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Review Report on the doctoral thesis

Inclusive production of b jets in collisions of p–Pb and pp in ALICE

Thesis author: Ing. Artem Isakov

Background & the research goals

The primary goal of high-energy nuclear physics experiments, like ALICE at the LHC or STAR at RHIC is to study the properties of a matter with partonic degrees of freedom, the Quark-Gluon Plasma (QGP). Heavy quarks, charm and bottom, are highly useful tools for this purpose. Because of their large mass, they are produced very early in the collision, in the initial interactions with large momentum transfer, before the QGP phase. Therefore, they carry information about all stages of the evolution of the created system. Their production cross section is very well described by perturbative Quantum chromodynamics (QCD), especially in the case of bottom quarks.

The main topic of the doctoral thesis of Ing. Artem Isakov is a measurement of the production of jets containing bottom quarks in proton+proton and proton+lead collisions registered by the ALICE experiment. Using these results Ing. Artem Isakov computed the nuclear modification factor R_{pA}. Such a measurement is of interest from at least three perspectives. First, traditionally R_{pA} served as a baseline for studies of the QGP properties in heavy-ion collisions. The measurement of R_{pA} provides the information how “normal” nuclear matter effects (modification of parton distribution functions (PDF) in a bound nucleon compared to a free one, encoded in nuclear parton distribution function, or a possible coherent parton energy loss) affects the process of interest. Second, the R_{pA} is used to constrain nuclear parton distribution functions, which cannot be computed using perturbative QCD. Last but not least, recent years brought intriguing results of the collective behavior of particles registered in p+A (and d+A) collisions, which suggest partonic medium being created in these so-called small systems. Measurement of R_{pA} provides an addition handle for studying these phenomena.

Regarding the studies of the QGP properties, experiments provide strong evidence that charm and bottom quark loos significant energy when traversing a partonic medium. However, there is no consensus regarding the details of their in-medium interactions – a few theoretical calculations with different assumptions reproduce the experimental data reasonably well. One of the expected effects is a mass dependence of energy loss (the larger the mass, the smaller the energy loss - it is so-called “dead cone” effect), which should manifest itself at the intermediate transverse momentum range. It is a topic of high interest in the relativistic heavy-ion community (for example, recent STAR results are published in EPJC 82 (2022) 12, 1150; and the PHENIX results are available in preprint arXiv:2203.17058). The work presented in this PhD thesis is a part of this community-wide effort to understand better the energy loss mechanism of heavy quarks, which is a necessary condition to extract the QGP properties from the experimental results.

In summary, the topic of this PhD thesis is timely, important and highly interesting for the high-energy nuclear physics community.

Structure of the thesis

The dissertation has a structure typical for a PhD thesis. The first part is a brief introduction to the underlying theory and phenomenology; then, there is an extensive review of the state-of-the-art and available experimental results related to the topic of the thesis. This part is very well developed and comprehensive, and also serves as an excellent motivation for undertaking the given research problem by identifying the open questions in the field. The following chapters cover the experimental part: the ALICE detector, details of the analysis and finally, the physics results. The last part focuses on the contribution of the author to the development of the ALICE experiment: the description the new Inner Tracking System and author’s work on quality control software for this detector, including presentation of selected results.

The thesis is carefully written and well prepared. The text is competently written, the figures and illustrations are of good quality, and they support the content well. The general goals and specific objectives of the conducted research are clearly identified. The largest part of the thesis is devoted the author work (data analysis and technical contribution to the ALICE detector), which I find highly appropriate.

Experimental methods

The study of the production of jets containing bottom quarks (b jets for short) is based on two main approaches: reconstruction of jets and their energy using charged tracks registered in ALICE, and tagging these jets which likely originate from b quark fragmentation. The first part is very well established in ALICE, although it is a complicated procedure, which includes jet reconstruction with anti-k_T algorithm; then one needs to apply corrections for jet energy scale shift and smearing due to finite detector efficiency, momentum resolution, and fluctuations from a so-called underlying event. These corrections include utilization of unfolding procedure, which is nontrivial. The b jet tagging exploits the relatively long lifetime of b-hadrons, and the author reconstructed the secondary vertex, where b quark fragmentation happened. This part of the analysis required estimation of the tagging efficiency, and also purity, because some light-flavor and charm quark jets can satisfy b-tagging criteria. The b-tagging part is especially crucial, because cross section for b quark production is significantly lower than for charm and light-flavor jets.

The research methods used in this PhD thesis are very well justified, credible, and appropriate for the given topic. They are described in detail, and related systematic uncertainties were thoroughly evaluated. The decisions taken at various stages of the studies are sensible and convincingly motivated.

In addition, the author performed his studies within the ALICE experiments, which assure a high standard of the analysis. The b-jet results are published in a peer-reviewed journal, which attests the state-of-the-art methods were used, and the study is robust.

Overall, the text convincingly demonstrates the author has an in-deep understanding of the experimental techniques and all the complicated steps necessary to obtain the final physics results.

Results

The physics results of this PhD thesis include transverse momentum (p_T) differential production cross section of b jets measured in proton+proton and proton+lead collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, and the nuclear factor R_{pPb} as a function of p_T. The author also computed what is the fraction of b jets within all jets measured in p+p and p+Pb collisions. The experimental data were compared to next-to-leading order parturbative QCD computations, and the theoretical calculations match well all the experimental results.

The nuclear modification factor for b-jet production is consistent with unity, and the results for b-tagged jets are consistent with inclusive jets measured by ALICE. Within the current uncertainties, there is no evidence of energy loss of b jets in p+Pb collisions at the LHC, nor the flavor dependence of such a process. Thus, the results are compatible with a scenario that possible nuclear effects (nuclear PDF modification, change of p_T spectrum due to coherent energy loss or interaction with a QGP droplet created in a p+Pb collision) are small at the LHC.

The results presented in this PhD thesis are scientifically sound and robust. It is word stressing that the obtained p_T spectrum and R_{pPb} vs p_T extend the p_T coverage of such measurements at the LHC to relatively low p_T, and the ALICE b-jet results are complementary to data from the CMS experiment.

I find the results obtained by Ing. Artem Isakov very interesting and important. Their high scientific value is confirmed by their publication in a high-impact peer-reviewed journal – *Journal of High Energy Physics*.

Summary and the final evaluation

The thesis presents extensive experimental data analysis, which produced a measurement of p_T spectra of jets containing b quarks in p+p and p+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at the LHC, and then computation of the nuclear modification factor R_{pPb} for b jets. Ing. Artem Isakov also compared these results with model calculations to provide interpretation of the obtained data.

The results presented in the doctoral thesis of Ing. Artem Isakov are new and original, and form a significant scientific achievement. The conclusions from the conducted research are sound and sensible. I find the results of this PhD thesis interesting and important for the high-energy nuclear physics community, which is confirmed by publishing them in *Journal of High Energy Physics*.

The goal of this doctoral thesis was fully achieved. In addition to the impressive amount of work needed to perform the analysis for two collision systems, the author contributed to the development of the new ITS detector, which is a crucial addition to an experimental PhD thesis.

The author demonstrated a good understanding of the underlying theory and knowledge of other experimental results and state-of-the-art in his research topic. In addition, the thesis clearly establishes that the author mastered all the technical and data analysis skills that a researcher needs to work in a high-energy particle or nuclear experiment.

I find the doctoral thesis of Ing. Artem Isakov of very high scientific value. His results are new and original, and interesting for the field of the high-energy nuclear physics. His technical work is also an important contribution to the ALICE experiment. The thesis is convincing evidence of the author's scientific maturity and ability to conduct research projects in experimental high-energy physics independently.

Overall, I think the doctoral thesis of Ing. Artem Isakov "*Inclusive production of b jets in collisions of p–Pb and pp in ALICE*" is of excellent quality. I fully recommend proceeding to the next steps of the PhD procedure, including the doctoral thesis presentation and defense.

Daniel Kikoła