Single Vector-Like Quark Production via Chromo-magnetic Moment at the LHC

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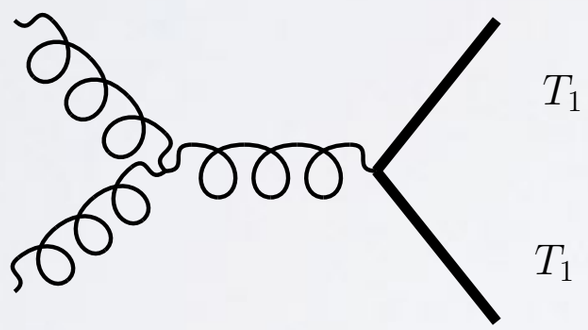
with Alexander Belyaev, R. Sekhar Chivukula, Benjamin Fuks, and Elizabeth Simmons
to appear on arXiv soon

Top-Partner at LHC

- Top-partners are important for solving naturalness problem.

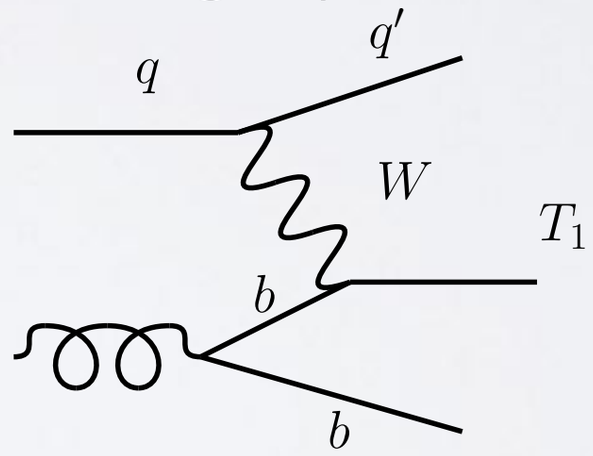
- They have been actively searched at LHC.

QCD pair production



- Model independent
- Strong couplings
- Kinematically expensive

EW single production



- Depend on mixing (L)
- EW couplings
- Kinematically affordable

$$\text{current bound } m_T \lesssim 1.5 \text{ TeV}$$

Simplified Model

- Partial compositeness:

$$\text{Elementary} \quad q_L = \begin{pmatrix} t_L^0 \\ b_L^0 \end{pmatrix} \quad \& \quad t_R^0,$$

$$\text{Composite} \quad Q_L^0 = \begin{pmatrix} T_{L,R}^0 \\ B_{L,R}^0 \end{pmatrix} \quad \& \quad \tilde{T}_{L,R}^0$$

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$$\mathcal{L}_{mass} = -M_Q \bar{Q} Q - M_{\tilde{T}} \bar{\tilde{T}} T - y^* (\bar{Q}_L \tilde{\phi} \tilde{T}_R + \bar{Q}_R \tilde{\phi} \tilde{T}_L) + h.c.$$

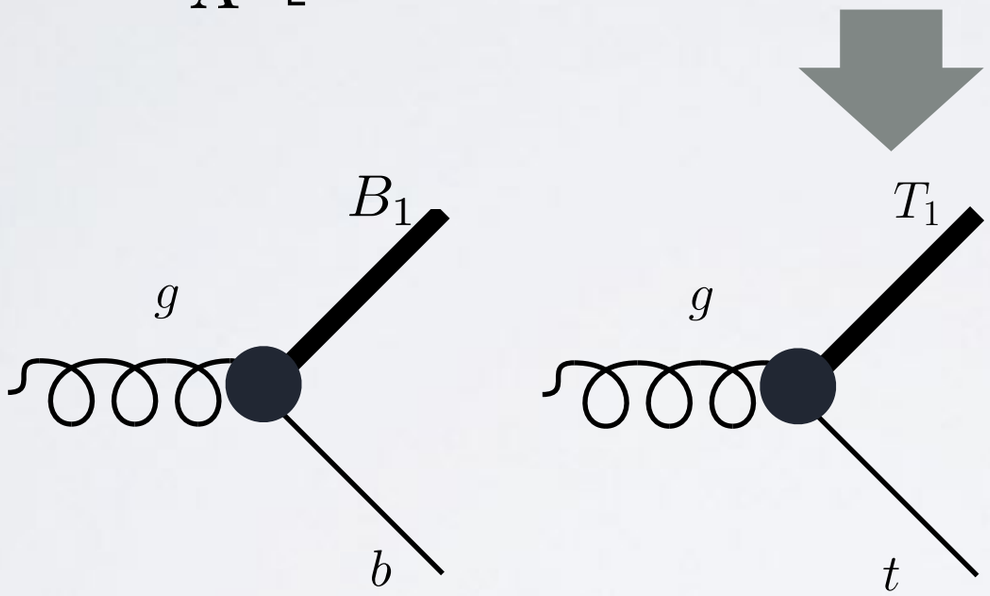
$$-\Delta_L \bar{q}_L Q_R - \Delta_R \bar{t}_R \tilde{T}_L + h.c.$$ mixing

$$\epsilon_L = \frac{\Delta_L}{M_Q}, \quad \epsilon_R = \frac{\Delta_R}{M_{\tilde{T}}} \qquad m_t \simeq \frac{\Delta_L \Delta_R y^* v}{\sqrt{2}(M^2 - m^2)}$$

Chromo-magnetic Moment

- If composite fermions carry chromo-magnetic moment,

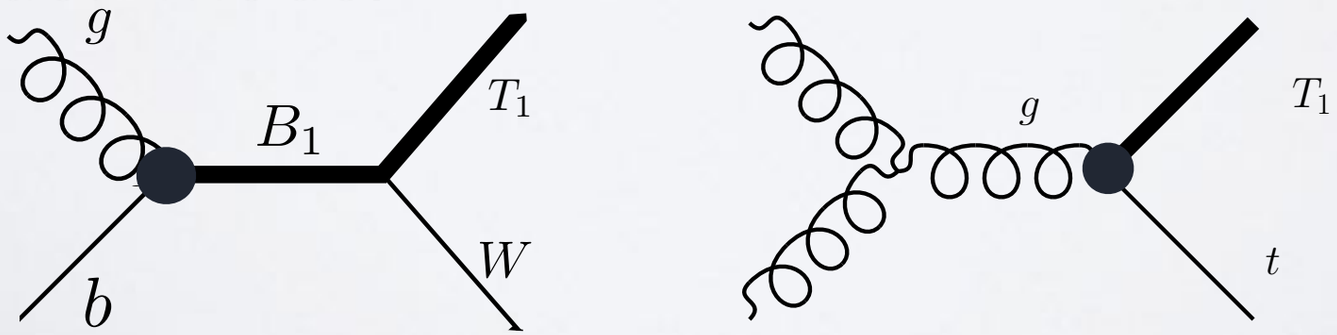
$$\mathcal{L} = \frac{g_s}{\Lambda}\left[\bar{T}_L^0 \sigma^{\mu\nu} G^a_{\mu\nu} T^a T_R^0 + \bar{\tilde{T}}_L^0 \sigma^{\mu\nu} G^a_{\mu\nu} T^a \tilde{T}_R^0\right] + h.c.$$



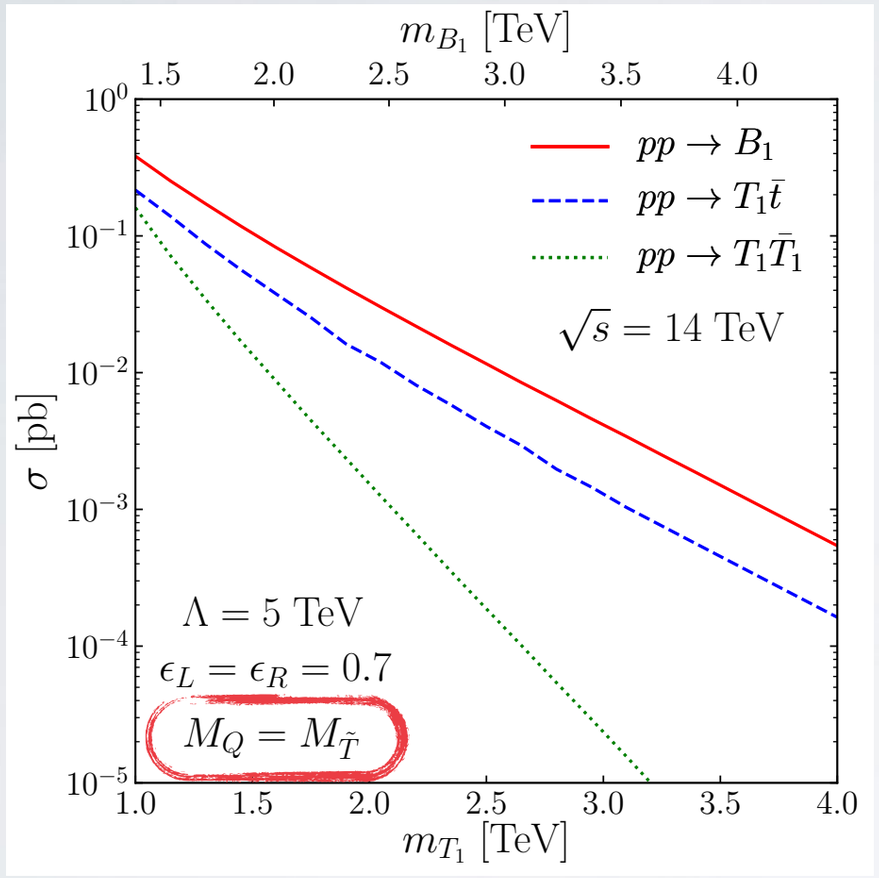
$$\sim \frac{g_s}{\Lambda}\frac{\Delta}{M}\bar{F}\sigma^{\mu\nu}G^a_{\mu\nu}T^a f$$

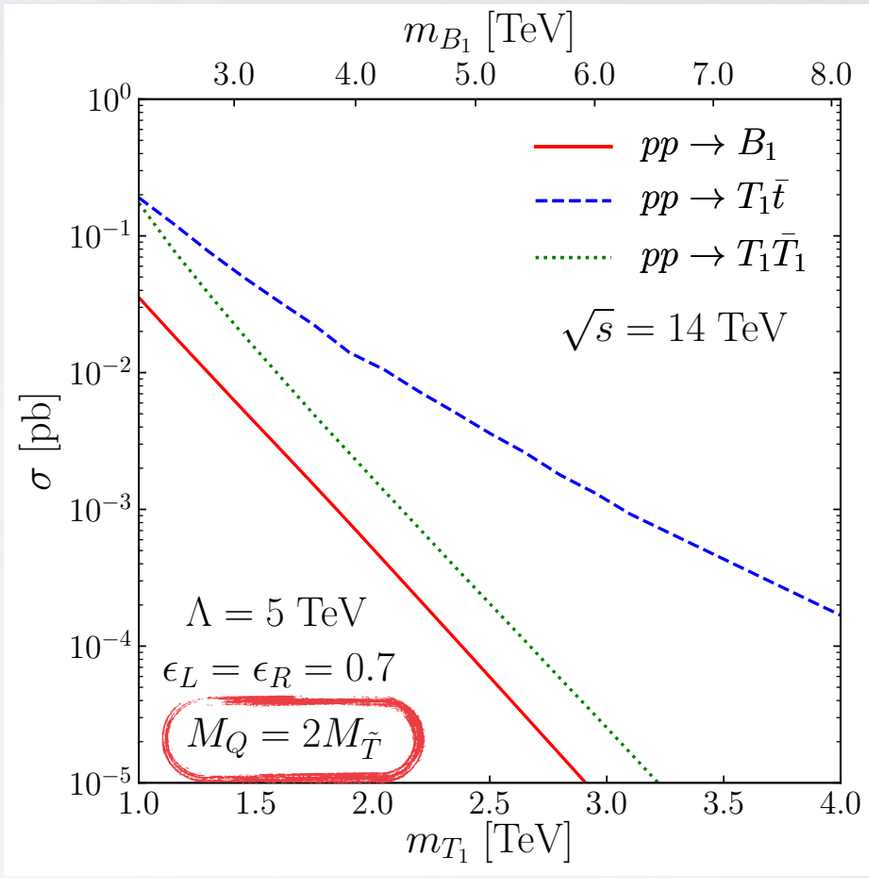
(analogous to proton magnetic dipole moment)

- Production mode.



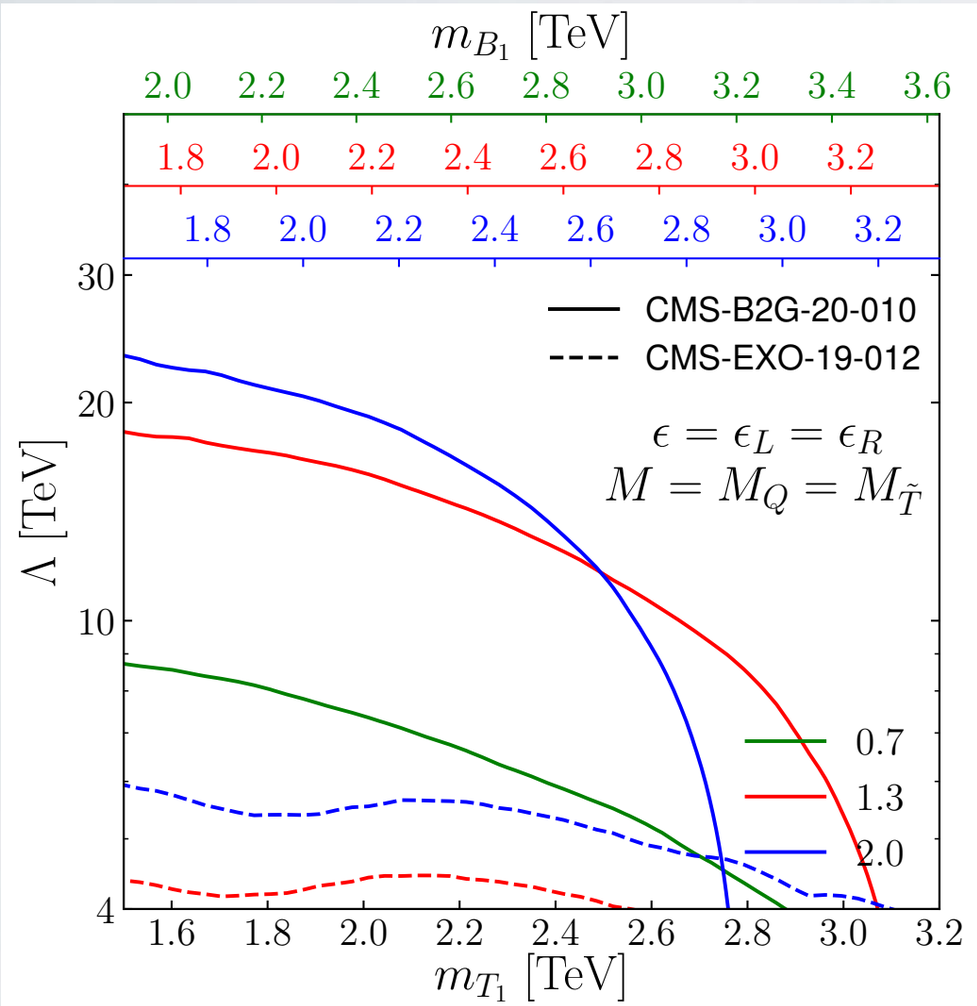
Production





- For $M_{T_1} \gtrsim 1$ TeV, tT_1 exceed pair production.
- B_1 production dominates if $m_{B_1} \sim m_{T_1}$

Single Production of B_1



Search for a heavy resonance decaying into a top quark and a W boson in the lepton+jets final state at 13 TeV

$B_1 \to tW$

The CMS Collaboration

CMS B2G-20-010

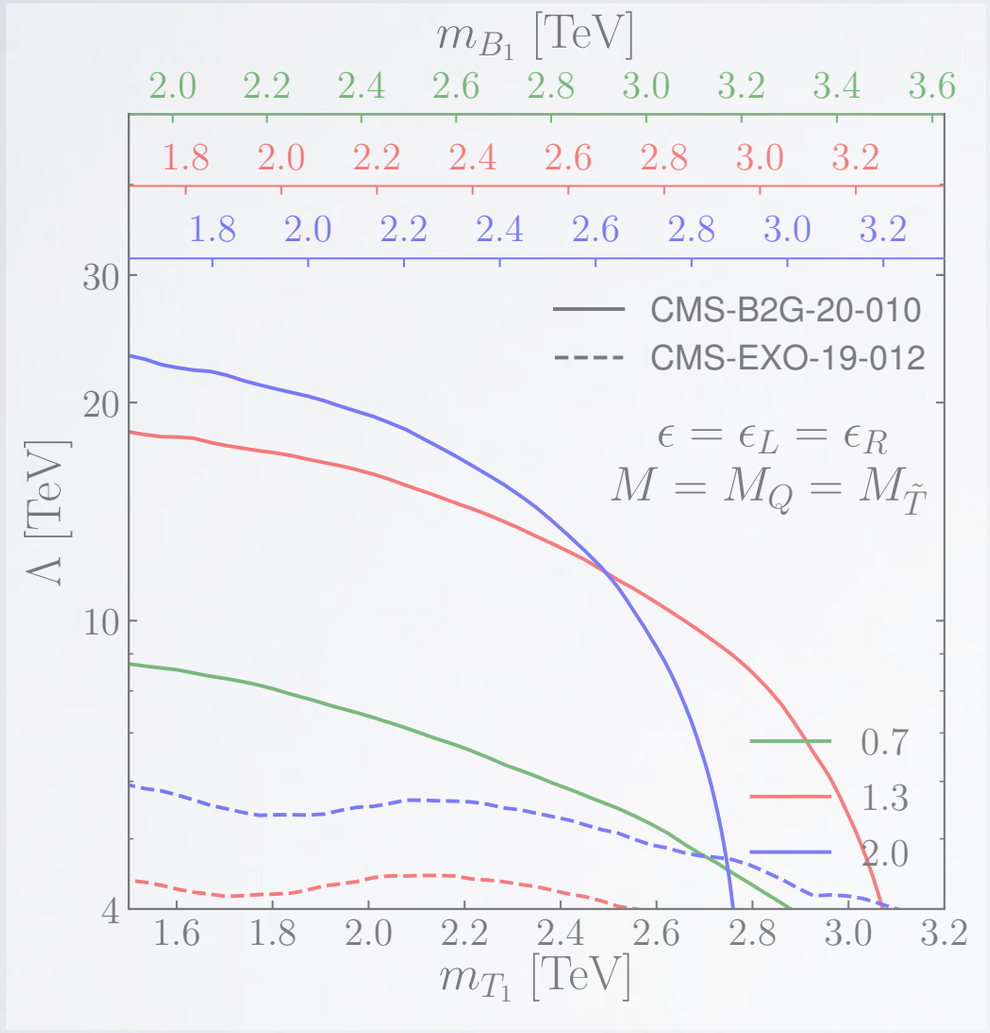
Search for high mass dijet resonances with a new background prediction method in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$

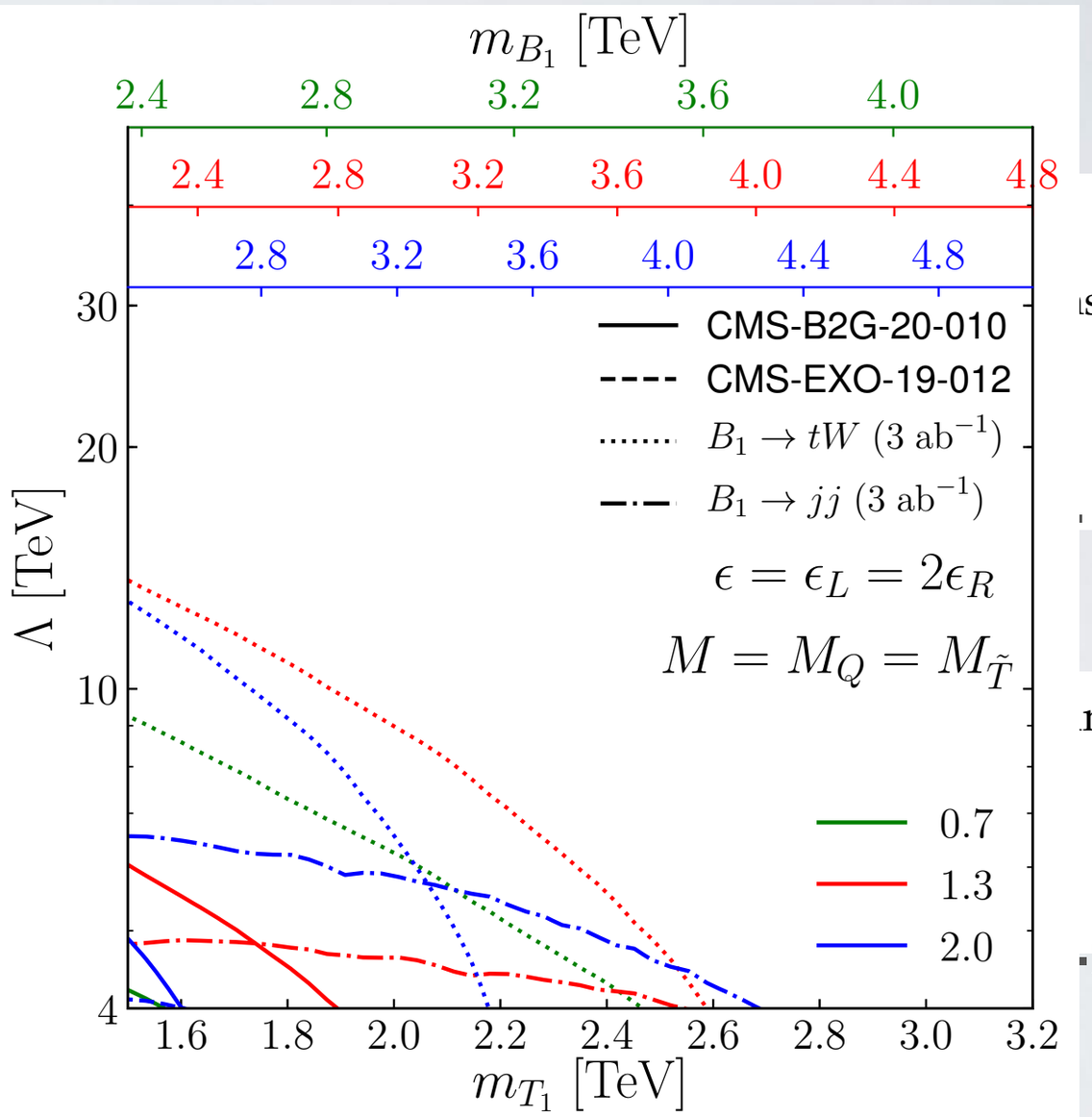
$B_1 \to bg$

The CMS Collaboration*

CMS EXO-19-012

Single Production of B_1

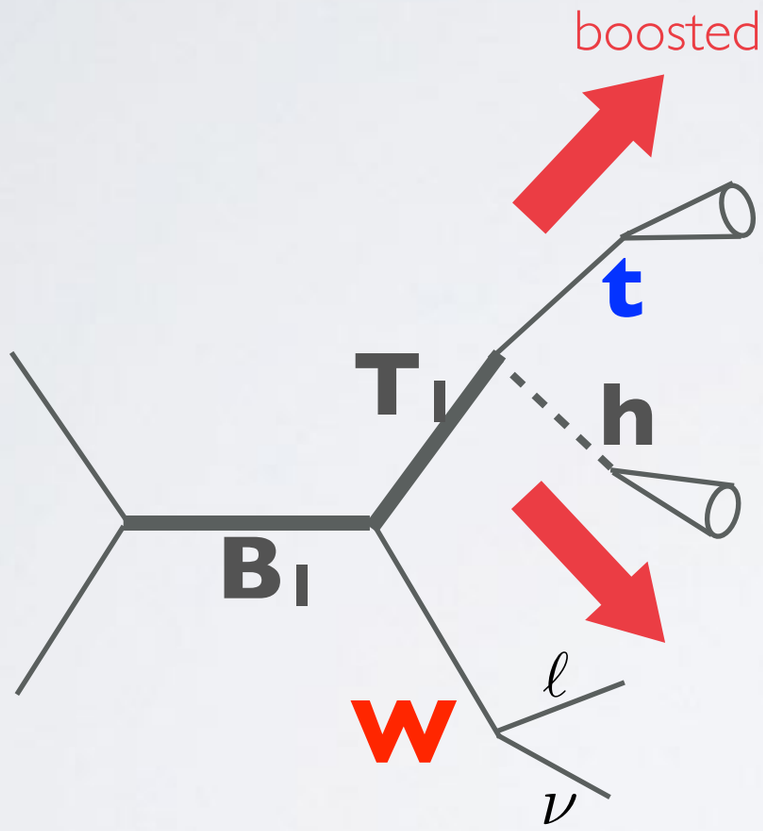


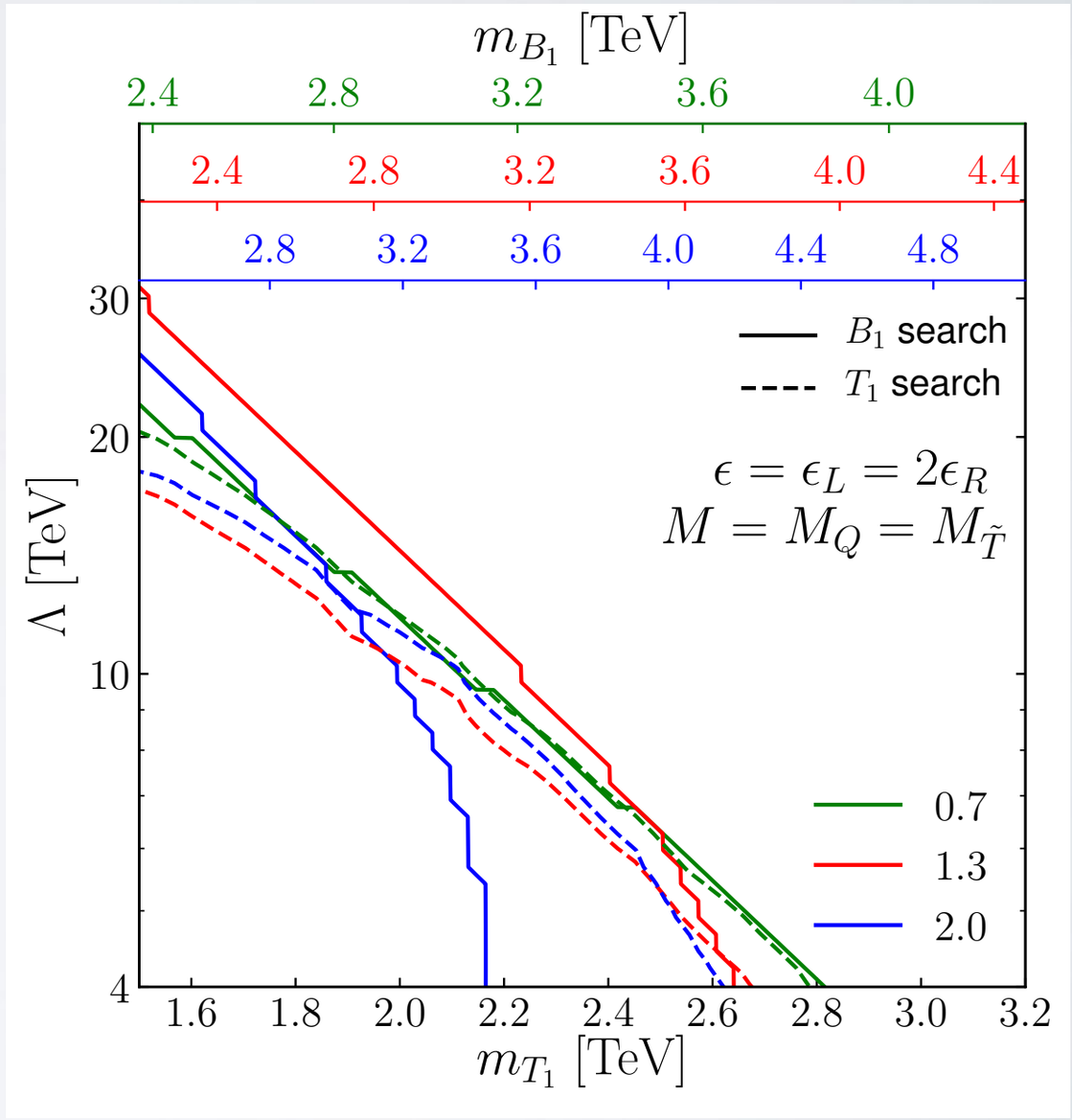


$B_1 \to T_1 W$ dominates once $m_{B_1} - m_{T_1} \gg m_W$

Single Production of B_1

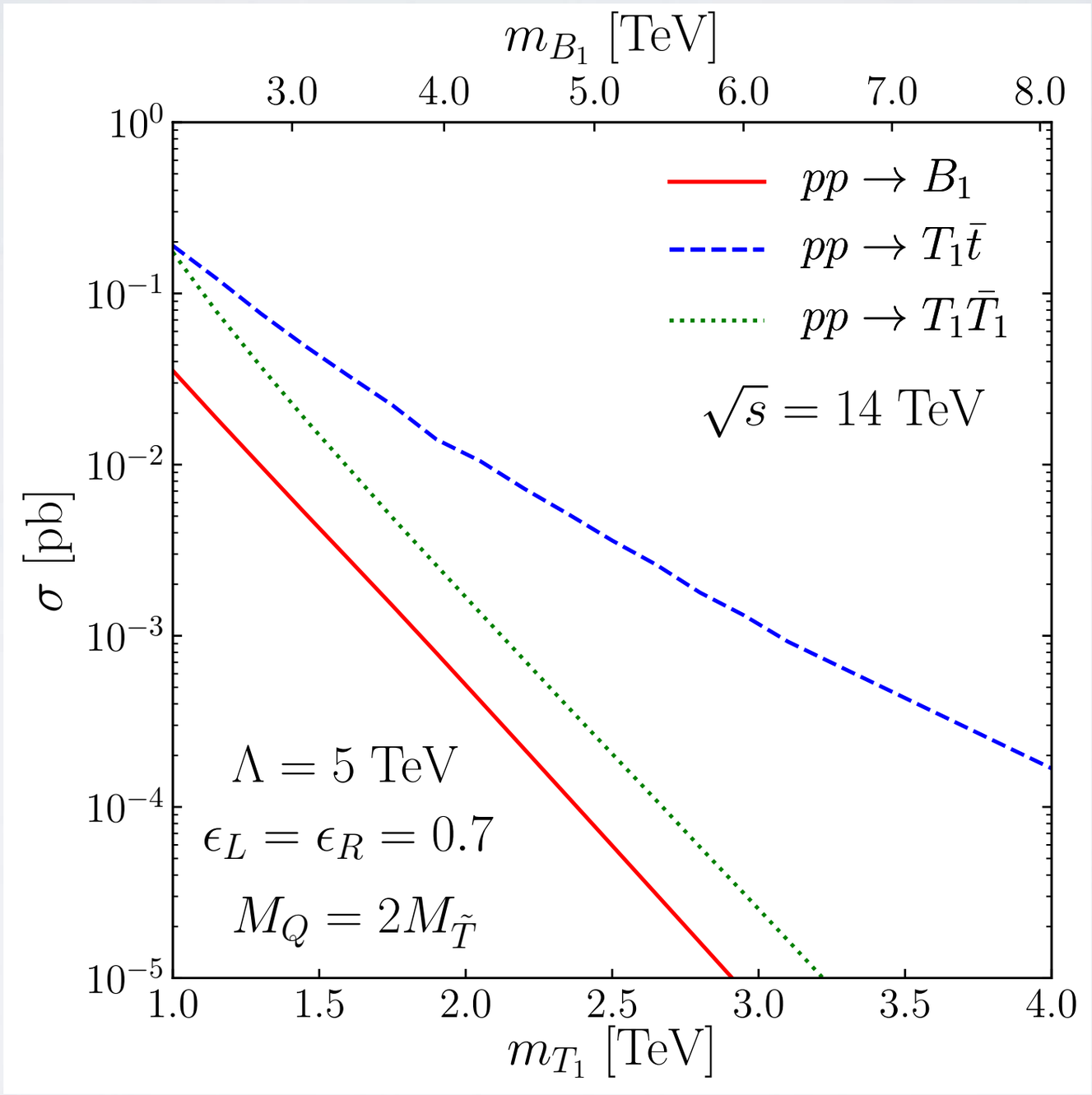
$$B_1 \to T_1 W^- \quad T_1 \to t\ h,\ h \to b\bar{b}$$



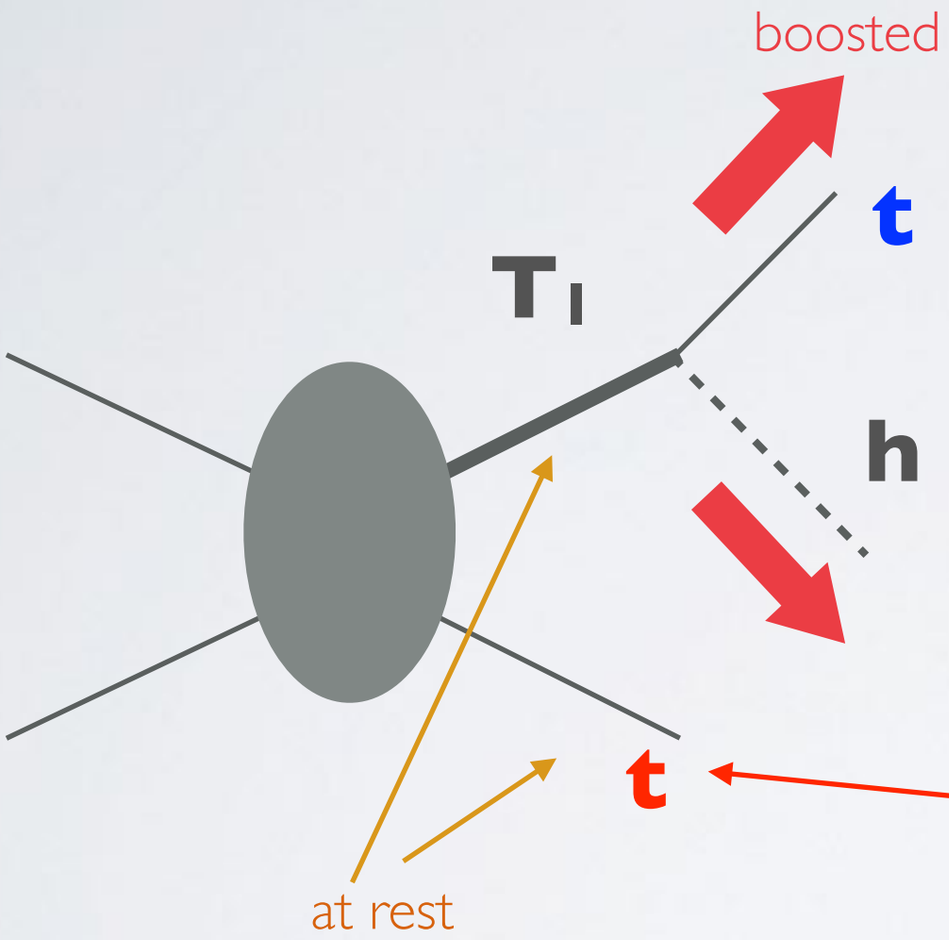


- Madgraph + Pythia + Delphes
- Dominant background $t\bar{t} + \text{jets}$
- Event selection optimized with XGBoost

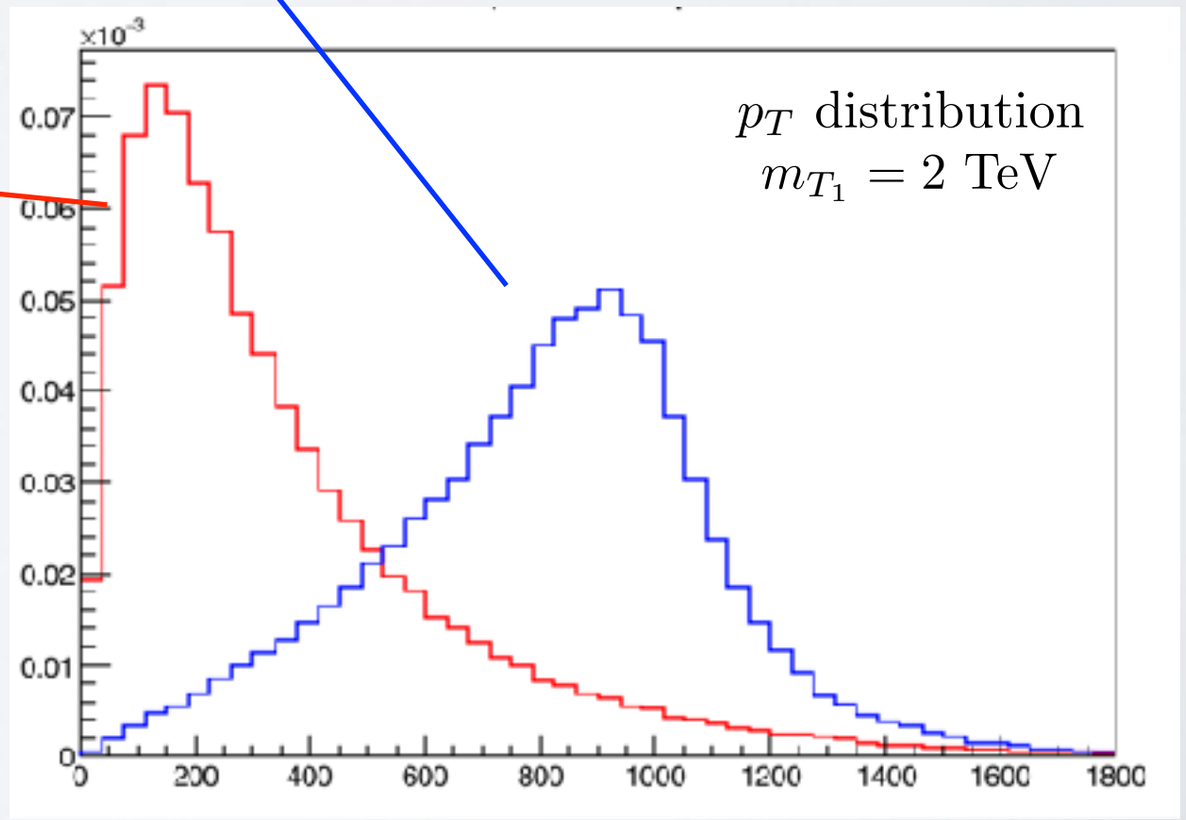
Single Production tT_1



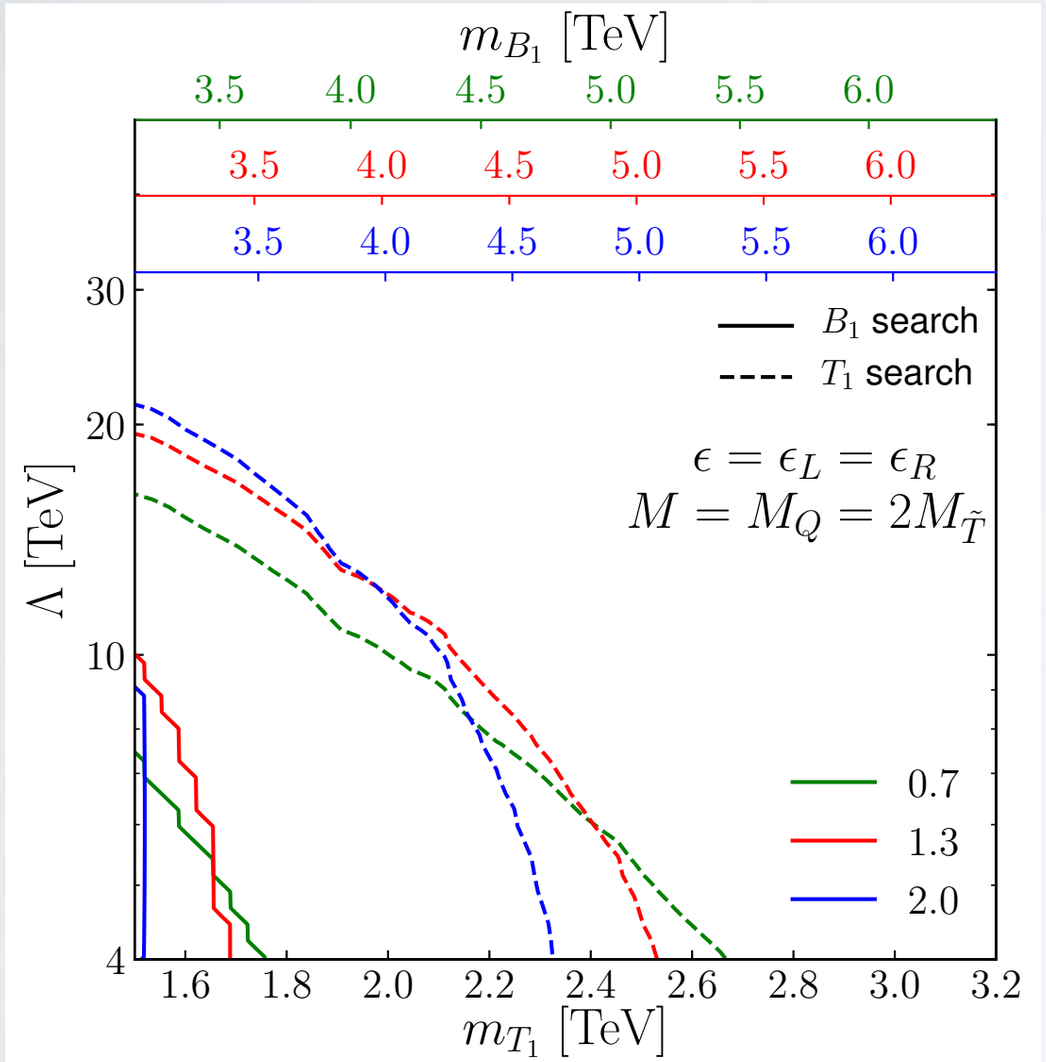
Single Production tT_1

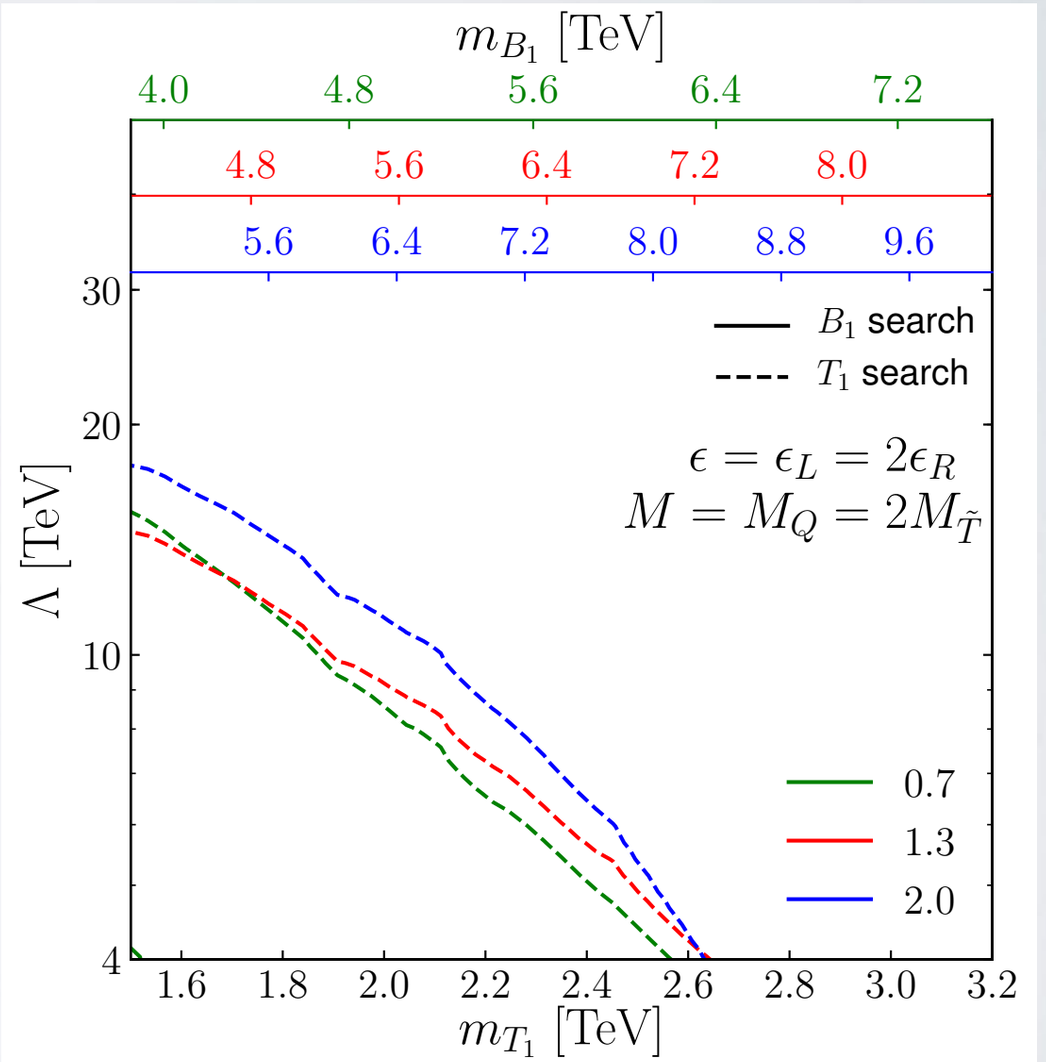


- Asymmetric top pair
- Fewer combinatorial issues
- Boosted objects



Single Production tT_1

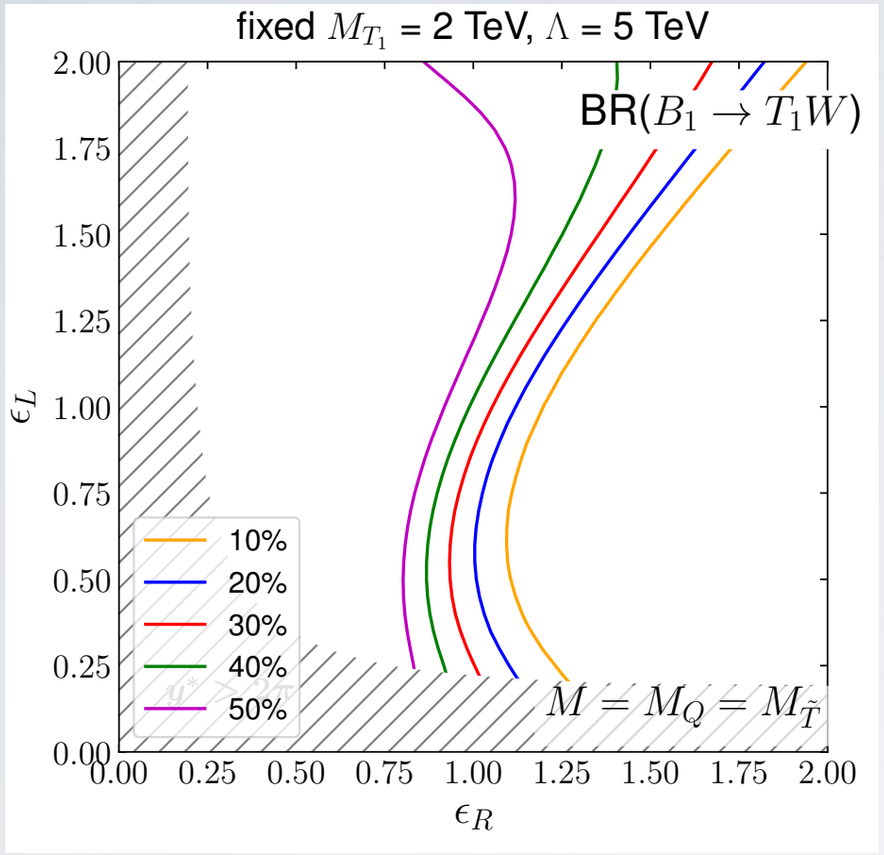


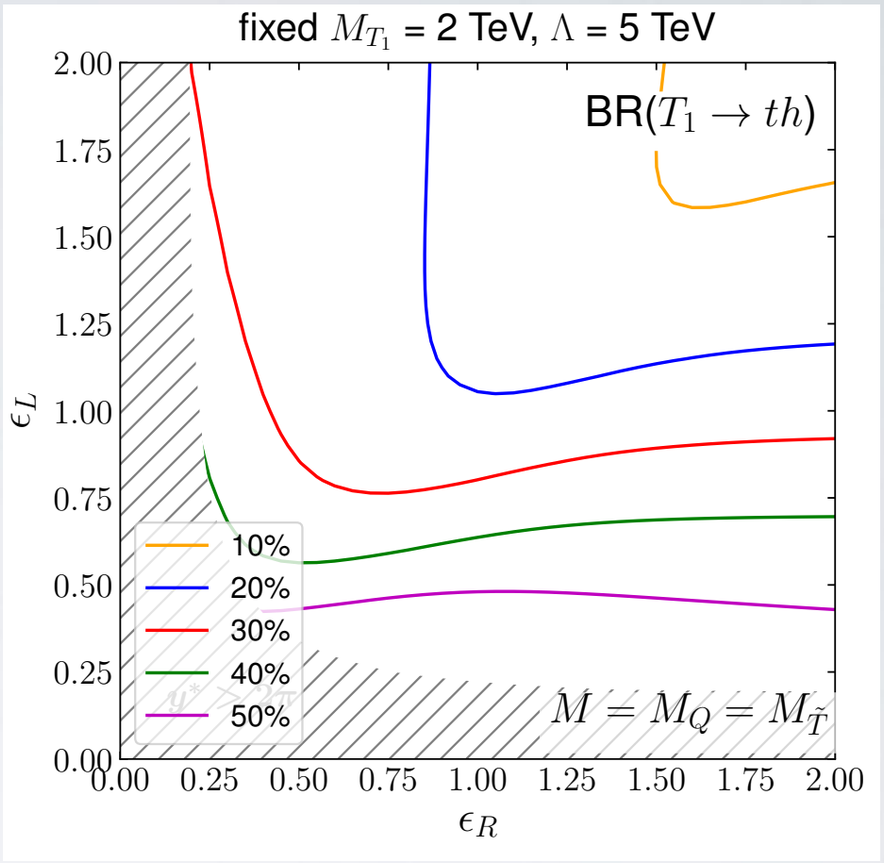


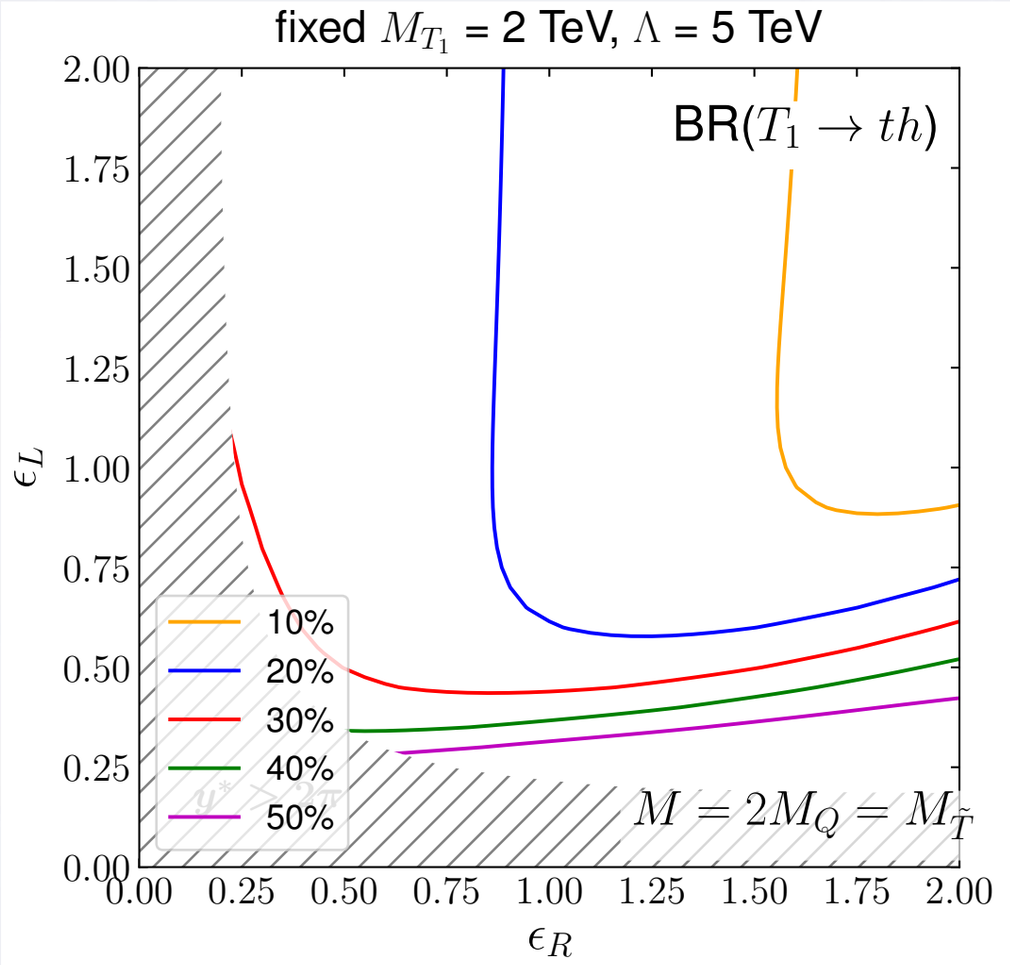
Summary

- Chromo-magnetic moment interaction leads to new production modes
- We study $B_1 \to T_1 W^-$ channel, complementary to the current searches
- Single production tT_1 is more kinematically affordable
- In $T_1 \to t\ h$, channel, top-partner can be probed up to ~2.7 TeV.

Back-ups


fixed M_{T_1} = 2 TeV, Λ = 5 TeV
BR($B_1 \to T_1 W$)
10%
20%
30%
40%
50%
$y^* > 3$
$M = M_Q = M_{\tilde{T}}$
ϵ_L
ϵ_R
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00


fixed M_{T_1} = 2 TeV, Λ = 5 TeV
BR($T_1 \to th$)
10%
20%
30%
40%
50%
$y^* > 3$
$M = M_Q = M_{\tilde{T}}$
ϵ_L
ϵ_R
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00


fixed M_{T_1} = 2 TeV, Λ = 5 TeV
BR($T_1 \to th$)
10%
20%
30%
40%
50%
$y^* > 3$
$M = 2M_Q = M_{\tilde{T}}$
ϵ_L
ϵ_R
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00