INTRODUCTION

Studies of the single-spin asymmetries (SSA’s) is a sensitive tool to probe QCD at small and large distances. Experimentally, significant SSA’s were observed in various processes of elastic scattering, inclusive and exclusive hadron production.

The processes of hadron interactions are complicated, there is no proof of factorization theorem for these processes and it could results from the real absence of hard and soft parts of interaction factorization in hadronic reactions. The origin of SSA in these reactions is not clear. Despite significant efforts in theoretical studies devoted to this problem, the phenomenological success is rather limited; at the moment there is no comprehensive approach able to describe the existing set of experimental data on polarization, asymmetries, spin correlations and the unpolarized cross-section. Theoretically, there are various approaches to generation of the nonzero SSA but the problems mentioned above.

The decreasing dependence of SSA with $p_T$—common feature for the listed above approaches—has not been observed experimentally. The experimental data including the most recent data obtained at RHIC [9], are consistent with a flat transverse momentum dependence at $p_T \geq 1$ GeV/c. Another important point is related to the unpolarized inclusive cross-section. For example, it has been also demonstrated [10] that the description of the inclusive cross-section for $\pi^0$-production, at the energies lower than the RHIC energies also meets difficulties in the framework of the perturbative QCD. Deviation from the pQCD scaling is mostly noticeable in the forward region where the most significant asymmetry in the $\pi^0$

production in $pp \rightarrow \pi^0 X$ has also been observed by STAR collaboration at RHIC [9] at $\sqrt{s} = 200$ GeV (in the fragmentation region of the polarized proton).

Of course, more experimental data are needed to perform a conclusive test of various theoretical approaches and their predictions should be more specified and elaborated for the observables at the hadronic level. In this connection it should be noted that one of the most interesting and persistent spin phenomenon is a very significant polarization of $\Lambda$-hyperon which has been discovered almost three decades ago in collisions of unpolarized hadron beams [12]. It should be also noted, that the asymmetry $A_{\chi} = 0$ in the neutral pion production in the backward and midrapidity regions. SSA has also zero value in the $pp \rightarrow pX$, while $A_{\chi} \neq 0$ in the $pp \rightarrow nX$ in the polarized proton fragmentation region. The approaches based on the assumed pQCD factorization meet in these processes the problems mentioned above.

Thus, it is (more or less depending on the particular personal taste) evident that the problems mentioned above can be related to the illegitimate use of the methods based on perturbative expansion, factorization and accounts for higher twists in the region and in the processes where they actually cannot be valid, and it is the kinematical region of the modern experiments dealing with rather modest transverse momenta and energies. In contrast, it might happen that SSA’s originate from the genuine nonperturbative sector of QCD (cf. e.g. [16]). Such point of view, i.e. that the polarization has its roots in the nonperturbative sector of QCD was widely used in the earlier models and becomes less isolated one nowadays. In the nonperturbative sector of QCD the two phenomena, confinement and chiral symmetry spontaneous breaking ($\chi SB$) [17] should be reproduced. The relevant scales are characterized by the parameters $\Lambda_{QCD}$ and $\Lambda_{\chi}$, respectively. Chiral $SU(3)_c \times SU(3)_R$ symmetry is spontaneously broken at the distances between these two scales. The $\chi SB$ leads to generation of quark masses and appearance of quark condensates. It describes transition of cur-

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rent into constituent quarks. Constituent quarks in its
turn are quasiparticles, i.e. they are a coherent superposition
of bare quarks and their masses are comparable to a
hadron mass scale. Therefore hadron is often represented
as a loosely bounded system of the constituent quarks.
These observations on the hadron structure lead to
understanding of several regularities observed in hadron
interactions at large distances. It is well known that such
picture provides reasonable values for the static character-
istics of hadrons, for instance, their magnetic
moments. The other well known result is appearance of
the Goldstone bosons. It has been successfully applied
for the explanation of the nucleon spin structure
including the most recent results obtained at JLab.

We are grateful to Dmitri Diakonov for the interesting commu-
nication on this matter regarding the polarization phenomena.

It is necessary to note that the structure functions are
represented by the distorted parton distributions in the
impact parameter plane in the polarized case. In this
work the approach based on nonperturbative QCD has
been used to relate A-polarization with large magnitude
of the transverse flavor dipole moment of the transversely
polarized baryons.

The instanton-induced SSA generation relates those asymmetries to a genuine nonperturbative
QCD interaction. It should be noted that the physics of
instantons (cf. e.g. [23]) can provide microscopic expla-
nation for the SB.

We discuss here the SSA generation based on chiral
quark model ideas (cf. e.g. [17]) and the filtering spin
states related to the account of unitarity in the s-channel.
It connects polarization with asymmetry in the position
(impact parameter) space. We show that the common
features of SSA measurements at RHIC and Tevatron
(linear increase of asymmetry with xF and flat transverse
momentum dependence at pT > 1 GeV/c) can be repro-
duced and described in the framework of the semiclas-
sical picture based on the further development of the chiral
quark model suggested in [24] and results of its adapta-
tion for the treatment of the polarized and unpolarized
inclusive cross-sections. The above mentioned data
obtained at RHIC [11] for the unpolarized inclusive
cross-section can be simultaneously described. Consis-
tency with other new experimental regularities found at
RHIC are discussed as well. Preliminary version of this
paper can be found in [18].

1. SEMICLASSICAL MECHANISM
OF SSA GENERATION

As it was argued the SSA could originate from the
nonperturbative QCD and is related to the mechanism of
spontaneous chiral symmetry breaking (SB) in QCD,
leading to generation of quark masses and appearance
of quark condensates.

Thus we consider a hadron as an extended object con-
sisting of the valence constituent quarks located in the
central core which is embedded into a quark condensate.
Collective excitations of the condensate are the Gold-
stone bosons and the constituent quarks interact via
exchange of Goldstone bosons [26]. This interaction is
mainly due to a pion field and has therefore a spin-flip
nature.

At the first stage of hadron interaction common
effective self-consistent field appears. This field is gen-
erated by Q̅Q pairs and pions interacting with quarks.
The time of generation of the effective field tff

\[ t_{\text{eff}} \ll t_{\text{int}}, \]

where tint is the total interaction time. This assumption on
the almost instantaneous generation of the effective field
obtained some support in the very short thermalization
time revealed in heavy-ion collisions at RHIC.

Valence constituent quarks are scattered simulta-
neously (due to strong coupling with Goldstone bosons)
and in a quasi-independent way by this effective strong
field. Such ideas were used in the model [24] which has
been applied to description of elastic scattering and had-
ron production [28].

In the initial state of the reaction pp → π0X the proton
is polarized and can be represented in the simple
SU(6) model as following:

\[ p^+ = \frac{5}{3} U^+ + \frac{1}{3} U_\perp + \frac{1}{3} D^+ + \frac{2}{3} D_\perp. \]

We exploit the common feature of chiral quark mod-
els; namely the constituent quark Q^+ with transverse
spin in up-direction can fluctuate into Goldstone
boson and another constituent quark Q^+ with opposite
spin direction, i.e. perform a spin-flip transition:

\[ Q^+ \rightarrow GB + Q^- . \]

The π0-fluctuations of quarks do not change the quark
flavor and assuming they have equal probabilities in the
processes:

\[ U^+, D^- \rightarrow π^0 \] and \[ D^+, D^- \rightarrow \pi^0 + D^- \]

the production of π0 by the polarized proton p^+ in this
simple SU(6) picture can be regarded as a result of the
fluctuation of the constituent quark Q^+ (Q = U or D) in
the effective field into the system π0 + Q^- (Fig. 1).

The contributions to the cross-sections difference of
the quarks polarized in opposite directions compensate
each other (as it will be clear in what follows), and it is not
the case for the π0-production in the unpolarized case.
Therefore the asymmetry AS should obey the inequality
\[ |A_S(π^0)| \leq \frac{1}{3}. \]

To compensate quark spin flip δS, an orbital angular
momentum δL = −δS should be attributed to the final
state of reaction (2). The presence of δL in its turn means
a shift in the impact parameter value of the Goldstone
boson π0:

\[ δS = δL = δb. \]