Optimisation of compact radiation sources for NTR applications

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NTR network

Motivation

Radiation sources have been shown to have many applications in nuclear threat reduction, including:

- **Radiography:** Whether in (air)ports or 'in the field', radiation sources have long been used for absorption imaging. Smaller sources would increase resolution of such scanners, and open the possibility of phase contrast imaging to extend the range of elements detectable.
- **Nuclear Scattering:** Either polarised or unpolarised gamma rays can identify isotope specific content.

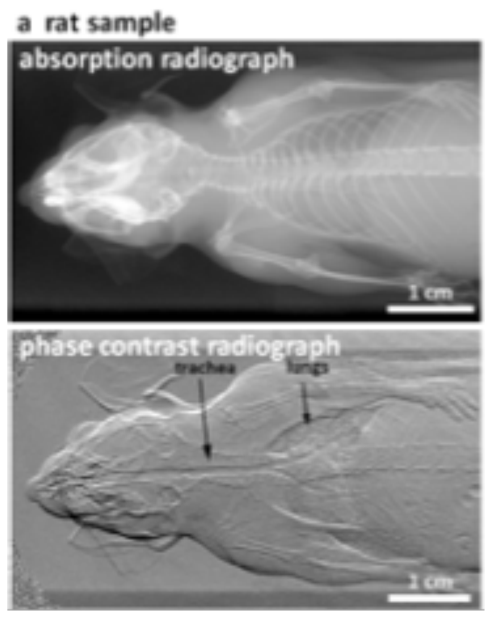


Image from: Rawson et al. BMC Biology (2020) 18:21 https://doi.org/10.1186/s12915-020-0753-2

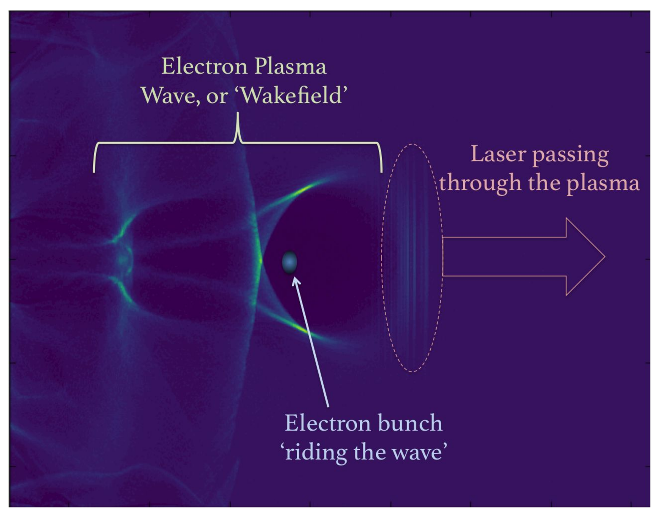
Laser Wakefield Acceleration (LWFA)

A laser incident on a low density gas will ionise it and form a plasma. The transverse variation of the laser intensity results in a ponderomotive force which predominantly expels electrons, resulting in a charge separation and strong longitudinal electric field.

Electron beams produced by laser wakefield acceleration (LWFA) can be:

- Short (sub-10 fs)
- Small (sub 10 microns)
- High energy (keV - GeV)

with acceleration distances of mm - cm



Radiation Mechanisms

LWFA electrons are commonly used to generate radiation sources through three mechanisms:

- **Betatron oscillations:** While accelerating, transverse fields in the wakefield result in oscillations of the electrons, causing **synchrotron-like radiation.**
- **Inverse Compton scattering (ICS):** After leaving the accelerator, a second laser pulse can scatter from the relativistic electron bunch, producing a **narrow-band high energy photon source**
- **Bremsstrahlung:** After accelerating, the electrons may be directed into a high-Z radiator target, generating a **high flux, high energy but lower quality x-ray source**.

Methodology

EPOCH

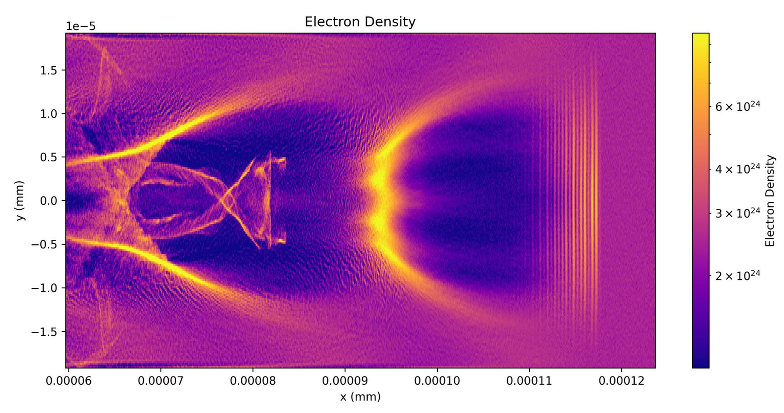
A particle-in-cell code was run in order to study how novel laser-focusing geometries, might be used to optimise the radiation source. This was done in two ways:

1. Driving two side-by-side wakefields which then merge. This was to result in increased transverse oscillations which should drive brighter radiation from betatron oscillations.
2. Driving a wakefield with a central region where the transverse fields are absent. This was to result in less oscillatory motion, such that the electron beam might be suitable for ICS or bremsstrahlung.

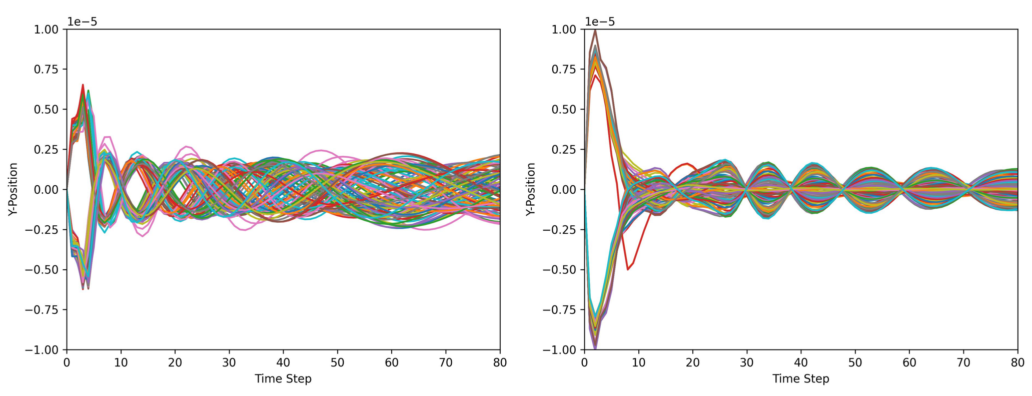
Simulation Results

Double Pulse for Increased Oscillations

Electrons can be seen oscillating in the wakefield regardless of whether a single, or double pulse is used.

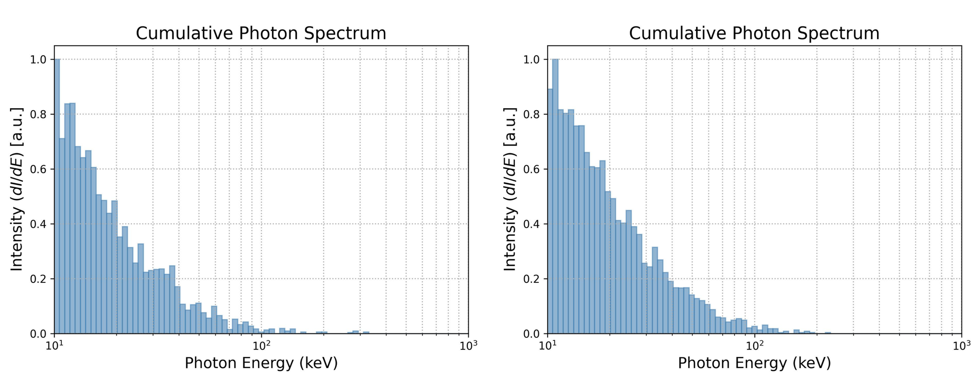


Particles injected into the wakefield



Electrons tracked in a wakefield generated by one pulse (left) or two pulses (right)

A single pulse results in uncontrolled oscillations, generating radiation, but through chaotic oscillations. A double pulse results in in-phase oscillations

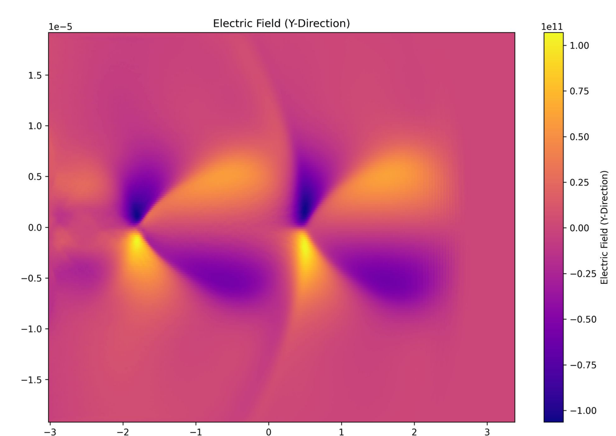


X-ray spectrum shows a similar shape with one pulse (left) and two pulses (right) but approximately 50% increase in flux

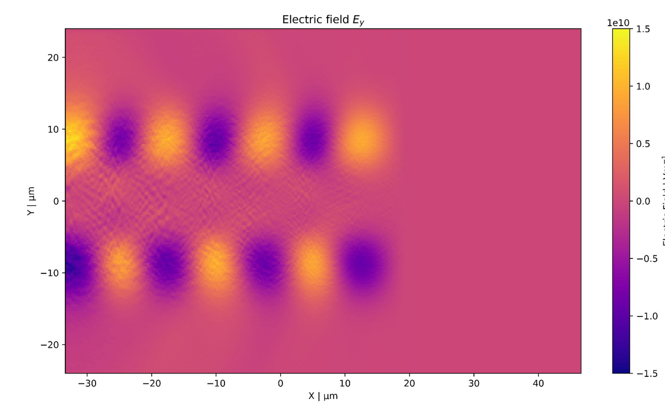
Spectrum of the x-rays were also shown to extend into higher energy.

Double Pulse for Smaller Transverse Fields

Ordinarily, transverse fields in the plasma accelerator result in oscillations of the electrons, reducing pointing stability and reproducibility

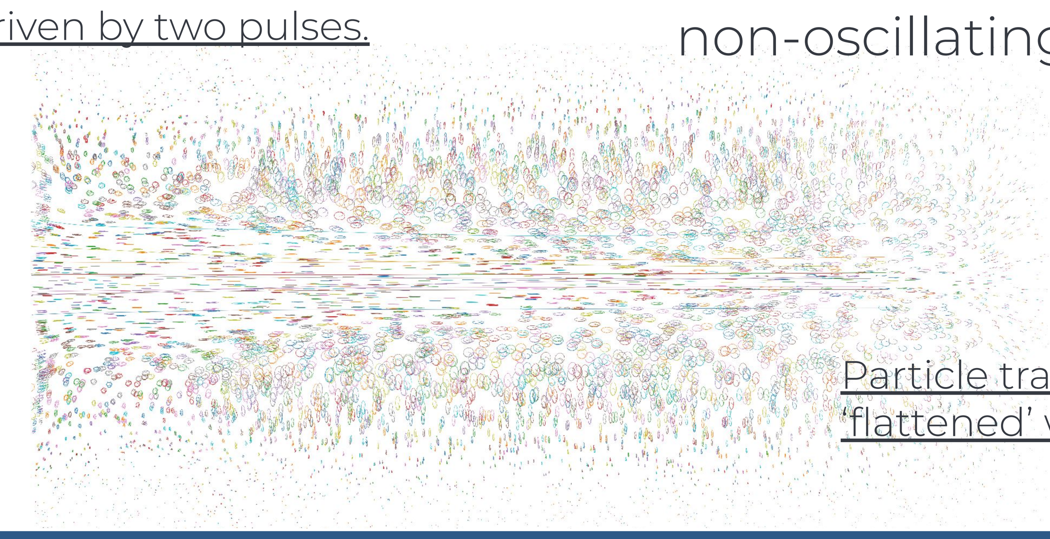


Transverse fields in the wakefield driven by a single pulse.



Transverse fields in the wakefield driven by two pulses.

Two pulses can be used to suppress the transverse fields in the centre of the wakefield, resulting in a population of electrons which have non-oscillating trajectories.



Particle tracking of electrons in a 'flattened' wakefield

Conclusions

- Significant progress has been made in understanding how novel laser focusing geometry can affect the injection and acceleration of laser wakefield accelerated electron beams.
- Photon sources with energies of NTR-relevance have been simulated, and future work is ongoing in order to demonstrate that such photon sources can be generated using compact and affordable laser systems opening up the possibility of portable gamma sources at 100 Hz - 1kHz.
- Future work will extend these results.

Acknowledgements

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