Diagnostics for Laser Plasma Accelerators

Jeroen van Tilborg

LOASIS Program
Lawrence Berkeley National Laboratory

Workshop on Future Light Sources

March 2\textsuperscript{nd} 2010
Outline of this talk

LPA characteristics

Focus on
• Energy, energy-spread & divergence
  • Optical & EUV undulator radiation
• Longitudinal bunch profile
  • THz radiation
  • EOS and semiconductor switching
• Source size
  • X-rays from betatron motion

Conclusion
The LOASIS group
http://loasis.lbl.gov

Lasers, Optical Accelerator Systems Integrated Studies (LOASIS)

Scientific Staff
- Dr. Wim Leemans, Program Head
- Dr. Eric Esarey, Deputy Program Head
- Dr. Cameron Geddes
- Dr. Anthony Gonsalves
- Dr. Nicholas Matlis
- Dr. Carl Schroeder
- Dr. Csaba Töth, Deputy Head for Operations
- Dr. Jeroen van Tilborg

Doctoral and Graduate Students
- Michael Bakeman, University of Nevada, Reno
- Chen Lin, Peking University, People's Republic of China
- Tanguy Le Corre, École Nationale Supérieure de Physique de Strasbourg, France
- Guillaume Plateau, École Polytechnique, France
- Satomi Shiraiishi, University of Chicago, Chicago
- Daniel Mittelberger, UC Berkeley

Postdoctoral Researchers
- Dr. Carlo Benedetti, University of Bologna, Italy
- Dr. Min Chen, Institute of Physics, Chinese Academy of Sciences
- Dr. Estelle Cormier-Michel, University of Nevada, Reno
- Dr. Kei Nakamura, University of Tokyo, Japan
- Dr. Jens Osterhoff, University of Munich, Germany
- Dr. Thomas Sokollik, Technical University of Berlin, Germany

Administrative Support
- Martha Condon
- Olivia Wong

Technical Support
- Zachary Eisenraut
- David Evans
- Mark Kirkpatrick
- Greg Mannino
- Donald Syversrud
- Nathan Ybarrolaza
Laser plasma accelerator:
Femtosecond MeV-GeV beams

Expected:
- Bunch duration < $\lambda_p$ (~10’s fs)
- Energy MeV’s to GeV
- Energy spread few-%
- Divergence ~ few mrad
- Source size < $w_0$ (~μm’s)
Undulator radiation as energy, energy-spread & emittance diagnostic

- Undulator radiation provides phase-space moments of beam: charge, energy, x, x', y, y', energy spread, transverse emittance

LBNL-LWFA

Laser beam

~ cm plasma channel

0.5 GeV, Electron beam

BPM

BPM

BPM

~1 m

Undulator

2.18 cm period

44 periods

K=1.85

Compact high-gradient quadrupoles:

B(r_{bore})~1.5 T

magnetic spectrometer

(1.2 T)

ICT

e-beam

undulator radiation

phosphor imaged onto CCD

grating

~500 T/m

Talk by Mike Bakeman (500 MeV, 30 nm)

Photons/shot/(0.1% BW)

σ/γ = 0.25%

1 mm-mrad

σ/γ = 0.25%

10 mm-mrad

Photon energy (eV)

Photon energy (eV)
Undulator radiation around 800nm (65 MeV) and 18nm (210 MeV)

Information in spectral width

\[
\left(\frac{\delta \lambda}{\lambda}\right)_{\text{measured}} = (2 \sigma_f / \gamma)^2 + (\vartheta^2 / 2)^2 + 1/N_u^2
\]

\[\varepsilon_n \approx 1\pi \text{ mm mrad} \quad \sigma_f / \gamma \approx 1\%\]

A compact synchrotron radiation source driven by a laser-plasma wakefield accelerator

Schlenvoigt et al., Nat. Phys 2008

Laser-driven soft-X-ray undulator source

Fuchs et al., Nat. Phys 2009
Longitudinal charge diagnostic:
Coherent Transition Radiation

\[ E_{CTR}(\omega) \sim N \cdot \varepsilon(\theta, \gamma) \cdot D(\theta, \gamma, \rho, \omega) \cdot F(\omega, \theta) \]

- \( \omega \) = THz frequency
- \( \theta \) = Angle of observation
- \( \gamma \) = Electron energy
- \( \rho \) = Transverse emitter size
THz measurement reveals 40-50 fs ebeam length

**Scanning**

- ZnTe: Elliptical polarized probe beam
  - 50 fs (rms) electron bunch

**Single-shot (cross-cor.)**

- Phase retardation \( \phi_{\text{ret}}(\tau) \) (rad)
- Single-shot (spectral)

**Talk by Nicholas Matlis**

- Laser Pulse
- OAP1
- Target Chamber (w)
- PE window
- Lens
- Polarizer
- ZnTe or GaP
- \( \lambda/4 \) plate
- Analyzer
- BBO
- Transverse axis—temporal axis

---

*van Tilborg et al., PRL 2006*

*van Tilborg et al., Opt. Lett. 2006*
THz measurement reveals two-component ebeam
Semiconductor switching
Timing & bunch length diagnostic

Potential: non-EOS-based timing
Intrinsic production of X-rays in LPA

\[ \theta \sim \frac{a_\beta}{\gamma} \]

\[ \lambda_\beta = \left(2\gamma\right)^{1/2} \lambda_p \propto \sqrt{\gamma/n_e} \]

- 1-10 keV X-rays
- Directional source
- Image crosshair \( \rightarrow \) size

\[ \lambda \beta = 2 \gamma \left(\frac{1}{2}\right) \lambda_p \propto \gamma / n_e \]
Utilize intrinsic LPA radiation for diagnostics

- THz for longitudinal bunch profile
  - From plasma/vacuum boundary
  - From foil
- EUV and OR for energy, energy-spread & divergence
  - Undulator radiation
- X-rays for source size
  - LPA betatron oscillations