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Physics and Astronomy Department, Catania University

ISOTROPIZATION OF QGP

Initial Stages 2014

December 5

Napa, CA

In this talk:

- Transport theory for heavy ion collisions

More in Plumari’s talk

- *Isotropization*
- Conclusions and Outlook

Catania Transport Group

Collaborators:

-*Vincenzo Greco*

- *Lucia Oliva*

- *Armando Puglisi*

- *Salvatore Plumari*

- *Francesco Scardina*

More in Plumari's talk

Boltzmann equation and QGP

In order to ***simulate*** the temporal evolution of the fireball we solve the ***Boltzmann equation*** for the parton distribution function ***f***:

$$\left\{p^{\mu}\partial_{\mu}+\left[p_{\nu}F^{\mu\nu}+m\partial^{\mu}m\right]\partial_{\mu}^{p}\right\}f(x,p)=C[f]$$

Field interaction (EoS)

Collision integral

Collision integral: change of ***f*** due to collision processes in the phase space volume centered at (***x***,***p***).
Responsible for deviations from ideal hydro (non vanishing η/s).

We map by C[f] the phase space evolution of a fluid which dissipates with a given value of η/s.

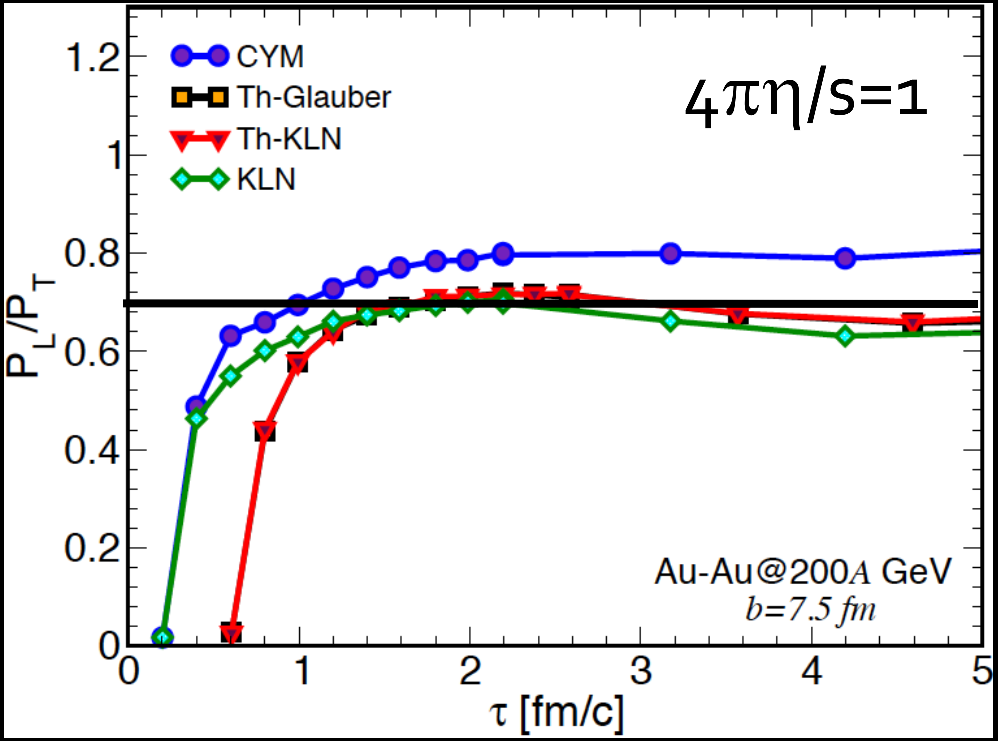
One can expand C[f] over microscopic details (2<->2,2<->3…), but in a hydro language this is irrelevant: ***only the global dissipative effect of C[f] is important.***

M. R. *et al.*, PRC 89 (2014)

Pressure isotropization

$$T^{\mu\nu} = \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu p^\nu}{E} f(x,p) \quad \longrightarrow \quad P_L = T_{zz}\ , \quad P_T = \frac{T_{xx}+T_{yy}}{2}$$

computed in the local rest frame



CYM (IP-Glasma) spectrum:
Courtesy of B. Schenke & R. Venugopalan

M. R. *et al.*, PRC 89 (2014)

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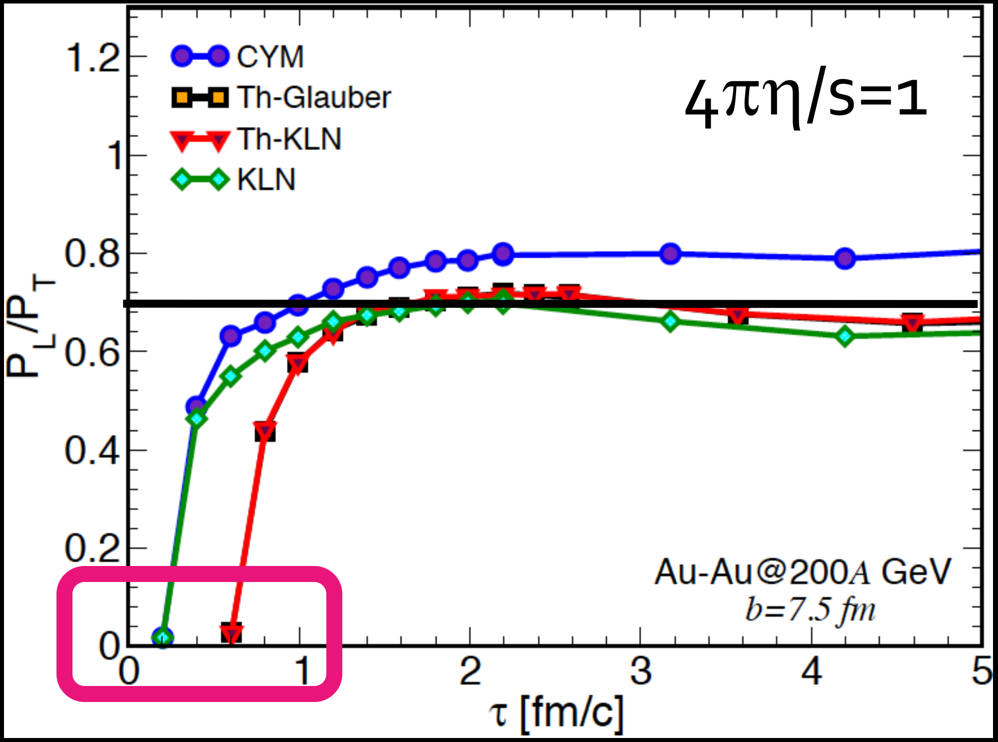

*Initially **PL=0**: the motion in the longitudinal direction is a **pure flow***

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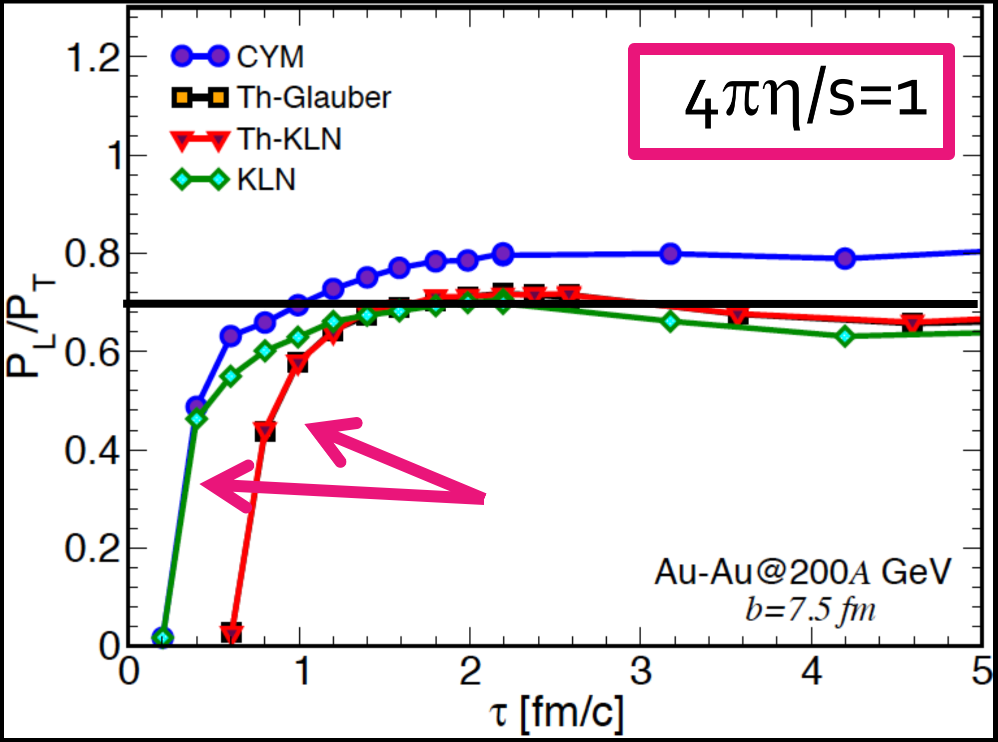


Initially ***PL=0****: the motion in the longitudinal direction is a* ***pure flow***

Thanks to strong coupling, the system efficiently removes the anisotropy

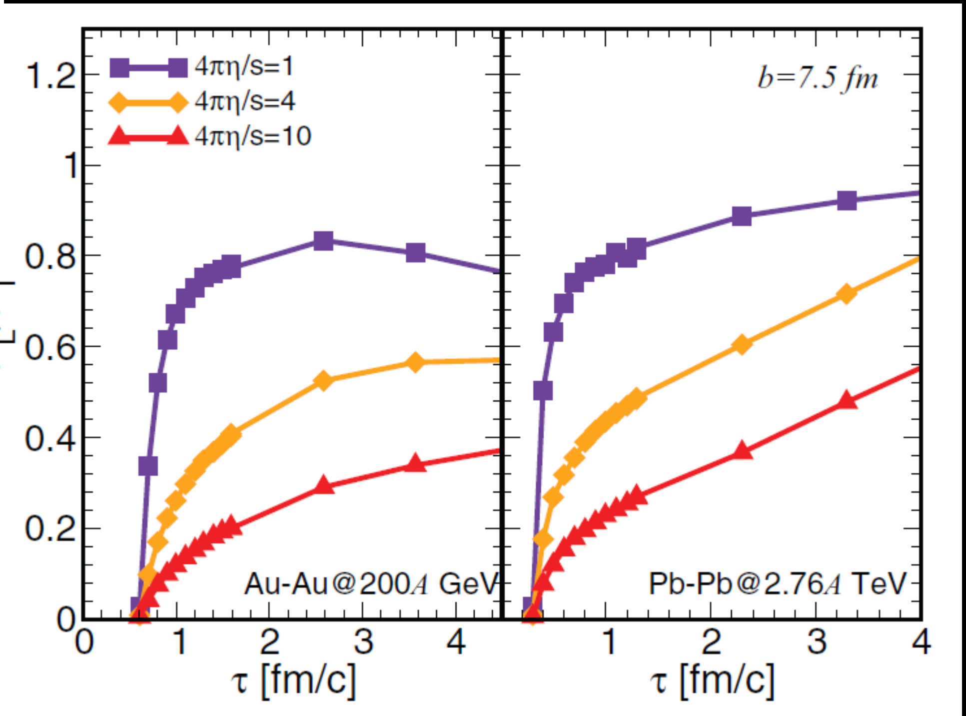
CYM (IP-Glasma) spectrum:
Courtesy of B. Schenke & R. Venugopalan

Fast isotropization in strong coupling: τ less then 1 fm/c

M. R. *et al.*, PRC 89 (2014)

Pressure isotropization

Role of the coupling strength



M. R. *et al.*, PRC 89 (2014)

Pressure isotropization

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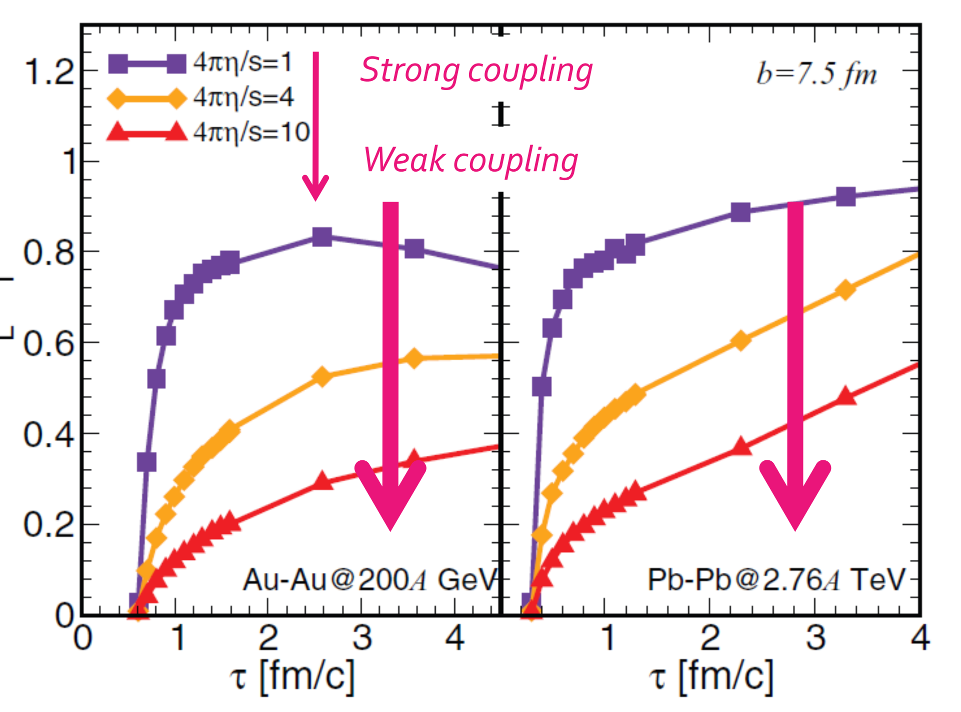


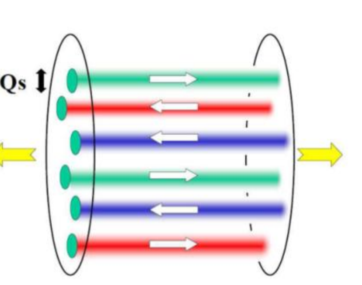
*With **larger viscosities** the system does not remove efficiently anisotropy*

- ✧ For $\eta/s > 0.3$ one misses fast isotropization in P_L/P_T (τ about 2-3 fm/c)
- ✧ For $\eta/s \approx$ pQCD no isotropization

These calculations ignore the initial fields dynamics, which instead plays a role in the initial stages.

M. R. *et al.*, in preparation

Abelian Flux Tube



Purpose: understanding the role of the initial fields on isotropization and evolution of QGP

Method: implementing a simple model of initial field configuration, simpler to treat analytically/numerically than glasma

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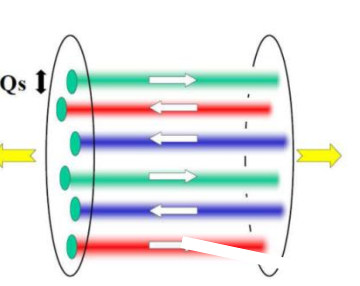
Abelian Flux Tube



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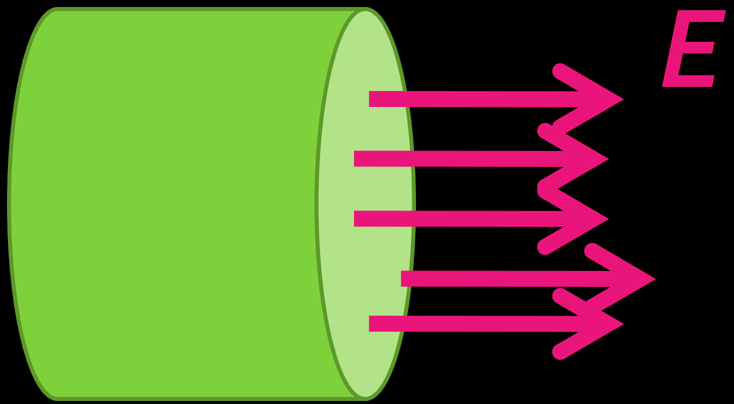

Abelian Flux Tube (AFT)

[Florkowski and Riblevsky., PRD 88 (2013)]

Working assumptions

- Fields evolve according to abelian (i.e. Maxwell) equations
- No longitudinal (chromo-)magnetic field
- Flux tubes decay via Schwinger mechanism

Further simplifications

- Only 1-dimensional (longitudinal) expansion
- Only gluons

M. R. *et al.*, in preparation

Abelian Flux Tube

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- Only 1-dimensional (longitudinal) expansion

$$\partial_\mu F^{\mu\nu} = j^\mu_D + j^\mu_M \quad \Longrightarrow \quad E_z(t) = E_z(0) - \int_0^t d\tau \left(j^z_D(\tau) + j^z_M(\tau) \right)$$

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j^z_D — ***Polarization current***: *electric current resulting from pair creation via Schwinger mechanism*

j^z_M — ***Electric current***: *current resulting from motion of charges under the effect of the electric field*

M. R. *et al.*, in preparation

Abelian Flux Tube

Working assumptions

- Fields evolve according to abelian (i.e. Maxwell) equations
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Further simplifications

- Only 1-dimensional (longitudinal) expansion

$$\partial_\mu F^{\mu\nu} = j_D^\mu + j_M^\mu \Rightarrow E_z(t) = E_z(0) - \int_0^t d\tau \, (j_D^z(\tau) + j_M^z(\tau))$$

j_D^z ***Polarization current***: *electric current resulting from pair creation via Schwinger mechanism*

j_M^z ***Electric current***: *current resulting from motion of charges under the effect of the electric field*

jD e jM depend on distribution function, hence link Maxwell and Boltzmann equations

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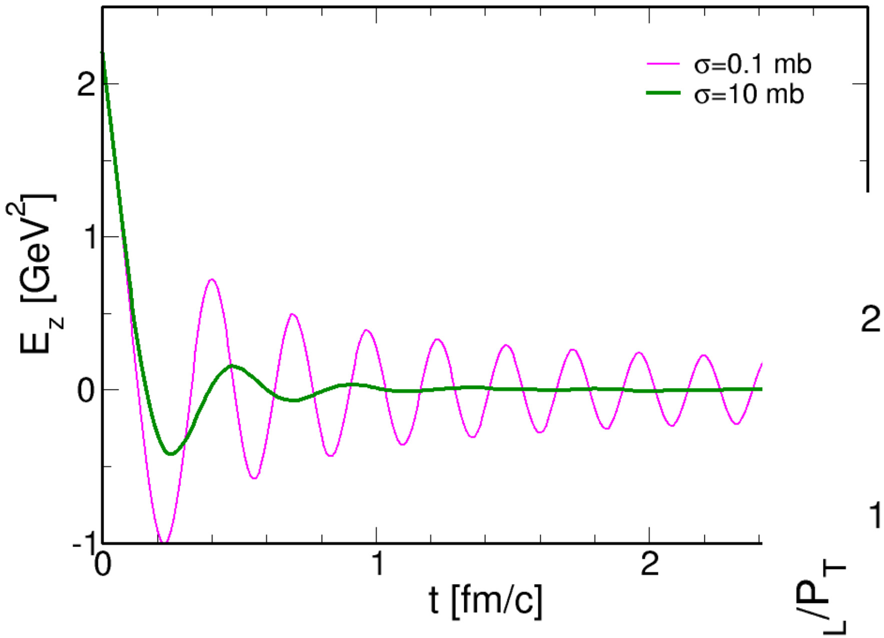
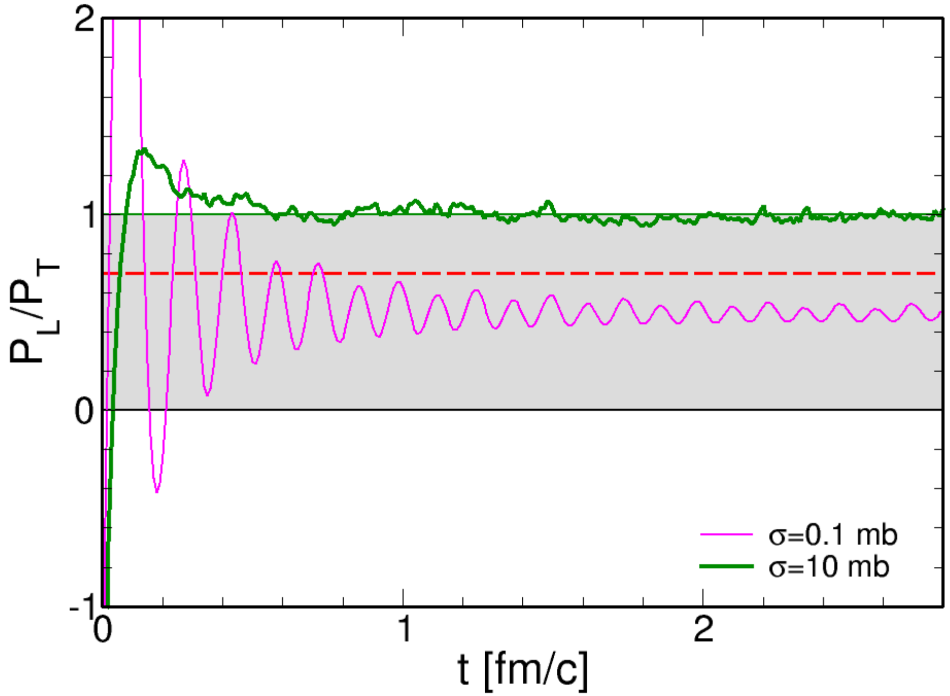
Abelian Flux Tube

Electric field for static box



Pressures for static box



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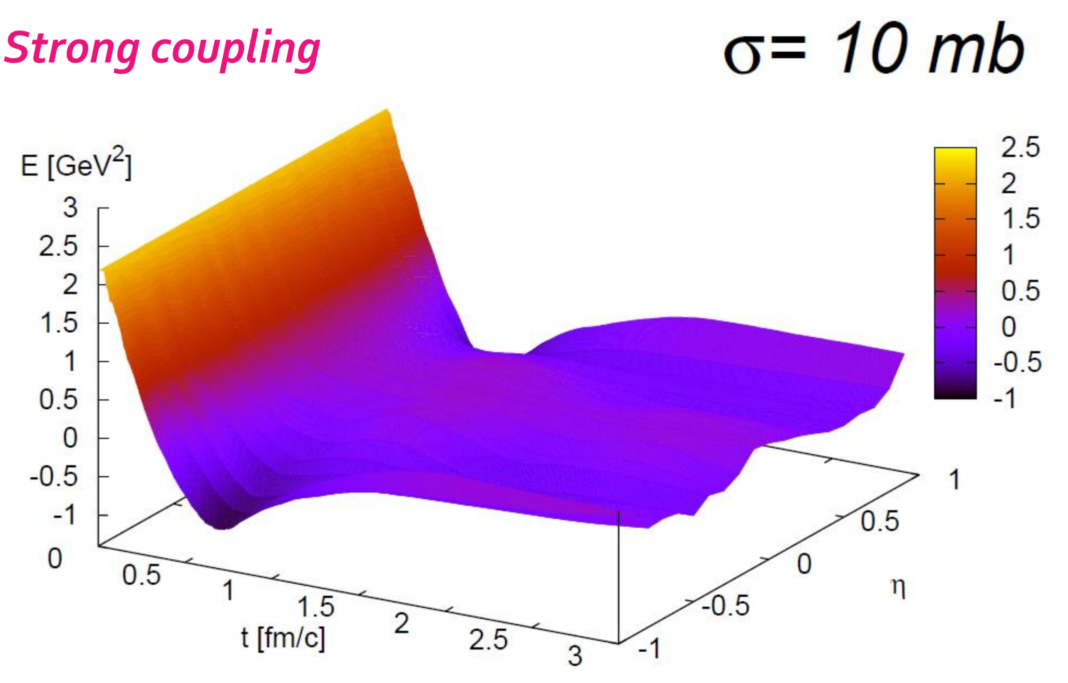
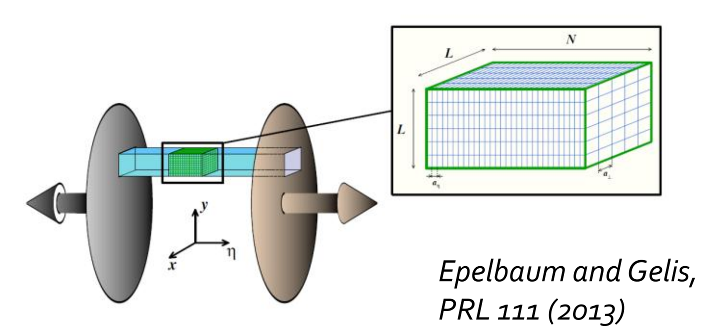
Abelian Flux Tube

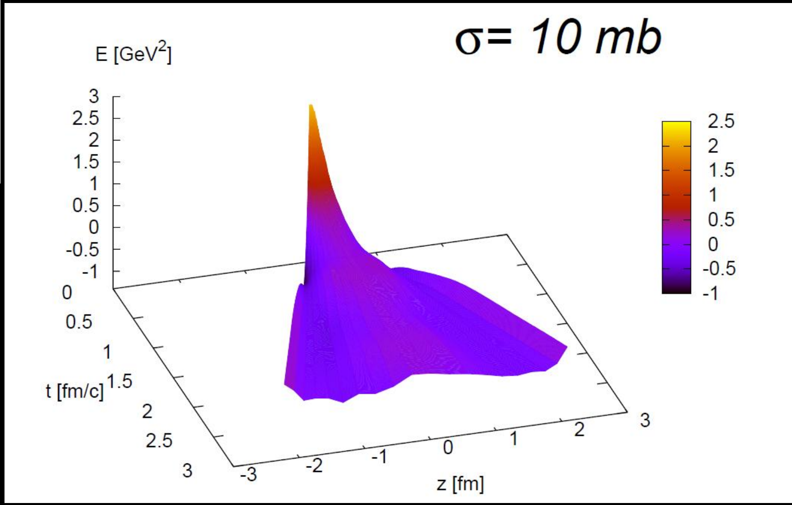
Electric field for expanding geometry

Strong coupling





Electric field for expanding geometry t-z space



In strong coupling regime the electric field decays very quickly because currents are suppressed

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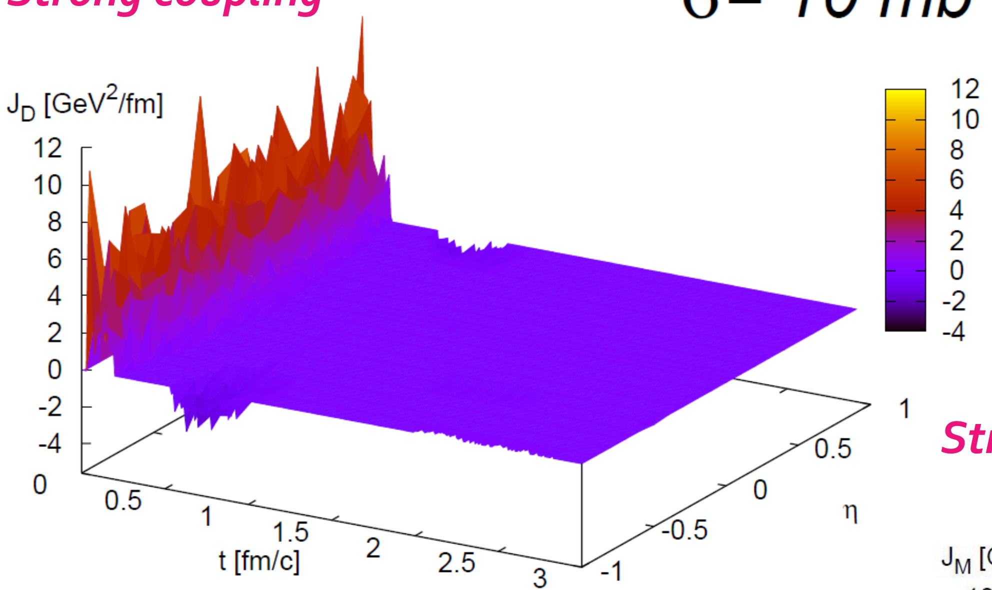
Abelian Flux Tube

Polarization current

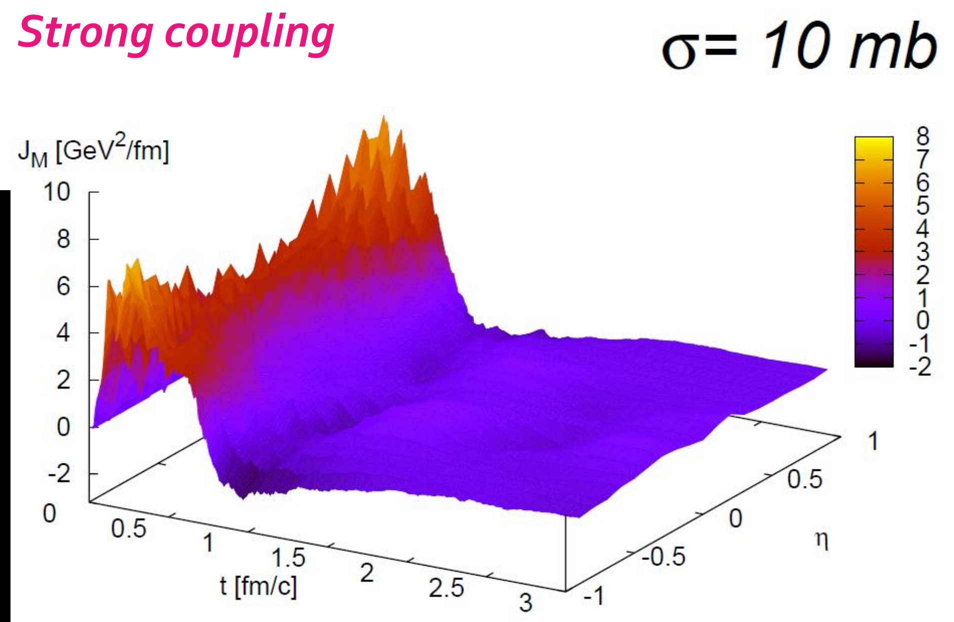
Strong coupling



Fast decay of electric field allows pair creation just in a very short initial time range

Electric current

Strong coupling



Strong coupling favors momentum randomization , inhibiting electric current

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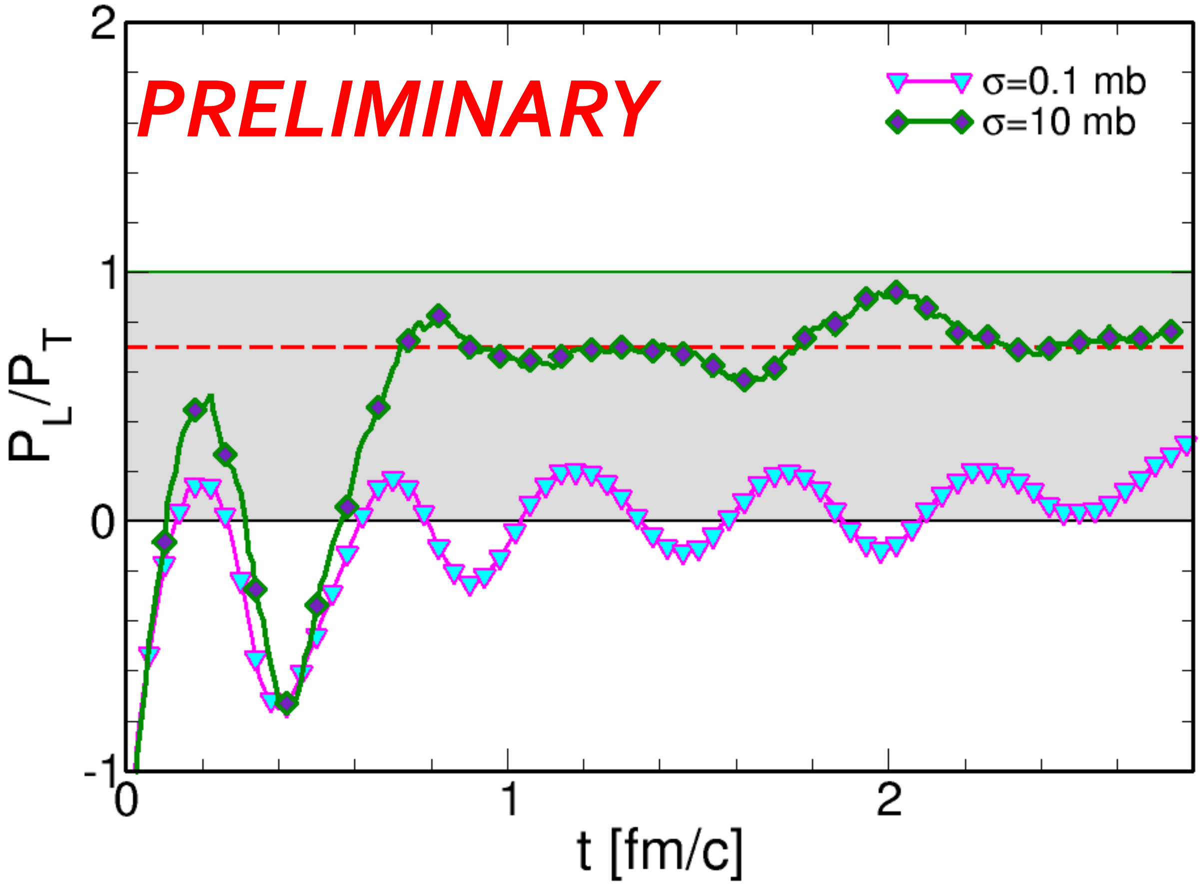
AFT isotropization

Pressure isotropization for expanding geometry



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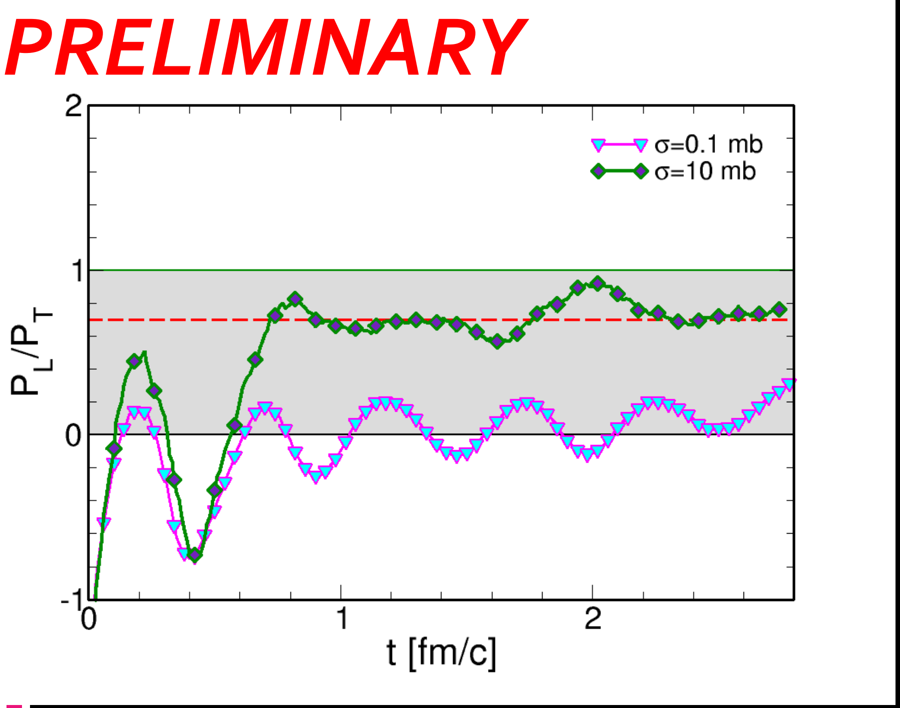
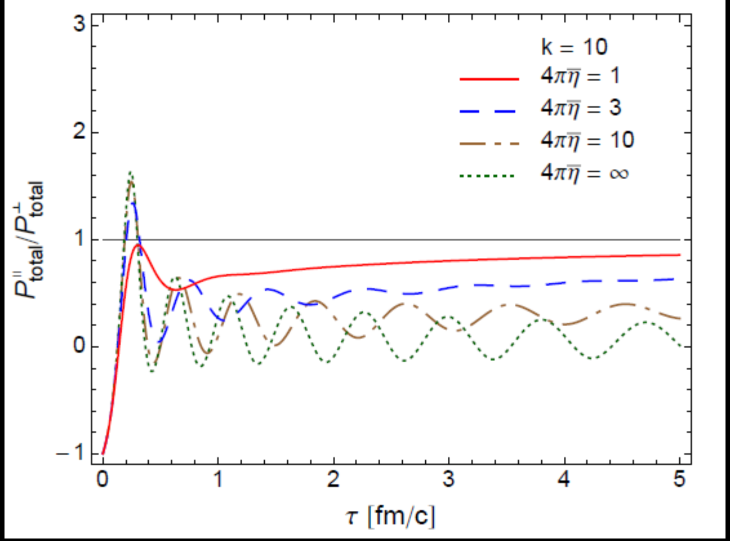
AFT isotropization

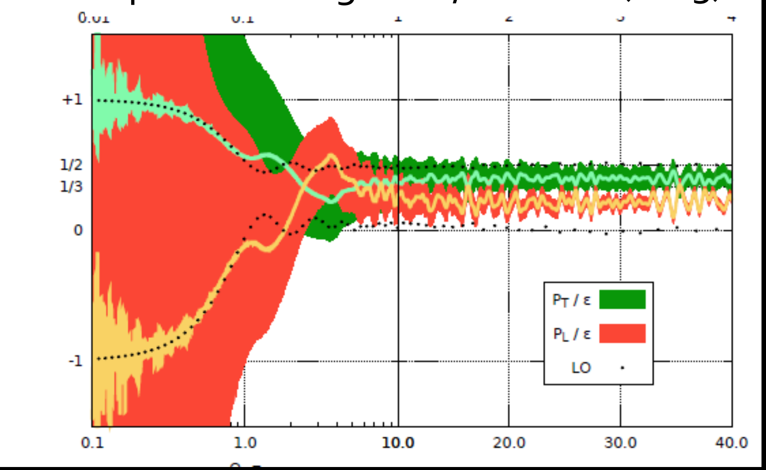
Qualitative agreement with previous calculations



Florkowski and Rivlebsky, PRD 88 (2013)



Epelbaum ang Gelis, PRL 111 (2013)



Conclusions and Outlook

- ***Relativistic Kinetic Theory*** permits to compute ***isotropization efficiency*** when initial field dynamics is included.
- ***Include quarks and study particle production via flux tube decay***
- ***Going beyond 1D expansion***

Thanks for your attention

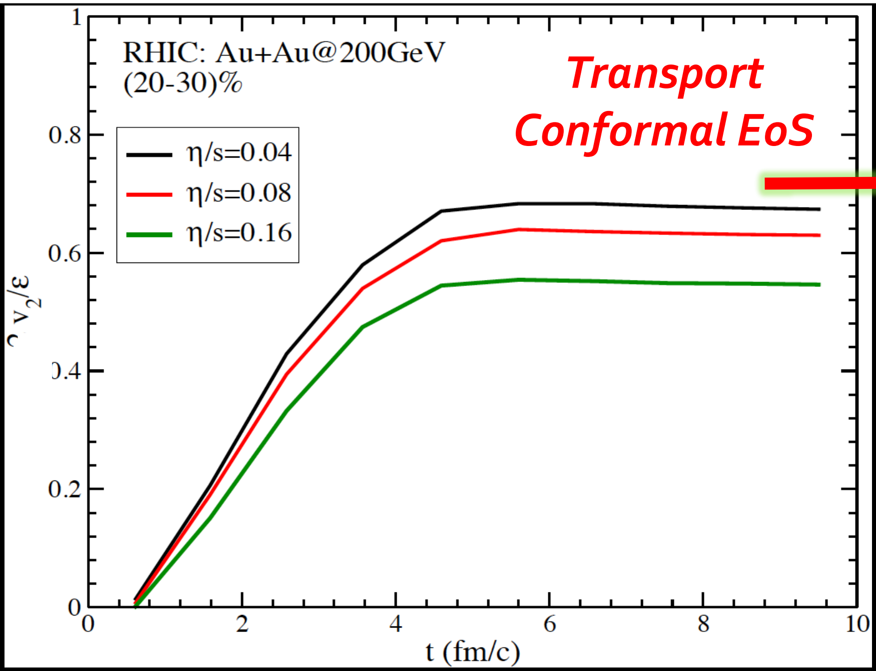
Good wood does not grow in comfort:
the stronger the wind, the stronger the tree is.

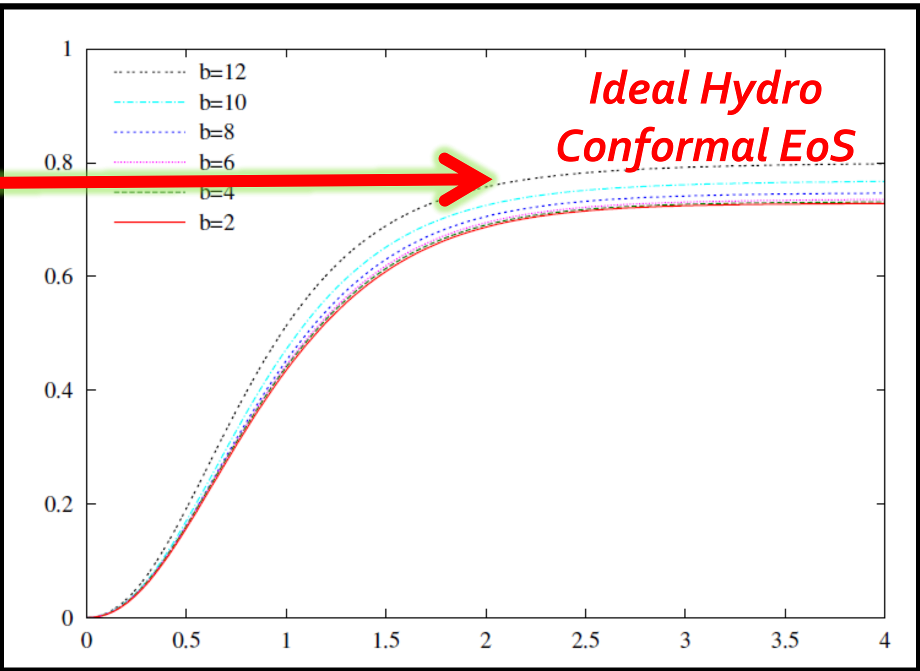
Appendix

Transport *gauged* to hydro

We use ***Boltzmann equation*** to simulate a fluid at ***fixed eta/s*** rather than fixing a set of microscopic processes.

Total Cross section is ***computed*** in ***each configuration space cell*** according to ***Chapman-Enskog equation*** to give the ***wished value of eta/s***.





Bhalerao *et al.*, PLB627 (2005)

There is agreement of hydro with transport also in the non dilute limit

Transport *gauged* to hydro

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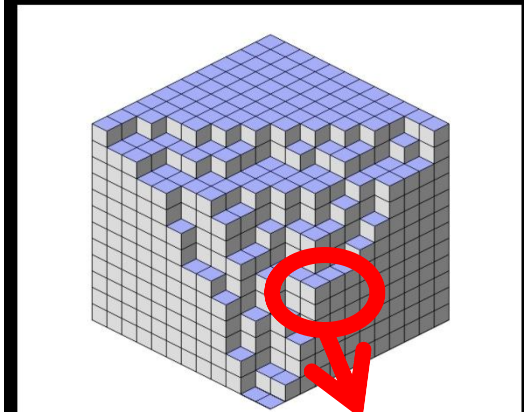
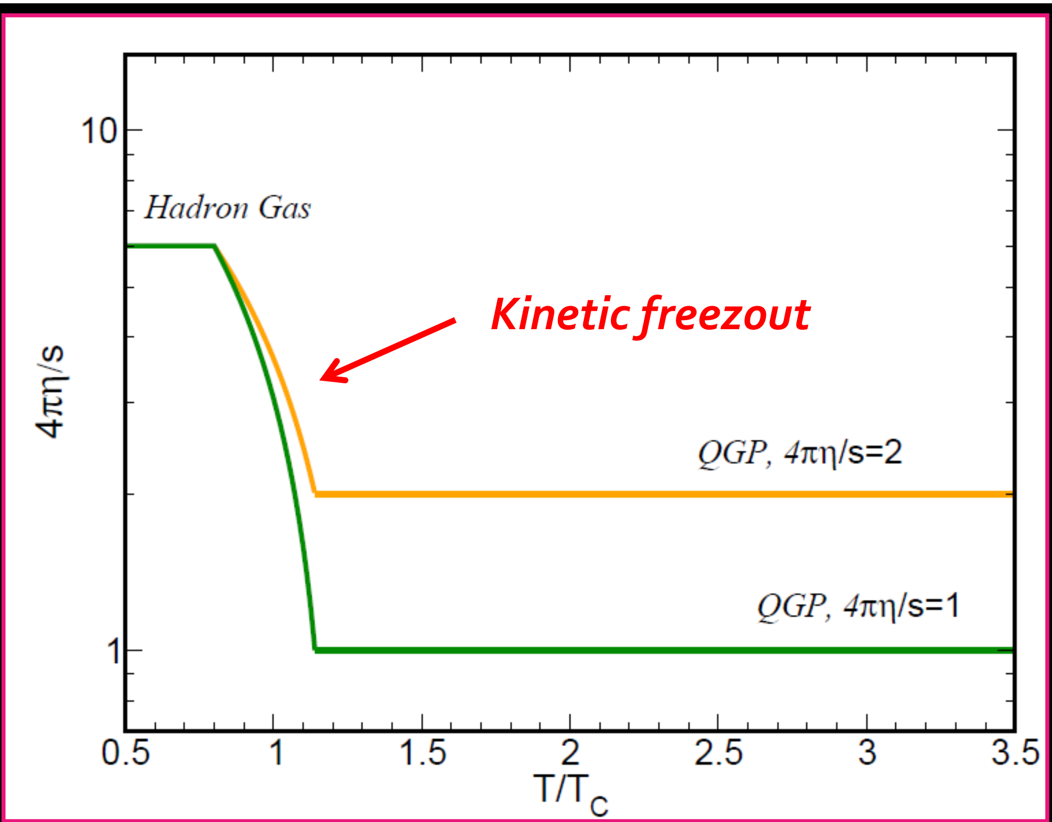


$$\frac{\eta}{s} = \frac{\langle p \rangle}{g(m_D)\rho} \frac{1}{\sigma}$$



A ***smooth kinetic freezout*** is implemented in order to gradually reduce the strength of the interactions as the temperature decreases below the critical temperature.

Transport *gauged* to hydro

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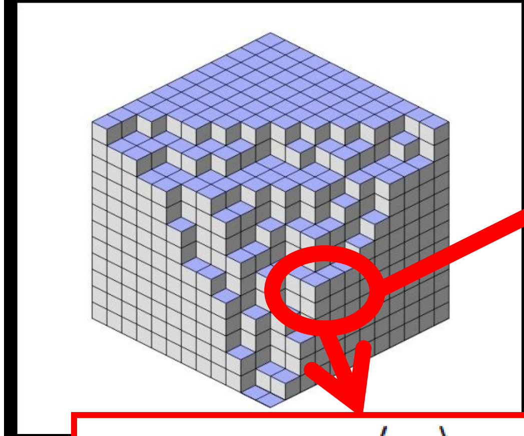

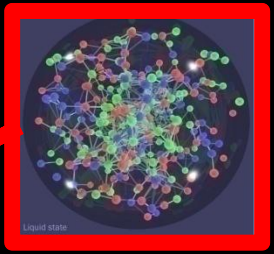

$$\frac{\eta}{s} = \frac{\langle p \rangle}{g(m_D)\rho}\frac{1}{\sigma}$$

(.) Collision integral is gauged in each cell to assure that the fluid dissipates according to the desired value of eta/s.

(.) Microscopic details are not important: the specific microscopic process producing eta/s is not relevant, only macroscopic quantities are, in analogy with hydrodynamics.

Transport

Description in terms of parton distribution function

Hydro

Dynamical evolution governed by macroscopic quantities

Why transport for uRHICs?

$$\left\{p^{\mu}\partial_{\mu}+\left[p_{\nu}F^{\mu\nu}+m\partial^{\mu}m\right]\partial_{\mu}^{p}\right\}f(x,p)=C[f]$$

- Starting from 1-body distribution function f(x,p) and not from $T_{\mu\nu}$:
  - Implement non-equilibrium implied by CGC-Qs scale (beyond ε_x)
  - Include off-equilibrium at high and intermediate p_T :
    Relevant at LHC due to large amount of minijet production
  - freeze-out self-consistently related with $\eta/s(T)$
- It's not an expansion in η/s:
  - valid also at high η/s -> LHC ($T>>T_c$)
- Appropriate for heavy quark dynamics
- f(x,p) and kinetic equations are useful to grasp informations about early glasma evolution

M. R. *et al.*, in preparation

AFT isotropization