N-subjettiness as a jet shape to study the antenna effect in heavy-ion collisions

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Abstract

I hereby briefly outline the work that I have done at CERN as a Summer Student. It consisted in the characterization of a new observable called N-subjettiness, from raw level to fully corrected, as a probe for the coherence effect in the QGP environment. The data analysed are the pp and PbPb collisions detected by the ALICE experiment during LHC run 1, as well as monte carlo simulated events[1].

In my 12 weeks at CERN as a Summer Student I have worked on jet analysis within the ALICE collaboration, studying a new jet shape called N-subjettiness, which quantifies the tendency of a jet to be composed of N sub-jets.

The physical idea behind the utilisation of this shape relies on the principle of antenna radiation [1]. For medium-induced gluon radiation, a jet is composed of a set of coloured emitters, which may not correspond to the actual number of partons in the shower. A given medium configuration defines an effective number of emitters, giving rise to a transverse resolution scale (see Figure 1) which determines the role of the coherence effects: partons separated in transverse plane less than this characteristic size remain colour correlated and hence emit induced gluons as a single parton.

With this picture in mind, N-subjettiness might be a powerful tool, since it characterizes the general jet substructure without introducing any fragmentation bias: no cut on sub-jet constituents p_T is applied. The

[1]This document doesn't include any plot or result from actual data because they are all preliminary.

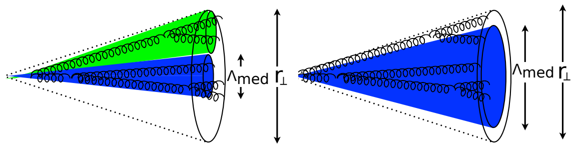

Figure 1: A sample jet event resolved with $R_{med} = 0.1$ (left panel) and 0.15 (right panel). The blue denotes the hardest resolved-subjet, the green the next-to-hardest one [1].

observable is defined as [2]:

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min \left\{ \Delta R_{1,k}, \ldots, \Delta R_{N,k} \right\} ,$$

where k runs over the constituent particles in a given jet, $\Delta R_{J,k} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, J is the candidate subjet, $d_0 = \sum_k p_{T,k} R_0$, R_0 is the main jet radius. Thus τ_N quantifies to what degree a jet can be regarded as composed of N subjets, how well the jet energy is aligned into sub-jets. For $\tau_N \gtrsim 0$, the radiation is aligned with the candidate sub-jets directions. $\tau_N \lesssim 1$, instead, means that a large fraction of the energy is distributed away from the candidate sub-jets (there are at least N+1 sub-jets). Furthermore, τ_2/τ_1 turns out to be an effective discriminating variable to identify two-prong objects [2].

The idea of the analysis is to identify the most 2-prong objects and study their p_T yield, in pp as well as in PbPb, looking for different behaviours. The expected trend, as far as the antenna radiation is concerned, is a suppression of these objects in PbPb with respect to pp.

I started by analysing the behaviour of the observable on simulated collisions, using Pythia8 [3] as an event generator. The jet finding is performed with the FastJet software [4], using the anti-k_t finding algorithm, the E-scheme for the recombination, and different jet and sub-jet radii (*i.e.* $R^{\text{jet}} = 0.2,\ 0.4,\ R^{\text{subjet}} = R^{\text{jet}}/2$). I then moved on studying pp and PbPb real events, using the constituent subtraction method [5] as a background subtraction strategy, observing how the shapes changed after the correction. I also ran the analysis on a set of monte carlo background events (these being generated with a PSM-generator [6]) in order to see how the observable reacts to events without structure. The same was performed on randomized data, *i.e.* background events whose η and ϕ distributions were generated randomly and uniformly within the detector acceptance.

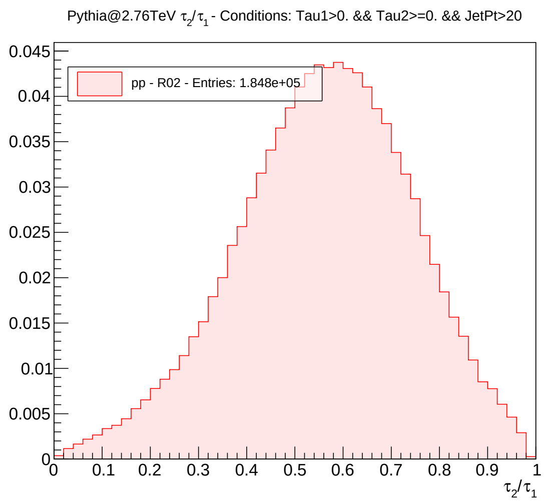

Figure 2: The 2-prong discriminating variable, τ_2/τ_1.

The next step was to start making cuts on the discriminating variables. First of all, I tagged the most 2-prong objects using their τ_2/τ_1 value, studying their p_T yield. In Figure 2 it is reported the selec-

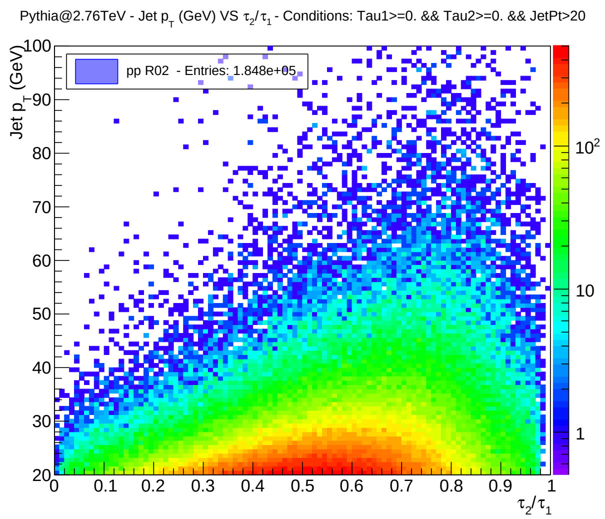

Figure 3: Correlation of the jet p_T with τ_2/τ_1. It is apparent that a selection on small τ_2/τ_1 causes a bias towards the low p_T range of the jet spectrum.

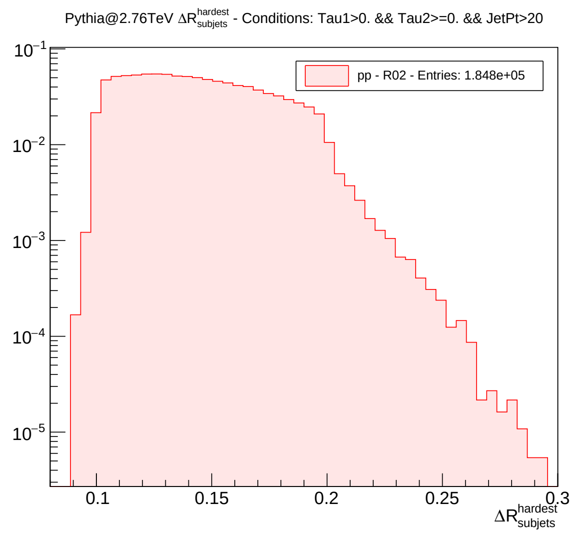

Figure 4: Spectrum of $\Delta R^{hardest}_{subjets}$.

tion variable spectrum, while in Figure 3 there is its correlation with the p_T. Also, the distance between the hardest sub-jets, $\Delta R^{hardest}_{subjets}$, turned out to be an interesting discriminating variable. Indeed, it may be a suitable observable to probe the medium resolution length, since it truly measures how spread the momentum of a jet is (see Figure 4 and 5 for its spectrum and correlation with p_T).

Up until this point I had been working with raw spectra. The following step was to fully correct the measured spectra using the unfolding. In order to do so, we studied the behaviour of the observables on the so called *embedded* events. The procedure requires to generate an event, simulate the detector efficiency and smearing, embed this event on a PbPb event, and then run the background subtraction. By tagging the original (true) jet to the final one (hybrid subtracted), it is possible to study different background behaviours as well as quenching effects. For instance, by comparing the true level with the detector level we were able to quantify the detector inefficiencies at high p_T, while in the low p_T range we understood how background fluctuations influence the jet spectrum.

With the embedding data ready, we proceeded with the unfolding, performed with the RooUnfold software [7], using the iterative Bayesian algorithm [8]. The idea is to reconstruct the real distributions from the measured, knowing from the embedding analysis how the true are affected by background, inefficiencies, etc. Since we were interested in the correlation of the jet p_T with two different observables, *i.e.* the one to identify the 2-prong objects (τ_2/τ_1) and the distance between sub-jets, we performed two different bi-dimensional unfolding. In order to do that, we needed to build

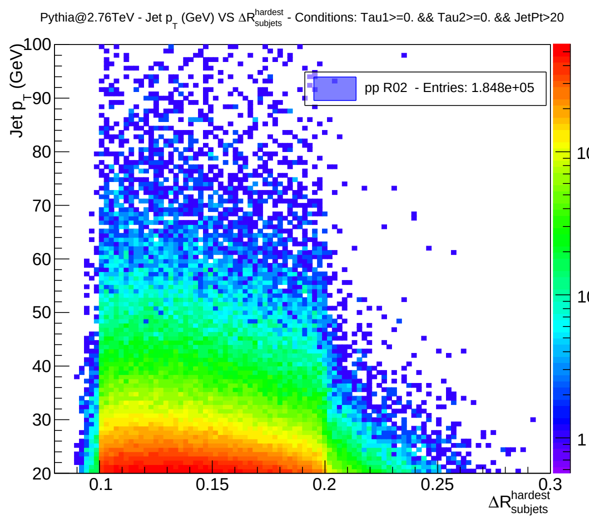

Figure 5: Correlation of the jet p_T with $\Delta R^{hardest}_{subjets}$.

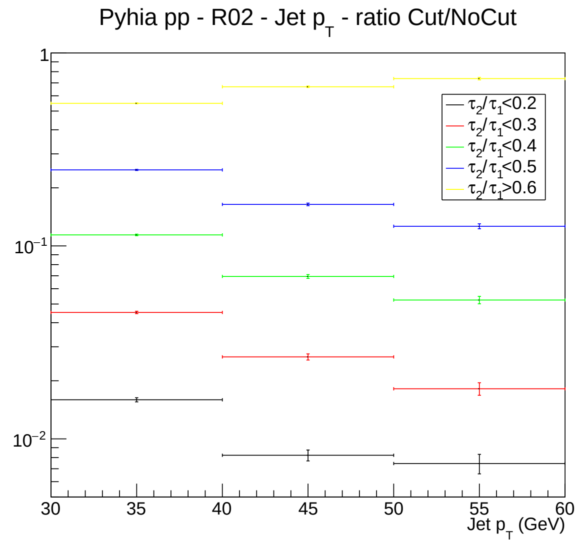

Figure 6: Ratio plot Cut/NoCut with different cuts in τ_2/τ_1. The data shown are Pythia8 simulations at 2.76 TeV.

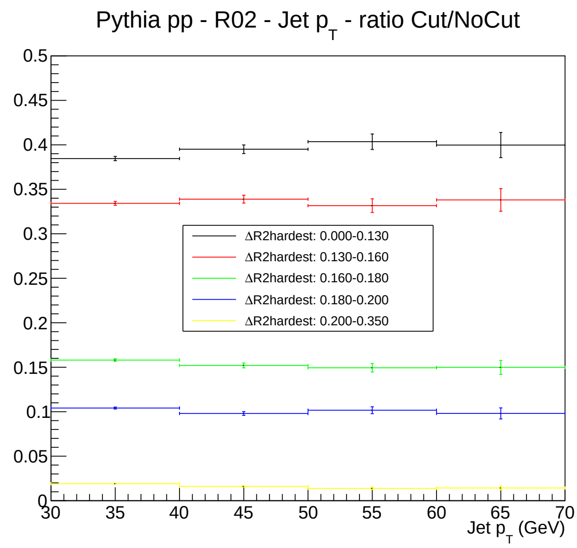

Figure 7: Ratio plot Cut/NoCut for different classes of $\Delta R^{hardest}_{subjets}$, applying a cut of $\tau_2/\tau_1 < 0.8$. The data shown are Pythia8 simulations at 2.76 TeV.

two 4D response matrices, to fully take into account the relative dependencies between the variables at true and measured levels.

With the fully corrected unfolded spectra, thus taking into account kinematic efficiencies, background effects, systematic biases, and detection inefficiencies, it was possible to study the true jet p_T yield with different cuts on corrected discriminating variables.

One last step was to run the analysis on Pythia8-generated events at the same energy as the PbPb events (*i.e.* 2.76 TeV), so that we had a reference with which we could compare our unfolded results. With that in our hands, we finally studied the different behaviour of pp and PbPb shape-tagged-jets. In Figures 6 and 7 we show the ratio plots (cut distribution over the uncut one) used as a reference for the PbPb; there we compare the jet p_T shape behaviour in different regions of τ_2/τ_1 and $\Delta R^{hardest}_{subjets}$.

To sum up, I did an explorative work, characterising the behaviour of a new observable in proton collision and in nuclear collisions, starting from the raw level, ending with fully corrected spectra. The tagging procedure selected some interesting kinematic regions for the ALICE spectrometer capabilities, there was enough statistics to apply the selection cuts, so that we could start exploring how this newly predicted effect, *i.e.* the antenna radiation, affects jets in the hot and dense QCD matter.

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