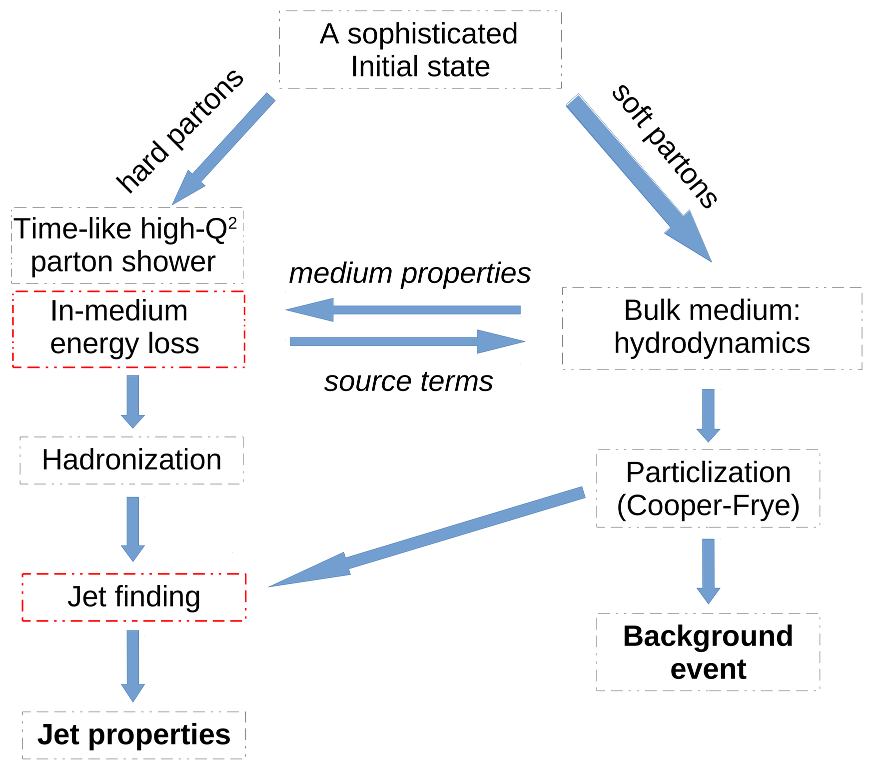
SUBA-Jet, a new coherent jet energy loss model

Alexander Lind[1], Iurii Karpenko[3], Joerg Aichelin[2], Pol Gossiaux[2], Martin Rohrmoser[4]

[1] INFN Frascati, [2] CNRS/SUBATECH Nantes, [3] FNSPE CTU in Prague, [4] Jan Kochanowski University

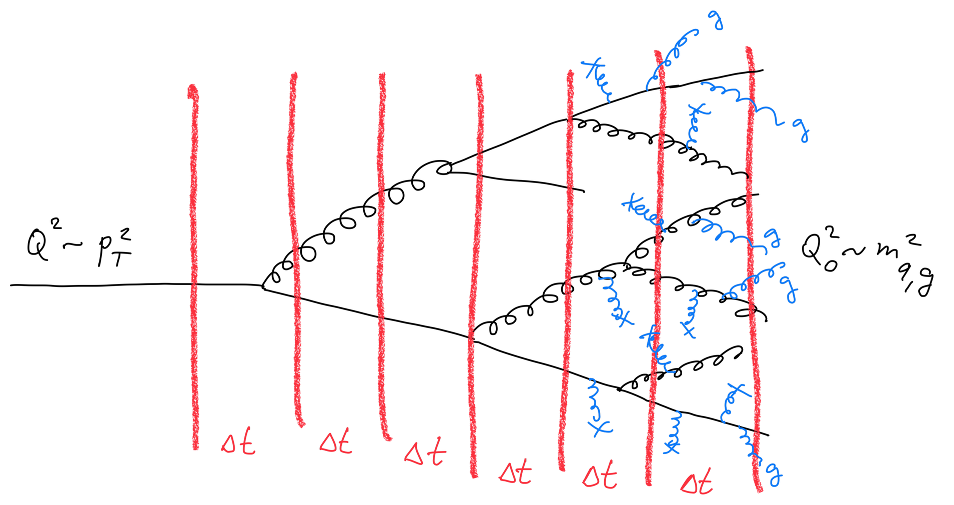
Our project

To get both hydrodynamic IS and initial hard partons from preferrably the same initial state,
make hydrodynamic and jet parts talk to each other, add hadronization scheme and jet finding.



Time-like parton shower + spacetime picture

- Monte Carlo simulation of DGLAP equations for a parton shower between virtuality scales $Q_\uparrow$ (from Born process in hard scattering) and $Q_\downarrow = 0.6$ GeV.



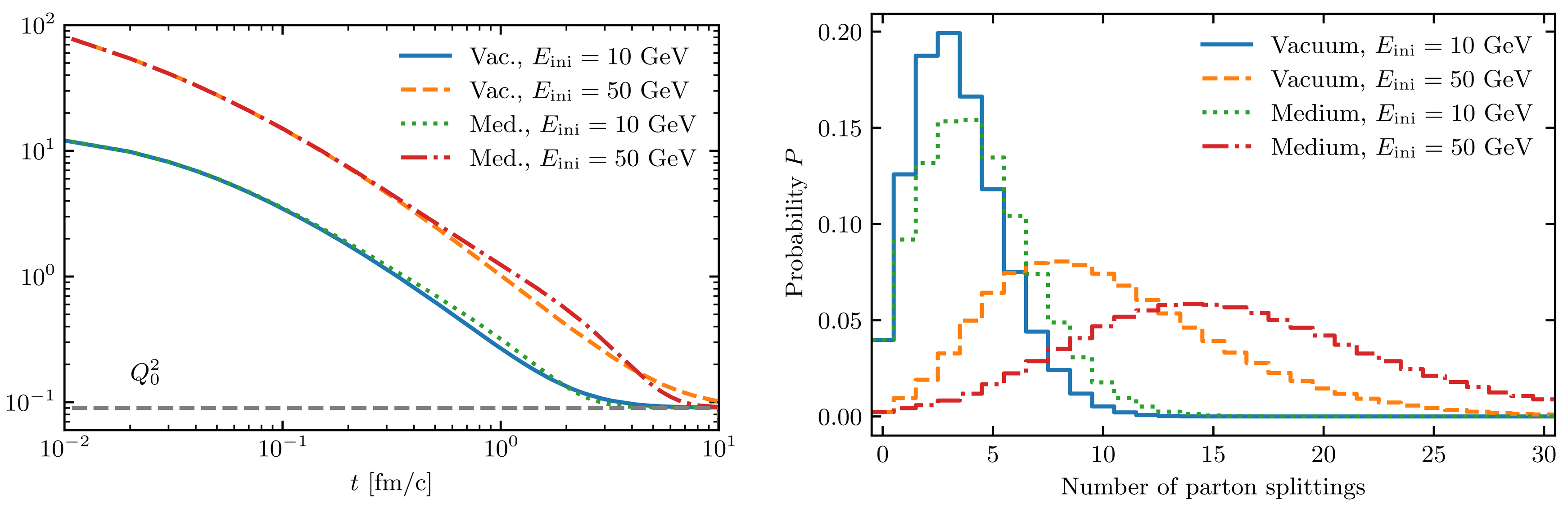
On top of that:

- The *time* evolution is split into timesteps (ideal for merging with hydrodynamic medium evolution)
- Parton splitting (for high-Q^2 partons) happens with a probability according to mean life times between the splittings $\Delta t = E/Q^2$.

Medium modifications: high Q^2 sector

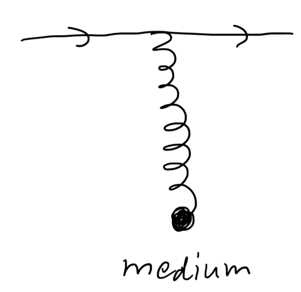
We adopt effective treatment from T. Renk, Phys. Rev. C78 (2008) 034908: $\frac{dQ^2}{dt} = \hat{q}(T,p)$

$\hat{q}(T,p) = \hat{q}_{\rm JET}(T) \times q_{\rm cof}(p)$, the latter from Gossiaux, Aichelin, Phys. Rev. C 78 (2008) 014904.
There is a small continuous virtuality increase, which causes more splittings, leads to a wider jet with some *apparent* energy loss.



low Q^2 sector: elastic scatterings

$t-$channel, IR-regulated

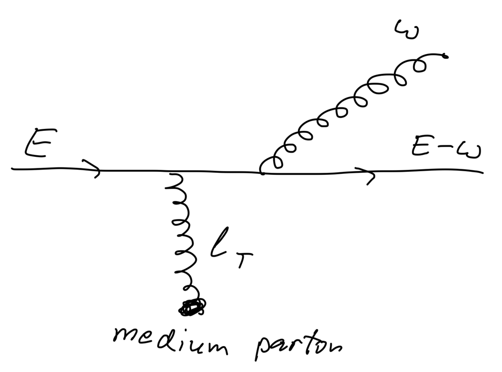


$$\frac{d^2\sigma_{\rm el}^{qq(\bar{q})}}{d^2q_T} = \frac{2C_F}{N_c}\frac{\alpha_s^2}{(q_T^2+\mu^2)^2} \quad \text{and} \quad \frac{d^2\sigma_{\rm el}^{qg}}{d^2q_T} = \frac{C_A}{C_F}\frac{d^2\sigma_{\rm el}^{qq}}{d^2q_T},$$

$\mu^2 = \kappa m_{\rm D}^2$ [Gossiaux, Aichelin, Phys. Rev. C 78 (2008) 014904], $\kappa = 0.16$.

$$\alpha_{s,\rm eff}(T) \approx \frac{0.42}{\ln\left(1.15 + 0.64\frac{T}{T_c}\right)}, \quad \text{with } T_c = 0.15 \text{ GeV}.$$

Medium-induced radiation: single (incoherent) radiation process



Basic idea: Gunion, Bertsch '82

Extension for heavy quark projectile and dynamical light quarks: Aichelin, Gossiaux, Gousset, Phys. Rev. D**89**, 074018 (2014):

In the region of small x, the matrix elements from QCD can be approximated by so-called *scalar* QCDwhich at high energy leads to a factorized formula for the total cross section of the radiation process:

$$\frac{d\sigma^{Qq\to Qqg}}{dx d^2k_T d^2l_T} = \frac{d\sigma_{\rm el}}{d^2l_T}P_g(x,k_T,l_T)\theta(\Delta), \quad \text{where}$$

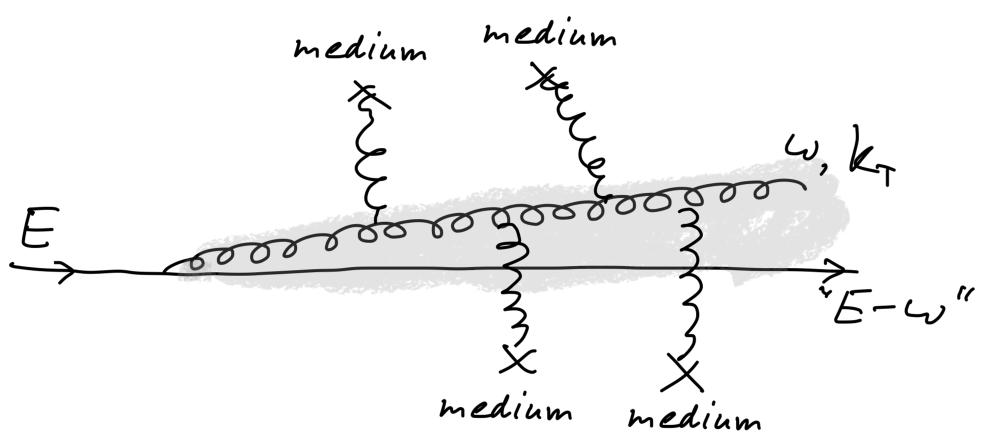
$$P_g(x,\vec{k_T},\vec{l_T};M) = \frac{C_A\alpha_s}{\pi^2}\frac{1-x}{x}\left(\frac{\vec{k_T}}{\vec{k_T}^2+x^2M^2} - \frac{\vec{k_T}-\vec{l_T}}{(\vec{k_T}-\vec{l_T})^2+x^2M^2}\right)^2,$$

Allows for finite quark/gluon masses → heavy quark jets

Summary: a building block of a new jet+medium framework SUBA-Jet

- We've constructed a Monte Carlo implementation of coherent radiative energy loss.
- Radiation seed is based on Gunion-Bertsch ⇒ massive quarks/gluons.
- In a benchmark setup, BDMPS-Z and GLV limits are reproduced.
- In a more realistic setup, considerable deviations from BDMPS-Z *even in static medium*.
- One way to state the reason is that there is no clear separation of scales: $E \gg \omega \gg k_T$ in theory, but in practice they may and do overlap.

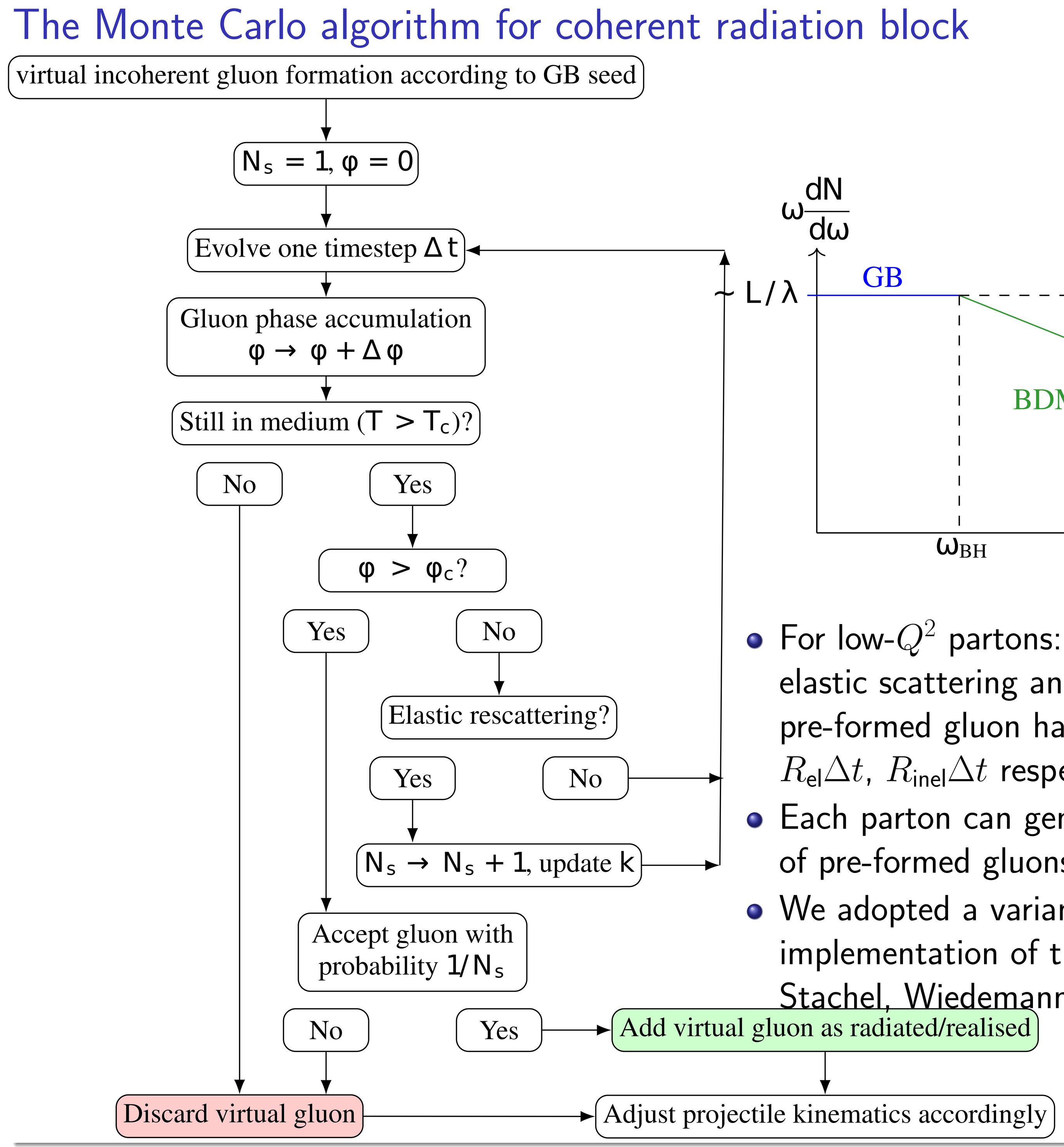
Medium-induced radiation is actually coherent

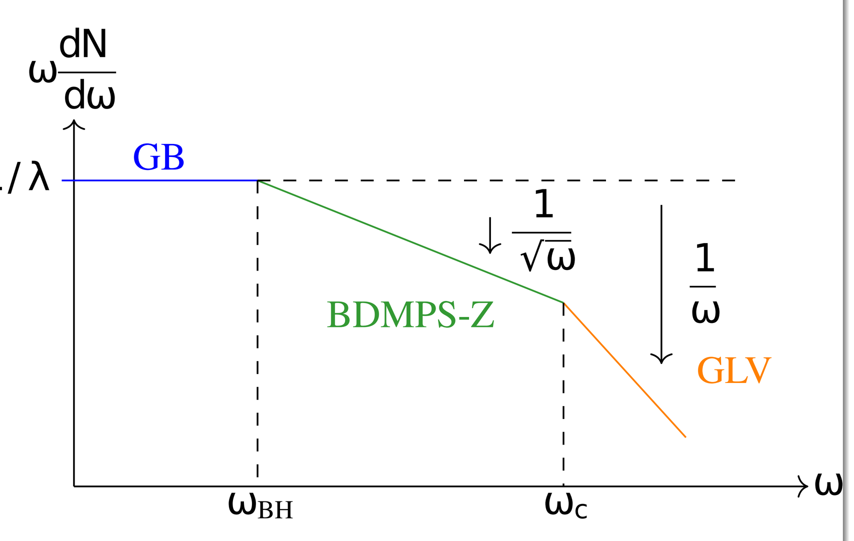


One expects to have three regimes:

- GB: Gunion-Bertsch regime, incoherent radiation
- BDMPS-Z: radiation from multiple coherent scatterings
- GLV: radiation with a single hard scattering

The Monte Carlo algorithm for coherent radiation block

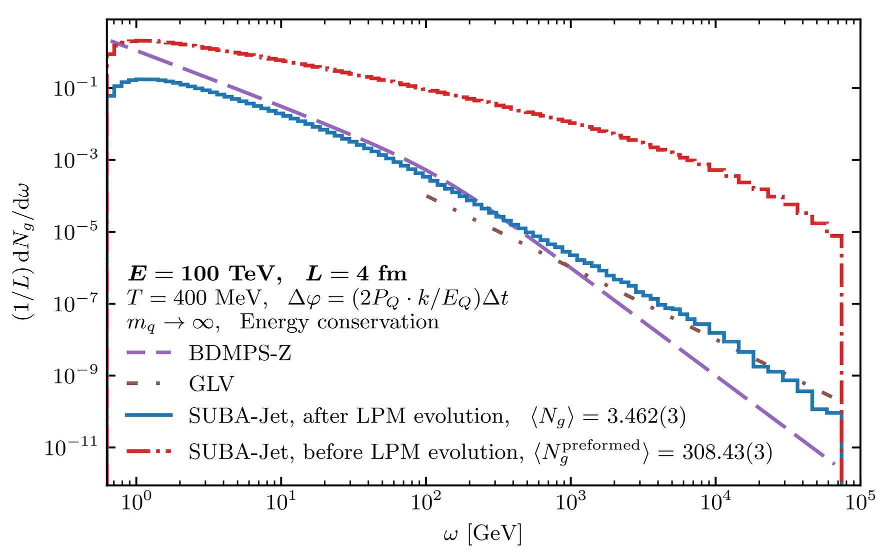




- For low-Q^2 partons: at each timestep, an elastic scattering and/or a radiation of pre-formed gluon happens with a probability $R_{\rm el}\Delta t$, $R_{\rm inel}\Delta t$ respectively.
- Each parton can generate arbitrary number of pre-formed gluons (∝blob).
- We adopted a variant of the faithful implementation of the BDMPS-Z by Zapp, Stachel, Wiedemann, JHEP **07** (2011), 118

Coherent radiation benchmark

1) 100 **TeV** jet, a proxy for $E \to \infty$ limit.



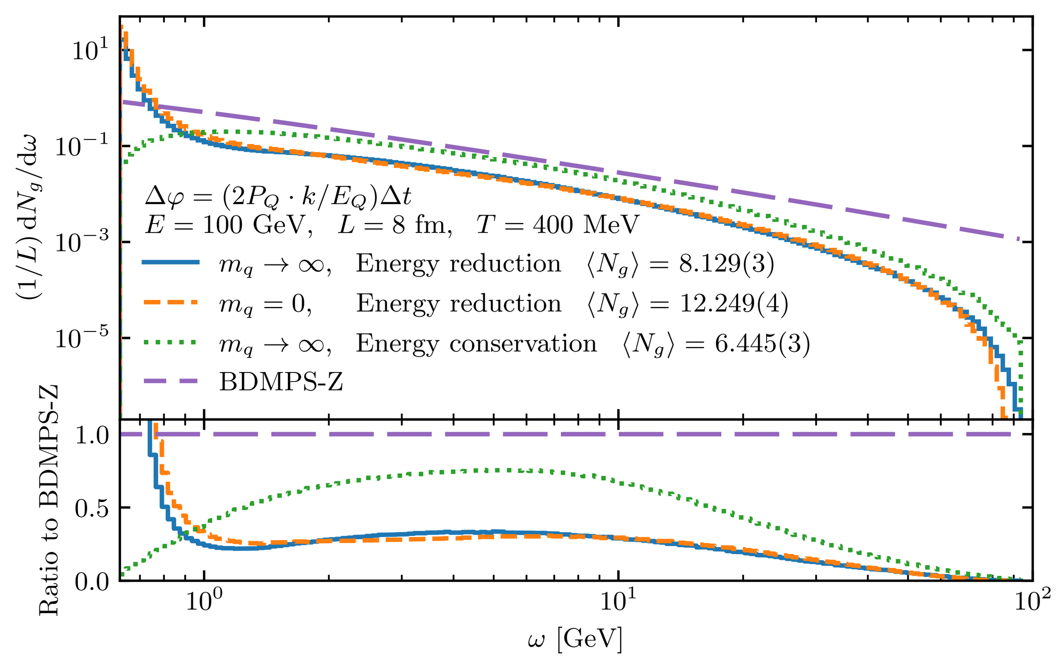
$$\omega\frac{dN^{\rm BDMPS\text{-}Z}}{d\omega} \simeq \frac{2\alpha_s C_R}{\pi}\ln|\cos(\Omega L)|$$

(Caron-Huot, Gale, 2010; Mehtar-Tani, 2019)

Setup:
$T = 400$ MeV, $\alpha_s = 0.4$
$\mu \approx 0.44$ GeV, $m_g^{\rm therm} = 0.626$ GeV, $m_q^{\rm therm} = 0.367$ GeV, $\lambda_{\rm el}^q = 0.18$ fm, and $\lambda_{\rm el}^g = 0.08$ fm.

- LPM modifies radiation spectrum at all scales (BH behaviour not present at small ω - too dense medium)
- At large ω, GLV limit is reproduced.
- A very strong LPM suppression: out of 300 virtual gluons only 1% become real radiated gluons.

Relaxing BDMPS-Z assumptions



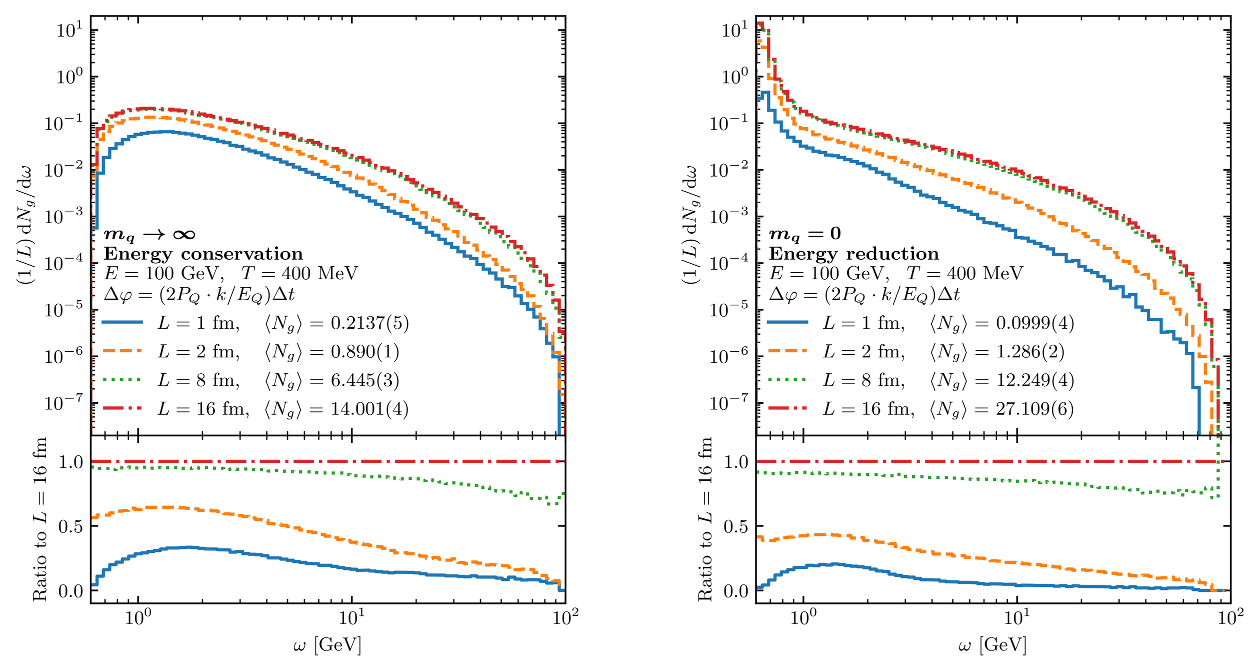
Curves in reverse order:

- $m_q \to \infty$ + energy conservation: (dotted) original BDMPS-Z
- $m_q \to \infty$ + energy reduction: (solid) account for energy reduction in scatterings
- $m_q = 0$ + energy reduction: (dashed) the most realistic case

⇒ both improvements change the low-ω spectrum significantly w/r/t/ BDMPS-Z.

Path length dependence of radiative energy loss

In both BDMPS-Z mimicking (left) and realistic (right) cases, the pathlength dependence is:



- for large L approx. $\propto L$
- for smaller L: $\propto L^\alpha$, $\alpha > 1$

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