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Momentum anisotropy at freeze out

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Motivation

- The description of the fireball evolution needs to include a prescription for switching from the hydrodynamic approach at Kn $\ll 1$ to the transport models used at Kn $\gg 1$.
- This prescription should conserve all relevant quantum numbers of the fireball as well as its local energy and momentum densities.
- Aim: We want to smoothen the transition of the two asymptotic physical descriptions/tools.

Free streaming solution

- At very end of the fireball expansion, the emitted particles end up in a radially free streaming system, fulfilling the corresponding Boltzmann equation:

$$\left[p^\tau \partial_\tau + p^r \partial_r - \frac{2}{r} p^r p^\phi \frac{\partial}{\partial p^\phi} + r p^\phi p^\phi \frac{\partial}{\partial p^r}\right] f(x^\mu, p^i) = 0 \qquad (1)$$

where ϕ-symmetry in position space and mid rapidity is assumed.

- We found a steady state, free streaming solution for the one-particle density:

$$F_{fs}(x^\mu, p^i) = C e^{-\frac{1}{T}\sqrt{p^r p^r + r^2 p^\phi p^\phi \left(1+\frac{r^2}{R^2}\right)}} \qquad (2)$$

$\Longrightarrow$ Anisotropic distribution in momentum space

Temperature and Pressure Evolution

- One can identify the so called "anisotropic temperature" for the ϕ-direction T_ϕ as:

$$T_\phi = \frac{T}{\sqrt{1+\frac{r^2}{R^2}}}$$

As r increases, the effective temperature for the ϕ-component decreases: momentum is mostly radial

- Computing the energy momentum tensor components with respect to the free streaming solution gives the following plot for the quotient of the two important pressures $\frac{\mathcal{P}_\phi}{\mathcal{P}_r}$:

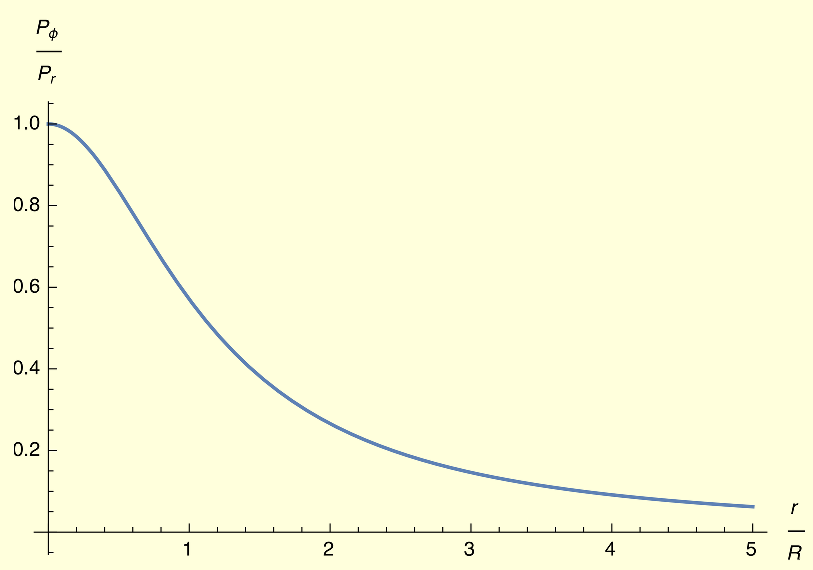

Figure 1: Ratio of the pressure component $\mathcal{P}_\phi$ over $\mathcal{P}_r$ plotted over r.

- During the free streaming period the azimuthal pressure component $\mathcal{P}_\phi$ decreases faster than the radial pressure component $\mathcal{P}_r$, due to the fact that the azimuthal temperature decreases with distance.

$\Longrightarrow$ Anisotropy in momentum space increases

Cooper-Frye kinetic freeze out

- Injecting the anisotropic free-streaming solution (2) into the Cooper-Frye integral, we find that a number of resulting observables are insensitive to the temperature at kinetic freeze out.

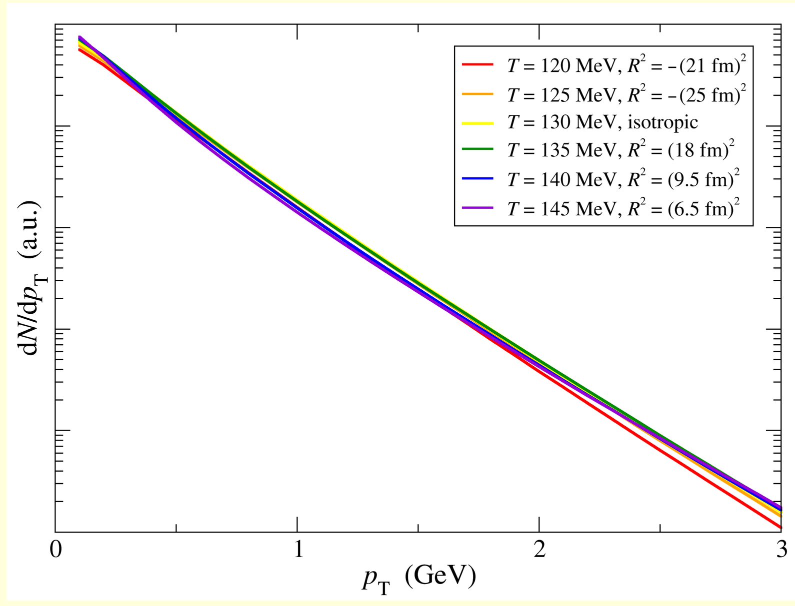

Figure 2: Particle spectrum for different freeze out temperatures and anisotropy parameters plotted over transverse momentum

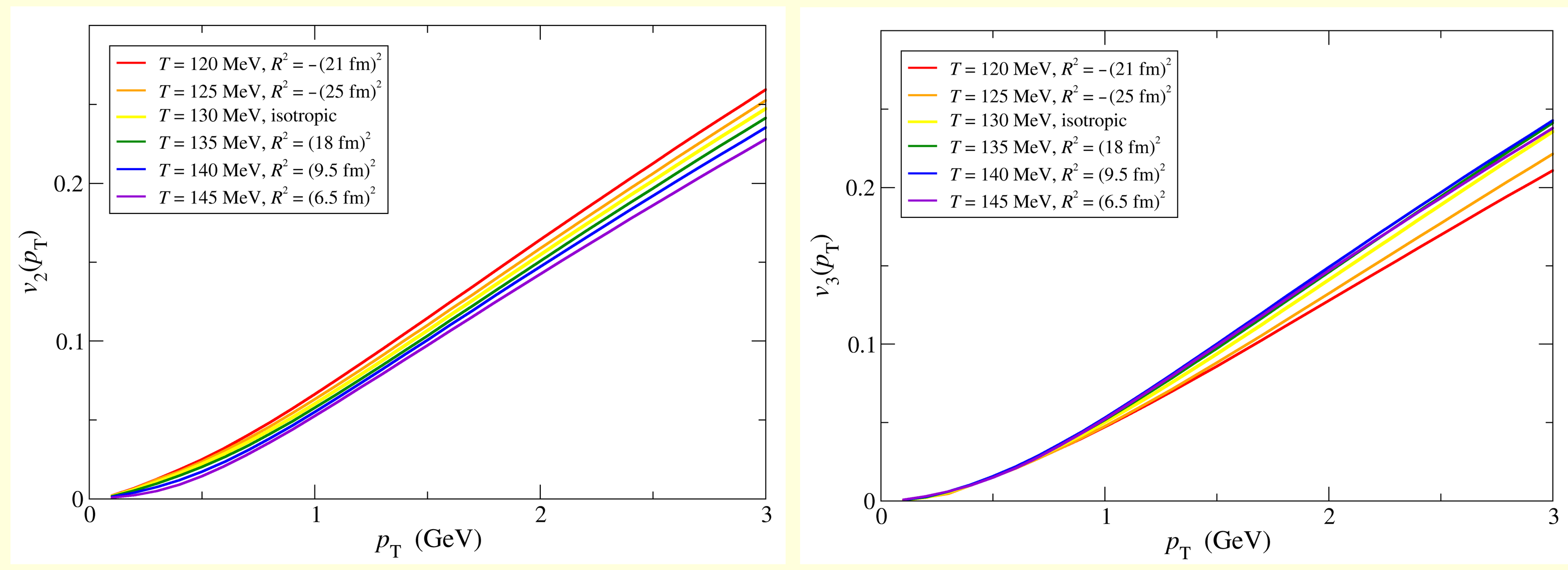

Figure 3: Anisotropic flow coefficients v_2 and v_3 for different freeze out temperatures and anisotropy parameters plotted over transverse momentum.

$\Longrightarrow$ It is possible to find a whole interval for the temperature to which the "early time" signals like anisotropic flow - which carry information on the properties of the fireball along its whole evolution, rather than on decoupling itself - are to a large extent insensitive.

- In addition the HBT-Radius R_{out} is rather insensitive to the chosen decoupling temperature.

Conclusion and Outlook

- While solving (1) we get a new (mesoscopic) parameter, which enables us to reduce the strong dependence of observables on the chosen freeze out temperature.
- We achieve a much smoother crossover between hydrodynamics and kinetic theory.
- As an outlook (and work in progress) it is interesting to go beyond free streaming, and study the era of last interactions, via including a physically reasonable ansatz for the right hand side of (1).
- This can be either achieved by
  - Linearization of the collision kernel with respect to the free streaming solution (2)
  - or by inserting (2) directly into the collision kernel using as a first step hard spheres for the cross section.

References and Acknowledgement

[1]N. Borghini, S. Feld and C. Lang, Eur. Phys. J. C 75 (2015) 275

[2]N. Borghini, S. Feld work in progress

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