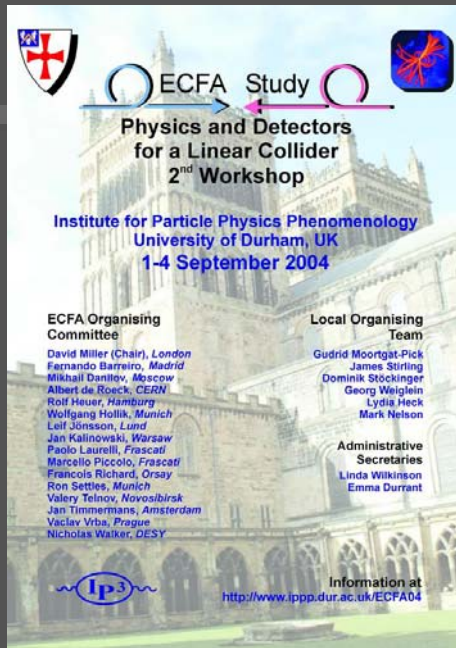


# Model independent determination of the top quark Yukawa coupling from LHC and ILC data

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The poster features a background image of a large Gothic cathedral. At the top, there is a logo with a shield on the left and a particle detector image on the right. The text 'ECFA Study' is in the center, with 'Physics and Detectors for a Linear Collider 2nd Workshop' below it. The location and date are 'Institute for Particle Physics Phenomenology, University of Durham, UK, 1-4 September 2004'. The poster lists the ECFA Organising Committee and the Local Organising Team, along with administrative secretaries. At the bottom, there is the IP3 logo and the website URL.

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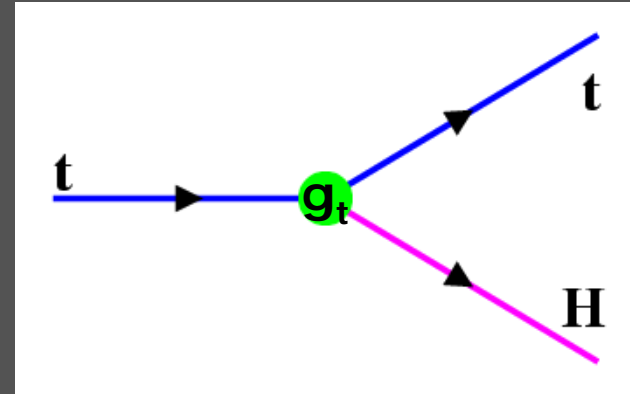
Information at  
<http://www.ippp.dur.ac.uk/ECFA04>

- ❖ Motivation and Idea
- ❖ LHC rate measurement
- ❖ ILC branching ratio measurement
- ❖ Determination of  $g_t$

ECFA LC WS, September 2004, Durham

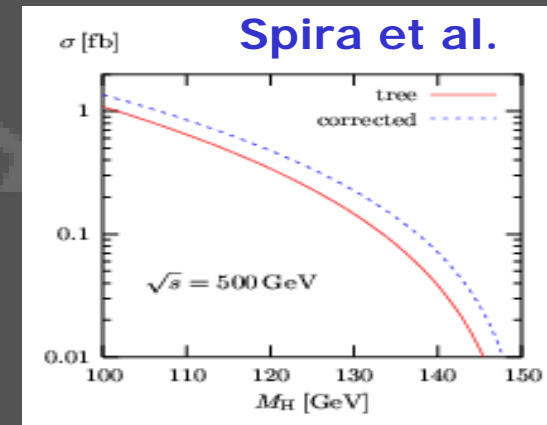
# Motivation

- test whether:  $m_f \sim g_f$
- top Yukawa coupling largest:  
 $g_t \sim O(1)$  ( $g_b \sim O(10^{-4})$ )
- theoretical prejudice:  
maybe surprises for top quark ?



- light Higgs:  $g_t$  from  $ttH$  associated production
- framework: data from LHC ( $L = 30$  and  $300 \text{ fb}^{-1}$ )  
data from ILC at  $E_{\text{CM}} = 500 \text{ GeV}$ ,  $L = 500 \text{ fb}^{-1}$

- ILC: small cross section  $\sim 1.5$  to  $0.01 \text{ fb}$   
for  $M_H = 100$  to  $145 \text{ GeV}$  @  $E_{\text{CM}} = 500 \text{ GeV}$



- LHC: only rate  $pp \rightarrow ttH$ ,  $H \rightarrow xx$  model independent measurable

# Idea

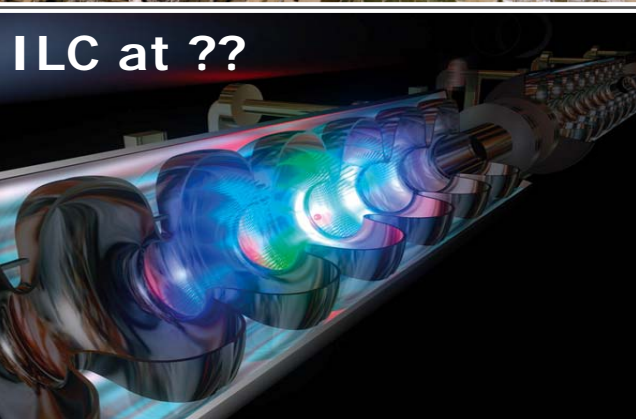
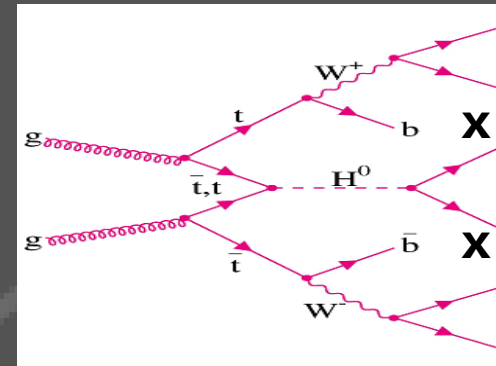


**LHC:** measurement of rate

$$\sigma_{t\bar{t}h} \times \text{BR}(H \rightarrow b\bar{b})$$

$$\sigma_{t\bar{t}h} \times \text{BR}(H \rightarrow WW)$$

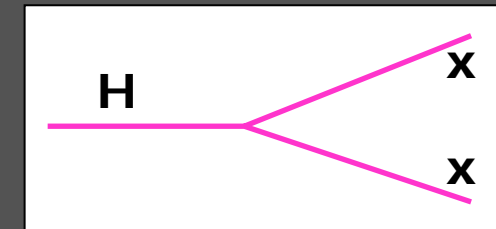
$$\rightarrow g_t^2 \times \text{BR}(H \rightarrow xx)$$



**ILC:** measurement of branching ratio

$$\text{BR}(H \rightarrow b\bar{b})$$

$$\text{BR}(H \rightarrow WW)$$

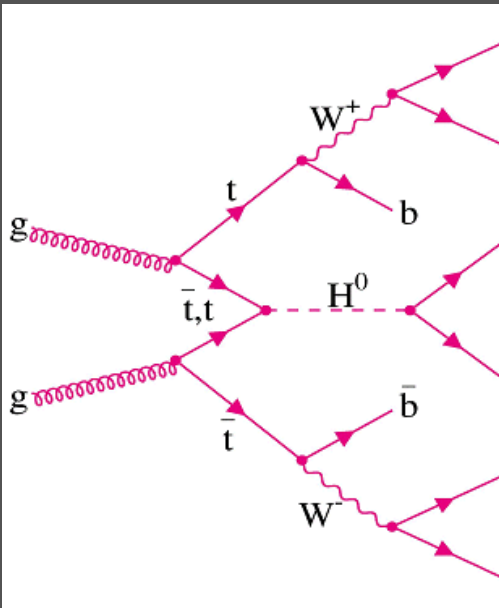


**Combination of both measurements**

$\rightarrow$  model independent determination  
of top quark Yukawa coupling

H

# LHC rate measurements



## $H \rightarrow bb$ :

$t \rightarrow bqq$   $t \rightarrow b\nu$   $H \rightarrow bb$

$\sigma \sim 110 \text{ fb @ } M_H = 120 \text{ GeV}$

## $H \rightarrow WW$ :

a) 2 likesign leptons:  $t \rightarrow bl^+\nu$   $t \rightarrow qq$   $H \rightarrow l^+ \nu qq$

b) 3 leptons:  $t \rightarrow bl\nu$   $t \rightarrow bl\nu$   $H \rightarrow WW \rightarrow qq l \nu$

$t \rightarrow bl\nu$   $t \rightarrow bqq$   $H \rightarrow WW \rightarrow l \nu l \nu$

$\sigma \sim 2 \times 18 \text{ fb @ } M_H = 160 \text{ GeV}$

## Backgrounds considered :

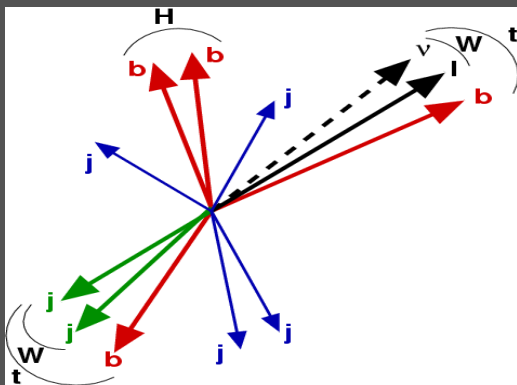
$tt + W, Z, Wj, tt, WW, bb, jj$   $WW, WZ, Wbb, Z+j, W+j, W+t$

Cross sections: 492 pb to  $5 \times 10^{-3}$  pb

Results from published ATLAS fast MC studies:

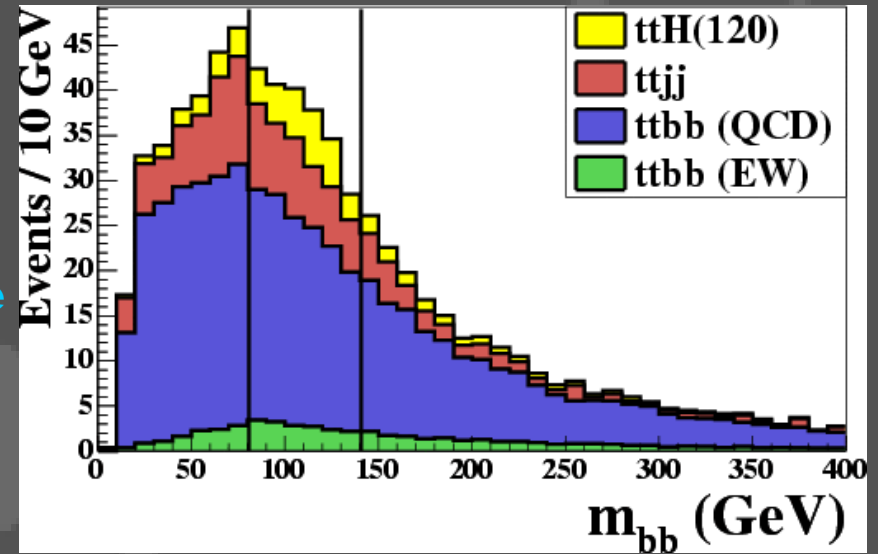
b-tagging, mass resolutions, lepton isolation from full simulation

# ttH with $H \rightarrow bb$ (ATL-PHYS-2003-024, J. Cammin, MS)



1 lepton, missing energy, 6 jets, 4 b-tagged  
consistent with  $ttH, H \rightarrow bb$  production,  $m_{bb} \sim m_H$

background estimate  
from data foreseen

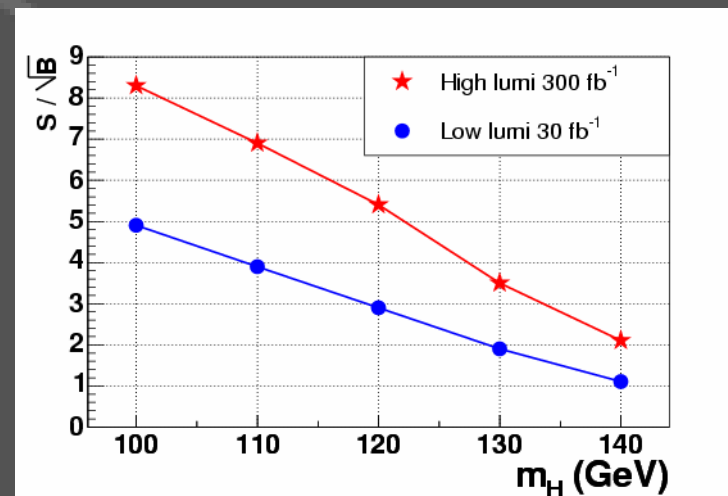


## expected signal and background events

$m_H$ (GeV)	$30\text{fb}^{-1}$		$300\text{fb}^{-1}$	
	$t\bar{t}H^0$	$H^0 \rightarrow bb$	$t\bar{t}H^0$	$H^0 \rightarrow bb$
100	83.4	303.4	279.0	1101.3
110	63.0	275.7	232.5	1140.6
120	43.0	234.1	173.1	1054.2
130	26.5	200.1	112.5	1015.8
140	13.9	178.2	62.4	947.1

Eff. = 1.5%

0.5%



# ttH with $H \rightarrow WW$ (ATL-PHYS-2002-019, J. Leveque et al.)

## 2 lepton topology:

$t \rightarrow bl + \nu$   $t \rightarrow bqq$   $H \rightarrow l + \nu qq$

2 likesign leptons,

6 jets, 2 b-tagged

b-lepton veto

„mass“ reconstruction

## 3 lepton topology:

$t \rightarrow bl\nu$   $t \rightarrow bl\nu$   $H \rightarrow qq\nu l\nu$

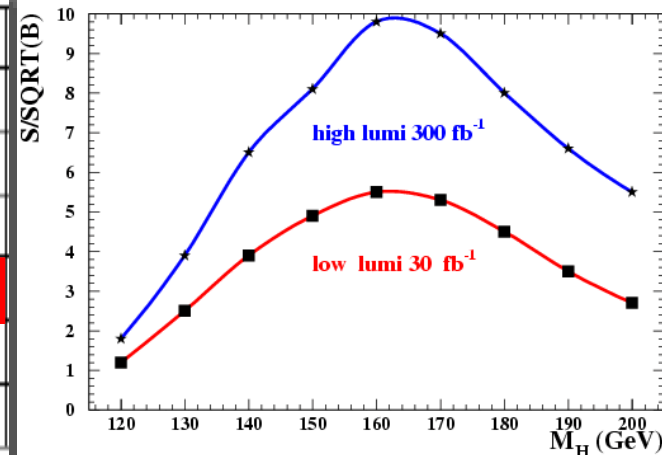
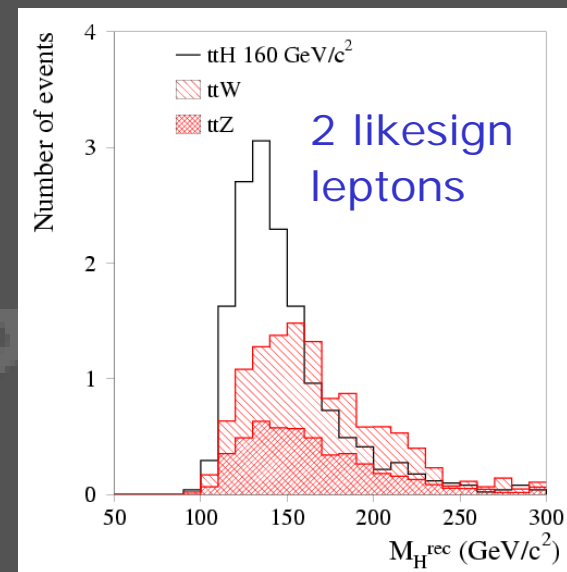
$t \rightarrow bl\nu$   $t \rightarrow bqq$   $H \rightarrow l\nu l\nu$

three leptons

4 jets, 2 b-tagged

b-lepton veto

Z veto



$m_H$ (GeV)	$30 \text{ fb}^{-1}$				$300 \text{ fb}^{-1}$			
	$ttH^0 H^0 \rightarrow WW(2\ell)$		$ttH^0 H^0 \rightarrow WW(3\ell)$		$ttH^0 H^0 \rightarrow WW(2\ell)$		$ttH^0 H^0 \rightarrow WW(3\ell)$	
	signal	bckgr	signal	bckgr	signal	bckgr	signal	bckgr
120	4.4	19.6	2.7	21.2	12.7	80.6	10.5	97.6
140	15.0	19.6	8.7	21.2	50.0	80.6	33.7	97.6
160	21.1	19.6	13.0	21.2	72.3	80.6	55.3	97.6
180	17.3	19.6	10.3	21.2	60.9	80.6	41.7	97.6
200	10.5	19.6	5.7	21.2	43.2	80.6	26.4	97.6

# Rate measurement $\sigma \times \text{BR}$

$$\left(\frac{\Delta(\sigma \times \text{BR})}{\sigma \times \text{BR}}\right)^2 = \frac{S+B}{S^2} + \left(\frac{\Delta B_{\text{sys}}}{S}\right)^2 + \left(\frac{\Delta \mathcal{L}}{\mathcal{L}}\right)^2 + \left(\frac{\Delta \epsilon}{\epsilon}\right)^2$$

$\Delta B_{\text{sys}}$ : from sidebands + control samples  
 10% for  $H \rightarrow bb$  at low luminosity  
 5% otherwise

$\Delta \epsilon$ : efficiency uncertainty from (depends on nr. of leptons and bs):  
 lepton isolation + reconstruction : 3 % + 2 %  
 b-tagging: 3%      overall reconstruction: 2 %

$\Delta \mathcal{L}$ : luminosity uncertainty 5%

Expected accuracy on  
 $\sigma \times \text{BR}$  including  
 systematic uncertainties

$m_H$ (GeV)	$30 \text{ fb}^{-1}$		$300 \text{ fb}^{-1}$	
	$H^0 \rightarrow bb$	$H^0 \rightarrow WW$	$H^0 \rightarrow bb$	$H^0 \rightarrow WW$
100	0.398(0.236)		0.249(0.133)	
110	0.476(0.292)		0.287(0.159)	
120	0.598(0.387)	1.023(0.974)	0.345(0.202)	0.732(0.611)
130	0.840(0.568)	0.524(0.492)	0.488(0.299)	0.362(0.295)
140	1.444(0.997)	0.370(0.339)	0.804(0.509)	0.252(0.193)
160		0.287(0.254)		0.196(0.137)
180		0.331(0.300)		0.221(0.163)
200		0.486(0.454)		0.282(0.222)

# From $\sigma \times \text{BR}$ to $g_t^2 \times \text{BR}$

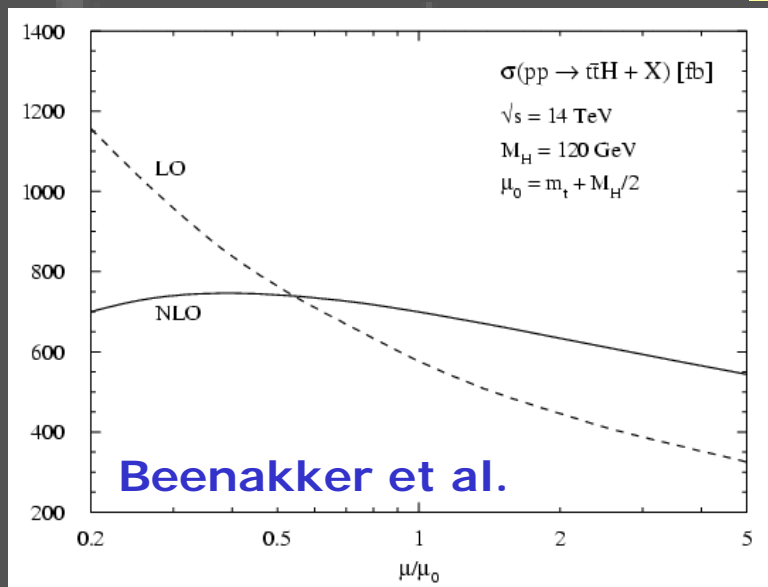
Comparing observed rate with theoretical prediction:

$\sigma \times \text{BR}$

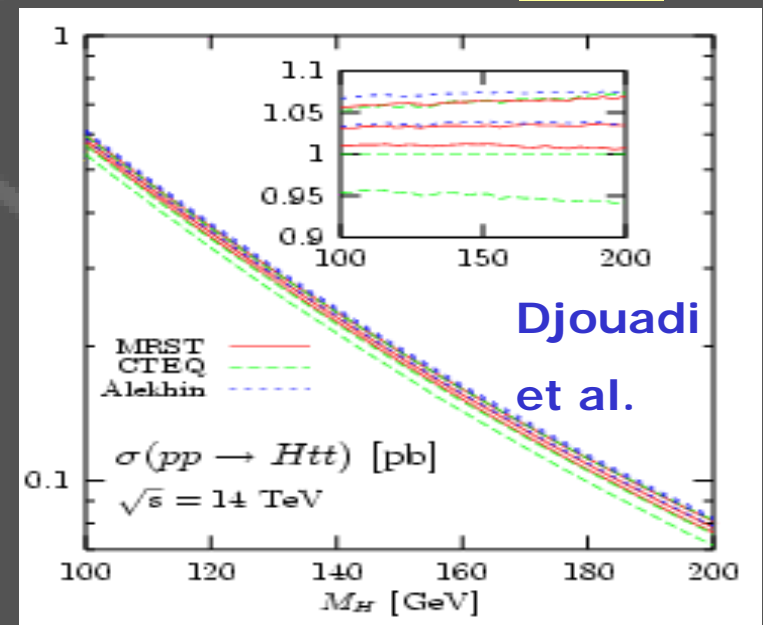
$g_t^2 \times \text{BR}$

$$\left( \frac{\Delta(g_{ttH}^2 \times \text{BR})}{g_{ttH}^2 \times \text{BR}} \right)^2 = \left( \frac{\Delta(\sigma \times \text{BR})}{\sigma \times \text{BR}} \right)_{\text{exp}}^2 + \left( \frac{\Delta\sigma}{\sigma} \right)_{\text{theo}}^2$$

Estimate of higher order uncertainty in cross section: **15%**



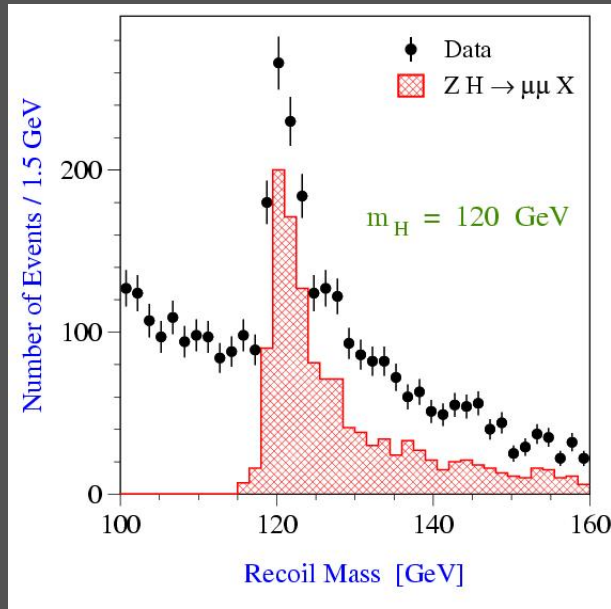
PDF uncertainty: **5%**



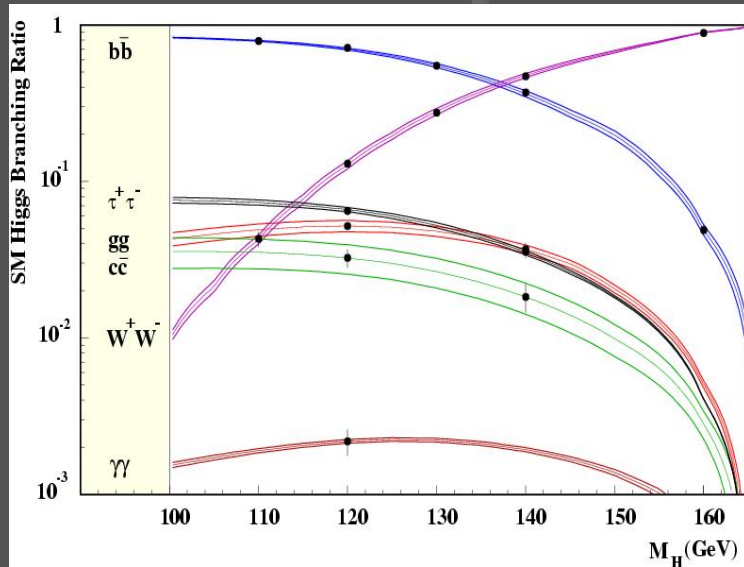
Both contributions added quadratically



# Measurement of branching ratios at ILC



- model independent determination of  $\sigma_{ZH}$  from recoil mass in  $e^+e^- \rightarrow ZH \rightarrow \mu\mu X$
- measurement of rate  $\sigma_{ZH} \times BR(H \rightarrow xx)$ 
  - i)  $e^+e^- \rightarrow ZH \rightarrow \mu\mu bb$
  - ii)  $e^+e^- \rightarrow ZH \rightarrow \mu\mu WW$
- determination of  $BR(H \rightarrow bb)$  and  $BR(H \rightarrow WW)$



accuracy on BR determination

$m_H$ (GeV)	$\Delta BR(bb)/BR(bb)$	$\Delta BR(WW)/BR(WW)$
100	0.024	
120	0.024	0.051
140	0.026	0.025
160	0.065	0.021
200		0.021

(TESLA TDR,  $500 \text{ fb}^{-1}$ )

# Determination of $g_t$

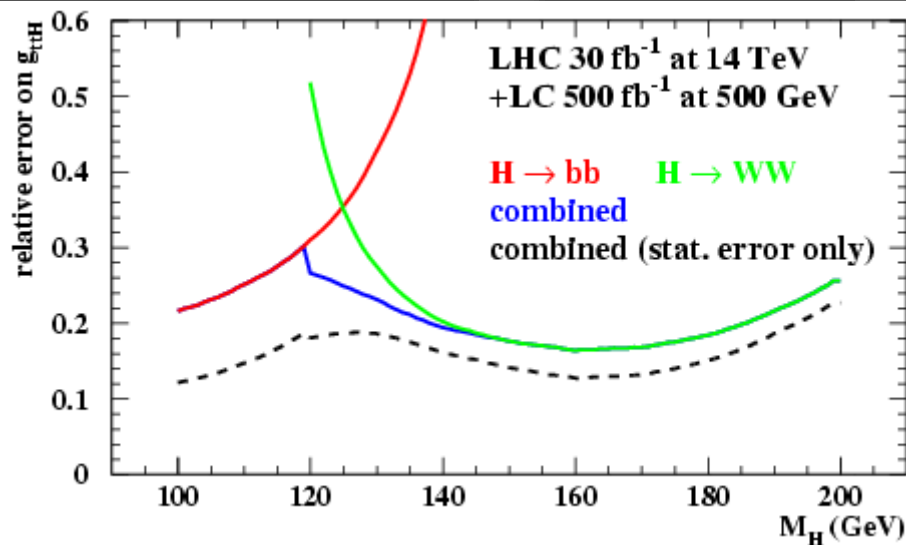
Assume Born level relation:  $\sigma \sim g_t^2$

Combination of  
LHC and ILC

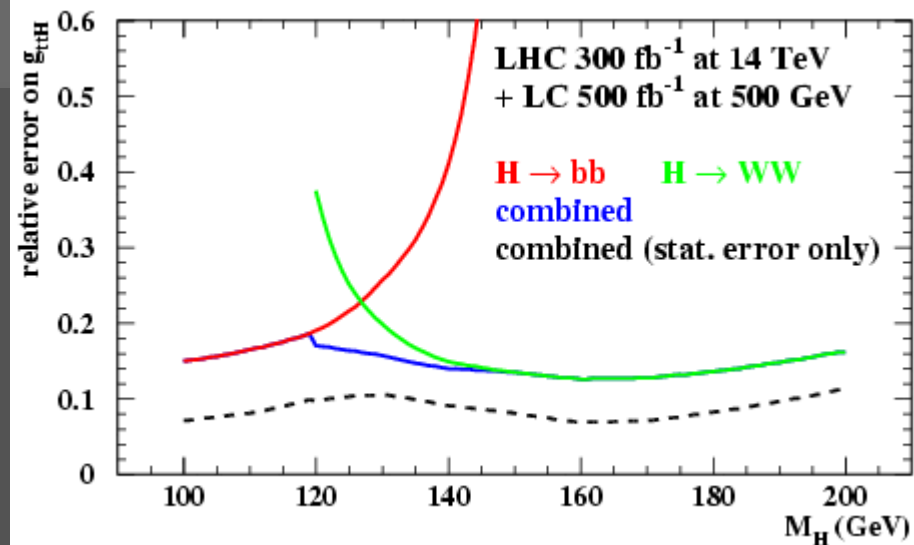
$$\frac{\Delta g_t}{g_t} = \frac{1}{2} \sqrt{\left( \frac{\Delta(g_{ttH}^2 \times BR)}{g_{ttH}^2 \times BR} \right)_{\text{LHC}}^2 + \left( \frac{\Delta BR}{BR} \right)_{\text{ILC}}^2}$$

Combination of  
 $H \rightarrow bb$  and  $H \rightarrow WW$

$$\left( \frac{\Delta g_{tth}}{g_{tth}} \right)_{\text{comb.}}^{-2} = \left( \frac{\Delta g_{tth}}{g_{tth}} \right)_{\text{WW}}^{-2} + \left( \frac{\Delta g_{tth}}{g_{tth}} \right)_{b\bar{b}}^{-2}$$



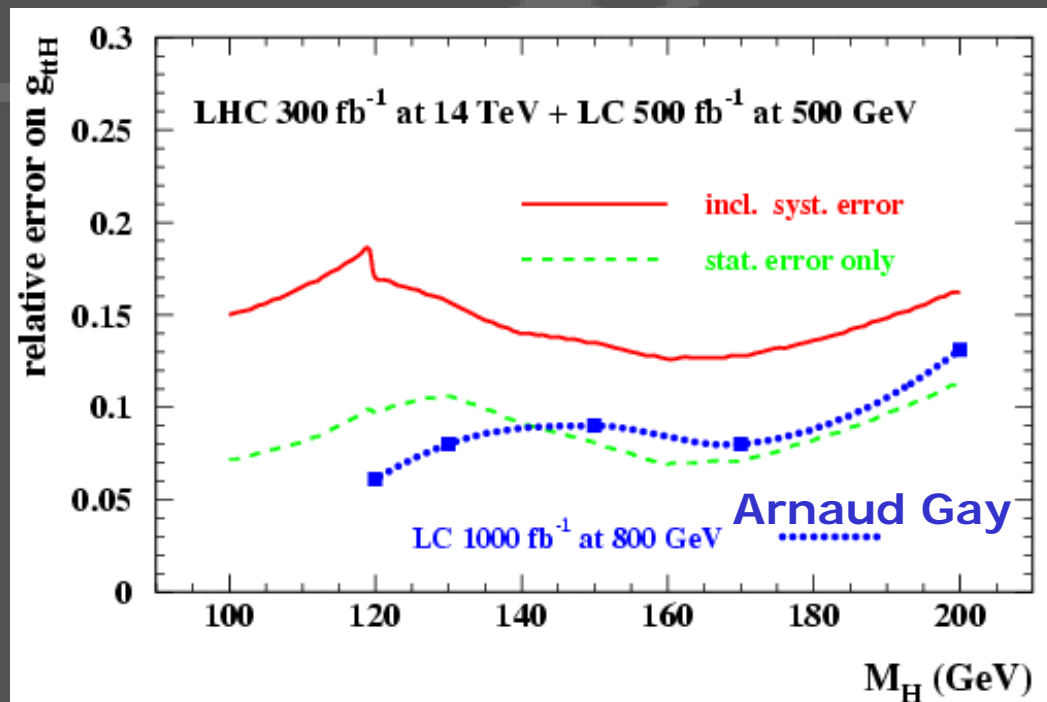
$\Delta g_t \sim 16$  to  $27$  % (12 to 23%)



$\Delta g_t \sim 13$  to  $17$  % (7 to 11%)

# Conclusions

- ❖ synergy of LHC and ILC allows model independent determination of top quark Yukawa coupling from combination of data
- ❖ expected error on  $g_t$ :  
 $\Delta g_t / g_t = 13 \text{ to } 17 \%$   
dominated by systematic uncertainties



More info: [hep-ph 0407159](https://arxiv.org/abs/hep-ph/0407159)

# Accuracy in determination of $g_t$

$m_H$ (GeV)	$30 \text{ fb}^{-1}$			$300 \text{ fb}^{-1}$		
	bb	WW	bb+WW	bb	WW	bb + WW
100	0.22(0.12)			0.15(0.07)		
110	0.25(0.15)			0.17(0.08)		
120	0.31(0.19)	0.52(0.49)	0.27(0.18)	0.19(0.10)	0.38(0.31)	0.17(0.10)
130	0.43(0.28)	0.28(0.25)	0.23(0.19)	0.26(0.15)	0.20(0.15)	0.16(0.11)
140	0.72(0.50)	0.20(0.17)	0.19(0.16)	0.41(0.26)	0.15(0.10)	0.14(0.09)
150		0.18(0.14)		1.88(1.21)	0.14(0.08)	0.14(0.08)
160		0.16(0.13)			0.13(0.07)	
170		0.17(0.13)			0.13(0.07)	
180		0.18(0.15)			0.14(0.08)	
190		0.22(0.19)			0.15(0.10)	
200		0.26(0.23)			0.16(0.11)	