Jet and hadron production in e^+e^- annihilations

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The DELPHI detector at LEP is particularly suited for hadron identification and for the identification of b-initiated jets. This note presents recent results based on such characteristics.

1. INTRODUCTION

This note covers three topics in the study of identified hadrons and jet production, coming from recent analyses by the DELPHI experiment at LEP. A description of DELPHI can be found in [1]; its performance is discussed in [2].

The selection of $q\bar{q}$ events at the Z peak (LEP 1) is easy: being the production of hadronic final states enhanced by three orders of magnitude over the continuum, simple cuts against lepton-antilepton and two-photon events allow easily the definition of samples with contaminations at the per mil level.

The situation is different at LEP 2 (above the Z). The hadronic cross-section is at the present energies of the order of 100 pb, and it is dominated by the radiative return to the Z peak. The cross-section corresponding to effective c.m. energies above $0.85\sqrt{s}$ is presently of the order of 20 pb, with a sizeable contamination from WW events; thus, even with large luminosities, we are left with a few hundreds of events per energy point (Table 1). As a consequence, the cuts against contaminations cannot be too severe (reaching purities of about 0.8, with efficiencies of about 0.8).

Table 1

$\sqrt{s}$ (GeV)	Lumi/exp. (pb^{-1})	Events with $\sqrt{s'} > 0.85\sqrt{s}$
133	12	900
161	10	350
172	10	290
183	55	1,300
189	175	3,800

The system of hadron identification of DELPHI [2] covers the momentum region between 100 MeV/c and 30 GeV/c, by the superposition of the separations given by: the dE/dX mainly in the region below 1 GeV/c; the liquid radiator of the Ring Imaging CHerenkov Radiator (RICH) between 1 and 5 GeV/c; the gaseous radiator of the RICH at high momenta. K^0_s (Λ) are reconstructed by invariant mass distributions for opposite-sign particles coming from a secondary vertex, with typical efficiency and purity of 30% (25%) and 95% (90%) respectively.

The influence of the detector on the analysis is studied with the full DELPHI simulation program, DELSIM [2]. The efficiency of identification of charged hadrons is computed directly from the data, using samples of $\pi^\pm$ and protons coming from the decay of K^0_s and Λ.

2. IDENTIFIED HADRONS IN HIGH ENERGY $q\bar{q}$ EVENTS

The way quarks and gluons transform into hadrons is not entirely understood by present theories; the most satisfactory description is given by Monte Carlo simulations. A different, analytical, approach (see e.g. [3], [4] and references therein) are QCD calculations using the so-called Modified Leading Logarithmic Approximation (MLLA) under the assumption of Local Parton Hadron Duality (LPHD) [3]. In this picture the particle yield is described by a parton cascade, and the virtuality cut-off Q_0 is lowered to values of the order of 100 MeV, comparable to the hadron masses; it is assumed that the results obtained for partons apply to hadrons as well.

The momentum spectra of particles produced

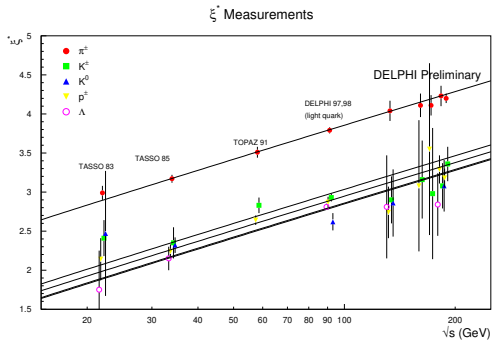

Figure 1. Measurements of ξ^* for different identified hadrons.

can be calculated as a function of the variable ξ_p, where $\xi_p = -\log(\frac{2p}{\sqrt{s}})$ (p is the momentum of the particle), and it depends on three parameters: an effective scale parameter Λ_{eff}, a momentum cut-off Q_0 in the evolution of the parton cascade and an overall normalization factor k. The function has the form of a "humped-backed plateau", approximately Gaussian in ξ_p [3].

To check the validity of the MLLA+LPHD approach, it is interesting to study the evolution with the centre of mass energy of the maximum, ξ^*, of the ξ_p distribution. In the framework of the MLLA+LPHD the dependence of ξ^* on the centre of mass energy can be expressed as:

$$\xi^* \simeq a + b \ln \sqrt{s} \qquad (1)$$

where the slope b depends just on the effective Λ and not on Q_0: one can thus assume that b is independent of the mass of the particle produced.

In Fig. 1 the evolution of ξ^* with the centre of mass energy is presented for identified hadrons [5]. The data up to centre of mass energies of 91 GeV were taken from previous measurements [6]. The fit to expression (1) is superimposed to the data points (solid line). Within the statistics of the data samples analysed, the fitted functions follow the data points rather well.

The average multiplicity of the identified hadrons was obtained from the integration of the ξ_p distributions inside a range varying according to the particle type and energy; outside this range the fraction of particles was extrapolated using the JETSET 7.4 [7] prediction. The predictions

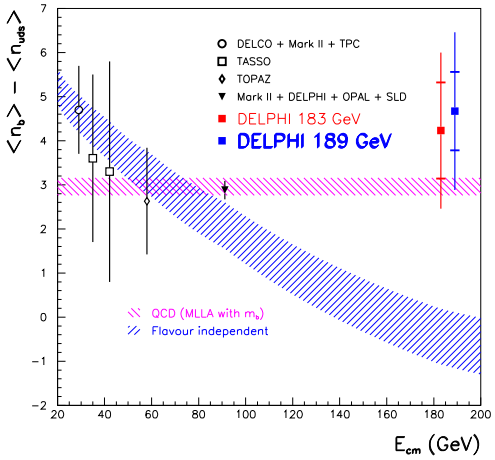

Figure 2. The present measurement of δ_{bl} compared to previous measurements as a function of the centre-of-mass energy, to the QCD prediction, and to the prediction from flavour-independent fragmentation.

from JETSET and HERWIG [8], tuned at the Z, are consistent with the observation.

3. CHARGED PARTICLE MULTIPLICITY IN $b\bar{b}$ EVENTS

QCD predicts that the difference in charge multiplicity between light quark and heavy quark initiated events in e^+e^- annihilations is energy independent; this is motivated by mass effects on the hadronization (see [4] for a review). In a model in which the hadronization is independent of the mass, this difference [9] decreases with the c.m. energy, eventually becoming negative at LEP 2 energies.

Experimental tests at LEP 1 energies and below were not conclusive. At LEP 2, the difference between the QCD prediction and the model ignoring mass effects is large, and the experimental measurement can firmly distinguish between the two hypotheses.

Data collected by DELPHI at centre-of-mass energies around 183 GeV and 189 GeV were analysed [10]. 90% b-enriched samples have then been

obtained by tagging on the present of tracks with nonzero impact w.r.t. the primary vertex [2]. From such samples the average $b\bar{b}$ multiplicity has been measured by unfolding via simulation for detector effects, selection criteria and initial state radiation. The difference δ_{bl} between the $b\bar{b}$ multiplicity and the multiplicity in generic light quark $l = u, d, s$ events was measured:

$$\delta_{bl}(183\,\mathrm{GeV}) = 4.23 \pm 1.09(stat) \pm 1.40(syst);$$
$$\delta_{bl}(189\,\mathrm{GeV}) = 4.69 \pm 0.89(stat) \pm 1.55(syst).$$

The result (Fig. 2) is fully consistent with the hypothesis of energy independence, and larger than predicted by mass-independent fragmentation. The systematic error will be further reduced by directly measuring the $c\bar{c}$ multiplicity.

4. IDENTIFIED HADRONS IN QUARK AND GLUON JETS

Jets originated from quarks and gluon are expected to show differences in their particle multiplicity, energy spectrum and angular distributions, due to the different colour charges carried. The LEP detectors can select gluon jets in $b\bar{b}g$ events by tagging the b quarks.

2.2 MZ collected by DELPHI are considered in the analysis [11]. 3-jet events are clustered using Durham with $y_{cut} = 0.015$, optimizing the performance and still allowing a reliable comparison with perturbative QCD.

For a detailed comparison with minimum bias, it is necessary to obtain samples of quark and gluon jets with similar kinematics. To fulfill this condition, two different 3-jet event topologies have been used: *Y events* (mirror symmetric), and *Mercedes events* (three-fold symmetric).

The number of Mercedes and Y 3-jet events was equal to 11,685 and 110,628 respectively. After anti-tagging of heavy quark jets, gluon jet purities of $\sim 82\%$ for Y events and Mercedes events were achieved. There are 24,449 Y events and 1,806 Mercedes with identified gluon jets.

Three different jet classes, namely normal mixture jets, b tagged jets and gluon tagged jets, with different compositions in terms of quark and gluon jets, were selected. From the comparison of these, the content in terms of protons, $K^{\pm}$, K^{*0} and ϕ was calculated as a function of the momentum of the hadron for quark and gluon jets.

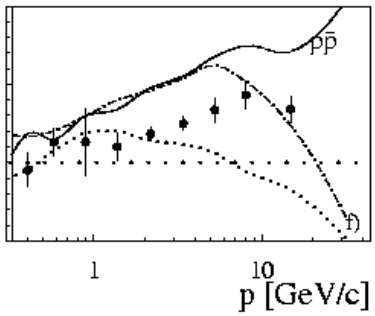

Figure 3. Ratio of protons in gluon jets to quark jets, normalized to the ratio of all charged particles, as a function of momentum.

As for inclusive charged particles, the production spectrum of identified hadrons is softer in g jets compared to q jets, and the multiplicity is larger. The ratio of the average multiplicity in g jets over q jets is consistent with the ratio for charged particles, but for protons, where:

$$\frac{\langle n_p \rangle^{(g)} / \langle n_p \rangle^{(q)}}{\langle n_{ch.} \rangle^{(g)} / \langle n_{ch.} \rangle^{(q)}} = 1.205 \pm 0.041\,.$$

HERWIG underestimates both the K and the p production in g jets; JETSET and ARIADNE overestimate the proton production in g jets.

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