Exploring the universality of jet quenching via Bayesian inference

A data-driven perspective on jet quenching

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ABSTRACT

Experimental data on a wide range of jet observables measured in heavy ion collisions provide a rich picture of the modification of jets as perturbative probes and of the properties of the created quark-gluon plasma. However, their interpretation is often limited by the assumptions of specific quenching models, and it remains a challenge to establish model-independent statements about the universality in different jet quenching observables. In this work, we propose a treatment that is agnostic to the details of the jet-medium interactions and relies only on the factorization picture of QCD. Bayesian inference is used to learn the quark- and gluon-jet quenching directly from experimental data of inclusive jet observables. Evidence of the universality of jet quenching is provided by validating the learned jet energy loss through the prediction of photon-tagged jet measurements, for which the quark/gluon fraction differs from that in inclusive jets, across momenta. The extracted posterior distributions can then serve to retrieve theoretical insight in a data-driven way and can be employed to constrain theoretical models for jet quenching.

Jet quenching and energy loss

In heavy-ion collisions, quark-gluon plasma is formed. Meanwhile, jets are created from hard scatterings. Contrary to what happens in proton-proton collisions, these jets evolve while interacting with the hot medium via strong force, which changes the jet structure, and makes it lose energy via medium-induced radiation that might end up outside the jet cone. This is known as jet quenching.

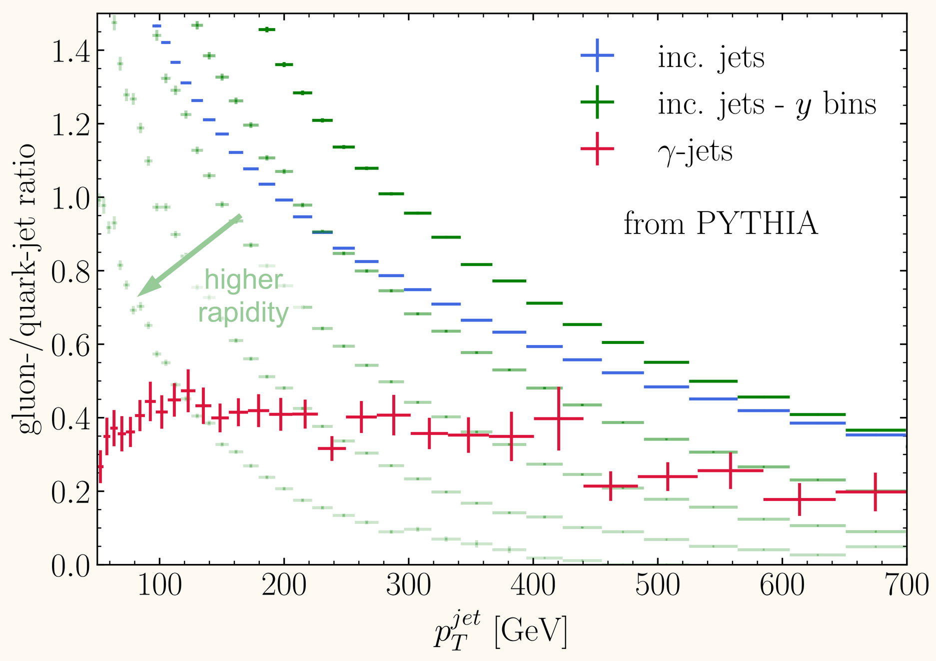
Modeling the jet energy-loss

The difference in energy scales of the plasma and the hard scattering, and consequent jet evolution, allows for the following factorization of the jet spectrum in heavy-ion collisions,

$$\left.\frac{d\sigma^{AA}}{dp_T}\right|_{p_T} = \int_0^\infty d\varepsilon \sum_{i=q,g} D_i(\varepsilon) \left.\frac{d\sigma_i^{vac}}{dp_T}\right|_{p_T+\varepsilon} .$$

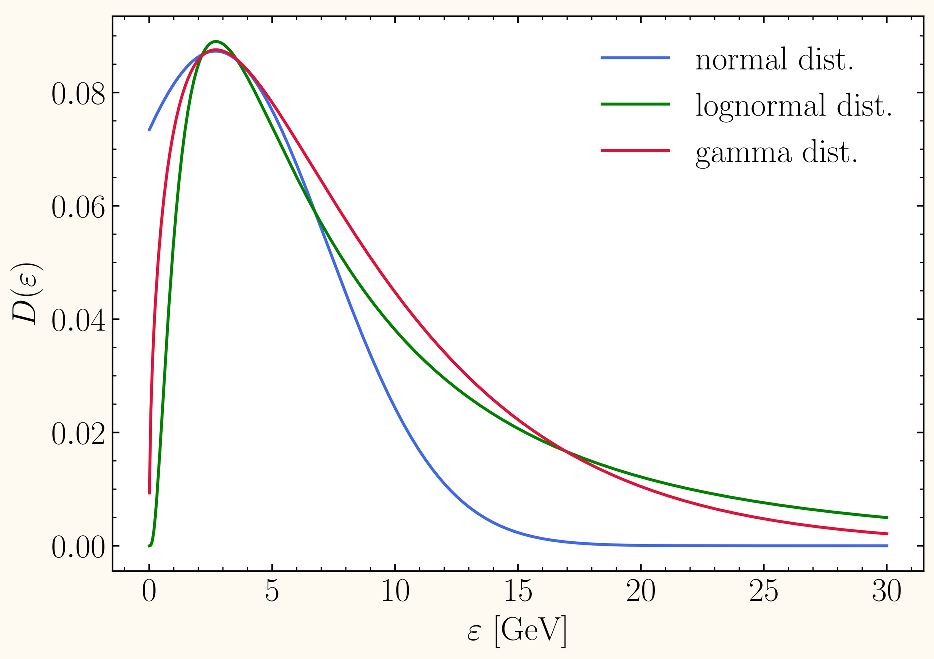
The medium spectrum ${}^{d\sigma^{AA}}/_{dp_T}$ is given by the equivalent vaccum spectrum ${}^{d\sigma^{vac}}/_{dp_T}$ convuluted with an energy-loss distribution $D(\varepsilon)$.

This factorization picture leads to the non-dependence of the energy loss on the process that created the jet, but only on how the jet interacts with the medium. This means a universality of the jet energy loss across different observables and kinematic cuts.



Quark- vs. gluon-initiated jets

The ratio between quark- and gluon-initiated jets varies for different processes, and for different kinematical cuts. Depending on the initiating parton, the jet interacts and evolves in a distinct way inside the medium.



Energy-loss parameterization

We consider three parameterizations for the energy-loss distribution $D(\varepsilon)$:

- a normal distribution;
- a lognormal distribution;
- a gamma distribution,

the main difference being the probability of losing a higher amout of energy.

Bayesian inference

The parameterization of the energy-loss is constrained by training the model with data from inclusive jet observables. Measurements from different hard processes can be predicted. Two analyses are done:

Analysis A

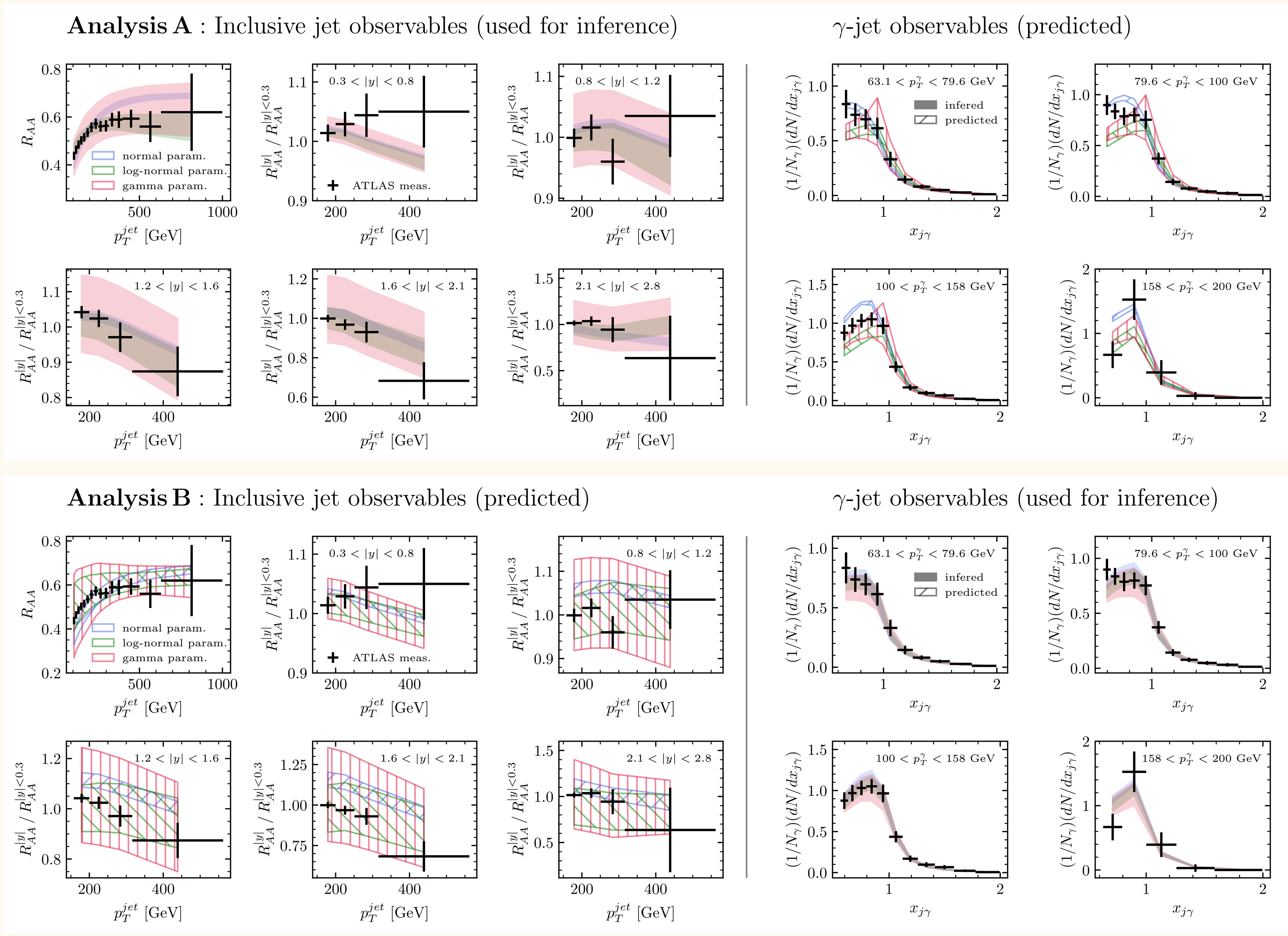
Inference is performed using only inclusive jet observables, and the posterior distributions are used to predict photon-tagged jet observables

Analysis B

Inference is performed using only photon-tagged jet observables, and the posterior distributions are used to predict inclusive jet observables.

Evidence of universality

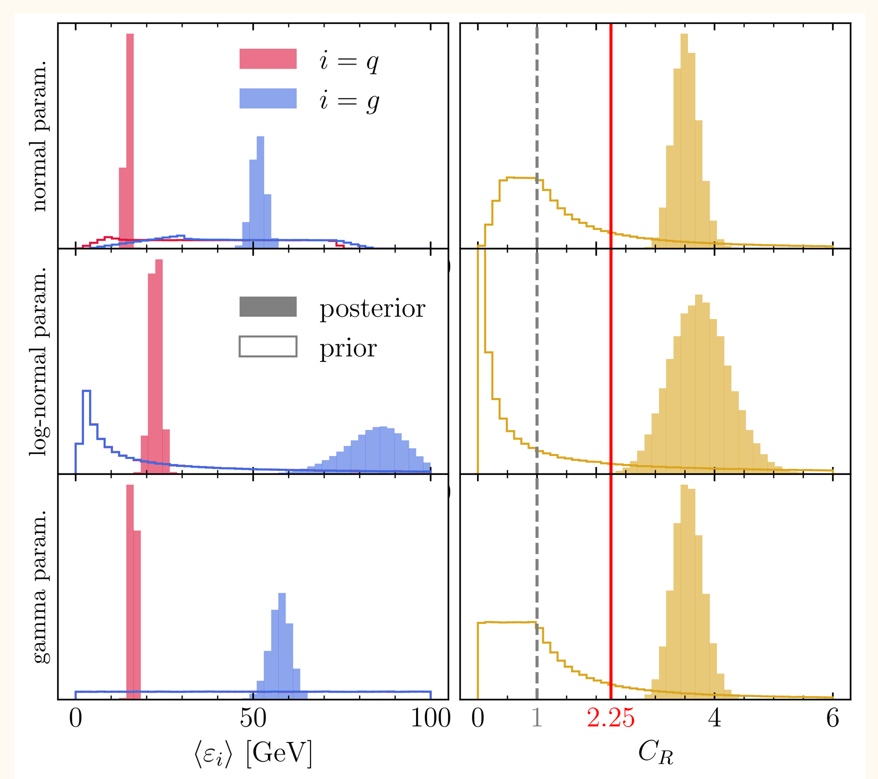
Having performed inference on inclusive jet observables (analysis A), photon-tagged jet observables are successfully predicted. This shows the universality of the factorization picture, since the different kind of observables have a different ratio of quark-/gluon-initiated jets. The fact that the inference on photon-tagged jet observables (analysis B) does not result in a well constrained prediction for inclusive jet observables shows the limited constraining power of the photon-tagged jet observables on the energy loss of gluon jets.



High density interval of the posterior distribution for the training data: inclusive R_{AA}, and ratio of R_{AA}'s for four different rapidity bins of inclusive jets; and predicted data: photon-tagged spectrum $1/N_\gamma \cdot dN/dx_{j\gamma}$.

Analysis of the posterior

From the posterior distributions, we can access the mean energy loss of the jets. The method can distinguish between the energy loss of quark- and gluon-initiated jets, with the jets initiated by gluons being more probable to lose more energy than the ones initiated by quarks (as expected from theory). The resulting color ratio is consistently higher than the predicted Casimir scaling, across the three parameterizations.



Posterior ditribution of the mean energy loss of quark- and gluon-initiated jets (left), for different parameterizations, together with respective color ratio (right).

Conclusion

With the information about the jet initiating parton, and after being fitted to inclusive jet observables, the model successfully predicts the experimental data for different processes, for the three energy loss parameterizations. This validates the factorization picture in a minimal theory-dependent model and data-driven way, hinting for the universality of jet energy loss in quark-gluon plasma across different processes.

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