A Compact Electron Spectrometer for an LWFA and Other Challenges

Alex H. Lumpkin*, Rob Crowell, Yuelin Li, and Karoly Nemeth
Argonne Accelerator Institute
Argonne National Laboratory
Presented at FEL07, Novosibirsk, Russia
August 29, 2007

*Guest Scientist at Fermilab
OUTLINE

- Introduction
- Laser Wakefield Accelerator (LWFA) background
- Compact Electron Spectrometer Design
- Experimental and Analytical Results
- Challenges of FELS for the LWFA
- Summary
Terawatt Ultrafast High Field Facility (TUHFF)

- Ti:Sapphire oscillator with three amplifiers used.

TUHFF Laser Output

30fs, 0.6 J (20 TW) @ 10 Hz
Acknowledgments

Radiation Chemistry Group
Eli Shkrob
Sergey Chemerisov
Chuck Jonah
Bob Lowers
Chris Elles
Tim Marin
Alex Lumpkin
Oleg Korovanko - Coherent
Roberto Rey-Castro - Princeton
Rui Lian – Coherent
Dmitri Oulianov - Spectra

Collaborators

Yuelin Li (APS)  Bill Gropp (MCS)  Eric Landahl (APS)
Dohn Arms (APS)  Jin Wang (APS)  Don Walco (APS)
Wei Gai (HEP)  Yong Chul Chae (XFD)  Lynne Soderholm (CHM)
John Powers (HEP)  Bob Soliday (XFD)  Ronato Chiarizia (CHM)

Dave Bartels (NDRL)
Prof. John Cary (U. Colorado, Tech-X)
Prof. Steve Bradforth (USC)
Prof. Don Umstadter (U. Mich./Nebraska)
Prof. Christoph Rose-Petruck (Brown)

Stanislas Pommeret (CEA/Saclay)
Compact Electron Spectrometer Components Evaluated*

- Two NdFeB magnets
- Lanex converter screen (LOA)
- Roper 16-bit ICCD camera
- Bergoz ICT
- APS Magnet lab
- previous studies LOA
- S35 Optics lab
- Electronics lab

*Based On Y. Glinec et al. Design, LOA
Permanent Magnets Used in Compact Spectrometer Characterized in APS Magnet Measurement Lab

- NdFeB magnets are 5 x 2.5 x 1.2 cm³
- Assembly with 12-mm gap measured
16-bit Camera Characterized in APS S35 Optics Lab

- Roper Scientific Camera tested

![Image of 15-μm Diam Pinhole](image)

<table>
<thead>
<tr>
<th>Working Distance (cm)</th>
<th>Calibration factor (μm/pixel)</th>
<th>FOV (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>13.7</td>
<td>1.4</td>
</tr>
<tr>
<td>17.3</td>
<td>19.6</td>
<td>2.0</td>
</tr>
<tr>
<td>29</td>
<td>36.9</td>
<td>3.8</td>
</tr>
<tr>
<td>40</td>
<td>50.0</td>
<td>5.1</td>
</tr>
<tr>
<td>50</td>
<td>62.5</td>
<td>6.3</td>
</tr>
<tr>
<td>60</td>
<td>74</td>
<td>7.6</td>
</tr>
<tr>
<td>70</td>
<td>89.3</td>
<td>9.1</td>
</tr>
</tbody>
</table>

15-um Diam pinhole used for test source.

Image of 15-μm Diam Pinhole
Working distance=17.3 cm
105 mm FL Nikon Zoom lens

![Graph](graph)
ICT Tested in Lab with Calibration Loop

Bergoz ICT Data (2-28-07)

Equiv. Charge (nC) vs int. of ICT (nV-s)
Schematic of the Compact Spectrometer Setup
**Electron Beam Parameters:**

Transverse e- beam profile measured at 27 mm after the jet average of 100 shots, single shot much better

**Electron beam spectrum**

\[ F(E) \sim \exp(-E/\langle E \rangle) \]

\[ \langle E \rangle = 2.3 \pm 0.3 \text{ MeV} \]

**Electron pulse charge:**

2-3 nC ± 15-30%

**Electron pulse duration:**

~1-2 ps at the sample?

Will be measured by EOS
Simulation of laser plasma interaction and the bubble regime

Goal and means

- Support the femto chemistry experiment by mapping the laser and plasma condition for optimum beam generation
- Support advanced accelerator research by investigating the laser plasma accelerator physics
- Using 3-D PIC code VORPAL with several computer clusters at ANL

Topics

- Plasma and laser condition for femto chemistry
- Bubble regime laser plasma physics
- Injection of electron in the bubble regime: laser injection and nano wire trigger of wave breaking
- Beam properties: structure, propagation, and radiation
- Data visualization

VORPAL
Y. Li ANL
J. Cary, U. Colorado

Laser plasma bubble
Electron beam

Laser
Gas jet
Laser Modulation of the Beam Structure in the Bubble

Laser

![Diagram showing laser modulation in x-z and y-z planes.](image)

x-z plane
Polarization plane

y-z plane

 Courtesy of Y. Li

z (mm)
Laser modulation of the beam structure in the bubble

Beam modulation in the bubble

Micro bunching of the output beam

Courtesy of Yuelin Li
Towards sub-ps Electron Beams

Nature 431, Sept. 2004


Estimated $\tau \sim 10$ fs

Low divergence

Physics is very complicated and must be understood to optimize LWFA
For reliable quasi-monochromatic electron beam generation
LOA Experiments Show Quasi-monoenergetic Beams with Beat-Wave Injection Technique

**Injection Technique Provides More Reproducible Performance and Energy Tuning**

- 20-shot statistics tabulated.
- Energy tuning by adjustment of injection timing.

<table>
<thead>
<tr>
<th></th>
<th>&lt;Peak energy&gt;*</th>
<th>σ_{peak}_energy</th>
<th>&lt;Energy spread&gt;</th>
<th>σ_{Energy spread}</th>
</tr>
</thead>
<tbody>
<tr>
<td>117 MeV</td>
<td>7 MeV</td>
<td>11 % (FWHM)</td>
<td>2 %</td>
<td></td>
</tr>
<tr>
<td>&lt;Charge&gt;</td>
<td>σ_{charge}</td>
<td>&lt;Divergence FWHM&gt;</td>
<td>σ_{beam divergence}</td>
<td></td>
</tr>
<tr>
<td>16 pC</td>
<td>68 pC</td>
<td>5.8 mrad</td>
<td>1.8 mrad</td>
<td></td>
</tr>
</tbody>
</table>

* <X> refers to the mean value of X and σ to the standard deviation of X.

LBNL LOASIS Experiments Attain 1 GeV

GeV electron beams from a « centimetre-scale » accelerator

310-μm-diameter channel capillary

\[ P = 40 \text{ TW} \]

density \( 4.3 \times 10^{18} \text{ cm}^{-3} \).

Courtesy of V. Malka
TUHFF as an Ultrafast x-ray/VUV Source

- X-ray absorption, scattering studies of solvent structure and dynamics
- VUV (1-photon) probing of excited states
SUMMARY

- The ANL LWFA is preparing for quasi-monoenergetic beam generation tests in CY07.
- Rapid progress in the LWFA community on generating higher charge and more controllable beams by using some form of electron injection process has occurred.
- Charge, energy spread, and beam emittance are still challenges that need addressing to move from an LWFA beam driving spontaneous radiation to FEL. First spontaneous results recently at Jena. Like to see e-beams so well defined that OTR techniques apply with standard camera.
- The next LWFA community target is to generate a 10-GeV beam by the AAC08 meeting in July 2008.
- Plans at LBNL and LOA for FEL experiments soon.
ACKNOWLEDGMENTS

- We acknowledge assistance on tests for magnet measurements by Isaac Vasserman, camera tests with Bingxin Yang and John Power, ICT tests with A. Brill and T. Pietryla of ASD/APS/ANL.
- The loan of the Roper Scientific 16-bit camera and Bergoz ICT by AWA staff is noted and appreciated.
- The support of Kwang-Je Kim, Rod Gerig, and Harry Weerts of the Argonne Accelerator Institute is acknowledged.