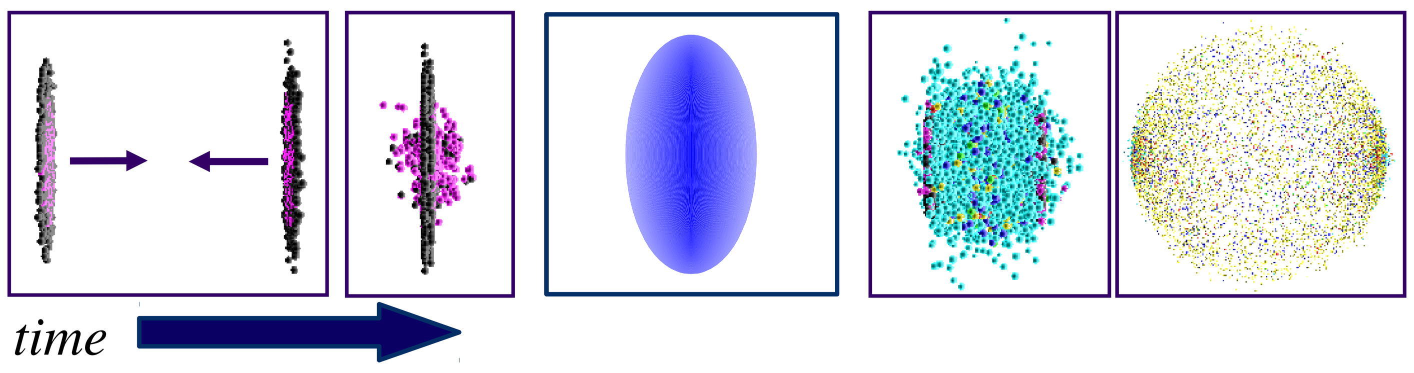
Study of the influence of initial-state fluctuations on hydrodynamic simulations

Marcin Słodkowski, Patryk Gawryszewski, Dominik Setniewski

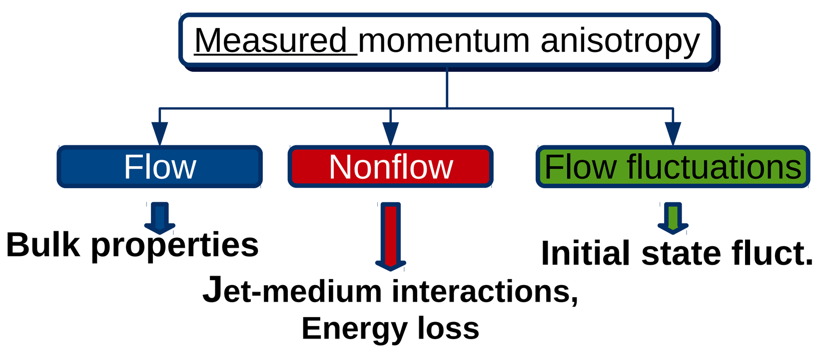
Faculty of Physics, Warsaw University of Technology

Motivation

Evolution of heavy ion collision:



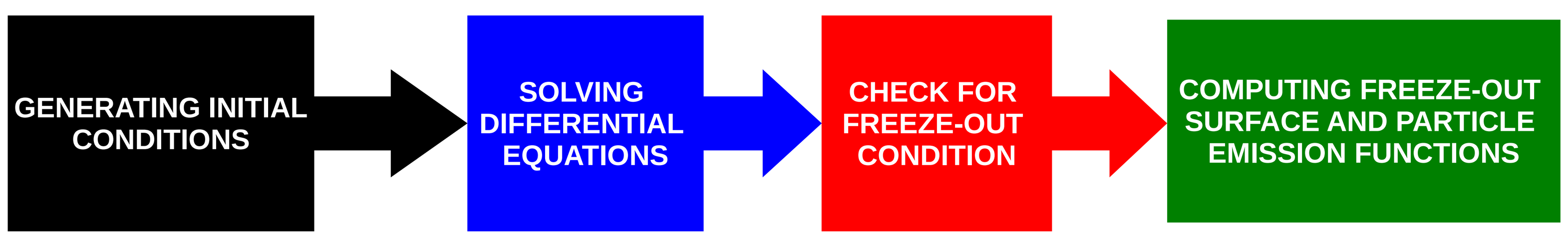
- Relativistic hydrodynamic is employed to extract the properties of the Quark-Gluon Plasma (**QGP**) in the high-energy heavy-ion interactions. (see: P. Huovinen, Ann. Rev. Nucl. Part. Sci., vol. 56, 2006, arXiv:nucl-th/0605008)
- The relativistic fluid dynamic is used in the computer modeling of the nuclear bulk matter.
- The evolution of heavy ion collision divides into 5 phases: pre-equilibrium – early stage, QGP, mixed-phase, hadron gas and particles. The QGP, mixed-phase, hadron gas are described using hydrodynamic with the global or local equilibrium assumption.
- A potential source of fluctuation coming from the pre-equilibrium stage.
- We focus on assessing the contribution of the initial-state fluctuations of heavy ion collision in the hydrodynamic simulations.
- The question is whether the hydrodynamic simulation retains the same level of fluctuation in the **final-state** as for the **initial-stage**.

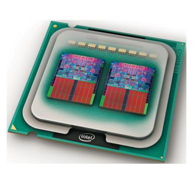


- Event-by-event flow and flow fluctuations - requires large data samples and fast simulations.
- High resolution simulation of jets dynamics.

Hydrodynamics software on GPU

Simulation chain:





- Our implementation has fully (3+1) - dimensional simulations with very good accuracy / resolutions of the computational grid up to 200^3 in the **Cartesian system**. (see: J. Sikorski et al. J. Phys.: Conf. Ser.509 012059, 2014 arXiv:1604.03360)
- Our program using parallel computing on the graphics card processors Graphics Processing Unit (GPU). (see: S. Cygert et al. Concurrency and Computation: Practice and Experience, 27(6), 1591-1602., 2015)
- The simulation chain contains the main program for hydrodynamics and external program for initial-state generation and freeze-out.
- The program can simulate the collective behaviors of QGP.
- Event-by-event flow and flow fluctuations study demand fast enough for good statistic (see: P. Marcinkowski et al., Journal of Physics: Conference Series (Vol. 668, No. 1, p. 012115, 2016, arXiv:1511.02137)
- Study of the high resolution of jets dynamics (see: M. Slodkowski, Journal of Physics: Conference Series (Vol. 1085, No. 5, p. 052001,2018)
- **WENO** (5th and 7th order) and **Runge-Kutta** (3rd order) (see: M. Slodkowski et al., International Journal of Nonlinear Sciences and Numerical Simulation, 19(1), 25-35, 2018)
- A lot of computer power (a large amount of data grid)
- Single thread simulation on **CPU** takes ~ a few days
- Our multi-thread simulation on **GPU** takes ~ a few minutes (see: M. Slodkowski et al., Federated Conference on Computer Science and Information Systems (pp. 441-446), 2013)

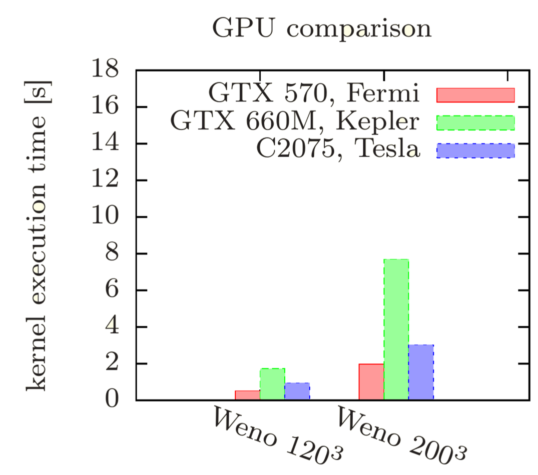
Parallel computing on GPU

The main component solves the set of partial hydrodynamic equations based on universal hyperbolic equations of the conservation laws:

$$\frac{\delta U}{\delta t}+\nabla\cdot F(U)=S^{\nu}(\vec{r})$$

U - universal vector conserved hydrodynamic quantities such as **energy**, **momenta**, **net charge** densities.

$F(U)$ is the flux vector and $S^{\nu}(r)$ sources term of modification in the hydrodynamics quantities.



The code is **object-oriented**, written in the **C++** language. One of its main features is the use of parallel computing on general-purpose graphical processing units (**GPGPU**). The objective was able to generate event-by-event heavy-ion collision data in high resolution and the smallest possible time frame. For **GPU** code, we use nVidia **CUDA**. The algorithms are written in a natural, parallel way and are easy to modify thanks to CUDA C++ features. Out of several memory types available on the GPU we chose surface memory interface for best performance and simple extensibility.

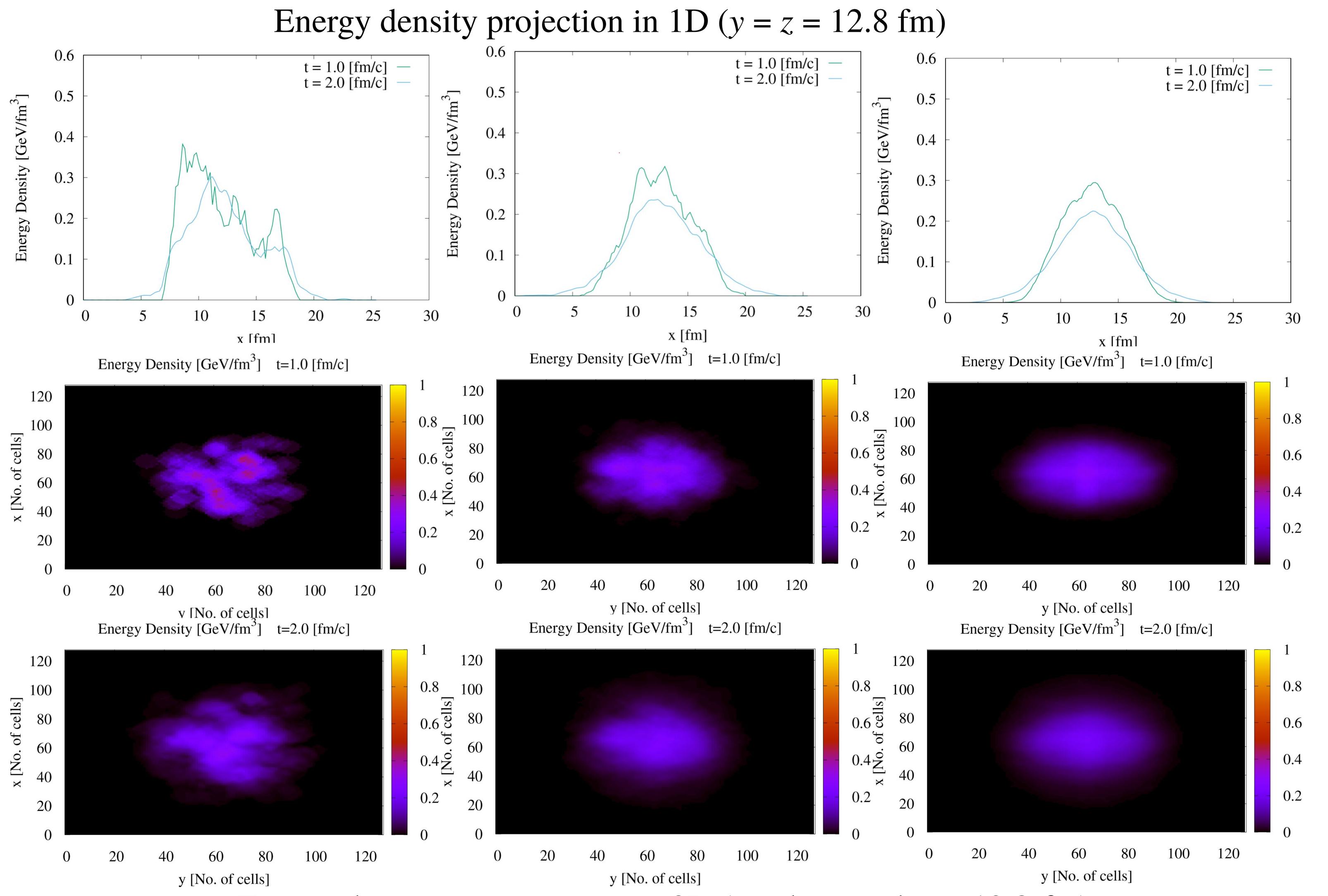
Comparison or various GPUs was done using 5th order WENO on 120^3 and 200^3 grids.

Results of simulations A+A interactions

Initial-state fluctuations can be obtained using Glauber Monte-Carlo, models like **UrQMD**, other string models and another approach. The UrQMD is used to simulate only the early phase of the collision. The time of the UrQMD simulations was set to 1 fm.

Simulation scenarios: **Au+Au @ 200 GeV/c** 0-10% most central, initial conditions for averaging 1,10 and 100 UrQMD events.

Energy density projection in 1D ($y = z = 12.8$ fm)



Energy density cross-section in 2D (xy plane with $z = 12.8$ fm)

$$\Delta=\sum_{i=0}^{N}|A_i-S_i| \qquad \Sigma_E=\sum_{i=0}^{N}A_i \qquad \Delta[\%]=\frac{\Delta}{\Sigma_E}\times 100\,\%$$

Δ - divergence factor, Σ_E – the sum of energy density for average conditions, A_i - value from the average conditions, S_i - value from a single collision, N - number of cells compared

Time [fm/c]	1.5	2	2.5	3
Δ [%]	32.77	27.76	25.19	28.39
Δ [GeV/fm³]	2.13	1.18	0.66	0.44
Σ_E [GeV/fm³]	6.50	4.25	2.62	1.55

Projection along the x axis for $y = z = 12.8$ fm.

These results confirm the hypothesis of hydrodynamic simulation retains information on fluctuations from initial conditions. Nevertheless, fluctuations decrease as a function of time.

24th International Conference on Computing in High Energy & Nuclear Physics
4-8 November 2019, Adelaide, Australia
CHEP 2019

Warsaw University of Technology