Searches for New Physics in Top Decays at D0

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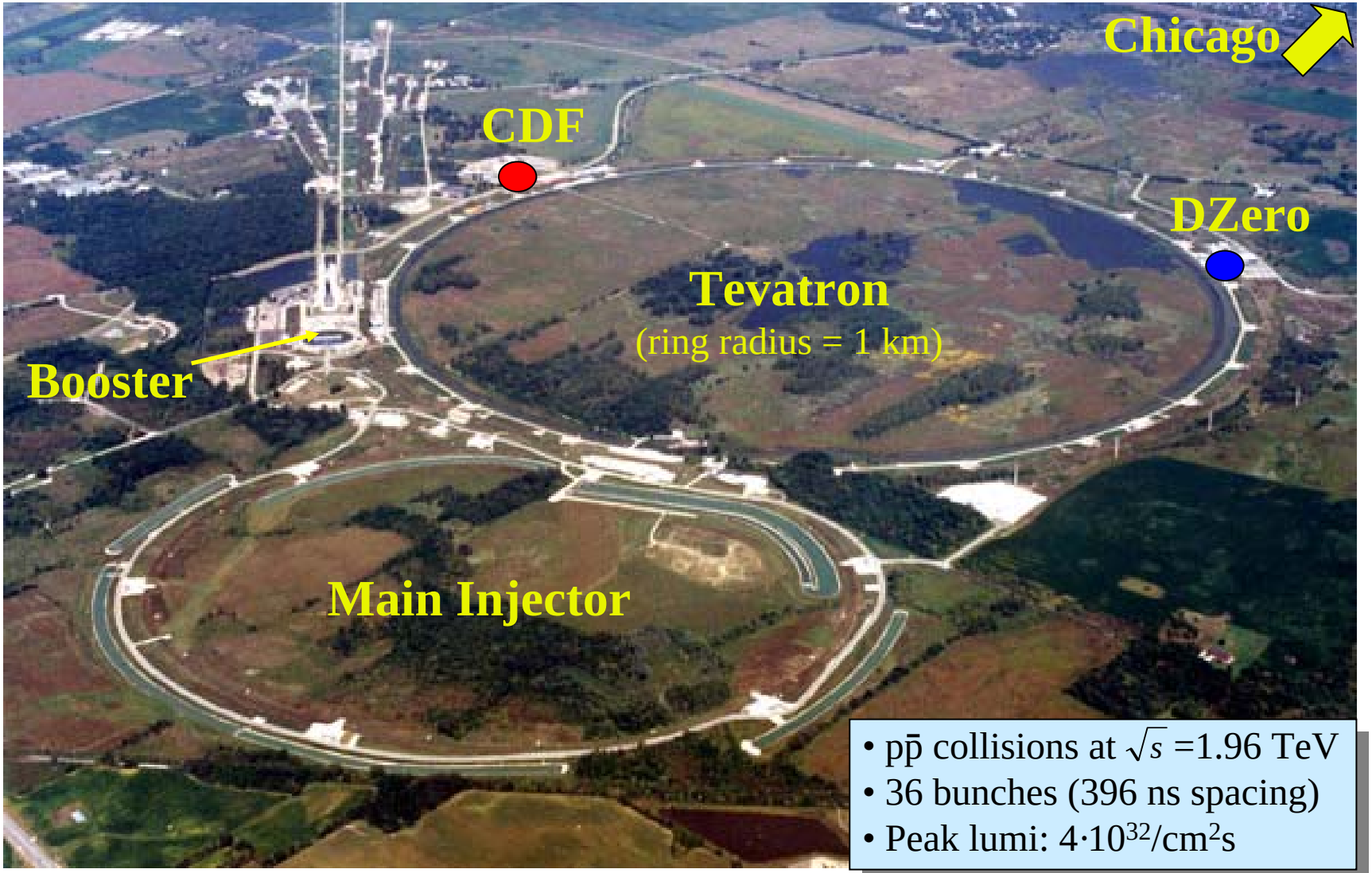
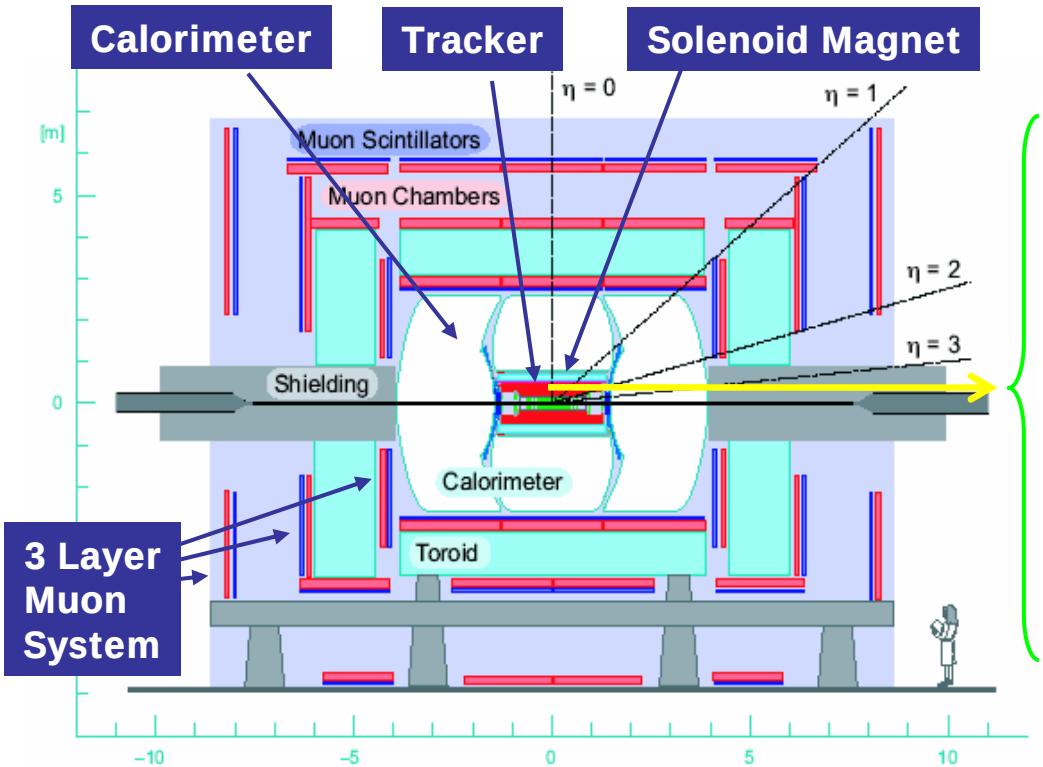
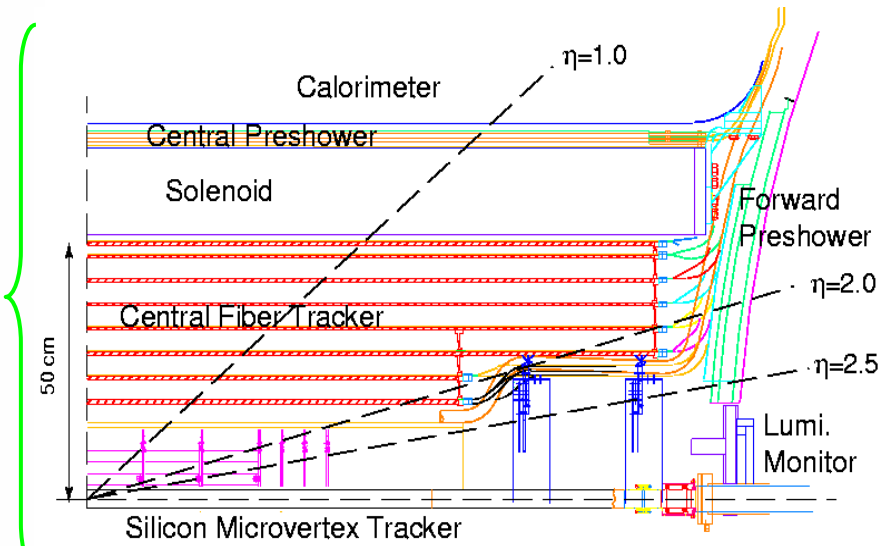
The Tevatron @ Fermilab



- $p\bar{p}$ collisions at $\sqrt{s}$ =1.96 TeV
- 36 bunches (396 ns spacing)
- Peak lumi: $4 \cdot 10^{32}/cm^2s$

The DZero Detector





- Excellent calorimetry

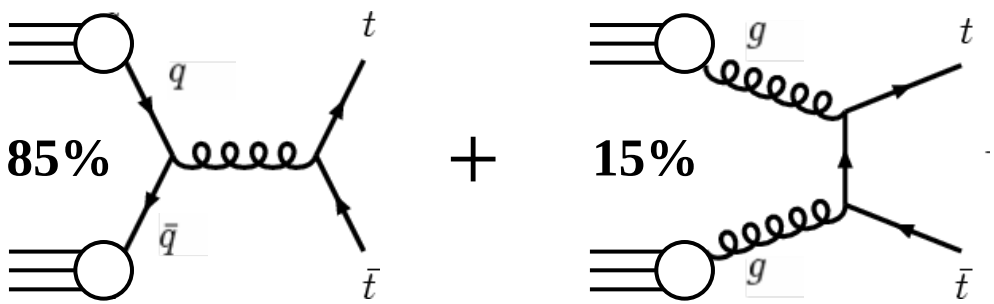
$$\frac{\sigma_E}{E} = \frac{15\%}{\sqrt{E}} \oplus 0.3\%\,(\text{elm}), \quad \frac{\sigma_E}{E} = \frac{45\%}{\sqrt{E}} \oplus 4\%\,(\text{had})$$

- Large muon acceptance

- Central tracking inside 2 T solenoid
  - –Silicon vertex detector (=>b-jet ID)
  - –Scintillating fiber tracker

Top Quark Production & Decay

- Main **production** of Top Quarks – via strong interaction in *pairs*:

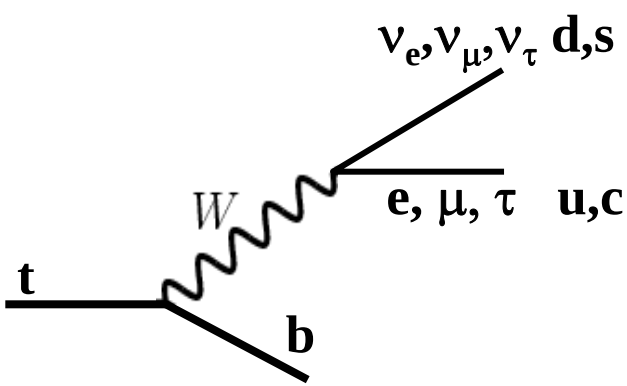


Theoretical expectation:

$$\sigma_{t\bar{t}} = (7.5^{+0.6}_{-0.7})\ \text{pb}$$

PRD 80, 054009, m_t=172.5 GeV

- SM Top **decay** ≈100% Wb ⇒ Final states determined by W decay mode
  - ⇒ 2 b-jets
  - ⇒ Up to two charged leptons/neutrinos
  - ⇒ Up to four additional jets



Need to reconstruct/identify:

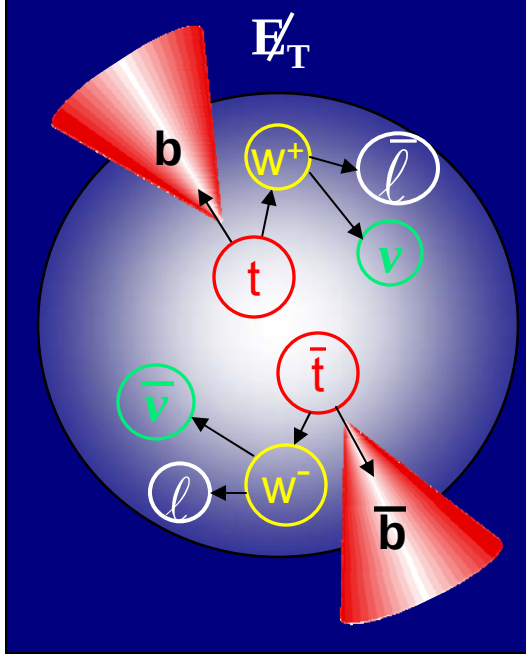
- **Electrons, muons, taus**
- **Missing transverse energy**
- **Jets/b-jets**

Classification of Top Quark pair events

Dilepton: 10%

Two high-p_T jets

Two high-p_T leptons

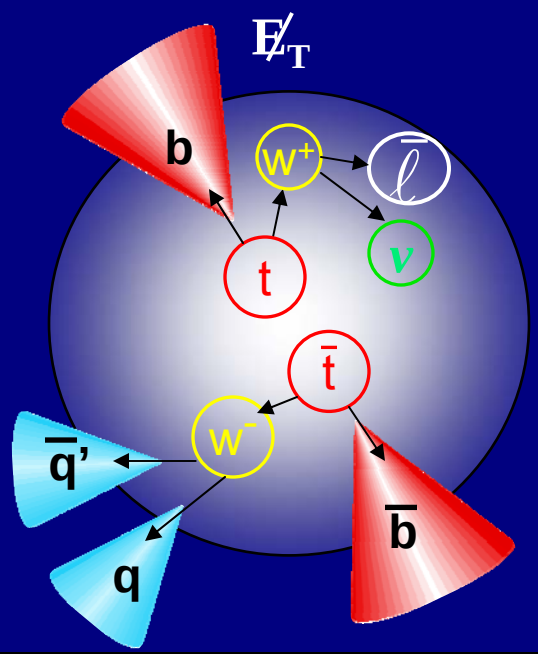


- low branching fraction
- low background
  (WW+jets, Z+jets, W+jets)

Lepton + Jets: 44%

Four high-p_T jets

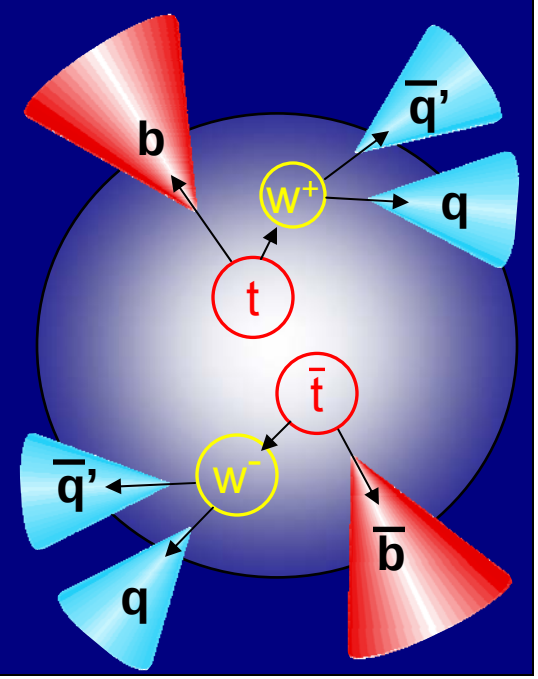
One high-p_T lepton



- high branching fraction
- manageable background
  (W+jets, "QCD" multijet prod.)

All Hadronic: 46%

Six high-p_T jets

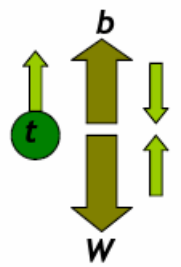


- high branching fraction
- high background
  ("QCD" multijet production)

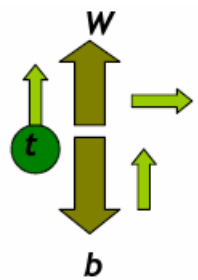
W Helicity in top decay

Standard Model top decay: V-A interaction (like for all fermions)

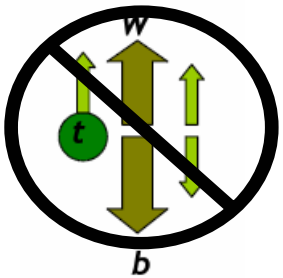
W helicity states:



left-handed fraction: f_-



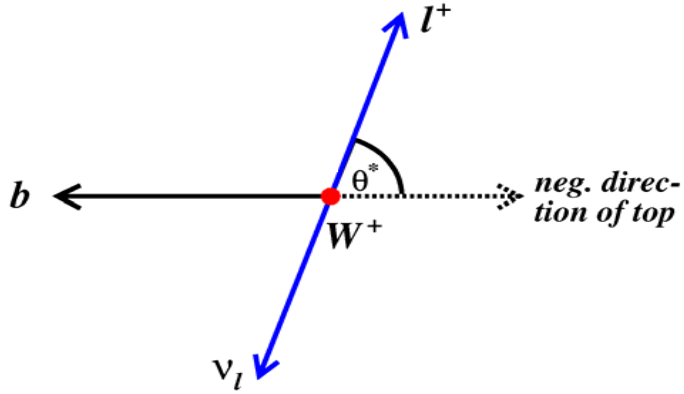
longitudinal fraction: f_0

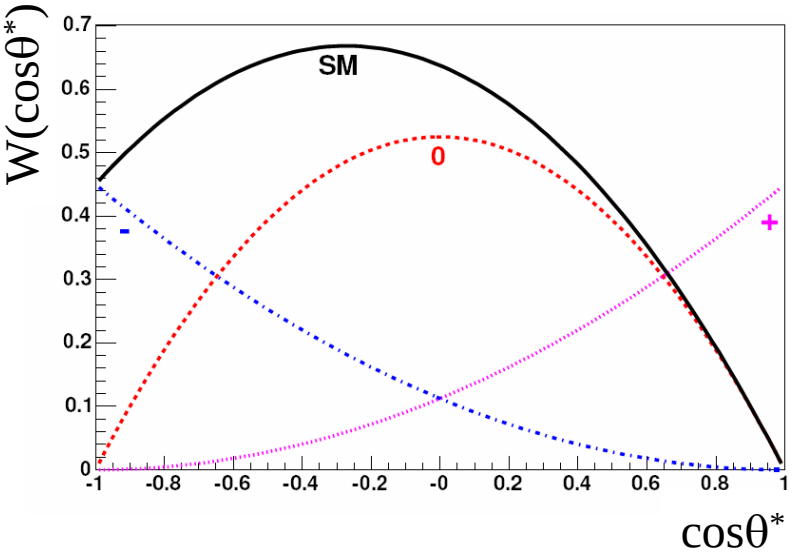


right-handed fraction: f_+

In Standard Model: **~30%** **~70%** **~0.036%**

⇒ Measure angular distribution of charged lepton wrt. top in W rest frame: cosθ*

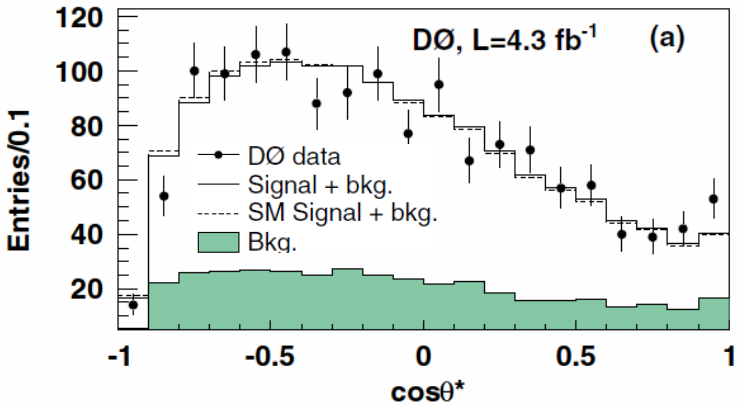


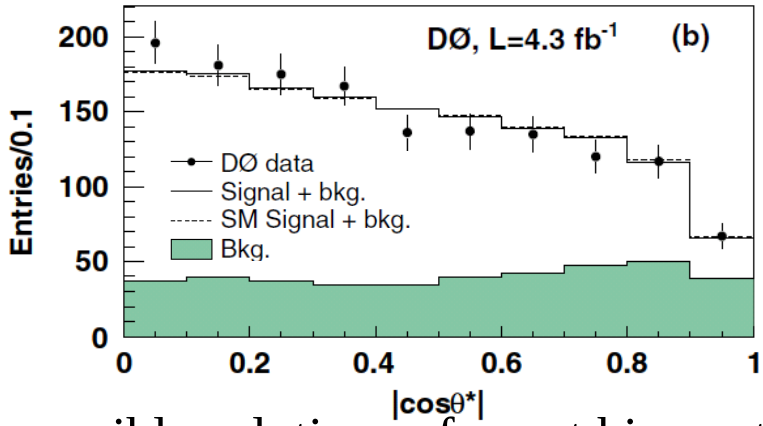


W Helicity in top decay

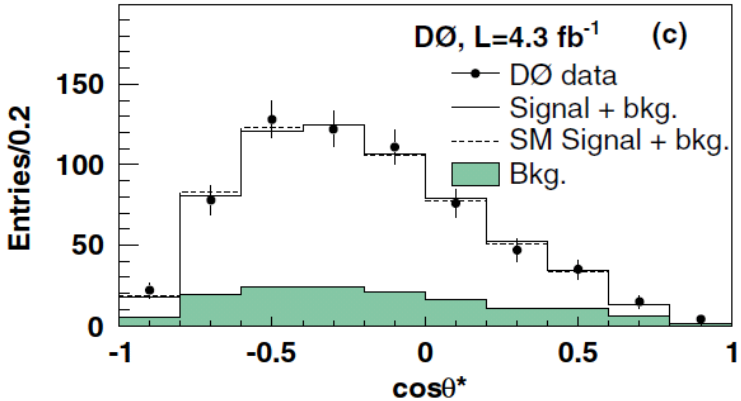
Preselection: use optimised multivariate LH built from event topology/kinematics

l+jets events: calculate cosθ* through full event reconstruction w/ kinematic fit; use hadronic W decay as well: |cosθ*|, helps distinguish $f_{\pm}$ and f_0.



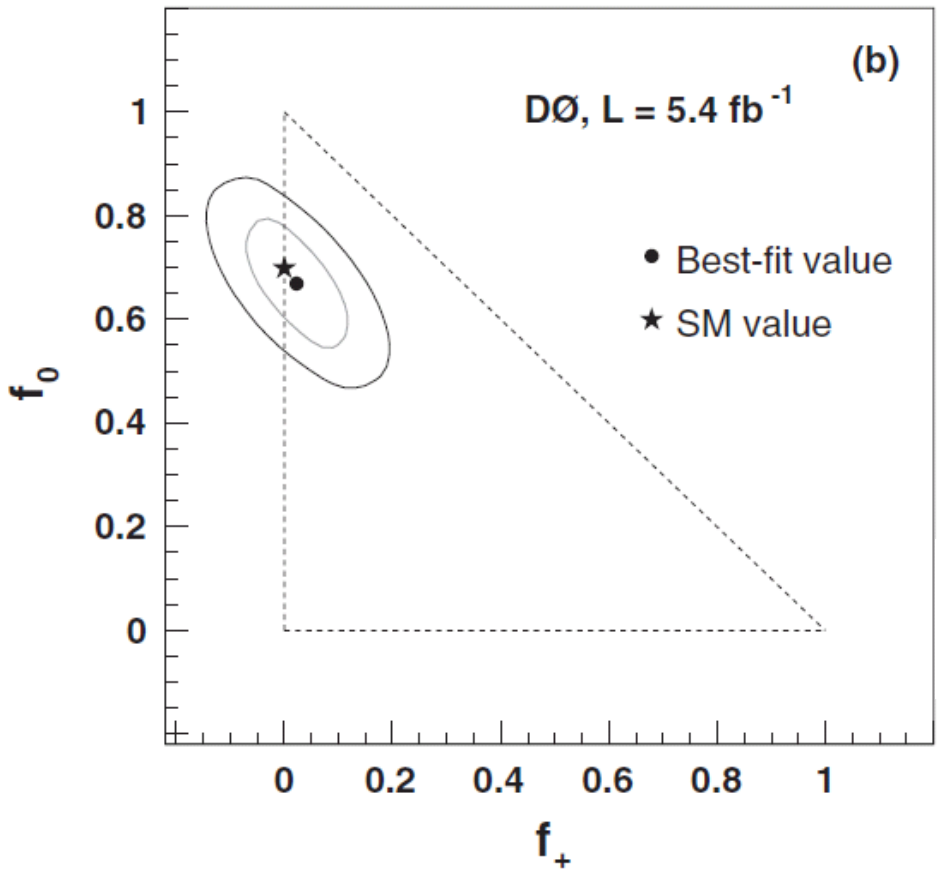


dilepton events: assume m_t, average over all possible solutions of event kinematics & varying lepton/jet energies w/in uncertainties. 2 entries/event!



W Helicity in top decay

Model-independent result: Fit f_0, f_+ simultaneously.



PRD 83, 032009 (2011)

$$f_0 = 0.669 \pm 0.078(\text{stat.}) \pm 0.065(\text{syst.}),$$
$$f_+ = 0.023 \pm 0.041(\text{stat.}) \pm 0.034(\text{syst.}).$$

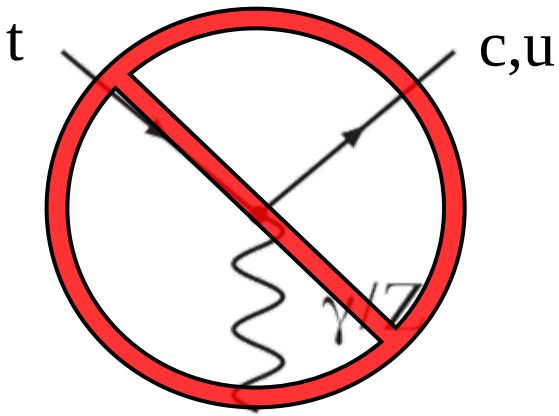
→ Consistent with SM expectation.

FCNC in top decay?

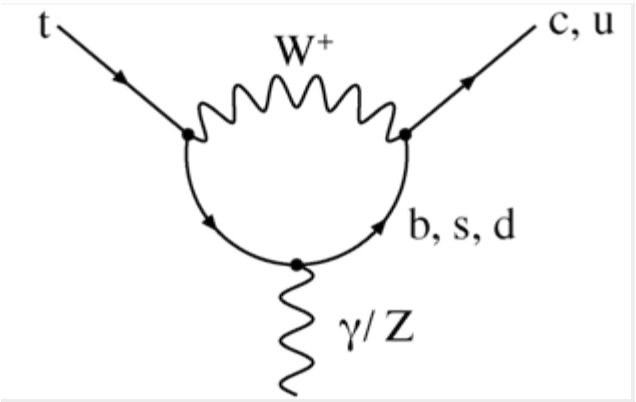
(Flavour Changing Neutral Currents)

No FCNCs in SM at tree level – allowed in higher order penguins:

Tree level FCNC



Penguin



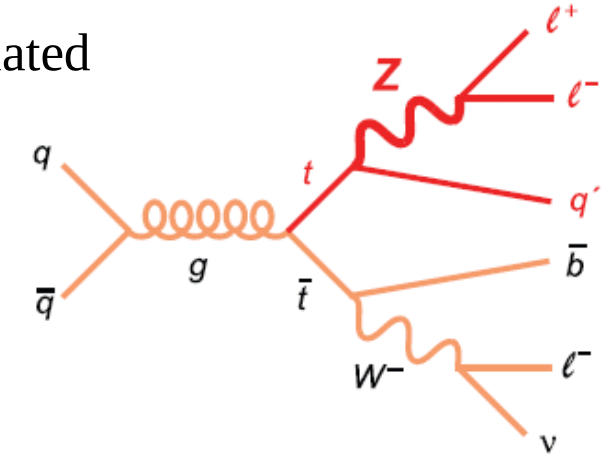
- SM branching fraction $t \to Zq$ (q=u,c): ~10^{-14} (best limit so far: 3.7%)
- New Physics models (SUSY, composite q's): predict up to 10^{-4}
- Analysis assumes either $t \to Wb$ or $t \to Zq$, the latter by adding:

$$\mathcal{L}_{\mathrm{FCNC}} = \frac{e}{2\sin\theta_W \cos\theta_W}\, \bar{t}\,\gamma_\mu (v_{tqZ} - a_{tqZ}\gamma_5)\, q\, Z^\mu \; + h.c.,$$

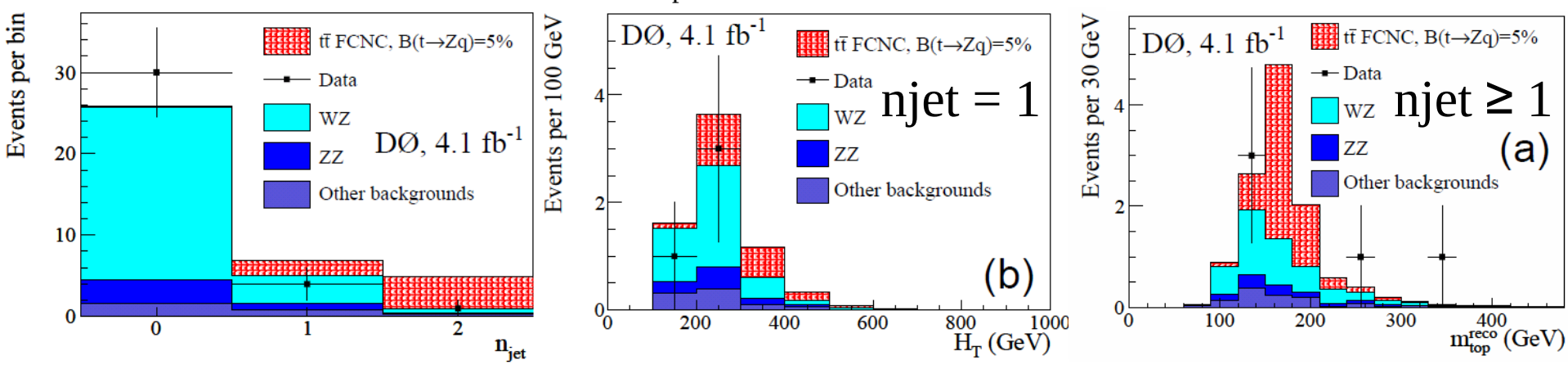
FCNC in top decay

Preselection: use trilepton final state: ℓ p_T>15 GeV, isolated
MET > 20 GeV,
jets (p_T > 20 GeV, |η|<2.5).

n_{jet}	0	1	≥ 2
Background	$25.66 \pm 0.28 \pm 3.26$	$5.06 \pm 0.14 \pm 0.56$	$0.92 \pm 0.08 \pm 0.09$
$t\bar{t} \to WbZq$	0.20 ± 0.03	1.80 ± 0.27	3.87 ± 0.56
$t\bar{t} \to ZqZq$	0.002 ± 0.001	0.020 ± 0.003	0.050 ± 0.007
Observed	30	4	1



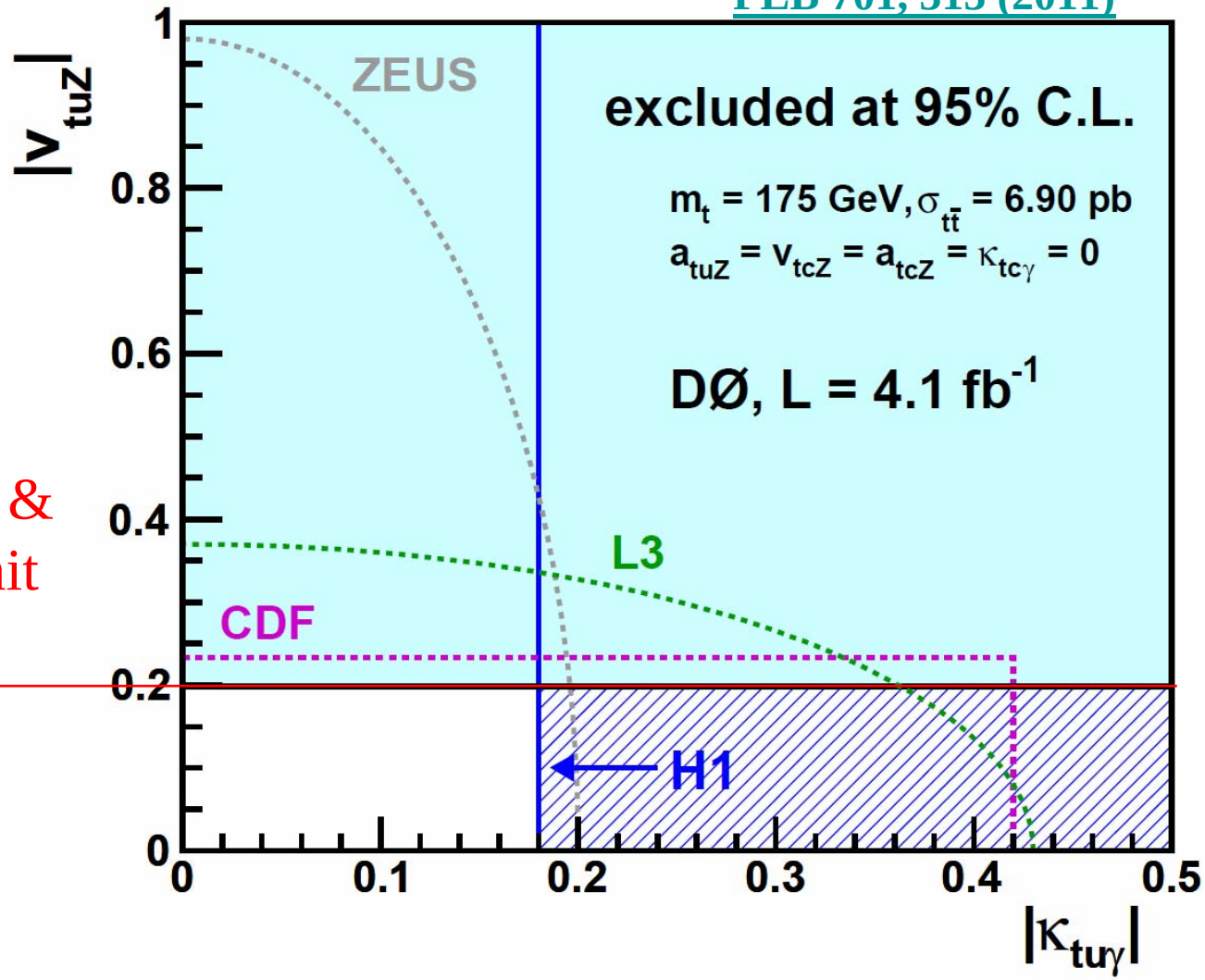
Signal/Background separation: use njets, H_T (scalar sum of ℓ p_T, jet p_T, MET),
m_{top} = M(Z,jet)



No evidence for FCNC signal ⇒ B(t→Zq) < 3.2% @ 95% C.L. (expected: 3.8%)

FCNC in top decay

PLB 701, 313 (2011)



Assume $a_{tqZ} = 0$ & convert into limit $v_{tqZ} < 0.19$

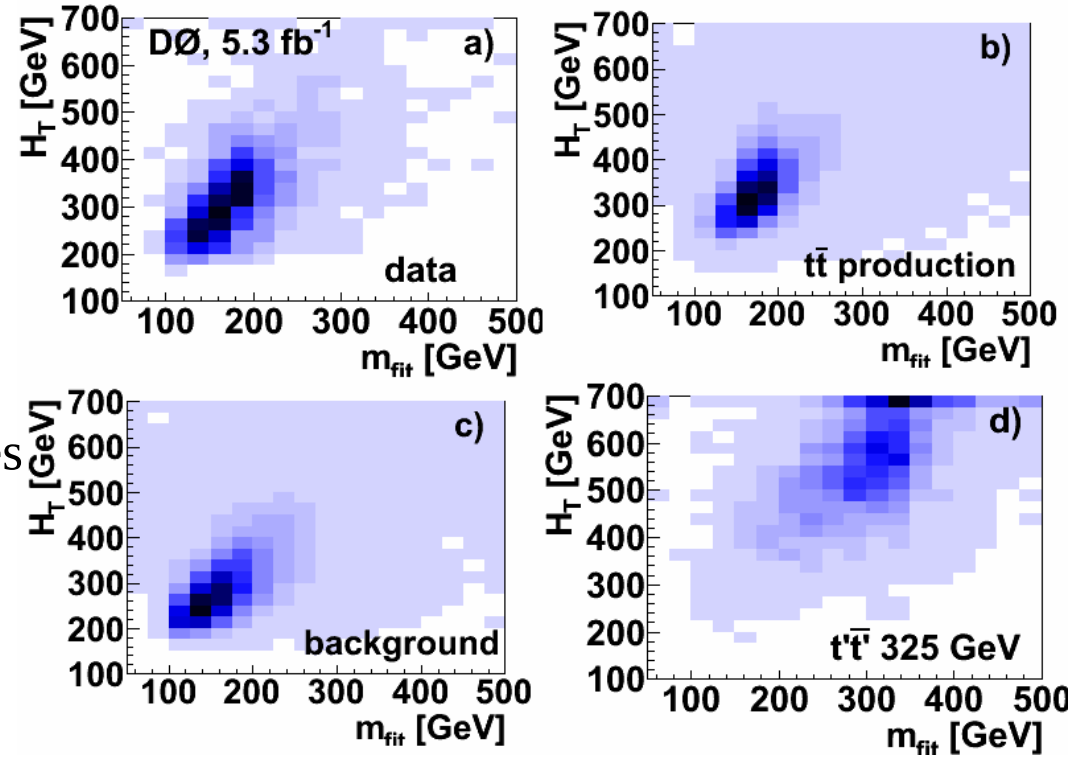
Search for t' pair production

- 4th fermion generation with $m_\nu > m_Z/2$ is not ruled out
- EW precision data favor small mass splitting ($m_{t'} - m_{b'} < m_W$) $\Rightarrow$ t'$\rightarrow$Wq decays
- Assume 10 GeV width of t' (< detector resolution)
- Search for t' pair production, similar final state to SM top pair prod, l+jets final state (no b-jet identification)

Signal/Background separation:

H_T (scalar sum of ℓ p_T, jet p_T, MET), m_{fit} from kinematic fit

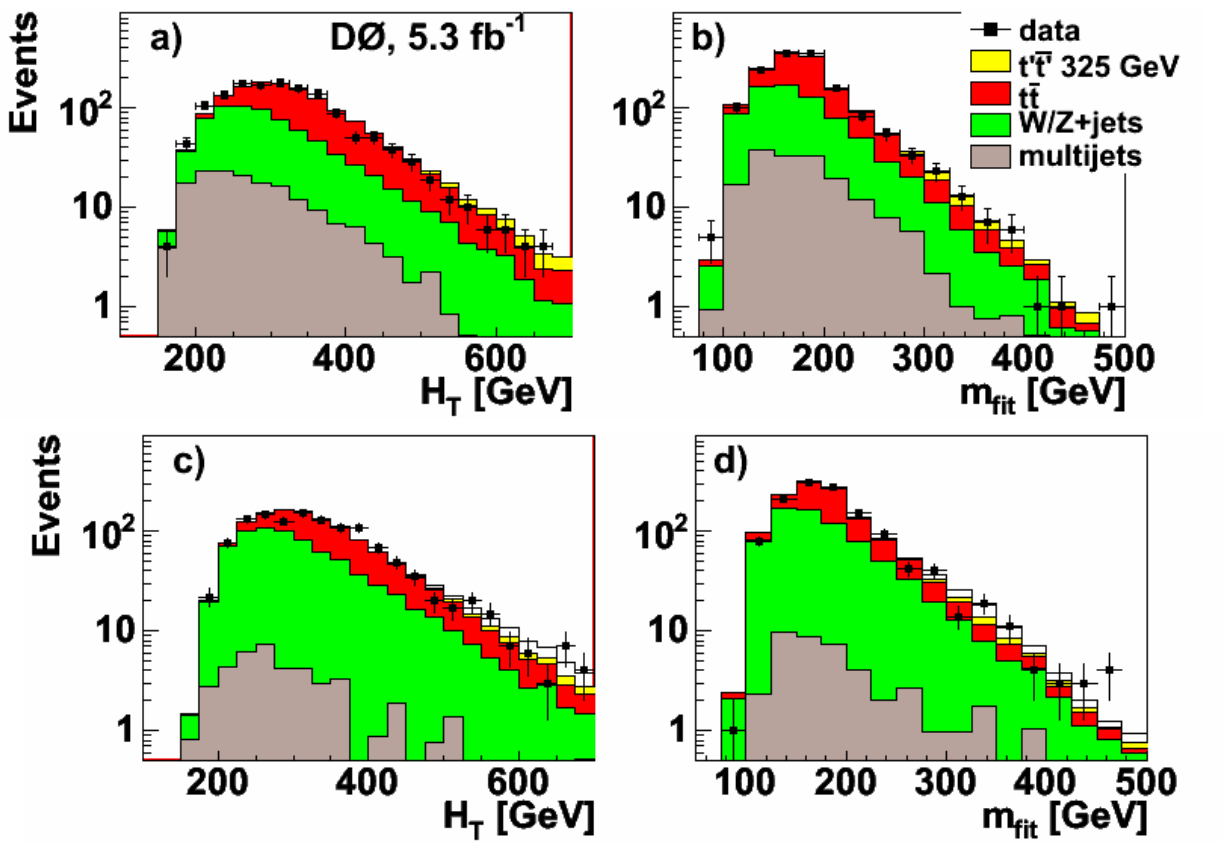
Fit data to SM and SM+t' hypotheses for $m_{t'} \in [200,500]$ GeV, set limits



Observed distributions for t' search

e+jets:

μ+jets:

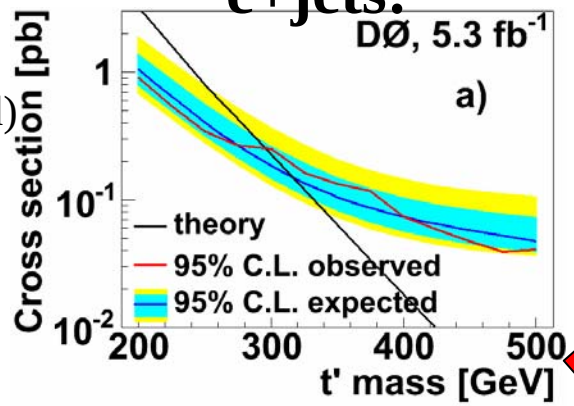


Excess in μ+jets channel corresponds to 3.2 ±1.1 325-GeV-t'-pair production xsec
Local deviation from SM: 2.5 σ significance.

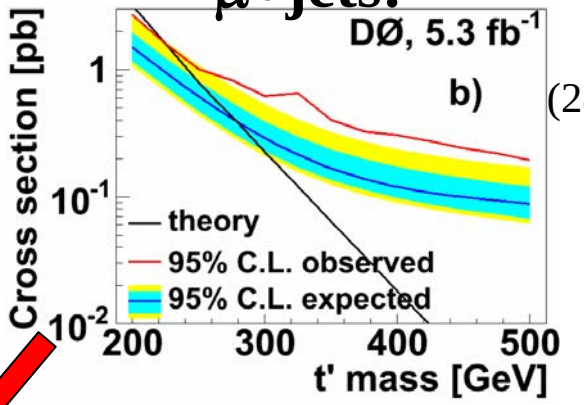
Search for t' pair production

e+jets:

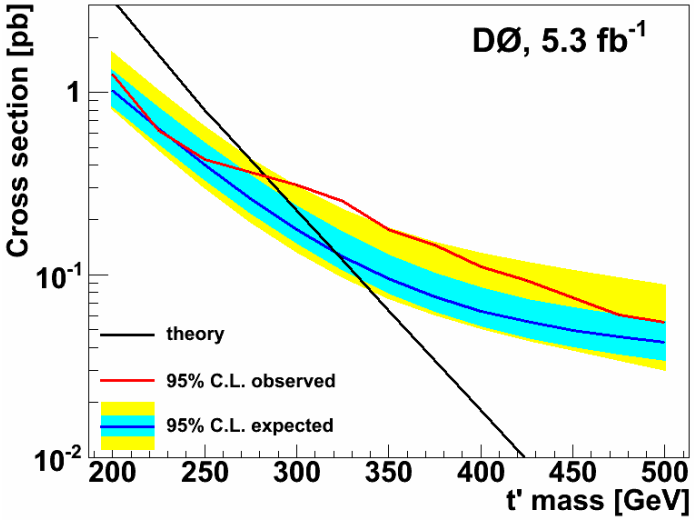
$m_{t'} < 295$ GeV
(315 GeV expected)



μ+jets:



$m_{t'} < 225$ GeV
(280 GeV expected)



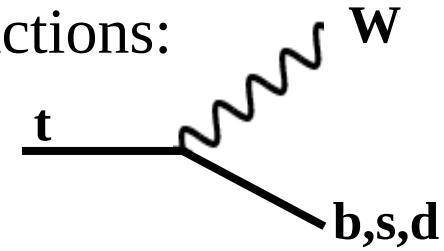
Accepted in PRL

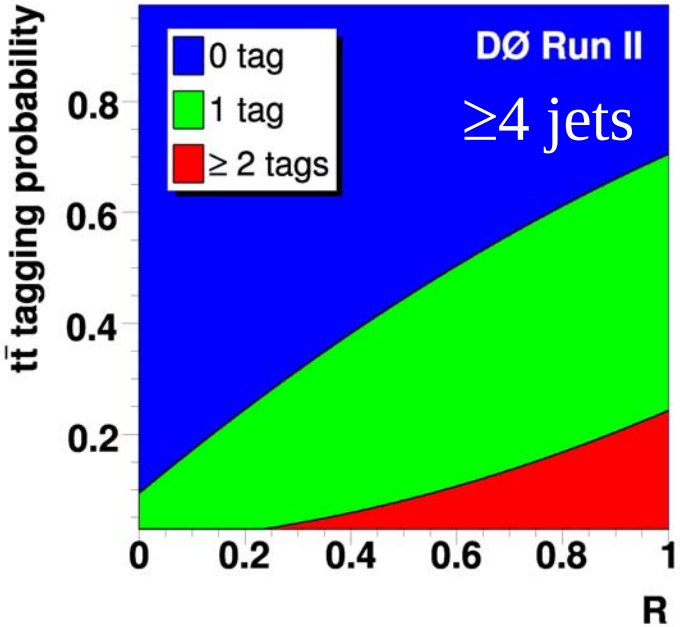
Observed xsec limit ⇒ $m_{t'} < 285$ GeV @ 95% C.L. (320 GeV expected)

Simultaneous measurement of σ_{ttbar} and R

SM: top decay rate $\propto |V_{tq}|^2$ – study ratio of branching fractions:

$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$





- Measure σ_{ttbar} and R simultaneously via tagging prob.
- No assumption of $B(t \to Wb) = 1$
- Higher precision on R,σ: different sensitivity to syst.
- Simultaneous fit of l+jets and dilepton final states

$$R = 0.90 \pm 0.04 \text{ (stat+syst)}$$ (2.5σ from SM)

$$\sigma_{t\bar{t}} = 7.74^{+0.67}_{-0.57} \text{ (stat+syst) pb.}$$

5.4 fb^{-1} dataset, for m_t=172.5 GeV

Submitted to PRL

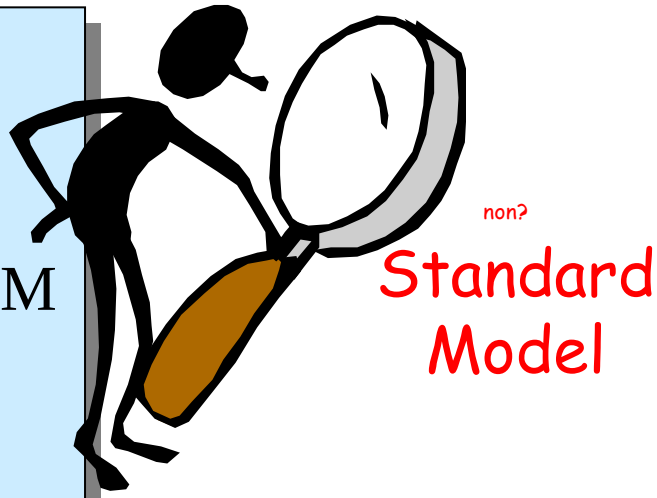
$0.82 < R < 0.98$ @ 95% C.L.

$0.90 < |V_{tb}| < 0.99$ @ 95% C.L.

(3x3 unitary CKM matrix)

Summary

- W-Helicity consistent with SM expectation
- No evidence for FCNC in top decays
- No evidence for t' production
- Branching fractions t→Wq consistent with SM
- Will keep updating analyses (x2 more data), esp. where "tension" wrt. SM is observed.



More measurements / information available online:

http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html