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LIGHT QUARK HADRONS IN HADRONIC Z DECAYS

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The results on the inclusive production of light quark hadrons in the hadronic decays of the Z are reviewed. Particular attention is paid to the new results on the inclusive production in Z $\to b\bar{b}$ events.

1 Introduction

More than 16 million hadronic decays of the Z have been recorded since 1989, mostly at LEP.

The events at the Z have many features making them interesting for fragmentation studies. In particular:

- The energy at which primary quarks are produced is much larger than the masses of quarks and hadrons: this gives good separation between the fragmentation phase and the hard process. The production of light quark hadrons is dominated by the production of $q\bar{q}$ (and diquark-antidiquark) pairs from the vacuum, and the remnants of valence quarks are small. The production of light quark hadrons from the Z is a good testing-ground for testing thermodynamical models of multiparticle production, as well as for investigating symmetries in particle production.
- The high statistics collected makes it possible to perform detailed studies on particular subsamples of events, e.g. separating quark jets from gluon jets, $b\bar{b}$ events etc. with minimum bias algorithms.
- The performance of the detectors (most equipped with powerful particle identification systems) is well understood.

LEP has produced results of unprecedented precision in any experiment in the measurement of identified final states. For the SU(3) pseudoscalar and vector meson nonets, and for the baryon octet and decuplet, at least one state per isospin multiplet has been measured, plus the scalar $f_0(980)$ and the tensors $f_2(1270)$ and $K_2^*(1430)^0$.

2 What is New

In the last year, the first measurements of the ω production rate were performed by ALEPH[1] and L3[2], of the Δ^{++} by DELPHI[3] and OPAL[4], and of the $\Sigma^\pm$ and Σ^0 by DELPHI[5,6] and OPAL[7].

The measurement of the Δ^{++} multiplicity is difficult because of the large combinatorial background (such a measurement was not performed at PETRA), and can be done only with a substantial use of particle identification. The two first measurements of the Δ^{++} multiplicity, based on different techniques, are inconsistent. OPAL measures an average multiplicity of 0.22±0.04±0.04 (the first error is statistical, the second is systematic), slightly larger but in agreement with the predictions of the JETSET and HERWIG Monte Carlo models. DELPHI measures instead an average multiplicity of 0.079±0.009±0.011.

The measurements related to $\Sigma^\pm$ are performed in the $n\pi$ channel (detecting the kink in the track corresponding to the charged Σ to π); OPAL sees also the decay $\Sigma^+ \to p\pi^0$. No difference is observed in the Σ^+ and Σ^- production rates. Σ^0 is detected in the $\Lambda\gamma$ channel, where both DELPHI and OPAL use converted photons because of their superior resolution.

Finally, ω is detected by L3[2] in the $\pi^+\pi^-\pi^0$ (B.R. $\simeq 0.89$) and in the $\gamma\pi^0$ (B.R. $\simeq 0.09$) channels; ALEPH[1] reconstructs the $\pi^+\pi^-\pi^0$ channel only. The results from the two experiments, and in the two channels measured by L3, are consistent.

Many new precise measurements were also presented, which improve substantially the results from Glasgow. In particular the quality of the data related to the production of Ω^- (ALEPH[8], DELPHI[6]), ρ^0 (ALEPH[1]), ϕ (ALEPH[1], DELPHI[9], OPAL[10]), η (L3[11]), π^0 (DELPHI[12]), p and K$^\pm$ (ALEPH[13], DELPHI[14], SLD[15]) improved considerably. In my opinion the following results should be stressed:

- The Ω^- production rate seems established at the level of 1.6±0.5 per 1000 events, superseding the old claims of an anomalous high production of this decuplet baryon.
- L3 observes an enhancement with respect to string and cluster models of the η production in gluon jets. This enhancement (a factor of two at a momentum fraction $x_p = 0.2$) increases with momentum, and it is not observed in quark jets.
- All experiments converge on a rather low ϕ rate (this required an important tuning of JETSET to be reproduced).
- The production of light quark baryons seems significantly softer than predicted by JETSET, thus indicating, in the string picture, the need for an extra suppression of diquarks in the endpoint of strings.

3 Average Multiplicities and Cross Sections

When averaging among different experiments, special care has to be taken to account for inconsistent results and to catch common systematics which would make the error on the average too low. An underestimate of the error is especially dangerous for the optimization procedures presently used in Monte Carlo tuning.

In this review the following (very conservative) approach was followed. When the quantity $S^2 = \chi^2/DF$ was larger than one (possible indication of underestimated errors), the procedure suggested in the PDG[16] was used (essentially the error was multiplied by the "scale factor" S, after removing experiments with too large errors). When S was less than 1, the procedure suggested in Ref.[17] was used (essentially off-diagonal terms were inserted in the covariance matrix until $S = 1$), unless the error so obtained was larger than the minimum experimental error, in which case the latter was taken for the error on the average. In order to avoid biases towards experiments measuring small values[18], the average weighted by the relative errors is quoted, whenever it was more than one third of the error from the average coming from the absolute errors.

The average multiplicities are listed in Tab. 1, and compared with the predictions from the tuned[19] JETSET 7.4 (J74) and HERWIG 5.8 (H58).

Models account reasonably for the observed rates. There is also good agreement with thermodynamical models[20], and with a recently proposed simple mass dependence of the particle rates[21].

It should be noted that the average multiplicities in the baryon decuplet have a "scale factor" $S > 2.0$ for all particles excluding the Ω^-. Hopefully the experiments will soon provide a clear measurement for this sector, which is crucial for the tuning of models.

QCD calculations[22] in the framework of the Modified Leading Logarithm Approximation (MLLA) and Local Parton Hadron Duality (LPHD) make predictions of inclusive hadronic spectra in $\xi = \ln(1/x_p)$. The calculation predicts that the distribution is bell-shaped. The peak values ξ^* from single particle distributions and their dependence on the hadron mass have been measured by several experiments. The averages are reported in Tab. 2. In the framework of MLLA+LPHD, smaller peak values are expected for more massive particles. In Fig. 1 the peak positions ξ^{*0}, corrected for decays, are shown. The shift $\Delta\xi^*$ due to this correction is listed in Tab. 2, and was computed using the JETSET Monte Carlo tuned as in Ref.[19]. A systematic error was added in quadrature to the error on ξ^* in the figure, corresponding to the half difference between $\Delta\xi^*$ (the shift of the peak values) and the shift of the averages of the ξ distribution. The full line is a fit linear in $-\ln(M_{hadron})$ which describes the data satisfactorily.

Particle	Multiplicity	Exp	J74	H58
Charged	20.92±0.24	ADLMO	20.81	20.94
π^+	17.06±0.44	O	17.09	17.66
π^0	9.19±0.73	DL	9.83	9.81
K^+	2.37±0.13	DO	2.23	2.11
K^0	2.012±0.033	ADLMO	2.17	2.08
η	0.95±0.11	AL	1.10	1.02
$\eta'(958)$	0.22±0.07	AL	0.09	0.14
$f_0(980)$	0.140±0.034	DL	0.16	
$\rho(770)^0$	1.29±0.13	AD	1.27	1.43
$\mathrm{K}^*(892)^+$	0.715±0.067	DO	0.77	0.74
$\mathrm{K}^*(892)^0$	0.759±0.041	ADO	0.77	0.74
$\phi(1020)$	0.107±0.009	ADO	0.107	0.099
$\omega(782)$	1.11±0.14	AL	1.32	0.91
$f_2(1270)$	0.25±0.08	DL	0.29	0.26
$\mathrm{K}_2^*(1430)^0$	0.19±0.07	O	0.15	0.16
p	0.98±0.10	DO	0.97	0.78
Λ	0.371±0.015	ADLMO	0.349	0.368
Σ^0	0.071±0.013	DO	0.072	0.053
$\Sigma^\pm$	0.175±0.025	DO	0.137	0.119
Ξ^-	0.0257±0.0014	ADO	0.030	0.049
Δ^{++}	0.124±0.065	DO	0.160	0.154
$\Sigma(1385)^\pm$	0.044±0.008	ADO	0.036	0.065
$\Xi(1530)^0$	0.0061±0.0011	ADO	0.0069	0.0025
Ω^-	0.0016±0.0005	ADO	0.0019	0.0077
$\Lambda\bar{\Lambda}$	0.089±0.007	ADO	0.085	0.134
$\Lambda\Lambda$	0.0249±0.0022	ADO	0.023	0.029

Table 1: Average multiplicities in the hadronic decays of the Z, compared to the predictions from HERWIG and JETSET. A=ALEPH, D=DELPHI, L=L3, O=OPAL, M=MARK II, S=SLD.

4 Multiplicities in $b\bar{b}$ Events

The study of the charged particle multiplicity and of the production of identified final states in $b\bar{b}$ events is important in many respects for understanding the nature of fragmentation, and to constrain the probability of hadronization of the b quark[23]. b hemispheres are selected by lifetime tags on the opposite side. Inside a b hemisphere, the products of the decay of a B hadron are separated from fragmentation particles by a cut in rapidity[24] or in apparent lifetime.

In the last year, new results have been published[24,25] on the charged multiplicity in Z$\rightarrow b\bar{b}$ (and Z$\rightarrow c\bar{c}$), on the difference of the average charged particle multiplicities between $b\bar{b}$ and light quark events (δ_{bl}) and between $c\bar{c}$ and light quark events (δ_{cl}), and on the production of ϕ and π^0 in $b\bar{b}$ events and in the decays of B hadrons[9,12]. The experimental data are summarized in Tab. 3 and 4, to be compared, for example. with predictions in ref. [26].

These studies have a large experimental potential, since the use of lifetime tags to separate the products of B decays from the fragments is just starting.

Particle	ξ^*	Exp	$\Delta\xi^*$
π^+	3.79±0.02	AOS	-0.19
π^0	3.94±0.13	DL	-0.19
K^+	2.64±0.04	ADO	0.42
K^0	2.68±0.05	ADLOS	0.42
η	2.52±0.10	L	0.17
$\eta'(958)$	2.47±0.49	L	0.63
$\rho(770)^0$	2.80±0.19	A	0.22
$K^*(892)^0$	2.35±0.07	AO	0.44
$\phi(1020)$	2.21±0.04	ADO	0.83
$\omega(782)$	2.80±0.36	L	0.22
p	2.97±0.09	ADO	0.03
Λ	2.72±0.04	ADLOS	0.08
Ξ^-	2.58±0.11	DO	0.08

Table 2: Maximum ξ^* of the ξ distribution for various particles, and correction $\Delta\xi^*$ applied to account for decays.

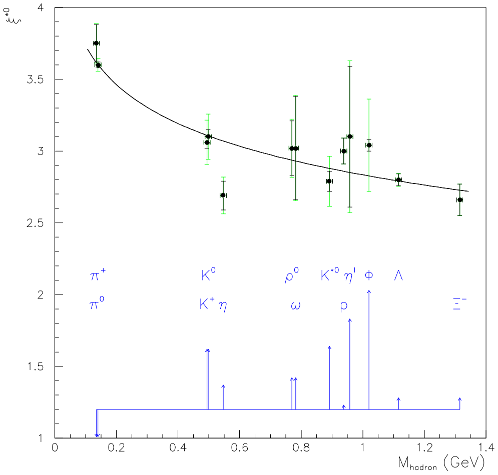

Figure 1: The corrected maximum ξ^{*0} of the ξ distribution for primary hadrons is shown as function of the particle mass. The arrows represent the corrections for decays.

Particle	Multiplicity	From B Decay	Exp
Charged	23.43±0.48	5.72±0.38	DOS
π^0	10.1±1.2	2.78±0.53	D
K^+	2.74±0.50	0.88±0.19	D
K^0	2.16±0.12	0.58±0.06	D
ϕ	0.126±0.023	0.032±0.011	D
p	1.13±0.27	0.141±0.059	D
Λ	0.338±0.047	0.059±0.011	D

Table 3: Average multiplicities in $Z \to b\bar{b}$ and in the decay of single B hadrons at LEP.

	Value	Exp
$< n^\pm >_{c\bar{c}}$	21.44±0.62	OS
δ_{bl}	2.90±0.30	DOS
δ_{cl}	0.89±0.62	OS

Table 4: Results on the average multiplicity in $Z \to c\bar{c}$ and on the average differences δ_{bl}, δ_{cl} (see text).

5 Summary and Future

The results from LEP and SLD give the most complete picture we ever had on the production of identified final states from e^+e^- annihilations. In the immediate future, I think that the main lines of research will be:

- The experimental understanding of baryon production, especially in the decuplet sector.
- Study of the tensor states, which seem abundantly produced in Z decays, and of excited baryons. This will be like a " rare search" in hadronic events, since the experimental information is in this sector very meager. There could be surprises in store, thanks to the detectors' powerful systems of particle identification.
- Study of the production of hadrons in the cascade initiated by different quark flavors.
- Study of masses and lifetimes. For many particle species, the samples collected by LEP are cleaner and more abundant than the sets on which the averages in the PDG are based.

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