Prospects for the top Yukawa coupling from

$e^+ e^- \rightarrow \bar{t} t H \rightarrow b\bar{W}^- b W^+ \bar{b} b$

(Status of the Analysis)

Hajrah Tabassam

Supervisor: Victoria Martin

University of Edinburgh

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Introduction

- Once Higgs is found, its coupling with fermions is interesting to study.
- $g_{ffH} = \frac{m_f}{v}$, v is vacuum expectation value of Higgs field.
- Top is heaviest fermion, so top-Higgs Yukawa coupling is largest.
- The coupling of top to the Higgs is modified in the SUSY models
- This analysis was not done for LOI
- ILD software framework is used for this analysis

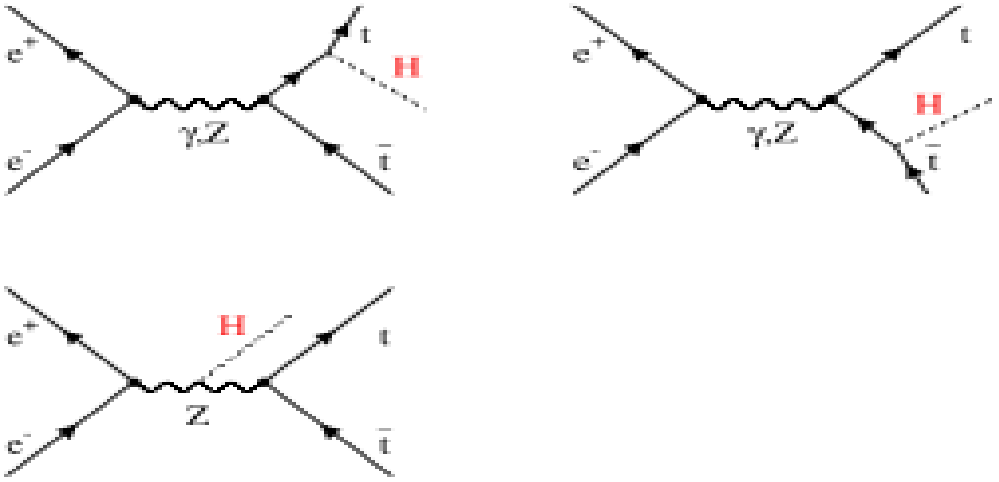


Fig. 1. Lowest order Feynman diagrams of the process $e^+e^- \to t\bar{t}H$

Samples

- ILD_00 centrally reconstructed sample with center of mass energy √s = 500 GeV.
- $t\bar{t}$-Higgs events with M_h = 120 GeV/c^2, M_t = 175 GeV/c^2.

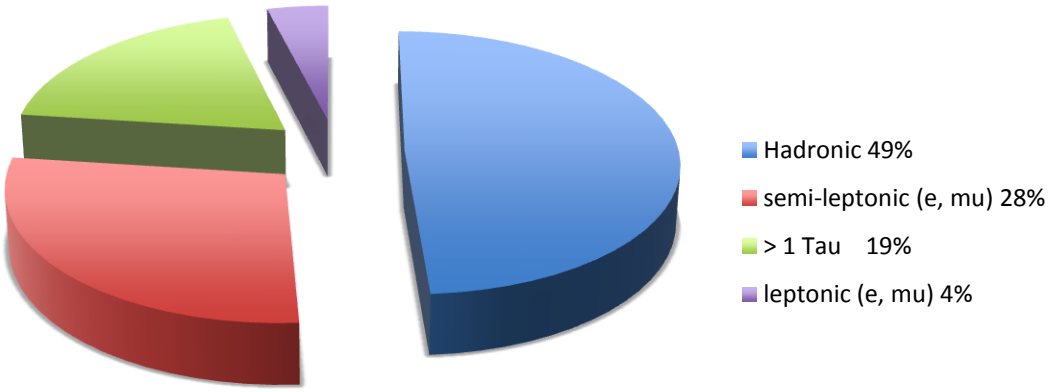
Process	σ (fb)	N_{Events} *
$e^+ e^- \rightarrow t\bar{t}H$	0.577 [arXiv:hep-ph/0604166v2]	20,000
$e^+ e^- \rightarrow t\bar{t}$	521	
$e^+ e^- \rightarrow t\bar{t}Z$ **	0.58	24,000
$e^+ e^- \rightarrow ZZ$	577.2	
$e^+ e^- \rightarrow W^-W^+$	7890	
$e^+ e^- \rightarrow q\bar{q}$	3951.8	

* Number of events used in the analysis so far corresponds to luminosity L = 34 ab^{-1}

** Currently our only background is $t\bar{t}Z$ which often mimic the signal We will include other backgrounds at a later stage but due to their different topology, it will be easy to get rid most of them.

Semi-Leptonic Channel

- $e^+ e^- \rightarrow \bar{t} t H \rightarrow b\bar{W}^- b W^+ \bar{b} b$
- Focus on semi-leptonic final state with one W decaying into lepton and neutrino and other W decaying into light jets
- Final state is 1 lepton, missing energy, 6 Jets with 4 b-jets
- Remove the leptons and force remaining particles into 6-jets (JetFinder Algorithm)
- High momentum Lepton and large missing momentum signature



Filtering of Semi-Leptonic Channel for Monte Carlo Sample

- Initially 20,000 MC events with full final state where Higgs and W decay into anything
- Filter events with one lepton (μ, e), and H decaying to $b\bar{b}$, 4466 events are left.

Lepton Identification

(From study of Single MC Lepton with P >15 GeV)

- Muon Identification:
  - Cut based selection is being used. Efficiency from single Muon sample is 98%.

    (1) $E_{Ecal} < 2.5$ GeV **(2) $E_{Hcal} < 15$ GeV**

    (3) $E_{Ecal} / E_{Tot} < 0.5$ **(4) $E_{tot} / p < 0.3$**
- Electron Identification:
  - Cut-based selection on single Electron sample has showed that 98.57% electron are identified by using:

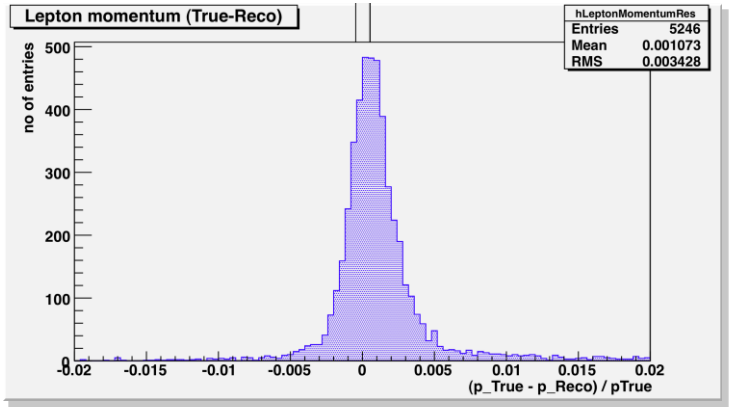
    (1) $E_{Ecal} / E_{Tot} > 0.6$

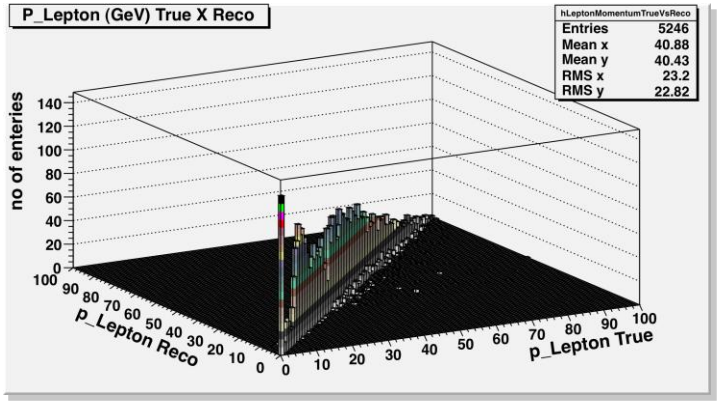
    (2) $E_{Tot} / p > 0.7$

efficiencies in %	electron cuts	muon cuts
e	98.57±0.06	~0
μ	0.03±0.01	97.5±0.05
π	3.88±0.06	0.46±0.003

$W \rightarrow \nu\ell$ (Lepton Identification)

- we identify our reconstructed leptons (e, μ) using same cut variables as for single lepton case.
- Most of the reconstructed leptons are correctly identified as leptons.
- These lepton tracks are then removed from the PandorPFOs collection.



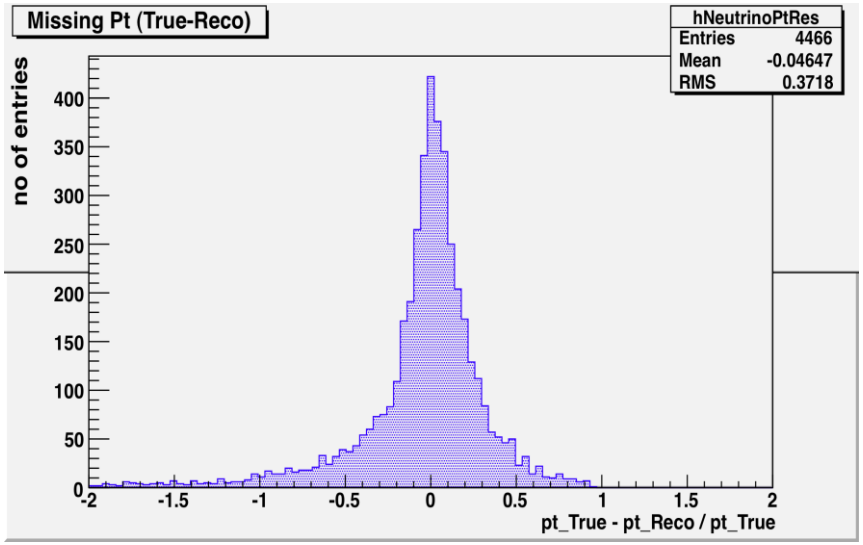


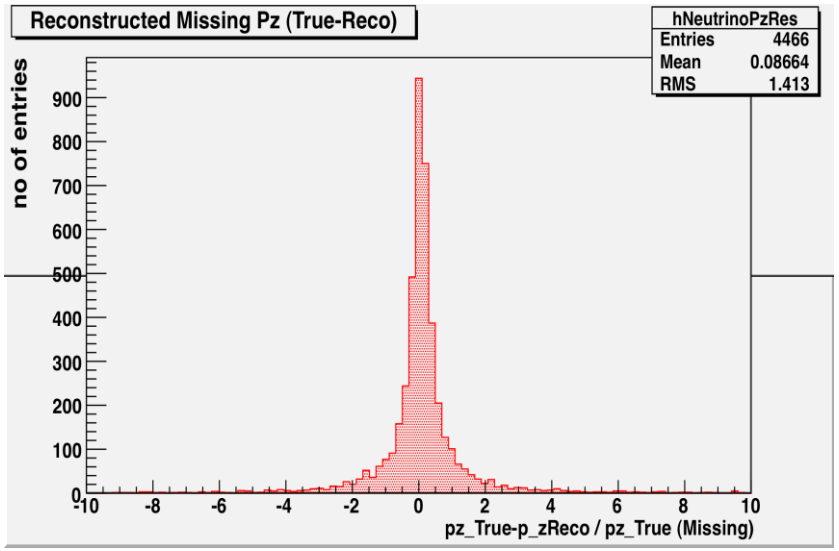
$W \rightarrow \nu e$ (Missing Momentum)

- Using the information for all reconstructed particles, missing momentum is reconstructed.

$$p_x^{miss} = -\Sigma_i p_{xi}, \quad p_y^{miss} = -\Sigma_i p_{yi}, \quad p_z^{miss} = -\Sigma_i p_{zi}, \qquad p_T^{miss} = \sqrt{(p_x^{miss})^2 + (p_y^{miss})^2}$$

- Z-component of missing energy isn't as accurate as x and y components
- However, z-component can be used to reconstruct Semi-leptonic W mass.

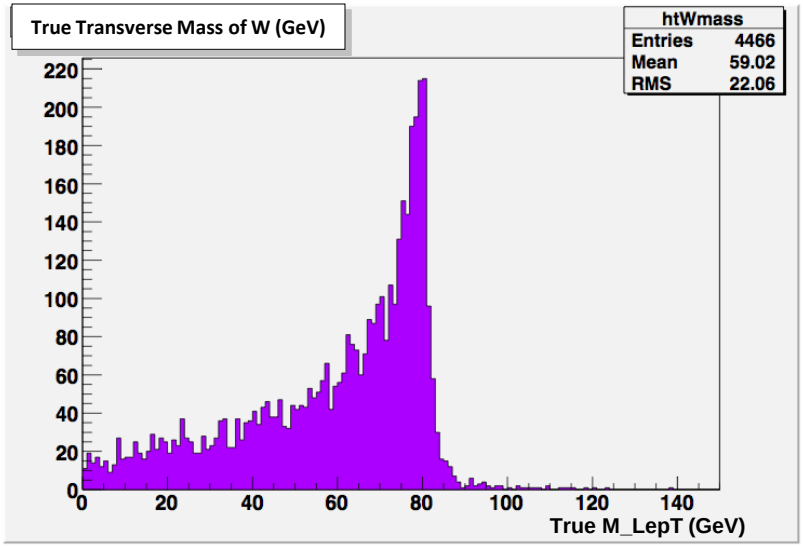


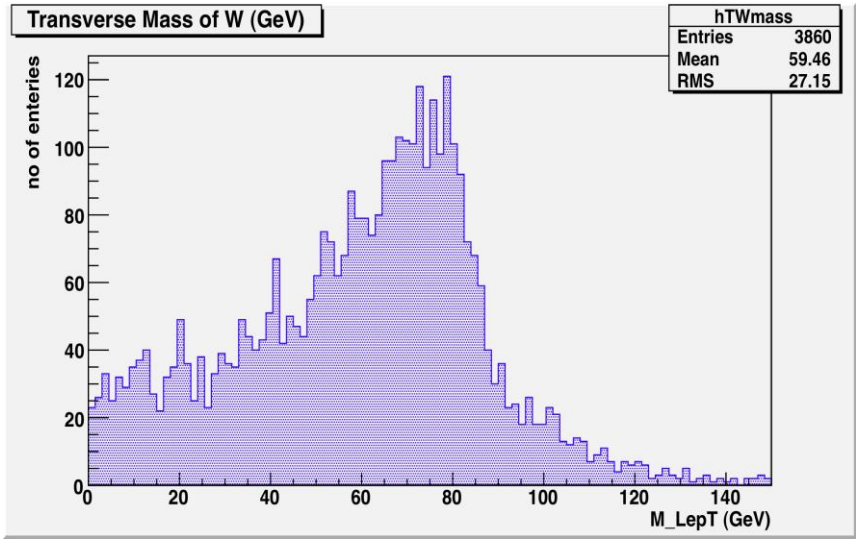


$W \rightarrow e\nu$ (Transverse Mass)

- To reconstruct semi-leptonic W, we select events which have lepton momentum not equal to zero and one lepton with highest momentum
- The transverse momentum of lepton and Missing Momentum are used to reconstruct the transverse mass of W.

$$M_{WT} = \sqrt{2p_T^l p_T^\nu (1 - cos(\phi^l - \phi^\nu))}$$





Jets reconstruction

- Identified leptons are removed from the sample
- remaining particles are forced into 6 Jets using JetFinder algorithm
- Jets pass LCFIVertex reconstruction [arXiv:0908.3019v1]
- LCFI flavour tagging is used to separate light and b-jets
- Jets are sorted in descending order of b-tag value
- top four jets with highest b-tag value are selected as b-jets
- Light jets are used to reconstruct hadronic W

Final State Reconstruction

- As we have a good reconstruction of z-component of the missing momentum, it is used to reconstruct the Mass of semi-leptonic W

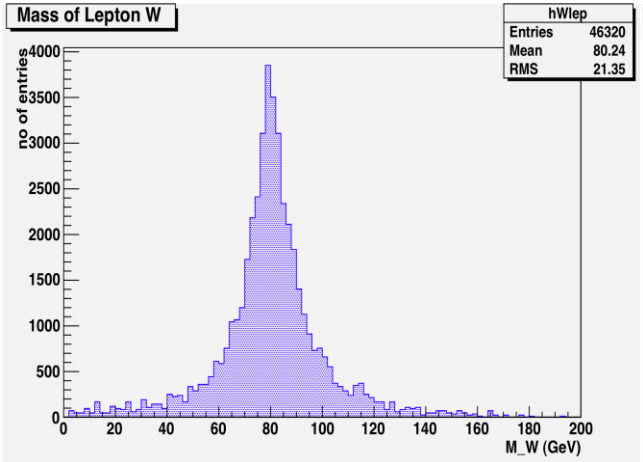
$$M_W = \sqrt{(E_\nu + E_l)^2 - (p_{\nu x} + p_{lx})^2 - (p_{\nu y} + p_{ly})^2 - (p_{\nu z} + p_{lz})^2}$$

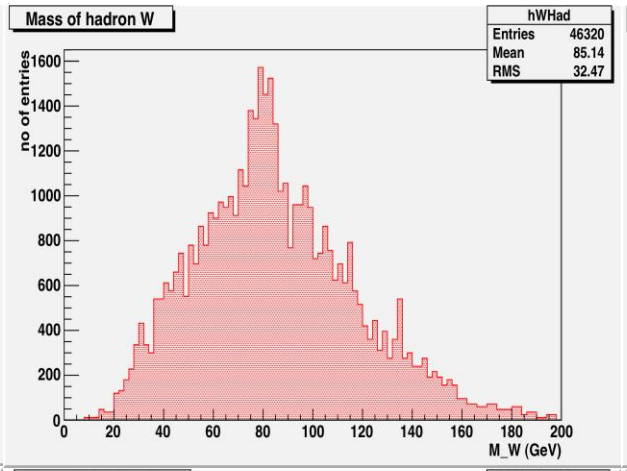
- Four b-jets are used to reconstruct two tops and Higgs particle
- To reduce combinatorial backgrounds, minimisation of χ^2 technique is used

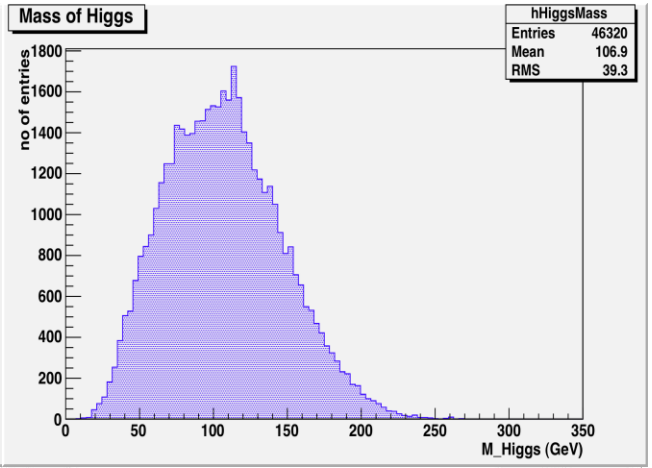
$$\chi^2 = \frac{(M_{l\nu b} - M_t)^2}{\sigma_{l\nu b}^2} + \frac{(M_{jjb} - M_t)^2}{\sigma_{jjb}^2} + \frac{(M_{bb} - M_{Higgs})^2}{\sigma_{bb}^2}$$

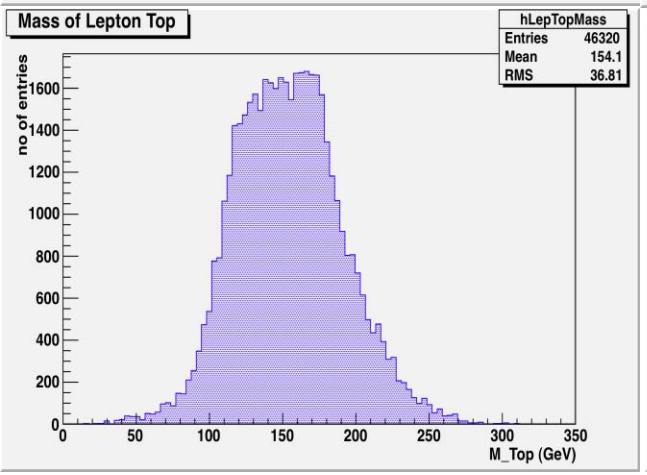
currently we have set *σ's* equals to one GeV.

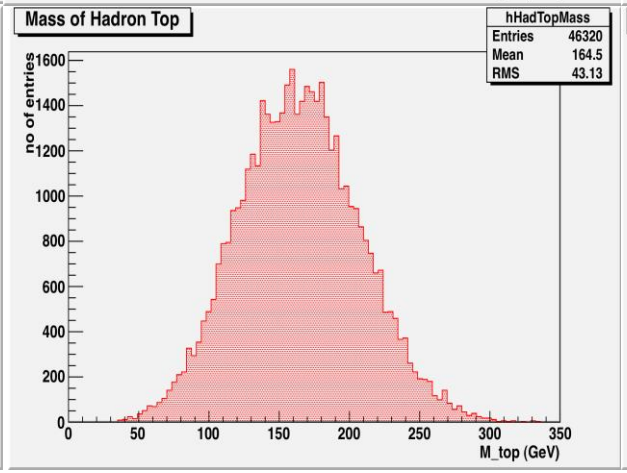
Reconstructed Final State

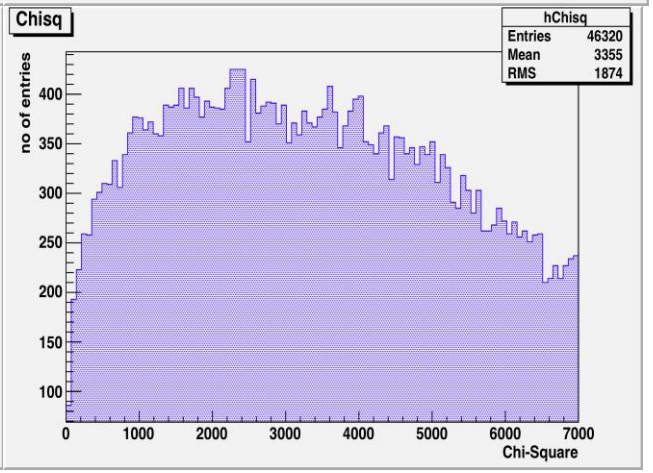






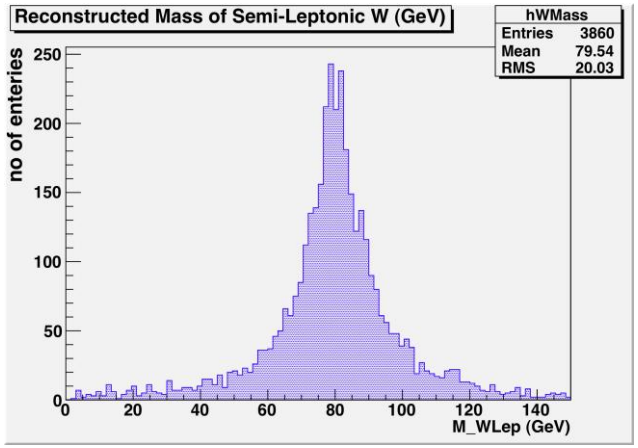


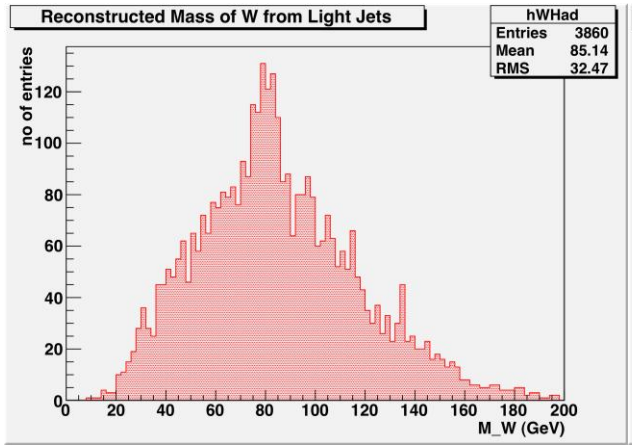


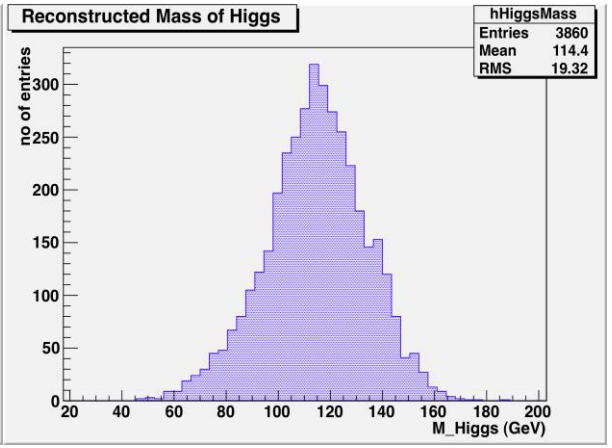


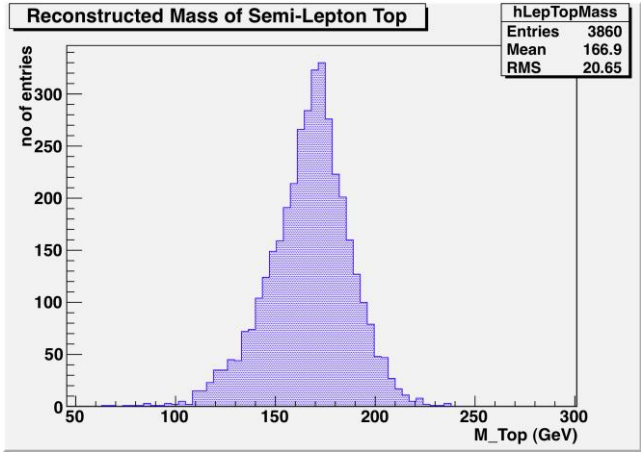
There are 12 entries for each event due to different combinations

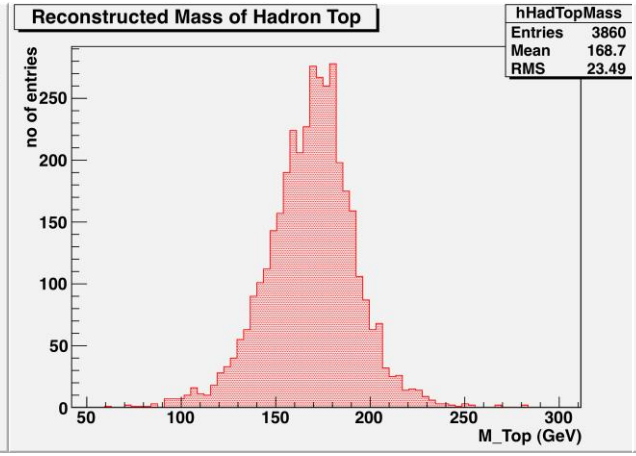
Reconstructed Final State after Minimizing χ^2

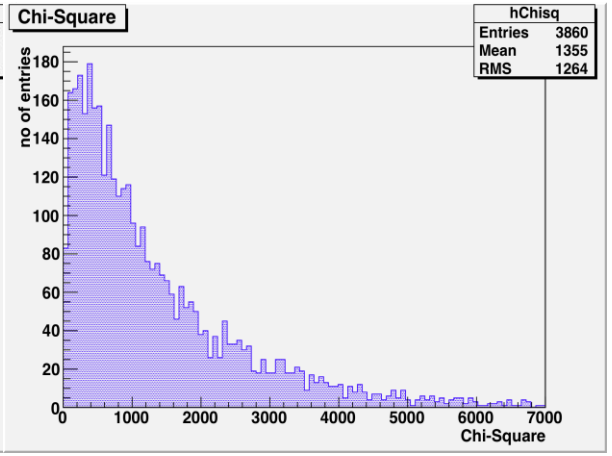




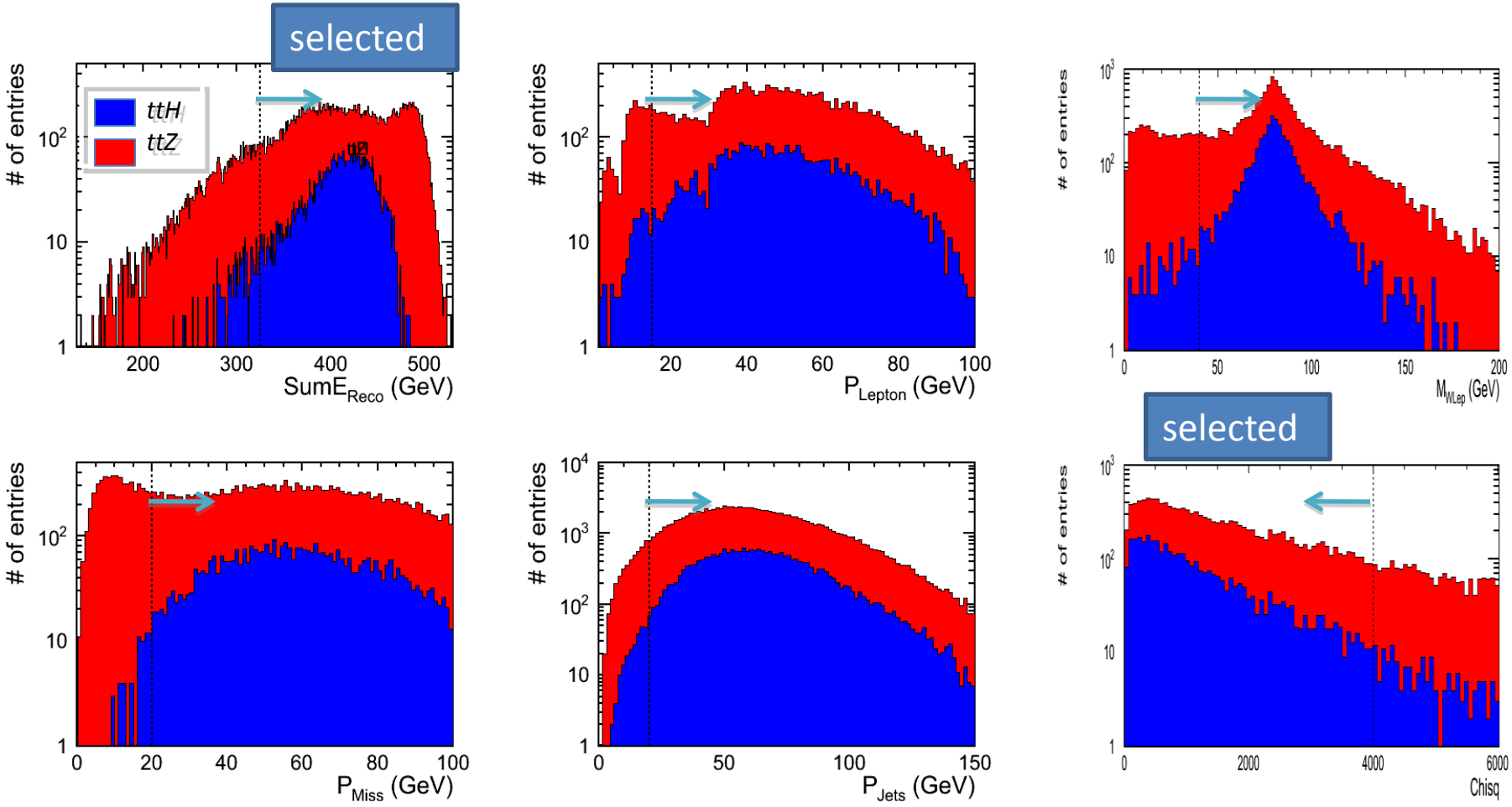








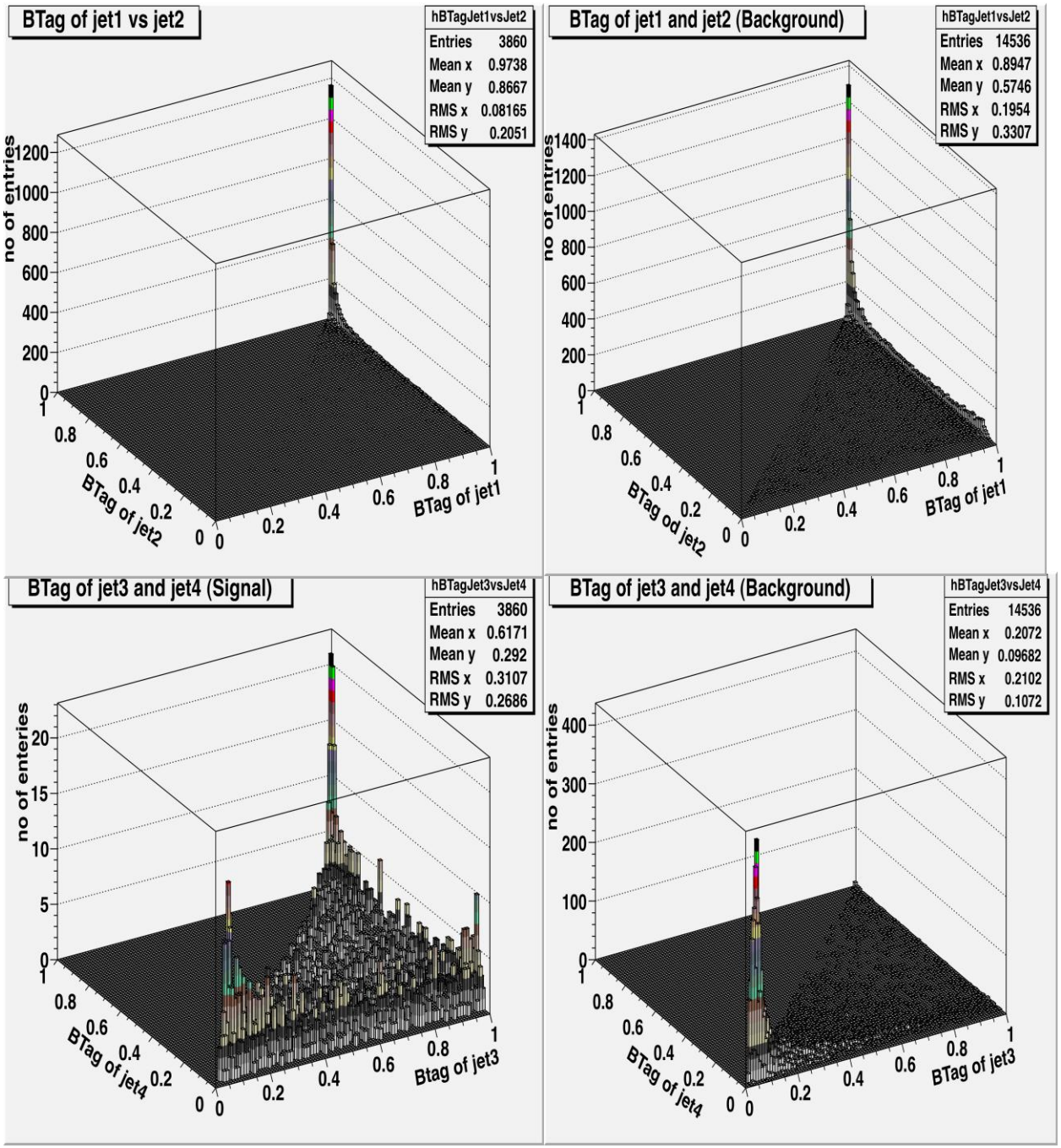
Selection variables



Signal and background are arbitrarily normalised
Cuts are selected by optimising S/√(S+B)

b-tagging

- B-tag of all 6 jets are looked at
- 4 with largest b-tag value are considered as b-jets
- Cut on b-tag values of jet3 and jet4 can reduce a significant number of background events



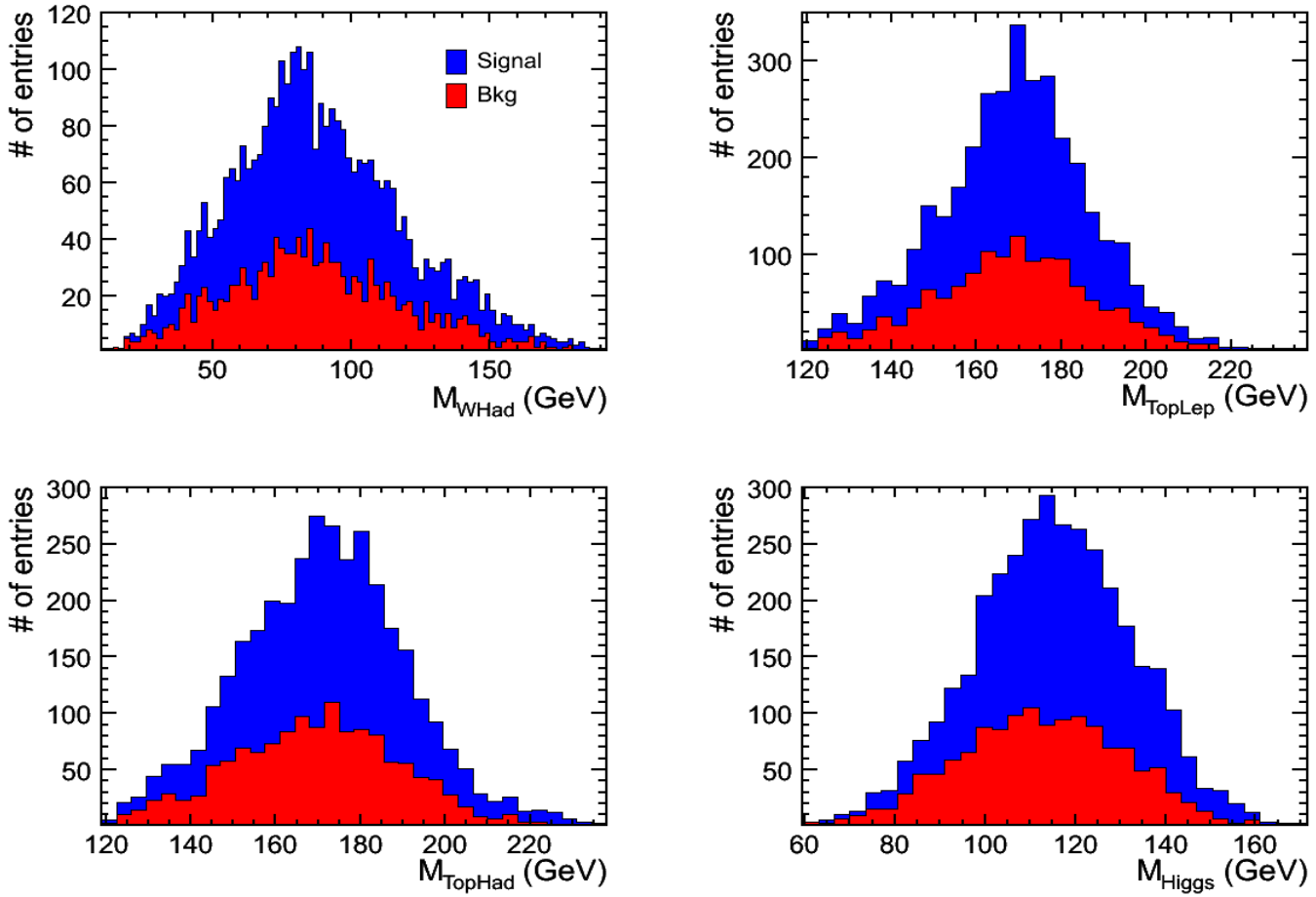
b-tag efficiency (3rd and 4th Jets)

b-tag (both jets)	No of Signal events (S)	No of bkg events (B)	S/√S+B
0	3097	7304	30.36
> 0.08	2410	2371	34.84
> 0.09	2237	1666	35.80
> 0.1	2154	1525	35.51
> 0.15	1708	771	34.30
> 0.2	1429	515	32.41
Btag (3^{rd} jet) > 0.09 Btag (4^{th} jets) > 0.08	2406	2282	35.14

Signal and Background separation

Cuts	No. of signal events S	No. of bkg events B
initial	20000	24000
#Lep > 0	3860 ** After semi-leptonic selection	14536
E_Reco > 325 GeV	3600	8021
P_Lep > 15 GeV	3167	7128
P_miss > 20 GeV	3119	5610
P_Jet >20 GeV	2978	4837
3^{rd} & 4^{th} jet b-tag > 0.09	2215	1544
Chisq < 4000	2161	1487
M_Lep > 40 GeV	2135	1330

Signal and Background Final State after applying selection cuts



Signal and background are arbitrarily normalised

Summary/Future Plans

- Reconstruction of final state for analysis of Top-Higgs Yukawa coupling is presented and results will be soon ready
- Higgs reconstruction would benefit from taken out of the χ^2 formula
- Using other variables to reduce more background contamination and hence optimise selection
- Multivariate will be used to improve the background suppression
- It will be necessary to extended this study to a higher energy but b-tagging will needed to be optimised
- We are intended to do this study for CLIC

Extra slides

Cross section of $t\bar{t}H$