Prospects for top-prime quark discovery at the Tevatron

Rakhi Mahbubani
arXiv:0902.0792

with Bogdan Dobrescu and Kyoungchul Kong

Introduction

- Motivation: it is likely that our first glimpse of new physics at colliders will be due to production of one or two new particles

- Colored particles have large production cross section

- We add to SM heavy vector color octet and heavy vector-like quark

- Present in various models of BSM physics e.g. topcolor, warped and flat extra dimensions, technicolor

- Study Tevatron phenomenology in a generic renormalizable theory containing these particles, with minimal theoretical prejudice

Rakhi Mahbubani - Pheno 2009

Introduction

- In addition CDF search for QCD production of t' quarks (heavy top partner) decaying to Wj places limit on mass of 311 GeV

- Could the Tevatron sensitivity to t' quarks be improved?

  (Answer: yes, if it is resonantly produced through s-channel heavy gluon-prime)

SM + Vectorlike Quark

- A vectorlike quark χ transforming as (3,1,2/3) under the SM can mix with the top quark:

$$\begin{pmatrix} \overline{u}_L^3 & \overline{\chi}_L \end{pmatrix} \begin{pmatrix} \lambda_t v_H & 0 \\ M_0 & M_\chi \end{pmatrix} \begin{pmatrix} u_R^3 \\ \chi_R \end{pmatrix}$$

- This mass matrix can be diagonalized for the two mass eigenstates t and t', with LH mixing angle

$$s_L = \sqrt{\frac{\lambda_t v_H}{m_{t'}^2 - m_t^2}} = \frac{\lambda_t v_H}{m_{t'}} \left(1 + \cdots \right) \quad \text{for} \quad \lambda_t \gg 1$$

and related RH mixing angle, where $0 \leq \theta_L,\ \theta_R \leq \frac{\pi}{2}$

Top-prime interactions

With gauge bosons:

$$t_L \bar{b}_L W_\mu^+ : \quad \frac{g}{\sqrt{2}} c_L \gamma^\mu \Rightarrow s_L < 0.57 \quad \text{(from single top)}$$

$$t'_L \bar{b}_L W_\mu^+ : \quad \frac{g}{\sqrt{2}} s_L \gamma^\mu$$

$$t_L \bar{t}_L Z_\mu : \quad \frac{g}{c_W} \left(\frac{c_L^2}{2} - \frac{2}{3} s_W^2 \right) \gamma^\mu$$

$$t_L \bar{t}_L Z_\mu : \quad \frac{g}{c_W} \left(\frac{c_L^2}{2} - \frac{2}{3} s_W^2 \right) \gamma^\mu$$

$$t_L \bar{t'}_L Z_\mu : \quad \frac{g}{c_W} \frac{s_L c_L}{2} \gamma^\mu$$

With Higgs:

$$\bar{t}_L t_R h^0 : \quad -\frac{m_t c_L^2}{\sqrt{2} v_H}$$

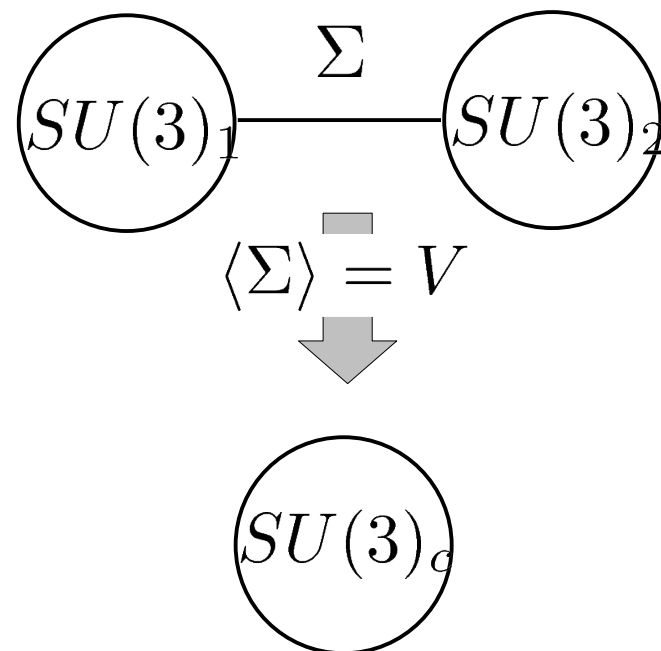$$\bar{t'}_L t'_R h^0 : \quad -\frac{m_{t'} s_L^2}{\sqrt{2} v_H}$$

$$\bar{t}_L t'_R h^0 : \quad -\frac{m'_t s_L c_L}{\sqrt{2} v_H}$$

$$\bar{t'}_L t_R h^0 : \quad -\frac{m_t s_L c_L}{\sqrt{2} v_H}$$

Z interactions with RH quarks same as SM

Extension of Color Sector

	$SU(3)_1$	$SU(3)_2$	$SU(2)_W$
q_L^i, u_R^i, d_R^i	3	1	2, 1, 1
$\chi_L, \; \chi_R$	1	3	1, 1
Σ	3	$\overline{3}$	1

$SU(3)_1$ —Σ— $SU(3)_2$

$\langle \Sigma \rangle = V$

$SU(3)_c$

- Σ VEV results in mixing between two SU(3) gauge bosons

- Diagonalizing $\Longrightarrow$ massless gluon, massive gluon-prime.

Gluon-prime interactions

- Gluon interactions with quarks vector-like, with strength

$$g_s = \frac{h_1 h_2}{\sqrt{h_1^2 + h_2^2}}$$

- Gluon-prime interactions with light quarks also vector-like with strength diluted by $r = h_1/h_2$, where $0.15 \leq r \leq 6.7$

$$\bar{t}tG'_\mu : \quad g_s \gamma_\mu \left(g_L P_L + g_R P_R\right) \qquad g_L = rc_L^2 - \frac{s_L^2}{r}$$

$$\overline{t't'}G'_\mu : \quad g_s \gamma^\mu \left(g_L'' P_L + g_R'' P_R\right) \qquad g_L'' = rs_L^2 - \frac{c_L^2}{r}$$

$$\bar{t}t'G'_\mu : \quad g_s \gamma^\mu \left(g_L' P_L + g_R' P_R\right) \qquad g_L' = \left(r + \frac{1}{r}\right) s_L c_L$$

Rakhi Mahbubani - Pheno 2009

Gluon-prime interactions

- Gluon interactions with quarks vector-like, with strength

$$g_s = \frac{h_1 h_2}{\sqrt{h_1^2 + h_2^2}}$$

- Gluon-prime interactions with light quarks also vector-like with strength diluted by $r = h_1/h_2$, where $0.15 \le r \le 6.7$
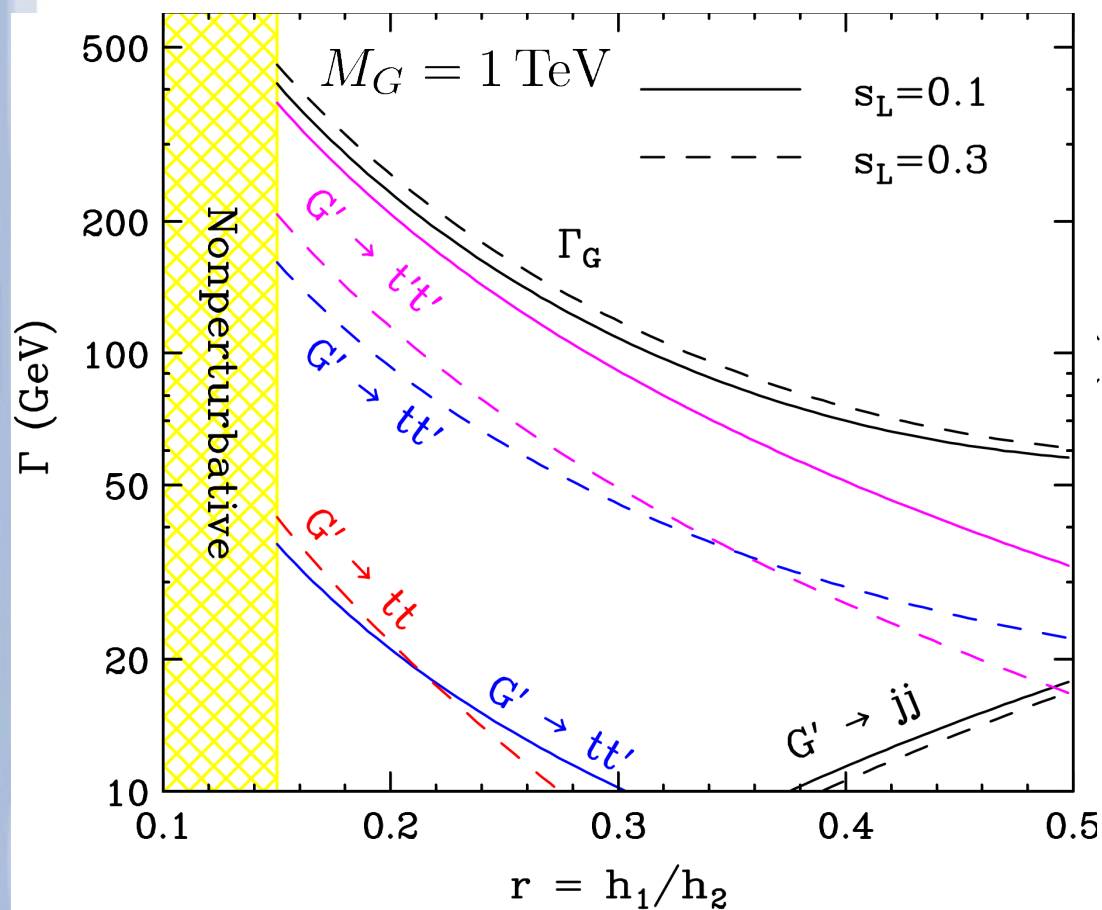
5 free parameters:

$$(m_{t'}, \; M_G, \; s_L, \; r, \; M_h)$$

$\bar{t}t G'_\mu :$ $g_s \gamma_\mu \left(g_L P_L + g_R P_R\right)$ $g_L = r c_L^2 - \dfrac{s_L^2}{r}$

$\overline{t't'} G'_\mu :$ $g_s \gamma^\mu \left(g_L'' P_L + g_R'' P_R\right)$ $g_L'' = r s_L^2 - \dfrac{c_L^2}{r}$

$\bar{t}t' G'_\mu :$ $g_s \gamma^\mu \left(g_L' P_L + g_R' P_R\right)$ $g_L' = \left(r + \dfrac{1}{r}\right) s_L c_L$

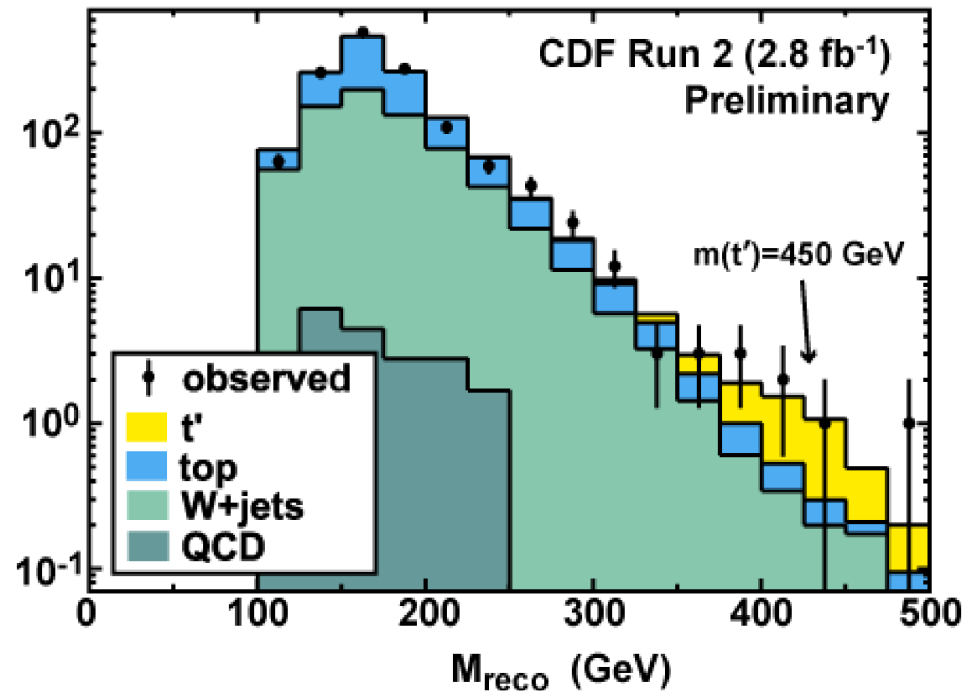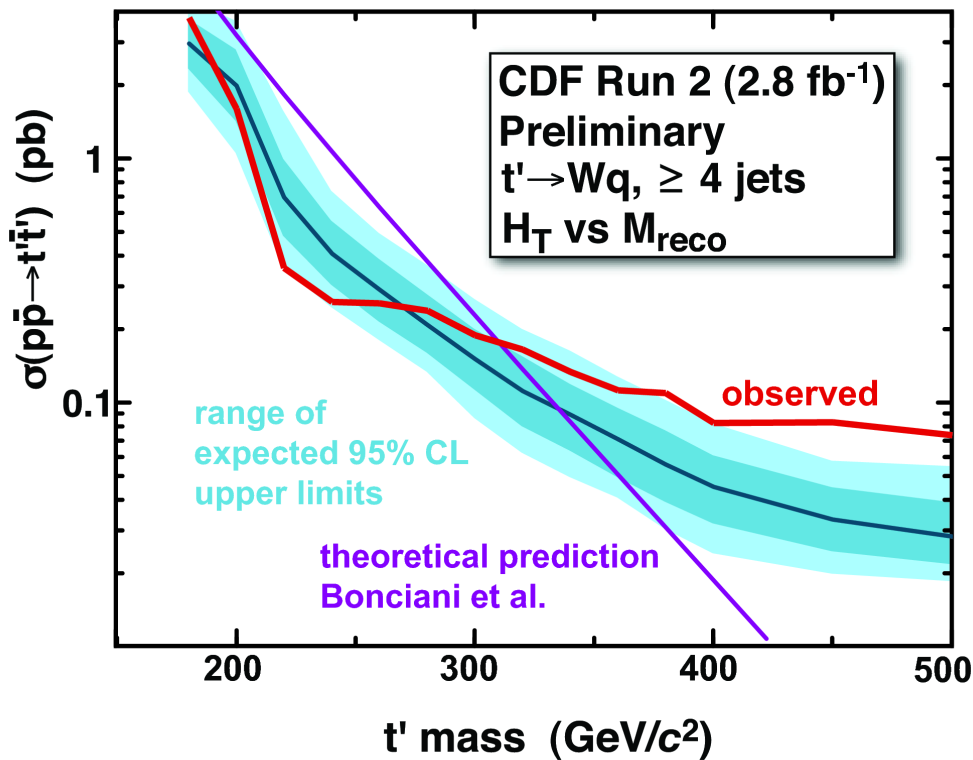Rakhi Mahbubani - Pheno 2009

Decay widths

Gluon-prime

Top-prime
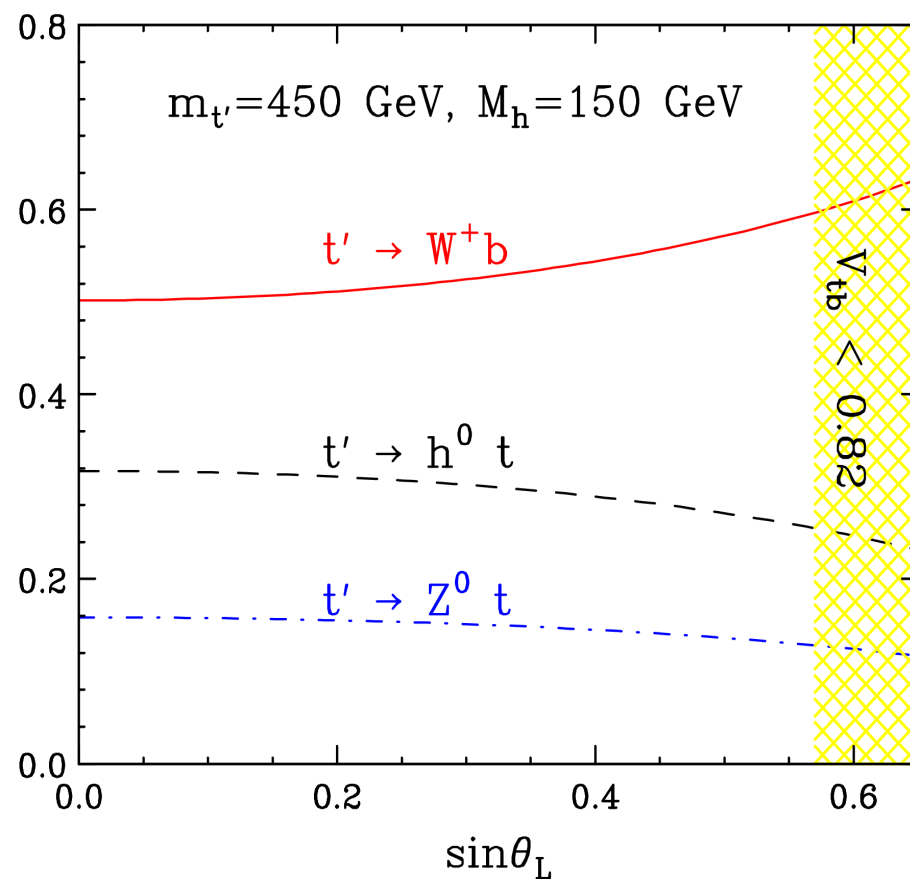
CDF search for massive t' quark

http://www-cdf.fnal.gov/physics/new/top/2008/tprop/Tprime2.8/public.html

Observed cross section order of magnitude larger than SM QCD production!

Rakhi Mahbubani - Pheno 2009
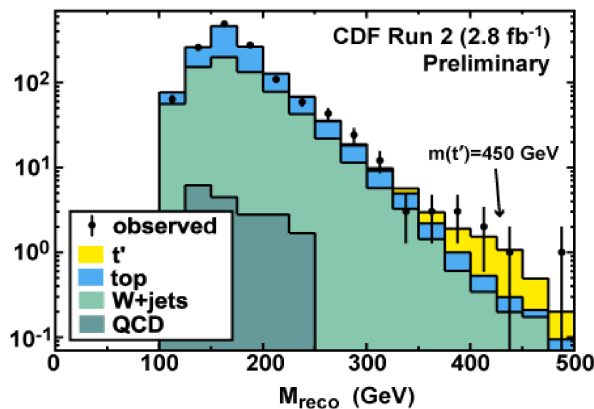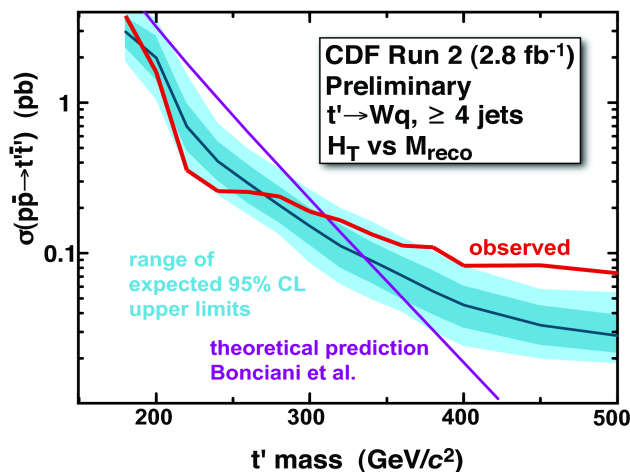
7 candidate t' pair events with reconstructed mass of 375-500 GeV, for SM background of 2.1 events

our interpretation
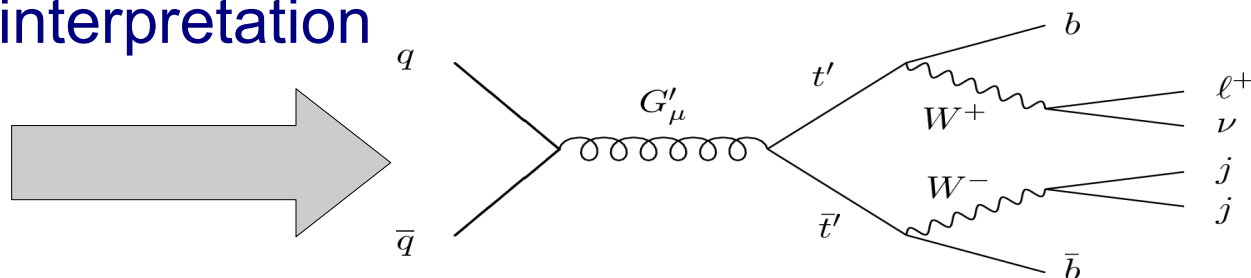
Resonant t' pair production through heavy gluon - $\sigma \sim 40\ \mathrm{fb}$

Rakhi Mahbubani - Pheno 2009

Limits from dijet searches

http://www-cdf.fnal.gov/physics/exotic/r2a/20080214.mjj_resonance_1b/8

CDF Run II Preliminary, 1.13 fb^{-1}

Legend:
- 95% CL limits (for R-S G, Technirho)
- 95% CL limits (for the others)
- Technirho
- R-S G (k/$\overline{M}_{pl}$=0.1)
- Excited quark
- Axigluon/Coloron
- E6 diquark

Axes: $\sigma \times Br \times$ Acceptance ($|y^{jet1,2}|<1$) (pb) vs Mass [GeV/c^2]
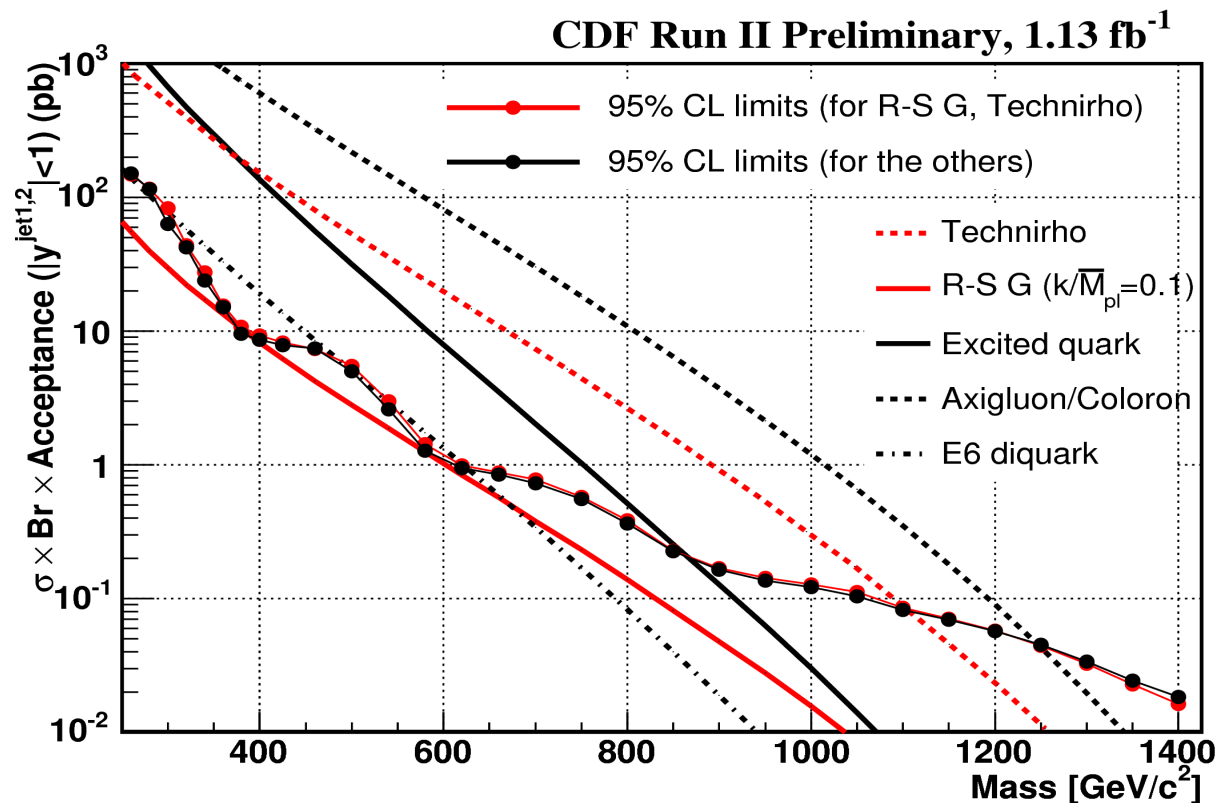
Dijet cross section suppressed by relative factor of r^4

Rakhi Mahbubani - Pheno 2009

Limits from D0 (Wb)(Wb) search
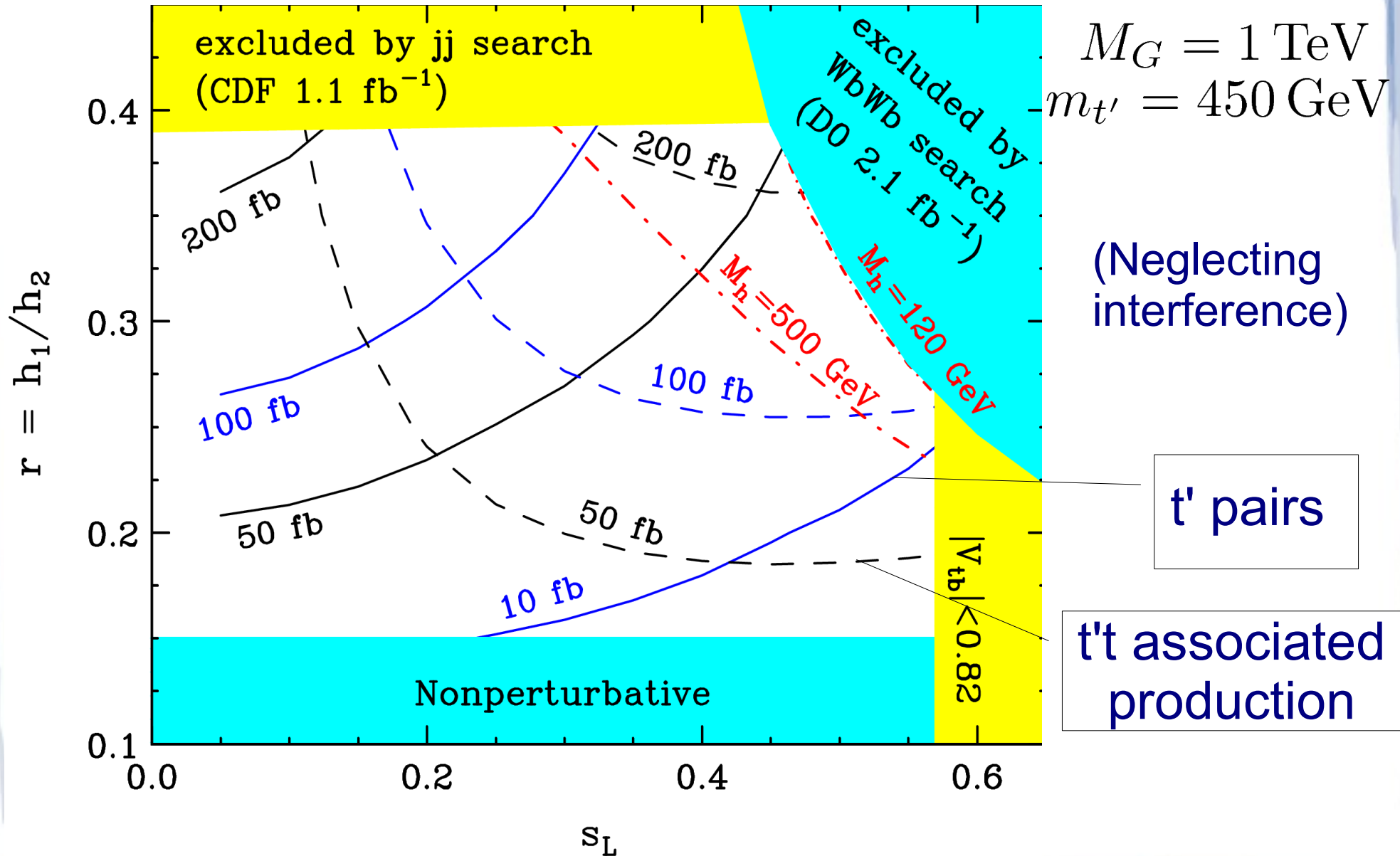
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/TOP/T83/

18th March 2008

Rakhi Mahbubani - Pheno 2009

Production cross section

Gluon-prime interactions

- Gluon interactions with quarks vector-like, with strength

$$g_s = \frac{h_1 h_2}{\sqrt{h_1^2 + h_2^2}}$$

- Gluon-prime interactions with light quarks also vector-like with strength diluted by $r = h_1/h_2$, where $0.15 \leq r \leq 6.7$

$$\bar{t}t G'_\mu : \quad g_s \gamma_\mu \left(g_L P_L + g_R P_R\right) \qquad g_L = r c_L^2 - \frac{s_L^2}{r}$$

$$\overline{t'}t' G'_\mu : \quad g_s \gamma^\mu \left(g_L'' P_L + g_R'' P_R\right) \qquad g_L'' = r s_L^2 - \frac{c_L^2}{r}$$

$$\bar{t}t' G'_\mu : \quad g_s \gamma^\mu \left(g_L' P_L + g_R' P_R\right) \qquad g_L' = \left(r + \frac{1}{r}\right) s_L c_L$$
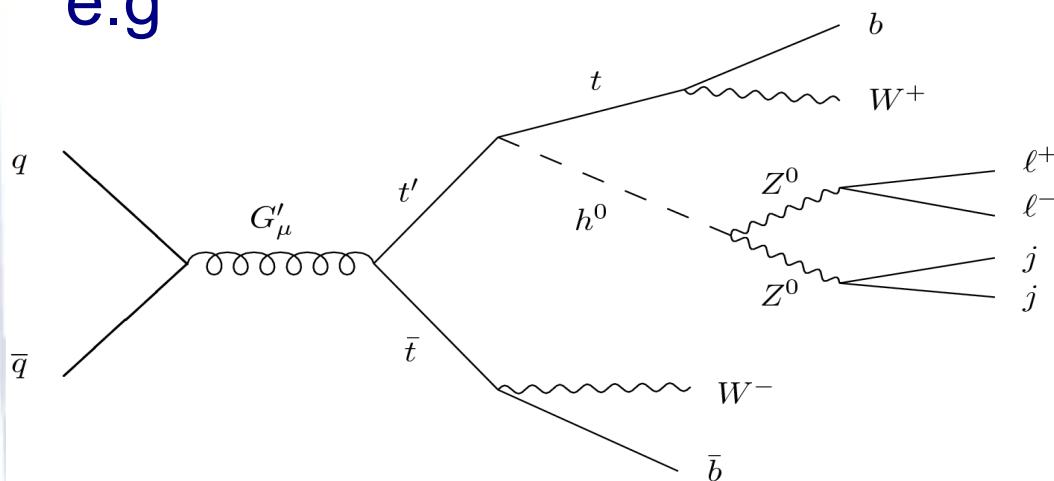
Rakhi Mahbubani - Pheno 2009

Other interesting channels

Associated t't production:

$$\bar{p}p \to G' \to \bar{t}t' \to \bar{t}\,(tZ)\,,\ \bar{t}\,(th)\,,\ \bar{t}\,(Wb)$$

Enhanced relative to SM production

e.g

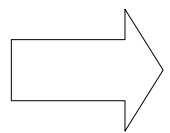~10 events with 10 fb^{-1} of data

Small backgrounds

Rakhi Mahbubani - Pheno 2009

Conclusion

- This simple, bottom-up model with two additional ingredients

    – vectorlike quark mixing with the SM top

    – produced resonantly through heavy vector color octets

can yield a range of interesting phenomenology

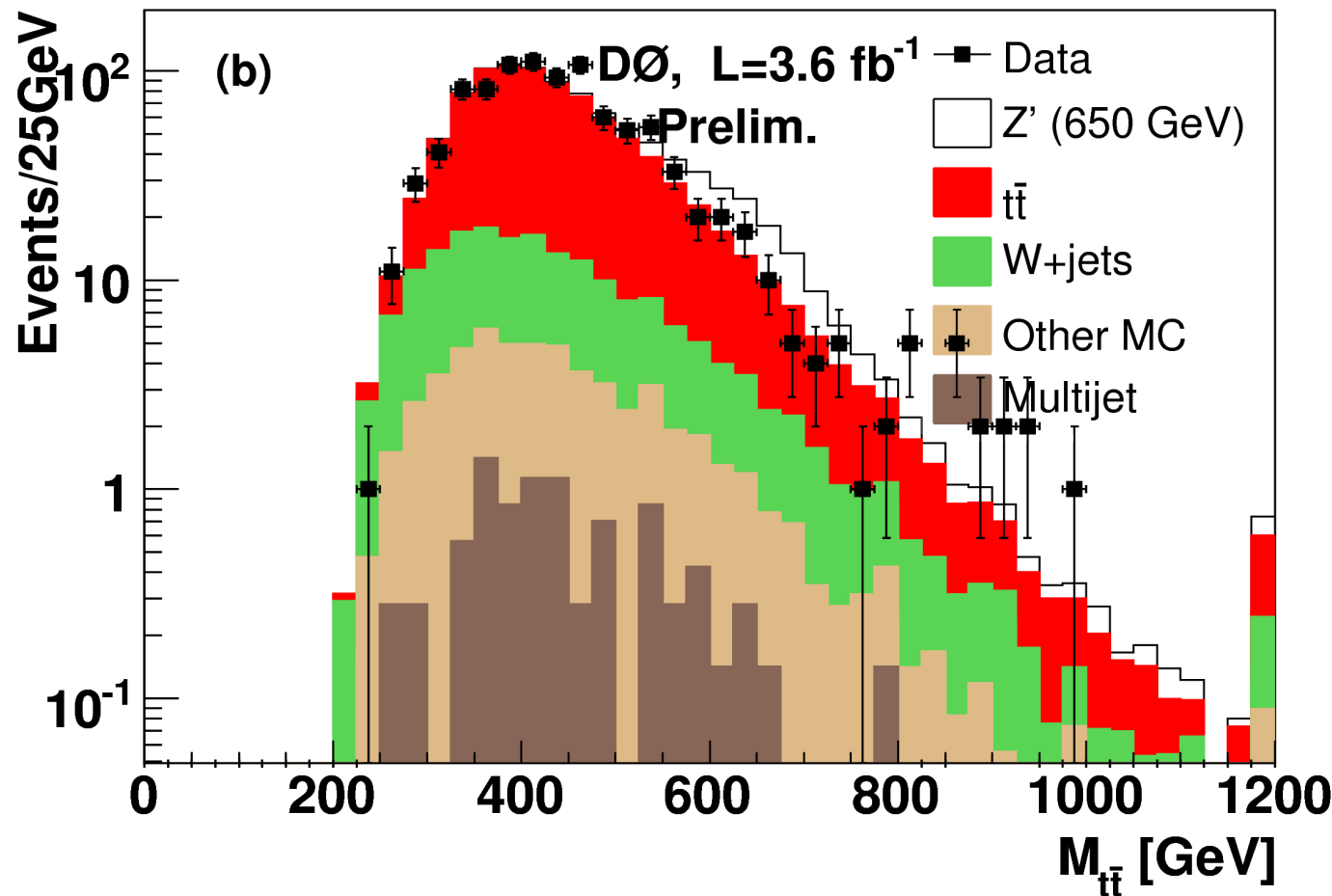Tevatron can be sensitive to t' with masses of up to 600 GeV

Could explain excess events in semileptonic channel

Backup Slides

Rakhi Mahbubani - Pheno 2009

Speculation on (Wb)(Wb) search

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/TOP/T83/

17 events from 800-1000 GeV; expected SM background of 6.4

Potential gluon-prime signature?

Rakhi Mahbubani - Pheno 2009

CDF X ⟶ top pair search

CDF Run 2 preliminary, L=682pb^{-1}

- CDF data, Nev=447
- W+ ≥ 4j
- QCD
- SM t$\bar{t}$, 6.7 pb
- Diboson (NLO)

events/10GeV/c^2

$M_{t\bar{t}}$ [GeV/c^2]

09