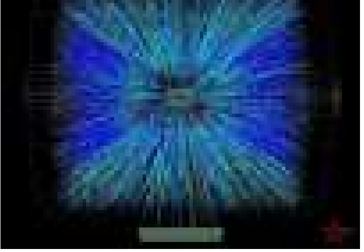


Chromo-Weibel instabilities in an expanding Quark-Gluon Plasma *

Maximilian Attems

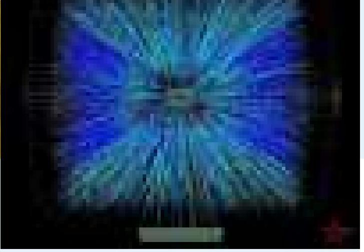
Institute for Theoretical Physics, TU Vienna

CPhT, Ecole Polytechnique

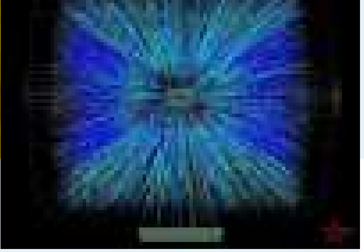
Collaborators: Anton Rebhan, Michael Strickland

November 27, 2011

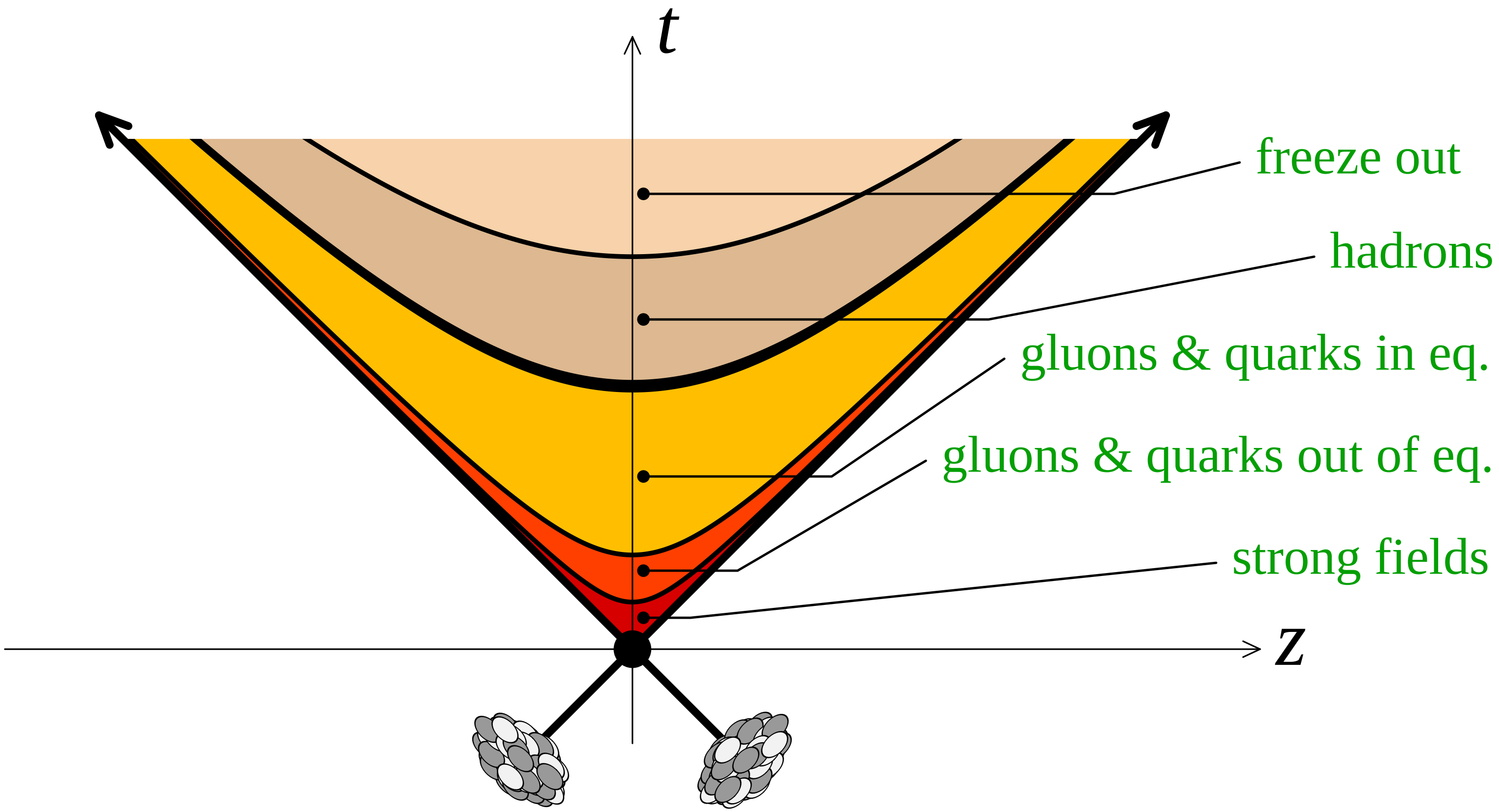
*“ Dans la vie, rien n’est à craindre, tout est à comprendre.” Marie Curie



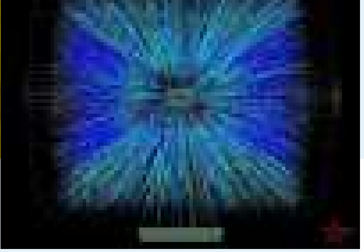
Hard Expanding Loops (HEL)



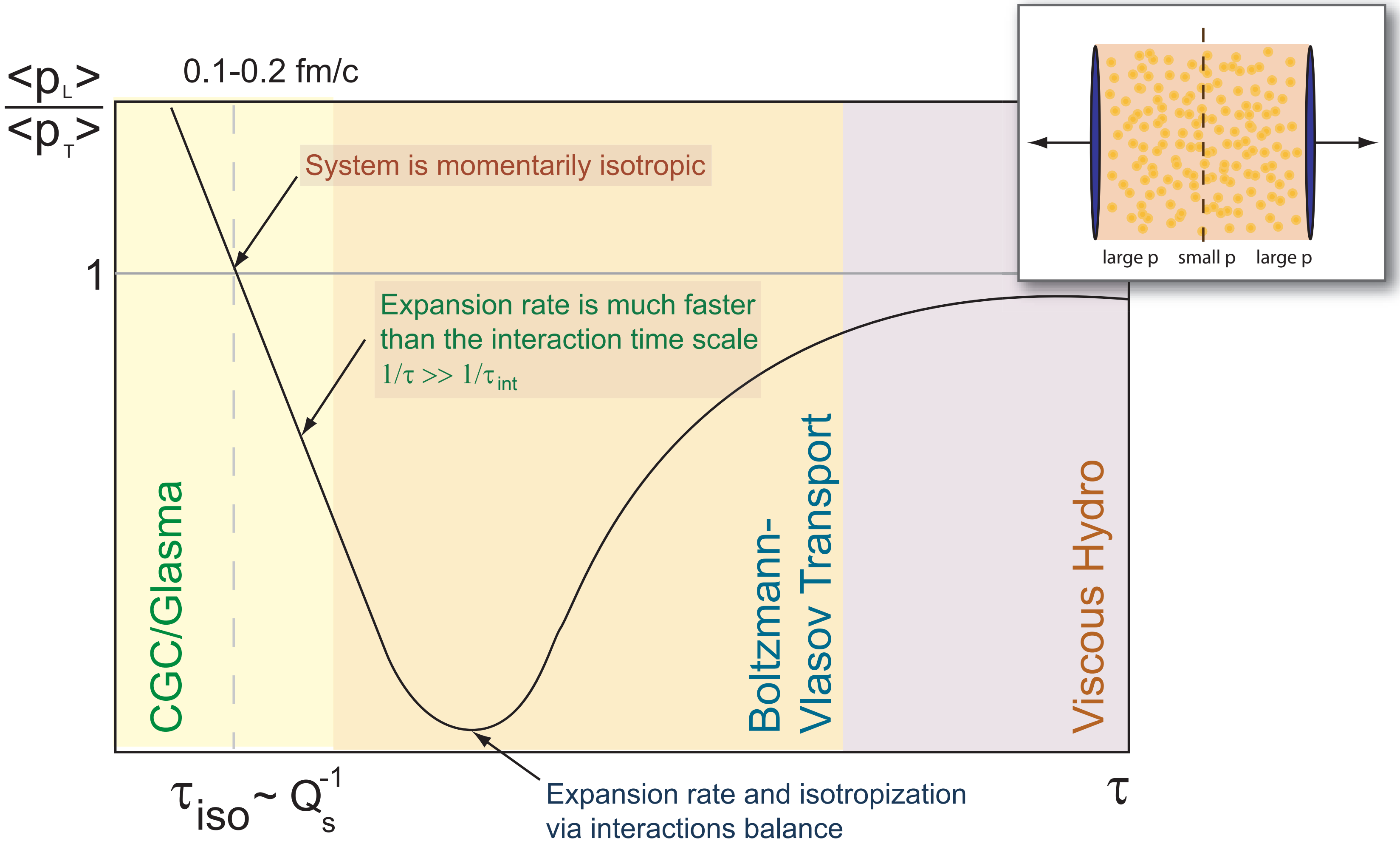
Stages of the Little Big Bang



[Gelis 2010] Illustration of the stages of a heavy ion collision.

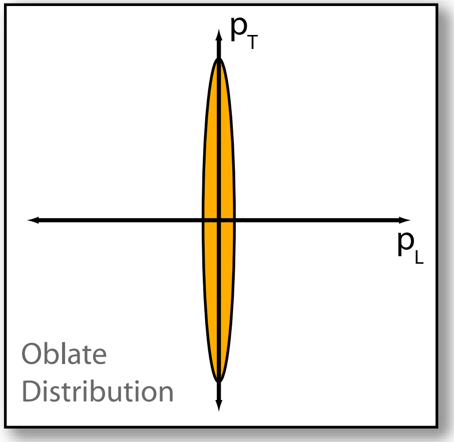


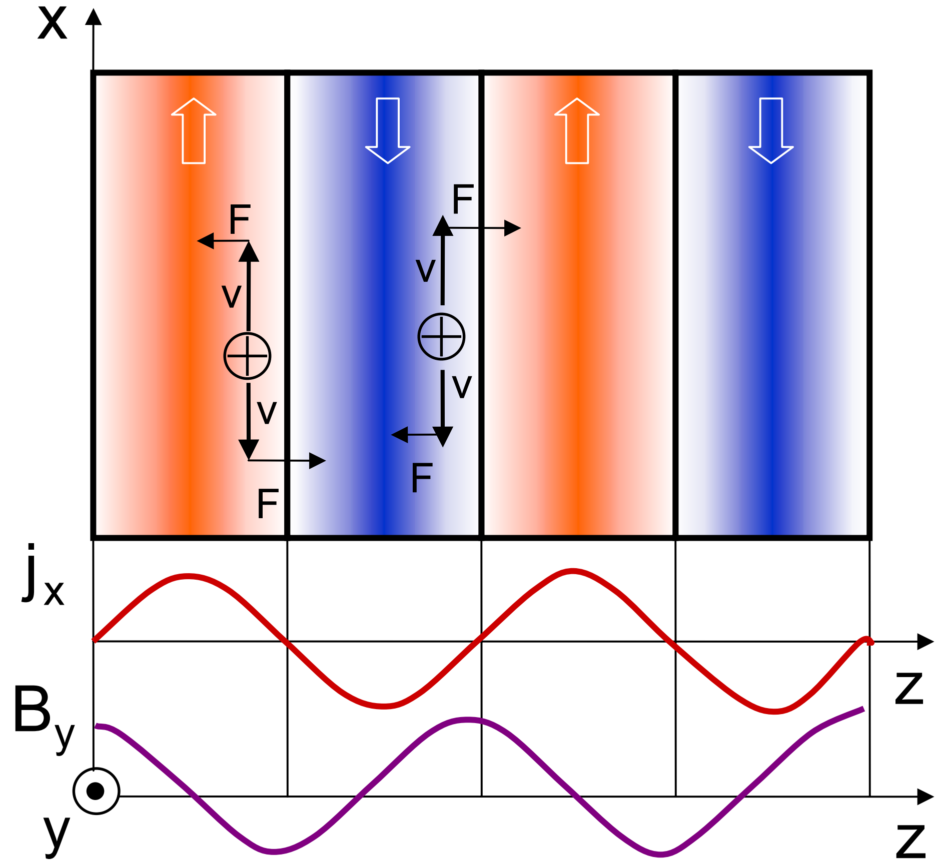
Momentum Anisotropy



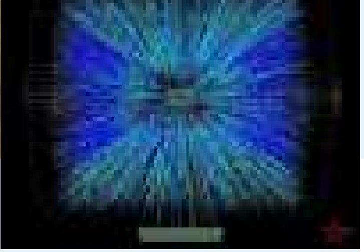
[Strickland 2004]: Momentum space anisotropy time dependence at the early stages of a heavy ion collision

Weibel instabilities



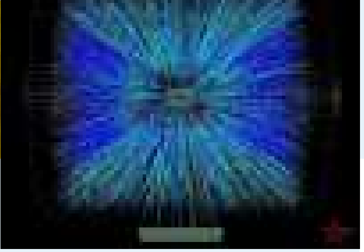


[Strickland 2006]: Illustration of the mechanism of filamentation instabilities.



Scales of weakly coupled QGP

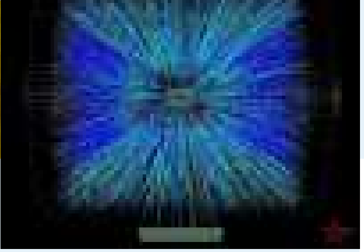
- T: energy of hard particles
- gT: thermal masses, Debye screening mass, Landau damping, plasma instabilities [Mrowczynski 1988, 1993, ..]
- g^2T: magnetic confinement, color relaxation, rate for small angle scattering
- g^4T: rate for large angle scattering, $\eta^{-1}T^4$



Hard (Thermal) Loops - Boltzmann - Vlasov

Assuming free streaming, one solves the gauge covariant Boltzmann-Vlasov equation

$$v \cdot D\partial f_a(\mathbf{p}, \mathbf{x}, t) = g v_\mu F_a^{\mu\nu} \partial_\nu^{(p)} f_0(\mathbf{p}, \mathbf{x}, t) \qquad (1)$$



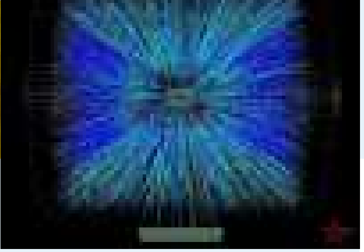
Hard (Thermal) Loops - Boltzmann - Vlasov

Assuming free streaming, one solves the gauge covariant Boltzmann-Vlasov equation

$$v \cdot D\partial f_a(\mathbf{p}, \mathbf{x}, t) = g v_\mu F_a^{\mu\nu} \partial_\nu^{(p)} f_0(\mathbf{p}, \mathbf{x}, t) \tag{1}$$

coupled to Yang-Mills equation

$$D_\mu F_a^{\mu\nu} = j_a^\nu = g \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu}{2p^0} \delta f_a(\mathbf{p}, \mathbf{x}, t) \tag{2}$$



Hard (Thermal) Loops - Boltzmann - Vlasov

Assuming free streaming, one solves the gauge covariant Boltzmann-Vlasov equation

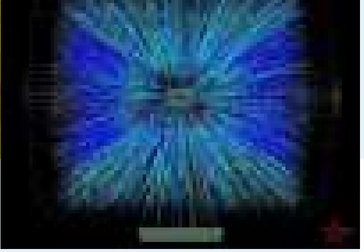
$$v \cdot D\partial f_a(\mathbf{p},\mathbf{x},t) = g v_\mu F_a^{\mu\nu} \partial_\nu^{(p)} f_0(\mathbf{p},\mathbf{x},t) \tag{1}$$

coupled to Yang-Mills equation

$$D_\mu F_a^{\mu\nu} = j_a^\nu = g \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu}{2p^0} \delta f_a(\mathbf{p},\mathbf{x},t) \tag{2}$$

in the HTL approximation

$$g A_\mu \ll \left|\mathbf{p}_{hard}\right| , \tag{3}$$



Hard (Thermal) Loops - Boltzmann - Vlasov

Assuming free streaming, one solves the gauge covariant Boltzmann-Vlasov equation

$$v \cdot D\partial f_a(\mathbf{p}, \mathbf{x}, t) = g v_\mu F_a^{\mu\nu} \partial_\nu^{(p)} f_0(\mathbf{p}, \mathbf{x}, t) \tag{1}$$

coupled to Yang-Mills equation

$$D_\mu F_a^{\mu\nu} = j_a^\nu = g \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu}{2p^0} \delta f_a(\mathbf{p}, \mathbf{x}, t) \tag{2}$$

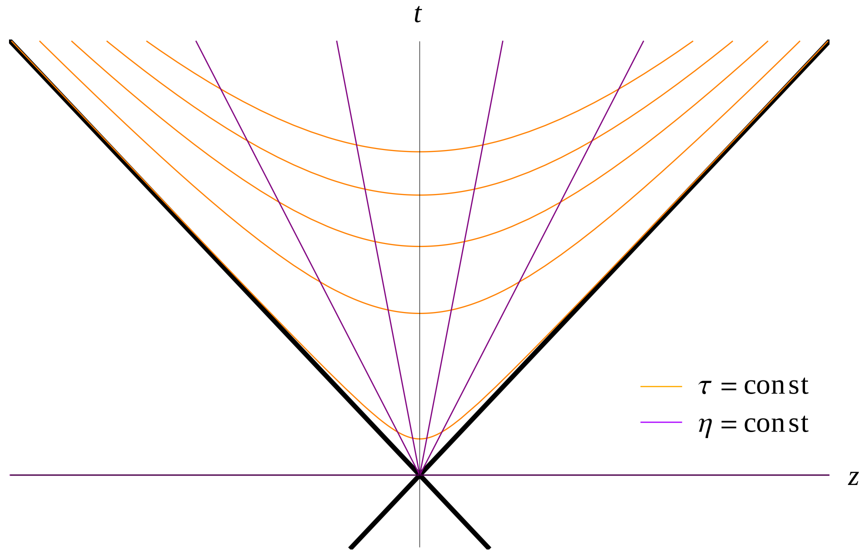
in the HTL approximation

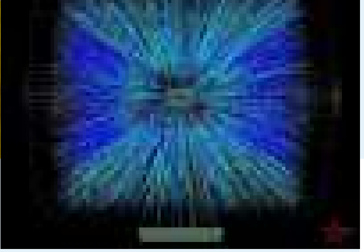
$$g A_\mu \ll \left| \mathbf{p}_{hard} \right| , \tag{3}$$

with the Romatschke, Strickland background distribution function

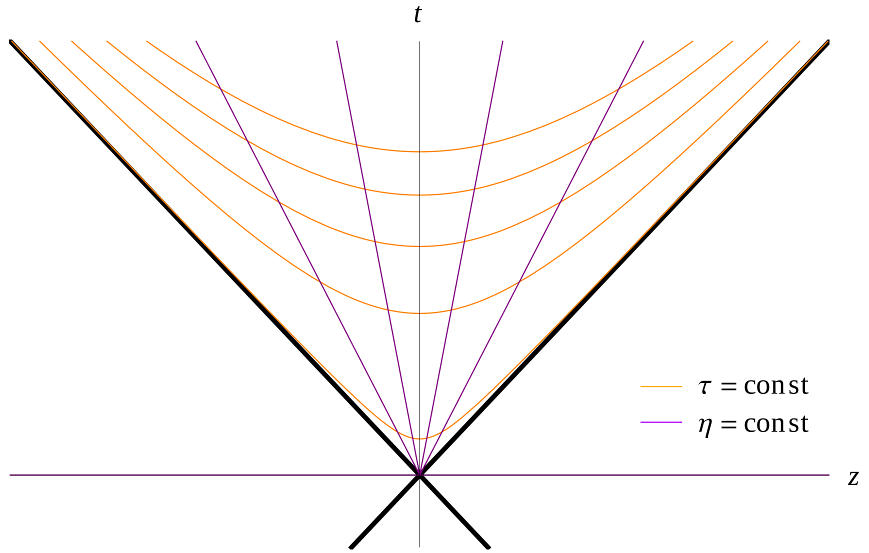
$$f_0(p_\perp, \tilde{p}_\eta) = f_{\rm iso}\left([\mathbf{p^2} + \xi(\tau)(\mathbf{p} \cdot \hat{\mathbf{n}})^2] / p_{\rm hard}^2(\tau) \right) . \tag{4}$$

Bjorken expansion





Bjorken expansion

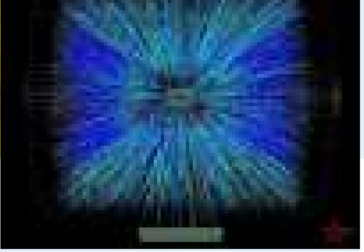


It is convenient to switch to comoving coordinates

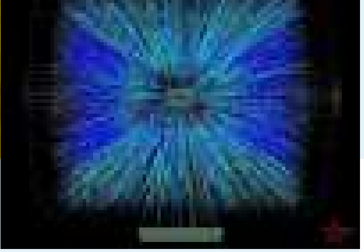
$$t = \tau \cosh \eta \,, \qquad \tau = \sqrt{t^2 - z^2} \,,$$
$$z = \tau \sinh \eta \,, \qquad \eta = \mathrm{arctanh} \frac{z}{t} \,, \tag{5}$$

with the corresponding metric

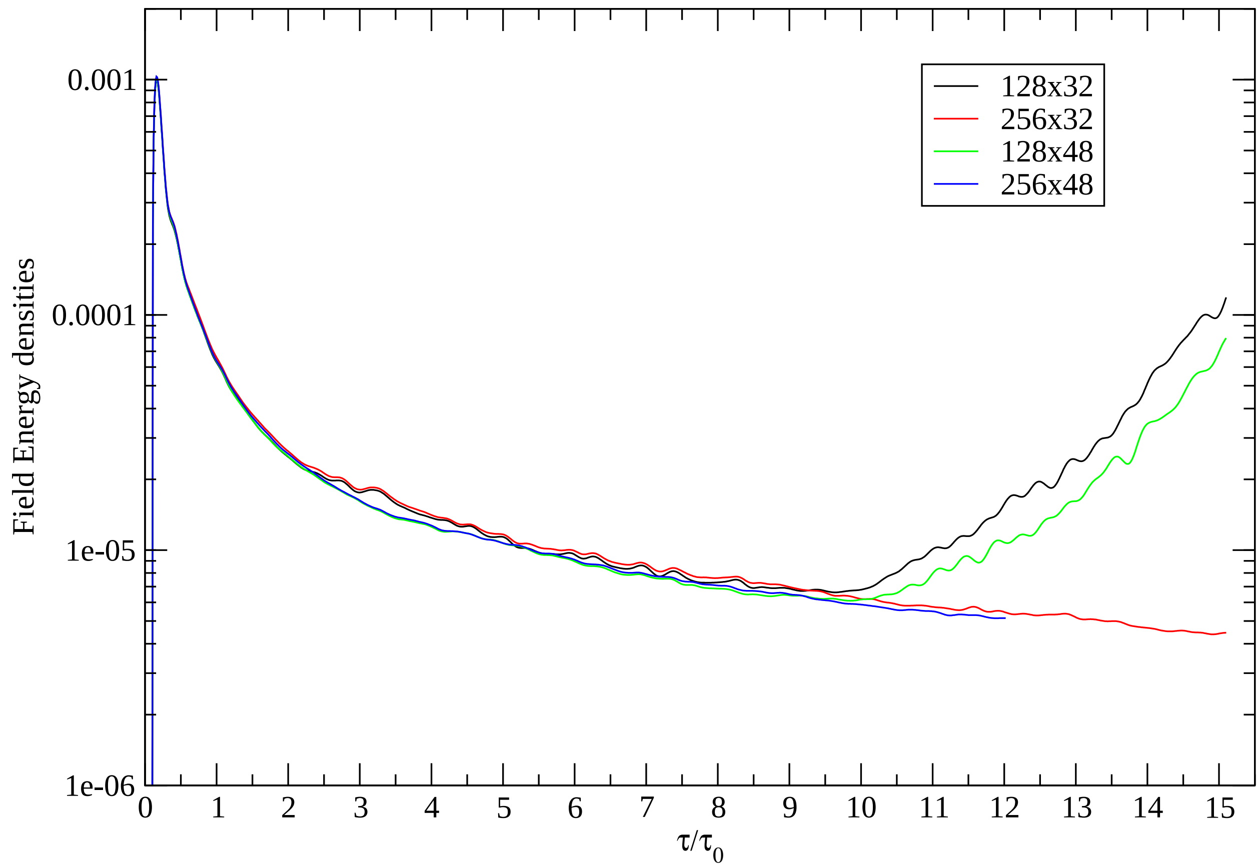
$$ds^2 = d\tau^2 - d\mathbf{x}_\perp^2 - \tau^2 d\eta^2 \,. \tag{6}$$



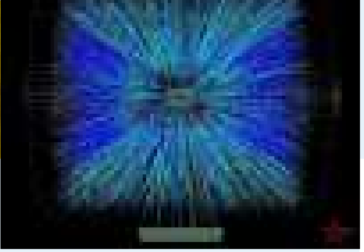
Plasma Instabilities



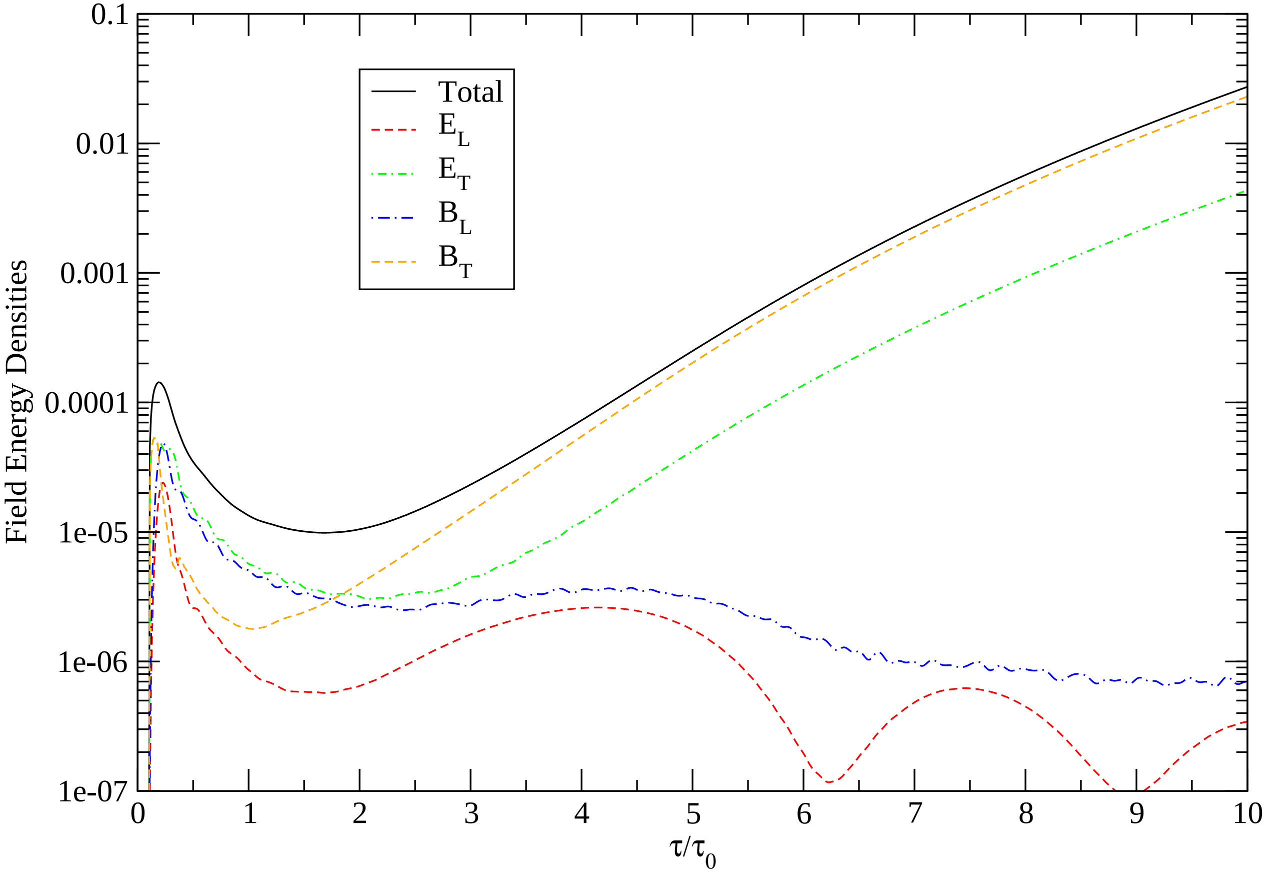
HEL 3D+3V Check



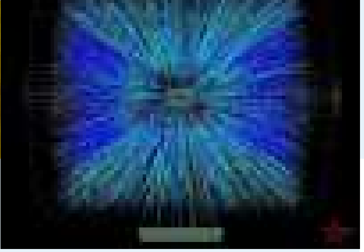
[Attems, Rebhan, Strickland arXiv:1111.XXXX]
Preliminary runs from the HEL 3d IC "stable nodes".



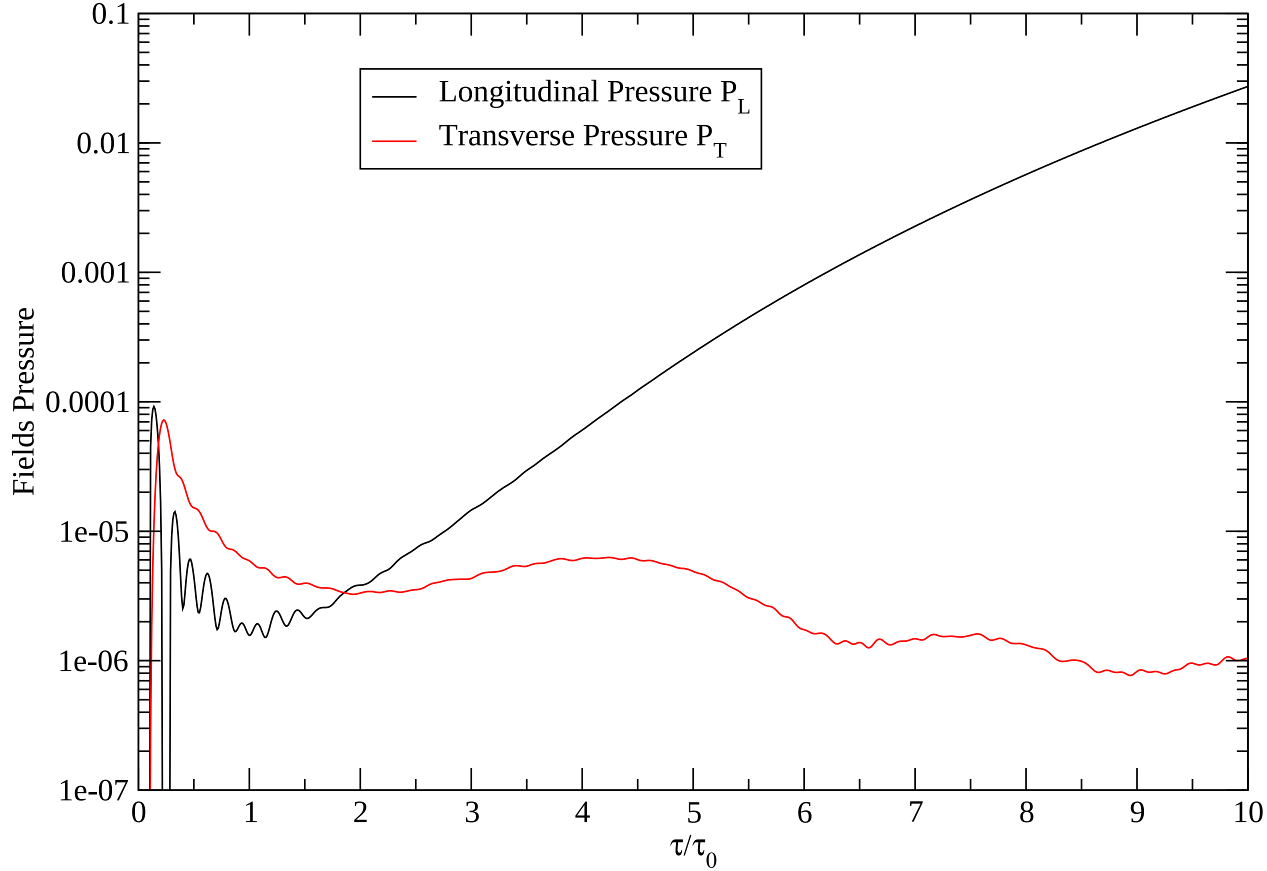
Expanding 3D+3V Abelian plasma



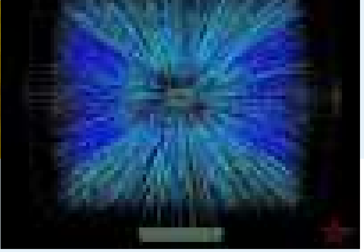
[Attems, Rebhan, Strickland arXiv:1111.XXXX]
Preliminary runs from the HEL 3d IC "transverse current".



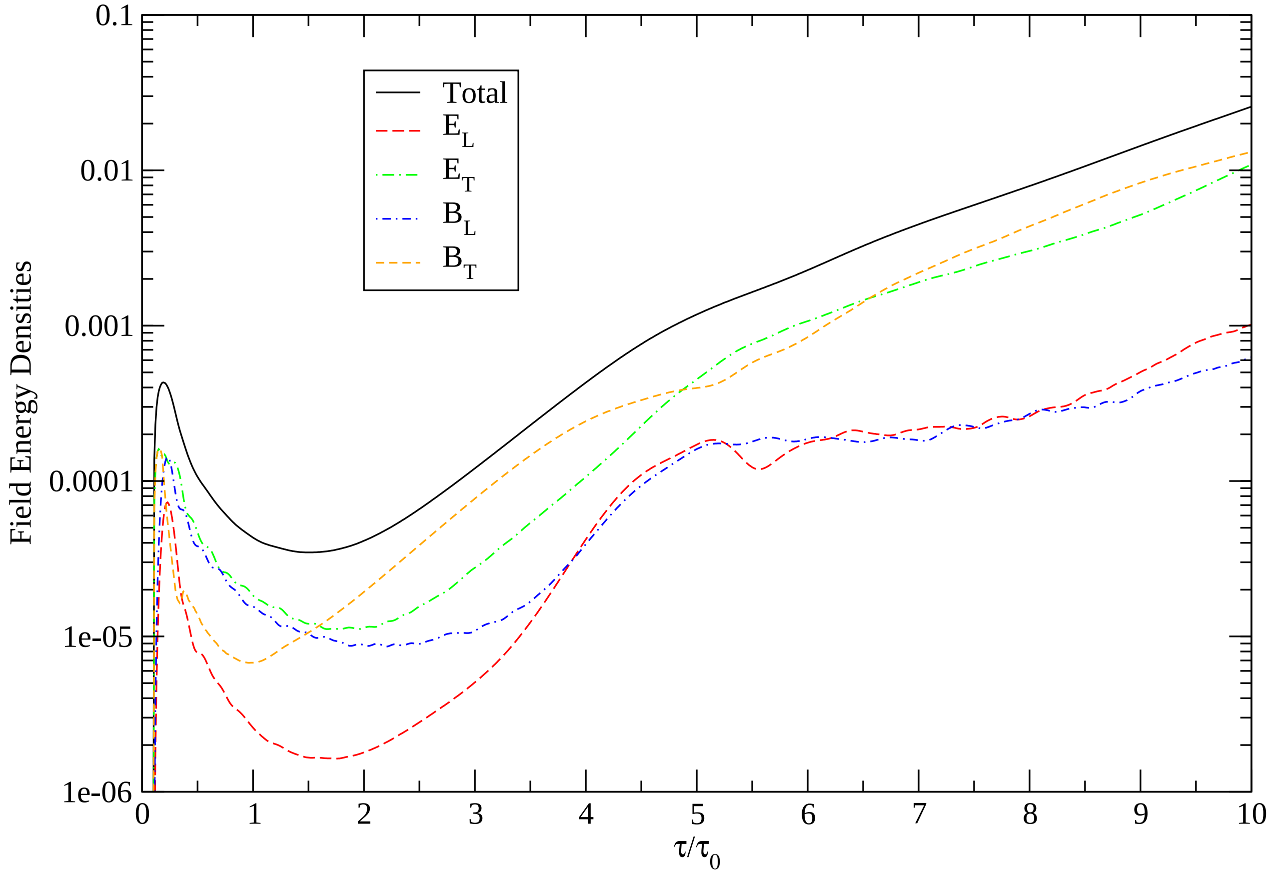
Expanding 3D+3V Abelian plasma



[Attems, Rebhan, Strickland arXiv:1111.XXXX]
Preliminary runs from the HEL 3d IC "transverse current".

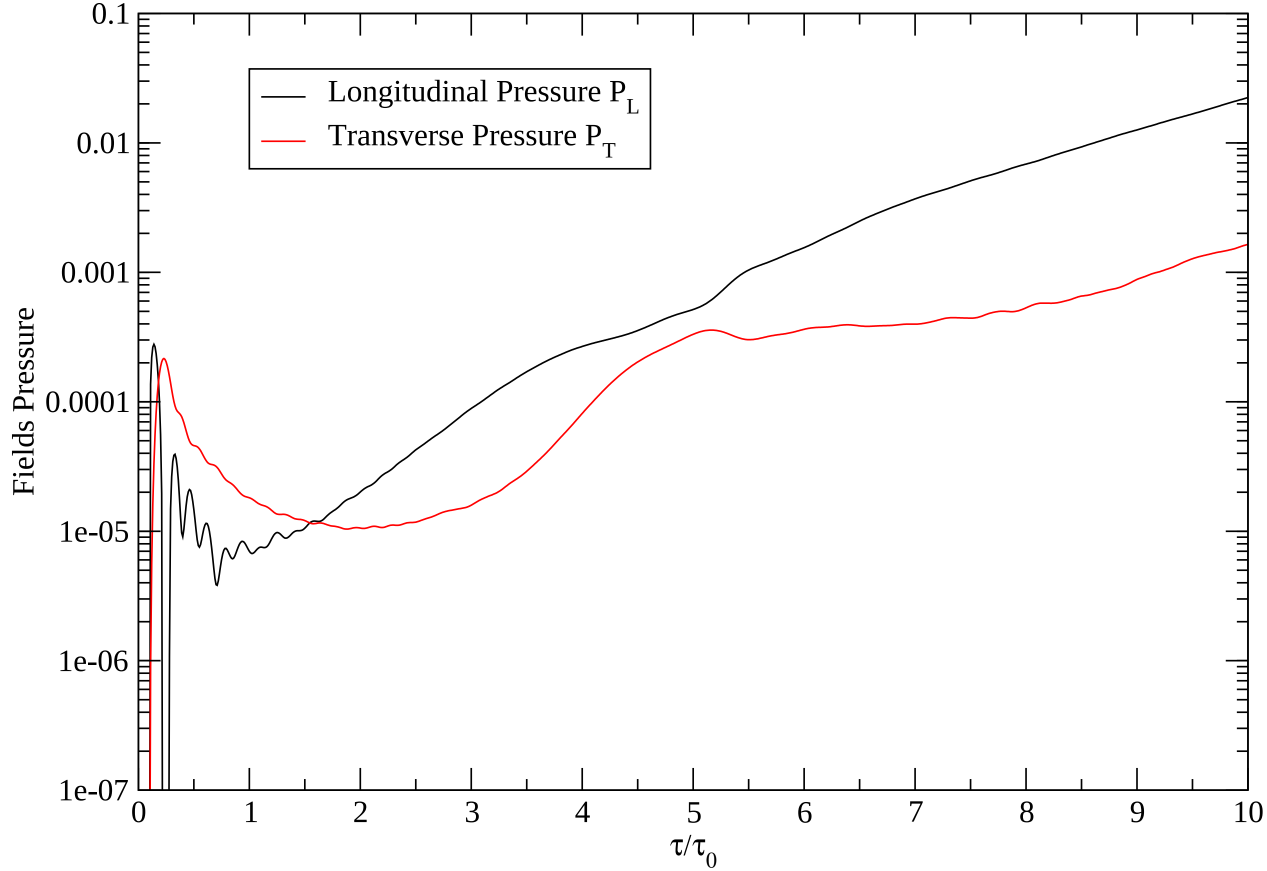


Expanding 3D+3V non-Abelian plasma

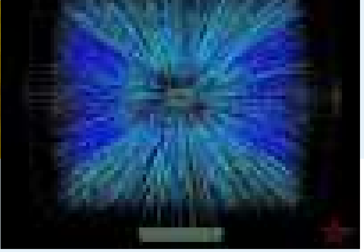


[Attems, Rebhan, Strickland arXiv:1111.XXXX]
Preliminary runs from the HEL 3d IC "transverse current".

Expanding 3D+3V non-Abelian plasma



[Attems, Rebhan, Strickland arXiv:1111.XXXX]
Preliminary runs from the HEL 3d IC "transverse current".



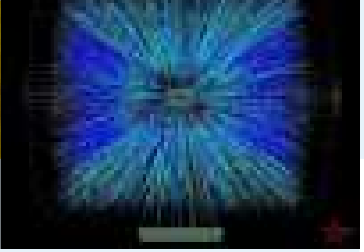
Conclusions

Non-abelian plasma instabilities play a significant role in a weakly coupled Quark Gluon Plasma at high T.

Chromo-Weibel instabilities are an important candidate process accelerating isotropization and thermalization of the Quark Gluon Plasma fireball maybe already at LHC.

The previous 1D HEL code has been extended to full 3D+3V parallel MPI-code with improved "transverse current" initial conditions. This significantly reduces the onset time of chromo-Weibel instabilities in the expanding setup.

Final results are being computed on the Vienna Scientific Cluster.



Backup - Equation of motions

Yang-Mills equations

$$\tau^{-1}\partial_\tau \Pi_i = j^i - D_j F^{ji} - D_\eta F^{\eta i}\,, \tag{7}$$

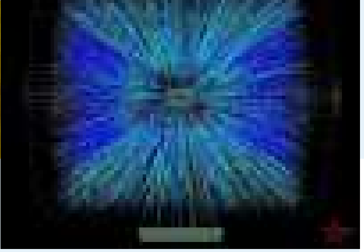
$$\tau \partial_\tau \Pi^\eta = j_\eta - D_i F^{i}{}_{\eta}\,. \tag{8}$$

Gauss law constraint

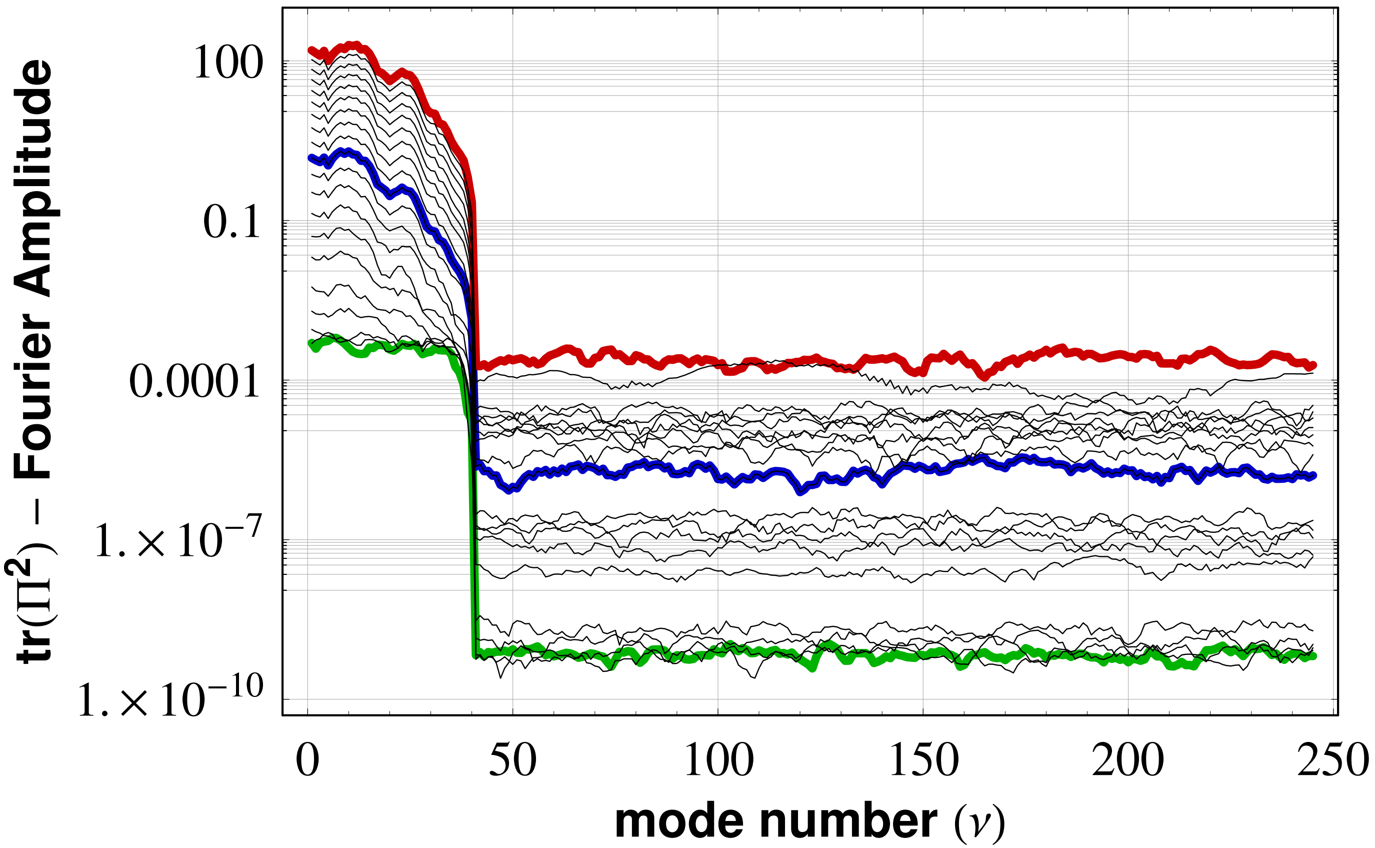
$$\tau j^\tau = D_\eta \Pi^\eta - ig[A^i, \Pi_i]\,, \tag{9}$$

Canonical conjugate field momenta

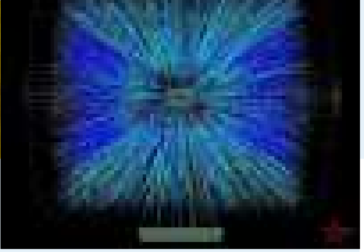
$$\Pi^i \equiv \tau \partial_\tau A_i, \quad \Pi^\eta \equiv \frac{1}{\tau}\partial_\tau A_\eta\,. \tag{10}$$



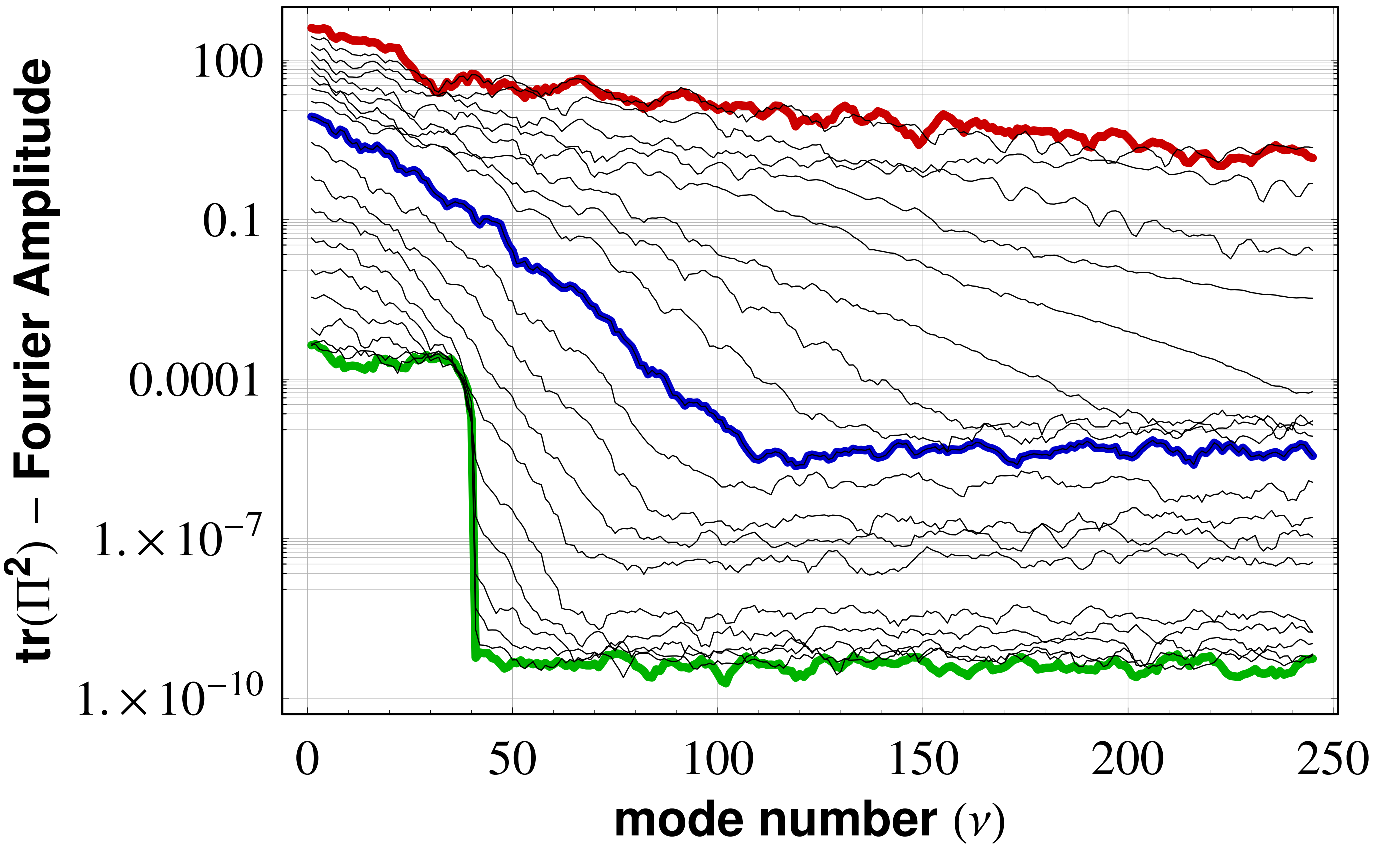
Backup - Expanding 1D+3V Abelian plasma



[Rebhan, Strickland, Attems 2008] Fourier spectrum of the color-traced conjugate field momentum obtained from Abelian run with FGM initial conditions.

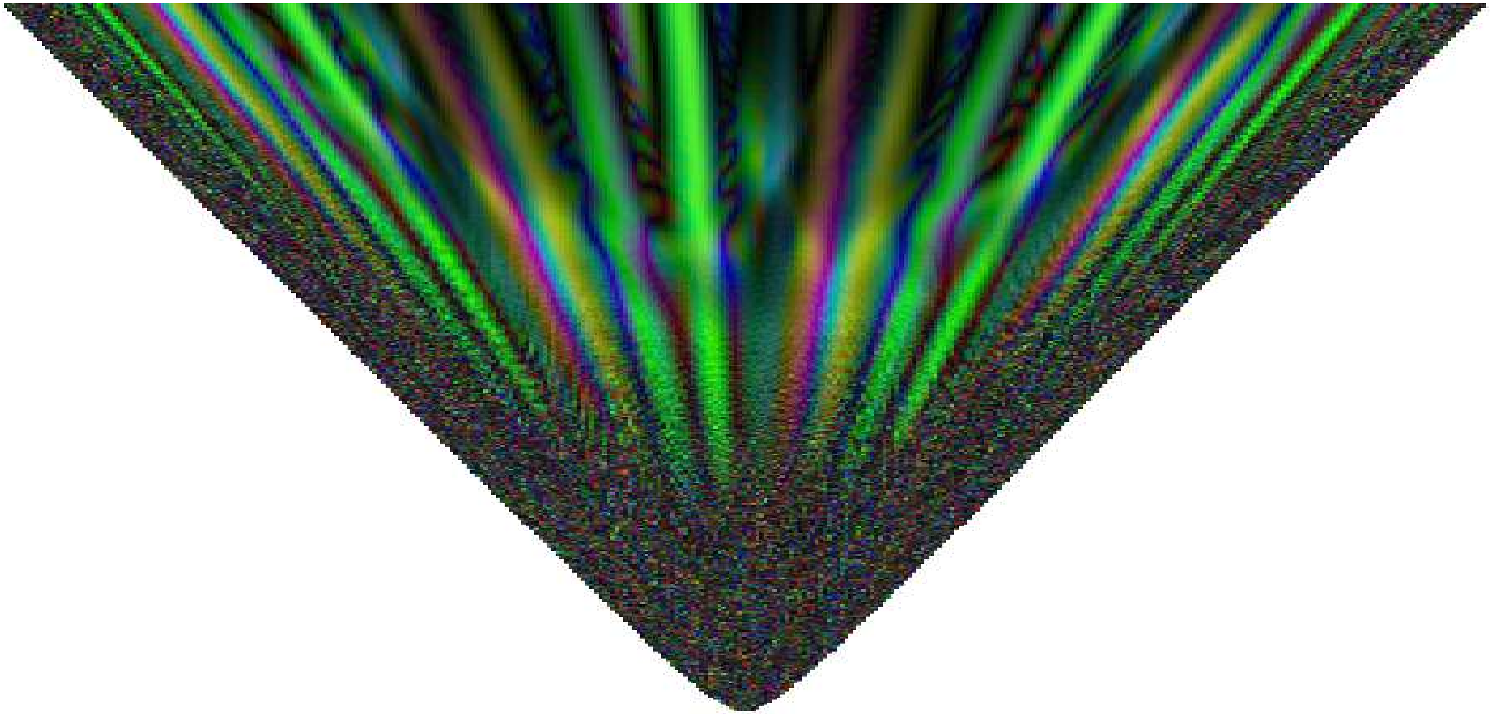


Backup - Expanding 1D+3V non-Abelian plasma

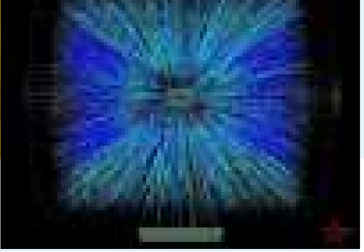


[Rebhan, Strickland, Attems 2008] Fourier spectrum of the color-traced conjugate field momentum obtained from non-Abelian run with FGM initial conditions.

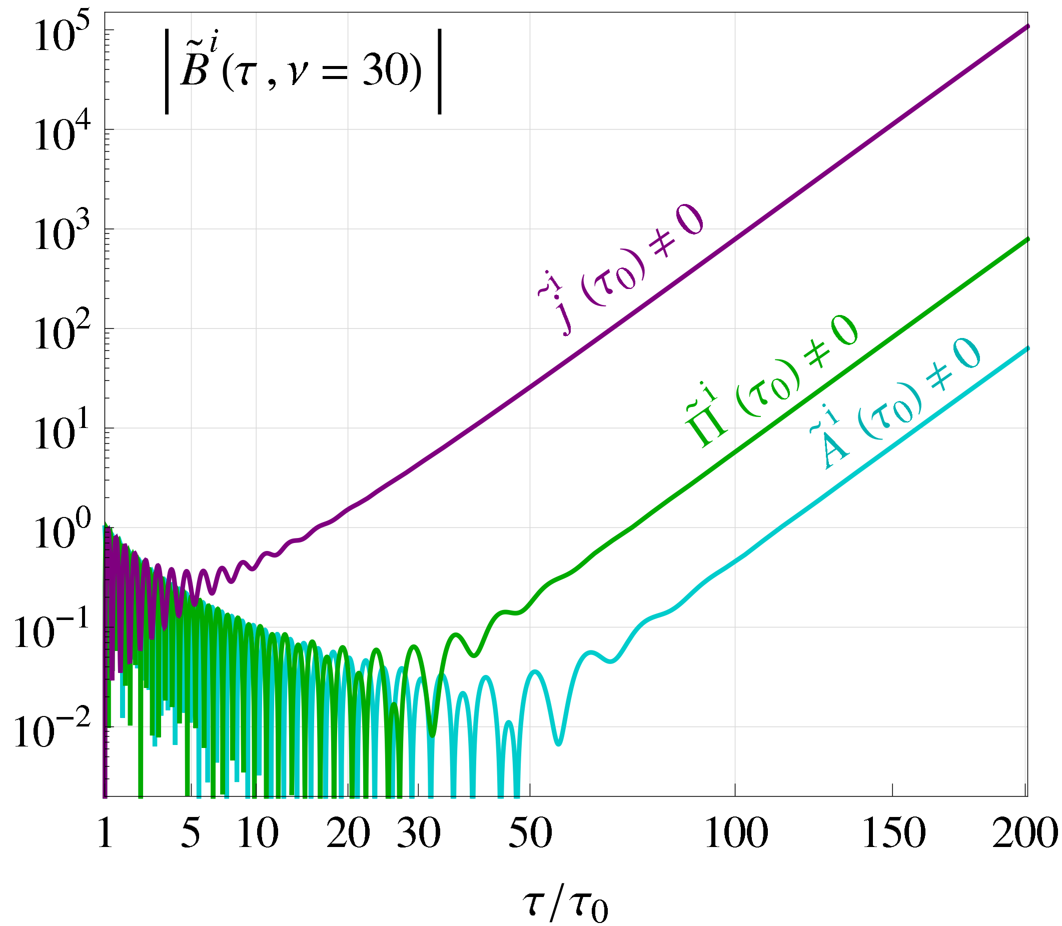
Backup - Expanding 1D+3V non-Abelian plasma



[Strickland 2008] Visualization of the space-time development of color correlations in a non-Abelian plasma instabilities in Bjorken expansion.



Backup - Unstable transverse modes



[Rebhan, Steineder 2009] Influence of different initial conditions for a specific mode with $\nu = 30$.