Search for Anomalous Top Quark Production at Tevatron

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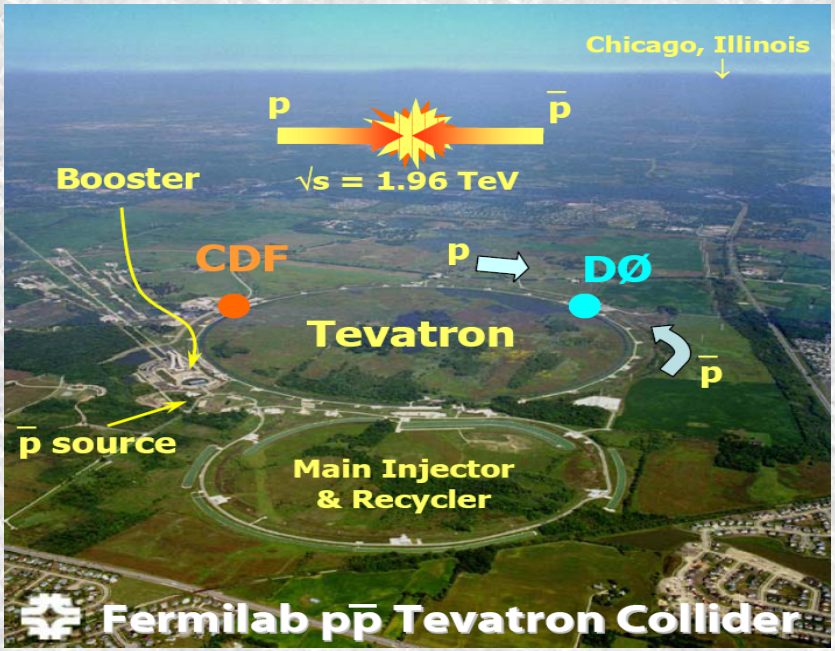
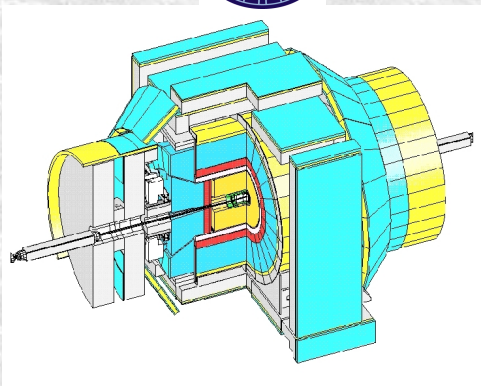
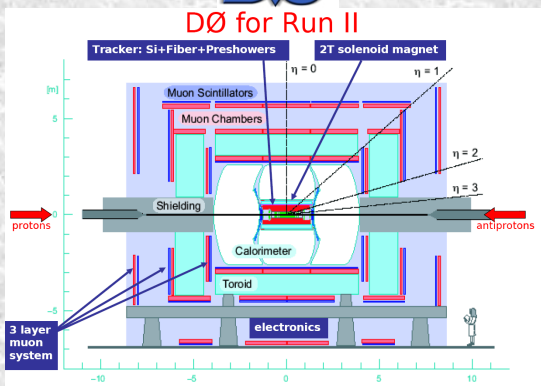
on behalf of
CDF and D0 collaborations

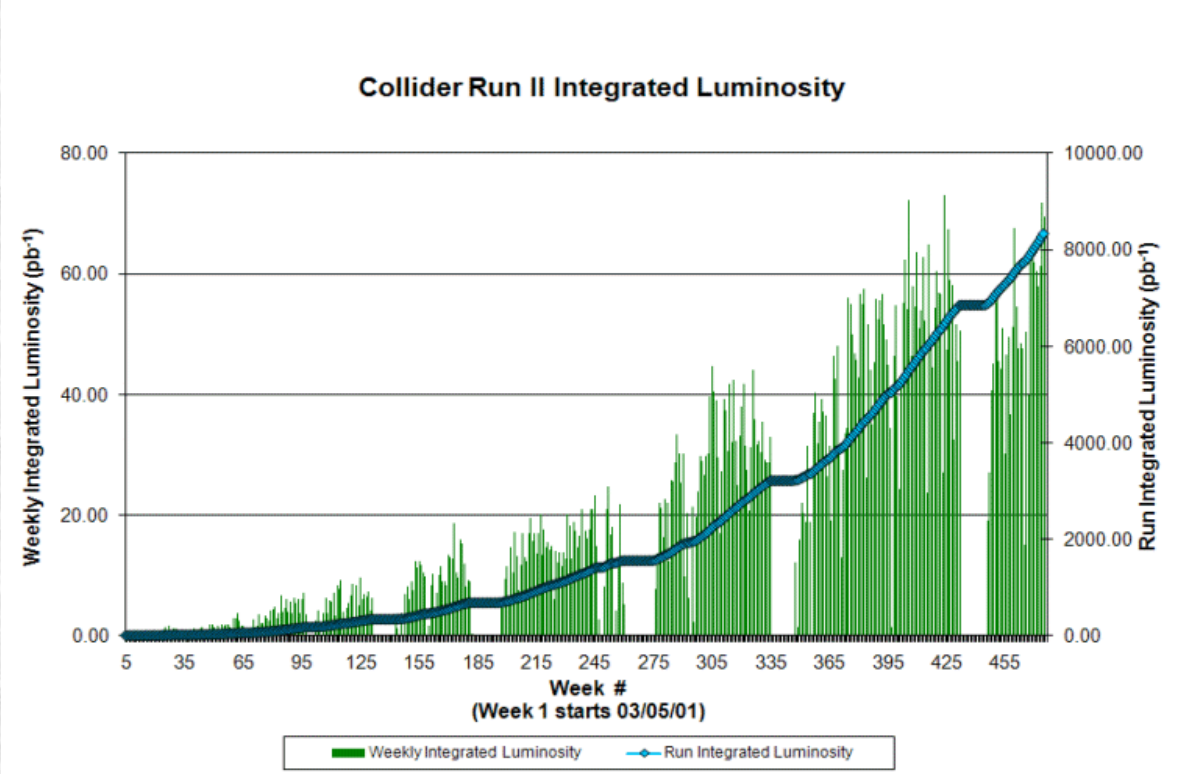
DIS-2010

Anomalous Top Quark Production: Tevatron









- 396 ns between bunches
- has delivered about 8fb^{-1} since 2001

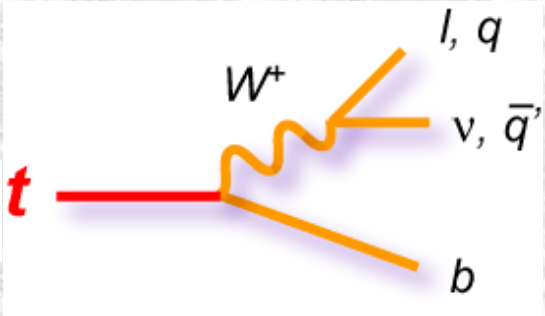
A few words about Top Quark:

- The heaviest (and the point-like) quark: Mtop = 173.1 ± 1.3 GeV (Tevatron March 2009 combination)
  - has a mass on the same order as the EW symmetry breaking scale
- Top Quark decays before hadronization

$$\tau_{top} = 4 \cdot 10^{-25}\,\mathrm{sec}\ ,\ \tau_{hadr} = 3.3 \cdot 10^{-24}\,\mathrm{sec}$$

- Top Quark decays through ONE decay channel

$$t \to bW^+,\ \mathrm{BR}(t \to \mathrm{other}) \leq \mathcal{O}(10^{-3})$$

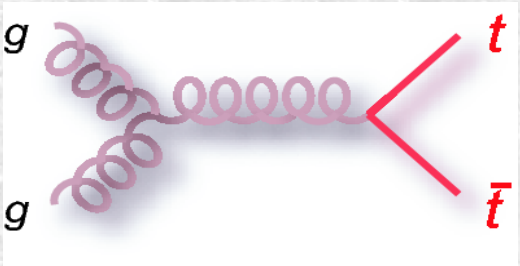


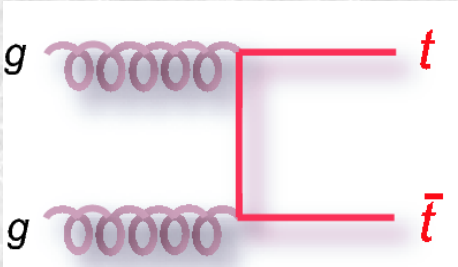
  - spin information of the Wtb vertex
- Many of the SM extensions explain the large Top mass by allowing the Top to participate in new dynamics
- Top Quark is the good candidate to test the SM
  - and search for the possible deviations from the SM

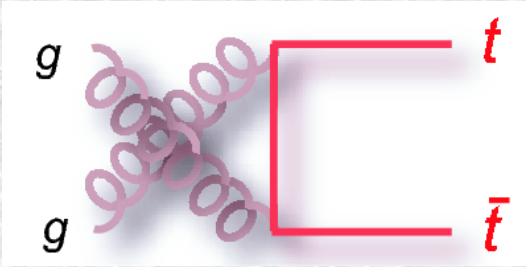
The main Top Quark production processes at Tevatron:

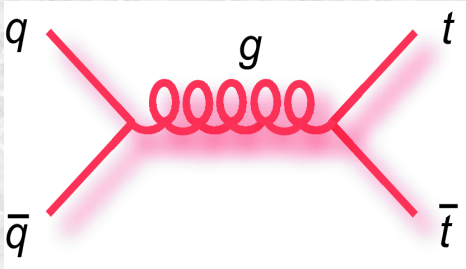
- Pair production: cross sections

Top mass: **175 GeV**





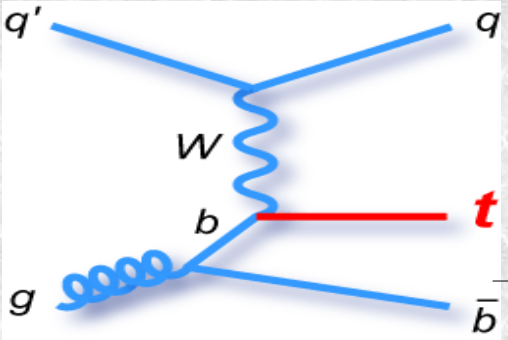


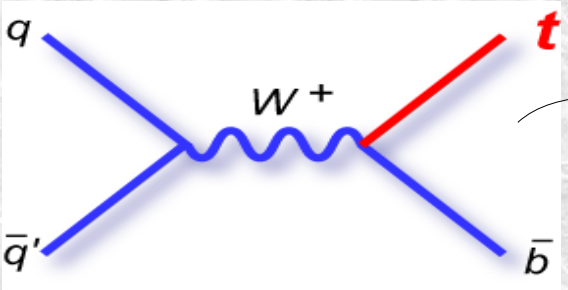


(Moch and Uwer)

$6.90^{+0.44}_{-0.62}$ pb

- Single Top production: cross sections





s-channel tb → 0.98 ± 0.04 pb

t-channel tqb → 2.16 ± 0.12 pb

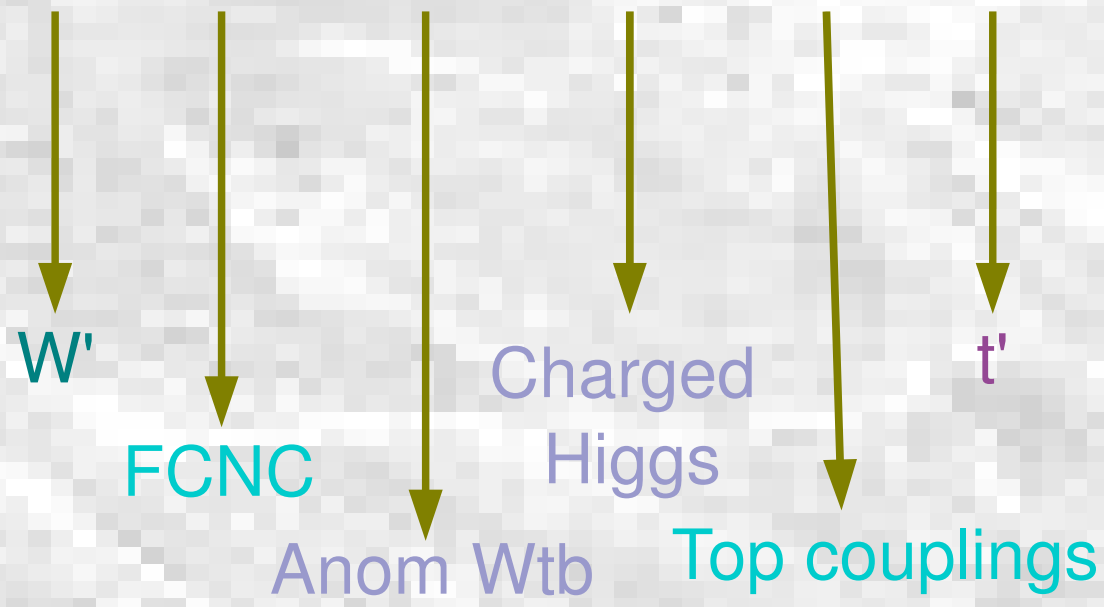
(Kidonakis)

Anomalous Top Quark Production: BSM directions

The New Physics can show itself eighter in terms of

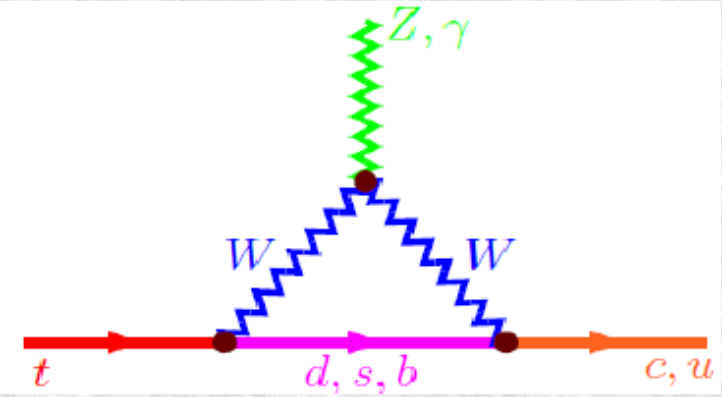
- *new particles*
- *modified couplings changing the cross sections of the existing processes and some distributions of SM processes*

- Anomalous top production and decay



FLAVOUR CHANGING NEUTRAL CURRENTS (FCNC)

- change the flavour of the quarks without changing the charge
- SM: absent on the tree level but do occur at higher order in perturbation theory through loop diagrams
- can be realized in extensions of the SM
- through photons, Z-bosons, gluons



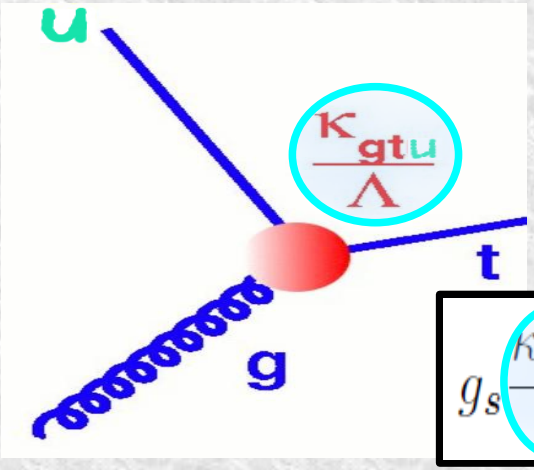
	SM	two-Higgs	SUSY
$B(t \to cg)$	$5 \cdot 10^{-11}$	10^{-6}	10^{-3}
$B(t \to c\gamma)$	$5 \cdot 10^{-13}$	10^{-6}	10^{-5}
$B(t \to cZ)$	$\sim 10^{-13}$	10^{-9}	10^{-4}

- limits for the FCNC processes involving photons and Z:

  from HERA and LEP

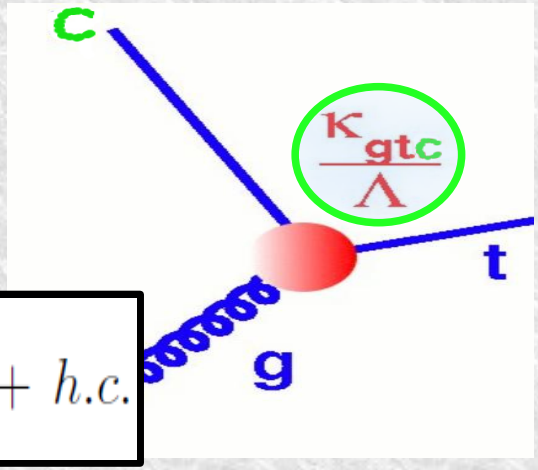
Anomalous Top Quark Production: FCNC

- CDF and D0 are looked for FCNC processes with gluons



Effective lagrangian

$$g_s \frac{\kappa_{tug}}{\Lambda} \bar{u}\, \sigma^{\mu\nu} \frac{\lambda^a}{2} t\, G^a_{\mu\nu} + g_s \frac{\kappa_{tcg}}{\Lambda} \bar{c}\, \sigma^{\mu\nu} \frac{\lambda^a}{2} t\, G^a_{\mu\nu} + h.c.$$



G: gauge field tensor of gluon

κ : strength of *tug* or *tcg* couplings

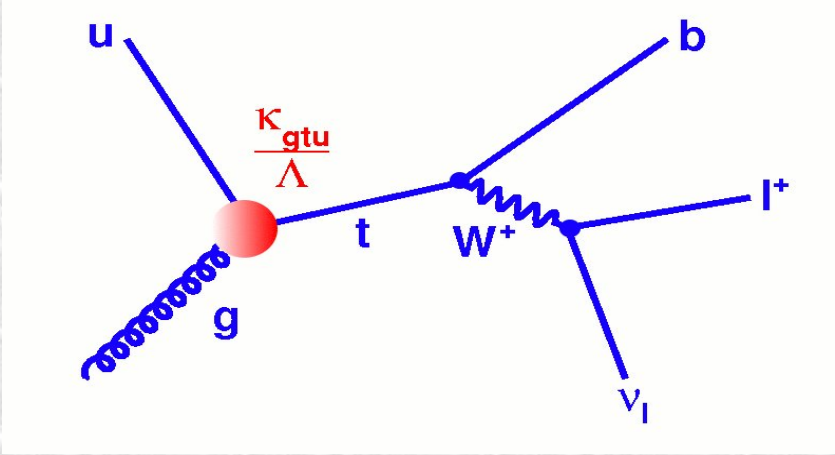
Λ: scale of new physics

related to the mass cutoff above which the effective theory breaks down

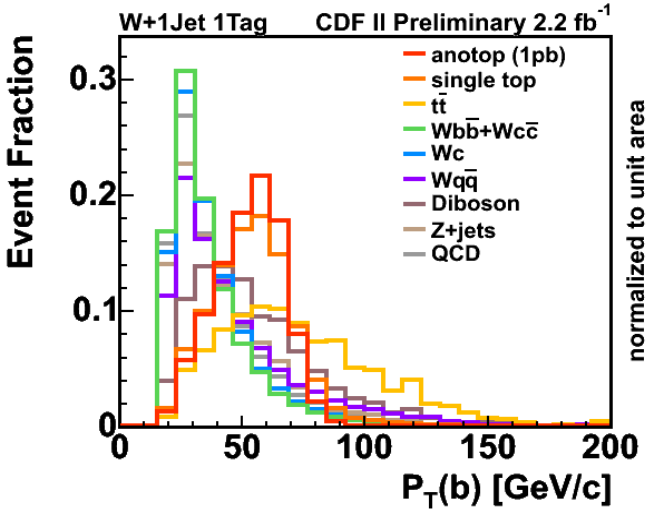
- Results from D0 and CDF - limits on FCNC parameters

Anomalous Top Quark Production: FCNC at CDF

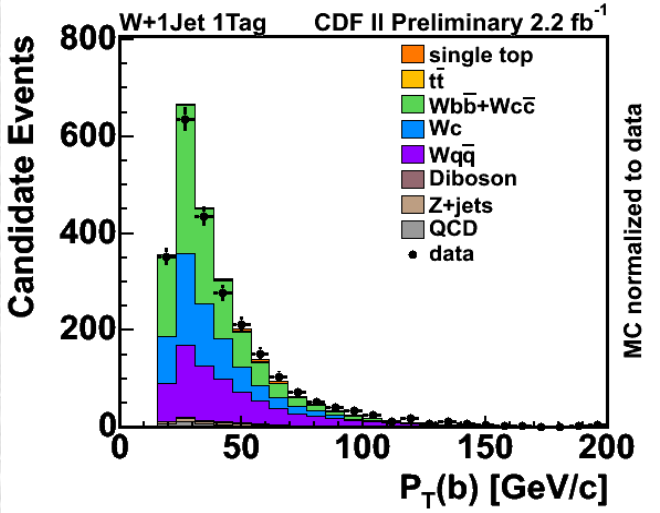
- $2.2\,\mathrm{fb}^{-1}$ (Phys. Rev. Lett. 102, 151801 (2009))
- the first one at the Tevatron searching for 2->1 process
- $\mathbf{u(c)+g \rightarrow t \rightarrow Wb \rightarrow l\nu b}$ topology
- apply NN



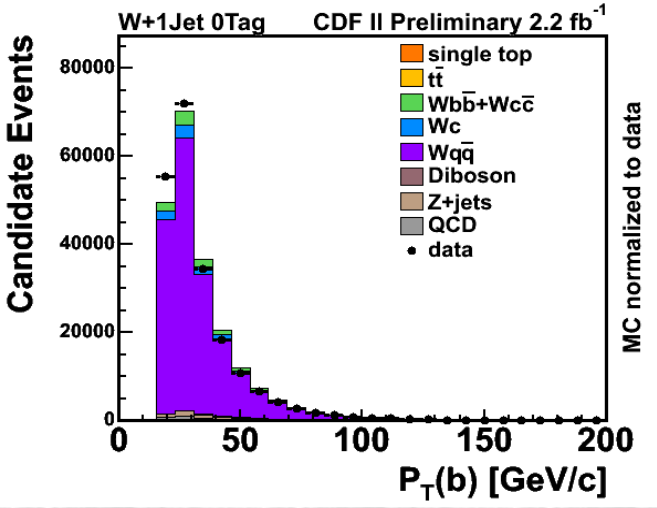
- NN input variables for the anomalous top-quark network:



MC distribution



DATA-MC comparison



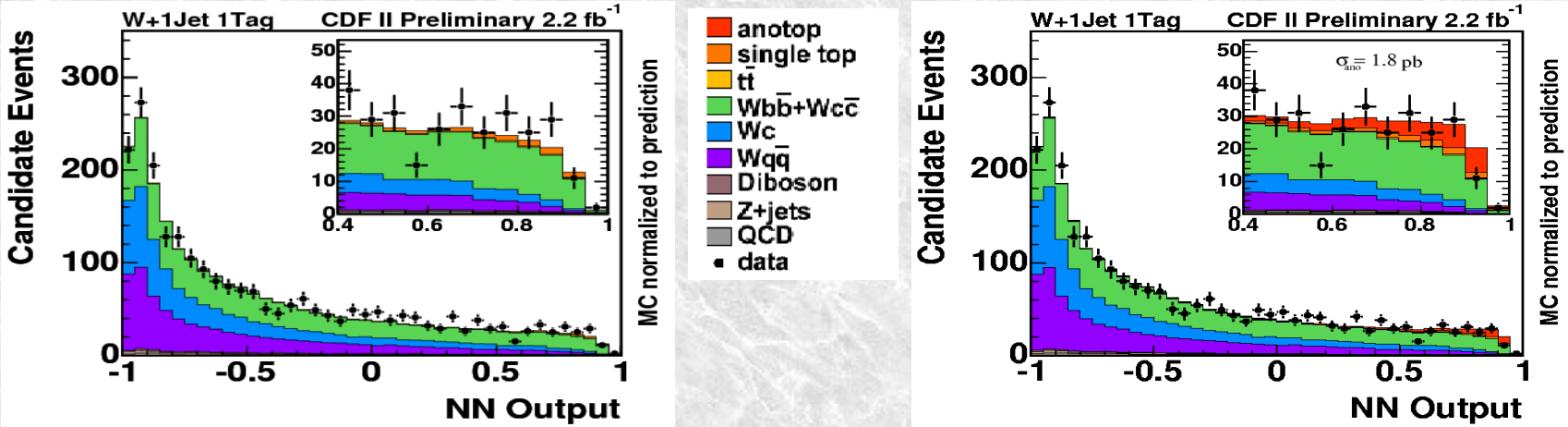
DATA-MC comparison (zero tag)

Anomalous Top Quark Production

- NN application to the observed events:

  - output distributions of the observed events are compared to the expected distributions

  - the templates are fitted to the observed distributions to determine an upper limit on the CS

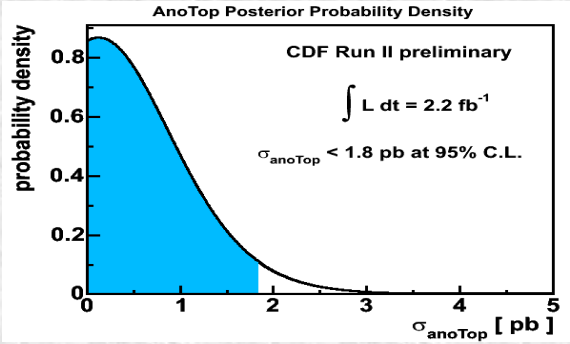


The predicted and measured distributions for the case

(left) no anomalous top-quark exists ; (right) anom. top-quark has CS of 1.8 pb

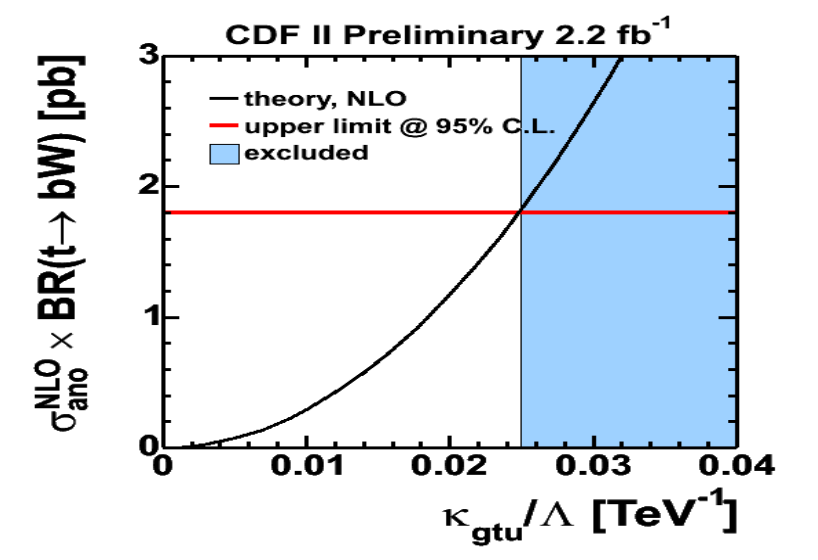
- Upper limit on the CS of anomalous single-top quark production at the 95% C.L.:

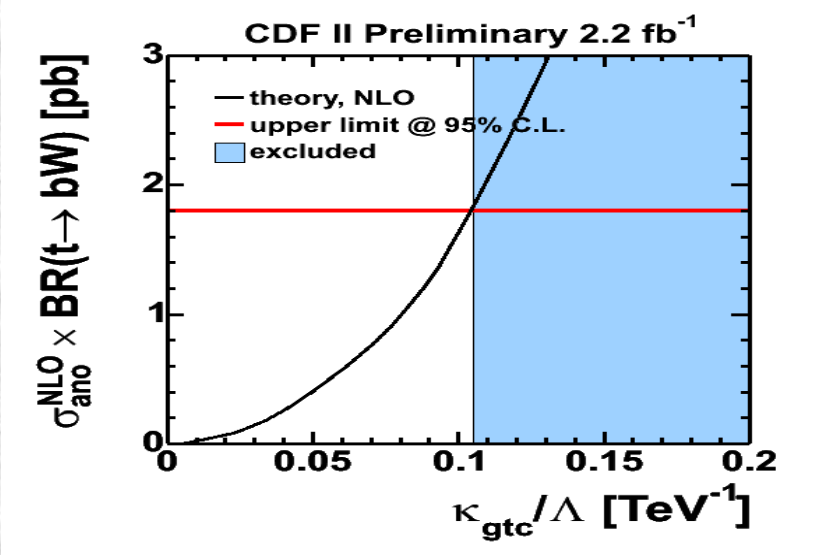
$$\sigma(u(c) + g \rightarrow t) < 1.8$$



Anomalous Top Quark Production: FCNC at CDF

- converted to coupling limits:





$$\kappa_{tug}/\Lambda < 0.018 \ \mathrm{TeV}^{-1} \ \text{assuming} \ \kappa_{tcg} = 0$$

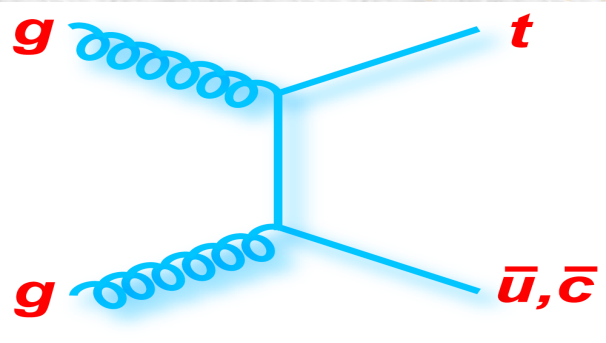
$$\kappa_{tcg}/\Lambda < 0.069 \ \mathrm{TeV}^{-1} \ \text{assuming} \ \kappa_{tug} = 0$$

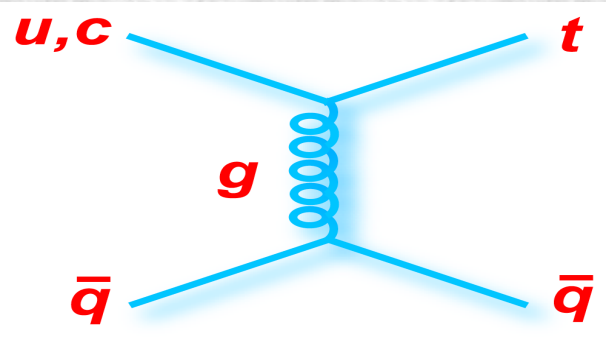
- limits on the FCNC branching ratios

$$\mathcal{B}(t \to u + g) < 3.9 \times 10^{-4} \qquad \mathcal{B}(t \to c + g) < 5.7 \times 10^{-3}$$

Anomalous Top Quark Production: FCNC at D0

- $230\,\mathrm{pb}^{-1}$ (Phys. Rev. Lett. 99, 191802 (2007))
- t-channel processes
- lepton + jets topology
- 2 set of signal events:

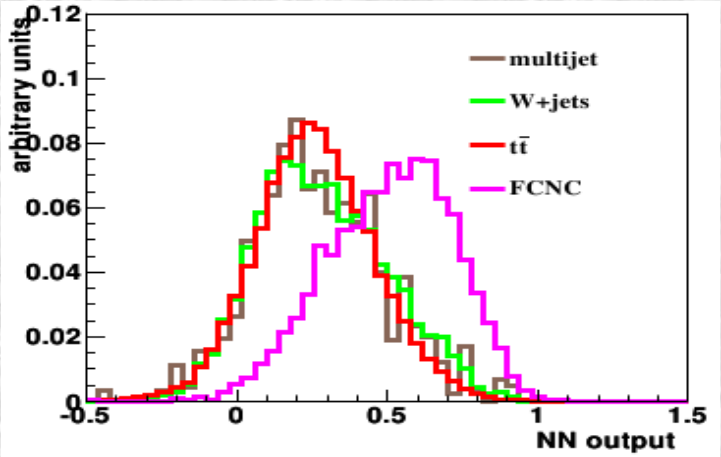


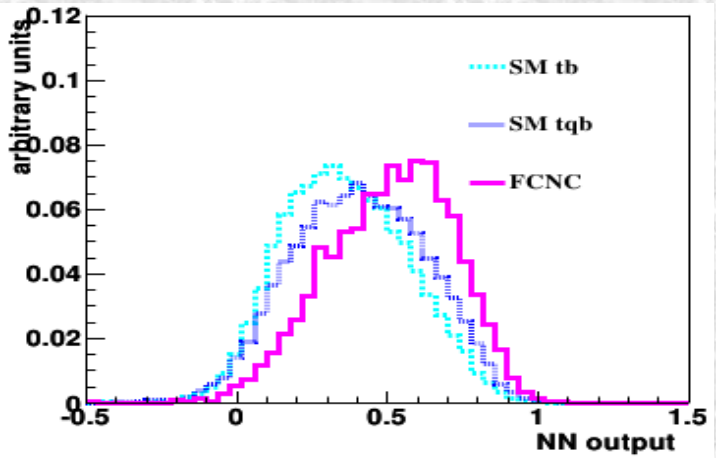


- one anom. coupling set to 0.03 and another set to 0.0

- scale the distributions to obtain them at any other value of couplings

- NN for separation of the expected signal from the background

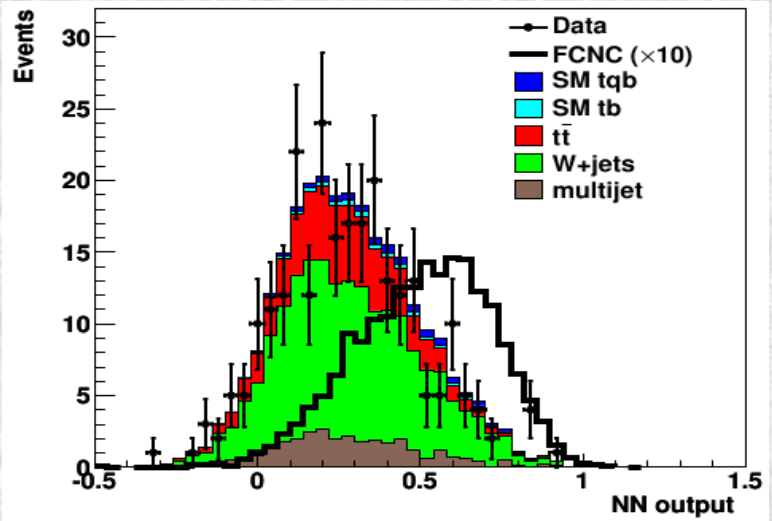




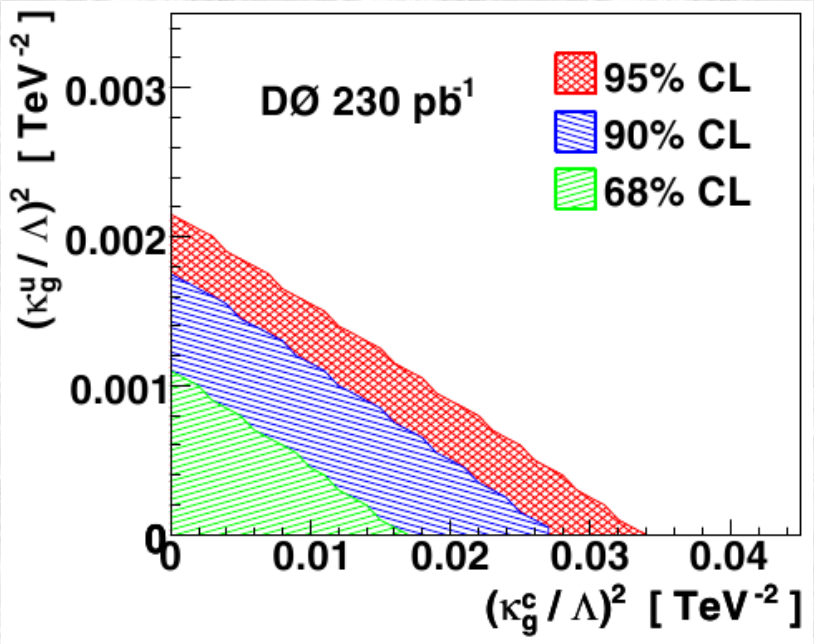
- separate FCNC signal from the SM also

Anomalous Top Quark Production: FCNC at D0

- good agreement between the observed lepton+jets data with the predicted SM-bckgr.
- set upper limits on FCNC couplings (using Bayesian approach)



Distribution of NN outputs



Exclusion contours at various levels of confidence

TABLE V. Upper limits on κ_g^c/Λ and κ_g^u/Λ, at 95% C.L.

	Observed (expected) limits [TeV^{-1}]	
	κ_g^c/Λ	κ_g^u/Λ
Electron channel	0.16 (0.19)	0.046 (0.052)
Muon channel	0.21 (0.21)	0.049 (0.050)
Combined	**0.15(0.16)**	**0.037(0.041)**

Anomalous Top Quark Production: W' origin

Heavy gauge boson

W'

models of
Universal Extra Dimensions
*Datta et al, Phys. Lett B **483**, 203 (2000)*

Technicolor models
*Chivukula et al, Phys Rev D **53**, 5258 (1996)*

composite models , Little Higgs models
Grand Unification Theory

Left-Right symmetric models
Pati, Salam, Phys Rev D 10, 275 (1974)
*Mohapatra, Pati, Phys Rev. D **11**, 566 (1975)*

top-flavor models
*Malkawi et al, Phys Lett. B **385**, 304 (1996)*

Effective lagrangian of W' interaction to fermions in model-independent form:

$$L=\frac{V_{q_i q_j}}{2\sqrt{2}} g_W \bar{q}_i \gamma_\mu [a^R_{q_i q_j}(1+\gamma_5)+a^L_{q_i q_j}(1-\gamma_5)] W' q_j + H.C.$$

$a^R_{q_i q_j}, a^L_{q_i q_j}$ - *left and right couplings of W' to fermions*

$g_W = \frac{e}{\sin(\theta)}$ - *Standard Model weak coupling constant*

$V_{q_i q_j}$ - *Standard Model CKM matrix element*

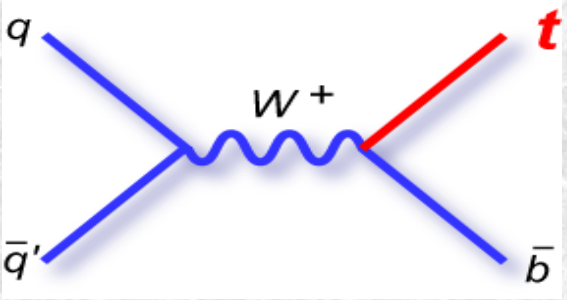
- Different scenarios of W' interaction to fermions:

Left-Handed W' (SM-like couplings)	Right-Handed W'	Mixed case
$a^L_{q_i q_j}=1, a^R_{q_i q_j}=0$	$a^L_{q_i q_j}=0, a^R_{q_i q_j}=1$	$a^L_{q_i q_j}=1, a^R_{q_i q_j}=1$

$$M_{W'} > M_{\nu_R} \; ; \; M_{W'} < M_{\nu_R}$$

Anomalous Top Quark Production: W' at CDF

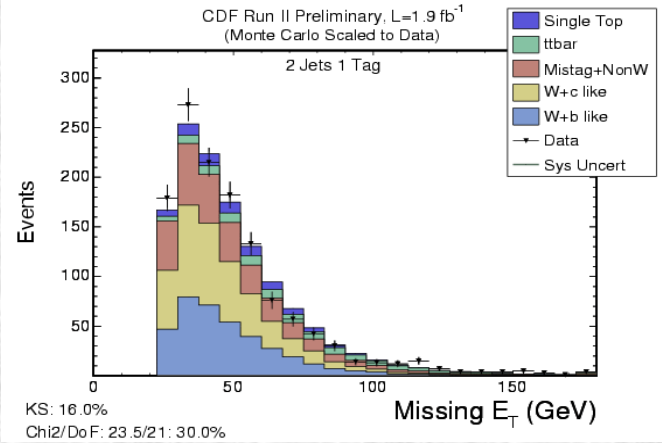
- $1.9\,\mathrm{fb}^{-1}$ W'-like Resonances in the tb Decay Channel
- modeled the Left-handed and Right-handed W'
- $W' \to tb \to Wbb \to l\nu jj$ (W+jets) topology



- many features from the single top analysis
- neglect interference between W and W' in the s-channel
- performing ensembles of the pseudo-experiments with comparison of the agreement of two hypothesis with Poisson-fluctuated data (pseudo-data)

  1) null hypothesis: all pseudo-data described by the SM as characterized by the background model

  2) signal + backgr. hypothesis: all pseudo-data are comprised of the SM background plus some fraction of W' events

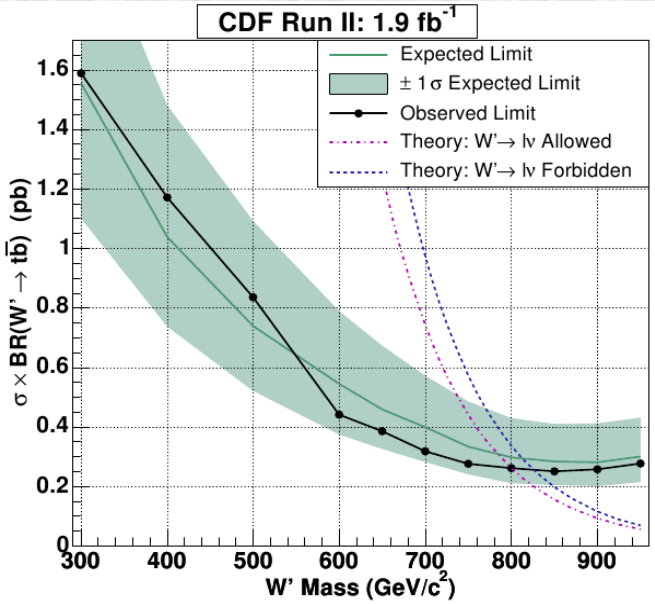


Anomalous Top Quark Production: W' at CDF

- including all uncertainties in the model results in the expected upper limit on the cross-section
- set 95% C.L. limits on the $\sigma \times \mathrm{BR}(W' \to t\bar{b})$ for Right-handed W' with SM-like couplings
- results:

$$M_{W'} > 800\,\mathrm{GeV}/c^2 \qquad M_{W'} > M_{\nu_R}$$

$$M_{W'} > 825\,\mathrm{GeV}/c^2 \qquad M_{W'} < M_{\nu_R}$$

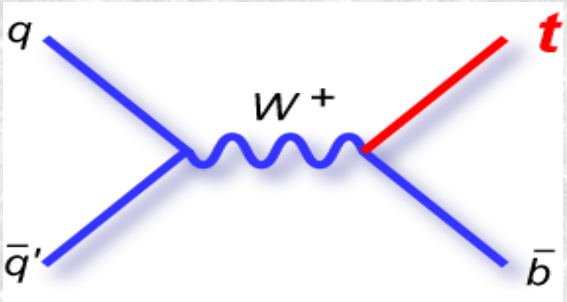


- relaxing the assumption of the universal weak coupling, CS limits can be rewritten as upper limits on g_W

$$g_W(W') < 0.4 \cdot g_W(W)$$

- resonant tB production between 750 GeV and 900 GeV is found to be less 0.28pb.

Anomalous Top Quark Production: W' and D0



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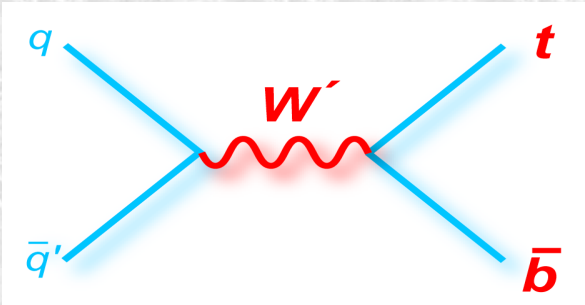


- $0.9\ \mathrm{fb}^{-1}$

PRL 100, 211803 (2008)

- considered three scenarios of W' interaction to fermions:

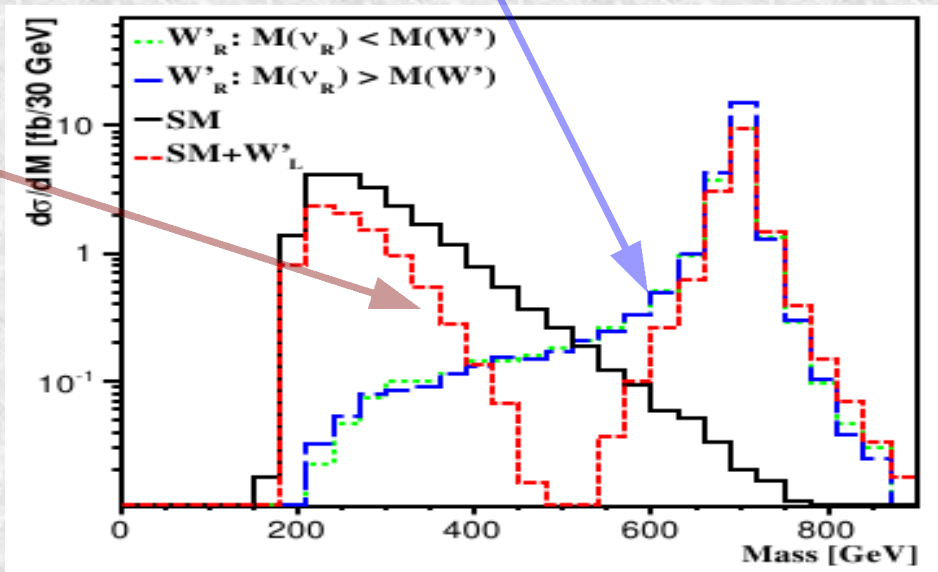
  1) SM + purely left-handed W' , 2)purely right-handed W', 3) mixed case

- Interference of W and W'

  in the s-channel has been taken

  into account

  - destructive influence on the CS



- squared matrix element of the process:

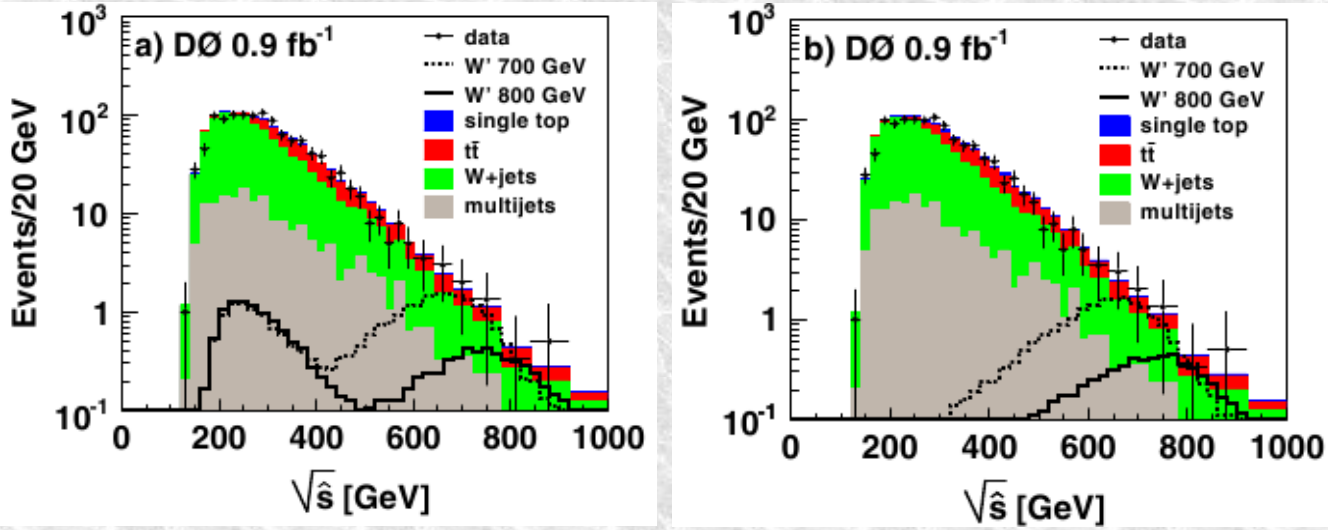
$$|M|^2 = \text{SM} + 2\cdot a_{ud}^{L}\cdot a_{tb}^{L} \quad \text{Interference of W and W'} \quad + \quad \text{W' part}$$

Anomalous Top Quark Production: W' and D0

- s-channel single top production is included in the background only for Right-handed W' search

  - for Left-handed W' search single top production is the part of signal

- Reconstruct $\sqrt{s}$



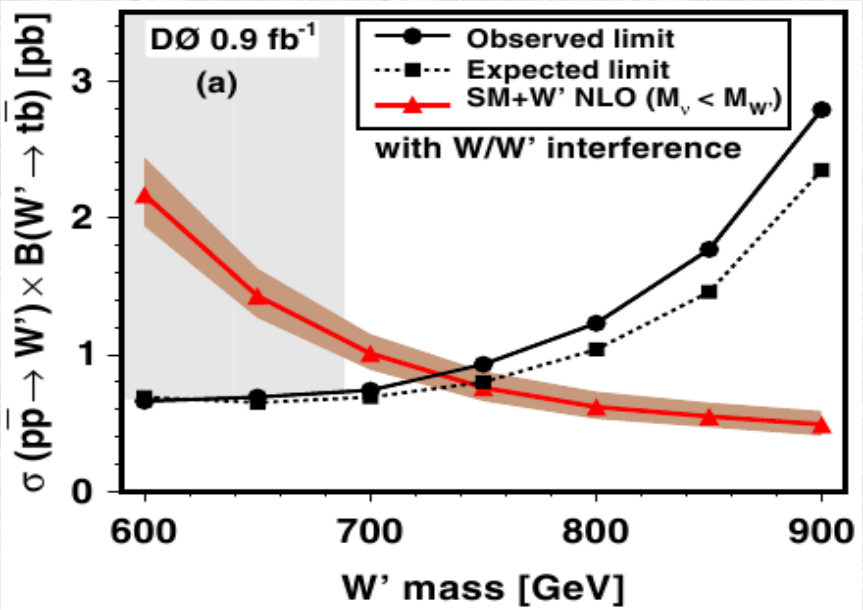
distribution for the data and the SM-background:
a) Left-handed W' signal,
b) Right-handed W' signal for two different masses, normalized to the NLO prediction

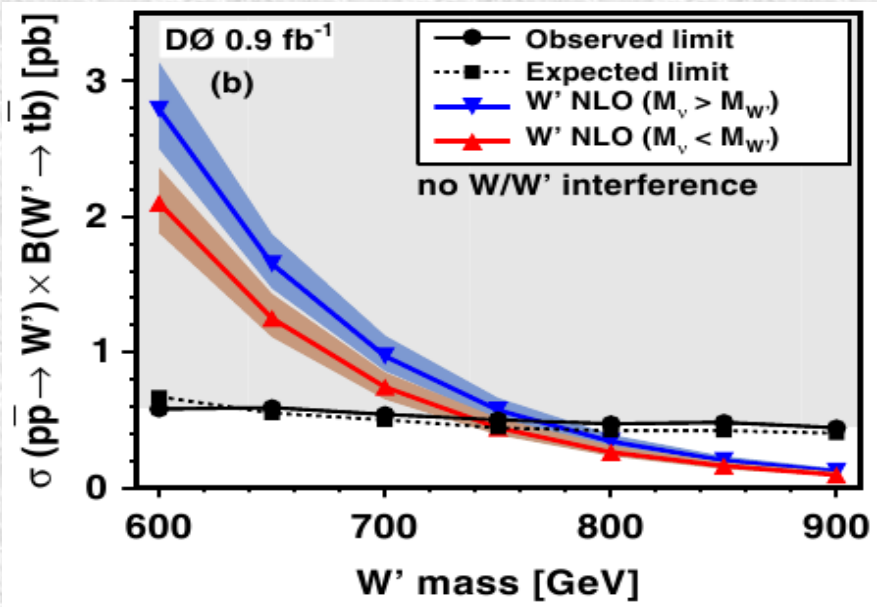
- observed distribution in the data is consistent with background prediction within uncertainties and show no evidence for the signal

- set upper limits on W' masses for different cases

Anomalous Top Quark Production: W' and D0

- set 95% C.L. limits on the W' masses:

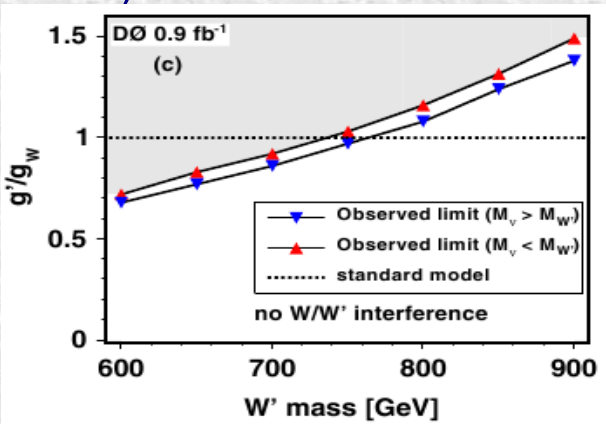




M(W´) > 731 GeV (SM-like W´)
M(W´) > 739 GeV (right W´, decays to quarks and leptons)
M(W´) > 768 GeV (right W´, decays to quarks only)

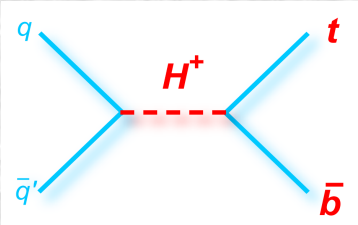
- set 95% C.L. limits on the ratio of coupling constants:

$$g_W(W') < 0.68(0.72) \cdot g_W(W)$$
$$for\ M_{\nu_R} > M_{W'}(M_{\nu_R} < M_{W'});\ M_{W'} = 600\,GeV$$

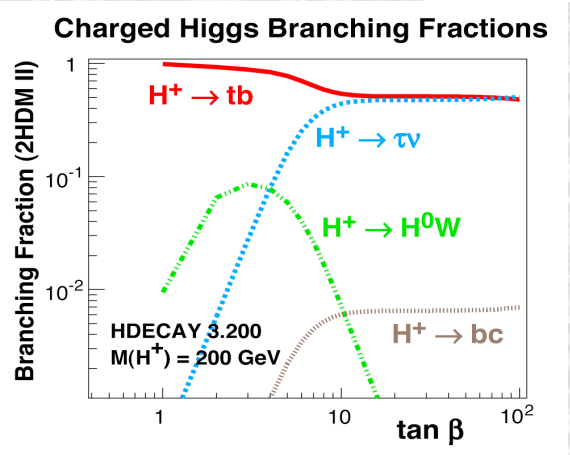


Anomalous Top Quark Production: H+

- S-channel production of Charged Scalar



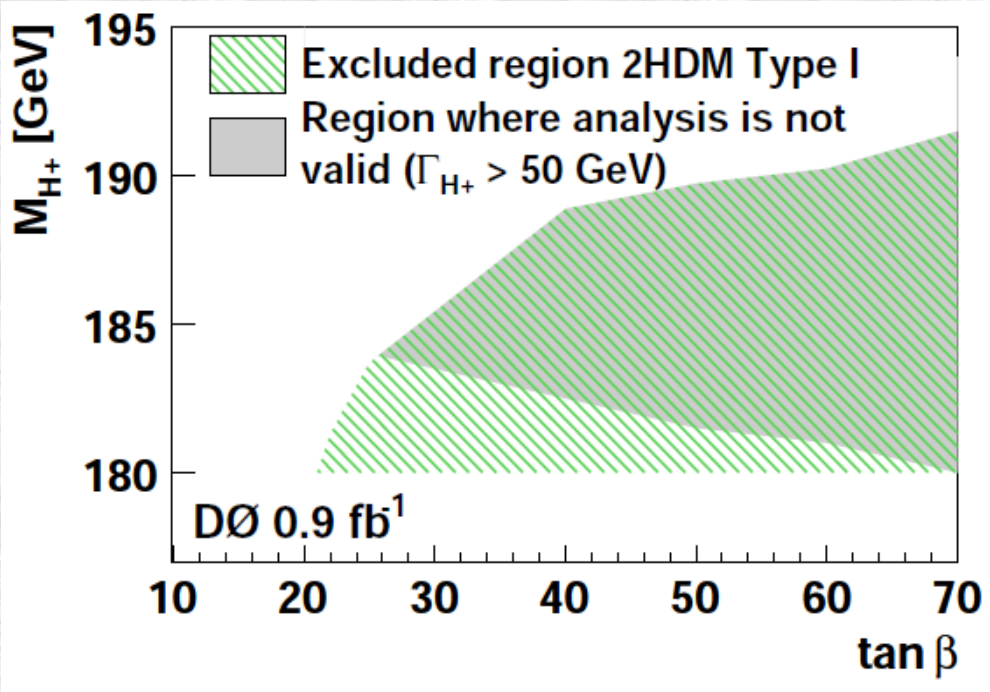
$$\mathcal{L} = H^+ \bar{q}_i \left[g_L^{ij} \left(\frac{1-\gamma^5}{2} \right) + g_R^{ij} \left(\frac{1+\gamma^5}{2} \right) \right] q_j$$



- $0.9\,\mathrm{fb}^{-1}$ Phys. Rev. Lett. 102, 191802 (2009)

- Various types of 2HDM are distinguished by their strategy for avoiding FCNC

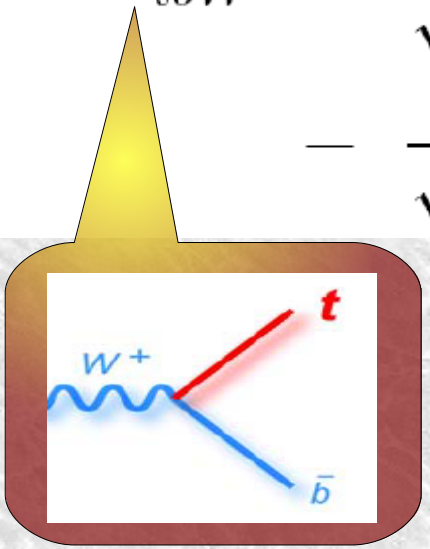
M_{H^+} (GeV)	$\tan\beta < 0.1$	$\tan\beta = 1$	$\tan\beta = 5$	$\tan\beta > 10$
180	12.9 (11.4)	14.3 (12.2)	13.7 (11.7)	13.7 (12.2)
200	[5.9 (9.6)]	6.3 (9.9)	6.5 (10.0)	6.5 (10.0)
220	[2.9 (4.2)]	3.0 (4.4)	3.0 (4.5)	3.0 (4.5)
240	[2.3 (3.1)]	2.4 (3.3)	2.6 (3.5)	2.6 (3.5)
260	[3.0 (2.8)]	3.0 (2.9)	3.0 (3.0)	3.0 (3.0)
280	[4.0 (2.6)]	4.2 (2.7)	4.5 (2.9)	4.5 (2.9)
300	[4.5 (2.4)]	4.7 (2.4)	4.9 (2.5)	4.9 (2.5)



- Effective Lagrangian in model-independent form:

vector left and right couplings

$$\mathcal{L}_{tbW} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b}\gamma^\mu \left(f_1^L P_L + f_1^R P_R\right) t - \frac{g}{\sqrt{2}M_W} \partial_\nu W_\mu^- \bar{b}\sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R\right) t + h.c.$$

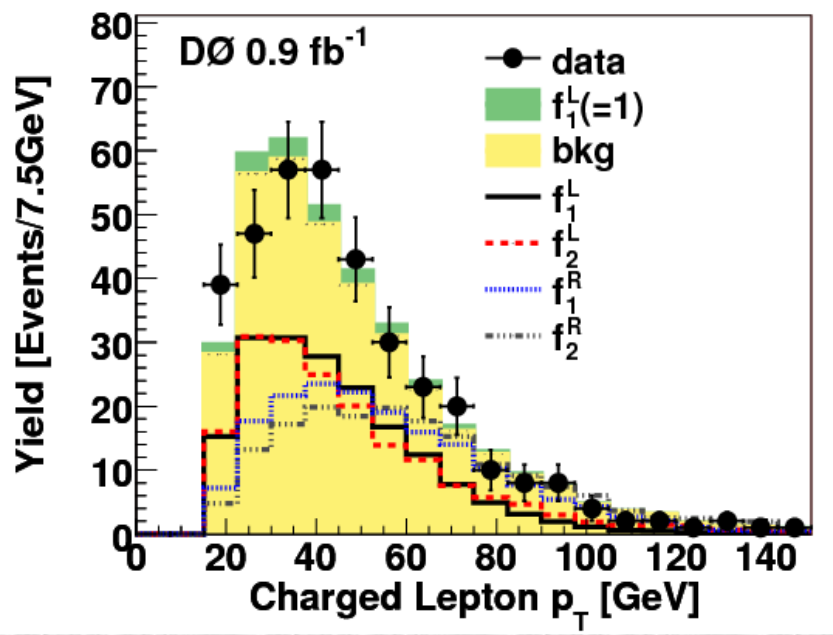


tensor left and right couplings

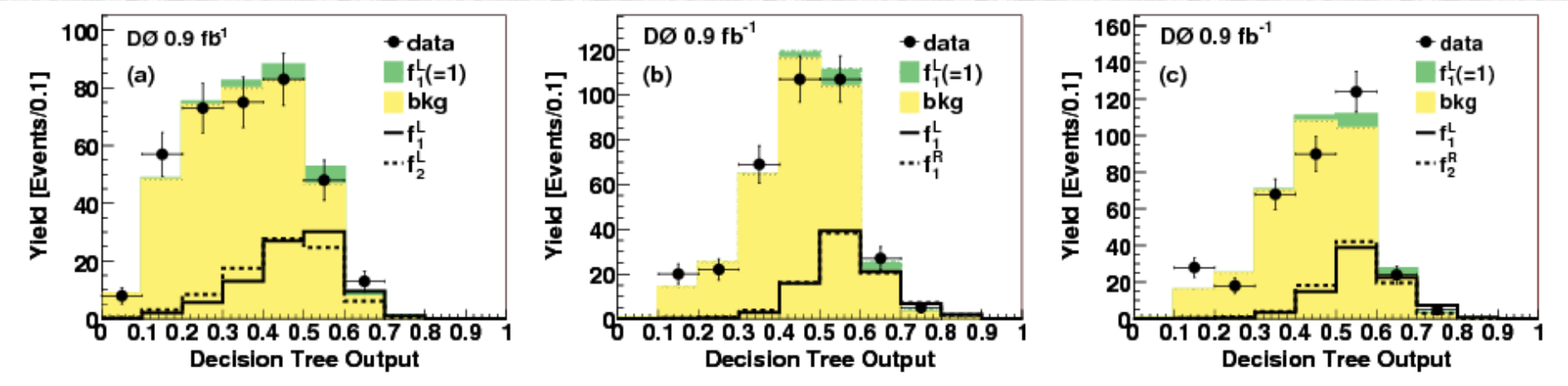
$$P_{L,R} = 1/2 \cdot (1 \mp \gamma_5) \quad , \quad \sigma^{\mu\nu} = i/2[\gamma^\mu, \gamma^\nu]$$

Anomalous Top Quark Production: AnomWtb in D0

- $0.9\,\mathrm{fb}^{-1}$, Phys. Rev. Lett. 101, 221801 (2008)
- look at two couplings at a time and assume that the others are negligible
- consider three cases
  - allow the left-handed vector coupling and any one of the others to be non-zero
- use boosted decision trees to discriminate between signal and background
  - different composition of the signal samples for each scenario
- The same variables as for D0 single top observation paper
  - plus lepton Pt (helps to distinguish the signals for the different couplings)



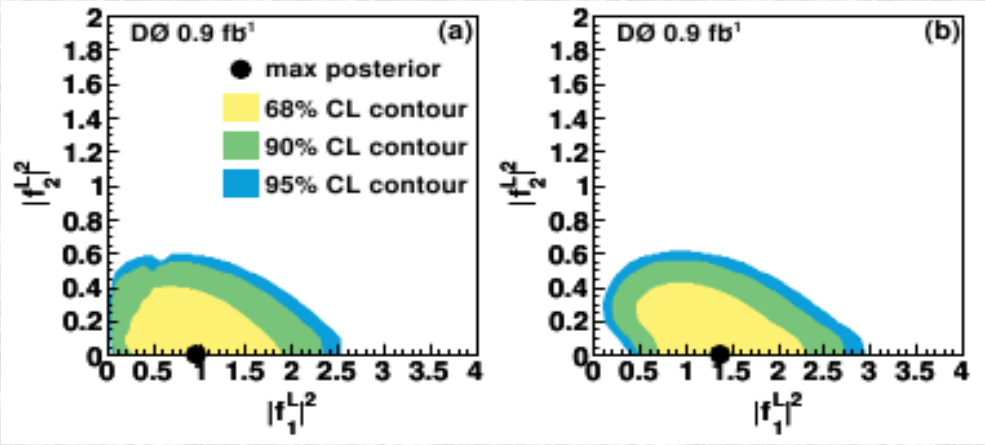
Anomalous Top Quark Production: AnomWtb in D0



Representative output distributions for the data and the sum of SM signal and bckgrds

- compute 95% C.L. Upper limits on anomalous couplings

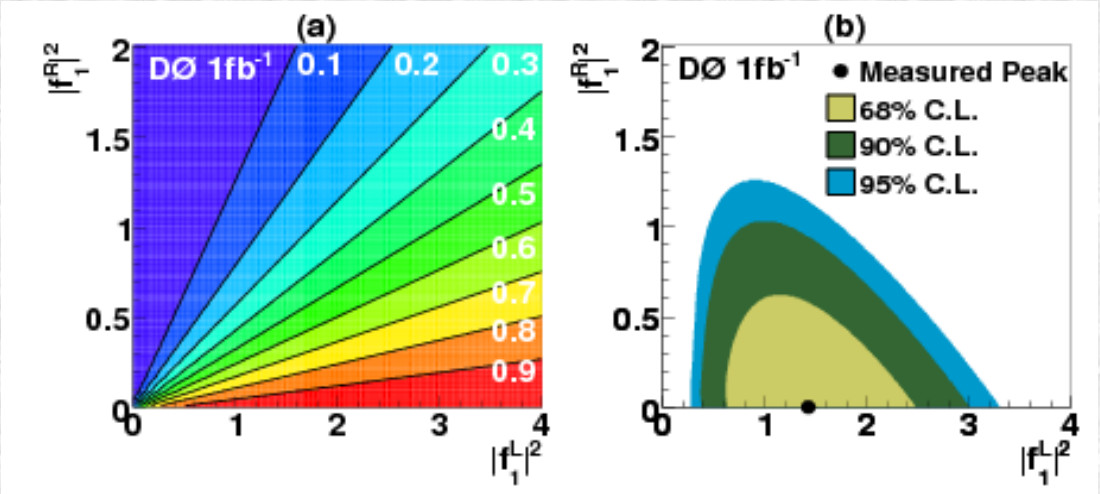
Scenario	Cross section	Coupling
(L_1, L_2)	$4.4^{+2.3}_{-2.5}$ pb	$\lvert f_1^L\rvert^2 = 1.4^{+0.6}_{-0.5}$
		$\lvert f_2^L\rvert^2 < 0.5$ at 95% C.L.
(L_1, R_1)	$5.2^{+2.6}_{-3.5}$ pb	$\lvert f_1^L\rvert^2 = 1.8^{+1.0}_{-1.3}$
		$\lvert f_1^R\rvert^2 < 2.5$ at 95% C.L.
(L_1, R_2)	$4.5^{+2.2}_{-2.2}$ pb	$\lvert f_1^L\rvert^2 = 1.4^{+0.9}_{-0.8}$
		$\lvert f_2^R\rvert^2 < 0.3$ at 95% C.L.



Plots of the 2D posterior probability density for left-vector and left-tenzor couplings

Anomalous Top Quark Production: Top couplings

- **0.9 fb^{-1}** Phys.Rev.Lett.102:092002,2009.
- combination of the D0 results for W helicity fractions in tT events with information about single-top quark production
- investigate one pair of couplings at a time - the others have SM values



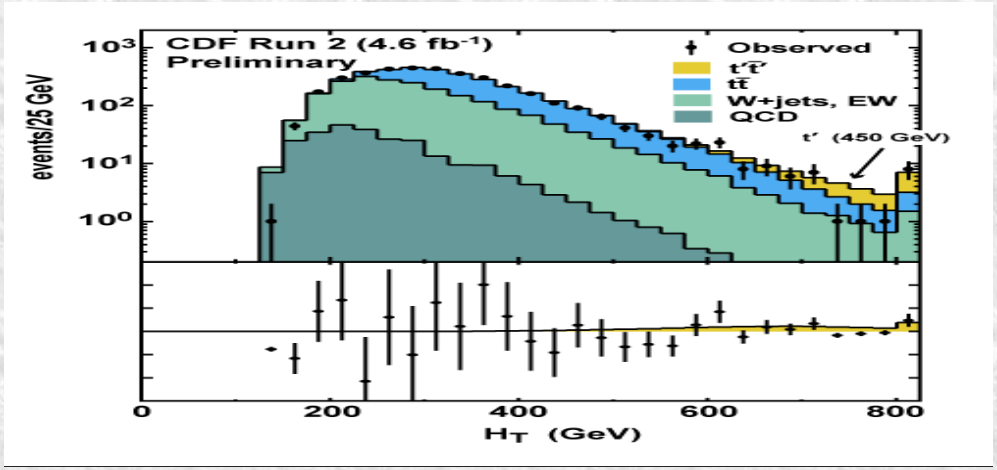
W helicity prior (a) and final posterior density (b)
For right- vs left-handed vector coupling

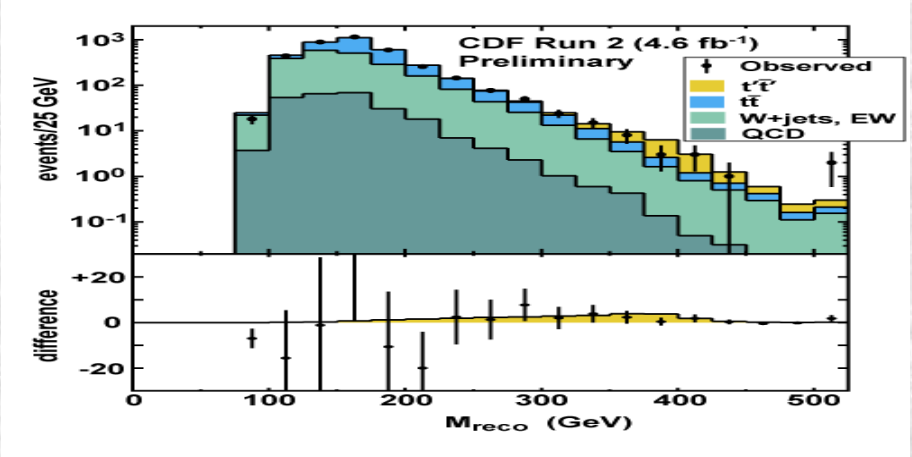
- 95% C.L. combined limits on anomalous couplings

Scenario	Coupling	Coupling limit if $f_1^L = 1$
(L_1, R_1)	$\lvert f_1^L\rvert^2 = 1.27^{+0.57}_{-0.48}$	
	$\lvert f_1^R\rvert^2 < 0.95$	$\lvert f_1^R\rvert^2 < 1.01$
(L_1, L_2)	$\lvert f_1^L\rvert^2 = 1.27^{+0.60}_{-0.48}$	
	$\lvert f_2^L\rvert^2 < 0.32$	$\lvert f_2^L\rvert^2 < 0.28$
(L_1, R_2)	$\lvert f_1^L\rvert^2 = 1.04^{+0.55}_{-0.49}$	
	$\lvert f_2^R\rvert^2 < 0.23$	$\lvert f_2^R\rvert^2 < 0.23$

Anomalous Top Quark Production: t' search

4.6 fb^{-1} CDF likelihood search

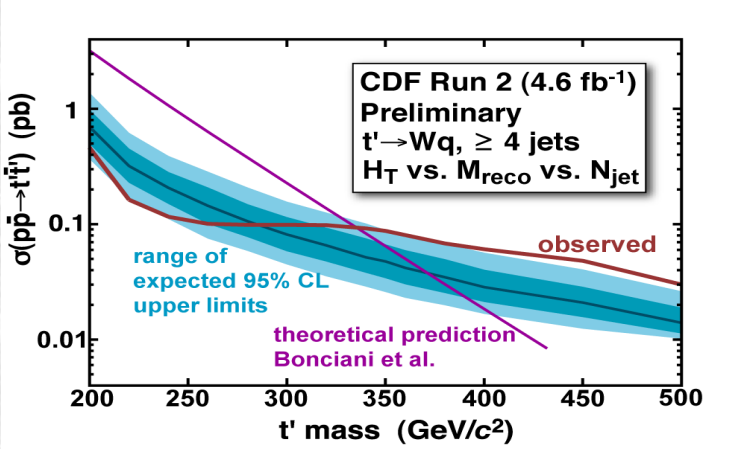




Distributions of HT (left) and Mreco (right)

showing expected signal contribution for a t' mass of 450 GeV.

- exclude the standard model forth-generation t'-quark with mass below 335 GeV at 95% C.L.



Anomalous Top Quark Production: Conclusion

- Tevatron demonstrates a good agreement with SM predictions.

  - there are no any evidence of deviations from the SM in top physics.

- Tevatron searches for anomalous Top production:

  - the limits on the anomalous cross sections, W' mass, FCNC couplings, AnomWtb couplings, t' mass.

- we expect more analyses in the nearest future statistic.

- details of all analyses listed here are available at the common pages:

CDF results

D0 results

Anomalous Top Quark Production: Summary

- The main latest constraints from Tevatron:

W ':

$$M_{W'} > 800\,\mathrm{GeV}/c^2 \qquad M_{W'} > M_{\nu_R}$$

$$M_{W'} > 825\,\mathrm{GeV}/c^2 \qquad M_{W'} < M_{\nu_R}$$

FCNC:

$$\kappa_{tcg}/\Lambda < 0.069\ \mathrm{TeV}^{-1} \text{ assuming } \kappa_{tug} = 0$$

$$\kappa_{tug}/\Lambda < 0.018\ \mathrm{TeV}^{-1} \text{ assuming } \kappa_{tcg} = 0$$

Anom couplings:

$$|f_1^R|^2 < 1.01$$

$$|f_2^L|^2 < 0.28$$

$$|f_2^R|^2 < 0.23$$

Mass of t':

$$M_{t'} > 335\ GeV$$