Density perturbations in heavy ion collisions around the critical point

Kerstin Paech and Adrian Dumitru
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Motivation:


Weights Map: WMAP Science Team
http://lambda.gsfc.nasa.gov/product/map/m_images.cfm

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How to find the critical endpoint?

- Critical Fluctuations?
  (massless order parameter)

- Bulk Properties?

  In HICs small system size and short time scales
Gell-Mann Levy - Model

\[ \mathcal{L} = \bar{q} \left[ i \gamma^\mu \partial_\mu - g(\sigma + i \gamma_5 \vec{\pi} \cdot \vec{\pi}) \right] q + \frac{1}{2} \left( \partial_\mu \sigma \partial^\mu \sigma + \partial_\mu \vec{\pi} \partial^\mu \vec{\pi} \right) - U(\sigma, \vec{\pi}) \]

\[ U(\sigma, \vec{\pi}) = \frac{\lambda^2}{4} (\sigma^2 + \vec{\pi}^2 - v^2)^2 - h_q \sigma - U_0 \]

\[ \phi_a = (\sigma, \vec{\pi}) \]

**Finite Temperatures:**

One-loop effective Potential

\[ V_{eff}(\phi_a, T, \mu) = U(\phi_a) - d_q T \int \frac{d^3 p}{(2\pi)^3} \left\{ \log \left( 1 + e^{-\frac{E+\mu}{T}} \right) + \log \left( 1 + e^{-\frac{E-\mu}{T}} \right) \right\} \]

\[ E = \sqrt{p^2 + (g\phi)^2} \]

q and \( \bar{q} \) have been integrated out to generate the effective Potential for the chiral fields \( \varphi_a \)
Coupled Dynamics of Field and Fluid

Equations of Motion:

Field: \( \Box \phi_a + \frac{\delta V_{\text{eff}}}{\delta \phi_a} = 0 \)

Fluid: \( \partial_\mu T_{\text{fluid}}^{\mu\nu} = \partial_\mu [(e + p)u^\mu u^\nu - pg^{\mu\nu}] \)
\( \partial_\mu j^\mu = \partial_\mu (\rho u^\mu) = 0 \)
\( p = p(e, \rho, \phi) = -(V_{\text{eff}}(e, \rho, \phi) - U(\phi_a)) \)

Coupling of field and fluid: \( \partial_\mu \left( T_{\text{fluid}}^{\mu\nu} + T_{\text{field}}^{\mu\nu} \right) = 0 \)

Scavenius, Mocsy, Mishustin, Rischke; Phys. Rev. C64 045202, 2001
Effective Potential and Equation of State

Crossover

\[ V_{\text{eff}}/T^4 \]

\[ \sigma (\text{MeV}) \]

\[ \rho (e_0) \]

\[ e(e_0) \]
1st Order Transition

Effective Potential and Equation of State

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Initial Conditions

\[ \mu = T = 0 \]
\[ \sigma = 93 \text{ MeV} \]

\[ T > T_c \]
\[ \mu > \mu_c \]
\[ \sigma \approx 0 \]
\[ \vec{\pi} = 0 \]
Results:
Evolution of Baryon- and Energy density
Results:
Time dependence of Baryon Density

\[ \rho [\rho_0] \]

1st order

WMAP Science Team
http://lambda.gsfc.nasa.gov/product/map/m_images.cfm
Results:
Density Inhomogeneities
Summary and Outlook

non-eq dynamics of order parameter field in HIC can lead to large
density inhomogeneities: $\Delta e/e_0, \Delta \rho/\rho_0 \sim 1$

amplitude of baryon density fluctuations depends on structure of
eff. potential:
larger effect in the regime of 1st-\(O\) transitions than for \(X\)-over

observables? one possible effect: "little bang hadroproduction", i.e.
relative hadron abundancies


effects of a damping term for the order parameter field

Talk by S. Pratt