PROCEEDINGS OF SCIENCE

LHCb in the International Particle Physics Masterclasses

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The Large Hadron Collider Beauty (LHCb) Experiment joined the International Particle Physics Masterclass programme in 2013. The experiment proposed the measurement of the D^0 meson lifetime, using real data gathered at the Large Hadron Collider in 2012. We describe the exercise as well as the lessons learned during this first participation in the International Masterclass programme

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1. Introduction

The International Particle Physics Masterclasses [1] are an organization that provides an opportunity for thousands of high school students world-wide to discover particle physics and its methods. This programme has been running since 2005, with exercises from the CMS [2], ATLAS[3] and ALICE[4] experiments at CERN. The LHCb [5] Outreach team decided in 2013 to prepare such an exercise for the 2014 session, demonstrating the principles of the measurement of the D^0 meson lifetime with experimental data. The ROOT [6] Data Analysis framework was used to implement a stand-alone C++ application that guides the students through the measurement.

2. The LHCb collaboration and experiment

The Large Hadron Collider Beauty (LHCb) collaboration gathers more than 800 members from 69 institutes from 17 countries. They have collaborated to build and operate the LHCb detector [7], a single-arm forward spectrometer installed at interaction point 8 of the Large Hadron Collider (LHC) at CERN (fig. 1). LHCb covers the pseudorapidity[1] range $2 < \eta < 5$, and is designed for the study of particles containing beauty or charm quarks and their decays. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector called VErtex LOcator (VELO) surrounding the proton-proton interaction region [8], a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes [9] placed downstream of the magnet. The minimum distance of a track to a primary vertex, the impact parameter, is measured with a resolution of $(15+29/p_{\mathrm{T}})\,\mu\mathrm{m}$, where p_{T} is the component of the momentum transverse to the beam, in GeV$/c$. Different types of charged hadrons are distinguished using information from two ring-imaging Cherenkov detectors [10]. Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers [11]. The trigger [12] consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction.

3. D^0 lifetime measurement exercise

3.1 LHCb in the Masterclasses

Started in 2005, the International Particle Physics Masterclass programme [1] provides an opportunity to 15-19 year old students to discover particle physics. Every year, during the month of March, around 10000 high school students spend a day in a research institute, meeting particle physicists who guide them through a measurement on real data. They get the opportunity to learn about the tools and methods of experimental physics, and about the careers in the field. The day finishes with an international video conference between the various sites working on the same exercise, to summarize and discuss the results of the day.

[1] The pseudorapidity $\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$ where θ is the angle between the particle momentum and the beam axis.

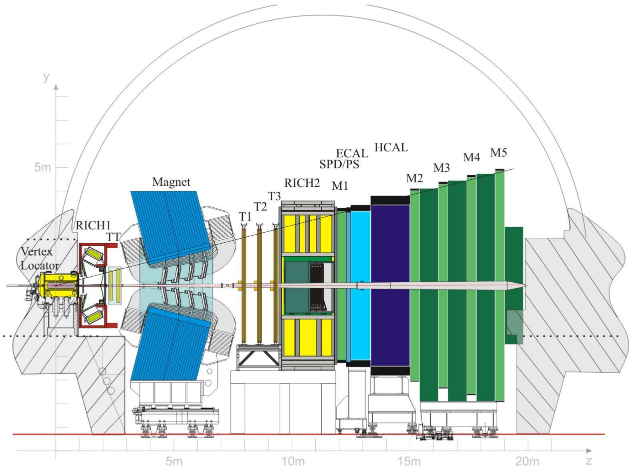

Figure 1: LHCb Detector

The programme has been a resounding success and around 200 institutes or universities from 41 countries participated in 2014. The LHCb experiment joined the Masterclasses for their 10^{th} edition in 2014, with a measurement of the D^0 meson lifetime.

3.2 Why the D^0 lifetime?

This measurement is representative of lifetime measurements made at the LHCb experiment. The D^0 is composed of a charm quark, and of an up antiquark. According to the Particle Data Group (PDG) [13], its lifetime is 410.1 ± 1.5 fs and it therefore travels several millimeters within the LHCb VErtex LOcator (VELO). The LHCb detector has a resolution of around 45 fs and can therefore measure the D^0 meson lifetime.

The D^0 itself is neutral and cannot be detected by the LHCb Vertex Locator, but it decays in a kaon K^- and a pion π^+ around 3.9% of the time. This 2-body decay is relatively easy to detect with the LHCb detector, provided both the pion and the kaon are within its acceptance.

We therefore pre-selected D^0 to K^- π^+ decay events in the LHCb 2012 data set. The typical characteristic of such an event is a displaced vertex, from which the pion and the kaon originate (figure 2).

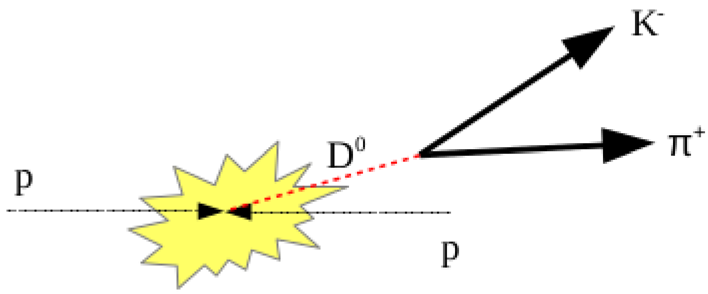

Figure 2: D^0 decaying to K^- π^+

3.3 The Masterclass exercise

In order to guide students through the LHCb Masterclass exercise, an application (available on Linux, Windows, MacOS X) was implemented with detailed instructions in five languages (English, French, Italian, German and Romanian). The exercise consists of two parts:

- D^0 identification
- D^0 lifetime fit

3.3.1 D^0 identification

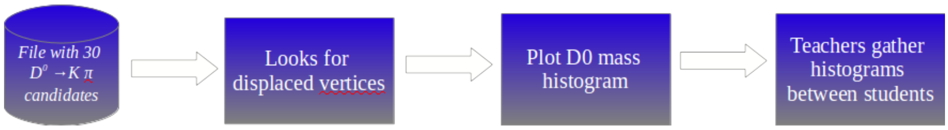

Figure 3: D^0 identification process

The goal of this exercise is to identify D^0 decay vertices in preselected LHCb events: the student uses the LHCb event display to analyse 30 events and to find displaced vertices from which a kaon and a pion originate (fig. 3). The interface shows view of the detector, in order for the student to get accustomed to LHCb's forward geometry (figure 4)

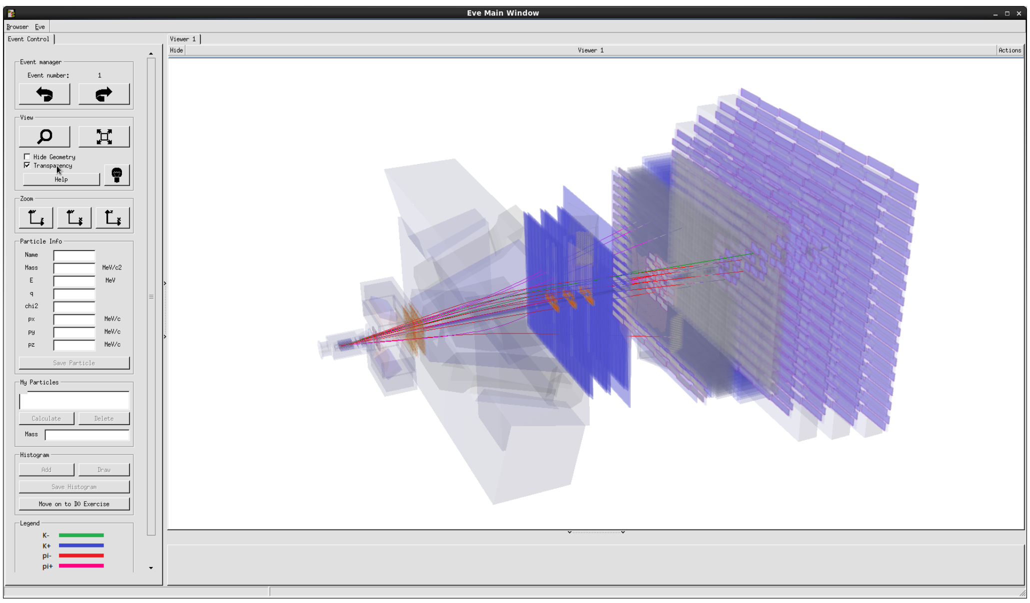

Figure 4: LHCb Masterclass event display

She/he can then use the tools on the left panel to zoom (figure 5) to the proton collision point as D^0 decays typically occur a few millimetres away (compare with the detector length of about 20m).

Once she/he has selected two candidates, she/he can compute the invariant mass of the original particle. If this mass is between 1814 and 1916 MeV/c^2 (i.e. around 3% of the D^0 mass), then this is a good candidate for a D^0 decay and the student can add it to their mass histogram.

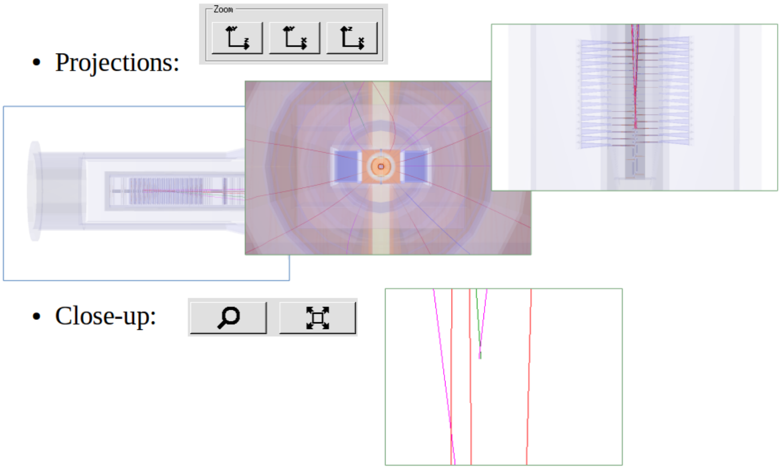

Figure 5: Zooming to the collision point

Repeating this process for multiple events, the student builds up the histogram of the mass of the various D^0 candidates, and can see a peak appear. Teachers can merge histograms between all students participating (they have a different sample each), as shown in figure 6.

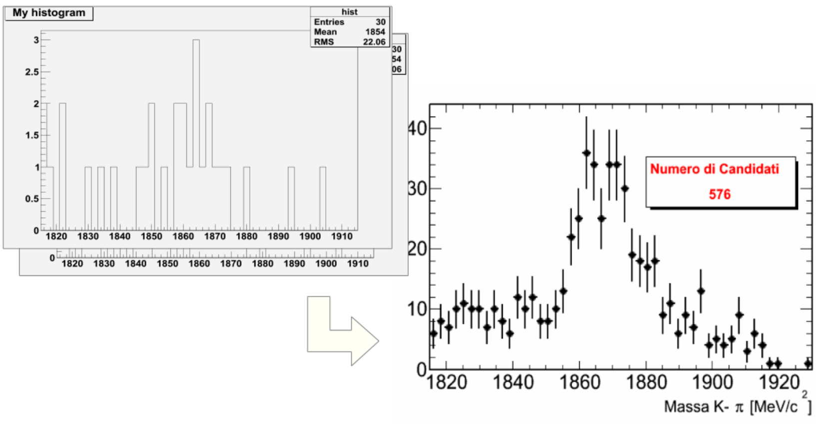

Figure 6: Building the mass histogram. Individual results on the left are merged into the mass histogram on the right.

At this point of the exercise, students have a better understanding of the identification of D^0 decay vertices, but not enough events to derive the meson's lifetime.

3.3.2 D^0 lifetime fit

In order to have enough statistics to derive the D^0 lifetime, the students use a file with around 54000 candidate events that they can analyse in the user interface provided.

The step is to identify the signal region within the D^0 mass distribution, and specify it to the tool that fits a flat background and a Gaussian signal to the sample (fig. 7). It is then possible to view the histograms of:

- P_T: the transverse momentum of the reconstructed D^0

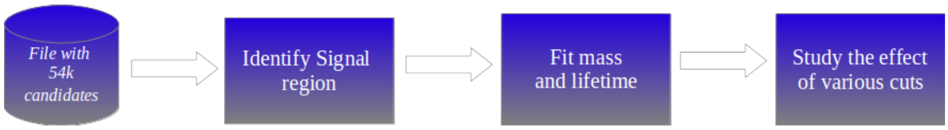

Figure 7: Evaluating the D^0 lifetime

- τ: distribution of decay times of the D^0 candidates
- IP: the impact parameter of the D^0 i.e. its distance of closest approach to the collision point between the two protons.

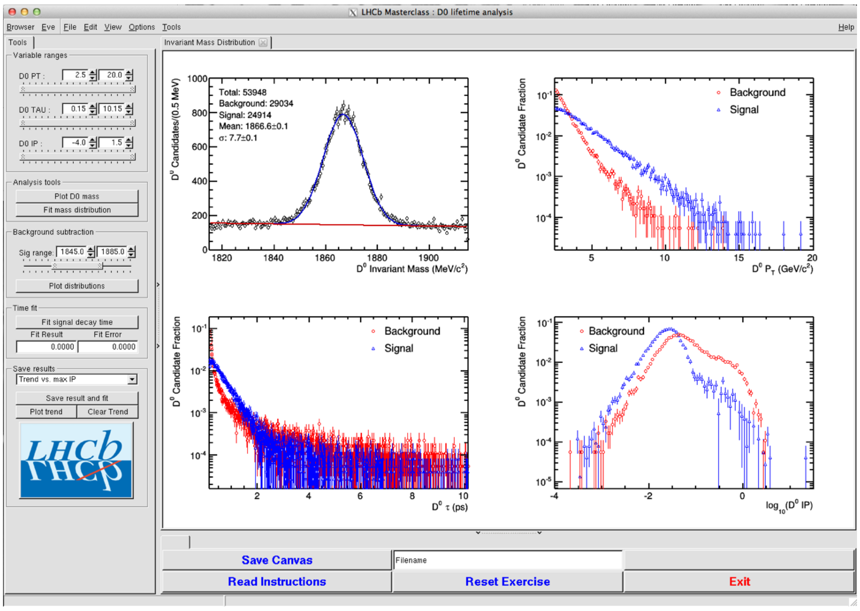

Figure 8: Selecting the signal region

An exponential fit to the decay times of the D^0 candidates gives the lifetime of the D^0. With such a data sample, it is quickly possible to see that we have very small statistical uncertainty, but that the value using the default cuts is around 470 fs (with a 4 fs uncertainty), around 15% above the PDG value !

This difference is due to a systematic error, which comes from the fact that some D^0 mesons are not produced in the proton-proton collision, but are the decay products of B mesons. We therefore overestimate their lifetime as what we measure is in fact the travel distance of the B meson plus the one of the D meson, as shown in figure 9.

To realize this, the students are asked to repeat the lifetime fit varying the cut on the impact parameter. A typical results of their repeated measurements is shown in figure 10 , where the horizontal line is the PDG value.

The cut on the impact parameter is effective in limiting the unwanted contribution because the D meson produced produced by B meson decay is unlikely to point back to the protons' collision point. In practice, using this technique we can get within a few percents of the D^0 lifetime.

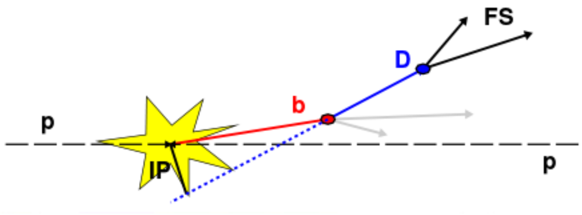

Figure 9: D meson produced by a B meson decay

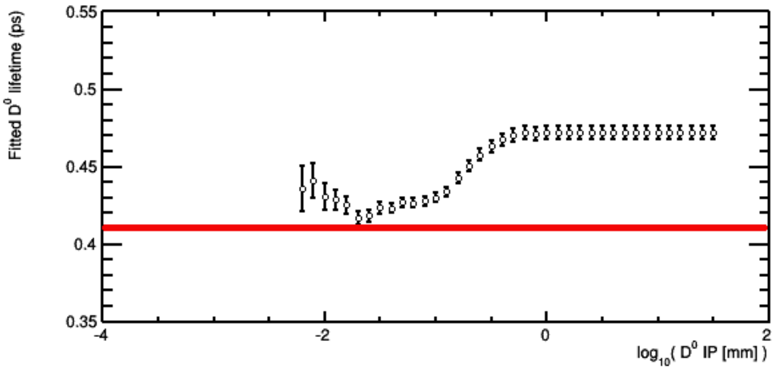

Figure 10: τ as a function of the IP cut. The red line corresponds to the PDG value of the D^0 lifetime

This second part of the exercise allows the instructor to discuss typical analysis techniques used in particle physics, i.e. the sidebands method to extract signal and background distributions of the variables describing the event, and the difference between statistical and systematic errors, and how to investigate and possibly remove them.

4. Technical aspects

4.1 Current implementation

The current version of the LHCb Masterclass exercise was implemented in the C++ language, using the ROOT Data Analysis Framework [6]. The reason for this choice was that:

- The LHCb geometry was already available in a format readable by the framework, therefore making the implementation of the event display interface straightforward.
- This is the framework used for the LHCb physics analyses. The team was therefore comfortable with an implementation with this technology.
- ROOT is open source and can be distributed (it is already available in the package repositories for Debian Linux for example).

- ROOT is portable to Linux, MacOS, Windows. It is mandatory for a Masterclass exercise to run on as many different platforms as possible.

However, there were drawbacks to this choice, as the software has to be pre-installed on the machines used for the Masterclass day. This installation should be as easy as possible, in order to reduce the workload of the Masterclass instructors. Our long term goal is to implement a web based version of the exercise, so as to remove the need for software installation altogether.

4.2 Future Implementation

In view of improving the application, and to make the life of the Masterclass days organizers easier, a cooperation was setup with the CERN Media Labs (the group in charge of interactive exhibitions at CERN) to develop a Web based event viewer using the Unity game engine [14]. The project called Total Event Visualizer (TeV) will integrate the event displays for several LHC Experiments. A prototype for LHCb is available as shown in figure 11. It is however not yet ready for use during the Masterclass.

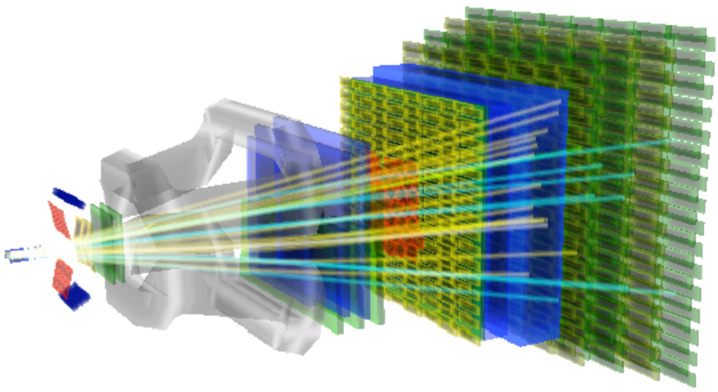

Figure 11: LHCb Event viwer using the Unity game engine

5. The 2014 Masterclass days

Seven LHCb Masterclass days were organized in March 2014. 19 institutes from the United Kingdom, United States, France, Germany, Italy and Romania participated and around 600 students completed the exercise. The feedback from students and organizers was very positive. The Video conference gathering all participating schools and the CERN team was also very appreciated.

The complexity of running such an exercise for tens of students should however not be underestimated and it is clear that web based exercises will be a lot easier for local organizers.

6. Conclusion

The LHCb's experiment's first participation was a great success, and the LHCb exercise was appreciated by both Masterclass days organizers and students. The Outreach team is however continuing to improve the exercise for the coming years.

7. Acknowledgements

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