Institution: Royal Holloway, University of London
Unit of Assessment: B9 Physics
Title of case study: Engaging the public with current research in Particle Physics

1. Summary of the impact

The Royal Holloway Centre for Particle Physics has long recognised the need to engage with audiences beyond academia to explain particle physics research and respond to the very high level of interest and desire for further knowledge that the public have. Through a series of coordinated outreach events and the development of hands-on demonstrations we have been generating cultural impact on a diverse audience (A-level students, school teachers of physics, young professionals, general public interested in science) by raising awareness of particle physics, engaging the public with current research, and informing the debate on its value.

2. Underpinning research

The Centre for Particle Physics (CPP) at Royal Holloway, University of London, carries out research addressing some of the most fundamental questions in Nature. These questions include clarifying the origin of mass of elementary particles (via the search, discovery and study of Higgs particles) and the ongoing search for Dark Matter, which constitutes approximately 25% of the energy density of the Universe. There is a huge level of interest in these topics in the public and the media, as evidenced, for instance, by the number of hits generated by a Google search for “dark matter” (“higgs”): in excess of 5 million (10 million) hits.

The group at Royal Holloway that works on the ATLAS experiment at the Large Hadron Collider (LHC) in the CERN laboratory has had a long-standing involvement in the search for, and now the study of, the Higgs particle since Dr Pedro Teixeira-Dias joined the Department in 2001. Dr Teixeira-Dias formed the Higgs group at Royal Holloway and has led it since then. This group has had 8 PhD students (2 still ongoing), a post-doctoral research assistant (Dr Ricardo Gonçalo, 2003-13) and 2 academics (Teixeira-Dias and Prof. Glen Cowan) that have contributed directly to the ATLAS searches for a light Higgs particle decaying either to photons or to b-quarks. Gonçalo and Teixeira-Dias have both lead the UK-wide ATLAS Higgs working group, Gonçalo has lead the ATLAS search for Higgs to b-quarks at CERN, and Cowan - while convenor of the ATLAS Statistics Forum at CERN - led the development of the statistical methods that were central to the ATLAS Higgs searches and discovery. Other members of the extended ATLAS group at Royal Holloway (totalling ~20 collaborators) contribute to other physics topics (academics Drs Boisvert and Berry direct work on the study of the top quark, and on the searches for extra space-time dimensions and new exotic particles, respectively) and contribute to essential aspects of the design, construction, commissioning and operation of the detector’s data acquisition system and its high-level trigger.

In September 2010, Dr Monroe (promoted to Professor in 2013) joined the Department of Physics from MIT to start the Royal Holloway group working on the search for dark matter. The group’s research is focused on dark matter search experiments with world-leading sensitivity and on the development of novel sensitive particle detection techniques for future experiments. The group was reinforced in January 2012 with the appointment of Dr James Nikkel, a world-leading expert in liquid noble detectors, who made many of the pioneering measurements establishing this technique for dark matter detection. In addition, the group has 2 post-doctoral research assistants, 5 PhD students (all ongoing) and 4 Masters students (who have all completed). The group works on the DEAP/CLEAN programme to develop large liquid Argon detectors capable of reaching kilo-tonne scales for dark matter and low-background frontier physics, on the LUX liquid Xenon dark matter search, and on the DMTPC experiment. Monroe established a new collaboration of UK institutions on the DEAP/CLEAN experiment when she moved to Royal Holloway, and leads the UK’s contribution of the detector calibration system hardware, software, and analysis. Royal Holloway leads the neutron calibration sub-system and the dark matter search analysis software development. Nikkel is the Detector Commissioning Manager and leads the refrigeration system for DEAP/CLEAN, collaborates on the LUX liquid Xe dark matter search, and the liquid noble detector R&D effort in the laboratory at Royal Holloway. On DMTPC, Monroe is the spokesperson of the DMTPC international scientific collaboration (since 2011), which is developing optical-readout time projection chambers to search for the dark matter wind. Monroe led the first DMTPC dark matter search result, published in 2011, and the establishment of an underground laboratory

at the WIPP facility where DMTPC is now deployed. The Royal Holloway group lead the time projection chamber and optical system design for the next-generation DMTPC detector, currently under construction at MIT.

The group's research in these areas is further enhanced by Dr Kauer (Higgs theorist) and Dr West (dark matter theorist.)

3. References to the research

2012 Recent Progress from the MiniCLEAN Dark Matter Experiment; J Monroe, J. Phys.: Conf. Ser. 375 012012 (http://dx.doi.org/10.1088/1742-6596/375/1/012012)

Publication in co-authorship within the DMTPC collaboration (incl. Monroe):

2012 **Background rejection in the DMTPC dark matter search using charge signals; Nucl. Instr. Meth. A696, 121-128. (http://dx.doi.org/10.1016/j.nima.2012.08.073)**

Publications in co-authorship within the ATLAS collaboration (incl. Berry, Boisvert, Cowan, Gonçalo, Teixeira-Dias):

2011 Search for the Standard Model Higgs boson in the two photon decay channel with the ATLAS detector at the LHC; Phys. Lett. B705, Issue 5, 452-470. (http://dx.doi.org/10.1016/j.physletb.2011.10.051)

2012 **Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC; Phys. Lett. B716, Issue 1, 1-29. (http://dx.doi.org/10.1016/j.physletb.2012.08.020)**

2012 Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b-quark pair with the ATLAS detector; Phys. Lett. B718, Issue 2, 369-390. (http://dx.doi.org/10.1016/j.physletb.2012.10.061)

Evidence of the quality of the research: our ATLAS, dark matter and accelerator science programmes have attracted very significant STFC and EU funding. The research has been published in high-quality peer-reviewed journals. The Higgs discovery paper reports a result which constitutes a major step forward in our understanding of the origin of mass of elementary particles, and has been cited more than 1800 times in the 15 months since July 2012. The 2013 EPS High Energy and Particle Physics Prize was awarded jointly to the ATLAS and CMS collaborations for this discovery, and the Englert & Higgs 2013 Physics Nobel Prize citation included explicit mention of the key role played by the ATLAS and CMS discovery of the Higgs particle.

4. Details of the impact

The impacts are of a cultural, societal and educational nature and have been, in relation to particle physics: to raise awareness; to respond to the very high level of interest demonstrated by the public; to inform and stimulate debate on research and its value; to motivate individuals and students in particular to learn more and possibly pursue a career based on the sciences. The beneficiaries have been A-level students and their teachers; young professionals in the London area; the general public interested in science. These impacts have been achieved, with the engagement of all members of the CPP, by the targeted development of hands-on demonstrations, and by our participation in, and organisation of, a series of co-ordinated outreach events (Particle Physics masterclasses, science lectures and open days for the general public, the Royal Society exhibit on the Higgs boson in 2013). More detail on these activities is provided below.

Development of hands-on particle physics demonstrations & activities: Members of the CPP have developed several custom-made hands-on demonstrations designed to engage a wider public with our research on (i) particle accelerators, (ii) dark matter and (iii) the search for the Higgs particle. These demonstrations have been used in 2013, all before the end of July. They are:

- a 3 m-long table-top demonstrator ("Accelerate!") of the principle behind linear charged particle accelerators. This was developed by Dr Stephen Gibson, who joined the John Adams Institute for Accelerator Science at Royal Holloway in January 2013, and has been used in the Royal Holloway Particle Physics masterclasses, the Royal Holloway Science Open Day (in excess of 650 visitors to the Department of Physics, mostly families with children), and a Physics Taster Day for A-level students, held at Royal Holloway and attended by 50 prospective undergraduates.

- a demonstration of how galaxy-rotation curves provide evidence for the existence of dark matter in the Universe, based on a 1-m diameter rotating “drum”. This demonstration was created by Nikkel and has been used at Royal Holloway in 2013, for the Particle Physics masterclasses and the Physics Taster Day.
- a custom-made histogram made out of wood, and some loaded dice, to explain how evidence of the existence of the Higgs was obtained in the LHC data, and to demonstrate the statistical aspects behind the discovery of a signal in the presence of background (a computer-based version of this demonstration was also developed, to be used in tablets); a “Higgs hunt” activity aimed at younger children, aged 4-12, complete with a “Wanted poster” including other age-appropriate activities; and a set of specially-labelled polyhedral 12-sided dice to illustrate the probabilistic nature of the decay of the Higgs particle. All of these activities were used extensively to engage the public during the Royal Society exhibition described below.

Particle Physics masterclasses: an annual one-day event for lower sixth form students and their teachers, which we run twice a year, in March or April. Every year, all available members of the group (PhD students, PDRAs and academics) are involved in the running of this event. The programme includes two talks, on the structure of matter, and on the Large Hadron Collider and the search for the Higgs particle. In addition, there are three hands-on activities for the students to complete. Teachers and academics are encouraged to talk with each other during the day; the teachers use this opportunity to ask about particle physics and, in particular, topics which form part of the A-level curriculum that they have to deliver. This increases their confidence and familiarity with the material. The masterclasses are always oversubscribed. We receive 75-80 students and 9-10 teachers for every masterclass, making in excess of 900 students impacted in the REF period. In total 110 school groups have attended a masterclass in this period, from 71 different schools. The masterclasses are integrated in the National Particle Physics Masterclass programme. The Royal Holloway Centre for Particle Physics was one of the first UK groups to organise these masterclasses, and have done so every year since 1999. In student feedback collected in 2013 (39 questionnaires) 50% of the students responded that attending the masterclass had helped them feel more confident about their ability to enter Higher Education.

Royal Society Summer Science Exhibition 2013: The ATLAS and Theoretical Particle Physics groups at Royal Holloway contributed to the organisation and the running of the “Understanding the Higgs boson” exhibit that was open to the general public in the Royal Society, in London, July 2-7 2013. (One additional day, July 1, was dedicated to visits from schools.) The exhibit had contributions from 18 university groups in the UK, and was co-ordinated by a colleague from the University of Birmingham. The Royal Holloway group was one of the main contributors to the exhibit: in particular, Teixeira-Dias and Boisvert developed several of the hands-on activities (described above) which were used [1]. In addition, Teixeira-Dias and Cowan contributed eight written pages with personal accounts of their involvement in the Higgs search, included in the free 110-page booklet [2] that accompanied the exhibit (2000 copies of which were given to visitors at the exhibition), and 8 Royal Holloway staff did 9 shifts of 4 hours each, interacting with the public at the exhibition. The Royal Society exhibition had more than 12,500 visitors overall [3], with at least 7,000 estimated to have visited the Higgs exhibit (based on actual peak-time and out-of-peak time visitor counts). The Royal Society staff estimated that the Higgs exhibit was one of the most sought-after exhibits (based on direct observation of how busy the exhibit was throughout the week, and the observation that often visitors arriving at the exhibition would ask reception specifically for directions to the Higgs exhibit). A total of 307 questionnaires were returned by visitors to the Higgs exhibit, with 47% of respondents in the 12-18 years age group (22% in 19-29 y; 24% in 30-65 y). 64% of respondents found the exhibit "very informative" (with a further 30% selecting "quite informative"), and 81% left the exhibit with an increased interest in physics [4]. The website of the exhibition overall (http://sse.royalsociety.org/2013/; including a link to the Higgs exhibit web page) had in excess of 110,000 visits from 83,000 Absolute Unique Visitors [3].

Particle Physics outreach lectures and media engagement: Members of the Centre for Particle Physics regularly give talks on their research to audiences outside HEIs and academia, and have engaged with the media. The audiences impacted have ranged from professionals with a physics or engineering degree, GCSE and A-level students and their teachers, young professionals, and the general public. Topics covered include the LHC and the search for the Higgs and other new particles, the search for Dark Matter, anti-matter, overviews of Particle Physics, etc. (A digest of

relevant events is available in https://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/Public/RefPageB.) Our contributions to the following are also worthy of note:

- In August 2012, following on from the announcement of the Higgs discovery at CERN, Boisvert gave a lecture on “Finding the Higgs”, as part of “The Lost Lectures” series that is very popular with young professionals based in and around London. The event - sold out - had a paying audience of 500 on the night. Boisvert’s talk (one of six) inspired and enthused the audience, was described by the founder of The Lost Lectures series as an “exceptional talk” [5], “without doubt one of [the] most popular and most appreciated speakers ever! (…) making difficult research interesting, entertaining and accessible to the wider public” [6]. It also generated very positive comment on Twitter [5] and Facebook [7]. The video of the presentation, freely available online, has been viewed in excess of 2000 times since [8].
- Members of the Particle Physics group have been assiduous contributors to the "Science For Society - Particle Physics" one-week residential course to inform and stimulate A-level Physics teachers. This is an annual event organised at Brunel University and funded by The Goldsmiths' Company (Charity & Education). Every year since 2002 (2010 excepted) Cowan has contributed a talk on anti-matter: “Discovering the particles of Nature: the picture that was not reversed”. Since 2008 the group has contributed one additional talk every year, on either “ATLAS and the search for New Physics” (Berry) or "A tunnel to the beginning of time: the LHC and ATLAS" (Boisvert). Typically, 25 teachers attend every year; since 2008 an estimated 150 teachers have benefitted from the pedagogical talks given by our academics [9].
- Cowan's contribution to the BBC4 "Beautiful Equations" one-hour documentary [10] written and presented by artist and writer Matt Collings. The programme addressed the question as to whether, like art, equations in physics can also be beautiful. The program includes a five minute segment filmed at Royal Holloway, with a demonstration of the existence of anti-matter using a cloud chamber, in the context of the discussion of the Dirac equation (one of five equations covered in the program). The program was originally broadcast on December 14, 2010 and the official viewing figures show it was watched by an audience of 336,000 and was in the top 5 most-watched BBC4 programs that week [11]. There were also 5 repeat broadcasts, in 2010, 2011 and 2012.

5. Sources to corroborate the impact

Copies of all documents below are available on request. [1], [2], [3], [4], [5] and [11] are also available from https://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/Public/RefPageA .

[1] Guide to the activities and demonstrations developed by the Royal Holloway group for the Higgs exhibit at the Royal Society Exhibition. [Quality and authorship of activities and demonstrations.]

[2] "Understanding the Higgs Boson" booklet. Copy also available from http://www.understanding-the-higgs-boson.org/exhibit/booklet/ [Quality and authorship of written contributions.]

[3] The Royal Society (RS) report "Summer Science Exhibition 2013: review for exhibitors" on the exhibition overall. Copy also available from the Summer Science Exhibition Team coordinator, who can also corroborate. [Reach of impact.]

[4] Report on the RS Higgs exhibit. Copy also available from the Higgs Exhibit Team coordinator at the University of Birmingham, who can also corroborate. [Reach and significance of impact.]

[5] Twitter reaction: the collected tweets are available at https://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/Public/RefPageLLtweets [Secondary reach of impact.]

Three supporting statements from the founder and organiser of The Lost Lectures:
[6] September 1, 2012 [Significance of impact]; [7] October 11, 2012 [Significance of impact, secondary reach]; [8] September 6, 2013 [Secondary reach of impact].

[9] The Brunel University organiser of the Science for Society Particle Physics residential courses for teachers can be contacted to corroborate any details of our participation in the courses.

[10] The BBC documentary producer can be contacted to corroborate any details related to our participation in the programme.

[11] Official viewing figures, by BARB (the Broadcasting Audience Research Board) can be obtained online at http://www.barb.co.uk/viewing/weekly-top-10? (selecting Channel: BBC4, Year: 2010, Month: December, Week: Dec 13- Dec 19). [Reach and significance of impact].