Direct Measurements of V_{tb}
and a little bit on V_{ts} and V_{td}

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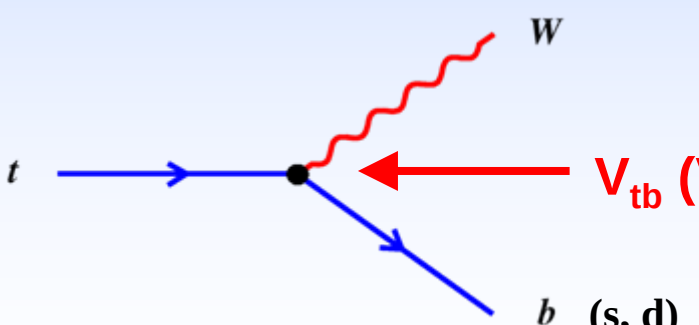
CKM-Workshop, Warwick, 10.09.2010

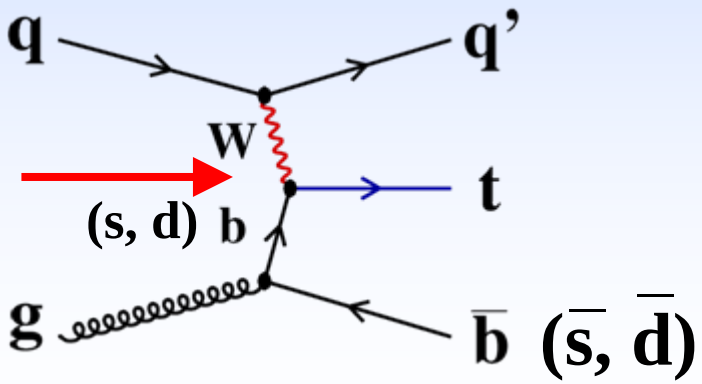
Measurements involve on-shell top quarks produced at a hadron collider.

Top-Quark Decay



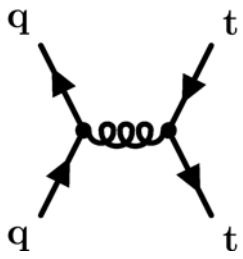
V_{tb} (V_{ts}, V_{td})

Single-Top Production



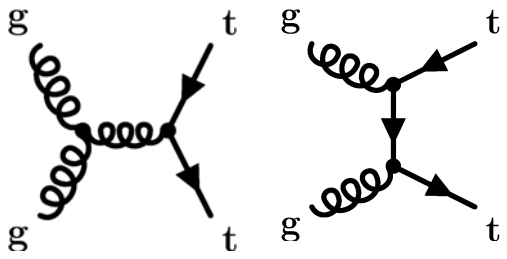
1) Top-Antitop-Quark Production

quark-antiquark annihilation



~85%
~10%

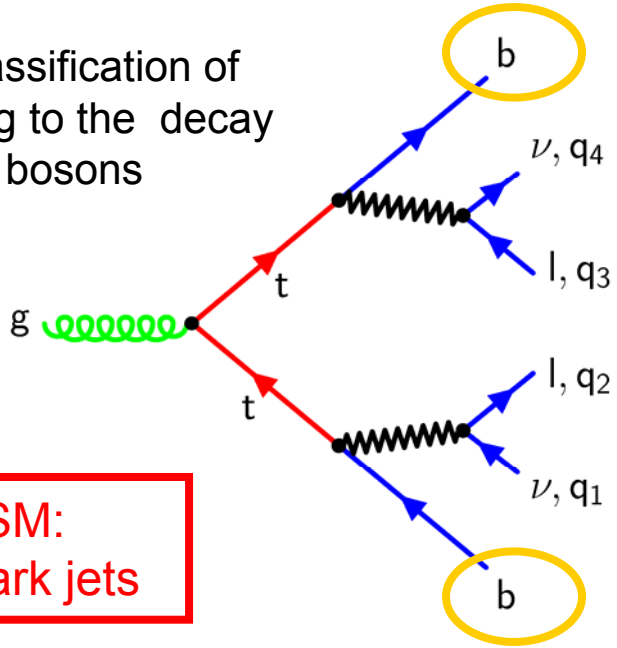
gluon-gluon fusion



Tevatron
LHC

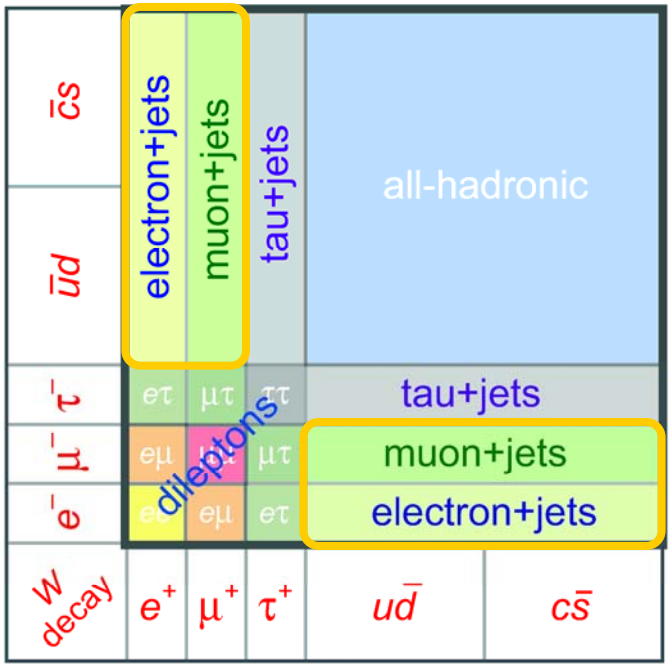
~15%
~90%

experimental classification of events according to the decay modes of the W bosons



in the SM:
2 b-quark jets

Top Pair Decay Channels

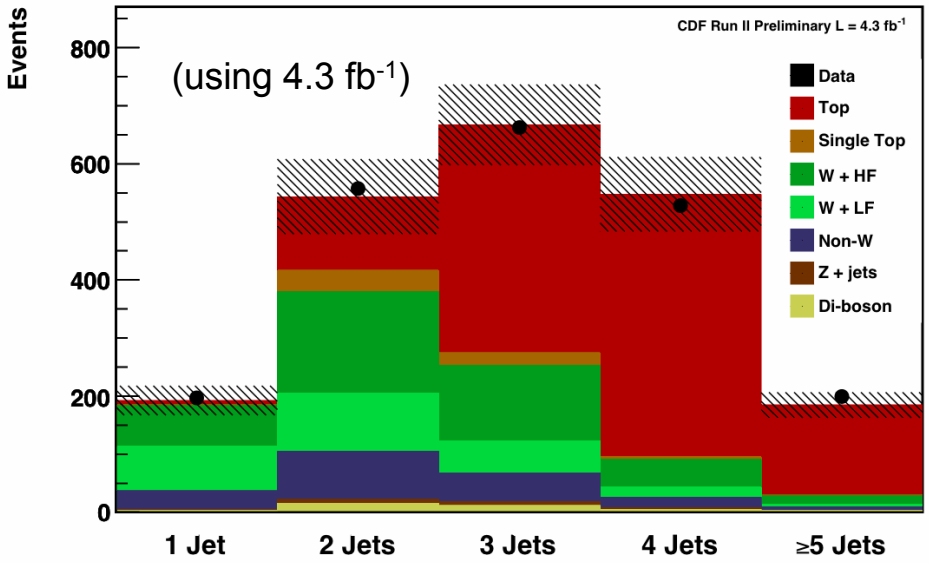


lepton (e, μ) + jets channel = "golden channel"

+ large branching fraction (30%)
+ manageable backgrounds
+ allows full event reconstruction

Cross Section Using b-Tag

e.g. counting experiment with secondary vertex reconstruction, includes cut on $H_T > 230$ GeV



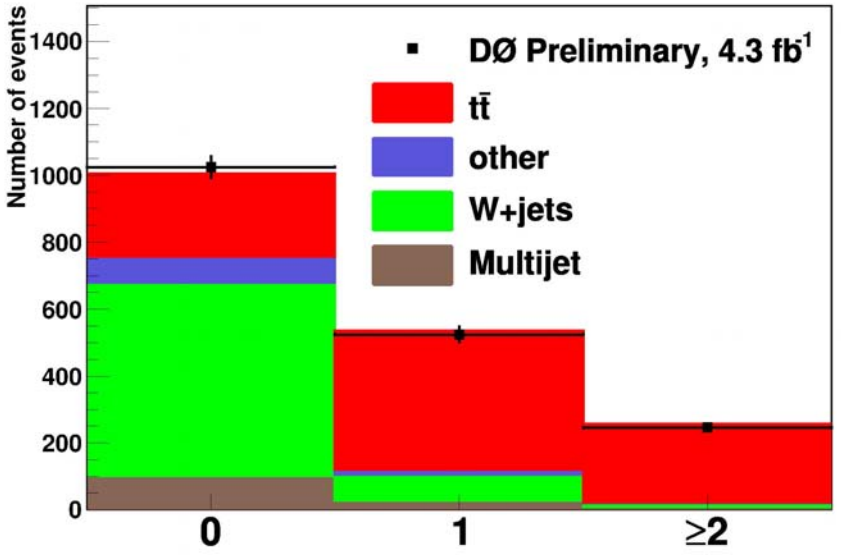
inclusive measurement
using excess in W + ≥ 3 jets

$$\sigma(t\bar{t}) = 7.32 \pm 0.36_{\text{stat}} \pm 0.59_{\text{syst}} \pm 0.14_{\text{Ztheo}}\ \text{pb}$$

Phys. Rev. Lett. 105 (2010) 012001

luminosity uncertainty (5.8%) reduced by simultaneously measuring the Z cross section

using neural network b-tagging algorithm



number of b-tagged jets per event

$$\sigma(t\bar{t}) = 7.93^{+1.04}_{-0.91}\,(\text{stat} + \text{syst} + \text{lumi})\ \text{pb}$$

for $m_t = 172.5$ GeV/c²

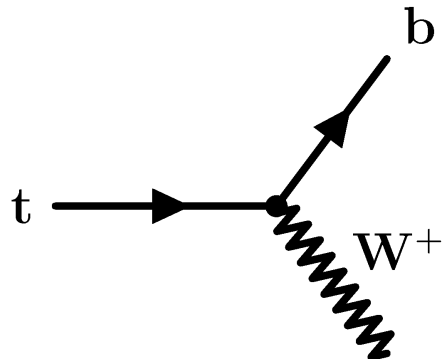
DØ note 6037-CONF (2010)
method: Phys. Rev. Lett. 100 (2008) 192003

Top-Quark Branching Ratio

decay via weak interaction to a real W boson ($\rightarrow$ special)

standard model prediction:

$$\mathrm{BR}(t \rightarrow W^+ + b) \simeq 100\%$$



decays $t \rightarrow d + W^+$ and $t \rightarrow s + W^+$ strongly CKM suppressed
$0.0048 < |V_{td}| < 0.014$ and $0.037 < |V_{ts}| < 0.043$ (using CKM unitarity)

Identifying b-quark jets (b-tagging) we separate experimentally the Wb final state from W.

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

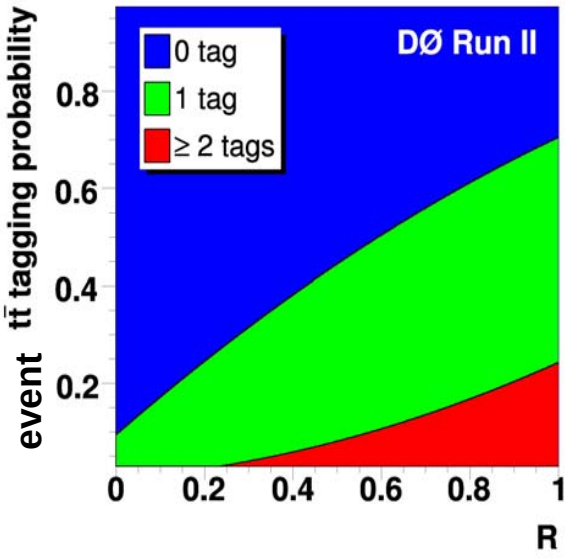
Adressed questions:

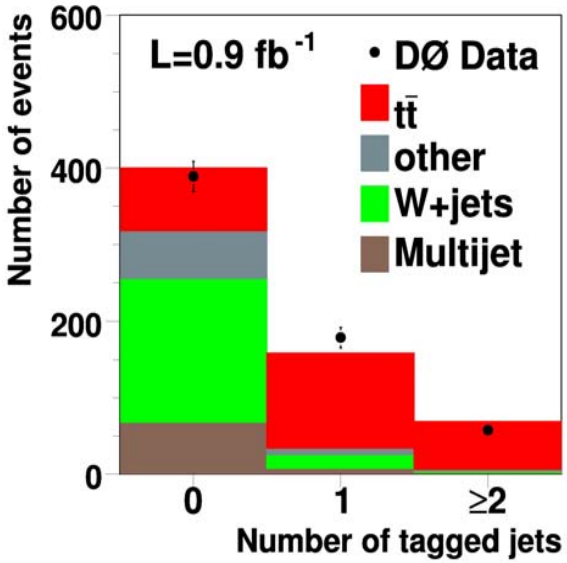
- Is $|V_{tb}| >> |V_{ts}|, |V_{td}|$ as predicted?
- Is there room for an additional (fourth generation) $t \rightarrow W + q_x$ decay ?

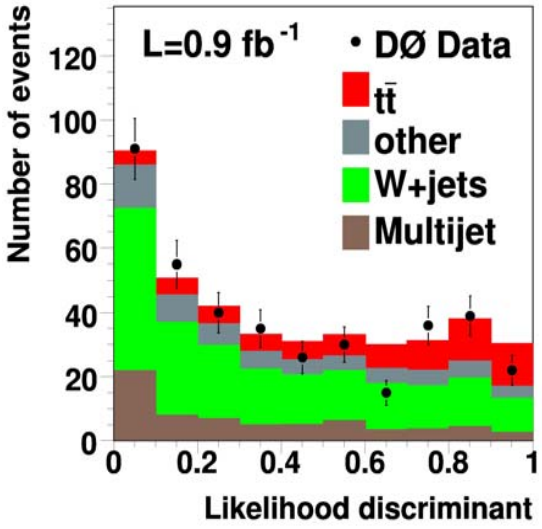
Branching Ratio R_b

simultaneous measurement of R and σ (ttbar)

→ split data set in disjoint subsets: N (jets) × lepton type × N (b tags)







discriminant between signal and backghround in the 0 tag sample

Phys. Rev. Lett. 100 (2008) 192003

Unfortunately, only available with L_{int} = 0.9 fb-1.

$R_b = 0.97^{+0.09}_{-0.08}$ (stat.+sys.)

R > 0.79 @ 95% C.L.

$$\Rightarrow |V_{ts}|^2 + |V_{td}|^2 < 0.263 \cdot |V_{tb}|^2$$

Projections on R_b

Tevatron

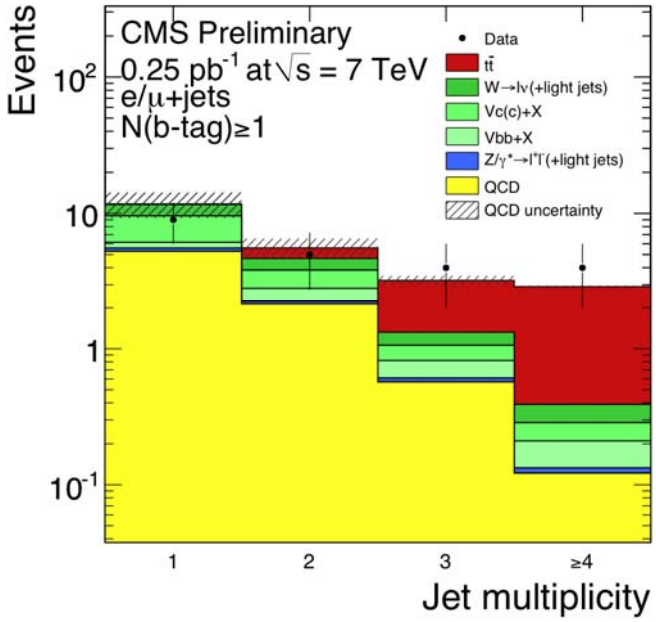
Two important uncertainties:

statistical	+ 0.067	-0.065
b-tagging efficiency	+0.059	-0.047
total @ 0.9 fb^{-1}	+0.092	-0.083

- by updating from 0.9 fb^{-1} to 8 fb^{-1} (available now) reach: +0.067 / -0.056 (syst. already dominant; no improvements on syst. uncertainty assumed)
- by updating to 16 fb^{-1} (run until 2014) reach:+0.065 / -0.054
  $\Rightarrow$ possible reach $|V_{ts}|^2 + |V_{td}|^2 < 0.19 \cdot |V_{tb}|^2$

LHC

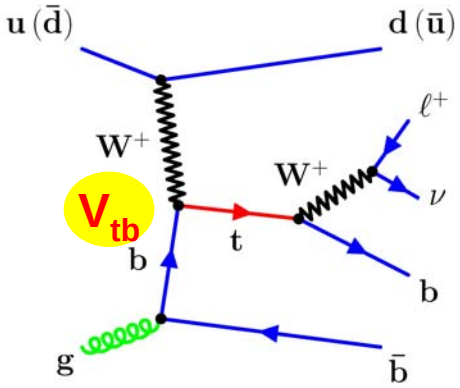
- first top candidates seen by ATLAS and CMS
- recorded luminosity now $L_{int} > 3\ pb^{-1}$
- at the end of 2011 with L_{int} = 1 fb-1 one expects ≈ 8000 ttbar reconstructed events in the lepton+jets channel
- need to control b-tagging systematics, for example special working point, etc. 3% uncertainty may be achievable



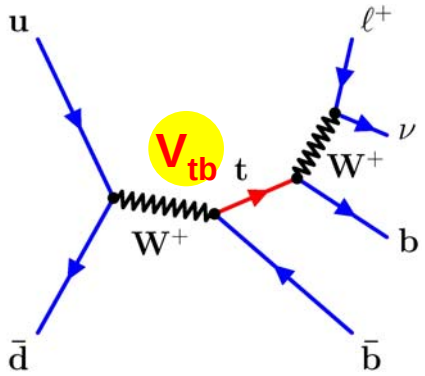
2) Single Top-Quark Production

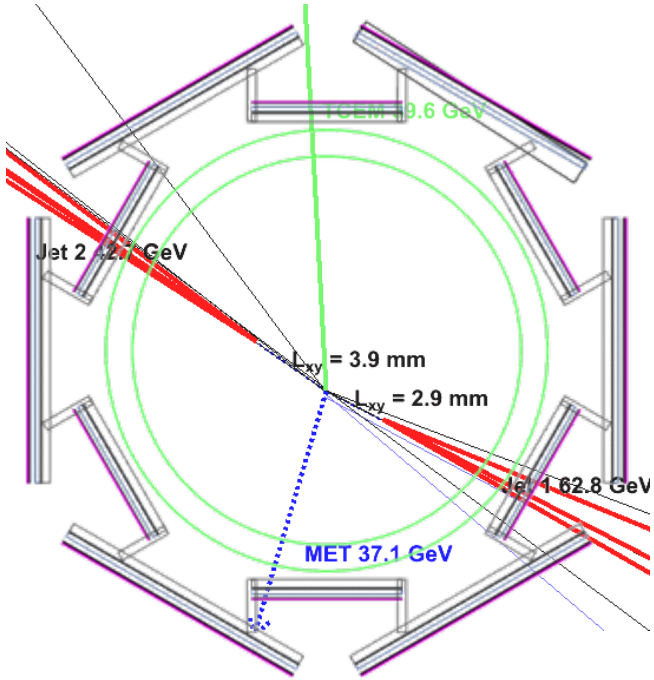
top-quark production via the weak interaction

t-channel



s-channel

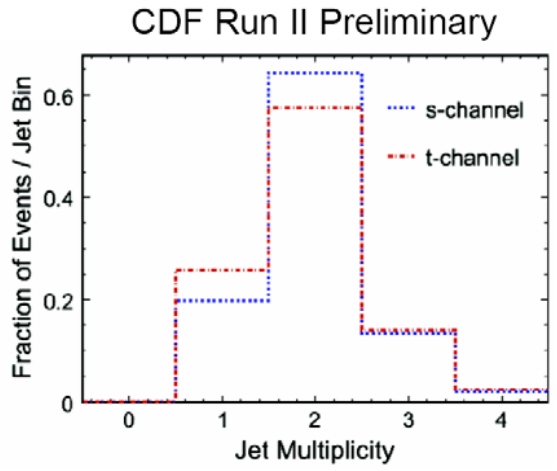




Experimental Signature:
charged lepton + missing E_T + 2 or 3 energetic jets

Theoretical cross section predictions at $\sqrt{s}$ = 1.96 TeV

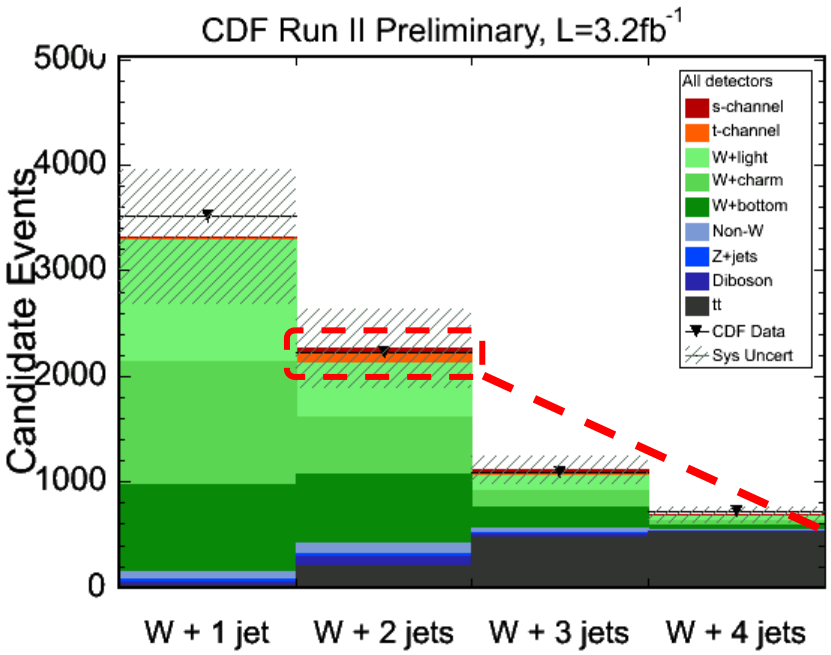
$\sigma_t = 1.98 \pm 0.25$ pb **$\sigma_s = 0.88 \pm 0.11$ pb**



B.W. Harris et al. Phys. Rev. D 66, 054024 (2002),
Z. Sullivan, Phys. Rev. D 70, 114012 (2004)

compatible results:
Campbell/Ellis/Tramontano, Phys. Rev. D 70, 094012 (2004),
N. Kidonakis, Phys.Rev. D 74, 114012 (2006)

Finding the Needle in the Haystack



- After the object based event selection the S/B is still too low.
- Background uncertainties are larger than the signal.

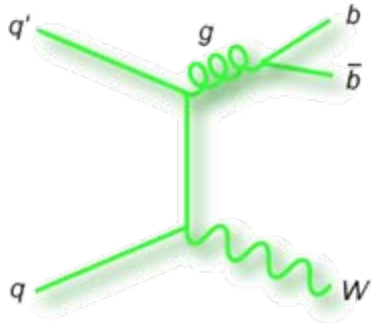
→ need to optimize separation power between signal and background

→ multivariate techniques

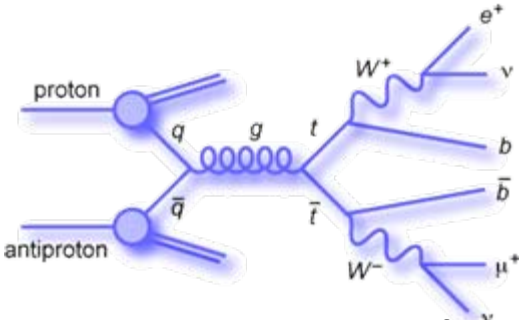
the CHALLENGE: S/B = 6.9%

Main Backgrounds

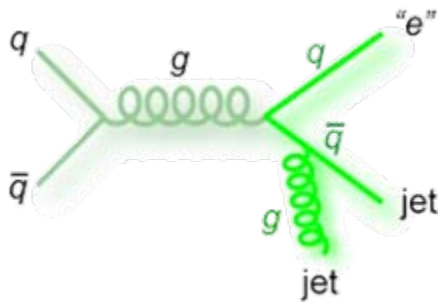
W + jets



top-antitop-pairs



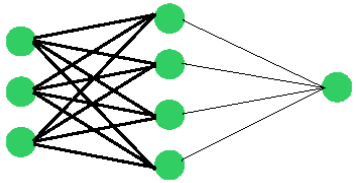
QCD multijet production



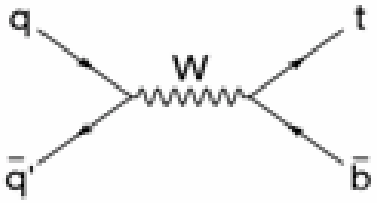
Multivariate Analyses

Need optimized discrimination between signal and background.

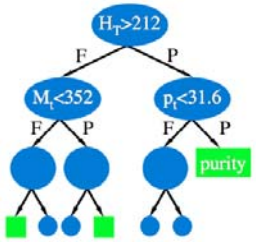
1.) neural networks



2.) matrix elements



3.) boosted decision trees



4.) likelihood discriminants

$$L^j(\vec{x}) = \frac{\prod_{i=1}^{n_{\text{var}}} p_i^j(x_i)}{\sum_{k=1}^{5} \prod_{i=1}^{n_{\text{var}}} p_i^k(x_i)}$$

Single Top Publications

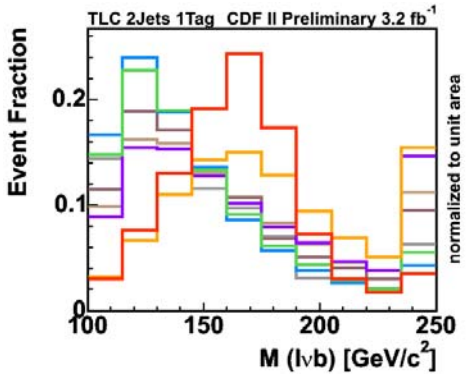
CDF

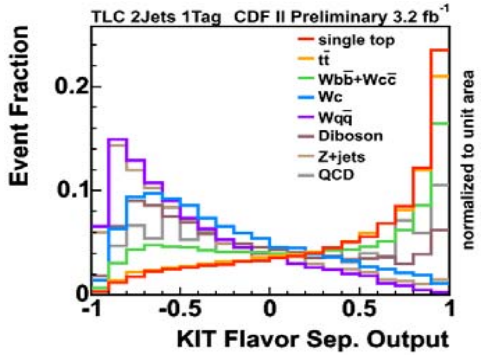
- evidence: Phys. Rev. Lett. 101 (2008) 252001
- observation:
  Phys. Rev. Lett. 103 (2009) 092002
  arXiv:1004.1181 [hep-ex]

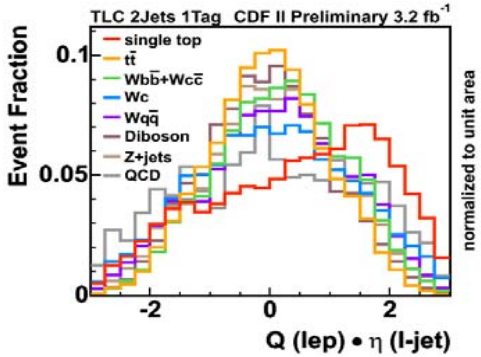
DØ

- evidence:
  Phys. Rev. Lett. 98 (2007) 181802
  Phys. Rev. D 78 (2008) 012005
- observation:
  Phys. Rev. Lett. 103 (2009) 092001

Neural Network Analysis







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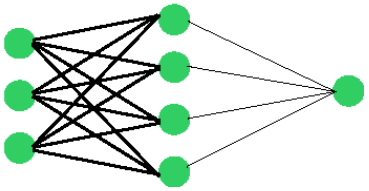
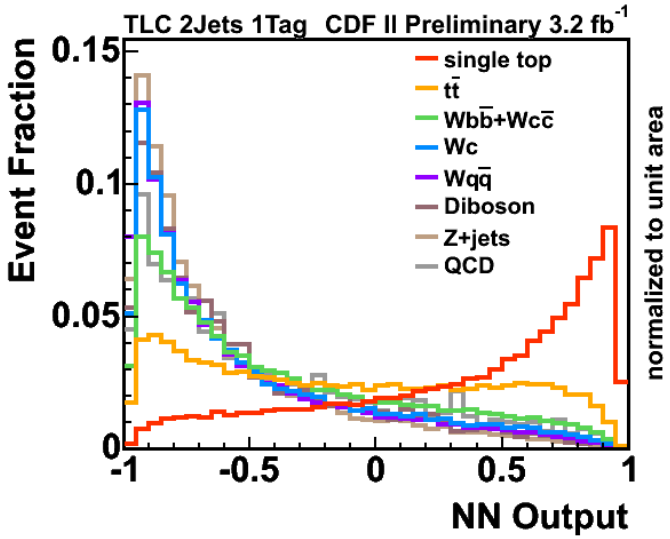
Idea:
combine many variables into one more powerful discriminant

important variables:
$Q \cdot \eta$, reconstructed top quark mass, top quark polarisation angle, Jet E_T and η, NN b tagger output, W boson η, …

neural network



exploits correlations between variables

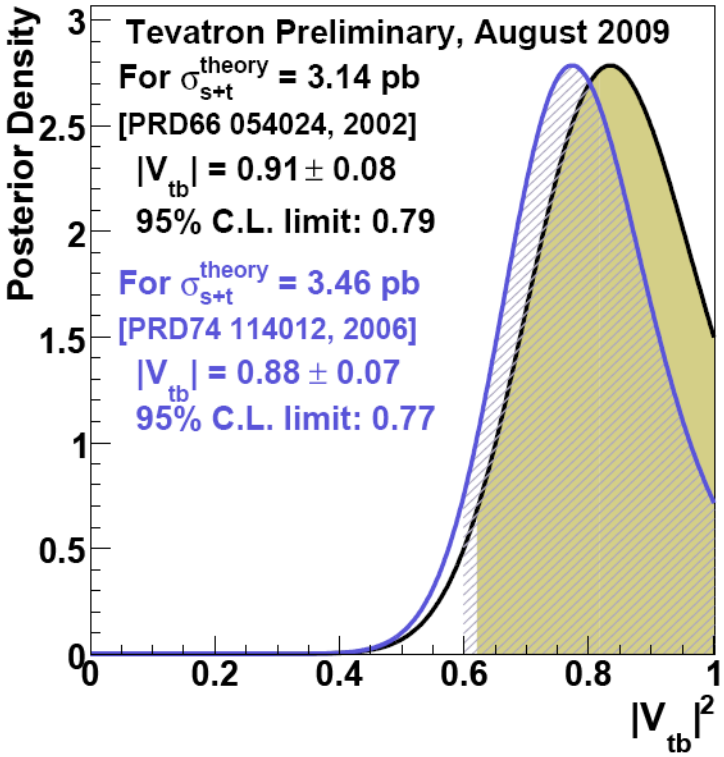


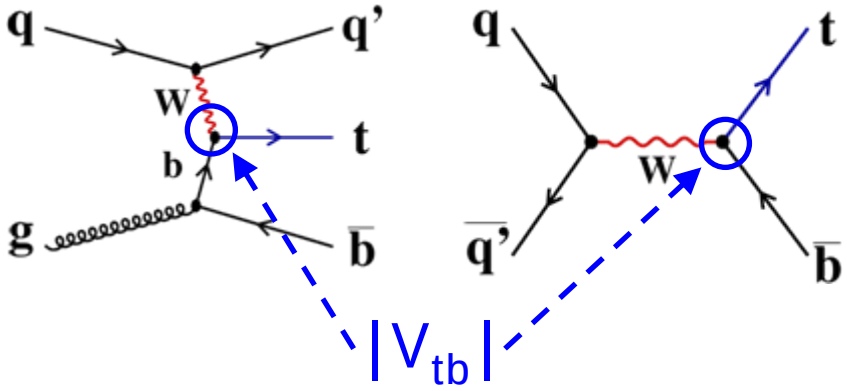
background like signal like

$|V_{tb}|$ Determination

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

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





$|V_{tb}|$= 0.88 ± 0.07 (stat+syst) ± 0.07 (theory)

CDF and DØ Collaborations:
arXiv: 0908.2171 [hep-ex]

Projections on $|V_{tb}|$

Tevatron

- Observation analyses use 2.3 and 3.2 fb-1 of data.
- DØ is preparing an analysis with 5.4 fb^{-1}.
- Analyses use Bayesian approach → difficult to separate statistical and systematic uncertainties.
- Systematic uncertainties on signal detection efficiency will be limiting factor: JES, ISR/FSR, PDF, b-tagging and lepton ID efficiency approx. at 10% level
- Theory cross section: $\Delta\sigma_{theo} = 14\%$
- $\Delta|V_{tb}| = ½\ \Delta\sigma \quad \Rightarrow \Delta|V_{tb}| = 5\%$ (exp.) + 7% (theo.)

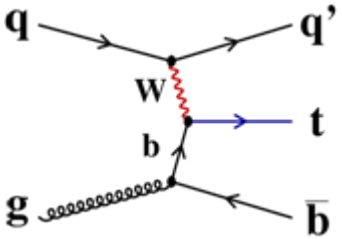
LHC

Preparations for single top at the LHC

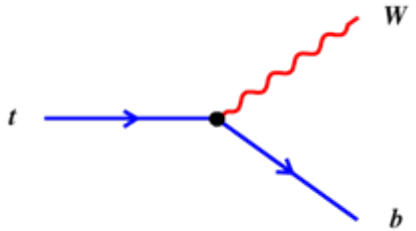
- t-channel is by far dominating: σ (@ 7 TeV) ≈ 60 pb
- Preparing studies are available:
  - ATLAS: ATL-PHYS-PUB-2010-003
  - CMS: CMS-PAS-TOP-09-005
- Several 100 pb^{-1} are needed. Control of systematic uncertaintes is key.

Beyond $|V_{tb}|$

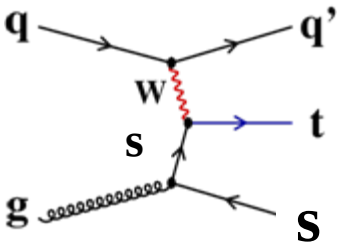
Consider also production and deacy via $|V_{ts}|$ and $|V_{td}|$



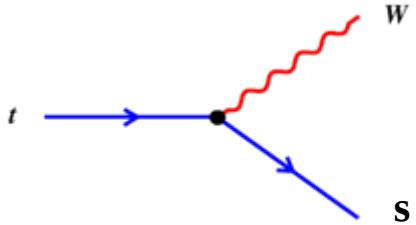
$|V_{tb}|^2$



R_b

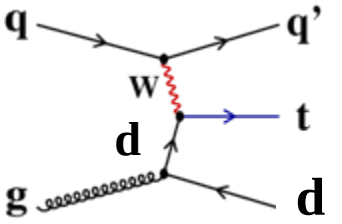


$|V_{ts}|^2$ ⊗

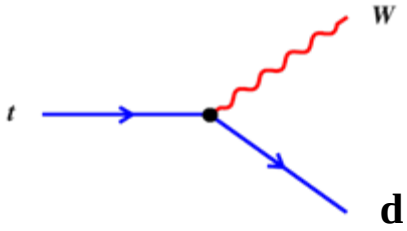


R_s

in SM: $\sigma_s = 1\% \cdot \sigma_b$



$|V_{td}|^2$



R_d

in SM: $\sigma_d = 0.1\% \cdot \sigma_b$

- Need samples of simulated events for all combinations to compute efficiencies.
- Priority at the LHC: „rediscover“ single top-quarks.
- Limits on $|V_{ts}|$ and $|V_{td}|$ at the 10% level may be possible in the long run.

Summary

- Top-Quark physics at hadron colliders contributes to our knowledge on the CKM element V_{tb}, and a bit on V_{ts} and V_{td}.
- Studying top-quark decay in top-antitop events probes the SM prediction $|V_{tb}| >> |V_{ts}| + |V_{td}|$.
- Single top-quark production measures $|V_{tb}|$ (currently using the assumption above).
  status: $|V_{tb}| = 0.88 \pm 0.07$ (stat+syst) ± 0.07 (theory)
- Systematic uncertainties start to limit measurements already now, even at the Tevatron.
  $\Rightarrow$ need excellent understanding of b-tagging, jet energy scale, lepton ID, etc.
- Priority at the LHC: „rediscovery“ of single top-quarks.
  In a second step more involved analyses will emerge.