STATE RESEARCH CENTER OF RUSSIA
INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 2003-27
ОЭФ

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Indication on the universal hadron substructure — constituent quarks.

Protvino 2003

UDK 539.12.142 M–24

Abstract

V.V. Mochalov, S.M. Troshin and A.N. Vasiliev. Indication on the universal hadron substructure — constituent quarks.: IHEP Preprint 2003-27. – Protvino, 2003. – p. 3, figs. 2, refs.: 8.

The universality of single-spin asymmetry on inclusive π-meson production is discussed. This universality can be related to the hadron substructure — constituent quarks in the frame of the quark model for U-matrix.

Аннотация

А.Н. Васильев, В.В. Мочалов, С.М. Трошин. Указание на наличие универсальной структуры адронов — конституентных кварков.: Препринт ИФВЭ 2003-27. – Протвино, 2003. – 3 с., 2 рис., библиогр.: 8.

Обсуждается универсальность односпиновой асимметрии инклюзивного образования π-мезонов. Такая универсальность поведения односпиновой асимметрии может быть связана с наличием универсальной структуры адронов — конституентных кварков.

Polarization experiments give us an unique opportunity to probe the nucleon internal structure. While spin averaged cross-sections can be calculated within acceptable accuracy, current theory of strong interactions can not describe large spin asymmetries and polarization. Polarization is a precision tool for measuring the electroweak parameters, spin dependent structure functions etc. After establishing the fact that the nucleon spin is not described by simple summing of the quark spins, the study of gluonic and orbital momentum contribution to it is very important and intriguing.

Unexpected large values of single spin asymmetry (SSA) in inclusive π-meson production are real challenge to current theory because perturbative Quantum Chromodynamics predicts small asymmetries decreasing with transverse momentum. Various models were developed to explain results from E704 (FNAL), PROZA-M and FODS (both Protvino) and several BNL experiments. Most of the models analyse experimental data in terms of $x_{\rm F}$ and/or p_T. To investigate the dependence of SSA on a secondary meson production angle, the measurements in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ were carried out at the PROZA-M experiment (Protvino) at 40 GeV pion beam in the two different kinematic regions: at Feinman scaling variable $x_{\rm F} \approx 0$ [1] and in the polarized target fragmentation region [2]. The papers [2,3] reported that the asymmetry of inclusive π^0 production in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ begins to grow up at the same centre of mass energy $E_0^{cms} \approx 1.7$ GeV. The result is presented

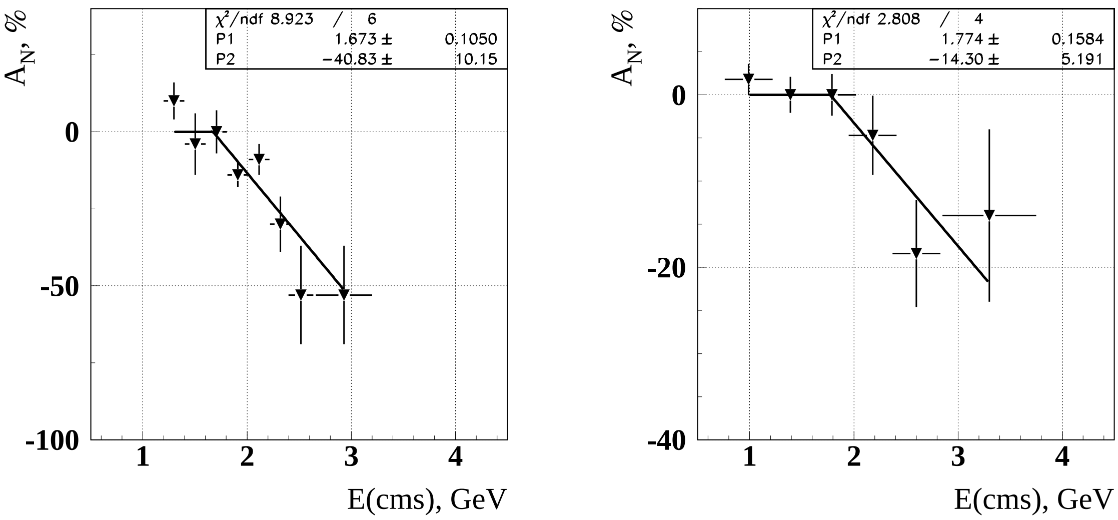

Figure 1. The dependence of the single-spin asymmetry A_N on π^0-meson centre of mass energy in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at the central region (left, [1]) and in the polarized target fragmentation region (right, [2]) at 40 GeV.

in **Fig. 1**. Nevertheless from this statement we can not make the conclusion whether the SSA behaviour depends on a beam energy or not.

The π^+ asymmetry in E704 experiment (200 GeV proton beam) [4] and in E925 experiment (BNL, 22 GeV)[5] begins to rise up at different values of $x_{\rm F}$ ($x_{\rm F}^0 \approx 0.18$ for E704 and $x_{\rm F}^0 \approx 0.46$ for E925). It was also found that the asymmetry for these two experiments begins to grow up at the same longitudinal or full energy in the centre of mass system, $E_0^{cms} \approx 1.6$ GeV. It happened to be surprisingly the same energy as for the PROZA-M experiment. The comprehensive analysis of all fixed target polarized experiments of inclusive π-meson production was done in [3]. The result of the analysis is presented in **Fig. 2**.

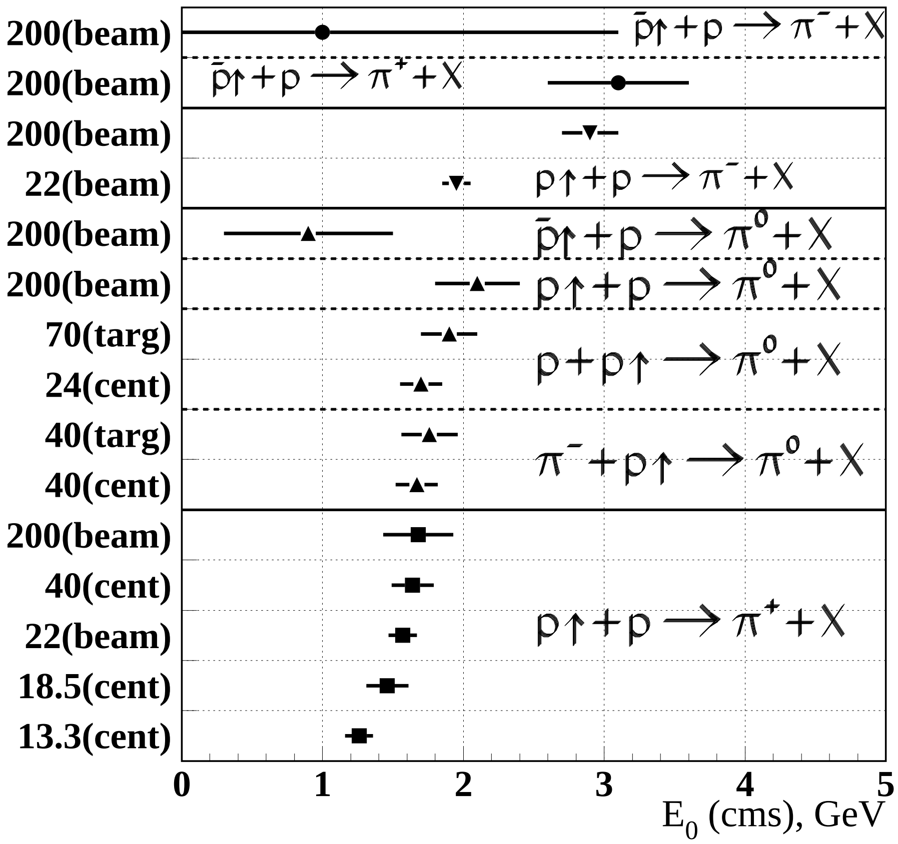

Figure 2. Centre of mass energy values where the pion asymmetry begins to grow up for different experiments. The energy along the Y-axis is in GeV; *cent* – corresponds to experiments in the central region ($x_f \approx 0$), *targ* – the polarized target fragmentation region; *beam* – the polarized beam fragmentation region.

The main conclusion is that the asymmetry begins to grow up at the same centre of mass energy $E_0^{cms} = 1.5$ to 2.0 GeV for most of the experiments in the energy range between 13 and 200 GeV. The analysis was done only for those experimental data where a transverse momentum p_T was greater than 0.5 GeV/c to exclude very soft interactions. We did not include the experiments when the asymmetry was close to zero. The conclusion is valid for all π^+ and π^0 asymmetries. We have to mention that π^- production seems to contradict to this. We can explain this fact that π^--meson at small x_F can be produced not only from the valence d-quark but also from other channels. The interference of different channels is also responsible for asymmetry cancellation in

π^0 and π^- production in the central region. In the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ in the central region we found significant asymmetry in the contrary to the $p_\uparrow + p \to \pi^0 + X$ reaction. If in the $p_\uparrow + p \to \pi^0 + X$ reaction the asymmetry is cancelled because of different channel interference from a polarized and non-polarized proton, in the $\pi^- p_\uparrow$ collisions the valence u-quark from a polarized proton combining with the valence $\bar{u}$-quark from π^- gives the main contribution to π^0 production, while other channels are suppressed.)

In this scheme the asymmetry behaviour in $\bar{p}_\uparrow p$ interactions in π^+ and π^- production should be inversed in comparison with the $p_\uparrow + p \to \pi^0 + X$ data. The result from E704 experiment [6] is consistent with this model. The asymmetry of π^+-production begins to grow up at the same value $E_0^{cms} \approx 2.9$ GeV as for π^- in reaction $p_\uparrow + p \to \pi^0 + X$, and the asymmetry in the reaction $\bar{p}_\uparrow + p \to \pi^- + X$ begins to grow up at small value E^0_{cms}.

We may conclude that the meson asymmetry produced by valence quark begins to grow up at the same universal energy E^0_{cms}.

The obtained universality of the value E^0_{cms} can manifest the presence of the universal substructures in the hadrons — constituent quarks. The concept of constituent quark has [7,8] been used extensively since the very beginning of the quark era but has just obtained recently a possible direct experimental evidence at Jefferson Lab [9].

A particular model for single spin asymmetries which used the constituent quark concept in the hadron interaction was proposed in [10]. The constituent quark appears as a quasiparticle, i.e. as current valence quark surrounded by the cloud of quark-antiquark pairs of different flavours, i.e. they are structured hadron-like objects. SSA in the model is due to an orbital angular momentum of quarks inside the constituent quark: spin of constituent quark, e.g. U-quark is given by the sum:

$$J_U = 1/2 = S_{u_v} + S_{\{\bar{q}q\}} + L_{\{\bar{q}q\}} = 1/2 + S_{\{\bar{q}q\}} + L_{\{\bar{q}q\}}. \tag{1}$$

On the grounds of the experimental data for polarized DIS the conclusion was made that the significant part of the spin of constituent quark in the model should be associated with the orbital angular momentum of the current quarks inside the constituent one [10]. In the model SSA reflects internal structure of the constituent quarks and is proportional to the orbital angular momentum of current quarks inside the constituent quark. Evidently, SSA related to the internal orbital momentum will be non-zero only when the constituent quark will be excited and broken up. The value E^0_{cms} can be related then to the minimal energy which is needed for constituent quark excitation and its dissolution. In this approach it is natural that this energy is universal since it is adherent to the properties of the constituent quarks. It should be related anyway to the scale of chiral symmetry breaking Λ^2_χ.

Thus the revealed scaling dependence of asymmetry can be interpreted as another indication of the presence of constituent quarks in the hadrons.

We are thankful to N.E. Tyurin for fruitful discussions.

The work is partially supported by Russian Foundation for Basic Research grant 03-02-16919.

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