Institution: University of Liverpool

Unit of Assessment: 9 (Physics)

Title of case study: Creating awareness and improving public understanding of particle physics research at CERN's LHCb experiment through art, philosophical debate and international media

Period when the underpinning research was undertaken: 2008 - 2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof Tara Shears	Professor	2000 - present
Prof Themis Bowcock	Professor	1991 - present
Dr David Hutchcroft	Senior Lecturer	2002 - present

Period when the claimed impact occurred: August 2013 - December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Through Liverpool University's research at CERN's LHCb experiment, Prof Shears has created an awareness and improved public understanding of cutting-edge particle physics for audiences worldwide through art, philosophical debates, and international media. Impacts include:

- **influenced artistic practice** and **co-developed a touring Arts at CERN art exhibition** visited by 199,996 people at galleries in the UK, Spain, Belgium, Taiwan, and Estonia;
- **shaped public debate** and **stimulated public interest** in particle physics research through debates on Radio 4 and at '*the world's largest philosophy and music festival*', and the creation of a BBC documentary and animation recommended by the British Portrait Gallery;
- **created awareness** and **improved public understanding** of LHCb research across the UK, Europe, and North America through high-profile print, radio, and broadcast media coverage that "*reached audiences of many tens of millions of people",* including: Financial Times, The Guardian, New Scientist, RTÉ Radio, BBC World Service, ITV News, and BBC Breakfast.

2. Underpinning research

Based at CERN, the European Organization for Nuclear Research, the Large Hadron Collider (LHC) is the most powerful particle physics facility ever constructed. LHC data provide the sole source of our knowledge of the elusive Higgs Boson and allow the investigation of matter and antimatter differences (CP violation), Dark Matter and other phenomena that cannot be explained by our current understanding of particle physics, encapsulated in a theory termed the Standard Model. Each of these topics is of outstanding importance to our knowledge of fundamental physics and the structure of the universe. Four main experiments are based at the LHC: ATLAS, CMS, LHCb and, ALICE. STFC coordinates and manages the UK's involvement and subscription with the LHC at CERN – the UK's national laboratory for particle physics.

Comprised of 23 academic researchers, the Liverpool Particle Physics Group have been members of the LHCb and ATLAS collaborations throughout the REF period. Shears leads the Liverpool LHCb group which currently consists of five academics, four postdoctoral researchers and six PhD students. Shears established the field of electroweak physics on LHCb and previously led the relevant LHCb physics working groups. She convened the LHC Electroweak Working Group (2011-2020) and Precision Electroweak Working Group (2017-2020) that together span all LHC experimental and theoretical physicists at CERN. Besides performing Standard Model analyses **[3.1]**, the Liverpool group has research interests that span CP violation and rare decay physics (Hutchcroft). The group designed, constructed, commissioned and maintained the VELO particle detector (Bowcock) which provided the data necessary to perform all LHCb physics analyses in this REF period. Shears plays a key role in communicating the results from Liverpool's research on the LHCb experiment at CERN to audiences worldwide through the Arts at CERN program, philosophical debates, and international media engagement.

Notable particle physics research breakthroughs took place during the REF period as a result of Liverpool's LHCb research that were covered extensively by international media, including:

- The first observation of CP violation in charm decays **[3.2]**: CP violation is a major open question in particle physics. So far it has only been possible to study it by looking at differences between quark and antimatter quark behaviour. Differences have been seen previously in two of the six quark types. LHCb showed that there are also differences in charm quarks, a third type, providing a new laboratory for effects to be studied in. The analysis is only possible thanks to the precision measurements of the VELO detector that the Liverpool particle physics group designed, constructed, commissioned and maintained.
- Intriguing Standard Model discrepancies in lepton universality measurements **[3.3]**: the idea that all lepton types should behave in the same way ("universality") is a cornerstone of the Standard Model. However, lepton universality can be broken if new, unseen particles interfere with normal particle decays. LHCb has observed differences compared to Standard Model predictions, hinting at the existence of new particle interference. If true, this provides the first pointer to a deeper and more fundamental understanding of the universe. The measurement was only possible thanks to the Liverpool-built VELO detector. Recent measurements also rely on the Liverpool group's electron efficiency data.
- The observation of new baryon and pentaquark states **[3.4, 3.5]**: not only do these new states expand our table of known particles, but their existence tests our understanding of the strong force that binds quarks together to form matter. Pentaquark states in particular had ambiguous evidence before LHCb's breakthrough measurements, and extend our understanding of particle structure. This particle physics research breakthrough was only possible due to the VELO detector, built by the Liverpool group.
- The first observation of rare B decays to dimuons sensitive to New Physics **[3.6]**: this is a "golden" channel to observe the indirect effects of new physics mechanisms and particles. It is predicted to be rare; a measurement different to the prediction would signal new particle interference. Such a breakdown would be incredibly important – the Standard Model must fail at some point, and this would show which potential new physics mechanisms could replace it. The observation demonstrates the power of indirect searches to probe the limits of our knowledge. It was only possible thanks to the VELO detector built by Liverpool and the Liverpool LHCb group were, and continue to be, instrumental in this measurement at CERN.

3. References to the research

3.1 "Measurement of forward W and Z boson production in pp collisions at $\sqrt{s}$=8 TeV", the LHCb collaboration (R. Aaij et al), JHEP 1601 (2016) 155 DOI: 10.1007/JHEP01(2016)155

3.3 "Observation of CP violation in charm decays", the LHCb collaboration (R. Aaij et al) Phys. Rev. Lett. 122 (2019) no.21, 211803 DOI: 10.1103/PhysRevLett.122.211803

3.3 "Test of lepton universality using $B^+ \to K^+ \ell^+ \ell^-$ decays", the LHCb collaboration (R. Aaij et al) Phys.Rev.Lett. 113 (2014) 151601 DOI: 10.1103/PhysRevLett.113.151601

3.4 "Observation of five new narrow Ω_c^0 states decaying to $\Xi_c^+ K^-$", the LHCb collaboration (R. Aaij et al), Phys.Rev.Lett. 118 (2017) no.18, 182001 DOI: 10.1103/PhysRevLett.118.182001

3.5 "Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays", the LHCb collaboration (R. Aaij et al), Phys.Rev.Lett. 115 (2015) 072001 DOI: 10.1103/PhysRevLett.115.072001

3.6 "Observation of the rare $B_s^0 \to \mu^+ \mu^-$ decay from the combined analysis of CMS and LHCb data", the CMS and LHCb collaborations, Nature 522 (2015) 68-72 DOI: 10.1038/nature14474

4. Details of the impact

Prof Shears has engaged audiences worldwide with Liverpool University's LHCb particle physics research through art, philosophical debates, and international media. Impacts include:

- influenced artistic practice and co-developed a touring Arts at CERN art exhibition;
- shaped public debate and stimulated public interest in particle physics research through '*the world's largest philosophy and music festival*', a Radio 4 debate and a BBC documentary;

- created awareness and improved public understanding of LHCb research discoveries through media work that "*reached audiences of many tens of millions of people*" worldwide.

4.1 Influenced artistic practice and co-developed an international Arts at CERN exhibition

Recognising the power of art in communicating abstract concepts and complex ideas, such as those found in particle physics research, Shears has been involved with international art projects through Arts at CERN since its foundation in 2009. Between 2016 and 2018, Shears played a key role in Collide International – "*a flagship foundational program for Arts at CERN*" that involved Shears' LHCb research group at Liverpool and FACT (Foundation for Art and Creative Technology) **[5.1]**. "*It's vitally important that we have scientists at CERN like Prof Shears who strongly believe that interactions with artists are very useful*," says Head of Arts at CERN **[5.1]**.

Collide International provided ten successful artists - from countries including South Korea, Colombia, and Finland - with a two-month residency at CERN to immerse themselves in particle physics research, and a one-month residency at FACT to explore ways of realising their work **[5.2a]**. "*Prof Shears was involved from the very beginning of the Collide International collaboration. In fact, she was involved before this project as a scientific partner for Arts at CERN. So, when we decided to take up this collaboration with Liverpool, it was clear that involving Prof Shears was going to be very valuable for us,*" **[5.1]** says Head of Arts at CERN. The Collide International award is highly competitive and judged by a panel of leading gallery curators, commissioners, and scientists including Shears **[5.1, 5.2a]**. "*We are passionate about staying true to the science and facts that inspire artists. Prof Shears contributed greatly … to help us to understand if a proposal was feasible*," says Head of Arts at CERN **[5.1]**.

British-Taiwanese artist Yu-Chen Wang was one of the ten artists involved in Collide International. Wang describes how Shears' mentorship during the CERN residency was critical to her art: "*Without Professor Shears' expertise and assistance, my understanding of particle physics, the scientific method and the way that researchers collaborate would not have been sufficient to create* [my artwork] *for Broken Symmetries*," **[5.3]**. "*Not only did Professor Shears give me a fundamental overview about how we "do" science, but she ensured that the science was always explained to me. I've tried to reflect all of the major points which came out of my conversations with Professor Shears... I think it is a major feature of my work*," says Wang **[5.3]**.

The collaboration also had an impact upon Wang's creative practice. "*As an artist, I am more open to different approaches and better able to link up different ideas as a result of working with Professor Shears through the Arts at CERN Collide International Award*," says Wang **[5.3]**. According to the Head of Arts at CERN, Shears' "*mentorship of artists during the residencies at CERN and in Liverpool was instrumental*" in the overall success of the project **[5.1]**.

The resulting art exhibition, 'Broken Symmetries', showcased artworks from all ten artists that took part in Collide International. Broken Symmetries premiered at FACT in Liverpool in 2018 and received 73,464 visitors (November 2018 - March 2019), with 15,113 "*deeply engaged gallery visits*" **[5.2a]**. "*The exhibition was a huge critical and audience success*," says FACT's Head of Development **[5.2a]**. "*Prof Shears was key in supporting FACT: visiting the Large Hadron Collider with FACT staff and artists; enabling us to better understand the nuances of being a researcher at CERN, so we could best support our residencies; in the selection of artists; and as a guest speaker at public programme events*" **[5.2a].** According to a FACT report, Broken Symmetries generated significant national attention with 29 pieces of media coverage reaching over 703,000 people, including Financial Times, BBC World Service, and *i* newspaper **[5.2b]**. Shears and the partnership "*had a profound relationship on FACT's experience at working at the intersection of art and science*", says the Head of Development at FACT **[5.2a]**.

Broken Symmetries toured across Europe and Asia, and was attended by 199,996 visitors. It was exhibited at Centre de Cultura Contemporània de Barcelona (CCCB), Spain in 2019 (80,096 visitors), National Taiwan Museum of Fine Arts in Taichung, Taiwan in 2020 (34,146 visitors), iMAL (interactive Media Art Laboratory) in Brussels, Belgium in 2020 (1,490 visitors), and Kumu in Tallinn, Estonia in 2020 (10,800 visitors) **[5.1]**. The Broken Symmetries exhibition in Barcelona was "*the third most visited exhibition in CCCB's history*" **[5.1]**. "*We were very impressed about the number of visitors that came to the exhibitions. It was quite extraordinary. We also had a great reception to the exhibition from the Spanish and Belgian media*," says Head

of Arts at CERN **[5.1]**. Throughout the collaboration, Shears took part in public debates **[5.1, 5.2a]** alongside artists (including Geneva 2016, Liverpool School of Art 2017, FACT 2018) to provide insight into the particle physics concepts behind the art and Liverpool's LHCb research.

Broken Symmetries built on a successful project in which Shears worked with artists Evelina Domnitch and Dmitri Gelfand to provide insights into particle physics for 'No Such Thing as Gravity' - an artwork based on Liverpool's antimatter research. It was exhibited at FACT in 2016 (15,772 visitors) and the National Taiwan Museum of Fine Arts in 2017 **[5.4a]**. No Such Thing as Gravity received widespread critical acclaim across national media, with coverage on BBC Radio 3, New Scientist and The Guardian **[5.4b]**. No Such Thing as Gravity was described by Liverpool Echo as a "*fascinating exhibit on what we think we know about science and its possibilities*" and a "*show designed to get non-scientists thinking scientifically*" by New Scientist magazine **[5.4b]**.

4.2 Shaped debate and stimulated public interest in particle physics through philosophy

By exploring particle physics concepts through rigorous philosophical debate, Shears opened up Liverpool's LHCb research to new audiences and shaped public debate. At HowTheLightGetsIn Festival, '*the world's largest philosophy and music festival'* hosted by the Institute of Art and Ideas (IAI), Shears has engaged audiences with particle physics concepts from Liverpool's LHCb research **[5.5]**. Shears participated in six debates with philosophers (2014, 2015, 2016), and hosted an additional four debates (2015, 2016) on subjects as diverse as *whether the universe is mathematical* and *the role of evidence in science* **[5.5]**. These debates were attended in-person by 3,000 people and received 121,394 views across IAI Player and YouTube **[5.5]**. The IAI cited two of Shears' debates in their end of year "best of IAI TV 2016" list **[5.5]**.

To enhance public and cultural understanding of particle physics research, Shears took part in a philosophical debate on BBC Radio 4 (2015) and provided insights from Liverpool's LHCb research at CERN **[5.6]**. Hosted by Melvyn Bragg, the debate explored "*How can I know anything at all*?" and was commissioned as part of the BBC's 'A History of Ideas' series. The debate is available on-demand via BBC Sounds **[5.6]**. Shears further explored the importance of the scientific method within Liverpool's LHCb research on a separate Radio 4 documentary about falsification (2015) which also remains available on-demand via BBC Sounds **[5.6]**. Based on her Radio 4 documentary on falsification, Shears co-created a short BBC animation about philosopher of science Sir Karl Popper that has been viewed 295,309 times on YouTube **[5.6]**. Feedback described it as "*enlightening*", "*succinct*" and "*beautiful*" **[5.6]**. This animation is showcased by London's National Portrait Gallery (1.5 million visitors per year) as recommended background visitor information for their portraits of Popper and philosopher Karl Marx **[5.7]**.

4.3 Raised awareness and improved public understanding of Liverpool's LHCb particle physics research breakthroughs through international press and media coverage

Shears has "*reached audiences of many tens of millions of people*" worldwide during the REF period through print, radio and broadcast media interviews that have "*raised awareness and increased public understanding of a number of key LHC research discoveries*" **[5.8]**. These include antimatter (2014-2020) **[3.2]**, LHC Run 2 re-start (2015), lepton universality (2015-2019) **[3.3]**, and pentaquark and baryon discoveries (2017-2019) **[3.4,3.5].** "*Prof Shears' work with journalists and the media allows the research we fund at the LHC to be better understood by our stakeholders and the public*," according to the Co-Head of Communications at STFC **[5.8]**.

During the REF period, Shears has provided quotes used in 12 STFC press releases about major LHCb research stories and has been interviewed by numerous major journalists **[5.8],** generating 66 unique pieces of high-quality coverage **[5.9a]** across national and international print, radio and broadcast media. Major mainstream and scientific digital and print media outlets worldwide have covered Shears' LHCb research and included quotes from her within their coverage, including New Scientist, Nature, Scientific American, Wired (UK, Italy), Engineering and Technology Magazine, Financial Times, the Independent, The Guardian, The Times, Daily Mail, Daily Mirror, Daily Express, and Buzzfeed **[5.9a]**. Shears "*has a profound understanding of what interests a lay audience*," according to New Scientist's Creative Director **[5.10]**. "[Shears] *has explained to the public all the outstanding questions that particle physics has to answer and demystified the process of discovery*" **[5.10]**.

Shears has also raised awareness and increased public understanding of Liverpool's latest research results from the LHCb experiment at CERN through radio appearances on RTÉ Radio (Ireland), LBC Radio, BBC Radio 3, BBC Radio 4, and BBC World Service **[5.9a]**, as well as public radio stations in the US, Finland, and Mexico **[5.9a]**. Through broadcast media appearances, Shears has engaged television audiences with cutting-edge research developments from LHCb, including interviews on BBC Breakfast, BBC News, BBC World, ITV News, and Arte (France), as well as an appearance on a documentary for the Discovery Channel in the US **[5.10b]**. For STFC's Co-Head of Communications, "*Shears really helps the public to understand particle physics research at the LHC at a deeper level*," **[5.8]**.

The significance of Shears' media engagement is highly regarded by journalists, editors, and producers alike, as evidenced by repeat media interviews including, BBC News, The Guardian, BBC World Service and BBC Radio 4 **[5.8, 5.9a]**. "*For New Scientist journalists,* [Shears] *is a go-to source because she can explain the physics so clearly and crucially, put it in context*" **[5.10]**. *"She has an innate ability to quickly understand what a journalist is interested in, and explain her research to them in a way that they can use to tell a powerful story to their readers and the public*," says STFC's Co-Head of Communications **[5.8]**. "*The BBC Science team come back to her time and time again because they find her insight and input incredibly valuable*," **[5.8]**.

Working with the Royal Institution (October 2013 - 2020), Shears co-created and presented six short videos about major LHCb research developments including antimatter **[3.2]**, the Standard Model **[3.3]**, and pentaquarks **[3.4]**, which have been viewed online 877,275 times during the REF period **[5.9b]**. Shears has also delivered two TED talks in Liverpool and Arendal (2014, 2016) about LHCb research into antimatter **[3.2]** which have been viewed 374,956 times **[5.9b]**.

As a result of her media work being viewed as exemplary by the scientific press, Shears was approached by Nature (2018) to provide expert advice and best practice on how scientists can interact with journalists successfully **[5.9c]** and she is cited within STFC media training as an "*exemplar of how to marry up media work alongside continuing to do your research*" **[5.8]**. Shears continues to receive a high number of requests for interviews about particle physics research developments from LHCb. For "*particle physics research at CERN, there are three or four experts in the UK that I always direct journalists to, and Prof Shears is one of them*," according to Co-Head of Communications at STFC who states that she "*has reached audiences of many tens of millions of people during this period as a result of her STFC media work.*" **[5.8]**.

5. Sources to corroborate the impact

5.1 Testimonial from Head of **Arts at CERN**, supporting the impact of Shears' engagement with Collide International and her influence on the Broken Symmetries art exhibition.

5.2 Evidence from **FACT**, supporting the impact of the **Broken Symmetries** exhibition:
- **5.2a** Testimonial from Head of Development at FACT.
- **5.2b** FACT media report demonstrating critical reception to the exhibition.

5.3 Testimonial from **Yu-Chen Wang** who took part in Collide International and created work for Broken Symmetries, supporting the impact of Shears' research on her art and creative practice.

5.4 Evidence from **FACT** supporting the impact of the **No Such Thing as Gravity** exhibition:
- **5.4a** Emails from FACT relating to visitor numbers.
- **5.4b** FACT media report demonstrating critical reception to the exhibition.

5.5 Evidence of debates at **HowTheLightGetsIn Festival** with viewing figures and IAI TV email.

5.6 Evidence for **BBC Radio 4** programs and animations, supporting the impact of Shears' work.

5.7 Evidence from the **National Portrait Gallery**, supporting the impact of Shears' animation.

5.8 Testimonial from **STFC**'s Co-Head of Communications on the impact of Shears' media work.

5.9 Summary of Shears' **press and media contributions**:
- **5.9a** List of print, broadcast and radio interviews and media appearances.
- **5.9b** List of films and animations, with weblinks and viewing figures.
- **5.9c** Nature article, *On the record*, featuring Shears' advice on media engagement work.

5.10 Testimonial from Creative Director at **New Scientist**, supporting the impact of Shears' work with New Scientist Live and New Scientist magazine.