



STATE RESEARCH CENTER OF RUSSIA
INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 2001-37

V.A. Uvarov

**DETERMINATION OF THE STRANGENESS CONTENT
OF LIGHT-FLAVOUR ISOSCALARS
FROM THEIR PRODUCTION RATES
IN HADRONIC Z DECAYS AT LEP**

Talk given at the 9th International Conference on Hadron Spectroscopy, Protvino, Russia, August 25 – September 1, 2001

Protvino 2001

EXT-2001-055
26/09/2001



Abstract

Uvarov V.A. Determination of the Strangeness Content of Light-flavour Isoscalars from Their Production Rates in Hadronic Z Decays at LEP: IHEP Preprint 2001-37. – Protvino, 2001. – p. 5, figs. 3, refs.: 22.

A new phenomenological approach is suggested for determining the strangeness content 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. From the total production rates per hadronic Z decay of all light-flavour hadrons, measured so far at LEP, the values of the nonstrange-strange mixing angles are found to be $|\varphi_P| = 42.3^\circ \pm 3.5^\circ$, $|\varphi_V| = 10^\circ \pm 8^\circ$, $|\varphi_T| = 16^\circ \pm 11^\circ$ and $|\varphi_S| = 13^\circ \pm 9^\circ$. Our results on the η - η' , ω - ϕ and f_2 - f_2' isoscalar mixing are consistent with the present experimental evidence. The strangeness content obtained for the $f_0(980)$ scalar/isoscalar is not consistent with the values supported by recent model studies and is discussed further in the framework of our approach and the K -matrix analysis.

Аннотация

Уваров В.А. Определение содержания странности в изоскалярах с легкими ароматами на основе измеренных значений их выходов при адронных распадах Z-бозона на ускорителе LEP: Препринт ИФВЭ 2001-37. – Протвино, 2001. – 5 с., 3 рис., библиогр.: 22.

Предложен новый феноменологический подход для определения содержания странности в изоскалярах с легкими ароматами. Этот подход основан на феноменологических закономерностях образования адронов, связанных со спином, изоспином, содержанием странности и массой частиц. Используя полные выходы (в расчете на один адронный распад Z-бозона) всех измеренных до сих пор на ускорителе LEP адронов с легкими ароматами, были получены следующие значения углов смешивания в базисе нестранных-странных кварков: $|\varphi_P| = 42,3^\circ \pm 3,5^\circ$, $|\varphi_V| = 10^\circ \pm 8^\circ$, $|\varphi_T| = 16^\circ \pm 11^\circ$ и $|\varphi_S| = 13^\circ \pm 9^\circ$. Полученные результаты для углов смешивания η - η' , ω - ϕ и f_2 - f_2' изоскаляров согласуются с современными экспериментальными данными. Приведенный результат для содержания странности в скалярном изоскалярном $f_0(980)$ мезоне не согласуется с оценками, полученными в недавних модельных исследованиях. Это расхождение обсуждается в рамках предложенного подхода и анализа, проводимого с использованием K -матрицы.

The quark contents of pseudoscalar (P), vector (V), tensor (T) and scalar (S) mesons have been discussed many times since the discovery of unitary SU(3)-flavour symmetry. This is still quite an interesting question because the quark contents of the lightest isoscalars differ from the predictions of the SU(3) quark model and are very important SU(3)-breaking hadronic parameters.

In terms of the $n\bar{n} = (u\bar{u}+d\bar{d})/\sqrt{2}$ and $s\bar{s}$ quark basis, the strangeness contents of the physical isoscalars are given by the *nonstrange-strange mixing angles* φ_P , φ_V , φ_T and φ_S . Assuming orthogonality of the isoscalar partners and no mixing with other states and glueballs, the flavour wave functions of the η - η' pseudoscalars are defined to be $\eta = n\bar{n} \cdot \cos \varphi_P - s\bar{s} \cdot \sin \varphi_P$ and $\eta' = n\bar{n} \cdot \sin \varphi_P + s\bar{s} \cdot \cos \varphi_P$. The flavour wave functions of the ω - ϕ vectors (f_2 - f_2' tensors) are defined in a way analogous to the η - η' case, replacing $\eta \rightarrow \omega(f_2)$, $\eta' \rightarrow \phi(f_2')$ and $\varphi_P \rightarrow \varphi_V(\varphi_T)$. The flavour wave function of the $f_0(980)$ scalar is written as $f_0(980) = n\bar{n} \cdot \cos \varphi_S + s\bar{s} \cdot \sin \varphi_S$.

The values of these mixing angles have been estimated from different phenomenological and theoretical analyses (see Refs. [1-13] and references therein). Estimates of the mixing angle φ_P were obtained from the available world data on different decay processes. The corresponding average value was found to be $\varphi_P = 39.2^\circ \pm 1.3^\circ$ [2,3]. For the mixing angles φ_V and φ_T , most theoretical and phenomenological analyses (see, e.g., Refs. [4-6,13]) predict values which are close to the “ideal” mixing: $\varphi_V \simeq +3.4^\circ$ and $\varphi_T \simeq -7.3^\circ$. The interpretation of the $f_0(980)$ scalar is one of the most controversial ones in meson spectroscopy [7]. The question is whether the $f_0(980)$ consists mostly of $n\bar{n}$ or of $s\bar{s}$ states. The phenomenological analyses of the experimental data on different decay processes [9-12] favour the $s\bar{s}$ dominance of the $f_0(980)$.

Recently the strangeness contents of light-flavour isoscalars have been obtained for the first time [14] from their total production rates per hadronic Z decay at LEP. Here only some key points and the final results of that analysis [14] are discussed.

It has been shown [15-19] 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 (k) and mass (m) of the particles. These regularities can be combined into one empirical formula

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

where $H = M$ or B , $m_0 = 1$ GeV, 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 m dependence. The values of the power N_H and of the coefficient β_H are different for mesons and baryons: $N_M = 1$, $N_B = 2$ and $\beta_M = 1$, $\beta_B = 4/(C_{\pi/p} \lambda_{QS})$, where $\lambda_{QS} = (2J+1)(2I+1)$ can be interpreted as a fermion suppression factor originating from the 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. The slope b_M has two values: one for vector, tensor and scalar mesons and the other for pseudoscalar mesons. In spite of this “splitting”, Eq. (1) assumes the validity of the relation $V/P = 3$ at the zero mass limit. This difference in slopes can probably be explained by the influence of the spin-spin interaction between the quarks of the meson. However, there is no influence of the spin-orbital interaction of the quarks.

The *purpose of this analysis* [14] is to determine the mixing angles of the η - η' , ω - ϕ , f_2 - f_2' and $f_0(980)$ isoscalars from the *simultaneous* fit of Eq. (1) to the total production rates per hadronic Z decay of all light-flavour hadrons measured so far at LEP, assuming that the mixing angle φ and the strangeness contents k_1 and k_2 of the isoscalar partners are related by: $k_1 = 2 \sin^2 \varphi$ and $k_2 = 2 \cos^2 \varphi$. The strangeness contents of baryons and $I \neq 0$ mesons are taken from the predictions of the SU(3) quark model.

The total production rates *per isospin state* $\langle n \rangle$, used in the fit, were obtained by averaging the total production rates \bar{n} of hadrons belonging to the same isomultiplet. The rates \bar{n} themselves were obtained for at least one state of a given isomultiplet as a weighted-average of the measurements of the four LEP experiments (see details in Ref. [14] and references therein).

Firstly we tested the sensitivity of Eq. (1) to the values of the power N_H . In the test fit the following parameters were fixed: $\varphi_P = 44.7^\circ$, $\varphi_V = 3.7^\circ$, $\varphi_T = -7.3^\circ$ predicted by the quadratic Gell-Mann–Okubo mass formula [13], $\varphi_S = 0$ suggested as an ad hoc value in [15], and $C_{\pi/p} = 3$ predicted by quark combinatorics for production of direct or massless particles. The values obtained, $N_M = 1.04 \pm 0.06$ and $N_B = 2.07 \pm 0.05$, strongly suggest the use of the fixed values of $N_M = 1$ and $N_B = 2$ in our approach.

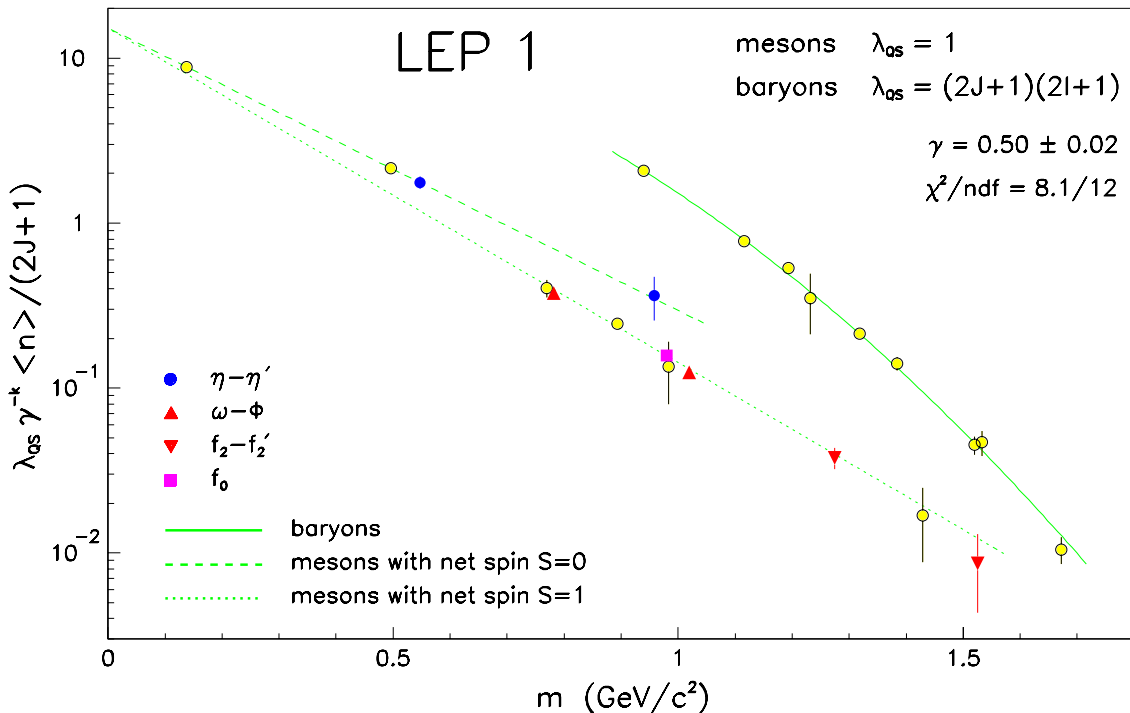


Fig. 1. Mass dependences of the total production rates per spin and isospin state for hadrons in hadronic Z decays weighted by a factor $\lambda_{QS} \gamma^{-k}$, where $\lambda_{QS} = 1$ for mesons and $\lambda_{QS} = (2J+1)(2I+1)$ for baryons. The references for all data points can be found in Ref. [14].

In the final fit only the values of $N_M = 1$ and $N_B = 2$ are fixed, all other parameters are free. This fit (with $\chi^2/\text{dof} = 8.1/12$) is illustrated in Fig. 1, where the three curves are the result of the fit for baryons, for mesons with net spin $S = 0$ (pseudoscalars), and for mesons with net spin $S = 1$ (vectors, tensors and scalars). The values of the strangeness suppression factor and of the π/p ratio at the zero mass limit are found to be $\gamma = 0.50 \pm 0.02$ and $C_{\pi/p} = 2.8 \pm 0.2$, in good agreement with our previous results [17-19]. The values of the isoscalar mixing angles are found to be $|\varphi_P| = 42.3^\circ \pm 3.5^\circ$, $|\varphi_V| = 10^\circ \pm 8^\circ$, $|\varphi_T| = 16^\circ \pm 11^\circ$ and $|\varphi_S| = 13^\circ \pm 9^\circ$. Quite remarkably, our values of the $\eta-\eta'$, $\omega-\phi$ and f_2-f_2' mixing angles are compatible within the errors with the predictions of theoretical and phenomenological analyses (see, e.g., Refs. [2-6, 13]). However, our value of the mixing angle φ_S is not consistent with the results of recent phenomenological studies which favour the $s\bar{s}$ dominance of the $f_0(980)$ scalar [9-12].

The disagreement obtained for the $f_0(980)$ can probably be related to 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) [8,20]. In this way the scalar/isoscalars have been found to be $f_0^{\text{bare}}(720 \pm 100)$ and $f_0^{\text{bare}}(1260 \pm 30)$ with the mixing angle $\varphi_S[f_0^{\text{bare}}(720)] = -70^{+5}_{-16}^\circ$.

As was observed by Montanet [21], the $f_0(980)$ data point (Fig. 2) shifted from the real mass to the “bare mass” (720 MeV) is close to the line corresponding to the mesons with $k = 2$. This interesting relation between our phenomenology and the K -matrix analysis can probably be considered as a *speculative* argument for re-determining the scalar mixing angle, replacing in the fit the real mass of the $f_0(980)$ by the “bare” one. Such a fit gives a scalar mixing angle of $|\varphi_S^{\text{bare}}| = 73^\circ \pm 7^\circ \pm 24^\circ$, where the second error is due to the uncertainty (± 100 MeV) of the “bare mass”. This value is well consistent with the predictions of recent phenomenological studies [8, 10-12].

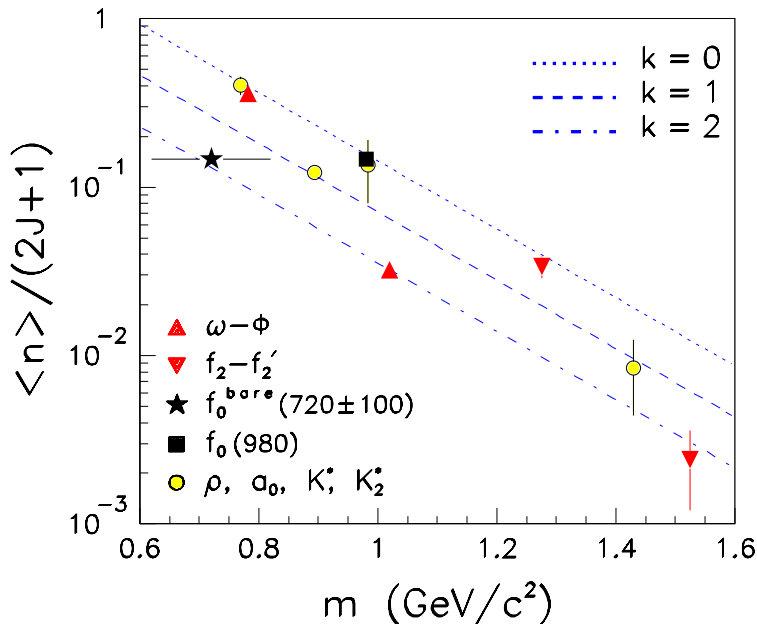


Fig. 2. Total production rate per spin and isospin state as a function of m for vector, tensor and scalar mesons in hadronic Z decays. Curves are the result of the final fit with $k = 0$, $k = 1$ and $k = 2$.

In conclusion, a new phenomenological approach has been suggested for determining the mixing angles of light-flavour isoscalars. For the first time, the total production rates per hadronic Z decay of all light-flavour hadrons, measured so far at LEP, have been used for this purpose. The following values of the pseudoscalar, vector and tensor mixing angles have been obtained: $|\varphi_P| = 42.3^\circ \pm 3.5^\circ$, $|\varphi_V| = 10^\circ \pm 8^\circ$ and $|\varphi_T| = 16^\circ \pm 11^\circ$, in good agreement with the present experimental evidence. Also two values of the scalar mixing angle have been obtained: $|\varphi_S| = 13^\circ \pm 9^\circ$ 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” 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”.

In addition, after this analysis had been published [14] the DELPHI Collaboration presented the *preliminary* results [22] on the measurement of inclusive production of two axial-vector mesons $f_1(1285)$ and $f_1(1420)$ in hadronic Z decays at LEP. Their total production rates per hadronic Z decay are compared in Fig. 3 with all the available data for those mesons with net spin $S=1$. It is seen that both $f_1(1285)$ and $f_1(1420)$ mesons come very close to the line corresponding to other mesons with $k=0$. According to our approach it suggests that the quark constituents of these mesons are mainly of the type $n\bar{n}$.

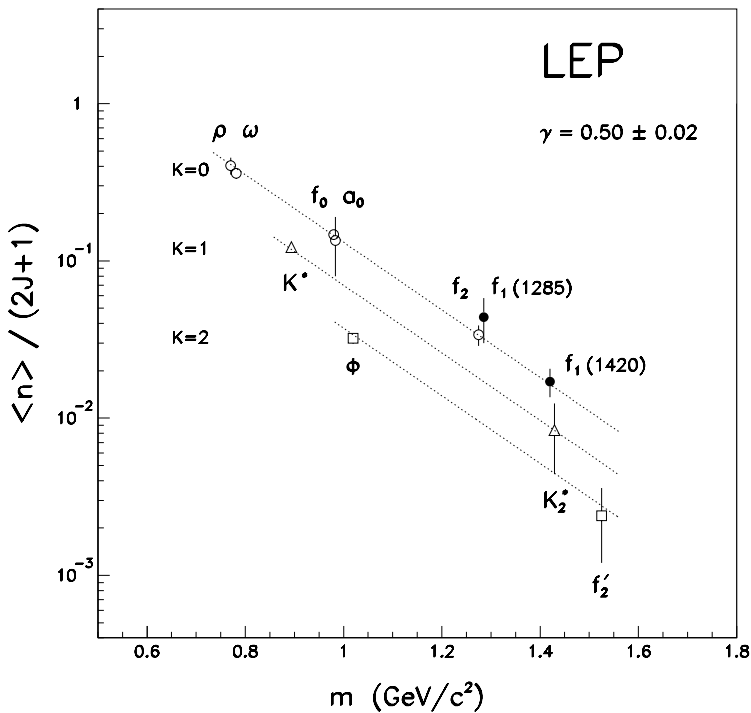


Fig. 3. Total production rate per spin and isospin state for vector, tensor and scalar mesons in hadronic Z decays as a function of the mass (open symbols). The two solid circles correspond to the axial-vector mesons $f_1(1285)$ and $f_1(1420)$.

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Received September 26, 2001

Препринт отпечатан с оригинала-макета, подготовленного автором.

В.А. Уваров

Определение содержания странности в изоскалярах с легкими ароматами на основе измеренных значений их выходов при адронных распадах Z-бозона на ускорителе LEP.

Оригинал-макет подготовлен с помощью системы L^AT_EX.

Подписано к печати 06.10.2001. Формат 60 × 84/8.
Офсетная печать. Печ.л. 0.62. Уч.-изд.л. 0.5. Тираж 160. Заказ 155.
Индекс 3649. ЛIP №020498 17.04.97.

ГНЦ РФ Институт физики высоких энергий
142284, Протвино Московской обл.

