PROCEEDINGS OF SCIENCE

The search for New Particles at CERN on the Zooniverse citizen-science platform

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The REINFORCE EU project engages and supports citizens to cooperate with researchers and actively contribute to the development of new knowledge for the needs of science and society. REINFORCE offers four "discovery demonstrators" in different areas of physics. The infrastructure of all demonstrators is based on Zooniverse, the most popular citizen-science platform. The demonstrator titled "Search for new particles at CERN" engages citizen-scientists in searches for new long-lived particles produced in the high-energy proton-proton collisions at the LHC of CERN and registered by the ATLAS experiment. To make this possible, the demonstrator adopts a three-stage architecture. The first two stages use simulated data to train citizens, but also to allow for a quantitative assessment of their performance and comparison with machine-based algorithms. The third stage uses real data from the ATLAS Open-Data subset, providing two research paths: (a) study of Higgs boson decays to two photons, one of which could be converted to an electron-positron pair due to interactions with detector material and (b) search for yet undiscovered long-lived particles, predicted by certain Beyond-the-Standard-Model theories. Since the launch of the demonstrator on Zooniverse, it has attracted over 3000 volunteers.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)1037

1. Introduction

REINFORCE [1] (Research Infrastructures FOR Citizens in Europe) is a Research & Innovation Project, supported by the European Union's Horizon 2020 SwafS "Science with and for Society" framework programme. The project engages citizens in research done in Large Research Infrastructures through a participatory design methodology that takes into account the special characteristics of different target groups. Through the use and analysis of open data, citizens perform their own inquiries, supported by the REINFORCE experts.

Large Scale Citizen-Science demonstrators developed by the consortium partners on the Zooniverse platform [2] are the vehicle that REINFORCE utilizes in order to bring frontier science and society together. Each demonstrator engages citizens in research experiences by providing tasks which are essential for the needs of scientific research, extending where possible the senses used in the scientific inference to include in the effort sense-disabled and senior citizens. The REINFORCE demonstrators are titled: (a) *GWitch Hunters*, (b) *Deep Sea Explorers*, (c) *New Particle Search at CERN*, and (d) *Cosmic Muon Images*.

New Particle Search at CERN is a work package of the REINFORCE project, engaging non-expert citizens in searches for new elementary particles that may be produced in the high-energy proton-proton collisions at the Large Hadron Collider (LHC) of CERN, the world's most powerful particle accelerator. This is achieved through a three-stage process, which is described below. In each stage, citizens are guided throughout the given task by detailed tutorials and help sections including video instructions and examples.

2. Stage 1 - Displaced Vertex Identification

In Stage 1 of the demonstrator, citizens inspect stationary images displaying reconstructed tracks of charged particles in the innermost detector of ATLAS [3]. Each image, such as the one shown in Figure 1, corresponds to a single simulated proton-proton collision event, whereas the displayed tracks satisfy quality criteria used in searches for Long-Lived Particles (LLPs) in the ATLAS experiment, along with few additional requirements to facilitate the processing by human eye. Citizens are asked to identify the coordinates of any displaced vertex (DV) in each displayed event, i.e. the decay location of a simulated LLP, using the mouse pointer. Since preliminary quality criteria have already been applied, DVs can be identified as the common origin of any two or more tracks in the ATLAS inner detector. Citizens' reported selections are finally assessed by Zooniverse based on the true location of the DV, which has been uploaded to the platform, and feedback is provided after each processed event, before moving to the next one. The goal of Stage 1 is to compare in terms of accuracy and efficiency the performance of human volunteers to that of an automated identification algorithm. Therefore, this stage makes use of simulated events, since they allow the knowledge of the true position of each DV. The same events are analysed by both the algorithm and the citizens for an accurate and impartial comparison.

From the launch of the project on Zooniverse on October 19, 2021 to September 30, 2022, more than 3K citizens participated in Stage 1 of the demonstrator providing over 170K classified events. Their selections are presently being analysed in terms of identification efficiency (number of true DVs identified over number of true DVs encountered) and purity (number of true DVs

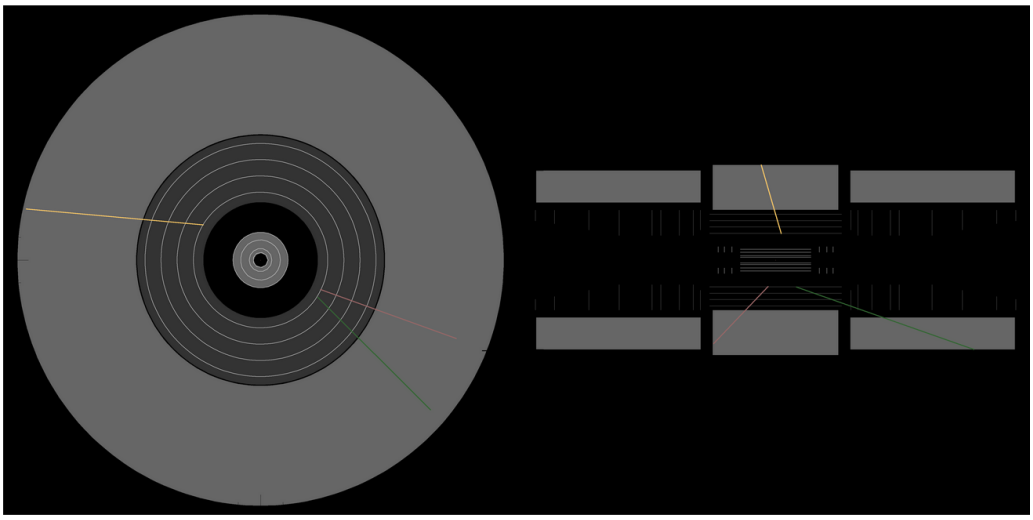

Figure 1: Collision event containing a DV, as displayed on Zooniverse. Two projections of the ATLAS inner detector are shown; transverse (left) and longitudinal (right).

identified over number of DVs reported). An interesting finding of Stage 1 is that the combination of citizen responses for the same event provides significantly higher identification efficiency than that of individual citizens. For example, considering events classified by at least 10 citizens, the mean of the reported coordinates (the so-called "consensus") provides an identification efficiency of 86% in the transverse and 95% in the longitudinal detector projection, which is on par with the efficiency achieved by the automated algorithm. On the other hand, the average efficiency of individual citizens is 72% and 79%, respectively. Such combination of parallel citizen selections could be further exploited in citizen-science.

3. Stage 2 - Particle Identification

In Stage 2, citizens go a step further; instead of examining stationary images of collision events, they interact with the event display provided by HYPATIA [4] (HYbrid Pupil's Analysis Tool for Interactions in ATLAS) to perform in-depth analysis and familiarize themselves with the identification of particles through their characteristic signatures in the ATLAS detector. In each displayed event, citizens select individual tracks in the ATLAS inner detector, or energy clusters in the electromagnetic calorimeter, and classify them as muons, electrons, converted or non-converted photons using the functionalities of HYPATIA. For each selected track or cluster, they need to inspect its properties (momentum, charge, direction) to assist them in their classification. The simulated event sample used in this stage is derived from the ATLAS Open Data set [5] and provides knowledge of the true type of each particle. Based on this knowledge, citizens' selections, which are automatically logged by HYPATIA, are being analysed and compared to that of a machine-learning algorithm trained using the same input in order for the comparison to be impartial.

4. Stage 3 - Introduction to Real Data Analysis

In Stage 3, citizens study real events recorded by the ATLAS detector during the second running period of the LHC, which are part of the 13 TeV ATLAS Open Data set. The stage is divided into two sub-stages; Stage 3a, titled "Study of Higgs Bosons", in which citizens study the decays of Higgs bosons to photons, and Stage 3b, titled "Discovery of Long-Lived Particles", in which they identify DVs reconstructed by ATLAS and determine if they are consistent with the decay of a LLP. Both parts of Stage 3 require additional interaction with the event display of HYPATIA to select traces of particles but also calculate kinematic quantities, such as the mass of Higgs boson, or investigate properties of the sought-after LLP. For this purpose, HYPATIA has been adapted to provide the necessary information and functionalities needed for each sub-stage.

In both parts of Stage 3, citizens have been performing equally well, identifying, according to the given instructions, candidate photon pairs with invariant mass close to the mass of the Higgs boson (Stage 3a) and DVs (Stage 3b). Furthermore, they have been using the star-rating system provided by HYPATIA to classify events according to how interesting they are. In Stage 3a, citizens have so far rated a few hundred events with 5 stars (maximum), as possible complex Higgs boson production mechanism, whereas in stage 3b, multiple users reported certain events as candidates for LLP decays. These events are being examined by the expert scientists and discussed with the citizens on the Zooniverse talk forum.

5. Conclusion

The REINFORCE demonstrator *New Particle Search at CERN* has so far attracted a few thousands of citizens who are interested in further understanding and contributing to frontier scientific research. The data gathered from all three stages of the demonstrator are presently being analysed and are expected to reveal the potential of citizen contribution to science and highlight possible directions in order to maximize the benefit of such contribution to science and to society.

References

[1] REINFORCE project webpage: https://www.reinforceeu.eu.

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[3] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

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[5] ATLAS Open Data webpage: http://opendata.atlas.cern.

Acknowledgments

The REINFORCE project has received funding from the European Union's Horizon 2020 project call H2020-SwafS-2018-2020 funded project Grant Agreement no. 872859.