K^0_s and Λ Production in Two- and Three-Jet Events

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Abstract. A measurement of the K^0_s and Λ production rates and momentum spectra in two- and three-jet events is presented. On the basis of about 3.1 million Z decays collected with the L3 detector at LEP, we observe that the production of these particles is well modeled by string fragmentation.

Hadronic Z decays provide important data to study the process of hadronization which is too complex to be calculated in details by perturbative QCD. The properties of quark and gluon jets may highlight some hidden aspects of the hadronization related to the quark and gluon nature. The measurements of the production rates and momentum spectra of particles, within quark and gluon jets, allow to test QCD predictions and to compare some hadronization models. The JETSET 7.3 and HERWIG 5.9 programs are used to generate Monte Carlo events. Both include QCD calculations but the hadronization is modeled by string fragmentation in JETSET and by cluster fragmentation in HERWIG. According to both models, about 72% of the less energetic jets of three-jet events are originating from the fragmentation of an energetic gluon radiated by one of the two primary quarks of $Z \rightarrow q\bar{q}$ events. This is the used signature to define enriched quark and gluon jets samples. In this report, the measure of the production rates and momentum spectra of K^0_s mesons and Λ baryon's in the above defined quark and gluon jets are presented. Comparisons of K^0_s, Λ and also charged particles reveal differences in hadronization due to the presence of strange quarks as well as to the mesonic and baryonic nature of these particles.

The main features of this analysis can be found in reference[2]. The K^0_s mesons and Λ baryons are reconstructed in the same way, excepted for Λ's, for which the mass of a proton, instead of a pion, is associated to the most energetic charged particles. The number of candidates is obtained by counting, within appropriate mass windows, the number of unlike sign combinations of charged particles less the combinatorial background obtained from the number of like sign combinations. Slight corrections on

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[2)] see: L3 collaboration, M.Acciarri *et al*, Phys Lett. B407 (1997) 389-401.

this background (0.4%) are applied to take into account of its natural underestimation for events with more than one wrong combination and its excess due to additional tracks originating for nuclear interactions inside the detector. The obtained total production rates in hadronic Z decays are given in Table 1[3].

TABLE 1. Measured total production rates for K^0_s, Λ and charged particles with their respective Monte Carlo expectations.

	DATA	JETSET	HERWIG
$\langle K^0_s \rangle_{total}$	1.012 ± 0.003(stat.) ± 0.021(syst.)	1.024	1.041
$\langle \Lambda \rangle_{total}$	0.364 ± 0.004(stat) ± 0.017(syst.)	0.347	0.378
$\langle Nch \rangle_{total}$	21.0 ± 0.001(stat) ± 0.26(syst.)	20.8	21.0

The LUCLUS jet finder algorithm is used to reconstruct jet energies and directions. The parameter d_{join}, used to discriminate jets, is fixed to 7 GeV. Hence, the fraction of two-jet events is found to be 70.6%. This is in agreement with our QCD event generators JETSET and HERWIG. The measurements are repeated in two- and three-jet events and given relative to the total production rate (Table 2). These relative rates are more accurate because systematic uncertainties cancel in the ratio and their Monte Carlo expectations do not depend any more on the expected total production rate. Reconstructed K^0_s and Λ, as well as single charged particles, are associated to the closest jets in the laboratory rest frame. This allows to repeat the measurements within three-jet events (Table 2).

TABLE 2. Measured relative rates for K^0_s, Λ and charged particles observed in different species of jets and events with their respective Monte Carlo expectations. The results labeled as "Quark jets" are the averaged rate per jet for the two most energetic jets in three-jet events. Uncertainties are statistical and systematic added quadratically.

	$\langle K^0_s \rangle_{per\ jet}/\langle K^0_s \rangle_{total}$			$\langle \Lambda \rangle_{per\ jet}/\langle \Lambda \rangle_{total}$			$\langle Nch \rangle_{per\ jet}/\langle Nch \rangle_{total}$		
	Data	**Jetset**	**Herwig**	**Data**	**Jetset**	**Herwig**	**Data**	**Jetset**	**Herwig**
Two-jet events	.460±.004	.464	.481	.451±.011	.444	.470	.460±.001	.460	.455
Three-jet events	.399±.005	.391	.360	.421±.013	.423	.375	.400±.001	.398	.395
- Quark jets	.417±.009	.413	.400	.436±.014	.436	.400	.417±.001	.416	.412
- Gluon jets	.361±.007	.347	.281	.403±.015	.403	.326	.363±.001	.358	.361

Both Monte Carlo event generators reproduce rather well the proportions of charged particles found in the different species of jets and events. Nevertheless, only JETSET succeeds to reproduce K^0_s and Λ production both in quark and gluon jets. Only K^0_s are found slightly more abundant than expected in gluon jets (3%). HERWIG disagrees essentially in gluon jets.

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[3] The presented Monte Carlo expectations are those obtained from our tuned version of JETSET and HERWIG programs. The tuning is done in order to reproduce as well as possible the event shape variables as observed by the L3 detector.

These measurements are repeated for different momentum ranges to compare the momentum spectra (Figures 1). Both predictions are rather good for mesons but are quite different for large momentum for Λ baryons. Nevertheless, these later remain consistent with data. The disagreement previously seen for HERWIG goes with an expected too soft momentum spectra in gluon jets.

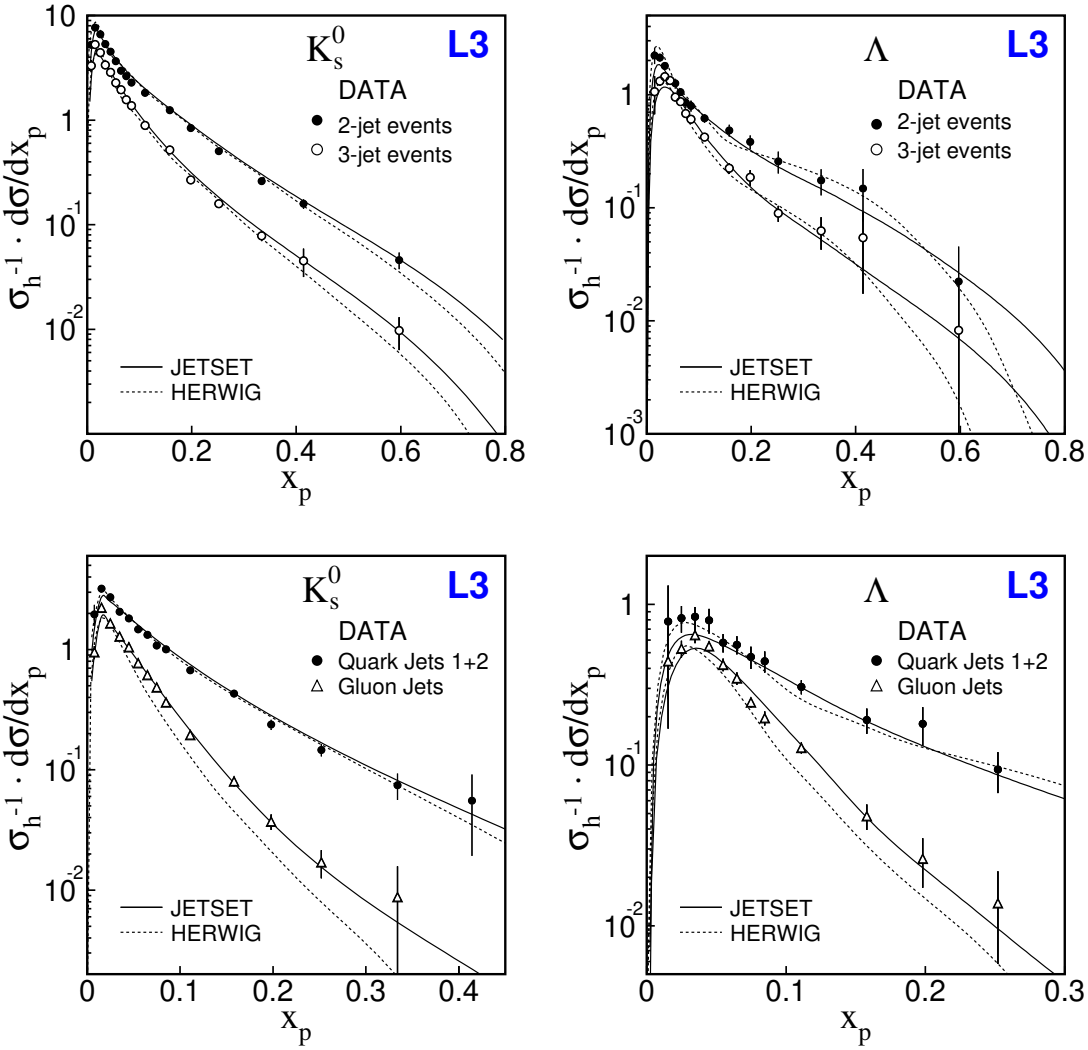

FIGURE 1. At the top, the differential inclusive production rates measured in two- and three-jet events for K_s^0 mesons and for Λ baryons. At the bottom, the corresponding results measured within three-jet events for quark and gluon jets. The results labeled as "Quark jets" is the sum of the rates measured in the two most energetic jets. The difference between the two quark jets was not significant. The total hadronic cross section is denoted by σ_h and x_p stands for p/E_{beam}. Error bars include statistical and systematic uncertainties.

The reduced rate of particle production observed in gluon jets is expected to be mainly due to the reduced energy available during the fragmentation. However, it is

also expected, because of the higher color charge of gluons, that this reduction be partially compensated by an increase of particle production from gluon fragmentation relative to quark fragmentation. Hence, to investigate a possible difference in the K^0_s and Λ production in gluon jets related to the nature of these particles rather to the jet energy, a comparison is made with the rate of charged particles. The Figure 2 shows the evolution with the jet energy of the ratios, $R(K^0_s)$ and $R(\Lambda)$, of the relative production rates $\langle K^0_s \rangle_{\text{per jet}} / \langle K^0_s \rangle_{\text{total}}$ and $\langle \Lambda \rangle_{\text{per jet}} / \langle \Lambda \rangle_{\text{total}}$, divided by the corresponding relative rate for charged particles, namely $\langle N_{ch} \rangle_{\text{per jet}} / \langle N_{ch} \rangle_{\text{total}}$.

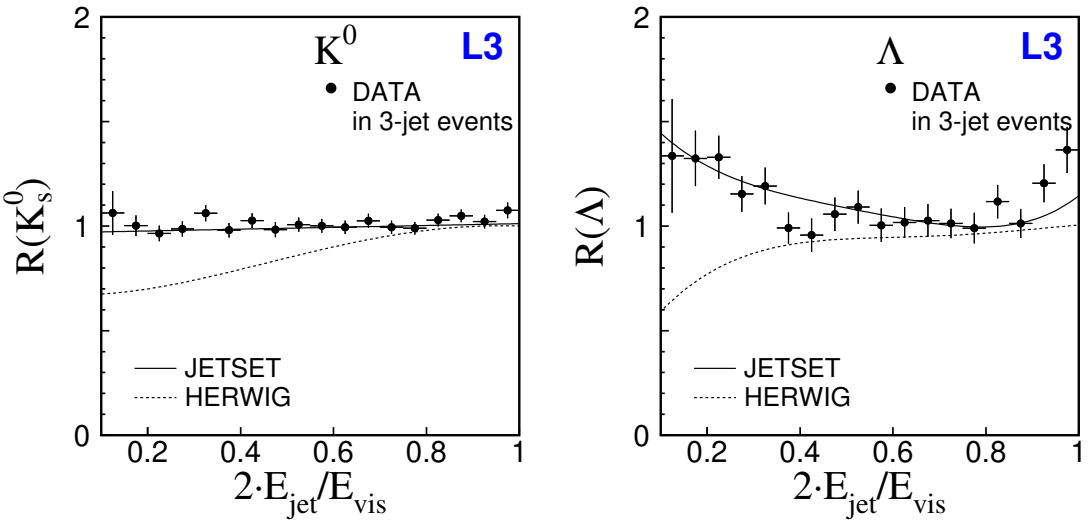

FIGURE 2. The values of $R(K^0_s)$ and $R(\Lambda)$ as function of the scaled jet energy ($2 \cdot E_{jet}/E_{vis}$) in three-jet events. The error bars include statistical and systematic uncertainties.

Here, the disagreement from HERWIG increases with less energetic jets where the enrichment in gluon jets is the highest. Studies have shown this is related to a reduced available phase space for more massive quark production in the less energetic jets. Hence the disagreement observed with the cluster fragmentation model is seen caused by an reduced available phase space for strange quark production. In Figure 2, data show a relative independence of K^0_s production with the jet energy and an enhancement of Λ production for the less energetic jets. This later is well reproduced by JETSET thanks to a softer di-quark fragmentation function relative to the one for quarks. This implicitly favors di-quark production, and consequently baryon production, in regards to quark and light mesons, when there is less energy during the fragmentation.

In conclusion, we observe that QCD, through the string fragmentation model, describes relatively well data in quark and gluon jets as well for K^0_s mesons as for Λ baryons.