Top into Dileptons

Stano Tokar
Comenius University, Bratislava

With a kind permissison of the CDF top group

Talk Outline

- **Top quark is treated in Dilepton mode**
- **Main subjects:**

  $\Rightarrow$ $t\bar{t}$ **production cross section**

  (Details in: CDF6588, c.f. also CDF6517,-79,-90,-91,92)

  $\Rightarrow$ **Top quark mass reconstruction**

  (Details in: CDF-6465)

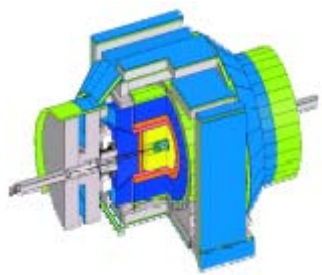
www-cdf.fnal.gov/internal/physics/top/run2dil/summer03/doc.html)

Top Dilepton Characteristics

- **Top dilepton topology:**

$$p\bar{p} \to t\bar{t} + X, \quad t\bar{t} \to \left(W^+ b\right)\left(W^- \bar{b}\right) \to \left(l^+ \nu b\right)\left(l^- \tilde{\nu} \bar{b}\right)$$

- **Branching ratio: 2/9 × 2/9 ≈ 4.9 % of all $t\bar{t}$ events**
- **Characteristics of top dilepton mode**
  - **Two high P_T opposite charge leptons**
  - **High missing E_T (due to neutrinos)**
  - **Two high P_T *b*-jets**
- **Advatages: Very clean $t\bar{t}$ events sample.**
- **Disadvantages: low branching ratio**



Top Dilepton Selection criteria

Top dilepton event selection cuts: Run I vs Run II

Cut	Run I	Run II (Winter 2003)
1	Two $\geq$ 20 GeV opposite signed leptons, $\geq$1 isolated	Two $\geq$ 20 GeV isolated leptons
2	Remove Z bosons $76 < M_{ee,\mu\mu} < 106$ GeV	Remove Z bosons $76 < M_{ee,\mu\mu} < 106$ GeV
3	$\not\!\!E_T > 25$ GeV	$\not\!\!E_T > 25$ GeV
4	$\Delta\varphi(\not\!\!E_T$, nearest l or j$) > 20°$ if $\not\!\!E_T < 50$ GeV	$\Delta\varphi(\not\!\!E_T$, nearest l or j$) > 20°$ if $\not\!\!E_T < 50$ GeV
5	$\geq$ 2 jets with $\not\!\!E_T^{raw} > 10$ GeV $\lvert\eta_{detector}\rvert < 2.0$	2 jets with $\not\!\!E_T^{raw} > 10$ GeV $\lvert\eta_{detector}\rvert < 2.0$
6		$H_T > 200$ GeV
7		Opposite charge requirement

$$H_T = \sum E_T^{tight\ leptons} + \not\!\!E_T + \sum E_T^{pass.jets}$$ (motivation: CDF5676)

Cross section

- **Run II status (Summer'03)**

  ⇒ **CMS energy:** $\sqrt{s} = 1.96\,TeV$

  ⇒ **Integrated luminosity:** $\int \mathcal{L} \cdot dt = 126\ pb^{-1}$

- **Cross section:** $\sigma = \left(N_{obs} - N_{bg} \right) \Big/ A \cdot \varepsilon \cdot \int \mathcal{L} dt$

  N_{obs} ≡ # of events observed

  N_{bg} ≡ # of estimated background events

  A ≡ Kinematic and geometrical acceptance

  ε ≡ Total efficiency

- **Winter'03 selection criteria modified:**

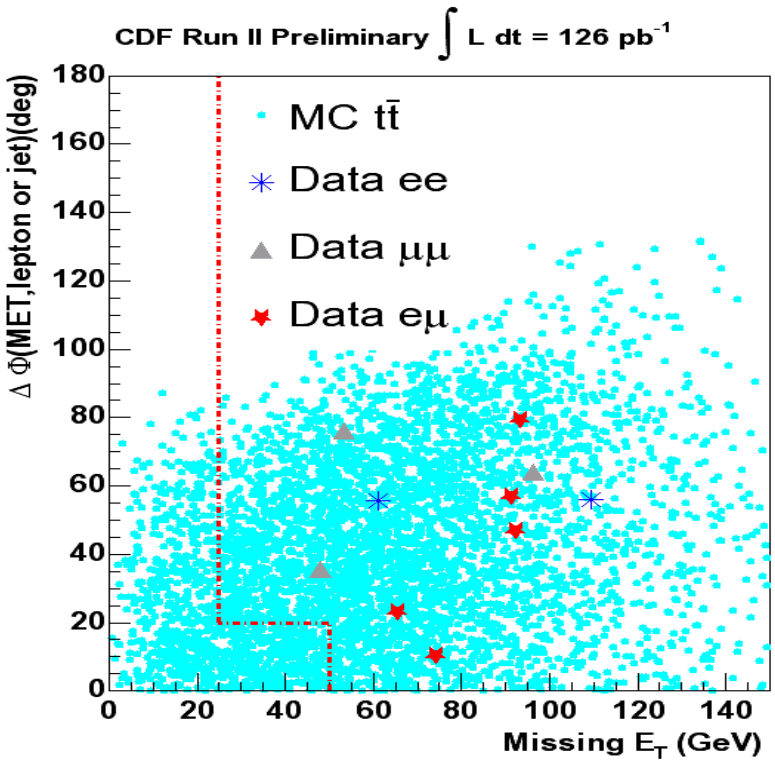
  Only one isolated lepton required

  Plug electrons and CMIO muons included

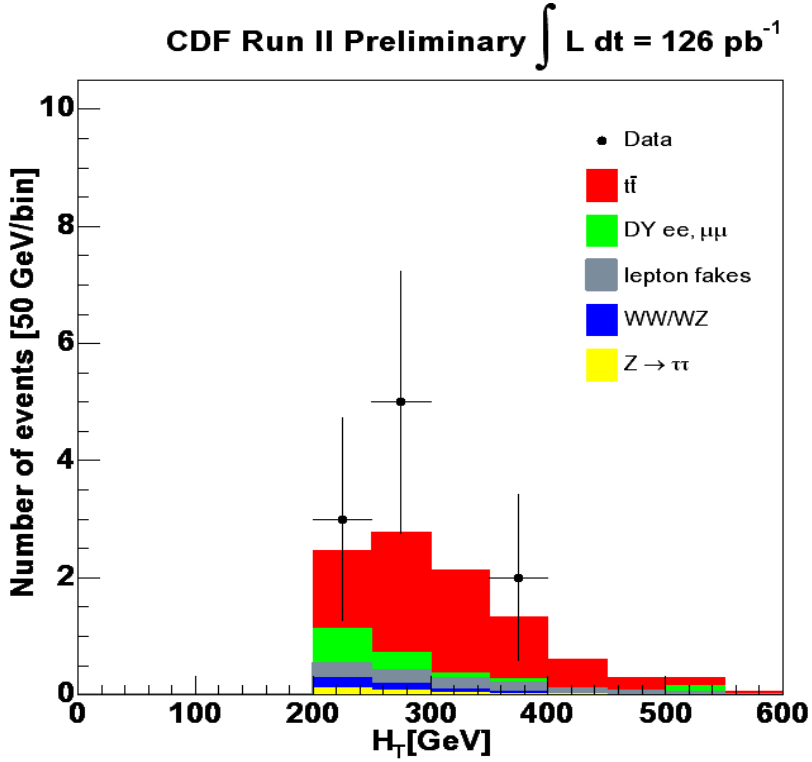
  Z mass window cut replaced by a special procedure

X-section: Event Selection, $\Delta\phi$, H_T...

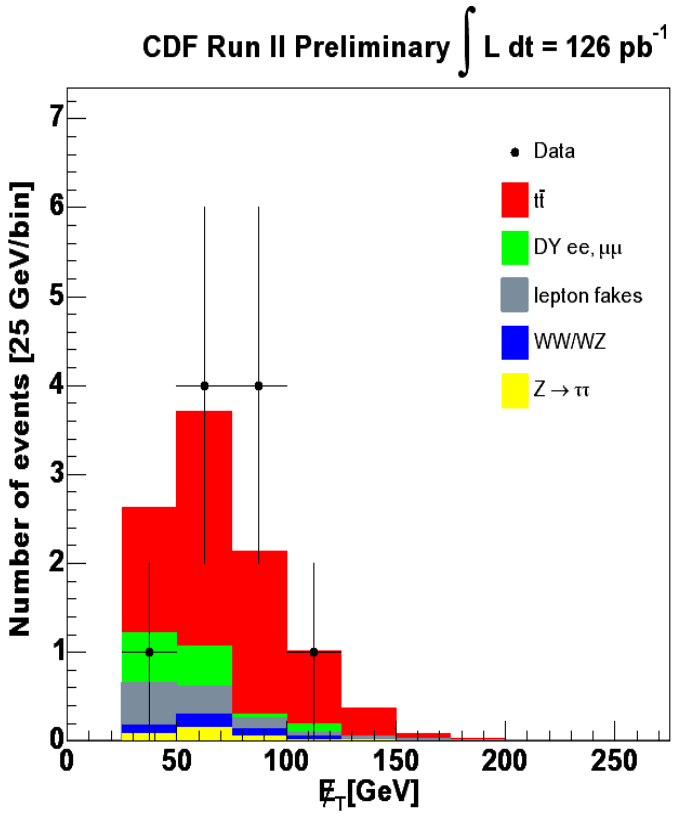
Cuts in ($\Delta\phi$, missing E_T)-plane: MC vs data (ee, $\mu\mu$, eμ)

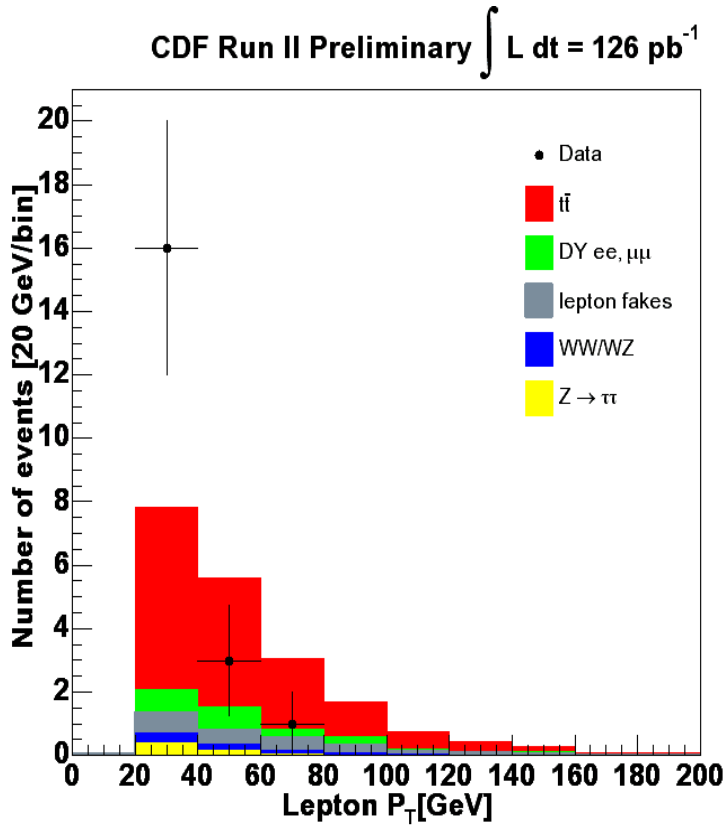


Cut in H_T: Data vs MC Signal and BKGD(DY, WW/WZ, $Z\rightarrow\tau\tau$, fake leptons)



X-section: Event Selection - miss-E_T, P_T

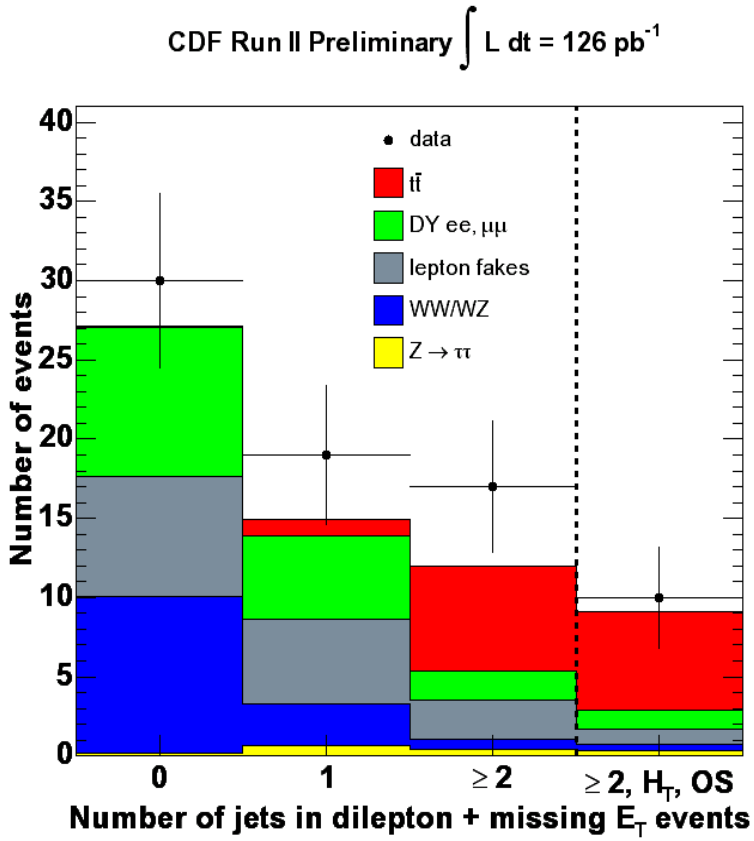


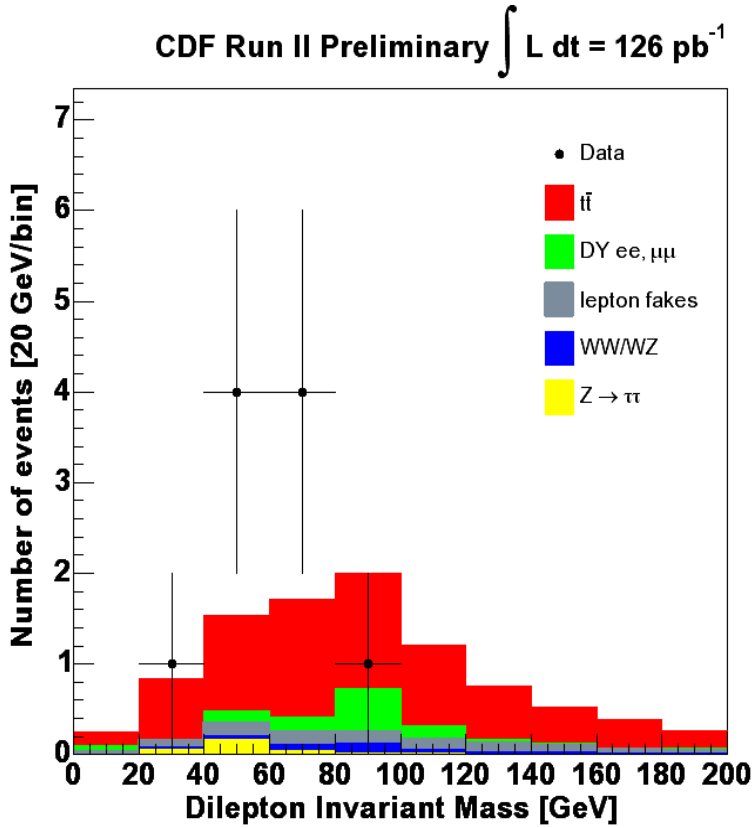


Cut in miss-E_T(>25 GeV):
Data vs MC Signal and BKGD(DY, WW/WZ, Z→ττ, fake leptons)

Cut in lepton P_T(>20 GEV):
Data vs MC Signal and BKGD(DY, WW/WZ, Z→ττ, fake leptons)

X-section: # of jets, dilepton mass





# of jets in dilepton + $\not\!\!E_T$ events vs MC signal and background

Dilepton invariant mass: Data vs MC signal and bkgd

Cross-section

Summary

$$\int \mathcal{L}\, dt = 98 - 126 \text{ pb}^{-1}$$

$$A\, \epsilon_{trig} \int \mathcal{L}\, dt = 0.935 \pm 0.099(syst) \pm 0.056(lum) \text{ pb}^{-1}$$

Source	Events per 126 pb^{-1} after all cuts			
	ee	$\mu\mu$	eμ	$\ell\ell$
WW/WZ	0.14 ± 0.06	0.09 ± 0.04	0.17 ± 0.07	0.40 ± 0.17
Drell-Yan	0.46 ± 0.29	0.73 ± 0.56	-	1.2 ± 0.7
$Z \to \tau\tau$	0.07 ± 0.02	0.08 ± 0.03	0.17 ± 0.06	0.32 ± 0.11
Fakes	0.64 ± 0.21	0.02 ± 0.007	0.30 ± 0.10	0.95 ± 0.31
Total Background	1.31 ± 0.41	0.92 ± 0.29	0.64 ± 0.20	2.9 ± 0.9
$t\bar{t}$	1.54 ± 0.16	1.37 ± 0.15	3.36 ± 0.36	6.3 ± 0.7
Total SM expectation	2.85 ± 0.44	2.29 ± 0.33	4.00 ± 0.41	9.2 ± 1.1
Run II data	2	3	5	10

$$\boxed{\sigma_{t\bar{t}} = 7.6 \pm 3.4(stat) \pm 1.5(syst) \text{ pb}}$$

A good agreement with others and theory!

Top Mass in the Dilepton Channel

Summary of the top mass reconstruction method:

- Kinematic reconstruction of events selected by the dilepton selection criteria
- 24 parameters looked for at 23 constraints + assumption on the $P_{t\bar{t},z}$ distribution introduced
- MC templates employed in exper. data and bkgd analyses

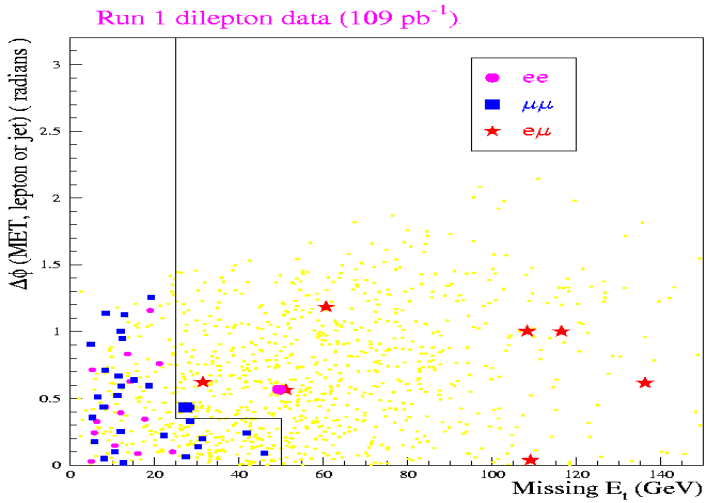
$$f\left(m_{t,rec}, m_t^{inp}\right), \quad m_t^{inp} = 140, 150, \cdots, 210$$

- Top mass is obtained using likelihood fit with the likelihood function defined:

$$L = \prod_{i=1}^{n} f\left(m_{t,rec}^{(i)}, m_t^{inp}\right)$$

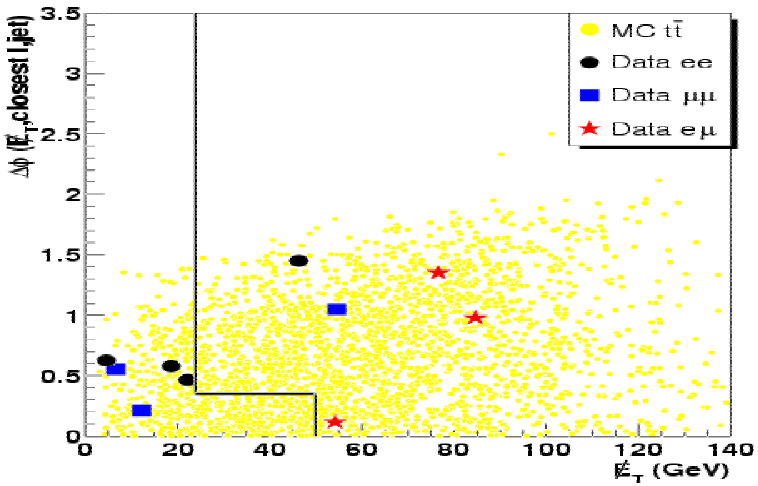
$n \equiv$ # of events passed the selection criteria

Top Candidates in Dilepton Mode



Run I selected top candidates,
cut carried out in plane $(\not\!\!E_T, \Delta\phi)$
$\Delta\phi \equiv$ angle(MET, lepton (jet) direction)

Sample: 109 pb^{-1}



Run II selected top candidates,
cut carried out in plane $(\not\!\!E_T, \Delta\phi)$

Sample: 126 pb^{-1}

6 top dilepton candidates found

Winter'03 selection criteria applied!

Masses of Top Candidates in Dilepton Mode

CDF Run II preliminary ($\mathcal{L} = 126 pb^{-1}$)

$\ell\ell$	**reconstructed** M_{top}
(ee-1)	201 ± 13.7
($\mu\mu$-1)	136 ± 11.6
($\mu\mu$-2)	173.9 ± 20.0
(eμ-1)	123 ± 29.4
(eμ-2)	190.7 ± 19
(eμ-3)	161 ± 17.9

Only 6 events (vs 10 in xsec) due to more stringent criteria

MC Signal Templates

- Samples of $t\bar{t}$ events produced (Pythia) for different input top masses:

$$m_t^{inp} = (140, 150, \ldots 210)\ GeV/c^2$$

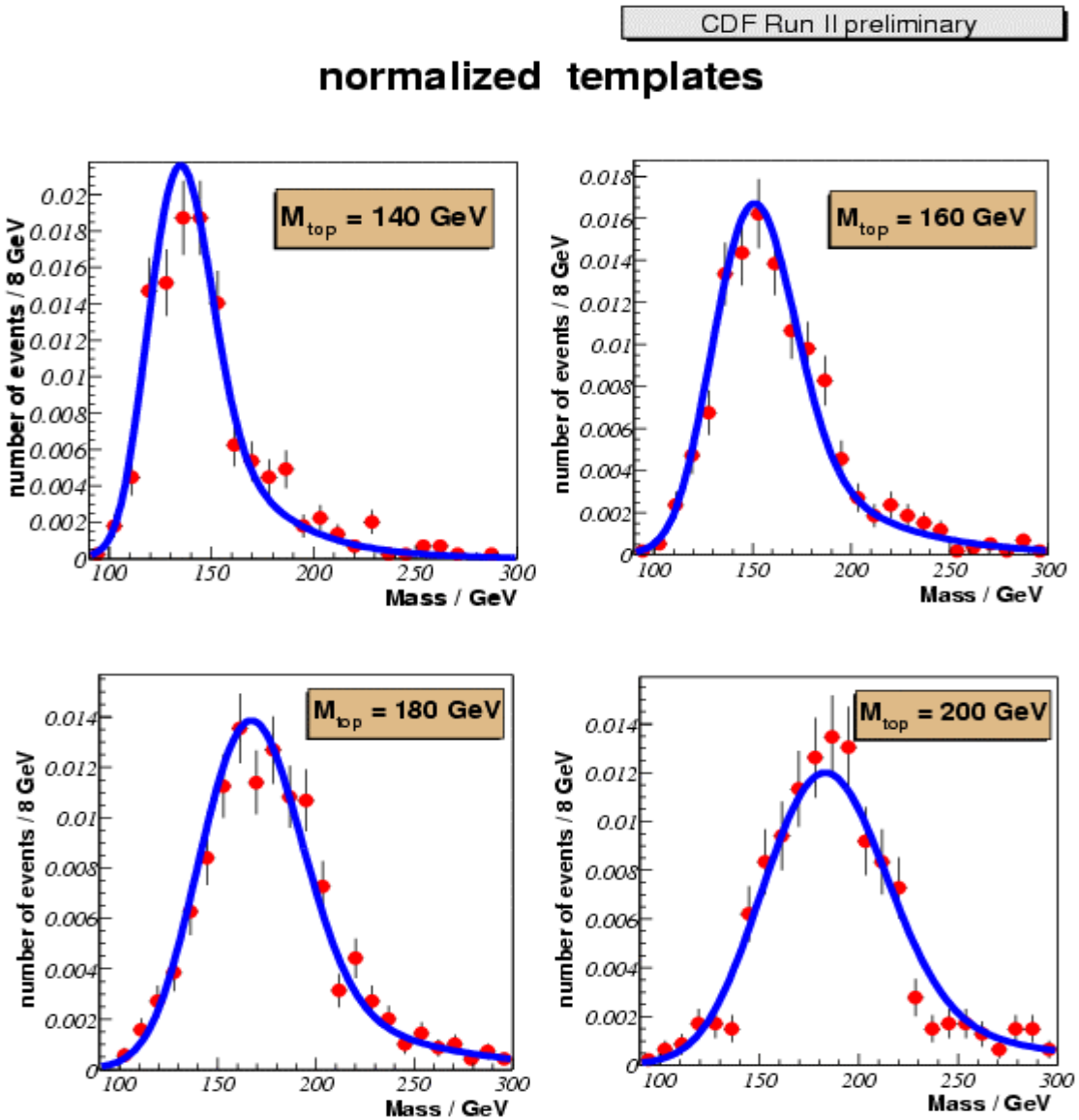
- Simulated events are reconstructed (top dilepton selection criteria applied) and template – normalized distribution of m_t^{rec} (reconstructed top mass) – is found and fitted for each m_t^{inp}

- Template parametrization $\Rightarrow$ a combination of Landau-like distribution and Gaussian:

$$f(m_t^{rec}, m_t^{inp}) = \frac{p_3(m_t^{inp})}{I_1}\exp\left(-0.5\left(\lambda + \exp(-\lambda)\right)\right) + \frac{\left(1 - p_3(m_t^{inp})\right)}{I_2}\exp\left(-0.5\lambda^2\right)$$

$$\lambda = \frac{m_t^{rec} - p_1(m_t^{inp})}{p_2(m_t^{inp})} \qquad p_i(m_t^{inp}) = a_i + b_i \cdot m_t^{inp}$$

Signal MC templates



- p_i parametrization

	a	b
p_1	22.57 ± 2.82	0.8 ± 0.017
p_2	-21.35 ± 2.3	0.26 ± 0.017
p_3	1.0 ± 0.16	- .0036 ± .0003

- From

$$p_i = a_i + b_i \times m_t^{inp}$$

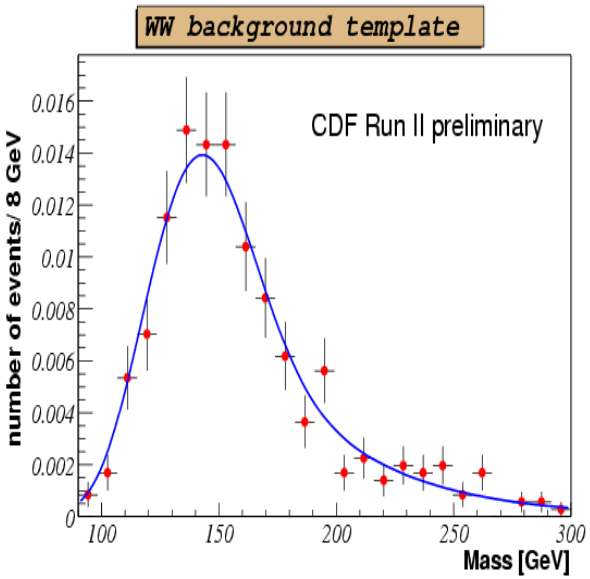
$\Rightarrow$

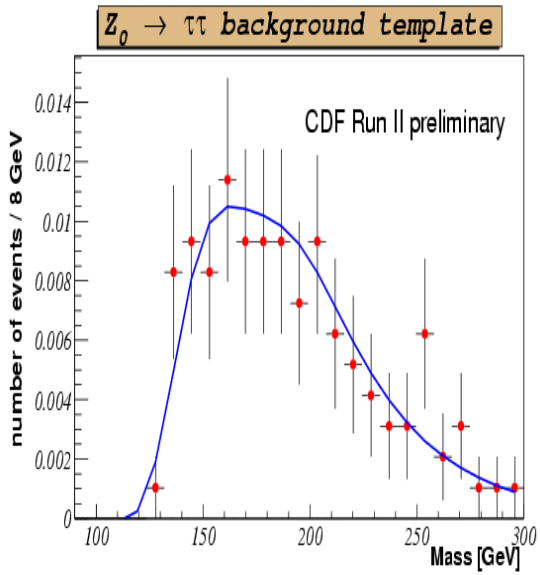
Signal template

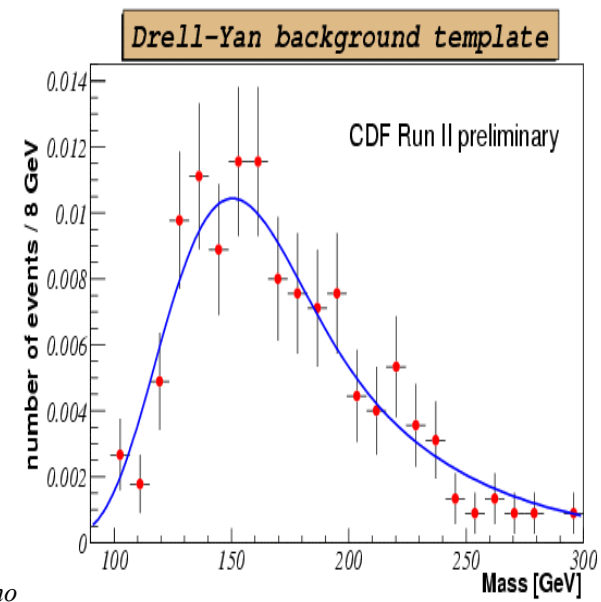
$$f_s\left(m_t^{rec}, m_t^{inp}\right)$$

is known for any m_t^{inp}

Background Templates



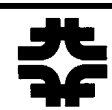




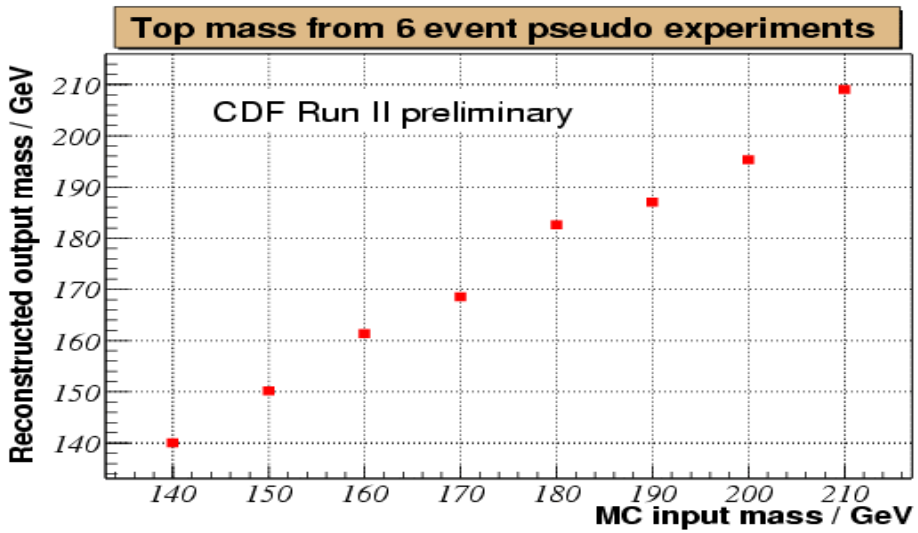
Bkgd templates have the same form as the signal ones, but

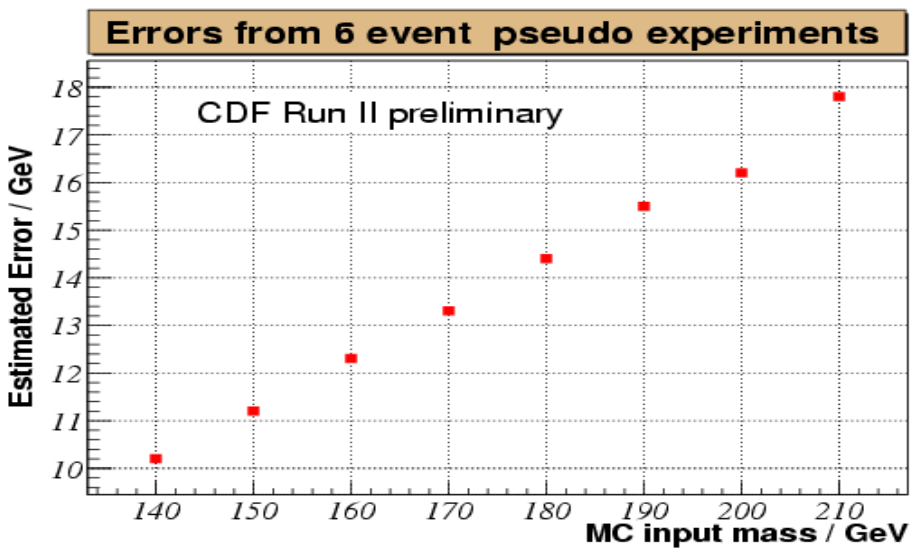
p_i do not depend on m_t^{inp}

Bkgd	p_1	p_2	p_3
WW	143.0 ± 1.83	21.93 ± 1.59	0.63 ± 0.095
$Z_0 \rightarrow \tau\tau$	150.5 ± 3.11	26.37 ± 3.01	0.86 ± 0.13
Drell-Yan	167.2 ± 11.9	32.28 ± 9.4	1.19 ± 0.31



Templates & Top Quark Mass





⇒ **Pseudo-experiments with 6 random events repeated for each of 8 input top masses**

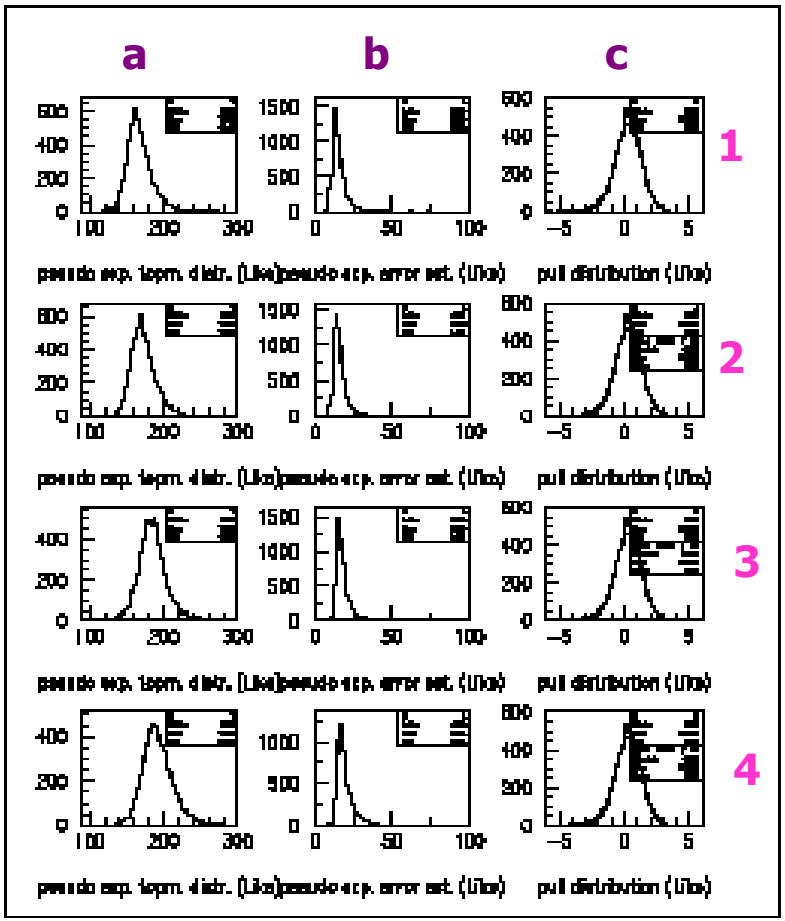
⇒ **6 top masses resulted from each pseudo-experiment are put into likelihood fit:**

$$L = \prod_{i=1}^{n} \left[b \cdot f_b\left(m_{t,i}^{rec}\right) + (1-b) \cdot f_s\left(m_{t,i}^{rec}, m_t\right) \right]$$

⇒ **top mass m_t & its error are got from the likelihood fit**

Mean values of top masses (⇑)
And their errors (⇐)

Pseudo-experiment Results



6 events pseudo-experiments with different input top masses (160, 170, 180 and 190 GeV)

1 2 3 4

have been carried out.

Each pseudo-experiment gives 6 "raw" top masses – from them Likelihood fit finds:

a) top mass

b) its error

c) pull ($= m_t^{fit} - m_t^{inp}$)

⇑

Distributions of top masses, errors and pulls from likelihood fits

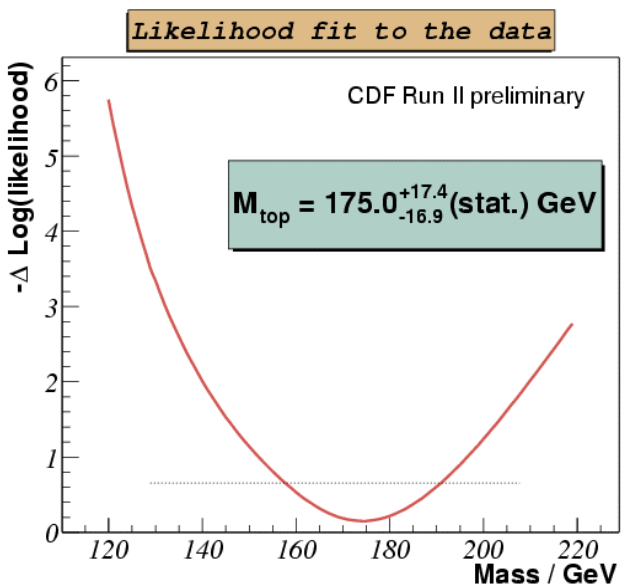
Dilepton Top Quark Mass

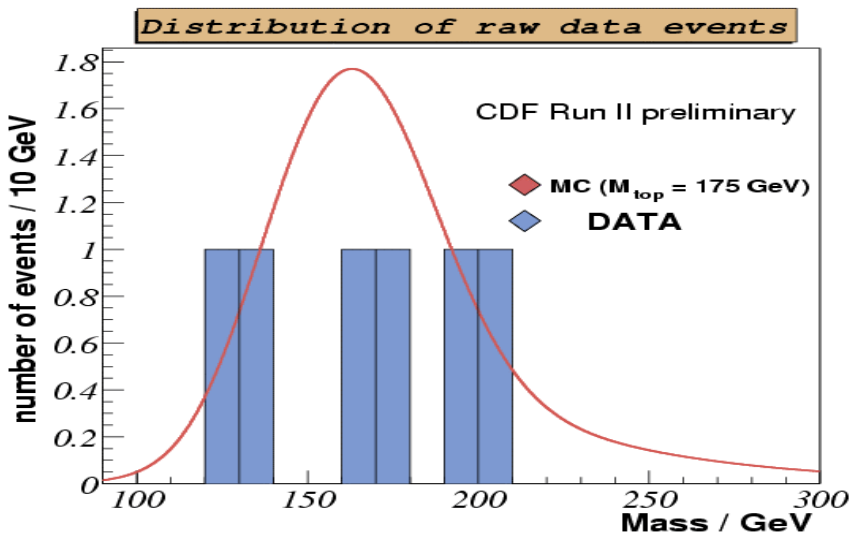
Top mass is obtained from data using likelihood fit – likelihood function is known for any top mass (at least for (140, 210) GeV):

$$L = \prod_{i=1}^{n} \left[b \cdot f_b\left(m_{t,i}^{rec}\right) + (1-b) \cdot f_s\left(m_{t,i}^{rec}, M_{top}\right) \right]$$

b **≡ bkgd percentage**

Applied to *6 experimental events* ⇒





Background

Background expectation at 126 pb^{-1}

Bkgd	Exp. # of events
WW/WZ	0.165 ± 0.132
Drell-Yan	0.173 ± 0.121
$Z \rightarrow \tau\tau$	0.165 ± 0.069
Fake	0.065 ± 0.052
Total	0.52 ± 0.20

Bkgd expectation values are scaled from those at 72 pb^{-1}(CDFNOTE 6319)

Probability of finding in 6 dilepton events :

- no background is 59.5 %
- 1 bkgd event – 32.3 %
- 2 bkgd events – 7.3 %

Uncertainty $\Delta m_t \approx 1.2 \pm 0.2$ GeV is obtained from likelihood fit assuming different sole background contributions.

Systematics $\approx$ 0.2 GeV comes from 1σ variation of individual bkgd templates

Dilepton Top Mass Systematics

Mass determination is sensitive to MC templates , jet reconstruction

- **Jet energy systematics:**
  Sample of $t\bar{t}$ events (Pythia) at m_t=170 GeV generated,
  sets of events for each jet correction created and reconstructed,
  pseudo-experiments with 5 events carried out,
  $\pm 1\sigma$ deviation applied for each jet correction.
- **Generator systematics:**
  2 PDF sets used: CTEQ5L and MRST
  Pythia vs Herwig
  ISR and FSR taken from Run I

CDF Run II preliminary

Source	$\Delta M_{top}(\mathrm{GeV}/c^2)$
Jet Energy Scale	7.1 ± 0.85
Generators + PDF + ISR + FSR	3.5 ± 0.6
Background	1.3 ± 0.2
Total	7.9 ± 1.1

Dilepton Top Mass

- **Top mass determined in the dilepton mode**
  - ⇒ **the experimental sample of 126 pb^{-1} processed**
  - ⇒ **the winter conference top dilepton selection criteria applied**

$$M_{top} = 175.0^{+17.4}_{-16.9}\,(stat) \pm 7.9\,(syst)\ GeV/c^2$$

Conclusions

- **Raw data sample of 126 pb^{-1} processed in dilepton mode**
- **for Top mass - likelihood fit gives (6 events):**

$$M_{top} = 175.0^{+17.4}_{-16.9}\,(stat) \pm 7.9\,(syst)\ GeV/c^2$$

- **Cross section of $t\bar{t}$ production determined (dilepton mode):**

$$\sigma = 7.6 \pm 3.4_{stat} \pm 1.5_{sys}\ pb$$

$\Rightarrow$ X-section is compatible with that of CDF "one lepton+jets" mode

($\sigma = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.8_{lum}$ pb) and with

$\Rightarrow$ D0 ($\sigma = 8.4^{+4.5}_{-3.7}\,(stat)\ ^{+5.3}_{-3.5}\,(syst) \pm 0.8\,(lumi)\ pb$)

$\Rightarrow$ QCD calculations: $\sigma = 4.75^{+0.73}_{-0.62}\ pb$

(resumation of log soft gluon corrections included,

S.Catani et al., Phys. Lett. B378 (1996)329)