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Baryon production at LHC energies and very high energy cosmic ray spectra

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Abstract. The spectra of baryons at LHC can explain the features of CR proton spectra. It seems important to study all baryon data that are available from collider experiments in a wide range of energies. Transverse momentum spectra of baryons from RHIC ($\sqrt(s) = 62$ and 200 GeV) and LHC experiments ($\sqrt(s) = 0.9$ and 7 TeV) have been considered. It is seen that the slope of low p_T distributions is changing with energy. The QGSM fit of distributions gives the average transverse momenta which behave approximately as $s^{0.06}$ that is similar to the previously observed behavior of Λ baryon spectra. This slow growing of $<p_T>$ in hadron interactions of VHE in CR detectors cannot cause the "knee" in experimental proton spectra. In addition, the available data on Λ_c production from LHCb at $\sqrt{s} = 7$ TeV were also studied. The preliminary dependence of hadron average transverse momenta on their masses at the LHC energy is presented. The possible source of cosmic ray antiparticle-to-particle ratios that are growing with energy was also analyzed. The growing ratios are the result of local leading asymmetry for spectra of baryons and antibaryons that are produced in the kinematical region of proton target fragmentation. This asymmetry of baryon spectra, as they are converted into the energy distributions in the laboratory system, seems to result in an increasing ratio of secondary antiparticle-to-particle spectra up to a few hundreds of GeV. This conclusion makes important the particle production at the sources of very high energy cosmic rays where the VHE interactions with positive matter target may take place.

1. Introduction

The spectra of baryons at the LHC can explain the features of cosmic ray particle spectra at very high energies. The transverse momentum distributions are the primary data that can be obtained in the study of hadron spectra at modern colliders. Interpretation of these distributions in up-to-date phenomenological models can shed a light on the physics of hadroproduction processes at high energies. The phenomenological approach is applied here to the description of p_T spectrum of various sorts of baryons in the framework of Quark-Gluon String Model [1]. The model has described the data of previous colliders up to energies $\sqrt(s) = 53$ GeV at the area of low p_T that gives main contribution to the average value of transverse momenta [2]. Recently Λ^0 production has been studied [3] in an updated version of this model.

The complete study of baryon spectra at LHC energies ($\sqrt(s) = 0.9$–7 TeV) [4] did not show important changes that may be responsible for the "knee" in CR proton spectra, see Fig. 1.

It was observed that the average p_T of baryons is slowly growing with energy. The average transverse momenta dependence on the mass of baryon (meson) at the LHC energy is also considered up to the masses of charmed and beauty hadrons.

It is suggested in QGSM as well that the explanation of growing charge ratios of secondary antiparticle-to-particle spectra in cosmic rays can be done with the leading production asymmetry of baryon spectra toward the antibaryon spectra in the kinematical region of fragmentation of targets, which are mostly of positive matter. The procedure of spectra transfer from center-of-mass system at LHC p-p collisions into the laboratory system at cosmic ray interactions is given in the Appendix.

2. QGSM model for the production of baryons

Let us first describe the QGSM approach, which has been applied for recent studies of Λ^0. According to this approach baryon production can be parameterized in the following way:

$$\frac{d\sigma}{p_T dp_T} = A_0 \exp[-B_0 \cdot (m_T - m_0)], \qquad (1)$$

where, $m_T = \sqrt(p_T^2 + m_0^2)$, m_0 is the mass of the produced hadron and B_0 is the slope parameter for the considered energy. In the early paper [3], it was also shown that the value of the slope parameter B_0 becomes dependent on the collision energy. This approximation works well up to p_T=6 GeV, that gives 85% of integral cross section.

3. Average transverse momenta of baryons at LHC

Let us now discuss the mean transverse momenta of produced baryons [4] and look at its dependence on the collision energy, $\sqrt{s}$. It is reasonable also to compare

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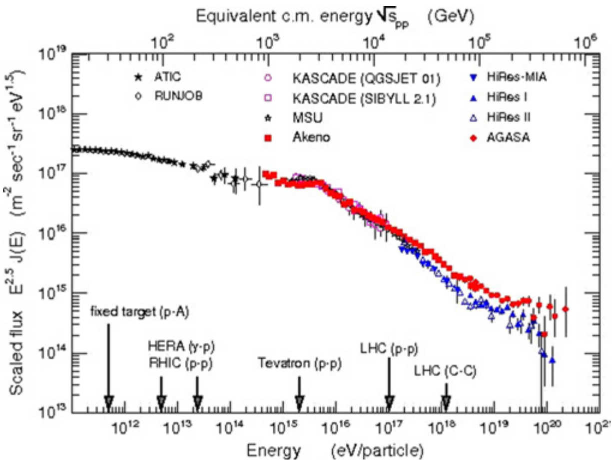

Figure 1. The cosmic proton spectrum with the "knee" between Tevatron and LHC energies.

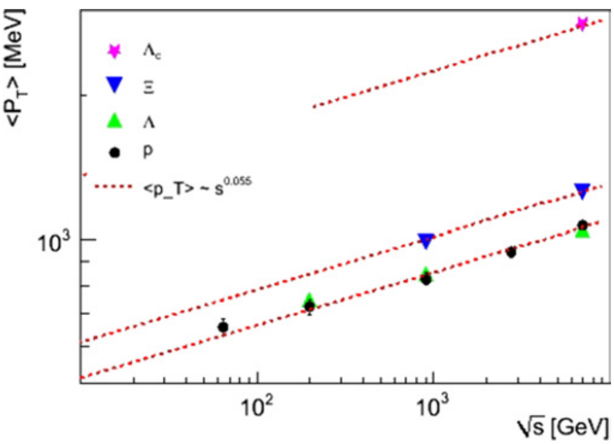

Figure 2. Mean transverse momenta of charged baryons [5–8] as a function of $\sqrt{s}$. Lines show the power-law dependence $s^{0.055}$.

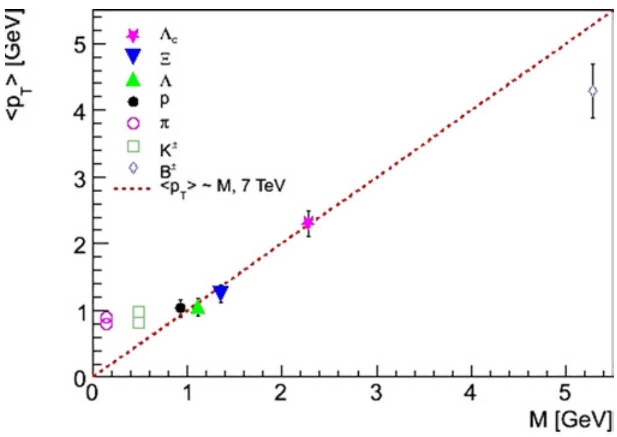

Figure 3. Average transverse momenta of baryons [5,7,8] as a function of their mass are presented at the same energy. Red dashed line shows linear dependence.

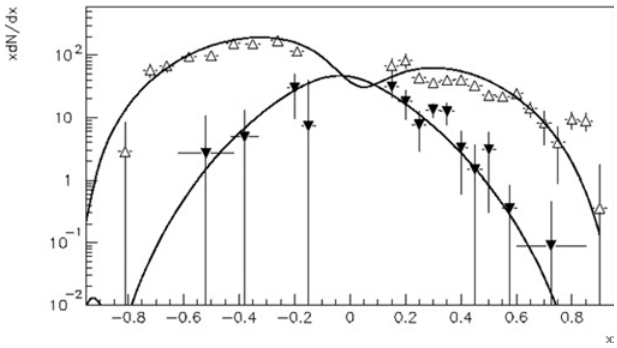

Figure 4. The form of energy spectra of Λ^0 produced in hyperon-proton collisions as compiled from two fix target experiments [9].

the values calculated for the proton spectra with other available data on baryon production: Λ, Ξ [5] and Λ_c [8] spectra. Figure 2 shows such dependence for the available experimental data. The steep rise of the mean transverse momenta $< p_T >$ with energy is seen in Fig. 2. Remarkably, this rise can be parameterized by the same power-like $s^{0.055}$ behavior in the case for all the species of produced baryons.

Another interesting implication reveals in the comparison of the average transverse momenta of various produced baryons at certain collision energies as a function of their masses, shown in Fig. 3. There a linear dependence between the mean transverse momenta $< p_T >$ and the baryon mass M is observed. At $\sqrt{s} = 7$ TeV the average transverse momentum reaches the value of baryon mass, i.e. $< p_T > \sim M$. Further measurements at LHC Run-II should clarify whether or not the average transverse momentum expansion in the baryon production has a limit $< p_T > = M$.

It also would be interesting to compare $< p_T >$ as a function of produced baryon mass, M, with the mass dependence of the average transverse momenta that have been calculated from the description of charged meson production.

4. Antiparticle-to-particle ratios as a result of leading baryon asymmetry

The important feature on baryon production in proton-proton interactions is valuable asymmetry between antibaryon and baryon energy distributions in the kinematical regions of beam fragmentation. It is seen in Fig. 4, where the spectra of Λ_c are described in QGSM for the entire kinematical x_F range [9].

Larger asymmetry appears in the spectra of protons and antiprotons as seen in Fig. 5. What is also important, there is a dip between the growing central part of distribution (the "table") and the stable proton fragmentation region. Such a whimsical form of c.m.s. spectra would give "knees" and "shoulders" at the end of spectra in laboratory system of cosmic ray interactions.

In the laboratory system of cosmic ray interactions, the spectra are to be converted into the energy distributions like those shown in Fig. 6, where the valuable asymmetry takes place at the energies near proton mass. The procedure of transformation of spectra at the pass from center-of-mass system into laboratory system of coordinates is presented in the Appendix.

The growing ratio between antiparticle and particle spectra appears in the left side of spectra due to influence of positive proton target, as was already learned from an early publication [11].

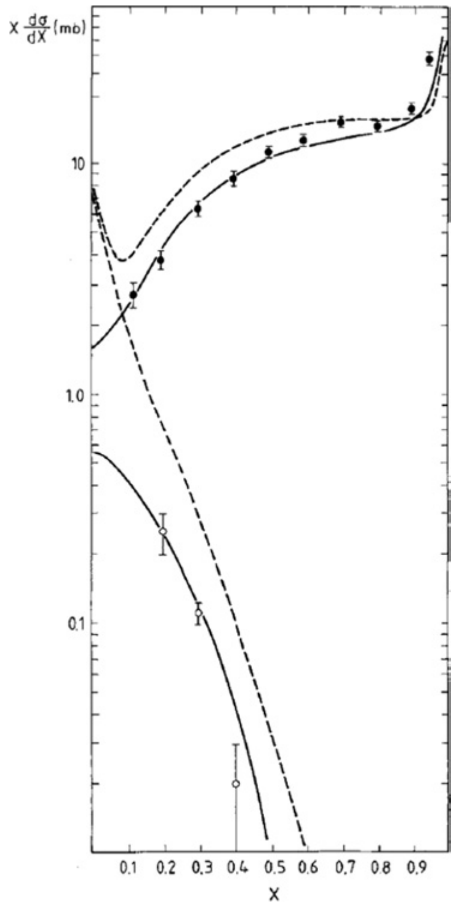

Figure 5. Spectra of protons (black circles) and antiprotons (empty circles) in the low energy experiment and the spectra expected at high energy [1].

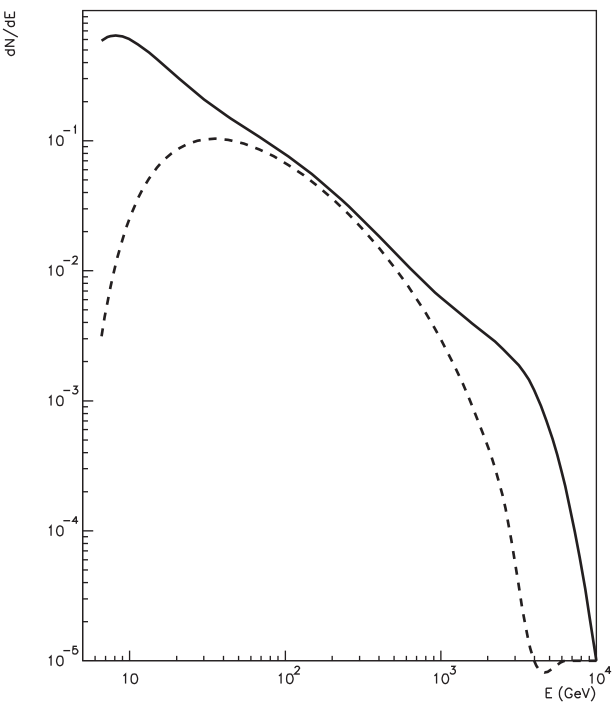

Figure 6. The form of energy spectra of Λ_c baryons produced in the proton-proton collisions and recalculated into the laboratory system in [10].

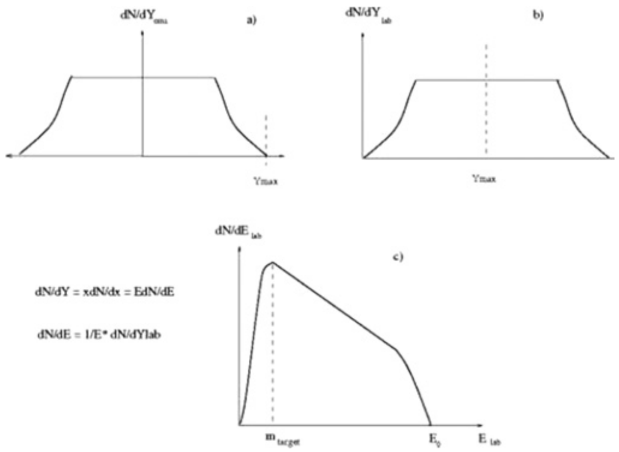

Figure 7. The graphical procedure of recalculation of baryon dN/dY spectra measured in c.m. system at collider experiments into the spectra dN/dE, as they are seen in the laboratory system at cosmic ray measurements. This procedure was first used in [12].

This conclusion makes the particle production at the sources of very high energy cosmic rays important.

5. Conclusions

Transverse momentum spectra of protons and antiprotons from RHIC ($\sqrt{(s)} = 62$ and 200 GeV) and LHC experiments ($\sqrt{(s)} = 0.9$ and 7 TeV) have been described in the QGSM approach. This model seems to work for the up-to-date collider energies, because spectra at low p_T are still giving the main part of integral cross section. It seems that the enhancement of the power-law contribution into the spectra at high p_T causes the change of low p_T exponential slopes, so that the mean transverse momenta are growing with energy. These average transverse momenta are also growing with mass if we analyze the spectra of different baryons independent of their masses. Nevertheless, all these changes in hadroproduction spectra cannot be dramatic enough to cause the “knee” in the primary proton spectra in cosmic rays at the energy in the laboratory system correspondent to the LHC energy. Another aspect of application of QGSM approach is charge asymmetry of CR spectra. The growing antiparticle/particle ratios cannot be the result of acceleration of matter that is mostly positive around us. Growing charge ratios of secondary particle spectra in CR may be generated by the baryon production in the CR interactions with positive matter targets.

6. Appendix

It was found in an earlier paper [12] that the typical rapidity distributions of hadrons at collider experiments are easily convertible into dN/dE energy spectra in the laboratory system, where one beam particle becomes the target. This procedure is graphically illustrated in Fig. 7.

As we know the rapidity distribution, dN/dY, at high energy proton collisions looks like the “table”. Rapidity spectrum in laboratory system are reached by the shift of the “table” on the value of Y_{max}, so that all rapidity range is positive as in fixed target collisions. Then our distribution should be expressed in energy variable x=E/$E_{collision}$: dN/dY=xdN/dx. It is clear that the energy spectrum in the laboratory system will be power like dN/dE $\sim$ 1/E.

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