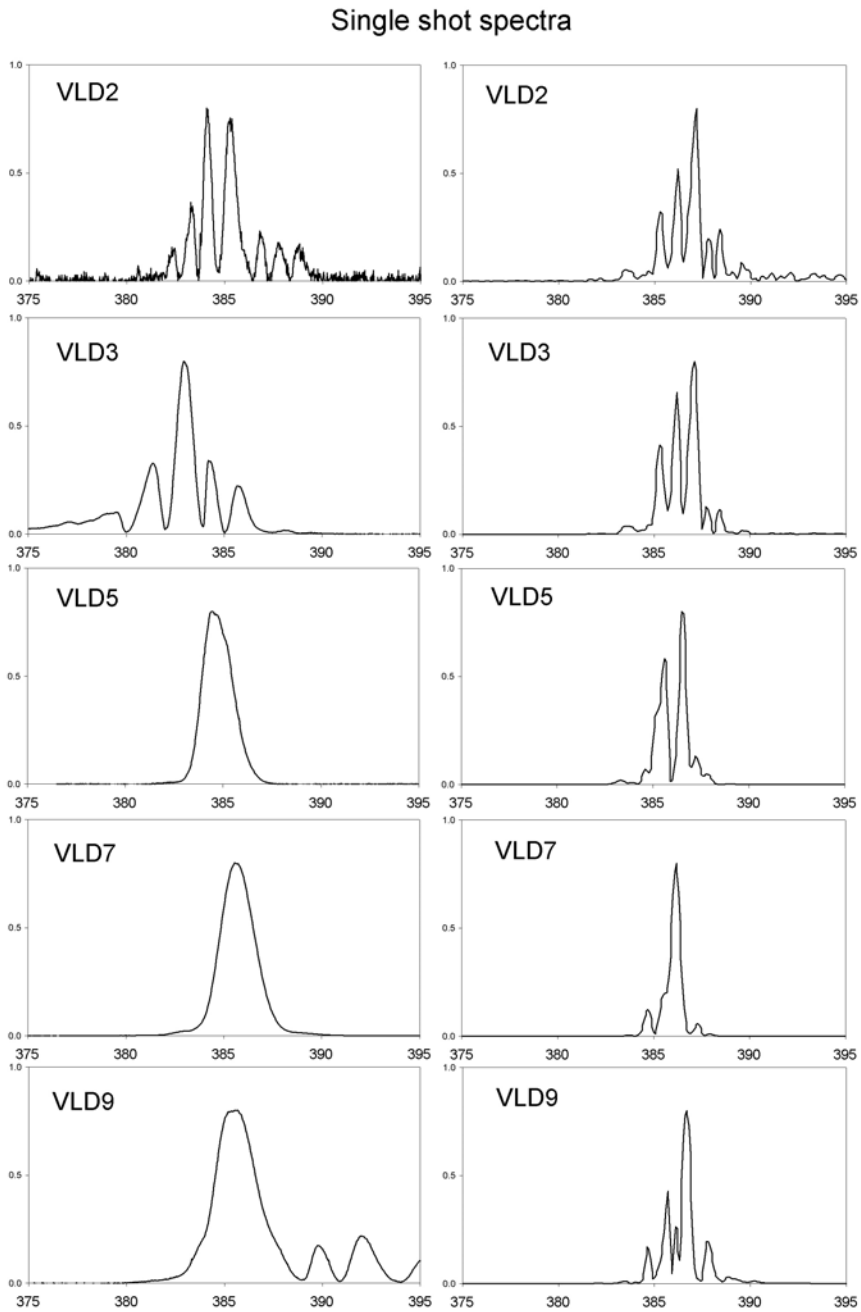
Grating	Grooves/mm	600
	Curvature radius [mm]	1000
	Blaze wavelength [nm]	482
CCD camera	Number of pixels	1100×330
	Pixel size [μm]	24
Concave mirror curvature radius [mm]		4000
Spectral resolution [Å]		0.4
Bandpass [nm]		44
Resolving power at 530 nm		10000
Wavelength range [nm]		250 - 1100

Spectrum of spontaneous radiation

- All electrons radiate with random phases
- The resulting spectrum consists of sharp spikes
- The spike width is proportional to the reciprocal of the electron bunch length



Z-dependent single shot spectra

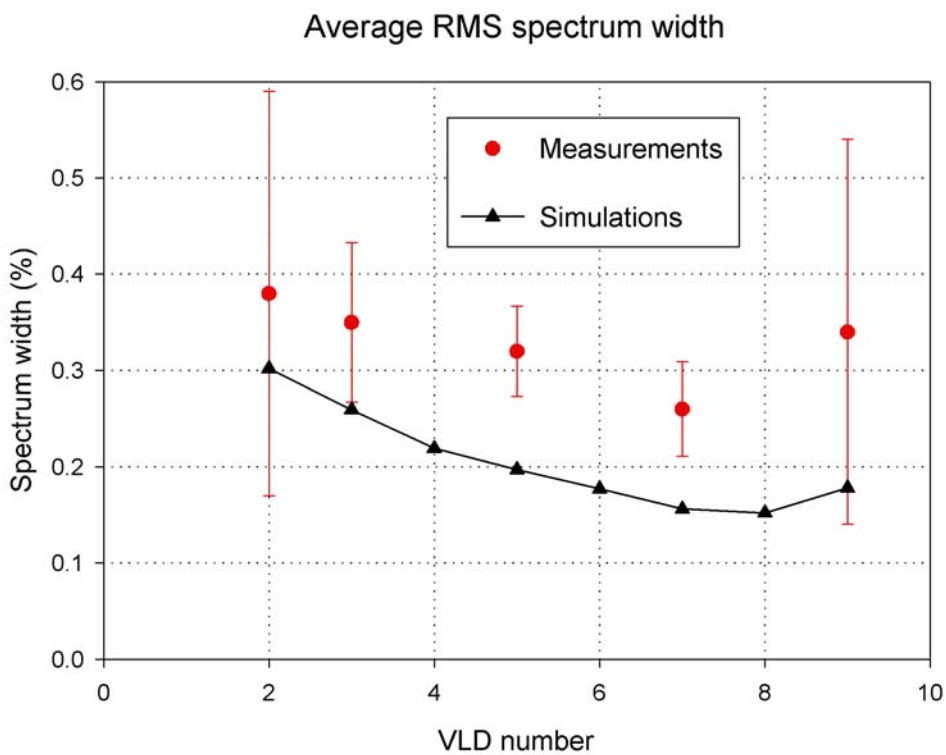


Spectrum bandwidth

- From the 1D theory of SASE, the bandwidth decreases as

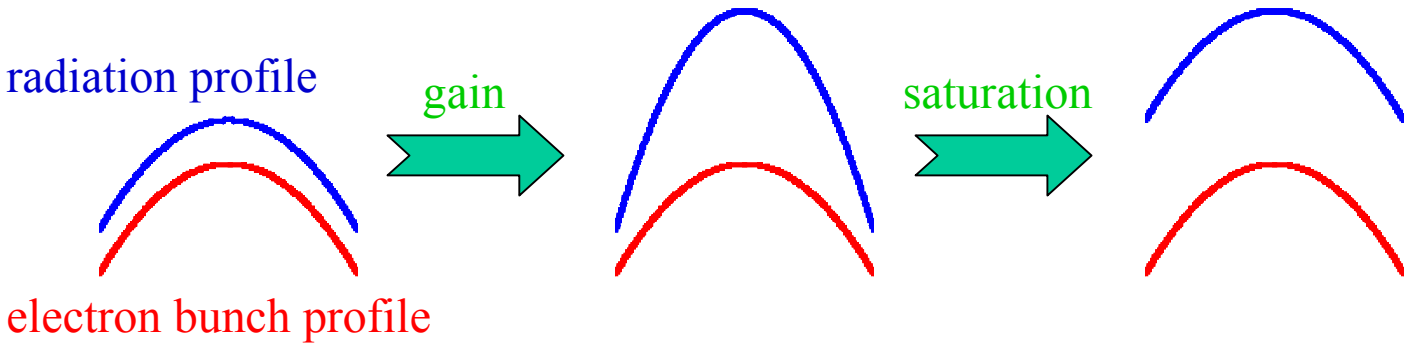
$$\frac{\delta\lambda}{\lambda} = \sqrt{\frac{0.83\rho}{N_U}} \sim \frac{1}{\sqrt{z}}$$

- After saturation, the spectrum width increases again due to the synchrotron instability of the electrons and sideband development



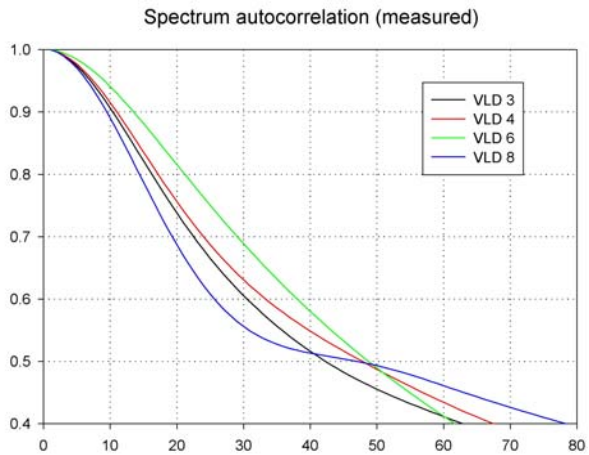
Spike width

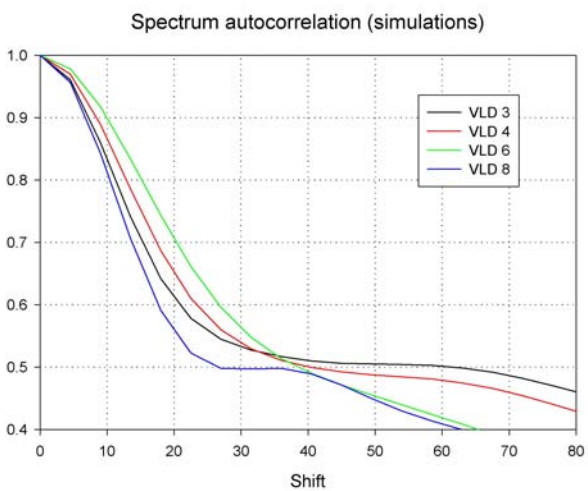
- For spontaneous radiation the width of the spectral spikes corresponds to the reciprocal of the bunch length.
- Because the gain depends on the local current, radiation emitted by different parts of the beam experiences different gain. This results in a decrease in effective bunch length.

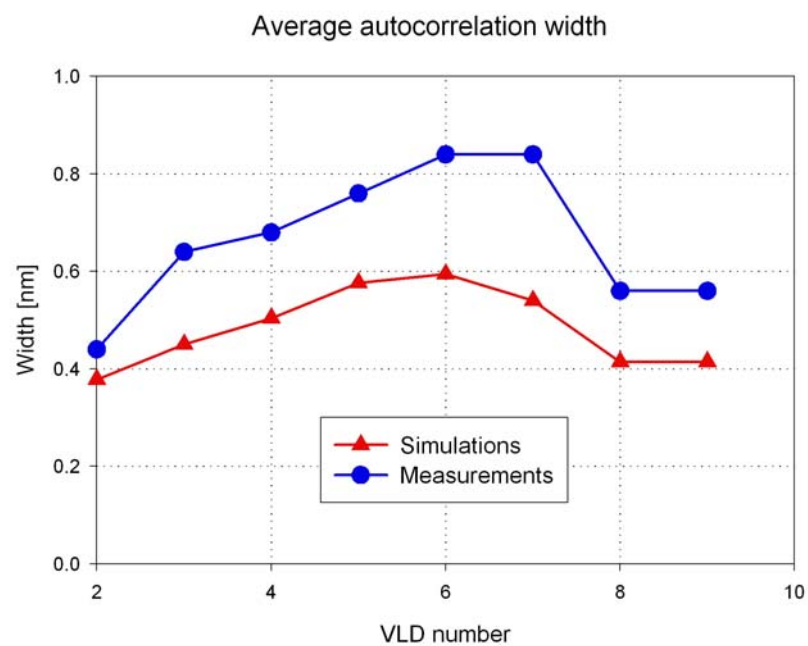


- At saturation, the process is opposite.

Spike width

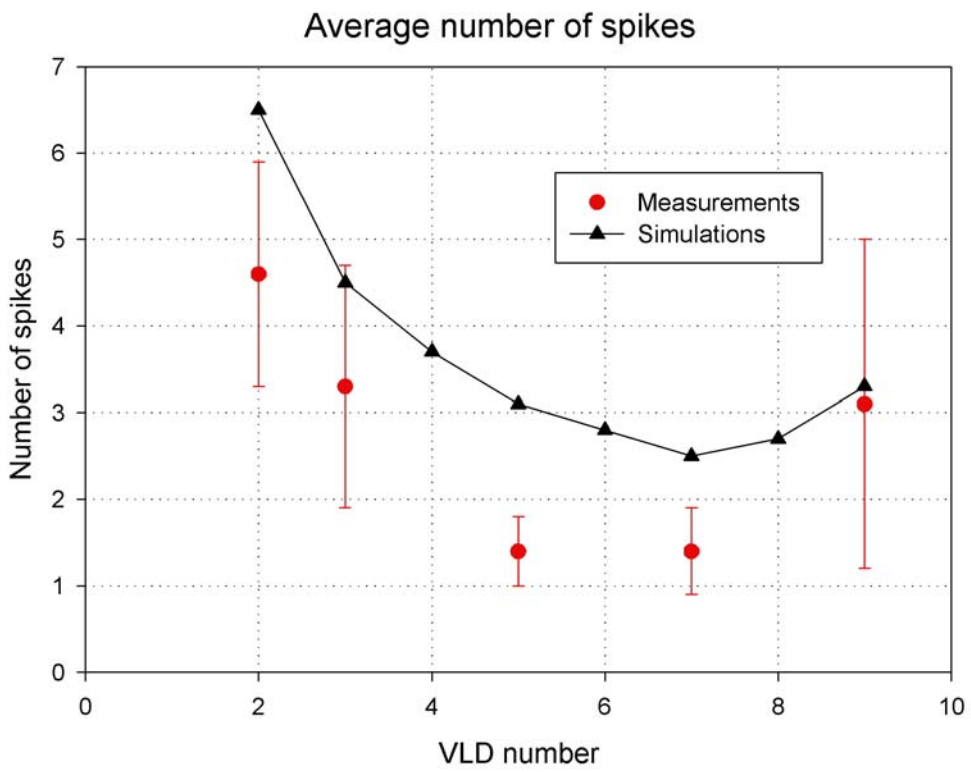

Spectrum autocorrelation (measured)
VLD 3
VLD 4
VLD 6
VLD 8


Spectrum autocorrelation (simulations)
VLD 3
VLD 4
VLD 6
VLD 8
Shift


Average autocorrelation width
Width [nm]
VLD number
Simulations
Measurements

Number of spikes

- The number of spectral spikes corresponds to the number of coherence modes.
- Since the coherence length increases along the undulator, the number of coherent modes decreases, resulting in a decreased number of spikes.
- When saturation is achieved, the sidebands appear, increasing the number of spikes again

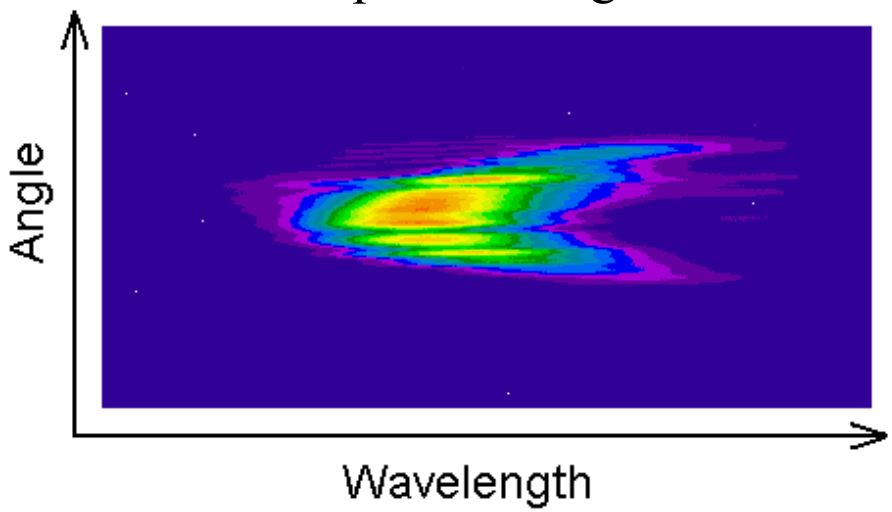


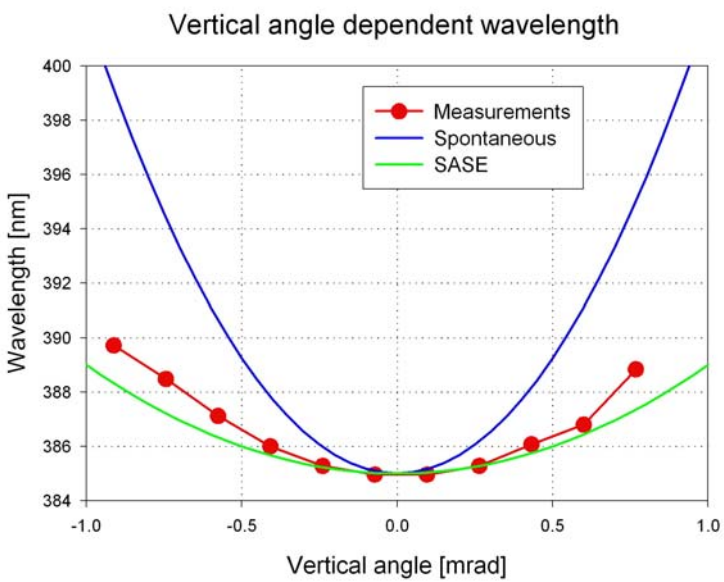
Vertical angle dependence of the wavelength

Spontaneous – $\frac{\delta\lambda}{\lambda} = \frac{\gamma^2\theta^2}{1+K^2/2}$

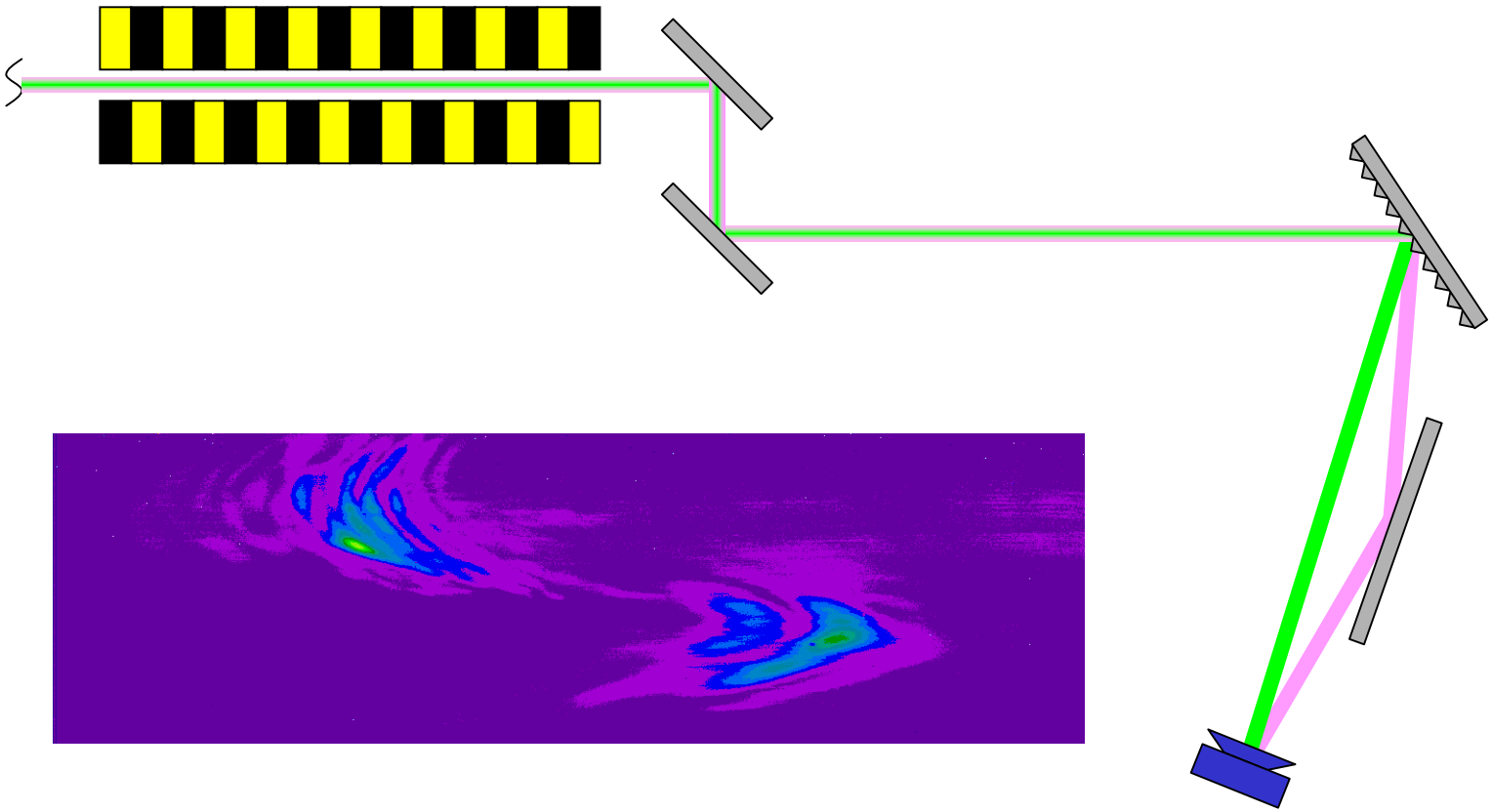
SASE – divergence increases with the wavelength due to diffraction

Spectral image

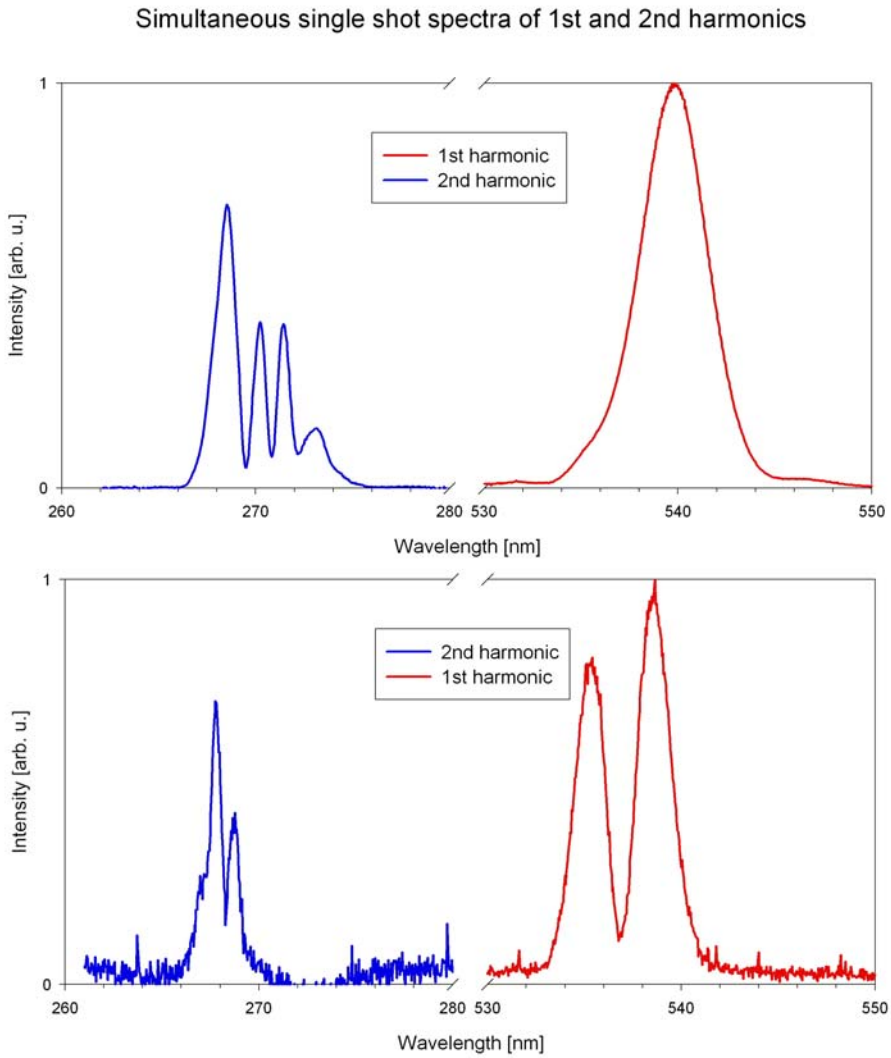




Simultaneous Spectra: Fundamental and 2nd Harmonic



Second harmonic measurements



1st harmonic (530 nm) $\frac{\delta\lambda}{\lambda} = 2.9 \cdot 10^{-3}$

2nd harmonic (265 nm) $\frac{\delta\lambda}{\lambda} = 4.4 \cdot 10^{-3}$

Conclusions

- The z-dependence of the spectrum of SASE FEL radiation has been measured
- It shows a narrowing of the spectral bandwidth during the exponential gain regime and the appearance of sidebands after saturation is achieved
- So far, reasonable agreement between theory, simulation and experiment

Acknowledgements and Thanks

C. Benson, M. Borland, Y.-C. Chae, R.J. Dejus, B. Deriy,
M. Erdmann, Y.I. Eidelman, M.W. Hahne, A.H. Lumpkin,
Nassiri, R. Soliday, B.J. Tieman, E.M. Trakhtenberg,
I.B. Vasserman, N.A. Vinokurov, G. Wiemerslage,
M. Zolotorev