Study of selections for $\eta' \rightarrow \rho^0 \gamma$ desintegration at LHCb

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Chapter 1

Introduction

The general frame of this study is the LHCb detector mainly devoted to the beauty quark and the violation of CP. This project focuses on the preliminary analysis necessary for the study of CP.

Since it is conducted within the frame of the Physic Master Program at the EPFL, a strong accent is put on the educational aspect.

1.1 Aim

The aim is to get familiar with the general functioning of the LHCb, the simulation process, and mainly on the tools of analysis. The other aspect of the study is the understanding of the particle physics behind the disintegration.

In practical terms, the goal is to find $\eta'$ particle in the LHCb data from 2010. This is done in three steps: first, the possible cuts and parameters are studied in the case of simulated data corresponding to a particular B decay channel. Then, equivalent parameters are tried on the minimum bias data, before testing them on the real data.

1.2 Motivations

As previously mentioned, the goal is to highlight $\eta'$ particle. In a general context, LHCb experiment studies particle physics involving the b-quark.

This project restrains its field of study to the $\eta'$ particle. Further work is to combine this particle with other light mesons to reconstruct $B$ and conduct deeper analysis on its properties.
Chapter 2

Frame of the study

This chapter presents the general aspect of the LHC and the LHCb experiment. The subdetectors are shortly introduced and the computer tools for simulation and analysis are described.

2.1 LHC

The Large Hadron Collider (LHC) is the largest experimental device ever built to validate physical theories. It is primarily designed to accelerate bunches of protons to an energy of 7 $[\text{TeV}]$ (14 $[\text{TeV}]$ center of mass).

The LHC has a design luminosity of $10^{34} [\text{cm}^{-2}\text{s}^{-1}]$ and a bunch-crossing frequency of 40 $[\text{MHz}]$. Four main detectors are located at the crossing-points of the main ring: ATLAS, CMS, LHCb and ALICE. Apart from the two general-purpose detectors, CMS and ATLAS, each experiment is designed with different physics aims in mind.

Operating Conditions

The LHC has been able to produce proton-proton collisions for sustained periods of time last winter, and has been able to reach higher energy in 2010. The nominal LHC beam conditions are given in Table 2.1. All simulated data used in this project are simulated to reproduce LHCb optimum conditions. 2010 data used for analysis were acquired at 3.5 $[\text{TeV}]$ per beam and reduced luminosity.

<table>
<thead>
<tr>
<th>Nominal conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per beam</td>
</tr>
<tr>
<td>Number of protons per bunch</td>
</tr>
<tr>
<td>$\beta$</td>
</tr>
</tbody>
</table>

Table 2.1: Nominal parameters of the LHC beam.

<table>
<thead>
<tr>
<th>2010 data collection conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per beam</td>
</tr>
<tr>
<td>Number of protons per bunch</td>
</tr>
<tr>
<td>$\beta$</td>
</tr>
</tbody>
</table>

Table 2.2: Parameters of the LHC beam in early 2010.

1A. Bay, LPHE, EPFL, class notes "Particules Elementaires"
2.2 LHCb Experiment

The Large Hadron Collider beauty (LHCb) experiment at CERN is a forward one-arm spectrometer. Its design reflects the predicted distribution of b-quarks produced at the LHC. The detector covers a polar angle of 25 to 300 [mrad] in the horizontal direction and 25 to 250 [mrad] in the vertical direction.

Its aim is to study CP violation and other rare phenomena in the decay of hadrons containing b-quarks at the LHC. Other physics goals are to check the consistency of the Standard Model through precise measurements and to search for new physics in decays.

The LHCb sub-detectors

[Diagram of LHCb detector layout]

Figure 2.1: View of the Large Hadron Collider beauty (LHCb) detector in the non-bending plane.

LHCb detector is composed of several sub-detectors, listed here from the left (upstream) to the right (downstream):
- Vertex LOcator (VELO)
- First Ring-Imaging CHerenkov Detector (RICH 1)
- Trigger Tracker (TT)
- Magnet
- three Tracking Stations (T1 - T3)
- second Ring-Imaging CHerenkov Detector RICH 2
- the Silicon Pad Detector and PreShower (SPD/PS)
- first Muon Station (M1)
- the Electron and Hadron CALorimeters (ECAL, HCAL)
- the remaining Muon Stations (M2 - M5)
Description and role of different detectors forming LHCb (Fig. 2.1)

**Vertex Locator** The VELO surrounds the interaction region, its role is to provide track coordinates close to the interaction region which can be used to calculate the position of the Primary Vertex and reconstruct the position of B- and D-mesons vertices. Basically, it measures the radial and azimuthal position \((r, \phi)\) of each track.

**Tracking System** The tracking system is composed of several tracking stations designed to measure the momentum of particles. It consists of the VELO, the Trigger Tracker (TT) and the Tracking Stations. The TT and Tracking Stations are each composed of four detection layers. Each Tracking Station is divided into an Inner and an Outer Tracker to limit the occupancy of the detector. The information collected by these stations are then used in the reconstruction of the Rings RICH detectors (I and II) which requires a good measurement of the momentum of the detected particles.

**Ring Imaging Cherenkov Counter** The RICH allows identification of particles. Its principle is based on the Cherenkov effect. A measure of the Cherenkov angle \(\theta_c\) yields the velocity of the particle passing through it. By measuring the momentum of that particle using the tracking system it is thus possible to calculate the particle’s mass. In the case of LHCb, two RICH detectors are used. RICH 1 identifies low-momentum particles with momenta in the range 1 to 60 \([GeV]\). RICH 2 identifies high-momentum particles with momenta reaching up to 150 \([GeV]\).

**Calorimeters** The information from the Electronic (ECAL) and Hadronic CALorimeters (HCAL) is used to identify photons, electrons and hadrons and to measure their positions and their energies.

**Muon Detector** The muon stations are located furthest from the IP because muons interact weakly with matter and are the only particles able to reach such distances. The muon system consists of five stations, M1 - M5, positioned along the beam axis. Two detector technologies are used, Multi Wire Proportional Chambers (MWPC) and Gas Electron Multipliers (GEM).

---

2Electromagnetic radiation emitted when a charged particle passes through an insulator at a constant speed greater than the speed of light in that medium
2.3 LHCb softwares

The armada of softwares necessary to collect, treat and analyze the data are described, including the one simulating the data.

The LHCb software framework is illustrated in Fig. 2.2.

**Gauss**: Gauss is the LHCb simulation package. The detector response to particles from proton-proton collisions are simulated in full. It is composed by two sub-program:

- **PYTHIA**: generates the pp collision and the product of their collision
- **EvtGen**: takes then over the simulation of the particle decays in function of the detector environment.

**Boole**: Boole simulates the detection of the particle by the detector. The signal is digitalised taking in account the electronic imprecision of the hardware.

**Brunel**: Brunel can process either real data from the LHCb, or the output of the detector digitization coming from Boole. This part of the simulation reconstructs the events from all data. It reconstructs the tracks of these particles and their associated data measured by different detectors (P, pt, Mass, ...).

**DaVinci**: performs the physical analysis of the data reconstructed by Brunel and selection of some candidate (decay channels). Typically in the case of this report, DaVinci selects the channel $\eta' \to \rho^0\gamma$. The selections made at this level are referred as preselection.

**Root**: Analysis and plotting program, used to perform selection cuts and to generate all graphics and fits in this report.

![LHCb applications diagram](image-url)
Chapter 3

Study of $B^+$ decay

This chapter introduces the particle physics and properties necessary to this study. First, $B^+$ properties and its different modes of disintegration are introduced. Then, the choices made to select the $\eta'$ decay channel are detailed.

3.1 Properties of $B$

$B$ is a bottom meson, that is to say a particle with one quark and one anti-quark, where one of them has a beauty flavor\(^1\).

<table>
<thead>
<tr>
<th>Properties of $B^+$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark composition</td>
<td>$ub$</td>
</tr>
<tr>
<td>Mean life</td>
<td>$\tau = (1.638 \pm 0.011) \times 10^{-12}[s]$</td>
</tr>
<tr>
<td>Quantum numbers</td>
<td>$I(J^P) = \frac{1}{2}(0^-)$</td>
</tr>
<tr>
<td>Mass</td>
<td>$5279.15 \pm 0.31$ [MeV]</td>
</tr>
<tr>
<td>$c\tau$</td>
<td>$491.1$ [$\mu$m]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties of $B^0$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark composition</td>
<td>$db$</td>
</tr>
<tr>
<td>Mean life</td>
<td>$\tau = (1.530 \pm 0.009) \times 10^{-12}[s]$</td>
</tr>
<tr>
<td>Quantum numbers</td>
<td>$I(J^P) = \frac{1}{2}(0^-)$</td>
</tr>
<tr>
<td>Mass</td>
<td>$5279.53 \pm 0.33$ [MeV]</td>
</tr>
<tr>
<td>$c\tau$</td>
<td>$458.7$ [$\mu$m]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties of $B^0_s$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark composition</td>
<td>$sb$</td>
</tr>
<tr>
<td>Mean life</td>
<td>$\tau = (1.470 \pm 0.027) \times 10^{-12}[s]$</td>
</tr>
<tr>
<td>Quantum numbers</td>
<td>$I(J^P) = 0(0^-)$</td>
</tr>
<tr>
<td>Mass</td>
<td>$5366.3 \pm 0.6$ [MeV]</td>
</tr>
<tr>
<td>$c\tau$</td>
<td>$441$ [$\mu$m]</td>
</tr>
</tbody>
</table>

$B$ mesons are of particular interest to study CP violation. This can be in a direct or indirect manner detailed in the next paragraphs.

\(^1\) All particles properties and branching fractions inside this report are from C. Amsler et al. (Particle Data Group), Physics Letters B667, 1 (2008) and 2009 partial update for the 2010 edition Cut-off date for this update was January 15, 2009.
- $B^0_{(s)} - \overline{B^0}_{(s)}$ oscillations

Neutral $B$ or $B_s$ can transform into their antiparticles and vice versa, but such transformation does not occur with exactly the same probability in both directions. This is CP violation. It is incorporated in the Standard Model by including a complex phase in the Cabibbo–Kobayashi–Maskawa (CKM) matrix describing quark mixing.

![Feynman box diagrams for B mixing](image)

**Figure 3.1:** Feynman box diagrams for B mixing

By studying the life-time of the particle before decaying, one can deduce if the particle has oscillated. Feynman diagram of the oscillation mentions CKM matrix factors. If difference is shown between the two cases, $B^0 - \overline{B^0}$ or $\overline{B^0} - B^0$, CP violation can be evaluated. It can also occur in the interference between mixing and decay.

- Asymmetry between $B^+$ and $B^-$

CP violation can be observed by comparing the $B^+$ and $B^-$ branching fractions to a specific decay channel. This is called direct CP violation. Its interpretation is complicated by QCD effects.

**B desintegrations**

$B$ has numerous ways to decay, due to its important mass. It disintegrates mainly in four categories:

- $D$, $D^*$ or $D_s$ modes represent the most consequent part
- Charmonium mode (containing c-quarks, $D$ modes excluded)
- $K$ or $K^*$ mode
- lepton or semileptonic mode

In every modes, decay channels containing $\eta'$ are found. For instance, for $D$, $D^*$ or $D_s$, decays containing $\eta'$ reach several percent.

This project focuses only on this particle with the bigger objective to combine it with other mesons to reconstruct $B$ particles and get additional results on rare decay channels, etc.
3.2 Properties of $\eta'$

$\eta'$ is a light unflavored meson.

<table>
<thead>
<tr>
<th>Properties of $\eta'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark composition</td>
</tr>
<tr>
<td>Full width</td>
</tr>
<tr>
<td>Quantum numbers</td>
</tr>
<tr>
<td>Mass</td>
</tr>
</tbody>
</table>

Disintegration of $\eta'$

$\eta'$ decays mainly in the following ways:

<table>
<thead>
<tr>
<th>$\eta'$ decay modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta' \rightarrow \eta \pi^+ \pi^-$</td>
</tr>
<tr>
<td>$\eta' \rightarrow \gamma \gamma$</td>
</tr>
<tr>
<td>$\eta' \rightarrow \pi^0 \pi^0 \pi^0$</td>
</tr>
<tr>
<td>$\eta' \rightarrow \rho^0 \gamma$</td>
</tr>
<tr>
<td>$\eta' \rightarrow \pi \pi$</td>
</tr>
<tr>
<td>$\eta' \rightarrow \pi^0 \pi^0 \eta$</td>
</tr>
</tbody>
</table>

Choice of decay mode

The study is conducted on a single decay mode:

$$\eta' \rightarrow \rho^0 \gamma \rightarrow \pi^+ \pi^- \gamma$$

This choice is done by elimination and motivated by the following reasons:

- The abundance of $\gamma$ generated at the collision creates numerous misconstruction. The first disintegration via the $\eta \rightarrow \gamma \gamma$ channel is thus put aside.
- $\pi^0$ are hard to reconstruct precisely since they are neutral. This argument rejects the first mode via the $\eta \rightarrow \pi^0 \pi^0$ channel, and the third decay channel alike.

Despite its lower branching fraction, the second decay channel is therefore preferred. This choice is tempered by the presence of a photon, but its important energy might be of some help.
CHAPTER 3. STUDY OF $B^+$ DECAY
This chapter develops the followed process from data generation to obtained results

The first step of the study is to perform a preliminary analysis to define whether it is possible to observe the particle $\eta'$ and under which conditions. As previously detailed, the simulated signal corresponds to the geometrics and characteristics of the detector. This preliminary analysis gives leads to explore for minimum bias data.

4.1 Generation of the data

Data is generated by Monte Carlo. MC2010 at 7 TeV in center of mass with the full detector is used in the present case, allowing comparison with real data. The set for signal events analysis is constructed through c++ and python codes at DaVinci level.

In this case, $\eta'$ particle are taken from the following decay mode:

$$B^+ \rightarrow \eta' K^+$$

This mode represents only $(7.02 \pm 0.25) \times 10^{-5}\%$ of $B^+$ desintegration, which is relatively large branching fraction compare to other charmless decays.

From DaVinci physical analysis, the particles, tracks and vertex of interests are taken to construct the set. The following table details the restriction applied for the preselection.

<table>
<thead>
<tr>
<th>Preselections on particles</th>
<th>Mother $\eta'$ massWindow $100\text{MeV}$</th>
<th>Daughters $\rho^0$ massWindow $300\text{MeV}$</th>
<th>$\gamma$ $p_t &gt;$ $300\text{MeV}$</th>
</tr>
</thead>
</table>

4.2 Cuts

This section develops all the different methods approached during this study to obtain the best results

Once the data-set is ready for analysis, Root is used to find the best cuts to apply in order to reduce the background noise to the minimum while keeping most of the signal. This is mathematically evaluated through two variables:

- Significance : this is the ratio between $\frac{N_s}{\sigma_{N_s}}$
• Purity: this gives the proportion of signal events compare to the background events $\frac{S}{B}$

The ideal cuts are the ones maximizing both variables. In the present case, cuts are judged mainly on significance.

A parameter inside the Monte Carlo simulation keeps track of the real $\eta'$ called "MC-Truth". This parameter was not accessible in the data used. The cuts are therefore judged by the quality of the fitted results.

4.2.1 Explored leads

As the fraction of $\eta'$ is very small in a $B^+$ desintegration, one can expect that the cuts need to be quite radical to eliminate the dominating background.

Here are presented the different leads explored with or without success.

Selection of the primary vertex

This is done by selecting the primary vertex the closest to the reconstructed $\eta'$. The variable representing this is "etap_PVDoca", $\eta'$ Distance Of Closest Approach to the Primary Vertex. By minimizing the distance between $\eta'$ tracks and the vertex, $\eta'$ origin is forced to be the closest to the vertex.

In addition, $\eta'$ vertex position is asked to be in front of the primary vertex, along the direction of the detector.

$\eta'$ transverse momentum

As $B^+$ mass is much bigger than the mass of $\eta'$, $\eta'$ transverse momentum must be important to respect energy conservation. Fig. 4.1 show a slight peak for $\eta'$ mass. As the background remain important, the argument is reported on daughter-particles to try to improve that aspect.

![Figure 4.1: $p_t(\eta')$](image-url)
4.2. **CUTS**

**$\rho^0$ and $p$ transverse momentum**

The set of data is signal events, meaning only events with all decay products within the detector are generated. The same argument for $\eta'$ transverse momentum can then be used. Indeed, the mass difference between $\eta'$ and $\rho^0$ is not as important, compare to $m_{B^+}$.

The graphics in Fig. 4.3 seem to reduce the background more systematically. The cuts are fixed at:

\[
\begin{align*}
  p_t(\rho^0) &> 2000 \,[\text{MeV}] \\
  p_t(\gamma) &> 800 \,[\text{MeV}]
\end{align*}
\]

Fig. 4.2 shows how radical those cuts are.

**$\eta'$ vertex $\chi^2$**

By acting on this variable, one can force the tracks to be the closest. Indeed, $\chi^2$ evaluates the proximity of the different tracks taken to form the vertices. This parameter is also exploited to choose the best candidate. In this present study, the applied cut is:

\[
\eta'\text{ vertex } \chi^2 < 10
\]

![Figure 4.2](image-url)  
*Figure 4.2: Plots of the variables on which the cuts are applied.*
Figure 4.3: Plots of $\eta'$ mass, cuts after cuts. 1° best vertices selected, 2° $p_t(\rho^0) > 2000$ MeV, 3° $p_t(\gamma) > 800$ MeV, 4° $\eta'$ track vertex DOCA, 5° $\eta'$ vertex $\chi^2$.

<table>
<thead>
<tr>
<th>Parameters of Fig. 4.3 plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-3$</td>
</tr>
<tr>
<td>entries</td>
</tr>
<tr>
<td>$S$</td>
</tr>
<tr>
<td>$B$</td>
</tr>
<tr>
<td>$\frac{S}{\sqrt{B}}$</td>
</tr>
<tr>
<td>avg.</td>
</tr>
</tbody>
</table>

Table 4.1: As cuts are added, the significance increases. The result is thus improved

Dalitz plots

Observing that the background is still important, a different lead is explored: Dalitz plots.

When treating the case of a three-body decays, one can plot on the x-axis the effective mass of particles 1 & 2 and on the y-axis the effective mass of part. 2 & 3 by example. The results are equally distributed if it really is a three-particle decay.

On the contrary, if the plot shows a higher density at some points, two particles are the product of the desintegration of a heavier one, whose square mass is the effective mass of the . The three-body decay is actually a two-body decay.

In this present case, as the particles are two pions and one photon, a higher density at $\rho^0$ square mass is not readable because it is at the tip of the distribution (photons are massless). No information can be retrieved from this.

The interest of the graphic is if high density areas are shown at lower effective masses, that would mean that those particles are actually the product of desintegration of other particles.
The borders of the plot are calculated through the relations\(^1\):

For a value of \(m^2_{\pi\pi}\),

\[
(m^2_{\pi\gamma})_{\max} = (E^*_\pi + E^*_\gamma)^2 - \left(\sqrt{E^2_{\pi} - m^2_{\pi}} - E^*_\gamma\right)^2
\]

\[
(m^2_{\pi\gamma})_{\min} = (E^*_\pi + E^*_\gamma)^2 - \left(\sqrt{E^2_{\pi} - m^2_{\pi}} + E^*_\gamma\right)^2
\]

The results outside the limit are unphysical in Fig. 4.4. It can be very simply understood by the flexibility allowed around \(\eta'\) mass window. A tighter cut around its mass rejects those points in Fig. 4.5.

\(^1\)References: C. Amsler et al. (Particle Data Group), Physics Letters B667, 1 (2008), chapter: Kinematics
Before or after the different cuts, the diagram does not reveal any clue for selection. This lead is then dropped.

Selection of the best candidate

For each events (i.e. one proton-proton collision per bunches crossing), the simulation proposes numerous candidates, between 1 and 300, and even up to 700 candidates. Only one is the actual fruit of the decaying particle. The others comes from misconstructions: two random crossing tracks are associated to form a particle.

To select the best candidate, all the previous cuts are applied. For each event, from the remaining candidates, the choice of the best one is made according to the best reconstruction of $\eta'$ vertex. This is evaluated by $\chi^2$ of the fitted tracks. If the difference between the two plots in Fig. 4.6 is not striking, it is hoped to be important on bigger data sets.

Figure 4.6: Plots of $\eta'$ mass without or with selection of the best candidates
4.3 Result and analysis

The previous section leads to the final plot in Fig 5.1.

Only 191 events on the 12850 generated remain after the selections and only 0.6% of the events formed the signal. At this point, MC Truth would be of great interest, because it can be suspected that a not small part of $\eta'$ have been rejected. Also, that would allow a better judging of the quality of the result.

![Figure 4.7: Fit of $\eta'$ mass](image)

<table>
<thead>
<tr>
<th>Parameters of Fig. 5.1 plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>entries</td>
</tr>
<tr>
<td>$S$</td>
</tr>
<tr>
<td>$B$</td>
</tr>
<tr>
<td>$\frac{S}{S_0}$</td>
</tr>
<tr>
<td>avg.</td>
</tr>
</tbody>
</table>

**Fit**: The fit of the plot is composed of two elements: The signal curve is described by a gaussian. And not a Breit-Wigner since the width of $\eta'$ resonance is largely inferior to the resolution. The background is considered to be an affine line.

The best fit is chosen with the optimization of the likelihood. The fit could be done by optimizing the $\chi^2$ but Root tends to give better results that way.
Extrapolation of minimum bias 
MC and real data results

This chapter details the attempts undertaken to find $\eta'$ in minimum bias and real data. The two sets are presented together as the study was conducted in parallel and led to similar conclusion.

5.1 Origin of the data

Minimum bias data

This set of data is also generated by Monte Carlo (MC2010). It attempts to generate the most realistic data. The set includes 1'593'438 entries for 352'457 events.

Real data

This data comes from the experiment conducted early 2010. The sample contains 16$^6$ events. This was performed under the conditions listed in Table 2.2.

5.2 Attempts to find $\eta'$

5.2.1 Transposition of signal events data results

In the first place, identical cuts are applied on the new sets of data.

No signal can be detected, the cuts are not sufficient.

5.2.2 Radicalization of the selection and additional cuts

The cuts on transverse momentum are increased. The cut on $p_{t,\eta'}$ is tried again. The results are reported in Fig. ??.

No $\eta'$ take shape, no matter how severe or loose the selection are.
### Figure 5.1: Identical selection of candidates and best vertex, and cuts from signal events analysis are applied to minimum bias data (top) and real data (bottom)

### Figure 5.2: An example of the more restrictive plots tried. This is on minimum bias data with $p_{t\eta'} > 3000$, $p_{t\rho} > 2500$ and $p_{t\gamma} > 2000$
5.2. ATTEMPTS TO FIND $\eta'$

5.2.3 Considered leads

**Calorimeters information**
Selection of $\gamma$ could be optimized via additional restrictions. Photons are detected by the calorimeters. But it is also the case for hadrons. And because they emit photons when they are slowed down, the selected photon could come from a hadron. To ensure that the detected photon is actually the fruit of an earlier desintegration, the photon must be alone and not associated with a cascade of photons. Information from the calorimeters allow this selection.

**Delta-Log-Likelihood($\pi$)** have not been used so far in this analysis. This variable is a measure of confidence that the particle is an actual pion. The mathematic concept behind it is similar to the "likelihood" fit exposed previously : the difference between probability that a particle is a pion and not a kaon for instance.

**Selection of best candidate**
The choice of the best candidate could be explored in more details. If the current choice seems very straightforward and logical, there might have other parameters to consider.

**Reconstruction of heavier particles**
As detailed in 3.1, $\eta'$ is found in many decay channel. When combining $\eta'$ with other particles, additional parameters can be added :

- Since $B$ (or $D$) daughter particles do not have long flight distance, $B$ (or $D$)vertex needs to be at the crossing of four or five tracks. This should exclude a consequent part of the background.

- Since $B$ (or $D$) have an important life-time, their flight distance is not negligible. This displaced vertex asks to reject most particles coming from the primary vertex, thereby deleting an important part of the background.
In conclusion, as expected when looking at the branching fraction, finding $\eta'$ did not reveal to be easy. The failure to detect the particle is lessened by the wide panorama of prospective work that is ahead.

As previously mentioned, the recombination with other light meson sounds promising and not devoided of interest. After exploring the different leads for further deepening of the knowledge of $\eta'$, the next important step is the reconstruction of $D$ meson and study the different branching fractions, for two reasons: firstly because data are missing in this area, and secondly because of the possibility to reconstruct $B$ particles.

To conclude this report, I would say that pedagogic objectives are fulfilled and if breathing an interest for particle physics to student can be qualified as a goal, it is definitively achieved.