Precision hydrodynamic predictions for particle production in isobar collisions at RHIC

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FluiduM overview

Describe event ensemble instead of single event
→ symmetric background
→ BG-fluctuation splitting

\[ \Phi(\tau, r, \varphi, \eta) = \Phi_0(\tau, r) + \epsilon \Phi_1(\tau, r, \varphi, \eta) \]

1+1D BG equations of motion for second order relativistic Israel-Stewart hydrodynamics

- Background expansion gives average quantities (yields and \(<p_T>\))
- Able to reproduce multiplicities from ALICE measurements

Particlization+Resonance decays:
Cooper-Frye with FastReso (1809.11049)
Isobar collisions @RHIC

Isobar Zr+Zr and Ru+Ru collisions @200GeV
→ Original goal: find signatures of electromagnetic field (e.g. Chiral magnetic effect)
→ High precision data (4B collisions for each system)
→ Signatures of EM-field investigated in ratios of observables (departures from unity)

Expectation: same multiplicity
Experimental data: Percent level deviations from unity

WHY?

STAR Collaboration (2109.00131)
Origin of the differences: nuclear structure

Main diff.: number of protons/neutrons
→ bigger neutron skin in Zr
→ different nuclear geometry

Woods-Saxon parametrization:

\[
\rho(r, \theta, \phi) \propto \frac{1}{1 + e^{[r - R_0 (1 + \beta_2 Y_2^0 (\theta, \phi) + \beta_3 Y_3^0 (\theta, \phi))]/a_0}}
\]

Half-width radius  Nuclear deformations  Diffusivity

Diffusivity related to neutron skin thickness

Multiplicity ratio dominated by neutron skin (2111.14812, 2111.15559, 2112.13771, 1808.06711, 2103.05595)

But only transport/initial state/limited hydro calculations
→ FluiduM
Setup

- Run TrenTo for initial state
- Define 0.5% centrality bins using 50M minimum bias events
- Run 400k events in select bins (→ effectively 80M events)
- Scan large range of nuclear (R, a, $\beta_2, \beta_3$), collision (k→multiplicity fluctuation, p→energy deposition, $w$→nucleon size, d→nucleon repulsive core, m→number of partons, $v$→parton size) and QGP ($\eta/s, \zeta/s, T_{fo}, \tau_0$) parameters

Histogram multiplicity through linear rescaling of TrenTo entropy
Initial State Results

Histogram multiplicity ratio dominated by diffusivity

Default: $p=0$, $w=0.5$ fm, $k=1$
Final state results

QGP parameters
Final state results

Multiplicity ratio dependent on “degree of sharpness” of QGP

Default: $p=0$, $w=0.5$ fm, $k=1$

Multiplicity ratio dominated by diffusivity
Outlook

Extend scan to more observables (mean pT & flow coefficients)

Include more physics in hadronic phase (e.g. PCE)

Improve BG-fluct splitting with Hatree-Fock

\[
\partial_r \psi^a + B_b^a \partial_r \psi^b - S^a + \frac{1}{2} \left[ \frac{\partial^2 B_b^a}{\partial \psi^c \partial \psi^d} \partial_r \psi^b - \frac{\partial^2 S^a}{\partial \psi^c \partial \psi^d} \right] C^{cd}(x, x')
\]

\[
+ \left[ \frac{\partial B_b^a}{\partial \psi^c} \partial_r + \frac{\partial C_b^a}{\partial \psi^c} \partial_\varphi + \frac{\partial D_b^a}{\partial \psi^c} \partial_\eta \right] C^{bc}(x, x') \bigg|_{x' = x} = \delta(\tau - \tau_{in}) \psi^a_{in}(r)
\]