Low Charge Ultra-Short Pulse Operation and Results

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Low Charge Operation

- Bunch length limited by CSR breakup – related to peak current
  - Lower charge -> shorter bunch after compression
  - Emittance lower -> higher gain.
- Bunch length too short to measure, but believe <10 fsec FWHM
- Operation with 20pC, near full compression results in good lasing from 800eV to 8.3 KeV
- Switching from normal to low-charge mode typically takes ~1 hour.
Beam conditions

- Laser FWHM = 3.6ps (Gaussian shape), -15 deg; bunch length RMS = 220 um after injector, slice emittance ~ 0.15 um;

- L1 = -20.5 deg (effective -22 in LiTrack), L2 = around full compression
- Laser heater off
Emittances – Injector

X emittance 0.18 um

Y emittance 0.19 um
Emittances – Start of Undulator

X-emittance 0.83 μm
At 4.3 GeV

Y-emittance 0.38 μm
At 4.3 GeV

Normal compression
(~ KA peak currents)
Lasing at 20pC, 8.3 KeV

Gain length 3.9 M

Intensity noise ~10% RMS

120μJ
User Operation with short bunches

Normla 250pc

Most users took significant data in this mode

Oct 09 Dec 09

20pC

40pC
Machine Stable With Fedbacks and Operator Tuning

- Normal longitudinal feedbacks operate except for BC1 bunch length (signal too small).
- Power reasonably stable for 1-day continuous operation
Bunch Length Measurement

- Transverse cavity can't measure bunch lengths below ~20fs FWHM
- Need to rely on simulations and indirect measurements to estimate bunch length
- Work underway to develop new bunch length measurement techniques
- Bunch length measurement would be helpful for optimizing ultra-short bunch operation
Simulation (4.3 GeV) 1.5 nm

Heater off

Heater 5 keV

$\sigma_\delta = 0.25\%$

$\sigma_\delta = 0.23\%$

rms=1.76 \mu m

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Simulation 13.6 GeV: 1.5 Å

BC2 END, 4.3 GeV

Undulator entrance, 14 GeV

$\sigma_\delta = 0.16\%$

$\sigma_\delta = 0.07\%$

1.39 μm RMS

1.32 μm RMS
FEL lases well at ~0.5 degree on either side of full compression

<10 fs FWHM

over-compressed

peak current Monitor (CSR)

gas detector

fully compressed

under-compressed
Simulated bunch length vs compression

Phase = +1 deg

Phase = +0.5 deg

Phase = 0 deg

Phase = -0.5 deg

Phase = 1 deg

ΔT = 5.0 fs

ΔT = 2.3 fs

ΔT = 1.1 fs

ΔT = 1.9 fs

ΔT = 4.2 fs  we typically operate here

Genesis Simulation for over compression 5 fs FWHM
Jitter at 8.3 KeV

Over-compress 11% RMS  Under-compress 13% RMS  Full-compress 25% RMS

Peak current vs. FEL power shows anti-correlation
Bunch Length Diagnostics - Ideas

- **Brute force:** Higher frequency, higher power transverse cavity
  - We are investigating a X-band transverse cavity that should give <5fs FWHM.

- **Brute force and cleverness:**
  - Optical transverse TCAV – use udulator for coupling

- **Spectral measurements:** Need broadband (~20X wavelength) spectrometer

- **Atomic core hole burning:** Look at ration of ionization states
Even Shorter Bunches?

- LCLS BPMs work down to about 10pc
  - Have lased here, but don't know pulse length
- “Slotted foil”: Spoil emittance for part of the bunch before final compression. Will test during this run
- Optical slicing / optical replica: Pre-seed part of the bunch
- So far no schemes increase peak power. Some of our users prefer longer 40pc bunch to get more total photons.
Slotted-spoiler for pulse length control

LCLS BC2

P. Emma et al. PRL, 2004

1 µm emittance

15-µm Be foil

6 µm emittance

1 µm emittance

$x \propto \Delta E/E \propto t$

$2\Delta x$
• X-ray pulse length adjustable by slit width

• 400 as single x-ray spike possible by changing e-beam configuration
Summary

- LCLS regularly provides users with ultra-short (10fs) bunch X-rays.
- Lack of electron and X-ray bunch length monitors is a significant limit.
- Even shorter bunches are likely possible through a variety of techniques, but some users may need more photons / bunch