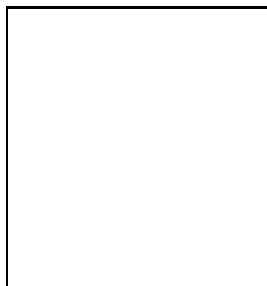# INCLUSIVE PARTICLE PRODUCTION AT LEP

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New results on inclusive production of Σ^- and $\Lambda(1520)$ and on proton production in quark and gluon jets are presented. These results are based on 2 million hadronic Z decays collected with the DELPHI detector at LEP. They are compared with the results of other LEP experiments and with models. It has been shown that the total production rates of all light-flavour hadrons measured so far at LEP 1 follow phenomenological laws related to the spin, isospin, strangeness and mass of the particles. A significant proton enhancement in gluon jets is observed, indicating that baryon production proceeds directly from colour objects.

1 Introduction

At LEP it has been shown that a large fraction of the mesons without orbital angular momentum (L=0) stem from decays of scalar and tensor mesons ($L\neq0$). For baryons this is not yet proven, as $L\neq0$ baryons typically have a large decay width and complicated decay modes. Hence these states are difficult to access experimentally in a multihadronic environment. In any case, it is still a question of basic importance as to how far baryon production leads to excited baryonic states. So far the only $L\neq0$ baryon measured in e^+e^- annihilation is the $\Lambda(1520)$ [1,2,3].

The different colour charge of quarks and gluons leads to specific differences in the particle production properties of the corresponding jets. Beyond the study of these differences [4], which are related to the perturbative properties of QCD fields, the comparison of quark and gluon jets [5] opens up the possibility to infer properties of the non-perturbative formation of hadrons.

2 Results and Discussion

The DELPHI analysis of the inclusive production of Σ^- and $\Lambda(1520)$ and of the proton production in quark and gluon jets, using 2 million hadronic Z decays recorded at LEP during 1994–95, has recently been published [3,5].

The Σ^- is directly reconstructed as a charged track in the DELPHI microvertex detector and is identified by its $\Sigma^- \to n\pi^-$ decay leading to a kink between the Σ^- and π^- tracks. For reconstruction of the $\Lambda(1520)$ resonance in the pK$^-$ mass spectrum, tight selection criteria were required to achieve the highest possible purities of particle identification using the DELPHI barrel Ring Imaging Cherenkov detectors and the ionisation loss measurement of the Time Projection Chamber. The production rates per hadronic Z decay including charge conjugated states are measured to be:

$$\langle \Sigma^- \rangle = 0.081 \pm 0.002 \pm 0.010 \qquad \text{and} \qquad \langle \Lambda(1520) \rangle = 0.029 \pm 0.005 \pm 0.005.$$

The differential distributions have been measured for both particles. In Ref.[3] they are compared to the OPAL results[6,2] and to predictions of tuned[3] Jetset 7.4 and Herwig 5.9 models. $\Lambda(1520)$ production has been implemented in these models either by replacing the $\Sigma^{*0}(1385)$ by the $\Lambda(1520)$ in the case of Jetset, or by adding the $\Lambda(1520)$ to the particle list in the case of Herwig. The model predictions have been renormalised to the observed $\Lambda(1520)$ rate. The general shape of the $\Lambda(1520)$ fragmentation function is reproduced well by both models. At low x_E, DELPHI and OPAL[2] measurements agree within errors, but for $x_E > 0.3$ the DELPHI rate is about three times higher.
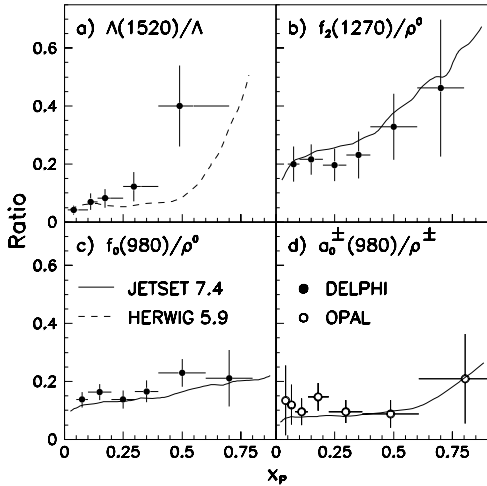

Figure 1: Ratios of the differential x_p distributions of $L=1$ and $L=0$ hadrons.

Fig. 1a shows the ratio of $\Lambda(1520)$ to Λ production as a function of the scaled momentum x_p. For this comparison the Λ measurement[7] is taken, as it covers a similar range in x_p to the $\Lambda(1520)$ measurement. It is seen that at small x_p, $\Lambda(1520)$ production is about a factor 20 less than Λ production. At large x_p, this reduces to a factor ~ 2.5. A similar behaviour was found[8] for the ratio of tensor to vector meson production, $f_2(1270)/\rho^0$ (Fig. 1b). However, no increase is seen for the ratios of scalar to vector meson production[8,9], $f_0(980)/\rho^0$ (Fig. 1c) and $a_0^\pm(980)/\rho^\pm$ (Fig. 1d).

Such a behaviour would be expected from general fragmentation dynamics due to the higher mass of the $\Lambda(1520)$. An increase of this ratio with x_p is also expected if many Λ's stem from resonance decays. Finally it is interesting to note that the ratio of $\Lambda(1520)$ to proton production is identical, within errors, at low energies[1] and in hadronic Z decays (as calculated from Refs.[3,10]).

To check for a possible spin alignment of the $\Lambda(1520)$, the distribution of the cosine of the kaon angle in the $\Lambda(1520)$ rest system with respect to the $\Lambda(1520)$ direction has been measured[3] for $x_p > 0.07$ and fitted with the expected form, yielding the spin density matrix element value

$$\rho_{+\frac{1}{2}+\frac{1}{2}} + \rho_{-\frac{1}{2}-\frac{1}{2}} = 0.4 \pm 0.2.$$

Thus no significant $\Lambda(1520)$ spin alignment is observed.

The total production rates of light-flavour hadrons in hadronic Z decays were measured at least for one state of an isomultiplet in ALEPH[7,11], DELPHI[3,8,10,12], L3[13] and OPAL[2,6,9,14]. It has been shown that the total production rates of vector, tensor and scalar mesons[15] and of baryons[3] follow phenomenological laws related to the spin (J), isospin (I), strangeness (S) and mass (M) of the particles. The main idea of this analysis was to plot the baryon and meson production rates in a different way. For baryons we analyse *the sum of the production rates* of all states of an isomultiplet as a function of M^2. In the case that not all states of an isomultiplet are measured at LEP, equal production rates for the other states is assumed. For mesons we
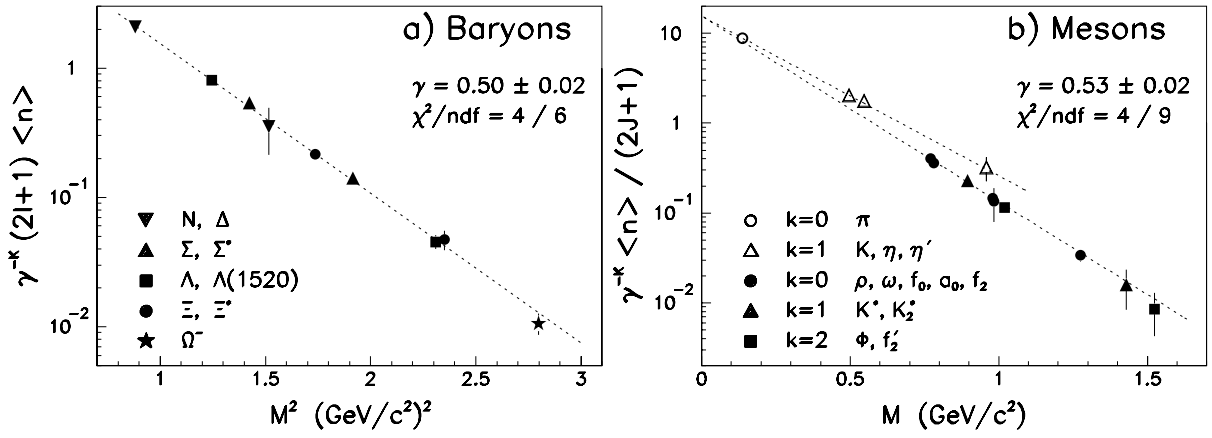
Figure 2: The weighted production rates of baryons as a function of M^2 and of mesons as a function of M.

analyse *the production rates per spin and isospin projection* as a function of M. These rates were obtained by averaging the rates of particles belonging to the same isomultiplet, excluding charge conjugated states and divided by a spin factor $(2J+1)$.

The total production rates of all light-flavour hadrons measured so far at LEP 1 are well fitted by the formulas

$$(2I+1)\,\langle n\rangle \;\equiv\; \Sigma_i\,\Sigma_j\,\langle n\rangle_{ij} \;=\; A\,\gamma^k\,\exp\left(-b\,M^2\right) \quad\text{and}\quad \langle n\rangle\,/\,(2J+1) \;\equiv\; \langle n\rangle_{ij} \;=\; A\,\gamma^k\,\exp\left(-b\,M\right)$$

for baryons and mesons respectively, where $\langle n\rangle_{ij}$ is the production rate per spin and isospin projection and k is the number of s and $\bar{s}$ quarks in the hadron. The values of the fitted parameters are given [a] in the Table. The factor γ is the same for all hadrons: $\gamma_{average} =$

Particles		A	b	γ	χ^2/ndf
Baryons	(B)	22.1±1.6	2.66±0.08	0.50±0.02	4.1 / 6
Vectors, Tensors, Scalars	(V,T,S)	18.6±4.3	4.95±0.26	0.53±0.02	2.2 / 6
Pseudoscalars	(P)	15.1±1.2	3.87±0.57	0.49±0.10	0.5 / 1

0.51±0.02. If the production rates are weighted by γ^{-k}, a universal mass dependence is observed for all baryons (Fig. 2a). But for mesons there are two dependences: one for pseudoscalar mesons and another for vector, tensor and scalar mesons (Fig. 2b). The slopes b are different for mesons with net spin 0 and 1, but they are the same for baryons with net spin $\frac{1}{2}$ and $\frac{3}{2}$. The slopes b do not depend on the value and orientation of the *orbital angular momentum L* of the quarks for mesons with net spin 1 and for baryons with net spin $\frac{1}{2}$.

Using the values of the parameter A, the hadron ratios can be extrapolated to $M = 0$:

$$\rho^+/3\,\pi^+ \;=\; A_{V,T,S}\,/\,A_P \;=\; 1.2 \pm 0.3 \quad\text{and}\quad \pi^+/p \;=\; 4\cdot A_M\,/\,A_B \;=\; 2.8 \pm 0.3,$$

where $A_M = 15.4 \pm 1.2$ is the weighted average of $A_{V,T,S}$ and A_P. These ratios agree with predictions of the quark combinatorics model [16], $\rho^+ : \pi^+ = 3 : 1$ and $\pi^+ : p : \bar{p} = 3 : 1 : 1$.

The inclusive distributions of π^+, K^+ and p in hadronic Z decays have been measured in quark and gluon jets [5]. Three-jet events were clustered using the Durham algorithm with a jet resolution parameter $y_{cut} = 0.015$. To obtain samples of quark and gluon jets with similar kinematics, only the low energy jets for Y events and all jets for Mercedes events were used. Gluon jets were selected in $b\bar{b}g$ events by anti-tagging the b quarks using an impact parameter technique.

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[a] b in $(\text{GeV}/c^2)^{-2}$ for baryons and in $(\text{GeV}/c^2)^{-1}$ for mesons.

The point of intersection of the $\xi_p = -\ln x_p$ (with $x_p = p_{particle}/p_{jet}$) distributions (see Fig. 9 in Ref. [5]) of quark and gluon jets is approximately the same for pions and kaons, $\xi_p^{(s)} \sim 1.73$. For protons the crossing point between the quark and gluon distributions is shifted to higher momentum at $\xi_p^{(s)} \sim 0.74$. Thus proton production is enhanced in gluon jets, but preferentially at high momenta. A surplus of baryon production in gluon jets with the observed kinematical properties can be qualitatively understood if baryons are directly produced from coloured partons or equivalently from a colour string (see Ref. [5] for more details).

3 Summary

DELPHI has recently measured total Σ^- and $\Lambda(1520)$ production rates per hadronic Z decay including charge conjugated states to be 0.081 ± 0.010 and 0.029 ± 0.007. The differential distributions for both particles are well described by the tuned Jetset 7.4 and Herwig 5.9 Monte Carlo models. No significant $\Lambda(1520)$ spin alignment was observed.

The ratio of $\Lambda(1520)$ to Λ production increases with increasing scaled momentum x_p. A similar behaviour was found for the ratio of tensor to vector meson production, $f_2(1270)/\rho^0$. However, no increase was seen for the ratios of scalar to vector meson production, $f_0(980)/\rho^0$ and $a_0^\pm(980)/\rho^\pm$.

The total production rates of all light-flavour hadronic states measured so far at LEP 1 follow phenomenological laws related to the spin, isospin, strangeness and mass of the particles. The hadron ratios, $\rho : \pi$ and $\pi : p$, extrapolated to $M = 0$ using these laws agree with predictions of the quark combinatorics model.

The production spectra of the identified particles have been measured in quark and gluon jets. A significant proton enhancement in gluon jets is observed, consistent with baryon production proceeding directly from coloured objects.

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