Photons from Isolated Neutral Mesons in Hadronic Events in L3

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Abstract

We present a study of the production of energetic, isolated neutral mesons decaying into photons. The analysis is based on ~90,000 \( Z^0 \) hadronic decays collected with the L3 detector at \( \sqrt{s} \approx 91.2 \) GeV. We find the rate of isolated \( \pi^0 \)'s and \( \eta \)'s to be underestimated by the JETSET 7.2; fonte-Carlo generator.

1 Introduction

For this study we make use of the high performances of the L3 BGO calorimeter [1], namely its excellent energy resolution (\( \sigma(E)/E < 1.5\% \) for \( E > 2 \) GeV) and its good spatial resolution (\( \sigma(\theta) \approx 0.5^\circ \) for \( E > 1 \) GeV).

Our aim is to understand the behaviour of the background to final state photon radiation (FSR) arising from neutral mesons. Indeed an analysis of FSR [2] gives us various indications that the background predicted by JETSET [3] is underestimated.

2 Overview of the Prompt Photon Selection

To select \( q\bar{q} \gamma \) events we start from a sample of hadronic \( Z^0 \) decays collected at \( 91.0 < \sqrt{s} \ (GeV) < 91.4 \). An event is required to have at least one electromagnetic cluster with the following characteristics:

- The cluster should be well contained inside the electromagnetic calorimeter barrel.
- The transverse energy distribution of the cluster should be compatible with an electromagnetic particle.
- The cluster should not be associated with any charged track in the central tracking chamber (TEC).
- The energy of the cluster should be greater than 10 GeV.
- The cluster should be isolated: two alternative criteria are used.

In one case, "Local Isolation", we define a cone of half aperture 20° around the cluster direction. Inside this cone we ask to have no other electromagnetic cluster of more than 200 MeV and to have less than 2 GeV deposited in the hadronic calorimeter.

In the other case, "Jet Isolation", we reconstruct jets in the event excluding the photon candidate. The angle between the candidate and the closest jet should then be greater than 20°.

The first criterion is more drastic and results in a larger background rejection. However it is sensitive to fragmentation through fluctuations in the particle flow far from jet cores.

The distribution of the transverse energy with respect to the thrust axis is shown in figure 1 for locally isolated clusters. The spectrum obtained with the data is compared to the JETSET prediction (normalised to the number of hadronic events at \( \sqrt{s} = M_{Z^0} \)). We observe an excess of events in the data in the low part of the spectrum (\( E_t < 8 \) GeV) where the background - mainly \( \pi^0 \)'s (70%) - is concentrated.

Moreover, when we analyse the energy profile of the cluster candidates in order to reject part of the background, we find the rejection to be larger in the data by a factor 1.50 ± 0.38.
3 Production of Isolated Neutral Hadrons Decaying into Photons

As pointed out in the previous section, JETSET seems to underestimate the production of isolated neutral mesons in the kinematic region of prompt photons. To clarify this point we try to identify such hadrons by selecting isolated pairs of photons and reconstructing their invariant mass. As very energetic $\pi^0$'s rarely decay into two photons resolvable by the calorimeter and the overall statistics is small, the cuts have to be released. We then select pairs of electromagnetic clusters satisfying the following conditions:

- Each electromagnetic cluster should have an energy greater than 500 MeV.
- The sum of the energies of the two clusters should be greater than 5 GeV.
- Each cluster should be neutral (no track associated).
- There should be less than 3 GeV deposited in the hadronic calorimeter inside a cone of half aperture 15° around the direction of each cluster.
- The reconstructed particle should be isolated. The isolation criteria are defined as above but the isolation angle (cone half aperture or angle to closest jet) is smaller: 15°.

This selection is applied on the same sample of hadronic events on the $Z^0$ peak as for the FSR analysis. We then compute the invariant mass of the two electromagnetic clusters. Figure 1 shows the invariant mass distributions obtained under the local isolation condition with the data and with events simulated with JETSET. The JETSET distribution is normalized to the number of hadronic events on the $Z^0$ peak. We observe more isolated $\pi^0$'s and $\eta$'s in the data than in JETSET:

$$R_{\pi} \left( \frac{Data}{MC} \right) = 2.0 \pm 0.3$$

$$R_{\eta} \left( \frac{Data}{MC} \right) = 2.7 \pm 0.8$$
Figure 2: Invariant mass distribution of locally isolated cluster pairs

As already pointed out, the local isolation criterion is very sensitive to fragmentation: If a jet fragment enters the isolation cone around the $\pi^0$ candidate, the isolation criterion is not satisfied and the candidate is rejected. The first hypothesis to explain the observed discrepancy is that the particle flow far from jet cores is not correctly reproduced by the Monte-Carlo. Indeed an excess of soft outer fragments in the simulation would lead to a loss of hadrons passing the isolation condition.

In order to check this hypothesis we use the jet isolation criterion which is less sensitive to such a fragmentation effect. The invariant mass distributions of pairs of clusters isolated with respect to jets are shown in figure 3 both for data and JETSET. An excess of $\pi^0$'s and $\eta$'s is again observed in the data. The excess is as significant as in the local isolation case but the ratios are smaller: $R_\pi = 1.23 \pm 0.09$ and $R_\eta = 1.7 \pm 0.4$.

Figure 3: Invariant mass distribution of jet isolated cluster pairs
Figure 4 shows the evolution of $R_\pi$ with the minimum angle to the closest jet. $R_\pi$ remains roughly constant over a range of angles from 15° to 45°. However, we expect $R_\pi$ to get closer to one at smaller angles since the total rate of $\pi^0$'s - isolated or not - is correctly reproduced by JETSET [4]. The value of $R_\pi$ in the case of jet isolation is smaller than in the case of local isolation: part of the loss of isolated $\pi^0$'s in the simulation is recovered - as expected in the case of a fragmentation effect such as described above. Nevertheless, the fragmentation effect cannot totally account for the discrepancy, since even for jet isolation $R_\pi$ still significantly departs from unity. We therefore conclude that there is a fragmentation effect, on top of an underestimate of the rate of isolated mesons in JETSET.

![Graph showing $\alpha$ vs. Minimum Angle to Closest Jet (Deg)](image)

**Figure 4: Evolution of $R_\pi$ with the minimum angle to closest jet**

## 4 Plans for the Future

One of the crucial points in the FSR analysis is background subtraction. Our study enables us to check the JETSET prediction and to confirm that the background from neutral hadrons is not properly described. The subtraction has to rely on the data, trusting Monte-Carlo only as far as the shape of the background is concerned. We obtain ratios between data and Monte-Carlo which cross-check the scaling factor - derived from cluster shape analyses - to be applied to the predicted background.

It would be most interesting to reconstruct neutral mesons in a kinematic region closer to that of the prompt photons. To illustrate the current situation, figure 5 shows the energy distribution of the locally isolated, identified $\pi^0$'s in the data. All $\pi^0$'s have energies below 10 GeV - the minimum energy required to select prompt photons. With higher statistics we hope to reconstruct slightly more energetic $\pi^0$'s, actually the small fraction of them that decay into two photons asymmetric enough to be resolved by the calorimeter.

We wish to complete this study with

- a comparison with other Monte-Carlo generators; a first look at HERWIG seems to indicate that the rate of isolated $\pi^0$'s is also underestimated.

- an analysis of the charged pion behaviour which on the basis of isospin invariance should be similar to that of $\pi^0$'s. The result are still too preliminary to be discussed here.
Figure 5: Energy distribution of locally isolated, identified $\pi^0$'s

In another approach [6] we deal with $\pi^0$'s that decay into two unresolvable photons, thus resulting in one cluster in the calorimeter. If the profile of the cluster is asymmetric, the contributions of the two photons are disentangled in order to compute their invariant mass. The method is being developed with simulated, isolated photons and $\pi^0$'s. The invariant mass distributions thus obtained are shown on figure 6. The method could be used to distinguish $\pi^0$'s from single photons. The current results are encouraging, but tests have been performed only on simulated particles and not yet in the kinematic region of interest to us.

Figure 6: Invariant mass distributions for single photons and single $\pi^0$'s
5 Conclusion

We have studied the production of energetic, isolated neutral mesons which provide the main background to final state radiation. We find the JETSET prediction to disagree with the data, thus confirming results obtained from cluster shape analyses in the real phase space region of prompt photons. The discrepancy amounts to ~ 3 (~ 2) standard deviations in the case of $\pi^0$'s ($\eta$'s). The ratios between data and Monte-Carlo are summarized in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Local Isolation</th>
<th>Jet Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0$</td>
<td>2.0 ± 0.3</td>
<td>1.23 ± 0.09</td>
</tr>
<tr>
<td>$\eta$</td>
<td>2.7 ± 0.8</td>
<td>1.7 ± 0.4</td>
</tr>
</tbody>
</table>

We distinguish two reasons for this disagreement:

- The rate of energetic and isolated $\pi^0$'s and $\eta$'s is underestimated in JETSET.
- Details of the fragmentation, namely particle flows far from jet cores, are not correctly reproduced by JETSET, enhancing the discrepancy in the case of local isolation.

The failing of the Monte-Carlo to describe correctly the main background to PSR makes it necessary to rely on the data to proceed to the subtraction, thus introducing an important systematic error.

References