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REVIEW
of the dissertation by Oleksandr Kovalenko
Measurement of π^0 and η mesons in pp collisions at $\sqrt{s}$= 13 TeV with ALICE Photon Spectrometer at CERN Large Hadron Collider

The study of the yield of hadrons in proton-proton collisions at LHC energies is an important task of modern high-energy physics, which makes it possible to verify the predictions of quantum chromodynamics (QCD) in the new kinematic region. In particular, a study of the hadron yield allows one to obtain the information necessary to clarify the distribution of quarks and gluons in a proton. It is well known that the yield of π^0 mesons at energies of several TeV and p_T<20 GeV/c comes from the fragmentation of gluons and, therefore, the measurement of the yield of mesons is a source of information on the distribution of gluons in a proton at small x values. The η composition includes strange quarks and, therefore, studying the η yield allows one to study the distribution and fragmentation of s quarks. However, it should be noted that at very low p_T the hadron yield cannot be described in terms of pQCD, because in this kinematic region, hadrons are born from a collision of soft partons. In this case, one has to resort to statistical (or, as the author of the dissertation calls them, "thermal") models, which, in particular, were previously used in the analysis of data obtained in accelerators of older generations (RHIC, SPS, etc). Therefore, when analysing the data obtained at the LHC, the problem arises of how to describe a smooth transition between statistical and pQCD approaches. To solve this problem, the author, in my opinion, managed to find a suitable phenomenological model.

Thus, we can safely conclude that the topic of A. Kovalenko's dissertation, obtaining and analyzing yield of π^0 and η mesons at maximum LHC energy, is an extremely urgent problem of modern high-energy physics, which allows one to advance further in understanding the processes occurring in proton-proton collisions in a wide kinematic area.

The dissertation has the following structure. Chapter 1 is an introductory one, which provides general information about the Standard Model, quantum chromodynamics and modern ideas about the mechanism of hadron production in hard collisions. In addition, in this chapter, the author discusses the previously obtained results of studies of the yield of neutral mesons at the LHC and RHIC accelerators in *pp*, *pA*, and *AA* collisions.

Chapter 2, "Setup," describes the basic parameters of the LHC accelerator, discusses the ALICE experiment and the detectors used in the experiment.

The analysis of the yield of π^0 and η mesons at maximum LHC energy is discussed in Chapter 3. The author discusses the data condition (the data description and the event selection) in the experiments of 2016, 2017 and 2018, and neutral meson reconstruction, which was carried out when studying the distribution of the output of two photons by their invariant mass.

Chapter 4 describes an algorithm for estimating systematic measurement errors.

The central chapter, in my opinion, is Chapter 5. It gives the final data, which are compared with the results obtained at lower energies ($\sqrt{s}$ =8, 7, 2.76 and 0.9 TeV) and analyses the predictions obtained on the basis of various theoretical models.

As I noted above, approaches based on pQCD are not applicable for small p_T, which for π^0 and η is p_T< 0.8 GeV/c and p_T<2 GeV/c, respectively. Therefore, in this area "thermal models" should be adequate, i.e. approaches based on the Boltzman distribution of stationary hadron gas. Of course, such models lead to an exponential decrease in the distribution function, which contradicts the predictions of the pQCD, which claims that for large p_T the behavior should have-a power law-form.

One of the thermal models is the Hagedorn model, in which the exponentially decreasing distribution function is replaced by the following function

$$f(pl) = (1 + p_l / p_0) - n,$$

where p_0 and n are the fitting parameters. When $p_t \ll p_0$, the Hagedorn function reduces to the Boltzmann distribution:

$$f(p_t) \approx 1 - np_t / p_0 \approx \exp(-np_t / p_0) = \exp(-p_t / T),$$

and when $p_t \gg p_0$ it leads to a power-law decrease in the distribution.

However, the author does not directly use the Hagedron model to describe the obtained data but uses its generalization made by Tsallis (Tsallis model, TM). The thesis discusses in detail the advantages of TM, which I will not dwell on in detail. The data fit showed that such a model describes well the data, both for π^0 and η yields, in the region of "average" p_T, 3 < p_T <10 GeV/c. However, for small (p_T<3 GeV/c) and large p_T (p_T > 10 GeV/c), there are significant deviations from the TM predictions. An analysis of the data obtained by other authors at lower energies made it possible to determine the energy dependence of the TM parameters.

Further, the author compares the data with the so-called two-component model (TCM). In this model, the differential cross-section for the hadron yield is described by the sum of two terms – a Boltzman-Gibbs component (describes the soft part of the spectrum) and a power component. The latter component mimics the yield of hadrons as a result of hard pQCD processes. The dissertator concludes that in the whole measured region of p_T TCM describes data better than TM. This conclusion confirms the earlier observations based on the analysis of data obtained in ALICE at lower energies.

The dissertator also compares the yield of π^0 and η mesons at maximum LHC energy with the results of calculations obtained with the Monte-Carlo generator PYTHIA-6 and direct calculations of pQCD. PYTHIA-6 is a very complex scheme that includes both pQCD calculations of various processes, and a number of phenomenological models. This analysis showed that at p_T <6 GeV/c, the result obtained using PYTHIA-6 exceeds approximately 1.5–2 times the experimentally obtained spectra. At large p_T, the PYTHIA-6 calculations are in good agreement with the data obtained.

Comparison of the π^0 yield with the results of NLO pQCD, which uses PDF (parton distribution function) and FF (fragmentation function) extracted from the LEP data, showed that this calculation greatly exceeds the experimentally measured spectrum. This, as correctly noted in the dissertation, "indicates that the dynamics of high-energy collisions follows a somewhat different pattern".

A very interesting analysis of the data was done in subsection 5.6 ("x_T-scaling"). x_T-scaling means that the invariant differential cross-section for the hadron yield is expressed as the ratio of the universal dimensionless form factor $G(x_T)$ and ($\sqrt{s}$):

$$E\frac{d^3\sigma}{dp^3} = \frac{G(p_T)}{\sqrt{s}},$$

where $x_T = p_T / \sqrt{s}$ and $n = n(x_T, \sqrt{s})$ is the effective index. By analyzing the entire body of data obtained in ALICE at VJ from 2.76 to 13 TeV, the author was able to obtain the effective index value n = 5.036 ±0.009 for 0.01> x_T > 0.003. According to the author, this value is in excellent agreement with the theoretical calculations in the framework of NLO pQCD, found by other authors. On the other hand, the value of n given above is slightly lower than the values obtained earlier in pp collisions at much lower energies ($\sqrt{s}$ = 62 and 200 GeV) and in Au-Au collisions at $\sqrt{s}$ = 200 GeV.

Assessing the dissertation as a whole, it should be said that it represents a complete and detailed study of one of the most actual problems of modern experimental high-energy physics. The Author has done a great job of obtaining and processing data on the production of π^0 and η mesons in pp collisions at a maximum energy of LHC 13 TeV, comparing them with data obtained at lower energies and existing theoretical approaches.

The disadvantages of the work include, for example, that the author did not analyse in sufficient detail the discrepancy that he obtained for the value of the effective index n with its value the other authors found at significantly lower energies (subsection 5.6 "x_T-scaling"). Also, in the dissertation, I noticed a number of typos and inaccuracies. An example is a formula at the top of page 18 for a ratio $R_{\eta/\pi 0}$.

The noted shortcomings, however, are of a peripheral nature and do not detract from the merits of the work. I believe that the dissertation of Oleksandr Kovalenko "Measurement of / π^0 and η mesons in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE Photon Spectrometer at CERN Large Hadron Collider" is executed at the highest level, and its author undoubtedly deserves the desired degree.

This work meets all the requirements for doctoral dissertations. I recommend therefore to acknowledge the author of a dissertation to further stages of the doctoral procedure.

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