Vol. 31 (2000) ACTA PHYSICA POLONICA B No 10–11

HADRON ELECTROMAGNETIC FORM FACTORS AND QCD*

Masami Nakagawa

Department of Physics, Meijo University Tempaku Nagoya 468-8502, Japan

Hirohisa Ishikawa

Department of Economics, Meikai University, Urayasu, Chiba 279-8550, Japan

and Keiji Watanabe

Department of Physics, Meisei University Hino Tokyo 191-8506, Japan

(Received June 29, 2000)

Electromagnetic form factors of hadrons are studied with recourse to the superconvergent dispersion relation, by which the QCD prediction and the VMD are synthesized. We analyzed experimental data of pion, kaon and nucleon form factors and obtained reasonable agreement with experiments. The experiments on the electromagnetic form factors are expected to provide important data in investigating structure of hadrons.

PACS numbers: 11.55.Fv, 24.85.+p, 13.40.Gp

According to the perturbative QCD, the hadron electromagnetic form factor decreases more rapidly than a power in the squared momentum transfer t [1]. For the pseudo-scalar boson the form factor becomes

$$F_B(t) \to -32\pi^2 f_B^2/\beta_0 t \ln(|t|/\Lambda^2) \quad (t \to \infty),$$

where f_B is the decay constant of the boson B and Λ is the QCD scale parameter. For the nucleon form factors F_1 and F_2, the charge and magnetic moment form factors respectively, become asymptotically

$$F_1 \to t^{-2}[\ln(|t|/Q_0^2)]^{-\gamma},\ F_2(t) \to t^{-3}[\ln(|t|/Q_0^2)]^{-\gamma} \quad (t \to \infty), \tag{1}$$

* Presented at the Meson 2000, Sixth International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19–23, 2000.

where Q_0 is a constant and $\gamma = 2 + 4/3\beta_0$, $\beta_0 = 11 - 2n_f/3$ with n_f being the number of flavor.

These conditions are realized by utilizing the following asymptotic formula of the dispersion integral for $t \to \infty$ [2]:

$$\int_{s_0}^{\infty} dt' \frac{1}{(t'-t)\ln^{\nu}(t'/Q_0^2)} \;\to\; \frac{1}{(\nu-1)\ln(|t|/Q_0^2)}, \tag{2}$$

where ν is a constant with $\nu > 1$. Let the function $F(t)$ be given by the dispersion integral

$$F(t) = \int_{s_0}^{\infty} dt' \frac{\mathrm{Im}F(t')}{t'-t} \tag{3}$$

satisfying the superconvergence condition

$$\int_{s_0}^{\infty} dt' t'^k \mathrm{Im}F(t') = 0, \quad k = 0, 1, \cdots, n \tag{4}$$

and the imaginary part $\mathrm{Im}F(t')$ be given asymptotically as $t'^{n+1}\mathrm{Im}F(t') \to c/\ln^{\nu}(t'/Q_0)$, $(t \to \infty)$ then for $t \to \infty$

$$F(t) \to c/(\nu-1)t^n \ln^{\nu-1}(t/Q_0^2).$$

For the boson form factor we assume that the absorptive part is given as summation over the Breit–Wigner and the QCD terms, $\mathrm{Im}F^{\mathrm{BW}}$ and $\mathrm{Im}F^{\mathrm{QCD}}$, respectively. We take into account mixing among resonaces. F^{QCD} is assumed to be given as a power series in the running coupling constant of QCD, α_S. That is,

$$F^{\mathrm{QCD}}(t) = \sum_{j\geq 1} c_j^{\mathrm{QCD}} (\alpha_S(t))^j h(t). \tag{5}$$

Here $h(t)$ is a function introduced to assure the convergence of the superconvergence condition and the threshold behavior. $\mathrm{Im}F^{\mathrm{QCD}}$ is obtained by taking the imaginary part, where α_S is extended to the timelike momenta through the replacement $Q^2 = t\mathrm{e}^{-i\pi}$ [2]. We take three loop approximation for the running coupling constant.

We analyzed the data on the pion and kaon form factors, for the spacelike and timelike momenta, and obtained reasonable agreement with the experimental data [2]. It is necessary to take the masses and the widths as adjustable parameters to fit the data. Besides, mixing among resonances are necessary, especially, mixing of ω–ϕ and $\rho'(1450)$–$\rho''(1700)$ have large effect. The mass of $\rho'(1450)$ should be taken smaller and $\rho'(1700)$ larger than the experimental values. The unconfirmed heavy resonance is assumed with the mass $m_{\rho'''} = 2.11$ GeV with the width $\Gamma_{\rho'''} = 0.368$ GeV. Although the data for the timelike momentum are reproduced very well, the fit of the spacelike momentum was not good.

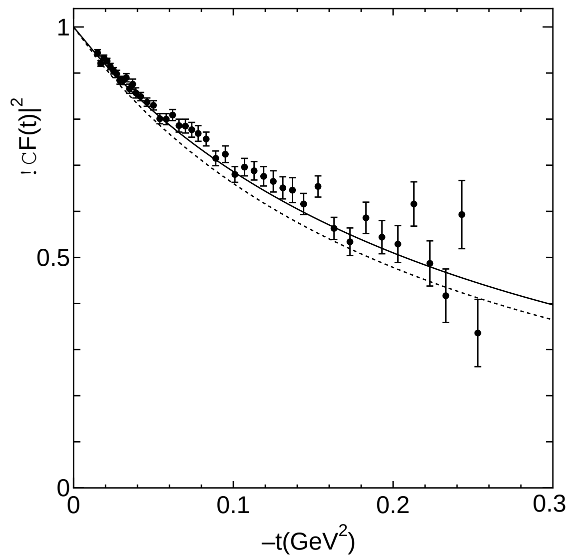

Fig. 1. The pion form factor for the spacelike momentum. The solid curve is the result with the resonance at 1.23 GeV, and the dotted one without the resonance.

In addition to these resoances here we take account of the unconfirmed resonance around the mass 1.25 GeV [5] and performed reanalysis of the data. We found that the resonance greatly improves the result for the spacelike momentum. In Fig. 1 we illustrate the result obtained by assuming the resonance with the mass 1.23 GeV (the solid curve) and the experimental data [4] together with the case without the resonance (the dotted curve) [2]. The masses and the widths of resonances, being taken as parameters, are obtained as $m_\rho = 0.76$ GeV, $\Gamma_\rho = 0.134$ GeV; $m_{\rho'} = 1.40$ GeV, $\Gamma_{\rho'} = 0.31$ GeV; $m_{\rho''} = 1.82$ GeV, $\Gamma_{\rho''} = 0.26$ GeV. The parameters appearing in our formula, definitions of which are given in Ref. [2], are summarized as follows: The residues at the ρ resonance poles are $c_\rho = 1.483$, $c_{\rho'} = 1.130$, $c_{\rho''} = -0.5524$, $c_{\rho'''} = 0.05$. The mass of the unconfirmed resonance is determined as 1.23 GeV with the residue $c_{\rho(1230)} = -0.45$. For the ω and ϕ bosons we have $c_\omega = -0.004$, $c_\phi = 0.005$. The mixing parameters are $c_{\rho\text{-}\omega} = 0.970$, $c_{\rho\text{-}\phi} = 4.78$, $c_{\omega\text{-}\phi} = 0.486$, $c_{\rho'\text{-}\rho''} = -13.00$ and $c_{\rho'\text{-}\rho'''} = -5.07$. The

QCD parameters are determined as the follows: The QCD coefficients are determined as $c_2^{\rm QCD} = -0.963$ and $c_3^{\rm QCD} = 0.133$, where $c_1^{\rm QCD}$ is fixed at the value of QCD prediction, $c_1^{\rm QCD} = -0.02683$ and the QCD scale parameter is fixed at $\Lambda = 0.8$ GeV. We take n_f =2. The chi squares for the timelike and spacelike momenta become $\chi^2_{\rm time} = 250$, $\chi^2_{\rm space} = 250$ for the case without the resonance around 1.2 GeV, while the assumption of $\rho(1230)$ leads to $\chi^2_{\rm time}=$ 250, $\chi^2_{\rm space} = 80$. The result for the spacelike region is thus remarkably improved. The numbers of data are 157 and 45 for the timelike and the spacelike momenta, respectively.

The experiments on the kaon and the nucleon electromagentic form factors are also reproduced by our supercovergent dispersion relation very well [2, 3]. We compare in Fig. 2 the result of Ref. [3] with the recent data of neutron electric form factor [6]. We find that the theoretical result agrees with the recent experiment on G_E^n.

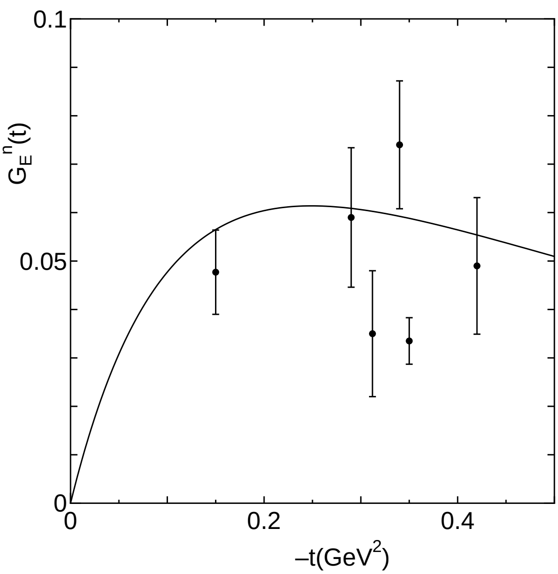

Fig. 2. The neutron electric form factor. The data points are taken from Ref. [6] and the curve stands for the theoretical calculation in Ref. [3].

The experimental data on the hadron electromagnetic form factors can be reproduced very well through the unsubtracted dispersion relation with the superconvergence condition, which works as an interpolation of the low energy hadronic phenomena and the QCD. It is expected that the data on the electromagnetic form factors of hadron provide important data in investigating the subhadronic properties.

REFERENCES

[1] S.J. Brodsky, G. Farrar, *Phys. Rev.* **D11**, 2157 (1981).

[2] M. Nakagawa, K. Watanabe, *Nuovo Cimento* **112A**, 873 (1999); *Phys. Rev.* **C61**, 055207 (2000).

[3] S. Furichi, K. Watanabe, *Prog. Theor. Phys.* **92**, 39 (1994); *Nuovo Cimento* **110A**, 577 (1997).

[4] S.R. Aendolia *et al.*, *Nucl. Phys.* **B277**, 168 (1986).

[5] L.M. Barkov *et al.*, *Nucl. Phys.* **B256**, 365 (1985).

[6] M. Ostrick *et al.*, *Phys. Rev. Lett.* **83**, 276 (1999); D. Rohe *et al.*, *Phys. Rev. Lett.* **83**, 4257 (1999).