A New Model for Jet Energy Loss in Heavy Ion Collisions

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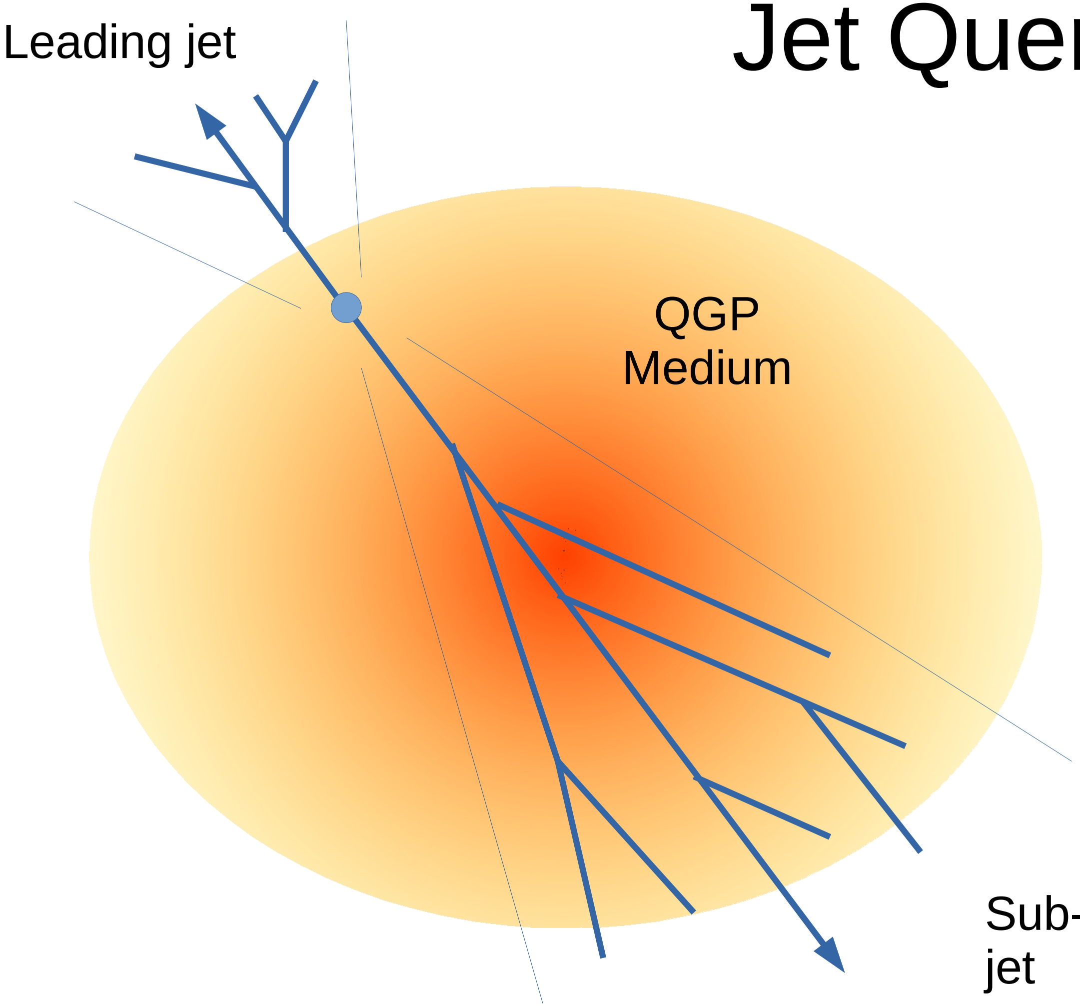
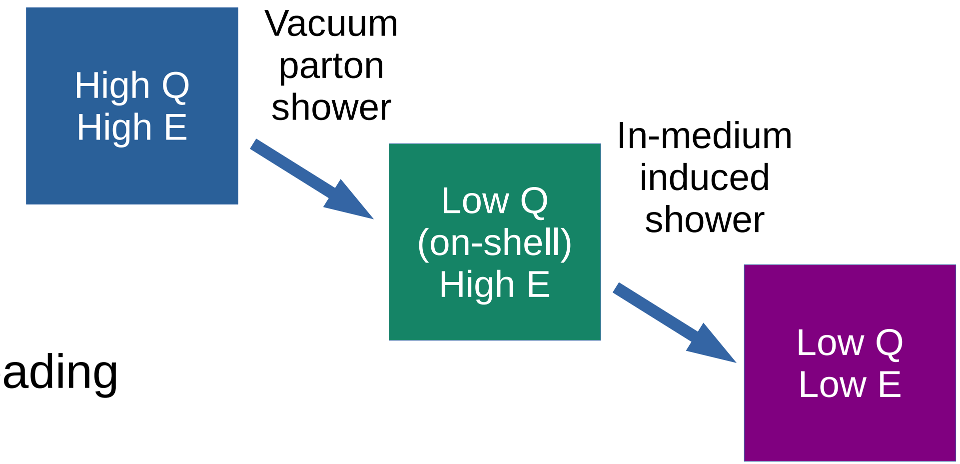
Hard Probes 2023
28 March 2023

Jet Quenching

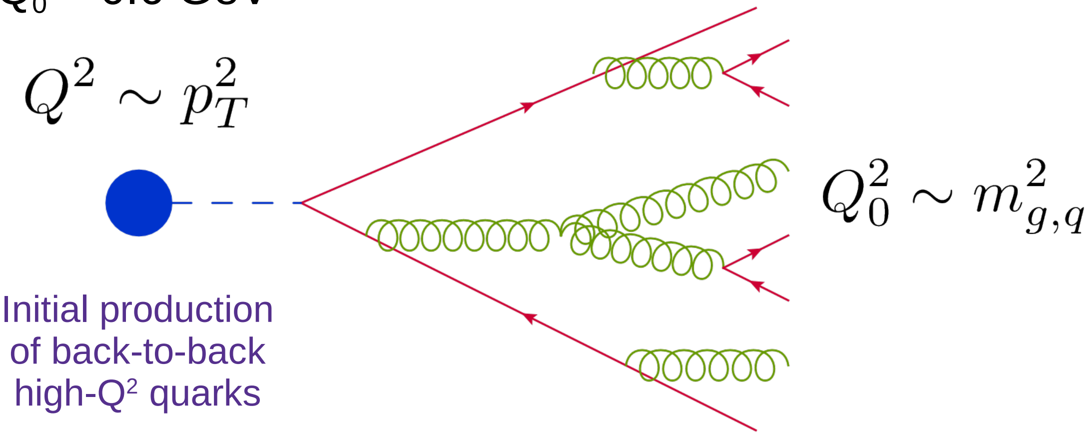


- Interactions between jet partons and the QGP medium leads to modification of jet properties
- **SUBA-Jet:**
  Monte Carlo for jet energy loss in heavy ion collisions

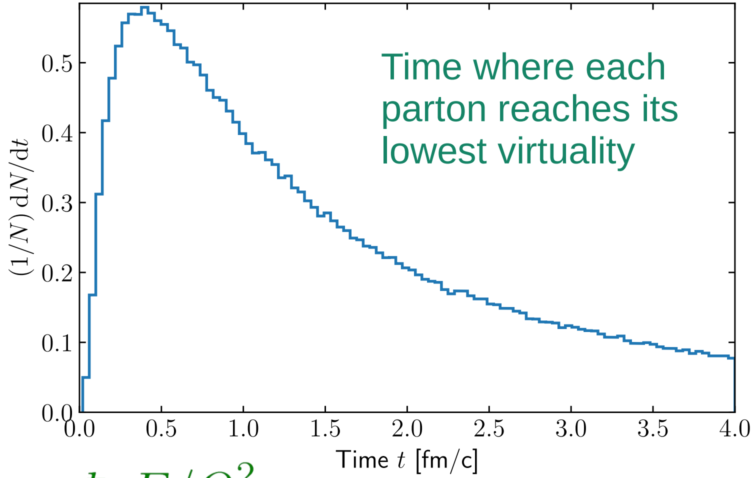


High Q: Vacuum Shower

- 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 $Q_0 = 0.6$ GeV



Initial production of back-to-back high-Q^2 quarks



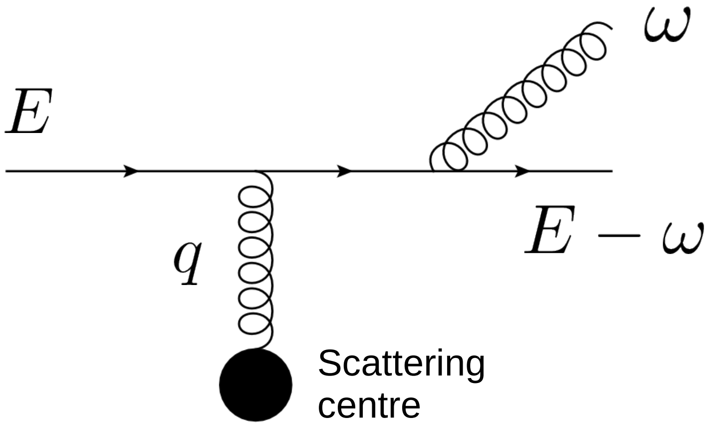
Time where each parton reaches its lowest virtuality

- Time evolution split into time steps, mean life time $\Delta t = \tau = \hbar c E/Q^2$
- 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 Q: 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)



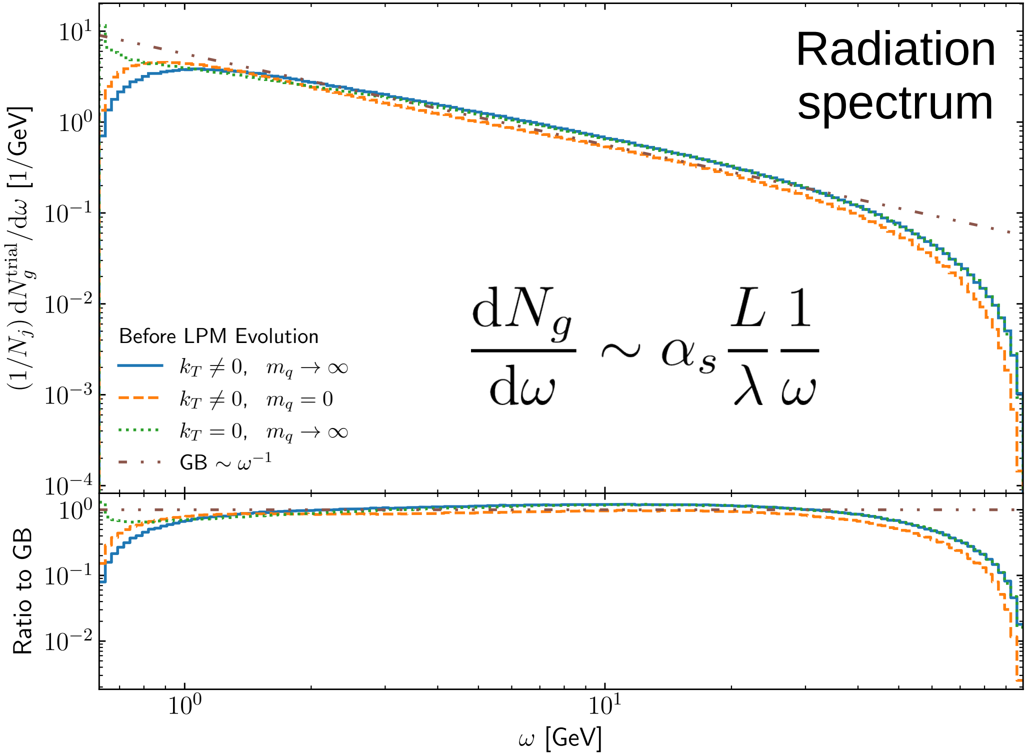
- Initial Gunion-Bertsch seed: i.e. radiation of a **preformed gluon** from a single scattering (Each parton can generate a number of preformed gluons)

- Gunion-Bertsch cross-section from scalar QCD

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

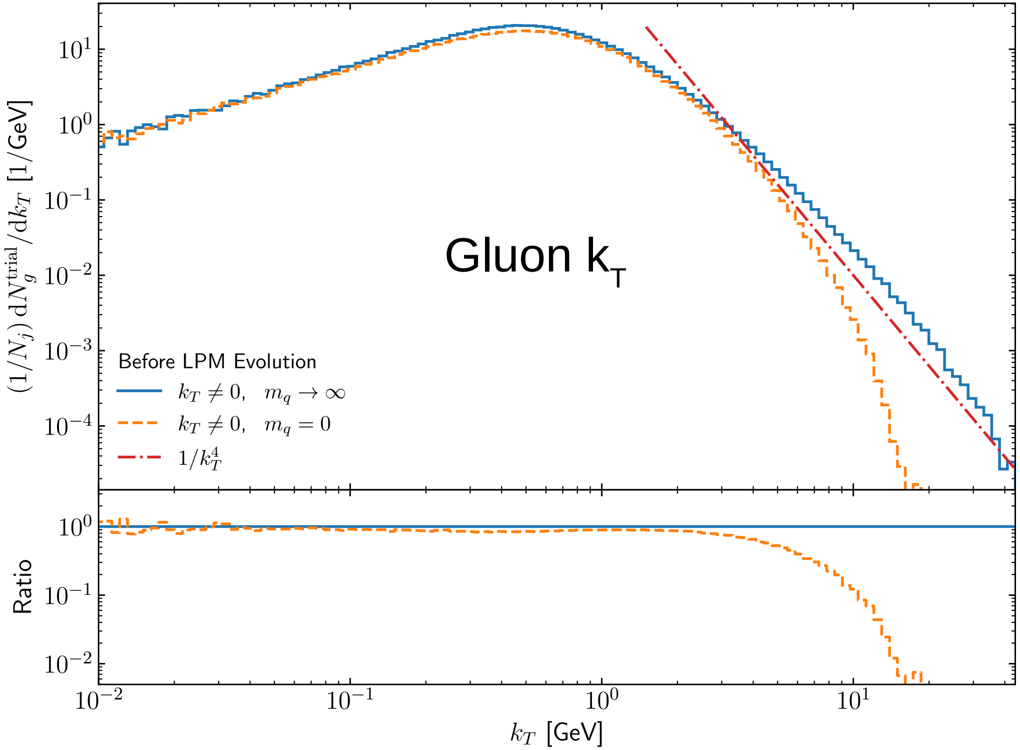
$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}^2l_t} \sim \frac{8\alpha_s^2}{9(l_T^2+\mu^2)^2}$$

Low Q: Medium-Induced Single Radiation



Radiation spectrum

$$\frac{\mathrm{d}N_g}{\mathrm{d}\omega} \sim \alpha_s \frac{L}{\lambda} \frac{1}{\omega}$$



Gluon k_T

Low Q: LPM Effect and Coherent Radiation

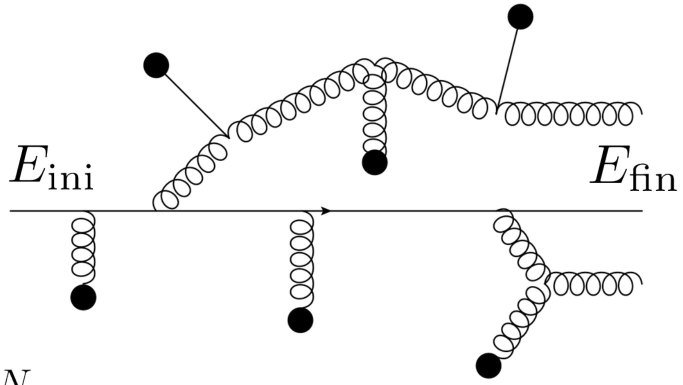
- Coherence effects (LPM) for multiple scatterings with medium
- At each timestep:
  - Elastic scattering with prob. $\Gamma_{\mathrm{el}}\Delta t$

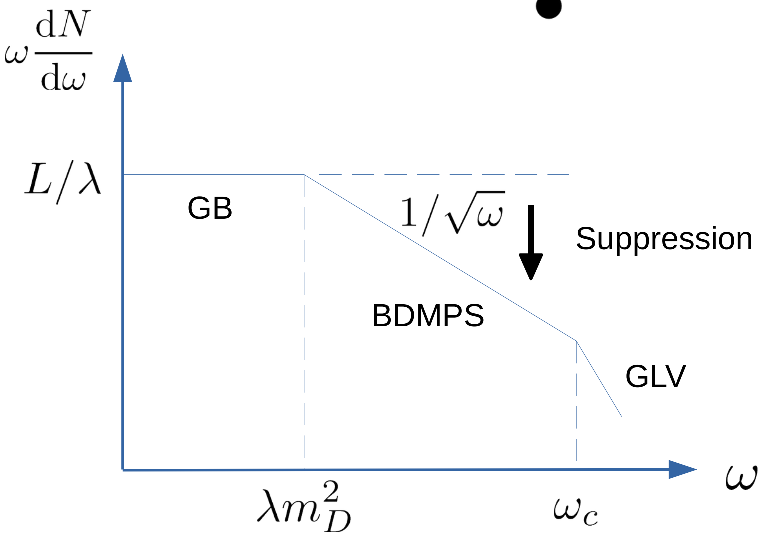
$$\Gamma^q_{\mathrm{el}} = \left(1 + \frac{N_f}{N}\right)\frac{(N^2-1)T^3}{\pi\hbar c}\frac{4\alpha_s^2}{\mu^2}$$

  - Radiation of preformed gluon with prob. $\Gamma_{\mathrm{inel}}\Delta t$
- BDMPS spectrum at intermediate energies achieved by suppressing GB seed by $1/N_s$

$$N_s \sim \frac{t_f}{\lambda} \qquad t_f \sim \sqrt{\omega}$$

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



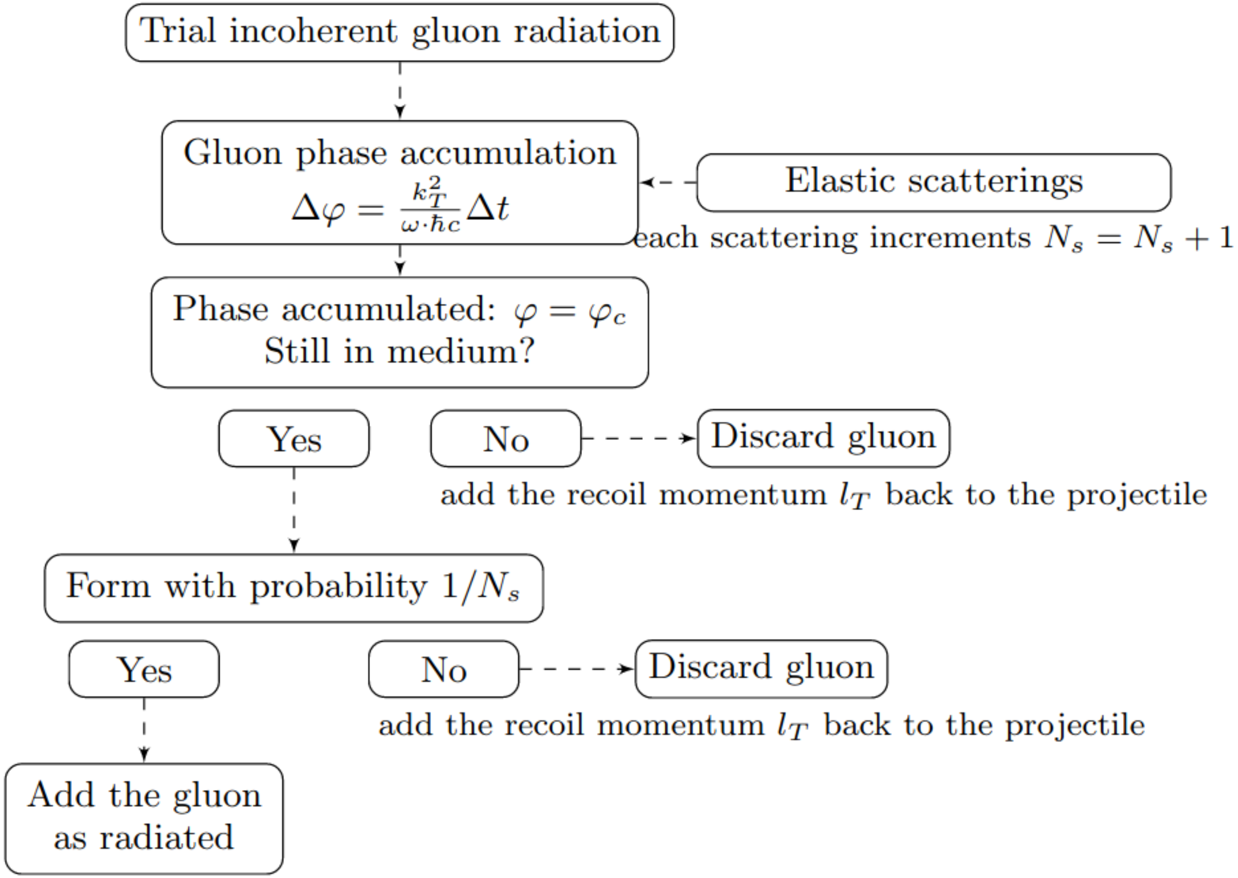


The Algorithm

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



Trial incoherent gluon radiation

Gluon phase accumulation $\Delta\varphi = \frac{k_T^2}{\omega \cdot \hbar c}\Delta t$

Elastic scatterings

each scattering increments $N_s = N_s + 1$

Phase accumulated: $\varphi = \varphi_c$ Still in medium?

Yes

No

Discard gluon

add the recoil momentum l_T back to the projectile

Form with probability $1/N_s$

Yes

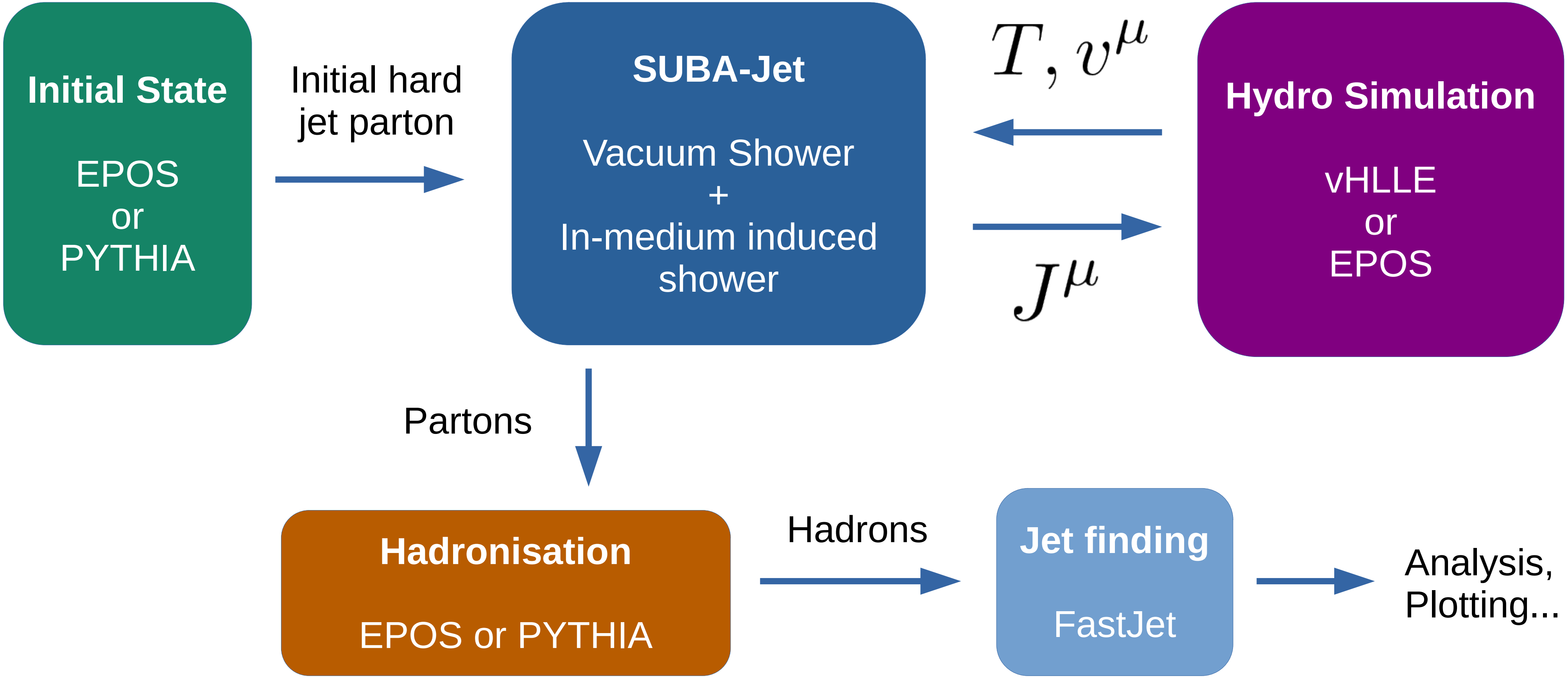
No

Discard gluon

add the recoil momentum l_T back to the projectile

Add the gluon as radiated

The Monte Carlo



Initial State

EPOS
or
PYTHIA

Initial hard
jet parton

SUBA-Jet

Vacuum Shower
+
In-medium induced
shower

T, v^μ

J^μ

Hydro Simulation

vHLLE
or
EPOS

Partons

Hadronisation

EPOS or PYTHIA

Hadrons

Jet finding

FastJet

Analysis,
Plotting...

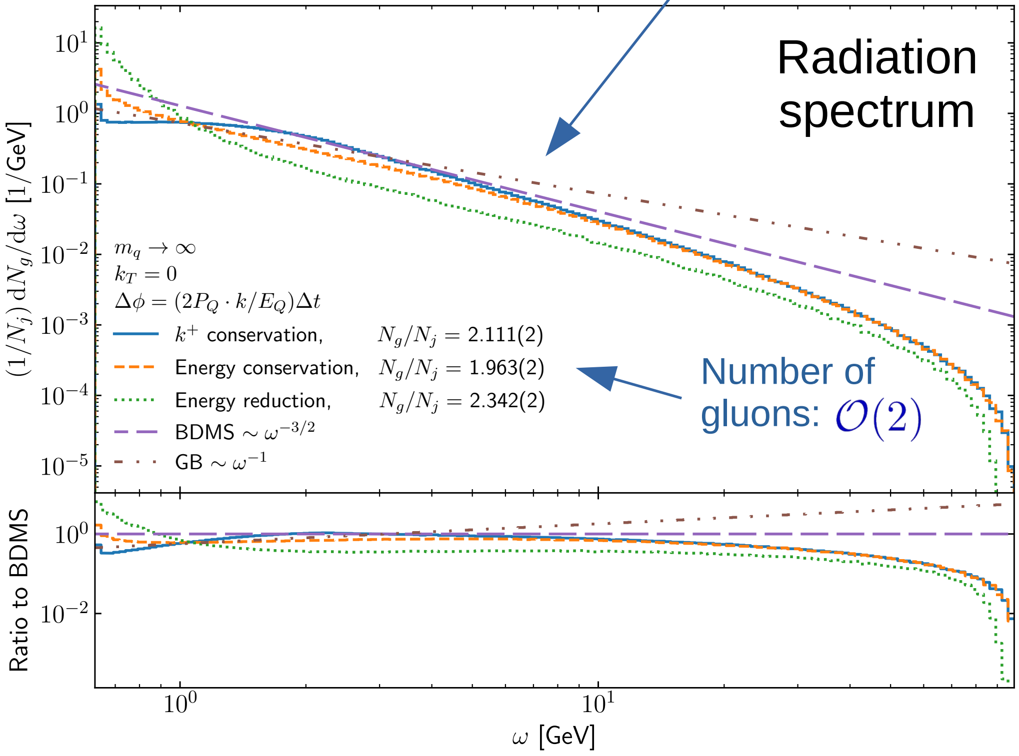
Reproduction of BDMPS Limit

- Initial state: Low Q
  Mono-energetic quark gun of 100 GeV
- Medium:
  Brick of constants temperature 400 MeV
  Path length: L = 4 fm $\alpha_s = 0.3$
- Scattering centres with infinite mass
- Initial $k_T = 0$
- Phase accumulation:

$$\Delta\phi = (2P_Q \cdot k/E_Q)\Delta t/(\hbar c)$$

- BDMS normalisation:

$$\frac{\mathrm{d}N_g}{\mathrm{d}\omega} \sim \alpha_s \sqrt{\frac{Lm_D^2}{\hbar c}} \frac{1}{\omega^{3/2}}$$



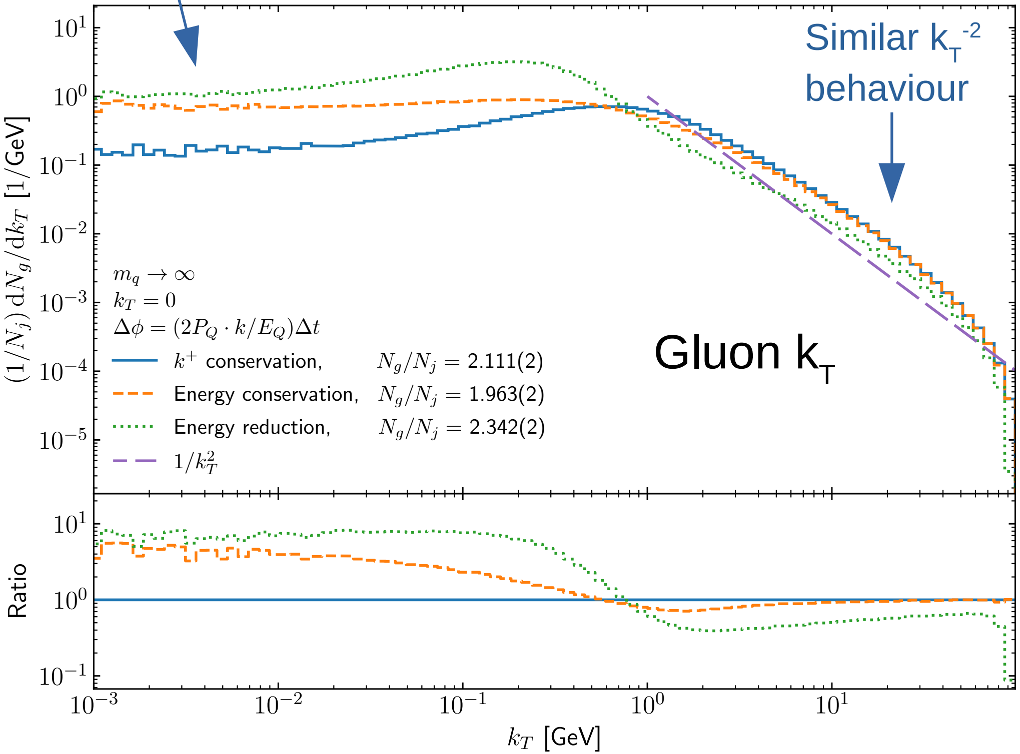
Follows BDMPS nicely

Radiation spectrum

Number of gluons: $\mathcal{O}(2)$

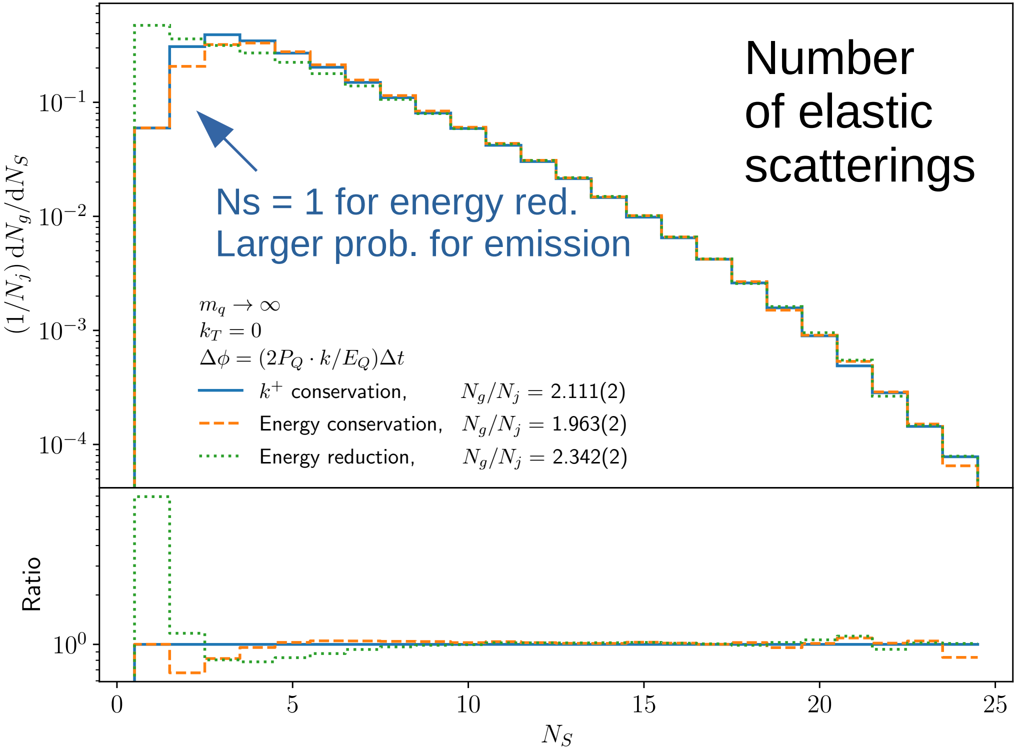
Reproduction of BDMPS Limit

Large difference



Similar k_T^{-2} behaviour

Gluon k_T

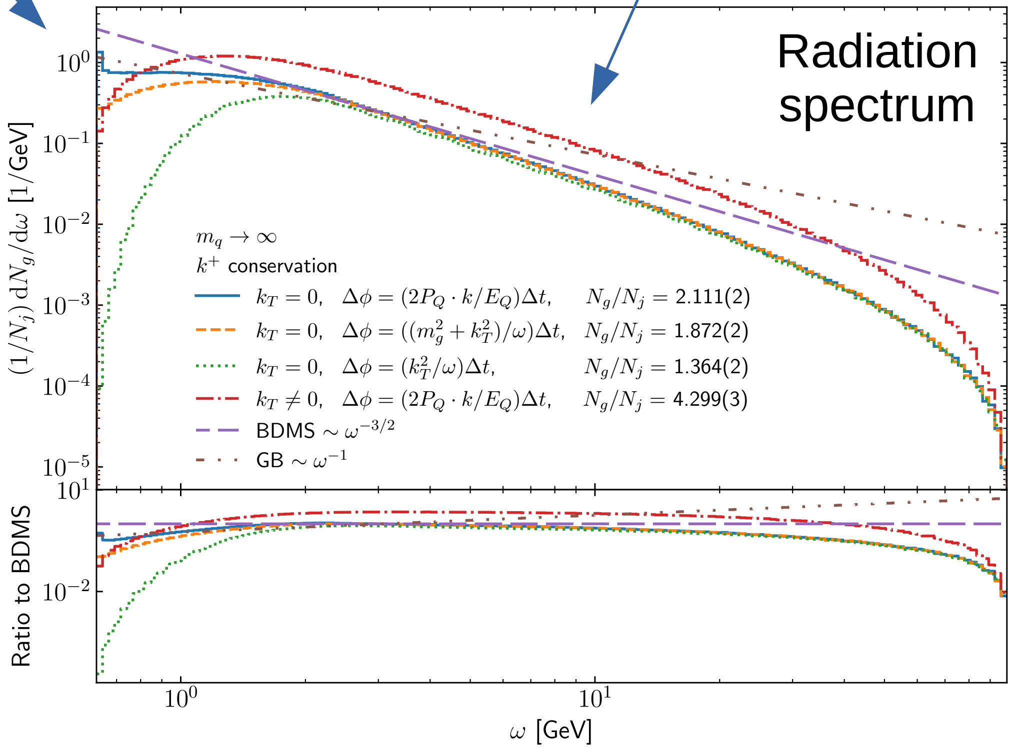


Number of elastic scatterings

Ns = 1 for energy red.
Larger prob. for emission

The Effect of the Phase Accumulation

- Same details as before, but …
  - Keep k^+ conservation in the elastic scatterings
  - Vary the form of the phase accumulation
  - Also see effect of k_T



Effects at low energy

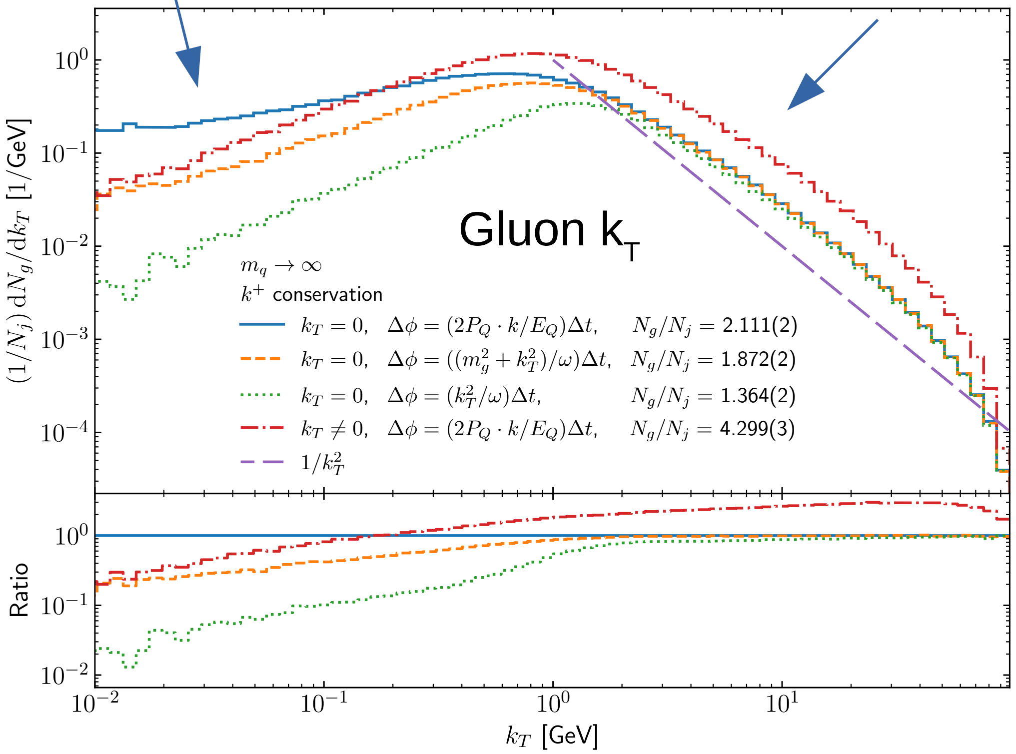
Non-zero kT means earlier formation

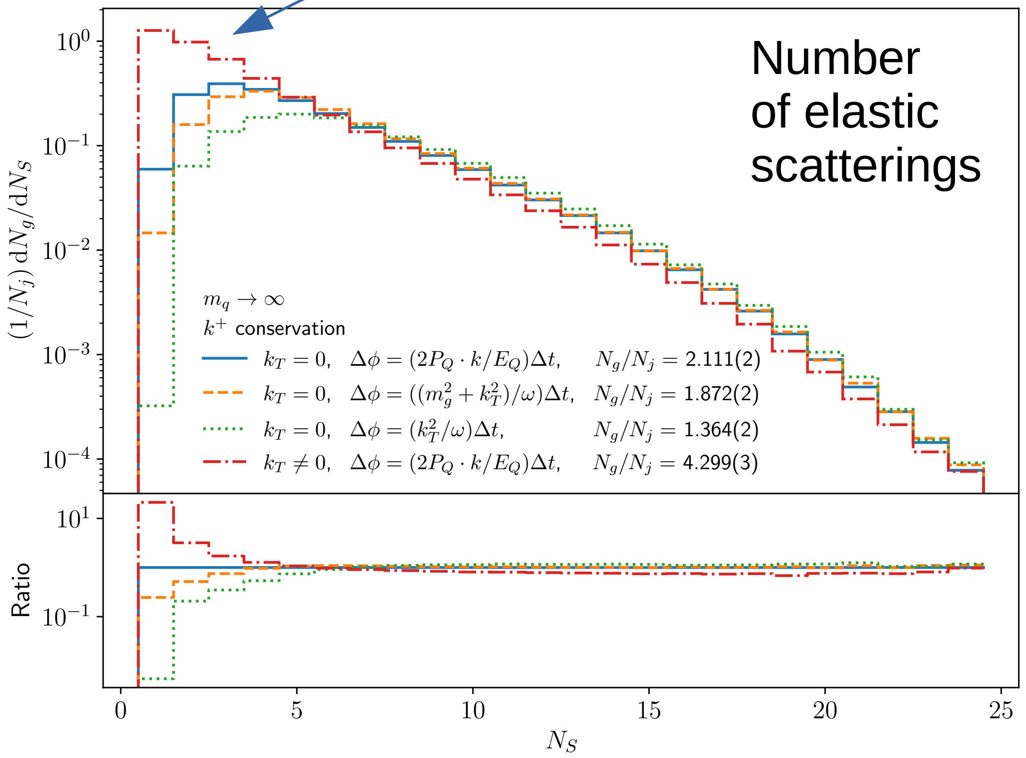
The Effect of the Phase Accumulation

Effect at low k_T

Similar behaviour in BDMPS region

Non-zero kT means earlier formation


Gluon k_T


Number of elastic scatterings

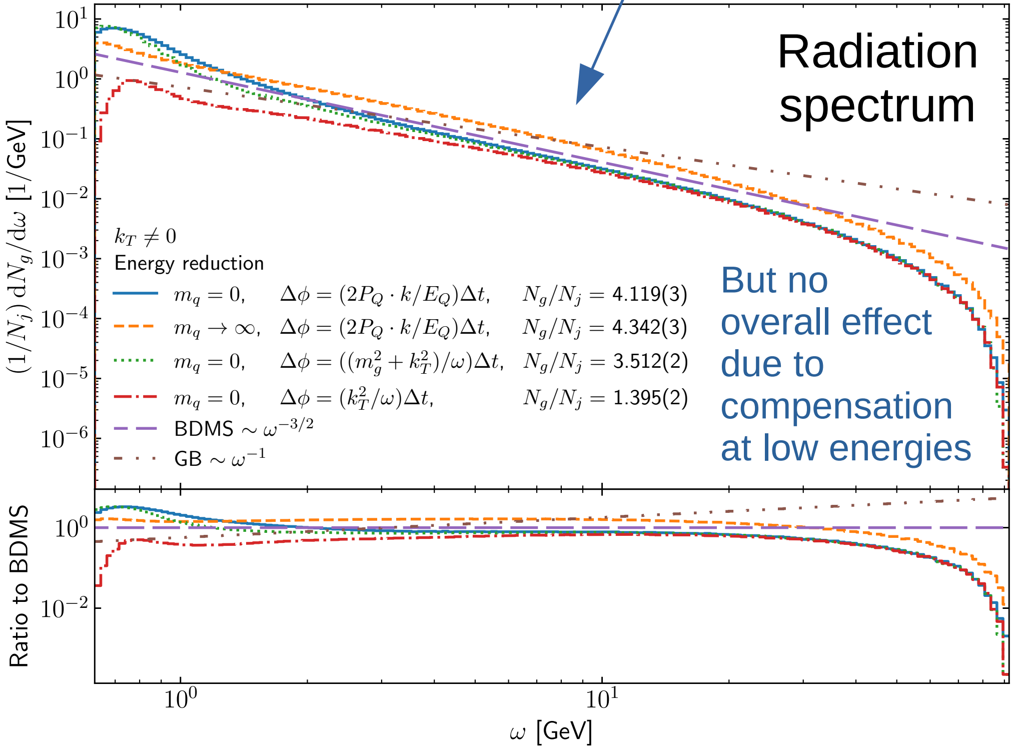
More Realistic Case

- Relax assumptions and consider a more realistic scenario:
  - Scattering centres of zero mass

$$m_q = 0$$

  - Energy reduction
  - Non-zero k_T

- And vary the phase space accumulation



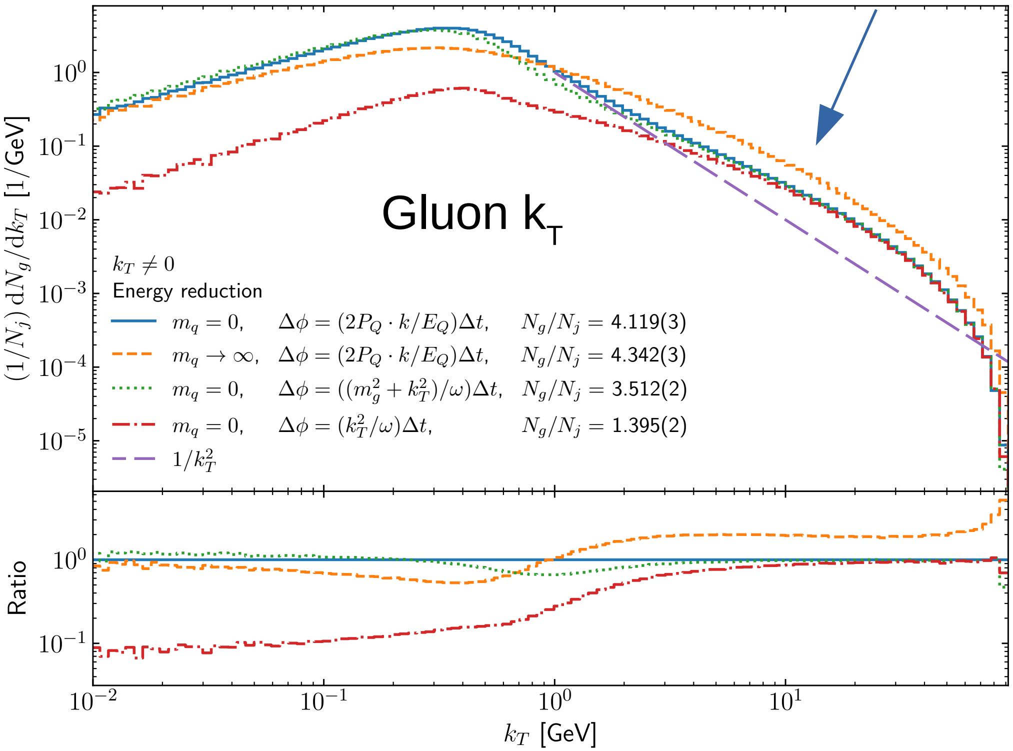
Similar shapes
but larger yield by factor 2

Radiation spectrum

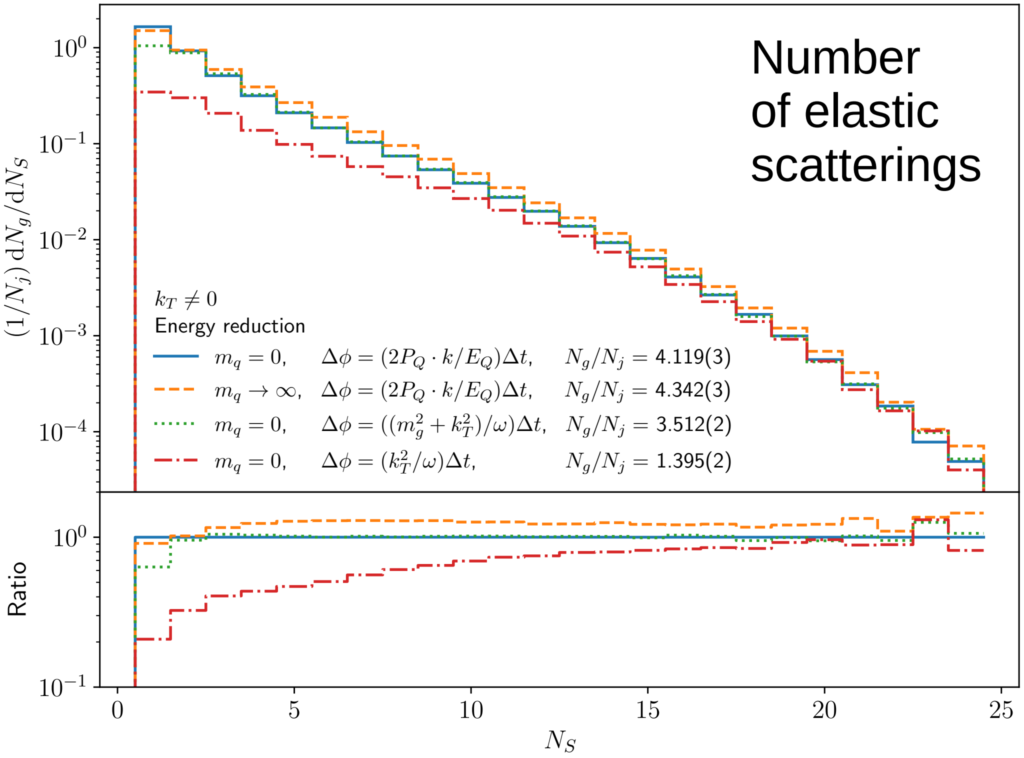
But no overall effect due to compensation at low energies

More Realistic Case

Similar shapes
but larger yield



Gluon k_T



Number
of elastic
scatterings

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 Q, high E 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

Summary

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

- Reproduction of the BDMPS radiation energy spectrum
- Shown effects of different model assumptions

- **Next step:** First results with hydro evolution interface to vHLLE
- **Later goal:** Implementation within the new EPOS4
  - Initial state, hydro, and hadronisation from EPOS