Fragmentation Function and Jet Shapes

MUHAMMAD ASADUZZAMAN *, PH/ AIP-PAP (ALICE)
University of Dhaka
Supervised by: Andreas Morsch, PH/AIP-PAP (ALICE)

August 21, 2015

Abstract

In this project work, fragmentation function, jet shapes for hard particles and jet shapes for soft particles have been calculated in different P_t range using Pythia Monte-Carlo Simulation at $\sqrt{s} = 7$ TeV. For Jet reconstruction, anti-k_t algorithm has been used with jet resolution parameter R=0.6 with momentum cut of particles at 4 GeV. Pseudorapidity was taken to be $|\eta| < 2.8$. The effects of P_t cut on the jet shapes of soft particles ($P_t < 4$ GeV) and hard particles ($P_t > 4$ GeV) have been studied. For verification of the working procedure, jet shape for all particles were also calculated with no transverse momentum cut during jet reconstruction and the results were compared to the results of ATLAS measurements. Statistical errors were computed and is well-matched with the order of error with ATLAS measurements.

I. INTRODUCTION

The study of jet shapes in proton-proton collision is important for quark jet and gluon jet discrimination. Understanding soft contribution is crucial to understand jet production in hadron-hadron collison and for verifying pQCD calculation. Besides, jet shapes are used to search for new physics with highly boosted particles in the final state decaying into multiple jets of particles.

This project report first describes the tools that were used for analysis in section II, jet reconstruction algorithm that is used in the study is described in section III, then important definitions for analysis is presented in section IV and V. Finally the key results obtained in the work is illuminated in section VI with a conclusion in the final section, section VII.

II. MONTE CARLO SIMULATION

For the calculation of jet shapes, samples of inclusive jet events in proton-proton collsions are produced at center of mass energy, $\sqrt{s} = 7$ TeV using Pythia 6.425 event generator [1].This MC simulator uses Lowest Order pQCD Matrix Elements for $2 \to 2$ processes with parton shower in leading logarithmic approximation. Pythia uses to all order Lund String model for fragmentation into hadrons. The samples were generated using tuned set of parameters Perugia2011 [2]. In this tune, proton parton-distribution set is CTEQ6L.

The MC generatend samples are passed through fastjet3.0.6 [3] [4] to reconstruct the jets from final state hadrons.

III. JET RECONSTRUCTION ALGORITHM

For jet reconstruction, anti-k_t algorithm is used with resolution paramter, R=0.6. R is almost equivalent to cone site in cone algorithm defined as,

$$R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} \tag{1}$$

where, $\eta = -\ln\tan\frac{\theta}{2}$ is the pseudorapidity with θ is the polar angle with the beam axis and ϕ is the azimuthal angle. In MC simulation, number of jet distribution was found to be ϕ independent and to have parabolic dependence on η with peak at $\eta = 0$.

The Anti-k_t algorithm can be written by the following equation,

$$d_{ij} = min(p_{ti}^{-2}, p_{tj}^{-2})\frac{\Delta R_{ij}^2}{R^2}, \tag{2}$$

$$d_{iB} = P_{ti}^{-2}, \tag{3}$$

where $(\Delta R)_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$. p_{ti} is the transverse momentum of particle i with respect to the beam direction. In Anti-k_t algorithm, all the distances d_{ij} and d_{iB} are calculated and stored. Among the stored values, if the smallest one is d_{ab}, four momentums of a and b are added and the list is updated. If the smallest distance is d_{iB}, the object is tagged as the 'jet'and removed from the list of objects. Resolution parameter (R) sets the limit to resolve two separate jets.

IV. FRAGMENTATION FUNCTION

The coupling constanst for strong interaction decreases logarithmically to zero at large energy. Hence, high energy parton-parton scattering can be calculated by pQCD, but low energy parton-parton scattering require perturbative approach. In pQCD, high P_t hadron production cross-section through the collsion of hadrons can be written by QCD factorization theorem. QCD factorization theorem says, cross-section of produced hadron can be expressed as multiplication of parton density function (PDF), parton-parton

*asaduzzamanm@mail.presidency.edu.bd

cross-section and fragmentation function.

$$\mathbf{d}\sigma^{hard}_{AB\to h} = f_{a/A}(x_1,(Q^2)) \otimes f_{a/A}(x_1,(Q^2)) \times \mathbf{d}\sigma^{hard}_{ab\to c} \otimes D_{c\to h}(y,Q^2) \quad (4)$$

Here, the last term in the factorization is fragmentation function which measures the probablity of a parton to fragment into a hadron with a momentum fraction, $y = \frac{P_{hadron}}{P_{Parton}}$.

In this project, fragementation function is calculated in logarithmic scale. Here, $\zeta = \ln(1/z)$ is calculated with $z = P_{T,track}/P_{T,jet}$.

V. Jet Shapes

Jet shapes are like picture of how the energy is distributed inside a jet. Here, jet structure is studied using differential jet shape.

$$\rho(r) = \frac{1}{N_{jet}}\frac{1}{dR}\sum_{jets}\frac{\sum_{tracks[r_a,r_b]} P_t}{P_t^{jet}} \quad (5)$$

where, r_a and r_b are distances from the jet axis and $dR = r_b - r_a$. Hence the differential area that is considered is like $2\pi r_a dR$

- N_{jet} in the equation is the number of jets in the definite transverse momentum range of jet.
- P_t is the transverse momentum of the particle which is in between distance r_a and r_b from the jet axis.

In this study, jet shapes for hard particles ($P_t > 4$ GeV) and soft particles ($P_t < 4$ GeV) are calculated separately to observe the effect of constituent momentum cut on particle during jet reconstruction at 4 GeV.

VI. Results

The results in this article used ant-k_t jet algorithm with jet resolution parameter $R = 0.6$, pseudorapidity, $|\eta| < 2.8$. Simple results were obtained to verify the working procedure of simulator. In fig.1a, jet distribution w.r.t P_t, η and ϕ are presented.

In fig. 1b, fragmentation function for all particles have been plotted for different P_t bins within $30GeV < P_T < 210$ GeV. These are momentum distribution of particle with respect to jet transverse momentum.

In fig. 2a, differential jet shapes for hard particles are plotted in different range and in fig. 2b, differential jet shapes for soft particles are plotted in different energy range.

Main motivation of this work is to observe how the jet shapes change for hard particles and soft particles if we apply the cut in particle momentum during the reconstruction of jet. The momentum cut of particle, $P_{T,cut}$ during jet reconstruction applied in this study is 4 GeV. It would be interesting to investigate further about the jet shapes for soft particles with more statistics and applying lower momentum cut of particles $P_{T,cut}$. It is expected to give quantitatively similar jet shape for $r >> R$ in different energy since these soft particles are not used for jet reconstruction in our study.

The figure in 3a shows the difference in jet shapes for hard particles in $30 < P_t < 40$ GeV and in $110 < P_t < 160$ GeV. There is scope of searching some new variable which can give similar jet shapes in different energy range for hard particles. The figure in 3b, shows comparison of jet shapes in the two P_t range for soft particles.

Finally, in fig. 3c, jet shapes from the working macro is superimposed onto jet shapes obtained from the Atlas paper [5]. This plot ensures that the result obtained so far are reliable. Statistical errors in different bins were also calculated and it seems to be of the same order to that of ATLAS collaboration [5].

VII. Summary and Conclusion

Jet shapes for soft particles and hard particles have been measured in inclusive jet production in p-p collisions at center of mass energy $\sqrt{s} = 7$ TeV, with anti-k_t algorithm and jet resolution parameter $R = 0.6$, pesudorapidity $|\eta| < 2.8$ and momentum cut in particle during jet reconstruction, $P_{T,cut} = 4$ GeV. In different energy ranges of jet, jet shapes for hard particles and soft particles were calculated and compared. Further investigation with this study may lead to some very interesting conclusion for jet shapes of hard particles and soft particles.

References

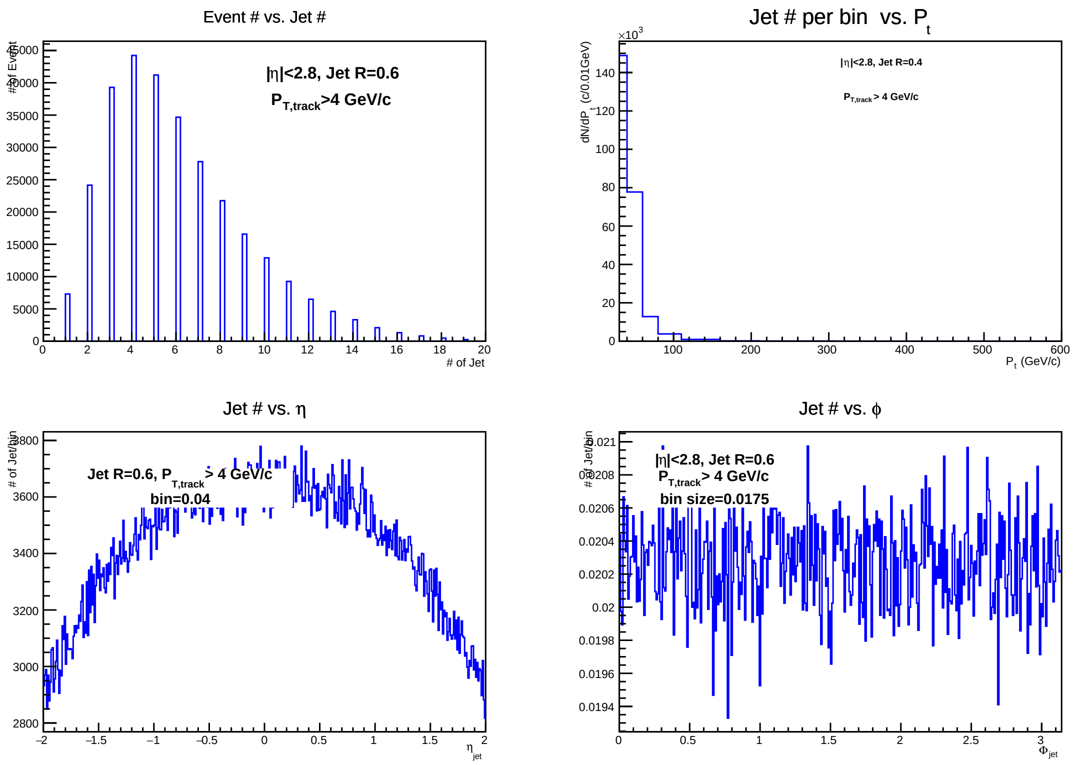
[1] Torbjörn Sjöstrand, Stephen Mrenna, and Peter Skands. Pythia 6.4 physics and manual. *Journal of High Energy Physics*, 2006(05):026, 2006.

[2] Peter Z. Skands. Tuning monte carlo generators: The perugia tunes. *Phys. Rev. D*, 82:074018, Oct 2010.

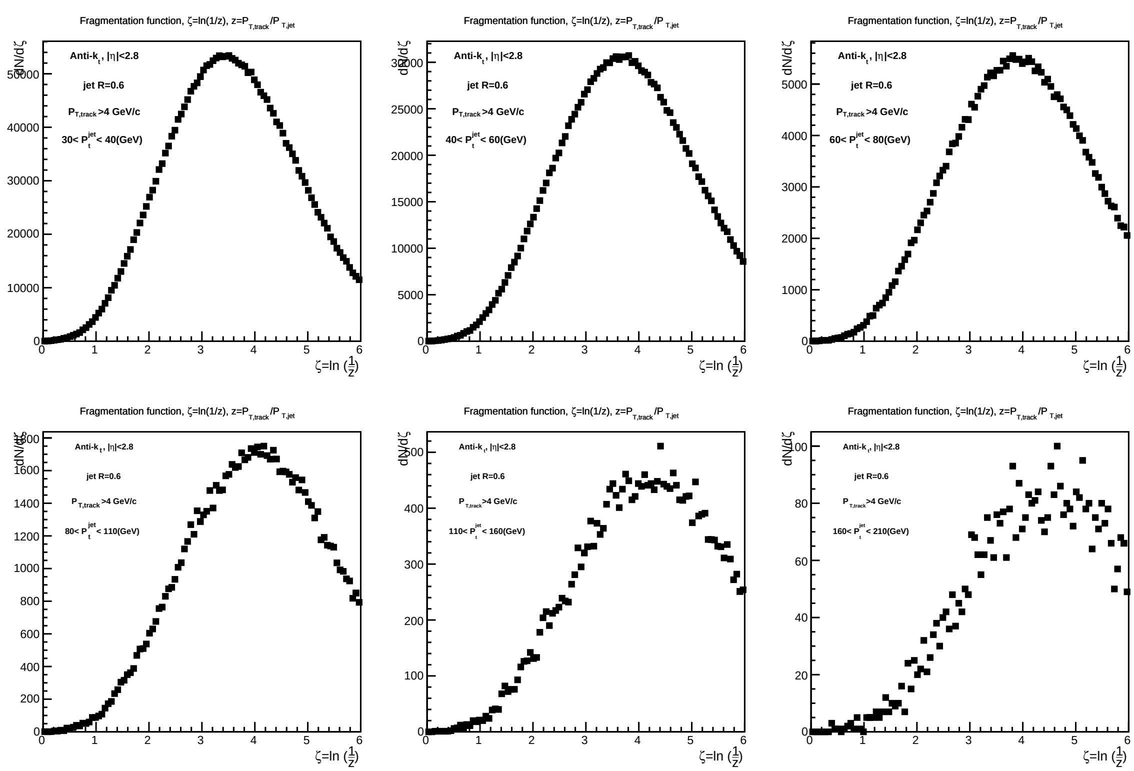
[3] Matteo Cacciari, Gavin P Salam, and Gregory Soyez. Fastjet user manual. *The European Physical Journal C*, 72(3):1–54, 2012.

[4] Matteo Cacciari and Gavin P. Salam. Dispelling the myth for the jet-finder. *Physics Letters B*, 641(1):57 – 61, 2006.

[5] Adam Gibson-Even, ATLAS Collaboration, et al. Measurement of the inclusive jet cross section in pp collisions at sqrt (s)= 2.76 tev and comparison to the inclusive jet cross section at sqrt (s)= 7 tev using the atlas detector. 2013.

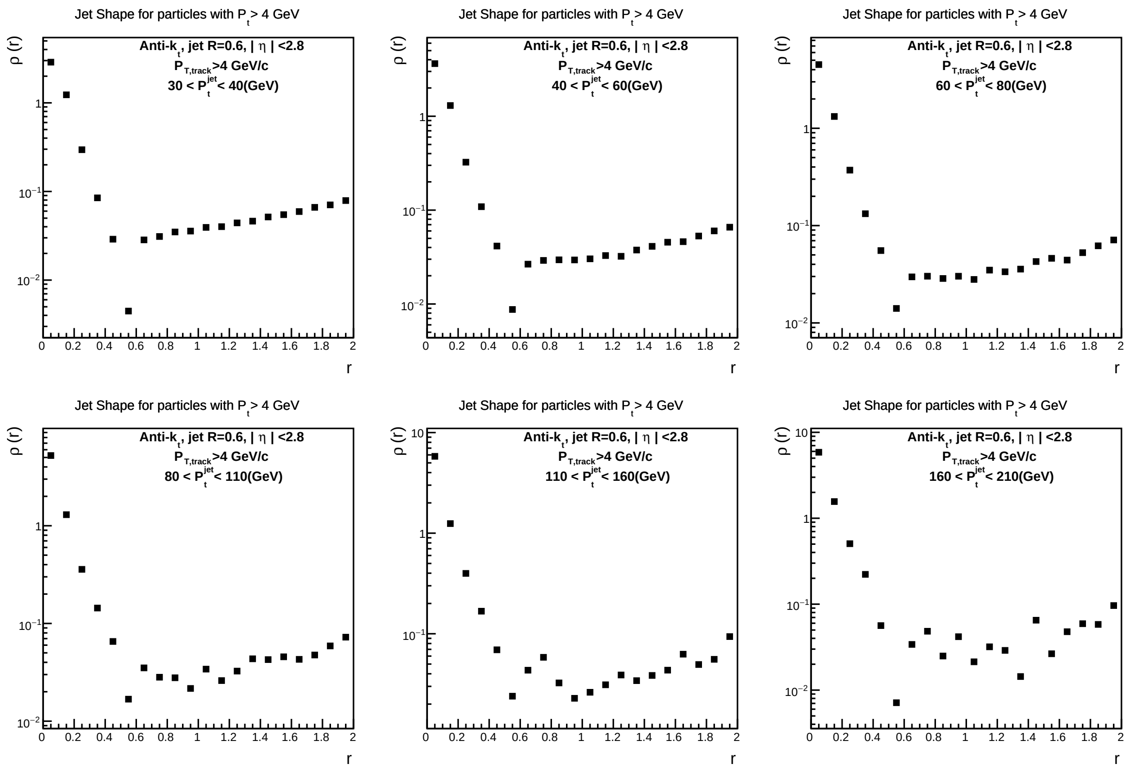


(a) *Event number vs. produced jets in a event at the topmost left. Number of jet distribution w.r.t* P_t, η, ϕ.

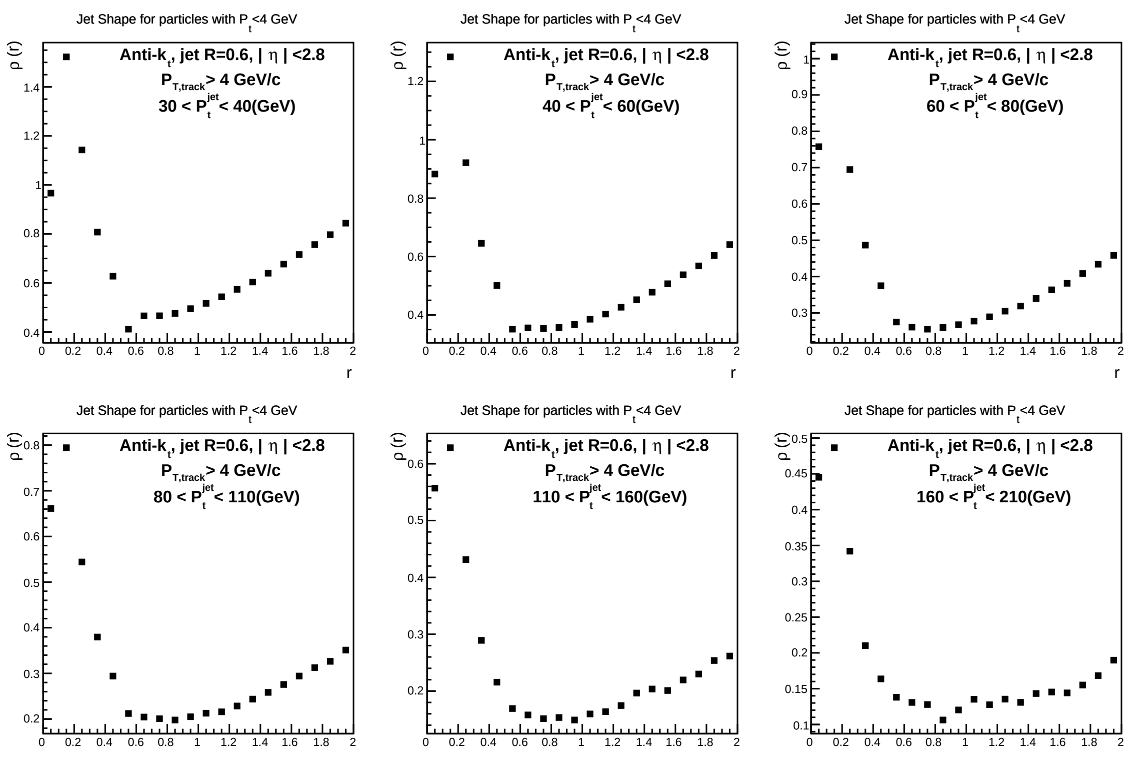


(b) *Fragmentation function(FF) in different energy range. The peaks in the FFs are due to the applied* P_t*-cut during jet reconstruction. It shifts rightwards as the* $P_{T,jet}$ *increases, since the ratio of particle momentum and jet momentum, z is reduced hence* $1/z$ *in increased.*

Figure 1

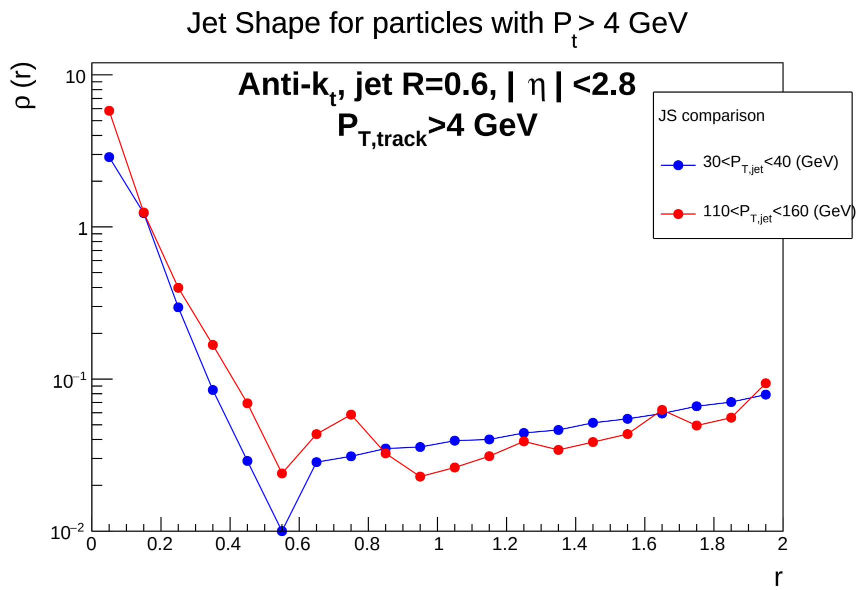


(a) *Jet Shapes in different energy range with $P_T > 4$ GeV*

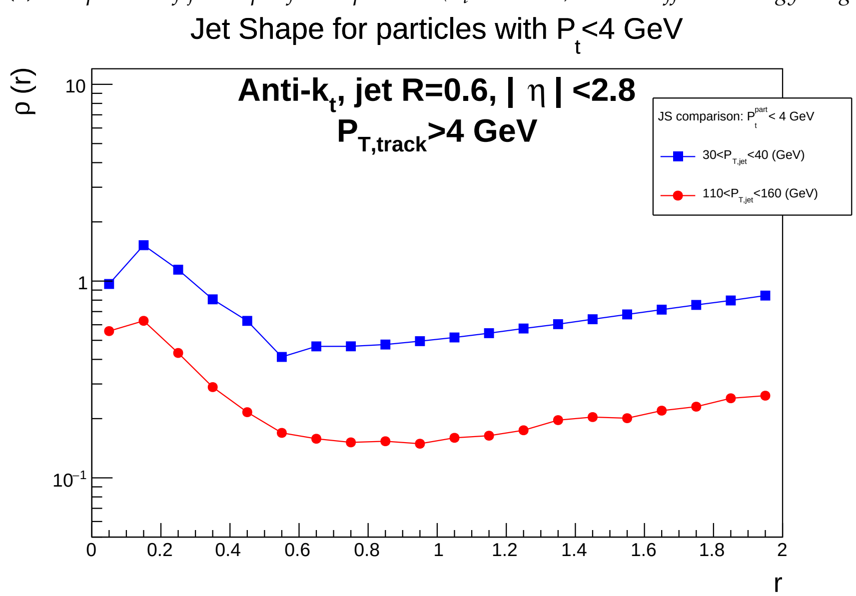


(b) *Jet Shape for soft particles with $P_T < 4$ GeV.*

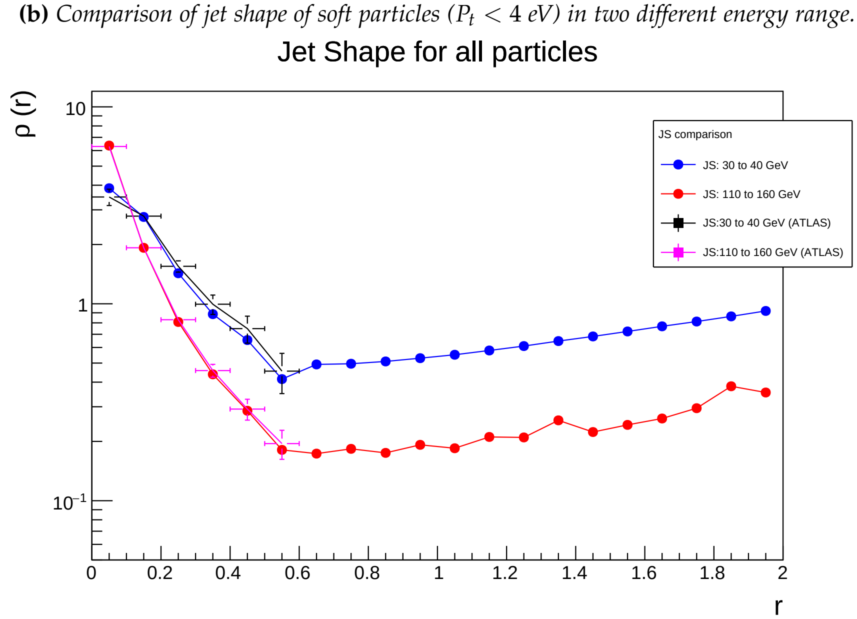
Figure 2



(a) *Comparison of jet shape of hard particles ($P_t > 4$ GeV) in two different energy range.*



(b) *Comparison of jet shape of soft particles ($P_t < 4$ eV) in two different energy range.*



(c) *Comparison of jet shape of all particles in two different energy range. Here, no $P_{T,cut}$ during jet reconstruciton. Results seem to agree well with Atlas paper[[5]]*

Figure 3