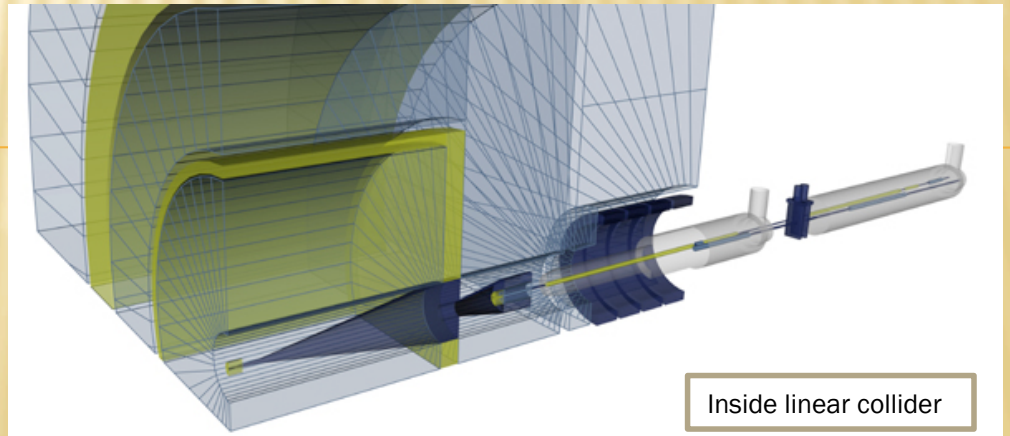
PHYSICS STUDIES FOR THE LINEAR COLLIDER

Hajrah Tabassam
University of Edinburgh
Supervisor: Victoria Martin

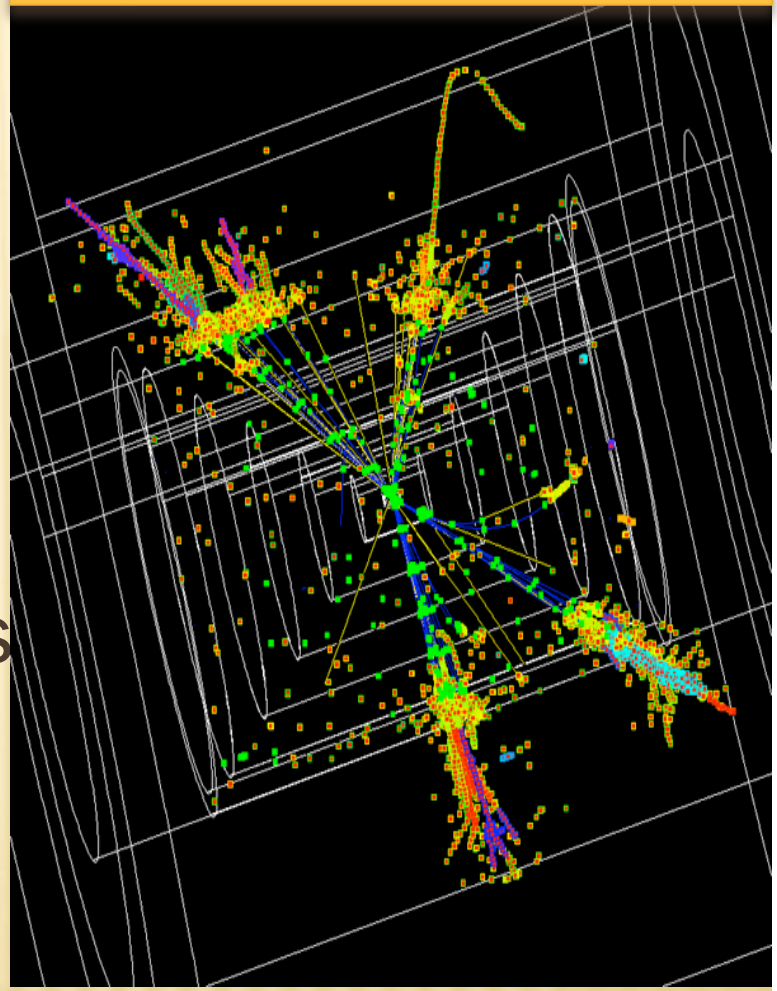


Inside linear collider

CONTENTS

- ILC & ILD
- Motivation
- Sample
- Lepton Identification
- Higgs Branching ratio analysis
- Top Higgs Yukawa coupling
- Summary

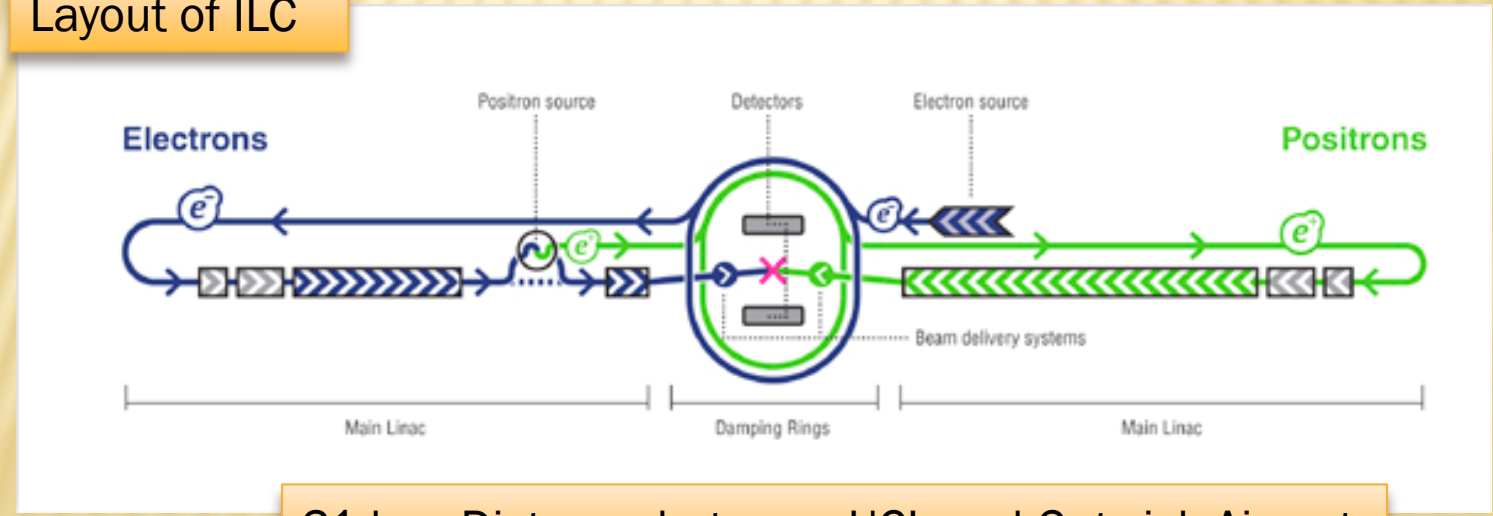
simulation of the decay of a ZH to four jets



ILC (INTERNATIONAL LINEAR COLLIDER)

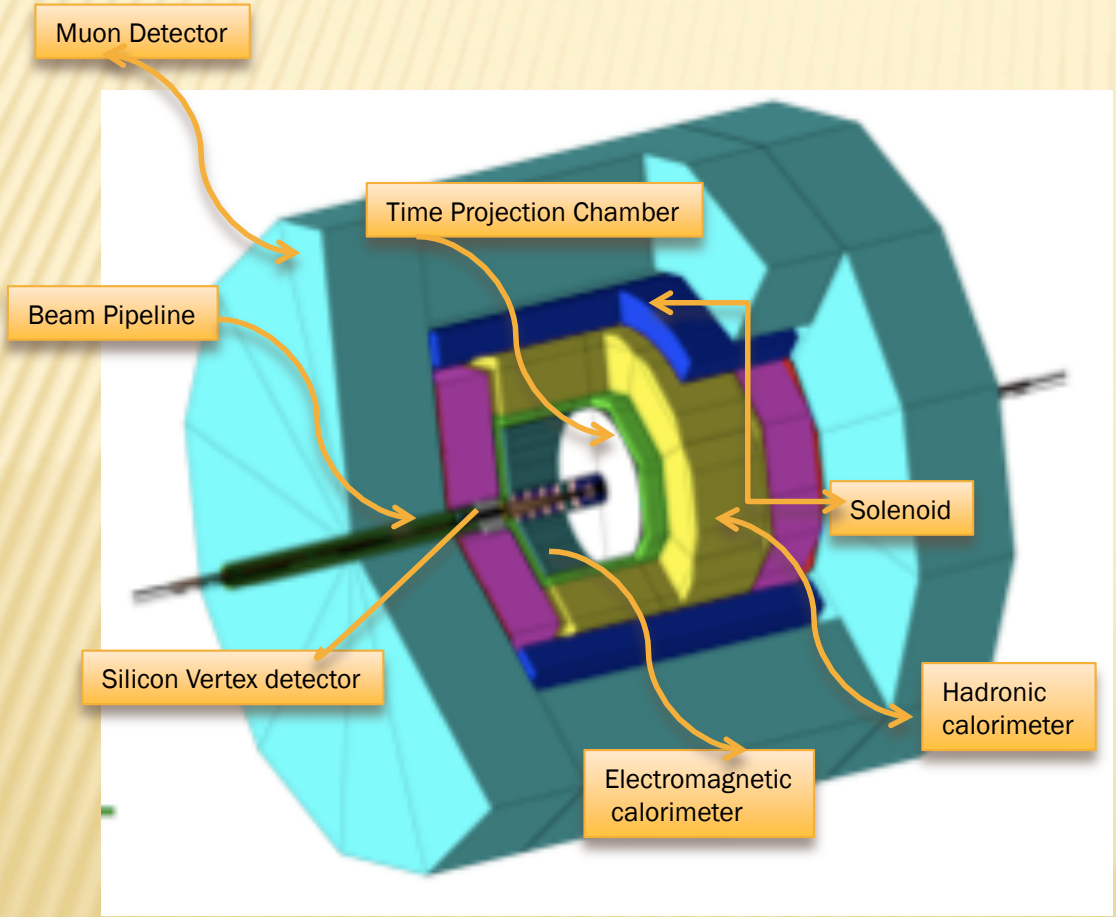
- The ILC is a proposed electron-positron collider.
- Center of mass energies from 200-500 GeV upgrade to 1TeV.
- Luminosity at ILC is $1 - 2 \times 10^{34}\ cm^{-2}\ s^{-1}$
- ILC is a powerful engine in terms of its energy and luminosity.
- We know the initial momenta of particles at ILC, so it allows the reconstruction of the final states with high efficiency and resolution.

Layout of ILC

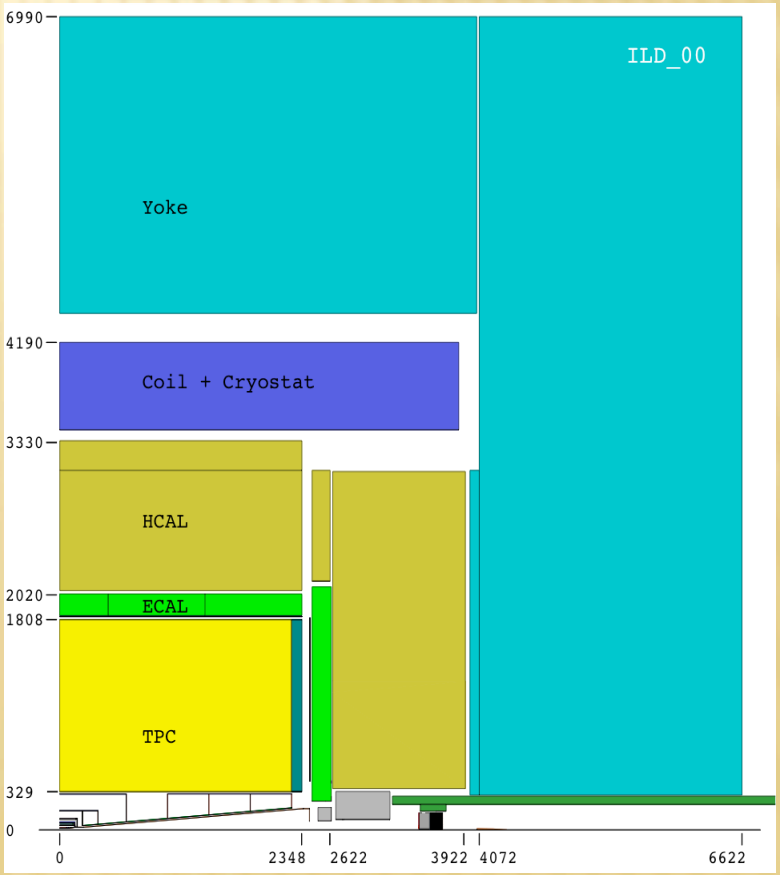


31 km, Distance between UCL and Gatwick Airport

INTERNATIONAL LARGE DETECTOR (ILD)

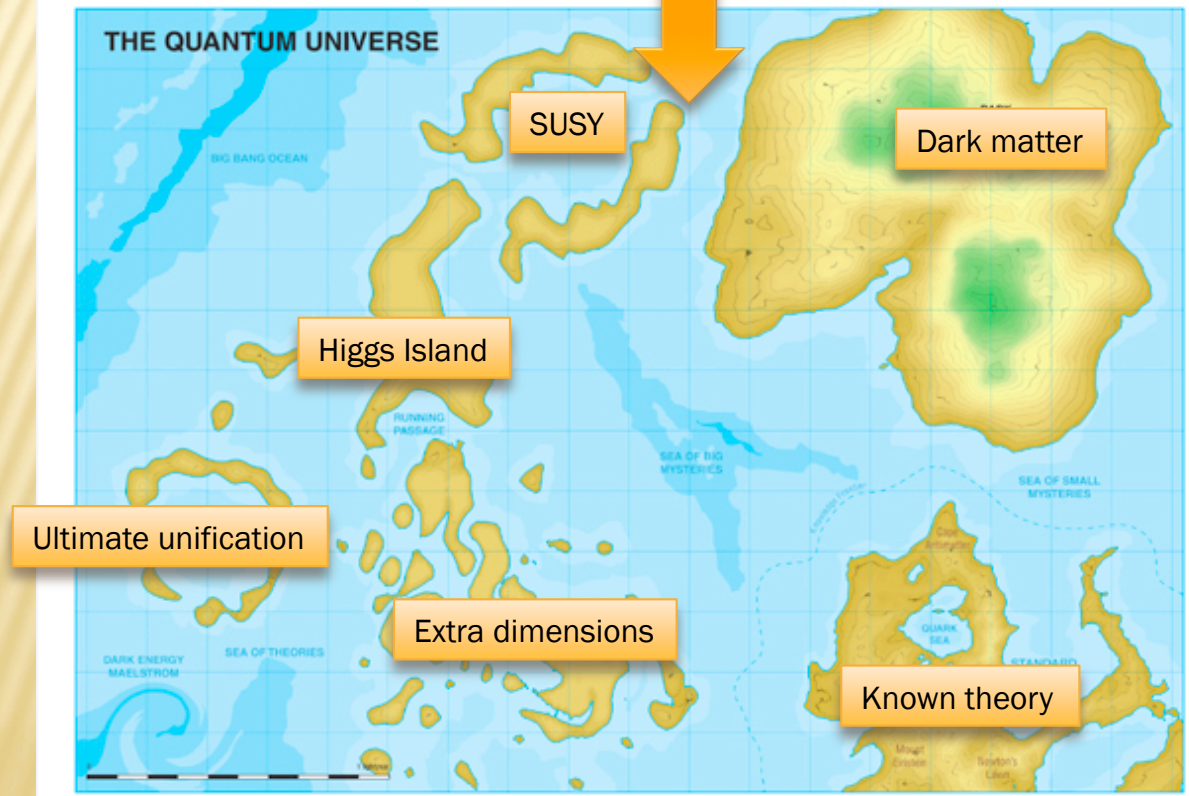


Quadrant layout of ILD



ILC DISCOVERY POTENTIAL

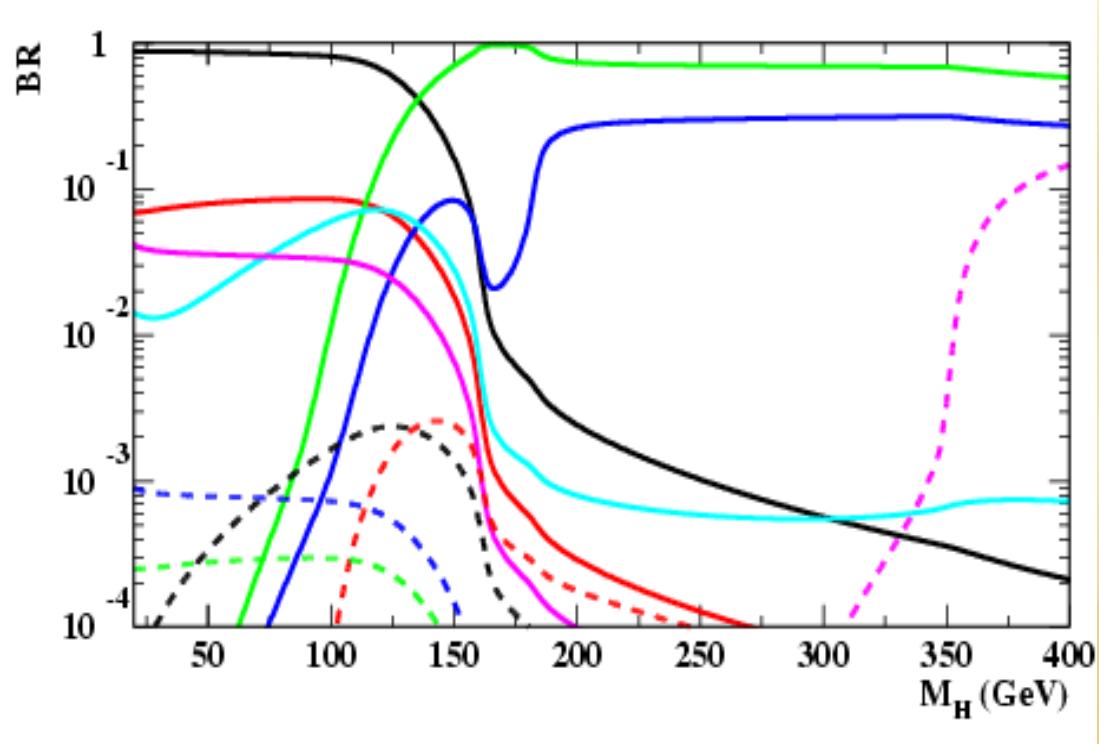
A map of the Quantum Universe, highlighting the discovery scenarios of the ILC.



Discovery potential of the ILC.

HIGGS DECAY

- for M<135 GeV: H→ bb, ττ dominant
- for M>135 GeV: H→ WW, ZZ dominant
- channels which can be identified and observed at ILC:
- WW, ZZ, γγ, Zγ bb, ττ, cc, μμ



HIGGS COUPLINGS

- Once Higgs is found, its coupling with fermions is interesting to study.
- $g_{ffH} = m_f/v$, v is vacuum expectation value of Higgs field.
- Top is heaviest fermion, so top-Higgs Yukawa coupling is largest.
- For the International Large Detector, this is the first study.

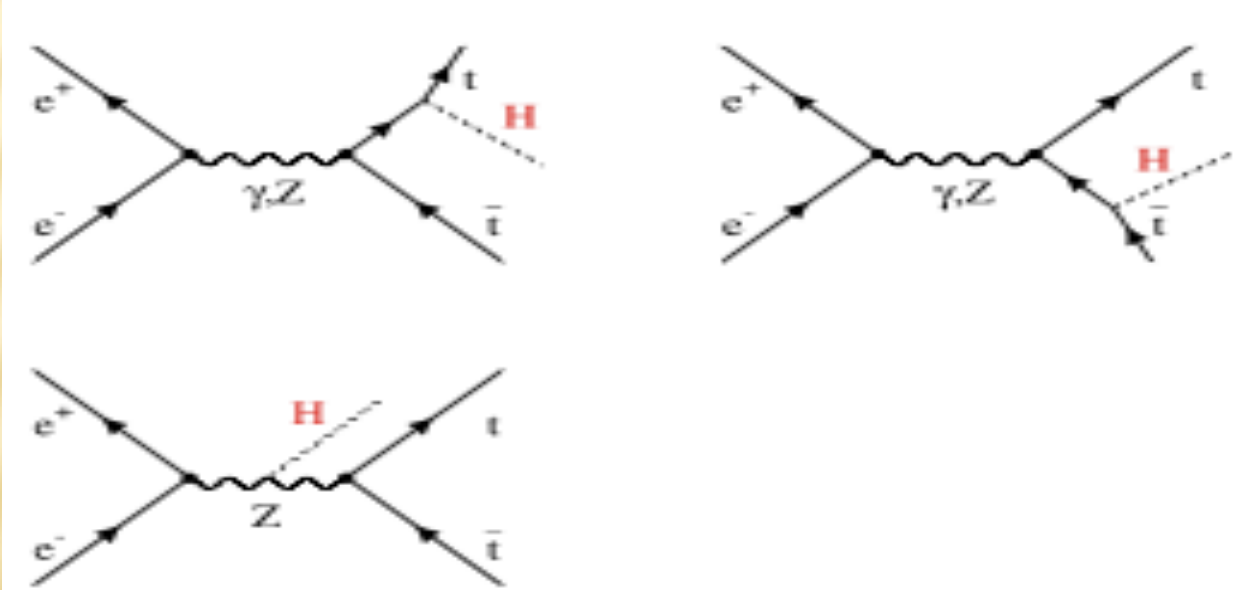


Fig. 1. Lowest order Feynman diagrams of the process $e^+e^- \rightarrow ttH$

SAMPLES AND CROSS SECTION

- Samples are generated centrally at SLAC
- M_h = 120 GeV/c^2, M_t = 175 GeV/c^2

For Higgs branching ratio
$\sqrt{s}$ = 250 GeV

Process*	σ (fb)
$e^+ e^- \to Z H \to \mu^+ \mu^- H$	17.1
$e^+ e^- \to \mu^+ \mu^- b\bar{b}$	56.5
$e^+ e^- \to \mu^+ \mu^- d\bar{d}$	57.5
$e^+ e^- \to \mu^+ \mu^- s\bar{s}$	57.6
$e^+ e^- \to \mu^+ \mu^- u\bar{u}$	53.0
$e^+ e^- \to \mu^+ \mu^- c\bar{c}$	53.1

For Top-Higgs Yukawa coupling
$\sqrt{s}$ = 500 GeV

Process*	σ (fb)
$e^+ e^- \to t\bar{t}H$	0.11
$e^+ e^- \to t\bar{t}$	521
$e^+ e^- \to t\bar{t}Z$	0.58
$e^+ e^- \to ZZ$	577.2
$e^+ e^- \to W^-W^+$	7890
$e^+ e^- \to q\bar{q}$	3951.8

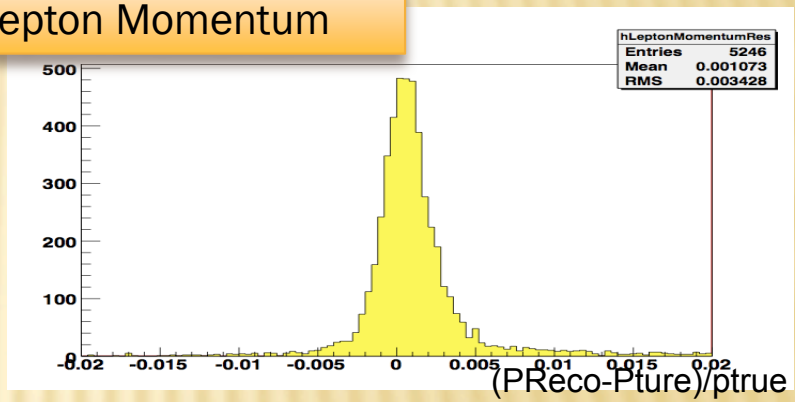
* Red Is the signal process (~5,000) and black are background processes (~100,000).

LEPTON IDENTIFICATION (FROM STUDY OF SINGLE LEPTON)

- Muon Identification:
  - Cut based selection is being used. Efficiency from single Muon sample is 98%.
  - $E_{Ecal} < 2.5$ GeV
  - $E_{Hcal} < 15$ GeV
  - $E_{Ecal}/E_{Tot} < 0.5$
  - $E_{Tot}/p < 0.3$
- Electron Identification:
  - Cut-based selection on single Electron sample has showed that 98.57% electron are identified by using:

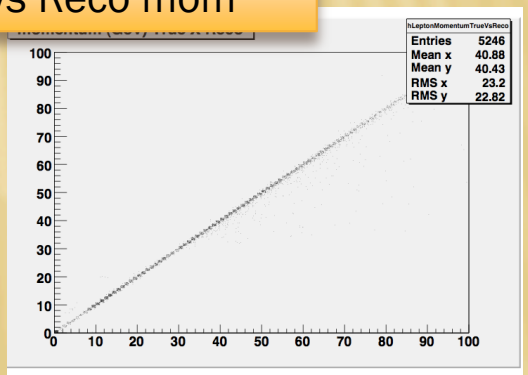
1) $E_{Ecal}/E_{Tot} > 0.6$
2) $E_{Tot}/p > 0.7$

Lepton Momentum

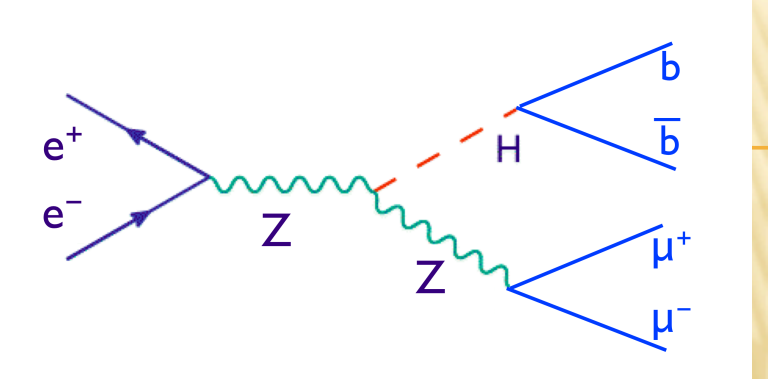


efficiencies in %	electron cuts	muon cuts
e	98.57±0.06	~0
μ	0.03±0.01	97.5±0.05
π	3.88±0.06	0.46±0.003

True vs Reco mom



HIGGS BRANCHING RATIO ANALYSIS



Z Reconstruction

A pair of oppositely charged muons are selected to reconstruct the Z boson.

Higgs Reconstruction

Two quarks from the decay of Higgs boson are reconstructed as jets.

Event selection

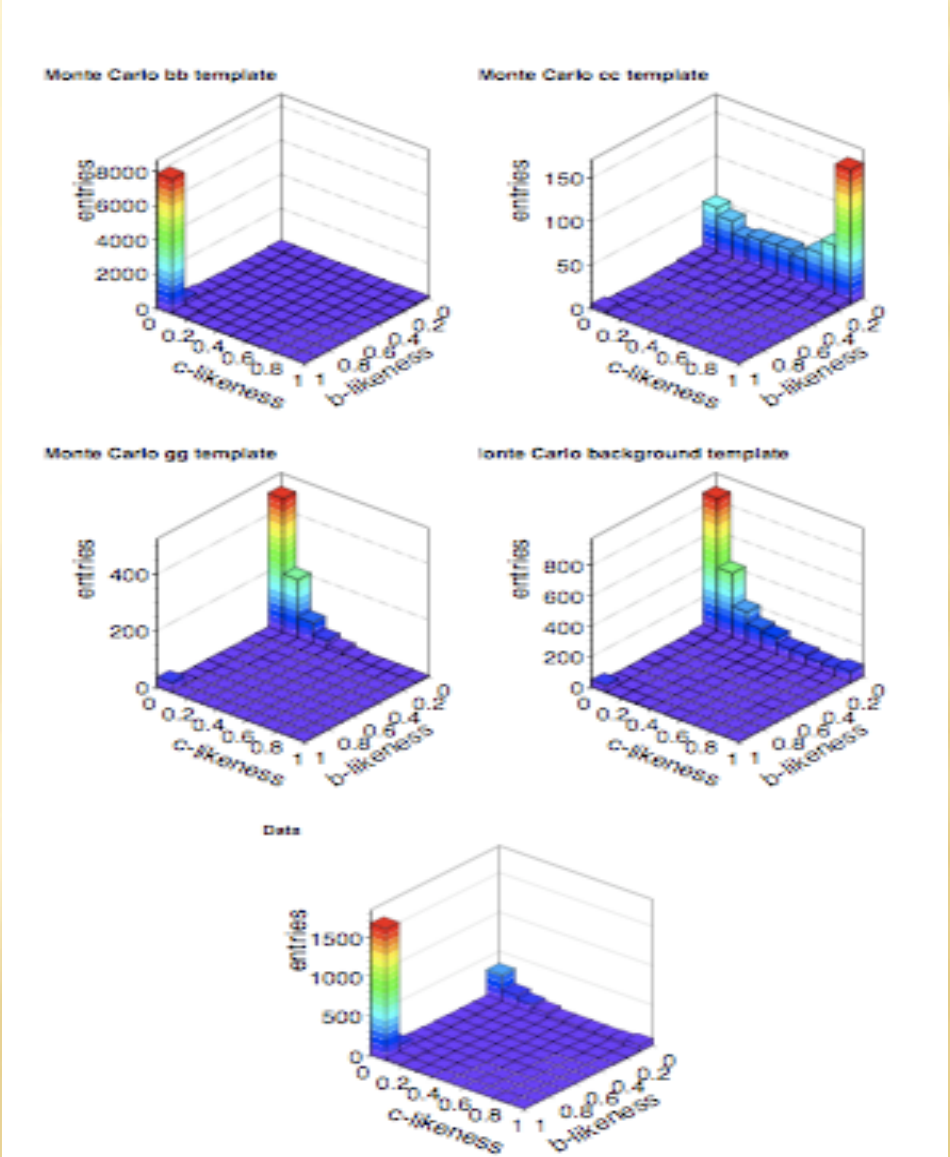
To reduce background contamination and event selection, we used cut based and likelihood methods.

Branching Ratio Extraction

The fraction of $H \rightarrow b\bar{b}$, $H \rightarrow c\bar{c}$ and $H \rightarrow gg$ and background is determined from the distribution of b-likeness and c-likeness. The branching ratios is extracted by minimizing a χ^2 function.

HIGGS BRANCHING RATIO MEASUREMENT (II)

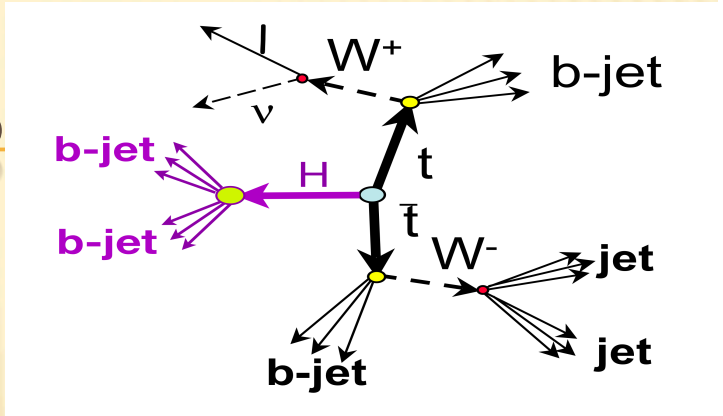
Flavor likeness distributions for exclusive samples of $H \to b\bar{b}$, $H \to c\bar{c}$ and $H \to gg$ and background and an independent combined "data" sample



Conclusion:

SM branching ratios are measured with an accuracy of (2.7±5)% for BR($H \to b\bar{b}$), (28±5)% for BR($H \to c\bar{c}$) and (29±5)% for BR($H \to gg$).

HIGGS COUPLING ANALYSIS



- Channel Selection

  Depending on the decay of W boson, semi-leptonic channel is selected. Final state is therefore 1 lepton, 1 neutrino and 6 jets (2 light and 4 b-jets).

- W Reconstruction

  Missing energy is reconstructed using reconstructed information of all particles. Leptons are identified and removed from the sample. Lepton W is reconstructed using *lν* and hadron W is reconstructed using light jets.

- Tops and Higgs Reconstruction

  Two b-jets and two Ws are combined to reconstruct two Tops and the two remaining b-jets are used for the Higgs reconstruction simultaneously.

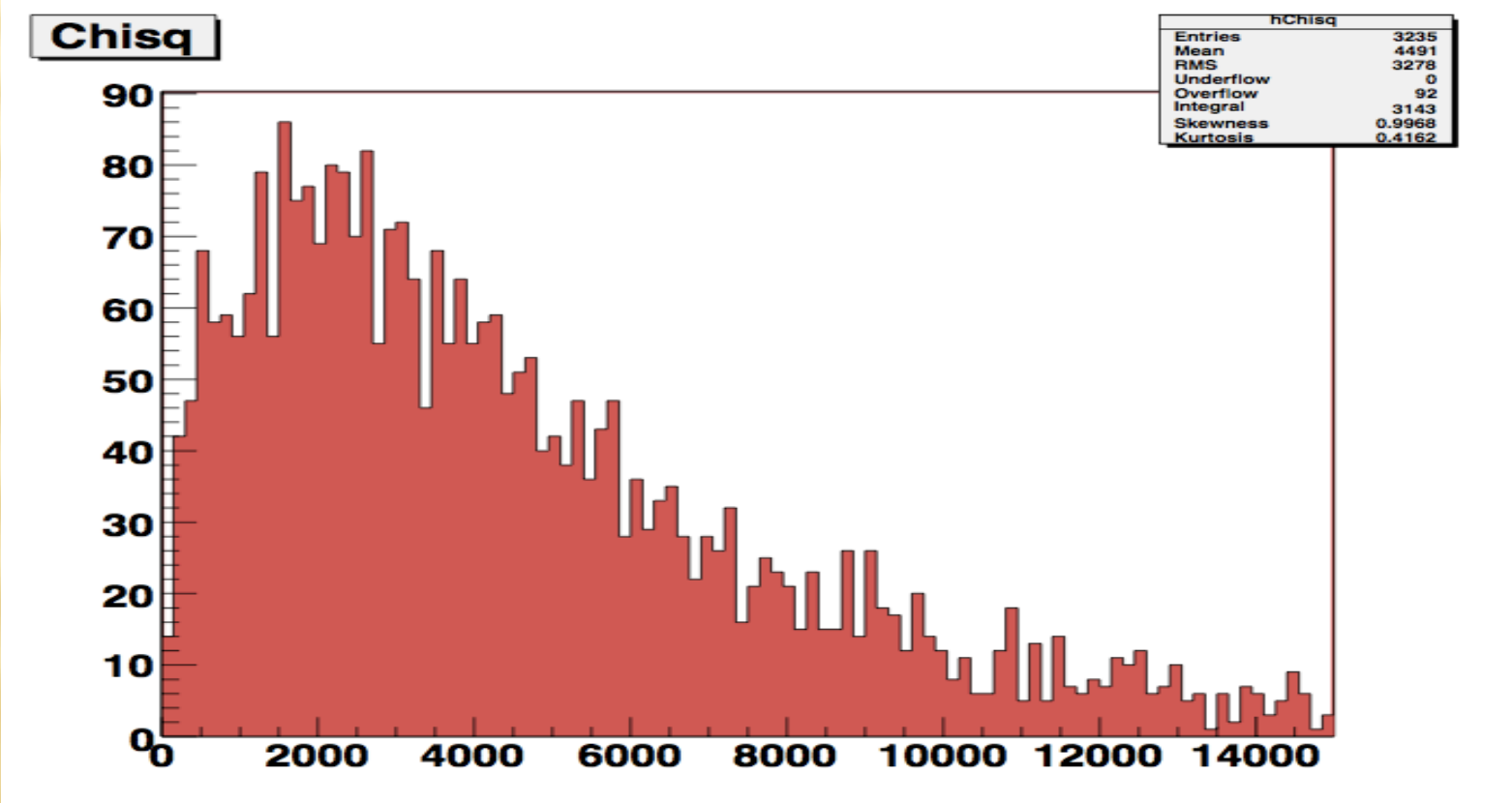
- Chi-square technique

  Presence of 6 jets poses challenge to use different techniques to get the best combination of particles for reconstruction. We used Chi-Square method to reconstruct tops and Higgs.

CHI-SQUARE FIT

- Minimization of Chi-square is used to reconstruct the final state of the event.
- Using:

$$\chi^2 = \frac{(m_{\ell\nu b} - m_{\text{top}})^2}{\sigma^2_{\ell\nu b}} + \frac{(m_{jjb} - m_{\text{top}})^2}{\sigma^2_{jjb}} + \frac{(m_{bb} - m_H)^2}{\sigma^2_{bb}}$$



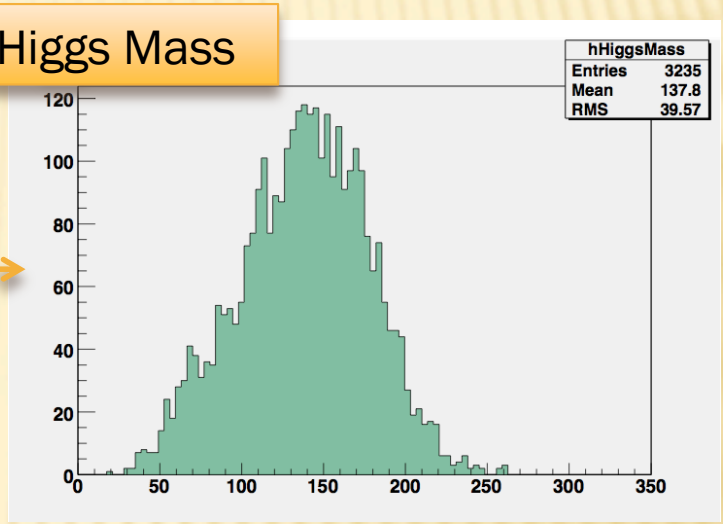
HIGGS, LEPTONIC AND HADRONIC TOP RECONSTRUCTION

Mass of Higgs

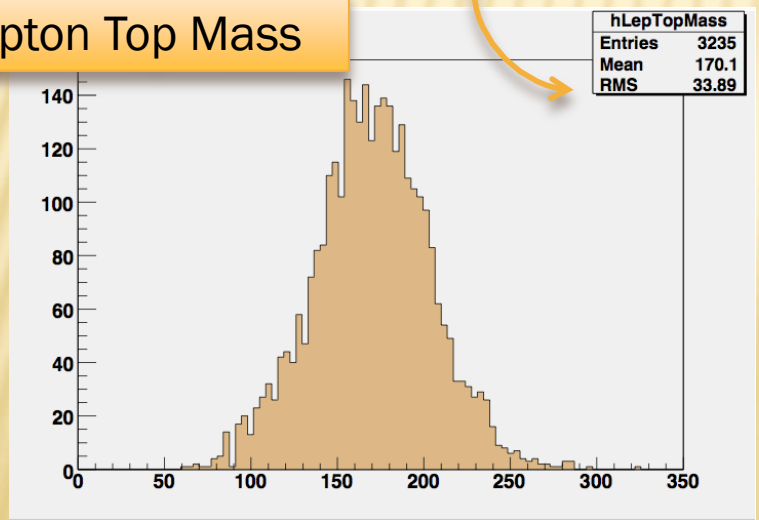
Mass of Top using W reconstructed from Lepton and missing energy

Mass of Top using W reconstructed from light jets

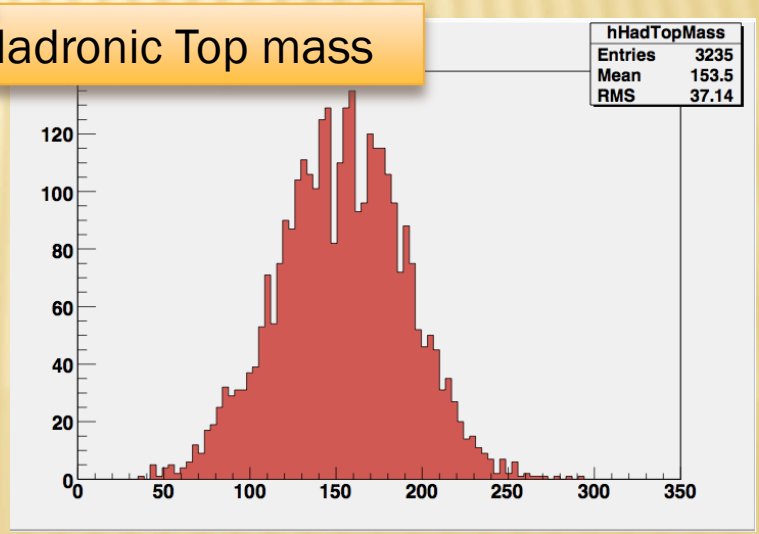
Higgs Mass



Lepton Top Mass



Hadronic Top mass



SUMMARY

- A analysis of Higgs branching ratio for Z-boson decaying into leptons is presented .
- A full study has been done.
- Analysis for the Higgs-Top Yukawa coupling is still going on.
- Results are being finalized
- And hopefully we will get some results before LHC will give some results. ☺

Extra Slides

HIGGS BRANCHING RATIO

Signal sample is split into "data" and "monte carlo", with same number of events. Monte carlo sample is split into the decay modes bb, cc, gg and others.

$$\text{X-likeness} = \frac{X1 \cdot X2}{X1 \cdot X2 + (1 - X1) \cdot (1 - X2)}$$

where X = b or c and X_1 , X_2 = b-tag or c-tag of the 2 jets.

HIGGS BRANCHING RATIO

- Branching ratio is given by

$$\sigma(e^+e^- \to Zh) \times BR(h \to s) =$$
$$\mathrm{r}_s \times BR(h \to s)_{SM} \times \sigma(e^+e^- \to Zh)_{SM}$$

where $r_s = r_{bb}, r_{cc}, r_{bkg}$ are parameters obtained by minimizing

$$\chi 2 = \Sigma_{i,j} (N_{data}^{ij} - f \Sigma_s r_s N_s^{ij})^2 / \sigma_{ij}^2$$

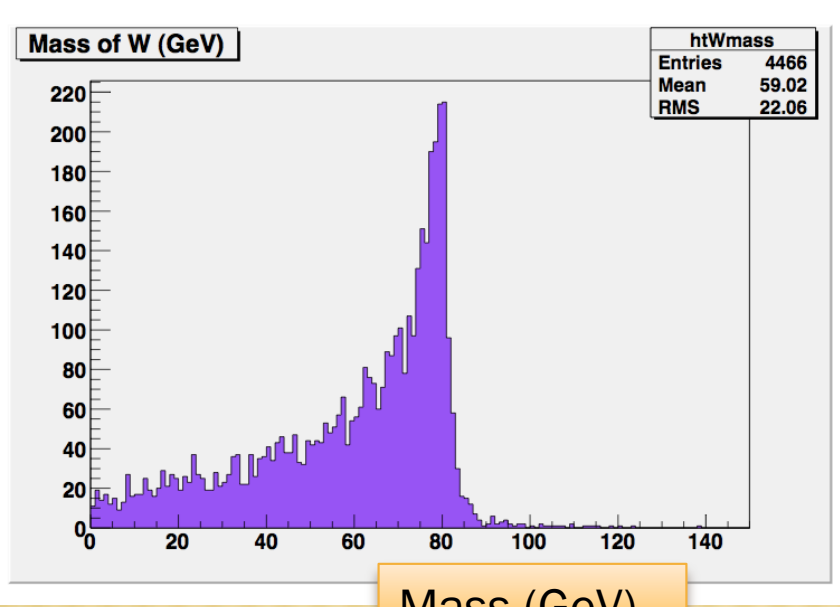
here N_{data}^{ij} and N_s^{ij} are number of events in the b- and c-likeness bins of the data and bb, cc, gg and background templates.

- $\sigma_{ij}^2 = N_{data}^{ij} + f^2 \Sigma_s N_s^{ij}$ takes into account the limited statistics of samples with $f = 0.217$, the ratio of luminosity of simulated data and the luminosity of MC samples .

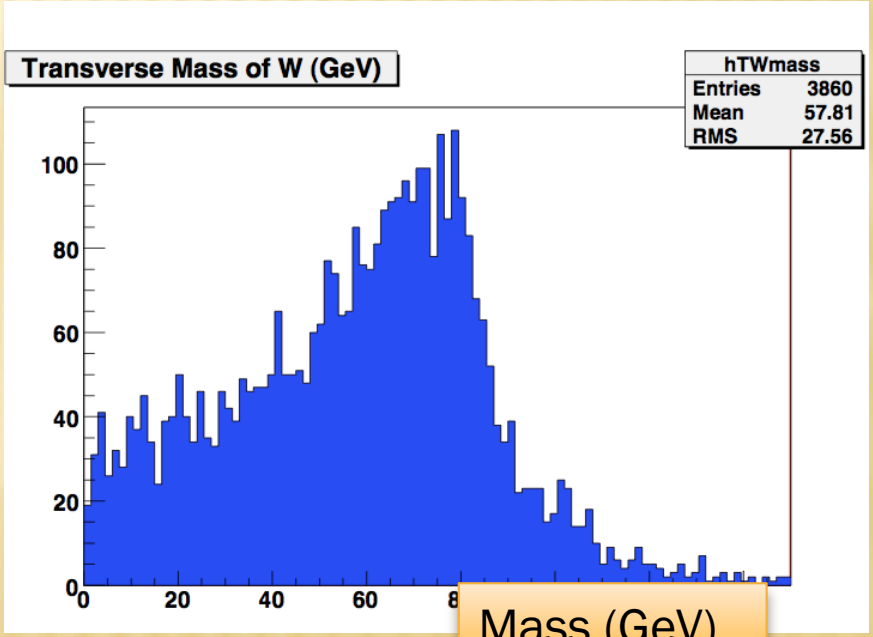
W (Transverse mass) RECONSTRUCTION

- The transverse momentum of lepton and Neutrino are used to find the transverse mass of W.
- $W_T = \sqrt{[2p^l_T p^\nu_T(1-\cos(\varphi^l-\varphi^\nu))]}$

True Transverse Mass



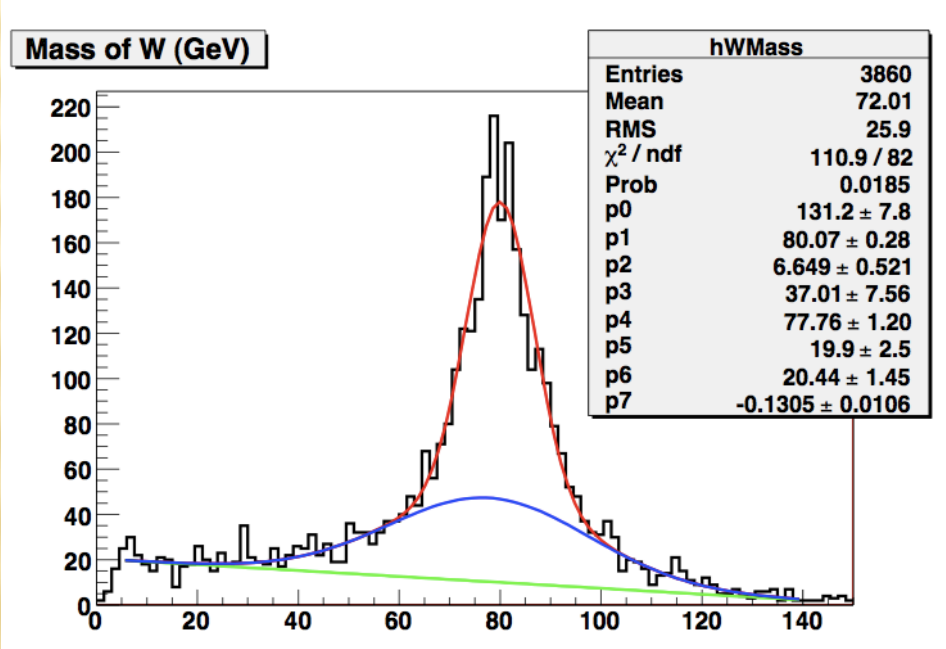
Reco Transverse Mass

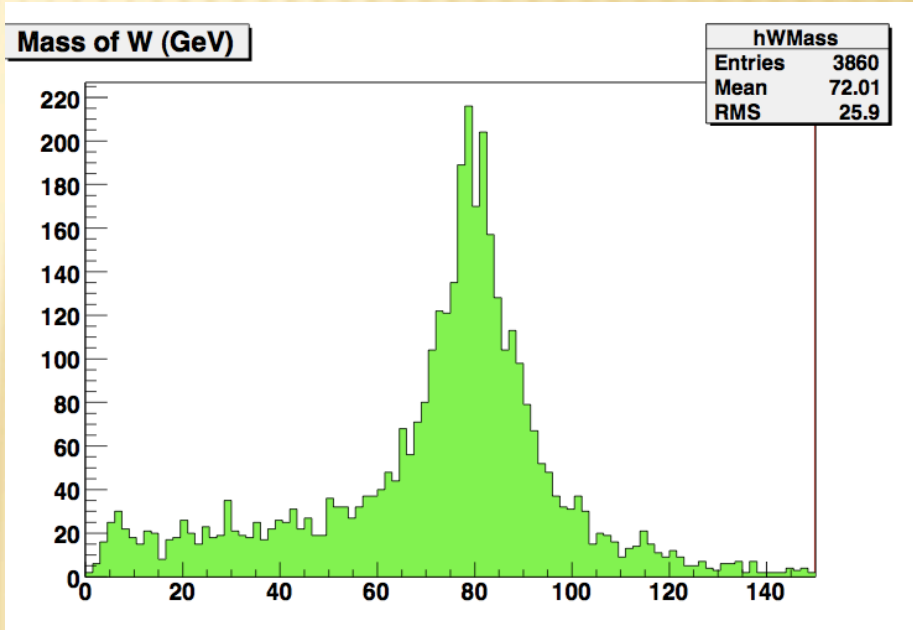


W RECONSTRUCTION (*l*ν)

- We used the z-information of Neutrino to reconstruct the mass of W.

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

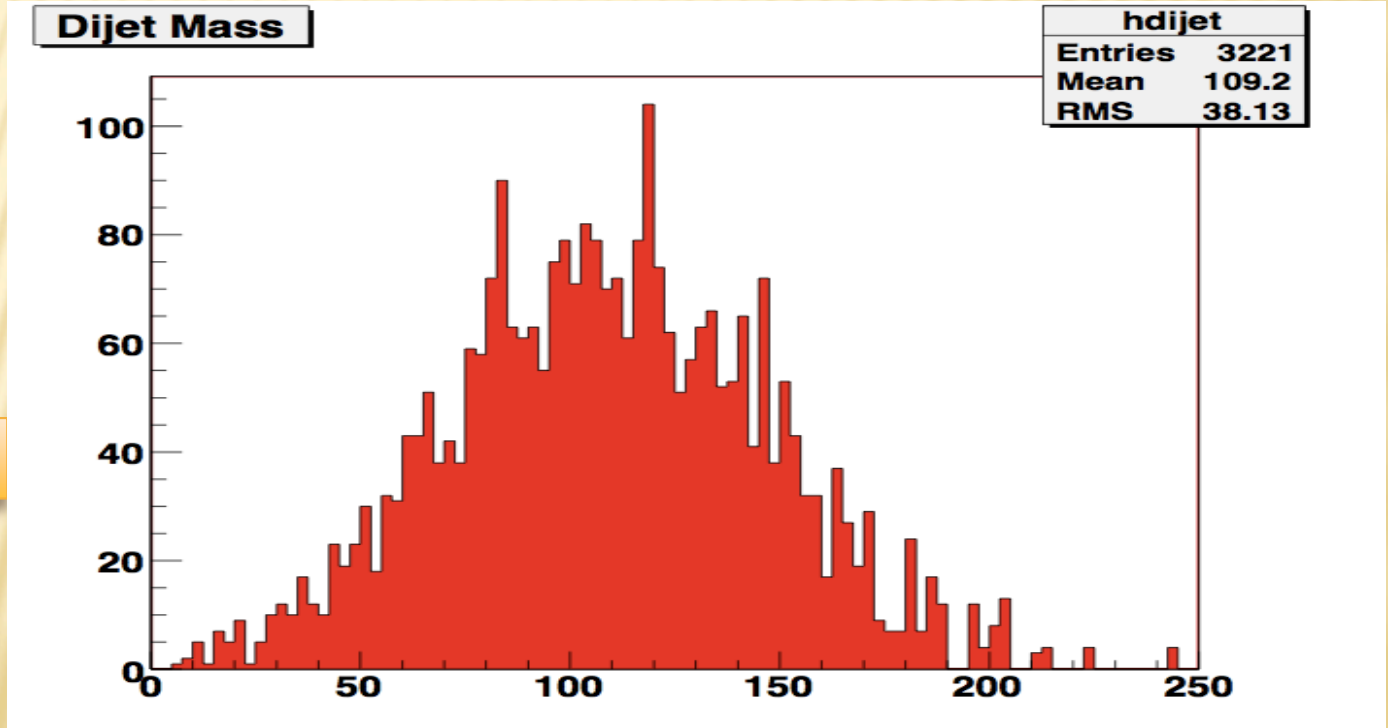




Mass (GeV)

W RECONSTRUCTION (Dijet)

- Selecting only light quarks, we have reconstructed the mass of W.



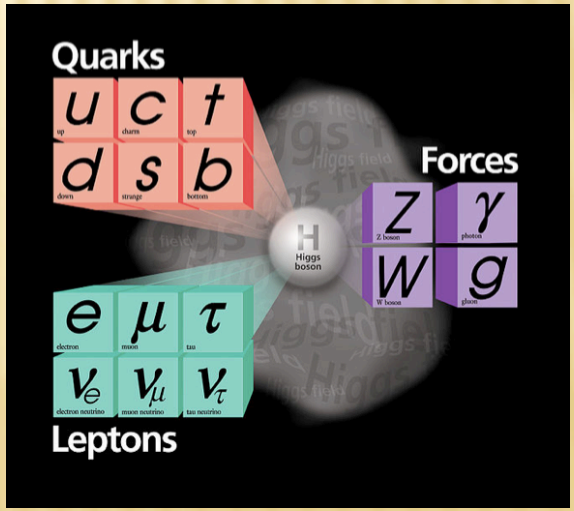
Di-jet Mass

Mass (GeV)

STANDARD MODEL AND HIGGS COUPLING

The Standard Model explains what the world is made of and what holds it together. It is a simple and comprehensive theory that explains all the hundred of particles and complex interactions with only: 6 Quarks including bottom (b), charm (c) 6 Leptons including electron (e), muon (μ)Force carrier particles: photon (ϒ), gluon and W- and Z- bosons1 Higgs particle

Only one of the ingredients of the Standard Model is still to be experimentally discovered: the Higgs particle. The interactions of the Higgs boson are responsible for giving mass to all other particles. Although a Higgs will probably be discovered at LHC, however LHC is not suitable for measuring the Higgs branching ratios (fig 4) with high accuracy. Such a measurement of branching ratios will allow a test of the hypothesis that the strength of the Higgs coupling depends linearly on particle masses.The aim of our analysis is to understand how well we can measure the Higgs branching ratios to $b\bar{b}$ *and* $c\bar{c}$ *at ILC.*



MC SAMPLES

- ILD_00 centrally reconstructed sample with center of mass energy $\sqrt{s}$ = 500 GeV.
- $\bar{t}t$-Higgs events with M_h = 120 GeV/c^2, M_t = 175 GeV/c^2.
- Signal process: $e^+ e^- \rightarrow t\bar{t}H \rightarrow WbW\bar{b}H$ σ = 0.11fb
- Background Processes:

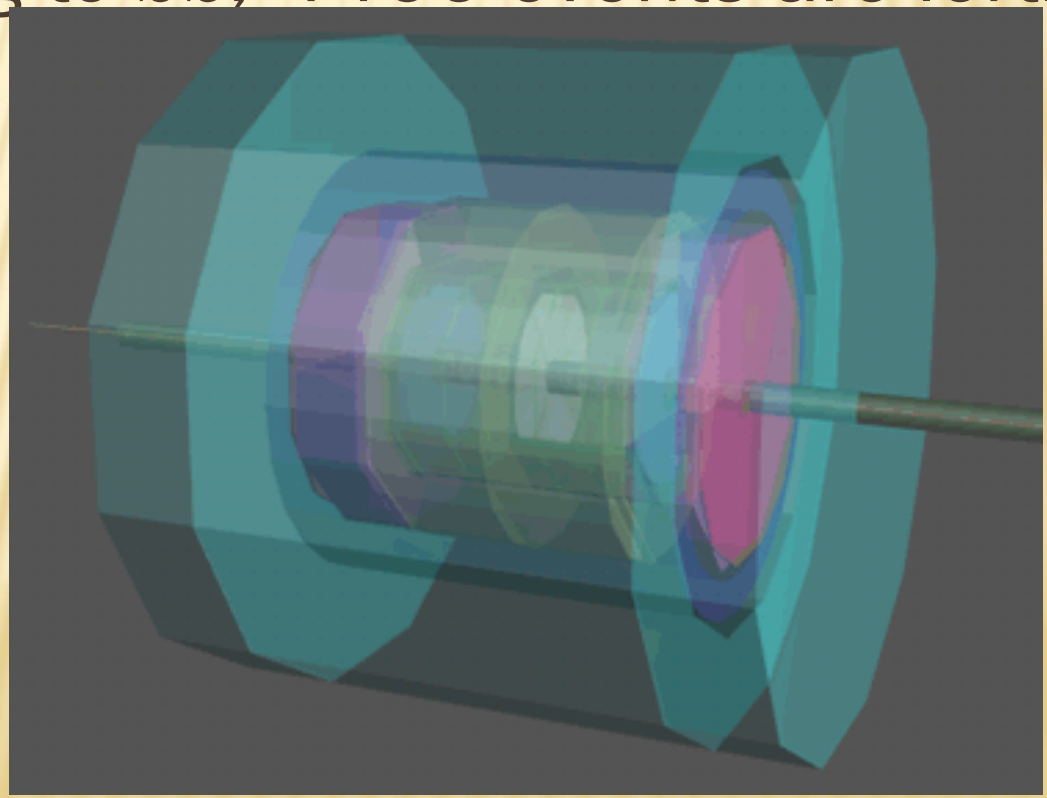
Largest background will be $e^+ e^- \rightarrow t\bar{t}$ σ = 521fb

$e^+ e^- \rightarrow t\bar{t}Z$ will often mimic the signal σ = 0.58fb

$e^+ e^- \rightarrow ZZ$, σ = 577.2fb $e^+ e^- \rightarrow W^-W^+$, σ = 7890fb $e^+ e^- \rightarrow q\bar{q}$ σ = 3951.8fb are some other backgrounds

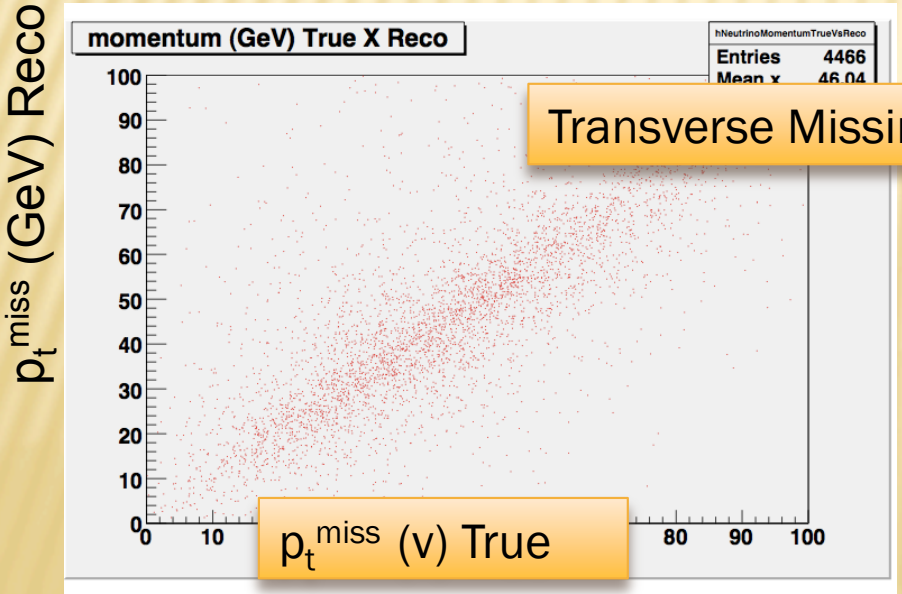
FILTERING OF SEMI-LEPTONIC CHANNEL

- Initially 20,000 MC events
- Filter events with one lepton (μ, e), and H decaying to $b\bar{b}$, 4466 events are left.

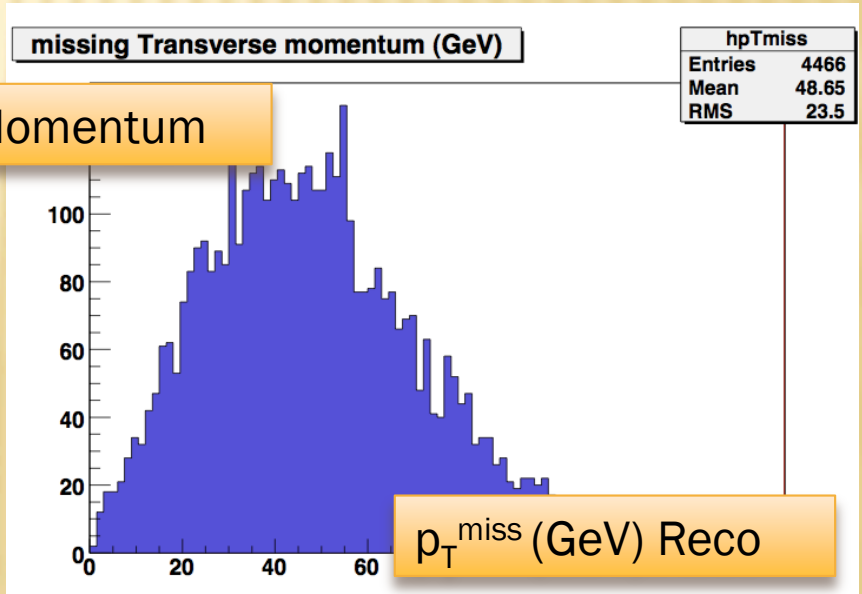


MISSING ENERGY OF NEUTRINO

- Using the information for all reconstructed particles, missing energy of Neutrino is reconstructed.
- $p_x^{miss} = -\sum_i p_{x,i}$, $p_y^{miss} = -\sum_i p_{y,I}$
- $p_t^{miss} = sqrt\{(p_x^{miss})^2 + (p_y^{miss})^2\}$



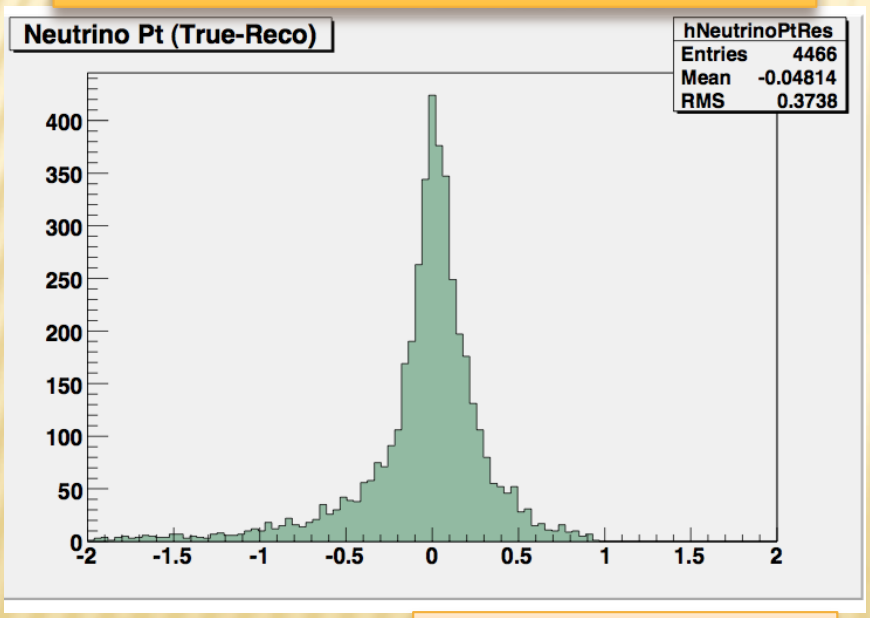
Transverse Missing Momentum



NEUTRINO MISSING MOMENTUM Pz

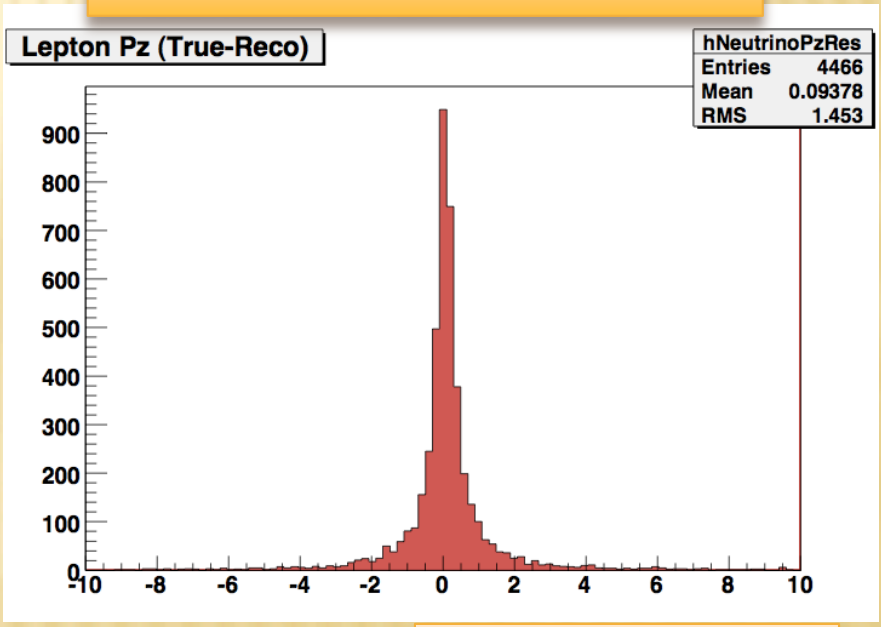
- Reconstructing the Mass of W
- The z-component missing energy can be reconstructed but with less accuracy than x and y components

Transverse Mom of Neutrino



(True-Reco)/True

z-Momentum of Neutrino



(True-Reco)/True

HIGGS BRANCHING RATIO MEASUREMENT (I)

- The branching ratio results: r is the ratio between the measured BR and the SM BR. r should be 1, within errors

	r_{bb}	r_{cc}	r_{gg}
Electron Channel	0.95 ± 0.06	1.3 ± 0.6	1.2 ± 0.5
Muon Channel	1.0 ± 0.04	0.87 ± 0.5	0.93 ± 0.5

- Fit error from pseudo experiment studies. This error indicates the accuracy with which the BR can be measured at ILC

	r_{bb}	r_{cc}	r_{gg}
Electron Channel	4%	36%	38%
Muon Channel	4%	46%	45%
Combined	3%	28%	29%