Study of the $\mathrm{WW} \to \mathrm{H} \to \mathrm{t\bar{t}}$ Process at TESLA

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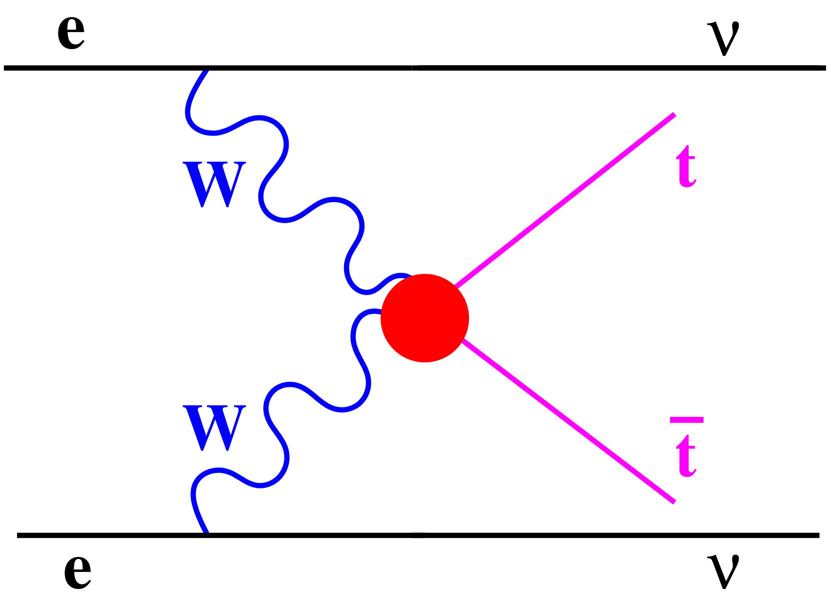
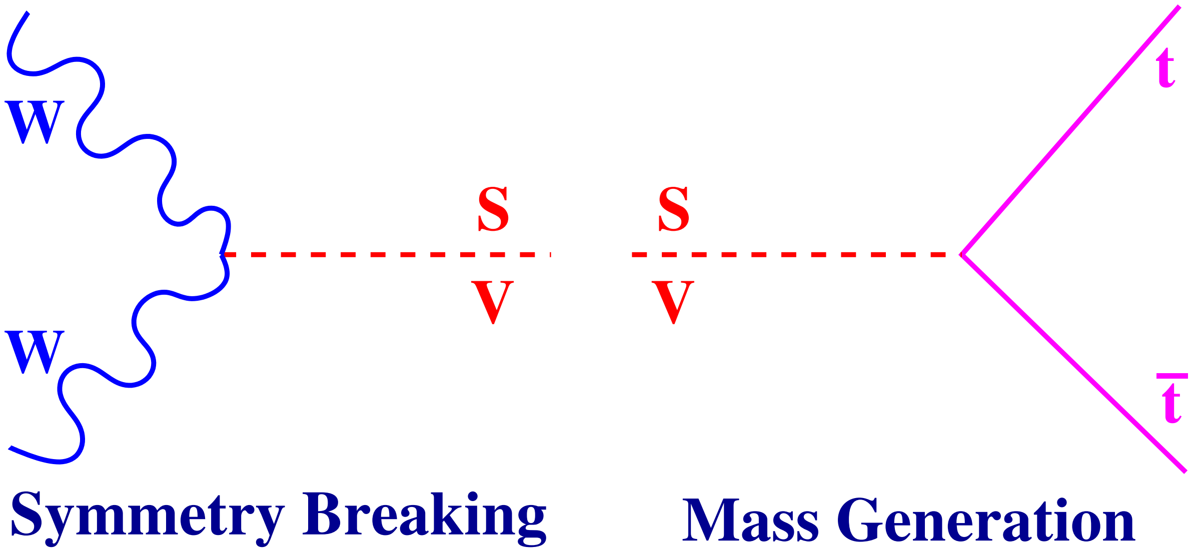
- Motivation
- At the generator level
- At the reconstruction level: selection cuts
- Results
- Conclusions and Outlook

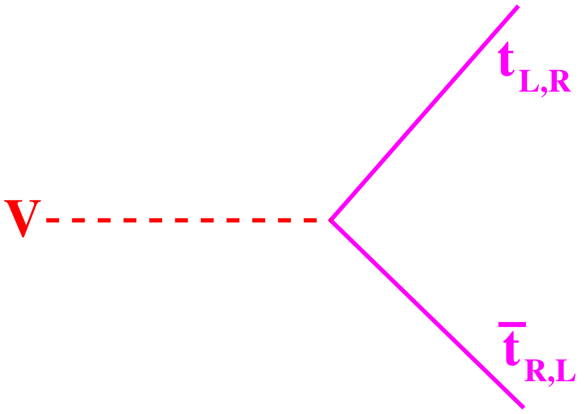
If there is no light Higgs . . .
Symmetry Breaking via Strong Interactions?



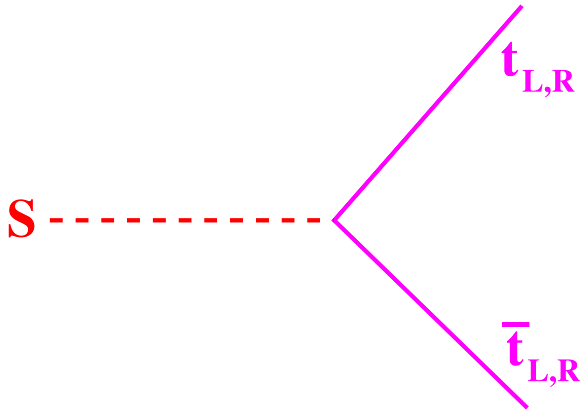
Mechanisms under test



Top polarization analysis may help . . .

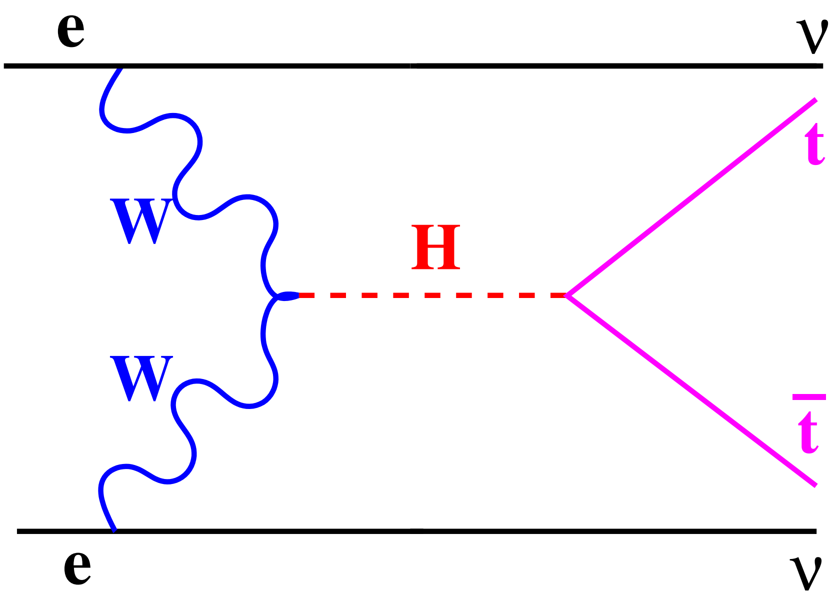


Opposite helicities



Same helicities

Our target process



Not observable at LHC (high QCD backgrounds)

Observable at planned e^+e^- Colliders ?

Previous Studies

Theoretical Studies

- E. Ruiz Morales and M. Peskin, Sitges 99
  - $WW \to t\bar{t}$ in different strong-interaction scenarios
  - $\sqrt{s} = 1.5$ TeV
  - Polarization analysis based on experimental "guesses"
- T. Han *et al.*, 2000
  - $WW \to t\bar{t}$, and also $WZ \to tb$
  - $\sqrt{s} \gtrsim 1.5$ TeV

Simulation Studies

- T. Barklow at Snowmass (1996), $\sqrt{s} = 1.5$ TeV
- Tsukamoto, JLC study (1991)

Our Analysis

- Realistic simulation study for TESLA: $\mathcal{L} = 1$ ab^{-1}, $\sqrt{s} = 1$ TeV, 800 GeV.
- Full calculation including reducible and irreducible backgrounds. Need reliable event generators.
- Include ISR and Beamstrahlung (CIRCE).
- Realistic Detector Simulation and reconstruction (SIMDET, V3.02).
- Reliable conclusions $\Rightarrow$ cut-based analysis, do not push performance to the limit.

$e^+e^- \to \nu\bar{\nu}t\bar{t}$ *generators*

Easy task? Not at all

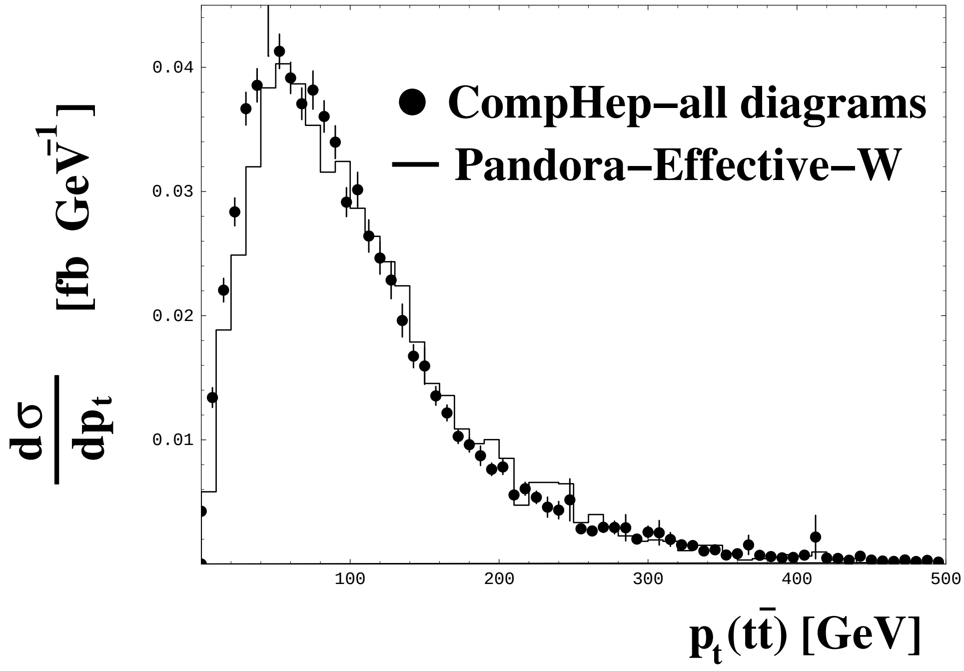
Generator	Advantages	Shortcomings
Pandora	- Full helicity - Top decays - Easy to modify	- Only Fusion Diagrams - Effective-W approximation with p_T functions
CompHep	- All SM Diagrams - Fast - Reliable	- Hard to include: beamstrahlung, new models - No access to helicities
NextCalibur	- All SM diagrams - Separate $t\bar{t}$ helicities	- Slow - Improvements needed

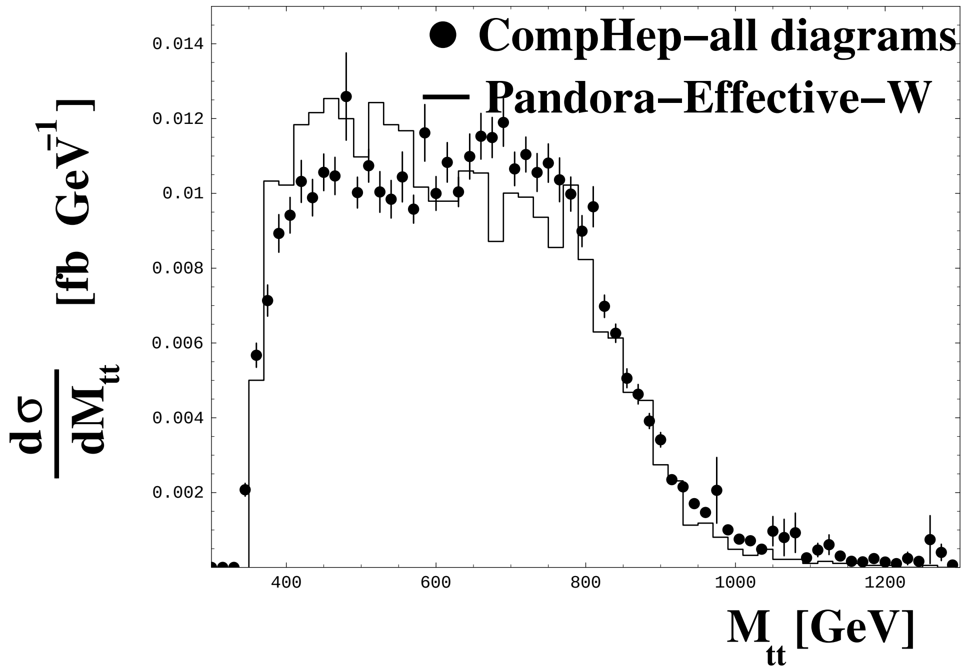
Main Problem

- At $\sqrt{s} = 1.5$ TeV, WW-fusion + effective-W approximation with helicity-, p_T-dependent W distributions OK, BUT
- At $\sqrt{s} \lesssim 1$ TeV, there are negative interference effects among irreducible diagrams.

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

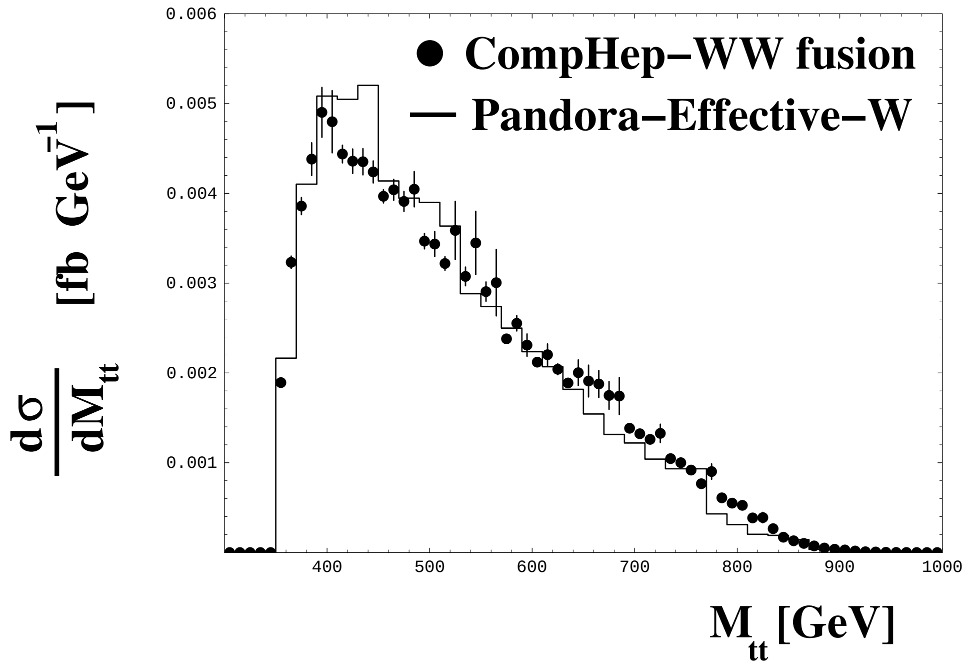
Generator Level, no ISR, no Beamstrahlung

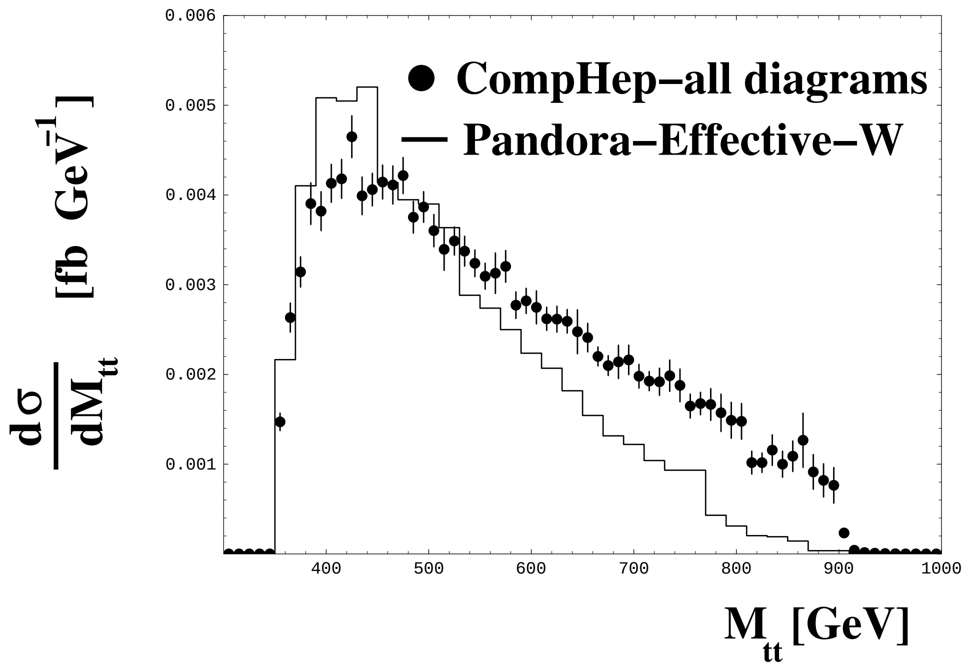




$\sqrt{s} = 1$ TeV, $m_{\rm H} = 800$ GeV

Generator Level, no ISR, no Beamstrahlung





NEXTCALIBUR

- $e^+e^- \to 4f$ generator including all possible diagrams with fermions and gauge bosons (EXCALIBUR),
- Higgs diagrams,
- Fermion masses (critical for top quarks),
- Initial State Radiation (p_t improved),
- Access to helicity amplitudes.

Comparisons with CompHep: OK

We had to implement:

- Weighter $\to$ Event Generator,
- Run on LinuX and other platforms,
- Introduce beamstrahlung (CIRCE),
- Program control on Higgs mass, fermion polarizations, Higgs-top Yukawa coupling,
- Helicity-dependent top-decay kinematics (PANDORA).

SM Signal

- Signal: $e^+e^- \to \nu\bar{\nu}t\bar{t}$ helicity cross sections ($\sqrt{s} = 1$ TeV, in fb):

m_H (GeV)	$\sigma(LL) = \sigma(RR)$	$\sigma(LR)$	$\sigma(RL)$	Total
100	0.11	0.22	0.21	0.65
400	1.89	0.34	0.33	4.45
800	0.33	0.22	0.21	1.09

(Generator Level, with ISR and Beamstrahlung)

- Signal: $e^+e^- \to \nu\bar{\nu}t\bar{t}$ helicity cross sections ($\sqrt{s} = 800$ GeV, in fb):

m_H (GeV)	$\sigma(LL) = \sigma(RR)$	$\sigma(LR)$	$\sigma(RL)$	Total
100	0.07	0.16	0.12	0.42
400	0.89	0.19	0.15	2.12
500	0.58	0.16	0.12	1.44

(Generator Level, with ISR and Beamstrahlung)

Backgrounds (at $\sqrt{s} = 1$ TeV)

- Huge (but manageable) backgrounds:

$$\sigma(e^+e^- \to q\bar{q}) = 3400 \text{ fb}$$
$$\sigma(e^+e^- \to WW) = 3700 \text{ fb}$$

Hard cuts required

- Critical backgrounds:

$$\sigma(e^+e^- \to t\bar{t}) = 243 \text{ fb}$$

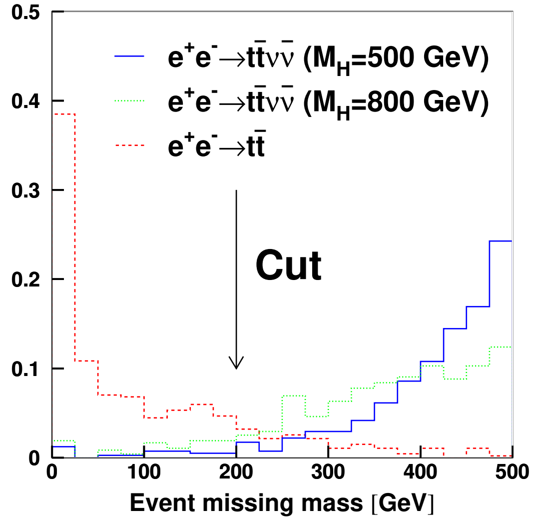
Cut on MISSING MASS

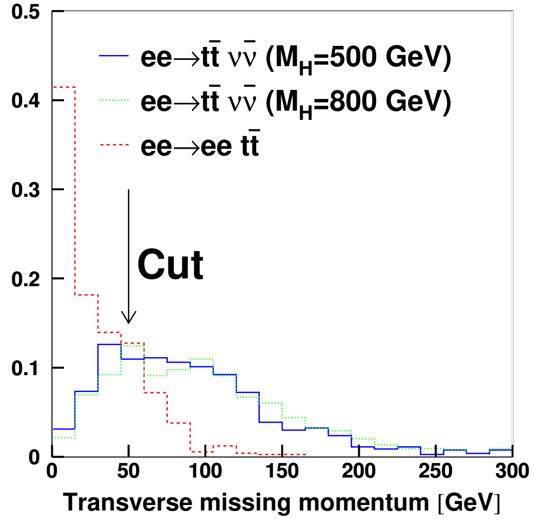
$$\sigma(e^+e^- \to e^+e^- t\bar{t}) = 17 \text{ fb}$$

Cut on MISSING $E_\perp$

- Backgrounds generated with PYTHIA

- Only 6 jet events used in the analysis

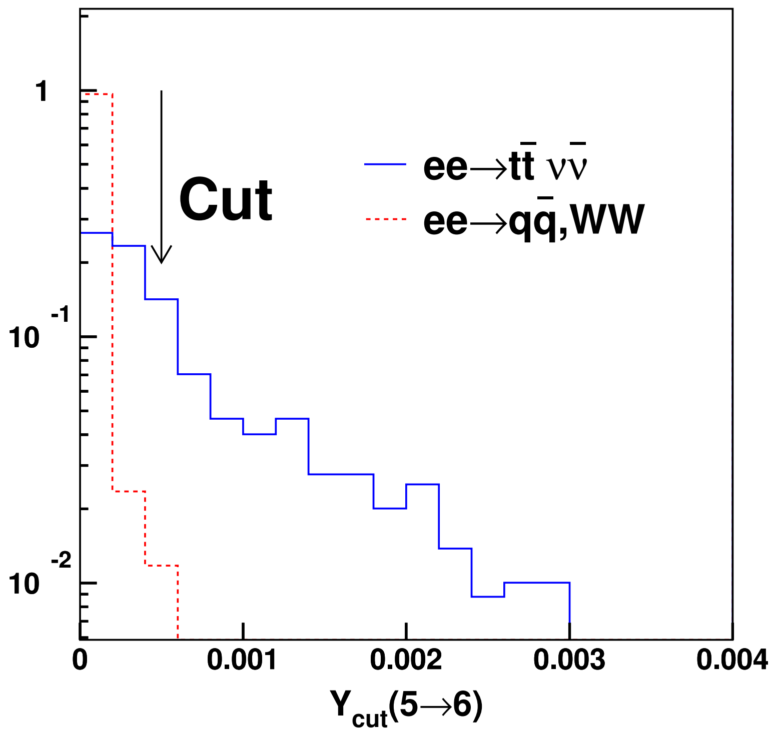




(Normalized to 1, no cuts)

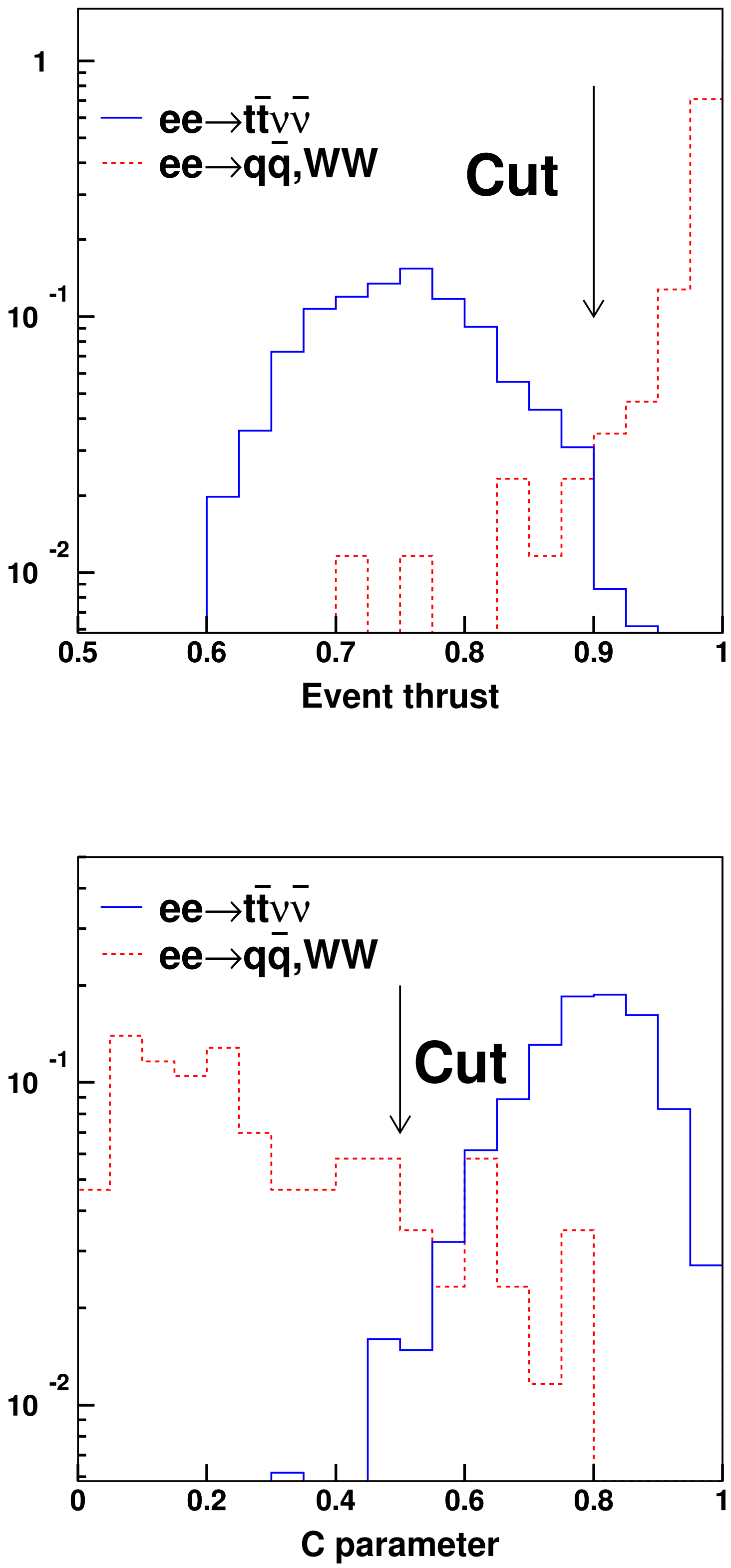
Hard Cuts required

- **No lepton:** Force the event into 5 jets and reject if $E_{\text{lepton}} > 0.7\ E_{\text{jet}}$
- **6 jets:** Durham Algorithm, $Y_{\text{cut}} > 0.0005$
- **Spherical events:** Thrust< 0.9, Major> 0.3, C parameter> 0.5
- **Moderate b-tagging:** Based on consistency with the primary vertex



Background rejection factor after all cuts $\approx 5\ 10^{-6}$

$q\bar{q}$ *and* $\mathbf{WW}$ *Backgrounds*

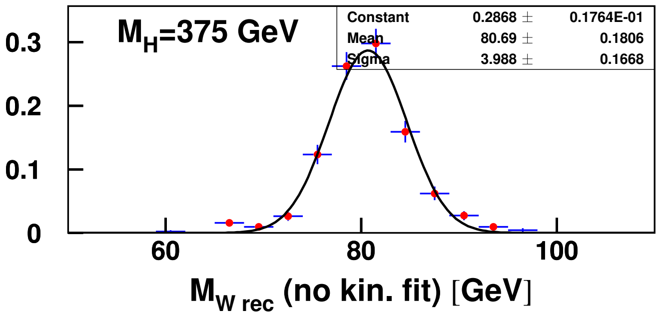


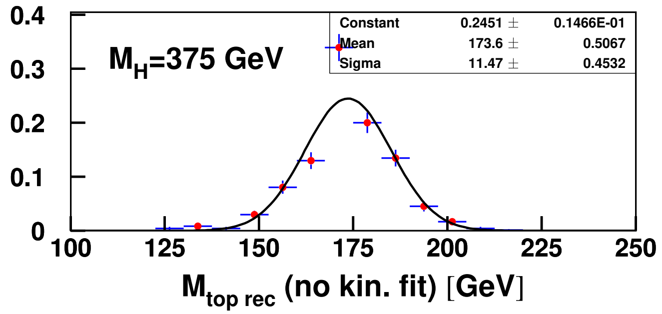
(Normalized to 1, no cuts)

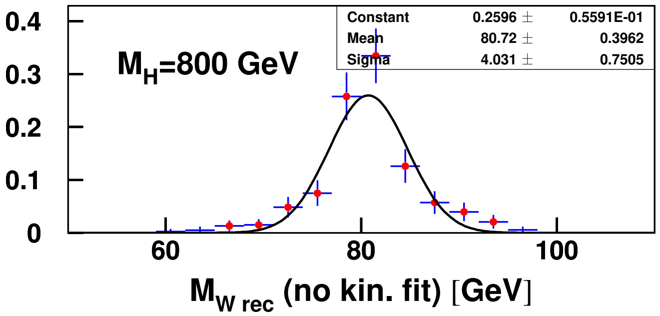
- Kinematic assignment:

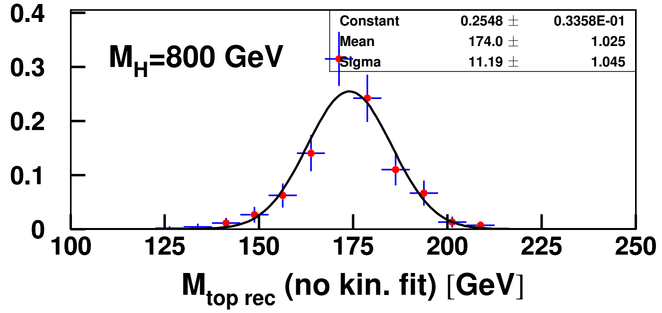
$$\chi^2_{\min} = \frac{(M_{W_1} - m_W)^2}{\sigma_W^2} + \frac{(M_{W_2} - m_W)^2}{\sigma_W^2} + \frac{(M_{t_1} - m_t)^2}{\sigma_t^2} + \frac{(M_{t_2} - m_t)^2}{\sigma_t^2}$$

- Rejection of misreconstructed background events (mainly $e^+e^- \to t\bar{t}$):



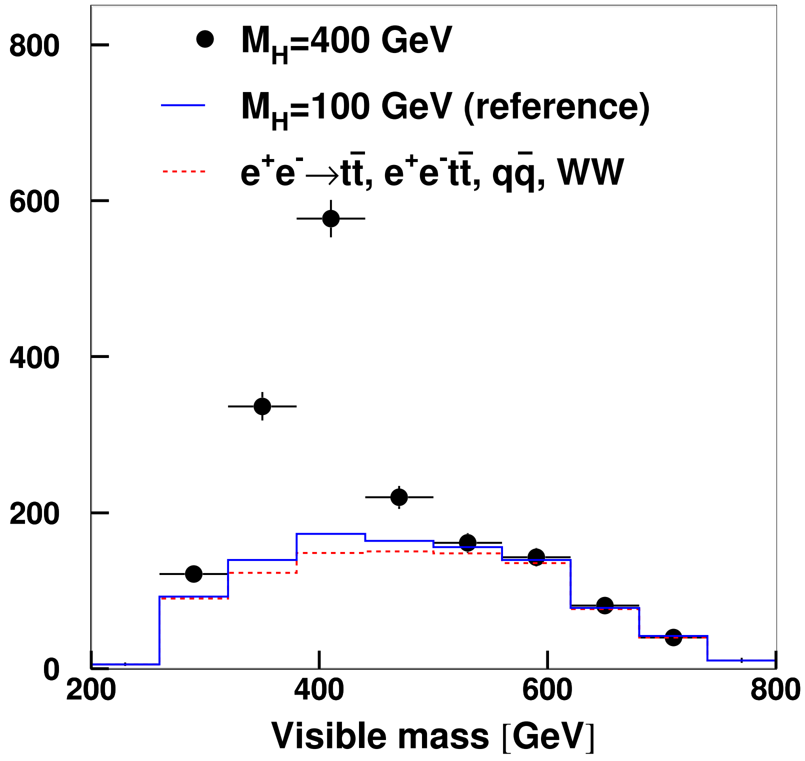


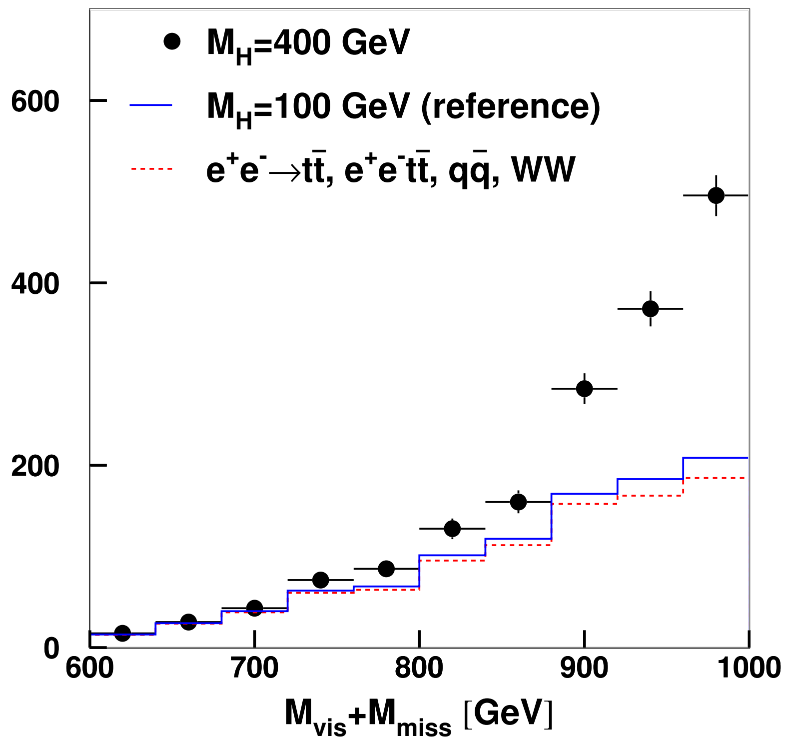




$\Delta m_W \leq 5\ \sigma_W \approx 25$ GeV $\qquad$ $\Delta m_t \leq 5\ \sigma_t \approx 50$ GeV

$$\sqrt{s} = 1\ \mathrm{TeV}, m_{\mathrm{H}} = 400\ \mathrm{GeV}$$

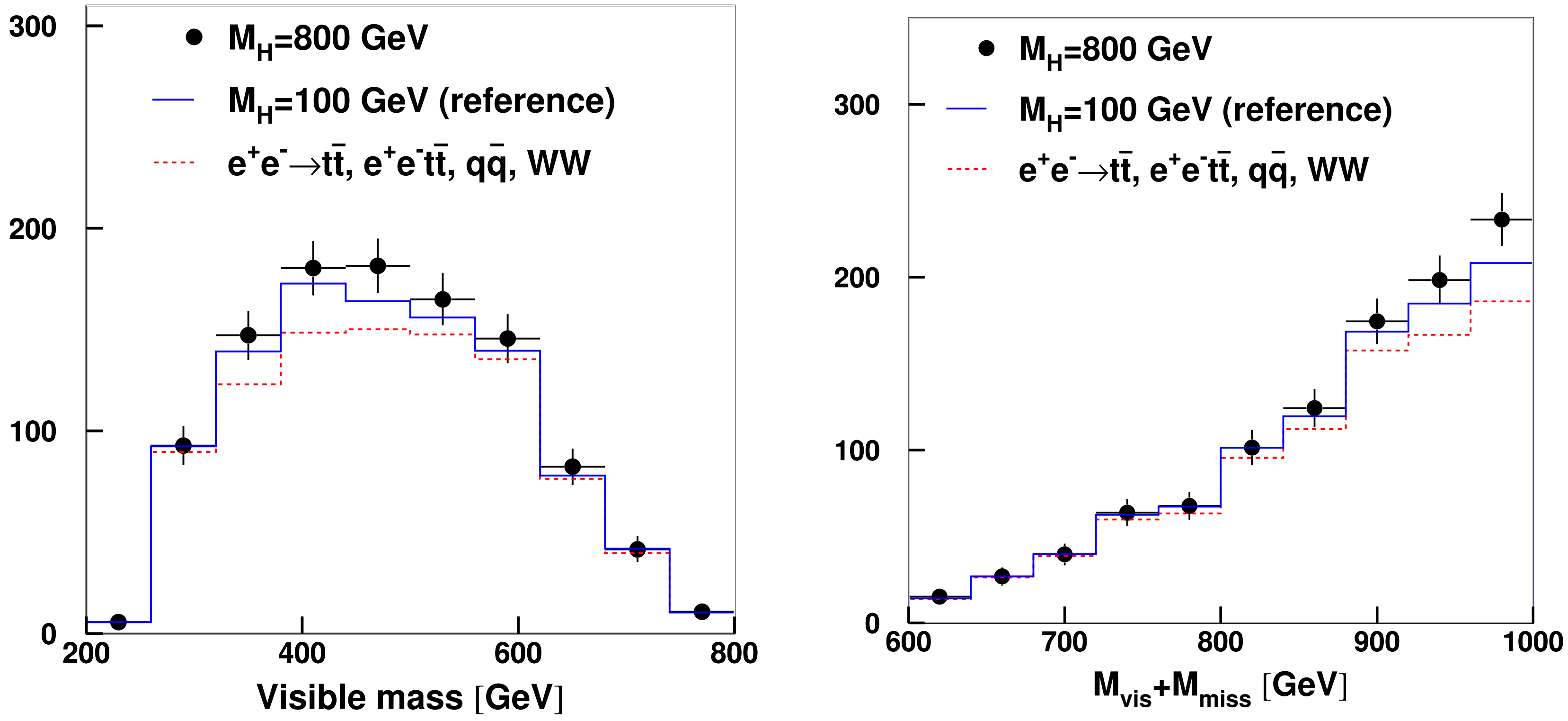




Signal=695, Acceptance=18%, Background=993

Higgs Signals

$\sqrt{s} = 1\ \mathrm{TeV}, m_{\mathrm{H}} = 800\ \mathrm{GeV}$



Signal=52, Acceptance=12%, Background=993

Results: Signal Sensitivity

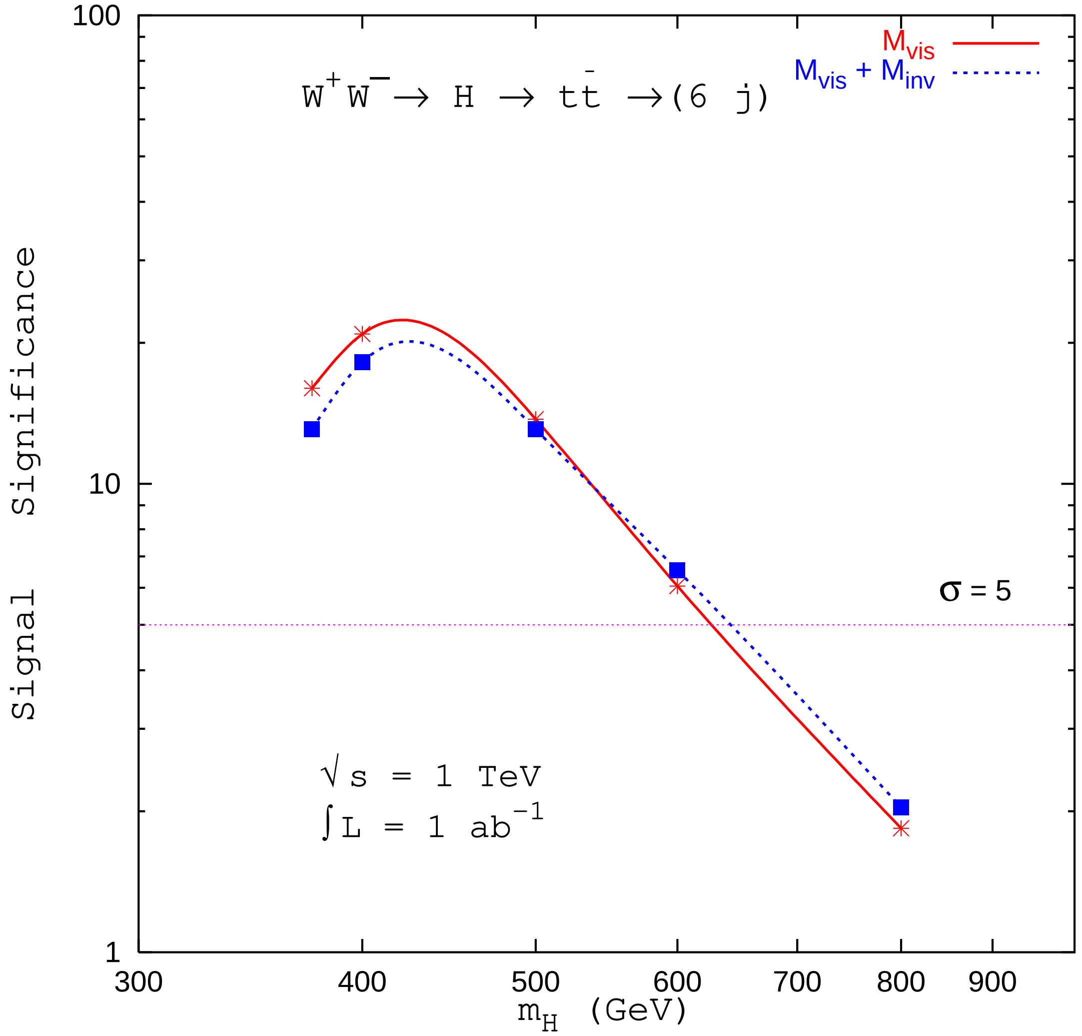
$\boxed{\sqrt{s} = 1 \text{ TeV}}$

Events with $M_{\text{vis}} + M_{\text{miss}} > 900$ GeV

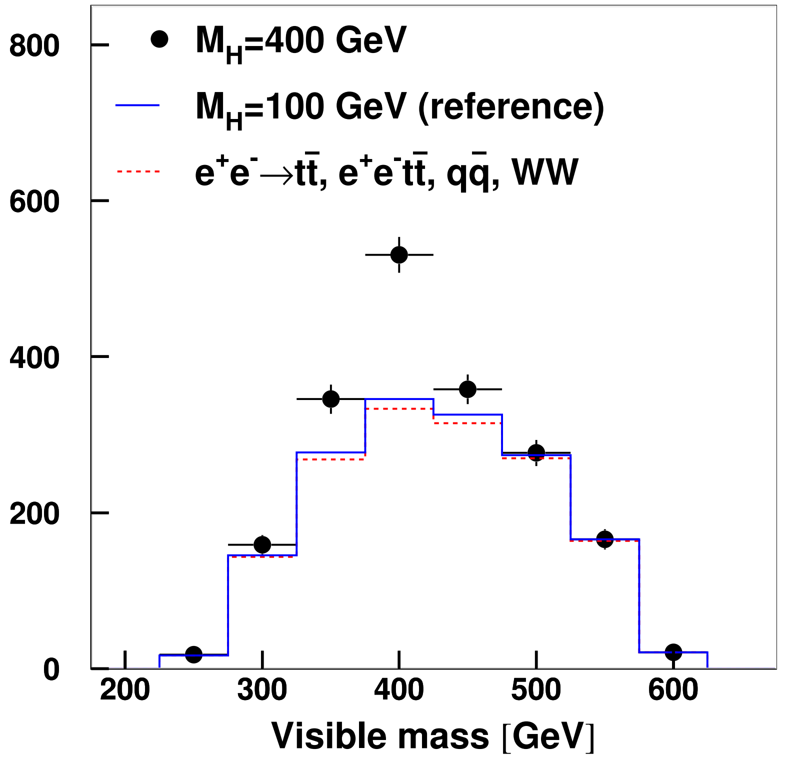
m_{H}(GeV)	375	400	500	600	800
Signal	342	542	351	158	41

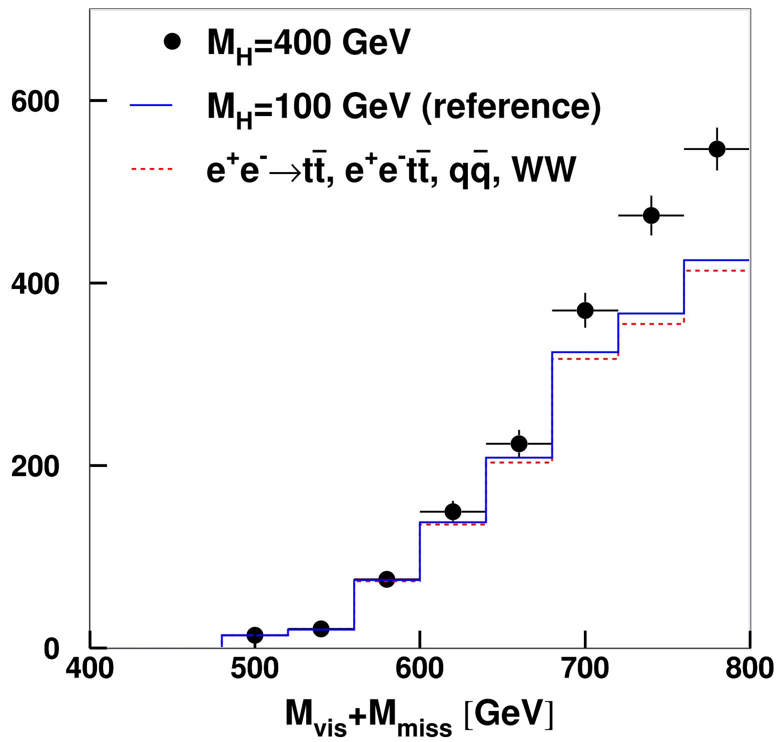
Background $\equiv N_{\text{expected}}(m_{\text{H}} = 100 \text{ GeV})$: 519

Fit to the distributions



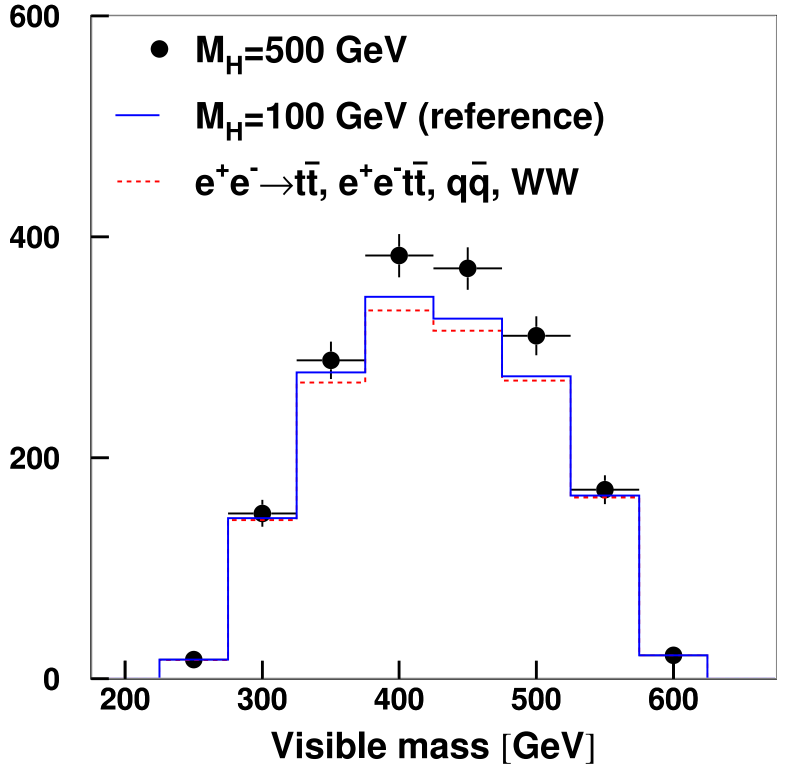
$$\sqrt{s} = 800\ \mathrm{GeV}, m_{\mathrm{H}} = 400\ \mathrm{GeV}$$

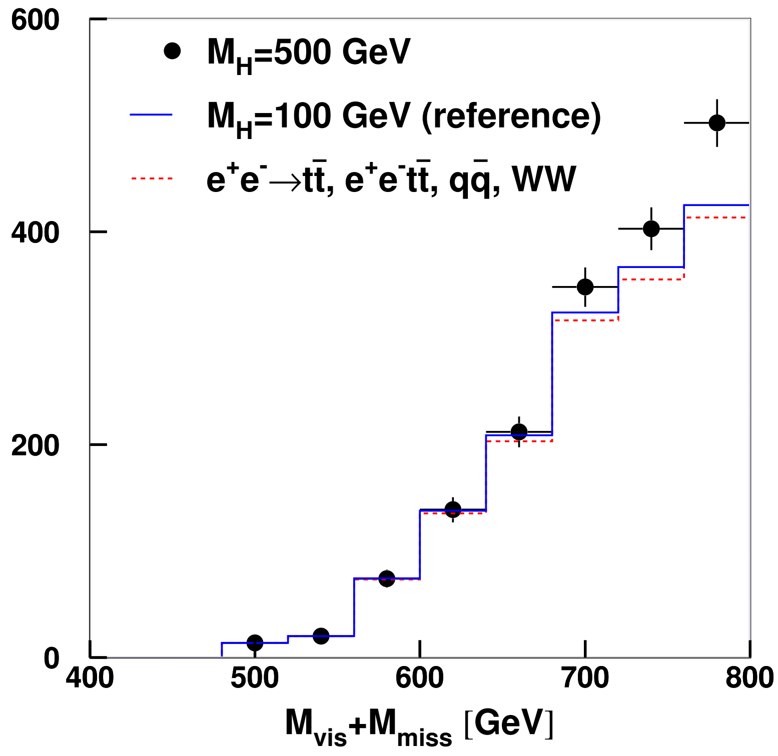




Signal=303, Acceptance=18%, Background=1571

$$\sqrt{s} = 800\ \text{GeV}, m_{\text{H}} = 500\ \text{GeV}$$





Signal=141, Acceptance=14%, Background=1571

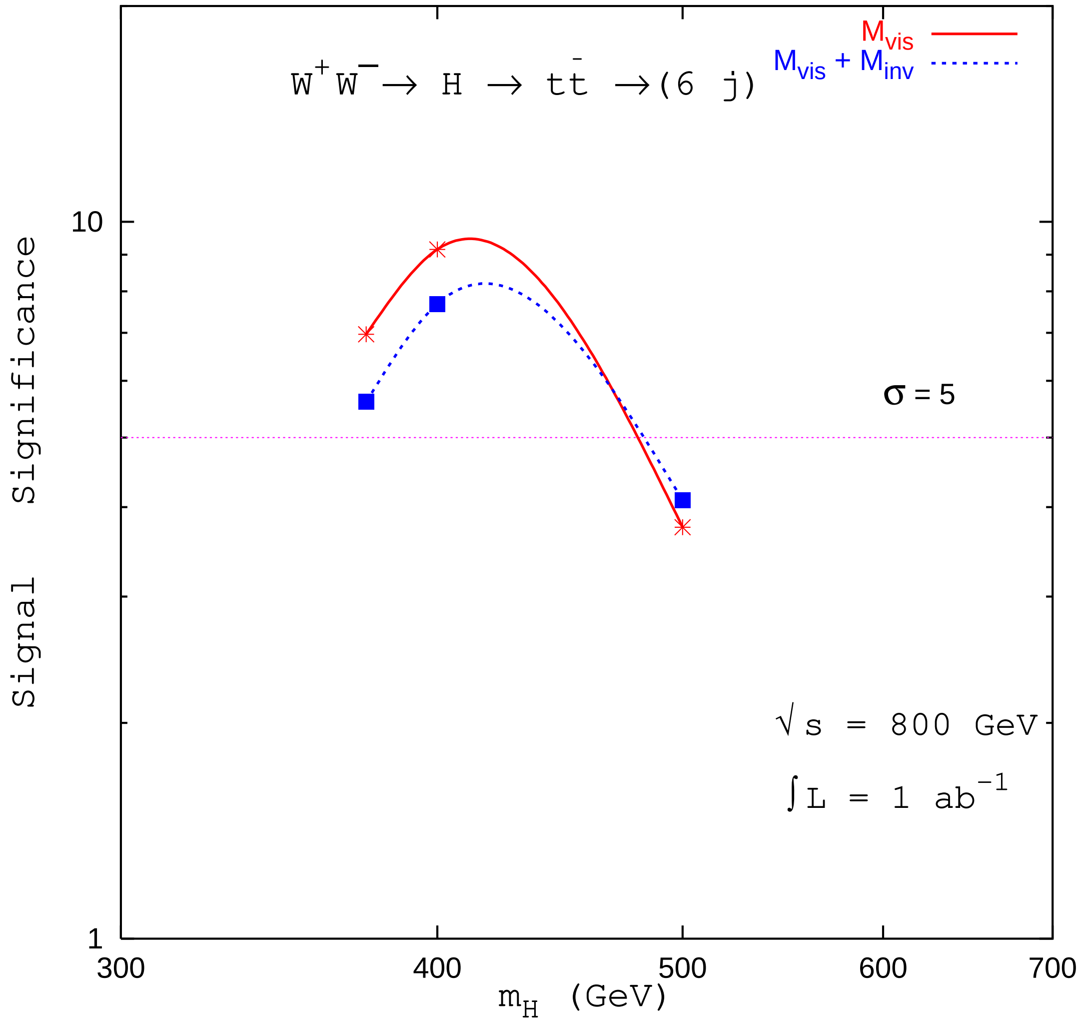
$$\sqrt{s} = 800\ \mathrm{GeV}$$

Events with $M_{\rm vis} + M_{\rm miss} > 700\ \mathrm{GeV}$

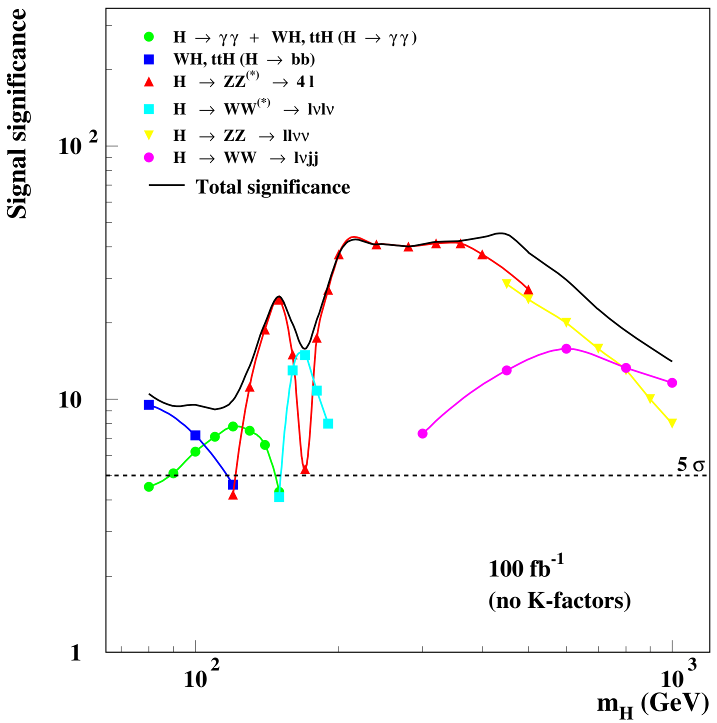
$m_{\rm H}(\ \mathrm{GeV})$	375	400	500
Signal	179	261	127

Background $\equiv N_{\rm expected}(m_{\rm H} = 100\ \mathrm{GeV})$: 1003

Fit to the distributions



Comparison with LHC



m_{H}(GeV)	TESLA 800 GeV $\mathrm{H} \to t\bar{t} \to 6$ jets	TESLA 1 TeV $\mathrm{H} \to t\bar{t} \to 6$ jets	ATLAS (14 TeV, 100 fb^{-1}) $\mathrm{H} \to \mathrm{VV} \to$ all
375	7	16	35
400	9	21	40
500	4	14	40
600	-	7	40
800	-	2	12

Previous Studies

- At LHC: Associated $t\bar{t}H$ Production ($m_H \lesssim 120$ GeV):

$$\frac{\Delta y_t}{y_t} \approx 10\% \text{ (ATLAS TDR)}$$

- At e^+e^- LC: Associated $t\bar{t}H$ Production ($m_H \lesssim 130$ GeV):

$$\frac{\Delta y_t}{y_t} \lesssim 10\% \text{ (Baer, Dawson, Reina) (Juste, Merino)}$$

- At e^+e^- LC: $e^+e^- \to HZ \to t\bar{t}Z$ ($m_H \approx 2m_t$):

$$\frac{\Delta y_t}{y_t} \approx 10\% \text{ (Fujii)}$$

Results with $WW \to H \to t\bar{t}$ at TESLA for $m_H > 2m_t$ ...

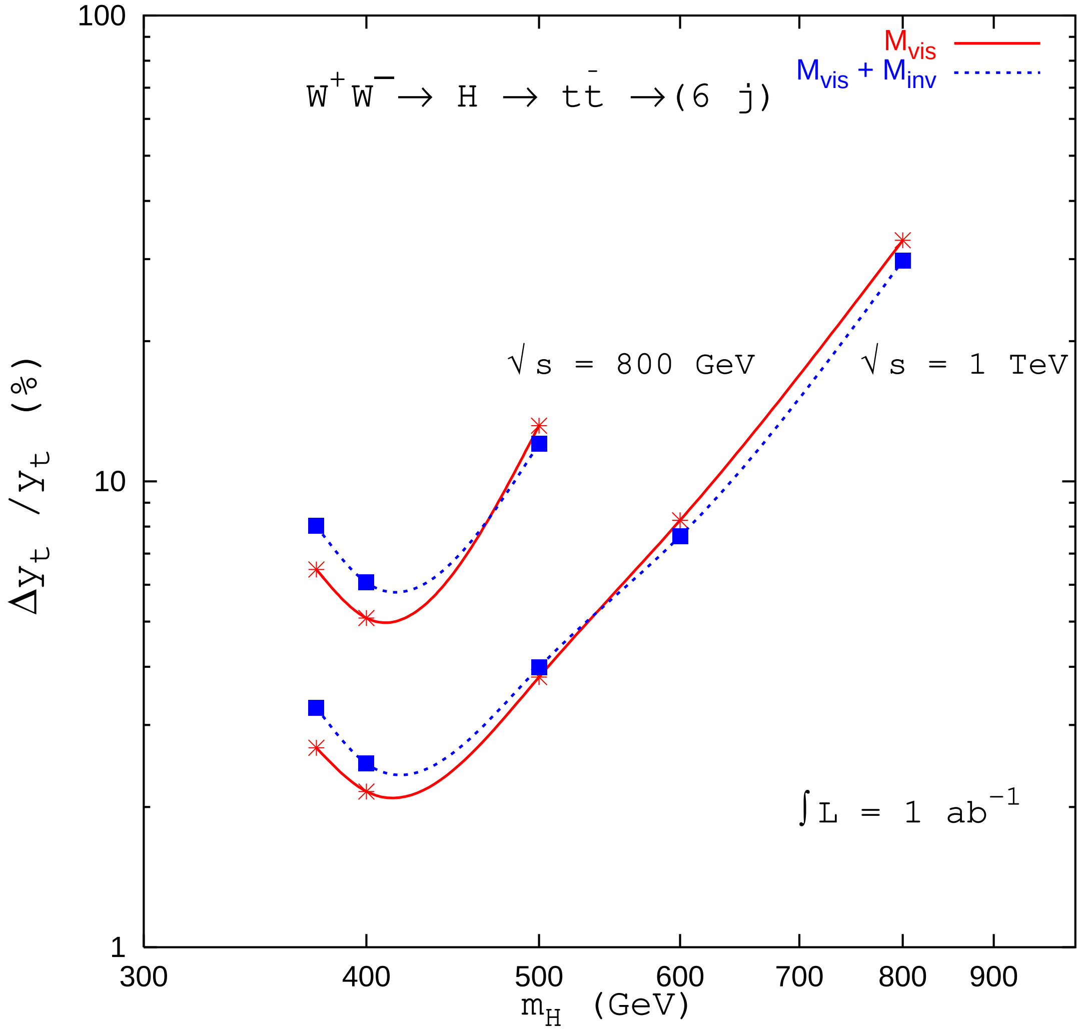
Top Quark Yukawa Measurement

$\sqrt{s} = 1$ TeV

m_H(GeV)	375	400	500	600	800
$\frac{\Delta y_t}{y_t}(\%)$	2.7	2.2	3.8	7.6	29.8

$\sqrt{s} = 800$ GeV

m_H(GeV)	375	400	500
$\frac{\Delta y_t}{y_t}(\%)$	6.5	5.1	12.1



Conclusions

- $\mathrm{WW} \rightarrow \mathrm{H} \rightarrow \mathrm{t\bar{t}}$ interesting if there is no light Higgs boson.

- It will be observable ($> 5\sigma$) and it will lead to a precise Higgs-top Yukawa measurement ($\frac{\Delta y_\mathrm{t}}{y_\mathrm{t}} < 10\%$) at the TESLA $\mathrm{e^+e^-}$ collider, provided that:

$$350\ \mathrm{GeV} < m_\mathrm{H} < 650\ \mathrm{GeV}, (\sqrt{s} = 1\ \mathrm{TeV}, \mathcal{L} = 1\ \mathrm{ab}^{-1})$$

$$350\ \mathrm{GeV} < m_\mathrm{H} < 500\ \mathrm{GeV}, (\sqrt{s} = 800\ \mathrm{GeV}, \mathcal{L} = 1\ \mathrm{ab}^{-1})$$

- Similar sensitivities are expected in other scenarios of strong symmetry breaking (i.e. technicolor).

- Extensions of this analysis under study:
  - Include semileptonic $\mathrm{t\bar{t}}$ decays,
  - Top polarization studies,
  - Higher $\sqrt{s}$.