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Hands-on particle physics, an overview of masterclass efforts

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International Masterclasses is a program that enables high school students worldwide to experience particle physics data analysis up close. We explore what masterclasses are, how they work, and their reach. We also look at the masterclass measurements for the four major LHC detector experiments as well as other masterclasses and masterclass-related opportunities. Finally, we take a look at how a masterclass is done with a very short, very simplified LHC dimuon demonstration measurement. This work is presented on behalf of the International Particle Physics Outreach Group.

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1. Introduction

Masterclasses in particle physics are one-day events for high school students at universities and laboratories. There are multiple flavors of masterclasses based on measurements from different experiments. Generally, a masterclass will focus on an experiment in which the host institution takes part, i.e. a CMS group will host a CMS masterclass. Students learn to analyze actual data presented at their level from an actual experiment. In a masterclass, students do their own analysis, combine results, and finish by participating in a videoconference moderated by physicists; students become "particle physicists for a day."

2. Masterclasses measurements

While a masterclass can be held anytime, the majority of masterclasses occur in the February-March-April International Masterclasses (IMC) season. IMC is a program under the umbrella of the International Particle Physics Outeach Group (IPPOG). [1] IMC 2024 took place in February and March with over 14,000 students in over 350 masterclasses worldwide. Videoconference moderators were at major international laboratories: CERN, Fermilab, GSI, KEK, and Pierre Auger. [2]

2.1 LHC masterclasses

The four major experiments in the Large Hadron Collider (LHC) at CERN each offer at least one masterclass measurements. The two most popular are ATLAS and CMS.

2.1.1 ATLAS

ATLAS promotes a Z-path and a W-path measurement. The Z-path enables students to create mass plots from dilepton, four-lepton, and diphoton events across a range of invariant masses from the J/Ψ mass up through the Z boson, Higgs, and beyond to Monte Carlo of hypothetical 1000 GeV-and-above particles. The W-path shows single- and two-lepton events to enable students to find the W+:W- ratio and search for excesses in WW events. [3] Videoconferences are based at CERN and, for the Z-path, Fermilab.

2.1.2 CMS

The CMS experiment offers its WZH measurement for IMC. Students look at single visible lepton events to study the W+:W- ratio mixed in with dilepton and four-lepton events from which they can create mass plots similar to those in ATLAS but without the additional Monte Carlo. CMS also offers a J/Ψ masterclass for in-school use. [4] For CMS, videoconferences are based at CERN and Fermilab.

2.1.3 LHCb and ALICE

LHCb has a masterclass that enables students to measure the D^0 lifetime from displaced vertices. [5] ALICE has two masterclasses: a search for strange particles and a measurement of the nuclear suppression factor R_{AA}. [6] LHCb and ALICE masterclasses have vidceoconference moderators at CERN.

2.1.4 Special LHC masterclass events

Each year, IMC holds two special events with LHC measurements. February 11 is the International Day of Women and Girls in Science (IDWGS) and IMC offers special masterclasses on or close to this day. Women as masterclass leaders and tutors act as role models; discussions in and out of videoconferences focus not only on the physics but also on the special considerations of young women becoming scientists. Moderators, mostly women, are based at CERN. [7]

World Wide Data Day (W2D2) is a simple dimuon measurement from ATLAS and CMS data that teachers can do with their students. The students measure directions of muons and plot them in histograms to learn how detectors perform. The measurement and short videoconference with a physicist take about two hours total. Data is combined from participating schools around the world. All videoconferences are on the same day in or near November, hence the event title. [8]

2.1.5 Non-LHC masterclasses

GSI Darmstadt offers a very popular and growing Particle Therapy masterclass which enables students to makes treatment plans for hyopthetical patients with tumors. [9] KEK in Japan has two masterclasses based on the Belle II experiment – one to create multiple kinds of mass plot using block-progrmming and another to find the number of color charges in strong interactions. [10] Pierre Auger sponsors an eponymous cosmic ray masterclass [11] and Fermilab has two neutrino masterclasses based, respectively, on the MINERvA [12] and NOvA [13] experiments. Each laboratory moderates its own videoconferences.

3. A micro-masterclasses measurement

To demonstrate the “bare bones” of a masterclass measurement for interested teachers and physicists, we have devised a very short measurement that takes 5-10 minutes to complete using LHC data. We have isolated and printed images of a number of dimuon events in CMS and ATLAS which are just about entirely transverse to the beamline and in which the muons appear to be nearly back-to-back. The momentum of each muon in GeV/c is printed next to the track. For these events, the net momentum of the system is close to zero, so the mass of the parent particle (upsilon or Z) is close to the sum of the two energies, read from the two momenta, thus using the $E=mc^2$ formulation with which students are familiar. A small histogram of masses shows small peaks near 10 and 90 GeV. This short, simple activity was developed for the presentation of this paper but there can be other uses. [14]

References

[1] IPPOG website, https://ippog.org/.

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[3] ATLAS masterclass website, https://atlas.physicsmasterclasses.org/start.htm.

[4] CMS masterclass website, https://web.quarknet.org/mc/cms/.

[5] LHCb masterclass website, https://lhcb-outreach.web.cern.ch/lhcbinternationalmasterclasses/d0-lifetime/.

[6] ALICE Education website, https://alice.cern/education.

[7] IPPOG International Masterclasses Women in Science Day website, https://ippog.org/international-masterclasses/imc-women-science-day.

[8] W2D2 website, https://quarknet.org/content/world-wide-data-day.

[9] Particle Therapy Masterclass website, https://indico.cern.ch/event/840212/.

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[12] MINERvA Neutrino Masterclass website, https://indico.fnal.gov/event/22340/.

[13] NOvA Neutrino Masterclass website, https://indico.fnal.gov/event/63011/.

[14] Events, https://web.quarknet.org/mc/micro/IMC_LHCP_06may2024.pdf.