Quantized fermions in semi-classical Yang-Mills evolution

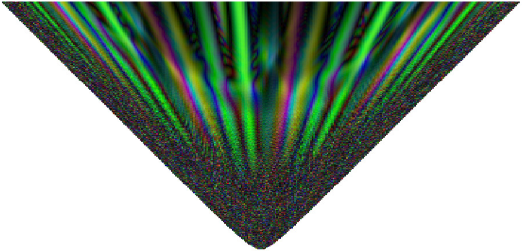
Maximilian Attems

University of Barcelona

Collaborators: Owe Philipsen, Christian Schäfer

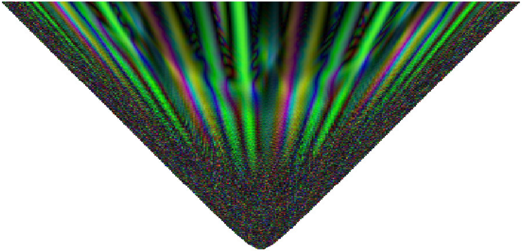
Initial State 2014

Motivation



Visualization of Chromo-Weibel instabilities in Bjorken expansion [Attems, Rebhan, Strickland 09]

Motivation

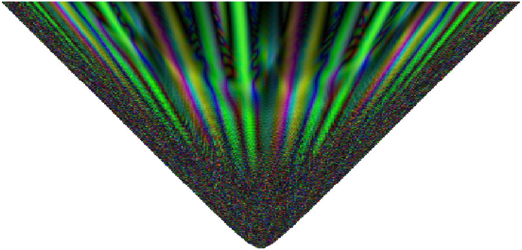


Visualization of Chromo-Weibel instabilities in Bjorken expansion [Attems, Rebhan, Strickland 09]

Weak coupling setup:

- CGC initial condition
- SU(3)
- Addition of fermionic degree of freedom

Motivation



Visualization of Chromo-Weibel instabilities in Bjorken expansion [Attems, Rebhan, Strickland 09]

Weak coupling setup:

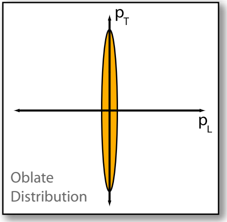
- CGC initial condition
- SU(3)
- Addition of fermionic degree of freedom

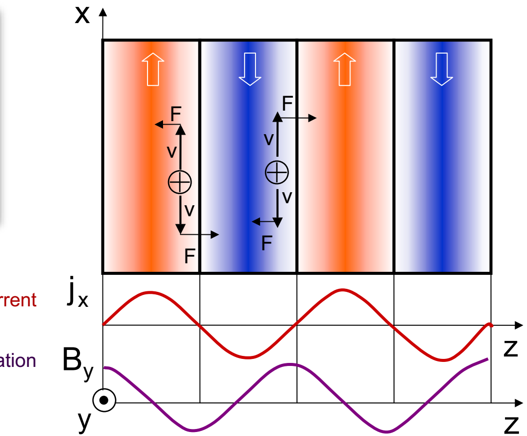
Ultimate goals:

- Derivation of the thermalization time
- Hydrodynamization for both strongly and weakly coupled approaches

Outline

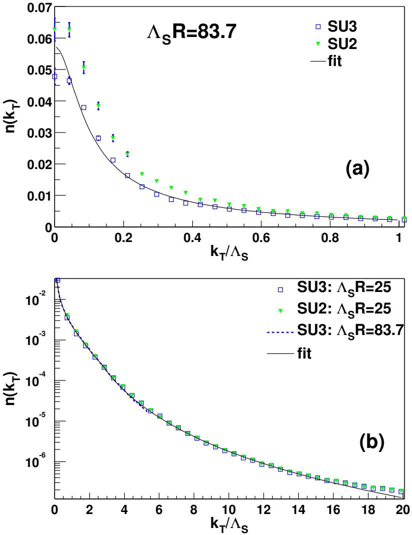
Weibel instabilities





[Mrowczynski 1993; Strickland 2006]: Illustration of the mechanism of filamentation instabilities with Lorentz force.

Transverse thermalization



CGC setup at time scales Q_s^{-1} [Krasnitz, Nara, Venugopalan 2001]

Lattice setup

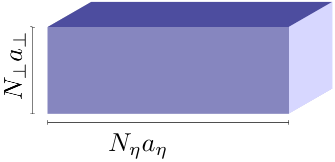
$$\mathcal{L}^G = \frac{1}{g^2 a^3} Tr\left(-\frac{1}{\xi}\sum(\mathbb{1} - U_{ij}(x)) + \xi\sum(\mathbb{1} - U_{i0})\right)$$

USQCD lattice gauge software with SU(3) particle content:

$E_i(x) = \partial_0 A_i$
$U_i(x) = e^{igaA_i(x)}$

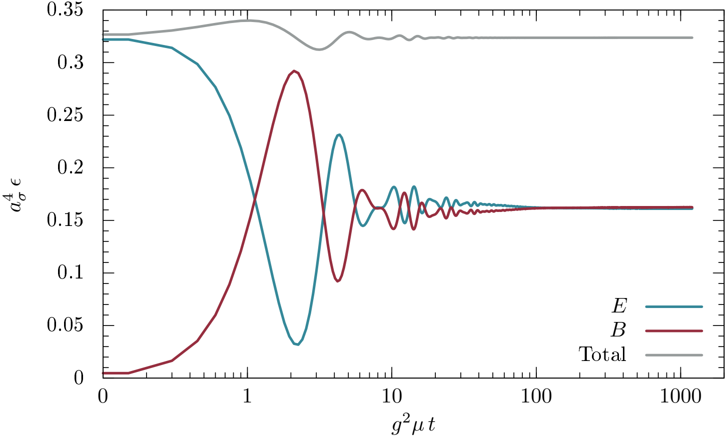
temporal gauge:
$A_0(x) = 0,\ U_0(x) = 1$

lattice size for leapfrog EOM:
$g^2\mu \approx 2\mathrm{GeV},\ a_\perp = \frac{g^2\mu^L}{2\mathrm{GeV}}$



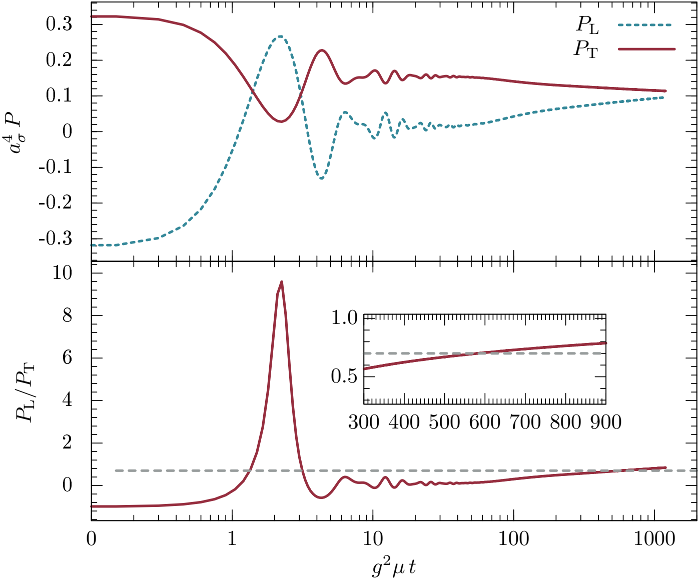
isotropic lattice length:
$a_\perp = a_z$
${N_\eta \times N_\perp}^2 = 128 \times 40^2$

CGC IC Yang-Mills Box

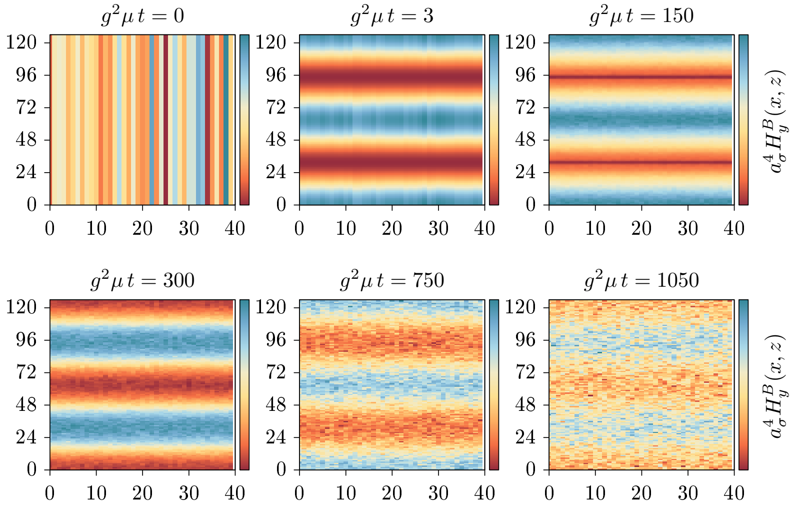


Chromo-electric and chromo-magnetic energy density evolution
[MA, Philipsen, Schäfer 2014]

CGC IC Yang-Mills Box

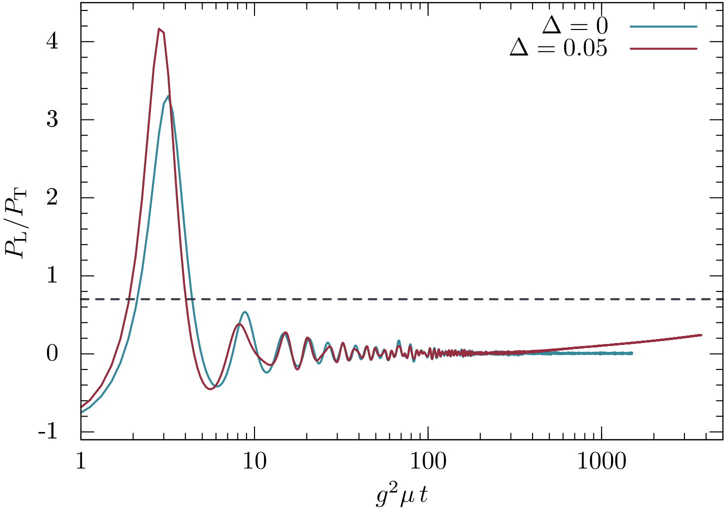


Pressures evolution [MA, Philipsen, Schäfer 2014]

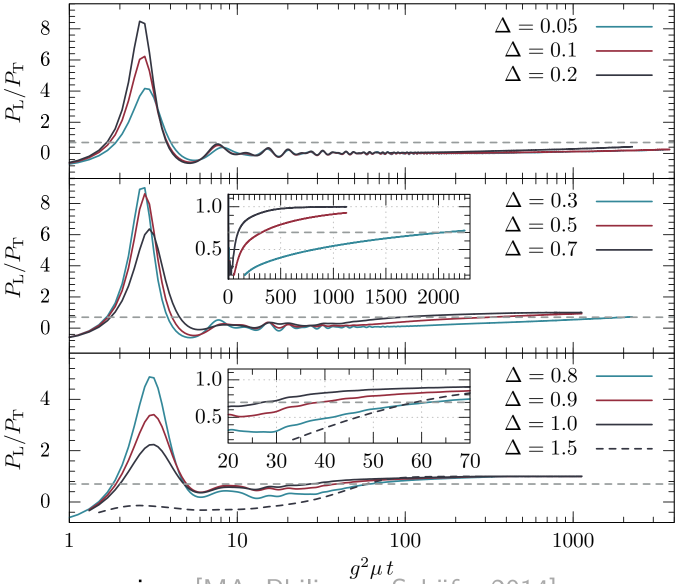


Local B_y energy density evolution [MA, Philipsen, Schäfer 2014]

CGC IC Yang-Mills Box



Pressures comparison [MA, Philipsen, Schäfer 2014]



Pressures comparison [MA, Philipsen, Schäfer 2014]

Outline

- Quantum mechanical treatment via mode function expansion [Aarts, Smit 1998]
- Introduce two kinds of fermions: Male and female

$$D(x,y) = \left\langle \psi_M(x)\bar{\psi}_F(y) \right\rangle = \left\langle \psi_F(x)\bar{\psi}_M(y) \right\rangle .$$

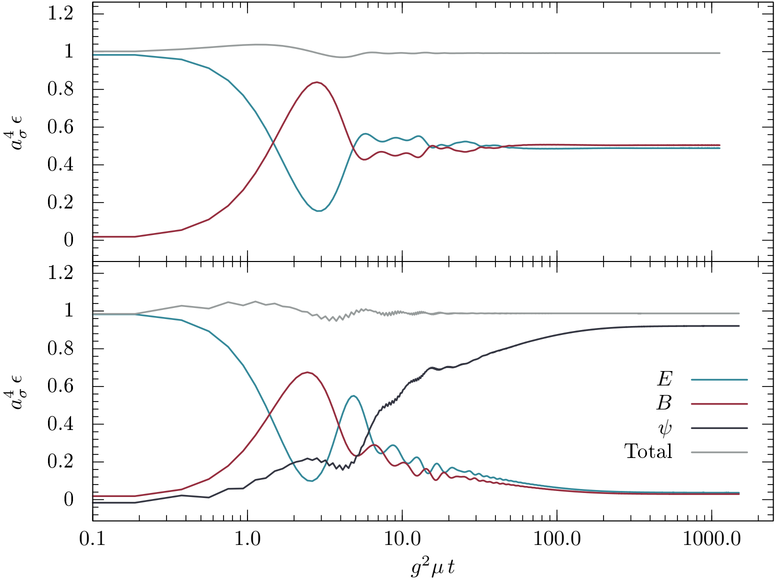
$$(i\gamma^\mu \partial_\mu - m + g\Re\Phi(x) - ig\Im\Phi(x)\gamma^5)\psi_g(x) = 0 .$$

- Define Fourier transformed stochastic fields

$$\psi_g(\vec{p}) = \int_{\vec{x}} e^{ip_j x^j} \psi_g(\vec{x}), \quad \psi_g(\vec{x}) = \int_{\vec{p}} e^{-ip_j x^j} \bar{\psi}_g(\vec{p}) . \qquad (1)$$

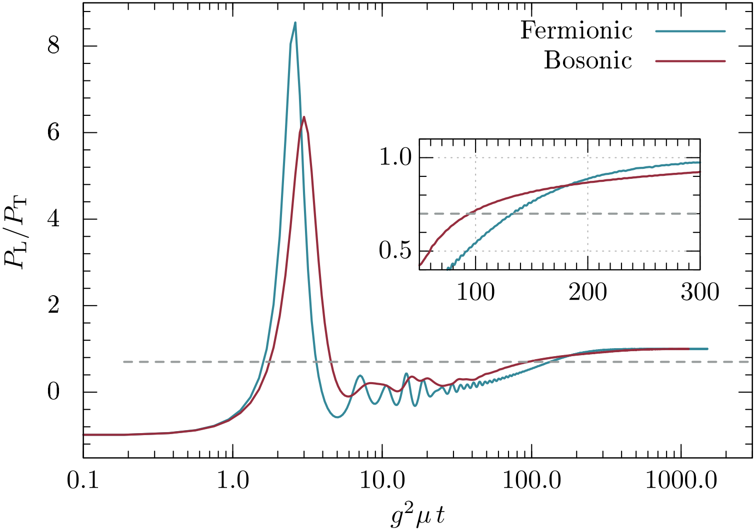
- Simulate ladder operators with complex random numbers ξ and η [Borsanyi, Hindmarsh 2009]

CGC IC Yang-Mills Box



Quantized fermions [MA, Philipsen, Schäfer 2014]

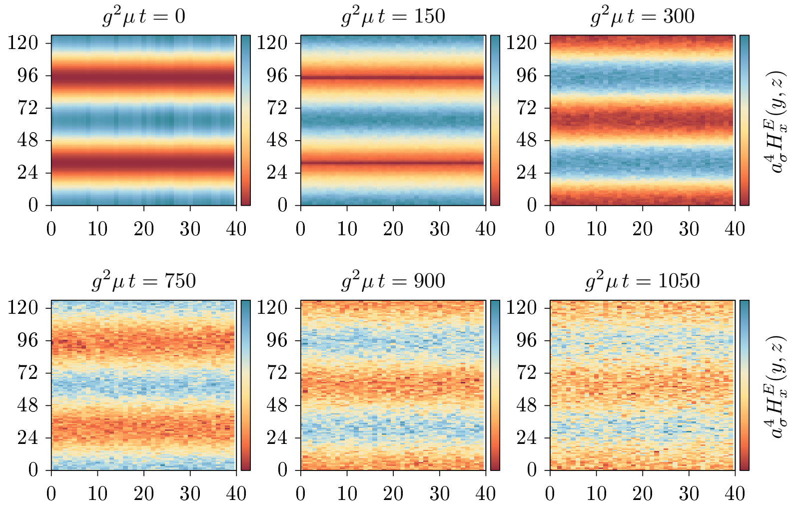
CGC IC Yang-Mills Box



Quantized fermions [MA, Philipsen, Schäfer 2014]

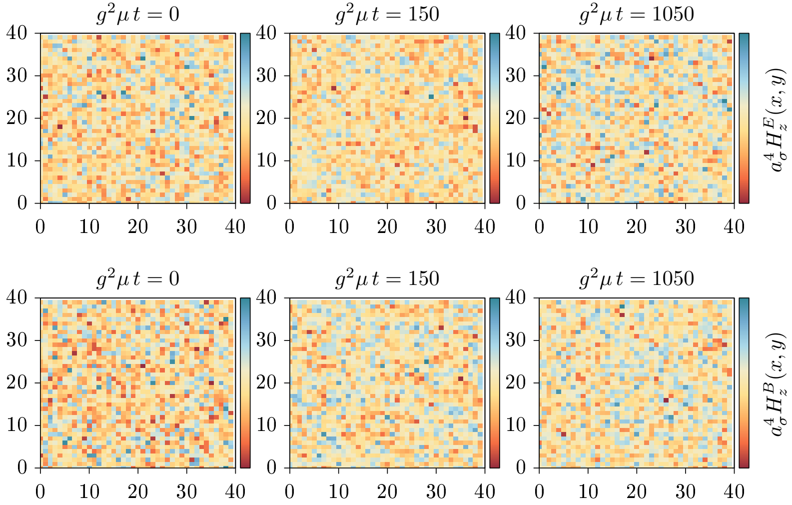
Conclusions

- In order to achieve an isotropisation time comparable with results from equivalent SU(2) simulations for SU(3) the fuctuation seed has to be increased from $\Delta = 0.2$ to $\Delta = 0.7$.
- We found evidence for the emergence of the chromo-Weibel instability displayed by the filaments in the local energy densities.
- We investigated the effect of fermionic degrees of freedom on the isotropisation process: We observe a strong increase of fermionic energy density from the highly populated bosonic fields. This leads to a slight change of the isotropisation time.



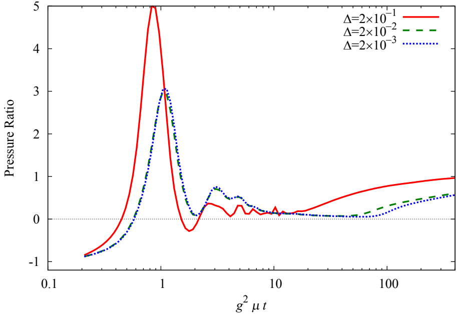
Local E_x energy density evolution [MA, Philipsen, Schäfer 2014]

CGC IC Yang-Mills Box

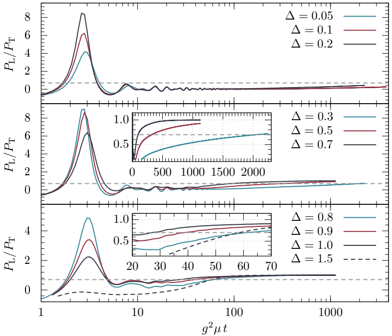


Local E and B energy density evolution in xy plane [MA, Philipsen, Schäfer 2014]

SU(2) versus SU(3)

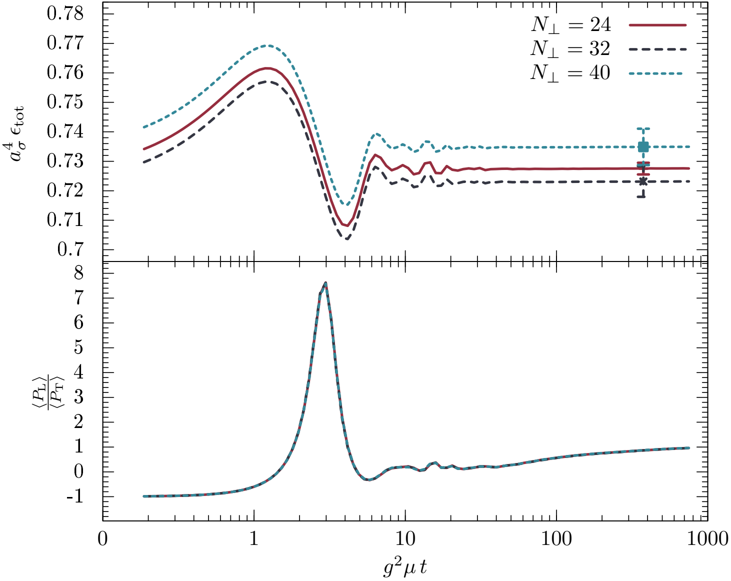


SU(2) [Fukushima 2013]

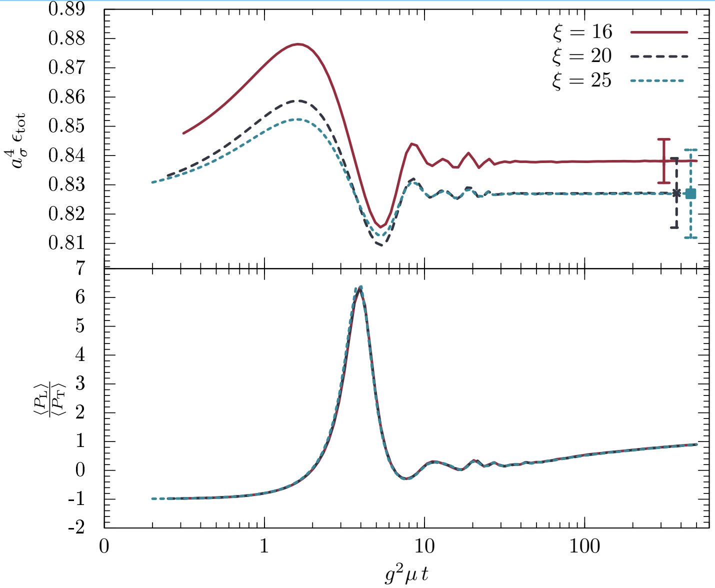


SU(3) [MA, Philipsen, Schäfer 2014]

CGC IC Yang-Mills Box



Check for volume effects [MA, Philipsen, Schäfer 2014]



Check for anisotropy effects [MA, Philipsen, Schäfer 2014]