Top Mass at the Tevatron

Tomonobu Tomura

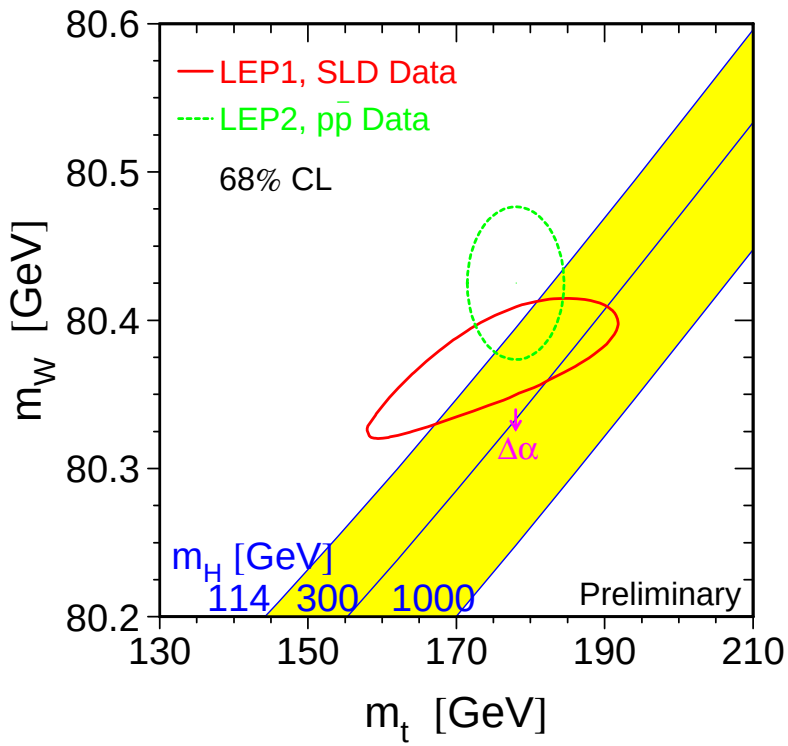
(*University of Tsukuba*)

For the CDF and DØ Collaborations

Introduction

- In the Standard Model,
  - Top mass is a fundamental parameter.
  - Top mass can constrain the Higgs mass through the loop diagrams.

  - Also important input for other top property measurements.

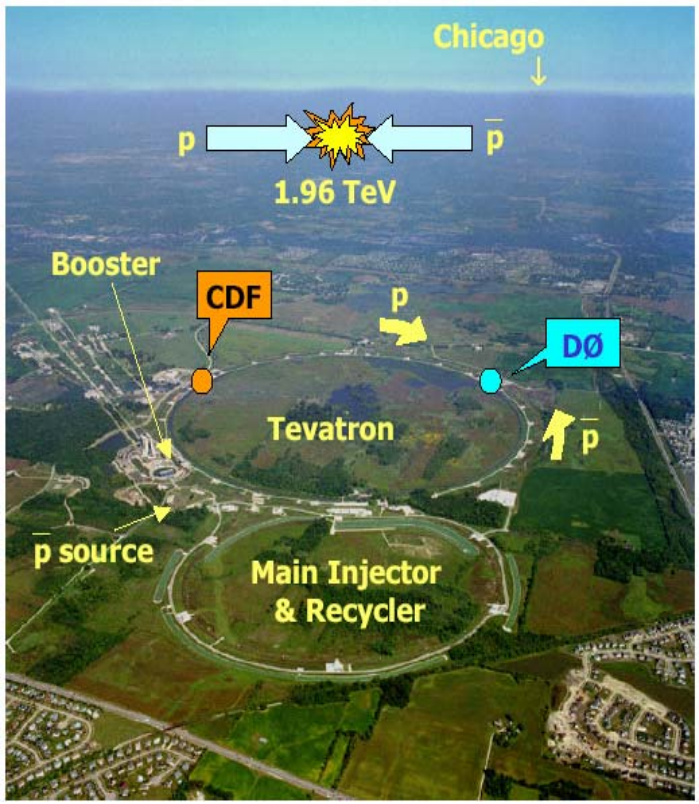


Tevatron Run I average

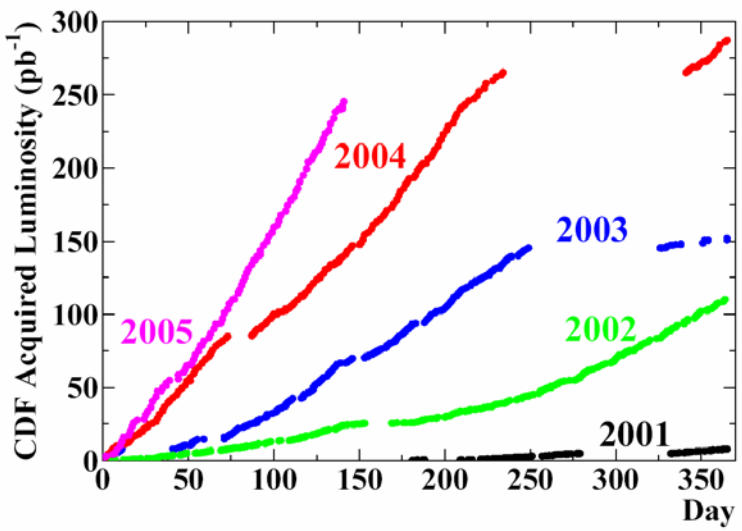
$178.0 \pm 2.7 \pm 3.3\ \mathrm{GeV}/c^2$

Tevatron Run II

- The world's only top factory!

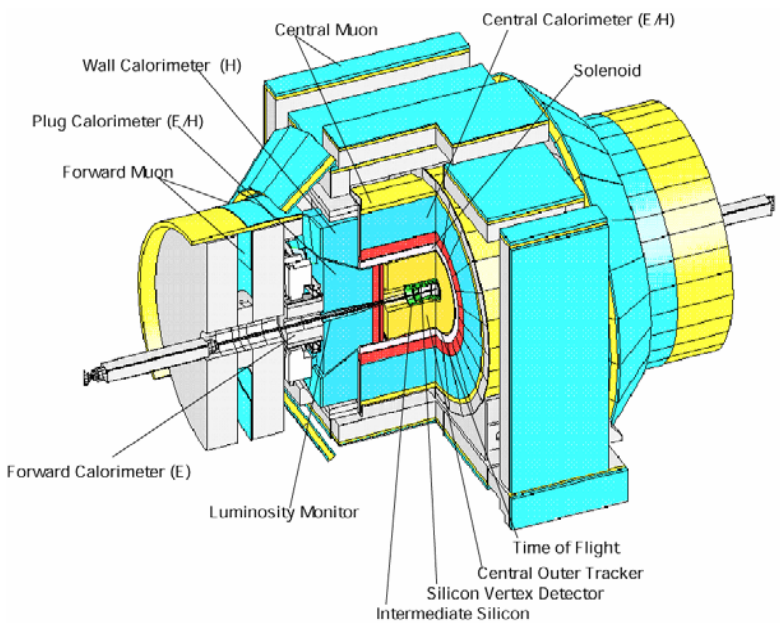


- Peak luminosity:
  1.3×10^{32} cm^{-2}s^{-1}
- Delivered luminosity: > 1 fb^{-1}

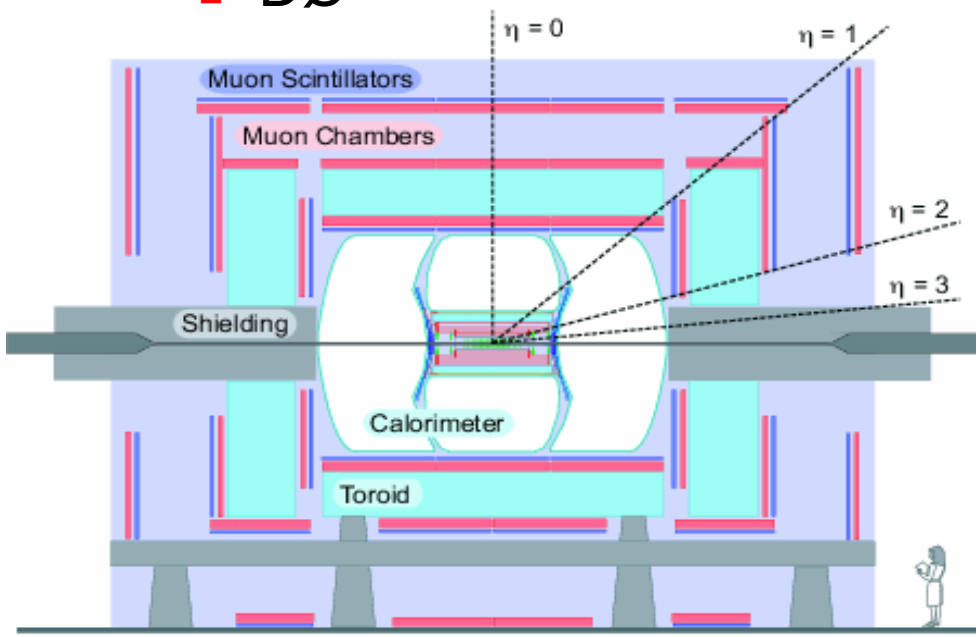


Detectors for Run II

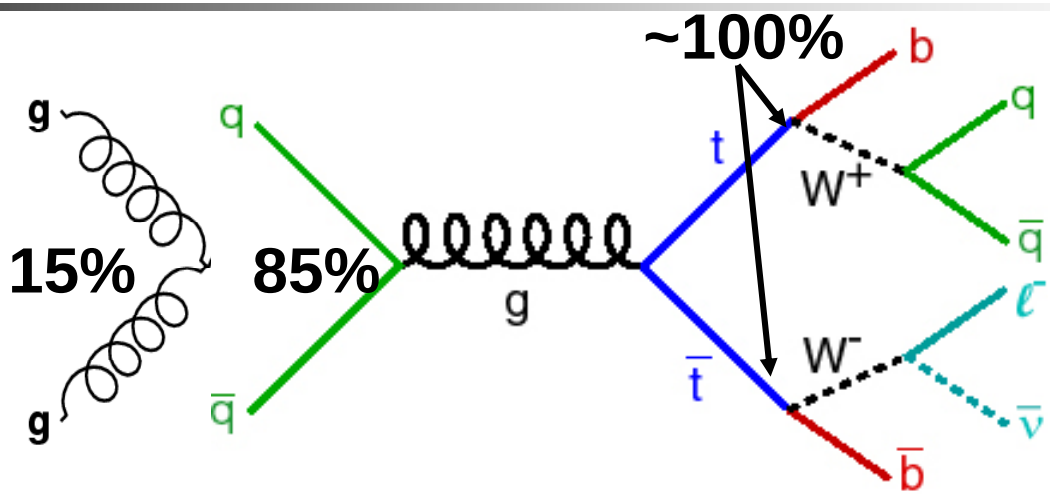
- Both detectors upgraded tracking system, electronics, trigger, DAQ…
  - CDF



  - DØ



Top Quark Production and Decay

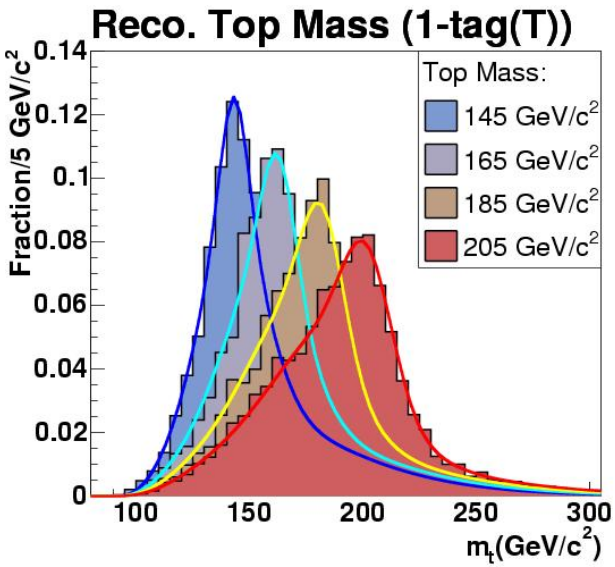


- Final states
  - Dilepton (5%, small backgrounds – QCD fakes, Drell Yan, Diboson)
    - 2 high-p_T leptons(e/μ), 2 b jets, large missing E_T
  - Lepton+Jets (30%, manageable backgrounds – W+jets, QCD fakes)
    - 1 high- p_T lepton(e/μ), 4 jets (2 b jets), large missing E_T
  - All-hadronic (44%, large backgrounds - QCD)
    - 6 jets

CDF Lepton+Jets Template Method

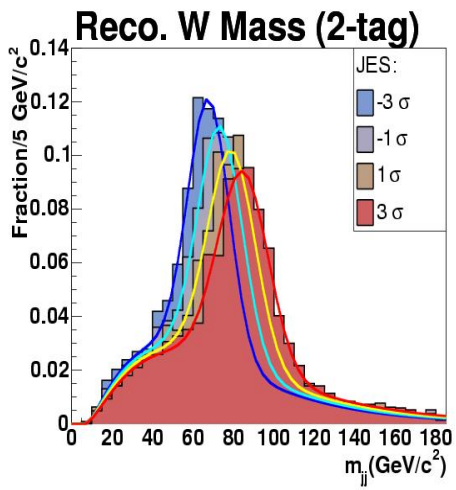
- Reconstruct the top mass event by event using the following χ^2 fitter:

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

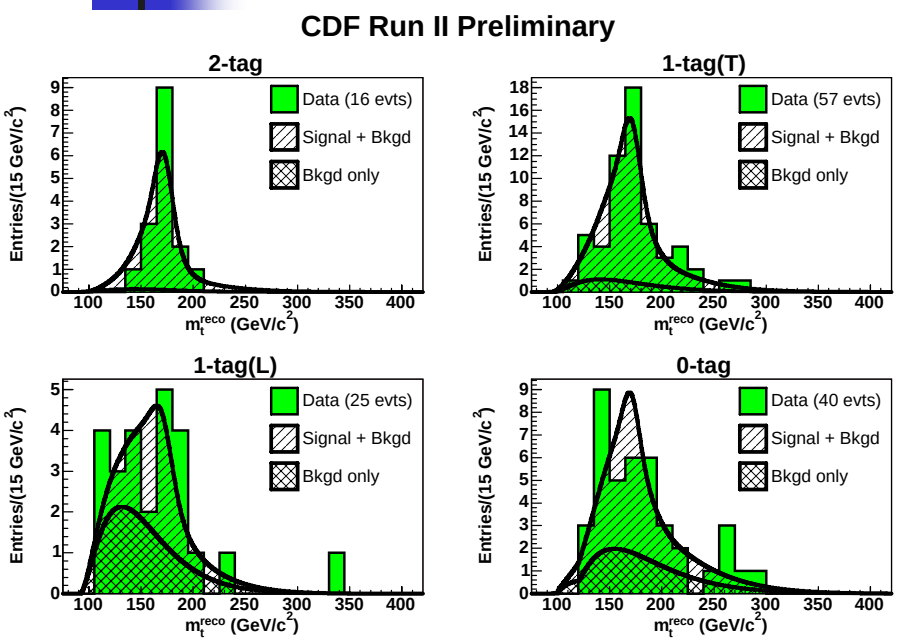


- Build the template of reconstructed top mass distribution for each input top mass.
- Build the 2-D templates of reconstructed $W \to jj$ mass and top mass distributions for each Jet Energy Scale (JES) and input top mass.
  - Fit the top mass and JES simultaneously.
  - Reduce dominant syst. err. due to JES.

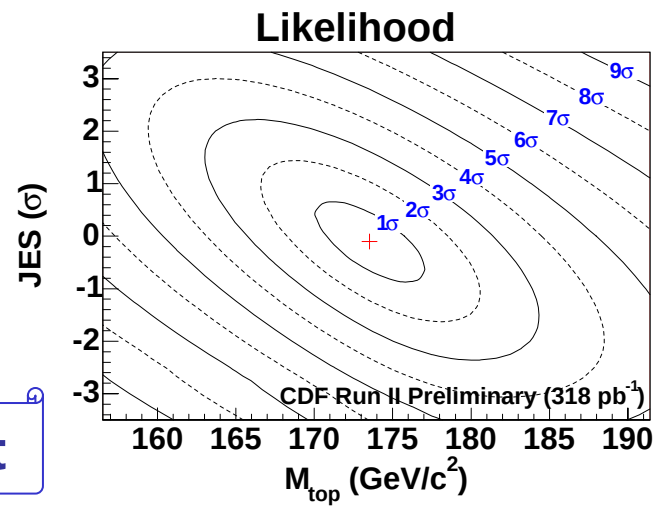
NEW



CDF Lepton+Jets Template Method (Result)



	2-tag	1-tag(T)	1-tag(L)	0-tag
events	16	57	25	40
Bkgds	1.89 ±0.52	10.4 ±1.72	14.3 ±2.45	—



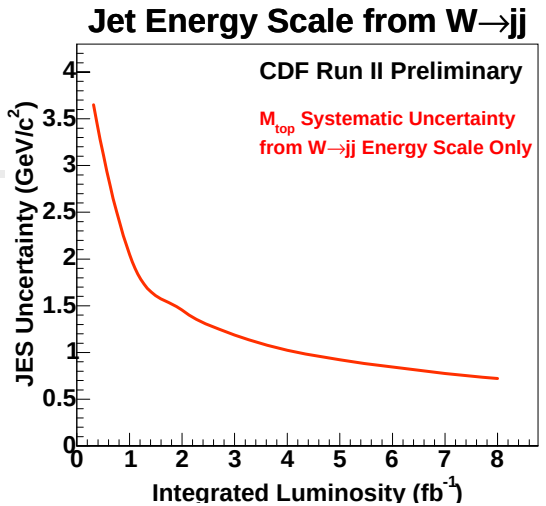
$\int L = 318\,\mathrm{pb}^{-1}$

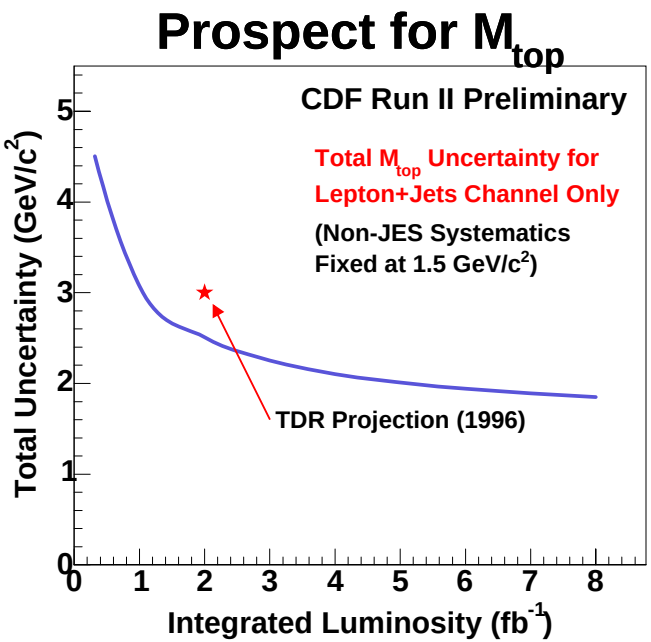
Best single measurement

$$m_t = 173.5^{+2.7}_{-2.6}(\mathrm{stat.}) \pm 2.5(\mathrm{JES}) \pm 1.7(\mathrm{syst.})\ \mathrm{GeV}/c^2$$

CDF Lepton+Jets Template (Future)

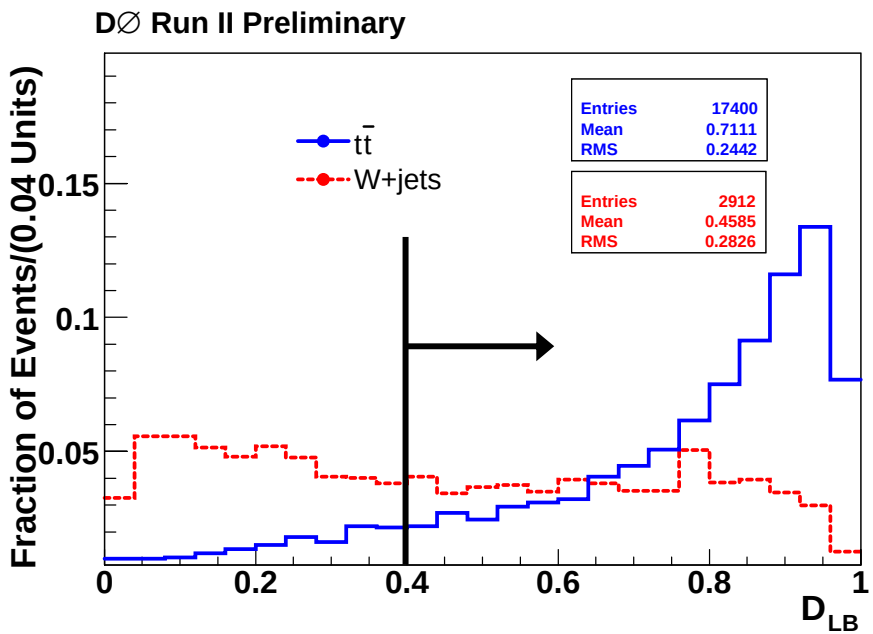
- JES uncertainty is dominated by $W \rightarrow jj$ statistics.
  - We can constrain more with more statistics.
- Expect to reach JES uncertainty below 1 GeV/c^2.
- Total top mass uncertainty can reach 2 GeV/c^2 in Run II.
  - With only single measurement.
  - Improve by combining with other measurements.





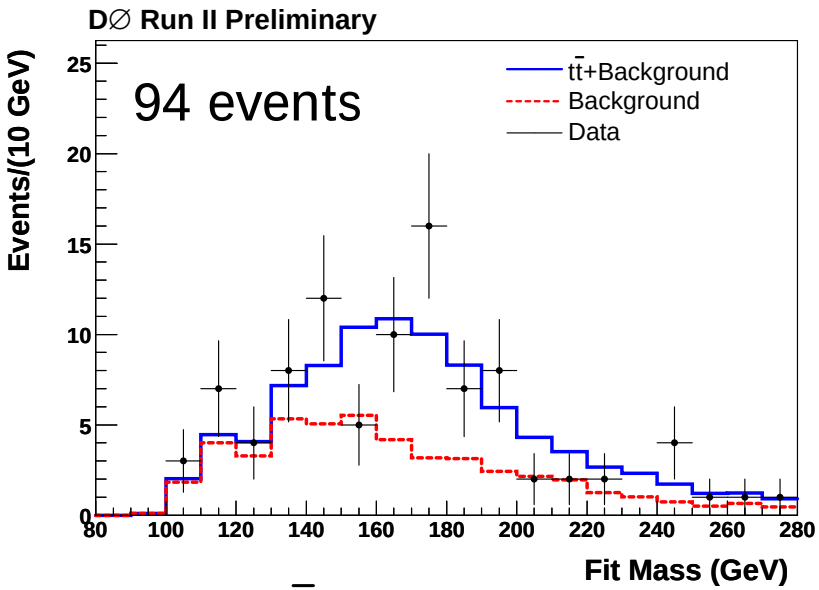
DØ Lepton+Jets Template Method

- Build templates for reconstructed top mass
- Two analyses
  - Topological analysis
    - No *b*-tag requirement
    - Low bias discriminant (D_{LB}) using topological variables
      - $D_{LB} > 0.4$
  - *b*-tagged analysis
    - Require ≥1 *b*-tagged jet
    - No cut on D_{LB}



DØ Lepton+Jets Template Method (Result)

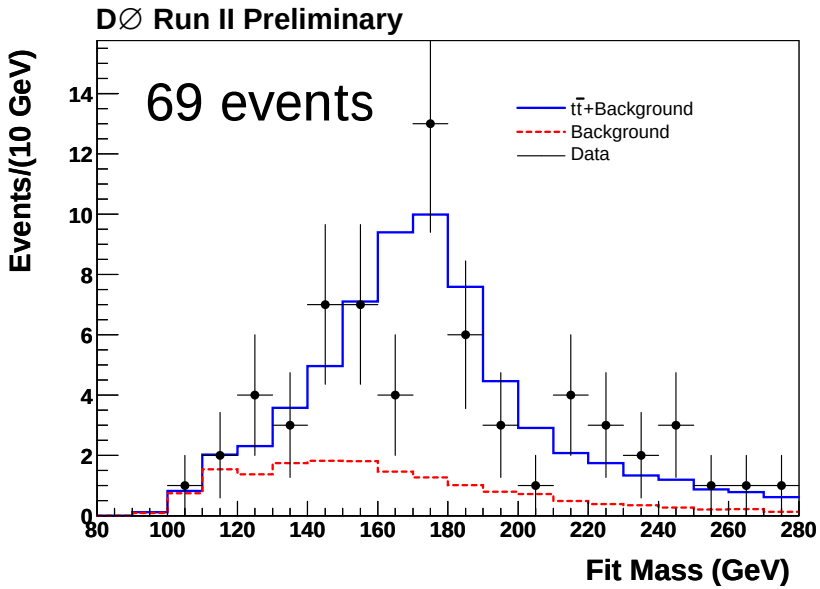
- Topological analysis



$44.2 \pm 6.6\, t\bar{t}$ events

$m_t = 169.9 \pm 5.8(\text{stat.})^{+7.8}_{-7.1}(\text{syst.})\,\text{GeV}/c^2$

- *b*-tagged analysis



$49.2 \pm 6.3\, t\bar{t}$ events

$m_t = 170.6 \pm 4.2(\text{stat.}) \pm 6.0(\text{syst.})\,\text{GeV}/c^2$

$\int L = 229\ \text{pb}^{-1}$

CDF Lepton+Jets Dynamical Likelihood Method

- Maximum likelihood method using matrix element

$$L^i(M_{\text{top}}) = \sum_{I_t}\sum_{I_s}\int \frac{2\pi^4}{\text{Flux}} F(z_a, z_b, p_T)\,|M|^2\; w(\mathbf{x},\mathbf{y})d\mathbf{x}$$

- F : Parton distribution function for (z_a, z_b) and P_T of $t\bar{t}$ system
- M : Matrix element of $t\bar{t}$ process $\quad |M|^2 = |M_{\text{prod}}|^2\,\Pi(s_r)\,|M_{\text{dec}}|^2$
- w : Transfer function $\quad x$ (partons) $\leftrightarrow$ y (observables)
- Sum over all jet-parton assignments (I_t), solutions for p_z of ν (I_s)

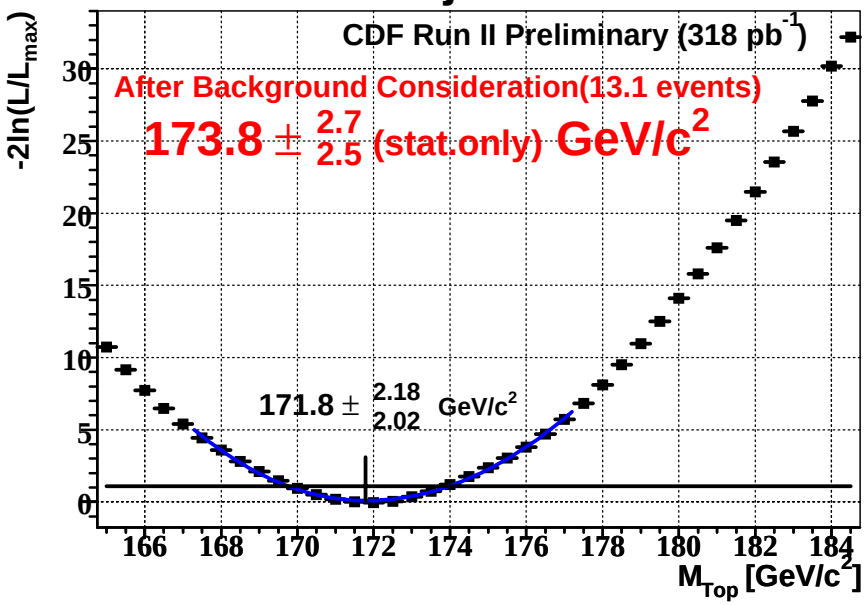
CDF Lepton+Jets
Dynamical Likelihood Method (Result)

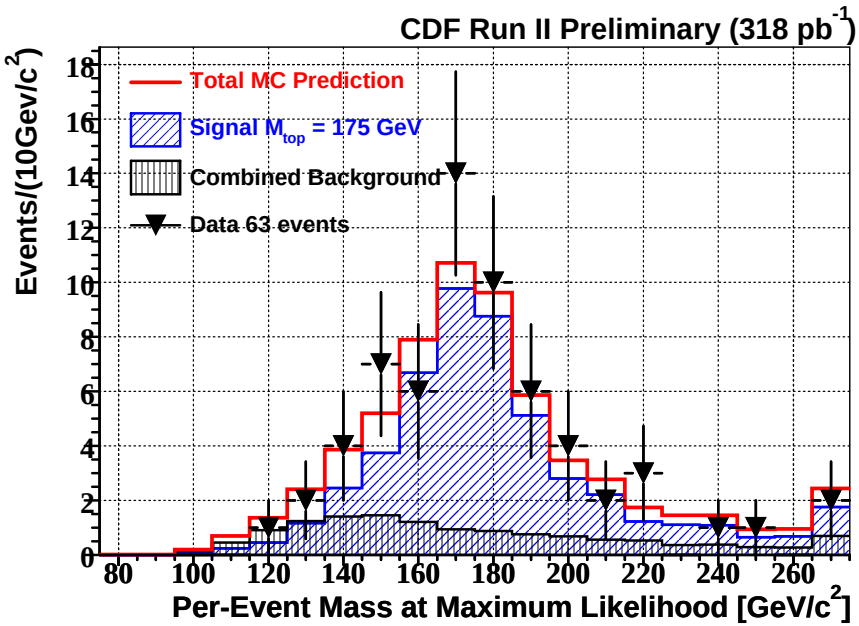
Exact 4-jet events, at least 1 *b*-tagged jet

$\int L = 318\,\text{pb}^{-1}$

63 events
13.1±**2.2 Bkgds**

63 events joint likelihood

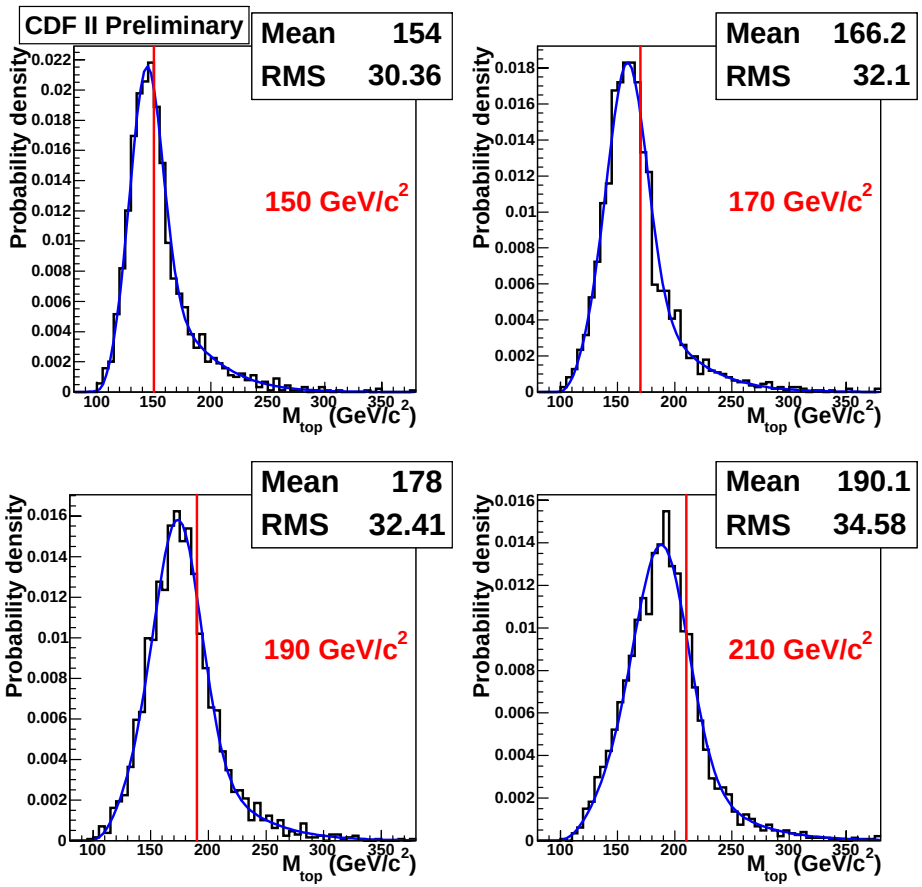




$$m_t = 173.8^{+2.7}_{-2.5}(\text{stat.}) \pm 3.3(\text{syst.})\ \text{GeV}/c^2$$

CDF Dilepton Neutrino Weighting Algorithm

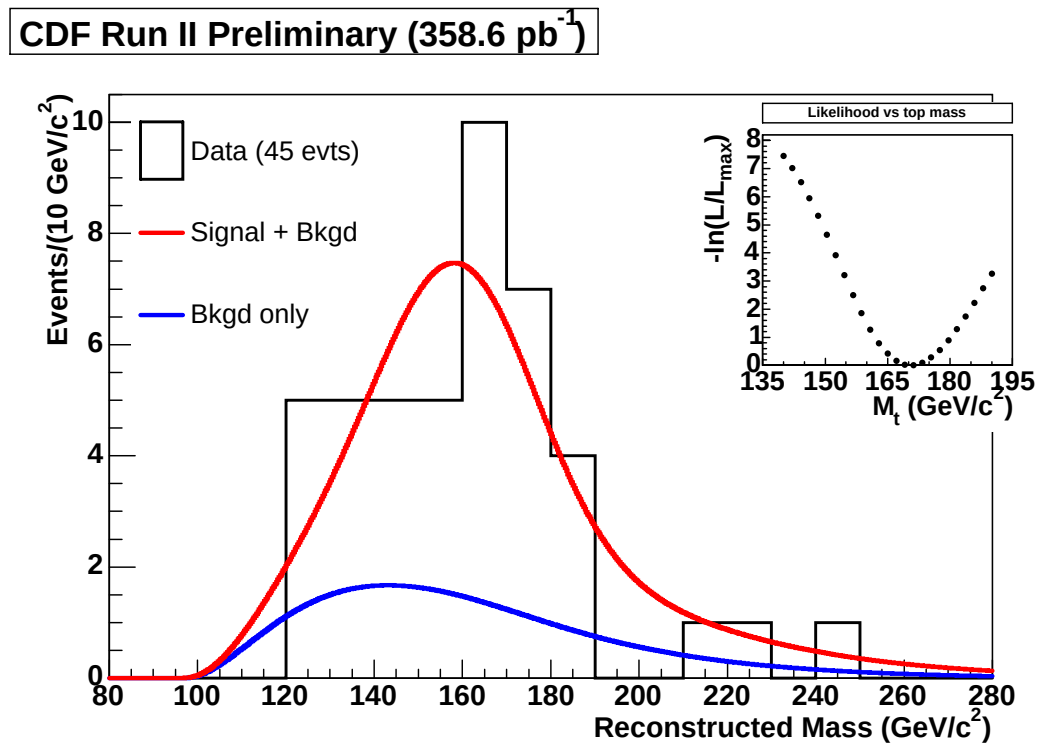
- Template method
- Calculate the weight as a function of top mass
  - Scan η of two neutrinos
  - 4 solutions for neutrino pair
  - Weight from missing E_T resolution, neutrino η distribution
  - Integrate over unknowns
- Choose largest-weight mass for each event



CDF Dilepton
Neutrino Weighting Algorithm (Result)

45 lepton+track events
14.7±5.7 backgrounds

$$\int L = 359\ \text{pb}^{-1}$$



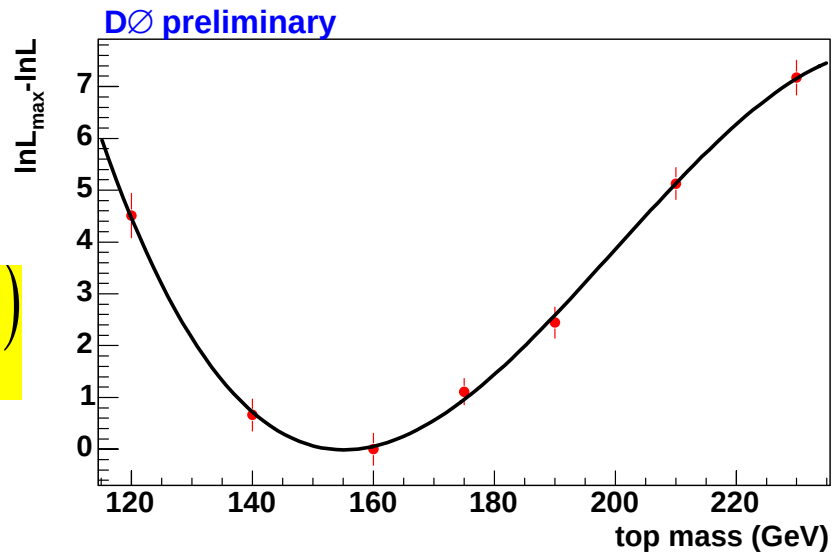
$$m_t = 170.6^{+7.1}_{-6.6}(\text{stat.}) \pm 4.4(\text{syst.})\ \text{GeV}/c^2$$

DØ Dilepton Template Method

- Calculate weight as a function of top mass for each event using Dalitz and Goldstein method.

13 dilepton events
3.3 backgrounds

$$\int L = 230\ \text{pb}^{-1}$$



$$W(m_t) = \sum_{\text{solutions}} \sum_{\text{jets}} f(x) f(\bar{x}) p\left(E_\ell^* \middle| m_t\right) p\left(E_{\bar{\ell}}^* \middle| m_t\right)$$

- f : parton distribution function
- p : probability of observing E_l from m_t

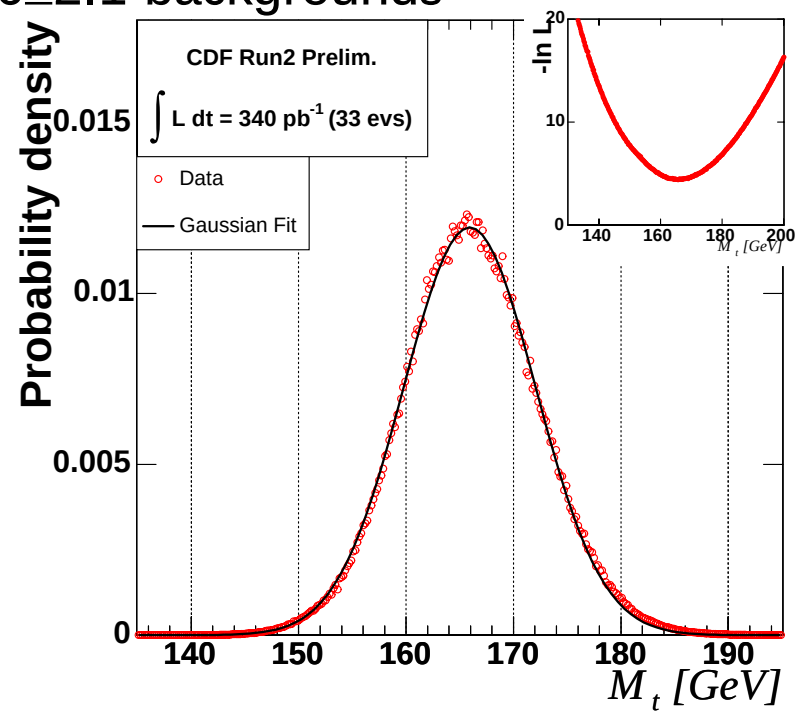
$$m_t = 155^{+14}_{-13}(\text{stat.}) \pm 7(\text{syst.})\ \text{GeV}/c^2$$

CDF Dilepton Matrix Element

- Use LO matrix element to build differential cross-section
- Evaluate diff. cross-sections for bkgds
- Make top mass posterior distribution from above diff. cross-sections

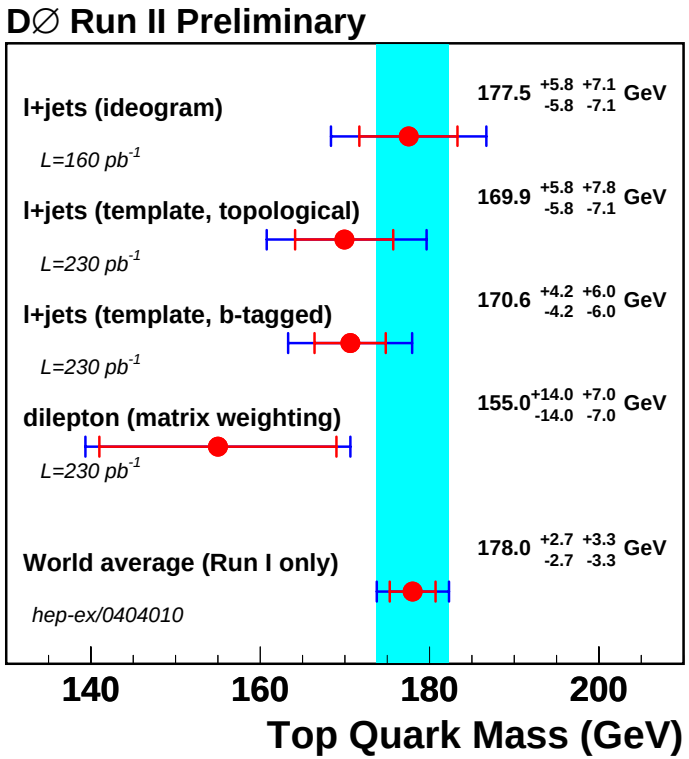
33 dilepton events
11.6±2.1 backgrounds

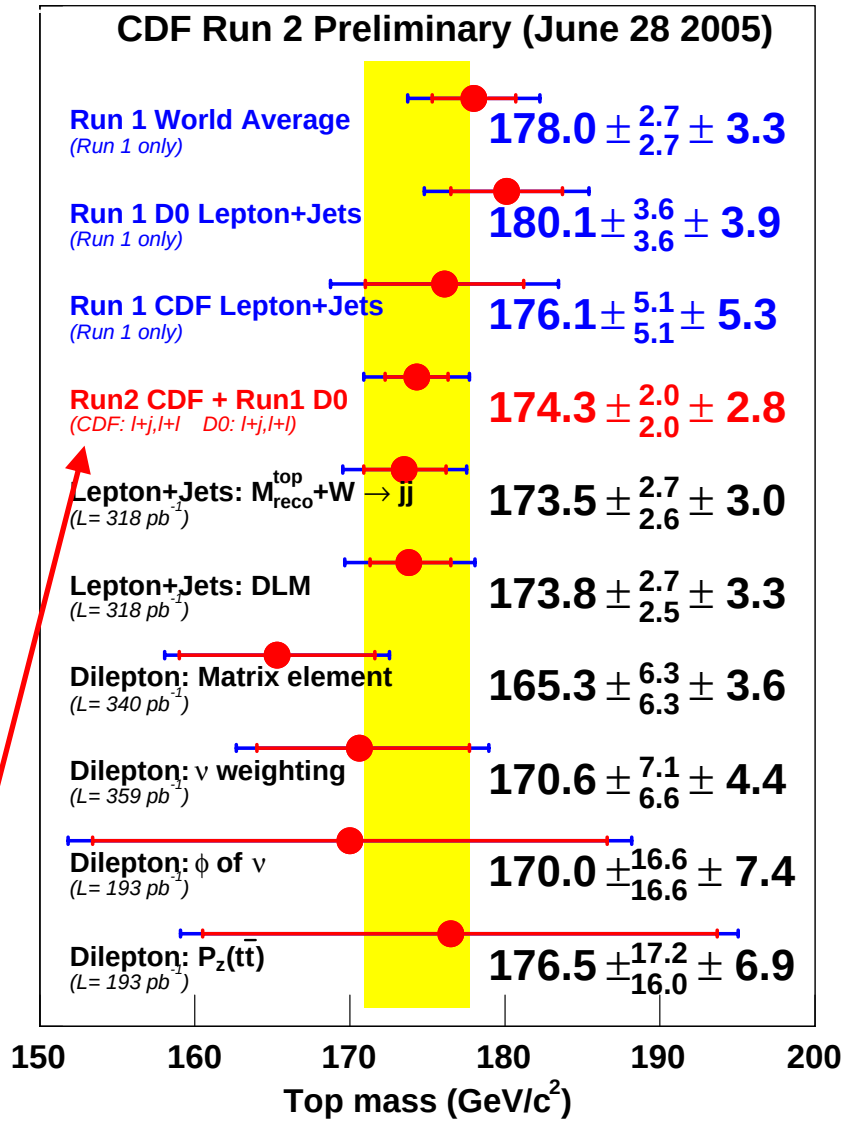
$\int L = 340\ \text{pb}^{-1}$



$m_t = 165.3 \pm 6.3(\text{stat.}) \pm 3.6(\text{syst.})\ \text{GeV}/c^2$

Comparison





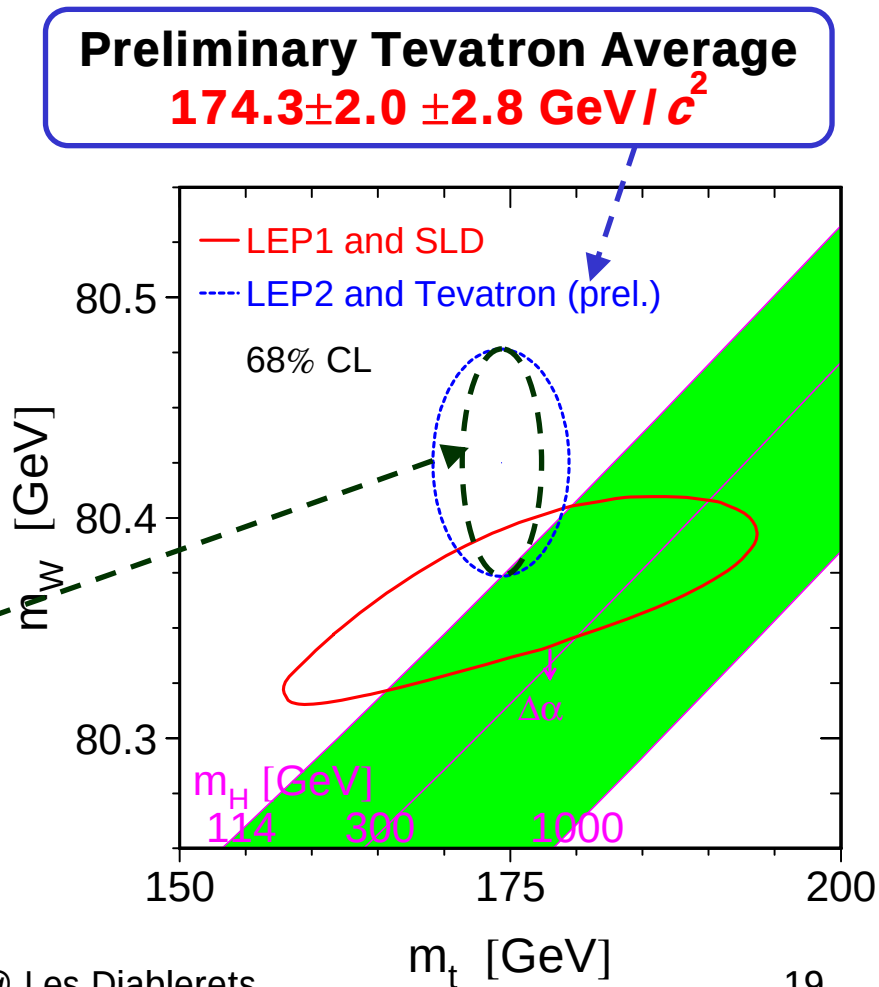
Preliminary Tevatron Average

Comparison of Errors

Channel	Lepton+Jets				Dilepton		
Method	Templ. (CDF)	Topol. (DØ)	*b*-tag (DØ)	DLM (CDF)	NWA (CDF)	Templ. (DØ)	ME (CDF)
Luminosity	318	229	229	318	359	230	340
Stat. Err.	$^{+2.7}_{-2.6}$	±5.8	±4.2	$^{+2.7}_{-2.5}$	$^{+7.1}_{-6.6}$	$^{+14}_{-13}$	±6.3
JES Err.	±2.5	$^{+6.8}_{-6.5}$	$^{+4.7}_{-5.3}$	±3.0	±2.6	±5.6	±2.6
Other Main Sys. Err.	BG Shape ±1.1	Gluon Rad. ±2.6	Gluon Rad. ±2.4	BG Frac. ±0.6	BG Shape ±3.0	Ev. Gen. ±3.0	BG MC ±1.5
Tot. Sys. Err.	±3.0	$^{+7.8}_{-7.1}$	±6.0	±3.3	±4.4	±7	±3.6

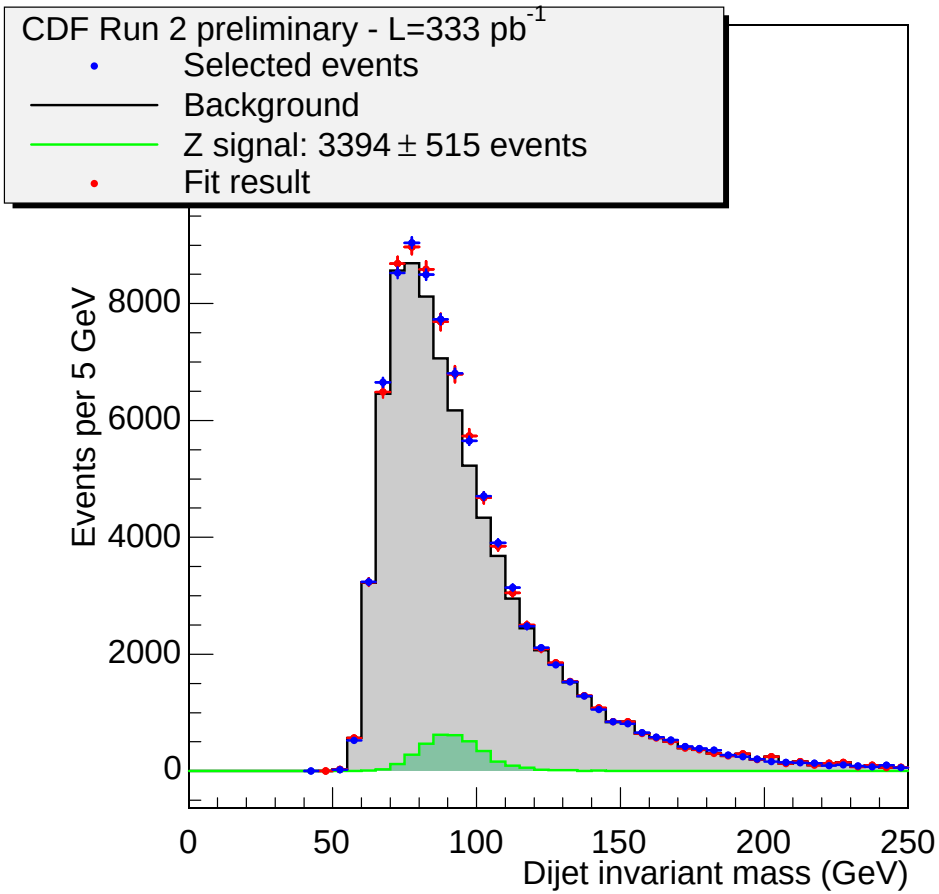
Summary

- Tevatron is performing very well.
  - Delivered luminosity: > 1 fb^{-1}
- CDF lepton+jets 2D-Template method provides the best measurement.
  - New techniques are developed.
- Will reach goal of measuring top mass to ~2 GeV/c^2 in Run II.
  - By combining different measurements, more improvement is expected.



Backup

CDF
b-jet Energy Scale ($Z \rightarrow b\bar{b}$)



Selected Events : 85730
$Z \rightarrow b\bar{b}$: 3394±515 (4%)

- Further Studies:
  - Evaluate systematic biases, if any
  - Improve $Z \rightarrow b\bar{b}$ modeling
  - Aim 1% *b*-jet energy scale (10k $Z \rightarrow b\bar{b}$)

Systematic Errors (CDF L+J)

CDF Lepton+Jets Template

Source	Δm_t (GeV/c^2)
JES	2.5
b-jet modeling	0.6
ISR	0.4
FSR	0.6
PDFs	0.3
Generators	0.2
BG shape	1.1
b-tagging	0.1
MC statistics	0.3
Method	0.5
TOTAL	**3.0**

CDF Lepton+Jets DLM

Source	Δm_t (GeV/c^2)
JES	3.0
Transfer Functions	0.2
ISR	0.4
FSR	0.5
PDFs	0.5
Generators	0.3
BG fraction	0.6
BG Modeling	0.6
b-tagging	0.2
b-jet Modeling	0.6
Total	**3.3**

Systematic Errors (CDF Dil)

CDF Dilepton NWA

Source	Δm_t (GeV/c^2)
JES	2.6
b-jet Energy	0.6
MC Generator	0.5
PDFs	0.4
ISR	0.8
FSR	0.6
Missing Energy	0.2
Signal Template	0.2
BG Template	1.3
BG Shape	3.0
Total	**4.4**

CDF Dilepton ME

Source	Δm_t (GeV/c^2)
JES	2.6
Generators	1.0
Method	0.6
Sample Composition	0.7
BG MC	1.5
BG Model	0.8
ISR	0.5
FSR	0.5
PDFs	1.1
TOTAL	**3.6**

Systematic Errors (DØ)

DØ Lepton+Jets Template

Source	Δm_t (GeV/c^2)	
	Topological	*b*-tagged
JES	+6.8/-6.5	+4.7/-5.3
Jet Resolution	±0.9	±0.9
Gluon Radiation	±2.6	±2.4
Signal Model	+2.3	+2.3
BG Model	+0.7	±0.8
b-tagging	—	±0.7
Calibration	±0.5	±0.5
Trigger Bias	±0.5	±0.5
MC statistics	±0.5	±0.5
TOTAL	**+7.8/-7.1**	**±6.0**

DØ Dilepton Template

Source	Δm_t (GeV/c^2)
JES	5.6
Event Generation	3.0
PDFs	0.9
Underlying Event	1.0
Background	1.0
Calibration	1.1
Total	**6.7**