Average transverse momenta in hyperon production at p-p collider experiments

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Average transverse momenta in hyperon production at p-p collider experiments

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Abstract. The transverse momentum spectra of Λ⁰ hyperon from LHC experiments (ALICE, ATLAS, CMS in the comparison with earlier experiments are considered from the point of view of Quark-Gluon String Model (QGSM) as examples of typical baryon spectra at very high energies. The LHC data at √s = 0.9 and 7 TeV and STAR data at √s = 200 GeV are fitted with the universal QGSM formula that includes the energy dependent slope as the main parameter. The dependence of average transverse momenta on √s has been obtained with the help of this formula. The asymptotics of the energy dependence of <pₜ> shows the behavior s₀.055. This conclusion is very important for cosmic ray physics. It means that the long debated "knee" in the cosmic proton spectra at Eₚ = (2.5 - 4)*10¹⁵ eV in laboratory system can not be considered any more as the result of dramatic changes in the dynamics of baryon hadroproduction. In the same time it may indicate the maximal energy of protons that can be produced in our Galaxy (or in other Galaxies).

1. Introduction

As you will see from the reference list to this paper, my study is following to the basical works of general authors of Quark-Gluon String Model: A.B.Kaidalov and K.A.Ter-Martirosyan [1]. Our collaboration began in early 1980th, while it was necessary to predict proton and pion spectra in whole kinematical regions (including the arrea of the beam particle fragmentation) that was caused by the problems in cosmic ray physics. Practically, only quark-gluon strings have been able to account correctly the energy conservation between different regions of hadron spectra. The entire corpus of the data on hadron spectra that have been measured at collider experiments those times was described and the cross sections for the production of heavy quark hadrons were predicted. In 90th, when it became clear that the quark structure of interacting particles can be revealed in the charge asymmetry of produced hadron spectra, we have studied all posible effects of leading/nonleading asymmetries in heavy-quark hadron spectra. This asymmetry should be caused by different quark contents of interacting and produced hadrons. The approach doesn’t require the absolute values of differencial cross sections.

Only one subject of QGSM application left non-upgraded with new data, it is the description of transverse momentum spectra of produced particles. So, now I continue this activity on the new level of up-to-date collider investigation.

The transverse momentum spectra of Λ⁰ hyperons that were measured by many hadron collider experiments: ISR [2], STAR [3], UA1 [4], UA5 [5], CDF [6] and experiments at LHC [7, 8, 9] show the form of distributions which is changing from lower energy to higher. As it was
established in the previous publication [10], there is specific dependence of spectra on the type of colliding hadrons. Due to this difference, we have to confine ourself to the considering only the proton-proton collision results: ISR, STAR, ALICE, ATLAS and CMS in the wide range of \( \sqrt{s} \): beginning from 53 GeV to LHC energy 7 TeV.

This range of energy has motivated me to investigate the behaviors of baryon spectra, because the proton spectrum in cosmic rays (CR) shows the "knee" at the very energy between Tevatron and LHC energies [11], see Fig.1. The change in the slope of proton spectrum may be of the astrophysical origin otherwise it means a substantial change in dynamics of particle production. We have to study the behaviors of baryon production at the collider experiments moving from one energy to another in order to conclude about whether or not the dramatic changes have place in hadroproduction processes at the "knee" energy and a little above.

![Figure 1](image-url)  
**Figure 1.** The cosmic proton spectrum at the energies between Tevatron and LHC.

The average transverse momenta of hyperons can show the specifical points in the characteristics of baryon production especially in the given range of energies. As it was learned in QGSM, the typical average transverse momentum at the production of certain hadrons is almost constant. It should slightly grow with energy due to the growing contributions from multipomeron exchanges that gives more fluctuations in transverse momenta.

2. Baryon transverse momentum distributions at LHC and QGSM description.

The recent data on A^0 hyperon distributions are obtained in the following LHC groups: ALICE [7] at 900 GeV, ATLAS [8] at 900 GeV and 7 TeV and CMS [9] at 900 GeV and 7 TeV. The lower energy experiment, which we can compare with the results of LHC groups, is STAR [3] (\( \sqrt{s} = 200 GeV \)).

If we fit the data with a simple exponential function \( e^{-B*pt} \), experiments, ATLAS and CMS, have presented the spectra with the similar slopes, see Fig.2. The different form of the distributions at low \( pt \)'s may be caused by specifics in the efficiency of the detecting procedure. It should be mentioned here that ATLAS spectra have systematically low efficiency at \( pt < 1 \) GeV in comparison to the results of other LHC groups.

It was studied in early QGSM paper [12] that the transverse momentum spectra of hadrons after proton-proton collisions can be perfectly described with a bit more complicate dependence:

\[
\frac{dN^H}{dp_t} = p_t * \int d^2 \sigma^H_{xFd^2p_t} * p_t * e^{-B_0*(m_t-m_0)},
\]  

(1)
where \( m_0 \) is the mass of produced hadron, \( m_t = \sqrt{p_t^2 + m_0^2} \) and \( B_0 \) used to bring the dependence on \( x_F \), but in central region of rapidity this slope is constant. The slopes of the spectra of many types of hadrons (\( \pi, K, p \) and \( \Lambda^0 \)) were estimated for the data of early proton-proton collision experiments of the energies that were available those times. The slopes of baryon spectra were approximately constant, \( B_0 = 6.0 \), which has been considered to be stable at all energies. Now we have to conclude that \( B_0 \) depends strongly on the energy. More, as it is seen from the spectra at LHC and RHIC, the value of \( m_0 \) is not equal nor to proton nor to hyperon masses.

### Figure 2. The comparison of ATLAS and CMS data at \( \sqrt{s} = 7 \text{ TeV} \).

The better description of hyperon spectra, which is shown in Fig.4, can be achieved with \( m_0 = 0.5 \text{ GeV} \) that is kaon mass. This fact can be explained by the minimal quark-antiquark chain at hyperon production. In the short view, this chain is consisted of \( K + \Lambda^0 \) (only in the case of proton-proton collision) and the minimal transverse momentum of \( \Lambda \), such a way, should be of order of kaon mass. In suggested fit, the values of slope parameter have to be equal for all LHC experiments of the same energy. It means that as soon as we estimate the slopes for various collider energies we are getting a chance to calculate (using the formula above) the energy dependence of average transverse momentum for the wide range of energy of proton-proton collisions.

### Figure 3. The description of STAR, ALICE and CMS data with the QGSM function.

The resulting dependence of average \( p_t \) on the energy of interaction is shown in Fig.5. It seems reasonable to expect that the energy dependence of the average \( p_t \) value would somehow
reproduce the multipomeronic behavior of high energy hadron interactions, which have been studied in QGSM within three decades, see [1, 13, 14, 15, 16]. The enhancing of the contributions from multipomeron components in the production diagrams has to cause the growing of fluctuations in transverse momenta of proton constituents that should result in the stable slight growing of the average $p_t$.

![Figure 4](image_url)

**Figure 4.** The average transverse momentum of hyperons vs. the energy of colliding protons.

We could only suggest that the fast growing of average $p_t$ before STAR energy is due to valuable impact of baryon production from fragmentation region of beam proton. For the higher energy, the leading production of $\Lambda^0$ doesn’t play an important role.

### 4. Conclusions

The review of results on transverse momentum distributions of hyperons that are produced in proton-proton collisions of up-to-date energies reveals a significant change in the slopes of spectra in the region of $p_t = 0.3 - 4.0$ GeV/c. The spectra of baryons are becoming harder and harder with the energy growth from RHIC ($\sqrt{s}=200$ GeV) to LHC (0.9 and 7 TeV). The detailed analysis of hyperon spectra, which is analogous to our early studies in frameworks of Quark-Gluon String Model, demonstrates the change of slopes from $B_0 = 5.7$ (ISR at 53 GeV) to $B_0 = 2.1$ (LHC at 7 TeV).

As a result, the average $<p_t>$ value is growing very fast up to approximately $\sqrt{s}= 200$ and then it goes with the asymptotics $s^{0.05}$. This behavior cannot be considered as important change in the hadroproduction processes. Thus, it makes us conclude that processes that are taking place in baryon production at the energies of LHC are not anything unpredictable. This statement is very important for cosmic ray physics, where the ”knee” (the change in the slope) at $E_{lab} \approx 3 \times 10^{15}$ eV in cosmic proton spectra might have an origin in hadronic interactions.

As we have discussed above, nothing unpredictable happens with baryon spectra up to $\sqrt{s}= 7$ TeV that corresponds to $E_{lab} = 2.5 \times 10^{16}$ eV. It means that the ”knee” can be caused only due to astrophysical reasons. On the other hand, the ”knee” may indicate the maximal energy of proton that are being produced in other Galaxies. But the idea of production of very high energy protons in space assumes a further detailed investigations of the production dynamics of quark systems by means of QGSM. It seems very intriguing to observe whether or not the average transverse momenta of baryons become constant at further energies of LHC.

Some brief analysis of growing-with-energy antiparticle-to-particle ratios of elementary particles that are measured in cosmic experiments was done in this QGSM technics as well. The growing ratios may be explained by the leading behavior of hadron production spectra that is inavitable result of ”positiveness” of our Universe. The antibaryon/baryon production asymmetries, which are already measured in LHC experiments, are intended to be discussed in the upcoming publication.
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