SUBA-Jet
A New Model for Jet Energy Loss in Heavy Ion Collisions

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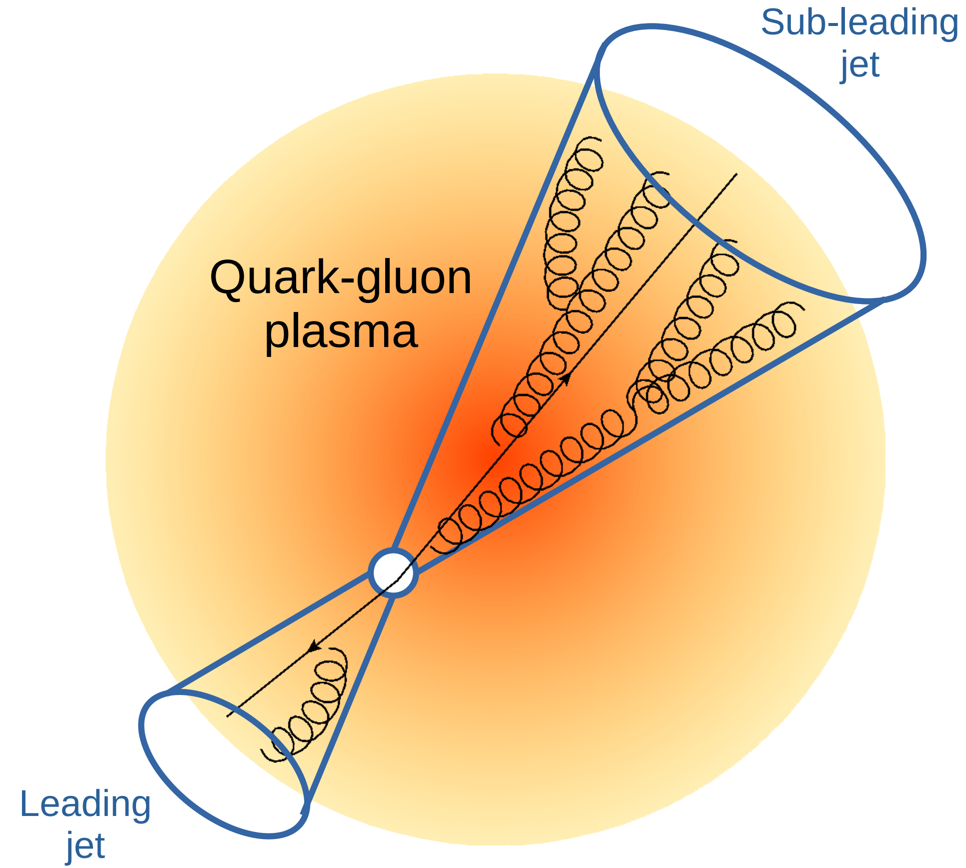
Jets in Heavy Ion Collisions



- Jets can be produced alongside the QGP in heavy ion collisions

- Interactions between jet partons and the QGP medium leads to modifications of jet properties

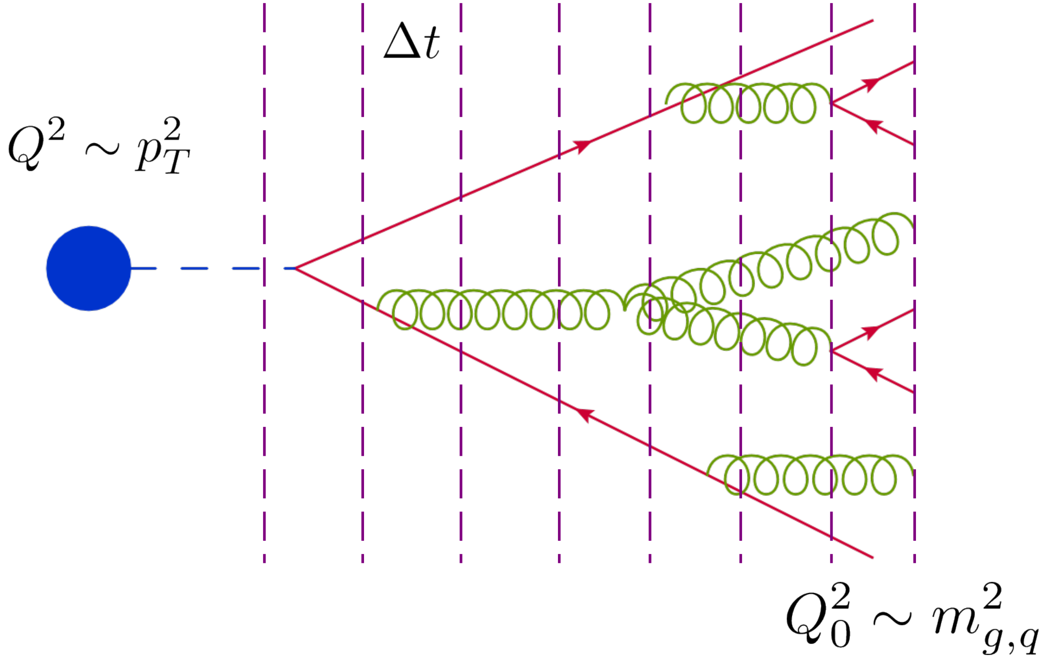
  ⟶ **Jet Energy Loss / Quenching**

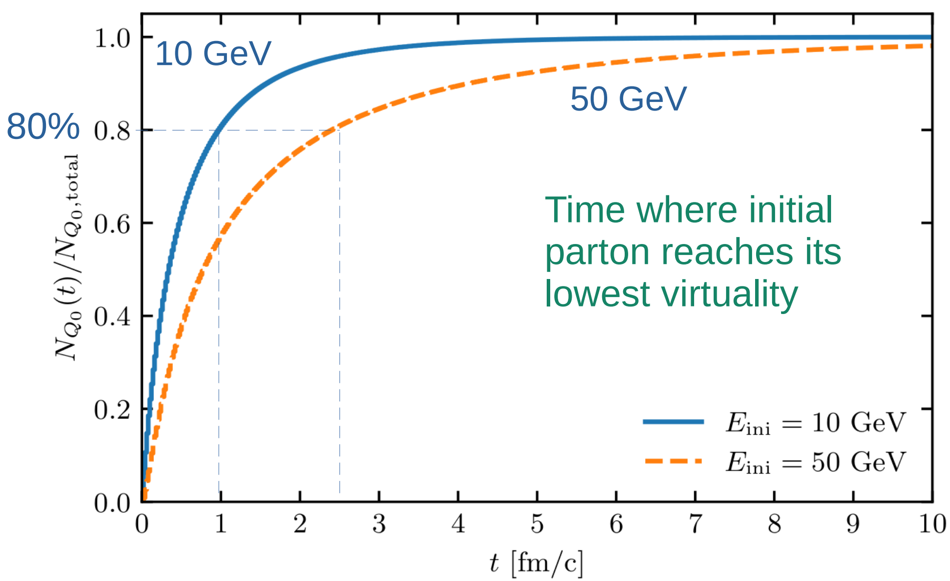
- **SUBA-Jet:**
  Monte Carlo for jet energy loss in heavy ion collisions

Vacuum Parton Shower

- Monte Carlo of a vacuum parton shower originally developed by Martin Rohrmoser
- Evolution according to the DGLAP equations from high virtuality $Q_{max} \sim p_T$ to low virtuality Q_0
- Time evolution split into time steps, mean life time

$$\Delta t = \tau = \frac{E}{Q^2}$$

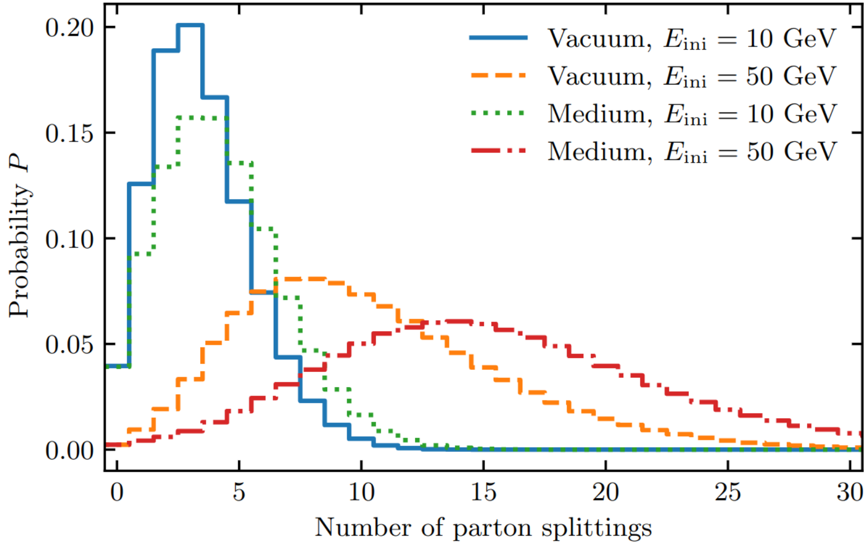


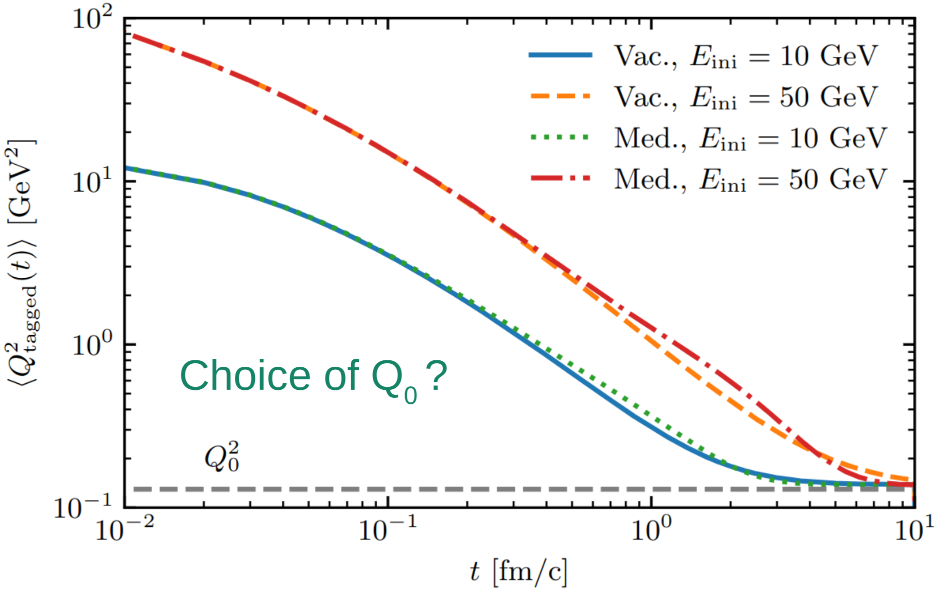


"Vacuum" Parton Shower in Medium

- Medium interactions for high Q regime resulting in virtuality increase, similar to YaJEM (T. Renk, 2008)

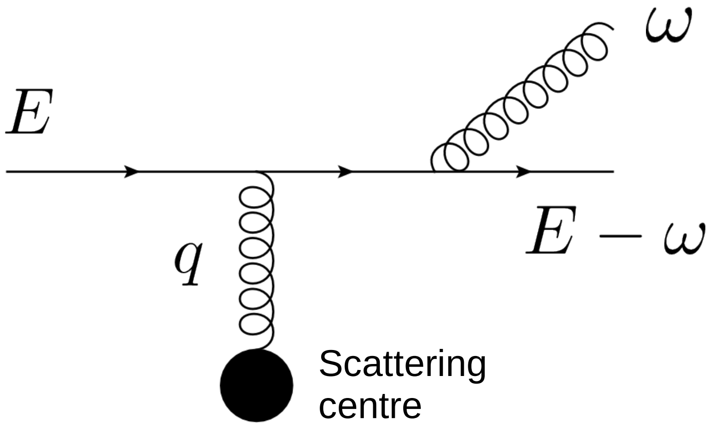
$$\frac{\mathrm{d}Q^2}{\mathrm{d}t} = \hat{q}(T)$$





Medium-Induced Single Radiation

- **Inelastic collision:**
  Single gluon emission from single medium scattering
- Original result from Gunion-Bertsch (1982)
  Generalised to massive case by Aichelin, Gossiaux, Gousset (2014)

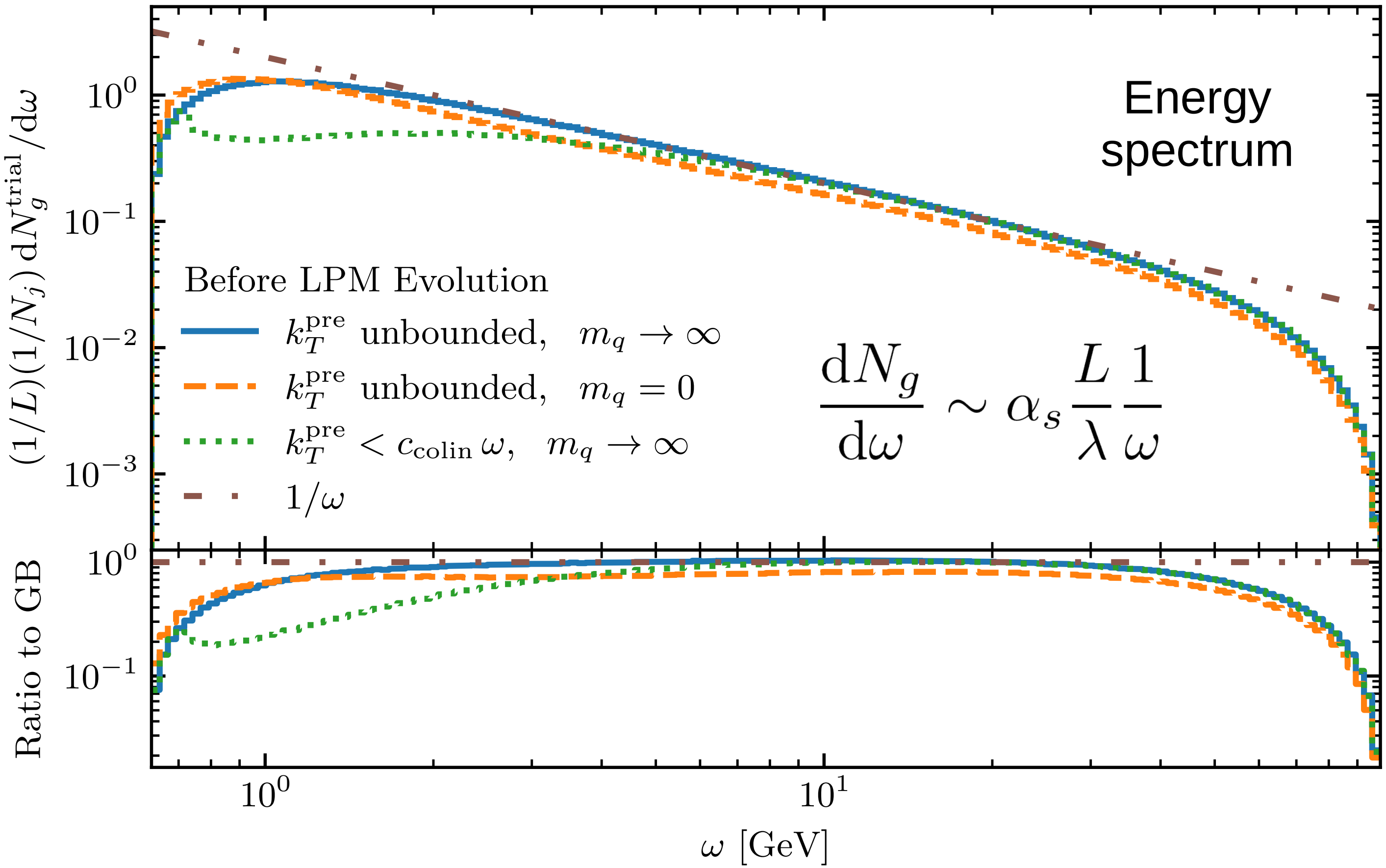


- Initial Gunion-Bertsch seed: i.e. radiation of a **preformed gluon** from a single scattering (Each parton can generate a number of preformed gluons)
- Gunion-Bertsch cross-section from scalar QCD

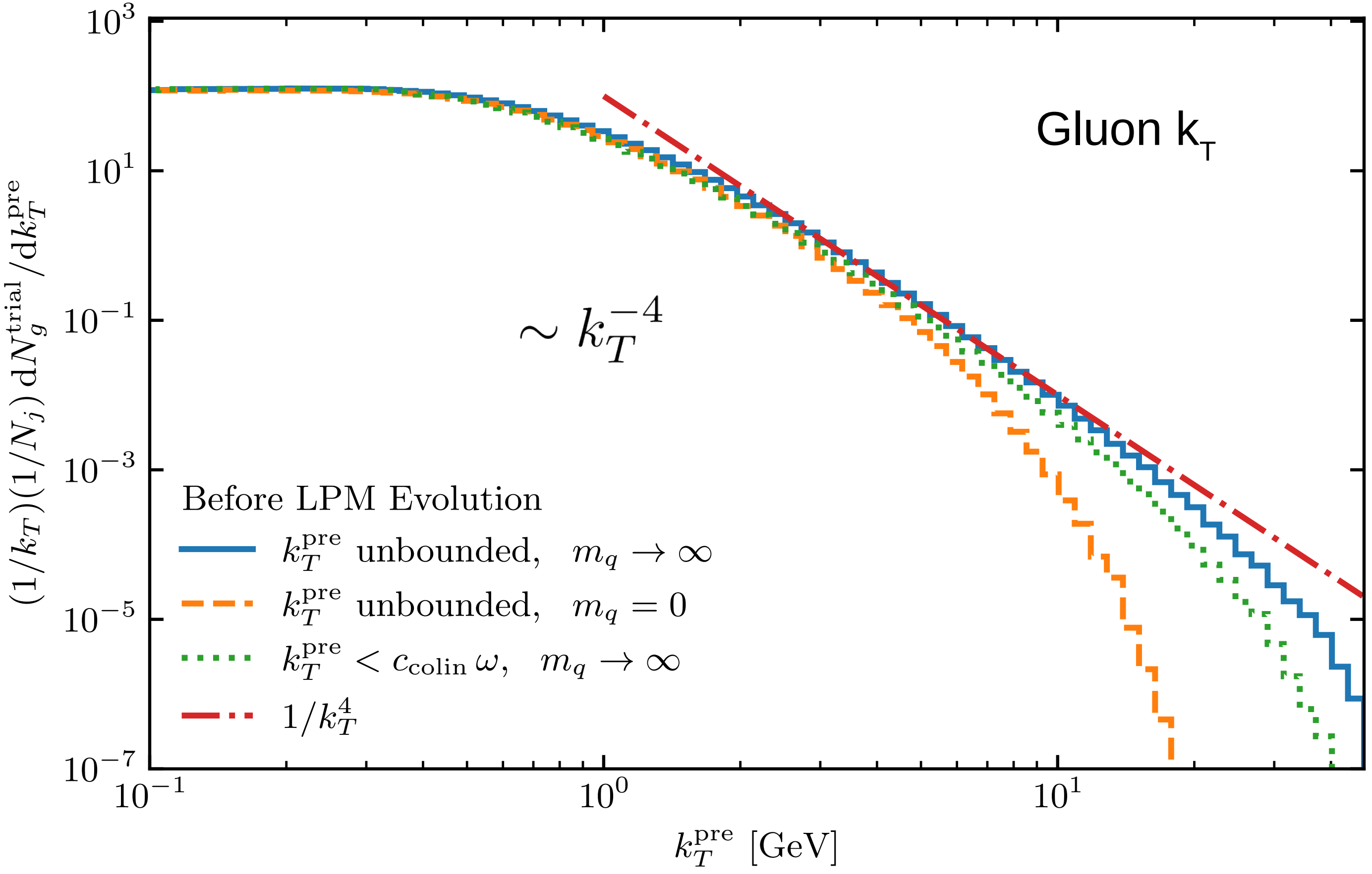
$$\frac{\mathrm{d}\sigma^{Qq\to Qqg}}{\mathrm{d}x\,\mathrm{d}^2k_T\,\mathrm{d}^2l_t} = \frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}^2l_t} P_g(x, k_T, l_T)\theta(\Delta)$$

$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}^2l_t} \sim \frac{8\alpha_s^2}{9(l_T^2+\mu^2)^2}$$

Medium-Induced Single Radiation



Medium-Induced Single Radiation



Coherency and the LPM Effect

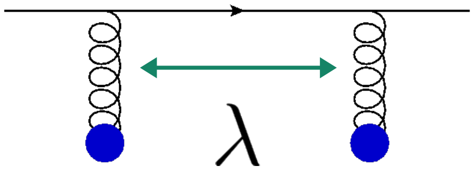
- The formation of the radiated gluon is a quantum mechanical process

  Formation time: $$t_f \sim \sqrt{\frac{\omega}{\hat{q}}}$$

- Coherence effects:
  Landau-Pomeranchuk-Migdal (LPM) effect

- Have to take into account multiple scatterings with the medium during the formation time

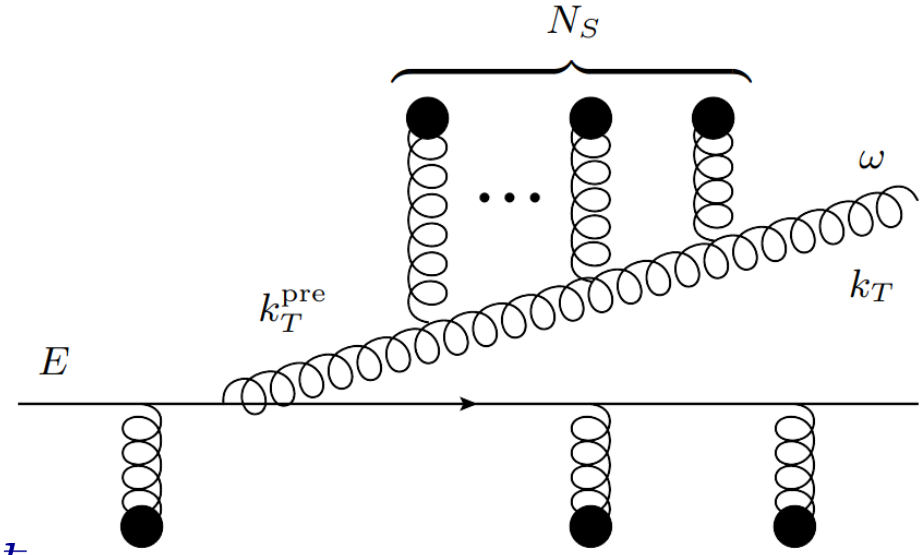
$$N_s = \frac{t_f}{\lambda}$$



$$\lambda \simeq \frac{\hbar c}{\alpha_s T}$$

$\omega =$ gluon energy

$\hat{q} =$ medium modifications



$L =$ path length of medium

Implementation of the LPM Effect

- At each timestep:
  - Elastic scattering with prob. $\Gamma_{\mathrm{el}}\Delta t$

$$\Gamma^q_{\mathrm{el}} = \left(1 + \frac{N_f}{N}\right) \frac{(N^2-1)T^3}{\pi\hbar c} \frac{4\alpha_s^2}{\mu^2}$$

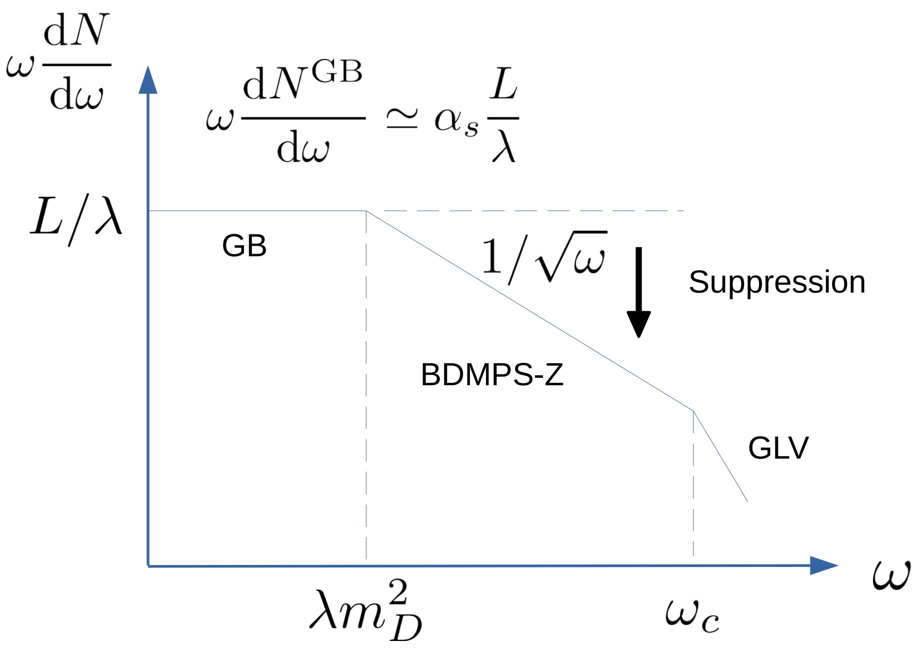
  - Radiation of preformed gluon with prob. $\Gamma_{\mathrm{inel}}\Delta t$

- BDMPS-Z spectrum at intermediate energies achieved by suppressing GB seed by

$$1/N_s$$

Like in Zapp, Stachel, Wiedemann, JHEP 07 (2011), 118

Radiation energy spectrum:



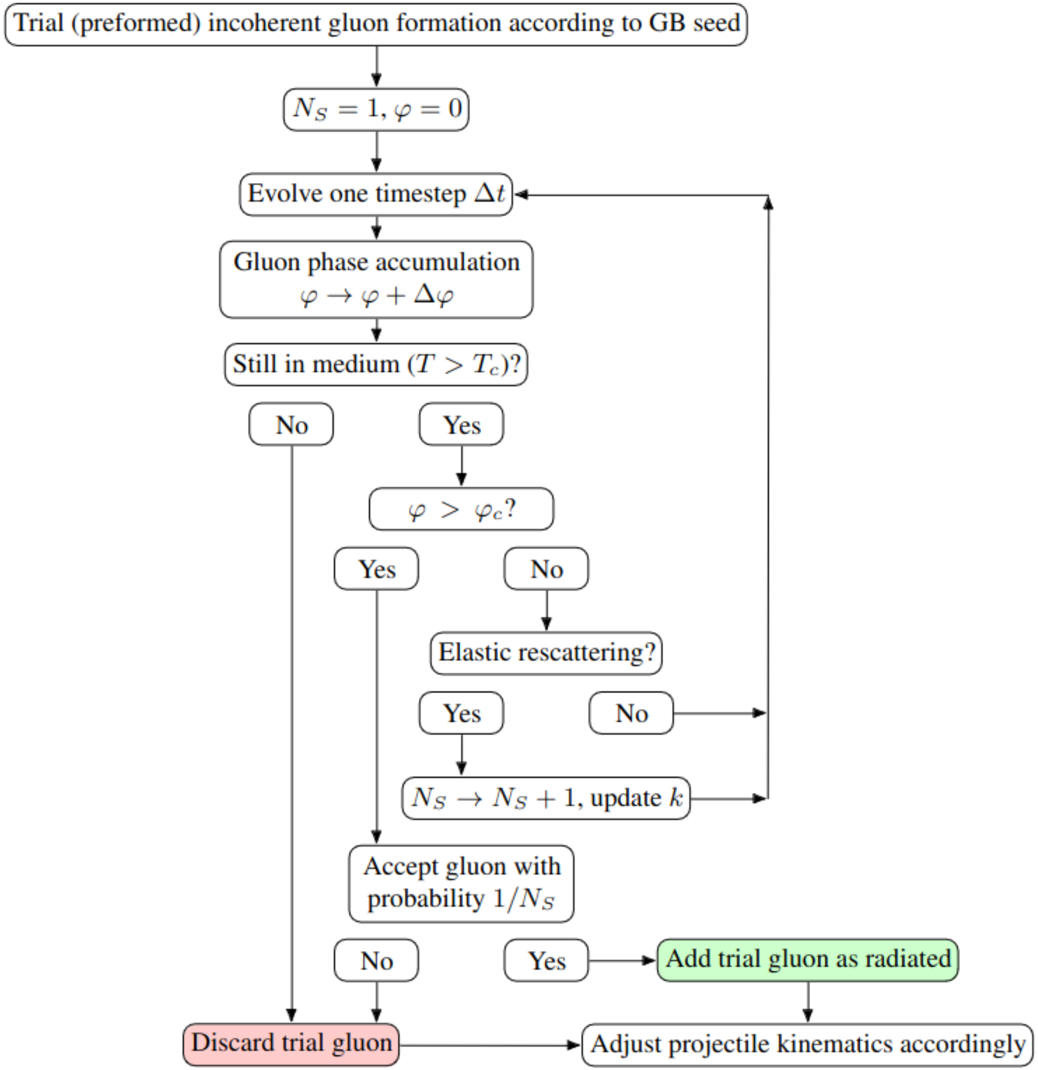
$$\omega\frac{\mathrm{d}N^{\mathrm{BDMPS\text{-}Z}}}{\mathrm{d}\omega} \simeq \alpha_s \sqrt{\frac{\hat{q}L^2}{\omega}}$$

The Algorithm

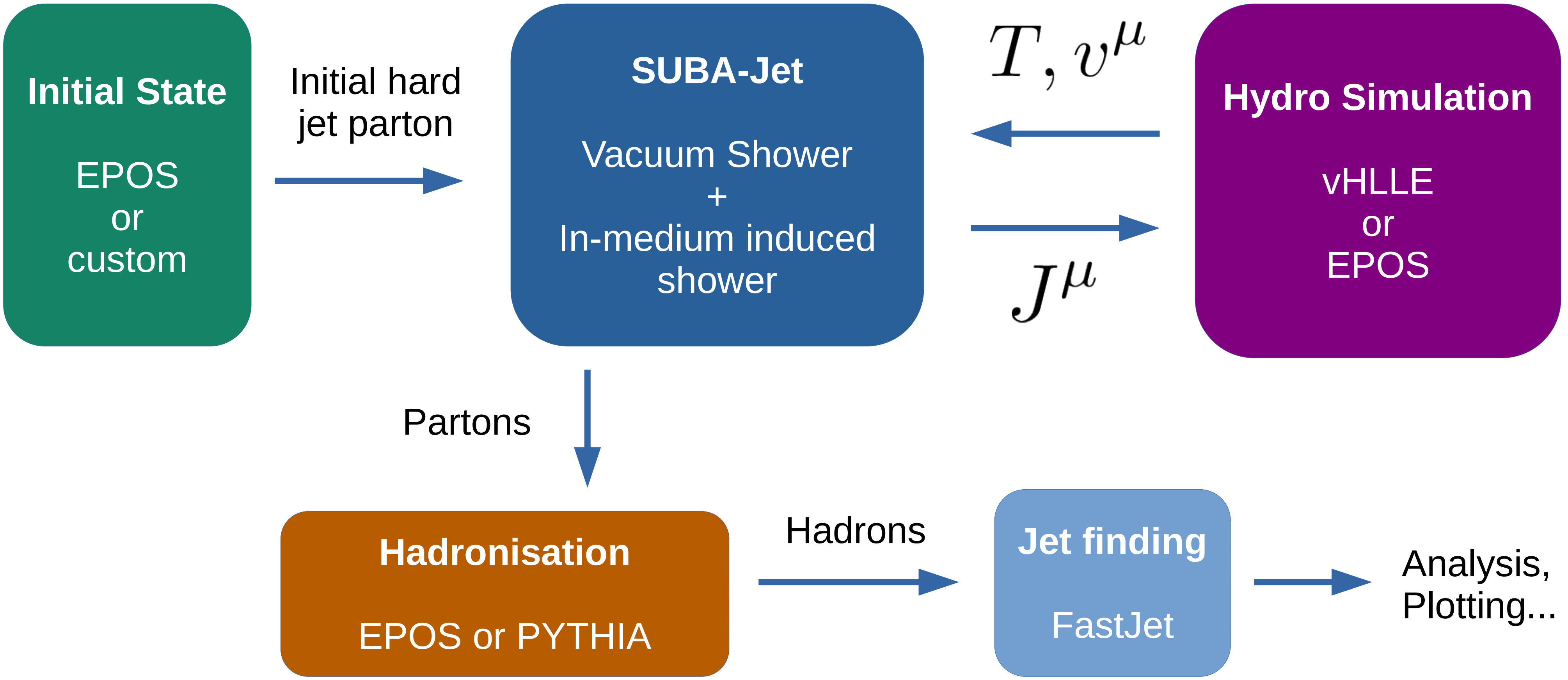
Flow diagram:

Monte Carlo algorithm for the coherent medium-induced gluon radiation in our model

Various parameters and settings can be changed and tuned to compare distributions

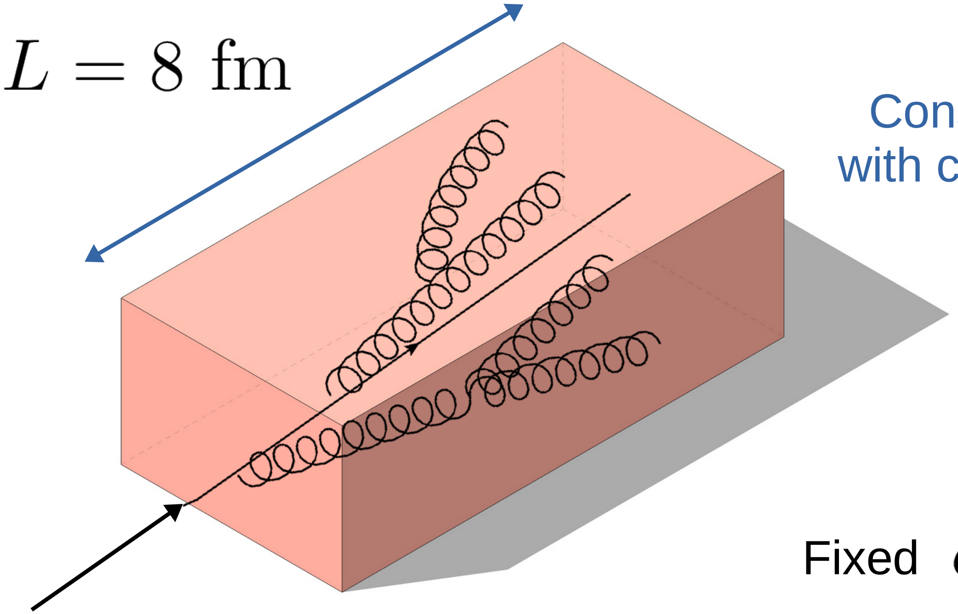


The Monte Carlo



First Results

$L = 8$ fm



Consider brick medium
with constant temperature

$T = 400$ MeV

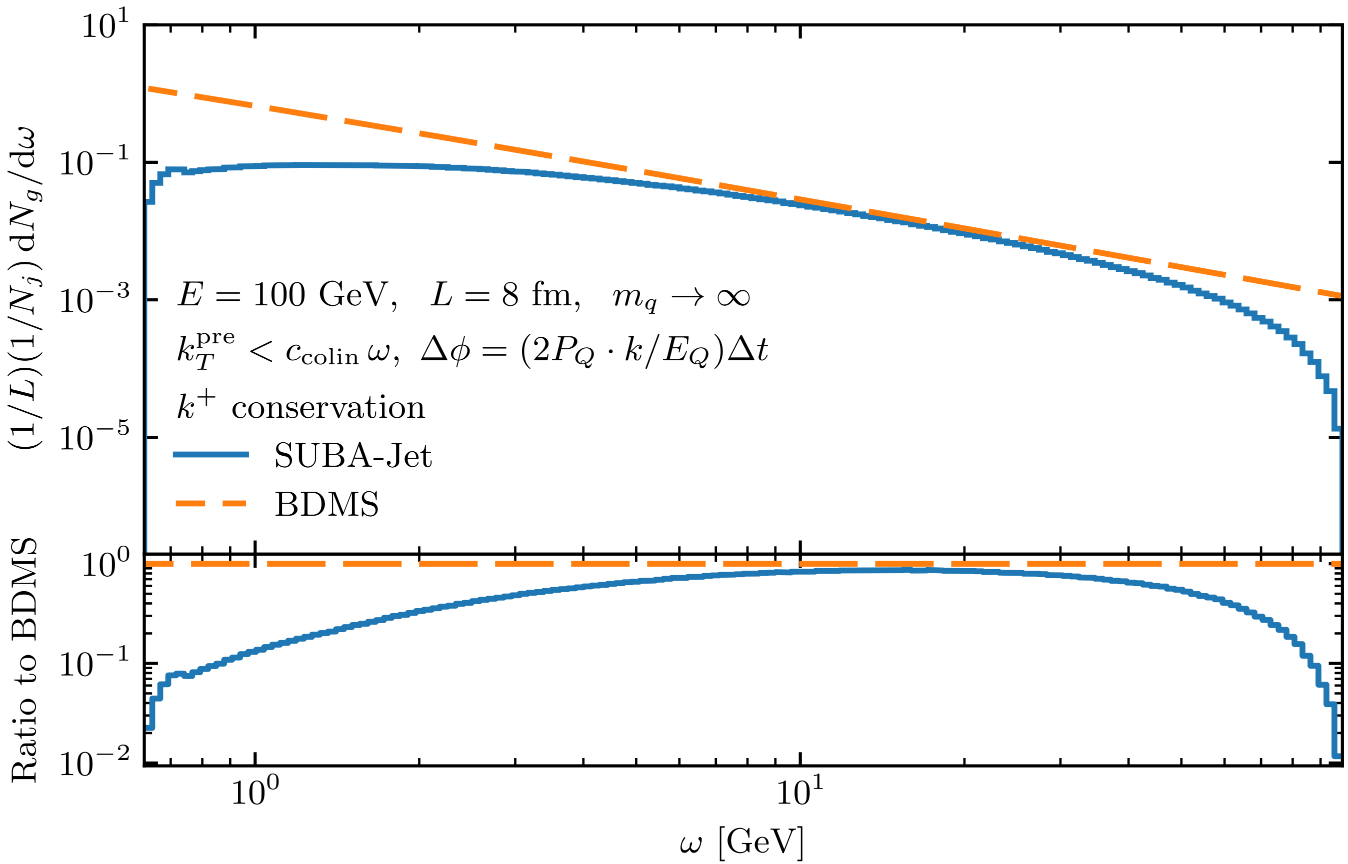
Mono-energy
(low virtuality)
quark gun

$E = 100$ GeV

Fixed $\alpha_s = 0.4$

**We want to reproduce theoretical expectation
and check effect of model parameters**

Reproduction of the BDMPS-Z Limit



Energy spectrum

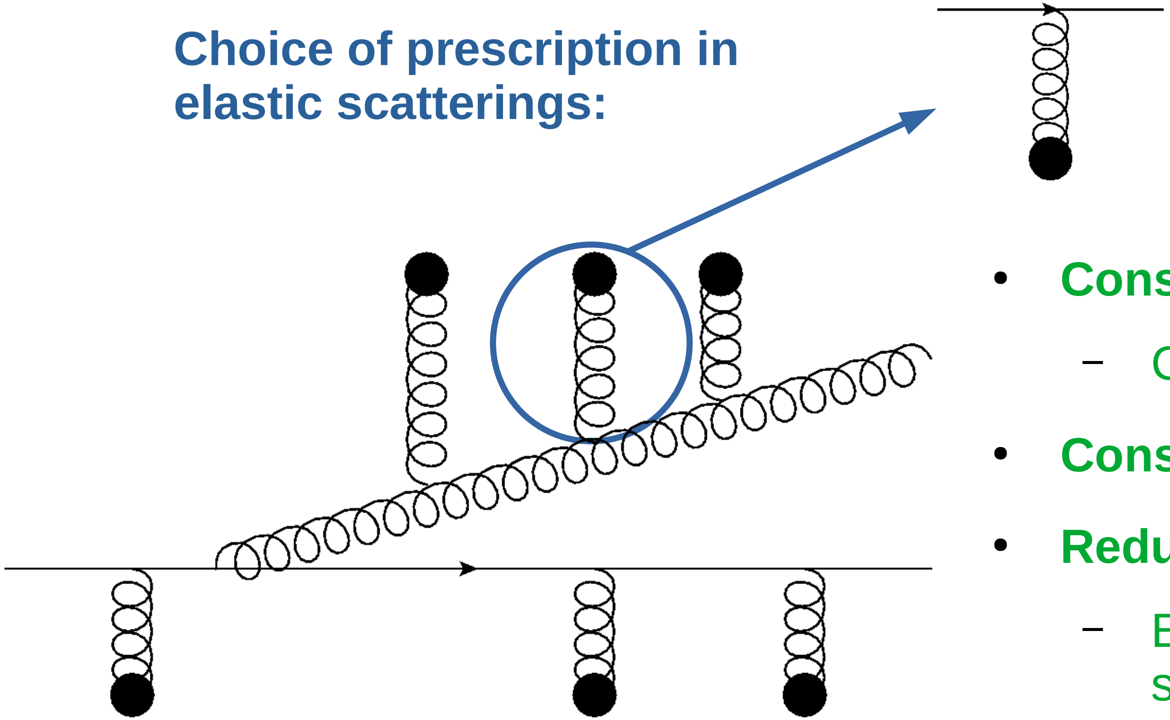
$$\frac{\mathrm{d}N}{\mathrm{d}\omega} \quad \text{vs} \quad \omega$$

Reproduces BDMPS-Z for intermediate energies

$$\frac{\mathrm{d}N}{\mathrm{d}\omega} \sim \frac{1}{\omega^{3/2}}$$

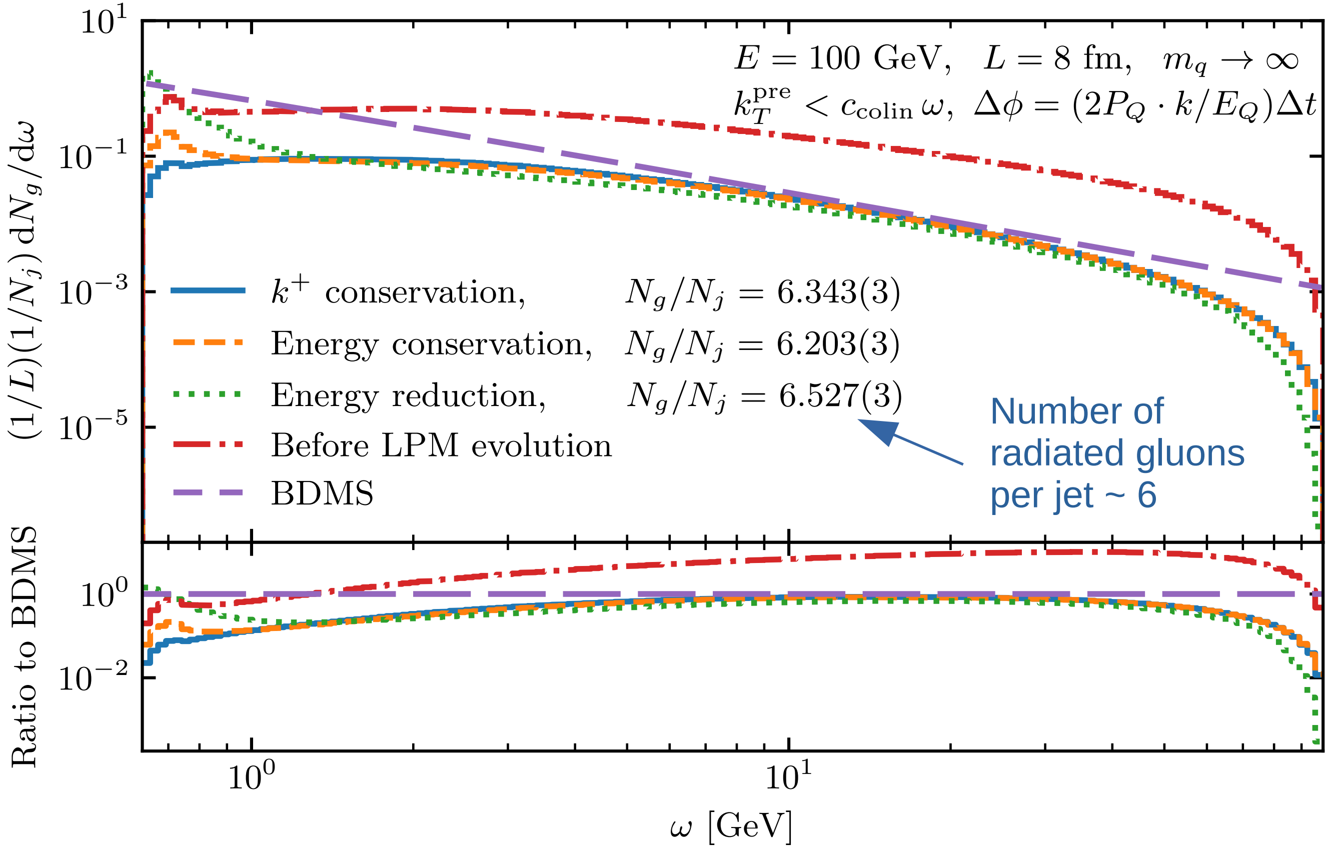
Reproduction of the BDMPS-Z Limit

Choice of prescription in elastic scatterings:



- **Conserve k^+?**
  - Considered by BDMPS-Z
- **Conserve energy?**
- **Reduce energy?**
  - Energy gain by the medium parton is subtracted from the projectile parton

Reproduction of the BDMPS-Z Limit

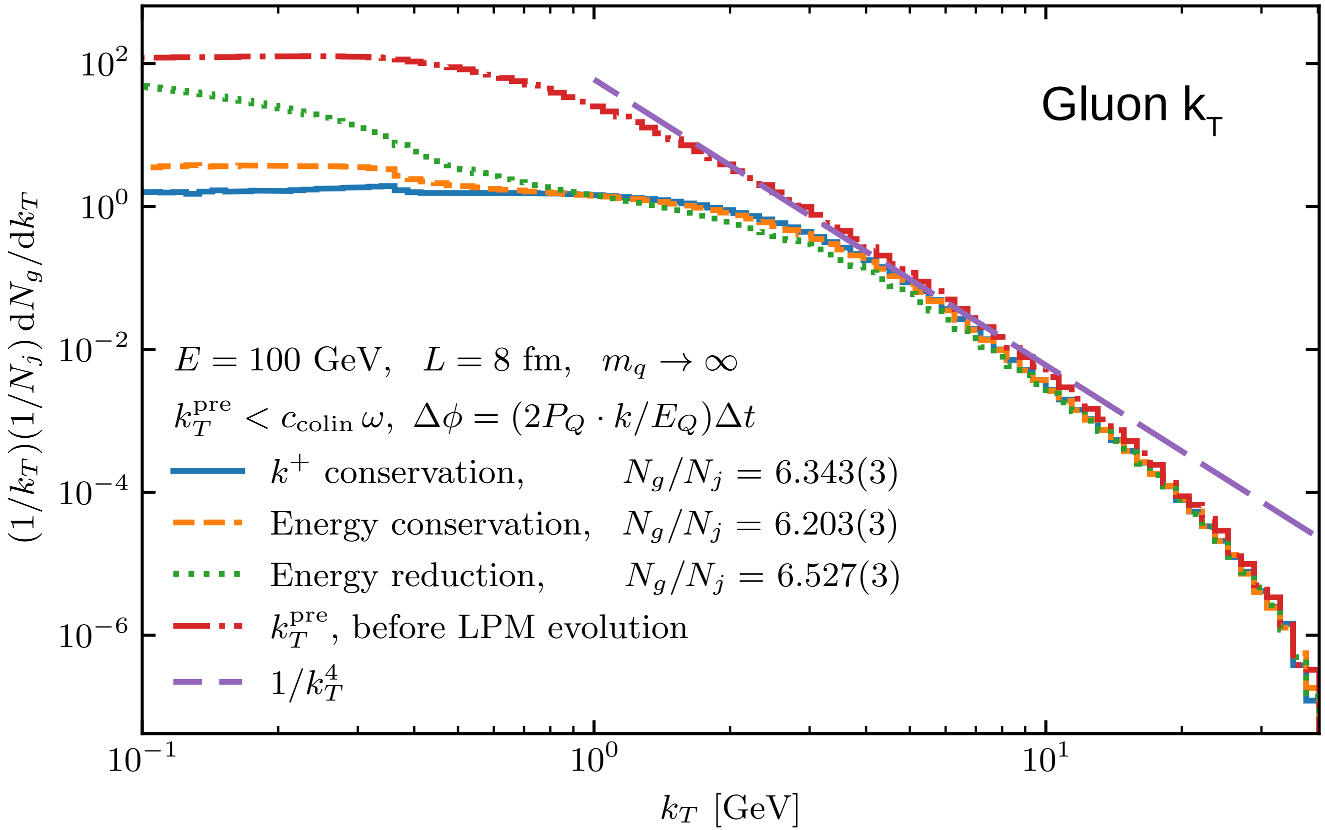


Same BDMS behaviour at intermediate energies

Difference at small energies

Effect of the phase accumulation on the energy distribution

Reproduction of the BDMPS-Z Limit

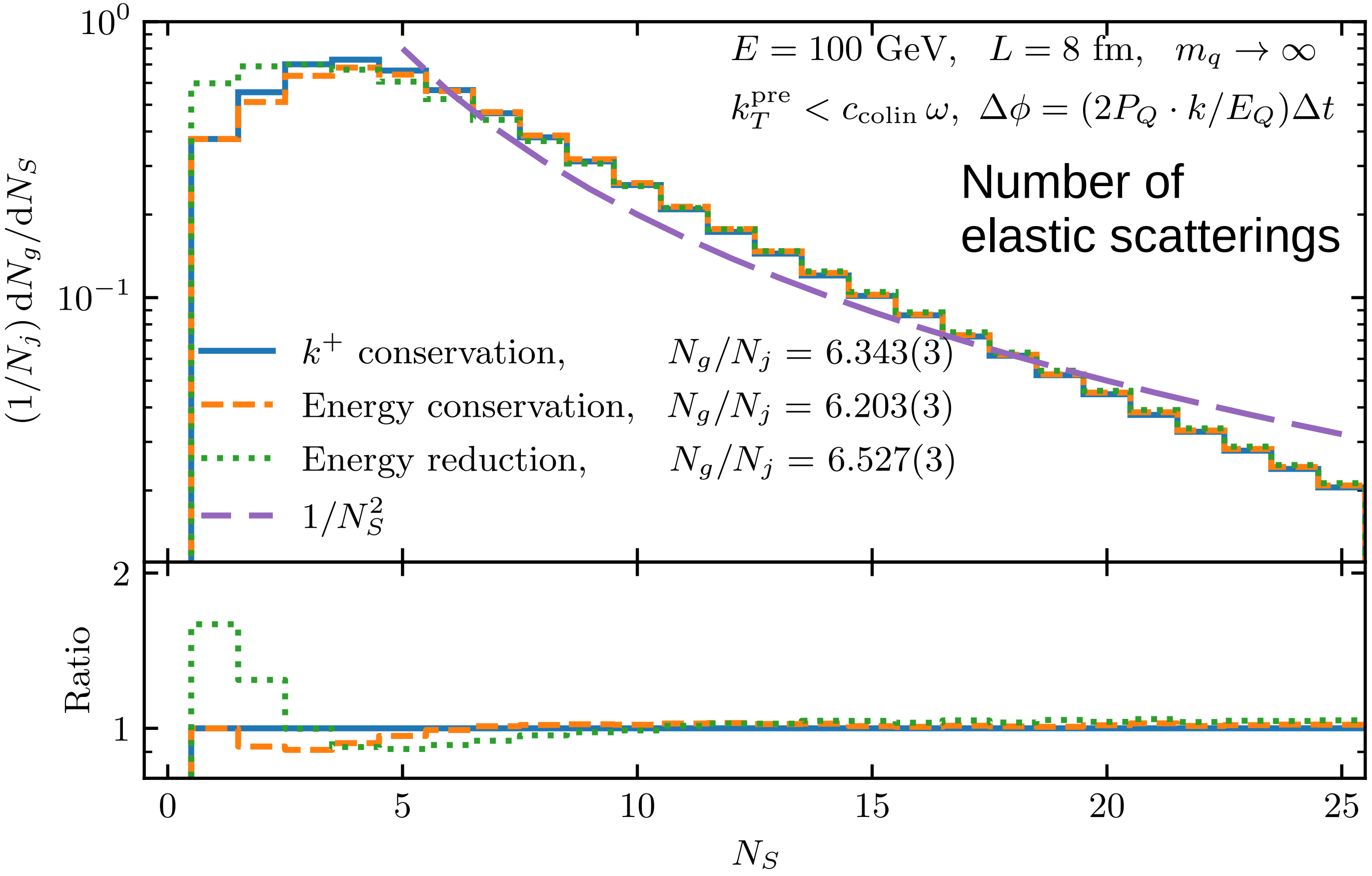


Large difference at small k_T

The large k_T tail goes as ~ k_T^{-4} as expected

$$\frac{\mathrm{d}N}{\mathrm{d}k_T} \sim \frac{1}{k_T^3}$$

Reproduction of the BDMPS-Z Limit



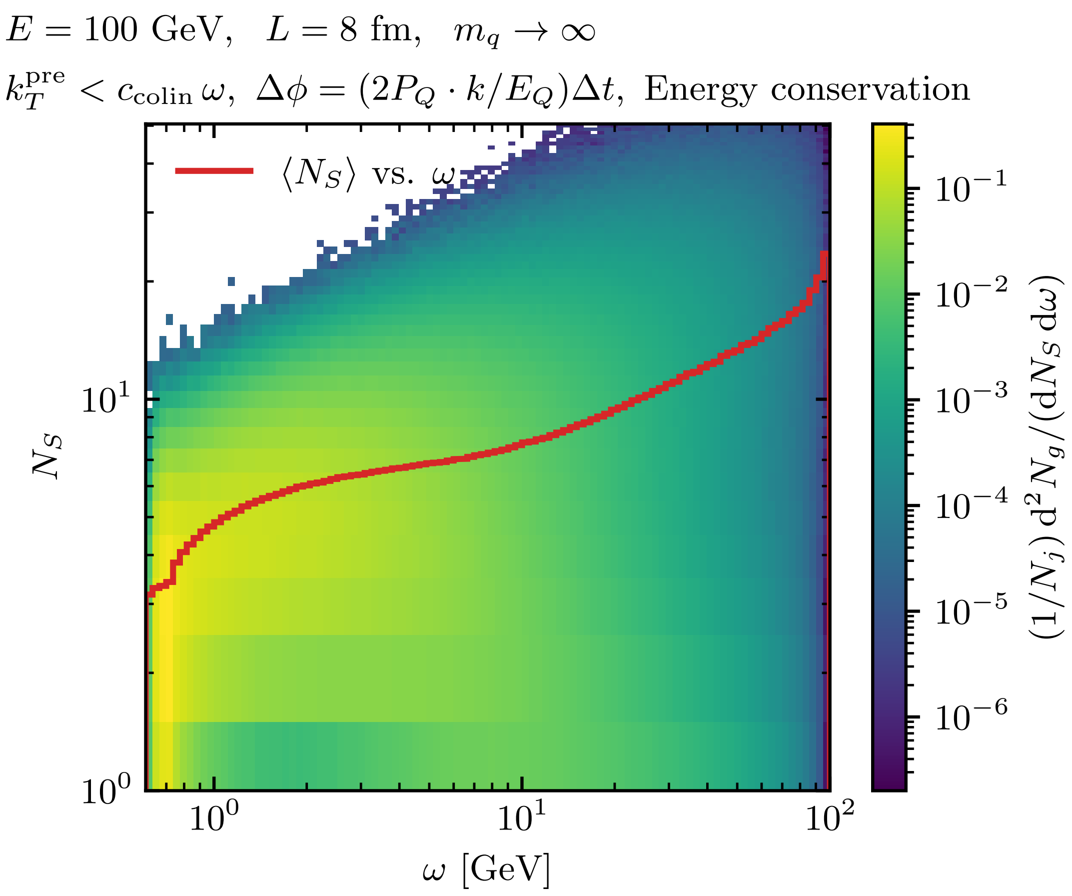
The number of elastic scatterings during LPM evolution is expected to go as

$$\frac{\mathrm{d}N}{\mathrm{d}N_S} \sim \frac{1}{N_S^2}$$

The energy reduction case is larger at $N_S = 1$

→ Larger probability of emission

Reproduction of the BDMPS-Z Limit



Double differential plot in N_s and ω

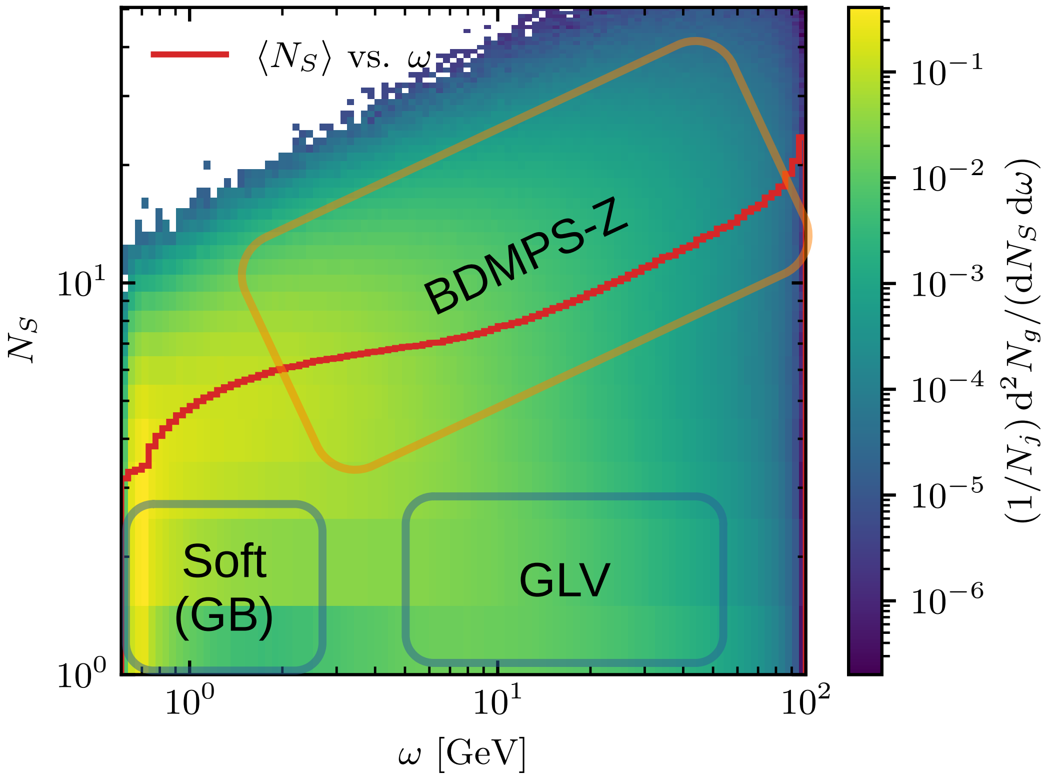
Red line: ‹N_s› vs. ω

$$N_S \sim t_f \sim \sqrt{\omega}$$

Reproduction of the BDMPS-Z Limit

$E = 100$ GeV, $L = 8$ fm, $m_q \to \infty$

$k_T^{\mathrm{pre}} < c_{\mathrm{colin}}\,\omega$, $\Delta\phi = (2P_Q \cdot k/E_Q)\Delta t$, Energy conservation



Double differential plot in N_s and ω

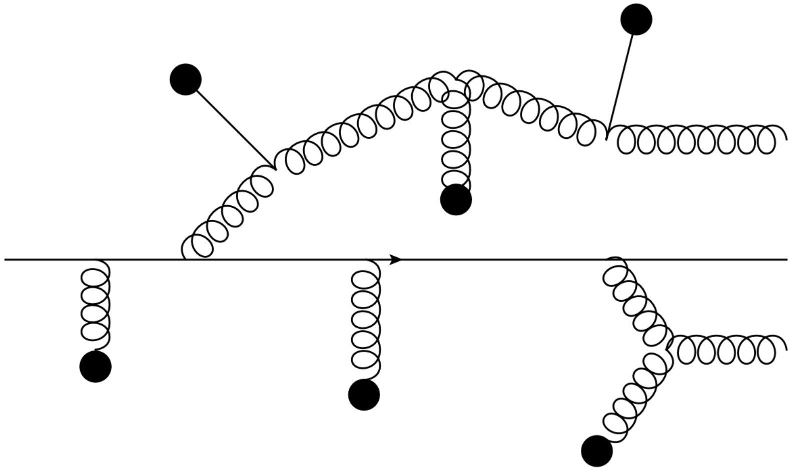
Red line: $\langle N_s \rangle$ vs. ω

$$N_S \sim t_f \sim \sqrt{\omega}$$

Convolution of different distributions

The Role of the Phase Accumulation

Choice of phase accumulation of the preformed (trial) gluons:



- **What is used in JEWEL:**

$$\Delta\varphi = \frac{k_T^2}{\omega}\Delta t$$

- **Including thermal gluon mass:**

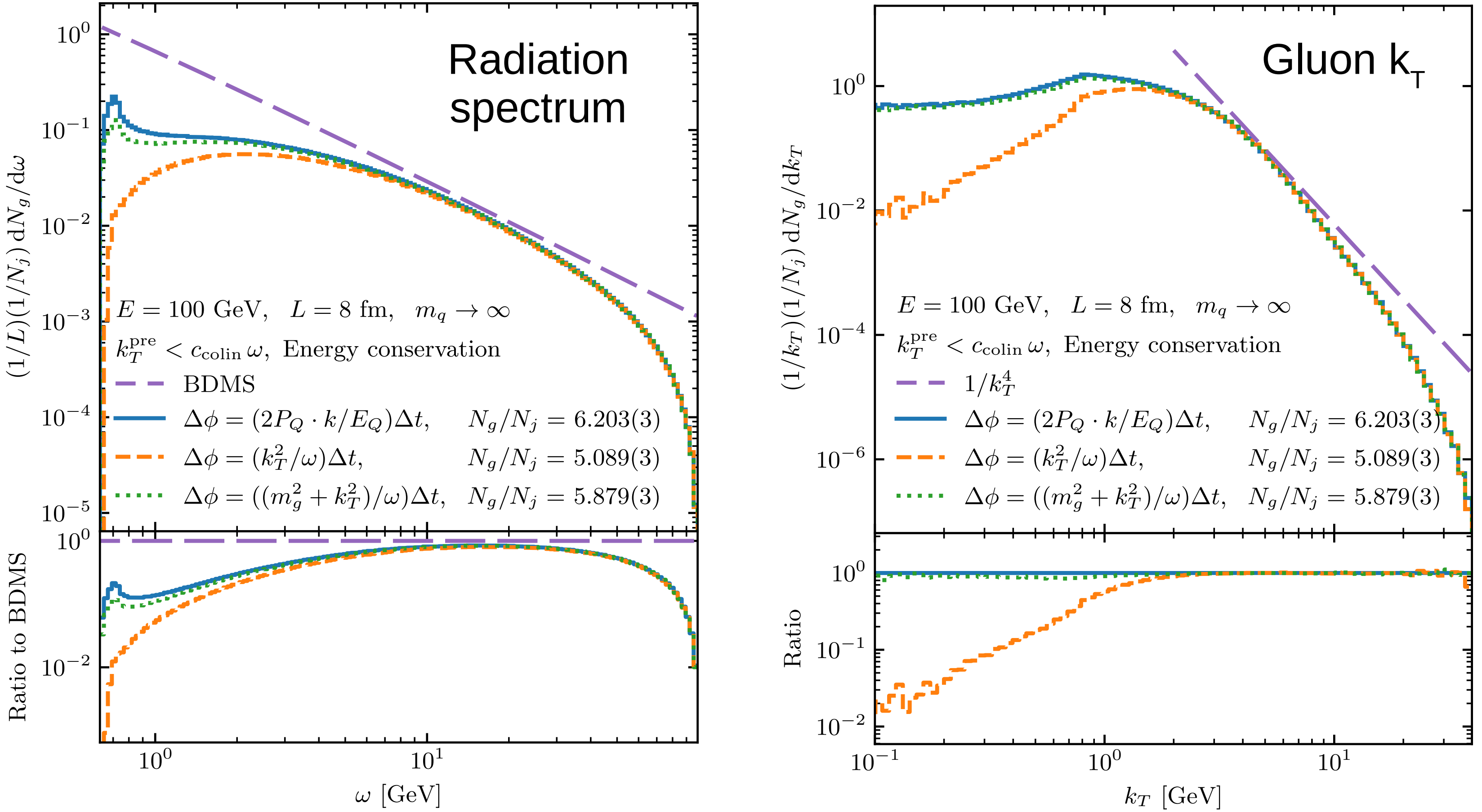
$$\Delta\varphi = \frac{m_g^2 + k_T^2}{\omega}\Delta t$$

- **More general formula:**

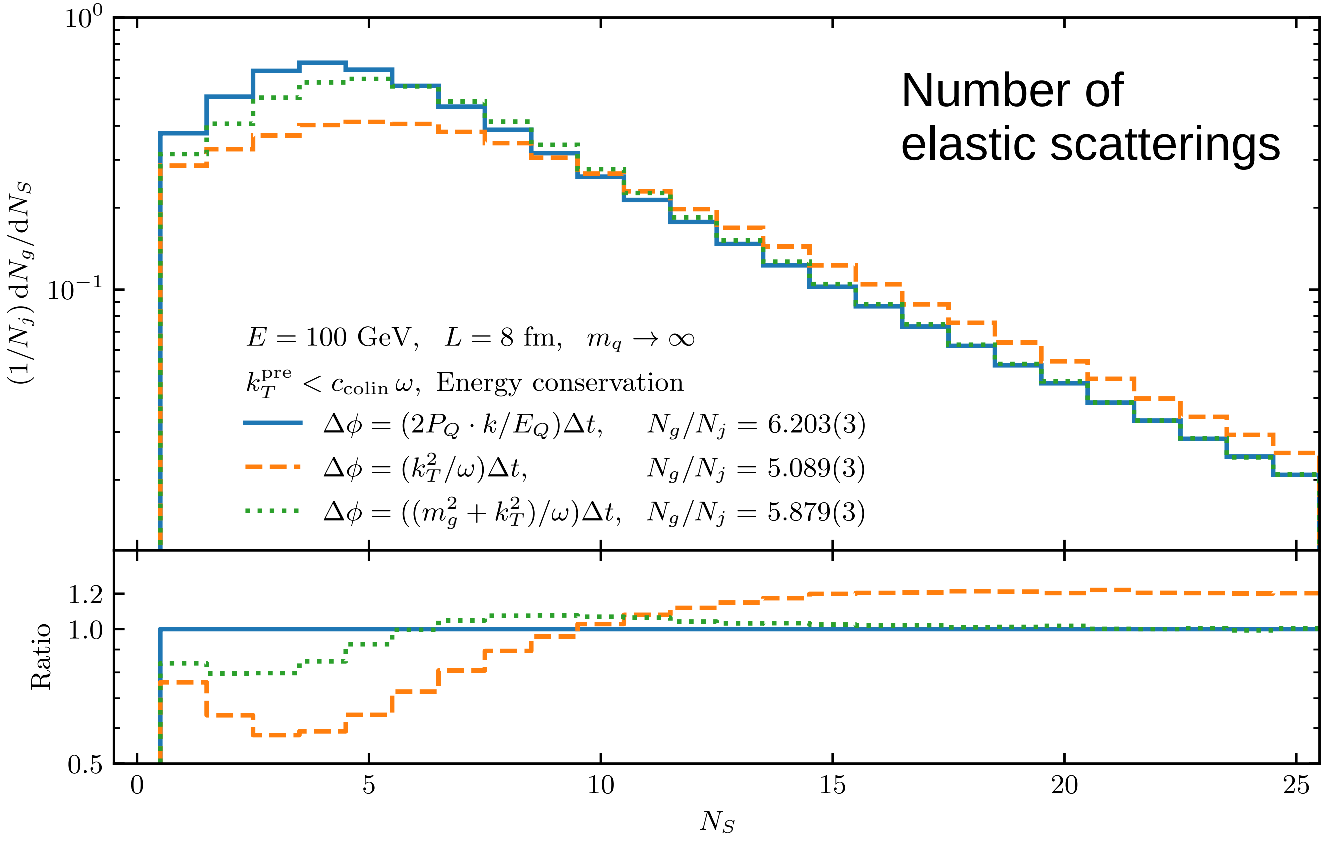
$$\Delta\varphi = \frac{2P_Q \cdot k}{E_Q}\Delta t$$

The Role of the Phase Accumulation

Effects at low energy & low k_T



The Role of the Phase Accumulation



When neglecting the gluon mass in the phase accumulation, a larger path length is required to have a comparable overall mumber off radiations

Looking Forward: Towards More Realism

Next step:

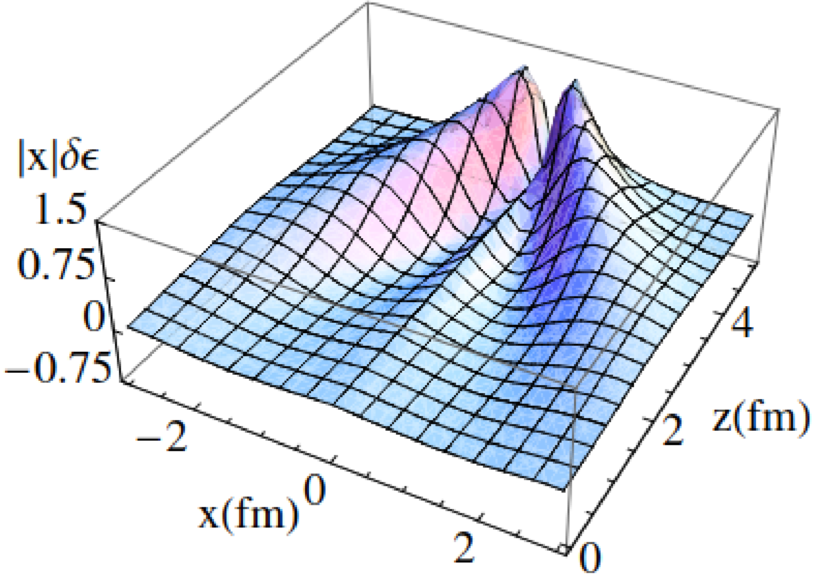
- Interface with vHLLE to get hydro evolution of the medium
- Running strong coupling in elastic scatterings
- Start with high virtuality partons
- Sampling of initial parton p_T

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} \sim p_T^{-6.5}$$

- Run with hadronisation and jet finding

Looking Forward: Effect on the Medium

The jet also affects the medium



G.-Y. Qin, A. Majumder, H. Song, U. Heinz
0903.2255 [nucl-th]

'Wake wave'
in the medium
due to the jet

Summary

- We have presented a new model for jet energy loss in heavy ion collisions
- Implementation in a Monte Carlo framework

- **1st step done**:
  - Reproduction of the BDMS radiation energy spectrum
  - Shown effects of different model assumptions

- **2nd step:** First results with hydro evolution interface to vHLLE
- **3rd step:** Implementation within the new EPOS4
  - **EPOS4+JETS –** Initial state, hydro, and hadronisation from EPOS4

Thank you for your attention!