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Sensitivity of tensor analyzing power in the process $d+p \rightarrow d+X$ to the longitudinal isoscalar form factor of the Roper resonance electroexcitation

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The tensor analyzing power of the process $d+p \rightarrow d+X$, for forward deuteron scattering in the momentum interval 3.7 to 9 GeV/c, is studied in the framework of ω exchange in an algebraic collective model for the electroexcitation of nucleon resonances. We point out a special sensitivity of the tensor analyzing power to the isoscalar longitudinal form factor of the Roper resonance excitation. The main argument is that the $S_{11}(1535)$, $D_{13}(1520)$ and $S_{11}(1650)$ resonances have only isovector longitudinal form factors. It is the longitudinal form factor of the Roper excitation, which plays an important role in the $t-$dependence of the tensor analyzing power. We discuss possible evidence of swelling of hadrons with increasing excitation energy.

25.40.Ny, 25.10+s, 13.40.Gp, 14.20.Gk

I. INTRODUCTION

In a previous paper [1] it was shown that the polarization observables in inclusive scattering of high energy deuterons by protons at zero scattering angle, are sensitive to the ratio

$$r = \sigma_L/\sigma_T,$$

where σ_L and σ_T are the cross sections of absorption of virtual isoscalar photons with longitudinal and transversal polarizations by nucleons. In the framework of the $\omega-$exchange mechanism for the considered reaction, it was found that this sensitivity is especially large in the region of N^*-excitations with masses $1.4-1.6$ GeV, for $r \leq 0.5$. This interval is especially interesting when compared with the data obtained by inclusive $eN-$scattering. This sensitivity is due, in particular, to the properties of the deuteron electromagnetic form factors. In [1] a simplified assumption was used, namely, the ratio r was taken to be a free parameter independent of the four momentum transfer square, $t=-q^2$. The value that best fitted the data was $r=0.1$. It is then interesting to compare this value with that of a realistic model for the nucleon resonances electroexcitation. In this work we present the results of the analysis of polarization phenomena in $d+p \rightarrow d+X$, using the predictions of the model [2–4] for the t-dependence of the isoscalar form factors of electromagnetic $N \rightarrow N^*$transitions. We show that hadronic probes of nucleon structure, in particular, using polarized particles, may give interesting and important information concerning form factors of N^*-excitations. The selectivity of reactions such as $p(d,d')X$ or $p(\alpha,\alpha')X$ to the isoscalar part of the N^*-electroexcitation makes these processes complementary to electron-nucleon inelastic scattering, for the study of the N^*-structure. Note that in the framework of the ω-exchange model [1], all polarization phenomena for $d+p \rightarrow d+X$ can be predicted without any free parameters, using only existing information about the deuteron electromagnetic form factors and about the ratio r.

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This paper is organized as follows. In section II we give the t-dependence of the tensor analyzing power T_{20} and r in the model [1]. Formulas for transverse and longitudinal amplitudes of the algebraic collective model [2-4] are recalled in section III. Results and discussions are presented in section IV and the conclusions are drawn in section V.

II. t-DEPENDENCE OF T_{20} AND r

We will analyze here the polarization phenomena in the process $d+p \to d+X$, for forward deuteron scattering, in the framework of the model [1] based on $\omega-$exchange (Fig. 1). The ω-meson is preferred, among the isoscalar mesons as σ or η, for several reasons. The $\omega NN-$ coupling is large; the ω-meson, being a spin 1 particle, can induce strong polarization effects and an energy-independent cross section. When considered as an *isoscalar photon*, then the cross sections and the polarization observables can be calculated from the known electromagnetic properties of the deuteron and N^*, through the vector dominance model. These special properties of the $\omega-$exchange mechanism allow an experimental test of the validity of this model, similar to the Rosenbluth test of the one-photon mechanism, in case of elastic and inelastic electron-hadron scattering. The details of the model are described in [1]. We will recall here only the final expressions, necessary for the present analysis.

The tensor analyzing power in $d+p \to d+X$, T_{20}, can be written in terms of the electromagnetic form factors as:

$$T_{20} = -\sqrt{2}\frac{V_1^2 + (2V_0V_2 + V_2^2)r}{4V_1^2 + (3V_0^2 + V_2^2 + 2V_0V_2)r}, \tag{1}$$

where $V_0(t)$, $V_1(t)$ and $V_2(t)$ are related to the standard electromagnetic deuteron form factors: $G_c(t)$ (electric), $G_m(t)$ (magnetic) and $G_q(t)$ (quadrupole) by:

$$V_0 = \sqrt{1+\tau}\left(G_c - \frac{2}{3}\tau G_q\right), \quad V_1 = \sqrt{\tau}G_m, \quad V_2 = \frac{\tau}{\sqrt{1+\tau}}\left[-G_c + 2\left(1-\frac{1}{3}\tau\right)G_q\right],$$

and $\tau = -t/4M_d^2$, where M_d is the deuteron mass. The ratio r characterizes the relative role of longitudinal and transversal isoscalar excitations in the transition $\omega + N \to X$. In case of the Roper excitation we can write:

$$r_R(t) = \frac{|A_\ell^p + A_\ell^n|^2}{|A_{1/2}^p + A_{1/2}^n|^2}, \tag{2}$$

where A_ℓ^N ($A_{1/2}^N$) is the longitudinal (transversal) form factor of the $P_{11}(1440)$-excitation on proton ($N=p$) or neutron ($N=n$) targets. This formula can be generalized to the excitation of any nucleon resonance N^* as follows:

$$r_{N^*}(t) = \frac{|A_\ell^p + A_\ell^n|^2}{|A_{1/2}^p + A_{1/2}^n|^2 + |A_{3/2}^p + A_{3/2}^n|^2} \equiv \sigma_L(t)/\sigma_T(t), \tag{3}$$

where $A_{1/2}^N$ and $A_{3/2}^N$ are the two possible transversal form factors, corresponding to total $\gamma^* + N-$ helicity equal to 1/2 and 3/2 respectively.

In case of overlapping resonances, taking into account the finite values of the resonance widths, Eq. (3) can be generalized to

$$r \to r(t,W) = \frac{\sum_i \sigma_{L,i}(t)B_i(W)C_i}{\sum_i \sigma_{T,i}(t)B_i(W)C_i}, \tag{4}$$

where $B_i(W)$ is a Breit-Wigner function for the $i-th$ N^*-resonance with a definite normalization:

$$C_i^{-1} = \int_{M+M_\pi}^{\infty} dW B_i(W), \tag{5}$$

M is the nucleon mass, M_π is the pion mass and W is the effective invariant mass of the $X-$system in $d+p \to d+X$ (i.e. the mass of the resonance). Let us mention that for forward deuteron scattering in $d+p \to d+X$ the variables t and W are not independent, for a fixed energy of the incoming deuteron there is a definite correspondance between t and W [1]. The following observations, based on Eq. (1), can be made. All information about the ωNN^*-vertex is contained in the function r only. T_{20} is especially sensitive to the small value of $r(t,W)$ in the interval $0 \le r \le 0.5$. A zero value of r results in a $t-$independent value for T_{20}, namely $T_{20} = -1/\sqrt{8}$, for any value of the deuteron

The experimental values of T_{20} for $p(\vec{d},d)X$ [5,6], for different momenta of the incident beam are shown as open symbols. These data show a scaling as a function of t, with a small dependence on the incident momentum in the interval 3.7–9 GeV/c. On the same plot the data for the elastic scattering process $e^- + d \to e^- + d$ [7] are shown (filled stars). All these data show a very similar behavior: negative values, with a minimum in the region $|t| \simeq 0.35$ GeV^2 and an increase towards zero at larger $|t|$. The lines are the result of the ω-exchange model calculation for the $d + p \to d + X$ process. The dashed-dotted line correspond to $r = 0$, i.e. to $T_{20} = -1/\sqrt{8}$ as mentioned previously. Calculations based on the algebraic collective model [2,3] are shown for the case when only the Roper resonance is considered (dotted line) and for the case when all the four resonances (6) are considered (solid line). The required deuteron form factors, G_c, G_q, G_m, were taken from [8] (calculated in a relativistic impulse approximation) and they reproduce well the T_{20}−data for ed elastic scattering [7]. When $r \gg 0$ or if the contribution of the deuteron magnetic form factor V_1 is neglected, then T_{20} does not depend on the ratio r, and coincides with t_{20} for the elastic ed-scattering (with the same approximation).

From Fig. 3 it appears that the t−behavior of T_{20} is very sensitive to the value of r, at relatively small r, $r \leq 0.5$. The values of r, predicted by the collective model [2,3] give a good description of the data, when taking into account the contribution of all four resonances (6). These data, in any case, exclude a very small value of r, $r \ll 0.1$ as well as very large values of r. Such sensitivity of T_{20} for $d + p \to d + X$ to the ratio of the corresponding isoscalar form factors of the N^*-excitation clearly indicates the presence of the Roper resonance in this process. Such an indication was hardly found in the differential cross section for inclusive scattering with unpolarized particles [9].

In the framework of the ω-exchange mechanism, electromagnetic isovector components of the $N \to N^*$ transition cannot contribute. This is important as the other resonances in this mass region, $S_{11}(1535)$, $D_{13}(1520)$ and $S_{11}(1650)$ are essentially isovector in the collective model [2,3] (as well as in other quark models), so the isoscalar longitudinal form factors for $N \to N^*$ are identically zero for any value of t. The ratio r contains (in the numerator) the contribution of only the Roper resonance. It is this specific property of the Roper resonance (combined with the t−dependence of the deuteron form factors) that induces the specific t−behavior of the isoscalar ratio r and of the analyzing power T_{20} as shown in Figs. 2 and 3, repectively.

In this connection, we mention that the ω-exchange model predicts the general features of the polarization observables. For example, the crossing of all the theoretical curves for T_{20} at two points, is determined by the relative value of the deuteron electromagnetic form factors. For any model of r we will have $T_{20} \leq -1/\sqrt{8}$ in the region $2 \leq q \leq 5$ fm^{-1}. Future data from Jefferson Lab [10], concerning T_{20} in $e^- + d \to e^- + d$ will help in defining the exact position of these points. For $q \leq 6$ fm^{-1}, T_{20} cannot be positive.

Using the generalized formula, Eq. (4), the t−behavior of the ratio $r(t, W)$ depends on the initial deuteron momentum. From Fig. 4 one can see that, in the interval 3.7–9 GeV/c this dependence is not so large, in agreement with experimental data. This is also true for the momentum dependence of T_{20}, (Fig. 5). The agreement between theoretical predictions and experimental data is generally good, at least for $q \leq 2$ fm^{-1}.

Of course, this model for $d + p \to d + p$ can be improved, taking into account for example, other meson exchanges, or the effects of the strong interaction in initial and final states. However these corrections are strongly model- and parameter- dependent; the existing experimental data are not good enough to constrain the additional parameters which have to be added. In this case we lose the predictive power of our "parameter free" model. The successful description of the polarization observable T_{20} can be considered as a strong indication that the $\omega-$ exchange is the main mechanism for the considered process.

We analyzed also the sensitivity to a possible stretching mechanism [3], leading to the swelling of hadrons with increasing excitation energy. We use the parameterization of Eq. (8) for the scale parameter a, with $\xi = 0.5$ and $\xi = 1$ (the last value is consistent with the analysis of the experimental mass spectra, Regge trajectories). The results are reported in Figs. 6 and 8 for $r(t, W)$ and Figs. 7 and 9 for T_{20}, for the different values of initial deuteron momentum. The behavior of $r(t, W)$ is seen to be very sensitive to ξ. Introduction of swelling gives a more negative slope to T_{20} in better agreement with experiment although the position of the minimum at p_d= 3.7 and 9 GeV/c is still shifted to higher q values compared to that measured by the data.

Similar results can be obtained for other polarization observables. In Fig. 10 we show the t−dependence of the vector polarization transfer coefficient, $K_y^{y'}$, from the initial to the scattered deuteron. It is characterized by a strong sensitivity to the ratio r for $q \geq 3$ fm^{-1}. This observable is especially interesting in this region, because T_{20} vanishes around $q \simeq 5$ fm^{-1} (for any value of r). Our calculations predict quite a large absolute value of this observable and a strong dependence on the variable t.

Let us note in this connection, that, all T-even polarization observables are nonzero and large in absolute value. This is an intrinsic property of ω-exchange. In contrast, all T-odd polarization effects cancel, because we neglected the effects of strong interaction in initial and final states. However, for collinear kinematics, all spin-one T-odd polarization observables must be zero, in any model. The most simple T-odd polarization observable, which exists in the general case for the collinear kinematics, corresponds to the correlation coefficient $\vec{u} \cdot \vec{P} \times \vec{Q}$, $Q_a = Q_{ab}u_b$,

[2] R. Bijker, F. Iachello, and A. Leviatan, Ann. Phys. (N.Y.) **236**, 69 (1994).
[3] R. Bijker, F. Iachello, and A. Leviatan, Phys. Rev. C **54**, 1935 (1996).
[4] R. Bijker, F. Iachello, and A. Leviatan, Phys. Rev. D **55**, 2862 (1997).
[5] Exp. LNS250 (unpublished).
[6] L.S. Azhgirey et al., Phys. Lett. B **361**, 21 (1995);
L.S. Azhgirey et al., Phys. Lett. B **387**, 37 (1996);
L.S. Azhgirey et al., JINR Rapid Communications No. 2[88]-98.
[7] M. Garçon et al., Phys. Rev. C **49**, 2516 (1994) and Refs. herein.
[8] P.L. Chung et al., Phys. Rev. C **37**, 2000 (1988).
[9] P. Morsch et al., Phys. Rev. Lett. **69** (1992) 1336.
[10] S. Kox, E.J. Beise et al., CEBAF proposal E-94-018.

Figure Caption

FIG. 1. $t-$channel meson exchange for $d+p \to d+X$

FIG. 2. The ratio r for the case when only the Roper excitation is considered (dotted line) and for the case when all four resonances (6) are considered, (solid line), from Eq. (3).

FIG. 3. Experimental data for T_{20} for $e^- + d \to e^- + d$ elastic scattering (filled stars) [7] and $d+p \to d+X$ at incident momenta of 3.75 GeV/c (open diamonds) [5], 5.5 GeV/c (open circles), 4.5 GeV/c (open squares), 9 GeV/c (open triangles) [6]. Prediction of the $\omega-$exchange model for $r=0$ (dashed-dotted line). Calculations with r using collective form factors (Tables I-II) are shown for the case when only the Roper resonance is considered (dotted line) and for the case when all the four resonances (6) are considered (solid line).

FIG. 4. $q-$ dependence of $r=\sigma_L/\sigma_T$ for excitation of only the Roper resonance (dashed line), for excitation of all resonances (6) with (solid line) and without (dotted line) width effects, for different deuteron momenta p_d: (a) p_d=3.7 GeV/c, (b) p_d=4.5 GeV/c, (c) p_d=5.5 GeV/c, (d) p_d=9 GeV/c.

FIG. 5. $q-$dependence of T_{20} for different deuteron momenta p_d: (a) p_d=3.7 GeV/c, (b) p_d=4.5 GeV/c, (c) p_d=5.5 GeV/c, (d) p_d=9 GeV/c.

FIG. 6. $q-$dependence of $r=\sigma_L/\sigma_T$ for $\xi=0.5$ (same notations as in Fig. 4).

FIG. 7. $q-$dependence of T_{20} for $\xi=0.5$ (same notations as in Fig. 5).

FIG. 8. $q-$ dependence of $r=\sigma_L/\sigma_T$ for $\xi=1$ (same notations as in Fig. 4).

FIG. 9. $q-$ dependence of T_{20} for $\xi=1$ (same notations as in Fig. 5).

FIG. 10. Vector polarization transfer coefficient $K_y^{y'}$ as a function of q, for $d+p \to d+X$. Prediction of the $\omega-$exchange model for $r=0$ (dashed-dotted line). Calculations using the collective form factors (Tables I-II) are shown for the case when only the Roper resonance is considered (dotted line) and for the case when all the four resonances (6) are considered (solid line).

TABLE II. Longitudinal proton (A_ℓ^p) and neutron (A_ℓ^n) helicity amplitudes of nucleon resonances below 2 GeV in the collective model [2,3]. Notation as in Table ??.

Resonance	State	A_ℓ^p	A_ℓ^n
$N(1440)P_{11}$	$^{2}8_{1/2}[56,0^+]_{(1,0);0}$	$2\chi_1\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\frac{4ka(1-2k^2a^2)}{(1+k^2a^2)^4}$	0
$N(1520)D_{13}$	$^{2}8_{3/2}[70,1^-]_{(0,0);1}$	$2i\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\frac{1-3k^2a^2}{(1+k^2a^2)^3}$	$A_\ell^n=-A_\ell^p$
$N(1535)S_{11}$	$^{2}8_{1/2}[70,1^-]_{(0,0);1}$	$-i\sqrt{2}\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\frac{1-3k^2a^2}{(1+k^2a^2)^3}$	$A_\ell^n=-A_\ell^p$
$N(1650)S_{11}$	$^{4}8_{1/2}[70,1^-]_{(0,0);1}$	0	0
$N(1675)D_{15}$	$^{4}8_{5/2}[70,1^-]_{(0,0);1}$	0	0
$N(1680)F_{15}$	$^{2}8_{5/2}[56,2^+]_{(0,0);0}$	$-\sqrt{3}\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\left[\frac{4ka}{(1+k^2a^2)^3}-\frac{3}{ka}Z(ka)\right]$	0
$N(1700)D_{13}$	$^{4}8_{3/2}[70,1^-]_{(0,0);1}$	0	0
$N(1710)P_{11}$	$^{2}8_{1/2}[70,0^+]_{(0,1);0}$	$-\sqrt{2}\chi_2\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\frac{4ka(1-2k^2a^2)}{(1+k^2a^2)^4}$	$A_\ell^n=-A_\ell^p$
$N(1720)P_{13}$	$^{2}8_{3/2}[56,2^+]_{(0,0);0}$	$\sqrt{2}\sqrt{\frac{\pi}{k_0}}\mu\frac{mk_0a}{g}\left[\frac{4ka}{(1+k^2a^2)^3}-\frac{3}{ka}Z(ka)\right]$	0

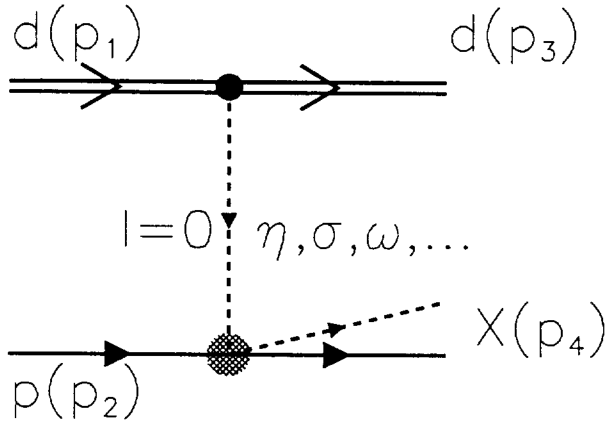


Fig. 1

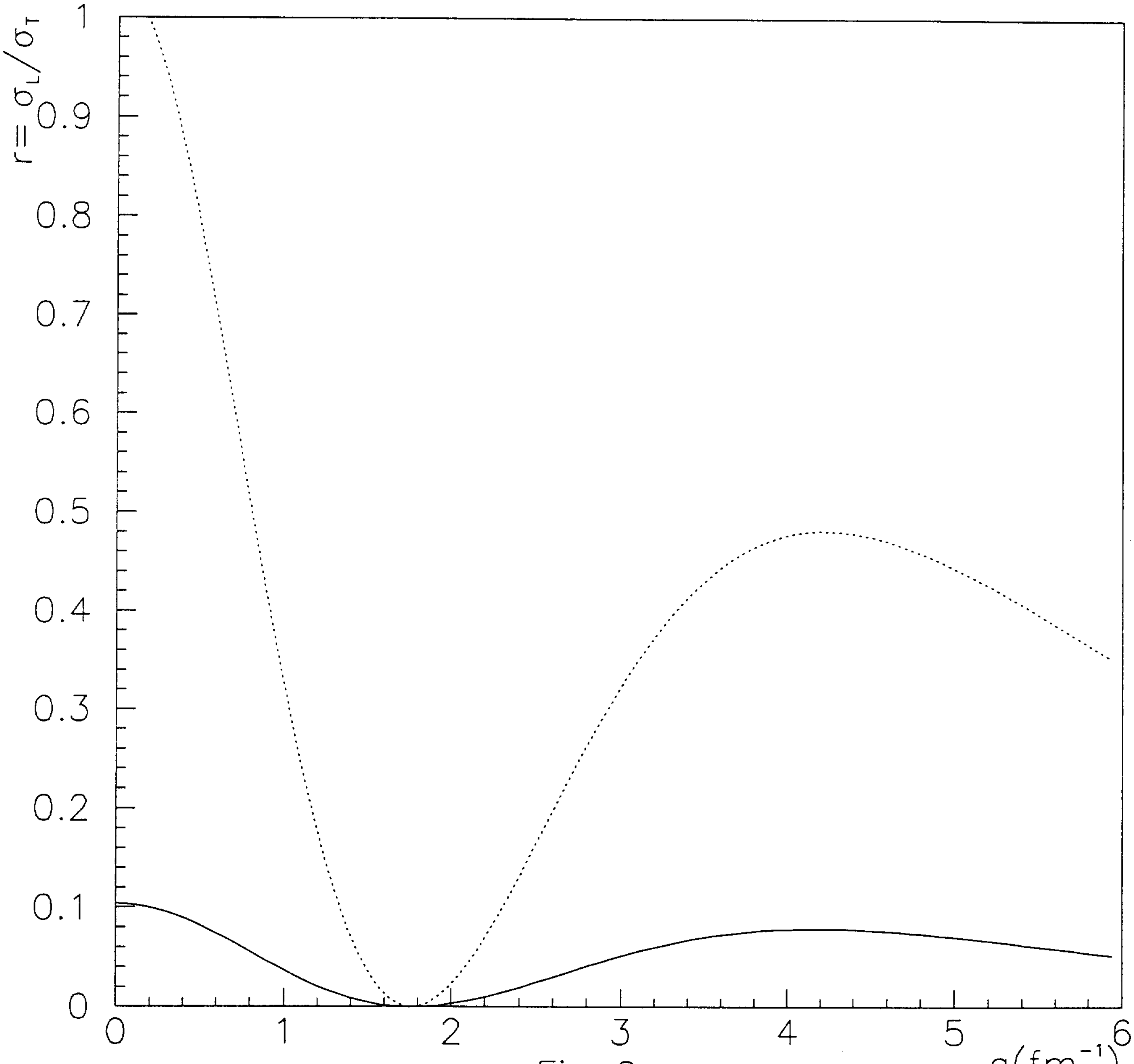


Fig. 2

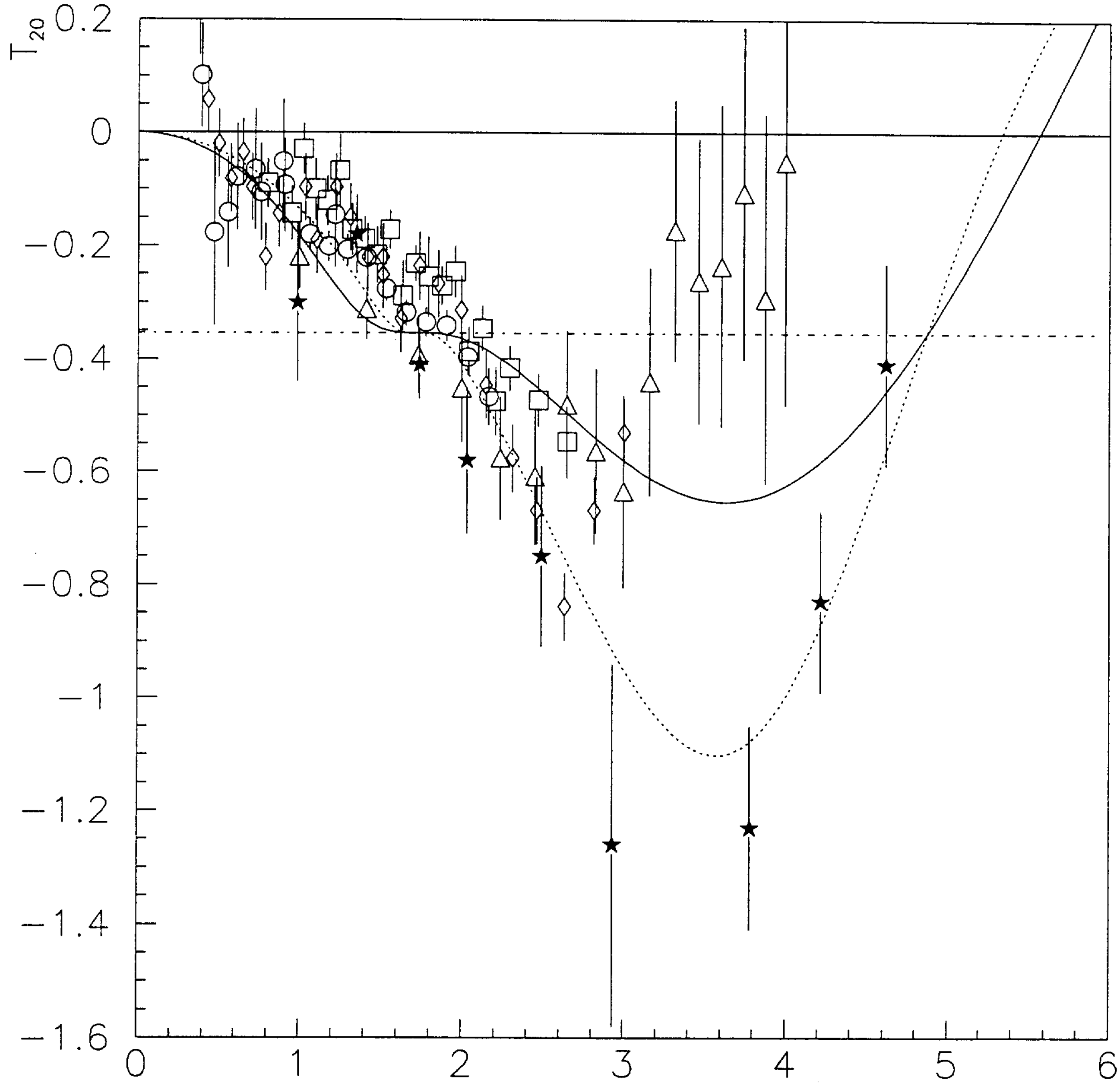


Fig. 3

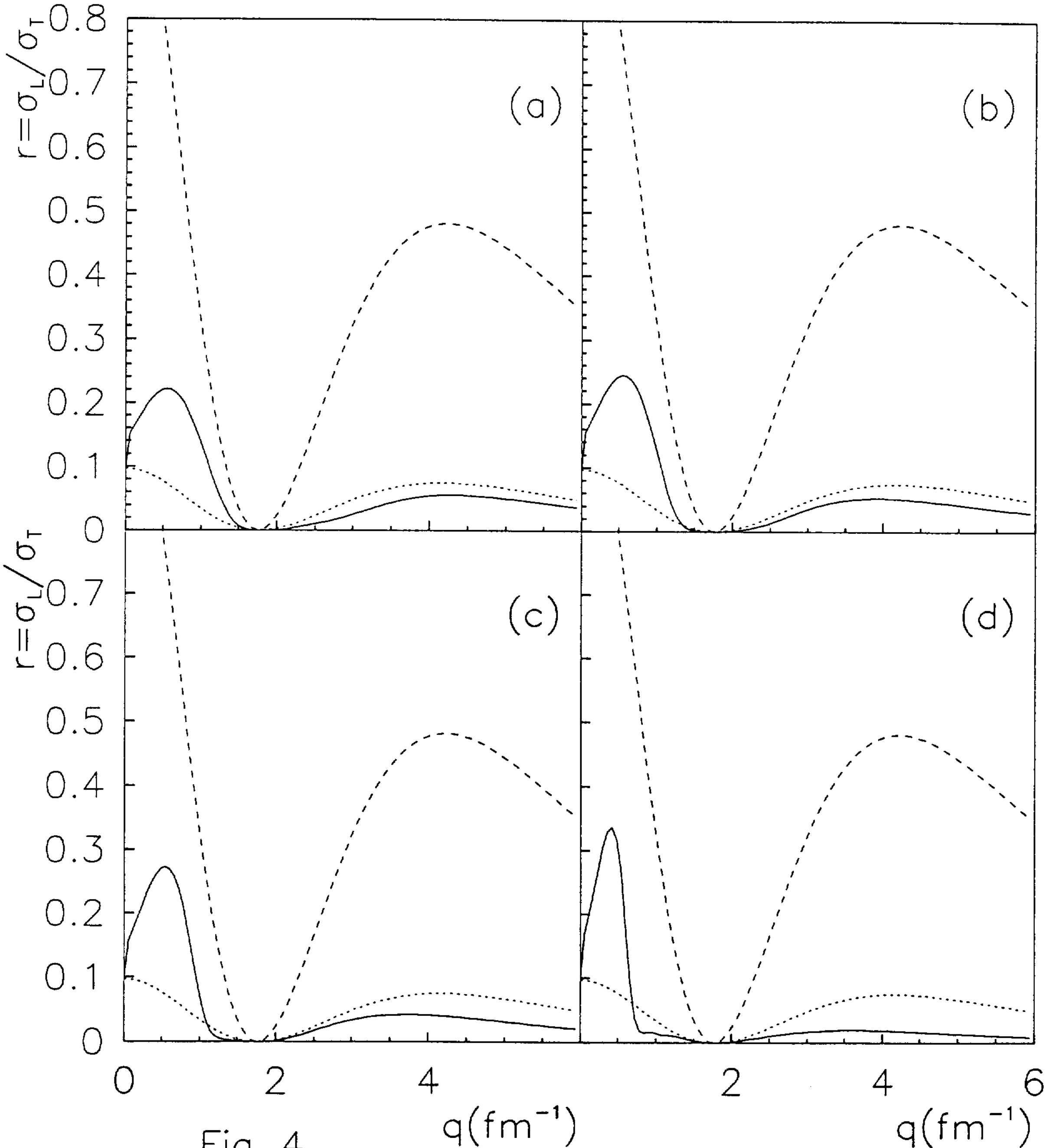


Fig. 4

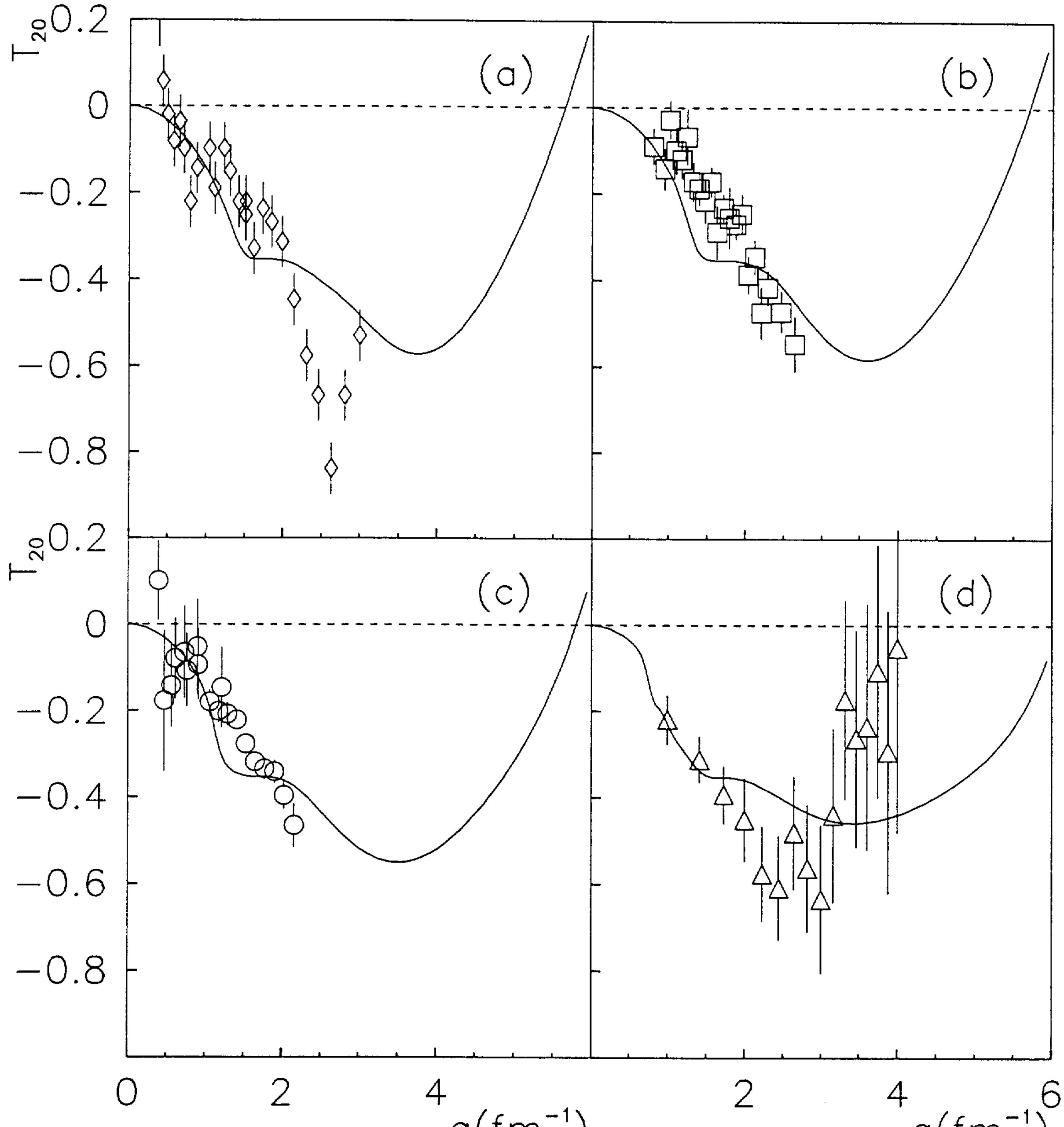
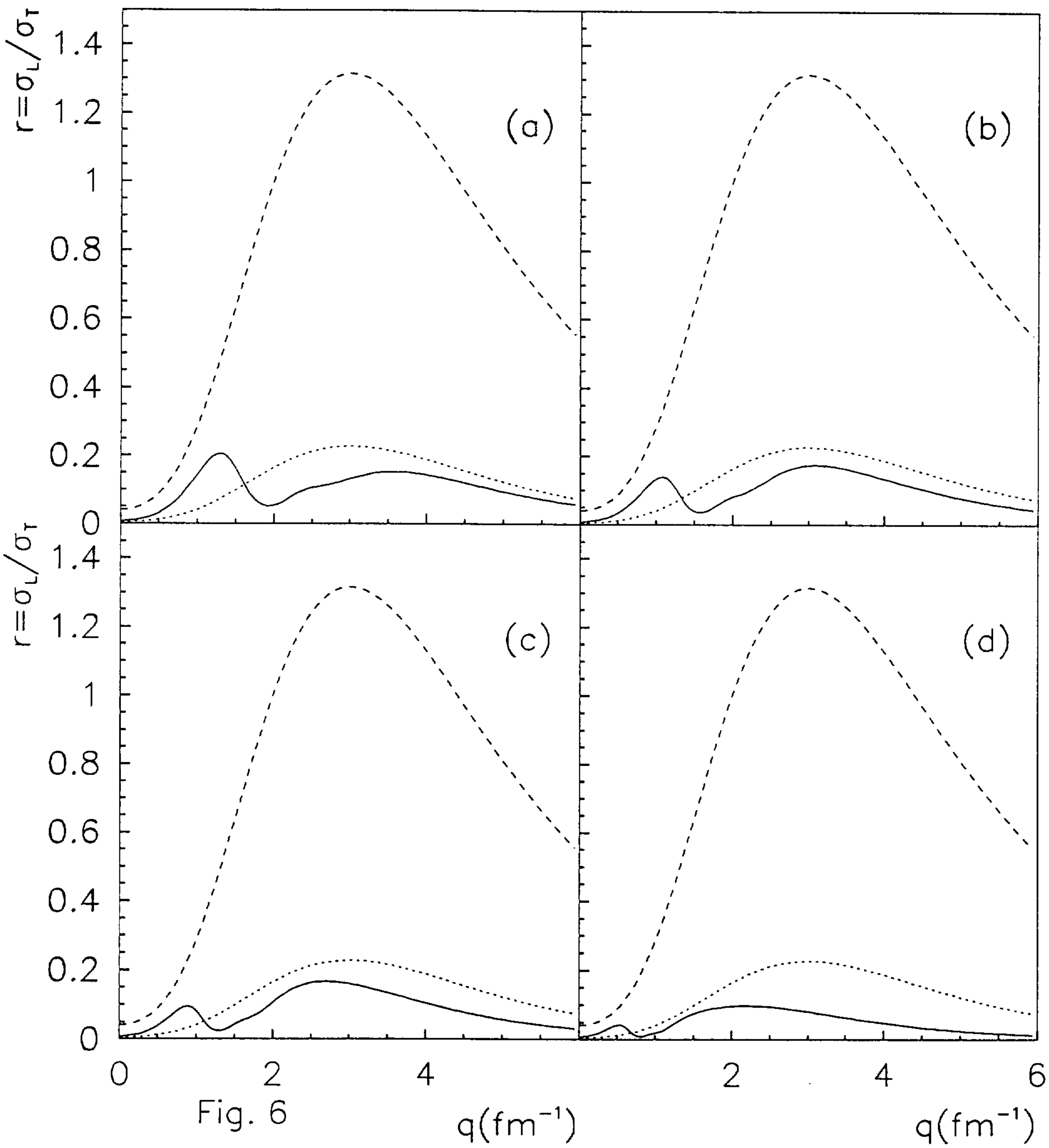


Fig. 5



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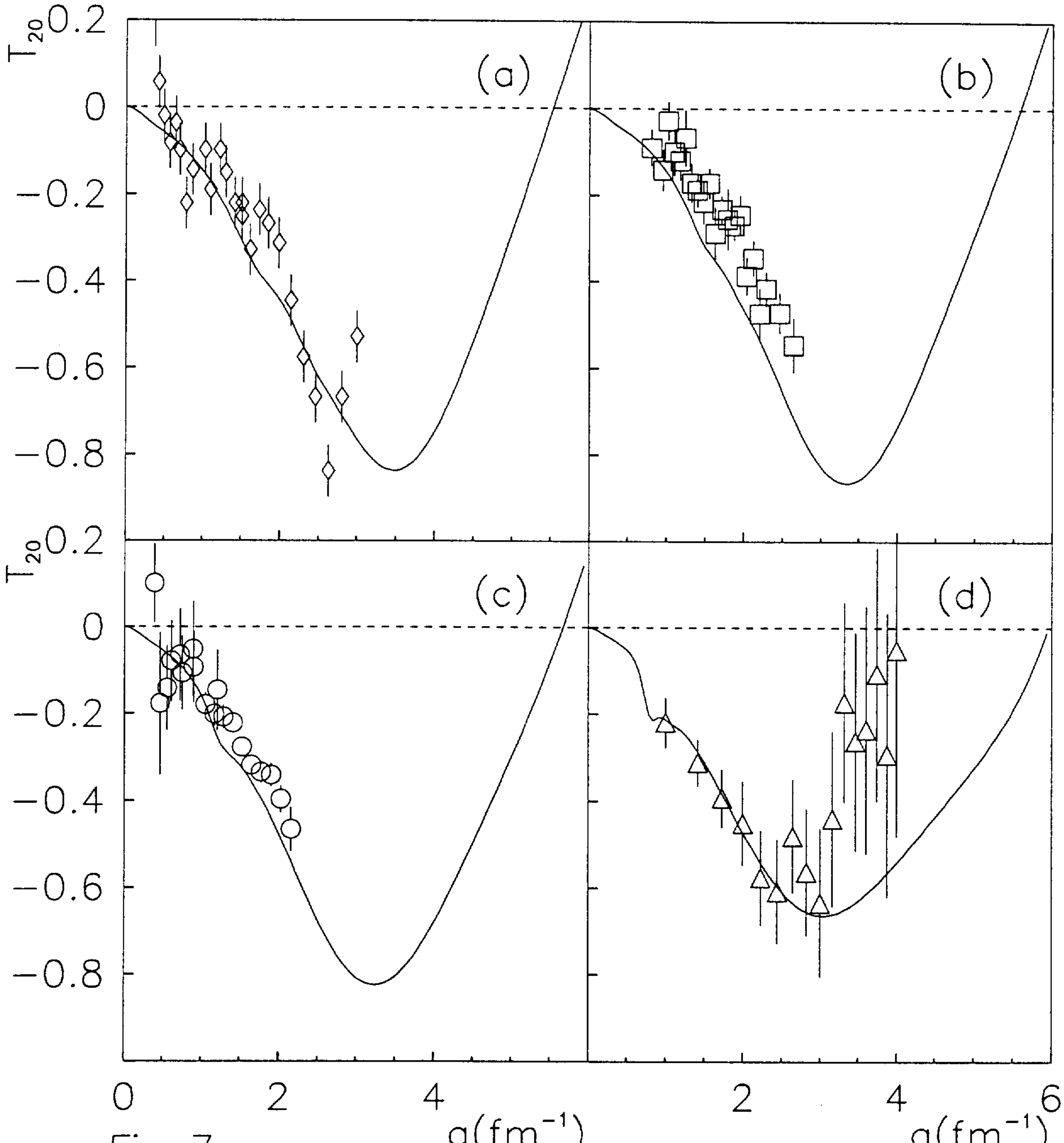

Fig. 7

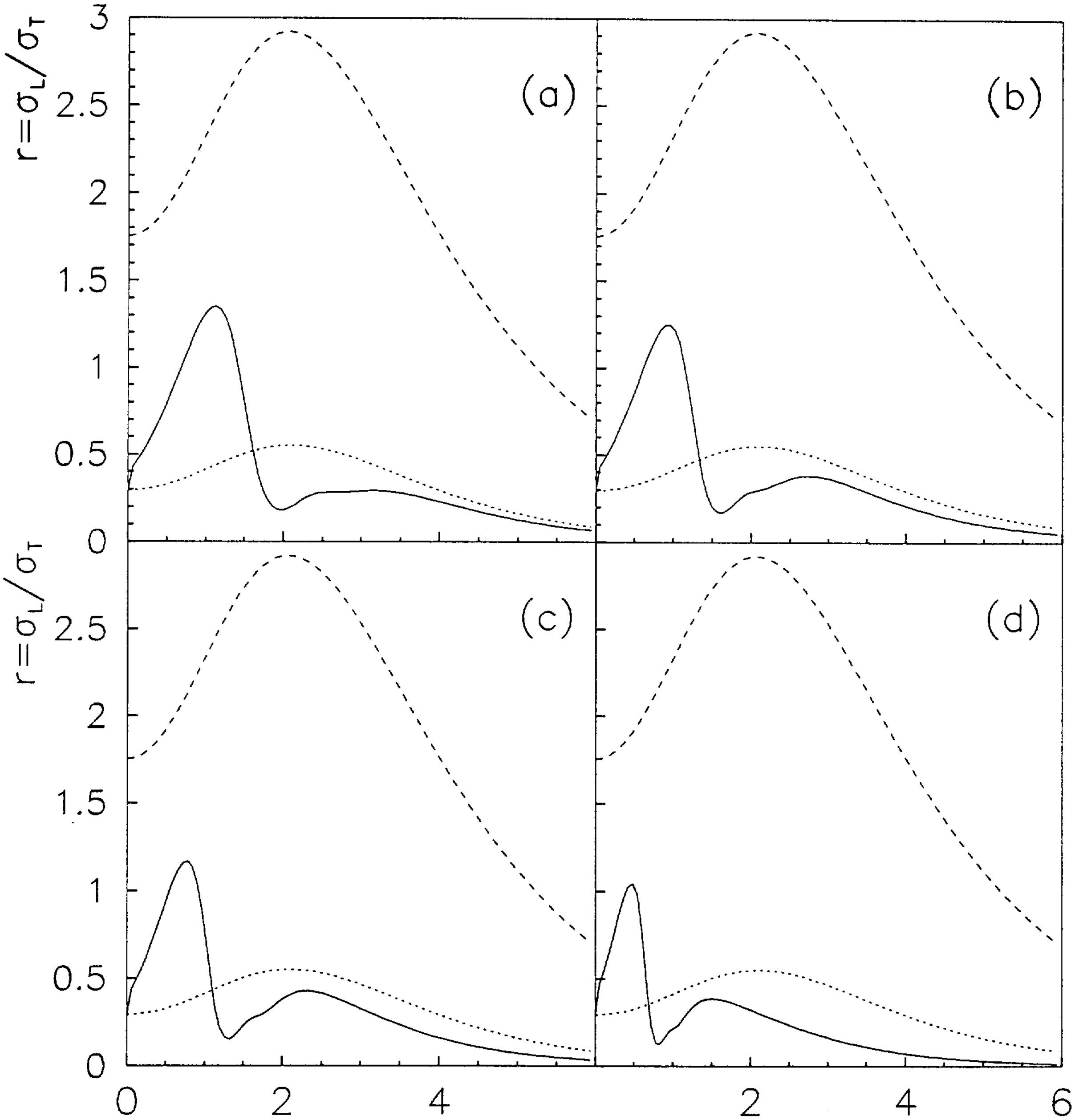

Fig. 8

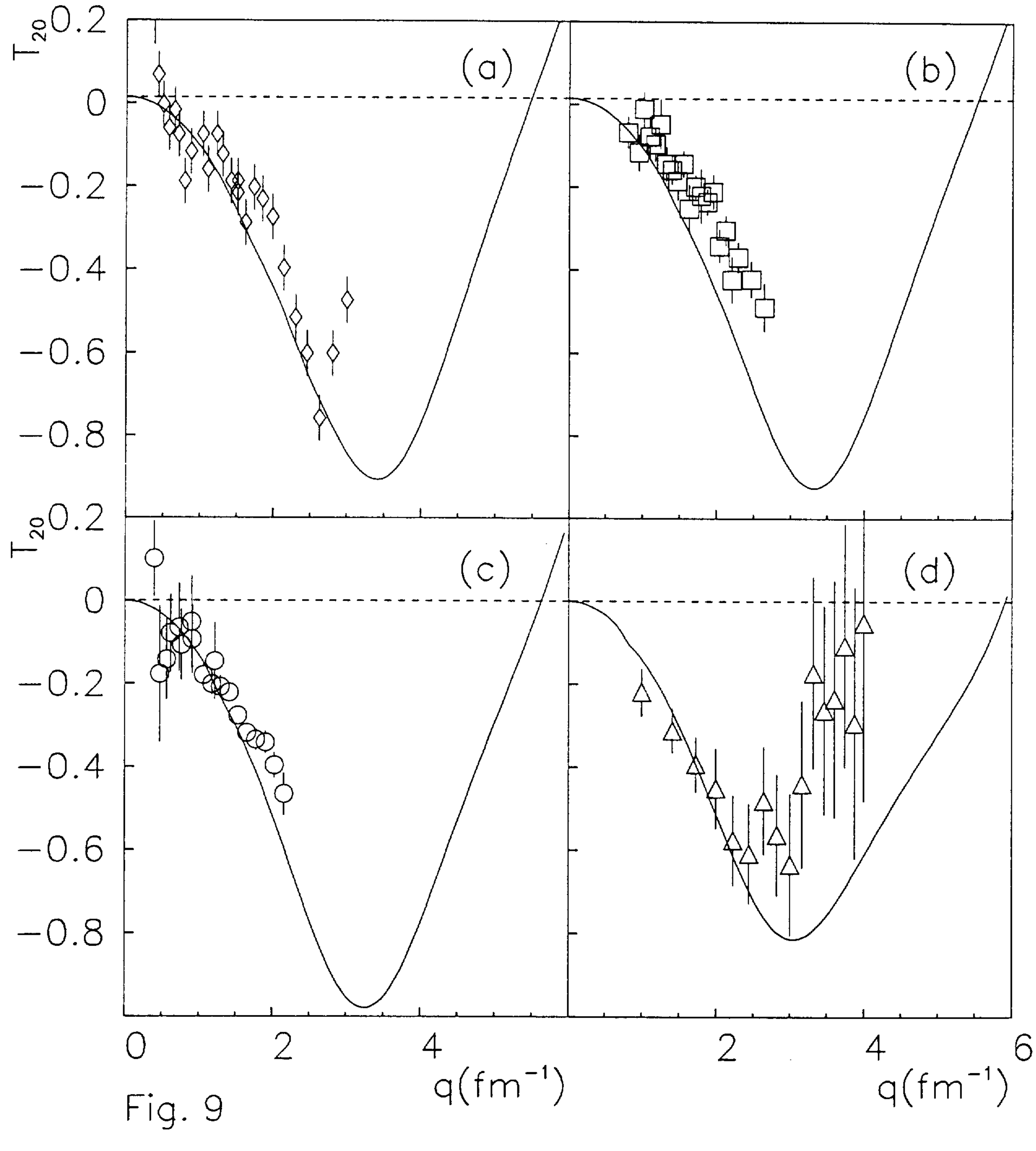

Fig. 9

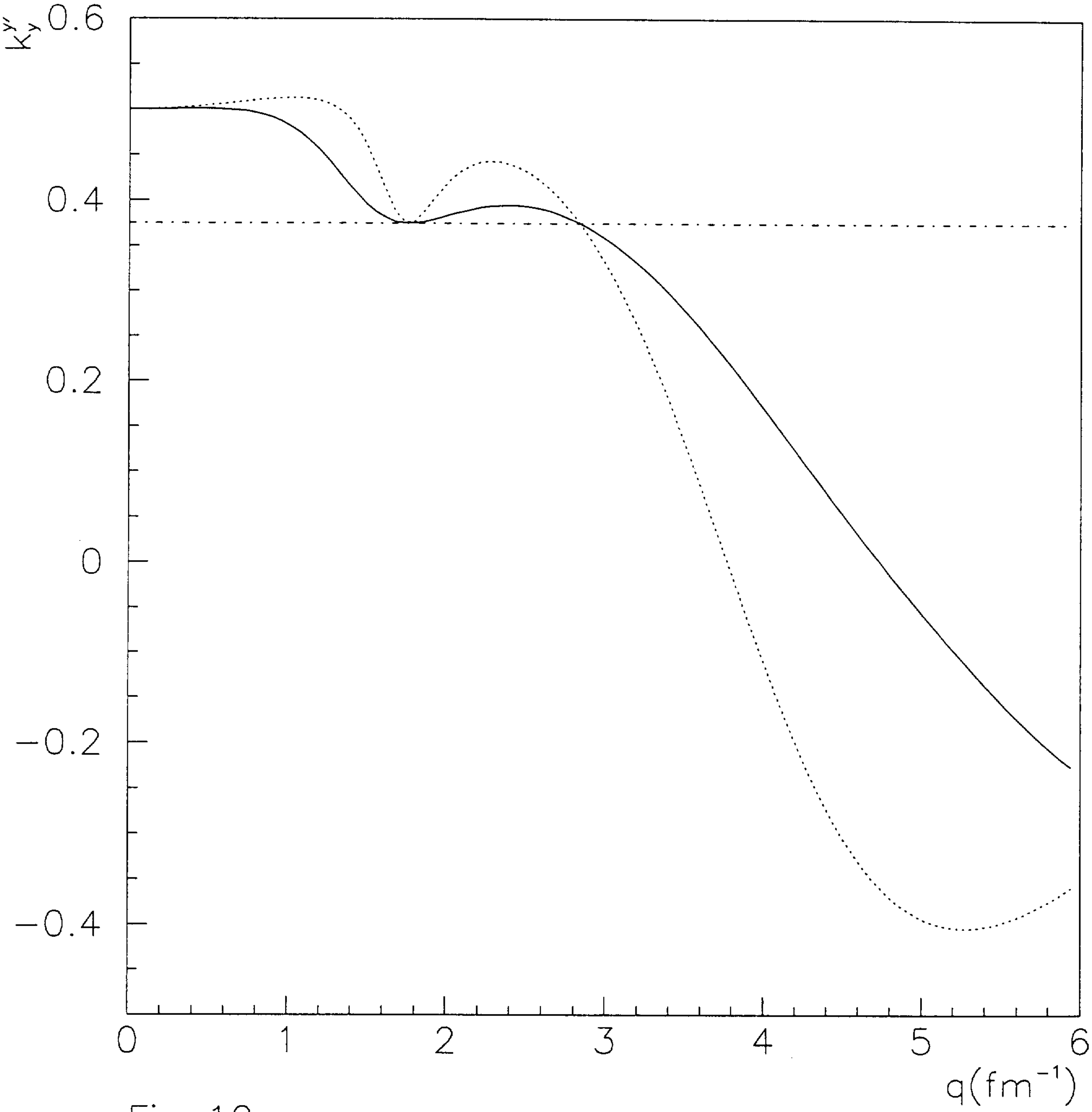

Fig. 10