Fully hadronic Higgs decay $H \to WW^* \to qqqq$ in Higgsstrahlung HZ, $Z \to qq$ at 250 GeV CepC

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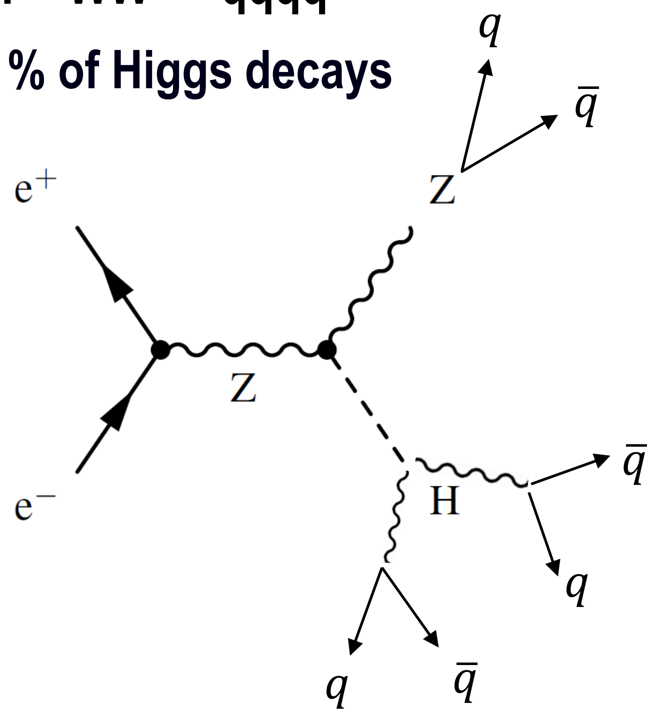
Introduction

- **Analyzed HZ fully hadronic decay, signal : Z→qq , H→WW*→qqqq**
- **$BF_{H126\to WW}$~23.0% , $BF_{WW\to qqqq}$~45.4% ⇒ signal ~ 10 % of Higgs decays**



- $\sigma_{HZ,\,Z\to qq}$ ~ 143,39 fb (unpolarized beams)
- $\sigma_{(HZ,\,Z\to qq\,,\,H\to WW^*\to qqqq)}$ ~ 16,12 fb

- Measurement of the relative branching fraction

$$\frac{g^2_{HZZ}\cdot g^2_{HWW}}{\Gamma_H}$$

- **Signal signature: 6 central jets in the final state**
- Goal of the analysis:
  - Calculate the statistical potential for the determination of the specific Higgs couplings
  - Verify the analysis strategy

Two Analysis strategies

Fast Jet : Forcing events into 6 jets

⇓

Lcfi Vertexing

⇓ ⇓

Preselection

⇓

MV selection

⇓

Static cuts analysis

⇓

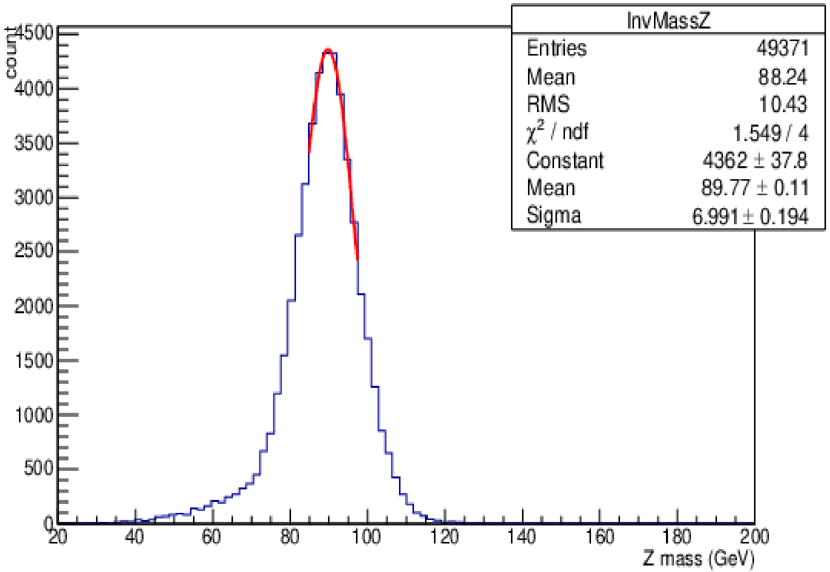
Relative statistical precision

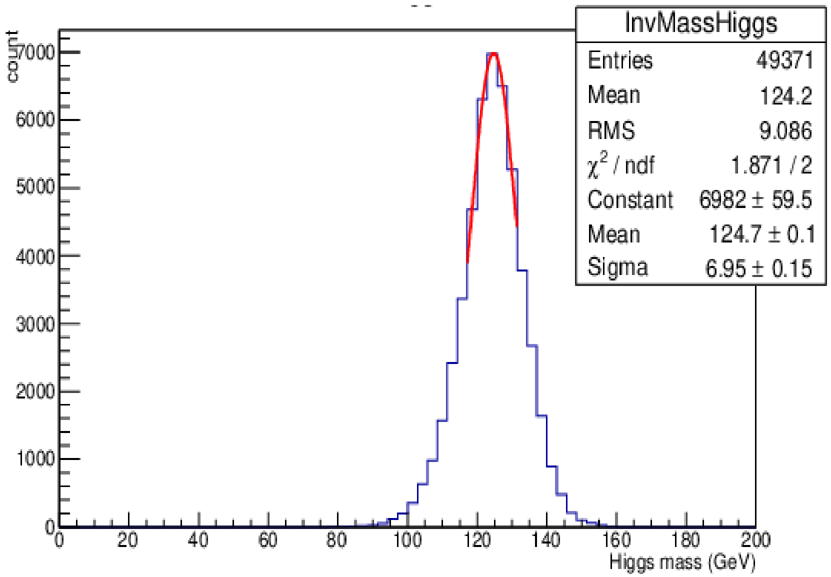
$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S}$$

Signal reconstruction

- k_T **exclusive, particle flow with Arbor v3.1**
- **Jet formation: force events into 6 jets, do the jet pairing to form H (W and W*), Z**

  - Fit in boson the peak vicinity (±10 GeV, ±5 GeV,) for the Higgs and the Z boson for several jet openings **R=0.8, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5**
  - The best result is obtained for R=1.5





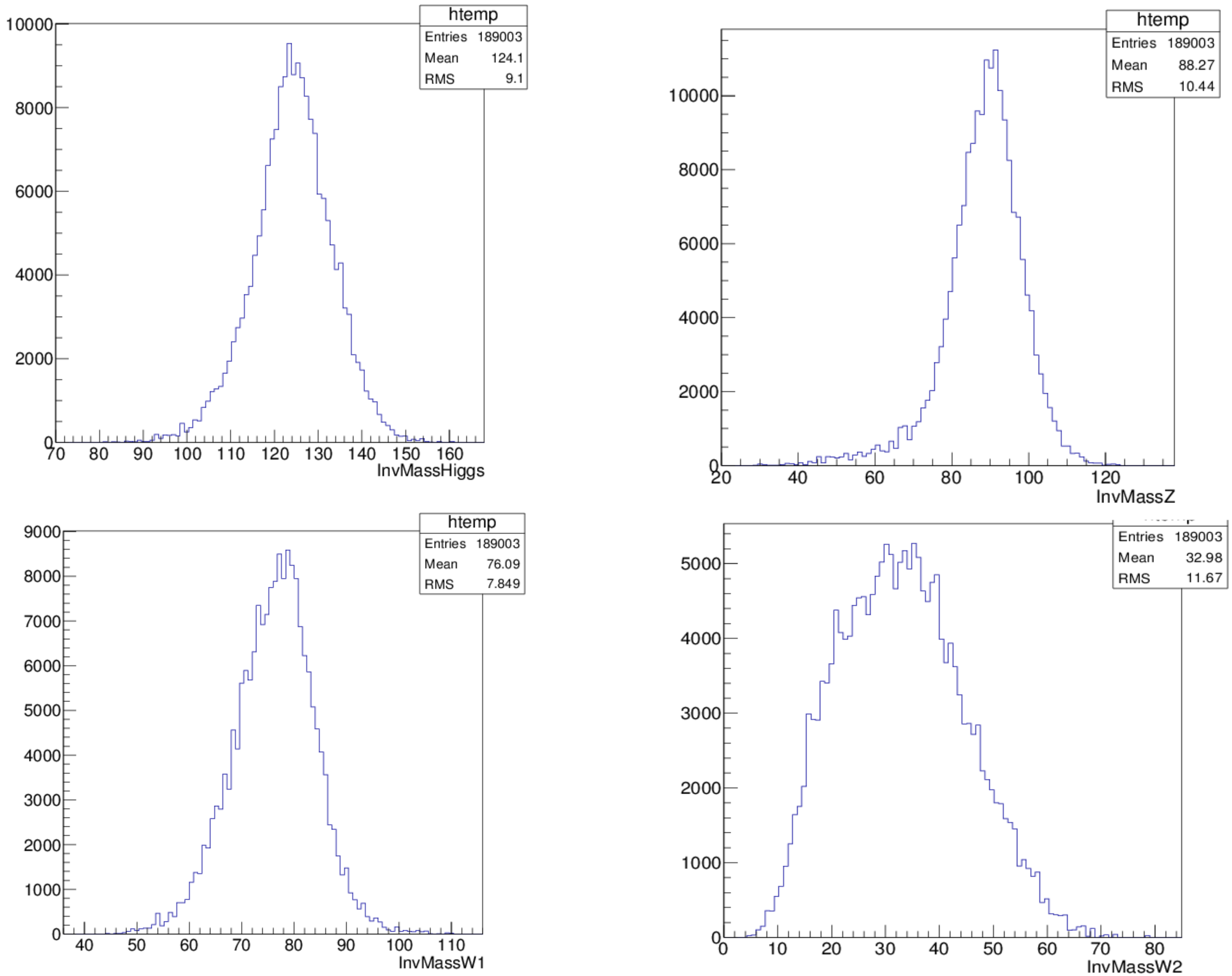
Reconstruction of the Higgs, Z and W bosons

- In order to reconstruct the Higgs, Z, W boson reconstruction the event is forced into six jets
- Obtained jets are grouped into three pairs to form the W, W* and Z bosons
- From WW* pair - the Higgs boson
- The combination which minimizes the χ^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 corresponding σ are the WA width was taken $\sigma^2_{H,W,Z}$

Reconstructed boson invariant masses for signal



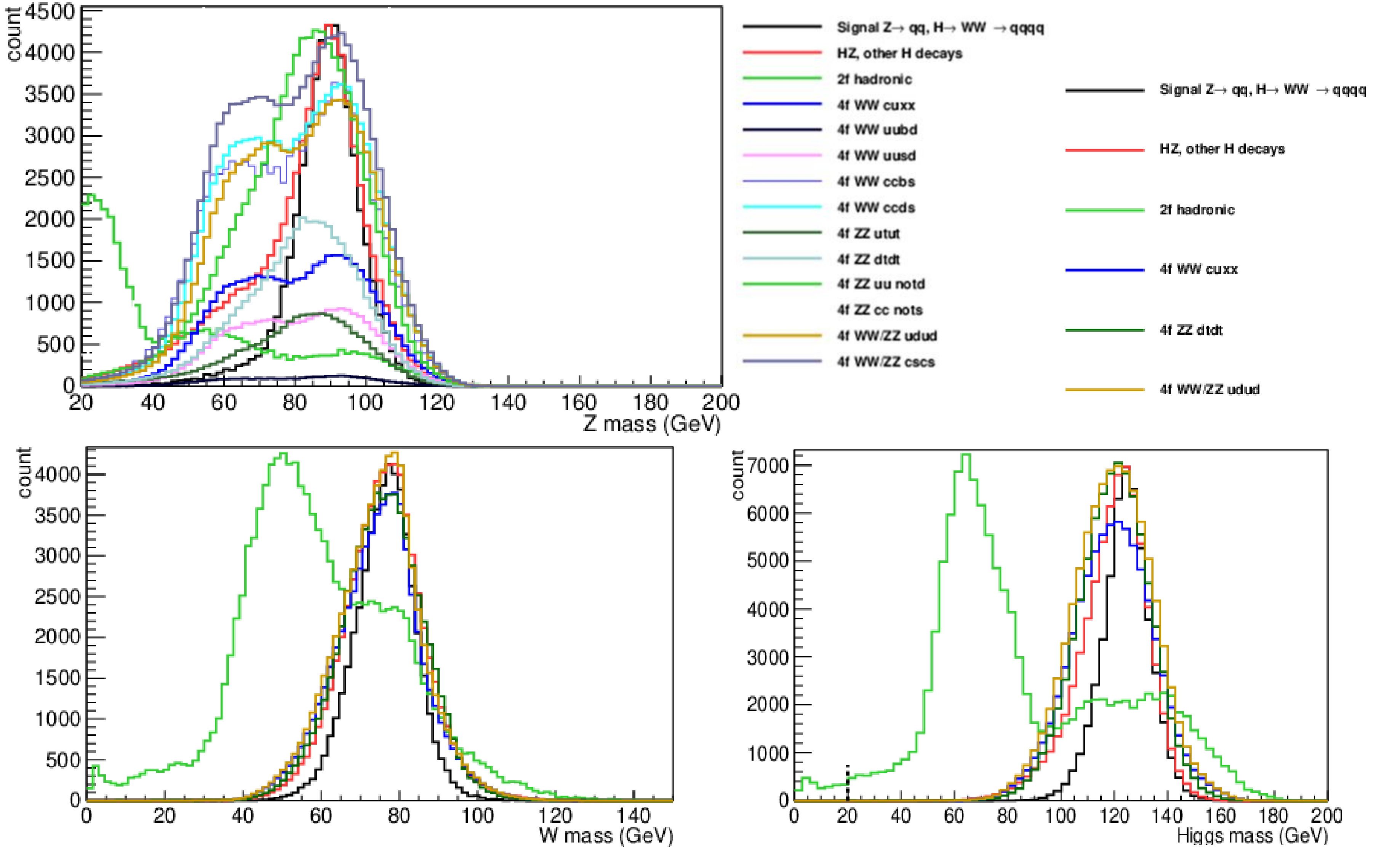
Signal and background samples

sample	$\sigma[fb]$	$\#evts/5ab^{-1}$	$\#evts\ used$
$qqh \rightarrow q\bar{q}WW^* \rightarrow q\bar{q}q\bar{q}q\bar{q}$	16,12	80600	74342
$other\ Higgs\ decays$ $non\ qqh \rightarrow q\bar{q}WW^* \rightarrow q\bar{q}q\bar{q}q\bar{q}$	127,27	636350	644354
$2f$	49561,30	247806500	100000
$4f\_ww\_cuxx$	3395,48	16977400	1220200
$4f\_ww\_ccbs$	5,74	28700	99400
$4f\_ww\_ccds$	165,57	827850	1343474
$4f\_ww\_uubd$	0.05	250	99800
$4f\_ww\_uusd$	165,94	829700	691057
$4f\_Mix\_udud$	1570,40	7852000	2782962
$4f\_Mix\_cscs$	1568,94	7844700	2375076
$4f\_zz\_utut$	83,09	415450	400000
$4f\_zz\_dtdt$	226,20	1131000	332600
$4f\_zz\_uu\_notd$	95,65	478250	477400
$4f\_zz\_cc\_nots$	96,04	480200	337400

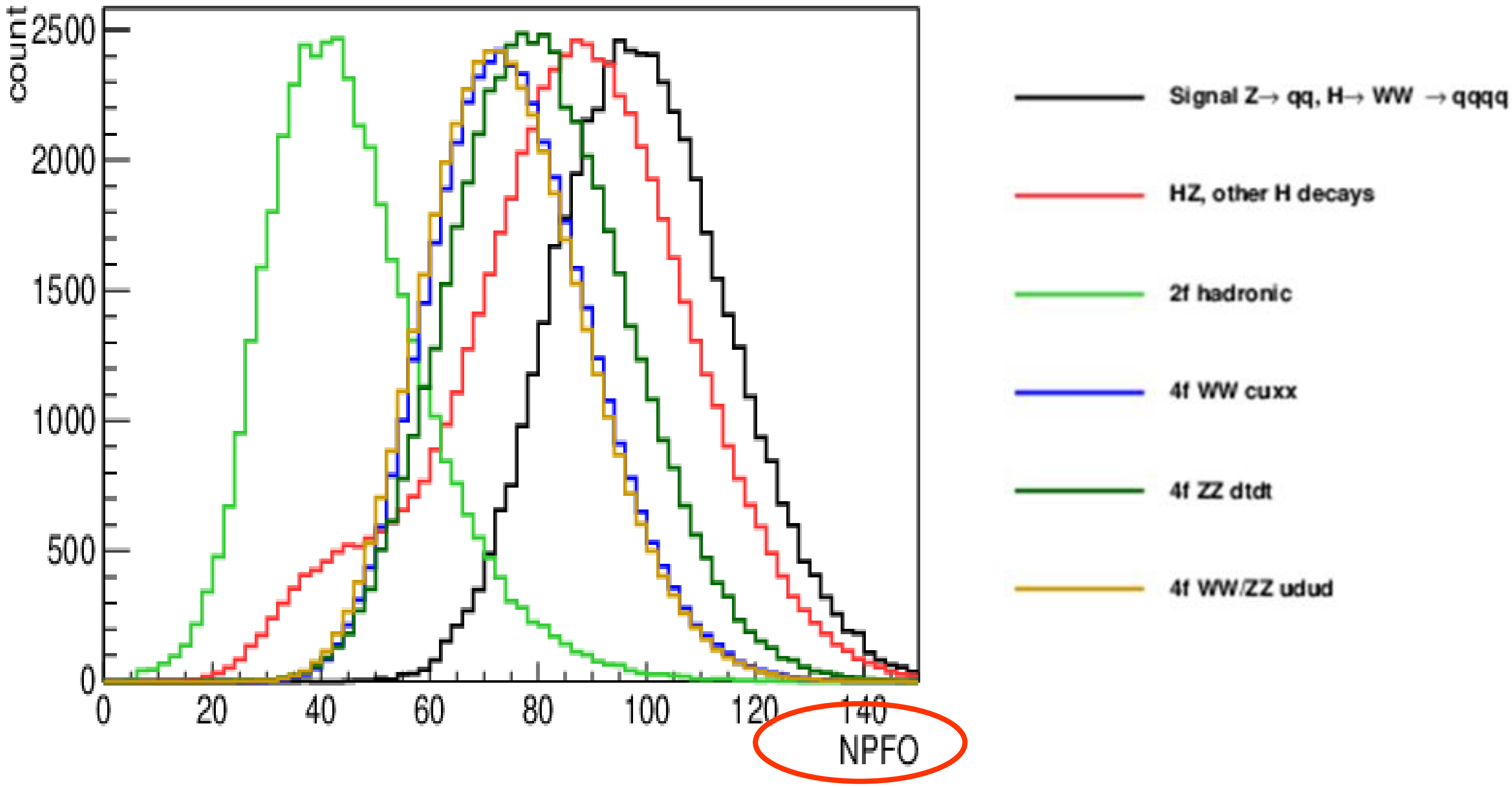
Investigated variables

- Invariant masses: m_{Higgs} m_Z m_W m_{w*}
- Number of particle flow objects NPFO
- Visible energy E_{vis}
- The highest transverse momentum of the jet in the event –highestPtJet
- Transverse momentum of the Higgs boson PtOfHiggsJets
- Event shape variables: thrust, oblatness, sphericity, aplanarity
- Jet transitions: y_{12} y_{23} y_{34} y_{45} y_{56} y_{67}
- Force event into 2 jet: btag1, btag2, btag1*btag2
- ctag1, ctag2
- Force event into 6 jet: $btag_{i,}$ $ctag_i$
- Angle between jets that comprise W boson: ThetaWqq,
- Angle between jets that comprise Z boson: ThetaZqq
- Angle between W and W* that comprise the Higgs boson : ThetaHiggsW1W2
- Arithmetic variable Energy*Theta of the W, Higgs and Z boson

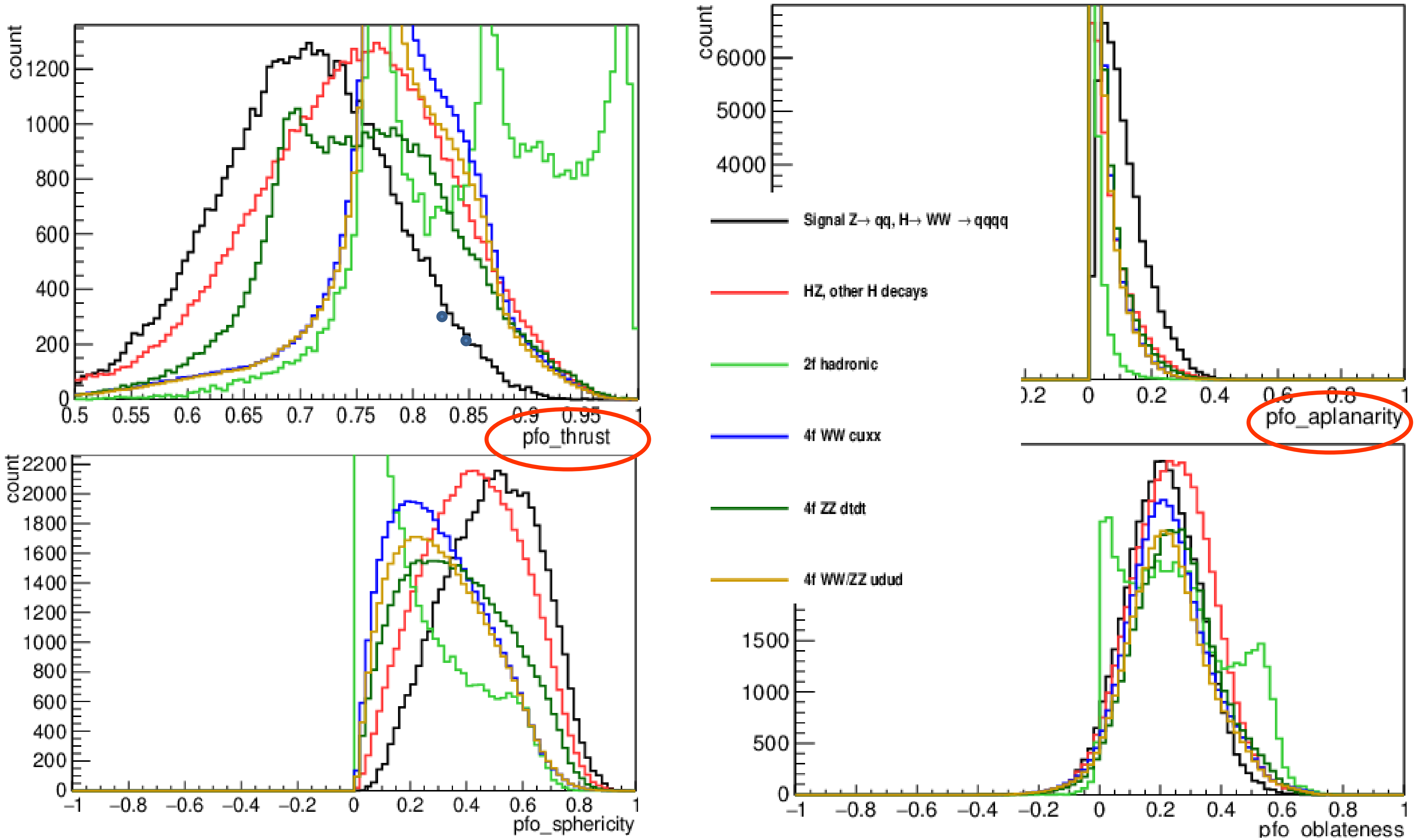
Invariant masses



Number of particle flow objects

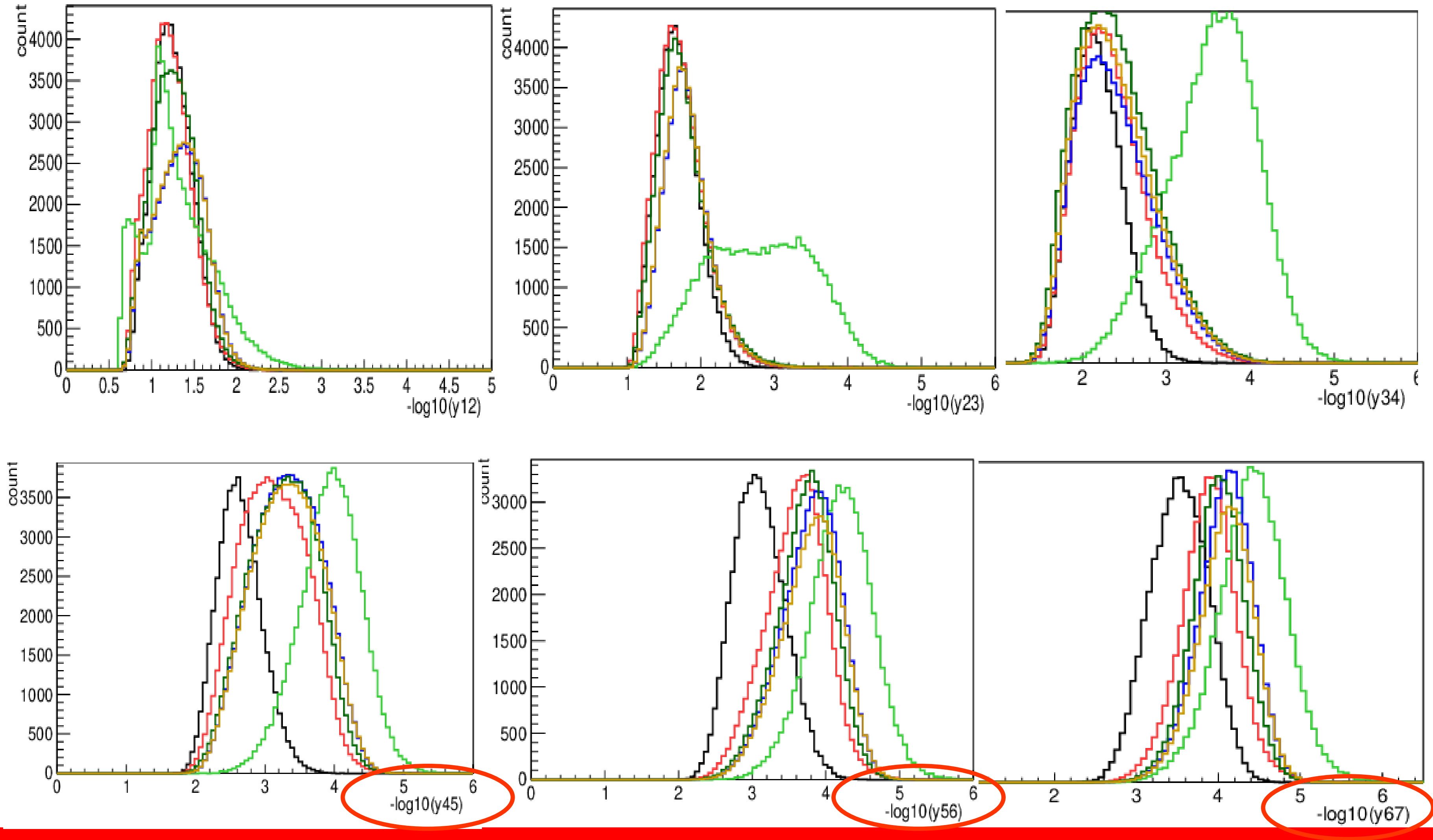


The event shape variables



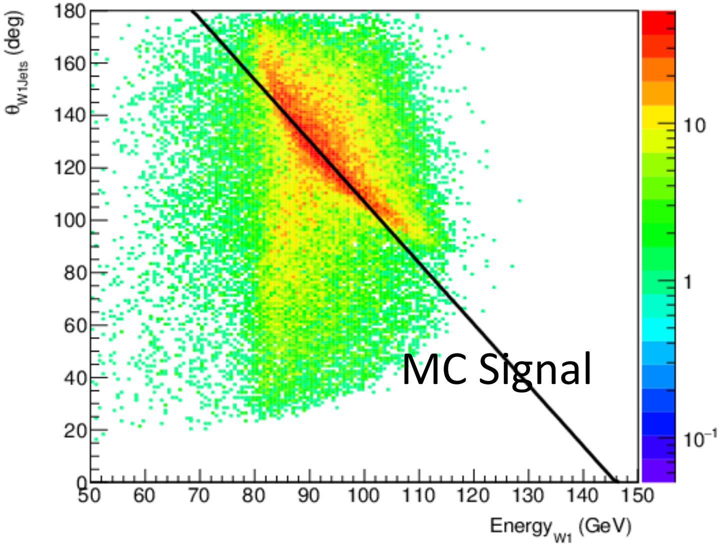
Jet transitions

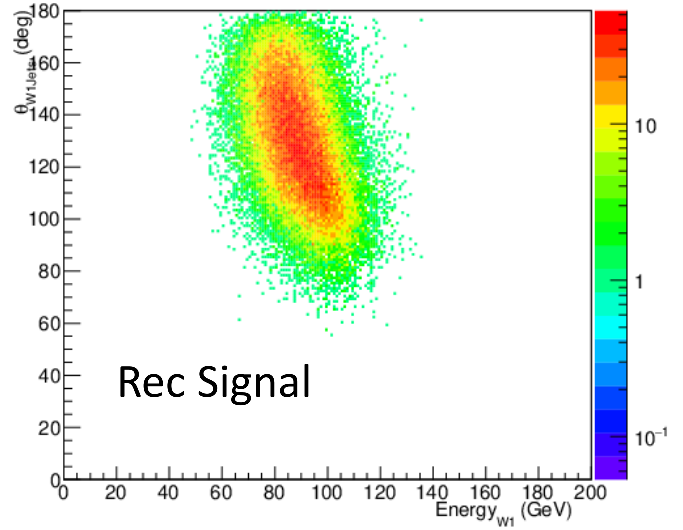
- The k_t values at which the number of jet goes from $i \rightarrow i + 1$ number of jets

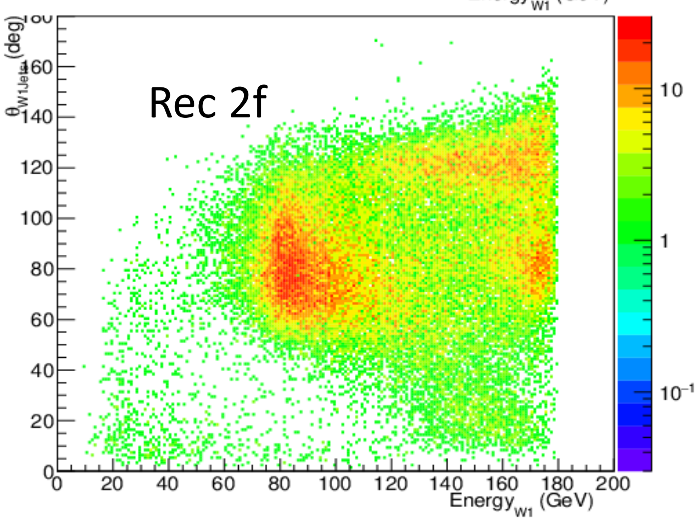


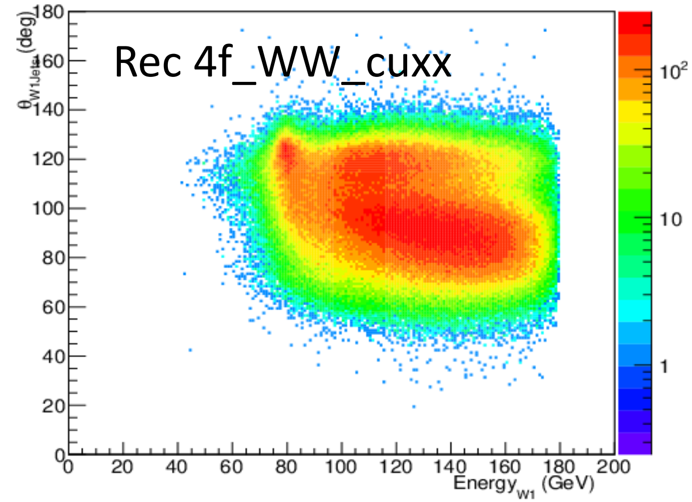
New variable construction based on signal Monte Carlo information

The distribution of the energy of the W real boson versus the angle between jets that comprise it



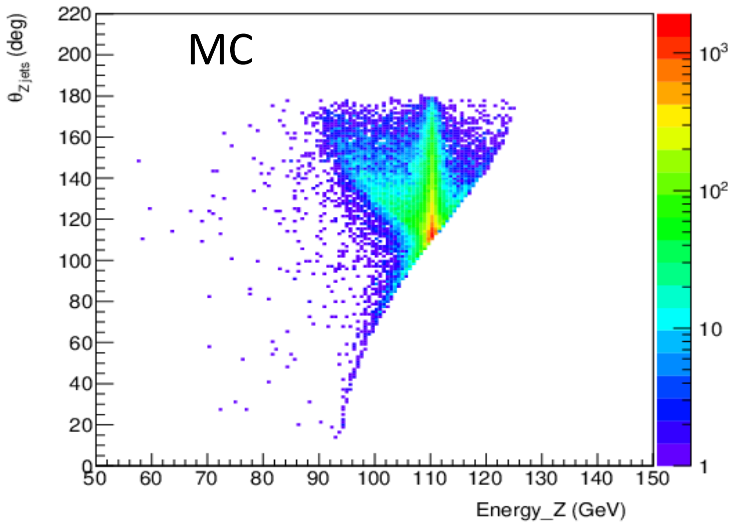


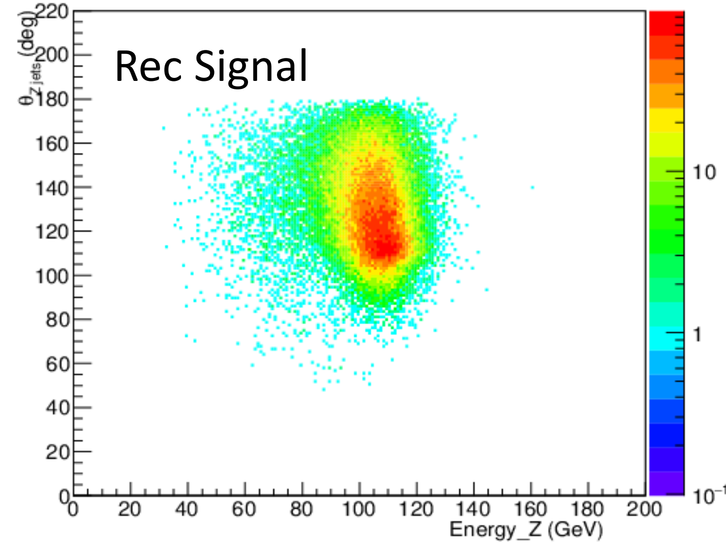


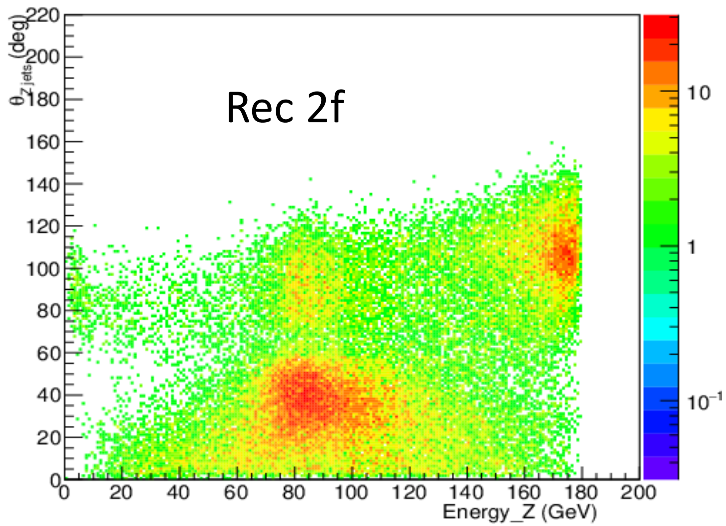


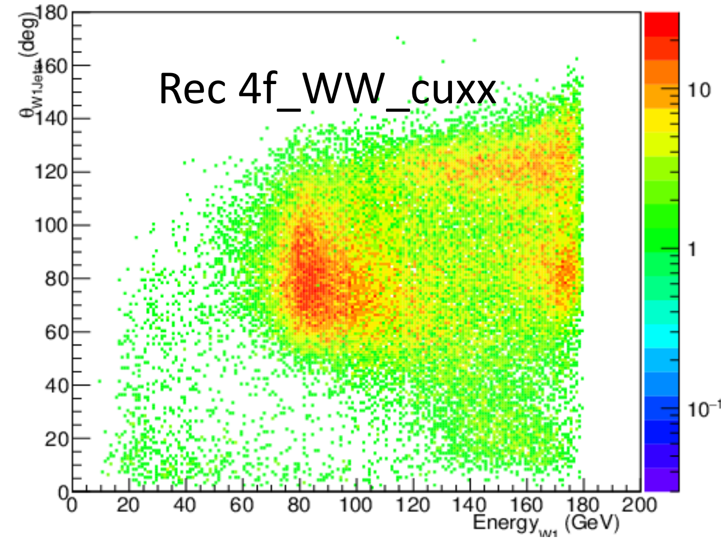
New variable construction energy theta of the Z boson

The distribution of the energy of the W real boson versus the angle between jets that comprise it

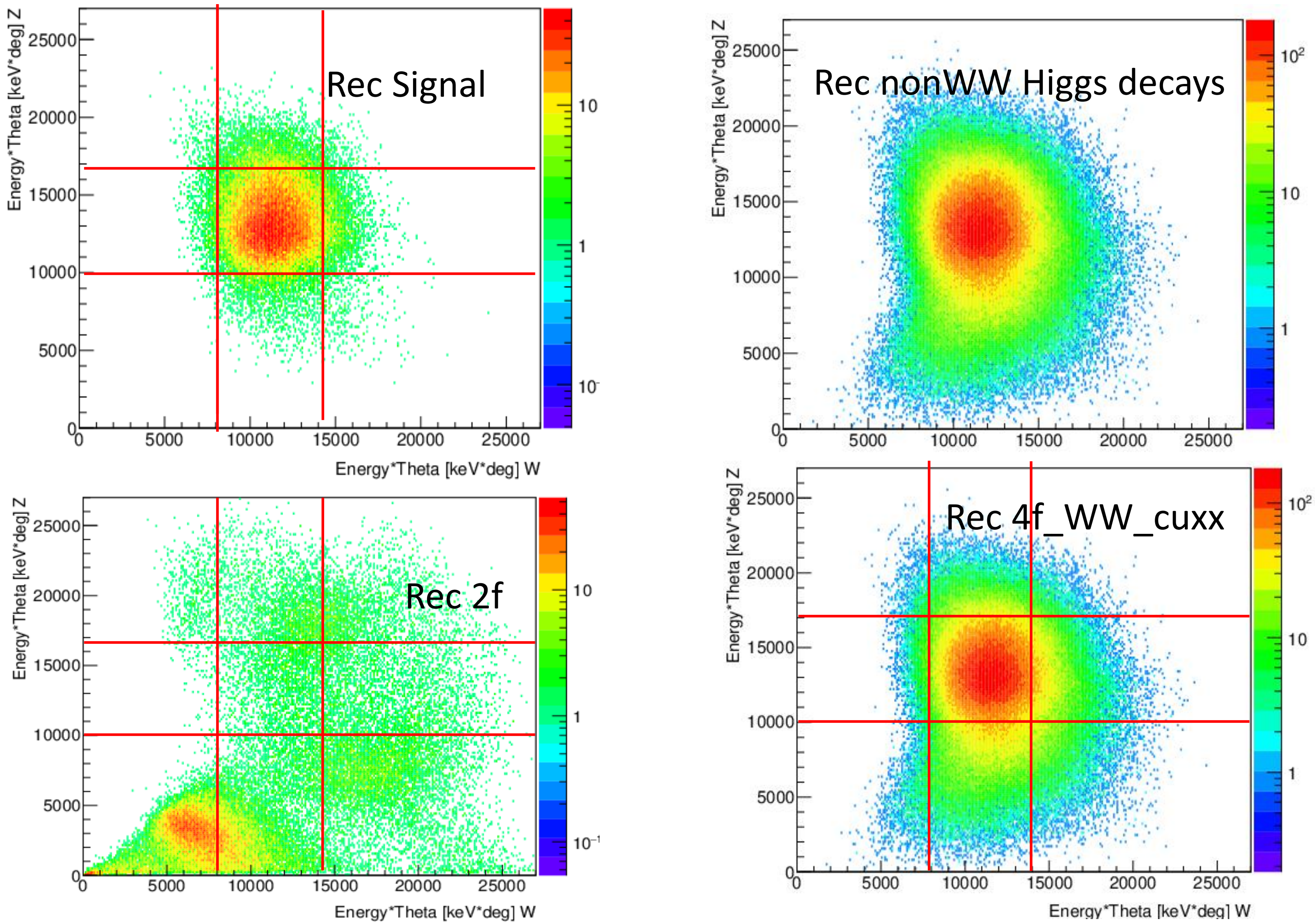








Arithmetic Variables Energy*Theta for W boson



Multivariate approach : preselection

- 8000< EnergyThetaW <14000. 10000<EnergyThetaZ <17000. NPFO>80.

sample	$\sigma[fb]$	$\#evts/5ab^{-1}$	$\varepsilon_{pres}[\%]$	$evts\ after\ preselection$
$qqh \to q\bar{q}WW^{*} \to q\bar{q}q\bar{q}q\bar{q}$	16,12	80600	70.0	56380
$other\ Higgs\ decays$ $non\ qqh \to q\bar{q}WW^{*} \to q\bar{q}q\bar{q}q\bar{q}$	127,27	636350	43.0	273975
$2f$	49561,30	247806500	0.8	1990414
$4f\_ww\_cuxx$	3395,48	16977400	16.7	2838452
$4f\_ww\_ccbs$	5,74	28700	22.5	6453
$4f\_ww\_ccds$	165,57	827850	18.3	151787
$4f\_ww\_uubd$	0.05	250	19.8	50
$4f\_ww\_uusd$	165,94	829700	15.3	127241
$4f\_ww\_zz\_udud$	1570,40	7852000	16.0	1255551
$4f\_ww\_zz\_cscs$	1568,94	7844700	17.9	1406147
$4f_zz_$utut	83,09	415450	22.0	91366
$4f\_zz\_dtdt$	226,20	1131000	27.5	311025
$4f\_zz\_uu\_notd$	95,65	478250	23.7	113345
$4f\_zz\_cc\_nots$	96,04	480200	27.8	133496

Multivariate analysis

- The training of BDTG was performed on ten background samples excluding:
  - 2f backgrounds , 4f_WW_ccbs and 4f_WW_uubd

- The variables set was optimized to a set with the minimal stable relative statistical error (41 variables investigated – 18 final variables)
  - Invariant masses: m_{Higgs} m_Z m_W
  - Number of particle flow objects NPFO
  - Highest PtJet, transverse momentum of jets that comprise Higgs boson - PtOfHiggsJets
  - Event shape variables: thrust, oblatness, aplanarity
  - Jet transitions: y_{12} y_{34} y_{45} y_{56} y_{67}
  - Force event into 2 jet: btag1, btag2
  - ctag1
  - Arithmetic variable Energy*Theta of the Z boson

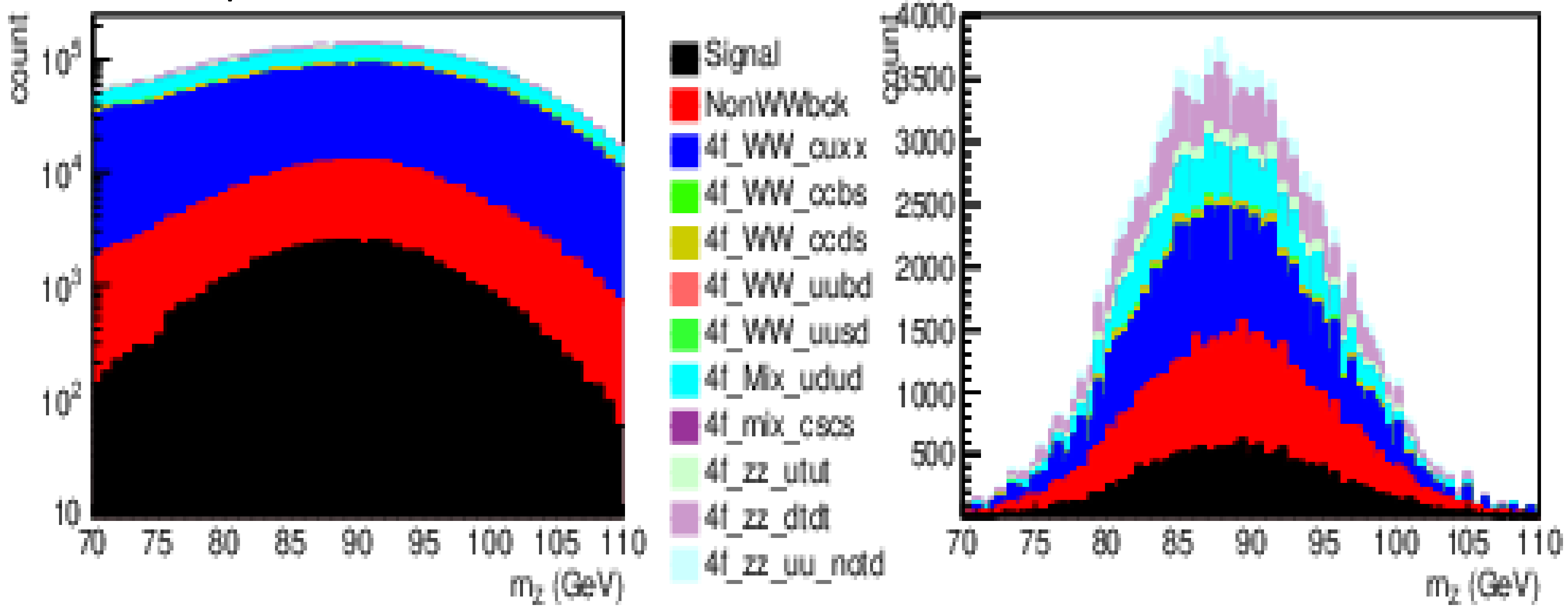
Final selection

- After preselection and multivariate analysis ~99% of the background is reduced

sample	$\sigma[fb]$	$\#evts$ $/5ab^{-1}$	$evts\ after$ $preselection$	ε_{tmva} $[\%]$	ε_{total} $[\%]$	$evts\ after$ $final\ selection$
$qqh \to q\bar{q}WW^* \to q\bar{q}q\bar{q}q\bar{q}$	16,12	80600	56380	41.3	28.85	23257
$other\ Higgs\ decays$ $non\ qqh \to q\bar{q}WW^* \to q\bar{q}q\bar{q}q\bar{q}$	127,27	636350	273975	14.1	6.1	38629
$2f$	49561,30	247806500	1990414	0.25	0.002	4976
$4f\_ww\_cuxx$	3395,48	16977400	2838452	1.45	0.24	41188
$4f\_ww\_ccbs$	5,74	28700	6453	1.7	0.38	110
$4f\_ww\_ccds$	165,57	827850	151787	1.5	0.28	2294
$4f\_ww\_uubd$	0.05	250	50	2.0	0.4	1
$4f\_ww\_uusd$	165,94	829700	127241	0.8	0.13	1073
$4f\_ww\_zz\_udud$	1570,40	7852000	1255551	1.5	0.24	19102
$4f\_ww\_zz\_cscs$	1568,94	7844700	1406147	1.6	0.29	22514
$4f_zz_$utut	83,09	415450	91366	5.5	1.2	4997
$4f\_zz\_dtdt$	226,20	1131000	311025	6.4	1.8	19845
$4f\_zz\_uu\_notd$	95,65	478250	113345	5.9	1.4	6675
$4f\_zz\_cc\_nots$	96,04	480200	133496	6.0	1.7	7949

The relative statistical uncertainty: MVA method

After preselection | After final selection



- The dominant background after final selection are ee →qqqq backgrounds
- The high cross-section $2f \rightarrow q\bar{q}$ background show good response to the preselection and multivariate analysis. The obtained relative statistical precision is 1.9 % with the corresponding signal efficiency of 29%

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \approx 1.9\%$$

Static cut analysis

- The statatic cut variables used:
  - Invariant masses: 80 <m_Z < 100 GeV
  - Invariant masses: 115 <m_H < 135 GeV
  - Number of particle flow objects NPFO > 90 GeV
  - Highest PtJet <90
  - transverse momentum of jets that comprise Higgs boson < 80 GeV
  - Jet transitions: y_{23} <2.4
  - y_{34} <2.4
  - Y_{45} <2.7
  - y_{56} <3.2
  - y_{67} <3.5
  - Arithmetic variable Energy*Theta of the Z boson 8000< EnThW<14000
  - Arithmetic variable Energy*Theta of the Z boson 10000< EnThZ<17000

Static cuts analysis results

sample	$\sigma[fb]$	$\#evts/5ab^{-1}$	$\varepsilon_{tot\ mva}$ [%]	ε_{static} [%]	$evts\ after\ final\ selection$
$qqh \to q\bar{q}WW^{*} \to q\bar{q}q\bar{q}q\bar{q}$	16,12	80600	28.85	28.9	23293
$other\ Higgs\ decays$ $non\ qqh \to q\bar{q}WW^{*} \to q\bar{q}q\bar{q}q\bar{q}$	127,27	636350	6.1	8.1	51544
$2f$	49561,30	247806500	0.002	0.02	49561
$4f\_ww\_cuxx$	3395,48	16977400	0.24	1.5	254661
$4f\_ww\_ccbs$	5,74	28700	0.38	1.9	545
$4f\_ww\_ccds$	165,57	827850	0.28	1.6	13246
$4f\_ww\_uubd$	0.05	250	0.4	1.8	5
$4f\_ww\_uusd$	165,94	829700	0.13	1.3	10786
$4f\_ww\_zz\_udud$	1570,40	7852000	0.24	1.4	109928
$4f\_ww\_zz\_cscs$	1568,94	7844700	0.29	1.6	125515
$4f_zz_$utut	83,09	415450	1.2	2.4	9971
$4f\_zz\_dtdt$	226,20	1131000	1.8	2.9	32799
$4f\_zz\_uu\_notd$	95,65	478250	1.4	2.5	11956.
$4f\_zz\_cc\_nots$	96,04	480200	1.7	2.9	13926

- After the static cut analysis ~98% of the background is reduced.
- The obtained relative statistical uncertainty 3.6 % with the corresponding signal efficiency of 29%

Summary

- The fully hadronic decay is most abundant channel in the $H \to WW^*$ decay
- In Higgsstrahlung, $Z \to qq$, this decay leads complex central six jet final state
- High cross section hadronic backgrounds
- The channel is analysed with two types of analysis flow:
  - multivariate analysis
  - static cut analysis
- The multivariate approach showed better reduction capabilities in comparison to the static cut analysis
- This is due to lack of distinct cut variables for hadronic final state
- The obtained relative statistical precission with the static cut analysis is 3.6% with the signal efficiency of 29 %, while the result obtained with the multivariate analysis is 1.9% with the corresponding signal efficiency of 29% also
- The result is obtained for the integrated luminosity of 5 ab^{-1}

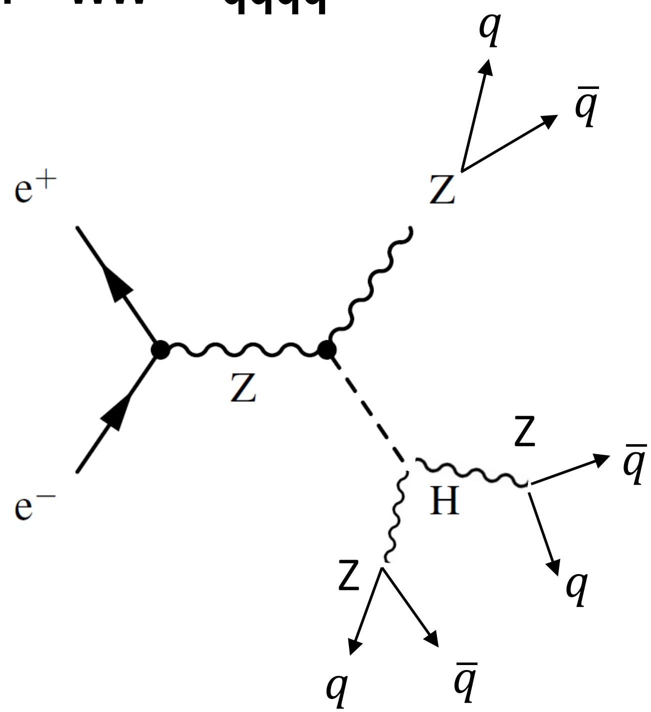
Fully hadronic Higgs decay $H \rightarrow ZZ^* \rightarrow qqqq$

in Higgsstrahlung HZ, $Z \rightarrow qq$ at 250 GeV CepC

Very preliminary test of the estimation of the stat. uncertainty

Introduction

- **Analyzed HZ fully hadronic decay, signal : Z→qq , H→WW*→qqqq**
- **$BF_{H126 \rightarrow WW}$~2.67% , $BF_{WW \rightarrow qqqq}$~48.87%**
- $\sigma_{HZ,\ Z \rightarrow qq}$ ~ 143,39 fb (unpolarized beams)
- $\sigma_{(HZ,\ Z \rightarrow qq\ ,\ H \rightarrow WW^{*} \rightarrow qqqq\ )}$ ~ 1,87 fb



- Measurement of the relative branching fraction

$$\frac{g^{4}_{HZZ}\ \cdot}{\Gamma_{H}}$$

- **Signal signature: 6 central jets in the final state**
- **Low cross section**

- Possibility of the estimation of the rel. statistical uncertainty of the cross-section xBF

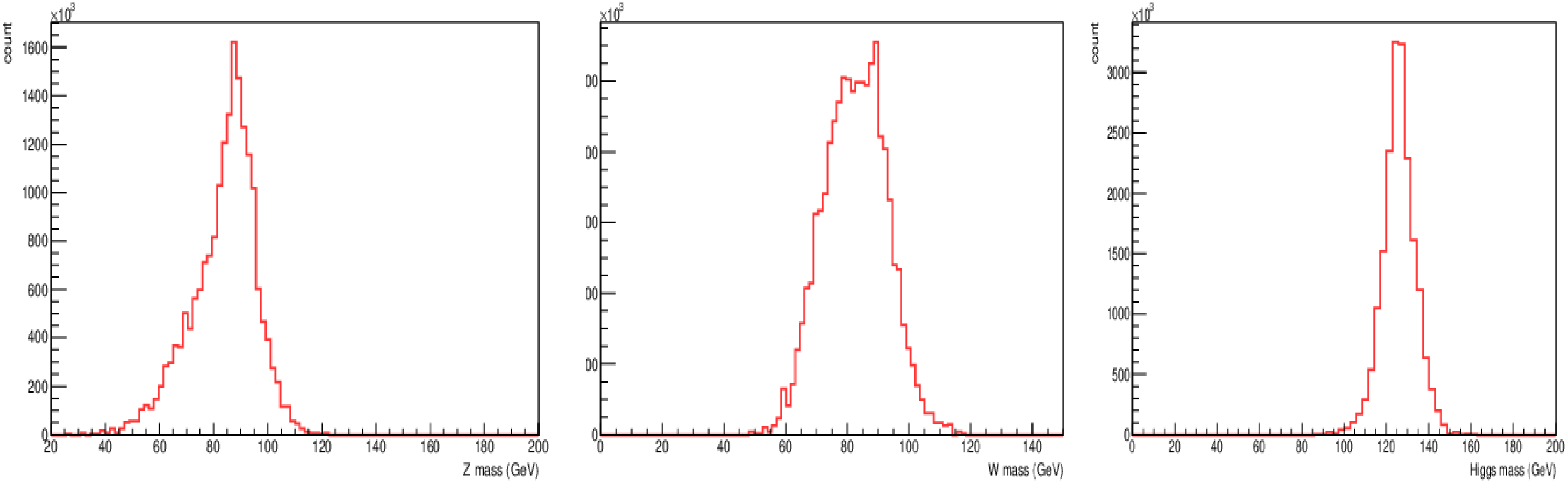
Reconstruction of the Higgs, Z and W bosons

- In order to reconstruct the Higgs, Z, Z,Z* boson reconstruction the event is forced into six jets
- Obtained jets are grouped into three pairs to form the Z, Z* from Higgs decay and Z boson from HZ
- The combination which minimizes the χ^2 is chosen :

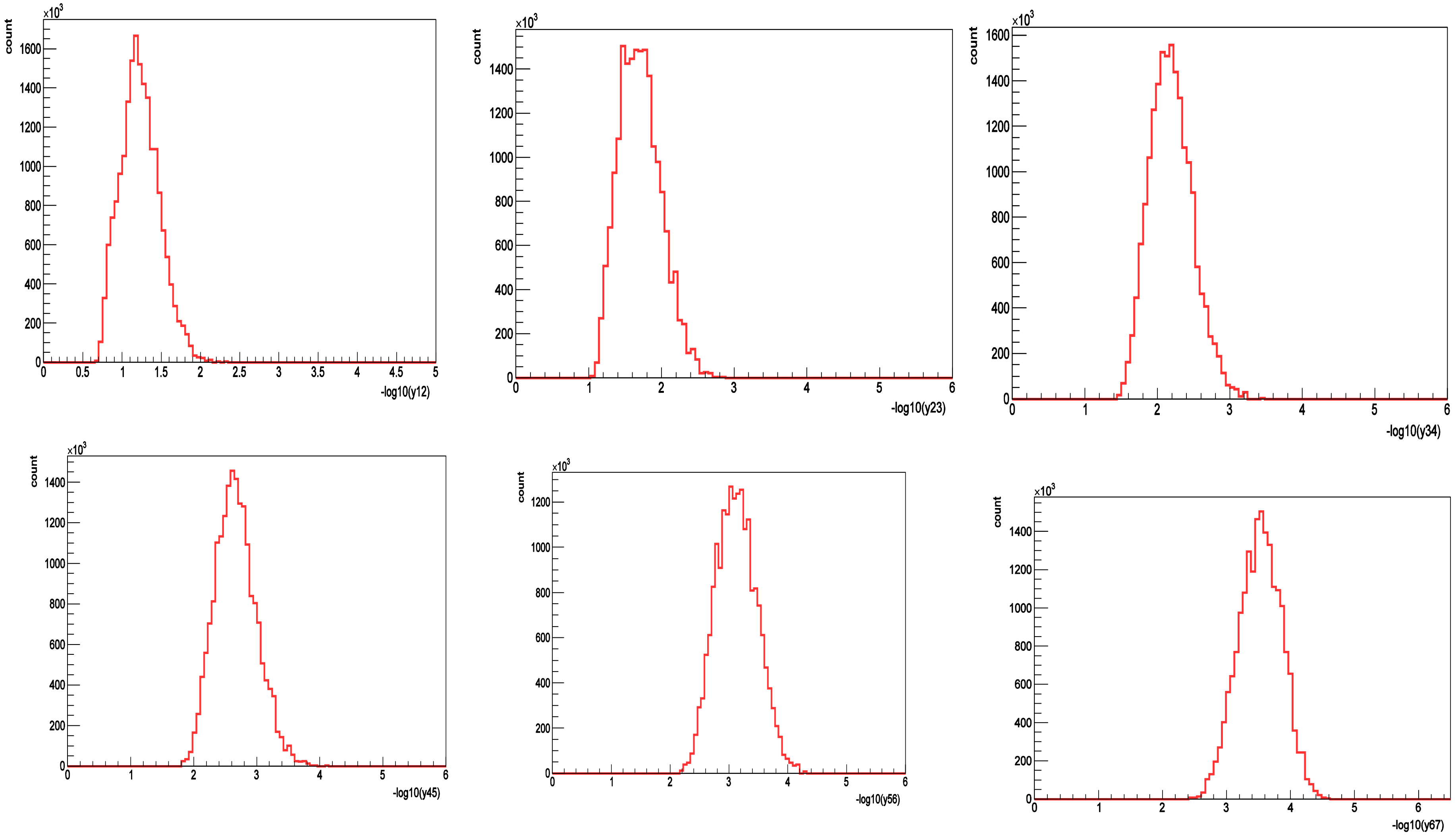
$$\chi^2 = \frac{(m_{ij} - m_Z)^2}{\sigma^2_Z} + \frac{(m_{kl} - m_Z)^2}{\sigma^2_Z} + \frac{(m_{ijmn} - m_H)^2}{\sigma^2_H}$$

- For the corresponding σ are the WA width was taken $\sigma^2_{H,Z}$
- The used chi2 is favouring the reconstruction of the Z boson which is coming from the Higgs decay

Reconstructed invariant masses



Jet transitions



Discussion

- The chi2 which was used is favoring the reconstruction of the Z boson which is coming from the decay of the Higgs boson – refinement of the chi2 is needed
- The cross-section of the other Higgs decays is nearly two orders of magnitude higher
- Fast simulation does not contain btagging tools to reduce H-bb background
- Severe other backgrounds especially 4f_WW_cuxx
- Using the fast simulation using this channel would lead to severe under estimation of the rel. statistical uncertainty
- At this point suggest to use the extrapolation that is currently used for the white paper