SUBA-Jet

A New Coherent Jet Energy Loss Model For Heavy Ion Collisions

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arXiv:2404.14579 [hep-ph]

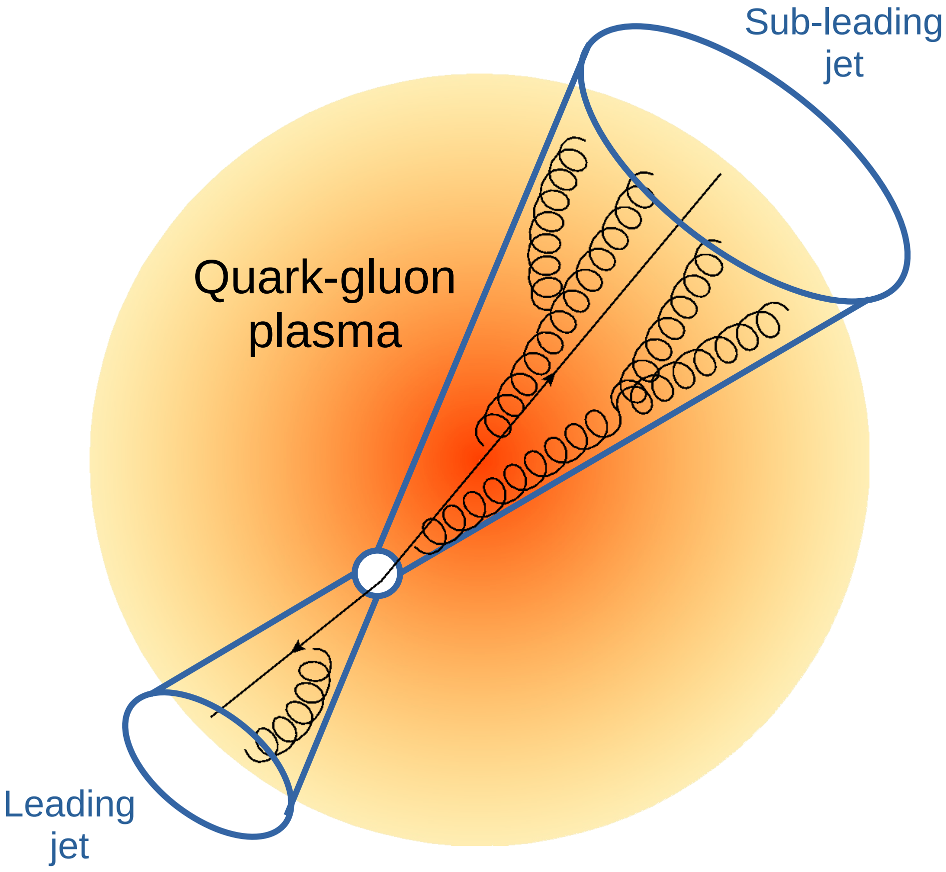
CNRS IN2P3 Les deux infinis

Assemblée Générale 2024 du GDR QCD
Université de Tours

28 May 2024

Subatech

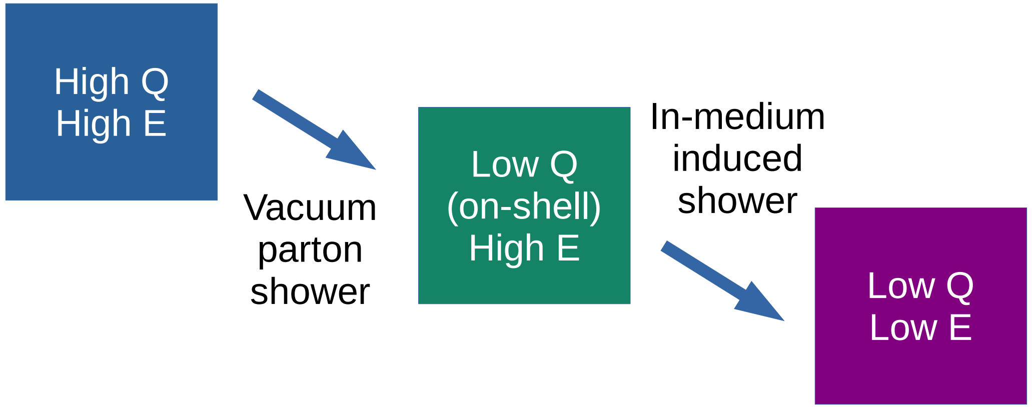
Jets in Heavy Ion Collisions



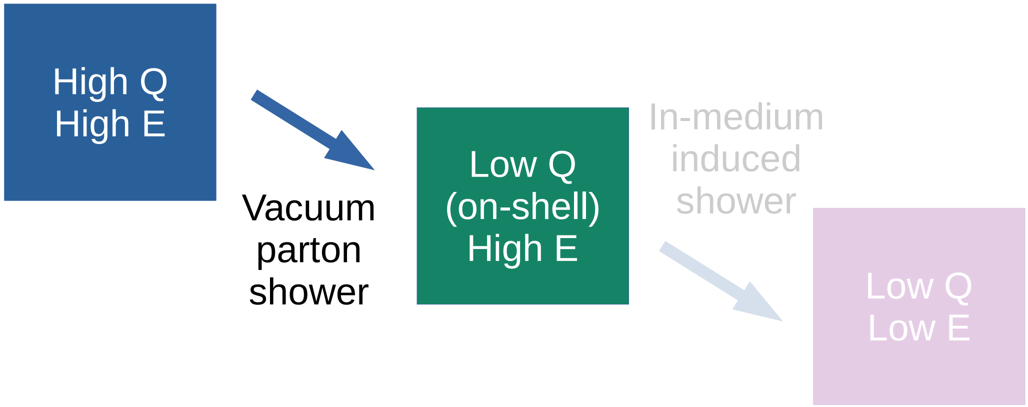
- Interactions between jet partons and the QGP medium leads to modifications of jet properties

  → **Jet Energy Loss / Quenching**

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



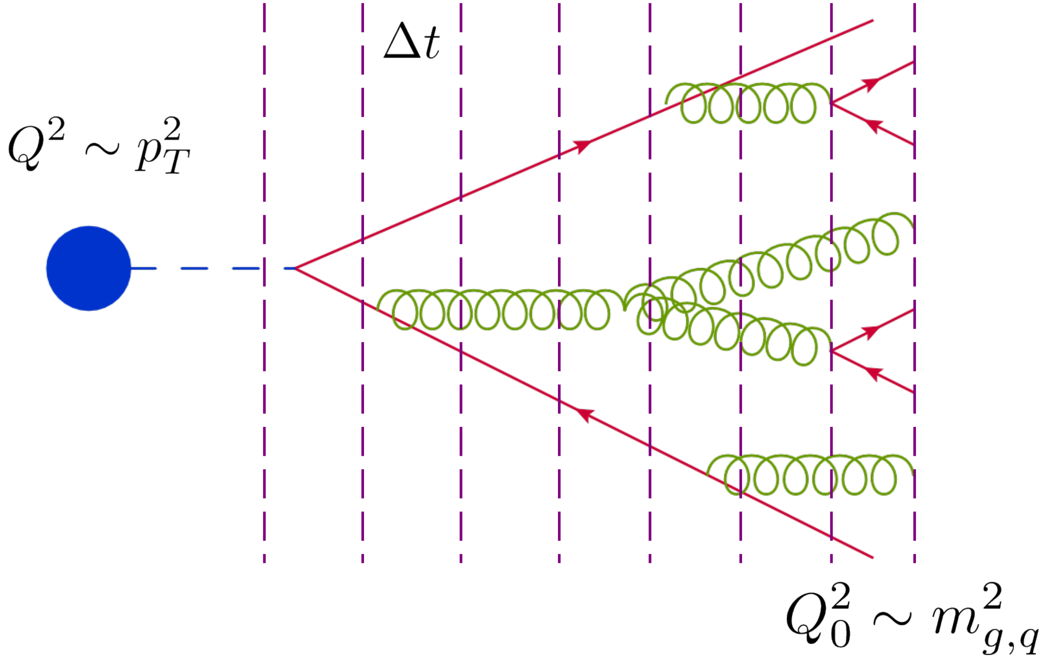
High Virtuality Regime

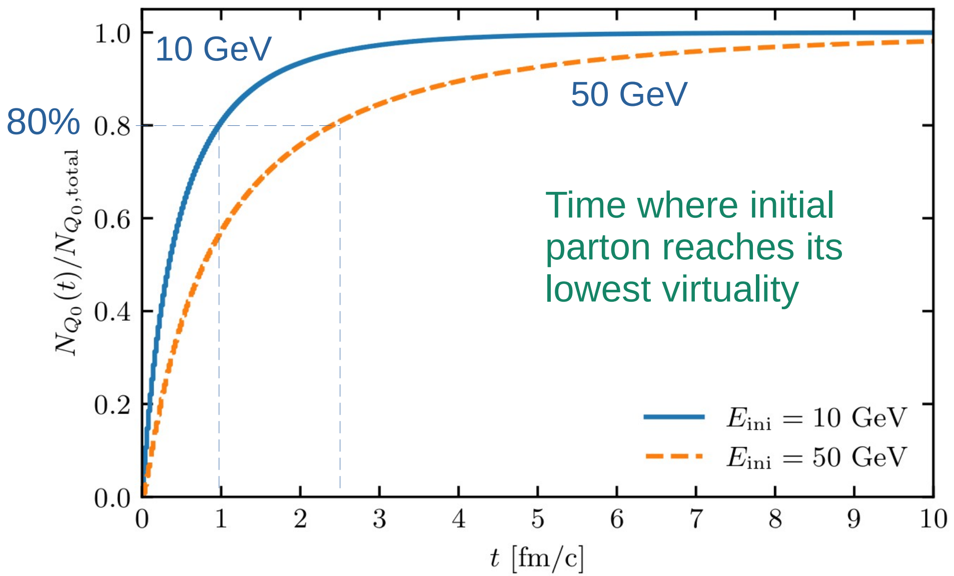


Vacuum Parton Shower

- 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

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

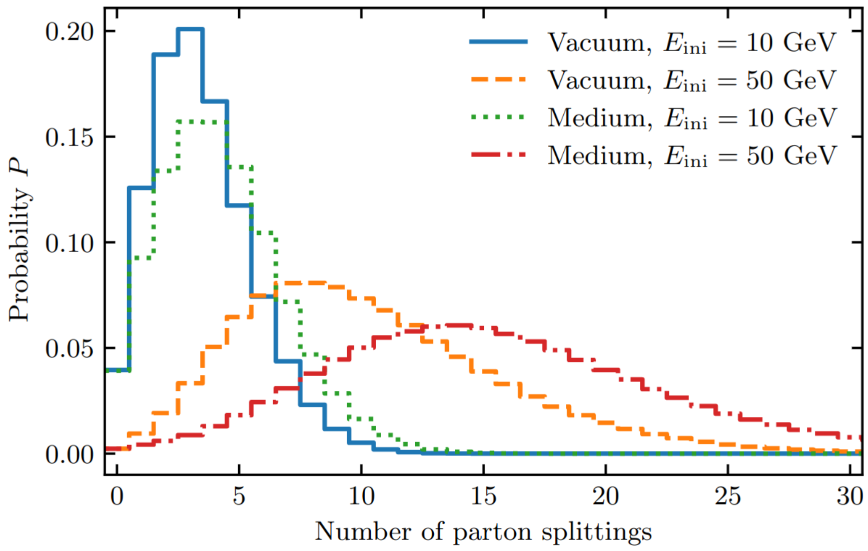


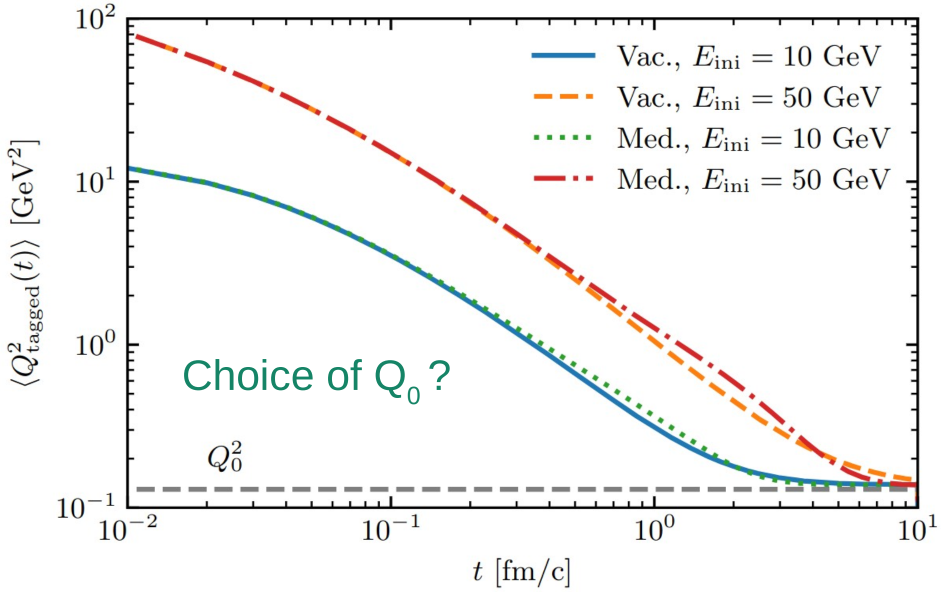


“Vacuum” Parton Shower in Medium

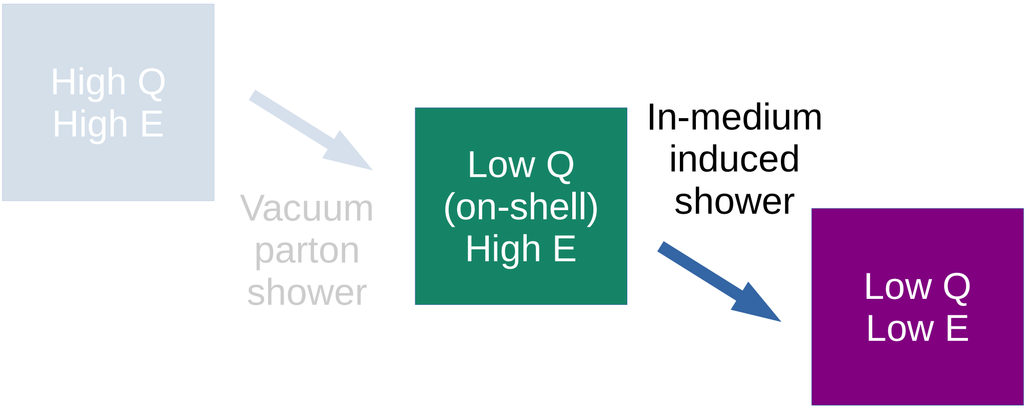
- Medium interactions for high Q regime resulting in virtuality increase, similar to YaJEM (T. Renk, 2008)

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





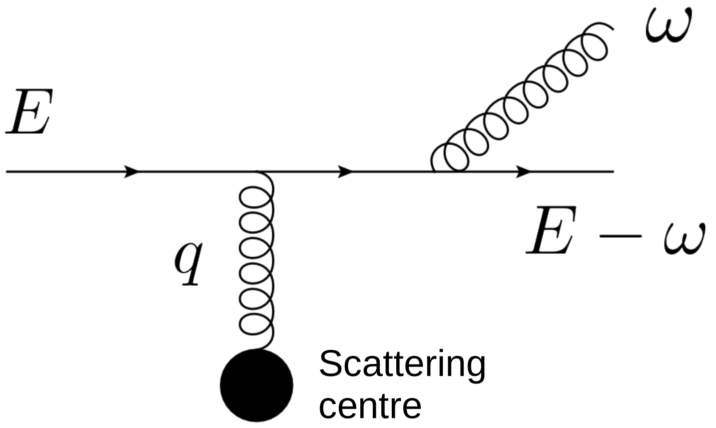
Low Virtuality Regime



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)



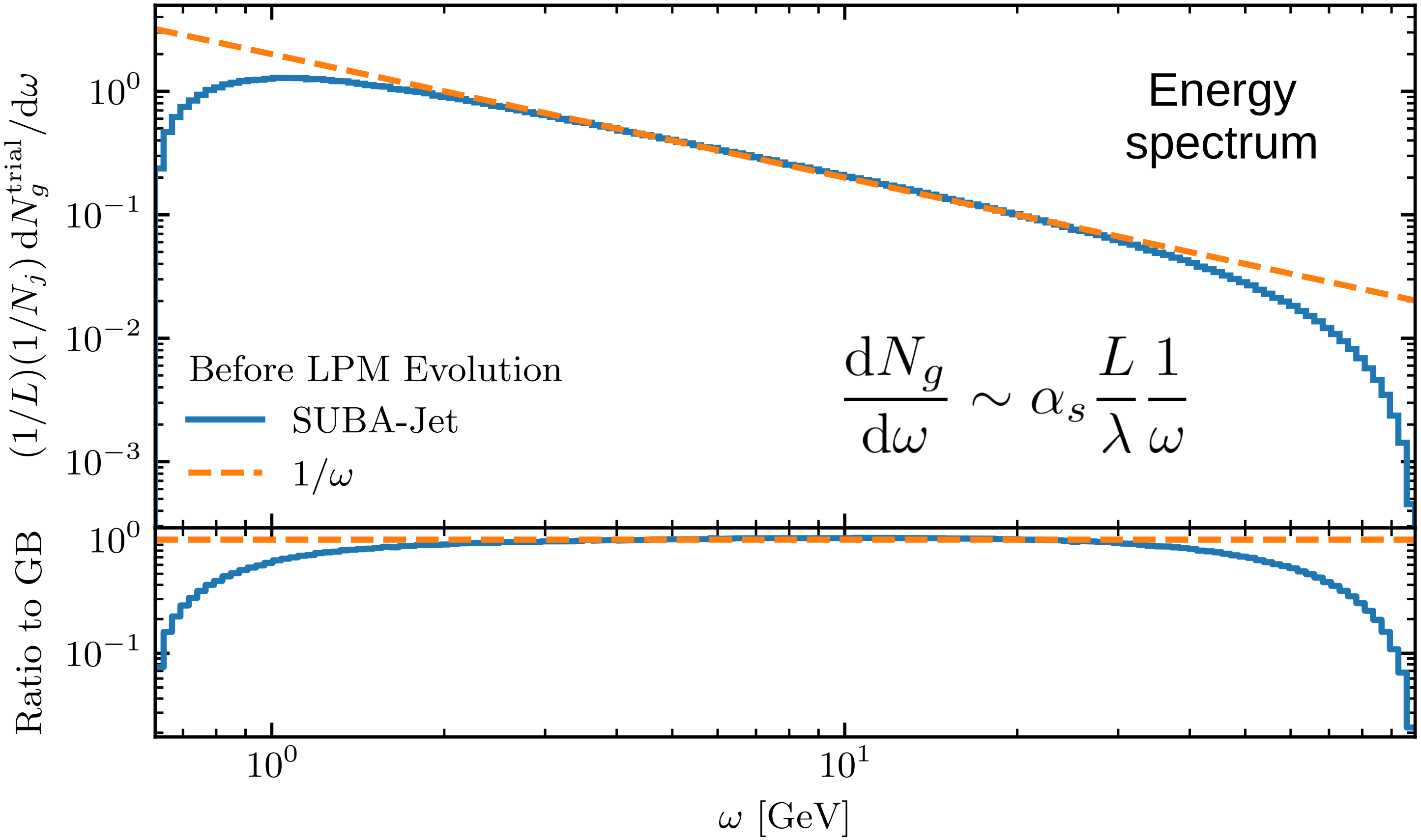
- Initial Gunion-Bertsch seed: i.e. radiation of a **preformed gluon** from a single scattering
  (Each parton can generate a number of preformed gluons)

- Gunion-Bertsch cross-section from scalar QCD

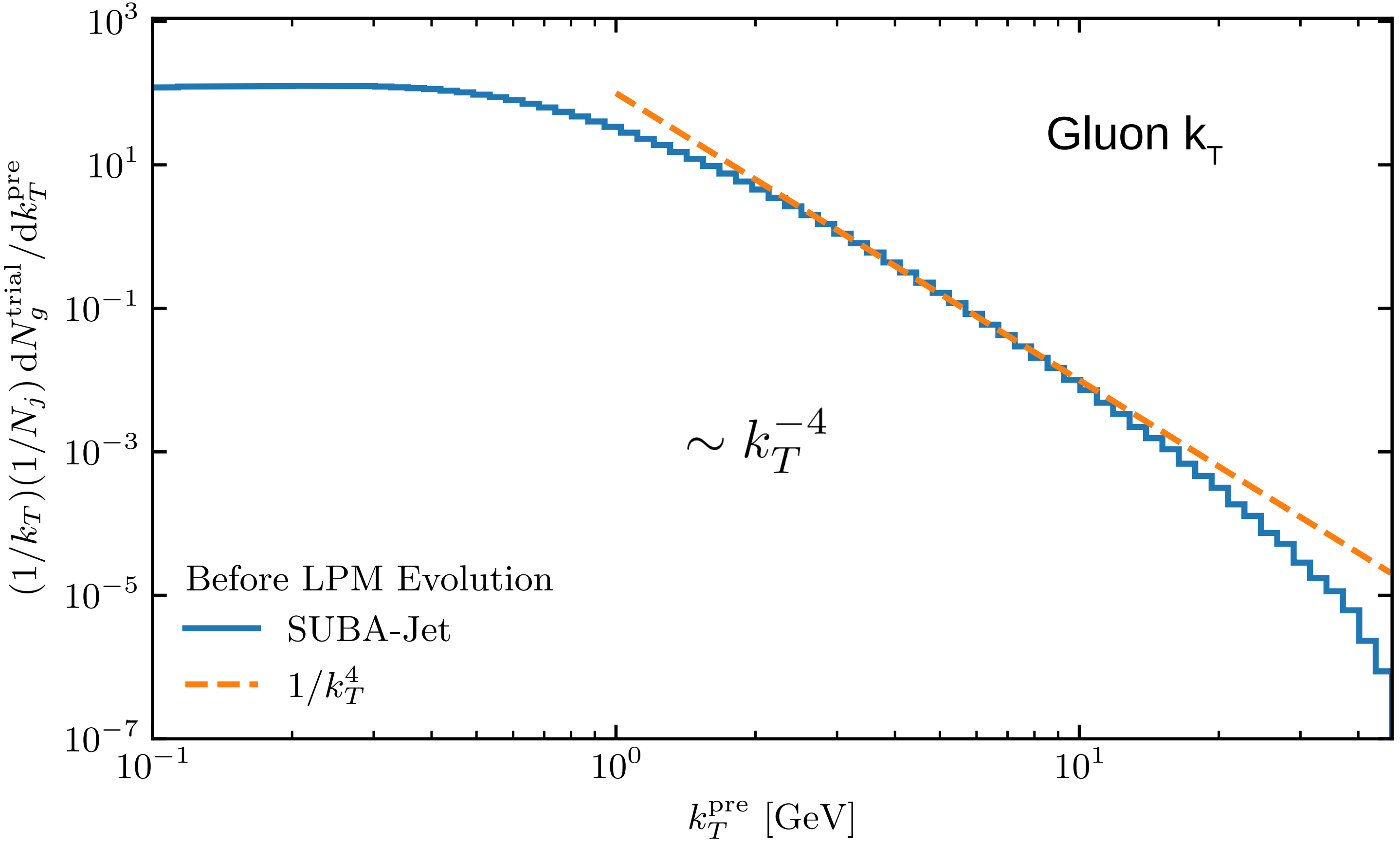
$$\frac{\mathrm{d}\sigma^{Qq\to Qqg}}{\mathrm{d}x\,\mathrm{d}^2k_T\,\mathrm{d}^2l_t} = \frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}^2l_t} P_g(x, k_T, l_T)\theta(\Delta)$$

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

Medium-Induced Single Radiation



Medium-Induced Single Radiation



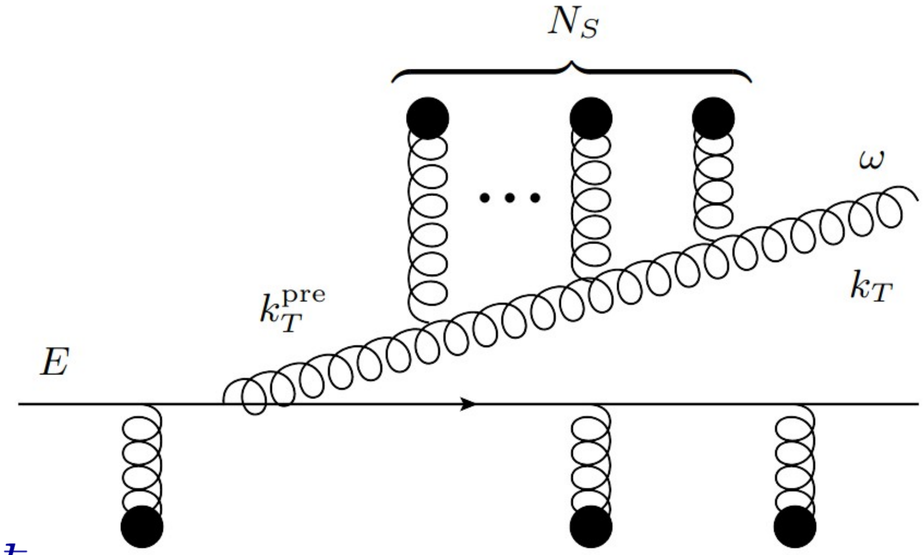
Coherency and the LPM Effect

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

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

$\omega =$ gluon energy

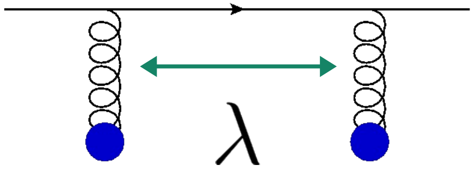
$\hat{q} =$ medium modifications



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

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

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



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

$L =$ path length of medium

Implementation of the LPM Effect

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

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

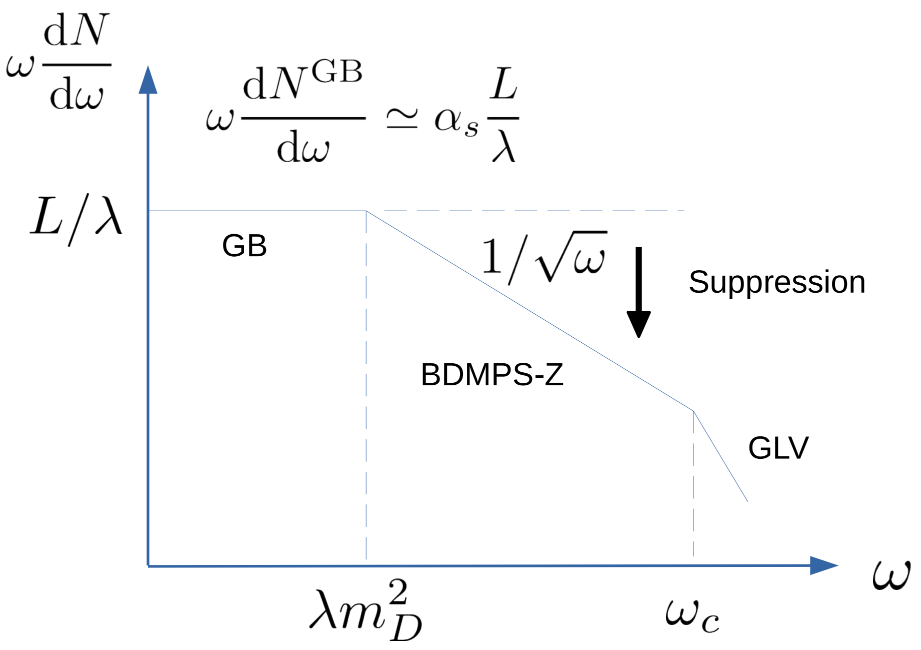
  - Radiation of preformed gluon with prob. $\Gamma_{\mathrm{inel}}\Delta t$

- 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:



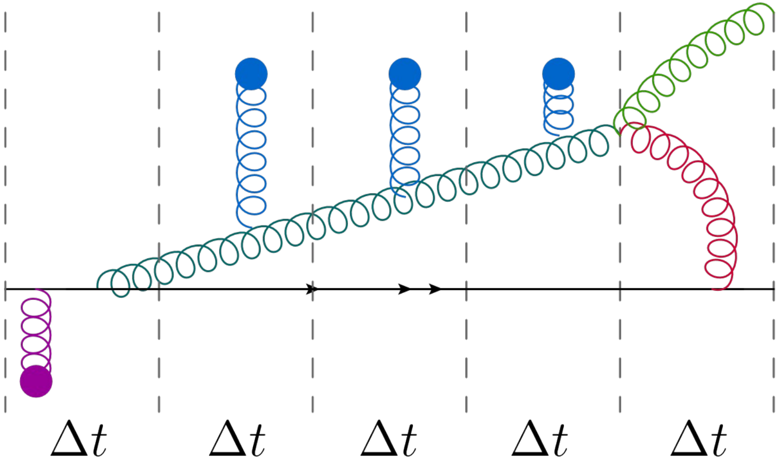
$$\omega\frac{\mathrm{d}N^{\mathrm{BDMPS\text{-}Z}}}{\mathrm{d}\omega} \simeq \alpha_s\sqrt{\frac{\hat{q}L^2}{\omega}}$$

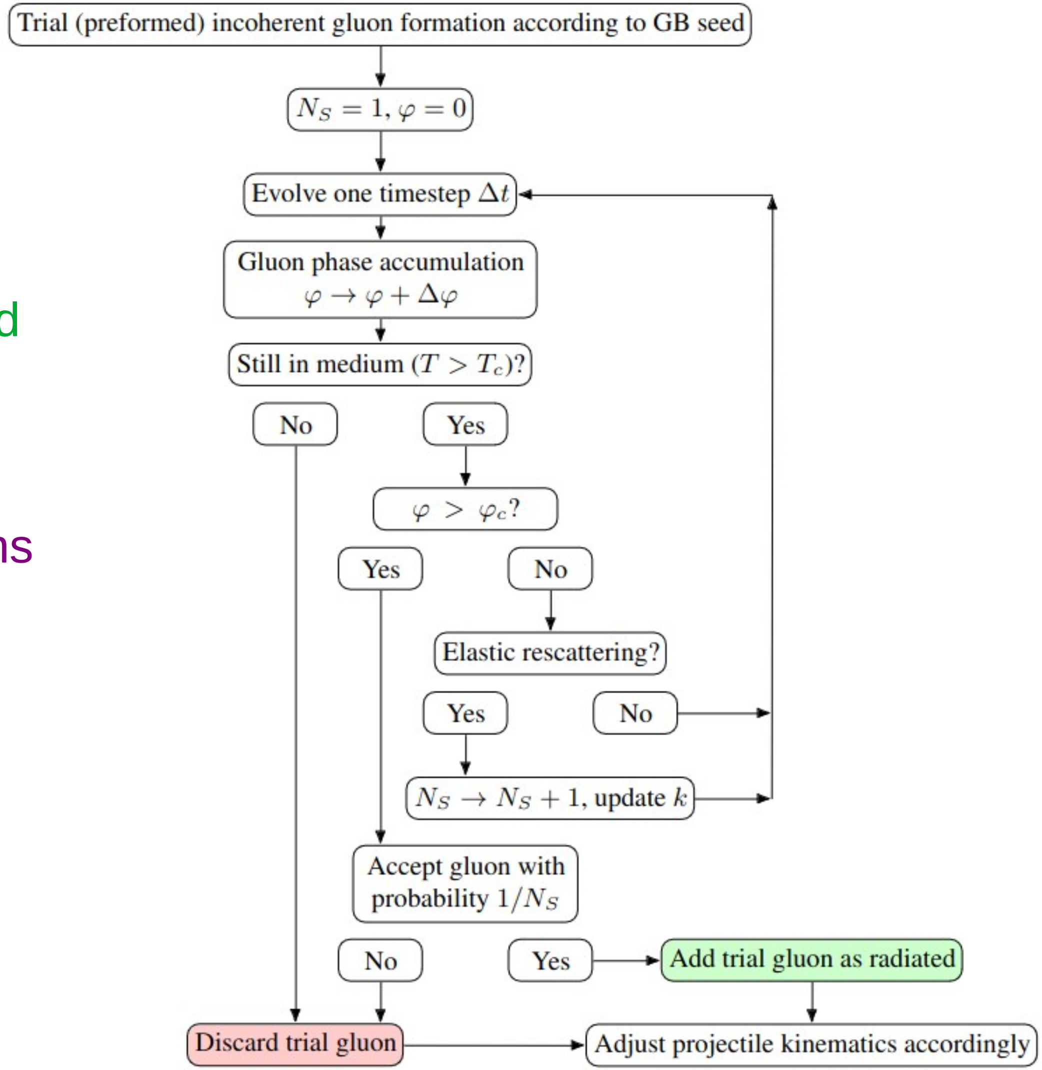
The Algorithm

Flow diagram:

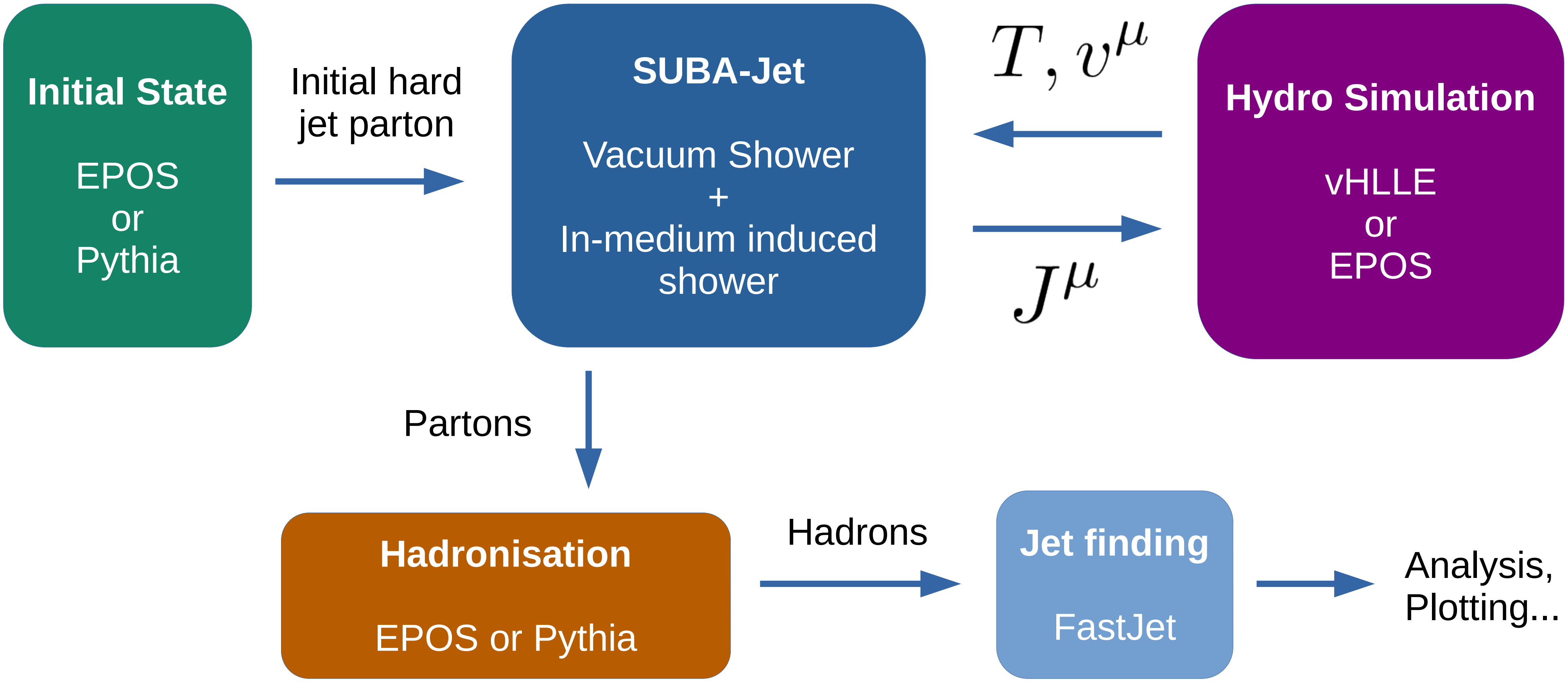
Algorithm for the coherent medium-induced gluon radiation in our model

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



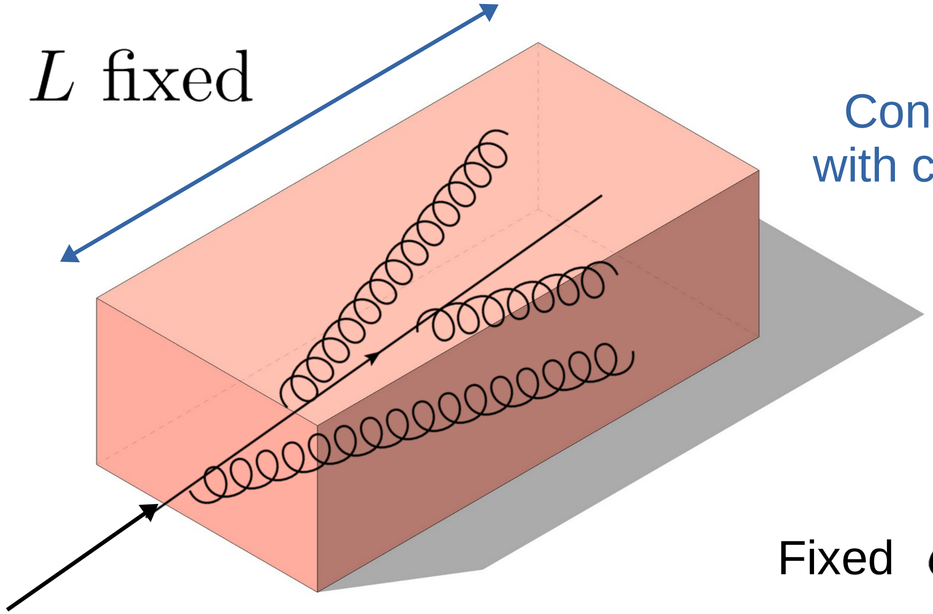


The Monte Carlo



First Results

L fixed



Consider brick medium
with constant temperature

$T = 400$ MeV

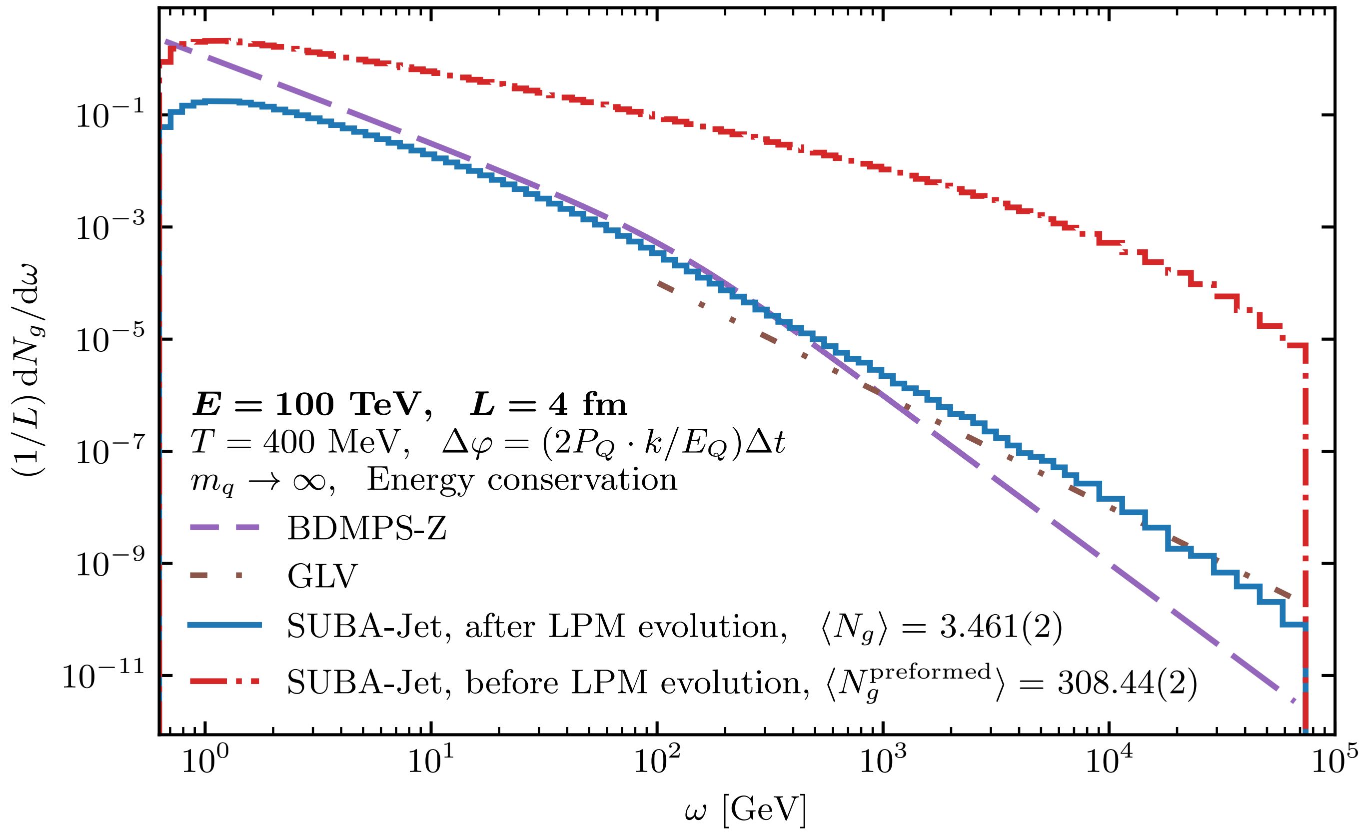
Mono-energy
(low virtuality)
quark gun

E fixed

Fixed $\alpha_s = 0.4$

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

Reproduction of the LPM and GLV regimes

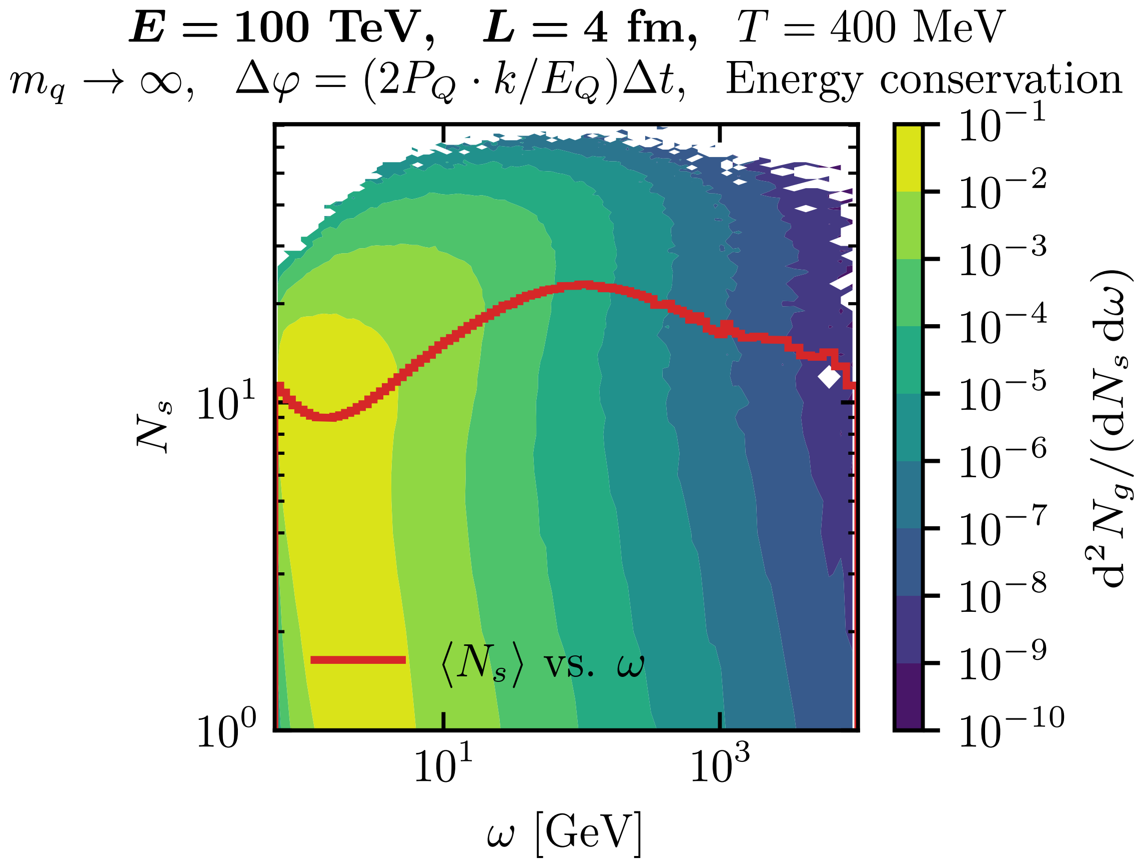


Gluon energy ω spectrum

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

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

Reproduction of the LPM and GLV regimes



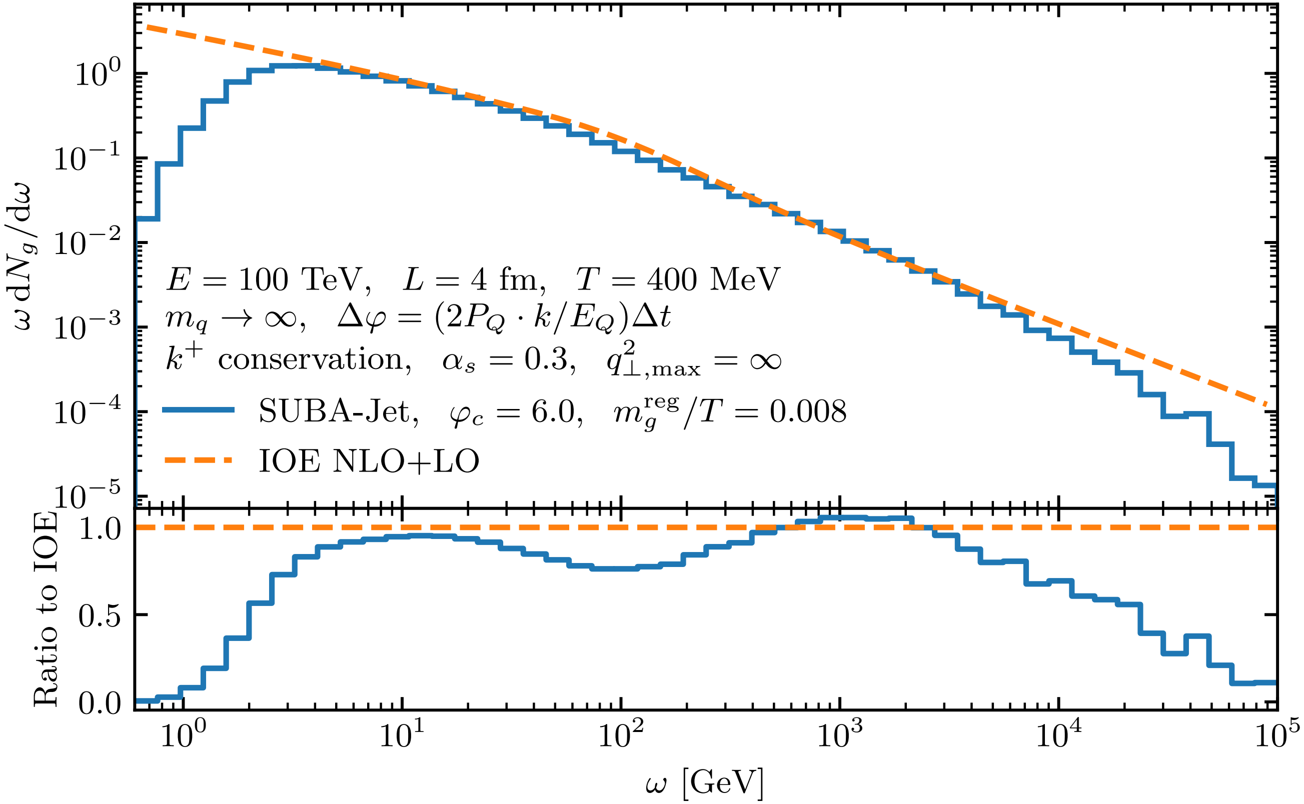
Double differential plot in N_s and ω

Red line: ‹N_s› vs. ω

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

Convolution of different distributions

Reproduction of the IOE



Improved Opacity Expansion

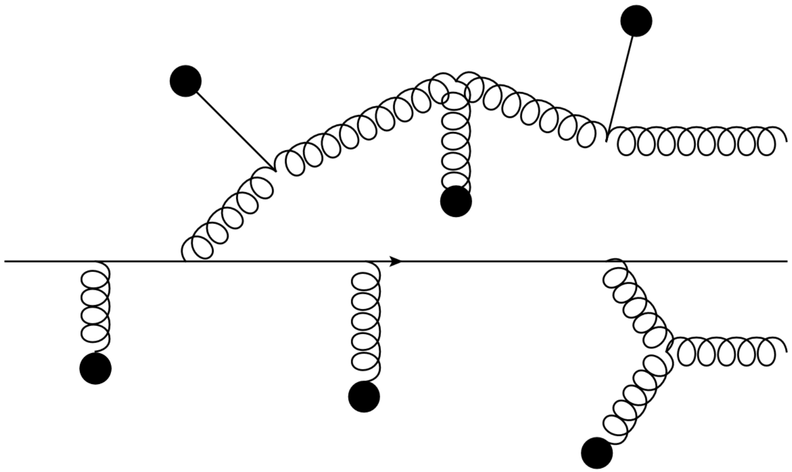
arXiv:1910.02032 [hep-ph]

$$\frac{\mathrm{d}N^{\rm IOE}}{\mathrm{d}\omega} = \frac{\mathrm{d}N^{\rm IOE}_{\rm LO}}{\mathrm{d}\omega} + \frac{\mathrm{d}N^{\rm IOE}_{\rm NLO}}{\mathrm{d}\omega}$$

$$\omega \frac{\mathrm{d}N^{\rm IOE}_{\rm NLO}}{\mathrm{d}\omega} \simeq \frac{1}{2}\frac{\alpha_s C_R}{\pi}\hat{q}_0\, \mathrm{Re}\int_0^L \mathrm{d}s\, \frac{1}{k^2(s)}\left[\ln\frac{k^2(s)}{Q^2} + \gamma_E\right]$$

The Role of the Phase Accumulation

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



- **More general formula:**

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

- **What is used in JEWEL:**

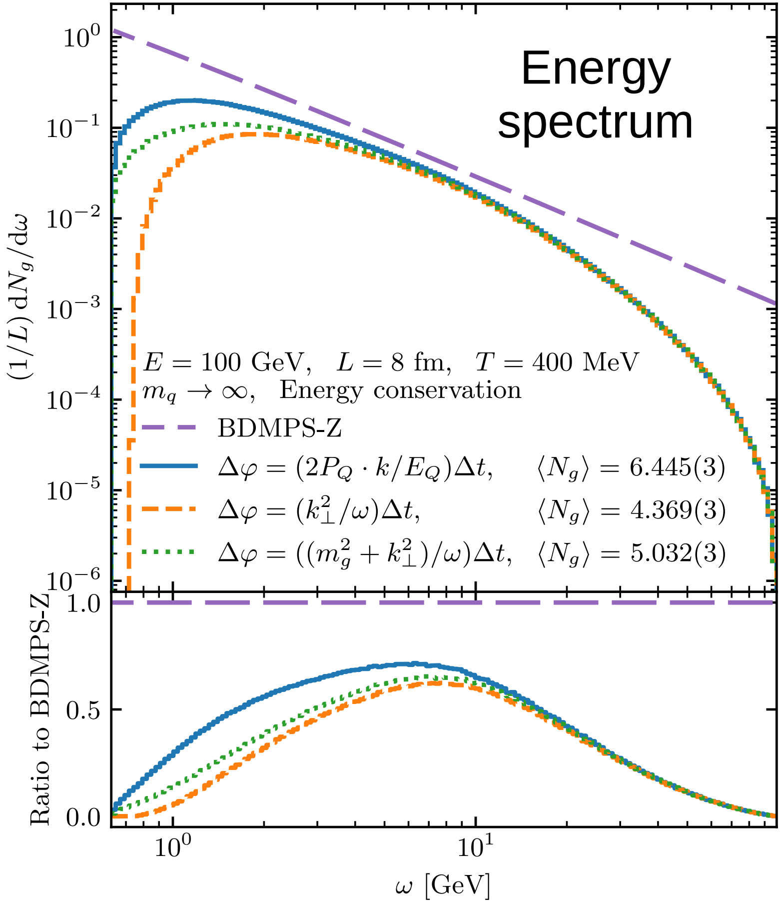
$$\Delta\varphi = \frac{k_T^2}{\omega}\Delta t$$

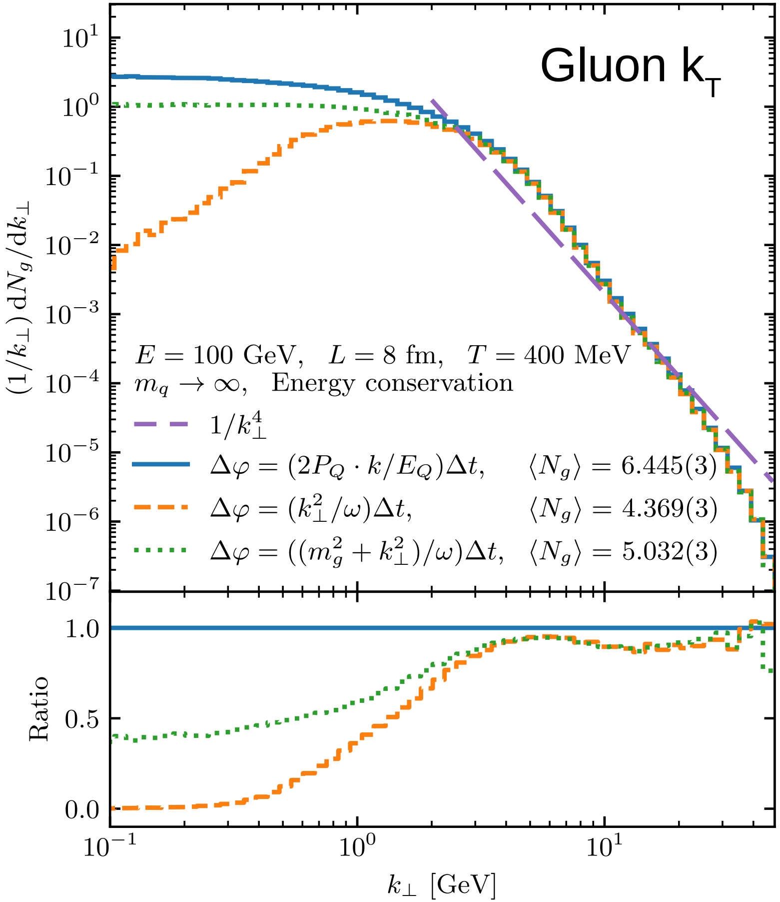
- **Including thermal gluon mass:**

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

The Role of the Phase Accumulation

Effects at low energy & low k_T

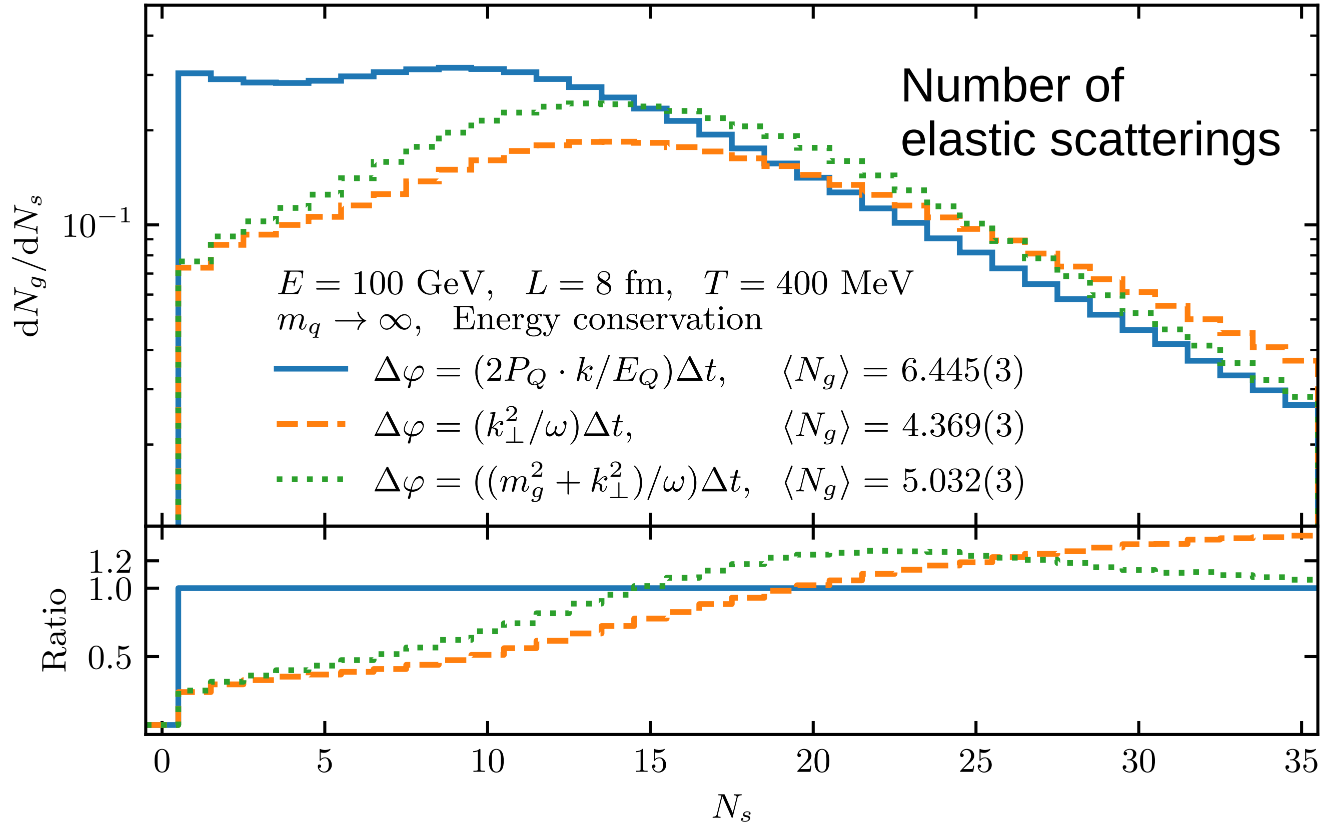




Number of radiated gluons per jet ~ 5 -- 6

The Role of the Phase Accumulation

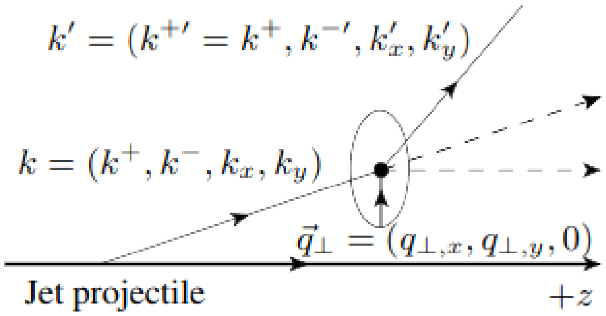
Effects at low N_S



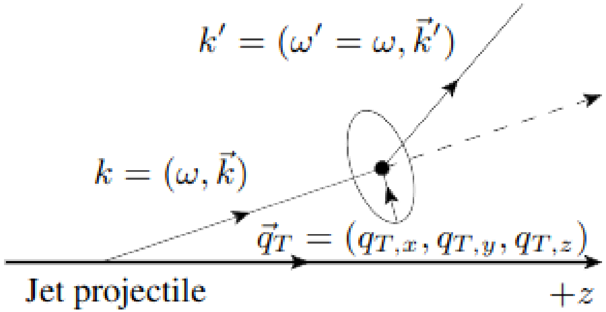
When neglecting the gluon mass in the phase accumulation, a larger path length is required to have a comparable overall number off radiations

The Role of the Elastic Scatterings

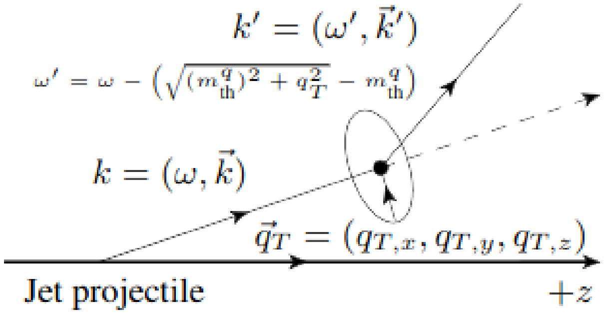
Choice of prescription in elastic scatterings:



k+ conservation

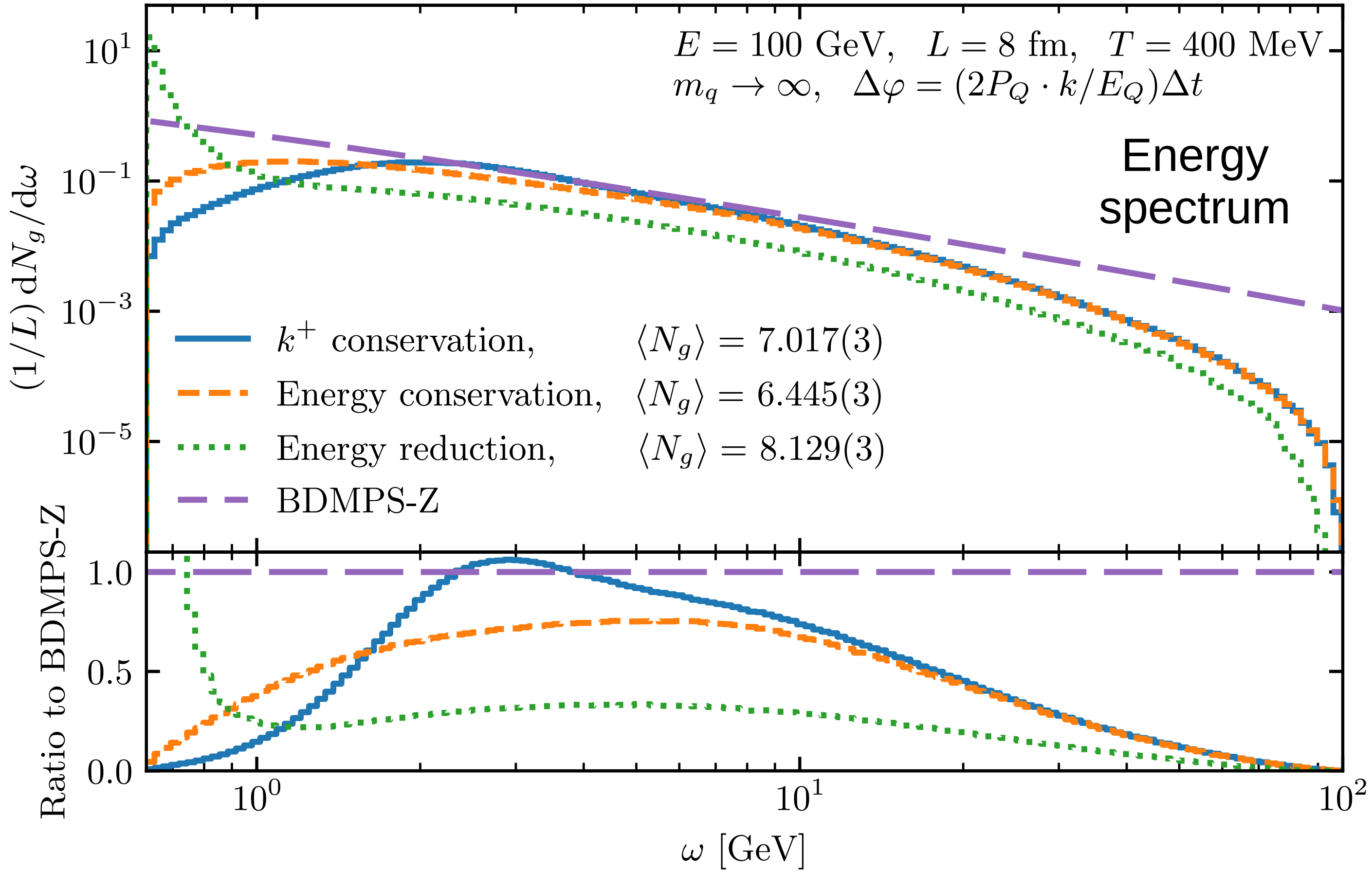


Energy conservation



Energy reduction

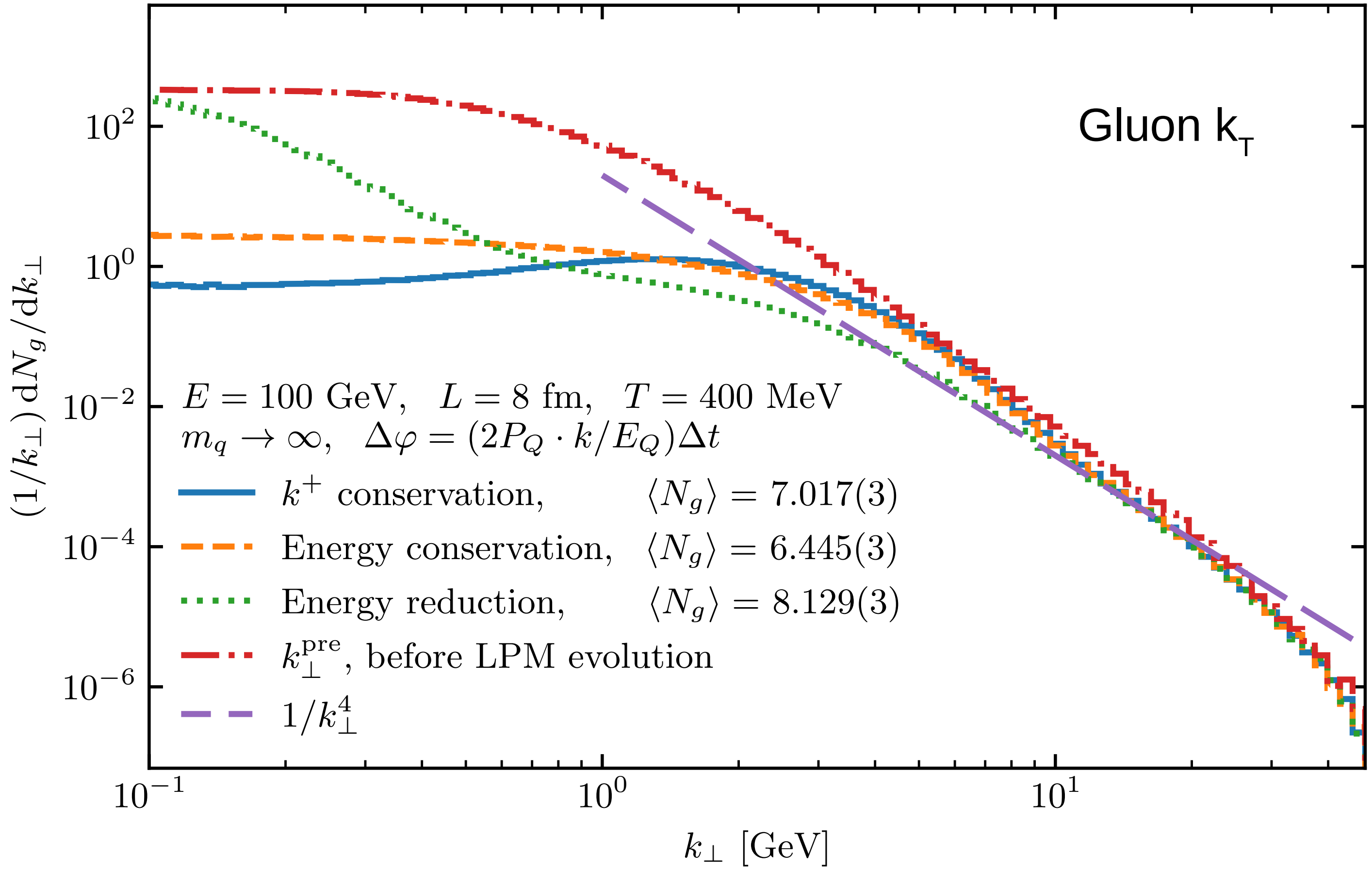
The Role of the Elastic Scatterings



Same BDMS behaviour at intermediate energies

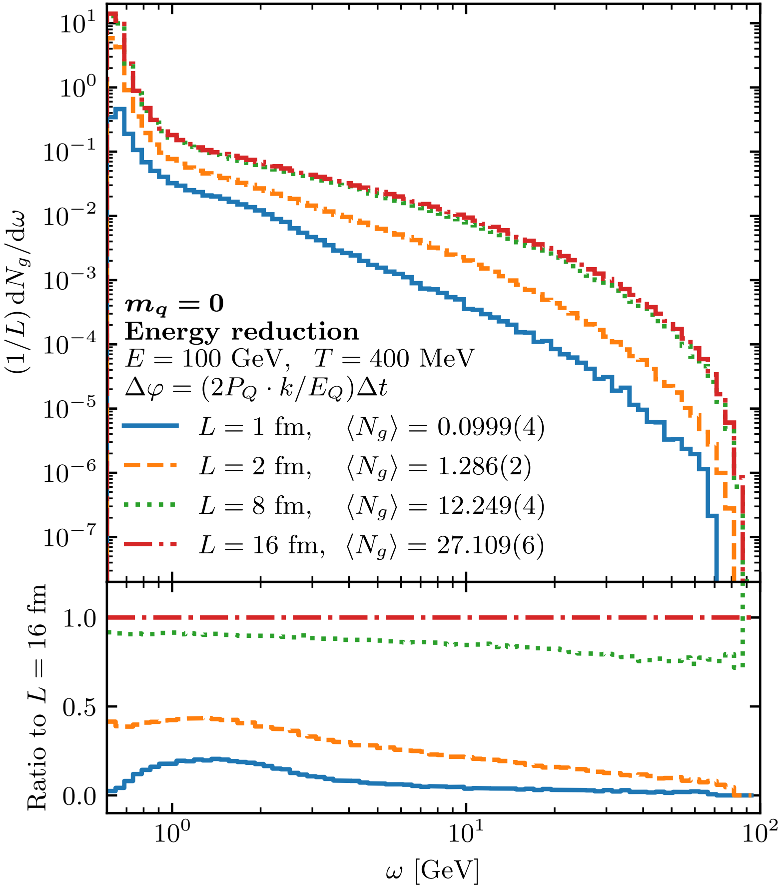
Difference at small energies

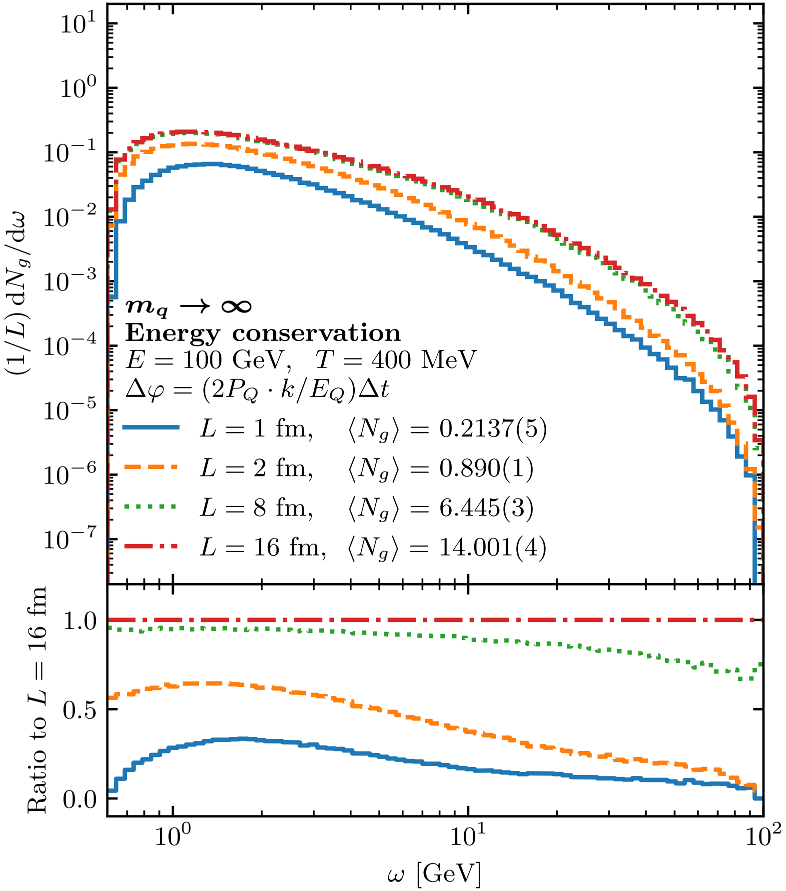
The Role of the Elastic Scatterings



Large difference at small k_T

The Role of the Path Length





$$\frac{\mathrm{d}N}{\mathrm{d}\omega} \overset{L\to\infty}{\approx} L$$

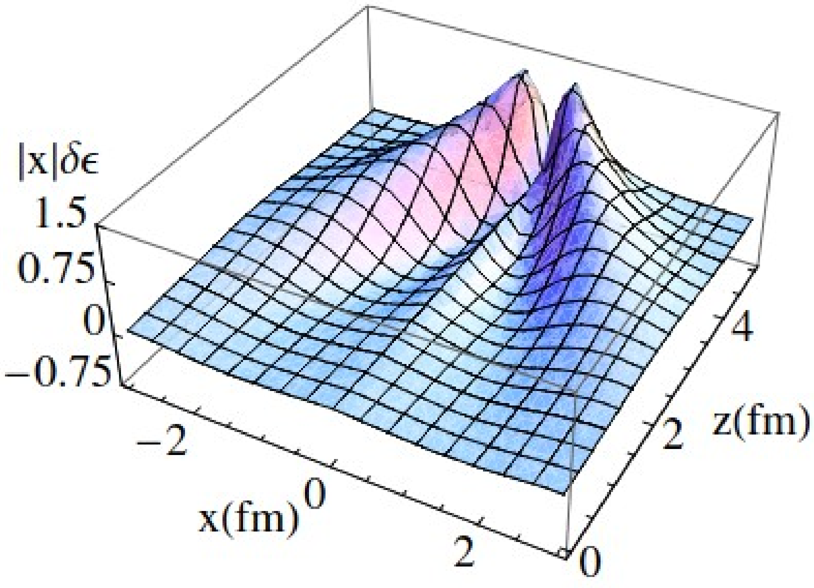
Looking Forward: Towards More Realism

Next step:

- **Implementation in two different MC frameworks:**
  - SUBA-Jet + EPOS4
  - SUBA-Jet + Pythia 8
- Realistic QGP evolution
- Pre-equilibirum stage
- Hadronisation
- Hadronic phase

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

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

- **Next step:** Implementation within the new EPOS4
  - **EPOS4+JETS –** Initial state, hydro, and hadronisation from EPOS4

Thank you for your attention!