Institution:	The University of Oxford
Unit of Assessment:	9
Title of case study:	[4] Exploring live events from the LHC on a smartphone

1. Summary of the impact

A smartphone application, *LHSee*, has enabled members of the public to understand better one of the experiments at the Large Hadron Collider, by presenting interactive displays of real collision events from the ATLAS experiment including those contributing to the Higgs boson discovery. The software has enabled users to understand and be engaged with the process of discovery at the LHC and has raised aspirations for further engagement with science and the study of physics. It has been downloaded over 60,000 times and has achieved excellent user reviews and awards.

2. Underpinning research

Oxford Physics is one of the leading institutes worldwide in searches for supersymmetry (SUSY) at the ATLAS experiment in CERN, and has major roles including in analysis strategy, energy resolution, particle identification, and Standard Model and detector background studies. More widely, Oxford Physics played crucial roles in the development and construction of the ATLAS detector, in particular the semiconductor tracker in the inner detector, and has since been vigorously involved in physics analysis as well as software development, operations and maintenance. In July 2013, the ATLAS group at Oxford comprised 11 academic staff, 4 PDRAs and 15 doctoral students.

One member of the Oxford group, Dr Alan Barr, was convenor of one of the ATLAS SUSY subgroups (missing-E_T), responsible for defining, managing and editing the first SUSY search analyses (2010-2011). The highly sensitive and robust search strategies he proposed [1] were adopted in the early data analyses. A necessary prerequisite for discovery is the understanding of Standard Model backgrounds, for which Barr proposed and performed background measurements (multijet, boson+jet and detector-resolution) for five SUSY search publications [e.g. 2,4,5]. Of these, three were edited by Barr and one of the Oxford research students. These searches extended the sensitivity for first-generation squarks and gluinos up to the TeV scale, and include one of the most highly cited ATLAS publications. Amongst them is a particularly innovative method for searching for SUSY in complex events where particles decay to six or more jets [5].

These papers all include a description of the ATLAS detector, the object (particle track) reconstruction, and the subsequent selection of events specific to each analysis. A comprehensive understanding of the components of the detector, and the process by which events are deduced from the raw data it collects, are thus critical to all analysis of ATLAS experiments. In order to examine individual reconstructed events and the underlying data, the global ATLAS collaboration uses the ATLANTIS and VP1 visualisation codes (both written elsewhere) to render detector signals and event reconstructions in 2D and 3D respectively. Although powerful, VP1 is available only within other software, is restricted to the ATLAS collaboration and is of considerable size and complexity. The impact reported here arose through software that is the only 3D event display outwith the ATLAS collaboration and of considerably smaller size than VP1.

Dr Alan Barr joined Oxford as a University Lecturer in particle physics in 2007. He was Physics (analysis) coordinator of the ATLAS UK collaboration from 2008-2011. He has also been a trained data acquisition shift expert for ATLAS. Mr Chris Boddy was a STFC-funded doctoral student at the University of Oxford (2008-12), supervised by Dr Chris Hays, a lecturer in the Department since 2007. Boddy's thesis topic was the search for Higgs boson(s) with ATLAS.

3. References to the research (Oxford authors underlined; * denotes best indicators of quality)

[1] A.J. Barr and C. Gwenlan (2009). The race for supersymmetry: Using m_{T2} for discovery. *Phys.Rev.* **D80**, 074007. doi:10.1103/PhysRevD.80.074007 [24 citations, Scopus].
This paper describes how a very simple event selection, using only one kinematic variable, may be used to search for new particles at the LHC.

[2] *ATLAS Collaboration [46 Oxford authors including A.R. Barr and C.R. Boddy] (2011). Search for Supersymmetry Using Final States with One Lepton, Jets, and Missing Transverse Momentum with the ATLAS Detector in $\sqrt{s}$=7 TeV pp Collisions. *Phys. Rev. Lett.* **106**, 131802. doi:10.1103/PhysRevLett.106.131802 [103 citations, Scopus].
This paper presented the first search for supersymmetry at the LHC and its significance was described in a Physics Viewpoint article [Physics 4, 27 (2011)].

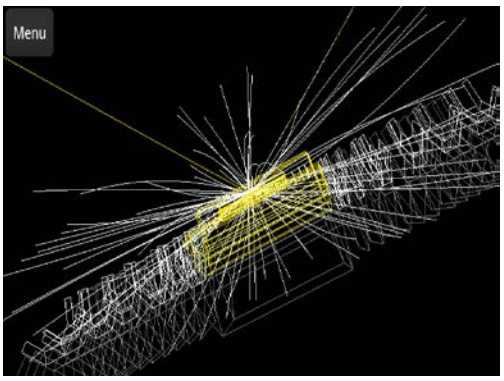
[3] *ATLAS Collaboration [44 Oxford authors including A.R. Barr and C.R. Boddy] (2011). Search for the Higgs boson in the $H\rightarrow WW^{(*)}\rightarrow \ell^{+}\nu\, \ell^{-}\nu$ decay channel in *pp* collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector. *Phys. Rev. Lett.* ***108*** *111802*. doi:10.1103/PhysRevLett.108.111802 [13 citations, Scopus].
This paper presents the first Higgs to WW analysis, to which Barr contributed. Featured in the Physics Viewpoint article, 'Homing in on the Higgs Boson' [Physics 5, 32 (2012)].

[4] ATLAS Collaboration [45 Oxford authors including A.R. Barr and C.R. Boddy] (2011). Search for new phenomena in final states with large jet multiplicities and missing transverse momentum using $\sqrt{s}$ = 7 TeV pp collisions with the ATLAS detector. *JHEP* **11**, 99. doi:10.1007/JHEP11(2011)099 [42 citations, Scopus].
The increased data from ATLAS was used to extend searches to events with much more complicated decays than previously possible, giving increased sensitivity, with the help of innovative methods for evaluation of background.

[5] *ATLAS Collaboration [44 Oxford authors including A.R. Barr and C.Boddy] (2012). 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. *Phys Lett* **B710**, 67-85 (2012). *doi:*10.1016/j.physletb.2012.02.051 [116 citations, Scopus].
This paper presented what was at the time the most sensitive SUSY search using the early LHC data with hadronic final states at ATLAS, led by Barr.

4. Details of the impact

Barr realised that the graphics capabilities and wide usage of smartphones offered groundbreaking possibilities for engagement with science. A prototype smartphone application, "LHSee", was created by Barr and Boddy with support from a STFC small award (ST/I507069/1). The app shows users real collision events from ATLAS, rendered in 3D, necessarily simplified for clarity and bandwidth. Just as in the tools used within ATLAS, the detector elements can be shown, as can 2D projections. With the guidance provided, the user can learn to use these displays to interpret the events using logic analogous to the processes used in the ATLAS collaboration. The technical implementation and educational potential was presented in *Physics Education* [A].



A collision event in the ATLAS experiment rendered with LHSee.

The app was launched through Android Marketplace, now Google Play, on 7th October 2011, and is described there as *"LHSee makes the Hadron Collider accessible to anybody with an Android smartphone or tablet PC. … For the first time you can now grab live collision events from the underground detectors in Geneva, and beam them direct to your own device."* [B]. By including some test data, it also allowed users to "Hunt the Higgs", and thus gain a conception of what 'discovery' entails. Concurrent with the CERN press conference in July 2012 on the discovery of the new particle, real data from observed candidate Higgs events was made available in LHSee. This was given publicity by CERN and resulted in several thousand new downloads.

Development of this app required (i) the reduction of each large event dataset to something that is feasible to transmit to a smartphone and (ii) the trust of the ATLAS collaboration to access live events without conveying meaningful numerical data. Neither would have been possible without a detailed knowledge of the ATLAS detectors, an understanding of the physics that could be appreciated from a simplified rendering of the event, and a respected role in the collaboration. Barr, Hays and Boddy's research, and the wider context of the Oxford ATLAS group, thus directly underpins both the conception and implementation of this app.

Barr's roles on this project were as application content advisor, project manager, and liaison with CERN, ATLAS and STFC. Boddy was the lead content and software developer. They were advised by a wide range of other experts, including commercial smartphone application developers, the ATLAS outreach group, the ATLAS UK collaboration, the STFC media team, the CERN press office, and – at the time of release – various contacts in the popular press. Text for the app has been translated into six languages by volunteers from the ATLAS collaboration.

Reach

One week after release, the app had been downloaded by over 25,000 people across the world: only 12% of downloads were from the UK. The app incorporates a feedback form, from which analysis of a set of 1000 responses indicated a wide user age range: 10% were aged 18 or under; 45% 19-35, 20% 36-50 and 11% 51 or over [C]. Downloads had increased to over 60,000 by June 2012 [B].

Comments from users indicate that the reach has been widened further by teachers, and practising or aspiring particle physicists who had used or intended to use it to explain the experiment to others [B,C], for example: "*I have been showing all my non technical friends*" [C]. The report in *Physics Education* has been downloaded over 500 times [A] and LHSee was identified as an educational 'app of the week' in October 2011 [D].

The app also featured in the exhibit 'Higgs Boson' at the Royal Society Summer Science Exhibition in July 2013, which was presented by members of the ATLAS collaboration from a number of UK universities and visited by an estimated 7000 people. It allowed visitors to investigate ATLAS events themselves, to plot mass distributions for W and Z bosons and to identify candidate Higgs boson events.

Significance to users

At January 2013, LHSee had an average user rating of 4.8 out of 5 "stars" from 520 reviews on Google Play [B], which was the highest rating of the 100 most-downloaded free apps [E]. Free-text responses were also obtained through the app's own feedback [C]. From these sources, benefits to users fall into three principal categories:

Raising interest and inspiration: User comments include "*Glorious beyond words*" [B], '*LHSee is an excellent effort to make us feel a part of grand discovery*' and '*its like being able to reach out and lay a hand on the pulse of super science*' [C]. Many users were sufficiently engaged to suggest extra features they would like to see, some of which have since been implemented.

Understanding the experiment: Free-text responses included some confirmation that users had used the app to gain a better understanding of how events are analysed: *'I almost felt like I was working beside the physicists while analysing those real-time events'; 'Quite complicated, but I understand the basics now'; 'It only took me a few tries to be able to discern the types of events*

described' and '*Thank you for helping us visualize what the LHC is.*' [C]

Encouragement to study further: 73% of those aged 18 or under in the feedback forms analysed agreed or strongly agreed that the app 'encouraged them to study physics at a higher level' [C]. Free-text responses included '*It has rekindled an interest in science and mathematics. I do intend on studying the subject now'* and *'Wish [I] was part of the team. Wish I could continue my higher education in particle physics.'* [C]

Press and media coverage

LHSee has been featured in a number of publications and websites, including positive reviews in *The Times* [F], the *Daily Mail* [G], a *Guardian* blog, *Forbes* [H] and other international media. It has also been flagged specifically for its educational value e.g. [D,I]. A detailed review on the AndroidTapp website noted, "*you really have to apply and learn how things work to get the most out of the app*" and "*given a little time, you can really begin to understand how important the work is that they are doing*" [I]. The Gizmodo site awarded it 'App of the Day', commenting, "*The LHC is .. a very important part of human history and… I know so very little about it. This app presents the LHC's mission and various experiments in a much more digestible package.*" [J].

Sustainability and third-party support

The version described here was limited to a single application, containing only a few key 'demonstrator' features and available only to users with Android devices. To ensure engagement can be widened further and to support greater understanding of the Higgs discovery, a follow-on STFC Large Award was secured in April 2012 (ST/K000462/1, £43k). This funded development of a subsequent version, 'Collider', including creation of a version for iPhone/iPad, and extension to a wider range of educational and outreach application resources. This project is ongoing.

5. Sources to corroborate the impact

Launch, downloads and feedback

A. A. Barr and C. Boddy (2012). The ATLAS detector on a smartphone. *Physics Education* **47**, 270-273. doi: 10.1088/0031-9120/47/3/F05 (510 downloads at Sept 2013)
B. https://play.google.com/store/apps/details?id=com.lhsee [520 reviews at Jan 2013 and downloads listed as being between 50,000 and 100,000.]
C. Responses to feedback form (N~1000) held in Oxford
D. *Birmingham Grid for Learning, App of the Week,* October 2011*:* http://www.bgfl.org/bgfl/index.cfm?p=0,view_info_item&start=0&id=23159
E. Data from Google Play, June 2012, held on file.

Recognition in the media

F. 'Scientists create smartphone app to help users hunt for the Higgs', Hannah Devlin, *The Times*, 11th Oct 2011, http://www.thetimes.co.uk/tto/science/article3188856.ece
G. *Daily Mail*: 10th Oct 2011 http://www.dailymail.co.uk/sciencetech/article-2047336/The-Higgs-boson-Theres-app--scientists-phone-users-direct-3D-feed-events-inside-LHC.html [14 comments]
H. *Forbes,* 9th Oct 2011: http://www.forbes.com/sites/alexknapp/2011/10/09/want-to-find-the-higgs-boson-theres-an-app-for-that/
I. Review of app including potential for learning: http://www.androidtapp.com/lhsee/
J. Review of app by Gizmodo (Australia) including learning about the LHC: http://www.gizmodo.com.au/2011/10/lhsee-for-android-find-out-whats-going-on-inside-the-large-hadron-collider/