# Single and Pair Production of Excited Top Quarks in Hadronic Collisions

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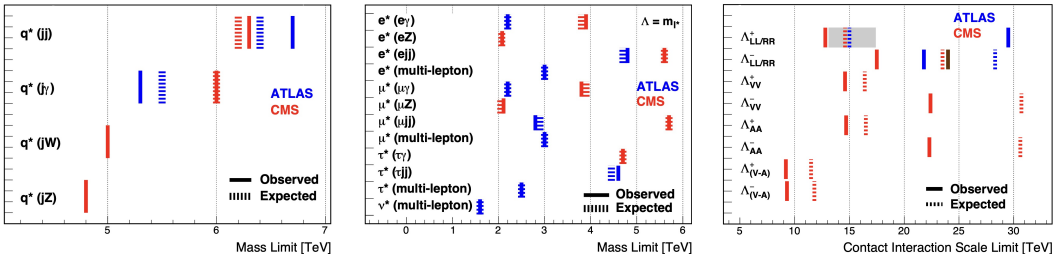
# What if fermions are composite?

- Compositeness generically predicts excited fermions $\ell^*$, $q^*$, $t^*$.
- Such states are expected at the compositeness scale $\Lambda$.

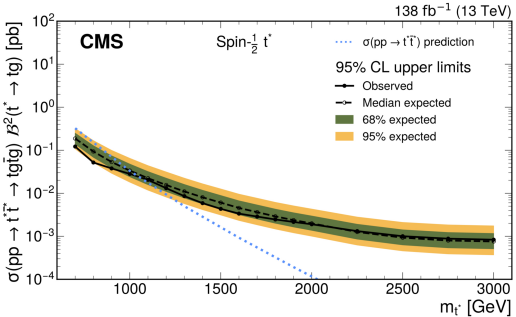



Particle Data Group, Phys. Rev. D 110, 030001 (2024), 2025 update

Current limits mainly probe light fermions.

# What if the top quark is not elementary?

- The top sector is a natural place to look for compositeness.: large mass, strong coupling, and excellent collider reach.
- We consider a minimal EFT with a single QCD magnetic transition operator.




CMS Collaboration, EPJC 85 (2025) 342

# Effective interaction

**Gauge interaction of the excited top:**

$$\mathcal{L}_{\rm kin} = \bar{t}^* \left( i\partial\!\!\!/ - g_{\rm s} T^A \mathcal{G}\!\!\!/^A \right) t^*. \tag{1}$$

*The whole story hangs on one operator.*

**Magnetic transition operator:**

$$\mathcal{L}_{\rm int} = \frac{f_{\rm s} g_{\rm s}}{\Lambda} \bar{t}^* \sigma^{\mu\nu} T^A t_{\rm R} G^A_{\mu\nu} + {\rm h.c.} \tag{2}$$

$$\mathcal{B}(t^* \to tg) \simeq 1. \tag{3}$$

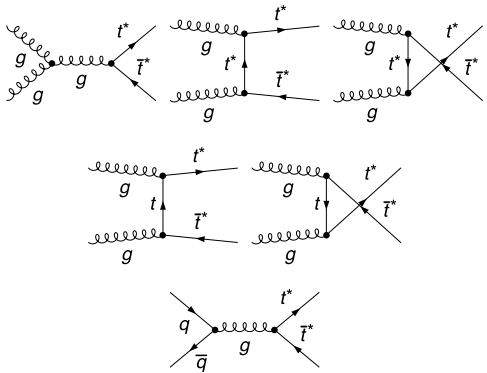
Alhazmi et al., JHEP 01 (2019) 139

Minimal model, maximal lesson:
pair production is QCD-dominated, while single production directly probes the compositeness scale $\Lambda$.

# Production of excited top quarks

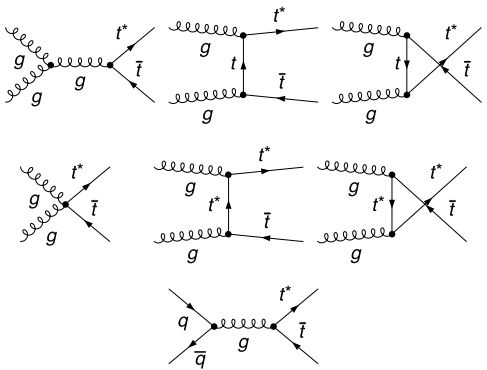
Two qualitatively different mechanisms

Pair production




QCD dominated mechanism

Single production




Driven by the magnetic operator

*Topology is similar; scaling is not.*

# Analytic partonic cross sections for pair production

Pair-production cross section naturally separates into

$$\sigma(gg \to \bar{t}^* t^*) = \sigma_0 + \sigma_4 + \sigma_2. \tag{4}$$

pure QCD + interference + magnetic contribution

$$\sigma_0 = \frac{\pi\alpha_s^2}{48s}\left\{(33 - 18\beta_2^2 + \beta_2^4)\ln(\frac{1+\beta_2}{1-\beta_2}) - 59\beta_2 + 31\beta_2^3\right\}. \tag{5}$$

$m_{t^*} \gg m_t$:

$$\sigma_4 = \frac{f_s^4}{\Lambda^4}\frac{\pi\alpha_s^2 s}{768}\beta_2^2\left[(1-\beta_2^2)^2\ln(\frac{1+\beta_2}{1-\beta_2}) + 2\beta_2\left(\frac{5}{3} - \beta_2^2\right)\right], \tag{6}$$

$$\sigma_2 = \frac{f_s^2}{\Lambda^2}\frac{\pi\alpha_s^2}{3072}\left[(1-\beta_2^2)\left(\frac{192}{3+\beta_2^2} - 25 + 58\beta_2^2 - 9\beta_2^4\right)\ln(\frac{1+\beta_2}{1-\beta_2}) - 2\beta_2\left(39 - 64\beta_2^2 + 9\beta_2^4\right)\right]. \tag{7}$$

$$\sigma(q\bar{q} \to \bar{t}^* t^*) = \frac{4\pi\alpha_s^2}{27s}\beta_2\left(3 - \beta_2^2\right). \tag{8}$$

$$\beta_2 = \sqrt{1 - \frac{4m_{t^*}}{s}}. \tag{9}$$

# Analytic partonic cross sections for single production

Single production appears only through the magnetic operator.

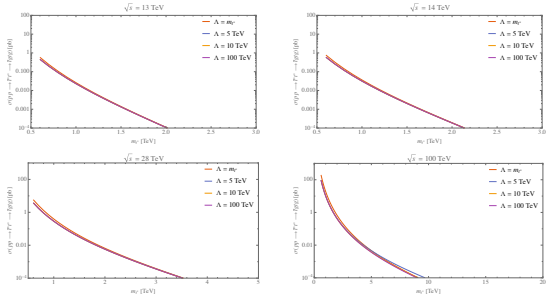
$$\sigma(gg \to \bar{t}t^*) = \frac{\pi\alpha_s^2}{1536}\frac{f_s^2}{\Lambda^2}\Bigg\{8\beta_1\left(15-3\beta_1^2+68\delta^2\right)$$
$$-\left[1+\delta\left(55+\delta\left[143+\delta\left(153+8\delta\right)\right]\right)-2\beta_1^2\left(3+9\delta+4\delta^2\right)+\frac{8\left(1-\beta_1^2\right)^2}{\delta}+\frac{\beta_1^2\left(4+\beta_1^2\right)}{1+\delta}\right]\ln\left(\frac{1+\beta_1+\delta}{1-\beta_1+\delta}\right)$$
$$-\left[1-\delta\left(55-\delta\left[143-\delta\left(153-8\delta\right)\right]\right)-2\beta_1^2\left(3-9\delta+4\delta^2\right)-\frac{8\left(1-\beta_1^2\right)^2}{\delta}+\frac{\beta_1^2\left(4+\beta_1^2\right)}{1-\delta}\right]\ln\left(\frac{1+\beta_1-\delta}{1-\beta_1-\delta}\right)\Bigg\}. \tag{10}$$

$$\sigma(q\bar{q} \to \bar{t}t^*) = \frac{\pi\alpha_s^2}{108}\frac{f_s^2}{\Lambda^2}\beta_1\left[3\left(1-\delta^2\right)-\beta_1^2\right]. \tag{11}$$

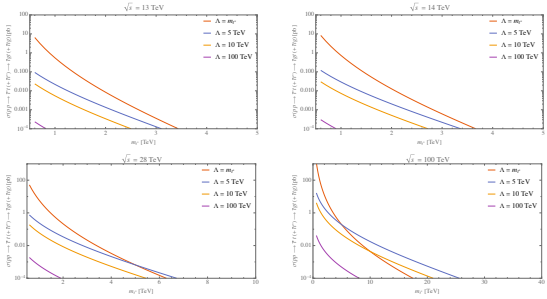
$$\beta_1 = \frac{\lambda^{1/2}(m_{t^*}^2, m_t^2, s)}{s}, \quad \delta = \frac{m_{t^*}^2 - m_t^2}{s}. \tag{12}$$

# Numerical results

**Pair production**

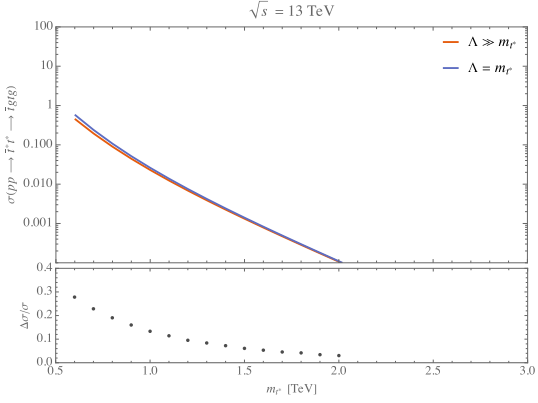


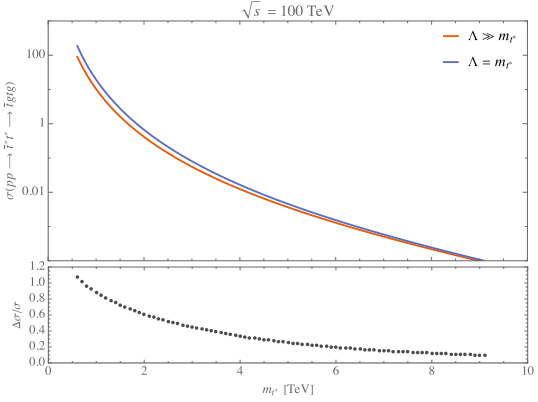

**Single production**



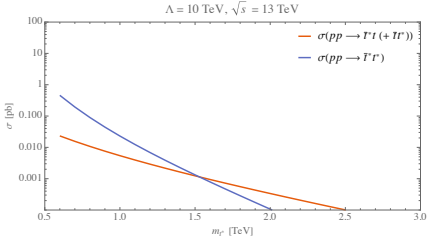

- cross sections decrease rapidly with $m_{t^*}$
- higher collider energies extend the mass reach

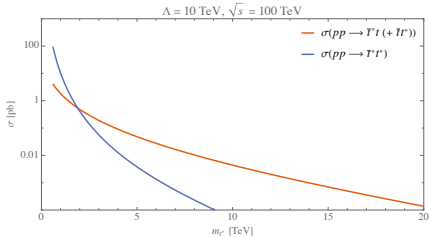
# Numerical results

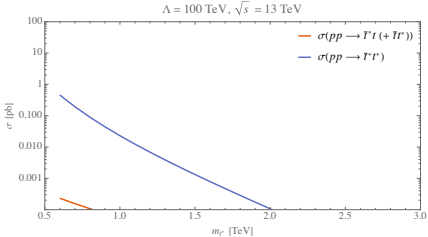


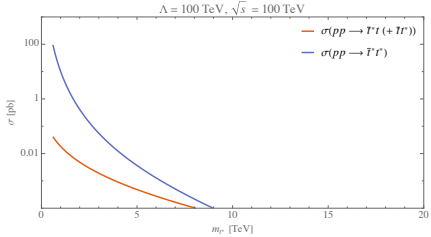



# Single vs Pair production



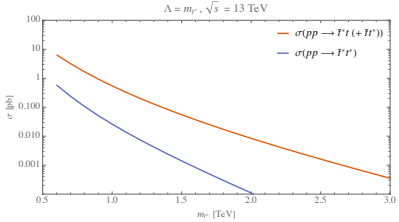



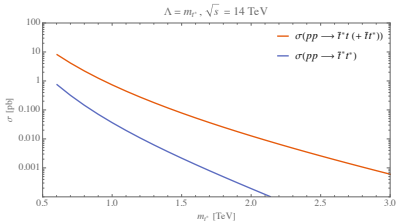



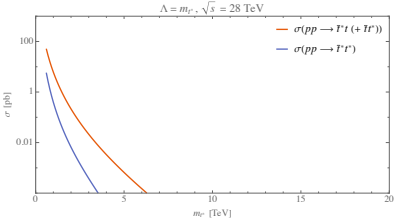



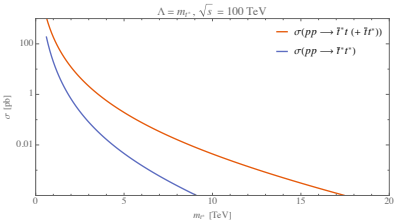
# Single vs Pair production

Natural scenario: $\Lambda = m_{t^*}$




Single production dominates

# Conclusions

- Excited top production studied in a minimal EFT framework.
- Analytic partonic cross sections derived.
- Pair production is QCD dominated.
- Single production probes the compositeness scale and can dominate for $\Lambda \sim m_{t^*}$.

Future colliders extend the discovery reach.

Thank you for your attention!

Questions?