Introduction: The Aims of the Workshop

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This workshop is organized on the initiative of physicists involved in the four LEP experiments. Its purpose is to gather experimentalists and theorists to discuss all aspects of photon production in hadronic $Z^0$ decays.

The main topics to be discussed include:

- QCD tests;
- Electroweak tests;
- Searches for New Physics/New Phenomena and Rare Decays.

Some $4.5 \times 10^5 Z^0$ — hadrons events have already been collected by each LEP experiment, of which typically one third has been presently analyzed. One can hope that some $2 \times 10^6 Z^0$ — hadrons will be collected in the next two years. It is therefore an appropriate time to review the latest experimental results as well as the future prospects, and to learn about the recent evolution of theoretical ideas on the subject.

The idea of studying gamma hadrons final states in $e^+ e^-$ collisions is not new. It was first proposed as a test of the quark-parton model[1][2], and then as a test of QCD and jet fragmentation[3][4]. What is new at LEP energies is the use of the $Z^0$ as a quasi democratic source of the five known quarks.

The different processes contributing to the reaction $e^+ e^- \rightarrow \text{hadrons} + \gamma$ are illustrated in figure 1:

- a) Initial State Radiation:
  Figure 2, extracted from ref[4], shows that this contribution relative to the off quark radiation, and the interference term between radiation off quarks and radiation off leptons are minimal at or just above the $Z^0$ pole.

- b) Radiation from Primary Quark (or Antiquark):
  This is mainly emitted at large angle and with high energy. These photons can, in principle, bring information on the "femto- universe" of QCD. They could be used to perform a measurement of the weak coupling of quarks of different charge.(see later)

- c) and d) Radiation from Secondary Partons:
  This is emitted at intermediate angle and moderate energy. This radiation is related to the space-time development of jet formation and fragmentation.

- e) and f) Radiation from Hadronization Products:
  Example are $\pi^+, \pi^-$ and decay products such as $\pi^0, \eta^0$. These photons are emitted at relatively small angles and with limited momentum transfer.
Each process is a background for the study of one of the others. The possibility to disentangle them experimentally and to reproduce the data with the models will be an important matter for discussion at this workshop.

In addition, since the radiation off quarks is proportional to the square of the charge of the primary quark, it has been noticed [5] that the \( Z^0 \) — hadrons width, \( \Gamma_{\text{had}} \), and the \( Z^0 \) — hadrons + gamma width, \( \Gamma_{\bar{q}q\gamma} \), can be written as:

\[
\Gamma_{\text{had}} \propto (1 + \frac{\alpha_s}{\pi})(3Cd + 2Cu)
\]

\[
\Gamma_{\bar{q}q\gamma} \propto \alpha_{\text{em}}(3Cd + 8Cu)
\]

where \( C_f = v_f^2 + a_f^2 \) (\( f = u \) for quark with charge \( +\frac{2}{3} \)) (\( f = d \) for quark with charge \( -\frac{1}{3} \)).

The authors of ref [5] claim that, if QCD corrections are understood and the fragmentation and the hadronization are under control, this method could allow the determination of \( Cu \) and \( Cd \), the weak couplings of up and down quarks to the \( Z^0 \). This, definitively, will also be a major topic of discussion at this workshop.

The reaction \( Z^0 \) — hadrons + gamma can also be used to search for new particles and new physics, such as:

- a) Higgs: Neutral Higgs, in the Standard Model or in the Minimal Super Symmetric Model, are expected [6] to be produced with a rather small branching ratio \( \text{Br} (Z^0 \rightarrow H\gamma) \approx 1 - 10 \times 10^{-7} \). Nevertheless, this production would be a dominant one in \( Z^0 \) decays for Higgs with a mass larger than 60 GeV or so. In Composite Models, this branching ratio could be increased by a factor 2 to 1000, depending on the value of \( \Lambda \) compositeness. [7]

- b) Technicolour: Technicoloured Pseudogoldstone Bosons could also manifest themselves as an increased rate [8] in the "Higgs Search" previously mentioned.

- c) Triple Gauge Boson decays: The \( Z^0 \) — \( gg\gamma \) decays are also expected to occur with a typical branching ratio \( \sim 8 \times 10^{-7} \). An excess of this production could also be a manifestation of Compositeness[9].

- d) Excited quarks: They could be singly or pair produced in the reactions \( Z^0 \rightarrow q^*\bar{q} \) or \( Z^0 \rightarrow q^*\bar{q}^* \) with subsequent decays \( q^* \rightarrow q, \bar{q} + \gamma \)

It is then an important task of this Workshop to update the decay rate estimates for these processes and to investigate if they could be disentangled from the \( Z^0 \) — \( q\bar{q}\gamma \) "background".

Finally, high statistics \( Z^0 \) production is a source of a large number of selected \( q\bar{q} \) pairs, and especially of \( b\bar{b} \) pairs. Rare decays of \( b \) quarks such as: \( b \rightarrow s\gamma (g), d\gamma (g) \) will be looked at. These flavour changing neutral current decays, forbidden at tree level, could only occur through loops. Taking into account the important QCD corrections, typical decay rates are predicted to be: [10]

\[
B_{d,s} = X_{d,s}\gamma = 3 - 4 \times 10^{-4} \\
K^*-\gamma = 3 - 8 \times 10^{-5} \\
X_{d,s}\gamma = 2 - 4 \times 10^{-5}
\]

Again, an increased rate would be the manifestation of new physics, such as, Supersymmetry. One of the aims of this workshop is to discuss these rates, possibly to include new ones such as
$B_s \rightarrow \phi \gamma$, and also to consider the prospects for the detection of these decays.

For all these studies and in order to make comparisons between experimental results and model predictions, it is fundamental to understand under which conditions the results have been obtained and what are the theoretical limitations due to the various assumptions.

One then expects that at this meeting detailed discussions will take place on:

- **a) Experimental problems such as:**
  - Detector performance: acceptance, granularity, energy resolution ...;
  - Photon selection criteria: "particle isolation", "jet isolation"...
  - $\pi^0/\gamma$ or $\eta/\gamma$ separation;
  - Background estimates from the data...

- **b) Theoretical problems such as:**
  - Transition from analytic formulae to Monte Carlo simulations;
  - Precision of approximations, i.e. Leading-Log or Next-to-Leading-Log;
  - Influence of fragmentation/hadronization processes and of the number of parameters;
  - Implementation of experimental cuts and singularity regions.

In conclusion, this workshop is an opportunity to review in depth:

- The latest results on the channel $Z^0 \rightarrow \text{hadrons} + \gamma$ obtained by the four experiments;
- The latest ideas and computations proposed by theorists.

It is also a unique opportunity to enhance the interaction between theorists and experimentalists. Let's hope that this continues after the workshop.

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References


