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e^+e^- ANNIHILATION INTO HADRONS BELOW 2 GeV. TEST OF Q C D PREDICTIONS

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e^+e^- ANNIHILATION INTO HADRONS BELOW 2 GeV. TEST OF Q C D PREDICTIONS

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A b s t r a c t

Results of comparison of Q C D predictions with experimental data on e^+e^- annihilation into hadrons with $I = 1$ are presented. It is shown that experimental data follow the expected pattern of the breaking of asymptotic freedom by power corrections.

where M is an external parameter with the dimension of mass,

$$R^{I=1} = \frac{\sigma(e^+e^- \to hadrons, I=1)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

α_s is the strong coupling constant, $G^a_{\mu\nu}$ is the gluon field strength operator, q is the light quark (u or d) field operator. The derivation details can be found in /1/, where the following estimates for the vacuum expectation values have been obtained:

$$\langle 0 | \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^a_{\mu\nu} | 0 \rangle \simeq 1.2 \cdot 10^{-2}\ GeV^4,$$
$$\alpha_s |\langle 0 | \bar{q} q | 0 \rangle|^2 \simeq 1.8 \cdot 10^{-4}\ GeV^6 . \quad (2)$$

For $\alpha_s(M)$ the expression

$$\frac{\alpha_s(M)}{\pi} = \frac{1}{4.5 \ln \frac{M}{\Lambda}} = \frac{1}{10.6 + 4.5 \ln M}, \quad \Lambda = 0.095\ GeV,$$

normalized to 0.2 at $M = m_{J/\psi}$ has been used. Note that the sum rule (1) is valid as far as power corrections $\propto 1/M^4$, $1/M^6$ do not become dominant.

In Refs. 1 the eq. 1 has been applied to the calculation of the ρ - meson parameters (mass and leptonic width). It is essential for this calculation that the integral (1) over the experimental cross section at the values of the parameter $M \sim m_\rho$ is dominated by the ρ - peak contribution, while that of continuum is rather small.

To compare the sum rule (1) with the experiment at higher values of M the detailed information on the continuum region is needed. We shall consider values of M less than 2 GeV. For such range of M the integral (1) is dominated by the energy region $\sqrt{s} < 2$ GeV for which experimental data on $R^{I=1}(s)$ are available.

Figure 1 presents the modern status of these data. They include the processes $e^+e^- \to 2\pi$, 4π, 6π. The data in the region of the ρ - meson peak and that left to it are taken from the experiments in Novosibirsk /2,3/ and Orsay /4-6/. The region above the ρ -peak and up to 1.34 GeV has recently been studied with good precision in the Novosibirsk experiment /7,8/. In the region of $\sqrt{s}$ higher than 1.34 GeV the data of Frascati /9/ on the reaction $e^+e^- \to \pi^+\pi^-$ and those of Orsay (DCI) /10,11/ on the multipionic production have been used.

Some comments are in order. First of all we neglect the contribution to $R^{I=1}$ of the processes involving K- and η - mesons, because there is experimental evidence for the smallness of the corresponding cross sections in the energy region under consideration /9, 10/.

The second point is that of experimental errors. It is clear that statistical errors of separate experimental points do not result in a large error of the integral (1), systematical errors being the most dangerous. The latter are especially large in the region of $\sqrt{s} > 1.4$ GeV, where many different channels are opened. The authors /10/ estimate this error as 25%. In this connection note that the values of the cross-section in this region presented by the Orsay group to the Tokyo Conference /11/ are about 30% below their preliminary results /10/. The latest data are confirmed by the recent Frascati experiment /11/, therefore we use them in our calculations.

The last comment is about the values of $R^{I=1}$ at $\sqrt{s} > 2$ GeV. Existing experimental data give the values of the total R only. We use for $R^{I=1}$ in this region the theoretical asymptotic estimation:

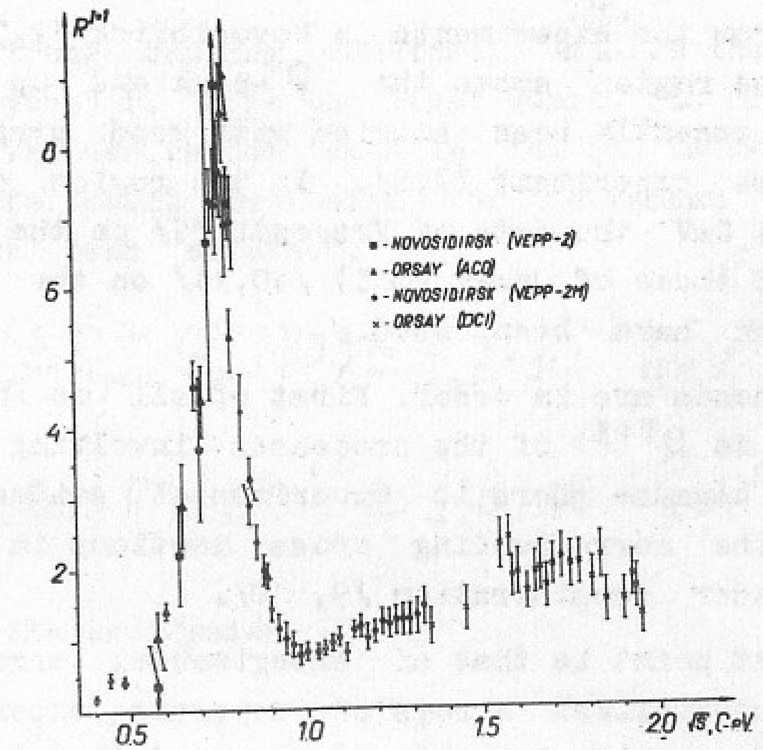

Fig. 1. Experimental data on $R^{I=1}(s)$.

$$R^{I=1}(s) = \frac{3}{2}\left[1 + \frac{\alpha_s(\sqrt{s})}{\pi}\right] . \qquad (3)$$

It is necessary to underline that the contribution of this region to the integral (1) is small. It grows with M up to a 30% level at M = 2 GeV (but for M = 1.3 GeV it is only 9%).

The results of comparison are presented in Fig. 2. The shaded area corresponds to a 25% systematical uncertainty mentioned above. It is clear that the width of the shaded area characterizes the relative contribution of the data with 1.34 GeV $< \sqrt{s} <$ 2 GeV. In particular, for M = 1.1GeV this region gives only 17%, while the dominant contribution comes from the ρ - meson region. One can see that the theoretical curve is in good consistence with the experiment up to the very low values of M. The deviation becomes considerable at $M <$ 0.6 GeV. The theoretical reason is that the power corrections become large and it is necessary to know the next terms of the power expansion, the eq. (1) being no longer valid at such small M.

It is amusing that the asymptotic freedom regime for the integral (1) over $R^{I=1}(s)$ is achieved very early and sharply as compared with the quantity $R^{I=1}(s)$ itself. It is this very property that correlates asymptotic freedom and resonance parameters.

In Fig. 3 we present the results of comparison with the experiment for the quantity

$$\int_{4m_\pi^2}^{\infty} s e^{-s/M^2} R^{I=1}(s)\, ds \qquad (4)$$

which can be obtained from (1) by differentiating over $1/M^2$. Therefore, this test is not independent. However, for the

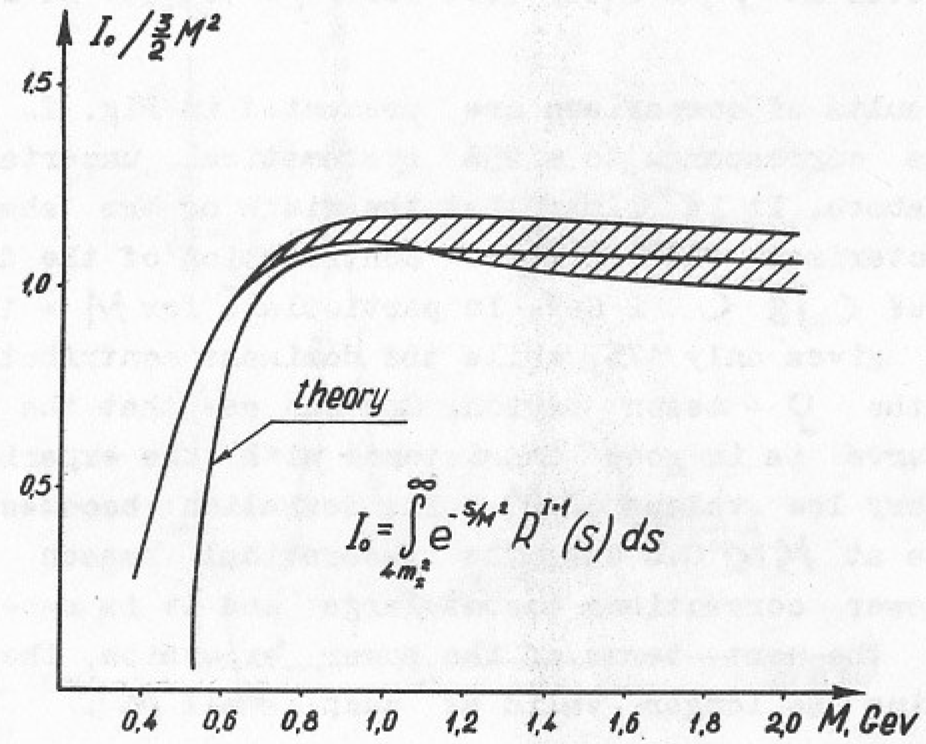

Fig. 2. Comparison of the first sum rule with the experiment.

integral (4) the relative contributions of the different energy regions vary as compared with (1), the higher energies being more essential.

It is interesting to extract α_s and vacuum matrix elements from the comparison of the formula (1) with the experimental data independently of the theoretical estimates (2). To this end we apply the following procedure. To proceed to the region of M as low as possible, where the experimental precision is higher, the term proportional to $1/M^8$ has been added to (1). The coefficients in power terms $1/M^4$, $1/M^6$, $1/M^8$ are fitted under the conditions: i) the theoretical curve lies inside the shaded area of systematical errors, ii) the contribution of the $1/M^8$ term doesn't exceed 10% of that $\propto 1/M^6$. The latter condition provides the smallness of higher power terms.

The described procedure allows to reproduce the experimental curve beginning from M as low as 0.6 GeV with the following parameters:

$$\Lambda = 0.17\ GeV,$$
$$\langle 0|\frac{\alpha_s}{\pi} G^a_{\mu\nu} G^a_{\mu\nu}|0\rangle = 0.61\cdot 10^{-2}\ GeV^4, \qquad (5)$$
$$\alpha_s\, |\langle 0|\bar{q}q|0\rangle|^2 = 1.2\cdot 10^{-4}\ GeV^6.$$

If a weaker requirement, that the coincidence starts from M = 0.65 GeV, is imposed, one comes to the limits:

$$0.07\ GeV < \Lambda < 0.21\ GeV,$$
$$0.30\cdot 10^{-2}\ GeV^4 < \langle 0|\frac{\alpha_s}{\pi} G^a_{\mu\nu} G^a_{\mu\nu}|0\rangle < 2.1\cdot 10^{-2}\ GeV^4, \qquad (6)$$
$$1.2\cdot 10^{-4}\ GeV^6 < \alpha_s |\langle 0|\bar{q}q|0\rangle|^2 < 2.4\cdot 10^{-4}\ GeV^6.$$

The values of parameters in (5) and (6) should be compared to the estimates (2).

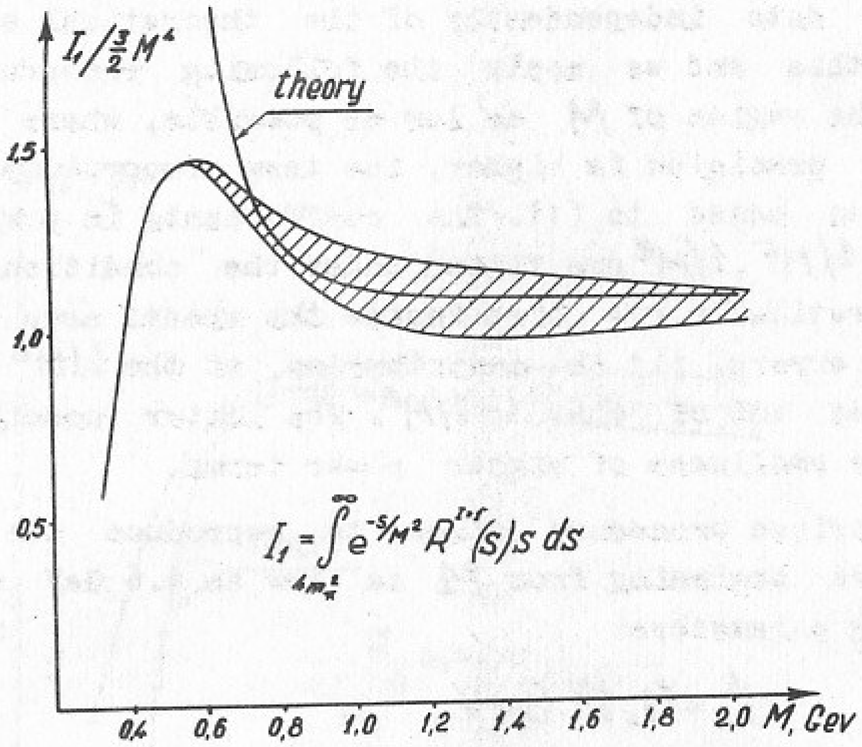

Fig. 3. Comparison of the second sum rule with the experiment.

The general conclusion is that the experimental data follow the expected pattern of the breaking of asymptotic freedom in Q C D. The further increase of the experimental pre precision will provide the possibility to determine the interesting parameters characterizing the Q C D vacuum. Thus, we call upon new experimental efforts in the energy re - gion $\sqrt{s} < 2$ GeV.

R e f e r e n c e s

1. M.A.Shifman, A.I.Vainshtein, V.I.Zakharov. Preprints ITEP-73, 80, 81, Moscow, 1978.
2. V.L.Auslander et al. Yadernaya Fizika, 9 (1969) 114.
3. I.B.Vasserman et al. Report at the Irkutsk Conference on Strong Interactions at Low Energies, 1978.
4. J.E.Augustin et al. Phys. Lett. 28B (1969) 508.
5. G.Cosme et al. Phys. Lett. 39B (1972) 289.
6. A.Quenzer et al. Phys. Lett. 76B (1978) 512.
7. A.D.Bukin et al. Phys. Lett. 73B, (1978) 226.
8. V.A.Sidorov. Proceedings of the 18 International Confe - rence on High Energy Physics, v. 2, B13, Tbilisi, 1976.
9. M.Bernardini et al. Phys. Lett. 46B (1973) 261.
10. G.Cosme et al. Preprint LAL-30, Orsay, 1977.
11. See the rapporteur's talk of G.J.Feldman at the Tokyo Conference, 1978.

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