Institution: University of Liverpool		
Unit of Assessment: 9 (Physics)		
Title of case study: Accelerator physics reaches new audiences through innovative public engagement		
Period when the underpinning research was undertaken: 2008 – Present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr Chris S Edmonds Prof Dr Carsten P Welsch	**Role(s) (e.g. job title):** Lecturer Professor	**Period(s) employed by submitting HEI:** 2014 – Present 2008 – Present
Period when the claimed impact occurred: 08/2013 – 12/2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Accelerator research is of great value to science, society and industry, but this technology does not traditionally feature in mainstream media, nor is it part of school curricula. Public awareness of how accelerators work therefore remains low despite their importance. To address this challenge, the QUASAR Group at the University of Liverpool has taken a novel approach to public engagement to make the benefits of its research accessible and understandable.

The wide-ranging outreach activities and strategic communication have engaged millions of people around the globe, improved public understanding of accelerator science, triggered public debate and set best practice for science communication. Innovative workshops and events have educated new and underrepresented audiences, raised young people's aspirations towards science, and created award-winning educational content for visually impaired children.

2. Underpinning research

The research that underpins this impact case study has been carried out in the University of Liverpool's Quantum Systems and Accelerator Research (QUASAR) Group, based at the Cockcroft Institute – an international centre of excellence in accelerator science and technology that was founded 2006. The QUASAR Group, founded by Professor Welsch in 2007, develops and optimizes particle accelerators, light sources and related technologies, with a focus on novel beam diagnostics. Present research includes: frontier accelerators - LHC and its upgrade and Future Circular Collider (FCC); novel accelerators - laser- and beam-driven plasma wakefield accelerators; accelerator applications - medical applications and beam instrumentation.

Prof Welsch and Dr Edmonds are the key researchers in this impact case. Their research has:

- Developed novel instrumentation solutions based on supersonic gas jets to measure the profile of the HL-LHC beam [3.1].
- Contributed to an international effort that led to the first demonstration of proton beam crabbing and helped optimize the design of future facilities [3.2].
- Developed new instrumentation to measure 3D electrostatic field distributions in low energy antiproton and ion experiments, performed simulations into beam transport and tracking, optimized the FLAIR, AD and ELENA facilities, designed new experiments [3.3].
- Demonstrated first proton-driven acceleration of electron beams, as part of the AWAKE collaboration; Prof Welsch is the scientific project manager of AWAKE-UK and leader of the UK beam diagnostics work package. His research has targeted improved monitors for a full characterization of the electron beam, as well as underpinning simulation studies [3.4].
- Successfully developed high-energy physics detectors into stand-alone beam monitors that give access to online monitoring of proton and ion beams used in cancer treatment [3.5].
- Used beam physics and instrumentation expertise to assist the continuous improvement of national and international accelerator facilities [3.6].

Professor Welsch has also initiated and coordinated the EU-funded networks LA³NET (Laser Applications at Accelerators), oPAC (Optimization of Particle Accelerators), OMA (Optimization of Medical Accelerators) and AVA (Antimatter Research) in this REF period. These have attracted 18M EUR of funding, linked 106 academic and commercial institutions, and launched the careers of 72 Fellows with a considerable future impact for science and the economy.

3. References to the research

[3.1] *'A non-invasive beam profile monitor for charged particle beams',* V. Tzoganis, C.P. Welsch, Applied Physics Letters 104, 204104 (2014) (1.4879285), doi.org/10.1063/1.4879285

[3.2] *'FCC-hh: The Hadron Collider'*, A. Abada,..., C.P. Welsch, et al., European Physical Journal Special Topics volume 228, pages 755–1107(2019), doi.org/10.1140/epjst/e2019-900087-0

[3.3] *'Noninvasive 3D Field Mapping of Complex Static Electric Fields'*, A. Kainz,..., C.P. Welsch, et al., Phys. Rev. Lett. 122, 244801, doi.org/10.1103/PhysRevLett.122.244801

[3.4] *'Acceleration of electrons in the plasma wakefield of a proton bunch'*, E. Adli, (...), C.P. Welsch, et al., Nature (2018), doi.org/10.1038/s41586-018-0485-4

[3.5] *'Development of the LHCb VELO Detector Modules into a Standalone, Non-Invasive Online Beam Monitor for Medical Accelerators'*, R. Schnuerer, (...), and C.P. Welsch, Instruments 2019, 3(1), 1, doi.org/10.3390/instruments3010001

[3.6] *'Reconstruction of lattice parameters and beam momentum distribution from turn-by-turn beam position monitor readings in circular accelerators'*, C.S. Edmonds, et al., Phys Rev AB 17, 054401 (2014), doi.org/10.1103/PhysRevSTAB.17.054401

4. Details of the impact

Particle accelerators are wide-ranging in their applications and indispensable for society: They are at the heart of cancer treatment, and drive forward the frontiers of fundamental scientific knowledge. However, public understanding of the technology and awareness of UK research remains low. The University of Liverpool, together with the Cockcroft Institute and partners, is a hotbed of world-class accelerator science research. As coordinator of four large international research and training networks and a key contributor to major European accelerator R&D projects, the QUASAR Group is in a unique position to communicate globally its interdisciplinary research results, as well as the importance of accelerator science in society.

Since August 2013, a strategic outreach and public engagement programme based on the Group's research has inspired and educated audiences from diverse backgrounds across the UK, Europe, Asia and the Americas; improved awareness of accelerator science in new and underrepresented groups; enthused young people to engage in science; supported public debate, and communicated accelerator science to industry. A range of tactics were used to great effect: workshops, events, teaching resources, films, media relations.

Award-winning workshops: World's first Tactile Collider "*an opportunity for children with sight loss to feel excited and empowered to pursue a career in science*" [5.1]

Tactile Collider - an immersive workshop for visually impaired (VI) children co-created and delivered by Dr Edmonds - has revolutionized the way they learn about accelerators by using soundscapes and specially developed tactile objects to make the physics accessible.

There are around 5,500 VI children in England and Wales aged 12-18. Since 2017, Tactile Collider has reached around 30% of them, directly engaging 286 children and through training of 124 specialist teachers in the Tactile Collider material extending its impact by an estimated further 1,300 VI children. When participants were asked about the impact of the workshop, 50% reported increased confidence talking about physics, 73% said they'd learned something new, and 69% felt inspired to learn more [5.2].

In 2019, Tactile Collider was awarded the European Physical Society's HEPP Outreach Prize for *"outstanding outreach achievement as a unique project"* and the Royal National Institute of Blind People (RNIB) See Differently Award for Innovator of the Year [5.1].

International media coverage endorsed quality, e.g. Symmetry Magazine and CERN Courier, radio appearances on In Touch on BBC Radio 4 and a monthly podcast on RNIB Connect Radio since 2019 [5.2]. To raise public awareness of the challenges that affect people with VI and to promote the concept to wider audiences, Tactile Collider was invited to demonstrate at major international cultural and science events, including BlueDot Festival (2017, 2018), Africa Oyé (2018), North West Big Bang (2018, 2019) and CERN Open Days (2019) [5.2].

Engaging events: "*bringing the science to life*" [5.2]

Prof Welsch and his Group designed, organized and delivered four large-scale science *outreach symposia*, three *'Physics of Star Wars'* events, and eight *'Accelerator Experience Days'* in the North-West of England. All events were based on Liverpool's accelerator science research, featured engaging talks and hands-on demonstrations that explained Liverpool research, promoted interaction with scientists and sparked global media interest.

The Ogden Trust's CEO found *"The innovative combination of in-person attendance, online streaming and additional media activity has given these events an exceptionally wide reach and created impressive impact. In addition, teachers reported positive changes in attitudes to pursuing physics further, both at university and beyond."* [5.3]

Outreach symposia engaged a total of 893 high school and college students and 81 teachers from Liverpool City Region in 2015, 2018 and in March and June 2019 in the Arena and Convention Centre. The March 2019 event welcomed almost 1,000 participants, including high school students and their teachers, undergraduate students, scientists and industry, making it one of the largest accelerator science events ever held in England. High profile speakers including former CERN Director of Accelerators, Prof Steve Myers, and EPS Outreach Prize winner Dr Kate Shaw gave live-streamed talks about projects the Group is involved in.

- Symposia engaged pupils and teachers with the Group's research and improved their interest in science: *"Accelerators are involved in everyday life and students don't know about that. We've come away feeling inspired and excited about physics,"* said Mossland's STEM Coordinator after the 2018 symposium. Another teacher said: *"The symposium also offered a good way for me to gain experience and continuing professional development"* [5.2].
- March 2019 symposium was the first-ever VI-inclusive accelerator science event by including Tactile Collider and using a narrator who explained all visual content via Bluetooth headsets to 14 VI young people. *"A lot of people can feel daunted by particle physics, but it is possible to make complex ideas accessible and the kids come away feeling like they've achieved something",* said a science teacher of VI pupils attending the symposium [5.2].
- New industry audiences engaged through repeat sector-specific media coverage about the symposia, e.g. Laboratory News, E&T Magazine, Science Business, Technology Networks, AZO Optics [5.4]. New Electronics editor found: *"The blend of science and its application in these articles has helped to widen access to information about accelerators as a key underpinning technology for industry and society. (...) Professor Welsch is my 'go to' person for opinions and in-depth information about this fascinating subject."* [5.5]
- New 3M EUR Future Circular Collider Innovation Study, coordinated by CERN, highlighted the March 2019 symposium as an exemplary event for community engagement [5.6].

Physics of Star Wars events, developed by Prof Welsch and delivered annually 2017-2019, use the iconic films to explain applications of his accelerator R&D to science, society and commerce, improving public awareness and understanding of this technology. They inspired 323 secondary pupils, 22 teachers, 356 members of the public [5.2] and millions via media coverage [5.4].

- Impact is shown through positive feedback from pupils and teachers: *"We had a fantastic time – there are a number of students who've been enthused to consider physics at degree level in the future"*, said the Head of Science at Heath School [5.2].
- Interest in science was improved: *"I was extremely impressed… being from a single sex (girls) school it is vital that our pupils are able to visualize themselves in STEM subjects,"* said a physics teacher at Prenton High School for Girls. *"Our pupils talked about their experience with others within their peer group; many pupils from the year group came to ask when it could be run again so they could attend!"* The headteacher from St Gregory's High School added that the events *"enhance[d] interest in particular accelerators and the role of CERN (...) They are a magnificent way of not only improving learning but also to build bridges with Liverpool University and raising aspirations."* [5.2]
- Significance is further evidenced through subsequent invitations to deliver *'Physics of Star Wars'* for example at Manchester Science and Industry Museum's *Science Late*, Daresbury Lab's *Talking Science*, Lymm summer festival, and at Barnsley Museums.[5.2]
- The events created awareness about Liverpool accelerator research around the world through multiple appearances in local TV; UK and US radio stations; national and international press, including Cordis (EU), BBC Science Focus, Total Film and New Electronics (UK), Frankfurter Rundschau (Germany), Gazete Duvar (Turkey), La Nacion (Argentina), National Interest Magazine (USA) [5.4].

Accelerator Experience Days, held by the Group in 2016 and 2017 to inspire young people to consider a career in STEM, engaged 277 year 9 and 10 secondary school children and 22 school teachers from across North West England with Liverpool's research [5.2]. Impact is demonstrated through feedback, re-use of resources, media coverage, invitations to speak.

- Over 97% of the school children found the workshops 'informative' and 93% 'interesting'.*"I have learned about magnetic fields, antimatter, electric forces and energy, as well as particles and matter. I really saw the fun side of science and felt eager to learn more and try new things."*, *"They (the experiments) made me more interested in physics."*, commented pupils who attended the workshops [5.2].
- "*These workshops gave students an important opportunity to learn about the practical applications of particle accelerators in society, while testing their experimental skills.*" commented the STFC magazine Fascination [5.2].
- Videos of experiments and explanations of the setups used in the workshops have created an educational resource for pupils and teachers with 67,012 views and 92.5% positive rating on YouTube (5/11/2020) [5.7].
- Quality is evidenced through invitations to present novel approach e.g. in BBC Radio Manchester and IOP's *Interact* symposium (2017); re-use of setups developed for the workshops at other events, including *"Coder Dojo"* at Beamont Collegiate Academy (2017) and *"Small particles, big machines"* exhibition in Berlin (2017). [5.2]

Teaching resources: enhancing science education

Science education was enhanced more widely by publishing the educational videos, teaching resources and material from Liverpool's outreach events to explain accelerator R&D in teaching magazines such as Science in School, Education Technology, and Teaching Times [5.4]. These have provided *"an additional reference point for further reading for both pupils and staff.",* said a teacher from Warrington [5.2].

Resources also included acceleratAR, an augmented reality app developed by Dr Edmonds that uses paper cubes to create a virtual accelerator that helps students to learn about accelerator science. The app has been downloaded almost 5,000 times since February 2019 [5.2] and has received excellent reviews from scientific press and was listed as favourite science app by BBC Focus and Popular Science [5.2].

The quality of our educational material is further evidenced by feedback from the publisher of Teaching Times: *"We would be very interested in getting more articles of the same sort in the future. It was great the way the article linked serious science with popular culture."* [5.2].

Award-winning films: improving public understanding and supporting public debate

Prof Welsch has co-created four critically acclaimed short films about antimatter '*AVA - Nature (anti)matters*' and collider facilities '*Future Circular Collider*', '*Science knows no Borders*' and their applications '*Busy bees and mighty magnets*' with CERN (2018-2019) to showcase accelerator R&D at Liverpool and its partners. The films feature Prof Welsch, other Liverpool staff and Liverpool University campus, as well as collaboration partners, Nobel Laureate Peter Higgs and former CERN Director-General Rolf-Dieter Heuer. Reach and significance is demonstrated through awards, views, feedback, third party endorsement, and re-use:

- Awards: *'Future Circular Collider'* - 2020 w3 Silver Award; *'Science knows no Borders'* - shortlisted for 2019 EVCOM Award [5.1].
- *'AVA - Nature (anti)matters'* selected by EU as excellent communication practice, shown to 232 coordinators and managers from 147 networks in 2018 ITN Coordinator's meeting [5.7].
- 647,905 total views (5/11/2020), positive rating of 98% from 6.318 engagements [5.7].
- *'AVA - Nature (anti)matters'* was the most viewed film out of 380 projects on the EU's official science short film playlist [5.7].
- Social media re-posts, positive comments and endorsements from science influencers such as Professors Jim Al-Khalili *"very inspirational"* and Brian Cox *"this is brilliant!"* [5.7].
- Widely shown at major science events: *FCC Week* (Amsterdam 2018, Brussels 2019), *Der Code des Universums* (Vienna, 2018), as well as by the Royal Institution (London, 2019), and learned societies such as the IOP.
- Supporting global debate about the future of high energy colliders: Video snippets and imagery of *"Future Circular Collider"* re-used by media outlets in the UK, Germany and USA, including BBC, NBC, Guardian, Nature, London Science Museum and leading science portal Seeker, reaching over 1 million people through film, online and print media [5.4], [5.7].

Nature Physics chief editor described *'Future Circular Collider'* as *"clear, engaging and inspiring [that] has been used across different media platforms during a global public debate"* [5.8].

Media engagement: bridging the knowledge gap with storytelling

The Group worked with mainstream and scientific media on stories for science-engaged and general audiences in the UK, Europe and the Americas e.g. '*Plugging the skills gap'*; '*What's the (anti)matter?'*; '*What have particle accelerators ever done for us?'; 'Do you want to boldly go where science has not gone before?'.* Coverage by BBC Radio 5 Live, BBC's Naked Scientists, The Times, Times Higher Education and New Statesman (UK), IFL Science (USA), Horizon Magazine and EU Research Magazine (EU), Die Welt (Germany), and BBC Mundo (Spanish-speaking world) improved awareness of Liverpool's accelerator R&D and the projects the group is involved in for *broad, media-engaged public* [5.4].

Articles in scientific and technology press for *science-inclined public*, including Scientific American (USA), New Scientist, New Electronics, BBC Science Focus, Laboratory News, Physics World, UKSPA Magazine, Materials World, Haynes Manual - LHC (UK), Science (EU), and CERN Courier deepened knowledge about the Group's technology developments [5.4]. Success is evidenced through invited talks about accelerator R&D at events outside academia, including IET workshops (2016, 2018); Lab Innovations - the UK's largest annual exhibition for the laboratory industry - (2018); International Festival for Business (2016). The curator at Lab Innovations said: *"There were not many accelerator scientists at the show, everyone that heard Carsten speak will now absolutely be aware of the wide variety of different applications... especially in the medical field."* [5.9] Quality in stimulating public interest in accelerator R&D is demonstrated by Prof Welsch being appointed as communication lead for the Cockcroft Institute (since 2015), the EU Design Studies EuroCirCol (coordinated by CERN) and EuPRAXIA (coordinated by DESY).

Success story: best practice in accelerator science communication

The significant impact of Liverpool's public engagement has been recognised by invitations to speak about the communication activities at international events including ESOF (2014), Europe's largest interdisciplinary meeting on science and innovation, and UKRO national training days (2017) [5.2].

Formal project evaluations have commended the communication and outreach as "*exemplary*" and *"outstanding in disseminating project results to the general public"*. The Cockcroft Institute's external Advisory Committee found in its 2018 report that the *"communication initiatives continue to be impressive and exceptional"* and highlighted them as *"world-leading"*. The European Commission has identified the accelerator science communication as a *"success story"* and invited Prof Welsch to present his approach in Brussels to project coordinators from across Europe [5.6].

To guarantee sustainability of the Group's public engagement activities, the Fellows in Liverpool's accelerator training networks and the Group's staff and PhD students followed a science communication training programme developed by Prof Welsch. This created more than 100 accelerator science ambassadors, engaging with schools and the public around the world, including India, Mexico, Ukraine and all across the EU, consulting ministries in their home country about accelerator science, creating innovative social media platforms and blogs [5.2]. They continue to help raise awareness about accelerator research and Liverpool's projects on a global scale.

5. Sources to corroborate the impact

[5.1] Award letters from RNIB, EPS, w3 and EVCOM.
[5.2] Internal analysis reports, evidencing reach and impact for Tactile Collider, Symposia, Physics of Star Wars, Accelerator Experience Days, and acceleratAR, as well as selected invitations to speak and an overview of Fellows' public engagement activities.
[5.3] Testimonial from CEO of *Ogden Trust.*
[5.4] Media report, corroborating examples of press coverage of Liverpool's accelerator science outreach events and media engagement, including URLs to articles and potential reach.
[5.5] Testimonial from editor of *New Electronics.*
[5.6] Extracts from external reports, verifying quality of Liverpool accelerator science outreach.
[5.7] Data report on co-created short films and educational videos, demonstrating reach and impact through views, re-use, feedback, third party endorsement.
[5.8] Testimonial from chief editor *Nature Physics.*
[5.9] Testimonial from curator *Lab Innovations.*