

Generated by elijahsheridan on 25 March 2020, 19:53:54

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Please cite:

E. Conte, B. Fuks and G. Serret,
MadAnalysis 5, A User-Friendly Framework for Collider Phenomenology,
Comput. Phys. Commun. **184** (2013) 222-256,
arXiv:1206.1599 [hep-ph].

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1 Setup

1.1 Command history

```
ma5># set directory where running "./bin/ma5"; set lumi; define the signal significance
ma5>set main.currentdir = /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno # need to
change this directory path -> exit and type "pwd" to get the path
ma5>set main.lumi = 40.0
ma5>set main.SBratio = 'S/sqrt(S+B)'
ma5># import samples -> change the path to the LHE file
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/axion_signal/-
axion_signal_gurrola_cuts_1MeV.lhe.gz as signal
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_0_100_merged.lhe.gz as bg_vbf_0_100
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_100_200_merged.lhe.gz as bg_vbf_100_200
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_200_400_merged.lhe.gz as bg_vbf_200_400
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_400_600_merged.lhe.gz as bg_vbf_400_600
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_600_800_merged.lhe.gz as bg_vbf_600_800
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_800_1200_merged.lhe.gz as bg_vbf_800_1200
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_1200_1600_merged.lhe.gz as bg_vbf_1200_1600
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/vbf_diphoton_background_
merged_lhe/vbf_diphoton_background_ht_1600_inf_merged.lhe.gz as bg_vbf_1600_inf
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_0_100_merged.lhe.gz as bg_dip_0_100
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_100_200_merged.lhe.gz as bg_dip_100_200
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_200_400_merged.lhe.gz as bg_dip_200_400
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_400_600_merged.lhe.gz as bg_dip_400_600
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_600_800_merged.lhe.gz as bg_dip_600_800
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_800_1200_merged.lhe.gz as bg_dip_800_1200
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_1200_1600_merged.lhe.gz as bg_dip_1200_1600
ma5>import /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/madgraph_data/diphoton_double_isr_back
merged_lhe/diphoton_double_isr_background_ht_1600_inf_merged.lhe.gz as bg_dip_1600_inf
ma5># define bg and signal samples
ma5>set signal.type = signal
ma5>set bg_vbf_0_100.type = background
ma5>set bg_vbf_100_200.type = background
ma5>set bg_vbf_200_400.type = background
ma5>set bg_vbf_400_600.type = background
```

```

ma5>set bg_vbf_600_800.type = background
ma5>set bg_vbf_800_1200.type = background
ma5>set bg_vbf_1200_1600.type = background
ma5>set bg_vbf_1600_inf.type = background
ma5>set bg_dip_0_100.type = background
ma5>set bg_dip_100_200.type = background
ma5>set bg_dip_200_400.type = background
ma5>set bg_dip_400_600.type = background
ma5>set bg_dip_600_800.type = background
ma5>set bg_dip_800_1200.type = background
ma5>set bg_dip_1200_1600.type = background
ma5>set bg_dip_1600_inf.type = background
ma5># define weights for the samples
ma5>#set sample_1.weight = 1
ma5>#set sample_2.weight = 1
ma5># line styles and colors
ma5>set signal.linecolor = red
ma5>set signal.linestyle = dashed
ma5>set signal.linewidth = 3
ma5>set bg_vbf_0_100.linecolor = blue-4
ma5>set bg_vbf_0_100.linestyle = dash-dotted
ma5>set bg_vbf_0_100.linewidth = 4
ma5>set bg_vbf_100_200.linecolor = blue-3
ma5>set bg_vbf_100_200.linestyle = dash-dotted
ma5>set bg_vbf_100_200.linewidth = 4
ma5>set bg_vbf_200_400.linecolor = blue-2
ma5>set bg_vbf_200_400.linestyle = dash-dotted
ma5>set bg_vbf_200_400.linewidth = 4
ma5>set bg_vbf_400_600.linecolor = blue-1
ma5>set bg_vbf_400_600.linestyle = dash-dotted
ma5>set bg_vbf_400_600.linewidth = 4
ma5>set bg_vbf_600_800.linecolor = blue
ma5>set bg_vbf_600_800.linestyle = dash-dotted
ma5>set bg_vbf_600_800.linewidth = 4
ma5>set bg_vbf_800_1200.linecolor = blue+1
ma5>set bg_vbf_800_1200.linestyle = dash-dotted
ma5>set bg_vbf_800_1200.linewidth = 4
ma5>set bg_vbf_1200_1600.linecolor = blue+2
ma5>set bg_vbf_1200_1600.linestyle = dash-dotted
ma5>set bg_vbf_1200_1600.linewidth = 4
ma5>set bg_vbf_1600_inf.linecolor = blue+3
ma5>set bg_vbf_1600_inf.linestyle = dash-dotted
ma5>set bg_vbf_1600_inf.linewidth = 4
ma5>set bg_dip_0_100.linecolor = green-4
ma5>set bg_dip_0_100.linestyle = dash-dotted
ma5>set bg_dip_0_100.linewidth = 4
ma5>set bg_dip_100_200.linecolor = green-3
ma5>set bg_dip_100_200.linestyle = dash-dotted
ma5>set bg_dip_100_200.linewidth = 4

```

```

ma5>set bg_dip_200_400.linecolor = green-2
ma5>set bg_dip_200_400.linestyle = dash-dotted
ma5>set bg_dip_200_400.linewidth = 4
ma5>set bg_dip_400_600.linecolor = green-1
ma5>set bg_dip_400_600.linestyle = dash-dotted
ma5>set bg_dip_400_600.linewidth = 4
ma5>set bg_dip_600_800.linecolor = green
ma5>set bg_dip_600_800.linestyle = dash-dotted
ma5>set bg_dip_600_800.linewidth = 4
ma5>set bg_dip_800_1200.linecolor = green+1
ma5>set bg_dip_800_1200.linestyle = dash-dotted
ma5>set bg_dip_800_1200.linewidth = 4
ma5>set bg_dip_1200_1600.linecolor = green+2
ma5>set bg_dip_1200_1600.linestyle = dash-dotted
ma5>set bg_dip_1200_1600.linewidth = 4
ma5>set bg_dip_1600_inf.linecolor = green+3
ma5>set bg_dip_1600_inf.linestyle = dash-dotted
ma5>set bg_dip_1600_inf.linewidth = 4
ma5># a jet can be from a light quark or b quark
ma5>define jets = j
ma5>define e = e+ e-
ma5>define mu = mu+ mu-
ma5>define ta = ta+ ta-
ma5>define lept = e mu ta
ma5>define Zprime = 32 -32
ma5># reduce contribution from V+Zp ==> jj+Zpz
ma5>select M(jets[1] jets[2]) > 120
ma5># define which plots to make
ma5>plot PT(jets[1])
ma5>plot ETA(jets[1])
ma5>plot PHI(jets[1])
ma5>plot PT(jets[2])
ma5>plot ETA(jets[2])
ma5>plot PHI(jets[2])
ma5>plot DELTAR(jets[1], jets[2])
ma5>plot M(jets[1] jets[2])
ma5>plot MET
ma5>plot sdETA(jets[1] jets[2])
ma5>plot M(a[1] a[2])
ma5>plot PT(a[1])
ma5>plot PT(a[2])
ma5>plot THT
ma5>plot MET
ma5>plot TET
ma5>#set the plot/graph parameters
ma5>set selection[2].xmax = 1000
ma5>set selection[2].xmin = 0
ma5>set selection[2].nbins = 200
ma5>set selection[2].logY = true

```

```

ma5>set selection[2].logX = false
ma5>set selection[2].rank = PTordering
ma5>#set selection[2].stacking_method = normalize2one
ma5>set selection[2].titleX = "p_{T}[j_{1}] (GeV)"
ma5>set selection[3].xmax = 8
ma5>set selection[3].xmin = -8
ma5>set selection[3].nbins = 160
ma5>set selection[3].logY = false
ma5>set selection[3].logX = false
ma5>set selection[3].rank = PTordering
ma5>#set selection[3].stacking_method = normalize2one
ma5>set selection[3].titleX = "#eta[j_{1}]"
ma5>set selection[4].xmax = 3.2
ma5>set selection[4].xmin = -3.2
ma5>set selection[4].nbins = 64
ma5>set selection[4].logY = false
ma5>set selection[4].logX = false
ma5>set selection[4].rank = PTordering
ma5>#set selection[4].stacking_method = normalize2one
ma5>set selection[4].titleX = "#phi[j_{1}]"
ma5>set selection[5].xmax = 500
ma5>set selection[5].xmin = 0
ma5>set selection[5].nbins = 100
ma5>set selection[5].logY = true
ma5>set selection[5].logX = false
ma5>set selection[5].rank = PTordering
ma5>#set selection[5].stacking_method = normalize2one
ma5>set selection[5].titleX = "p_{T}[j_{2}] (GeV)"
ma5>set selection[6].xmax = 8
ma5>set selection[6].xmin = -8
ma5>set selection[6].nbins = 160
ma5>set selection[6].logY = false
ma5>set selection[6].logX = false
ma5>set selection[6].rank = PTordering
ma5>#set selection[6].stacking_method = normalize2one
ma5>set selection[6].titleX = "#eta[j_{2}]"
ma5>set selection[7].xmax = 3.2
ma5>set selection[7].xmin = -3.2
ma5>set selection[7].nbins = 64
ma5>set selection[7].logY = false
ma5>set selection[7].logX = false
ma5>set selection[7].rank = PTordering
ma5>#set selection[7].stacking_method = normalize2one
ma5>set selection[7].titleX = "#phi[j_{2}]"
ma5>set selection[8].xmax = 15
ma5>set selection[8].xmin = 0
ma5>set selection[8].nbins = 75
ma5>set selection[8].logY = false
ma5>set selection[8].logX = false

```

```

ma5>set selection[8].rank = PTordering
ma5>#set selection[8].stacking_method = normalize2one
ma5>set selection[8].titleX = "#DeltaR[j_{1},j_{2}]"
ma5>set selection[9].xmax = 8000
ma5>set selection[9].xmin = 0
ma5>set selection[9].nbins = 160
ma5>set selection[9].logY = false
ma5>set selection[9].logX = false
ma5>set selection[9].rank = PTordering
ma5>#set selection[9].stacking_method = normalize2one
ma5>set selection[9].titleX = "M[j_{1},j_{2}] (GeV)"
ma5>set selection[10].xmax = 1000
ma5>set selection[10].xmin = 0
ma5>set selection[10].nbins = 100
ma5>set selection[10].logY = true
ma5>set selection[10].logX = false
ma5>set selection[10].rank = PTordering
ma5>#set selection[10].stacking_method = normalize2one
ma5>set selection[10].titleX = "#slash{E}_{T} (GeV)"
ma5>#set selection[11].stacking_method = normalize2one
ma5>set selection[11].titleX = "#Delta#eta(j_{1},j_{2})"
ma5>#set selection[12].xmax = 2000
ma5>#set selection[12].xmin = 0
ma5>set selection[12].nbins = 400
ma5>set selection[12].logY = true
ma5>set selection[12].logX = false
ma5>set selection[12].rank = PTordering
ma5>#set selection[12].stacking_method = normalize2one
ma5>set selection[12].titleX = "M[a_{1},a_{2}] (GeV)"
ma5>#set selection[13].xmax = 4
ma5>#set selection[13].xmin = -4
ma5>set selection[13].nbins = 80
ma5>set selection[13].logY = false
ma5>set selection[13].logX = false
ma5>set selection[13].rank = PTordering
ma5>#set selection[13].stacking_method = normalize2one
ma5>set selection[13].titleX = "p_{T}[a_{1}]"
ma5>#set selection[14].xmax = 2000
ma5>#set selection[14].xmin = 0
ma5>set selection[14].nbins = 400
ma5>set selection[14].logY = true
ma5>set selection[14].logX = false
ma5>set selection[14].rank = PTordering
ma5>#set selection[14].stacking_method = normalize2one
ma5>set selection[14].titleX = "p_{T}[a_{2}] (GeV)"
ma5>#set selection[15].xmax = 4
ma5>#set selection[15].xmin = -4
ma5>set selection[15].nbins = 80
ma5>set selection[15].logY = false

```



```

ma5>set selection[15].logX = false
ma5>set selection[15].rank = PTordering
ma5>#set selection[15].stacking_method = normalize2one
ma5>set selection[15].titleX = "THT"
ma5>#set selection[16].xmax = 1000
ma5>#set selection[16].xmin = 0
ma5>set selection[16].nbins = 200
ma5>set selection[16].logY = true
ma5>set selection[16].logX = false
ma5>set selection[16].rank = PTordering
ma5>#set selection[16].stacking_method = normalize2one
ma5>set selection[16].titleX = "MET"
ma5>#set selection[17].xmax = 4
ma5>#set selection[17].xmin = -4
ma5>set selection[17].nbins = 80
ma5>set selection[17].logY = false
ma5>set selection[17].logX = false
ma5>set selection[17].rank = PTordering
ma5>#set selection[17].stacking_method = normalize2one
ma5>set selection[17].titleX = "TET"
ma5># apply selections
ma5>select (sdETA(jets[1] jets[2]) > 4.6 or sdETA(jets[1] jets[2]) < -4.6) and M(jets[1]
jets[2]) > 500
ma5>submit analysis_deltaeta4.6_mmjj_500

```

1.2 Configuration

- MadAnalysis version 1.6.33 (2017/11/20).
- Histograms given for an integrated luminosity of 40.0fb^{-1} .

2 Datasets

2.1 signal

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [signal](#) events.
- Generated events: [1000000](#) events.
- Normalization to the luminosity: [4094+/- 2](#) events.
- Ratio (event weight): [0.0041](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/-madgraph_data/axion_signal/-axion_signal_gurrola_cuts_1MeV.lh | 1000000 | 0.102 @ 0.028% | 0.0 |

2.2 bg_vbf_0_100

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1000000](#) events.
- Normalization to the luminosity: [12150+/- 24](#) events.
- Ratio (event weight): [0.012](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/madgraph_data/-vbf_diphoton_background_data/-merged_lhe/-vbf_diphoton_background_ht_0_100 | 1000000 | 0.304 @ 0.19% | 0.0 |

2.3 bg_vbf_100_200

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [965662](#) events.

- Normalization to the luminosity: 9695 \pm 17 events.
- Ratio (event weight): 0.01 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- vbf_diphoton_background_data/- merged_lhe/- vbf_diphoton_background_ht_100_ | 965662 | 0.242 @ 0.17% | 0.0 |

2.4 bg_vbf_200_400

- Samples stored in the directory: /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-
optimization .
- Sample consisting of: background events.
- Generated events: 984165 events.
- Normalization to the luminosity: 5413 \pm 11 events.
- Ratio (event weight): 0.0055 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- vbf_diphoton_background_data/- merged_lhe/- vbf_diphoton_background_ht_200_ | 984165 | 0.135 @ 0.2% | 0.0 |

2.5 bg_vbf_400_600

- Samples stored in the directory: /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-
optimization .
- Sample consisting of: background events.
- Generated events: 1000000 events.
- Normalization to the luminosity: 986 \pm 2 events.
- Ratio (event weight): 0.00099 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- vbf_diphoton_background_data/- merged_lhe/- vbf_diphoton_background_ht_400_ | 1000000 | 0.0247 @ 0.14% | 0.0 |

2.6 bg_vbf_600_800

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1000000](#) events.
- Normalization to the luminosity: [252+/- 1](#) events.
- Ratio (event weight): [0.00025](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- vbf_diphoton_background_data/- merged_lhe/- vbf_diphoton_background_ht_600_ | 1000000 | 0.0063 @ 0.13% | 0.0 |

2.7 bg_vbf_800_1200

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [400839](#) events.
- Normalization to the luminosity: [114+/- 1](#) events.
- Ratio (event weight): [0.00028](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- vbf_diphoton_background_data/- merged_lhe/- vbf_diphoton_background_ht_800_ | 400839 | 0.00287 @ 0.16% | 0.0 |

2.8 bg_vbf_1200_1600

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [953803](#) events.
- Normalization to the luminosity: [20+/- 1](#) events.
- Ratio (event weight): [2.1e-05](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/madgraph_data/-vbf_diphoton_background_data/-merged_lhe/-vbf_diphoton_background_ht_1200 | 953803 | 0.000515 @ 0.16% | 0.0 |

2.9 bg_vbf_1600_inf

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [270148](#) events.
- Normalization to the luminosity: [7+/- 1](#) events.
- Ratio (event weight): [2.6e-05](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|---|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/madgraph_data/-vbf_diphoton_background_data/-merged_lhe/-vbf_diphoton_background_ht_1600 | 270148 | 0.000191 @ 0.11% | 0.0 |

2.10 bg_dip_0_100

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1040000](#) events.
- Normalization to the luminosity: [2710847+/- 4614](#) events.

- **Ratio (event weight): 2.6 - warning: please generate more events (weight larger than 1)!**

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 1040000 | 67.8 @ 0.17% | 0.0 |

2.11 bg_dip_100_200

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1040000](#) events.
- Normalization to the luminosity: [1095362+/- 1528](#) events.
- **Ratio (event weight): 1.1 - warning: please generate more events (weight larger than 1)!**

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 1040000 | 27.4 @ 0.14% | 0.0 |

2.12 bg_dip_200_400

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1040000](#) events.
- Normalization to the luminosity: [239548+/- 414](#) events.
- **Ratio (event weight): 0.23** .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 1040000 | 5.99 @ 0.17% | 0.0 |

2.13 bg_dip_400_600

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1040000](#) events.
- Normalization to the luminosity: [28798+/- 53](#) events.
- Ratio (event weight): [0.028](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/madgraph_data/-diphoton_double_isr_background_cmerged_lhe/-diphoton_double_isr_background_l | 1040000 | 0.72 @ 0.18% | 0.0 |

2.14 bg_dip_600_800

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [662009](#) events.
- Normalization to the luminosity: [6674+/- 28](#) events.
- Ratio (event weight): [0.01](#) .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/-MG5_aMC_v2_6_5/-axion_pheno/madgraph_data/-diphoton_double_isr_background_cmerged_lhe/-diphoton_double_isr_background_l | 662009 | 0.167 @ 0.41% | 0.0 |

2.15 bg_dip_800_1200

- Samples stored in the directory: [/Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization](#) .
- Sample consisting of: [background](#) events.
- Generated events: [1040000](#) events.
- Normalization to the luminosity: [2942+/- 6](#) events.

- Ratio (event weight): 0.0028 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 1040000 | 0.0736 @ 0.17% | 0.0 |

2.16 bg_dip_1200_1600

- Samples stored in the directory: /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization .
- Sample consisting of: background events.
- Generated events: 337115 events.
- Normalization to the luminosity: 513+/- 3 events.
- Ratio (event weight): 0.0015 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 337115 | 0.0128 @ 0.51% | 0.0 |

2.17 bg_dip_1600_inf

- Samples stored in the directory: /Users/elijahsheridan/MG5_aMC_v2_6_5/axion_pheno/-optimization .
- Sample consisting of: background events.
- Generated events: 1040000 events.
- Normalization to the luminosity: 187+/- 1 events.
- Ratio (event weight): 0.00018 .

| Path to the event file | Nr. of events | Cross section (pb) | Negative wgts (%) |
|--|---------------|--------------------|-------------------|
| /Users/elijahsheridan/- MG5_aMC_v2_6_5/- axion_pheno/madgraph_data/- diphoton_double_isr_background_c merged_lhe/- diphoton_double_isr_background_l | 1040000 | 0.00469 @ 0.15% | 0.0 |

3 Histos and cuts

3.1 Cut 1

* Cut: select M (jets[1] jets[2]) > 120.0

| Dataset | Events kept: K | Rejected events: R | Efficiency: K / (K + R) | Cumul. efficiency: K / Initial |
|-------------|-------------------|--------------------|-------------------------|--------------------------------|
| signal | 4094.04 +/- 1.14 | 0.04 +/- 0.20 | 1.00e+00 +/- 4.89e-05 | 1.00e+00 +/- 4.89e-05 |
| bg_vbf_0_10 | 3934.7 +/- 52.1 | 8215.6 +/- 53.9 | 0.32384 +/- 0.00425 | 0.32384 +/- 0.00425 |
| bg_vbf_100 | 8757.0 +/- 32.7 | 938.4 +/- 29.2 | 0.903 +/- 0.003 | 0.903 +/- 0.003 |
| bg_vbf_200 | 5358.8 +/- 13.1 | 54.50 +/- 7.35 | 0.98993 +/- 0.00136 | 0.98993 +/- 0.00136 |
| bg_vbf_400 | 983.78 +/- 2.22 | 3.07 +/- 1.75 | 0.99689 +/- 0.00177 | 0.99689 +/- 0.00177 |
| bg_vbf_600 | 251.851 +/- 0.571 | 0.226 +/- 0.475 | 0.99910 +/- 0.00189 | 0.99910 +/- 0.00189 |
| bg_vbf_800 | 114.64 +/- 0.39 | 0.12 +/- 0.35 | 0.99895 +/- 0.00302 | 0.99895 +/- 0.00302 |
| bg_vbf_1200 | 20.553 +/- 0.209 | 0.0426 +/- 0.2061 | 1.00 +/- 0.01 | 1.00 +/- 0.01 |
| bg_vbf_1600 | 7.513 +/- 0.378 | 0.146 +/- 0.378 | 0.9810 +/- 0.0494 | 0.9810 +/- 0.0494 |
| bg_dip_0_10 | 714692 +/- 1416 | 1996154 +/- 3473 | 0.263642 +/- 0.000268 | 0.263642 +/- 0.000268 |
| bg_dip_100 | 855479 +/- 1268 | 239882 +/- 546 | 0.781001 +/- 0.000395 | 0.781001 +/- 0.000395 |
| bg_dip_200 | 234627 +/- 411 | 4920.9 +/- 69.9 | 0.97946 +/- 0.00029 | 0.97946 +/- 0.00029 |
| bg_dip_400 | 28616.2 +/- 53.6 | 182.4 +/- 13.5 | 0.993665 +/- 0.000468 | 0.993665 +/- 0.000468 |
| bg_dip_600 | 6658.9 +/- 27.8 | 15.43 +/- 3.92 | 0.997689 +/- 0.000588 | 0.997689 +/- 0.000588 |
| bg_dip_800 | 2939.96 +/- 5.28 | 2.38 +/- 1.54 | 0.999192 +/- 0.000524 | 0.999192 +/- 0.000524 |
| bg_dip_1200 | 513.34 +/- 2.66 | 0.17 +/- 0.41 | 0.999669 +/- 0.000803 | 0.999669 +/- 0.000803 |
| bg_dip_1600 | 187.742 +/- 0.345 | 0.0414 +/- 0.2034 | 0.99978 +/- 0.00108 | 0.99978 +/- 0.00108 |

3.2 Histogram 1

* Plot: PT (jets[1])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 445.82 | 317.0 | 0.0 | 6.28 |
| bg_vbf_0_100 | 3934 | 1.0 | 46.784 | 11.01 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 87.0579 | 20.21 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 159.249 | 38.06 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 274.434 | 50.77 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 386.332 | 64.57 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 524.594 | 93.61 | 0.0 | 0.1816 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 738.34 | 109.5 | 0.0 | 3.383 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 1048.57 | 221.9 | 0.0 | 46.27 |
| bg_dip_0_100 | 714691 | 1.0 | 44.2861 | 11.5 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 84.0902 | 19.87 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 155.663 | 38.1 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 272.939 | 53.09 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 382.903 | 65.7 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 517.996 | 90.51 | 0.0 | 0.2342 |
| bg_dip_1200_1600 | 513 | 1.0 | 728.639 | 100.1 | 0.0 | 2.272 |
| bg_dip_1600_inf | 187 | 1.0 | 1036.29 | 211.5 | 0.0 | 43.96 |



Figure 1.

3.3 Histogram 2

* Plot: $\text{ETA}(\text{jets}[1])$

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|--------------|--------|-------------|------------|
| signal | 4094 | 1.0 | -0.0023996 | 1.616 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | -0.00133609 | 2.635 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 0.0043695 | 2.247 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 0.00194377 | 1.965 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | -0.000999715 | 1.682 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 0.000513382 | 1.499 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | -0.00310292 | 1.329 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | -0.000169046 | 1.134 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 0.00127081 | 0.9541 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 0.000508343 | 2.224 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 0.00260979 | 1.71 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | -0.0010006 | 1.468 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | -0.00170173 | 1.279 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | -0.0049065 | 1.157 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 0.00133618 | 1.052 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | -0.00486624 | 0.9226 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | -0.00107396 | 0.8 | 0.0 | 0.0 |



Figure 2.

3.4 Histogram 3

* Plot: PHI (jets[1])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|--------------|-------|-------------|------------|
| signal | 4094 | 1.0 | 0.00102738 | 1.813 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | 0.00419195 | 1.813 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | -0.00148977 | 1.814 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 0.00192437 | 1.814 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | -0.00356173 | 1.813 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | -0.000882503 | 1.813 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | -0.00348627 | 1.813 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 0.00205129 | 1.813 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 0.00218185 | 1.813 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | -0.00108067 | 1.816 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 0.00213448 | 1.814 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | -0.00158683 | 1.812 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | -0.00239958 | 1.813 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 0.00121432 | 1.814 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 0.000396081 | 1.814 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 6.26217e-05 | 1.814 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 0.0014267 | 1.814 | 0.0 | 0.0 |



Figure 3.

3.5 Histogram 4

* Plot: PT (jets[2])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 161.87 | 136.0 | 0.0 | 3.02 |
| bg_vbf_0_100 | 3934 | 1.0 | 31.2504 | 7.217 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 57.5348 | 16.74 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 111.536 | 32.69 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 201.545 | 47.5 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 293.986 | 62.63 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 415.077 | 90.48 | 0.0 | 15.1 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 613.849 | 108.4 | 0.0 | 90.47 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 917.972 | 221.8 | 0.0 | 98.03 |
| bg_dip_0_100 | 714691 | 1.0 | 29.8777 | 7.014 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 54.688 | 15.89 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 106.13 | 33.69 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 201.059 | 51.01 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 296.97 | 64.64 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 421.627 | 88.69 | 0.0 | 16.13 |
| bg_dip_1200_1600 | 513 | 1.0 | 623.471 | 99.67 | 0.0 | 93.34 |
| bg_dip_1600_inf | 187 | 1.0 | 926.302 | 210.5 | 0.0 | 98.92 |



Figure 4.

3.6 Histogram 5

* Plot: $\text{ETA}(\text{jets}[2])$

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|--------------|--------|-------------|------------|
| signal | 4094 | 1.0 | 0.00500696 | 2.329 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | -0.0019532 | 2.674 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | -0.0066 | 2.371 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 0.000228824 | 2.132 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | -0.000744275 | 1.863 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | -0.00168321 | 1.667 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | -0.000452317 | 1.473 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 0.000595874 | 1.238 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | -0.00207042 | 1.017 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 1.01009e-05 | 2.147 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | -0.00108977 | 1.645 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | -0.00265008 | 1.446 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | -0.000387923 | 1.29 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | -0.000303381 | 1.182 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 0.00119018 | 1.078 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | -0.000424092 | 0.9457 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 0.000907805 | 0.8179 | 0.0 | 0.0 |



Figure 5.

3.7 Histogram 6

* Plot: PHI (jets[2])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|--------------|-------|-------------|------------|
| signal | 4094 | 1.0 | -0.00274458 | 1.814 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | -0.00276363 | 1.814 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | -3.00875e-05 | 1.815 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | -0.00153572 | 1.814 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 0.00312538 | 1.814 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 0.00050346 | 1.815 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 0.000132195 | 1.813 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | -0.0034209 | 1.815 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | -0.00282812 | 1.814 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 0.00324102 | 1.813 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | -0.00116298 | 1.815 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 0.000793162 | 1.815 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | -1.20627e-05 | 1.814 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | -0.00250468 | 1.815 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | - | 1.813 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 0.000669513 | 1.813 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | -0.00203746 | 1.813 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 0.00234294 | 1.814 | 0.0 | 0.0 |



Figure 6.

3.8 Histogram 7

* Plot: DELTAR (jets[1] , jets[2])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|--------|-------------|------------|
| signal | 4094 | 1.0 | 4.02835 | 1.056 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | 5.21509 | 1.267 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 4.68485 | 1.264 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 4.4049 | 1.096 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 4.11552 | 0.8948 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 3.92644 | 0.7722 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 3.75826 | 0.6584 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 3.58482 | 0.5257 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 3.44779 | 0.4108 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 4.20916 | 0.7369 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 3.45656 | 0.6833 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 3.29993 | 0.6389 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 3.28686 | 0.5815 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 3.28486 | 0.5273 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 3.28621 | 0.4662 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 3.28098 | 0.3842 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 3.26771 | 0.3022 | 0.0 | 0.0 |



Figure 7.

3.9 Histogram 8

* Plot: $M(j_1, j_2)$

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 1376.2 | 772.9 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | 469.964 | 412.4 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 609.152 | 529.4 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 888.626 | 671.3 | 0.0 | 0.0003082 |
| bg_vbf_400_600 | 983 | 1.0 | 1211.77 | 761.1 | 0.0 | 0.0006018 |
| bg_vbf_600_800 | 251 | 1.0 | 1465.23 | 805.1 | 0.0 | 0.001401 |
| bg_vbf_800_1200 | 114 | 1.0 | 1732.47 | 822.0 | 0.0 | 0.002495 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 2125.32 | 815.8 | 0.0 | 0.002832 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 2691.74 | 857.1 | 0.0 | 0.01037 |
| bg_dip_0_100 | 714691 | 1.0 | 202.321 | 105.0 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 222.194 | 129.4 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 364.432 | 195.6 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 626.063 | 277.8 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 872.986 | 337.8 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 1178.48 | 408.8 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 1647.88 | 468.4 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 2311.56 | 635.4 | 0.0 | 0.0001923 |



Figure 8.

3.10 Histogram 9

* Plot: MET

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|-------------|-----------|-------------|------------|
| signal | 4094 | 1.0 | 8.33083e-09 | 1.078e-08 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | 5.97855e-10 | 4.233e-10 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 9.55638e-10 | 1.098e-09 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 3.23057e-09 | 2.219e-09 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 4.52485e-09 | 2.611e-09 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 4.90226e-09 | 2.72e-09 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 5.15622e-09 | 2.979e-09 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 5.81971e-09 | 5.339e-09 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 1.30635e-08 | 1.639e-08 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 5.87329e-10 | 4.134e-10 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 8.95295e-10 | 1.036e-09 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 3.11256e-09 | 2.186e-09 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 4.43451e-09 | 2.58e-09 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 4.80208e-09 | 2.678e-09 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 5.06231e-09 | 3.026e-09 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 5.58908e-09 | 4.823e-09 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 1.25075e-08 | 1.605e-08 | 0.0 | 0.0 |



Figure 9.

3.11 Histogram 10

* Plot: sdETA (jets[1] jets[2])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|--------------|-------|-------------|------------|
| signal | 4094 | 1.0 | -0.00740656 | 3.704 | 0.2057 | 0.2022 |
| bg_vbf_0_100 | 3934 | 1.0 | 0.000617109 | 4.726 | 0.5803 | 0.6083 |
| bg_vbf_100_200 | 8756 | 1.0 | 0.0109695 | 4.015 | 0.1029 | 0.1176 |
| bg_vbf_200_400 | 5358 | 1.0 | 0.00171495 | 3.569 | 0.004928 | 0.003696 |
| bg_vbf_400_600 | 983 | 1.0 | -0.000255441 | 3.09 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 0.00219659 | 2.754 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | -0.0026506 | 2.428 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | -0.00076492 | 2.046 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 0.00334122 | 1.694 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 0.000498242 | 3.363 | 0.0 | 0.0007299 |
| bg_dip_100_200 | 855479 | 1.0 | 0.00369956 | 2.156 | 0.0001229 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 0.00164949 | 1.795 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | -0.00131381 | 1.639 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | -0.00460312 | 1.539 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 0.000145998 | 1.448 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | -0.00444215 | 1.327 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | -0.00198176 | 1.196 | 0.0 | 0.0 |



Figure 10.

3.12 Histogram 11

* Plot: $M (a[1] a[2])$

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 950.206 | 725.5 | 0.0 | 36.84 |
| bg_vbf_0_100 | 3934 | 1.0 | 59.2471 | 49.28 | 0.0 | 0.002778 |
| bg_vbf_100_200 | 8756 | 1.0 | 70.2822 | 64.56 | 0.0 | 0.01548 |
| bg_vbf_200_400 | 5358 | 1.0 | 92.2723 | 92.82 | 0.0 | 0.0622 |
| bg_vbf_400_600 | 983 | 1.0 | 117.071 | 124.4 | 0.0 | 0.1777 |
| bg_vbf_600_800 | 251 | 1.0 | 132.524 | 146.0 | 0.0 | 0.3347 |
| bg_vbf_800_1200 | 114 | 1.0 | 143.801 | 162.6 | 0.0 | 0.5078 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 153.519 | 177.9 | 0.0 | 0.6926 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 159.525 | 184.7 | 0.0 | 0.7897 |
| bg_dip_0_100 | 714691 | 1.0 | 48.4767 | 39.08 | 0.0 | 0.002553 |
| bg_dip_100_200 | 855479 | 1.0 | 55.4245 | 50.97 | 0.0 | 0.004558 |
| bg_dip_200_400 | 234627 | 1.0 | 74.3979 | 76.83 | 0.0 | 0.0267 |
| bg_dip_400_600 | 28616 | 1.0 | 95.1626 | 107.9 | 0.0 | 0.1108 |
| bg_dip_600_800 | 6658 | 1.0 | 108.836 | 127.8 | 0.0 | 0.2203 |
| bg_dip_800_1200 | 2939 | 1.0 | 119.749 | 143.7 | 0.0 | 0.3484 |
| bg_dip_1200_1600 | 513 | 1.0 | 131.534 | 157.2 | 0.0 | 0.4736 |
| bg_dip_1600_inf | 187 | 1.0 | 143.672 | 167.2 | 0.0 | 0.5656 |



Figure 11.

3.13 Histogram 12

* Plot: PT (a[1])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 588.092 | 368.7 | 0.0 | 12.98 |
| bg_vbf_0_100 | 3934 | 1.0 | 33.0393 | 18.87 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 46.4939 | 31.54 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 72.005 | 60.42 | 0.0 | 0.000308 |
| bg_vbf_400_600 | 983 | 1.0 | 106.886 | 103.6 | 0.0 | 0.002407 |
| bg_vbf_600_800 | 251 | 1.0 | 132.381 | 141.7 | 0.0 | 0.009208 |
| bg_vbf_800_1200 | 114 | 1.0 | 154.148 | 182.0 | 0.0 | 0.3163 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 172.887 | 223.7 | 0.0 | 1.906 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 181.168 | 246.2 | 0.0 | 2.06 |
| bg_dip_0_100 | 714691 | 1.0 | 29.8019 | 18.74 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 42.2098 | 31.98 | 0.0 | 0.0001231 |
| bg_dip_200_400 | 234627 | 1.0 | 67.1266 | 63.03 | 0.0 | 9.834e-05 |
| bg_dip_400_600 | 28616 | 1.0 | 95.4197 | 106.8 | 0.0 | 0.001258 |
| bg_dip_600_800 | 6658 | 1.0 | 113.382 | 139.4 | 0.0 | 0.00999 |
| bg_dip_800_1200 | 2939 | 1.0 | 126.721 | 168.3 | 0.0 | 0.3807 |
| bg_dip_1200_1600 | 513 | 1.0 | 138.701 | 193.4 | 0.0 | 1.426 |
| bg_dip_1600_inf | 187 | 1.0 | 146.238 | 198.9 | 0.0 | 1.065 |



Figure 12.

3.14 Histogram 13

* Plot: PT (a[2])

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 334.941 | 290.0 | 0.0 | 3.619 |
| bg_vbf_0_100 | 3934 | 1.0 | 18.2641 | 11.16 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 21.2596 | 15.54 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 25.9605 | 23.17 | 0.0 | 0.0002055 |
| bg_vbf_400_600 | 983 | 1.0 | 31.2333 | 32.38 | 0.0 | 0.0009032 |
| bg_vbf_600_800 | 251 | 1.0 | 34.5946 | 38.91 | 0.0 | 0.0001002 |
| bg_vbf_800_1200 | 114 | 1.0 | 37.1093 | 44.62 | 0.0 | 0.0009971 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 39.4356 | 49.91 | 0.0 | 0.002623 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 40.8098 | 52.8 | 0.0 | 0.004823 |
| bg_dip_0_100 | 714691 | 1.0 | 16.5201 | 9.637 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 18.8185 | 12.99 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 22.8735 | 19.58 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 26.8872 | 27.11 | 0.0 | 0.0001937 |
| bg_dip_600_800 | 6658 | 1.0 | 29.3925 | 32.02 | 0.0 | 0.0003031 |
| bg_dip_800_1200 | 2939 | 1.0 | 31.3973 | 35.97 | 0.0 | 0.0007697 |
| bg_dip_1200_1600 | 513 | 1.0 | 33.6461 | 39.79 | 0.0 | 0.001184 |
| bg_dip_1600_inf | 187 | 1.0 | 35.6015 | 42.32 | 0.0 | 0.002116 |



Figure 13.

3.15 Histogram 14

* Plot: THT

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 607.69 | 391.1 | 0.0 | 15.4 |
| bg_vbf_0_100 | 3934 | 1.0 | 78.0345 | 14.32 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 144.593 | 27.95 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 270.786 | 53.37 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 475.979 | 55.0 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 680.318 | 55.83 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 939.672 | 106.7 | 0.0 | 27.89 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 1352.19 | 109.7 | 0.0 | 100.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 1966.54 | 391.6 | 0.0 | 100.0 |
| bg_dip_0_100 | 714691 | 1.0 | 74.1637 | 15.18 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 138.778 | 26.45 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 261.793 | 50.89 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 473.998 | 54.59 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 679.873 | 55.79 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 939.623 | 106.7 | 0.0 | 27.8 |
| bg_dip_1200_1600 | 513 | 1.0 | 1352.11 | 109.8 | 0.0 | 100.0 |
| bg_dip_1600_inf | 187 | 1.0 | 1962.59 | 386.0 | 0.0 | 100.0 |



Figure 14.

3.16 Histogram 15

* Plot: MET

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|-------------|-----------|-------------|------------|
| signal | 4094 | 1.0 | 8.33083e-09 | 1.078e-08 | 0.0 | 0.0 |
| bg_vbf_0_100 | 3934 | 1.0 | 5.97855e-10 | 4.233e-10 | 0.0 | 0.0 |
| bg_vbf_100_200 | 8756 | 1.0 | 9.55638e-10 | 1.098e-09 | 0.0 | 0.0 |
| bg_vbf_200_400 | 5358 | 1.0 | 3.23057e-09 | 2.219e-09 | 0.0 | 0.0 |
| bg_vbf_400_600 | 983 | 1.0 | 4.52485e-09 | 2.611e-09 | 0.0 | 0.0 |
| bg_vbf_600_800 | 251 | 1.0 | 4.90226e-09 | 2.72e-09 | 0.0 | 0.0 |
| bg_vbf_800_1200 | 114 | 1.0 | 5.15622e-09 | 2.979e-09 | 0.0 | 0.0 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 5.81971e-09 | 5.339e-09 | 0.0 | 0.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 1.30635e-08 | 1.639e-08 | 0.0 | 0.0 |
| bg_dip_0_100 | 714691 | 1.0 | 5.87329e-10 | 4.134e-10 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 8.95295e-10 | 1.036e-09 | 0.0 | 0.0 |
| bg_dip_200_400 | 234627 | 1.0 | 3.11256e-09 | 2.186e-09 | 0.0 | 0.0 |
| bg_dip_400_600 | 28616 | 1.0 | 4.43451e-09 | 2.58e-09 | 0.0 | 0.0 |
| bg_dip_600_800 | 6658 | 1.0 | 4.80208e-09 | 2.678e-09 | 0.0 | 0.0 |
| bg_dip_800_1200 | 2939 | 1.0 | 5.06231e-09 | 3.026e-09 | 0.0 | 0.0 |
| bg_dip_1200_1600 | 513 | 1.0 | 5.58908e-09 | 4.823e-09 | 0.0 | 0.0 |
| bg_dip_1600_inf | 187 | 1.0 | 1.25075e-08 | 1.605e-08 | 0.0 | 0.0 |



Figure 15.

3.17 Histogram 16

* Plot: TET

| Dataset | Integral | Entries per event | Mean | RMS | % underflow | % overflow |
|------------------|----------|-------------------|---------|-------|-------------|------------|
| signal | 4094 | 1.0 | 1530.72 | 825.3 | 0.0 | 70.59 |
| bg_vbf_0_100 | 3934 | 1.0 | 129.338 | 32.52 | 0.0 | 0.001235 |
| bg_vbf_100_200 | 8756 | 1.0 | 212.346 | 54.5 | 0.0 | 0.00344 |
| bg_vbf_200_400 | 5358 | 1.0 | 368.751 | 98.32 | 0.0 | 0.04948 |
| bg_vbf_400_600 | 983 | 1.0 | 614.098 | 136.7 | 0.0 | 1.955 |
| bg_vbf_600_800 | 251 | 1.0 | 847.293 | 172.9 | 0.0 | 15.03 |
| bg_vbf_800_1200 | 114 | 1.0 | 1130.93 | 233.4 | 0.0 | 66.91 |
| bg_vbf_1200_1600 | 20.6 | 1.0 | 1564.51 | 271.2 | 0.0 | 100.0 |
| bg_vbf_1600_inf | 7.66 | 1.0 | 2188.52 | 475.9 | 0.0 | 100.0 |
| bg_dip_0_100 | 714691 | 1.0 | 120.486 | 31.72 | 0.0 | 0.0 |
| bg_dip_100_200 | 855479 | 1.0 | 199.807 | 52.08 | 0.0 | 0.0009859 |
| bg_dip_200_400 | 234627 | 1.0 | 351.793 | 94.87 | 0.0 | 0.02749 |
| bg_dip_400_600 | 28616 | 1.0 | 596.305 | 134.8 | 0.0 | 1.993 |
| bg_dip_600_800 | 6658 | 1.0 | 822.647 | 165.9 | 0.0 | 10.92 |
| bg_dip_800_1200 | 2939 | 1.0 | 1097.74 | 215.8 | 0.0 | 61.64 |
| bg_dip_1200_1600 | 513 | 1.0 | 1524.46 | 238.7 | 0.0 | 100.0 |
| bg_dip_1600_inf | 187 | 1.0 | 2144.43 | 445.2 | 0.0 | 100.0 |

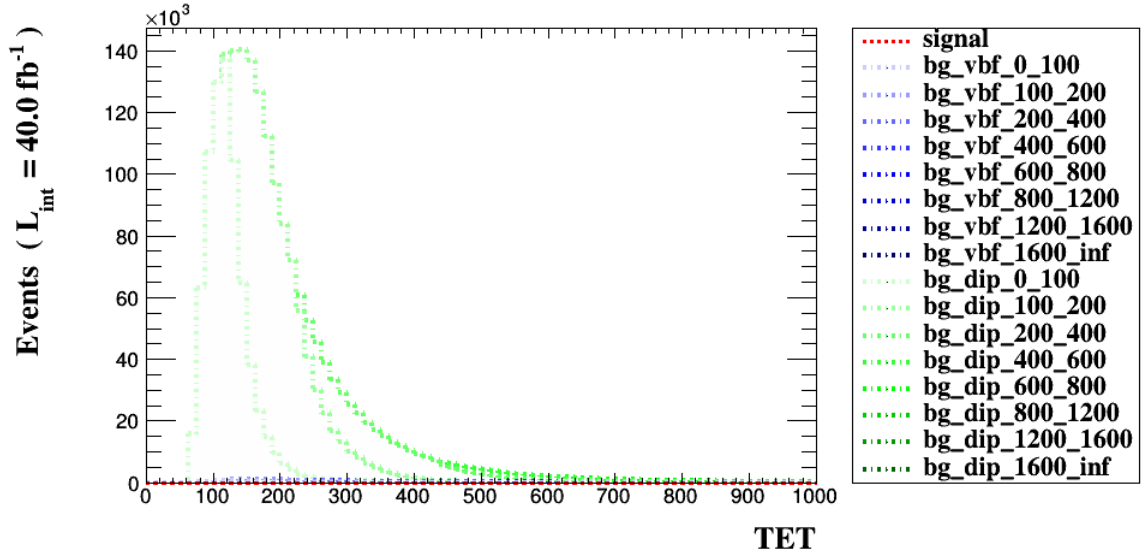


Figure 16.

3.18 Cut 2

* Cut: select (sdETA (jets[1] jets[2]) > 4.6 or sdETA (jets[1] jets[2]) < -4.6) and M (jets[1] jets[2]) > 500.0

| Dataset | Events kept: K | Rejected events: R | Efficiency: K / (K + R) | Cumul. efficiency: K / Initial |
|-------------|---------------------|--------------------|-------------------------|--------------------------------|
| signal | 599.7 +/- 22.6 | 3494.3 +/- 22.6 | 0.14649 +/- 0.00553 | 0.14649 +/- 0.00553 |
| bg_vbf_0_10 | 1240.4 +/- 33.5 | 2694.3 +/- 46.1 | 0.31525 +/- 0.00741 | 0.10209 +/- 0.00275 |
| bg_vbf_100_ | 2609.6 +/- 43.9 | 6147.3 +/- 48.6 | 0.29801 +/- 0.00489 | 0.2692 +/- 0.0045 |
| bg_vbf_200_ | 1060.7 +/- 29.3 | 4298.1 +/- 31.0 | 0.19794 +/- 0.00544 | 0.19595 +/- 0.00539 |
| bg_vbf_400_ | 91.35 +/- 9.11 | 892.43 +/- 9.32 | 0.09286 +/- 0.00925 | 0.09257 +/- 0.00923 |
| bg_vbf_600_ | 9.89 +/- 3.08 | 241.96 +/- 3.13 | 0.0393 +/- 0.0122 | 0.0392 +/- 0.0122 |
| bg_vbf_800_ | 1.31 +/- 1.14 | 113.3 +/- 1.2 | 0.01141 +/- 0.00992 | 0.01140 +/- 0.00991 |
| bg_vbf_1200 | 0.023 +/- 0.152 | 20.530 +/- 0.258 | 0.00112 +/- 0.00738 | 0.00112 +/- 0.00737 |
| bg_vbf_1600 | 0.001 +/- 0.032 | 7.512 +/- 0.379 | 0.000133 +/- 0.004215 | 0.000131 +/- 0.004135 |
| bg_dip_0_10 | 16497 +/- 131 | 698195 +/- 1389 | 0.023083 +/- 0.000178 | 6.09e-03 +/- 4.72e-05 |
| bg_dip_100_ | 14504 +/- 121 | 840975 +/- 1252 | 0.01695 +/- 0.00014 | 0.013242 +/- 0.000109 |
| bg_dip_200_ | 1626.4 +/- 40.3 | 233001 +/- 410 | 0.006932 +/- 0.000171 | 0.006789 +/- 0.000168 |
| bg_dip_400_ | 77.6 +/- 8.8 | 28538.6 +/- 54.2 | 0.002711 +/- 0.000307 | 0.002694 +/- 0.000305 |
| bg_dip_600_ | 7.20 +/- 2.68 | 6651.7 +/- 27.9 | 0.001081 +/- 0.000403 | 0.001079 +/- 0.000402 |
| bg_dip_800_ | 1.08 +/- 1.04 | 2938.88 +/- 5.38 | 0.000367 +/- 0.000353 | 0.000366 +/- 0.000353 |
| bg_dip_1200 | 0.0305 +/- 0.1745 | 513.31 +/- 2.67 | 5.93e-05 +/- 3.40e-04 | 5.93e-05 +/- 3.40e-04 |
| bg_dip_1600 | 0.00253 +/- 0.05027 | 187.740 +/- 0.349 | 1.35e-05 +/- 2.68e-04 | 1.35e-05 +/- 2.68e-04 |

4 Summary

4.1 Cut-flow charts

- How to compare signal (S) and background (B): $S/\sqrt{S+B}$.
- Object definition selections are indicated in cyan.
- Reject and select are indicated by 'REJ' and 'SEL' respectively

| Cuts | Signal (S) | Background (B) | S vs B |
|---|------------------|------------------|---------------------|
| Initial (no cut) | 4094.08 +/- 1.13 | 4113516 +/- 4877 | 2.01760 +/- 0.00132 |
| SEL: M (jets[1] jets[2]) > 120.0 | 4094.04 +/- 1.14 | 1863145 +/- 1947 | 2.99607 +/- 0.00177 |
| SEL: (sdETA (jets[1] jets[2]) > 4.6 or sdETA (| 599.7 +/- 22.6 | 37727 +/- 193 | 3.064 +/- 0.115 |