

DOES THE COORDINATE SYSTEM MATTER FOR THE BEAM ENERGY SCAN?

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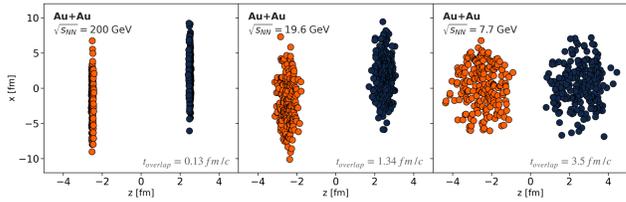


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Introduction

- At lower energies Lorentz contraction decreases, and the longitudinal radius is comparable to the transverse radius and passing time is large



- Raises the question if hyperbolic is optimal for lower energies

- Hyperbolic coordinates

$$\tau = \sqrt{t^2 - z^2}$$

$$\eta = \frac{1}{2} \ln \left(\frac{t+z}{t-z} \right)$$

Captures boost invariance

Widely used for hydrodynamics simulations

(2+1)D simulations at high energies

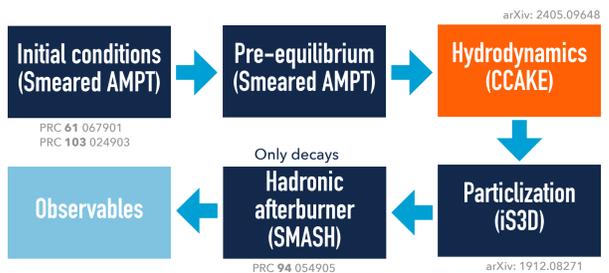
Objective

- Determine the optimal way of running hydrodynamics at lower beam energies comparing execution time and effects on observables

Method

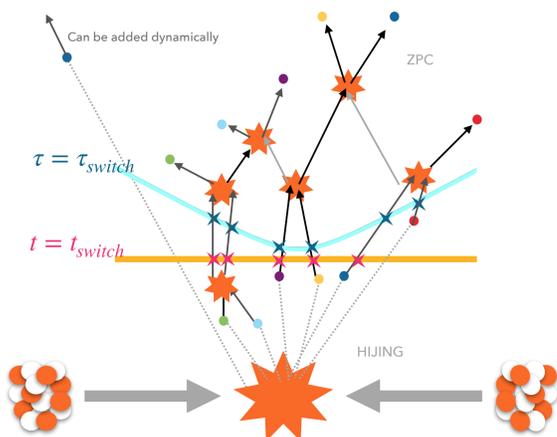
Hybrid-hydrodynamic

- Hybrid hydrodynamics simulates different stages of evolution



Smeared AMPT

- AMPT generates a full event, but we look only at the initial stages
- Generates a list of partons and their histories



- Take the partons at desired x^0 (τ or t) and smear them

$$T^{\mu\nu}(x^1, x^2, x^3) = \sum_{i=\text{partons}} \frac{p_i^\mu p_i^\nu}{p_i^0} \phi_i(x^1, x^2, x^3)$$

$$\phi_i(x^1, x^2, x^3) = \frac{K}{(2\pi)^{3/2} \sqrt{-g} \sigma_{x^1, x^2, x^3}^3} e^{-\frac{(x^1-x^1)^2 + (x^2-x^2)^2 + (x^3-x^3)^2}{2\sigma_{x^1}^2 + 2\sigma_{x^2}^2 + 2\sigma_{x^3}^2}}$$

CCAKE

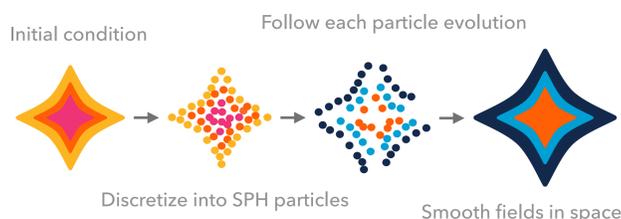
- Performs (3+1)D relativistic viscous hydrodynamic, and it is significantly improved version of v-USPhydro

- Performance portability, BSQ charges evolution, cartesian and hyperbolic coordinates, source terms, full IR and DNRM

- Smoothed-Particle Hydrodynamics (SPH) method for solving the equations of motion

SPH

- Lagrangian mesh-free method



$$A(\mathbf{r}) = \sum_{i=1} A(\mathbf{r}_i) W(\mathbf{r}_i - \mathbf{r}, h) \Delta V_i$$

$$\nabla_j A(\mathbf{r}) = \sum_{i=1} A(\mathbf{r}_i) \nabla_j W(\mathbf{r}_i - \mathbf{r}, h) \Delta V_i$$

SPH Kernel

Smoothing scale

$$\lim_{h \rightarrow 0} W(\mathbf{r}, h) = \delta(\mathbf{r})$$

Parallelization

- ECP-COPA/Cabana used in CCAKE, and provides performance portability:

Personal Computers

Workstations

Clusters w/wo GPUs

Consumer-grade GPUs

Equations of motion

- Solve in generalized coordinates:

$$\frac{d}{dx^0} \left(\frac{s}{\sigma} \right) = \dots$$

$$\frac{d}{dx^0} \left(\frac{p_X}{\sigma} \right) = \dots$$

$$\frac{d}{dx^0} \left(u_a^j \right) = \dots$$

$$+ \text{dissipative}$$

$$\sigma_i = \frac{1}{V_i} = \frac{1}{\sqrt{-g} u^0} \sum_j W_{ij}$$

$$M_j^i = - \left[(\sigma_0^i - \Pi) \frac{u_j}{u^0} - \pi_j^i + u^0 \sigma_{\mu\nu} M^{\mu\nu} \right] \frac{1}{\sigma u^0 T}$$

$$F^S = \left[u_\mu j^\mu + (\sigma_\mu^i - \pi_\mu^i) \partial_\mu u^i - u^0 \Pi \nabla \cdot \vec{v} - u^0 \sigma_{\mu\nu} F^{\mu\nu} \right] \frac{1}{u^0 \sigma T}$$

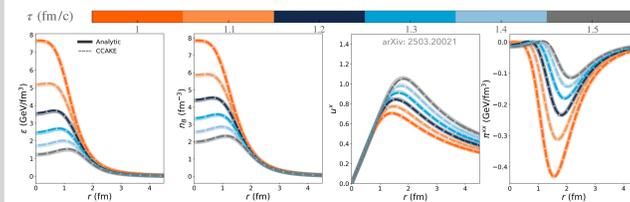
$$+ \pi_\mu^i \Gamma_{\mu\nu}^{\alpha\beta} u^\alpha u^\beta - \Pi u^0 \frac{d \ln \sqrt{-g}}{dx^0} + (\sigma_0^i - \Pi) \mathcal{D}_\nu u^i$$

$$\frac{d}{dx^0} u^i = M_j^i F^j \quad \text{Function of all } F^j$$

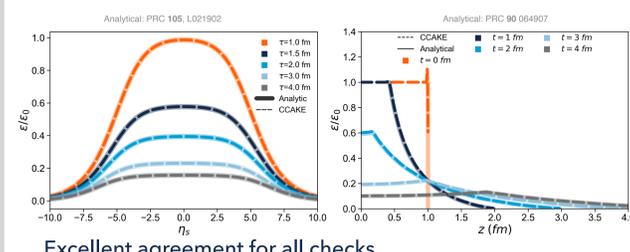
- Solve in generalized coordinates:

Checks

- Transverse expansion with shear and $\mu_b \neq 0$



- Longitudinal expansion in hyperbolic and cartesian



Excellent agreement for all checks

Dynamical initialization

- Compare cartesian and hyperbolic evolution using two ways of initializing

$$\tau_0 = t_0 = t_{\text{overlap}} = \frac{2R}{\sinh y_{\text{beam}}}$$

$$\tau_0 = t_0 = 0.5 + \text{Partons as source terms}$$

$$j^\mu(x_i^0, \mathbf{r}_i) = \frac{1}{dx^0} \sum_{j=\text{partons}} \frac{K}{\sqrt{-g}} p_j^\mu W(\mathbf{r}_i - \mathbf{r}_j, h_{\text{source}})$$

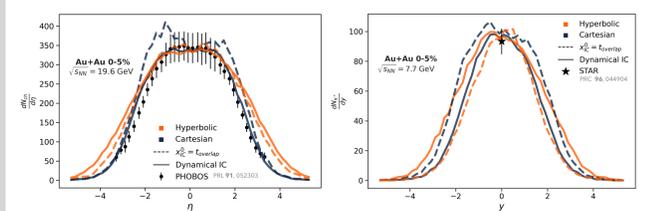
$$x^0 - \Delta x^0 < x_j^0 \leq x^0$$

Results

- Single event for each energy, ideal hydrodynamics

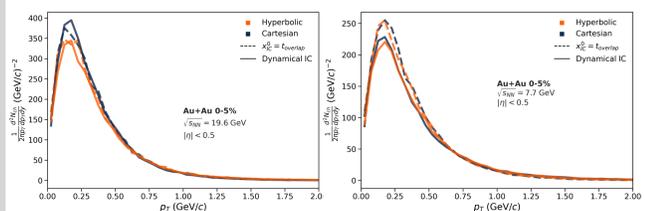
Observables

- Normalize to match experimental data at mid-rapidity



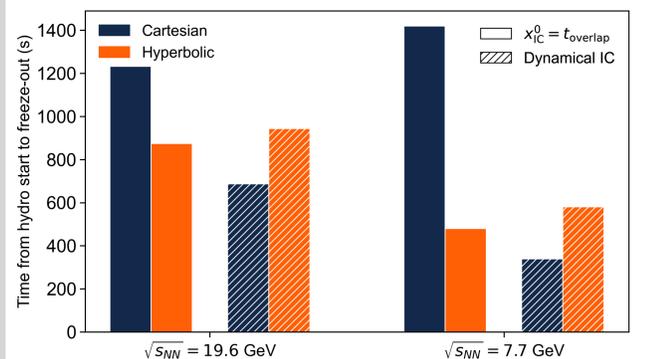
- Dynamically initializing makes the distribution more consistent with respect to the coordinate system

- Effects of initialization and coordinate system more noticeable for large η



- Small effects on p_T distribution caused by differences in the pseudo-rapidity distribution

Time comparison



- Cartesian is slower for fixed time, but is faster for dynamical initialization, with largest difference the lowest energy

- Executing hyperbolic in dynamical mode makes it slower than initializing at fixed time

Summary and outlook

- The different methods of initialization can impact observables and execution times, and it is necessary to initialize hydrodynamics in a more consistent way

- Cartesian coordinates can be optimal for initializing hydrodynamics dynamically at lower energies, while dynamical hyperbolic is worse on performance

- Fine tuning of Smeared AMPT and SPH parameters is necessary to optimize both coordinates systems

- Future work: systematic study with more events, different initial conditions, viscous effects, and variations of the equation of state to better understand the optimal run time and best method for initialization