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AI-Driven Exploration of Strongly Interacting Nuclear Matter under Extreme Conditions

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Investigating the properties of QCD matter at extreme temperatures and densities is a fundamental objective of high energy nuclear physics. Such matter can be created in facilities like CERN and FAIR for short periods of time through heavy-ion collisions. Particularly interesting are the intermediate energy heavy-ion collision experiments such as CBM@FAIR, STAR-FXT@RHIC and experiments at NICA and HIAF which stand to benefit significantly from modern data driven AI techniques.

The talk provides a comprehensive overview of diverse applications and potential of AI in studying heavy-ion collisions, emphasizing on the exploitation of raw, detector-level, point cloud information for ultra fast, real-time analysis and mitigating biases introduced by preprocessing algorithms. PointNet-based models are employed to reconstruct crucial collision event features [1,2] and extract physics information such as the Equation of State [3] directly from detector level information of the hits and/or tracks of particles in experiments. The PointNet-based models, distinguished by their ability to handle detector data directly, are shown to be versatile tools for studying heavy-ion collisions [4]. Additionally, a novel autoregressive Point cloud generator which can perform fast simulations of heavy-ion collisions on an event-by-event basis is also introduced. This innovative tool holds promise to meet the demand for large scale simulations by future, next generation experiments [5]. The choice of point cloud data structures not only amplifies the adaptability of these models to particle/high-energy physics but also establishes them as resilient tools applicable across a diverse range of physics disciplines dealing with electronic data [6].

[1] **Omana Kuttan, M.**, Steinheimer, J., Zhou, K., Redelbach, A., & Stoecker, H. (2020).
A fast centrality-meter for heavy-ion collisions at the CBM experiment. **Physics Letters B,** 811, 135872.

[2] **Omana Kuttan, M.**, Steinheimer, J., Zhou, K., Redelbach, A., & Stoecker, H. (2021)
Deep Learning Based Impact Parameter Determination for the CBM Experiment. **Particles**, 4, 47-52.

[3] **Omana Kuttan, M.,** Zhou, K., Steinheimer, J., Redelbach, A., & Stoecker, H. (2021).
An equation-of-state-meter for CBM using PointNet. **Journal of High Energy Physics**, 2021(10), 1-25.

[4] **Omana Kuttan, M.**, Steinheimer, J., Zhou, K., Redelbach, A., & Stoecker, H. (2022).
Extraction of global event features in heavy-ion collision experiments using PointNet. In **PoS FAIRness2022** (2023) 040, Contribution to: FAIRNESS 2022, 040

[5] **Omana Kuttan, M.**, Steinheimer, J., Zhou, K., & Stoecker, H. (2023).
QCD Equation of State of Dense Nuclear Matter from a Bayesian Analysis of Heavy-Ion Collision Data. **Physical Review Letters**, 131(20), 202303.

[6] **Omana Kuttan, M.** (2023). Artificial intelligence in heavy-ion collisions: bridging the gap between theory and experiments (**Doctoral dissertation**, Universitätsbibliothek Johann Christian Senckenberg).

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