Implementing betatron radiation for beam diagnostics studies

Debdeep Ghosal[1,2], Joe Noakes[1], Hossein Saberi[3], Joseph Wolfenden[1,2], Carsten P. Welsch[1,2], Guoxing Xia[3]
[1] . Department of Physics, University of Liverpool, L69 7ZE, UK
[2] .The Cockcroft Institute, Warrington, WA4 4AD, UK
[3] . Department of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

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INTRODUCTION & MOTIVATION

Betatron radiation (BR) is a form of synchrotron radiation emitted by accelerated electron or positron-like charged particles. As a valuable tool it can provide useful information about their trajectories, momentum and acceleration. It has good potential as a novel non-destructive diagnostic for laser-driven plasma wakefield acceleration (LWFA) and beam-driven plasma wakefield acceleration (PWFA) [1,2].
BR encapsulates valuable information about the properties of the witness beam [1], measurements of which can provide a non-invasive means to reconstruct **beam parameters** (energy, emittance, and divergence), offering insights into the dynamics of the plasma wakefield and facilitating advancements in particle accelerator technology.
One method of extracting this rich information about beam parameters from measurements of BR is- maximum Likelihood Estimation (MLE) technique, while machine learning (ML) approaches can then be applied to improve the accuracy of these measurements. Furthermore, a hybrid ML-MLE simulation approach was attempted to obtain a finer insight, where ML and MLE individually have their limitations.

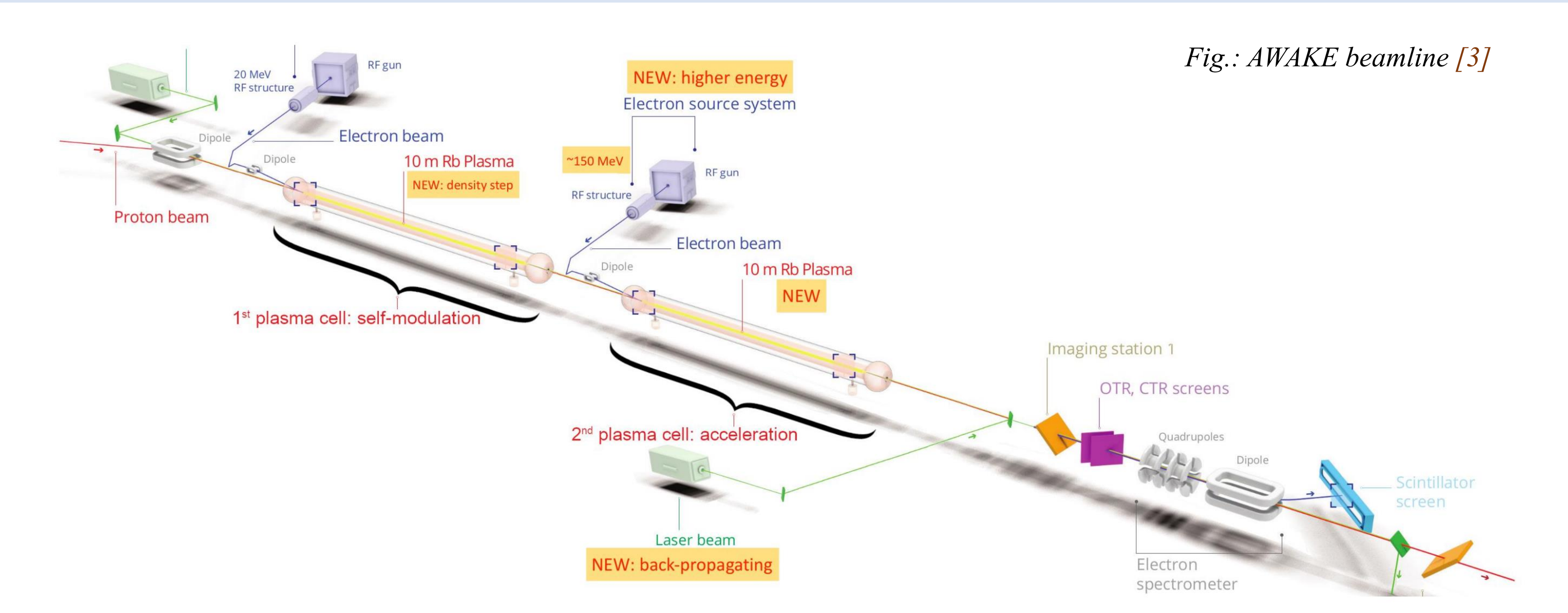


Fig.: AWAKE beamline [3]

SIMULATION (BEAM) PARAMETERS

Parameter	Value of p driver beam	Value or e trailing beam
σ (x,y) (μm)	2	0.5 to 10
σ (z) (μm)	4	1
Q (C)	1×10^{-9}	-5×10^{-10}
Density (m^{-3})	10^{23}	10^{22}
Energy (GeV)	1	0.01

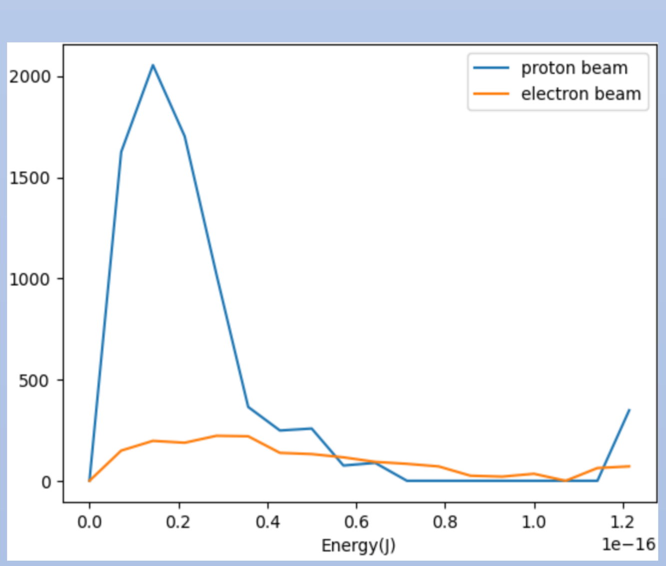
SIMULATION STEPS

- Spot sizes were chosen by setting RMS beam size in x and y direction
- BR calculated with the particle trajectories from the PyWarpX simulation
- Beam profile of the trailing beam and plasma distribution were checked
- **MLE:** Training data consisted of each spot size and its spectrum; Perfect match of predicted spot size to actual spot size (initially 20 simulations)
- **ML:** Multi-layer perception ANN architecture used, consistency of training data with the spot sizes
- **Hybrid ML+MLE:** perfect matching of predicted and actual spot size values
  Hybrid method is faster for large data sets as MLE takes considerably less time than machine learning algorithms
  Note: Only faster for large data sets; smaller/reduced arrays slowed down algorithm as data is harder to find patterns.

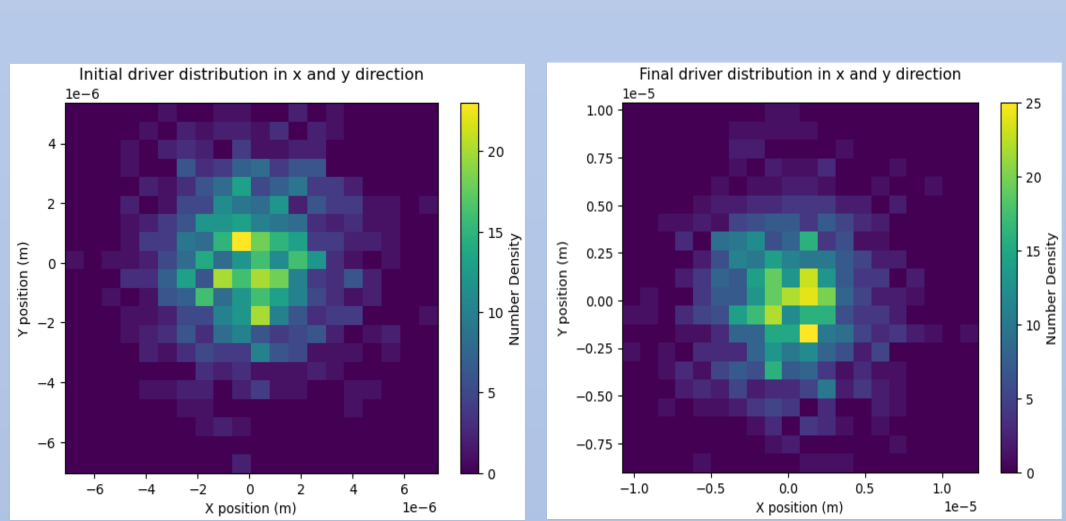
RADIATION DETECTION ASPECT

- Primary radiation is understood to be in the X-ray spectrum range [3]
- Narrowing down the various types of possible X-ray detectors (imp. factors- **energy** and **spatial resolution**, **sensitivity**, **fast response time**, **cost** etc.
- MC Simulation: Understanding physics from the interaction between SPS proton beam and a thin high density (probably metal) slab

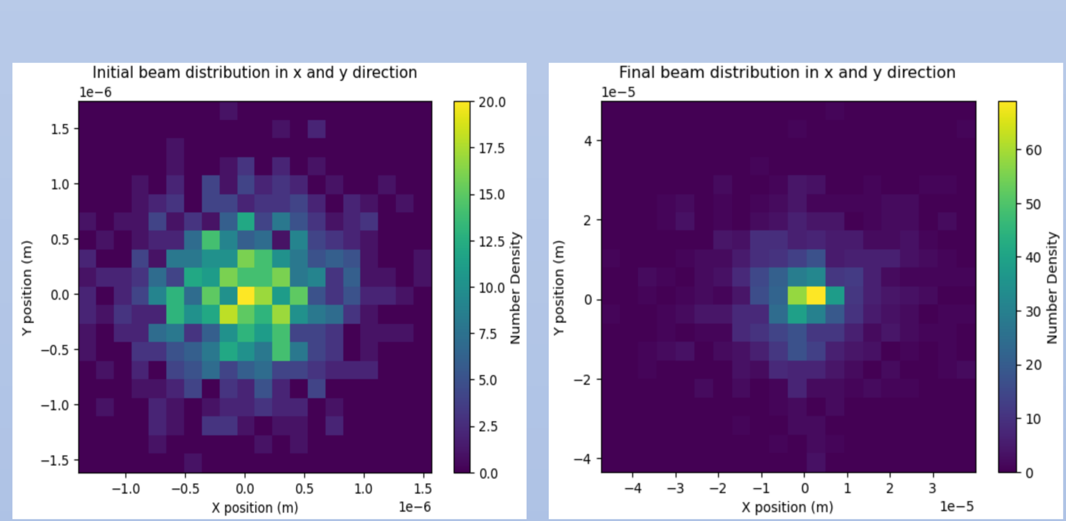
PRELIMINARY RESULTS



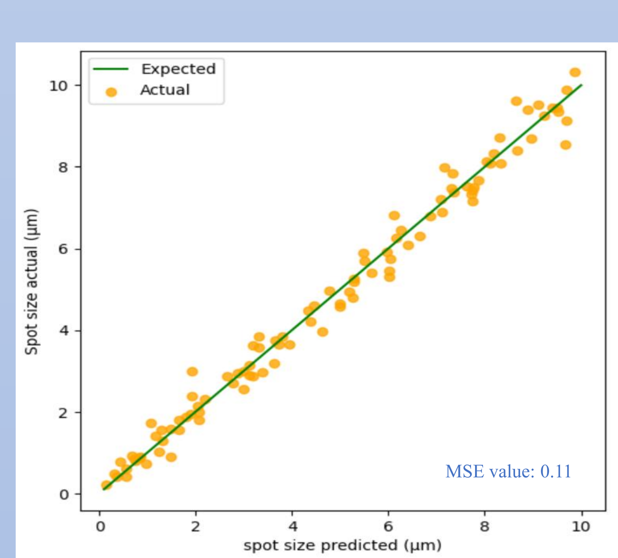
BR spectra



Beam distribution profile before (initial) and after acceleration (final) for proton driver beam



Beam distribution profile before (initial) and after acceleration (final) for electron trailing beam



Spot size prediction test result

DISCUSSION & OUTLOOK

- Betatron diagnostics has the potential to be applied for the case of AWAKE like PWFA experiment, while beam spot size is under investigation and successfully tested with the hybrid model compared to the previous work [4].
- Beam emittance is also be noteworthy to be considered afterwards.
- BR spectra for proton driver case much higher than the electron driver beam.
- A hybrid ML-MLE model can be effective to exploit betatron radiation as a tool for beam diagnostics (initially beam spot size is mainly tested).
- Detector specifications is being explored mainly aiming at the soft X-ray region of the betatron spectrum.
- Geant4 simulation is to be conducted to study the particle interaction processes of proton beam with different materials.

REFERENCES

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https://www.cockcroft.ac.uk/
dghosal@liverpool.ac.uk

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