Simultaneous Heavy Flavor Fractions and Top Cross Section Measurement at CDF

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May 11th 2010

Motivation for this Method

- The four largest systematic uncertainties in a previous method:
  - Luminosity
    - Can be reduced by normalizing result to Z cross section.
  - B tagging uncertainty
  - Jet energy scale
  - Heavy Flavor correction

- Can we use the data to help us with the remaining big systematic uncertainties?

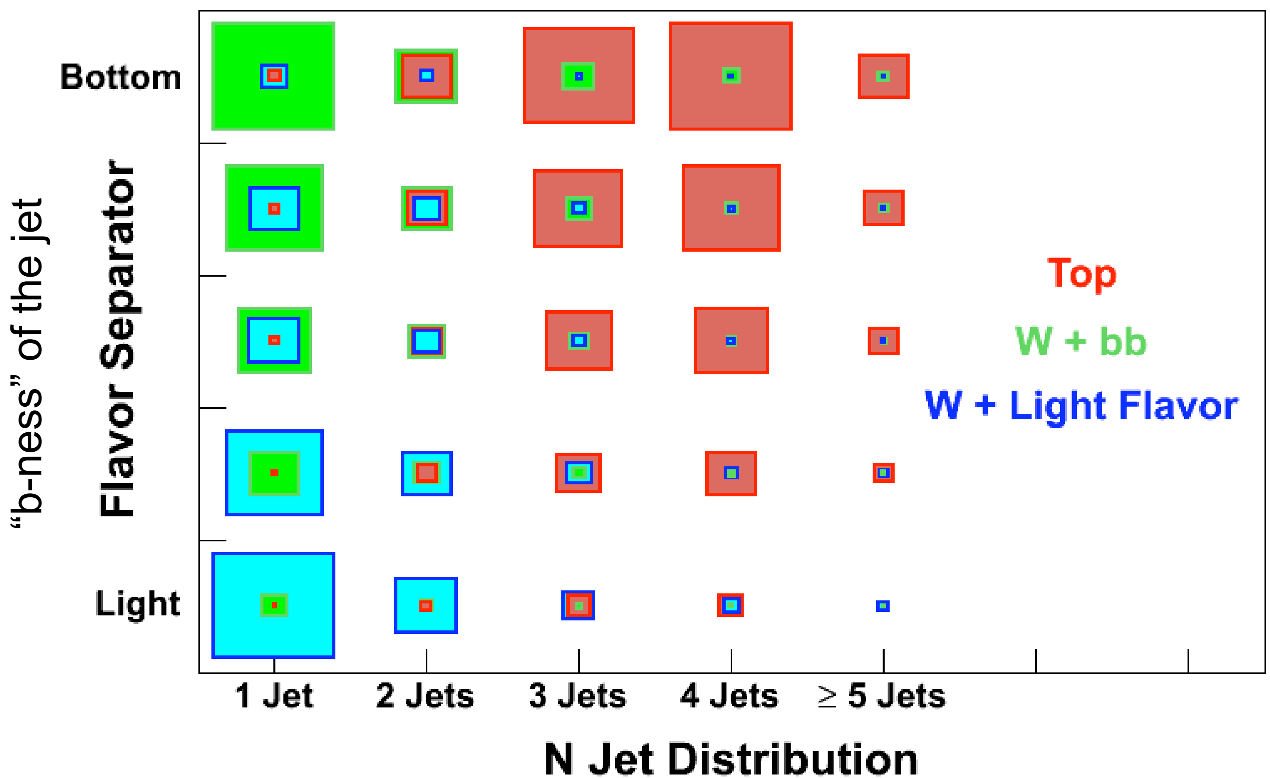
SYSTEMATIC	Δ	Δ%
JET ENERGY SCALE	0.29	4.1
TAGGING	0.39	5.5
MISTAGS	0.17	2.4
HEAVY FLAVOR CORRECTION	0.27	3.8
LUMINOSITY	0.43	6.1
QCD	0.06	0.8
MONTE CARLO GENERATOR	0.21	3.0
INITIAL/FINAL STATE RADIATION	0.06	0.8
LEPTON ID	0.04	0.6
Z0	0.02	0.3
PDF	0.04	0.6
TOTALS	0.76	10.7

CDF Run II Preliminary L = 2.7 fb^{-1}

What variables are available?

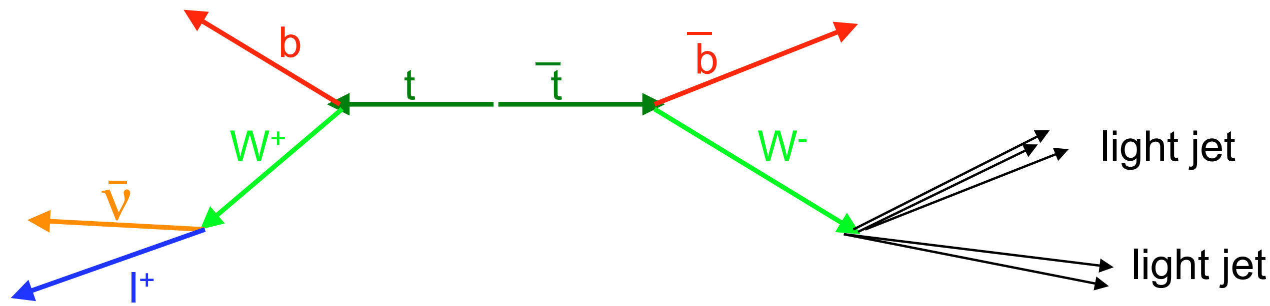
- What discriminating variables are available:
  - "Flavor separator" ⇒ Distinguish Wbb from Wc/Wcc and W LF
  - N-Jet distribution ⇒ Distinguish Top from Wbb

Flavor Separator versus N-Jet Distribution

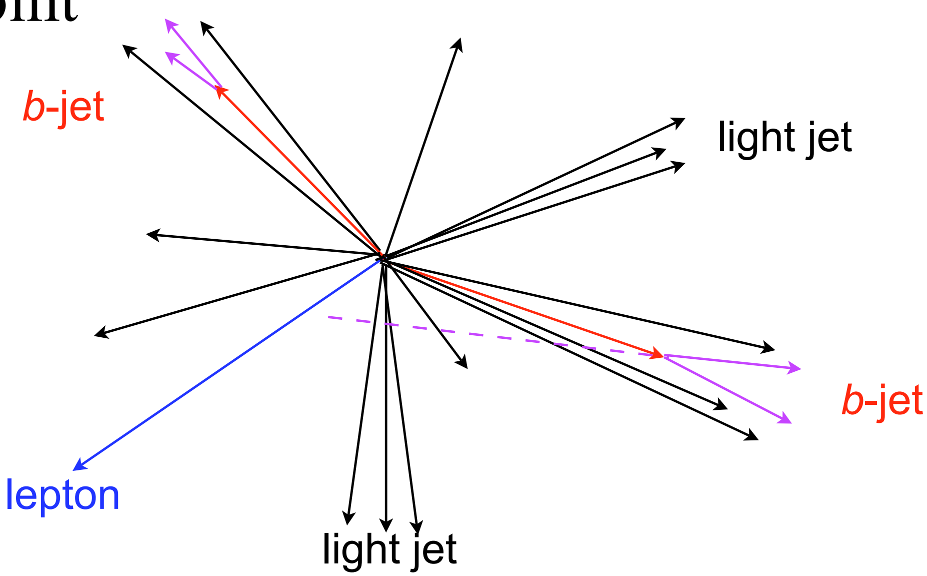


Identify a *b*-jet

- *b*-tagging: algorithm to identify jets that originated from a b quark



- B hadron is long lived, so its daughters are displaced from interaction point



Event Selection and QCD

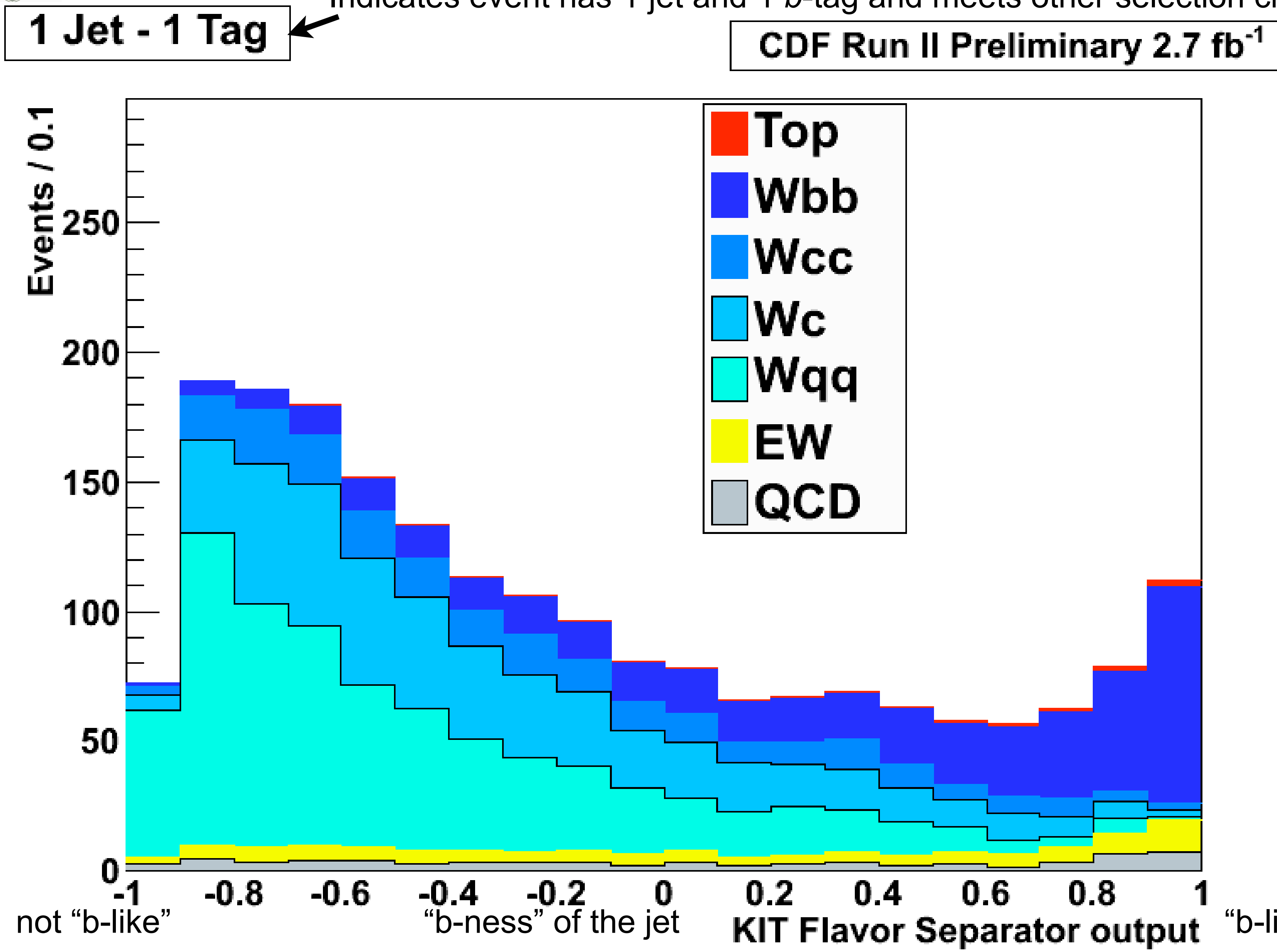
- Apply selection criteria to enhance the signal and suppress the background
- Event selection: Lepton-plus-jets channel
  - $\geq$ 1 Jet (Corrected $E_T \geq 20$ GeV and $\eta < 2.0$)
  - 1 Electron or Muon (ET $\geq$ 20 GeV)
  - Missing transverse energy $\geq$ 20 GeV
  - $\geq$1 Jet identified as a *b*-jet
  - Using 2.7 fb^{-1} of data
  - QCD Veto using transverse W mass
    - $m_T^W > 10$ GeV/c^2 for muons
    - $m_T^W > 20$ GeV/c^2 for electrons
  - Event selection taken as-is, and is ***not*** optimized for uncertainties.
  - ***Compare directly to previous method!***

Making the Templates

- Run Monte Carlo simulations to estimate both signal and background contributions.
  - Top
  - $W + b\bar{b} + jets$
  - $W + c\bar{c} + jets$
  - $W + c + jets$
  - $W + q\bar{q} + jets$
  - Single top, di-boson, Z + jets (other Electroweak)
- QCD background is estimated from data

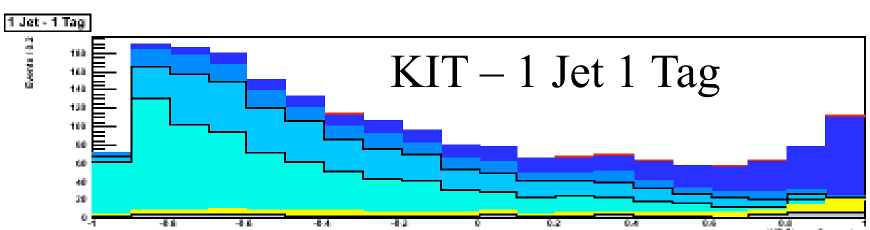
What Are We Fitting?

Indicates event has 1 jet and 1 *b*-tag and meets other selection criteria



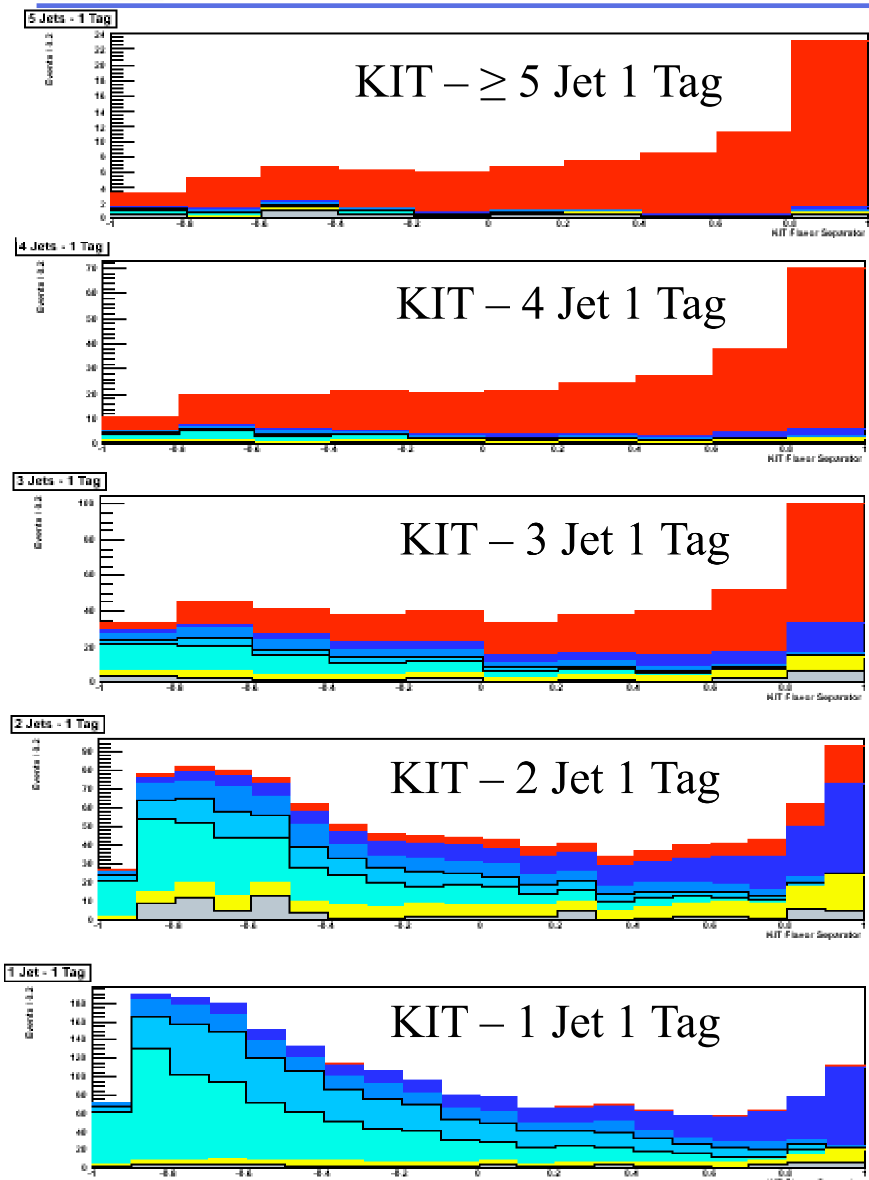
not “b-like” “b-ness” of the jet “b-like”

What Are We Fitting?



KEY	Top	Wbb	Wcc	Wc	Wqq	EW	QCD

What Are We Fitting?



KEY	Top	Wbb	Wcc	Wc	Wqq	EW	QCD

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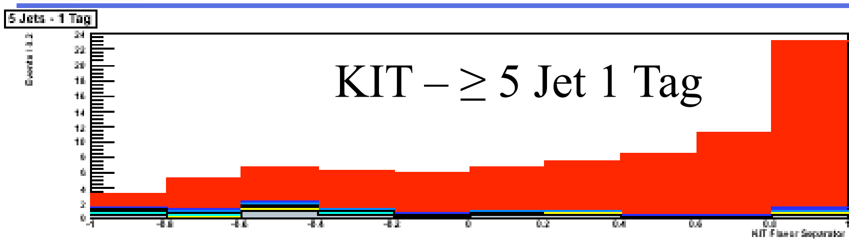
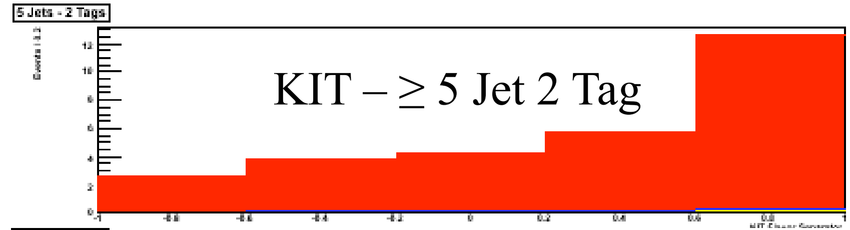
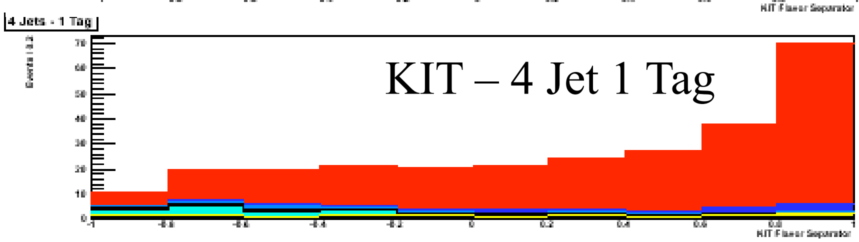
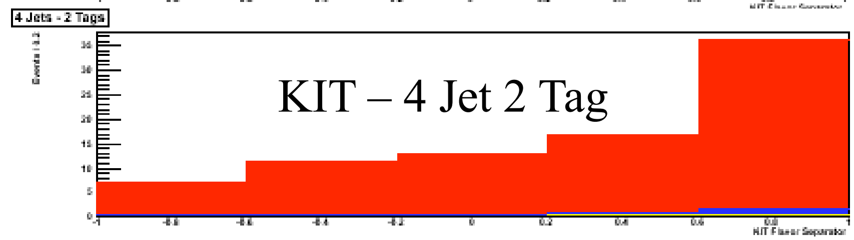
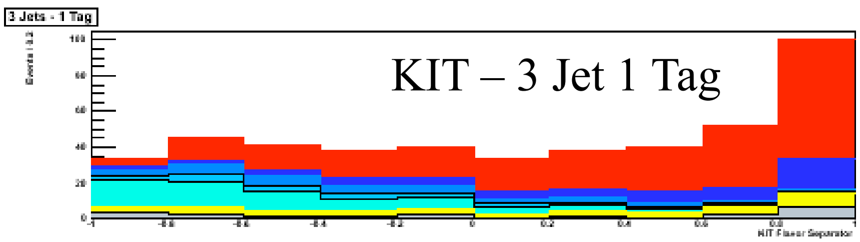
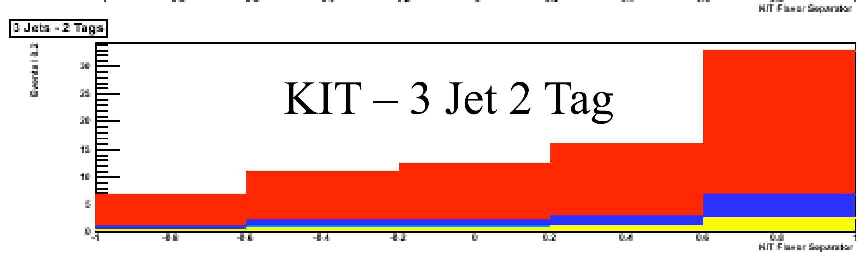


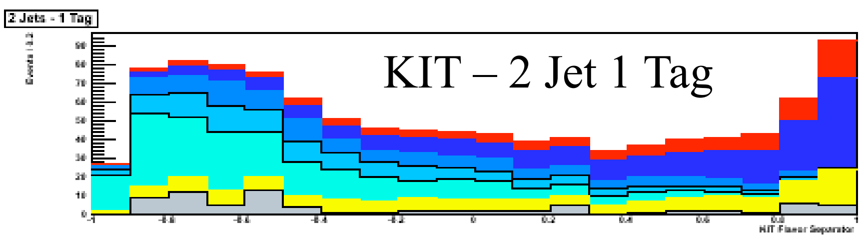


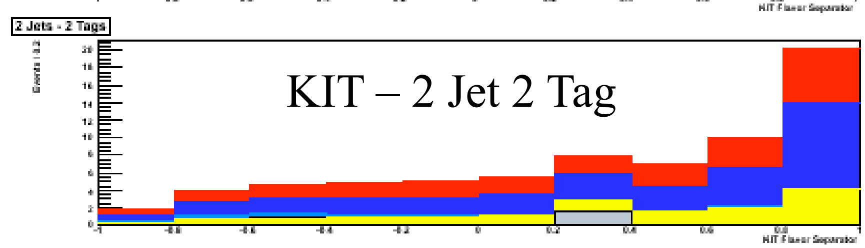


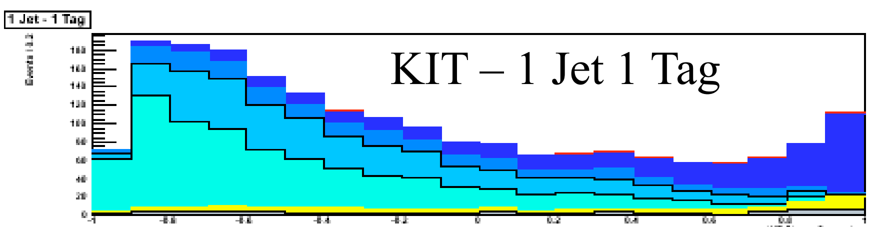








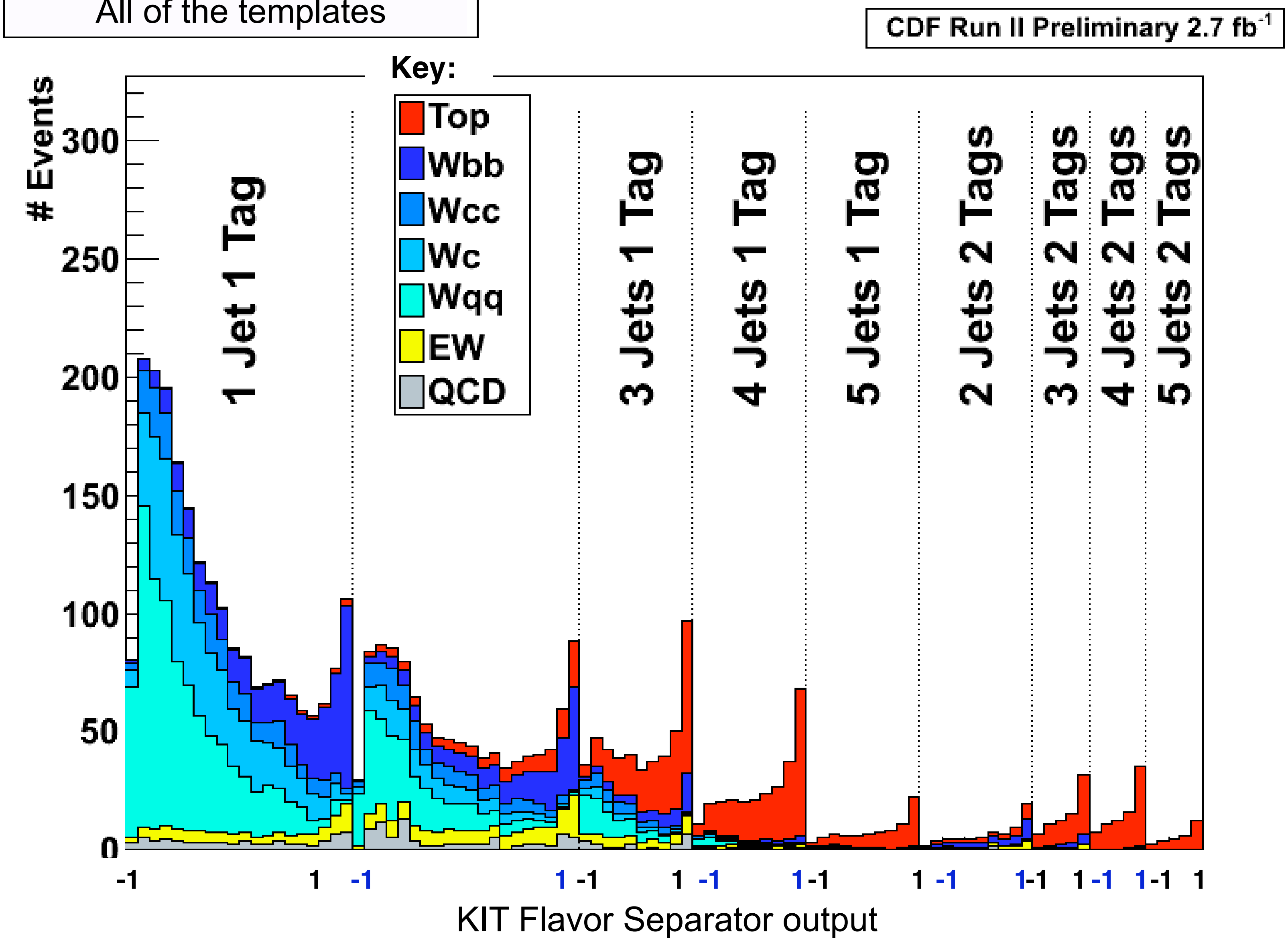




KEY	Top	Wbb	Wcc	Wc	Wqq	EW	QCD

Summary of the Templates

All of the templates

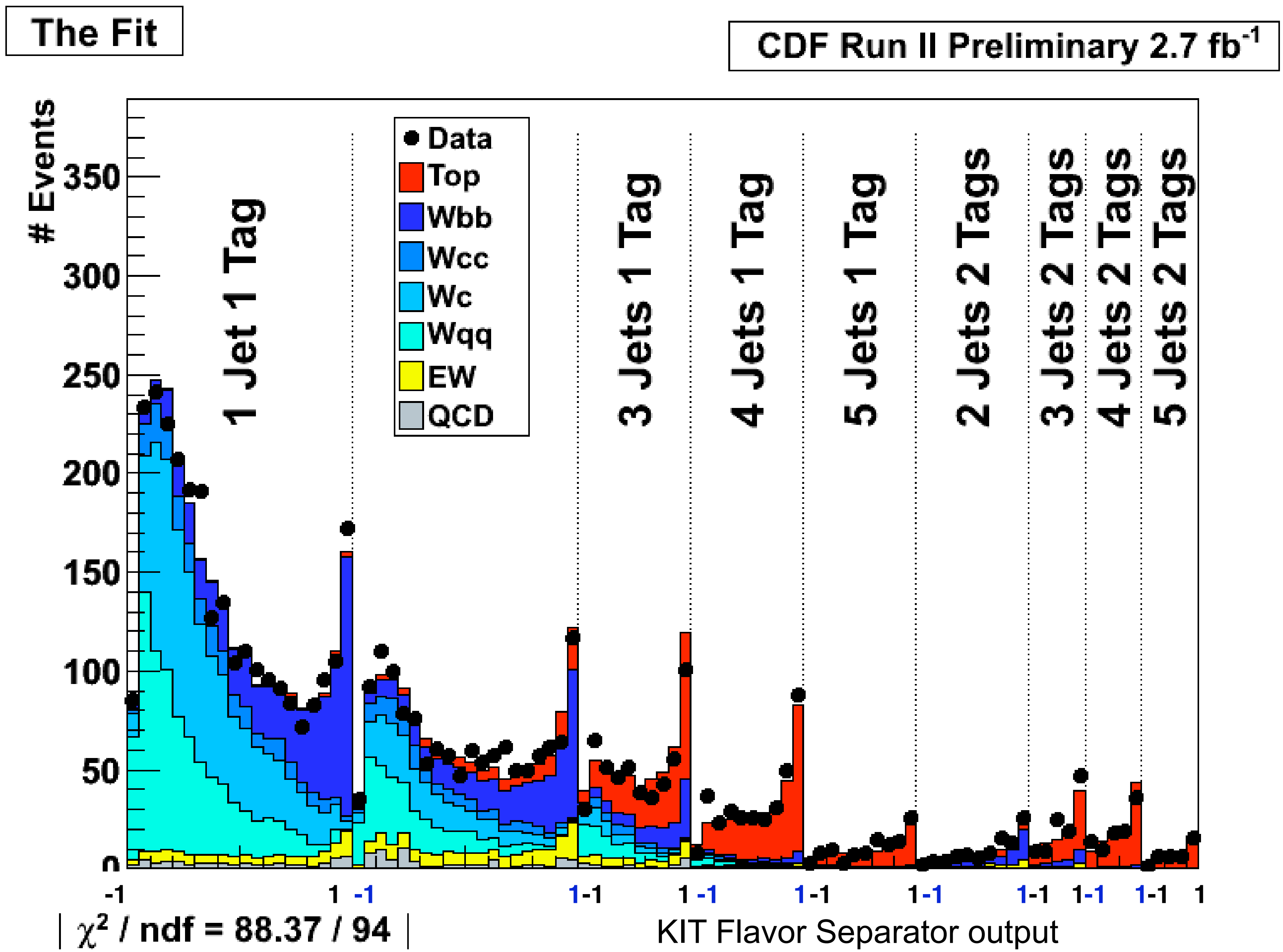


Summary of Fitting Strategy

- Split events into single and double tags.
- W + jets no longer treated as a background, but now another signal.
- Everything is fit simultaneously
  - Top, Wbb, Wcc, Wc, Wqq
  - EW (single top, diboson, etc) and QCD are constrained to calculated/fit cross sections.
  - Unlike previous analysis, different pieces of same templates are tied together.
    - Jet bins ***not*** normalized separately.
    - *E.g.*, Except for systematic uncertainties, Top 2-jet 1-tag size tied directly to Top 5-jet 2-tag size.
  - Systematic uncertainties are included in the fit:
    - *b*-tag and mistag uncertainties
    - Jet energy scale
    - Q^2 for W + jets
    - ISR/FSR for top

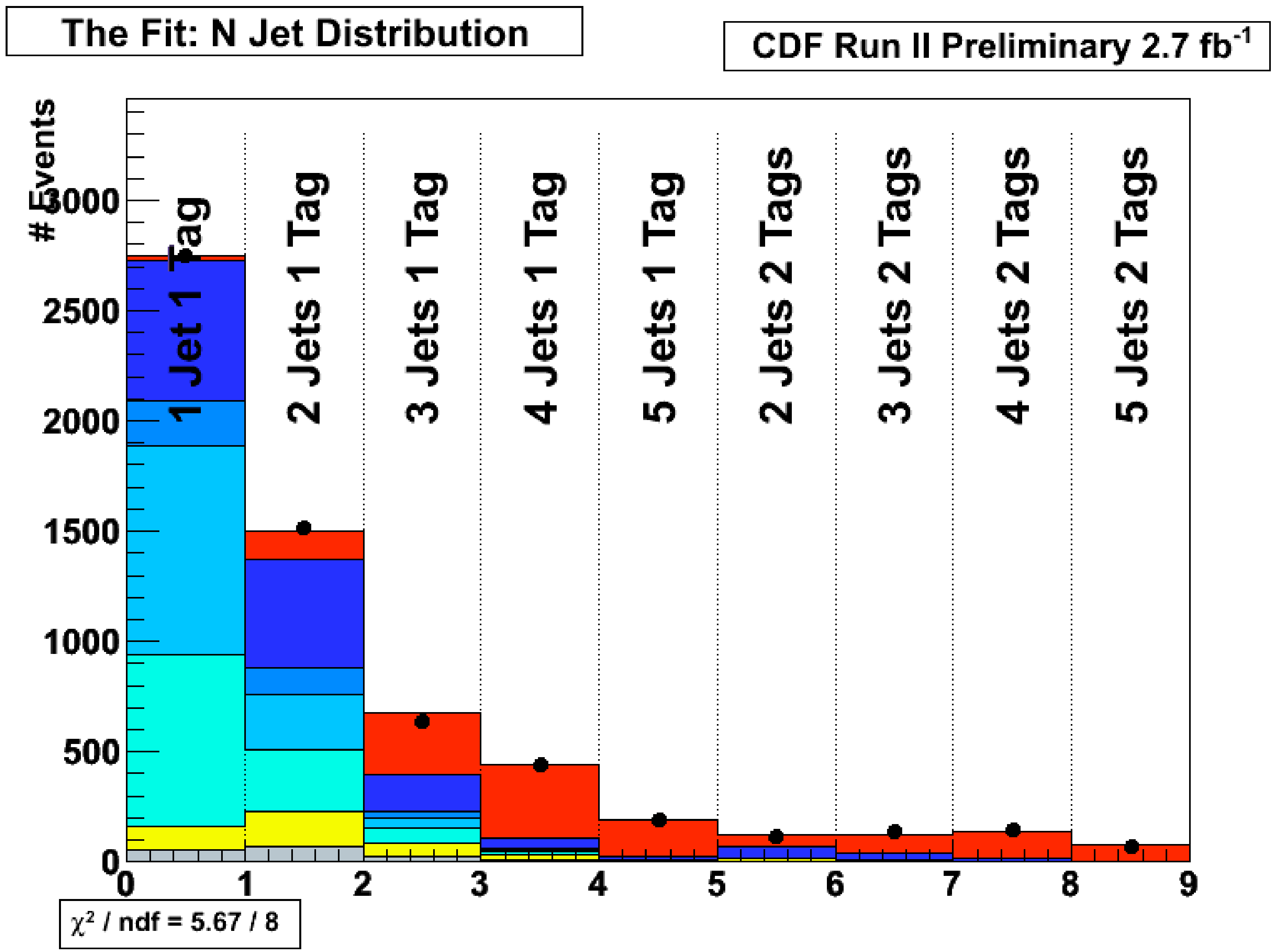
Results

The Fit



The Fit
CDF Run II Preliminary 2.7 fb^{-1}
Events
Data
Top
Wbb
Wcc
Wc
Wqq
EW
QCD
1 Jet 1 Tag
3 Jets 1 Tag
4 Jets 1 Tag
5 Jets 1 Tag
2 Jets 2 Tags
3 Jets 2 Tags
4 Jets 2 Tags
5 Jets 2 Tags
χ^2 / ndf = 88.37 / 94
KIT Flavor Separator output

N Jet Spectrum



Results

Sample	Measured Value	Expected Uncertainty (mean $\pm$ rms)
$\sigma_{t\bar{t}}$	$7.64^{+0.57}_{-0.54}$ pb	0.53 ± 0.04 pb
K_{Wbb}	$1.57^{+0.28}_{-0.22}$	0.27 ± 0.17
K_{Wcc}	$0.94^{+0.90}_{-0.71}$	0.93 ± 0.36
K_{Wc}	$1.90^{+0.34}_{-0.32}$	0.43 ± 0.31
K_{Wqq}	$1.10^{+0.34}_{-0.25}$	0.27 ± 0.07
K_{EW}	$1.00^{+0.10}_{-0.10}$	0.10 constraint
K_{QCD}	$0.82^{+0.26}_{-0.26}$	0.30 constraint
r_{Btag}	$0.31^{+0.64}_{-0.64}$	0.68 ± 0.02
r_{Mistag}	$-0.05^{+0.98}_{-0.98}$	0.99 ± 0.06
r_{IFSR}	$0.13^{+0.90}_{-0.89}$	0.87 ± 0.09
r_{JES}	$0.47^{+0.63}_{-0.61}$	0.65 ± 0.09
r_{Q^2}	$0.07^{+0.43}_{-0.44}$	0.44 ± 0.09

Scale Factors*

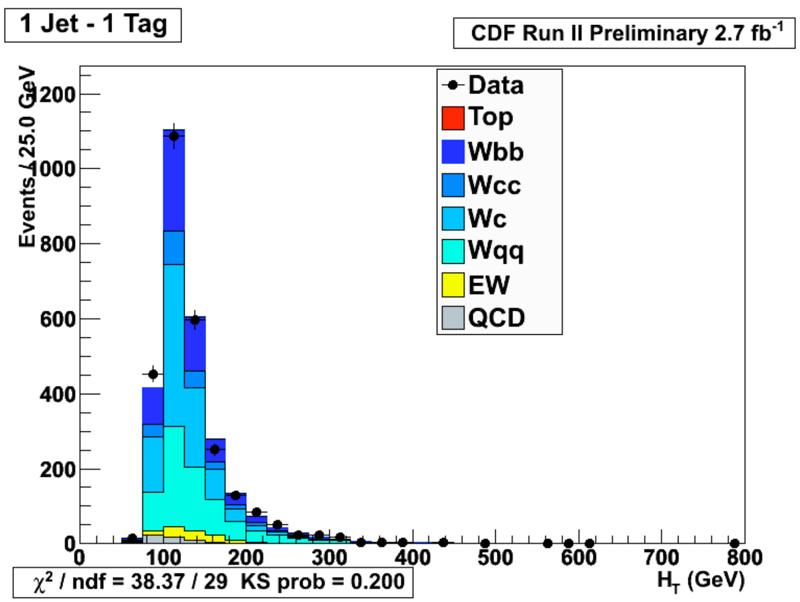
Systematic Shifts**

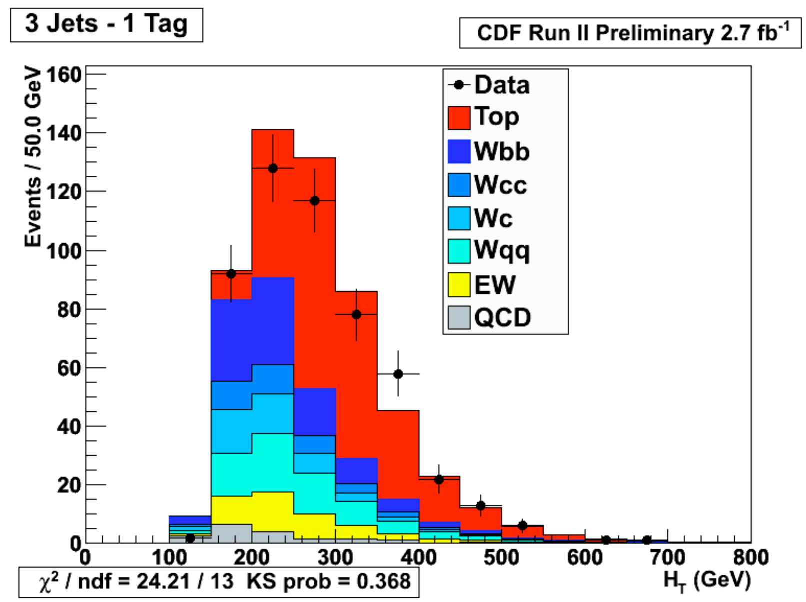
Fit with Gaussian Constraints

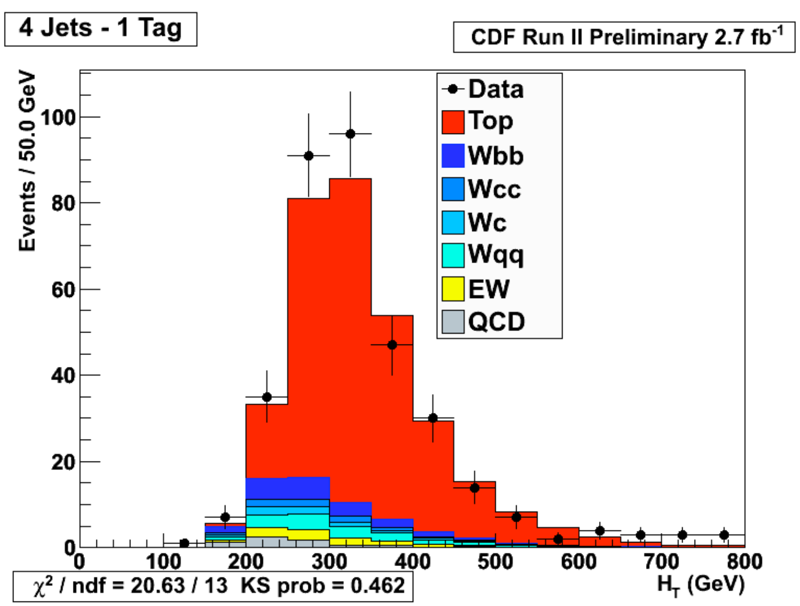
*All Scale Factors are relative to QCD predictions

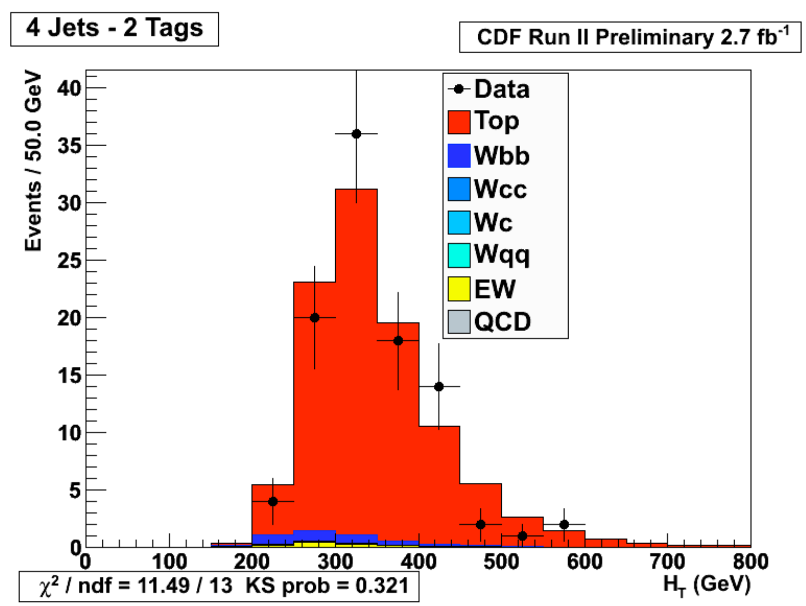
**Systematic shifts are relative to external errors

Kinematic Distributions: H_T

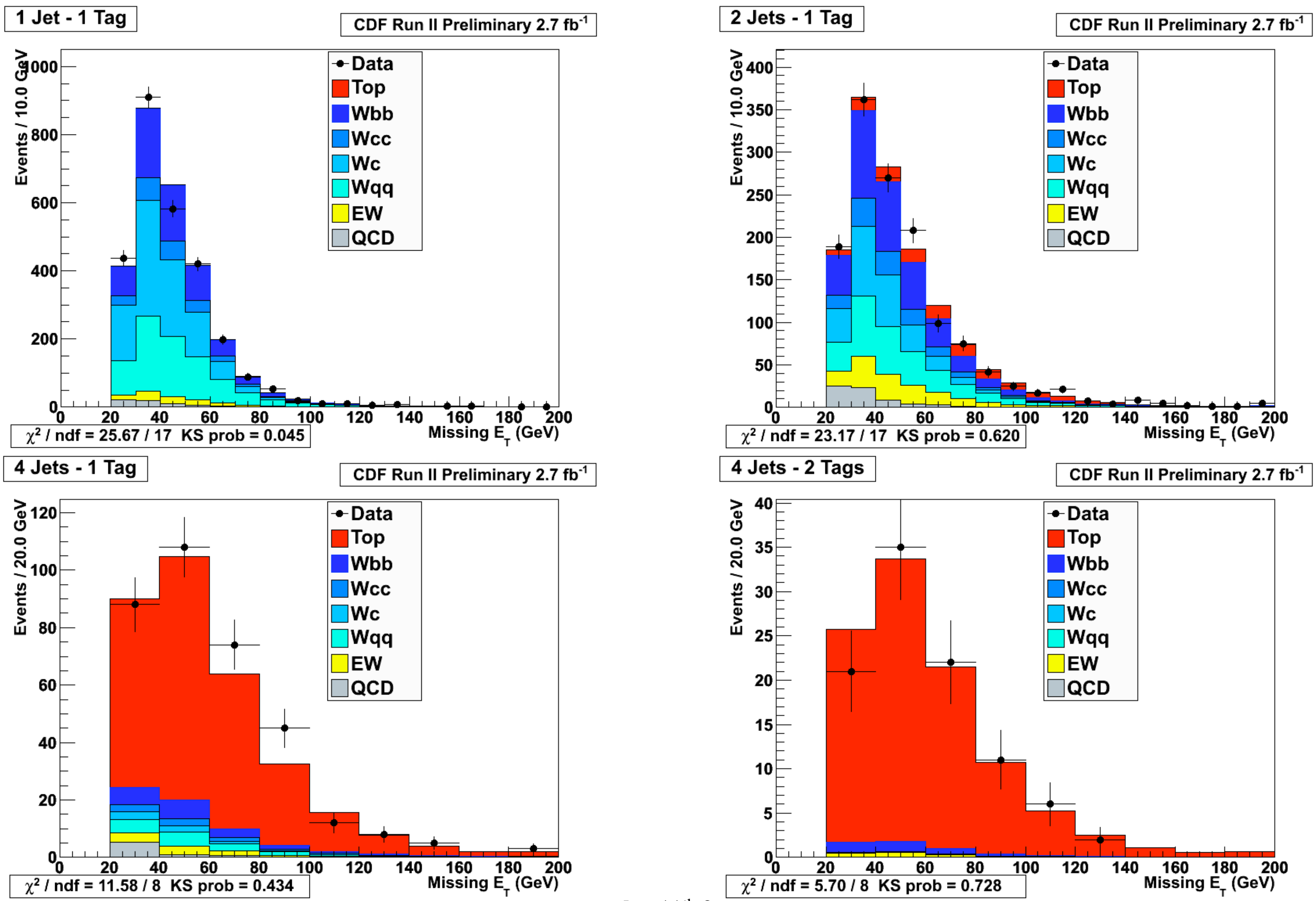




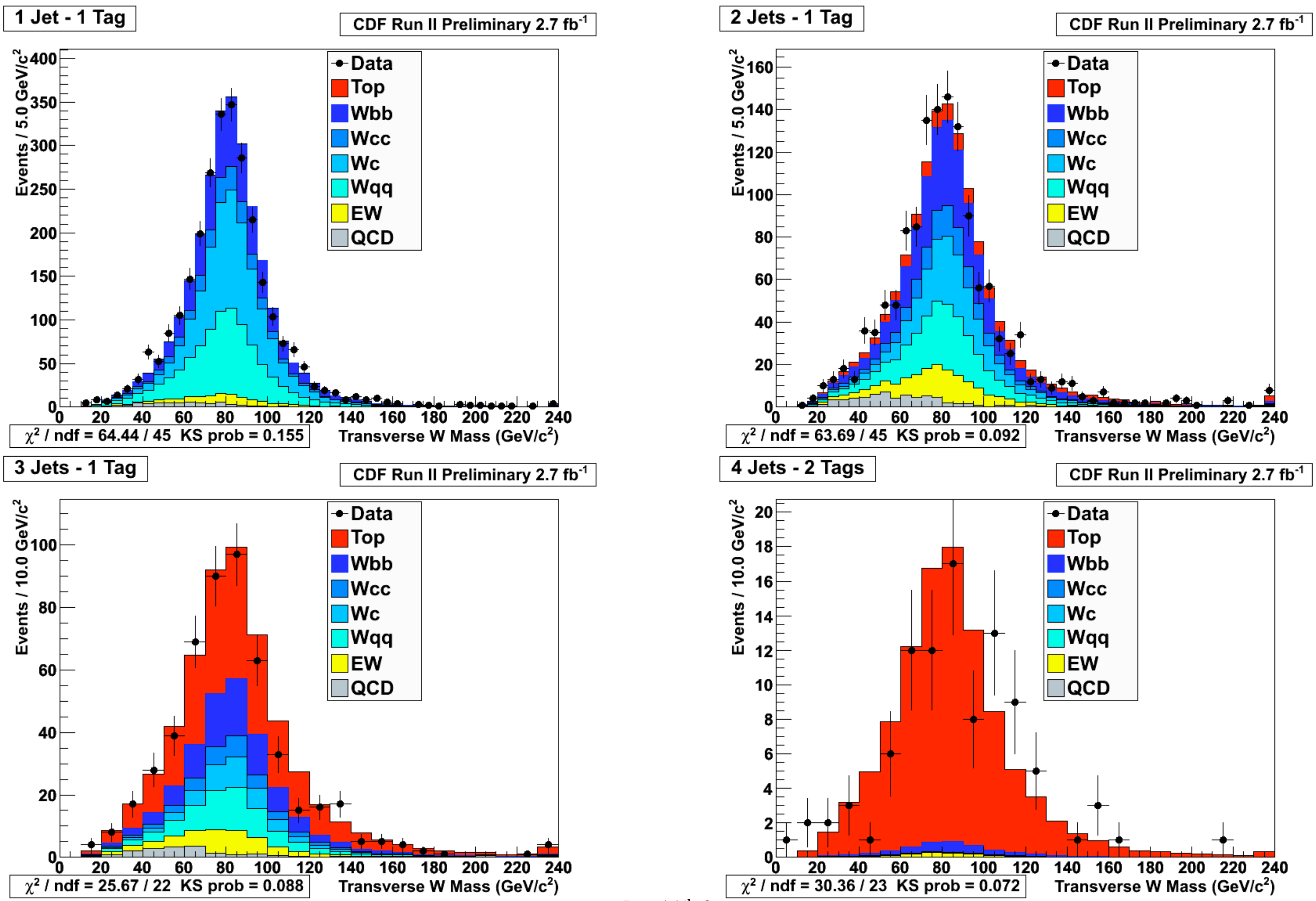




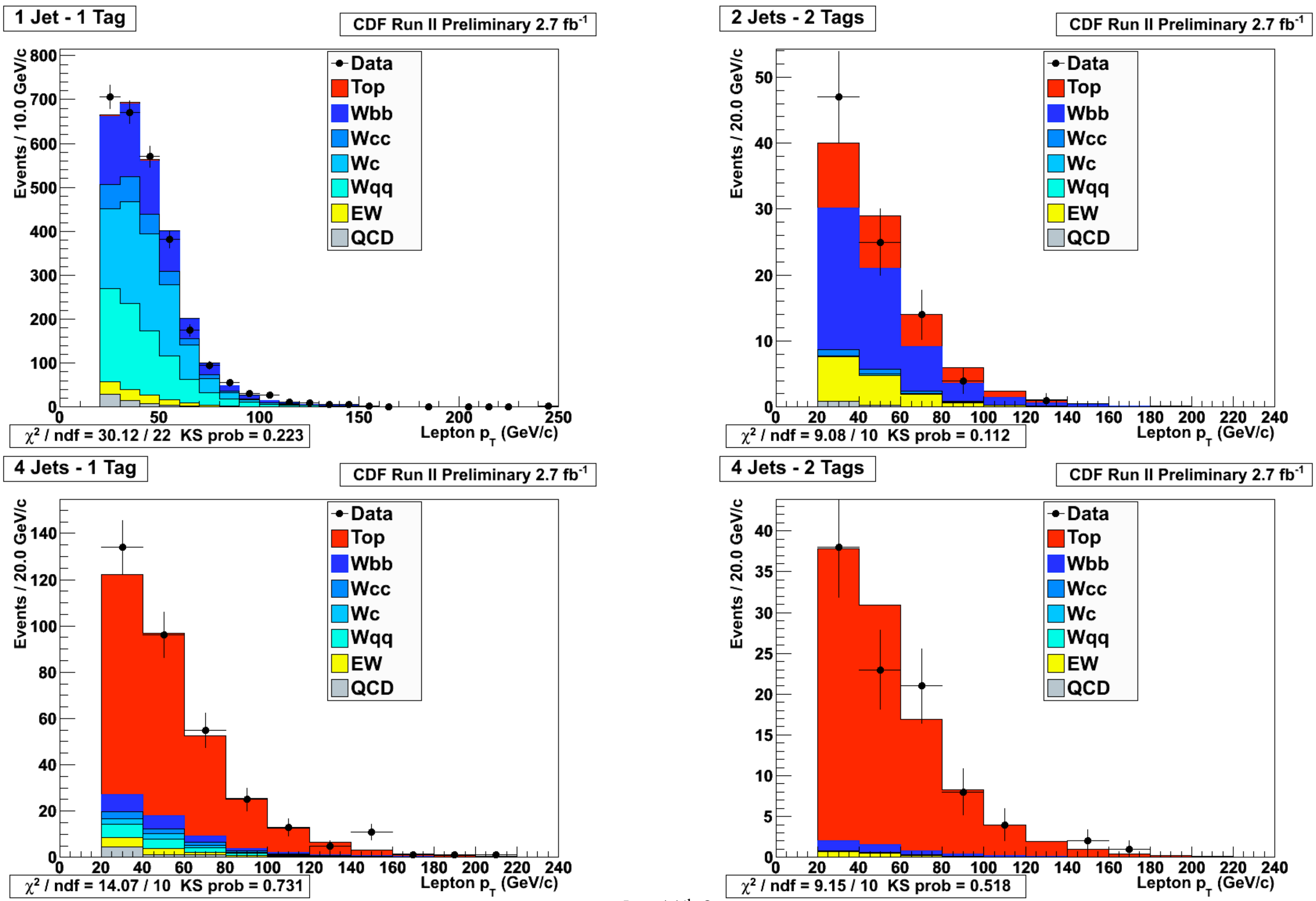
Kinematic Distributions: Missing E_T



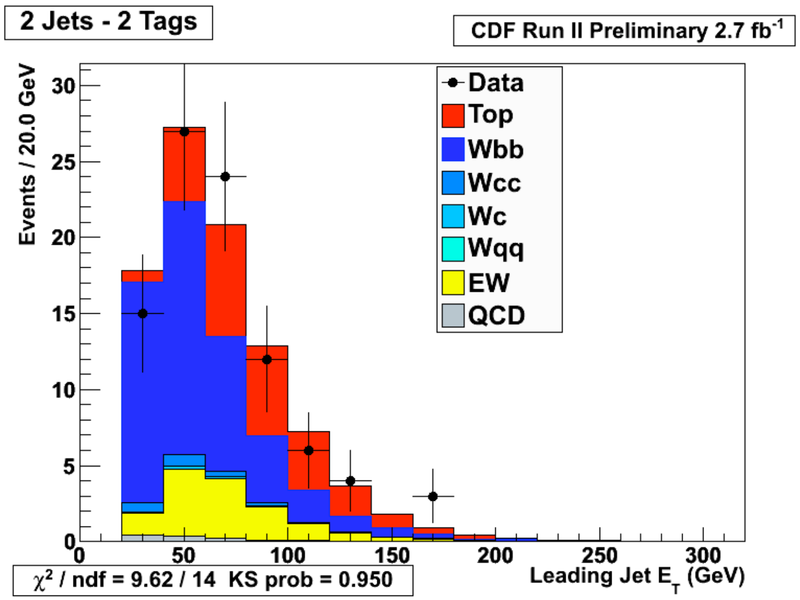
Kinematic Distributions: Transverse W Mass

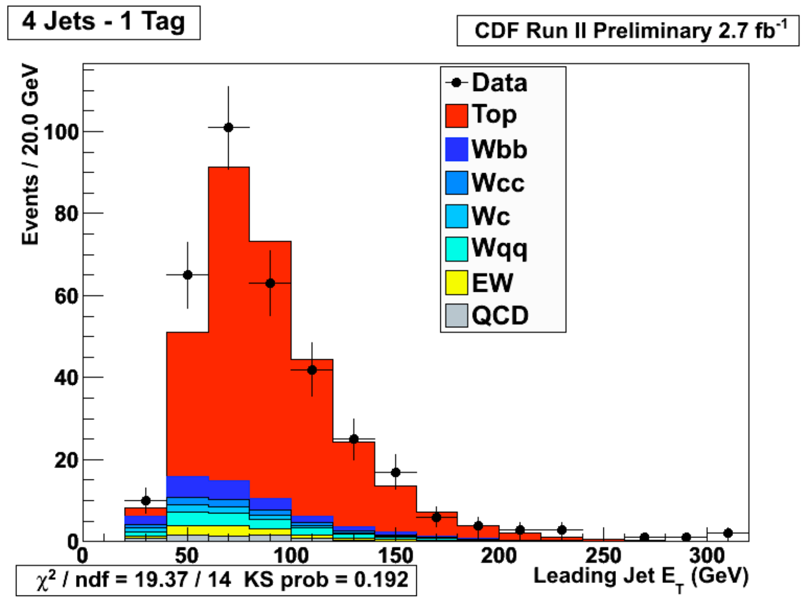


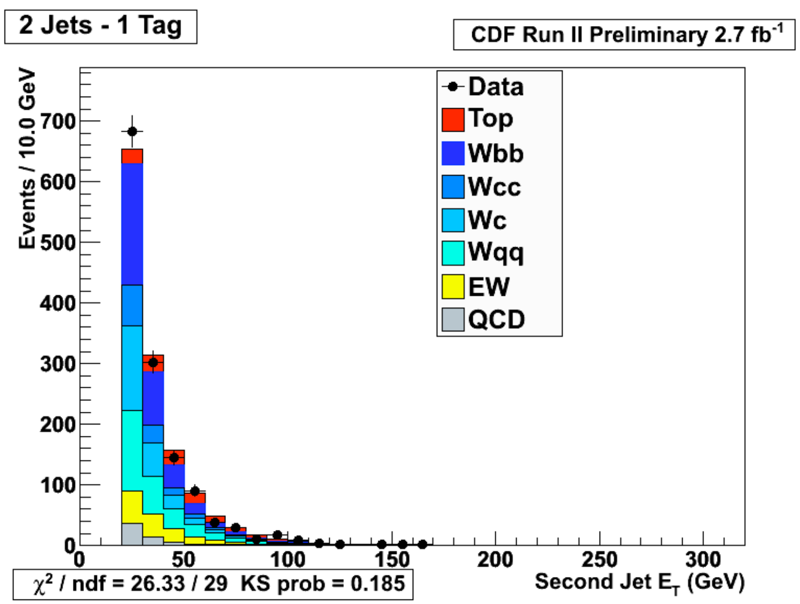
Kinematic Distributions: Lepton P_T

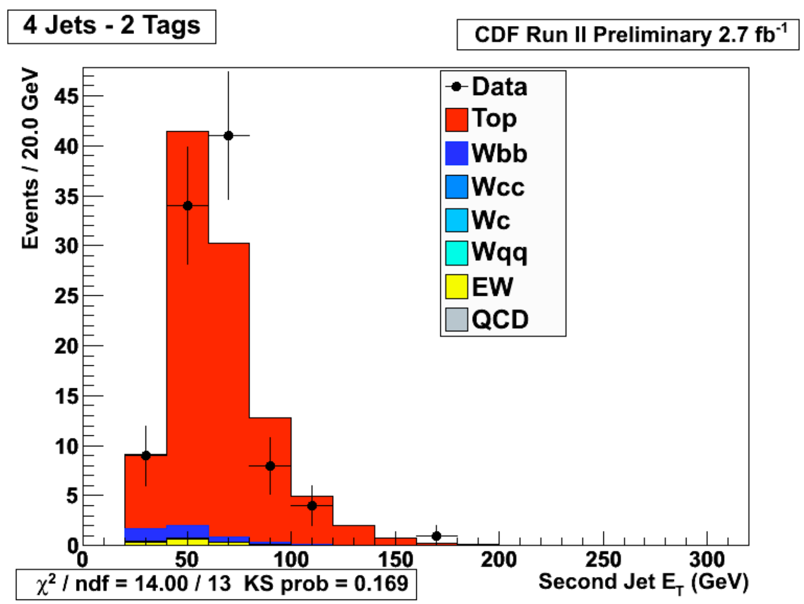


Kinematic Distributions: Jet E_T

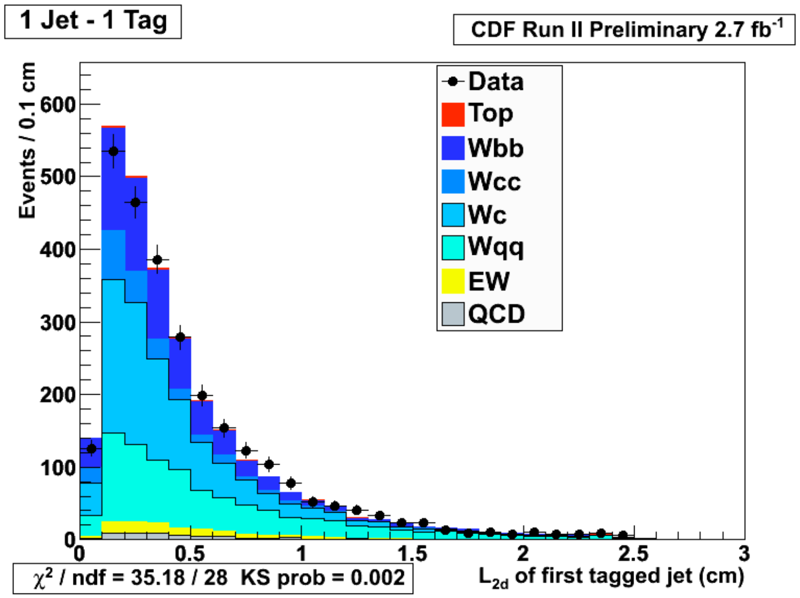


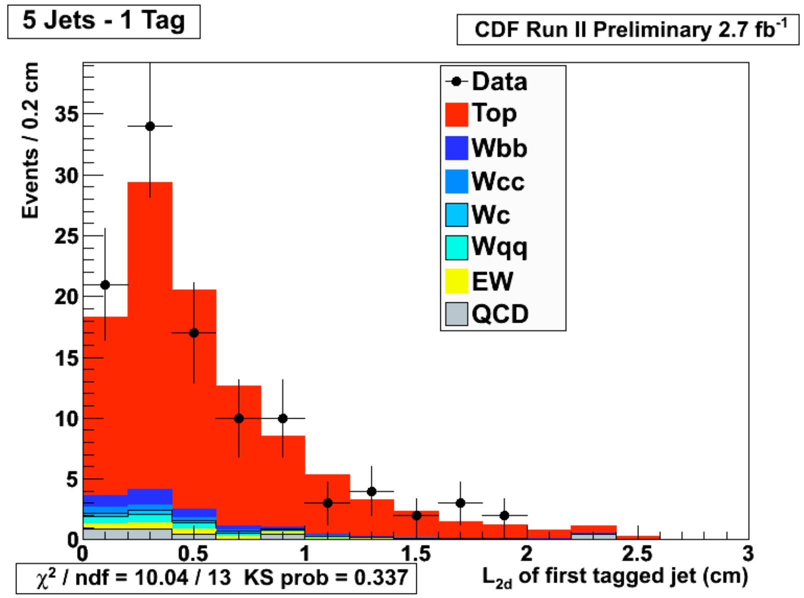


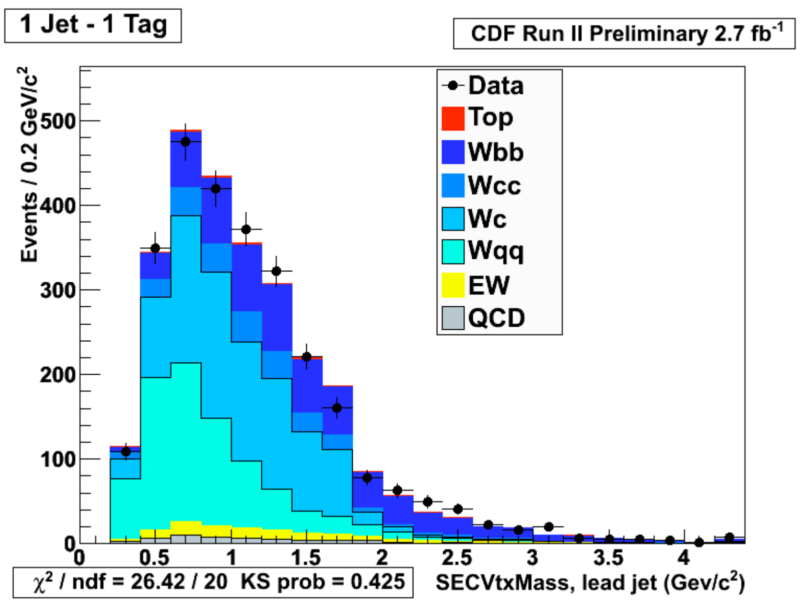


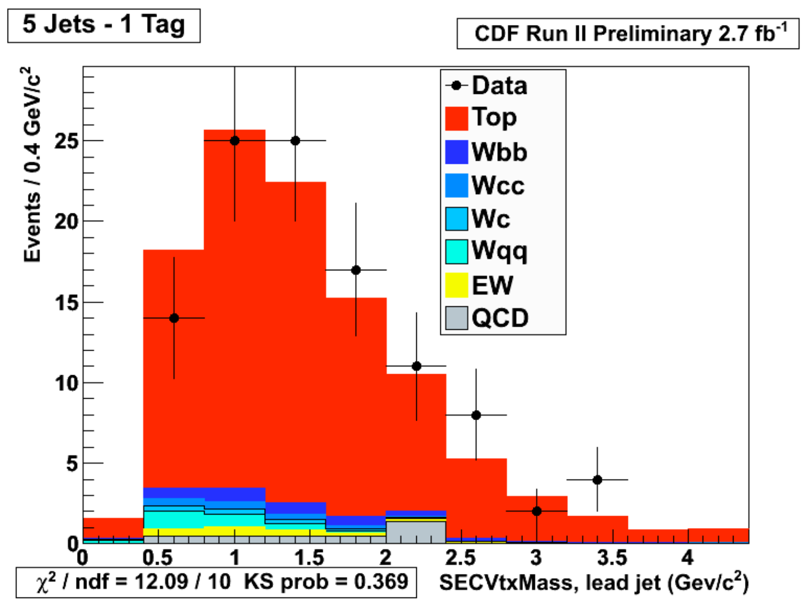


Kinematic Distributions: KIT Variables









Comparing Uncertainties to M2

❖ Table of Uncertainties:

CDF Run II Preliminary 2.7 fb^{-1}

Uncertainty	Method II	Method III
Statistical	0.36 pb	0.33 pb
HF K-Factor	0.27 pb	Inc in stat
Q^2	Not estimated	0.21 pb
B Tagging	0.39 pb	0.23 pb
Mistags	0.17 pb	0.08 pb
JES	0.29 pb	0.29 pb
ISR/FSR	0.06 pb	0.01 pb
Parton Showering	0.21 pb	0.11 pb
QCD Shape	0.06 pb	0.01 pb
KIT FS Correction	Not estimated	0.10 pb
PDF	0.04 pb	0.05 pb
Lepton ID / trigger	0.04 pb	0.05 pb
Z0	0.02 pb	0.02 pb
Total without Lumi	0.72 pb	0.57 pb
Luminosity	0.43 pb	0.45 pb
Total	0.84 pb	0.73 pb

Systematic uncertainties included in the fit

20% Improvement!

Summary

- This is an exciting new technique for measuring the top pair cross section, and has the potential to measure W + HF cross sections as well.
- Measure the top cross section to be

$$\sigma_{t\bar{t}} = 7.64 \pm 0.57\ (\mathrm{stat} + \mathrm{syst}) \pm 0.45\ (\mathrm{lumi})\ \mathrm{pb}$$

$$\sigma_{t\bar{t}} = 7.64 \pm 0.73\ \mathrm{pb}$$

- Assumed top mass of 175 Gev/c^2

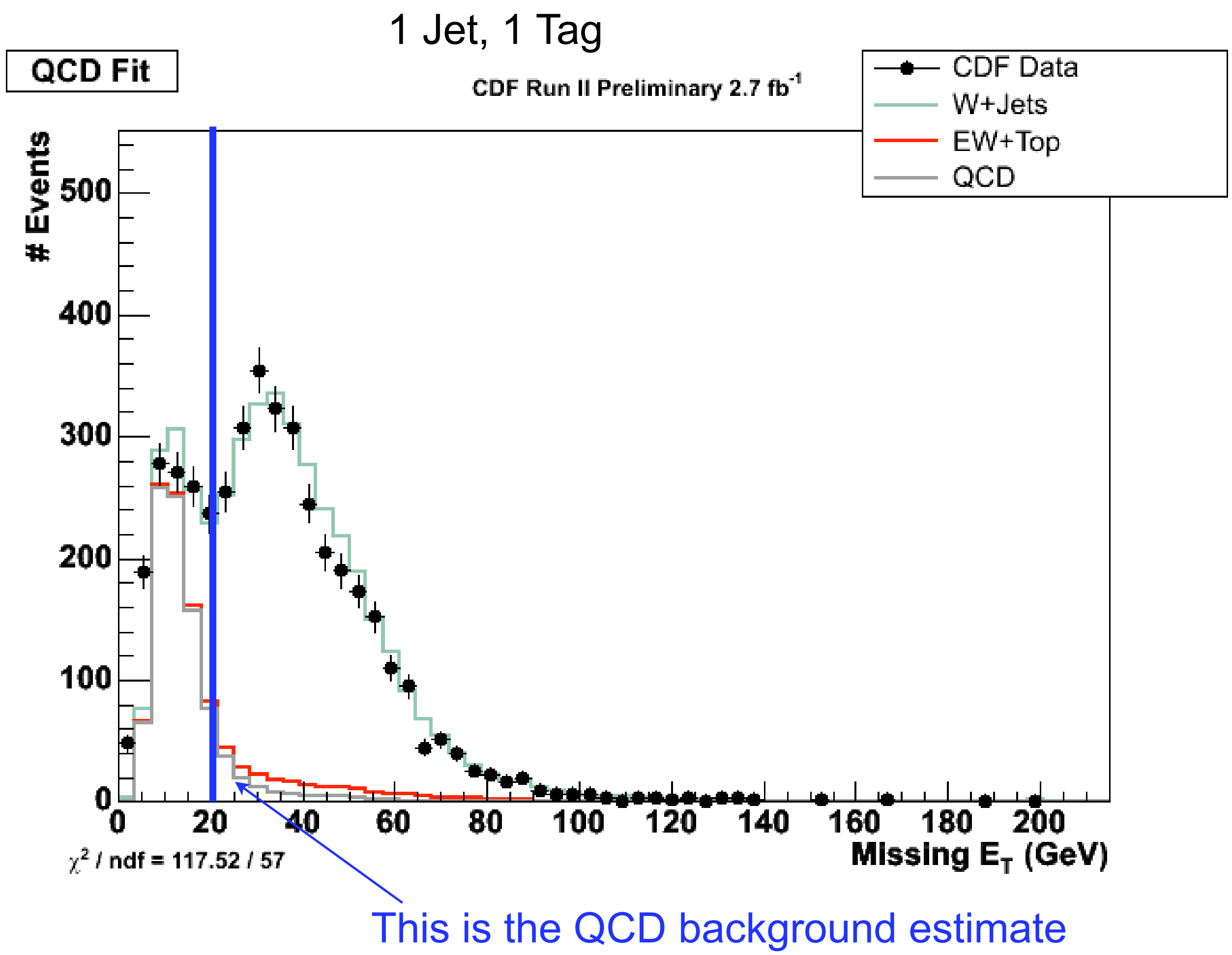
- Uncertainty decreased by 20% (ignoring luminosity) as compared to a previous analysis using *b*-tagging

- By construction, more data would reduce systematic uncertainties, similarly to statistical uncertainties

Backup Slides

QCD Background Estimation

❖ Use "anti-electrons" to estimate QCD background

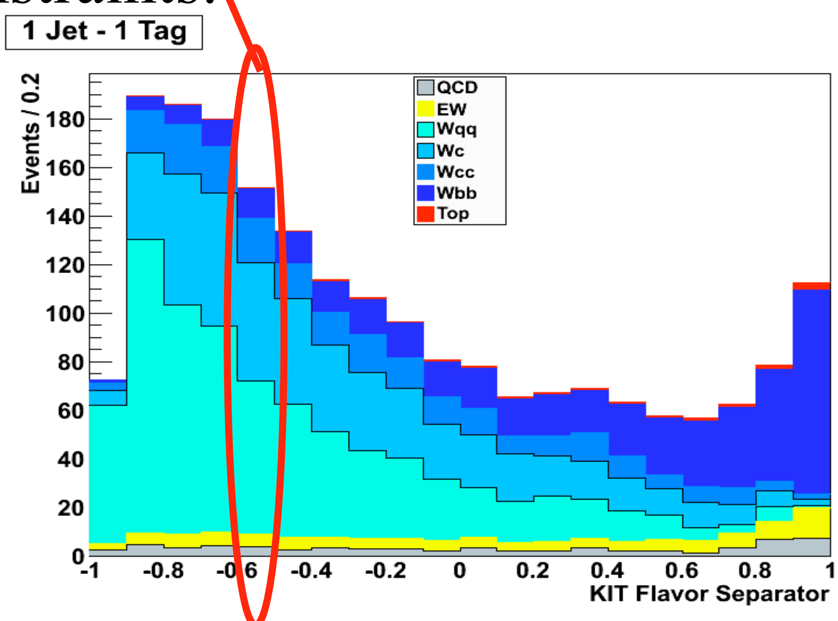


The Fitter

- The fitter is a custom-written fitter using Minuit
  - Binned Poisson Likelihood templates fitter

$$-2\cdot ln(\mathscr{L}) = -2\cdot[\sum^{\text{points}} ln(\mathscr{P}(\text{data}|\text{prediction})) - \frac{1}{2}\cdot\sum^{\text{constraints}}\frac{(x_i - x_i^{\text{constraint}})^2}{\sigma_i^2}]$$

- Templates / factors with constraints:
  - EW
  - QCD
  - *b*-tag scale factor
  - Mistag rate
  - ISR/FSR
  - JES
  - Q^2



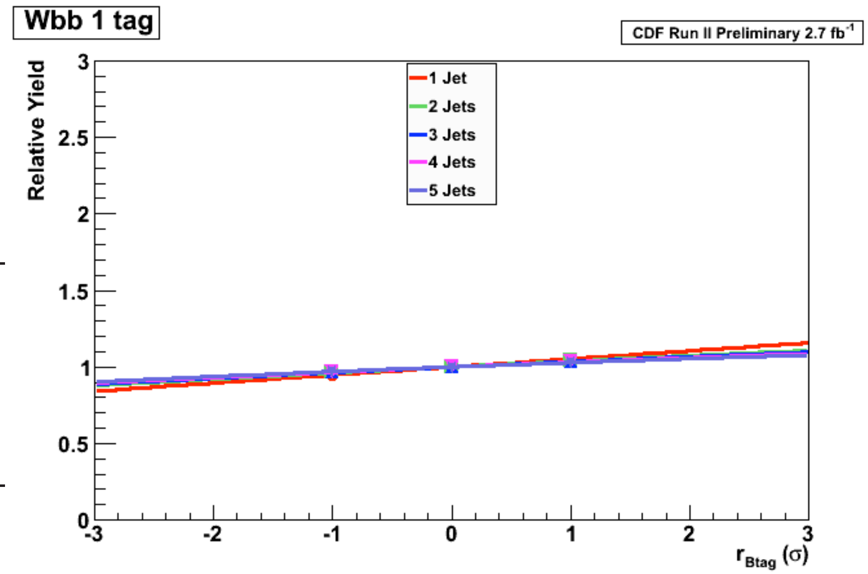
Systematic Uncertainties

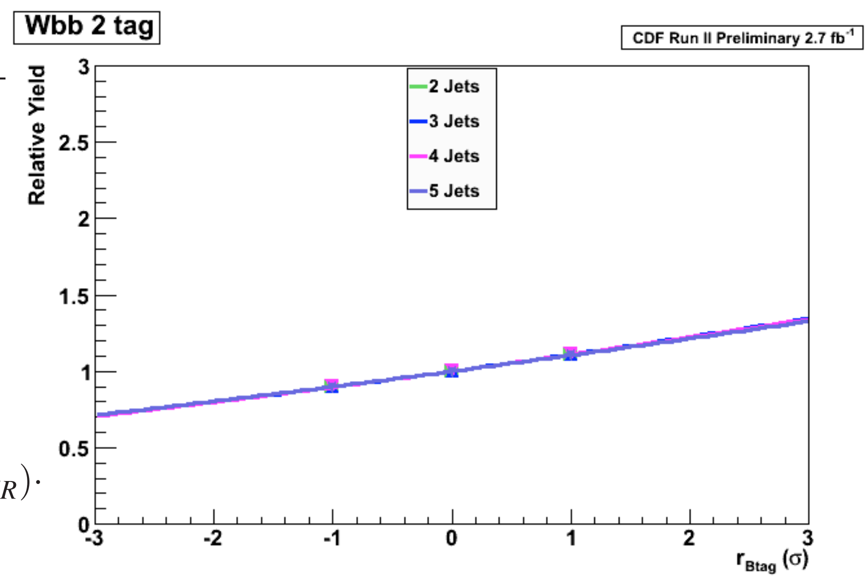
- How do we put systematic uncertainties in?
  - Create shifted templates
  - Compare shifted and nominal templates

	-1 σ b-tag		Nominal		+1 σ b-tag	
	Wbb	Top	Wbb	Top	Wbb	Top
1 jet 1 tag	385.9	16.0	407.3	16.8	428.7	17.7
2 jet 1 tag	220.1	108.3	229.0	111.9	237.6	115.3
3 jet 1 tag	54.7	223.9	56.7	229.6	58.7	234.6
4 jet 1 tag	10.8	217.1	11.1	220.7	11.5	223.4
5 jet 1 tag	2.1	71.6	2.1	72.6	2.2	73.3
2 jet 2 tag	27.1	20.6	30.2	23.0	33.5	25.5
3 jet 2 tag	8.0	56.9	8.9	63.5	9.9	70.5
4 jet 2 tag	1.8	72.1	2.0	80.4	2.2	89.1
5 jet 2 tag	0.4	25.4	0.4	28.2	0.5	31.2
total	710.7	811.8	747.9	846.8	784.8	880.6

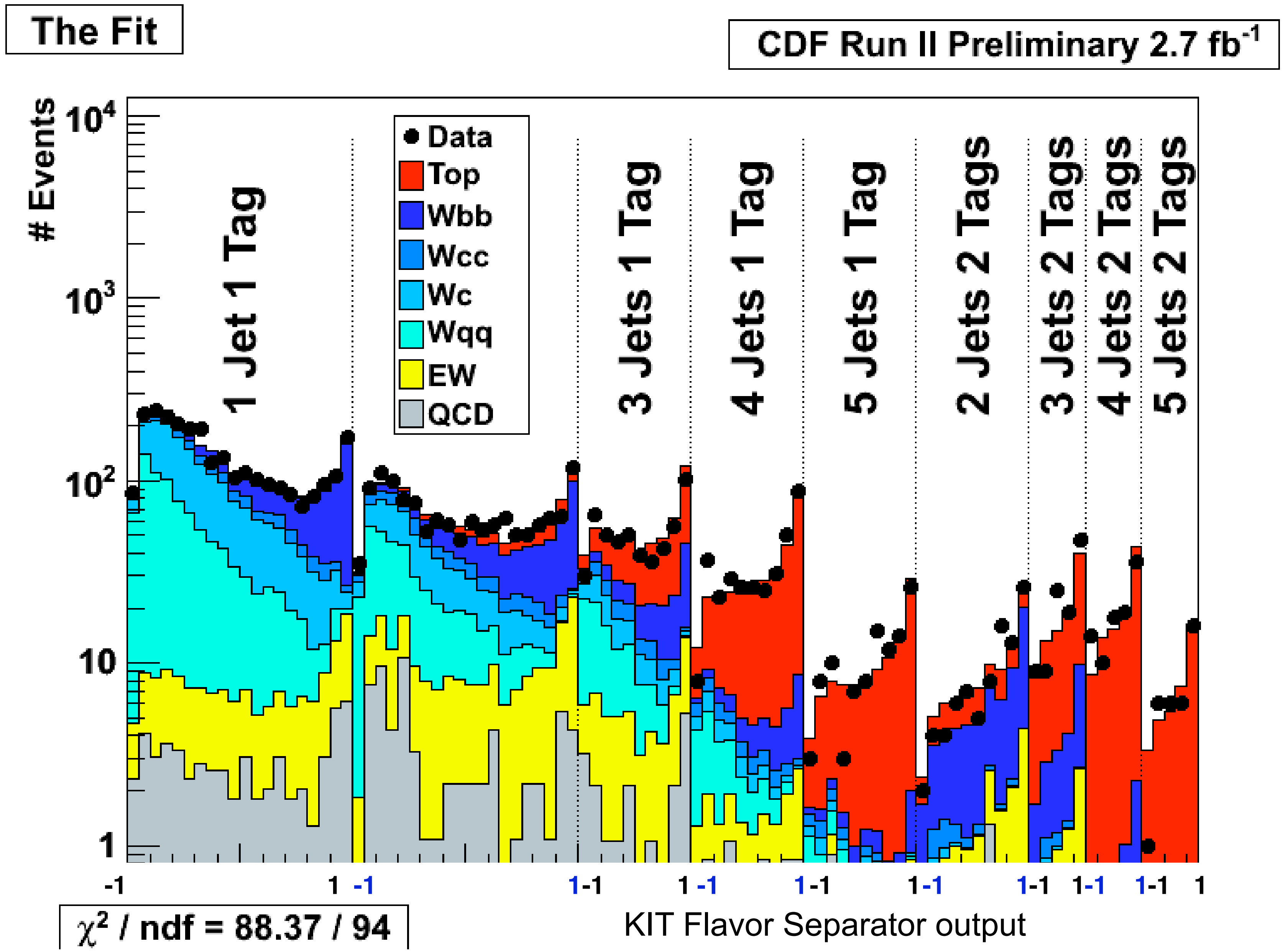
  - Fit ***relative*** shifts for each jet/tag bin.
- All functional forms are parameterized as polynomials $P_N^{Syst}(i,j,R_{Syst})$
  - Generally 2nd order.
  - Func (0) ≡ 1.
  - Are applied as multiplicative factors.

$$N_{t\bar{t}}^{pred}(i,j) = N_{t\bar{t}}^{MC}(i,j)\cdot w_{ALP}\cdot \varepsilon_{lep}\cdot L\cdot \mathscr{B}(i,j)\cdot P_N^{I/FSR}(i,j,R_{I/FSR})\cdot$$
$$P_N^{Btag}(i,j,R_{Btag})\cdot P_N^{Mistag}(i,j,R_{Mistag})\cdot P_N^{JES}(i,j,R_{JES})$$





Log plot



The Fit
CDF Run II Preliminary 2.7 fb^{-1}
Events
10^4
10^3
10^2
10
1
Data
Top
Wbb
Wcc
Wc
Wqq
EW
QCD
1 Jet 1 Tag
3 Jets 1 Tag
4 Jets 1 Tag
5 Jets 1 Tag
2 Jets 2 Tags
3 Jets 2 Tags
4 Jets 2 Tags
5 Jets 2 Tags
-1
1 -1
1-1
1 -1
1-1
1-1
1-1
1-1
1-1
1
KIT Flavor Separator output
χ^2 / ndf = 88.37 / 94