Compact X-Ray Sources

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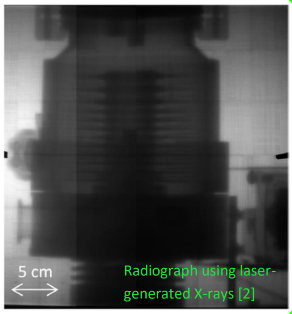
Background and Motivation

Seaports and airports process high volumes of cargo: In 2015, 3.8 billion tonnes passed through European seaports alone [1]. Scanners with highly penetrating X-rays are often used to look for heavy elements through absorption imaging. X-rays directly from laser-plasma interactions have been used for radiography with spatial resolution limited to around 0.1mm [2]. Here we explore the use a compact plasma accelerator to generate electrons which in turn will produce bremsstrahlung X-rays upon impact with a thin foil. The aim of the study is to simulate both the plasma and nuclear processed which lead to the production of X-rays with high energy and micron source size.

[1] Eurostats: (http://ec.europa.eu/eurostat/statistics-explained/index.php/Maritime_ports_freight_and_passenger_statistics) Last Accessed on 13/9/17

[2] C M Brenner et al. Plasma Physics and Controlled Fusion **58** 014039 (2016)



Radiograph using laser-generated X-rays [2]

Laser-based electron acceleration simulations

A particle-in-cell code (EPOCH [3]) was used to model wakefield acceleration of electrons. The laser parameters were chosen to match the 10Hz Gemini TA2 laser. The plasma density was also adjusted to give an optimal electron spectrum.

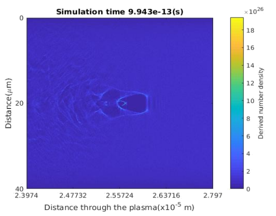
Laser intensity	5.6E18 Wcm^{-2}
Pulse duration	40 fs
Focal spot diameter	7.2 microns

[3] T D Arber et al., Contemporary particle-in-cell approach to laser-plasma modelling, Plasma Phys. Control. Fusion **57** 113001 (2015)

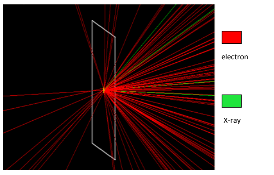
Monte Carlo simulation of X-ray production from bremsstrahlung

Geant4 [4] is a toolkit for the simulation of particles through matter and is developed by CERN. The code used in this project was a highly modified version of the B2aExample simulation, with the added physics list of "FTFP BERT 2.0" to simulate the required physics. The simulations shown here weighted the input electron spectrum using the data provided from EPOCH.

[4] Agostinelli S., et al.Geant4 - a simulation toolkit, NIM Phys. Res. Sect. A, **506** (2003)

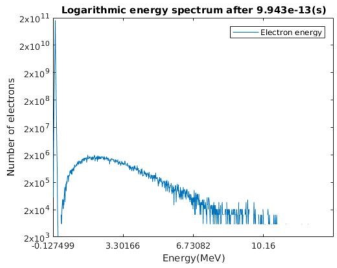


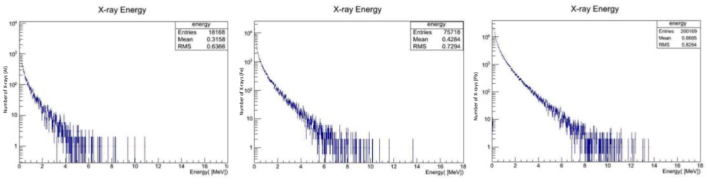
EPOCH simulation of wakefield acceleration



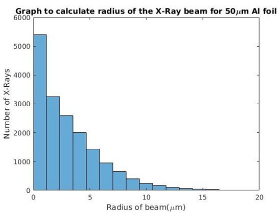
Geant4 simulation of the bremsstrahlung

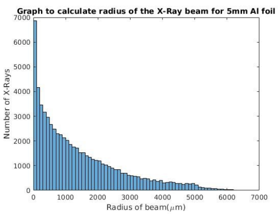
- An intense laser pulse travels through the plasma leaving a strong electron density modulation in its wake.
- This generates high electric fields capable of accelerating electrons to 100 MeV in around a millimetre.
- Geant4 uses a Monte Carlo algorithm to model X-ray generation.
- The energy of the generated photon can be recorded as well as its position and direction.





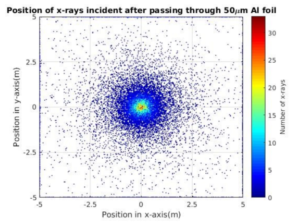
- The electron spectrum extends to 10 MeV
- The spectrum of the X-rays can be modified by using different radiator materials

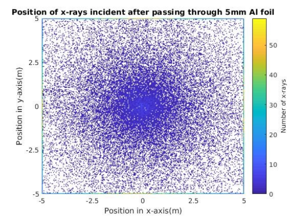




- The X-ray generation coordinates were extracted from Geant4 to find the source size of the bremsstrahlung.
- The sources size is taken to be the standard deviation of the distance from axis.
- The source size is found to increase with the thickness of the radiator foil.

Al Foil Thickness	Source Size	Number of Photons
50 microns	4.4 microns	18168
5 mm	1.9 mm	721993





- The position of the x-ray was also measured around 3 metres away.
- While the source size increased for thicker foils, this also resulted in a broader region being radiated, speeding up any potential scanner.
- For a specific resolution it would be possible to pick a target thickness to increase x-ray flux and radiated region.

This project has demonstrated the use of laser wakefield accelerated electrons to generate a compact X-ray source. The X-rays created are of (or above) the energies used in commercial scanners. The material and thickness of the radiator has been shown to alter the X-ray energy and divergence broadening the range of applications. With the appropriate optimisation, such a source may be used for high resolution x-ray imaging, large area scanning or, potentially, imaging with isotopic sensitivity. Future work could include modelling detectors to determine a minimum flux and thus a lower bound on resolution capability for various laser parameters.

NuSec Nuclear Security Science Network

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