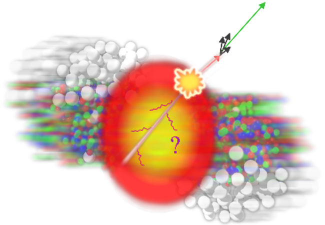
Jet evolution in a dense QCD medium

Linnéa Gräns Samuelsson

Internship at CEA Saclay
Supervisors: Edmond Iancu and Gregory Soyez

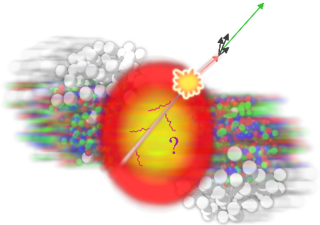
June 30, 2017

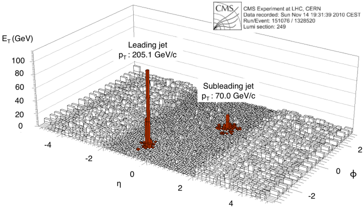
- *the medium: a quark gluon plasma created in a heavy ion collision*
- *the jet: a collimated spray of particles generated via successive branchings of a parton with high energy produced in the collision*



Structure of presentation:

- Context
- Physical picture
- Markov process
- Monte Carlo simulation ← my contribution

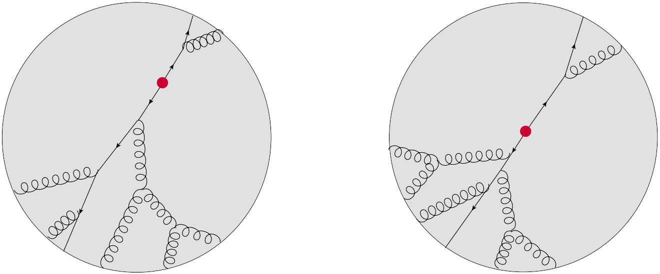




Observation: jet loses energy in medium. Missing energy found among soft hadrons at large angles.

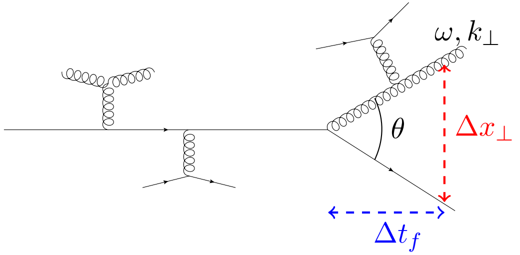
- Question 1: why large angles?

Difference in energy loss, competition between geometry and fluctuations:



- Question 2: how large fluctuations?

Physical picture



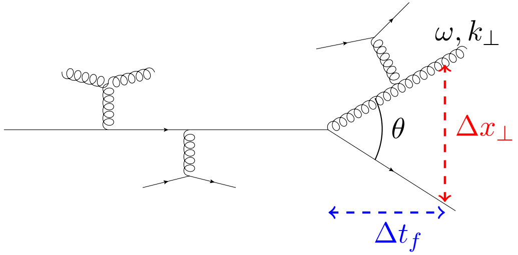
Source of energy loss: medium induced radiation.

- Scattering destroys quantum coherence

Formation time: $\Delta t_f = \frac{\omega}{k_\perp^2}$, from criterion $\lambda_\perp < \Delta x_\perp$.

(Note: mostly gluon emissions $\Rightarrow$ consider only these.)

Physical picture



- Scattering gives broadening of transverse momentum

$\Delta t_f \gg$ mean free path $\gg$ Debye length
$\Rightarrow$ multiple scatterings lead to one emission *and* scattering centers are independent
$\Rightarrow$ random walk
$\Rightarrow \langle k_\perp^2 \rangle \sim \hat{q}\Delta t$, with $\hat{q}$ being the jet quenching parameter.

$$\Delta t_f = \frac{\omega}{k_\perp^2} \qquad \langle k_\perp^2 \rangle \sim \hat{q}\Delta t$$

$$\Delta t_f \sim \sqrt{\frac{\omega}{\hat{q}}}$$

Angles: $\theta_f = \frac{k_\perp}{\omega} = \left(\frac{\hat{q}}{\omega^3}\right)^{1/4}$

$\Rightarrow$ we favour soft gluons at large angles!

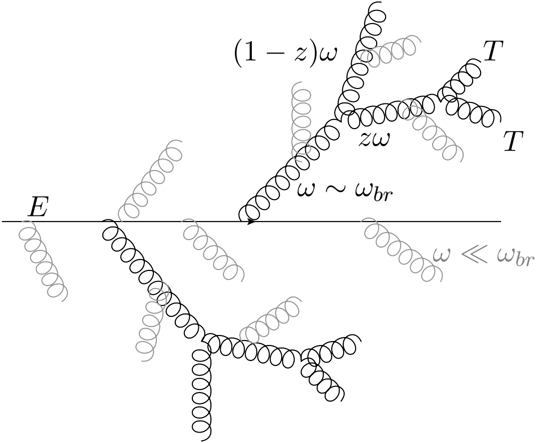
BUT not the end of the story...

Small ω gives small $\Delta t_f \Rightarrow$ need to consider multiple branchings. Hardest scale for multiple branchings:

$$\omega_{br} = \bar{\alpha}^2 \hat{q} L^2.$$

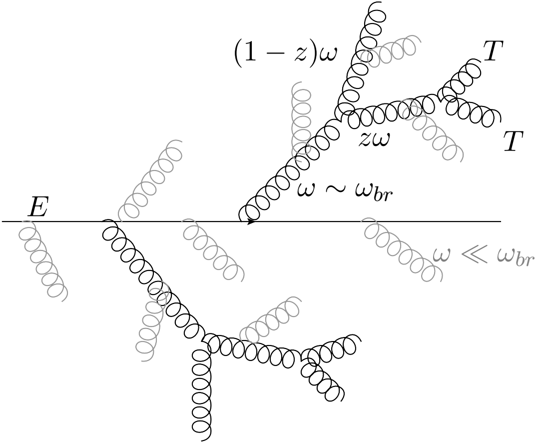
$(\bar{\alpha} = \alpha_s N_c / \pi)$

Primary gluons emitted with ω_{br} can undergo democratic branchings (child gluons split energy $\sim$ equally).



Mechanism for energy loss:

- $\mathcal{O}(1)$ of primary gluon emissions with $\omega \sim \omega_{br}$.
- They then branch democratically, transporting away all energy.
- Hence both energy loss and its fluctuations on the scale ω_{br}.



Time between branchings $\gg$ formation time

$\Rightarrow$ branchings are independent

$\Rightarrow$ Markov process

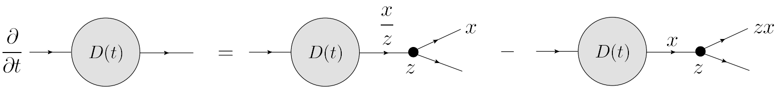
Markov process

Branching rate from BDMPS-Z spectrum:

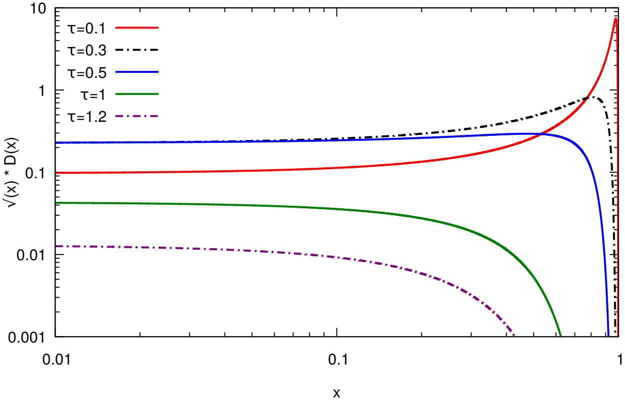
$$\frac{\mathrm{d}^2 P(z,\tau)}{\mathrm{d}z\mathrm{d}\tau} = \frac{K(z)}{2\sqrt{x}}$$

- $\tau = \frac{\text{propagation time}}{\text{democratic branching time for leading particle}}, \qquad x = \frac{\omega}{E}$
- Splitting kernel: $K(z) = \frac{[1-z(1-z)]^{5/2}}{[z(1-z)]^{3/2}} \approx \frac{1}{[z(1-z)]^{3/2}}$

For the energy spectrum we consider $D(x,\tau) \equiv xn(x,\tau)$, for the fluctuations we also need $D^{(2)}(x, x'\tau) \equiv xx'n^{(2)}(x,x',\tau)$.

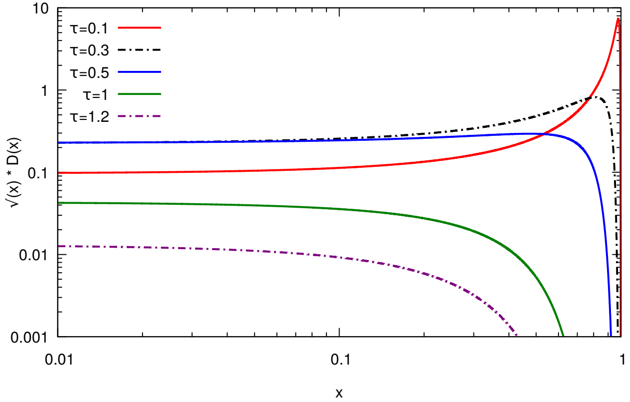


Analytic result, simple kernel:



- $D(x,\tau) = \frac{\tau}{\sqrt{x}(1-x)^{3/2}} \exp\left(-\frac{\pi\tau^2}{1-x}\right)$.
- $\int_0^1 \mathrm{d}x\, D(x,\tau) = e^{-\pi\tau^2} \Rightarrow$ energy decreasing in time.
- Formally: condensate at $x = 0$. Physically: thermalization.

Analytic result, simple kernel:



- At small τ, loss $\simeq \pi\omega_{br}$.
- $D^{(2)}(x, x'\tau)$ used to find fluctuations. To order τ^4:

$$\sigma_\epsilon(\tau) \simeq \langle\epsilon(\tau)\rangle/\sqrt{3}$$

.

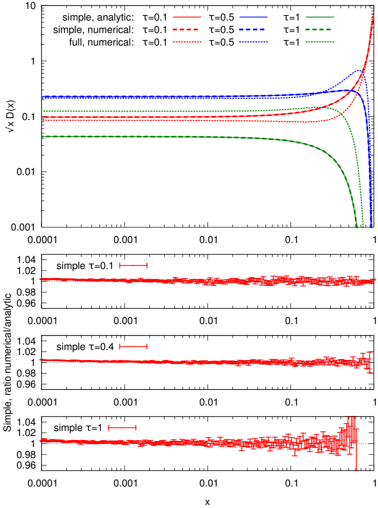
New work: Monte Carlo simulation

https://github.com/gsoyez/SimpleMediumBranching

Monte Carlo simulation

Result: full kernel $\Rightarrow$ less efficient branching

$\sqrt{x}D(x)$



Simple splitting kernel, numerical versus analytic:

- Good agreement overall
- Small x bias $< 1\%$

Corrections from the full splitting kernel:

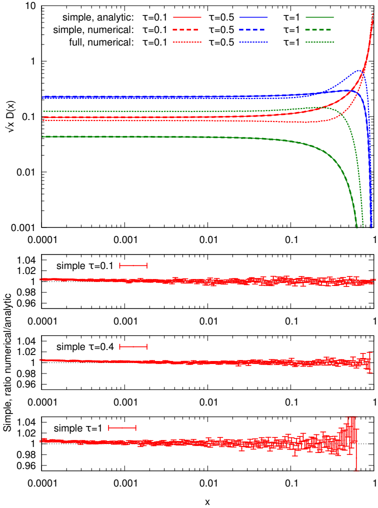
- Leading peak still present at $\tau = 0.5$
- Less energy lost at $\tau = 1$

Recall:
Simple $K(z) = \frac{1}{[z(1-z)]^{3/2}}$
Full $K(z) = \frac{[1-z(1-z)]^{5/2}}{[z(1-z)]^{3/2}}$

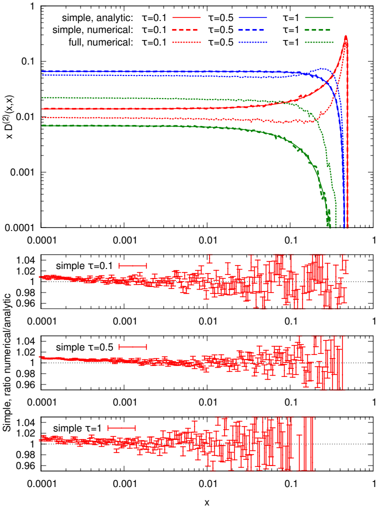
Monte Carlo simulation

Result: full kernel $\Rightarrow$ less efficient branching

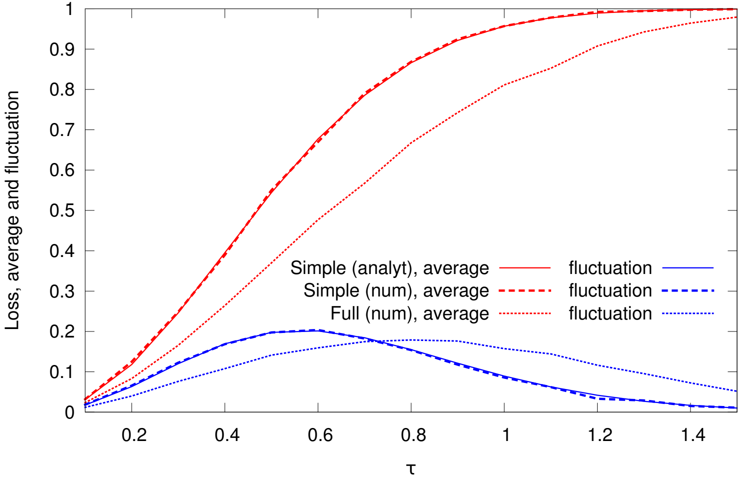
$\sqrt{x}D(x)$



$xD^2(x,x)$



Energy loss and its fluctuations - new result!



Full kernel $\Rightarrow$ shifted in τ but same qualitative picture.

Summary:

- Democratic branchings $\Rightarrow$ energy found at large angles
- Prediction: large fluctuations in energy loss
- My contribution: Monte Carlo simulation
- First results for full kernel: same qualitative behaviour, quantitative differences

THE END

Questions?