Supplemental Material: Experimental setup

At LCLS, the x-ray pulse duration was controlled by varying the electron-bunch length in the undulator. Although the electron-bunch length is well characterized [26], the x-ray pulse duration has proven difficult to measure. We have applied a new method, developed by Lutman, et al. [9], to determine the multiple-shot averaged x-ray pulse duration from statistical analysis of single-shot spectra. Since only part of the electron bunch lases, we find the photon pulse lengths produced by 70, 150, and 300 fs electron bunches are approximately 40, 60, and 80 fs, respectively, within an error of 30 %.

The LCLS pulse energy was measured for each shot using a nitrogen-fluorescence detector [10] located in the LCLS Optics and Diagnostics Hall. It was cross-calibrated to the electron energy loss measurements after the undulator. By placing an absolutely-calibrated ionization-based pulse-energy detector just downstream of our experimental setup, the transmission of the beamline was determined to be about (15±3) % [11].

[26] E.L. Saldin, E.A. Schneidmiller, and M.V. Yurkov, Optics Commun. 148, 383, (1998).