Latest developments in anisotropic hydrodynamics

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Motivation

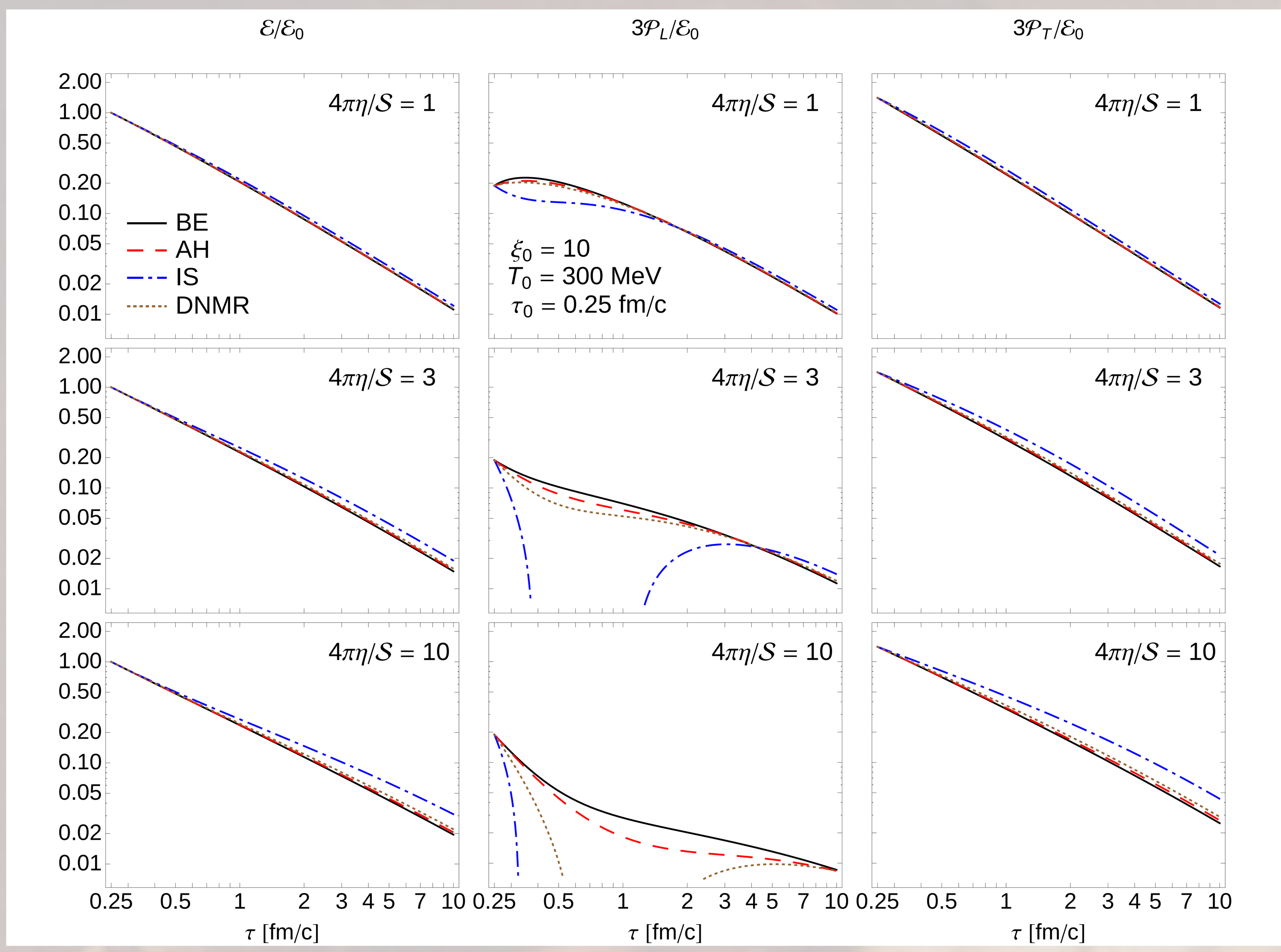
- heavy-ion experimental data from RHIC and the LHC are very well described by 2nd order viscous hydrodynamics with early starting time, $\tau_0 < 1$ fm/c, but
- viscous corrections combined with rapid longitudinal expansion induce a substantial pressure asymmetry in the created system
- at early times the microscopic models (string models, color glass condensate, pQCD kinetic calculations) predict also a large momentum anisotropy
- and AdS/CFT correspondence predicts a large difference between $\mathbf{P}_\perp$ and $\mathbf{P}_\parallel$, which slowly decays with time (Heller, Janik, Witaszczyk)

Hydrodynamics expansion

- viscous hydrodynamics is based on the linearization around an isotropic background $\mathbf{f} \simeq \mathbf{f}_{\rm eq.} + \delta\mathbf{f}$, $\delta\mathbf{f}$ should be small $\longrightarrow$ small corrections to the equilibrium stress-energy tensor $\mathbf{T}^{\mu\nu} = \int \mathbf{dP\, p}^\mu \mathbf{p}^\nu\, \mathbf{f} = \mathbf{T}^{\mu\nu}_{\rm eq.} + \pi^{\mu\nu}$
- large shear corrections (of the order of the isotropic pressure) are present, invalidating the working hypothesis of Israel-Stewart theory (IS) and leading to unphysical results at early times
- the new framework of anisotropic hydrodynamics is based on the reorganization of the hydrodynamic expansion around a non isotropic background instead of the local equilibrium $\mathbf{f} = \mathbf{f}_{\rm aniso.} + \delta\tilde{\mathbf{f}}$
- momentum (and pressure) anisotropies already at the leading order, corrections from $\delta\tilde{\mathbf{f}}$ can be treated as small perturbations

First success in the 0+1 case

W Florkowski, R Ryblewski, and M Strickland, *Phys Rev C* **88**, 024903 (2013)



- 0+1 dimension conformal system, massless particles, longitudinally boost invariant, homogeneous in the transverse plane
- collisional kernel treated in the relaxation time approximation $\Rightarrow$ exact solution of the relativistic Boltzmann equation (BE)
- anisotropic hydrodynamics uses the Romatchke-Strickland form as the background distribution

$$\mathbf{f}_{\rm aniso.} = \mathbf{k}\exp\left[-\frac{1}{\Lambda}\sqrt{\mathbf{p}_\perp^2 + \left(1+\xi\right)\mathbf{p}_\parallel^2}\right]$$

- the anisotropy parameter ξ is an independent degree of freedom, therefore it requires an extra dynamical equation, the zeroth moment of the Boltzmann equation was chosen in the earlier formulation.

Extending to a more general case

- the zeroth moment of the Boltzmann equation is no longer able to guarantee the matching with second order viscous hydrodynamics in the close-to-equilibrium limit
- the anisotropic background needs more degrees of freedom for taking into account the full dynamics
- otherwise it is necessary a next-to-leading order treatment, D Bazow, U W Heinz, M Strickland, *Phys.Rev. C* **90** 054910 (2014); D Bazow, U W Heinz, M Martinez, *Phys.Rev. C* **91** 064903 (2015)

Latest prescription for the leading order

L. Tinti, arXiv:1506.07164

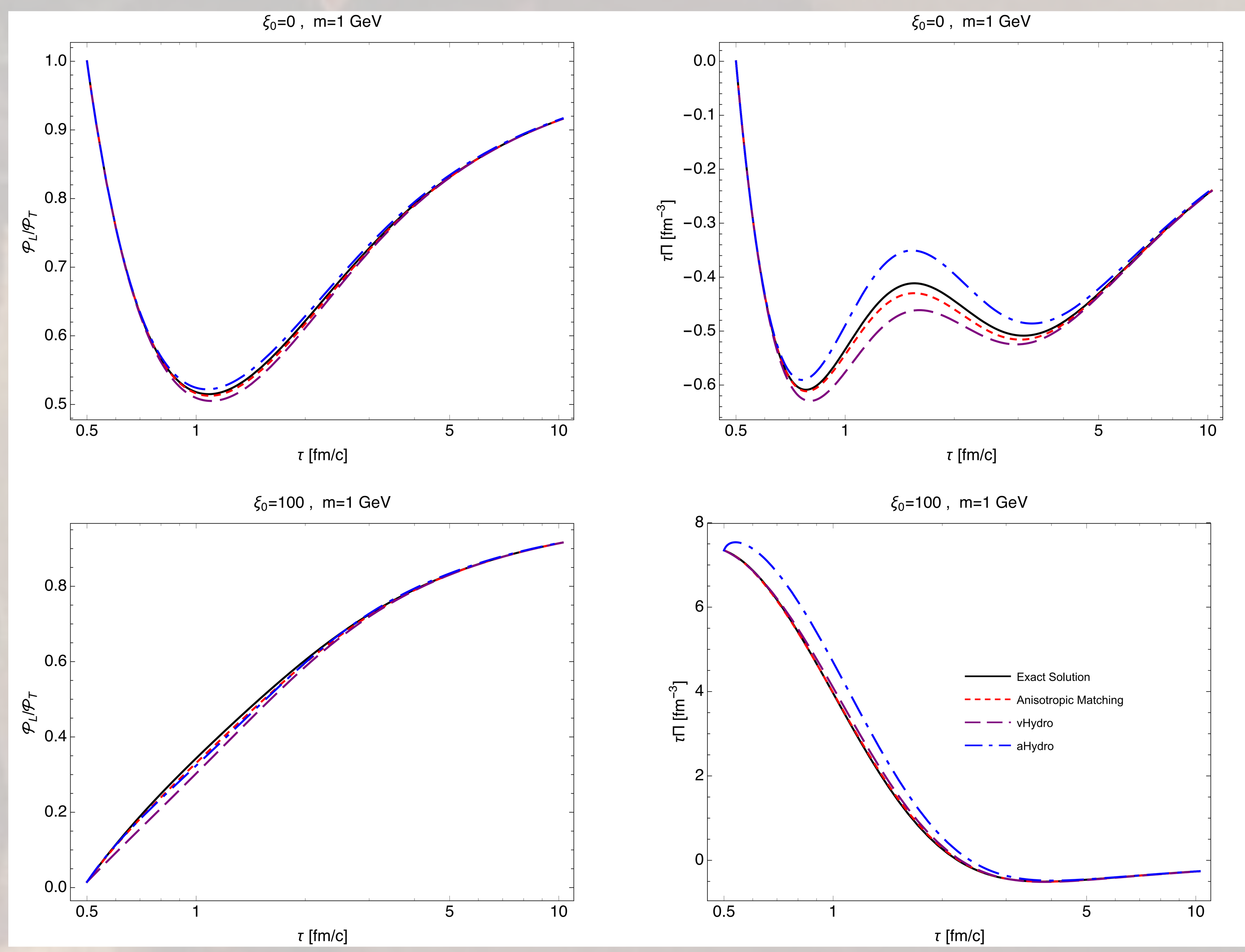
- the leading order of the anisotropic expansion have been improved, making use of a generalized Romatchke-Strickland form

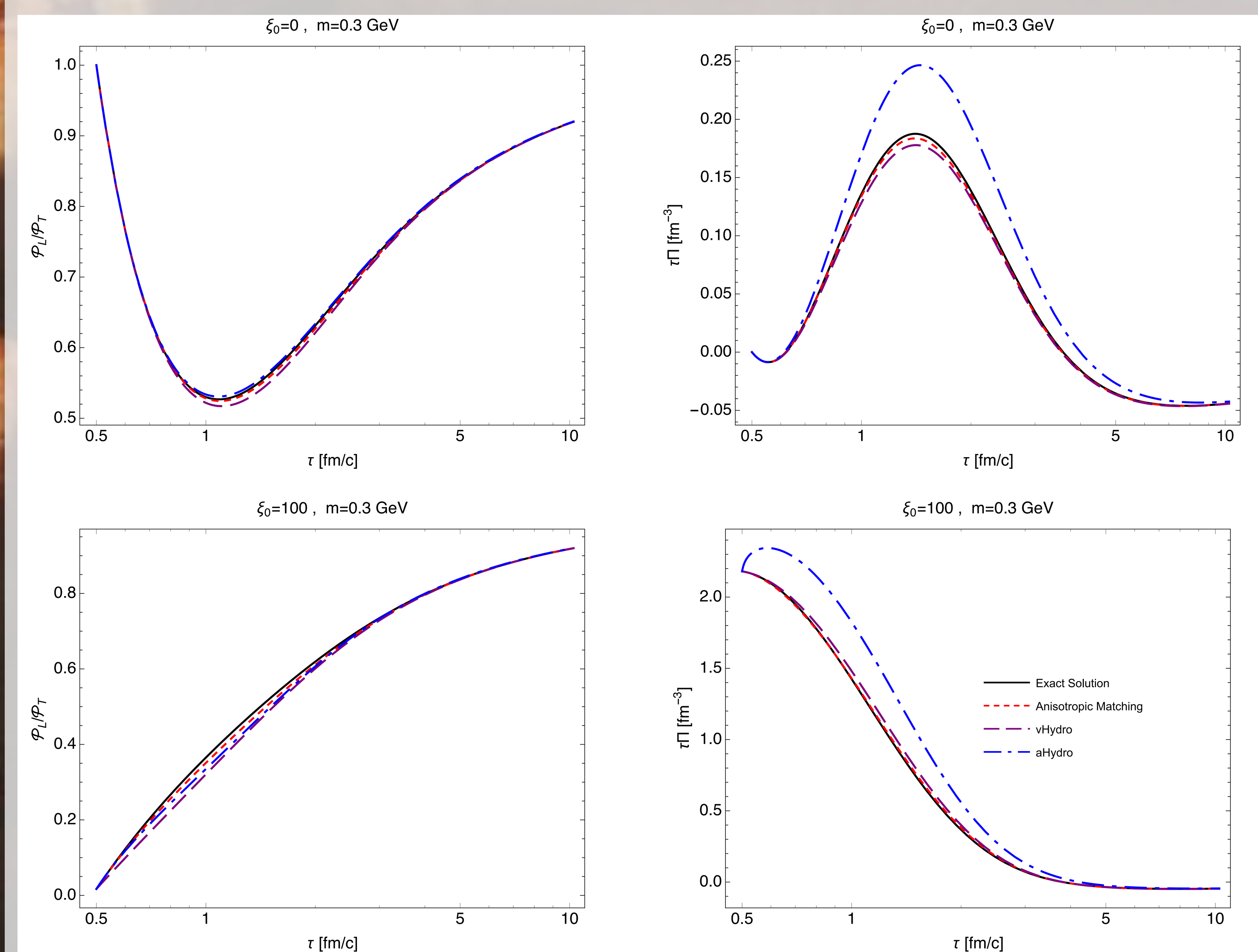
$$\mathbf{f}_{\rm aniso.} = \mathbf{k}\exp\left[-\frac{1}{\lambda}\sqrt{\mathbf{p}^\mu \Xi_{\mu\nu}\mathbf{p}^\nu}\right]$$

- the latest prescription for the leading order avoids making use of the moments of the Boltzmann equation, extracting the dynamical equations directly from the evolution of the pressure corrections according to kinetic theory
- the equations are natively in $\mathbf{3+1}$ dimensions, the close-to-equilibrium limit is preserved

Numerical results

the numerical results for the $\mathbf{0+1}$ dimensional expansion show that this is the best leading order approximation, solving the problems connected with the bulk dynamics, without using a next to leading order treatment





Conclusions

- GENERALIZED Romatchke-Strickland form, all of the pressure corrections in the anisotropic background
- DYNAMICAL EQUATIONS directly from the kinetic evolution, no symmetry constraints on the flow
- CORRECT BEHAVIOR close to equilibrium
- STRIKING AGREEMENT with the exact solutions

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