УДК 539.125 + 539.143.24

ON THE POSSIBILITY OF THE DETERMINATION OF THE CONSTITUENT MASSES OF COMPOSITE PARTICLES BY MEASURING FOUR-MOMENTUM TRANSFER

N.G.Fadeev

The method of determining the constituent masses of composite particles by measuring four-momentum transfer is given in this paper. The idea of the new approach proceeds from the quark-parton presentation of deep-inelastic interactions and differs from the traditional methods connected with the phenomena of particle passage through the matter. The method was substantiated and tested using experimental data on the reaction of deuteron breakdown in a hydrogen chamber. The possibility of practical application of the new approach to other inelastic particle interactions is discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

О возможности определения масс конституентов составных частиц на основе измерения переданного 4-импульса

Н.Г.Фадеев

В работе излагается метод определения масс конституентов составных частиц на основе измерения переданного 4-импульса. В отличие от традиционных способов, связанных с явлениями прохождения частиц через вещество, идея нового подхода исходит из кварк-партонного представления глубоконеупругих взаимодействий. Метод обоснован и проверен на экспериментальных данных реакции развала дейтрона в водородной камере. Обсуждаются возможности практического применения нового подхода к другим неупругим взаимодействиям частиц.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Introduction

The present-day methods of particle mass determination are based on a variety of phenomena accompanying the passage of particles through the matter: ionization, multiple scattering and so on. The suggested approach differs in principle from the traditional methods and its idea lies in the quark-parton picture of inelastic interactions.

A systematic investigation of the deep-inelastic scattering process

$$\ell + N \to \ell + X, \quad (\ell = e, \mu, \nu, \quad N = n, p) \tag{1}$$

allows one to find an interesting feature of these reactions, namely leptons are elastically scattered on free constituents (partons) of the nucleon [1]. The parton mass xm_N (m_N is the nucleon mass) is completely determined by four-momentum transfer. Thus, the hadron mass M_x can be always presented as an effective mass of two partons xm_N and $(1-x)m_N$.

On the other hand, the presentation of nucleon as a composite particle of unbound partons contradicts the real situation: the nucleon manifests itself as a sufficiently hard system.

In this situation it seems logical to assume the existence of real bound constituents of the nucleon instead of free partons. So, the question on the relation of free partons to real constituents and their masses arises.

From all the variety of properties, which the real constituents may have, the property of constancy of their masses is enough to determine them, at least in the specific cases.

Method

An obvious example of the reaction, in which both assumptions (i.e., constituents exist and their masses are the same in different events) are satisfied,

$$d + p \to p + X, \quad X \to p + n \tag{2}$$

is the reaction of deuteron breakdown in a hydrogen bubble chamber [2]. In this reaction the proton from the deuteron is simply identified from the target-proton, consequently, four-momentum transfer is known.

To illustrate our approach and also to control its validity, let us restrict the selection of events just to the type (2), i.e., the reactions with pion production will not be under consideration.

It is easy to notice that the kinematics of reaction (2) in the anti-lab. system is identical to that of reaction (1) in the lab. system.

Let us introduce the following notations for reaction (2):

$$K_b + K_a = K'_a + K_x ,$$
$$q = K_a - K'_a , \quad Q^2 = -q^2 , \quad x = Q^2/2m_b\nu , \quad \nu = E_a - E'_a , \tag{3}$$
$$K_x^2 = M_x^2 = m_b^2 + 2m_b\nu - Q^2 ,$$

where K_a, K_b and K_x are the four-momenta of the projectile, target and hadron system X, respectively, Q^2 is the 4-momentum transfer squared; x, the Bjorken variable; ν , the difference between the energies of the projectile before and after scattering; and M_x, the effective mass of the hadron system X.

Figure 1 illustrates the x, Q^2 and M_x^2 distributions for reaction (2) at a 3.31 GeV/c deuteron momentum per nucleon.

It should be stressed that the parton representation of inelastic interactions (1) and (2) allows the hadron vector K_x to be expressed as a sum of two four-vectors corresponding to the partons with masses xm_b and $(1-x)m_b$:

$$K_x = K_{x1} + K_{x2} ,$$
$$K_x^2 = M_x^2 = (xm_b)^2 + (ym_b)^2 + 2xy\, m_b^2 \mathrm{ch}(\rho_x + \rho_y) , \tag{4}$$

where $y = 1 - x$, ρ_x and ρ_y are parton rapidities in the rest system

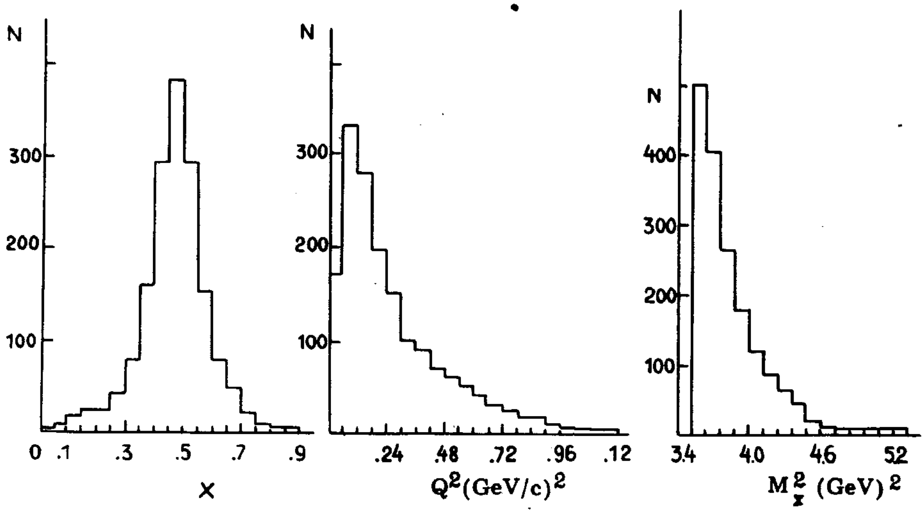

Fig.1. x, Q^2, M_x^2 *distributions for the reaction of deuteron breakdown in a hydrogen bubble chamber at a momentum of 3.31 GeV/c per nucleon.*

of the hadron mass M_x (see Fig.2). In Eq. (4) the masses of all particles are known, therefore their velocities (rapidities) are also defined [3]:

$$\mathrm{th}\,\rho_x = y m_b \,\mathrm{sh}\,\rho_{xy} / (x m_b + y m_b \,\mathrm{ch}\,\rho_{xy}),$$
$$\mathrm{th}\,\rho_y = x m_b \,\mathrm{sh}\,\rho_{xy} / (y m_b + x m_b \,\mathrm{ch}\,\rho_{xy}), \qquad (5)$$

where $\rho_{xy} = \rho_x + \rho_y$.

By analogy with (4), let us introduce the real constituents with masses m_1 and m_2:

$$K_x = K_1 + K_2,$$
$$K_x^2 = M_x^2 = m_1^2 + m_2^2 + 2m_1 m_2 \,\mathrm{ch}(\rho_1 + \rho_2), \qquad (6)$$

where ρ_1, ρ_2 are the corresponding rapidities of the new particles. From Eq. (6) one can express the masses m_1 and m_2 through their velocities (rapidities):

$$m_1 = M_x \,\mathrm{sh}\,\rho_2 / \mathrm{sh}\,\rho_{12}, \quad m_2 = M_x \,\mathrm{sh}\,\rho_1 / \mathrm{sh}\,\rho_{12}, \qquad (7)$$

where $\rho_{12} = \rho_1 + \rho_2$. From Eq. (7) one can see that m_1 and m_2 are defined by the values of ρ_1 and ρ_2 and do not depend on the space orientation of ρ_{12}, i.e. the masses m_1 and m_2 are independent of angle α (Fig.2). Therefore it is more worth-while to change the variables:

$$\rho_1 = \rho_x - \Delta_1, \quad \rho_2 = \rho_y + \Delta_2. \qquad (8)$$

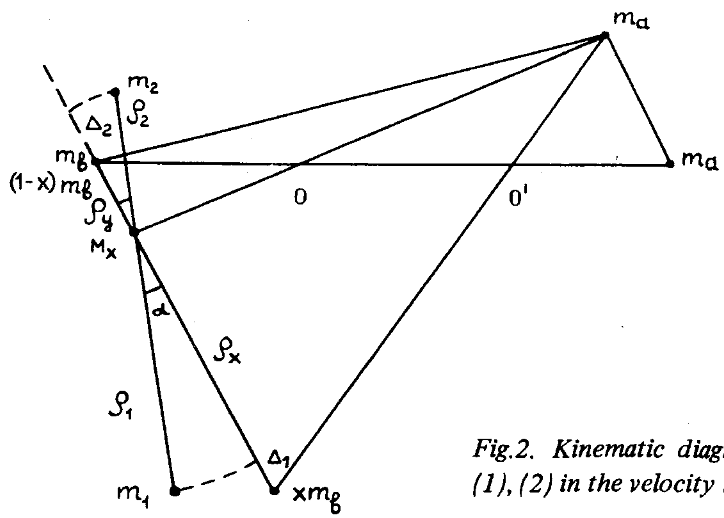

Fig.2. Kinematic diagram of reactions (1), (2) in the velocity space.

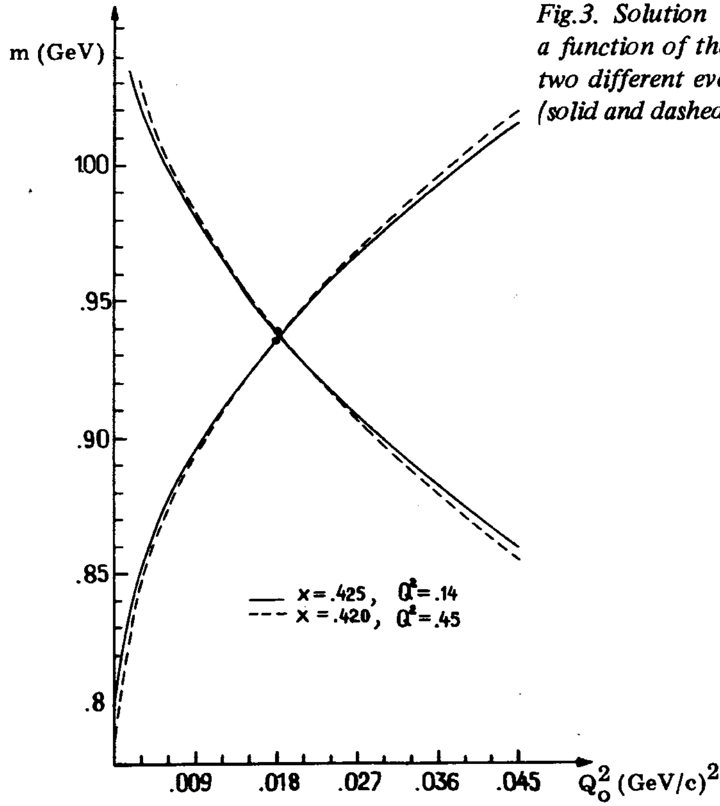

Fig.3. Solution of system (10) as a function of the parameter Q_o^2 for two different events of reaction (3) (solid and dashed lines).

Comparing Eqs.(4) and (6), we have:

$$
\begin{aligned}
&(K_1 - K_{x1})^2 = (K_2 - K_{x2})^2 = Q_\alpha^2 ,\\
&m_1^2 + (xm_b)^2 - 2\,xm_b m_1 \,\mathrm{ch}\,\Delta_1 = Q_o^2 ,\\
&m_2^2 + (ym_b)^2 - 2ym_b m_2 \,\mathrm{ch}\,\Delta_2 = Q_o^2 ,
\end{aligned}
\tag{9}
$$

where Q_o^2 is a new unknown parameter corresponding to Q_α^2 for $\alpha = 0$. The parameter Q_o^2 reflects the above statement that the masses m_1 and m_2 are functions of the values of ρ_1 and ρ_2 and do not depend on the space orientation of ρ_{12}.

Expressing m_1 and m_2 by Eq. (9) and comparing them with (7) taking (8) into account, one can find:

$$
\begin{aligned}
&xm_b \,\mathrm{ch}\,\Delta_1 \pm ((xm_b \,\mathrm{sh}\,\Delta_1)^2 + Q_o^2)^{1/2} = M_x \frac{\mathrm{sh}(\rho_y + \Delta_2)}{\mathrm{sh}(\rho_{xy} - \Delta_1 + \Delta_2)}\\
&ym_b \,\mathrm{ch}\,\Delta_2 \mp ((ym_b \,\mathrm{sh}\,\Delta_2)^2 + Q_o^2)^{1/2} = M_x \frac{\mathrm{sh}(\rho_x - \Delta_1)}{\mathrm{sh}(\rho_{xy} - \Delta_1 + \Delta_2)} ,
\end{aligned}
\tag{10}
$$

i.e., the system of two nonlinear equations with three unknown parameters Δ_1, Δ_2 and Q_o^2. The experimental data of the reaction (2) show how to select the appropriate sign in Eqs. (10): (+) for the first equation, (—) for the second one if $x \leq 0.5$ and vice versa if $x > 0.5$.

The limits of Q_o^2 can be set for the requirement that m_1 and m_2 are positive (upper limit), and radical expressions are positive too (lower limit):

$$-(xm_b \,\mathrm{sh}\,\rho_x)^2 < Q_o^2 < (ym_b)^2, \quad x \leq 0.5 ,$$
$$-(ym_b \,\mathrm{sh}\,\rho_y)^2 < Q_o^2 < (xm_b)^2, \quad x > 0.5 . \qquad (11)$$

For the fixed value of Q_o^2 from system (10) one can find the values of m_1 and m_2 as a function of Q_o^2. Figure 3 presents the solution of system (10) for two real events. The lower limit of Q_o^2 was chosen only from the positive part of interval (11).

It is necessary to determine the approprative value of Q_o^2 for a final choice of the values of m_1 and m_2. For this purpose let us assume that different events of reaction (2) (i.e., different x and Q^2) have the same constituents with the same masses:

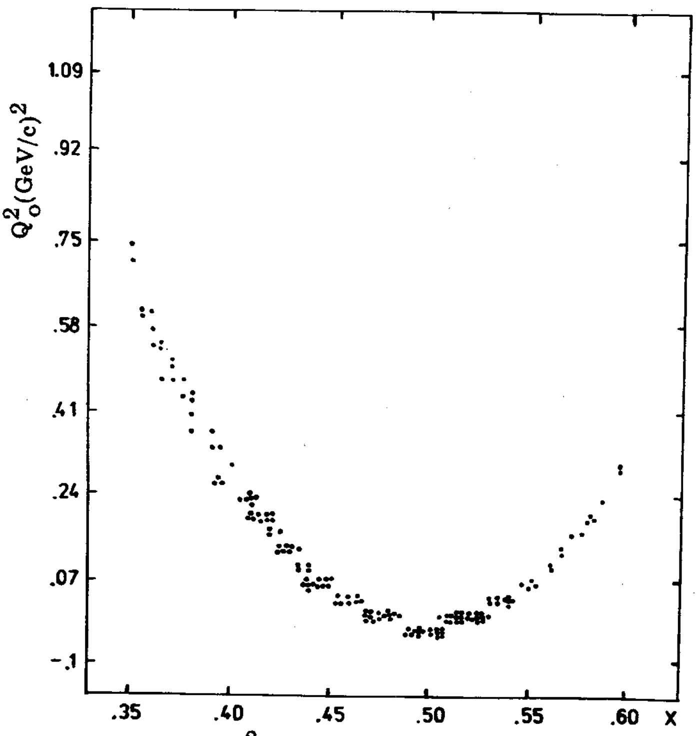

Fig.4. x – Q_o^2 distribution for reaction (2).

$$m_1(Q_0^2)_i + m_2(Q_0^2)_i = \text{const}_1,$$
$$m_1(Q_0^2)_i \cdot m_2(Q_0^2)_i = \text{const}_2, \quad i = 1 \div n, \tag{12}$$

where n is the number of events.

Figure 4 gives the experimental x and Q_0^2 distributions. The neutron and proton masses for m_1 and m_2 were used to calculate the values of Q_0^2. From these data one can see that different events have the same value of Q_0^2 over a small interval of x. This experimental fact can be used to choose the appropriate values of Q_0^2. Namely, from all events one should select those which have crossover points of the curves for $m_1(Q_0^2)$ or $m_2(Q_0^2)$ and find the intersection point of Q_0^2. Figure 3 illustrates the validity of these statements: two curves, which correspond to different events, intersect at the value of Q_0^2 just for the right masses m_1 and m_2.

So, the procedure of determination of the real constituent masses reduces to solving the nonlinear system of equations (10) for each event and to finding the groups of events with the same value of Q_0^2.

Conclusion

For a practical application of the new approach it is useful to stress the main conditions in the framework of which it has been formulated: 1) the components of the four-momentum transfer are measured, 2) real constituents exist, 3) there is a set of events with similar constituents.

Obviously, there is no doubt that this approach can be applicable to reaction (2): just on the basis of this reaction it was substantiated and tested. But its extension to reactions (1) and (2) with secondary pion production still seems unambiguous and requires some further investigation.

On the other hand, poor information on inclusive reactions presents some difficulties in studying details of the dynamics of particle interactions. Thus, the suggested method can be useful in its application to different kinematic regions. This approach seems promising for the investigation of a hadron shower in reaction (1): quark and diquark fragmentation, selection of prompt secondaries and jets. For instance, the selection of prompt particles will make it possible to redetermine the values of four-momentum transfer and to reduce the task to the above version.

Future neutrino experiments at UNK with spectrometers used to measure and to identify all particles of a hadron shower look promising for such kinds of investigations.

In conclusion the author would like to express his gratitude to A.M.Baldin, V.V.Kukhtin, I.A.Savin, G.I.Smirnov, G.A.Emelyanenko, A.V.Efremov, M.I.Soloviev, A.P.Cheplakov and V.V.Glagolev.

References

1. Feymann R.P. — Phys. Rev. Lett., 1969, 23, p. 1415;
   Bjorken J. — Phys. Rev., 1969, 179, p. 1547;
   BCDMS Collaboration — JINR, E1-89-540, Dubna, 1989.
2. Glagolev V.V. et al. — Yad. Fiz., 1979, 30, p. 1569;
   JINR, 1-7645, Dubna, 1973, P1-88-6, Dubna, 1988.
3. Chernikov N.A. — Particles and Nuclei, 1973, 4, p. 733.

Received on November 13, 1989.