Ching-Wei Chen

September 11, 2015

Contents

1 Introduction

The analysis I worked on is Higgs to b$\bar{b}$.The reconstruction of boosted Higgs needs b-tagging. In this report I briefly explain the method which can be used to enhance the b-tagging efficiency by using a MVA based analysis. This is essential to have high efficiency of purity of b-tagged jets coming from boosted Higgs boson. Another object needed is MET, missing transverse energy. Since this physics process has high MET, it is important to study it in details. There are a couple of source which can lead to fake MET. I will conclude the method I used to separate signal and background, including ABCD method, fitting method. In addition, I scanned over a dark matter model which is similar to another one we focus. Because of the relation of MET and dark matter, I am working in MET scanning group at the same time. Besides, I did the optimization for soft drop mass and pruned jet mass of Higgs.

2 Dark Matter Simplified Model $H_{z'z'}$

2.1 Introduction

Many theories of physics beyond the Standard Model predict the existence of stable, neutral, weakly-interacting and massive particle. Though we can only observe it stable on the distance-scales of 10's of meters, we refer to such matter as dark matter. There is not any evidence for nongravitational interaction between dark matter and Standard Model particles. If such interactions exist, dark matter matter particles could be produced at the LHC, Large Hadron Collider.

Because of their weakly-interacting, they will not produce signal in the detectors. We can observe the production when there are other detectable Standard Model particles produced in association with dark matter. The transverse momentum always conserves. If all the particles are well reconstructed in the detector, the vector sum of their transverse energy will be zero.If the vector sum of transverse energy of all particles has large value pointing to either way, that means there could be dark matter particles going out through the opposite way, which will not produce signals in the detector. We call this transverse energy opposite to the vector sum of transverse energy of all detected particles MET, missing transverse energy. Besides,the production including dark matter and Standard Model particles X(=q, g, Z, W, or h) is called "mono-X" or MET+X reactions.

2.2 Simplified Model Hzpzp

There are some grounding assumption of simplified models. First, we assume the interactions between dark matter and Standard Model particles exist. Second, the dark matter itself is assumed to be a single particle, a Dirac fermion WIMP, weak interacting massive particle, stable on collider time scales and non-interacting with the detector.The choice of Dirac fermions permits some precesses forbidden for Majorana fermions.Next,the interactions are explained by assuming a mediating force or particle.For now, only one mediator and one search channel are enough in the opening stage of an LHC discovery.Last,all models are assumed to produce paris of dark matter particles.

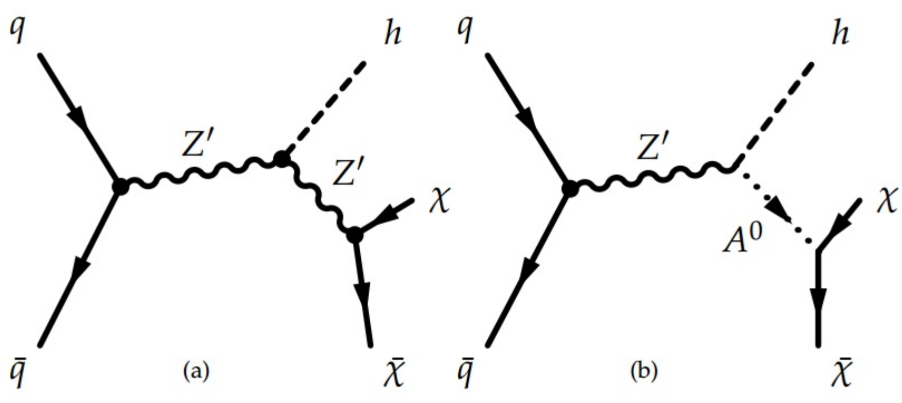


Figure 1: Feynman diagrams leading to Higgs+MET events:(a)$H_{z'z'}$ model (b)2HDM modle

2.3 Parameter Scanning

Our focus is the simplified model 2HDM, which is figure 1(b).Since the simplified model hzpzp, wihich is figure 1(a) is very same as the one we are interested.I am assigned to simulate the model by Monte Carlo method and to see the variation of cross section with different parameters and its kinetic distribution.The simulation is done by MadGraph5. The parameters are g_{DM}, the coupling strength between mediator Z' and two dark matter particles χ , g_f, the coupling strength between protons and Z', g_z, the coupling strength between two Z's and Higgs, m_{DM}, mass of dark matter particle ,and $m_{Z'}$, mass of Z'.The constraints are:

1. g_f,g_{DM} $< 4\pi$
2. $g_z < \sqrt{4\pi} m_{Z'} sin\theta$

The cross section result is shown in Figure 2.

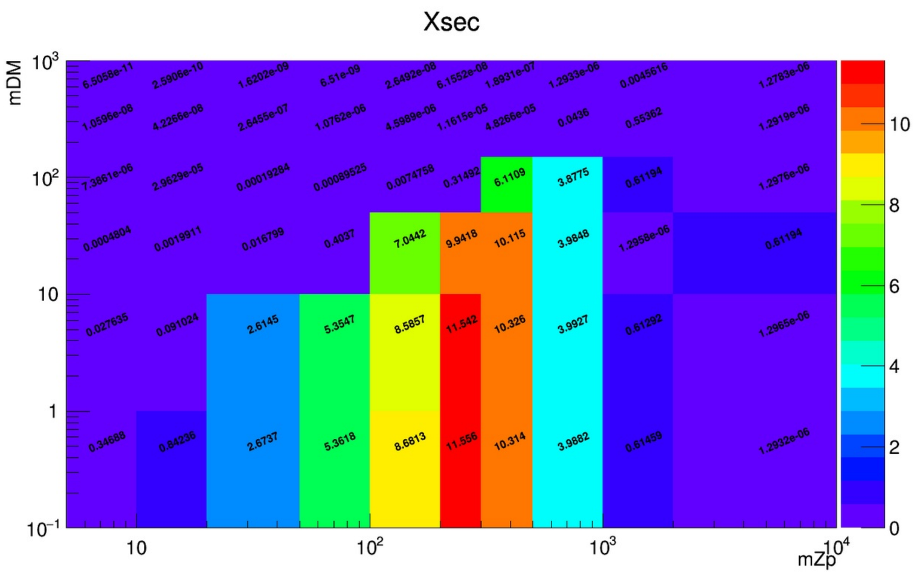


Figure 2: Cross section(pb) with different mass point.X axis is mass of mediator Z'(GeV), and Y axis is mass of dark matter particle()GeV. Other parameters are set at fixed values: g_{DM}=1, g_f=1/3, g_z=$m_{Z'}$

Next, I want to see whether kinetic distribution changes with parameters changing. The most important kinetic distribution to us is the MET, which can be seen from the transverse momentum of Lorentz vector sum of two dark matter particles. I choose these parameters for benchmark: g_{DM}=1, g_f=1/3, g_z=100, m_{DM}=50, $m_{Z'}$=100.I just changed one parameter at a time. Table 1 is the coupling strength I tried, three coupling strength turned out to have no effect on the kinetic distribution. Table 2 is the mass point I tried. It show that

g_{DM}	g_f	g_z
1.45	1.45	100
1	1	50
0.5	0.5	10
0.1	0.33	5
-	0.25	1
-	0.1	0.5
-	-	0.1

Table 1: The coupling strength I tried.

when mass of dark matter larger that half of the mass of Z',kinetic distribution will change, while others will not.

Other kinetic distributions are ΔR of two sub-bjets of Higgs and transverse momentum of Higgs.They are shown in figure 3 and 4.

mass of Z'(GeV)	10	20	50	100	200	300	500	1000	2000	5000
mass of dark matter(GeV)										
1	x	x	x	x	x	x	o	o	o	o
10	x	x	x	x	-	-	-	-	-	o
50	x	-	x	x	x	x	-	-	-	o
150	o	-	-	-	o	o	x	o	-	o
500	o	-	-	-	-	-	o	o	o	o
1000	o	-	-	-	-	-	-	o	o	o

Table 2: The mass point I tried. Mark o means kinetic distribution, the transverse momentum of Lorentz vector sum of two dark matter particles, changes. Mark x means kinetic distribution, the transverse momentum of Lorentz vector sum of two dark matter particles, does not change. Mark - means the mass point has not been tried.

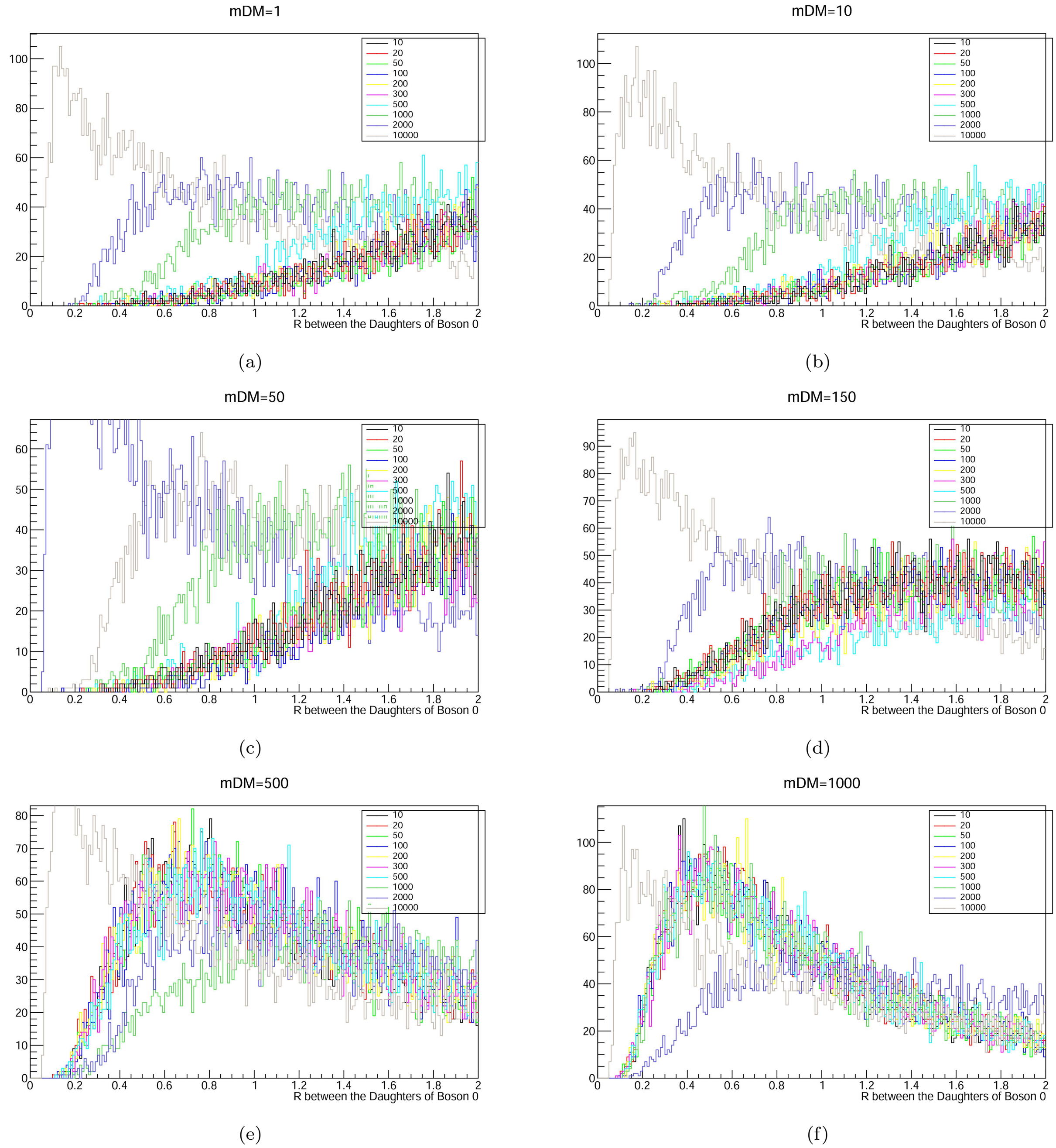
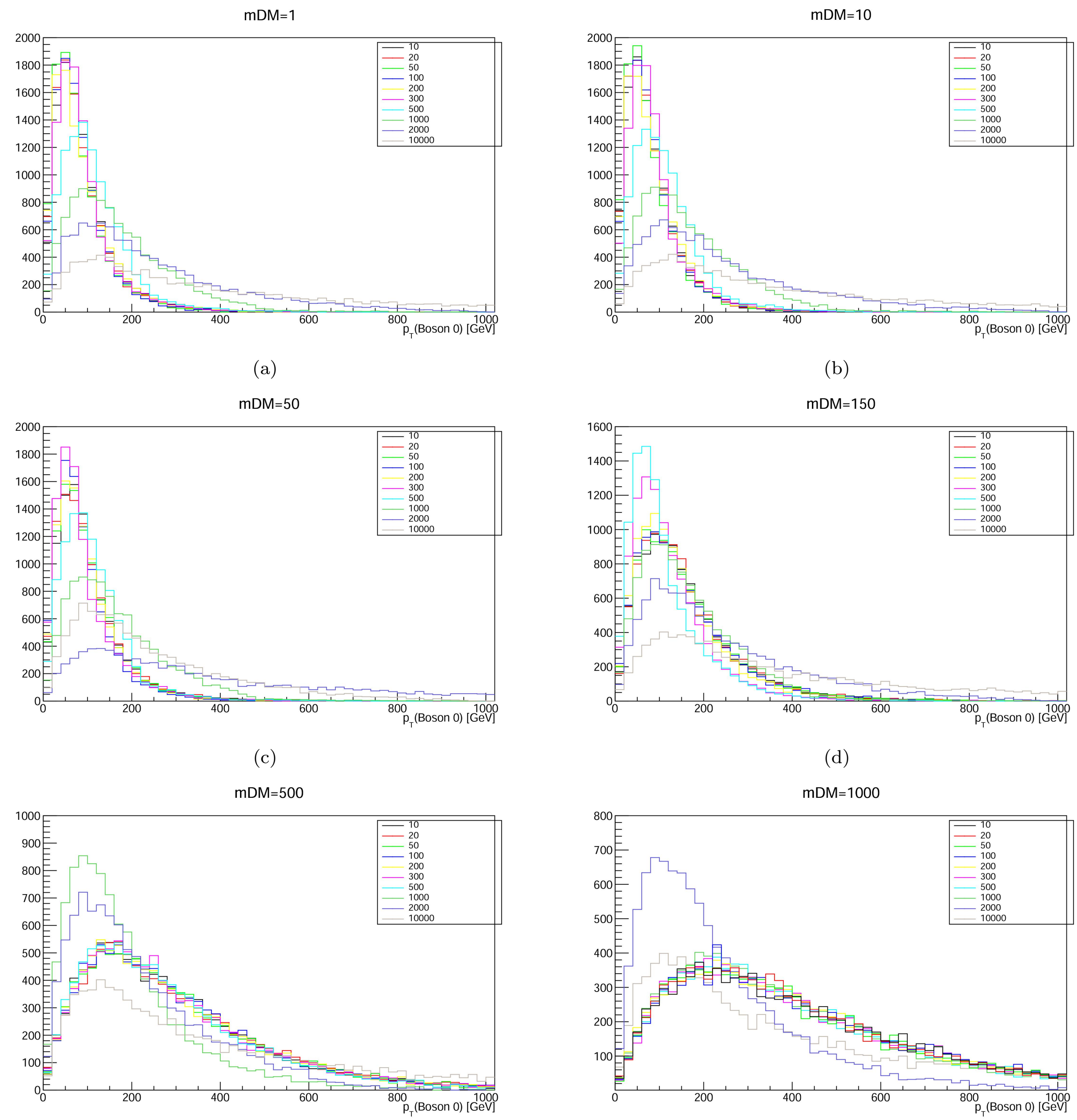


Figure 3: ΔR of two sub-bjets of Higgs. (a)m_{DM}=1GeV (b)m_{DM}=10GeV (c)m_{DM}=50GeV (d)m_{DM}=150GeV (e)m_{DM}=500GeV (f)m_{DM}=1000GeV .Legends are $m_{Z'}$(GeV)



(a) (b) (c) (d) (e) (f)

Figure 4: Transverse momentum of Higgs. (a)m_{DM}=1GeV (b)m_{DM}=10GeV (c)m_{DM}=50GeV (d)m_{DM}=150GeV (e)m_{DM}=500GeV (f)m_{DM}=1000GeV .Legends are $m_{Z'}$(GeV)

3 ABCD method

3.1 Introduction

ABCD method can estimate background rate when events are discriminated by two uncorrelated variables which both can separate signal and background.Then,We make a 2-dimensional plot of the two variable, and separate it into four region by drawing a line on each variable. They are called A, B, C ,D region, as figure 5. For now ,We can just consider axes two different variable .I will give them meaning in next subsection. Because the result of statistic , the numbers of events in A ,B ,C ,D region will have a relation: A/B=C/D.

There are four assumptions:

1. There is no signal leakage in A, B ,D region. (If signal distributes in C region).
2. There is no correlation between x and y variables.
3. Background is only from one single source.
4. There should be enough events to propagate the statistic uncertainty.

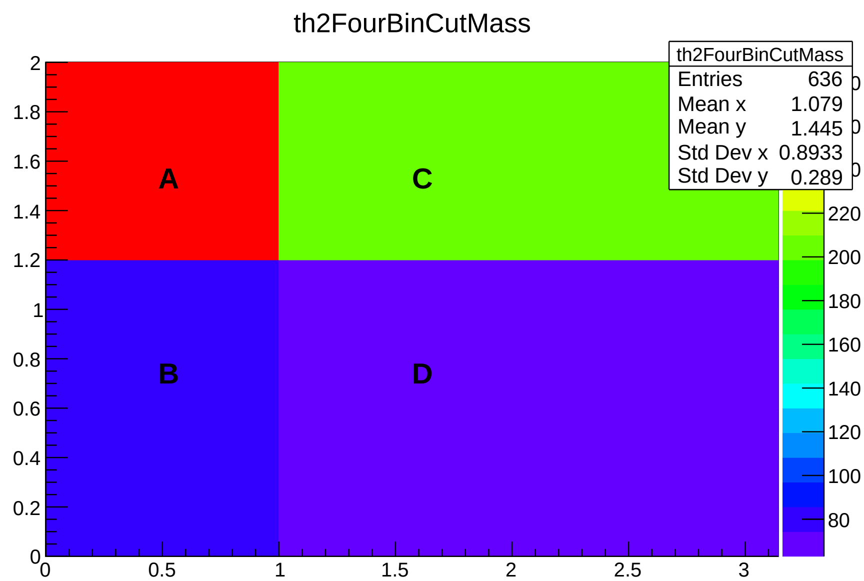


Figure 5: an example of ABCD method

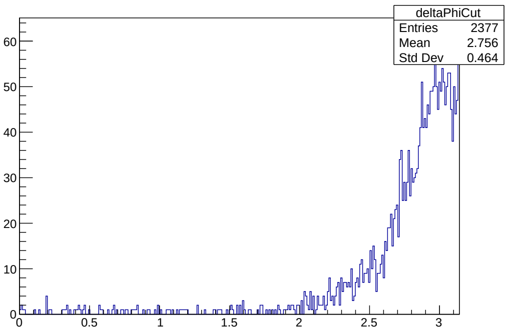
3.2 Application

Figure 6 are the two variables wich can separate the signal, Higgs to b,$\bar{b}$, and the background, QCD, Drell-Yen,W+Jet, and T$\overline{T}$ by using Monte Carlo simulation. Two variables are $\Delta\phi$ of two sub-jets in the AK8-jet and the sum of CSV[1] of two sub-jets in the AK8-jet. In figure 6(e), we can see that signal tends to be at the upper right corner, while background is more likely to be at upper left corner. Before separating into four region ,I make another selection that the mass of Higgs, Lorentz vector sum of two jet, should be between 90(GeV) and 150(GeV), as figure 7.Finally,there are 4-bins histograms in figures 8 produced by signal and different backgrounds. Because signal is almost in C region, we want to use the numbers of events of backgrounds in A, B ,D region to get the numbers of events of backgrounds in C region.The results are in table 3.

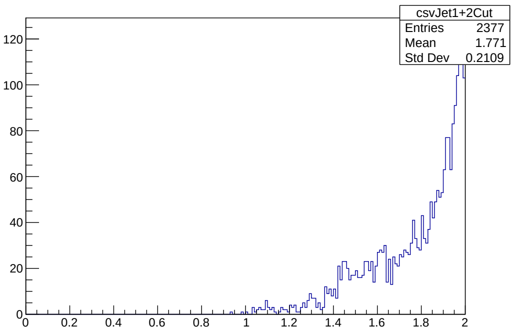
background	A*D/B	C
QCD	236.4	235
DY	202	150
W+Jet	6951.8	6953
T$\overline{T}$	401321.3	383063

Table 3: The coupling strength I tried.

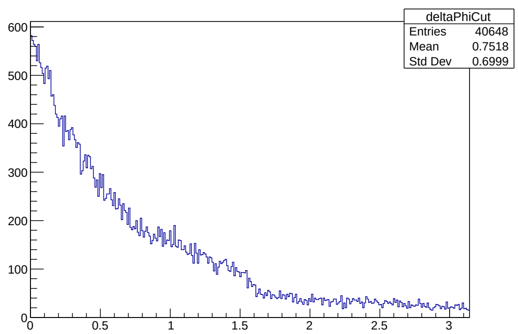
[1]Combined Secondary Vertex, a method used within CMS to tag b-jets, which uses the secondary vertex information to train a MVA and result is used to tag jets.



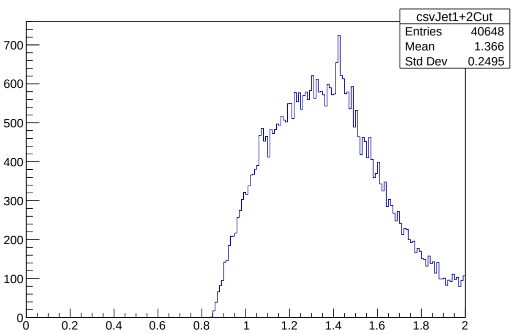
(a)



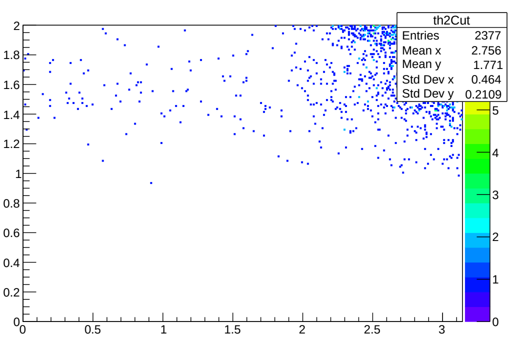
(b)



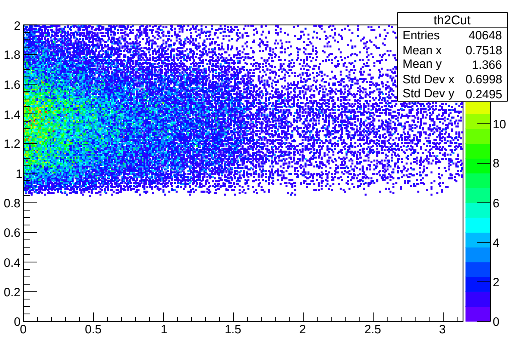
(c)



(d)

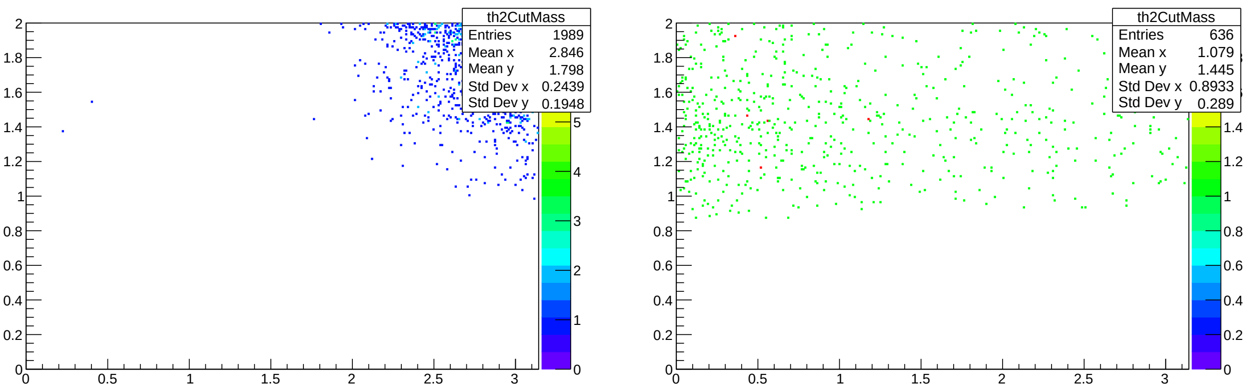


(e)



(f)

Figure 6: (a)$\Delta\phi$ of two sub-jets in the AK8-jet of signal. (b)The sum of CSV of two sub-jets in the AK8-jet of signal. (c)$\Delta\phi$ of two sub-jets in the AK8-jet of QCD. (d)The sum of CSV of two sub-jets in the AK8-jet of QCD. (e)The sum of CSV of two sub-jets in the AK8-jet versus $\Delta\phi$ of two sub-jets in the AK8-jet of signal. (f)The sum of CSV of two sub-jets in the AK8-jet versus $\Delta\phi$ of two sub-jets in the AK8-jet of QCD.All of them pass the selection that both CSVs of sub-jet are larger than 0.423.



(a)

(b)

Figure 7: (a)The sum of CSV of two sub-jets in the AK8-jet versus $\Delta\phi$ of two sub-jets in the AK8-jet of signal. (b)The sum of CSV of two sub-jets in the AK8-jet versus $\Delta\phi$ of two sub-jets in the AK8-jet of QCD.All of them pass the selection that both CSVs of sub-jet are larger than 0.423. In addition, their Higgs mass should between 90Gev and 150GeV

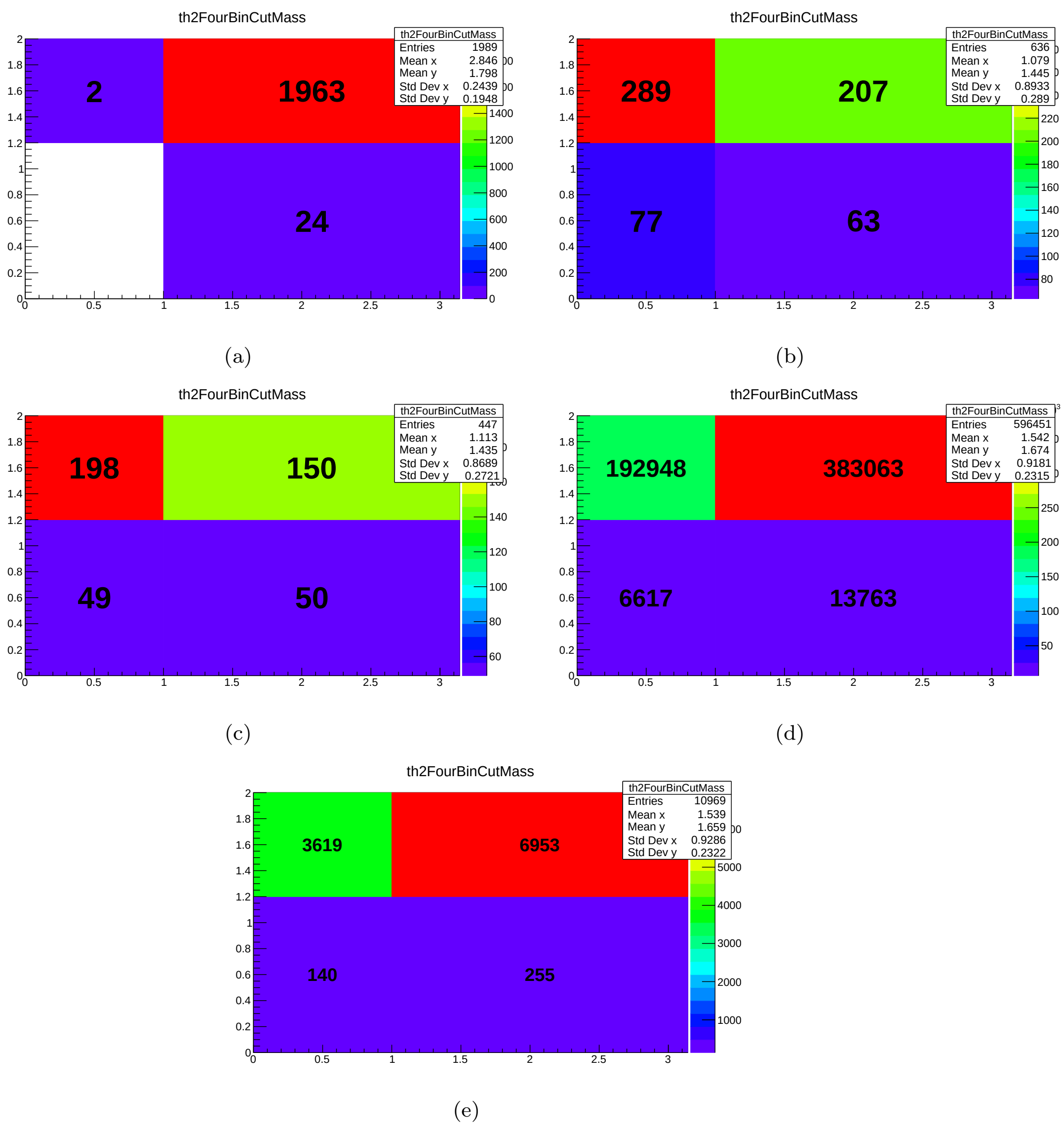
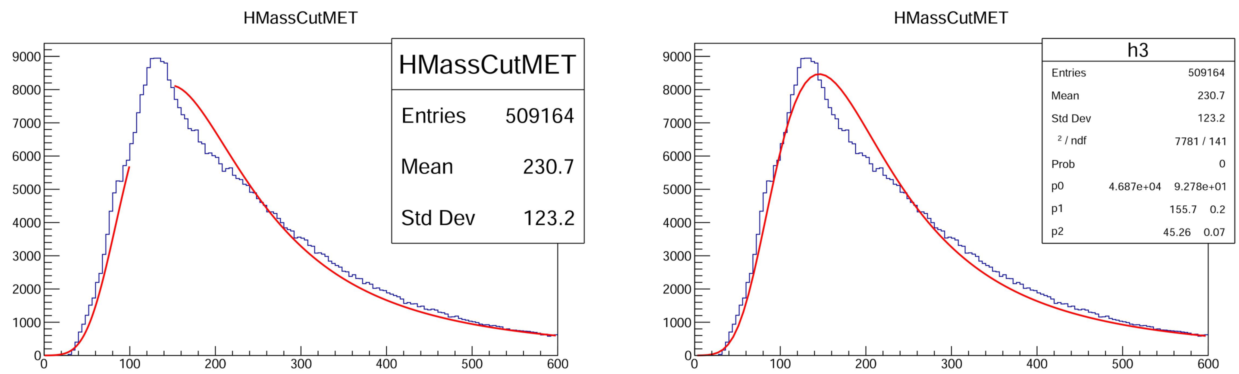


Figure 8: The sum of CSV of two sub-jets in the AK8-jet versus $\Delta\phi$ of two sub-jets in the AK8-jet. (a)signal (b)QCD (c)DY (d)T$\overline{T}$ (e)W+Jet.All of them pass the selection that both CSVs of sub-jet are larger than 0.423. In addition, their Higgs mass should between 90Gev and 150GeV



(a) (b)

Figure 9: Fitting the mass of Higgs. (a)Without region [90,150]. (b)Full region.

4 Fitting method

4.1 The purpose

Beside ABCD method, another way to propagate the number of event of background is fitting.If we can find a function that can well fit some variables of signal merged background in simulation at a same time.We can use the function to fit the data collected in the detector.The premise is that we believe the shape of variables in simulation is same as true data.

4.2 pre-selection

1. CSV of jet > 0.423
2. P_t of leading jet >80Gev,P_t of sub-leading jet >30Gev
3. η <2.5
4. MET $>$ 100GeV

4.3 Histogram Fit

In this subsection, I will use the fitting given by the class TH1F written by ROOT6.The sample is T$\overline{T}$ simulation.The target is the mass of Higgs, the Lorentz vector sum of two jets.

The results are in figure 9.

4.4 RooFit

RooFit is another class written in ROOT6.It should perform better than histogram fit.

1. sample: background T$\overline{T}$ simulation, target: mass of Higgs, results: figure 10,11.
2. sample: background T$\overline{T}$ simulation, target: transverse mass[2], results: figure 12.
3. sample: signal Higgs to b$\bar{b}$ simulation, target: mass of Higgs, results: figure 13, 14.
4. sample: signal Higgs to b$\bar{b}$ merged background T$\overline{T}$ simulation, target: mass of Higgs, results: figure 15.

From the result of previous three points, the best fitted function for signal and background are Gauss function convoluted with BreitWinger and Landau function convoluted with Gauss function. Therefore, I tried to use the addition of these two function to fit the sum of both histograms of mass of Higgs. The conclusion is that the fitting result will change with different initial values, its parameters do not convergent. The fitting method needs to be further studied.

[2] $m_1^2 + m_2^2 + 2[E_T(1)E_T(2) - p_T(1)p_T(2)]$

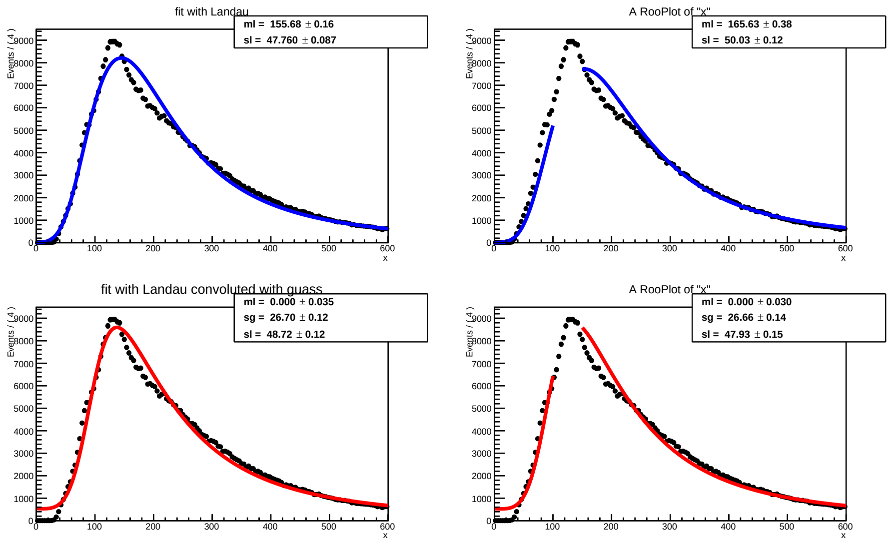


Figure 10: Fitting the mass of Higgs by RooFit. Upper left and right are Landau function with and without range 90GeV to 150GeV. Lower left and right are Landau function convoluted with Gauss function with and without range 90GeV to 150GeV.

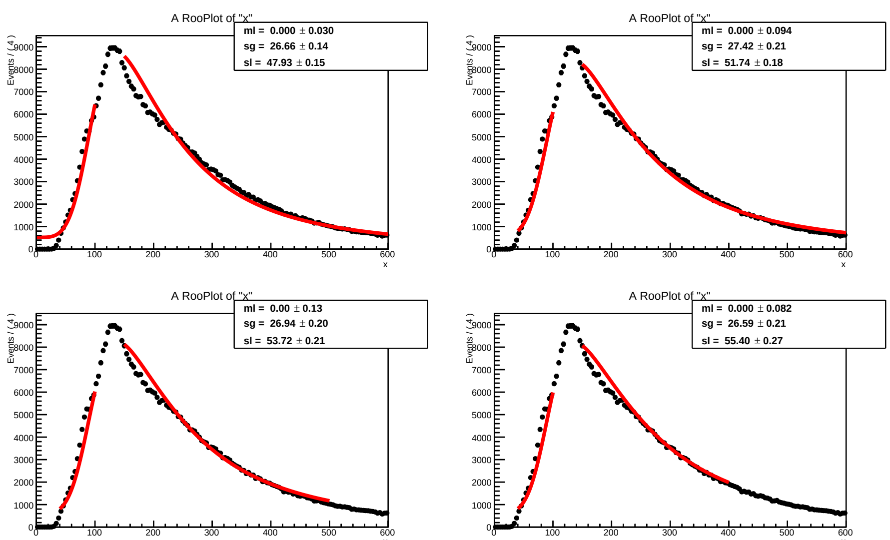


Figure 11: Fitting the mass of Higgs of T$\overline{T}$ by RooFit. Upper left is Landau function without range 90GeV to 150GeV. Upper right is Landau function without range 0GeV to 40GeV and 90GeV to 150GeV. Lower left is Landau function convoluted with Gauss function without range 0GeV to 40GeV, 90GeV to 150GeV, and 500GeV to 600GeV. Lower right is Landau function convoluted with Gauss function without range 0GeV to 40GeV, 90GeV to 150GeV, and 400GeV to 600GeV.

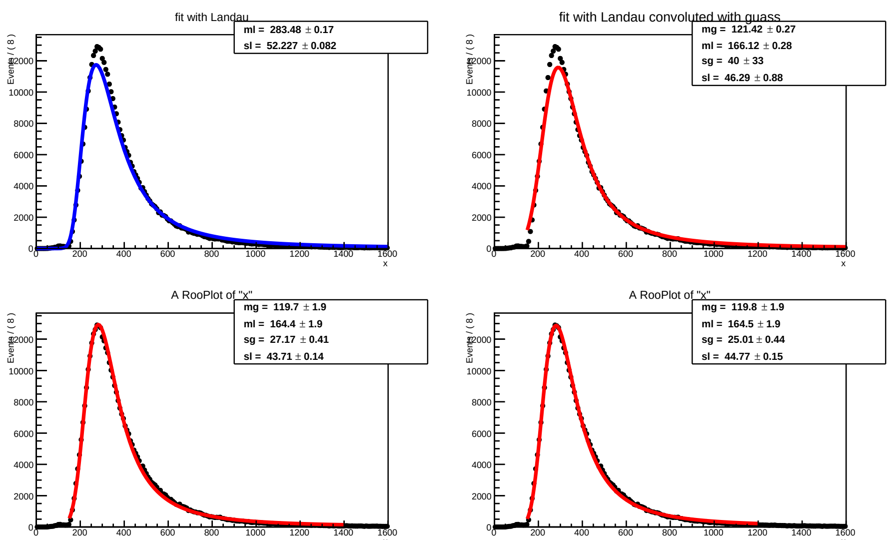


Figure 12: Fitting the transverse mass of T$\overline{T}$ by RooFit. Upper left is Landau function. Upper right is Landau function convoluted with Guass function. Lower left is Landau function convoluted with Guass function in range 150GeV to 1400GeV. Lower right is Landau function convoluted with Guass function in range 150GeV to 1200GeV .

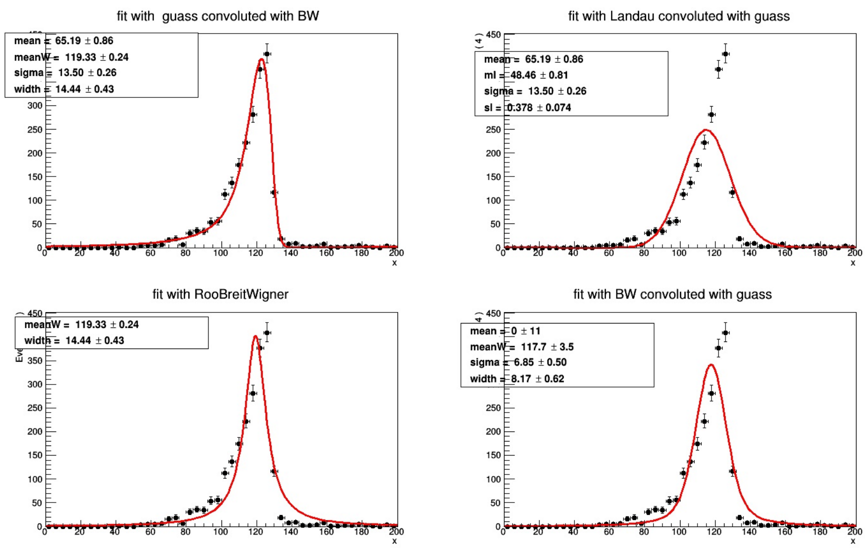


Figure 13: Fitting the mass of Higgs of signal by RooFit. Upper left is Guass function convoluted with Landau function. Upper right is Landau function convoluted with Guass function. Lower left is BreitWinger function . Lower right is BreitWinger function convoluted with Guass function.

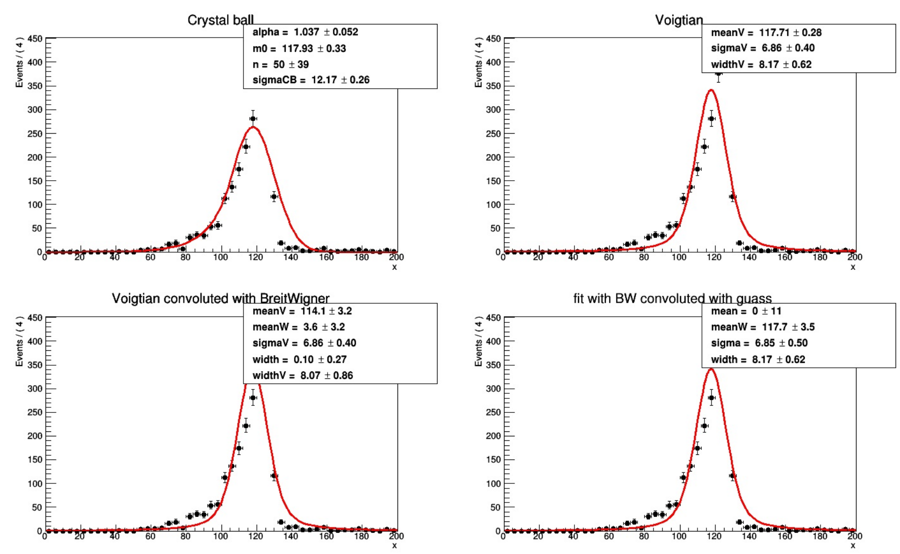


Figure 14: Fitting the mass of Higgs of signal by RooFit. Upper left is Crystal ball function. Upper right is Voigtian function. Lower left is Voigtian function convoluted with BreitWinger function . Lower right is BreitWinger function convoluted with Guass function.

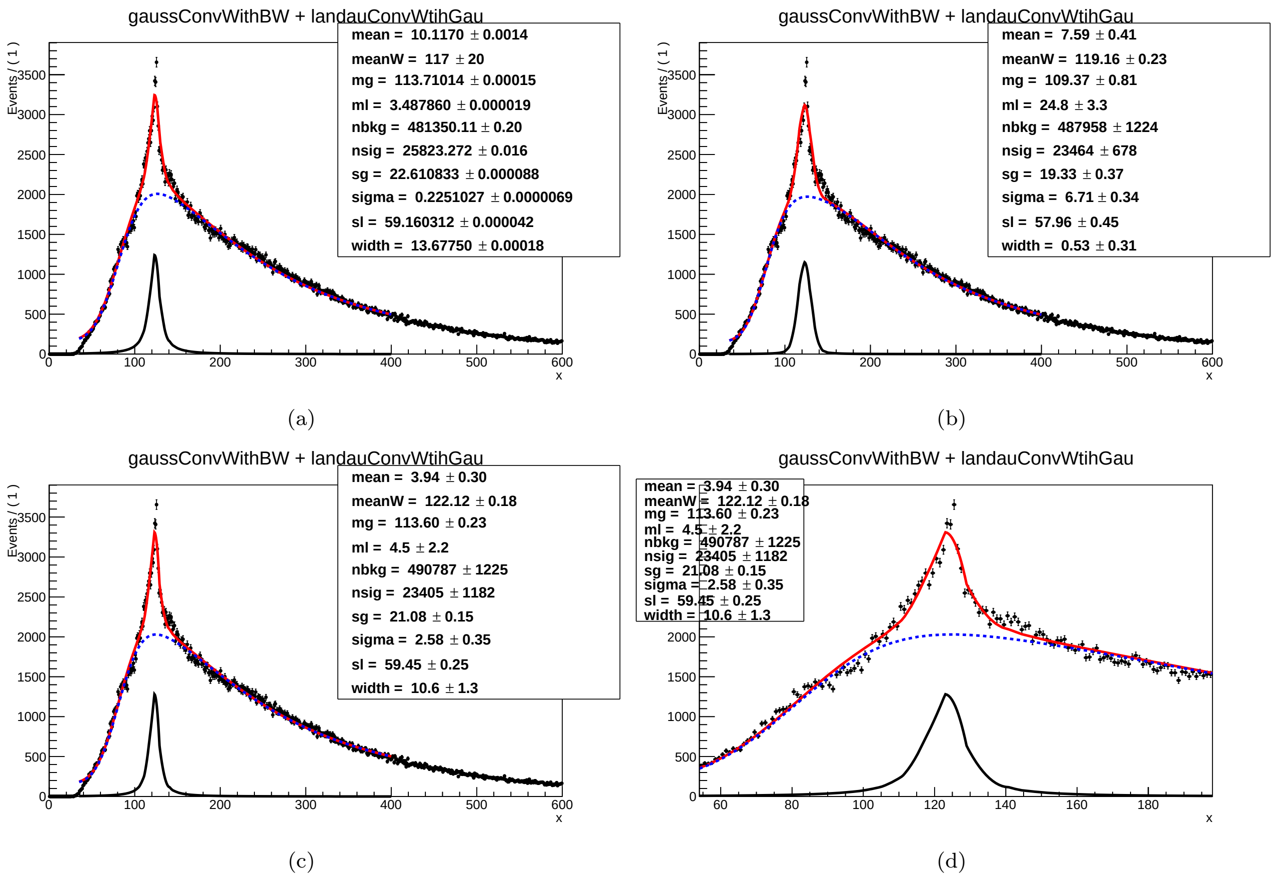


Figure 15: (a)(b)(c)Fitting the mass of Higgs of addition of signal and background by RooFit. The function is the addition of Gauss function convoluted with BreitWinger and Landau function convoluted with Gauss function with different initial values. (d)a zoom-in of (c)

5 Optimization

5.1 Introduction

We want to find a cut on the mass of Higgs, Lorentz vector sum of two jets to reduce the background and not to lose the signal too much. In addition,we want to avoid choosing the cut within the mass of the other particles like Z(91GeV) or W(80GeV), which are the channels other people are researching.

5.2 selection

1. Electron channel
2. 70GeV <Mass of Z(ll)<200GeV, p_T of Z(ll)>200GeV
3. p_T of AK8-jet>200GeV, $|\eta|$ of AK8-jet< 2.4
4. 20GeV <soft drop mass/ pruned mass of AK8-jet<220GeV
5. ΔR of AK8-jet and any good electron >0.8. Good electron selection:
   (a) $|\eta| < 2.5$
   (b) $1.442 < |eleSCEta| < 1.566$ [3]
   (c) p_T >115GeV
   (d) passHEEPIDNoIso=1[4]
   (e) eleMiniIso < 0.1
6. mass of Z'(Zh) >its mass point × 0.85

5.3 Samples

5.3.1 Signal

$ZprimeToZhToZlephbb_narrow_M - *_13TeV - madgraph$.

5.3.2 Background

1. Drell-Yen
   (a) $DYJetsToLL\_M - 50\_HT - 100to200\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
   (b) $DYJetsToLL\_M - 50\_HT - 200to400\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
   (c) $DYJetsToLL\_M - 50\_HT - 400to600\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$

[3]eleSCeta, eta of the super cluster which belong to a given electron.
[4]HEEP, High energy electron and photon identification used within CMS based on showe-shape and isolation variables.

(d) $DYJetsToLL\_M - 50\_HT - 600toInf\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$

2. $BulkGravToZZToZlepZhad_narrow_M - *_13TeV - madgraph$

Factor of Normalizing to luminosity: luminosity ($5fb^{-1}$) × cross section / number of events. The cross sections are list in table 4, 5.The cross sections of bulk graviton is calculated by cross section (graviton) (pb) × branch ratio (graviton to ZZ) × branch ratio (Z to ll), 0.03366, × branch ratio (Z to qq), 0.6991.

Drell-Yen	Cross Section(pb)
HT-100to200	139.4
HT-200to400	42.75
HT-400to600	5.497
HT-600toInf	2.21

Table 4: The cross sections of Drell-Yen samples.

Mass point (Gev)	Cross section (graviton) (pb)	Branch ratio (graviton to ZZ)
600	4.6e-2	0.184219
800	1.1e-2	0.142802
1000	3.3e-3	0.125936
1200	1.2e-3	0.117445
1400	4.7e-4	0.112554
1600	2.5e-4	0.109472
1800	7.5e-5	0.101401
2000	4.5e-5	0.10594
2500	8.6e-6	0.103732
3000	1.9e-6	0.012549
3500	4.3e-7	0.101841
4000	9.4e-8	0.101384
4500	2.1e-8	0.100927

Table 5: The cross sections of Bulk Graviton samples.

5.4 Target, Significance, and Windows

5.4.1 Target

There are two kind of mass of Higgs($b\bar{b}$), soft drop mass and pruned jet mass shown in figure 16.These are our targets.

5.4.2 Significance

I used Punzi significance: P=$\frac{efficiency\ of\ signal}{1+\sqrt{efficiency\ of\ background}}$, or P=$\frac{efficiency\ of\ signal}{1+\sqrt{number\ of\ events\ of\ background}}$. I used second definition when using Drell-Yen sample.Because the cross section of bulk graviton is quite low, the number of events of bulk graviton is small after normalized. Therefore, I used the efficiency of background instead when using bulk graviton.

5.4.3 Windows

1. wide ones
   (a) width: 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 GeV
   (b) lower edges of windows: 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110 GeV (upper edge = lower edge + width)
2. narrow ones: Table 6.

Width(GeV)	Lower Edge (GeV)
60	90
55	90, 95
50	90, 95, 100
45	90, 95, 100, 105
40, 35, 30, 25, 20	90, 95, 100, 105, 110

Table 6: The narrow windows.

5.5 Soft Drop Mass

5.5.1 Most Significant Wide Windows and Windows 90 to 150 GeV

First, I compare the significance of wide windows given in section 5.4.3-1. However, the wide windows will cover the mass of other particles. I am recommended to use narrow windows, which are all within the range 90 to 150 GeV. Then, I compare the windows having the highest significance within the wide windows and the windows 90 to 150 GeV.The background sample is Drell-Yen in this subsection.

5.5.2 Narrow Window

I use another set of windows here, the section 5.4.3-2. Then, I made a table of 15 highest significance windows of Drell-Yen(figure 18) and bulk graviton(figure 19).

5.5.3 Summary

Because the difference among the 15 highest significances is little, I choose the window whose signal efficiency is highest. It will be the 90-150 GeV.

Mass Point(GeV)	Highest Significance Window (GeV)(its significance)	Significance of Window 90 -150 GeV
600	50-145(0.05)	0.036
800	105-145(0.09)	0.08
1000	105-140(0.12)	0.11
1200	105-135(0.15)	0.14
1400	100-135(0.18)	0.17
1600	100-135(0.22)	0.2
1800	100-135(0.25)	0.24
2000	95-135(0.29)	0.28
2500	90-135(0.4)	0.4
3000	80-135(0.49)	0.48
3500	75-145(0.57)	0.54
4000	80-155(0.65)	0.61
4500	80-155(0.76)	0.71

Table 7: The comparison of the windows having the highest significance of soft drop mass within the wide windows and the windows 90 to 150 GeV.

5.6 Pruned Jet Mass

5.6.1 Most Significant Wide Windows and Windows 90 to 150 GeV

For same reason, I compared the significance of these two windows listed in table 8.

5.6.2 Narrow Window

Same as previous method, there are windows having the 15 highest significance in figure 18, 19.

5.6.3 Summary

Because the difference among the 15 highest significances is little, I choose the window whose signal efficiency is highest. It will be the 90-150 GeV.

Mass Point(GeV)	Highest Significance Window (GeV)(its significance)	Significance of Window 90 -150 GeV
600	50-140(0.046)	0.03
800	95-135(0.088)	0.084
1000	95-130(0.118)	0.108
1200	95-125(0.15)	0.13
1400	95-125(0.18)	0.16
1600	90-125(0.22)	0.19
1800	90-125(0.24)	0.22
2000	85-130(0.28)	0.26
2500	85-125(0.38)	0.36
3000	75-130(0.46)	0.43
3500	75-135(0.54)	0.49
4000	75-145(0.62)	0.54
4500	75-145(0.68)	0.6

Table 8: The comparison of the windows having the highest significance of pruned jet mass within the wide windows and the windows 90 to 150 GeV.

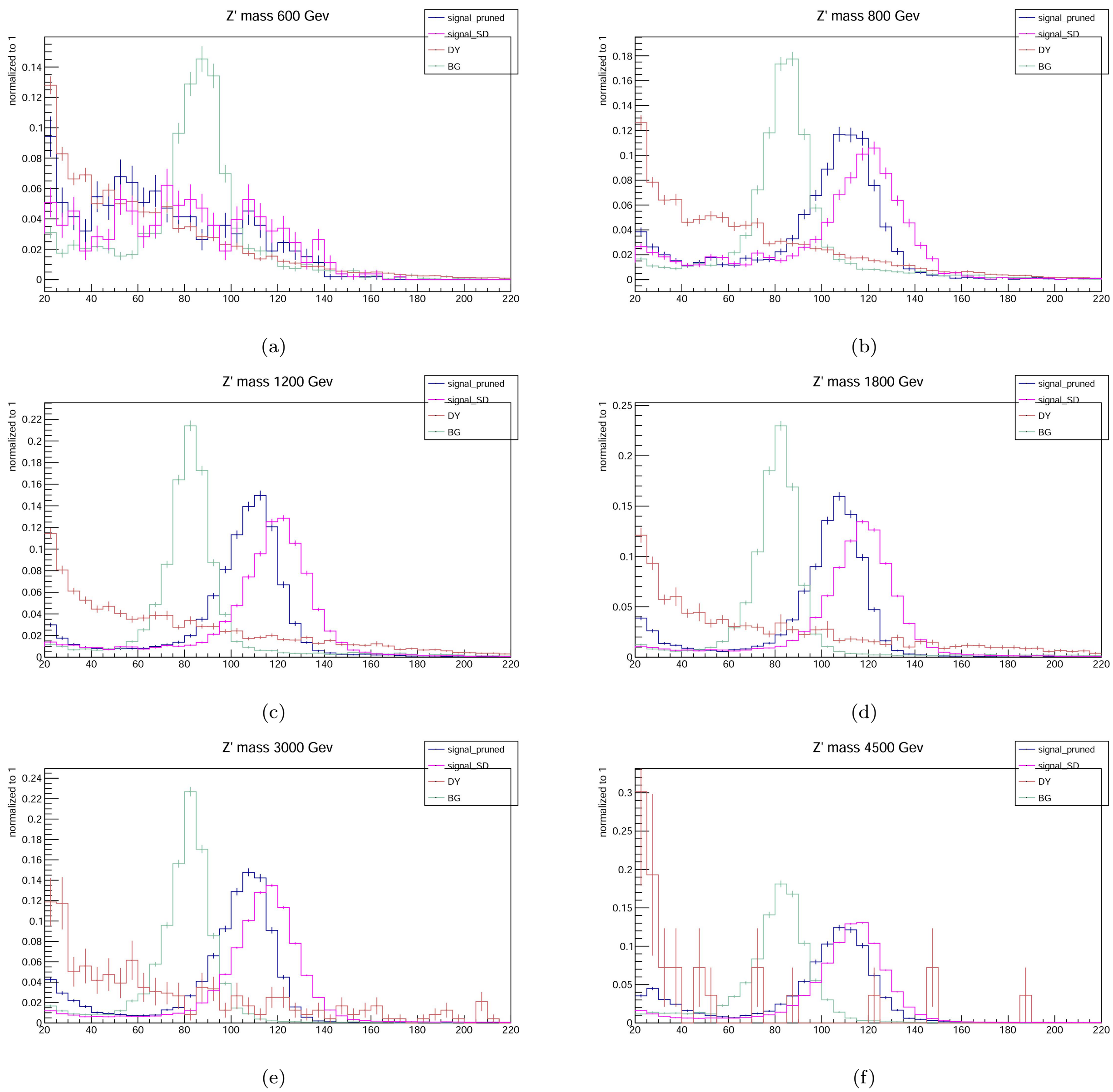


Figure 16: The pruned jet mass of Higgs of signal(blue), Drell-Yen(red), and Bulk-Graviton(green) and the soft drop mass of Higgs of signal(pink) for different mass points.(a)600GeV (b)800GeV (c)1200GeV (d)1800GeV (e)3000GeV (f)4500GeV

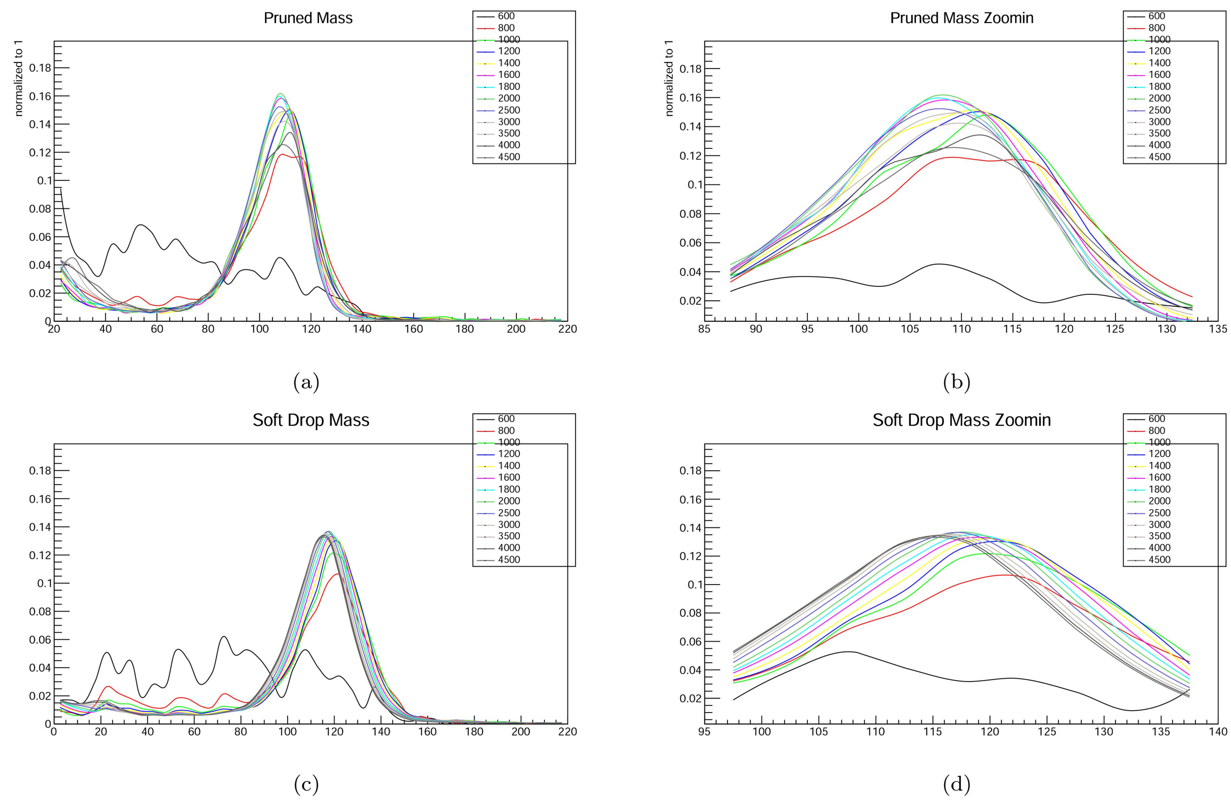


Figure 17: The pruned jet mass of Higgs of signal for different mass points (GeV)(a)and its zoom-in (b).The soft drop mass of Higgs of signal for different mass points (GeV)(c)and its zoom-in (d).

rank(signalEff)	600Num	800Num	1000Num	1200Num	1400Num	1600Num	1800Num	2000Num	2500Num	3000Num	3500Num	4000Num	4500Num
1	90to145(0.364)	105to145(0.668)	105to140(0.715)	105to135(0.685)	100to135(0.741)	100to135(0.754)	100to135(0.75)	95to135(0.805)	90to135(0.843)	90to145(0.841)	90to145(0.825)	90to150(0.816)	90to150(0.792)
2	90to150(0.368)	105to140(0.636)	105to145(0.744)	105to140(0.722)	100to140(0.774)	95to135(0.797)	95to135(0.796)	90to135(0.839)	90to140(0.856)	90to135(0.825)	90to150(0.827)	90to145(0.812)	90to145(0.787)
3	90to140(0.352)	105to150(0.687)	100to140(0.757)	100to140(0.771)	105to135(0.68)	95to140(0.824)	95to140(0.821)	90to140(0.858)	95to135(0.805)	90to150(0.843)	90to140(0.818)	90to140(0.806)	90to140(0.781)
4	100to145(0.3)	100to145(0.709)	100to145(0.785)	100to135(0.734)	95to135(0.78)	100to140(0.781)	100to140(0.775)	100to135(0.752)	90to145(0.862)	90to140(0.836)	90to135(0.808)	90to135(0.795)	90to135(0.77)
5	95to145(0.324)	100to150(0.728)	105to135(0.66)	110to135(0.609)	95to140(0.813)	90to135(0.824)	90to135(0.825)	95to140(0.824)	90to130(0.814)	90to130(0.804)	95to145(0.779)	90to130(0.767)	90to125(0.69)
6	100to140(0.287)	100to140(0.678)	110to140(0.645)	100to145(0.792)	100to145(0.792)	95to145(0.837)	90to140(0.85)	100to140(0.771)	90to150(0.865)	95to145(0.796)	95to150(0.782)	95to150(0.765)	95to150(0.745)
7	100to150(0.304)	110to140(0.569)	105to150(0.757)	105to145(0.742)	105to140(0.714)	90to140(0.851)	100to130(0.706)	95to130(0.769)	95to140(0.818)	95to135(0.779)	95to140(0.773)	95to145(0.762)	95to145(0.741)
8	95to150(0.328)	110to145(0.6)	100to150(0.798)	95to140(0.805)	95to145(0.831)	100to130(0.705)	95to145(0.831)	90to130(0.804)	95to130(0.775)	95to150(0.798)	90to130(0.784)	95to140(0.755)	90to130(0.74)
9	95to140(0.312)	95to150(0.763)	110to145(0.674)	110to140(0.647)	90to140(0.84)	95to130(0.748)	95to130(0.752)	100to130(0.717)	95to145(0.824)	95to140(0.79)	95to135(0.763)	95to135(0.744)	95to140(0.734)
10	90to135(0.324)	95to145(0.743)	100to135(0.702)	95to135(0.768)	90to135(0.807)	100to145(0.794)	100to145(0.785)	90to145(0.867)	95to150(0.827)	95to130(0.758)	90to125(0.735)	90to125(0.717)	95to135(0.723)
11	90to130(0.312)	110to150(0.62)	95to140(0.785)	95to145(0.825)	100to150(0.802)	105to135(0.685)	90to145(0.86)	95to145(0.832)	100to135(0.742)	90to125(0.754)	95to130(0.739)	100to150(0.699)	95to125(0.643)
12	105to145(0.261)	105to135(0.586)	95to145(0.813)	100to150(0.804)	105to145(0.732)	90to145(0.864)	95to150(0.837)	90to150(0.872)	90to125(0.754)	95to125(0.708)	100to145(0.71)	100to145(0.696)	95to130(0.693)
13	105to140(0.249)	95to140(0.712)	110to135(0.59)	105to150(0.755)	90to145(0.858)	95to150(0.844)	105to135(0.678)	95to150(0.838)	100to130(0.712)	100to145(0.729)	100to150(0.712)	95to130(0.717)	100to150(0.679)
14	100to135(0.259)	100to135(0.628)	95to150(0.826)	95to150(0.838)	95to150(0.841)	105to140(0.712)	90to130(0.781)	100to145(0.779)	100to140(0.755)	100to135(0.712)	100to140(0.703)	100to140(0.689)	100to145(0.675)
15	105to150(0.265)	90to150(0.785)	110to150(0.687)	110to145(0.667)	110to135(0.596)	100to150(0.8)	90to150(0.866)	100to150(0.785)	95to125(0.716)	100to150(0.731)	95to125(0.69)	100to135(0.678)	100to140(0.669)

Figure 18: 15 highest significance windows of soft drop mass using Drell-Yen

rank(signalEff)	600Eff	800Eff	1000Eff	1200Eff	1400Eff	1600Eff	1800Eff	2000Eff	2500Eff	3000Eff	3500Eff	4000Eff	4500Eff
1	90to150(0.368)	105to150(0.687)	105to150(0.757)	105to150(0.755)	100to150(0.802)	100to150(0.8)	100to150(0.791)	100to150(0.785)	95to150(0.827)	95to150(0.798)	95to150(0.782)	95to150(0.765)	95to150(0.745)
2	90to145(0.364)	100to150(0.728)	105to145(0.744)	100to150(0.804)	100to145(0.792)	100to145(0.794)	100to145(0.785)	100to145(0.779)	95to145(0.824)	95to145(0.796)	95to145(0.779)	95to145(0.762)	95to145(0.741)
3	90to140(0.352)	105to145(0.668)	100to150(0.798)	105to145(0.742)	105to150(0.742)	100to140(0.781)	100to140(0.775)	100to140(0.771)	100to150(0.764)	100to150(0.731)	95to140(0.773)	100to150(0.699)	95to140(0.734)
4	95to150(0.328)	100to145(0.709)	100to145(0.785)	100to145(0.792)	100to140(0.774)	105to150(0.732)	95to150(0.837)	95to150(0.838)	100to145(0.761)	100to145(0.729)	100to150(0.712)	95to140(0.755)	100to150(0.679)
5	95to145(0.324)	110to150(0.62)	110to150(0.687)	105to140(0.722)	105to145(0.732)	105to145(0.725)	95to145(0.831)	95to145(0.832)	95to140(0.818)	95to140(0.79)	100to145(0.71)	100to145(0.696)	100to145(0.675)
6	100to150(0.304)	95to150(0.763)	105to140(0.715)	100to140(0.771)	105to140(0.714)	95to150(0.844)	105to150(0.719)	95to140(0.824)	100to140(0.755)	100to140(0.723)	95to135(0.763)	100to140(0.689)	95to135(0.723)
7	100to145(0.3)	105to140(0.636)	110to145(0.674)	95to150(0.838)	95to150(0.841)	95to145(0.837)	100to135(0.75)	100to135(0.752)	95to135(0.805)	95to135(0.779)	100to140(0.703)	95to135(0.744)	100to140(0.669)
8	95to140(0.312)	110to145(0.6)	100to140(0.757)	95to145(0.825)	95to145(0.831)	105to140(0.712)	95to140(0.821)	95to135(0.805)	100to135(0.742)	100to135(0.712)	100to135(0.693)	100to135(0.678)	90to150(0.792)
9	90to135(0.324)	95to145(0.743)	95to150(0.826)	110to150(0.68)	100to135(0.741)	100to135(0.754)	105to145(0.713)	105to150(0.706)	95to130(0.775)	95to130(0.758)	90to150(0.827)	90to150(0.816)	90to145(0.787)
10	100to140(0.287)	100to140(0.678)	95to145(0.813)	110to145(0.667)	95to140(0.813)	95to140(0.824)	105to140(0.703)	105to145(0.7)	100to130(0.712)	90to150(0.843)	90to145(0.825)	90to145(0.812)	100to135(0.658)
11	105to150(0.265)	90to150(0.785)	110to140(0.645)	100to135(0.734)	105to135(0.68)	105to135(0.685)	95to135(0.796)	105to140(0.692)	90to150(0.865)	100to130(0.691)	95to130(0.739)	90to140(0.806)	90to140(0.781)
12	105to145(0.261)	90to145(0.765)	95to140(0.785)	105to135(0.685)	110to150(0.657)	95to135(0.797)	105to135(0.678)	100to130(0.717)	90to145(0.862)	90to145(0.841)	90to140(0.818)	95to130(0.717)	90to135(0.77)
13	90to130(0.312)	95to140(0.712)	105to135(0.66)	95to140(0.805)	110to145(0.647)	100to130(0.705)	100to130(0.706)	90to150(0.872)	90to140(0.856)	90to140(0.836)	90to135(0.808)	90to135(0.795)	95to130(0.693)
14	105to140(0.249)	110to140(0.569)	90to150(0.844)	110to140(0.647)	95to135(0.78)	90to150(0.871)	90to150(0.866)	105to135(0.673)	105to150(0.666)	90to135(0.825)	100to130(0.669)	100to130(0.65)	100to130(0.628)
15	95to135(0.283)	105to135(0.586)	100to135(0.702)	90to150(0.858)	90to150(0.868)	90to145(0.864)	90to145(0.86)	90to145(0.867)	90to135(0.843)	105to150(0.634)	90to130(0.784)	105to150(0.604)	105to150(0.594)

Figure 19: 15 highest significance windows of soft drop mass using bulk graviton

rank(signalEff)	600Num	800Num	1000Num	1200Num	1400Num	1600Num	1800Num	2000Num	2500Num	3000Num	3500Num	4000Num	4500Num
1	90to140(0.275)	95to135(0.655)	95to130(0.705)	95to125(0.685)	95to125(0.691)	90to125(0.762)	90to125(0.748)	90to130(0.765)	90to125(0.74)	90to130(0.739)	90to135(0.735)	90to145(0.727)	90to145(0.714)
2	90to145(0.277)	95to130(0.632)	95to125(0.668)	95to130(0.716)	90to125(0.749)	90to130(0.781)	90to130(0.764)	90to125(0.749)	90to130(0.755)	90to135(0.745)	90to145(0.74)	90to140(0.724)	90to140(0.709)
3	95to140(0.249)	90to135(0.705)	90to130(0.75)	90to130(0.768)	90to130(0.773)	95to125(0.701)	95to125(0.69)	90to120(0.709)	90to120(0.699)	90to125(0.724)	90to140(0.738)	90to135(0.718)	90to135(0.703)
4	90to135(0.264)	90to130(0.682)	95to135(0.721)	90to125(0.737)	95to130(0.715)	90to120(0.708)	90to120(0.7)	90to135(0.77)	90to135(0.76)	90to140(0.747)	90to130(0.724)	90to130(0.705)	95to145(0.663)
5	90to150(0.279)	95to140(0.663)	90to125(0.714)	95to135(0.729)	95to120(0.634)	95to130(0.719)	95to130(0.706)	90to140(0.772)	90to140(0.762)	90to145(0.748)	90to125(0.701)	90to150(0.728)	90to130(0.686)
6	95to145(0.25)	90to140(0.714)	100to125(0.598)	90to135(0.781)	90to135(0.781)	90to135(0.787)	90to135(0.77)	95to125(0.686)	90to145(0.763)	90to150(0.749)	90to150(0.74)	95to145(0.669)	95to140(0.658)
7	95to135(0.237)	95to125(0.59)	100to130(0.634)	100to125(0.607)	90to120(0.692)	95to120(0.647)	90to140(0.774)	95to130(0.701)	95to125(0.676)	90to120(0.679)	90to120(0.652)	90to125(0.676)	90to150(0.717)
8	95to150(0.252)	100to130(0.566)	90to135(0.766)	100to130(0.638)	95to135(0.723)	90to140(0.791)	95to120(0.642)	95to120(0.646)	95to130(0.691)	95to130(0.679)	95to135(0.677)	95to140(0.666)	95to135(0.652)
9	90to130(0.249)	100to135(0.588)	95to140(0.728)	95to120(0.618)	100to125(0.612)	95to135(0.726)	95to135(0.712)	90to145(0.774)	90to150(0.764)	95to135(0.685)	95to145(0.682)	95to135(0.661)	95to130(0.635)
10	95to130(0.222)	90to145(0.719)	90to140(0.774)	90to140(0.787)	90to140(0.785)	100to125(0.62)	90to145(0.776)	95to135(0.706)	95to120(0.635)	95to125(0.663)	95to140(0.68)	95to130(0.647)	90to125(0.653)
11	90to125(0.23)	95to145(0.669)	100to135(0.65)	95to140(0.735)	100to130(0.636)	90to145(0.793)	95to140(0.715)	90to150(0.775)	95to135(0.696)	95to140(0.687)	95to130(0.667)	95to150(0.67)	95to150(0.666)
12	95to125(0.203)	90to125(0.64)	95to120(0.591)	90to120(0.67)	95to140(0.727)	100to130(0.639)	100to125(0.602)	95to140(0.709)	95to140(0.698)	95to145(0.688)	95to125(0.643)	90to120(0.619)	95to125(0.602)
13	100to140(0.207)	90to150(0.723)	95to145(0.732)	90to145(0.791)	90to145(0.789)	95to140(0.73)	100to130(0.618)	100to125(0.596)	95to145(0.699)	95to120(0.619)	95to150(0.683)	100to145(0.594)	95to120(0.54)
14	100to145(0.209)	100to125(0.523)	90to145(0.777)	100to135(0.652)	100to120(0.555)	100to120(0.566)	90to150(0.777)	100to130(0.611)	95to150(0.7)	95to150(0.689)	95to120(0.594)	100to140(0.591)	90to120(0.591)
15	100to135(0.196)	95to150(0.673)	100to140(0.657)	95to145(0.739)	95to145(0.731)	90to150(0.795)	95to145(0.718)	95to145(0.71)	90to115(0.603)	90to115(0.588)	100to135(0.593)	100to135(0.585)	100to145(0.59)

Figure 20: 15 highest significance windows of pruned jet mass using Drell-Yen

rank(signalEff)	600Eff	800Eff	1000Eff	1200Eff	1400Eff	1600Eff	1800Eff	2000Eff	2500Eff	3000Eff	3500Eff	4000Eff	4500Eff
1	90to150(0.279)	95to150(0.673)	95to150(0.736)	95to145(0.739)	95to150(0.734)	95to140(0.73)	95to145(0.718)	95to140(0.709)	95to140(0.698)	95to145(0.688)	95to145(0.682)	95to150(0.67)	95to150(0.666)
2	90to145(0.277)	95to145(0.669)	95to145(0.732)	95to150(0.742)	95to145(0.731)	95to145(0.732)	95to140(0.715)	95to145(0.71)	95to150(0.7)	95to150(0.689)	95to150(0.683)	95to145(0.669)	95to145(0.663)
3	90to140(0.275)	95to140(0.663)	95to140(0.728)	95to140(0.735)	95to140(0.727)	95to135(0.726)	95to150(0.719)	95to150(0.712)	95to145(0.699)	95to140(0.687)	95to140(0.68)	95to140(0.666)	95to140(0.658)
4	95to150(0.252)	95to135(0.655)	95to135(0.721)	95to135(0.729)	95to135(0.723)	95to150(0.734)	95to135(0.712)	95to135(0.706)	95to135(0.696)	95to135(0.685)	95to135(0.677)	95to135(0.661)	95to135(0.652)
5	95to145(0.25)	90to150(0.723)	95to130(0.705)	95to130(0.716)	95to130(0.715)	95to130(0.719)	95to130(0.706)	95to130(0.701)	95to130(0.691)	95to130(0.679)	95to130(0.667)	90to150(0.728)	90to150(0.717)
6	95to140(0.249)	90to145(0.719)	90to150(0.781)	90to150(0.794)	90to150(0.792)	90to145(0.793)	90to150(0.777)	90to150(0.775)	90to150(0.764)	90to150(0.749)	90to150(0.74)	90to145(0.727)	90to145(0.714)
7	90to135(0.264)	90to140(0.714)	90to145(0.777)	90to145(0.791)	90to145(0.789)	90to150(0.795)	90to145(0.776)	90to145(0.774)	90to145(0.763)	90to145(0.748)	90to145(0.74)	90to140(0.724)	90to140(0.709)
8	95to135(0.237)	90to135(0.705)	100to140(0.657)	90to140(0.787)	90to140(0.785)	90to140(0.791)	95to125(0.69)	90to140(0.772)	90to140(0.762)	90to140(0.747)	90to140(0.738)	95to130(0.647)	90to135(0.703)
9	90to130(0.249)	100to150(0.606)	90to140(0.774)	90to135(0.781)	90to135(0.781)	90to135(0.787)	90to140(0.774)	90to135(0.77)	90to135(0.76)	90to135(0.745)	90to135(0.735)	90to135(0.718)	100to150(0.593)
10	95to130(0.222)	100to145(0.603)	100to145(0.661)	100to145(0.661)	90to130(0.773)	95to125(0.701)	90to135(0.77)	95to125(0.686)	95to125(0.676)	90to130(0.739)	90to130(0.724)	100to150(0.595)	95to130(0.635)
11	100to150(0.211)	100to140(0.597)	100to150(0.665)	100to150(0.664)	95to125(0.691)	90to130(0.781)	90to130(0.764)	90to130(0.765)	90to130(0.755)	95to125(0.663)	95to125(0.643)	100to145(0.594)	100to145(0.59)
12	100to145(0.209)	95to130(0.632)	100to135(0.65)	100to140(0.657)	100to140(0.648)	90to125(0.762)	90to125(0.748)	90to125(0.749)	90to125(0.74)	90to125(0.724)	100to145(0.597)	100to140(0.591)	100to140(0.585)
13	100to140(0.207)	100to135(0.588)	90to135(0.766)	90to130(0.768)	100to145(0.652)	100to140(0.649)	100to135(0.625)	100to140(0.619)	100to135(0.606)	100to145(0.602)	100to140(0.596)	100to135(0.585)	100to135(0.579)
14	90to125(0.23)	90to130(0.682)	100to130(0.634)	100to135(0.652)	100to135(0.644)	100to135(0.645)	100to140(0.628)	100to145(0.621)	100to140(0.608)	100to140(0.601)	100to150(0.598)	90to130(0.705)	90to130(0.686)
15	100to135(0.196)	100to130(0.566)	90to130(0.75)	95to125(0.685)	100to150(0.655)	100to145(0.651)	100to145(0.63)	100to135(0.617)	100to145(0.609)	100to150(0.603)	100to135(0.593)	95to125(0.618)	100to130(0.562)

Figure 21: 15 highest significance windows of pruned jet mass using bulk graviton

6 Missing Transverse Energy Scanning

6.1 Introduction

The next main task is to find the dark matter particles. They can not be detected and will not leave energy in calorimeter. However, there are many other events can cause MET, missing transverse energy, like neutrino. That is the reason why we want to see events which have large MET. That means there will be large genuine MET, if such events are produced. Besides, fake MET which is produced by noise made by detector and calorimeter need filtered. Our scanning is to pick out the large MET events and to check whether it is a interesting physical event or a noise.

6.2 Noise

1. Bean-Halo: muons produced by a proton hitting the beam pipe passing CSC detector.
2. HCAL Noise: particles interacting with the light guides and photomultiplier tubes.
3. ECAL Noise: particles striking sensors.
4. ECAL Super Crystal: a crystal in ECAL having large MET
5. Cosmic: cosmic muons passing through detector.

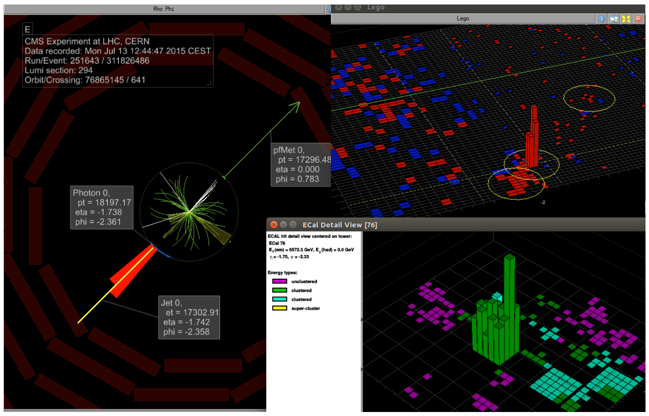
6.3 Filter

1. HBHE noise filter: HCAL noise.
2. HCAL isolation filter: isolated noisy HCAL towers.
3. CSC beam halo filter: Bean-Halo noise.
4. ECAL dead cell filter: problematic dead cell in ECAL.
5. EE super crtstal filter: ECAL Super Crystal noise.

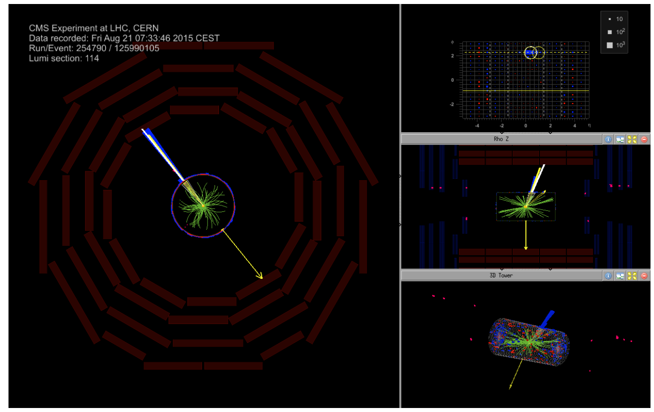
6.4 2015RunB

6.4.1 MET dataset

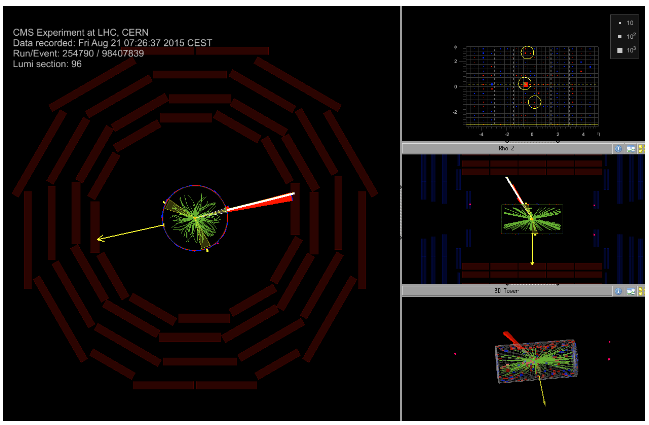
- Sample: /MET/Run2015B-PromptReco-v1/RECO
- $CMSSW\_7\_4\_6\_patch5$
- Skim : 4 T configuration from Robert.
- Three criteria to check interesting events.



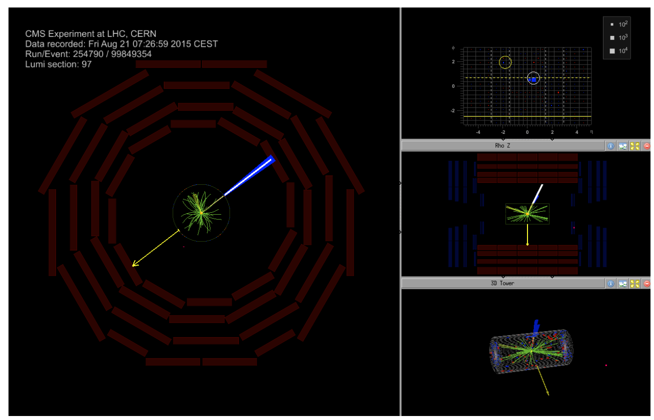
(a)



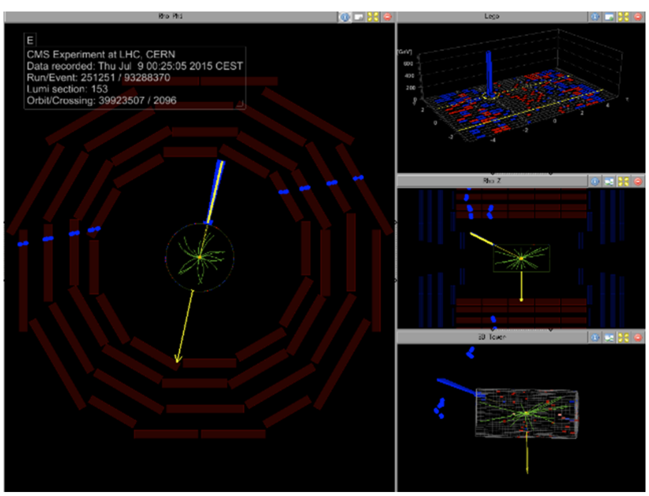
(b)



(c)



(d)



(e)

Figure 22: The Noise.(a) ECAL Super Crystal (b) Bean-Halo+HCAL (c) Bean-Halo+ECAL (d) HCAL Noise (e) Cosmic

1. PFMET > 300 GeV
2. PFMET/PFSumET > 0.6
3. CaloMET/CaloSumET > 0.7

- Selected events: one is cosmic noise, and another is HCAL noise.
- Problem of HBHE noise: very low HBHE filter efficiency shown in Table.

Filter	Number of Events
no filtered	25468
CSC	24297
HBHE	4845
both	4478

Table 9: Number of events with different filters.

6.4.2 Golden Jason

We found the ECAL Super Crystal noise for first time. EE super crtstal filter was changed from under scrutiny to be used.

6.5 2015RunC Hotline

Hotline is ready in one to two hours after collision.Most of events are CSC beam-halo.

Filter	Number of Events
No filter	1244
PV	1189
MET	952
CSC	244
HBHE	738
EEBadSc	797
ECAL dead cell	795
all	224

Table 10: The number of events passing different filters in hotline 2015RunC

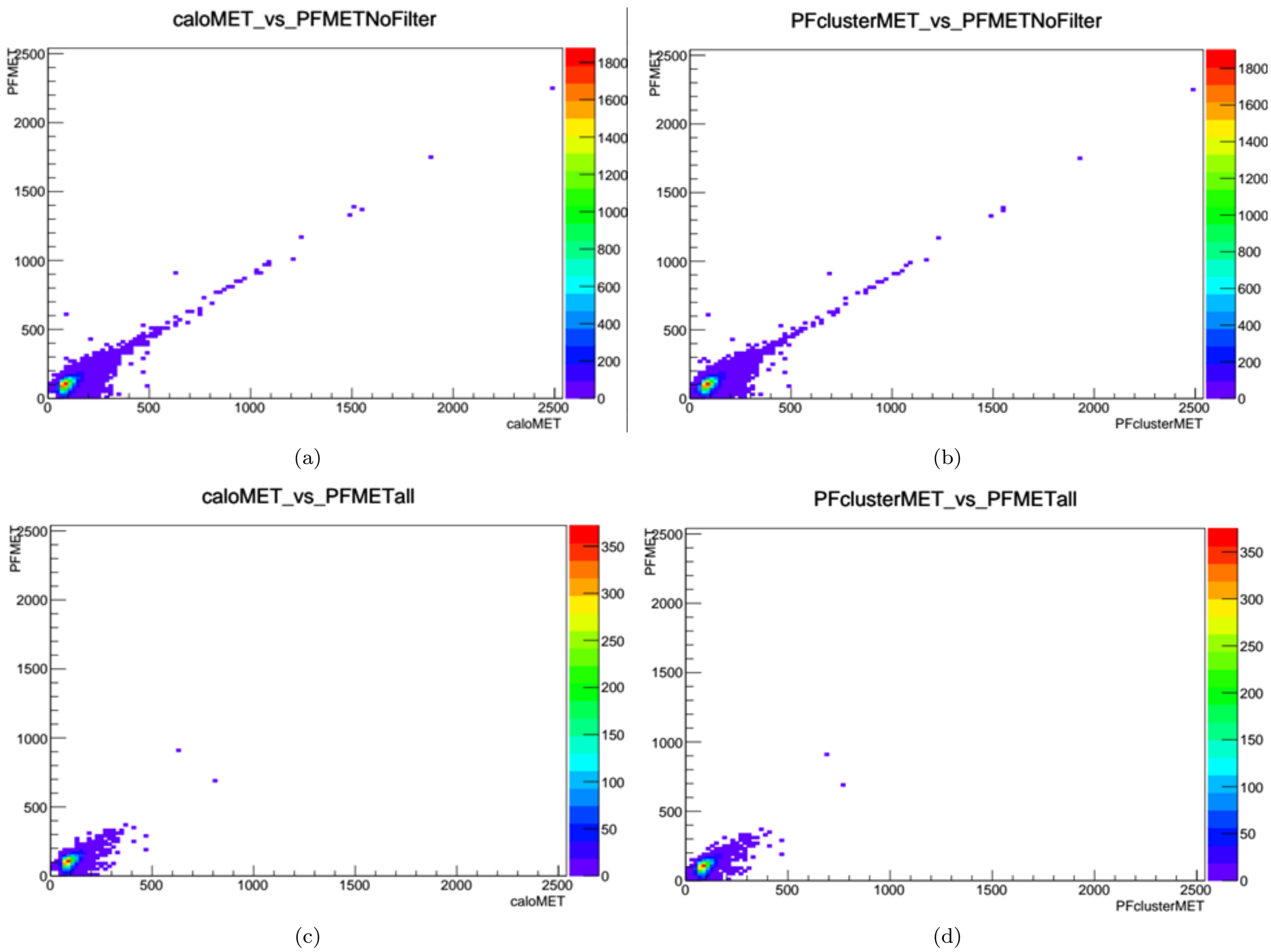
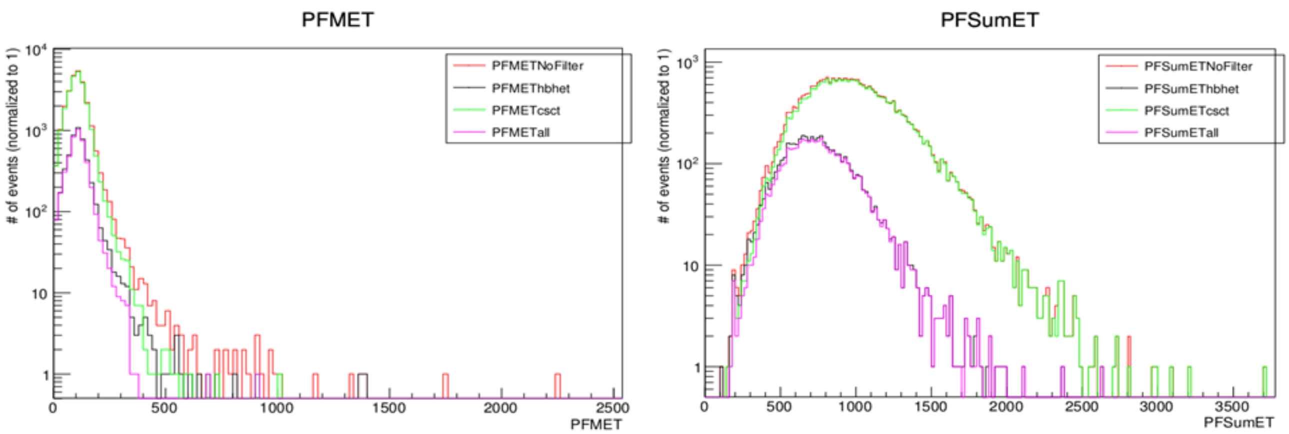
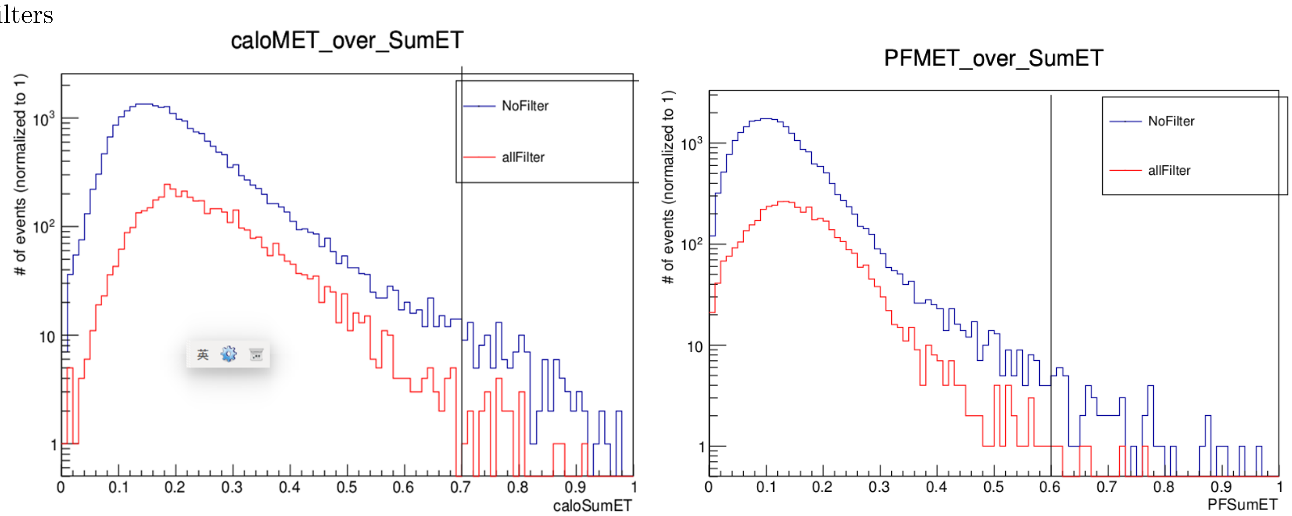


Figure 23: The MET from MET dataset 2051RunB.(a) PFMET versus caloMET, no filtered (b) PFMET versus PFclusterMET, no filtered (c) PFMET versus caloMET, passing HBHE, CSC filters (d) PFMET versus PFclusterMET, passing HBHE, CSC filters



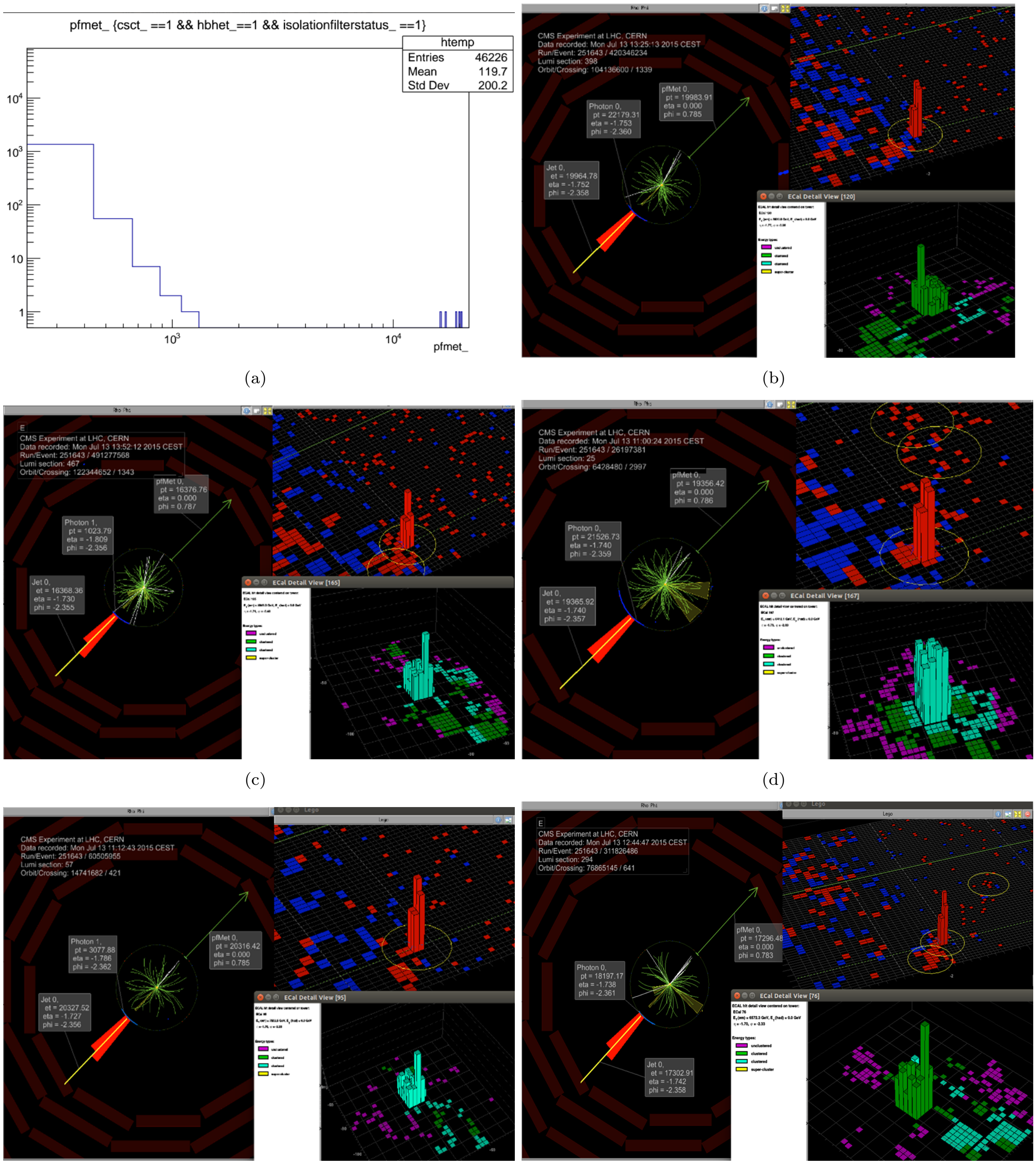
(a) (b)

Figure 24: The MET from MET dataset 2051RunB.(a) PFMET, no filtered, passing HBHE filter, passing CSC filter, and passing all filters (b) PFSumET, the scalar sum of transverse energy, no filtered, passing HBHE filter, passing CSC filter, and passing all filters



(a) (b)

Figure 25: The MET from MET dataset 2051RunB.(a) caloMET/caloSumET, no filtered, passing HBHE, CSC filters (b) PFMET/PFSumET, no filtered, passing HBHE, CSC filters

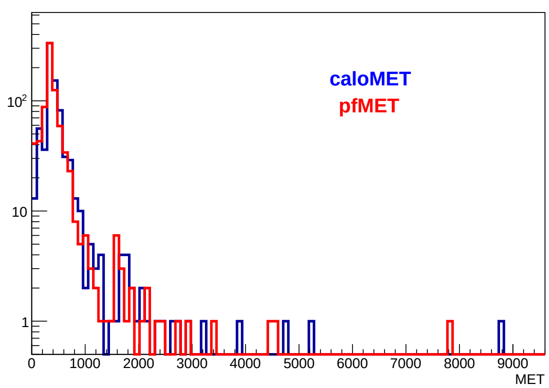


(a) (b)

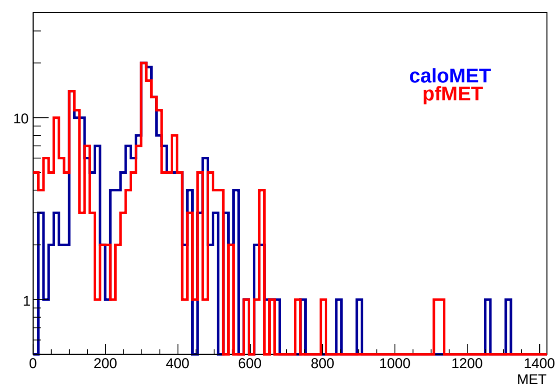
(c) (d)

(e) (f)

Figure 26: The MET from golden jason 2051RunB.(a) PFMET ,passing CSC, HBHE, HCAL isolation filters (b)-(f)Noise displays

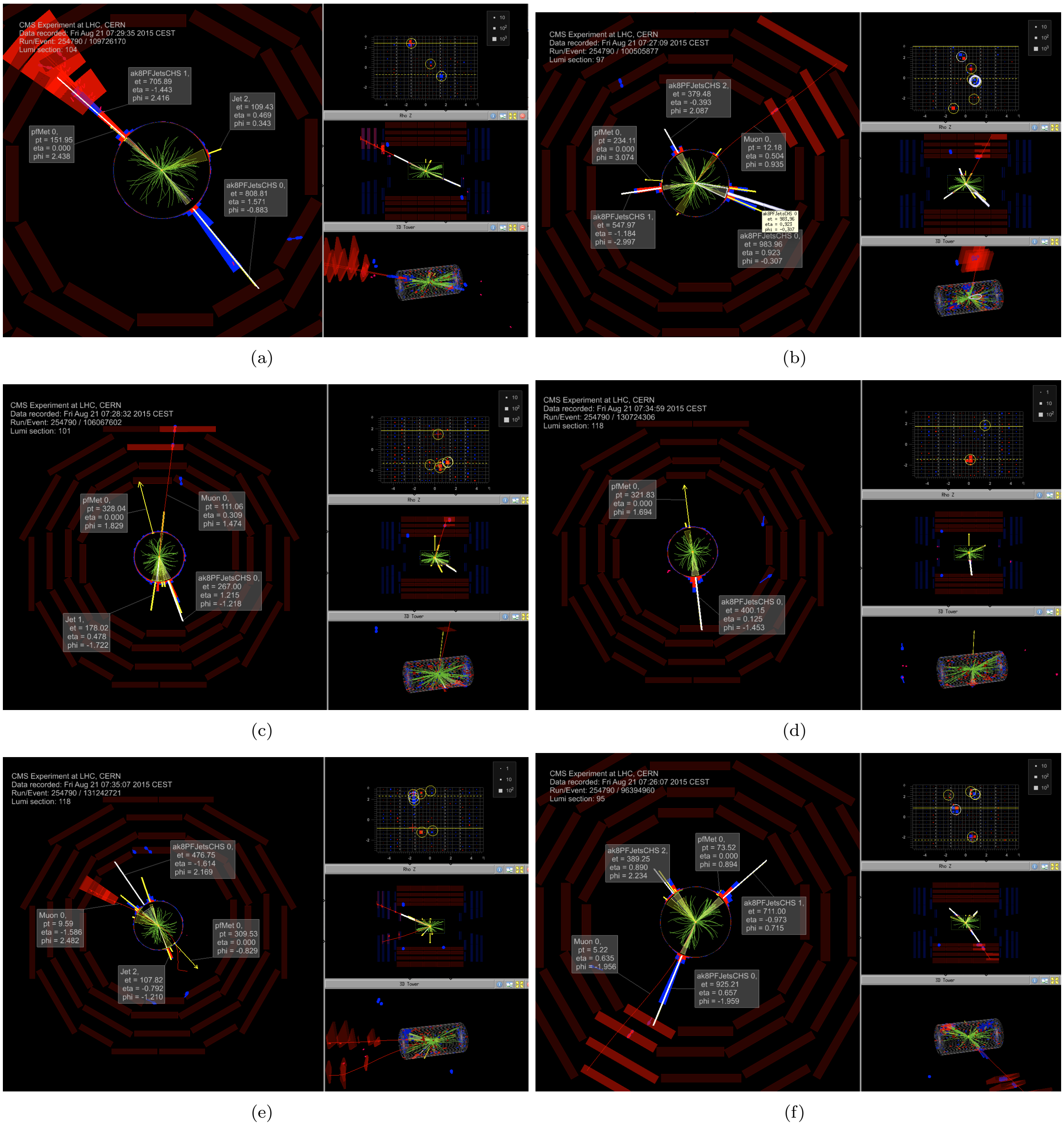


(a)



(b)

Figure 27: The MET from Hotline 2051RunC.(a) PFMET and caloMET, no filtered (b) PFMET and caloMET, passing CSC, HBHE, HCAL isolation filters



(a) (b) (c) (d) (e) (f)

Figure 28: The interseting events from Hotline 2051RunC.(a)(d)(e) di-jet (b)(c) multi-jet (f) three-jet

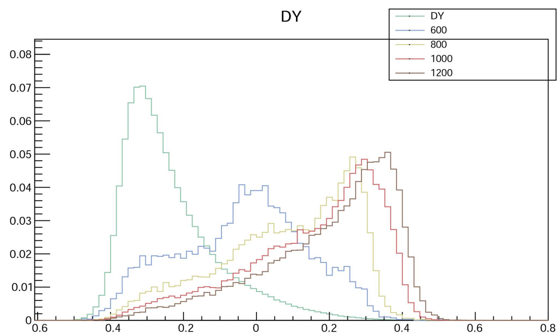
7 BDT

7.1 TMVA and BDT

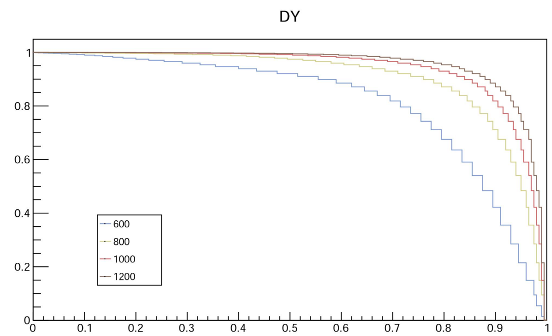
TMVA, Toolkit for Multivariate Analysis has various application designed to the needs of high-energy physics application. BDT, Boosted decision trees, is one of its application. The process is that we input samples of signal and background and parameters which can separate them. It will train with most of events in these files and give out the weight of parameters, like a linear combination. This linear combination will discriminate signal and background by giving a value from -0.8 to 0.8. The value will be closer to +0.8 if events are signal-like,and vice versa. After training, it will test with the remain event in the files which will not tell if it is a singal or background. All of it does in the testing is getting the variables of unknown event, using the weight, or linear combination, it produced in training, and giving its "BDT" value. Then, we can tell whether it is a good training by seeing if events having BDT closer to 0.8 are from signal.

7.2 BDT Training and Testing

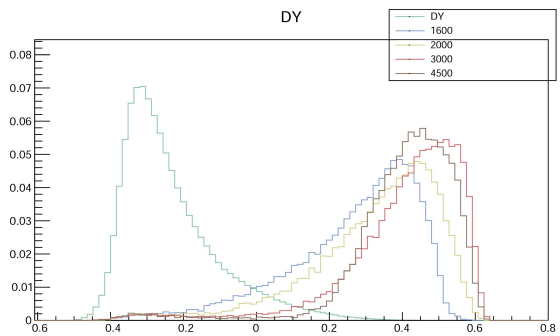
- signal: $ZprimeToZhToZlephbb_narrow_M - *_13TeV - madgraph$.
- background:
  1. $DYJetsToLL\_M - 50\_HT - 100to200\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
  2. $DYJetsToLL\_M - 50\_HT - 200to400\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
  3. $DYJetsToLL\_M - 50\_HT - 400to600\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
  4. $DYJetsToLL\_M - 50\_HT - 600toInf\_TuneCUETP8M1\_13TeV - madgraphMLM - pythia8$
- input variables:
  1. p_T of AK8-jet and sub-jet
  2. CSV of AK8-jet and sub-jet
  3. τ_1, τ_2, τ_2/τ_1
  4. ΔR of two sub-jets



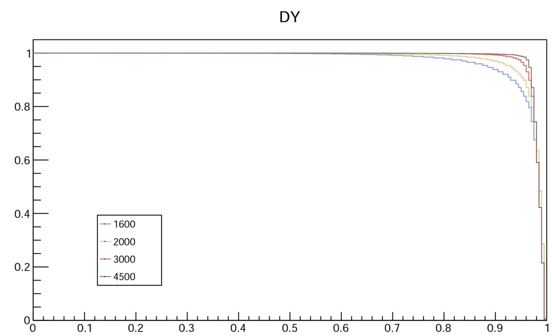
(a)



(b)



(c)



(d)

Figure 29: BDT reader results. Here I used the weight file from merged signal and DY. (a)(c) BDT values (b)(d) background rejection versus signal efficiency.

7.3 BDT Reader

A BDT reader can read the weight file. With it, we can get BDT value directly when reading files. I will compare these results with ones using CSV of AK8-jet and sub-jets shown in figure 31, 32. Here I used the weight file from merged signal and DY.

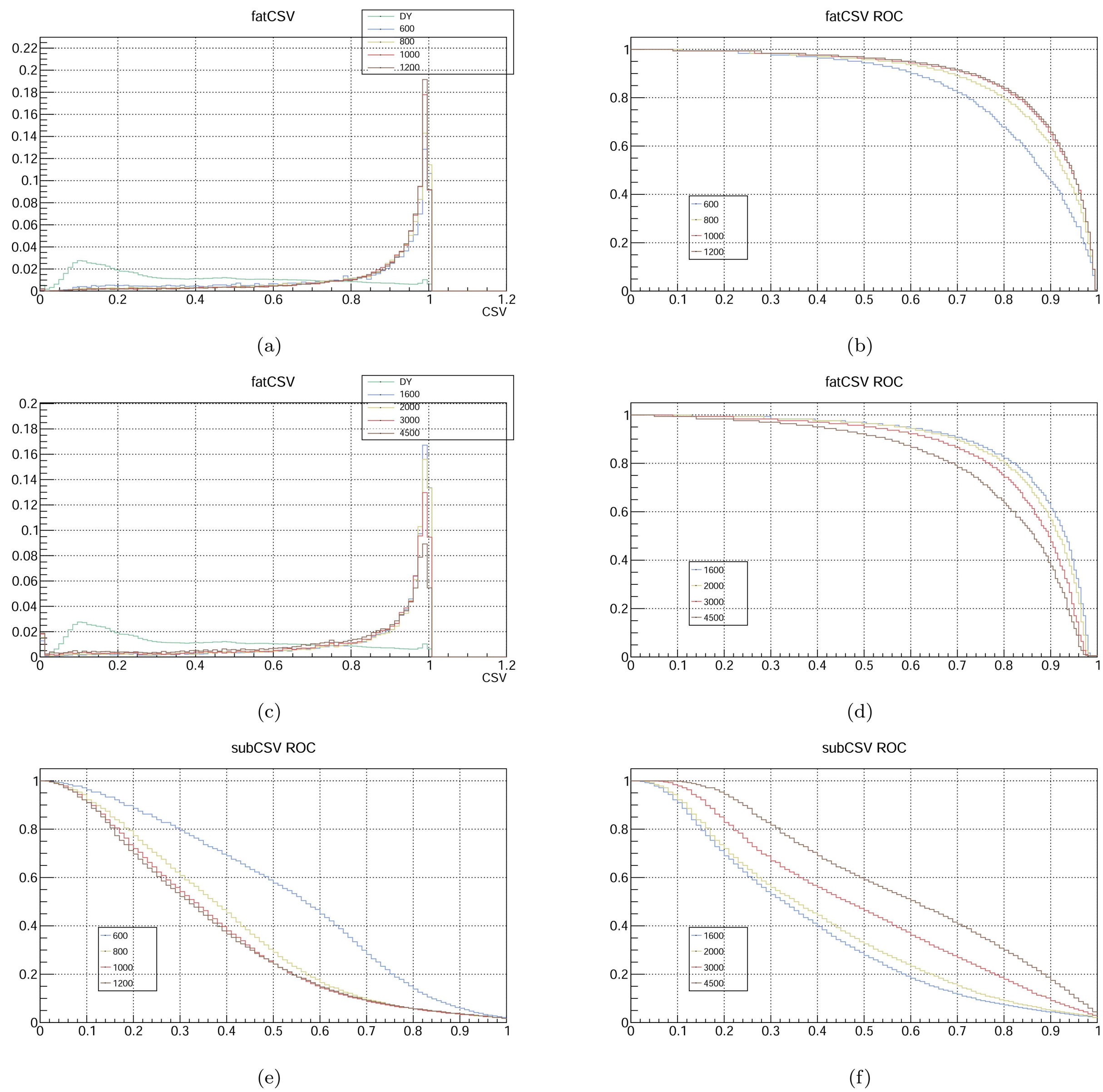
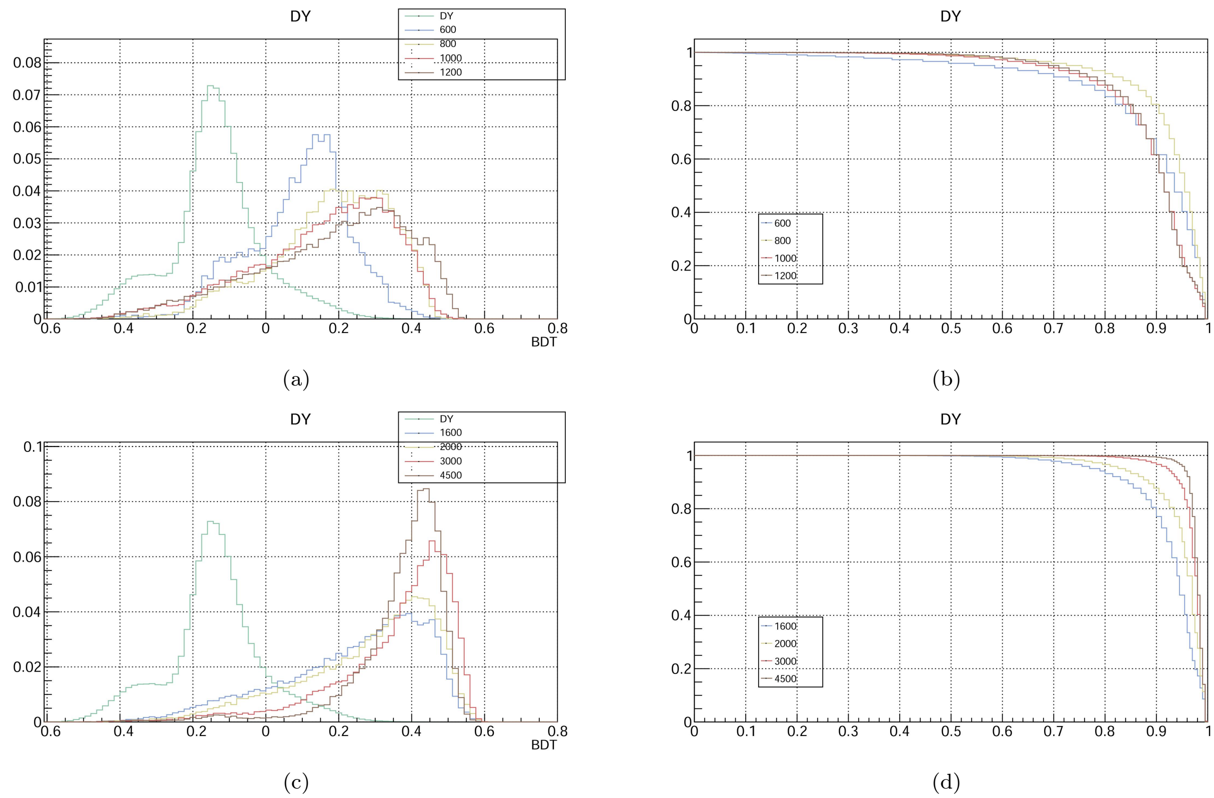


Figure 30: CSV cut results. (a)(c) CSV of AK8-jet values (b)(d) background rejection versus signal efficiency of CSV of AK8-jet. (e)(f) background rejection versus signal efficiency of CSV of sub-jets.

7.4 Separating into Two Category

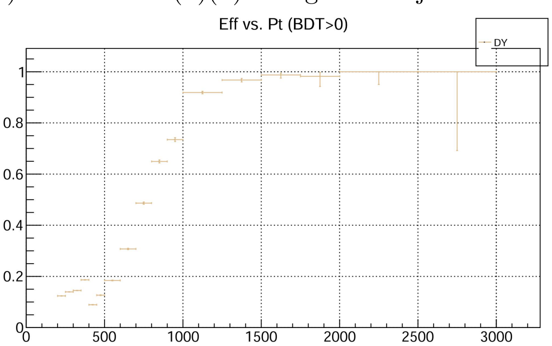
In previous section, it shows that efficiency of p_T of AK8-jet of background is increasing with p_T of AK8-jet. However, it should be flat ideally. Therefore, I separated the files into two category: p_T of AK8-jet from 200 to 400, and from 400 to infinity, trained them, and read weight files individually.The results are shown in figure 31, 32. There is little difference from old ones. This might because of the correlation of BDT and p_T of AK8-jet shown in figure 33.



(a) (b)

(c) (d)

Figure 31: BDT reader results using two category. Here I used the weight file from merged signal and DY. (a)(c) BDT values (b)(d) background rejection versus signal efficiency.



(a)

Figure 32: Efficiency of p_T of AK8-jet versus p_T of AK8-jet of background.

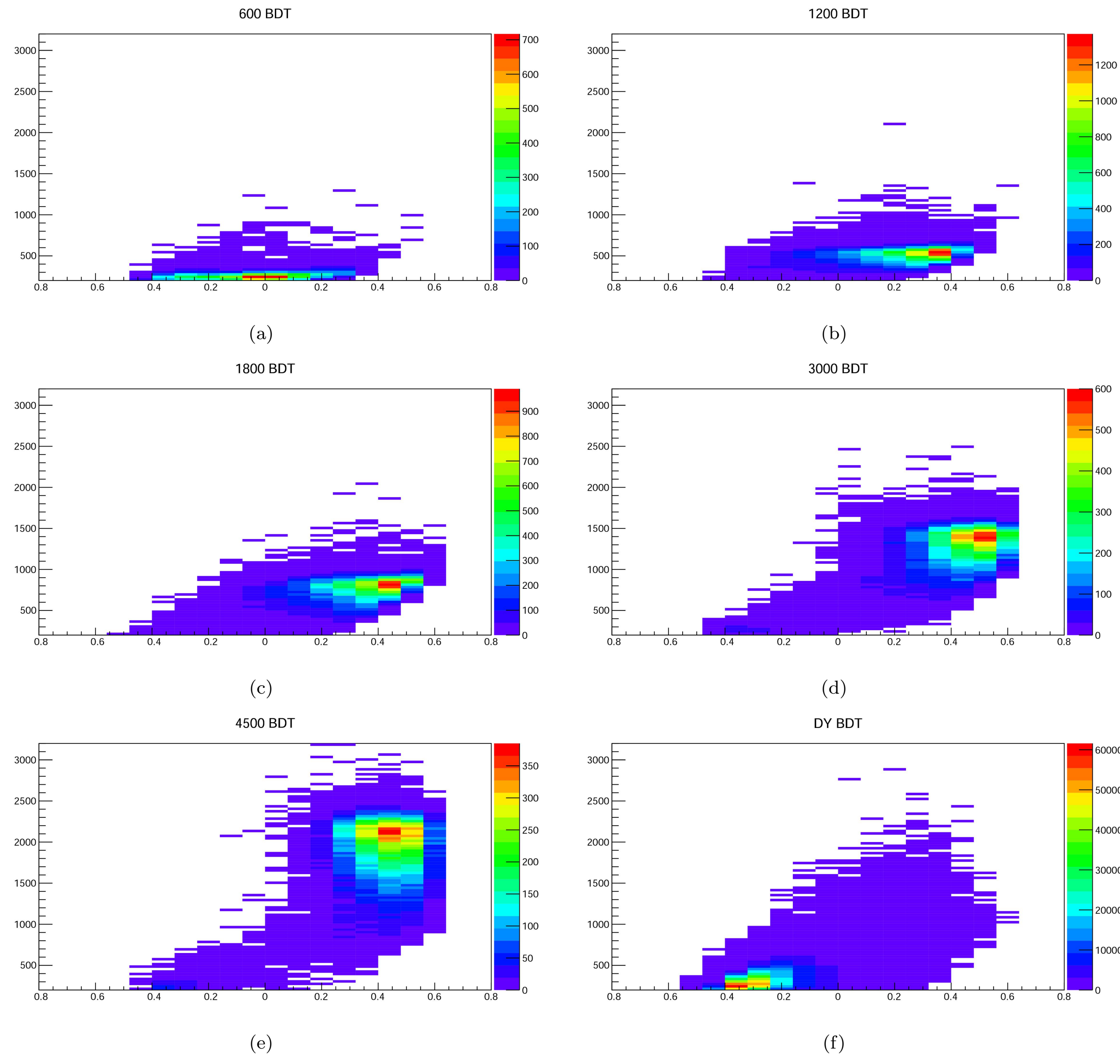


Figure 33: The p_T of AK8-jet versus BDT. (a) signal 600 GeV. (b) signal 1200 GeV. (c) signal 1800 GeV. (d) signal 3000 GeV. (e) signal 4500 GeV. (f) DY background.

7.5 Separating into various Category

After trying in two category,I tried with various category.I separate the files by p_T of AK8-jet(GeV):

1. 200-400
2. 400-600
3. 600-800
4. 800-1000
5. 1000-1200
6. 1200-infinity

Because the binning in p_T of AK8-jet(GeV). I remove the p_T of AK8-jet(GeV) and sub-jets from input variables, shown in figure 34. Their correlation matrices are in figure 35, 36. The result are in figure 36-43. We can see that the efficiency of p_T of AK8-jet(GeV) of background is mostly flat.

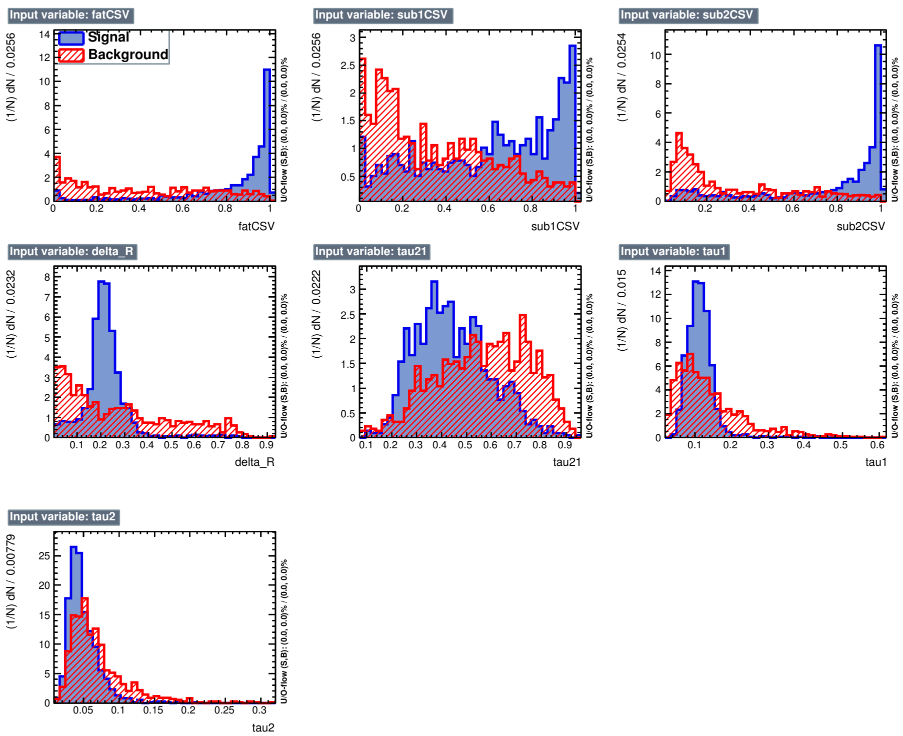


Figure 34: Input variables in BDT training(signal:Z' mass600-4500GeV, p_T of AK8-jet:1000-1200GeV).

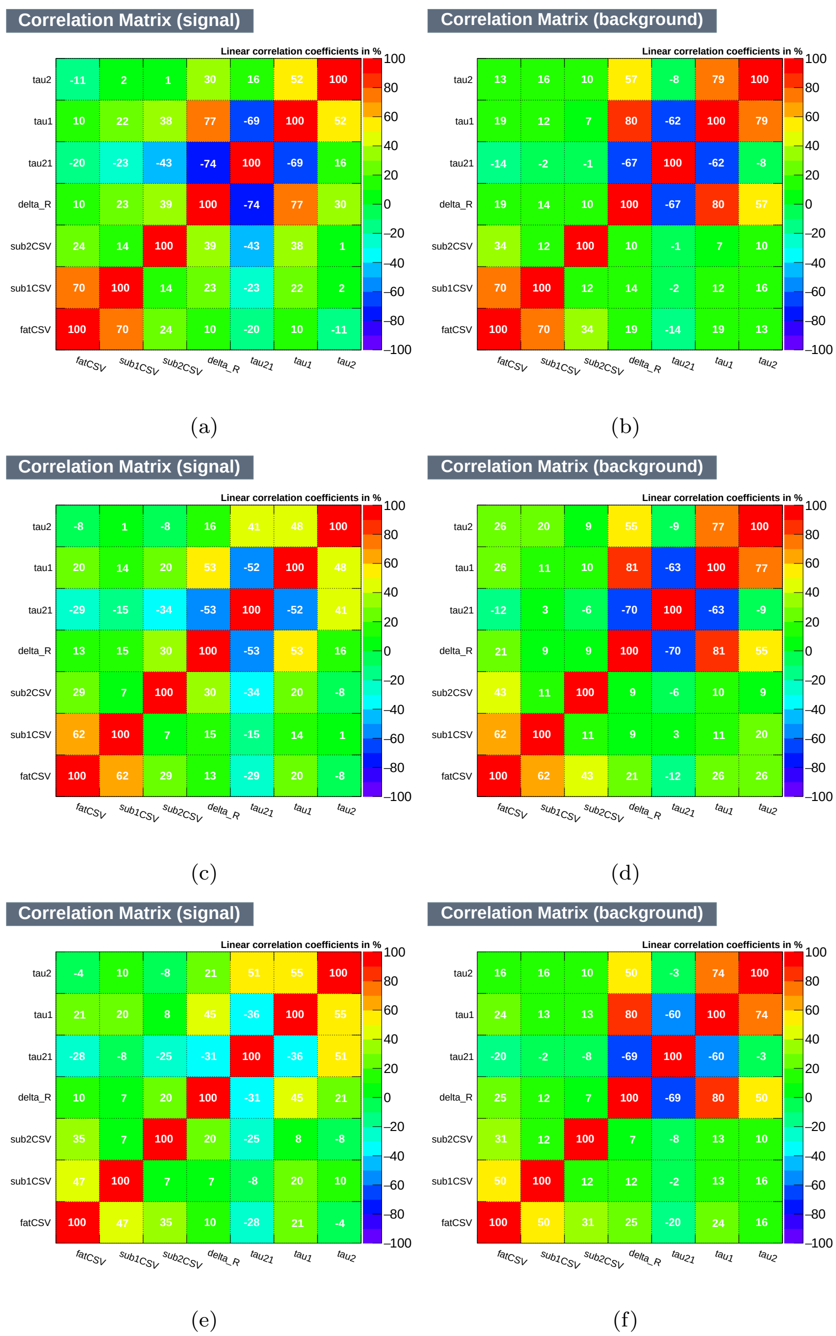


Figure 35: Correlation matrices of input variables. (a)(b)p_T of AK8-jet:200-400GeV. (c)(d)p_T of AK8-jet:400-600GeV. (e)(f)p_T of AK8-jet:600-800GeV. Signal:Z' mass600-4500GeV. Background:Drell-Yen.

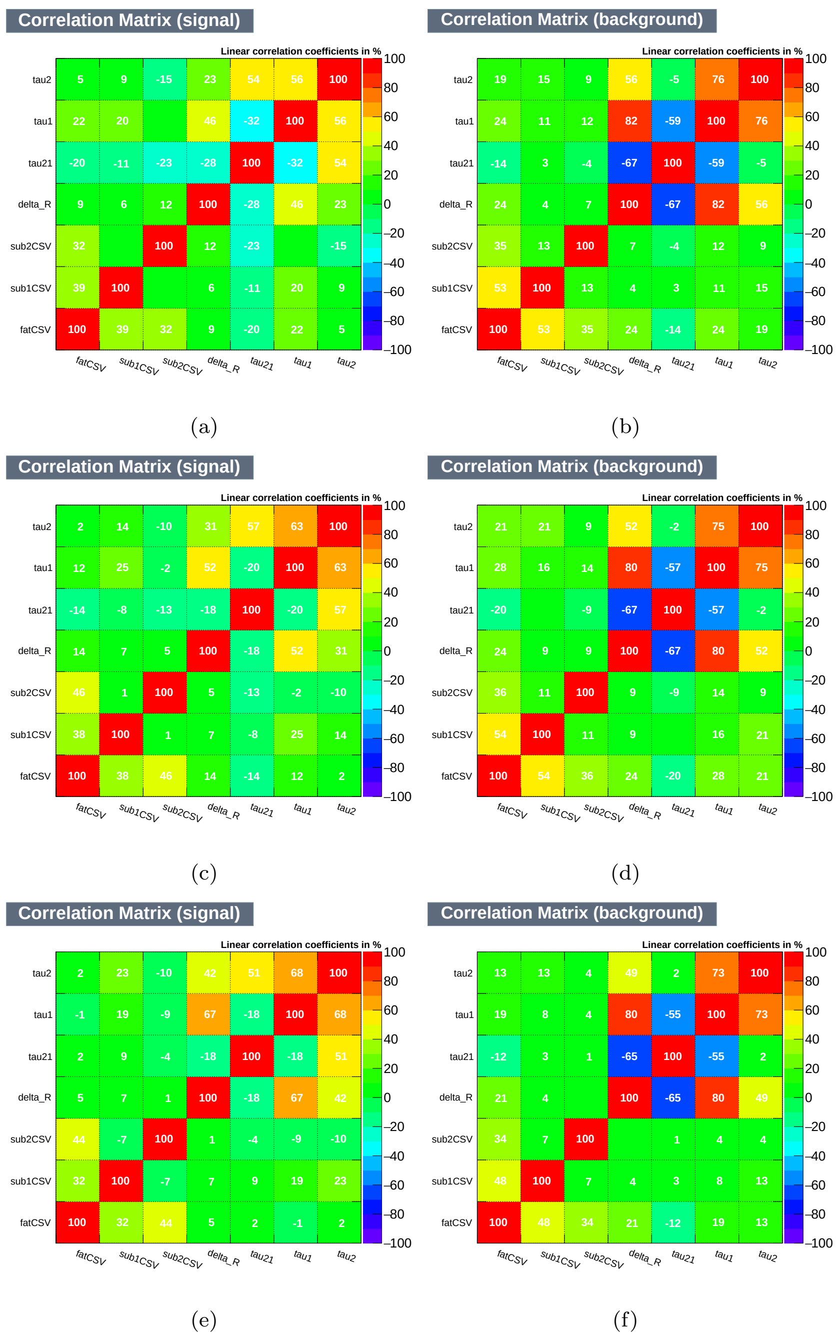
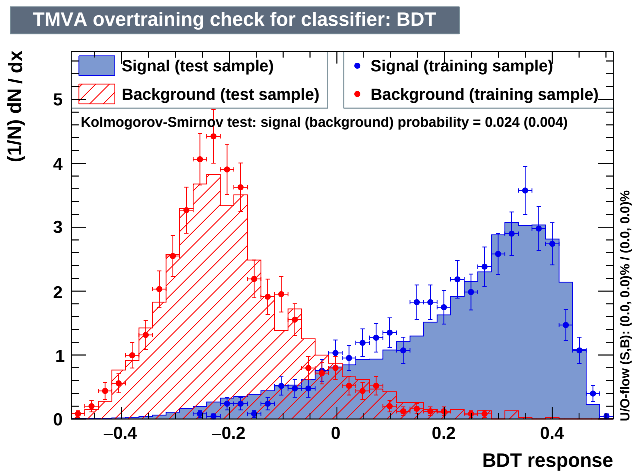
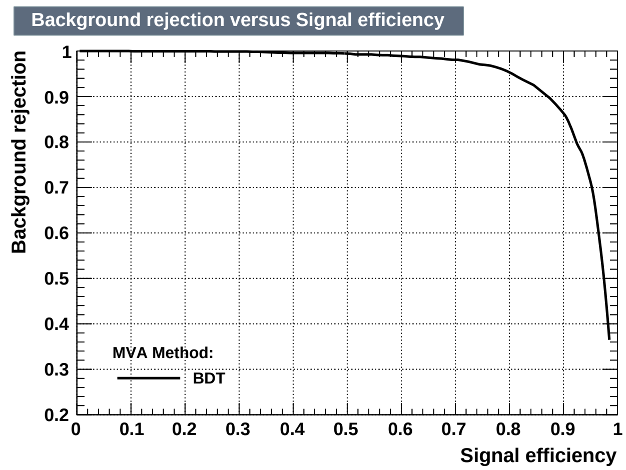


Figure 36: Correlation matrices of input variables. (a)(b)p_T of AK8-jet:800-1000GeV. (c)(d)p_T of AK8-jet:1000-1200GeV. (e)(f)p_T of AK8-jet:1200-inf.GeV. Signal:Z' mass600-4500GeV. Background:Drell-Yen.

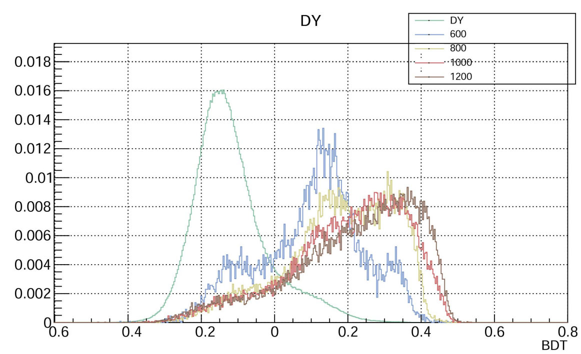


(a)

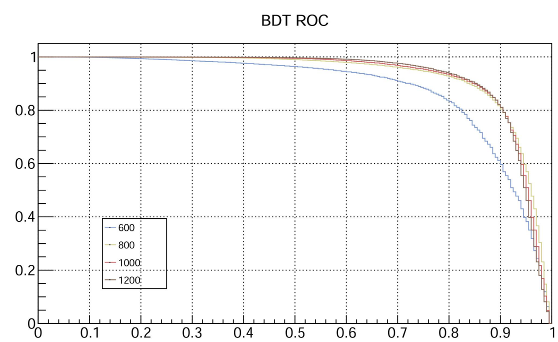


(b)

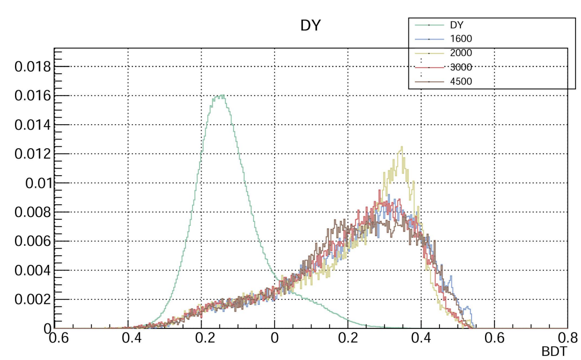
Figure 37: Training and testing result from p_T of AK8-jet:1000-1200GeV. Signal:Z' mass600-4500GeV. Background:Drell-Yen. (a)BDT value. (b)ROC curve.



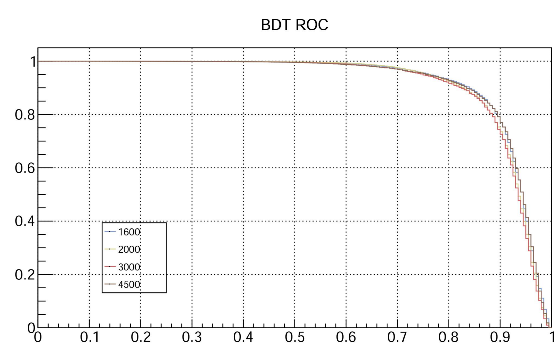
(a)



(b)



(c)



(d)

Figure 38: BDT reader results using various category. Here I used the weight file from merged signal and DY. (a)(c) BDT values (b)(d) background rejection versus signal efficiency.

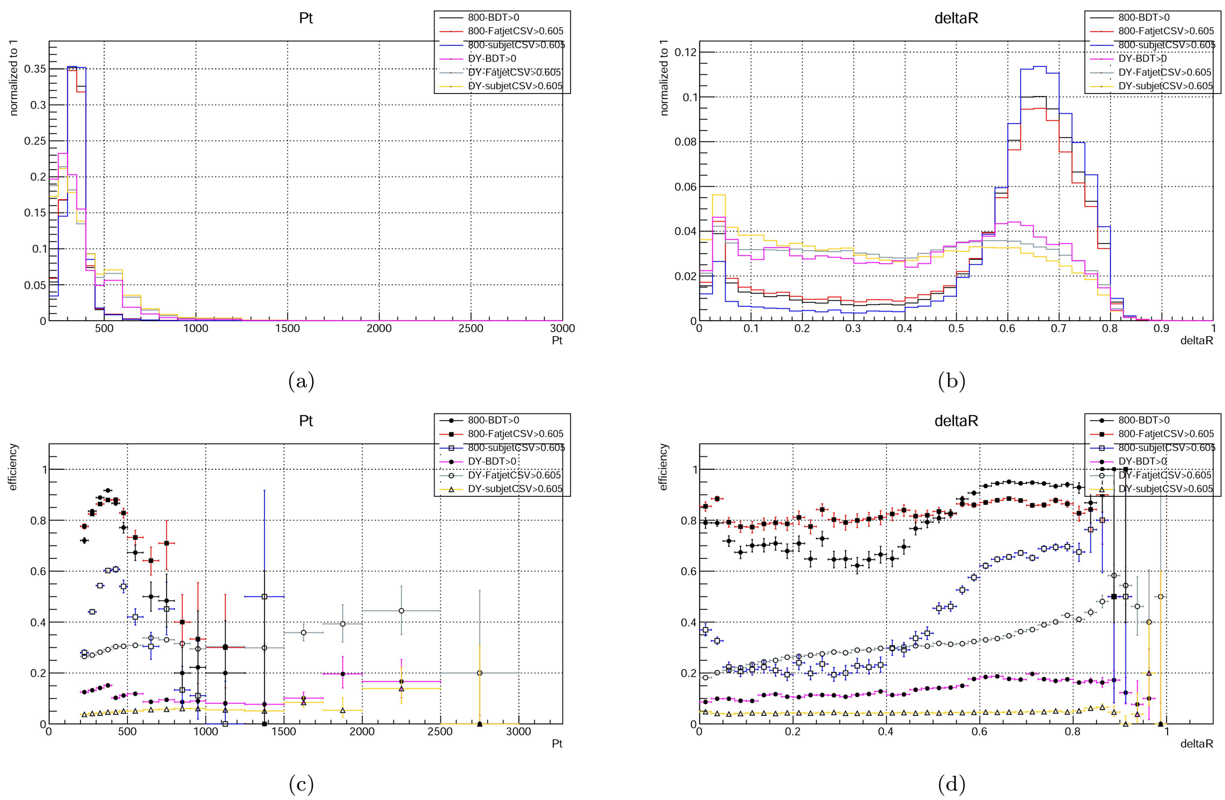
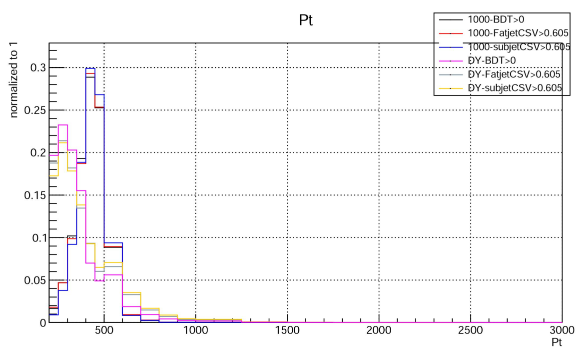
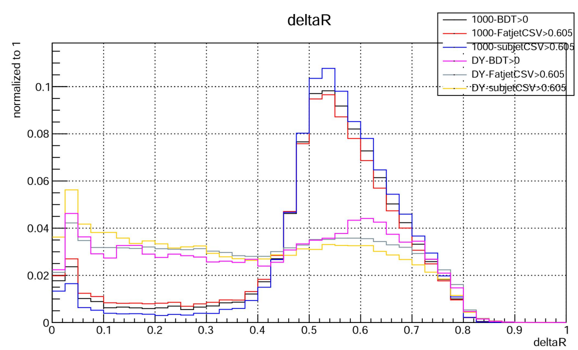


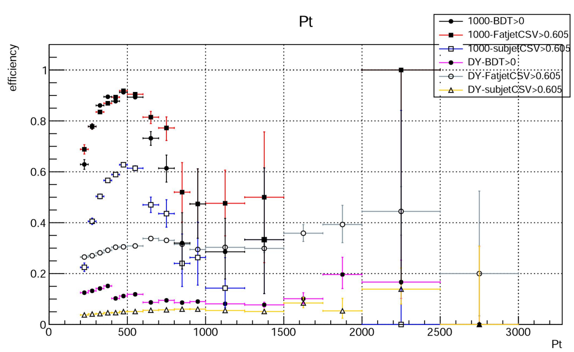
Figure 39: BDT and CSV cut results with 800 GeV signal mass point by training with various bins of p_T of AK8-jet. (a) p_T of AK8-jet. (b) ΔR of two sub-jets. (c) efficiency of (a). (d) efficiency of (b).



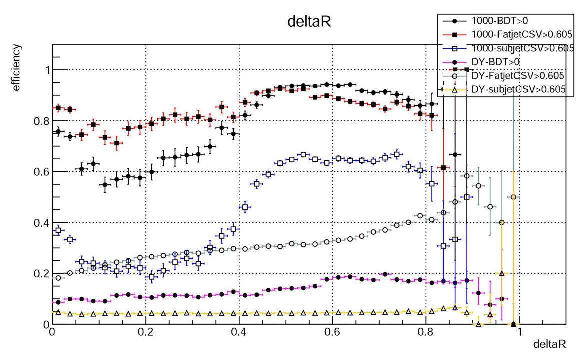
(a)



(b)

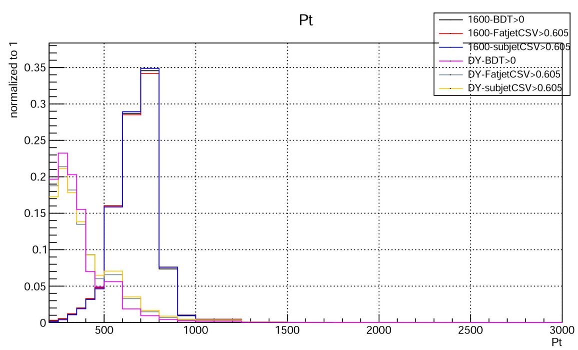


(c)

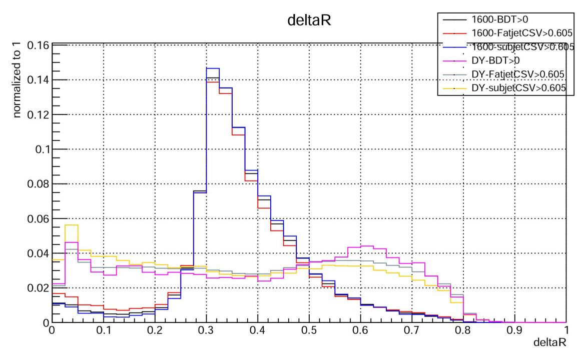


(d)

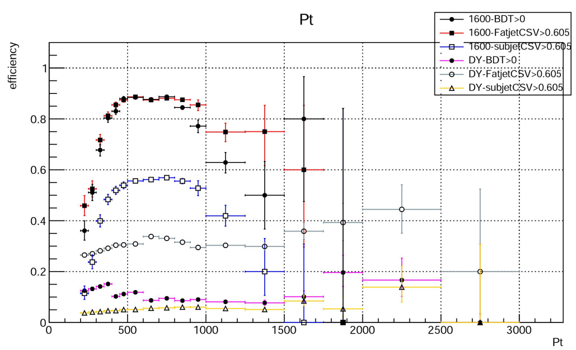
Figure 40: BDT and CSV cut results with 1000 GeV signal mass point by training with various bins of p_T of AK8-jet. (a) p_T of AK8-jet. (b) ΔR of two sub-jets. (c) efficiency of (a). (d) efficiency of (b).



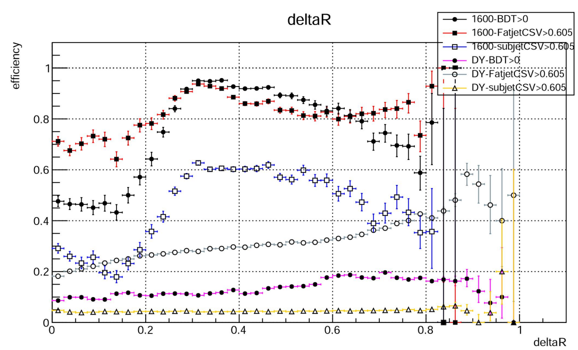
(a)



(b)



(c)



(d)

Figure 41: BDT and CSV cut results with 1600 GeV signal mass point by training with various bins of p_T of AK8-jet. (a) p_T of AK8-jet. (b) ΔR of two sub-jets. (c) efficiency of (a). (d) efficiency of (b).

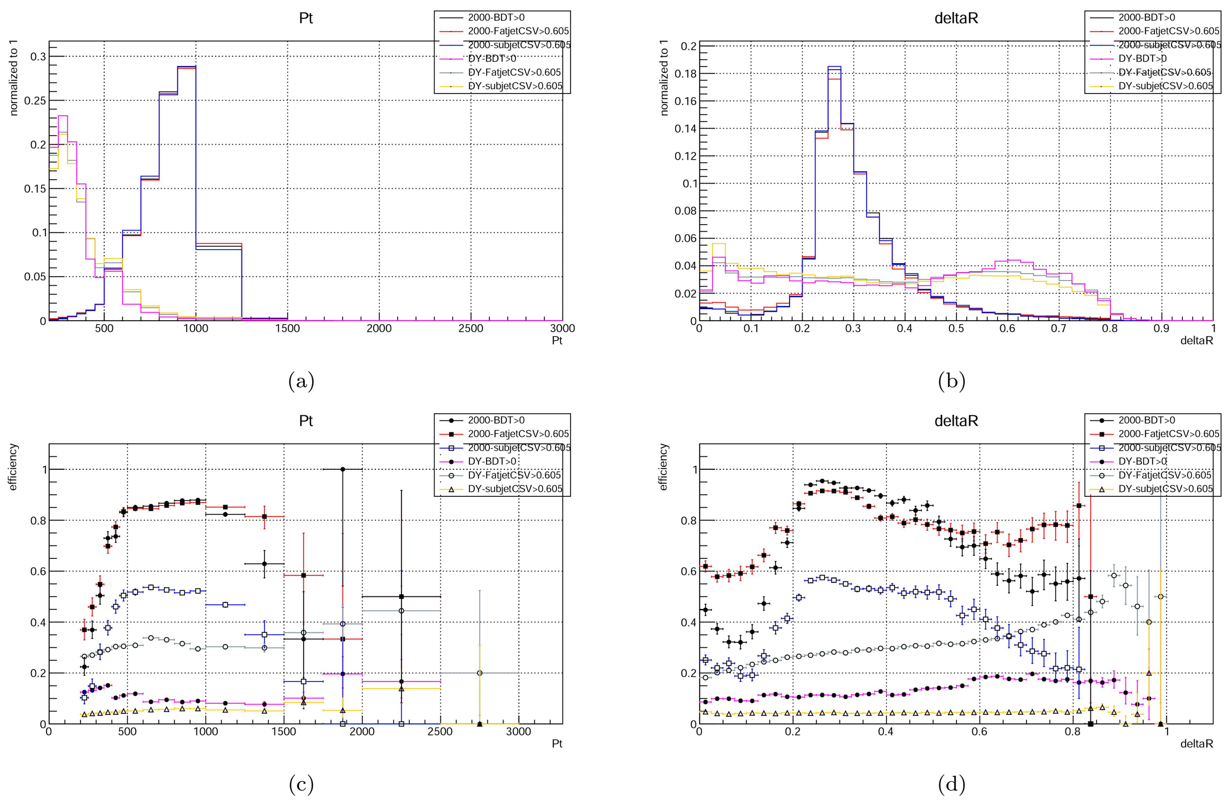
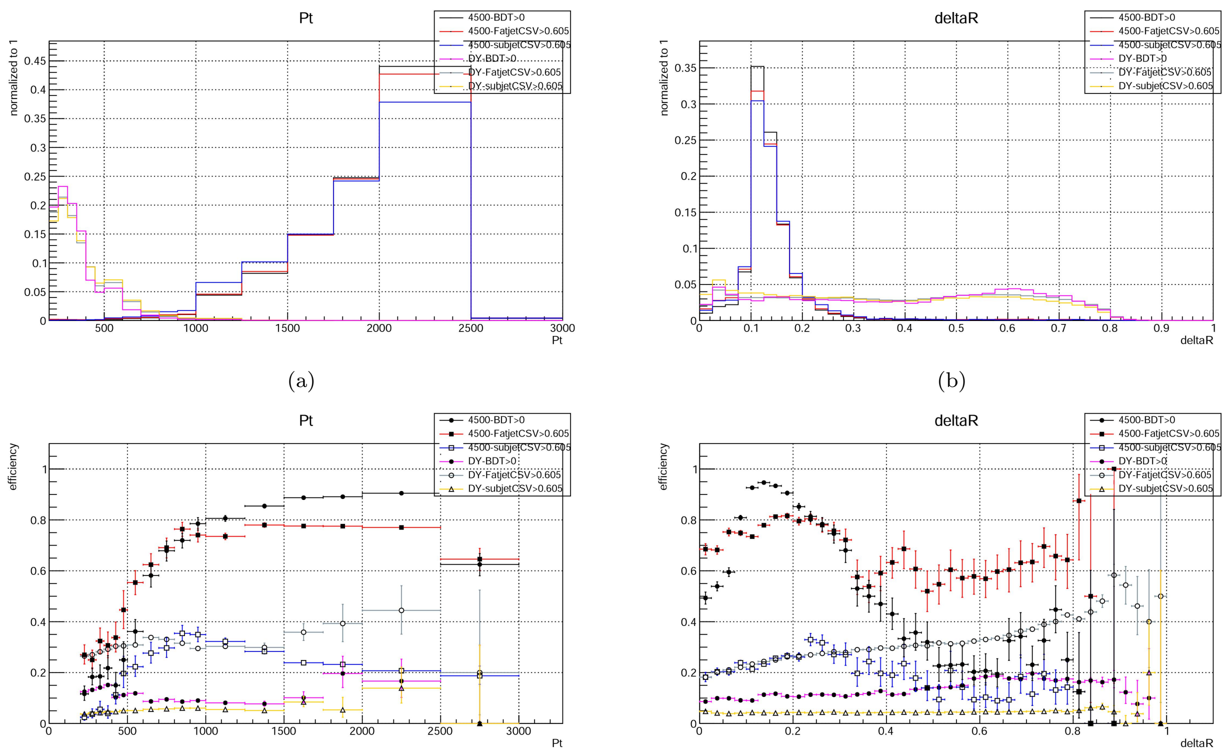


Figure 42: BDT and CSV cut results with 2000 GeV signal mass point by training with various bins of p_T of AK8-jet. (a) p_T of AK8-jet. (b) ΔR of two sub-jets. (c) efficiency of (a). (d) efficiency of (b).



(a) (b)

(c) (d)

Figure 43: BDT and CSV cut results with 4500 GeV signal mass point by training with various bins of p_T of AK8-jet. (a) p_T of AK8-jet. (b) ΔR of two sub-jets. (c) efficiency of (a). (d) efficiency of (b).

8 Future Progress

Among all the method to separate signal and background I tried, the BDT seems to have the promising result so far. I will improve the BDT result and try to solve the problem mentioned above. If it needs, we can also change input variables to those of research of dark matter particle.