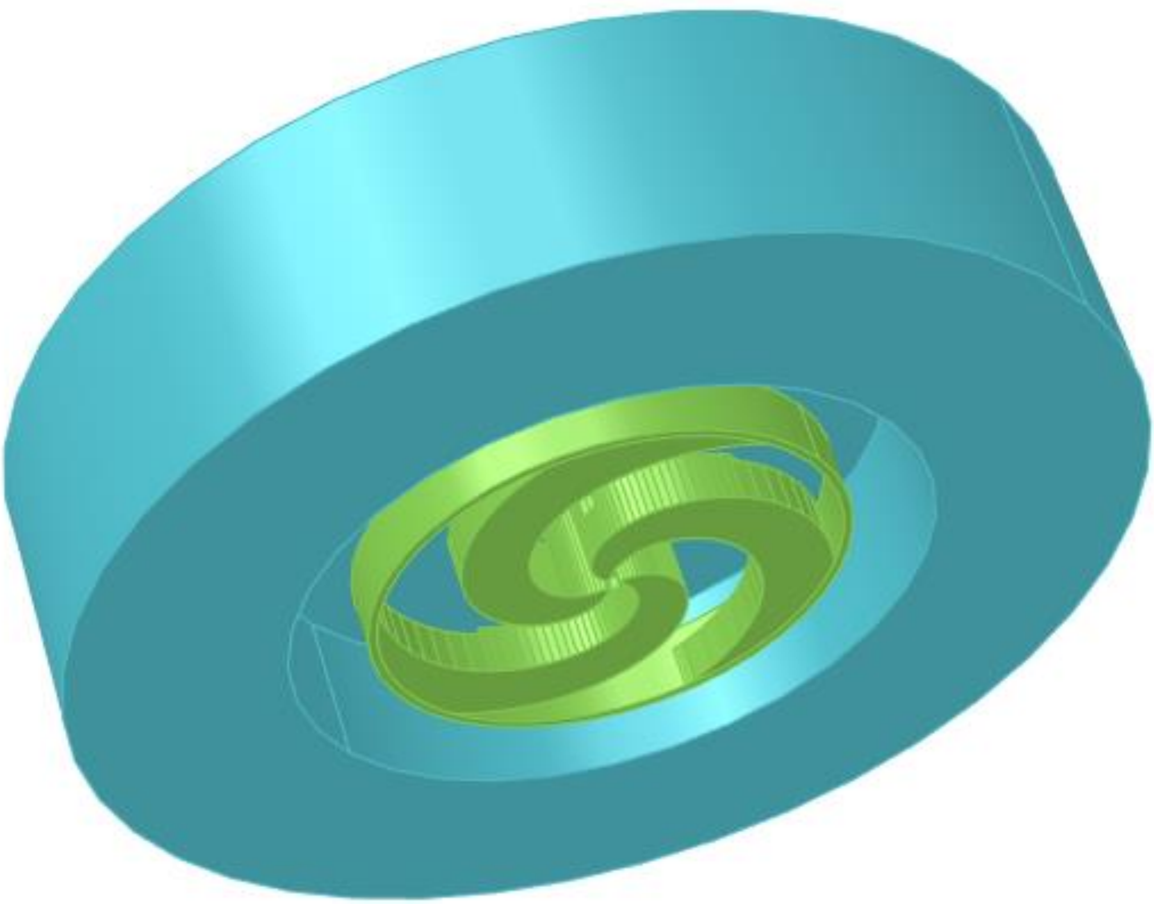
ASHE
Accelerators for Security, Healthcare and Environment

Part of The Cockcroft Institute

Cockcroft Institute: Accelerators for Security, Healthcare and Environment

Newsletter Issue1, March 2020



MANCHESTER 1824 The University of Manchester · University of Strathclyde · UKRI Science and Technology Facilities Council · University of Liverpool · Lancaster University

Introduction

Welcome to the inaugural ASHE newsletter where we hope to update stakeholders on industrially relevant work going on within the Cockcroft Institute. Each issue we will update on some of the students working within ASHE as well as news items from Daresbury Laboratory. For those of you new to ASHE, ASHE is a doctoral training centre based within the Cockcroft Institute focused on collaboration with UK healthcare and industry. Initially funded by STFC, ASHE is now arching over all PhD research with industry excluding those explicitly part of our other DTC's and EU training networks.

During the COVID-19 outbreak our students are working hard from home on their projects, as well as partaking in our online courses at Cockcroft. We are hoping to have some online ASHE seminars in the coming weeks as well. Any placements will be delayed until travel is again allowed. We understand that some of our industrial partners may be struggling at present, and if there is anything that we can do to help then please let us know. We hope that everyone is safe and well.

Regards, Graeme Burt (Head of ASHE), Hywel Owen (Head of Education at Cockcroft) and Peter Ratoff (Director of Cockcroft)

70 MeV Superconducting Cyclotron for Proton Therapy

Cyclotrons are today the principle means to make protons for medical and industrial uses, due to their mature design, simple operation and ability to provide high intensities. Most medical radionuclides are made with cyclotrons, and the rapidly expanding application of the proton therapy market is now dominated by cyclotron-based systems. At both low energy (around 20 MeV) and high energy (250 MeV) new designs have become available that utilise superconducting coils to enable large magnetic fields above 2 T (tesla) that in turn gives a more compact, more cost-effective system. Surprisingly, though, there is so far no demonstrated superconducting cyclotron at the intermediate energy of 70 MeV required for ocular and other shallow particle therapies, and which could be used also for making several future therapeutic radionuclides.

Our aim is to deliver the world's most compact intense source of protons at 70 MeV, in a total volume of around 1 cubic metre.

Our collaboration is a partnership between the University of Manchester (part of the Cockcroft Institute) and Antaya Group. Company founder Timothy Antaya helped develop the K500 – the world's first superconducting cyclotron – and he has been at the forefront of

superconducting cyclotron technology ever since. Examples of his superconducting designs include the Mevion 250 MeV synchrocyclotron for proton therapy, which operates at an extraordinarily high magnetic field of 9 T – the highest magnetic field achieved in any operating particle accelerator – and the Ionetix 12 MeV cyclotron now in use at several centres for PET radioisotope production. The ASHE programme has generously funded the work of Jacob Kelly, a joint postgraduate researcher who has worked both at Cockcroft and at Antaya's main site in New Hampshire (USA) since late 2017. During his work Jacob has examined a number of magnetic designs, eventually deciding upon a unique pole focusing scheme but which still allows the use of industry-standard niobium-titanium coils. The next stage, to design an integrated 200 MHz resonator to provide acceleration, is underway along with the design of a high-intensity ECR injector. The complete accelerator will be less than a metre tall, just over a metre in diameter, and weighs less than 10 metric tons – vastly smaller than existing proton cyclotrons at this energy and allowing it to fit it into conventional hospital environments.
A practical cyclotron design takes several years to develop and by the end of the ASHE programme in September 2021 we foresee a design ready for prototyping.

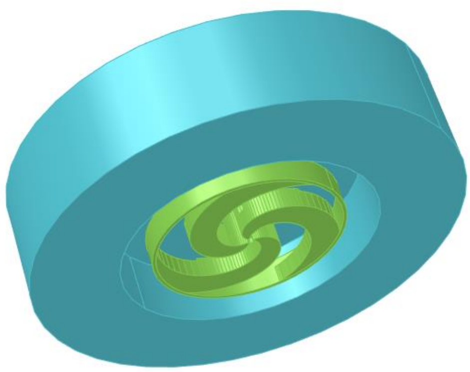
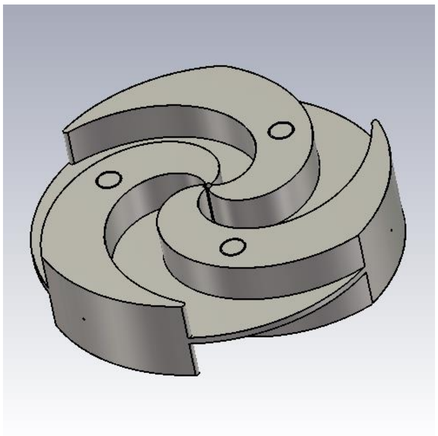



Figure: (Left) Cutaway showing half of the cyclotron magnet; the central (green) pole is carefully designed to provide stable focusing of protons up to 70 MeV; the outer (blue) steel yoke encloses the magnetic field in an outer diameter of just over 1 metre. (Right) 200 MHz resonator structure that accelerates protons in less than 1 ms from the ECR injection energy up to 70 MeV.

STFC and Teledyne e2v collaboration accelerates innovation for industry

ASTeC, Technology Department and Teledyne e2v, a leading supplier of technologies and components for industry, have formed a strategic relationship that is advancing the world's next generation of particle accelerator technologies and brings exciting new opportunities for UK industry.

Through the agreement Teledyne e2v have gained access to the Compact Linac accelerator and radiation enclosure at STFC's Daresbury Laboratory, supporting the development of new products and integrated RF and X-ray systems. Meanwhile, for ASTeC, the agreement delivers specialist technical support for the Compact Linac, provided by Teledyne e2v, which manufactured a number of the original components.

The Compact Linac is a compact electron beam and X-ray linear accelerator that is extremely applicable to industry market areas such as security scanning, healthcare and environmental applications. Housed in a fully supported radiation test enclosure, it provides a ready-made space for industry and the research community to test X-ray and electron beam generation technologies and systems.

Dr Ewan Livingstone, President of RF Power Commercial at Teledyne-e2v, commented: "Teledyne e2v is delighted to be collaborating with STFC. The collaboration provides Teledyne e2v with access to the Council's world class facilities and people. It is a fantastic platform for joint innovation and is already helping us to accelerate the development of new products and solutions for our customers."

The Compact Linac has until recently be configured with a 3.5 MeV accelerating cavity designed by Lancaster University and STFC. Having already achieved significant advances in its research programme due to the partnership, Teledyne e2v have provided a new accelerating cavity manufactured by one of its technology partners, Accelerad. This means that the Compact Linac facility can now additionally support an accelerating capacity of up to 6 million electron volts, a level that is particularly suitable for testing new radiotherapy and security scanning technologies.

The ability to test products within such a flexible system makes the system extremely applicable to industry. It will enable Teledyne e2v to assess the impact of new products and system designs against the wider performance and reliability aspirations of its customers, enabling Teledyne e2v to develop optimised solutions meeting current and future customer needs. In parallel, ASTeC is able to use the supported infrastructure to continue to expand its societal application programmes in high impact sectors such as healthcare, environmental science and security.

As with all particle accelerators, the system is highly complex, with a number of particularly specialised and bespoke components. Teledyne e2v provide the technical support to ensure that the Compact Linac system can continue to provide a reliable platform for industrial engagement.

Thomas Primidis to present his PhD project at Westminster

Taking place in March at Westminster, London is the annual STEM for BRITAIN poster competition for early-career researchers which aims to offer opportunities for scientific exhibitions, networking and discussions among early career scientists and members of parliament. The competition was an initiative of Dr Eric Wharton back in 2006 and continued as STEM for BRITAIN from 2009 until today.

Thomas, a physics PhD researcher and member of the QUASAR Group will present his latest work on simulations of a highly mobile, multi-source, medical 3D X-ray imaging system made by Adaptix Ltd.

Through simulations, Thomas aims to optimise the system's performance by offering data unavailable through experiments or data challenging to get due to lack of equipment or due to the high cost of performing such experiments.

Thanks to the High Performance Computing facilities at the University of Liverpool, realistic simulations of the system and of human anatomy are built *in-silico* (in a computer program) and Thomas will present his findings on what the 3D image quality of this multi-source system will be when it is built and how this will be affected by the system's performance, be it perfect across all of the sources or with various scenarios of underperformance. During the competition, he will have the opportunity to communicate his findings and the importance of HPC in search for improved healthcare in the future.

STEM for BRITAIN is split into 5 scientific categories: Biosciences, Chemistry, Engineering, Mathematics and Physics. In each of the categories, the researchers who best communicate high level science to a lay audience are awarded with a medal and a cash prize of up to £3000.

The Westminster Medal in memory of Dr Eric Wharton is awarded to the overall winner. During the event, the researchers will present their posters and discuss their research among themselves, MPs and with the judges. This is a unique opportunity for everyone to see what is the research profile across the United Kingdom, what are the future prospects and how UK universities and their national and international collaborations shape it. It will also be an opportunity for Thomas to share the work done by the rest of the QUASAR group members which spans from antimatter physics all the way to proton therapy.

Thomas' project is an industrial collaboration between the University of Liverpool and Adaptix Ltd and is funded by the Accelerators for Security, Healthcare and Environment program launched by the UK Research and Innovation Science and Technology Facilities Council.

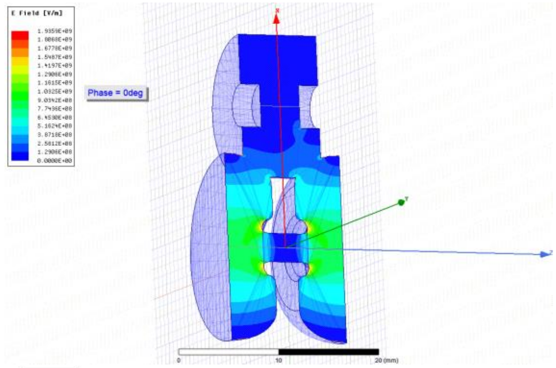
More information:
http://www.setforbritain.org.uk/index.asp

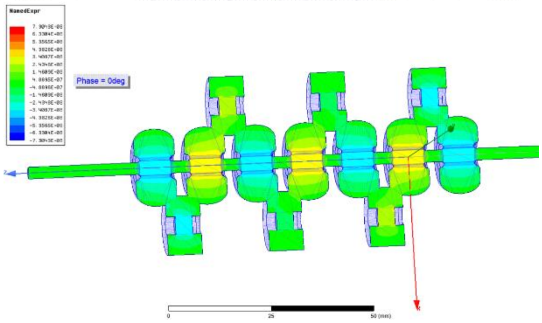
Very High Energy Electron Radiotherapy

As a doctoral candidate on the ASHE programme I've been undertaking research into medical linear accelerators for a proposed new radiotherapy modality, VHEE (Very High Energy Electron) radiotherapy, using electron beams at energies 100 – 250 MeV. VHEE has potential clinical advantages for some cancers, for example the lung and bowel where relative insensitivity to inhomogeneous media and improved dose-deposition characteristics compared to extant therapies can be particularly advantageous. This work has involved design of medical linear accelerators through adaption of high gradient linac technology from linear collider projects. Over the course of the project I've had opportunity to attend a number of conferences in the fields of high gradient acceleration and radiotherapy, the CLIC workshop at CERN in Jan 2018 and Jan 2019, the High Gradient workshop in Chamonix in June 2019, and the second international meeting on the novel flash radiotherapy technique in Lausanne September 2018.

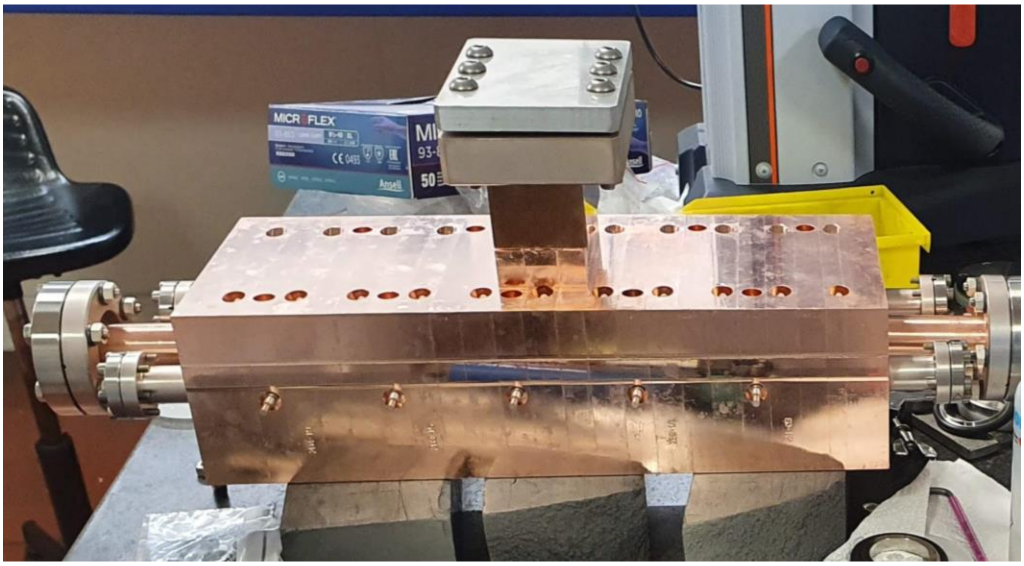
I came to the Cockcroft institute as a University of Manchester postgraduate following a few years in photonics manufacturing, after having studied undergraduate Physics at the University of Liverpool. This ASHE project was of particular interest as I had this physics engineering background, and as part of my project I have been collaborating with Elekta. In December 2019 I visited Elekta in Crawley (pictured below in Fig. 1) and it was agreed to fabricate and test a prototype X-band structure. Some earlier simulations of mine on a limited number of cells are illustrated in Figs 3 and 4. This will represent a first of its kind 12 GHz side-coupled CCL for medical applications. I will take part in a secondment at Elekta during the summer of 2020.

To date my work has focussed on delivering an optimised RF design of a linear accelerator for medical applications. This is a stable field linac operating in the pi/2 mode, with high shunt impedance (a figure of merit for efficiency of beam cavity interaction), and with a high accelerating electric field gradient within acceptable surface field limits. The goal being to design a compact and robust linac suitable for a medical facility.





Prototype of High gradient Proton booster for medical imaging constructed



A prototype of a very high gradient (~52 MV/m for 250 MeV protons) cavity has been developed at the Cockcroft Institute in collaboration with CERN. A collaboration between Lancaster University, The University of Manchester and CERN is investigating the use of a linac to boost the energy of protons coming from a 250 MeV cyclotron up to 350 MeV required for full body proton CT. This is clinically useful as the range error in treatment planning of proton CT is much smaller than using X-rays or MRI. The cavity was designed as part of a PhD project of Sam Pitman (Lancaster University) who spent the final year of her

MANCHESTER 1824 The University of Manchester · University of Strathclyde · UKRI Science and Technology Facilities Council · University of Liverpool · Lancaster University

PhD at CERN preparing the existing high gradient S-band test stand (SBOX) at CERN for testing this cavity. The cavity was machined by VDL in the Netherlands and brazed by Bodycote in France. The cavity is now being transported to CERN for testing. The key patented innovation is the development of a new manufacturing method which allows a reduction in the peak magnetic field on a side coupled cavity.

The collaboration is now looking at the development of similar cavities for proton therapy directly.