High-Mass Higgs decaying to $WW \rightarrow l\nu qq$

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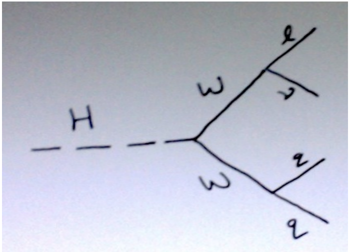
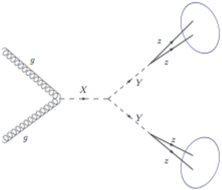
Brief Overview

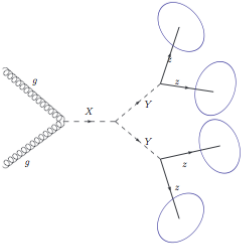


- We wish to find a Standard Model-like Higgs in the high mass region
- Ratio between Higgs and W mass determines degree of boost ($r_M = \frac{M_H}{2M_W}$)
- This study will focus on two modes of Higgs production: gluon-gluon fusion (ggF) and vector boson fusion (VBF).

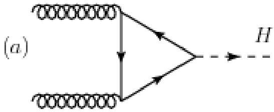
Change of Scale from 300 to 1000 GeV

Problem: Across this regime, the proportion of fat jets to resolved jets changes. This means that jet substructure techniques that work well close to 200 GeV might fail around 1 TeV. In the high-mass range, the ratio r_M will be large, so the jets produced will be highly boosted (and thus fat). In the low-mass range, r_M is small, so the jets will be resolved. In the intermediate range, it is possible to get combinations of fat and resolved jets.

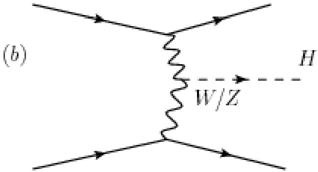




ggF and VBF Feynman Diagrams



a) ggF Higgs Production



b) VBF Higgs Production

Jet Algorithms

The two-body or three-body decays of a high p_T vector boson or top quark result in a hard substructure that is not found in high p_T jets formed from gluons and light quarks.

- Jets resulting from the decay of single massive particles will have hard, wide-angle components resulting from the individual decay products.
- These jets will also have large reconstructed jet mass.
- The hard components of such jets also show kinematic relationships.
- Jets formed from gluons or light quarks will have a single dense energy core surrounded by soft radiation.

Jet Algorithms (cont.)

For the resolved jets, the anti-k_T algorithm was used with $R = 0.4$. For the fat jets, the Cambridge-Aachen algorithm was used with $R = 1.0$.

These are sequential algorithms. At each step, the distances d_{ij} between two particles i and j and between any particle k and the beam B are found:

$$d_{ij} = min(p_{Ti}^{2p}, p_{Tj}^{2p})\frac{\Delta_{ij}}{R}, \ \Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i^2 - \phi_j^2)^2.$$

R adjustable. For anti-k_T, $p = -1$. For Cambridge-Aachen, $p = 0$.

$$d_{iB} = p_{Ti}^{2p}$$

Compute all distances d_{ij} and d_{kB}, and find the smallest. If the smallest is a d_{ij}, combine i and j's four momenta and repeat. If the smallest is a d_{kB}, remove k and call it a jet. Repeat until all particles are clustered.

Mass-drop filtering

This algorithm uses C/A jets to identify concentrations of energy by finding relatively symmetric subjects with a much smaller mass than that of the original jet. The mass-drop filtering algorithm has two stages:

- *Mass-drop and symmetry*: The last stage of C/A clustering is undone, splitting the jet into two subjects j_1 and j_2, such that the mass of j_1 is larger. Check if the following requirements for the mass and symmetry are fullfilled: $m^{j1}/m^{jet} < \mu_{frac}$ where μ^{frac} is a parameter of the algorithm (optimized to 0.67 in this study)

$$\frac{min[(p_T^{j1})^2,(p_T^{j2})^2]}{(m^{jet})^2} \times \Delta R^2_{j1,j2} > y_{cut}$$

  where $\Delta R_{j1,j2}$ is a measure of the opening angle betwen j_1 and j_2 and y_{cut} defines the energy sharing between the two subjects in the original jet (set to 0.09 for two-body decays).

Mass-drop filtering (cont.)

If the mass and symmetry requirements are met, then redefine j_1 as j and return to step 1. Otherwise, continue.

- *Filtering*: The constituents of j_1 and j_2 are reclustered using C/A with radius parameter R_{filt} =min$[0.3, \Delta R_{j1,j2}/2]$ where $R_{filt} < \Delta R_{j1,j2}$. Then all three contituents outside the hardest three subjects are discarded (filtered).

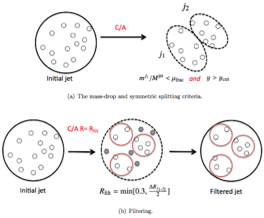


Figure 1. Diagram depicting mass-drop filtering algorithm

Trimming

The trimming algorithm uses momentum and mass differences in a jet to "trim off" the softer elements of the jet. Removing softer components tends to remove pile-up, multiple parton interactions (MPI), and initial-state radiation (ISR) and removes only a small part of the hard-scatter decay products and final-state radiation (FSR). The procedure works as follows:

- Creates subjets of size R_{sub} from the constituents of a jet.
- Any subjet with $p_{Ti}/p_T^{jet} < f_{cut}$ are removed, where f_{cut} is an adjustable parameter.

The remaining constituents form the trimmed jet.

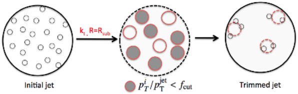


Figure 2. Diagram depicting trimming algorithm

Pruning

Pruning is similar to trimming, but it also places requiements on wide-angle radiation. During each recombination step of the jet algorithm (either C/A or k_t), the following requirement is placed on jets j_1 and j_2 (with $p_T^{j_1} > p_T^{j_2}$):

$$\text{Either } p_T^{j_2}/p_T^{j_1+j_2} > z_{cut} \text{ or } \Delta R_{j_1,j_2} < R_{cut} \times (2m^{jet}/p_T^{jet})$$

where z_{cut} and R_{cut} are adjustable parameters. If the criteria is met, then j_1 and j_2 are merged; if not, they are discarded.

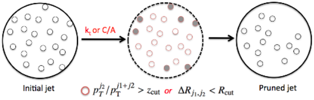
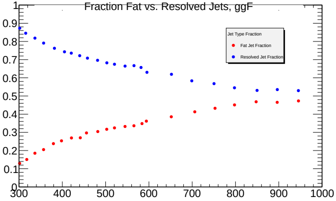


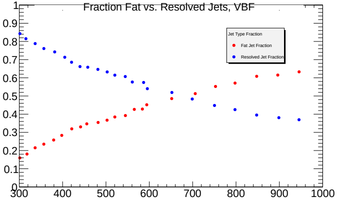
Figure 3. Diagram depicting pruning algorithm

Jet Fractions

ggF Fraction



VBF Fraction



$$frac = \frac{Number\ events\ passing\ all\ signal\ cuts}{Number\ events\ pre-selection}$$

The ggF samples always consist of more resolved jets than fat jets, although the sample becomes closer to half-and-half with increasing Higgs mass. The VBF samples, however, are dominated by resolved jets at low mass, are about half-resolved, half-fat around 650 GeV, and are dominated by fat jets at high mass.

Summary

In this talk, I have summarized some of the problems with boosted jet analysis techniques and a few possible solutions. These include applying different jet techniques in different regions and using jet-trimming techniques.

What still needs to be done:

1. Try to understand the data-Monte Carlo agreement in the control regions
2. Decide whether the current fat jet analysis is optimal
3. Try anti-k_T with $R = 1.0$ for fat jets.

Thank You

Thank you to the University of Michigan, the Lounsbery Foundation, and my fellow students for a great experience. Special thanks to Steve Goldfarb and Jean Krisch for all their support!

Backup slide-ATLAS Software Tutorial

In the ATLAS software tutorial, we talked about current ATLAS dataset types, such as AOD's and DPD's and how to generate them. We also talked about the problems facing ATLAS software in Run 2 and the new data types that will be used–xAOD's. These will replace AOD's and DPD's and will hopefully reduce the amount of CPU used to generate separate DPD's for different groups. It will also make it easier to share data between groups.