Development of a non-invasive diagnostic for local acceleration gradient and dephasing length

LWFA at PlasMed-X

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Simon Bohlen¹, Theresa Brümmer¹, Florian Grüner², Martin Meisel¹, Kristjan Põder¹, Theresa Stauffer², Matthew Veale³ and Jens Osterhoff¹

¹ Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany
² Universität Hamburg, Luruper Chaussee 149, 22607 Hamburg, Germany
³ STFC, Rutherford Appleton Laboratory, Didcot, OX11 0QX, United Kingdom
PLASMED-X in a nutshell

Goal: detect Gold nanoparticles via x-ray fluorescence

Method: Use LWFA + Thomson Scattering

understand and control electrons

optimise bandwidth and flux

LWFA at PlasMed-X

Overview of the experimental labs

Laser lab:
- Amplitude laser system
- 25 TW Ti:Sa Laser
- 25 fs, 10 Hz

See Talk by J. Garland: Thu. 18:00, WG5

Target characterisation setup

LWFA setup to test diagnostics and do medical imaging
Experimental setup

Schematic of the LWFA setup

E \sim 550 \text{ mJ}

\text{t} \sim 30 \text{ fs}
Experimental setup

**Differential pumping cube**

E $\sim$ 550 mJ, $t \sim$ 30 fs

- Differential pumping cube
- Gas jet target
- Dipole
- Magnet
Differential pumping setup

Enclosed differential pumping allows 10 Hz repetition rate

- Cube with 2mm holes, differentially pumped
- Surrounding vacuum pressure < $3 \times 10^{-4}$ mbar with 10 Hz gas pulsing
- Allows for systematic studies of LWFA at high repetition rates
- Forms a robust and reliable electron beam source at high repetition rate
Experimental setup

Experimental setup for comparison of charge diagnostics

\[ E \sim 550 \text{ mJ} \]
\[ t \sim 30 \text{ fs} \]
Charge Diagnostics

Integrating Current Transformer\(^2\) (ICT, Toroid)

- Electron pulse induces current in toroid

- By integrating the induced voltage it is possible to measure the bunch charge.

\(^2\) bergoz ICT: ICT-082-10.0-VAC
image from bergoz.com

\(^3\) Courtesy of Gorgia State University:
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/toroid.html
Charge Diagnostics

Dark Current Monitor\textsuperscript{[4,5]} (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

\[ \text{Courtesy of D. Lipka} \]

\[ \text{[4]} \text{D. Lipka et al., Proc. of DIPAC 2011, Hamburg, WEOC03} \]
\[ \text{[5]} \text{D. Lipka et al., Proc. of IBIC 2013, Oxford, WEPF25} \]
Charge Diagnostics
Comparison of ICT and DaMon as non-invasive charge diagnostics

[DaMon Channel 1] [DaMon Background]
+[ICT] [ICT Background]
+[DRZ Background]

$10^0$ $10^1$ $10^2$

$10^{-2}$ $10^{-1}$ $10^0$

$10^5$ $10^6$

DRZ Counts$^{[6,7]}$

References:
Gas jet electron beams with Ionisation Injection

Clean electron profile and stable pointing

Divergence $6.3 \pm 0.5$ mrad in x and $11.9 \pm 1.2$ mrad in y

Pointing stability of $1.4$ mrad
Gas jet electron beams with Ionisation Injection

Spectral stability during Thomson Scattering runs at actual repetition rate
Gas jet electron beams with Ionisation Injection

Electrons peaked at 58.2 MeV with a spectral stability of ± 2.3 MeV at 50,000 shots
Gas jet electron beams with Ionisation Injection

Average charge changed by 0.5 fC after 50,000 shots

Charge: 14.4 ± 3.9 pC
Fit: 14.4 + Shotnumber × 9.5 × 10^{-9} pC
Active Plasma lenses$^{[8,9,10]}$

Focusing and emittance measurement of LWFA generated electron beams

Charge Diagnostics

Comparison of ICT and DaMon in discharge environments
Charge Diagnostics
Comparison of ICT and DaMon in discharge environments

ICT Trace

DaMon Trace

Desy | Development of non invasive diagnostics | EAAC 2019 | Simon Bohlen et. al.
Thomson Scattering (TS)

Working Principle

- Energy of scattered photons
  \[ E_\gamma \approx \frac{4\gamma_e^2 \times E_{\text{Laser}}}{1 + \gamma_e^2 \theta^2 + a_0^2 / 2} \]
Experimental setup

Experimental Setup for Thomson Scattering Experiments

E \sim 550 \text{ mJ} \\
t \sim 30 \text{ fs}

Gasjet target

Dipole

magnet

Up to 10 m of propagation

HexiTec CdTe detector
HexiTec$^{1,2}$ CdTe pixellated detector

4-200 keV sensitivity with high spectral resolution

- 1 mm thick CdTe, 0.8 keV energy resolution
- 80x80 pixels, 250 μm

Kindly loaned from CLF

$^1$Seller et al., J Instrum. 6 (2011)

Experimental setup

Experimental Setup for Thomson Scattering Experiments

E \sim 550 \text{ mJ} \\
t \sim 30 \text{ fs}

Gasjet target

HexiTec CdTe detector

Up to 10 m of propagation
Thomson Scattering
Non-invasive energy measurement

Measure Thomson spectrum

\[ E_\gamma \approx \frac{4\gamma_e^2 \cdot E_{\text{Laser}}}{1 + a_0^2 / 2} \times F_K \] [11]


Calculate Electron spectrum
Experimental setup

Experimental Setup for Thomson Scattering Experiments

E \sim 550 \text{ mJ}

\frac{t}{c} \sim 30 \text{ fs}

Gasjet target

Up to 10 m of propagation
Experimental setup

Experimental Setup for Thomson Scattering Experiments

\[ E \approx 550 \text{ mJ} \]
\[ t \approx 30 \text{ fs} \]

Gasjet target

Up to 10 m of propagation
Experimental setup

Experimental Setup for Thomson Scattering Experiments

- GasJet target
- DaMon
- DRZ profile screen
- ICT
- Dipole
- Magnet
- HexiTec CdTe detector
- E ~ 550 mJ
- t ~ 30 fs
- Up to 10 m of propagation
Thomson Scattering as energy measurement

Good agreement between peak on spectrometer and calculation from Thomson spectrum
Thomson Scattering as energy measurement

Non-invasive measurement of electron energy and local acceleration gradient inside plasma
Thomson Scattering as energy measurement

Non-invasive measurement of electron energy and local acceleration gradient inside plasma

\[ W_e(z) = E(z_0) \left( 1 - \frac{1}{2L_D} (z - z_0) \right) (z - z_0) \times q \]
Thomson Scattering as energy measurement

Non-invasive diagnostic to measure local field gradient, injection point and dephasing length

\[ W_e(z) = E(z_0) \left( 1 - \frac{1}{2L_D} (z - z_0) \right) (z - z_0) \times q \]

\[ z_0 = -377.6 \pm 28.3 \text{ um} \]

\[ E(z_0) = 289.5 \pm 39.6 \frac{GV}{m} \]

\[ L_D = 404.7 \pm 64.5 \text{ um} \]
Summary

Development of a non-invasive diagnostic for local acceleration gradient and dephasing length

- Stable acceleration of electrons over long time scales with high repetition rate using II

- DaMon diagnostic insensitive to EMP allowing use of plasma lenses

- Use of Thomson scattering as non invasive diagnostic to measure:
  - electron peak energy
  - local acceleration gradient
  - injection point
  - dephasing length