



## Citizen scientist community engagement with the HiggsHunters project at the Large Hadron Collider

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### Abstract

The engagement of citizen scientists with the HiggsHunters.org citizen science project is investigated through analysis of behaviour, discussion and survey data. More than 38,000 citizen scientists from 179 countries participated, classifying 1.5 million features of interest on about 39,000 distinct images. While most citizen scientists classified only a handful of images, some classified hundreds or even thousands. Analysis of frequently used terms on the dedicated discussion forum demonstrated that a high level of scientific engagement was not uncommon. Evidence was found for an emergent and distinct technical vocabulary developing within the citizen science community. A survey indicates a high level of engagement and an appetite for further citizen science projects related to the Large Hadron Collider.

**Keywords:** citizen science; physics; engagement; LHC

### Key messages

- The first mass-participation citizen science project for particle physics analysis was a success, with large participation and generally positive survey feedback.
- When provided with the communication tools to do so, citizen scientists formed a community that developed its own experts and its own technical language.
- Citizen scientists report increased engagement with science as a result of participation, and a strong appetite for more projects of this nature.

## Introduction

The Large Hadron Collider (LHC) is arguably the highest-profile scientific project of our time. The discovery (ATLAS Collaboration, 2012; CMS Collaboration, 2012) of the Higgs boson has been the scientific highlight to date. The accelerator continues to be the subject of much media attention as searches for other new particles continue.

Matching this cutting-edge science with the public's curiosity to understand it can present a challenge. The particles created at the LHC are themselves invisible. Many, including the Higgs boson, decay a tiny fraction of a second after their creation, and

can only be detected and reconstructed using large dedicated detectors assembled over decades by large international collaborations.

Nevertheless, there is a strong drive within science policy to allow the public to be involved in not just reading about science, but actually performing it. Citizen science projects – which directly involve the public in the scientific process – represent an ideal vehicle for meaningful engagement with a large community. Particular citizen science projects previously have shown that participants were engaged in thinking processes similar to those of scientific investigations (Trumbull *et al.*, 2000). Crowdsourced research has itself been shown to be reliable, scalable and connective (Watson and Floridi, 2018).

When considering what might be viable citizen science projects for the particular case of the LHC reported here, several factors were considered. The subject matter should be sufficiently appealing to attract a large number of citizen scientists. The tasks assigned to the citizen scientists must be within their capability, or be possible rapidly to be understood, to maintain volunteers' interest. And to motivate continued engagement, there should be the possibility of making a very significant contribution to knowledge.

It was noted that citizen scientists have previously been shown to be good classifiers of images (see [www.zooniverse.org/about/publications](http://www.zooniverse.org/about/publications)). They are also efficient at spotting unusual objects in images, including unexpected galaxy features (Lintott *et al.*, 2009).

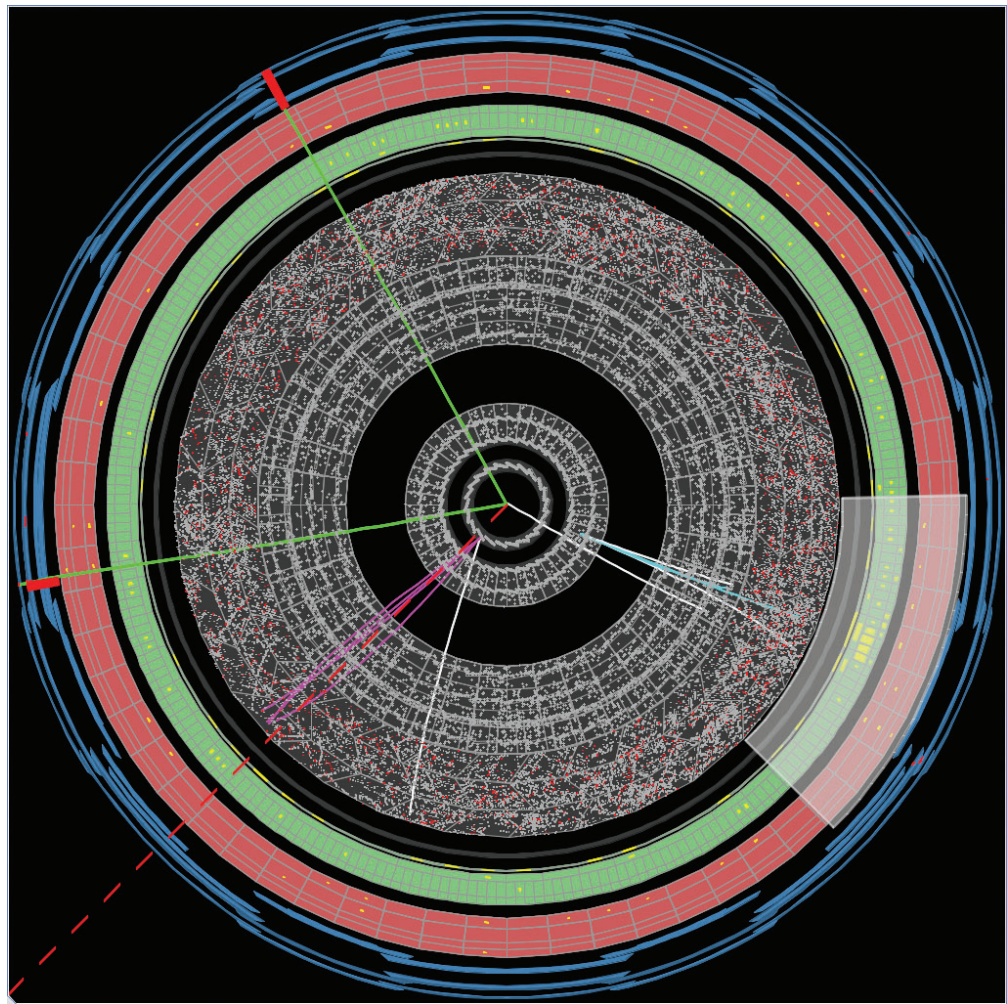
Through the Galaxy Zoo ([www.galaxyzoo.org/](http://www.galaxyzoo.org/)) project alone, citizen scientists have contributed to the results of 48 scientific papers. Using the data from the HiggsHunters.org project described below, the present study evaluates the extent to which analysis by citizen scientists might also be possible at the Large Hadron Collider, and the extent of the engagement of those citizen scientists with that subject matter.

Previously within the field of particle physics, the public has been invited to contribute to CERN's science by donating idle time on their computers to help simulate proton–proton collisions (Purcell, 2014; ATLAS Collaboration, 2018). That project aids the scientific endeavour, however the volunteers are providers of computing resources, rather than active researchers. More direct involvement in the research has previously been restricted to the relatively small fraction of the public that has a high level of computing coding skills.

Such high-skilled individuals have been able to directly analyse data from CERN experiments via the CERN opendata portal (<http://opendata.cern.ch>). The Kaggle project (ATLAS Collaboration, 2014), in which members of the public were challenged to use machine learning to identify Higgs boson events, was very successful, but also demanded a high level of coding expertise, making it inaccessible to most members of the public. The HiggsHunters.org project is, to the best of our knowledge, the first to allow the non-expert general public a direct role in searching for new particles at the LHC.

For the HiggsHunters.org project, a task was created that lent itself well to the strengths of non-expert citizen scientists – in particular, their abilities to classify elements in images and to spot unusual features. The task selected was to ask citizen scientists to identify any sets of tracks originating from points away from the centre of the image – known as off-centre vertices (OCV). Such tracks can be observed in the image of a simulated collision shown in Figure 1.

Figure 1: An example ATLAS detector image presented to citizen scientists. This image contains two off-centre vertices, each visible as a V-like structure, at about 4 o'clock and 7 o'clock, a little distance from the centre of the image. The image was generated from a computer simulation.



Such features indicate the presence of a relatively long-lived neutral particle, which travelled some centimetres from the interaction point at the centre of the image before decaying, producing a spray of many tracks. An introduction to the physics model that predicts such features may be found in Box 1.

**Box 1: 'Baby' bosons**

The physics theories under test predict the existence of hypothetical new particles  $\phi$  that are not in the Standard Model of particle physics and that have not yet been observed experimentally. In such theories, the usual Higgs boson  $H$ , after it is created, would most often decay as predicted by the Standard Model, however a fraction of the time it would decay into the new particles:

$$H \rightarrow \phi + \phi$$

The new particles  $\phi$  interact with the Standard Model only very weakly. This weak coupling means they have a slow decay rate, and hence a relatively long lifetime on the particle scale – typically of the order of nanoseconds. They can therefore travel a macroscopic distance, perhaps tens of centimetres, before themselves decaying.

Collective evidence from the body of citizen scientists about these OCVs could indicate new particles beyond the knowledge of particle physics – dramatically changing our understanding of the subatomic realm. The high impact of a potential discovery meets the important motivating feature of citizen science projects that the volunteers have a real opportunity of discovering something previously unknown to science (Cox *et al.*, 2015). It also satisfies the ethical criterion (Riesch and Potter, 2014) that the time of the citizen scientists is being used productively.

The citizen scientists were also given the task of identifying anything they thought was ‘weird’ in any image. Serendipity can have an important role in scientific discovery, so it was considered important to flag such particularly unusual features.

The citizen science web interface was constructed within the Zooniverse framework (Simpson *et al.*, 2014), using images from the ATLAS experiment at the Large Hadron Collider. Both images from real collisions and those from Monte Carlo simulations were displayed, with the citizen scientist being unaware (at the time of classification) as to whether the image was based on real or simulated data.

The ability of volunteers to identify the off-centre vertices could then be calibrated using the test images, which showed simulations of the decay processes of interest. All images, whether simulation or from real collisions, were processed using the ATLAS reconstruction software (ATLAS Collaboration, 2010), with some additions (ATLAS Collaboration, 2015).

### Citizen scientist behaviour

As of October 2017, classifications had been performed by 38,087 citizen scientists, of whom 10,849 had created Zooniverse accounts. New citizen scientists are invited to create a Zooniverse account after their first five classifications, and periodically thereafter. For those classifications made without Zooniverse accounts, it is assumed that classifications from different IP addresses are distinct scientists.

Figure 2A: Cumulative number of unique citizen scientists as a function of date

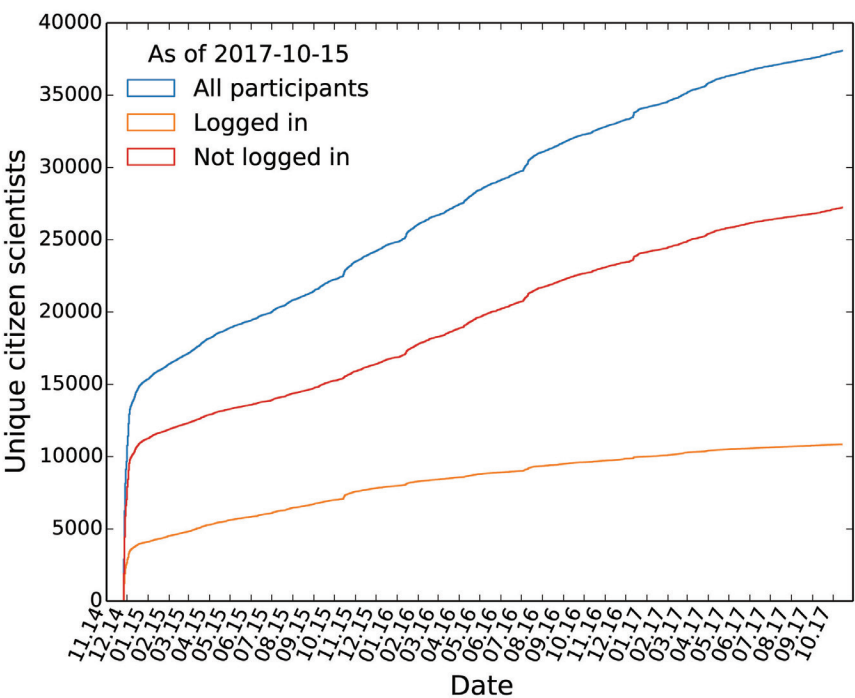
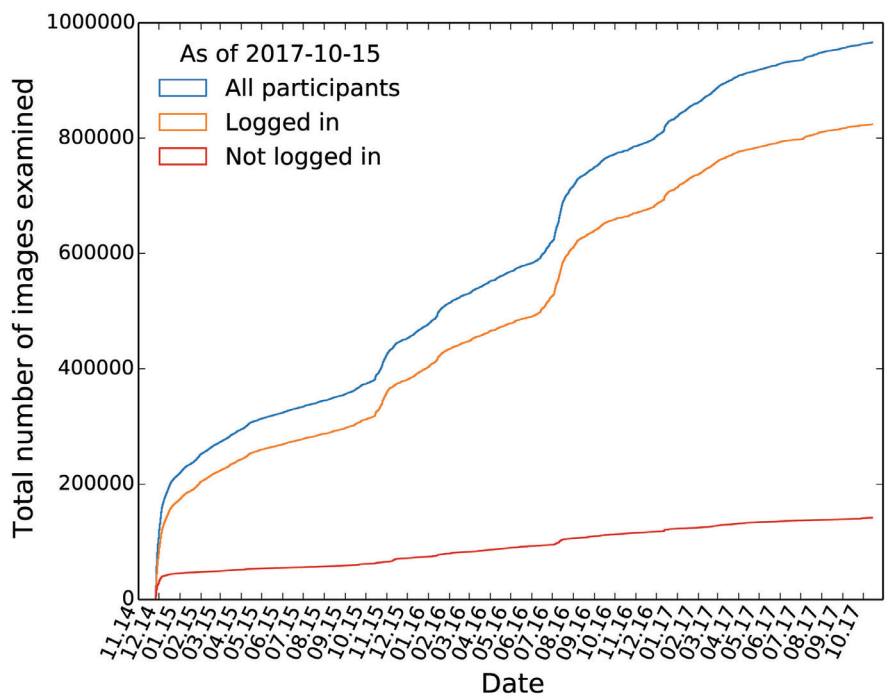


Figure 2B: Cumulative number of images examined as a function of date



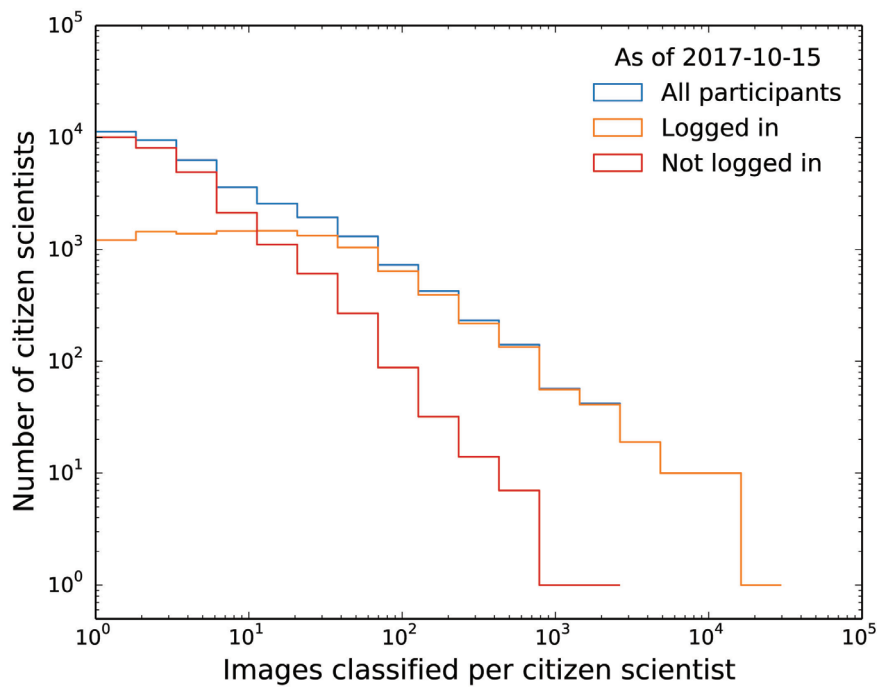
The number of citizen scientists is shown in Figure 2a, and the cumulative number of classifications is shown in Figure 2b. There was a rapid rise in the number of new scientists soon after the project launch, when the project was advertised via email to existing Zooniverse account holders, as well as in the press and social media. Subsequent periods during which new citizen scientists were attracted are observed, for example in July 2016 when a CERN news story was published about the project (Kalderon, 2016).

The number of classifications per citizen scientist (Figure 3) approximately follows power-law behaviour. Most volunteers dip in to classify just a handful of images, although more than 1,000 individuals provided 100 or more classifications. At the upper end of the distribution, more than 100 volunteers provided more than 1,000 classifications, with the most dedicated enthusiast providing more than 25,000 classifications.

Several moderators were selected from among the citizen scientists active on a dedicated ‘talk’ discussion forum (<https://talk.higgshunters.org/>) to help answer questions from other, less experienced volunteers. The moderators helped newer volunteers with identification of objects, and with some of their science questions. Other scientific questions were addressed by the science team, either via the talk forum or in the project’s blog forum (<https://blog.higgshunters.org/>).



Figure 3: Number of classifications per citizen scientist



## Science objectives

An initial determination (Barr *et al.*, 2016) has previously been made of the performance of citizen scientists relative to computer algorithms that were developed and used by the ATLAS collaboration to identify off-centre vertices (ATLAS Collaboration, 2015).

It was found that the performance of the citizen scientists competed very well with that of the computer algorithm. The collective ability of the citizen scientists was superior to the ATLAS computer algorithm for simulations with low-mass long-lived particles. A detailed comparison of the identification performance of the citizen scientists relative to the computer algorithm is described in Barr *et al.* (2016).

In addition to being able to mark off-centre vertices, the citizen scientists are also encouraged to select anything ‘weird’ in the images, and to follow up these on the talk forum, where the wider community discusses them. This raised several instances of known phenomena, such as cosmic ray showers passing through ATLAS, but also some that were unexpected, demonstrating the potential for untrained citizen scientists to isolate interesting features in real LHC collision data.

## Citizen scientist discussion

The Zooniverse platform provides a forum for citizen scientists to build community, discuss objects and images, and to ask questions. The forum is open to all citizen scientists, moderators and project scientists.

An analysis was performed of the content of the 20,257 comments received between November 2014 and May 2017. These comments were received from 1,345 different citizen scientists. The distribution of the number of words per comment is found to follow a falling exponential form, with a mean of 6.6 words, and with 6 per cent

of comments being 20 words or more, which suggests substantial observations and/or questions.

Figure 4A: Frequently used words, and their frequency of use, in 20,257 talk forum comments. The most common words used in everyday language, such as 'a', 'the' and 'of', are omitted.

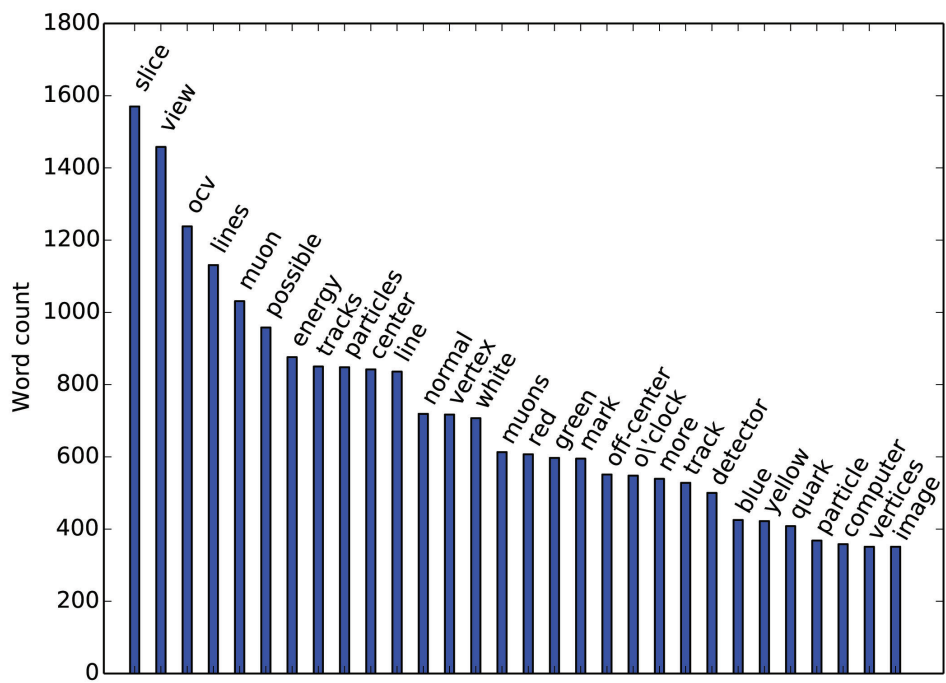
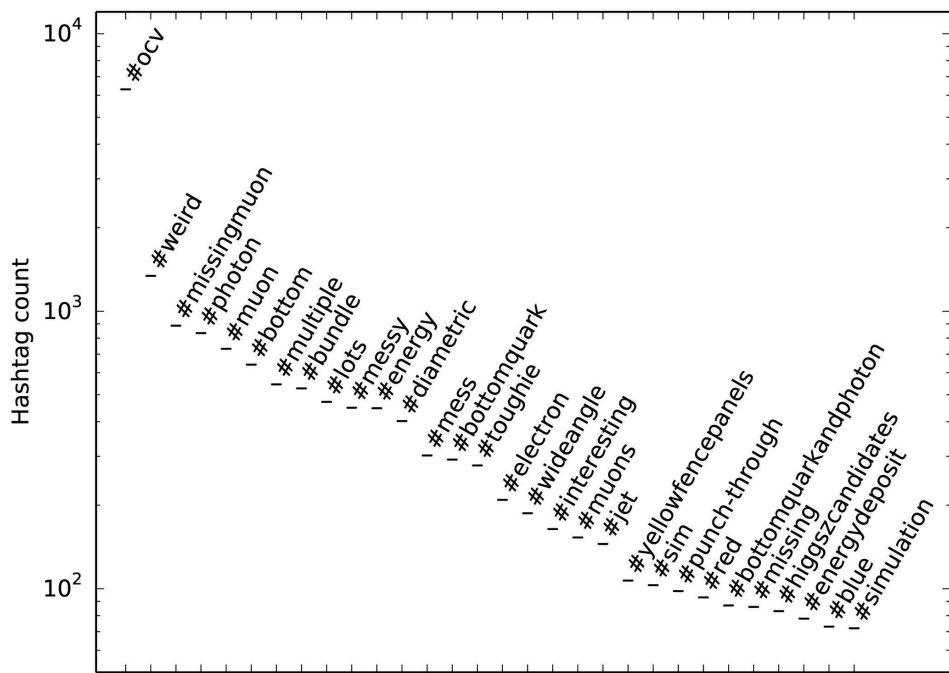


Figure 4B: Frequently used hashtags, and their frequency of use, in 20,257 talk forum comments



Frequently used words are shown in Figure 4a; frequently used hashtags are shown in Figure 4b. The most common hashtags are ‘#ocv’ and ‘#weird’, which indicate the two proposed tasks of identifying off-centre vertices and unusual features respectively.

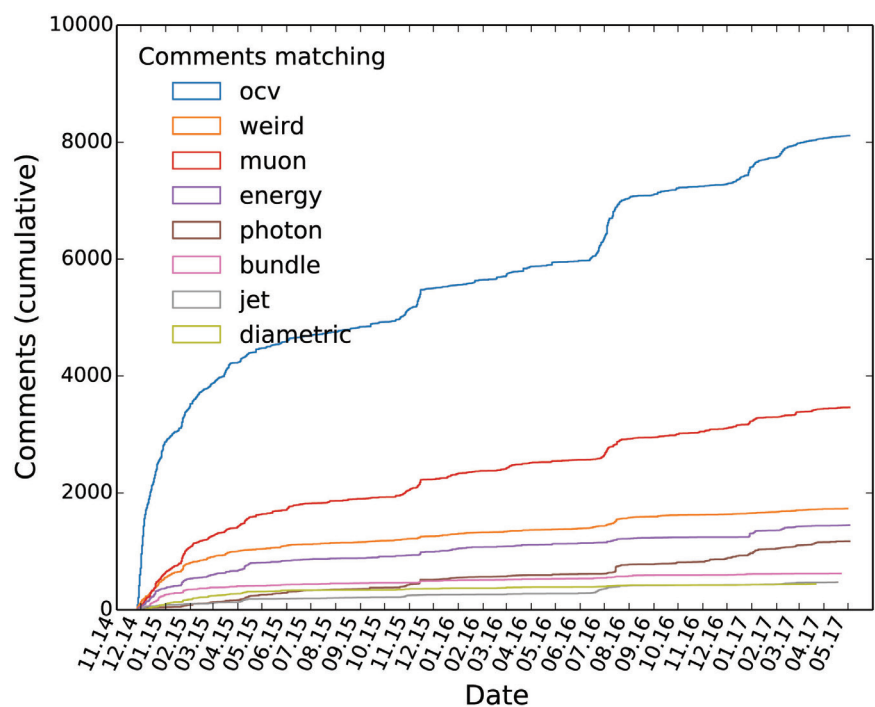
Other common words and hashtags include those denoting basic image features and descriptors, such as ‘white’, ‘line’ and ‘image’. Others describe the citizen scientists’ impressions of, or reactions, to the images, such as ‘#toughie’, ‘#mess’ and ‘#interesting’. A high level of insight and learning is demonstrated through the use of more technical and abstract terms, such as ‘#tracks’, ‘#muons’, ‘#electrons’ and ‘#energy’, which are physics objects represented in the images. The hashtags ‘#higgszcandidates’, ‘#punchthrough’ and ‘#bottomquarkandphoton’ are highly technical, and suggest a level of understanding similar to that of a particle physics professional.

The meanings of some terms used frequently by citizen scientists were later formalized by a citizen scientist moderator in a talk post, including:

- **#bundle**: Several particle tracks that appear to share a common origin, but do not meet at a vertex.
- **#diametric**: Many particles (or lots of energy) located on opposite sides of the detector, with relatively little between.
- **#messy**: Objects that are complicated by many crossing lines, which can make it difficult to find off-centre vertices.

The hashtag **#diametric**, used by 29 citizen scientists in 442 comments, was adopted by citizen scientists to describe what in the physics literature is called a ‘two-jet event’. The term **#bundle** was used by 43 different citizen scientists in 619 different comments. Unlike ‘diametric’, the term ‘bundle’ is also used in a technical sense in the general particle physics literature, but in a slightly different context – to indicate sets of near-collinear tracks but in the context of cosmic ray showers, rather than collider physics.

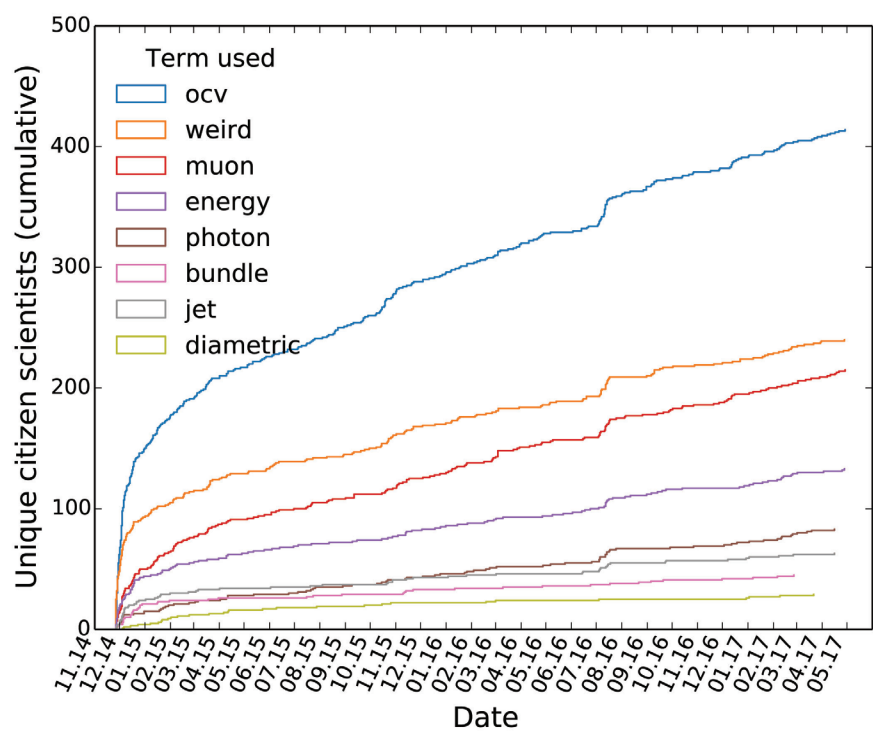
Figure 5: Cumulative number of comments matching particular words as a function of date





The cumulative distribution of the use of particular terms over time (Figure 5) shows different types of use at different times. For example, the cumulative frequency of use of the term ‘weird’ has a tendency to flatten out with time (presumably as citizen scientists become accustomed to particular features), whereas the cumulative counts of some technical terms such as ‘photon’ and ‘muon’ keep growing rapidly. The number of unique citizen scientists using particular words has continued to grow with time (Figure 6). Seemingly the non-standard term ‘bundle’ fell out of fashion after the first couple of months, being overtaken by the term ‘jet’, which is the usual word for this feature within the wider particle physics community.

**Figure 6: Cumulative number of unique citizen scientists using particular words as a function of date**



## Survey evaluation

To evaluate the impact of the project on the citizen scientists themselves, a web-based survey was undertaken, with an invitation to participate being sent to all registered HiggsHunters volunteers.

The number of respondents was 322 (including 63 partial responses), a sufficiently large sample to draw statistically meaningful conclusions. The survey was advertised via the Zooniverse website and in an email to those with Zooniverse accounts. The response rate represents about 1 per cent of those who participated in any way as citizen scientists in the project. This is a typical response rate for Zooniverse surveys. There is evidence of some bias towards respondents having a higher degree of prior engagement than the general population. This supposition is supported by the observation that about 80 per cent of survey respondents had previously participated in another Zooniverse project prior to HiggsHunters. Nevertheless, the respondents were uniformly distributed across the range of period of engagement with the

HiggsHunters project, so there is meaningful representation at all levels of participation in the present project.

The gender of respondents was 33 per cent female and 65 per cent male (with 2 per cent preferring not to say). A wide range of ages was represented (see Table 1). This is also reflected in the diversity of occupations, with 19 per cent of respondents being students, 37 per cent being in full-time work, and 22 per cent being retired (with the remainder having other employment status).

**Table 1: Age distribution of survey respondents**

Age	%	Count
16 to 17	7	17
18 to 19	3	8
20 to 24	5	14
25 to 34	15	39
35 to 44	15	37
45 to 54	15	38
55 to 64	21	53
65 to 74	12	30
75 or older	4	11
Prefer not to say	3	7

Well-represented occupations included teachers, engineers, consultants, developers and researchers. Respondents tended to be well educated: 74 per cent had at least an undergraduate degree, 39 per cent had at least a master’s degree and 14 per cent had a doctoral degree. It was notable that only about a quarter of those holding a master’s degree or higher held that degree in a physics-related subject, showing that the project had appeal to those trained in other disciplines, particularly in other areas of science, technology, engineering and mathematics.

The best-represented countries were the USA (25 per cent) and the UK (16 per cent), with a total of 35 countries represented among all respondents. A bias towards native English speakers (65 per cent of respondents) was perhaps unsurprising, given that the HiggsHunters.org website is only available in the English language. Of the respondents, 80 per cent had engaged in citizen science before, in another science area, while for the remainder it was their first citizen science project.

More than 80 per cent of respondents indicated that their knowledge of particle physics had been improved to some extent as a direct result of participating in HiggsHunters. In terms of future directions, 47 per cent of respondents said they were more likely (to some extent) to go on to study physics as a result of participating in the project (see Table 2). This can be considered a high percentage, given the broad age range of participants.

**Table 2: Responses to the question ‘To what extent are you more likely to study physics in the future as a result of participating in HiggsHunters?’**

Change	%	Count
A lot	13	35
Moderately	14	37
Slightly	20	54
No change	36	98
N/A	17	46

In terms of dissemination, many respondents had discussed the project with others, including friends, family and work colleagues (see Table 3). This indicates the project had a multiplier effect, in that it reached more people than just those citizen scientists directly involved. This willingness to discuss with others also indicates a high level of feeling of ownership and interest among the citizen scientists themselves.

**Table 3: Responses to the question ‘Have you ever discussed Zooniverse ...’**

Discussed ...	%	Count
... with your family?	58	99
... with your friends?	64	111
... with colleagues?	32	56
... on social media?	15	26

The hypothesis that the survey respondents were subject to some degree of selection bias (compared to the general population of HiggsHunters citizen scientists) towards the more highly engaged end of the spectrum is tested from their responses to a question asking about the duration of the period during which they performed classification (see Table 4). That distribution for respondents is more broadly distributed than would be expected from the general population of citizen scientists, which peaks at low numbers of classifications (see Figure 3). Nevertheless, the wide range of different levels of duration among the respondents shows that an interesting section of the citizen scientists has been sampled. No attempt has been made to extrapolate to the general population, since insufficient information is available about possible confounding factors that could affect that extrapolation.

**Table 4: Responses to the question ‘Over what duration did you classify images?’**

Duration	%	Count
A single session	10	26
One or two days	14	35
2–7 days	15	39
2–4 weeks	17	44
1–5 months	18	45
6–12 months	10	26
Over a year	15	37

A significant minority (37 per cent) of respondents had browsed the talk form, showing that while of interest to many, use of it was far from ubiquitous. The fact that so many did not refer to the forum suggests that the majority were able to perform the classification exercises without recourse to the additional information on those discussion boards. The primary reason stated for posting to the boards was to discuss findings with other citizen scientists.

**Table 5: Responses to the question ‘As a result of the HiggsHunters project, have you done any of the following?’**

Subsequent activity	%	Count
Read or watched more about science	87	152
Studied science more formally	29	51
Carried out your own research	20	35
Attended lectures or similar events	19	33
Attended science fairs or similar events	15	26

Most respondents reported that as a result of the project they were motivated to engage more fully with science (see Table 5), and the majority also went on to work with other citizen science projects (see Table 6).

**Table 6: Responses to the question “Have you subsequently participated in other citizen science projects?”**

Subsequent projects	%	Count
None (at time of response)	22	62
Zooniverse project(s)	74	209
Non-Zooniverse project(s)	13	38

Overall, the project was found to have a very positive response from respondents, with most having benefited from their engagement, and an overwhelming majority (more than 97 per cent) being keen to continue participation in a future CERN physics project.

Further analysis of the citizen science click data will be performed by school children in collaboration with the UK charity the Institute for Research in Schools (IRIS) ([www.researchinschools.org/higgs\\_hunters](http://www.researchinschools.org/higgs_hunters)). At the time of writing, 61 schools had signed up for this project through IRIS.

## Summary

The first mass-participation citizen science project for the Large Hadron Collider has been extremely successful. More than 38,000 citizen scientists participated, with a wide range of ages, backgrounds and geographical spread represented. More than 1.4 million features of interest were identified in images from the ATLAS detector.

A study of behaviour showed that most citizen scientists classified just a handful of images, although a minority classified hundreds or thousands. A dedicated discussion forum allowed citizen scientists to interact with one another, and with the project scientists.

The vocabulary used in the discussion forum ranged from identifying basic visual features to highly abstract and technical terms. The frequencies of some words in particular contexts indicated a distinct technical vocabulary emerging from the citizen scientists' discussions – one that would not immediately be understood by professional scientists in the field.

The societal impact was evaluated from a dedicated survey. Almost 90 per cent of respondents were motivated to find out more about science directly from the project, while 97 per cent of respondents would like to see a follow-up project with more CERN data.

The classification data from the citizen scientists have been released for final analysis by school students, in collaboration with the Institute for Research in Schools.

## Discussion and reflections

This project was something of an experiment in itself. No large-scale citizen science project had previously attempted mass-participation analysis of data from a CERN experiment. It was therefore pleasing to find that it was indeed possible to design a citizen science project that had broad appeal and large numbers of participants, even in a very technical subject area.

In designing and running the project, the expertise of the Zooniverse team was invaluable. That well-established team provided technical infrastructure for data display, selection, and community engagement via a linked blog and talk forum. Less obviously, but just as importantly, the Zooniverse team were actively engaged in the design process for the project tasks – their experience of the types of task that they had previously found to be well-suited to citizen-science participation was most instructive.

The survey of participants yielded valuable information about their motivation and demographics, and the impact of the research on their future behaviour. Some survey results differed considerably from what the authors had expected, for example the wide age range of respondents. While the number of survey responses was sufficiently large to give statistically meaningful results, incentivizing participation in the survey might have led to larger returns, which in turn would have reduced the concern that the survey respondents were not a fair sample of all participants.

The talk discussion forum was a big factor in deepening community engagement. It facilitated the development of sharing of expertise and experience, and the rise of community experts. The development within the community of a custom technical language was both impressive and unexpected.

Among the biggest surprises to the authors of the study were the very high commitment of some citizen science participants, the ability of the community collectively to develop rather deep technical expertise, and the very high appetite for future projects of this nature. Part of the motivation of this paper is to encourage other projects in other 'difficult' areas of science.

## Acknowledgements

The HiggsHunters.org project is a collaboration between the University of Oxford and the University of Birmingham in the United Kingdom, and New York University in the United States. It makes use of the Zooniverse Citizen Science platform, which hosts over 40 projects, from searches for new astrophysical objects in telescope surveys to following the habits of wildlife in the Serengeti. The HiggsHunters project shows collisions recorded by the ATLAS experiment, and uses software and display



tools developed by the ATLAS collaboration. The authors gratefully acknowledge the generous financial support of the UK Science and Technology Facilities Council, the University of Oxford and Merton College, Oxford. The project would have been impossible without the dedicated engagement of the many HiggsHunters volunteers, and in particular the moderators. We are grateful to Pete Watkins for helpful comments and suggestions.

## Notes on the contributors

**Alan Barr** is a professor of particle physics at the University of Oxford. He has published widely on particle detectors, and on searches for and measurements of particles at high-energy colliders. He has served as the physics coordinator of the ATLAS UK collaboration and as a STFC public engagement fellow. He led the LHSee and Collider public smartphone apps, which display collisions from the ATLAS experiment.

**Andy Haas** is Associate Professor of Physics at New York University. He has been hunting for long-lived particles at colliders since 1998, first at the Tevatron, outside Chicago, and since 2004 with the ATLAS Experiment at CERN. He also contributes to high-speed data acquisition and triggering for the experiments, leads efforts to simulate collisions in current or future detectors, and develops graphical displays such as those used for HiggsHunters.

**William Kalderon** is a postdoctoral research fellow at Lund University, Sweden. As a member of the ATLAS collaboration at CERN, his research focuses on searches for new particles and forces at high-energy colliders, on aspects of the ATLAS data recording system, and on novel techniques to use the latter most effectively in aid of the former.

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