Double Higgs Production in Vector Boson Fusion(VBF) Channel and Looking for Algorithms to Find VBF Jets

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Introduction

Among the four known fundamental forces of nature three are described by Standard Model of elementary particles. Gravity is the exception. The quantum description of gravitational field is still a live field of research.

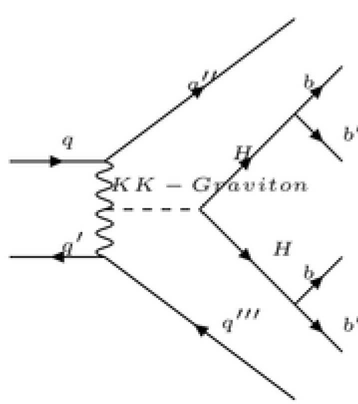
Out of all the fundamental forces, gravity is the weakest. It is weaker than all other forces by many orders of magnitude. The mass scale that weakens the gravitational interaction is known as the Planck mass. On the course of the last century it was realized that the existence of extra spatial dimensions (ED)- where the gravitational interaction could propagate modifying the gravity behaviour at short distances. The n-dimensional gravitational scale approaches the n-dimensional weak scale – justifying the weakness of gravity interactions with respect to the remaining forces of nature we experience on our four dimensional effective world. The Planck mass would not be a fundamental scale anymore.

The focus of the existence of one Warped Extra Dimension(WED) were to show a mechanism where the effective difference between the Planck mass and the weak mass is an outcome of the existence of one finite additional spatial dimension with non trivial metric. The five dimensional space defined between the two branes is referred as the bulk.

Quantum fluctuations of the five dimensional space-time metric are interpreted as particles, the fluctuations around the 3+1 infinite part of metric correspond to the five dimensional Graviton field (spin-2) while the fluctuations around the finite size of the spatial extra dimension manifest itself as a spin-0 field, commonly called Radion. The finiteness of the extra spatial dimension makes the four dimensional effective theory (our world) to contain the excitation modes, acting as heavy resonances, known as Kaluza-Klein (kk) modes. The mass properties of the kk modes are directly calculable from the space-time geometry. The mass of the first kk-mode of Graviton field (spin-2) is expected to be on TeV range if the size and curvature of the extra dimension is chosen such that the Planck-TeV hierarchy is solved on the full theory.

In the recent years, search for heavy particles on LHC data had consistently advanced on both CMS and ATLAS. So it would be worth looking for this heavy kk-graviton.

My focus in this project was on double higgs production on Vector Boson Fusion(vbf) channel. I worked on both Bulk and RS1 models. The W-bosons produces a kk-graviton and then it decays to a pair of higgs. Then this pair of higgs decays into pairs of b-jets. The whole process is showed in the following Feynman Diagram:



Finally, I worked on ways of finding the vbf jets from the reco level using different strategies.

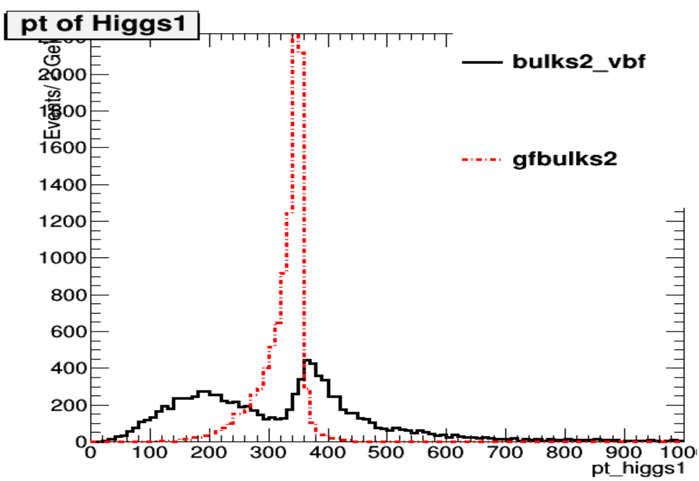
Monte-Carlo Generation:

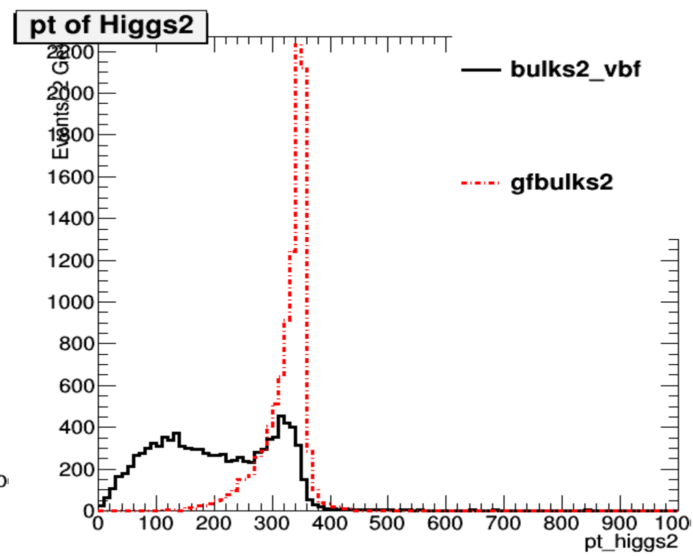
1. I initially used the already established models for the lagrangian generated by FeynRules.
2. I generated the events using Madgraph. There I had 2 higgs and 2 vbf jets.
3. I passed the file to Pythia to decay the higgs into a pair of b-jets and then did the showering.
4. I used Fastjet and ROOT to look at different kinematics of the partons and jets.
5. I used different algorithms to match jets after showering with vbf jets and calculated the level of MC truth.

Results and Analysis:

Higgs Momentum:

There are many ways to get a double higgs production, the two major ones are Gluon-Fusion(gf) and Vector-Boson-Fusion(vbf). Initially I generated some histograms to compare the double higgs production in both gf and vbf channels.

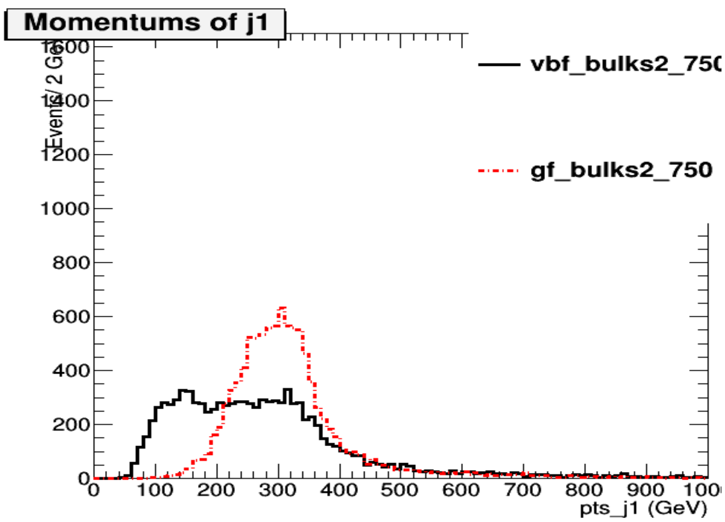


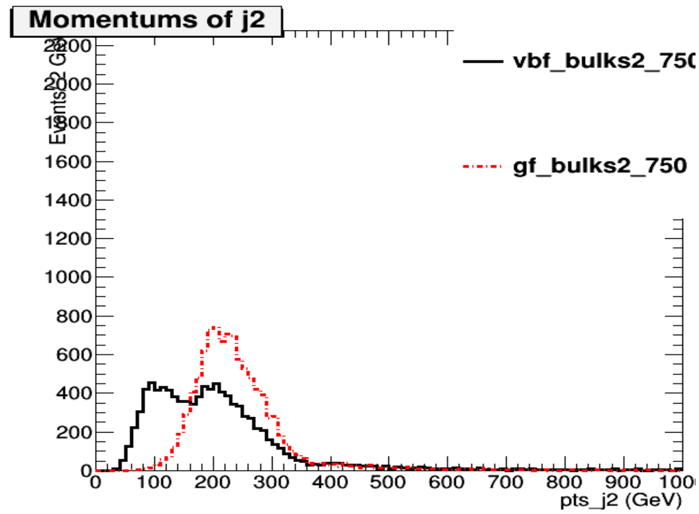


If we analyze these histograms, the momentum of the 2 higgs are equal in the gf channel. That shows that the KK-graviton produced was not moving. This can be seen by the value of the mometums. They add to the mass of the KK-graviton. But there are 2 peaks for higgs momentum in the vbf channel which still gives a scope for an answer to look for.

Momentum of the Hardest Jets:

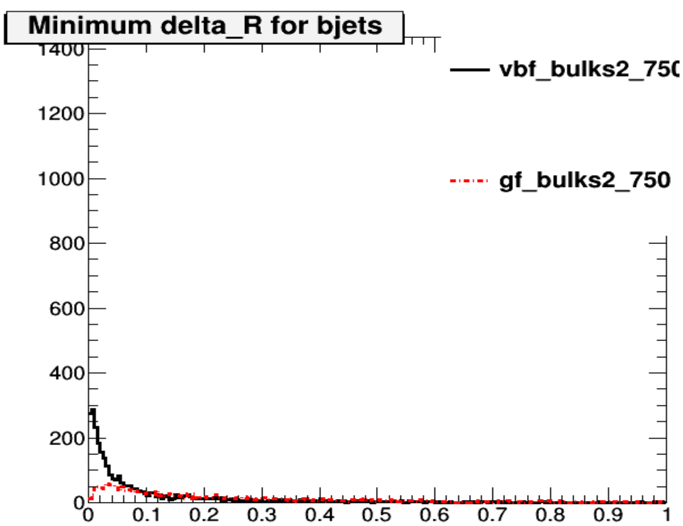
I could find a significant difference in the momentums of the two hardest jets at the reco level produced in the 2 channels we are looking at.

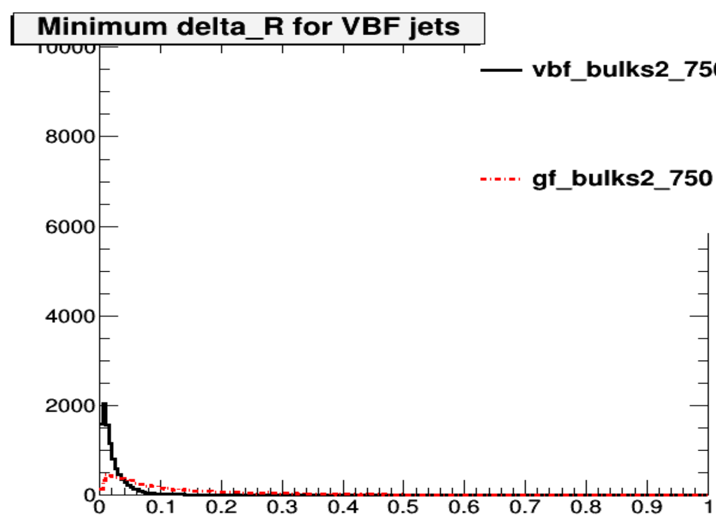




Finding the Minimum Angle between b-tagged and non b-tagged jets in reco and gen level:

I plotted the minimum angle between b-tagged and non b-tagged jets before and after showering. This helped me to choose the cut for finding the best vbf jet algorithm.





The minimum angle for vbf(non b-tagged) jet seems to be smaller then minimum angle for b-tagged jets.

Testing Algorithms to find VBF Jets:

I have tried different algorithms to check the MC truth for finding the vbf jets. These are: highest transverse momentum, highest delta_R, highest invariant mass and lowest Zeppenfeld variable for the four hardest jets. The results for different models and different KK-graviton masses are given below:

300 GeV

Bulk

Efficiency for Highest Momentum

x0pt =0.1622

x1pt =0.7583

x2pt =0.0767
Efficiency for Highest delta_R
x0dr =0.1941
x1dr =0.4964
x2dr =0.3029
Efficiency for Highest Invariant Mass
x0im =0.0741
x1im =0.4687
x2im =0.4437
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.437393
x1zv =0
x2zv =0.544633

RS1

Efficiency for Highest Momentum
x0pt =0.097
x1pt =0.8311
x2pt =0.0696
Efficiency for Highest delta_R
x0dr =0.3955
x1dr =0.4905
x2dr =0.1124
Efficiency for Highest Invariant Mass
x0im =0.1195
x1im =0.6345
x2im =0.2419
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.641414
x1zv =0.00010101
x2zv =0.350606

750 GeV

Bulk

Efficiency for Highest Momentum
x0pt =0.5739
x1pt =0.3982
x2pt =0.0277
Efficiency for Highest delta_R
x0dr =0.1436
x1dr =0.4303
x2dr =0.4248
Efficiency for Highest Invariant Mass
x0im =0.0667
x1im =0.397
x2im =0.5339
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.331932

x1zv =0.0002002
x2zv =0.663063

RS1

Efficiency for Highest Momentum
x0pt =0.3499
x1pt =0.6097
x2pt =0.0396
Efficiency for Highest delta_R
x0dr =0.4171
x1dr =0.4647
x2dr =0.117
Efficiency for Highest Invariant Mass
x0im =0.1923
x1im =0.5916
x2im =0.2136
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.636929
x1zv =0.000200481
x2zv =0.357057

2000 GeV

Bulk

Efficiency for Highest Momentum
x0pt =0.8669
x1pt =0.1234
x2pt =0.0097
Efficiency for Highest delta_R
x0dr =0.1104
x1dr =0.3549
x2dr =0.5347
Efficiency for Highest Invariant Mass
x0im =0.0445
x1im =0.3143
x2im =0.6406
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.236223
x1zv =0
x2zv =0.763573

RS1

Efficiency for Highest Momentum
x0pt =0.8526
x1pt =0.1383
x2pt =0.0089
Efficiency for Highest delta_R
x0dr =0.4198
x1dr =0.4456
x2dr =0.1343

Efficiency for Highest Invariant Mass
x0im =0.2839
x1im =0.4994
x2im =0.2157
Efficiency for Lowest value of Zepenfeld Variable
x0zv =0.608852
x1zv =0.000204897
x2zv =0.388792

<u>Conclusion:</u>
So for a overall selection, I think choosing the jets with highest invariant mass would be the most efficient choice. But choosing jets with lowest Zepenfeld variable gives some interesting results. This can be used to differentiate results with bulk and RS1 model.