

Jet Substructure with the Snowmass samples

Nukulsinh Parmar & Aran Garcia-Bellido

University of Rochester

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Sample Information

The samples for testing SVJ with diagonal unstable hadrons -

- ① 1 π decay
- ② 2 π decay
- ③ 3 π decay

The parameter settings are -

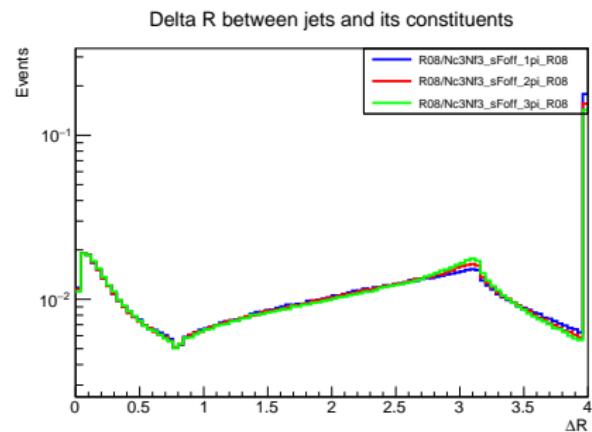
- $\Lambda_{dark} = 10 \text{ GeV}$
- $m_{q_d} = 10.2 \text{ GeV}$
- $m_\pi = 6 \text{ GeV}, m_\rho = 26 \text{ GeV}$
- $Nc = 3, Nf = 3$

We will be comparing the reconstructed jets with 1π , 2π and 3π decays and how they compare with different jet radius of $R = 0.4, 0.8, 1.2$.

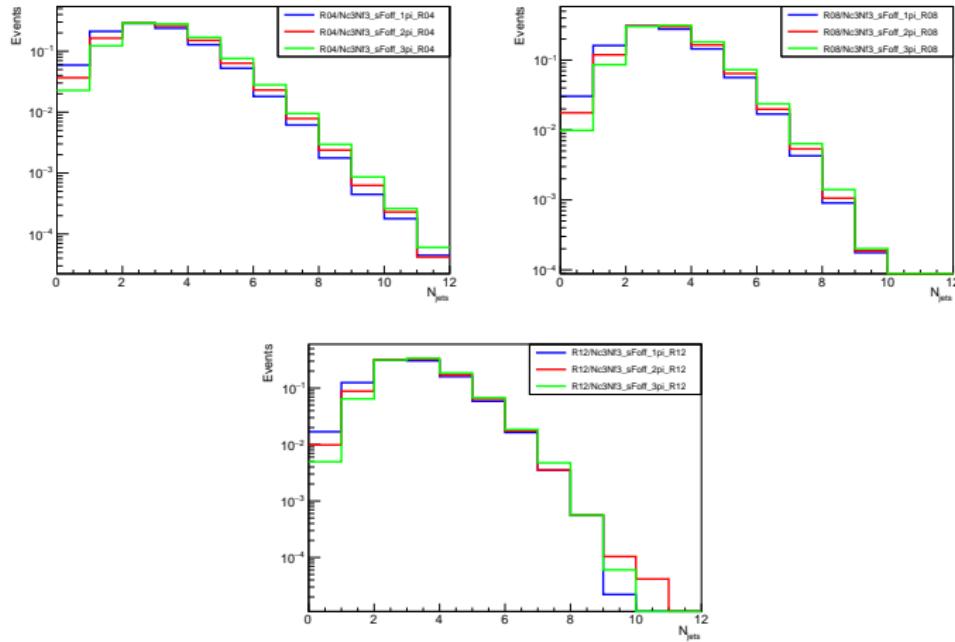
Jets which fall inside the detector acceptance are used - i.e. $|\eta| < 2.5$

Disclaimer

- It was noticed while accessing the Constituents of the ParticleFlowJet from the Delphes file that the jet constituents have $\Delta R(i, \text{jet})$ value higher than the Jet Radius.
- Only Tracks are part of the constituents, no Towers (energy deposits from neutral particles)
- We are investigating this issue with the constituents.
- The Jet substructure variable affected from this are - σ_{major} , σ_{minor} , σ_{avg} , Girth and Moment Half.
- The variables which we directly get from the Delphes file are - τ_{21} , τ_{32} , SoftDrop mass and PTD.

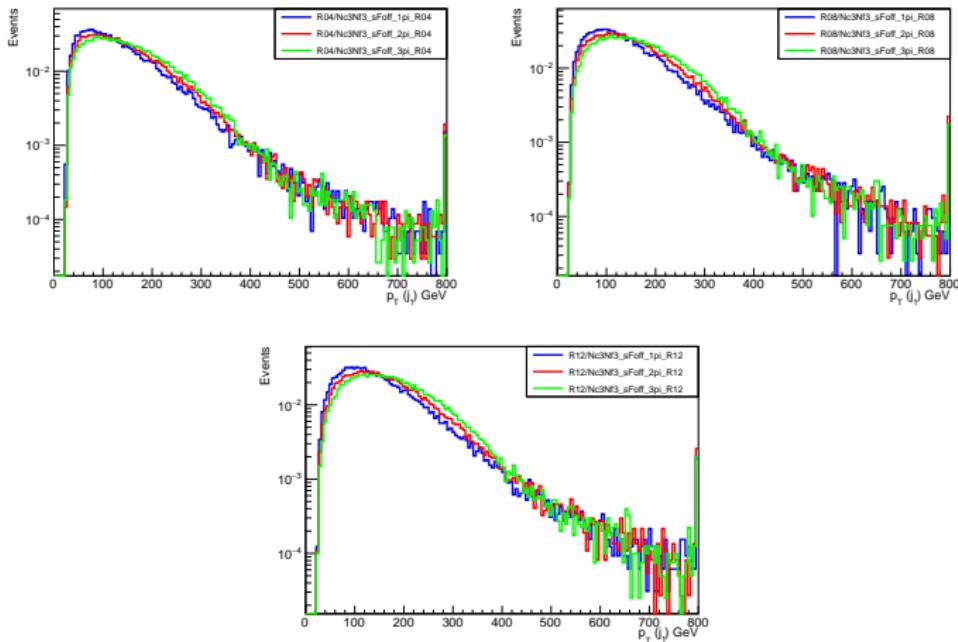


Number of Jets

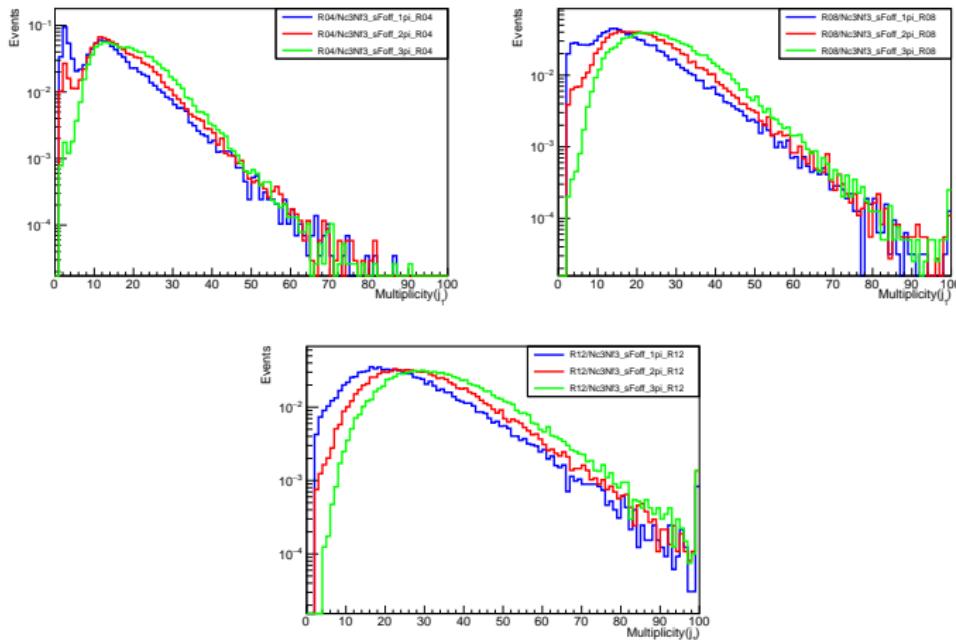


- As expected, the 3π has higher number of jets than 1π .

Jet p_T comparisons I



Jet Multiplicity

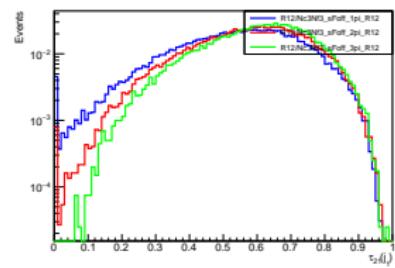
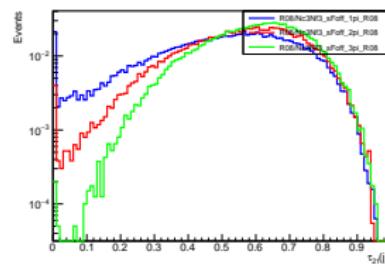
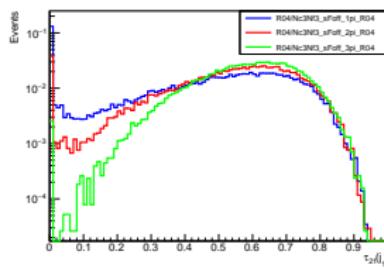


- The 3π has higher jet multiplicity. Also a shoulder near zero is observed for 2π and π which reduces as the Jet radius increases.

N-subjettiness - τ_{21}

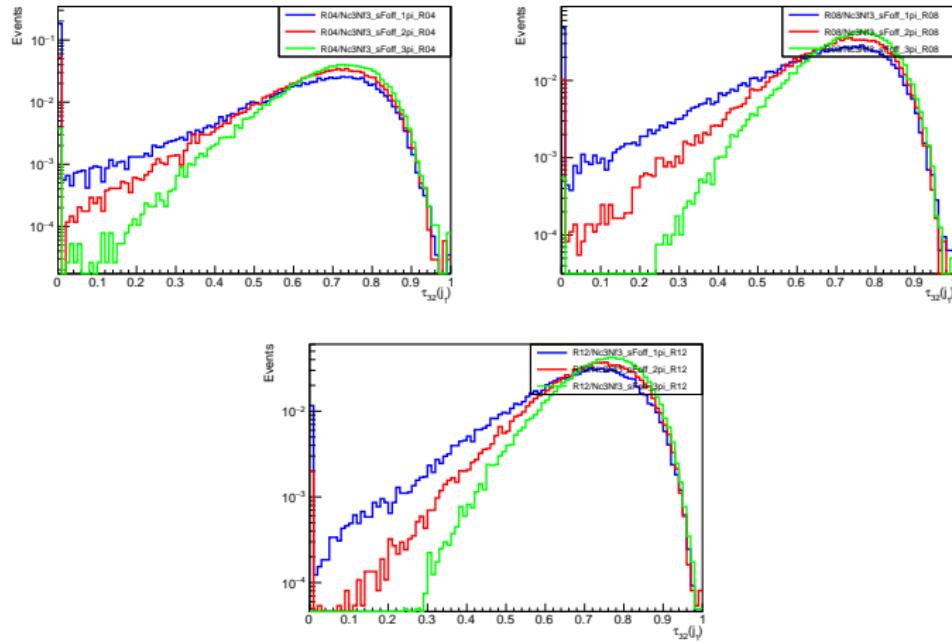
$$\tau_N^\beta = \frac{1}{\sum_k p_{T,k} R_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}^\beta, \dots, \Delta R_{N,k}^\beta\}$$

- The ratio τ_N/τ_{N-1} shows how likely the jet is to have N prongs than $N-1$ prongs.
- It is an effective discriminating variable for boosted jets.[1]



- The higher the number of π decay, the more likely it is to be a 2 prong jet.
- We are investigating the spike at 0.

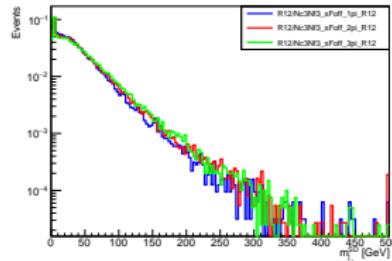
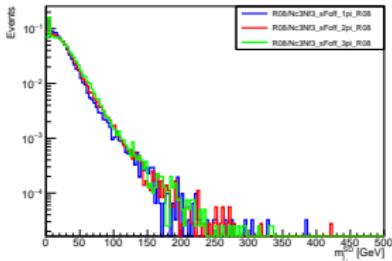
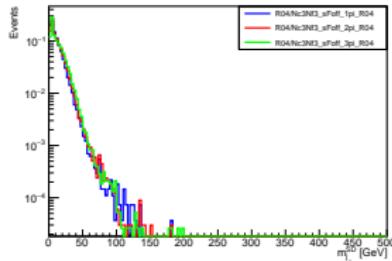
N-subjettiness - τ_{32}



- The higher the number of π decay, the more likely it is to be a 3 prong jet.

SoftDrop Mass

- Mass of the jet after the softdrop grooming algorithm which removes soft and wide angle radiations.
- *This parameter is useful for tagging heavy objects like t , W , Z , H* [2]

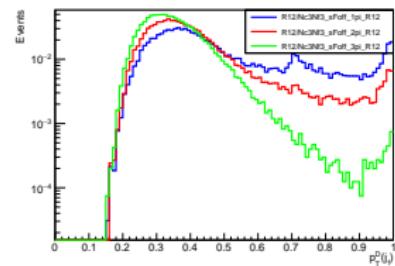
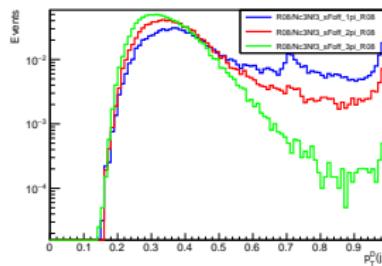
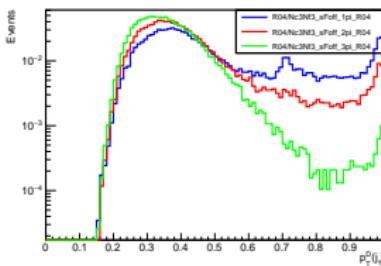


- As the Jet radius increases the mass of the jet increases, and there is almost no difference between the different π decays.

PTD

$$p_T^D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

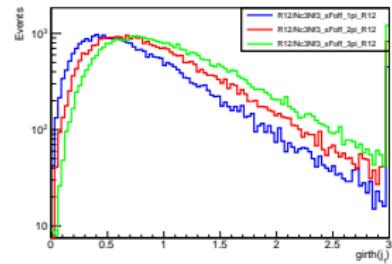
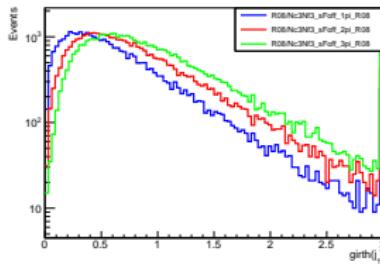
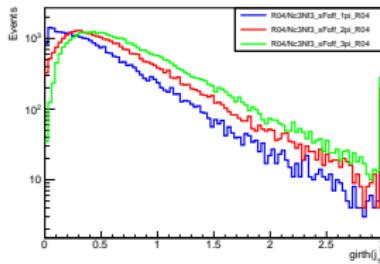
- fragmentation variable which quantifies the number of constituents carrying a significant fraction of the jet energy



- An interesting shoulder is seen for 1π and 2π but it is not seen 3π .
- The shoulder is dominated by the neutral particles.

Jet Girth

$$g = \sum_i \frac{p_{T,i}}{p_{T,jet}} \Delta(R_{i,jet})$$

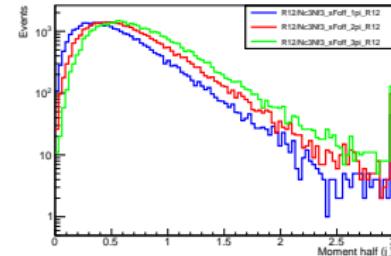
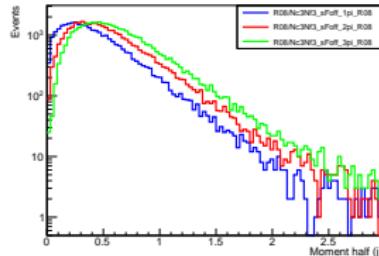
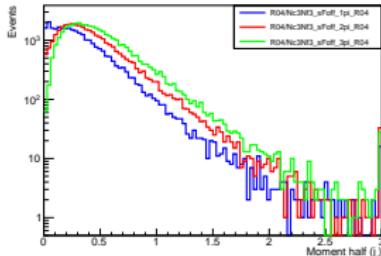


- Here we see the value of the Girth is going till 3 which is contaminated by the large ΔR problem of jet constituents from page 3.

Moment Half

- The paper [3] found that a very good discriminator for quark and gluon uses a lower power - Moment half.

$$M_{1/2} = \sum_i \frac{p_{T,i}}{p_{T,jet}} \sqrt{\Delta(R_{i,jet})}$$



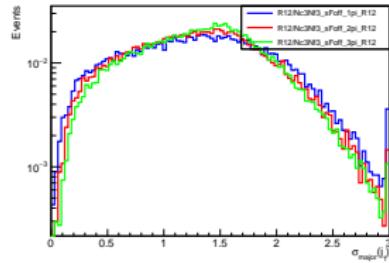
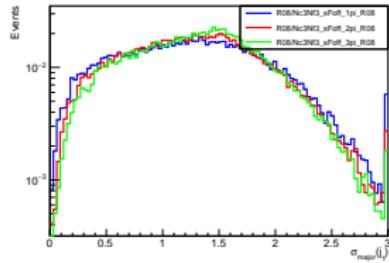
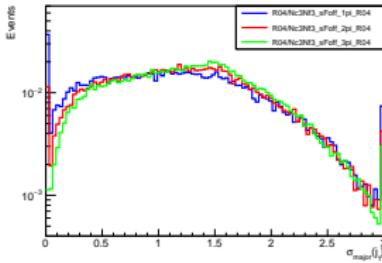
- Again, the value of the Moment half is going till 3 which is contaminated by the large ΔR problem of jet constituents from page 3.

Jet Axes I

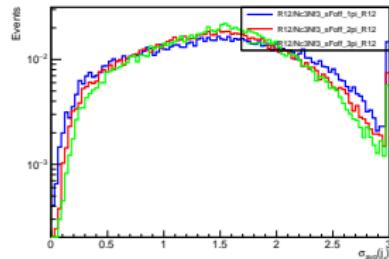
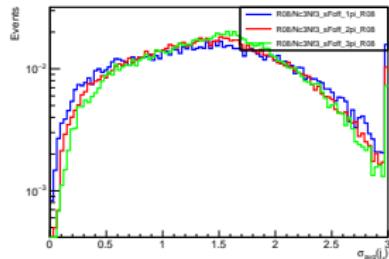
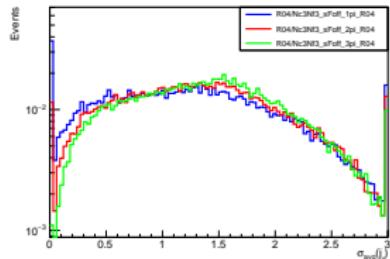
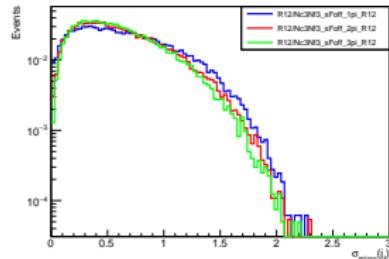
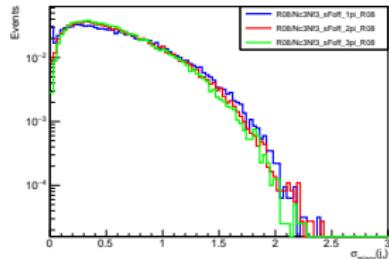
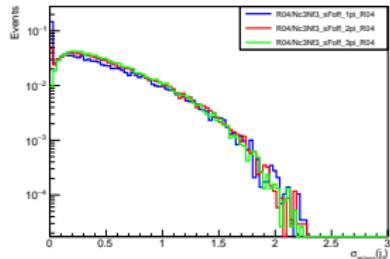
Computed using the eigenvalues λ_1, λ_2 of the p_T -weighted $\eta - \phi$ matrix M of the jet constituents:

$$\begin{bmatrix} \sum_i p_{T,i}^2 \Delta\eta_i^2 & -\sum_i p_{T,i}^2 \Delta\eta_i \Delta\phi_i \\ -\sum_i p_{T,i}^2 \Delta\eta_i \Delta\phi_i & \sum_i p_{T,i}^2 \Delta\phi_i^2 \end{bmatrix}$$

$$\sigma_{major} = \sqrt{\lambda_1 / \sum_i p_{T,i}^2}, \quad \sigma_{minor} = \sqrt{\lambda_2 / \sum_i p_{T,i}^2}. \quad \& \quad \sigma_{avg} = \sqrt{\sigma_{major}^2 + \sigma_{minor}^2}.$$



Jet Axes II



Next Steps...

- Figure out the problem in accessing the Constituents of the ParticleFlowJets from the Delphes file.
- Fix the jet substructure variables with the problem.
- Investigate the peak at 0 for the N-subjettiness variable.

Backup

Definitions I

- ❶ **N-subjettiness** quantifies how well the jet constituents can be assigned to N internal prongs.

$$\tau_N^\beta = \frac{1}{\sum_k p_{T,k} R_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}^\beta, \dots, \Delta R_{N,k}^\beta\}$$

Usually the β is assumed to be 1. The ratio τ_N/τ_{N-1} shows how likely the jet is to have N prongs than $N-1$ prongs. *It is an effective discriminating variable for boosted jets.* Example - QCD is likely to be one prong whereas W, Z + jets to be two prong and top to be 3 prong [1].

Definitions II

- ② **Softdrop mass** is the mass of the jet after the softdrop grooming algorithm which removes soft and wide angle radiations. The algorithm de-clusters the jet and removes the softer component unless the following condition is followed -

$$\frac{\min p_{T,j_i}}{\sum p_{T,j_i}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0} \right)^\beta$$

The parameters used are $z_{cut} = 0.1$ and $\beta = 0$. *This parameter is useful for tagging heavy objects like t, W, Z, H .* [2]

- ③ **Jet Girth** It is a generic measure of the distribution of the jet constituents defined as. -

$$g = \sum_i \frac{p_{T,i}}{p_{T,jet}} r_i$$

The paper [3] found that a very good discriminator for quark and gluon uses a lower power - Moment half.

Definitions III

- ④ **Moment half** It is similar to the Jet Girth with the square root of the distance -

$$M_{1/2} = \sum_i \frac{p_{T,i}}{p_{T,jet}} \sqrt{r_i}$$

- ⑤ p_T^D is a fragmentation variable which quantifies the number of constituents carrying a significant fraction of the jet energy.

$$p_T^D = \frac{\sqrt{\sum_i p_{T,i}}}{\sum_i p_{T,i}}$$

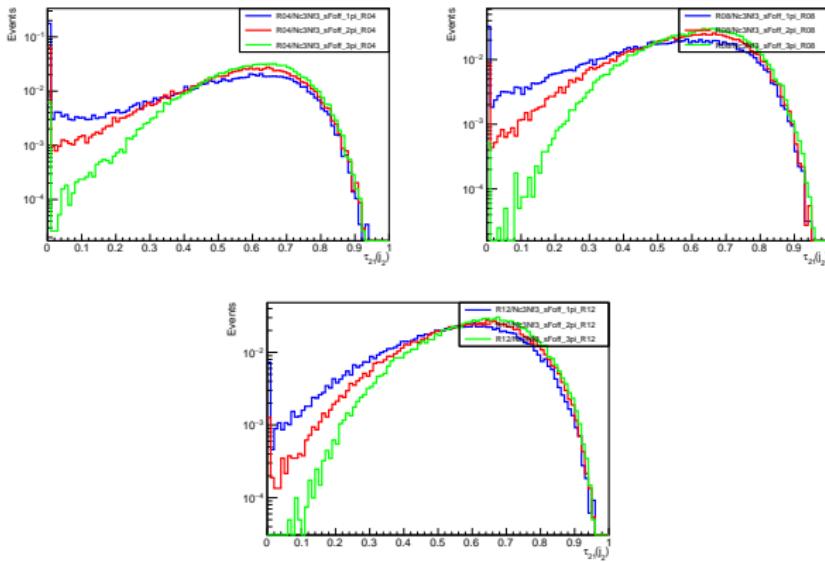
Definitions IV

- ⑥ **Major and Minor jet axes** Computed using the eigenvalues λ_1, λ_2 of the p_T -weighted $\eta - \phi$ matrix M of the jet constituents:

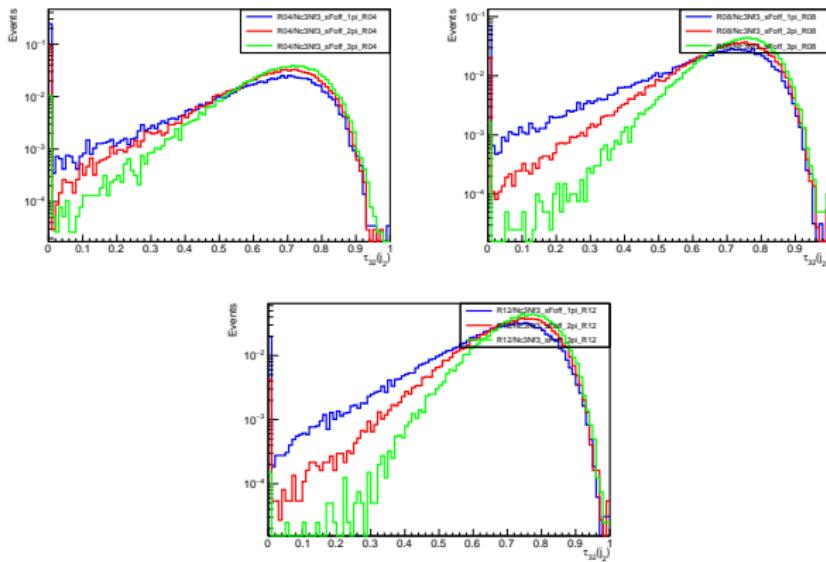
$$\begin{bmatrix} \sum_i p_{T,i}^2 \Delta\eta_i^2 & -\sum_i p_{T,i}^2 \Delta\eta_i \Delta\phi_i \\ -\sum_i p_{T,i}^2 \Delta\eta_i \Delta\phi_i & \sum_i p_{T,i}^2 \Delta\phi_i^2 \end{bmatrix}$$

The major and minor axes are - $\sigma_{major} = \sqrt{\lambda_1 / \sum_i p_{T,i}^2}$ and
 $\sigma_{minor} = \sqrt{\lambda_2 / \sum_i p_{T,i}^2}$. The average is given by $\sigma_{avg} = \sqrt{\sigma_{major}^2 + \sigma_{minor}^2}$.
These variables are useful in quark-gluon discrimination.

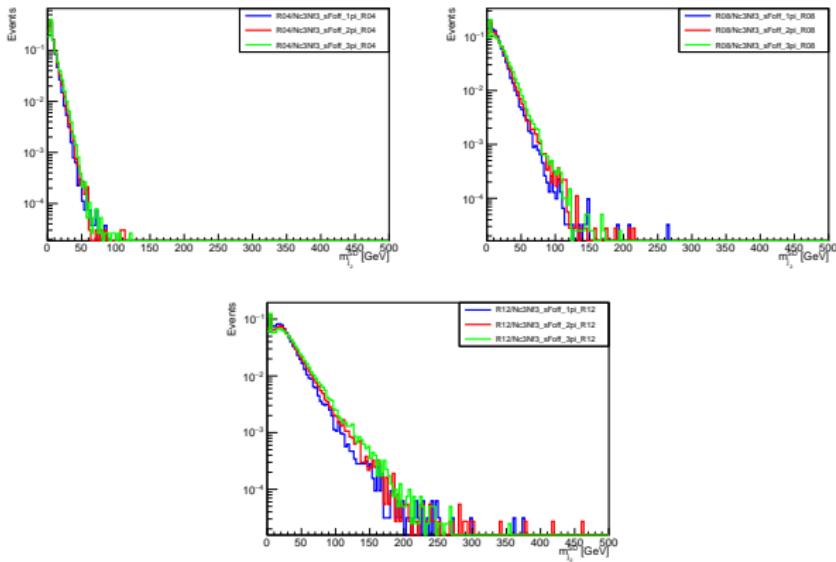
N-subjettiness I



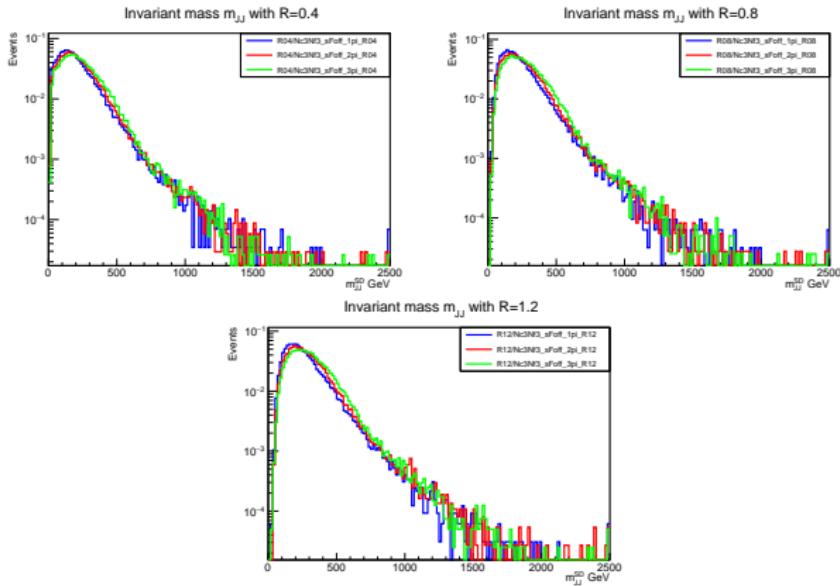
N-subjettiness II

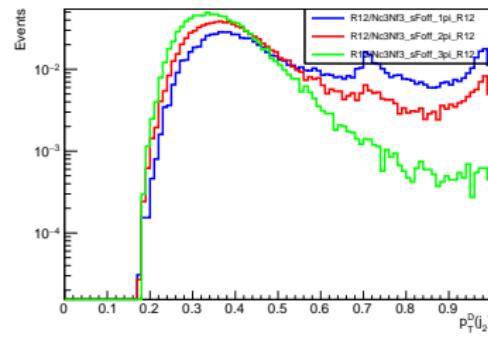
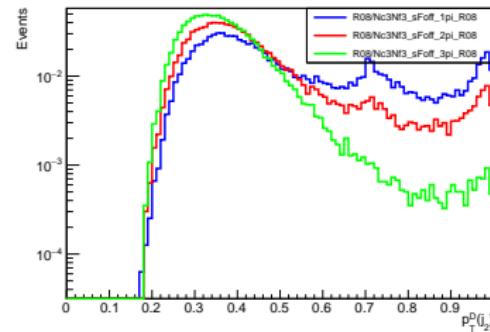
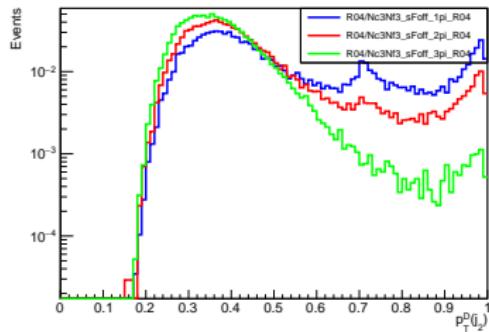


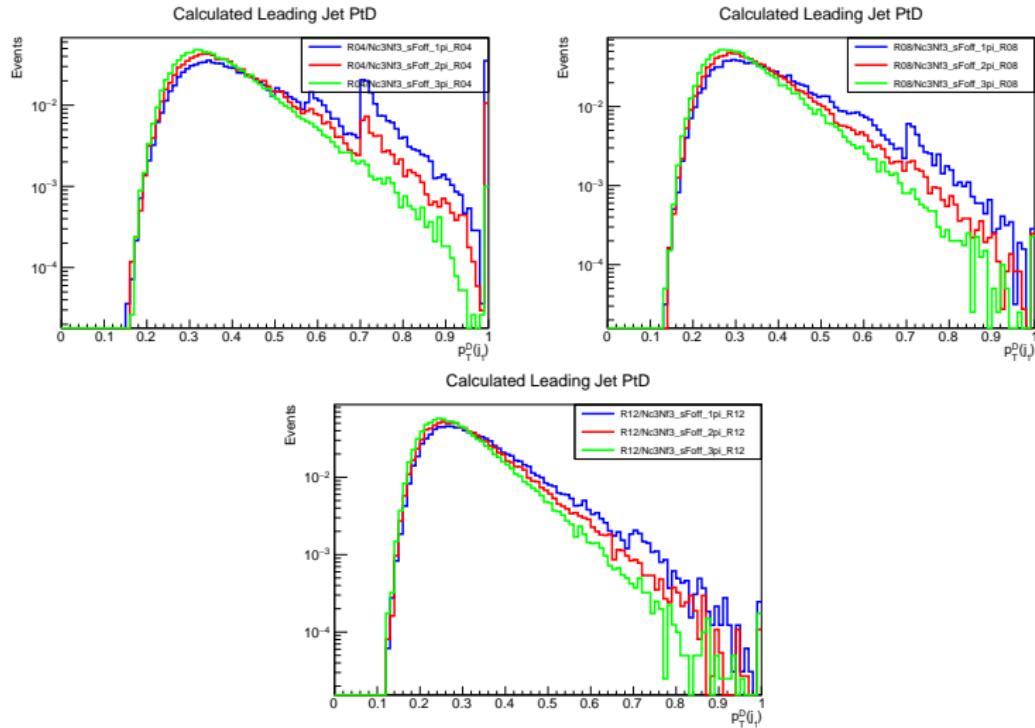
Softdrop mass I

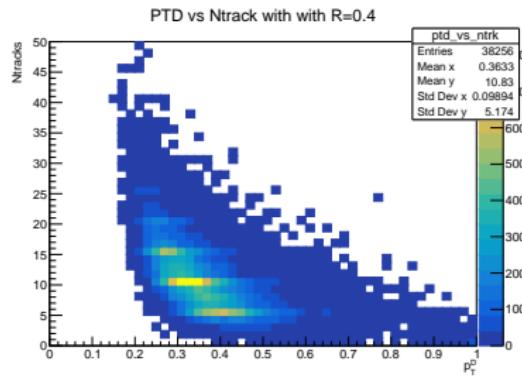
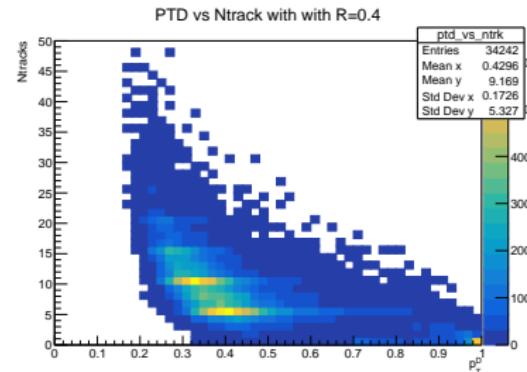
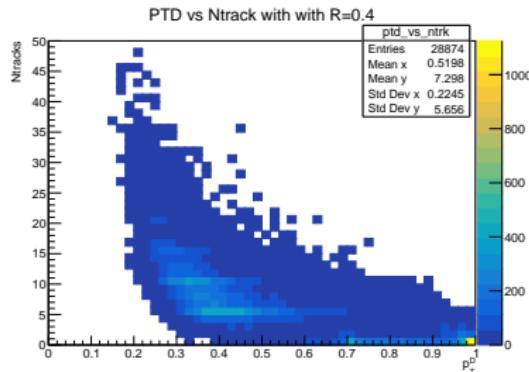


Softdrop mass II



p_T^D |

$p_T^D \parallel$ 

p_T^D III

Backup for disclaimer

```
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      Jet Constituents
Jet info --- PT = 178.0137939453125, Eta = 1.50488770000008716, Phi = 2.9929280281066895, Mass = 45.336524963378996
Moment girth calculated = 0.0
      Jet Particles
Moment girth calculated = 0.0
*****
      Jet Constituents
Jet info --- PT = 60.58276565551758, Eta = 1.3028100728988647, Phi = 0.032548401508475502, Mass = 6.096424579620361
Moment girth calculated = 0.0
      Jet Particles
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dphi = -0.021888974122703075, data = -3.2030144929888564, dR = 3.2830892852811763
type = <class 'cppyv.gbl.Track' at 0x14c34a790>, index = 1 Particles info --- PT = 0.5757505893707275, Eta = -2.9466061849594116, Phi = 2.4766628742218018, Charge = 1,
dphi = 2.444144727170467, data = -4.248871922492981, dR = 4.981694418208272
Moment girth calculated = 0.079880896664652
*****
      Jet Constituents
Jet info --- PT = 261.2532843457031, Eta = 0.489346444606781, Phi = 1.68115508555636597, Mass = 34.73927688598633
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Moment girth calculated = 0.01070157665629849
      Jet Particles
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dphi = 2.3130306291582032, data = -7.840375304222107, dR = 3.6195269942663155
type = <class 'cppyv.gbl.Track' at 0x14c34a790>, index = 3 Particles info --- PT = 2.0015666484832764, Eta = -1.865724802817212, Phi = -1.7695553302764893, Charge = 1,
dphi = 2.8292895841598513, data = -3.3587246623993, dR = 3.6812089983600032
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Moment girth calculated = 0.29349323338113587
*****
```

References I

-  J. Thaler and K. Van Tilburg, "Identifying boosted objects with n-subjettiness," *Journal of High Energy Physics*, vol. 2011, no. 3, Mar 2011. [Online]. Available: [http://dx.doi.org/10.1007/JHEP03\(2011\)015](http://dx.doi.org/10.1007/JHEP03(2011)015)
-  A. J. Larkoski, S. Marzani, G. Soyez, and J. Thaler, "Soft drop," *Journal of High Energy Physics*, vol. 2014, no. 5, May 2014. [Online]. Available: [http://dx.doi.org/10.1007/JHEP05\(2014\)146](http://dx.doi.org/10.1007/JHEP05(2014)146)
-  J. Gallicchio and M. D. Schwartz, "Quark and gluon jet substructure," *Journal of High Energy Physics*, vol. 2013, no. 4, Apr 2013. [Online]. Available: [http://dx.doi.org/10.1007/JHEP04\(2013\)090](http://dx.doi.org/10.1007/JHEP04(2013)090)