Supersymmetric Long-Lived Particle Search Using Proton-Proton Collision Simulations from the ATLAS Experiment

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Background

Many Beyond the Standard Model theories predict the existence of new long-lived particles. Our search focuses on the long-lived **R-hadron**, predicted by some supersymmetry models. R-hadrons are composite supersymmetric particles that consist of one supersymmetric particle and one or several Standard Model quarks or gluons. The R-hadrons in our search each decay to a neutralino and two quarks. These neutralinos pass through the detector without being detected; R-hadron decays are therefore characterized by large amounts of missing transverse energy (**MET**) in the final state.

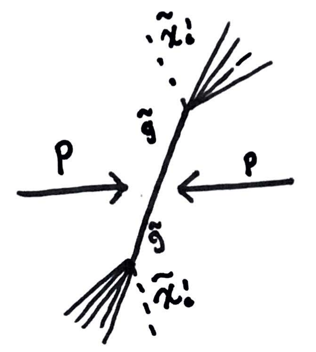
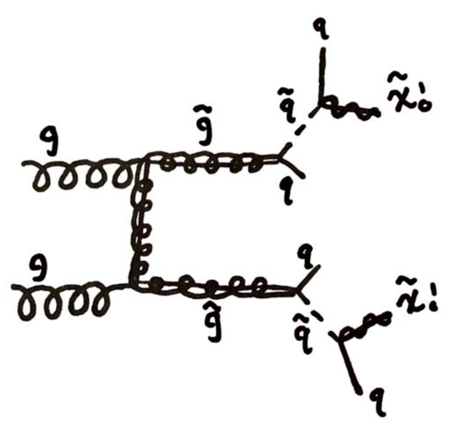


Diagram showing the orientation of the final products of the event: Each R-hadron will produce a jet and a neutralino in its decay.



Feynman Diagram showing the relevant process (production of two R-hadrons and their decay to two neutralinos)

ATLAS uses two main methods of collecting and categorizing clusters of particle showers into jets, regions of high particle density originating from the decay of a single particle: **EM Topo Jets** and the more recently developed **P-Flow**. P-Flow differs from EM Topo Jets, which is calorimeter-based, by using additional data from particle tracks in the Inner Detector to reconstruct individual particles in jets. EM Topo Jets has been the primary reconstruction used in long-lived particle searches, so the impact of a future shift to P-Flow on particle searches is largely uncertain. Since MET is a crucial part of long-lived particle identification, it is important to know how a switch to P-Flow will affect the MET of events with R-hadrons. Our project looks at this and other related questions.

Research Questions

- **What impact will the use of different reconstruction algorithms have on the selection efficiency and MET reconstruction we use in our searches for new particles?**
  - *What is the relationship between detector geometry, R-hadron decay radius, and MET?*
  - *What is the impact of **JVT** (a number with which jets are tagged that expresses the likelihood the jet came from the primary vertex of the event) on our searches - what does the JVT for jets from R-hadrons look like?*

Analysis

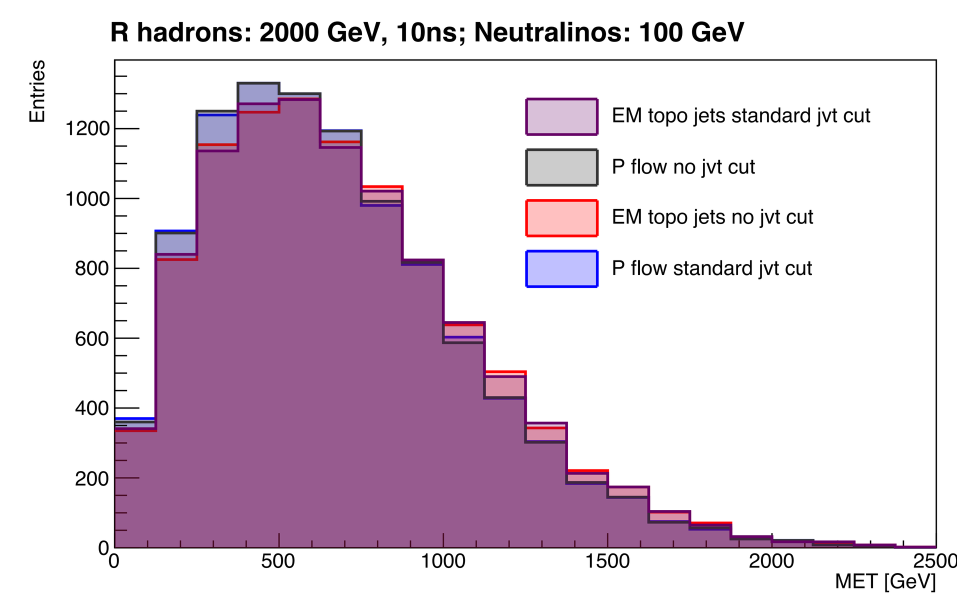
Our analysis uses two sets of signal simulations, with each set containing four different ways of reconstructing the jets in the simulated data. Both samples contain simulated proton-proton collisions with two 2000 GeV, 10 ns lifetime R-hadrons decaying to either 100 GeV or 1900 GeV neutralinos in the final state.

<u>The four reconstructions:</u>

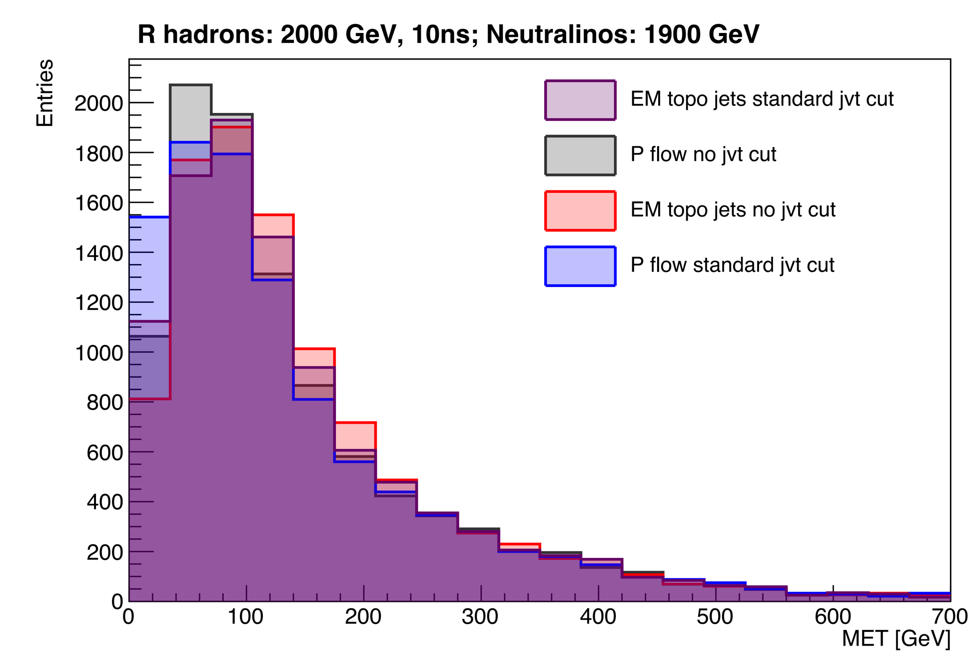
EM Topo Jets with no JVT cut on MET
EM Topo Jets with a standard JVT cut on MET
P Flow with no JVT cut on MET
P Flow with a standard JVT cut on MET

Our analysis compared the properties of MET from simulations using these different reconstruction algorithms and calculated the efficiency of different MET threshold selections for the four algorithms.

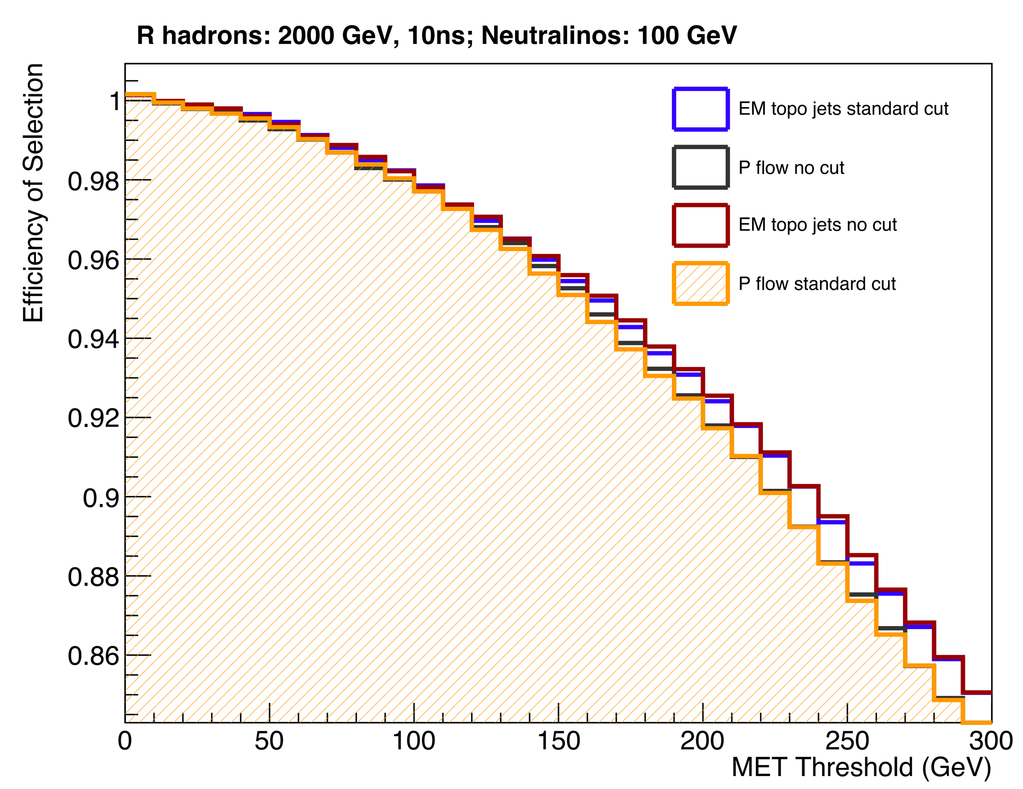
MET and Selection Efficiency



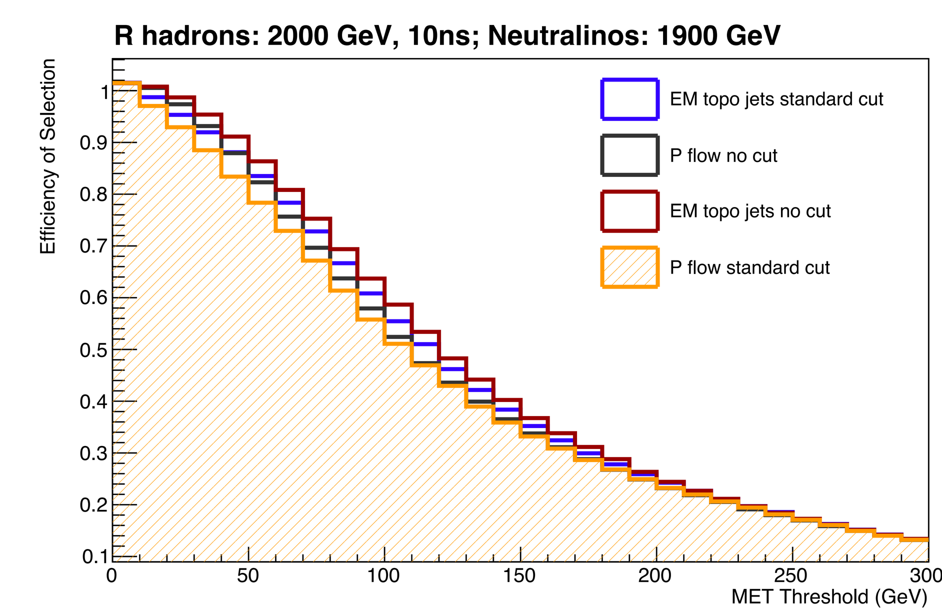
Above: Inclusive MET for different jet reconstruction algorithms; 100 GeV neutralinos in the final state



Above: Inclusive MET for different jet reconstruction algorithms; 1900 GeV neutralinos in the final state



Above: Selection efficiency for different MET requirements for each reconstruction algorithm; 100 GeV neutralinos in the final state



Above: Selection efficiency for different MET requirements for each reconstruction algorithm; 1900 GeV neutralinos in the final state

Conclusions

<u>**Impact of different reconstructions on MET**</u>

- P Flow gives a lower peak MET than EM Topo Jets and has fewer high MET entries than EM Topo Jets.
- There is not a significant difference between the distributions reconstructed using different JVT cuts on the MET.
- The same trend appears for the 1900 GeV neutralino samples, however, the mean MET is lower, so the differences are more statistically pronounced.

<u>**Efficiency of MET selections at different thresholds**</u>

- For low MET thresholds, there is not a big difference between the selection efficiencies of the different reconstruction methods. This difference increases at higher thresholds.
- EM Topo Jet reconstructions are slightly more efficient than P Flow for each selection, but the difference is not significant.
- Likewise, there is no strong relationship between JVT cut variations on MET and the selection efficiency, however, not having a JVT cut is slightly more efficient for most thresholds.
- The same behavior is shown for the 1900 GeV neutralino samples, but the decrease in efficiency is more rapid and the differences between efficiencies are more pronounced due to the lower average MET.

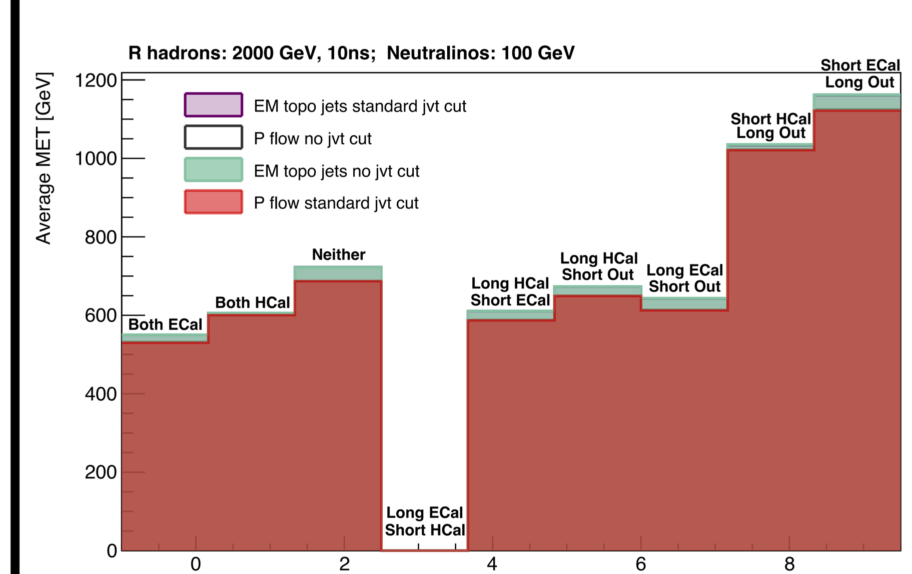
<u>**Decay Radius and MET relationship**</u>

- The relationship between MET and R-hadron Decay Radius is mostly uniform. There is only a significant difference in the mean MET if one of the R-hadrons decays outside of the calorimeter. This is consistent with what we would expect – in these cases, only one R-hadron's energy is captured, resulting in a significantly larger amount of missing energy in the final state.
- The relationship between the detector geometry and the MET is the same for EM Topo Jets and P-Flow.
- There is almost no difference between reconstructions with JVT cuts vs. reconstructions without JVT cuts.

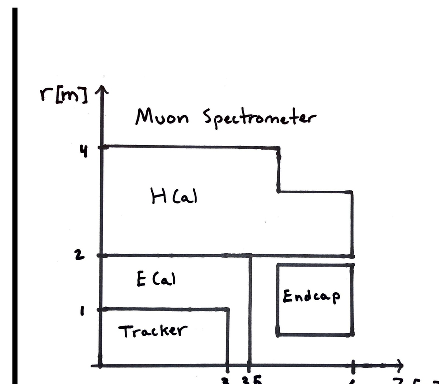
<u>**JVT analysis results**</u>

- There are at least two distinct JVT regions shown in the 2D histogram. This indicates that the jets from the R-hadrons and the initial state radiation (a jet-producing process at the primary vertex independent of the R-hadron event) could possibly be separated, allowing us to identify R-hadrons in our searches by their JVT.
- The 1D histogram, which shows the momentum of jets falling in different JVT spans, corroborates the observation of two JVT regions in the 2D histogram. The R-hadrons seem to have high momentum and high JVT jets, however, it is difficult to discern whether a significant portion of R-hadrons around the same momentum region are displayed in the low JVT distribution, as this distribution contains many more events. Further work in our project will look into developing a technique to identify R-hadrons with low JVT jets.

Decay Radius and MET

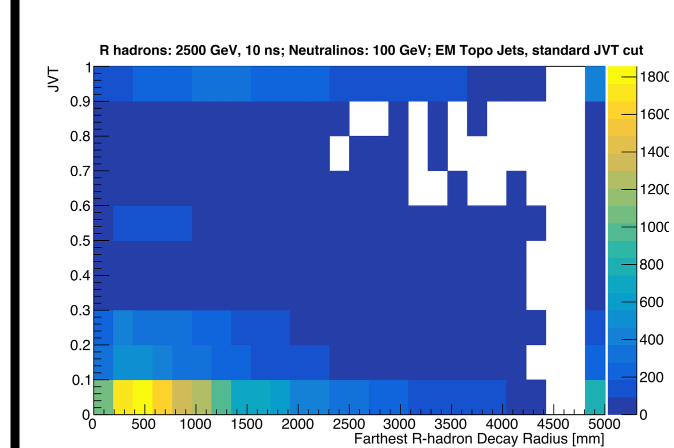


Average MET for events where the R-hadrons decay in different areas of the detector.

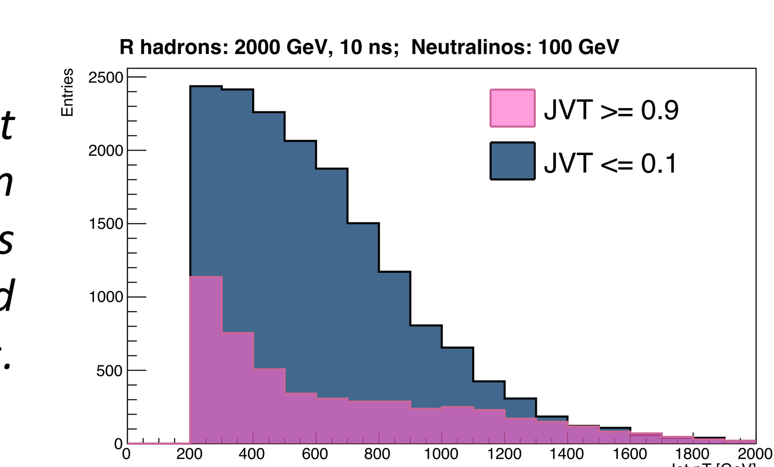


***<u>ATLAS Detector Schematic</u>**: The Inner Tracker of the ATLAS Detector is surrounded by an Electromagnetic Calorimeter (**ECal**) and the Hadronic Calorimeter (**HCal**).*

JVT of R-hadrons



Left: 2D histogram showing the JVT of jets compared with the farthest R-hadron decay radius.



Right: Jet momentum distributions for high and low JVT jets.

References

- *Atlas Collaboration*, "Search for heavy charged long-lived particles in proton-proton collisions at √s=13 TeV using an ionization measurement with the ATLAS detector" - 10.1016/j.physletb.2018.10.055
- *Atlas Collaboration*, "Jet reconstruction and performance using particle flow with the ATLAS Detector" - 10.1140/epjc/s10052-017-5031-2
- *Atlas Collaboration,* "The ATLAS Experiment at the CERN Large Hadron Collider" - 10.1088/1748-0221/3/08/S08003

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