Diquark effect on single top production at the LHC

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Outline

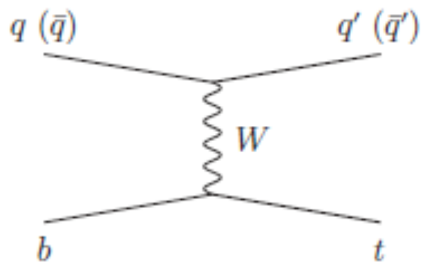
- Single top production at LHC
- Colored resonances at LHC
- Diquark contribution to single top production
- Numerical results & Discussions
- Summary

Single top production at LHC

- The heaviest fundamental particle in Standard Model
  - decays before it can hadronize
  - large production rate at LHC

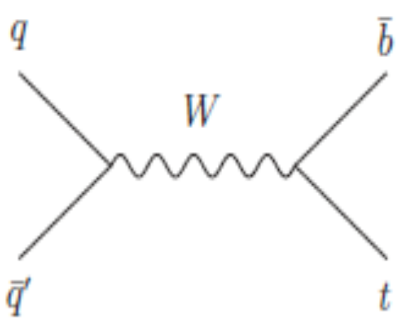
- Single production in three different channels

$qb \to q't$ and $\bar{q}b \to \bar{q}'t$



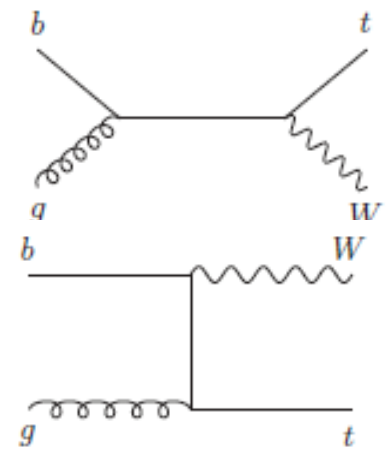
t-channel

$q\bar{q}' \to \bar{b}t$



s-channel

$bg \to tW^-$



- Measurement of the tbW vertex ⟶ in SM: $\sigma_t \propto |V_{tb}|^2$
- Source for polarized tops

Single top production at LHC

- The theoretical cross-sections at NLO+NNLL @LHC 7 TeV

Channel	NLO+NNLL cross-section (pb)
t-channel top	$41.7^{+1.6}_{-0.2} \pm 0.8$
t-channel anti-top	$22.5 \pm 0.5^{+0.7}_{-0.9}$
s-channel top	$3.17 \pm 0.06^{+0.13}_{-0.10}$
s-channel anti-top	$1.42 \pm 0.01^{+0.06}_{-0.07}$
tW^-	$7.8 \pm 0.2^{+0.5}_{-0.6}$

N. Kidonakis (2011)

- The different modes are affected differently by new physics

s-channel contribution will fall off with increasing mass in the final state but mode more sensitive to massive particle exchange

Colored resonances at LHC

- LHC data is already pushing the energy frontier of BSM physics predictions.

- Most sensitive to strongly interacting sector of new physics models exchanged in the s-channel

  - R-parity violating SUSY: squarks
  - Excited quarks in composite models (Kuhn+'84, Baur'87)
  - Color-sextet fermions, e.g. quixes.. (Martin'92)
  - Color-octet vector bosons (axigluons, colorons) (Frampton+'87)
  - Color-sextet scalars, scalar diquarks,.. (Pati+'74,Mohapatra+'80)
  - More exotics (group theory decomposition) (Han+'10)

Colored resonances at LHC

- Resonant states contribute to the dijet production

➢ Alters the dijet differential cross section at large invariant mass

➢ Effective strong constraints on such massive resonances

- CMS and ATLAS limits at 95% C.L. with 1 fb^{-1} data

➢ Excited quark mass > 2.99 TeV (ATLAS), 2.49 TeV (CMS)

➢ Axigluon/coloron mass > 3.32 TeV (ATLAS), 2.47 TeV (CMS)

➢ Color-octet scalar mass > 1.92 TeV (ATLAS)

➢ E_6 diquark mass > 3.52 TeV (CMS)

Colored resonances at LHC (Diquarks)

- Colored particles carrying quantum number of two quarks

  - Exotic baryon number – twice that of ordinary quarks
  - Can be a triplet or sextet of $SU(3)_C$ ($3X3 = \underline{3} + 6$)
  - Can be scalar or vector

- Produced through quark-quark annihilation as resonance

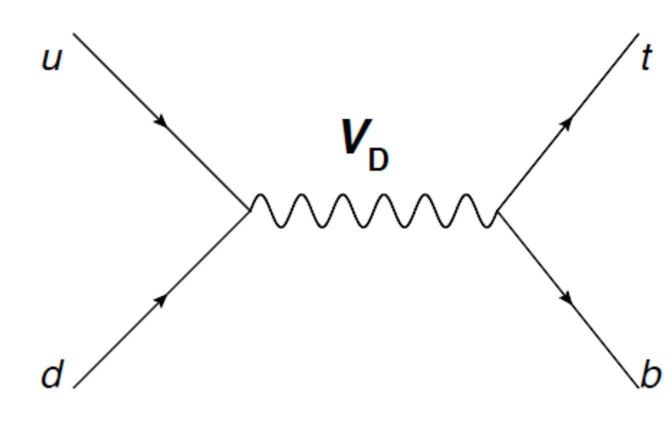
  - Dijet cross section (Cakir+'99'02'05, Beger+'10,Han+'10,Richarsdon+'11)
  - Same sign top pair (Barger+'08, Frederix+'09, Berger+'10,Kosnik+'11)
  - Single top quark production (Gogoladze+'10)

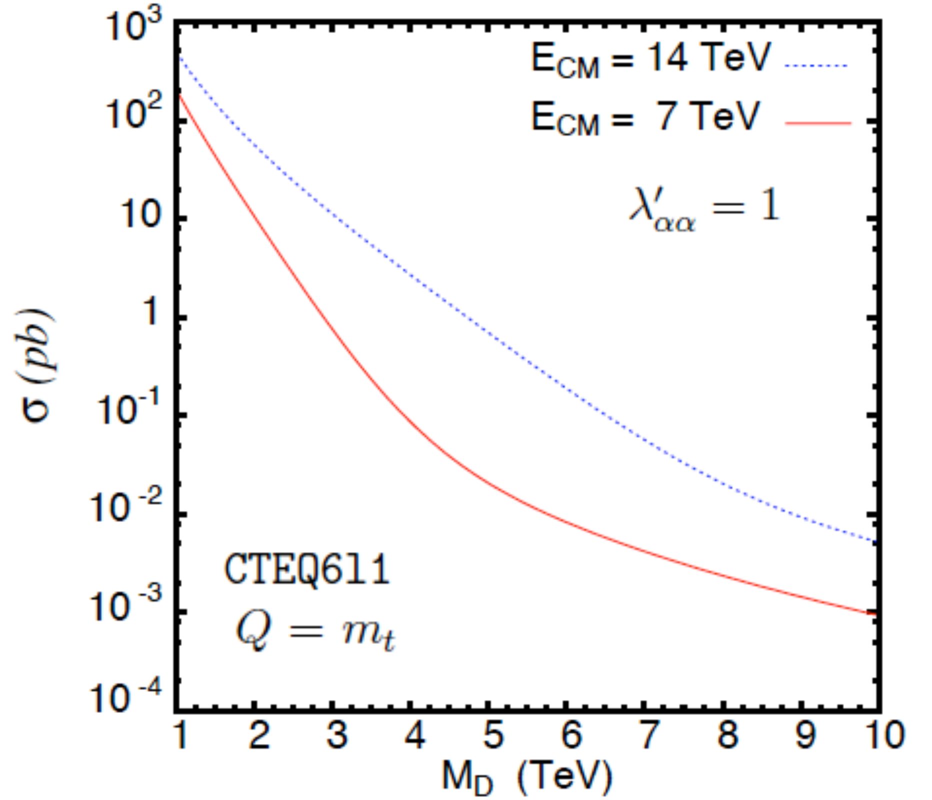
We focus on the vector diquark (sextet) exchange in the s-channel for single top production

The effective Lagrangian density for the vector diquark interacting with quark pair:

$$\mathcal{L}^V_{qqD} = K^j_{ab}\left[\lambda'^{2U}_{\alpha\beta} V^{j\mu}_{2U}\overline{u^c}_{\alpha a}\gamma_\mu P_R u_{\beta b} + \lambda'^{U}_{\alpha\beta} V^{j\mu}_{U}\overline{d^c}_{\alpha a}\gamma_\mu P_R d_{\beta b} + \boxed{\lambda'^{D}_{\alpha\beta} V^{j\mu}_{D}\overline{u^c}_{\alpha a}\gamma_\mu P_\tau d_{\beta b}}\right] + \mathrm{h.c.}$$

Diquark contribution to single top production





$$\hat{\sigma}(ud \to tb) = \frac{1}{48\pi \hat{s}^2} \frac{\lambda'^2_{11}\lambda'^2_{33}}{[(\hat{s} - M_D^2)^2 + M_D^2\Gamma_D^2]} (\hat{s} - m_t^2)^2 (m_t^2 + 2\hat{s})$$

$$\sigma(pp \to tb + X) = \sum_{i=1}^{2} \int dx_1 \int dx_2\, \mathcal{F}_{u_i}(x_1, Q^2) \times \mathcal{F}_{d_i}(x_2, Q^2) \times \hat{\sigma}(u_i d_i \to tb)$$

Note: The anti-top production is significantly suppressed with initial states $\overline{u}\overline{d}$

The diquarks also contribute to dijet cross section. We use the upper limits on the cross section ($\lambda^{'}_{33}$ is unconstrained)

1107.4771 (CMS), 1108.6311 (ATLAS)

We also use the upper bound on the single-top cross section in the s-channel < 26.5 pb at 95% C.L.

ATLAS-CONF-2011-118

Final State:

$$pp \longrightarrow (t \to bW^+)b \longrightarrow (W^+ \to \ell^+\nu_\ell)bb \longrightarrow \ell^+ bb\not{E}_T$$

Different sub-processes contributing to the SM background

$$p\,p \longrightarrow \quad W^+Z,\ \ t\bar{t},\ \ t\bar{b},\ \ W^+b\bar{b}$$

$$\hookrightarrow \quad tj,\ \ W^+jj,\ \ (tW^- + \bar{t}W^+),\ \ W^+W^-$$

Kinematic Cuts

To select the particles in the final state we demand that they satisfy some basic kinematic selection cuts.

- For the two b-jets we demand that they have a minimum transverse momenta given by $p_T^b > 20$ GeV and are within the rapidity gap $|\eta_b| < 2.5$.

- The charged lepton ($\ell^+ = e^+, \mu^+$) is required to have a minimum transverse momenta given by $p_T^{\ell^+} > 20$ GeV and is within the rapidity gap $|\eta_{\ell^+}| < 2.5$.

- The final states must account for a minimum missing transverse momenta given by $\not{E}_T > 50$ GeV.

- To resolve the final states in the detector they should be well separated. To achieve this we require that they satisfy $\Delta R_{ij} > 0.2$ with i, j representing the b-jets and the charged lepton. The variable ΔR_{ij} defines the separation of two particles in the (η, ϕ)

- We also demand that there are no additional jets with $p_T > 20$ GeV or additional charged leptons with $p_T > 10$ GeV.

Numerical Results @ LHC = 7 TeV

Sub-process	$\sigma(\ell^+ + 2b + \not{E}_T)$ (fb)
$pp \to WZ$	7.33
$pp \to Wjj$	9.97
$pp \to Wb\bar{b}$	87.55
$pp \to tW$	0.53
$pp \to t\bar{t}$	5.51
$pp \to tj$	6.24
$pp \to t\bar{b}$	23.32

- With the basic selection cuts we evaluate the LO contributions to the final state within the SM using the event generator MadGraph 5.

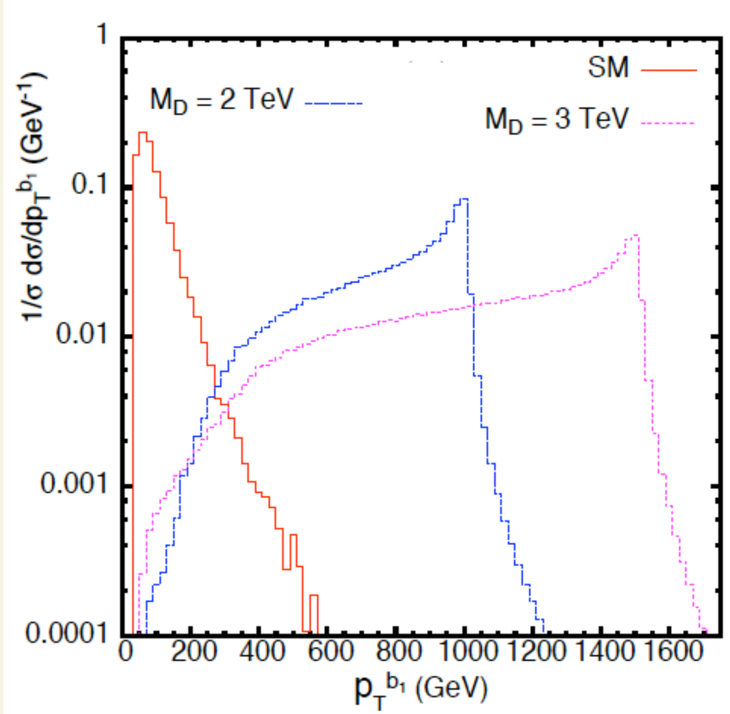
$\simeq 141$ fb.

$pp \to V_D^* \to tb$	51.02 (4.73)

- Signal for two values of diquark mass of $\mathbf{M}_D$ = 2(3) TeV and coupling $\lambda'_{11}\lambda'_{33} = 0.45$

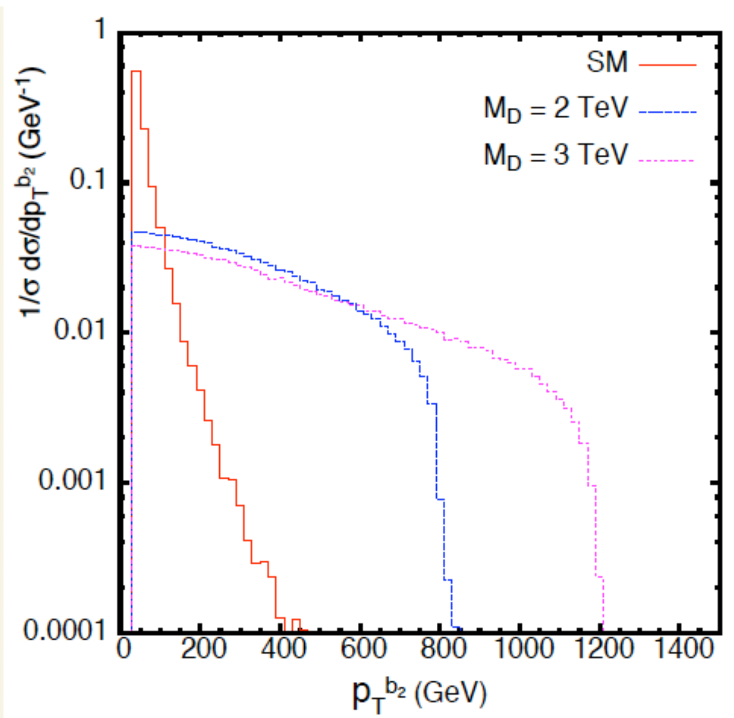
$\sigma \times B(pp \to qq) < 0.121$ pb for $M_D = 2$ TeV

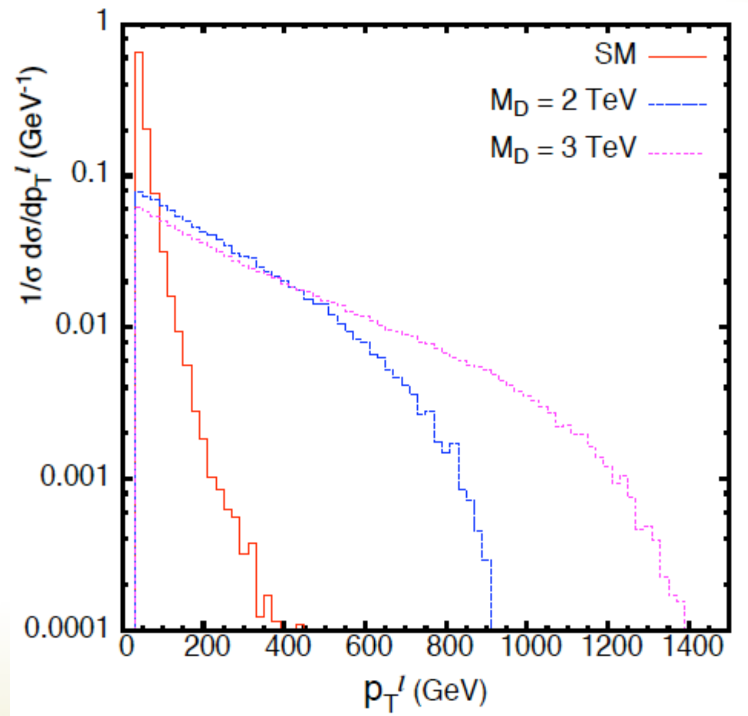
$\sigma \times B(pp \to qq) < 0.021$ pb for $M_D = 3$ TeV



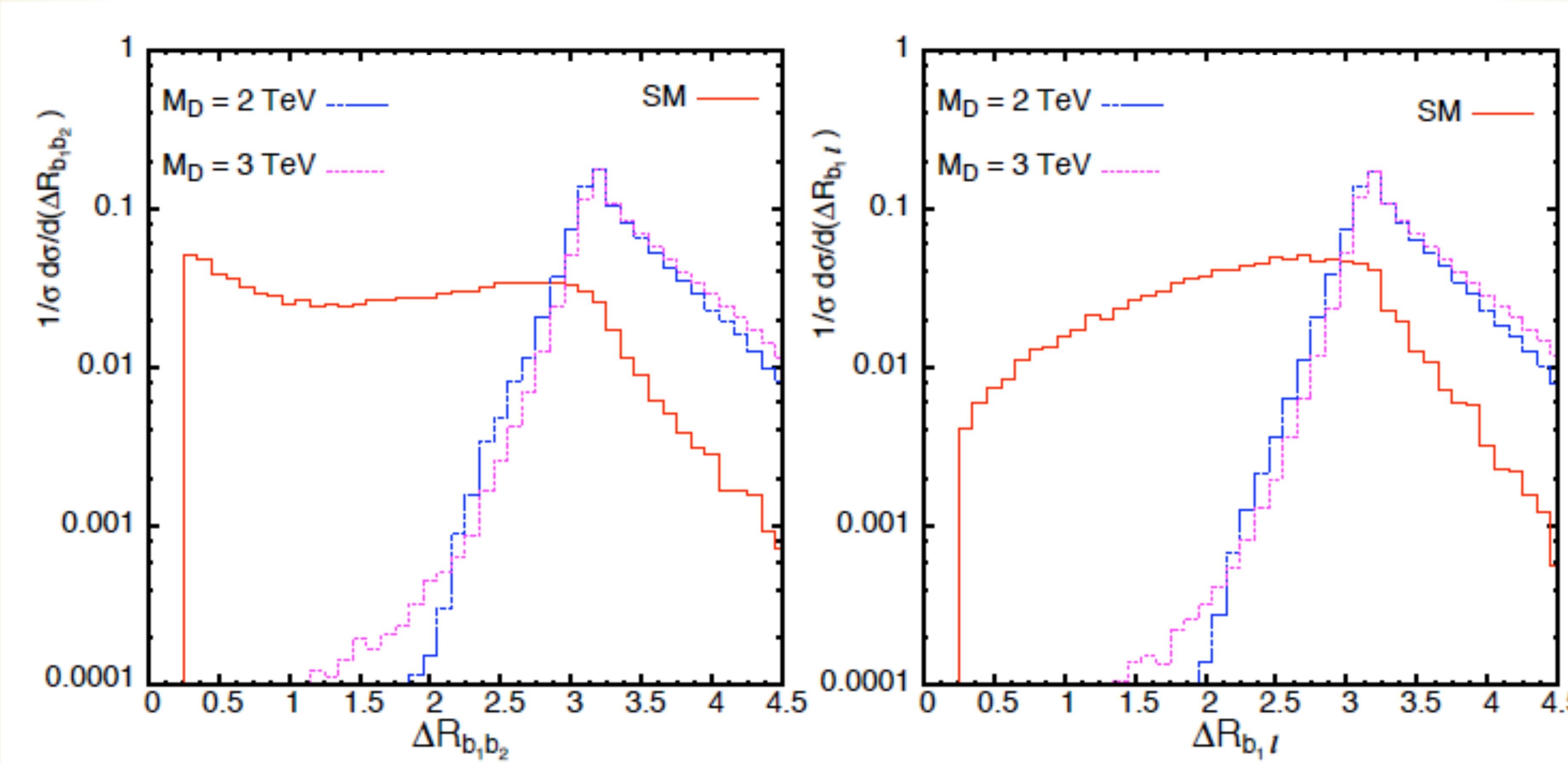
The transverse momenta distribution of the leading b-jet for the signal will tend to be hard and peak at around $p_T \approx M_D/2$

The sub-leading b-jet and charged lepton carry the boost of the top quark



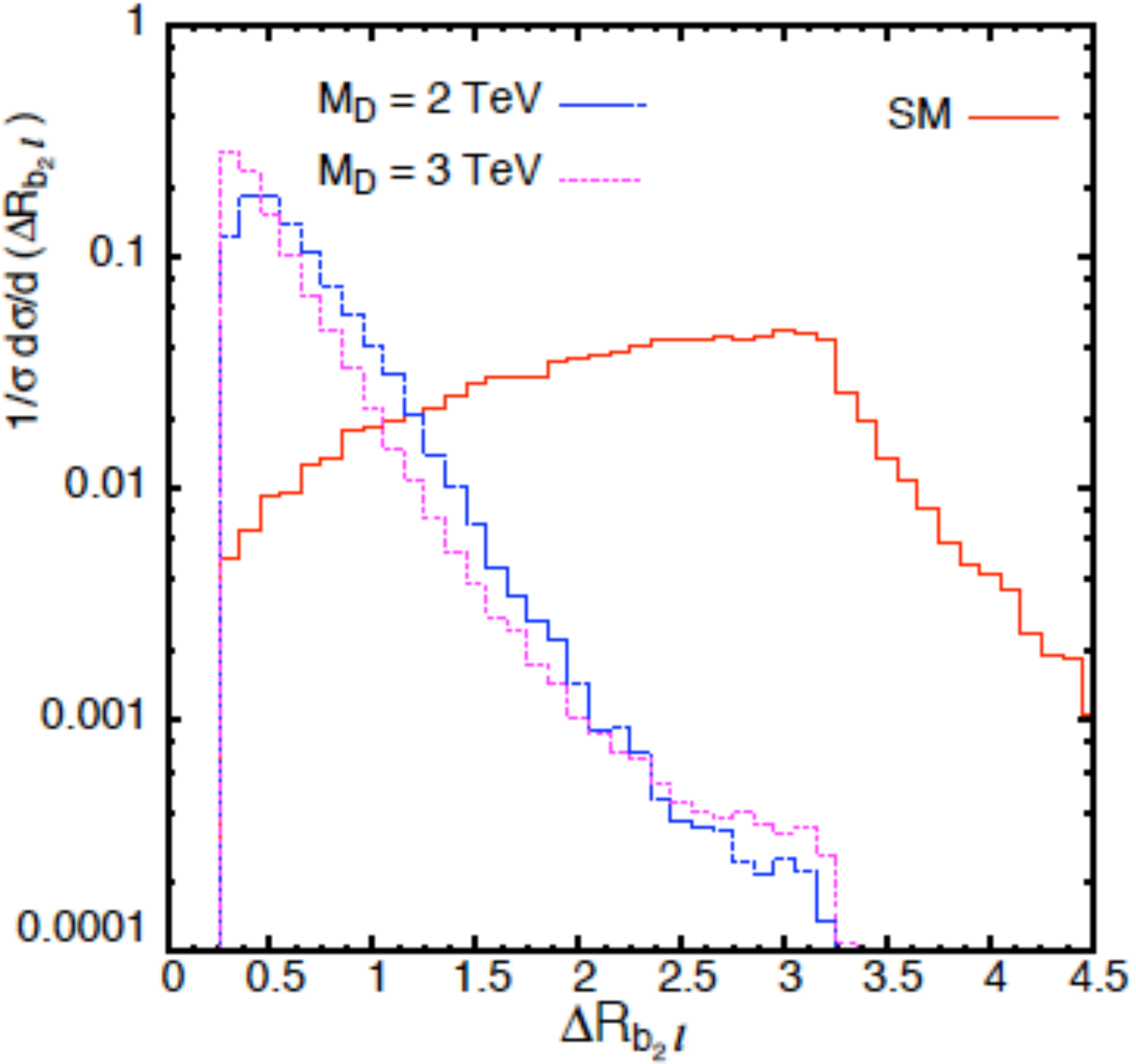


The leading b-jet is well isolated from the other particles for the signal

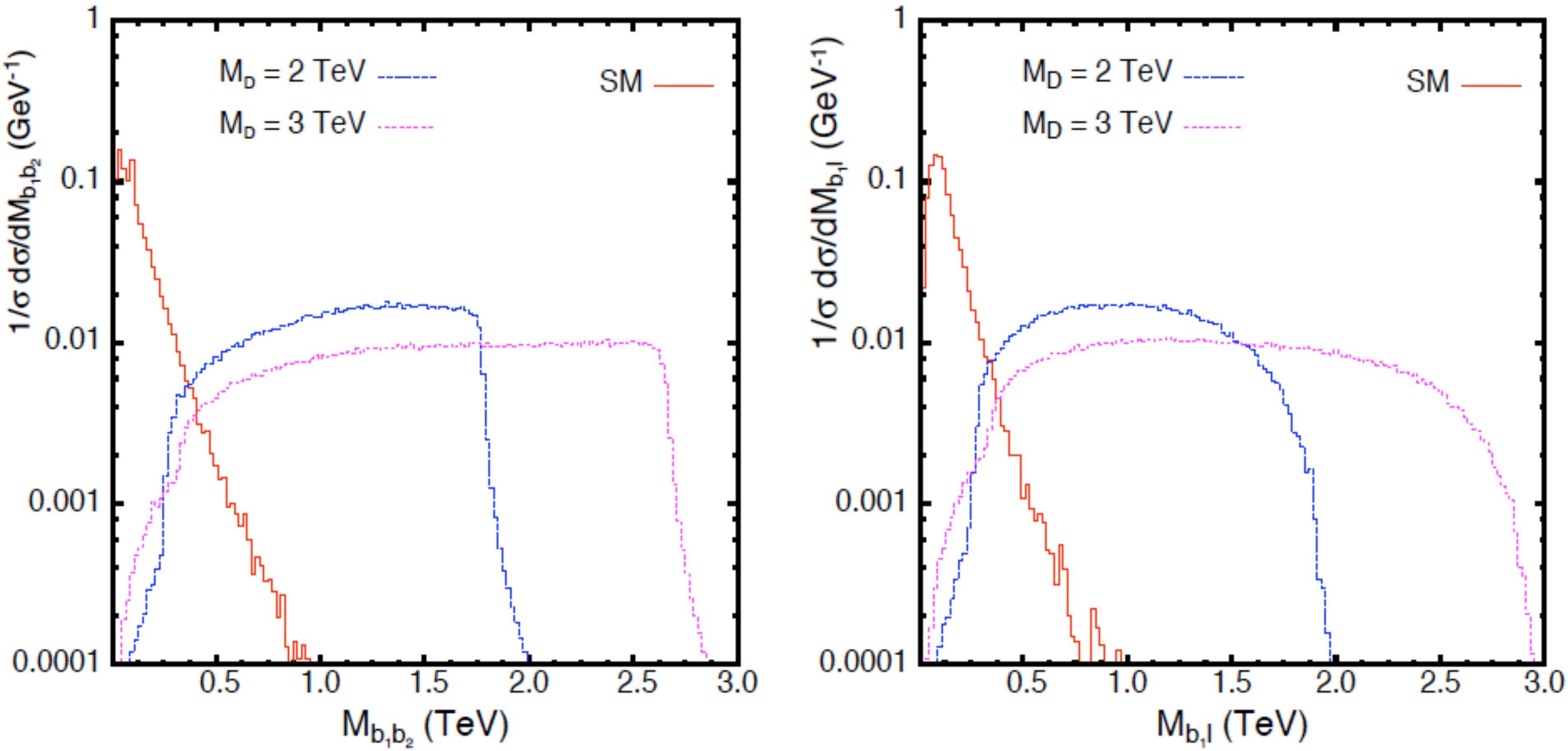


The characteristic behavior of particles coming from the decay of heavy resonance would be that they are produced back-to-back in the transverse plane and are well separated.

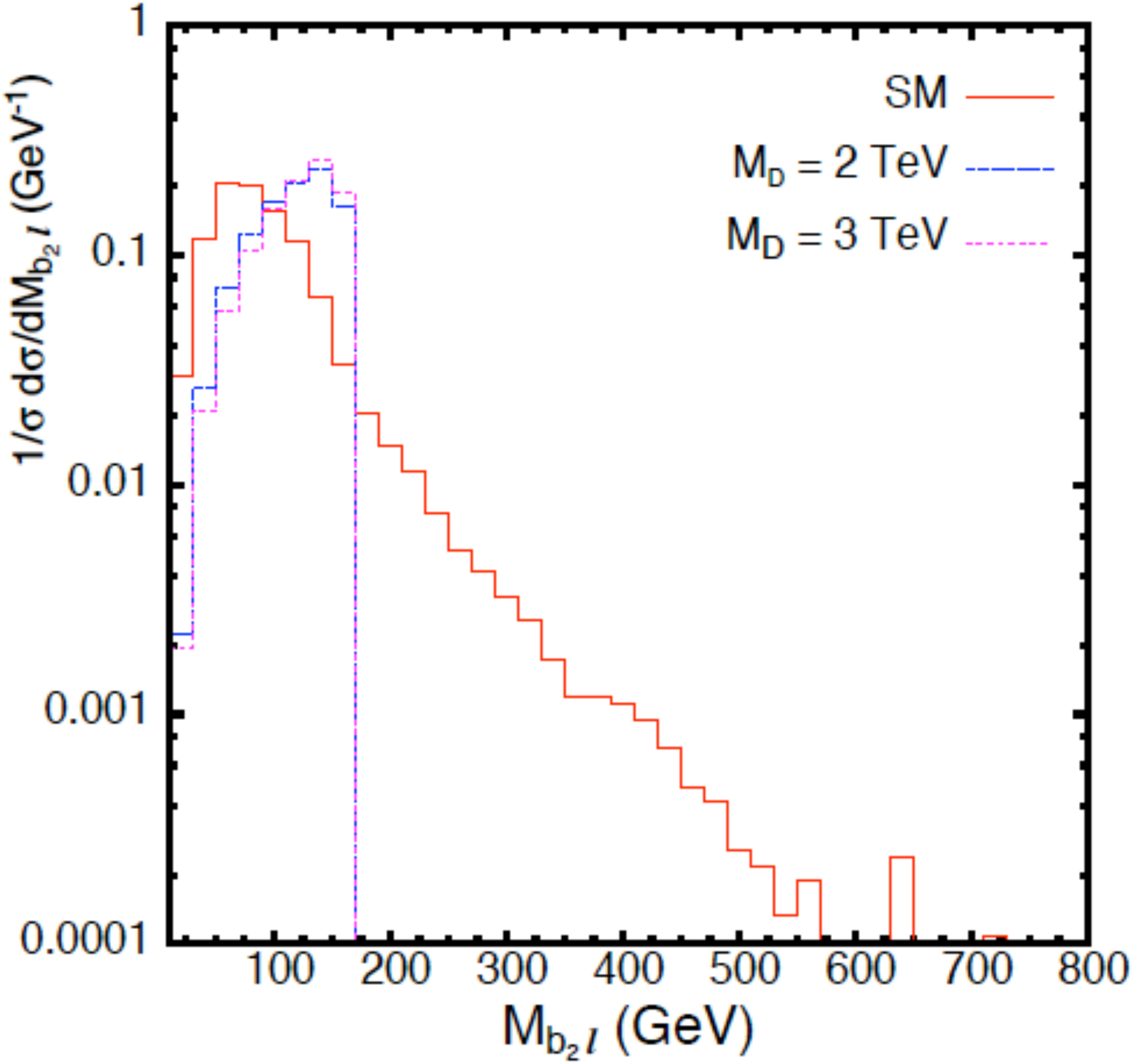
The sub-leading b-jet and the charged lepton (from the decay of highly boosted top) will tend to have less separation for the signal



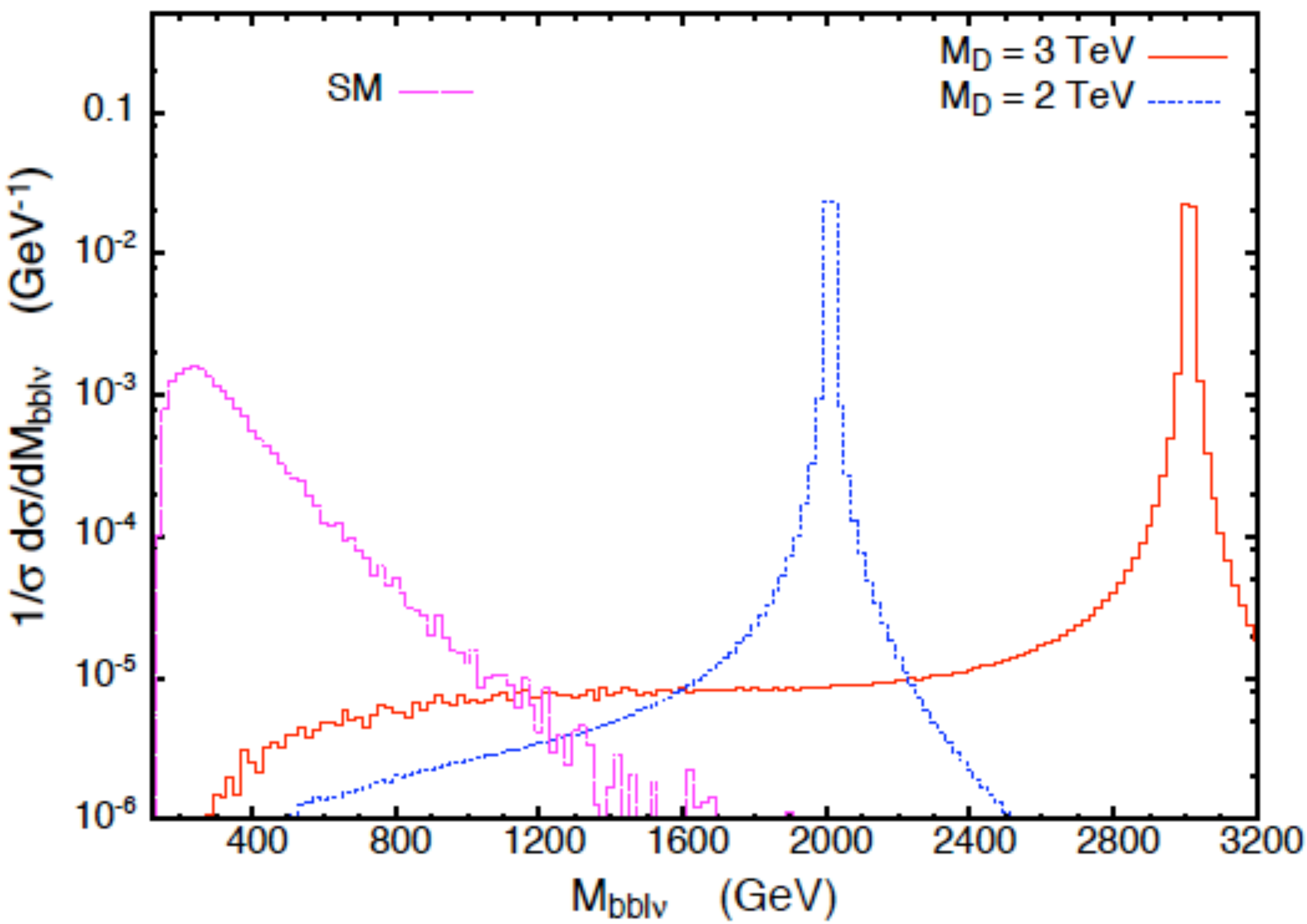
The diquark mass acts as an upper bound for the invariant mass value for the signal



In this case the top quark mass acts as an upper bound for the invariant mass value



As there is only a single neutrino in the final state, one can in principle reconstruct the diquark mass from the final states



Would be the best discriminant against the background !

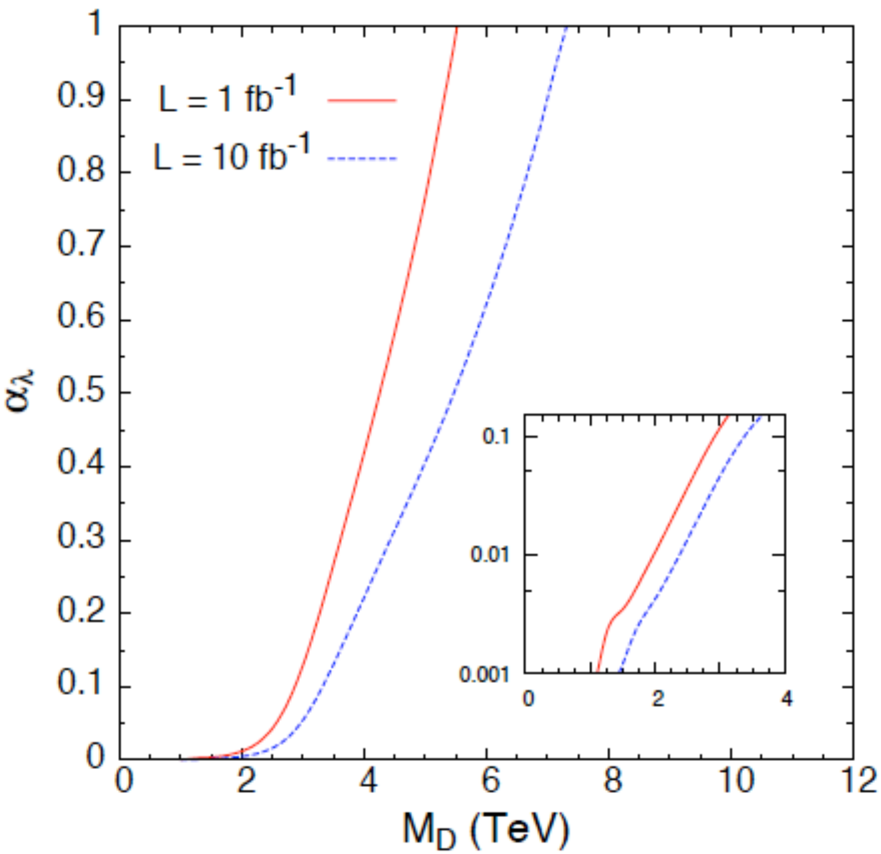
Modification in rates after introducing a stronger cut on the leading b-jet p_T

Sub-process	$\sigma(\ell^+ + 2b + \not{E}_T)$ (fb)	$\sigma(\ell^+ + 2b + \not{E}_T)$ (fb) (after cut $p_T^{b_1} > 400$ GeV)
$pp \to WZ$	7.33	4.25×10^{-3}
$pp \to Wjj$	9.97	4.54×10^{-2}
$pp \to Wb\bar{b}$	87.55	0.25
$pp \to tW$	0.53	2.58×10^{-4}
$pp \to t\bar{t}$	5.51	1.9×10^{-3}
$pp \to tj$	6.24	2.65×10^{-3}
$pp \to t\bar{b}$	23.32	0.26
$pp \to V_D^* \to tb$	51.02 (4.73)	47.24 (4.55)

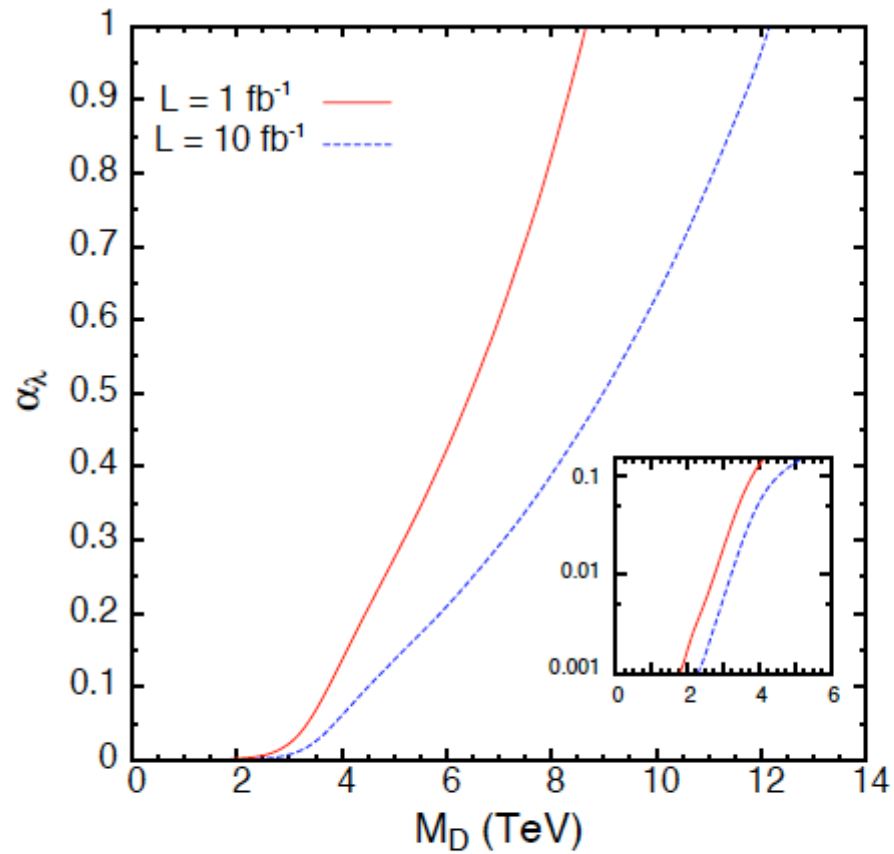
LHC sensitivity to the diquark mass as a function of the coupling

@ 7 TeV

Basic cuts



After $p_T > 400$ GeV cut



$M_D \simeq 2.8$ TeV
$1\ \text{fb}^{-1}$

$M_D \simeq 3.65$ TeV
$10\ fb^{-1}$

$M_D \simeq 3.25$ TeV
$1\ \text{fb}^{-1}$

$M_D \simeq 4.3$ TeV
$10\ fb^{-1}$

Summary

- We have considered the effects of a vector diquark resonance on the single top quark production.

- We find that there could be large enhancements in the single top quark production at LHC.

- Various kinematic distributions effectively capture the essence of a heavy particle exchange which distinguish it from SM background.

- Use of specific selection cuts on the kinematics helps increase the LHC sensitivity to heavier diquark mass.

- For the vector diquark which couples more strongly to the third generation quarks the LHC can be sensitive to higher values of the diquark mass when compared to the dijet channel.