GOETHE UNIVERSITÄT FRANKFURT AM MAIN

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QM12 QuarkMatter

Dissipative effects in multi-component systems

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Motivation

Dissipative hydrodynamics is a standard dynamic model for the early evolution in HIC

Comparison of observables from RHIC & LHC experiments with hydrodynamic calculations:

We learn about

> Initial conditions

> EoS

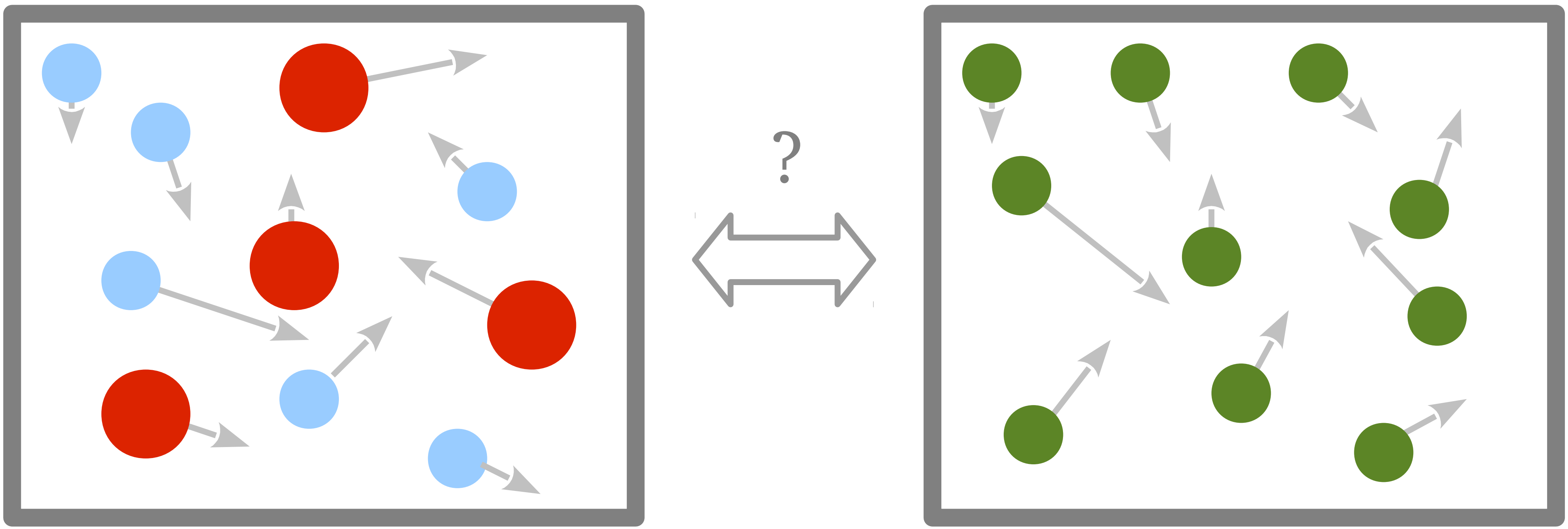
> Transport properties of the created medium

Motivation

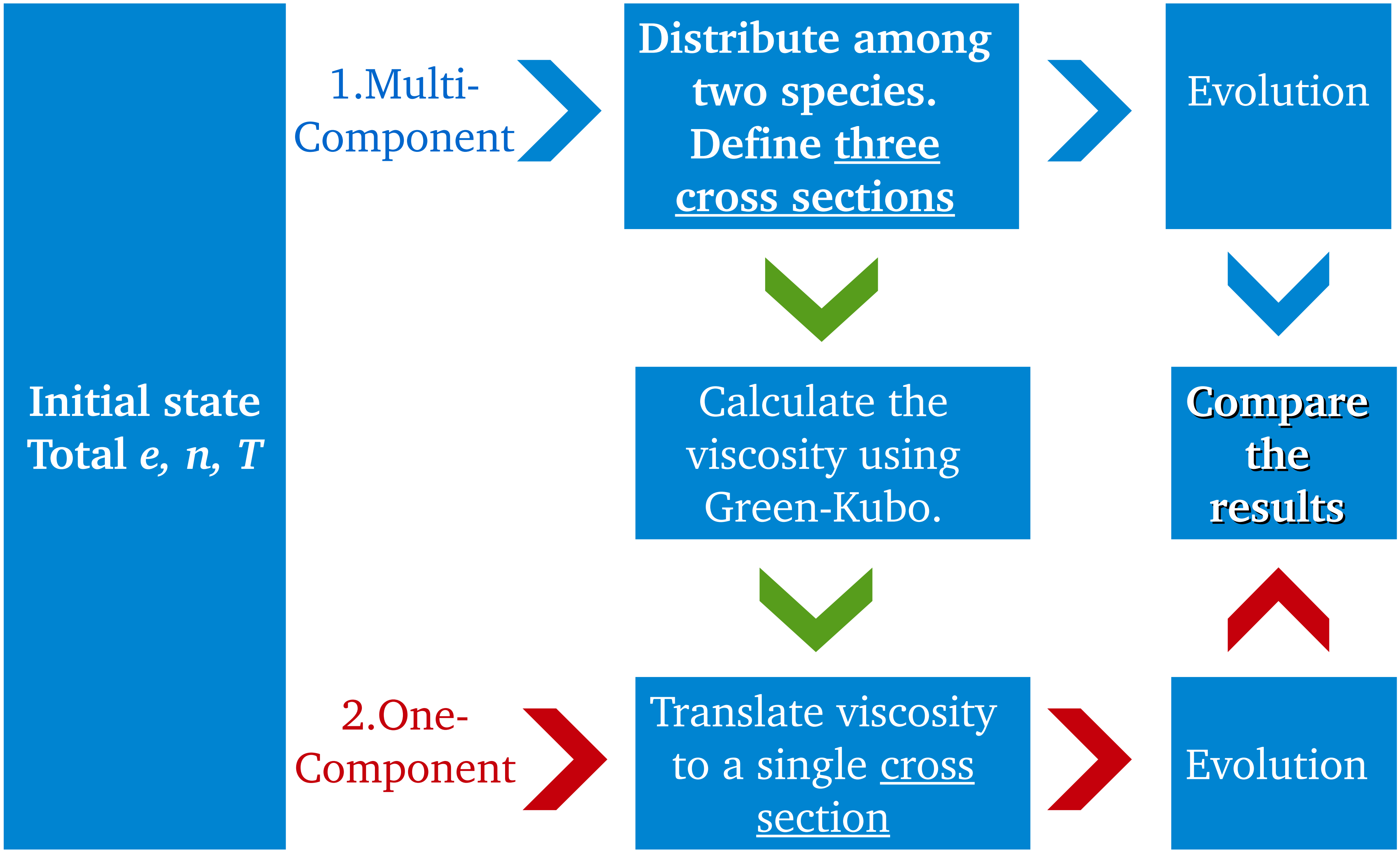
We want to learn about the inner dynamics in the medium and its composition

<u>Dissipative hydrodynamic models</u> include **one transport coefficient** to describe the dynamics

Is this a correct approach to deal with a mixture?



Approach


Initial state
Total *e*, *n*, *T*
1.Multi-Component
Distribute among two species. Define three cross sections
Evolution
Calculate the viscosity using Green-Kubo.
Compare the results
2.One-Component
Translate viscosity to a single cross section
Evolution

Our model : BAMPS

We investigate some hydrodynamic problems in **BAMPS:**

Boltzmann Approach to Multi-Parton Scatterings

$$p^{\mu}\partial_{\mu} f_i(x,p) = C_{ii}[f_i] + C_{ij}[f_j] + C_{inelastic}$$

Kn expansion

Dissipative hydrodynamics

Posters by

I. Bouras
O. Fochler
F. Senzel
J. Uphoff

In BAMPS calculations we will consider

A homogeneous mixture of two particle species

Elastic processes only (constant particle numbers)

Isotropic scatterings (angle-independent $d\sigma/d\Omega$)

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↓ *Kn* expansion

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Role of shear viscosity

Standard dissipative hydrodynamics

$\pi^{\mu\nu}$ ⟶ anisotropy of the energy-momentum tensor

$$\dot{\pi} = -\frac{\pi}{\tau_\pi(\eta)} + \textit{gradient} \quad \textit{terms}$$

Shear viscosity moderates relaxation of created anisotropy of the energy-momentum tensor towards equilibrium

> If no gradients present, η is a direct measure of the relaxation:

$$\pi(\tau) = \pi(\tau_0) \cdot \exp(-\tau / \tau_\pi(\eta))$$

Static Box

BAMPS BOX

n_1, n_2

$T_1 = T_2 = T$

$\sigma_{11}, \sigma_{12}, \sigma_{22}$

π_1, π_2

$$f_i = d \cdot e^{-E/T} \cdot \left(1 + \frac{3}{8 e_i T^2} \cdot \pi_i \cdot \left(\frac{1}{2} p_T^2 - p_z^2\right)\right)$$

Grad 's Formalism

Observe relaxation to equilibrium

1. Calculate shear viscosity using Green-Kubo formalism,
2. Compare evolution in BAMPS with analytic solution

$$\pi(\tau) = \pi(\tau_0) \cdot e^{-\frac{\tau}{\tau_\pi(\eta)}}$$

Green-Kubo method

Application of Green-Kubo formula in BAMPS:

C.Wesp et al, Phys.Rev. C84 (2011) 054911

$$\eta = \frac{V}{T} \int_0^\infty C(\tau)\, d\tau$$

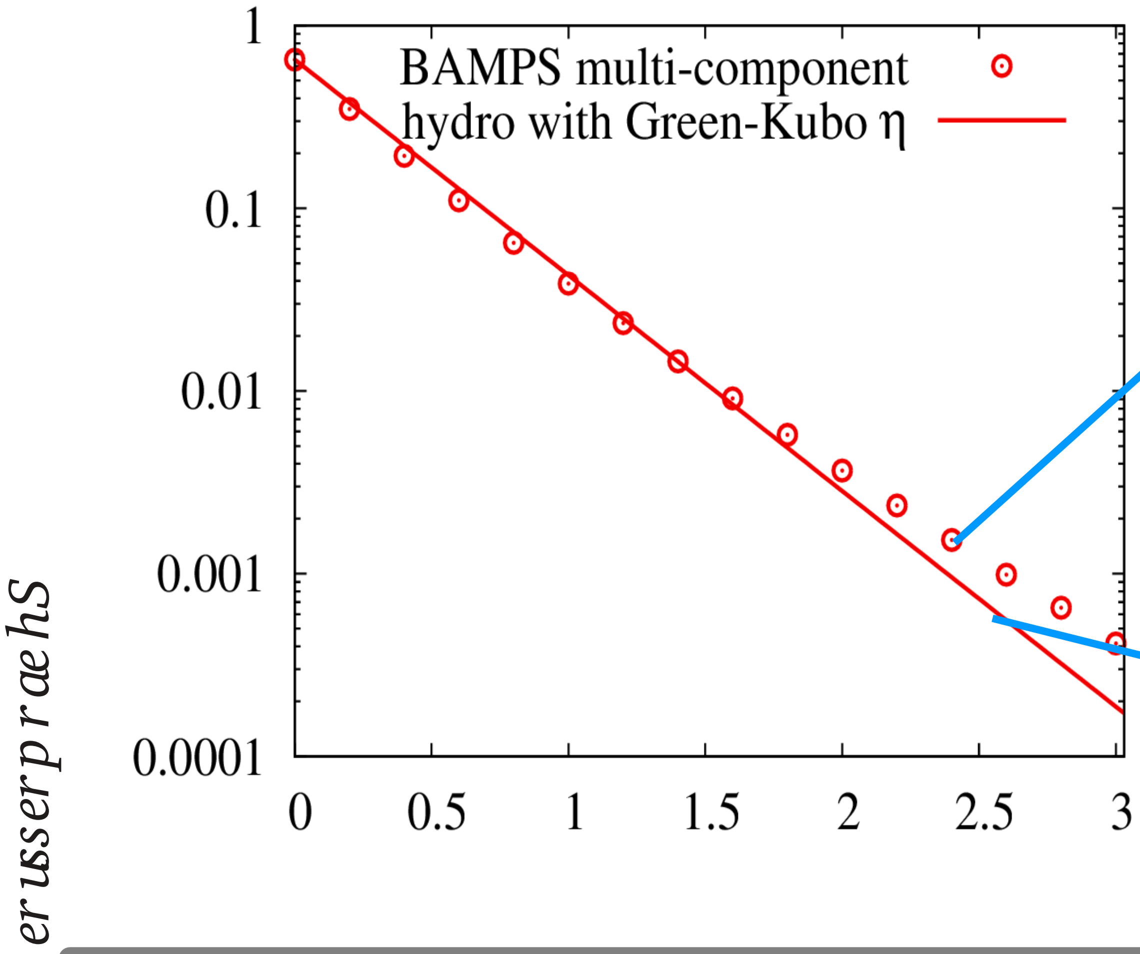
Auto-correlation function

$$C(\tau) = \frac{1}{3} \left(\langle \pi^{xy}(0)\pi^{xy}(\tau) \rangle + \langle \pi^{xz}(0)\pi^{xz}(\tau) \rangle + \langle \pi^{yz}(0)\pi^{yz}(\tau) \rangle \right)$$

τ = *correlation time*

In a static box η as well as the relaxation time from standard hydro are constant

Relaxation of anisotropy



et al., arXiv:1206.3465 [hep-th]

BAMPS data is a **double-exponential**

Solution of standard hydro with GK viscosity:

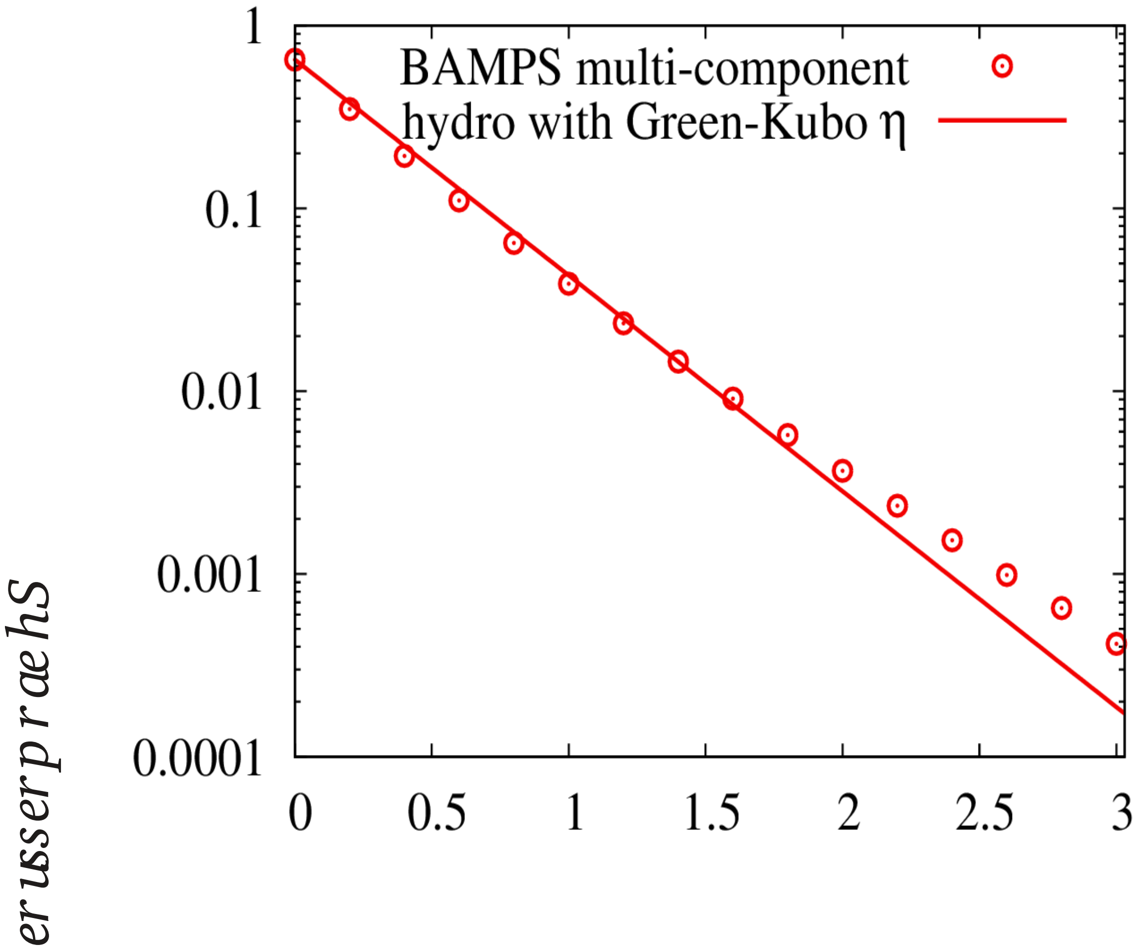
$$\pi(\tau)=\pi(\tau_0)\cdot e^{-\frac{\tau}{2\eta\beta_2}}$$

BAMPS BOX

$n_1/n_2 = 5$ $\sigma_{11} = 4$ mb, $\sigma_{12} = 2$ mb, $\sigma_{22} = 1$ mb

initial $\pi_1/\pi_2 = n_1/n_2$

Relaxation of anisotropy



et al., arXiv:1206.3465 [hep-th]

Standard hydrodynamics

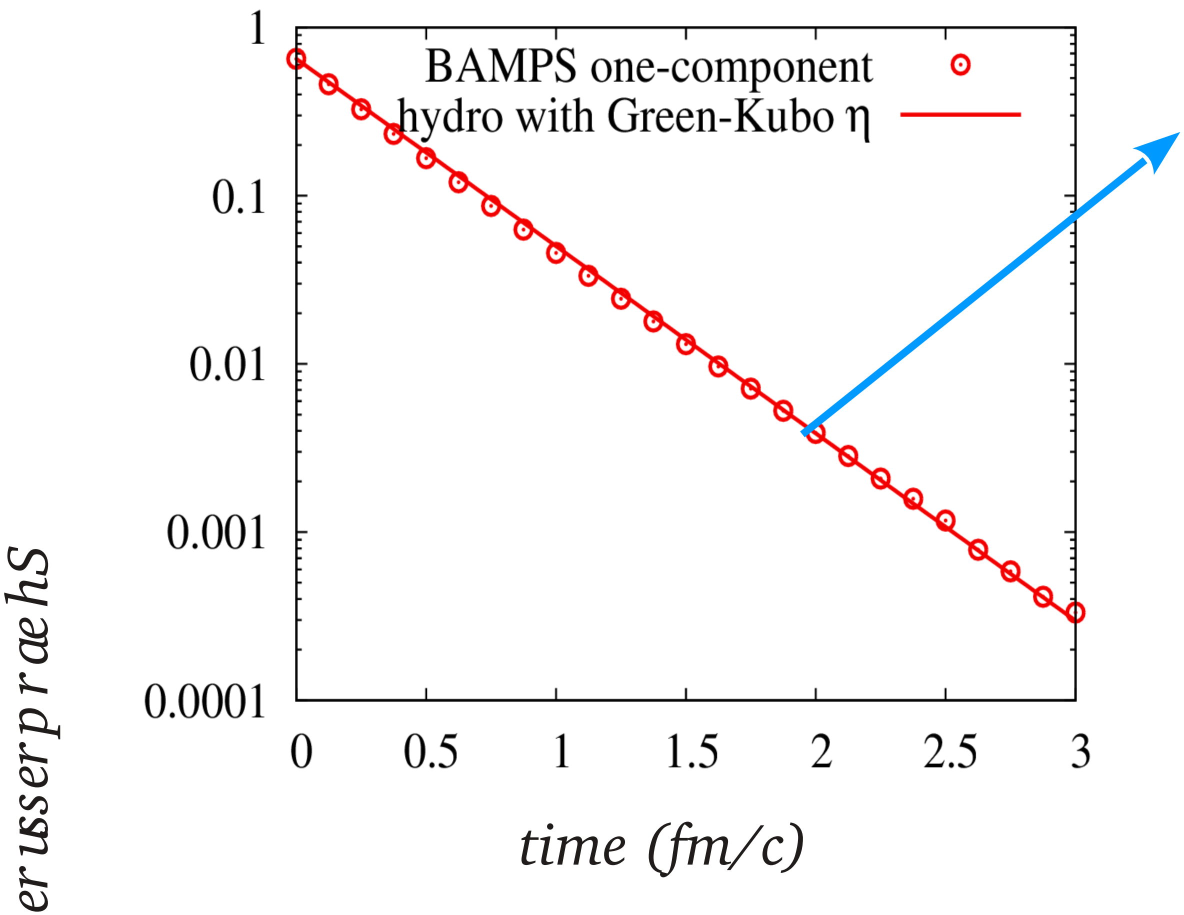
$$\dot{\pi} = -\frac{\pi}{\tau_{\pi}(\eta)} + \textit{gradient terms}$$

cannot describe a mixture

1 . Time-dependent
"effective shear viscosity"
needed.

2. Green-Kubo formalism
does not provide the "proper"
viscosity coefficient for
standard hydrodynamics, if
we deal with mixtures

Relaxation of anisotropy



Standard hydrodynamics

$$\dot{\pi} = -\frac{\pi}{\tau_{\pi}(\eta)} + \textit{gradient terms}$$

works fine for a one-component system though

Relaxation of anisotropy

In a box simulation, it appears that a time-dependent viscosity is needed to describe multi-component results

AE et al., arXiv:1206.3465 [hep-th]

> How strong is this effect if gradients are not negligible?

> Is a difference in behavior of single- and multi-component system visible under conditions, relevant for HIC?

We now investigate 3D expansion of a Glauber-type initial condition in BAMPS

Initial condition

Glauber:

$$f(t=0,\vec{x},p_T,y)=K\cdot\frac{1}{E}\cdot\left(\frac{Q^n}{Q^n+p_T^n}\right)^m\cdot\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\cdot\exp\left(\frac{-z^2}{2\sigma_z^2}\right)\cdot T_A(x_T-b/2)\,T_A(x_T+b/2)$$

T_A: nuclear thickness functions

y: momentum rapidity

We fix the parameters to obtain at ~4 fm/c

$dN/d\eta \sim 700$

$dE_T/d\eta \sim 600$ (rough correspondence to RHIC)

$Q=1.3$

$n=4.0$

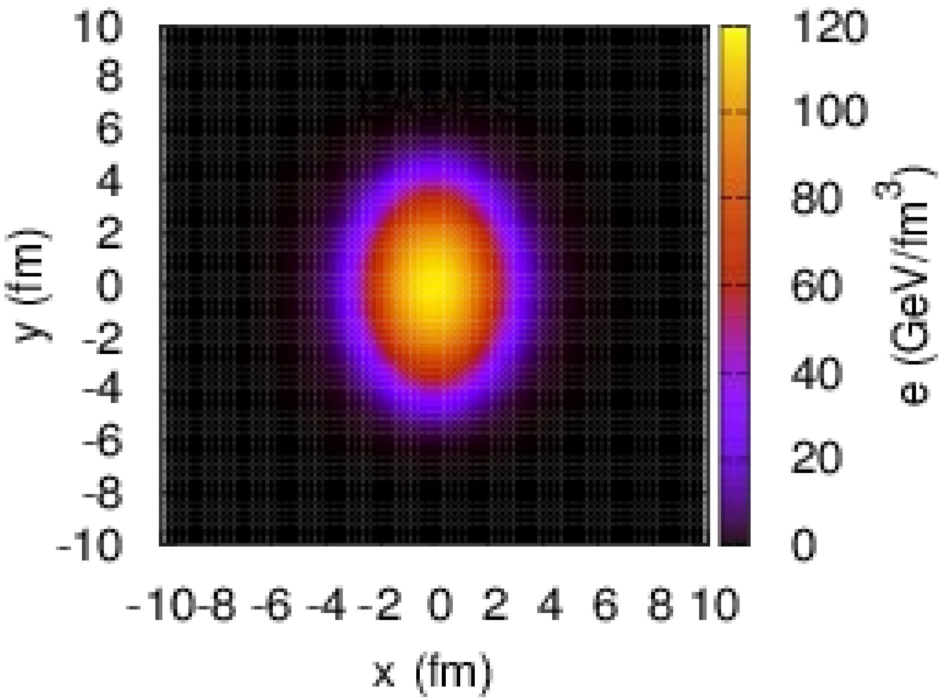
$m=1.5$

$\sigma_y=1.0$

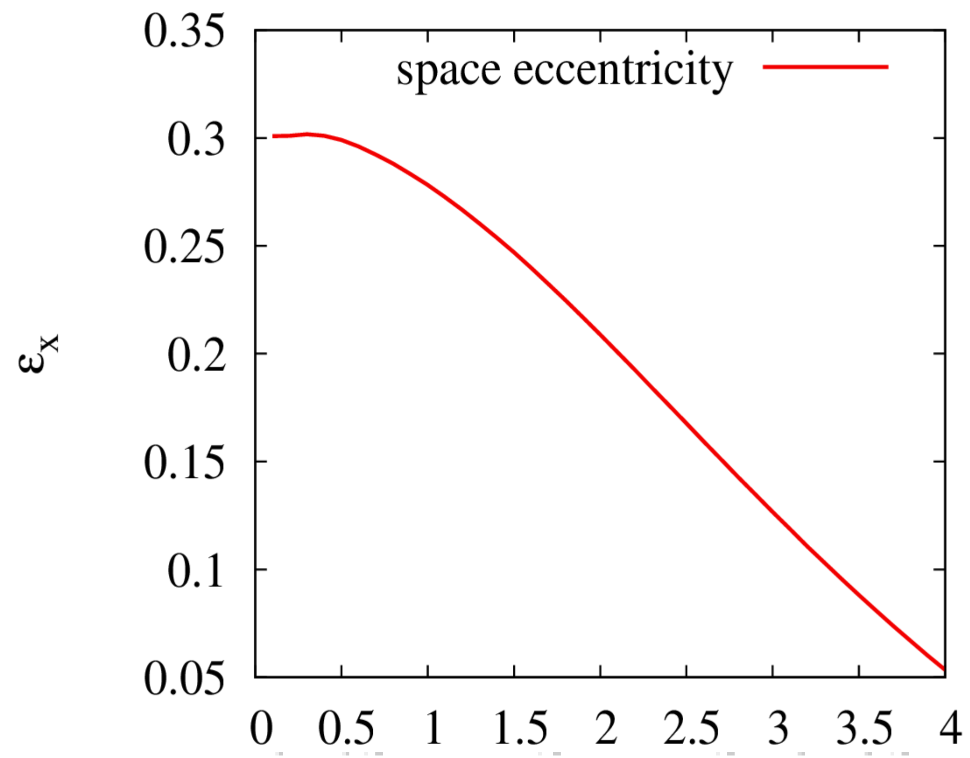
$\sigma_z=0.13$

Poster by I. Bouras

Initial condition



Data at t=0.1 fm/c, z=0 fm



Time evo of
spacial eccentricity

Poster by I. Bouras

Initial conditions & Interactions

The initial energy and particle densities are obtained from Glauber IC

Each species gets a portion of the initial energy and particle densities from Glauber IC:

$$n_1/n_2 = r\,(constant\,!) \qquad \qquad n_1/n_2 = 1$$
$$e_1/e_2 = r \qquad \textit{in particular} \qquad e_1/e_2 = 1$$
$$T_1 = T_2 = e/3n$$

Multi-component system

One-component system

Elastic processes with isotropic differential cross sections

$$\sigma_{11} = \frac{2}{T^2} \quad \sigma_{12} = \frac{1}{T^2} \quad \sigma_{22} = \frac{0.5}{T^2} \quad (\text{in } \; GeV^{-2})$$

Green-Kubo: η →

$$\sigma_{el} = 1.26\,\frac{T}{\eta}$$

↓

$$\sigma_{el} = \frac{a}{T^2}$$

T is the local temperature of the system

Interactions

For

$$\sigma_{11}=\frac{2}{T^2} \quad \sigma_{12}=\frac{1}{T^2} \quad \sigma_{22}=\frac{0.5}{T^2} \quad \left(\text{in} \quad GeV^{-2}\right)$$

$$n_1/n_2=1$$

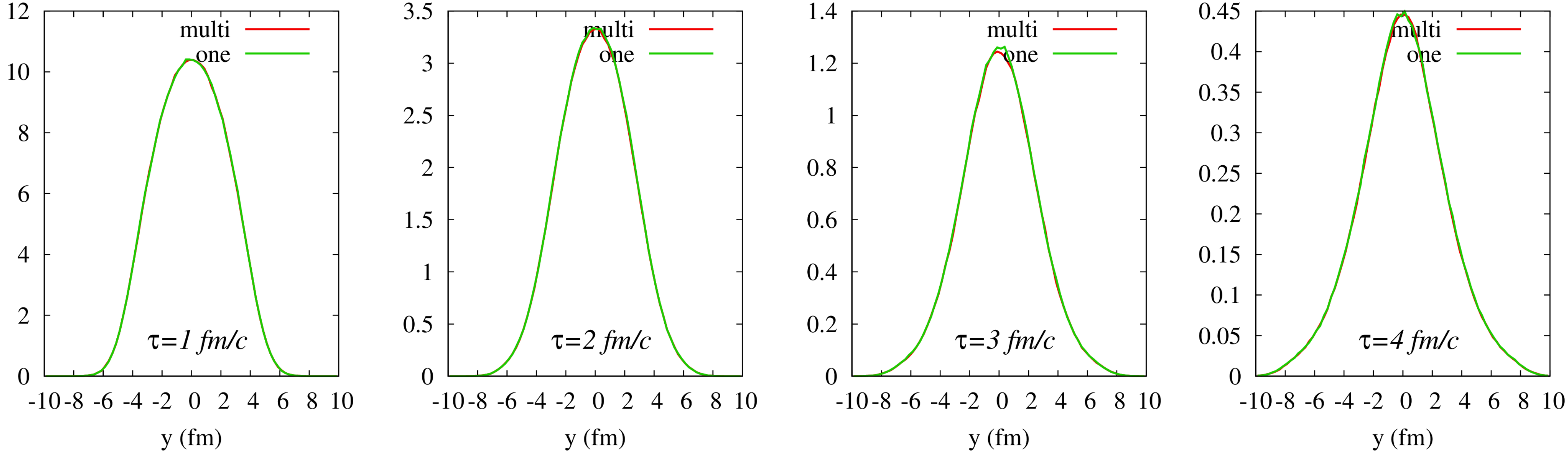
we find $\sigma_{el}=\frac{1.0}{T^2}$

Effective one-component cross section obtained from Green-Kubo formalism

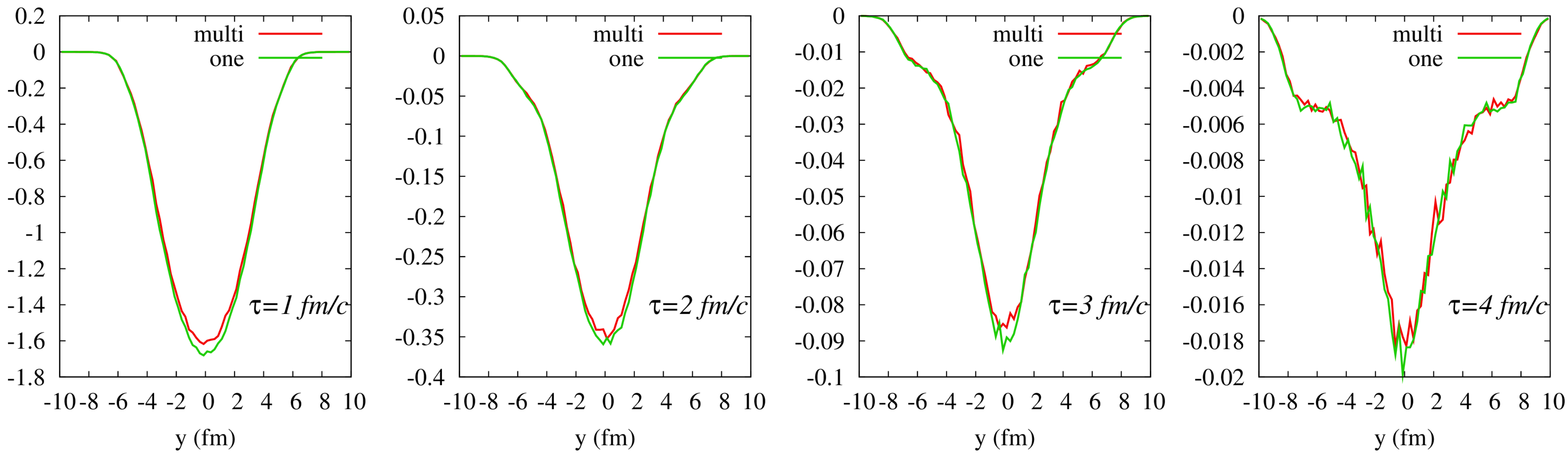
$\eta/s \sim 0.19$

All results shown in the next slides are for this configuration
Results are shown for mid-rapidity η=0

Energy density (GeV/fm^3)



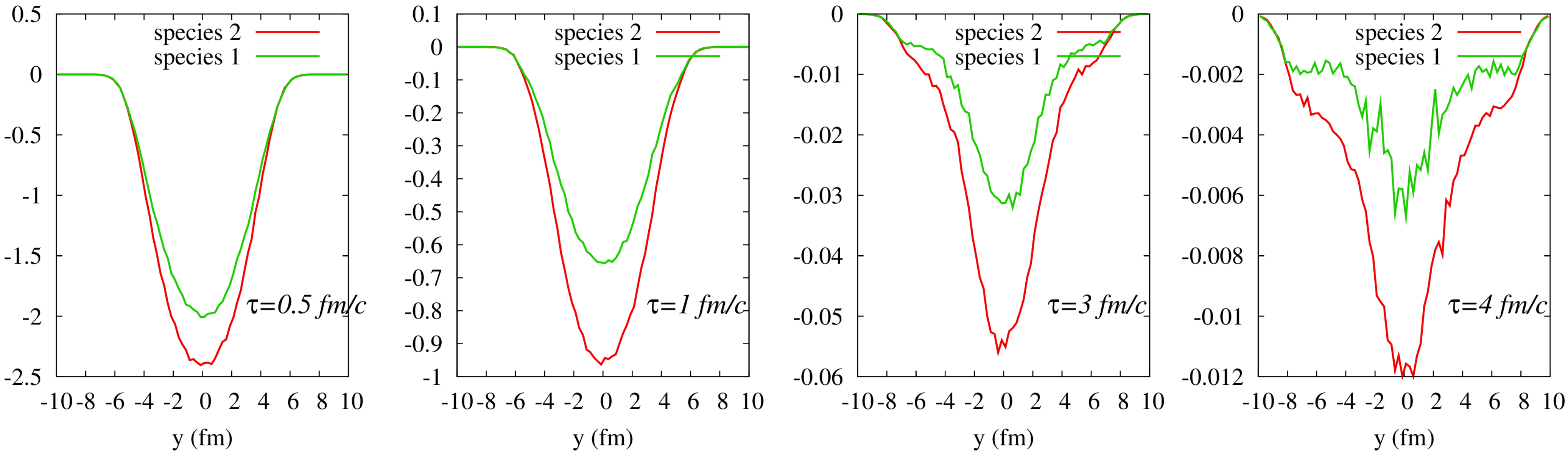
Shear tensor, zz-component (GeV/fm^3)



Shear pressure

?

$$\lambda_2/\lambda_1=2 \longrightarrow \pi_2/\pi_1=2$$

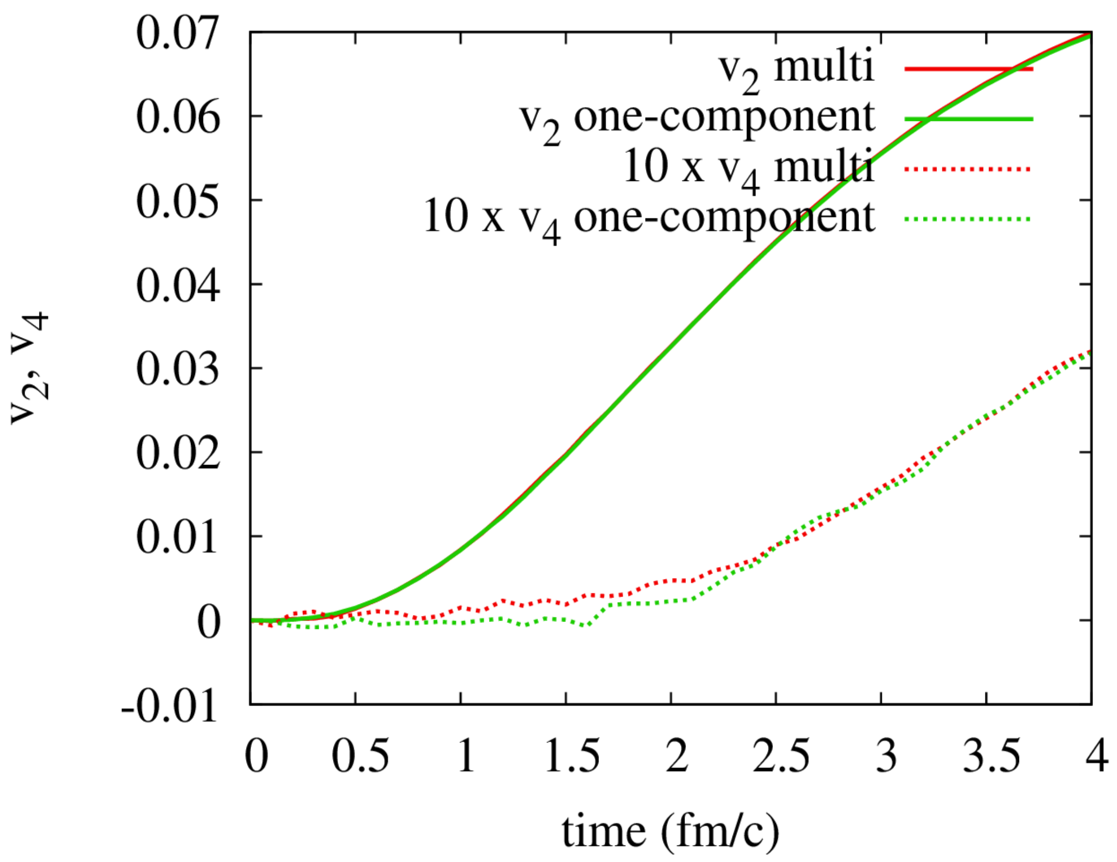


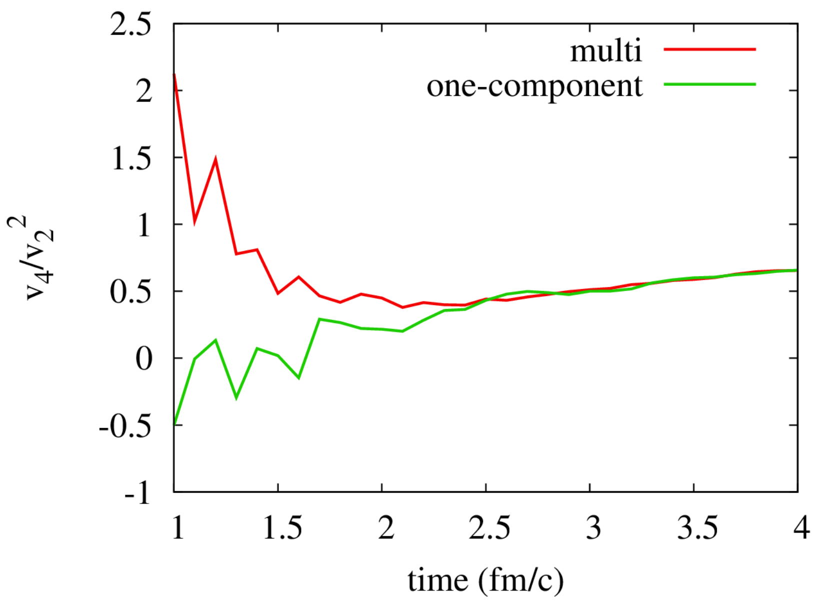
Flow

$$v_2(\tau) = \langle \cos(2\varphi_p) \rangle$$

$$v_4(\tau) = \langle \cos(4\varphi_p) \rangle$$

Averaging over BAMPS-particles in the central rapidity bin





Collision rates

The overall collision rate is different in multi- and one-component runs

→ different effective mean free path in the medium

→ if the freezeout criterion is chosen to be
mfp/expansion rate = 1 **(poster by P. Houvinen)**

the freezeout hyper surfaces will be different

Summary

We investigated differences in behavior of multi- and one-component systems

> Vanishing gradients but strong anisotropy:
Green-Kubo method cannot be applied together with standard dissipative hydrodynamics to reproduce multi-component results

> Strong gradients and anisotropy:
Green-Kubo method can be applied together with standard dissipative hydrodynamics to reproduce multi-component results. Visible differences are only at very early times

>> Observed difference in collision rates → different freezeout hypersurfaces?