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

PhD féléves beszámoló / Semester Report
3. félév / 3rd semester

Nuclear and Particle Physics PhD Programme

Mátyás Molnár [molnarmatyas@student.elte.hu]
Supervisor: Máté Csanád

Budapest, January 2026

1 Introduction

As stated in my 1st and 2nd semester report [1], [2] I intend to do analysis on RHIC–STAR experimental data, do phenomenological studies in order to better understand the underlying effects from a theoretical point of view, and also contribute to applied research in the field of medical physics during my doctoral studies.

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

During this semester, I continued my theoretical work on Lévy femtoscopy, specifically concentrating on the properties of the UrQMD Monte Carlo event generator, as the EPOS4 part was inherited by one of our postdoc coworkers and progressing to publication. The status with RHIC STAR charged particle pseudorapidity analysis results, in collaboration with Balázs Kórodi, also progressed towards publication (getting to STAR's GPC and code QA committees). I continued the applied medical physical research, progressing each week just as well as in the previous semesters [1], [2].

2.1 Theoretical and Phenomenological Research in High-Energy Physics

During the semester, I passed the EPOS4 [3]-specific theoretical source function analysis to our postdoctoral colleague Yan Huang, although still participated in generating the data and doing practical optimization. With me as the second author, we submitted the paper manuscript to Physics Letters B.

I extended the energy range of the previous UrQMD [4] simulations to match the collider and fixed target energies in the $\sqrt{s_{NN}} = 3$ to 27 GeV range of the Beam Energy Scan phase II at RHIC.

I made several improvements to the overall Lévy source analysis:

- implemented properly the (arbitrary) N_{evt} number of events averaging,
- did systematic uncertainty estimation in the case of the m_T and collision energy dependence (see Fig. **??**).
- Until the end of this semester, I only performed fits on the source averaged to one dimension. I implemented in my fitting code a complete three-dimensional fit as well in the three projections to Bertsch–Pratt directions out, side and long; see Fig. 2.

The comparison of the results of these theoretical frameworks with the experimental data is critical, mainly in the case of UrQMD (which does not include and explicit QGP phase nor critical behaviour), given that a divergence of the Lévy parameter α between those could indicate the presence of the critical endpoint (CEP).

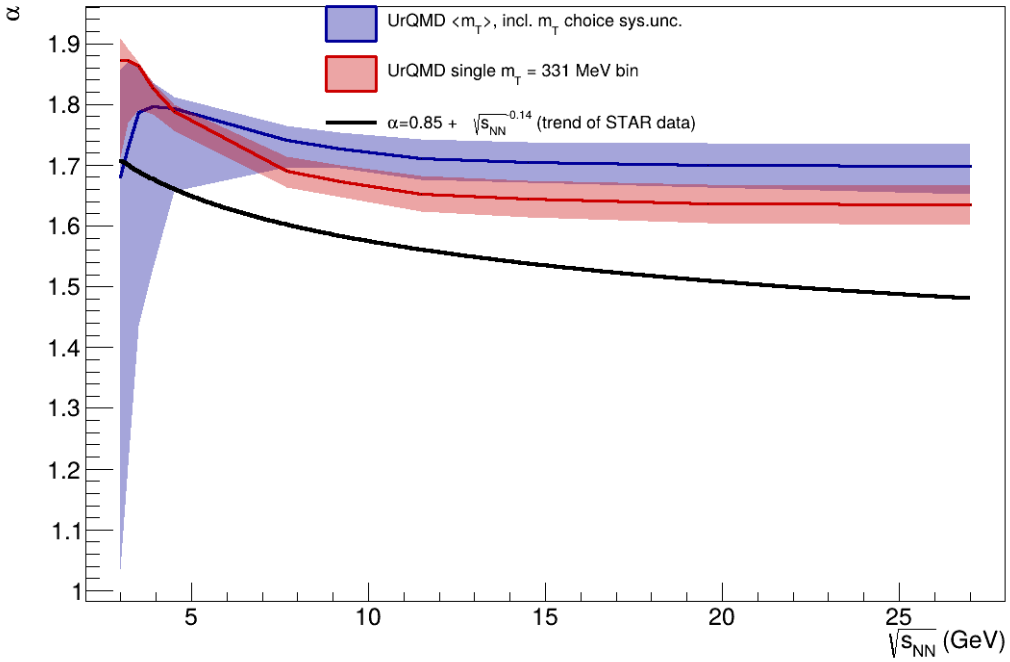

Figure 1: Lévy parameter α dependence as a function of the collision energy $\sqrt{s_{NN}}$; the trend fitted to STAR Preliminary experimental data also shown. The results are not final, as the uncertainties blow up towards high m_T bins with lower energies, mostly due to the lack of satisfactory statistics. Statistical analysis there with larger sample needed, the simulations for that purpose are already running.

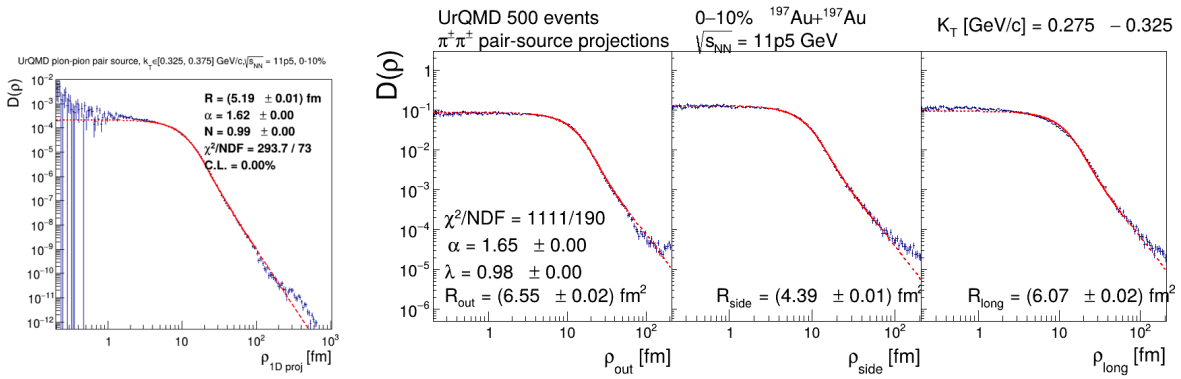

Figure 2: One-dimensional fitting and the newly implemented fitting to one-dimensional projections in all three Bertsch–Pratt coordinated (out, side. long) – or simply, the "3D fit".

2.2 Experimental research

With the theoretical UrQMD results compared to the trend of the preliminary experimental data, there tends to be an increasing divergence below 7.7 GeV, indicating an effect most probably missing from the theoretical framework, i.e. the Monte Carlo generator.

The charged particle pseudorapidity measurement ($\mathrm{d}N_{ch}/\mathrm{d}\eta$) analysis is already with the STAR GPC ("God-Parent Committee") and code QA, after several iterations waiting for approval within the collaboration.

As a remark, there would still be an opportunity to perform relativistic hydrodynamical fitting to the obtained data after this analysis; this could also be part of the experimental analysis planned to be started in the next semester.

2.3 Applied Medical Physics Research

As detailed in my previous semester reports [1], [2], I worked in collaboration with Norma Instruments Zrt., mostly within the Geant4 framework and FreeCAD 3D modelling software to model a blood cell counting device in development. This semester, I worked on making the background measurements (see Fig. 3) in contrast with the Mie scattering signal, perfecting the model to be as close as possible to the real device regarding its physical properties, performing simulations with different blood cell types.

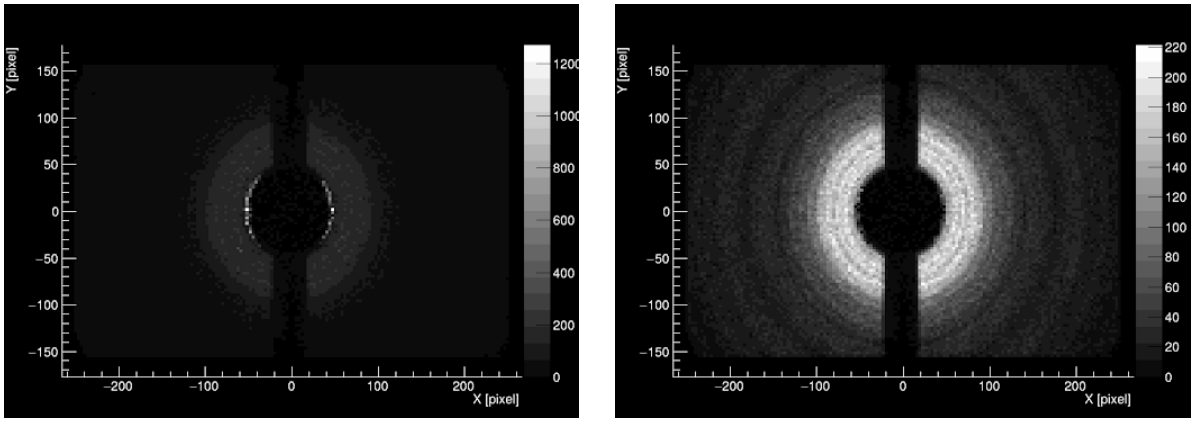

Figure 3: An example simulation of neutrophil cells in random positions within the flow cell, with extended laser beam source, before and after background subtraction.

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

3 Publication

As stated in previous parts, the EPOS4 theoretical paper and the $\mathrm{d}N_{ch}/\mathrm{d}\eta$ paper with me as second PA are in the progress of publication or collaboration review. Although having had to overcome several obstacles (long simulation times etc.), the UrQMD analysis is

coming close to be mature enough for me to write another theoretical paper very soon. I dropped writing the conference proceedings based on my poster and flash talk from the 24th Zimányi Winter School with the EPOS4 analysis, in favour to the paper submitted to PLB.

4 Studies in current semester

During the semester, I attended the following courses:

- FIZ/2/004E *Experimental Methods in Particle Physics II. (A részecskefizika kísérleti módszerei II.)*
- BSzKfizszem25 *Bolyai College Physics Seminar (Bolyai Fizika Szakszeminárium)*, compulsory subject for the college members
- BSzKcsütest25 *Bolyai College Interdisciplinary Lecture Series (Bolyai Szakkollégium Csütörtök Este)*, compulsory subject for the college members

Scored a mark "excellent" from the previous two and, the latter being a two-level assessment, ended with a "passed" result.

5 Conferences in current semester

Mostly about the progressing UrQMD analysis results, I held three talks this semester:

- *Collision energy dependence of the Lévy parameters in UrQMD*, talk, Day of Femtoscopy 2025, Gyöngyös
- *Pion emission source from UrQMD at STAR energies ranging from* $\sqrt{s_{NN}} = 3$ *to 27 GeV*, poster and flash talk, Zimányi Winter School 2025, Budapest
- *Femtometer-scale geometry of quark matter: Collision energy dependence of the Lévy parameters in a UrQMD pion source*, talk, Trojkráľová konferencia 2026, Bratislava

6 Teaching activity

I held laboratory practice in the Environmental Physics Laboratory for Environmental Studies BSc Students and did the long-standing curriculum development for the subject.

Carrying out the teaching activity in this semester corresponded to registering for FIZ/OKT/4 *Teaching activity* subject.

References

[1] M. Molnár, "Particle correlations in the strongly interacting matter at RHIC-STAR energies," *Semester report for 1st semester*, 2025.

[2] M. Molnár, "Particle correlations in the strongly interacting matter at RHIC-STAR energies," *Semester report for 2nd semester*, 2025.

[3] K. Werner, "Core-corona procedure and microcanonical hadronization to understand strangeness enhancement in proton-proton and heavy ion collisions in the epos4 framework," *Physical Review C*, vol. 109, no. 1, p. 014 910, 2024.

[4] H. Petersen, M. Bleicher, S. A. Bass and H. Stöcker, "Urqmd-2.3-changes and comparisons," *arXiv preprint arXiv:0805.0567*, 2008.