Determination of the strangeness contents of light-flavour isoscalars from its production rates in hadronic Z decays measured at LEP

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Abstract

A new phenomenological approach is suggested to determine the strangeness contents of light-flavour isoscalars. This approach is based on phenomenological laws of hadron production related to the spin, isospin, strangeness content and mass of the particles. The "effective" numbers of s and $\bar{s}$ quarks in the isoscalar partners i_1 and i_2 are given by the nonstrange-strange mixing angle φ: $k(i_1) = 2\sin^2\varphi$ and $k(i_2) = 2\cos^2\varphi$. From the total production rates per hadronic Z decay of all light-flavour hadrons measured so far at LEP the values for k are found to be: $k(\eta) \equiv 2-k(\eta')$ $= 0.91\pm0.12$, $k(\phi) \equiv 2-k(\omega) = 1.94\pm0.09$, $k(f_2') \equiv 2-k(f_2) = 1.84\pm0.21$ and $k(f_0) = 0.09\pm0.13$. Our results on the η–η', ω–ϕ and f_2–f_2' isoscalar mixing are consistent with the present experimental evidence. Quite remarkably, our value for $k(\eta)$ corresponds to the singlet-octet mixing angle $\theta_P = -12.4°\pm3.5°$. The obtained strangeness content of the $f_0(980)$ scalar/isoscalar is not consistent with the values supported by different model studies. However, taking the $f_0(980)$ in our analysis with the mass of the bare state (K-matrix pole) $f_0^{bare}(720\pm100)$, the mixing angle is found to be: $|\varphi_S^{bare}| = 73°\pm7°\pm24°$, in good agreement with the prediction of the K-matrix analysis.

The quark contents of pseudoscalar (P), vector (V), tensor (T) and scalar (S) mesons have been discussed many times from the beginning of the creation of unitary SU(3)-flavour symmetry. This is a quite interesting question because the quark contents of the lightest isoscalars are different from the prediction of the SU(3) quark model. The phenomenological studies of hadronic processes involving isoscalars usually make assumptions about their quark compositions. Therefore, to the understanding of the quark model and QCD, it is very important to determine the SU(3)-breaking hadronic parameters which define these quark compositions.

In terms of the SU(3) singlet and octet basis states

$$\eta_1 = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}, \qquad \eta_8 = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6} \tag{1}$$

the quark contents of the physical η and η' states are given by the singlet-octet mixing angle θ_P. Assuming the orthogonality of the physical states and no mixing with other isoscalars and glueballs the flavour wave functions of the η and η' pseudoscalars are defined to be:

$$\eta \;= \eta_8 \cdot \cos\theta_P - \eta_1 \cdot \sin\theta_P, \tag{2}$$

$$\eta' = \eta_8 \cdot \sin\theta_P + \eta_1 \cdot \cos\theta_P. \tag{3}$$

To determine the *strangeness* contents of the same isoscalars it is more convenient to use the so-called nonstrange-strange quark basis ($n\bar{n} = (u\bar{u} + d\bar{d})/\sqrt{2}$ and $s\bar{s}$):

$$\eta \;= n\bar{n} \cdot \cos\varphi_P - s\bar{s} \cdot \sin\varphi_P, \tag{4}$$

$$\eta' = n\bar{n} \cdot \sin\varphi_P + s\bar{s} \cdot \cos\varphi_P, \tag{5}$$

where φ_P is the nonstrange-strange mixing angle (with $\theta_P = \varphi_P - \arctan\sqrt{2}$). The quark contents of the ω–ϕ and f_2–f_2' isoscalars are defined in a way analogous to the η–η' case, replacing $\eta \to \phi(f_2')$, $\eta' \to \omega(f_2)$ in Eqs. (2)–(3) and $\eta \to \omega(f_2)$, $\eta' \to \phi(f_2')$ in Eqs. (4)–(5). The flavour wave function of the $f_0(980)$ scalar meson is written as

$$f_0 = n\bar{n} \cdot \cos\varphi_S + s\bar{s} \cdot \sin\varphi_S. \qquad (6)$$

The values of the mixing angles have been estimated from different phenomenological and theoretical analyses (see Refs. [1]-[12] and references therein). The phenomenological estimations of the pseudoscalar mixing angle θ_P (or φ_P) use the available world data on the following decay processes: strong decays of tensors and higher-spin mesons ($M_{J>2}$) into pseudoscalar pairs, radiative transitions between vectors and pseudoscalars, two-photon annihilation decays, leptonic decays of vectors, J/ψ decays into a vector plus a pseudoscalar, radiative J/ψ decays, semileptonic D_s decays plus transition form factors $\eta/\eta' \to \gamma\gamma^*$. There are also phenomenological analyses of θ_P which use the data on the quasi-two-body $\pi^- p$ and $\bar{p}p$ reactions. The values for θ_P (and φ_P) obtained from the above highlighted processes are given in Table 1 together with the corresponding references. The theoretical analyses of the mixing angles are

Table 1: Compilation of the values of the η–η' mixing angles φ_P and θ_P obtained from different processes (with $\theta_P = \varphi_P - \arctan\sqrt{2} \simeq \varphi_P - 54.7°$).

process	φ_P (°)	θ_P (°)	Ref.
$T(2^{++}) \to PP$	42 ± 2	-13 ± 2	[3]
	43.1 ± 3.0	-11.6 ± 3.0	[13]
$M_{J>2} \to PP$	41 ± 4	-14 ± 4	[3]
$V \to P\gamma;\ P \to V\gamma$	37.7 ± 2.4	-17.0 ± 2.4	[14]
	35.3 ± 5.5	-19.4 ± 5.5	[13]
$P \to \gamma\gamma$	41.3 ± 1.3	-13.4 ± 1.3	[3]
	36.3 ± 2.0	-18.4 ± 2.0	[15]
$P \to V\gamma/\gamma\gamma;\ V \to P\gamma/e^+e^-$	43.1 ± 0.8	-11.6 ± 0.8	[16]
$J/\psi \to VP$	35.5 ± 1.4	-19.2 ± 1.4	[17]
	35.6 ± 1.4	-19.1 ± 1.4	[18]
	37.8 ± 1.7	-16.9 ± 1.7	[3]
	39.9 ± 2.9	-14.8 ± 2.9	[13]
$J/\psi \to P\gamma$	39.0 ± 1.6	-15.7 ± 1.6	[13]
$D_s \to P\,e\,\nu_e;\ \eta/\eta' \to \gamma\gamma^*$	38.0 ± 2.8	-16.7 ± 2.8	[19]
	41.2 ± 4.7	-13.5 ± 4.7	[7]
$\pi^- p \to (\eta/\eta')\,n$	36.5 ± 1.4	-18.2 ± 1.4	[20]
	39.3 ± 1.2	-15.4 ± 1.2	[21]
$\bar{p}p \to (\eta/\eta')\,(\pi^0/\eta/\omega)$	37.4 ± 1.8	-17.3 ± 1.8	[22]
average	39.2 ± 1.3	-15.5 ± 1.3	[3, 13]
$Z^0 \to$ *hadrons*	42.3 ± 3.5	-12.4 ± 3.5	this analysis

usually model dependent, and the predictions for θ_P range from $-23°$ to $-10°$. Classic examples are the quadratic and linear Gell-Mann–Okubo (GMO) mass formulae which yield the values $\theta_P^{quad} \simeq -10°$ and $\theta_P^{lin} \simeq -23°$ [23]. For the vector (φ_V) and tensor (φ_T) mixing angles the most of theoretical and phenomenological analyses (see, for example, Refs. [23, 3, 14, 16, 24, 25, 26]) predict the values which are very close to the "ideal" mixing: $\varphi_V = \theta_V - \theta^{ideal} \simeq +3.4°$ and $\varphi_T = \theta_T - \theta^{ideal} \simeq -7.3°$ ($\theta^{ideal} = \arctan 1/\sqrt{2} \simeq 35.3°$).

The interpretation of the $f_0(980)$ scalar meson is one of the most controversial in meson spectroscopy [2]. The question is whether the $f_0(980)$ consists mostly of nonstrange or of strange quarks. The recent phenomenological analyses of the experimental data on the following decay processes $\phi \to \pi^0\pi^0\gamma$, $J/\psi \to \omega\pi\pi$ [27], $D_s^+ \to f_0(980)\pi^+$ [12] and $f_0(980) \to \pi\pi/K\bar{K}/\gamma\gamma$ [11] favour the $s\bar{s}$ dominance of the $f_0(980)$. The phenomenological study of low-energy $\pi\pi$ scattering [28] and the phase shift analysis of πK scattering [29] have led to the same conclusion.

In the present paper the strangeness contents of light-flavour isoscalars are obtained for the first time from its total production rates per hadronic Z decay measured at LEP. The new decay process ($Z^0 \to hadrons$) is added to the above-listed processes used to determine the mixing angles.

Recently it has been shown [30]-[34] that the total production rates per hadronic Z decay ($\langle n \rangle$) of all light-flavour mesons (M) and baryons (B) measured so far at LEP follow phenomenological laws related to the spin (J), isospin (I), strangeness content and mass (m) of the particles. These regularities can be combined into one empirical formula:

$$\langle n \rangle \; = \; A \cdot \beta_H \cdot (2J+1) \cdot \gamma^k \cdot \exp\,[-b_H (m/m_0)^{N_H}], \tag{7}$$

where $H = M$ or B, $m_0 = 1$ GeV/c^2, γ is the strangeness suppression factor with a value of $\gamma \simeq 0.5$ for all hadrons, k is the number of s and $\bar{s}$ quarks in the hadron and b_H is the slope of the mass dependence. The values of the degree N_H and of the coefficient β_H are different for mesons and baryons:

$$N_M = 1, \quad N_B = 2 \quad \text{and} \quad \beta_M = 1, \quad \beta_B = \frac{4}{C_{\pi/p} \cdot \lambda_{QS}}, \tag{8}$$

where $\lambda_{QS} = (2J+1)(2I+1)$ can be interpreted as a fermion suppression factor originating from quantum statistics properties of bosons and fermions and $C_{\pi/p}$ is the π/p ratio at the zero mass limit with a value of $C_{\pi/p} \simeq 3$ which could be expected from quark combinatorics.

According to the results of Refs. [32, 33, 34] the normalization parameter A in Eq. (7) is the same for all mesons, but the meson slope b_M is split into two: one for vector, tensor and scalar mesons ($b_{V,T,S}$) and another for pseudoscalar mesons (b_P). The slope splitting of the mass dependence of meson production rates can probably be explained by the influence of the spin-spin interaction between the quarks of the meson (the spins of quarks are parallel for vector, tensor and scalar mesons and anti-parallel for pseudoscalar mesons). However, there is no influence of the value and orientation (with respect to the net spin) of the orbital angular momentum of the quarks, i.e. of the spin-orbital interaction of the quarks.

In the analyses [30]-[34] the strangeness contents k of baryons and $I{\neq}0$ mesons were taken from the prediction of the SU(3) quark model. For isoscalars the following values for k were used: $k(\omega) = k(f_2) = k(f_0) = 0$, $k(\eta) = k(\eta') = 1$ and $k(\phi) = k(f_2') = 2$. The *purpose of the present paper* is to obtain the values of the "effective" numbers k of the η–η', ω–ϕ, f_2–f_2' and $f_0(980)$ isoscalars from the fit of Eq. (7) to the total production rates per hadronic Z decay of all light-flavour hadrons measured so far at LEP and then to determine the corresponding mixing angles. The *basic idea* of this analysis is the following relations between the numbers k and the nonstrange-strange mixing angles φ:

$$k(\eta) \; \equiv \; 2 - k(\eta') \; = \; 2\sin^2\varphi_P, \tag{9}$$

$$k(\phi) \; \equiv \; 2 - k(\omega) \; = \; 2\cos^2\varphi_V, \tag{10}$$

$$k(f_2') \equiv 2 - k(f_2) = 2\cos^2\varphi_T, \tag{11}$$

$$k(f_0) = 2\sin^2\varphi_S, \tag{12}$$

which assume the orthogonality of the physical isoscalar partners and no mixing with other isoscalars and glueballs.

The total[1] production rates per hadronic Z decay of light-flavour hadrons, used in this analysis, were obtained for at least one state of a given isomultiplet as a weighted-average[2] of the measurements of the four LEP experiments: ALEPH [35]-[37], DELPHI [31],[38]-[45], L3 [46]-[49] and OPAL [50]-[58]. Then, in the fits of our analysis, we use the *production rates per isospin state* ($\langle n \rangle$) which were obtained by averaging the above-obtained production rates of particles belonging to the same isomultiplet ($\langle n \rangle_i$):

$$\langle n \rangle = \frac{1}{X} \sum_{i=1}^{i=X} \langle n \rangle_i, \tag{13}$$

where $X \leq (2I+1)$ is the number of *measured* isospin states. The exact definitions (13) and the experimental values of the data points $\langle n \rangle$ are given in Table 2 together with the corresponding references.

In comparison with the analyses of Refs. [30]-[34], in the present analysis Eq. (7) is simultaneously fitted to all experimental data points given in Table 2 and it assumes the validity of the relation $V/P = (2J+1) = 3$ for the vector-to-pseudoscalar ratio at the zero mass limit. In the first fit (fit 1) the numbers k for the η–η', ω–ϕ and f_2–f_2' isoscalars are fixed and given by Eqs. (9)-(11) with the values of the mixing angles predicted by the quadratic GMO mass formula: $\varphi_P \simeq 44.7°$, $\varphi_V \simeq 3.7°$ and $\varphi_T \simeq -7.3°$ [23]. The fixed value of $k = 0$ is used for the $f_0(980)$ scalar. The result of the fit 1 is shown in Fig. 1 and in Table 3. Fig. 1 shows the mass dependence of the total production rates per spin and isospin state for hadrons in hadronic Z decays weighted by a factor $\lambda_{QS}\,\gamma^{-k}$ where $\lambda_{QS} = 1$ for mesons and $\lambda_{QS} = (2J+1)(2I+1)$ for baryons. Three curves on this figure are the result of the fit 1 for baryons, for mesons with the net spin S$\,=\,$0 (pseudoscalars) and for mesons with the net spin S$\,=\,$1 (vectors, tensors and scalars). The values for γ and $C_{\pi/p}$ are found to be $\gamma = 0.51 \pm 0.02$ and $C_{\pi/p} = 2.8 \pm 0.2$. The latter is consistent with the quark combinatorics prediction $\pi/\mathrm{p} = 3$ for the direct production rates. This coincidence can probably be explained by the absence of decay processes at zero masses.

In the second fit (fit 2) of our analysis we test the sensitivity of the empirical formula (7) to the values of the degree N_H. This was not discussed in the previous analyses [30]-[34]. In the fit 2 the numbers k for the isoscalars are still fixed with the same values as in the fit 1, the ratio $C_{\pi/p}$ is fixed with a value of $C_{\pi/p} = 3$ and the degrees N_M and N_B are free parameters. The values for N_M and N_B are found to be (see Table 3):

$$N_M = 1.04 \pm 0.06 \quad \text{and} \quad N_B = 2.07 \pm 0.05. \tag{14}$$

These values are close within the relatively small errors to the values of 1 and 2 used previously. So, we can conclude that this test (fit 2) strongly suggests the use of $N_M = 1$ and $N_B = 2$ in our phenomenological analysis. These values are fixed in the next fits.

[1] The quoted rates include decay products from resonances and particles with $c\tau < 10$ cm.

[2] In calculating the errors of averages, the standard weighted least-squares procedure suggested by the PDG [23] was applied: if the quantity $[\chi^2/(N-1)]^{1/2}$ was greater than 1, the error of the average was multiplied by this scale factor.

Table 2: Definitions and values of the total production rates per isospin state of light-flavour hadrons in hadronic Z decays obtained from the weighted-average values of the four LEP experiments. The baryon rates include charge conjugated states.

hadron	definition	$\langle n \rangle$	References
π	$\frac{1}{3}\,(\pi^0+\pi^\pm)$	8.83±0.15	[35, 36, 41, 44, 46, 51, 58]
K	$\frac{1}{4}\,(\mathrm{K}^0+\bar{\mathrm{K}}^0+\mathrm{K}^\pm)$	1.075±0.016	[36, 37, 39, 44, 48, 51, 53]
η		0.94±0.08	[46, 58]
η'		0.17±0.05	[47, 58]
ρ	$\frac{1}{3}\,(\rho^0+\rho^\pm)$	1.21±0.15	[35, 45, 58]
K^*	$\frac{1}{4}\,(\mathrm{K}^{*0}+\bar{\mathrm{K}}^{*0}+\mathrm{K}^{*\pm})$	0.367±0.014	[35, 39, 43, 50, 54]
ω		1.084±0.086	[35, 47, 58]
ϕ		0.0966±0.0073	[35, 43, 57]
N	p	1.037±0.040	[36, 44, 51]
Λ		0.388±0.011	[37, 40, 48, 55]
Σ	$\frac{1}{3}\,(\Sigma^-+\Sigma^0+\Sigma^+)$	0.089±0.005	[35, 42, 31, 49, 56]
Ξ	Ξ^-	0.0265±0.0011	[35, 40, 55]
Δ	Δ^{++}	0.088±0.035	[38, 52]
Σ^*	$\frac{1}{2}\,\Sigma^{*\pm}$	0.0234±0.0022	[35, 40, 55]
Ξ^*	Ξ^{*0}	0.0058±0.0010	[35, 40, 55]
Ω^-		0.0013 ±0.00024	[35, 42, 55]
$a_0(980)$	$\frac{1}{2}\,a_0^\pm$	0.135±0.055	[58]
$f_0(980)$		0.147±0.011	[45, 57]
$\mathrm{K}_2^*(1430)$	$\frac{1}{2}\,(\mathrm{K}_2^{*0}+\bar{\mathrm{K}}_2^{*0})$	0.042±0.020	[45, 54]
$f_2(1270)$		0.169±0.025	[45, 57]
$f_2'(1525)$		0.012±0.006	[45]
$\Lambda(1520)$		0.0225±0.0028	[31, 55]

Table 3: Values of the parameters in Eq. (7) obtained in the four fits of this analysis.

	fit 1	fit 2	fit 3	fit 4
A	15.4±0.4	14.7±0.9	15.4±0.4	15.2±0.4
$C_{\pi/p}$	2.8±0.2	3 fixed	3 fixed	2.8±0.2
γ	0.51±0.02	0.51±0.02	0.50±0.02	0.50±0.02
b_P	4.01±0.11	4.03±0.11	3.97±0.12	3.94±0.14
$b_{V,T,S}$	4.71±0.06	4.67±0.07	4.69±0.06	4.67±0.08
b_B	2.70±0.07	2.57±0.07	2.62±0.04	2.66±0.08
N_M	1 fixed	1.04±0.06	1 fixed	1 fixed
N_B	2 fixed	2.07±0.05	2 fixed	2 fixed
$k(\eta)$	0.99 fixed	0.99 fixed	0.90±0.12	0.91±0.12
$k(\phi)$	1.99 fixed	1.99 fixed	1.94±0.09	1.94±0.09
$k(f_2')$	1.97 fixed	1.97 fixed	1.86±0.20	1.84±0.21
$k(f_0)$	0 fixed	0 fixed	0 fixed	0.09±0.13
χ^2/ndf	9.4 / 16	8.6 / 15	9.8 / 14	8.1 / 12

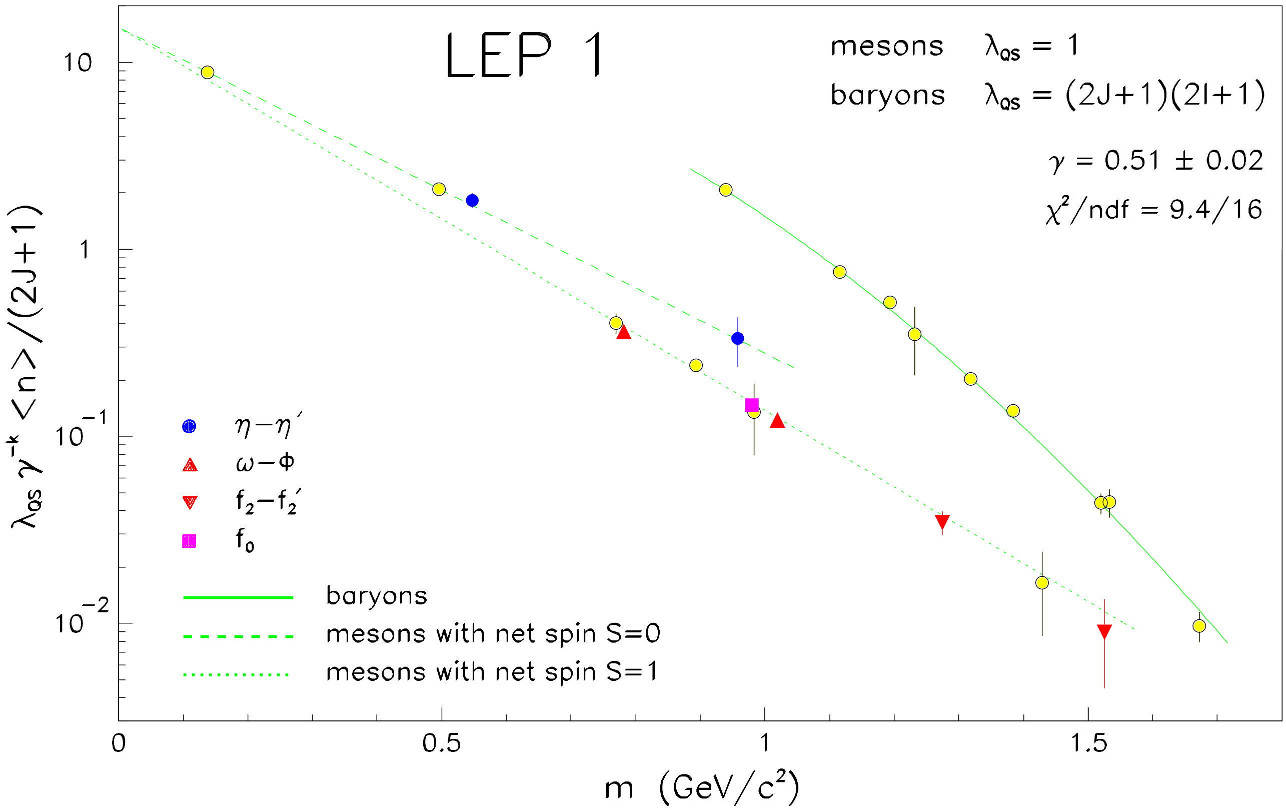

Figure 1: Total production rate per spin and isospin state weighted by a factor $\lambda_{QS}\,\gamma^{-k}$ as a function of the mass for mesons and baryons in hadronic Z decays. Curves are the result of the fit 1 (see text).

In the third fit (fit 3) the strangeness contents $k(\eta)$, $k(\phi)$ and $k(f_2')$ are free parameters. The values for $k(\eta')$, $k(\omega)$ and $k(f_2)$ are given by the constraints (9)-(11). The fixed parameters in the fit 3 are: $C_{\pi/p} = 3$, $N_M = 1$, $N_B = 2$ and $k(f_0) = 0$. The values for $k(\eta)$, $k(\phi)$ and $k(f_2')$ are found to be (see Table 3): $k(\eta) = 0.90 \pm 0.12$, $k(\phi) = 1.94 \pm 0.09$ and $k(f_2') = 1.86 \pm 0.20$. These values agree within the errors with theoretical and phenomenological analyses. Only one question in our analysis is still open. The strangeness content of the $f_0(980)$ scalar is fixed with the ad hoc value of $k(f_0) = 0$ which was suggested in Refs. [30, 32, 33, 34]. However, the recent phenomenological analyses of different physical processes suggest the $s\bar{s}$ dominance of the $f_0(980)$.

In our final fit (fit 4) only the values of $N_M = 1$ and $N_B = 2$ are fixed. All other parameters are free. Our final values for γ and $C_{\pi/p}$ (see Table 3) are:

$$\gamma \;=\; 0.50 \pm 0.02 \quad \text{and} \quad C_{\pi/p} = 2.8 \pm 0.2, \tag{15}$$

in good agreement with our previous results [32, 33, 34]. The strangeness contents of the isoscalars, the main purpose of this paper, are found to be:

$$k(\eta) \;\equiv\; 2 - k(\eta') \;=\; 0.91 \pm 0.12, \tag{16}$$

$$k(\phi) \;\equiv\; 2 - k(\omega) \;=\; 1.94 \pm 0.09, \tag{17}$$

$$k(f_2') \;\equiv\; 2 - k(f_2) \;=\; 1.84 \pm 0.21, \tag{18}$$

$$k(f_0) \;=\; 0.09 \pm 0.13. \tag{19}$$

The corresponding values of the mixing angles are given by Eqs. (9)-(12) with the values (16)-(19) for the numbers k.

Our value (16) for the number $k(\eta)$ corresponds to the following values of the singlet-octet and nonstrange-strange mixing angles:

$$\theta_P = -12.4^\circ \pm 3.5^\circ, \quad \varphi_P = 42.3^\circ \pm 3.5^\circ, \tag{20}$$

which are compared in Table 1 with the mixing angle values obtained from the well established and accepted phenomenology and from the experimental data available at present. Quite remarkably, our values (20) are compatible within the errors with the values for θ_P and φ_P obtained from very different physical processes (Table 1).

Our values (17)-(18) for the numbers $k(\phi)$ and $k(f_2')$ correspond to the following values of the vector (φ_V) and tensor (φ_T) nonstrange-strange mixing angles (our analysis is not sensitive to the sign of φ):

$$|\varphi_V| = 10^\circ \pm 8^\circ, \quad |\varphi_T| = 16^\circ \pm 11^\circ, \tag{21}$$

which are very close to the predictions $|\varphi_V| \simeq 3.4^\circ$ and $|\varphi_T| \simeq 7.3^\circ$ of most theoretical and phenomenological analyses (see, for example, Refs. [3, 14, 16, 24, 25, 26]) including the quadratic and linear GMO mass formulae [23]. The values (21) are also compatible with the "ideal" mixing angle $\varphi^{ideal} = 0$.

The value of the mixing angle φ_S for the $f_0(980)$ scalar meson is found from Eq. (12) with the value (19) for the number $k(f_0)$:

$$|\varphi_S| = 13^\circ \pm 9^\circ. \tag{22}$$

This value of the mixing angle φ_S is not consistent with the results of recent phenomenological studies. For example, the present data for decays of $f_0(980)$ into the channels $\pi\pi$, $K\bar{K}$ and $\gamma\gamma$ allow to interpret the $f_0(980)$ as either the quasi-singlet state with $\varphi_S \simeq 55^\circ$ or the quasi-octet one with $\varphi_S \simeq -43^\circ$ [11]. Also the studies of the decay processes $\phi \to \pi^0\pi^0\gamma$, $J/\psi \to \omega\pi\pi$ [27] and $D_s^+ \to f_0(980)\pi^+$ [12] have led (in terms of φ_S defined by Eq. (6)) to the values of $\varphi_S \simeq 70^\circ$ and $\varphi_S \simeq 76^\circ$, respectively.

The obtained disagreement for the $f_0(980)$ can probably be related with a question which is still open. This is whether the $f_0(980)$ belongs to the scalar $q\bar{q}$ nonet $1\,^3P_0$ or whether it should be considered as an exotic state. The scalar nonet classification can be performed in terms of so-called "bare states" (the K-matrix poles) corresponding to $q\bar{q}$ states "before" the mixing which is caused by the transitions $q\bar{q}$ *state* $\to$ *real mesons* [59, 60, 61, 10]. In this way [10] the scalar $q\bar{q}$ nonet $1\,^3P_0$ has been found to be: $f_0^{bare}(720\pm100)$, $f_0^{bare}(1260\pm30)$, $a_0^{bare}(960\pm30)$ and $K_0^{bare}(1220^{+\ 50}_{-150})$. The flavour wave functions of the orthogonal states $f_0^{bare}(720)$ and $f_0^{bare}(1260)$ are given in the form (6) by the mixing angle $\varphi_S[f_0^{bare}(720)] = -70^\circ{}^{+\ 5^\circ}_{-16^\circ}$ [10]. The transitions $q\bar{q}$ *state* $\to$ *real mesons* mix these bare states with each other as well as with nearly states. The real $f_0(980)$ meson is a result of this mixing and is related both to the $f_0^{bare}(720 \pm 100)$ and $f_0^{bare}(1260 \pm 30)$ states.

There is some interesting relation between our phenomenology and the K-matrix analysis which can be illustrated by Fig. 2, where the total production rates per spin and isospin state for vector, tensor and scalar mesons are plotted as a function of m and three curves with $k = 0$, $k = 1$ and $k = 2$ are the result of our final fit (fit 4). According to (22) the data point for the $f_0(980)$ is close to the curve with $k = 0$. As was observed by L. Montanet [62] using the figure from Ref. [33], the $f_0(980)$ data point shifted from the real mass (m = 980 MeV/c^2) to the bare mass ($m^{bare} = 720 \pm 100$ MeV/c^2) is close to the curve with $k = 2$ (Fig. 2). This fact can

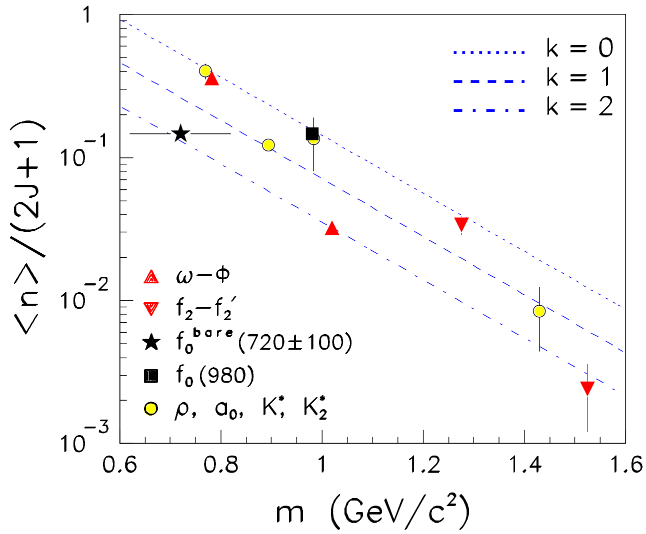

Figure 2: Total production rate per spin and isospin state as a function of the mass for vector, tensor and scalar mesons in hadronic Z decays. Curves are the result of the fit 4 (see text).

probably be considered as a speculative argument to re-determine the strangeness content of the $f_0(980)$ using our phenomenology, but replacing the real mass of the $f_0(980)$ to the bare one. Therefore the fit 4 is repeated with this replacement and gives the following value of the scalar mixing angle φ_S^{bare}:

$$|\varphi_S^{bare}| = 73^\circ \pm 7^\circ \pm 24^\circ, \tag{23}$$

where the second error is due to the uncertainty ± 100 MeV/c^2 of the bare mass. This value is well consistent with the predictions of the K-matrix analysis [60, 10] and of the recent phenomenological studies [11, 12, 27]. It can be noted also that there is only one more scalar meson in our analysis, i.e. $a_0(980)$, but the real mass of this scalar is very close to the bare mass of the $a_0^{bare}(960 \pm 30)$ state. So, if the $f_0(980)$ is mostly $s\bar{s}$ state, our results for the scalar mesons suggest that its total production rates are probably given by the bare masses.

In conclusion, the new phenomenological approach has been suggested to determine the strangeness contents of light-flavour isoscalars. For the first time for this purpose the total production rates per hadronic Z decay of all light-flavour hadrons measured so far at LEP were used. So, the new physical process ($Z^0 \rightarrow hadrons$) is added to the list of ones used in the world available analyses on the mixing angle determination. Assuming the one-mixing-angle scheme, the orthogonality of the isoscalar partners and no mixing with other states and glueballs, our approach gives us the following values of the pseudoscalar, vector and tensor mixing angles: $\varphi_P = 42.3^\circ \pm 3.5^\circ$ ($\theta_P = -12.4^\circ \pm 3.5^\circ$), $|\varphi_V| = 10^\circ \pm 8^\circ$ and $|\varphi_T| = 16^\circ \pm 11^\circ$, in good agreement with the present experimental evidence. The same analysis gives us two values of the scalar mixing angle: $|\varphi_S| = 13^\circ \pm 9^\circ$ if the $f_0(980)$ is taken with the real mass, but $|\varphi_S^{bare}| = 73^\circ \pm 7^\circ \pm 24^\circ$ if the $f_0(980)$ is taken with the bare mass (K-matrix pole) of the $f_0^{bare}(720 \pm 100)$ state. Only the second value is consistent with recent phenomenological analyses. *If their conclusions are correct*, it means that in the framework of our approach the total production rates of scalar mesons are probably given by the bare masses.

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References

[1] Th. Feldmann, Int. J. Mod. Phys. **A 15** (2000) 159.

[2] L. Montanet, Nucl. Phys. (Proc. Suppl.) **B 86** (2000) 381.

[3] A. Bramon, R. Escribano, M.D. Scadron, Eur. Phys. J. **C 7** (1999) 271.

[4] F.J. Gilman, R. Kauffman, Phys. Rev. **D 36** (1987) 2761.

[5] J.F. Donoghue, B.R. Holstein, Y.-C.R. Lin, Phys. Rev. Lett. **55** (1985) 2766.

[6] J. Schechter, A. Subbaraman, H. Weigel, Phys. Rev. **D 48** (1993) 339.

[7] P. Ball, J.-M. Frère, M. Tytgat, Phys. Lett. **B 365** (1996) 367.

[8] L. Burakovsky, T. Goldman, Phys. Lett. **B 427** (1998) 361.

[9] F.G. Cao, A.I. Signal, Phys. Rev. **D 60** (1999) 114012.

[10] V.V. Anisovich et al., Phys. Atom. Nucl. **63** (2000) 1410.

[11] V.V. Anisovich, L. Montanet, V.N. Nikonov, Phys. Lett. **B 480** (2000) 19.

[12] E. van Beveren, G. Rupp, M.D. Scadron, Phys. Lett. **B 495** (2000) 300.

[13] Th. Feldmann, P. Kroll, B. Stech, Phys. Rev. **D 58** (1998) 114006.

[14] A. Bramon, R. Escribano, M.D. Scadron, Phys. Lett. **B 503** (2001) 271.

[15] T.N. Pham, Phys. Lett. **B 246** (1990) 175.

[16] M. Benayoun et al., Phys. Rev. **D 59** (1999) 114027.

[17] Mark III Collab., D. Coffman et al., Phys. Rev. **D 38** (1988) 2695.

[18] DM2 Collab., J. Jousset et al., Phys. Rev. **D 41** (1990) 1389.

[19] V.V. Anisovich et al., Phys. Lett. **B 404** (1997) 166.

[20] W.D. Apel et al., Phys. Lett. **B 83** (1979) 131.

[21] N.R. Stanton et al., Phys. Lett. **B 92** (1980) 353.

[22] Crystal Barrel Collab., C. Amsler et al., Phys. Lett. **B 294** (1992) 451.

[23] *Particle Data Group*, D.E. Groom et al., Eur. Phys. J. **C 15** (2000) 1.

[24] H.F. Jones, M.D. Scadron, Nucl. Phys. **B 155** (1979) 409.

[25] G. Dillon, G. Morpurgo, Z. Phys. **C 64** (1994) 467.

[26] D.M. Li, H. Yu, Q.-X. Shen, J. Phys. **G 27** (2001) 807.

[27] R. Delbourgo, D. Liu, M.D. Scadron, Phys. Lett. **B 446** (1999) 332.

[28] N.A. Törnqvist, M. Roos, Phys. Rev. Lett. **76** (1996) 1575.

[29] S. Ishida et al., Prog. Theor. Phys. **98** (1997) 621.

[30] V. Uvarov, Proc. of the 15th Int. Conf. on Particles and Nuclei (Uppsala, 1999), Eds. G. Fäldt et al., Nucl. Phys. **A 663** (2000) 633.

[31] DELPHI Collab., P. Abreu et al., Phys. Lett. **B 475** (2000) 429.

[32] V. Uvarov, Phys. Lett. **B 482** (2000) 10.

[33] V. Uvarov, Proc. of the 35th Rencontre de Moriond on QCD and High Energy Hadronic Interactions (Les Arcs, 2000); hep-ex/0011058.

[34] V. Uvarov, Proc. of the 30th Int. Symp. on Multiparticle Dynamics (Tihany, 2000); hep-ph/0011239; preprint IHEP 2000-47, Protvino, 2000.

[35] ALEPH Collab., R. Barate et al., Phys. Rep. **294** (1998) 1.

[36] ALEPH Collab., R. Barate et al., Eur. Phys. J. **C 5** (1998) 205.

[37] ALEPH Collab., R. Barate et al., Eur. Phys. J. **C 16** (2000) 613.

[38] DELPHI Collab., P. Abreu et al., Phys. Lett. **B 361** (1995) 207.

[39] DELPHI Collab., P. Abreu et al., Z. Phys. **C 65** (1995) 587.

[40] DELPHI Collab., P. Abreu et al., Z. Phys. **C 67** (1995) 543.

[41] DELPHI Collab., W. Adam et al., Z. Phys. **C 69** (1996) 561.

[42] DELPHI Collab., W. Adam et al., Z. Phys. **C 70** (1996) 371.

[43] DELPHI Collab., P. Abreu et al., Z. Phys. **C 73** (1996) 61.

[44] DELPHI Collab., P. Abreu et al., Eur. Phys. J. **C 5** (1998) 585.

[45] DELPHI Collab., P. Abreu et al., Phys. Lett. **B 449** (1999) 364.

[46] L3 Collab., M. Acciarri et al., Phys. Lett. **B 328** (1994) 223.

[47] L3 Collab., M. Acciarri et al., Phys. Lett. **B 393** (1997) 465.

[48] L3 Collab., M. Acciarri et al., Phys. Lett. **B 407** (1997) 389.

[49] L3 Collab., M. Acciarri et al., Phys. Lett. **B 479** (2000) 79.

[50] OPAL Collab., P.D. Acton et al., Phys. Lett. **B 305** (1993) 407.

[51] OPAL Collab., R. Akers et al., Z. Phys. **C 63** (1994) 181.

[52] OPAL Collab., G. Alexander et al., Phys. Lett. **B 358** (1995) 162.

[53] OPAL Collab., R. Akers et al., Z. Phys. **C 67** (1995) 389.

[54] OPAL Collab., R. Akers et al., Z. Phys. **C 68** (1995) 1.

[55] OPAL Collab., G. Alexander et al., Z. Phys. **C 73** (1997) 569.

[56] OPAL Collab., G. Alexander et al., Z. Phys. **C 73** (1997) 587.

[57] OPAL Collab., K. Ackerstaff et al., Eur. Phys. J. **C 4** (1998) 19.

[58] OPAL Collab., K. Ackerstaff et al., Eur. Phys. J. **C 5** (1998) 411.

[59] V.V. Anisovich, Yu.D. Prokoshkin, A.V. Sarantsev, Phys. Lett. **B 389** (1996) 388.

[60] A.V. Anisovich, V.V. Anisovich, A.V. Sarantsev, Z. Phys. **A 359** (1997) 173.

[61] A.V. Anisovich, A.V. Sarantsev, Phys. Lett. **B 413** (1997) 137.

[62] L. Montanet, private communication.