Top Quark Mass Measurement in the lepton+jets channel using *Template Method* and *Dynamical Likelihood Method* at CDF

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Fermilab

Introduction

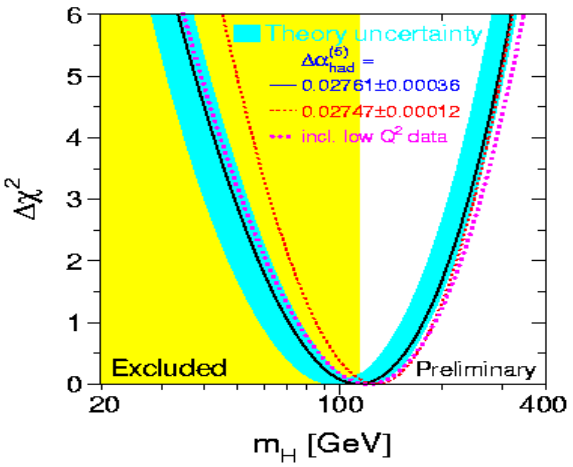
- **From RunI results : New World Average (2004)**
  M_t = 178.0 ± 4.3 GeV (±2.7±3.3) hep-ex/0404010

- **Top quark is heavy (~ 180 GeV)**
  Yukawa coupling ~ 1.

$$y_t = \frac{\sqrt{2}\, m_t}{v} \approx 1$$

*** The mass is near the Electro-Weak Symmetry Breaking Scale.**

- **Correlated with Higgs mass, together with W boson mass.**



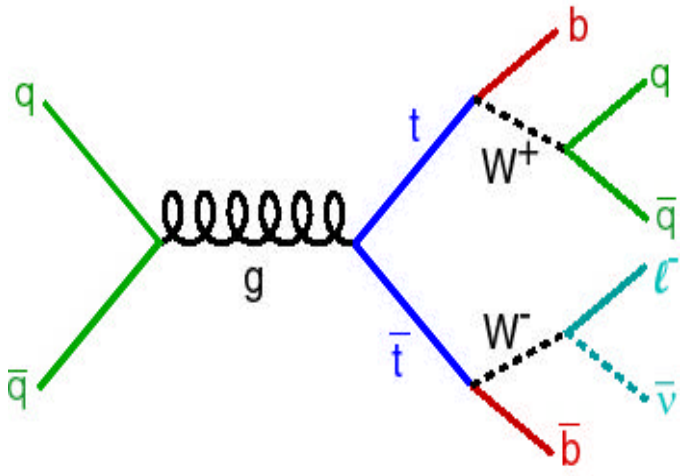
$$dM_W \propto (M_{top}^2,\ \ln(M_H))$$

- **Standard Model Higgs Mass:**
  Most probable: $114 \pm^{69}_{45}$ GeV
  Upper limit(95% CL): 260 GeV

- **In this talk,**
  (1) Dynamical Likelihood Method (DLM)
  lepton+jets ³ 1b tag
  (2) Template Method
  lepton+jets 0tag, ³ 1tag, ⟶ combined

RunII Goal : ± 2 ~ 3 GeV!

Event Selection



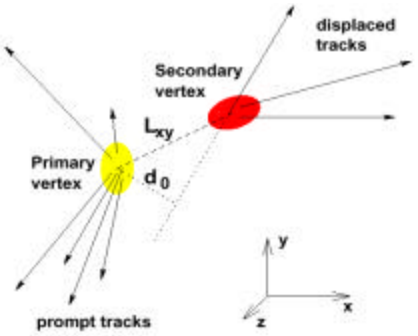
- **“lepton+jets” decay mode**

  Final State : lepton(e,μ), ν, 4jets(2bjets)

- **SVX b jet tagging**

  Identify by finding a vertex of displaced tracks

  Excellent silicon detector!



Cuts	DLM	Template(btag)	Template(0tag)
Lepton/MET	One central electron or muon(Et(Pt)>20GeV), Met>20GeV		
nJets	==4jets(Et>15)	>=3.5jets(Et>15,>8)	>=4jets(Et>21)
b tag	>= 1 btag	>= 1 btag	NO
kinematical fit	No	YES ($\chi^2 < 9$)	YES ($\chi^2 < 9$)
Observed	22 ev (L=162pb^{-1})	28 ev (L=162pb^{-1})	39 ev (L=194pb^{-1})
S/B	~ 4.2	~3.0	~ 0.7

Dynamical Likelihood Method

- Originally proposed in 1988 by K.Kondo.(J.Phys. Soc. 57, 4126)

- ***For i-th event, likelihood is defined as,***

$$L^i(M_{top}) = \sum_{I_t}\sum_{I_s}\int \frac{2p^4}{Flux} F(z_a, z_b, p_T)\,|M|^2\, d(s_w - (\ell+n)^2)\, w(I_t, \mathbf{x}\,|\,\mathbf{y}; M_{top})\, d\mathbf{x}\, ds_w$$

F : Parton distribution function for (z_a,z_b) and Pt of tt system

M : Matrix element of tt process, $|M|^2 = |M_{prod}|^2\, \Pi(s_x)\, |M_{dec}|^2$

w : Transfer function, x ; partons $\longleftrightarrow$ y ; observables

$S_w=(l+\nu)^2$

- ***Two Summations and one integration :***

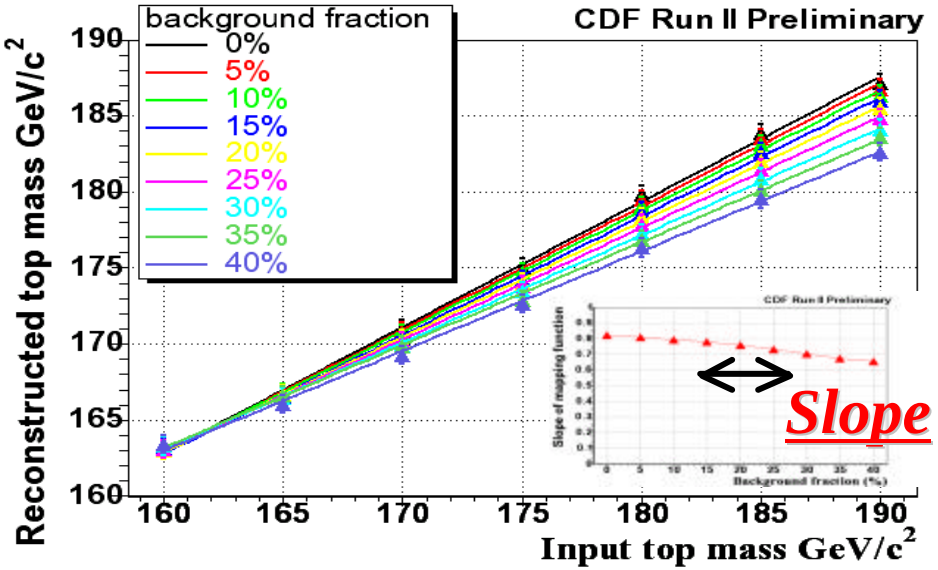
I_t :Jets to partons combination (6: 1-tag, 2: 2-tag), I_s : Two ν_z solutions,
In practice, integration of x, s_w made by Monte Carlo Method.

- ***Extract top mass by maximum likelihood method,***

$$\Lambda(M_{top}) = -2ln\left(\prod_{event} L^i(M_{top})\right) \longrightarrow \overline{M_{top}} = M_{top}\ \textit{min.}\ \Lambda(M_{top})$$

Background Correction : DLM

- In the method, first, all events are assumed to be signal. Need to correct background effect.
- Backgrounds pull likelihood peak down. (Have Lower Mass)
- Pseudo experiments(22ev) by varying background fraction to look at effects on signal tt events.

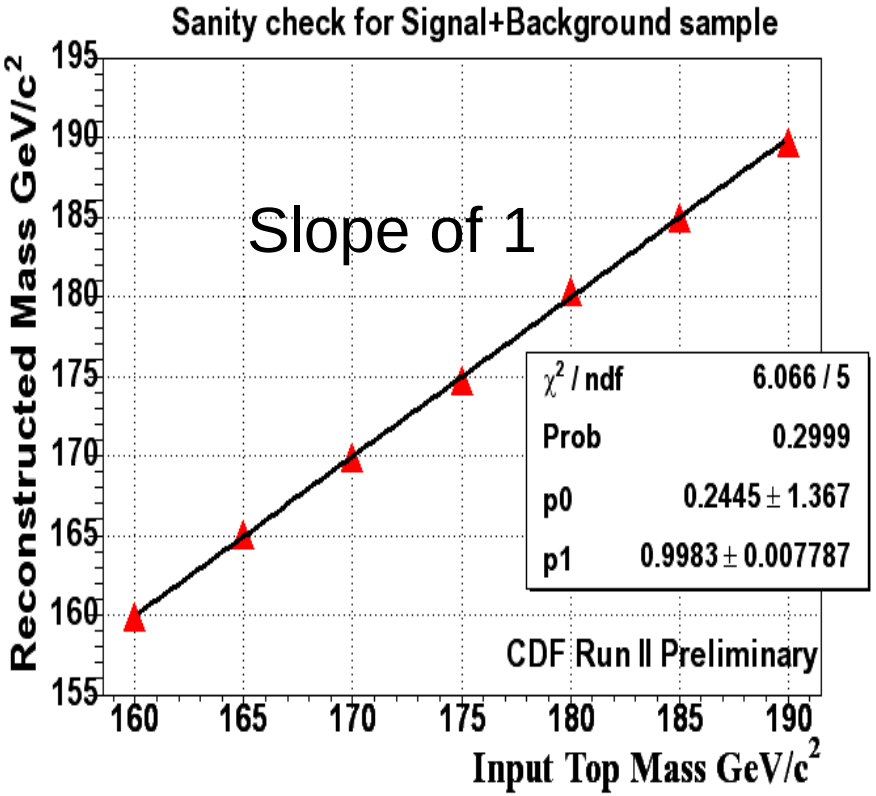


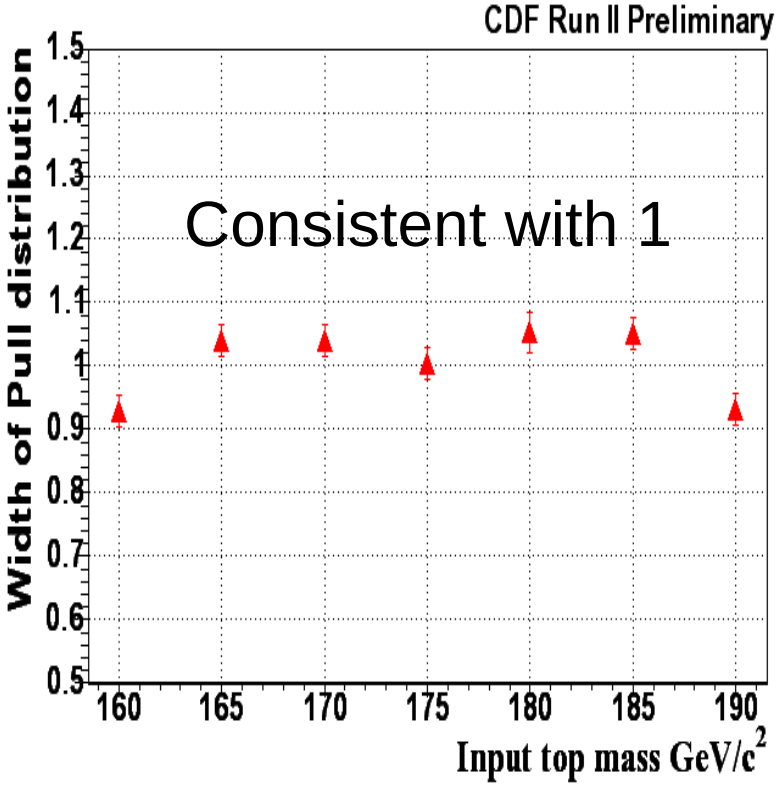
- **Use this map to extract the top mass.**

source	W+4j
Mistag	1.2 ± 0.37
Wbb	0.7 ± 0.29
Wcc	0.3 ± 0.12
Wc	0.2 ± 0.12
Single top	0.17 ± 0.03
WW	0.08 ± 0.05
nonW	1.6 ± 0.38
Bkg tot.	4.2 ± 0.71
N obs.	22
tt (6.7pb)	20.9

Pull Distribution : DLM

After applying mapping functions

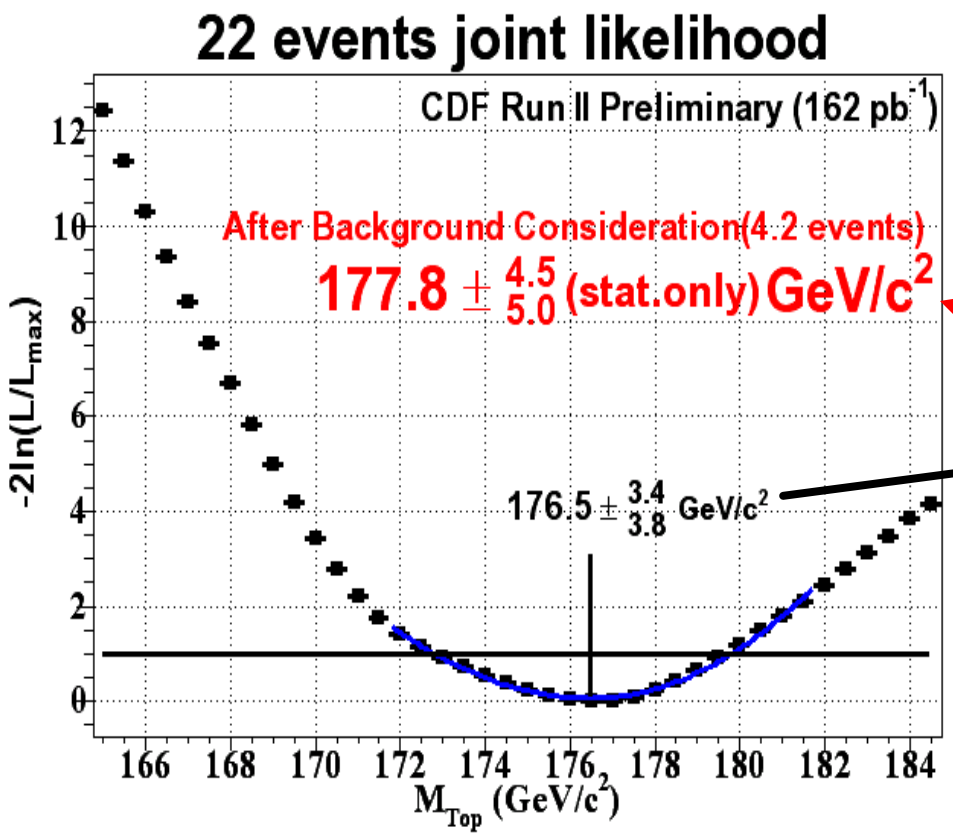




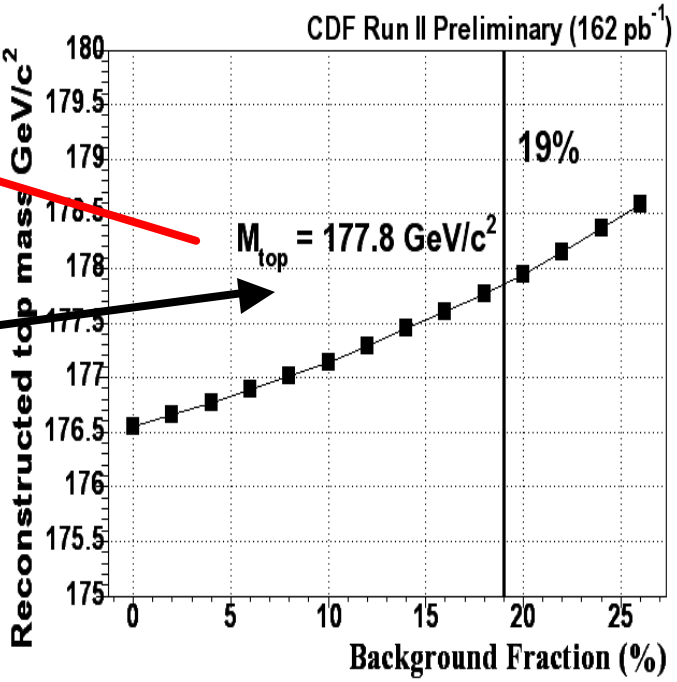
- **No bias was found. The statistical uncertainties are also scaled by the slope of mapping function properly.**

Results : DLM

- Observed events :Total 22 events; electrons 12, Muons 10



Correct background-pulling
4.2 events expected.



Statistical & Systematic Uncertainty

Expected statistical Error

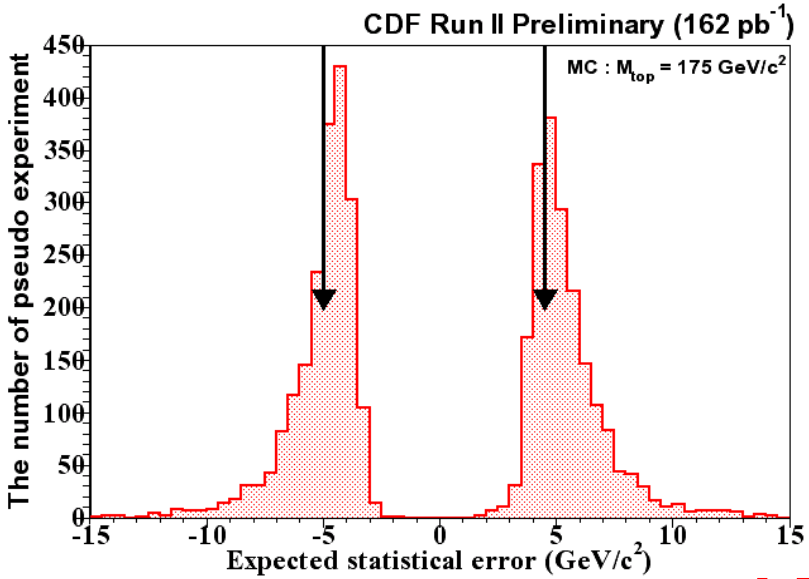
Black arrows :

Data : + 4.5, – 5.0 GeV

Monte Carlo :

Mean : + 5.4, – 5.0 GeV

MPV : + 4.5, – 4.1 GeV



Systematic uncertainty

Sources	delta M_{top}(GeV/c^2)
Jet Energy Scale	5.3
Transfer function	2.0
PDF	2.0
Generator	0.6
MC Modeling	0.6
ISR	0.5
FSR	0.5
Bkg fraction (±5%)	0.5
Bkg Modeling	0.5
Spin correlation	0.4
NLO effect	0.4
Total	6.2 GeV

(NLO: re-weighted qq and gg fractions)

DLM : M_{top} = 177.8 $\pm^{4.5}_{5.0}$ (stat.) ± 6.2 (syst.)GeV/c^2

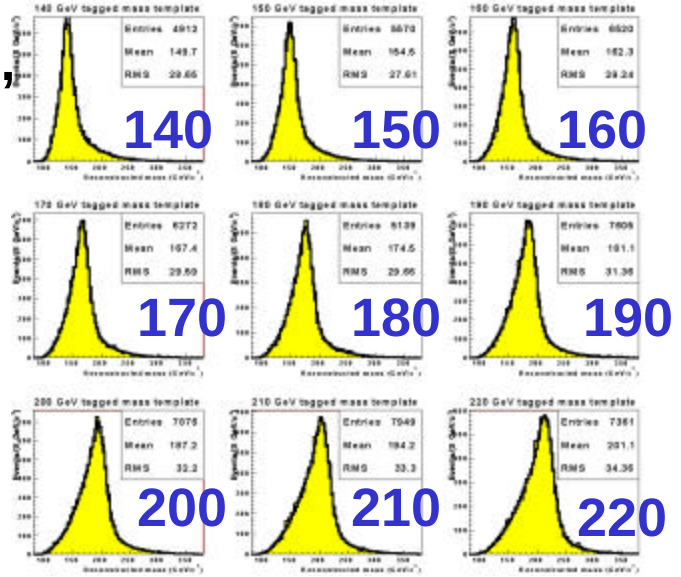
Template Method Overview

(1) For each event, invariant mass of top is reconstructed by minimizing χ^2 defined as,

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

- Jets resolution term
- Unclustered Energy term
- W mass and Top mass term

Top mass is free parameter

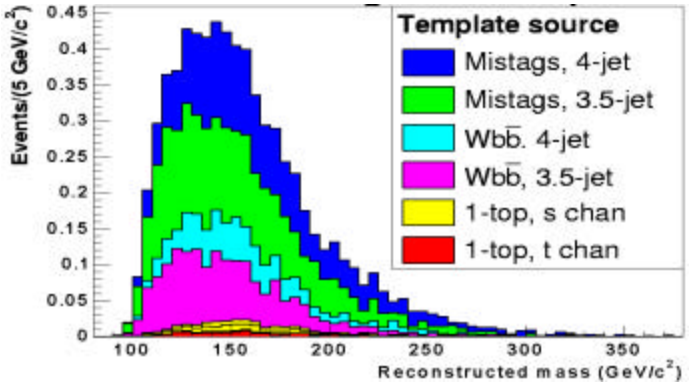


(2) Additional selection cut on resulting χ^2

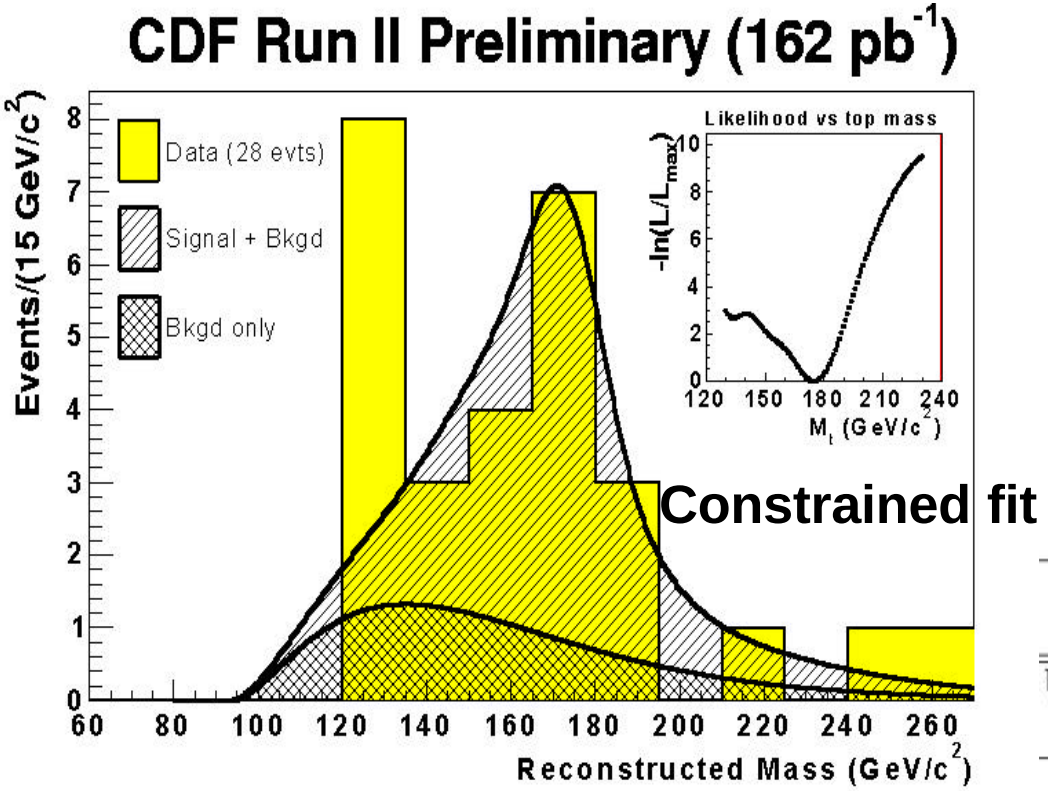
(3) Build templates of Mt with smallest χ^2 from MC for
- Signal with different top mass
- Each background source

(4) Parameterization : Build signal p.d.f. as a function of generated mass.

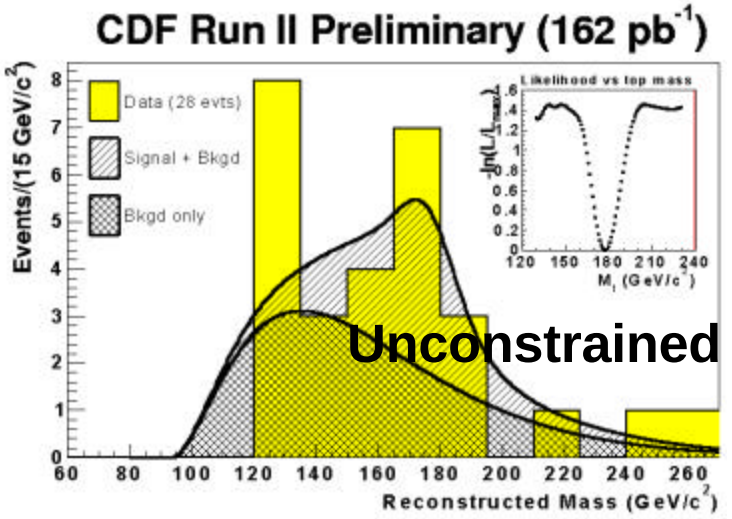
(5) Fit to the data using unbinned likelihood.



Template Method with >=1 b tag



Constrained fit



Unconstrained fit

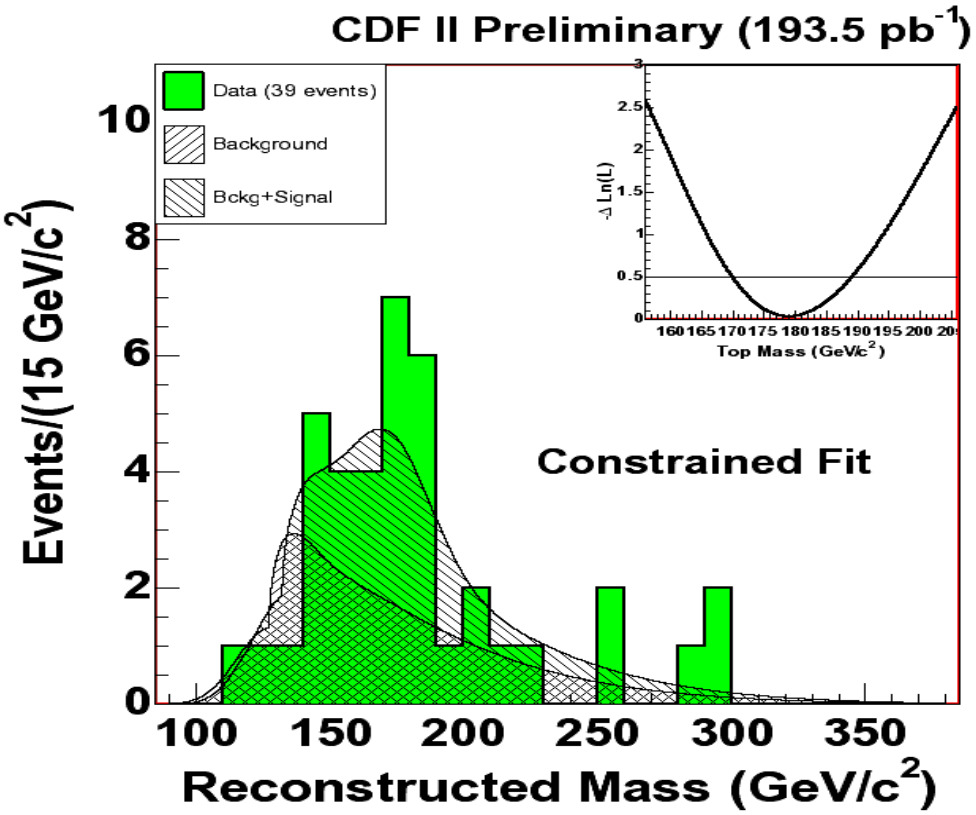
Category	Background (events)		M_{top}(GeV/c^2)
	input	output	
$W+ \geq 3.5$ jets	7.0 ± 0.8	7.1 ± 0.8	$174.9\ ^{+6.7}_{-7.2}$
	no constraint	$16.7\ ^{+8.2}_{-7.3}$	$177.7\ ^{+9.3}_{-8.4}$

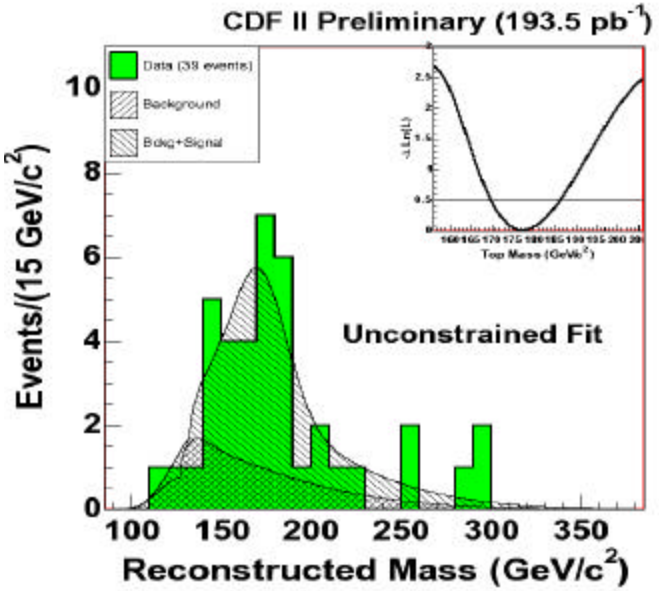
Template (btag) : $M_{top} = 174.9 \pm \begin{matrix}7.1\\7.7\end{matrix}$ (stat.) $\pm$ 6.5 (syst.)GeV/c^2

Stat. error from the fit is scaled up by 1.065 to provide 68% coverage of the true mass value

Jet Energy Scale : 6.3 GeV

Template Method with 0tag





Input (signal)	Output	M_{top}
15.5 ± 3.2	16 ± 3	$179.1 \pm {}^{10.5}_{9.5}$
No constraint	26 ± 13	$177.5 \pm {}^{9.1}_{7.7}$

Template (0tag) : $M_{top} = 179.1 \pm {}^{10.5}_{9.5}$ (stat.) ± 8.4 (syst.)GeV/c^2

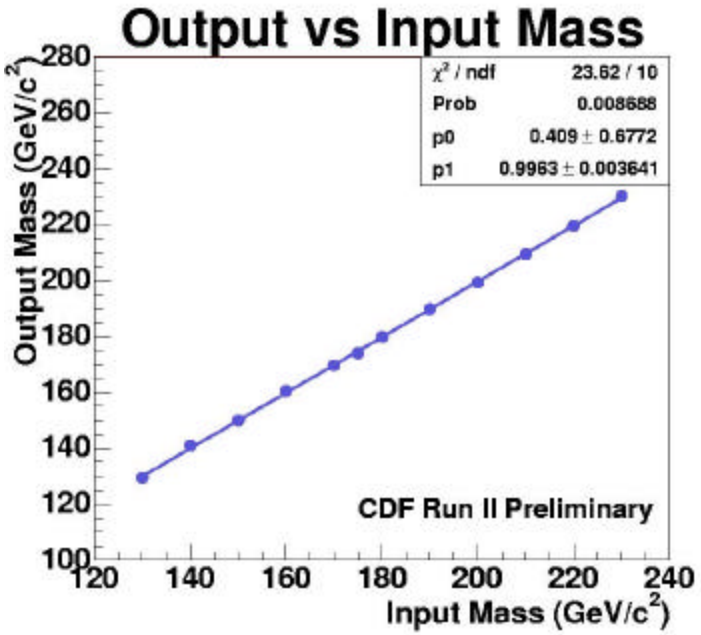
Jet Energy Scale : 8.3 GeV

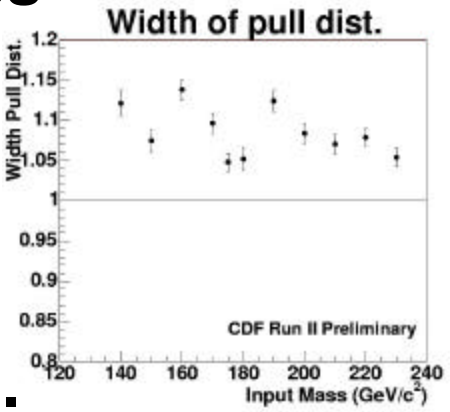
Template Method Combination

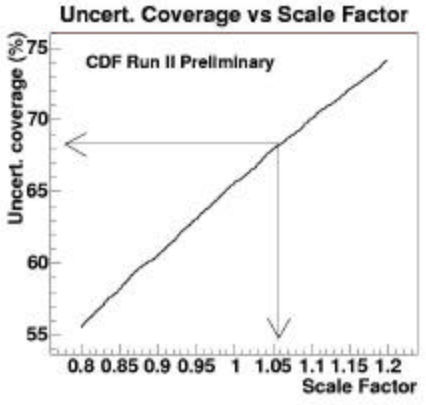
- Divided into 4 sub-samples :
  - -- 2 tag (4 combinations)
  - -- 1 tag (12 combinations)
    - 3.5 jets, 4jets different S/B
  - -- 0 tag, (24 combinations)
- Mass templates built for each sub-samples.
- Likelihood procedure uses information of all sub-samples simultaneously to determine best top mass.

$$L = L_{2tag} \times L_{1tag,4j} \times L_{1tag,3.5j} \times L_{0tag}$$

- Uncertainty is scaled up by 1.058 for 68% error coverage.



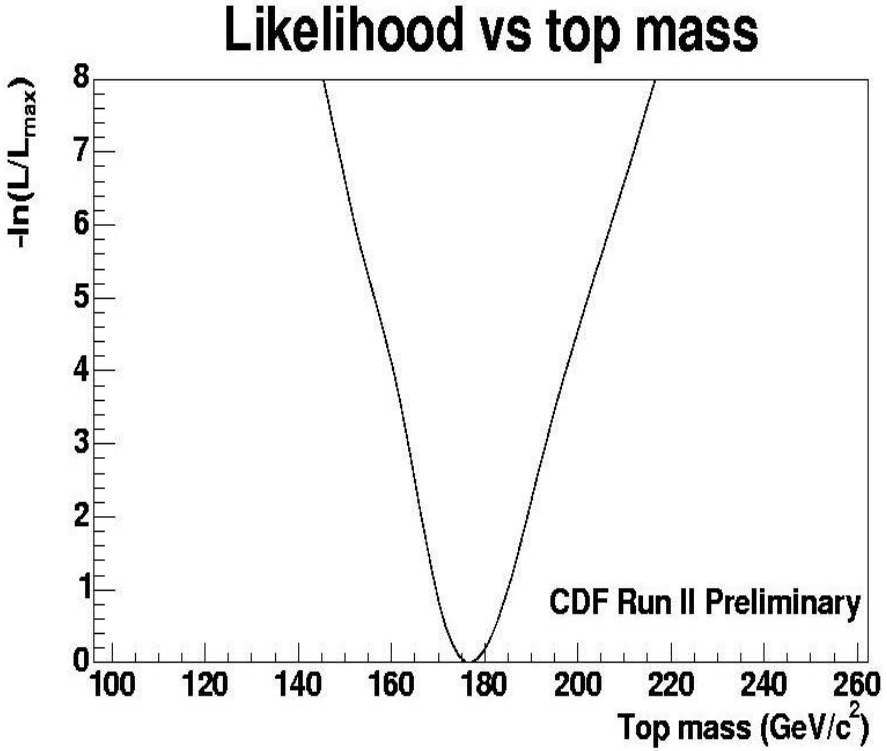


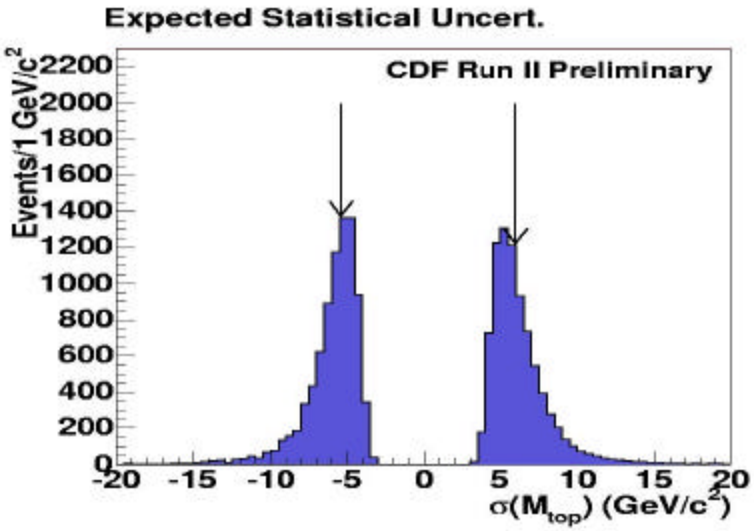


Results : Template Method

Combined likelihood curve

$$L = L_{2tag} \times L_{1tag,4j} \times L_{1tag,3.5j} \times L_{0tag}$$





CDF Run II Preliminary

Source of Systematics	ΔM_{top} (GeV/c^2)
Jet Energy Scale	6.8
ISR	1.2
FSR	1.2
PDFs	0.4
Generators	0.3
Background Shape	1.0
Other MC modeling	0.8
b tagging	0.1
MC statistics	0.3
Total	7.1

Template : $M_{top} = 176.7 \pm {}^{6.0}_{5.4}$ (stat.) $\pm$ 7.1 (syst.)GeV/c^2

Summary

DLM : (Current CDF official)

$M_{top} = 177.8 \pm {}^{4.5}_{5.0}\,(stat.) \pm 6.2\,(syst.)\,GeV/c^2$

Combined Template : (less assumption, RunI check)

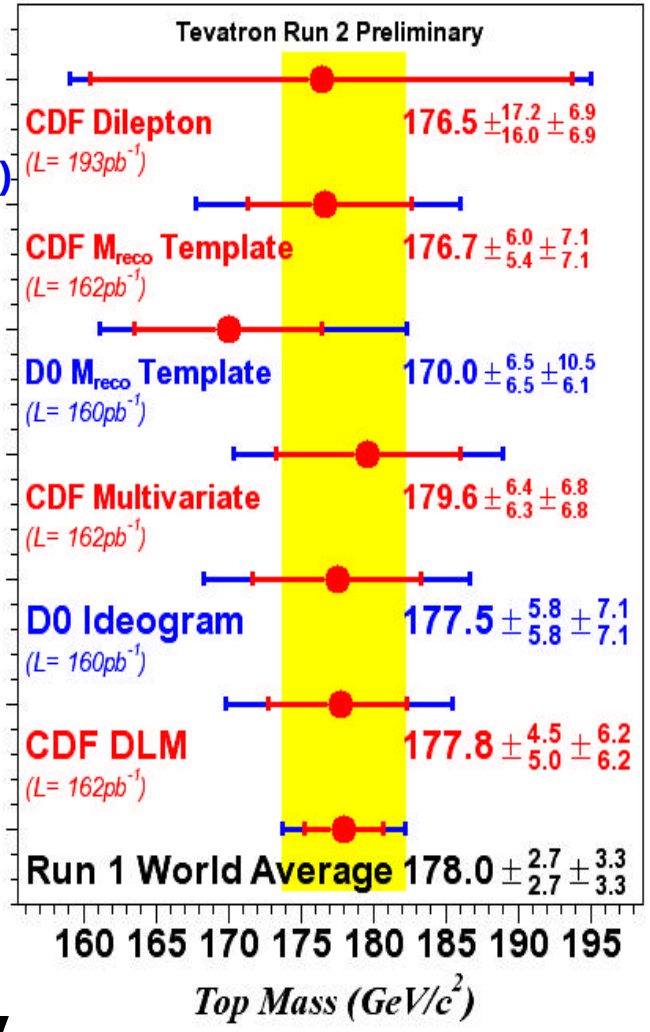
$M_{top} = 176.7 \pm {}^{6.0}_{5.4}\,(stat.) \pm 7.1\,(syst.)\,GeV/c^2$

(1) Now our measurements are dominated by systematics.
- Reduce Jet Energy Scale Uncert. by a better understanding of cal. simulation.

(2) Add more data (expect : >40´RunI in RunII)
(now : 1.5´RunI)

(3) Measurement of hadronic W mass
- constrain light jet energy scale

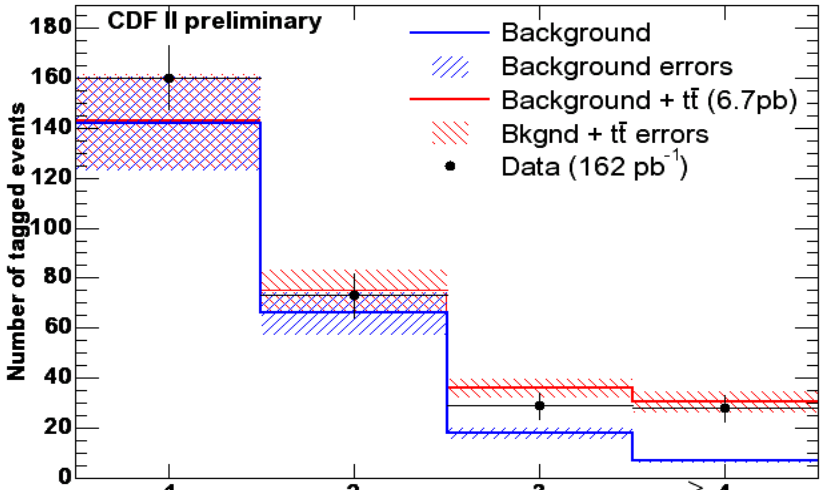
(4) Will try to combine diff. methods, diff. channels to get one value!



Again, RunII goal is an error of 2~3 GeV

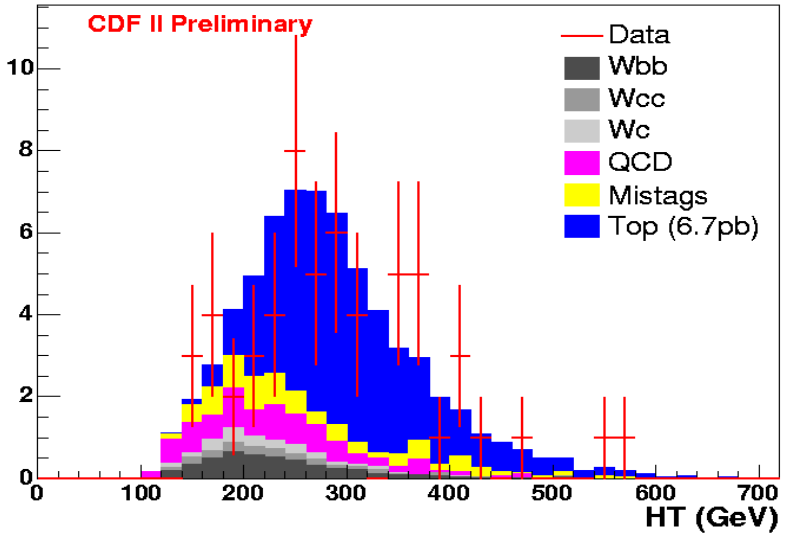
Back up slides

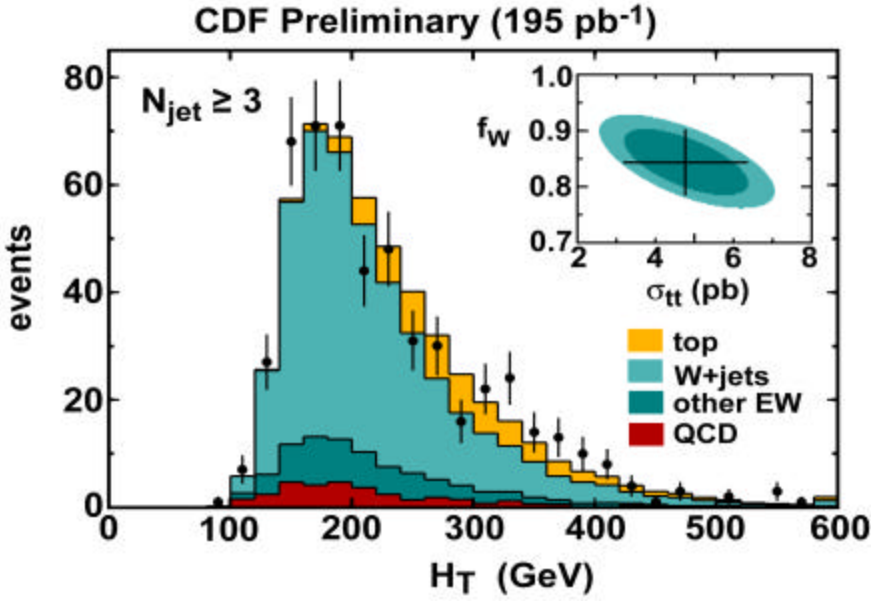
Some Plots (Data vs MC)



- The data are well understood by MC!
- Agreement is quite good!

(Ht : Et scalar sum of lepton , jets, Met)





DLM : Comparisons

- **Event-by-event Maximum Likelihood Mass with wide range of [125-225] GeV.**

  Note : First(last) bin includes under(over) flow.

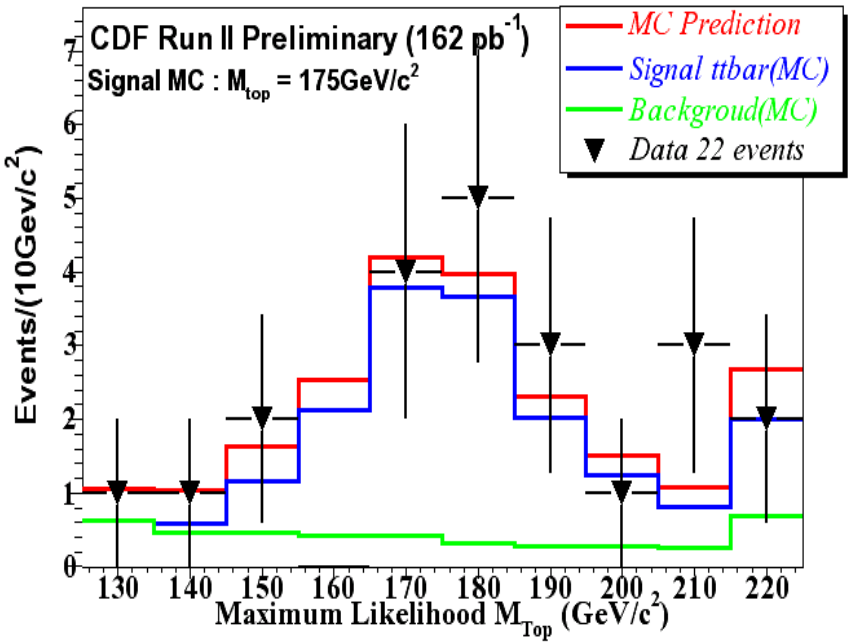
- **Event likelihood**

  For i-th event,

$$L^i_{ev} = \int L^i(M)\,dM$$

  A event has one likelihood value

Maximum Likelihood Mass



Event Likelihood distribution