Precision Measurement of the Undulator K Parameter using Spontaneous Radiation

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Topics

- Motivation
- Basic Scheme
- Theory of Two-Undulator Spectrum
- Details & Simulation
- Summary

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Motivation for *in-situ* K Measurements

- The LCLS Undulator consists of 33, essentially identical, independent undulator segments.
- Errors in segment K (= 0.934 B [T] λ [cm]), cause errors in the phase between the electron beam wiggle and the xray radiation.
  - Loss of microbunching and FEL gain.
- Tolerance of $\Delta K/K \leq 1.5\times10^{-4}$ is initially challenging, and must be maintained for years.
  - Temperature, alignment, radiation, presently unknown effects?… can easily change effective K.
- Direct in-situ magnetic measurements infeasible.

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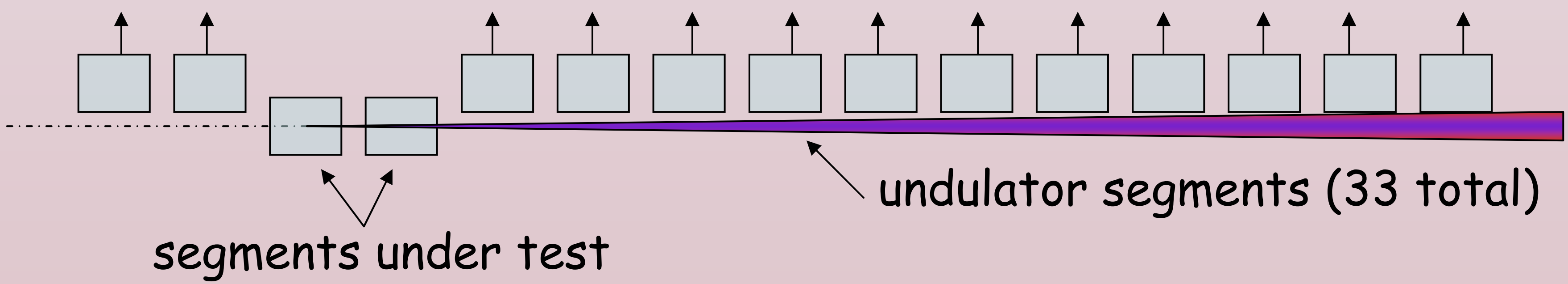
2-Segment Scheme

- Measure synchrotron radiation spectrum produced by two undulator segments, and scan K of one segment
  - Other schemes compare spectra from individual segments. (Pinhole technique, angle-integrated edge measurement, reference undulator)
- K's are matched when spectrum has the steepest slope on high energy side of 1st harmonic peak.
- Match segments pairwise until all segments are measured.



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Theory of Two Segment Spectrum

- Spectral intensity depends on relative detuning and phase difference

Detuning parameters, $\nu_{1,2}$
Phase difference, ϕ
Angle parameter, ξ
Spectral intensity, I
Includes angle energy correlation

$$\nu_1 = \pi N \frac{\omega - \omega_1(0)}{\omega_1(0)}$$

$$\xi = \pi N \theta^2 \frac{\omega}{2\omega_u}$$

$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + K^2/2 + \gamma^2\theta^2\right)$$

$$I(\nu_1, \nu_2, \xi, \phi) \propto \left| e^{i(\nu_1+\xi)} \frac{\sin(\nu_1+\xi)}{\nu_1+\xi} + e^{-i(\nu_2+\xi)-i\phi} \frac{\sin(\nu_2+\xi)}{\nu_2+\xi} \right|^2$$

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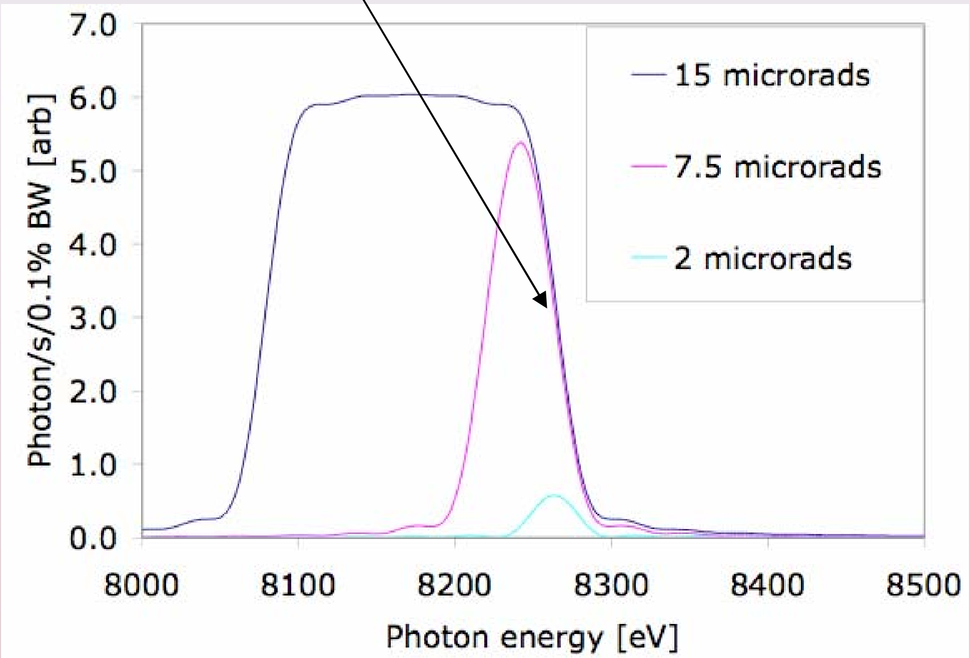
Theory - Angle Integration

- Two identical segments
- Most signal comes from first 7-8 μrad
- 20 μrad is max angle for 1st segment (chamber limit
- Maximum negative slope for K measurement doesn't depend on angle of integration much for angles ≈ 7-8 μrad or more.

Steepest (negative) slope



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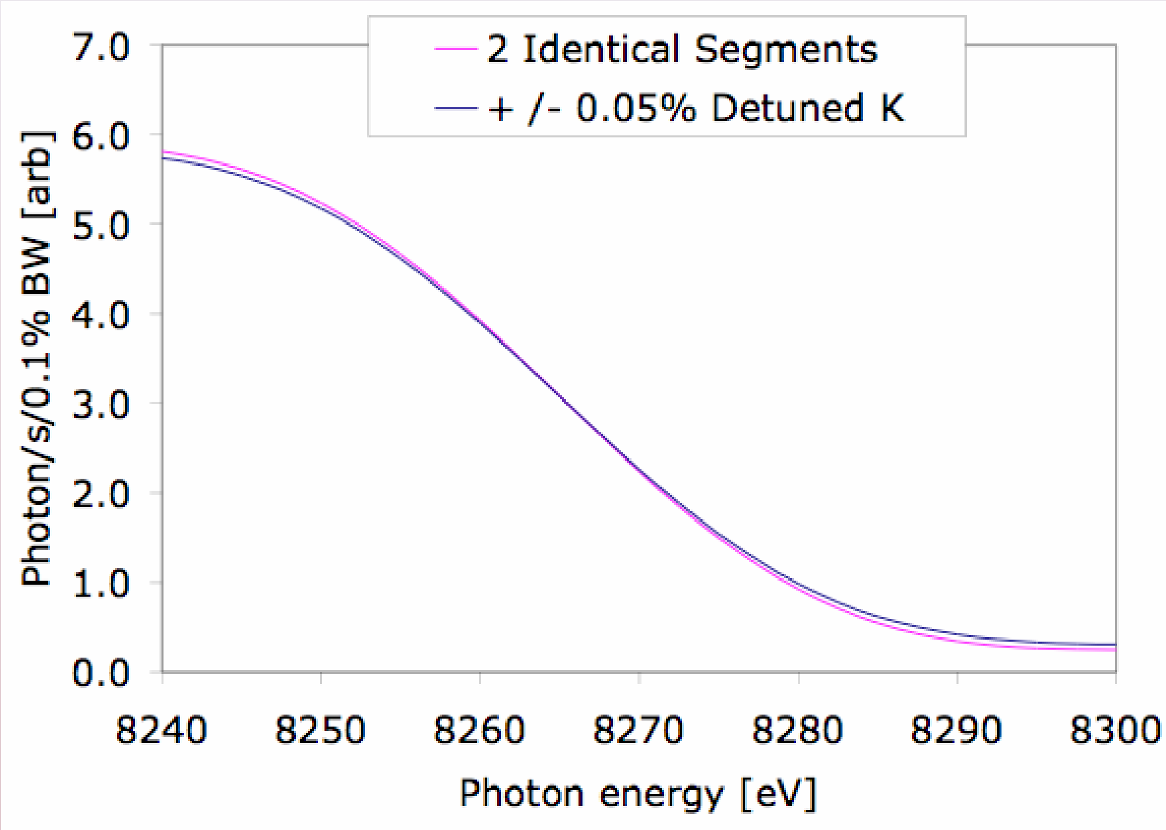
Theory - Angle Integrated, 2 Detuned Segments

- Detuning segments produces slight slope/linewidth change
- 3% slope change for 0.1% K change
- Steepest negative slope will be used to track K.



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Details and Simulation

- Energy Jitter
- Alignment of Central Rays
- Phase difference
- Computer generated spectra plus noise
- Fitting details

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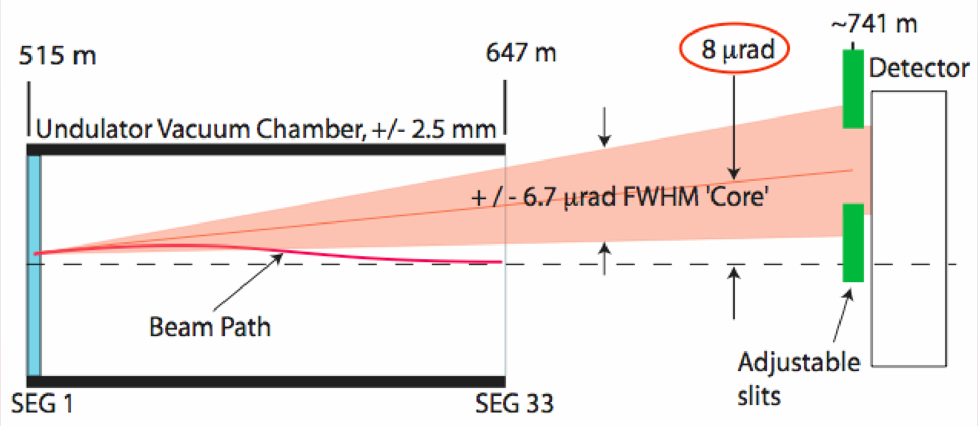
Details

- Beam energy jitter, 0.1% rms.
  - Detector is assumed to be narrow bandwidth (<< 1/N), high efficiency, Si crystal, Bragg diffraction
  - Measure each pulse to 3×10^{-5} and use to reconstruct the spectrum
  - Natural beam energy jitter is sufficient to sample region of steepest slope.
- Phase differences between segments
  - Shown to be neglible
- Alignment/Pointing errors
  - More than about 8 μrad beam angle will scrape core SR on the vacuum chamber and distort the high energy edge of the measured spectrum.



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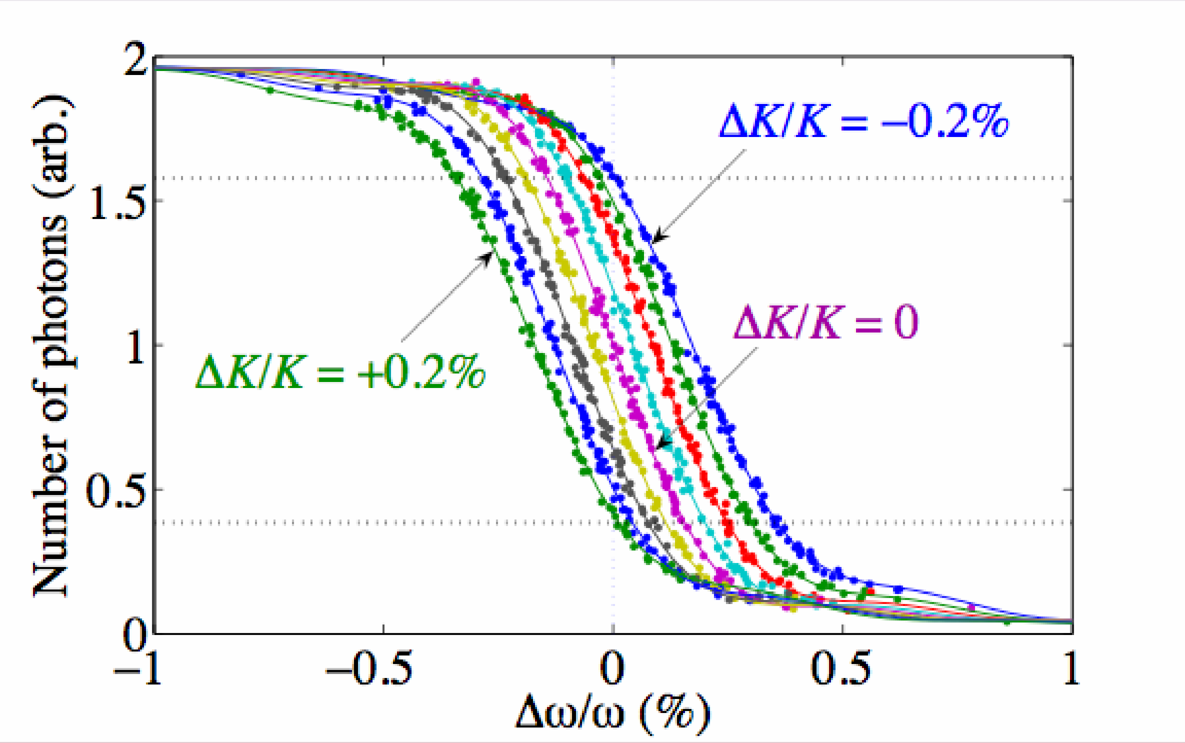
Simulated Data

- Theoretical angle-integrated spectrum was generated for 9 different K values
- "Data" points include effects of resolution and statistics



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Detector and Noise

- Noise effects that add error to the number of detected photons or the frequency -->

Charge meas res.	0.5%
Energy jitter	0.1% rms
Energy meas. Res.	0.003% rms
E- angle jitter	0.5 μrad rms
Detector noise	100 photons rms
Peak signal	10^5 photons

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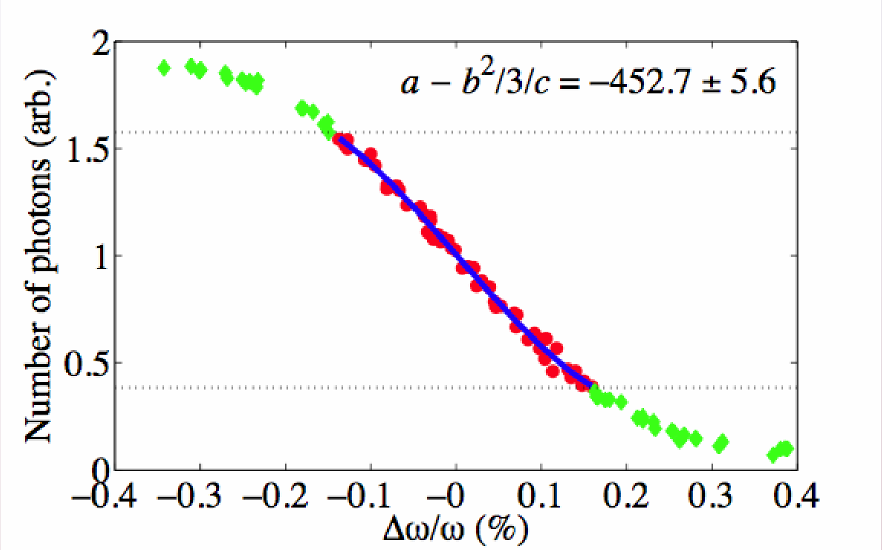
Simulation - Steepest Slope Determination

- Steepest slope depends on K difference, but not on spectrum absolute shift
- Third order polynomial fit to truncated spectrum data easily yields steepest slope



$$N = N_0 + a(\Delta\omega/\omega) + b(\Delta\omega/\omega)^2 + c(\Delta\omega/\omega)^3$$

$$\left(\frac{dN}{(\Delta\omega/\omega)}\right)_{\max} = a - \frac{b^2}{3c}$$

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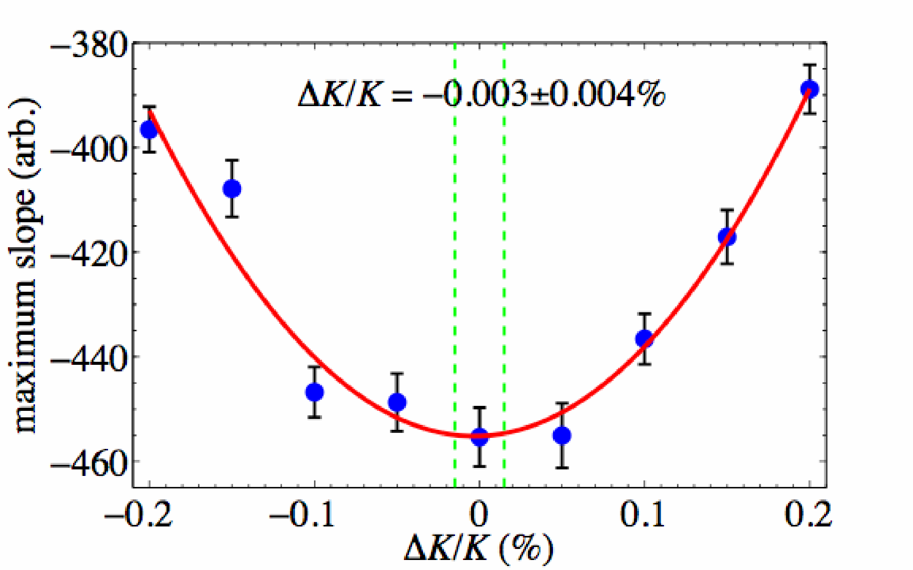
Finding ΔK=0

- Scan K of one segment and find value that maximizes the steepest slope
- Neglecting small energy loss between segments, the extremum value is when the segment K values are identical.
- Simulation shows resolution of ΔK /K of 0.004% rms



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Summary

- Scanning K of one segment, keeping a second segment fixed, and fitting the measured spontaneous radiation spectrum, appears to be a useful method for determining the relative K values of nearby segments.
- Energy jitter is measured each pulse and used to reconstruct spectra
- Beam angle/energy correlations are dealt with through angle integration and alignment of central rays.
- Phase difference effects are expected to be neglible

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