Részecskekorrelációk az erősen kölcsönható anyagban RHIC-STAR energiákon / Particle correlations in the strongly interacting matter at RHIC-STAR energies

PhD féléves beszámoló / Semester Report
1. félév / 1st semester

Nuclear and Particle Physics PhD Programme

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1 Introduction

The study of ultra-relativistic heavy-ion collisions provides crucial insights into the properties of quark-gluon plasma (QGP), a state of matter governed by quantum chromodynamics (QCD). My research at the STAR experiment at RHIC focuses on two key areas: charged particle pseudorapidity distribution measurements and femtoscopy techniques, particularly Bose–Einstein correlations. Both techniques aim to explore the QCD phase diagram and probe the existence of a critical point, and to refine source function modelling through Lévy-stable distributions. These investigations contribute to a deeper understanding of relativistic hydrodynamics and particle correlations in high-energy collisions. By leveraging data from the BES-II program and the STAR fixed-target setup, my work seeks to enhance experimental precision and advance theoretical modelling, ultimately providing new insights into the fundamental properties of strongly interacting matter.

2 Description of research and related work carried out in current semester

During this semester, my research activities have spanned multiple domains, covering both applied medical physics and theoretical work in high-energy physics. In the field of applied research, I collaborated on a joint project between Eötvös Loránd University and Norma Instruments Zrt., contributing to the Geant4 simulation of a blood cell counting device under development. In parallel, I continued my theoretical work on femtoscopy, utilizing the EPOS4 and CRAB (Correlation Afterburner) frameworks to extract key spatial and correlation functions.

2.1 Applied Medical Physics Research

Geant4 is a widely used Monte Carlo simulation toolkit for particle interactions in matter. In collaboration with Norma Instruments Zrt., I focused on modelling the operation of a novel blood cell counting device, aiming to enhance its precision and reliability through detailed simulations.

One of the key challenges in optical cell counting is accurately modelling the interaction of light with blood cells. While Geant4 provides robust support for Rayleigh and Compton scattering, Mie scattering – which is essential for describing interactions with particles comparable in size to the wavelength of light – was previously not fully implemented. As a result, Mie scattering with a given numerically calculated differential cross section was incorporated into the toolkit

Beyond the implementation of scattering models, I contributed to simulations of elements of the test bench used for evaluating the blood cell counting device. This mostly involved by now modelling the optical components to optimize the design and ensure reproducibility of experimental measurements.

2.2 Theoretical and Phenomenological Research in High-Energy Physics

Femtoscopy provides crucial insights into the space-time evolution of particle-emitting sources in heavy-ion collisions. My work focused on extracting the spatial source function $D(r)$ and the correlation function $C(k)$ using the EPOS4 event generator and the CRAB framework.

Using EPOS4, I simulated heavy-ion collision events at various center-of-mass energies. The generated event data was then processed to extract the spatial source function $D(r)$, which characterizes the distribution of particle emission points in coordinate space. Understanding the shape of $D(r)$ is crucial for interpreting the underlying particle production mechanisms and medium effects in quark-gluon plasma evolution.

The correlation function $C(k)$, describing the momentum-space correlations of emitted particle pairs, was extracted from the EPOS4 simulation data using the CRAB framework and then fitted using Lévy-stable distributions. This approach goes beyond traditional Gaussian parametrizations, providing a more general description of the spatial and dynamical properties of the source. Specifically, I worked on obtaining the Lévy index (α), which governs the shape of the source function and can provide insights into potential critical phenomena in heavy-ion collisions.

Moving forward, I plan to extend my femtoscopy analysis by incorporating three-dimensional Bose–Einstein correlation studies which I just started, in STAR Au+Au collisions at various RHIC energies and further investigating the scaling properties of Lévy distributions.

In this semester, no significant progress was made on charged particle pseudorapidity measurements with the STAR experiment, except for utilizing different unfolding methods used in these measurements, for different purposes.

This semester's research work corresponded to registering for FIZ/S1-S4/K18 *Guided research work 1., 2., 3., 4. semesters* subject.

3 Publication

In the next semester, I plan to write a conference proceedings based on my poster and flash talk from the 24th Zimányi Winter School, titled *Pion emission source and femtoscopic correlation functions from EPOS4 via CRAB*. From these phenomenological research results, I plan to write a theoretical paper in the near future.

The 3-dimensional analysis I have taken on should have a paper in preparation during the current year, 2025.

4 Studies in current semester

During the semester, I attended the following courses:

- FIZ/2/024E *The Phase Diagram of Strongly-Interacting Matter (Az erősen kölcsönható anyag fázisszerkezete)*
- FIZ/2/132 *Paricle Astrophysics (Asztro-részecskefizika)*

Furthermore, although not strictly related to my doctoral studies, I plan to finish the parallel Physics teacher's training after 31st January (after portfolio defence) and obtain a Physics teacher master's degree. The methodological, pedagogical and psychological knowledge obtained from this training should provide me more confidence in my (further) teaching activities, conference participation etc.

5 Conferences in current semester

As stated in Sec. 3, I attended the 24th Zimányi Winter School and presented my phenomenology related research work with a poster.

Furthermore, I attended the Day of Femtoscopy conference organized in Gyöngyös, but solely as an attendant without contribution.

6 Teaching activity

During the semester, I held laboratory practice in the Enviromental Physics Laboratory (Környezetfizikai laboratórium, subject coordinator Máté Csanád).

This semester's teaching activity corresponded to registering for FIZ/OKT/2 *Teaching Activity* subject.