Jet Analysis of Lund Monte Carlo and Quark-Recombination

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Abstract

To better understand the differences between parton and hadron level jets theoretically, event generators such as Pythia and Recombination were used in conjunction with FastJet to analyze the difference between the two levels. Using Pythia, two hadron levels were created, one with hadron decay and one without. This was done to examine the role that hadron decay played when comparing it the parton level jet. Using the same data, a comparison was made between Pythia and Recombination in order to observe the differences between the two models of hadronization.

1 Introduction

Accelerators around the world track jet-quenching, a phenomena that occurs when colliding particles at very high energies produce a jet of elementary particles, in order to study their behavior. At facilities like Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider (LHC) at CERN Laboratory, they collide hadrons and heavy ions at very high energies and study the jets that are produced. When hadrons collide, a shower of partons are produced, which are then hadronized leading to a shower of hadrons. Experimentally, one can only measure the jets created after hadronization as it is the only thing picked up by the detectors. This is significant as one cannot measure jets before hadronization when the shower is still at the parton level. Due to current technological limitations, detectors cannot detect particles at the parton level of the event.

However, theoretically one can calculate the jets in the parton level, thus one can compare the difference between parton and hadron level jets. This paper will include parton and hadron level jets created from an event generator PYTHIA that uses the Lund Monte Carlo model, which will be expanded on in the section 3 of the paper. Prior research by other physicists suggest that there is no difference between the two jet levels. The paper also includes a discussion about the importance in hadronization and how it can affect the difference in jet comparison between parton and hadron level jets. To evaluate this comparison, the quark Recombination model was also used for hadronization. This will be explained in the section 4 of the paper. The paper will also include a comparison in the calculation between the two hadronization models.

2 Lund Monte Carlo

In this paper PYTHIA Lund String model was used for hadronization to create a hadron shower. The Lund String model is a theoretical approach that strongly interacting particles classified as hadrons are viewed mathematically as massless strings whose ends move with the speed of the light in multidimensional space [1]. This model is based on a dynamical relativistic string, representing the color flux stretched between the initial $q\bar{q}$. The string breaks up into hadrons via $q\bar{q}$ pair production in its intense color field. At the LHC when two protons collide, partons are produced. Then using the string model, the string stretches as the quarks move further apart until the strings break resulting in the formation of hadrons. The calculation from PYTHIA's Lund String model closely resemble the experimental proton-proton data gathered from the LHC and RHIC. Thus, for this research the implication of PYTHIA was used for hadronization to compare the parton level and hadron level jets.

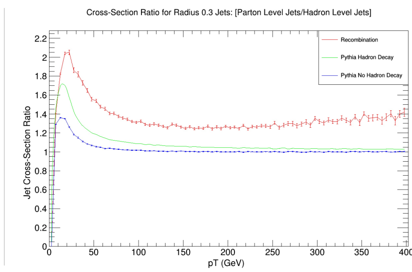
3 Quark Recombination

The implementation of the Quark Recombination model was used to compare parton and hadron level jets, which was then compared to the PYTHIA Lund String model. The Quark Recombination model is used in heavy-ion collision to deal with the enhancement of the proton-pion ratio seen in the LHC and RHIC experiments. Theoretically, protons are heavier than pions thus it is expected that more pions are produced from collisions than protons. However that's not the case when considering quark recombination. Quark Recombination is a model that uses probabilities based on position, time, and four momenta. The instantaneous recombination model projects quark states onto hadron states. The rate of hadronization through recombination will depend on the density of partons in phase space [2]. The recombination code calculates the probability for all pairs and triplets of partons in a shower, then uses Lund String for reaming partons. The upside to this code and model is that implementing medium effects is rather straight forward compared to PYTHIA. The writer of the recombination code claims that, when dealing with theoretical calculations including the quark-gluon plasma, it is easier to use his code for hadronization as the partons are interacting with the medium.

4 Data and Analysis

A proton-proton collision was simulated at 2.76 TeV, roughly around the same level as an collision experiment at the LHC. Another parameter limited the hard-pT from 10-900 in order to get an accurate statistical distribution when graphed from pT ranging from 0-400. By implementing these parameters in PYTHIA, a parton list with a million events were generated for every 10 hard-pT bin. The parton list was then hadronized by PYTHIA creating two different hadron lists. One list had hadron decay turned on, while the other had hadron decay off. The parton and two hadron list were put through a FastJet code with three different radii 0.3, 0.5, 0.7, which were then used to calculate the cross section ratio of the parton jets divided by the hadron jet. Using ROOT, the FastJet data was graphed to compare the Jet Cross-Section Ratio versus pT (GeV). Another simulation was created in PYTHIA to create a new parton list with a hundred-thousand events per 10 hard-pT bin, as the Recombination code was only compatible with very strict parton inputs. The Recombination code hadronized the parton list and was put through the same FastJet and ROOT code. By gathering all the data from PYTHIA and Recombination, a comparison was made using the no hadron decay data and the Recombination code.

For the six graphs to come, the error bars were statistical in nature and proportional to $\sqrt{N}$ where N is the particle count in each bin, due to the graph having a Poisson distribution. First the error bars were calculated for each level parton and hadron using the the the $\Delta S = \sqrt{\sum_i (\frac{\sqrt{N_i}\sigma_i}{TotalEvent})^2}$. In this case $S = \sum_i \frac{N_i \sigma_i}{TotalEvent}$, where $\sum_i$ takes the sum over all had-pT bins, and σ_i is the cross-section obtained from PYTHIA. To find the error of the ratio between the parton and hadron level jets, this equation was used $\Delta R = R\sqrt{\sum_i (\frac{\Delta S_{Pi}}{S_{Pi}}^2 + \frac{\Delta S_{Hi}}{S_{Hi}}^2)}$, where $R = \frac{\sum_i S_{Pi}}{\sum_i S_{Hi}}$.



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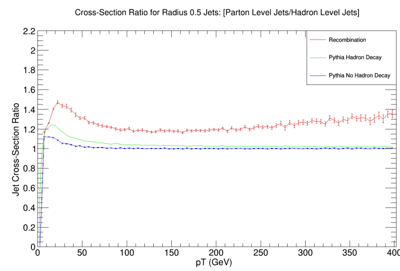

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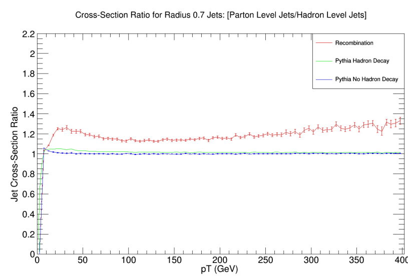

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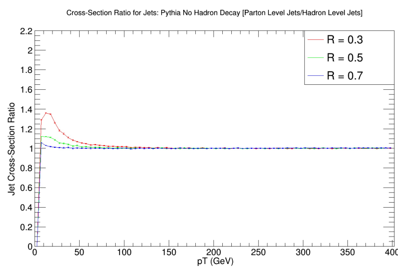
Figure 1: (a)Jet Cross-Section Ratio with jet radius 0.3(b)et Cross-Section Ratio with jet radius 0.5(c)et Cross-Section Ratio with jet radius 0.6, comparing no hadron decay, hadron decay, and Recombination ratio's: all three graphs compare the PYTHIA hadron decay, PYTHIA no hadron decay, and the Recombination code

From observing the three graphs it is shown that that at higher pT there is no significant difference between parton and hadron jets. However at lower pT there is measurable differences between the two jets, which increases as the jet radius decreases. Another observable difference is that the Recombination code seems to have a 20%-40% difference between the two PYTHIA jets, while the two PYTHIA jets ratio seems to not have that big of a difference. These graphs suggest that there might be an importance to the hadronization process and choosing the right model for the process must be taken into consideration.



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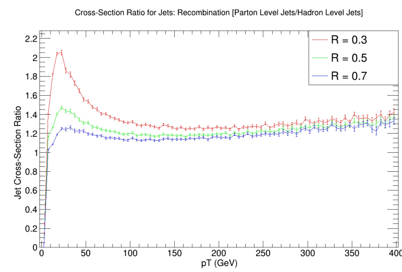

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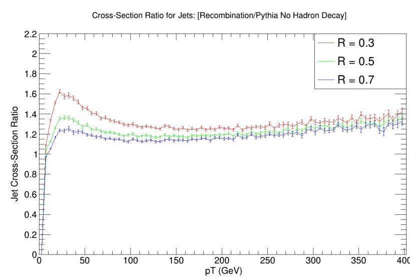

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Figure 2: (a) PYTHIA no hadron decay Jet Cross-Section Ratio at radii 0.3, 0.5, 0.7(b)Recombination Jet Cross-Section Ratio at radii 0.3, 0.5, 0.7(c) Recombination divided by PYTHIA no hadron decay Jet Cross-Section Ration at radius 0.3, 0.5, 0.7

By evaluating the graphs, we see that at higher pT for all three radii that ratio converges at 1.2, which suggests that at most there is a 20% difference. However, at lower pT, the two models differ over 20%. This disparity could be a result of the fact that the Quark recombination model allows for better jet clustering compared to the Lund String model

5 Final Thoughts

In conclusion, it seems that there is not much of a difference between parton and hadron level jets at higher pT, which contrasts the measurable difference at lower values of pT. The Recombination model differs from the PYTHIA Lund String model, which is possibly due to how these different codes account for jet clustering.

References

[1] Bryan R. Webber, Fragmentation and Hadronization

[2] Rainer J. Fries, Kyongchol Han, Che Ming Ko ,Jet Hadronization via Recombination of Parton Showers in Vacuum and in Medium