Analysis at a Hadron Collider

Lecture 3: Measurements

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- Lecture 1: Introduction
- Lecture 2: Searches
- Lecture 3: Measurements

Review

- Yesterday's lecture covered a lot of ground
  - Review of lecture 1 with an emphasis on the main challenges facing a hadron collider and suggested rules-of-thumb to help guide analysis strategy
  - Discussed in some detail CDF's first $B \rightarrow \mu\mu$ analysis as a specific example of a search
  - Introduced several important experimental techniques employed in that analysis and commonly used in HEP

Experimental Techniques

Yesterday we discussed the following:

- Using data-driven techniques especially when determining resolutions and important instrumental effects, which are often difficult to model accurately in simulation
- Using the “tag-and-probe” method to identify pure and unbiased samples used to measure efficiencies or other detector effects
- Using sideband subtraction to remove the effects of background (and the built-in assumptions of such a method)
- Using convolutions to fold-in data determined instrumental effects and efficiencies with the correct kinematics relevant for your signal
- Using event weights to correct for background contamination (a la SB subtraction) or to improve MC modeling of data
- Using control samples to verify background methodology and validate MC signal modeling (especially for searches)

Experimental Techniques

Today we will discuss the following:

- Several additional methods commonly employed to estimate backgrounds
- Using decay length information to identify b-quark jets ("b-tagging")
- Using "negative" decay lengths to estimate the rate of false positives for b-tag algorithms
- Using p_T^{rel} distribution for leptons from semi-leptonic decay or the vertex mass distribution to estimate the heavy flavor fraction of jets
- Using kinematic fits to improve the resolution of reconstructed quantities (e.g. reconstructed invariant mass)
- Jet Energy Corrections
- Missing transverse energy corrections
- Likelihood fits to extract physics parameters of interest

$\sigma(p\bar{p} \rightarrow t\bar{t})$ Introduction

- Today we'll discuss a Measurement type analysis

  "Measurement of the t-tbar production cross section from p-pbar collisions at E_{CM} = 2 TeV"

- Why?
  - Complicated final state requiring full compliment of detector components
  - Many contributing background processes, some are physics backgrounds, some instrumental
  - Top physics important part of LHC program, will need to start with cross section determination

σ(pp→tt) Motivation

- Why measure the ttbar production cross section?
  - Tests the QCD prediction
    - Discrepancies may indicate short comings of SM or NP
  - Requires that you understand your whole detector
    - Benefits much of rest of physics program
  - Requires a thorough understanding of sample composition, thus enabling many additional measurements
    - Top properties (M_t, A_{FB}, helicity fractions, BR, etc)
    - Searches for New Physics (NP) in t-tbar sample

Getting Started

- How did we start this analysis? Where did we begin?
  - Wrote down the expression we'd have to use to measure the cross section
    - Use this to itemize necessary inputs
    - Use this to help steer sensitivity studies
  - Considered the characteristics of the signal
    - Use this to help identify features which can be exploited to discriminate signal from background

Getting Started: Expression

$$\sigma(p\bar{p} \rightarrow t\bar{t}) = \frac{(N_{candidates} - N_{bg})}{\alpha \cdot \varepsilon_{total} \cdot \int L dt}$$

- This measurement requires that we:
  - Accurately estimate signal acceptance: $\alpha\varepsilon$
  - Accurately estimate background: N_{bg}
  - Intelligently optimize selection requirements
- Since it's a measurement we need to
  - Rigorously verify $\alpha\varepsilon_{total}$ estimate
  - Ensure our methodology is unbiased and yields an accurate estimate of the statistical uncertainty

Sensitivity

- For measurements, the figure-of-merit is obvious
  - You want to minimize the uncertainty on the quantity you're aiming to measure
  - Usually the optimization only worries about minimizing the statistical uncertainty
    - Well defined and predictable *a priori*
  - As a fuller understanding of the systematic uncertainties emerges, can revisit optimization accounting for systematic effects as well
    - You can minimize the total uncertainty

Sensitivity

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{\left(\delta N_{candidates}\right)^2 + \left(\delta N_{bg}\right)^2}{\left(N_{candidates} - N_{bg}\right)^2} + \left(\frac{\delta\alpha\varepsilon}{\alpha\varepsilon}\right)^2 + \left(\frac{\delta\int Ldt}{\int Ldt}\right)^2}$$

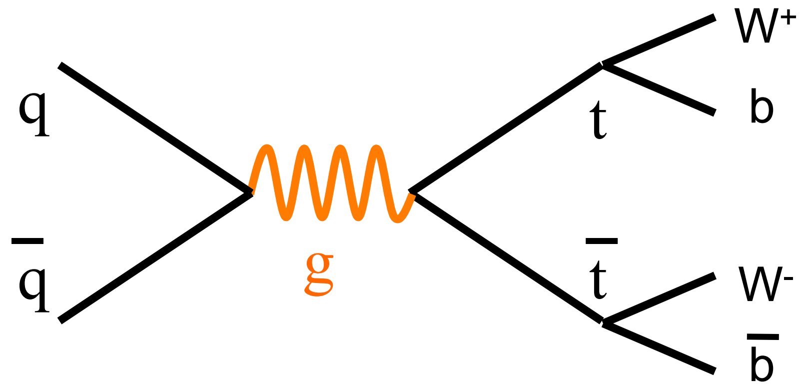
- To minimize $\delta\sigma$ you'll want to
  - Maximize $N_{sig} = (N_{candidates} - N_{bg})$
    - You can minimize your statistical uncertainty by maximizing the product efficiency*purity
  - Work hard to understand $\alpha\varepsilon_{total}$ estimate
    - The scale of how hard you have to work is discussed on the next page

Sensitivity

- Other notes
  - For "counting" measurements, δN_{cand} = sqrt(N_{cand})
  - If the purity of the selected sample is high enough, you can tolerate large δN_{bg}
  - Scale of $\delta(\alpha\varepsilon)$ you want to aim for set by
    - Expected N_{cand} (if small, you'll be dominated by stats)
    - Luminosity uncertainty typically ~5% at hadron collider

Signal Characteristics

- Within SM, top nearly always decays as t → W⁺b



- Final state dictated by decays of W-bosons:

$$t\bar{t} \to W^+ b W^- \bar{b} \to q\bar{q}'\, q\bar{q}'\, b\bar{b}$$ "All Jets"

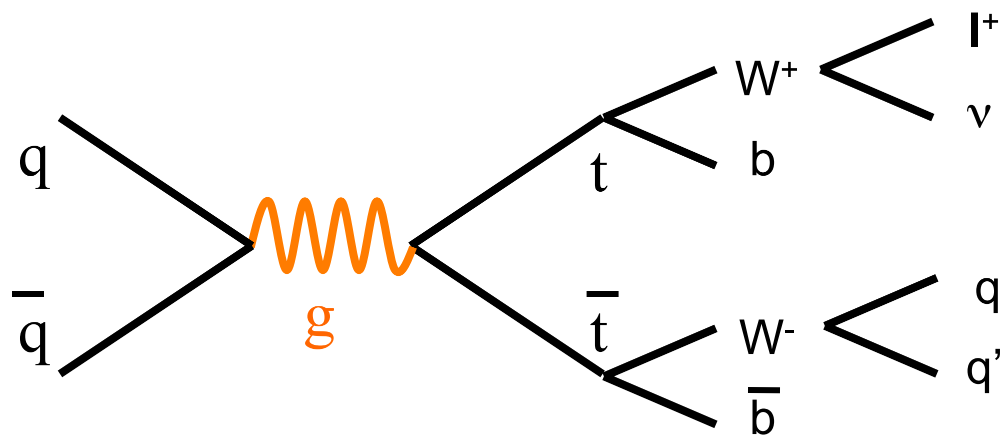
$$t\bar{t} \to W^+ b W^- \bar{b} \to \ell\bar{\nu}_\ell\, q\bar{q}'\, b\bar{b}$$ "Lepton+Jets"

$$t\bar{t} \to W^+ b W^- \bar{b} \to \ell\bar{\nu}_\ell\, \bar{\ell}\nu_\ell\, b\bar{b}$$ "Di-Lepton"

Signal Characteristics

- Have to choose which final state you want to use
  - All jets will suffer from very large QCD background… very challenging
  - Can trigger on high-p_T leptons and require large MET for Di-Lepton and Lepton+Jet final states
    - Doing so will dramatically reduce QCD background
    - Costs some BR since can only really use e/μ
  - In all cases, identifying jets originating from b-quarks ("b-jets") can further discriminate S from B
- Turns out Lepton+Jets most sensitive

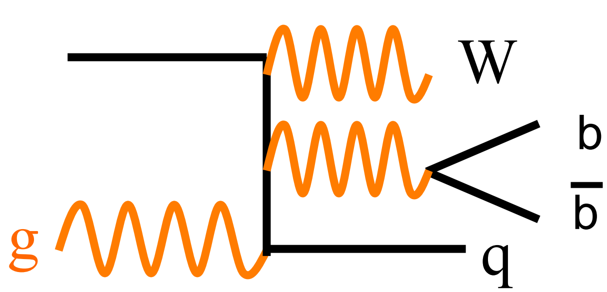
Signal Characteristics

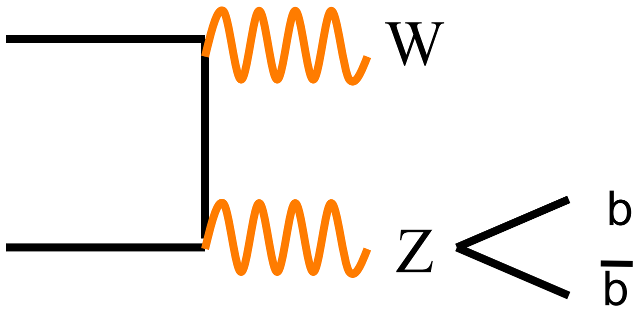


- For lepton+jets:
  - 1 high p_T lepton, in general isolated
  - Large MET from the high energy neutrino
  - 4 jets, 2 of which are b-jets

Backgrounds

- Physics backgrounds: W+bb, WZ





- Resolution/Acceptance effects: W+cc, Z+jets, ZZ
- Instrumental backgrounds:
  – Fake b-jets: W+qq, WW, WZ, ZZ
  – Fake leptons + Fake MET (+ Fake b): QCD

$\sigma(pp \rightarrow tt)$ Analysis Plan

- Can use the above to develop a plan
  - Signal data set: Inclusive high-p_T lepton triggers
    - Electron trigger
    - Muon trigger
  - Samples to measure trigger efficiency: use $Z \rightarrow \mu\mu$, $Z \rightarrow ee$ in tag-and-probe method; collected on unbiased, inclusive, single-leg lepton triggers (extrapolation to 4j bin?)
  - Sample to estimate b-jet identification ("b-tag") efficiency: use a high purity b-jet sample; exploit large BR($b \rightarrow l\nu X$) and collect using low-p_T inclusive lepton triggers (prescaled, so lumi profile is different? B-jet E_T distributions different?)

σ(pp→tt) Analysis Plan

- Determine fake b-jet rates ("mis-tags") using inclusive jets (removing bb contribtion? Luminosity profile? E_T distrib?)
- MC samples: ttbar, W+bb, W+cc, W+c, W+lf, WW, WZ, ZZ, Z+jets, b-bbar with 1 b→lνX (does MC model data?)
- Fit MET distribution to determine QCD contribution to initial data sample (Is MET shape in QCD MC reliable? How to include effects of b-tagging?)
- Use MC to estimate physics backgrounds (Is W+bb understood well enough?)
- Use MC to estimate WW, WZ, ZZ backgrounds (Are cross sections known accurately enough? What about instrumental contributions from same backgrounds?)

We have a plan, all that's left is to implement it!

$\sigma(pp \rightarrow tt)$ Analysis Plan

- Considerably more complicated than $B \rightarrow \mu\mu$!
  - To set the scale, there is approximately 200 pages of internal documentation describing the electron trigger efficiency, the muon trigger efficiency, the b-tagging efficiency, the jet energy corrections, and the W+bb background estimate… *each*
  - Well over 1000 pages total (I stopped counting)

Efficiency

$\sigma(pp \rightarrow tt)$ Signal Acceptance

- We factorize the total signal acceptance like this:

$$\alpha \cdot \varepsilon_{\text{total}} = \alpha \cdot \varepsilon_{\text{lepton-id}} \cdot \varepsilon_{\text{trigger}} \cdot \varepsilon^{\text{event}}_{\geq 1\ \text{b-tag}}$$

where

α = geometric and kinematic acceptance
$\varepsilon_{\text{lepton-id}}$ = lepton reconstruction and identification
$\varepsilon_{\text{trigger}}$ = trigger efficiencies
$\varepsilon_{\text{b-tag}}$ = b-tag efficiency per event

$\sigma(pp \rightarrow tt)$ Signal: Triggers

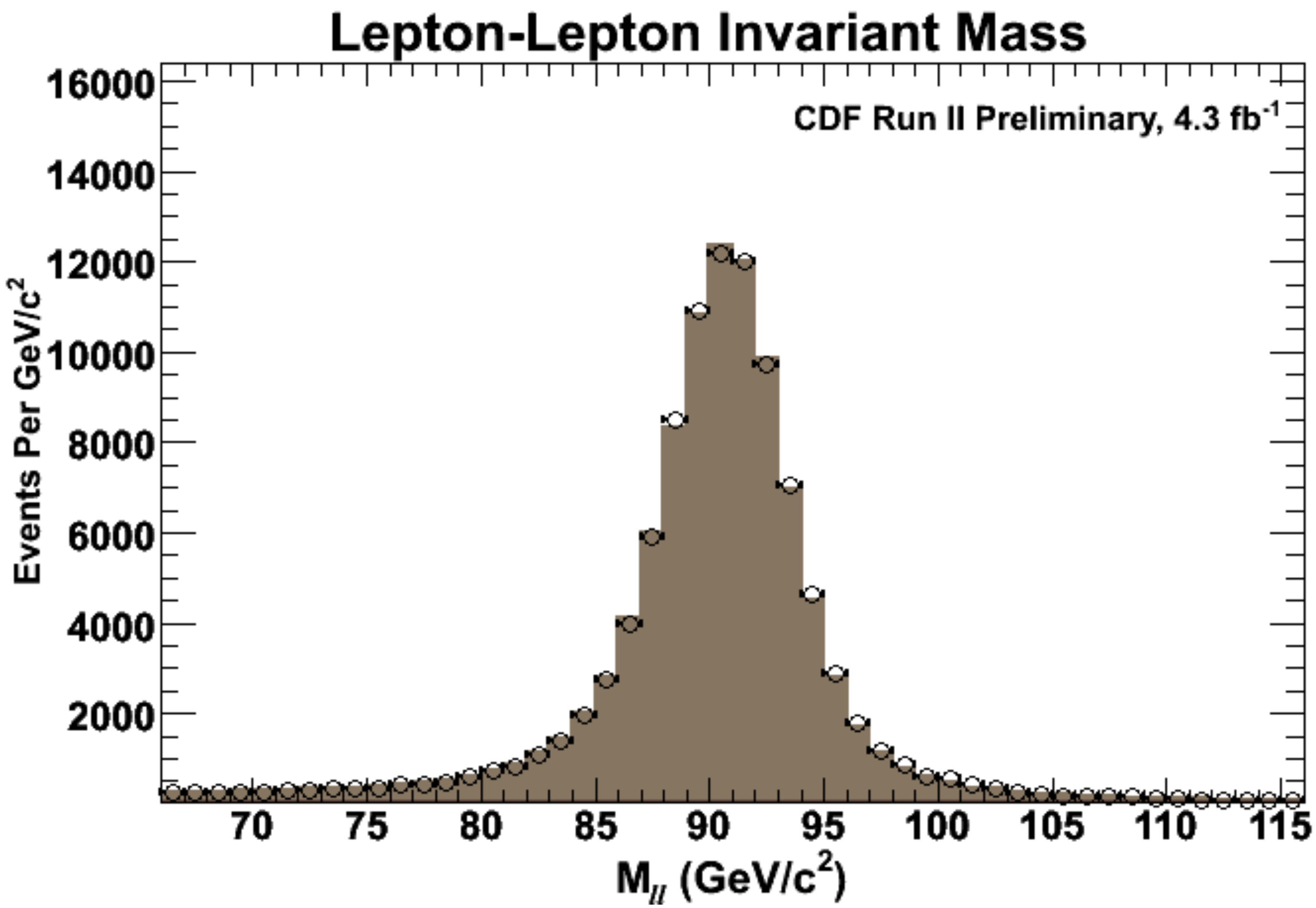
- Signal sample collected with high-p_T (18 GeV/c) inclusive lepton triggers
  - Electrons
    - ELECTRON18_CENTRAL
    - ELECTRON18_FORWARD
  - Muons
    - MUON18_CENTRAL
    - MUON18_FORWARD
  - Can employ tag-and-probe methodology using $Z \rightarrow ee$, $Z \rightarrow \mu\mu$ events collected on same triggers

$\sigma(pp \rightarrow tt)$ Signal: Triggers

<u>For example:</u>

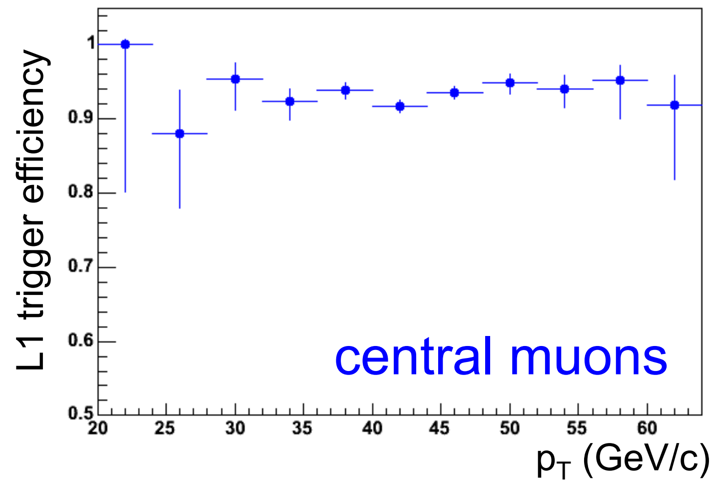
- Start with the MUON18_FORWARD trigger sample
- Identify sample of $Z \rightarrow \mu\mu$ (1 central, 1 forward)
- Determine number of central muons that satisfy MUON18_CENTRAL trigger requirements
- Find out how many of these fired the MUON18_CENTRAL trigger
- Ratio is the MUON18_CENTRAL efficiency
  – Small corrections for bgd using side band subtraction

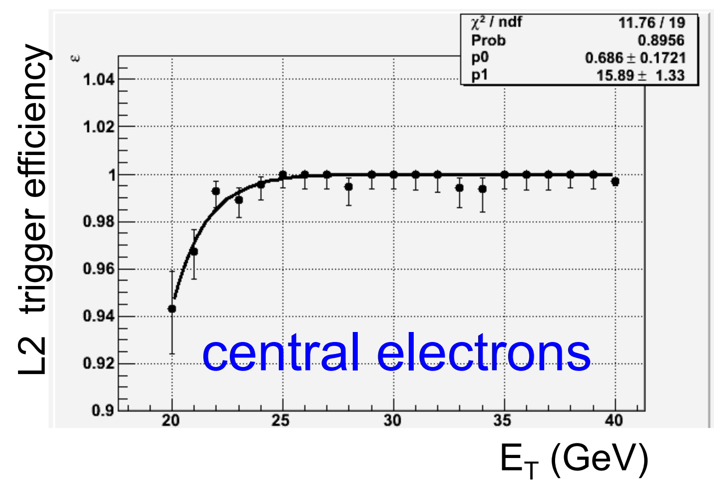
σ(pp→tt) Signal: Triggers

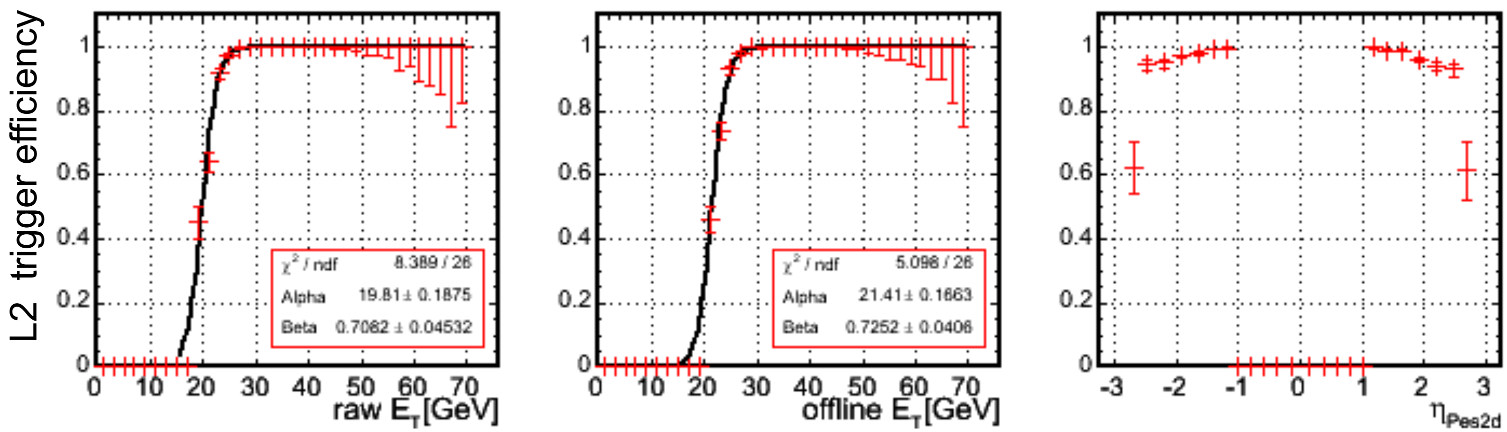


- Tag-and-Probe Z samples very clean

σ(pp→tt) Signal: Lepton Efficiencies



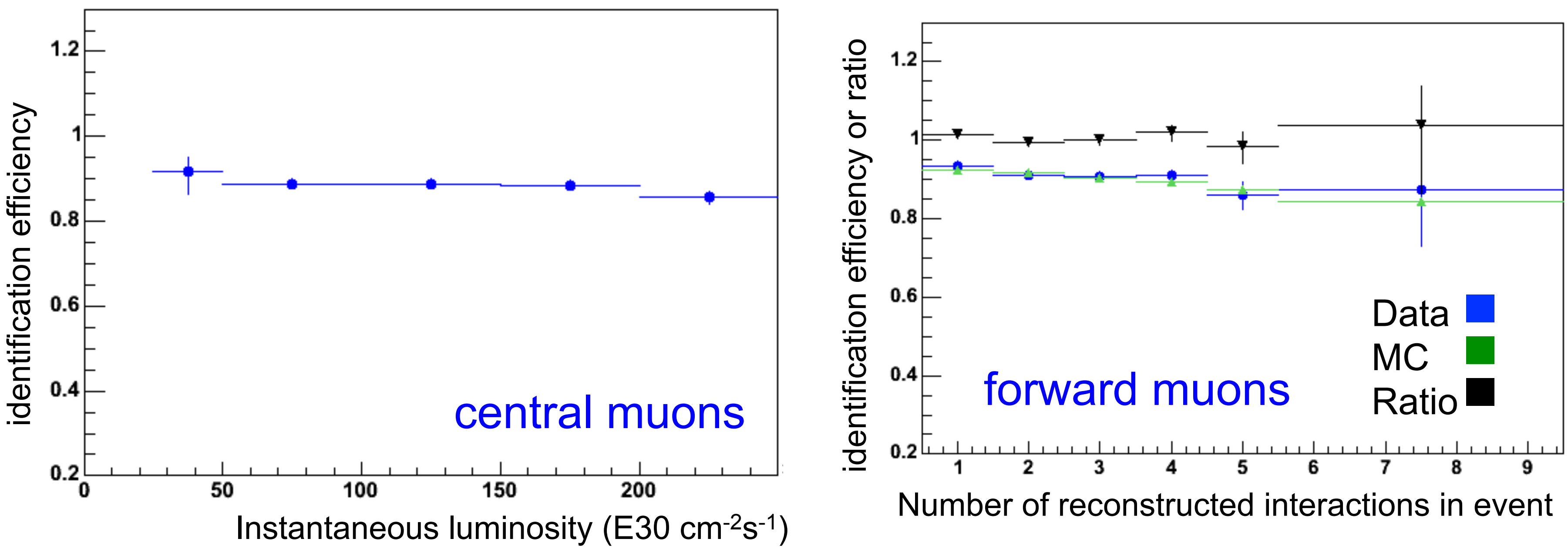




forward electrons

- Some resulting trigger efficiency turn-on curves

σ(pp→tt) Signal: Lepton Efficiencies



(efficiency flattens if isolation criteria removed)

- Some resulting cross-check plots

$\sigma(pp \rightarrow tt)$ Signal: b-tagging

- Identifying jets originating from b-quarks important to many analyses: ttbar, single top, Higgs, sbottom, etc
- Two main handles
  1) Identify leptons inside the jet originating from semi-leptonic decays

$$B \rightarrow \ell \nu \mathrm{X} \quad \text{or} \quad B \rightarrow D\mathrm{X} \rightarrow (\ell \nu \mathrm{Y})\mathrm{X}$$

  2) Exploit the long lifetime of B-hadrons
- Both important, but 2) usually more powerful

b-Tagging via Lifetime Information

- On average tracks from long lived B-decay
  - Have higher p_T
  - Have larger d_0
  - Vertex to a point displaced from the beam line

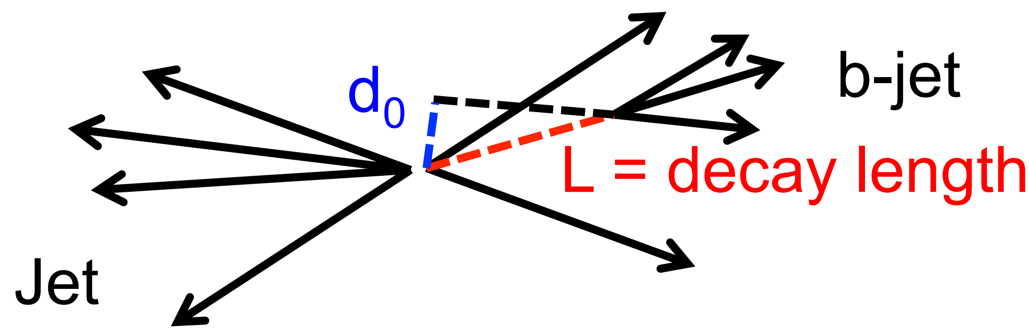
relative to tracks from light-flavored (lf=udsg) jets

- Above is also true for tracks from Charm decays, but to a lesser degree

- Typically achieved efficiencies

$$\varepsilon_b : \varepsilon_c : \varepsilon_{lf} \sim 50 : 10 : 1 \text{ (\% per jet)}$$

b-Tagging Algorithm

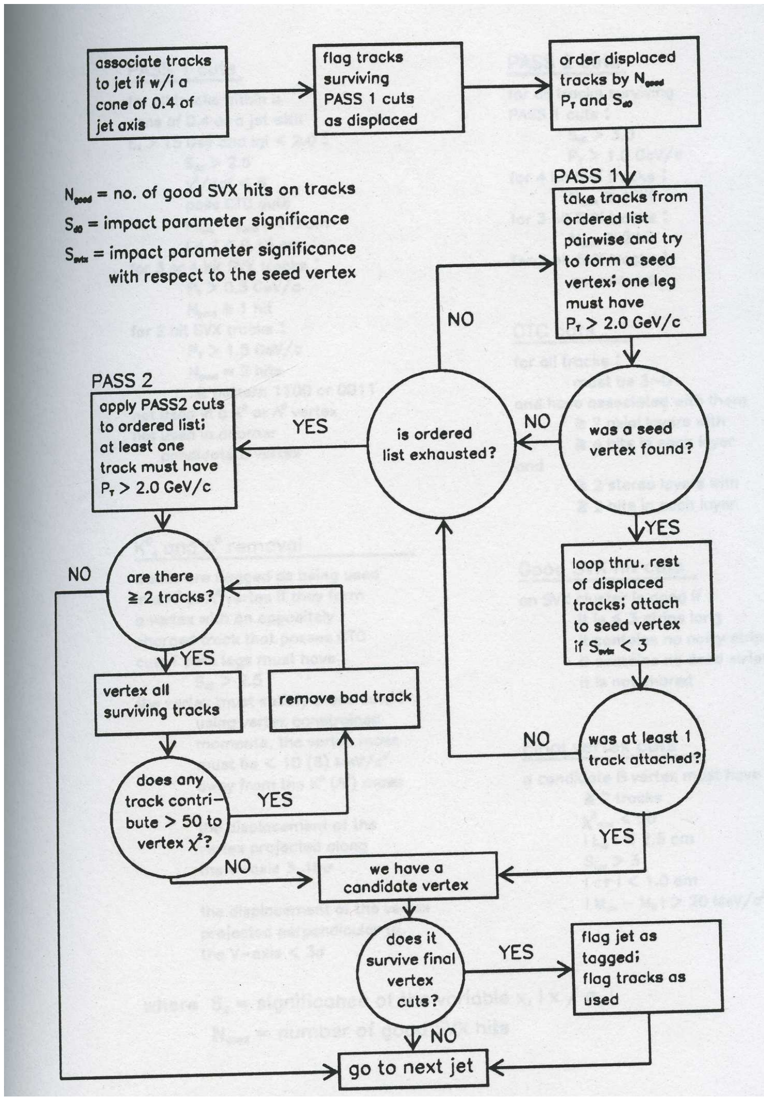


- Basically, b-tag algorithms that exploit lifetime
  1) Identify tracks likely to originate from B-decays using (p_T,d_0) information
  2) Constrain those tracks to a common vertex
  3) Remove backgrounds from $\gamma \rightarrow ee$, $V \rightarrow hh$ decays
  4) Require the "secondary vertex" to be significantly displaced from the primary interaction vertex

b-Tagging Algorithm

- Need to be sure to remove these other sources of large decay length vertices
  - Conversions
    - Easily done if you can require L < radius of beam pipe
    - Take care if beam line displaced from center of beam pipe!
  - V→hh decays (e.g. $K_s \rightarrow \pi\pi$, $\Lambda \rightarrow p\pi$)
    - Omit tracks that form a good K_s or Λ candidate with any other track in the jet

b-Tagging Algorithm



- Flow chart for CDF's most used b-tag Algorithm

b-Tagging Algorithm

PASS 1 cuts

for all tracks within a
cone of 0.4 of a jet with
$E_T > 15$ GeV and $|\eta| < 2.0$:

- $S_{d0} > 2.5$
- $\chi^2/dof < 6$
- pass CTC cuts
- $|z_{trk} - z_{pvtx}| < 5$ cm
- $|d_0| < 0.15$ cm

for 3 or 4 hit SVX tracks :

- $P_T > 0.5$ GeV/c
- $N_{good} \geqq 1$ hit

for 2 hit SVX tracks :

- $P_T > 1.5$ GeV/c
- $N_{good} = 2$ hits
- hit pattern 1100 or 0011

not used in a K^0 or Λ^0 vertex
not used in another
candidate B vertex

K^0_s and Λ^0 removal

tracks are flagged as being used
in a K^0 or Λ^0 vertex if they form
a vertex with an oppositely
charged track that passes CTC
cuts ; both legs must have

- $S_{d0} > 2.5$

the vertex must satisfy these cuts :

- using vertex constrained momenta, the vertex mass must be < 10 (6) MeV/c^2 away from the K^0 (Λ^0) mass
- the displacement of the vertex projected along the V–axis > 10σ
- the displacement of the vertex projected perpendicular to the V–axis < 3σ

PASS 2 cuts

for all tracks surviving
PASS 1 cuts :

- $S_{d0} > 3.0$
- $P_T > 1.0$ GeV/c

for 4 hit SVX tracks :

- $N_{good} \geqq 1$ hit

for 3 hit SVX tracks :

- $N_{good} \geqq 2$ hit

for 2 hit SVX tracks :

- not allowed

CTC cuts

for all tracks :

- must be 3–D

and have associated with them

- $\geqq 2$ axial layers with $\geqq 4$ hits in each layer

and

- $\geqq 2$ stereo layers with $\geqq 2$ hits in each layer

Good SVX hit cuts

an SVX cluster is good if :

- it is $\leqq 3$ strips long
- it contains no noisy strips
- it contains no dead strips
- it is not shared

Final vertex cuts

a candidate B vertex must have :

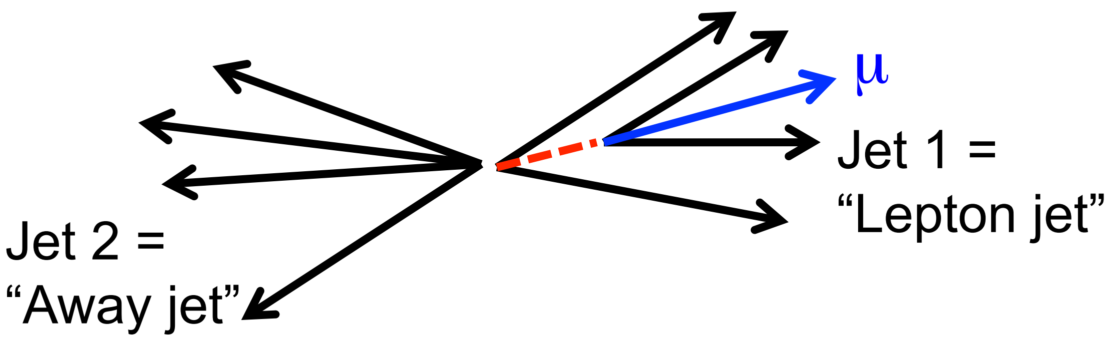
- $\geqq 2$ tracks
- $\chi^2_{max} < 50$
- $|L_{xy}| < 2.5$ cm
- $S_{Lxy} > 3$
- $|c\tau| < 1.0$ cm
- $|M_{vtx} - M_K| > 20$ MeV/c^2

where S_x = significance of the variable x, $|x / \sigma_x|$
N_{good} = number of good SVX hits

- The various categories of requirements
- These actually from Run I, but a similar (re-optimized) set exists for Run II
- Requires a thorough optimization

b-Tag Efficiency

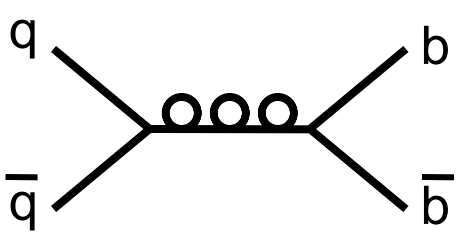
- To measure the efficiency for tagging a b-jet requires a pure sample of b-jets
- At the Tevatron we triggered on soft leptons in jets from semi-leptonic B-decays



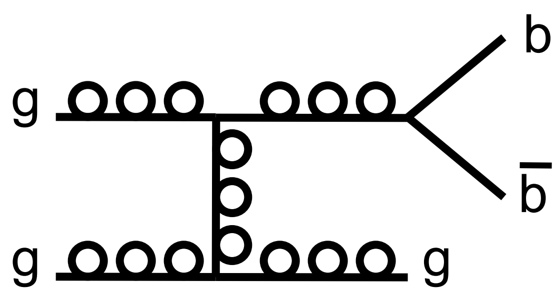
- Need to know fraction of b-jets in sample, F_b
- Cannot assume that flavor Jet 1 = Jet 2 !
- Requiring Jet 2 is B-tagged increases F_b

b-Tag Efficiency

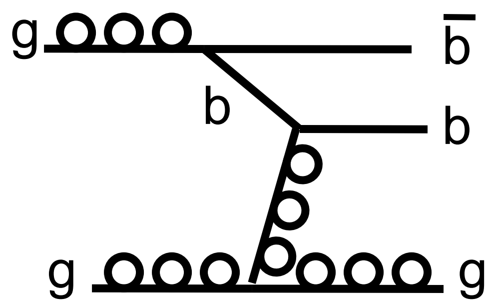
- Recall that several processes contribute to b-jet production at hadron colliders:



Direct Production
($\Delta\phi_{bb} \sim \pi$)



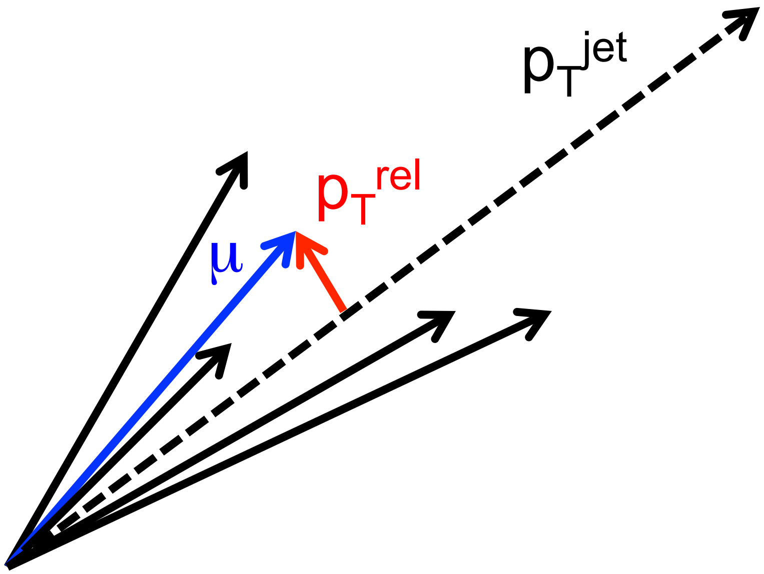
Gluon Splitting
($\Delta\phi_{bb} \sim 0$)

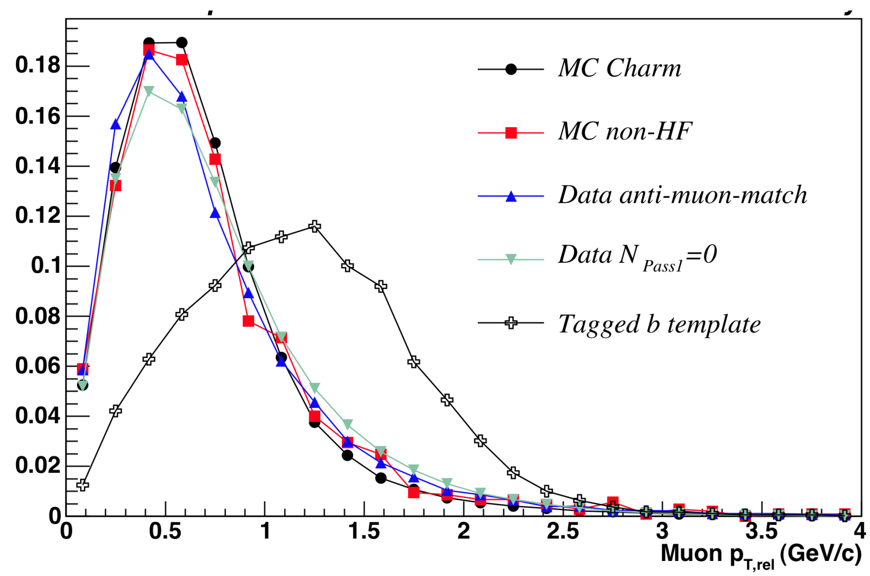


Flavor Excitation
($\Delta\phi_{bb} \sim$ flat)

- Only for one of these processes is the opposite jet also a b-jet, for the others it may (or may not) be so
  - Requires you to determine the b-fraction, F_b

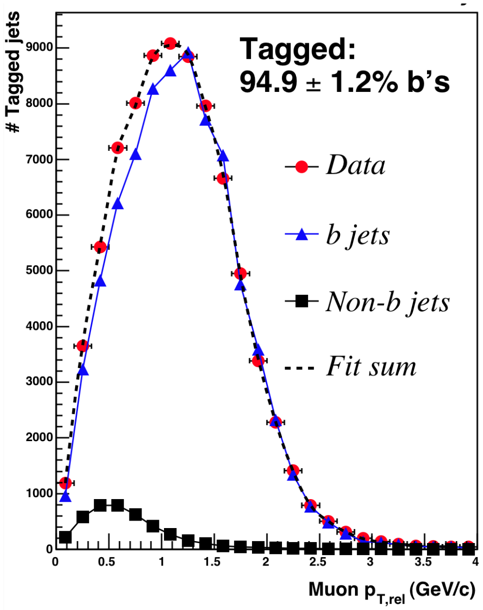
Determining F_b

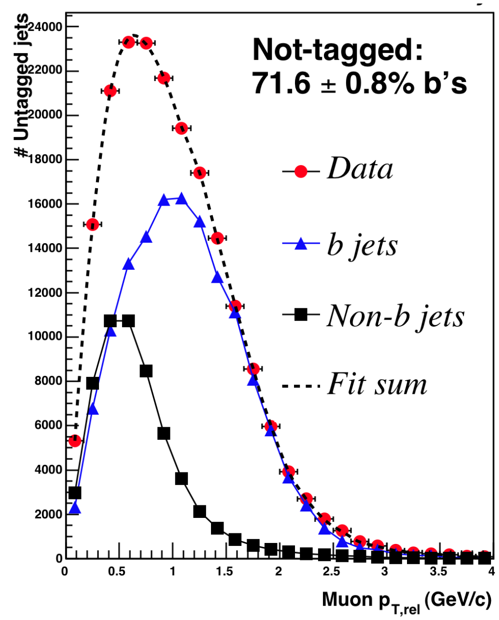




- A common methodology for determining the heavy-flavor fraction of jets with soft-leptons is to fit the p_T^{rel} distribution

b-tag Efficiency

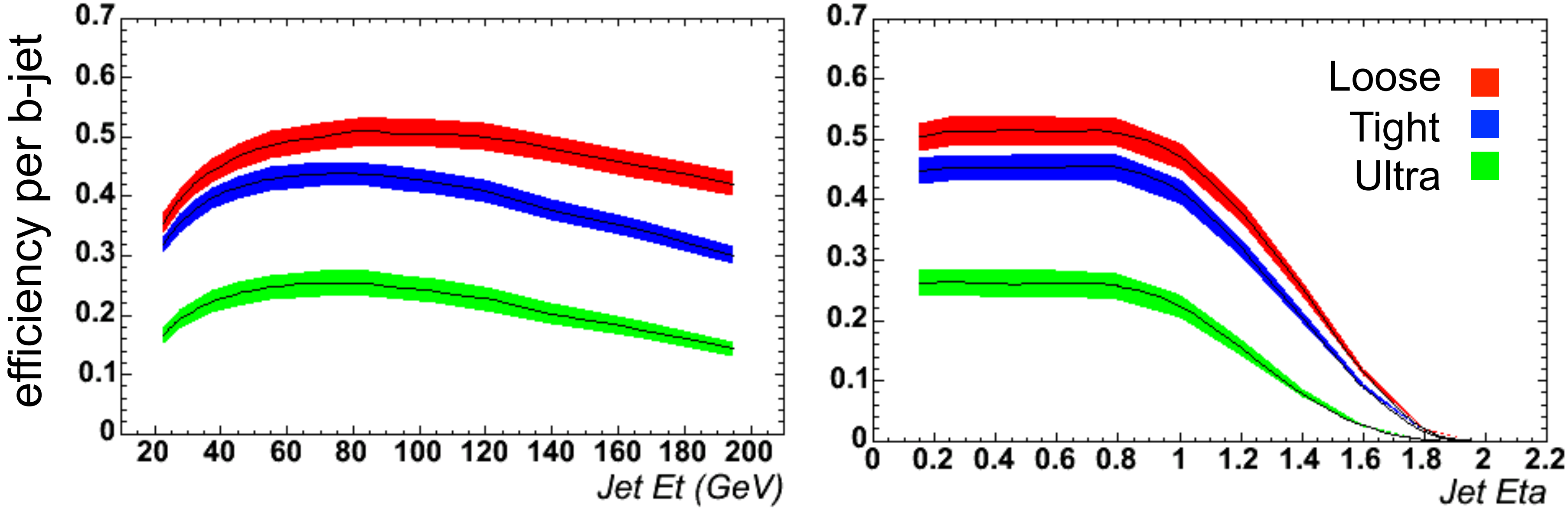




$$\varepsilon_b = \frac{N_{tag} \cdot F_b^{tag}}{N_{tag} \cdot F_b^{tag} + N_{no\text{-}tag} \cdot F_b^{no\text{-}tag}}$$

- Can also use p_T^{rel} fit to make small correction for contributions to tagged sample from non-b jets
  - do this in bins of jet E_T, η, N_{tracks}, etc.

b-Tag Efficiency

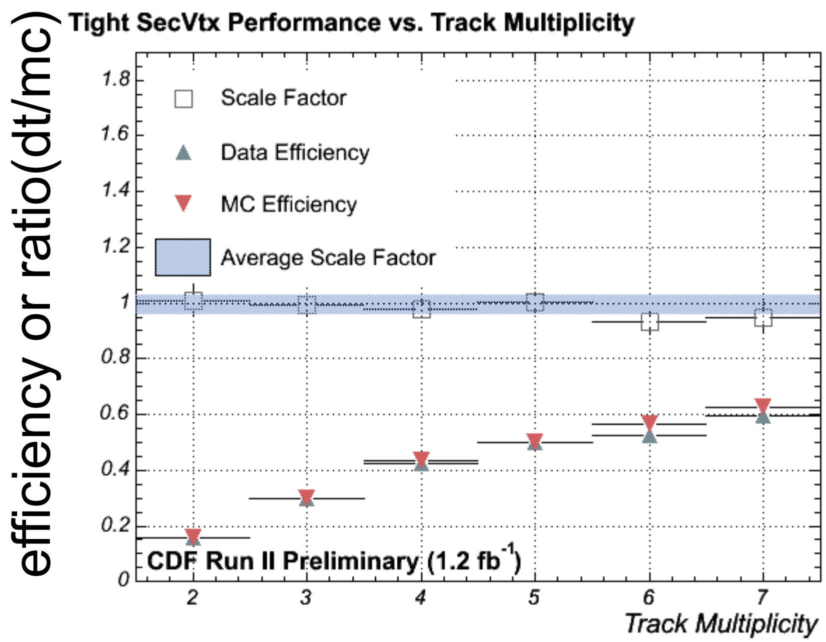


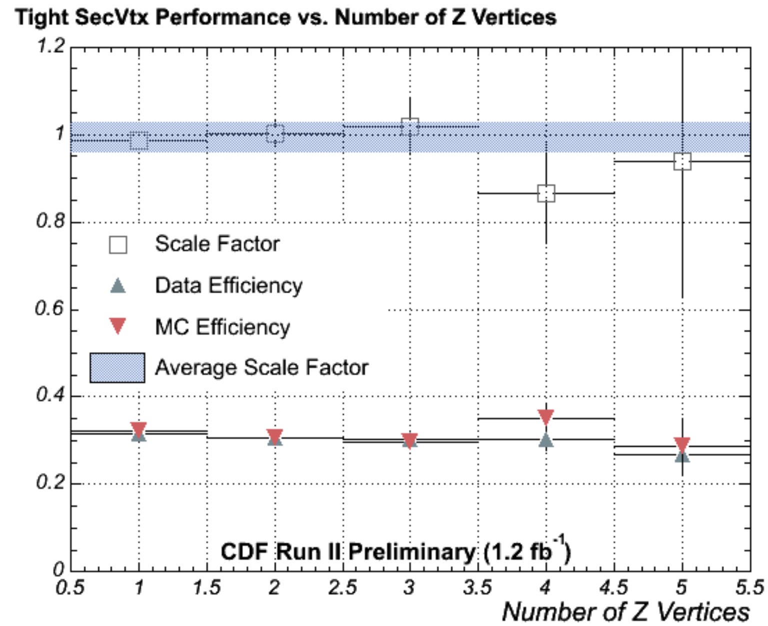
- Some performance plots for dominant CDF algorithm optimized at 3 operating points
  - Hit merging at high jet E_T causes ineff
  - Limited tracking coverage $|\eta|>1$ causes ineff

b-Tag Efficiency

- How do we use this number?
  - Determined for semi-leptonic B-decays
  - E_T distribution soft-ish (~30 GeV; ~60 GeV for ttbar)
  - This back-up trigger is pre-scaled
- Two obvious possibilities
  - Normalize your MC to the data for semi-leptonic B-decays at these E_T ($\varepsilon_b = \varepsilon_b^{mc}$ *Correction)
  - Derive a functional form, $\varepsilon_b(E_T,\eta,\ldots)$ and convolute with the $(E_T,\eta,\ldots)$ distribution from signal MC

b-Tag Efficiency

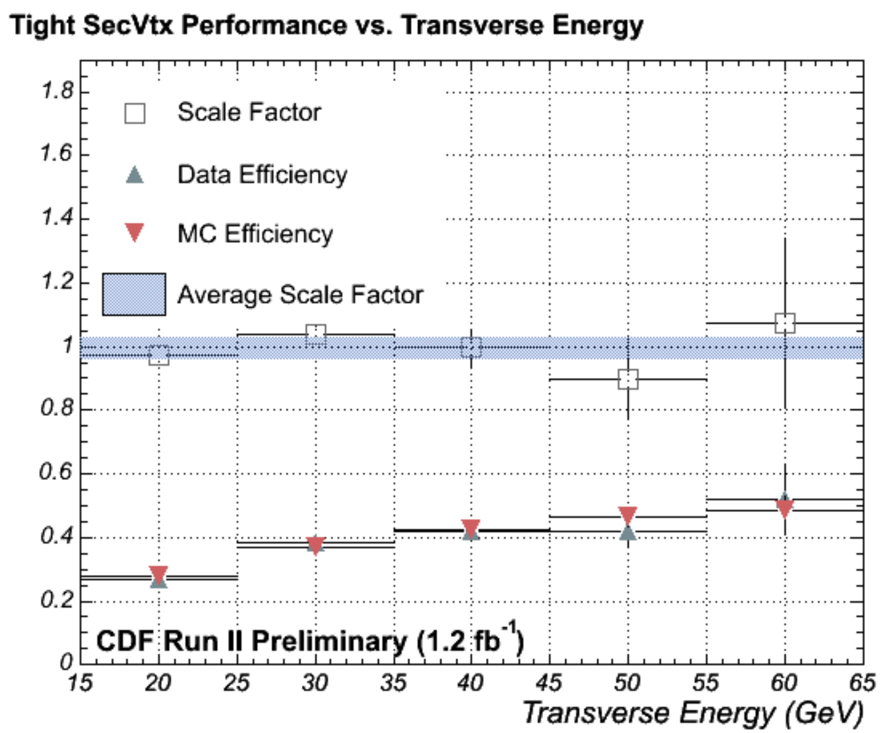




(the data/MC ratio is labeled "Scale Factor" in above plots)

- Investigations of how the ε_b ratio (data/MC) varies
  - Flat, so we have confidence in MC extrapolation

b-Tag Efficiency



- Investigations of how the ε_b ratio (data/MC) varies
  - Residual E_T dependence yields 5% (relative) systematic uncertainty on ε_b for tt-bar x-section

σ(pp→tt) Signal Acceptance

- The total acceptance times efficiency (for ttbar lepton+jet events in the W + >=3j topology) is:

$$\alpha \cdot \varepsilon_{\text{total}} = \alpha \cdot \varepsilon_{\text{lepton-id}} \cdot \varepsilon_{\text{trigger}} \cdot \varepsilon^{\text{event}}_{\geq 1\ \text{b-tag}} \approx 5\%$$

α = geometric and kinematic acceptance : 10%
$\varepsilon_{\text{lepton-id}}$ = lepton reconstruction and identification : 90%
$\varepsilon_{\text{trigger}}$ = trigger efficiencies : 90%
$\varepsilon_{\text{b-tag}}$ = b-tag efficiency per event : 60%

- Associated Systematic Uncertainties (relative):

b-tagging (5%)
Jet Energy Scale (2%)
t-tbar Modeling (2%)
Lepton ID +Trigger (<1%)

b-Tag Efficiency Detail

- What we measure in the data, is the b-Tag efficiency *per jet*, ε_b
- What we want in the acceptance is the efficiency of b-Tagging >=1 of the b-jets *per event*, $\varepsilon_{>=1b}^{event}$
- Use ttbar MC to determine fraction of events satisfying trigger, lepton-ID, MET, N_{jet} criteria that have 1 or 2 fiducial b-jets: $F_{1b}^{t\bar{t}}$ and $F_{2b}^{t\bar{t}}$

$$\varepsilon_{\geq 1\text{b-tag}}^{\text{event}} = F_{1b}^{t\bar{t}} \cdot \varepsilon_b C_b + F_{2b}^{t\bar{t}} \cdot \left(1 - \left(1 - \varepsilon_b C_b\right)^2\right) + \begin{matrix}\text{small corrections for fake} \\ \text{b-tags in non-b jets}\end{matrix}$$

Backgrounds

σ(pp→tt) Backgrounds

Process	1jet	2jets	3jets	4jets	5jets
Pre-tag Data	272347	44868	7605	1686	383
Wbb	802.3 ± 244.6	498.0 ± 154.5	136.9 ± 43.3	32.3 ± 10.5	6.5 ± 2.5
Wcc	431.4 ± 135.2	219.6 ± 69.6	64.3 ± 20.7	16.8 ± 5.6	3.6 ± 1.4
Wc	1002.9 ± 314.4	260.0 ± 82.5	48.8 ± 15.7	8.9 ± 2.9	1.5 ± 0.6
Mistags	946.7 ± 143.6	310.2 ± 53.9	83.5 ± 17.2	18.9 ± 4.8	3.5 ± 1.6
Non-W	487.9 ± 146.4	356.4 ± 106.9	102.2 ± 30.6	20.9 ± 17.5	6.4 ± 6.0
WW	17.7 ± 2.3	44.1 ± 5.7	14.0 ± 1.8	3.5 ± 0.5	1.0 ± 0.1
WZ	9.0 ± 1.0	19.2 ± 2.2	5.1 ± 0.6	1.2 ± 0.1	0.3 ± 0.0
ZZ	0.7 ± 0.1	1.9 ± 0.3	1.0 ± 0.1	0.3 ± 0.0	0.1 ± 0.0
Z+jets	48.7 ± 6.7	36.3 ± 4.6	13.6 ± 1.7	3.3 ± 0.4	0.7 ± 0.1
Single Top (s-channel)	11.4 ± 1.2	42.0 ± 4.1	13.1 ± 1.3	2.8 ± 0.3	0.6 ± 0.1
Single Top (t-channel)	37.6 ± 3.3	52.4 ± 4.6	14.3 ± 1.2	2.8 ± 0.2	0.4 ± 0.0
$t\bar{t}$ (6.7pb)	19.2 ± 2.7	154.9 ± 21.6	345.4 ± 48.0	358.6 ± 49.7	121.5 ± 16.8
Total Prediction	3815.5 ± 720.1	1995.1 ± 325.3	842.0 ± 99.1	470.3 ± 56.5	145.9 ± 18.5
Observed	3906	1926	813	494	156

CDF 2.7 fb^{-1}

- Full background table in all it’s “glory”

$\sigma(pp \rightarrow tt)$ Backgrounds

For events satisfying trigger, lepton, MET criteria
classify according to how many jets observed in events

Process	1jet	2jets	3jets	4jets	5jets
Pre-tag Data	272347	44868	7605	1686	383
Wbb	802.3 ± 244.6	498.0 ± 154.5	136.9 ± 43.3	32.3 ± 10.5	6.5 ± 2.5
Wcc	431.4 ± 135.2	219.6 ± 69.6	64.3 ± 20.7	16.8 ± 5.6	3.6 ± 1.4
Wc	1002.9 ± 314.4	260.0 ± 82.5	48.8 ± 15.7	8.9 ± 2.9	1.5 ± 0.6
Mistags	946.7 ± 143.6	310.2 ± 53.9	83.5 ± 17.2	18.9 ± 4.8	3.5 ± 1.6
Non-W	487.9 ± 146.4	356.4 ± 106.9	102.2 ± 30.6	20.9 ± 17.5	6.4 ± 6.0
WW	17.7 ± 2.3	44.1 ± 5.7	14.0 ± 1.8	3.5 ± 0.5	1.0 ± 0.1
WZ	9.0 ± 1.0	19.2 ± 2.2	5.1 ± 0.6	1.2 ± 0.1	0.3 ± 0.0
ZZ	0.7 ± 0.1	1.9 ± 0.3	1.0 ± 0.1	0.3 ± 0.0	0.1 ± 0.0
Z+jets	48.7 ± 6.7	36.3 ± 4.6	13.6 ± 1.7	3.3 ± 0.4	0.7 ± 0.1
Single Top (s-channel)	11.4 ± 1.2	42.0 ± 4.1	13.1 ± 1.3	2.8 ± 0.3	0.6 ± 0.1
Single Top (t-channel)	37.6 ± 3.3	52.4 ± 4.6	14.3 ± 1.2	2.8 ± 0.2	0.4 ± 0.0
$t\bar{t}$ (6.7pb)	19.2 ± 2.7	154.9 ± 21.6	345.4 ± 48.0	358.6 ± 49.7	121.5 ± 16.8
Total Prediction	3815.5 ± 720.1	1995.1 ± 325.3	842.0 ± 99.1	470.3 ± 56.5	145.9 ± 18.5
Observed	3906	1926	813	494	156

CDF 2.7 fb^{-1}

- Full background table in all it's "glory"

$\sigma(pp \rightarrow tt)$ Backgrounds

	Control Region		Signal Region		
Process	1jet	2jets	3jets	4jets	5jets
Pre-tag Data	272347	44868	7605	1686	383
Wbb	802.3 $\pm$ 244.6	498.0 $\pm$ 154.5	136.9 $\pm$ 43.3	32.3 $\pm$ 10.5	6.5 $\pm$ 2.5
Wcc	431.4 $\pm$ 135.2	219.6 $\pm$ 69.6	64.3 $\pm$ 20.7	16.8 $\pm$ 5.6	3.6 $\pm$ 1.4
Wc	1002.9 $\pm$ 314.4	260.0 $\pm$ 82.5	48.8 $\pm$ 15.7	8.9 $\pm$ 2.9	1.5 $\pm$ 0.6
Mistags	946.7 $\pm$ 143.6	310.2 $\pm$ 53.9	83.5 $\pm$ 17.2	18.9 $\pm$ 4.8	3.5 $\pm$ 1.6
Non-W	487.9 $\pm$ 146.4	356.4 $\pm$ 106.9	102.2 $\pm$ 30.6	20.9 $\pm$ 17.5	6.4 $\pm$ 6.0
WW	17.7 $\pm$ 2.3	44.1 $\pm$ 5.7	14.0 $\pm$ 1.8	3.5 $\pm$ 0.5	1.0 $\pm$ 0.1
WZ	9.0 $\pm$ 1.0	19.2 $\pm$ 2.2	5.1 $\pm$ 0.6	1.2 $\pm$ 0.1	0.3 $\pm$ 0.0
ZZ	0.7 $\pm$ 0.1	1.9 $\pm$ 0.3	1.0 $\pm$ 0.1	0.3 $\pm$ 0.0	0.1 $\pm$ 0.0
Z+jets	48.7 $\pm$ 6.7	36.3 $\pm$ 4.6	13.6 $\pm$ 1.7	3.3 $\pm$ 0.4	0.7 $\pm$ 0.1
Single Top (s-channel)	11.4 $\pm$ 1.2	42.0 $\pm$ 4.1	13.1 $\pm$ 1.3	2.8 $\pm$ 0.3	0.6 $\pm$ 0.1
Single Top (t-channel)	37.6 $\pm$ 3.3	52.4 $\pm$ 4.6	14.3 $\pm$ 1.2	2.8 $\pm$ 0.2	0.4 $\pm$ 0.0
$t\bar{t}$ (6.7pb)	19.2 $\pm$ 2.7	154.9 $\pm$ 21.6	345.4 $\pm$ 48.0	358.6 $\pm$ 49.7	121.5 $\pm$ 16.8
Total Prediction	3815.5 $\pm$ 720.1	1995.1 $\pm$ 325.3	842.0 $\pm$ 99.1	470.3 $\pm$ 56.5	145.9 $\pm$ 18.5
Observed	3906	1926	813	494	156

CDF 2.7 fb^{-1}

- Full background table in all it's "glory"

$\sigma(pp \rightarrow tt)$ Backgrounds

- I'll go through these estimates in a bit of detail
- Significantly more complicated than $B \rightarrow \mu\mu$ case from Lecture 2
- Offers opportunity to
  - Highlight additional methods for estimating bg
  - Introduce some additional experimental techniques commonly used in analyses
  - Give an example where "avoid double counting" warning from Lecture 2 put into practice

$\sigma(p\bar{p} \to t\bar{t})$ Backgrounds

Process	1jet	2jets	3jets	4jets	5jets
Pre-tag Data	272347	44868	7605	1686	383

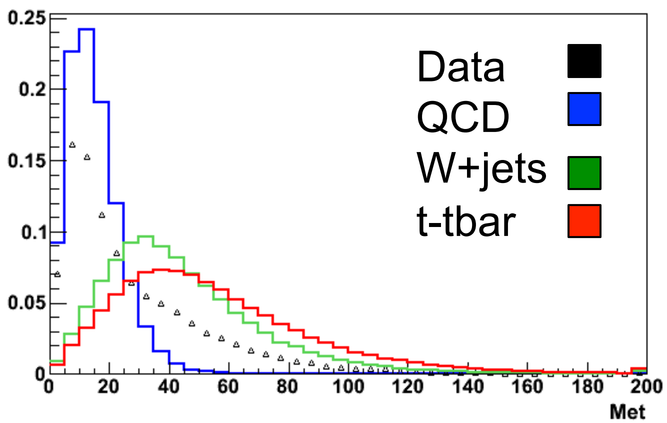
- "Pre-tag" = before any B-tagging
  - Nominally dominated by generic W+jets
  - Since theoretical uncertainties large for σ(W+j), use this sample to normalize W+j backgrounds
  - Also use this to normalize QCD background
- Rest of the table includes b-tag requirement

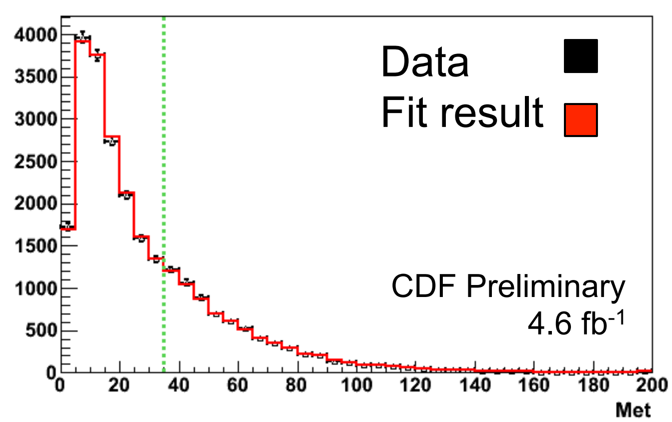
σ(pp→tt) Backgrounds

- Looks like this

$$N^{\text{pre-tag}}_{W+j} = N^{\text{pre-tag}}_{\text{data}} \cdot \left(1 - F_{\text{QCD}}\right) - N^{\text{pre-tag}}_{\text{di-boson}} - N^{\text{pre-tag}}_{t\bar{t}} - N^{\text{pre-tag}}_{\text{single-t}}$$

Acceptance from MC, use data determined Lepton-ID and trigger efficiencies.





QCD MET shape from data using a sample of events in which the "lepton" fails one of the lepton ID criteria

σ(pp→tt) Backgrounds

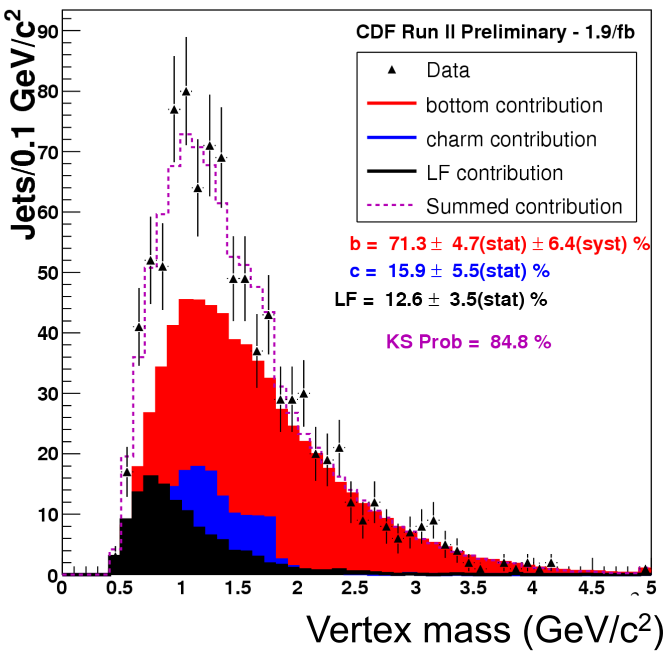
Process	1jet	2jets	3jets	4jets	5jets
Wbb	802.3 ± 244.6	498.0 ± 154.5	136.9 ± 43.3	32.3 ± 10.5	6.5 ± 2.5
Wcc	431.4 ± 135.2	219.6 ± 69.6	64.3 ± 20.7	16.8 ± 5.6	3.6 ± 1.4
Wc	1002.9 ± 314.4	260.0 ± 82.5	48.8 ± 15.7	8.9 ± 2.9	1.5 ± 0.6

- W+heavy flavor = backgrounds from W+j events, where the jets are real heavy flavor jets from b or c
  - Normalized to total W+j (ie. from Pre-tag data)
  - Fraction of W+hf in W+j per jet bin taken from MC normalized to the data W+hf fraction in 1j bin
  - Heavy flavor tag rates taken from MC normalized as discussed on slide 36

σ(pp→tt) Backgrounds

- W+hf estimate looks like this:

$$N^{tag}_{W+hf} = N^{pre\text{-}tag}_{W+j} \cdot F^{W+j}_{hf} \cdot C_{hf} \cdot \varepsilon_{b\text{-}tag} \cdot C_{b\text{-}tag}$$



From MC

Data driven corrections
- for b-tag as described pg 36
- for hf fraction
  - Use W+1j bin
  - For b-tagged jets, fit M_{vtx} to determine hf-fraction of tags
  - Unfold tag ε to get F_{hf} in pretags
  - Assume C_{hf} indep. of N_{jet} (+/-30% syst)

σ(pp→tt) Backgrounds

Process	1jet	2jets	3jets	4jets	5jets
Mistags	946.7 ± 143.6	310.2 ± 53.9	83.5 ± 17.2	18.9 ± 4.8	3.5 ± 1.6

- Mis-tags = W+lf events which are mistakenly b-tagd
  - Normalized to total W+j (ie. from Pre-tag data)
  - Probability of false b-tag parameterized from data control samples as a function of several variables
  - Convolute mis-tag parameterization with Pre-tag data events
  - Corrections to avoid double counting

$\sigma(p\bar{p} \rightarrow t\bar{t})$ Backgrounds

- Mis-tag estimate (basically) looks like this:

$$\mathrm{N}_{\mathrm{W+lf}}^{\mathrm{tag}} = \mathrm{N}_{\mathrm{W+j}}^{\mathrm{pre\text{-}tag}} \cdot \left(1 - \mathrm{F}_{\mathrm{hf}} \cdot C_{\mathrm{hf}}\right) \otimes R_{mistag}^{data}\left(\vec{x}\right)$$

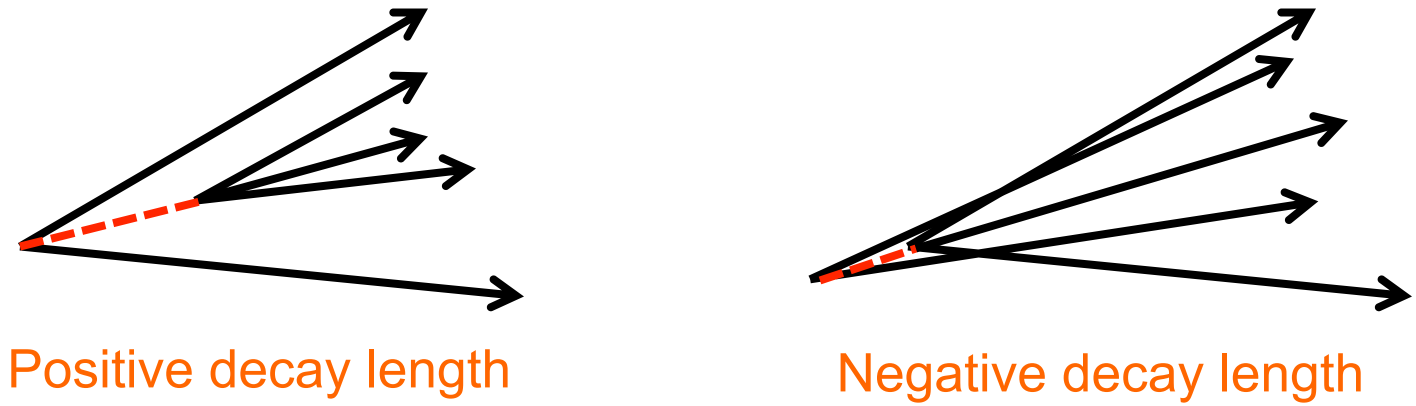
- *R* is a parameterization of the mis-tag probability per jet as a function of several variables $\{\vec{x}\}$
  - Derived from inclusive jet data
  - Uses jets with a negative decay length
  - Corrections for hf contributions and material

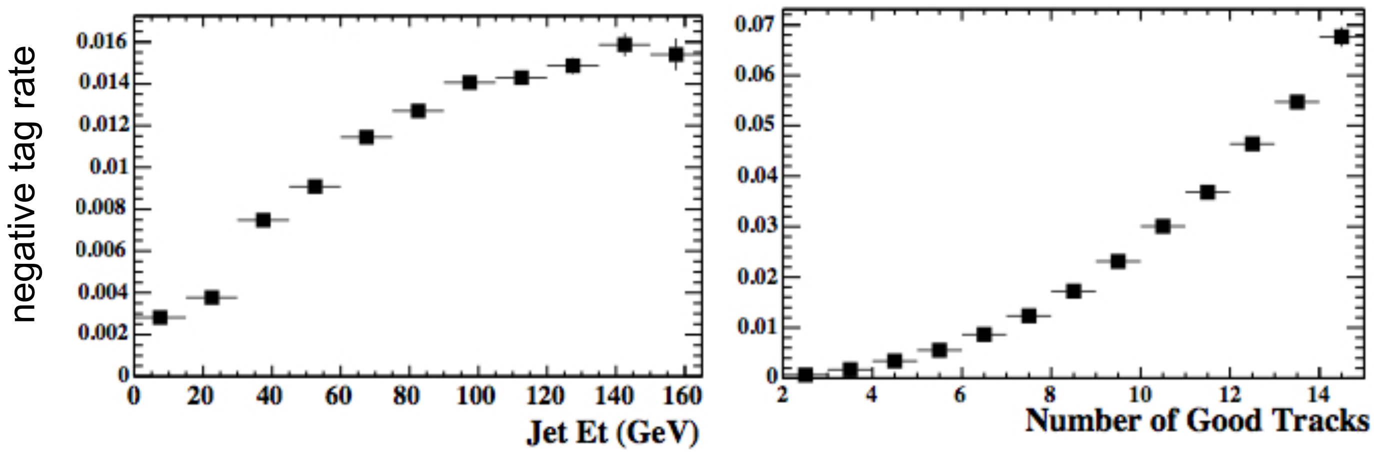
Negative Decay Length

- Decay length can be signed relative to the jet axis
  - Vertices from real hf will be displaced from the beam line in the same direction as the jet : +L
  - Vertices from lf arise from resolution effects and can be displaced in the opposite direction : -L
    - Since the resolutions are ~Gaussian and lf jets have no real lifetime ($c\tau$=0), lf tags equally populate +/- sides
    - Can use –L tag rates as estimate of light flavor contributions to +L rates
    - Correct for hf contribution to –L rates using fits to M_{vtx}

Negative Decay Length

- In pictures…





from CDF using inclusive jet data

Estimating mis-tag contributions

- In the end CDF finds that the mis-tag rate depends on several variables

$$R_{mis-tag}\left(\mathrm{E}_{\mathrm{T}}^{\mathrm{jet}},\ \eta_{jet},\ \mathrm{N}_{\mathrm{tracks}}^{\mathrm{jet}},\ \mathrm{N}_{\mathrm{interactions}}^{\mathrm{event}},\ \ldots\right) = R_{mis-tag}(\vec{x})$$

- This is a *per jet* mis-tag rate. To estimate the probability of generating a mis-tag *per event*

$$P_{mis-tag}^{event} = \sum_{\mathrm{j=jets}} \vec{\mathrm{x}}_{\mathrm{j}} \cdot R_{mis-tag}\left(\vec{x}\right) = \sum_{\mathrm{j=jets}} \mathrm{Pr}\,ob_{\mathrm{j}}^{\mathrm{mis\text{-}tag}}\ -\ \mathrm{O}(10^{-4})$$

where last term is a (negligible) correction for multiple mis-tags per event

σ(pp→tt) Backgrounds

Process	1jet	2jets	3jets	4jets	5jets
WW	17.7 ± 2.3	44.1 ± 5.7	14.0 ± 1.8	3.5 ± 0.5	1.0 ± 0.1
WZ	9.0 ± 1.0	19.2 ± 2.2	5.1 ± 0.6	1.2 ± 0.1	0.3 ± 0.0
ZZ	0.7 ± 0.1	1.9 ± 0.3	1.0 ± 0.1	0.3 ± 0.0	0.1 ± 0.0
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Single Top (t-channel)	37.6 ± 3.3	52.4 ± 4.6	14.3 ± 1.2	2.8 ± 0.2	0.4 ± 0.0

- “Electroweak” = diboson, single-top, Z+jets
  - Normalized to theoretical cross sections
  - Trigger and lepton ID efficiencies taken from data
  - B-tags from hf jets use MC efficiency normalized to data as discussed on page 36
  - B-tags from lf jets use probabilities from R_{mistag}

$\sigma(pp\rightarrow tt)$ Backgrounds

- The expression looks like this

$$\mathrm{N}_{\mathrm{EWK}}^{\mathrm{tag}} = \left\{ \sum_i \sigma_i \cdot \alpha_i \cdot \varepsilon_{\mathrm{trigger}} \cdot \varepsilon_{\mathrm{lepton}} \cdot \left(\mathrm{F}_{\mathrm{hf}}^{\mathrm{i}} \cdot \varepsilon_{\mathrm{b\text{-}tag}} \cdot C_{\mathrm{b\text{-}tag}} + \left(1 - \mathrm{F}_{\mathrm{hf}}^{\mathrm{i}}\right) \otimes R_{\mathrm{mistag}}^{\mathrm{data}} \right) \right\} \cdot \int L dt$$

- Sum is over the various physics processes
- F_{hf}^{i} is the heavy flavor fraction for the ith process
- Mis-tag contribution from these sources included explicitly using the data determined R_{mistag}

$\sigma(pp \rightarrow tt)$ Backgrounds

Process	1jet	2jets	3jets	4jets	5jets
Non-W	487.9 ± 146.4	356.4 ± 106.9	102.2 ± 30.6	20.9 ± 17.5	6.4 ± 6.0

- "Non-W" = QCD contribution to the tagged sample
  - Determined from a fit to the MET distribution in tagged events
  - Use looser MET requirement to reduce uncertainty on QCD normalization in signal region
  - Get QCD MET shape by using R_{mistag} to weight distribution from "fake lepton" sample

$\sigma(pp \rightarrow tt)$ Backgrounds

- Total background is

$$N_{bg}^{\geq 1b\text{-}tag} = N_{W+hf}^{tag} + N_{W+lf}^{tag} + N_{EWK}^{tag} + N_{non\text{-}W}^{tag}$$

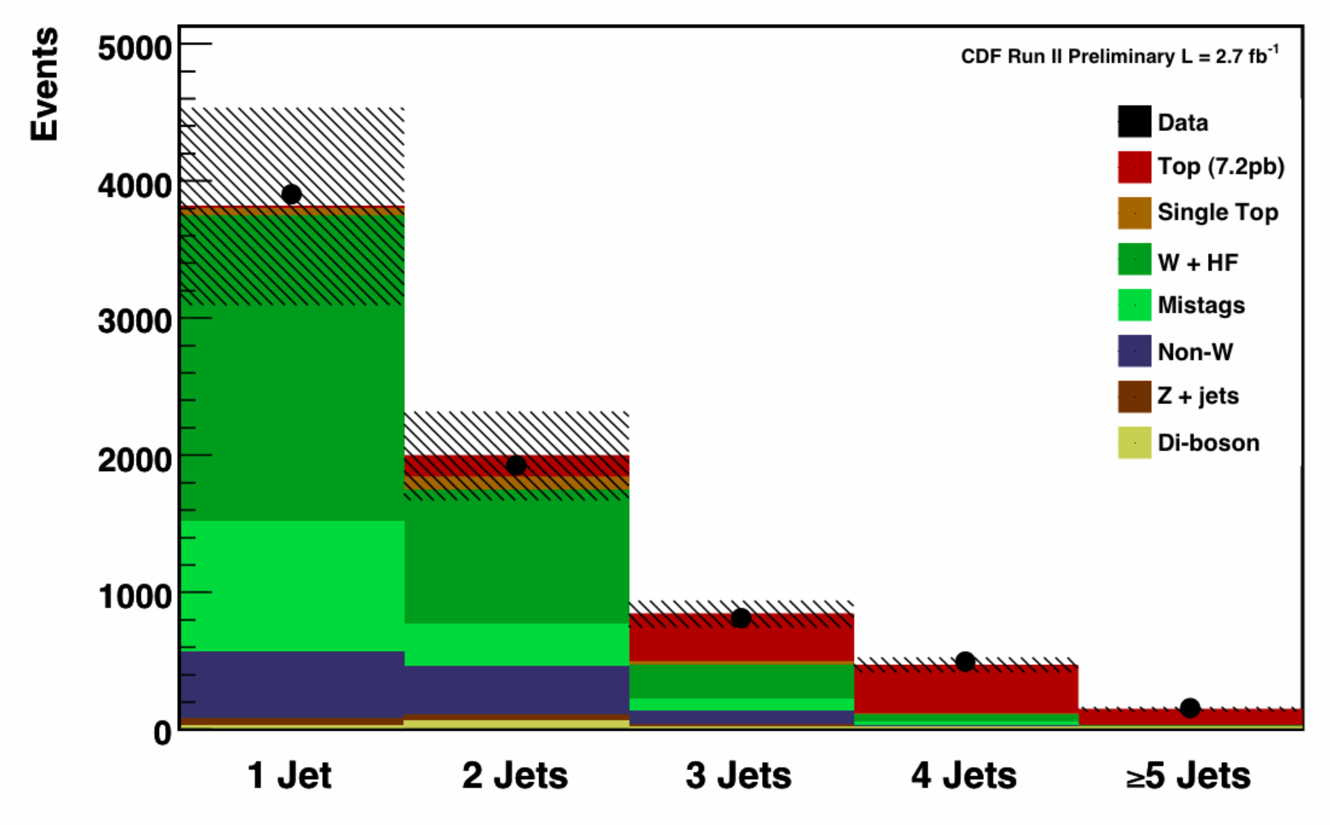
- Systematic uncertainties on background prediction (relative percentages)

Process	$\delta N/N$	Dominant Source of Uncert
W+hf	+/- 30%	C_{hf} extrapolations to signal region
W+lf	+/-15%	checks of R_{mistag}; hf corrections
QCD	+/- 30%	variations in QCD MET shape
Other	+/- 10%	C_b, $R_{mistag,}$ luminosity

- Total effect on cross section rather small though (<5% relative)

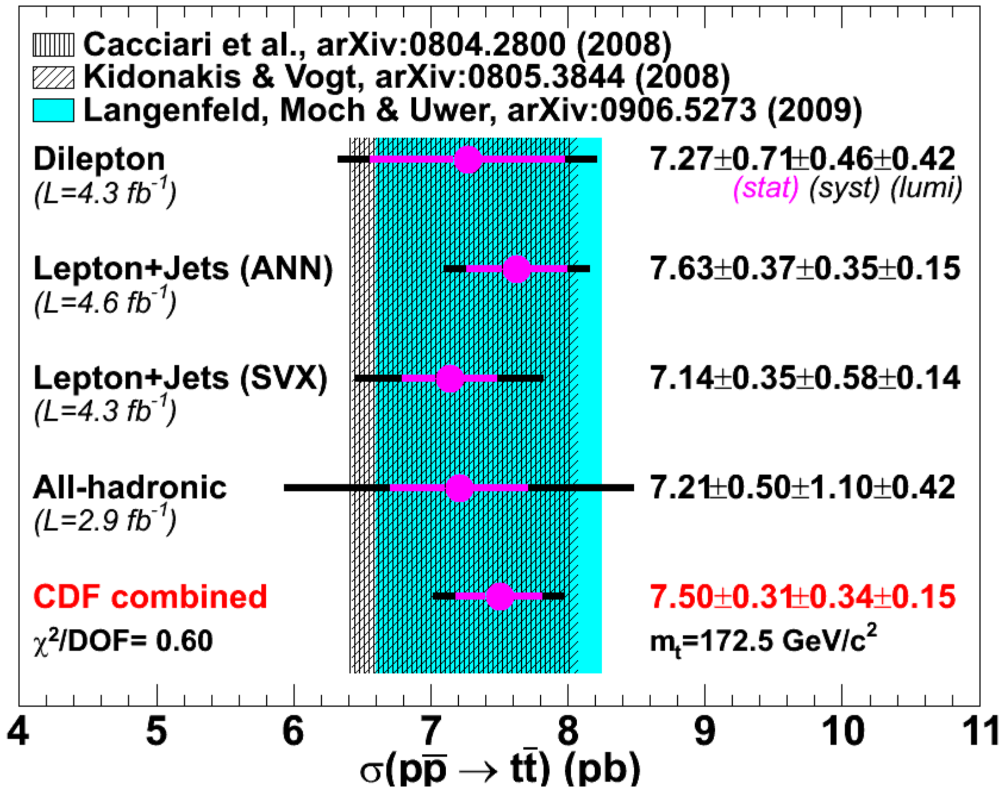
Extracting the Cross Section

Putting it all together



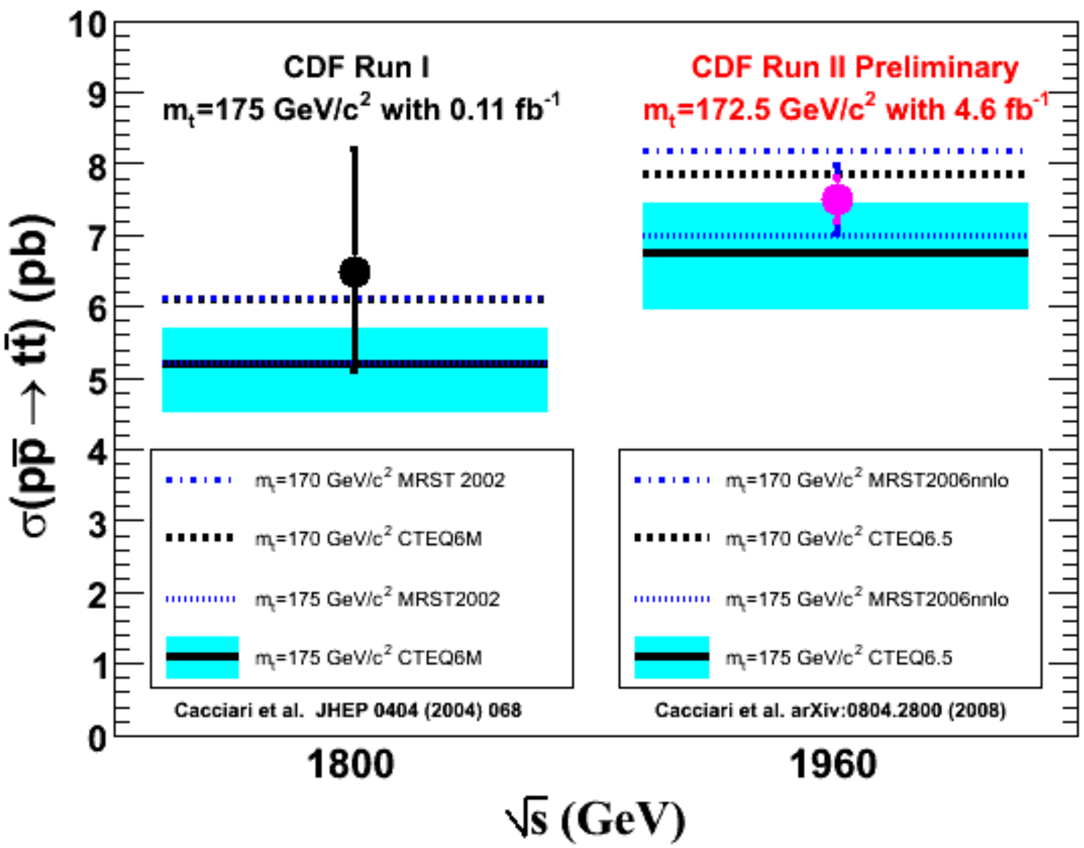
- Background methodology accurately predicts observation in control regions

Measured σ(pp→tt)



- Consistent across all channels and methods
- Measured uncertainty < theoretical uncertainty

Measured $\sigma(pp \rightarrow tt)$

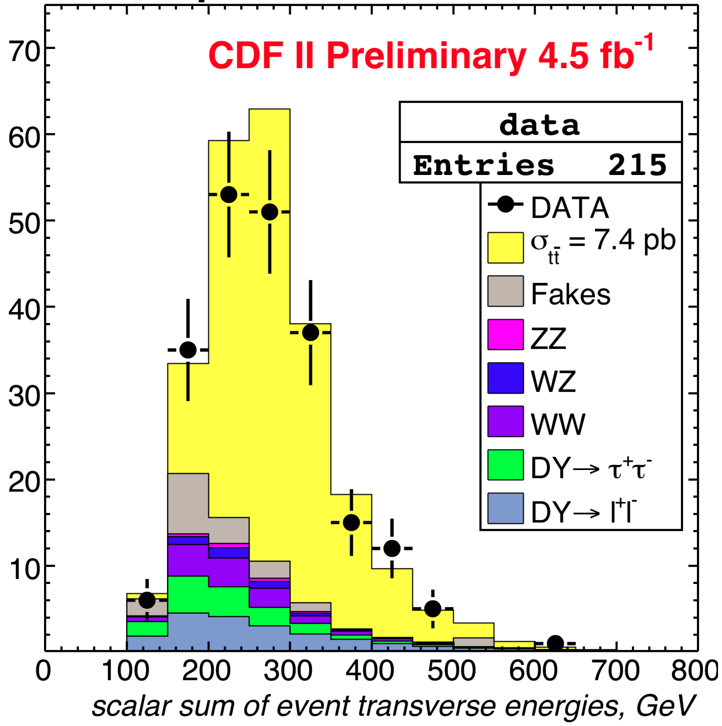


- Tevatron started it, LHC will add pts at 7, 10, 14 TeV

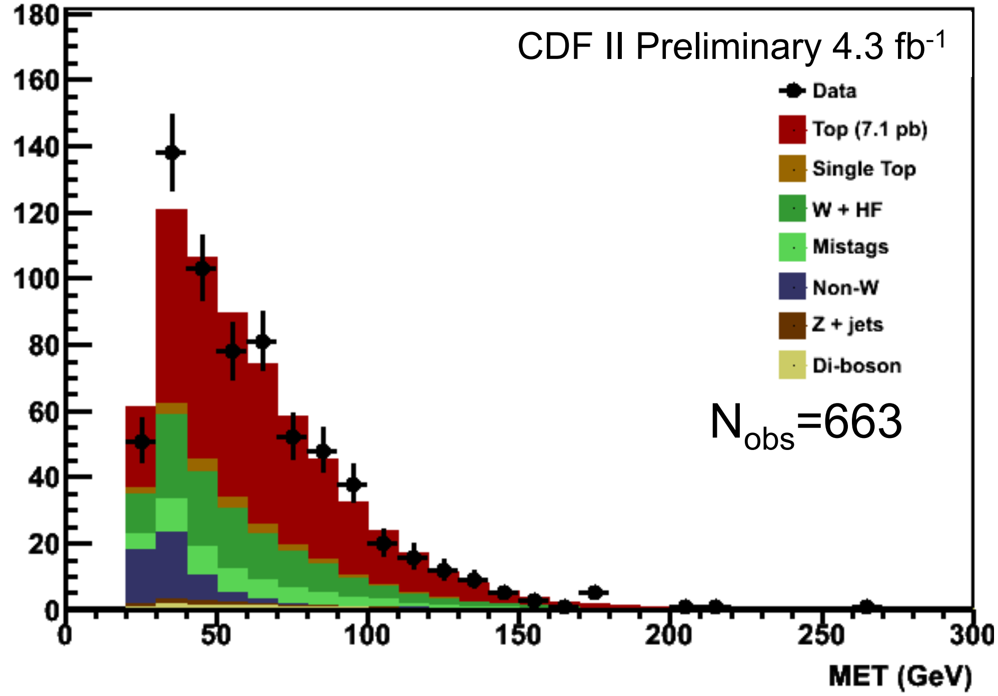
Leveraging Understanding of Sample Composition

t-tbar Distributions

Di-Lepton+2Jet Events



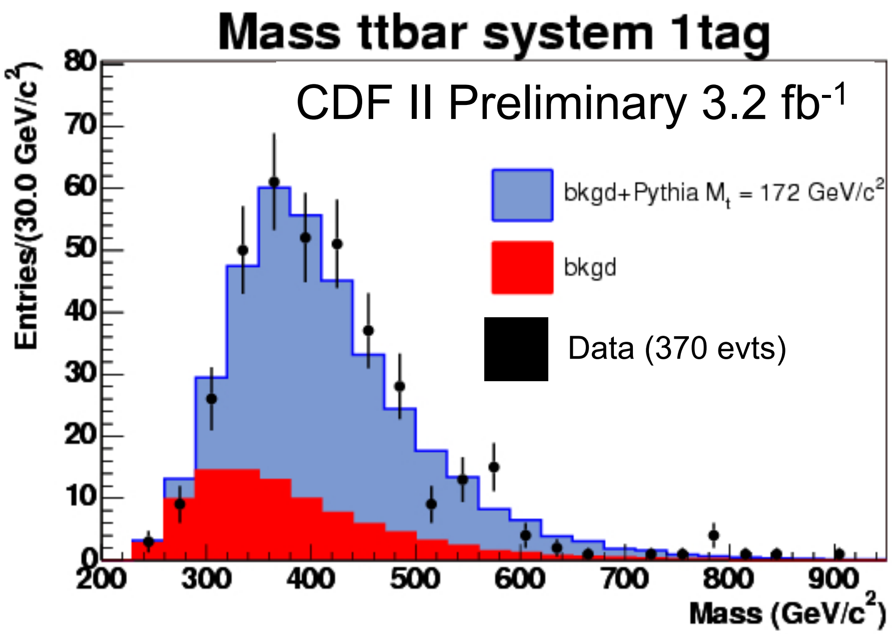
Lepton+3Jet Events

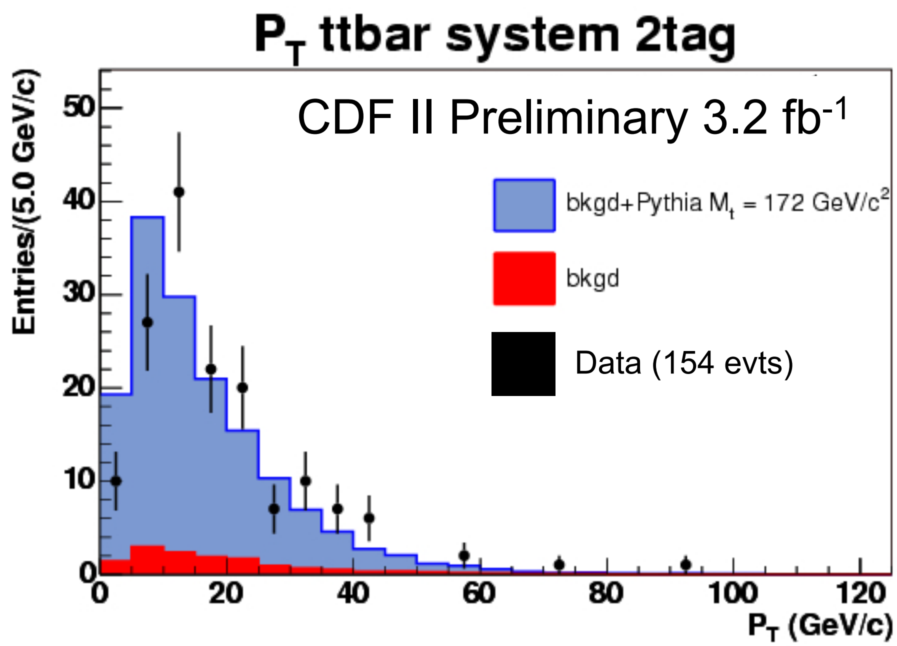


- Well modeled. Leverage understanding of sample composition to measure top properties.

t-tbar Distributions

For Lepton+4Jets Events





- Well modeled. Leverage understanding of sample composition to measure top properties.

Measuring Properties

- Use measurement of the top mass as an example
  - Concentrate on lepton+jets channel
  - This is an example of a “shape analysis”

- To measure the top-quark mass (M_t) we need to
  1) Select a sample of t-tbar events (>=4 jets)
  2) Reconstruct observable sensitive to M_t

$$M_{reco} = \sqrt{(E_W, \vec{p}_W)^2 + (E_b, \vec{p}_b)^2}$$

  3) Unfold detector effects

$$M_{reco} \rightarrow M_t$$

Top Mass: 2) Event Reconstruction

$$t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow \ell \nu \, q\bar{q}' \, b\bar{b}$$

Have		Need
Jet 1	?	q
Jet 2	⟷	$\bar{q}$'
Jet 3	Combinatoric Background	b
Jet 4		$\bar{b}$
Lepton		Lepton
$\not{E}_t$		ν

This sort of "combinatoric" background originates from ambiguities in the signal events… dilutes resolution

Top Mass: 2) Event Reconstruction

$$t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow \ell\nu\, q\bar{q}'\, b\bar{b}$$

Have		Need
Jet 1	?	q
Jet 2	⟷	$\bar{q}$’
Jet 3	Combinatoric Background	b
Jet 4	DIL : 2 combinations	$\bar{b}$
Lepton	LJT: 12 combinations	Lepton
$\not{E}_t$	AJT: 90 combinations	ν

This sort of “combinatoric” background originates from ambiguities in the signal events… dilutes resolution

Top Mass: 2) Event Reconstruction

$$t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow \ell\nu\, q\bar{q}'\, b\bar{b}$$

Have

Jet 1
Jet 2
Jet 3
Jet 4
Lepton
$\not{E}_t$

Have Jet Energies
Need Parton Energies

→

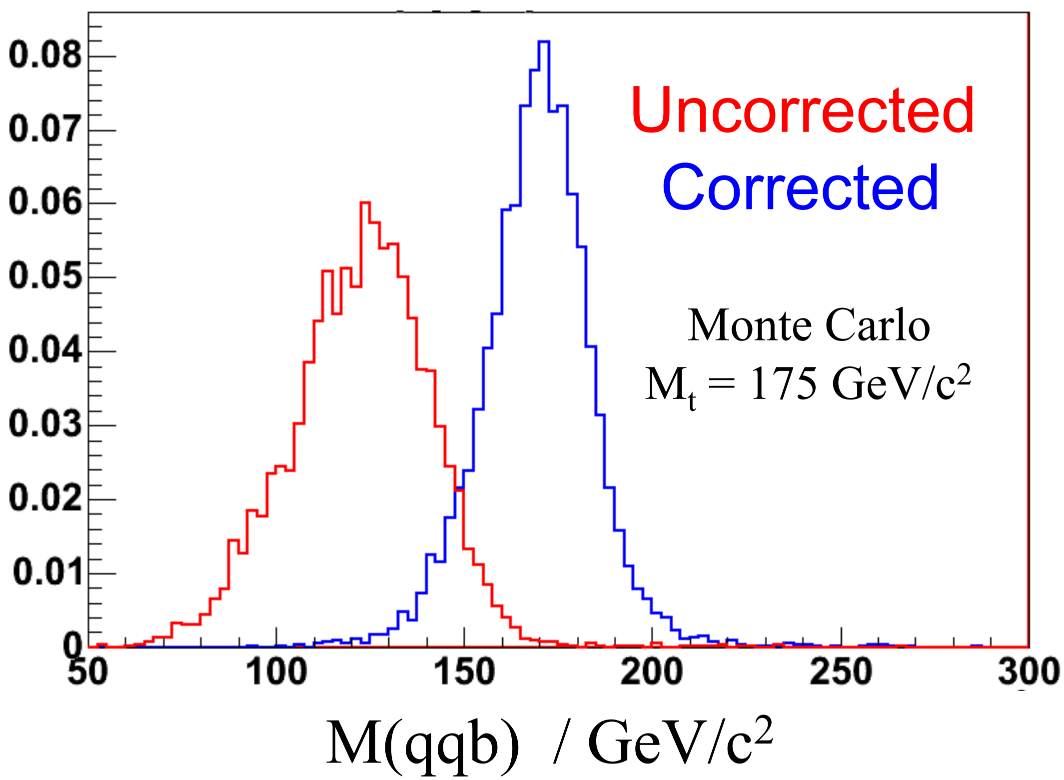
"Jet Energy Scale"(JES)

Need

q
$\bar{q}$'
b
$\bar{b}$
Lepton
ν

Top Mass: 2) Reconstruction

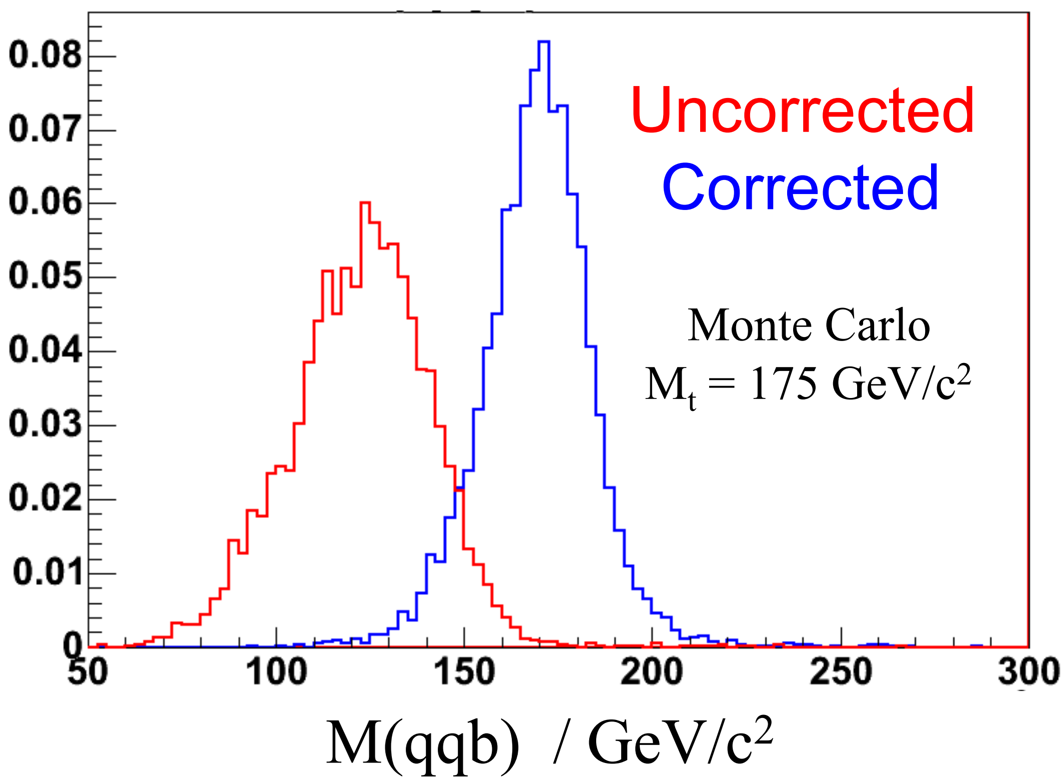
Jet Energy Scale == Absolute Mass Scale



- hadronization, non-linearities, pile-up, multiple-interactions, underlying event
- From Data and MC
- known to ~3% for M_t jet energies
- Leading Run I syst
- Reduced in Run II

Top Mass: 2) Reconstruction

Jet Energy Scale == Absolute Mass Scale

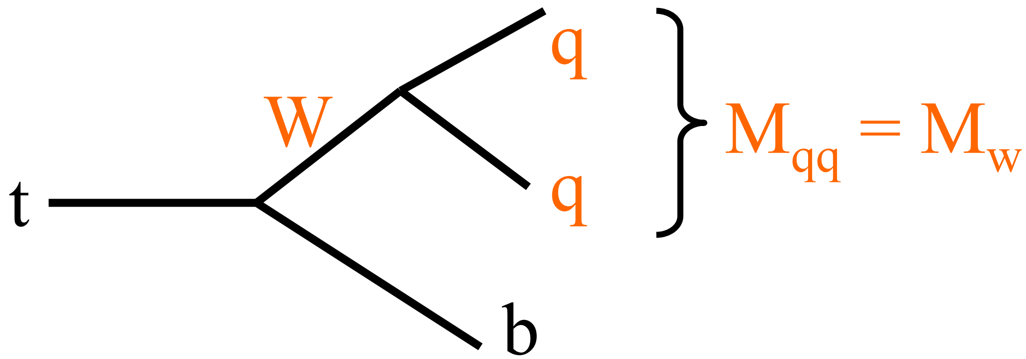


- hadronization, non-linearities, pile-up, multiple-interactions, underlying event
- From Data and MC
- known to ~3% for M_t jet energies
- Leading Run I syst
- Reduced in Run II

This is sufficiently important/complicated, could be it's own set of lectures

Top Mass: 2) Reconstruction

- Run II analyses further constrain JES
  - In-situ constraint possible by comparing observed M_{qq} to known M_w (in Lepton+jet and All-jets channels)

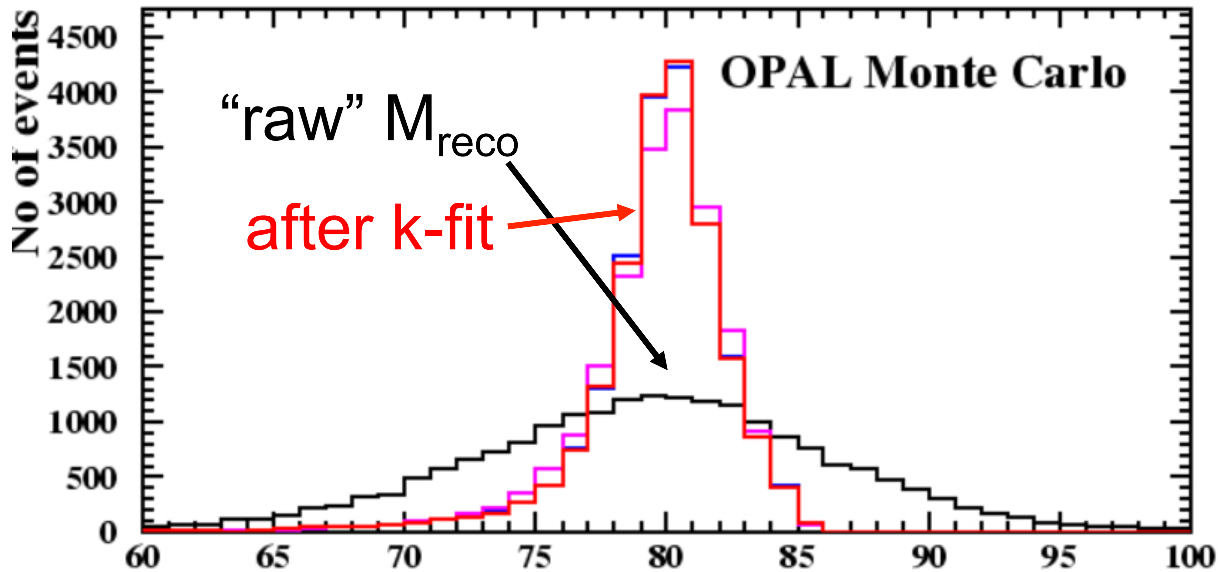


  - with 1 fb^{-1}, reduced δ(JES) syst by factor of 2
  - now δ(JES) systematic scales with statistics

Aside: Kinematic Fits

- Kinematic fits are a common technique for improving resolution on measured quantities (e.g. invariant M) by exploiting known kinematic constraints
- For reconstructing the invariant mass
  - All jets : have (E,p_x,p_y,p_z) for all 6 partons
  - Lepton+jets : missing (E,p_x,p_y,p_z) for 1 neutrino
  - Di-Lepton: missing (E,p_x,p_y,p_z) for 2 neutrinos
  - Constraints: $\Sigma p_T=0$, $M_{qq}=M_w$, $M_{l\nu}=M_w$, $M_t=M_{tbar}$
- M_{reco} resolution depends on final state, but in all cases a kinematic fit yields improvement

Aside: Kinematic Fits



Reconstructed W-boson mass from WW→lνqq events (GeV/c^2)

- Although taken from a LEP measurement, illustrates my point that a kinematic fit improves resolution

Aside: Kinematic Fit

$$\chi^2 = \sum_{i=\ell,4\ jets} \frac{\left(p_T^{i,fit} - p_T^{i,meas}\right)^2}{\sigma_i^2} + \sum_{j=x,y} \frac{\left(U_j^{fit} - U_j^{meas}\right)^2}{\sigma_j^2} + \frac{\left(M_{jj} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{\ell\nu} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{bjj} - M_{reco}\right)^2}{\Gamma_t^2} + \frac{\left(M_{b\ell\nu} - M_{reco}\right)^2}{\Gamma_t^2}$$

- As an example, in the lepton+jet final state, here's the χ^2 expression used in CDF's kinematic fit
  - Neutrino (p_x,p_y) taken from MET, which is vector sum over measured lepton and jets (p_T^i) and un-clustered energy in calorimeter (U_j)
  - Experimental resolutions included, $\sigma_{i,j}$
  - M_{bbj} and $M_{bl\nu}$ constrained to same value, M_{reco}

Aside-to-the-Aside: MET Details

- Recall the definition of MET from lecture 1:

$$\not{E}_T = -\left|\sum_{i=towers} E_i \cdot \hat{n}_T^i\right|$$

where $\hat{n}_T^i$ is the unit vector from the interaction vertex to the calorimeter tower center in *xy* plane

To get it right need to include corrections for μs:

$$\not{E}_T \rightarrow \not{E}_T' = \not{E}_T + E_{\mu-\mathrm{tower}} \cdot \hat{n}_T^\mu - \vec{\mathrm{p}}_\mathrm{T}^\mu$$

… and for response corrections to jet energies:

$$\not{E}_T \rightarrow \not{E}_T' = \not{E}_T - \sum_{\mathrm{j=jets}} \Delta \mathrm{E}_\mathrm{j}(\mathrm{corrected}) \cdot \hat{n}_T^j$$

- Sometimes written instead as:

$$\not{E}_T = -\left|\sum_{j=jets} E_j^{corrected} \cdot \hat{n}_T^j + \sum_{l=leptons} \vec{p}_T^l + \sum_{i=towers} U_i \cdot \hat{n}_T^i\right|$$

Top Mass 3) Unfolding Exp Effects

- Usually the physics parameter of interest needs to be extracted from the reconstructed distribution

- Maximum likelihood fits usually employed to do so
  - Binned or Unbinned
  - Inclusion of constraints
  - Inclusion of “nuisance” parameters
  - Marginalization vs Profiling

Example likelihoods

- Most basic, good for many things.
  - f_s is expected signal fraction from e.g. σ analysis
  - P_s is probability signal will yield M_{reco} assuming M_t
  - P_b is probability background will yield M_{reco}

$$L = \prod_{i=N_{evts}} f_s \cdot P_s\left(M^i_{reco} \middle| M_t\right) + (1 - f_s) \cdot P_b\left(M^i_{reco}\right)$$

- Often choose to allow f_s to vary within constraints
  - $G(x'|x,\sigma_x)$ is Gaussian probability of observing x' given expectation of x +/- σ_x

$$L = G(f_s' | f_s, \sigma_{f_s}) \cdot \left\{ \prod_{i=N_{evts}} f_s' \cdot P_s\left(M^i_{reco} \middle| M_t\right) + (1 - f_s') \cdot P_b\left(M^i_{reco}\right) \right\}$$

Example likelihoods

- Most sophisticated includes “nuisance parameters”… unknowns which can introduce systematic effects but which can be constrained by the data
  - P_s is probability signal will yield M_{reco} for a given jet-energy-scale (S_{JE}) assuming M_t
  - P_b is probability background will yield M_{reco} for a given S_{JE}
  - Here I’ve written a prior (Gaussian) constraint on S_{JE}

$$L = G(S_{JE}' | S_{JE}, \sigma_{S_{JE}}) \cdot G(f_s' | f_s, \sigma_{f_s}) \cdot \left\{ \prod_{i=N_{evts}} f_s' \cdot P_s\left(M_{reco}^i \middle| M_t, S_{JE}' \right) + (1 - f_s') \cdot P_b\left(M_{reco}^i \middle| S_{JE}' \right) \right\}$$

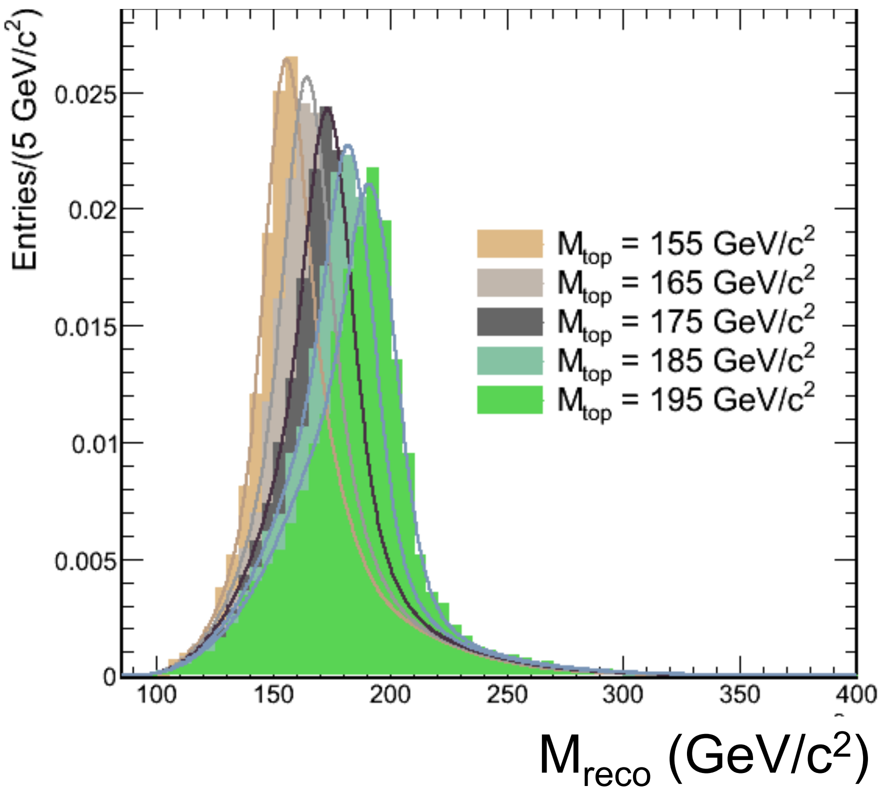
Extracting M_t from Likelihood

- In all cases, you determine the measured top-quark mass by maximizing the likelihood with respect to M_t
  - In practice people often minimize -ln(L)
  - Minimum –ln(L) gives the measured M_t
  - +/- δM_{stat} given by those M_t values corresponding to a change in likelihood of $|\ln(L)-\ln(L)_{min}|=0.5$
  - If nuisance parameters included, then

    $\delta M = \delta M_{stat}$ (+) $\delta M_{nuisance\text{-}1}$ (+) $\delta M_{nuisance\text{-}2}$ (+)…

Extracting M_t from Likelihood

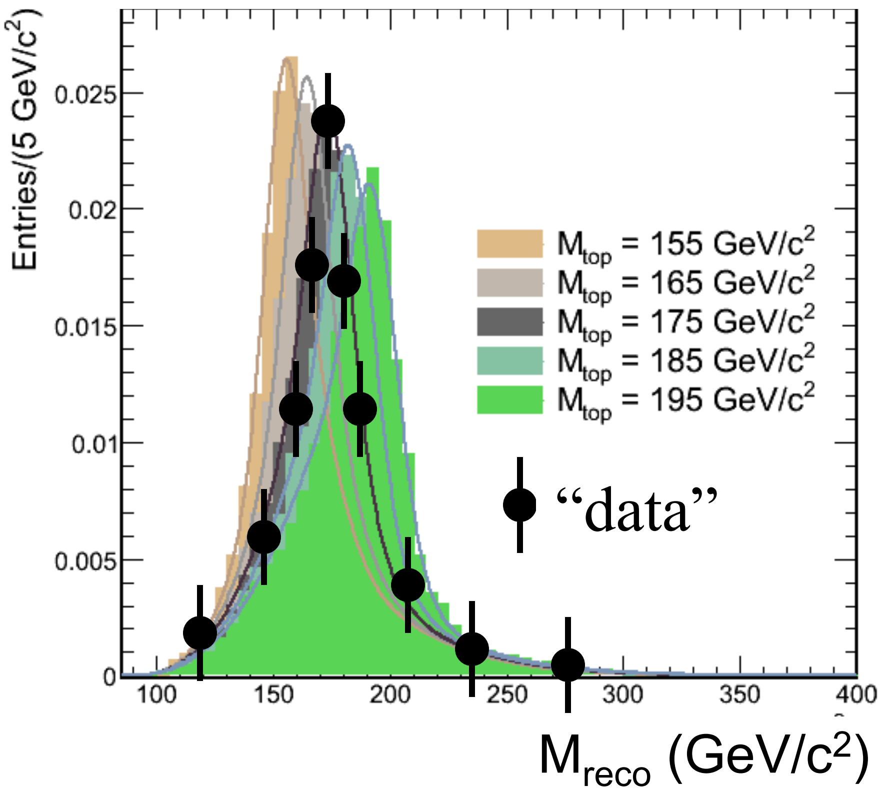
- In pictures…



- P_s and P_b often taken from MC
- Combined in ratio given by f_s
- Since P_s is a function of M_t the total M_{reco} shape varies with M_t

Extracting M_t from Likelihood

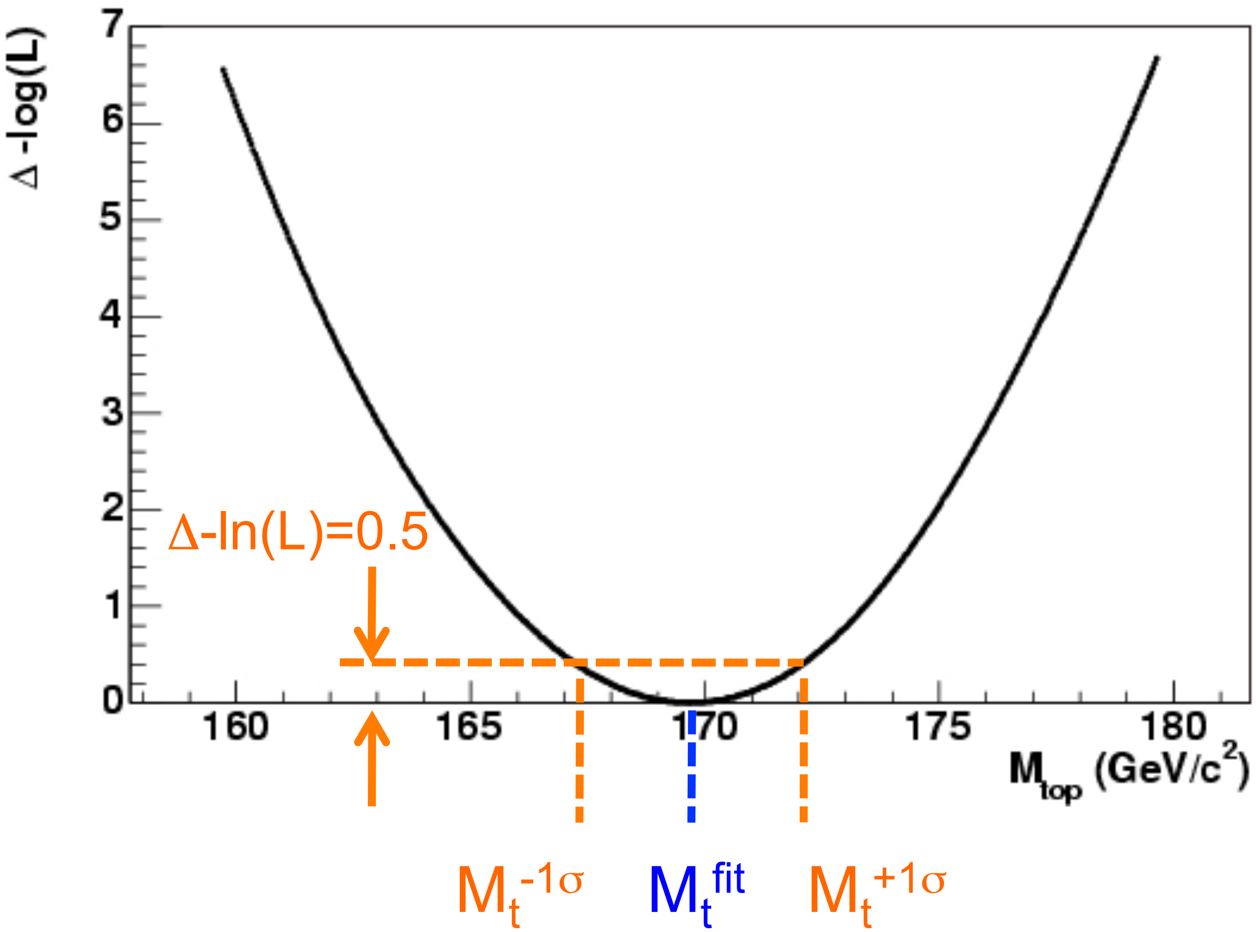
- In pictures…



- P_s and P_b often taken from MC
- Combined in ratio given by f_s
- Since P_s is a function of M_t the total M_{reco} shape varies with M_t
- Likelihood method is used to pick-out which of these best describe the data distribution

Extracting M_t from Likelihood

- In pictures…



Before fitting the data

- Imperative you demonstrate that your likelihood fit
  - Yields an unbiased estimate of “X”
  - Returns an accurate estimate of δX_{stat}
- Usually MC “pseudo-experiments” are generated and then treated like data to demonstrate that your likelihood fit is statistically well behaved
  - Look to see if it’s unbiased (ie. $M_t^{fit} = M_t^{true}$)
  - Look to see that δM_{stat} accurately estimated

Pseudo-Experiments

- Construct an ensemble of CDF data sets by mixing together MC events from various processes
  - sample composition taken from x-section analysis
- Treat each of these MC data sets as if real data
  - Perform fit and record for each M_{fit} +/- δM_{fit}
- Want to see your lh-fit is
  - Unbiased: $MEAN(residual) = 0$

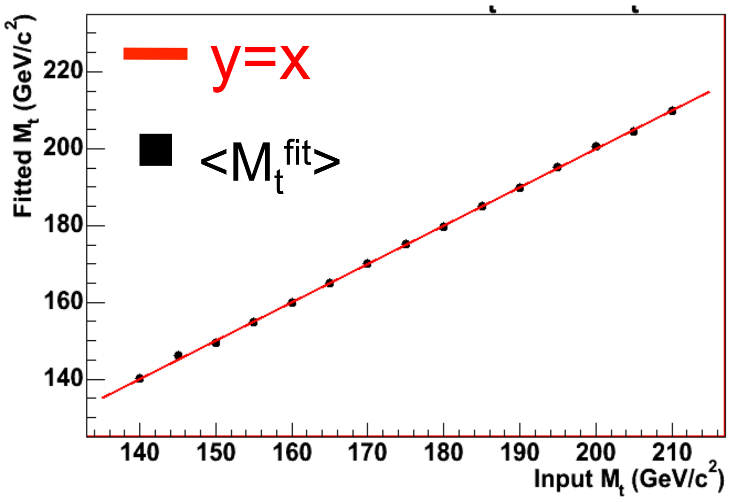
$$"residual" = \left(M_t^{fit} - M_t^{true}\right)$$

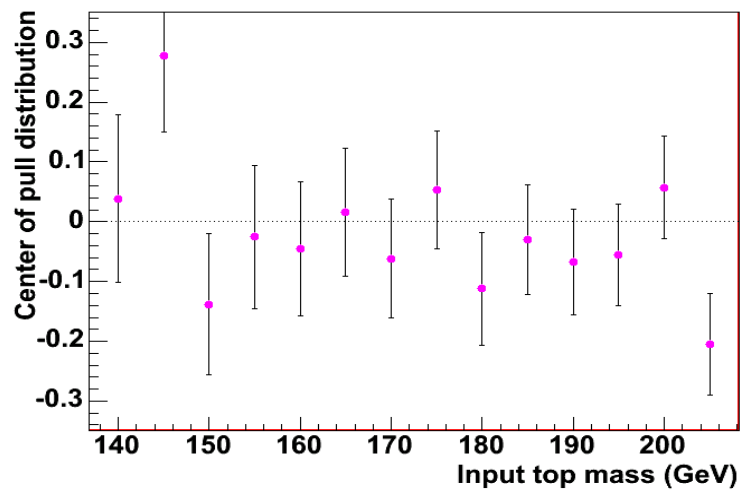
  - Accurately estimates stat uncertainty: $RMS(pull) = 1$

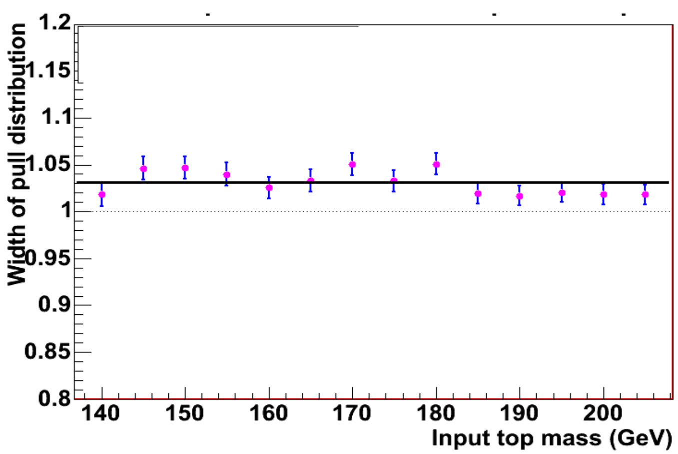
$$"pull" = \frac{\left(M_t^{fit} - M_t^{true}\right)}{\delta M_t^{fit}}$$

Top Mass: 3) Unfold Exp Effects

- Verifying likelihood fit behaves…

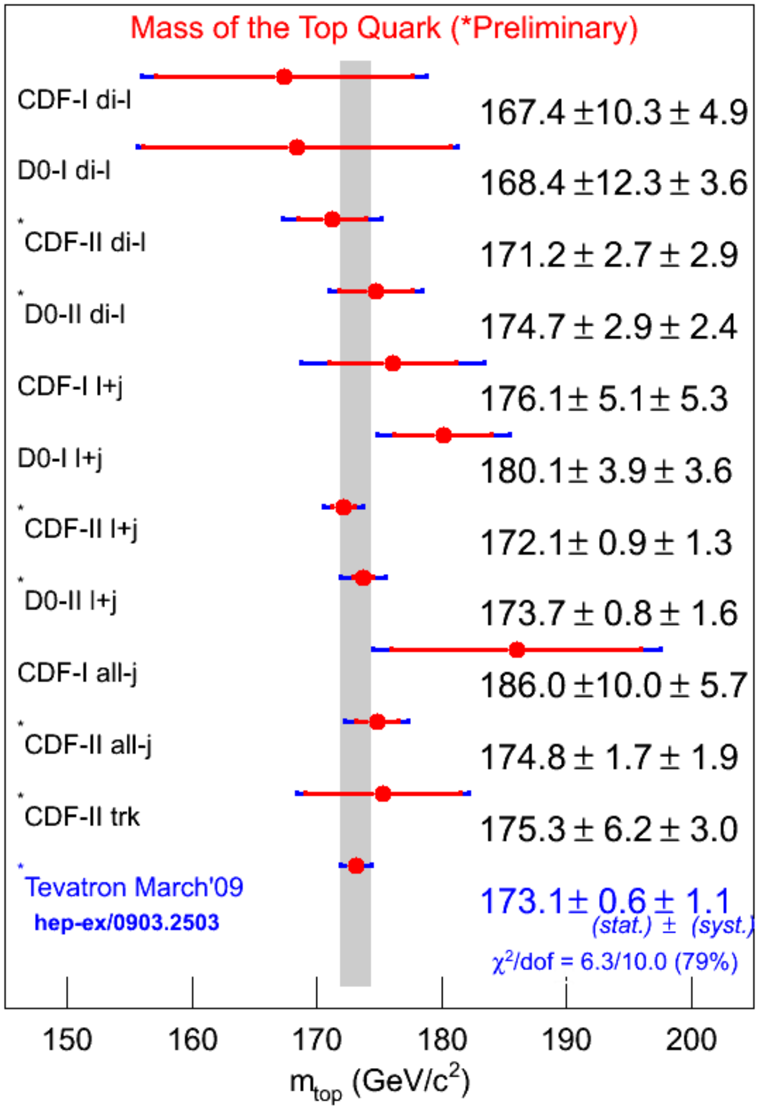






Lepton+Jets Channel

Top Mass: Results



- Excellent results in each channel
- Combine all CDF+D0, Run-I+Run-II
- Account for all correlations
- Uncertainty:

$$\delta M_t(\text{stat}) = \pm 0.64$$

$$\delta M_t(\text{JES}) = \pm 0.73$$

$$\delta M_t(\text{syst}) = \pm 0.78$$

$$\delta M_t(\text{total}) = \pm 1.3\ \text{GeV}/c^2$$

In Closing

Other Physics Results

CDF Results for 2009 Summer Conferences

(only new results since the 2009 Winter Conferences are listed)

Top, Bottom , QCD , Electroweak, Exotics, Higgs

Top Physics

Analysis	Luminosity	More Information
CDF t-tbar production cross section combination	4.6 fb^{-1}	WebPage
Measurement of the t-tbar production cross section in lepton+jet events using topological information	4.6 fb^{-1}	WebPage
Measurement of the t-tbar production cross section in lepton+jet events using secondary vertex tagging	4.3 fb^{-1}	WebPage
Measurement of the t-tbar production cross section in dilepton events	4.5 fb^{-1}	WebPage
Measurement of the t-ttbar production cross section in all-hadronic top decays	2.9 fb^{-1}	WebPage
Measurement of the t-ttbar + jet production cross section	4.1 fb^{-1}	WebPage
Measurement of the top quark mass using a matrix element technique	4.3 fb^{-1}	WebPage
Measurement of the top quark mass in lepton+jets using a matrix element technique	3.2 fb^{-1}	WebPage
Measurement of the top quark mass in dilepton events using lepton transverse momentum	2.8 fb^{-1}	WebPage
Measurement of the top quark mass in lepton+jet events using lepton transverse momentum	2.7 fb^{-1}	WebPage
Combined measurement of the top quark mass using lepton transverse momentum	2.8 fb^{-1}	WebPage
Measurement of t-tbar spin correlations in dilepton candidates	2.8 fb^{-1}	WebPage
Measurement of t-ttbar forward-backward asymmetry versus t-tbar invariant mass	3.2 fb^{-1}	WebPage
Search for resonant t-ttbar production in all-hadronic top decays	2.8 fb^{-1}	WebPage
Tevatron single top cross section and $|V_{tb}|$ combination	3.2 fb^{-1}	WebPage

Bottom Physics

Analysis	Luminosity	More Information
Tevatron Combination for the width difference and CP asymmetry in the B_s system	2.8 fb^{-1}	WebPage
Observation of the Ω_b baryon and measurement of the Ω_b and Ξ_b lifetimes	4.2 fb^{-1}	WebPage
Search for rare decays B_d and $B_s \rightarrow \mu^+ \mu^-$	3.7 fb^{-1}	WebPage
Measurement of the $B_s \rightarrow \phi\ \phi$ branching ratio	2.9 fb^{-1}	WebPage
Measurement of the B_c production cross section	1.0 fb^{-1}	WebPage

Electroweak Physics

Analysis	Luminosity	More Information
Measurement of the WW production cross section in the dilepton plus missing energy channel	3.6 fb^{-1}	WebPage
Limits on WW anomalous triple gauge couplings	3.6 fb^{-1}	WebPage
Observation of WW/WZ production in the lepton-neutrino-dijet channel	2.7 fb^{-1}	WebPage
Measurement of the WW/WZ cross section in the lepton-neutrino-dijet channel	3.9 fb^{-1}	WebPage
Measurement of the WW/WZ cross section in the dijet plus missing transverse energy channel	3.5 fb^{-1}	WebPage
Tevatron W mass combination	0.2-1 fb^{-1}	WebPage

http://cdf-fnal.gov/

DØ Results for 2009 Fall Conferences

(only new results since the 2009 Winter Conferences are listed)

Top, Bottom , QCD , Electroweak, New Phenomena, Higgs

New Phenomena

Analysis	Luminosity	More Information
Search for third generation leptoquarks and scalar bottom quarks in the bb(bar) plus missing energy topology in pp(bar) collisions at sqrt(s)=1.96 TeV	4.0 fb^{-1}	Web Page
Search for pair production of the supersymmetric partner of the top quark in the e+mu+b+b(bar)+MET decay channel at D0	3.1 fb^{-1}	Web Page
Search for high-mass narrow resonances in the di-electron channel at D0	3.6 fb^{-1}	Web Page
Search for pair production of first-generation leptoquarks in pp(bar) collisions at sqrt(s)=1.96 TeV	1.0 fb^{-1}	Publication
Measurement of dijet angular distributions at sqrt(s) = 1.96 TeV and searches for quark compositeness and extra spatial dimensions	0.7 fb^{-1}	Publication
Search for resonant pair production of neutral long-lived particles decaying to bb(bar) in pp(bar) collisions at sqrt(s)=1.96 TeV	3.6 fb^{-1}	Publication
Search for squark production with jets, hadronically decaying tau leptons and missing transverse energy at sqrt(s)=1.96 TeV	1.0-2.1 fb^{-1}	Publication
Search for dark photons from supersymmetric hidden valleys	4.1 fb^{-1}	Publication

Higgs Physics

Analysis	Luminosity	More Information
Combined CDF and D0 upper limits on standard model Higgs-boson production with up to 5.4 fb-1 of data	up to 5.4 fb^{-1}	Web Page
Combined upper limits on Standard Model Higgs boson production from the D0 experiment un 2.1-5.4 fb-1	0.9-5.0 fb^{-1}	Web Page
Search for the standard model Higgs boson in the WH-->taunubbar channel with 4.0 fb-1 of ppbar collisions at sqrt(s)=1.96 TeV	4.0 fb^{-1}	Web Page
Search for the standard model Higgs boson in the ZH-->nunubbar channel with 5.2 fb-1 of ppbar collisions at sqrt(s)=1.96 TeV	5.2 fb^{-1}	Web Page
Search for Higgs boson production in dilepton plus missing transverse energy final states with 5.4 fb-1 of ppbar collisions at sqrt(s)=1.96 TeV	5.4 fb^{-1}	Web Page
Combined CDF and D0 limits on MSSM Higgs boson production in tau-tau final states with up to 2.2 fb-1 of data	1.8-2.2 fb^{-1}	Web Page
Search for the SM Higgs boson in that tautauqq final state	4.9 fb^{-1}	Web Page
Search for WH associated production using neural networks with 5.0 fb-1 of Tevatron data	5.0 fb^{-1}	Web Page
A search for associated production of a b quark and a neutral Higgs boson which decays to taus in supersymmetric models	2.7 fb^{-1}	Web Page
Combined upper limits on MSSM Higgs-boson production with up to 2.6 fb-1 of data at D0	1.2-2.6 fb^{-1}	Web Page
Search for resonant pair production of neutral long-lived particles decaying to bb(bar) in pp(bar) collisions at sqrt(s)=1.96 TeV	3.6 fb^{-1}	Publication
Search for NMSSM Higgs bosons in the h->aa->4mu, 2mu2tau channels using pp(bar) collisions at sqrt(s)=1.96 TeV	4.2 fb^{-1}	Publication
Search for the standard model Higgs boson in tau final states	1.0 fb^{-1}	Publication

QCD Results

Analysis	Luminosity	More Information
Determination of the strong coupling constant from the inclusive jet cross section in pp(bar) collisions at sqrt(s)=1.96 TeV	0.7 fb^{-1}	Publication
Measurement of the dijet mass cross section in pp(bar) collisions at sqrt(s)=1.96 TeV	0.7 fb^{-1}	Web Page
[illegible]	[illegible]	[illegible]

http://d0-fnal.gov/

- These same methodologies are employed in one way or another for essentially all analyses

Closing Remarks

- These three lectures
  - Introduction to Hadron Collider Physics
  - Summary of some of the main Experimental Issues and Techniques employed
  - Aimed at graduate student level

- Suggested some analysis “Rules of Thumb” to help steer through the myriad problems and challenges you’ll face between now and finishing your analysis

Closing Remarks

- Expect surprises
  - Especially at start-up
- Concerning Peer Review… it can be grueling
  - Don’t take it personally
  - Important part of the scientific endeavor
  - Persevere
- You’re at an exciting place at an exciting time… enjoy and have fun!