A search for $\tau \to \mu\gamma$ at the LHCb detector

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1 Introduction

The lepton flavour violating decay $\tau \to \mu\gamma$ features in many New Physics models. This has motivated many experimental searches. However, it is generally believed that it is impossible to perform a search for this decay at the LHCb experiment. One challenge is reconstructing the position at which the τ lepton decayed, as the photon is only observed in the calorimeter, which lacks the spatial resolution required for a precise measurement of the vertex. However, it is possible to reconstruct photons which interact with the material of the upgraded VELO and convert into an electron-positron pair. The only problem with this electron-positron pair is that they are created on top of each other. This means that we can often find only one track coming from a converted photon and not two tracks. This makes it difficult to distinguish tracks coming from converted photons and tracks that come from a single electron.

This report describes the possibility for finding tracks from converted photons and distinguish those tracks from other tracks.

2 Method

To find a method to differentiate the tracks from converted photons and tracks coming from other particles, Monte Carlo simulations were used. Since we want to find parameters that distinguish between the tracks of the different particles, we used a particle gun to create events that only contain one type of a particle. With the particle gun, we created events that contain only photons and events that include only electrons.

Once the particles are created and the detector and the interactions of the particles with the material in the detector are simulated, we use Boole for the readout of the detector. This gives as output data that looks the same as the data coming from the real detector.

Now we have the data we can make a reconstruction. This reconstruction is done by using Brunel. Brunel reconstructs the clusters in the active material of the VELO, and from the clusters tracks are reconstructed.

2.1 'Real' events

For the search for good parameters, it is good to have clean events that only contain one type of particles and that have only two particles per event. At the same time, those events will never happen in the detector during collisions. Consequently, we have to test the discovered parameters in more realistic events. That is, in events that looks more like the events produced during *pp* collisions at the LHC. Therefore, when we found some parameters that could distinguish between the different tracks, we simulated more realistic events and tested the same limits on those events.

3 Results

Since only charged particles can be detected in the VELO, the photons must convert before we can find a track. If a photon converts into an electron-positron pair, it is possible to find the endvertices of those photons in the Monte Carlo simulation. Figure 1 shows the endpoints of those photons in the xy and xz plane.

Figure 1a shows the endvertices in the xy plane where all the points in the z direction are projected on the xy plane. In figure 1a it is possible to recognize a pattern, this is the RF foil.

Figure 1b shows the endpoints in the xz plane, and now all the points in the y direction projected on the xz plane. In this figure it is again possible to recognize a shape. First of all, we can see the positions of the modules of the VELO along the z direction of the detector. Secondly, it is possible to identify the RF foil again, which is located at -10 and 10 along the x axis. Finally, we can detect the beam line of the LHC, which does not contain any material and therefore no photons will convert there.

Combining both pictures we can conclude that most of the photons will convert in the RF foil.

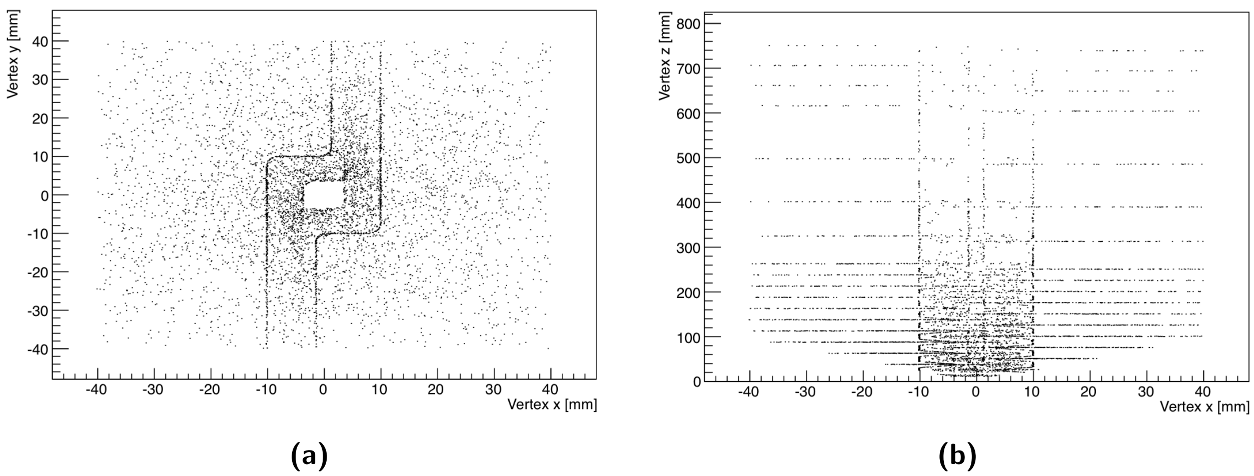
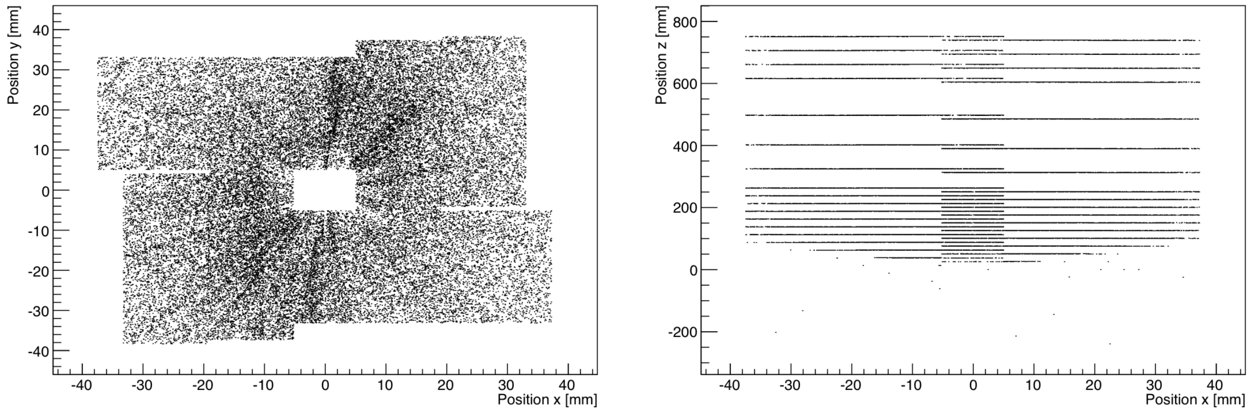


Figure 1 – The endpoints for the photons are plotted in the xy plane (a) and in the xz plane (b). An endpoint of the photon is defined as the point where a photon converts in an electron-positron pair.

After a photon has been converted, we are left with charged particles that can be detected in the VELO. If a charged particle flies through the active parts of the VELO it leaves a signal in some of the pixels. Those pixels are combined in clusters of pixels and it is possible to reconstruct the position of the clusters. Figure 2 shows the position of the clusters in the xy plane, figure 2a, and in the xz plane, figure 2b. In figure 2a we see the active parts of a VELO module, and in 2b we see again the position of the VELO modules along the beam pipe. The clusters that are located with a negative value for the z position, are clusters on the modules that are located before the interaction point.

Although the electron and positron are produced on top of each other, they will split up in the end, due to multiple scattering. Thus, if we find a track coming from a converted photon, it will have clusters nearby the track. It is possible to calculate the distance from those clusters to the track. To find clusters near a track, we look for the clusters in the track and define clusters nearby as clusters that have the same z position as the cluster in the track, but a different x and y position.

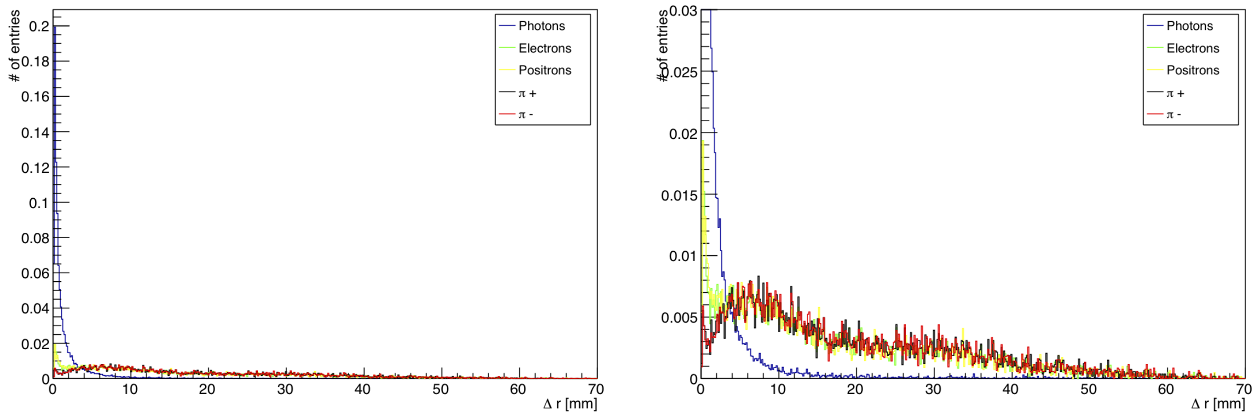
Figure 3 shows the distribution of the distance between clusters in and near a track. It is clear that there is a difference between the converted photons and other particles. For converted



(a) (b)

Figure 2 – The cluster position for the converted photons are plotted in the xy plane (a) and in the xz plane (b). A cluster is a set of pixels that gave a signal in the silicon sensors.

photons almost all of the clusters near a cluster a located within 2 mm of the track, while for the other particles this distribution is much more spread. Therefore, we can make a selection on track from converted photons by setting a limit on Δr.



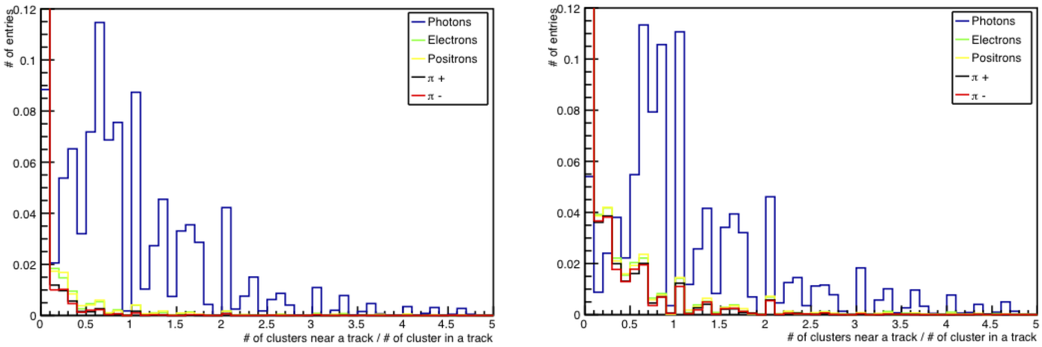
(a) (b)

Figure 3 – The distribution of the distance between a track and a cluster nearby for different types of particles. (a) shows the whole distribution, while (b) is a zoom of (a) to be able to see the distribution for electrons, positrons and pions better. Δr is defined as $\sqrt{(\Delta x)^2 + (\Delta y)^2}$, where Δx and Δy are the differences in the x and y coordinates between the clusters in a track and near a track.

To see which limit on Δr is the best one, we define a new parameter, the relative number of nearby clusters. This number is defined by the number of clusters within a certain Δr of a track divided by the number of all the clusters in that track.

Figure 4 shows the distribution of the relative number of nearby clusters for different limits on Δr. It is possible to select photon tracks by setting a limit on this ratio, especially when the limit on Δr is small. For small Δr it is possible to keep almost all of your converted photon tracks, while excluding all the tracks coming from other particles.

For these clean events it is possible to have an efficiency of 91% for finding tracks from converted photons, while you are left with a fake rate of 7%. Those numbers can be found by setting limits on Δr and the relative number of clusters. We require that $\Delta r < 2$ mm and the relative number of clusters must be at least 0.1



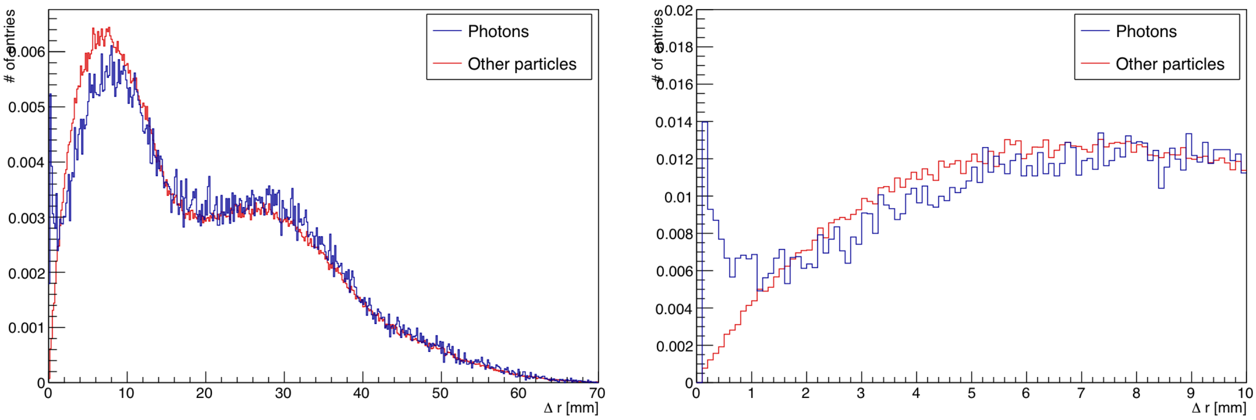
(a) Limit: $\Delta r < 2$ mm

(b) Limit: $\Delta r < 10$ mm

Figure 4 – The distribution for the relative number of clusters near a track (a) shows the distribution when we require $\Delta r < 2$ mm and (b) shows the distribution when $\Delta r < 10$ mm. The relative number of clusters near a track is defined as: number of clusters near a track / number of clusters in a track.

3.1 Real events

Now it is possible to test the limits in more realistic events. First, the Δr distribution is plotted again. Figure 5a shows this distribution. It is clear that this distribution is for real events less clean. However, we can still see a peak for photons at low distances between the clusters and the tracks. Figure 5b shows a zoom of figure 5a, and the peak at low Δr can be seen here. For photons a large number of clusters is located at a distance of less than 1 mm from the track. Although the difference between the distributions of photons and the other particles is less obvious, photons still have more clusters within a distance of 1 mm.

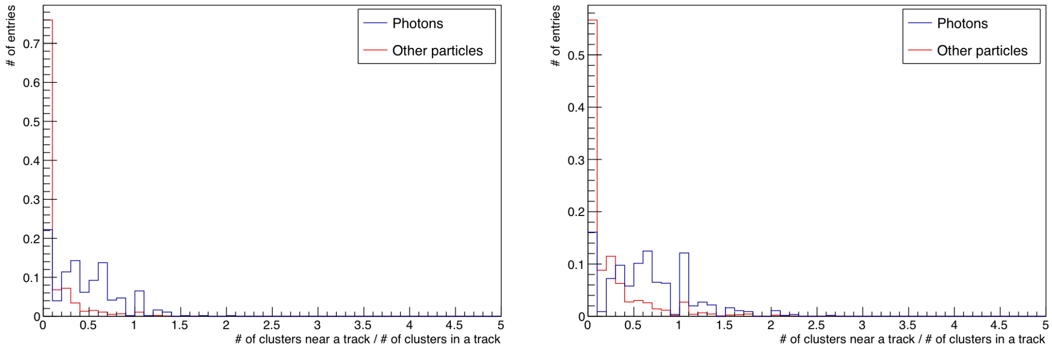


(a)

(b)

Figure 5 – The distribution of the distance between a track and a cluster nearby for real events. (a) shows the whole distribution, while (b) is a zoom of (a) to be able to see the peak for photons at low Δr better.

Since the distribution for the real events is different, the definition for nearby clusters was changed. To get to a better limit on Δr, the relative number of clusters near a track was calculated for $\Delta r < 0.5$ mm, $\Delta r < 0.65$ mm, $\Delta r < 0.75$ mm, and $\Delta r < 1$ mm. Figure 6 shows the results for $\Delta r < 0.65$ mm and $\Delta r < 1$ mm. It is still possible to select on this number, however it is less precise. It is not possible anymore to remove almost all the background tracks, while keeping all photon tracks. Table 1 shows the efficiency and fake rate for different limits on Δr. The limit on the relative number of clusters near a track is 0.1. The limit $\Delta r < 1$ mm, that worked for the clean events, has a high fake rate in the real events. Therefore, it would be better to reduce the limit on the distance to 0.65 mm, in order to reduce the fake rate. In that case the fake rate reduces a lot, while the efficiency is effected less.



(a) Limit: $\Delta r < 0.65$ mm

(b) Limit: $\Delta r < 1$ mm

Figure 6 – The distribution for the relative number of clusters near a track. (a) shows the distribution when we require that $\Delta r < 0.65$ mm and (b) shows the distribution when $\Delta r < 1$ mm.

Cluster near if:	Efficiency	Fake rate
$\Delta r < 0.5$ mm	0.73	0.16
$\Delta r < 0.65$ mm	0.78	0.23
$\Delta r < 0.75$ mm	0.79	0.28
$\Delta r < 1$ mm	0.84	0.42

Table 1 – The efficiency and fake rate for different limits on Δr. The limit on the relative number of clusters near a track is 0.1.

4 Conclusion

To search for the lepton flavour violating decay $\tau \rightarrow \mu\gamma$ at the LHCb experiment, it is needed to find a track for photons coming from this decay. Since photons are chargeless, they are only detected in the EM calorimeter. However, if photons produce an electron-positron pair in the material of the VELO, they will leave a track in the VELO. To distinguish between those tracks and the tracks coming from other particles, several parameters were investigated using simulation. For simulated events created with a particle gun it is possible to reconstruct the photon tracks with an efficiency of 91% and a fake rate of 7%. In that case we require that $\Delta r < 2$ mm and the relative number of clusters must be at least 0.1.

For more realistic events it turned out that with the limits that worked for the clean events, it is not possible to distinguish between tracks from converted photons and tracks from other particles. However, there is still a difference in the number of clusters near a track for photons and other particles. If the limit on Δr is set to be less than 0.65 mm and the relative number of clusters must be greater than 0.1, it is still possible to find converted photons. The efficiency becomes 78% and the fake rate is 23%. It might be possible to reduce this fake rate by using additional information from the other subdetectors of the LHCb detector.

Although it is possible to find converted photons, it will become hard to detect $\tau \rightarrow \mu\gamma$ at the LHCb detector, since only 8.5% of the photons convert inside the material of the VELO upgrade.