Top Triangle Moose at the LHC

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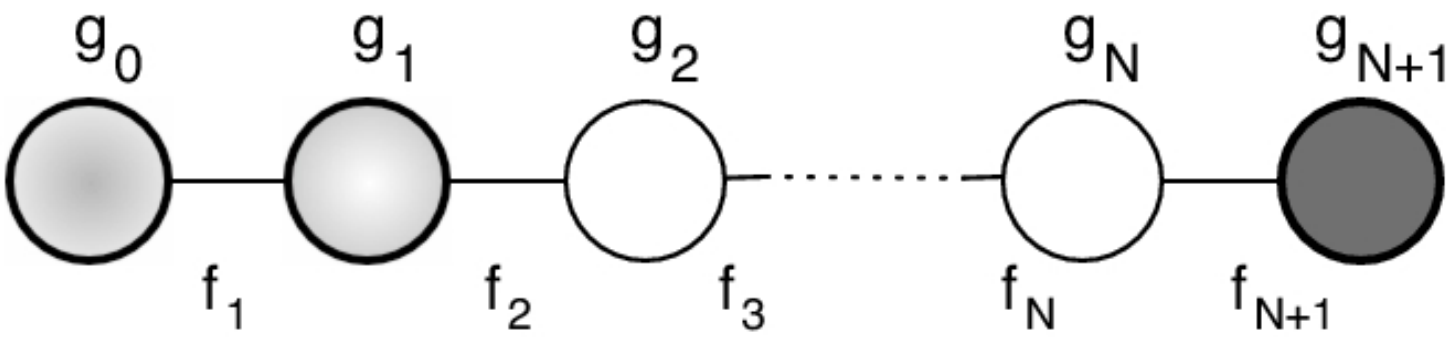
January 28, 2010

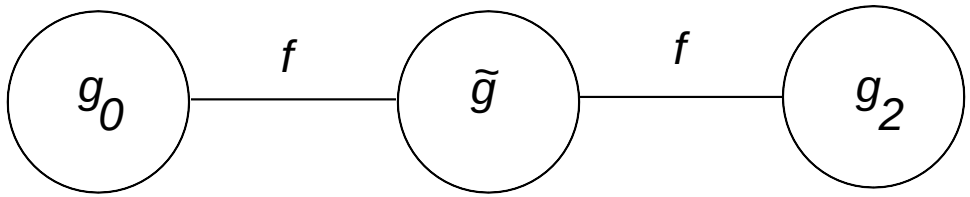
Higgsless Models

- Extra dimensional theories: EWSB via BC's.
- Unitarity in $W_L W_L$ scattering via KK resonances.
- Deconstruction $\Longrightarrow$ $5D = \sum 4D$.



A Simple Model

- Study the lowest KK resonance? A phenomenological model.
- "Three site Higgsless Model":

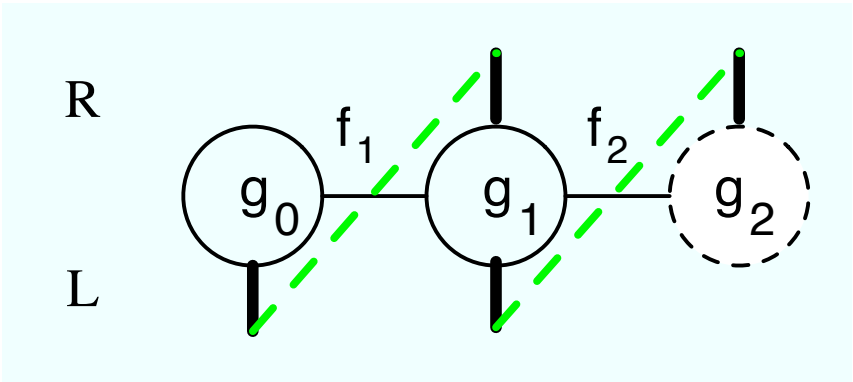


- Gauge spectrum: W, Z, W', Z', γ.
- Calculable theory: Small parameter: $g_0/\tilde{g} = x$.
- $M_W \propto g_0 v$, $M_{W'} \propto \tilde{g} v$.

A Three-Site Higgsless Model, Phys.Rev.D74:075011,2006.
arXiv:hep-ph/0607124

Fermions

- Fermions are "delocalized" along the moose.
- Two kinds of mass terms: diagonal and "hopping".

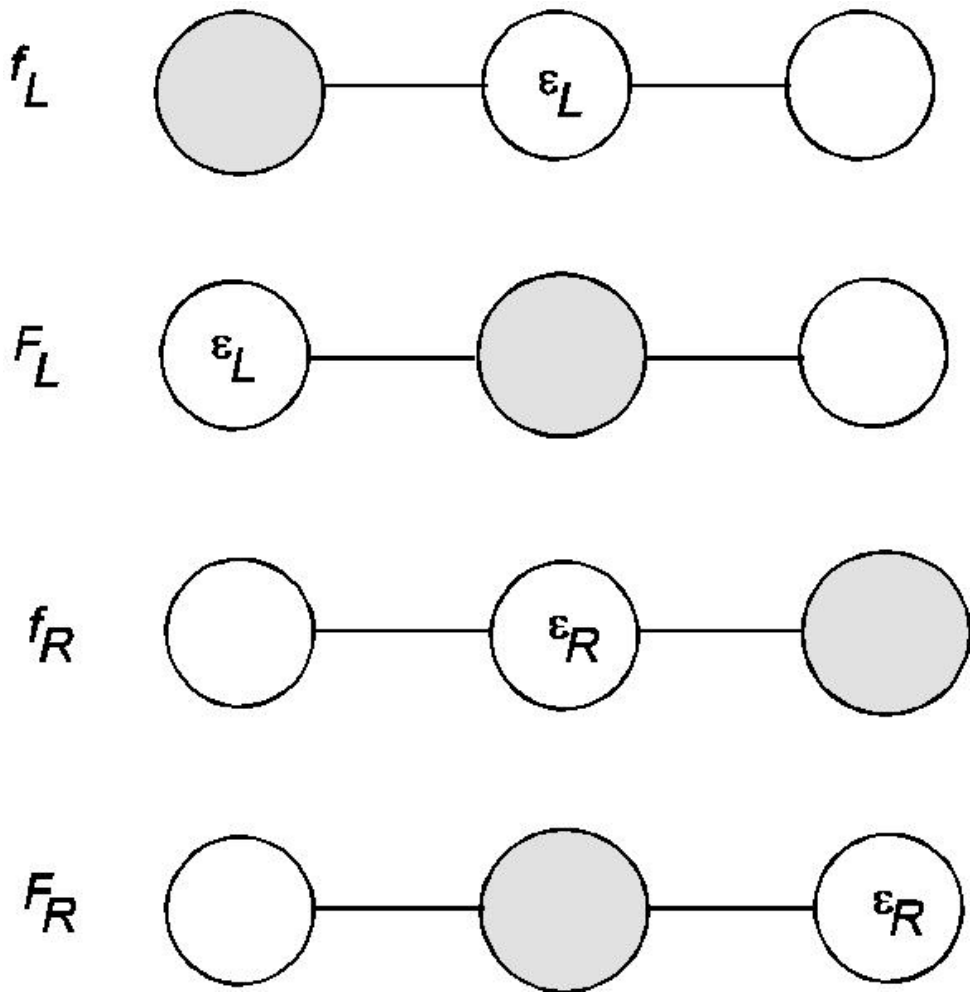


$$\mathcal{L} = M_D \left[\epsilon_L \bar{\psi}_{L0} \Sigma_{01} \psi_{R1} + \bar{\psi}_{R1} \psi_{L1} + \bar{\psi}_{L1} \Sigma_{12} \begin{bmatrix} \epsilon_{uR} & 0 \\ 0 & \epsilon_{dR} \end{bmatrix} \begin{bmatrix} u_{R2} \\ d_{R2} \end{bmatrix} \right]$$

Diagonalizing, we get two eigenvalues:

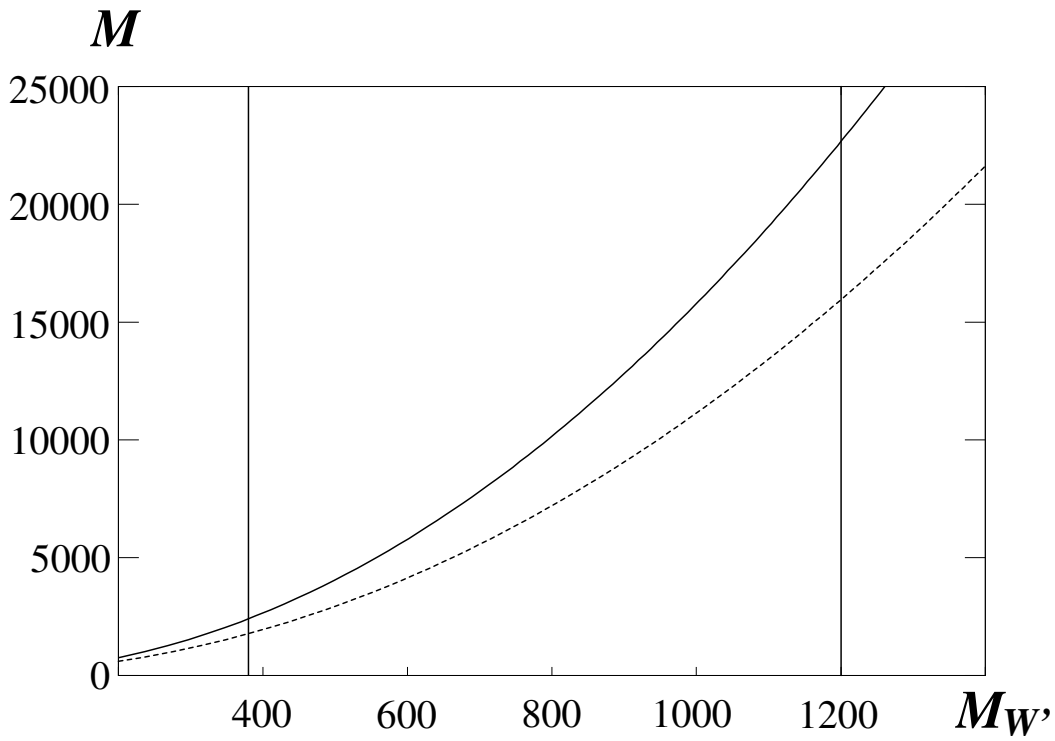
$$m_f = \epsilon_L \epsilon_{fR} M_D$$
$$m_F \approx M_D.$$

Delocalization



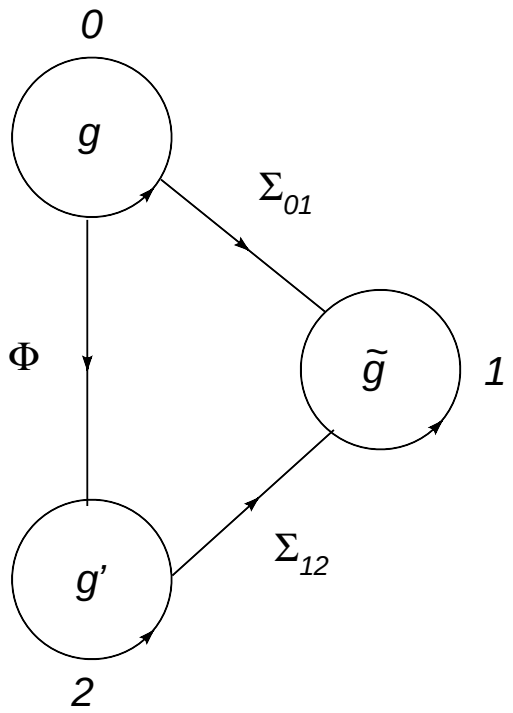
Heavy KK fermion?

- The top quark mass is $m_t = M_D \epsilon_L \epsilon_{tR}$
- $\Delta\rho$ constraint: $\frac{1}{16\pi^2} \frac{\epsilon_{tR}^4 M_D^2}{v^2}$.



Heavy KK fermion?

- Modify the minimal three-site model?
- Borrow from TopColor Assisted Technicolor - two sources of top mass!
- EWSB still largely Higgsless!



The Top Triangle Moose, Phys.Rev.D80:035011,2009. arXiv:0906.5567

Gauge bosons

- Gauge boson masses come from the covariant derivatives when the fields develop vev's.

$$\langle \Sigma_{01} \rangle = \langle \Sigma_{12} \rangle = F = \sqrt{2} v \cos\omega; \langle \Phi \rangle = v \sin\omega.$$

- Spectrum includes W, Z, W', Z', γ.

$$\mathcal{L}_{gauge} = \frac{F^2}{4} \mathrm{Tr}[(D_\mu \Sigma_{01})^\dagger D^\mu \Sigma_{01}] + \frac{F^2}{4} \mathrm{Tr}[(D_\mu \Sigma_{12})^\dagger D^\mu \Sigma_{12}] + (D_\mu \Phi)^\dagger D^\mu \Phi,$$

where

$$D_\mu \Sigma_{01} = \partial_\mu \Sigma_{01} + i g W_{0\mu} \Sigma_{01} - i \tilde{g} \Sigma_{01} W_{1\mu} \text{ etc.}$$

Parametrizing the gauge couplings as:

$$g = \frac{e}{\sin\theta\cos\phi} = \frac{g_0}{\cos\phi}, \tilde{g} = \frac{e}{\sin\theta\sin\phi} = \frac{g_0}{\sin\phi}, g' = \frac{e}{\cos\theta},$$

we find:

$$M_W^2 = \frac{g_0^2 v^2}{4}, M_{W'}^2 = \frac{g_0^2\, v^2 \cos^2\omega}{4\, x^2}$$
$$M_Z^2 = \frac{g_0^2\, v^2}{4\, \cos^2\theta}, M_{Z'}^2 = \frac{g_0^2\, v^2\, \cos^2\omega}{4\, x^2}$$

Top Quark

- Also couples to the top-Higgs.

$$\mathcal{L}_{top} = -\lambda_t \bar{\psi}_{L0}\, \Phi\, t_R + h.c.$$

$$m_t = \lambda_t v \sin\omega \left[1 + \frac{\epsilon_{tL}^2 + \epsilon_{tR}^2 + \frac{2}{a}\epsilon_{tL}\epsilon_{tR}}{2(-1+a^2)}\right],$$

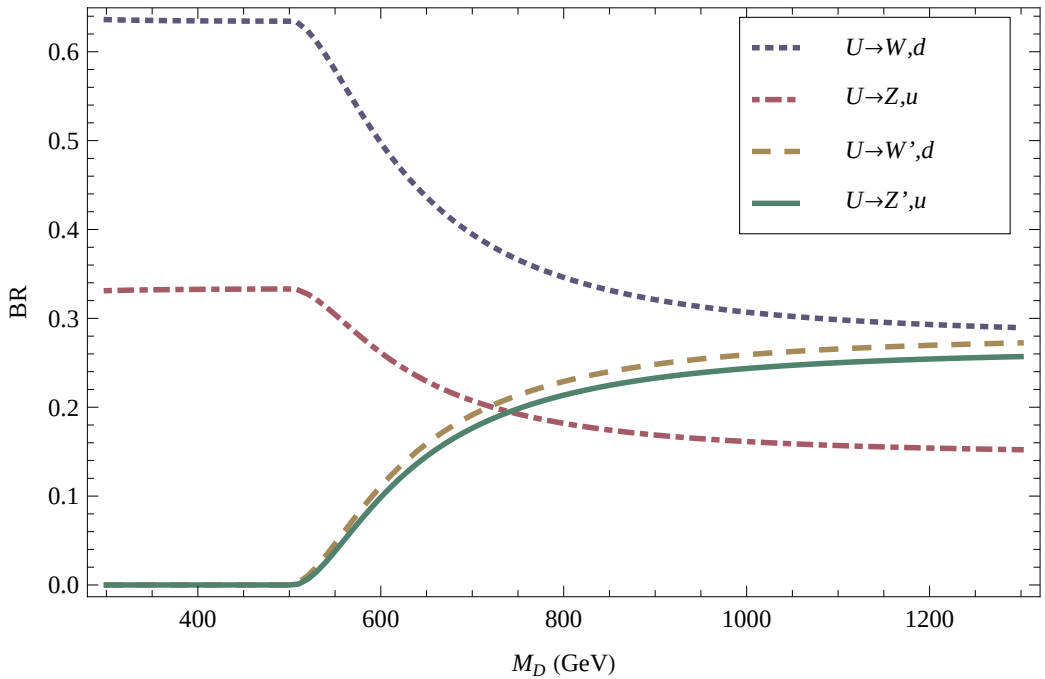
$a \equiv \frac{v \sin\omega}{\sqrt{2} M_D}$

- Uneaten top-pions!

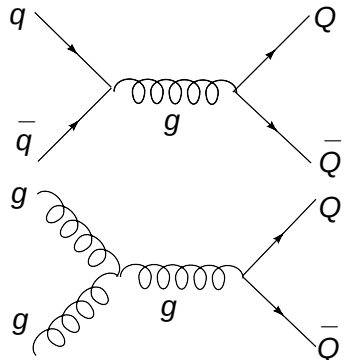
Heavy Quarks at the LHC

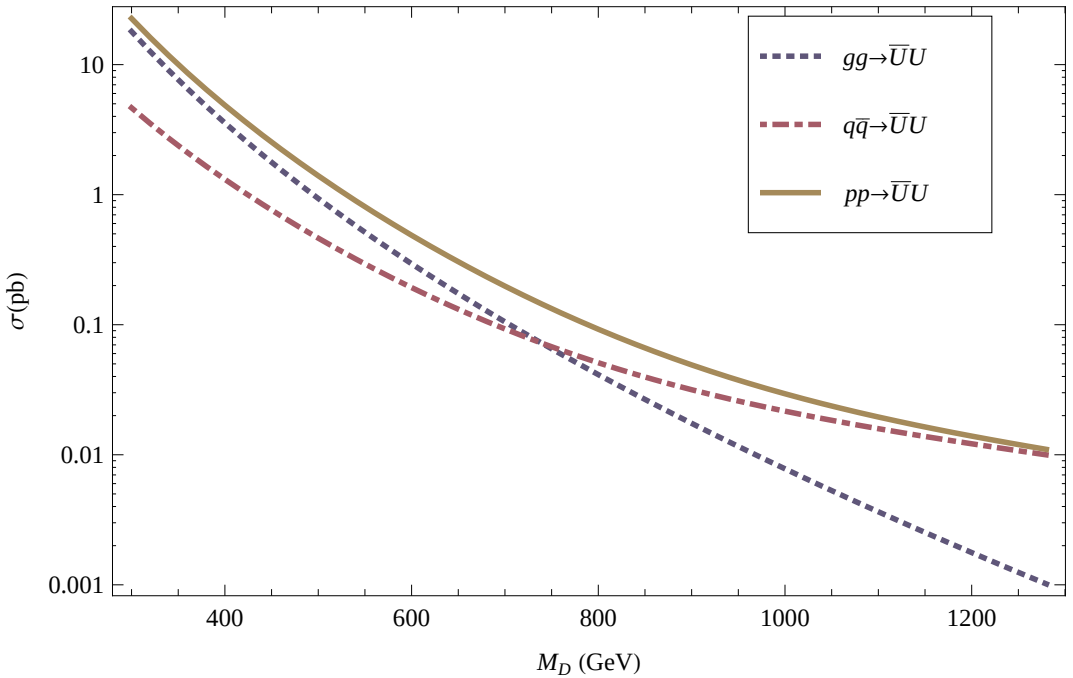
Heavy quark decay

- Look at the heavy partners of u, d, c, s.
- Decays to SM and heavy gauge bosons.
- $g_{Vqq} \sim g$, $g_{VQQ} \sim g$, $g_{Z'qq} \sim gx$, $g_{V'QQ} \sim g/x$.



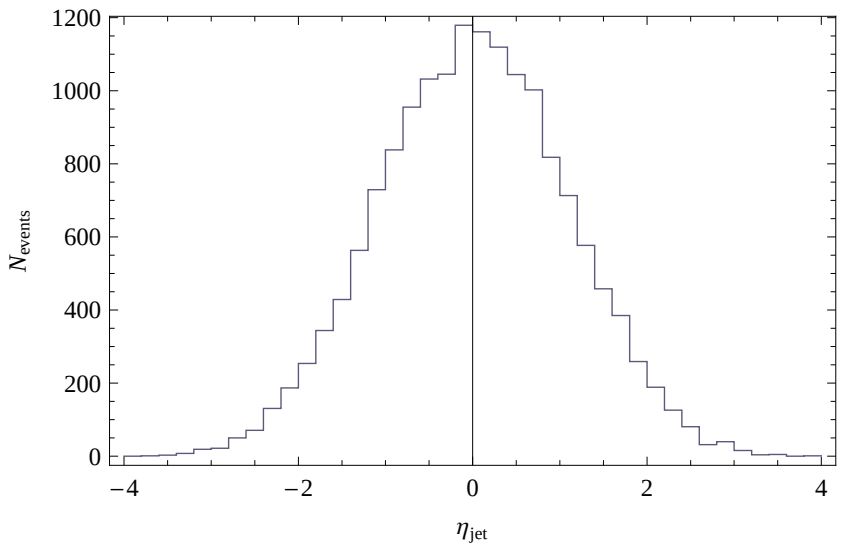
Pair production





$pp \to Q\bar{Q} \to WZjj \to l\nu lljj$

- Look at decays to SM gauge bosons.
- Choose WZ to avoid multiple sources of missing energy.
- Jets with high p_T, central rapidity



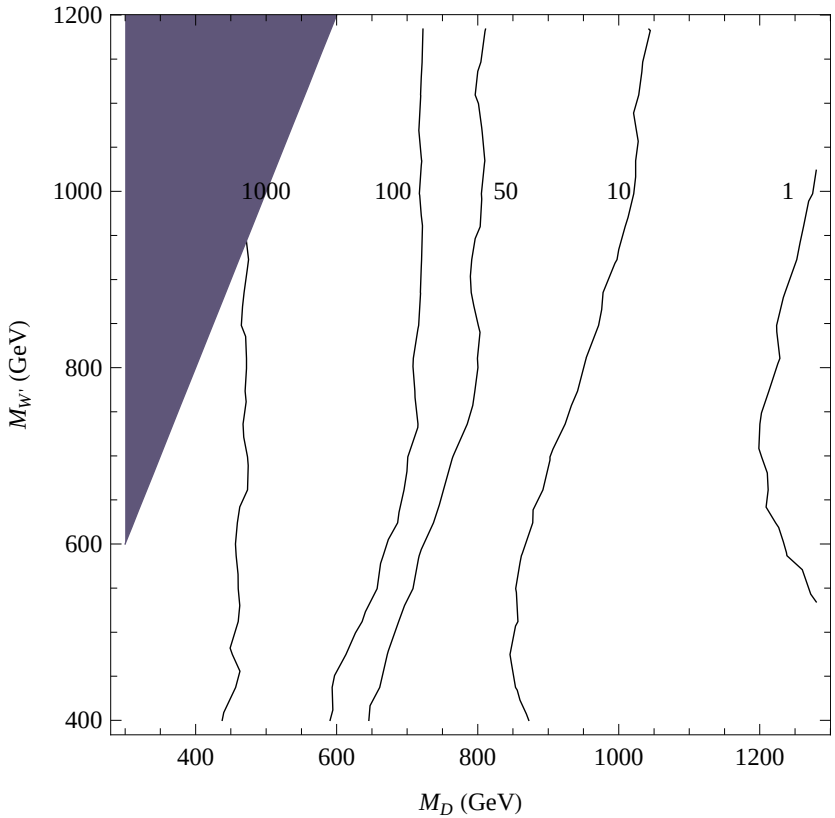
$pp \to Q\bar{Q} \to WZjj \to l\nu lljj$

- Reconstruct the heavy quark mass from the Z branch!
- SM background ≈ 0 with the cuts:

Kinematic variable	Cut
p_{T_j}	>100 GeV
p_{T_l}	>15 GeV
Missing E_T	>15 GeV
$\lvert\eta_j\rvert$	< 2.5
$\lvert\eta_l\rvert$	< 2.5
ΔR_{jj}	>0.4
M_{ll}	89 GeV$< M_{ll} <$ 93 GeV

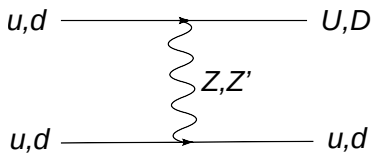
$pp \to Q\bar{Q} \to WZjj \to l\nu lljj$

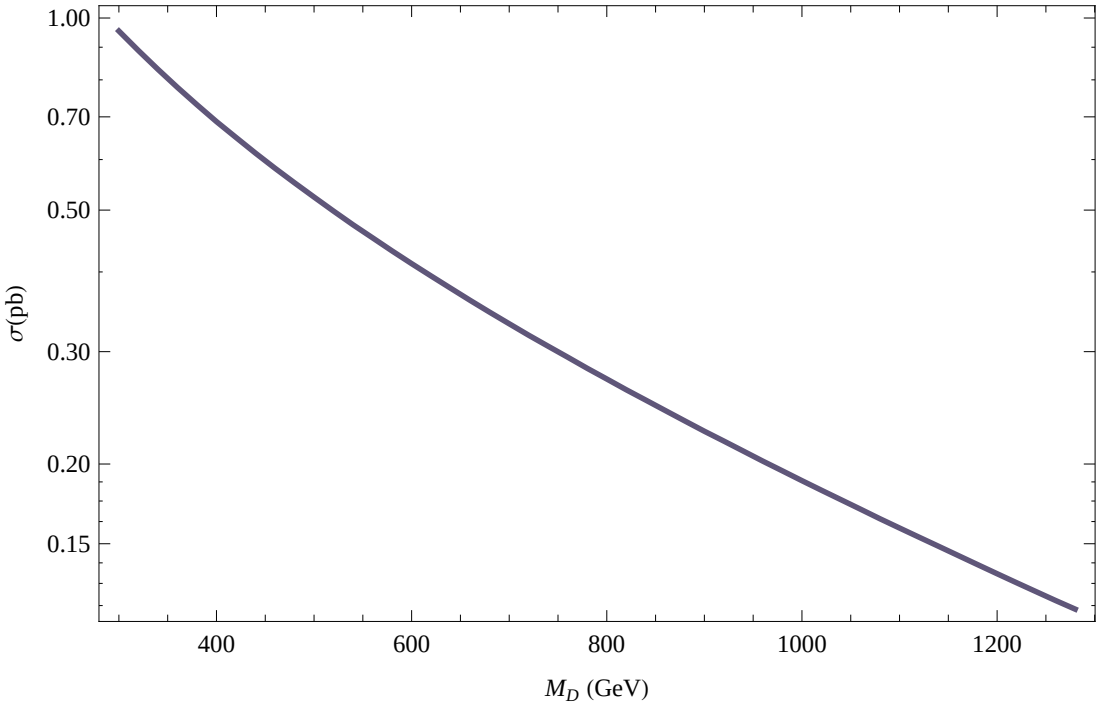
- Fixed luminosity - 100 fb^{-1}.



- Shaded portion: $\Gamma_{W'} \gg M_{W'}$!

Single production





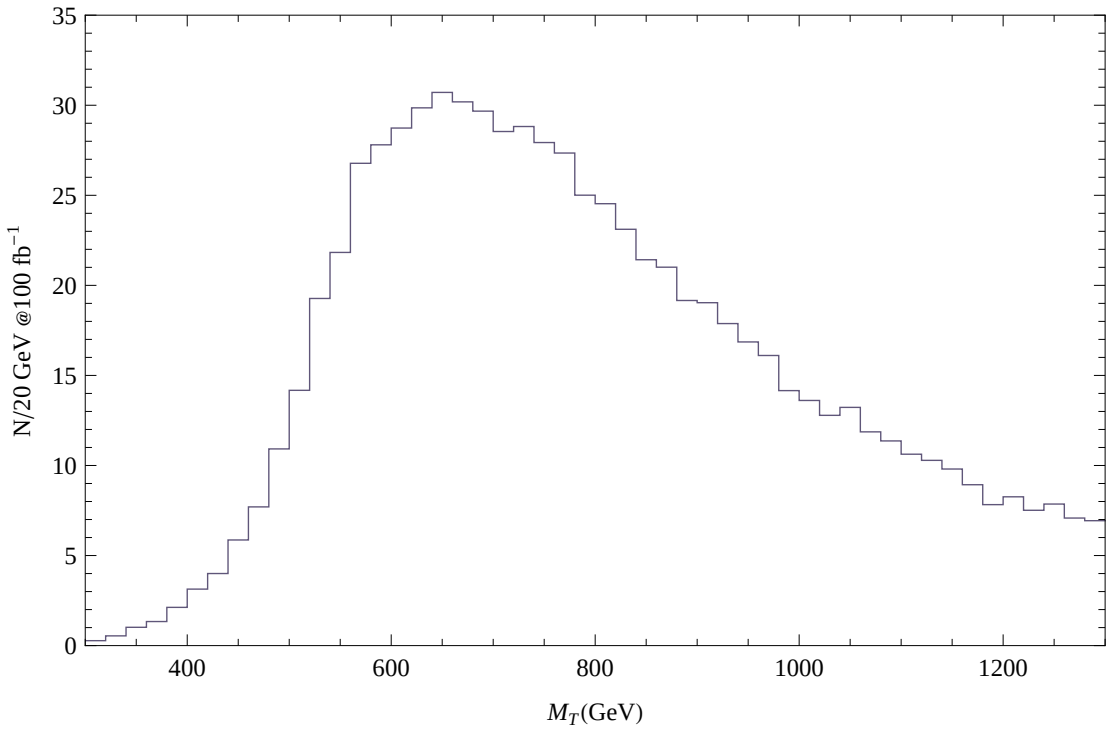
$pp \to Qq \to W'jj \to WZjj \to l\nu lljj$

- Same final state as before, different kinematics!
- W' decays to WZ 100% of the time.
- Do a transverse mass analysis.
- Cuts:

Kinematic variable	Cut
p_{T_j} hard	>200 GeV
p_{T_j} soft	>15 GeV
p_{T_l}	>15 GeV
Missing E_T	>15 GeV
$\lvert\eta_j \text{ hard}\rvert$	< 2.5
$\lvert\eta_j \text{ soft}\rvert$	$2 < \lvert\eta\rvert < 4$
$\lvert\eta_l\rvert$	< 2.5
ΔR_{jj}	>0.4

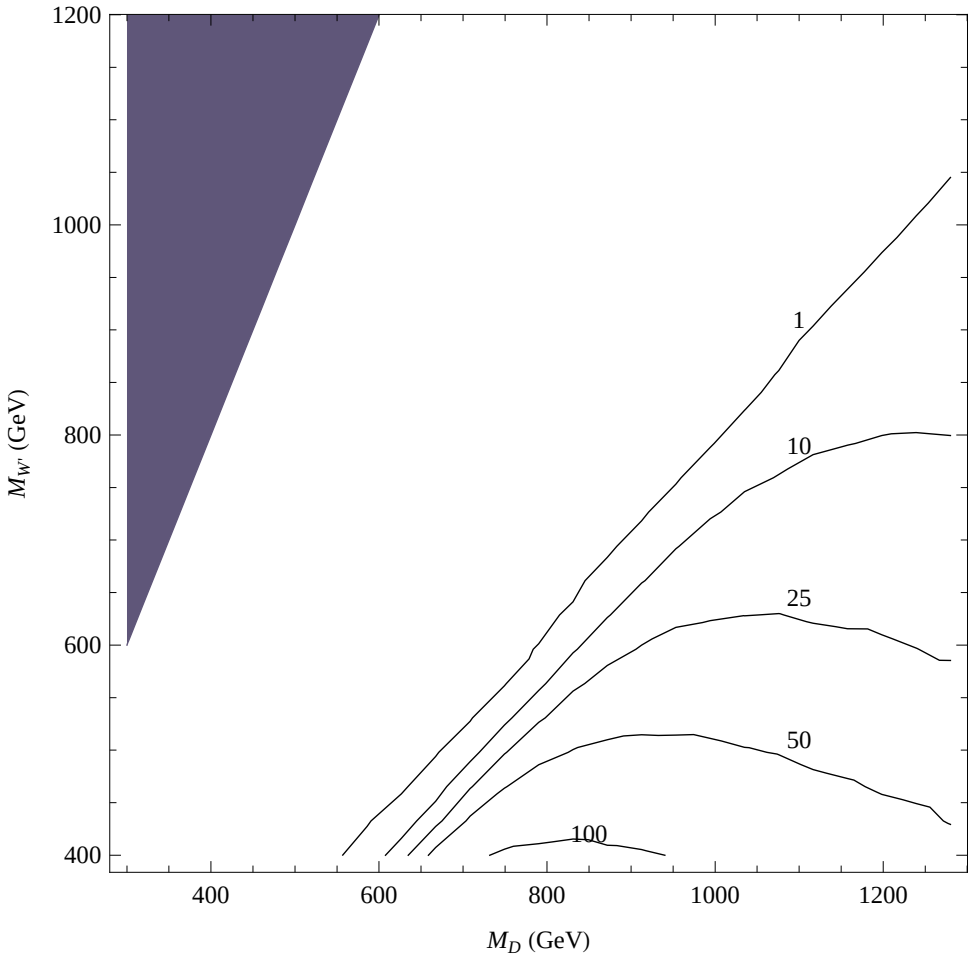
$pp \to Qq \to W'jj \to WZjj \to l\nu lljj$

- SM background is *not* zero!



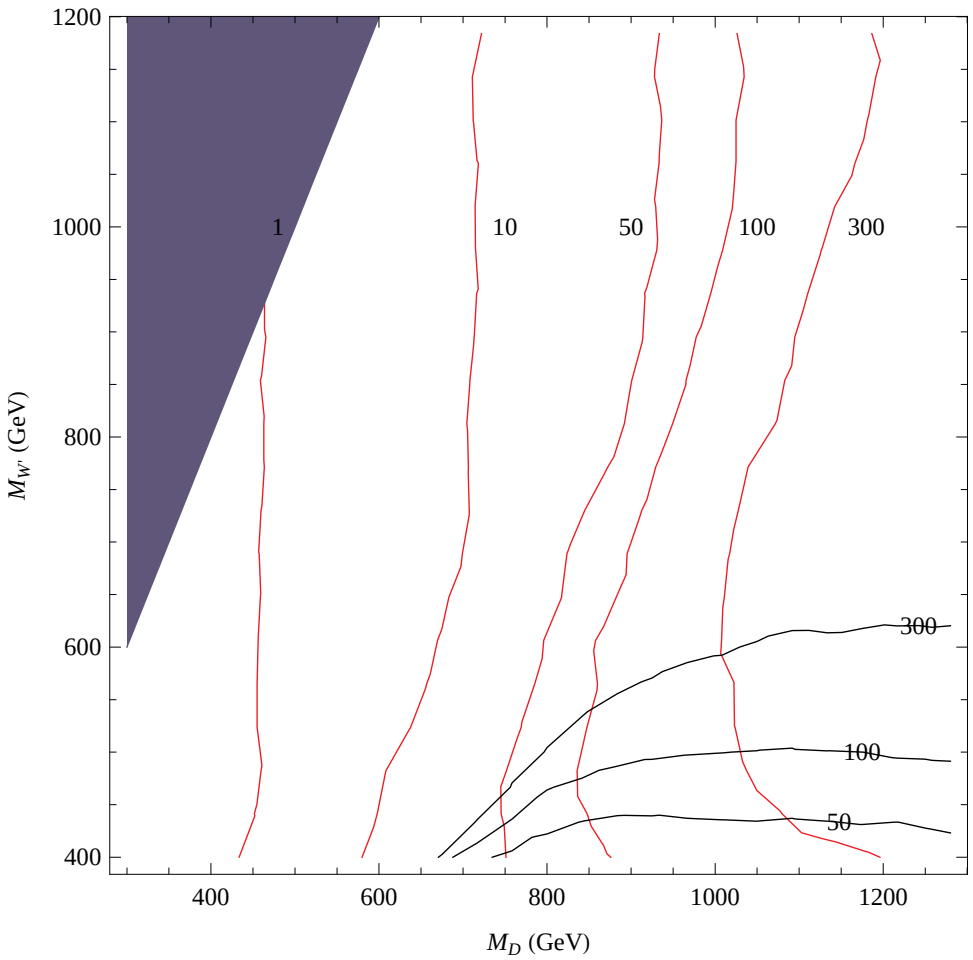
$pp \to Qq \to W'jj \to WZjj \to l\nu lljj$

- Cover the $M_{W'} > M_D$ region!



Putting them together.....

- Luminosity contours for 5σ discovery.



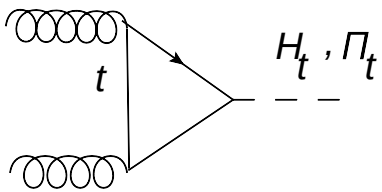
Top-Higgs and Top-pions at the LHC.

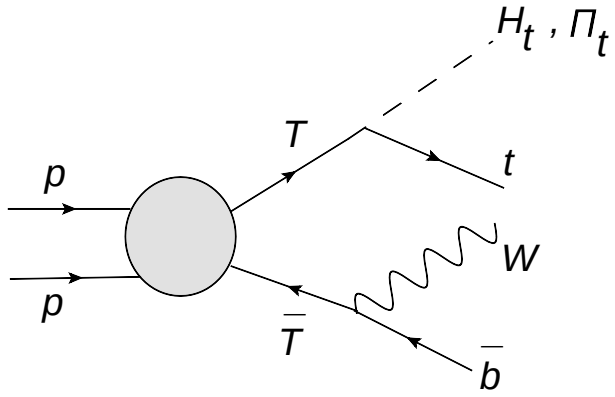
Production channels

- Enhanced coupling to the top-quark!

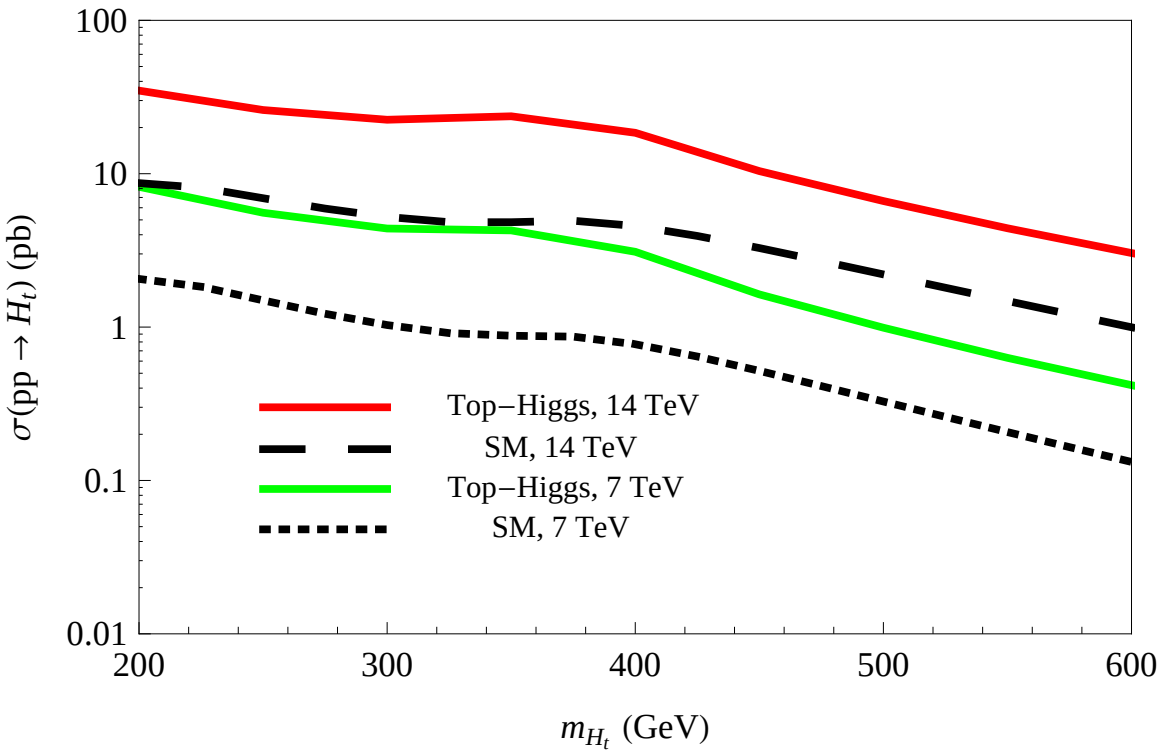
$$g_{H_t tt} = \frac{\lambda_t}{\sqrt{2}}, \; g_{\Pi_t tt} = \frac{\lambda_t \cos\omega}{\sqrt{2}},$$

  where $\lambda_t \approx \frac{\sqrt{2} m_t}{v \sin\omega}$.
- Higher production cross-section than H_{SM}.
- a) Top-loop, b) Decay of heavy-T.



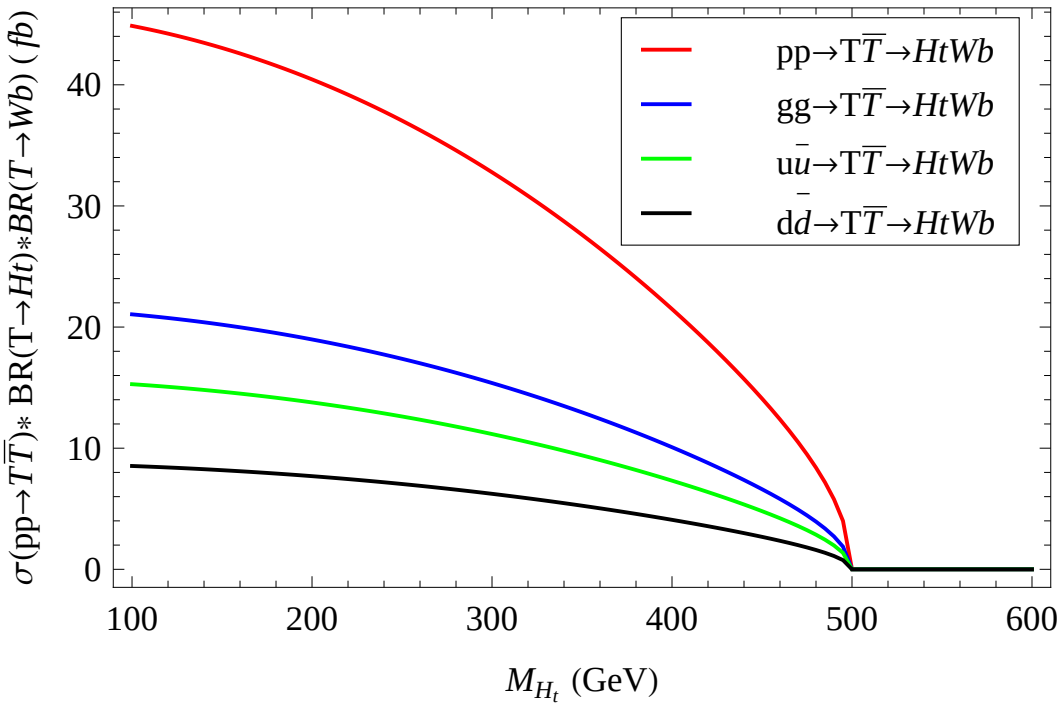


Top-Higgs-1


100
10
1
0.1
0.01
200
300
400
500
600
$\sigma(pp \to H_t)$ (pb)
m_{H_t} (GeV)
Top−Higgs, 14 TeV
SM, 14 TeV
Top−Higgs, 7 TeV
SM, 7 TeV

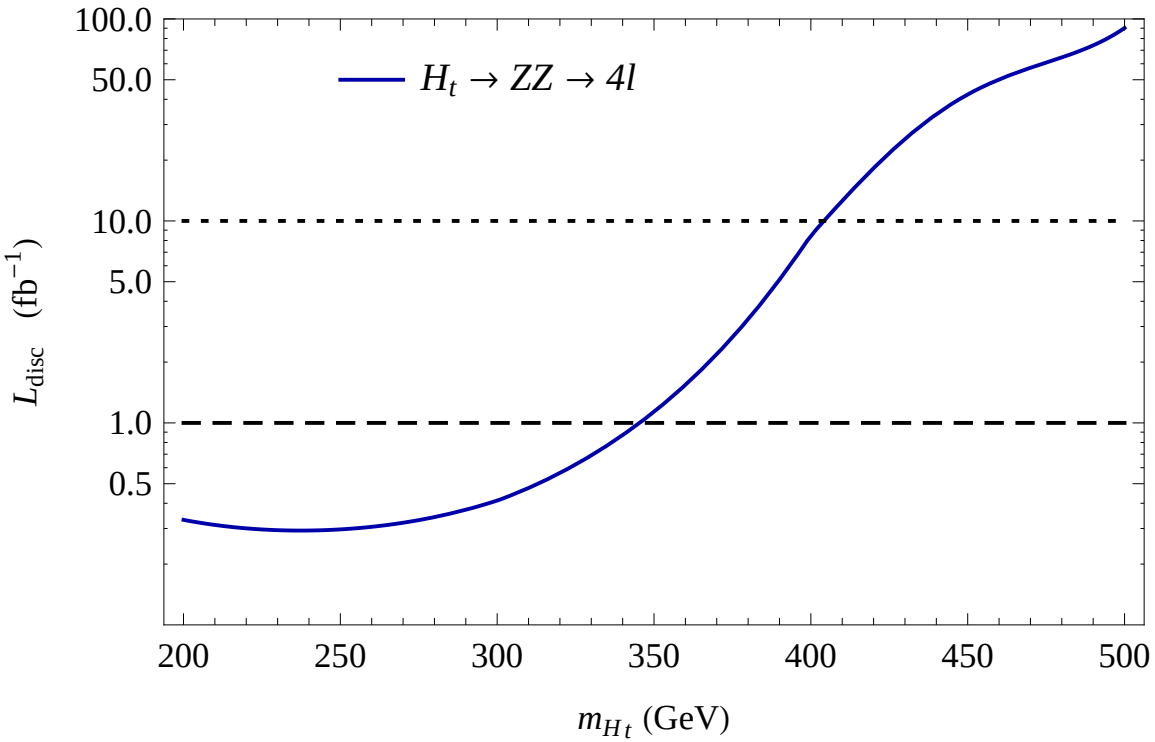
Top-Higgs-2

- $pp \to T\bar{T} \to WbH_t t$ for $M_{\Pi_t} = 200$ GeV, $M_D = 650$ GeV, $M_{W'} = 500$ GeV and $\sin\omega = 0.5$.

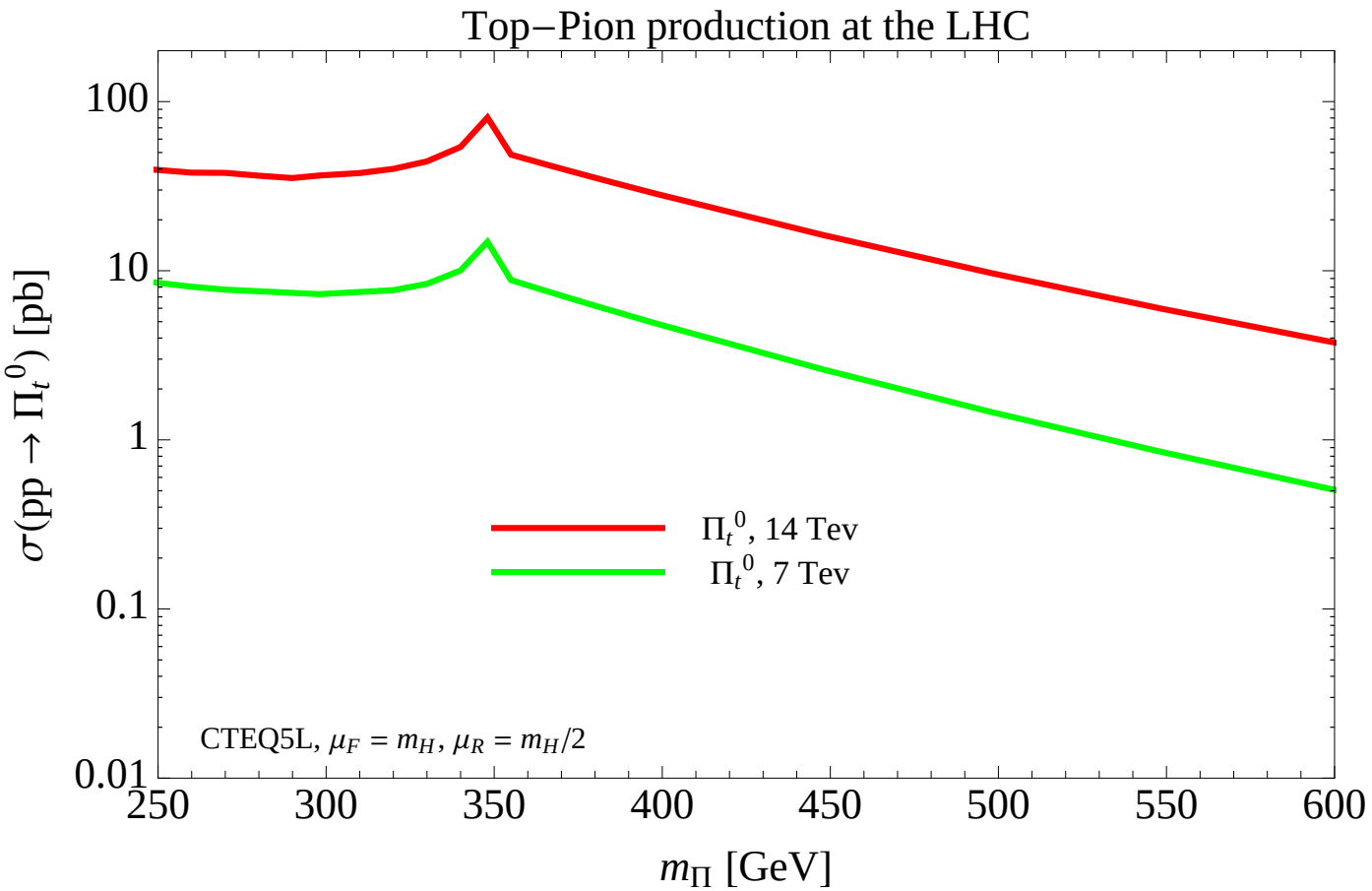


Prospects

- $M_{H_t} \lesssim 150$ GeV $\Longrightarrow$ decay to gluons - detection hard!
- Heavier Top-Higgs: Rescale SM Higgs couplings in the four lepton mode.

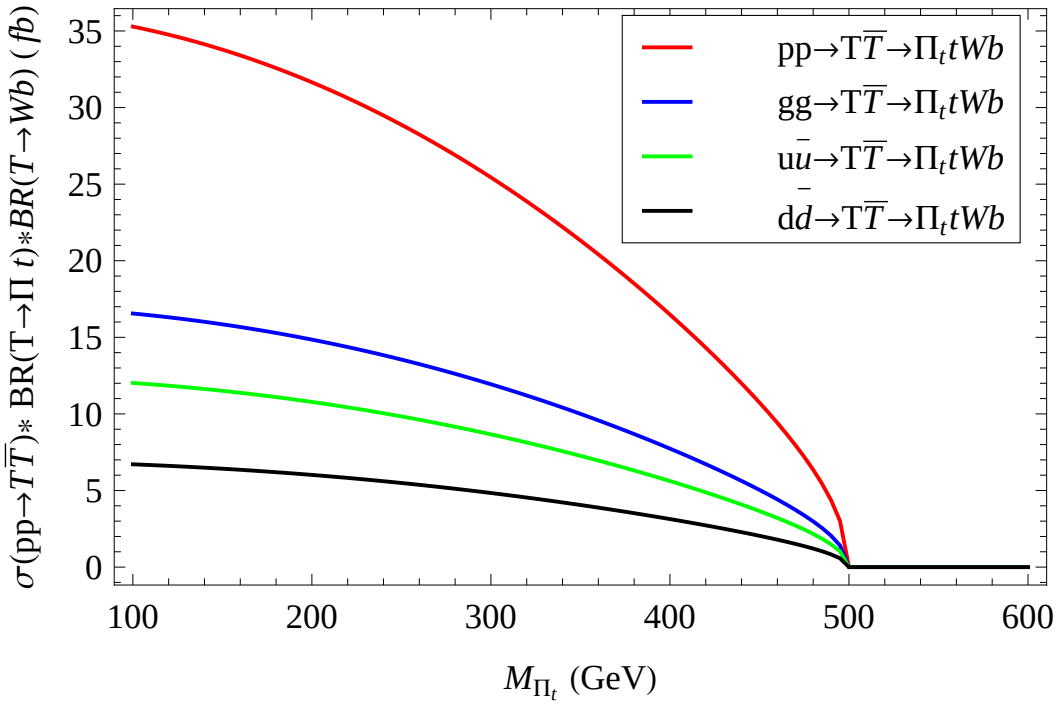


Top-pion-1

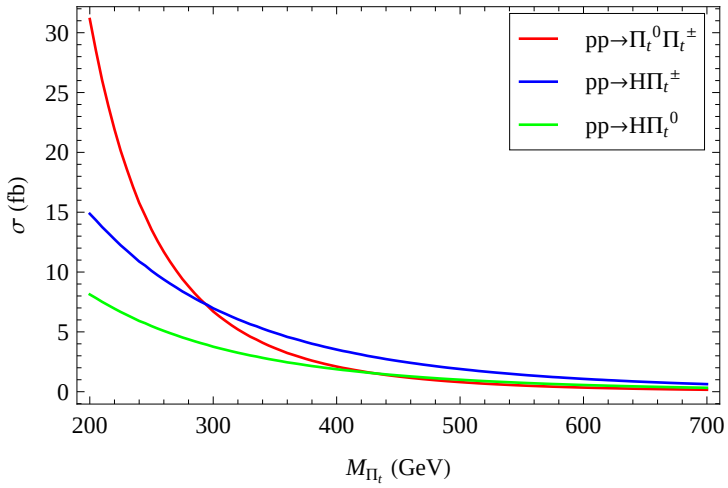

Top−Pion production at the LHC
100
10
1
0.1
0.01
$\sigma(pp \to \Pi_t^0)$ [pb]
250
300
350
400
450
500
550
600
m_Π [GeV]
Π_t^0, 14 Tev
Π_t^0, 7 Tev
CTEQ5L, $\mu_F = m_H$, $\mu_R = m_H/2$

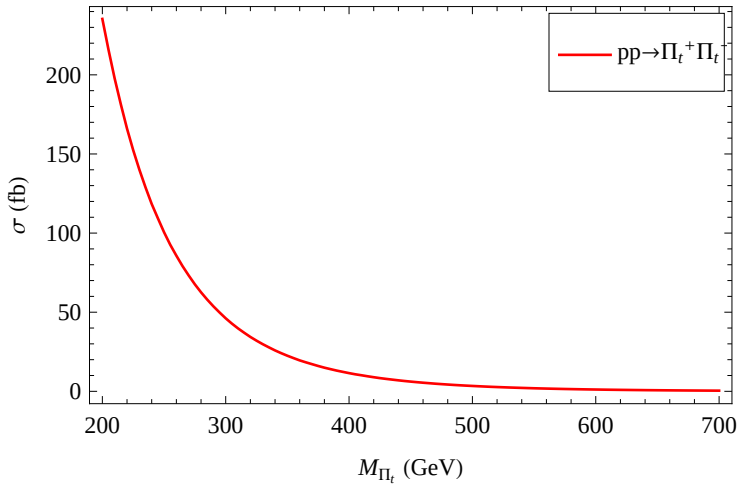
Top-pion-2

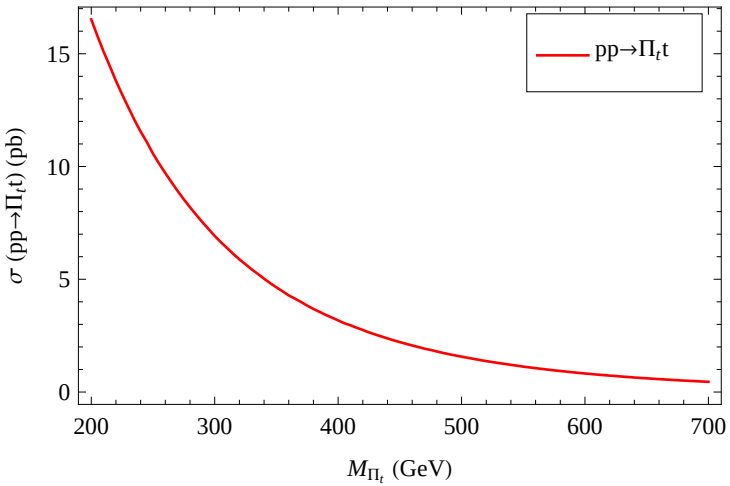
- $pp \to T\bar{T} \to WbP_t t$ for $M_{H_t} = 250$ GeV, $M_D = 650$ GeV, $M_{W'} = 500$ GeV and $\sin\omega = 0.5$.

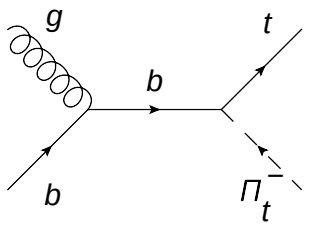


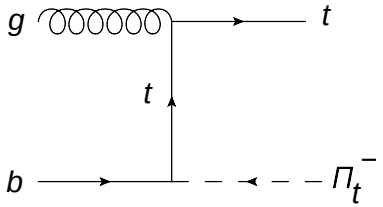
Other modes


pp→Π_t^0 Π_t^±
pp→HΠ_t^±
pp→HΠ_t^0
σ (fb)
M_Π_t (GeV)


pp→Π_t^+ Π_t
σ (fb)
M_Π_t (GeV)


pp→Π_t t
σ (pp→Π_t t) (pb)
M_Π_t (GeV)


g
t
b
b
Π_t^-


g
t
t
b
Π_t^-

Conclusions

- A simple "3-site" model incorporating Higgsless and Top-Higgs mechanisms.
- Heavy quarks light enough to be seen at the LHC.
- Extra scalar states - top-Higgs and top-pions with enhanced cross-sections!

Ideal delocalization

- Precision constraints satisfied by imposing $g_{W'qq}$=0.

$$g_{W'qq} = \sum_i g_i \psi_{W'_i} \left(\psi_{q_i}\right)^2 .$$

- W and W' are orthogonal, and hence choose:

$$g_i \left(\psi_{q_i}\right)^2 \propto \psi_{W_i}.$$

$$\Longrightarrow \epsilon_L^2 = \frac{x^2}{2}.$$

Heavy T-quark