

New heavy fermions

Roberto Contino



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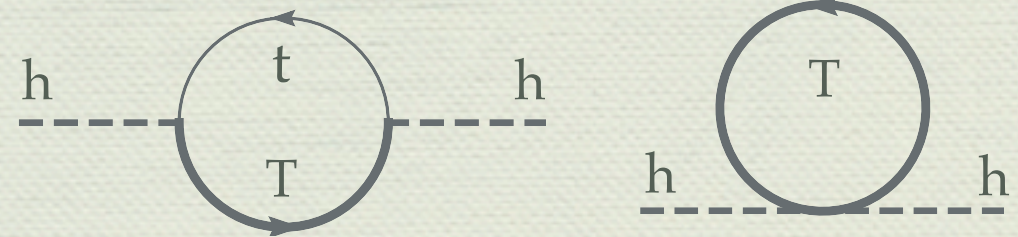
Disclaimer

- ◆ This is not an exhaustive survey of the physics of new heavy fermions
- ◆ I prefer to highlight a few specific topics and trigger the discussion on them
- ◆ I apologize with those whose work is not reported here

New heavy fermions arise in several extensions of the SM:

- ◆ 4th generation

- ◆ Little Higgs theories (as top partners)

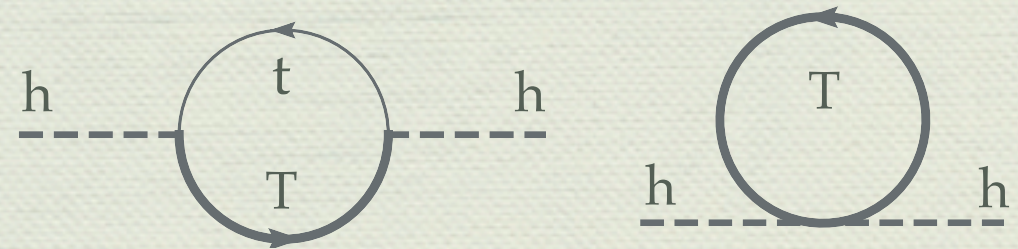


- ◆ Theories of strong EWSB with Partial Compositeness
(Composite Higgs and TC)

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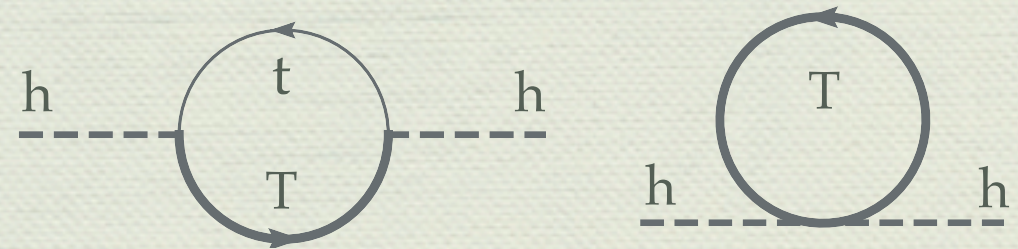


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- ◆ Theories of strong EWSB with Partial Compositeness
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\longrightarrow *I will consider this scenario in the following:*

$$\mathcal{L} = \mathcal{L}_{SM(\cancel{H})} + \mathcal{L}_{strong} + \mathcal{L}_{mix}$$

$$\mathcal{L}_{mix} = A^\mu J_\mu + \bar{\Psi}O + h.c.$$

$$\langle 0 | J_\mu | \rho \rangle = \epsilon_\mu^r f_\rho m_\rho$$

$$\langle 0 | O | \chi \rangle = \Delta$$

spin-1 resonance (ρ - γ mixing)

composite vector-like fermion

Example: composite partners of the top quark

$$\mathcal{L}_{SM(\cancel{H})} = \bar{q}_L i \not{\partial} q_L + \bar{t}_R i \not{\partial} t_R$$

$$\mathcal{L}_{strong} = \bar{Q}(i \not{\partial} - M_2)Q + \bar{\tilde{T}}(i \not{\partial} - M_1)\tilde{T} - Y_* \bar{Q} H \tilde{T} + h.c.$$

$$\mathcal{L}_{mix} = \Delta_{q_L} \bar{q}_L Q + \Delta_{t_R} \bar{t}_R \tilde{T} + h.c.$$

composite (vectorlike) fermions

$$Q = \begin{pmatrix} T \\ B \end{pmatrix} = 2_{1/6}$$

$$\tilde{T} = 1_{2/3}$$

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→ *Diagonalized through a composite/elementary rotation:*

[see: R.C., Kramer, Son and Sundrum
JHEP 0705:074 (2007)]

$$\begin{pmatrix} q_L \\ Q_L \end{pmatrix} \rightarrow \begin{pmatrix} \cos \varphi_L & -\sin \varphi_L \\ \sin \varphi_L & \cos \varphi_L \end{pmatrix} \begin{pmatrix} q_L \\ Q_L \end{pmatrix}$$

partial compositeness of SM fields

$$|\text{SM}\rangle = \cos \varphi |elem\rangle + \sin \varphi |comp\rangle$$

$$\tan \varphi_{q_L} = \frac{\Delta_{q_L}}{m} \quad M_Q = \frac{M_2}{\cos \varphi_{q_L}}$$

$$y_t = Y_* \sin \varphi_{q_L} \sin \varphi_{t_R}$$

same for $\{t_R \leftrightarrow \tilde{T}\}$

SM Yukawa via composite components

Light custodial partners of the top

- ◆ custodial invariance of the strong sector implies larger multiplets of $SU(2)_L \times SU(2)_R \times U(1)_X$

Ex: $Q = \begin{pmatrix} T \\ B \end{pmatrix} = 2_{1/6} \longrightarrow (2, 2)_{2/3} = \left[Q = \begin{pmatrix} T \\ B \end{pmatrix} \quad Q' = \begin{pmatrix} T_{5/3} \\ T_{2/3} \end{pmatrix} \right]$

$\tilde{T} = 1_{2/3} \longrightarrow (1, 1)_{2/3} = \tilde{T}$

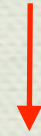
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*custodian with
exotic charge +5/3*



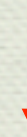
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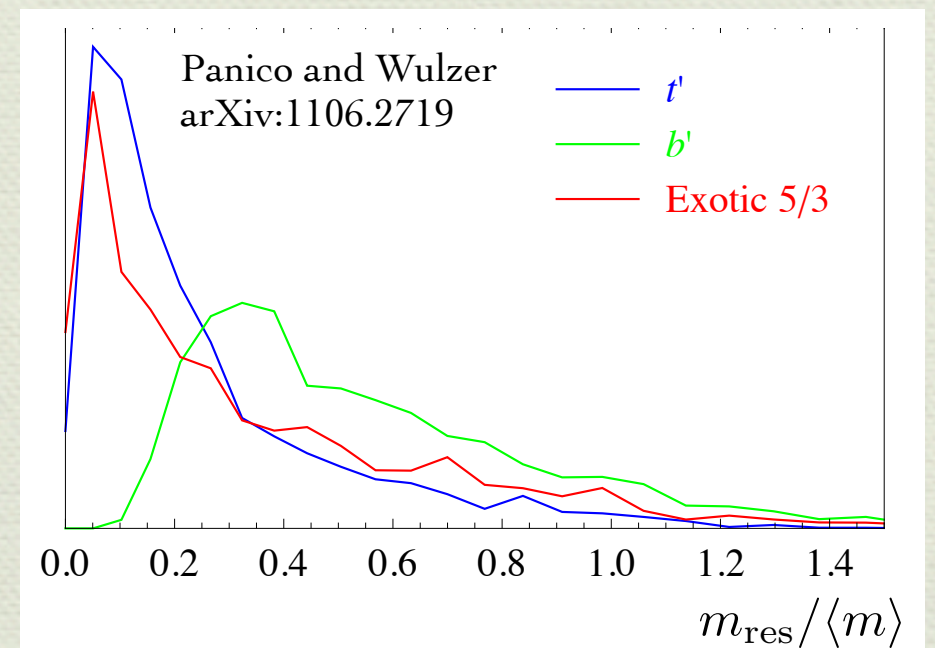
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- custodians become very light if SM top is largely composite

$$M_{Q'} = M_{(2,2)} = M_Q \cos \varphi_{qL}$$

$$M_{Q'} \rightarrow 0 \quad \text{for} \quad \sin \varphi_{qL} \rightarrow 1$$



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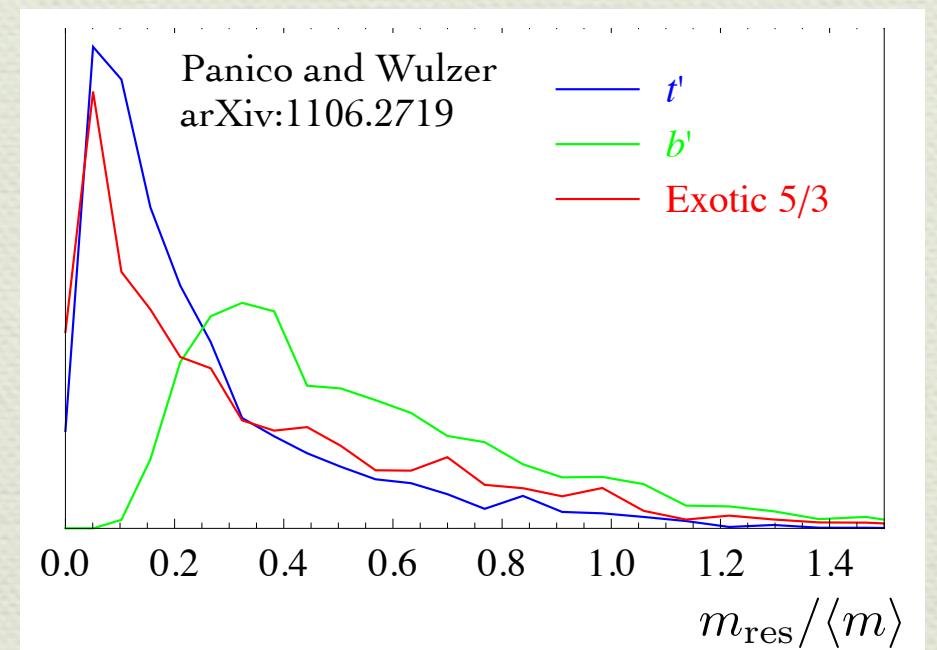
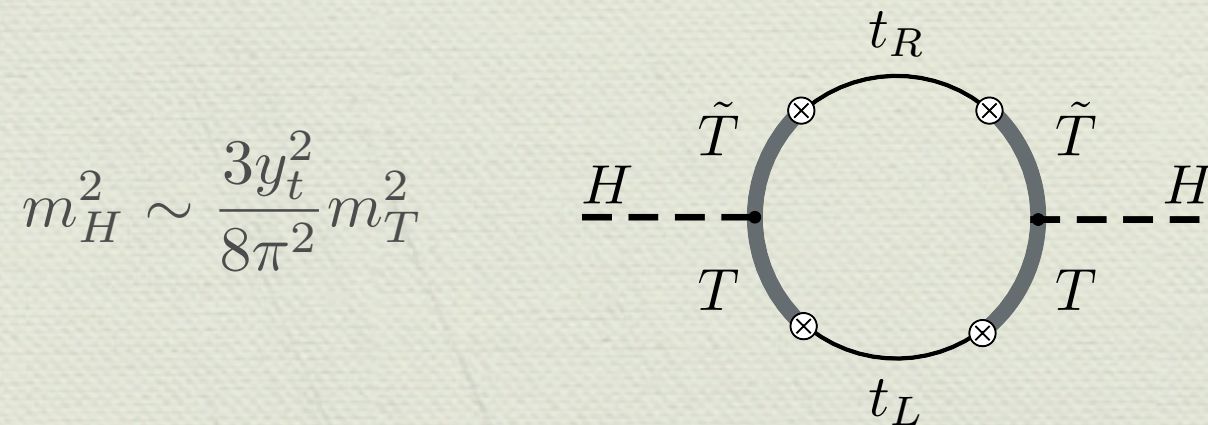


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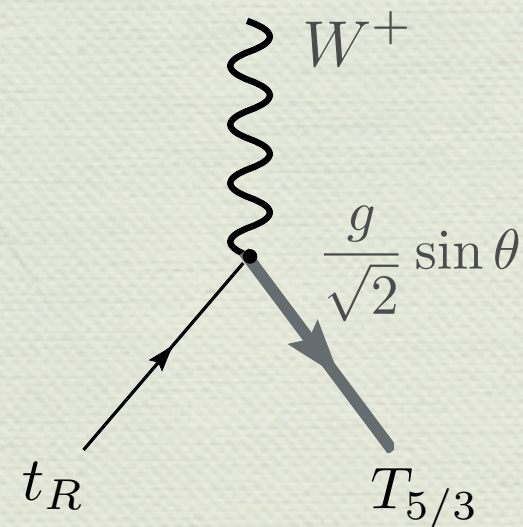
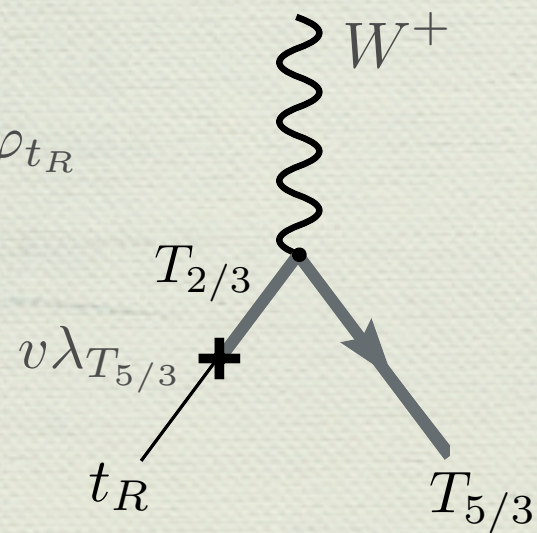


Mixed heavy-light vertices after EWSB

- ◆ The EWSB induces mixed heavy-light vertices with the W and the Z

For example:

$$\lambda_{T_{5/3}} = Y_* \sin \varphi_{t_R}$$



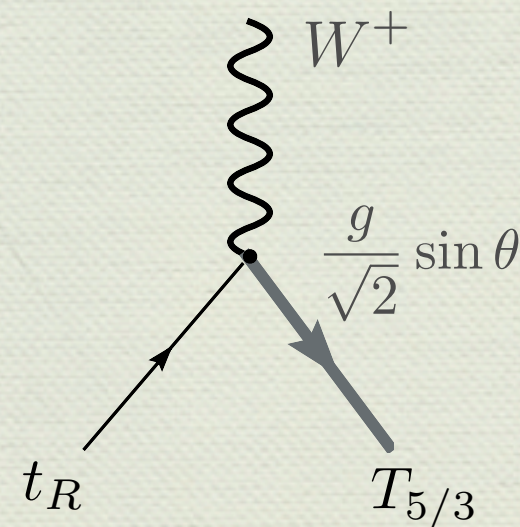
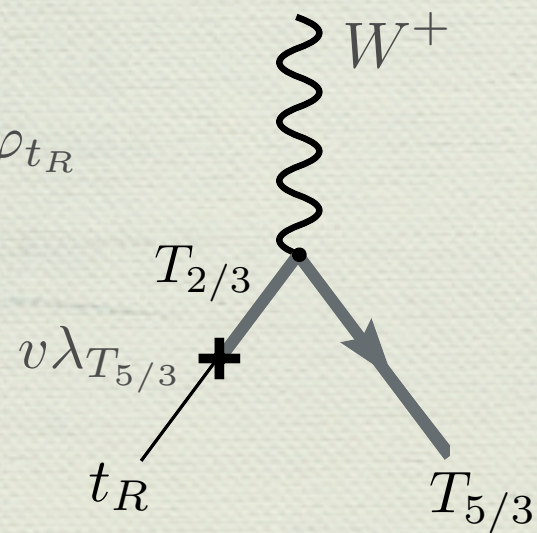
$$\sin \theta \sim \frac{v\lambda_{T_{5/3}}}{M_{T_{5/3}}}$$

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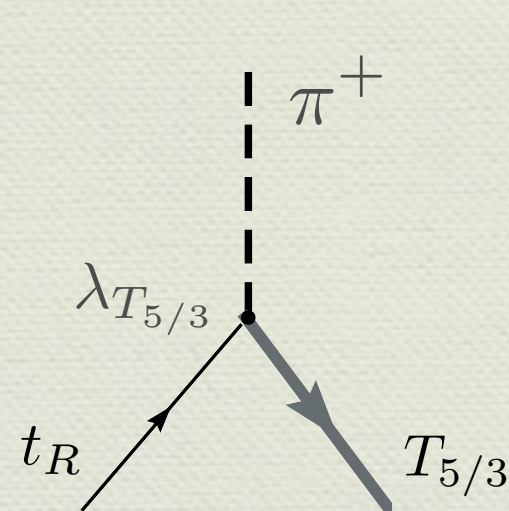
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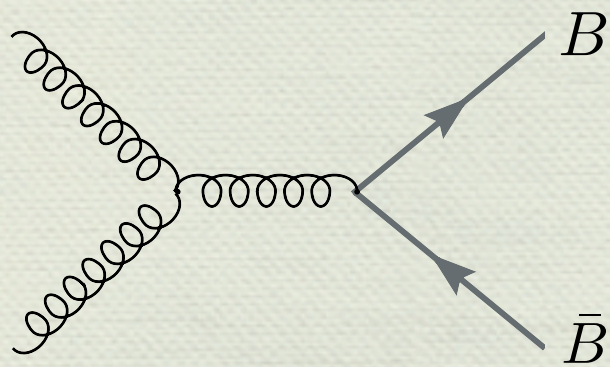


At large energy, using the Equivalence Theorem

$$W_\mu^L \sim \partial_\mu \pi / m_W$$

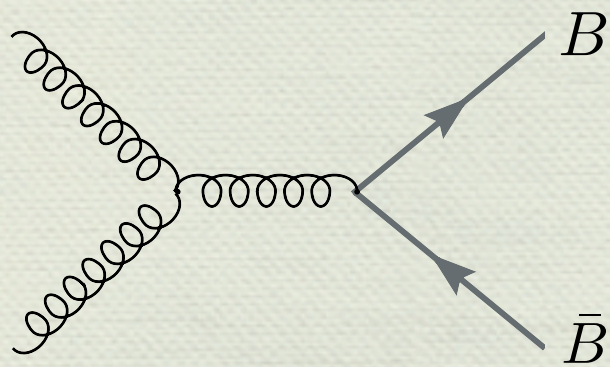
Production mechanisms

◆ Pair production

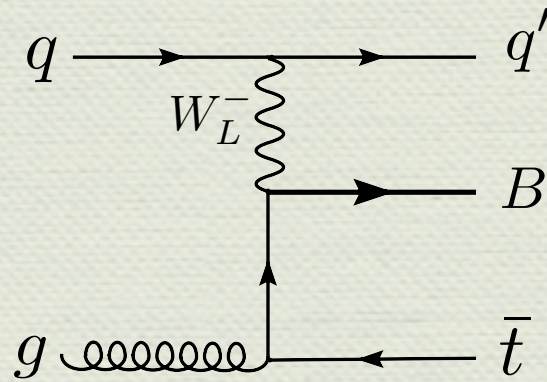


Production mechanisms

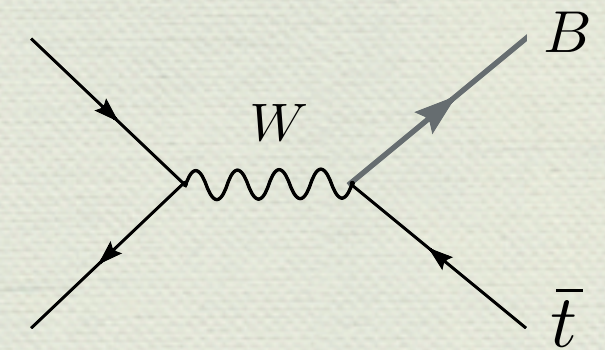
◆ Pair production



◆ Single production



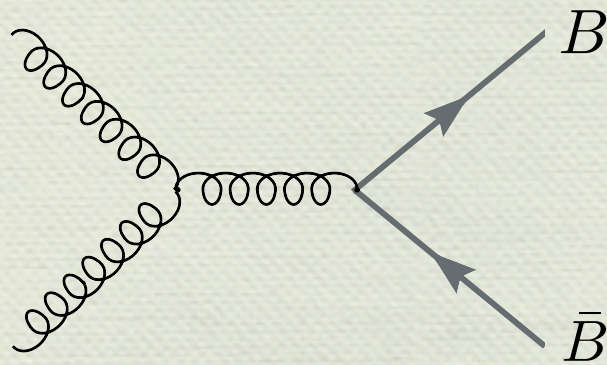
$$\sigma_{single}^{soft} \propto \bar{\lambda}^2$$



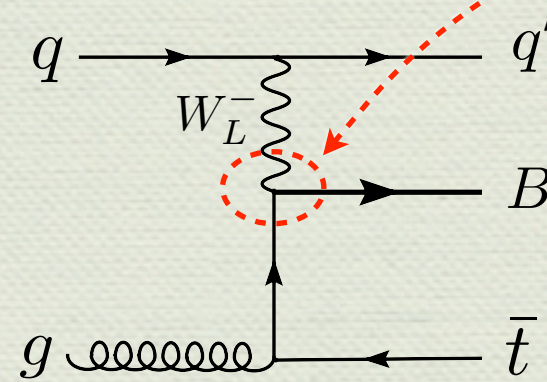
$$\bar{\lambda} \equiv \frac{g}{\sqrt{2}} \sin \theta \left(\frac{m_B}{m_W} \right)$$

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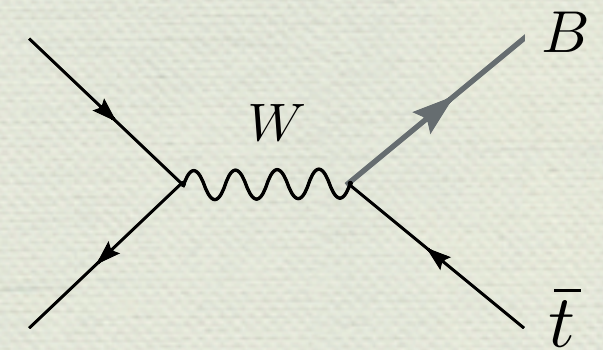


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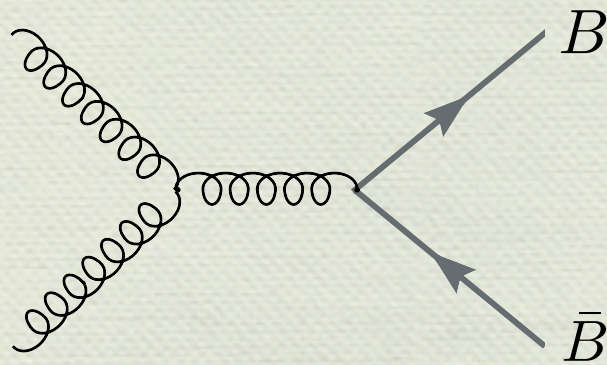
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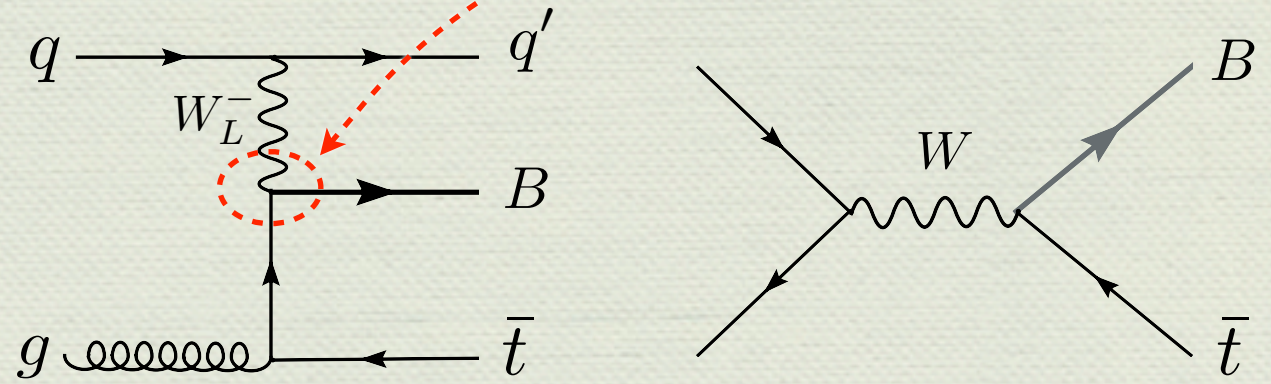
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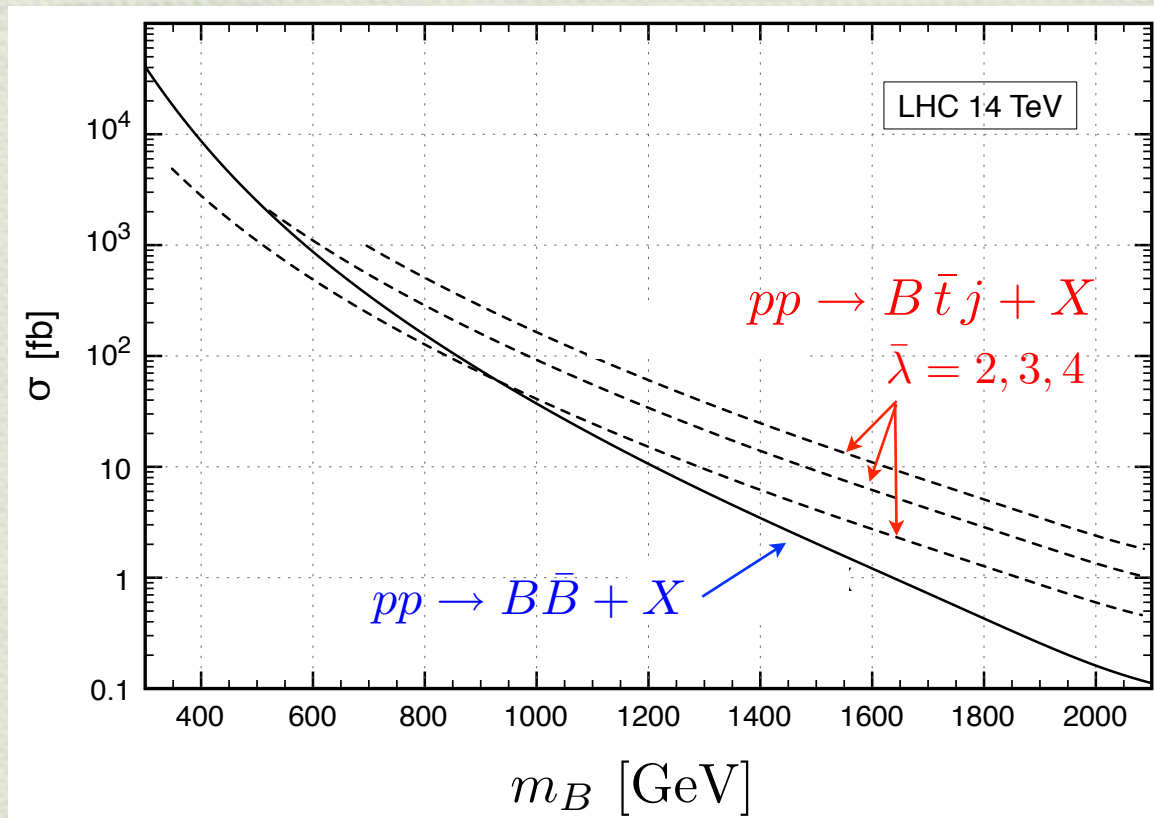
Single production



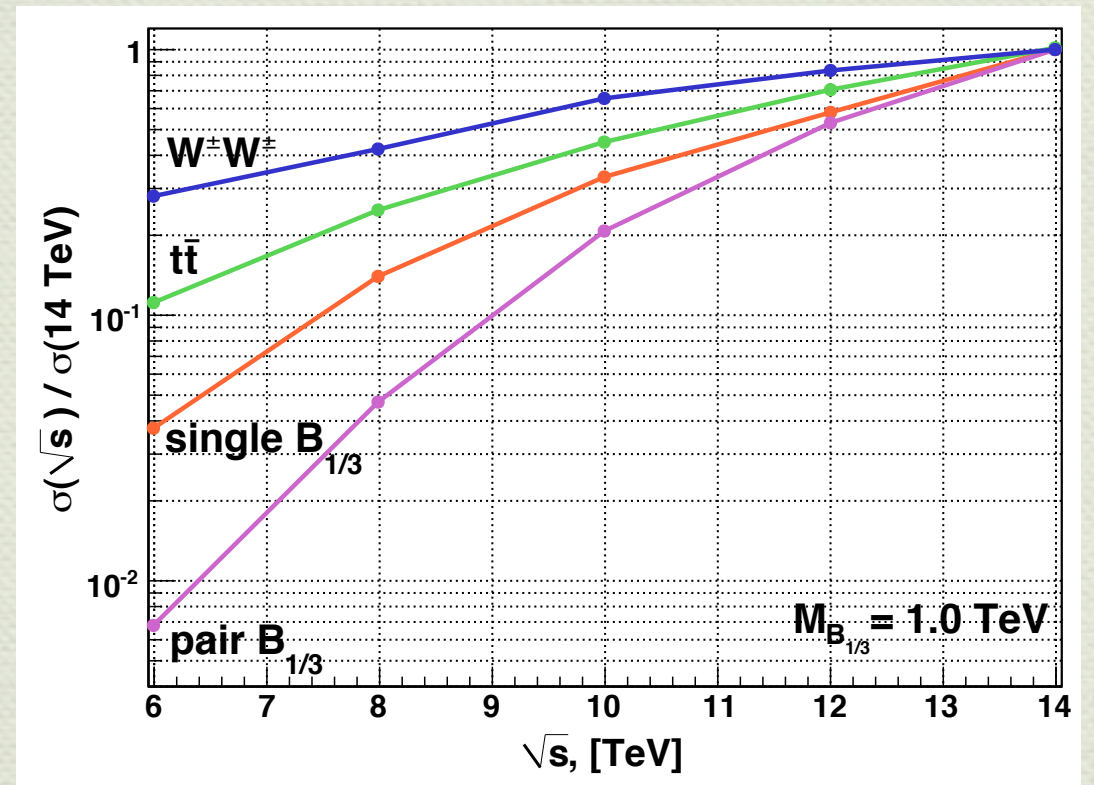
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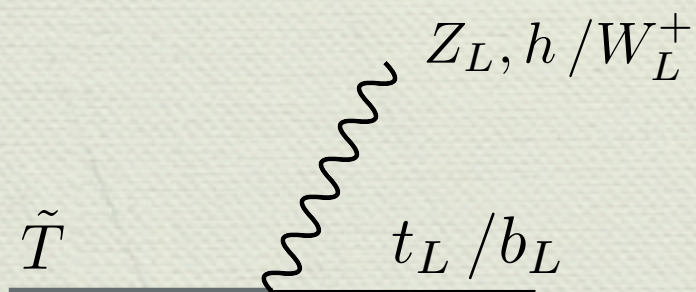
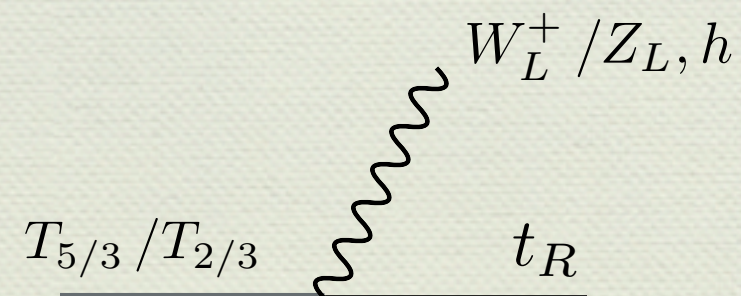
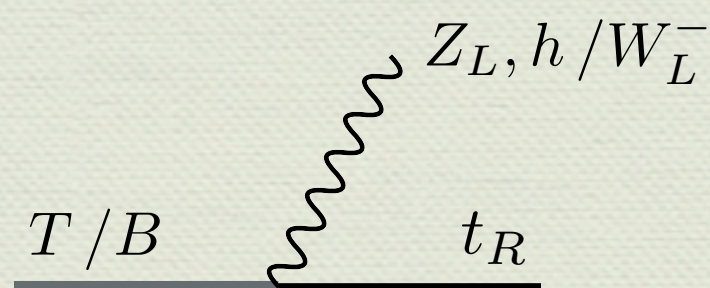


from: Mrazek and Wulzer PRD 81 (2010) 075006



Decay modes

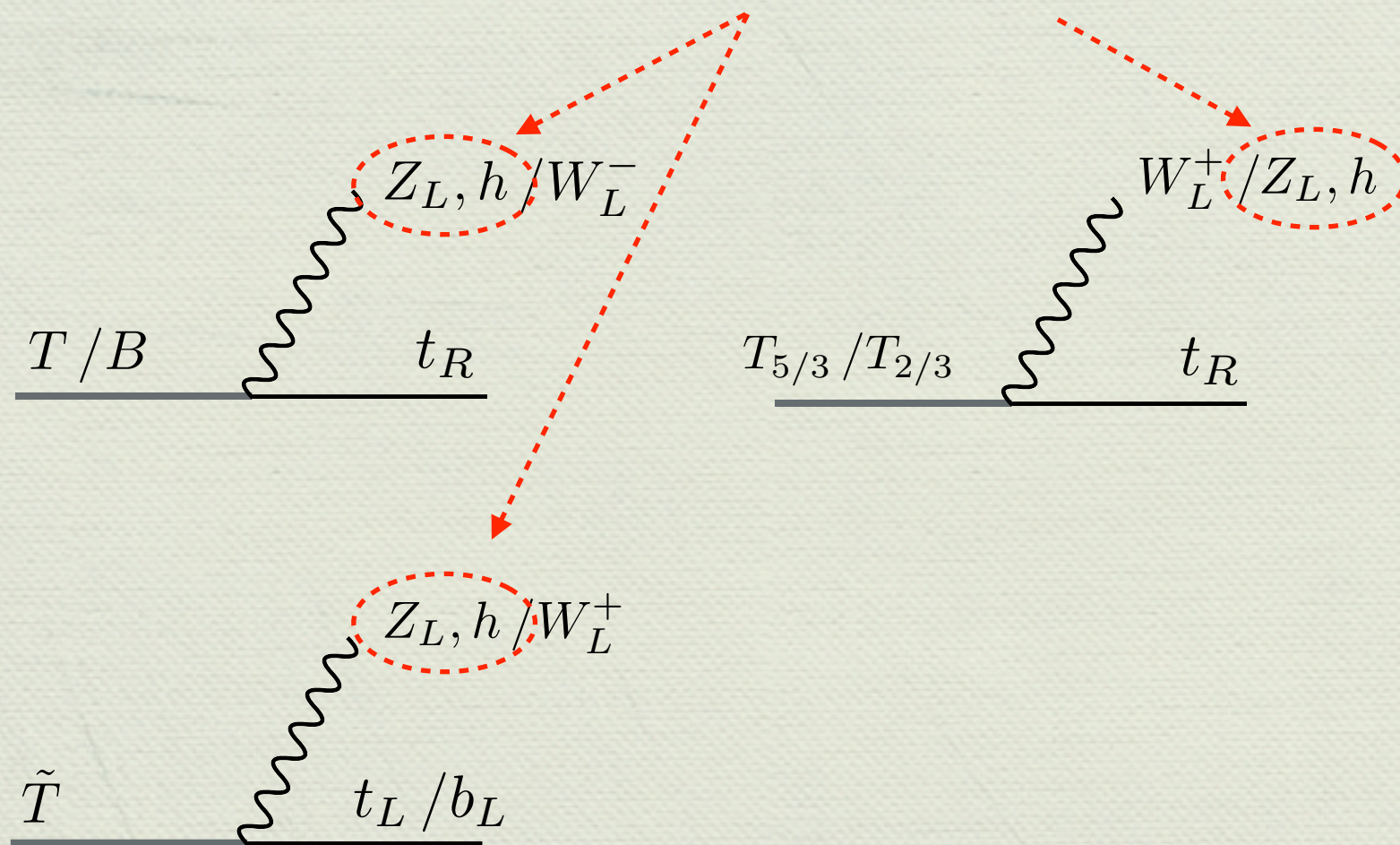
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FCNC: absent for a 4th generation

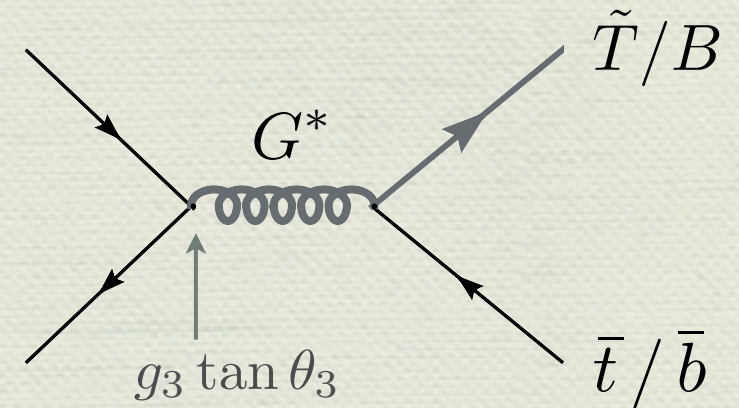


Production mechanisms (continued)

◆ Associated production (via a heavy gluon)

Dobrescu, Kong, Mahbubani, JHEP 0906 (2009) 001

Bini, R.C., Parisse, Vignaroli, work in progress

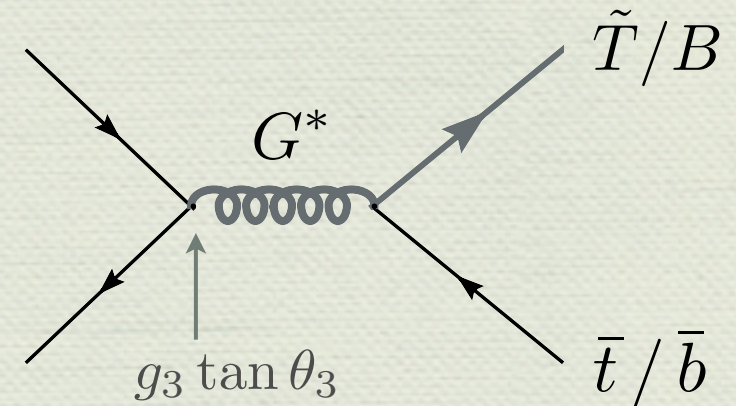


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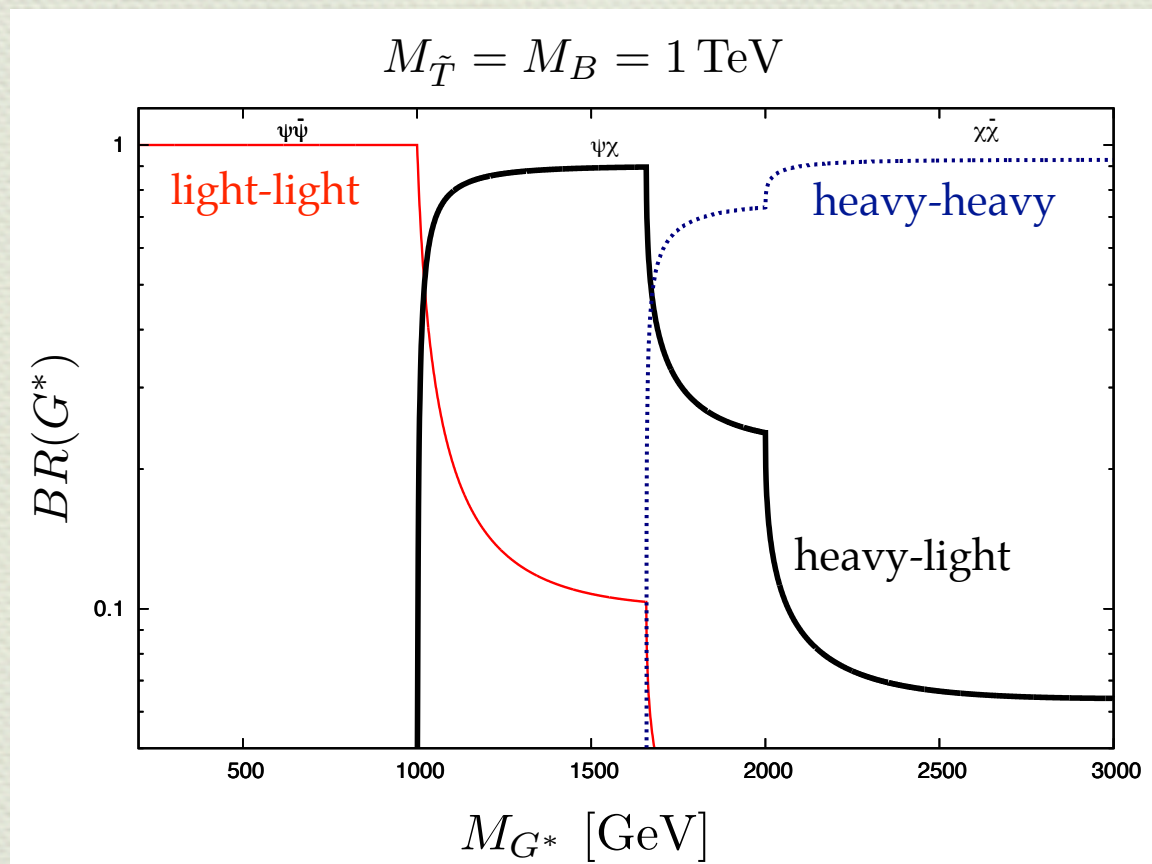
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Example: 2-site version of MHCM5

BR to heavy light can be sizable if

$$m_T < M_{G^*} < 2m_T$$

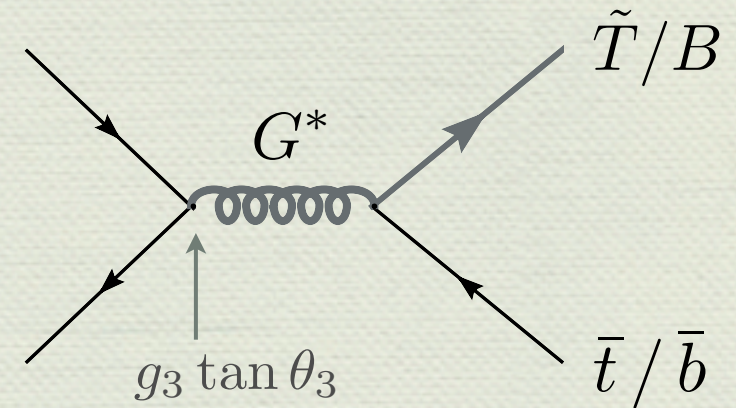


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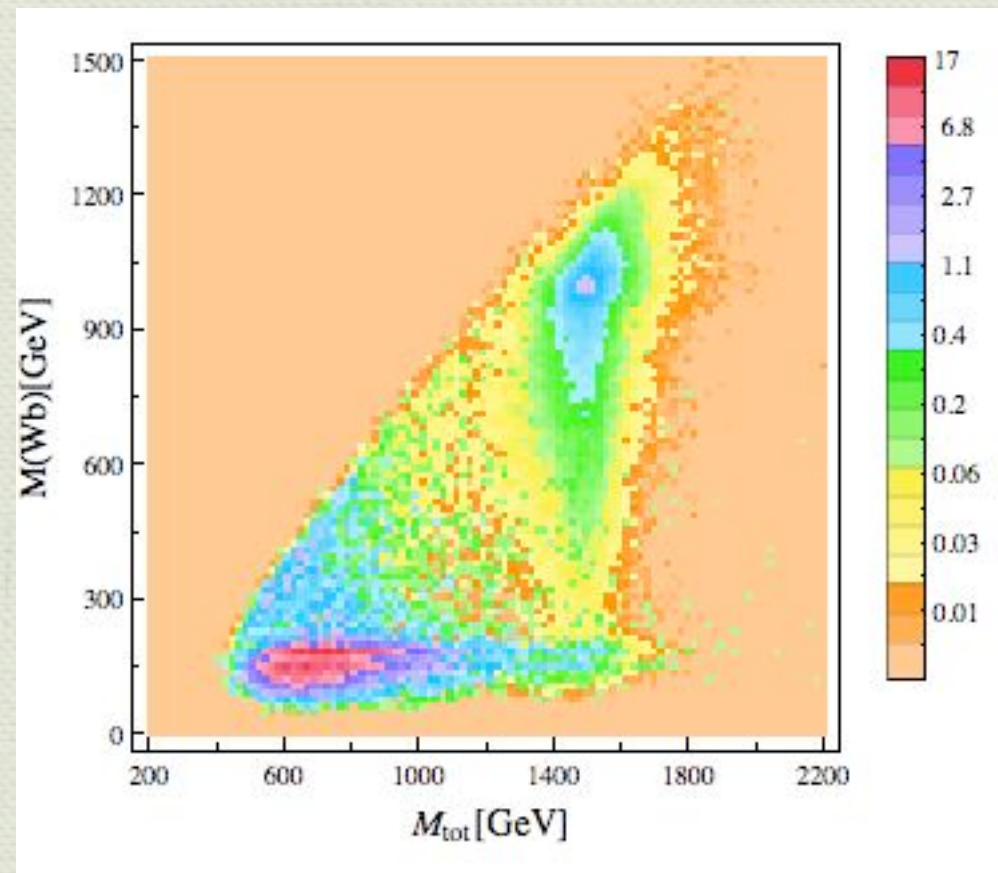
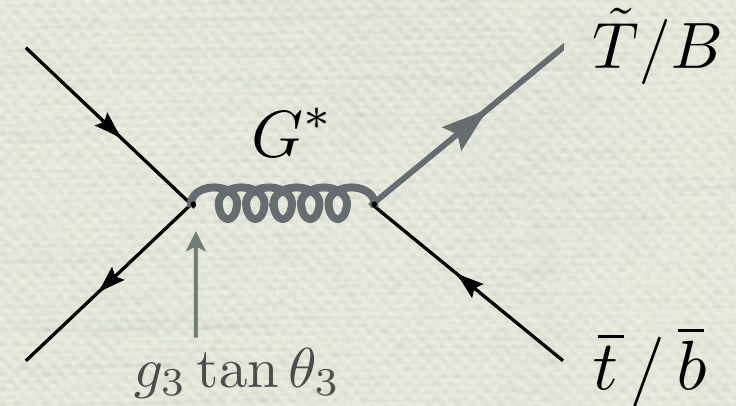
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[after reconstructing 1 top]

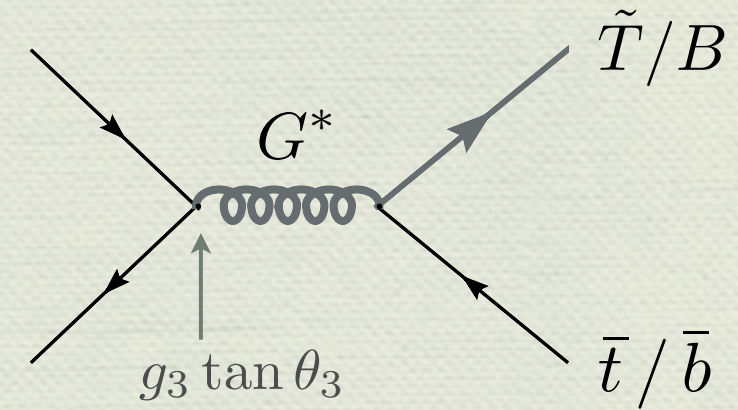
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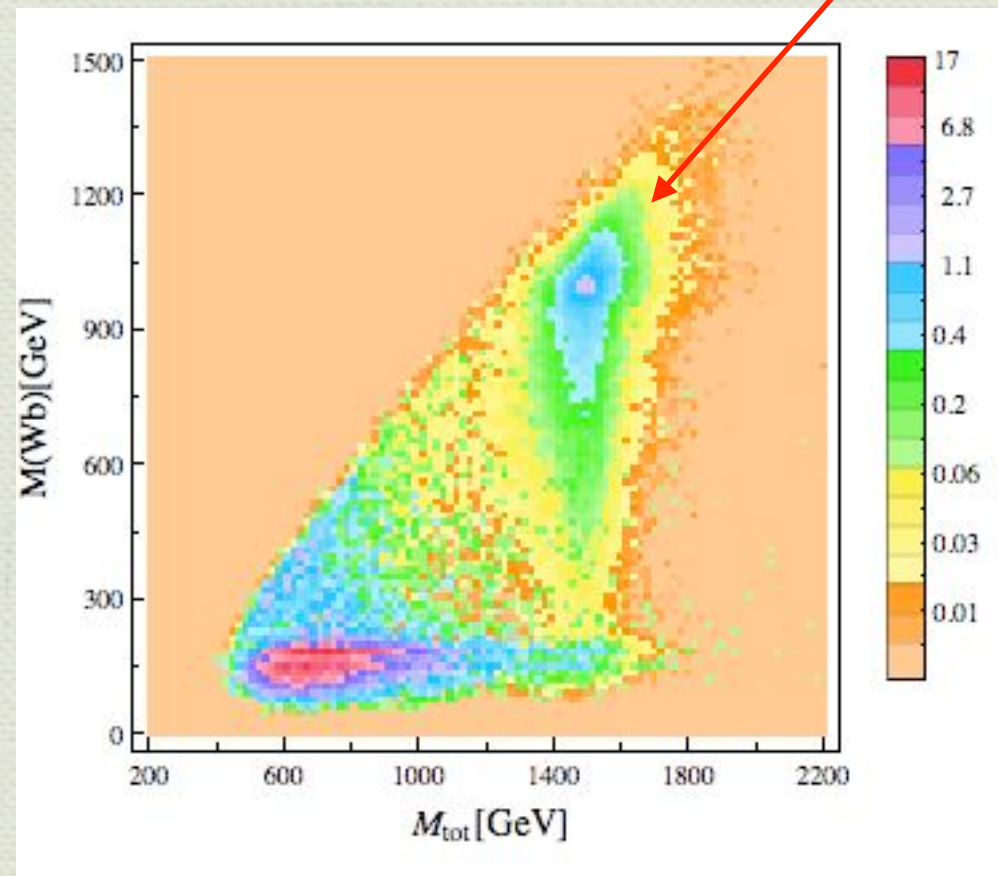
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$M_{G^*} = 1.5 \text{ TeV}$ $\tan \theta_3 = 0.44$ $\sin \varphi_R = 0.6$
 $M_{G^*}/M_{T_{5/3}, B} = 1.5$ $[\lambda_{T_{5/3}} = 1.8 \quad \lambda_B = 1.5]$



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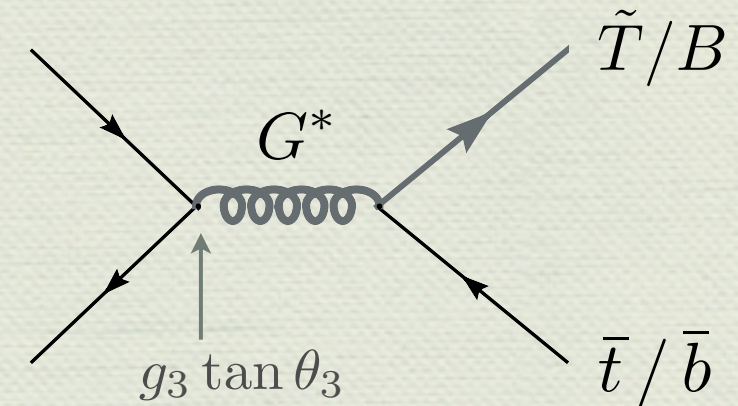
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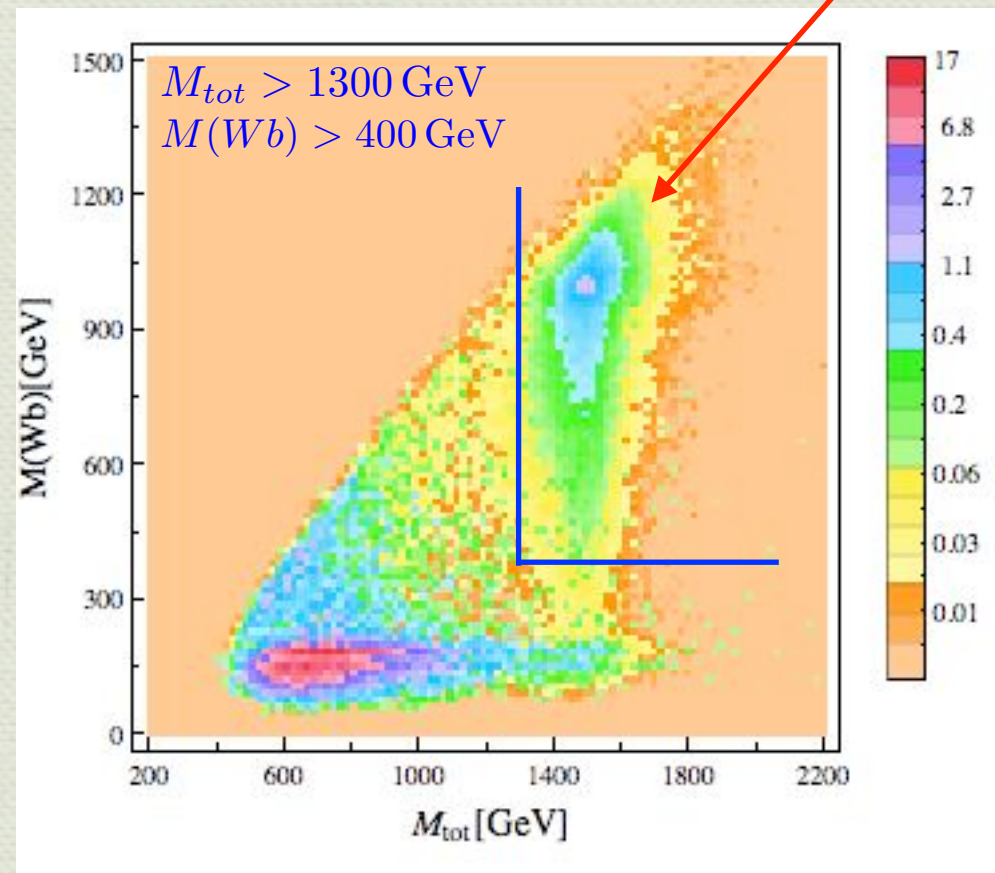
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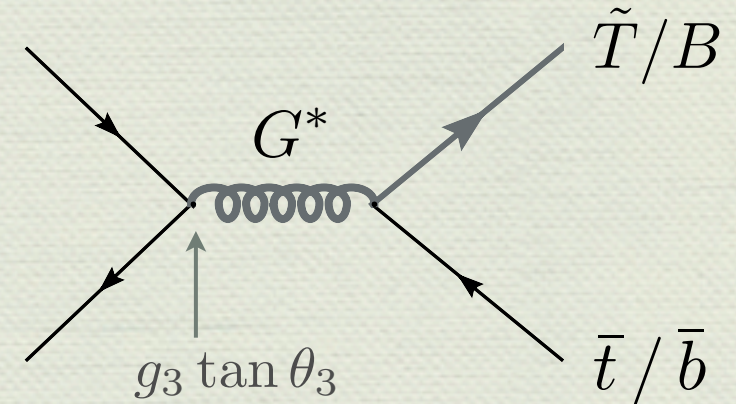
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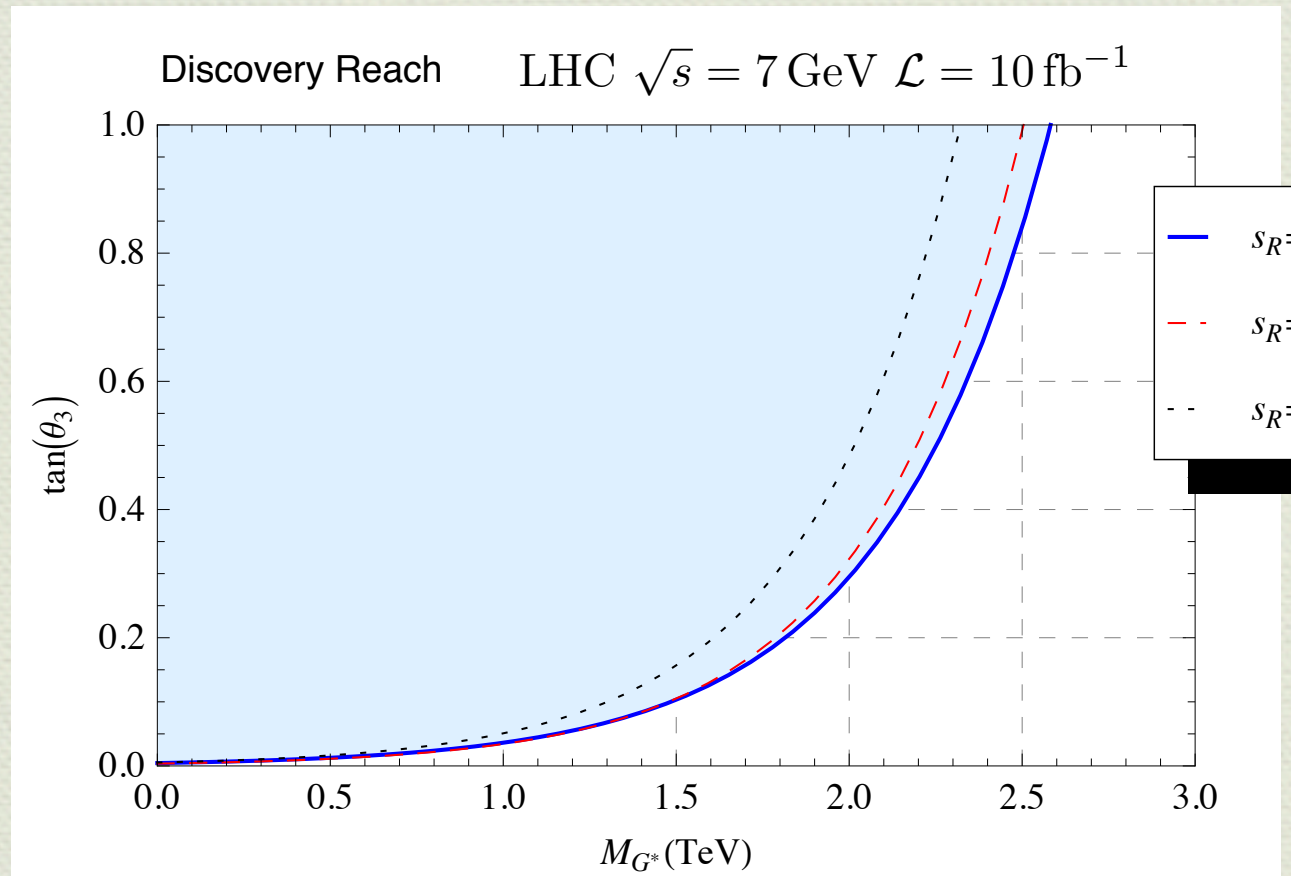
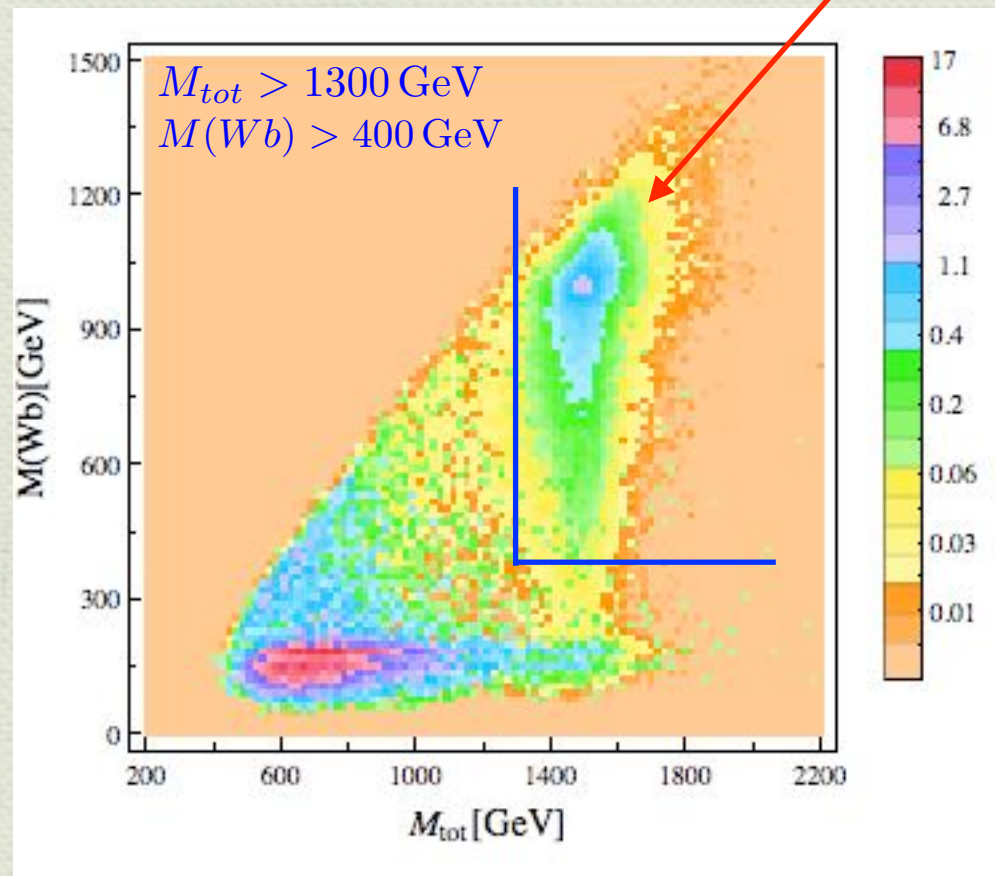
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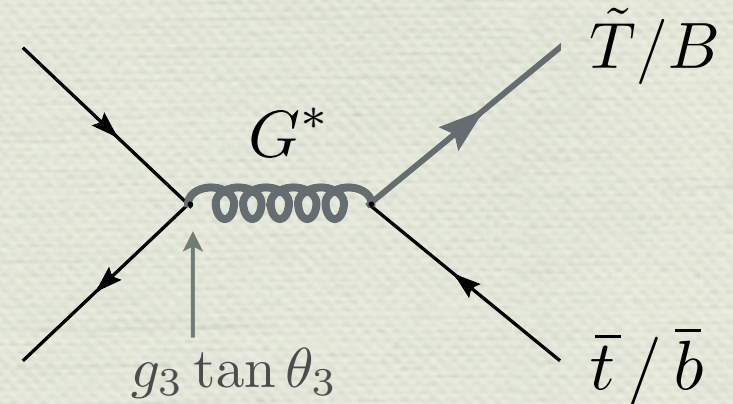
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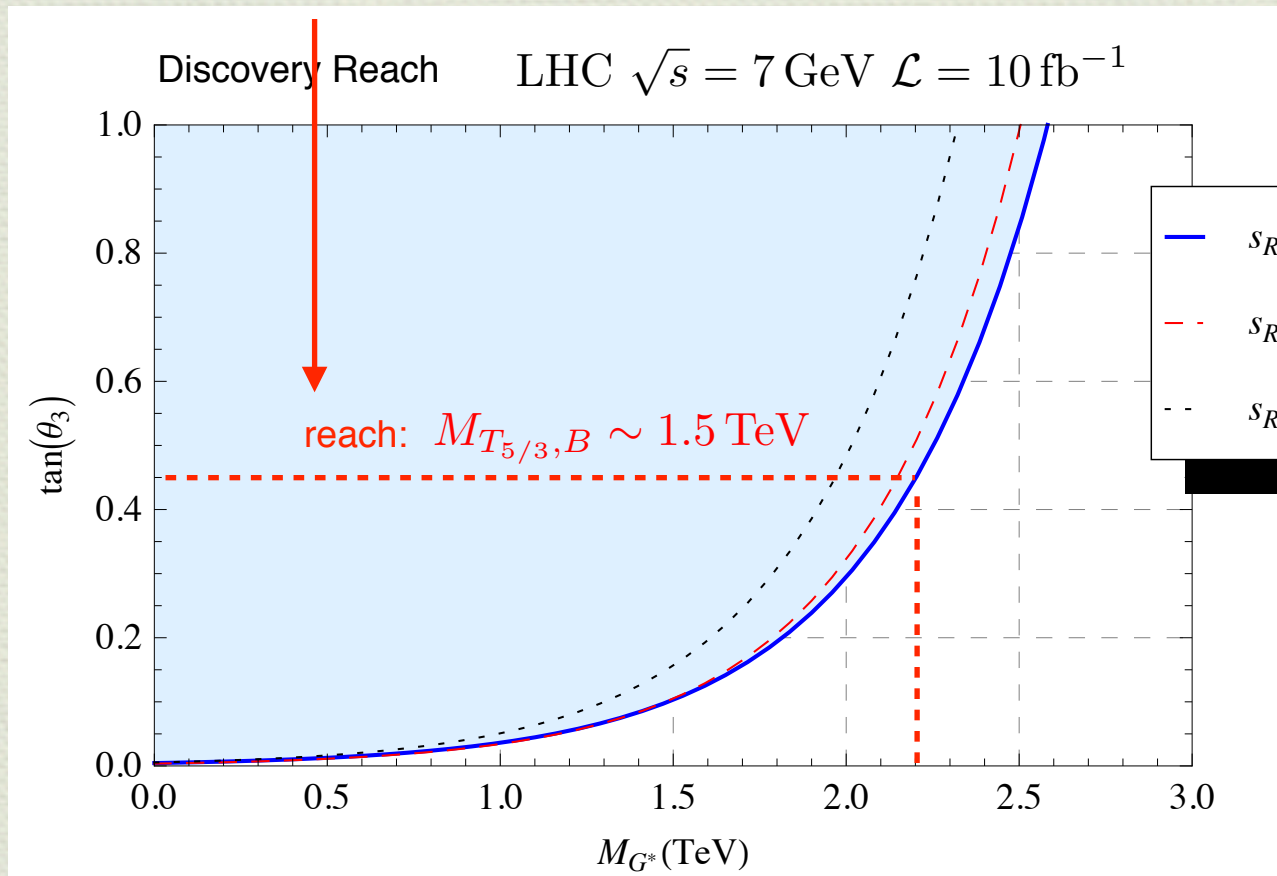
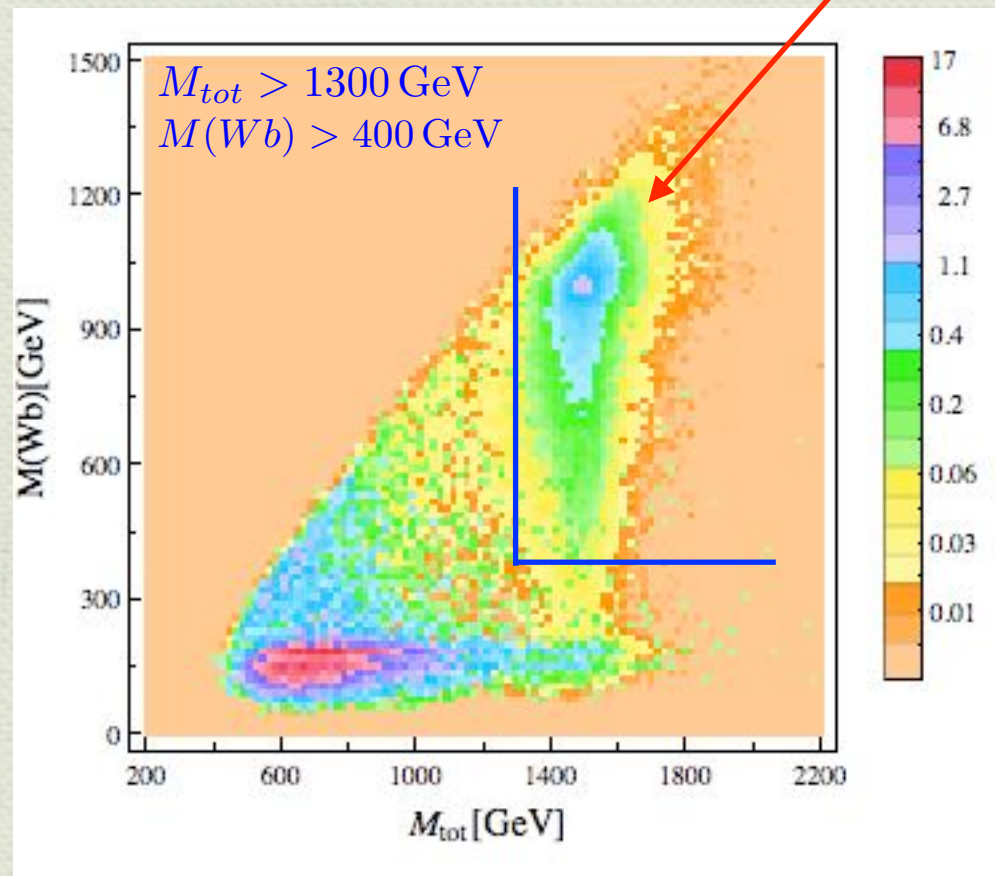
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Most sensitive experimental searches (1-slide snapshot)

◆ Looking for pair production

[CMS L=1.14 fb⁻¹] $T\bar{T} \rightarrow WbW\bar{b} \rightarrow b\bar{b}l^+l^-\cancel{E}_T$ $m_T > 422 \text{ GeV}$
PAS-EXO-11-050

[CMS L=0.80 fb⁻¹] $T\bar{T} \rightarrow WbW\bar{b} \rightarrow b3jl^\pm\cancel{E}_T$ $m_T > 450 \text{ GeV}$
PAS-EXO-11-051

[CMS L=191 pb⁻¹] $T\bar{T} \rightarrow tZ\bar{t}Z \rightarrow (l^+l^-)l^\pm jj$ $m_T > 417 \text{ GeV}$
PAS-EXO-11-005

[CMS L=1.14 fb⁻¹] $B\bar{B} \rightarrow WtW\bar{t} \rightarrow l^\pm l^\pm b3j\cancel{E}_T$ $m_B > 495 \text{ GeV}$
PAS-EXO-11-036 $\rightarrow lll b1j\cancel{E}_T$

◆ Looking for single production

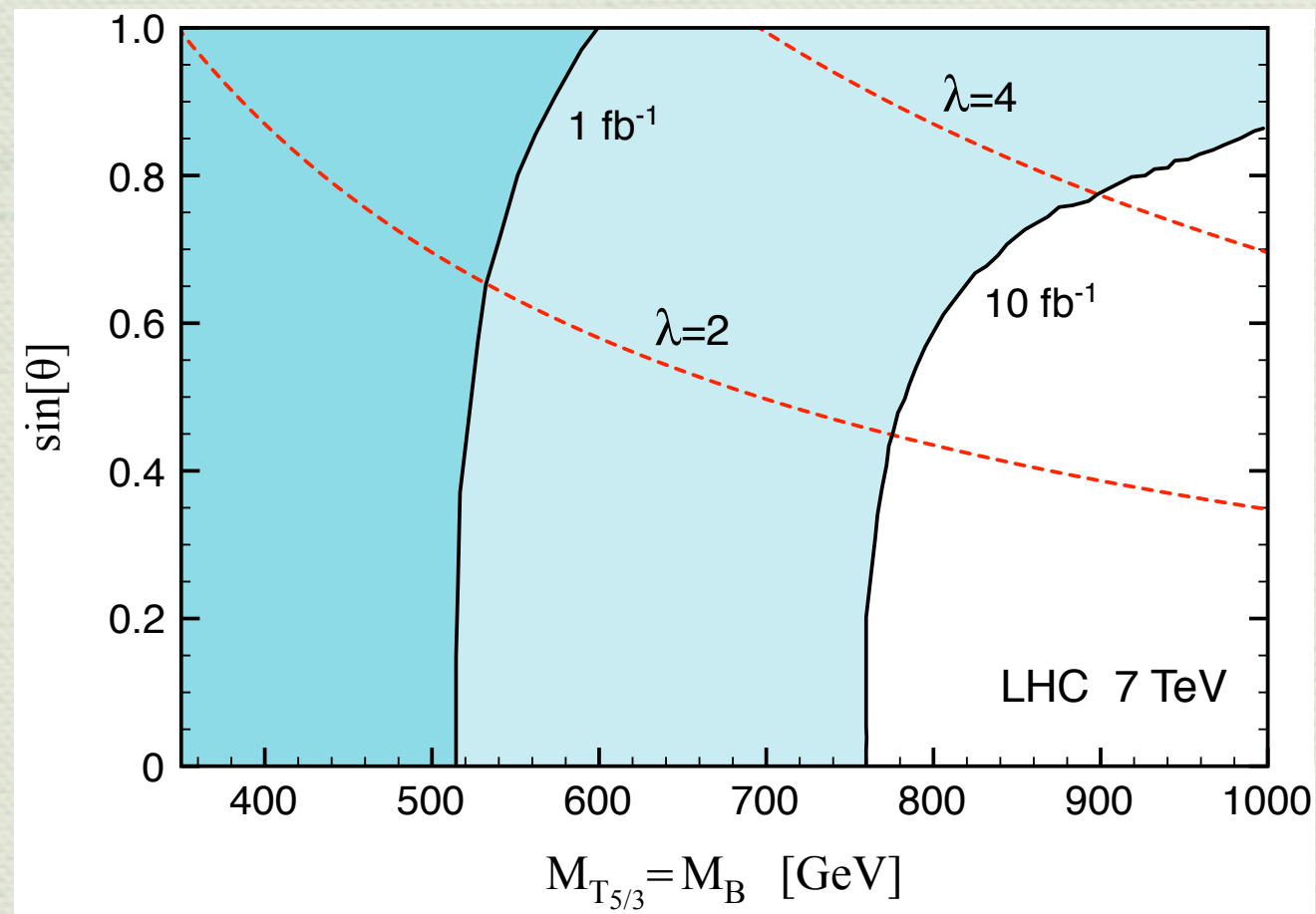
[D0 L=5.4 fb⁻¹] $Q\bar{q} \rightarrow Wq\bar{q} \rightarrow l^\pm jj\cancel{E}_T$
arXiv:1010.1466 $\rightarrow Zq\bar{q} \rightarrow (l^+l^-)jj$

Notice: All analyses assume 100% BR to the considered channel

LHC sensitivity on single production

Adapted from: Jan Mrazek Ph.D. Thesis (2011)

Based on: Mrazek and Wulzer PRD 81 (2010) 075006

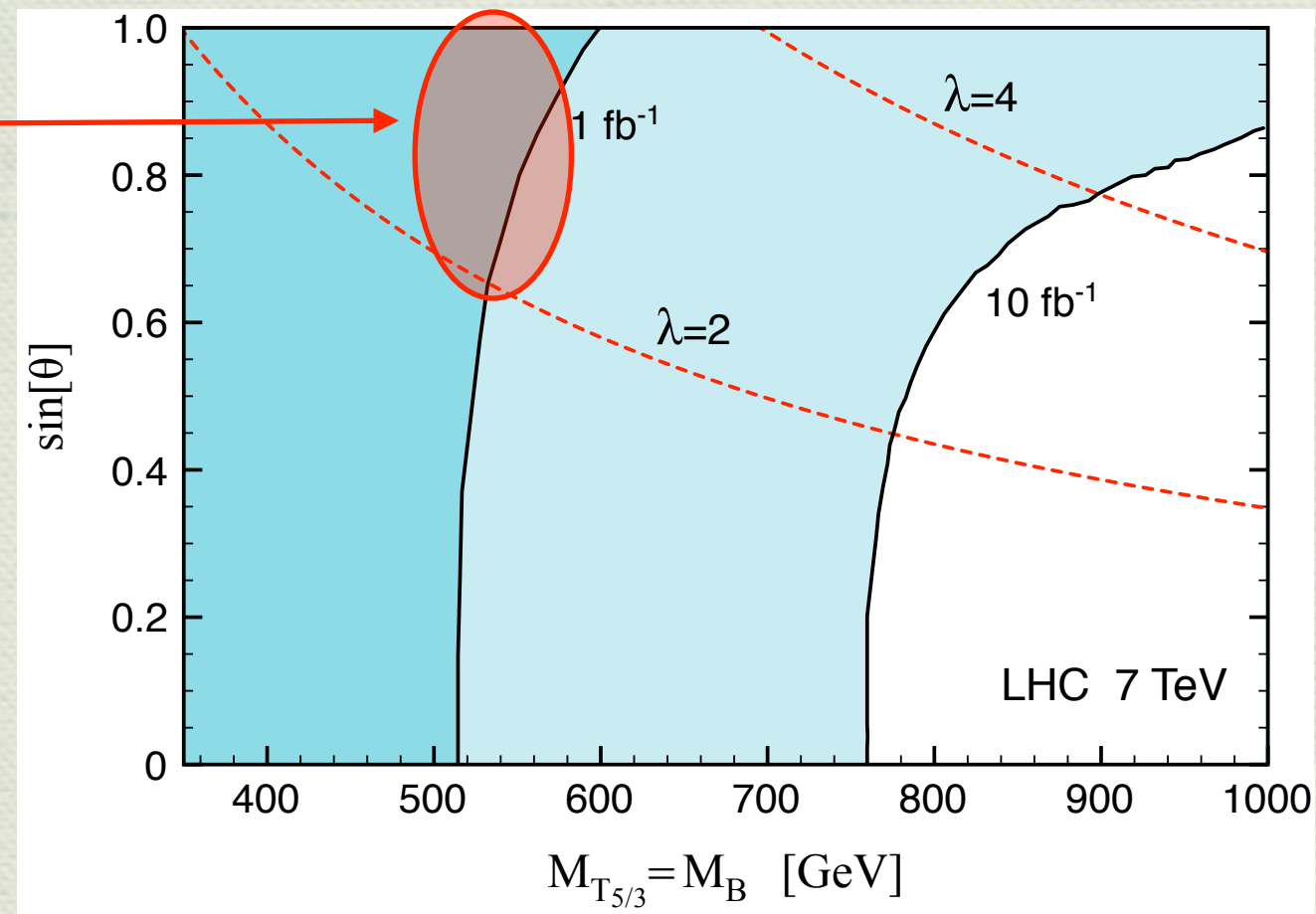


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*LHC at 7 TeV
with 1 fb^{-1} already
sensitive to single
production*



LHC sensitivity on single production

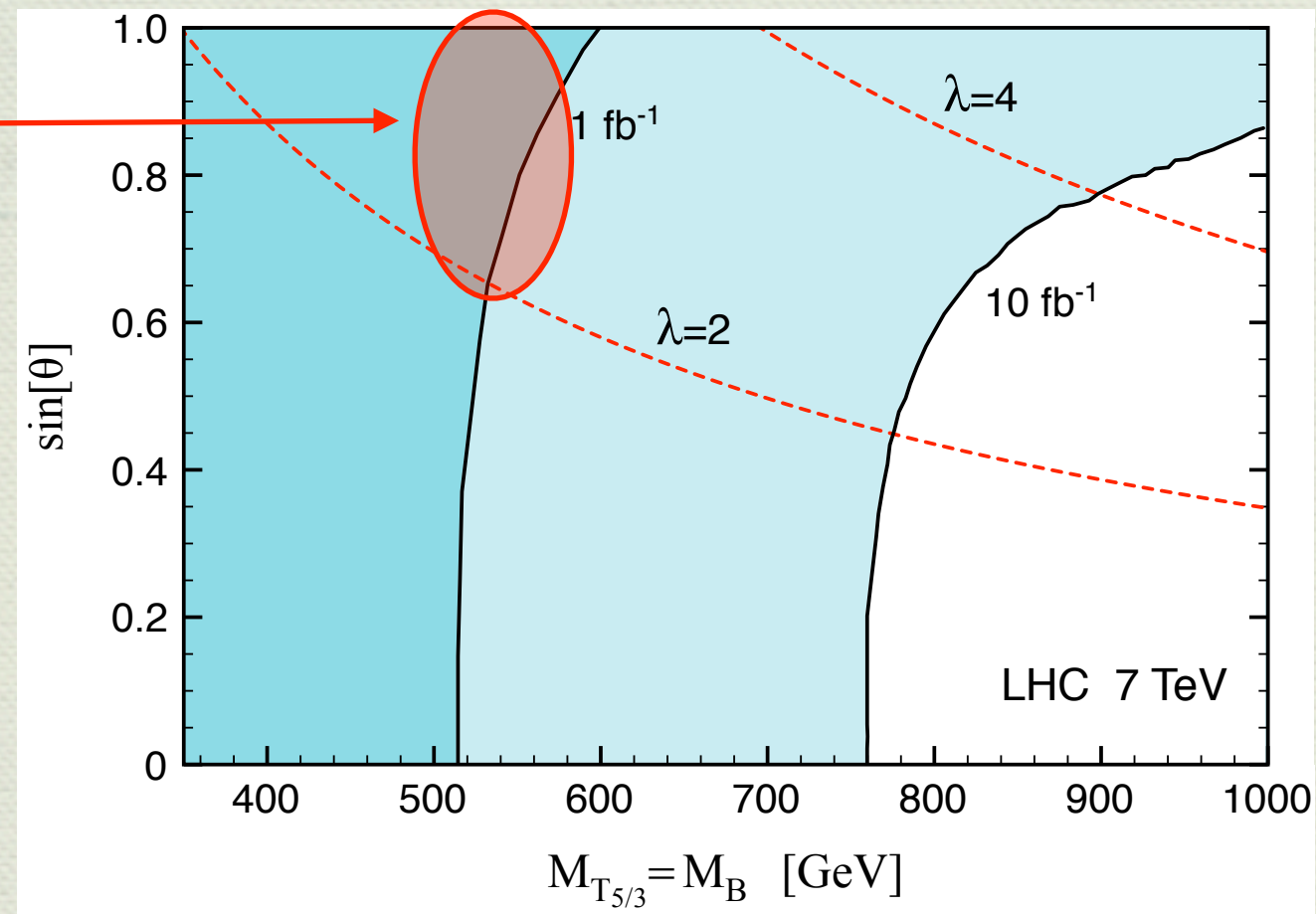
Adapted from: Jan Mrazek Ph.D. Thesis (2011)

Based on: Mrazek and Wulzer PRD 81 (2010) 075006

*LHC at 7 TeV
with 1 fb^{-1} already
sensitive to single
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Must be looked for!

*Might give first
evidence for strong
dynamics*

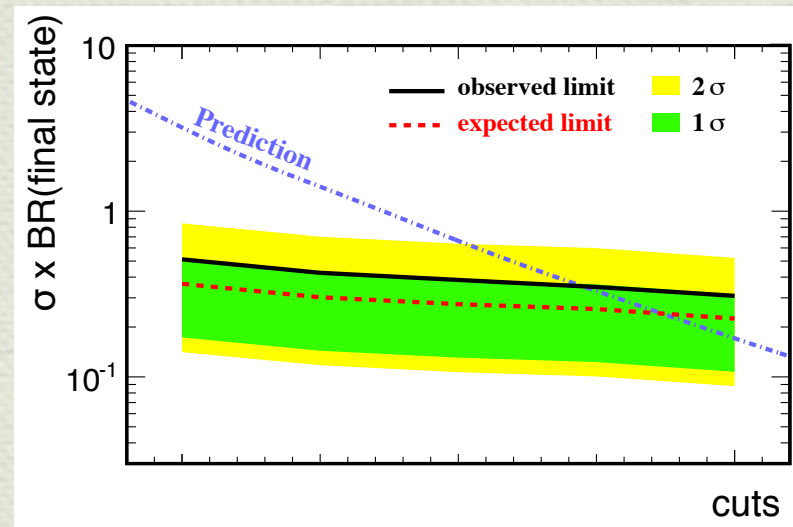


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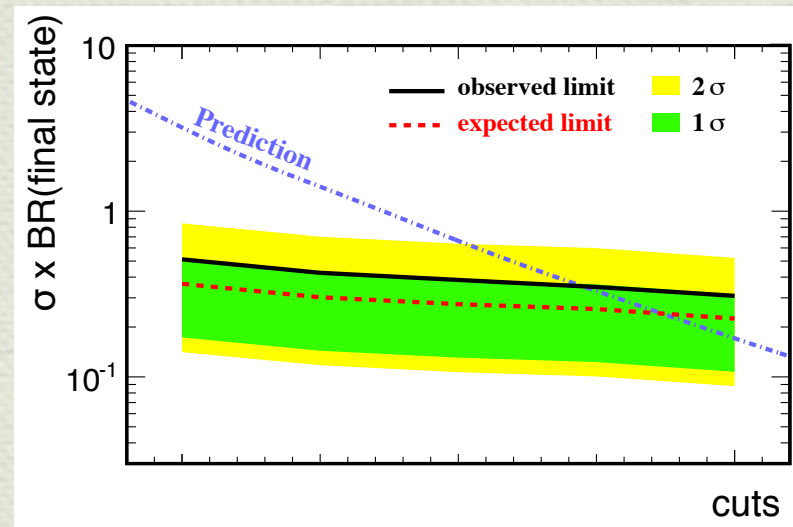
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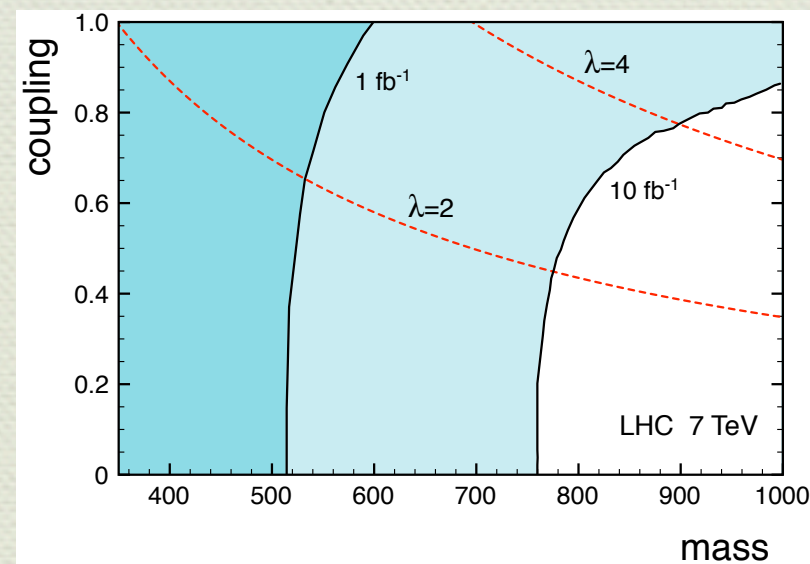
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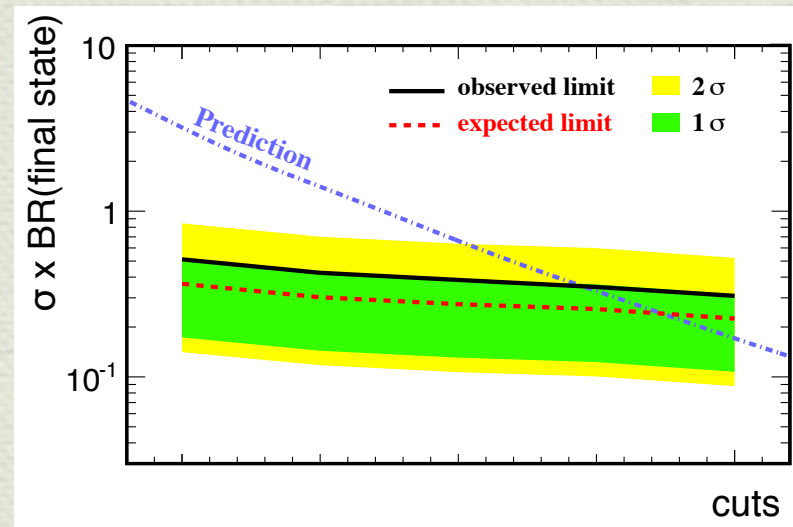
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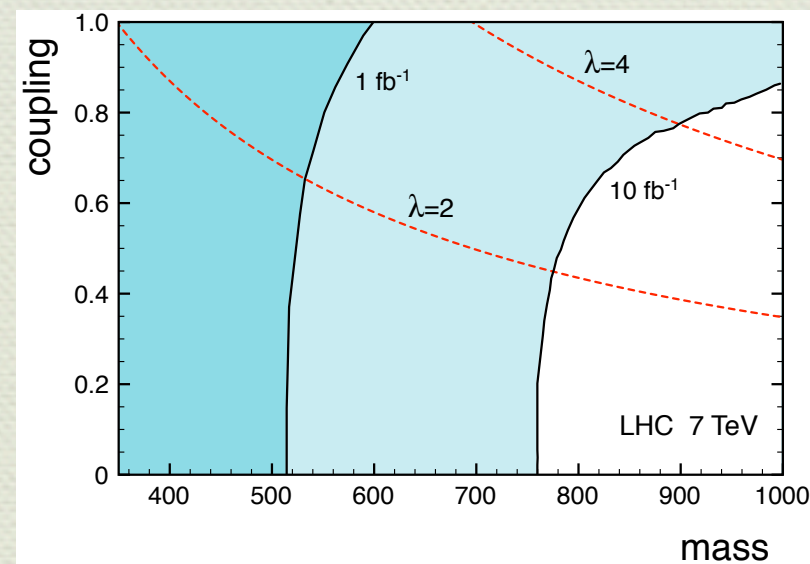
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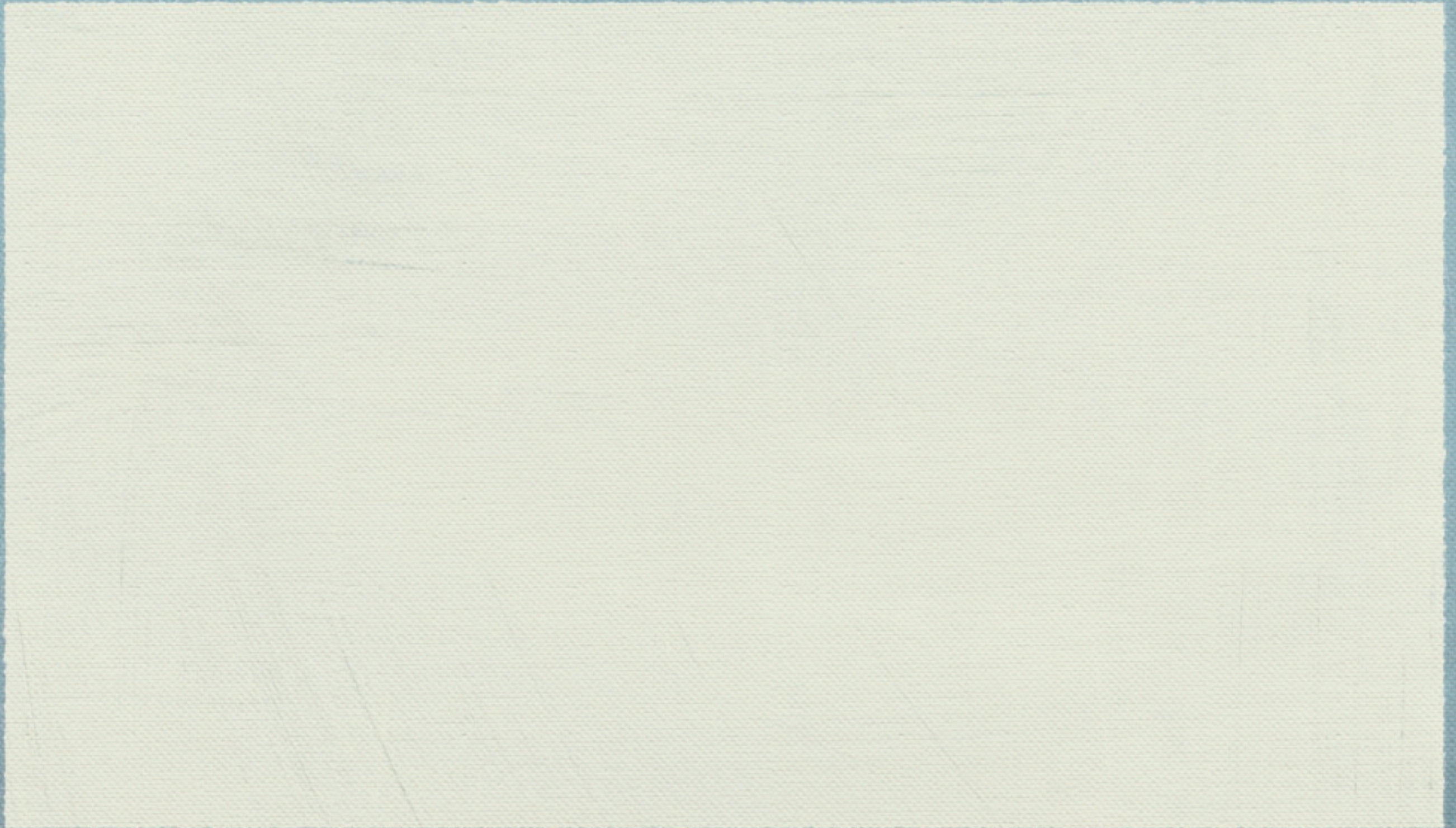
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◆ Using benchmark points of a specific model

[Useful, but difficult to extrapolate to other models]

Conclusions



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