FROM VECTOR MESONS TO Q^2 or QUARK-HADRON DUALITY

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Vector Meson Dominance (VMD)

An approach to deal with e. m. interactions of hadrons

J. J. Sakurai, “Theory of strong interactions’’, Ann. of Phys. 11 (1960) 1.
Vector mesons: gauge fields, universally coupled to hadrons via covariant derivatives (Yang-Mills).

Contrasting with theories treating all hadrons at the same level:

S-matrix unitarity and analicity,
Regge poles and linear trajectories,
Veneziano crossing-symmetric amplitude,
duality and FESR (strong interactions), ...

Today: Chiral Perturbation Theory (Gasser and Leutwyler, 1979)
vs
Gauge bosons in Hidden Symmetry (Bando et al. 1985)

Vector Meson Dominance 2 (VMD)

$$\frac{e m_{V^0}^2}{f_{V^0}} \qquad V^0 = \rho^0, \omega, \phi$$

Two paradigmatic applications:

1. Strong and radiative decays of P and V mesons

$$\omega \to \rho\pi \to \pi^+\pi^-\pi^0 \qquad \omega \to \pi^0\rho^0 \to \pi^0\gamma \qquad \pi^0 \to \omega\rho^0 \to \gamma\gamma$$

2. Total photoproduction cross section off nucleons related to forward photoproduction of VMs

$$\sigma_{\rm tot}(\gamma p) = \sum_{V=\rho^0,\omega,\phi} \frac{4\pi e}{f_V} \sqrt{\frac{1}{1+\eta_V^2} \frac{{\rm d}\sigma_0}{{\rm dt}}(\gamma p \to V p)}$$

Extended VMD

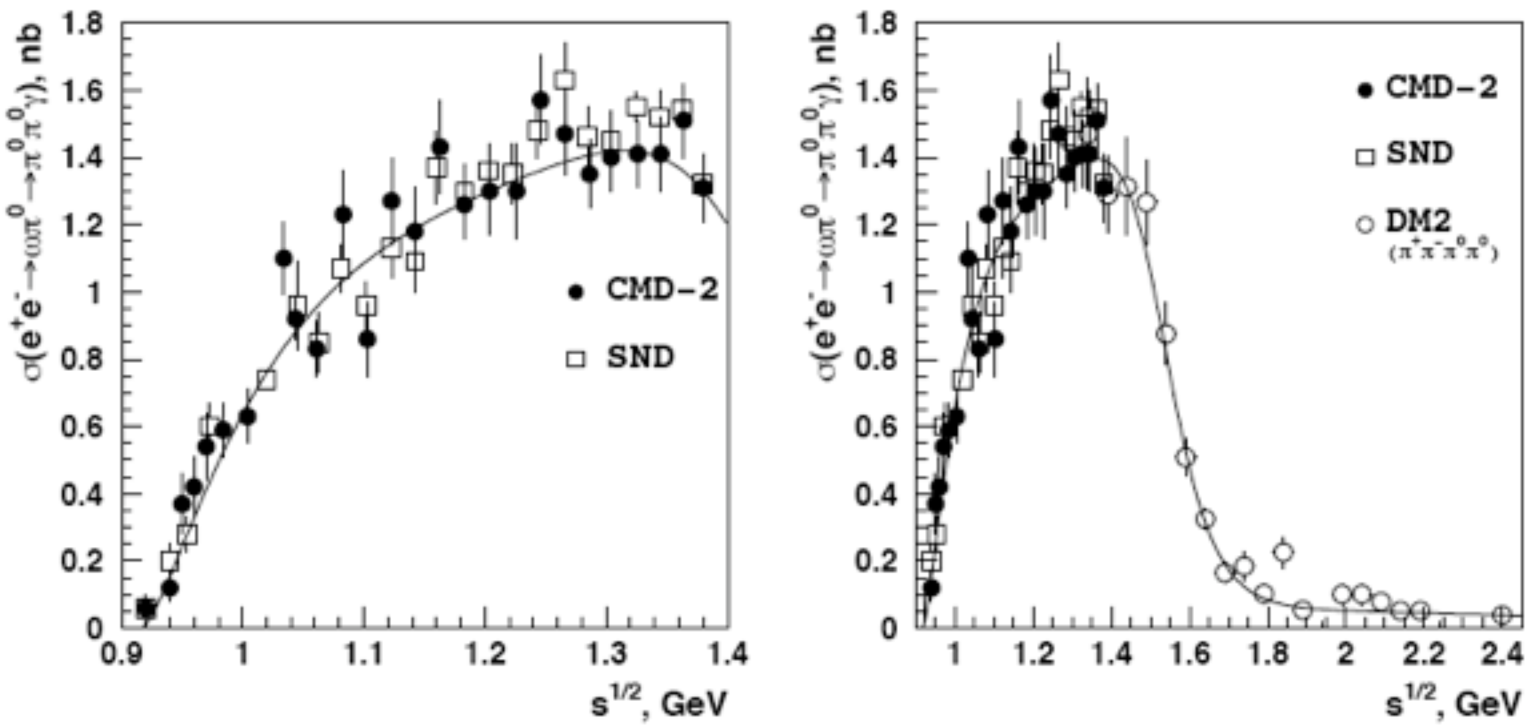
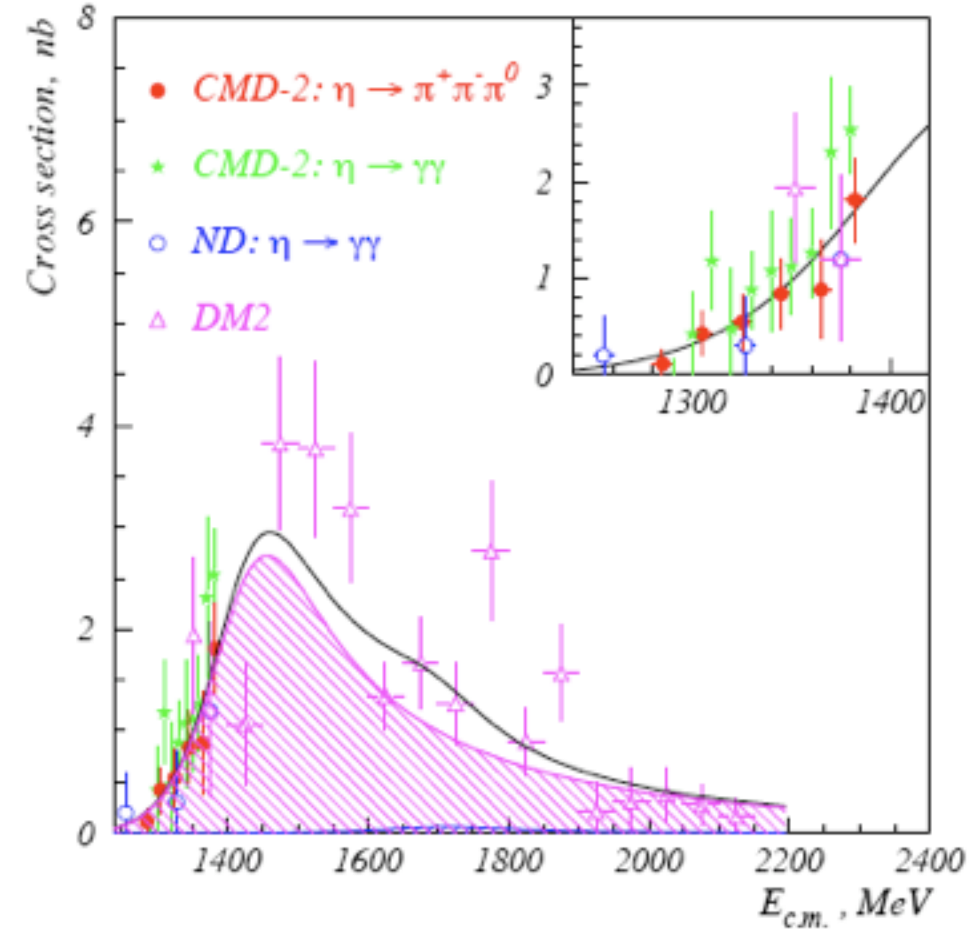


Fig. 3. The cross section of the process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$. The results of CMD-2 (this work), SND [9] and DM2 [5] are shown. The curves are the results: a fit to the CMD-2 data only (Fit I, left) and a combined fit to the CMD-2 and DM2 data (Fit II, right).

$$\sigma_{e^+e^-\to\omega\pi^0}(m^2_{\rho'}) \simeq 36 \text{ nb}$$

$$\sigma_{e^+e^-\to\omega\pi^0\to\pi^0\pi^0\gamma}(m^2_{\rho'}) \simeq 3 \text{ nb}$$



(b) $e^+e^- \to \eta\pi^+\pi^-$ cross section.

$$\sigma_{e^+e^-\to\rho\eta\to\pi^+\pi^-\eta}(m^2_{\rho'}) \simeq 2 \text{ nb}$$

A.B. and M. Greco, Lett. Nuovo Cim. 1 (1971) 739;
A.B. and M. Greco, Lett. Nuovo Cim. 3 (1972) 693;
G. Barbarino et al., Lett. Nuovo Cim. 3 (1972) 689;
A.B. and M. Greco, Nuovo Cim. 14 A (1973) 323

$$m_{\rho'} \simeq 1.5 \text{ GeV}$$

$$\frac{g_{\rho'\omega\pi} f_\rho}{g_{\rho\omega\pi} f'_\rho} \simeq -0.16$$

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A VECTOR MESON DOMINANCE APPROACH TO SCALE INVARIANCE

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Received 21 July 1972

A model of scale invariance for both deep inelastic scattering and e^+e^- annihilation incorporating an infinite number of vector mesons is proposed. Structure functions are calculated explicitly in good agreement with experiments. Precocious scaling arises naturally in the model.

Mario Greco, "Deep-inelastic processes", Nucl. Phys. B63 (1973) 398

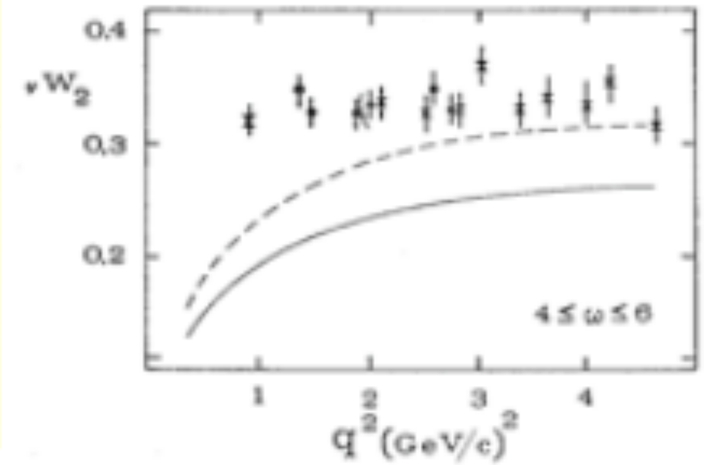


FIG. 3a

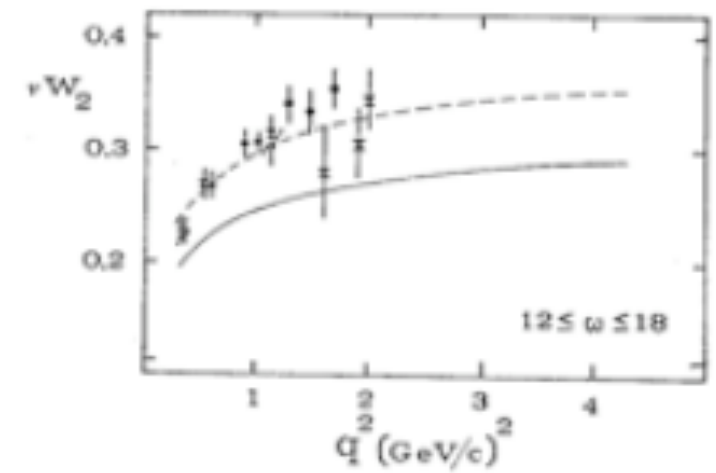


FIG. 3b

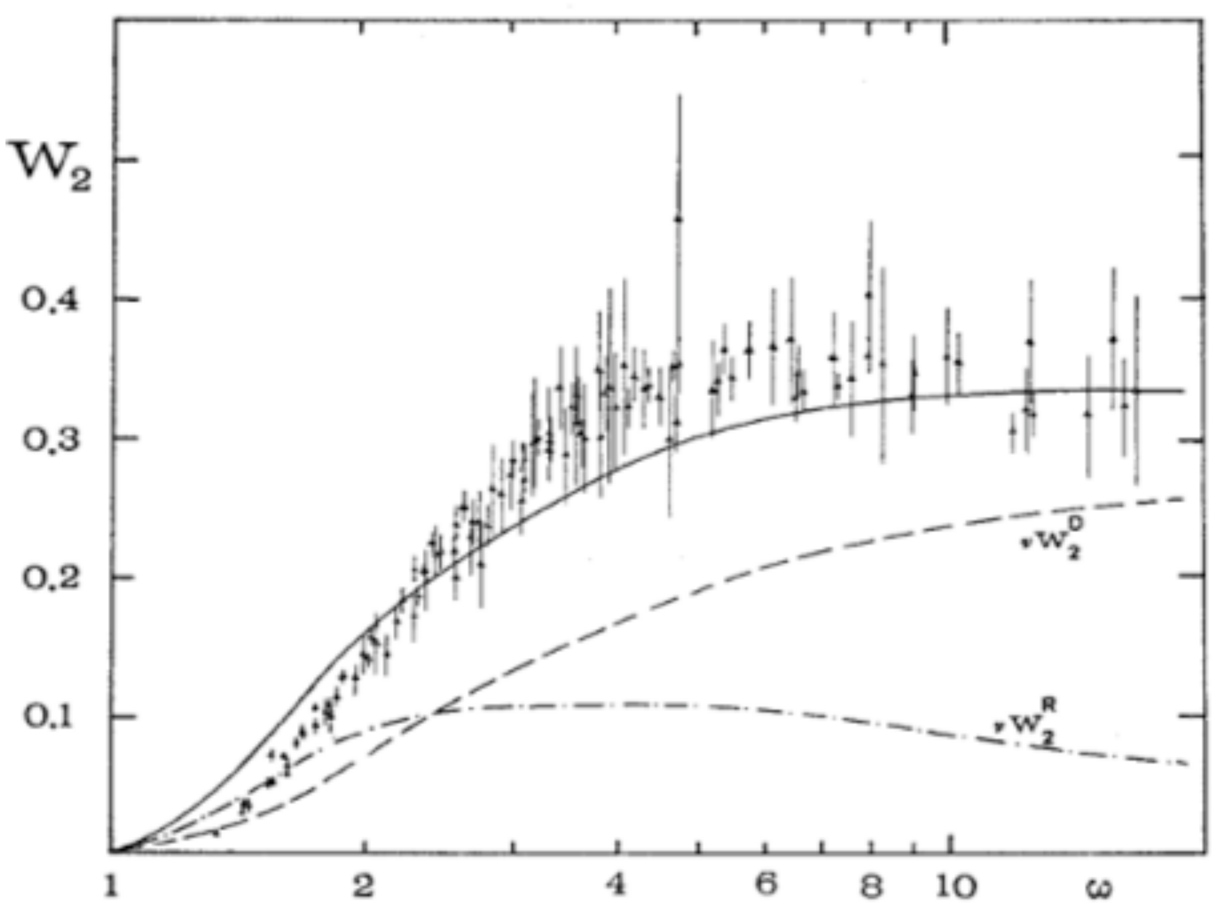


FIG. 2 - Diffractive (D) and non-diffractive (R) contributions to the transverse part of $\nu W_2(\omega)$. See the main text for details.

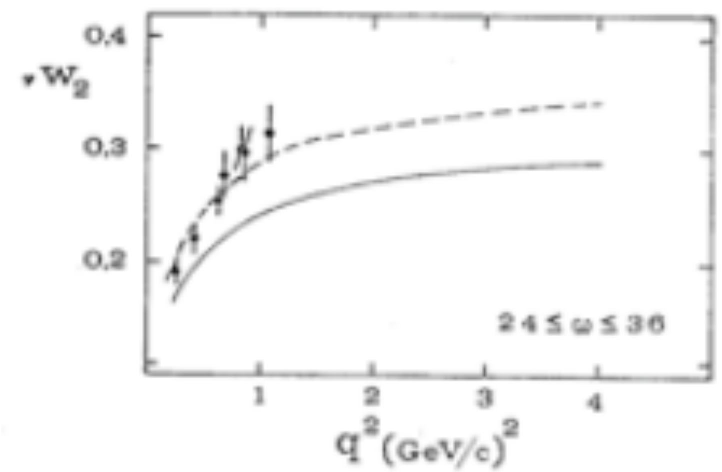
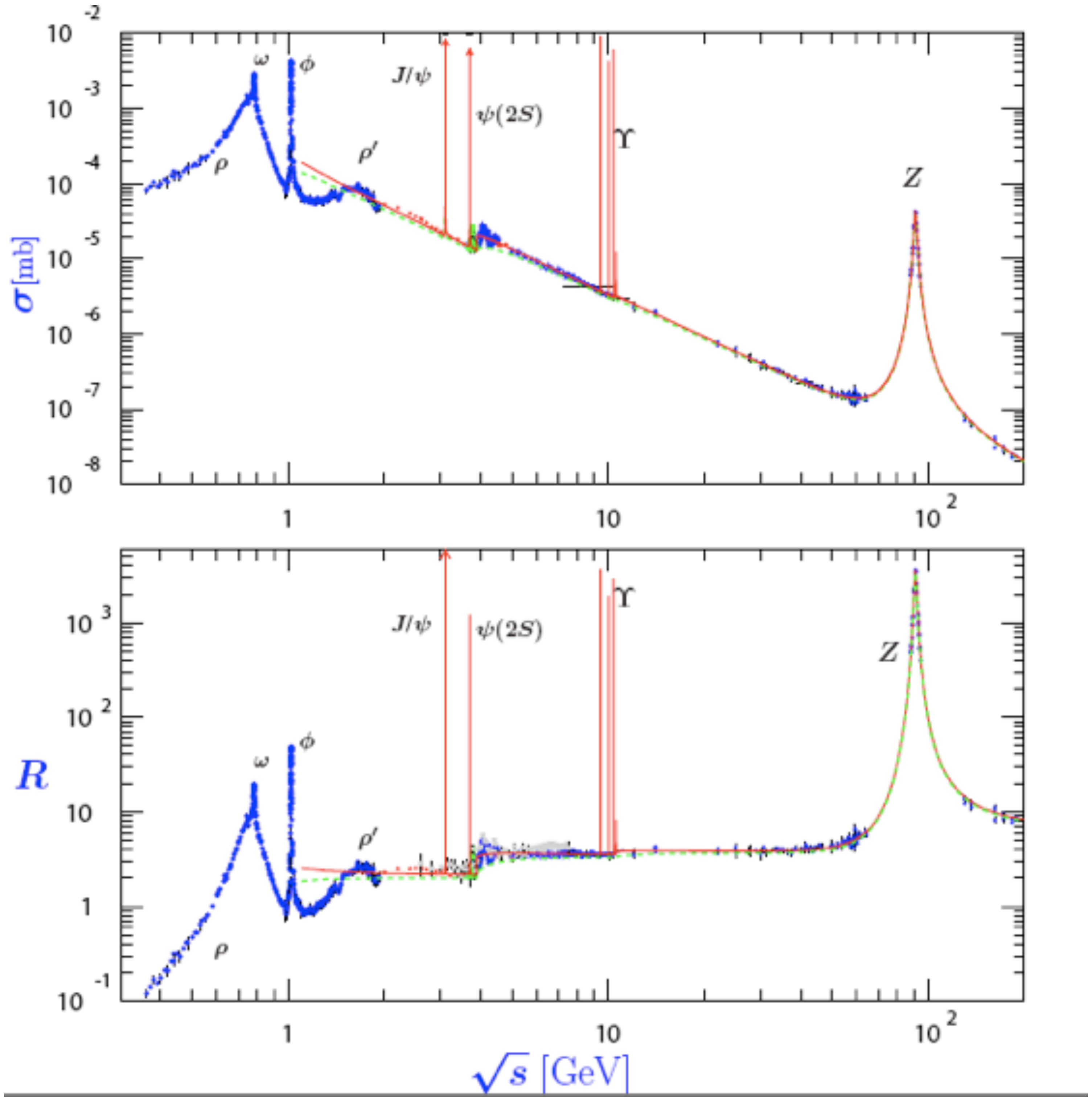


FIG. 3c

FIG. 3 - $\nu W_2(q^2)$ for various ranges of ω. Theoretical predictions (full and dashed lines as in Fig. 1) correspond to the values: a) $\omega = 5$, b) $\omega = 15$ and c) $\omega = 30$.



σ [mb]
R
√s [GeV]
ω
φ
ρ
ρ′
J/ψ
ψ(2S)
Υ
Z

DUALITY IN $e^+ + e^- \to$ HADRONS?★

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A new kind of duality relation is conjectured between vector meson formation and scaling ($1/s$) behavior in the total cross section $\sigma_{had}(s)$ for $e^+ + e^- \to$ hadrons On the basis of a finite-energy sum rule we demonstrate that the parameters of the ρ, ω and ϕ peaks are sufficient to determine the asymptotic value of $\sigma_{had}(s)$ to be three to five times the muon pair cross section provided $\sigma_{had}(s)$ goes like $1/s$ at high energies.

The total hadronic cross section in electron-positron collisions, denoted by $\sigma_{had}(s)$, is commonly believed to be made up of two independent and unrelated components – the ρ, ω and ϕ peaks without any background at low energies and the multihadron continuum perhaps exhibiting $1/s$ (scaling or "point-like") behavior [1] at high energies. Recently, however, this popular view was challenged for two reasons. First, there is now evidence for a higher-mass vector meson ρ' at $\sqrt{s} \approx 1.6$ GeV [2]; it is conceivable that there are many more vector mesons buried in the "Frascati continuum". Second, Greco and collaborators [3] have proposed an interesting model where the $1/s$ behavior of the colliding-beam cross section is built up from an infinite series of vector meson peaks in much the same way as smooth Regge behavior results from summing up a series of s-channel resonances in dual models of strong interactions. In this note we examine further empirical consequences of the conjecture that there is "duality" between vector meson formation and scaling behavior.

We begin by reviewing briefly the model of ref. [3]. Suppose hadron production in electron-positron collisions is completely dominated by vector meson formation. We can then write

$$\sigma_{had}(s) = \frac{12\pi}{s}\sum_V \frac{m_V^2\Gamma_V\Gamma_V(V\to e^+e^-)}{(s-m_V^2)^2 + m_V^2\Gamma_V^2}$$
$$= \sigma_{\mu\ pair}(s)\sum_V\left\{\frac{3}{(f_V^2/4\pi)}\ \frac{m_V^3\Gamma_V}{(s-m_V^2)^2+m_V^2\Gamma_V^2}\right\} \quad (1)$$

where em_V^2/f_V is the usual γ-V coupling constant and $\sigma_{\mu\ pair}(s)$ is the muon pair cross section ($s \gg m_\mu^2$)

$$\sigma_{\mu\ pair}(s) = 4\pi\alpha^2/3s. \quad (2)$$

One immediately sees that if $\sigma_{had}(s)$ at high energies is to behave like $1/s$ on the average, there must be an infinite number of vector meson states[†1]. Furthermore, the $1/s$ behavior is realized on the average only when a special relation exists between the density of vector meson states and the coupling constant, viz.,

$$P_V(m^2)m_V^2/f_V^2 = \text{const} \quad (3)$$

where $P_V(m^2)$ stands for the number of vector meson states per unit squared mass interval. Assuming that (a) the $1/s$ behavior is obtained on the average even for the prominent low-lying vector mesons, (b) the $I = 1$ vector meson spectrum is given by

$$m_n^2 = m_\rho^2(1+2n),\ n = 0, 1, 2 \ldots \quad (4)$$

as in the Veneziano model [4] and (c) the isoscalar contribution is 1/3 times the isovector contribution, Greco and collaborators [3] succeeded in deriving a remarkable relation

$$R \equiv \lim_{s\to\infty} \sigma_{had}(s)/\sigma_{\mu\ pair}(s) = 2\pi/(f_\rho^2/4\pi) \approx 2.5\ , \quad (5)$$

which is consistent with the Frascati data (see below).

Let us now look at this problem from a somewhat more general point of view. As is well known, the colliding beam cross section $\sigma_{had}(s)$ is related to the imag-

†1 We assume that for a given vector meson V, Γ_V and $\Gamma(V\to e^+e^-)$ are s independent numbers. With sufficiently complicated "tails" anything is possible.

Duality and the "new" Vector Mesons

$$
\begin{aligned}
R &= R_{u,d,s} + R_{charm} \\
&\simeq 2.5 + 1.2 \quad \text{or} \\
&\simeq 2.5 + 1.8 \quad \text{rad. corrections}
\end{aligned}
$$

C.A. Domínguez and M. Greco (December 74), Lett. Nuovo Cim. 12 A (1975) 439;
M. Greco, G. Pancheri-Srivastava and Y. Srivastava, Phys. Lett. B56 (1975) 367:

$$
\Gamma(\Upsilon(b\bar{b}) \to e^+e^-) \simeq 1.2\ \mathrm{keV}
$$

$$
Q_{b-\mathrm{quark}} = -1/3
$$

Mario Greco (January 78), Phys. Lett. 77B (1978) 84;

Duality Sum Rules

From canonical trace anomalies of energy-momentum tensor:

$$\int_{s_0}^{\bar{s}} ds\, s^n Im\,\Pi(s) = \frac{\alpha R}{3} \frac{\bar{s}^{n+1}}{n+1} - \frac{c_n}{n+1}$$

In particular,

$$\int_{s_0}^{\bar{s}} ds \left(Im\,\Pi(s) - \frac{\alpha R}{3} \right) = 0$$

$$\begin{aligned} Im\,\Pi(s) &= \frac{s}{4\pi\alpha}\sigma_{\text{hadrons}}(s) \\ &= 4\pi^2\alpha\frac{m_\rho^2}{f_\rho^2}\sum_n \delta(s - m_n^2) \end{aligned}$$

E. Etim and M. Greco,
Lett. Nuovo Cim. 12 (1975) 91;

Generalization to axial-vectors and strange-vector channels:

E. Etim, M. Greco and Y. Srivastava, Lett. Nuovo Cim. 16 (1976) 65;

Shifman, Vainshtein and Zakharov Sum Rules or QCD Sum Rules 1979