Laboratoire de physique subatomique et des technologies associées
Unité Mixte de Recherche 6457
IMT Atlantique – CNRS/IN2P3 - Université de Nantes

Barbara Erazmus
Email : Barbara.Erazmus@subatech.in2p3.fr

Nantes, 1 Octobre 2021

Report on the Ph.D. Thesis

Beam Energy Scan Dependence of Elliptic and Triangular Flow of Identified Hadrons in the STAR Experiment and the EPOS Model

The Thesis work of Maria Stefaniak is focused on the anisotropies of particles produced in the STAR experiment at Relativistic Hadron Collider (RHIC) at United-States and analysed in the frame of the EPOS model. This topic is highly relevant to the investigation of the properties of strongly interacting matter created in heavy ion collisions and to the search for the Critical Point in the Beam Energy Scan programme at RHIC.

The Thesis includes 9 Chapters and 3 Appendices.

In the Chapter 1, Introduction, Maria Stefaniak briefly presents the clear and challenging objectives of her work using both experimental and theoretical approaches to the study of nuclear matter. The relevance of the flow observables is demonstrated.

Chapter 2 is a review of the most important aspects of high-energy nuclear collisions.
The principles of the Standard Model and Quantum Chromodynamics as well as of the theory of the strong interaction between quarks, are summarized. The evolution of relativistic heavy ion collisions is described through the QCD Phase Diagram showing different phase transitions from the hadronic matter to Quark Gluon Plasma (QGP): first or second order and cross-over. The Equation of State allows to characterize the whole QCD diagram and provides information about the phase transition.

Chapter 3 is devoted to the azimuthal anisotropy which is due to the expansion of highly-compressed matter created in non-central heavy ion collisions. The collective flow is sensitive to the Equation of State and transport proprieties of QGP. The definition of flow harmonics is presented and different types of flow, directed, elliptic and triangular are described. The RHIC BES program provides excellent opportunity to study particle anisotropies as a function of beam energy searching for the phase transitions and possible existence of the Critical Point. The observed difference in the elliptic flow of particles and antiparticles will require more experimental data and further development of theoretical predictions.

In the Chapter 4, are presented the RHIC complex and the STAR experiment. The detectors crucial for the Thesis work, TPC, iTPC, TOF, and VPD are described in detail. Maria Stefaniak has been involved in the software development of the Inner Time Projection Chamber (iTPC).

The methods of the data analysis are described in the Chapter 5. The data were collected by the STAR experiment in the collisions of gold nuclei at energies 27, 39, 54.4 and 200 GeV. The main steps of the analysis, including systematic uncertainties, are clearly presented and illustrated with relevant figures.

Chapter 6 contains the main results of the Thesis work. The obtained flow measurements for identified hadrons for various centralities at 39 GeV, using the 2-particle cumulants (2PC), are compared with the published STAR data analysed with the Event Plane method. The difference between the two sets of the data is of the order of 10% and can be considered as an acceptable agreement. The first STAR results for the higher flow harmonics (3 and 4) of the identified hadrons at 200 GeV are presented. The observed scaling proprieties may indicate that the collective flow originates from the early partonic phase of the collision. The 2PC method was applied to study the behaviour of triangular flow of particles and antiparticles measured in the collisions of gold nuclei at 27, 39 and 54.4 GeV demonstrating the increasing difference between protons and antiprotons with decreasing energy and very small difference for mesons (pions and kaons). The results of the Thesis work provide very strong constraints on the theoretical approaches.

New theoretical developments of the EPOS generator are presented in the Chapter 7. Maria Stefaniak has studied the impact of EOS on the final experimental observables. The different EOS, describing the region of the QCD phase diagram studied in the BES program, were proposed by the Collaboration Beam Energy Scan Theory.

Chapter 8 is devoted to the implementation of the various Equations of State in the EPOS model to investigate, through the comparison with the STAR data, their influence on the dynamical evolution of the collision and on the final observables. Studies of particle yields, transverse momentum spectra and elliptic flow did not demonstrate significant sensitivity to EOS. The effects of changes of EOS are observed for all studied moments: mean and standard deviations, skewness and kurtosis, providing valuable insights into further model developments.
The number of produced mesons is overestimated by EPOS. The possible reason is attributed to the too wide rapidity distribution of the simulated events as compared to the experimental data. It would be interesting to try to estimate this effect reducing the simulated distribution.
Higher momentum data are also not reproduced by the model. On the other hand, EPOS has been not yet adapted to low collision energies.

In the Chapter 9 Maria Stefaniak presents a brief summary and outlook.

The manuscript includes 3 Appendices. The contributions of Maria Stefaniak to the software development of iTPC and Rivet are detailed.

All the Chapters of the Thesis are very well presented. The numerous references are provided in a clear way.

Laboratoire de physique subatomique et des technologies associées

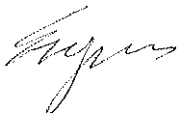
Unité Mixte de Recherche 6457
IMT Atlantique – CNRS/IN2P3 - Université de Nantes

The important experimental and theoretical aspects are described in detail.
It should be emphasized that the results carried out in the Thesis work are pioneering and highly important for the STAR collaboration and for the whole community of heavy ion physics.
The joint experimental and theoretical approach constitutes a powerful tool for the investigation of the dynamical evolution of strongly interacting nuclear matter.
Some results of the performed studies have been already published and few more will be submitted for publication.

In conclusion, the work performed by Maria Stefaniak meets all the requirements and
I strongly recommend the defence of the Thesis.

Barbara Erazmus

CNRS/IN2P3, Directeur de recherche
STRONG-2020 European Initiative, Coordinator
CERN, Scientific Associate
Deputy Spokesperson of the ALICE Collaboration



Subatech
IMT-Atlantique, rue Alfred Kastler 4 - La Chantrerie - BP 20722 - 44307 Nantes cedex 3
Tél. 02 51 85 81 00 - Fax 02 51 85 84 79 – http://www-subatech.in2p3.fr