Measurement of $R = B(t \to Wb) / B(t \to Wq)$ in Top–quark–pair Decays using Dilepton Events and the Full CDF Run II Data set

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Top Quark and Standard Model

In the picture of Standard Model of fundamental interactions

- 3 quarks generation;
- CKM unitary Matrix (4 parameters: 3 angles and 1 complex phase);

$\Rightarrow |V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1$

- $|V_{tb}| = 0.999146 \;{}^{+0.000021}_{-0.000046}$

(PDG),Phys. Rev. D 86, 010001 (2012)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Measurement of $|V_{tb}|$:

- Direct: Single Top production cross section

$$|V_{tb}| = 0.92^{+0.10}_{-0.08}\ (\text{stat+syst}) \pm 0.05\ (\text{th})$$

V.M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **103**, 092001 (2009); T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **103**, 092002 (2009).

- Indirect: Decay rate in $t\bar{t}$ events

Top Quark

- Discovered by CDF and D0 in (1995)

  Phys.Rev.Lett, 74:2626-2631,1995

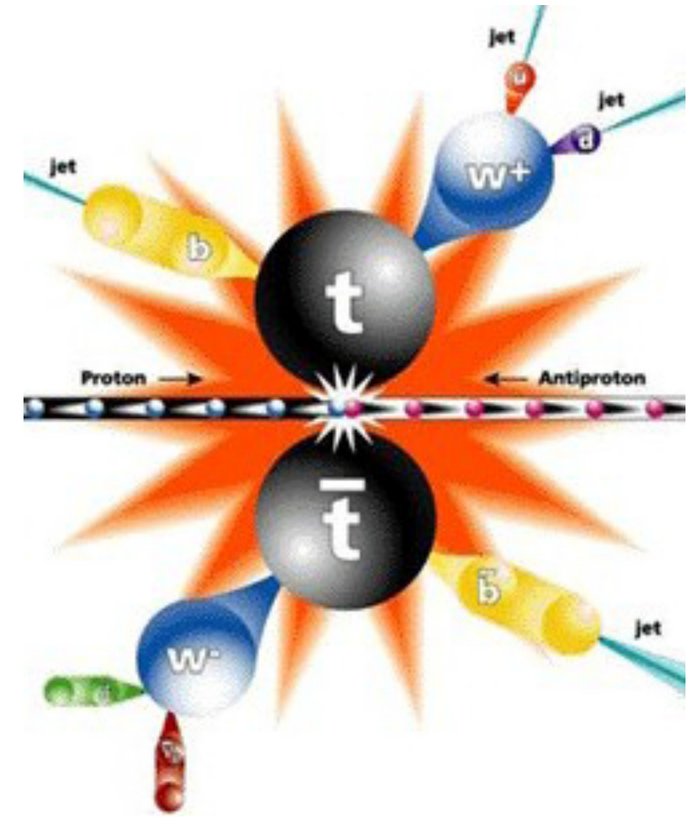
- Lifetime: $0.5\ 10^{-24}$ s

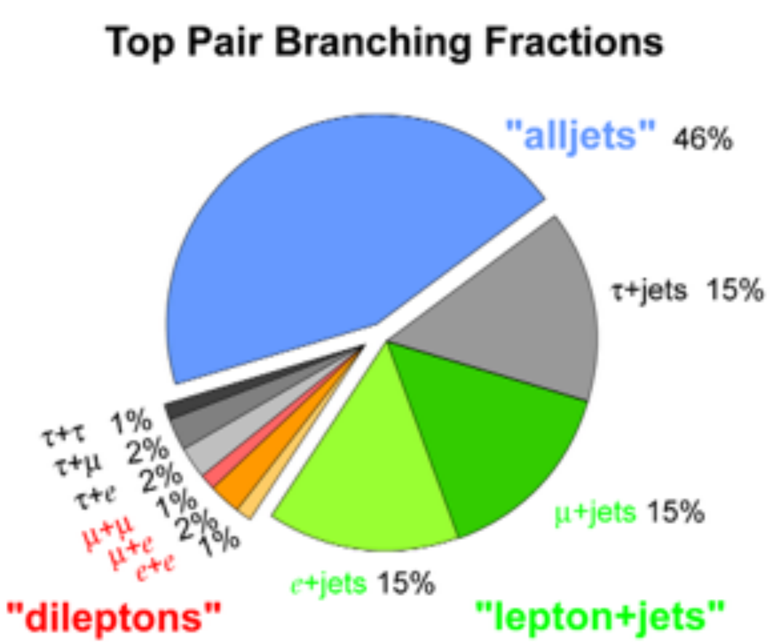
- Weak decay

  $t \to W q \propto |V_{tq}|^2$

  where q is a down-type quark

- Dilepton final state:
  - $p\bar{p} \to t\bar{t} \to W^+ W^- q\bar{q} \to \ell\bar{\ell}\nu\bar{\nu}q\bar{q}$





Analysis Strategy

Ratio between the top quark branching fraction to b quark and to the branching fraction to any type of down quark

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

- ⇒ Physic observable: number of b tagged jets in the event
- Once selected, data are divided in subsamples according on the dilepton type and the b-tagging content
    - (ee,μμ, eμ) × (0 ,1, 2 b-tagged jets)
- In each subsample the expectations for the signal (R dependent) and background yields (R independent) are compared to data

Selected Sample Composition

- Signal : $t\bar{t}$
- Irreducible Backgrounds
  - Dibosons (WW,WZ,ZZ)
  - Drell-Yan → $\tau\tau$
- Processes with different final state
  - W+jets (lepton jet contamination)
  - Drell-Yan → ee,μμ (MET from energy mis-measurement)

- Event selection:
  - Whole CDF dataset: 8.7 fb^{-1}
  - 2 Leptons (eμ):
    - E_T > 20 GeV (p_T > 20 GeV/c)
  - 2 neutrinos: MET > 25 GeV
  - 2 quarks:
    - At least 2 jets: E_T > 15 GeV
    - Number of b-tags

Process	Cross section (σ pb)
WW	11.3 ± 0.6
WZ	3.47 ± 0.21
ZZ	3.62 ± 0.22
$t\bar{t}$	7.4 ± 0.49

Events Selected

- Signal and background estimation
- Pre-tag sample is used to evaluate the top pair production cross section, that will be used for the normalization of the signal.

CDF Run II, $\mathcal{L}$=8.7 fb^{-1}

Process	Pre-tag	1 tag	2 tags
Dibosons	5.4 ± 0.6	0.66 ± 0.10	0.035 ± 0.014
DY+LF	10.7 ± 1.6	1.50 ± 0.70	0.029 ± 0.015
DY+HF	N/A	0.63 ± 0.12	0.17 ± 0.06
Fakes	21.8 ± 4.3	5.6 ± 1.9	1.0 ± 0.5
Total background	54 ± 7	8.3 ± 2.1	1.25 ± 0.53
$t\bar{t}$ (σ=7.4 pb)	223 ± 20	100 ± 9	29 ± 4
Total prediction	278 ± 21	110 ± 10	30.8 ± 4.2
Observed	286	96	35

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \cdot L}$$

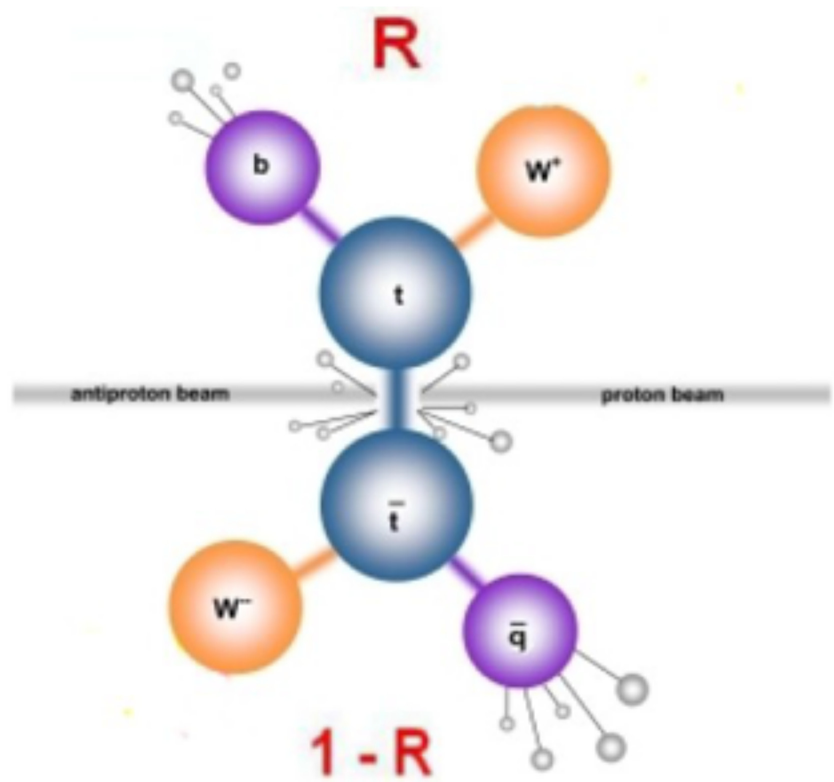
$$\sigma_{p\bar{p}\to t\bar{t}} = 7.64 \pm 0.55_{stat}\,\text{pb}$$

R Measurement

- In each sample, the number of events (μ) is predicted as the sum of number of background (b) and signal (s) events
  - $s_{d,t} = P(\, t \,;\, R\,)\, N_{d,\text{PRE-TAG}} = P(\, t \,;\, R\,)\, A_d\, L\, \sigma$

  A is the MC acceptance, L is the luminosity

  σ is the cross section; P(t;R) is the probability of having t tags



- R is measured with a Maximum Likelihood fit

$$L = \prod_i \wp(\mu^i_{exp}\,(R, x_j)|N_{obs}) \prod_j G(x_j|\bar{x}_j, \sigma_j)$$

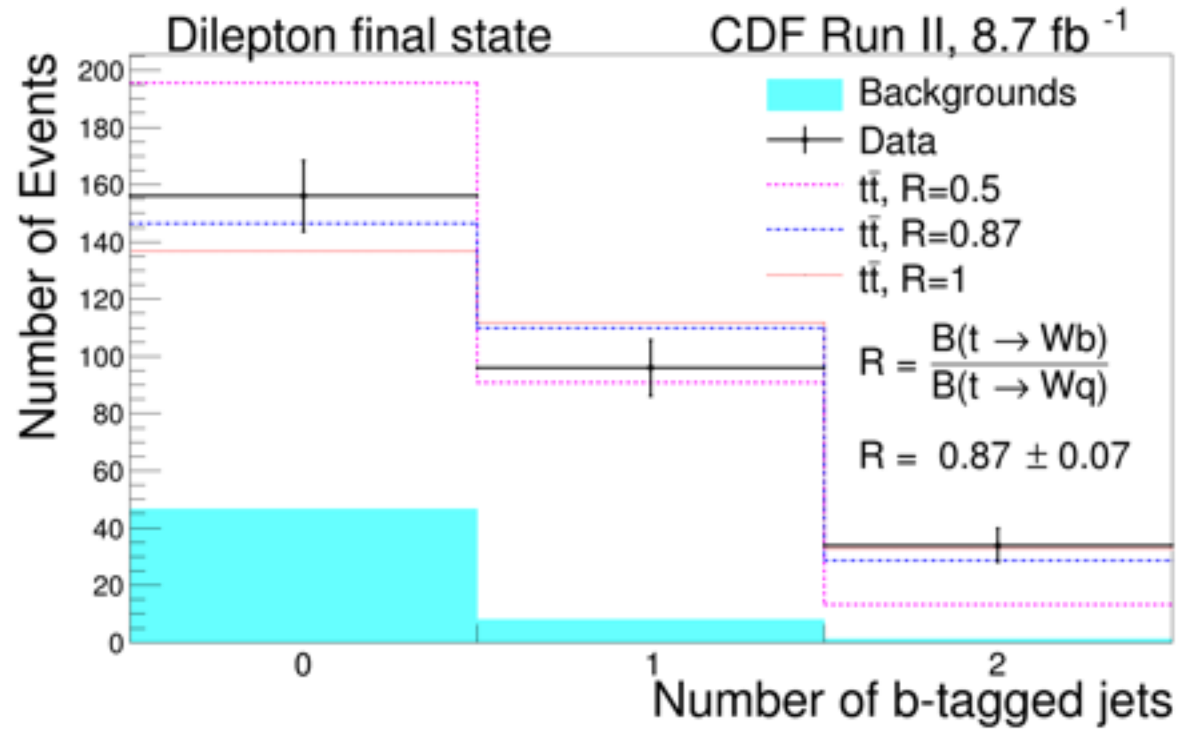
- Poisson probability of finding N_{OBS} events in the i-th sample, given the expected value μ_i
- Gaussian distribution constrains the nuisance parameters to vary among their measured value within their uncertainties

Result

R is measured:

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

$R = 0.87 \pm 0.07$ **(stat + syst)**



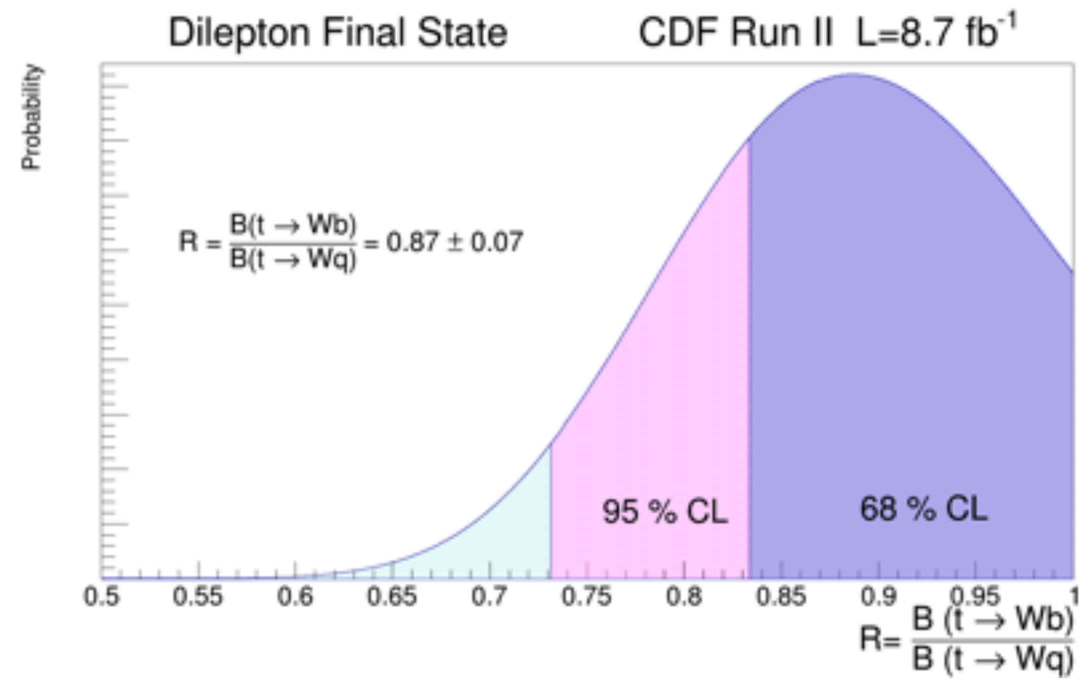
CDF Run II, $\mathcal{L}$=8.7^{-1}

Systematic source	Contribution
Correction DATA/MC to b-tagging efficiency	+0.045, -0.040
$\sigma_{t\bar{t}}$	± 0.01
Luminosity	+0.009, -0.012
Jet Energy Scale	+0.033, -0.025
ISR/FSR	+0.013, -0.025
Total Systematic uncertainty	+0.059, -0.057
Statistical uncertainty	±0.045
Total uncertainty	+0.74, -0.73

Summary

- The ratio between the top quark branching fraction to b quark and to the branching fraction to any type of down quark has been measured using the CDF complete dataset in the dilepton Channel

Dilepton Final State	CDF Run II (8.7 fb^{-1})		
	Value (*stat* + *syst*)	Lower Limit at 68 % CL	Lower Limit at 95 % CL
$R = \frac{B(t \to Wb)}{B(t \to Wq)}$	0.87 ± 0.07	0.83	0.73
$\lvert V_{tb} \rvert$	0.93 ± 0.04	0.91	0.86



- The CKM Matrix element V_{tb} is extracted and a credibility level limit is set using a Bayesian statistical approach

Thanks for your attention

Back up

Previous Result

Previous measurement:

CDF (162 pb^{-1}) (2004)		
Channel	R	$\|V_{tb}\|$
Lepton + jets	$1.06^{+0.27}_{-0.24}$	
Dilepton	$1.40^{+0.45}_{-0.38}$	
Combined	$1.12^{+0.27}_{-0.23}$	> 0.62 al 95% CL

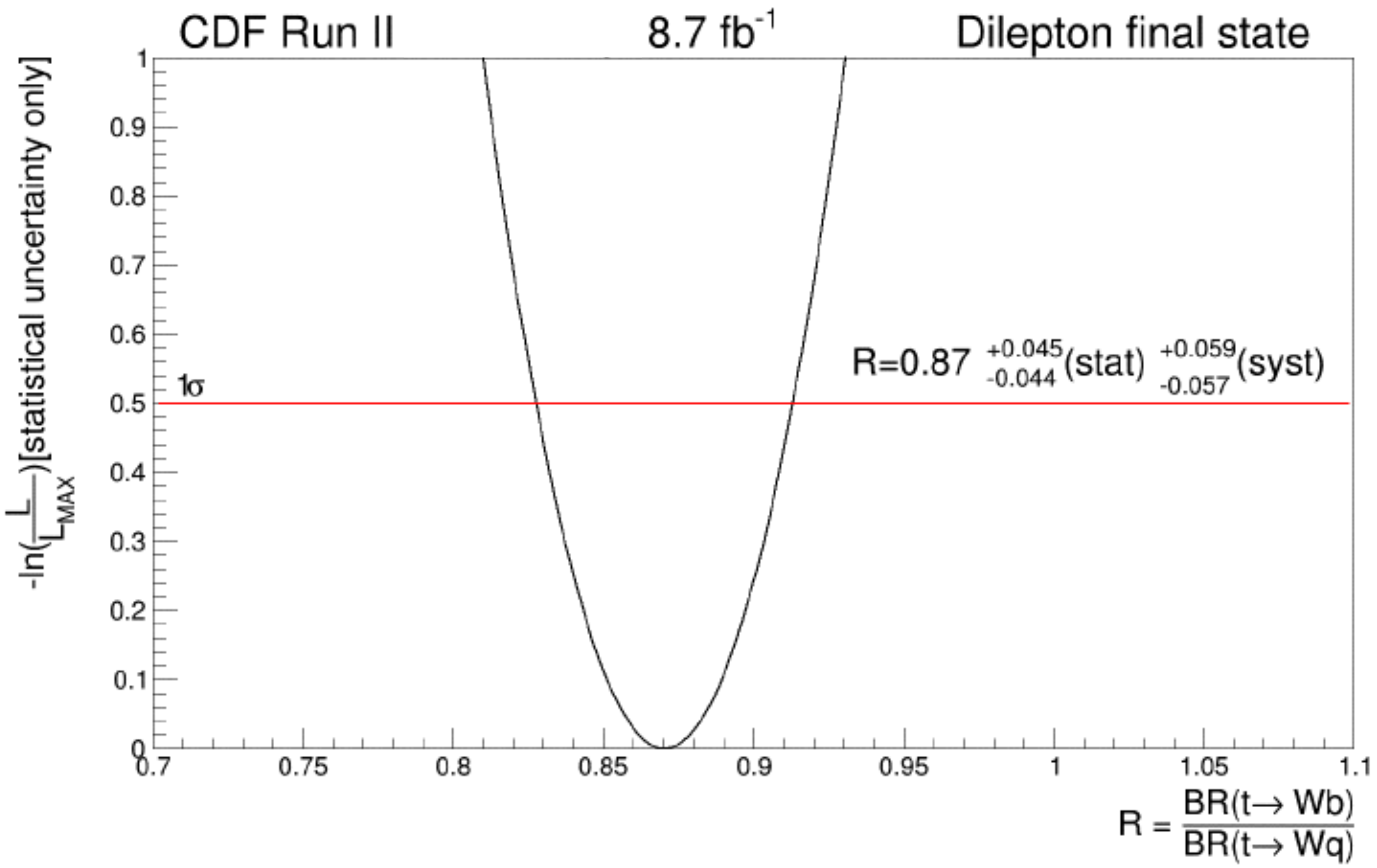
DØ (5.4 fb^{-1}) (2011)			
Channel	Cross Section (pb)	R	$\|V_{tb}\|$
Lepton + jets	$7.90^{+0.79}_{-0.67}$	0.95 ± 0.07	0.97 ± 0.04
Dilepton	$8.19^{+1.06}_{-0.92}$	0.86 ± 0.05	0.94 ± 0.04
Combined	$7.74^{+0.67}_{-0.57}$	0.90 ± 0.04	0.95 ± 0.02

CMS (17 fb^{-1})(2013)		
Channel	R	$\|V_{tb}\|$
Dilepton	$1.023^{+0.036}_{-0.034}$	$1.011^{0.018}_{0.017}$

CDF measurement in lepton+ jets with full statistics:

CDF (8.7 fb^{-1})			
Channel	Cross Section (pb)	R	$\|V_{tb}\|$
Lepton + jets	7.5 ± 1.0	0.94 ± 0.09	0.97 ± 0.05

Likelihood Profile



Additional requirements

Topological cut to improve signal $t\bar{t} \rightarrow \ell\bar{\ell}\ \nu\bar{\nu}\ q\bar{q}$

- Opposite sign leptons
- H_T >200 GeV
- L-Cut :
  - $|\not{E}_T|$ ≥ 50 GeV se $\Delta\phi(\not{E}_T$, nearest ℓ or jet$) < 20^o$
- Dilepton invariant Mass > 5 GeV/c^2
- Z-Veto:
  - MetSignificance: MetSig > 4 $GeV^{1/2}$ in the Z mass region;

$$MetSig = \frac{\not{E}_T}{\sqrt{E_T^{sum}}} \geq 4GeV^{1/2}$$

Background I

Monte Carlo based techniques or data-driven methods to calculate the number of event due to background processes that give their contribution to the signal region.

Monte Carlo:

- Dibosons (WW, WZ, ZZ and Wγ): MC PYTHIA
  - Corrected for jet multiplicity due to initial and final state radiation
- Drell-Yan $\rightarrow \tau\tau$: MC ALPGEN (gen) + PYTHIA (shower evolution)
  - Corrected for jet multiplicity due to initial and final state radiation

$$N^i_{p\bar{p}\rightarrow X} = \sigma_{p\bar{p}\rightarrow X}\ \epsilon^i\ C_{\ell_1\ell_2}\ L^i$$

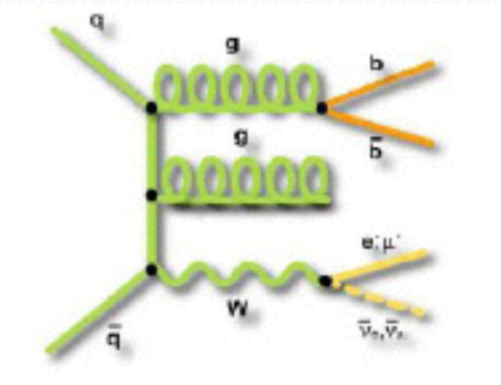
Process	Cross section (σ pb)
WW	11.3 ± 0.6
WZ	3.47 ± 0.21
ZZ	3.62 ± 0.22
$t\bar{t}$	7.4 ± 0.49

Background II

Monte Carlo based techniques or data-driven methods to calculate the number of event due to background processes that give their contribution to the signal region.

Real Data:

- Drell-Yan → ee/$\mu\mu$ with fake MET :
  - We estimate the contribution in a control region orthogonal to a signal region
  - We extrapolate the contribution to the signal region with MC ratios (New Ratios by Ziqing)
- W+jets, events in which a jet fakes a lepton:
  - Multi-jet sample: used to calculate the probability that a *fakeable* object (EM cluster/muon track) is reconstructed as a lepton
  - We apply this probability to events with a lepton + MET + *fakeable*



Drell Yan background

DIL channel: background estimate

The estimate of the background DY/Z→ ee ,μμ is based on the number of data events observed in Z region with high MET, after correcting for the presence of non DY events(Diboson, Z→ tautau, fakes, top).

2 Contributions:

$$N^{j}_{DY} = N^{j}_{IN} + N^{j}_{OUT}$$

- Outside the Z peak

$$N^{j}_{OUT} = R^{out/in}_{MET\&LCUT}(N^{DT,j}_{MET\&LCUT} - N^{BKG,j}_{MET\&LCUT})$$

- Inside the Z peak

$$N^{j}_{IN} = R^{high/low}_{MetSig}(N^{DT,j}_{MetSig} - N^{BKG,j}_{MetSig})$$

The R factors are MC ratios of events outside over inside Z peak region and events with high over low MetSig within the Z region.

MET&LCUT refers to events that pass the MET and L-Cut requirement, MetSig to events that pass the Met and L-cut cuts but fail the MetSig requirement.

Cross section

CDF Run II $\mathcal{L}$=8.7 fb^{-1}

Number of pretag events passing the full selection				
Process	ee	$e\mu$	$\mu\mu$	$\ell\ell$
WW	2.8 ± 0.3	4.3 ± 0.5	1.2 ± 0.2	8.4 ± 1.0
WZ	1.6 ± 0.2	0.7 ± 0.1	0.5 ± 0.1	2.7 ± 0.3
ZZ	1.0 ± 0.1	0.30 ± 0.05	0.45 ± 0.08	1.7 ± 0.2
DY$\rightarrow \tau\tau$	2.8 ± 0.5	4.1 ± 0.6	1.3 ± 0.2	8.0 ± 1.2
DY$\rightarrow ee, \mu\mu$	7.9 ± 1.1	1.5 ± 0.6	2.5 ± 0.8	12 ± 1
Fakes	5.9 ± 1.9	10.3 ± 3.4	5.7 ± 2.1	21.8 ± 4.3
Total background	21.9 ± 2.2	21.2 ± 3.6	11.6 ± 2.4	54 ± 7
$t\bar{t}$ (σ=7.4 pb)	70 ± 6	116 ± 10	37 ± 4	223 ± 20
Total prediction	92 ± 7	138 ± 11	49 ± 4	278 ± 21
Observed	92	147	47	286

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \cdot L}$$

- N_{obs} number of events observed in data
- N_{bkg} number of events due to background

$$\sigma_{p\bar{p}\rightarrow t\bar{t}} = 7.64 \pm 0.55\ (\text{stat})\ \text{pb}$$

- A acceptances (& efficiencies)
- L Integrated Luminosity (8.7 fb^{-1})

Already blessed results for comparison:

Pretag CDF official $\sigma_{p\bar{p}\rightarrow t\bar{t}} = 7.61 \pm 0.44_{stat} \pm 0.52_{syst} \pm 0.46_{lumi}\ pb$

Tag CDF official $\sigma_{p\bar{p}\rightarrow t\bar{t}} = 7.09 \pm 0.49_{stat} \pm 0.52_{syst} \pm 0.42_{lumi}\ pb$