Diagnostics for Measuring and Mitigating Femtosecond Microbunches at the LCLS

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Outline

Temporal Diagnostics:
- X-band transverse deflection structure for streaking the beam with femtosecond resolution.
- Dispersion downstream of XTCAV allows observation of full longitudinal phase space
- *Location downstream of undulator for reconstruction of x-ray emission*

Suppression of COTR in Profile Measurements
- SLAC test measurements with PSI profile monitor
- Sensitivity to bunch length
- Sensitivity to laser heater
Temporal Diagnostic Measurement Layout

XTCAV: Resolving the e-bunch $t$-$E$ phase space

\[ \sigma_t = \frac{1}{2\pi f_{\text{rf}}} \frac{E_e}{eV_{\text{rf}}} \sqrt{\frac{\varepsilon_x}{\gamma \beta_x}} \propto \sqrt{E_e} \]

Time resolution

High-$E$ FEL

Result:
1 fs rms @ SXR
3 fs rms @ HXR

x8 improvement with SLAC X-band @ 11.4 GHz
Installation in the LCLS Undulator Hall
A powerful, but not inexpensive diagnostic

50 MW klystron

430 kV modulator

waveguide

Controls:
PAC, PADS, MKSU

LLRF Drive:
TWTA, klystron Mag. Suppl.
Measurement examples: 4.7GeV, 150pC (1keV)

Three Images at the e-dump spectrometer screen

XTCAV Off
XTCAV On
FEL Supressed (baseline)

XTCAV On
FEL On
~1mJ FEL pulse energy
Real-Time data analysis

- Analyze energy difference between FEL On and FEL Off images

\[ P_{\text{FEL}}(t) = \left[ \langle E \rangle_{\text{FEL off}}(t) - \langle E \rangle_{\text{FEL on}}(t) \right] \times I(t) \]

- Alternative analysis based on change in energy spread

\[ P_{\text{FEL}}(t) \propto \left[ \sigma_{E,\text{FEL on}}^2(t) - \sigma_{E,\text{FEL off}}^2(t) \right] \times I^{2/3}(t) \]
Able to resolve individual features
-- 20pC, 1keV examples
Is it a suitable diagnostic for Microbunch Instabilities

- Previous slide demonstrated that temporal resolution is adequate
- Next question is whether features on the beam that are generated upstream in the bunch compressor are preserved all the way through to the measurement screen.
- Test this by generating temporal features using a pair of slits in the bunch compressor chicane
Features introduced upstream at BC are preserved.

Slotted-foil examples (lasing off) shows clearly the unspoiled beam region.

Double Slit

Single Slit

4.7GeV, 150 pC
Lasing with double-slotted foil
Second example with pulse stacking

Laser pulses are stacked at the LCLS photo-Injector to produce multiple electron bunches within one RF bucket. A Marinelli

XTCAV gives clear view of bunch separation and orientation in longitudinal phase space.
Double-bunch (two-color) example - A. Marineli

Shot #15, TREX-SIG_Images-2014-01-21-232217.mat

\[ \Delta E \text{ (MeV)} \]
\[ \text{time} \]

\[ \text{energy} \]

\[ Q \text{ (pC)} = \]
\[ Q_{\text{tot}} = 140 \text{ pC} \]
\[ E_{\text{DL2}} = 13601 \text{ MeV} \]
\[ \Delta t = 66 \text{ fs} \]
\[ \Delta E = 75.4 \text{ MeV} \]
Beam Line Optics

The graph shows the evolution of the parameters $\beta_x$, $\beta_y$, and $\eta_y$ along the beam line, with $S$ in meters on the x-axis. Key points marked include a deflector and a screen.
Summary (1)

- The LCLS XTCAV system has been implemented as a powerful diagnostic tool
- Can distinguish temporal microstructures in the beam down to 1 fs resolution
- Slice energy spread can also be resolved with keV resolution
- Examples of microbunching instability shown in Tim Maxwell’s talk.
2. Beam Profile Measurements and MBI induced COTR

- OTR foil screens unusable for beam size measurement downstream of BC at LCLS
- $10^5$ intensity enhancement
- With large variations

- Resorted to wire scanners for beam profiling
- Motivated to study COTR suppression with fluorescent screens
PSI Profile Monitor Tests at LCLS

- YAG screen monitor designed by Rasmus Ischebeck built at PSI was installed in the LCLS LTU beamline
- 30 micron thick crystal
- Beam loss is still significant
- Max rep rate of 10 Hz
- Undulator stopper must be in
Unique target geometry – R. Ischebeck

- COTR light is directed away from camera
- Requires use of Scheimpflug optics and Snell observation angle
• Observe the screen at the correct angle for Snell's law so that beam sizes smaller than the screen thickness are imaged.

• Camera image plane is also tilted to preserve depth of field across tilted crystal (Scheimpflug optics).
Beam tests at LCLS (together with M. Yan, DESY)

• Concern is that screen may still be illuminated by upstream COTR
• And, that COTR may be short enough wavelength to fluoresce in the YAG crystal
• Measure image intensity as a function of:
  • Beam size
  • Bunch charge
  • Peak current (bunch length)
  • Laser heater power
Screen intensity during beam size scan almost constant

Plot camera intensity vs beam area $\sigma_x^*\sigma_y$

Laser heater ON; Nominal under compression
Screen intensity versus laser heater power

Fixed spot size

10% light intensity increase with laser heater OFF
Bunch length scan

20 pC bunch charge at 13.1 GeV
Compare Laser Heater On/Off
Worst case, factor 1.2 enhancement

Analysis Minjie Yan
Bunch length scan

150 pC bunch charge at 13.1 GeV
Compare Laser Heater On/Off
Worst case, factor 2 - 7 enhancement

Analysis Minjie Yan
More recent result

Add a narrow band yellow filter to the camera
150 pC bunch charge at 13.1 GeV
Compare Laser Heater Off
Worst case, factor 4 enhancement
CDR visible on the edge of the screen

In the peak compression case, with LH off, we see coherent diffraction radiation at the edge of the screen (Probably generated from the edge of the mirror)
Summary (2)

- The PSI design effectively suppresses COTR
- Can be used for single shot transverse beam size measurements
- Only in the worst cases (6 kA) of beam operation in the LCLS when the laser heater is off do we see factor ~4 light intensity enhancement
- But, this has been reduced from $10^5$ enhancement!

Thank you!