Solving the RHIC puzzles[1]

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Heavy-Ion Forum
CERN, 31 March 2008

[1] Based on WB, M. Chojnacki, W. Florkowski, A. Kisiel, arXiv:0801.4361

Puzzles for the standard hydro approach:

- RHIC puzzle 1: apparent impossibility to fit simultaneously p_T-spectra, v_2, and HBT
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- azHBT also right
- Possible extrapolation to LHC

(see Adam Kisiel's talk)

pre-hydro stage $\rightarrow$
$\rightarrow$ initial condition for hydro $\rightarrow$
$\rightarrow$ hydrodynamics $\rightarrow$
standard sequence: $\rightarrow$ freeze-out $\rightarrow$
[Heinz ... Hirano]: $\rightarrow$ hadrons

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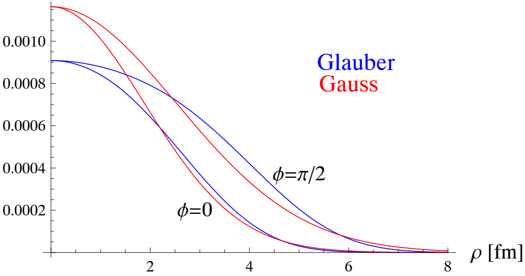

Left: initial energy-density profiles for $c = 20 - 30\%$

We take Gaussian:
$n_0 \sim \exp\left(-\frac{x^2}{2a^2} - \frac{y^2}{2b^2}\right)$

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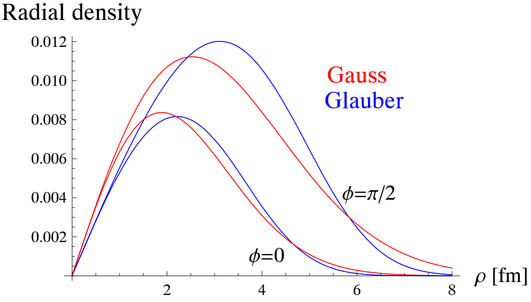

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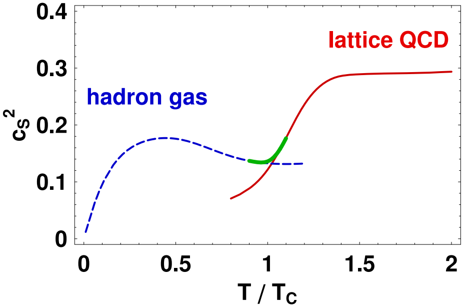
Equation of state

Inviscid, baryon-free, boost-invariant (for mid-rapidity) hydro $\partial_\mu T^{\mu\nu} = 0$, equation of state encoded solely in the sound velocity [Florkowski+Chojnacki]



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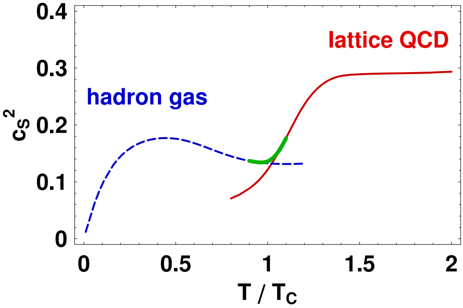

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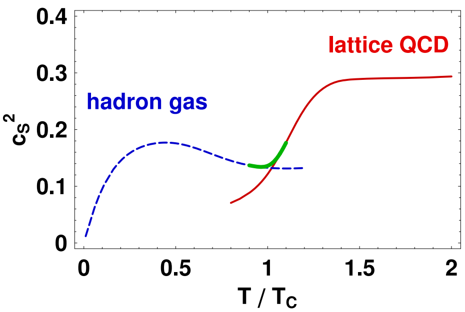

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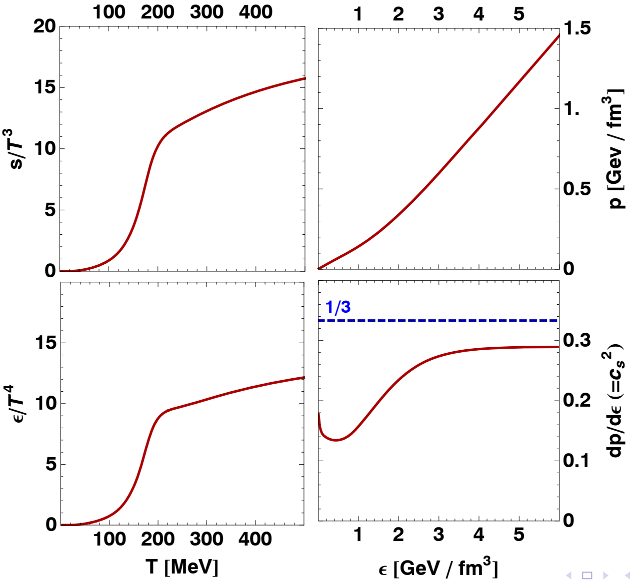
No shock waves, as

$$\frac{d}{dT}\frac{sc_s}{T} > 0$$

[Blaizot+Ollitrault]



Other quantities follow from thermodynamic relations

- Initial temperature profile follows from the energy-density (or entropy-density) profile
- Initial central temperature T_i adjusted to reproduce the multiplicities
- The proper time of the start set to $\tau = 0.25$ fm/c (early!)

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- Initial central temperature T_i adjusted to reproduce the multiplicities
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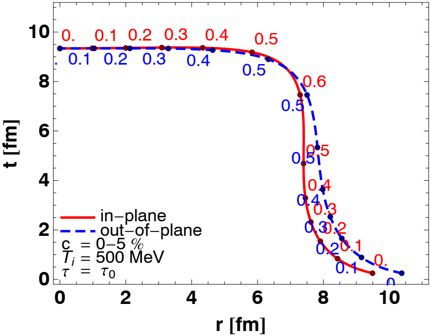
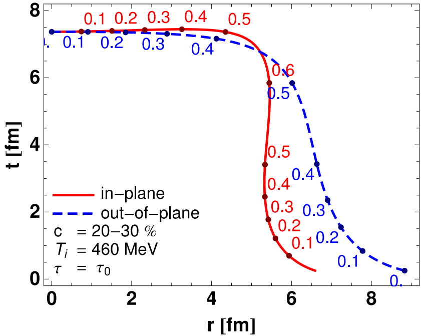
- Equations solved with the help of method of characteristics with Mathematica (Lhyquid - M. Chojnacki)

- Entropy conservation test at the relative level of 10^{-4} or better

Freeze-out hypersurfaces

Universal freeze-out temperature taken to be $T_f = 145$ MeV



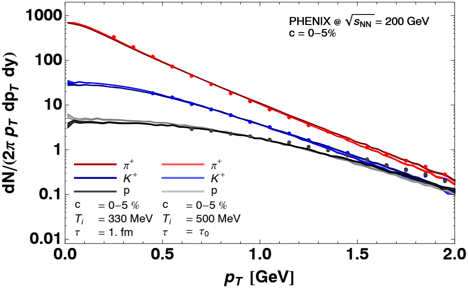


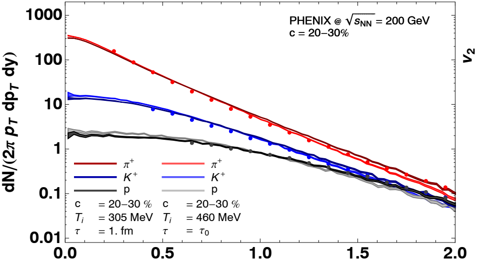
in plane, out-of-plane

Standard Cooper-Frye formalism used, THERMINATOR

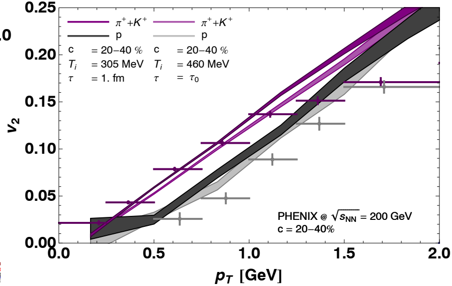
Due to large surface flow practically no hadrons fall back into the hydro zone 50% from volume, 50% from surface emission (volume part similar to the blast-wave parameterization)

p_T-spectra and v_2

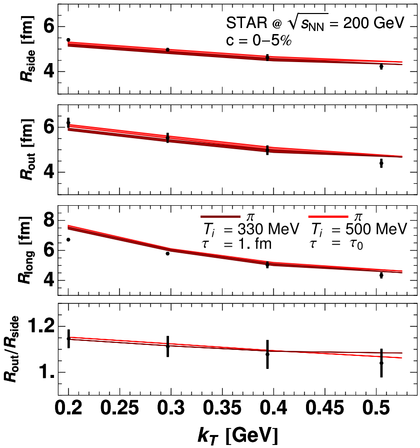




Look at lighter lines/bands



Pionic HBT radii



HBT, including $R_{\text{out}}/R_{\text{side}}$ works so well for the first time!

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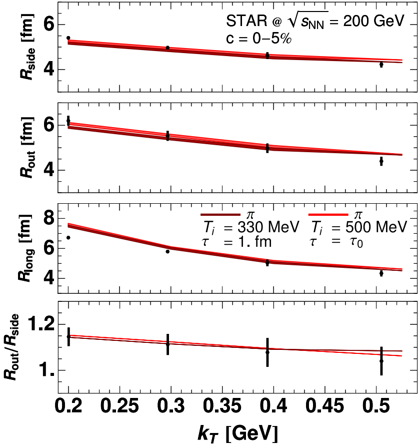

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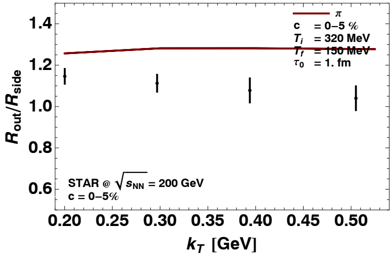
With the Glauber initial condition worse



More in Adam Kisiel's talk, azHBT also OK!

Basic picture

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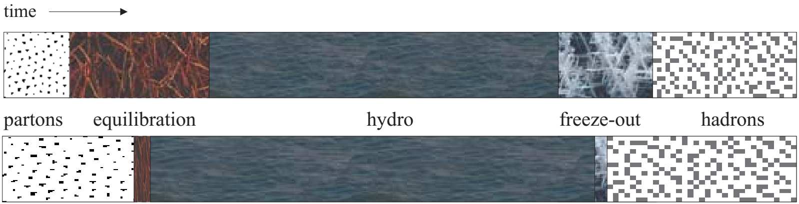
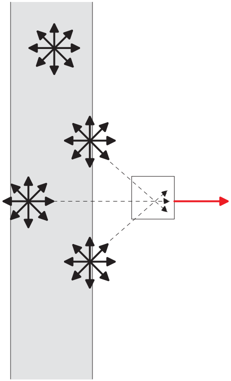


Approximate the initial phase of weakly-interacting partons gradually reaching equilibrium with free streaming and Landau matching to the thermalized system (instantaneous reaching of equilibrium)

Similar ideas in [Sinyukov, Karpenko, Gyulassy]

Free streaming generates flow



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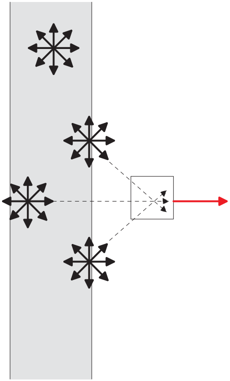

free streaming +
equilibration →
flow of the fluid

driven by the gradient
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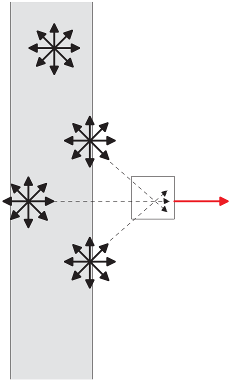

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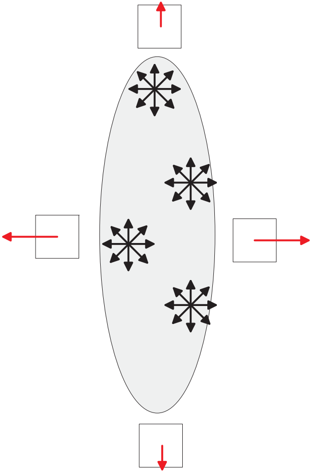

Landau matching

$$\forall x : \quad T^{\mu}_{\cdot\nu} u^{\nu} = \epsilon u^{\mu}$$

(in the rest frame of the fluid element the energy-densities match)

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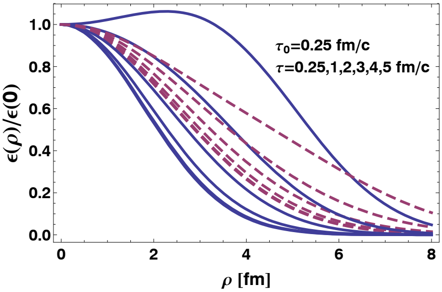
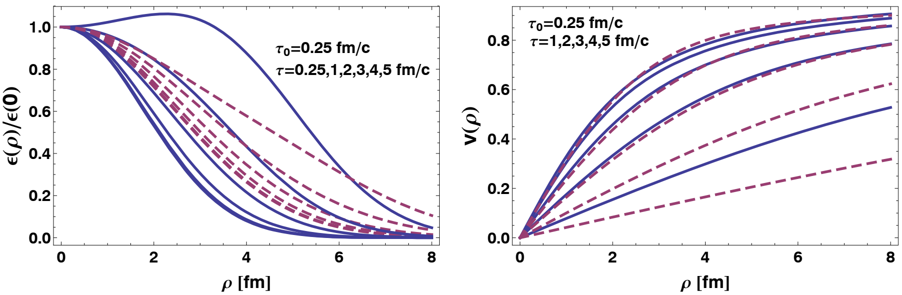
Energy-momentum tensor from free streaming from τ_0 to $\tau \gg \tau_0$:

$$T^{\mu\nu}(x, y, \eta = 0) = \int dY d^2 p_T \frac{d^6 N(\tau)}{dY d^2 p_T d\eta dx dy} p^{\mu} p^{\nu}$$

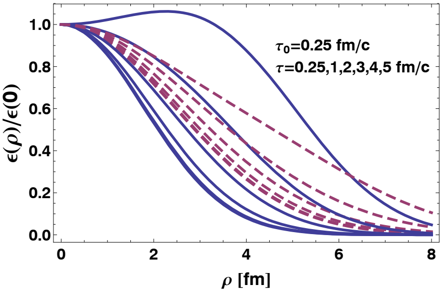
$$= A \int_0^{2\pi} d\phi \, n_0 \left(x - (\tau - \tau_0) \cos\phi, y - (\tau - \tau_0) \sin\phi \right) \times$$

$$\times \begin{pmatrix} 1 & \cos\phi & \sin\phi & 0 \\ \cos\phi & \cos^2\phi & \cos\phi\sin\phi & 0 \\ \sin\phi & \cos\phi\sin\phi & \sin^2\phi & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix},$$


τ_0=0.25 fm/c
τ=0.25,1,2,3,4,5 fm/c
$\epsilon(\rho)/\epsilon(0)$
ρ [fm]
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8



solid: in-plane, dashed: out-of-plane



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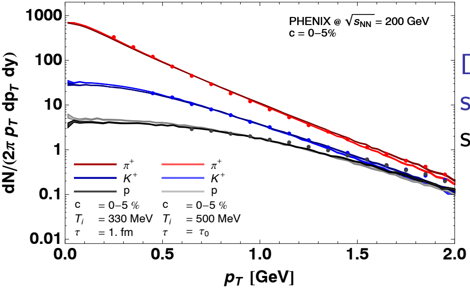
Hubble flow follows from the Gaussian profile at low $\rho\Delta\tau$, as $(\Delta\tau = \tau - \tau_0)$

$$\mathbf{v} \equiv (v_x, v_y, v_z) = -\frac{\Delta\tau}{3}\frac{\nabla n(x,y)}{n(x,y)} = \frac{\Delta\tau}{3}\left(\frac{x}{a^2}, \frac{y}{b^2}, 0\right)$$

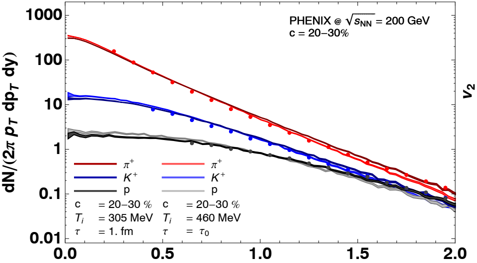
Results with free streaming up to $\tau = 1$ fm/c are basically indistinguishable to those without free streaming shown above

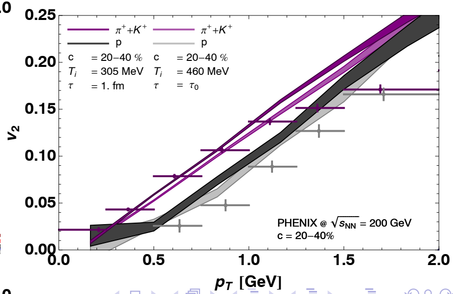
p_T-spectra and v_2 with free streaming



Darker lines/bands – with free streaming

slightly larger flow





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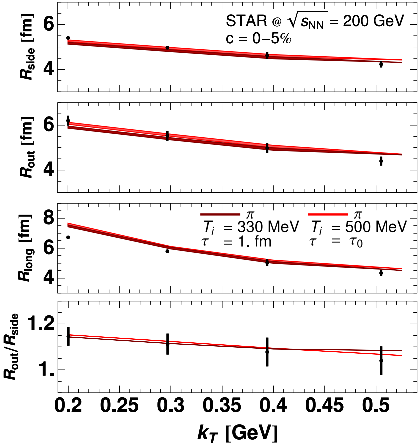

Darker lines/bands – with free streaming

- It is possible to fit uniformly the soft RHIC data with hydrodynamics, provided the initial condition is somewhat sharper that the typically used Glauber profile
- Realistic equation of state, precise solving (Lhyquid)
- THERMINATOR and all resonances
- "Rectangular" shape of the freeze-out hypersurface, large flow, volume and surface emission almost equal
- Free streaming + Landau matching to thermalized phase allow to delay the start of hydro to realistic times. The mechanism generates the initial transverse and elliptic flow
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- Advertisement: GLISSANDO: GLauber Initial State Simulations AND mOre ... [WB, Rybczyński, Bożek, arXiv:0710.5731] http://www.pu.kielce.pl/homepages/mryb/GLISSANDO/ (includes the eccentricity fluctuations, harmonic profiles, various Glauber models, written in ROOT...)