PROCEEDINGS OF SCIENCE

How Citizen-Scientists can search for new particles at the LHC

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The search was conducted within the framework of "The New Particle Search at the LHC" demonstrator, part of the REINFORCE project. The REINFORCE EU project (Research Infrastructures FOR Citizens in Europe) was a three-year SwafS initiative that engaged citizens in active collaboration with scientists at large research infrastructures across Europe. In this study, citizen-scientists visually analyzed events recorded by the ATLAS detector at the LHC, searching for signatures of new particles. Additionally, traces of known particles were sonified to enable participation by visually impaired citizens. The results of 450,000 classifications demonstrated that citizen-scientists can perform complex tasks responsibly, achieving performance comparable to purpose-built machine algorithms, while also identifying patterns or errors in individual event reconstructions.

This contribution is dedicated to the memory of late Prof. S. Katsanevas, the project's coordinator and former Director of EGO.

12th Large Hadron Collider Physics Conference (LHCP2024)

3-7 June 2024

Boston, USA

PoS(LHCP2024)214

1. Introduction

The REINFORCE project (Research Infrastructures FOR Citizens in Europe) was a three-year SwafS initiative [1] designed to engage citizens in research at large infrastructures through citizen-science activities, aiming to enhance science awareness and foster positive attitudes towards it. The goal is to engage non-expert volunteers in citizen-science projects, ranging across all age groups and in high numbers - with no prior computing knowledge requirement- in active collaboration with the scientists across Europe. The project was structured around four "demonstrators," offering research data to attract and motivate volunteers to contribute to cutting-edge scientific research.The demonstrators are hosted in the Zooniverse platform [2], the most widely used citizen science platform with over 2,5 M users.

One of the four demonstrators is the "New Particle Search at CERN" [3]: Data collected by the ATLAS detector at the Large Hadron Collider (LHC) were offered to the citizens in order to perform frontier research in high-energy physics,

In addition to the above four demonstrators, an important objective of REINFORCE managed to extend the data handling and research to the scientific community which is sense-disabled (especially visually-disabled) and senior citizens. It also emphasized the interplay of art and science, organizing exhibitions and contests.

2. The "New Particle at CERN" demonstrator

2.1 Description of the demonstrator

In the "New Particle Search at CERN," citizen-scientists visually analyzed events recorded by the ATLAS detector, searching for signs of new particles. To facilitate this, the demonstrator implemented a three-stage architecture. In the first stage, the users only inspected stationary images of the traces which charged particles leave in two views of the inner part of the ATLAS detector. The users search for tracks which intersect at a point other than the main proton-proton interaction point. They needed to inspect both views of the inner detector to be able to properly recognize the tracks' common origin. In the two different views/projections of the inner detector which are depicted in Figure 1, the tracks are coloured so that a user may identify the same track in both views. The user is then asked to spot the displaced vertices in both views using the mouse, and the answer is internally assessed by Zooniverse based on the truth information which is also provided to the platform.

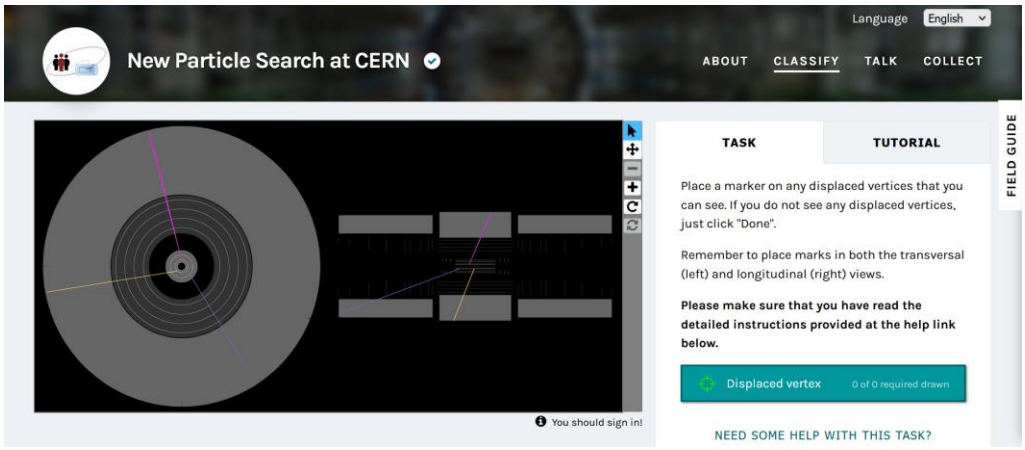

Figure 1: *The First stage of the demonstrator on Zooniverse*

For stages 2 and 3 the users are directed from Zooniverse to the HYPATIA [4] event display tool, which shows two views of all ATLAS detectors, together with a table of relative information on the collision products. Stage 2 trained participants to identify characteristic

signatures of electrons, muons, photons, and converted photons.The HYPATIA particle information table shown in Figure 2, displays momentum, charge and direction information for each track or cluster of the event. The user can identify tracks/clusters, using the button that corresponds to the type of track or cluster that they have and determine if it belongs to electron, muon, photon or converted photon respectively.

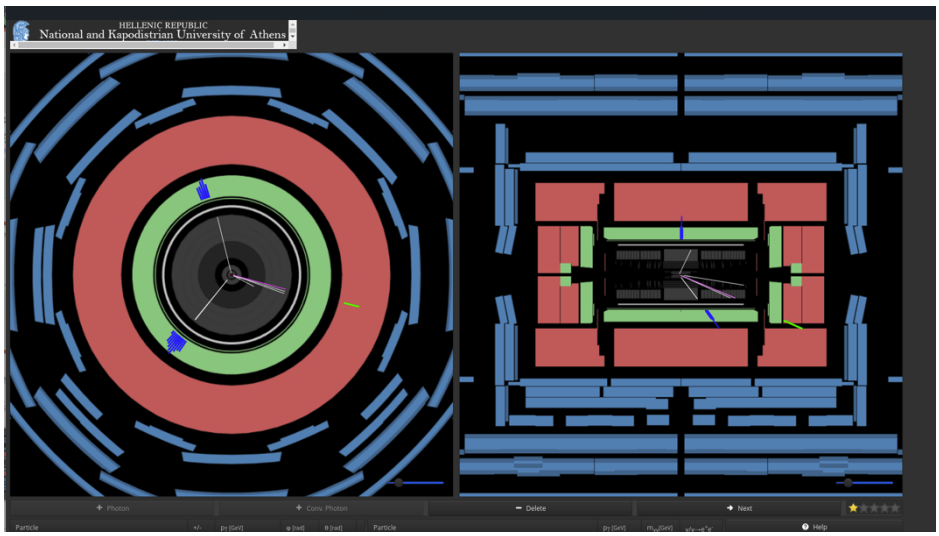

Figure 2*: The second stage of the demonstrator on HYPATIA.*

In stage 2, particle traces were sonified to accommodate visually impaired participants. The sonification was done by an Argetinian team of CONICET based on the SononUno interface [5]. This is done according to the following procedure. The HYPATIA image is transformed to an acoustical/visual representation based on the existence (a continuous sound of two seconds) or not (a silence of two seconds) of the track in the inner detector, the existence (a characteristic sound of one second) or not (a silence of one second) of the cluster in the calorimeter (the volume of the sound represents the energy), and the existence of a track beyond the inner detector (in this case the initial continuous sound length changed from two seconds to four seconds). So a muon is characterized by a long track which corresponds to a continuous sound of 4 sec, an electron of a s shorter 2 sec sound followed by cluster sound, a photon has only a clister sound and a converted photon is identified by a two close-by short tracks sounds plus a cluster sound. Figure 3 shows the corresponding image of the event and a youtube link given in the caption, demonstrates the sounds.

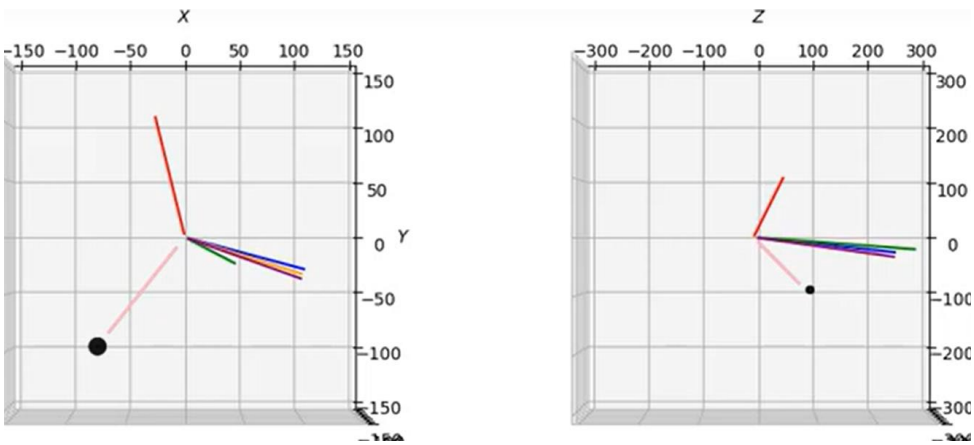

Figure 3: *The event corresponding to figure.2, produced by sonification (for live demonstration: https://www.youtube.com/embed/Foa_8fT2NYY?start=1&end=57)*

The first two stages are based on selected samples of simulated data in order to train citizens, but also to allow for a quantitative assessment of their performance and a comparison with specially developed automated algorithms.

The third stage of the demonstrator is a "discovery" one, employing datasets of real events from the ATLAS Open Data Set Release [6].The third stage provides two research paths: (a) study of Higgs boson decays to two photons, one of which could be converted to an electron-positron pair by interaction with detector material, and (b) search for yet undiscovered neutral long-lived particles, predicted by certain theories of the BSM [7]. The citizen research involves the identification of specific "signatures" which are produced from the decay of these new long-lived particles. These decay products could originate from displaced vertices (DVs), namely vertices - formed by two or more tracks - that are displaced with respect to the main collision point of the two protons. The demonstrator has developed visual analysis tools that allow the citizens not only to classify static images –in order to recognize the DVs- but also to interact with the event displays, select specific tracks and calculate kinematical quantities characteristic of the sought-after particles. Users were also asked **to rate each event from one to five stars,** according to how similar they believed it to be, to one of the sought-after decay.

2.2 Comparative study of user classification results and user results from the discovery phases

In stage 1, user identification efficiency was determined using a "consensus" approach. The consensus is based on events that have been classified by at least 10 different users and at their combined result. The consensus-based identification efficiency averaged 93%, varying by ATLAS detector view: 89% in the transverse view and 96% in the longitudinal view. This efficiency is very close to the respective identification efficiency obtained by the dedicated automated algorithm, being 94%.

In stage 2, the sample comprised simulated events with known particle identification, enabling comparisons with user classifications to assess their validity. Participants performed 45,000 classifications, 80.4% of which were correct.

Concerning the discovery stages, events that are found interesting by many users (classified with five stars) were closer inspected by the demonstrator team and discussed with the users through the "talk" tab. The users found some rare potential candidates which were finally attributed to background or misreconstruction.

3. Conclusion

Approximately 3,800 citizens participated in the New Particle Search at CERN demonstrator, completing around 450,000 classifications. The demonstrator was available in English, Spanish, and Greek. Comparative studies revealed that citizen performance often matched that of machine learning algorithms.

A portion of the stage 2 data was sonified by the CONICET team. The sonification hands-on results show that visually impaired citizens can equally participate in the analysis effort. Moreover, the project's site houses a platform of all artistic interventions.

As part of REINFORCE's sustainability we will continue with our sonification [8], making available more data and monitoring visually impaired user responses. This approach may yield additional insights into user abilities and strengths.

A long paper describing REINFORCE project has recently been published in a special EPJ+ series with focus on citizen science projects [9].

Acknowledgements

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

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