Harmonic Measurements at LCLS

D. Ratner
R. Bionta (LLNL, Livermore, California)
Introduction

Harmonic Content at LCLS

- Measure harmonics at normal operation
  - H.D. Nuhn will discuss amplification

- Third Harmonic
  - Strongest harmonic
  - Potential source of harder X-rays

- Second Harmonic
  - Background noise for users
Third Harmonic

- Third harmonic content
- Block fundamental
  - Gas ($\text{N}_2$) or solid (10um-30mm Be)
  - Measure counts on 100um YAG

X-ray Diagnostics (J. Welch, FROA1)
- Simplest harmonic measurement:
  - Take ratio of counts from two images
  - 900 eV fund: 1.7% 3rd Harmonic
  - 1.7 keV fund: 2.7% 3rd Harmonic

**Fundamental**

**3rd Harmonic**

**Speckle from Be**
Third Harmonic

- Scanning attenuation
  
  Counts $\propto T_{1st} \times P_{1st} + T_{3rd} \times P_{3rd}$
  
  $\Rightarrow$ Counts $\propto T_{1st} + T_{3rd} \times (P_{3rd}/P_{1st})$

- 900 eV fund: 2.5% 3rd Harmonic ($\sim 1$ mJ 1st)

![Graph showing counts as a function of transmission of fundamental pulse energy (a.u.)]
Fit proportion from attenuation

Counts $\propto T_{1st} \times P_{1st} + T_{3rd} \times P_{3rd}$

$\Rightarrow$ Counts $\propto T_{1st} + T_{3rd} \times \left( \frac{P_{3rd}}{P_{1st}} \right)$

- 6 keV fund: 0.6% 3rd Harmonic (0.6 mJ 1st)

![Graph showing the relationship between transmission and pulse energy for different harmonic powers.](graph.png)
Third Harmonic

- Fit proportion from attenuation

\[
\text{Counts} \propto T_{1\text{st}} \times P_{1\text{st}} + T_{3\text{rd}} \times P_{3\text{rd}}
\]

\[
\Rightarrow \text{Counts} \propto T_{1\text{st}} + T_{3\text{rd}} \times \left( \frac{P_{3\text{rd}}}{P_{1\text{st}}} \right)
\]

- 8 keV fund: 3% 3\text{rd} Harmonic (1.5 mJ 1\text{st})

Graph showing the relationship between transmission and pulse energy.
Third Harmonic

- Confirm 3rd Harmonic measurement at 6 keV
  - Zirconium K-edge
  - Confirms wavelength and intensity

Pulse Energy (a.u.)

Electron Energy Scan

Jump at K-edge is approximately ~1% of fund

Thanks to Alan Fisher!
What is 2\textsuperscript{nd} harmonic content in FEL?
What is 2\textsuperscript{nd} harmonic content in beamline?

- Measure transmission cutoff
Mirror Cutoff

- Soft X-ray beamline transmission

Cutoff near 2.2 keV

http://henke.lbl.gov/optical_constants/
Second Harmonic

- FEL is mostly 1\textsuperscript{st} and 3\textsuperscript{rd} harmonics
- Need to isolate 2\textsuperscript{nd} harmonic:
  - Block fundamental with solid and gas attenuators
  - 3\textsuperscript{rd} harmonic and higher absorbed in mirrors
  - Measure 2\textsuperscript{nd} harmonic on P3S
Second harmonic image:

Image on P3S, 900eV fund 0.4 mil Be + 5.5 torr atten

2.7 kev 3rd harmonic above cutoff

Single Particle
Second Harmonic Distribution

K.J. Kim, USPAS
Harmonics scale differently with attenuation

\[ \text{Counts} \propto T_{1st} \times M_{1st}^3 + T_{2nd} \times M_{2nd}^3 \times \left(\frac{P_{2nd}}{P_{1st}}\right) \]

\( T = \text{Transmission from attenuators, } M = \text{Mirror transmission} \)

1 keV fund (0.05%)

900 eV fund (0.06%)
Scan Gas Attenuator

- Second harmonic weaker than third harmonic
  - Bunching stronger at second harmonic, but...
  - Planar undulators only couple odd harmonics on axis

- Second Harmonic After Burners (SHABs)
  - Final undulators are tuned to second harmonic
  - H.D. Nuhn will discuss Thursday, 16:00, THOCI2
Summary of results:

- Approximately 0.5-3% 3rd Harmonic
- Proportion depends on FEL fundamental performance

<table>
<thead>
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<th>3rd Harmonic</th>
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</tr>
<tr>
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<td>0.05%</td>
<td>NA</td>
</tr>
<tr>
<td>1.7</td>
<td>NA</td>
<td>3%</td>
</tr>
<tr>
<td>6</td>
<td>NA</td>
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</tr>
<tr>
<td>8</td>
<td>NA</td>
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Second Harmonic

- Summary of results:
  - Approximately 0.05% 2\(^{\text{nd}}\) Harmonic
  - High energy will be measured soon

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Thanks to:
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