Fluctuations in Heavy Ion Collisions and Non-Perturbative Renormalization Group Equations

Stefan Flörchinger

CERN Theory Retreat 2012, Thoiry, 09/11/2012

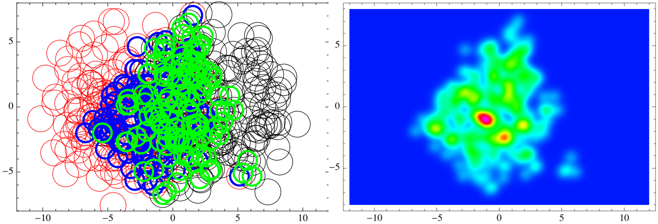
Short personal history

- Studies in Heidelberg (Germany) and Cambridge (UK)
- PhD with Christof Wetterich in Heidelberg 2009
- since 10/2010 at CERN with Scholarship from Germany
- since 10/2012 at CERN as Fellow

Research Interests

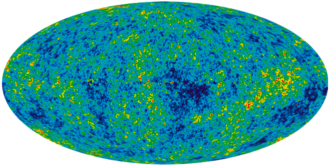
- PhD thesis: Functional Renormalization Group and applications to non-relativistic QFT (cold atoms)
- Quantum Field Theory in extreme situations: Non-zero temperature and density
- Heavy ion collisions
  - Hydrodynamics
  - Chemical freeze-out

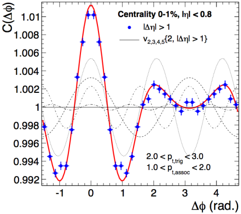
Heavy Ion Collisions 1



- **Hydrodynamic fluctuations**: Local and event-by-event perturbations around the average of hydrodynamical fields:
  - energy density ϵ
  - fluid velocity u^μ
  - more general also: baryon number density n_B, ...
- measure for deviations from equilibrium
- contain interesting information from early times
- constrains thermodynamic and transport properties
- leads to direct experimental observables

Heavy Ion Collisions 2





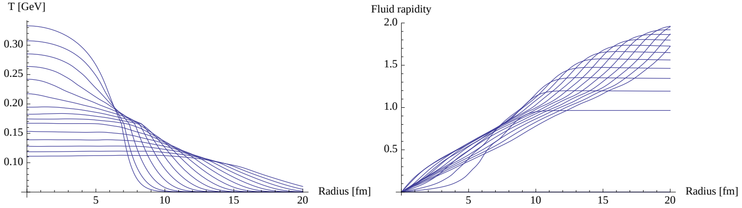
- Hydrodynamic description

$$
\begin{aligned}
D\epsilon + (\epsilon + p + \pi)\partial_\mu u^\mu - u_\nu \partial_\mu \pi^{\mu\nu} &= 0 \\
(\epsilon + p + \pi) D u^\alpha + \Delta^{\alpha\beta}\partial_\beta (p + \pi) + \Delta^\alpha{}_\nu \partial_\mu \pi^{\mu\nu} &= 0 \\
\ldots
\end{aligned}
$$

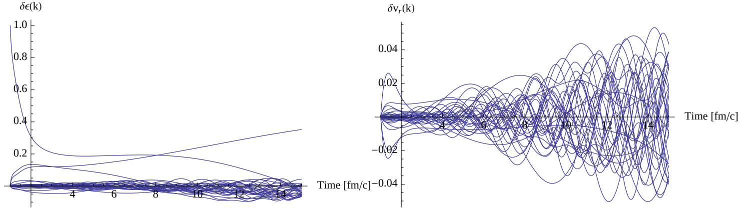
- Develop perturbation theory in small fluctuations around smooth average fields: $\epsilon = \bar{\epsilon} + \delta\epsilon$ etc.
- In spirit similar to treatment of fluctuations in cosmology.

Hydrodynamic perturbation theory for central collisions

Evolution for smooth (averaged) initial condtion



Evolution of perturbations



Non-perturbative Renormalization Group Equations 1

Exact flow equation (C. Wetterich 1993)

$$\partial_k \Gamma_k[\phi] = \frac{1}{2} \mathsf{STr} \left(\Gamma_k^{(2)}[\phi] + R_k \right)^{-1} \partial_k R_k$$

for a variant of the 1-PI or quantum effective action with

$$\lim_{k \to \Lambda} \Gamma_k[\phi] = S[\phi]$$

$$\lim_{k \to 0} \Gamma_k[\phi] = \Gamma[\phi]$$

- Fluctuations are included step by step.
- Differential formulation of functional integral.
- Used as a tool in many fields
  - Statistical field theories
  - Condensed matter
  - Gauge theories & Quantum gravity
  - Cosmology

Non-perturbative Renormalization Group Equations 2

Conceptual topics I work on

- Analytic continuation of flow equations from Euclidean to Minkowski space
- Determination of real-time properties such as decay width and transport coefficients
- Skale-dependent changes in the relevant degrees of freedom
- Composite fields / bound states

Applications of the formalism I work on

- Scalar $O(N)$-models
- Yukawa type theories for fermions
- Strongly interacting cold atoms