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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># 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># 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 ax = 9000005
ma5># selections
ma5>select (sdETA(jets[1] jets[2]) > 3.6 or sdETA(jets[1] jets[2]) < -3.6) and M(jets[1]
jets[2]) > 1250
ma5>select PT(a[1]) > 300 and M(a[1] a[2]) > 550
ma5>submit analysis_tight_pta300_maa550

```

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 (sdETA (jets[1] jets[2]) > 3.6 or sdETA (jets[1] jets[2]) < -3.6) and M (jets[1] jets[2]) > 1250.0

Dataset	Events kept: K	Rejected events: R	Efficiency: K / (K + R)	Cumul. efficiency: K / Initial
signal	814.6 +/- 25.5	3279.5 +/- 25.6	0.19896 +/- 0.00624	0.19896 +/- 0.00624
bg_vbf_0_10	204.2 +/- 14.2	11946.1 +/- 26.8	0.01681 +/- 0.00117	0.01681 +/- 0.00117
bg_vbf_100_	950.9 +/- 29.3	8744.4 +/- 32.9	0.09808 +/- 0.00302	0.09808 +/- 0.00302
bg_vbf_200_	1147.9 +/- 30.2	4265.4 +/- 31.3	0.21205 +/- 0.00556	0.21205 +/- 0.00556
bg_vbf_400_	273.7 +/- 14.1	713.1 +/- 14.1	0.2774 +/- 0.0143	0.2774 +/- 0.0143
bg_vbf_600_	47.78 +/- 6.22	204.30 +/- 6.23	0.1895 +/- 0.0247	0.1895 +/- 0.0247
bg_vbf_800_	12.06 +/- 3.29	102.70 +/- 3.29	0.1051 +/- 0.0286	0.1051 +/- 0.0286
bg_vbf_1200	0.678 +/- 0.810	19.92 +/- 0.81	0.0329 +/- 0.0393	0.0329 +/- 0.0393
bg_vbf_1600	0.0483 +/- 0.2191	7.610 +/- 0.219	0.00631 +/- 0.02860	0.00631 +/- 0.02860
bg_dip_0_10	229.4 +/- 15.1	2710617 +/- 4612	8.46e-05 +/- 5.59e-06	8.46e-05 +/- 5.59e-06
bg_dip_100_	990.1 +/- 31.5	1094372 +/- 1526	9.04e-04 +/- 2.87e-05	9.04e-04 +/- 2.87e-05
bg_dip_200_	1641.8 +/- 40.5	237907 +/- 412	0.006854 +/- 0.000169	0.006854 +/- 0.000169
bg_dip_400_	593.2 +/- 24.1	28205.5 +/- 56.5	0.020599 +/- 0.000837	0.020599 +/- 0.000837
bg_dip_600_	88.41 +/- 9.35	6585.9 +/- 28.8	0.0132 +/- 0.0014	0.0132 +/- 0.0014
bg_dip_800_	22.00 +/- 4.67	2920.34 +/- 6.86	0.00748 +/- 0.00159	0.00748 +/- 0.00159
bg_dip_1200	1.34 +/- 1.16	512.16 +/- 2.87	0.00261 +/- 0.00225	0.00261 +/- 0.00225
bg_dip_1600	0.0921 +/- 0.3034	187.691 +/- 0.412	0.00049 +/- 0.00162	0.00049 +/- 0.00162

3.2 Cut 2

* Cut: select $PT(a[1]) > 300.0$ and $M(a[1] a[2]) > 550.0$

Dataset	Events kept: K	Rejected events: R	Efficiency: K / (K + R)	Cumul. efficiency: K / Initial
signal	525.2 +/- 21.4	289.4 +/- 16.4	0.6447 +/- 0.0168	0.12828 +/- 0.00523
bg_vbf_0_10	0.0 +/- 0.0	204.2 +/- 14.2	0.0 +/- 0.0	0.0 +/- 0.0
bg_vbf_100_	0.542 +/- 0.736	950.4 +/- 29.3	0.00057 +/- 0.00077	5.59e-05 +/- 7.59e-05
bg_vbf_200_	3.2 +/- 1.8	1144.6 +/- 30.1	0.00282 +/- 0.00156	0.000597 +/- 0.000332
bg_vbf_400_	3.15 +/- 1.77	270.6 +/- 14.0	0.01153 +/- 0.00645	0.0032 +/- 0.0018
bg_vbf_600_	1.29 +/- 1.13	46.49 +/- 6.16	0.0270 +/- 0.0235	0.0051 +/- 0.0045
bg_vbf_800_	0.513 +/- 0.715	11.54 +/- 3.22	0.0426 +/- 0.0581	0.00447 +/- 0.00623
bg_vbf_1200_	0.046 +/- 0.214	0.632 +/- 0.783	0.0678 +/- 0.3054	0.00223 +/- 0.01040
bg_vbf_1600_	0.00498 +/- 0.07054	0.0433 +/- 0.2075	0.103 +/- 1.384	0.00065 +/- 0.00921
bg_dip_0_10	0.0 +/- 0.0	229.4 +/- 15.1	0.0 +/- 0.0	0.0 +/- 0.0
bg_dip_100_	1.06 +/- 1.03	989.0 +/- 31.5	0.00107 +/- 0.00104	9.63e-07 +/- 9.38e-07
bg_dip_200_	4.8 +/- 2.2	1637.0 +/- 40.4	0.00295 +/- 0.00134	2.02e-05 +/- 9.18e-06
bg_dip_400_	5.23 +/- 2.29	588.0 +/- 24.0	0.00882 +/- 0.00384	1.82e-04 +/- 7.94e-05
bg_dip_600_	2.11 +/- 1.45	86.30 +/- 9.24	0.0238 +/- 0.0162	0.000316 +/- 0.000217
bg_dip_800_	0.993 +/- 0.996	21.00 +/- 4.57	0.0451 +/- 0.0443	0.000337 +/- 0.000339
bg_dip_1200_	0.0853 +/- 0.2920	1.26 +/- 1.12	0.0636 +/- 0.2107	0.000166 +/- 0.000569
bg_dip_1600_	0.00867 +/- 0.09310	0.0834 +/- 0.2887	0.0941 +/- 0.9624	4.62e-05 +/- 4.96e-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: (sdETA (jets[1] jets[2]) > 3.6 or sdETA (814.6 +/- 25.5	6203.5 +/- 76.0	9.723 +/- 0.292
SEL: PT (a[1]) > 300.0 and M (a[1] a[2]) > 550	525.2 +/- 21.4	23.1 +/- 4.8	22.429 +/- 0.486