PROCEEDINGS OF SCIENCE

QuarkNet in LHC Education and Outreach

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QuarkNet [1] is a U.S. program for professional development of high school teachers. In QuarkNet, teachers deepen their understanding of physics, pedagogy, and how to engage students through the use of authentic data from a diverse set of contemporary particle physics experiments. The LHC figures prominently in these efforts. QuarkNet promotes and manages International Particle Physics Masterclasses [2] with Fermilab-moderated videoconferences, has partnered with physicists to develop and maintain the CMS masterclass used worldwide, and has created new masterclass opportunities such as World Wide Data Day. [3] QuarkNet makes these masterclasses available not only in the U.S. but also throughout the world. These international collaborations enrich the teachers and students involved. QuarkNet teachers also participate in LHC Data Workshops and similar opportunities. QuarkNet staff and select teachers are currently building short masterclasses and workshops for the 10th anniversary of the discovery of the Higgs.

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online

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1. Introduction

QuarkNet is a teacher professional development program funded by the United States National Science Foundation, US-ATLAS, and US-CMS. It includes nearly 50 centers located at universities and national laboratories across the United States. QuarkNet provides science teachers the means to develop their skills and bring real research experience into the high school science classroom. Here we describe some of the programs developed and supported by QuarkNet using data from two LHC experiments, CMS and ATLAS.

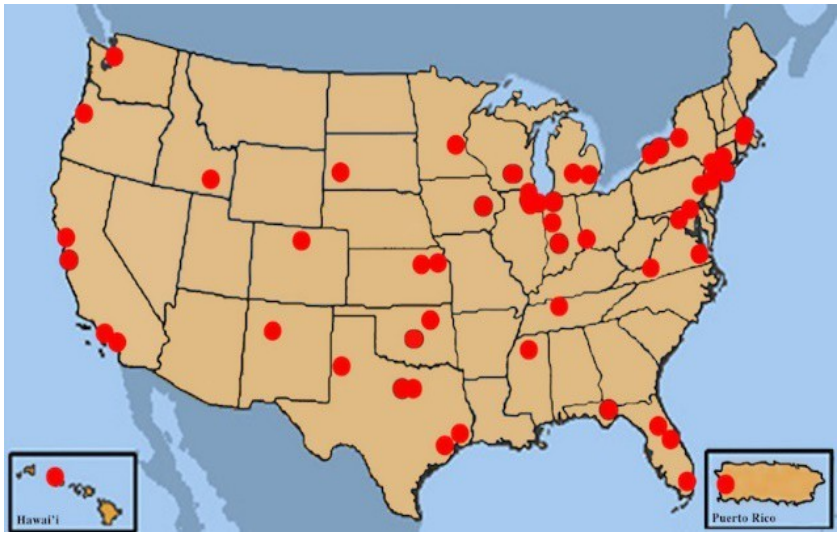

Figure 1. QuarkNet centers across the United States.

2. International Masterclasses

QuarkNet works with the International Particle Physics Outreach Group (IPPOG) [4] to develop and support International Masterclasses (IMC) each year. IMC is the flagship program of IPPOG. Each year thousands of students from countries around the world participate in the masterclasses.

2.1 CMS

The CMS masterclass program has been developed and maintained by QuarkNet. The data come from publicly-available CMS collision data. There are several measurements available. In a measurement used for in-school masterclasses, students classify dimuon events in an event displays as part of a study of the J/ψ measurement. The WZH measurement is a separate, more-involved measurement used for IMC. Students use an event display to classify events based on number and curvature of tracks, missing transverse energy, and more. The student datasets comprise W, Z, and four-lepton Higgs candidate events. Students create mass plots and investigate lepton universality as well as make a simple measurement of the W^+:W^- ratio. [5]. A four-lepton Higgs candidate event as seen by the student in the event display can be seen in Figure 2.

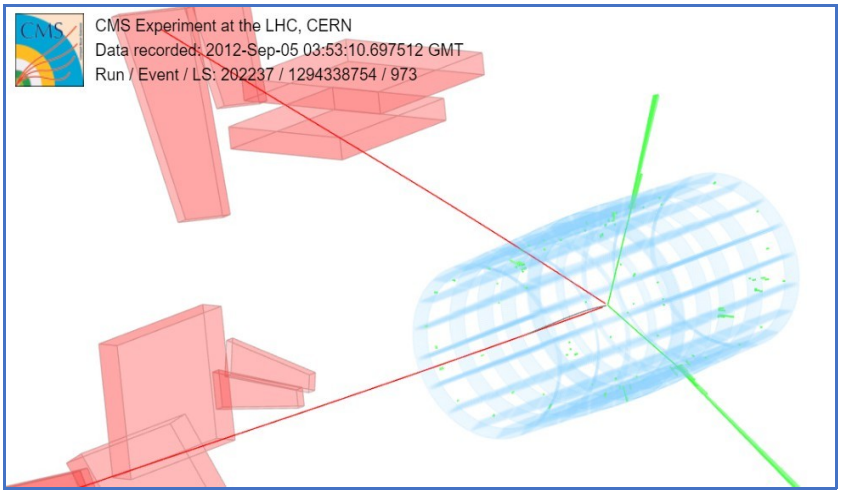

Figure 2. A 2-muon, 2-electron event in iSpy, the event display for the CMS masterclass. Muons show as red and electrons as green.

2.2 ATLAS

QuarkNet supports and promotes the ATLAS Z-path measurement for International Masterclasses. Students search for Z mass resonances and other phenomena. There are also Monte Carlo insertions to suggest hypothetical particles such as the Z'.

2.3 Fermilab Videoconferences

At the end of a day for the IMC, the students from around the world meet via a videoconference and discuss their results and what they've learned with each other and with the moderators. QuarkNet is responsible for organizing the videoconferences at Fermilab, which serve the North and South American time zones and beyond. The number of videoconferences for the IMC hosted at Fermilab and at CERN over recent years can be seen in Figure 3.

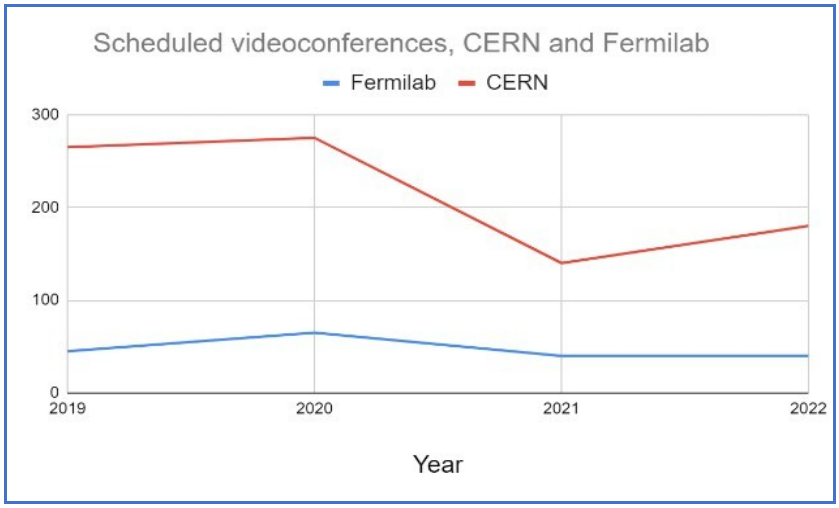

Figure 3. Scheduled masterclass videoconferences at CERN and Fermilab, 2019-2022. Most 2020 videoconferences were ultimately canceled due to the pandemic.

2.4 World Wide Data Day

World Wide Data Day (W2D2) is a one-day-a-year program that is a chance for students to make a simple ATLAS or CMS analysis in about two hours from beginning to end at their respective schools. It concludes with an international video conference with physicist moderators and other students. W2D2 was held on 1 December in 2021 and will be on 10 November in 2022.

3. Additional CMS Opportunities

Data Camp is a week-long workshop offered at Fermilab to 24 QuarkNet teachers each year. In Data Camp teachers analyze simplified datasets from CMS to help them understand how particle physicists analyze data and to apply this understanding to the classroom. Participants analyze csv files of CMS data and make mass plots of Z, W, J/Ψ, and other particles using spreadsheets and Python notebooks.

QuarkNet also organizes programs more focused on the computing side of data analysis. In a QuarkNet Coding Workshop or a Coding Camp students and teachers use datasets from CMS as an important part of learning how to use the Python language for data analysis.

4. Further Information

For most queries, please contact authors Kenneth Cecire and Shane Wood. For specific queries related to the iSpy event display, please contact author Thomas McCauley.

References

[1] QuarkNet, *https://quarknet.org*.

[2] International Masterclasses, *https://www.physicsmasterclasses.org*.

[3] World Wide Data Day, *http://tiny.cc/w2d2*.

[4] IPPOG, *https://ippog.org/*.

[5] CMS Masterclass, *https://web.quarknet.org/mc/cms/*.

[6] ATLAS Z-path Masterclass, *https://atlas.physicsmasterclasses.org/en/zpath.htm*.

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