Institution: University of Cambridge

Unit of Assessment: 9 – Physics and Astronomy

Title of case study: *Collider*: interactive exhibition promotes public understanding of particle physics and pioneers new approaches to science communication

Period when the underpinning research was undertaken: 2007 - 2013

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:
Professor Valerie Gibson	PI (LHCb)	1989 – present
Professor Andy Parker	PI (ATLAS)	1989 – present
Dr Harry Cliff	PDRA on LHCb, and Science Museum Lead Curator	2012 – present

Period when the claimed impact occurred: October 2013 – May 2017

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Collider was an exhibition about the Large Hadron Collider (LHC) based on University of Cambridge research, and developed by the University's Department of Physics, the Science Museum and the European Organization for Nuclear Research (CERN). Harry Cliff, a University of Cambridge LHCb researcher, acted as Lead Curator and Head of Content for the exhibition, which was co-sponsored by STFC (the Science and Technology Facilities Council) and Winton Capital Management, had a budget of GBP2 million and filled 800m^2. It ran for six months at the Science Museum, London from November 2013 to May 2014, before touring internationally to France, Singapore and Australia, attracting over 650,000 visitors and widespread critical praise. The sustained impacts of the exhibition include (*i*) enhancing the public's understanding of particle physics, (*ii*) pioneering new approaches to communicating science in museums and *(iii)* promoting the role of blue skies research amongst decision makers. For his work as Lead Curator and Head of Content, Harry Cliff was awarded the Institute of Physics HEPP Science in Society Prize (2015).

2. Underpinning research (indicative maximum 500 words)

The Significance of the Large Hadron Collider

The Large Hadron Collider LHC) at the European Organization for Nuclear Research (CERN) is the world's most powerful particle collider, designed to investigate the structure of matter and the laws of nature. The four LHC experiments – ATLAS, ALICE, CMS and LHCb – record high-energy proton collisions and use them to test the predictions of the Standard Model (SM) of particle physics, our current best theory of fundamental particles and their interactions. Experiments at the LHC search for signs of physics beyond the SM, which is required to address some of the most important questions in science: the nature of dark matter, the origin of matter, and the relative weakness of gravity compared to other fundamental forces.

Cambridge Research and the LHC

The aim of the Collider exhibition was to engage the public with the science and engineering of the LHC. The content was based directly on the research of the Department's High Energy Physics (HEP) group, in particular the development of detector technologies for ATLAS (Professor Andy Parker) and LHCb (Professor Valerie Gibson and Dr Harry Cliff), and the search for new physics, including discovery of the Higgs boson in 2012 .

Key research carried out by the HEP group and featured in the exhibition:

- The Cambridge group has played a leading role in the ATLAS experiment [R1] since 1986. Prof. Andy Parker was a founder of ATLAS and project leader for the ATLAS Inner Detector for six years. The Cambridge group developed, produced and quality controlled the silicon microstrip sensors, modules and readout electronics of the ATLAS semiconductor tracker (SCT), essential for tracking particles as they emerge from the collision region. It also played a leading role in the development of data acquisition and monitoring for the online commissioning, calibration, readout and offline software of the SCT. This was essential for the discovery of the Higgs boson [R2], verifying the SM of particle physics and the mechanism by which fundamental particles acquire mass. The discovery of the Higgs boson led to the 2013 Nobel Prize for Physics.
- The Cambridge group led the search for supersymmetry [R3], an extension of the SM that resolves many major unanswered questions in fundamental physics, including the nature of dark matter, the origin of matter, and the mass of the Higgs boson. It was instrumental in developing new techniques to search for supersymmetric particles. These measurements ruled out many of the most popular versions of supersymmetry, forcing theoretical physicists to rethink many of their ideas and profoundly affecting our understanding of fundamental physics. The group also made major contributions to the search for microscopic black holes, predicted by several theories featuring extra dimensions of space which attempt to reconcile the weakness of gravity with the strengths of other fundamental forces. These measurements disproved many versions of these theories, providing essential information for theorists.
- The Cambridge-LHCb group under Prof. Val Gibson makes a leading contribution to the LHCb experiment, developing read-out electronics and control systems for RICH (ring-imaging Cherenkov) detectors essential for identifying different types of particles [R4], which are key to almost all measurements at LHCb. Prof. Val Gibson and Dr. Harry Cliff have led studies of charge-parity symmetry violation in the decay of beauty quarks [R5, R6], attempting to understand why matter and not antimatter dominates the universe, and to search for deviations from the predictions of the SM that could indicate the existence of new particles. These measurements demonstrated that the SM has insufficient charge-parity symmetry violation to account for the preponderance of matter, profoundly impacting our understanding of high energy physics and cosmology. Prof. Gibson is a leading member of LHCb, having acted as UK Spokesperson and Chair of the Collaboration Board, representing 78 institutes worldwide.

Drawing on this body of research, and other work carried out at the LHC, University of Cambridge LHCb researcher Dr Harry Cliff – acting as Lead Curator and Head of Content for Collider - developed the content of the exhibition in collaboration with the University's Department of Physics, the Science Museum and CERN.

3. References to the research (indicative maximum of six references)

All research outputs have been through a rigorous peer-review process

R1. The ATLAS Experiment at the CERN Large Hadron Collider, ATLAS Collaboration including M A Parker, JINST 3 (2008) S08003, DOI: 10.1088/1748-0221/3/08/S08003
R2. Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, ATLAS Collaboration including M A Parker, Phys.Lett. B716 (2012) 1-29. DOI: 10.1016/j.physletb.2012.08.020
R3. Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s}$=7 TeV proton-proton collisions, ATLAS Collaboration including M A Parker, Phys.Lett. B701 (2011) 186-203, DOI: 10.1016/j.physletb.2011.05.061
R4. The LHCb Detector at the LHC, LHCb Collaboration including V Gibson, JINST 3 (2008) S08005, DOI: 10.1088/1748-0221/3/08/S08005
R5. Measurement of the CP Asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ decays, LHCb Collaboration including V Gibson and H Cliff, Phys.Rev.Lett. 110 (2013) no.3, 031801. DOI: 10.1103/PhysRevLett.110.031801

R6. Measurement of CP violation and constraints on the CKM angle γ in $B^{\pm}\to DK^{\pm}$ with $D\to K^0_S\pi^+\pi^-$ decays, LHCb Collaboration including V Gibson and H Cliff, Nucl.Phys. B888 (2014) 169-193, DOI: 10.1016/j.nuclphysb.2014.09.015

4. Details of the impact (indicative maximum 750 words)

Introduction

University of Cambridge LHCb researcher Dr Harry Cliff led the Collider exhibition team as Lead Curator and Head of Content. The exhibition, co-sponsored by STFC (Science and Technology Facilities Council) and Winton Capital Management, had a budget of GBP2 million and filled 800m^2. It ran for six months at the Science Museum, London from November 2013, before touring Manchester, Paris, Singapore, Sydney and Brisbane between May 2014 and May 2017, attracting over 650,000 people [E1]. The sustained impacts of the exhibition include (*i*) enhancing the public's understanding of particle physics, (*ii*) pioneering new approaches to communicating science in museums and *(iii)* promoting the role of blue skies research amongst decision makers. Harry Cliff was awarded the Institute of Physics HEPP Science in Society Prize (2015) 'for his work as Curator and Head of Content for the successful Collider exhibition and other outreach work with the Science Museum, CERN and the Cavendish Laboratory' [E2A].

Enhancing the Public's Understanding of Particle Physics

The Collider exhibition promoted public understanding of the LHC and LHC research. National and international press reviews emphasised the exhibition's ability to communicate the complexity of particle physics. David Blackburn from The Spectator [E3A] wrote: '*I have a new party piece. I can explain, with a degree of clarity and precision, how the Hadron Collider at CERN works and what it is looking for. I can't claim credit for this feat of exposition … I owe everything to Collider… This is the best show in town for world weary parents to share in their children's awe*'. Steve Connor from the Independent described Collider as *'a pocket version of the real thing, something that you can absorb and digest without getting a headache at the end of it all. It is a superb introduction to the esoteric world of experimental particle physics'* [E3B]. The Economist praised it as: *'A smashing show…admirably the curators do not shy away from the notoriously complicated science the LHC was designed to shed light on'* [E3C]. 92% of visitors reported being either satisfied or very satisfied with the exhibition, and 93% agreed that the '*LHC is the largest, most sophisticated and most powerful scientific device ever made*' [E4].

The Collider exhibition succeeded in attracting near-equal proportions of male (56%) and female (44%) visitors [E4]. Given the gender imbalance in physics (roughly 3:1 male to female at A-level in the UK [E5]) this was a substantial achievement and helped engage a previously under-served female audience. Increased visibility of women in science and engineering improves female recruitment and retention in STEM [E6]. The presence of senior female scientists and engineers in the exhibition showcased the leading positions taken by women, providing role-models for female enrolment.

The exhibition was able to influence a wide audience beyond those who visited through a package of online resources accessible via links on the Collider website, including Dr Harry Cliff's Royal Institution (RI) lecture on his research at LHCb in October 2017, which has been viewed 2.3 million times, the fourth most viewed RI lecture of all time. As with the exhibition, viewers commented on how particle physics was made accessible: *'Harry Cliff does such an amazing job of explaining incredibly difficult* physics'…'*Totally clear and engaging throughout*'…'*This was a spectacular presentation – the best I've seen about particle physics*'…'*superbly well explained (for a layman like me)*' [E7].

Transforming the way museums communicate science

The Collider exhibition broke new ground in science communication. The exhibition team led by Harry Cliff included an Olivier Award-winning playwright, an Olivier Award-winning video artist, theatre set designers, graphic designers and sound artists who created an immersive exhibition that recreated the environment at CERN and allowed visitors to 'meet' scientists and engineers through the use of video projection and sound [E8]. Genuine scientific apparatus, including

components of the accelerator and detectors were set in the context in which they are used, aiding understanding and engagement. Phillip Ball from Prospect Magazine described it as [E3D] '*a cultural shift...the transformation of an important scientific result (Higgs discovery) into an extraordinary cultural event isn't a triumph of style over substance. It marks a shift in science communication'*.

For its ground-breaking design, Collider won the The Dibner Award for Excellence in Museum Exhibits, with the citation praising it as a *'fine example of collaboration between scientists, historians and museum professionals'* [E2B]. A day after the exhibition opened, The Independent ran a front page news story 'Intelligent Design' describing the exhibition as 'one of *the most ambitious shows in the Science Museum's 150 year history…art and science collide with spectacular results*' [E3E;E3F]. Testimonials from visitors also support the success of the approach: '*exceptional in its conceptual design and portrayal. Pictures/videos of how the God particle was detected are superb…It is a must see'* [E9]. As well as being extremely engaging, the use of visual models helped visitor understanding of complex scientific concepts: '*It was one of my highlights…the 3D model, how it works, being in the beam. I understood after this the way the beams collide'* [E4].

Promoting the role of blue skies research amongst decision makers

Leading figures in government, science and the cultural sector attended the Collider launch event, including the then Chancellor of the Exchequer (George Osborne), the Minister of State for Universities and Science (David Willetts), the Chief Executive of STFC, the Director General of CERN, the Head of the Cavendish Laboratory, Professor Peter Higgs, Professor Stephen Hawking, novelist Ian McEwan and numerous members of the international particle physics community [E10].

Professor John Womersley, CEO of STFC at the time, noted the positive impact of Collider on government ministers:

'*an important bonus was the ability to use the launch event to target both David Willetts and George Osborne...it definitely helped form a positive impression of basic research... We can't make a causal connection, but a number of positive spending decisions followed. New money was made available for the Square Kilometre Array* [a multibillion-pound radio telescope] *and later for DUNE* [a major international neutrino experiment which subsequently attracted GBP119 million in UK government investment]' [E11A;E11B].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1]. Visitor figures for Collider from Science Museum Group
[E2]. Evidence of Prizes won by Harry Cliff and the Collider exhibition

- E2A: Harry Cliff, Institute of Physics HEPP Science in Society Prize (2015) https://www.iop.org/get-involved/special-interest-groups/high-energy-particle-physics-group/science-society-prize
- E2B: Collider exhibition, The Dibner Award https://www.historyoftechnology.org/about-us/awards-prizes-and-grants/the-dibner-award/

[E3]. PDF of media coverage

- E3A: The Spectator https://www.spectator.co.uk/article/how-i-felt-when-i-stepped-inside-the-hadron-collider
- E3B: The Independent http://www.independent.co.uk/news/science/large-hadron-collider-exhibition-review-art-and-science-collide-with-spectacular-results-at-the-8935484.html
- E3C: The Economist https://www.economist.com/prospero/2013/11/18/a-smashing-show#:~:text=Admirably%2C%20the%20curators%20do%20not%20shy%20away%20from,much%20as%20the%20atomic%20variety%2C%20is%20made%20of.
- E3D: Prospect magazine http://www.prospectmagazine.co.uk/blogs/philip-ball/the-science-museums-collider-marks-a-cultural-shift
- E3E: Science Museum blog https://blog.sciencemuseum.org.uk/designing-collider/

- E3F: Studio Plus Three press release https://www.studioplusthree.com/exhibition/collider-science-museum

[E4]. Collider: Summative Evaluation Summary Findings, Audience Research and Advocacy Group, May 2014. See pages 18, 19, 7 and 37 (relevant sections highlighted)
[E5]. Joint Council for Qualifications (JCQ) 2019 A Level Results https://www.jcq.org.uk/wp-content/uploads/2019/08/A-Level-and-AS-Results-Summer-2019.pdf See page 6
[E6]. Fogg-Rogers and Hobbs (2019) Catch 22 - improving visibility of women in science and engineering for both recruitment and retention. Journal of Science Communication, 18 (4). ISSN 1824-2049 https://doi.org/10.22323/2.18040305
[E7]. Royal Institution (RI) Lecture and accompanying viewer comments
https://www.youtube.com/watch?v=edvdzh9Pggg
[E8]. Curating the collider: using place to engage museum visitors with particle physics, Alison Boyle, Harry Cliff, Science Museum Group Journal, Autumn 2014, Issue 02, DOI: http://dx.doi.org/10.15180/140207
[E9]. Visitor review following visit to Collider in Singapore
[E10]. Record of the Chancellor of the Exchequer's attendance at the exhibition launch
https://www.gov.uk/government/news/chancellor-pays-tribute-to-leading-british-scientists-at-collider-exhibition-launch
[E11]. Evidence of impact of Collider on decision makers

- E11A: Testimonial from the CEO of STFC at the time of the Collider launch
- E11B: Press release: 'The SKA takes off with £119M contribution from the UK'

https://www.gov.uk/government/news/the-ska-takes-off-with-119m-contribution-from-the-uk