PROCEEDINGS OF SCIENCE

Inspiring Students Through Masterclasses

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Masterclasses are an excellent platform to inspire, motivate and educate students about High Energy Physics (HEP). They typically entail lectures on a chosen topic followed by a hands-on session where students get to experience being a researcher for the day. A number of HEP masterclasses have been developed, including the International Particle Physics Masterclasses, supported by IPPOG. These provide a programme structure for students to analyse real collision data collected by the four main LHC experiments (ATLAS, CMS, ALICE, and LHCb) and to interact with other students from all over the world via a video conference. Examples of the exercises students perform are given, including a measurement of the D^0 lifetime using LHCb data. The practicalities of organising masterclass events are also presented.

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1. Introduction

Masterclasses are an excellent opportunity for students to get an insight into what research actually involves. The use of hands-on activities using the same tools and data as real scientists helps cement their understanding of more basic concepts and teaches students something beyond what they would learn in the classroom. Students learn how teamwork and collaboration (often on an international scale) are essential for the success of science. In addition, masterclasses are an effective way to foster links between universities and local schools.

A typical particle physics masterclass programme would include the following:

- Lectures to introduce particle physics, experiments and detectors (two lectures, 45' each has been shown to work well).
- If appropriate, could also include a guided tour of labs.
- Lunch with lecturers, staff, PhD students.
- Students work in pairs to make measurements on data. For this a pool of PCs and 1 tutor per ten students (approximately) is required.
- Discussion and combination of results, either within the institute, or together with other institutes from around the world, via video conference.

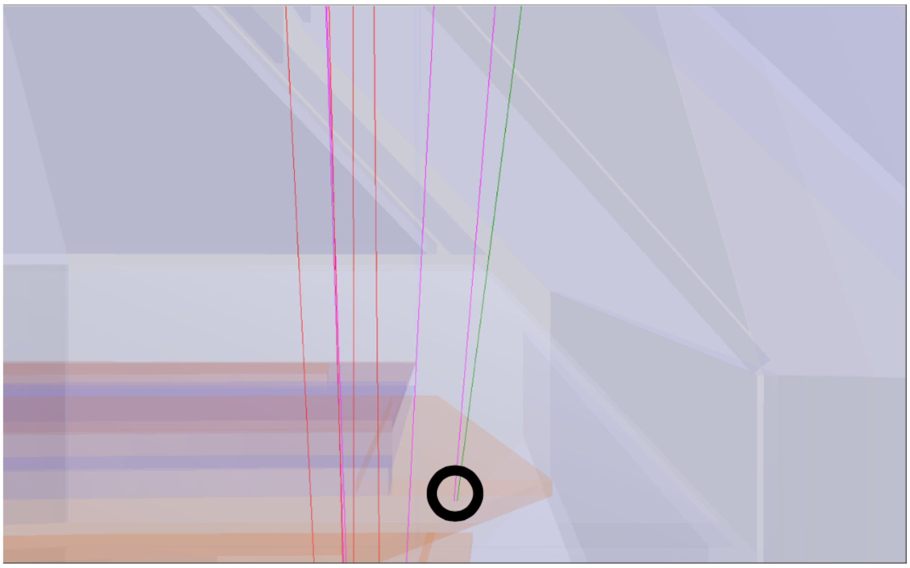
2. The International Masterclasses programme

The International Masterclasses programme is organised by IPPOG (International Particle Physics Outreach Group) [1] and runs every year in March. In 2015, 10,000 students from 42 different countries at 200 institutes participated in the masterclasses. All four main LHC experiments (ATLAS, CMS, ALICE and LHCb) offer exercises using real data they have recorded. Institutes are offered a choice of several different measurements to work with. An example measurement using data taken by the LHCb experiment is detailed below, together with summaries of the exercises offered by the other experiments.

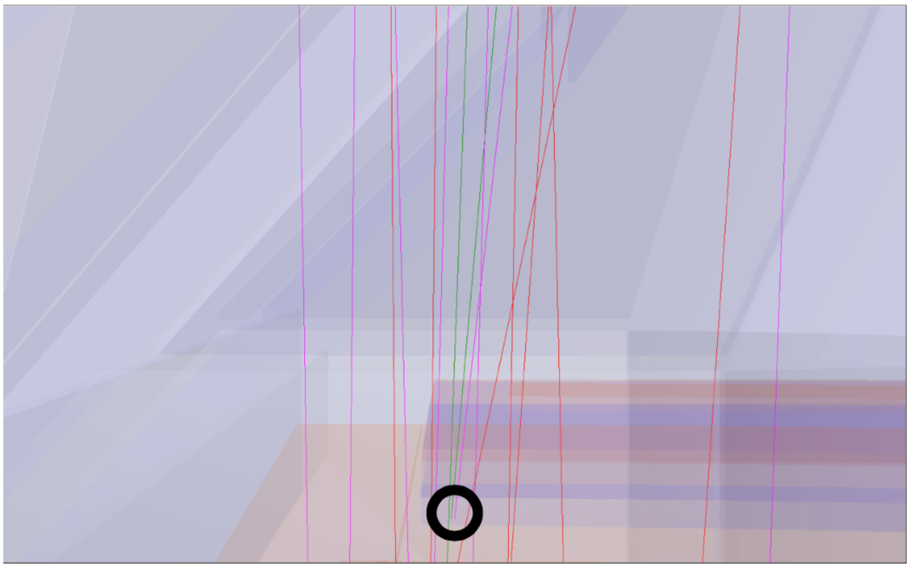
2.1 LHCb measurement of the D^0 lifetime.

This measurement uses real $D^0 \to K\pi$ events to make measurements of the D^0 mass and lifetime [2]. Proton-proton collision data collected by LHCb during 2012 (where the centre-of-mass energy $\sqrt{s}$ = 8 TeV) is used for the exercise. Students are introduced to the concepts of particle lifetimes and the wide range of values that these can take (e.g. the Z-boson has a lifetime of 10^{-25} seconds while the proton has a lifetime $> 10^{29}$ years). They are taught how to measure these lifetimes experimentally, using the correlation between lifetime and decay length. Particle oscillations are also introduced, in particular D^0 oscillations between charm/anti-up and anti-charm/up states. Students are also given an introduction to anti-matter, including a discussion of why it's important in terms of CP violation and what can be learnt by studying it.

Students use event displays to identify D^0 decays. Tools are provided so that they can zoom in around the interaction region to look for displaced vertices and tracks are colour-coded to aid with identification. Two examples are shown in figure 2.



(a)



(b)

Figure 1: Two examples of $D^0 \to K\pi$ events recorded by the LHCb detector. Some events have little or no other activity and are easy for students to identify are easy for students to identify (a) whereas others are more difficult (b) [2].

Students use events they have selected to create their own plot of the D^0 mass distribution. They are then given more data to do fits to the mass and lifetime distributions using a tool (see figure 2 for example display) which allows them to apply cuts on various quantities, including the $D^0 p_T$ and mass, in order to further refine their selection. After completing the exercise, students compare their lifetime measurement with those measured by LHCb and the world average. Systematic uncertainties, and the dependency of the result on the signal selection criteria are also discussed.

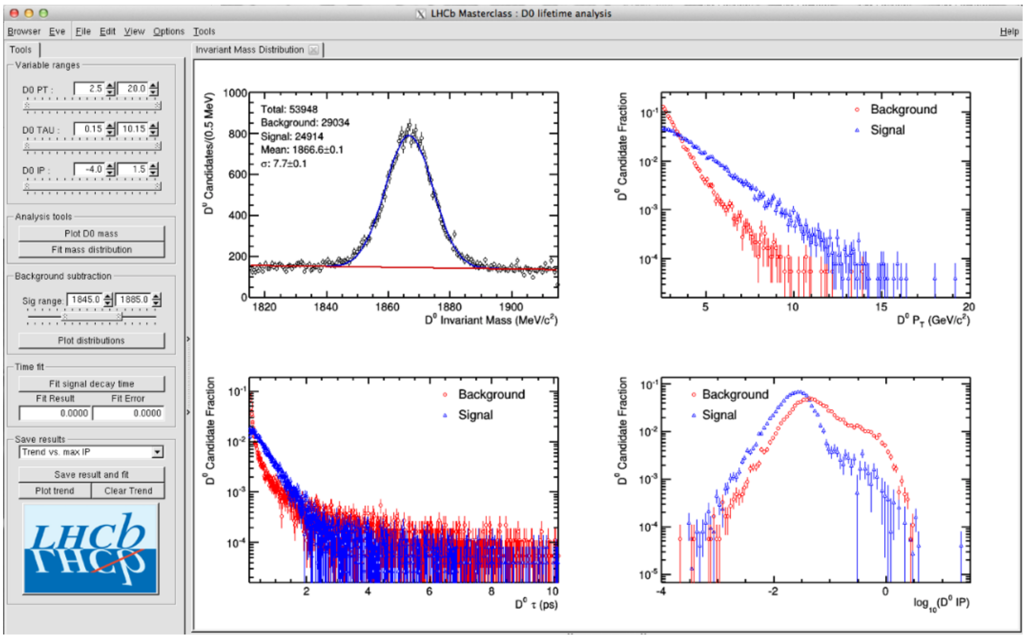


Figure 2: Screenshot of the tool students use to perform fits to the D^0 mass and lifetime measurements [2].

2.2 Summary of other masterclass measurements

- ATLAS Z-boson measurements: Students search for pairs of leptons (e/μ) or photons, and events with 4 leptons. These are used to reconstruct the di-lepton invariant mass spectrum and identify the J/Ψ, Υ, and Z-boson, and search for Higgs bosons in $H \to ZZ \to \ell\ell\ell\ell$ and $H \to \gamma\gamma$ events. Students also search for simulated Z' events (with $m_{Z'} = 1$ TeV and decaying to ee or $\mu\mu$ final states) that are mixed in with the data events [3].

- ATLAS W-boson measurements: W^+ and W^- events are reconstructed and then the ratio of the number of each of these is used to explore the structure of the proton. Higgs boson events are searched for the in the $H \to WW \to \ell\nu\ell\nu$ decay channel by measuring the opening angle (ϕ) between the two charged leptons [4].

- CMS W and Z boson measurements: Students learn to distinguish W and Z boson candidates from event displays. They look at ratio of number of W^+ and W^- events to probe the structure of the proton, make invariant mass plots to identify the J/Ψ, Υ, and Z boson, and find Higgs candidates from 4-lepton and di-photon events [5].

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- ALICE strange particles: Strange particles (K_s, Λ, anti-Λ) are identified from their decay patterns and a calculation of the invariant mass. Using lead-lead collision data, the number of strange particles are counted in different centrality regions and strangeness enhancement factors are calculated by comparing to proton-proton data [6].

2.3 Video conference with CERN or Fermilab

At the end of the day, institutes join a video conference moderated by two researchers at either CERN (for those in European timezones) or Fermilab (for those in the Americas) to share their results and make a combined measurement. The video conference lasts one hour and is joined by between 4 and 6 institutes. The main aims of the video conference are to:

- Convey the the internationality of the event.
- Demonstrate how particle physicists work together internationally.
- Encourage students to share their experiences with each other.
- Demonstrate how combining datasets improves accuracy.
- Be a fun end to a long day!

The format of the video conference is typically:

- Welcome and icebreaker (10’): All groups are introduced and a brief explaination of what will happen in the next hour is given.
- Reports of measurements (15’): A volunteer student from each institute presents their results to the other video conference participants. Students are also given the opportunity talk about any difficulties or problems they had with the exercise.
- Combination of results and discussion of measurement (10’): The CERN/Fermilab moderators present the combined results to all groups. This final result is compared to theoretical predictions and the latest experimental results. A discussion about why combining results from different sources is beneficial is held, and students are encouraged to ask questions about the measurements.
- Question time (15’): Students are invited to ask the CERN/Fermilab moderators questions in an open forum. Questions can cover any topic, and can cover anything from the Big Bang, dark matter, black holes, the life of a researcher, or how they themselves can to get into physics.
- Quiz (10’): The video conference finishes with a quiz, in the style of the popular TV show ‘Who Wants To Be A Millionaire’. The quiz is intended to be a light-hearted and fun end to the day and no record is kept of the scores.

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3. Organising a masterclass event at your institute

In order to plan a masterclass event at your institute at least one scientist is required to hold the lecture(s) and during the hands-on exercises approximately one tutor per ten students. In terms of infrastructure, a lecture theatre, PC pool (students work in pairs), and if possible a video conferencing facility are needed. For the IPPOG scheme first contact with your national representative (see [1]) should be established by July in order to register your preferred dates and measurement in October.

References

[1] `http://physicsmasterclasses.org`

[2] `http://lhcb-public.web.cern.ch/lhcb-public/en/LHCb-outreach/masterclasses/en/D0Lifetime.html`

[3] `http://atlas.physicsmasterclasses.org/en/zpath.htm`

[4] `http://atlas.physicsmasterclasses.org/en/wpath.htm`

[5] `http://cms.physicsmasterclasses.org/cms.html`

[6] `http://alice.physicsmasterclasses.org/alice-exercise-en-2013.pdf`