Measurement of the ratio $R = \mathscr{B}(t \to Wb) / \mathscr{B}(t \to Wq)$ at CDF

P.Butti, G.Chiarelli, S. Leone, F.Sforza

Nikhef
Collider Detector at Fermilab

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Outline

1 Overview

2 Motivations

3 L+Jets Event selection

4 Systematics

5 Blessing Items

Overview

Documentation

- Internal Note: CDF 10723
- Public Note: CDF 10887 **First Draft.**
- http://www-cdf.fnal.gov/ pbutti/internal/PublicPage/PlotsPage.html

Update

- Systematic table: checked with PEs

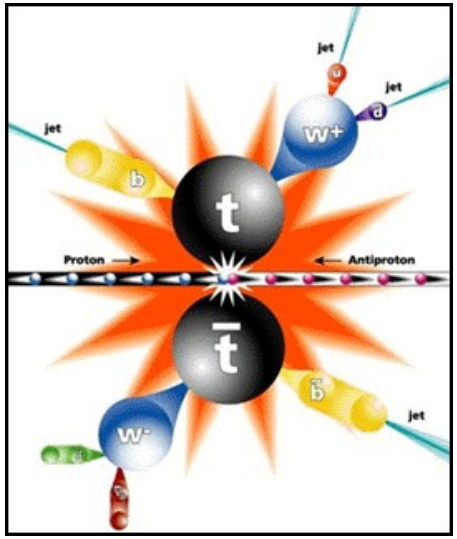
Motivations

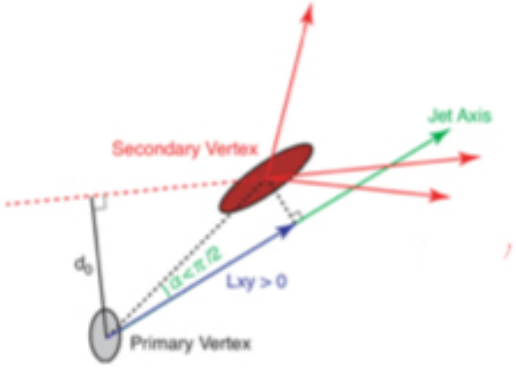
- Update of previous CDF analysis: statistics limited

Test of the Standard Model

- A deviation from the Standard Model prediction would indicate something new

Event Selection





- Full RII Data: $\mathscr{L} = 8.7$ fb^{-1}
- L+jets channel: ≥ 3 jets
- Offline Selection:
  - Central electrons (**CEM**): $E_T > 20$ GeV
  - Central muons (**CMUP,CMX**): $p_T > 20$ GeV/c
  - $\not{E}_T > 20$ GeV
  - Invariant l-ν mass: $W_M^T > 20$ GeV/c^2
  - Jets E_T: $1^{st} > 30$, $2^{nd} > 25$, $3^{rd} > 20$ GeV
  - Jets $|\eta| < 2$
  - Data/MC correction $SF = \frac{\epsilon_{data}}{\epsilon_{MC}} = 0.96 \pm 0.05$

Systematics

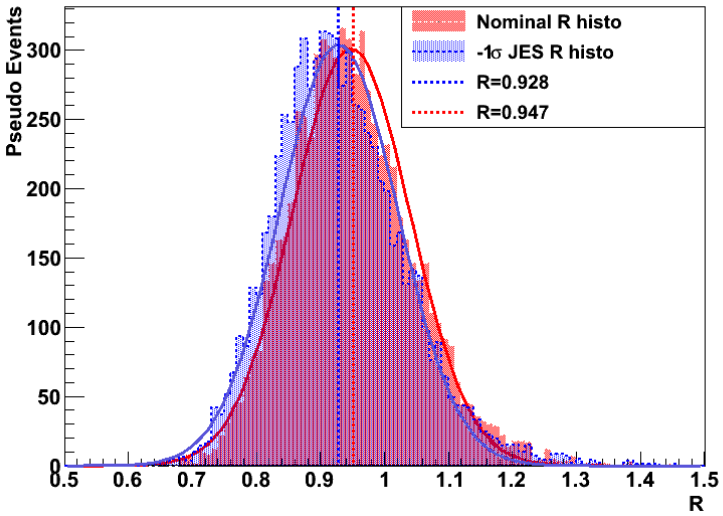
NEW!

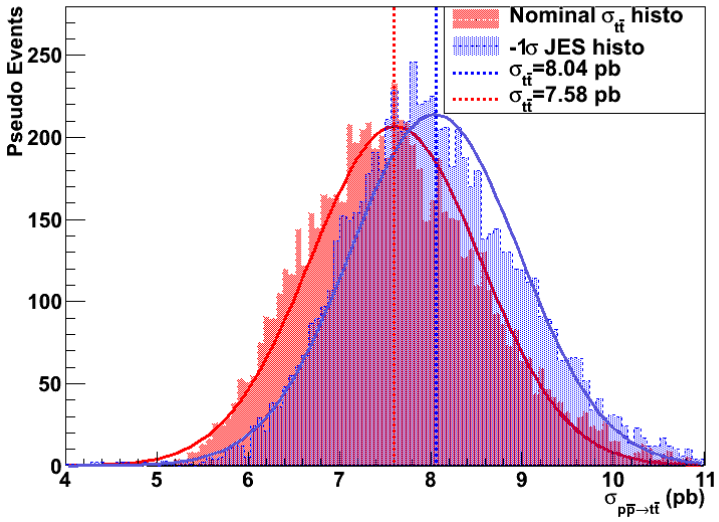
- Table of single systematic sources
- The contributions were checked performing PEs centered on DATA.
  - We fixed the constraint on nuisance parameter x_k by 1σ wrt the nominal mean
  - We performed a new set of PEs (CDF note 5776)
  - We calculated the shift on the mean of the distributions obtained for R and $\sigma_{t\bar{t}}$
- The single contributions were then square summed

$$\mathcal{L}(R, \sigma_{p\bar{p}\to t\bar{t}}, \vec{x}) = \prod_{i}^{N_{bins}} \mathscr{P}\left(\mu^{i}_{exp}(R, \sigma_{p\bar{p}\to t\bar{t}}, x_j) | N^{i}_{obs}\right) \prod_{j}^{N_{syst}} \mathscr{G}\left(x_j | 0, 1\right)$$

Systematics

- EXAMPLE: JES -1σ impact





- The results of the calculation will be shown later in the presentation

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Overview
Motivations
L+Jets Event selection
Systematics
Blessing Items

- Tables and Plots for Blessing

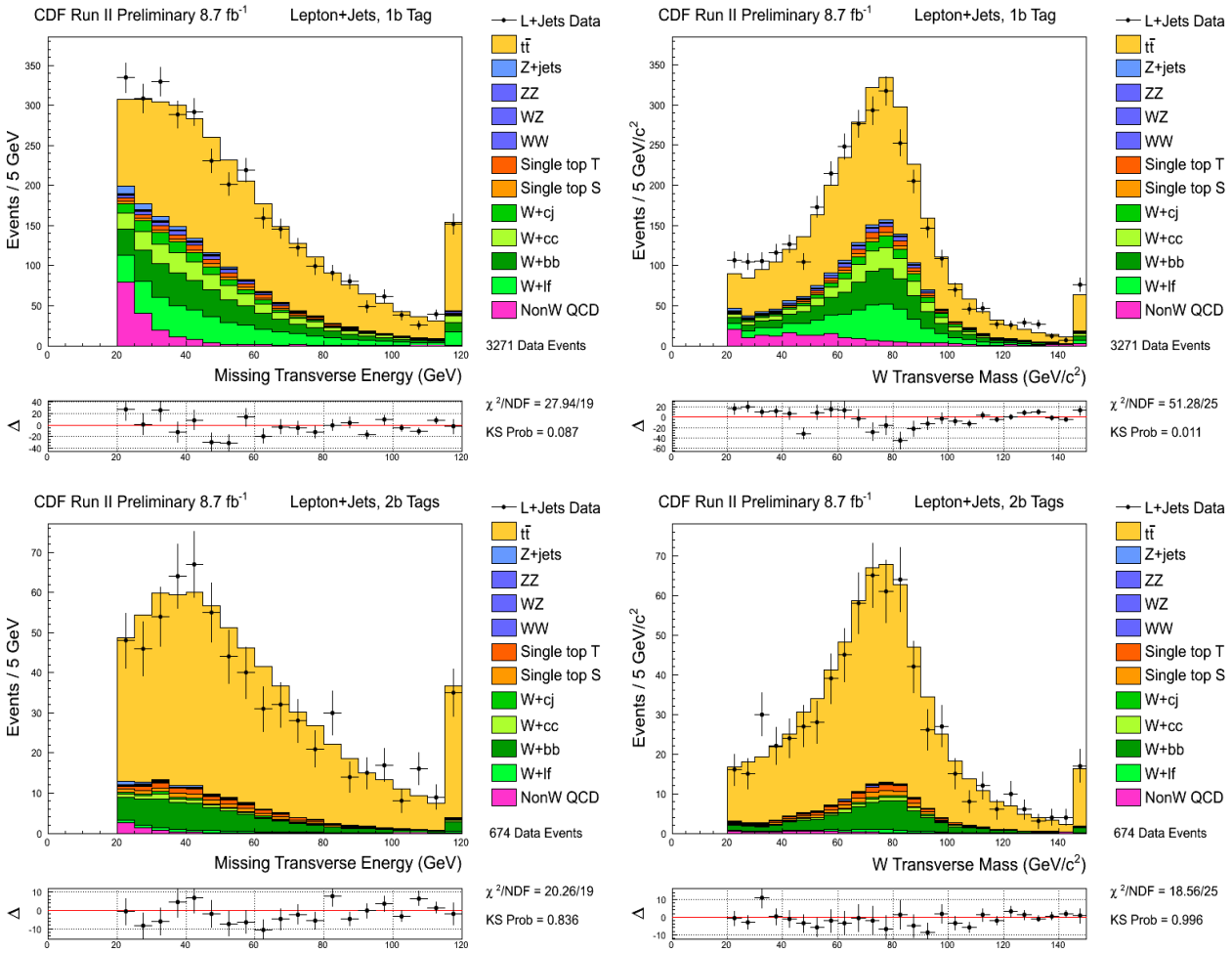
Sample Composition: MII tables R=1, $\sigma_{t\bar{t}} = 7.04$ pb

- Events collected by the three detectors

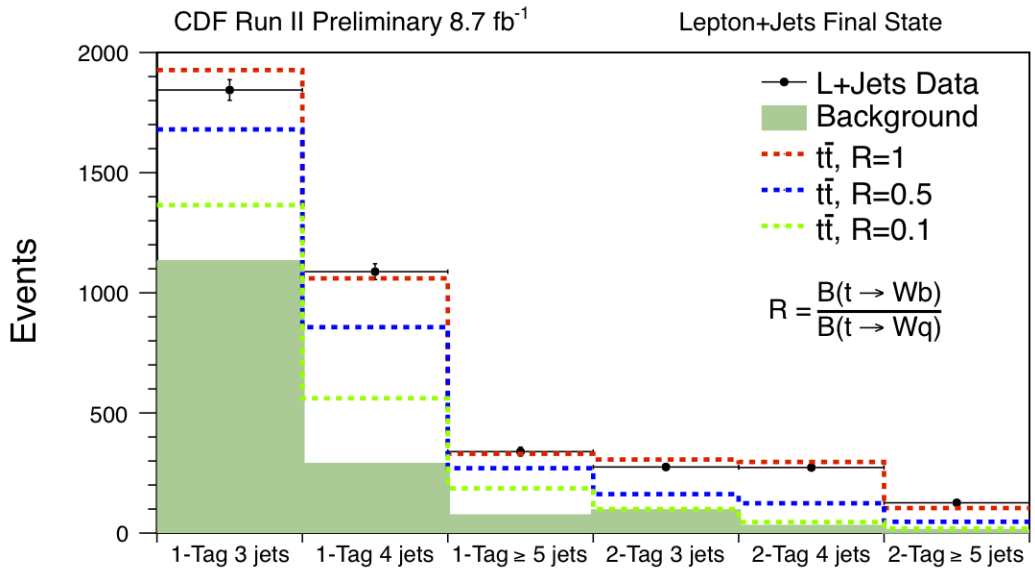
Lepton+Jets, 1b Tag		CDF Preliminary 8.7fb^{-1}	
Process	3 Jets	4 Jets	$\geq$5 Jets
$t\bar{t}$	800 $\pm$ 67	777 $\pm$ 64	260 $\pm$ 21
STopS	30 $\pm$ 2	6.5 $\pm$ 0.5	1.5 $\pm$ 0.1
STopT	48 $\pm$ 5	10$\pm$ 1	2.1 $\pm$ 0.2
WW	33 $\pm$ 4	8 $\pm$ 1	2.4 $\pm$ 0.3
WZ	9.9 $\pm$ 0.9	1.9 $\pm$ 0.2	0.6 $\pm$ 0.1
ZZ	1.8 $\pm$ 0.2	0.46 $\pm$ 0.04	0.12 $\pm$ 0.01
Z+jets	31 $\pm$ 3	9.1 $\pm$ 0.9	2 $\pm$ 0.2
W+bb	291 $\pm$ 118	74 $\pm$ 30	17 $\pm$ 7
W+cc	167 $\pm$ 68	47 $\pm$ 20	12 $\pm$ 5
W+c	87 $\pm$ 35	17 $\pm$ 7	4 $\pm$ 2
Mistags	303 $\pm$ 42	74 $\pm$ 14	17 $\pm$ 6
Non-W	125 $\pm$ 50	35 $\pm$ 29	10 $\pm$ 9
Total Prediction	1928 $\pm$ 243	1061 $\pm$ 93	330 $\pm$ 28
Observed	1844	1088	339

Lepton+Jets, 2b Tag		CDF Preliminary 8.7fb^{-1}	
Process	3 Jets	4 Jets	$\geq$5 Jets
$t\bar{t}$	216 $\pm$ 30	271 $\pm$ 36	97 $\pm$ 13
STopS	9 $\pm$ 1	2.0 $\pm$ 0.3	0.47 $\pm$ 0.06
STopT	9 $\pm$ 1	2.7 $\pm$ 0.4	0.60 $\pm$ 0.09
WW	0.9 $\pm$ 0.2	0.5 $\pm$ 0.1	0.22 $\pm$ 0.04
WZ	1.8 $\pm$ 0.3	0.27 $\pm$ 0.04	0.07 $\pm$ 0.01
ZZ	0.4 $\pm$ 0.1	0.14 $\pm$ 0.02	0.01 $\pm$ 0.00
Z+jets	2.1 $\pm$ 0.2	0.77 $\pm$ 0.08	0.29 $\pm$ 0.03
W+bb	48 $\pm$ 20	14 $\pm$ 6	4 $\pm$ 2
W+cc	5 $\pm$ 2	2 $\pm$ 1	0.8 $\pm$ 0.4
W+c	3 $\pm$ 1	0.8 $\pm$ 0.4	0.2 $\pm$ 0.1
Mistags	5 $\pm$ 1	1.7 $\pm$ 0.4	0.6 $\pm$ 0.2
Non-W	6 $\pm$ 3	0.1 $\pm$ 1.5	0.1 $\pm$ 1.5
Total Prediction	306 $\pm$ 40	296 $\pm$ 38	104 $\pm$ 13
Observed	275	273	126

Sample Composition:MET and WmT 1,2 Tag

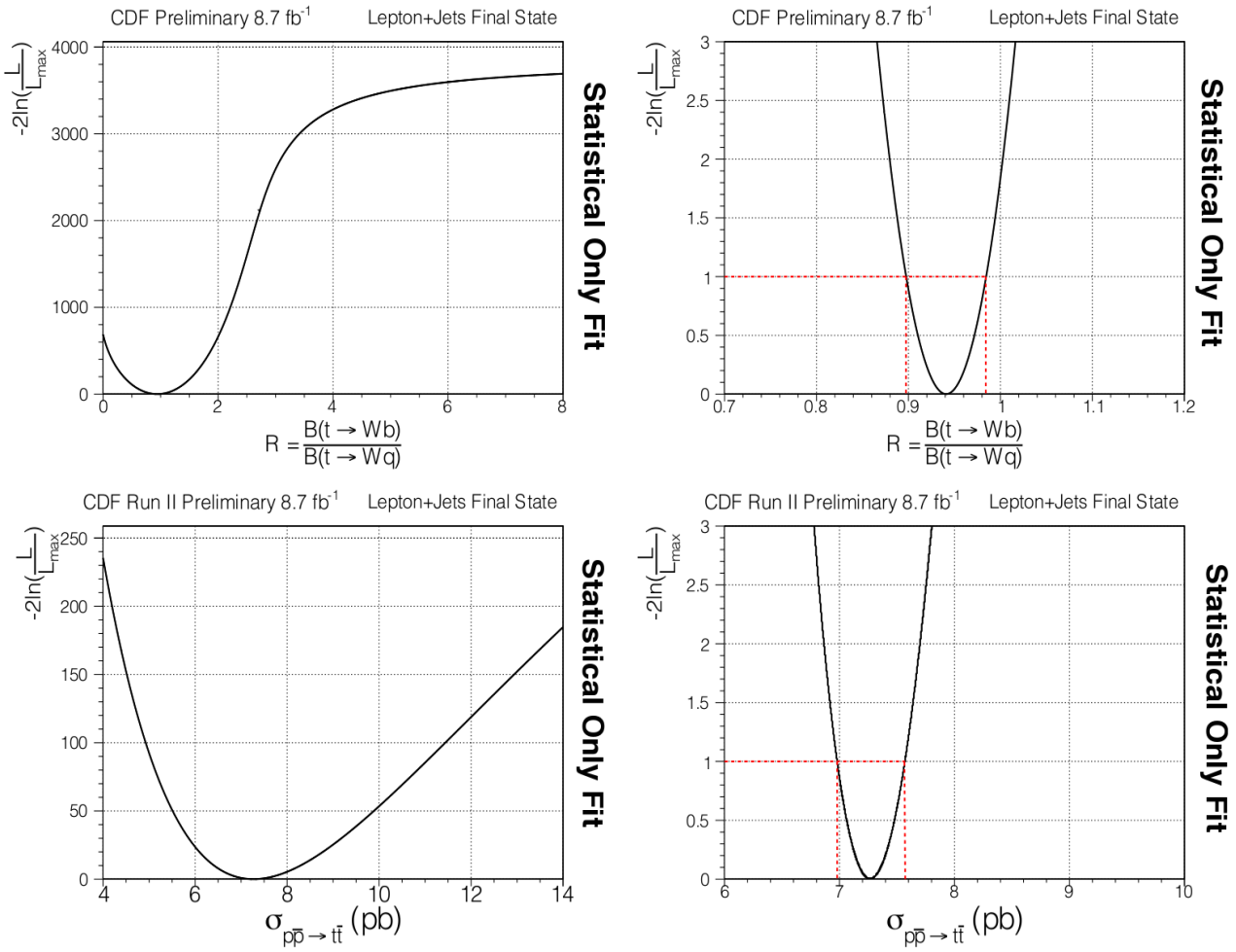


Method of the analysis: Results

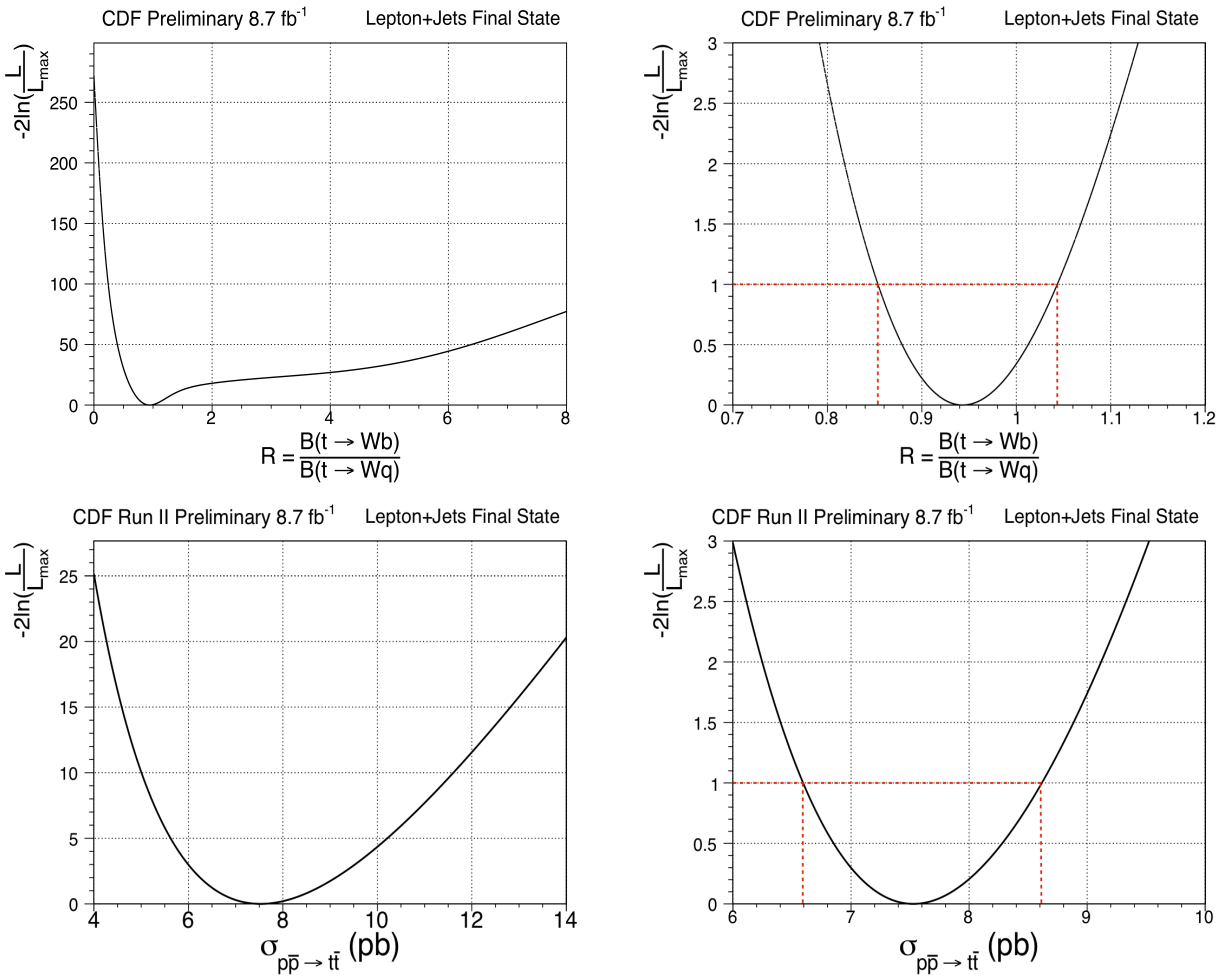


		Lepton+Jets	CDF Preliminary 8.7fb^{-1}				
			$1b$ Tag			$2b$ Tags	
		3jets	4jets	≥5jets	3jets	4jets	≥5jets
Background (N_B^i) Total Expected (μ_{exp}^i)	R=0.1	1117 ± 230	279 ± 65	68 ± 18	88 ± 24	25 ± 8	7 ± 3
		1365 ± 232	561 ± 72	186 ± 22	100 ± 24	46 ± 9	19 ± 4
	R=0.5	1123 ± 232	282 ± 68	70 ± 18	90 ± 27	25 ± 9	7 ± 3
		1680 ± 238	857 ± 84	270 ± 25	162 ± 27	124 ± 17	47 ± 7
	R=1.0	1127 ± 233	283 ± 67	69 ± 18	90 ± 27	25 ± 11	7 ± 3
		1927 ± 243	1060 ± 93	330 ± 28	306 ± 40	296 ± 38	104 ± 13
Observed(N_{obs}^i)		1844	1088	339	275	273	126

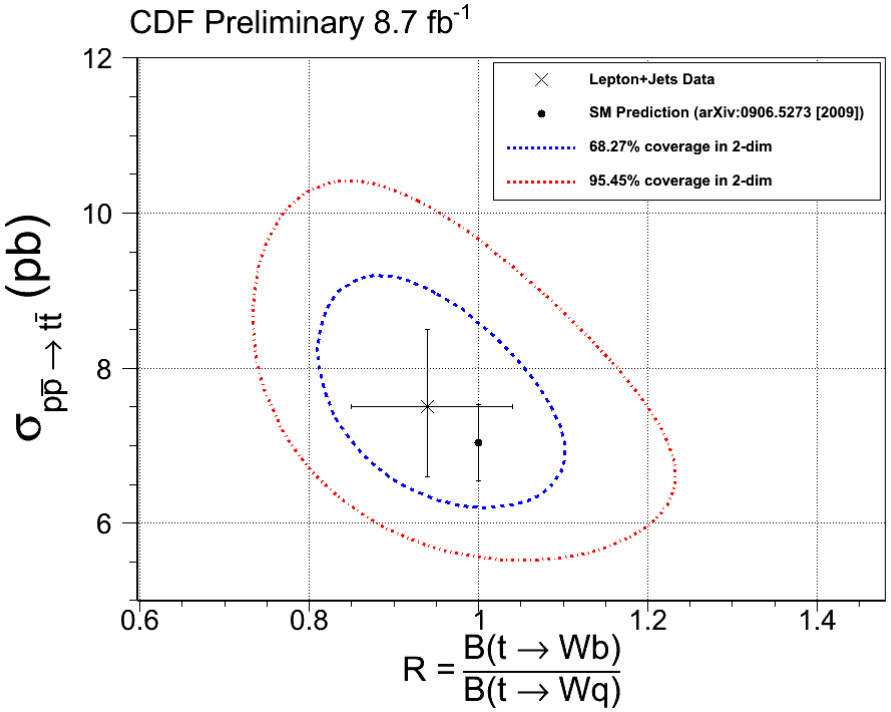
Results:Statistical Fit Only



Results:Combined Fit



Results: Bidimensional Fit and Table

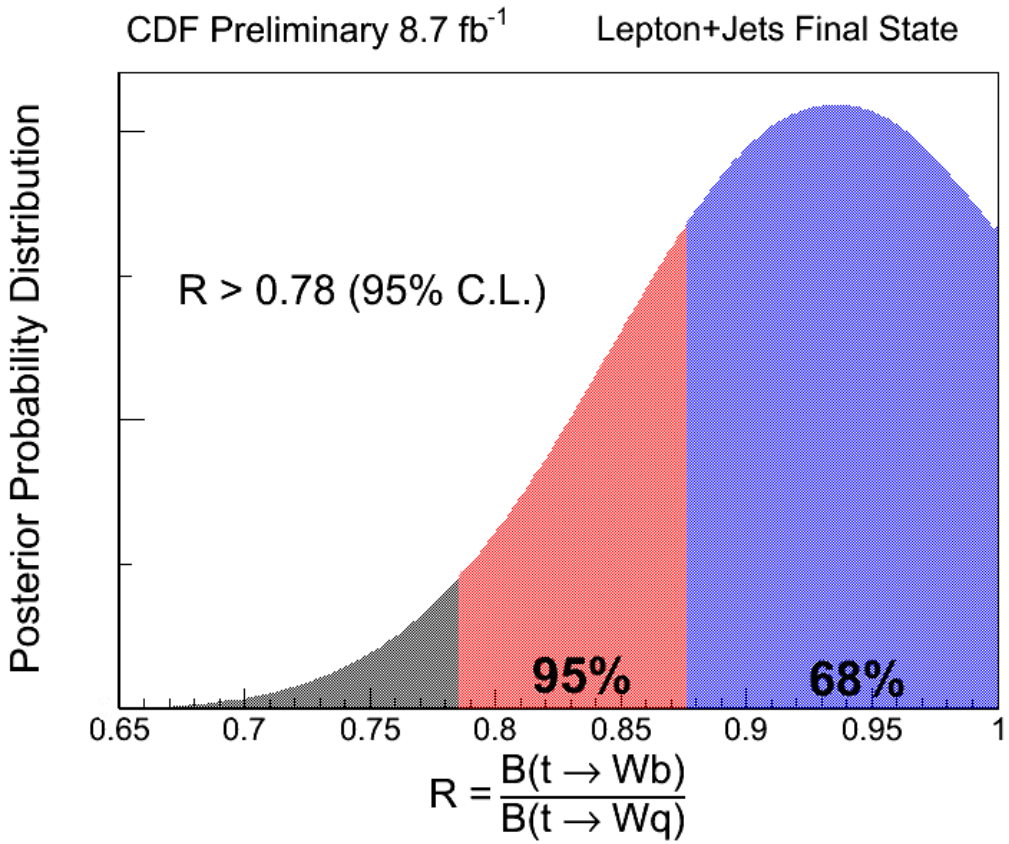


Lepton+Jets	CDF Preliminary 8.7 fb^{-1}
$\sigma_{p\bar{p}\to t\bar{t}}$ (pb)	7.5 ± 0.3 (stat) ± 0.9 (syst)
R	0.94 ± 0.04 (stat) ± 0.09 (syst)
$\lvert V_{tb}\rvert$	0.97 ± 0.05 (stat+syst)

Results: Systematics

Lepton + Jets			CDF Preliminary 8.7fb^{-1}	
Source	$+\delta R$	$-\delta R$	$+\delta\sigma_{p\bar{p}\to t\bar{t}}$ (pb)	$-\delta\sigma_{p\bar{p}\to t\bar{t}}$ (pb)
Statistical	0.043	-0.043	0.29	-0.29
Jet Energy Scale	0.016	-0.019	0.46	-0.41
ISR/FSR	0.006	-0.006	0.22	-0.21
Top mass	0.001	-0.000	0.33	-0.32
b-tagging	0.078	-0.073	0.06	-0.03
Background Normalization	0.056	-0.052	0.78	-0.66
Luminosity	0.001	-0.002	0.44	-0.39
Signal Modeling	0.001	-0.002	0.04	-0.02
Triggers	0.003	-0.002	0.13	-0.12
Muon Identification	0.002	-0.002	0.08	-0.08
Electron Identification	0.002	-0.003	0.04	-0.03
z_0 cut	0.000	-0.001	0.02	-0.01
Others	0.003	-0.003	0.02	-0.02
Squared sum	0.098	-0.092	1.08	0.96

Results: Lower Limit



Lepton + Jets			CDF Preliminary 8.7fb^{-1}
	Value (stat+syst)	Lower Limit 68% CL	Lower Limit 95% CL
$\sigma_{p\bar{p}\to t\bar{t}}$ (pb)	7.5 ± 1.0	-	-
R	0.94 ± 0.09	0.876	0.785
$\lvert V_{tb}\rvert$	0.97 ± 0.05	0.936	0.886

- SM assumption
- $R = |V_{tb}^2|$

Results: no SM assumption

Results without SM assumption

- Without the unitarity constraint we have

$$\frac{1-R}{R} = \frac{|V_{ts}|^2 + |V_{td}|^2}{|V_{tb}|^2} < 0.28 \tag{1}$$

- Using $|V_{ts}| = 42.9 \cdot 10^{-3}$ and $|V_{td}| = 8.4 \cdot 10^{-3}$ (PRD 86 010001 (2012))
- This leads to

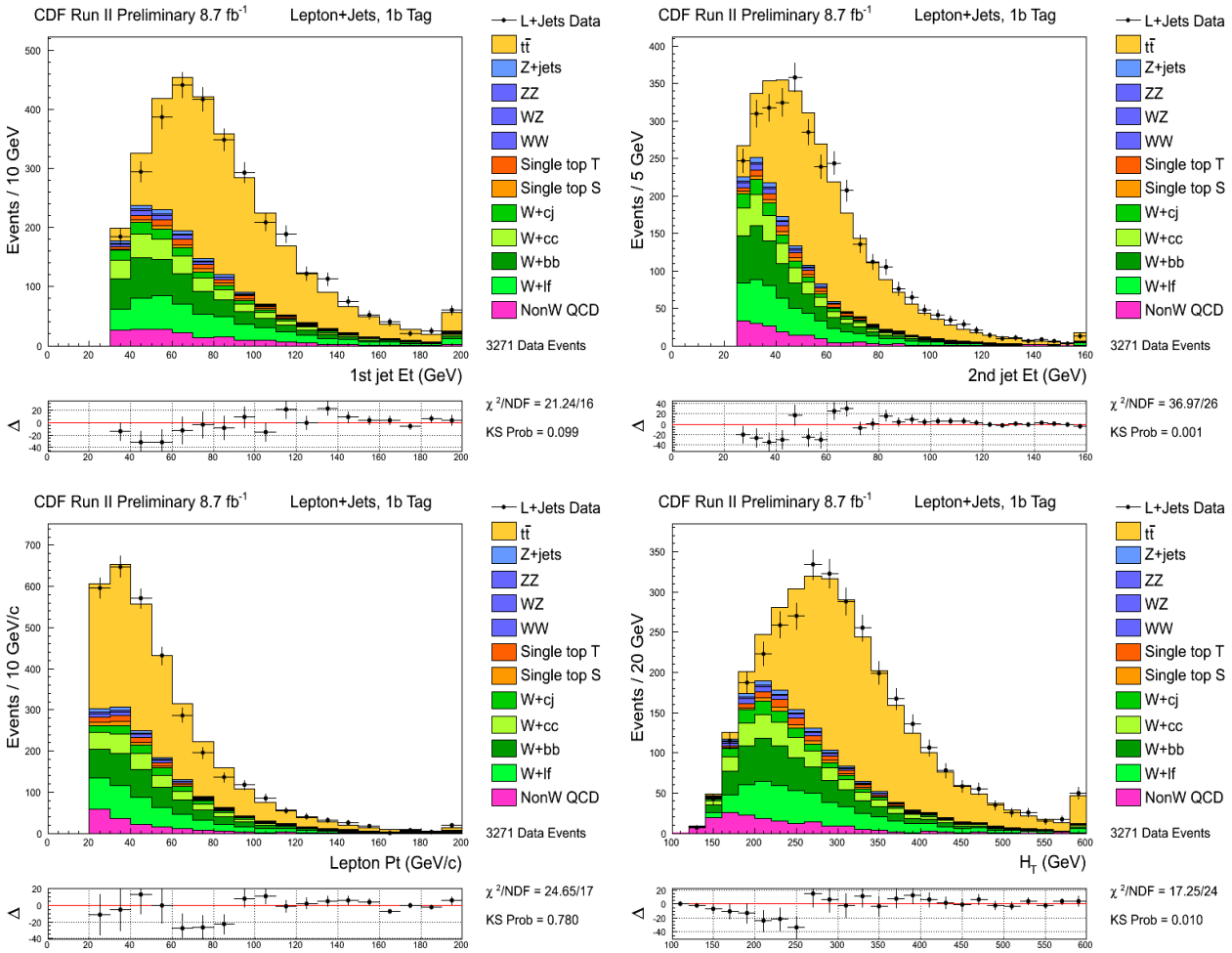
$$|V_{tb}| > 0.08 \tag{2}$$

Conclusions

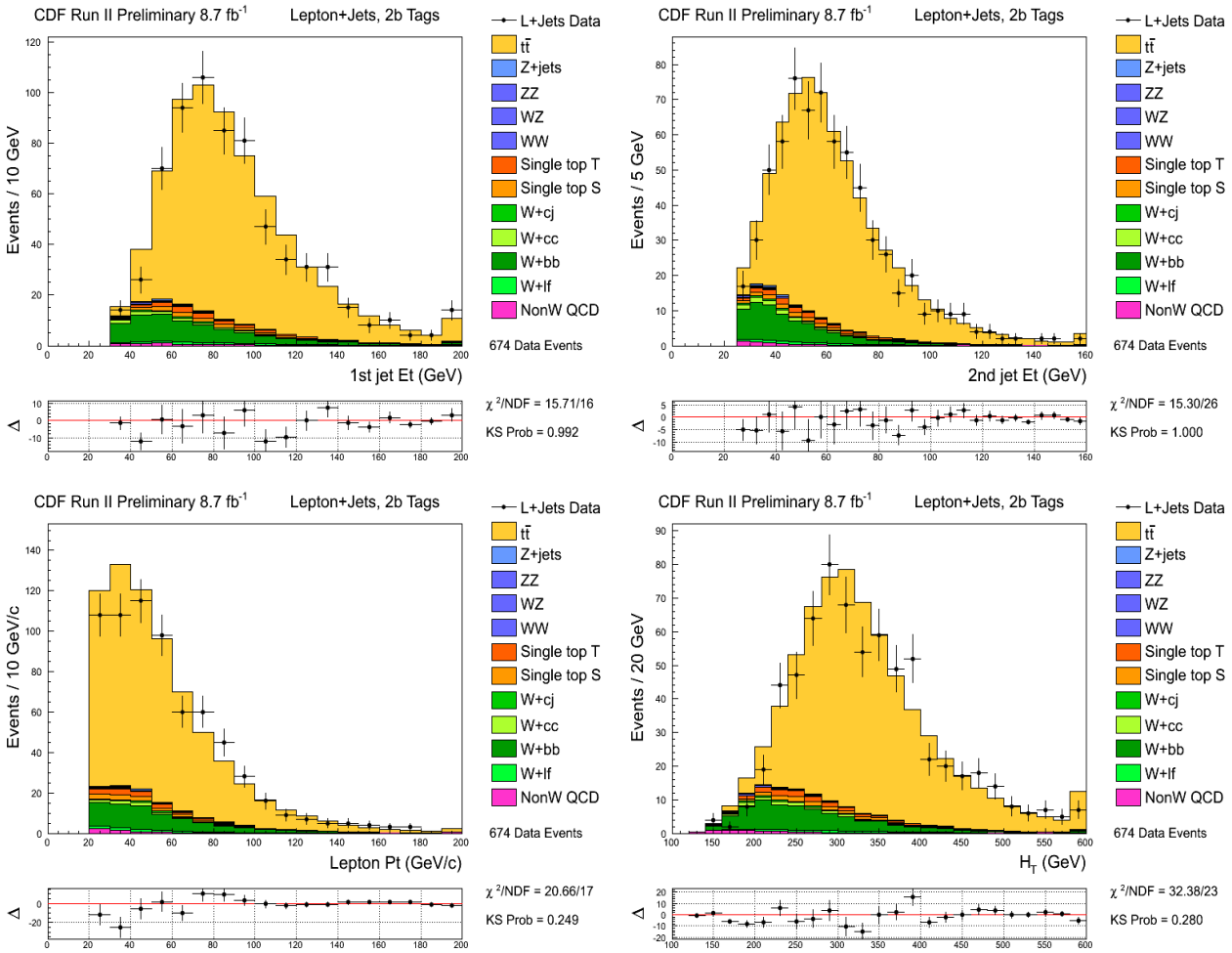
- We measured R and $\sigma_{t\bar{t}}$ simultaneously using 8.7fb^{-1} of data
- The results are consinstent with the Standard Model Prediction
- The first public note draft has been sent to John and Monica and to Dave and Costas as well
- After blessing we will go for the paper draft ASAP

BACKUP

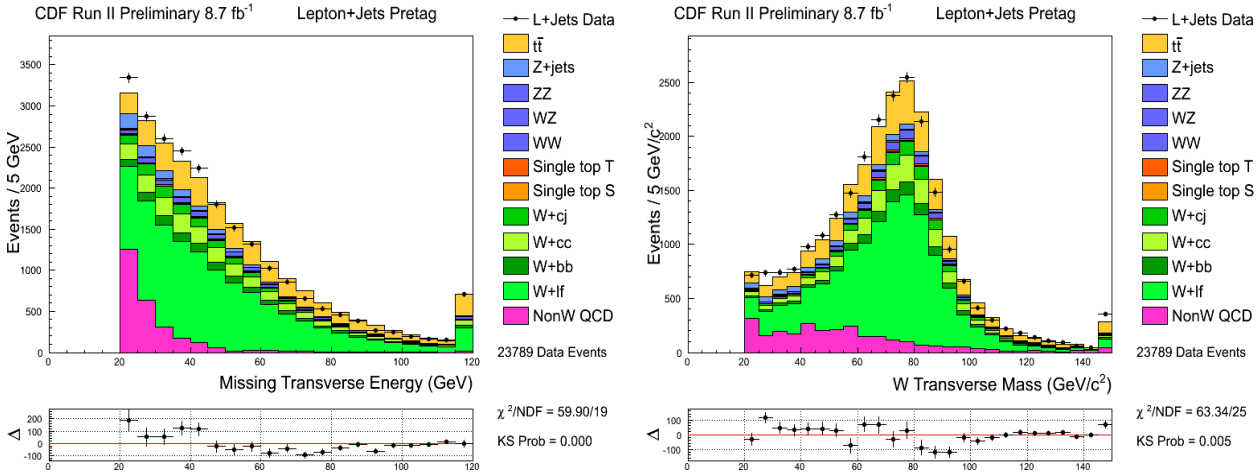
Sample Composition:J1Et,J2Et,LepPt,Ht 1Tag



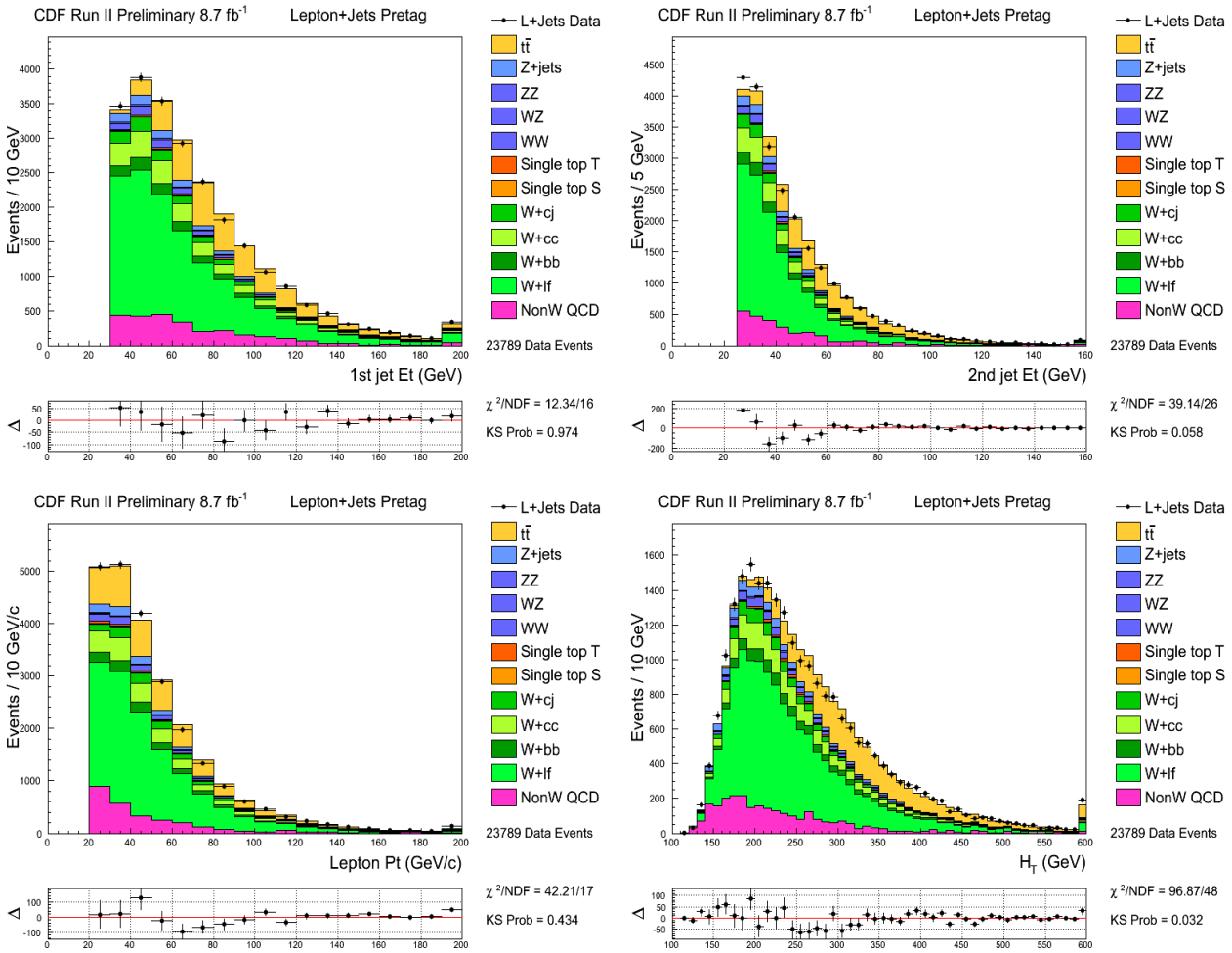
Sample Composition:J1Et,J2Et,LepPt,Ht 2Tag



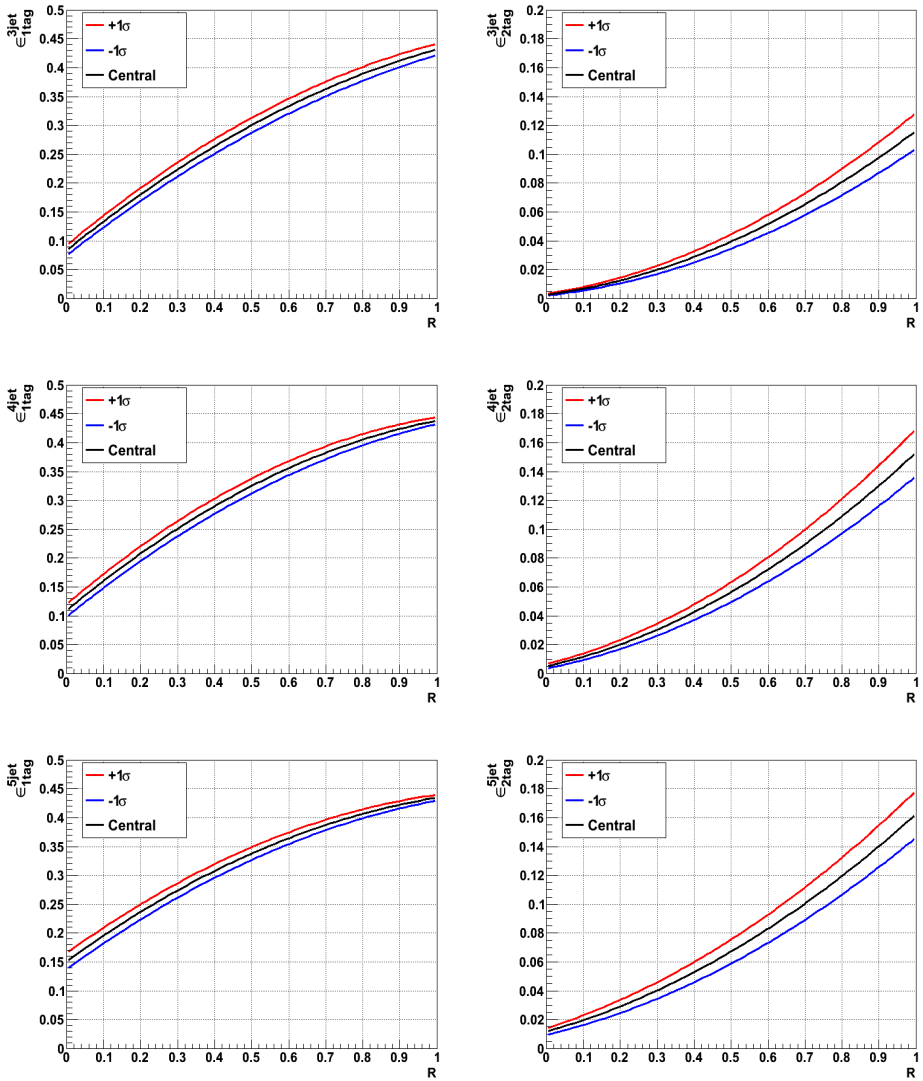
Sample Composition:Met, WMt PreTag



Sample Composition:J1Et,J2Et,LepPt,Ht Pretag



Sample Composition:Event Tagging Efficiencies



Event tag efficiency

The probability to tag an event P^{event}_{k-tag} (with 0,1 or 2 tags) is given by:

$$P^{event}_{1-tag} = \sum_{i=1}^{n} p_i^{tag} \cdot \left(\prod_{j=1, j\neq i}^{n} \left(1 - p_j^{tag}\right) \right) \tag{3}$$

$$P^{event}_{2-tag} = \sum_{i=1}^{n-1} p_i^{tag} \cdot \left(\sum_{j>i}^{n} p_j^{tag} \cdot \left(\prod_{k=1, k\neq i, k\neq j}^{n} (1 - p_k^{tag}) \right) \right) \tag{4}$$

p_i is the probability to tag a jet.

Event tag efficiency

Using P^{event}_{k-tag} we calculated the event tag efficiencies:

$$\epsilon_{k-tag} = \frac{\sum_j^{events} P^j_{k-tag}}{N_{pretag}}. \tag{5}$$

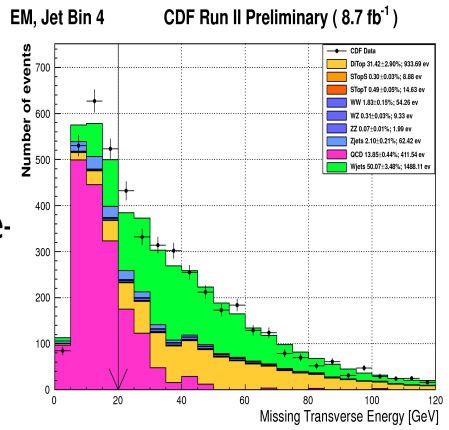
the sum is performed on N_{pretag}

Considerations:

- We are using the standard MC sample for the signal modeling: $t \to Wb$ only
- We should obtain standard results with $R = 1$ and simulate $t \to Wq$ per $R \neq 1$

Analysis Overview

- Selected sample composition
  - EWK processes (WW,WZ,ZZ,single-top,Z+jets,$t\bar{t}$ signal)
  - W+jets
  - non-W



Process	Cross section (pb)
$t\bar{t}$	7.04 ± 0.49
Single Top (t)	0.68 ± 0.06
Single Top (s)	0.34 ± 0.02
WW	11.34 ± 0.66
WZ	$3.22 \pm 0{,}02$
ZZ	1.20 ± 0.06
Z+jets	787 ± 85

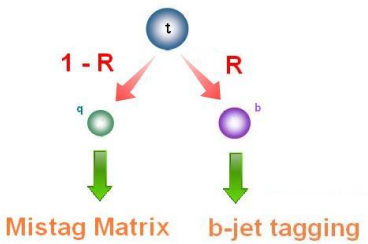
CEM+CMUP+CMX - CDF Preliminary 8.7 fb^{-1} - Lepton + jets

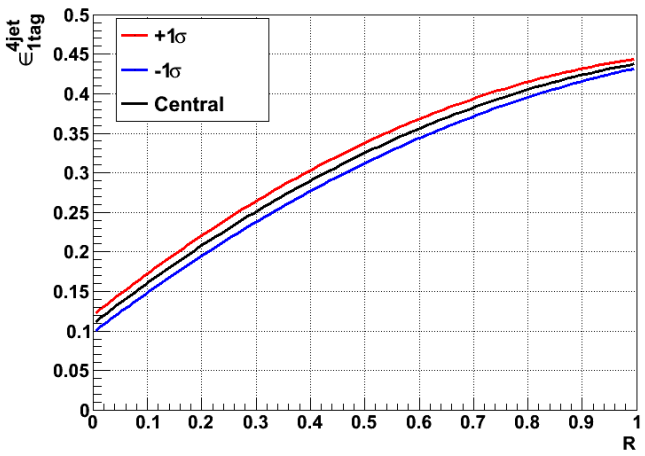
	1-Tag			2-Tag		
Process	3jets	4jets	5jets	3jets	4jets	5jets
EWK	954 ± 82	814 ± 67	269 ± 22	239 ± 33	277 ± 37	98 ± 13
W+jets (HF)	545 ± 220	138 ± 56	33 ± 14	56 ± 23	17 ± 7	5 ± 2
W+jets (LF)	303 ± 42	74 ± 14	17 ± 6	4 ± 1	1.7 ± 0.4	0.6 ± 0.2
non-W	125 ± 50	35 ± 29	10 ± 9	6 ± 3	0.1 ± 1.5	0.1 ± 1.5
Total	1928 ± 243	1061 ± 93	330 ± 28	306 ± 40	296 ± 37	104 ± 13
Observed	1844	1088	339	275	273	126

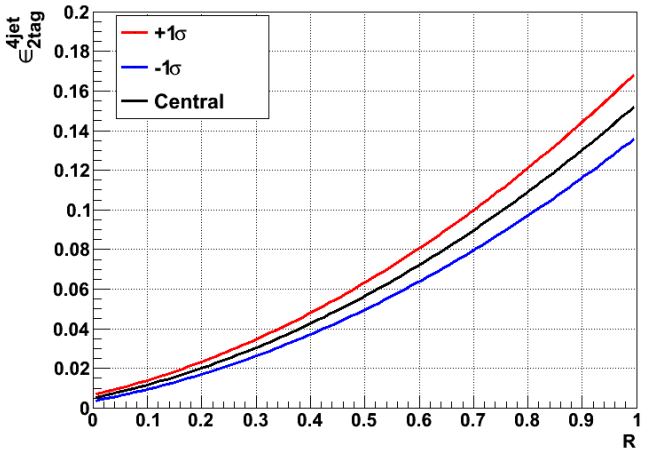
Measurement Method: Event Tag Efficiency

- So far: CDF standard analysis with $R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = 1$
- We removed this hypothesis, and we inserted R as a free parameter
- Prediction of $t\bar{t}$ events

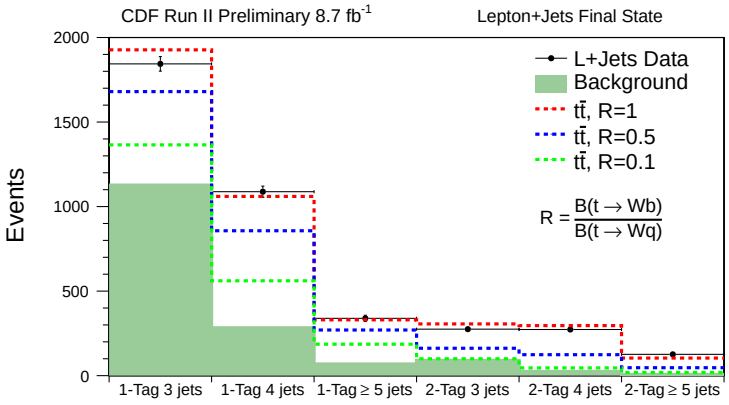
$$\mu_{t\bar{t}} = \mathscr{L} \cdot \epsilon_{evt} \cdot \sigma_{p\bar{p} \to t\bar{t}} \cdot \epsilon_{k-tag}(R)$$







Measurent Strategy: results



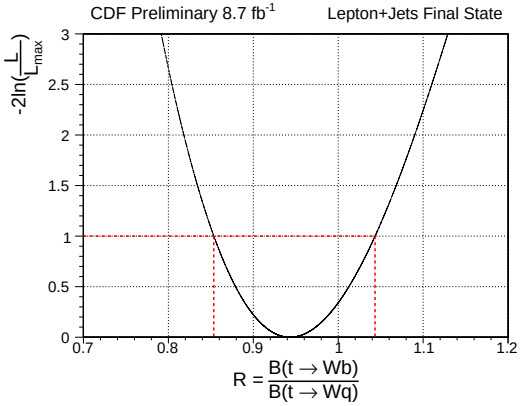
- Number of events with 1- or 2-Tag in the final state
- Total prediction μ_{exp} vs observed data N_{obs}

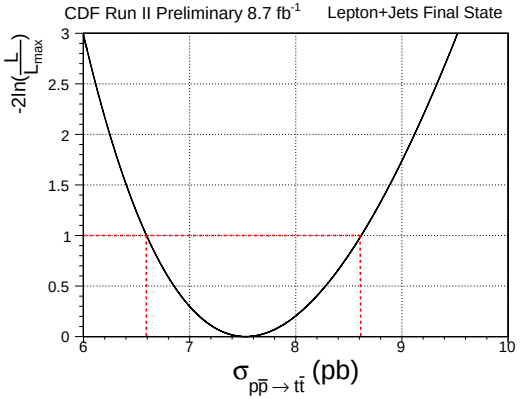
$$\mu_{exp} = \mu_{t\bar{t}}(R, \sigma_{p\bar{p}\to t\bar{t}}) + N_{bkg}$$

	Lepton+Jets	CDF Preliminary 8.7fb^{-1}					
		1b Tag			2b Tags		
		3jets	4jets	≥5jets	3jets	4jets	≥5jets
Background (N_B^i) Total Expected (μ_{exp}^i)	R=0.1	1117 ± 230 1365 ± 232	279 ± 65 561 ± 72	68 ± 18 186 ± 22	88 ± 24 100 ± 24	25 ± 8 46 ± 9	7 ± 3 19 ± 4
	R=0.5	1123 ± 232 1680 ± 238	282 ± 68 857 ± 84	70 ± 18 270 ± 25	90 ± 27 162 ± 27	25 ± 9 124 ± 17	7 ± 3 47 ± 7
	R=1.0	1127 ± 233 1927 ± 243	283 ± 67 1060 ± 93	69 ± 18 330 ± 28	90 ± 27 306 ± 40	25 ± 11 296 ± 38	7 ± 3 104 ± 13
Observed(N_{obs}^i)		1844	1088	339	275	273	126

Measurement Strategy: Likelihood fit

- Simultaneous fit on R and $\sigma_{p\bar{p}\to t\bar{t}}$
- Recursive procedure:
  - (1): Fit on data and extraction of R and $\sigma_{p\bar{p}\to t\bar{t}}$
  - (2): New sample composition analysis with the fitted $\sigma_{p\bar{p}\to t\bar{t}}$
  - (3): Go back to (1) until stable result: $\left|\frac{\Delta R}{R}\right| \sim 0.001$





$$\mathcal{L}(R,\sigma_{p\bar{p}\to t\bar{t}},\vec{x}) = \prod_{i}^{N_{bins}} \mathscr{P}\left(\mu^{i}_{exp}(R,\sigma_{p\bar{p}\to t\bar{t}},x_j)|N^{i}_{obs}\right) \prod_{j}^{N_{syst}} \mathscr{G}\left(x_j|0,1\right)$$