

## *tth Associated Production: An Update*

- Why is it interesting?
- What's new?
  - QCD effects
  - SUSY effects
  - Experimental studies
- How do the LC and LHC stack up?

S. Dawson, LC Meeting, Arlington, Texas, January, 2003

With L. Reina, D. Wackeroth, L. Orr

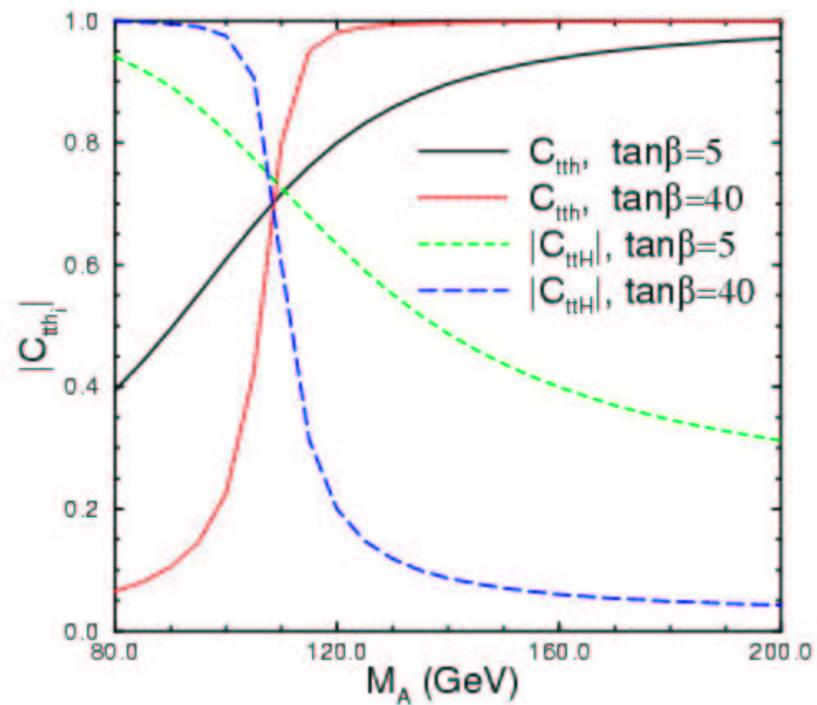
# Why is it interesting?

- $g_{tth}$  is largest Higgs Yukawa coupling
- If new physics exists in Higgs sector, maybe this is first place it's seen
- SUSY models,  $g_{tth}$  coupling suppressed for small  $M_A$
- Little Higgs models,

$$g_{tth} \cong (m_t/v)[1 + O(v/f)]$$

$$f \cong 10 \text{ TeV}$$

$$L = -\frac{m_t}{v} C_{tth} \bar{t} t h$$

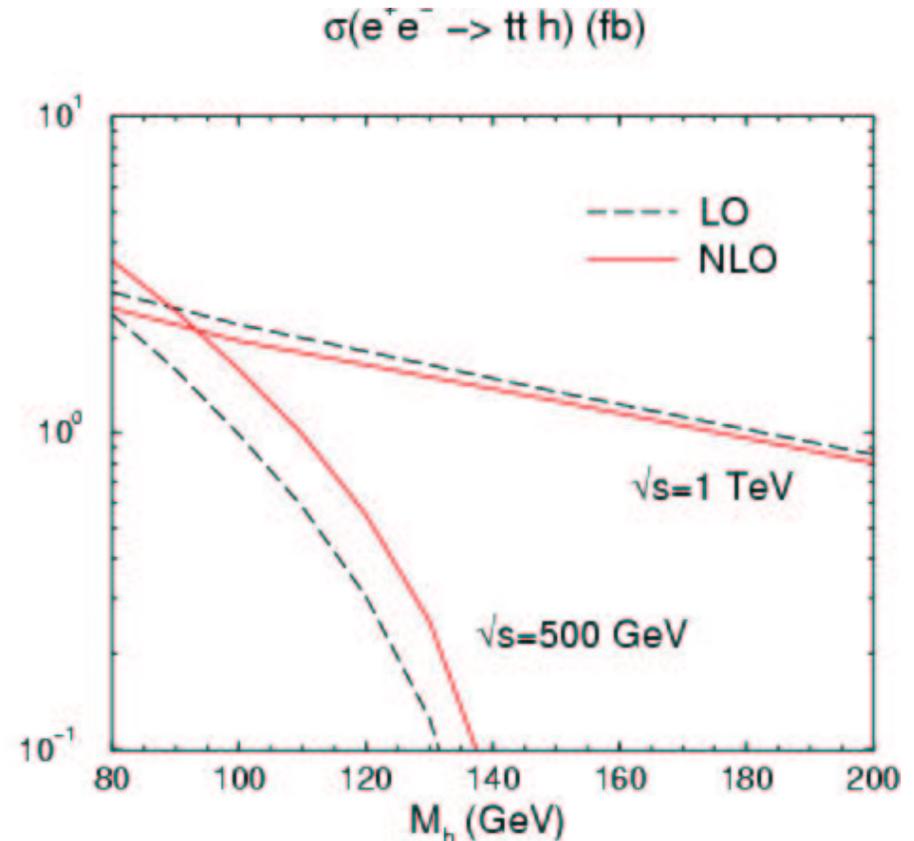


# *Is a deviation from the SM prediction new physics or QCD?*

- NLO QCD calculation in  $e^+e^-$  complete
- Rather large scale dependence  $\cong 15\text{-}20\%$

$$K = \frac{\sigma_{NLO}}{\sigma_{LO}} = 1 + \alpha_s(\mu) F\left(\frac{M_h^2}{s}\right)$$

- $K \cong 1.4\text{-}2.4$  for  $\sqrt{s}=500$  GeV

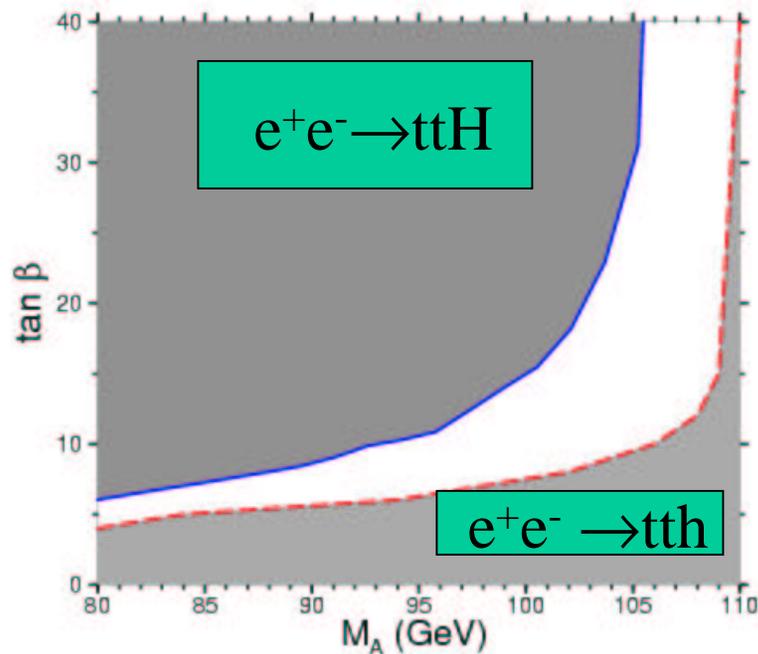


Dawson & Reina, hep-ph/0101079,  
hep-ph/9808443;

Dittmaier et al, hep-ph/9808433

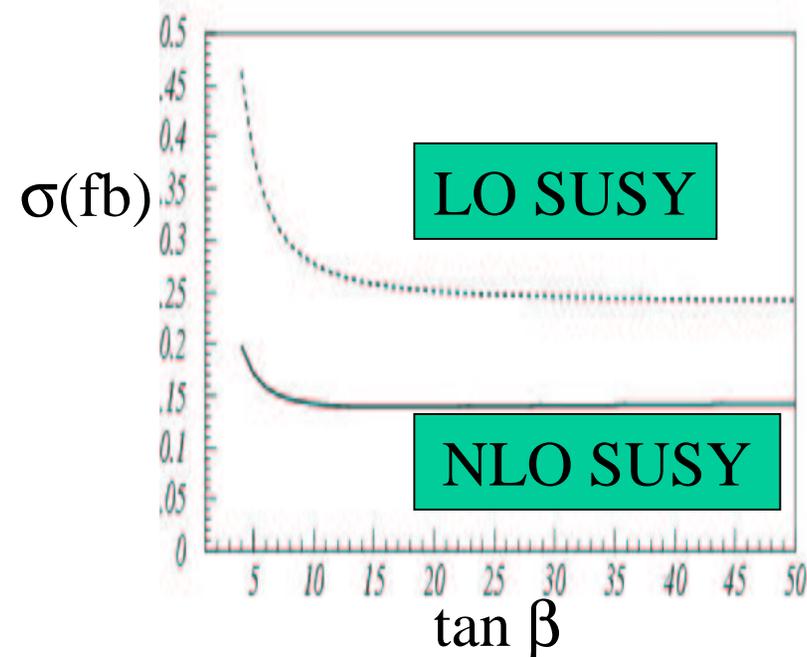
# Large Effects in SUSY

- New couplings; resonance effects
- Shaded regions have NLO  $\sigma > .75$  fb



Dawson & Reina, hep-ph/0011290

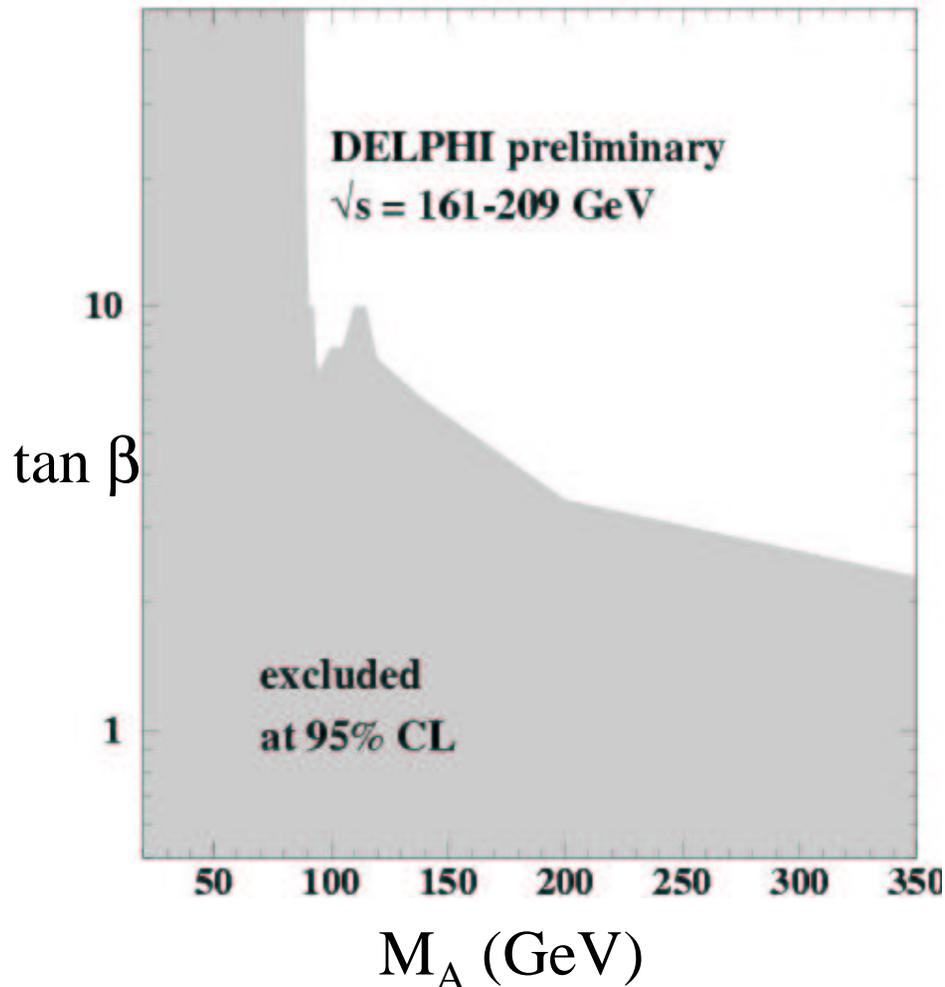
- SUSY QCD loops (squarks and gluinos) decrease  $\sigma$



S. Zhu, hep-ph/0212273

$A_t=1$  TeV,  $M_S=400$  GeV,  $\mu=-100$  GeV,  
 $M_A=300$  GeV,  $m_g=200$  GeV

Unfortunately.....



- Most of region where  $e^+e^- \rightarrow t\bar{t}h$  large in SUSY models excluded by LEP limits....

# Experimental Studies in $e^+e^-$ Colliders

- Optimal energy is  $\sqrt{s}=800$  GeV
- Large luminosity required  
( $L=1000 \text{ fb}^{-1}$ )
- $h \rightarrow W^+W^-$  channel, plus  
 $h \rightarrow bb$  channel gives

$$\delta g_{tth}/g_{tth} \cong 7.5-15\%$$

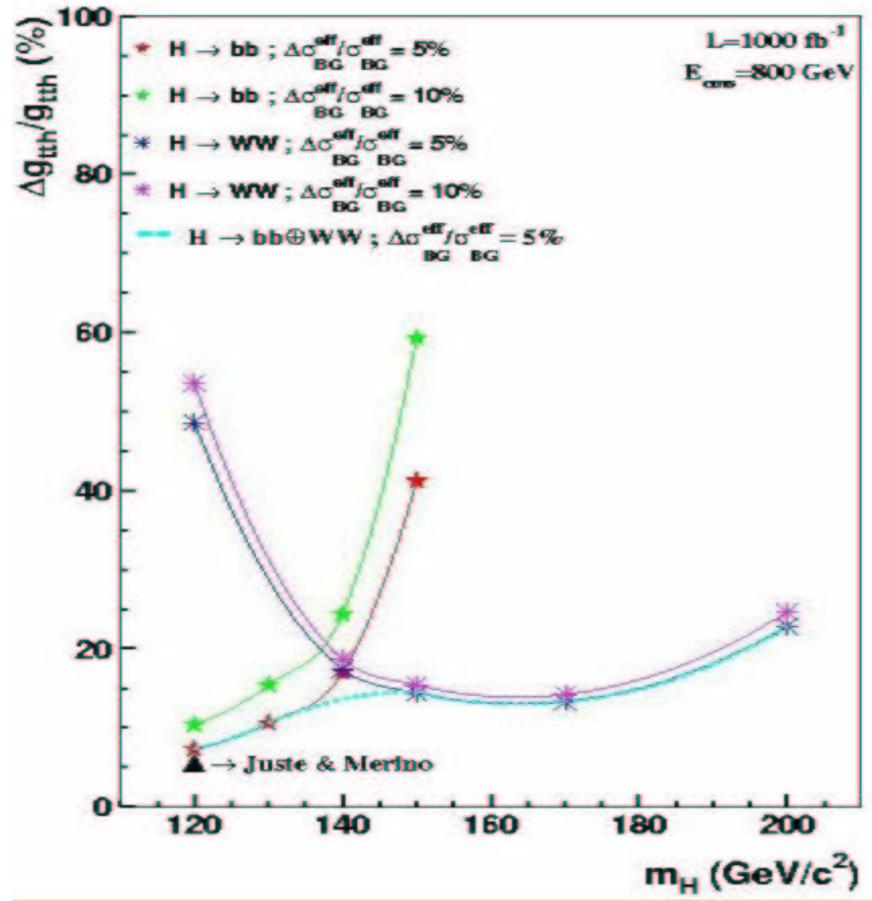
$$120 < M_h < 175 \text{ GeV}$$

What about  $\sqrt{s}=500$  GeV?

Semi-leptonic channel,  
 $\delta g_{tth}/g_{tth} \cong 33\%$

Baer, Dawson, Reina, hep-ph/9906419

Juste, Chicago LC Workshop, 1/02



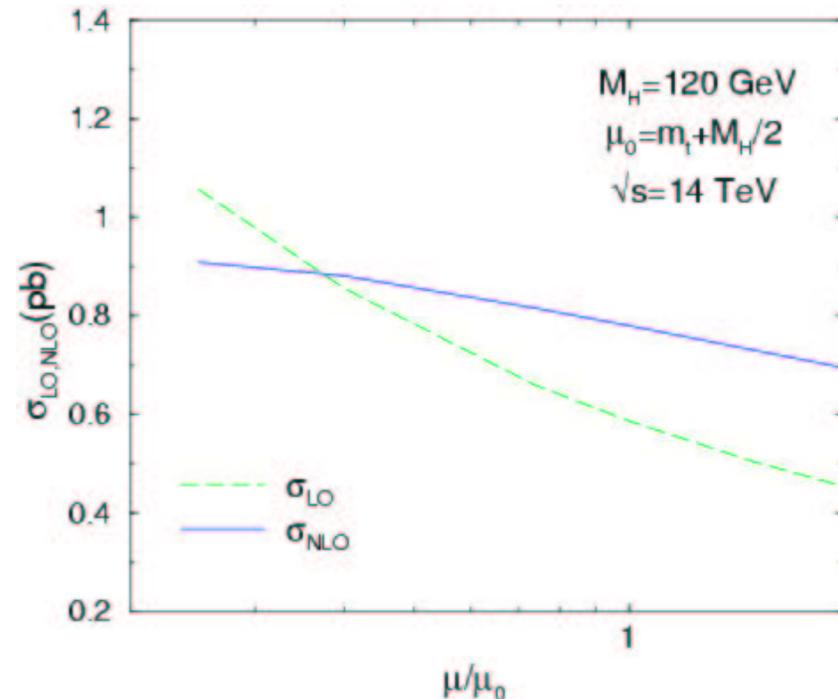
A. Gay, [www.desy.de/~desch/higgs/stmalo/gay.ps](http://www.desy.de/~desch/higgs/stmalo/gay.ps)  
Juste and Merino, hep-ph/9910301

# $pp \rightarrow tth$ at NLO QCD at the LHC

Dawson, Orr, Reina, Wackerth, hep-ph/0211438

Beenakker et al, hep-ph/0107081

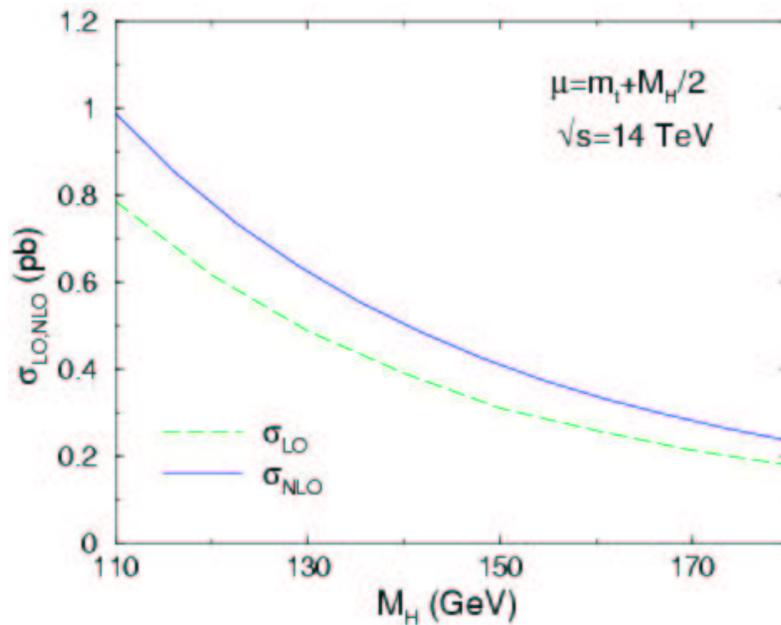
- Complete NLO calculation
- Dominant contribution from gg initial state at LHC
- State of the art: pentagon diagrams with 3 mass scales
- Real corrections evaluated with both 1 and 2 cutoff phase space slicing technique



Still 15-20 % uncertainty from  $\mu$  dependence at NLO (much smaller than LO calculation)

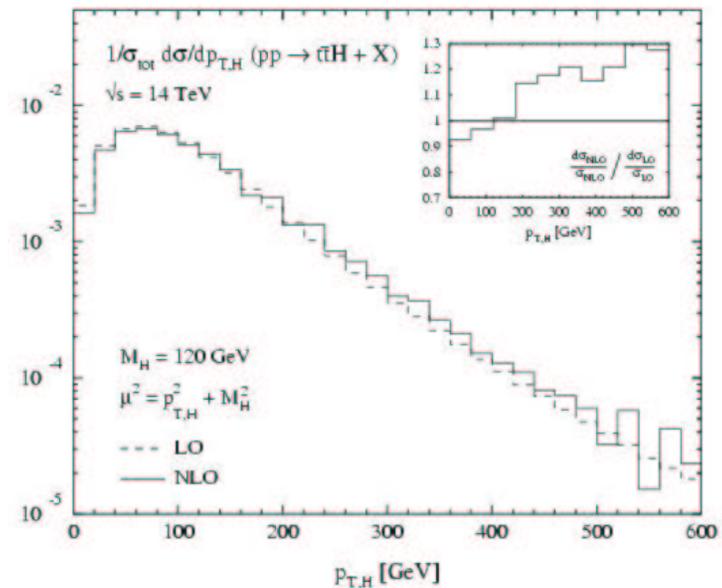
# pp → tth at NLO QCD at LHC

- NLO corrections give  $K \cong 1.2-1.4$



Dawson, Orr, Reina Wackerroth,  
 hep-ph/0211438

- Shape of distributions largely unaffected by NLO corrections

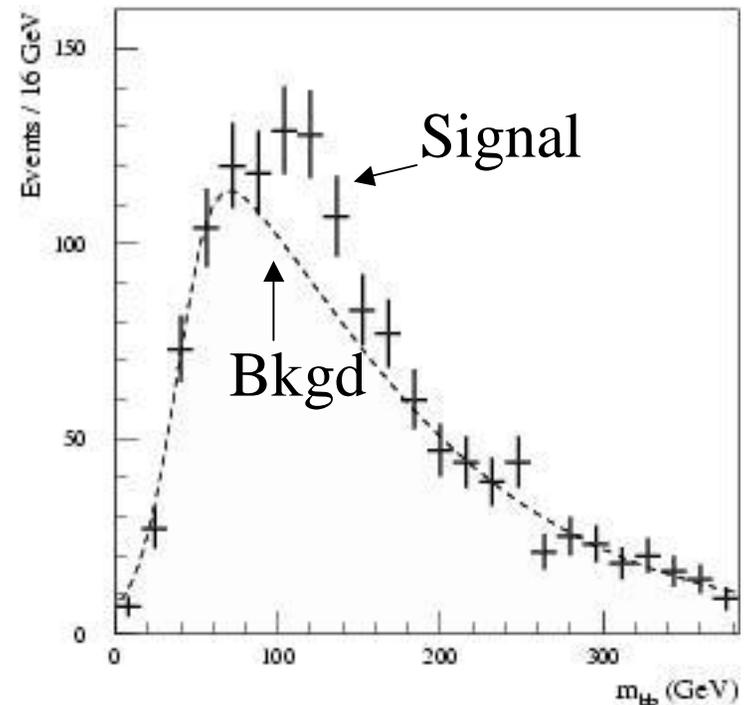
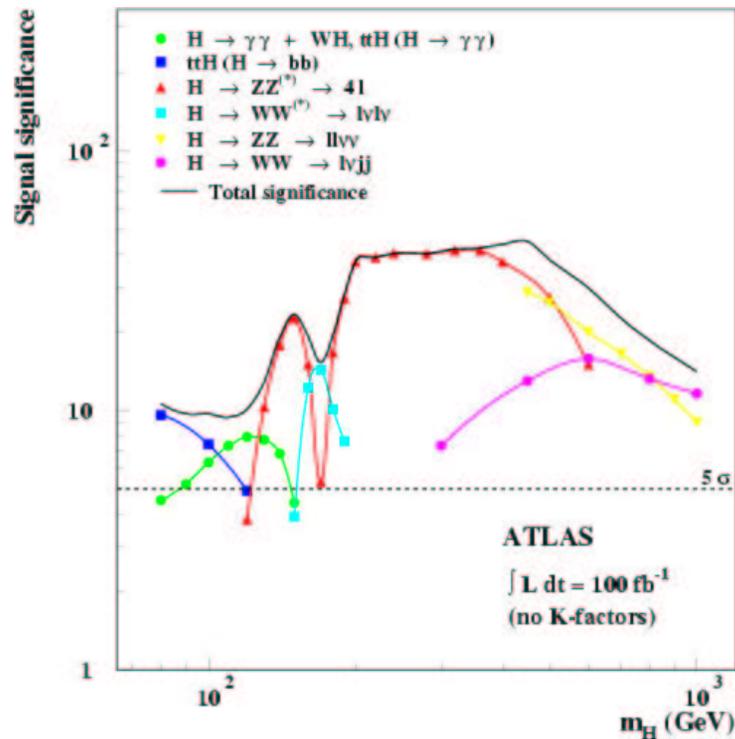


Beenakker et al, hep-ph/0211352

# tth is important channel at LHC

- tth is discovery mode for  $M_h < 130 \text{ GeV}$

$pp \rightarrow t\bar{t}h; h \rightarrow b\bar{b}$



$$\frac{\delta g_{t\bar{t}h}}{g_{t\bar{t}h}} \cong 16\%$$

## Conclusions on tth Production

- Theory for both  $e^+e^-$  and hadronic collisions complete to NLO QCD; need EW & SUSY corrections
- NLO QCD results show reduced scale dependence
- Precision on  $\delta g_{tth}/g_{tth}$  in  $e^+e^-$  at  $\sqrt{s}=500$  GeV much poorer than at LHC

Argument for higher energy  $e^+e^-$