Thermalization of a jet wake in QCD kinetic theory

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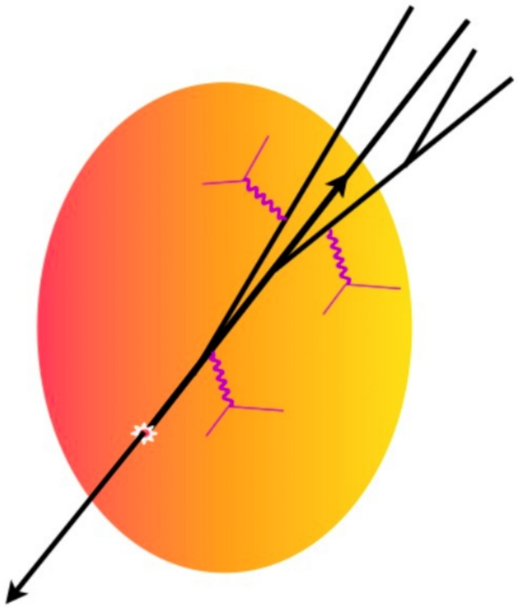
Motivation

- Medium interactions → jet quenching
- Study far from equilibrium evolution
- Interplay between jet quenching and thermalization



Goal:

Energy loss in an expanding plasma

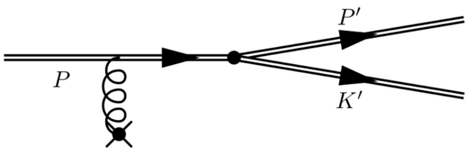
Framework

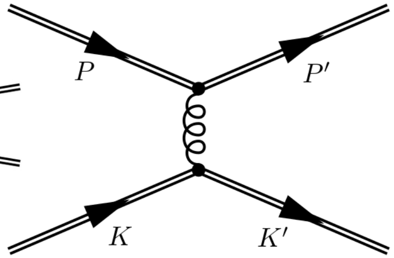
- Effective kinetic theory for hot gauge theories

AMY [hep-ph/0209353]

Background

$$\left(\partial_\tau + \frac{p_z}{\tau}\partial_{p_z}\right)\bar{f}(\tau,\mathbf{p}) = -C[\bar{f}]$$





Linearized perturbation

$$\left(\partial_\tau + \frac{p_z}{\tau}\partial_{p_z}\right)\delta f(\tau,\mathbf{p}) = -\delta C[\bar{f},\delta f]$$

Background thermalization: Kurkela, Zhu [1506.06647], Kurkela, Mazeliauskas [1811.03068]
Du, Schlichting [2012.09079]

Jet thermalization: Kurkela and Lu [1405.6318], Methar-Tani, Schlichting, Soudi [2209.10569]

New: Jet perturbations on top of an expanding background!

1. Initial conditions: thermal

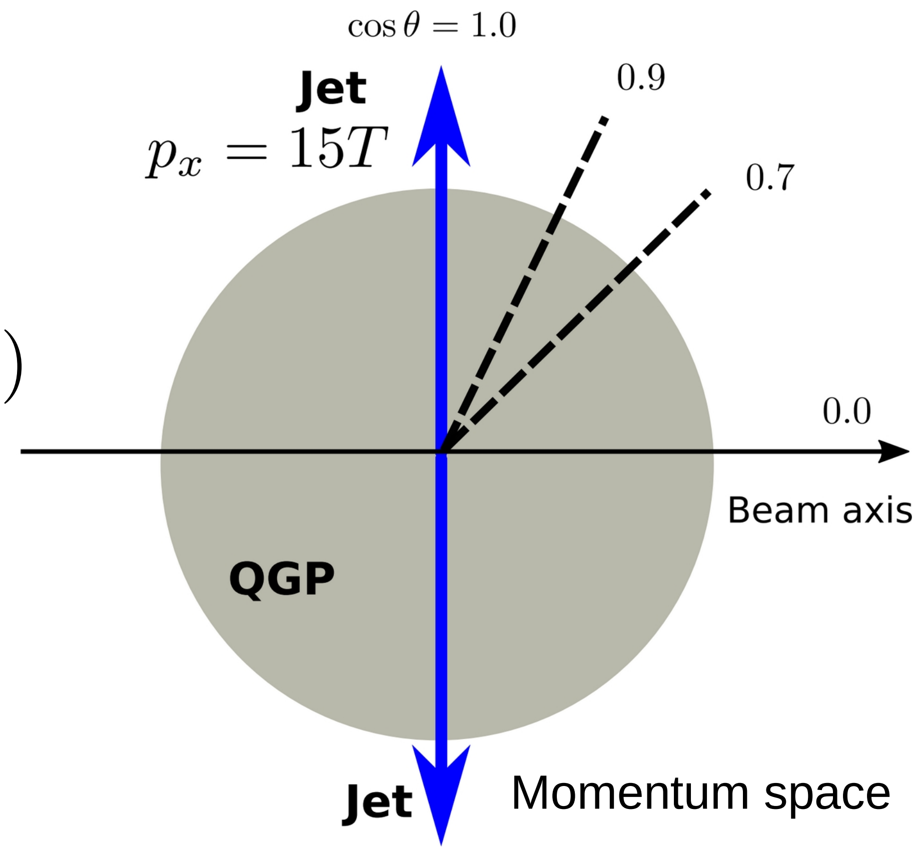
Parton interacting with the medium

No vacuum radiation

$$f(\tau_0, \mathbf{p}) = n_{\mathrm{BE}}(p) + \delta f_{\mathrm{Jet}}(\tau_0, \mathbf{p})$$

- Background: Bose-Einstein
- Jet: Gaussian at $p_x = 15T$

$$\boxed{\delta f(\tau_0, \mathbf{p}) \to \delta f_{\mathrm{eq}}(p)}$$



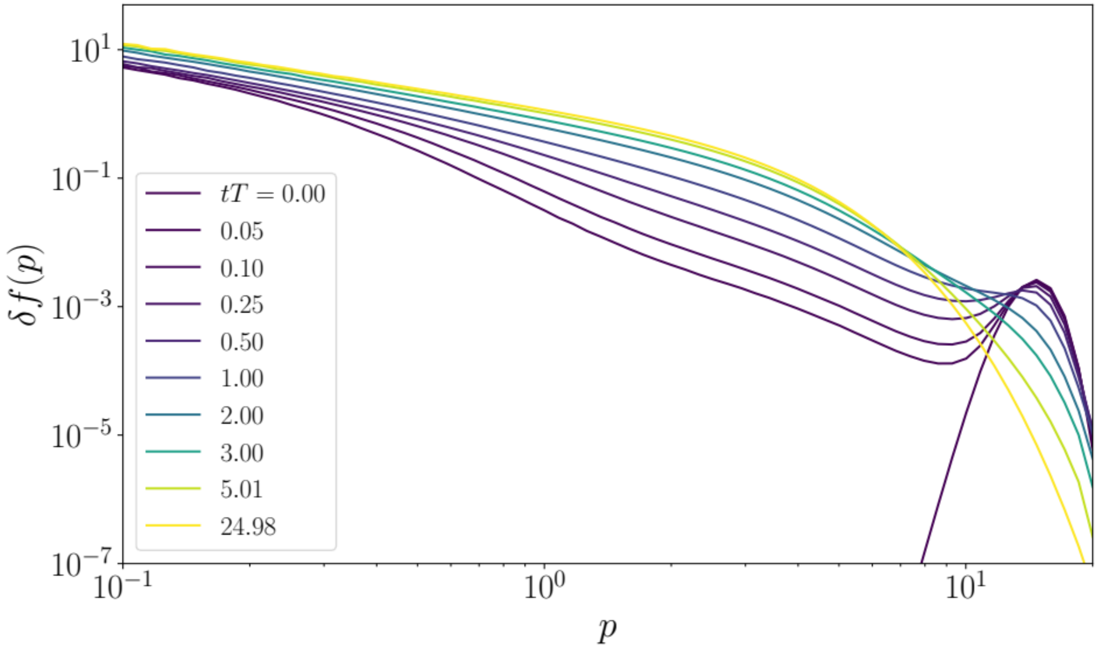
cf. Methar-Tani, Schlichting, Soudi [2209.10569]

Inverse energy cascade

- Underoccupied system

  Kurkela and Lu [1405.6318]

1) Number transport
2) Energy transport



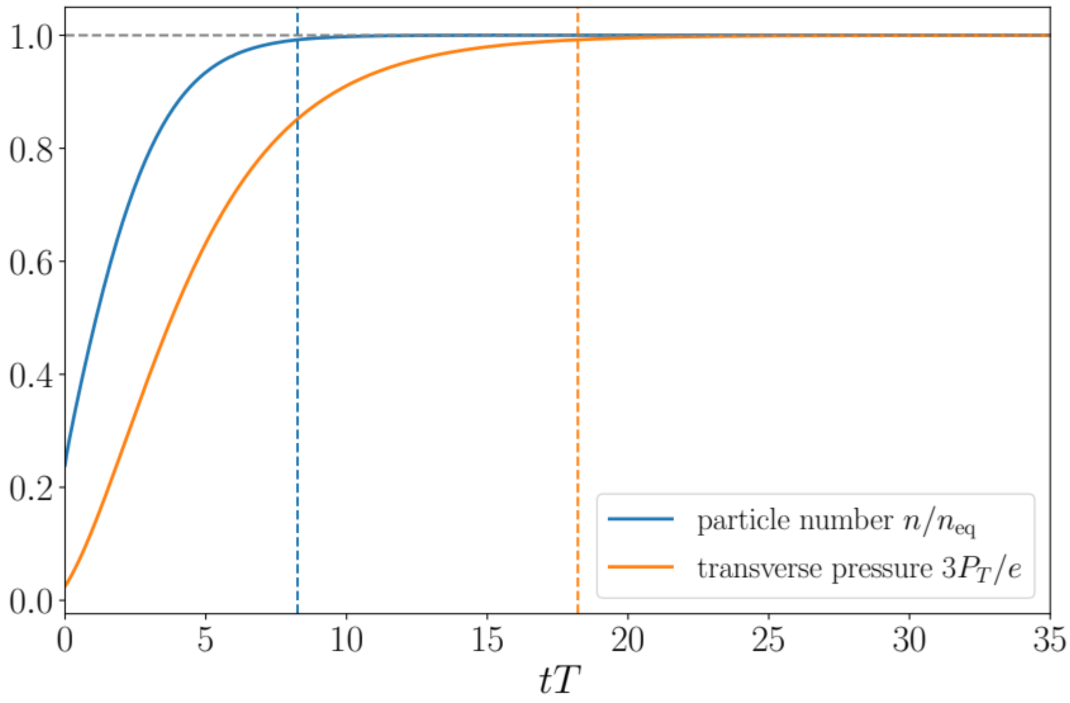
Now: study angular dependence!

Radiation vs. elastic scattering

2 stage thermalization

1) particle number stops changing

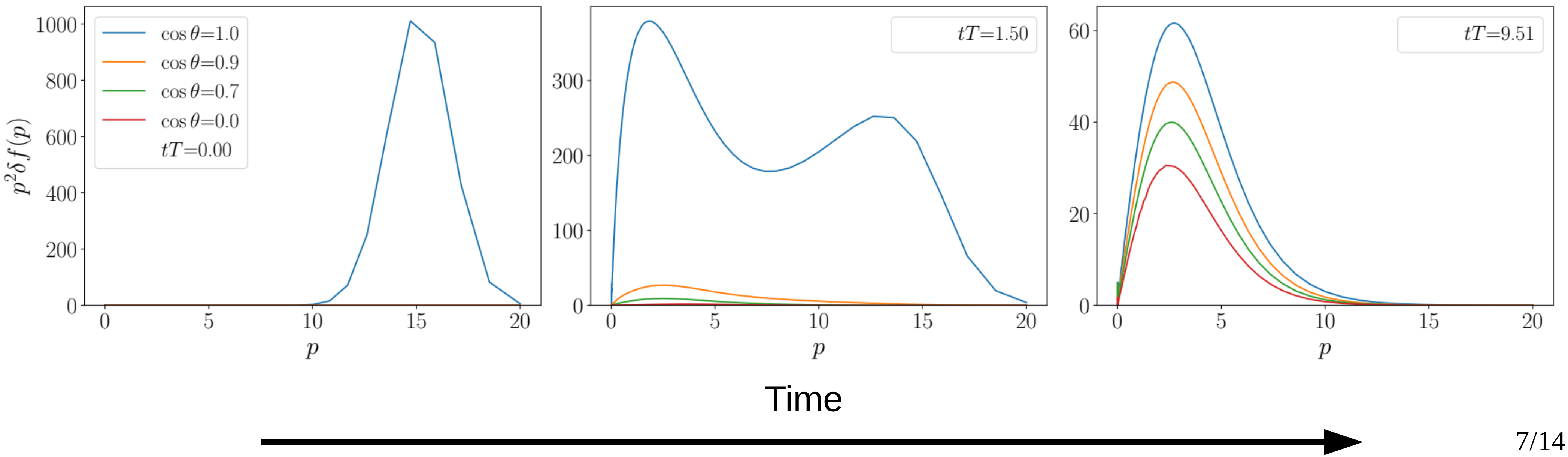
2) isotropization



Equilibration along each θ-slice?

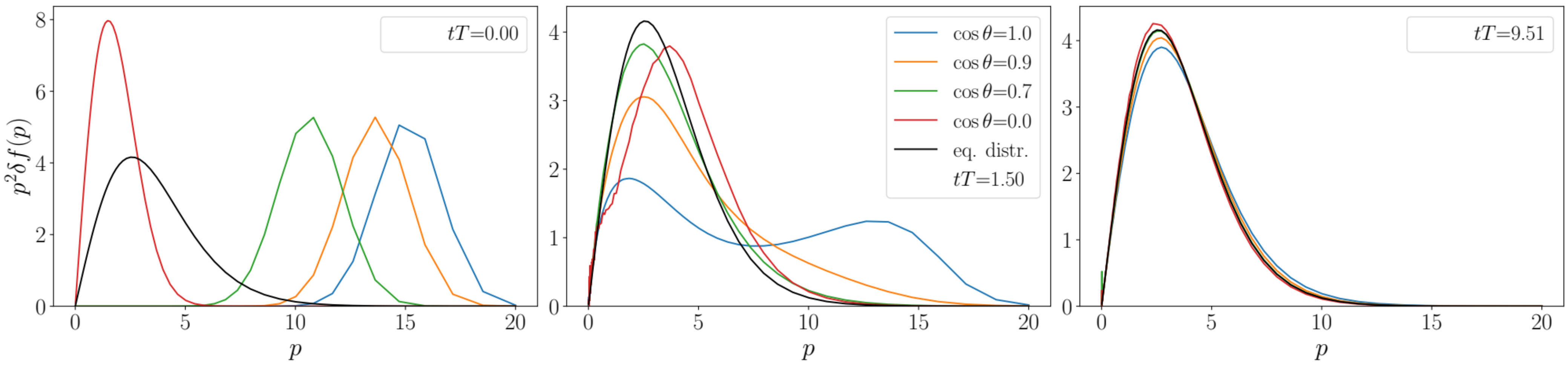
Jet distributions

- In equilibrium: $\delta f_{\mathrm{eq}}(p) = n_{\mathrm{BE}}\left(\frac{p}{T+\delta T}\right) - n_{\mathrm{BE}}\left(\frac{p}{T}\right) \sim \delta T$



Jet distributions

- In equilibrium: $\delta f_{\rm eq}(p) = n_{\rm BE}\left(\frac{p}{T+\delta T}\right) - n_{\rm BE}\left(\frac{p}{T}\right) \sim \delta T$
- Normalize $\int dpp^2 \delta f(p,\theta) = 1$



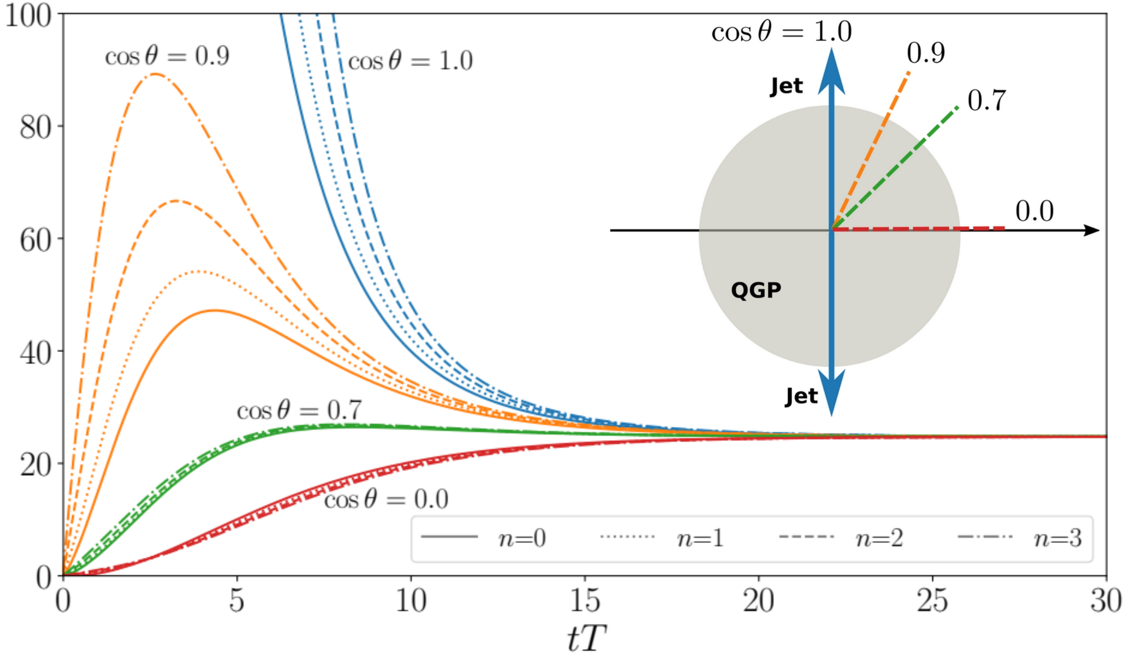
Equilibrium distributions with temperatures $\delta T(\theta)$!

Moments of δf

$$I_n(\theta) \equiv 4\pi \int \frac{p^2 dp}{(2\pi)^3} p^n f(p,\theta)$$
$$= \mathcal{N}_n \times T(\theta)^{n+3}$$

- Angular temperature
  $$\overline{T} + \delta T(\theta)$$
- Collapse of different n

$\delta T(\theta)/\overline{T}$



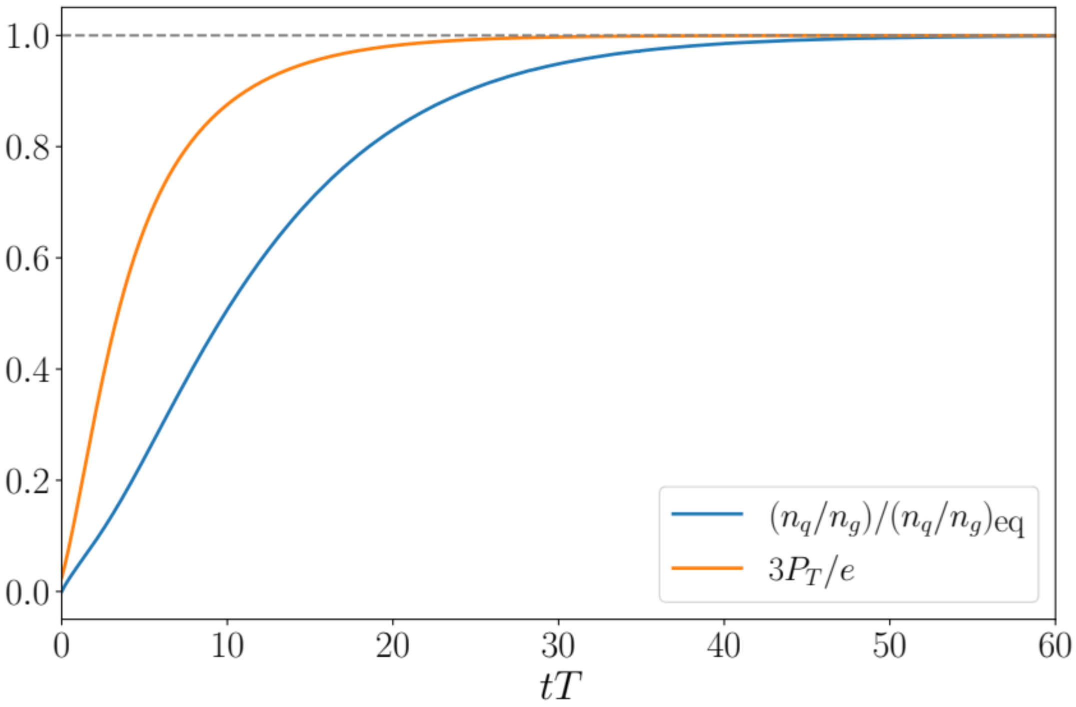
Thermalization in p along each θ -slice!

Chemical equilibration

- No expansion
- QCD → $C[f]$
- Start with gluonic $\delta f_{\mathrm{Jet}}(\tau_0, \mathbf{p})$

1)Isotropization

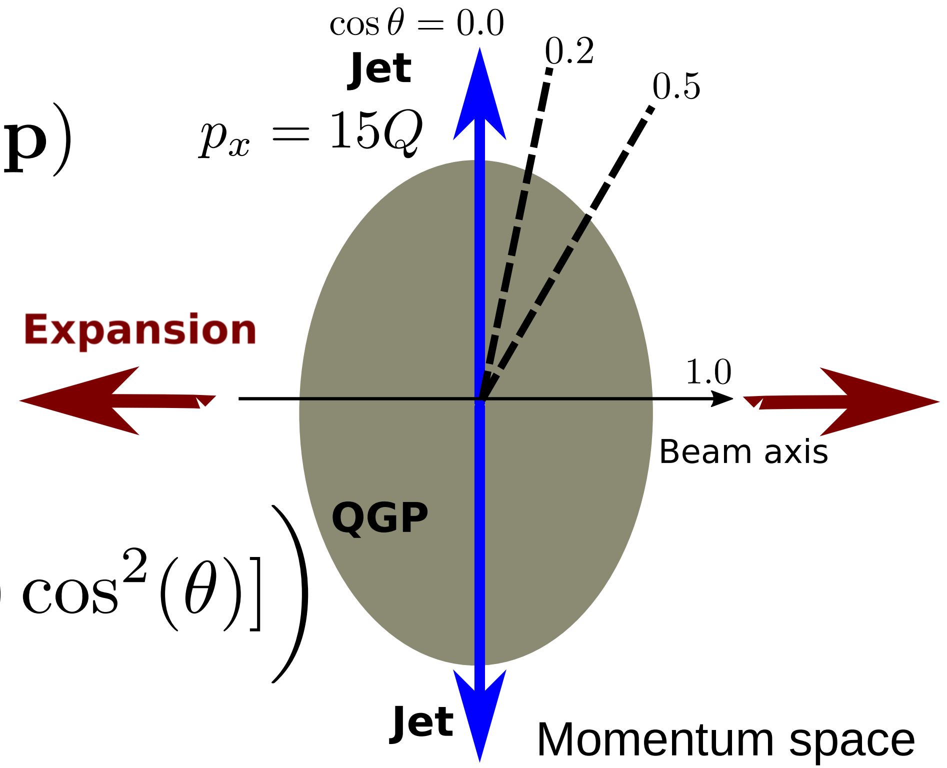
2)Chemical equilibration



cf. Sirimanna et al. 2211.15553

2. Initial conditions: anisotropic

$$f(\tau_0, \mathbf{p}) = \bar{f}(\tau_0, \mathbf{p}) + \delta f_{\text{Jet}}(\tau_0, \mathbf{p})$$



- Non-thermal background:

Kurkela, Zhu [1506.06647]

$$\bar{f}\,(p,\theta) \propto \exp\left(-\frac{2}{3}\frac{p^2}{Q^2}[1+(\xi^2-1)\cos^2(\theta)]\right)$$

$$\boxed{\delta f(\tau_0, \mathbf{p}) \rightarrow \delta f_{\text{hydro}}(\tau, p, \theta)}$$

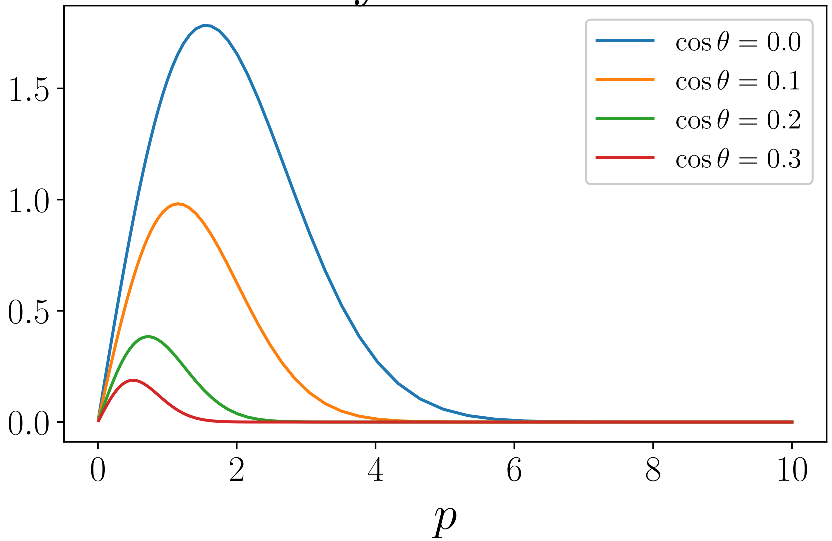
Comparison to azimuthal sym. perturbation

$$\delta f^{\mathrm{az.}}_{\mathrm{sym.}}(\tau_0, p, \theta) = \varepsilon \bar{f}(p, \theta)$$

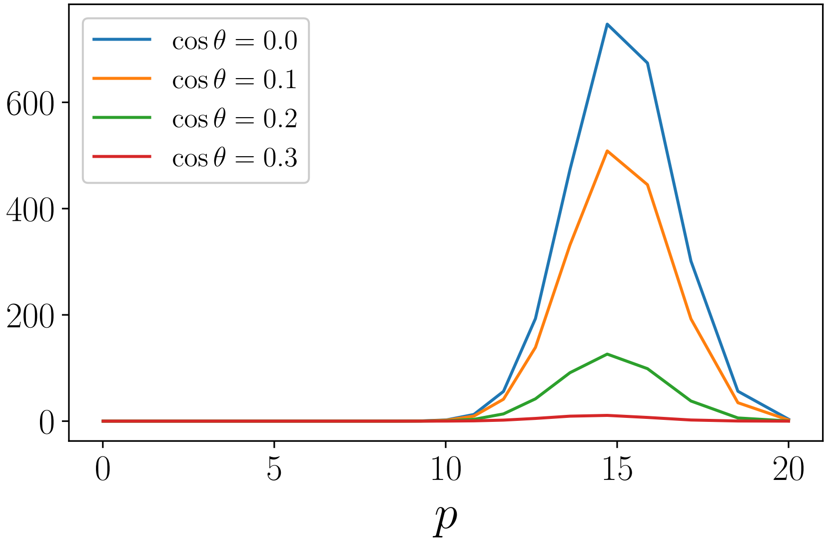
- Azimuthal symmetric

To study hydrodynamization, compare time evolution!

$p^2 \delta f^{\mathrm{az.}}_{\mathrm{sym.}}(\tau_0, p, \theta)$



$p^2 \delta f_{\mathrm{Jet}}(\tau_0, p, \theta)$



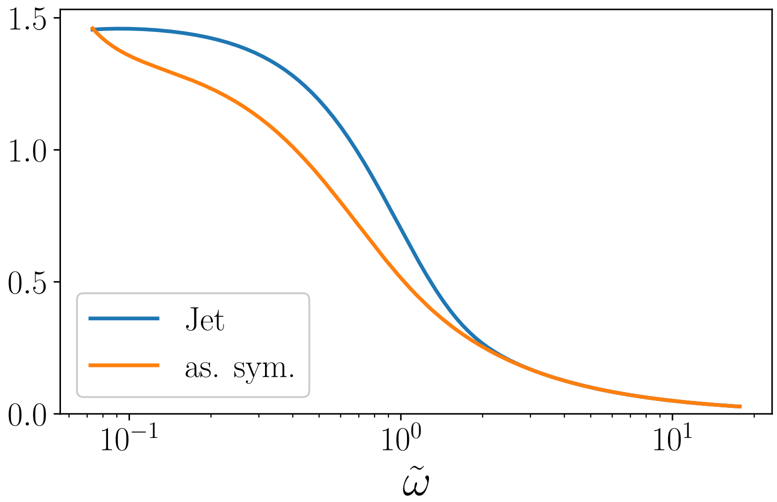
Hydrodynamization

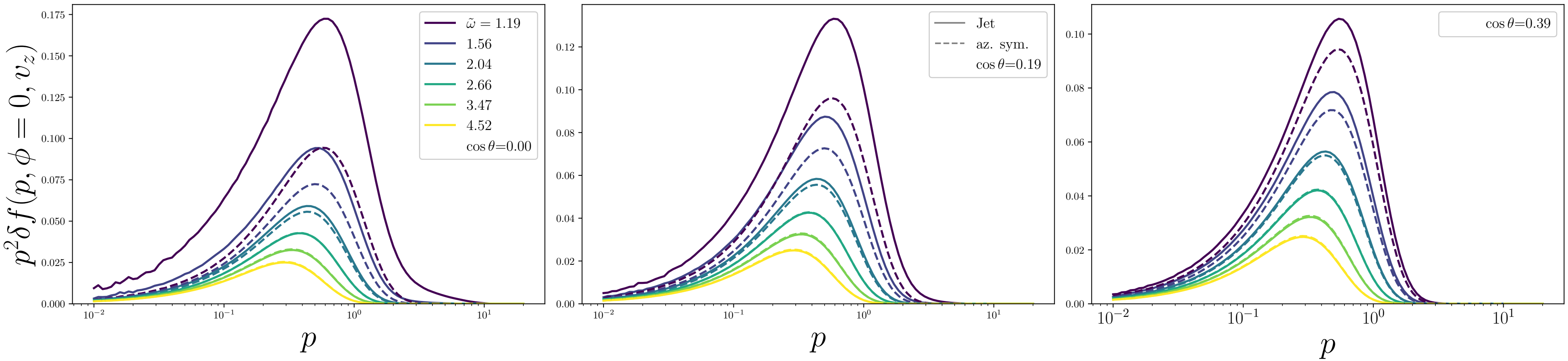
anisotropy $\frac{P_T - P_L}{e/3}$

- Scaled time $\tilde{\omega} = \frac{\tau T_{\text{eff}}(\tau)}{4\pi\eta/s}$
- Distributions agree at $\tilde{\omega} \approx 2$

  → Loss of memory

Hydrodynamization!





Summary & Outlook

We studied back to back parton thermalization in QCD kinetic theory:

Thermal background:

- Angular dependent equilibration due to colinear radiation
- Chemical equilibration after isotropization in QCD

Expanding background:

- No known analytical hydrodynamized distribution
- Different perturbations merge at later times than background hydrodynamization

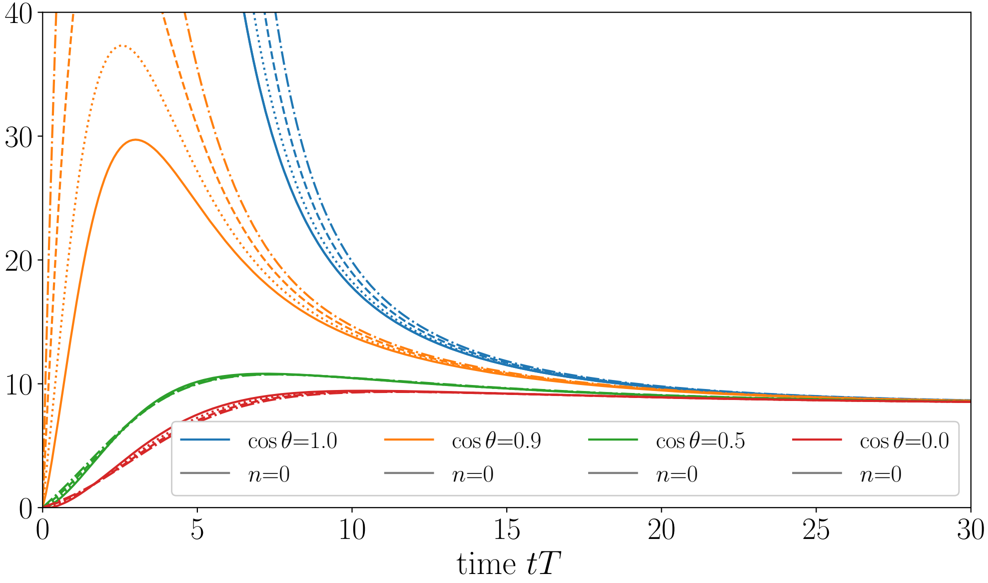
Outlook:

- Energy and coupling dependence of jet wake thermalization
- Extraction of jet response functions (a la KoMPoST) -> useful for phenomenology

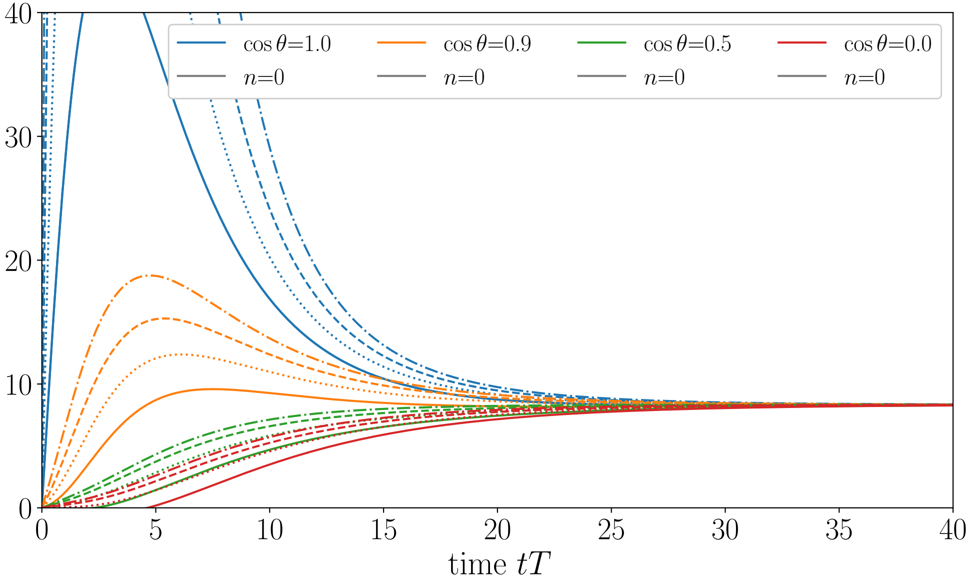
Backup

- Temperature perturbation $\delta T(\theta)/\overline{T}$

Gluons

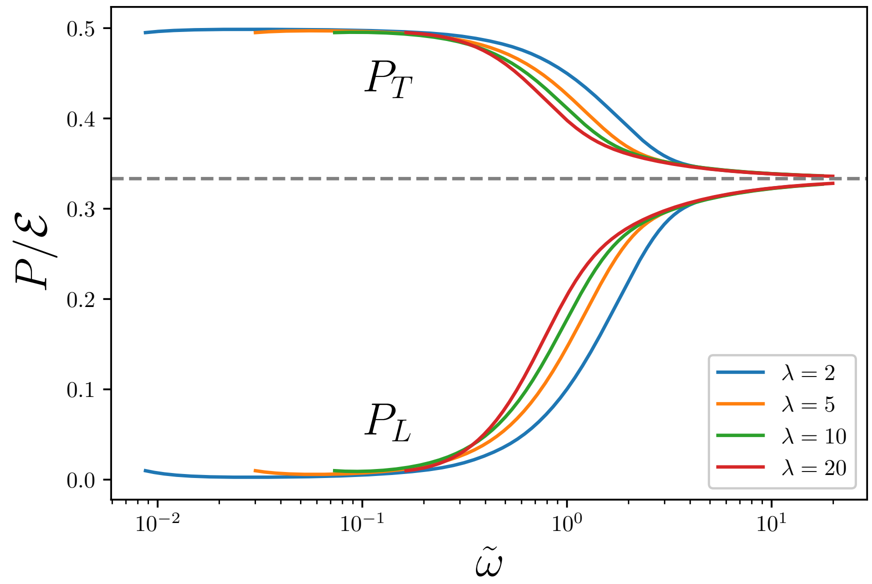


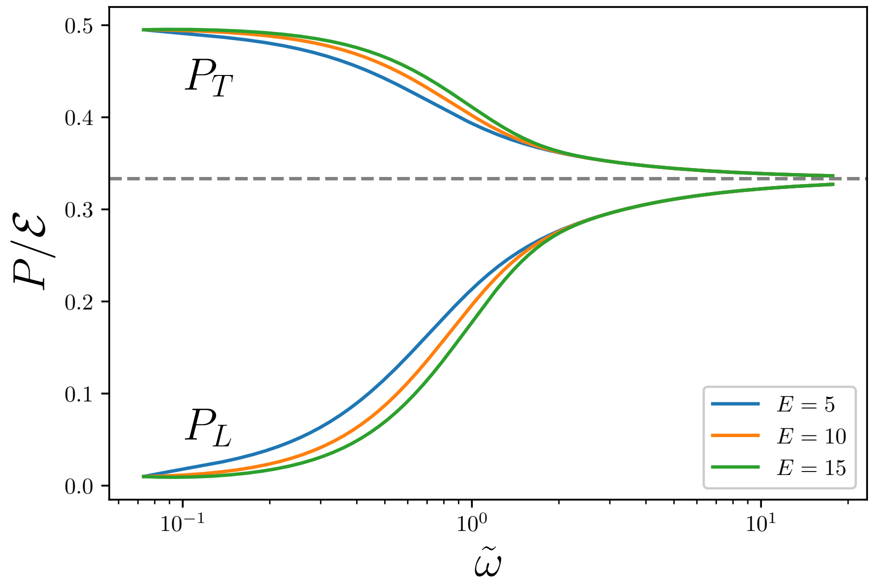
Quarks



Backup

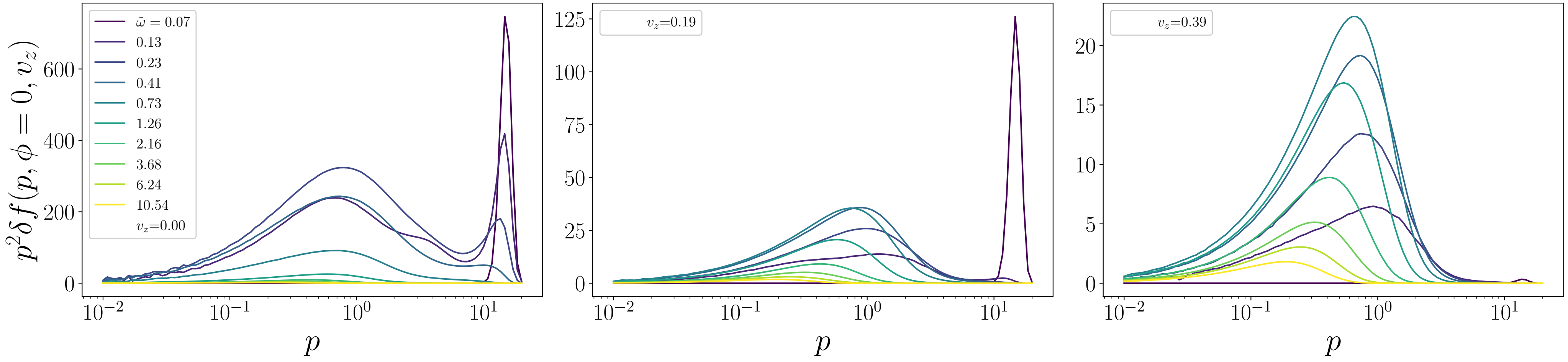
- Isotropization for different couplings and different energies (expanding case)





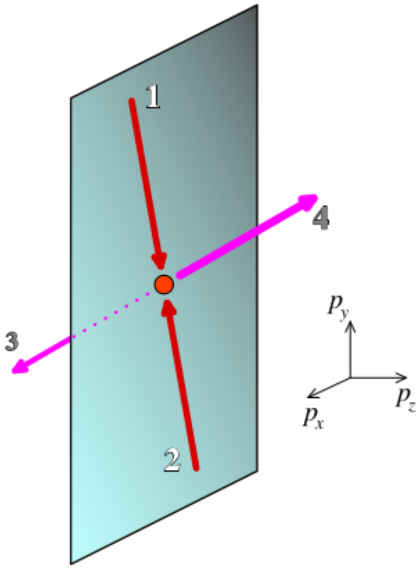
Backup

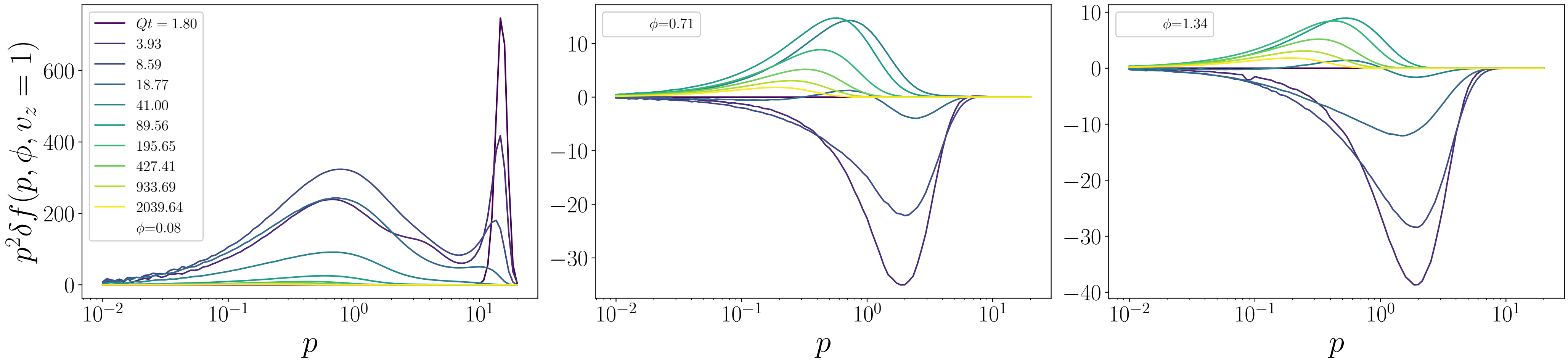
- Jet distributions as a function of time
- Reaction plane (x-z)



Backup

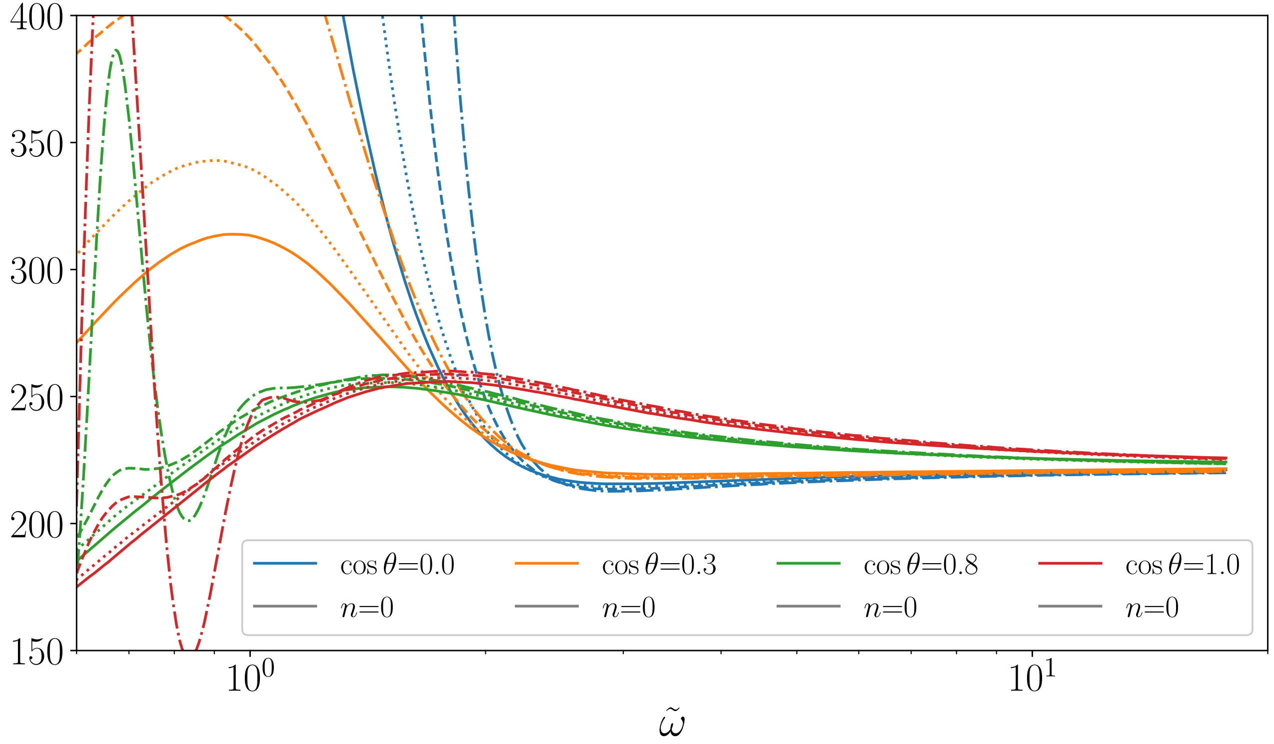
- Jet distributions as a function of time
- Transverse plane (x-y)
- Negative due to out-of-plane scatterings





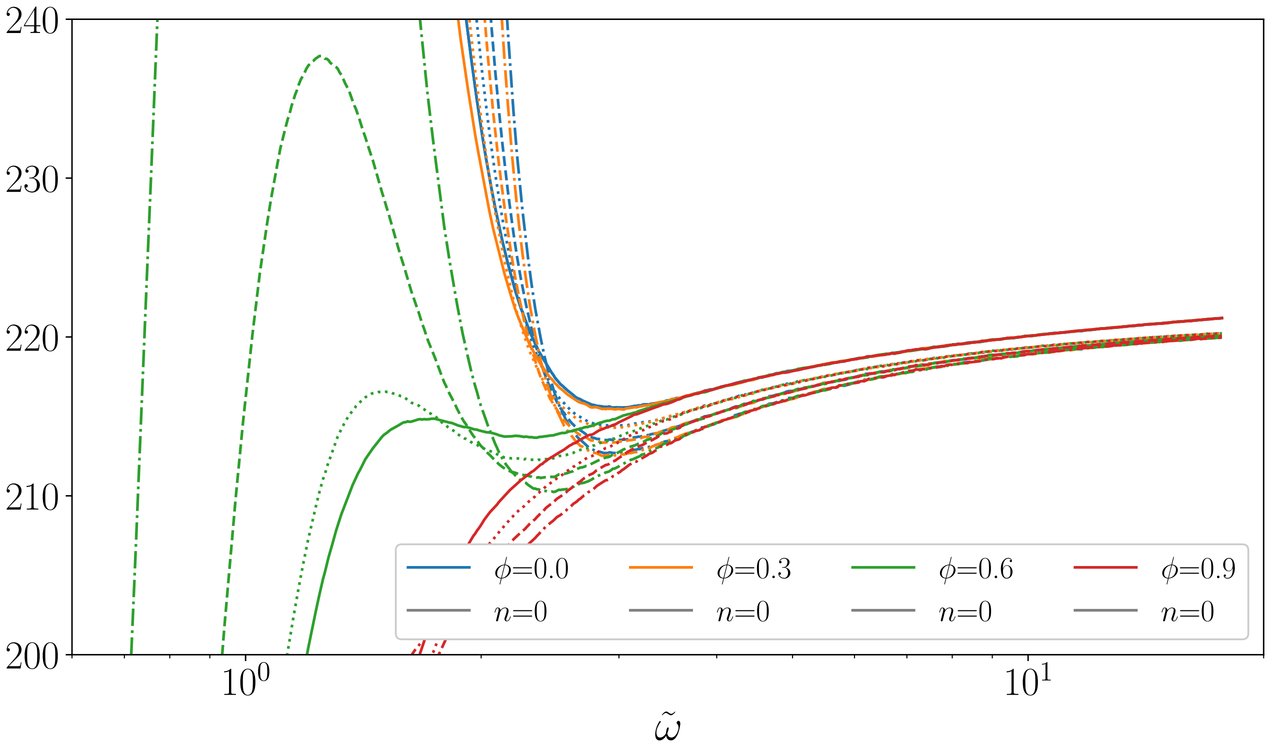
Backup

- Temperature perturbation $\overline{T}/\delta T(\theta)$ expanding background at $\phi = 0$



Backup

- Temperature perturbation $\overline{T}/\delta T(\phi)$expanding background at $\cos\theta = 0$ (transverse plane)



Backup

- Hydrodynamization in the transverse plane