# Measurement of

$$R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}$$

Monica Tecchio
University of Michigan

on behalf of
The CDF Collaboration

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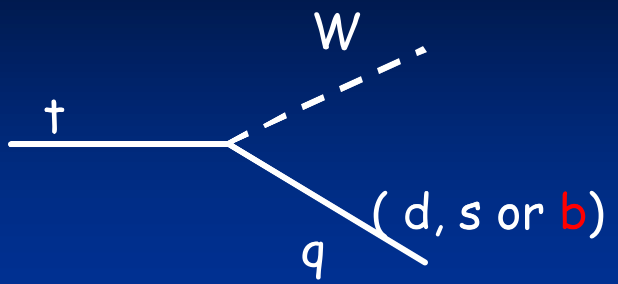
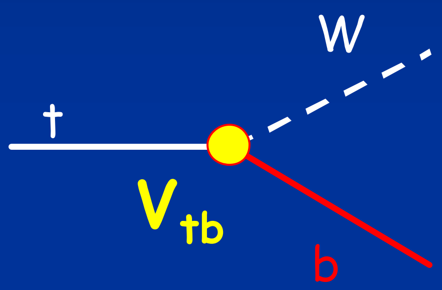
# What is R?




$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

If one assumes three quark generations and CKM unitarity:

$|V_{tb}| > 0.999$ @ 90% CL

➲ $R > 0.998$ (PDG'04).

We can test SM assumptions using the relative rates of 0-, 1- and 2 tagged b-quarks in top-pair events

If all b-quarks are identified with efficiency $\varepsilon_b$:

$$N_0 = N_{tt}(1 - R e_b)^2$$

$$N_1 = 2N_{tt} R e_b (1 - R e_b)$$

$$N_2 = N_{tt}(R e_b)^2$$

- sensitive to product $R\varepsilon_b$
- overdetermined problem
- $N_{tt}$, and therefore $\sigma_{top}$, cancels in the ratio

# How do we measure R?

Any two tagged rates can be used to measure $R\varepsilon_b$.

- $\varepsilon_b$ is estimated from $t\bar{t}$ simulation
- Knowing $\varepsilon_b$, we can extract R!

But....

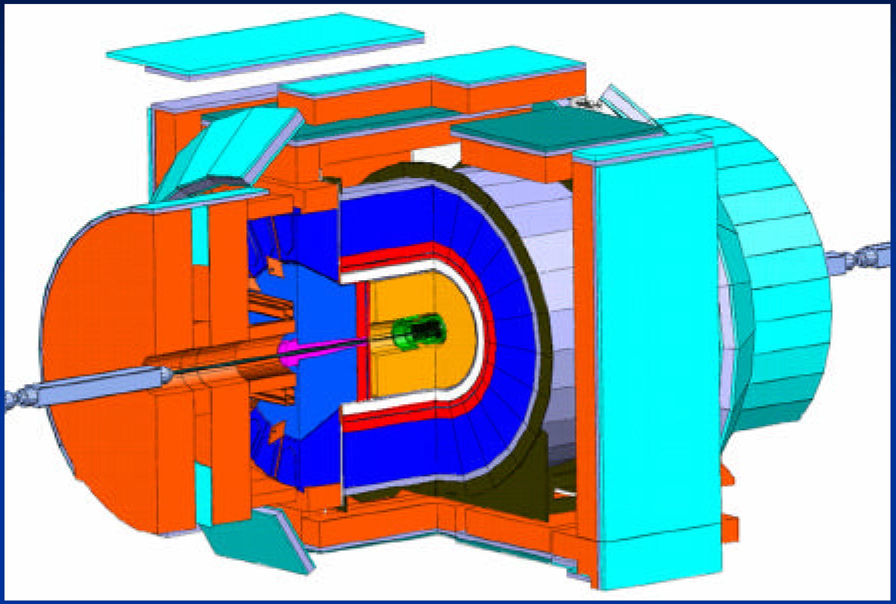
- we tag b-jets, not b-quarks
- not all b-jets are taggable
- non-b quarks can be tagged too!

Measure of R proceeds in three steps:

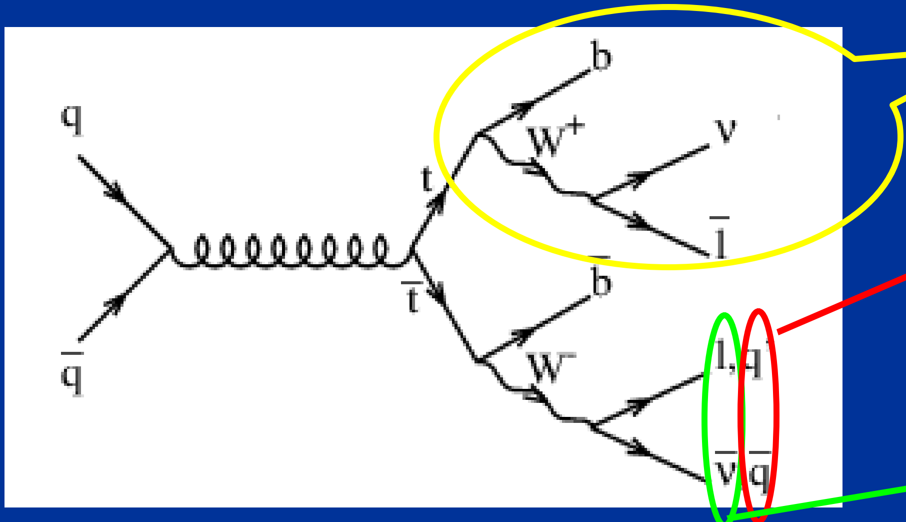
1. Identify samples enriched in $t\bar{t}$ events
   - Measure number of events in each tagged bin, $N_{i,\,obs}$
   - Estimate background in each bin, $N_{i,\,bkgr}$
2. Predict tag rates $\varepsilon_i = \varepsilon_i\ (R\ \varepsilon_b\ )$
3. Compare $N_{i,exp}$ to $N_{i,obs}$ using a likelihood technique

# Data Sample

Use 161 $pb^{-1}$ of data collected by CDF at $\sqrt{s}$ = 1.96 TeV with good SI detector



Use same samples as for top cross section analysis in lepton-plus-jets and dilepton channels.




- one 20 GeV isolated lepton (e,μ)
- high missing Et

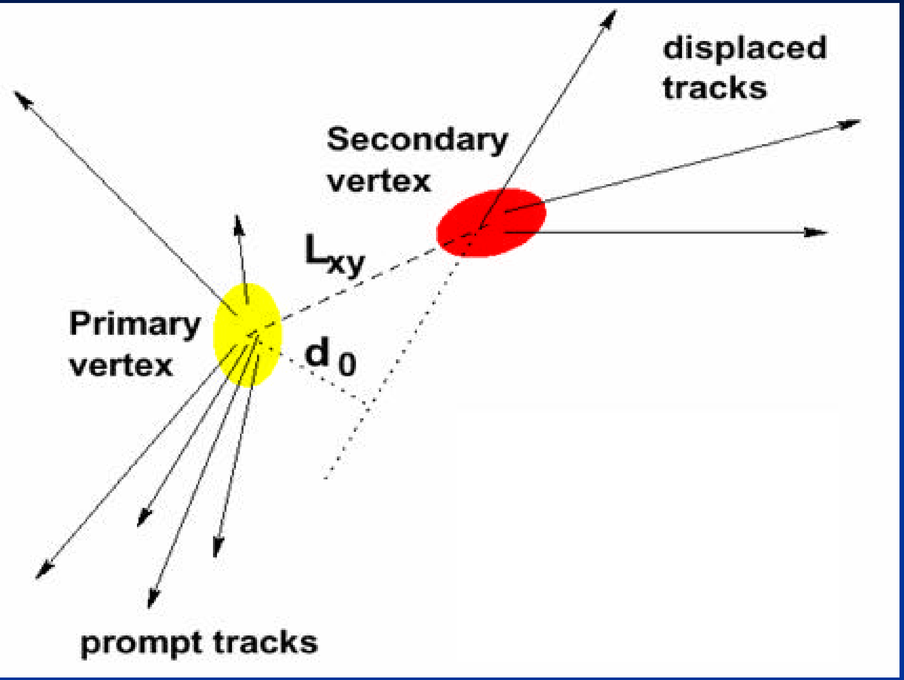
L3J: + exactly 3 jet (high stat.)
L4J: + >=4 jets (better S/B)

LL: + second lepton
+ 2 or more jets

# Tagged Samples: $N_{i,obs}$

b-jets are identified using the SecVtx algorithm.

- high $d_0$ tracks in jets are constrained to come from a displaced secondary vertex
- jet tagging efficiency: from MC and calibrated with independent data samples: 44%
- false tag rate, from generic QCD jets: 0.5%




| Sample | L3J | L4J | LL |
|---|---|---|---|
| 0-tag | 358 | 79 | 5 |
| 1-tag | 26 | 23 | 4 |
| 2-tag | 3 | 5 | 2 |

# Tagged Background: $N_{i,\ bkgr}$

## LL

- Mostly from generic QCD radiation in Z/WW+jets
- Apply false tag probability matrix to pretagged dilepton candidates

| LL | 0-tag | 1-tag | 2-tag |
|---|---|---|---|
| $N_{bkgr}$ | 2.0±0.6 | 0.2±0.2 | 0.0±0.0 |

| L3J (DE) | 0-tag | 1-tag | 2-tag |
|---|---|---|---|
| $N_{bkgr}$ | [0,358] | 16.0±2.4 | 0.8±0.2 |

| L4J (DE) | 0-tag | 1-tag | 2-tag |
|---|---|---|---|
| $N_{bkgr}$ | [0,79] | 4.2±0.1 | 0.2±0.1 |

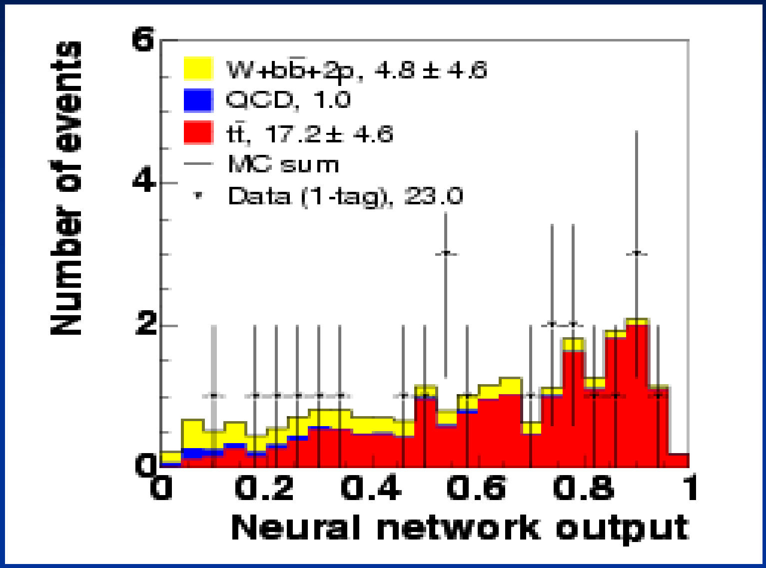
## L3J/L4J

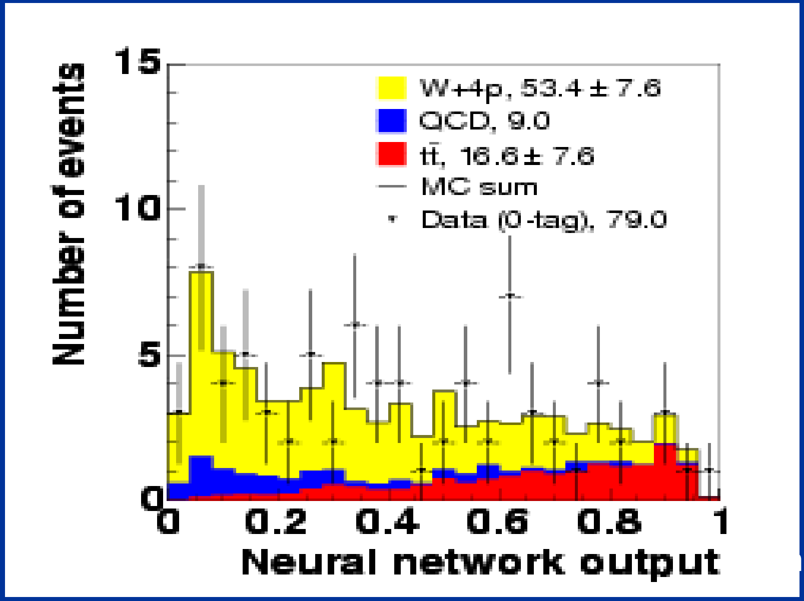
- Direct estimate of the SECVTX background rates, using data-driven and simulation based techniques, can be applied only to 1- and 2-tag bins.
- For 0-tag bin, can use at least knowledge of total number of events with no tags.
- Kinematic (NN) analysis provides independent estimate of background rates in each tagged bin which is consistent but less precise than DE.

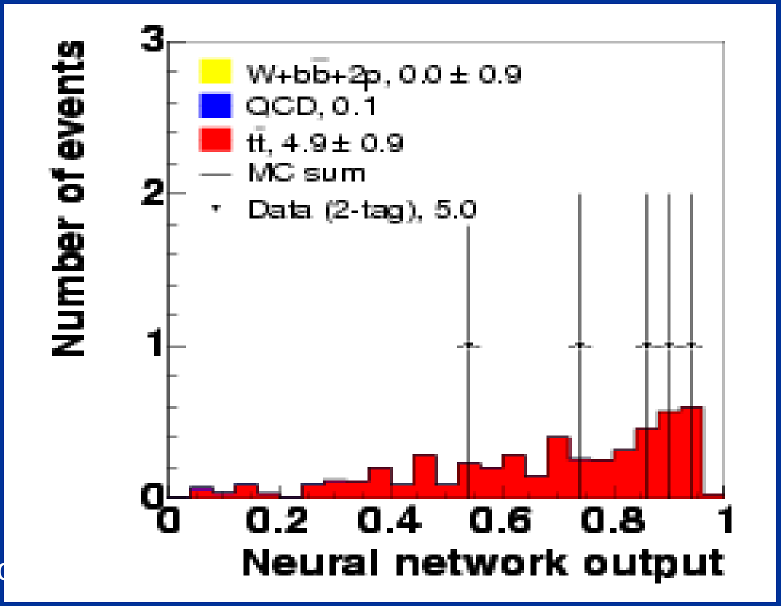
| L4J (NN) | 0-tag | 1-tag | 2-tag |
|---|---|---|---|
| $N_{bkgr}$ | $62.4^{+8.5}_{-9.3}$ | $5.8^{+5.6}_{-5.2}$ | $0.1^{+0.9}_{-0.0}$ |

# Lepton+jets Kinematic (NN) Analysis

- Single output NN trained on 9 kinematics variables, independent of b-tagging.
- Used for L4J channel only.
- Fit data to NN output templates for $t\bar{t}$ and W+jets background (plus fixed QCD component) to find top signal fractions.



# Event Tagging Efficiencies: $e_i$

Tagged jets can come from a variety of sources.

- We estimate the efficiency to tag different b-like jets using the Monte Carlo

1. b-quark in top decays
2. Light-quarks in top decays ($\varepsilon_q$< 0.01)

➔ efficiency to tag a jet from top decays is:

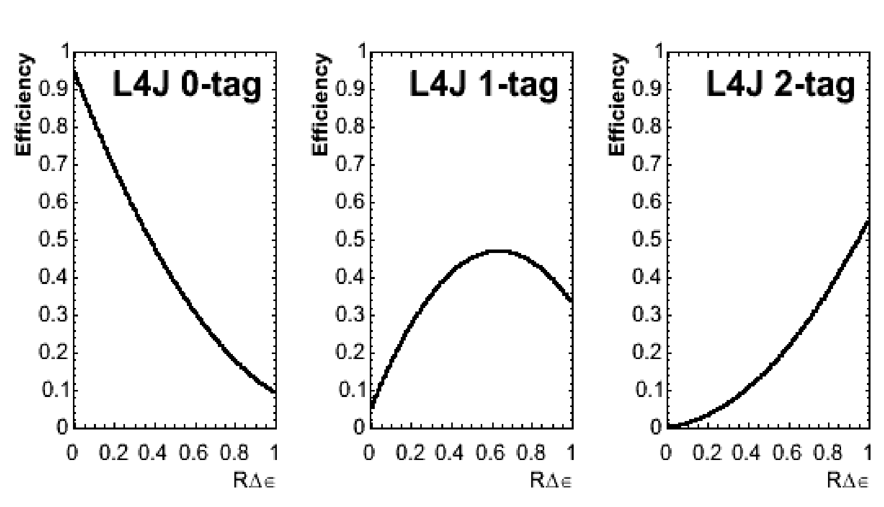
$$R\,e_b + (1-R)\,e_q = R\,(e_b - e_q) + e_q$$

3. Quarks from W-decay and "other" jets from additional QCD radiation.
Do not depend on R!

- Tagging efficiency apply only if jets are taggable i.e. within the SecVtx fiducial region.

Event tagging efficiency becomes:

$$e_i = e_i\,(R\,\Delta e, e_W, e_o, F_{bWo})$$



# Likelihood

- We use a likelihood function to characterize consistency of the observed tag rates with a given value of $R\Delta\varepsilon$.

$$\boxed{\mathcal{L} = \prod_{i-tag} \mathcal{P}(N_{i,obs}, N_{i,exp}) \times \mathcal{G}}$$

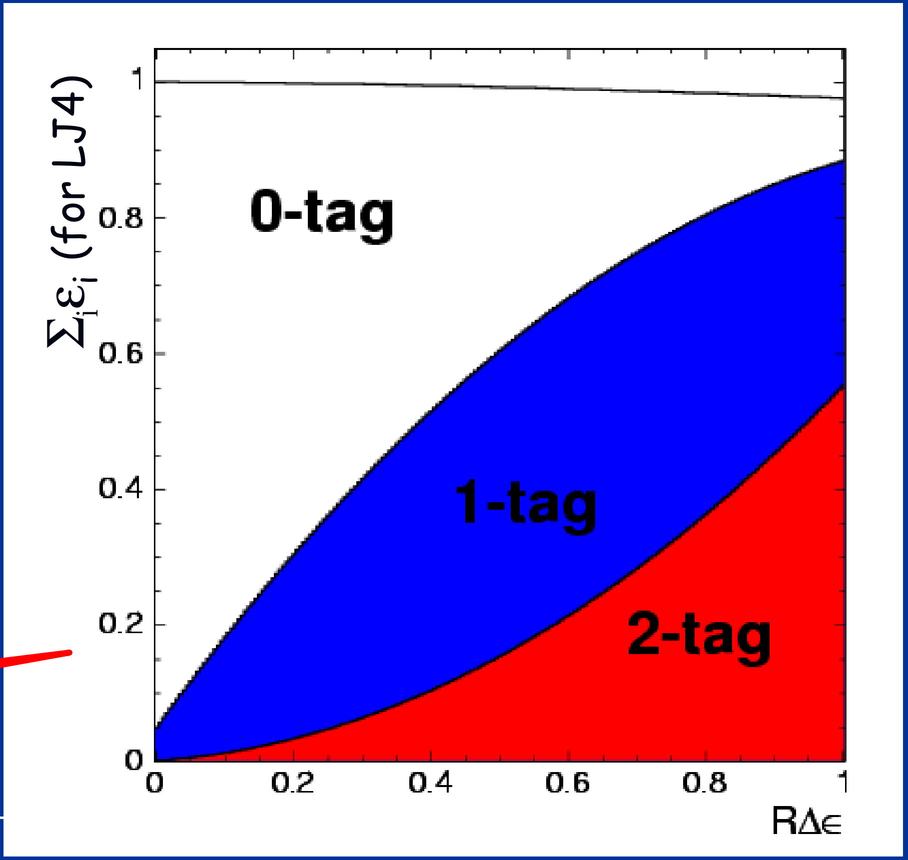
- Inside the Poisson terms $\mathcal{P}$

$$N_{i,exp} = N_{pre} \times e_i + N_{i,bkgr}$$

- The number of $t\bar{t}$ candidates before tagging, $N_{pre}$, is dependent on $R\Delta\varepsilon$

$$N_{pre} = \frac{\sum_j N_{i,obs} - \sum_i N_{i,bkgr}}{\sum_i e_i}$$

- The gaussian term $\mathcal{G}$ takes care of systematic uncertainties from backgr. normalization and jet efficiencies



# Combined Likelihood

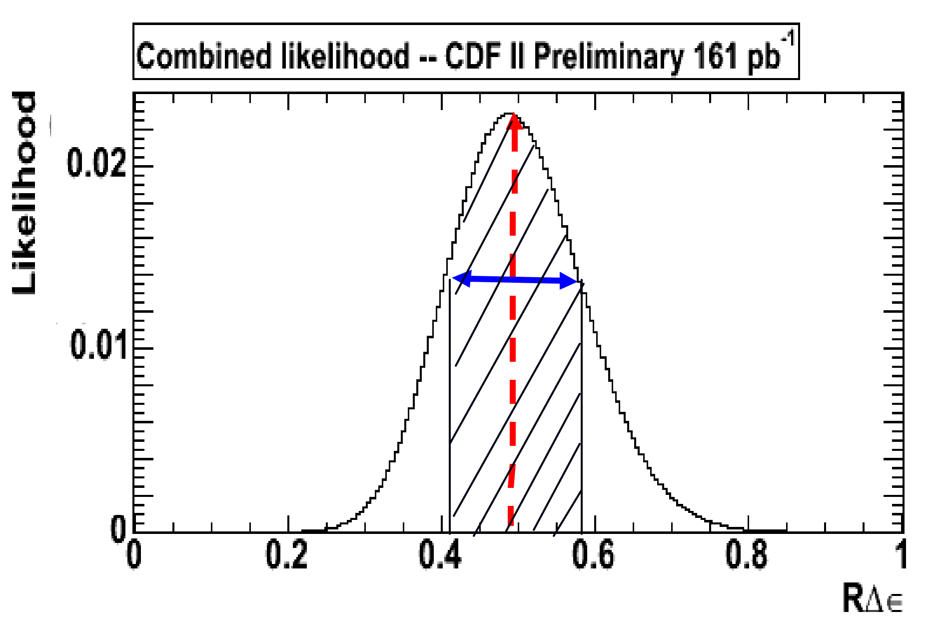
- Final likelihood is the product of likelihoods for the LL, L3J and L4J samples.
- From peak and interval containing 68% of area:

$$R\,\Delta e = 0.49^{+0.09}_{-0.08}$$

- Assuming nominal $\Delta\varepsilon = 0.44 \pm 0.03$:

$$R = 1.11^{+0.21}_{-0.19}$$

- Statistically limited. Systematics contribute ~15% of total uncertainty, dominated by uncertainty on $\varepsilon_b$.




- NN analysis alone produces a prediction for the number of top and background event in each tagged bin and can be used to extract R

$$R = 1.06^{+0.31}_{-0.29}$$

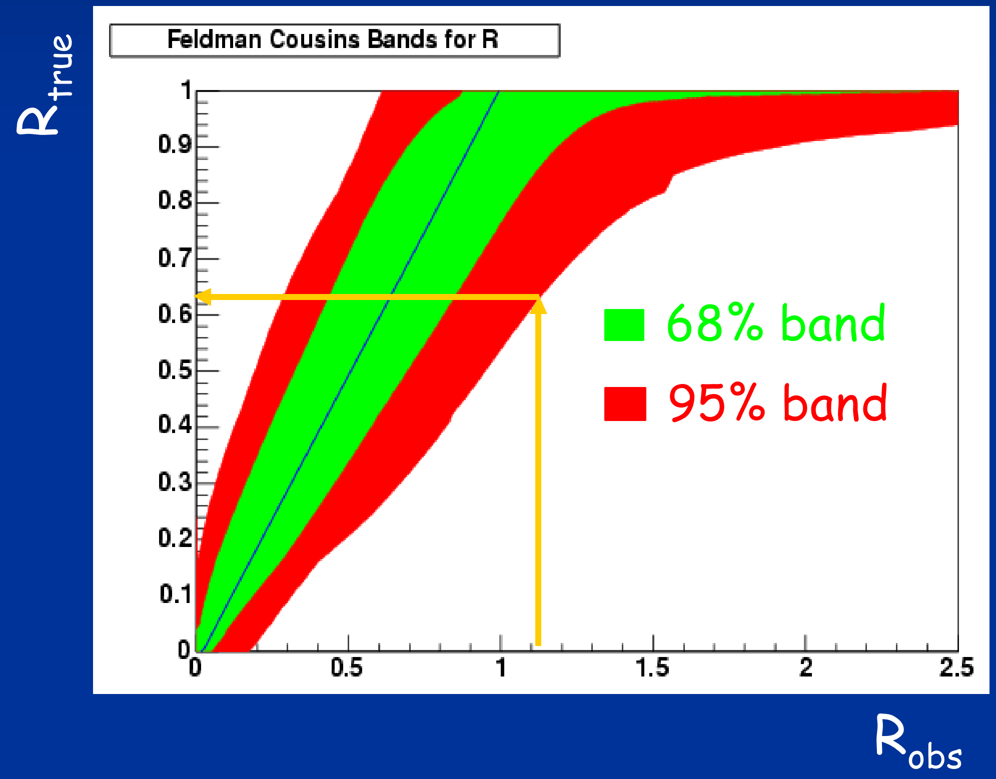
consistent with SecVtx result.

# Feldman-Cousins Limit

- To interpret our combined likelihood result, which is outside physical boundary of $0 \le R \le 1$, we use FC method to derive 95% acceptance bands for any $R_{obs}$ vs $R_{true}$
- Acceptance bands include statistical and systematic error

**R > 0.62 @ 95 C.L.**

CDF II Preliminary, 161 $pb^{-1}$



# Conclusions

- We have measured the ratio $R = \frac{B(t \to Wb)}{B(t \to Wq)}$ in 161 $pb^{-1}$ of top quark decays collected with CDF II

- By comparing the relative rates of identified b-jets in events reconstructed both as dilepton or lepton-plus-jets, we measure:

$$R = 1.11^{+0.21}_{-0.19}$$

or, using Feldman-Cousins limit prescription,

$$\boxed{R > 0.62 \text{ @ } 95\% C.L.}$$

- Improves CDF Run I limit of R > 0.56 @ 95 C.L.

- Expect more stringent limit with more statistics!

# Measurement of $R = \frac{B(t \to Wb)}{B(t \to Wq)}$

Backup slides

# Partial Sample Results

| Sample | $R\Delta\varepsilon$ Central value | R (assuming nominal $\Delta\varepsilon$) |
|---|---|---|
| SECVTX-only LJ | $0.42^{+0.15}_{-0.14}$ | $0.96^{+0.32}_{-0.34}$ |
| SECVTX + NN LJ | $0.45^{+0.10}_{-0.09}$ | $1.04^{+0.24}_{-0.21}$ |
| Dilepton | $0.61^{+0.19}_{-0.16}$ | $1.40^{+0.45}_{-0.38}$ |
| Combined | $0.49^{+0.09}_{-0.08}$ | $1.11^{+0.21}_{-0.19}$ |

- Uncertainty on R includes 7% from SF uncertainty.
- If we assume R=1:

$$\Delta e = 0.49^{+0.09}_{-0.08}$$

consistent with nominal value of $\Delta e = 0.44 \pm 0.03$

- $\Delta\varepsilon$ in dilepton and lepton plus jets agree.

# Feldman-Cousin Method

FC prescribes a method that unifies 1-sided vs 2-sided interval and ensures a physical results.

1. Find expected $R_{obs}$ for different values of $R_{true}$
2. For each $R_{true}$ set $\alpha$% confidence bands in $R_{meas}$ using a likelihood ratio ordering principle
3. Find smallest $R_{true}$ for which $R_{obs}$ is inside confidence band