Angular correlations between heavy and light jet-particles as a means to study in-medium heavy-quark energy loss

M. Rohrmoser*, P.-B. Gossiaux†, T. Gousset†, J. Aichelin†

email: rohrmoser.martin1987@gmail.com

* Institute of Physics, Jan Kochanowski University, 25-406 Kielce, Poland   † SUBATECH, 4 rue Alfred Kastler, 44307 Nantes, France

Motivation:

Parton Quenching in Heavy Ion Collisions ⟶ described well by processes of energy loss that are: purely collisional or collisional and radiative

Introduction:

- Quark Gluon Plasma (**QGP**) produced in heavy ion (AA) collisions.
- To study it experimentally: **hard probes** are used. i.e.: heavy flavored/hard partons (accessed via the resulting mesons) that are created at early stages of the collision and pass through the medium.
- R_{AA}: Measures suppression ($R_{\mathrm{AA}} < 1$) or enhancement ($R_{\mathrm{AA}} > 1$) of numbers of hard probes in the QGP.
- Strong suppression/Energy Loss: reproduced by combinations of collisional and radiative processes or collisional processes alone!

⇒ Need for more discriminative observables!

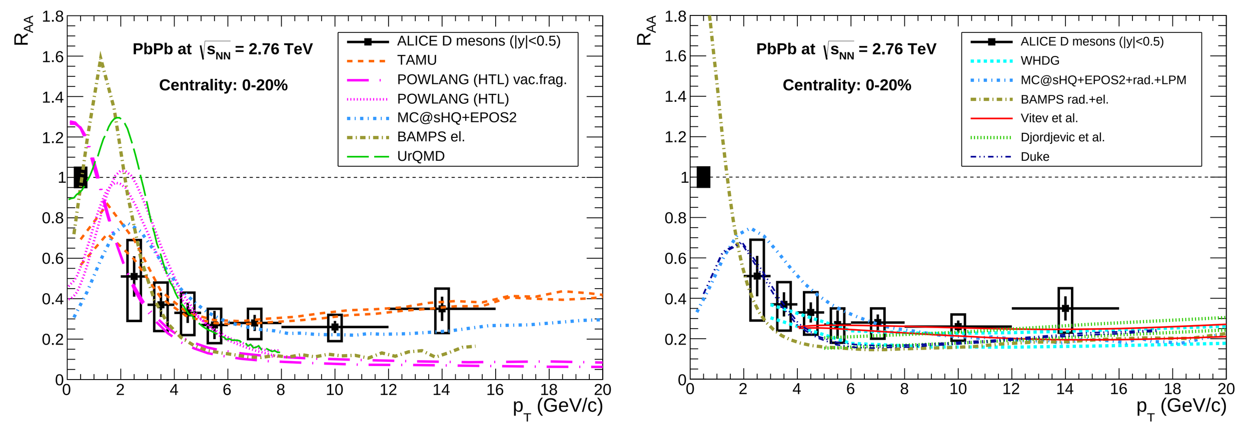
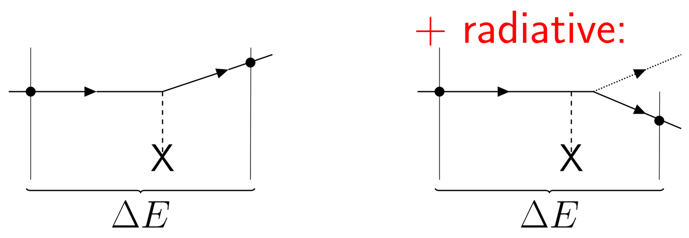


Figure 1: ALICE data for the R_{AA} of D mesons (black dots) compared to models of either purely collisional energy loss (left) or combinations of collisional and radiative energy loss (right). This figure was taken from Ref. [1].

The processes:

collisional: collisional + radiative:



⇒ Only 1 process radiates particles!

Study 2-particle correlations?

Monte-Carlo approach:

Parton fragmentation into jets is simulated by Monte-Carlo simulation of a large number (10^6 for the results shown here) of jets. The jet evolution in the vacuum is described by collinear emission of bremsstrahlung. The approach taken in this work as well as by many others, e.g. [2,3] is a Monte-Carlo simulation of the probabilistic approximation by Dokshitzer, Gribov, Lipatov, Altarelli, and Parisi (DGLAP) [4].

The Monte-Carlo tool programmed up to now simulates timelike parton cascades that originate from an initial quark with a maximal virtuality $Q_\uparrow$ and energy E_{ini}. Partons in the cascades can split above a virtuality scale $Q_\downarrow$, below of which it is assumed that they are on the mass shell.

In order to estimate the position of the jet particles inside of a medium the time Δt between 2 successive splittings of a virtual particles with energy E and virtuality Q has been estimated with the Heisenberg uncertainty relation as

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

Jet-Medium Interactions:

Effective Models:

While a virtual particle travels through the medium, its 4-momentum is changed over time t between 2 successive splittings in order to simulate the effects of scatterings with medium particles.

Induced radiation:

Virtuality is increased (based on YAJEM [3]):

$$\frac{dQ^2}{dt} = \hat{q}_R(t)$$

Virtuality increase ⇒ Additional emissions ⇒ Energy transfer to radiated particles.

Elastic scatterings:

Stochastic transverse deflections of the 3-momentum and longitudinal drag.

Transverse kicks: $\hat{q}_C(t) := \frac{d}{dt}\langle \vec{p}_\perp \rangle^2$,

Longitudinal drag: $\vec{A}(t) := -\frac{d}{dt}\langle \vec{p}_\parallel \rangle$,

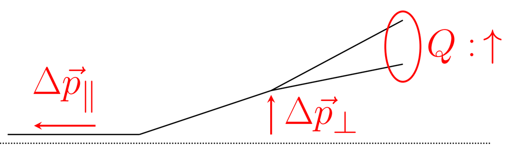
Assumption of a locally thermalized medium ⇒ $\hat{q}_C/|\vec{A}| \propto T$ (cf. Ref. [5])

Further Assumptions: $\hat{q}_C = \hat{q}_R$ and a temperature profile of the type

$$\hat{q}_C \sim T^3,$$

motivated by studies of the Jet-Collaboration [6].

Collisions: Jet-particle energy transferred to the medium (via drag force $\vec{A}$).



⇒ Radiative and collisional model + 2 hybrid models:

model	Q	$\vec{p}_\parallel$	$\vec{p}_\perp$	E
A (radiative/inelastic)	↑	=	=	↑
B (collisional/elastic)	=	↓	↑	↓↑
C (hybrid/no transverse force)	↑	↓	=	↓↑
D (hybrid/transverse force)	↑	↓	↑	↓↑

↑...component increases between splittings,
↓...component decreases between splittings,
=...component not affected,
↓↑...component decreases for high momenta/increases for low momenta.

Consistent framework to study effects of different processes of parton energy-loss on observables!

Angular 2-Particle Correlations:

Angular 2-particle correlations between the initial quark as trigger particle with other cascade particles were calculated. The results should correspond qualitatively to experimental data for the correlations between heavy and light mesons.

As a measure for the strength of jet-medium interactions in the simulations the scale

$$\Delta Q^2 := \int_0^L dt \hat{q}_{C,R}(t)$$

is introduced, where $L \approx 10$ fm/c is the spatial extension of the medium.

Distributions over $\Delta\phi$, the differences in azimuthal angles ϕ, are often studied experimentally, cf. e.g.: Ref. [7]. Here are some of our results for models A and B:

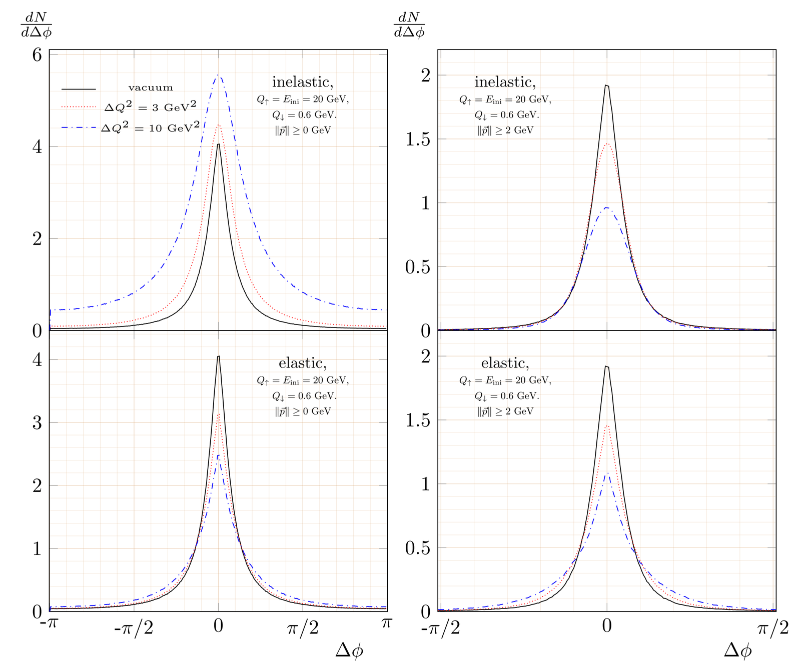


Figure 2: Azimuthal correlations between heavy and light particle pairs in jets.

$\|\vec{p}\|_{\mathrm{cut}}$...cut in parton momentum: only partons with larger absolute values of their 3-momenta are accepted.

Conclusion: Angular broadening depends differently on energy scales for radiative and collisional jet medium interactions!

⇒ Study the dependencies of the angles $\Delta\theta$ on the cuts directly:

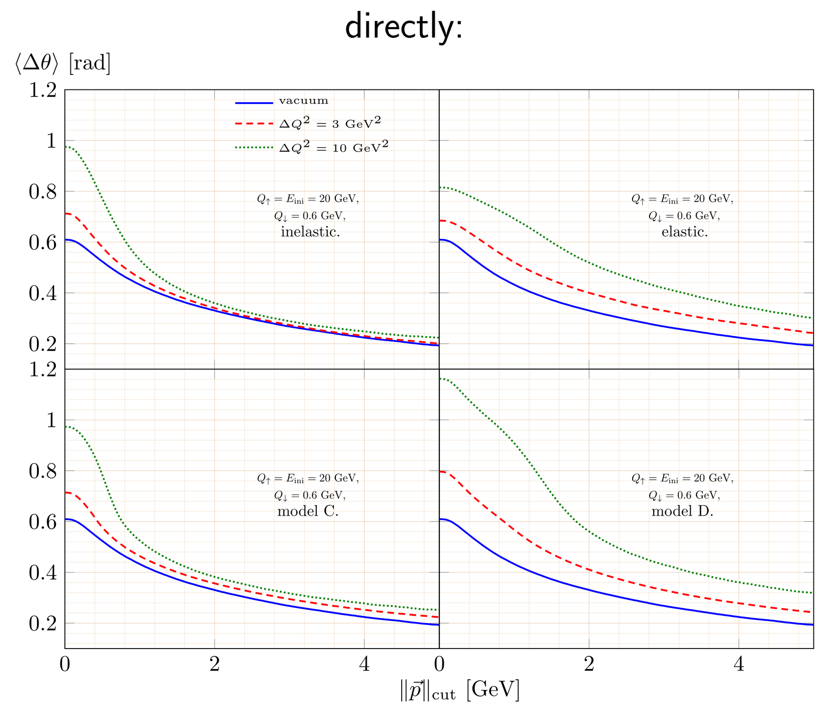


Figure 3: Average of angle $\Delta\theta$ between the momenta of the particle pairs in models A, B, C, and D, as functions of $\|\vec{p}\|_{\mathrm{cut}}$

Time evolution:

The time-evolution of angular correlations is studied via the evolution of the angles ϑ_i of branching i in successive parton emissions.

Only particles with absolute values of 3-momenta above a cut $\|\vec{p}\|_{\mathrm{cut}}$ are considered as cascade particles – yielding a number $N_{S\,eff}$ effective splittings:

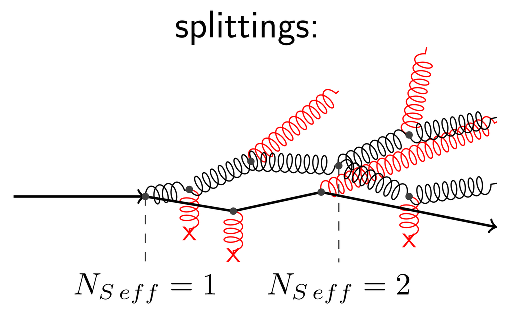


Figure 4: Example of a cascade with a number of $N_{S\,eff} + 1 = 3$ particles emitted (in black) above the threshold given by $\|\vec{p}\|_{\mathrm{cut}}$.

Particle cascades with different topologies were extracted to study the evolution of the branching angles in consecutive splittings:

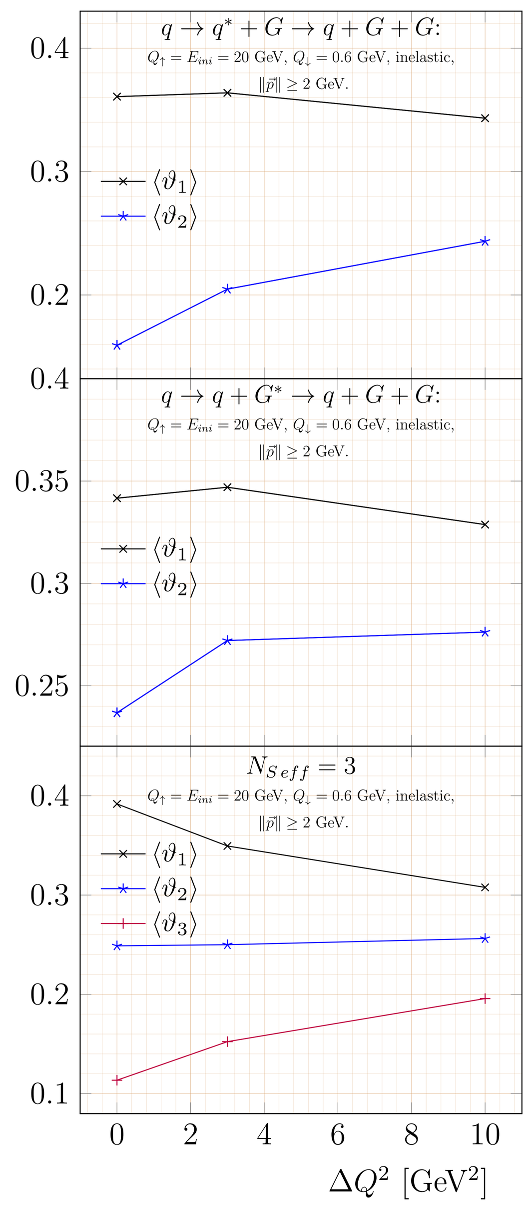


Figure 5: Branching angles in the vacuum and the purely radiative energy-loss model A for 3 different jet-topologies as indicated.

⇒

- In the vacuum, the jets are angularly ordered as expected!
- Angular ordering is weakened in the medium!
- **Later splittings are more affected by jet-medium interactions than earlier ones!**

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Conclusions:

Main Conclusion:

Angular Heavy-Light particle correlations allow to distinguish collisional and radiative mechanisms of in-medium parton-energy loss!

Key-Results:

- Radiative energy loss: Angular broadening at small energies. Collisional energy loss: Angular broadening at all energies.
- Later splittings are more affected than earlier splittings by the medium for the model of purely radiative energy loss.

References:

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[2] Eur. Phys. J. C **60** (2009) 617-632
[3] Phys. Rev. C **78** (2008) 034908
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[5] Phys. Rev. C **90** (2014) 064906, arXiv:1405.3243
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