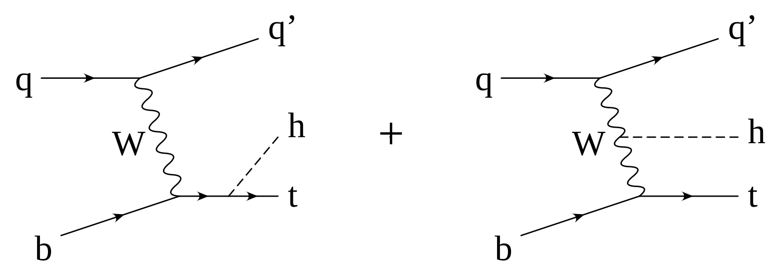
Single top plus Higgs production at the LHC



The future of the Higgs, FNAL, May $3^{\rm rd}$ 2001

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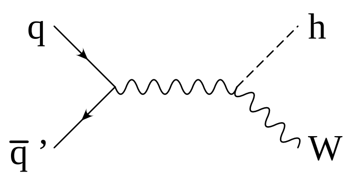
Outline

- Motivations
- Cross sections at hadron colliders
- t-channel production at the LHC
- Conclusions

The quest for an intermediate-mass Higgs at the LHC

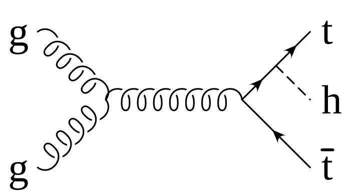
The outstanding discovery modes (see Zeppenfeld's talk):

- Wh and Zh with $h \to \gamma\gamma$:



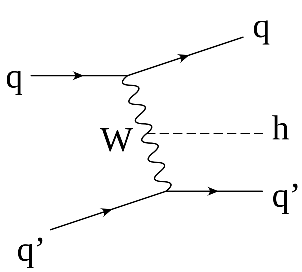
  - it depends on the coupling of the Higgs to vector bosons
  - even at high luminosity the significance is below 5σ

- $t\bar{t}h$ with $h \to \gamma\gamma$ and $h \to b\bar{b}$:



  - it depends on the coupling of the Higgs to the top
  - to reduce background both top quarks have to be fully reconstructed

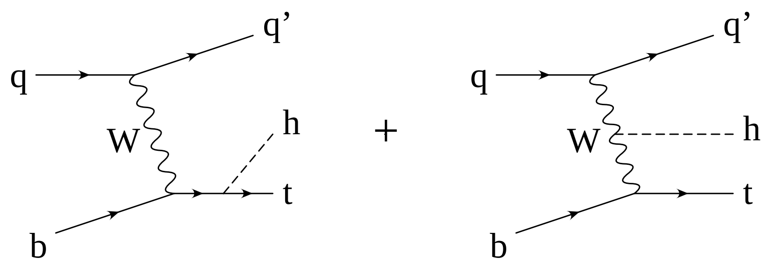
- $qq \to hqq$ with $h \to W^+W^-$:



  - it depends on the coupling of the Higgs to vector bosons
  - forward tagging jets are used to extract the signal from backgrounds

t-channel Production

Consider single top production in the t-channel (spacelike W boson) and add Higgs-strahlung from the W or from the top:



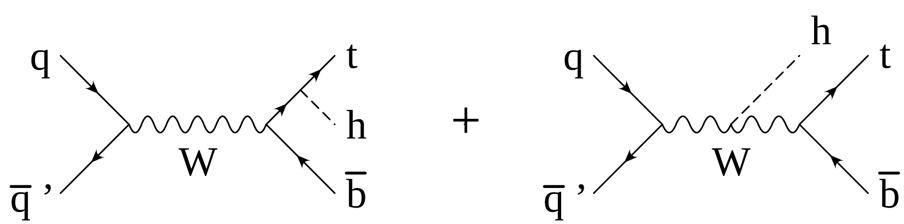
This process with the $h \to \gamma\gamma$ has been discussed by:
Diaz-Cruz and Sampayo (1992), Stirling and Summers (1992), Ballestrero and Maina (1993), Bordes and van Eijk (1993).

Interesting features:

- Shares similar dynamical features with single top production, such as a forward jet
- $\sigma(t) \simeq 1/3\,\sigma(t\bar{t}) \stackrel{?}{\Rightarrow} \sigma(th) \simeq 1/3\,\sigma(t\bar{t}h)$
- The Higgs couples to both the (spacelike) W and the top $\Rightarrow$ study the relative phase of the couplings

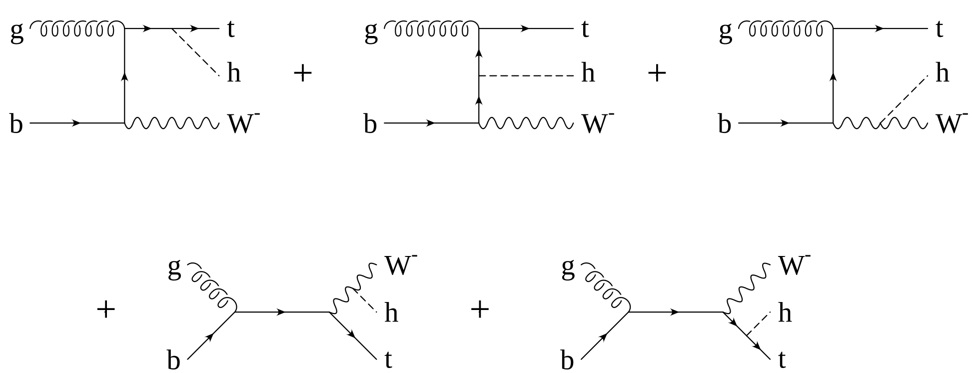
Other channels for single top + Higgs

The s-channel:



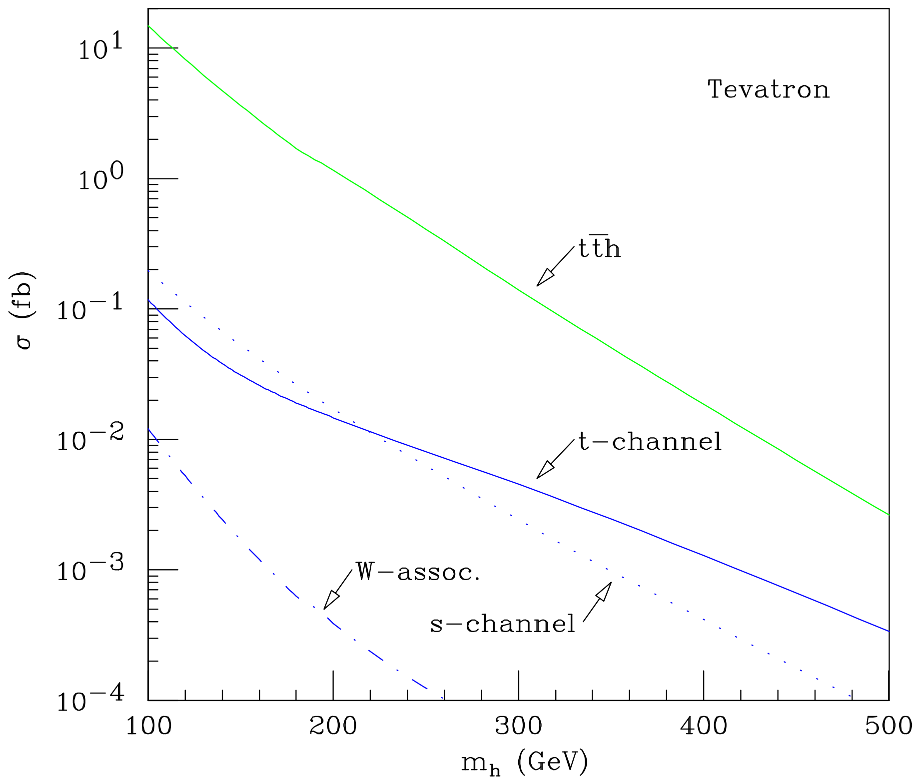
- Higgs couples to a timelike W boson ($q^2 > 0$)
- Cross section is small at pp colliders for single top only
- For an intermediate-mass Higgs, it gives the largest contribution at the Tevatron

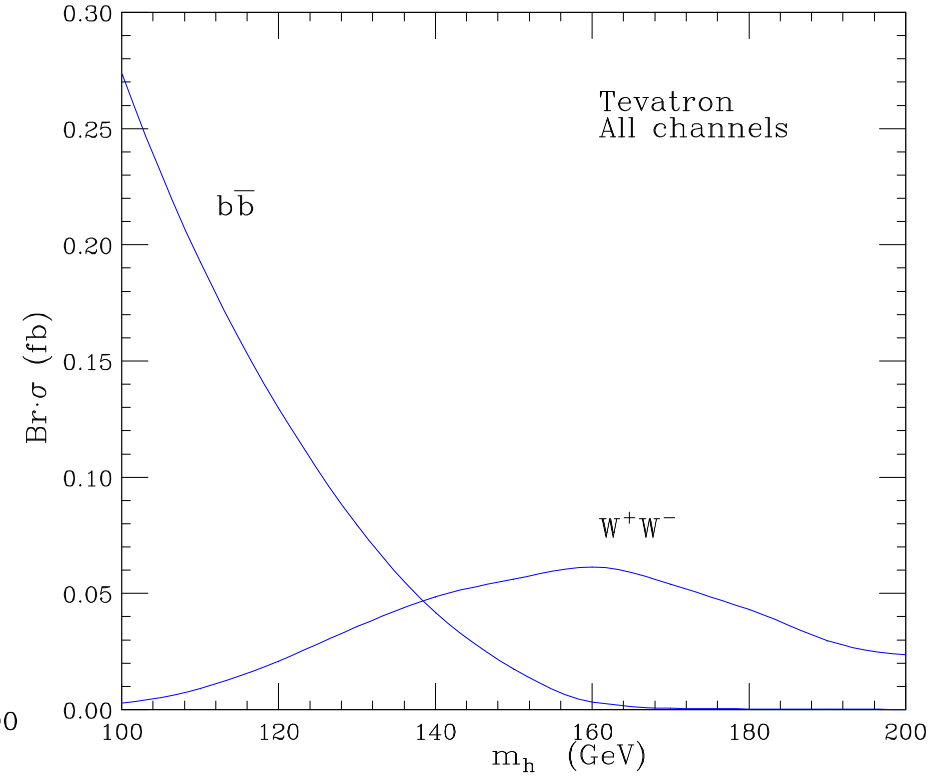
The W-associated channel:



- Higgs couples to an on-shell W boson ($q^2 = M_W$)
- Complicated final state
- Always smaller than the t-channel

Single Top + Higgs at the Tevatron

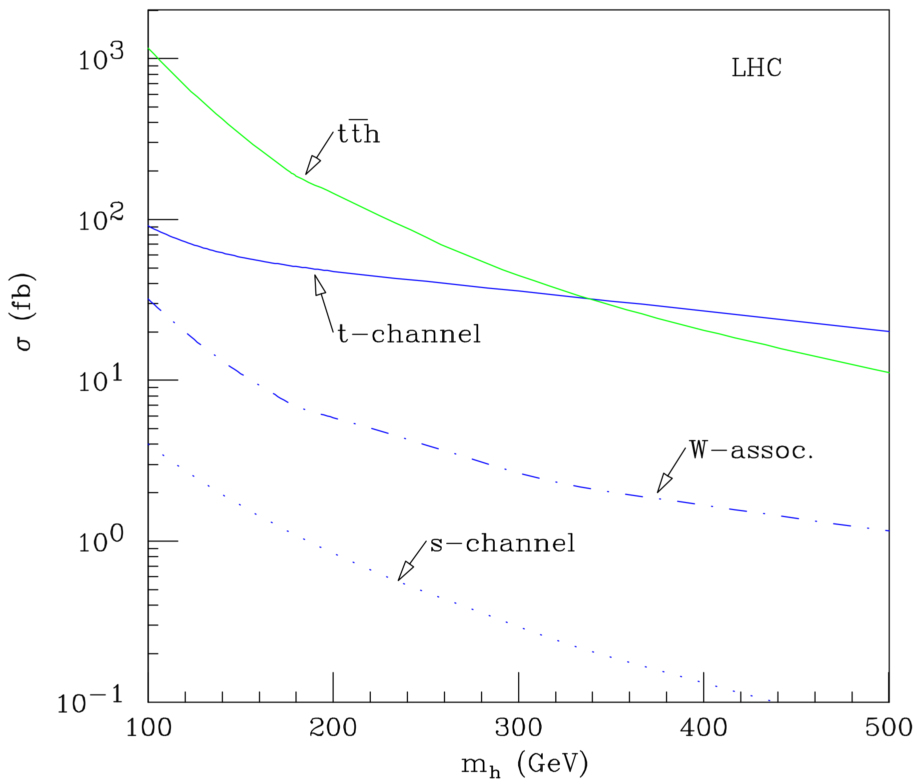


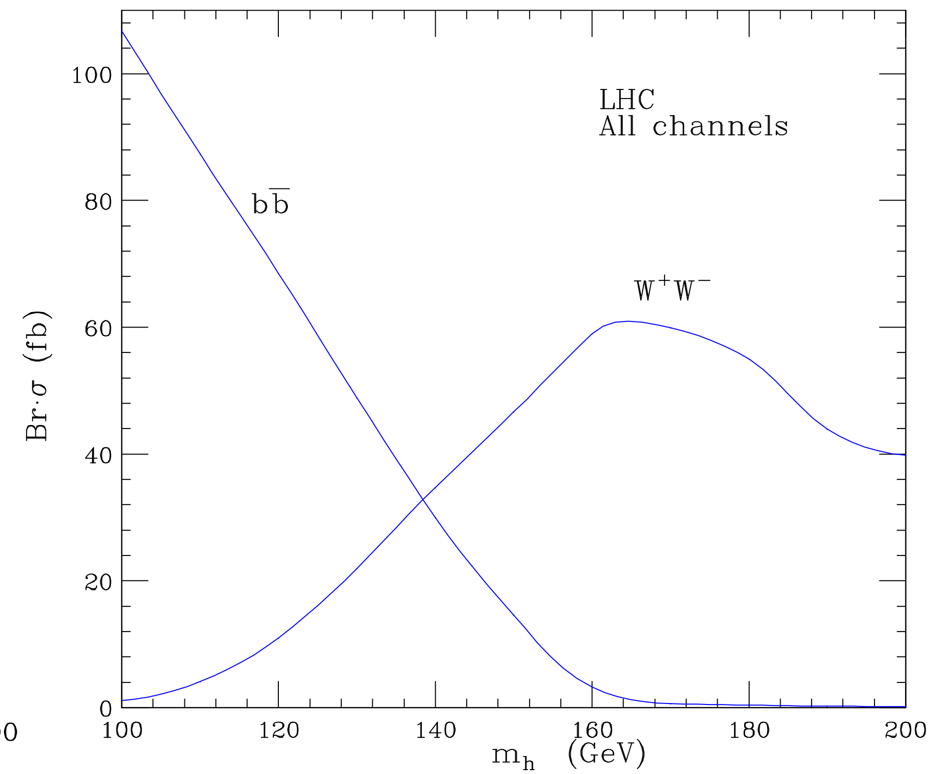


- $p\bar{p}$ @ $\sqrt{s} = 2$ TeV
- the s-channel is favoured (valence quarks and anti-quarks)
- s-channel cross section is around $1/50$ of $\sigma(t\bar{t}h)$ for $m_h = 115$ GeV

Conclusion : cross section far too small to have any events produced in Run II

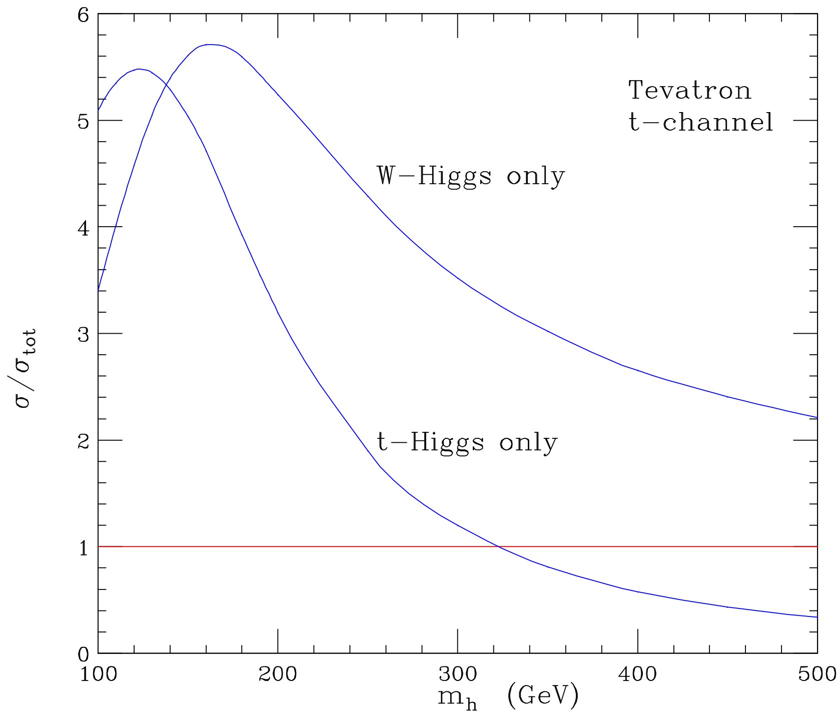
Single top + Higgs production at the LHC

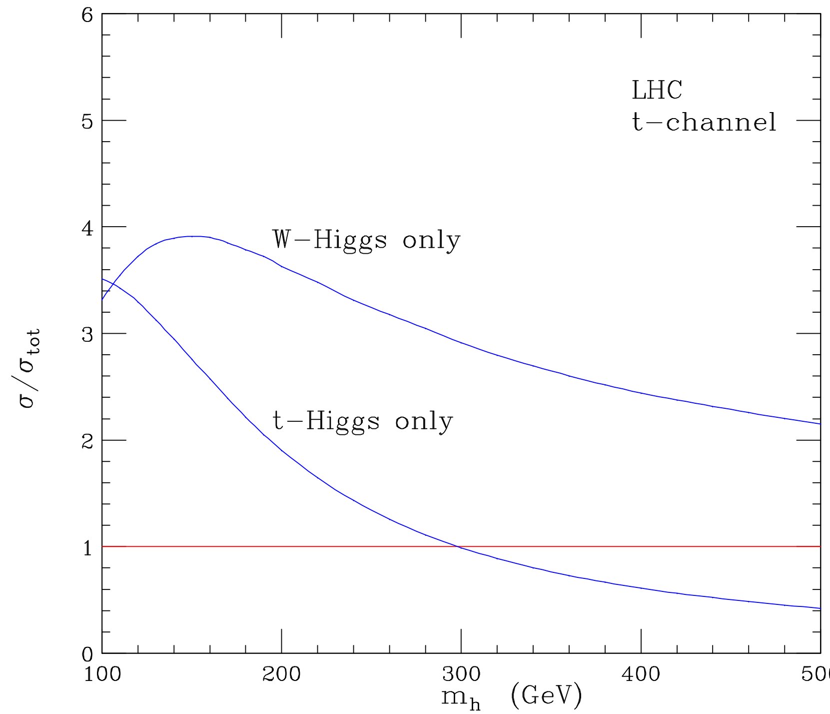


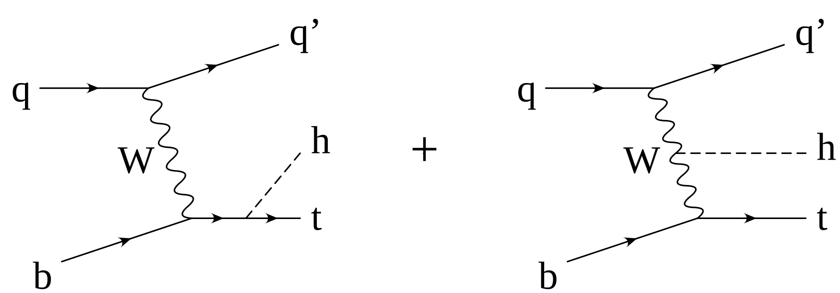


- pp @ $\sqrt{s} = 14$ TeV
- the t-channel gives the largest contribution, about one order of magnitude smaller than $t\bar{t}h$ (note the different fall off, though)
- for $m_h < 120$ GeV we expect a cross section of about 100 femtobarns
  $\Rightarrow$ no hope for $h \to \gamma\gamma$, but what about $h \to b\bar{b}$?

Interference in the t-channel



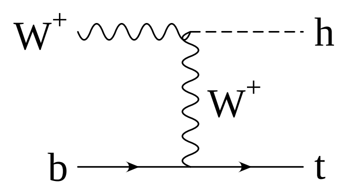


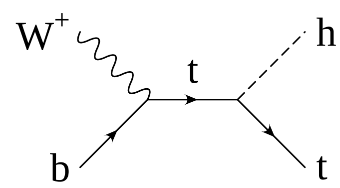


The interference is destructive and accounts for the smallness of the cross section

Unitarity cancellations in the t-channel

The largest contribution from the t-channel comes from the emission of longitudinal W's.
Using the effective-W approximation:





For $s \sim -t \sim -u \sim E^2 \gg m_h^2, m_W^2, m_t^2$, each of the two diagrams behaves like

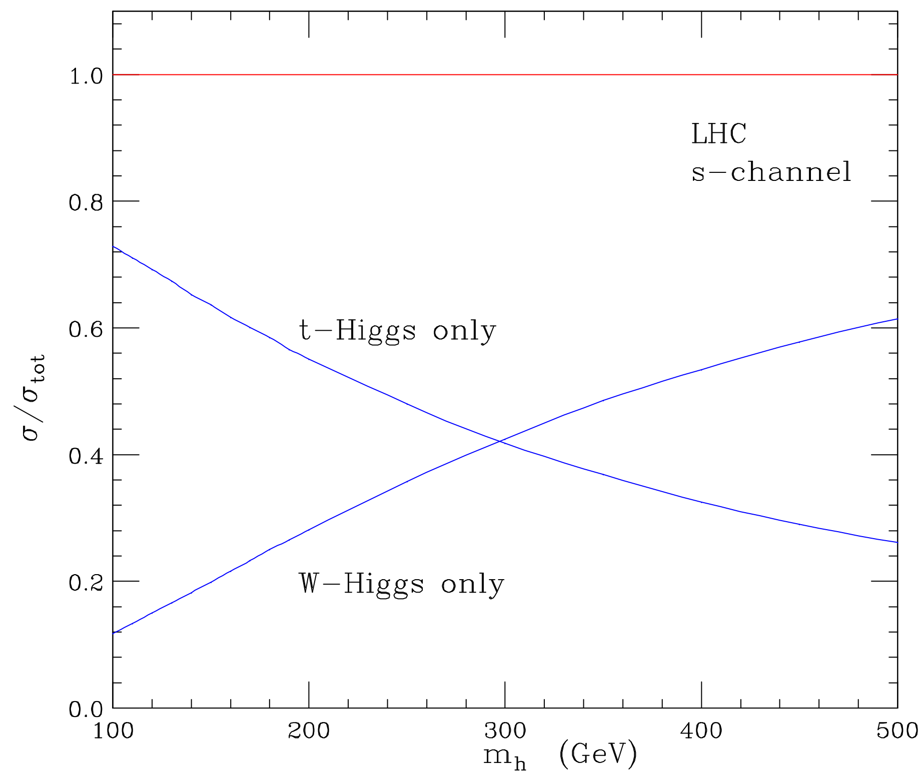
$$\mathcal{A} \sim g^2 \frac{m_t E}{m_W^2}$$

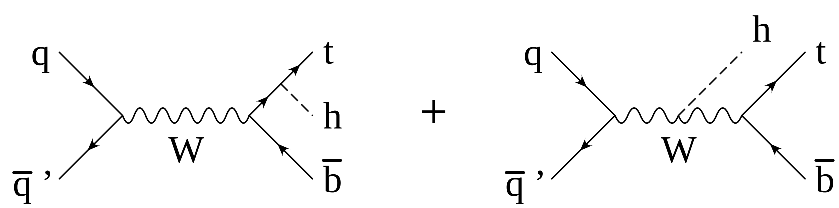
This entails a violation of unitarity at a scale $\Lambda \simeq m_W^2 / m_t g^2$.
The divergent terms cancel if the following relation between the Higgs couplings holds:

$$\frac{g_{W^- W^+ h}}{2} m_t + g_{t\bar{t}h} \, m_W = 0 \, .$$

True in the standard model!

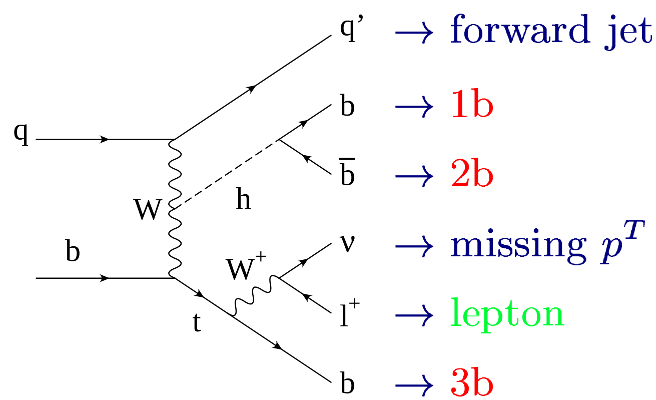
Interference in the s-channel





The interference is constructive. th production is suppressed by around 1/11 compared to $q\bar{q} \to t\bar{t}h$. Part of it ($\sim 1/3$) is due to p.d.f. effects, the rest ($\sim 1/4$) is due to the smallness of the Higgs coupling to the bottom.

t-channel production with $h \to b\bar{b}$ at the LHC



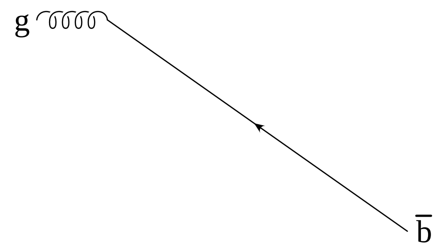
To simulate the detector acceptance we have used:

cut	$p_b^T >$	$p_{\ell,\nu}^T >$	$p_j^T >$	$\lvert\eta_{b,\ell}\rvert <$	$\lvert\eta_j\rvert <$	$\Delta R_{ij} >$	σ_{3b}
value	15 GeV	20 GeV	30 GeV	2.5	5	0.4	4.7 fb

Cuts applied to the t-channel signal, for $m_h = 115$ GeV.

Branching ratios $\mathrm{Br}(h \to b\bar{b})$ as well as $\mathrm{Br}(W \to \ell\nu)$ are included.

Detector efficiences are not included.

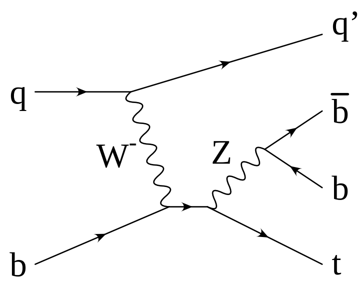


$\rightarrow$ 4b

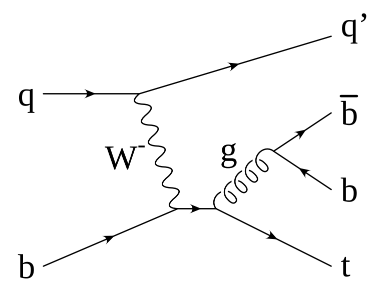
σ_{4b}

2.1 fb

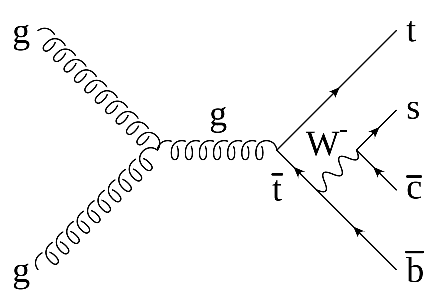
Signal vs. Backgrounds with 3 b-tags



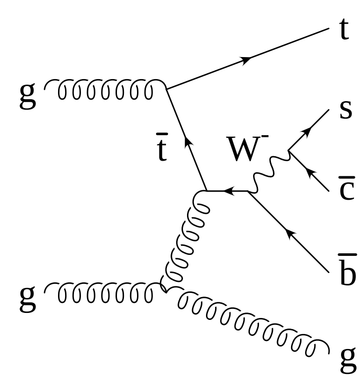
tZ : irreducible bkg



$tb\bar{b}$: irreducible bkg



$t\bar{t}$: reducible bkg

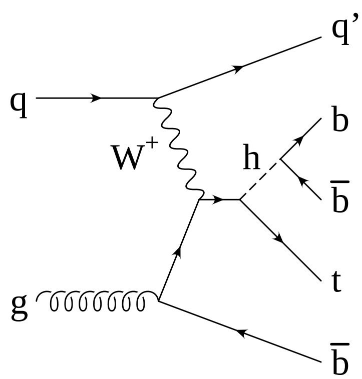


$t\bar{t}j$: reducible bkg

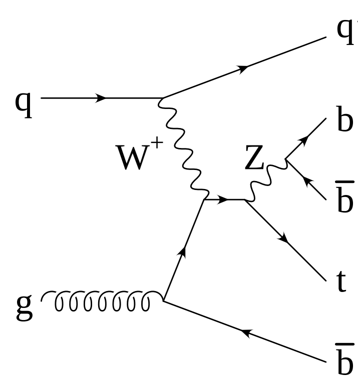
	values in femtobarns				
	Signal	tZ	$tb\bar{b}$	$t\bar{t}$	$t\bar{t}j$
Detector cuts	4.7	12	26	$3.3 \cdot 10^3$	350
$\lvert m_{b\bar{b}} - m_h \rvert < 22$ GeV	4.0	4.8	12	$2.3 \cdot 10^3$	220
$\lvert \eta_j \rvert > 2, p_j^T > 50$ GeV	2.1	2.6	4.7	100	50
Events with 30 fb^{-1}	12	15	27	970	500

The probability ($\epsilon_c = 10\%$) of mistagging a c-quark as a b-quark is included in the $t\bar{t}$ and $t\bar{t}j$ cross sections. In the number of events expected the b-tagging and lepton-tagging efficiencies are included ($\epsilon_b = 60\%, \epsilon_\ell = 10\%$). The s-quark jet is missed ($p^T < 15$ GeV) in the $t\bar{t}j$ background.

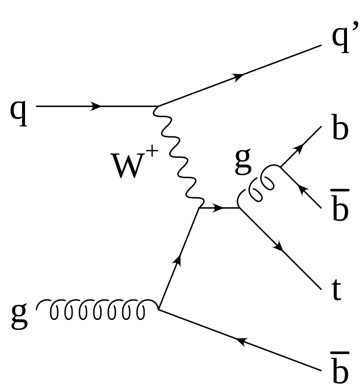
Signal vs. Backgrounds with 4 b-tags



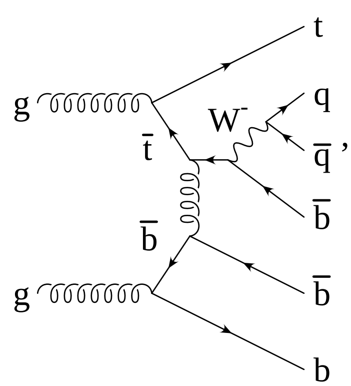
th : Signal



tZ : irreducible bkg



$tb\bar{b}$: irreducible bkg

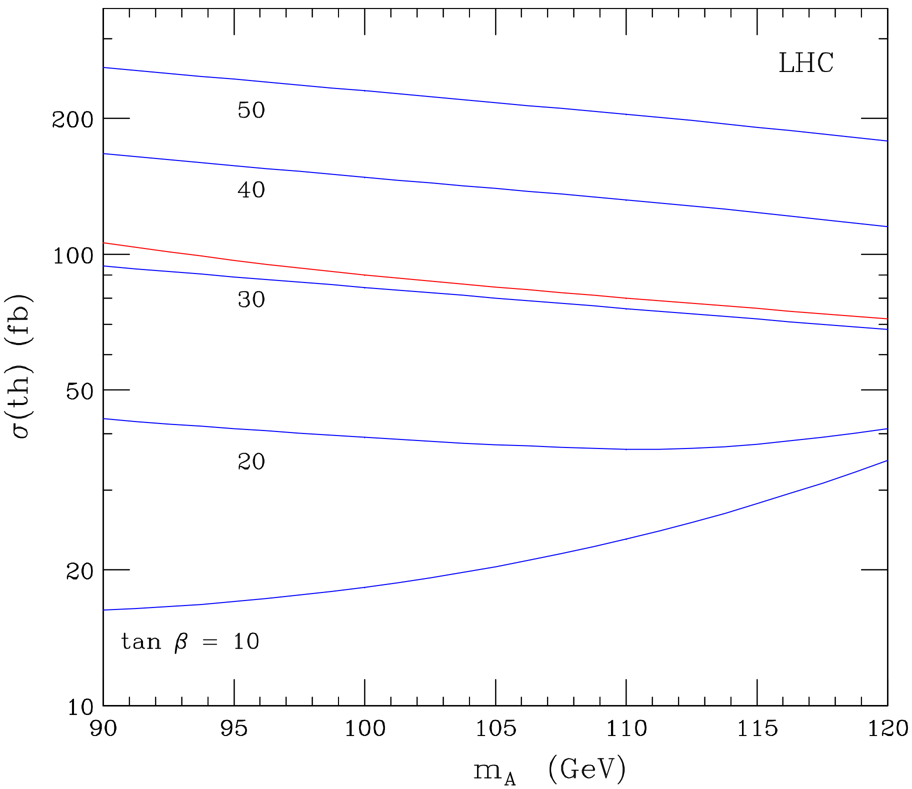


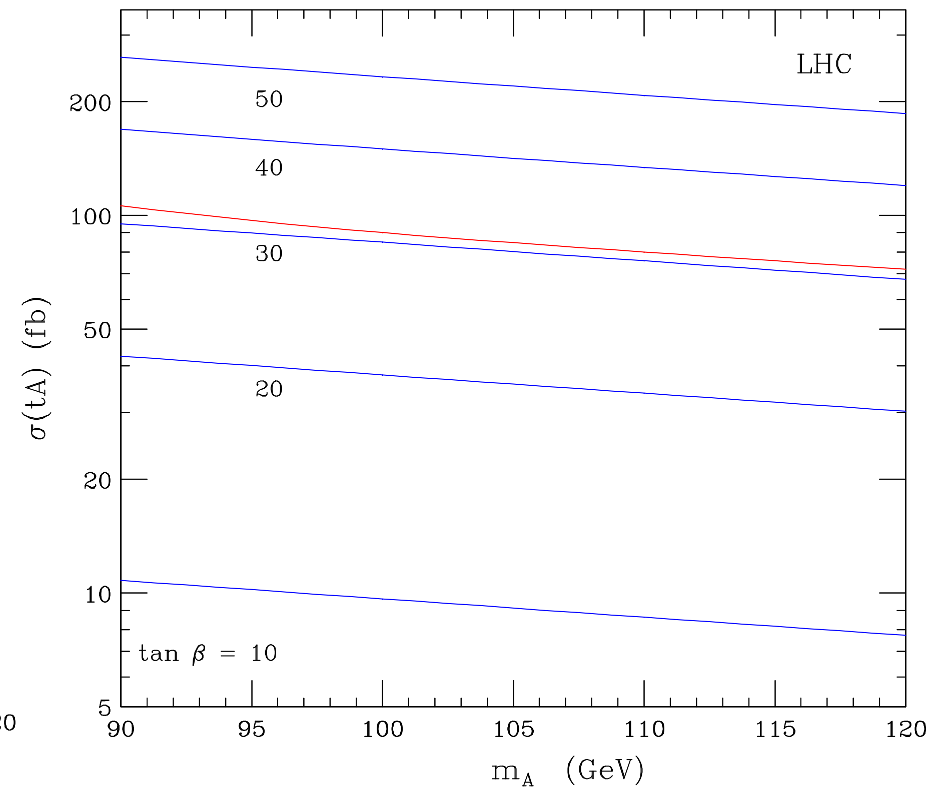
$tb\bar{b}$: reducible bkg

	values in femtobarns			
	Signal	tZ	$tb\bar{b}$	$t\bar{t}b\bar{b}$
Detector cuts	2.1	4.3	15	63
$\lvert m_{b\bar{b}} - m_h \rvert < 22$ GeV	1.8	1.7	10	45
$\lvert \eta_j \rvert > 2, p_j^T > 50$ GeV	0.94	0.95	4.7	2.8
Events with 30 fb^{-1}	3.2	3.2	18	11

In the number of events expected the b-tagging and lepton-tagging efficiencies are included ($\epsilon_b = 60\%, \epsilon_\ell = 10\%$). One jet is missed ($p^T < 15$ GeV) in the $t\bar{t}b\bar{b}$ background.

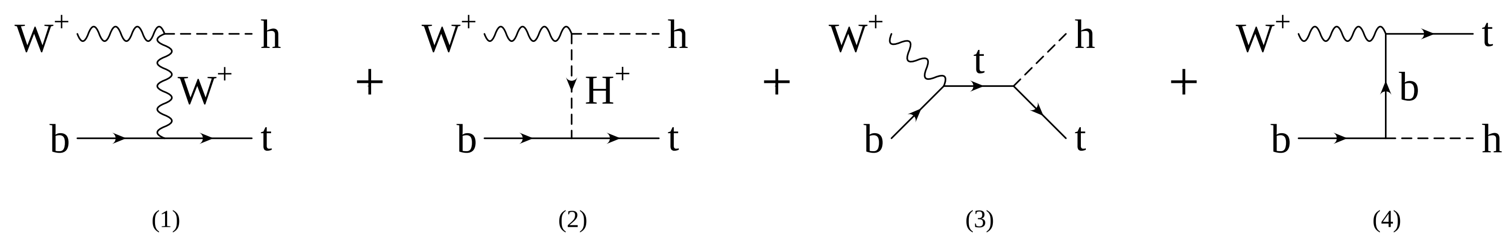
Single Top + SUSY Higgs production at the LHC





- $M_{\rm SUSY} = 1$ TeV, maximal stop mixing.
- The red line is the cross section for a standard model Higgs.
- The enhancement of the cross section is modest:
  for $m_h = m_A = 115$ GeV and $\tan\beta \simeq 50 \Rightarrow \sigma(th) + \sigma(tA) = 5\,\sigma(th_{\rm SM})$

Unitarity cancellations in the t-channel in the 2HDM (type II)



For $s \sim -t \sim -u \sim E^2 \gg m_h^2, m_{H^+}, m_W^2, m_t^2$, each diagram behaves like

$$\mathcal{A}_i \sim g^2 \frac{m_f E}{m_W^2}, \qquad \text{with} \qquad f = t, b.$$

This entails a violation of unitarity at a scale $\Lambda \simeq m_W^2/m_f g^2$. The divergent terms cancel if the following relations hold true:

$$\begin{aligned} \frac{g_{W-W+h}}{2}\, m_b + g_{W-H+h} \tan\beta\, m_b + g_{b\bar{b}h}\, m_W &= 0\,, \\ -\frac{g_{W-W+h}}{2}\, m_t + g_{W-H+h} \cot\beta\, m_t - g_{t\bar{t}h}\, m_W &= 0\,. \end{aligned} \quad \Leftarrow \quad \begin{aligned} g_{W-W+h} &= g\ \sin(\beta-\alpha)\,, \\ g_{W-H+h} &= -\frac{g}{2}\cos(\beta-\alpha)\,, \\ g_{t\bar{t}h} &= -\frac{g m_t}{2m_W}\,\frac{\cos\alpha}{\sin\beta}\,, \\ g_{b\bar{b}h} &= \frac{g m_b}{2m_W}\,\frac{\sin\alpha}{\cos\beta}\,. \end{aligned}$$

True in the 2HDM also!

Summary

- We have presented the cross sections for production of single top in association with a Higgs at hadron colliders.
- The cross sections are smaller than one would expect from comparison with $t\bar{t}$ and $t\bar{t}h$.
- For the leading contribution, the t-channel production, this is due to unitarity $\Rightarrow$ the same holds in more general Higgs sectors.
- t-channel production with the Higgs decaying into $b\bar{b}$, gives a fair amount of signal events at the LHC, but backgrounds from $t\bar{t}$+jets are at least one order of magnitude larger.
- Moderate enhancements of the signal are found for large $\tan\beta$ and $m_A < 120$ GeV in the SUSY Higgs sector.
- Is single top plus Higgs production doomed to never be detected?