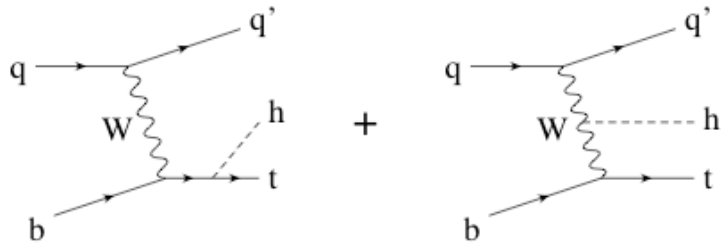
Single-top + Higgs



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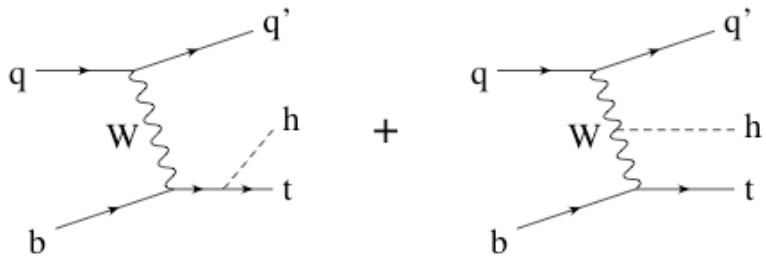
Outline

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

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:



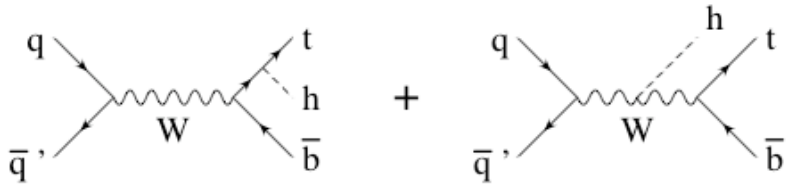
This process with the $h \to \gamma\gamma$ has been discussed by:
Diaz-Cruz and Sampayo (1992), Stirling and Summers (1992),
Ballestrero and Maina (1993), Bordes and van Eijk (1993).

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

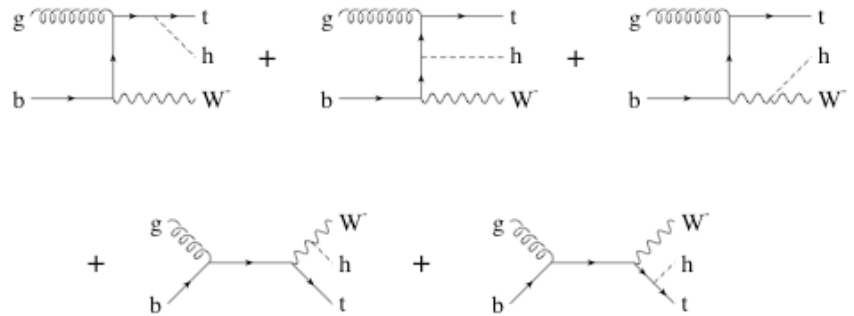
Other channels for single top + Higgs

The s-channel:



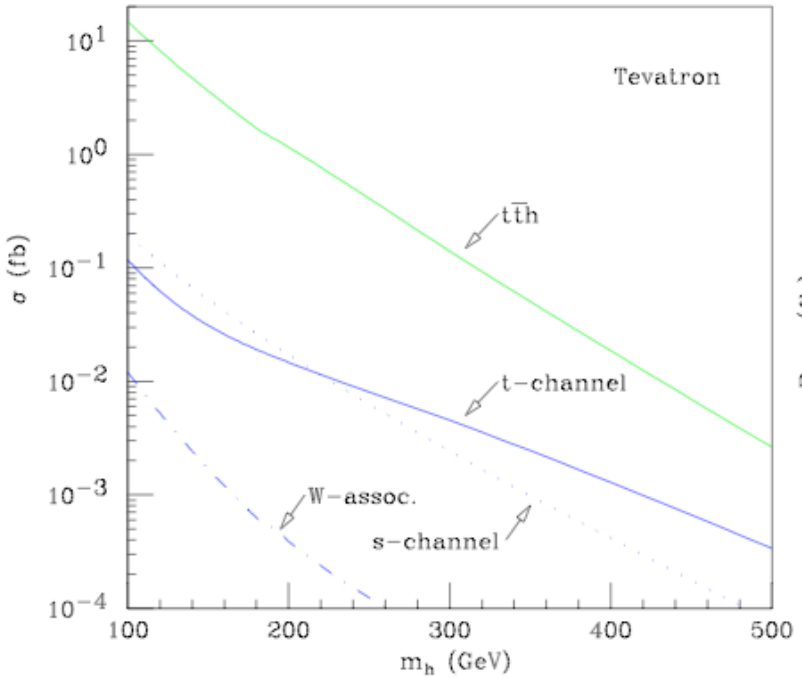
- Higgs couples to a timelike W boson ($q^2 > 0$)
- Cross section is small at pp colliders for single top only
- For an intermediate-mass Higgs, it gives the largest contribution at the Tevatron

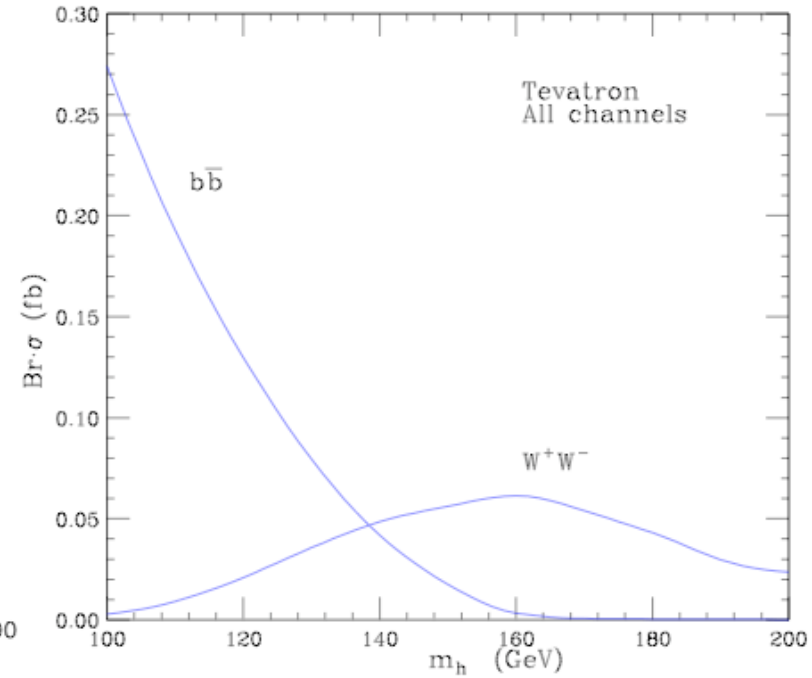
The W-associated channel:



- 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

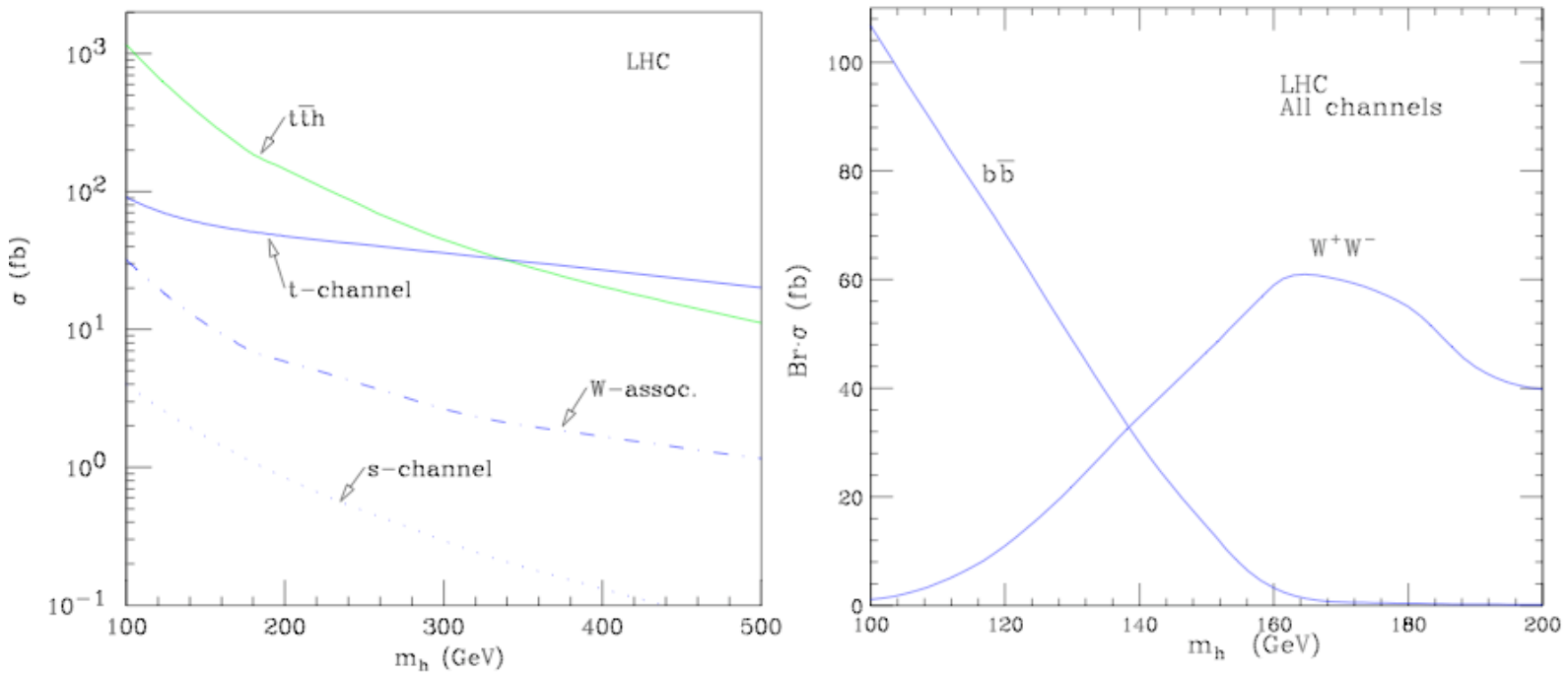




- $p\bar{p}$ @ $\sqrt{s} = 2$ TeV
- the s-channel is favoured (valence quarks and anti-quarks)
- s-channel cross section is around 1/50 of $\sigma(t\bar{t}h)$ for $m_h = 115$ GeV

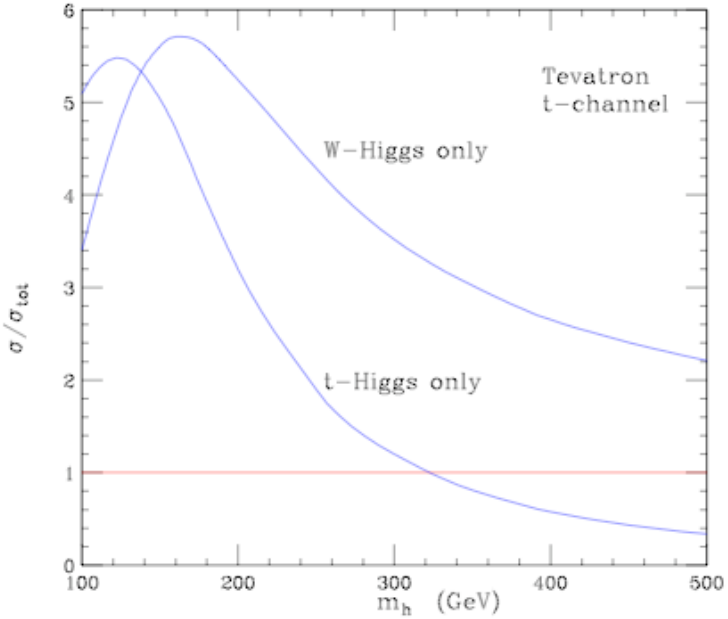
Conclusion : cross section far too small to have any events produced in Run II

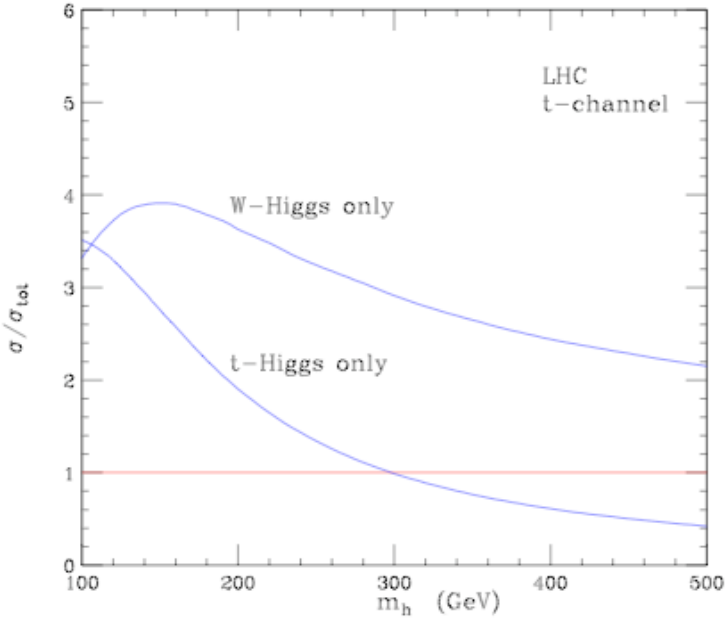
Single top + Higgs production at the LHC

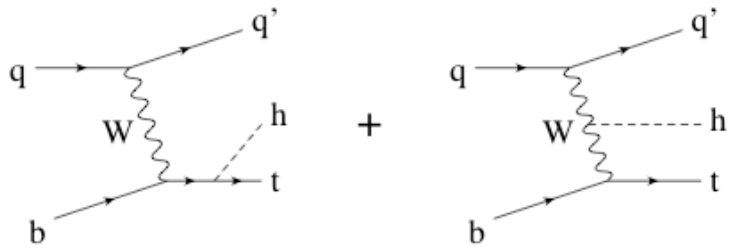


- pp @ $\sqrt{s} = 14$ TeV
- the t-channel gives the largest contribution, about one order of magnitude smaller than $t\bar{t}h$ (note the different fall off, though)
- for $m_h < 120$ GeV we expect a cross section of about 100 femtobarns
  $\Rightarrow$ no hope for $h \to \gamma\gamma$, but what about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

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:

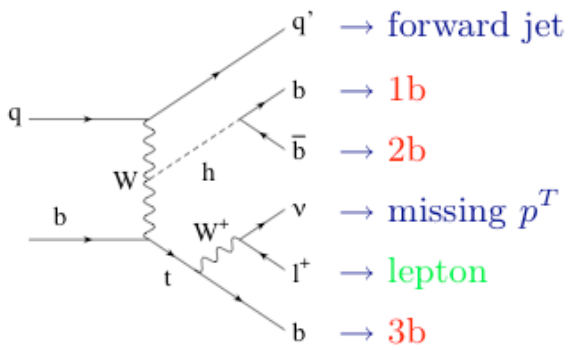
For $s \sim -t \sim -u \sim E^2 \gg m_h^2, m_W^2, m_t^2$, each of the two diagrams behaves like

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

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:

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

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



To simulate the detector acceptance we have used:

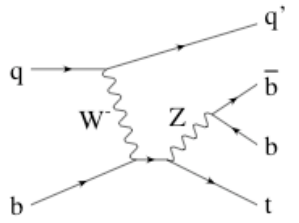
cut	$p_b^T >$	$p_{\ell,\nu}^T >$	$p_j^T >$	$\lvert\eta_{b,\ell}\rvert <$	$\lvert\eta_j\rvert <$	$\Delta R_{ij} >$	σ_{3b}
value	15 GeV	20 GeV	30 GeV	2.5	5	0.4	4.0 fb

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

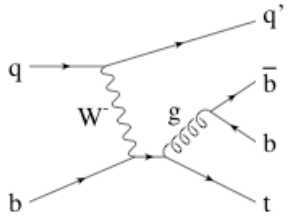
Branching ratios $\mathrm{Br}(h \to b\bar{b})$ as well as $\mathrm{Br}(W \to \ell\nu)$ are included.

Detector efficiences are not included.

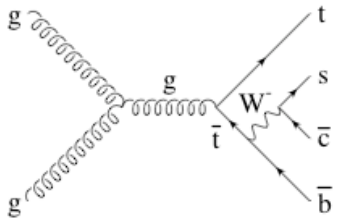
3 b's



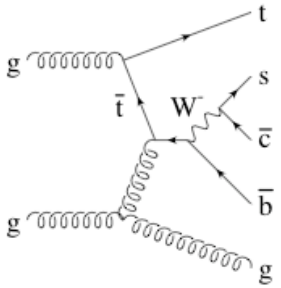
tZ : irreducible bkg



$tb\bar{b}$: irreducible bkg



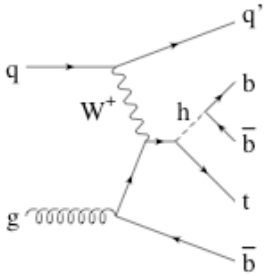
$t\bar{t}$: reducible bkg



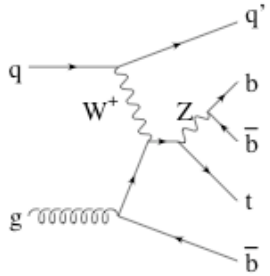
$t\bar{t}j$: reducible bkg

	$3b$-tag (low luminosity)				
	Signal	tZ	$tb\bar{b}$	$t\bar{t}$	$t\bar{t}j$
Detector cuts	0.80	2.1	4.1	810	100
$\lvert m_{b\bar{b}} - m_h \rvert < 22$ GeV	0.75	0.83	0.54	450	38
$\lvert\eta_j\rvert > 2, p_j^T > 50$ GeV	0.39	0.44	0.26	13	8.0
$m_{b\bar{b}j} > 250$ GeV	0.35	0.35	0.25	-	7.4
Events with 30 fb^{-1}	10	10	7	-	220

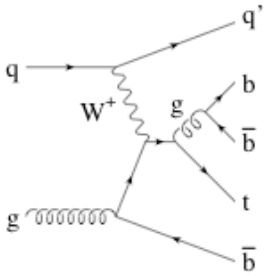
4 b's



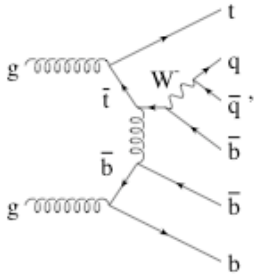
th : Signal



tZ : irreducible bkg



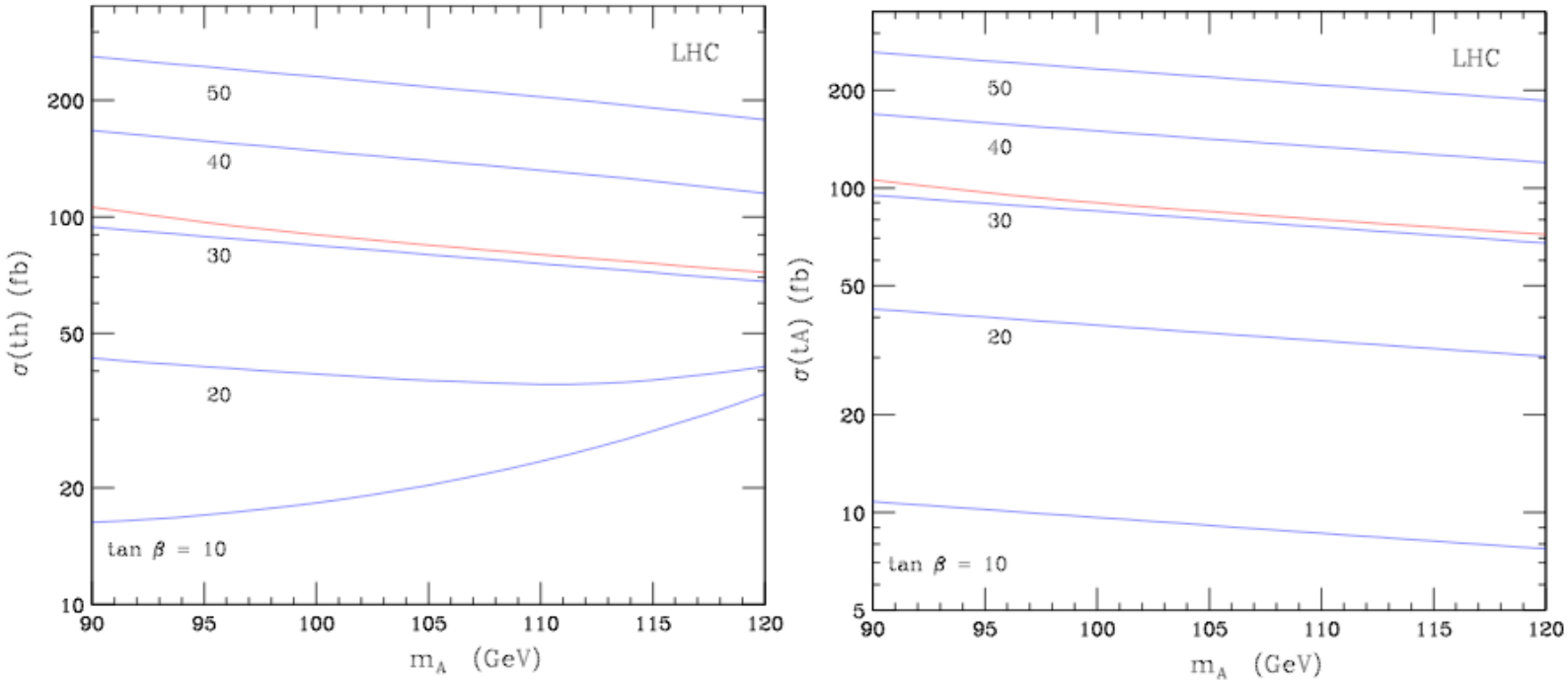
$tb\bar{b}$: irreducible bkg



$tb\bar{b}$: reducible bkg

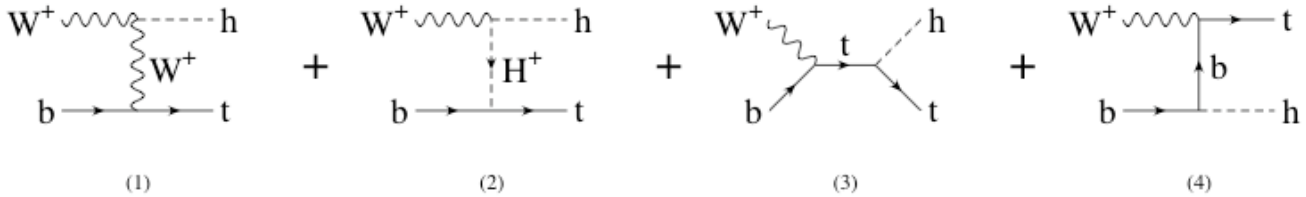
	4b-tag (low luminosity)					
	Signal	$tZ(b)$	$tb\bar{b}(b)$	$t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$ (mistag)	$t\bar{t}j$
Detector cuts	0.22	0.42	1.5	5.8	3.1	9.0
$\lvert m_{b\bar{b}} - m_h \rvert < 22$ GeV	0.21	0.17	0.61	2.6	2.3	6.3
$\lvert \eta_j \rvert > 2$	0.15	0.11	0.41	0.17	0.18	2.4
min $m_{b\bar{b}} > 90$ GeV	0.1	0.065	0.08	0.053	0.078	-
Events with 30 fb^{-1}	3.0	1.9	2.5	1.6	2.3	-

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:

$$\frac{g_{W-W+h}}{2} m_b + g_{W-H+h} \tan\beta \, m_b + g_{b\bar{b}h} \, m_W = 0\,,$$
$$-\frac{g_{W-W+h}}{2} m_t + g_{W-H+h} \cot\beta \, m_t - g_{t\bar{t}h} \, m_W = 0\,.$$

$$\Leftarrow$$

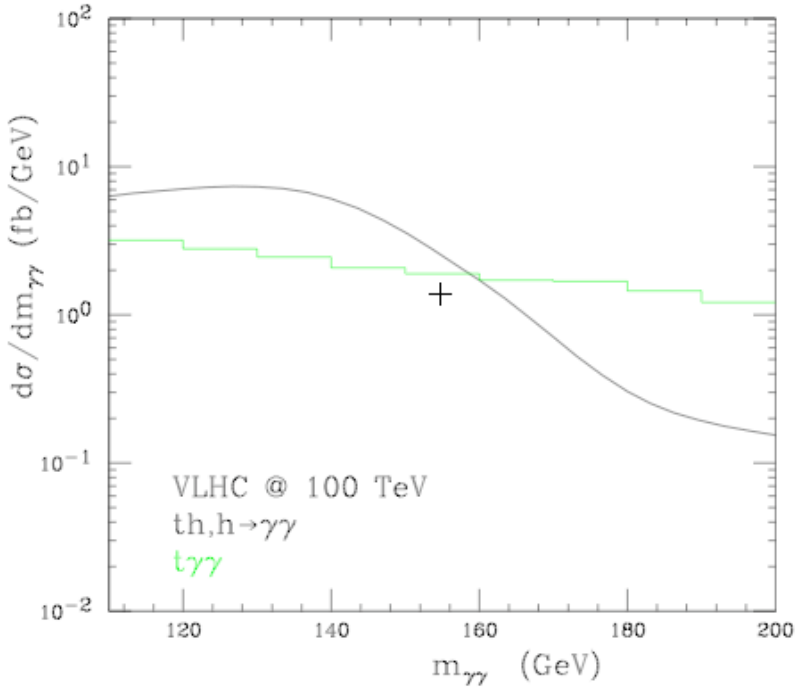
$$g_{W-W+h} = g \, \sin(\beta-\alpha)\,,$$
$$g_{W-H+h} = -\frac{g}{2}\cos(\beta-\alpha)\,,$$
$$g_{t\bar{t}h} = -\frac{g m_t}{2 m_W}\frac{\cos\alpha}{\sin\beta}\,,$$
$$g_{b\bar{b}h} = \frac{g m_b}{2 m_W}\frac{\sin\alpha}{\cos\beta}\,.$$

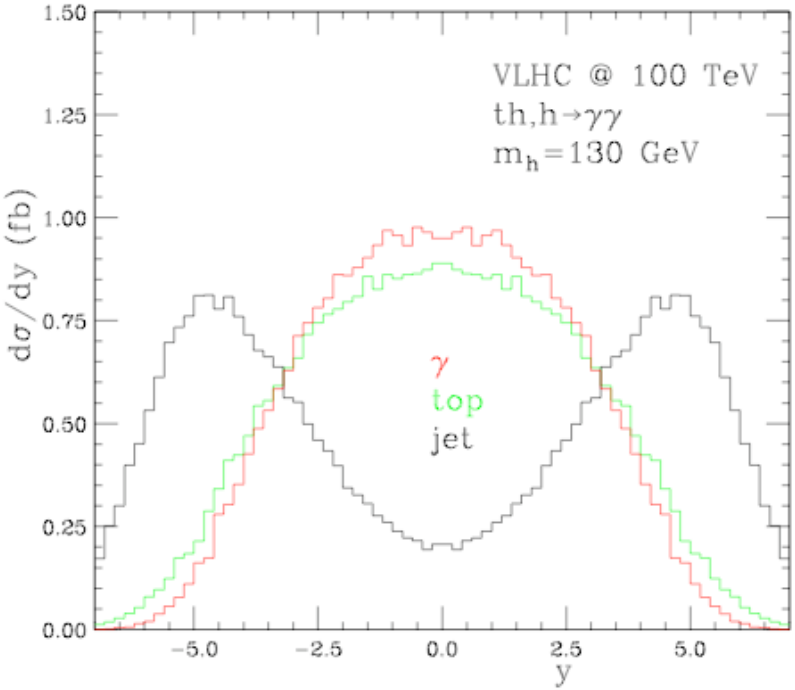
True in the 2HDM also!

Summary

- We have presented the cross sections for production of single top in association with a Higgs at hadron colliders.
- For a light Higgs, 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 are severe.
- Moderate enhancements of the signal are found for large $\tan\beta$ and $m_A < 120$ GeV in the SUSY Higgs sector.
- Preliminaries studies at the VLHC in the channel $h \to \gamma\gamma$ and $h \to W^+W^-$ are encouraging.

Single Top + $h \to \gamma\gamma$ at the VLHC





- $\sigma(th) = 3.2$ pb, for $\sqrt{s} = 100$ TeV and $m_h = 130$.
- $h \to \gamma\gamma$ offers a clean signature.
- $h \to W^+W^-$ might be the best shot.

Conclusion : more studies are needed !!