Dynamical freeze-out in ebye hydrodynamics

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Non-equilibrium Dynamics and TURIC
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Freeze-out

Freeze-out criterion: expansion rate equal to scattering rate

$$K = \frac{\partial_\mu u^\mu}{\tau_{\text{scatt}}^{-1}} \approx 1$$

Since $\tau_{\text{scatt}}^{-1} = \tau_{\text{scatt}}^{-1}(T)$

$\rightarrow T \approx$ const. at freeze-out

Especially in ebye hydrodynamics this approximation may not hold.

Scattering rate

Scattering rate of pions in thermal hadron gas

$$\tau_{\mathrm{scatt}}^{-1} = \frac{1}{n_\pi(T,\mu_\pi)} \sum_i \int d^3p_\pi d^3p_i f_\pi(T,\mu_\pi) f_i(T,\mu_i) \frac{\sqrt{(s-s_a)(s-s_b)}}{2E_\pi E_i} \sigma_{\pi i}(s)$$

Cross section $\sigma_{\pi i}(s)$ as in UrQMD.

More about scattering rate: Huovinen, Saturday morning

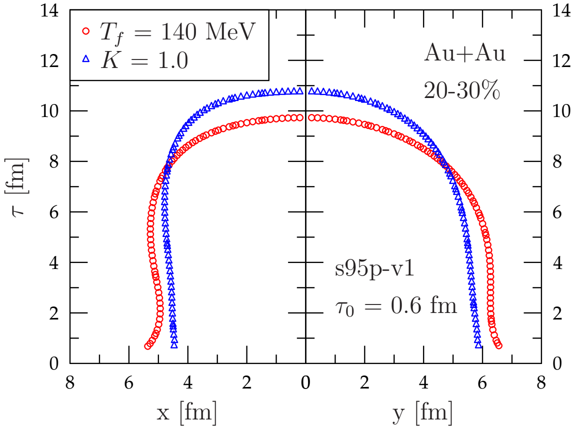
Hydrodynamical model

We use ideal event-by-event hydrodynamical framework
HH, Niemi, Eskola PRC83 (2011) 034901

- 2+1 ideal hydrodynamics, Bjorken in beam direction
- EoS: s95p-v1 Huovinen, Petreczky, NPA837 (2010) 26-53
- Finite net-baryon number (but not in EoS)
- Thermal spectra from Cooper-Frye, hadrons sampled from these
- Decays are done for one hadron at a time
- Optical Glauber for smooth initial states
- MC Glauber for ebye initial states

Smooth initial conditions

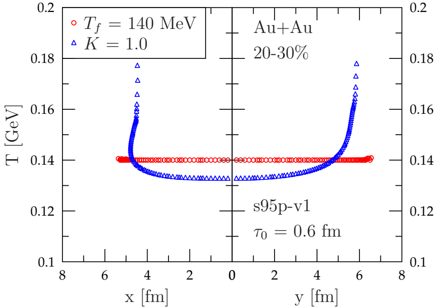
Dynamical vs. constant T

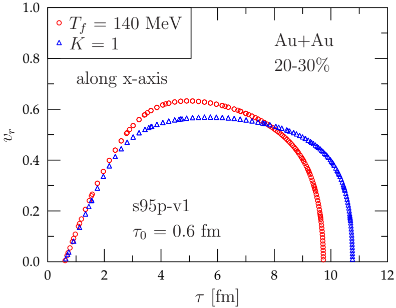


Center lives longer with dynamical fo

Edges decouple earlier with dynamical fo

Dynamical vs. constant T

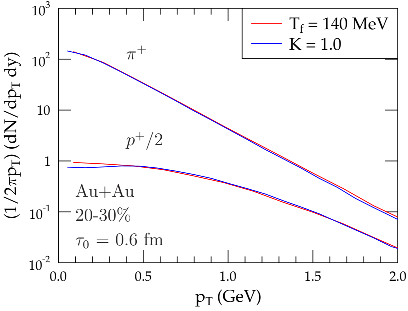


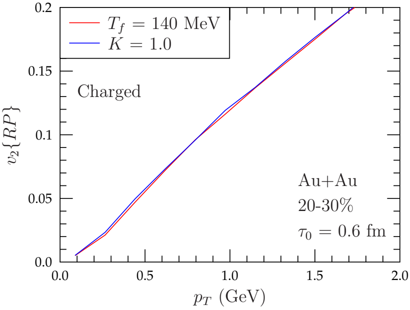


With dynamical fo the temperature varies a lot!

Largest velocities are cut away with dynamical freeze-out

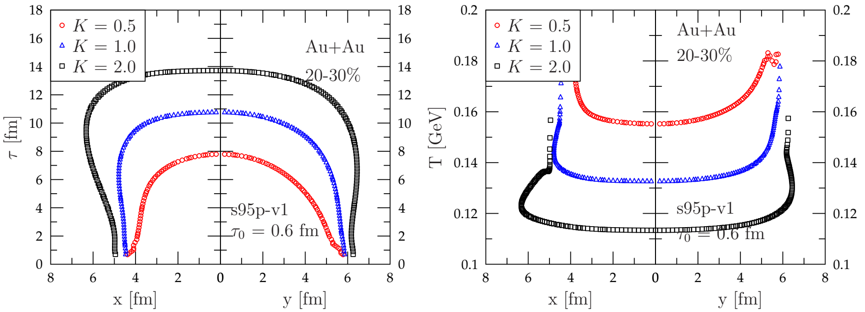
Dynamical vs. constant T





With these parameters, the spectra and v_2 are the same with both freeze-out criterions.

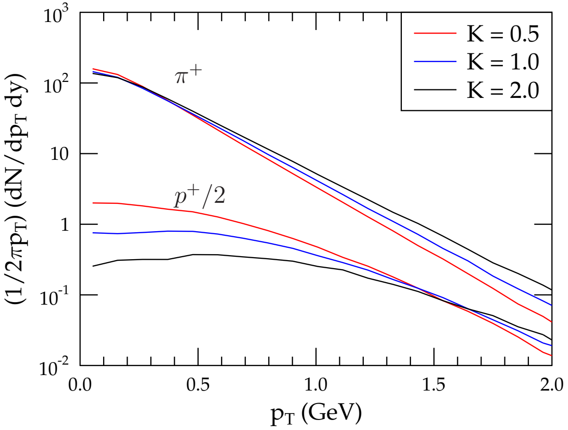
Sensitivity on K



Now the lifetime of the system is greatly varied.

Temperatures are very different!

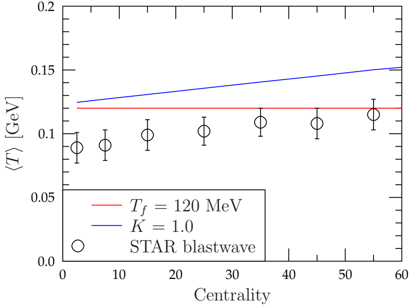
Sensitivity on K

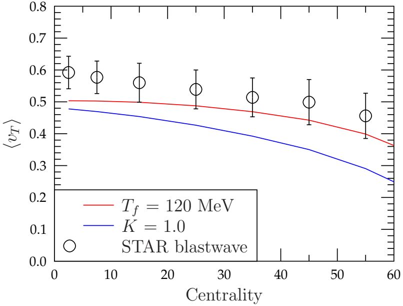


Shorter lifetime means smaller transverse flow.

Number of protons depends on the value of K because $\langle T \rangle \sim 1/K$.

Comparison with blast-wave fit





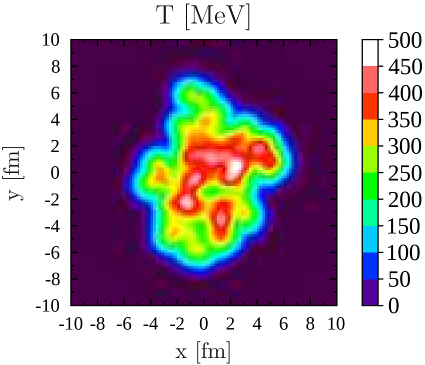
Averages are calculated with entropy current through the surface as a weight

Trends are very similar with dynamical freeze-out and blast-wave fit.

Fluctuating initial conditions

A word about initial states

- Monte Carlo Glauber
- Entropy density is distributed around the positions of WN and BC
- When distributing entropy we use Gaussian smearing

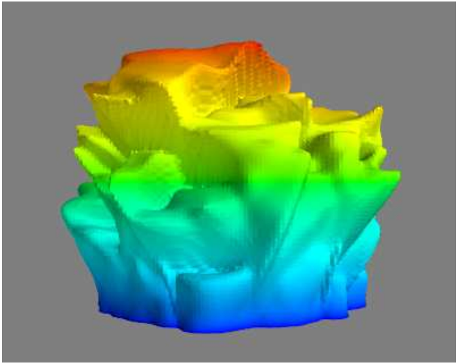


$$s(x,y) = \text{const.} \sum_{\text{wn,bc}} \frac{1}{2\pi\sigma^2} \exp\left[-\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma^2} \right]$$

Constant temperature surface

Much more structure than in the smooth case.

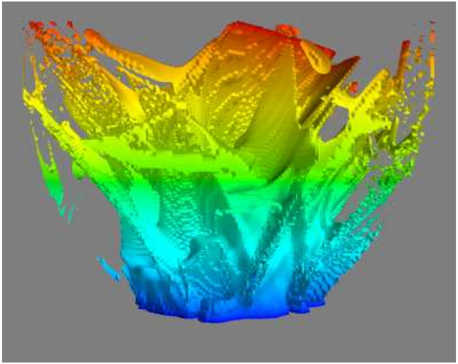
No problems finding constant temperature surfaces.



Dynamical freeze-out

Lots of separate surfaces, fins and horns.

In many places matter which has frozen-out goes again inside the surface. Let’s fix this first.



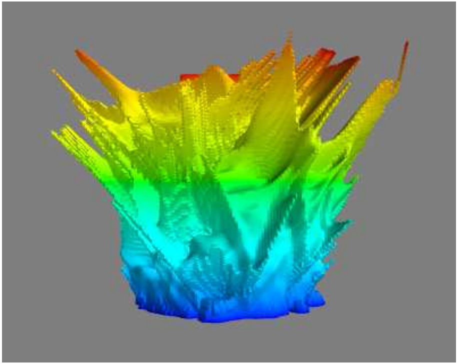
Improved dynamical freeze-out

We follow the flowline backwards and make sure that frozen-out element cannot thermalize again.

This removes the small separate surfaces.

However, many thin fins remaining.

Why do these fins appear?



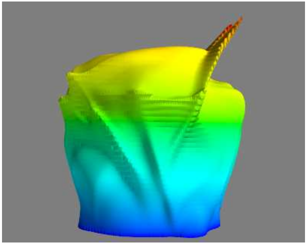
Wider Gaussians in the initial state

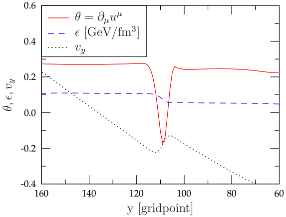
With larger smearing parameter $\sigma = 0.8$ fm, situation is much simpler.

The fins are due to the velocity differences of the different regions.

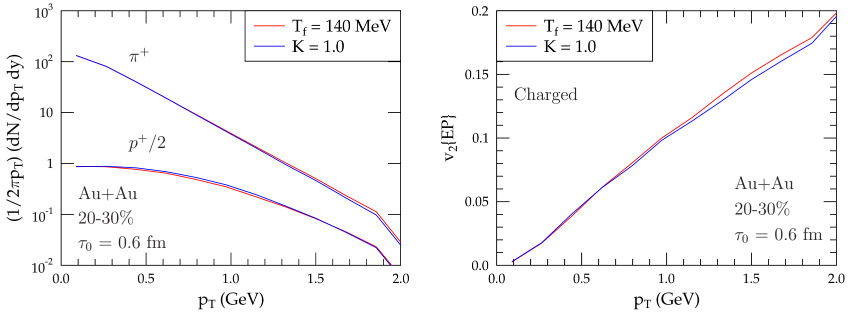
We do not try to remove these remaining fins (maybe in the future).

With this setup we can already make calculations!





Preliminary ebye calculation



Almost no difference!

Summary

Constant T freeze-out is a simplification.

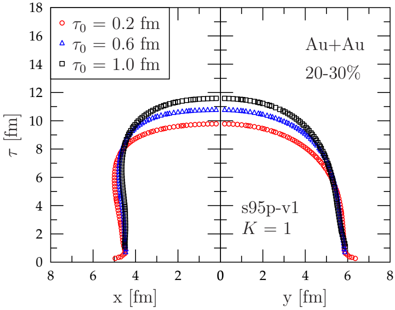
However, effect is small for spectra and v_2.

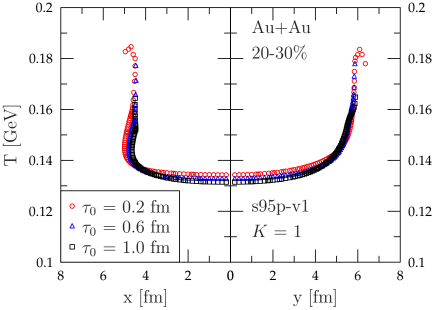
Centrality dependence of the freeze-out parameters (T, v_T) is reasonable with dynamical condition.

We still need to study what is the effect of the fins.

Backup slides

Sensitivity on initial time

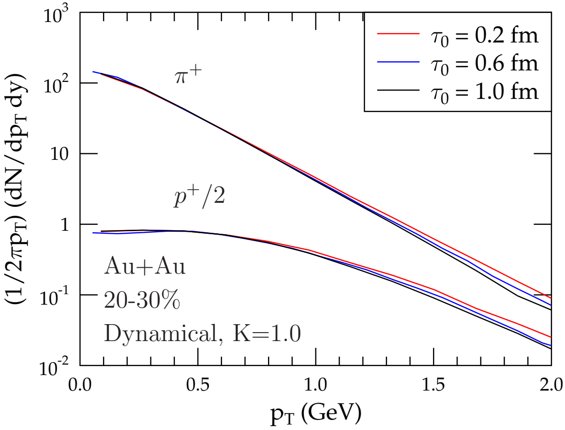




Center of the system lives a little bit longer if we start later.

Temperature changes only slightly.

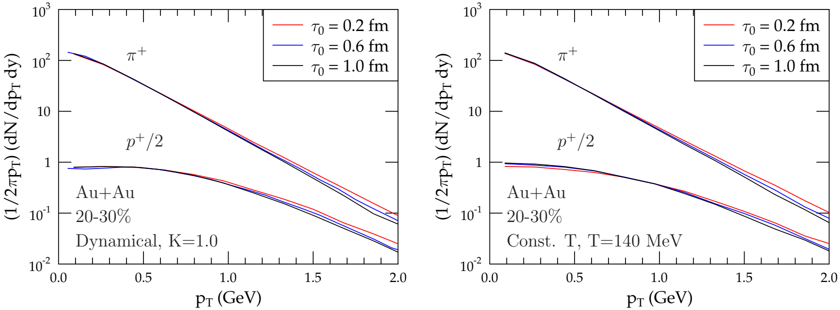
Sensitivity on initial time



Earlier initial time
→ steeper gradients
→ more flow

Same behavior than
with constant T surface.

Sensitivity on initial time



Very similar situation with both freeze-out criterions.