Spin-1 resonance production through t $\bar{t}$ fusion

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Why top?

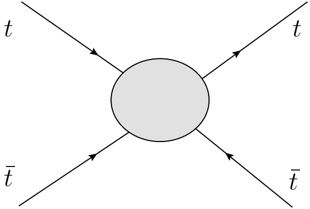
- The phenomenological constraints on the t_R is practically absent.
- If EWSB dynamics belongs to a strong sector, Higgs can be naturally light if it is a psedu-goldstone boson.

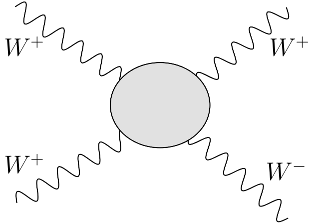
Why top?

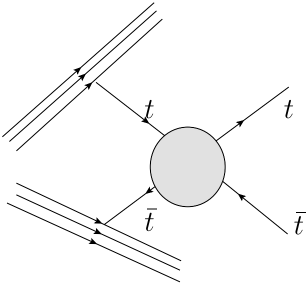
- Assuming partial compositeness, the top Yukawa $y_t \sim \frac{\lambda_L \lambda_R}{g_\rho} \Rightarrow \min(\lambda_L, \lambda_R) \gtrsim y_t$.
- Higgs potential will get contributions from top loops proportional to $(\lambda_L^2, \lambda_R^2, \lambda_L \lambda_R)$

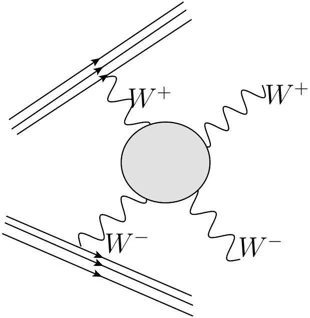
Why top?

- If t_R is fully composite , $\lambda_R = g_\rho, \lambda_L \sim y_t$.
- t_R respects the global symmetry of the strong sector and doesn't contribute to the Higgs potential. It will be easier to get a light Higgs.


t
t
$\bar{t}$
$\bar{t}$


W^+
W^+
W^+
W^-





To get a top from proton, we pay a factor of $\alpha_s \log(\frac{E}{m_t})$, while to obtain a W, we pay a factor of $\alpha_w \log(\frac{E}{m_W})$.

Factorization $\delta_m = \frac{m}{E} \ll 1, \qquad \delta_\perp = \frac{p_\perp}{E} \ll 1$

$$
\begin{aligned}
\sigma(pp \to X t\bar{t}) = & \int_0^1 f_g(x_1, Q) dx_1 \frac{\alpha_s}{\pi} \int_0^1 dx \frac{p_\perp^3 dp_\perp}{(p_\perp^2 + m_t^2)^2} P_{qg}(x) \\
& \int_0^1 f_g(y_1, Q) dy_1 \frac{\alpha_s}{\pi} \int_0^1 dy \frac{q_\perp^3 dq_\perp}{(q_\perp^2 + m_t^2)^2} P_{qg}(y) \\
& \sigma(t\bar{t} \to X)(x x_1 P_1, y y_1 P_2).
\end{aligned}
$$

The splitting function:

$$
P_{qg}(x) = \frac{1}{2}(x^2 + (1-x)^2)
$$

Top pdf

$$\frac{d}{dlogQ}f_t(x,Q) = \frac{\alpha_s(Q)}{\pi}\int_x^1 \frac{dz}{z}\{P_{qq}(z)f_t(\frac{x}{z},Q) + P_{qg}(z)f_g(\frac{x}{z},Q)\}$$

The splitting function:

$$P_{qq}(x) = \frac{4}{3}(\frac{1+x^2}{(1-x)_+} + \frac{3}{2}\delta(1-x))$$

$$P_{qg}(x) = \frac{1}{2}(x^2 + (1-x)^2).$$

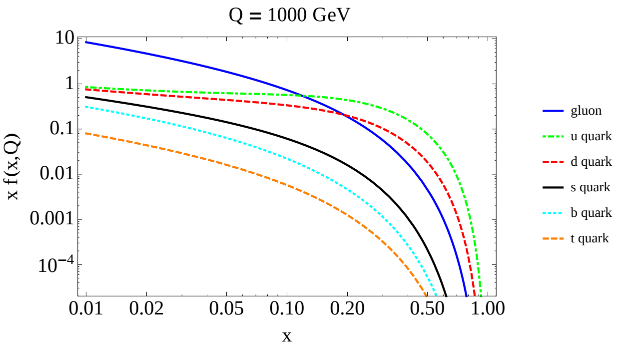
Top pdf

LO in $\alpha_s(Q)$

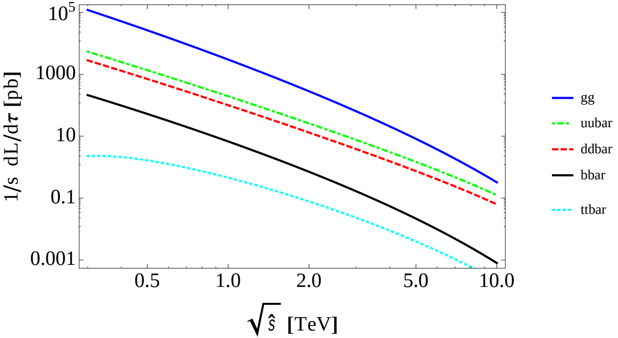
$$\frac{d}{dlogQ} f_t(x, Q) = \frac{\alpha_s(Q)}{\pi} \int_x^1 \frac{dz}{z} P_{qg}(z) f_g(\frac{x}{z}, m_t)$$

with initial condition $f_t(x, m_t) = 0$.

Top pdf


Q = 1000 GeV
10
1
0.1
0.01
0.001
10^{-4}
x f(x,Q)
0.01
0.02
0.05
0.10
0.20
0.50
1.00
x
gluon
u quark
d quark
s quark
b quark
t quark

parton luminosity



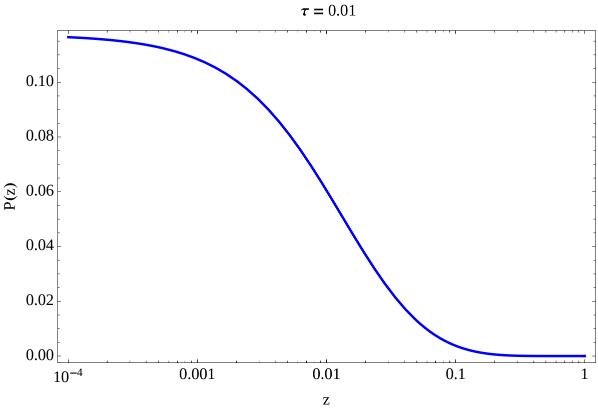
Fixing parton C.O.M energy $\hat{s} = \tau s$

$$(\frac{\alpha_s log \frac{E}{m_t}}{\pi})^2 \int_0^1 f_g(x_1, Q) f_g(y_1, Q) dx_1 dy_1 \times$$

$$\int_0^1 P_{qg}(x) P_{qg}(y) dx dy \delta(x x_1 y y_1 - \tau) \delta(x_1(1-x) - z)$$

z is the fraction of the proton energy carried away by the outgoing top.

Fixing parton C.O.M energy $\tau = 0.01$



ρ_X resonance

- In composite Higgs models, we need an $U(1)_X$ symmetry in the strongly interacting sector to correctly reproduce the hyper-charge quantum number of the SM fermions: $Y = T^{3R} + X$.
- The corresponding conserved current will excite the spin-1 resonance from the vaccum: ρ_X.

ρ_X resonance

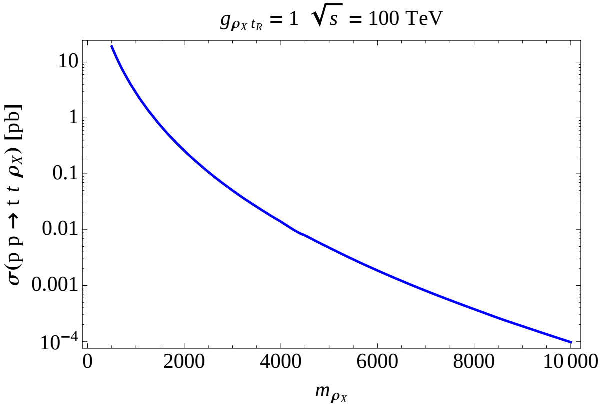
- The relevant phenomenology ρ_X is described by one coupling g_{ρ_X} and one mass scale m_{ρ_X}.
- Assuming that the right-handed top is a massless bound state of the strong sector, its interaction with ρ_X is controlled by g_{ρ_X}.

A very simplified model:

$$\mathcal{L} = -\frac{1}{4}\rho_X^{\mu\nu}\rho_{X\mu\nu} + \frac{1}{2}m_{\rho_X}^2(\rho_X^\mu)^2 + g_{\rho_X}\rho_X^\mu \bar{t}_R\gamma_\mu t_R$$

Preliminary results

XS with unit coupling: $pp \to \rho_X t\bar{t}$



- Benchmark point: 5 TeV ρ_X.

- XS:$\sim$ 3.7 fb with $g_{\rho_X} = 1$.

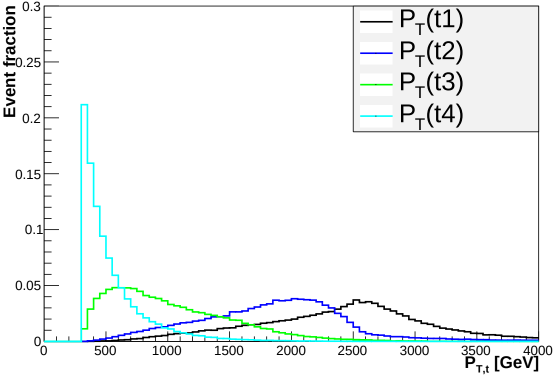
  (Require $p_T(t) > 300$ GeV, factorization scale setted to be the lowest p_T).

Simulation

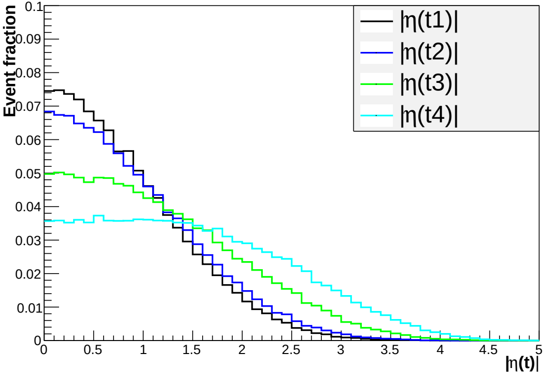
- All are simulated with parton-level event generator MadGraph5.
- Basic preselection criteria: $|\eta| < 5, p_T > 300 GeV$.

kinematics of the signal (Preliminary)

The tops are ordered by p_T



kinematics of the signal (Preliminary)



Remarks

- t_1, t_2 are mainly (80%) from ρ_X decay.
- The tops from gluon splitting t_3, t_4 are not very forward because of the mass of the top:

$$\langle p_T \rangle \sim E/log(E/m_t) \qquad \Rightarrow \qquad \langle |\eta| \rangle \sim 1.64.$$

Remarks

- As a first step, we consider four highly boosted tops ($p_T > 1$ TeV) in the central region ($|\eta| < 2.5$) which decay hadronically.

- Highly boosted tops ($p_T > 1$ TeV): looks like a single jet $\Delta R \sim \frac{2m_t}{p_T} \sim 0.4$.

Remarks

- Assuming top tagging efficiency 20%, QCD jet mistagging rate 2%.

S. Schaetzel and M. Spannowsky, 1308.0540.

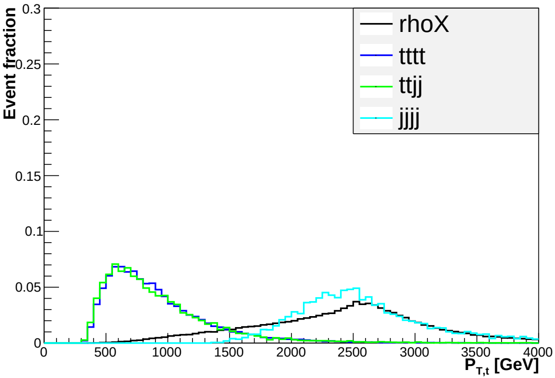
Backgrounds

- Considering the hadronically decaying of the tops, the main backgrounds are: ttjj , tttt, jjjj(including b)

- LO XS (calculated using MadGraph5):
  ttjj $\sim 1.22 \times 10^4$ pb, tttt $\sim$ 2.64 pb, jjjj $\sim$ 254 pb ($H_T > 5$ TeV).

  (Require $p_T(j) > 50$ GeV, $\Delta R > 0.4$)

p_T distribution for the LO top



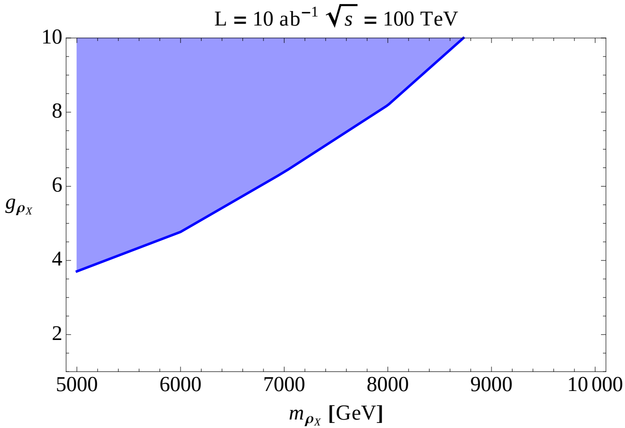
Basic cuts

- $p_T(t_1) > 2\,TeV,\, p_T(t_2) > 1\,TeV.$
- $|\eta(t_{3,4})| < 2.5,\, p_T(t_3) > 1\,TeV,\, p_T(t_4) > 1\,TeV.$

Cut flow for the signal VS. background

Process	XS[fb]	Basic cuts	multiplied by $\epsilon_{t,j}$
Signal	3.7	0.056	0.00009
ttjj	1.22×10^7	31.6	0.0005
tttt	2.64×10^3	0.059	0.000095
jjjj	2.54×10^5	1993	0.00032

5 σ discovery region (Preliminary)



Future directions

The results are not encouraging, but we expect to gain more sensitivity by:

- Consider the moderately boosted region $300\text{GeV} < p_T(t) < 1\text{TeV}$.

  The signal will be 10 times larger.

Future directions

- Consider the semi-leptonically decaying of the top.

$$\mathrm{BR}(\mathrm{t} \to \sum_{l=e,\mu} blv) \sim 20\%$$

$$\mathrm{BR}(\mathrm{t} \to \mathrm{hadrons}) \times \epsilon_t \sim 14\%$$

Future directions

- $\Gamma_{\rho X}/m_{\rho X} \sim (1/8\pi) g_{\rho X}^2 \sim 0.04 g_{\rho X}^2$
- As a complementray study, we will also consider the 4-top contact interactions.

Conclusion and Outlook

- At 100 TeV pp collider, if top (t_R) is belonging to the strong sector, top top scattering may become relevant for probing the strong EWSB dynamics.
- We have given an example for spin-1 resonance production through $t\bar{t}$ fusion.
- Other processes like tb fusion is also interesting.