Higgs tagging using $\mathrm{Z} \rightarrow \mathrm{q}\bar{\mathrm{q}}$ @ 250 GeV

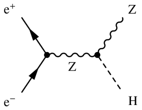
Y. Haddad
haddad@llr.in2p3.fr

LLR, École polytechnique, IN2P3-CNRS

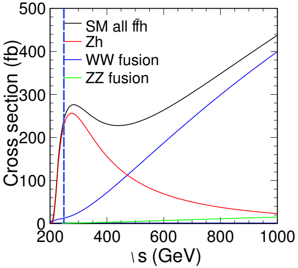
June 20, 2014

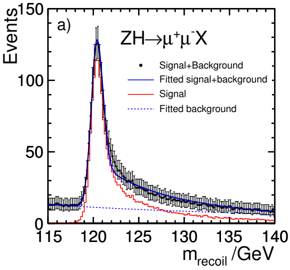
Motivation

- ZH is the dominant Higgs production process @ 250 GeV e^+e^- machine
- Signal topology: $e^+e^- \rightarrow Z^* \rightarrow ZH \rightarrow 2j + X$



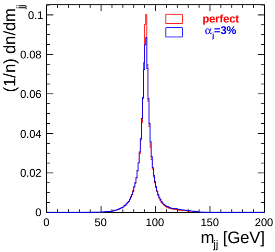
- $M_H^2 = M_{jj}^{recoil} = (\sqrt{s} - E_Z)^2 - P_Z^2$
  - Model in dependent extraction of $g_{ZZH} \propto \sigma = N/(L \cdot \epsilon)$
- Reconstruct the M_{jj}^{recoil} from the Z decay product only, without measuring the Higgs products.
- Can we exploit $Z \rightarrow jj$ decays ?
  - Increase the Higgs statistics $BR(Z \rightarrow q\bar{q}) \sim\rightarrow 70\%$ ($\sim 6\%$ for $Z \rightarrow ll$)
- Very difficult @250 GeV (ZZ/WW background)
  - $\rightarrow$ different Higgs efficiencies for different Higgs decay.
  - Almost model independent.

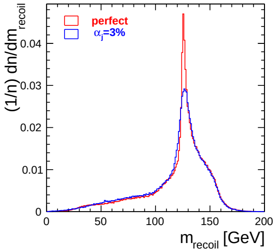




Analysis Strategy

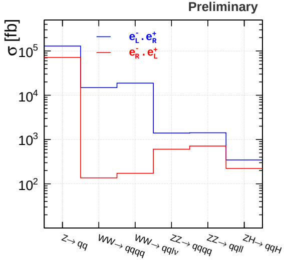
- Jet clustering of the stable + visible particles
  (no smearing of the particle energy at this stage)
- Smearing of the *reconstructed* jet's energy
  - Energy : $\sigma(E_j)/E_j = \alpha$
  - Momentum: $\sigma(p_j) = \left(\frac{E_j}{P_j}\right)\sigma(E_j) = \left(\frac{E_j^2}{P_j}\right)\alpha$
- A $\alpha = 3\%$ is chosen.
- Selection of the jet pair compatible with Z boson
  $\rightarrow$ the jet pair minimizing $D = |m_{jj} - m_Z|$
- Selection exploiting only (almost only) the kinimatics of the Z decay product.
- Analysis of the di-jet recoil mass spectrum.
- Only visible decays of Higgs are considered .





MC Samples

- Main processes at $250\ GeV$: ZH, W^+W^-, ZZ, $Z \to q\bar{q}$
- For $q\bar{q}$(Recoil) analysis → the main background : $WW \to 2j + X$, $ZZ \to 2j + X$
- 2012 DBD MC Generator samples (`WHIZARD-v1.95` Generator + `pythia-v6` for hadronization)
  - includes ISR + Beamstrahlung
  - → This analysis sould be better in TLEP case.
- Event weighting calculated for a processus "i" by $w_i = L \cdot \sigma_i / N_i$
- Weight for a given polarization:
  $w_i(e^-_R e^+_L) = (\frac{1+P(e^-)}{2})(\frac{1+P(e^+)}{2})$

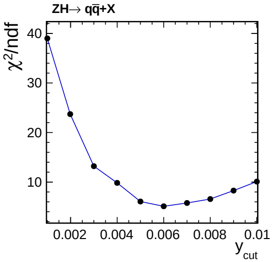


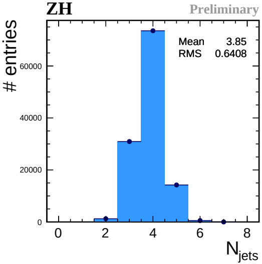
	$N_{jet} \geq 2$	$\sigma\ [fb]$	N_{events}	weight ($L = 500\ fb^{-1}$)
$e^-_L e^+_R$	$ZH(qq+X)$	346.013	437368	0.395563
	$WW(qqqq)$	14874.3	1074111	6.92401
	$WW(qql\nu)$	18781	1753663	5.35479
	$ZZ(qqqq)$	1402.06	1004632	0.697798
	$ZZ(qqll)$	1422.14	1299591	0.547149
	$Z(qq)$	129149	1629438	39.6299
$e^-_R e^+_L$	$ZH(qq+X)$	221.952	267357	0.415085
	$WW(qqqq)$	136.357	136325	0.500117
	$WW(qql\nu)$	172.733	158021	0.546551
	$ZZ(qqqq)$	604.971	603931	0.500861
	$ZZ(qqll)$	713.526	637256	0.559843
	$Z(qq)$	71272.8	1676503	21.2564

Jet Clustering

- No knowlege on the Higgs boson decay mode is employed in this analysis.
- Various topologies:
  - $ZH \to q\bar{q}b\bar{b}, q\bar{q}c\bar{c}, q\bar{q}gg, q\bar{q}\tau\tau \Rightarrow$ 4 jets
  - $ZH \to q\bar{q}WW \Rightarrow$ 4-6 jets (including isolated charged leptons)
  - $ZH \to q\bar{q} + inv \Rightarrow$ 2 jets
- Events cannot be forced into predifined number of jets $\Rightarrow$ Higgs selection must be unbiased
- Event resolved in aribtray number of exclusif jets using:
  - Durham algorithm implemented in `FastJet-v3.04`

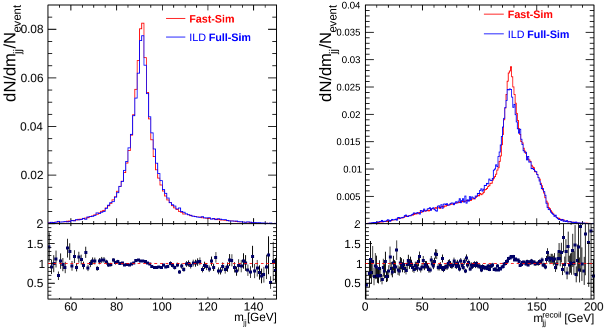
    $$y_{ij} = \frac{2\min\{E_i^2, E_j^2\}}{Q}(1 - \cos\theta_{ij})$$
  - Exclusive jet clustering with fixed-y_{cut}
- The Selected di-jet mass is fitted by a Voigtian p.d.f (Breit-Wigner⊗Gauss)
  - The $\chi 2$ vs $y_{cut} \to$ min at $y_{cut} = 0.006$
- The $y_{cut} = 0.006$ is chosen for the further analysis.





Full Simulation vs Fast Simulation

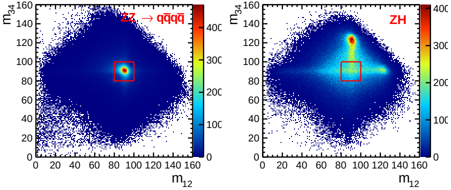
- Full simulation of ILD detector using the following configuration:
  - ECAL → Si-Tungsten ECAL option
  - HCAL → Semi-Digital HCAL option
- The Reconstruction of the Particle-Flow-Object is done by PandoraPFA



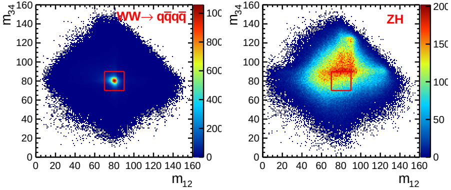
- ⇒ Very preliminary

Preselection: $ZZ/WW \to q\bar{q}q\bar{q}$ vetoes

- Consider that each event is $ZZ \to q\bar{q}q\bar{q}$ ($WW \to q\bar{q}q\bar{q}$) $\Rightarrow$ force jet-clustering into 4 jets
- for the ZZ veto $\to$ choose jet pairing minimizing $\chi^2 = (m_{ij} - m_Z)^2 + \left(m_{kj} - m_Z\right)^2$



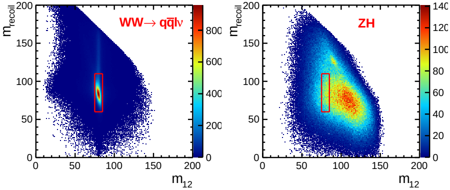
- for the WW veto $\to$ choose jet pairing minimizing $\chi^2 = (m_{ij} - m_W)^2 + \left(m_{kj} - m_W\right)^2$



- Cut on the selected pair masses (not on the recoil mass)

Preselection: $WW \to q\bar{q}l\nu$ veto

- Consider that each event is $WW \to q\bar{q}l\nu \Rightarrow$ force jet-clustering into 3 jets
- Choose jet pair closest to the W mass

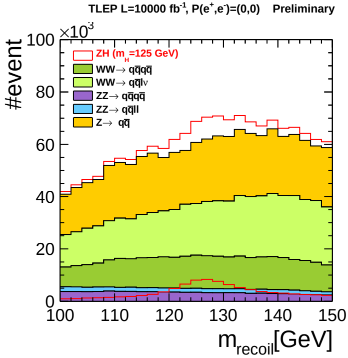


- Cut on the selected pair mass the corresponding recoil mass

Cut-based selection

Cut list

- WW/ZZ vetoes
- $|\cos\theta_j^Z| < 0.95$: (well measured jets)
- $E_Z/E_{vis} < 0.93$: (reduces off-shell $q\bar{q}$)
- $|cos\theta_Z| < 0.7$: (all background peak on the forward direction)
- $|cos\theta_{thrust}| < 0.8$
- $Sphericity > 0.1$: (reduces $q\bar{q}$)
- $83\mathrm{GeV} < \mathrm{m_{jj}} < 100\mathrm{GeV}$
- $100\mathrm{GeV} < \mathrm{m_{jj}^{recoil}} < 150\mathrm{GeV}$

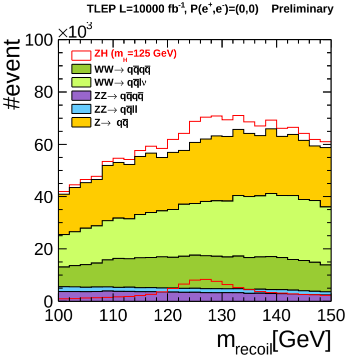


→ No clear peak but the measure of σ_{ZH} is possible

Cut-based selection

Cut list

- WW/ZZ vetoes
- $|\cos\theta_j^Z| < 0.95$: (well measured jets)
- $E_Z/E_{vis} < 0.93$: (reduces off-shell $q\bar{q}$)
- $|cos\theta_Z| < 0.7$: (all background peak on the forward direction)
- $|cos\theta_{thrust}| < 0.8$
- $Sphericity > 0.1$: (reduces $q\bar{q}$)
- $83\mathrm{GeV} < \mathrm{m_{jj}} < 100\mathrm{GeV}$
- $100\mathrm{GeV} < \mathrm{m_{jj}^{recoil}} < 150\mathrm{GeV}$

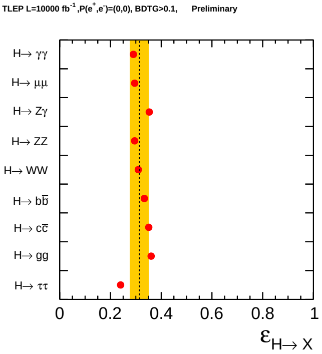


$\Delta(\sigma_{ZH})/\sigma_{ZH} \sim 1.4\%$

Cut-based selection

Cut list

- WW/ZZ vetoes
- $|\cos\theta_j^Z| < 0.95$: (well measured jets)
- $E_Z/E_{vis} < 0.93$: (reduces off-shell $q\bar{q}$)
- $|cos\theta_Z| < 0.7$: (all background peak on the forward direction)
- $|cos\theta_{thrust}| < 0.8$
- $Sphericity > 0.1$: (reduces $q\bar{q}$)
- $83\text{GeV} < \text{m}_{\text{jj}} < 100\text{GeV}$
- $100\text{GeV} < \text{m}_{\text{jj}}^{\text{recoil}} < 150\text{GeV}$

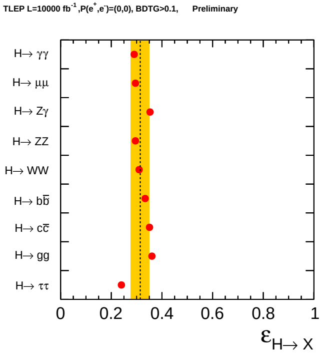


$\bar{\varepsilon} \sim \mathbf{44\%}$ $\quad \mathbf{\Delta}\varepsilon \sim \mathbf{2\%}$

Cut-based selection

Cut list

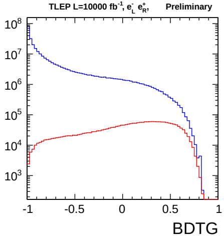
- WW/ZZ vetoes
- $|\cos\theta_j^Z| < 0.95$: (well measured jets)
- $E_Z/E_{vis} < 0.93$: (reduces off-shell $q\bar{q}$)
- $|cos\theta_Z| < 0.7$: (all background peak on the forward direction)
- $|cos\theta_{thrust}| < 0.8$
- $Sphericity > 0.1$: (reduces $q\bar{q}$)
- $83\mathrm{GeV} < \mathrm{m_{jj}} < 100\mathrm{GeV}$
- $100\mathrm{GeV} < \mathrm{m_{jj}^{recoil}} < 150\mathrm{GeV}$

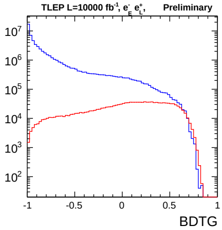


$\boldsymbol{\Delta(\sigma_{ZH})/\sigma_{ZH} \sim 1.4\%}$

MVA based selection

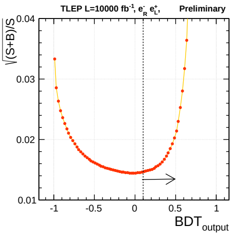
- Use of ROOT TMVA package → Boosted Decision Tree (BDT)
- The input variables are;
  - m_{jj} : The invariant mass of the di-jet system
  - $|\cos\theta_Z|$: di-jet production angle
  - $\Delta\theta_{12}$: opening angle of the di-jet
  - $\Delta\phi_{12}$: opening angle of the di-jet is the transverse plan
  - $|\Delta E_{12}|$: larger boost from Z-pair → larger jet energy spread
  - $-\log_{10}(y_{23,34})$: `Durham` resolution parameters
- Train the BDT for combined backgrounds
- One BDT of each polarization ($e^-_R e^+_L$ or $e^-_L e^+_R$)
  - The Gradient BDT (BDTG) is chosen, more powerful than the standard BDT.

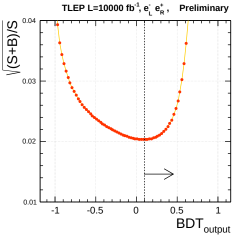




MVA based selection

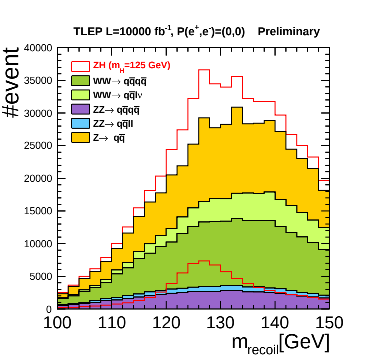
- Use of ROOT TMVA package → Boosted Decision Tree (BDT)
- The input variables are;
  - m_{jj} : The invariant mass of the di-jet system
  - $|\cos\theta_Z|$: di-jet production angle
  - $\Delta\theta_{12}$: opening angle of the di-jet
  - $\Delta\phi_{12}$: opening angle of the di-jet is the transverse plan
  - $|\Delta E_{12}|$: larger boost from Z-pair → larger jet energy spread
  - $-\log_{10}(y_{23,34})$: Durham resolution parameters
- Train the BDT for combined backgrounds
- One BDT of each polarization ($e^-_R e^+_L$ or $e^-_L e^+_R$)
  - The Gradient BDT (BDTG) is chosen, more powerful than the standard BDT.





MVA based selection

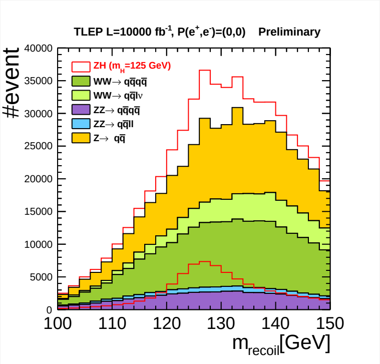
Result

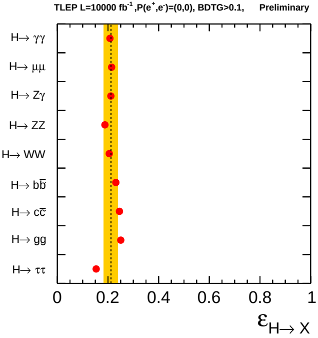


→ Cut on the BDTG output > 0.1 → More significance

MVA based selection

Result

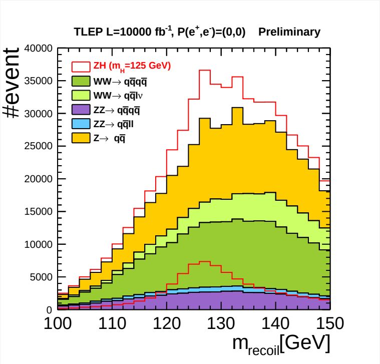


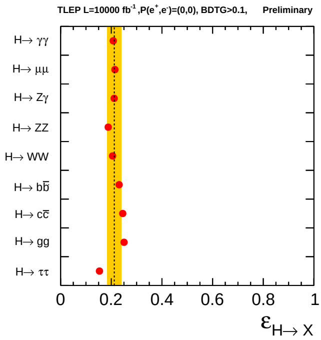


$$\mathbf{\Delta(\sigma_{ZH})/\sigma_{ZH} \sim 1.1\%}$$

MVA based selection

Result

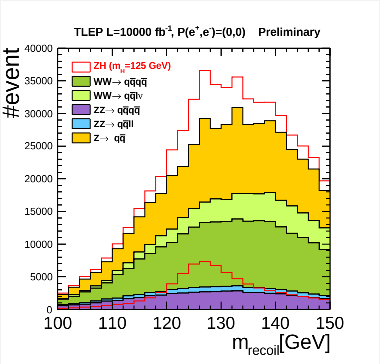


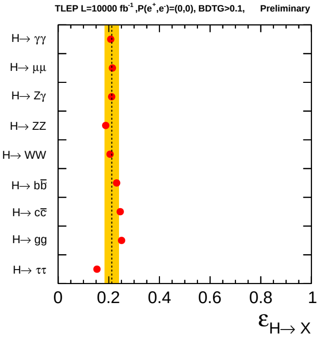


$\bar{\varepsilon} \sim \mathbf{21.2\%}$ $\quad \boldsymbol{\Delta}\varepsilon \sim \mathbf{2.7\%}$

MVA based selection

Result





Selection

Process	N_{tot}	N_{sel}	$\sim \varepsilon_{sel}$
$ZH \to q\bar{q} + X$	354140	76172	0.21
$WW \to q\bar{q}q\bar{q}$	605418	14546	0.02
$WW \to q\bar{q}l\nu$	1045940	6287	$<$ 0.01
$ZZ \to q\bar{q}q\bar{q}$	805200	36332	0.04
$ZZ \to q\bar{q}ll$	1067834	12751	0.01
$Z \to q\bar{q}$	1794082	2696	$<$0.01

- Large background rejection ($< 4\%$)
- Signal efficiency $\sim 21\%$

Conclusion & Outlook

- An model independent analysis on the $ZH \to q\bar{q} + X$ at $10000 fb^{-1}$ TLEP with $P(e^+, e^-) = (0,0)$ is possible
- Uses of both background vetoes and MVA based selection reduces a large fraction of background.
- Good significance : $\mathbf{\Delta(\sigma_{ZH})/\sigma_{ZH} \sim 1.12\%}$ with the very similar efficiencies for different Higgs decay modes ($\sim 21\%$)
- The uses of the "realistic" TLEP beam parameters could improve the results (reduction of beamstrahlung)
- Next :
  - Combination with other channels
  - Include a dedicated analysis for $H \to inv$