第44卷第3期 中国科学技术大学学报 Vol. 44, No. 3
2014年3月 JOURNAL OF UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA Mar. 2014

Article ID: 0253-2778(2014)03-0214-03

Test a perturbative QCD prediction with $e^+e^-\to D^{*+}D^{*-}$

GUO Han, ZHANG Ziping

(*Department of Modern Physics, University of Science and Technology of China, Hefei* 230026, *China*)

Abstract: The differential cross section for $e^+e^-\to D^{*+}D^{*-}$ process was calculated in terms of the electromagnetic form factors of D^* meson. After putting in the ratios of form factors predicted by perturbative QCD (quantum chromodynamics), the angular distribution obtained was found to be inconsistent with experimental measurement at $\sqrt{s}=10.58$ GeV.

Key words: D^* meson; electromagnetic form factor; perturbative QCD

CLC number: O572.2 **Document code**: A doi: 10.3969/j.issn.0253-2778.2014.03.008

Citation: Guo Han, Zhang Ziping. Test a perturbative QCD prediction with $e^+e^-\to D^{*+}D^{*-}$ [J]. Journal of University of Science and Technology of China, 2014, 44(3): 214-216.

用 $e^+e^-\to D^{*+}D^{*-}$ 检验一个微扰 QCD 预言

郭 晗，张子平

（中国科学技术大学近代物理系，安徽合肥 230026）

摘要：计算了 $e^+e^-\to D^{*+}D^{*-}$ 过程的微分截面，以 D^* 介子的电磁形状因子表示. 代入微扰 QCD 预言的电磁形状因子比值，得到的角分布与中心系能量为 10.58 GeV 的实验测量不一致.

关键词：D^* 介子；电磁形状因子；微扰 QCD

0 Introduction

For hard exclusive processes, perturbative QCD predicts the following selection rule[1-2]:

$$\sum_{\text{initial}} \lambda_H = \sum_{\text{final}} \lambda_H,$$

i.e., total hadronic helicity is conserved. The equality is up to corrections of order M/Q or higher. This selection rule is implied in a formula for the asymptotic power behavior of any form factor[3]:

$$\langle p'\lambda' \mid J^\mu \mid p\lambda\rangle \sim \left(\frac{1}{Q}\right)^{(n_{\min}+n'_{\min}-3)+|\lambda'-\lambda|}.$$

In particular, for processes $e^+e^-\to\gamma^*\to hh'$, the hadronic-helicity conservation rule is $0=\lambda+\lambda'$. Angular momentum conservation requires $|\lambda-\lambda'|\leqslant 1$. Therefore for meson pairs $\lambda=\lambda'=0$, and for baryon pairs $\lambda=-\lambda'=\pm 1/2$. Thus angular distributions are $\sin^2\theta$ and $1+\cos^2\theta$ for meson pairs and baryon pairs, respectively. These predictions are nontrivial for vector mesons and for all baryons[1].

Further, for spin-1 bound states, the dominance of helicity-conserving amplitudes implies that the charge, magnetic and quadrupole

Received: 2013-03-18; **Revised**: 2013-09-27

Foundation item: Supported by National Natural Science Foundation of China (10935008).

Biography: GUO Han, male, born in 1982, PhD candidate. Research field: Experimental particle physics. E-mail: guohan@mail.ustc.edu.cn

Corresponding author: ZHANG Ziping, Prof. E-mail: zpz@ustc.edu.cn

form factors have universal ratios, which will be shown in the next section.

Study of the process $e^+e^-\to D^{*+}D^{*-}$ provides a chance to test this perturbative QCD prediction. It also allows investigation of electromagnetic form factors in the time-like region of momentum transfer.

1 Electromagnetic structure of spin-1 particle

For the matrix element of the electromagnetic current J^μ of spin-1 system $G^\mu_{\lambda'\lambda}=\langle p'\lambda' | J^\mu | p\lambda\rangle$, where $|p\lambda\rangle$ is eigenstate of momentum p and helicity λ, conventionally the most general form allowed by parity conservation and time reversal invariance can be written in terms of three Lorentz-invariant form factors[4-7]:

$$G^\mu(Q^2)=-G_1(Q^2)\varepsilon'^*\cdot\varepsilon(p^\mu+p'^\mu)+G_2(Q^2)(\varepsilon'^{*\mu}\varepsilon\cdot q-\varepsilon^\mu\varepsilon'^*\cdot q)+G_3(Q^2)\frac{1}{2M^2}\varepsilon\cdot q\varepsilon'^*\cdot q(p^\mu+p'^\mu),$$

where $q=p'-p$ and $Q^2=|q^2|$. ε and ε' are initial and final polarization vectors, respectively. M is the mass of the particle.

These form factors are related to the charge, magnetic and quadrupole form factors[6]:

$$G_C=G_1+\frac{2}{3}\eta G_Q,$$

$$G_M=G_2,$$

$$G_Q=G_1-G_2+(1+\eta)G_3,$$

where $\eta=-q^2/(4M^2)$ is a kinematic factor. Their static limits are

$$eG_C(0)=e,$$

$$eG_M(0)=2M\mu_1,$$

$$eG_Q(0)=M^2Q_1$$

with μ_1 being the magnetic moment and Q_1 the quadrupole moment.

By inverting the relationship between current matrix elements and form factors in the standard light-cone frame, and assuming that G^+_{00} matrix element is the dominant amplitude[8], it is shown that the charge, magnetic, and quadrupole form factors have universal ratios[7]:

$$G_C:G_M:G_Q=\left(1-\frac{2}{3}\eta\right):2:-1.$$

These ratios hold for composite systems such as ρ meson or deuteron at large space-like or time-like momentum transfer, i. e. $Q\gg\Lambda_{QCD}$, up to corrections of order Λ_{QCD}/Q and Λ_{QCD}/M. It is argued that there should also be $Q\gg\sqrt{2M\Lambda_{QCD}}$[7]. In addition, these ratios hold for $W^\pm$ form factors at the tree level, which means that the ratios of form factors of bound states become identical to those of elementary particles at large momentum transfer.

2 $e^+e^-\to D^{*+}D^{*-}$ differential cross section

For $e^+e^-\to\gamma^*\to D^{*+}D^{*-}$ process, D^* current matrix element is

$$G^\mu(q^2)=-G_1(q^2)\varepsilon'^*\cdot\varepsilon^*(k'^\mu-k^\mu)+G_2(q^2)(\varepsilon'^{*\mu}\varepsilon^*\cdot q-\varepsilon^{*\mu}\varepsilon'^*\cdot q)+G_3(q^2)\frac{1}{2M^2}\varepsilon^*\cdot q\varepsilon'^*\cdot q(k'^\mu-k^\mu),$$

where k and k' are momentum of the D^*'s, and now $q=k+k'=\sqrt{s}$.

The unpolarized differential cross section in the center-of-mass frame is calculated:

$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2}{8E_{CM}^2}(1+1/\eta)^{3/2}(C_1+C_2\cos^2\theta),$$

$$C_{1,2}=\pm3|G_C|^2-2\eta|G_M|^2\pm\frac{8}{3}\eta^2|G_Q|^2.$$

The angular distribution of $D^{*\pm}$ in CM frame is of the form $1+\beta\cos^2\theta$. At the energy of BELLE experiment, $\sqrt{s}=10.58$ GeV, and given the predicted ratios of form factors,

$$G_C:G_M:G_Q=\left(1-\frac{2}{3}\eta\right):2:-1,\ \beta=-0.60$$

is obtained.

It should be noted that although it was mentioned in Ref. [7] that for the time-like reaction $\eta=s/(4M^2)$, its definition, as we have observed, should be coherent in the space-like and time-like region, $\eta=-q^2/(4M^2)$, which is $-s/(4M^2)$ in the time-like case.

3 Discussion

An experimental analysis at BELLE[9] gives $\beta = 0.79^{+0.34}_{-0.30}$, which is not in agreement with the perturbative QCD predictions: neither $\beta = -1(\sin^2\theta)$ as a result of hadronic-helicity conversation, nor $\beta = -0.60$ assuming the dominance of G^{+}_{00}.

BABAR Collaboration has presented an analysis of $e^+ e^- \to \rho^+ \rho^-$ process[10] and also reported an inconsistency with the prediction of perturbative QCD with a significance of 3.1 standard deviations including systematic uncertainties.

A discussion about relations between the Breit frame and the light-front frame[11] has shown that the angular condition in light-front frame, which is derived from conservation of angular momentum in Breit frame, contradicts the hypothesis that the scale of the asymptotic power-law falloff of non-leading amplitudes is set by Λ_{QCD}. It is suggested that this scale would be of the order of the particle mass. As a consequence, next-to-leading corrections are non-negligible and the underlying assumption in Ref. [7] that G^{+}_{00} is dominant at large Q^2 needs to be reconsidered.

References

[1] Brodsky S, Lepage G. Helicity selection rules and tests of gluon spin in exclusive QCD processes[J]. Phys Rev D, 1981, 24: 2 848-2 855.

[2] Chernyak V, Zhitnitsky A. Asymptotic behaviour of exclusive processes in QCD[J]. Physics Reports, 1984, 112: 173-318.

[3] Chernyak V. J/ψ thoery review, or from J → ψ [DB/OL]. arXiv: hep-ph/9906387.

[4] Durand L. Inelastic electron-deuteron scattering cross sections at high energies: Ⅱ, final-state interactions and relativistic corrections[J]. Phys Rev, 1961, 123: 1 393-1 422.

[5] Jones H. Dispersion theory of the deuteron form factor and elastic e-d scattering[J]. Nuovo Cimento, 1962, 26: 790-802.

[6] Arnold R, Carlson C, Gross F. Elastic electron-deuteron scattering at high energy[J]. Phys Rev C, 1980, 21: 1 426-1 451.

[7] Brodsky S, Hiller J. Universal properties of the electromagnetic interactions of spin-one systems[J]. Phys Rev D, 1992, 46: 2 141-2 149.

[8] Lepage G, Brodsky S. Exclusive processes in perturbative quantum chromodynamics[J]. Phys Rev D, 1980, 22: 2 157-2 198.

[9] Uglov T, et al (BELLE Collaboration). Measurement of the $e^+ e^- \to D^{(*)+} D^{(*)-}$ cross sections[J]. Phys Rev D, 2004, 70: 071102.

[10] Aubert B, et al (BABAR Collaboration). Observation of $e^+ e^- \to \rho^+ \rho^-$ near $\sqrt{s} = 10.58$ GeV[J]. Phys Rev D, 2008, 78: 071103.

[11] Carlson C, Ji C R. Angular conditions, relations between the Breit and light-front frames, and subleading power corrections[J]. Phys Rev D, 2003, 67: 116002.