Instrumentation for Diagnostics and Control of Laser-Accelerated Proton (Ion) Beams: First Workshop

Abstracts

Paul Bolton -

Role of Autonomous PET in Laser-Driven Ion Beam Radiotherapy (L-IBRT)

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Autonomous PET is positron emission tomography driven by the particle irradiation that is used for radiotherapy. The PET image reveals the spatial distribution of gamma emission (from electron-positron annihilation) which typically differs significantly from the physical dose distribution of particles. We focus mainly on proton irradiation where the half lives of prominent positron emitters in tissue, ^{15}O and ^{11}C are about 2 minutes and 20 minutes respectively. The corresponding decay rates are too low to promptly track the progress of tumour irradiation online; especially for spot scanning delivery. Mindful of these spatial and dynamic limitations it is important to determine an efficacious role for autonomous PET as a dose diagnostic in laser-driven ion beam radiotherapy, L-IBRT.

Ceri Brenner - "**Dosimetry calibration of radiochromic film used to detect laser accelerated protons"**

Currently, stacks of radiochromic film (RCF) are one of the primary diagnostic tools for monitoring the spatial features and energy spectrum of laser accelerated proton beams. Through calibration methods with RCF that has been exposed to known doses of energetic (MeV) proton radiation, one is able to convert the optical density measurement, as given by the exposed RCF, into a radiation dosage (Gy). It has been found that in measuring the optical density (OD) of the exposed RCF using a high resolution scanner, there are discrepancies between the response of the three (RGB) colour channels as well as the grey scale channel over the range of OD levels that, when not accounted for correctly, can lead to misleading results for the calculated dosage per proton energy. By way of example, we present our findings and the correction work to RGB calibration curves that was required before we could extract accurate proton energy spectra from the RCF diagnostic. We use this opportunity to highlight the benefit of the RGB calibration technique and how it can increase the dynamic range of this diagnostic.

Alessandro Flacco – **"Simultaneous Ion/Electron Detection, Absolute MCP Calibration Experiment Preparation and Advanced Software Solutions for Analysis of Thomson Parabola Tracks"**

Recent developments in LOA on the laser-produced beams diagnostics include simultaneous ion/electron detection, advanced software solutions for Thomson parabola tracks analysis and the preparation, in collaboration with the CEA, of an MCP absolute calibration experiment.

Vincent Floquet - **"Diagnostics of Laser-Accelerated Proton (Ion) Beams on UH1100"**

We present our recent (and forthcoming) activity concerning, on the one hand, the ion detection efficiency of the microchannel plates we use as the detector for our Thomson parabolas and, on the other hand, some preliminary studies about proton energy deposition in absorbing (NaCl, RCF) as well scintillating material ($CdWO_4$).

Dario Giove - **"Review of Laser-Induced Light Ion Acceleration Activities in Italy: Experimental Setup and Detector Devices for the First Proton Acceleration Experiment at Flame"**

A short review of the main activities that are undergoing in Italy in the field of laser induced light ion acceleration. In particular we will focus on the experimental setup for the the first proton acceleration experiment at the Flame facility in Frascati. Detector devices developed in this frame (a Thomson parabola, new detectors based on diode arrays and low noise readout electronics) will be presented.

James Green **- "Development and Calibration of a Scintillator-Based Ion Beam Profiler"**

New designs of active ion and gamma diagnostics are required to keep pace with the latest high power, high repetition rate laser facilities. A number of diagnostics are being updated and/or redesigned to use plastic scintillators as a re-usable, active imaging media. Here we present results from the first ion beam profiler diagnostic together with the steps being taken to absolutely calibrate the scintillators. Future diagnostic designs will be outlined that include the use of high resolution fibre optic bundles that not only reduce the harmful effects of EMP, but also have the potential to increase light collection and allow a more flexible diagnostic deployment.

Bleddyn Jones - **"Charged Particle Therapy from Lasers: Some Practical issues"**

Bleddyn Jones, Gray Institute for Radiation Oncology and Biology, University of Oxford

Charged particle therapy (CPT) offers considerable promise for the local treatment of cancer as a consequence of the Bragg peak effect, which allows better 3-D dose distributions, dose escalation for the cancer (in many instances) and an impressive reduction in radiation exposure to normal tissues and organ systems. CPT requires particle acceleration using cyclotrons or synchrotrons, although there are some novel approaches. One of these is to use fast laser pulses on thin targets. The potential advantages of the laser approach include:

- *Rapid coverage of target volumes, with a possible small energetic gamma ray component for imaging purposes.*
- *Reduced requirement for heavy and expensive gantry systems for optimal beam trajectories to the patient.*
- *Choice of protons and or different ions*

For laser-CPT to be successful, several practical and theoretical problems need to be solved. They include:

- *Reproducibility of energy spectrum and precision of dose deposition from a suitable range of targets*
- *Avoidance of neutron exposure or additional radiation dose to the patient*
- *Rapid repetition rates to allow magnetic 'spot scanning'*
- *Investigation of the potential for further oxygen depletion in already hypoxic tumour cells as a consequence of the ultra high (fentoseconds) dose rate.*

Paul McKenna - **“Ion Acceleration as a Diagnostic of Fast Electron Generation and Transport in Solid Targets”**

The fast electrons accelerated at the front surface of a laser-irradiated solid target propagate through the target and produce an electrostatic sheath field at the rear surface. Measurement of the beam properties of ions accelerated by this field provides a diagnostic of the electron transport through the target. I will provide an overview of our recent work on the development and use of ion acceleration to diagnose fast electron generation and transport in solid targets.

Rajendra Prasad -

Calibration of MCP and Image Plate detectors for multi-MeV ion spectroscopy

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Rajendra Prasad continued…-

Abstract

We report on the absolute calibration of a micro channel plate (MCP) detector, installed as detector in a Thomson parabola spectrometer. The calibration delivers the relation between a registered count numbers in the CCD camera (on which the MCP phosphor screen is imaged) as a result of the impact of an ion beam onto the MCP. The particle response of the whole detection system was evaluated by using laser accelerated ions with proton energies up to 3 MeV and carbon ion energies up to 16 MeV. In order to obtain an absolute measurement of the number of ions incident on the MCP detector, slotted CR-39 track detector was installed in front of the MCP. The signal registered on the MCP due to ions propagating through the CR-39 slots is compared to the number of particles counted on the adjacent CR-39 stripes after the etching. This sensitive detection set-up makes it possible to measure in a single laser shot the ion spectrum in absolute terms. The calibration of the response of MCP has been extended to higher energy ions and protons on the basis of a simple model validated by comparison with the calibration data.

We also present the calibration of an image plates detector carried out in a similar fashion as for the MCP. The ratio of equivalent PSL strength per unit energy to number of impinging ions per unit energy gives the response of the image plate for C^{6+} ions.

Sabine Reinhardt - **Radiation therapy with laser-driven accelerated particle beams: physical dosimetry and spatial dose distribution**

State of the art of detecting laser accelerated ion pulses are non-electronic detectors like radiochromic films (RCF), imaging plates (IP) or nuclear track detectors (CR39). Image plates (Fujifilm BAS-TR) have been calibrated in a proton beam at the Munich 14MV-Tandem accelerator in terms of PSL/proton/pixel for an energy range of 8 – 20 MeV. Results on fading behaviour and dose dependence of this type of IP are also presented. For radiobiological experiments Gafchromic EBT2 film has been calibrated in a proton beam for a dose range of 0.3 – 10 Gy. Dose verification in proton irradiation of subcutaneous tumours in mice was successfully accomplished using these films.

One main goal of the Munich Centre for Advanced Photonics (MAP) is the utilisation of laser driven accelerated (LDA) particle beams in radiation therapy where quantitative detection in real-time is an essential prerequisite. For monitoring LDA beams in real time we attempt to use pixel detectors. First tests of a commercially available system show good linearity between integrated detector signal and particle fluence as well as negligible blooming between adjacent pixels.

Ulrich Schramm – **"Dose-Dependent Biological Damage of Tumour Cells by Laser-Accelerated Proton Beams"**

We report on the first irradiation of in vitro tumour cells with laser-accelerated proton pulses showing dose-dependent biological damage. This experiment, paving the way for future radiobiological studies with laser-accelerated protons, demonstrates the simultaneous availability of all components indispensable for systematic radiobiological studies: A laser–plasma accelerator providing proton spectra with maximum energy exceeding 15MeV and applicable doses of a few Gy within a few minutes, a beam transport and filtering system, an in-air irradiation site, a dosimetry system providing both online dose monitoring and absolute dose information applied to the cell sample and the full infrastructure for analysing radiation-induced damage in cells. Special emphasis will be given to different technologies tested and/or used for beam monitoring.

Sargis Ter-Avetisyan -

Multipinhole Thomson Parabola arrangement for ion spectroscopy

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In recent years significant advances in laser technology have led to further enhancements in the provision of extremely short, high-intensity pulses. These developments have stimulated the emergence of new ideas and advanced diagnostics for measuring plasma effects and secondary source emission with high dynamic range, high temporal, spatial and spectral resolution, on a single shot basis.

The Thomson spectrometer has been widely and successfully used for analyzing the energy spectra of ions accelerated in laser plasma interaction experiments. Here we are presenting a modification of the standard arrangement where instead of a single entrance pinhole an array of pinholes is used. This allows precise measurement of the proton/ion trajectories emitted under different angles and source coordinates. The technique provides sectional images of the ion source (i.e. a tomography), which can be used to reconstruct the internal structure and dynamics of the ion source.

Martin Tolley - **“Targetry at LIBRA: Production and Delivery”**

A key part of the LIBRA project is the development of an integrated ensemble of next-generation microtarget production, control and injection technologies. In particular this includes wafer-based microtarget production, laser trapping of microtargets and the fabrication of a wafer-based microtarget levitator/injector. Techniques to address the release of microtargets from substrates have also been assessed. The talk will summarise the current status of the work.

Giorgio Turchetti - “**Optical Injector for Protons and Biomedical Applications: the Prometheus Project”**

We present a research program on laser accelerated proton beams and the subsequent transport, and collimation to render the beams suitable for injection into a high field linac. The goal is to reach energies and intensities of interest for medical therapy with a laser power in the 100-200 TW range. Virtual experiments with our PIC code AlaDyn are planned for the current year to design real experimentssuch as LILIA for the next year. This is the core of the design study of the facility PROMETHEUS, devoted to biomedical research which has been proposed for the Montecuccolino laboratory of the University of Bologna.