Manifestations of Top Compositeness at Colliders

Kunal Kumar, Tim M.P.Tait, Roberto Vega-Morales

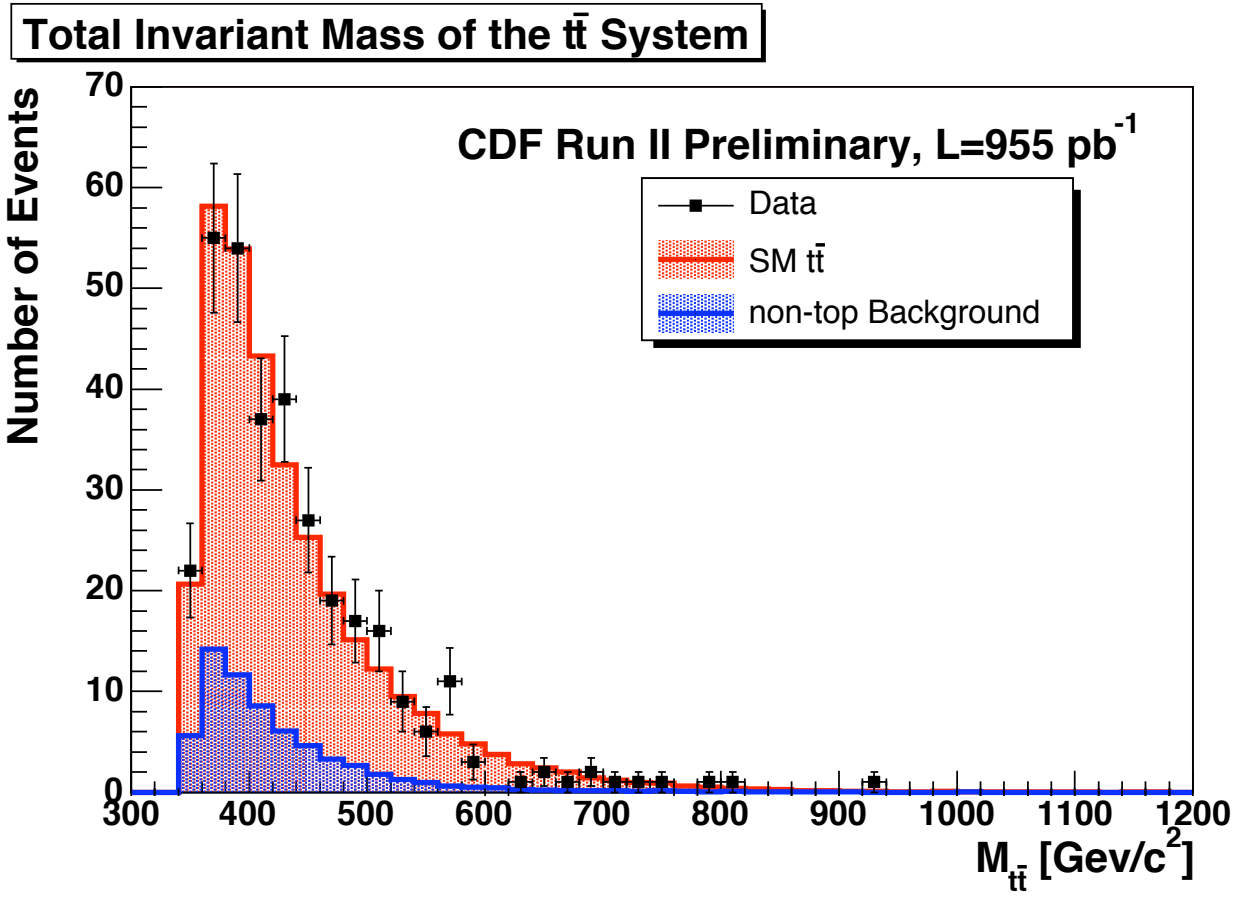
Northwestern University
Argonne National Laboratories

Pheno 2009 Symposium

Based on: KK, Tim Tait, Roberto Vega-Morales, JHEP 05(2009)022

Motivation for right handed top quark compositeness

- Large mass relative to other quarks (174 GeV)
- Only sector of the SM not currently strongly bounded by existing measurements such as LEP
- Take advantage of large amounts of top pair data from the Tevatron



Tevatron - Effects of Higher Dimensional Operators

- Most significant operator:

$$\mathcal{O}_t = g^2 \left[\bar{t}^i \gamma^\mu P_R t_j\right] \left[\bar{t}^k \gamma_\mu P_R t_l\right]$$

Georgi, Kaplan, Morin, Schenk PRD51, 3888 (1995)

- Dimension 6 operators which contribute to the top quark coupling to the gluon at tree level:

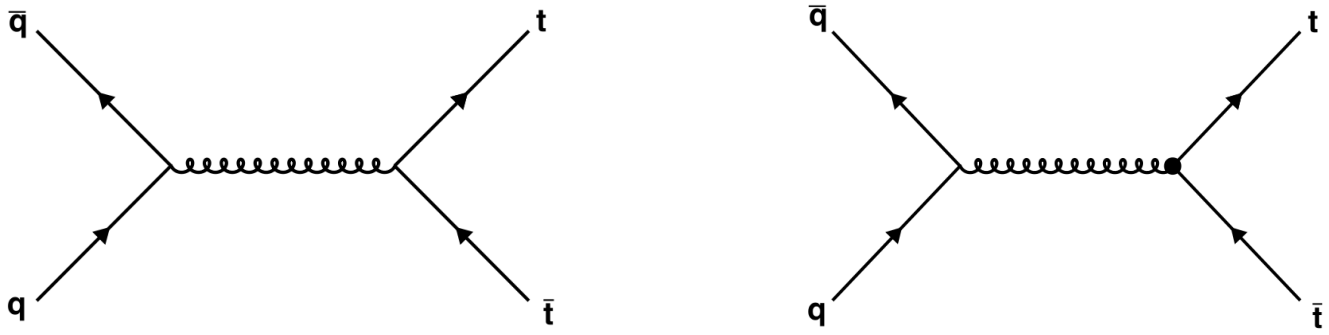
$$\begin{aligned}
\mathcal{O}_1 &= g_1 g_S \left[\left(H\bar{Q}_3\right) \sigma^{\mu\nu} \lambda^a P_R t\right] G^a_{\mu\nu} + H.c. \\
\mathcal{O}_2 &= g_2 g_S \left[\bar{t}\gamma^\mu \lambda^a D^\nu P_R t\right] G^a_{\mu\nu} + H.c. \\
\mathcal{O}_3 &= g_3 g_S \left[\bar{t}\gamma^\mu \lambda^a P_R t\right] \sum_q \left[\bar{q}\gamma_\mu \lambda^a q\right]
\end{aligned}$$

Buchmuller, Wyler NPB 268,621(1986) Atwood, Kagan, Rizzo PRD52, 6264(1995) Hill, Parke PRD49, 4454(1994)

- Equations of motion are used to rewrite $\mathcal{O}_3$ in terms of $\mathcal{O}_2$

- Feynman rule for gluon top vertex

$$\frac{g_s}{\Lambda^2}\{g_1[(H\overline{Q_3})\sigma^{\mu\nu}\lambda^a P_R t]G^a_{\mu\nu} + g_2[\bar{t}\gamma^\mu\lambda^a D^\nu P_R t]G^a_{\mu\nu}\} + h.c.$$



- Neglecting gluon initiated graph amounts to 10% error in the new physics, 1% error overall

Constraining new physics by looking at $t\bar{t}$ production

- Inclusive cross sections

$$\sigma(t\bar{t})_{CDF} = 7.0 \pm 0.3 \pm 0.4 \pm 0.4 \text{ pb}$$
$$\sigma(t\bar{t})_{D0} = 7.62 \pm 0.85 \text{ pb}$$
$$\sigma(t\bar{t})_{SM} = 6.6 \pm 0.8 \text{ pb}$$

Kidonakis, Vogt Eur Phys J C 33 S466(2004)
Mangano, Nason, Ridolfi JHEP0407, 033(2004)

- Conservative estimate after combining errors in quadrature

$$\sigma(t\bar{t})_{exp} = 7.0 \pm 0.61 \text{ pb}$$

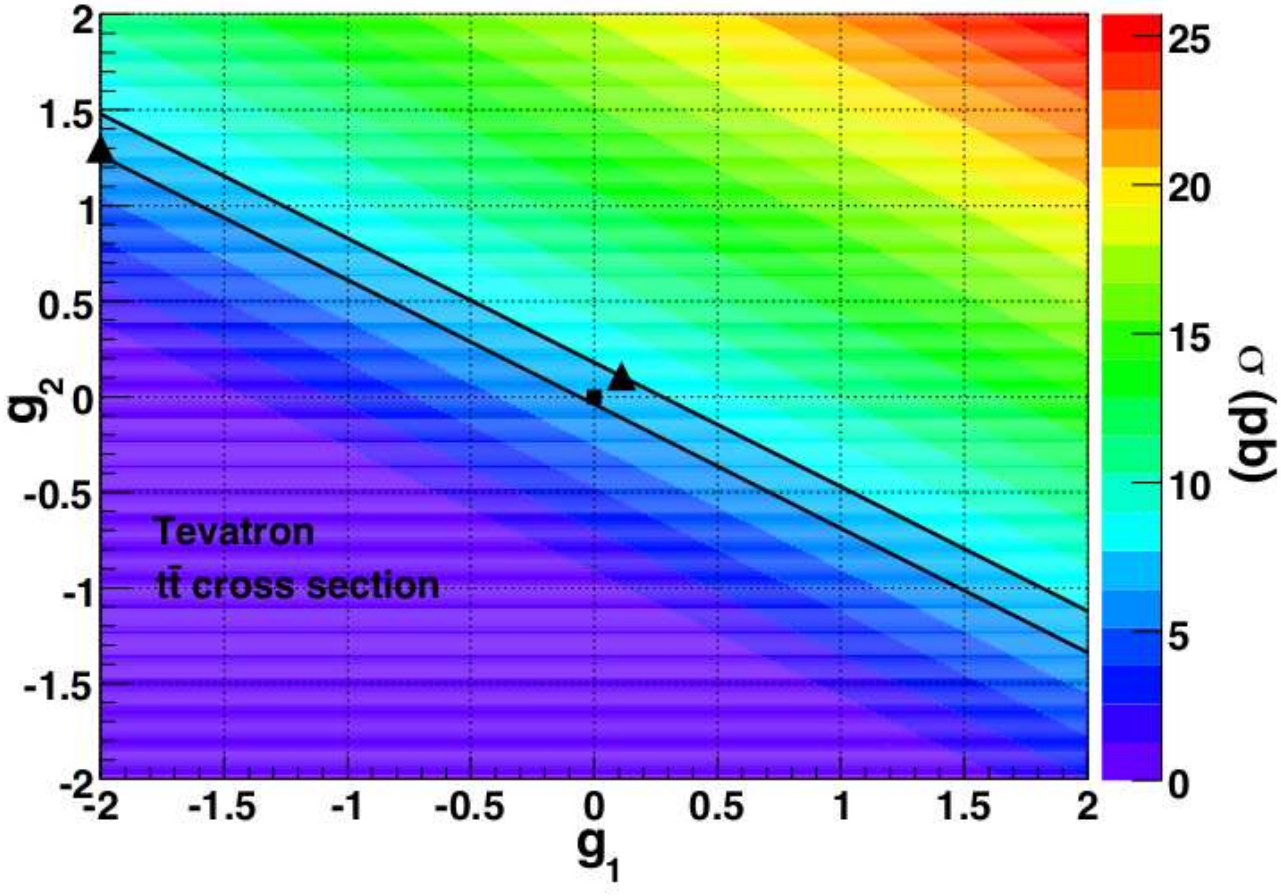
- SM cross section generated for $p\bar{p} \rightarrow t\bar{t}$ by Madevent reweighted event by event

$$\hat{\sigma} \propto |\mathcal{M}|^2 = |\mathcal{M}_{SM} + \mathcal{M}_{NP}|^2 = |\mathcal{M}_{SM}|^2 + 2\mathrm{Re}\left[\mathcal{M}^*_{SM}\mathcal{M}_{NP}\right] + O\left(\frac{1}{\Lambda^4}\right)$$

- Dropping higher order terms and rewriting NP cross section as proportional to SM cross section

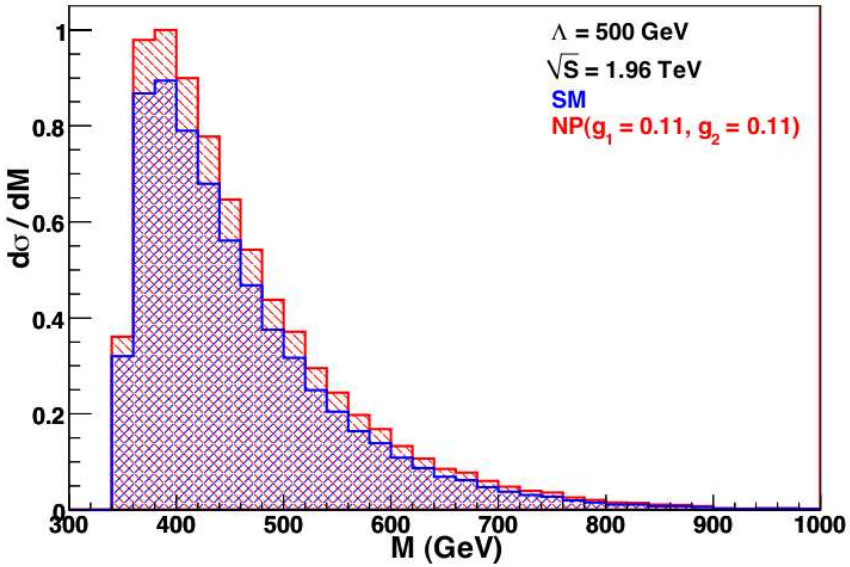
$$\hat{\sigma} = \sigma\hat{_{SM}}\left(1 + \mathrm{Re}\,\frac{g_1(16vms^2) + g_2(4m^2s^2 + s^3 + s(s+2t-2m^2)^2}{2\Lambda^2(2m^4 + s^2 - 4m^2t + 2st + 2t^2)}\right)$$

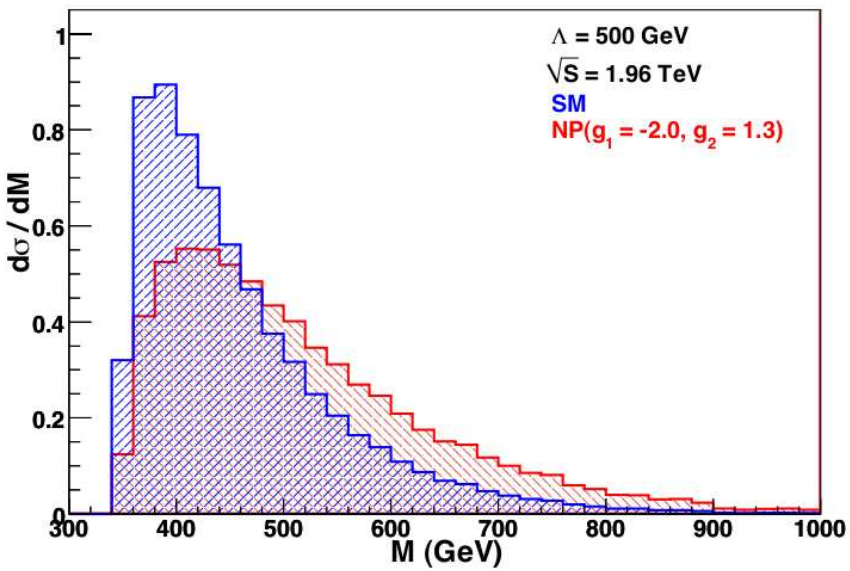
- At leading order, only the real parts of g_1 and g_2 contribute



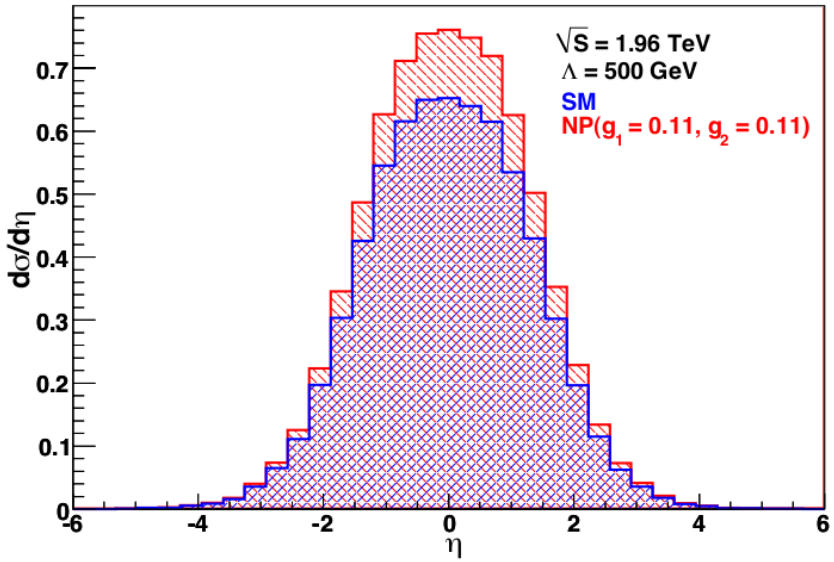
- Doesn't constrain New Physics very well because of potential cancellations between operators
- This serves as motivation to look at distributions.

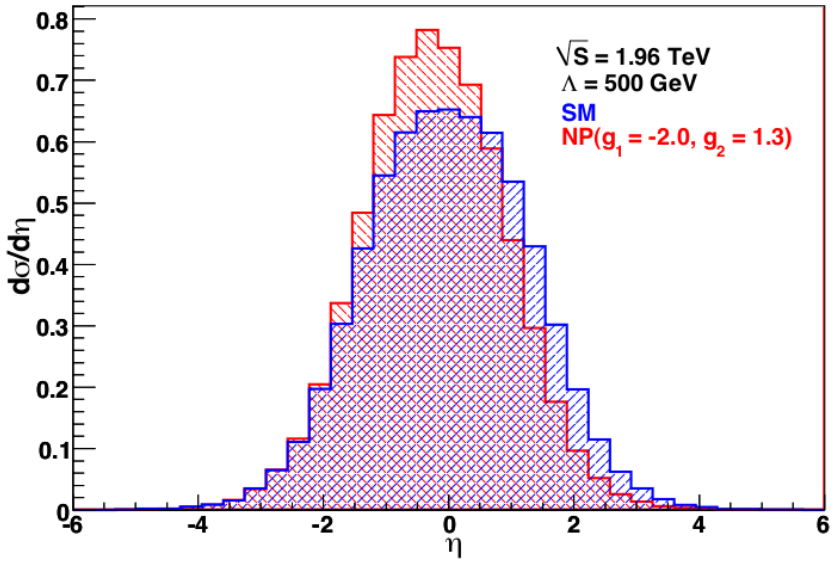
Distributions for PT 1(0.11, 0.11) and PT 2(-2,1.3)





- Studying invariant mass distribution.
- PT1 shows a slight shift to higher energies.
- PT2, which isn't eliminated from cross section considerations shows large deviations





- Studying rapidity distributions
- PT1 doesn't show significant asymmetry

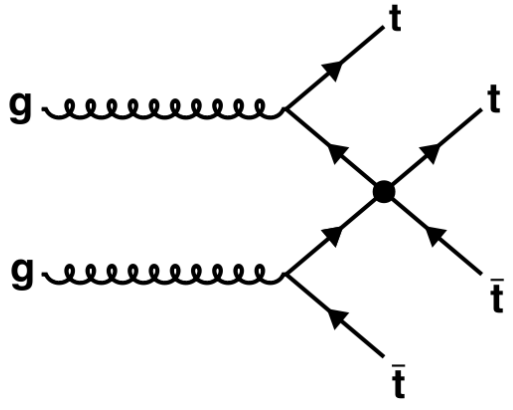
- PT2 is clearly more asymmetric

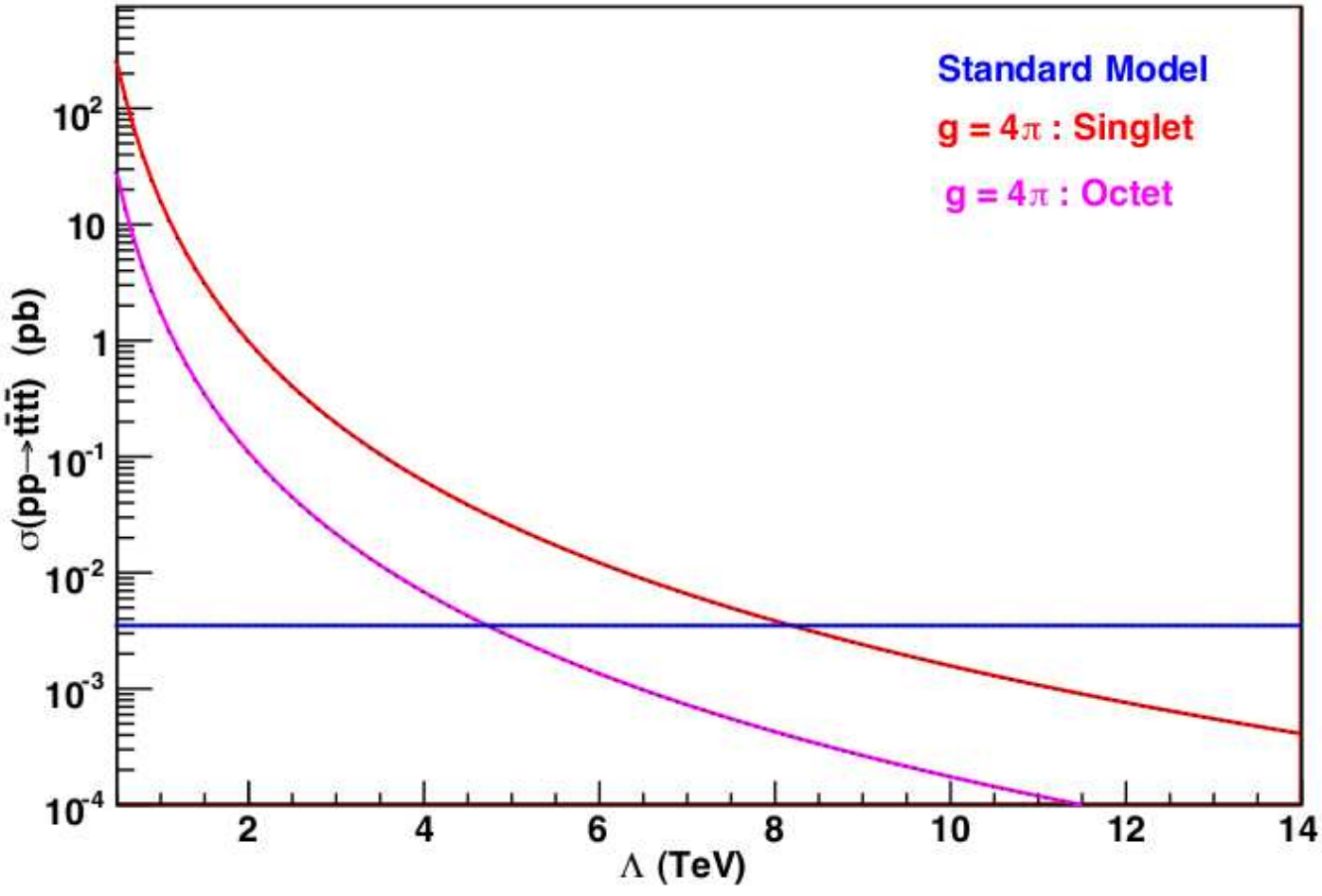
Tevatron Conclusion

- Order one values of g and Λ around 500 GeV are consistent with Tevatron data
- Analysis of distributions would help to come up with better constraints on the New Physics
- If the compositeness scale is indeed at 500 GeV, we could see constituents at LHC

LHC - Four tops

- Sufficient energy to consider processes mediated by four top operator
- Unlike the Tevatron, the gluon mediated process dominates
- Standard model cross section for four tops is small (3 fb)
- Implemented in Madevent by adding an Auxillary field (singlet or octet) to model effects of the dimension 6 operator.





- We see that for Λ below 5 GeV the correction to the standard model cross section is significant and could lead to a positive signal

Future Work

Tevatron

- Including effects of higher order terms and gluon initiated graphs
- Analysis of other distributions can lead to better constraints on the coefficients of dimension 6 operators

LHC

- A systematic study of four top signals