A new pQCD based parton shower for jets in the quark-gluon plasma

P. Caucal, E. Iancu, A.H. Mueller and G. Soyez

Institut de Physique Théorique, CEA, France

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The Myriad Colorful Ways of Understanding Extreme QCD Matter

Columbia University in the City of New York

De la recherche à l'industrie cea

IPhT Saclay

université Paris-Saclay

Short introduction

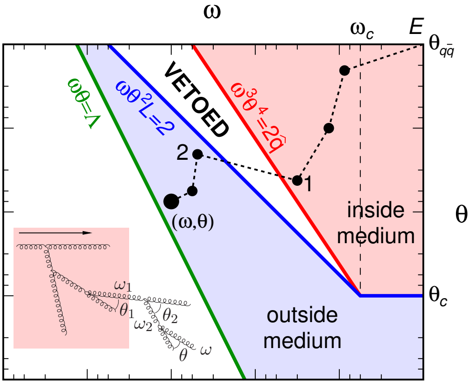
- Jets are important probes of the quark-gluon plasma produced in heavy-ions collisions at LHC or at RHIC.

- For high p_T jets such as those measured at LHC, pQCD provides a solid framework to compute jet observables within well-controlled approximations.

Introduction (reminder)

Edmond's lectures in a nutshell / Phys.Rev.Lett. 120 (2018) 232001

- The evolution of a jet **factorizes** into three steps:
  - one **angular ordered** *vacuum-like shower* inside the medium ,
  - followed by *medium-induced mini-jets* from by previous sources;
  - finally, a *vacuum-like shower* outside the medium.



Introduction (reminder)

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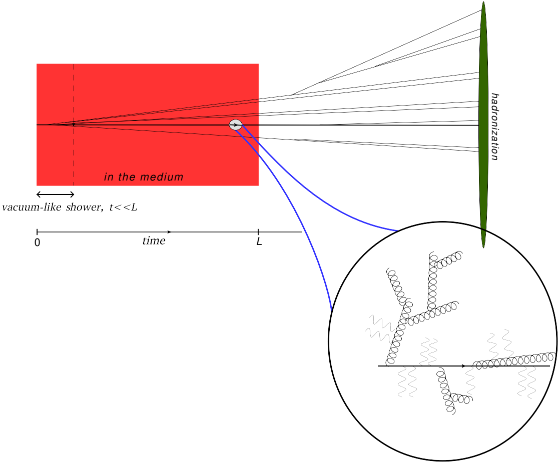


- Because of **decoherence** induced by the medium, the first emission outside the medium has no angular constraint.

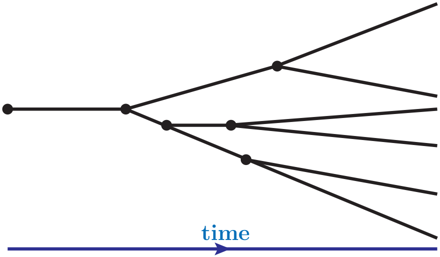
MC implementation of a branching process 1/3

- Because of quantum color coherence, the jet evolution can be seen as a Markovian branching process.

- How to simulate such a branching process on a computer ?

MC implementation of a branching process 2/3

- One defines the **evolution variable** of the branching process, that we call "time".
- At a given time, the branching process is a tree graph, with vertices labeled by the formation time of the vertex and edges labeled by the properties of the partons.



- A final parton is further evolved **if its kinematic is still in the phase space available**.

MC implementation of a branching process 3/3

Recurrence

- In practice, we proceed recursively.

- Initial tree graph: one parton at “time” $t = 0$ which physically represents the leading particle.

- By recurrence, we only need to understand how to evolve one final parton.

Angular ordered vacuum parton shower

- The angle plays the role of the "time" parameter of the branching process: $t = \log(\theta_{max}/\theta)$.

- The probability to have **no** branching between the angle θ_i and the angle θ_{i+1} is given by the Sudakov form factor:

$$\Delta_i(\theta_i^2, \theta_{i+1}^2) = e^{-\int_{\theta_{i+1}^2}^{\theta_i^2} \frac{d\theta^2}{\theta^2} \int_0^1 dz \frac{\alpha_s(zE\theta)}{2\pi} P_{ji}(z) \Theta(k_\perp > k_\perp^{cut})}$$
$$\simeq e^{-\frac{\alpha_s}{2\pi} \int_0^1 dz P(z) \times \Delta t}$$

$\Longrightarrow$ similar to the radioactive decay formula.

- To generate the time of the next branching, one picks an angle according to the probability distribution to have a **first** branching at angle θ_{i+1}.

- The representation and the energy fraction of the emitted parton is chosen according to the DGLAP splitting probability.

Medium-induced parton shower 1/2

- The evolution parameter is x^+ in light-cone coordinates with the longitudinal axis defined by the direction of motion of the leading particle.

- The probability to have **no** branching between time $\bar{t}$ and time t_0 is given by the Sudakov factor:

$$\Delta_{\mathrm{med}}(\bar{t}, t_0) = e^{-\int_{\bar{t}}^{t_0} dt \int_{z_c/x}^{1-z_c/x} dz \frac{d\mathcal{P}_{br}}{dzdt}}$$

  with the BDMPS-Z branching rate

$$\frac{d\mathcal{P}_{br}}{dzdt} = \frac{1}{4\pi}\frac{\bar{P}_{gg}(z)}{\tau_{br}(z,x)}\ ,\ \tau_{br}(z) = \frac{1}{\alpha_s}\sqrt{\frac{z(1-z)xE}{\hat{q}_{\mathrm{eff}}(z)}}$$

- Here again, one choose the next branching time according to the probability distribution given by this Sudakov.

Medium-induced parton shower 2/2

Momentum broadening

- At this stage, every splitting is assumed to be collinear with the leading particle. The angle of a parton is then determined by the transverse momentum broadening acquired between two successive branchings.
- In our MC, this is mimicked by ascribing to each parton an average transverse momentum $\langle k_\perp^2 \rangle = \hat{q}\Delta t$ with a Gaussian distribution.

Full parton shower

Succession of three showers

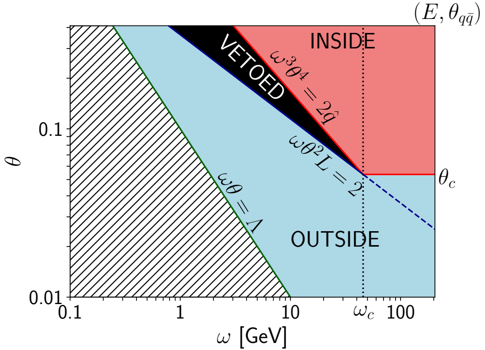
Vacuum parton shower in the medium (red region) with full splitting function, running coupling and color representations

$\otimes$

Medium-induced parton shower with fixed coupling

$\otimes$

Vacuum parton shower outside the medium (blue region) after reopening the phase space



Important results

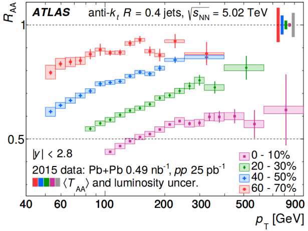
I will focus mainly on two observables:

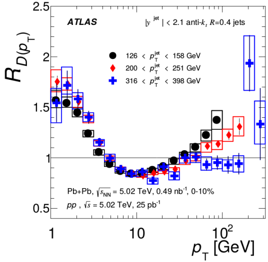
- the **nuclear modification factor for jets** R_{AA}^{jets},
- the **jet fragmentation function** $z\frac{dN}{dz}$,

Comparison with experimental data from LHC

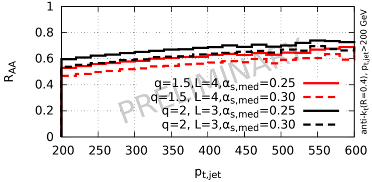
Jet cross section $\frac{d^2 N_{jet}}{dp_T dy}|_{AA}$

Energy distribution of hadrons inside jets $D(z = \frac{p_T}{p_{T,jet}}) = z\frac{dN}{dz}$

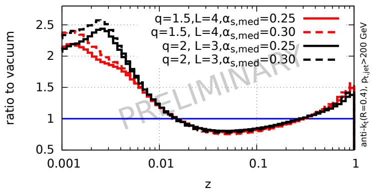




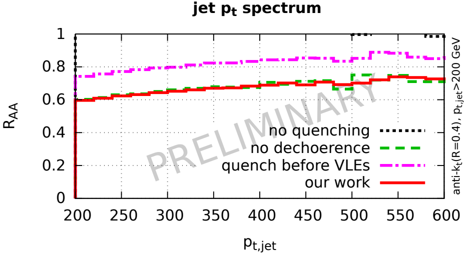
jet p_t spectrum

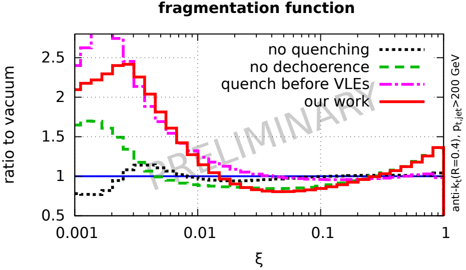


fragmentation function



(Short) physical discussion





Comments

- Saturation of R_{AA} due to vacuum-like fragmentation inside the medium.
- Enhancement at small z of the fragmentation function due to decoherence of the last emission inside the medium.

Conclusion

Summary

- Sketch of the MC implementation of our pPQCD based picture of jet evolution in a dense QCD medium.
- Results in good qualitative agreement with LHC data.

In perspective

- Application to other intrajet observables such that the z_g distribution.
- A more realistic description of the medium, hadronization effects, etc...

THANK YOU !