Top physics a LHC

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Top ID card

- $\begin{pmatrix} t_{2/3} \\ b_{-1/3} \end{pmatrix}_L^{i=1,2,3}$ $\qquad$ $t^i{}_R$

- mass set by the EWSB: $m_t = y_t v/\sqrt{2}$

  $m_t \sim 170\,\mathrm{GeV} \longrightarrow y_t \sim 1$

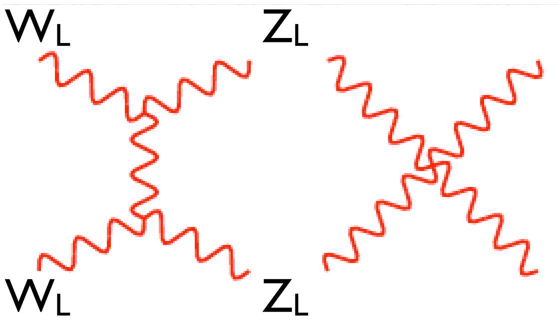
  strong interaction with the Higgs

- very short lifetime: it decays before hadronising

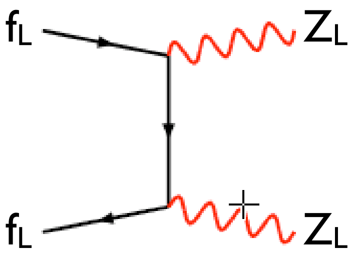
  $\tau_t \sim 10^{-24} s\,, \quad \Gamma^{-1} \sim (1.5\,\mathrm{GeV})^{-1} \ll \Lambda_{\mathrm{QCD}}^{-1} \sim (200\,\mathrm{MeV})^{-1}$

  - no spectroscopy
  - spin transferred to decay products: Wb

Top & unitarity



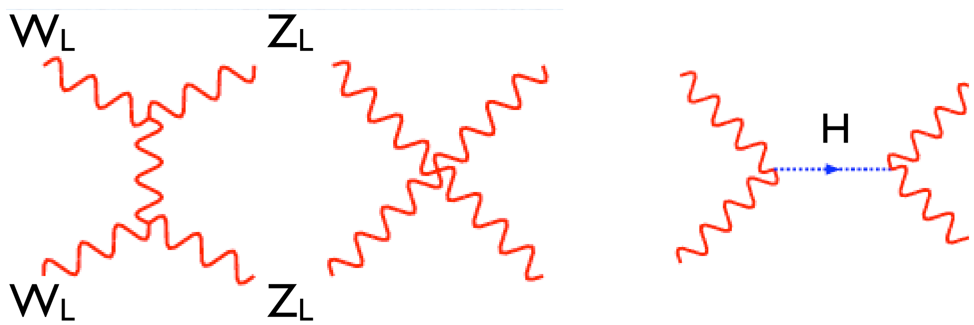
$$a_0 \sim \frac{s}{v^2}$$



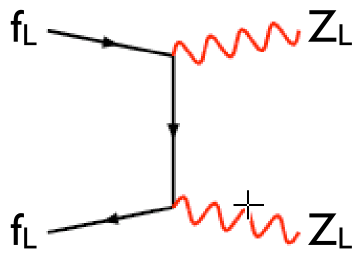
$$a_0 \sim \frac{\sqrt{s} m_f}{v^2}$$

top, Higgs and EWSB are intertwined

Top & unitarity



$$a_0 \sim \frac{s}{v^2} - \frac{s}{v^2} \sim \frac{m_H^2}{v^2}$$



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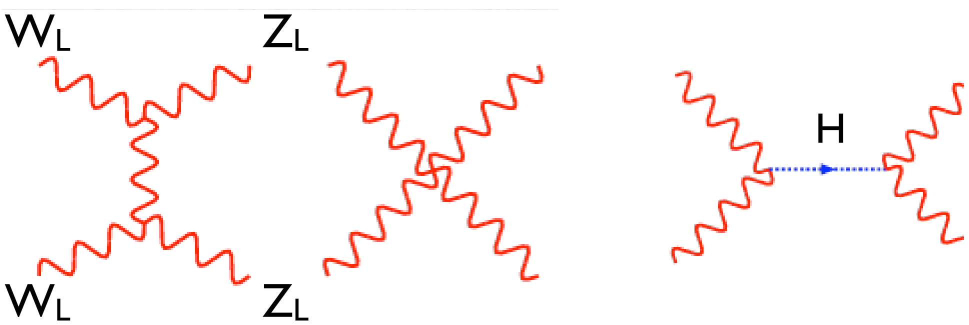

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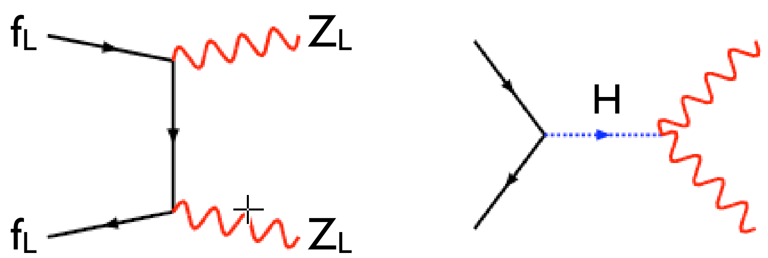

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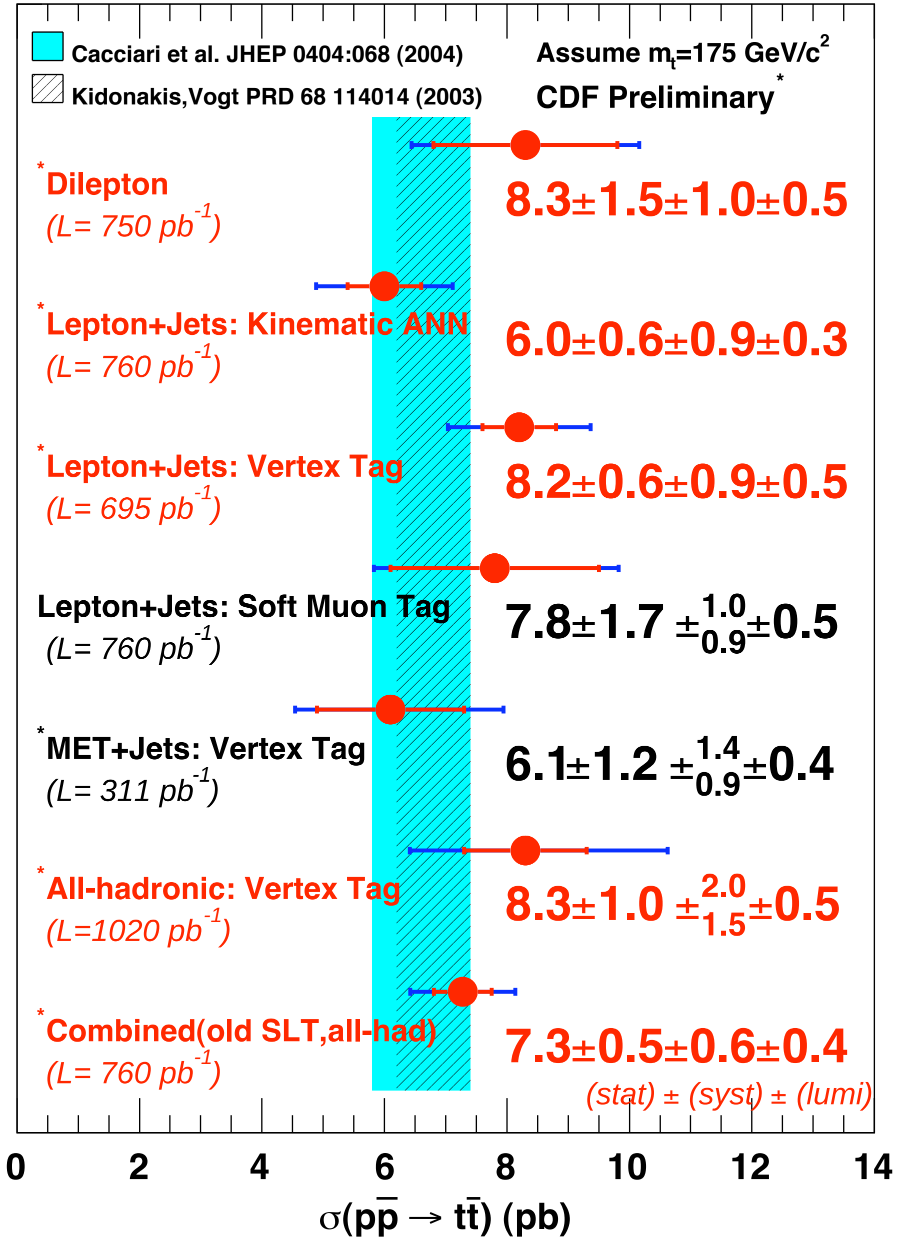
top, Higgs and EWSB are intertwined

t tbar x-section at Tevatron



assume m_t = 175 GeV

updated on 23/03/06

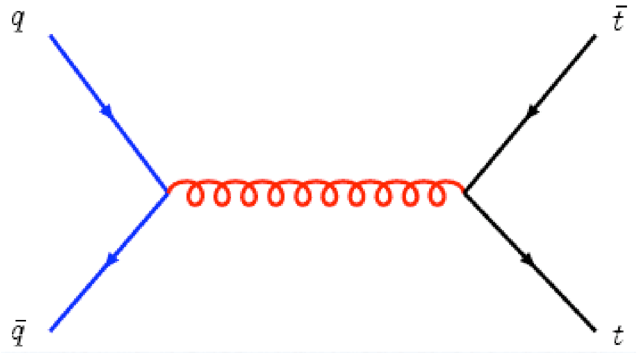
compare with theory (NLO + NLL)

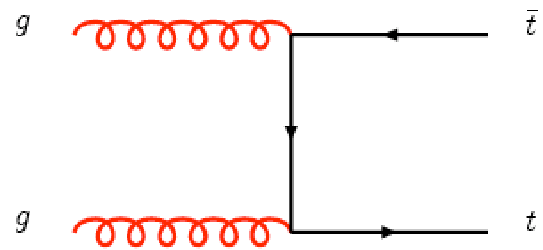
$$\sigma_{t\bar{t}} = 6.5\,\mathrm{pb}\ (1 \pm 5\%_{\mathrm{scale}} \pm 7\%_{\mathrm{PDF}})$$

Cacciari, Frixione, Mangano, Nason, Ridolfi 2003

TH & EXP have comparable errors

t tbar production



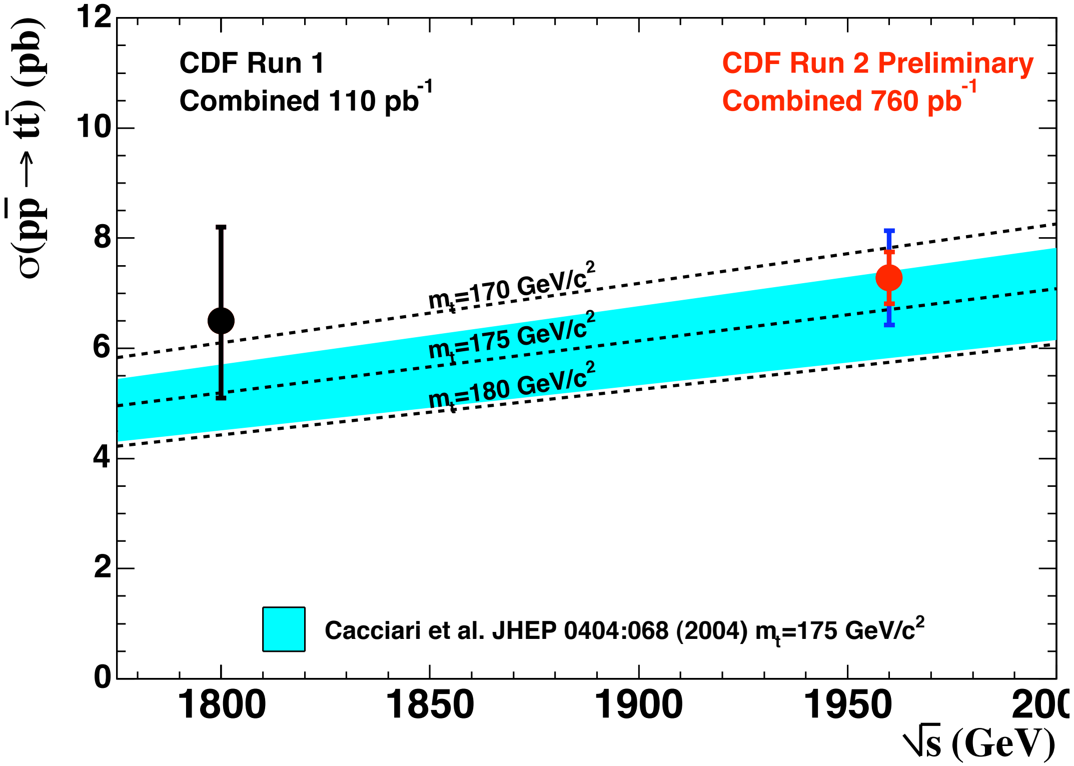


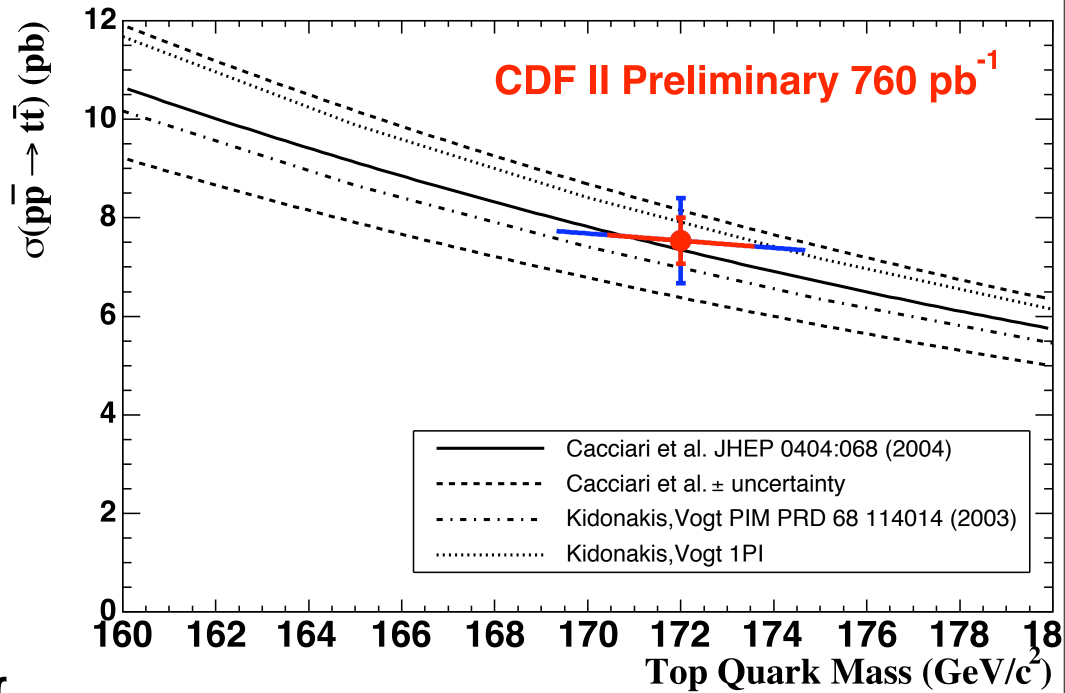
Tevatron	85 %	15 %
LHC	~ 10 %	~ 90 %

Tevatron
- 10 tt pairs/day → 7000 tt produced, 600 tt on tape
- 60 % with p_t(tt) > 15 GeV

LHC
- 1 tt pairs/sec → at hi lumi ~10^7 tt produced/year
- 70 % with p_t(tt) > 30 GeV

t tbar x-section: TH vs. EXP



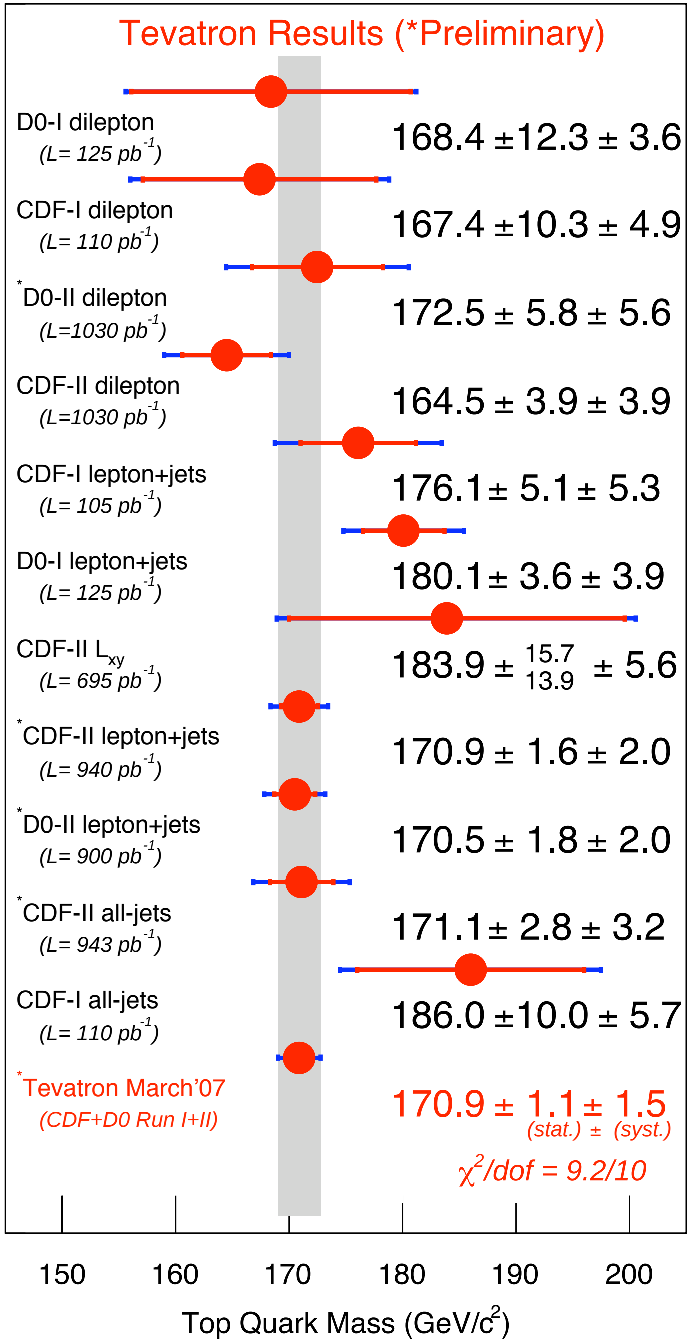


updated on 03/03/06

TH: $\delta m/m = 0.2\ \delta\sigma/\sigma$

$\Delta\sigma = \pm 6\,\% \to \Delta m = \pm 2\,\mathrm{GeV}$

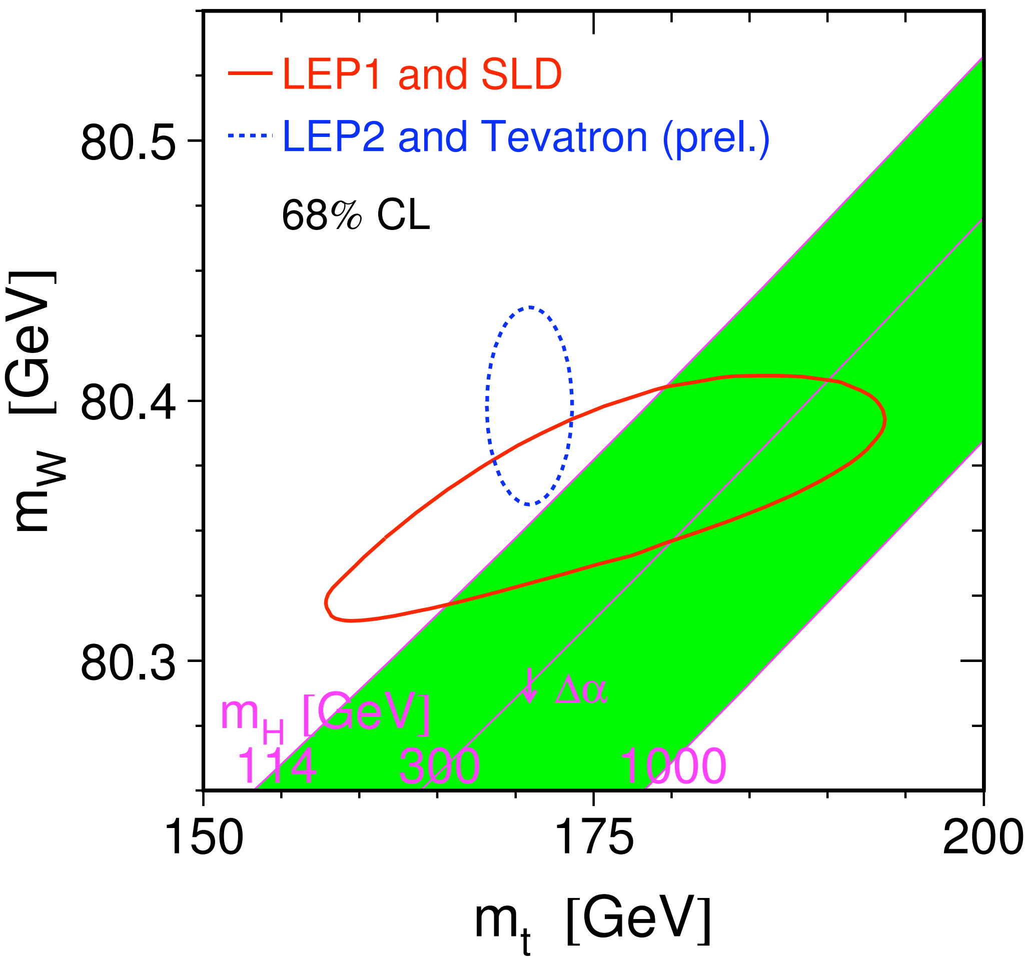
Top mass

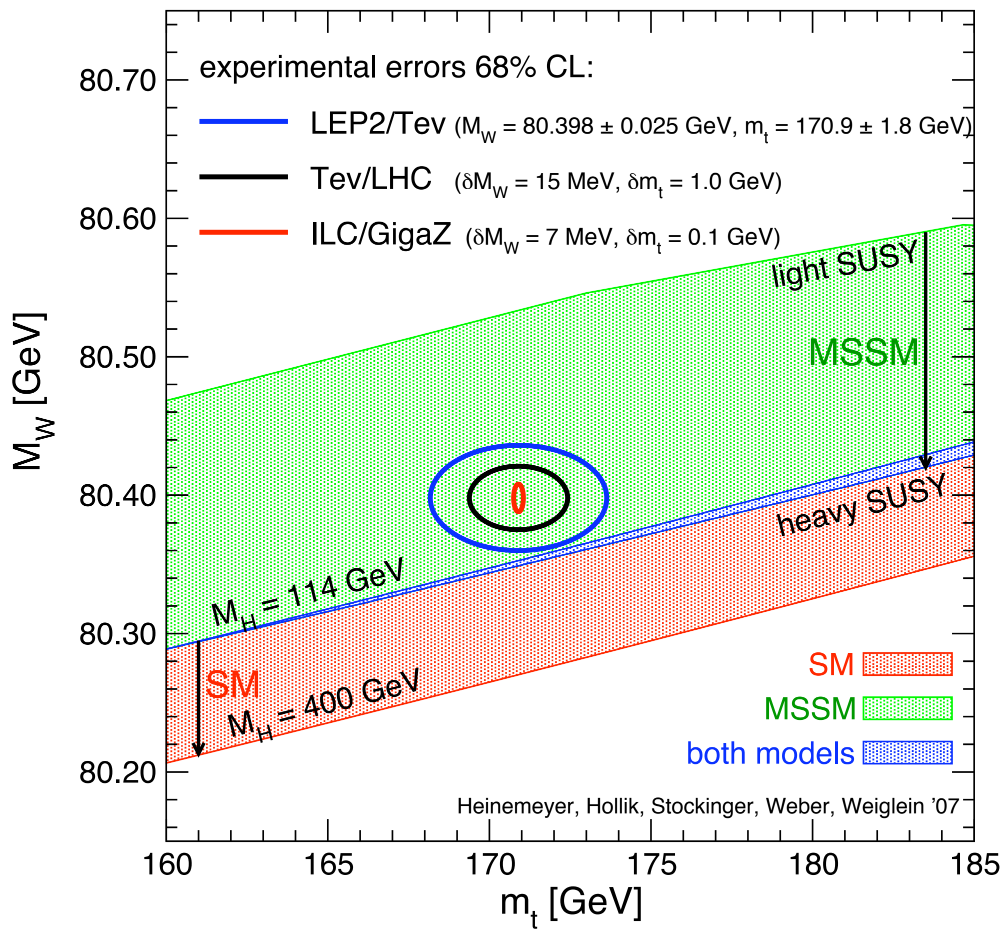


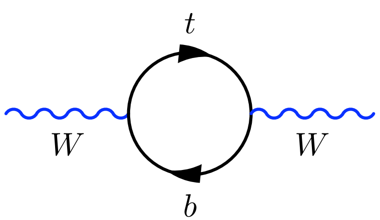
updated on 15/03/07

error is now at % level

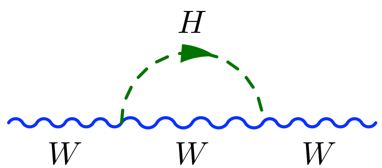
Effects on global EW fits







$\delta m_W \propto m_t^2$

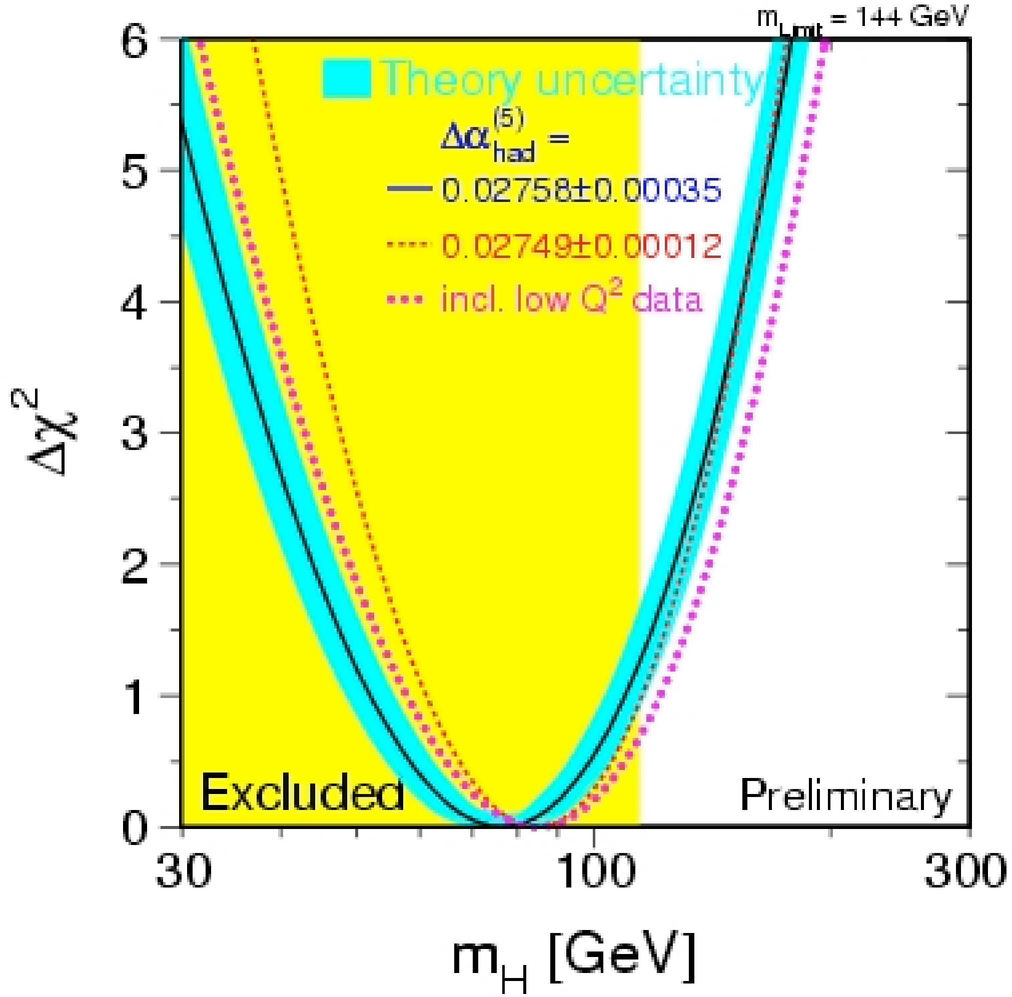


$\delta m_W \propto \ln m_H$

δm_t = 1 GeV $\Rightarrow$ $\delta m_W(m_t)$ = 6 MeV

if δm_W = 10-15 MeV
then δm_t = 1-2 GeV

Effects on Higgs mass



m_H > 114.1 GeV
from direct search at LEP

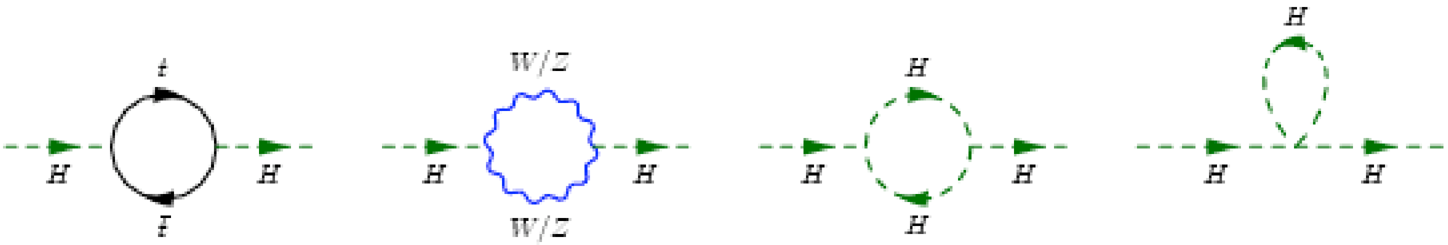
$m_H = 76^{+33}_{-24}$ GeV
from EW fits

m_H > 182 GeV
from EW fits combined with direct search at LEP

- use m_t to estimate m_H from EW corrections
- as m_t changes, large shifts in m_H

Hierarchy problem in the SM

the top affects sizeably the stability of m_H

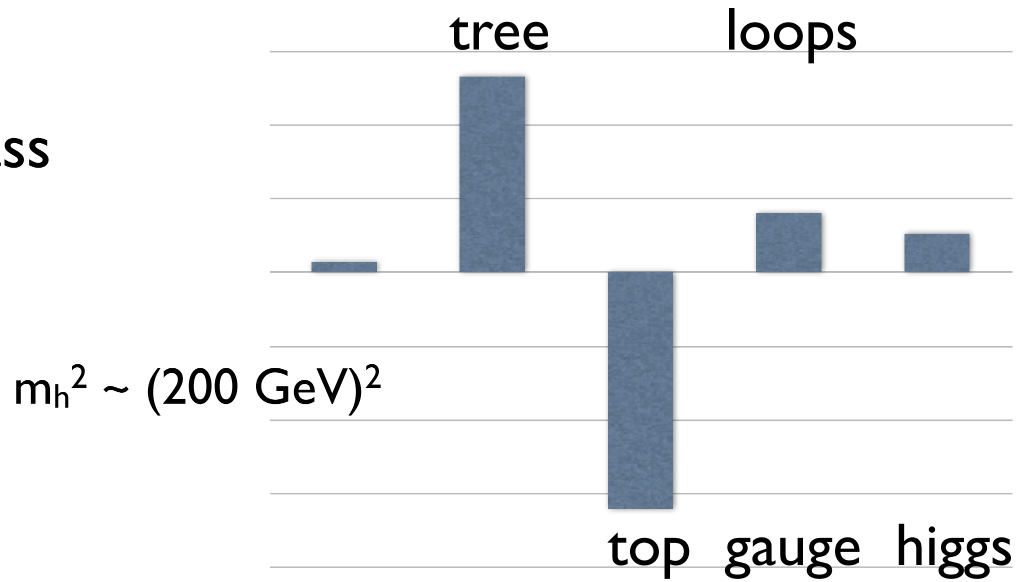


Higgs self-energy

$$\delta m_H^2 = \frac{3G_F}{4\sqrt{2}\pi^2}\left(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2\right)\Lambda^2$$

$$(200\,\mathrm{GeV})^2 = m_{H0}^2 + \left[(700\,\mathrm{GeV})^2 + (500\,\mathrm{GeV})^2 - (2\,\mathrm{TeV})^2\right]\left(\frac{\Lambda}{10\,\mathrm{TeV}}\right)^2$$

shift on the Higgs mass



Fine tuning and unnaturalness

Higgs self-energy

$$m_H^2(Q^2) - m_H^2(Q_0^2) = \frac{3G_F}{4\sqrt{2}\pi^2}(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2)(Q^2 - Q_0^2)$$

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because for $Q_0^2 = \mathcal{O}(\mathrm{v}^2)$ the Higgs mass is in the range of the EW data $m_H^2(Q_0^2) = \mathcal{O}(\mathrm{v}^2)$

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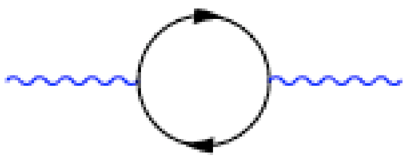
but for $Q_0^2 = \mathcal{O}(M_{Pl}^2)$ one must fine tune $m_H^2(M_{Pl}^2)$ to the level of $\mathrm{v}^2/M_{Pl}^2 \sim 10^{-33}$

for the cancellation to yield a figure of $\mathcal{O}(\mathrm{v}^2)$ $\Longrightarrow$ unnatural

Weakly coupled models at the TeV scale

Symmetry principles protect against power-like divergences



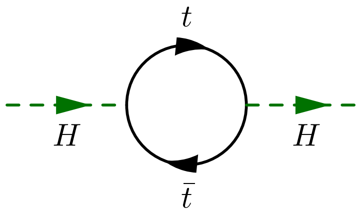
photon self-energy $\delta m_\gamma^2 \propto \cancel{\Lambda^2} + \; m_\gamma^2 \ln \Lambda$

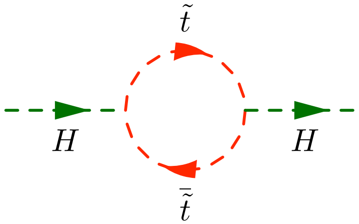
gauge symmetry protects against quadratic divergence

A *natural* solution to hierarchy: supersymmetry

postulate a new symmetry principle, which yields new particles that cancel the quadratic divergences of the Higgs self-energy, such that

$$\delta m_H^2 \sim \mathcal{O}(m_H^2) \ln \Lambda$$



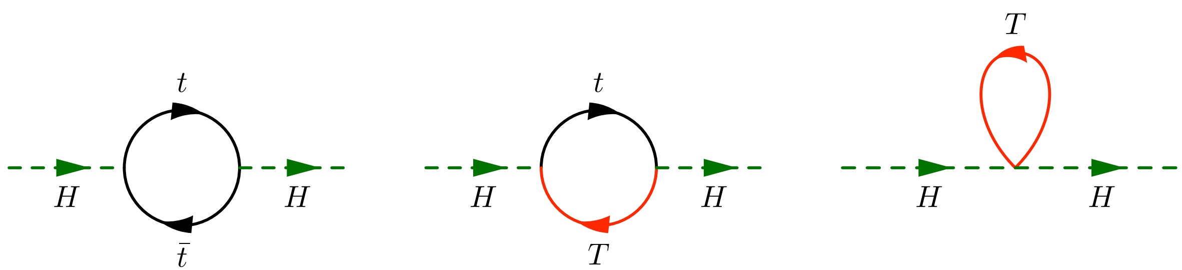


$$\delta m_H^2 \propto G_F \, m_t^4 \ln(m_t/m_{\tilde{t}})$$

Weakly coupled models at the TeV scale

Another solution to hierarchy: little Higgs models

- embed SM in a larger group
- Higgs field is a Goldstone boson from a global symmetry breaking
- cancel top loop with a heavy top-like quark, T



$$\frac{\Lambda}{16\pi^2}\left(+\lambda_t^2 \quad + \lambda_T^2 \quad - \frac{\lambda_T m_T}{f}\right) = 0$$

f symmetry-breaking scale of O(1 TeV)

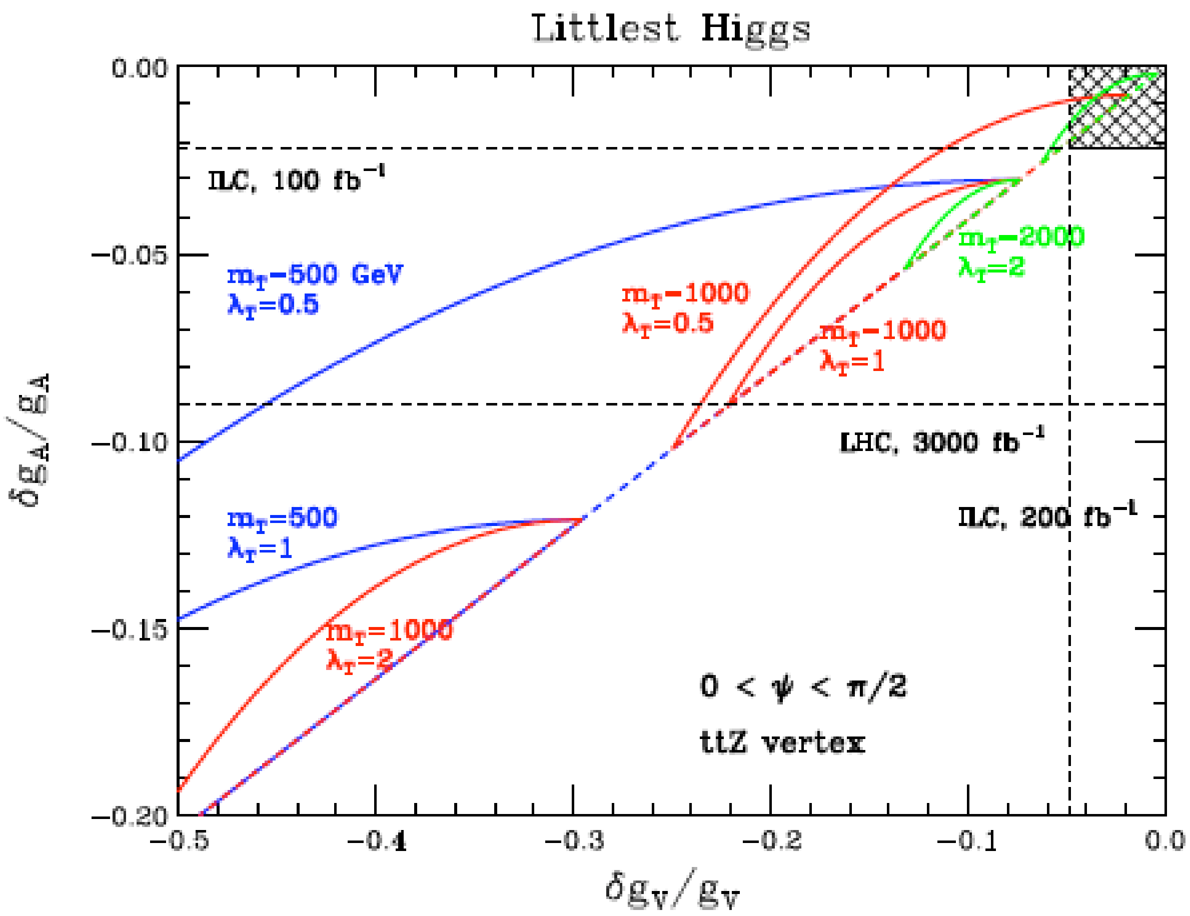
shift in Higgs mass $\quad \delta m_H^2 = \frac{6 G_F\, m_t^2}{\sqrt{2}\pi^2}\, m_T^2 \ln\frac{\Lambda}{m_T}$

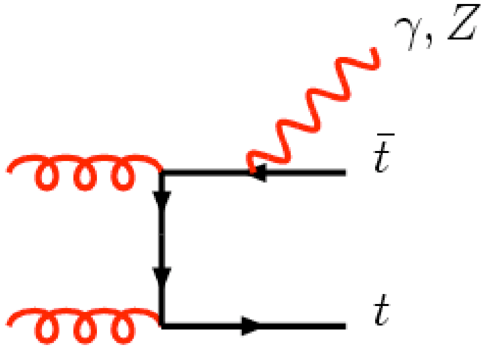
- EW precision measurements imply that m_T is large
  LHC can explore m_T up to 2 TeV, but huge statistics are required
- T ⇒ tH and tZ decays allowed

littlest Higgs

larger group: $SU(2) \otimes SU(2) \otimes U(1)$

new TeV-scale states for littlest Higgs:
vector-like weak-singlet quark T
gauge bosons $W_H^{\pm}$ W_H^3
weak-triplet scalar field ϕ





shifts in ttZ axial & vector couplings

ψ: $SU(2)$ weak mixing angle

t tbar as a background

- *tt* in $gg \Rightarrow H$ & $qq \Rightarrow qqH$, with $H \Rightarrow WW$
- *tt* in single top
- *tt jets* in *ttbb* & *ttH*
- *tt jets* & *ttW* in SUSY searches

*t*heory tools

- NLO + shower for *tt* production with spin correlations: MC@NLO
- NLO single-top production with spin correlations
- *tt + 1 jet* at NLO (almost done)
- *tt jets, ttQQ jets*: ME + shower in ALPGEN, MADEVENT, SHERPA

Top & flavour physics

$$|V_{\rm CKM}| = \begin{pmatrix} 0.9738 \pm 0.0005 & 0.2200 \pm 0.0026 & (3.67 \pm 0.47) \times 10^{-3} \\ 0.224 \pm 0.012 & 0.996 \pm 0.013 & (41.3 \pm 1.5) \times 10^{-3} \\ ? & ? & ? \end{pmatrix}$$

(assuming 3 generations) unitarity implies

$$|V_{td}| \simeq 0.0048 - 0.014, \quad |V_{ts}| \simeq 0.037 - 0.043, \quad |V_{tb}| \simeq 0.9990 - 0.9992$$

$$\mathcal{O}(\lambda^3) \qquad \mathcal{O}(\lambda^2) \qquad \mathcal{O}(1)$$

with $\lambda \cong 0.22$

CDF measurements on B_s mixing

$$\Delta M_s = 17.33^{+0.42}_{-0.21}(\text{stat.}) \pm 0.07(\text{syst.})\text{ps}^{-1}$$

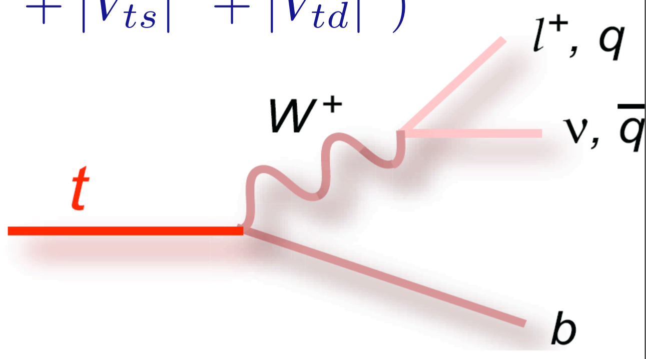
implies (in good agreement with SM predictions)

$$0.20 < |V_{td}/V_{ts}| < 0.22$$

Top & flavour physics at Tevatron

top can decay into a real W $\Gamma_t \sim G_F\, m_t^3\, (|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2)$

but only ratio of widths is measured

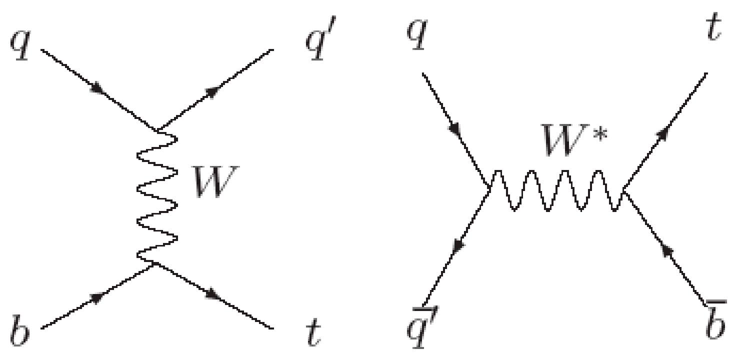


$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

$$\boxed{1.12^{+0.21}_{-0.19}(\text{stat})^{+0.17}_{-0.13}(\text{syst}),\ \text{CDF},\quad 1.03^{+0.19}_{-0.17}\ (\text{stat} + \text{syst}),\ \text{DØ}}$$

but this only entails that $|V_{ts}|/|V_{tb}|$ and $|V_{td}|/|V_{tb}|$ are small
it has no bearing on size of V_{tb}

Single Top & flavour physics at Tevatron



t channel

$$\sigma(pp \to tX) = |V_{tb}|^2\sigma_b + |V_{ts}|^2\sigma_s + |V_{td}|^2\sigma_d$$

s channel

$$\sigma(pp \to tX) = (|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2)\sigma^{s-\mathrm{channel}}$$

NLO: 1.85 pb 0.82 pb

from CDF talk at Moriond07

3 CDF analyses give different results:

matrix elements	neural networks	likelihood ratio
2.3 σ excess	no evidence	no evidence
σ (s+t) = $2.7^{+1.5}_{-1.3}$ pb	σ (s+t) < 2.6 pb	σ (s+t) < 2.7 pb
	σ (t) < 2.6 pb	
	σ (s) < 3.7 pb	

from D0 talk at Moriond07

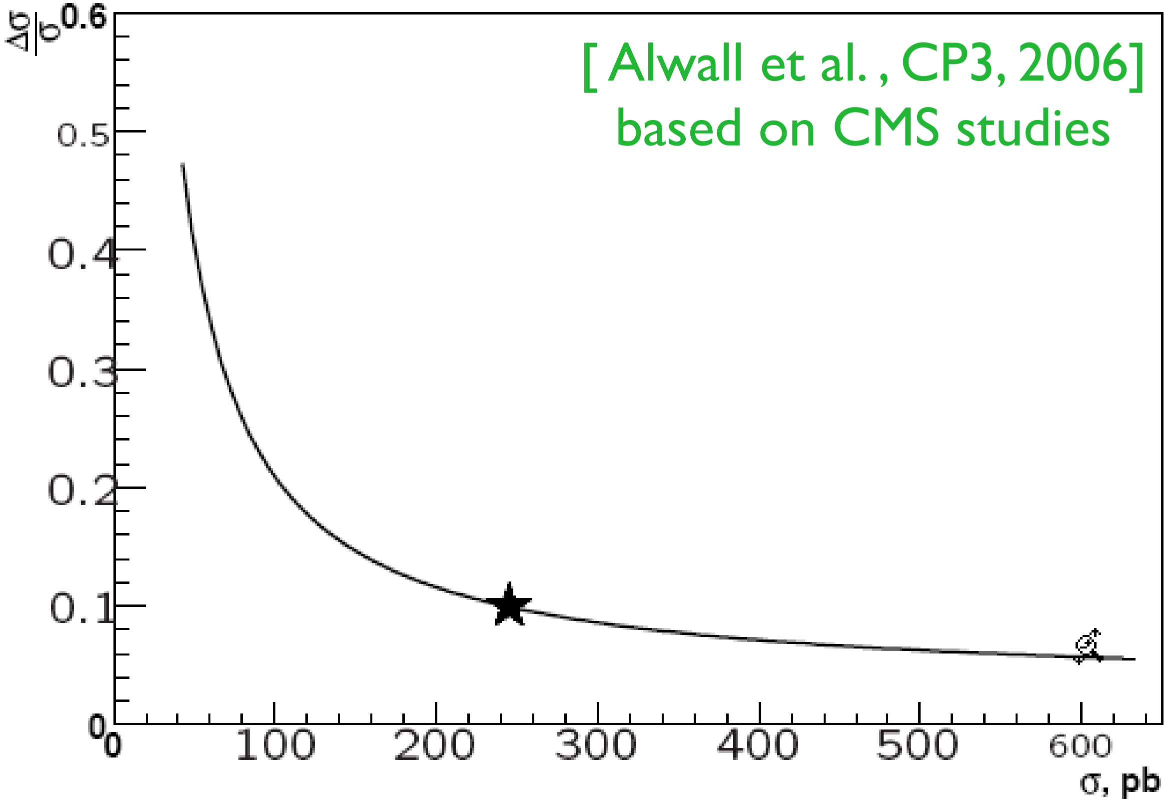
$\sigma(pp \to tbX, tqbX) = 4.8 \pm 1.3\ \mathrm{pb}$ with 3.5 σ significance

$0.68 \leq |V_{tb}| \leq 1$ at 95 % C.L. first direct measurement of V_{tb}

Single Top & flavour physics at LHC

NLO prediction for t+s channel $\sigma(pp \to tX) \simeq 250 \text{ pb}$

measurement of V_{tb} at LHC at 10 fb^{-1} inverse luminosity
is claimed to be feasible with 5% error



Conclusions

- top is one of best probes of EWSB and fermion masses
- measure top features (mass, spin, couplings) as well as possible to have hints on BSM physics
- common feature of BSM models is to have top partners
- EXP: Tevatron is doing a wonderful job, and lumi keeps growing
  LHC will be blessed by huge statistics
- TH: is steadily improving
  plethora of BSM models with top partners
  sophisticated MC models already available
  more NLO calculations are in progress