Calibration of Charge Diagnostics using Electrons from a Laser Plasma Accelerator

EAAC 2017, WG5 - High-gradient plasma structures/Advanced beam diagnostics

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Elba, Italy, 26.09.2017
Charge Measurement in PWA

- Plasma wakefield acceleration can accelerate electron bunches with charges from several fC\textsuperscript{[1]} up to nC range\textsuperscript{[2]}

- Charge important parameter to understand and control plasma acceleration

- Difficult to find devices with dynamic range of six orders of magnitude

- Background sources such as EMP or x-rays from betatron radiation and bremsstrahlung always present

- At FLASHForward different diagnostics installed to cross-calibrate and test for use in plasma wakefield experiments

\textsuperscript{[1]} e.g. C. Thaury \textit{et al.}, Scientific Reports 5:16310 (2015)

\textsuperscript{[2]} e.g. X. Wang, \textit{et al.}, nature comm. 4:1988, DOI: 10.1038/ncomms2988 (2013)
LWFA at FLASHForward for Diagnostic Calibration

Overview of the Experimental Labs

See Talk by Jens Osterhoff: Wed. 18:45, Joint Session
Laser lab:
- Amplitude laser system
- 25 TW Ti:Sa Laser
- 25 fs, 10 Hz

Experimental lab:
- LWFA setup to test diagnostics
- Ionisation test setup to study ionisation properties

Talk by G. Tauscher:
WG1, Mo., 17:00
LWFA at FLASHForward for Diagnostic Calibration

Experimental Setup

- Pre-interaction laser diagnostic
- Post-interaction laser diagnostic
- F/16
- DRZ/Mirror
- ICT
- DaMon
- Electron spectrometer
- X-ray diagnostic
- Beam dump
Charge Diagnostics

DRZ Screens

- Phosphor screens which emit stored energy in form of photons
- Screens can be stimulated by electrons or x-rays
- Light Emission peaked at 545 nm
- Installed for measurement of electron profile and spectrum
- Clear aperture: 70 mrad (profile screen)
Charge Diagnostics

Integrating Current Transformer\(^3\) (ICT, Toroid)

- Electron pulse induces current in toroid
- By integrating the induced voltage it is possible to measure the bunch charge.
- Clear aperture: 100 mrad

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image from bergoz.com

[4] Courtesy of Georgia State University:
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/toroid.html
Charge Diagnostics

Dark Current Monitor\textsuperscript{[5,6]} (DaMon)

- Stainless Steel cavity used as passive resonator
- Frequency of first monopole mode (TM01) at 1.3 GHz
- Induced TM01 mode used for charge measurement
- Amplitude of induced mode proportional to charge
- Two readout channels for high dynamic range
- Clear aperture: 35 mrad

\textsuperscript{[5]} D. Lipka \textit{et al.}, Proc. of DIPAC 2011, Hamburg, WEOC03
\textsuperscript{[6]} D. Lipka \textit{et al.}, Proc. of IBIC 2013, Oxford, WEPF25
Absolute calibration of DRZ screens

Collaboration of DESY¹, HZDR², LMU München³, MPQ Garching⁴, University of Jena⁵

- Absolute calibration of DRZ screens at ELBE in Dresden
  - Calibration of light output against ICT data for charge region of about 10 pC to 100 nC.
  - High light output of $1.05 \times 10^{10}$ photons/(sr * pC) for DRZ High
  - Light yield of DRZ High by a factor of 13 higher compared to LANEX Fine

<table>
<thead>
<tr>
<th>Screen Type</th>
<th>Light yield at 50 pC [arb. u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRZ High</td>
<td>13.1</td>
</tr>
<tr>
<td>Kodak Biomax</td>
<td>9.5</td>
</tr>
<tr>
<td>DRZ Plus</td>
<td>8.8</td>
</tr>
<tr>
<td>DRZ Standard</td>
<td>6.4</td>
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<tr>
<td>LANEX Fine</td>
<td>1.0</td>
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</tbody>
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Comparison of DRZ and DaMon

High dynamic range of DaMon and sensitivity on fC level
Comparison of DRZ, DaMon and ICT

ICT sensitive to noise from EMP

[7] similar as in e.g.:
[8] example for no factor:
K. Nakamura et al., PRSTAB 14, 062801 (2011)
High Dynamic Range of DaMon

Up to seven orders of magnitude from two channels
Future Plans

• Rotate setup to have non-destructive measurement devices in front

• Cross-calibration of our imaging of DRZ screens to be able to use absolute calibration of screens

• Investigate noise and scaling factor of ICT in more detail

• Install diagnostics at PWFA experiments at FLASHForward
Summary

- Three different types of charge diagnostics installed for LWFA experiments at FLASHForward:
  - DRZ screens, DaMon, ICT

- Absolute calibration of DRZ screens was performed at ELBE:
  - DRZ High was measured to have a very high light output

- ICT was tested in noisy environment:
  - Charge scaling required at our setup
  - Noise restricting measurement to charges above a few pC
  - Non-destructive measurement

- DaMon was first tested in LWFA setup:
  - High dynamic range from ~10 fC up to 100 nC
  - Insensitive to electromagnetic noise from plasma
  - Non-destructive measurement
DaMon Charge Measurement

Field distribution of 1. monopole mode
Simulation view

\[ U = U_0 \sin(\omega t) \exp \left( -\frac{t}{\tau} \right) \]

\[ \omega = 2\pi f \]

\[ \tau = \frac{Q_L}{\pi f} \]

\[ \frac{U_0}{q} = \pi f q \sqrt{Z/Q} \]

\[ \frac{R}{Q} = \text{normalized shunt impedance (simulated)} \]

\[ Z = \text{line Impedance} \]

\[ Q_{\text{ext}} = \text{resonator external quality factor} \]

\[ S = \text{const} \rightarrow U_0 \sim q \]

Courtesy of D. Lipka
DaMon Charge Measurement

Signal without electronics

\[ q \approx 0.34 \text{ nC} \]

Signal with electronics

Complete measured spectrum up to 6 GHz

First three monopole modes frequencies:
1.299; 3.236; 5.074 GHz

Courtesy of D. Lipka
High Dynamic Range of DaMon

Background shots included