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Oct 26, 2000

Linear Collider Workshop

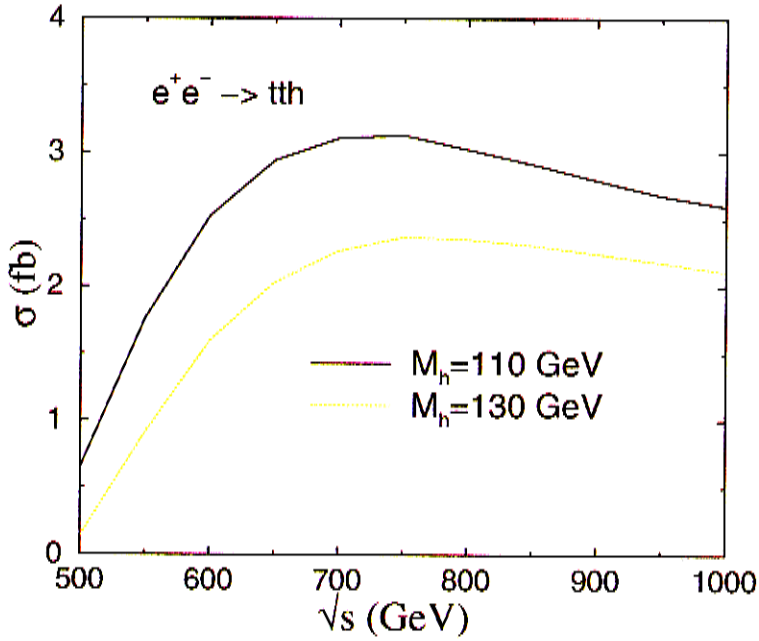
$t\bar{t}h$ Production at a Linear Collider

- Why is $t\bar{t}h$ interesting?
  - Measurement of g_{tth}
  - Window to New Physics
  - Handle on Higgs spin-parity
- What will we know from the LHC?
- What can a high energy e^+e^- collider tell us?
- Work to do....
  - Backgrounds
  - Detector simulations

(with L. Reina)

$e^+e^- \to t\bar{t}h$

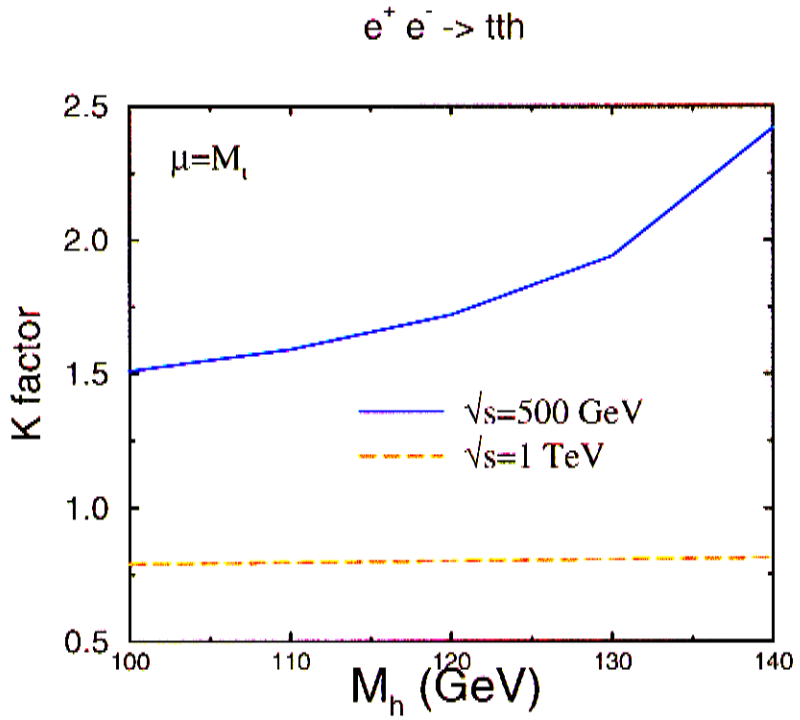
- There is optimal energy for $e^+e^- \to t\bar{t}h$



- Small rate, but spectacular signature: $W^+W^-b\bar{b}b\bar{b}$
- Needs high luminosity

QCD corrections known at e^+e^- collider:

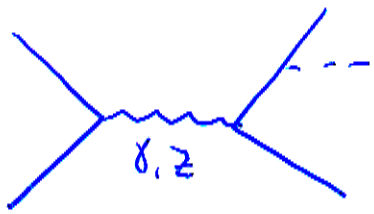
$$K \equiv \frac{\sigma_{NLO}}{\sigma_{LO}}$$

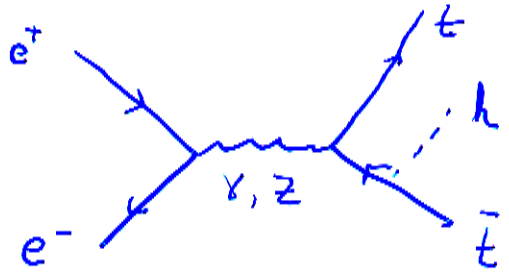


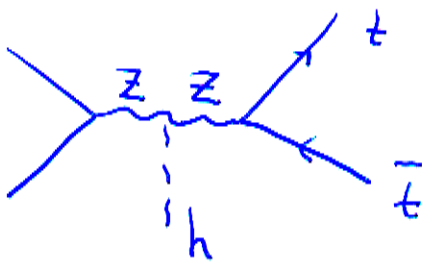
(Dawson and Reina; Dittmaier et al)

- K sensitive to μ:

$$K\left(\sqrt{s} = \mu = 500\ GeV, M_h \sim 100\ GeV\right) = 1.35$$
$$K\left(\sqrt{s} = \mu = \ 1\ TeV\right) = .95$$





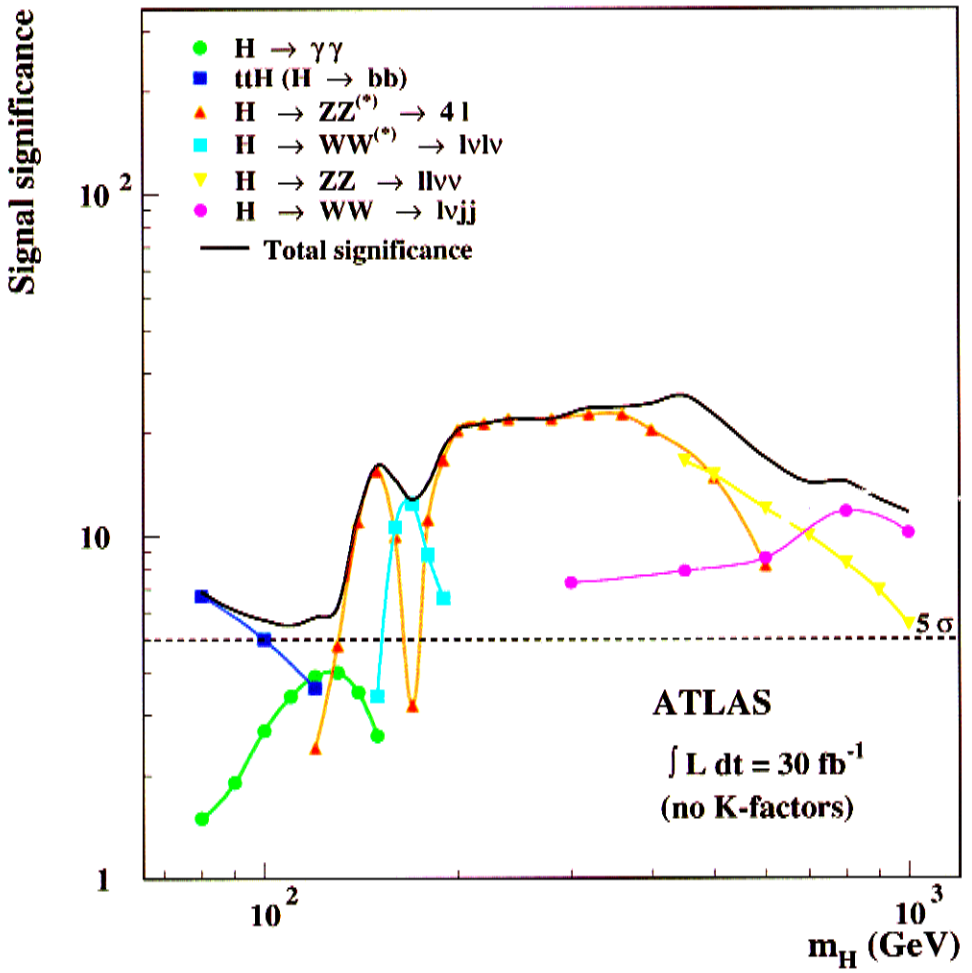


$< O(1\text{-}2\%$ of rate$)$

$t\bar{t}h$ is important channel at LHC for

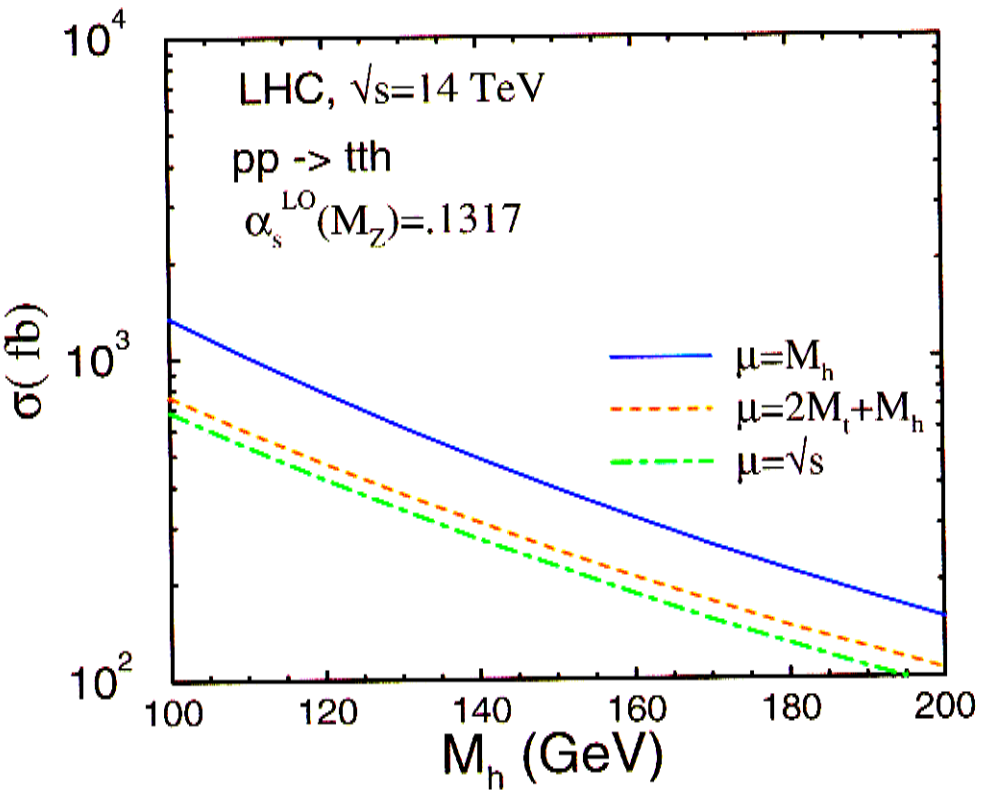
$$100\ GeV < M_h < 140\ GeV$$

- Helps confirm Higgs signal in difficult M_h region



(ATLAS Physics TDR)

- $t\bar{t}h$ is only Higgs production channel at LHC with uncalculated NLO QCD corrections (work in progress)
- Note large μ dependence

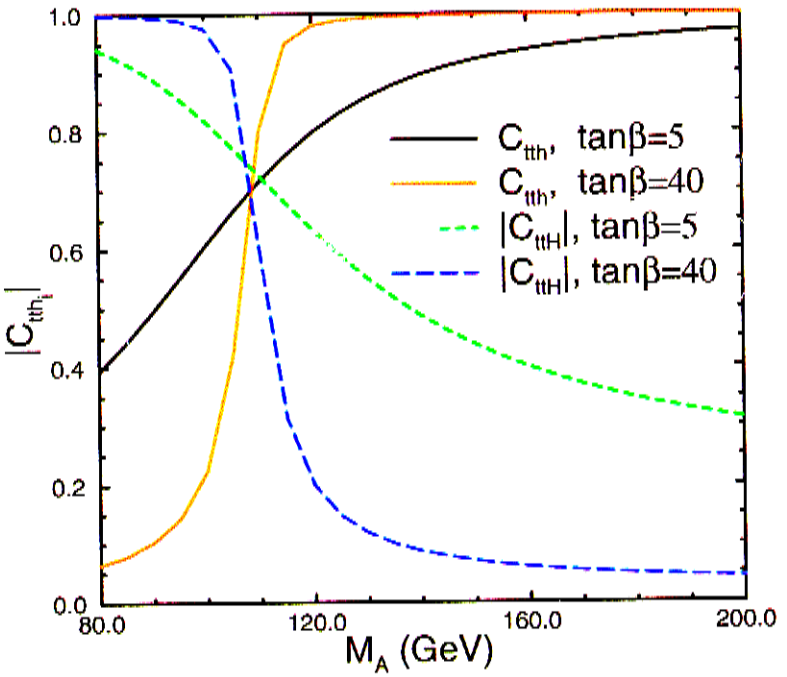


- $t\bar{t}h$ production gives direct measurement of $t\bar{t}h$ coupling
- Standard Model:

$$g_{tth}^{SM} = -\frac{M_t}{v}$$

- g_{ttH} can be very different in SUSY models:

$$g_{tth}^{SUSY} = C_{tth} g_{tth}^{SM}$$



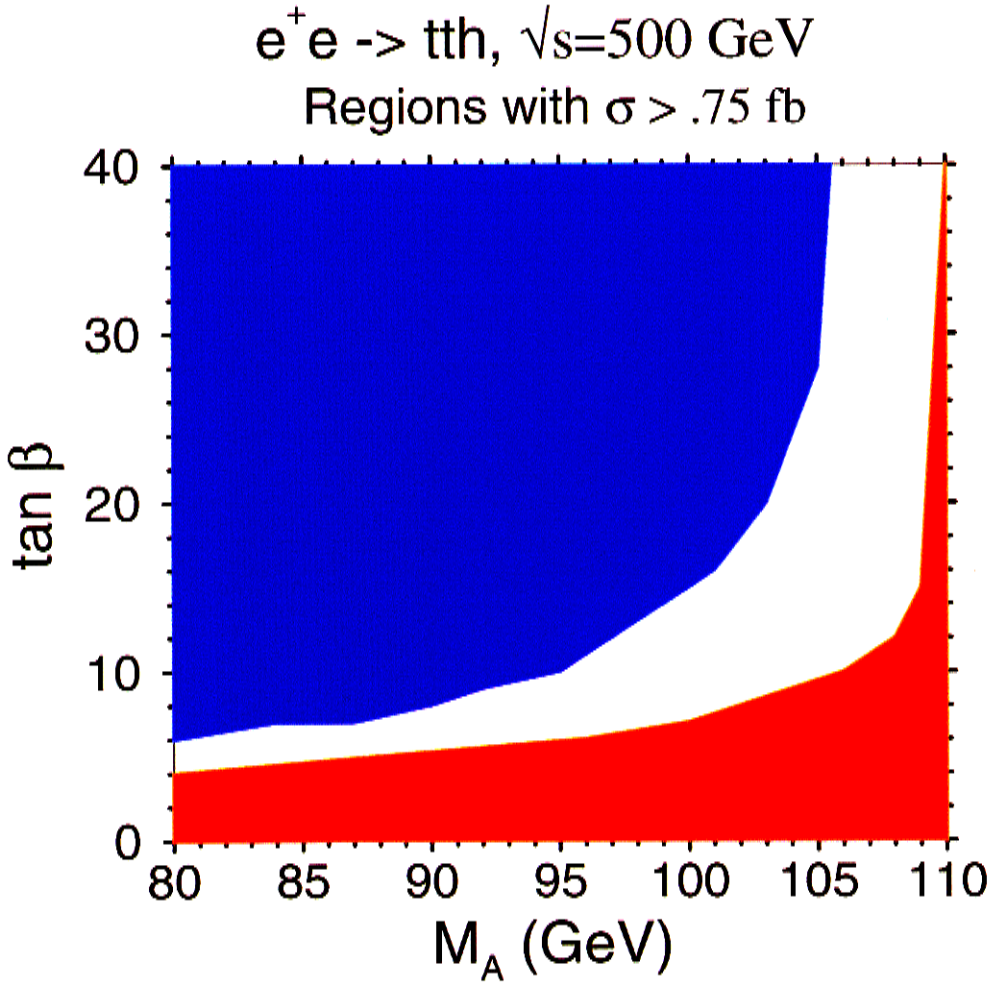
MSSM:

Couplings different; new processes; resonance effects

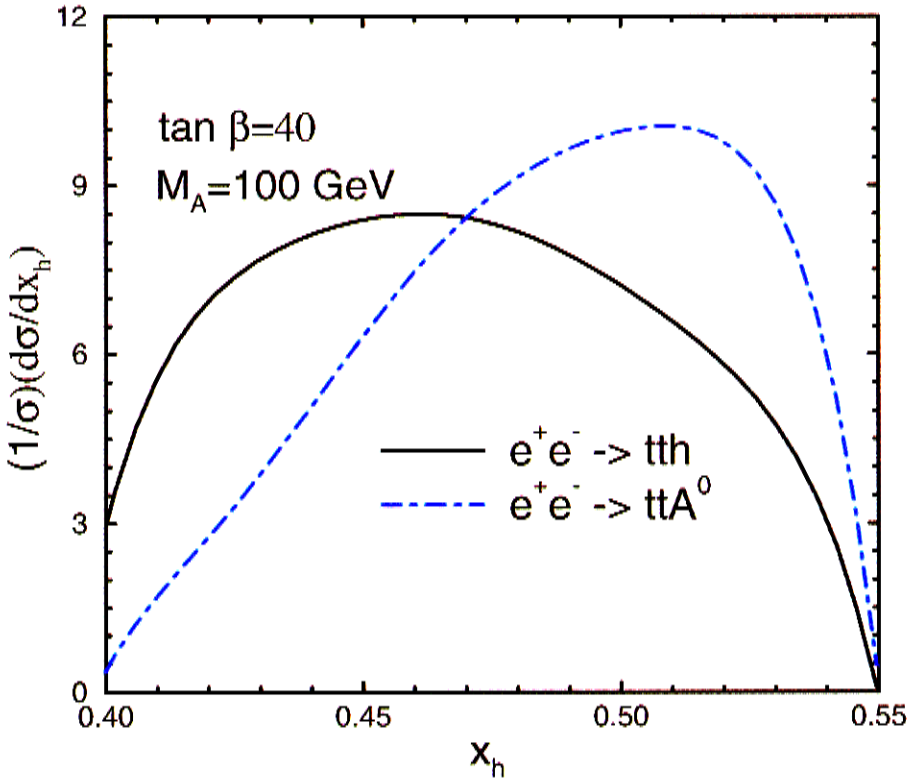
$$e^+e^- \to t\bar{t}h^0$$

$$e^+e^- \to t\bar{t}H^0$$

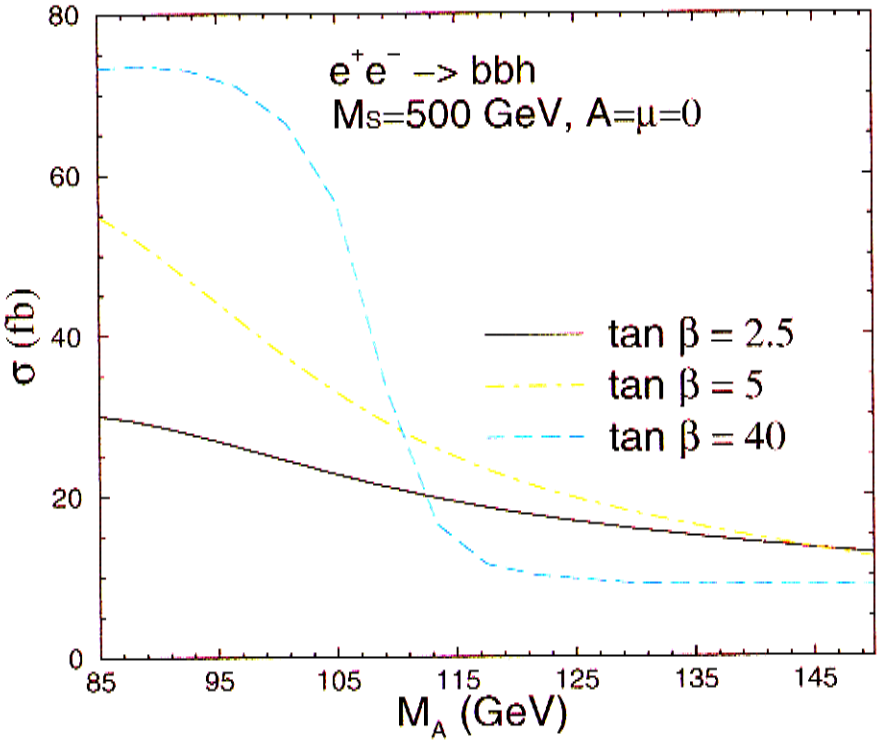
Still measures g_{tth_i} as in SM

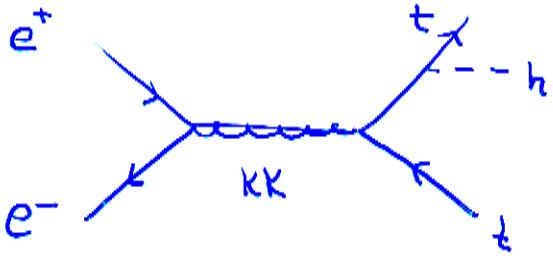


- $e^+e^- \rightarrow t\bar{t}A^0$ highly suppressed ($\sim 10^{-2}\ fb$ at $\sqrt{s} = 500\ GeV$)
- Shape of distribution sensitive to CP coupling of scalar/pseudoscalar
- No serious simulations on this



- $e^+e^- \to b\bar{b}h, b\bar{b}H, b\bar{b}A$ can be large
- Sensitive to large $\tan\beta$, small M_A region




e+
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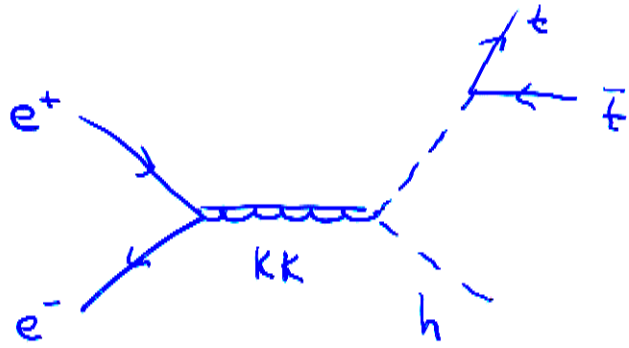
e+
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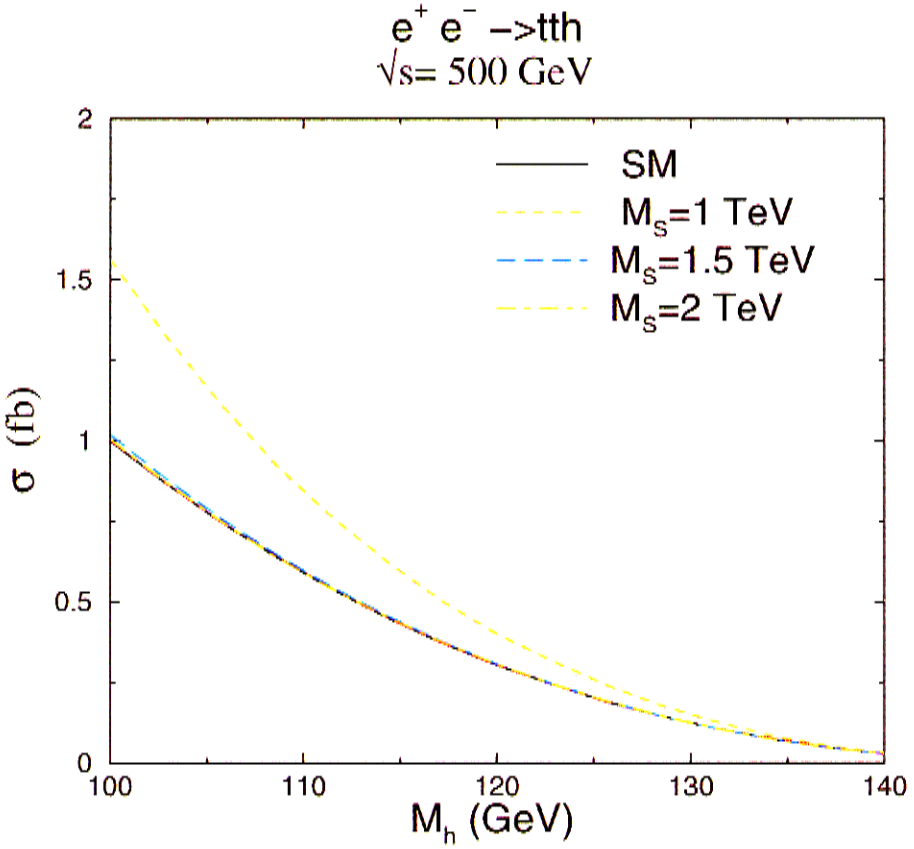
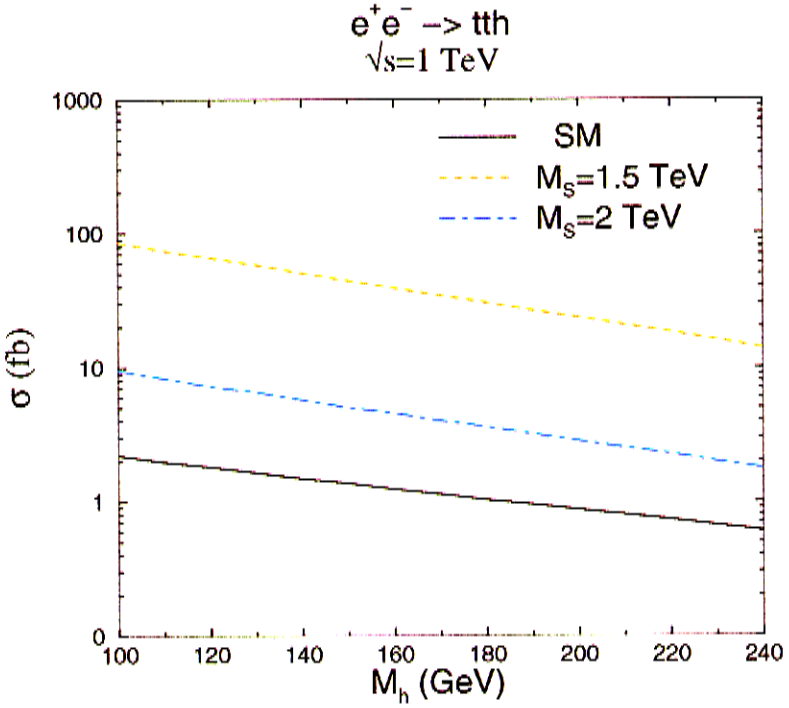
Extra dimensions at TeV scale

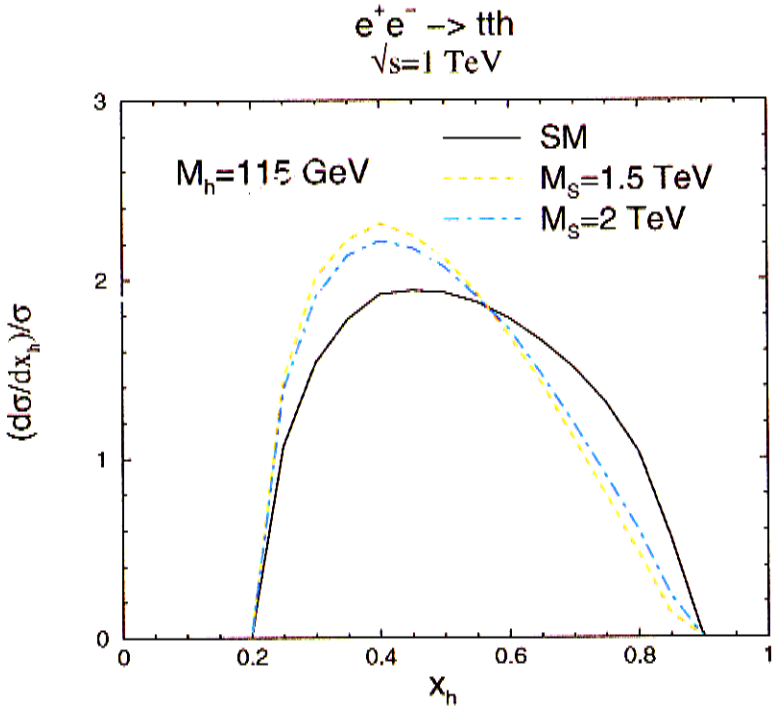
- $e^+e^- \to t\bar{t}h$ sensitive to Kaluza-Klein exitations of graviton
- Significant enhancement for $M_S \sim 1\ TeV$
- DO limit, $M_S > (1 - 1.4)\ TeV$

(Landsberg, hep-ex/0009038)



- Extra dimension effects interesting at $\sqrt{s} = 1\ TeV$:

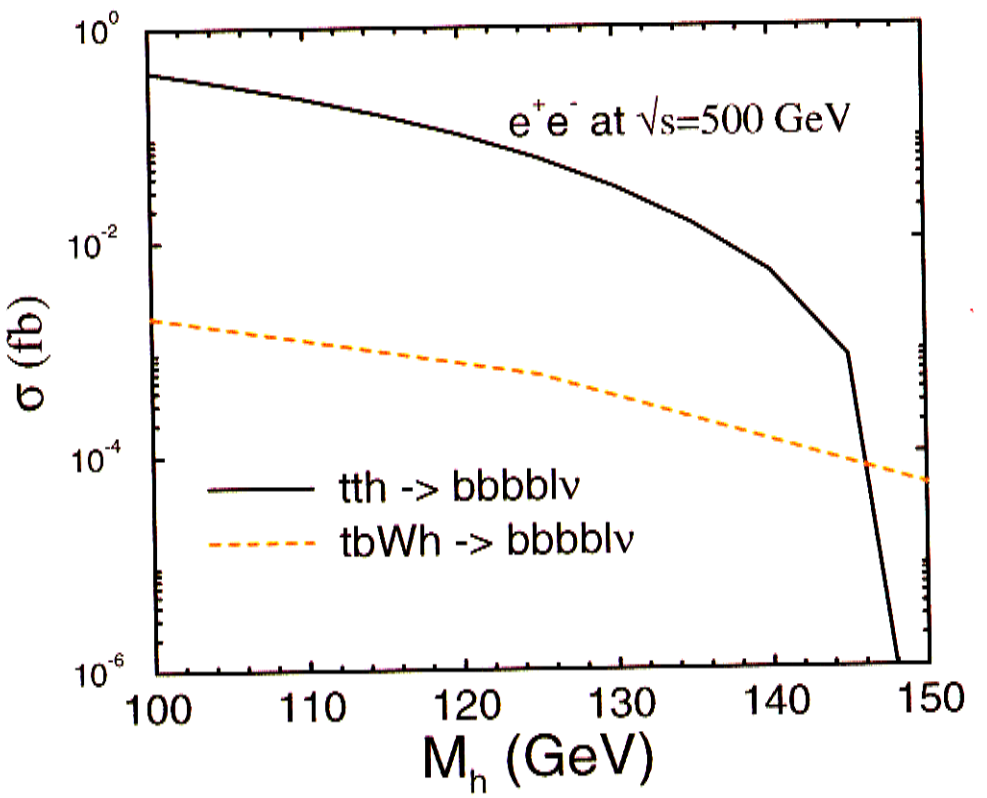




Signal: $e^+e^- \to t\bar{t}h;\ h \to b\bar{b};\ t \to bW$

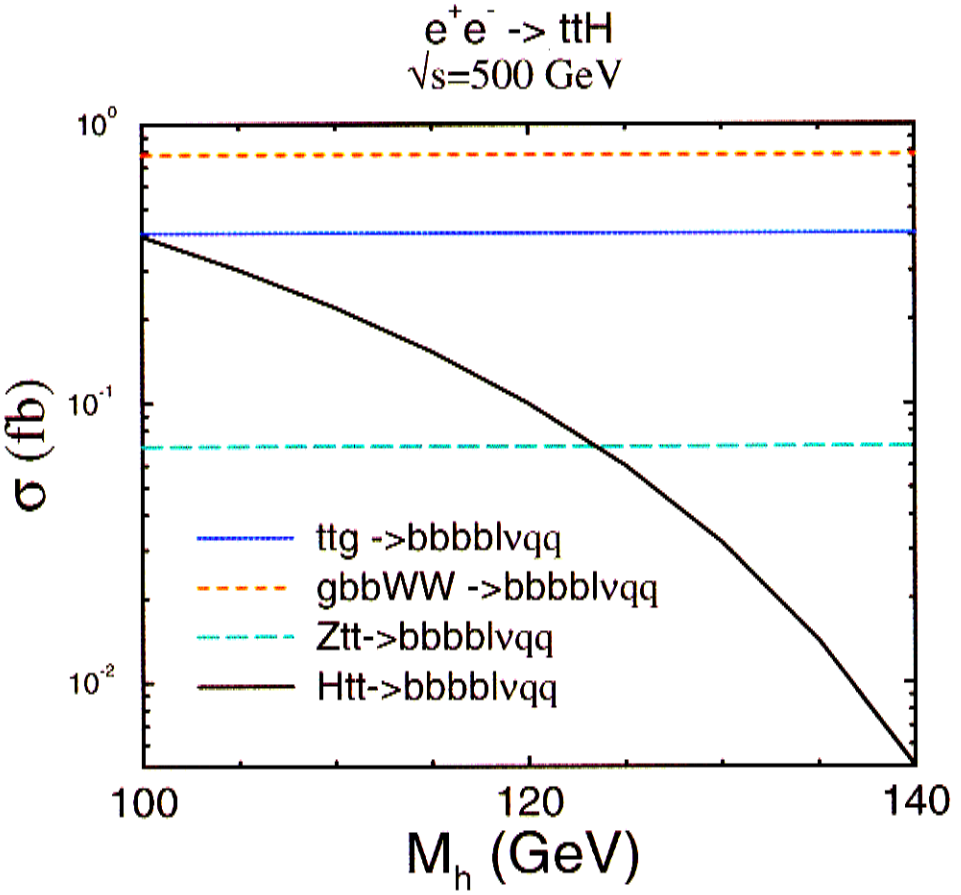
- Need to calculate $e^+e^- \to b\bar{b}b\bar{b}l^{\pm}\nu q\bar{q}'$

(S. Moretti, hep-ph/9911501)



- tth runs out of phase space for large M_h; other sub-processes are important

Backgrounds:

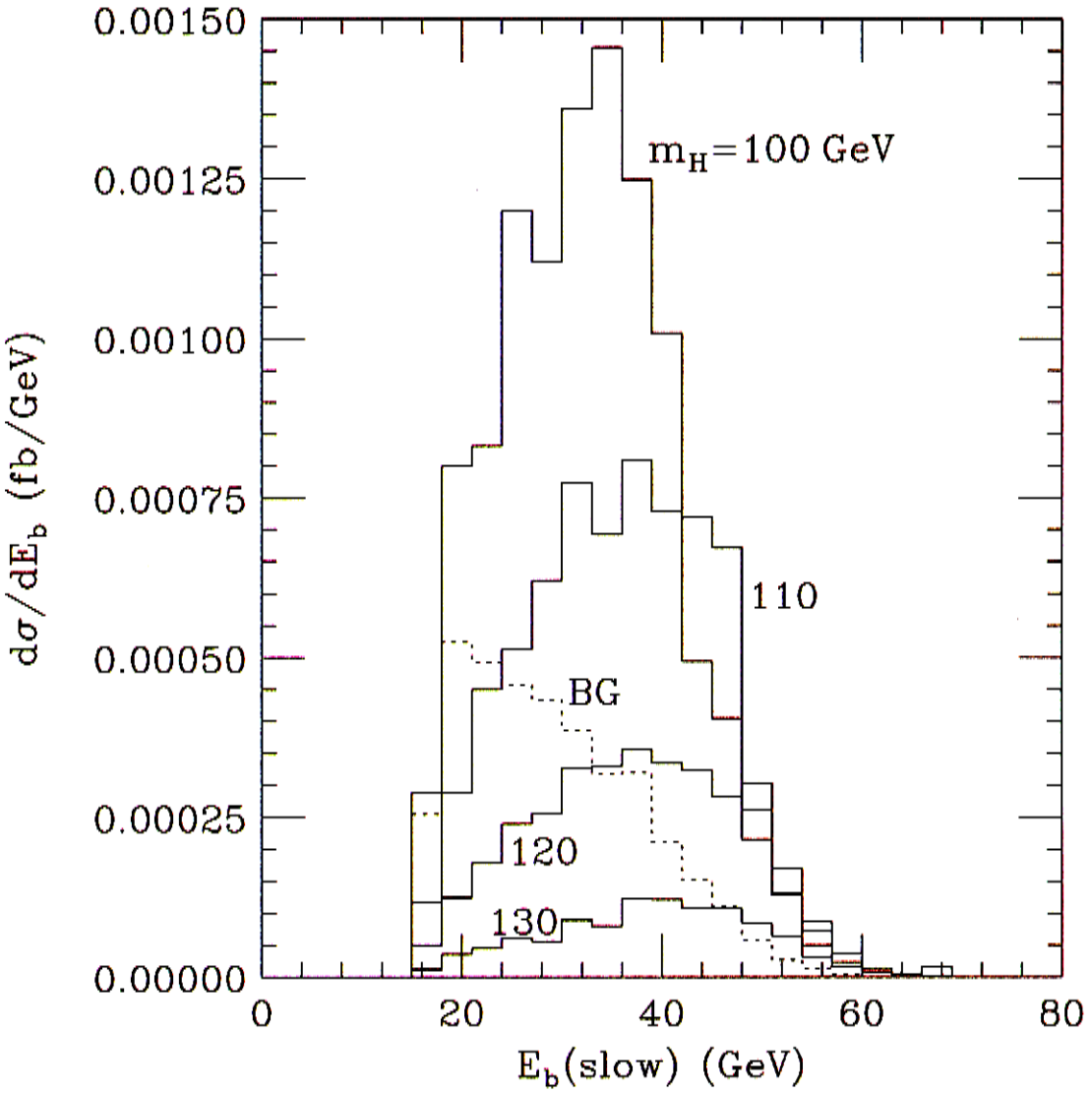


- Dominant background from QCD: radiative $t\bar{t}$ decays
- M_{bb} will peak at M_h, M_Z, or be logarithmically enhanced at low M_{bb}
- Cuts on M_{bb} effective at eliminating background

Approach:

Simulate events with ISAJET toy detector to include parton showers, hadronization, particle decays:

- Calorimetry for $-4 < \eta < 4$ and $\Delta\eta \times \Delta\phi = .1 \times .26$
- EM energy resolution: $\frac{.15}{\sqrt{E}} + .01$
- Hadronic energy resolution: $\frac{.5}{\sqrt{E}} + .02$
- Coalesce calorimeter cells with $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < .5$
- Jets have $E_T > 15\ GeV$
- Jets called b jet if they are within angle $\Delta R = .4$ of original b parton

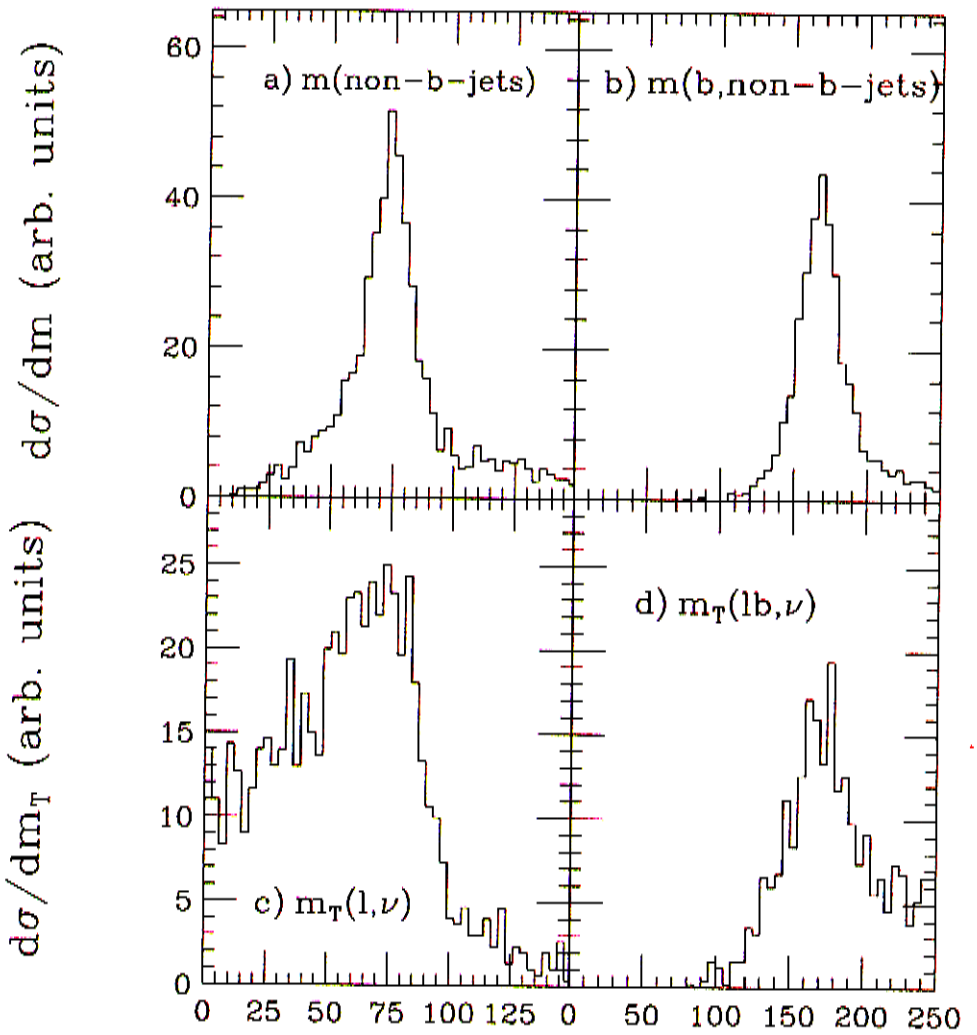


- Plot is slowest of 4 b jets in $e^+e^- \rightarrow l + 4b + jets + E_T^{miss}$ at $\sqrt{s} = 500\ GeV$
- Background peaks at low $E_b(slow)$; cuts on $E_b(slow)$ effective

Reconstruct masses:

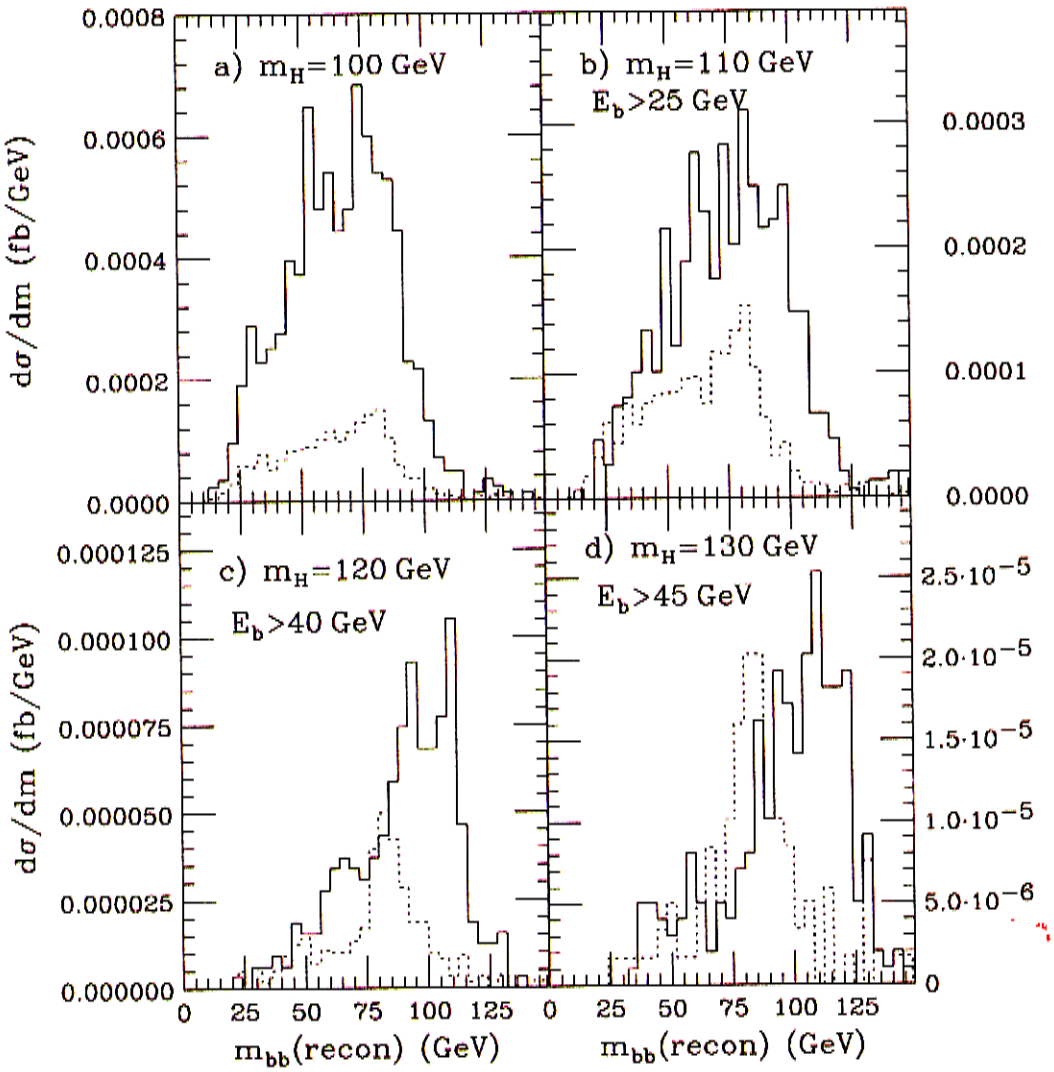
$e^+e^- \to l + 4b + jets + E_T^{miss}$

$\sqrt{s} = 1\ TeV$ for $M_h = 120\ GeV$



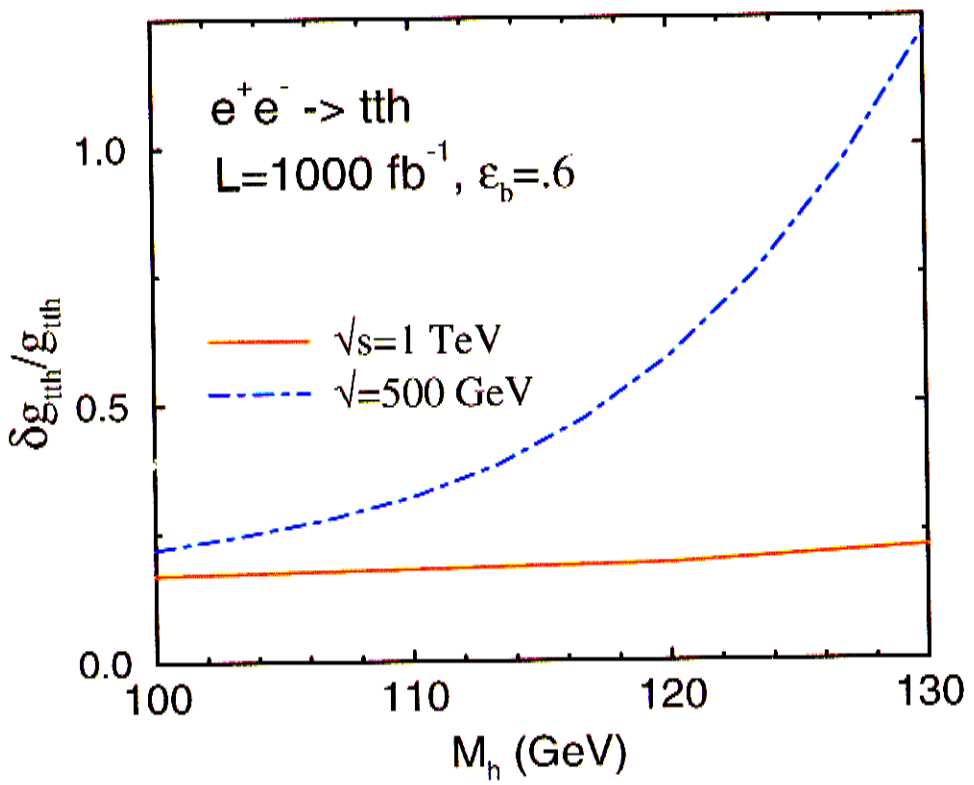
- (a) Invariant mass of non-b jets. Peaks slightly below M_W
- (b) Invariant mass of non-b jets plus b jet which best gives M_t
- (c) Transverse mass $m_T(l, E_T^{miss})$; peaks just below M_W
- (d) $m_T(b, l, E_T^{miss})$ which best gives M_t

After top reconstruction:



- Remaining b jets should reconstruct to M_h
- Distribution in M_{bb} for two remaining b-jets after top mass reconstruction for semi-leptonic events at $\sqrt{s} = 500\ GeV$
- Signal is solid; EW + QCD background dashed

Combine hadronic and semi-leptonic channels:



- Statistical error only in plot
- Interesting question is how well do you *need* to do?

- Juste and Merino (hep-ph/9910301): More sophisticated analysis with TESLA detector and neural net analysis
- Juste and Merino: $\sqrt{s} = 800\ GeV$: $M_h = 120\ GeV$

$$\frac{\delta g_{tth}}{g_{tth}} = 5.5\%$$

CONCLUSIONS

- $e^+e^- \to t\bar{t}h$ is window to new physics at $\sqrt{s} \sim 1\ TeV$
  - MSSM (new processes, couplings)
  - Extra dimensions
  - ???

- Need serious study of energy dependence of this process to see if it is useful at $\sqrt{s} = 500\ GeV$ NLC!