

Confronting jet quenching with jet grooming: jet mass distributions in heavy ion collisions

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In this proceeding we present a calculation of jet mass distributions for small-radius jets in proton-proton and heavy ion collisions using soft-collinear effective theory (SCET). A process-independent groomed jet mass function is defined which captures the soft-collinear radiation inside jets. The factorization expression simplifies significantly, allowing one to calculate jet mass distributions for jets in any hard process with the corresponding jet cross section. Additional contributions from initial and final state radiation as well as underlying events are discussed. With the medium-induced splitting functions calculated using SCET with Glauber gluon interactions, the medium correction to jet mass distributions is incorporated consistently within the resummation framework. We provide calculations of jet mass distributions for inclusive jets and jets recoiling against a prompt photon or a Z boson, and we compare them with PYTHIA simulations of pp collisions and with currently available measurements in pp and AA collisions at the LHC.

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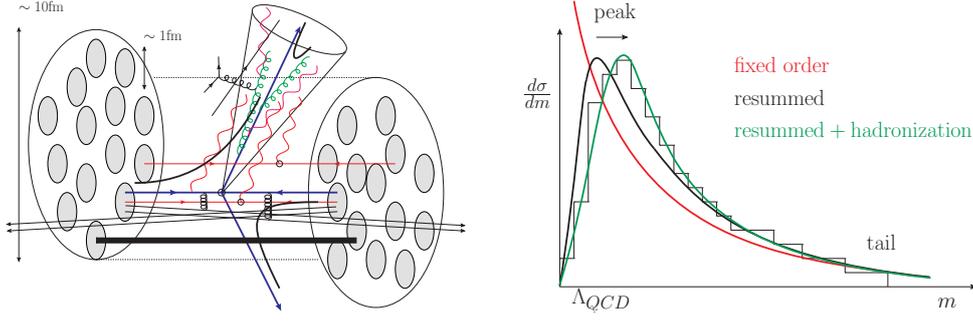


Figure 1: Left panel: Various radiation contributions inside a jet in a heavy ion collision. Right panel: The necessity of all-order resummation and the effect of hadronization to the jet mass distribution.

1. Introduction

A precise understanding of the redistribution of jet energy is among the priorities of jet physics in heavy ion collisions. Various proposed jet quenching mechanisms capture the picture of energy loss by transporting the jet energy to wider angle. Possible contributions from medium response to jets also affect the energy distribution. Therefore designing jet substructure observables which can probe aspects of jet-medium interaction is vital for revealing possible, novel signatures of jet quenching. On the other hand, techniques which help clean up jets – generally referred to as jet grooming – have been introduced to mitigate background soft radiation in order to enhance the signal sensitivity. Groomed jet observables with different grooming parameters thus have different sensitivities to radiation inside jets, giving the opportunities to test the details of jet quenching mechanisms and rigorously determine the medium properties.

In this proceeding we exploit the connection between jet quenching and jet grooming and present a calculation for groomed jet mass distributions. The jet mass is a classic jet observable which is sensitive to both energetic, collinear radiation as well as soft, wide-angle radiation (represented by the green and red lines, respectively, in the left panel of Fig. 1). There are many possible sources of soft radiation, including final-state and initial-state radiation, underlying events activity correlated or uncorrelated with the hard collision, medium-induced radiation and medium response. The calculation of jet mass distribution requires all-order resummation of logarithmically-enhanced terms, as well as modeling non-perturbative contributions (right panel of Fig. 1). We use soft-collinear effective theory (SCET) to factorize the cross section, and to resum, via the renormalization group evolution, the logarithmic corrections appearing among different scales (left panel of Fig. 2). We focus on the medium modification contribution caused by induced radiation via Glauber interaction [1]. We use the soft drop [2] grooming procedure to remove soft, wide-angle radiation (right panel of Fig. 2). Below we summarize the formalism for calculating the soft drop jet mass distribution and present some preliminary results.

2. Framework

Following the framework developed in [3, 4, 5, 6] for various jet substructure calculations, at next-to-leading logarithmic (NLL) accuracy one can define a process-independent groomed jet

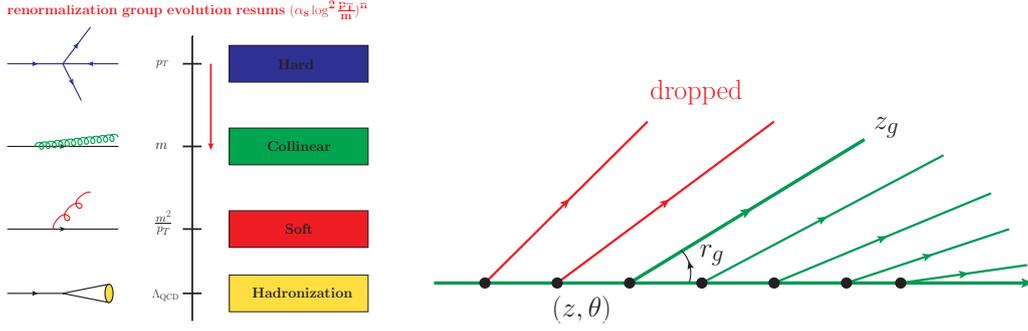


Figure 2: Left panel: Factorization of jet mass in SCET and resummation performed using renormalization group evolution. Right panel: The angular-ordered tree in the soft drop procedure.

mass function $J^{SD}(m^2, \mu)$ which captures all the soft-collinear radiation inside jets ($i = q, g$ labeling quark-initiated or gluon-initiated jets),

$$J_i^{SD}(m^2, \mu) = \int dp^2 dk J_i(p^2, \mu) S_i^{SD}(k, R, z_{\text{cut}}, \mu) \delta(m^2 - p^2 - 2E_j k), \quad (2.1)$$

where $S_i^{SD}(k, R, z_{\text{cut}}, \mu) = S_i^C(k, R, z_{\text{cut}}, \mu) S_i^G(R, z_{\text{cut}}, \mu)$ can be further factorized. At fixed-order, the jet mass function can be directly calculated using the collinear splitting function,

$$J_i^{SD}(m^2, \mu) = \sum_{j,k} \int_{PS} dx dk_{\perp} \mathcal{P}_{i \rightarrow jk}(x, k_{\perp}) \delta(m^2 - M^2(x, k_{\perp})) \Theta_{\text{alg}} \Theta_{SD}. \quad (2.2)$$

Here $M^2(x, k_{\perp}) = \frac{k_{\perp}^2}{x(1-x)}$ is the jet mass measurement function, while $\Theta_{k_T} = \Theta(E_J R x(1-x) - k_{\perp})$ and $\Theta_{SD} = \Theta(E_J R x(1-x) \left(\frac{x}{z_{\text{cut}}}\right)^{1/\beta} - k_{\perp})$ are the jet algorithm and soft drop phase space constraints, respectively. The medium modification can also be included using medium-induced splitting functions. The full jet mass distribution can then be calculated by weighing the groomed jet mass functions with the corresponding jet cross sections,

$$\frac{d\sigma}{dm^2} = \sum_{i=q,g} \int_{PS} dp_T dy \frac{d\sigma^i}{dp_T dy} P_i^{SD}(m^2, \mu), \text{ where } P_i^{SD}(m^2, \mu) = \frac{J_i^{SD}(m^2, \mu)}{J_{\text{un}}^i(\mu)}. \quad (2.3)$$

Note that the ratio $P_i^{SD}(m^2, \mu)$ between the jet mass function and the unmeasured jet function is renormalization-group invariant and can be interpreted as the probability distribution of the jet mass for jets initiated by parton i .

3. Preliminary results

Having outlined the framework of our calculation, we present some preliminary results to compare with PYTHIA simulations and to currently available measurements. The left panel of Fig. 3 shows the comparison between NLL SCET calculations and ALICE measurements [7] of inclusive charged jet mass distributions in 2.76 TeV PbPb and 5.02 TeV pPb collisions. In the calculation we relate the total jet mass to the charged jet mass assuming isospin symmetry. The calculation does not yet include non-perturbative effects therefore the jet mass is systematically lower than

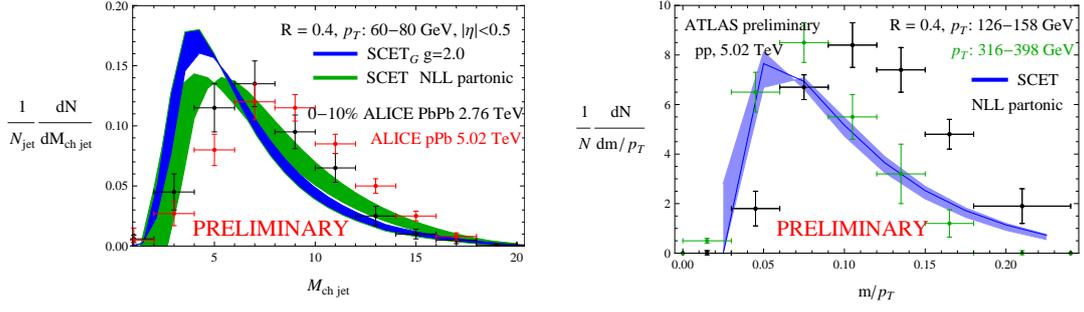


Figure 3: Left panel: NLL SCET calculations (assuming isospin symmetry) and ALICE measurements [7] of inclusive charged jet mass distributions in 2.76 TeV PbPb and 5.02 TeV pPb collisions. Right panel: NLL SCET calculation and ATLAS measurement [8] of inclusive jet mass over transverse momentum ratio in 5.02 TeV pp collisions.

the measured values. However, we can see that the medium modifies the jet mass towards smaller values. The right panel of Fig. 3 shows the comparison between SCET calculation and ATLAS measurement [8] of inclusive jet mass over jet transverse momentum (m/p_T) distribution in 5.02 TeV pp collisions. We see that the partonic calculation agrees well with the measured distribution for jets at higher p_T where non-perturbative effects are small.

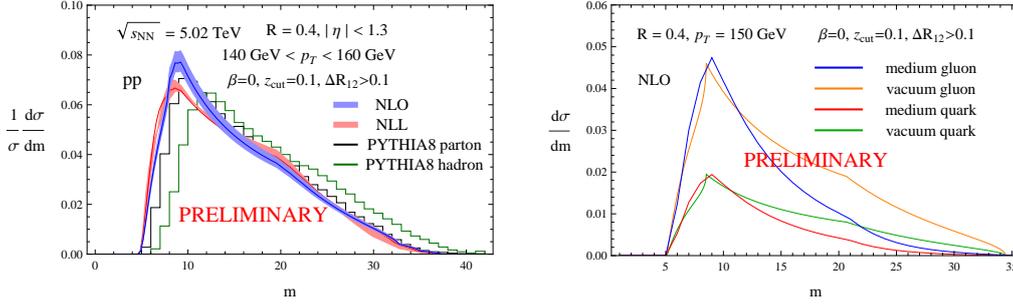


Figure 4: Left panel: PYTHIA simulations compared to the NLO and NLL+NLO SCET calculations of inclusive soft drop jet mass distribution in 5.02 TeV pp collisions. Right panel: NLO vacuum and medium contributions to inclusive soft drop jet mass distribution in SCET.

The left panel of Fig. 4 shows the comparison of NLO and NLL+NLO SCET calculation with PYTHIA simulations at parton and hadron level for inclusive soft drop jet mass distribution in 5.02 TeV pp collisions. We see that the parton level results agree quite well, and that hadronization affects the distribution significantly in all regions. The right panel shows the NLO vacuum and medium contributions and suggests that the small jet mass region is enhanced by the medium.

The CMS measurement imposes a ΔR_{12} cut to constrain the angle between two soft drop branches therefore removing the Sudakov peak region [9]. The formalism allows us to calculate the jet mass distribution for jets from arbitrary hard scattering process. Fig. 5 shows the NLL SCET calculation (left panel) of jet mass distribution for Z+jet events in 7 TeV pp collisions and compare with CMS measurements [10] (right panel). We see the very good agreement which further confirms the validity of the framework.

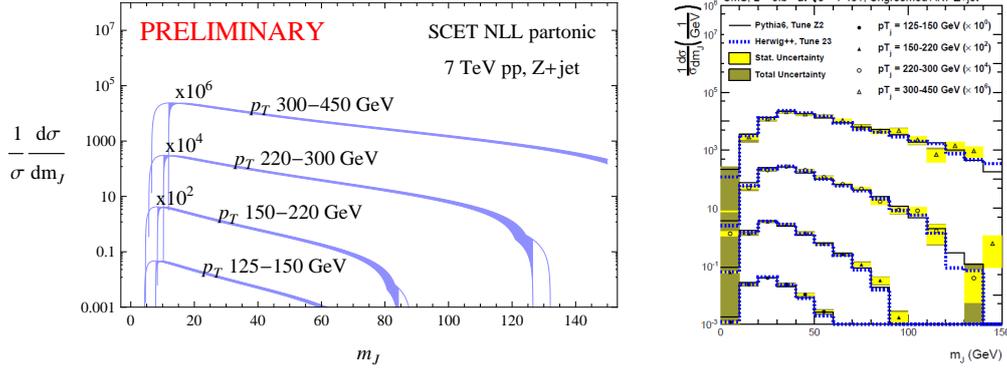


Figure 5: NLL SCET calculation (left panel) and CMS measurements [10] (right panel) of jet mass distribution in Z+jet events in 7 TeV pp collisions.

4. Conclusions

Jet mass contains rich information of the radiation inside jets, and jet grooming gives a concrete strategy to probe specific regions which can reveal possible jet quenching features. We provide an effective field theory framework to systematically resum logarithmically-enhanced contributions and calculate the jet mass distribution at NLL accuracy for any arbitrary hard scattering process with jets in the final state. This work provides a baseline for future precision jet substructure studies.

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