SINGLE HEAVY-QUARK PRODUCTION
AT HADRON COLLIDERS

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• A \textit{stealth} gluon of mass below 1 TeV can explain the $t\bar{t}$ FB asymmetry
• Does $A^{t\bar{t}}$ come alone? Single heavy-quark production
• Search for \( q\bar{q} \rightarrow G \rightarrow T\bar{t}, B\bar{b} \) at the LHC


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• The $t\bar{t}$ forward-backward asymmetry measured at the Tevatron is an order 1 (three $\sigma$) departure from the SM physics at $\sqrt{s} \approx 400–800$ GeV

CDF:

$$A^{t\bar{t}} \approx \begin{cases} 
-0.116 \pm 0.153, & m_{t\bar{t}} < 450 \text{ GeV} \\
0.475 \pm 0.114, & m_{t\bar{t}} > 450 \text{ GeV}
\end{cases}$$

D0:

$$A^{l}_{FB} \approx \begin{cases} 
0.127 \pm 0.055 & (l^{+}) \\
0.156 \pm 0.050 & (l^{-})
\end{cases}$$
• $s$-channel resonance (gluon excitation $G$) strongly coupled to the top quark, with smaller and mostly axial couplings to the light quarks, light enough to compete with QCD at Tevatron energies ($M_G < 1$ TeV). Appears naturally in holographic models.

• Why the Tevatron and the LHC do not see a peak at $m_{t\bar{t}} \approx M_G$?
• The strong coupling of $G$ to the top quark requires a proper treatment of its (energy-dependent) width:

\[
A \propto g^2 \left( \frac{1}{\hat{s}} + \frac{g^q g^t}{\hat{s} - M_G^2 + i\sqrt{\hat{s}} \Gamma_G(\hat{s})} \right)
\]

\[
\Gamma_{t\bar{t}}^G(\hat{s}) = \theta(\hat{s} - 4m_t^2) \frac{g^2}{24\pi} \frac{\hat{s}}{M_G} \beta_t \left[ \beta_t^2 g_A^{t2} + \left( \beta_t^2 + \frac{6m_t^2}{\hat{s}} \right) g_V^{t2} \right]
\]

• If $\Gamma_G$ is large, a constant width suppresses the effect of the gluon at $\hat{s} \ll M_G^2$. 
• A larger coupling of the top quark to $G$ increases $A^{t\bar{t}}$ and dilutes the peak (left figure).

• Adding a new decay channel for $G$ at $\sqrt{s} \approx 600$ GeV that increases its width further reduces top-quark production above that energy (right figure). $A^{t\bar{t}}$ at $m_{t\bar{t}} \leq 600$ GeV is unaffected.
• **STEALTH GLUON**: mass below 1 TeV, large width that makes the peak invisible at hadron colliders. Order 1 effect on top-quark physics at $m_{t\bar{t}} \leq 600$ GeV and new decay modes at higher energies:

$$q\bar{q} \rightarrow G \rightarrow T\bar{t}, \ B\bar{b}, \ Q\bar{q}$$

- $Q\bar{q} \rightarrow (Wq')q$
- $T\bar{t} \rightarrow (Wb)W\bar{b}$
- $B\bar{b} \rightarrow (Wt)\bar{b} \rightarrow (WWb)\bar{b}$

• Single $T$ or $B$ production gives the same final state as

$$q\bar{q} \rightarrow g \rightarrow t\bar{t} \rightarrow W^+bW^-\bar{b}$$
• Would the $T\bar{t}$ channel introduce an observable anomaly in current $t\bar{t}$ searches? How to perform a specific search?

Events with four jets (at least one of them tagged as a bottom), plus lepton, plus missing $p_T$. The reconstruction of the $t$ quarks is obtained minimizing a $\chi^2$.
One could instead reconstruct a $t$ quark plus a $T$ quark of arbitrary mass. Improves the $\chi^2$. We can then plot the reconstructed mass of the $T$ quark, and require (i) $\chi^2 \leq 5$; (ii) $m_{tt} \geq 600$ GeV.
\begin{itemize}
  \item $B\bar{b}$ production could also introduce anomalies in current $t\bar{t}$ searches.
  \item One could reconstruct only one top quark plus a $W$ boson in events of $m_{t\bar{t}} > 500, 700$ GeV, and plot the invariant mass.
\end{itemize}
• $2b + 2W$ is also studied in the search for $T\bar{T}$ pairs. Same final state as in $tt\bar{t}$ production but different cuts (larger transverse momenta). Reconstruction of two quarks with the same mass $M$.

$$q\bar{q} \rightarrow g \rightarrow T\bar{T} \rightarrow W^+b \ W^-\bar{b}$$
The processes \( q\bar{q} \rightarrow T\bar{t}, B\bar{b} \) would affect these analyses.
• Again, a plot of the reconstructed mass of the massive $T$ quark in events of $m_{t\bar{t}} > 600$ GeV would reveal a clear peak at $M_T$. 

![Graph showing event distribution](attachment:image.png)
Summary

If new physics is the explanation of the $t\bar{t}$ FB asymmetry, it should be relatively light (below 1 TeV) and strongly coupled.

A very wide gluon resonance would work. A stronger coupling to the top quark provides a larger asymmetry and weaker effects near the gluon peak. Stealth gluon: new decay channels $q\bar{q} \rightarrow G \rightarrow Q\bar{q}$ open at 600 GeV, suppressing $q\bar{q} \rightarrow G \rightarrow t\bar{t}$ at $m_{t\bar{t}} > 600$ GeV. $G$ is a very wide resonance at $m_{t\bar{t}} \approx M_G$ that becomes narrow at $m_{t\bar{t}} < 600$ GeV.

Natural scenario in Higgsless models. Csaki, Grojean, Murayama...

$q\bar{q} \rightarrow G \rightarrow T\bar{t}, B\bar{b}$ have same $2W + 2b$ final state but are easy to miss in current $t\bar{t}$ studies. Taylored analyses could optimize the search at the LHC.