$$t\bar{t}h(h \to \mu\mu)$$

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Shufang Su & BT, arXiv:08121798

Detecting a SM Higgs at the LHC

- For a light Higgs (115 GeV $\lesssim m_h \lesssim$ 130 GeV), only a few discovery channels are particularly promising:

1. $gg \to h \to \gamma\gamma$ (useful due to its low invariant mass resolution).
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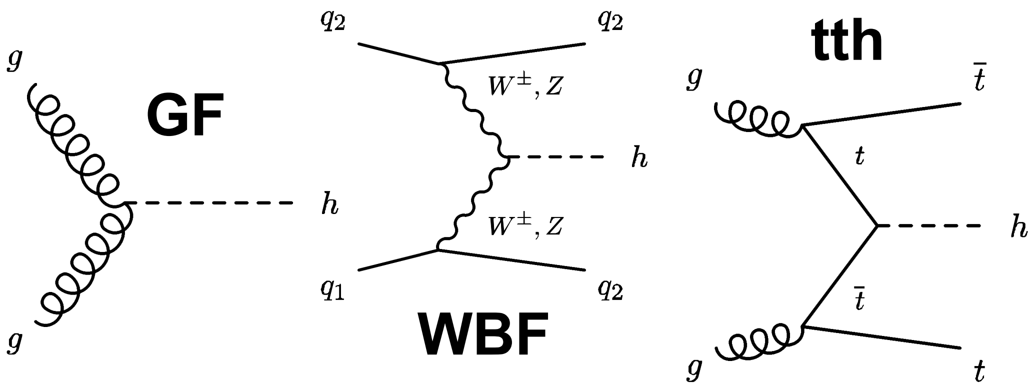
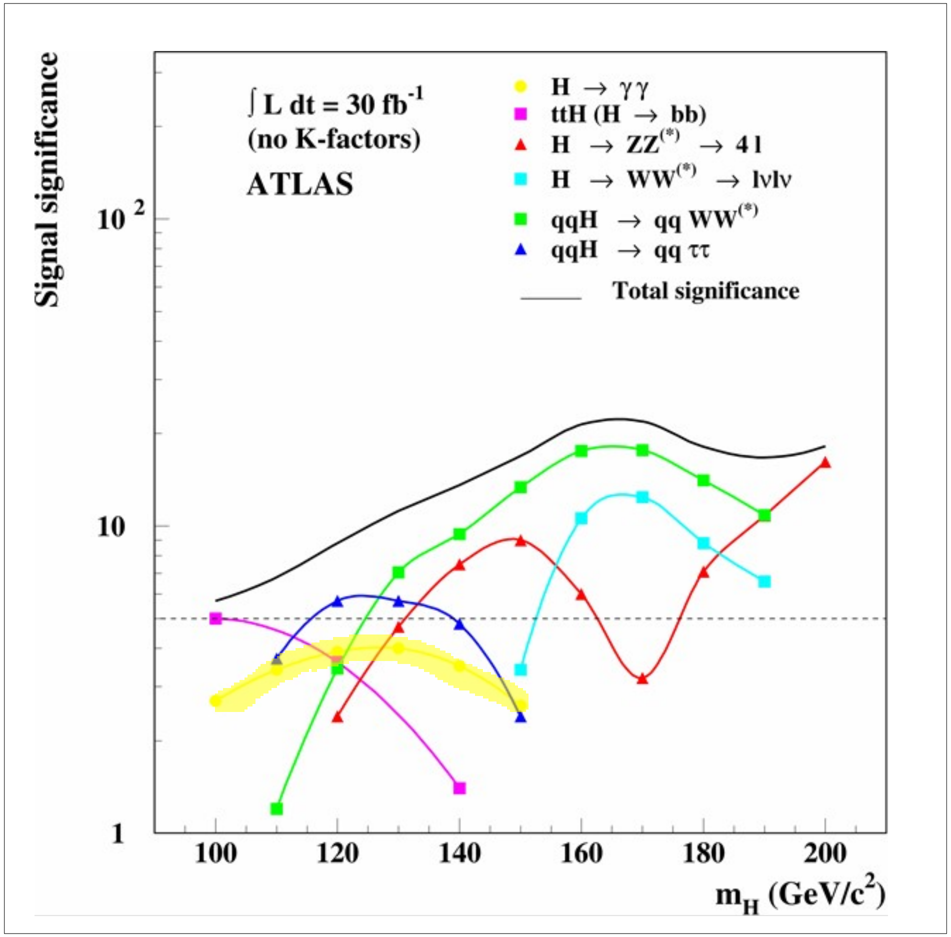
3. The tth process $tth(h \to \tau\tau)$ may also be of interest [Belyaev, Reina 2002].





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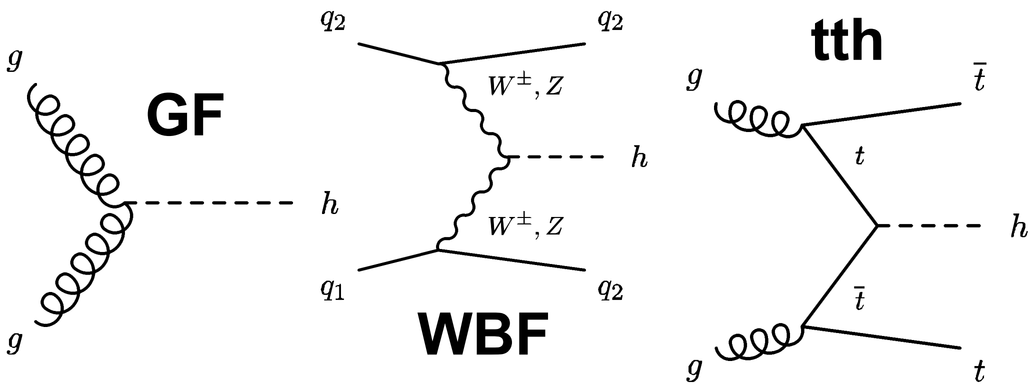

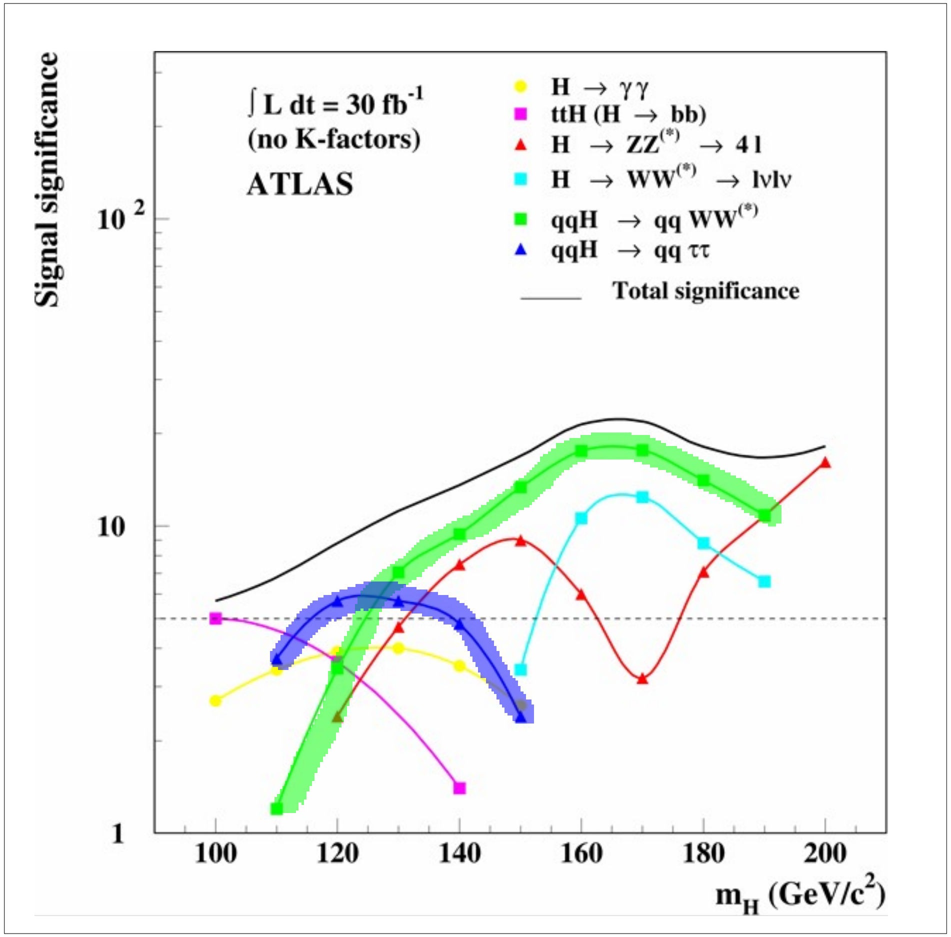

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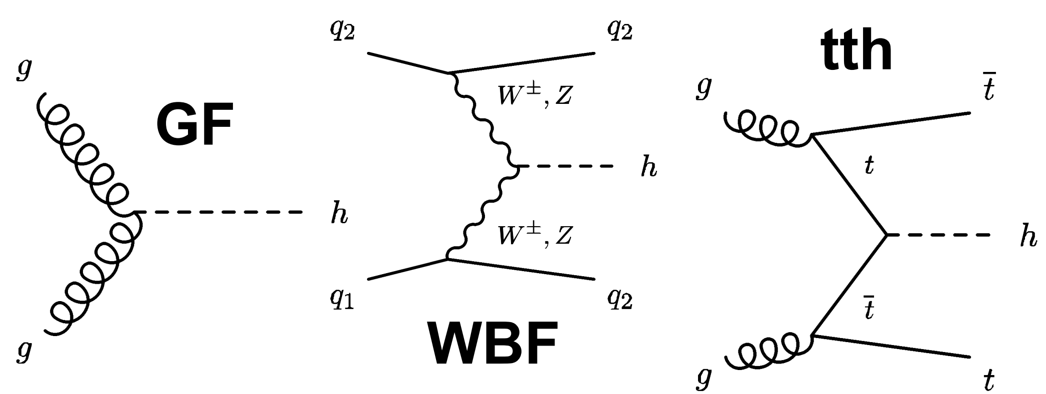

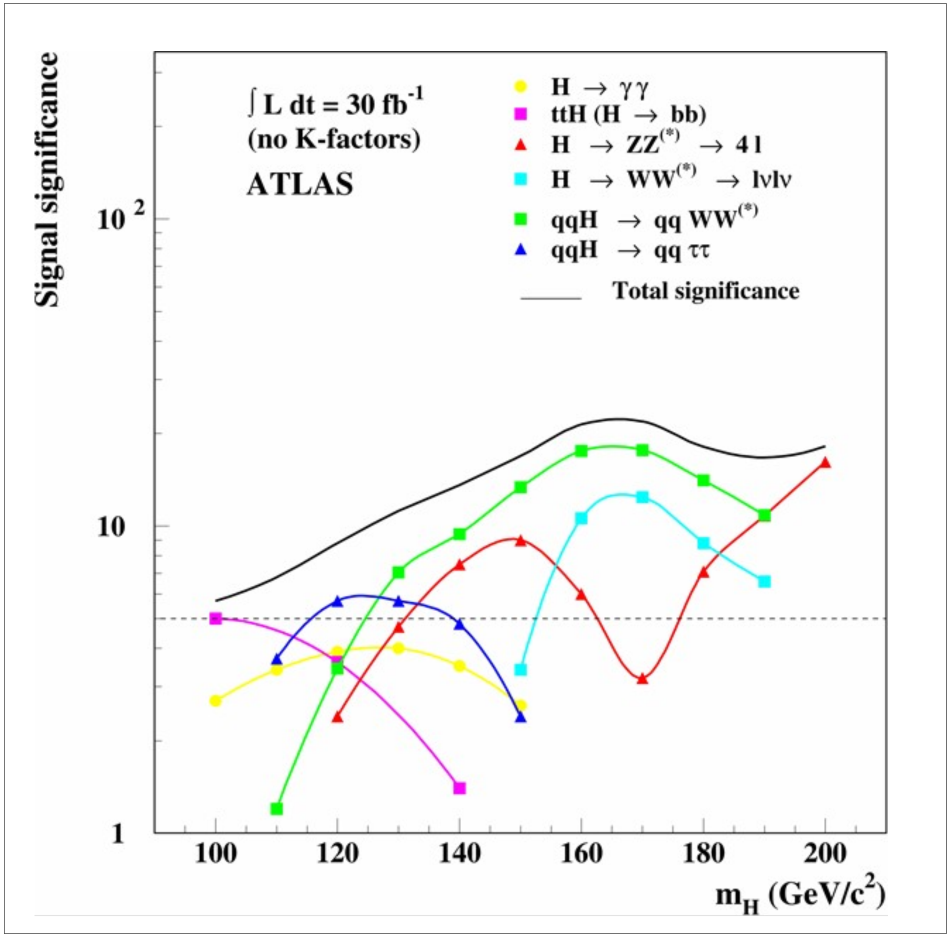

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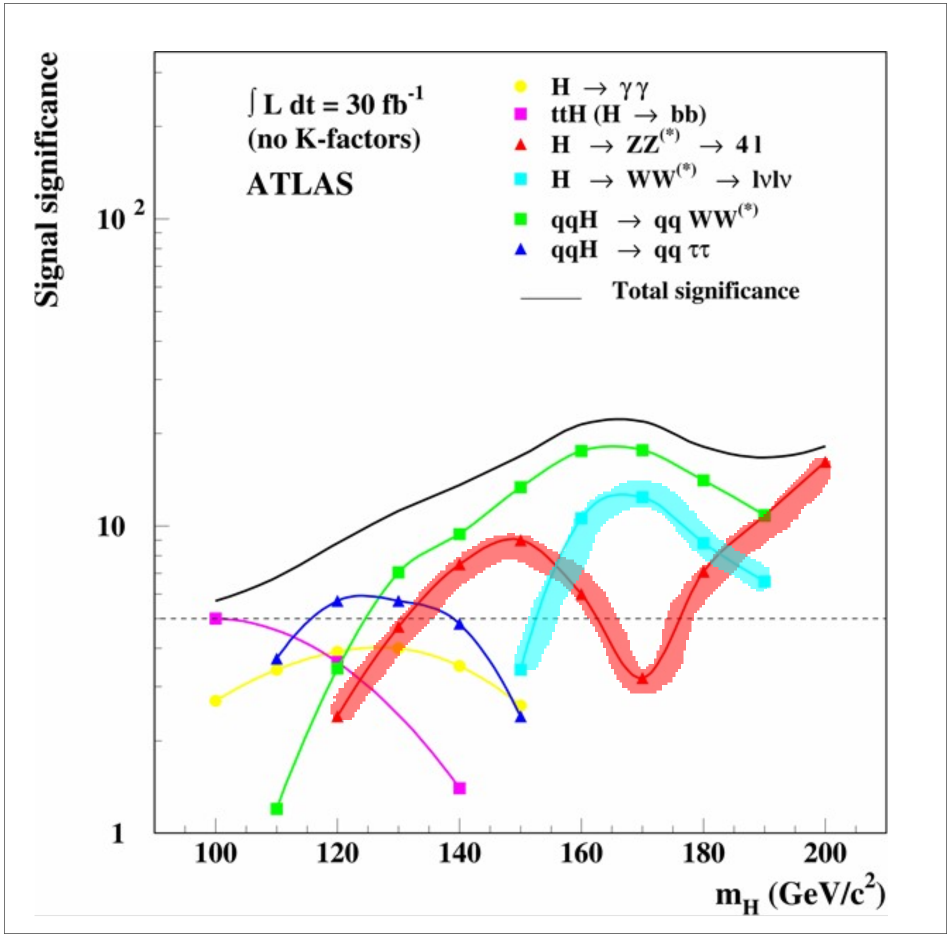

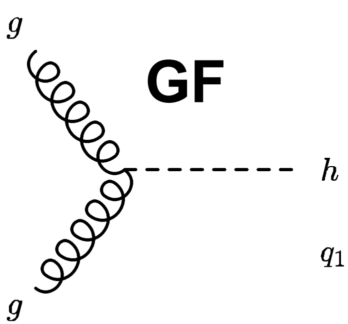

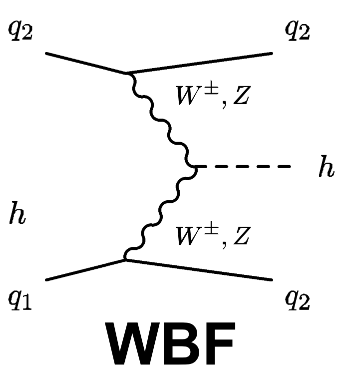

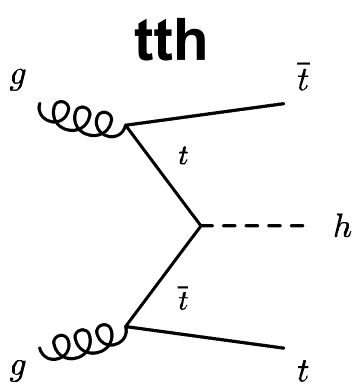

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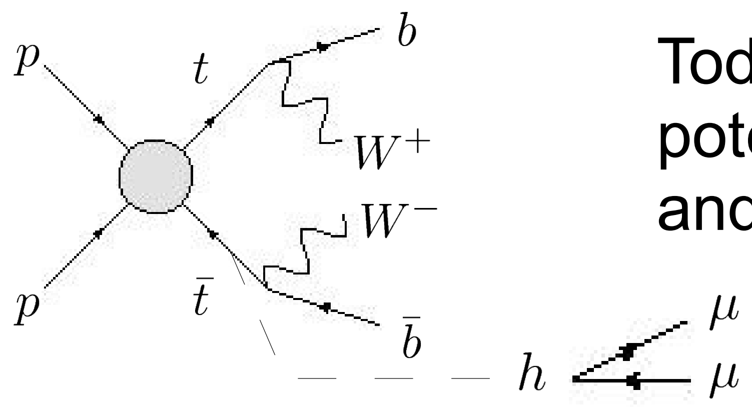
The $tth(h \to \mu\mu)$ Channel



Today, I'll be discussing the Higgs discovey potential of a Higgs boson produced by **tth** and decaying to a **muon pair** at the LHC.

Why has this channel been overlooked?

- Higgs decays to muons are suppressed due to the small mass of the muon:

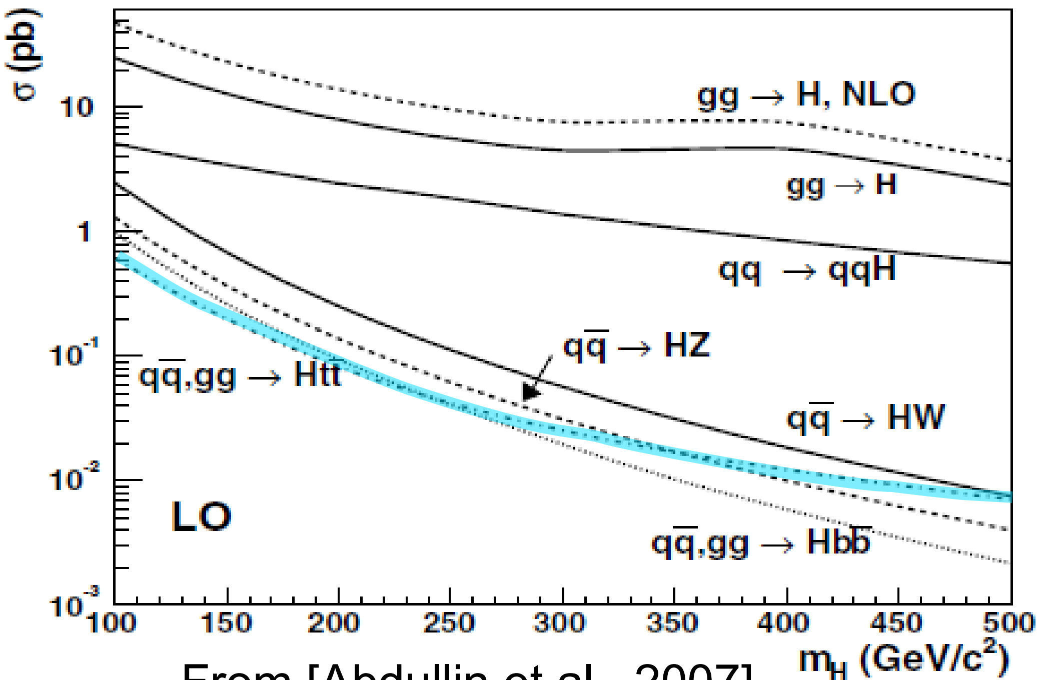
$$\mathrm{BR}(h \to \mu\mu) \propto m_\mu^2/v^2 \quad \Rightarrow \quad \mathrm{BR}(h \to \mu\mu) \simeq 1.2 - 2.6 \times 10^{-4}$$

While this is true, it does **NOT** mean this channel is uninteresting!

Small

m_h (GeV)	$\sigma_{t\bar{t}h}$ (fb)	BR($h \to \mu\mu$)
115	606.1	2.57×10^{-4}
120	538.1	2.40×10^{-4}
130	430.8	1.89×10^{-4}
140	347.5	1.24×10^{-4}

Not so small



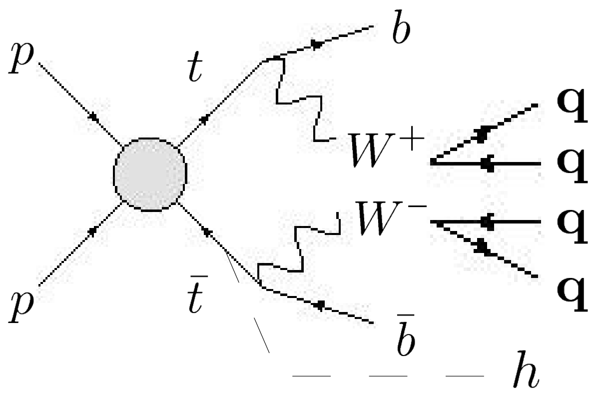
From [Abdullin et al., 2007]

The Advantages:

- The Higgs production cross-section via tth is only a factor of ~ 10 lower than that for WBF for a light Higgs.
- Very good invariant mass resolution for a muon pair (about 1%) — similar to that in the $gg \to h \to \gamma\gamma$ channel.
- Top reconstruction provides a powerful tool in reducing reducible backgrounds.

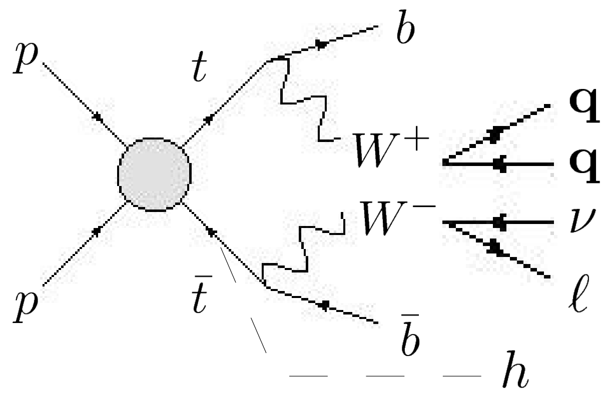
Signal and Background Processes

Fully Hadronic



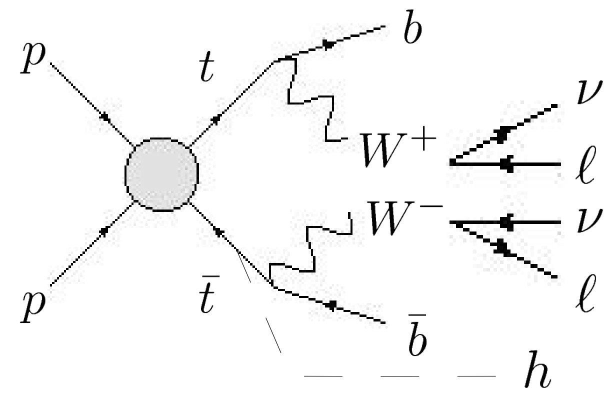
Mass reconstruction possible for both tops.

Semi-leptonic



Reconstruct hadronic top; reconstruct leptonic top by assuming all $\not{E}_T$ is from ν in W-decay.

Fully Leptonic



Mass reconstruction impossible: multiple ν's in final state.

Backgrounds include...

- $ttZ/\gamma^*(Z/\gamma^* \to \mu\mu)$
- $pp \to bWWZ$ processes, etc.

Primary irreducible background (Reduce with invariant mass cuts on the muon pair)

Reducible backgrounds (Reduce via top reconstruction)

Distinguishing Signal from Background

To distinguish signal from background, we impose two successive sets of cuts:

Level I

(To reproduce a realistic detector acceptance)

- $p_T^\ell > 20$ GeV for all charged leptons, $|\eta_e| < 2.5$, $|\eta_\mu| < 2.4$.
- $p_T^j > 15$ GeV for all jets (including b-jets), $|\eta_j| < 3.0$.
- $\Delta R_{\ell j} > 0.4$, $\Delta R_{jj} > 0.5$, $\Delta R_{\ell\ell} > 0.5$.

Note:b-tagging is **NOT** used in this analysis.

Reason: Event rates for signal process are small. A b-tagging efficiency of ~50% at ATLAS & CMS means a 75% reduction in signal events.

Level II

(Background reduction)

Fully Hadronic

- 6 jets passing level I cuts.
- Two groups of 3 jets for which $|M_{j_1 j_2 j_3} - m_t| < 50$ GeV.
- One jet pair within each such group for which $|M_{j_1 j_2} - M_W| < 40$ GeV.
- $|M_{\mu\mu} - m_h| < 2.5$ GeV.

- Semileptonic processes with $W \to \mu\nu_\mu$ and $W \to e\nu_e$ treated as separate channels.

Semi-leptonic

- 4 jets & 3 charged leptons passing level I cuts.
- A group of 3 jets for which $|M_{j_1 j_2 j_3} - m_t| < 50$ GeV.
- One jet pair within this group for which $|M_{j_1 j_2} - M_W| < 40$ GeV.
- $|M_{\mu\mu} - m_h| < 2.5$ GeV.
- One additional lepton and one additional jet for which $|M_{j\ell\nu} - m_t| < 50$ GeV and $|M_{\ell\nu} - M_W| < 40$ GeV.

Events generated using MadGraph, processed in Pythia, PGS.

Results:

Fully hadronic Channel

m_h (GeV)	ϵ_S	σ_S (ab)	ϵ_B	σ_B (ab)	S/B	Significance $\mathcal{L} = 300\ \text{fb}^{-1}$
115	8.1%	15.1	0.028%	12.3	1.22	2.66
120	7.9%	12.2	0.023%	10.0	1.21	2.36
130	8.2%	8.0	0.017%	7.3	1.10	1.81
140	8.2%	4.2	0.015%	6.6	0.64	0.81

Semi-leptonic Channel

m_h (GeV)	$W \to e\nu_e$					$W \to \mu\nu_\mu$					Significance ($\mathcal{L} = 300\ \text{fb}^{-1}$)
	ϵ_S	σ_S(ab)	ϵ_B	σ_B(ab)	S/B	ϵ_S	σ_S(ab)	ϵ_B	σ_B(ab)	S/B	
115	1.6%	3.0	0.0045%	1.9	1.55	0.74%	1.4	0.011%	5.0	0.28	0.96
120	1.8%	2.7	0.0025%	1.1	2.51	0.70%	1.1	0.013%	5.4	0.20	0.77
130	1.7%	1.7	0.0030%	1.3	1.26	0.76%	0.7	0.010%	4.4	0.17	0.48
140	1.7%	0.9	0.0013%	0.5	1.63	0.74%	0.4	0.008%	3.4	0.11	0.07

- The hadronic channel yields evidence for a light Higgs boson at the 2.5σ level.
- The semi-leptonic channel is not particularly useful.

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Even more auspicious are the combined results from *all* $h \to \mu\mu$ channels:

- Results for $qq' \to qq'h(h \to \mu\mu)$ [Plehn, Rainwater: 2001] $gg \to h \to \mu\mu$ [Han, McElrath: 2002] can be combined with the (hadronic) $tth(h \to \mu\mu)$ result.

Combined Results

m_h (GeV)	Significance				Significance	
	$t\bar{t}h_{\mathrm{comb}}$	$t\bar{t}h_{\mathrm{had}}$	GF	WBF	(GF+WBF)	Combined
115	2.43	2.66	2.41	2.49	3.37	4.04
120	2.02	2.36	2.51	2.52	3.45	3.94
130	1.43	1.81	2.25	2.40	3.18	3.41
140	0.38	0.81	1.61	1.71	2.26	2.09

(Combined confidence levels determined using Fisher's method)

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4σ evidence

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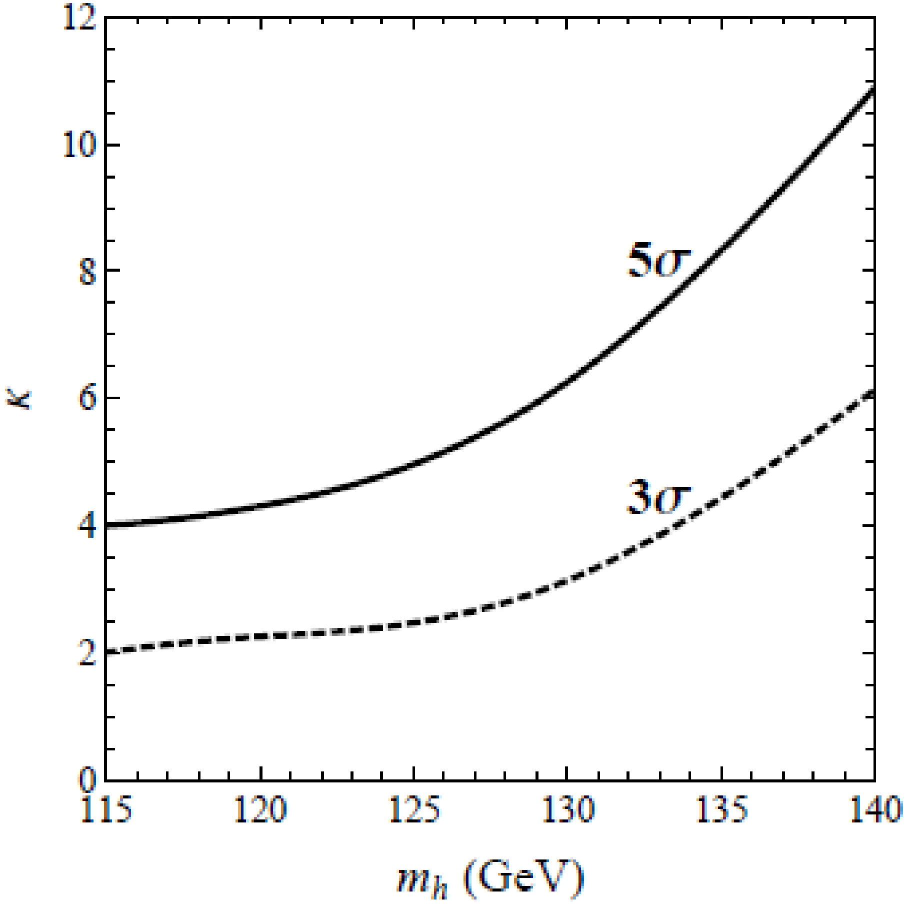
Higgs Bosons Beyond the SM

- IFurthermore, in BSM scenarios, especially those with enhanced couplings between the lightest Higgs boson and the SM leptons, the $tth(h \to \mu\mu)$ channel can play a crucial role in Higgs discovery.

($\mathcal{L} = 100\ \text{fb}^{-1}$ at both ATLAS & CMS)



- One can define a κ-factor to represent the deviation of the $tth(h \to \mu\mu)$ cross-section from its SM value:

$$\boxed{\kappa \equiv \frac{[\sigma(pp \to t\bar{t}h) \times \text{BR}(h \to \mu\mu)]_{NP}}{[\sigma(pp \to t\bar{t}h) \times \text{BR}(h \to \mu\mu)]_{\text{SM}}}.}$$

- A κ-factor of 2-3 results in 3σ evidence in this channel alone.

- A κ-factor of 4-5 is sufficient for a 5σ discovery.

Conclusions

- The $tth(h \to \mu\mu)$ channel merits further attention as a channel for Higgs detection — and perhaps detector-level analysis by CMS and ATLAS.
- Small BR$(h \to \mu\mu)$ is compensated for by the excellent invariant mass resolution of the OS muon pair.
- Evidence of a SM Higgs at the 2.6σ level can be obtained in this channel alone with $\mathcal{L} = 100\ \mathrm{fb}^{-1}$ at ATLAS & CMS.
- Evidence at the 4σ level can be obtained in the combined $h \to \mu\mu$ channel.
- In BSM scenarios with enhanced $h\bar{\ell}\ell$ couplings, this channel can play a crucial role in Higgs discovery.