# Higgs decay to WW* in Higgsstrahlung at 250 GeV

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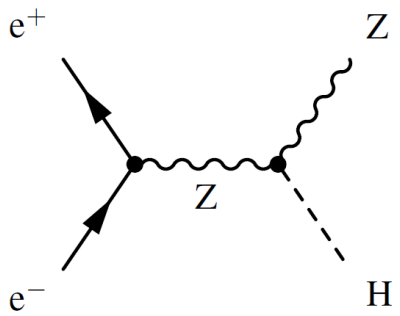
ILD analysis and sofware meeting January 2018.

# Introduction

- Analyzed HZ fully hadronic decay: $Z \rightarrow qq$ , $H \rightarrow WW^* \rightarrow qqqq$
- HZ @250GeV $\sigma(e^+e^- \rightarrow HZ, Zqq) \sim 346$ fb
- $BF_{H \rightarrow WW} \sim 23.0\%$ , $BF_{WW \rightarrow qqqq} \sim 45.5\% \Rightarrow \sim 10\%$ of Higgs decays
- $\sigma(e^+e^- \rightarrow HZ, Z \rightarrow qq , H \rightarrow WW^* \rightarrow qqqq) \sim$fb

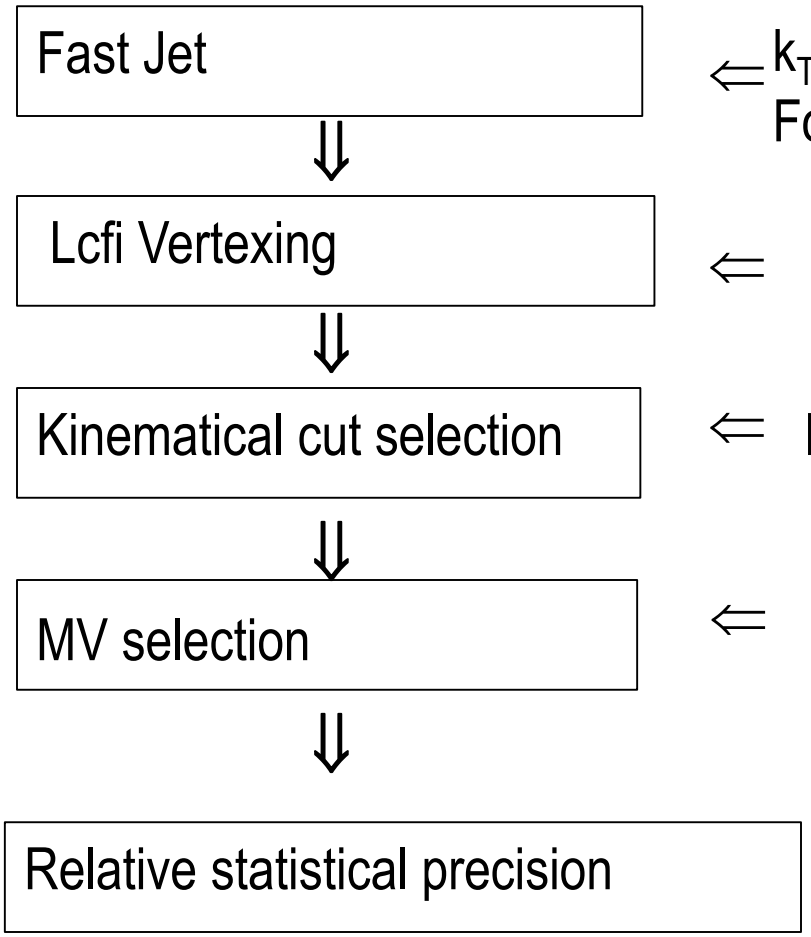



- Signal signature:

  6 central wide jets in the final state

- Considered luminosity scenarios:
  - 500 $fb^{-1}$ $P(e^+,e^-)=(-80\%,+20\%)$
  - Considered $P(e^+,e^-)=(+80\%,-20\%)$ polarization - statistics

# Analysis flow




⇐ $k_T$ exclusive, PandoraPFO's
Force events into 6 jets , R=1.5

⇐ 2/6 jet hypothesis to apply btagging

⇐ Reduction of large cross-section background

⇐ BDTG

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$$

# Jet grouping: Higgs, Z, W boson formation

- The event is forced into 6 jets
- Obtained jets are grouped into pairs to form the Higgs, W, W* and Z bosons
- The combination which minimizes the $\chi^2$ is chosen :

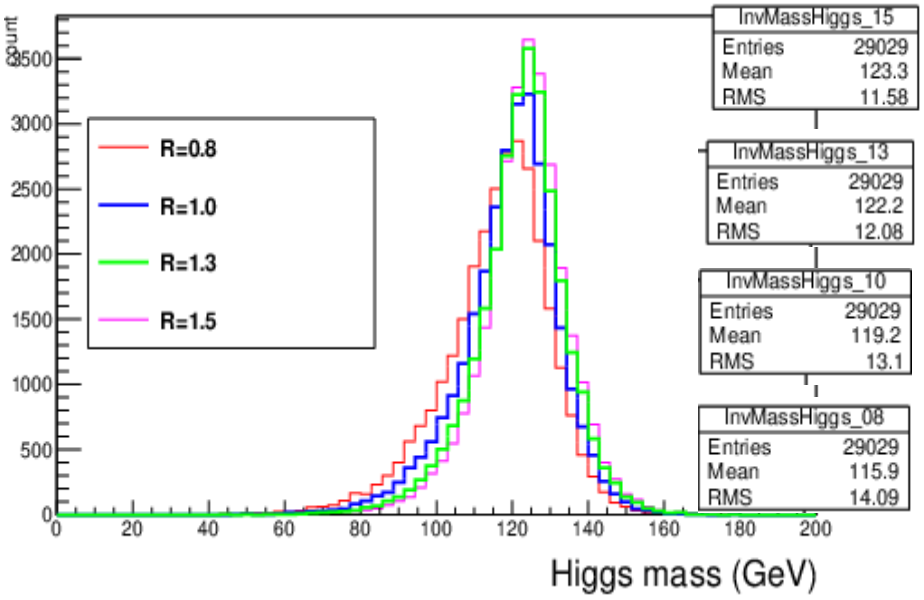
$$\chi^2 = \frac{(M_{ij} - M_W)^2}{\sigma^2_W} + \frac{(M_{kl} - M_Z)^2}{\sigma^2_Z} + \frac{(M_{ijmn} - M_H)^2}{\sigma^2_H}$$

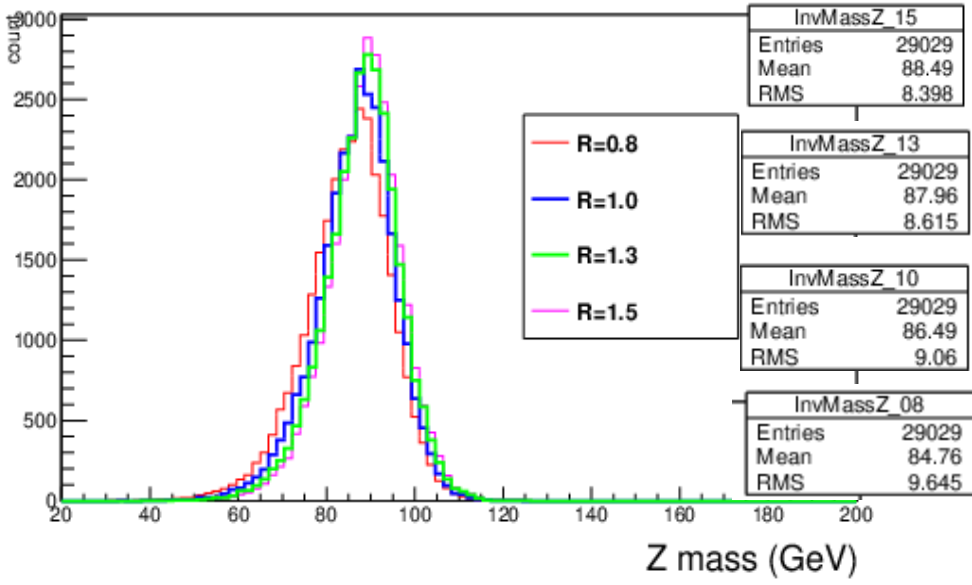
- For the $\sigma^2_{H,W,Z}$ - WA width

# R determination

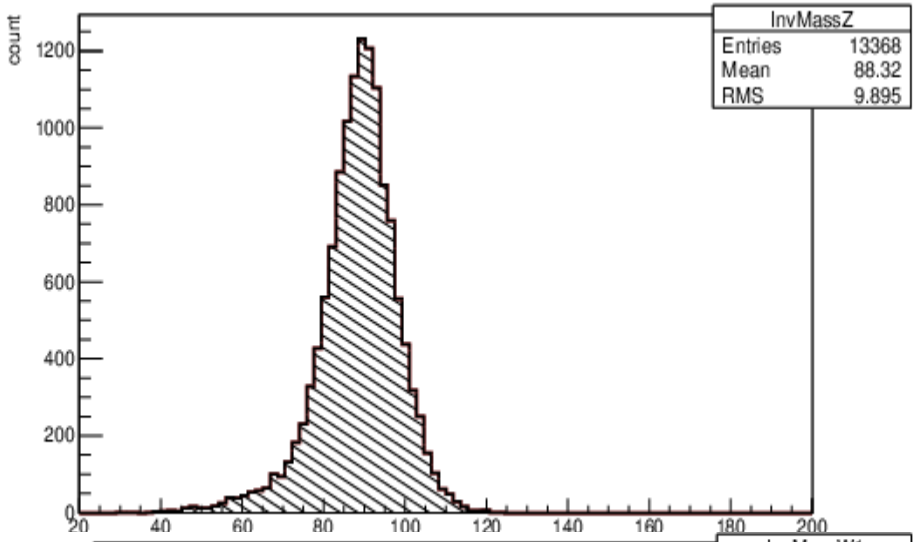
- Force event into 6 jets. R=0.8,1.0,1.1,1.2,1.3,1.4,1.5
- Jet Pairing to form Higgs, Z, W
- Fit of the invariant mass of the Z boson in an interval s around the peak

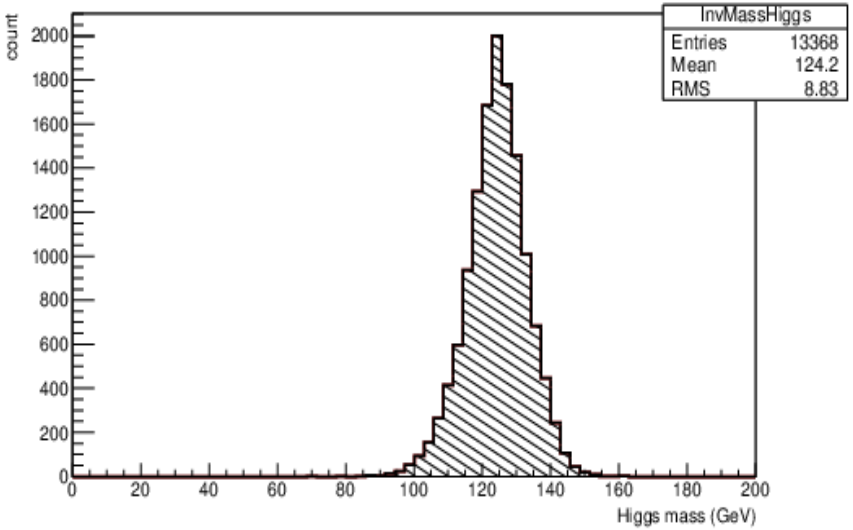
  85 GeV <$m_z$<95 GeV  125 GeV <$m_{Higgs}$<130 GeV
- The best fit results are obtained for the R=1.5

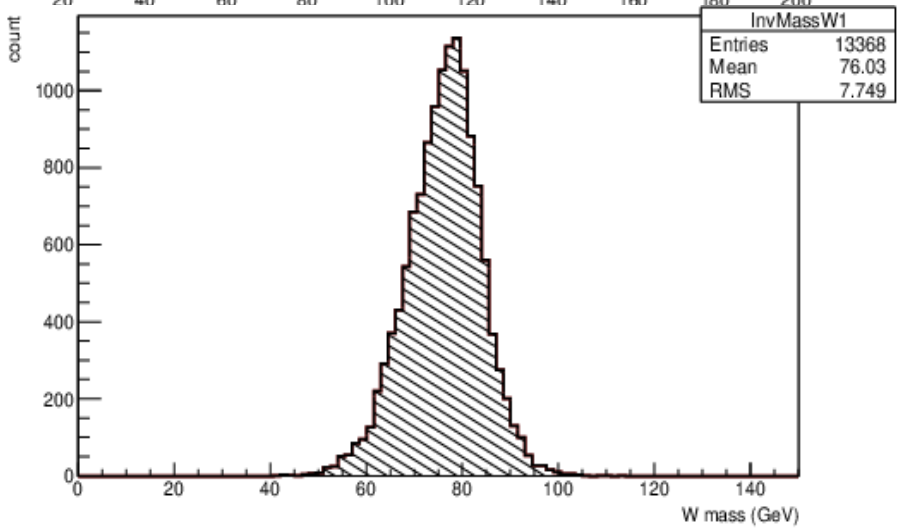


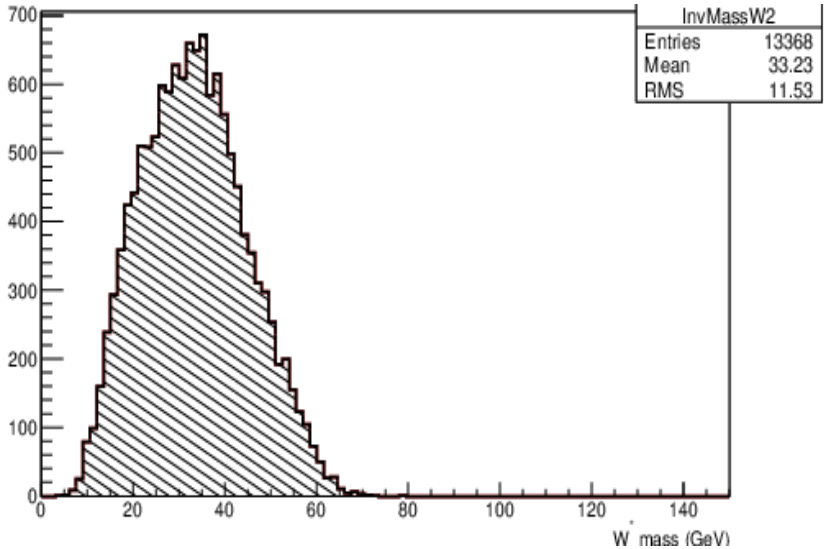



# Reconstructed boson masses

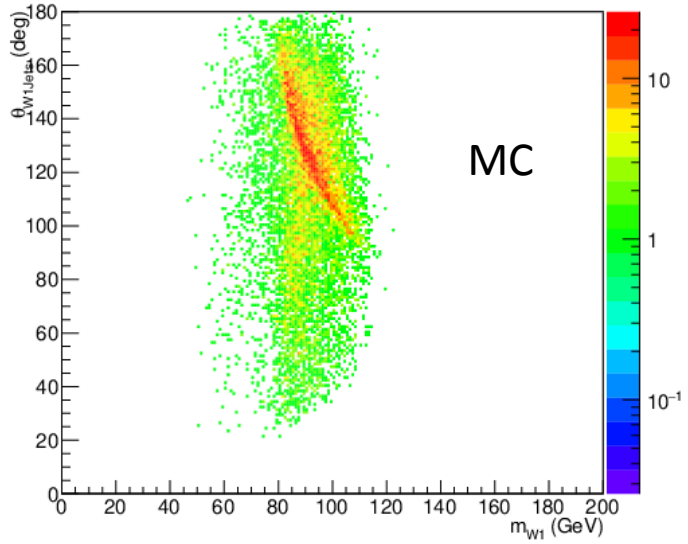


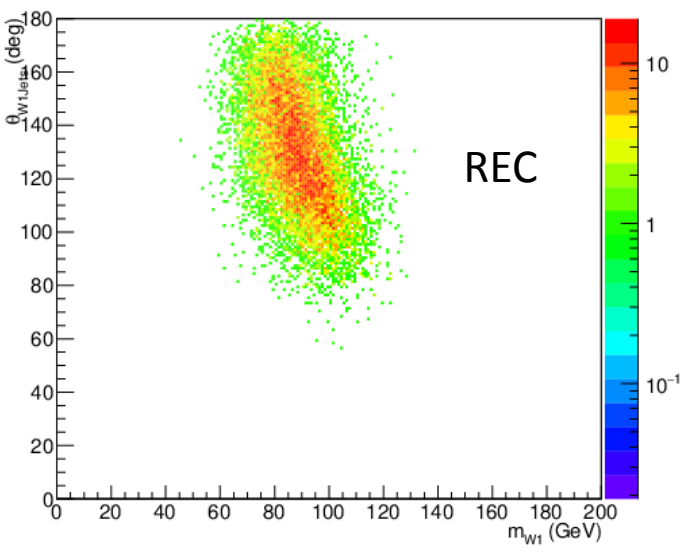



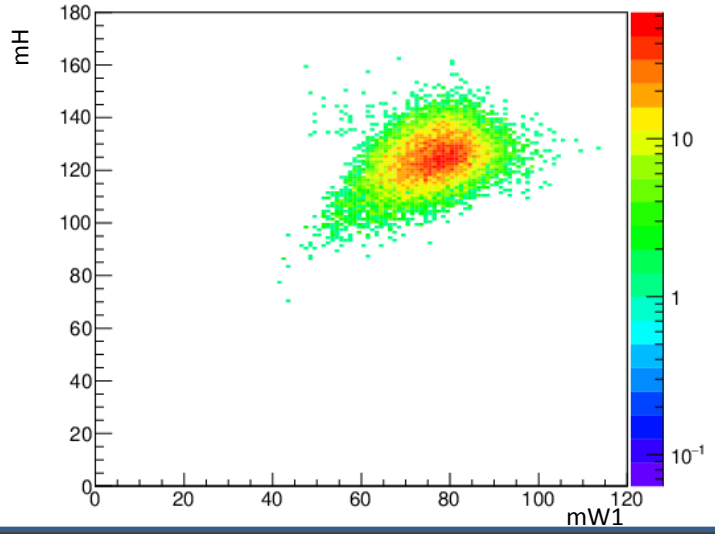



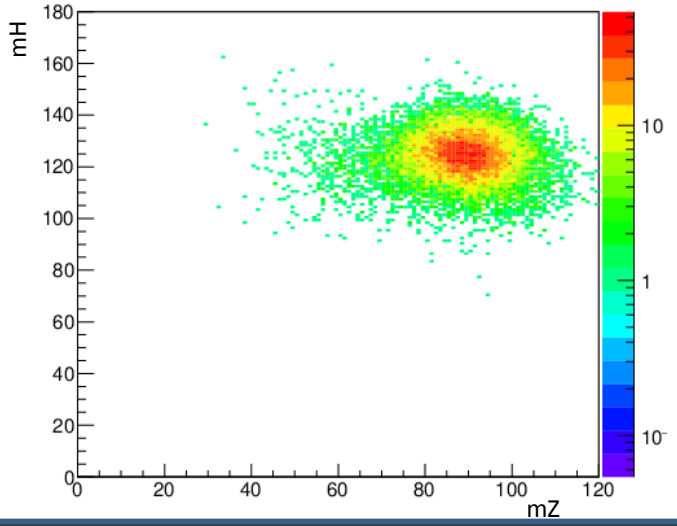



# Signal reconstruction



# Event samples

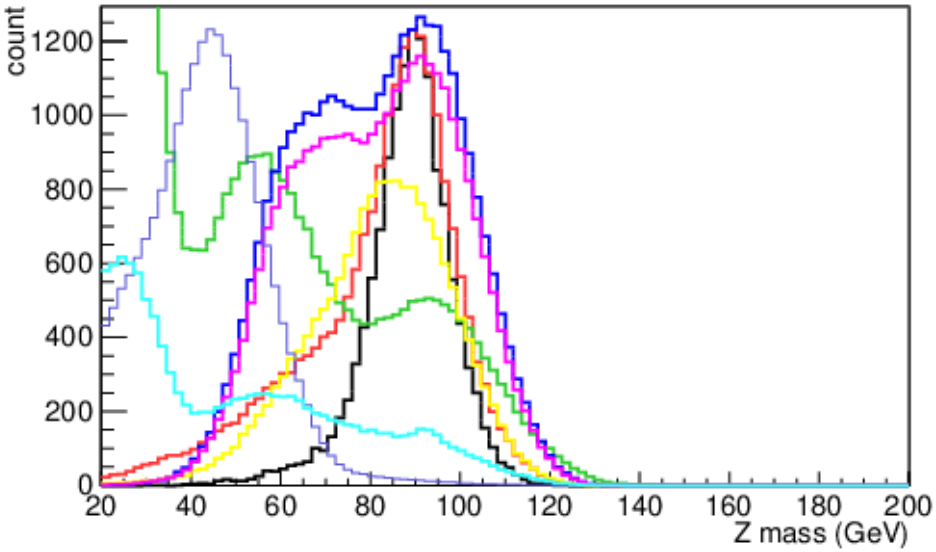
All relevant background included

criteria: signal like signature – purely hadronic; jets in the final state

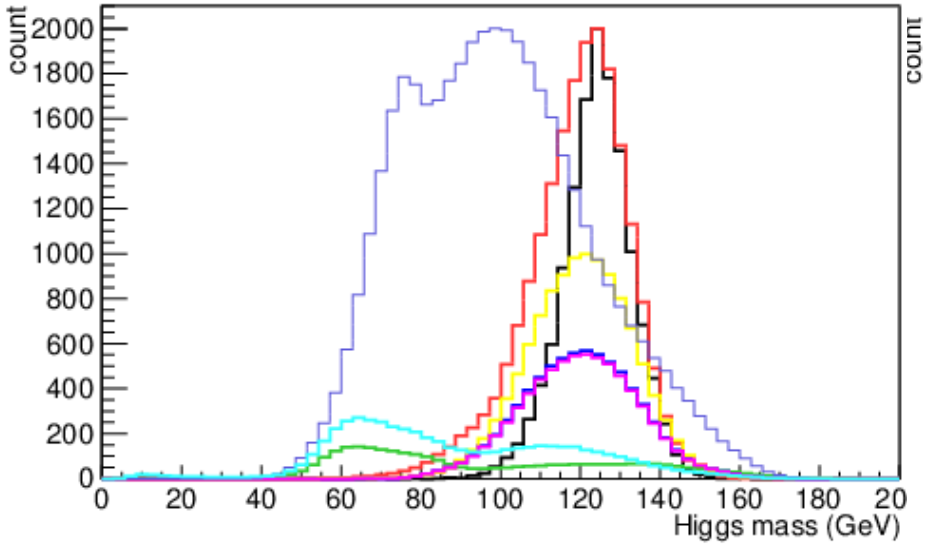
the considered backgrounds with the cut-off cross-section value $\leq \sigma_S$

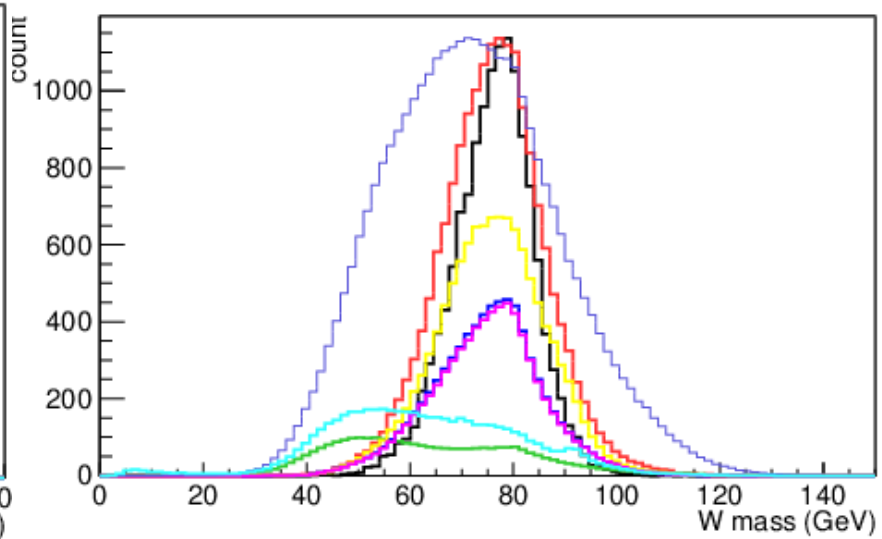
| | $\sigma$[fb$^{-1}$] P($e^+$,$e^-$)=(-80%,+20%) | expected #evts/500fb$^{-1}$ |
|---|---|---|
| Signal | 36,2 | 18 104 |
| Non WW Higgs decays | 309,8 | 154 900 |
| 2f | 129148,6 | 64 574 500 |
| 4f WW hadronic | 14874,3 | 7 437 000 |
| 4f ZZ hadronic | 1402,0 | 6 191 650 |
| 4f WW/ZZ hadronic | 12383,3 | 701 000 |
| 4f WW semileptonic | 18781,0 | 9 390 500 |
| 4f ZZ semileptonic | 1422,1 | 711 000 |

# Invariant masses of the reconstructed bosons



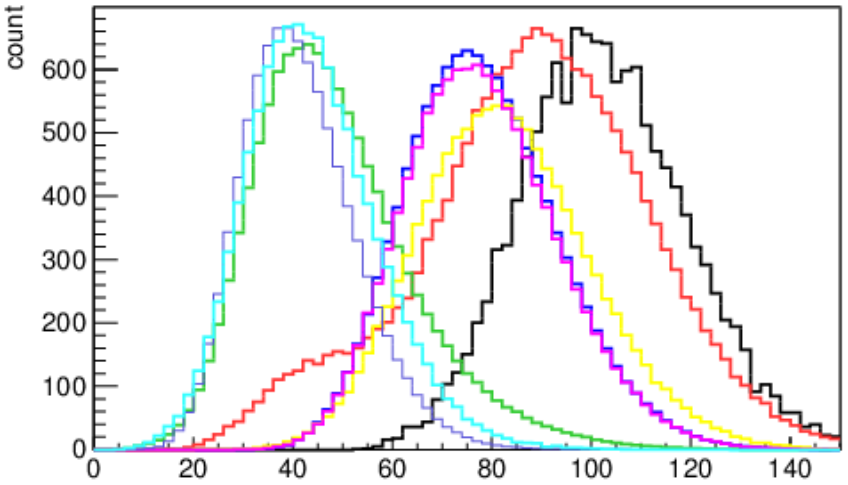


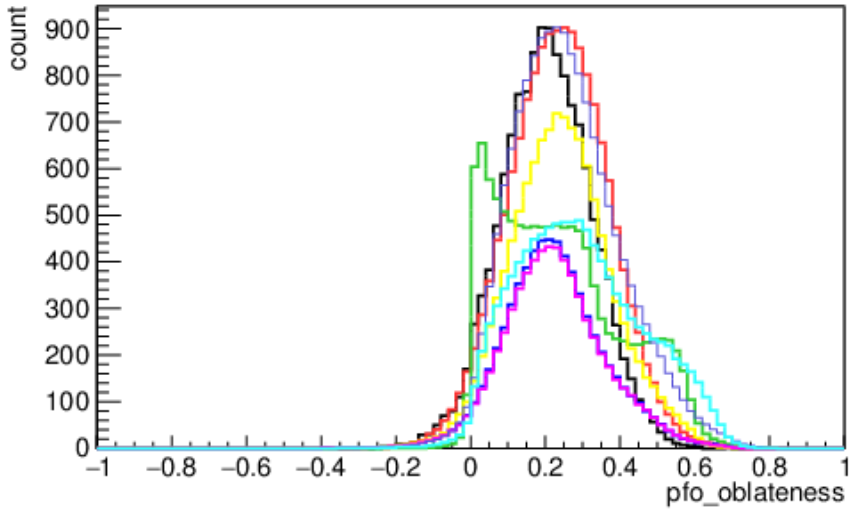


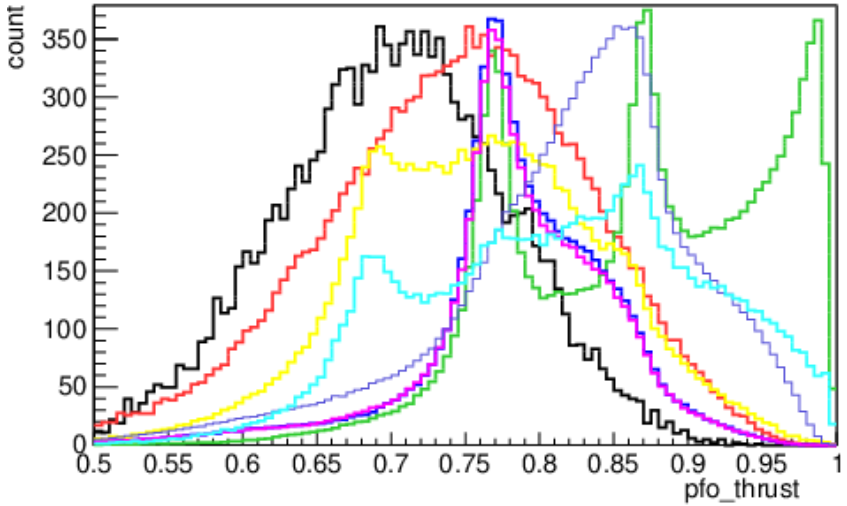
# Input variables

- Number of particle flow objects NPFO



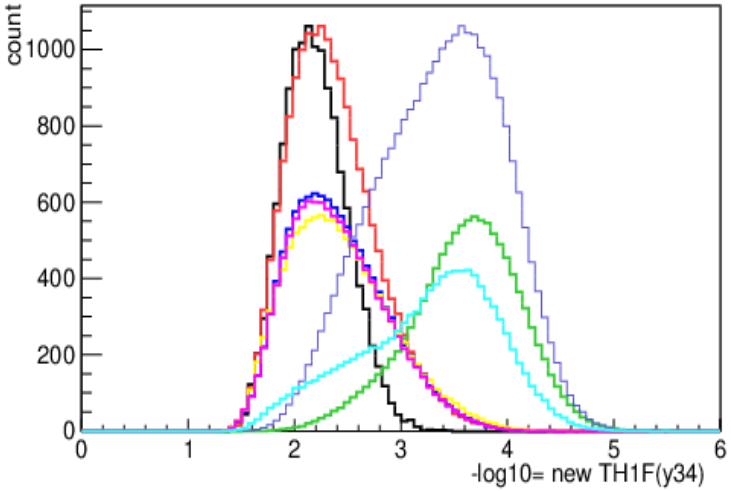



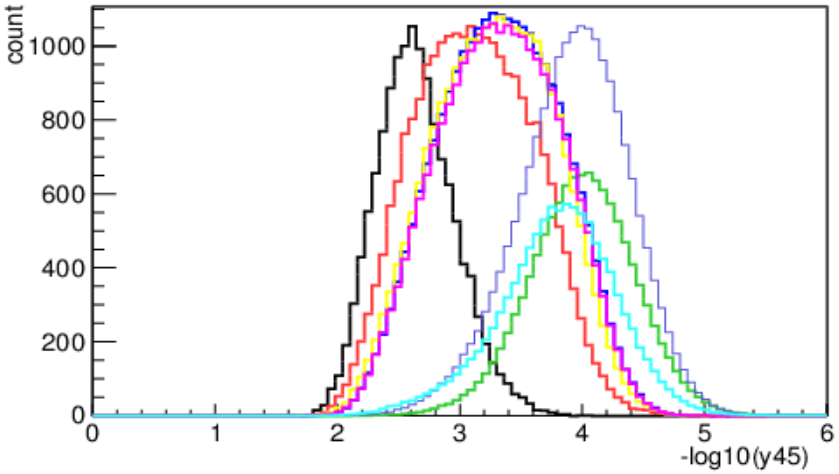

Event shape variable

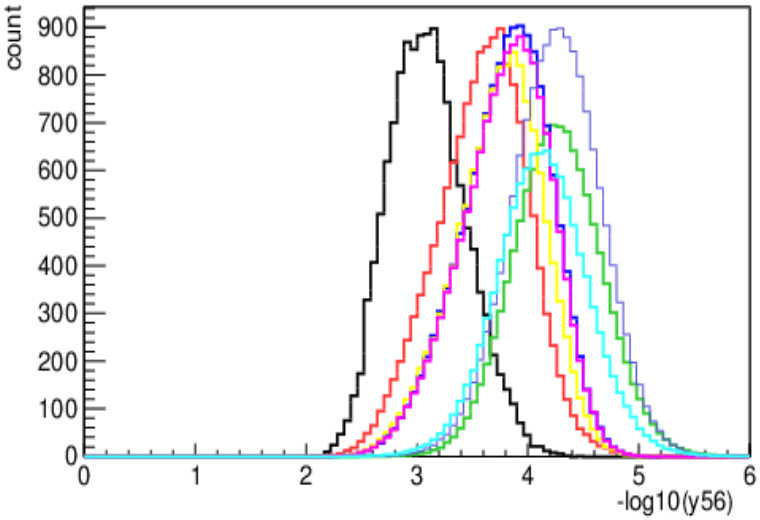



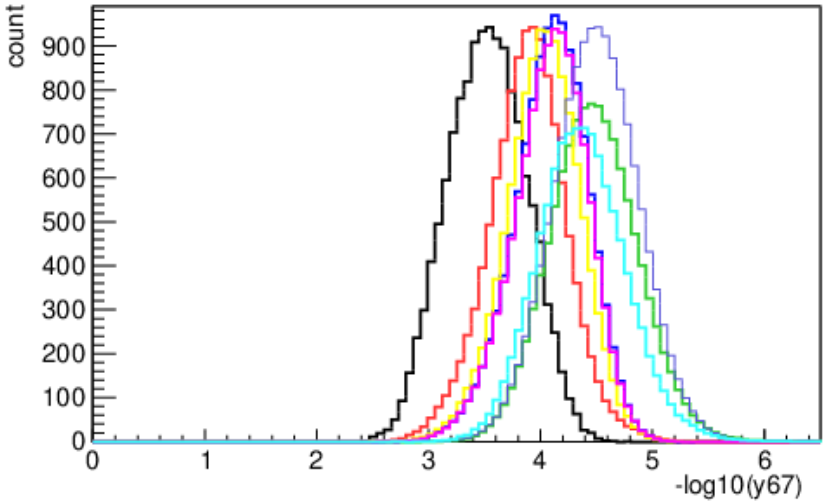
# Input variables

- Jet transition probabilities a kt value at which number of jets transits from i number of jets to j, $y_{ij}$



# Kinematical cut selection

- $m_Z$ >70. $m_H$ >100 $m_{W1}$>60
- number of particle flow objects NPFO>70  Visible energy >200 GeV  ptJet<20
- thrust<0.90
- A $k_t$ value at which a number of jets transits from (i) to (i+1) number of jets
- y12 < 2.2  y23 < 3.0  f_y34 < 3.5  y45 < 4.0  y56 < 4.0  y67 < 4.5

| | #evts / 500fb$^{-1}$ | Kinmatic Cut Eff | #evts After Kine cuts |
|---|---|---|---|
| Signal | 154 900 | **89.2** | 18856 |
| Non WW Higgs decays | 64 574 500 | 54.66 | 84448 |
| 2f | 7 437 000 | 1.47 | 950863 |
| 4f WW hadronic | 6 191 650 | 33.5065 | 2 492 230 |
| 4f WW/ZZ  hadronic | 701 000 | 33.8011 | 2 093 230 |
| 4f ZZ hadronic | 9 390 500 | 42.9216 | 300743 |
| 4f WW semileptonic | 711 000 | 0.00536228 | 503.52 |
| 4f ZZ semileptonic | 18 104 | 0.50039 | 3556.44 |

# Multivariate analysis BDTG

The training on five hadronic backgrounds (nonWW Higgs decays, 2f hadronic, 4f hadronic –WW,ZZ,Mix ZZ/WW) – better results then using also semileptonic backgrounds

- Invariant masses: $m_Z$ $m_{Higgs}$ $m_W$
- Number of particle flow objects NPFO
- Transverse momentum of;
  - Highest $P_t$ jet in the event
  - Higgs jets $P_{tHiggsJets}$
- Event shape variables: thrust, aplanarity, oblateness, sphericity
- Jet transitions: $y_{12}$ $y_{23}$ $y_{34}$ $y_{45}$ $y_{56}$ $y_{67}$
- 2jet hypothesis applied flavor tagging: second highest btag2, ctag2
- Angle between jets
  - Z: ThetaZqq
  - W: ThetaWqq

Variable set is optimized - disgarded variables: Evis, $m_{W^*}$, thetaW*qq, thetaHiggs(WW*) single jet Pt,

b tagging applied on 2 and 6 jets hypothesis- more efficient when targeting H→bb (2jet hypothesis) using only second highest

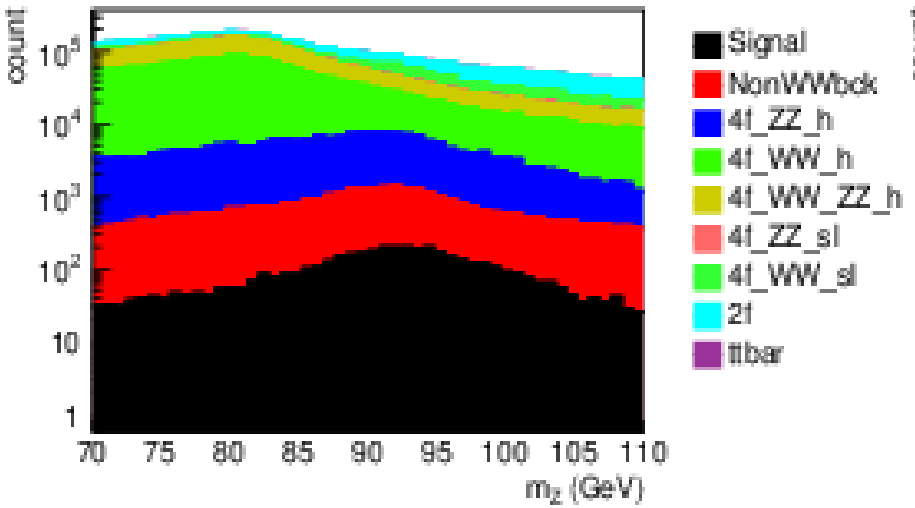
# MV Reduction efficiency

| | $\sigma$[fb$^{-1}$] | #evts after Kinematic cut 500 fb$^{-1}$ | $\varepsilon_{BDT}$ | #evts BDT 500 fb$^{-1}$ | |
|---|---|---|---|---|---|
| Signal | 22.6 | 18856 | | 5600 | |
| Non WW Higgs decays | 323.4 | 84448 | | 6338 | |
| 2fermion | 129148.6 | 950863 | | 5410 | |
| 4f WW hadronic | 14874.3 | 2 492 230 | | 14961 | |
| 4f WW/ZZ hadronic | 12383.3 | 2 093 230 | | 13340 | |
| 4f ZZ hadronic | 1402.0 | 300743 | | 7178 | |
| 4f WW semileptonic | 18781.0 | 503.52 | | - | |
| 4f ZZ semileptonic | 1422.1 | 3556.44 | | 49 | |

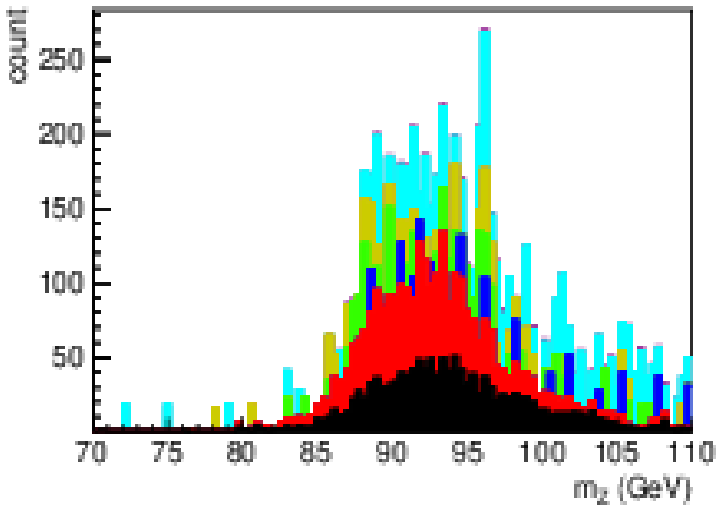
The dominant background are four fermion (jet) hadronic backgrounds due to the similar topology that can fake 6 jet signal signature

# Event selection using multivariate analysis

Cut analysis




After TMVA




- The result was obtained by optimization of significance
- The kinematic cuts prior to multivariate analysis largely reduce semileptonic backgrounds
- The training of the multivariate methods has been performed on the hadronic backgrounds
- The dominant background after final selection are 4f hadronic
- The extremely large cross section backgrounds $10^5$ , qq , can fake the signal six jet signature but it is largely reduced

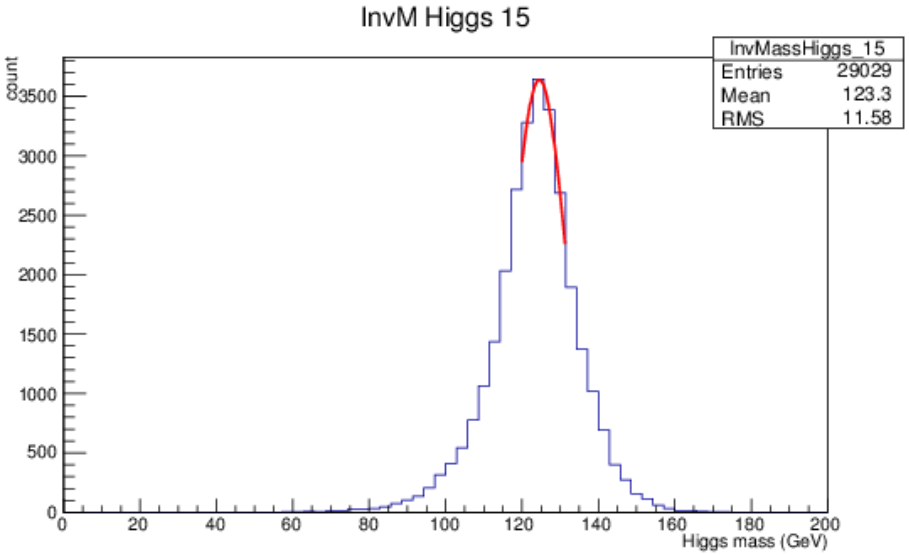
# Summary

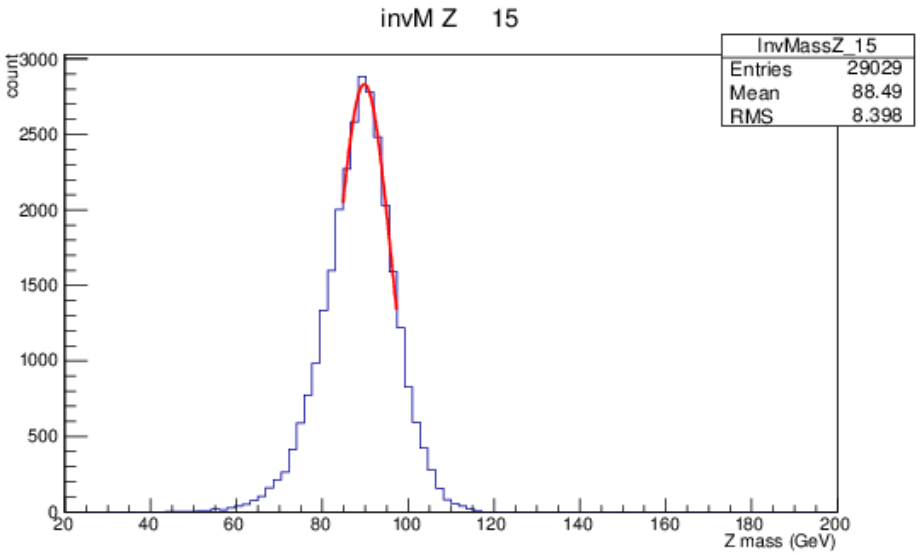
- Fully hadronic decay of H→ WW* analyzed
- All relevant background included – the considered backgrounds with the cut-off cross-section value ≤ $\sigma_S$
- High cross-section semileptonic backgrounds reduced by prior standard cut analysis
- Final background reduction performed MVA (BDTG)
- Minimization of the observable set done
- The obtained relative statistical uncertainty is 4.1 with the corresponding signal efficiency of 29%

| | |
|---|---|
| $N_S$ | 5600 |
| $\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$ | 4.1% |
| $\varepsilon_{sig}$ [%] | 29 |

# A place for slight improvement R parameter for jets

- Technicality: FastJet 2.4.2 exhibits maximum of jet opening of $R_{max} \cong 1.52$, not found in 3.1.2
- The best fit results are obtained for the R=1.5
- Jets are soft and widely spread needed slightly wider jet opening – invariant masses are slightly underestimated – better to increase over $R_{max}$ >1.52 –overload 2.4.2



# BACKUP

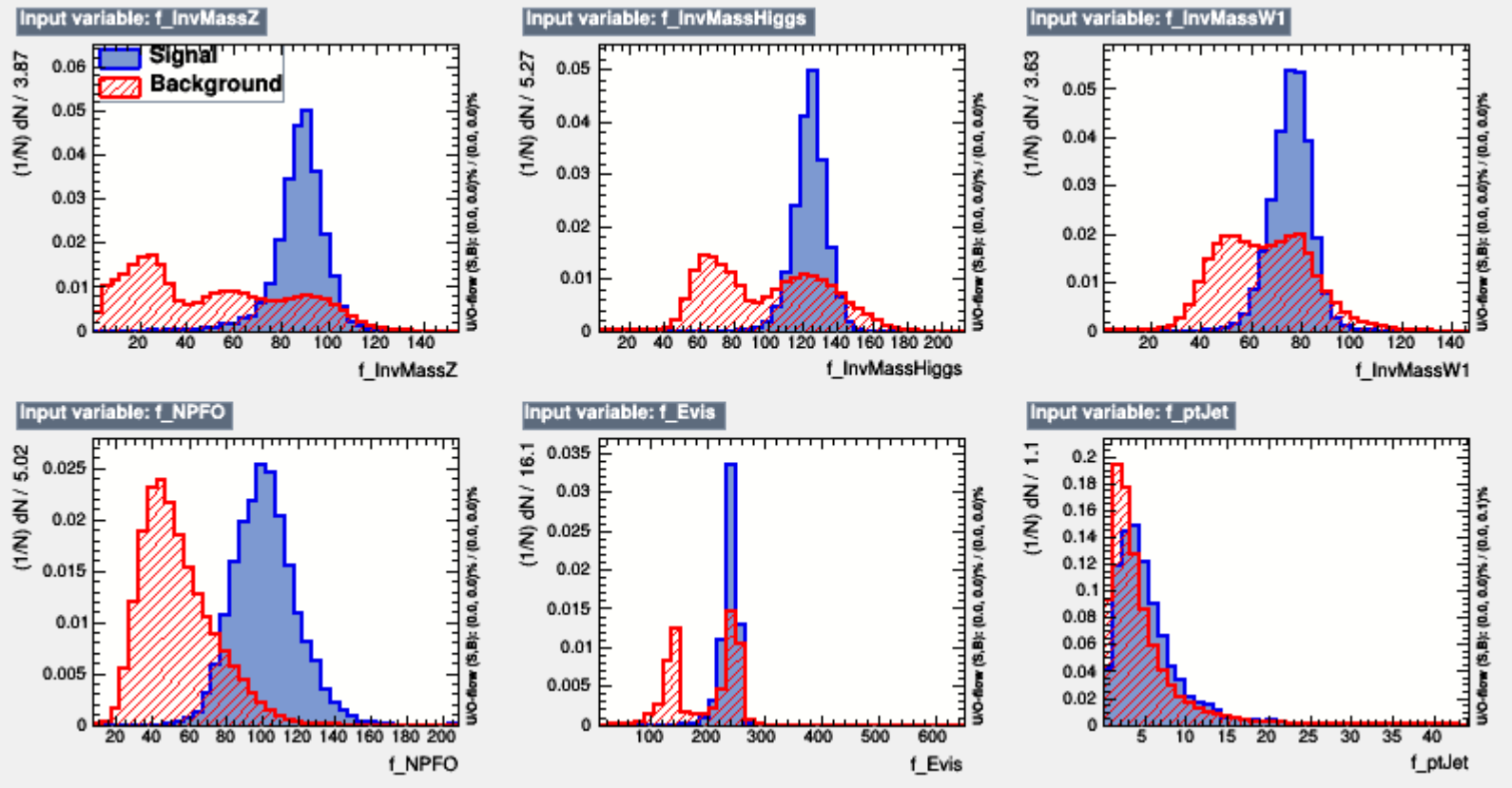
- Applying looser kinematic cut selection leads to the slight increase in the final result but with ~10% gain in signal efficiency
- Allows the optimization of the significance/signal efficiency

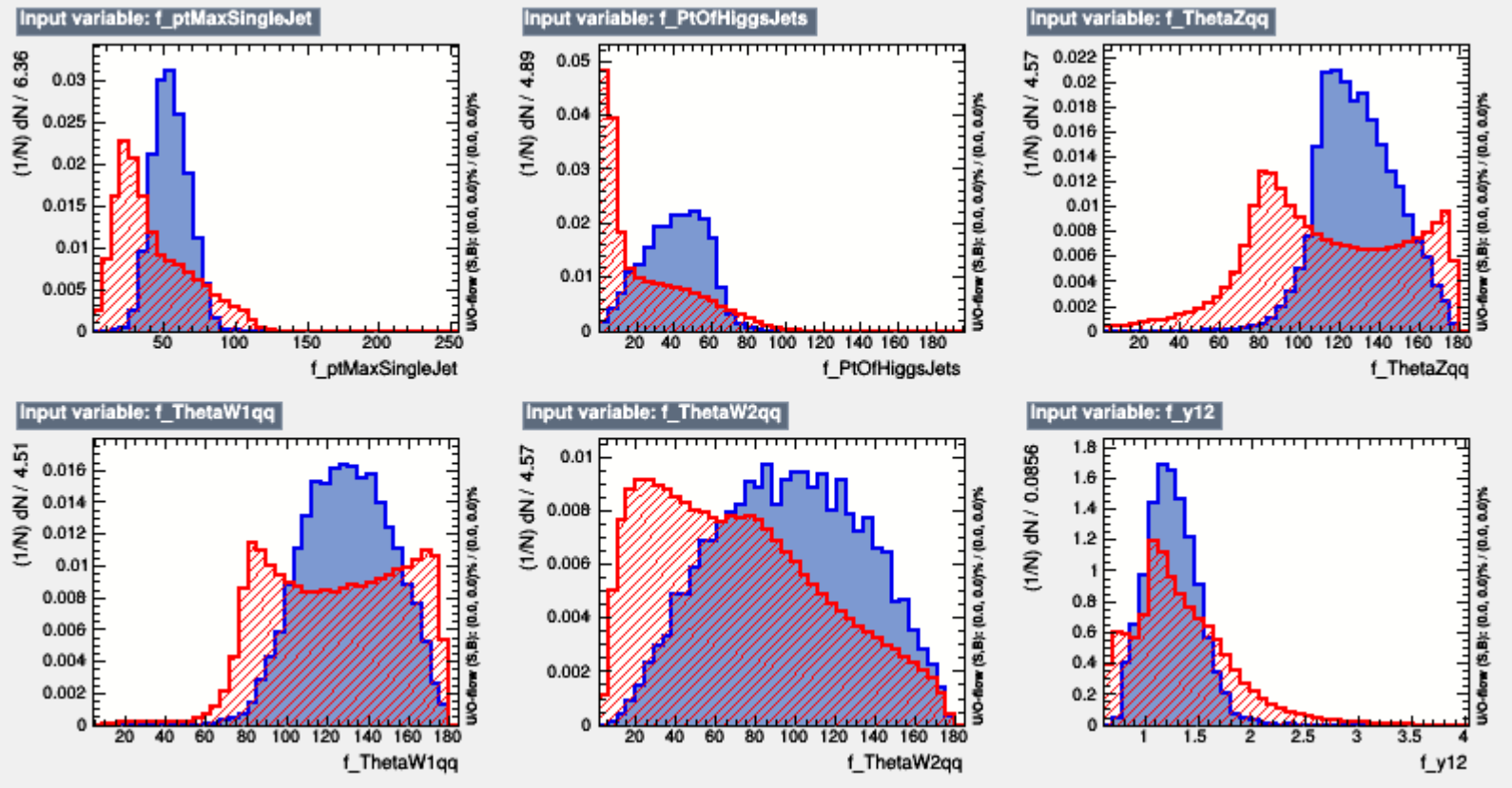
| | 250 GeV 500fb-1 | |
|---|---|---|
| Preselection criteria | | |
| $N_S$ | 5600 | 7679 |
| $\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$ | 4.1% | 4.5% |
| $\varepsilon_{sig}$ [%] | 29 | 37 |

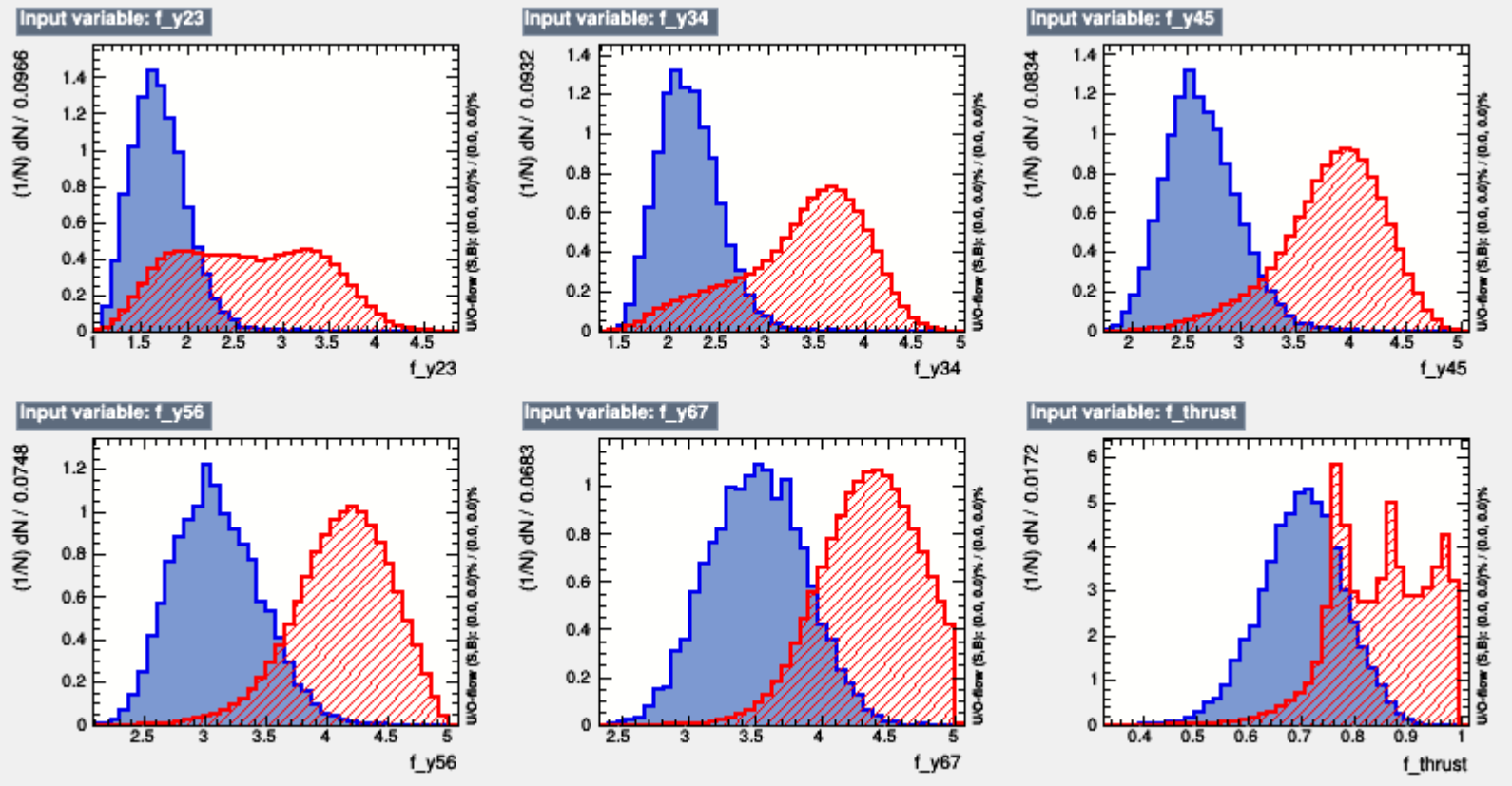
# Comparison 250 GeV vs 500 GeV

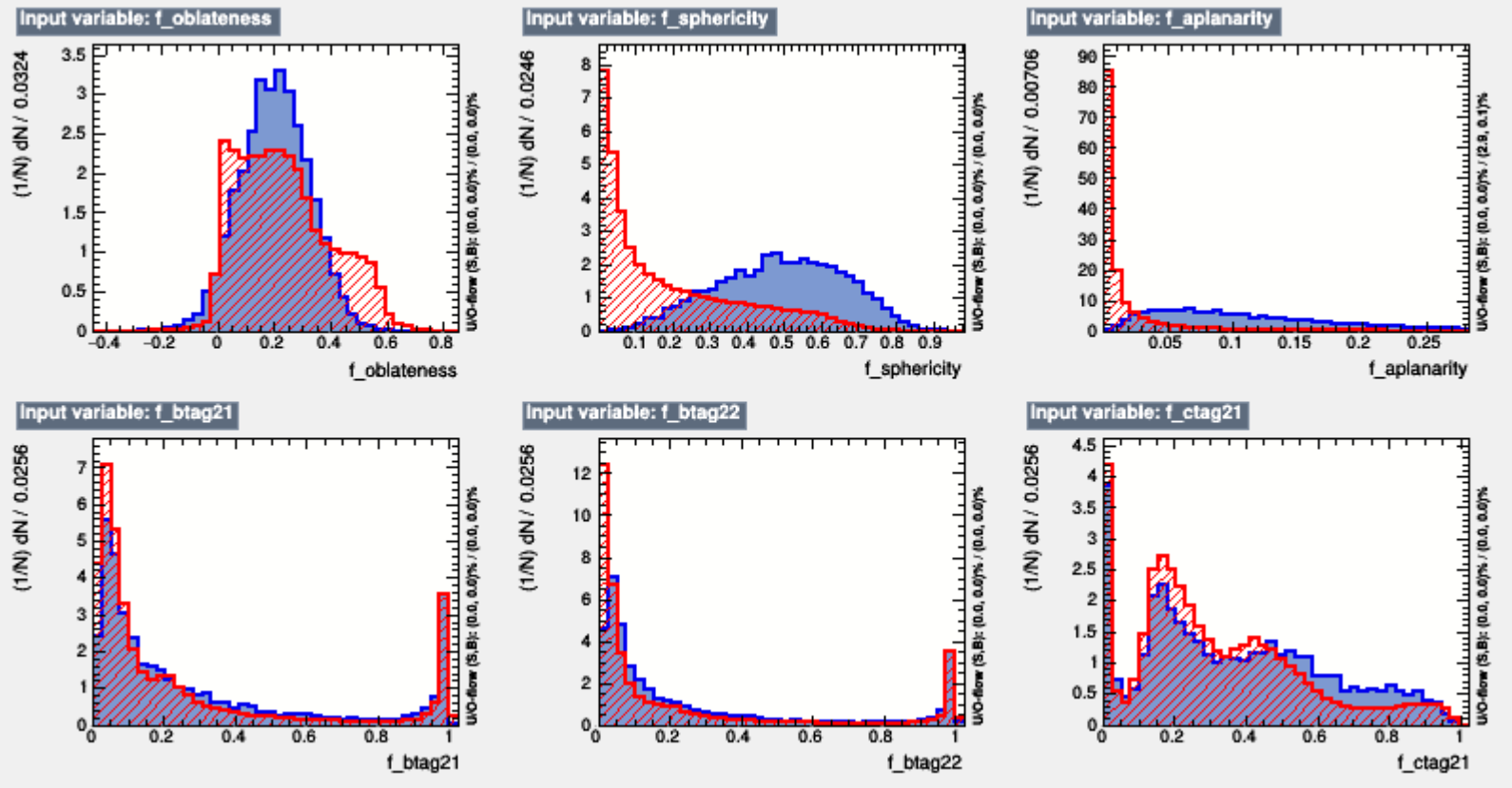
| | 250 GeV $\sigma$[fb$^{-1}$] P(e$^+$,e$^-$)=(-80%,+20%) | 500 GeV $\sigma$[fb$^{-1}$] P(e$^+$,e$^-$)=(-80%,+20%) |
|---|---|---|
| Signal | 36,2 | 11.3 |
| Non WW Higgs decays | 309,8 | 103.5 |
| 2f | 129148,6 | 32470.5 |
| 4f WW hadronic | 14874,3 | 7680.7 |
| 4f ZZ hadronic | 1402,0 | 680.2 |
| 4f WW/ZZ hadronic | 12383,3 | 6400.1 |
| 4f WW semileptonic | 18781,0 | 9521.5 |
| 4f ZZ semileptonic | 1422,1 | 608.6 |

| | | |
|---|---|---|
| $N_S$ | 5600 | 1348 |
| $\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$ | 4.1% | 6% |
| $\varepsilon_{sig}$ [%] | 29 | 30 |


Input variable: f_InvMassZ
Signal
Background
(1/N) dN / 3.87
f_InvMassZ
Input variable: f_InvMassHiggs
(1/N) dN / 5.27
f_InvMassHiggs
Input variable: f_InvMassW1
(1/N) dN / 3.63
f_InvMassW1
Input variable: f_NPFO
(1/N) dN / 5.02
f_NPFO
Input variable: f_Evis
(1/N) dN / 16.1
f_Evis
Input variable: f_ptJet
(1/N) dN / 1.1
f_ptJet
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


Input variable: f_ptMaxSingleJet
(1/N) dN / 6.36
f_ptMaxSingleJet
Input variable: f_PtOfHiggsJets
(1/N) dN / 4.89
f_PtOfHiggsJets
Input variable: f_ThetaZqq
(1/N) dN / 4.57
f_ThetaZqq
Input variable: f_ThetaW1qq
(1/N) dN / 4.51
f_ThetaW1qq
Input variable: f_ThetaW2qq
(1/N) dN / 4.57
f_ThetaW2qq
Input variable: f_y12
(1/N) dN / 0.0856
f_y12
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


Input variable: f_y23
(1/N) dN / 0.0966
f_y23
Input variable: f_y34
(1/N) dN / 0.0932
f_y34
Input variable: f_y45
(1/N) dN / 0.0834
f_y45
Input variable: f_y56
(1/N) dN / 0.0748
f_y56
Input variable: f_y67
(1/N) dN / 0.0683
f_y67
Input variable: f_thrust
(1/N) dN / 0.0172
f_thrust
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%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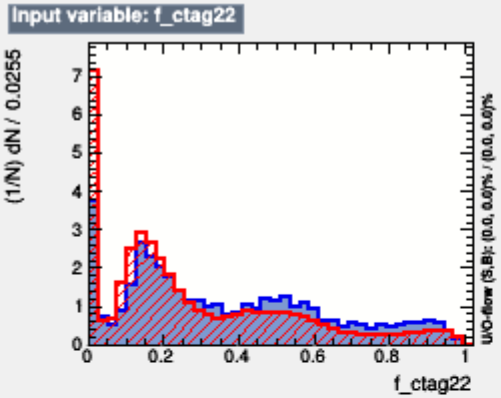
(1/N) dN / 0.0324
f_oblateness
Input variable: f_sphericity
(1/N) dN / 0.0246
f_sphericity
Input variable: f_aplanarity
(1/N) dN / 0.00706
f_aplanarity
Input variable: f_btag21
(1/N) dN / 0.0256
f_btag21
Input variable: f_btag22
(1/N) dN / 0.0256
f_btag22
Input variable: f_ctag21
(1/N) dN / 0.0256
f_ctag21


Input variable: f_ctag22
(1/N) dN / 0.0255
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
f_ctag22
0
1
2
3
4
5
6
7
0.2
0.4
0.6
0.8
1