Searches for new physics with the top quark
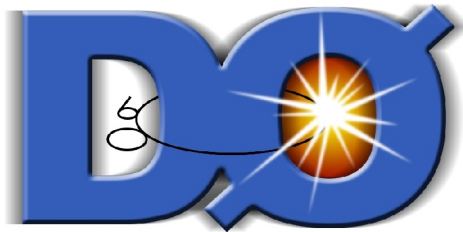
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for the D0 Collaboration

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Contents

Searches for

 – a pair-produced t' quark decaying like a top quark

 – a singly produced W' boson decaying into *tb*

Search for a t' quark

- A fourth generation of fermions with the neutrino heavier than $m_Z/2$ is not ruled out yet.

- $t' \to W q_d$ will dominate if $m(t') - m(b') < m(W)$ and there's moderate mixing between the 4th and the first 3 generations.

- Final state is similar in content to SM ttbar except for fewer b quarks. Kinematics are somewhat different, depending on $m(t')$.

- t' is assumed to be narrow compared to detector resolution.

- D0 analysis uses 5.3 fb[-1] of *pbar-p* collisions at $\sqrt{s} = 1.96$ TeV and *l+jets* final states ($l = e, \mu$).

t' search: event selection

- Exactly one clean isolated lepton:

  - an e with $p_T > 20$ GeV, $|\eta| < 1.1$,

  - OR a μ with $p_T > 20$ GeV, $|\eta| < 2.0$.

- At least 4 jets with $p_T > 20$ GeV, $|\eta| < 2.5$,

 at least one of them with with $p_T > 40$ GeV.

- Missing $p_T > 25$ GeV.

- $\Delta(\varphi)$ v. Missing p_T cuts to reject QCD fakes.
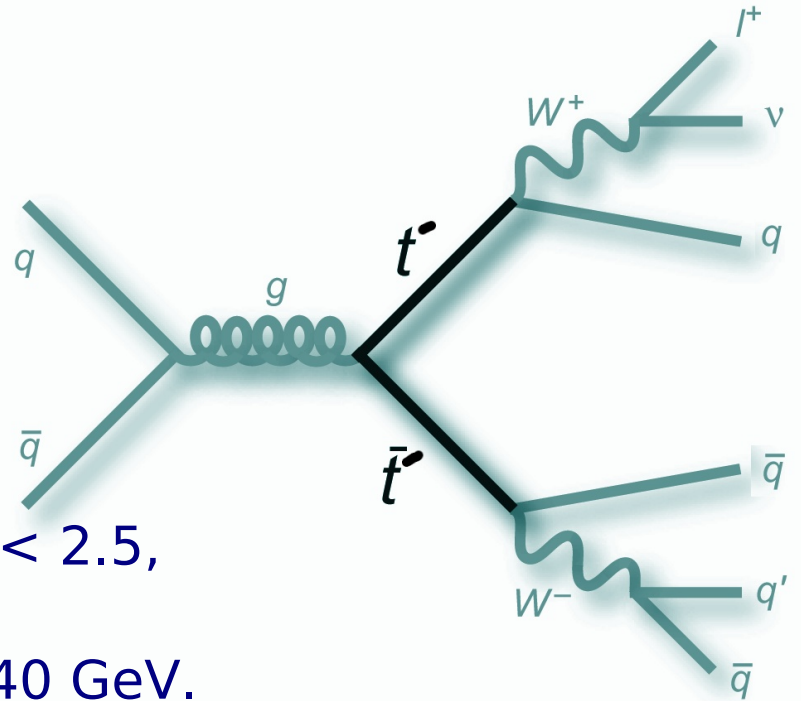
t' search: data compositon

Data & estimated SM contributions with systematic uncertainties. ALPGEN+PYTHIA are used to model all top and EW processes, except single top, for which COMPHEP is used. NNLO cross sections and $m(t) = 172.5$ GeV ($\rightarrow \sigma(tt) = 7.48^{+0.56}_{-0.72}$ pb) are assumed.

| Source	e+jets	μ+jets
$t\bar{t}$ production	678±76	508±55
Single t production	12±4	8±3
W+jets	503±87	648±59
Z+jets	41±7	40±7
WW, WZ, ZZ+jets	25±5	21±5
Multijets	173±42	43±18
Data	1431	1268

t' search: S, B, data

- Likelihood ratio $L = -2 \log(P_{S+B}/P_B)$ used as test statistic, where P_x is the Poisson probability of observing data with x only.

- 2d histo of H_T v. $m(t')$ from kin. fit used to derive limits by CL_S method.
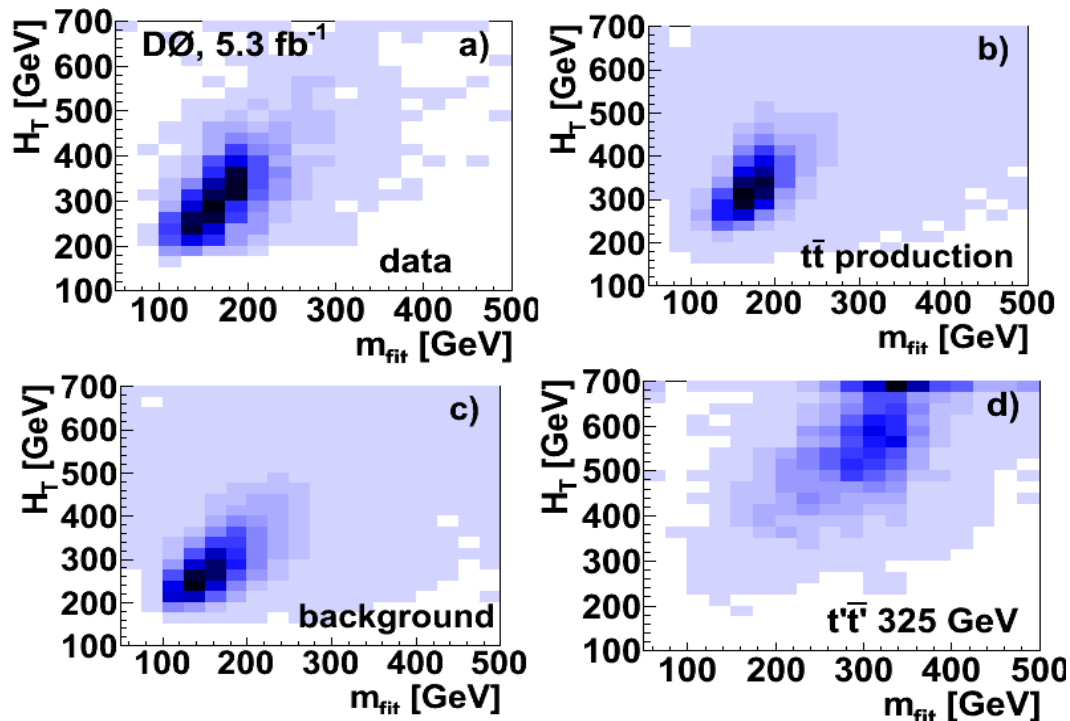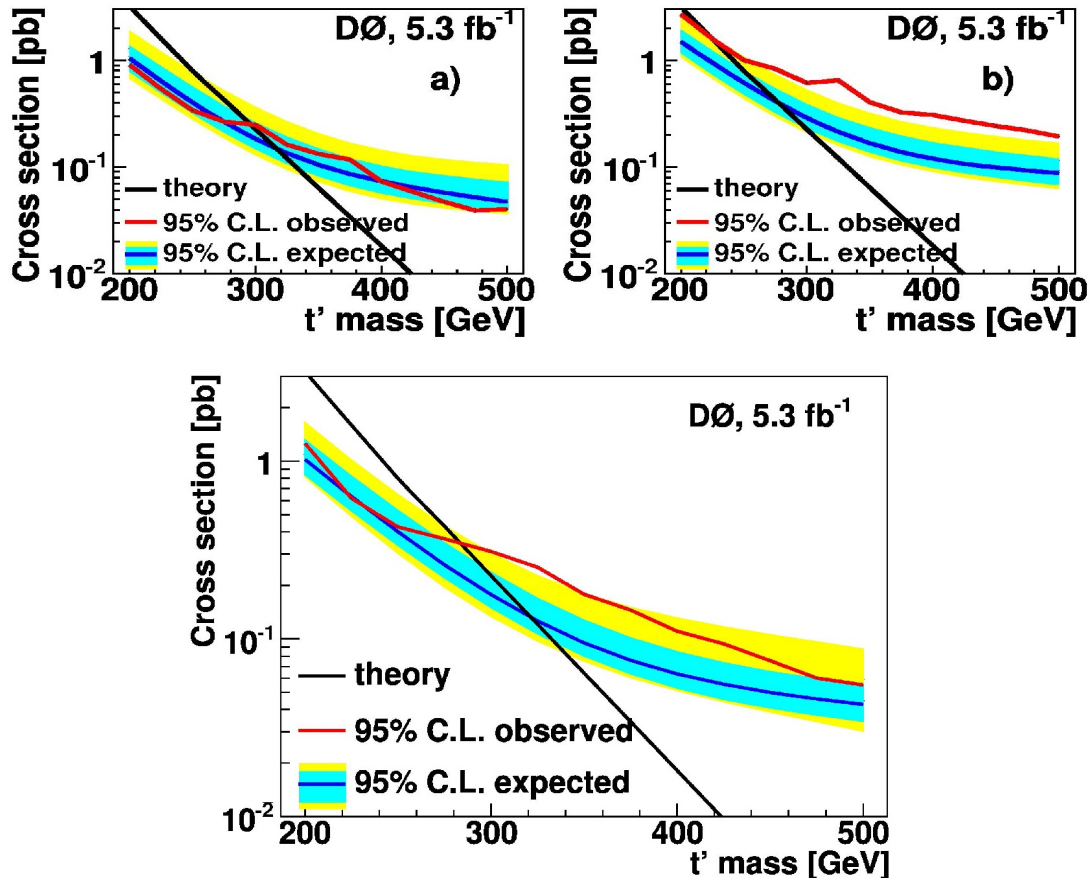
t' search: characteristics

1d distributions of H_T & $m_{fit}(t')$ (top: e+jets, bottom: μ+jets)
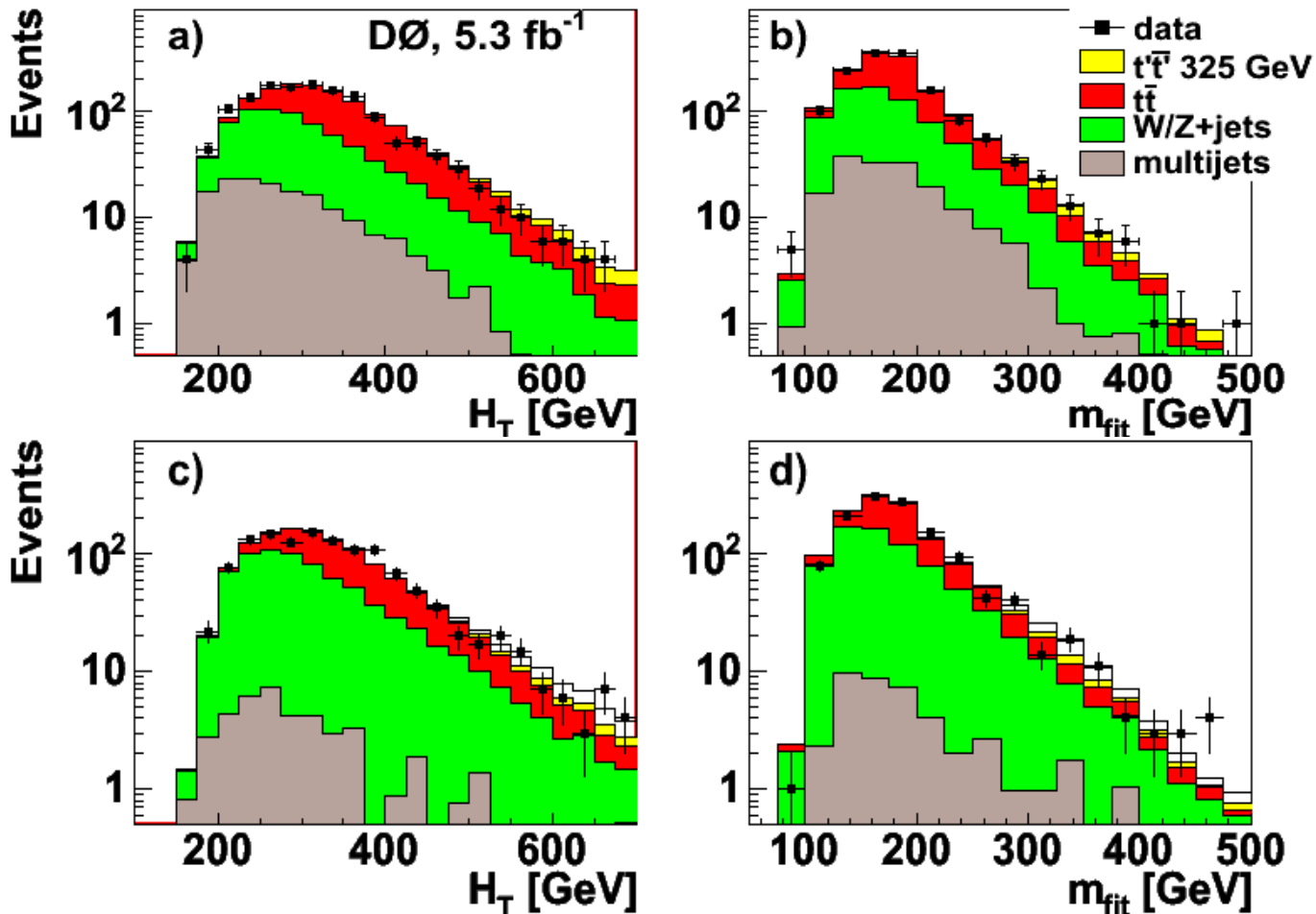
t' search: result

Top: (a) e+jets, (b) μ+jets, bottom: combined.

t' pair production with *m*(*t*') < 325 GeV excluded at 95% CL.

Search for a W' boson

- Additional fundamental charged vector bosons appear in many BSM theories including UED, L-R symmetric models etc.

- Generally, $\mathcal{L} = \frac{V_{ij} g_w}{2\sqrt{2}} \bar{f}_i \gamma_\mu \left(a_{ij}^R \left(1 + \gamma^5 \right) + a_{ij}^L \left(1 - \gamma^5 \right) \right) W'^\mu f_j + \text{h.c.}$

- *pbar p → W'X → tb X* interferes with SM single top production *pbar p → W*X → tb X* if LH couplings are allowed.

- Previous searches at D0 excluded, at 95% CL, $m(W') < 731$ GeV for purely LH couplings and $m(W') < 739$ (768) GeV for purely RH couplings with (without) a light RH neutrino.

- Present analysis: 2.3 fb^{-1} of *pbar-p* collisions at $\sqrt{s} = 1.96$ TeV, *W' → tb → l+jets* final states (*l = e, μ*) and admits $0 < a_{ij}^{L,R} < 1$

W' search: event selection

- Exactly one clean isolated lepton:

  - a μ with p_T > 20 GeV, $|\eta|$ < 2.0.

  - OR an e with p_T > 15 (20) GeV and $|\eta|$ < 1.1 for n_{jet} = (>) 2,

- At least 2 jets with p_T > 15 GeV and $|\eta|$ < 3.4, at least one of them with with p_T > 25 GeV.

- Missing p_T > 20 (25) GeV for n_{jet} = (>) 2.

- At least one of the jets must be b-tagged.
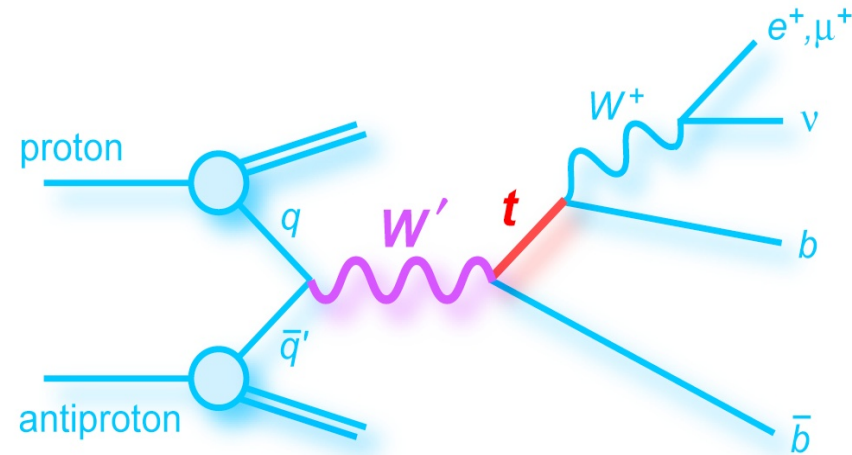
W' search: data compositon

Data & estimated SM contributions with systematic uncertainties in 24 channels combined (2 lepton flavors × 3 jet multiplicity bins × 2 b-jet multiplicity bins × 2 data collection periods).

| Process	Events
tqb	26.4 ± 2.5
$t\bar{t}$	424.7 ± 58.4
W+jets	279.5 ± 18.3
Z+jets	26.0 ± 3.2
Dibosons	13.0 ± 1.6
Multijets	60.5 ± 10.8
Total background	830 ± 62
Data	831

W' search: LH & RH couplings

The cross section for single top production in the presence of a *W'* boson can be written in terms of those for purely LH ($a_L=1$, $a_R=0$) & RH couplings ($a_L=0$, $a_R=1$), for mixed coupling ($a_L=a_R=1$), and the SM cross section ($a_L=a_R=0$):

$$
\begin{aligned}
\sigma &= \sigma_{SM} + a_{ud}^L a_{tb}^L \left(\sigma_L - \sigma_R \right) \\
&+ \left(\left(a_{ud}^L a_{tb}^L \right)^2 + \left(a_{ud}^R a_{tb}^R \right)^2 \right) \left(\sigma_R - \sigma_{SM} \right) \\
&+ \frac{1}{2} \left(\left(a_{ud}^L a_{tb}^R \right)^2 + \left(a_{ud}^R a_{tb}^L \right)^2 \right) \left(\sigma_{LR} - \sigma_L - \sigma_R + \sigma_{SM} \right).
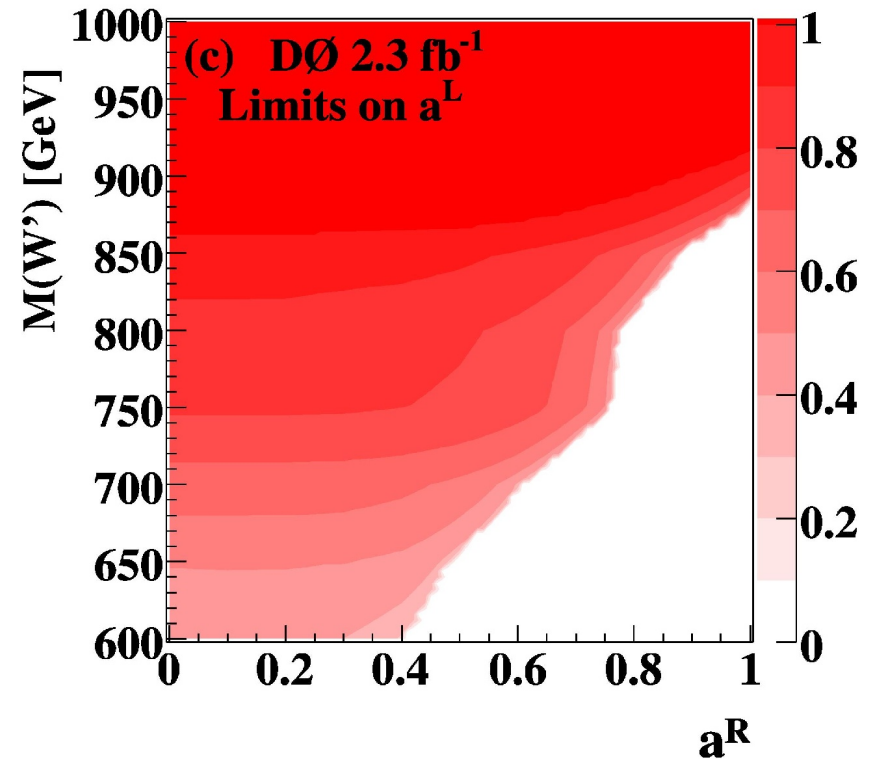\end{aligned}
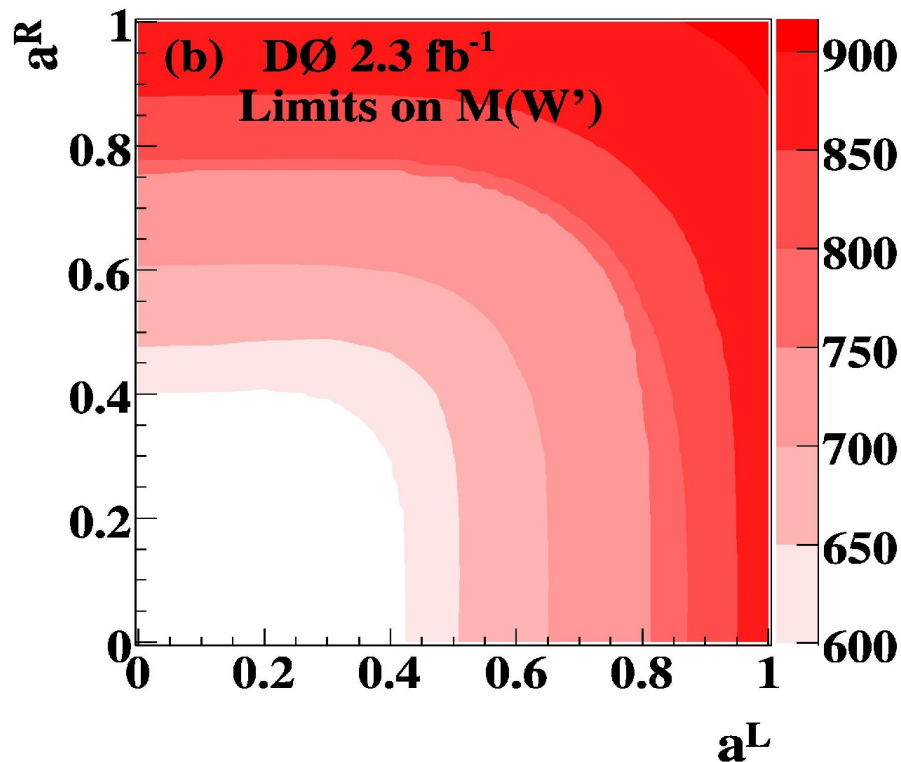\tag{2}
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W' search: S, B, data

A BDT is trained, using kinematic and angular characteristics of events, for each channel and each $m(W')$, using MC for a^L, a^R = 1.
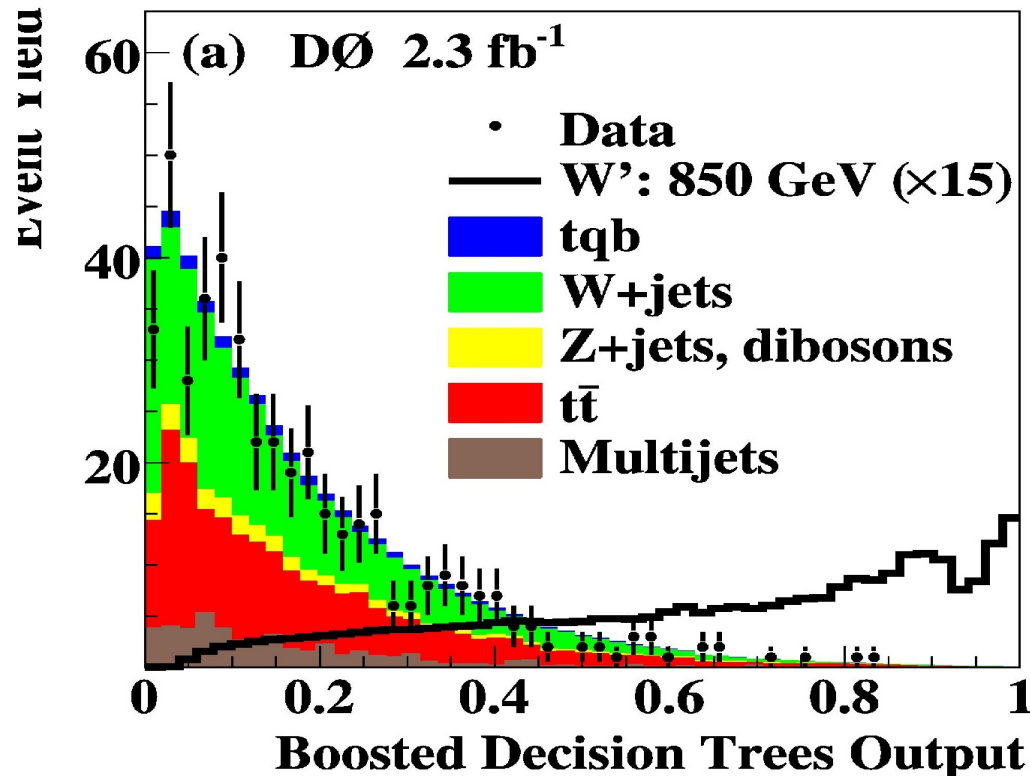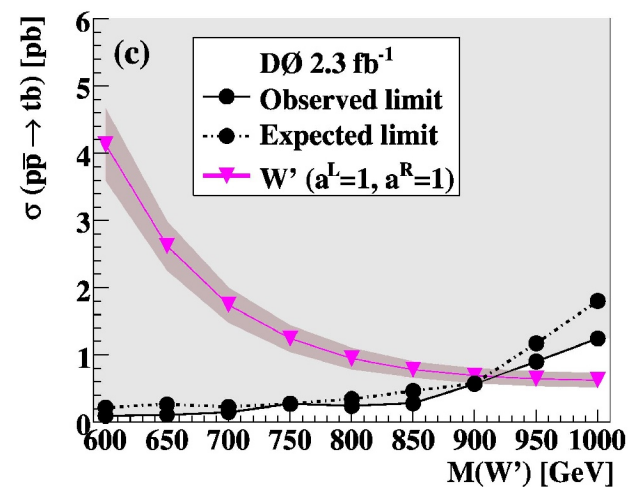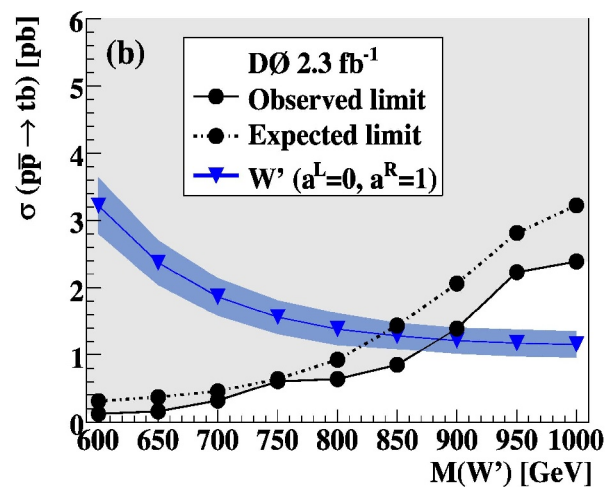
W' search: result (1)

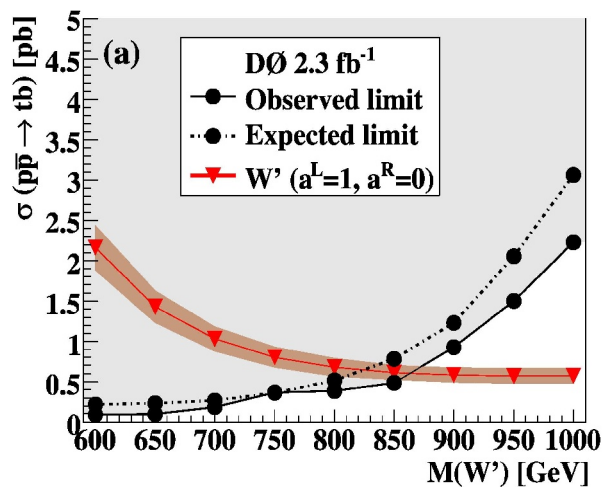Left: 95% CL lower limit on m(W') in the a^L, a^R plane.

Right: 95% Upper limit on a^L in the a^R, m(W') plane.

W' search: result (2)

(a) LH ($a_L=1$, $a_R=0$), (b) RH ($a_L=0$, $a_R=1$), (c) mixed coupling ($a_L=a_R=1$)

95% CL limits: $m(W') > 863$ GeV for purely LH coupling,

            $m(W') > 885$ GeV for purely RH coupling,

            $m(W') > 916$ GeV for mixed coupling.

Summary

D0 has searched for a pair-produced t' quark decaying like a top quark in 5.3 fb^{-1} of data using lepton+jets final states. While a ~2 s.d. excess is observed in the muon channel, the electron channel is most consistent with no signal. Combining the two, t' pair production with $m(t') < 325$ GeV is excluded at 95% CL. Accepted for publication in Phys. Rev. Lett. arXiv:1104.4522

Summary (contd.)

D0 has also searched for a singly produced W' boson decaying into tb in 2.3 fb^{-1} of data using lepton+jets final states. A fully general range of left- and right-handed couplings are investigated. 95% CL lower limits on $m(W')$ are set at 863, 885, & 916 GeV for purely LH, purely RH, & mixed couplings respectively. Results published in Phys. Lett. B 699, 145 (2011).

arXiv:1101.0806

Thank you!

Back-up slides

W' search: theory and limits

SM cross section for single top production ($a_L=a_R=0$) is 1.12 pb.

NLO x-sections, observed and expected limits for other scenarios:

$M(W')$ (GeV)	$(a^L, a^R) = (0, 1)$			$(a^L, a^R) = (1, 0)$			$(a^L, a^R) = (1, 1)$		
	σ_R	obs	exp	σ_L	obs	exp	σ_{LR}	obs	exp
600	3.22	0.12	0.31	2.16	0.09	0.22	4.13	0.09	0.21
650	2.37	0.16	0.37	1.43	0.10	0.23	2.62	0.10	0.26
700	1.86	0.32	0.46	1.03	0.18	0.26	1.74	0.15	0.23
750	1.56	0.60	0.64	0.80	0.37	0.36	1.24	0.27	0.28
800	1.38	0.64	0.92	0.68	0.39	0.51	0.95	0.24	0.34
850	1.28	0.85	1.44	0.61	0.48	0.78	0.78	0.28	0.46
900	1.21	1.39	2.06	0.58	0.93	1.23	0.69	0.56	0.57
950	1.18	2.23	2.81	0.57	1.50	2.05	0.64	0.90	1.17
1000	1.15	2.39	3.22	0.57	2.23	3.06	0.62	1.24	1.80