Full Simulation Study of

$W^+W^- \to t\bar{t}$

at TESLA

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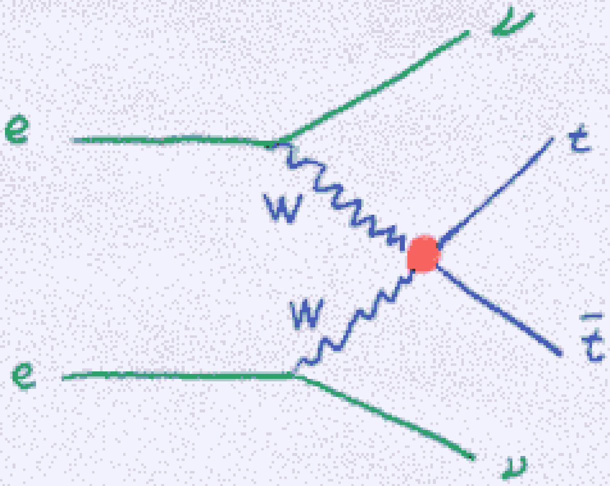
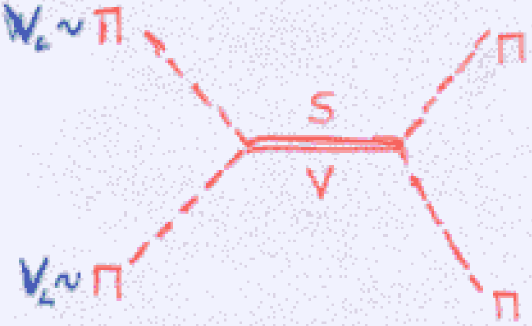
Motivation

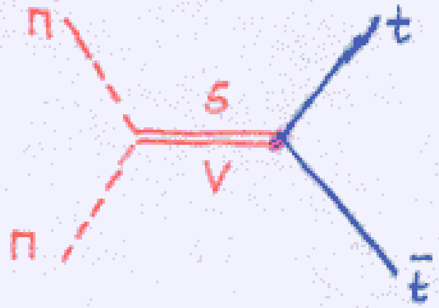


$W^+W^- \to t\bar{t}$
at High Energy
e^+e^- Colliders

Great physical interest in models of strong-interaction
Electroweak Symmetry Breaking

- High Energy $W_L \equiv \pi$-GB from the symmetry breaking interactions. In S.I. models: W_L amplitudes enhanced, may have new resonances.
- Depending on models: can be the same resonances as in VV-scattering, or new ones from the dynamics generating the top quark mass.





Test Higgs Mechanism

Test top-mass generation

- Scalar or Vector resonance exchange could be distinguished by top quark polarization analysis.
- At LHC, $WW \to t\bar{t}$ hidden under the huge QCD background.

Observable at planned e^+e^- Linear Colliders ?

Strong-interaction Electroweak Symmetry Breaking ≡

The Higgs sector responsible for EW symmetry breaking is formed by a new set of particles with new strong interactions with a typical scale ~ 1 TeV.
($\Rightarrow$ there is no fundamental / light Higgs boson)

- The strong interactions could form resonances ≡ bound states of the new set of particles.

- "SM heavy Higgs" means in this context: scalar bound state with the same couplings to W and t as a fundamental Higgs.
(this will happen, in general, if the strong-interactions that form the scalar resonance are responsible of all EW symmetry breaking)

Previous Studies

- Theoretical Study: (Sitges, ERM and M. Peskin)
  - $WW \to t\bar{t}$ in different S.I. Models:
    1. SM: Heavy Higgs gives LL and RR $t\bar{t}$ pairs.
    2. Technicolor: T_ρ couples to LR and RL final states. T_ρ exchange as in VV-scattering.
    3. Topcolor: New scalar (Top-Higgs) exchange. Not relevant in VV-scattering.
  - Signals at 1.5 TeV LC: In several models analyzed, the new resonances give cross section enhancements of similar size to the SM Higgs boson signals.
  - $t\bar{t}$ polarization analysis based on experimental assumptions.
- SM Simulation: (Snowmass, T. Barklow)
  1.5 TeV Collider
- SM Simulation: (JLC Study, Tsukamoto)
  Early ninetees, old collider parameters.

Our analysis

- Realistic simulation study for TESLA: $\sqrt{s} = 1$ TeV, $\mathcal{L} = 1$ ab^{-1}.
- Full calculation including reducible and irreducible backgrounds. Need reliable Event Generators.
- Include ISR and Beamstrahlung (CIRCE).
- Realistic Detector Simulation (SIMDET, V3.02).
- Detailed event reconstruction.

Event Generators 1

- We found some difficulties:

Generator	Advantages	Shortcomings
CompHep	- All SM Diagrams - Fast - Reliable	- Hard to include: Beamstrahlung New models
Pandora	- Full helicity - Top decays - Easy to modify models	- Only Fusion Diagrams - Effective-W approx with p_T functions
NextCalibur	- All $ee \to 4f$ SM diagrams - separate $t\bar{t}$ helicities	- Too slow - Improvements needed

- Main Problem:
  At $\sqrt{s} = 1.5$ TeV, WW-fusion + Effective-W approximation with helicity- and p_T- dependent W distributions OK, but
  At $\sqrt{s} = 1$ TeV, there are negative interference effects among irreducible backgrounds and non-fusion diagrams cannot be neglected

$\Rightarrow$ Need full $ee \to 4f$ generator for studies at TESLA

- NextCalibur = Excalibur $ee \to 4f$ program + Higgs diagrams + "Massive" fermions + ISR improved.

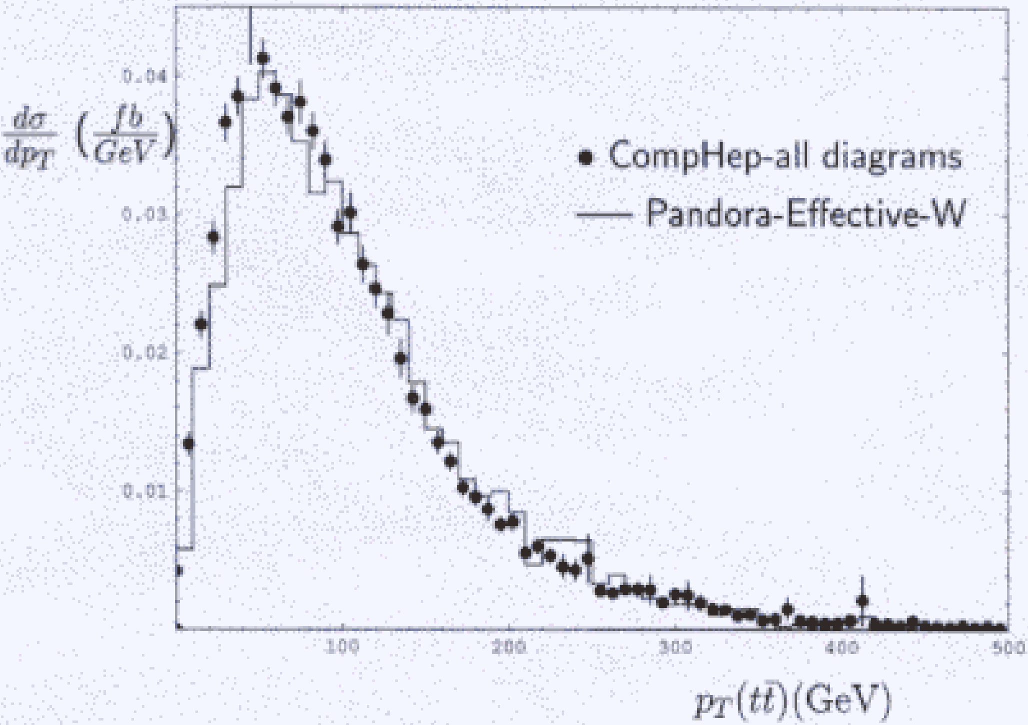
  We had to implement:

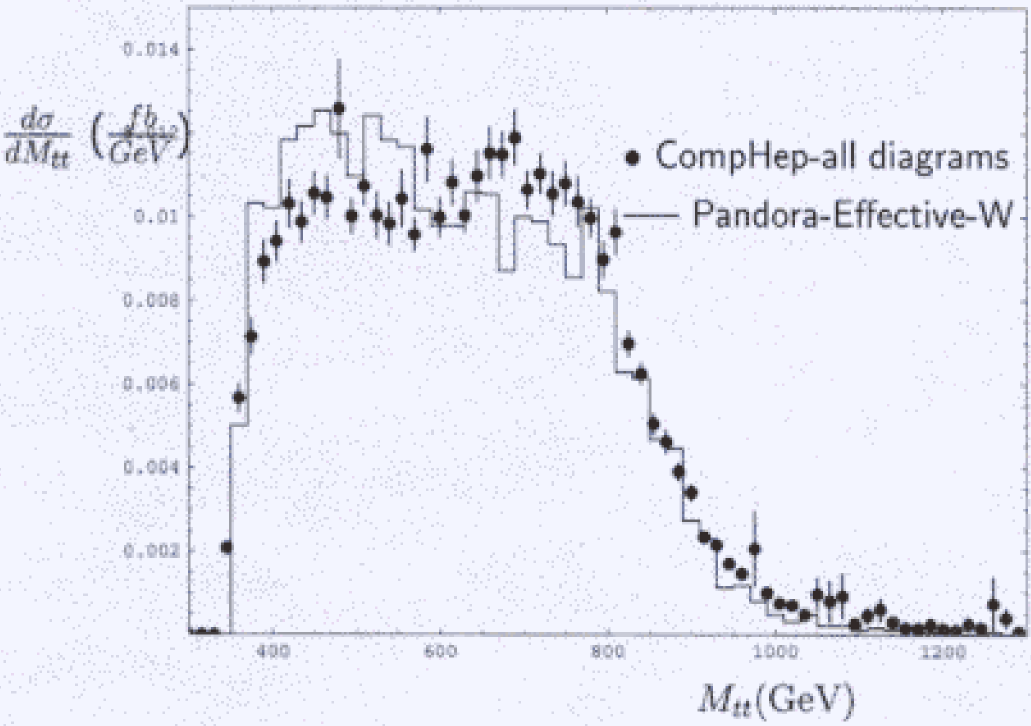
  – Weighter $\longrightarrow$ Event Generator.
  – Run on Linux and other platforms.
  – Include Beamstrahlung (CIRCE).
  – Control on Higgs mass, and final top polarizations.
  – Implement helicity-dependent top decay kinematics (Pandora).

Event Generators 2

$\sqrt{s} = 1.5$ TeV, $m_H = 800$ GeV

(Generator Level, no ISR, no Beamstrahlung)

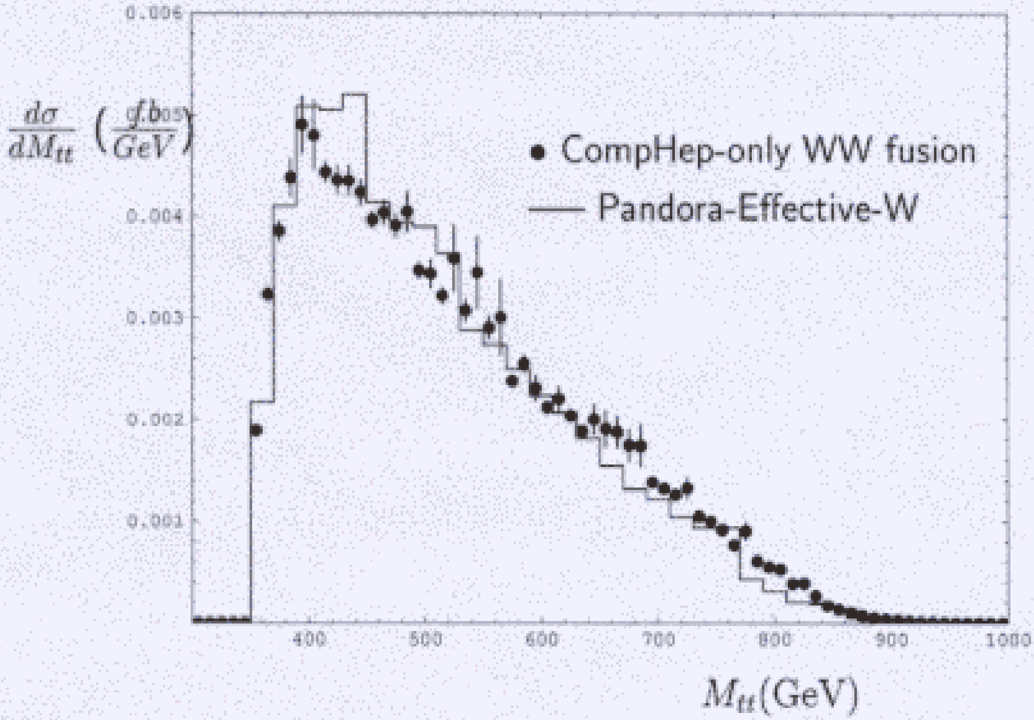


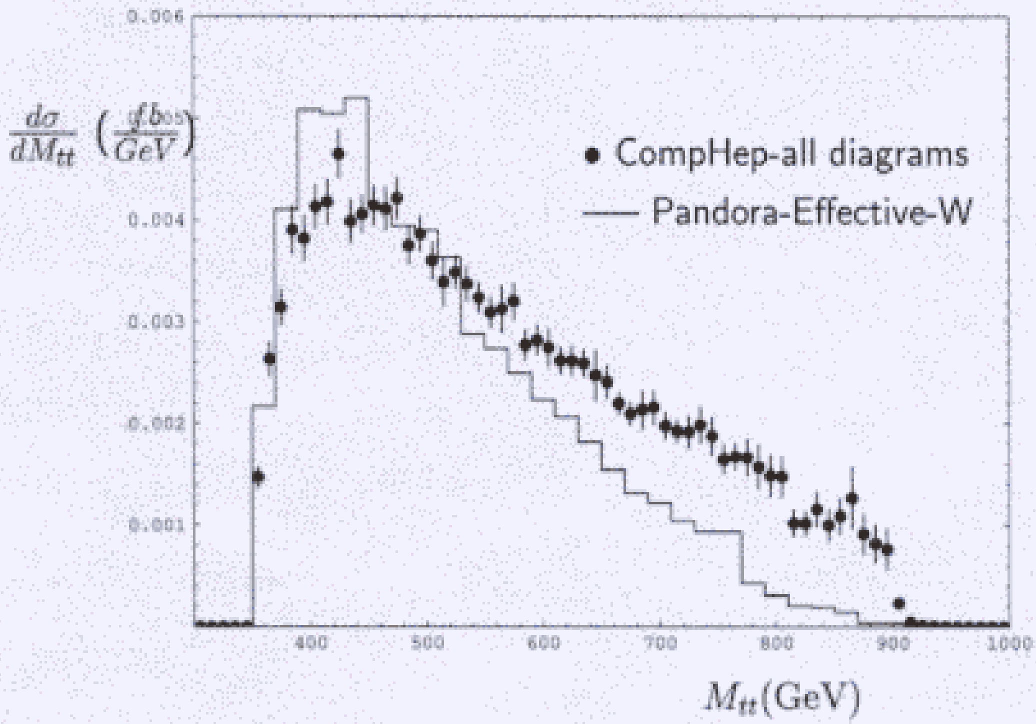


Event Generators 3

$\sqrt{s} = 1 \text{ TeV}, \quad m_H = 800 \text{ GeV}$

(Generator Level, no ISR, no Beamstrahlung)





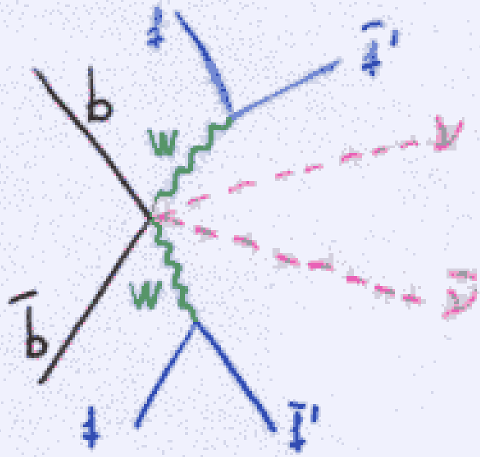
SM Signal and Backgrounds

- Signal: $e^+e^- \to \nu\bar{\nu}t\bar{t}$ Helicity Cross Sections (fb):

m_H (GeV)	σ(LL) = σ(RR)	σ(LR)	σ(RL)	Total
100	0.113	0.22	0.21	0.66
500	1.65	0.22	0.21	3.75
800	0.33	0.22	0.21	1.11

(Generator Level, with IRS and Beamstrahlung)

- Events looks like $e^+e^- \to t\bar{t}$ but:
  - Large missing T and L momentum from two ν's. $\sim \frac{M_W}{2}$
  - Lower visible mass, in general.



- Huge but manageable backgrounds:

  $\sigma(ee \to q\bar{q}) = 5400$ fb $\to$ (5.4 Mevents!)

  $\sigma(ee \to W^+W^-) = 3700$ fb $\to$ (3.7 Mevents!)

- Critical backgrounds:

  $\sigma(ee \to t\bar{t}) = 243$ fb

  $\sigma(ee \to eet\bar{t}) = 17$ fb

- Backgrounds generated with PYTHIA.

In this analysis, we have only used 6 jet events

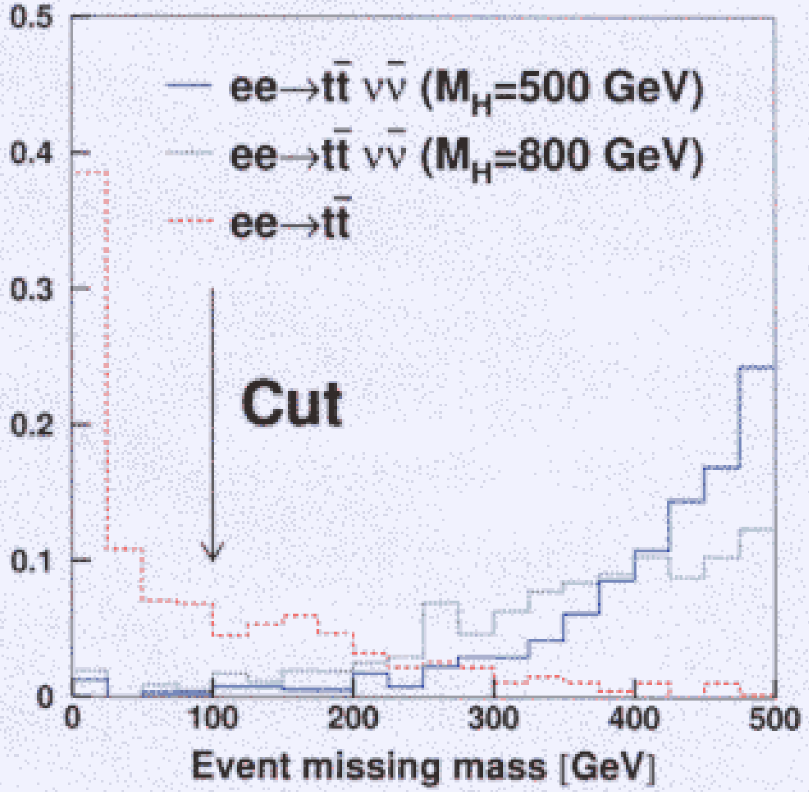
(4.000)

(60.000)

(200.000)
(20.000)

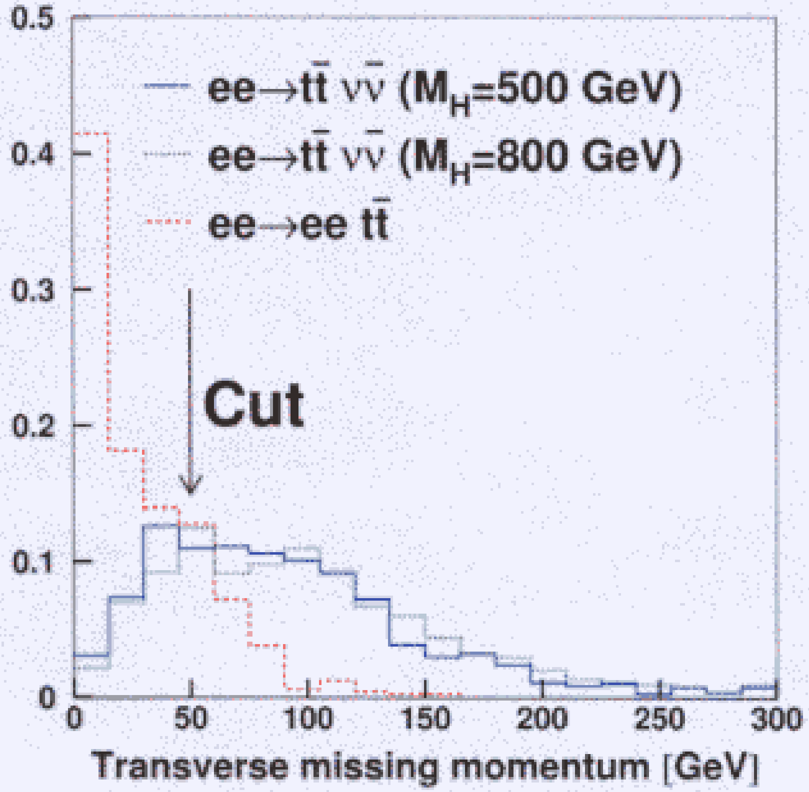
Preselection Cuts 1

- $M_{\text{Miss}} \geq 100$ GeV: Cuts $ee \to t\bar{t}$. (ISR + Beams.)



Normalized
No Cuts

- $E_T \geq 50$ GeV: Cuts $ee \to eet\bar{t}$. (γγ-fusion)

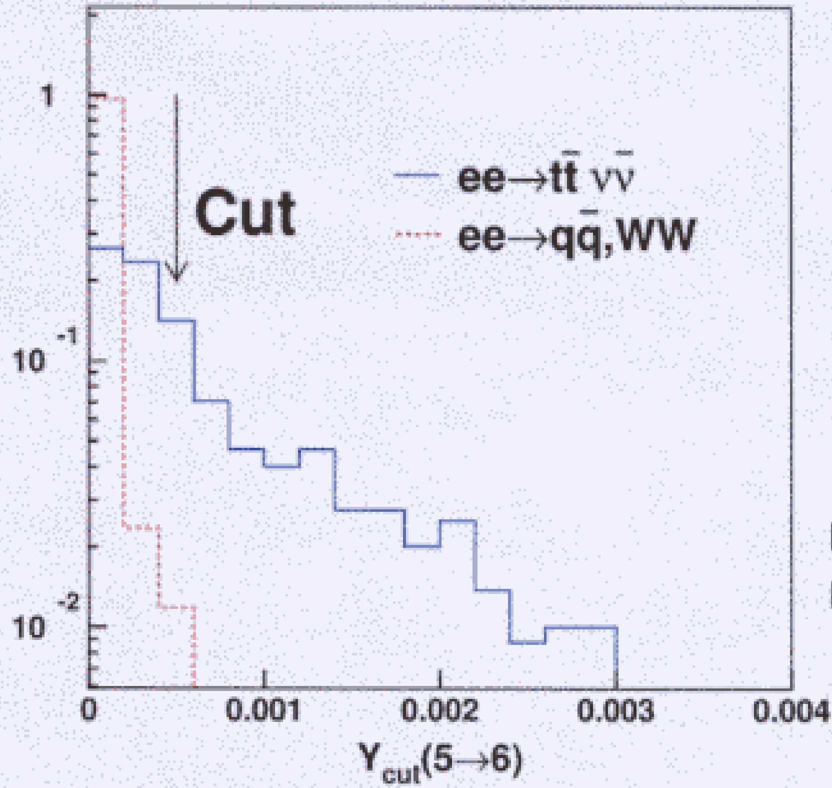


Normalized
No Cuts

Preselection Cuts 2

- No lepton: force event into 5 jets and reject it if find lepton with $E_{\rm Lept} \geq 0.7 E_{\rm Jet}$.

- Force six jet event: Durham Algorithm, require $Y_{\rm Cut}^{(5-6)} \geq 0.0005$. Cuts $ee \to q\bar{q}, WW$.



Normalized

No Cuts

After Preselection cuts

still huge background from missreconstructed $ee \to t\bar{t}$

Jet Association for the best χ^2

- Find the combination giving best

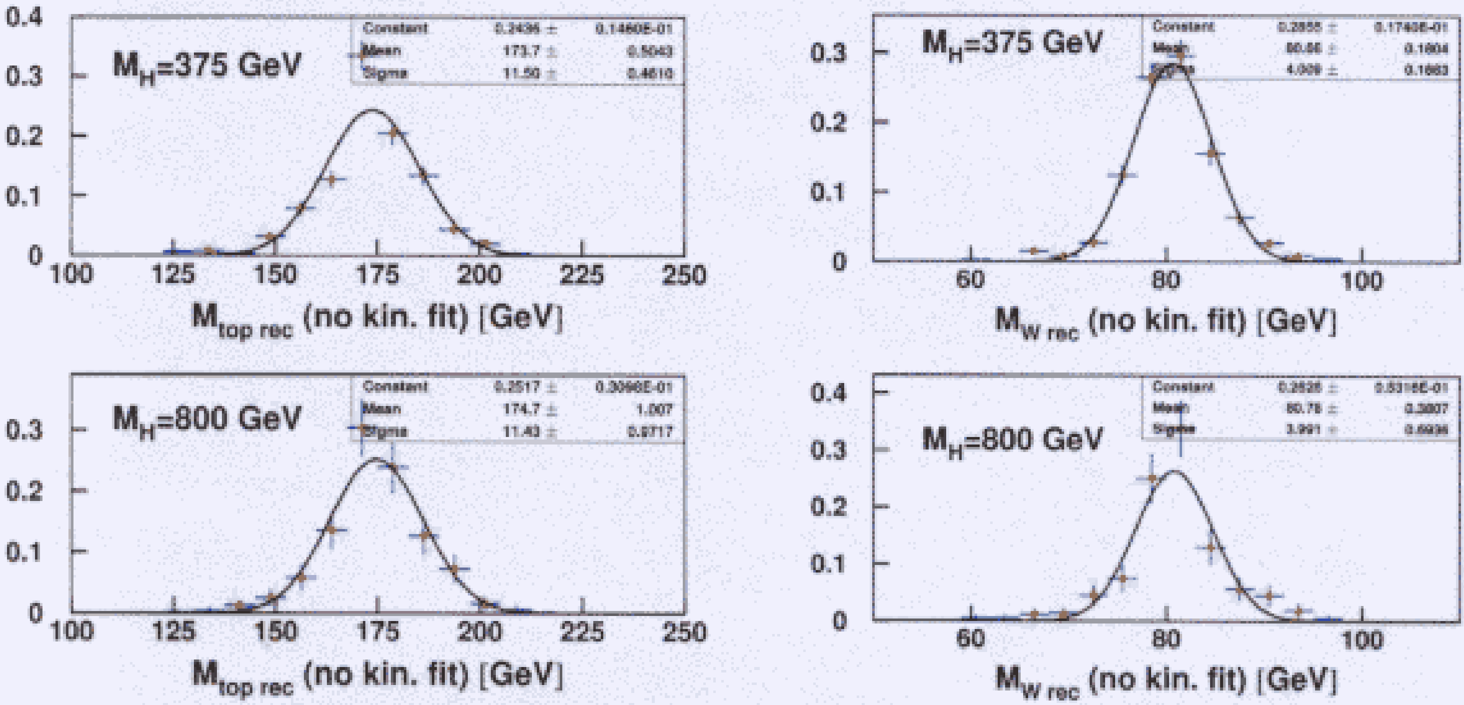
$$\chi^2_{\min} = \frac{(M_{W1} - M_W)^2}{(5GeV)^2} + \frac{(M_{W2} - M_W)^2}{(5GeV)^2} + \frac{(M_{t1} - M_W)^2}{(10GeV)^2} + \frac{(M_{t2} - M_W)^2}{(10GeV)^2}$$

  and keep the event only if this combination is within 5σ of the expected mass values

$$|M_{Wi} - M_W| \leq 5\sigma \approx 25GeV; \qquad |M_{Wi} - M_W| \leq 5\sigma \approx 50GeV$$

  This rejects missreconstructed $ee \rightarrow tt$ events.

- Reconstructed t and W masses:

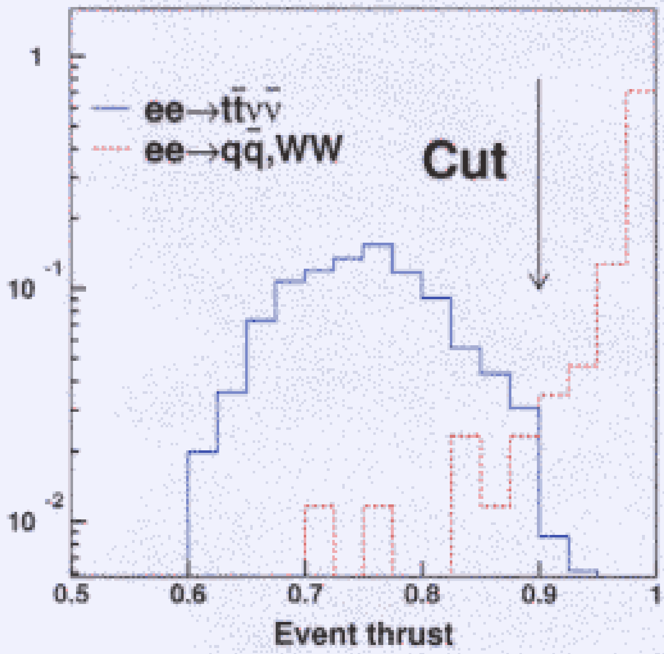


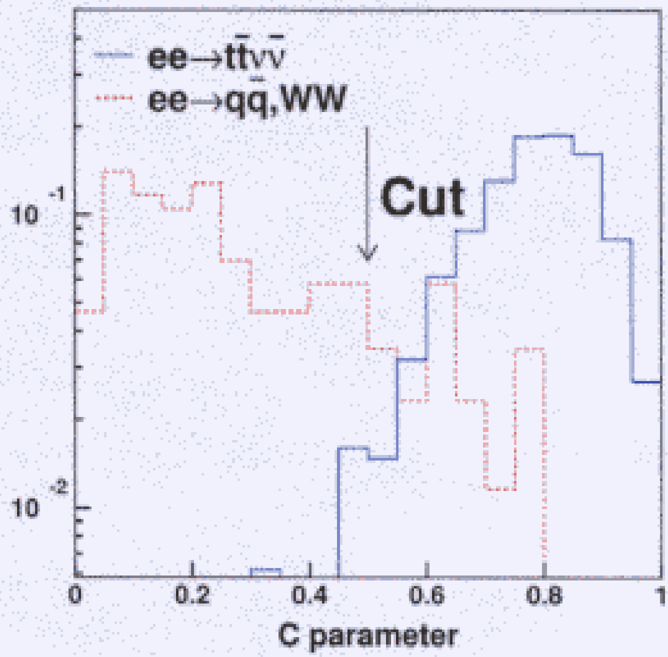
Final acceptance for signal events $\approx 10\%$.

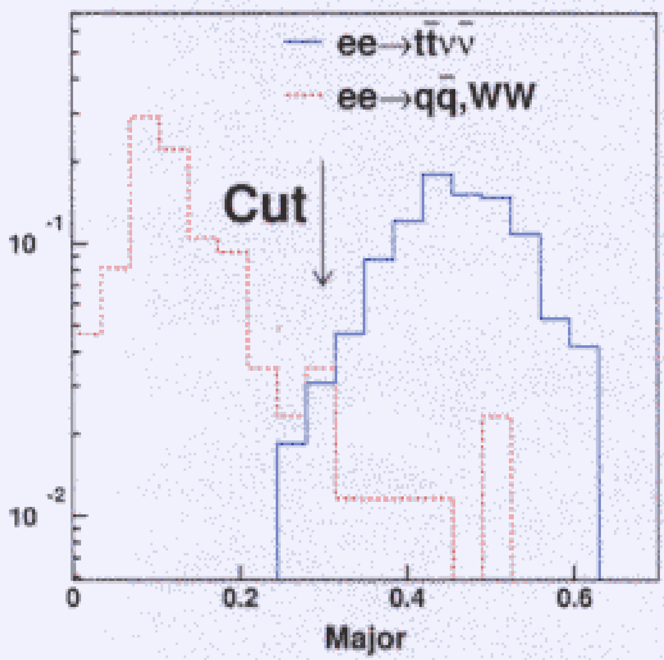
(OK with Tsukamoto)

Final Cuts

- Thrust ≤ 0.9, $C_{par} \geq 0.5$: Select spherical events.
- Major ≥ 0.3: Select non-planar events.
- Moderate b-tagging: To further reject $ee \to qq, WW$. Based on consistency with primary vertex.

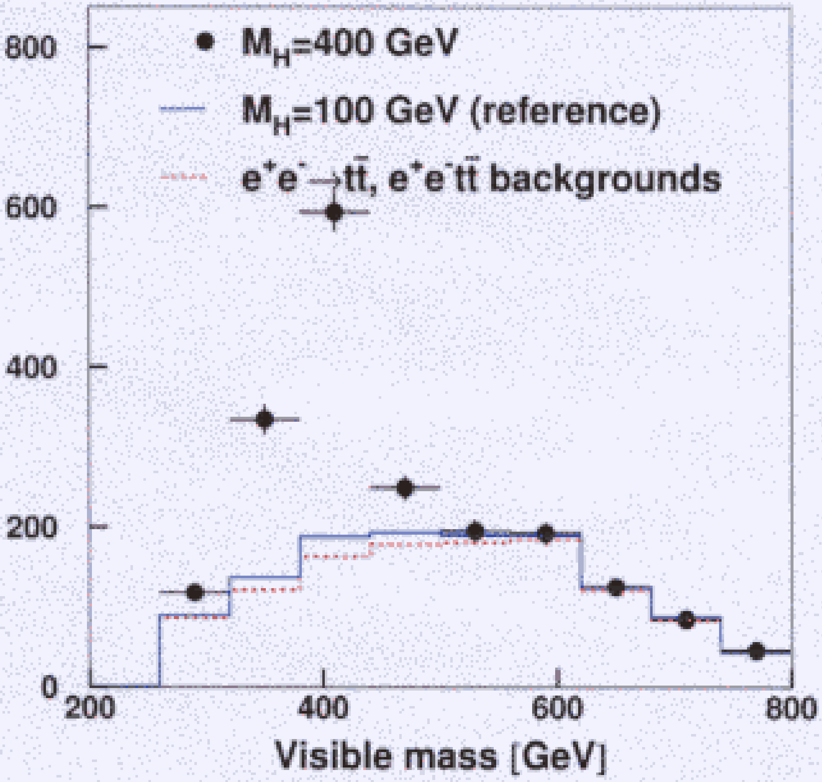




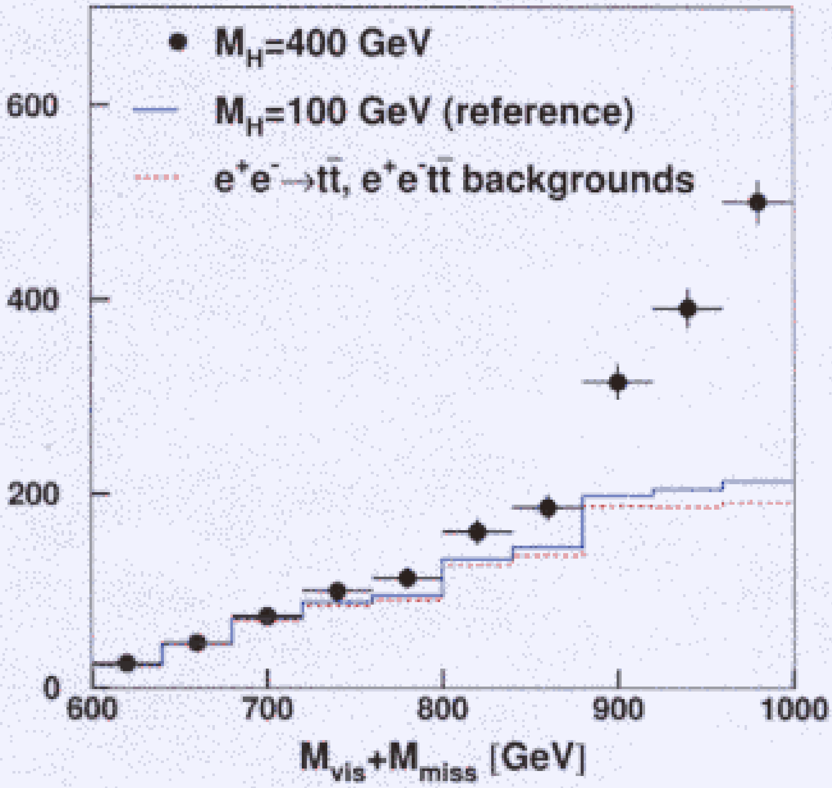


Negligible qq and WW backgrounds after these cuts

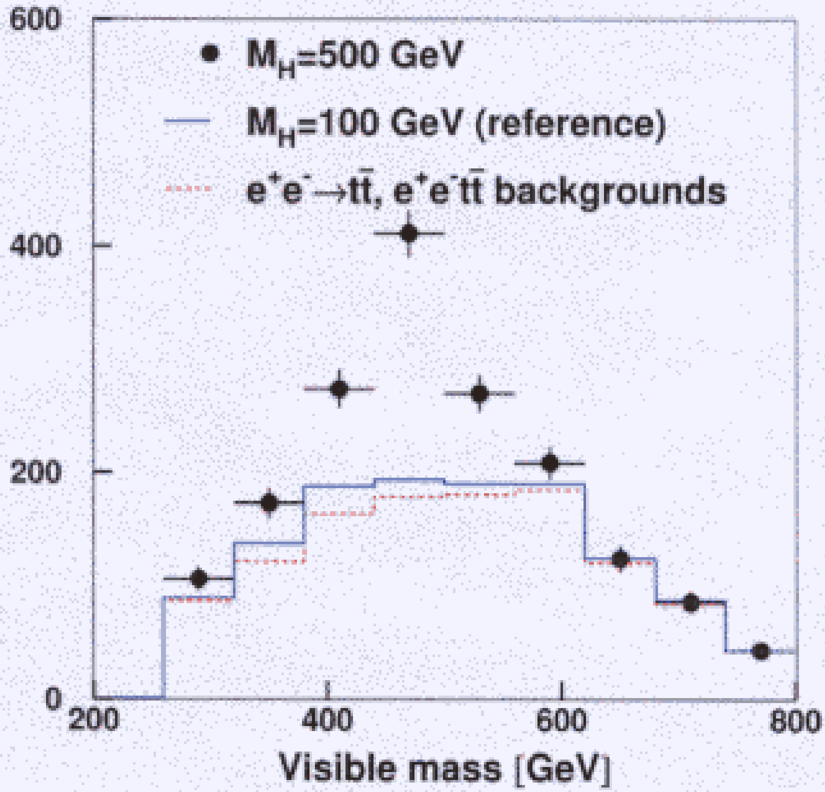
Higgs Signals

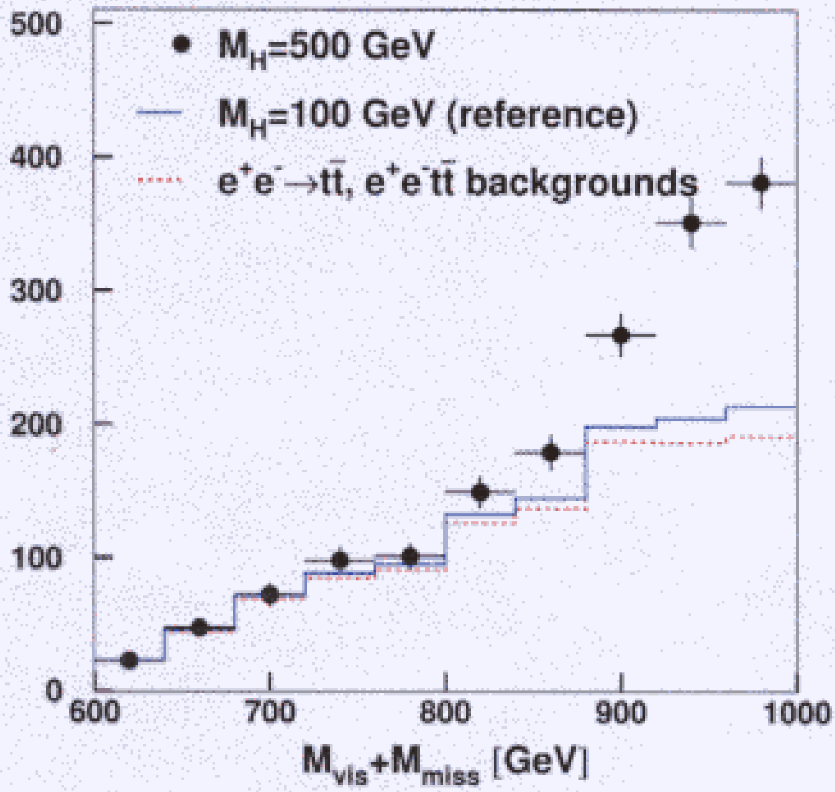


m_H = 400 GeV
Signal = 693
Bckgrd = 1218



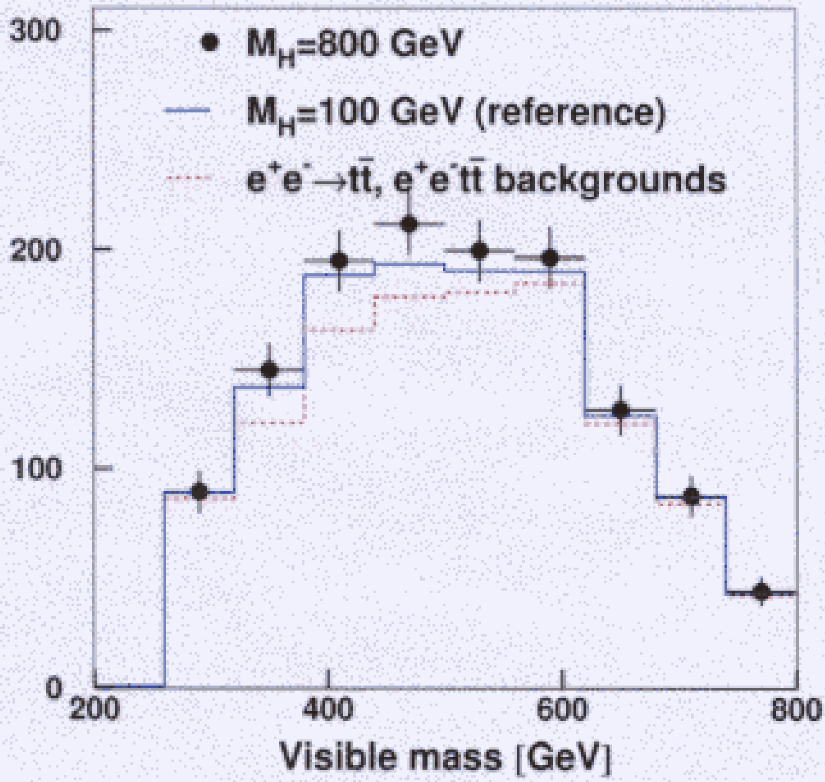
Higgs Signals

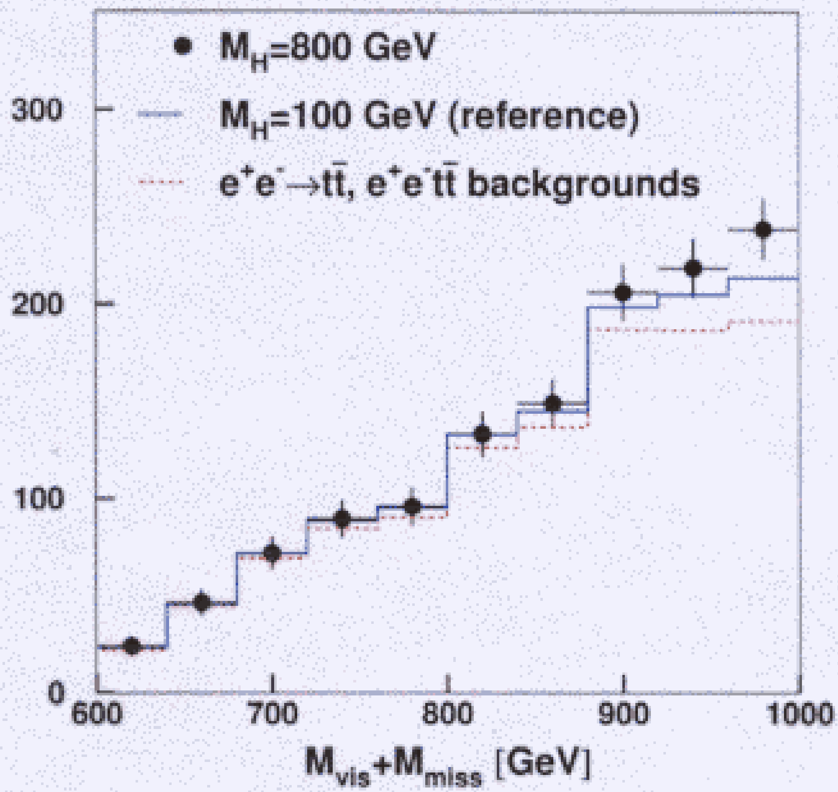




m_H = 500 GeV
Signal = 450
Bckgrd = 1218

Higgs Signals





$m_H = 800$ GeV
Signal = 54
Bckgrd = 1218

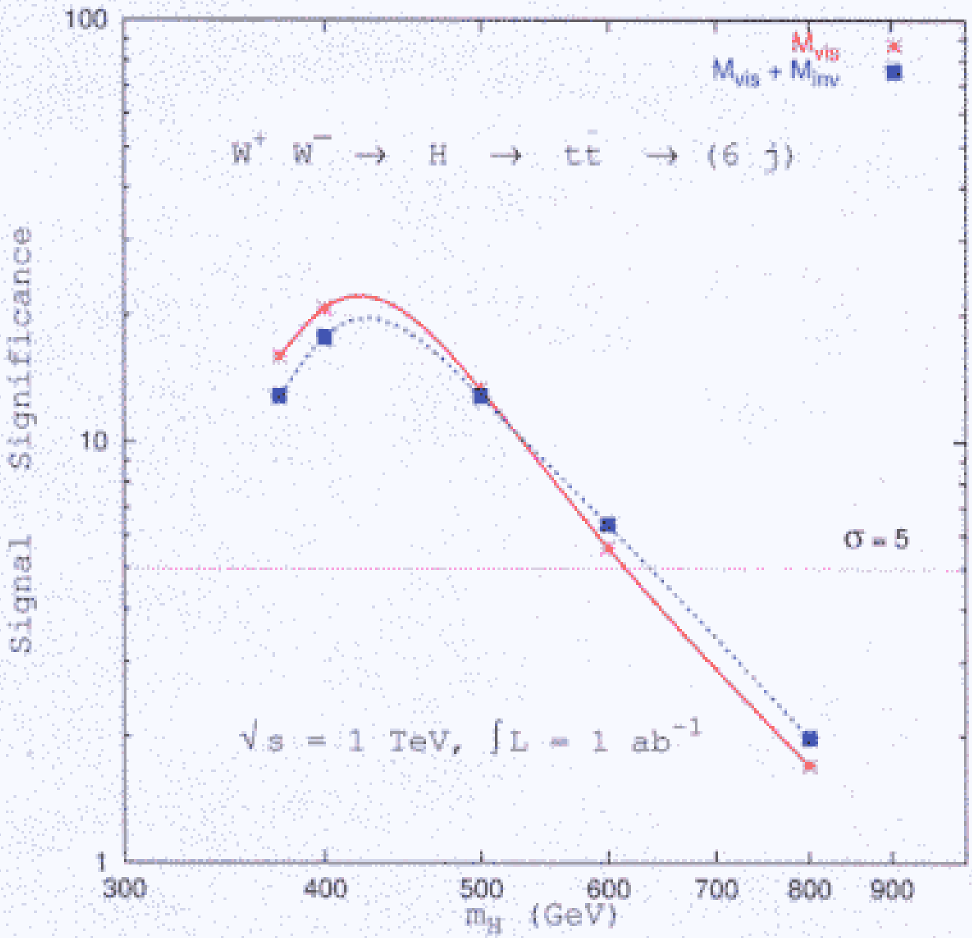
Higgs Signal Significance

- Signal: $X(m_H) \equiv \sigma_{\text{seen}}(m_H) - \sigma_{\text{expected}}(m_H = 100)$.
  Background: $\sigma_{\text{expected}}(m_H = 100)$.

m_H (GeV)	375	400	500	600	800
N. Signal Events	342	543	351	157	42
N. Backg. Events	520				

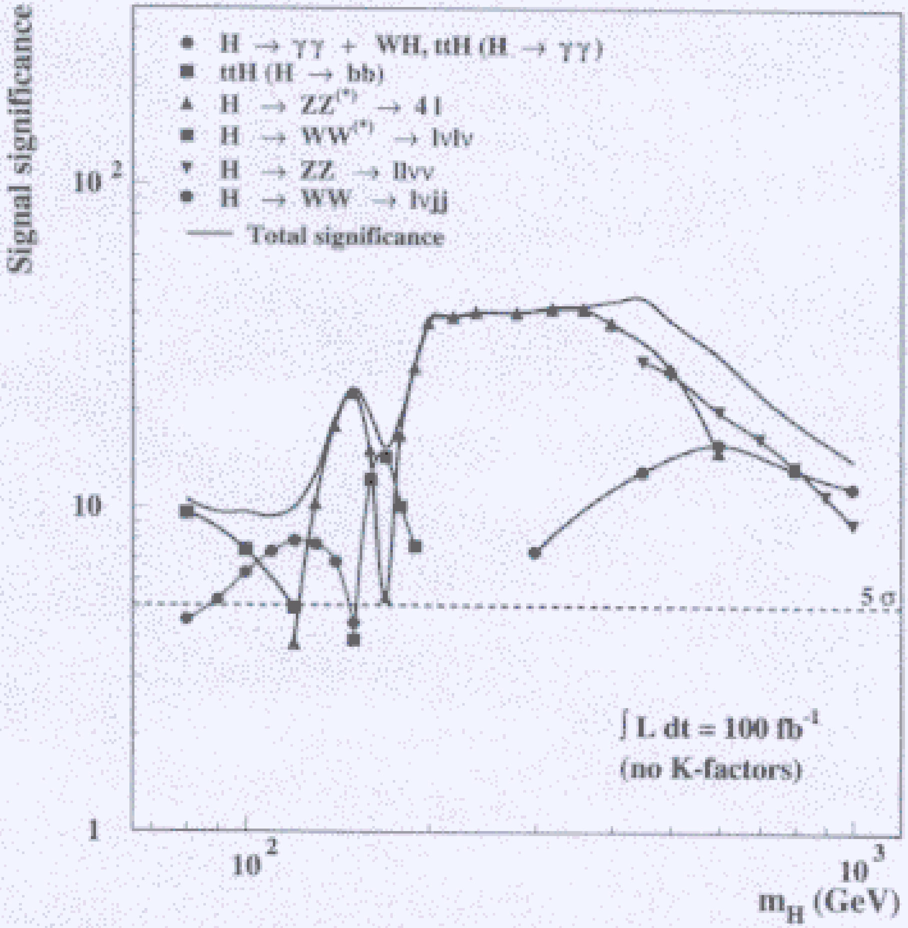
(Number of Events with $M_{\text{vis}} + M_{\text{miss}} \geq 900$ GeV.)

- Fits to $X(m_H)$ using: M_{vis} : 10 bins (300-800) GeV.
  $M_{\text{vis}} + M_{\text{miss}}$: 10 bins (600-1000) GeV.



$H \to t\bar{t}$ Signal Observable with Significance $\geq 5\sigma$ for m_H in 350-650 GeV range at TESLA.

Comparison with Higgs Signal from VV-Scattering



ATLAS TDR

Higgs Signal Significance

m_H (GeV)	TESLA (1 TeV, 1 ab^{-1}) $H \to t\bar{t} \to (6j)$	ATLAS (14 TeV, 100 fb^{-1}) $H \to VV \to$(all)
375	16	35
400	20	40
500	13	40
600	6	40
800	2	12

Top quark Yukawa Measurements

- At LHC: $t\bar{t}H$: $\frac{\delta Y_t}{Y_t}$(stat) $\approx$ 10 % for $m_H \leq 120$ GeV. (Atlas TDR)

- At e^+e^- LC:

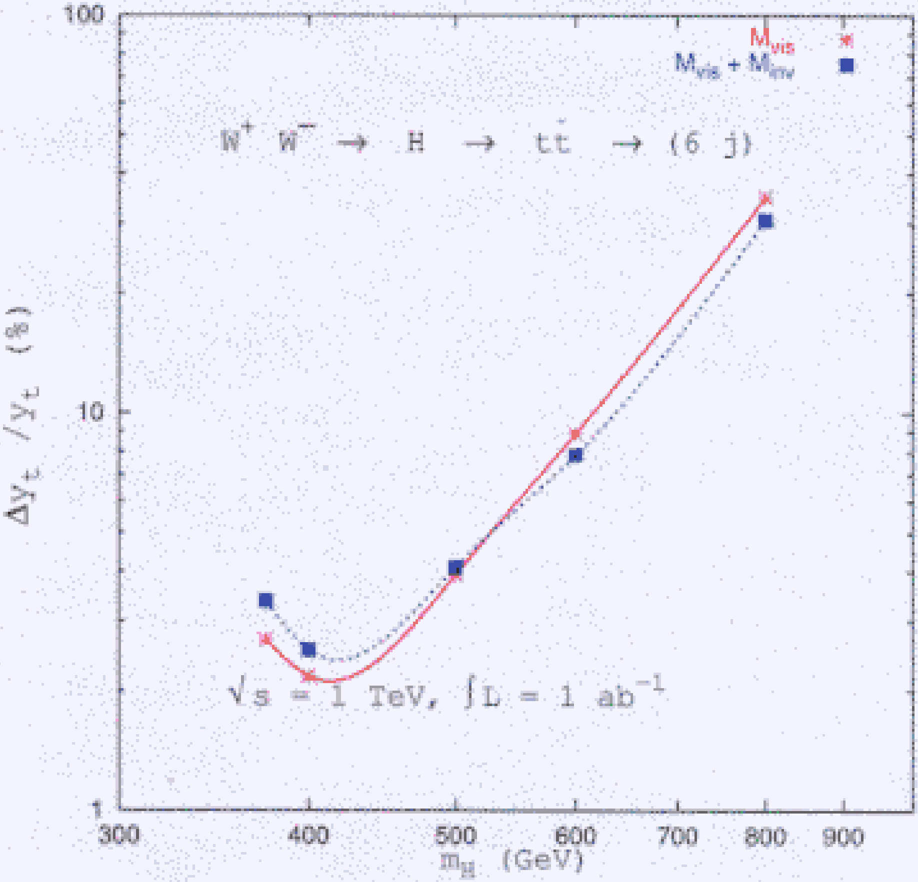
$e^+e^- \to t\bar{t}H(H \to b\bar{b})$: $\frac{\delta Y_t}{Y_t} \approx 10$ % for $m_H \leq 120$ GeV.

(Baer, Dawson, Reina), (Juste, Merino)

$e^+e^- \to t\bar{t}Z$: $\frac{\delta Y_t}{Y_t} \approx 10$ % , for $m_H \approx 2m_t$ GeV.

(Fujii) (old JLC setting)

$e^+e^- \to \nu\bar{\nu}t\bar{t}$: At TESLA ,$\sqrt{s} = 1$TeV, $\mathcal{L} = 1$ ab^{-1} we find



m_H (GeV)	$\Delta Y_t/Y_t$ (%)
375	2.7
400	2.2
500	3.9
600	7.8
800	30.5

Possible to measure Y_t with $\frac{\delta Y_t}{Y_t} \leq 10$ %,
for m_H in 350-650 GeV range at TESLA.

Conclusions

- $W^+W^- \to t\bar{t}$ interesting at TESLA, if there is no light Higgs boson.

- A $WW \to H \to t\bar{t}$ signal will be observable in TESLA if $\sqrt{s} = 1$ TeV, $\mathcal{L} = 1$ ab^{-1} and $m_H \leq 650$ GeV.

- The Higgs-top Yukawa coupling will be measured with a precision better than 10%, if $\sqrt{s} = 1$ TeV, $\mathcal{L} = 1$ ab^{-1} and $M_H \leq 650$ GeV.

- Unique way to measure the Top Yukawa coupling to a heavy Higgs boson (at LHC, $H \to t\bar{t}$ is not observable for $m_H > 120$ GeV.)

- Similar results can be expected in other scenarios of strong electroweak symmetry breaking (technicolor).

- Extensions of this analysis for TESLA still under study:
  - $\sqrt{s} = 800$ GeV.
  - Include semileptonic $t\bar{t}$ decays.
  - Top polarization studies.