



Non standard top signatures: monotop, multitops...

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Top LHC-France 2015



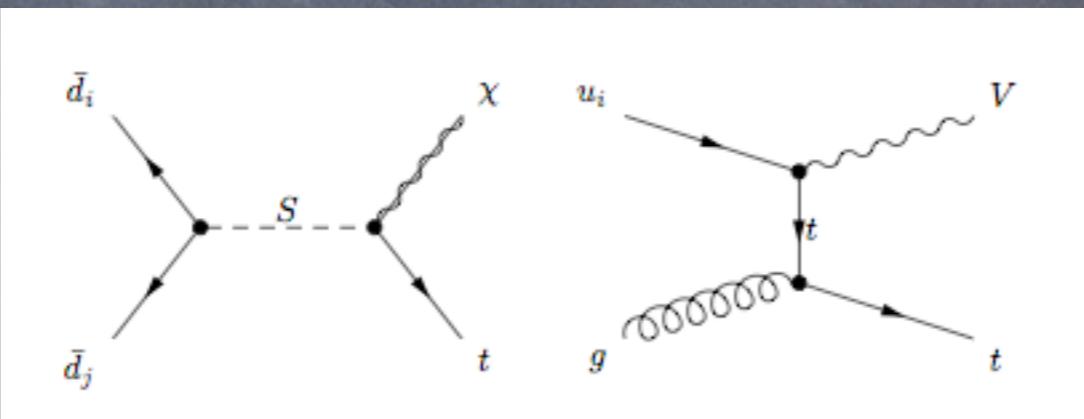
•

- The top is the most “natural” fermion in the SM
- However, giving it mass is usually a challenge in BSM models!

Monotop



- ⦿ One top + invisible particle



Andrea, Fuks, Maltoni
1106.6199

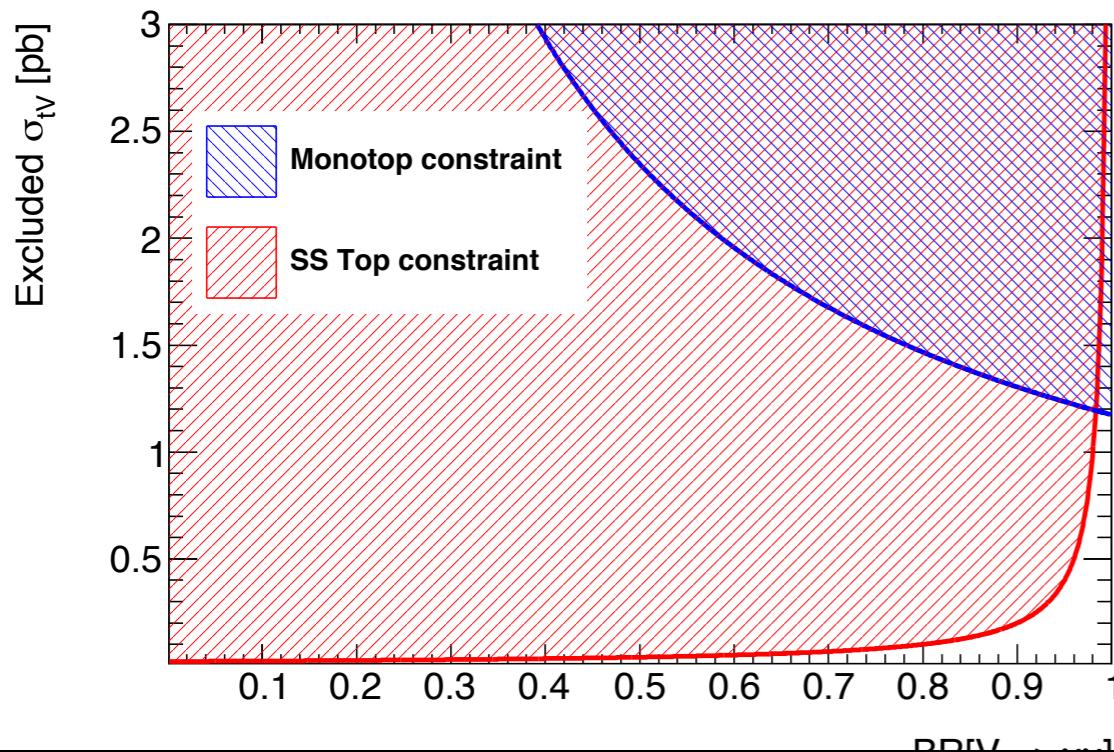
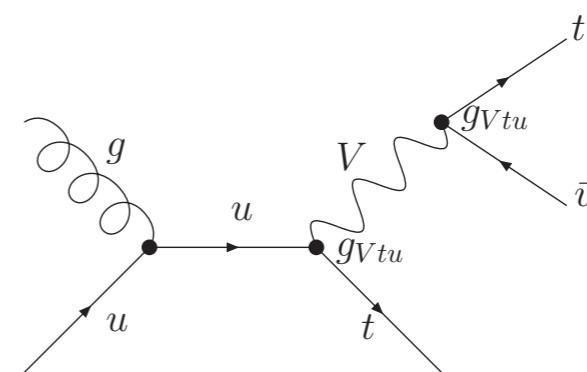
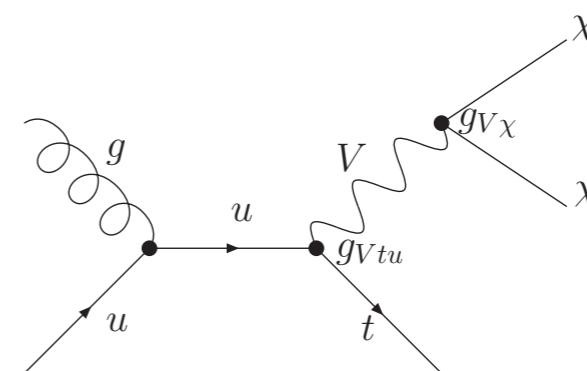
- ⦿ “Consistency” requires right-handed tops

Boucheneb, Cacciapaglia, Deandrea,
Fuks 1407.7529

Combining Monotop & Same Sign Top : illustration with run I data

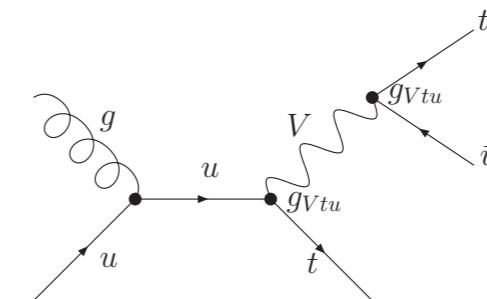
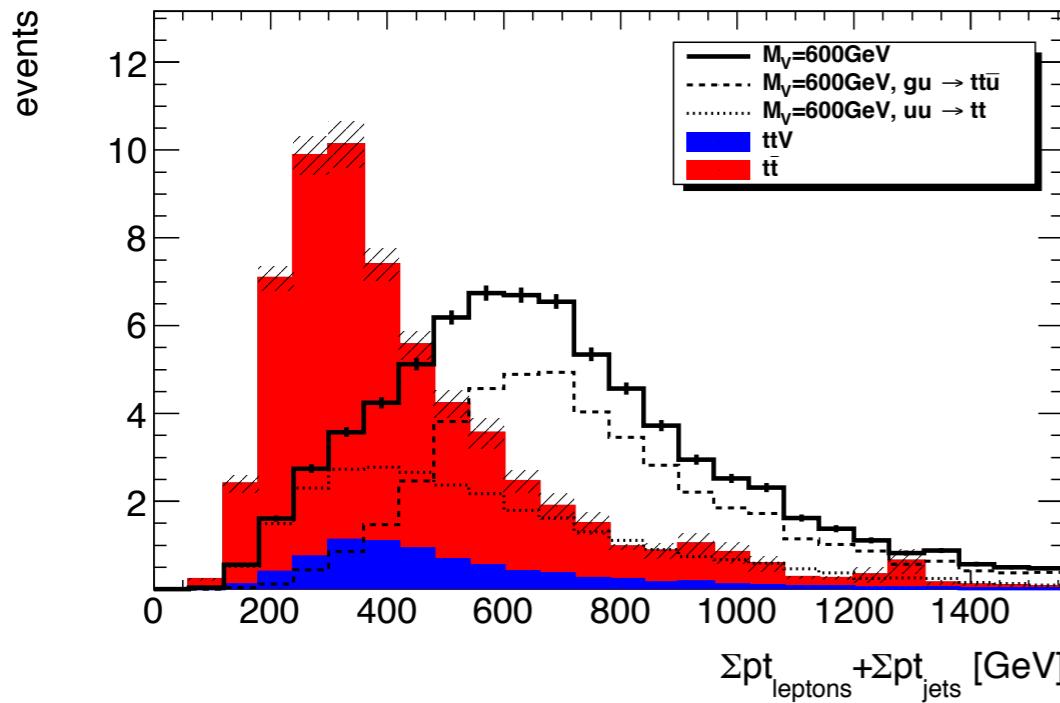
- → **Monotop** final state
- Run I SS dilepton analysis recast (arXiv :1410.5404v2)
 - $BR[V \rightarrow \chi\chi] = 100\%$
 - Excluded cross section $\sigma = 1 \text{ pb}$
- $\sigma_{monotop} = \sigma_{tV} \times BR[V \rightarrow \chi\chi]$

- → **Same Sign Top** final state
- Analysis at 8 TeV (arXiv :1504.04605)
 - Excluded cross section $\sigma = 10 \text{ fb}$
- $\sigma_{SStop} = \sigma_{tV} \times \frac{1 - BR[V \rightarrow \chi\chi]}{2}$



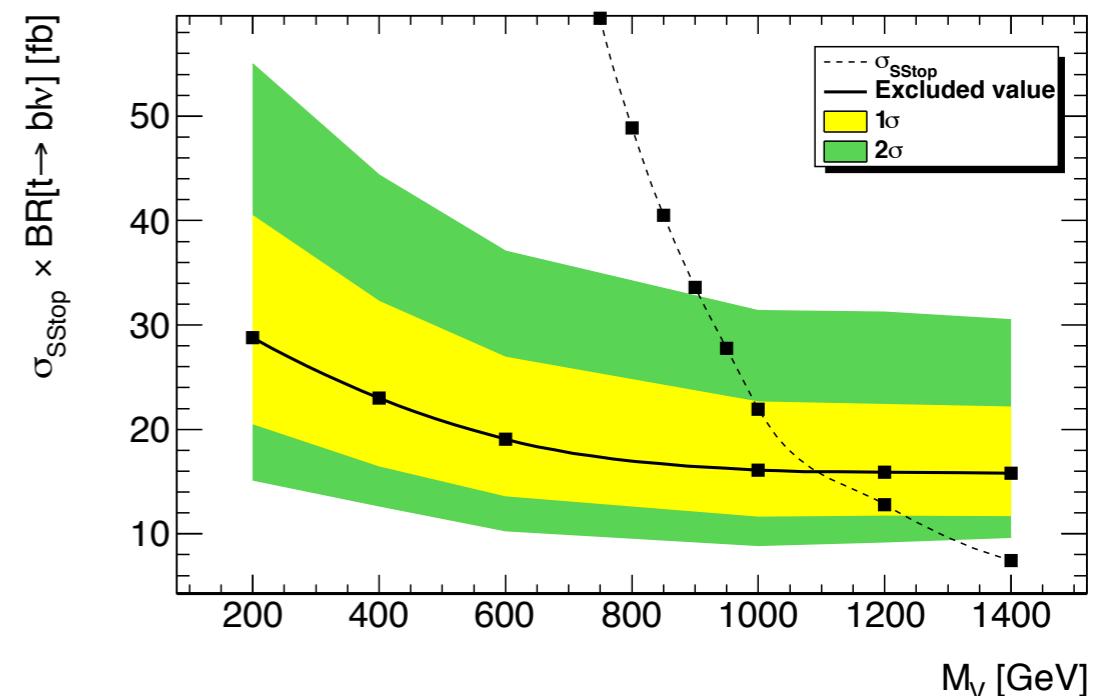
- ⇒ Probe different regions of parameter space with Monotop and SS Top
- SStop more sensible up to $BR[V \rightarrow \chi\chi] = 98\%$

Same Sign Top analysis at 13 TeV



- u -jet \rightarrow strong leading jet
- $\sum p_{\text{leptons}} + \sum p_{\text{jets}}$ stronger for signal

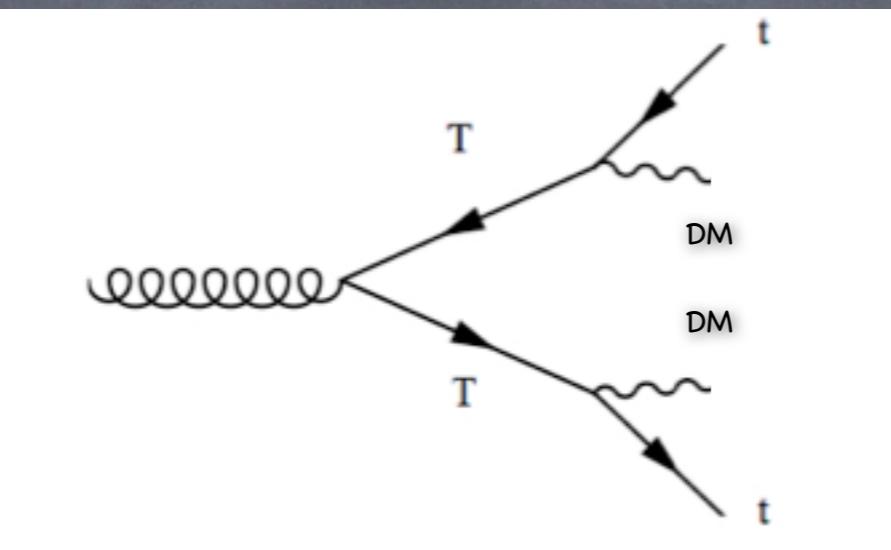
- Compute excluded cross-section for each M_V
 - using shapes
- Integrated luminosity $\mathcal{L} = 1\text{fb}^{-1}$
- **Limit mass** $\simeq 1100\text{GeV}$
- optimisations : cut&count/shapes, kinematical cuts



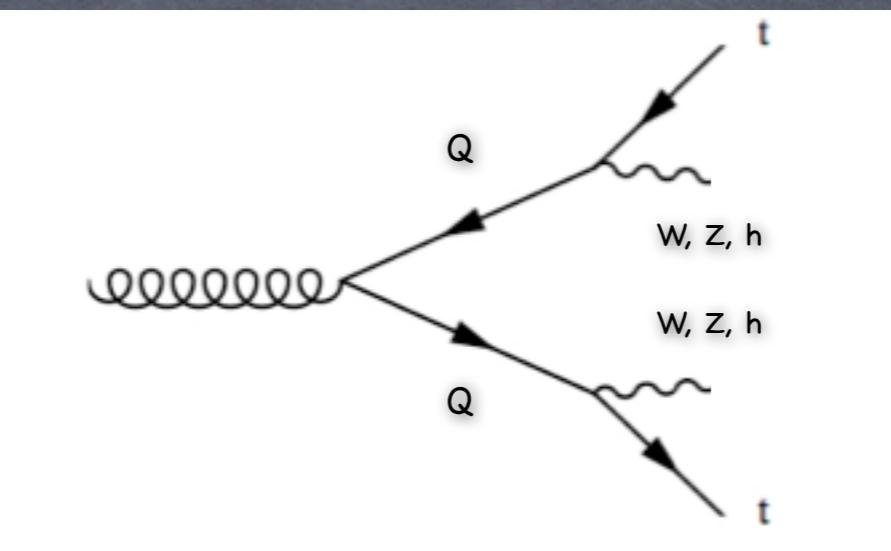
2 tops



- 2 tops + MET



- 2 tops + "stuff"



Vector-like quarks as a smoking gun for Higgs compositeness?

$$\lambda_L q_L \mathcal{O}_L + \lambda_R u_R \mathcal{O}_R$$

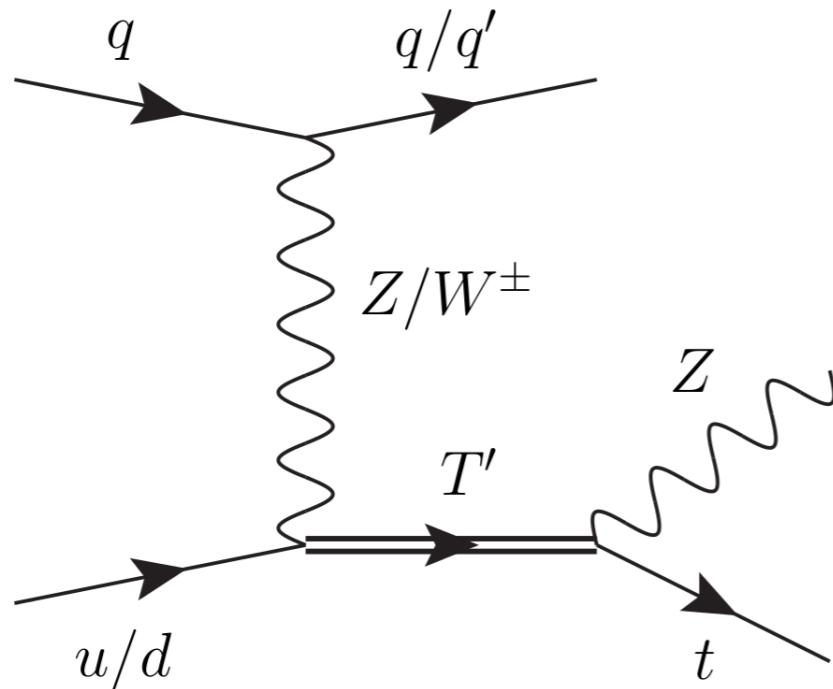
- the composite operators are coloured fermions
- they couple to the EW breaking source

$$5_{SO(5)} = \left(\begin{array}{c} T \\ B \end{array} \right)_{Y=\frac{1}{6}} \oplus \left(\begin{array}{c} X_{5/3} \\ X_{2/3} \end{array} \right)_{Y=\frac{7}{6}} \oplus \tilde{T}_{Y=\frac{2}{3}}$$

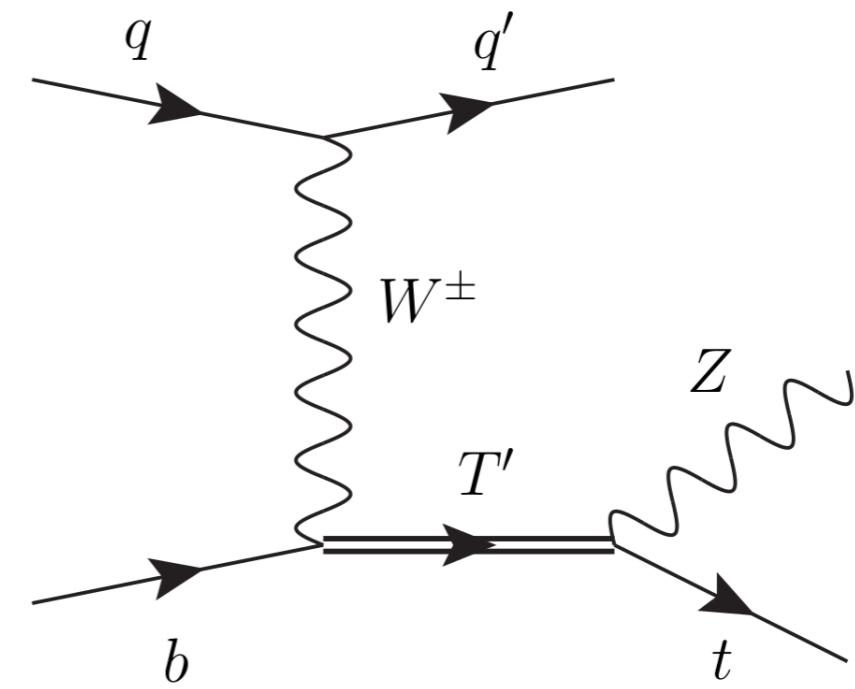
bi-doublet of SO(4)

necessary to keep
small tree-level corrections
to $Z b_L b_L$

Single production and $T' \rightarrow tZ$



(a) \mathcal{A}_1



(b) \mathcal{A}_3

$$\sigma_{pp \rightarrow T'}(M_{T'}, R_L) = \mathcal{A}_1(M_{T'}) \frac{R_L}{1 + R_L} + \mathcal{A}_3(M_{T'}) \frac{1}{1 + R_L}$$

$$BR_{T' \rightarrow tZ}(M_{T'}, R_L) = \mathcal{B}(M_{T'}) \frac{1}{1 + R_L}$$

$M_{T'} \text{ (GeV)}$	$\mathcal{A}_1(M_{T'}) \text{ (pb)}$	$\mathcal{A}_3(M_{T'}) \text{ (pb)}$	$\mathcal{B}(M_{T'}) \text{ (%)}$
800	1.2614	0.07242	22.4
1000	0.7752	0.03518	23.5
1200	0.5001	0.01826	24.0
1400	0.3331	0.00994	24.2
1600	0.2265	0.00561	24.4

Discovery power: benchmarks

Surviving events and significances for signal benchmark points
 $(g^* = 0.1, R_L = 0.5)$

- C&C: select a window around the peak in $M_T(b3\ell)$
- MVA: perform a LH cut on BDT output

to maximise the significance: $\sigma = S/\sqrt{S + B}$

Andrea, Basso 1411.7587

Analysis	$M_{T'} = 0.8 \text{ TeV}$	$M_{T'} = 1.0 \text{ TeV}$	$M_{T'} = 1.2 \text{ TeV}$	$M_{T'} = 1.4 \text{ TeV}$	$M_{T'} = 1.6 \text{ TeV}$
$M_T(b3\ell)$ cut (GeV)	[800 – 860]	[840 – 1200]	[1000 – 1340]	[1120 – 1640]	[1200 – 1800]
C&C	S (ev.)	18.00	12.28	7.16	3.40
	B (ev.)	8.90	4.88	1.74	0.90
	σ	3.47	2.96	2.40	1.64
MVA	cut	0.07	0.08	0.11	0.12
	σ	3.64	3.10	2.50	1.62

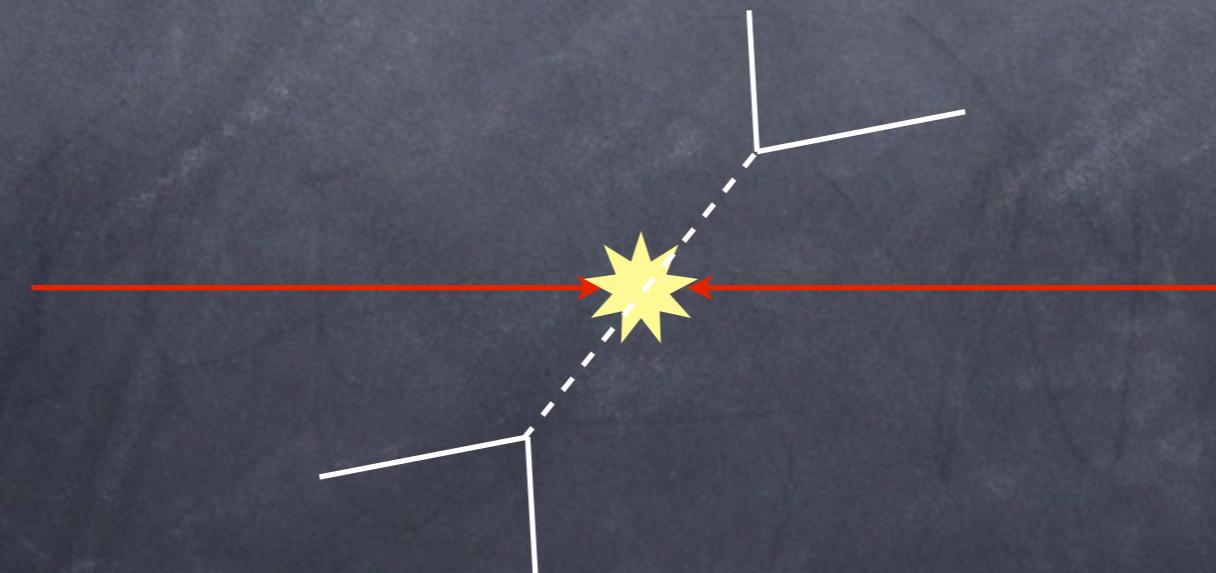
MVA: non-significant improvement (5%–8%)

Significance depends on g^* and R_L per fixed T' mass

4 tops

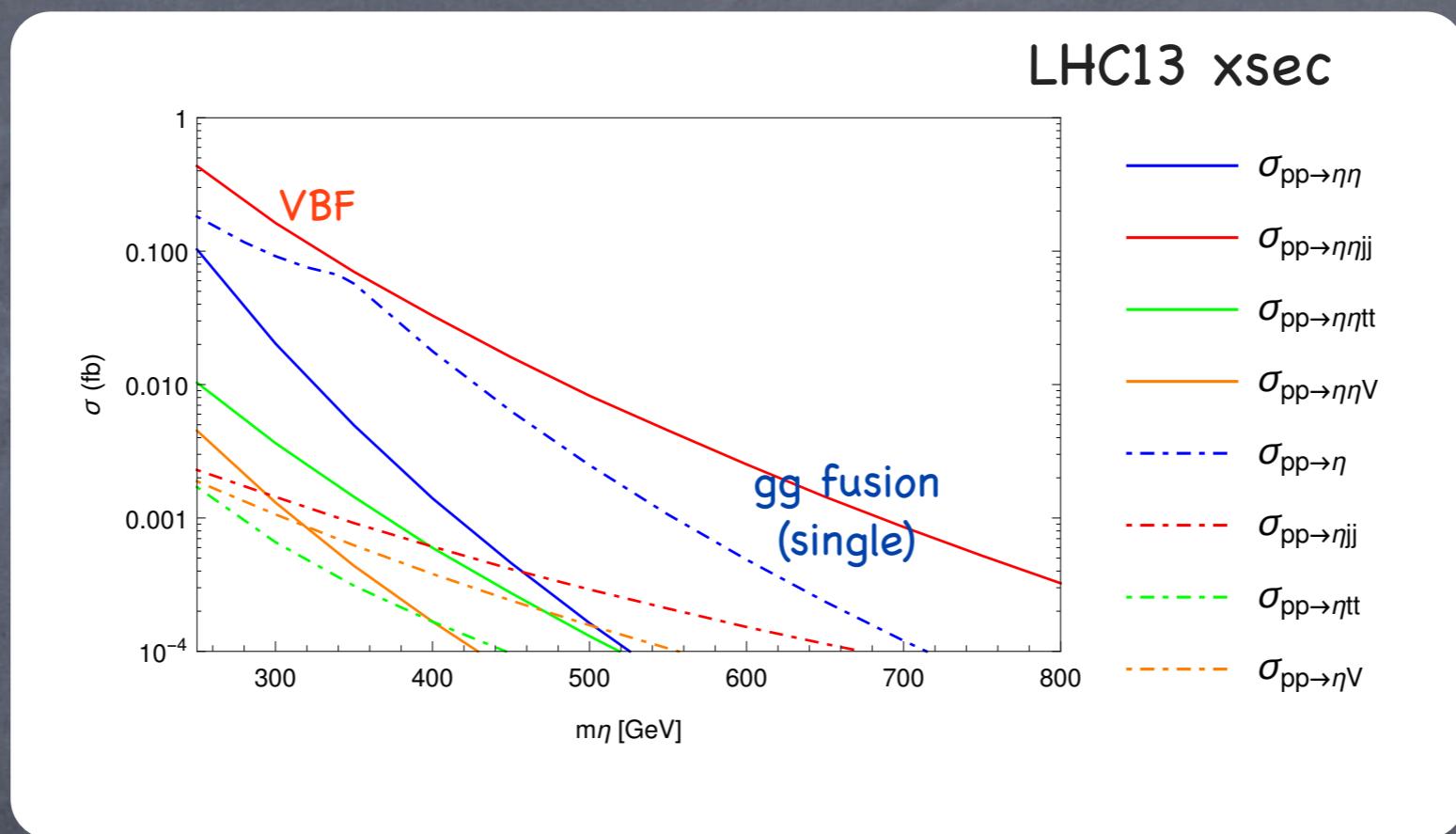


- Standard searches now in both ATLAS and CMS
- Signature arising in (non-minimal) composite Higgs models!



An example: SU(4)/Sp(4)

Arbey, Cacciapaglia, Cai, Deandrea, le Corre,
Sannino 1502.04718



BR ($\eta \rightarrow \tau\tau$) $\sim 100\%$

- Very challenging (maybe VBF tag?)
- Compatible with null results of Run I

Coloured techni-pions

$$\frac{\lambda'}{M^2} \bar{q}_L \psi^i \bar{\psi}^j \psi^k$$

The EWSB condensate carries colour!!

$$\frac{\lambda'}{M^2} \bar{q}_L \chi \bar{\psi}^j \psi^k$$

χ carries colour: potential condensate $\langle \chi \chi \rangle$

$$\frac{\lambda'}{M} G_{\mu\nu} \bar{q}_L \sigma^{\mu\nu} \psi^i$$

Typically loop-induced: no large mixing allowed

$$\lambda_L q_L \mathcal{O}_L + \lambda_R u_R \mathcal{O}_R$$


- the composite operators are coloured fermions
- they couple to the EW breaking source

Coloured techni-pions

- The condensate transforms as:

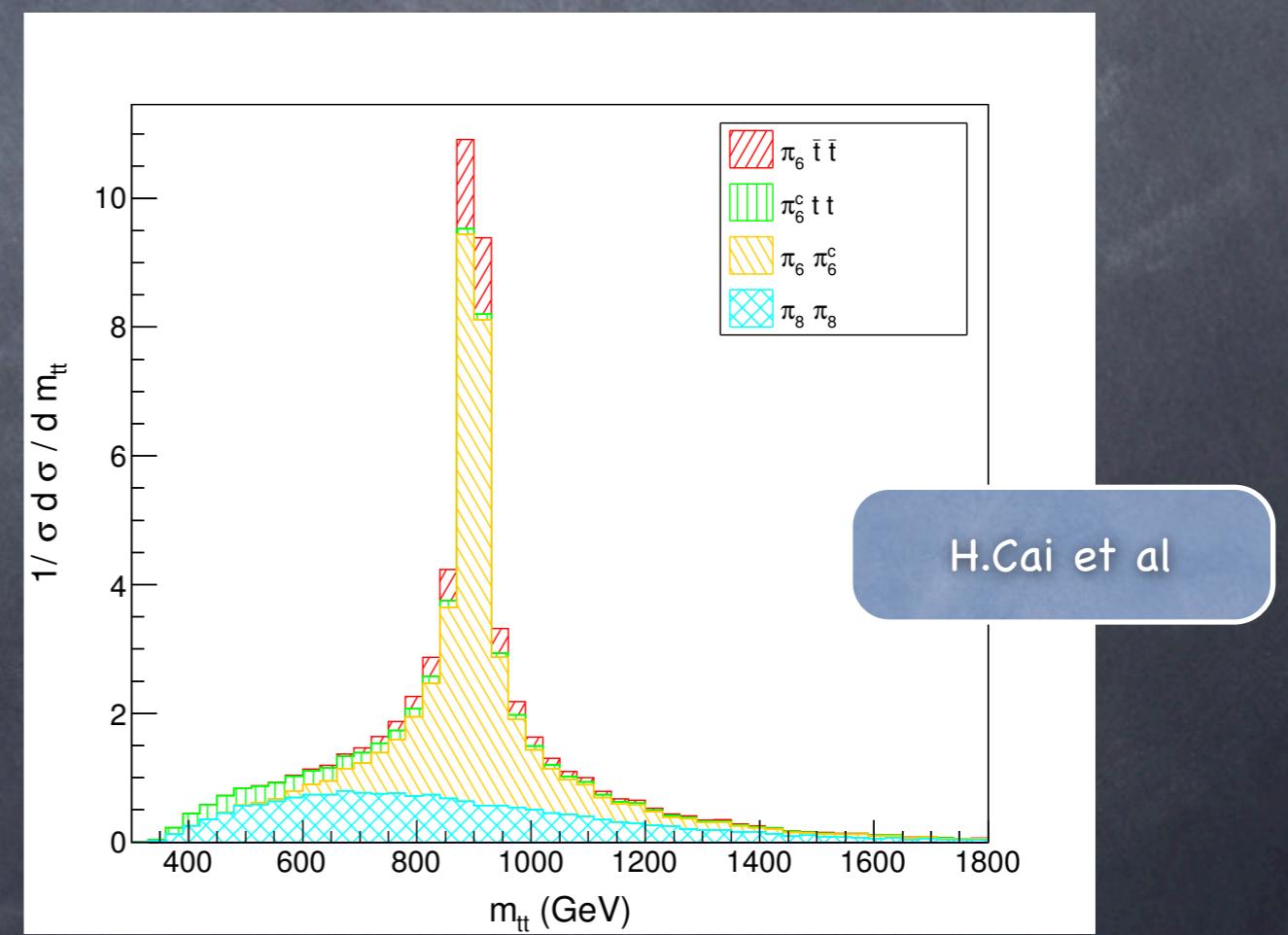
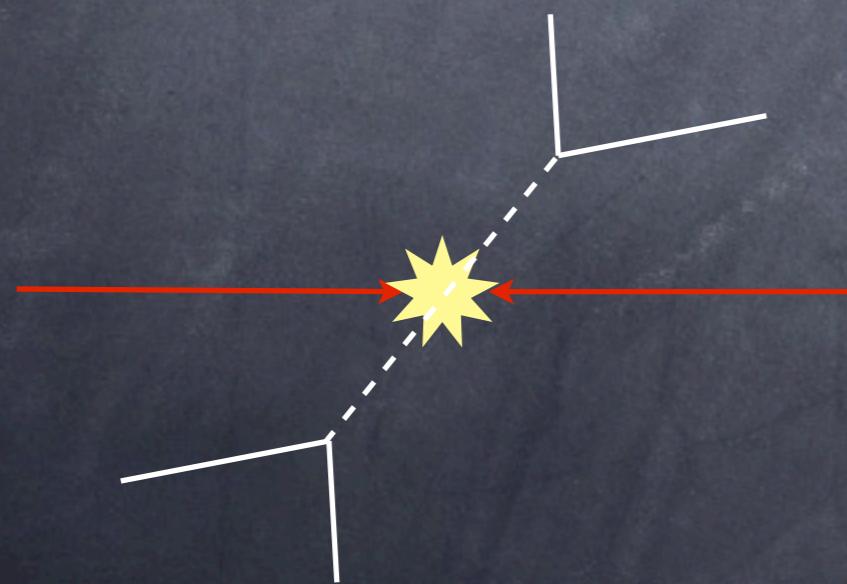
$$\langle \chi\chi \rangle = 21_{SU(6)} \rightarrow 20_{SO(6)} + 1_{SO(6)}$$

pseudo
Goldstone
bosons

$$20_{SO(6)} = 8_0 \oplus 6_{4/3} \oplus \bar{6}_{-4/3}$$

“sgluon”

of $SU(3) \times U(1)$:
octet + charged sextet



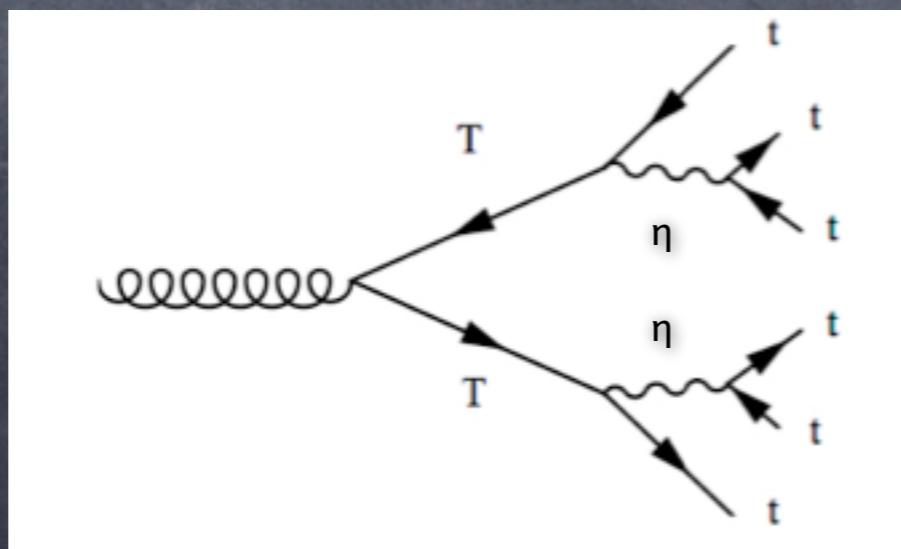
Multi-tops?



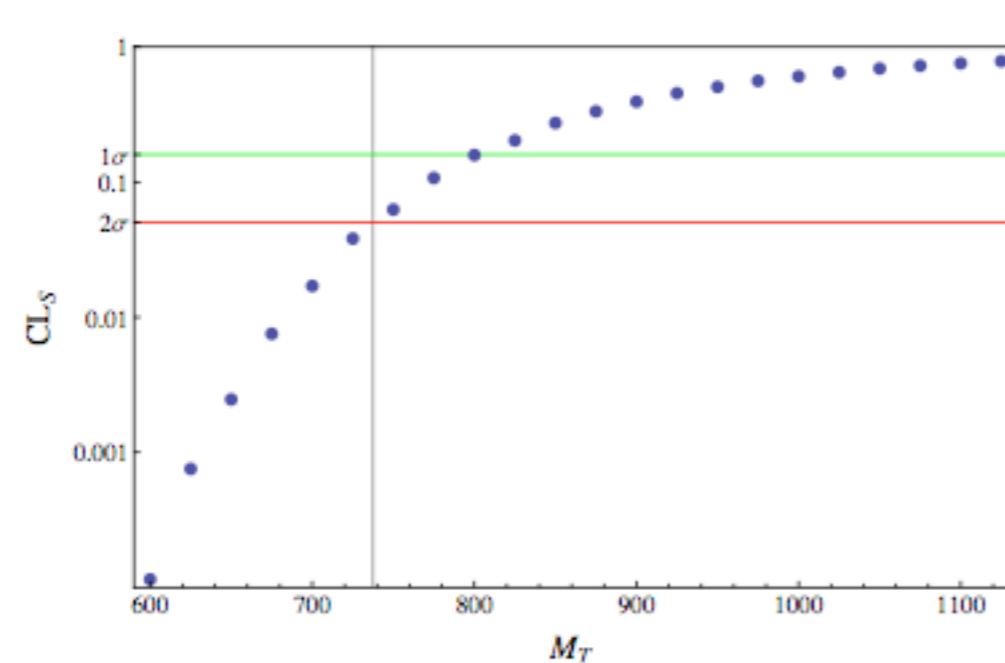
- ⌚ If we can produce 4 tops, why not more?

$$6_{SU(4)} = \left(\begin{array}{c} T \\ B \end{array} \right)_{Y=\frac{1}{6}} \oplus \left(\begin{array}{c} X_{5/3} \\ X_{2/3} \end{array} \right)_{Y=\frac{7}{6}} \oplus \tilde{T}_{Y=\frac{2}{3}}^5 \oplus \tilde{T}_{Y=\frac{2}{3}}^1$$

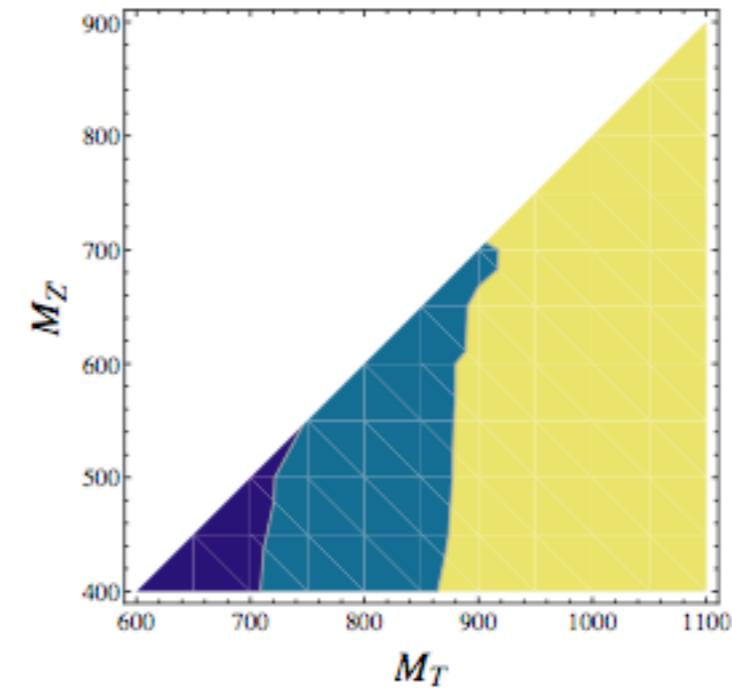
\longleftrightarrow
5 of $Sp(4) \sim SO(5)$



Multi-tops?



(a)



(b)

Figure 4. (a): CL_s confidence level in a scan over M_T with $M_{Z'} = 400$ GeV. (b): Limits in the plane $(M_T, M_{Z'})$ from CMS. Purple points are excluded at 2σ , blue points are excluded at 1σ and yellow points are not excluded.

CMS ssl + b-jets, 10.5/fb

Deandrea, Deutschmann 1405.6119

Conclusions

- ⦿ The LHC is a  !
- ⦿ The top is “natural” in the SM, but not in BSM
- ⦿ Expect signatures with many tops!
- ⦿ Question: seen an excess, how to establish the “top” nature? Top-jets?