Overview of Experimental Results on Single Top-Quarks

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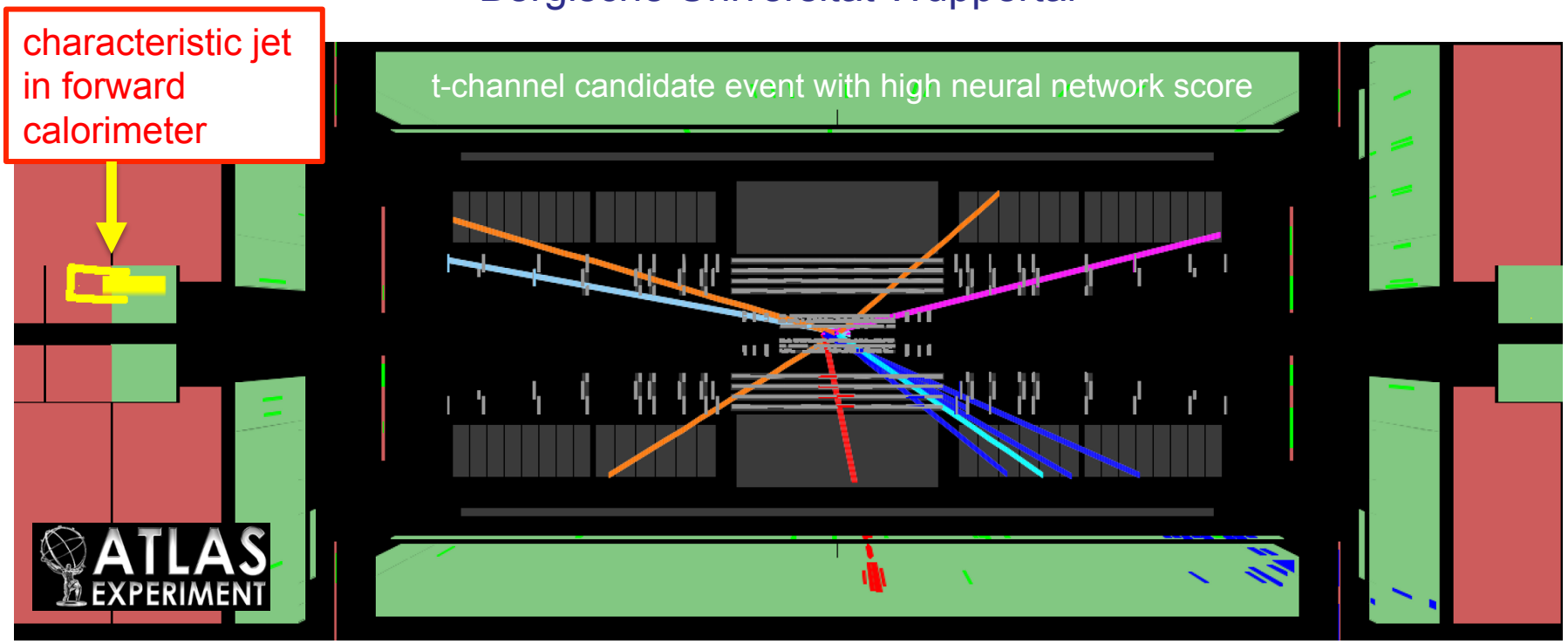


Potpourri of latest results

Caveat: not much on experimental work: triggering, reconstruction, selection, estimation of systematic uncertainties, statistical methods

Top-Quark Workshop
Humboldt University, Berlin
March 23, 2012

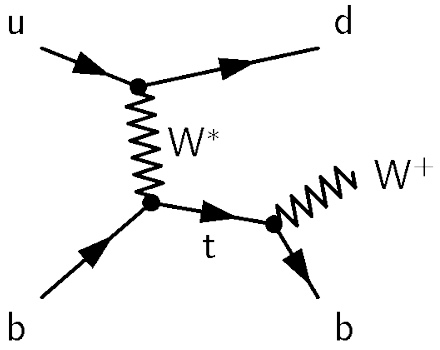
1) Introduction

What's special about these "funny" single top-quarks?

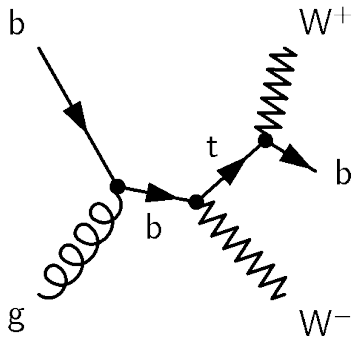
Single Top-Quark Production

top-quark production via the weak interaction.

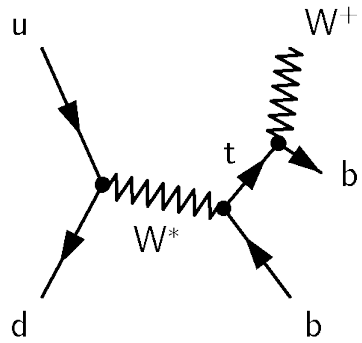
t-channel



associated Wt production



s-channel



64.6 ± pb

precision: ±

Single top and single-top-quark and antiquark cross sections are different for t- and s-channel at the LHC!
➔ u- and d-quark PDF

cross sections at the Tevatron with $\sqrt{s}$ = 1.96 TeV (m_t = 173 GeV)

2.1 ± 0.1 pb

0.25 ± 0.03 pb

1.05 ± 0.05 pb

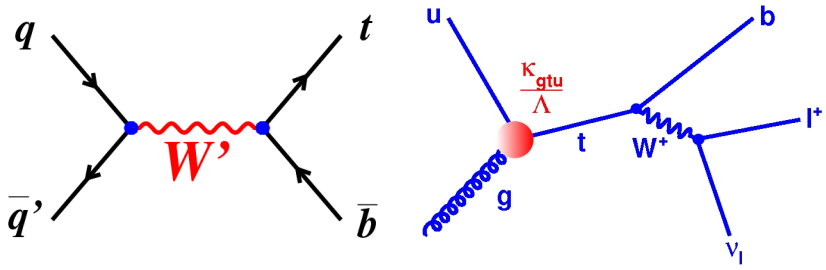
Calculations by N. Kidonakis: Phys. Rev. D 83 (2011) 091503, 1005.4451, 1001.5034
at NLO + NNLL resummation ($NNLO_{approx}$)

Why look for single top-quarks?

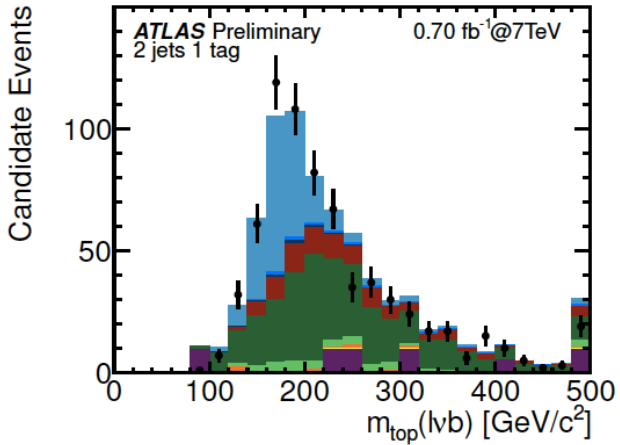
1. Test of the SM prediction.
   - Does it exist? ✔
   - Establish different channels separately. In progress.
   - Cross section $\propto |V_{tb}|^2$ ➔ test unitarity of the CKM matrix, .e.g. Hints for existence of a 4th generation ?
   - Test *b*-quark PDF: DGLAP evolution; also u-quark and d-quark PDF

$$V_{ub}^2 + V_{cb}^2 + V_{tb}^2 \stackrel{?}{=} 1$$

2. Search for non-SM phenomena
   - Search W' or H^+ (Wt or s-chan. signature)
   - Search for FCNC, e.g. ug → t
   - …



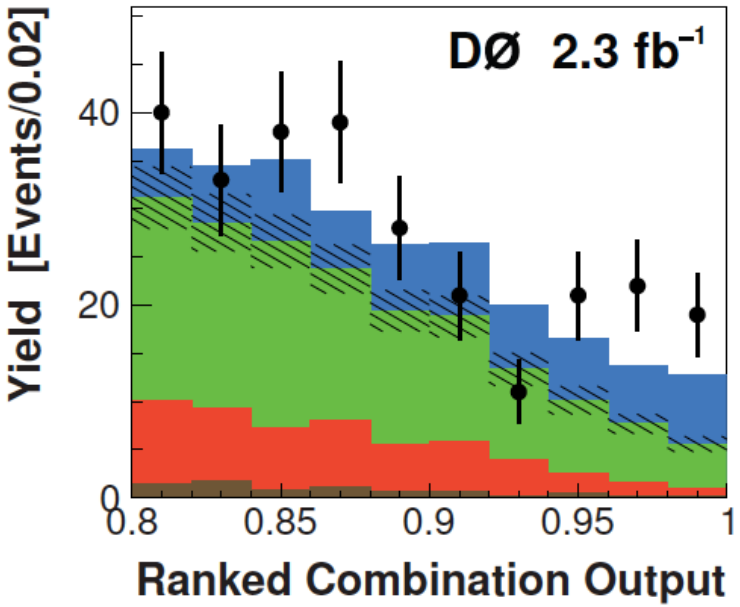
3. Single top as a complementary environment
   - Different color structure, almost no reconstruction ambiguities (jet assignment)
   - Redo measurements of top properties: M_{top}, W polarization in top decay, …



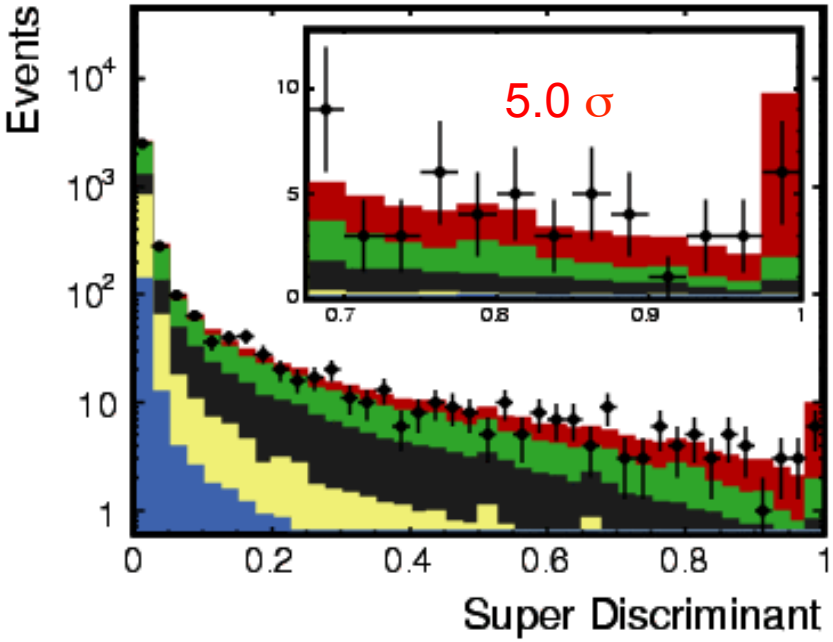
First Observation of Single-Top-Quarks

… at the Tevatron in 2009

- Combined t-channel + s-channel analysis
- Several multivariate analysis techniques.
- Combination of analyses (not results).
- Intense checks on kinematic modeling.
- Rely strongly on ALPGEN W+jets MC.
- Signal models: CompHep (DØ) and MadEvent (CDF)



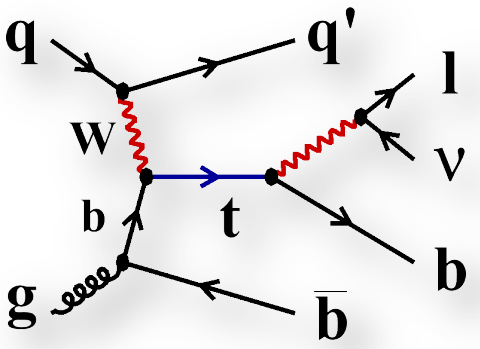
Combination of all multivariate analyses (observation at CDF 2009)



Observation Papers

- DØ: Phys. Rev. Lett.103 (2009) 092001.
- CDF: Phys. Rev. Lett. 103 (2009) 092002, Phys. Rev. D 81 (2010) 072003.

2) t- Channel Production

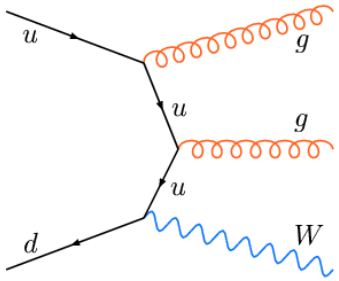


- Data sets defined by single lepton (e / μ) trigger, or lepton + jets trigger (DØ, CMS).
- Signature:
  charged lepton, E_t^{miss}, 1 light-quark jet at large $|\eta|$, 1 b-jet

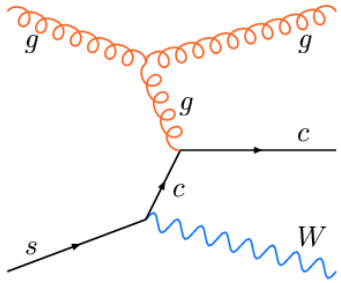
- Select only events with leptonic W decays, to suppress QCD-multijets background.
- Some acceptance due to W → τν decays.

- Main backgrounds:

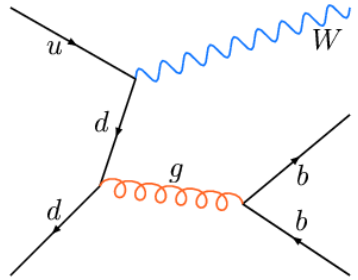
W + light jets



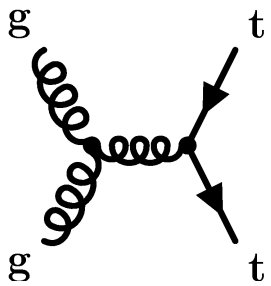
W + charm jets



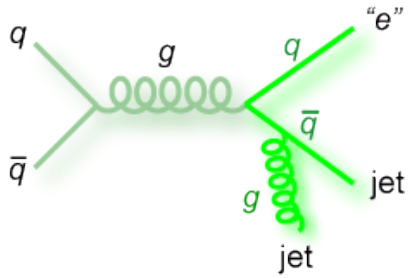
W + bottom jets



top-quark-antiquark pair production



QCD multijets (fake lepton) background (5 – 10%)



t-Channel and s-Channel Separation

- Update of discovery analysis.
- Separate discriminants for t-channel, s-channel and the combination.
- Three MVA techniques combined to super-discriminants.
- Phys. Rev. D 84 (2011) 112001

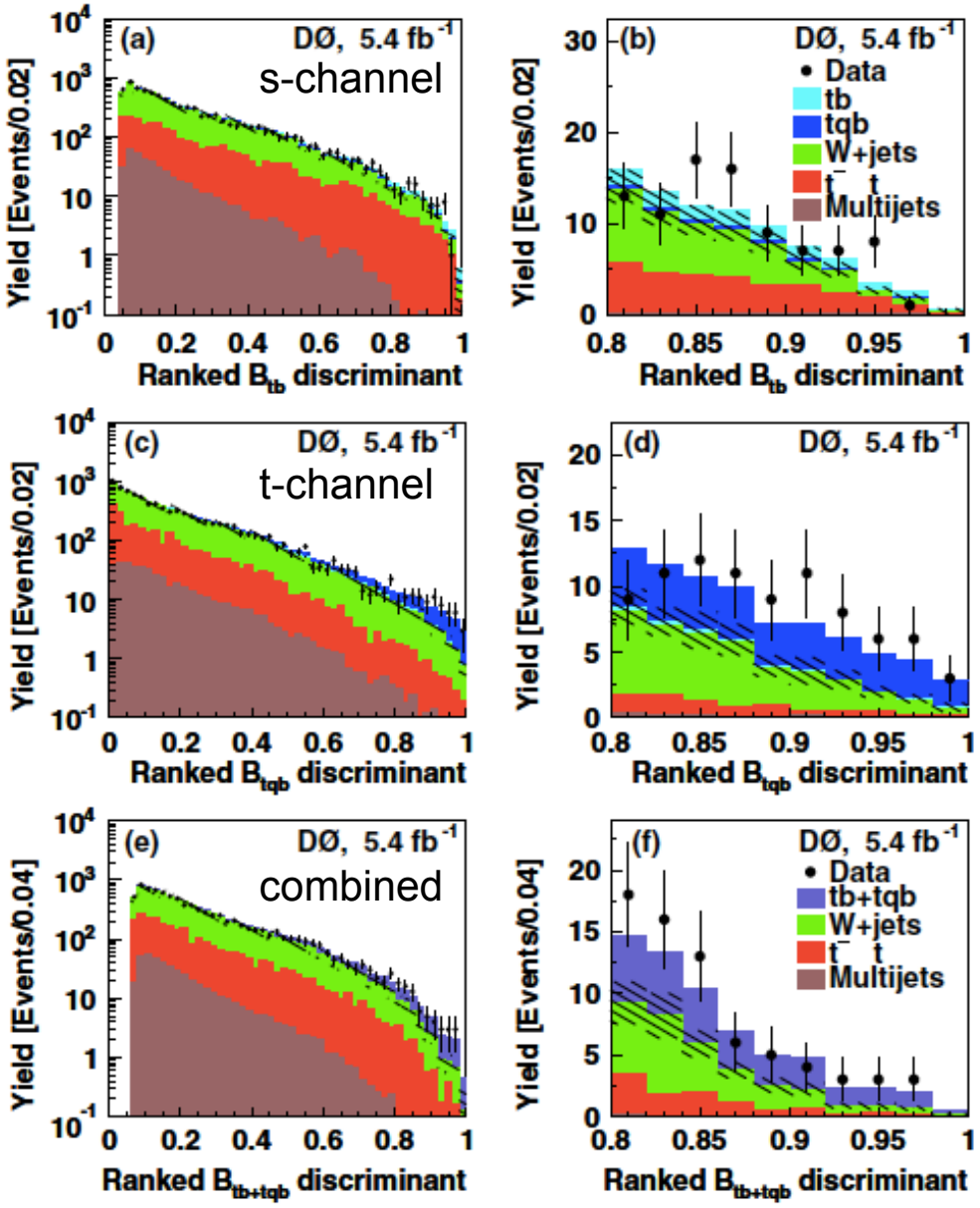
$\sigma_t = 2.86\ ^{+0.69}_{-0.63}$ (stat. + syst.) pb

prediction: $\sigma_t = 2.26 \pm 0.12$ pb

- relative uncertainty: +24% / -22%

$\sigma_s = 0.68\ ^{+0.38}_{-0.35}$ (stat. + syst.) pb
relative unc.: (+56% / -51%)

$\sigma_{t+s} = 3.43\ ^{+0.73}_{-0.74}$ (stat. + syst.) pb
relative unc.: (+21% / -22%)



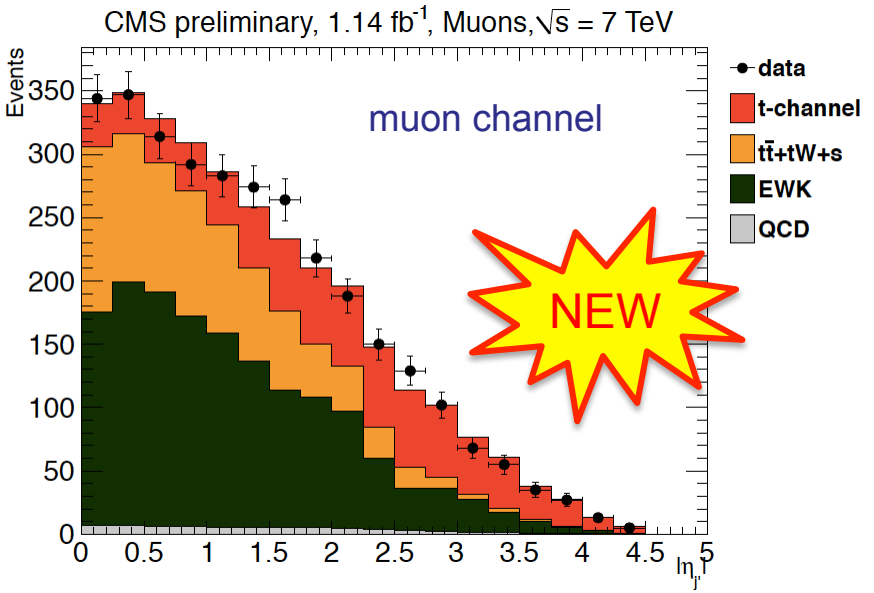
t-Channel Cross Section at CMS

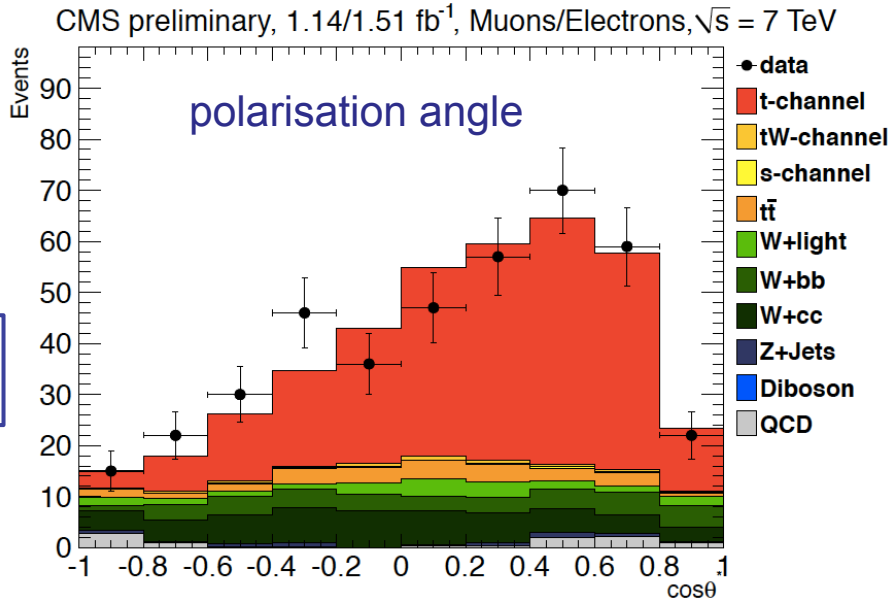
- Uses 1.14 fb^{-1} (muons), 1.51 fb^{-1} (electrons)
- Cut on reconstructed top-quark mass:
  130 < m(lνb) < 220 GeV
- S/B ≈ 20%
- signal MC: POWHEG + Pythia
- measured cross section:

σ_t = 70.2 ± 5.2 (stat.) ± 10.4 (syst.) ± 3.4 (lumi.)pb

prediction: σ_t = 64.6 ± 2.4 pb

- relative uncertainty: ± 17%

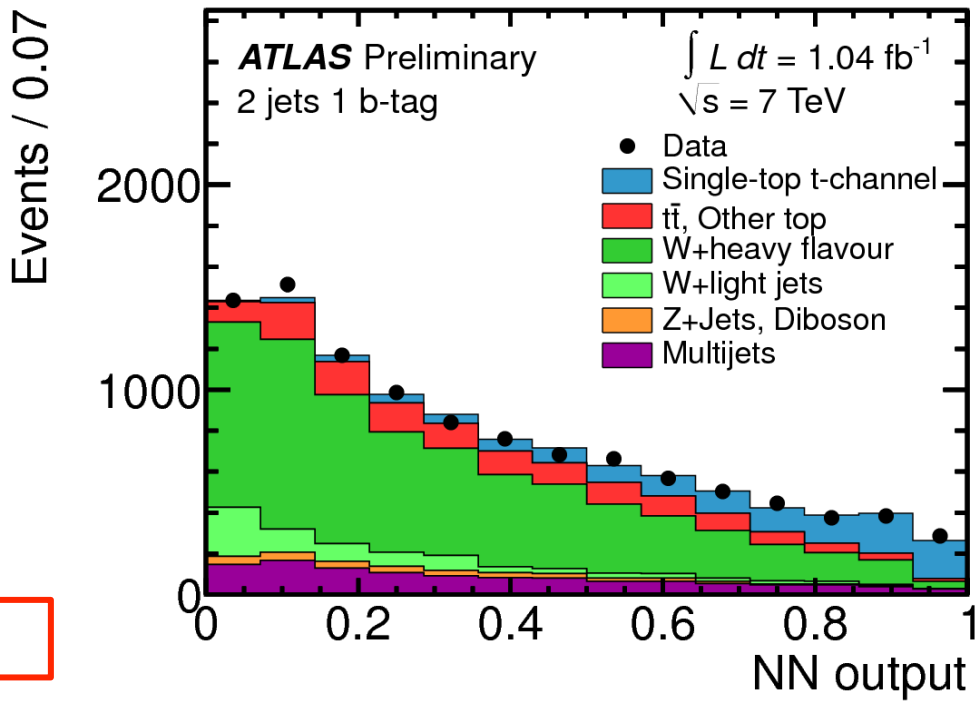




proofs V-A structure of production vertex

t-Channel Cross Section at ATLAS

- Uses 1.04 fb^{-1} of 2011 data set.
- Neural Network based discriminant.
- ML fit to NN output distribution
  ➔ simultaneous determination of background rates
- Signal MC: AcerMC



- measured cross section:

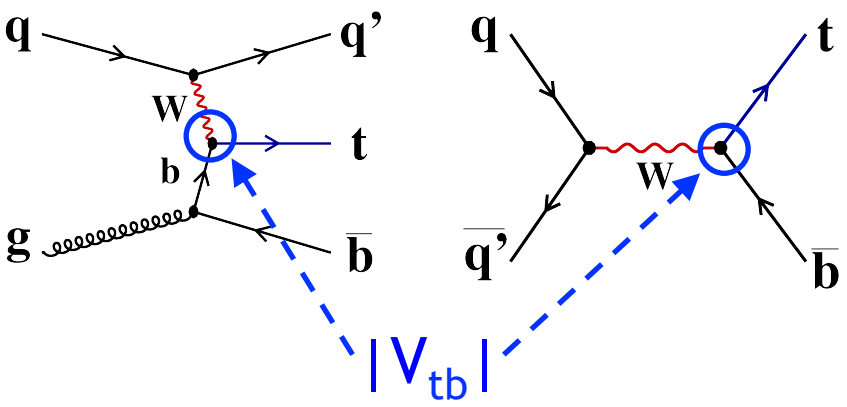
$$\sigma_t = 83 \pm 4\ (\text{stat.})\ ^{+20}_{-19}\ (\text{syst.})\ \text{pb}$$

prediction: $\sigma_t = 64.6 \pm 2.4$ pb

- relative uncertainty: ± 24%

- Observed significance 7.2 σ
  (expected: 6.0 σ)
- Dominating systematics:
  ISR / FSR modeling ±14%
  b-tagging efficiency ±13%

Summary of $|V_{tb}|$ Determinations



- Using cross section result measure $|V_{tb}|$
- Assume Standard Model (V-A) coupling and $|V_{tb}| >> |V_{ts}|, |V_{td}|$ (from BR(t →Wb) measurements)

$$|V_{tb,meas}|^2 = \frac{\sigma_{meas}}{\sigma_{SM}} \cdot |V_{tb,SM}|^2$$

Experiment	$\|V_{tb}\|$	rel. exp. precision
CDF & DØ discovery (3.2 fb^{-1} & 2.3 fb^{-1})	0.88 ± 0.07 (exp.) ± 0.07 (theo.)	8.0%
DØ (5.4 fb^{-1})	1.02 $^{+0.10}_{-0.11}$ (exp. + theo.)	+8.7% / -9.9%
CMS (1.14 fb^{-1} / 1.51 fb^{-1})	1.04 ± 0.09 (exp.) ± 0.02 (theo.)	8.7%
ATLAS (1.04 fb^{-1})	1.13 $^{+0.14}_{-0.13}$ (exp. + theo.)	11.9%

Determination of Γ_t

Use previous DØ results:

σ_t = 2.90 ± 0.59 (stat. + syst.) pb — Phys. Lett. B 705 (2011) 313

R = BR(t → Wb) / BR(t → Wq) = 0.90 ± 0.04 — Phys. Rev. Lett. 107 (2011) 121802

Use relations:

$$\Gamma(t \to Wb) = \sigma(t\text{−channel})\ \frac{\Gamma(t \to Wb)_{\rm SM}}{\sigma(t\text{−channel})_{\rm SM}} \qquad \Gamma_t = \frac{\Gamma_p}{\mathcal{B}(t \to Wb)}$$

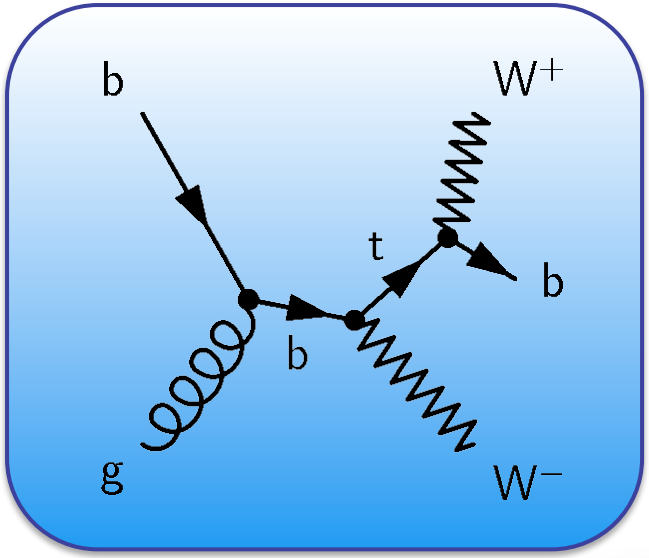
➔ $$\Gamma_t = \frac{\sigma(t\text{−channel})\ \Gamma(t \to Wb)_{\rm SM}}{\mathcal{B}(t \to Wb)\ \sigma(t\text{−channel})_{\rm SM}}$$

extracted result: $\Gamma_t = 2.00\ ^{+0.47}_{-0.43}$ GeV

➔ $\tau_t = 1/\Gamma_t = 3.29\ ^{+0.90}_{-0.63} \cdot 10^{-25}$ s

Γ (t → Wb)$_{SM}$ = 1.33 GeV @ m_t = 172.5 GeV

3) Wt analyses



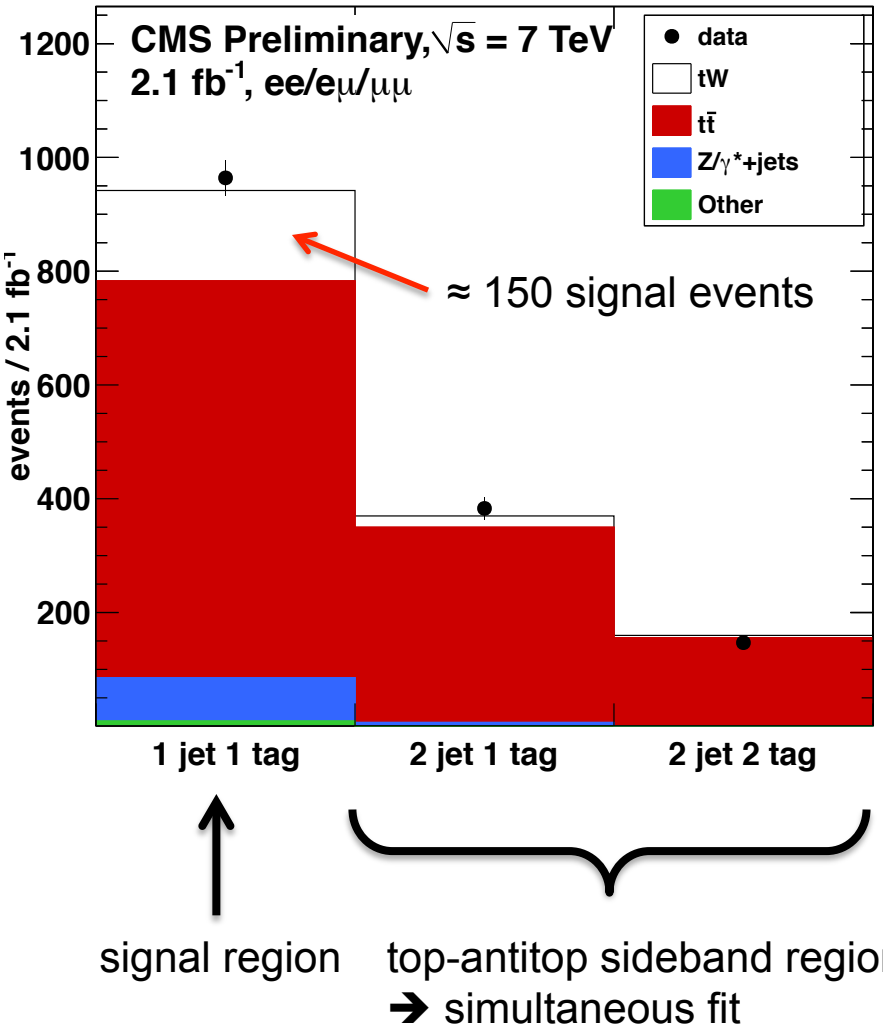
Two channels according to W decay modes:

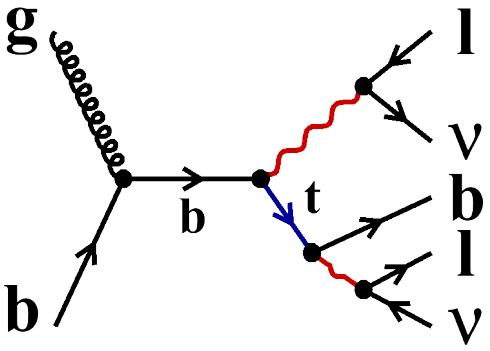
1) Dilepton channel
   both W: W → eν or W → μν
   ➔ 2 charged leptons, E_T^{miss}, 1 b-jet

2) Lepton + jets channel
   W → eν or W → μν + W → qqbar
   ➔ 1 charged lepton, E_T^{miss}, 3 jets

- CONF note with 35 pb^{-1} (Moriond)
  ATLAS-CONF-2011-027
- CONF note with 0.70 fb^{-1} (EPS)
  ATLAS-CONF-2011-104
- Physics Analysis Summary (TOP2011)
  CMS PAS TOP-11-022

Wt measurement in the dilepton channel





- Observed significance: 2.7σ (1.8σ expected)
- Observed cross section:

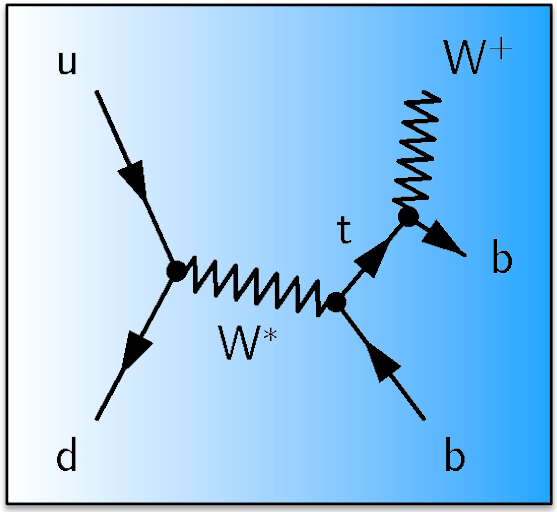
$\sigma_{Wt} = 22\ ^{+9}_{-7}$ (stat.+ syst.) pb

SM: $\sigma_{Wt} = 15.7 \pm 1.3$ pb

ATLAS:
Observed cross section (significance 1.2σ):

$\sigma_{Wt} = 14.4\ ^{+5.3}_{-5.1}$ (stat.) $^{+9.7}_{-9.4}$ pb

4) Search for s-channel production



- Smallest cross section of all single-top processes. (antiquarks in the initial state needed)
- Signature similar to t-channel, but:
  - No forward jet.
  - Two central b-quark jets.
  - Jet definition uses: $|\eta| < 2.5$.
  - Use double tagged events.
- First s-channel analysis at ATLAS using 0.70 fb^{-1}.

ATLAS-CONF-2011-118

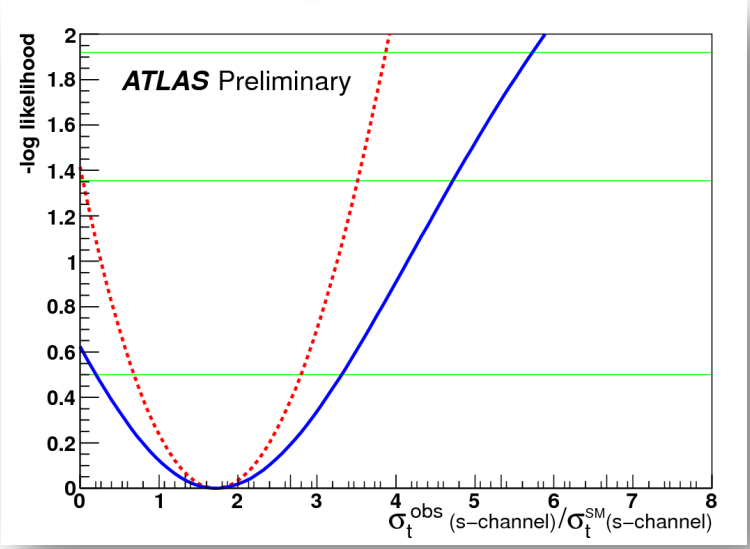
Cut-based analysis

Observed limit @ the 95% C.L.:

$\sigma_{s\text{-channel}} < 26.5$ pb

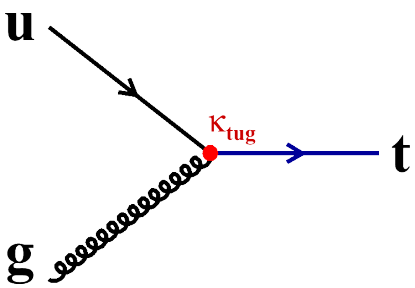
SM: $\sigma_s = 4.6$ pb

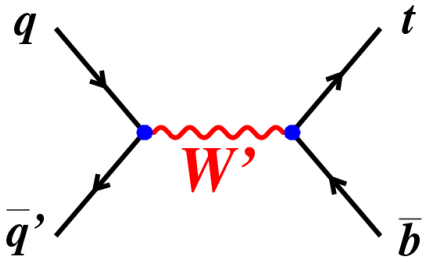
Statistical analysis: Profile likelihood



5) Single Top-Quarks …

… as a Window to New Physics



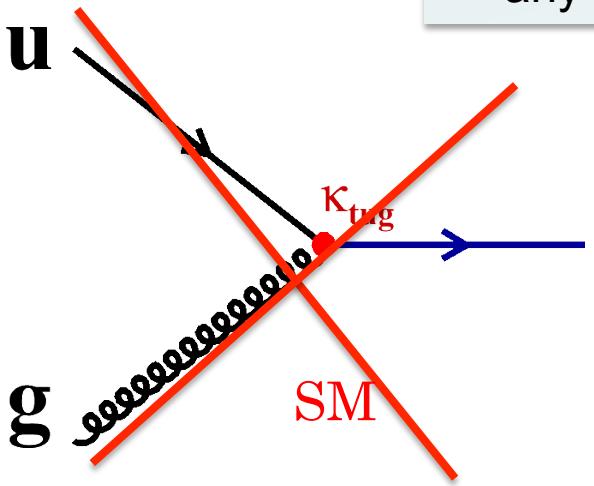


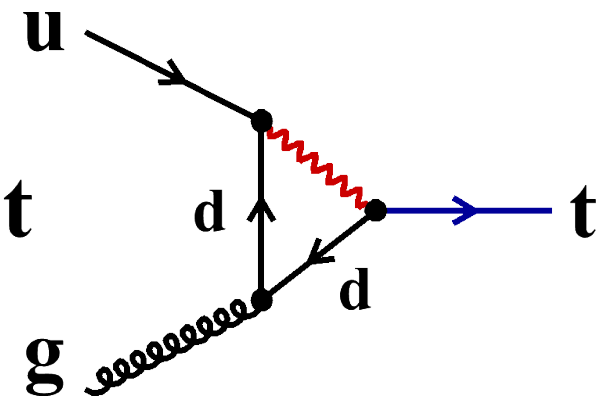
influential article on that topic:
T.M.P. Tait and C.P. Yuan, Phys. Rev. D 63 (2000) 014018

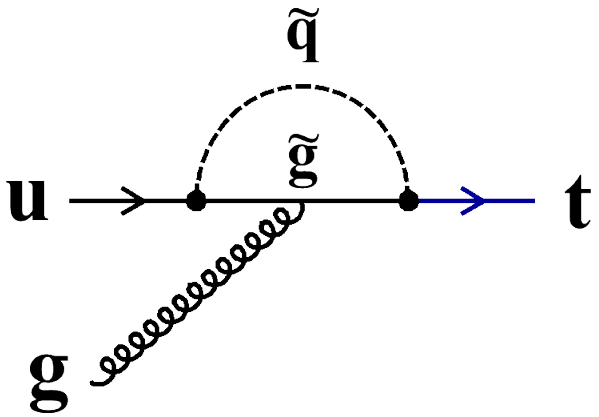
FCNC in Search in g + u(c) → t

FCNC: Flavor-Changing Neutral Currents

- significant in extensions of SM (e.g. SUSY)
- any evidence reveals new physics







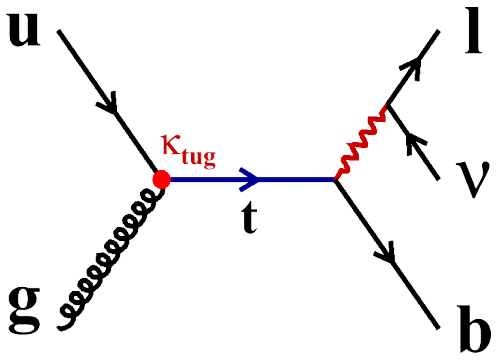
GIM mechanism
BR → 10^{-13}
Very effective in the top sector!

Process	SM	SUSY	2HDM
t → u + g	$3.7 \cdot 10^{-14}$	$8 \cdot 10^{-5}$	10^{-4}
t → c + g	$4.6 \cdot 10^{-12}$	$8 \cdot 10^{-5}$	10^{-4}

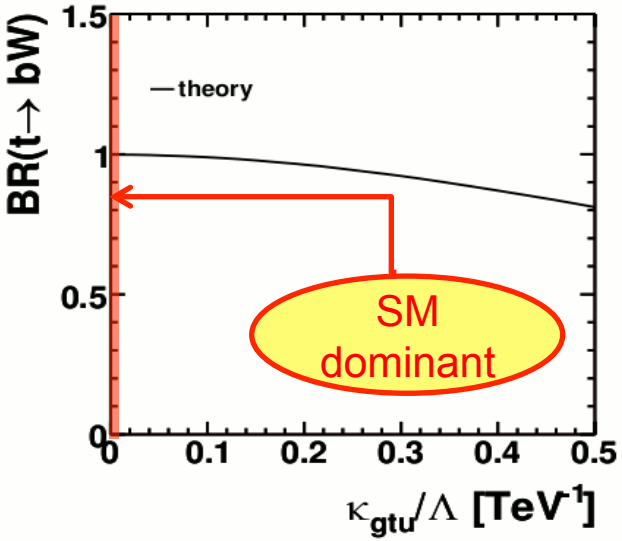
hep-ph/0409342

At a hadron collider more effective to look for FCNC production than decay.

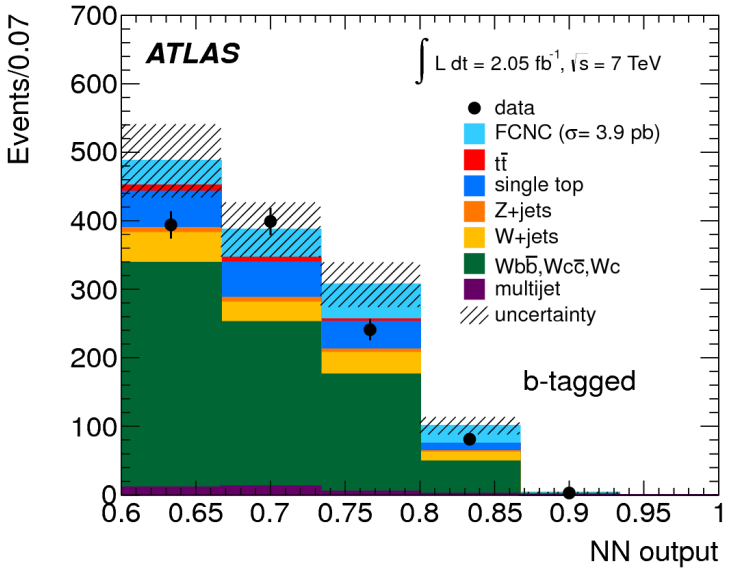
Results on top-quark FCNC limits



FCNC decays can be neglected since very large couplings are already excluded.



Neural network based analysis:

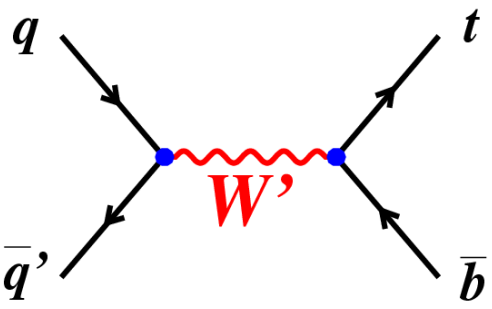


FCNC process normalized to excluded limit.

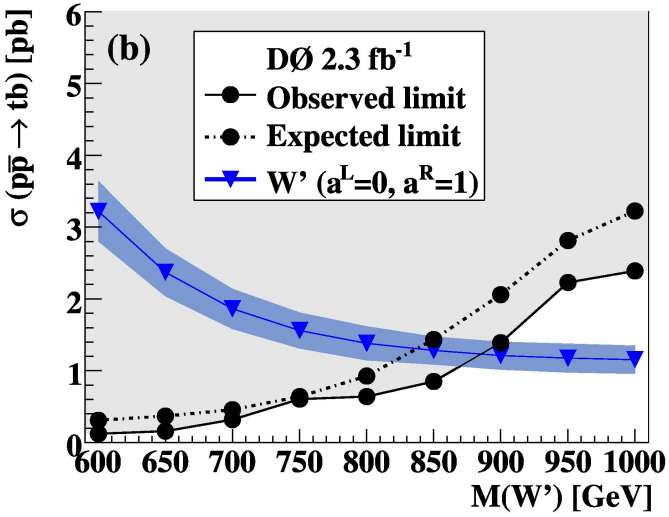
- Uses 2.05 fb-1 of lepton+jets data set.
- 1 b-tagged central jet ($|\eta| < 2.5$).
- arXiv:1203.0529
- Observed limit:
  $\sigma_{qg\to t} \cdot BR(t \to Wb) < 3.9$ pb @ 95% C.L.
- Interpreted using theoretical prediction {Phys. Rev. Lett. 107 (2011) 092002}:

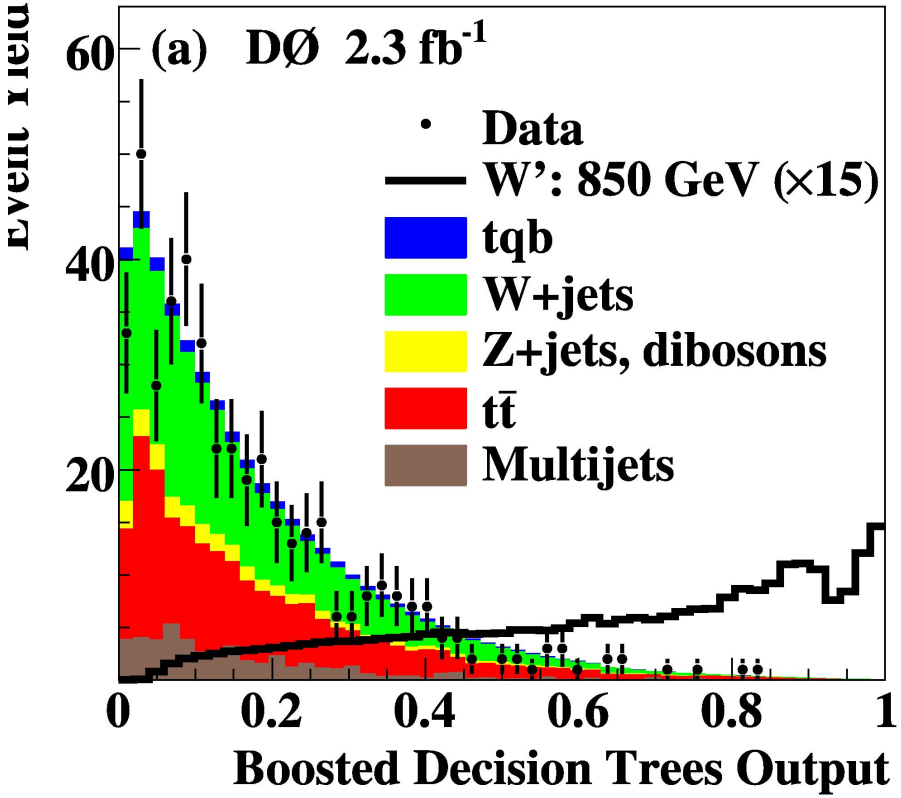
$BR(t \to ug) < 5.7 \cdot 10^{-5}$
$BR(t \to cg) < 2.7 \cdot 10^{-4}$

Search for W′ → tb Events



- Investigate different left- and right-handed couplings to fermions.
- Limits vary based on assumptions of couplings:
  m(W′) > 863 .. 916 GeV





Phys. Lett. B 699 (2011) 145 – 150

Anomalous W-t-b Couplings

general form of the W-t-b coupling: form factor approach

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(L_V P_L + R_V P_R)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(L_T P_L + R_T P_R)tW_{\mu}^{-} + h.c.$$

with $P_L = (1-\gamma_5)/2 \qquad P_R = (1+\gamma_5)/2$

$$L_V = V_{tb}\cdot f_{L_V} \quad R_V = V_{tb}\cdot f_{R_V} \quad L_T = V_{tb}\cdot f_{L_T} \quad R_T = V_{tb}\cdot f_{R_T}$$

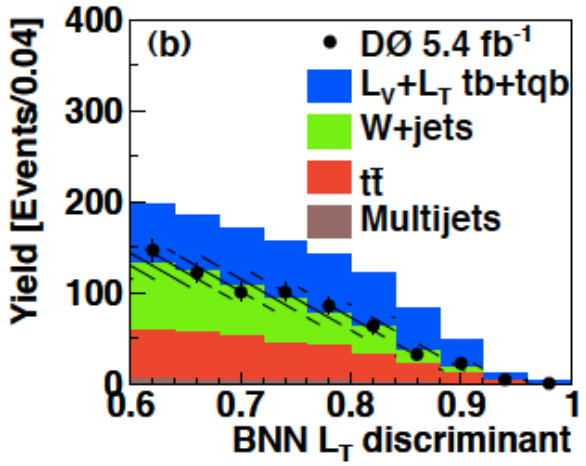
study 3 scenarios:

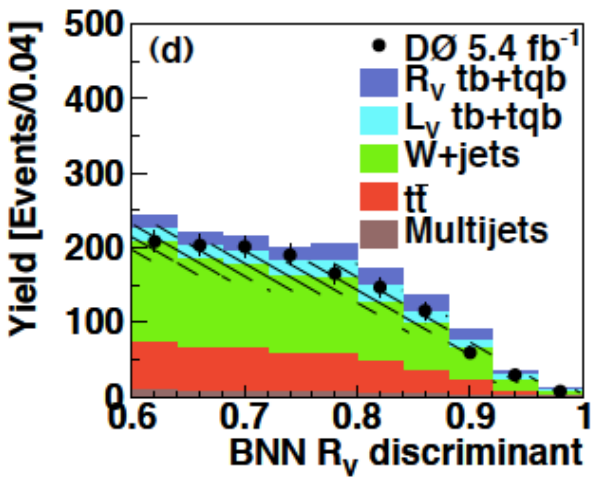
a) $f_{Lv} \neq 0$ and $f_{Rv} \neq 0$
b) $f_{Lv} \neq 0$ and $f_{LT} \neq 0$
c) $f_{Lv} \neq 0$ and $f_{RT} \neq 0$

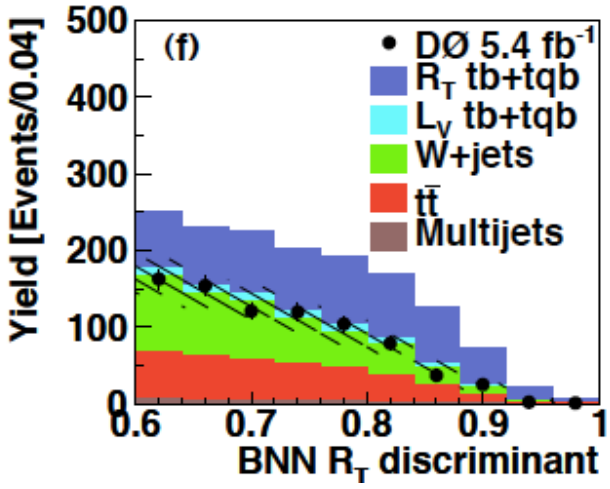
➔ modified rates of single top quarks
➔ modified angular distributions

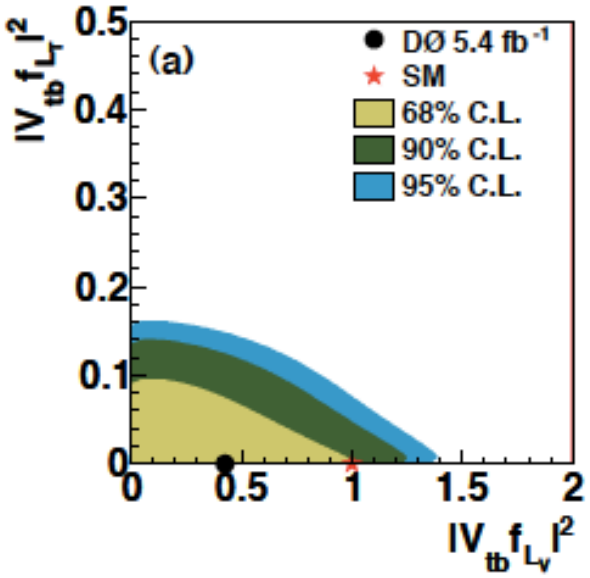
- train networks against different scenarios
- treat anomalous production as signal

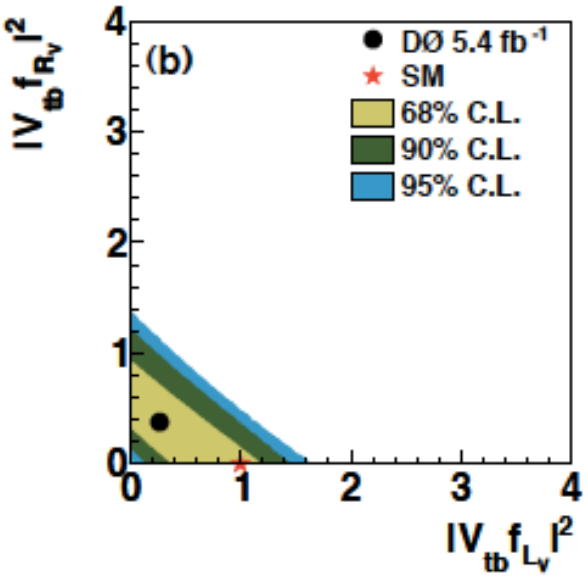
Limits on Anomalous Couplings

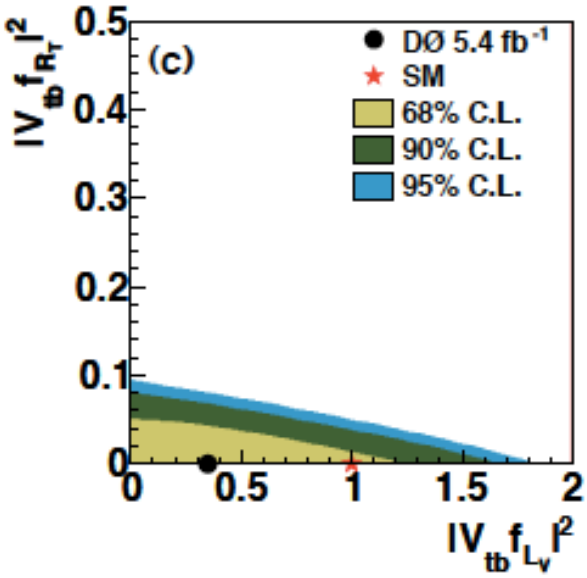












one-dimenional limits assuming: $|V_{tb} \cdot f_{L_V}| = 1$

$|V_{tb} \cdot f_{L_T}|^2 < 0.11$

$|V_{tb} \cdot f_{R_V}|^2 < 0.50$

$|V_{tb} \cdot f_{R_T}|^2 < 0.05$

Summary

Single Top Physics made its way from infancy to childhood.

= experiments went beyond (simple) discovery

- Measurement of the individual channels is under way.
  - t-channel at Tevatron and LHC
  - Wt under way. May be 5σ this year.
  - s-channel is tough.
- $|V_{tb}|$ measured at level of 8%(exp) + 2%(theo). Agrees with SM.
  - DØ derived Γ_t an τ_t.
- Probing physics beyond the SM
  - Limits on FCNC improved by factor 5 $t \rightarrow u(c) + g$ decays at level of 10^{-5} (10^{-4}) ➔ start to touch regime sensitive to BSM
  - W' searches: m(W´) > 900 GeV
  - Limits on non V-A W-t-b vertex structure