Physics at Tevatron

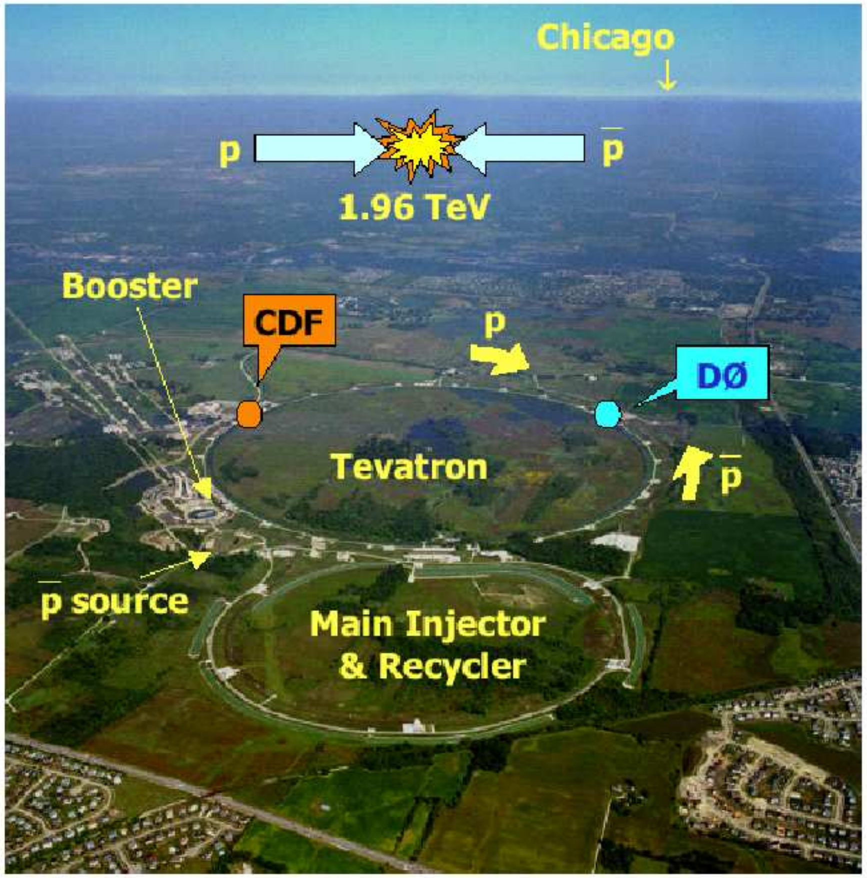
Koji Sato
KEK Theory Meeting 2005
"Particle Physics Phenomenology"
March 3, 2005

Contents

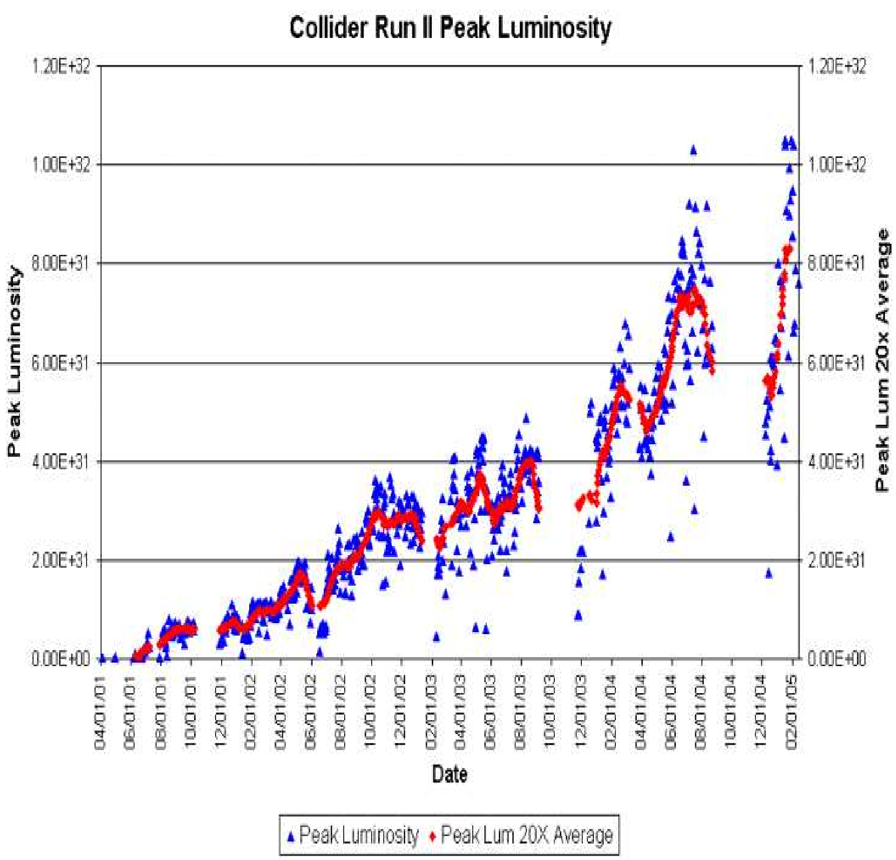
Tevatron Run II

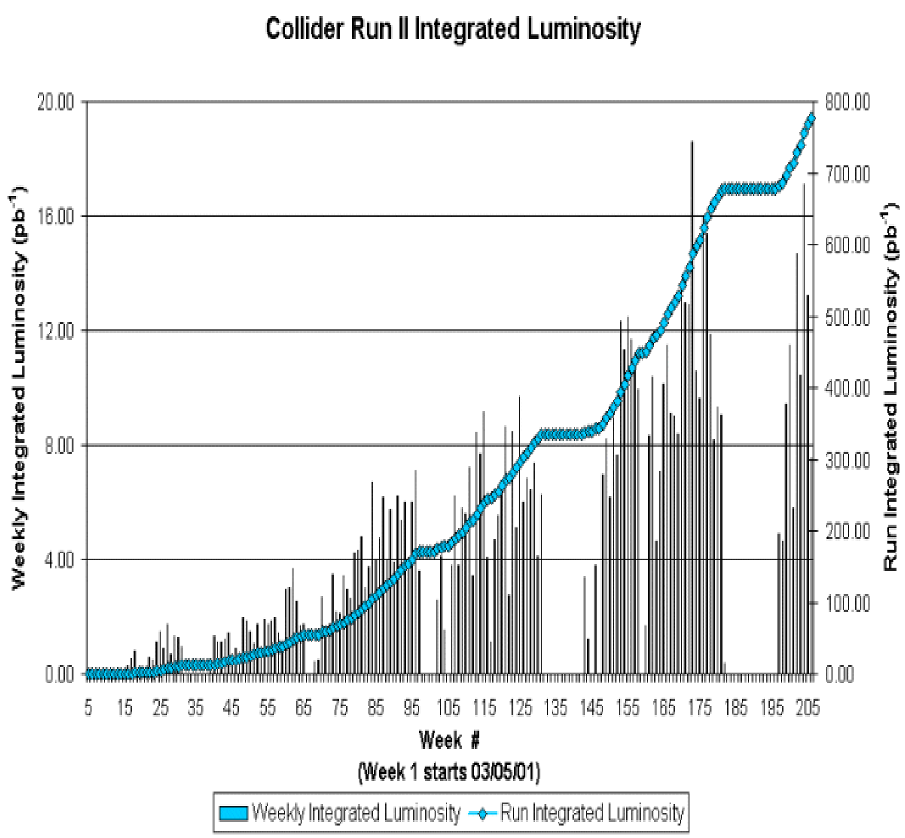
- Started Spring 2001.
- proton-antiproton collider with $\sqrt{s} = 1.96$ TeV (Run I : 1.8 TeV).
- antiproton recycler commissioning
  - electron cooling operational by Summer '05.
  - 40% increase in luminosity.
- 36 bunches $\times$ 36 bunches. 396 ns crossing time.
- Long term luminosity projection :
  - Base goal : $4.4\ \mathrm{fb}^{-1}$
  - Design : $8.5\ \mathrm{fb}^{-1}$

  by end FY2009.



Tevatron Performance



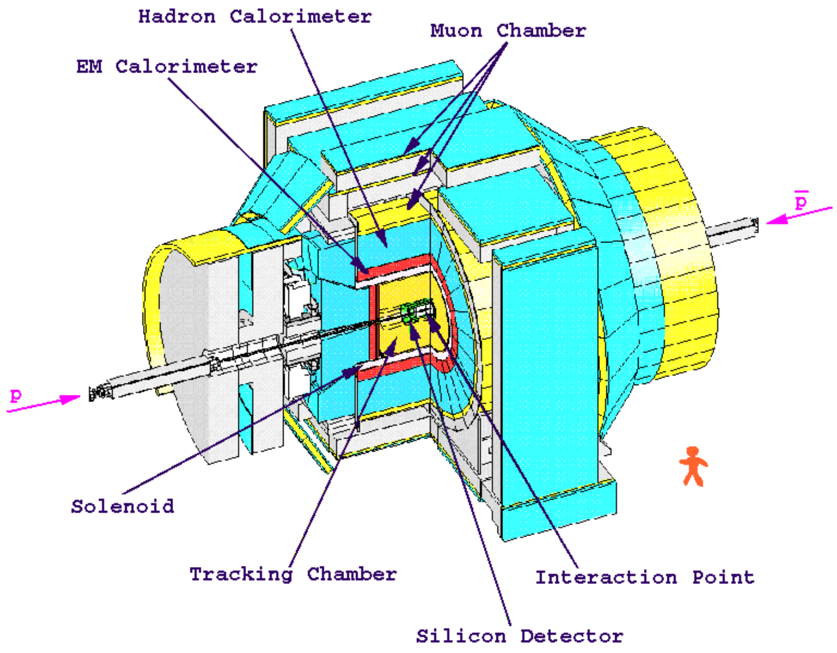


- Record : 1.2×10^{32} cm^{-2}s^{-1}.
- ~ 800 pb^{-1} of collisions delivered in Run II.
- Tevatron delivered more than ~ 350 pb^{-1} in 2004.

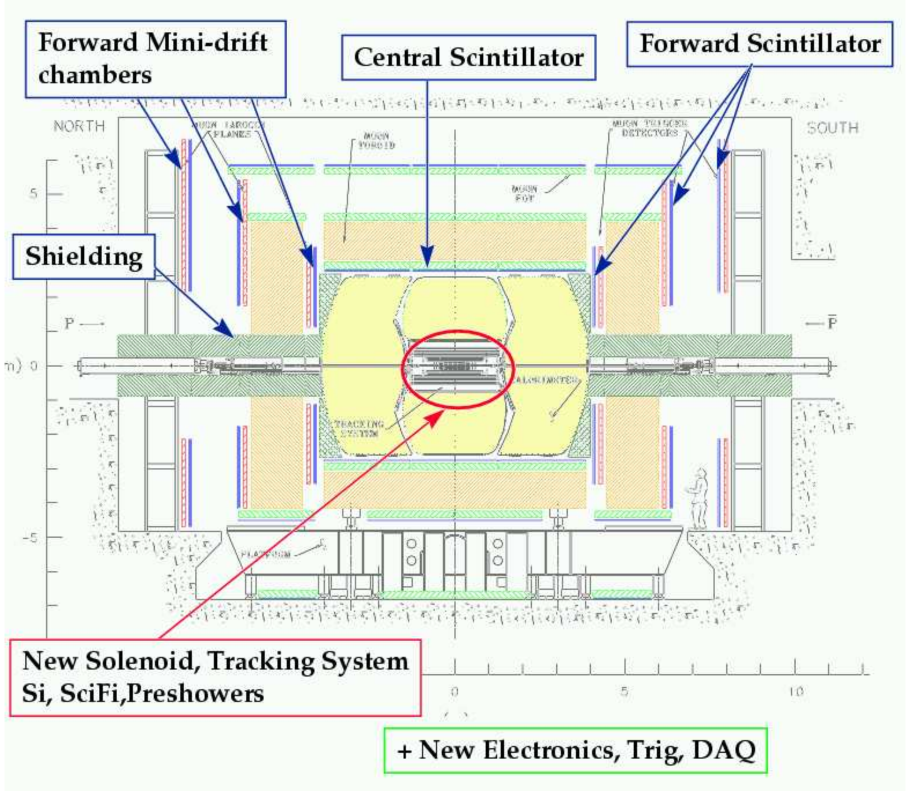
Tevatron Run II Detectors

Both general purpose detectors with tracking within magnetic field, precision tracking with silicon, calorimeter, muon chamber.

CDF



D0



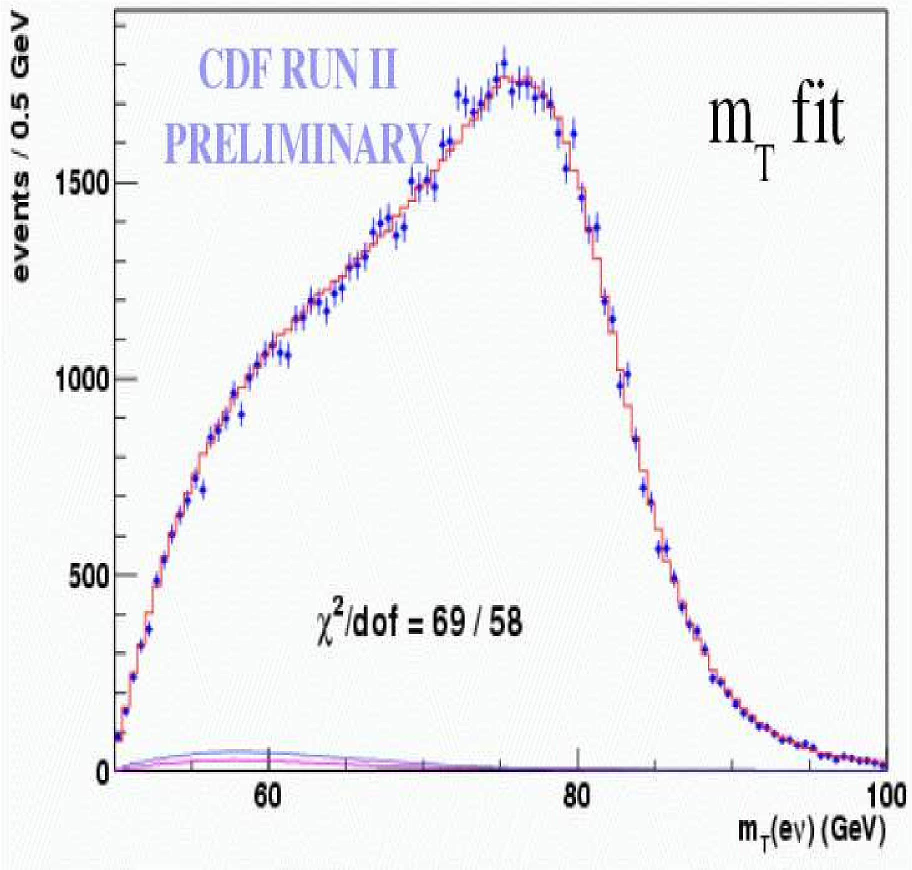
- Both detectors have already collected $\sim 600\ pb^{-1}$ on tape.
- Analyses presented here use $\sim 200\ \mathrm{pb}^{-1}$.

W Boson Mass Measurement (CDF)

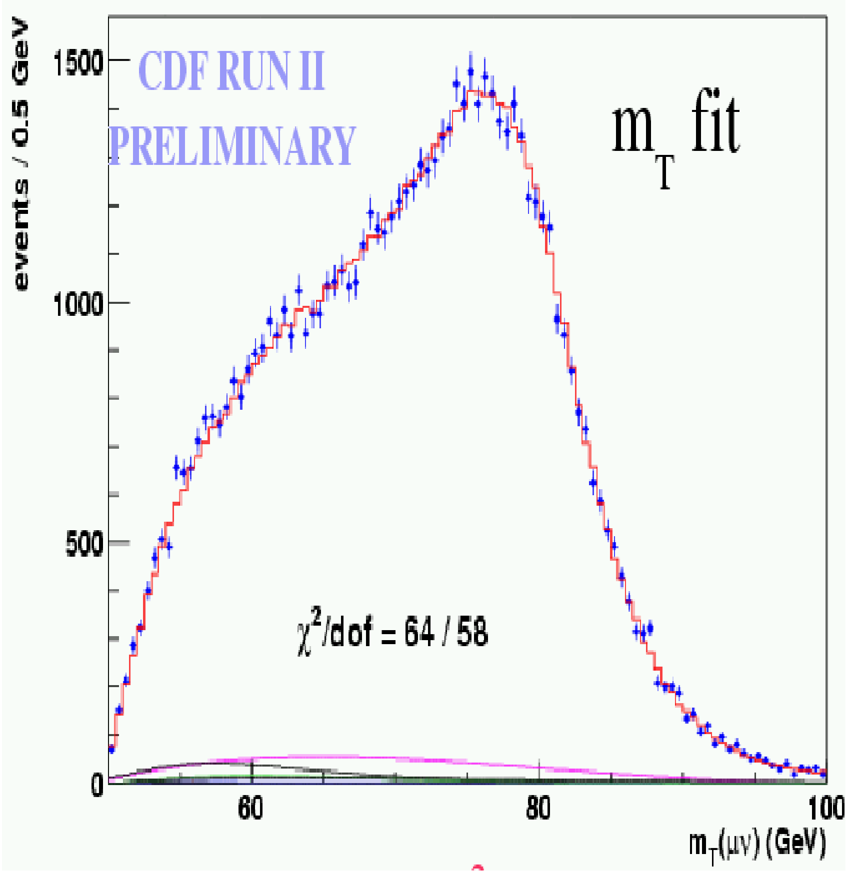
Important SM parameter setting bound to Higgs mass.

Fit of transverse mass distribution.

fit in e channel ($200\ \mathrm{pb}^{-1}$) :



fit in μ channel ($200\ \mathrm{pb}^{-1}$) :



W Boson Mass Measurement (CDF) 2

CDF Run II uncertainties ($200\ \mathrm{pb}^{-1}$) :

Systematic	Electrons (Run 1b)	Muons (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)
Recoil Scale and Resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Statistics	45 (65)	50 (100)
Production and Decay Model	30 (30)	30 (30)
Total	105 (110)	85 (140)

CDF RUN II PRELIMINARY

First Run II measurement coming soon!

Total uncertainty ($76\ \mathrm{MeV}/c^2$) already lower than Run I ($79\ \mathrm{MeV}/c^2$).

Could approach $50\ \mathrm{MeV}/c^2$ uncertainty during 2005

- Already have twice the data on tape.
- Work in progress to minimize systematic uncertainty (lepton energy and recoil scale).

Run I Results (GeV/c^2) :

CDF	80.433 ± 0.079
D0	80.483 ± 0.084
Average	80.454 ± 0.059
LEP	80.447 ± 0.042

.

Top Quark Physics - motivation -

Most recently discovered quark, and the least well understood.

- Discovered by CDF and D0 in 1995.

Intimate relationship with EWSB.

- Top mass is close to the EWSB scale.
- Strongly coupled to Higgs boson : $g_f \propto m_f$.

Top may be sensitive to new physics.

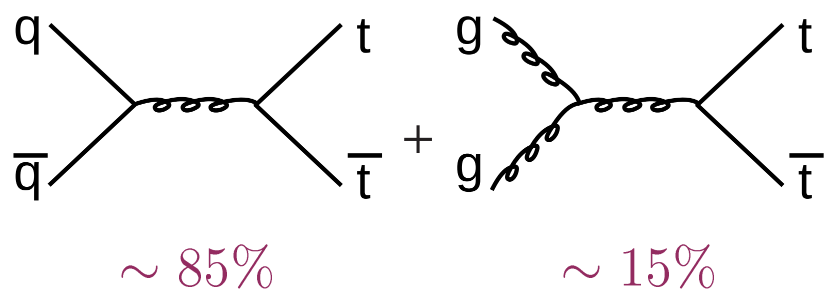
- Studying top tests electroweak theory.
- We can look for non-SM production or decay of top :
  $X \to t\bar{t}$ $\qquad\qquad$ $t \to Xb$

Background for new particle searches.
Study on top is only possible at Tevatron until LHC.

Production and Decay of Top Quark at Tevatron

Production

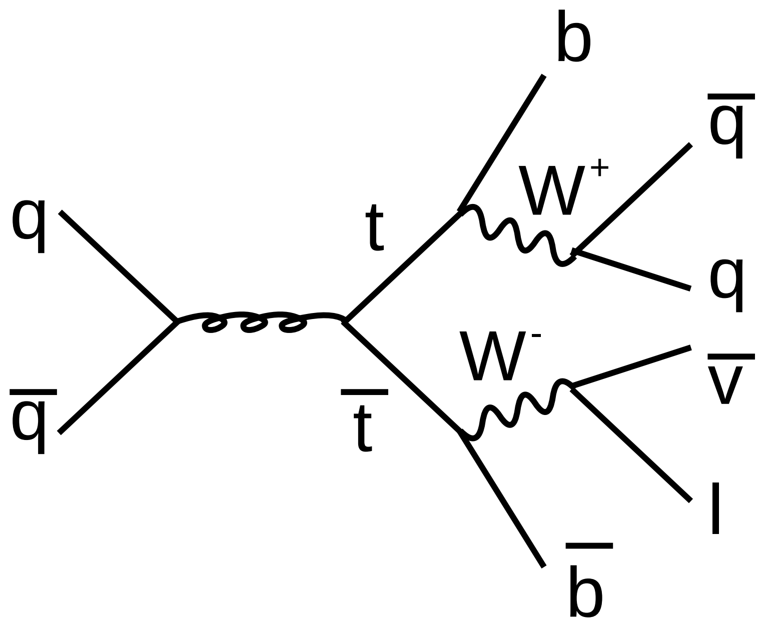
- Predominantly pair production.
- Theoretical total cross section : $\sigma_{t\bar{t}} \sim 6.7$ pb.
- $\sim$ 2 events in an hour at 10^{32} cm^{-2}s^{-1}.



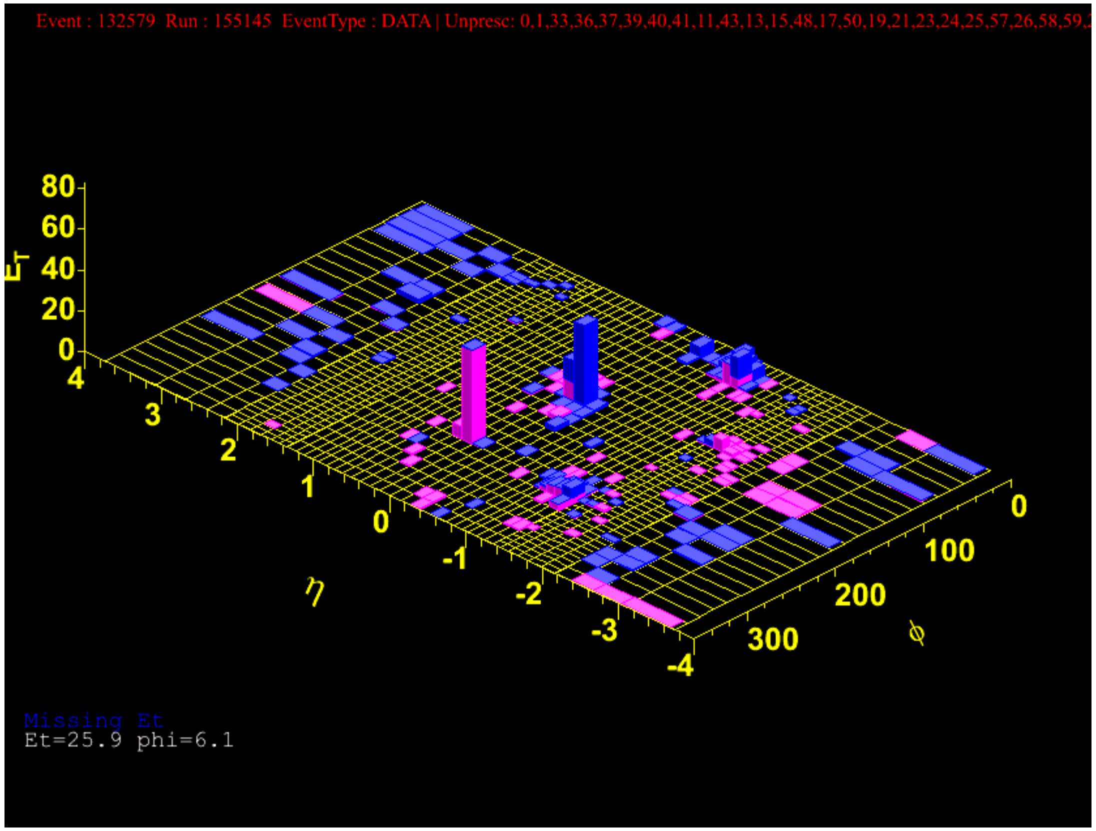
Decay

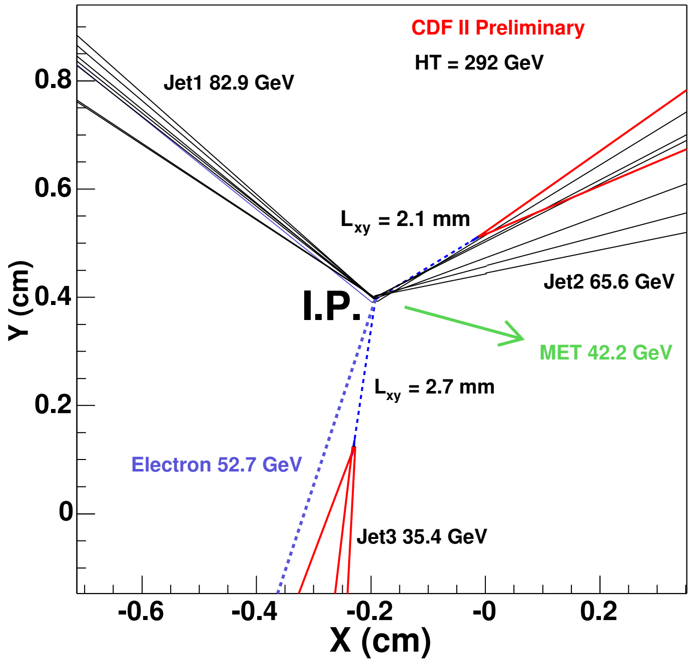
- Decays before it hadronizes.
  $\tau_{top} \sim 0.4 \times 10^{-24}$s $<$ $1/\Lambda_{QCD} \sim 10^{-24}$s
- $Br\,(t \rightarrow Wb) \approx 100\%$

Mode	Branching Ratio
Dilepton (e, μ)	5%
Lepton (e, μ) + jets	30%
All jets	44%
τ + X	21%



$t\bar{t} \to$ lepton + jets Candidate Event with 2 SECVTX Tagged Jets in CDF



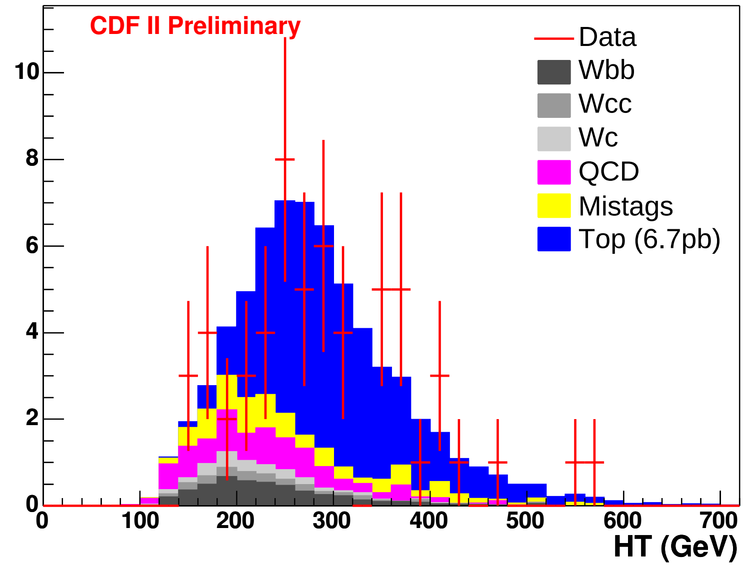


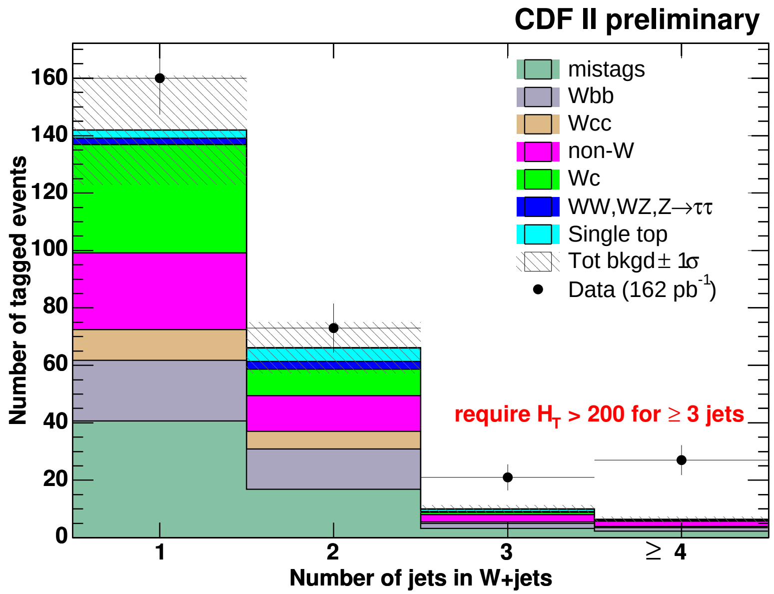
Top Cross Section Measurement in Lepton+Jets mode at CDF

Event Selection :

- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- $\not{E}_T > 20$ GeV.
- ≥ 3 jets with $E_T > 15$ GeV.
- ≥ 1 SECVTX tagged jet.

$$\sigma = \frac{N_{obs} - N_{bkgd}}{Acc \times \int \mathcal{L} dt}$$

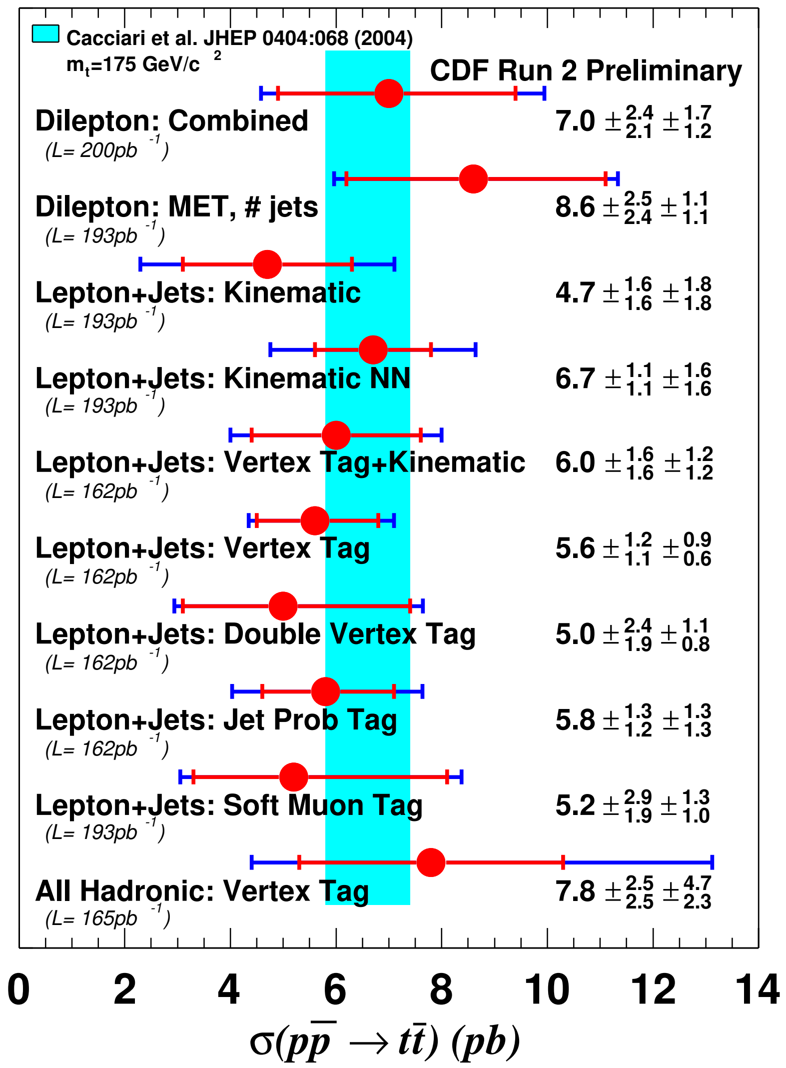


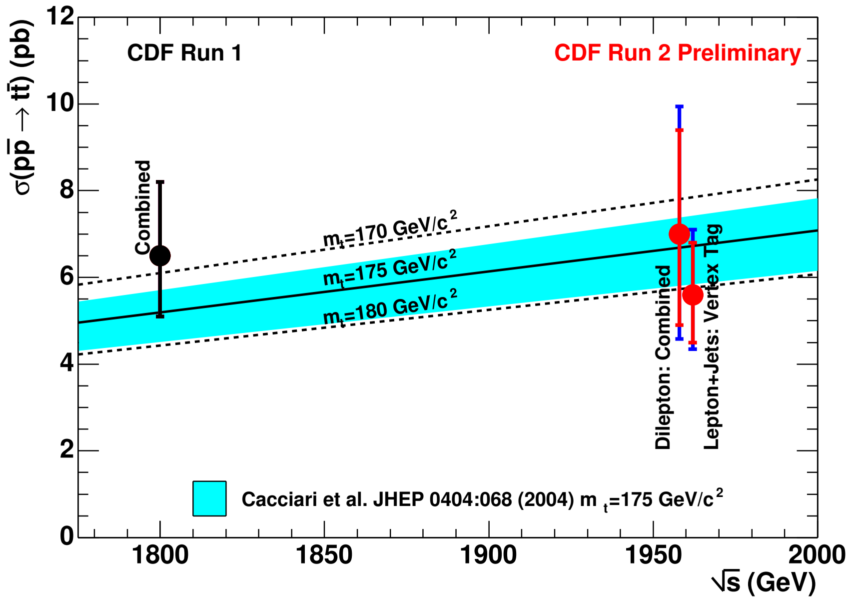


Result :

$\sigma_{t\bar{t}} = 5.6\ ^{+1.2}_{-1.1}\ (\mathrm{stat})\ ^{+0.9}_{-0.6}\ (\mathrm{syst})\ \mathrm{pb}$

Top Cross Section Measurements in CDF - summary





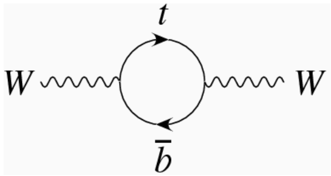
Many different methods have been applied.

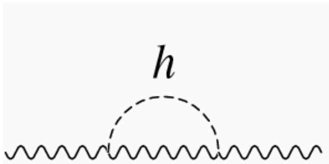
Measurements are consistent with each other.

Measurements are consistent with SM.

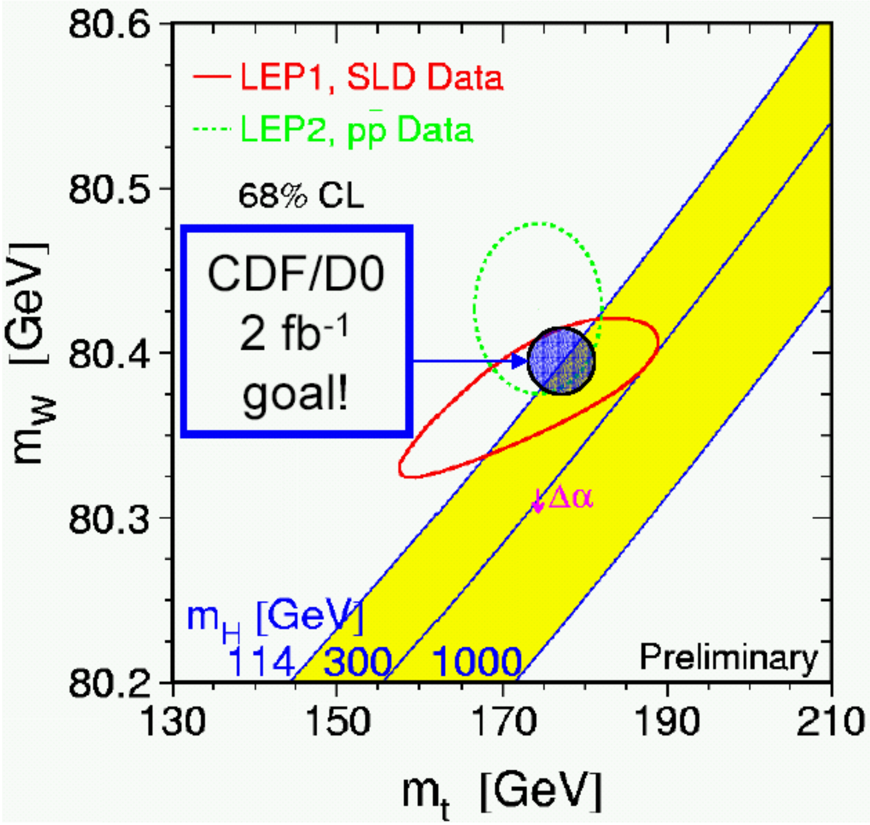
Top Mass Measurement - Motivation

Top mass is a fundamental parameter of SM.
Top and W mass measurements constrain Higgs mass.





$m_{top} \sim$ VEV of Higgd field - special role of top quark?



Mode	Br. (%)	
dilepton	5	Clean but few signal. Two ν in final state.
lepton+jets	30	One ν in final state.
all jets	44	Challenging background.

Top Mass in $l + jets$ - Template Method (CDF) 1

Event Selection :

- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- $\not{E}_T > 20$ GeV.
- ≥ 4 jets :
  - $E_T > 15$ GeV for 3 jets.
  - $E_T^{\text{4th jet}} > 8$ GeV.

2 jets from W, and 2 b-jets.

$\rightarrow$ 12 jet-parton permutations.

2 p_Z^ν solutions.

Wrong reconstruction

$\rightarrow$ combinatorial background.

# b-tagged jets	# solutions
0	24
1	12
2	4

χ^2 fit

$$\chi^2 = \Sigma_{l,jets}\frac{(\hat{P}_T - P_T^{meas.})^2}{{\sigma_{P_T}}^2} + \Sigma_{j=x,y}\frac{(\hat{UE_j} - UE_j^{meas.})^2}{{\sigma_{UE_j}}^2} + \frac{(M_{l\nu} - M_W)^2}{{\Gamma_W}^2} + \frac{(M_{q\bar{q}'} - M_W)^2}{{\Gamma_W}^2} + \frac{(M_{l\nu b} - M_t)^2}{{\Gamma_t}^2} + \frac{(M_{q\bar{q}'b} - M_t)^2}{{\Gamma_t}^2}.$$

- $p_T^{\vec{\nu}} = -\left(\Sigma_{l,jets} p_T^{\vec{}} + U\vec{E}\right)$
- $M_W = 80.41$ GeV, $\Gamma_W = 2.12$ GeV, $\Gamma_t = 2.5$ GeV

Minimization with M_t as a free parameter.

Choose solution with minimum χ^2.

$M_t \rightarrow$ reconstructed mass in each event.

Top Mass in $l + jets$ - Template Method (CDF) 2

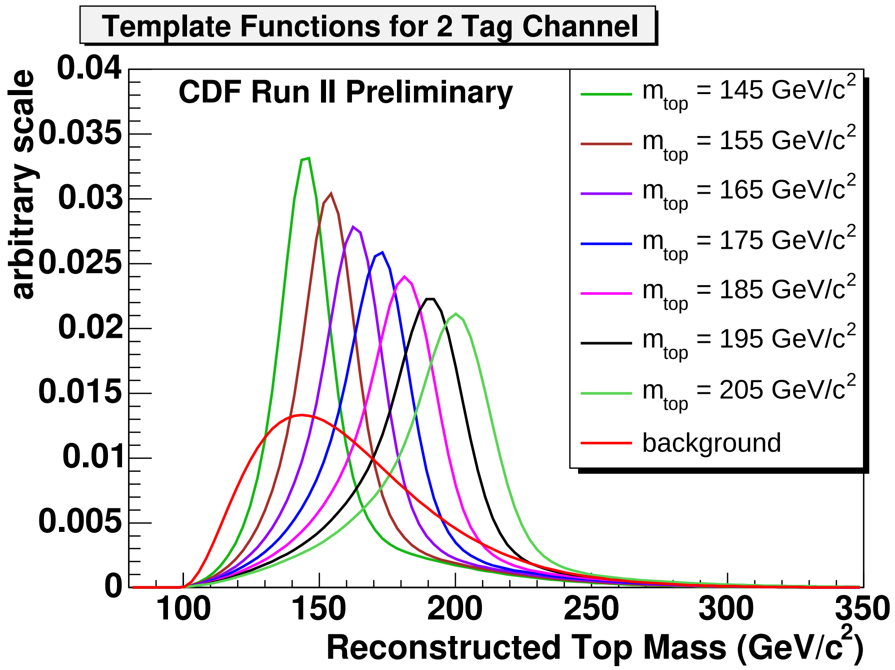
b-taggers :

- SECVTX - displacement of secondary vertex.
- Jet Probability - impact parameter of tracks.

Subdivide the sample into 0, 1, and 2 tag samples.

Parametrize the reconstructed mass distribution as a function of top mass using Monte Carlo events.

parametrized distributions for 2 tag sample



HERWIG $t\bar{t}$ signal samples with different m_{top} inputs.

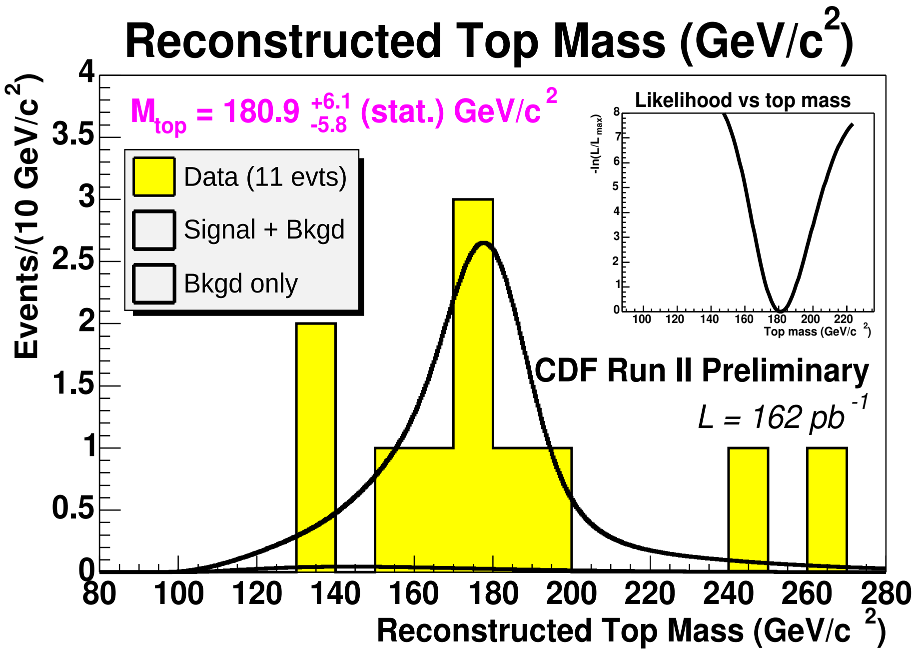
Background template is constructed adding different physics processes.

Top Mass in $l + jets$ - Template Method (CDF) 3

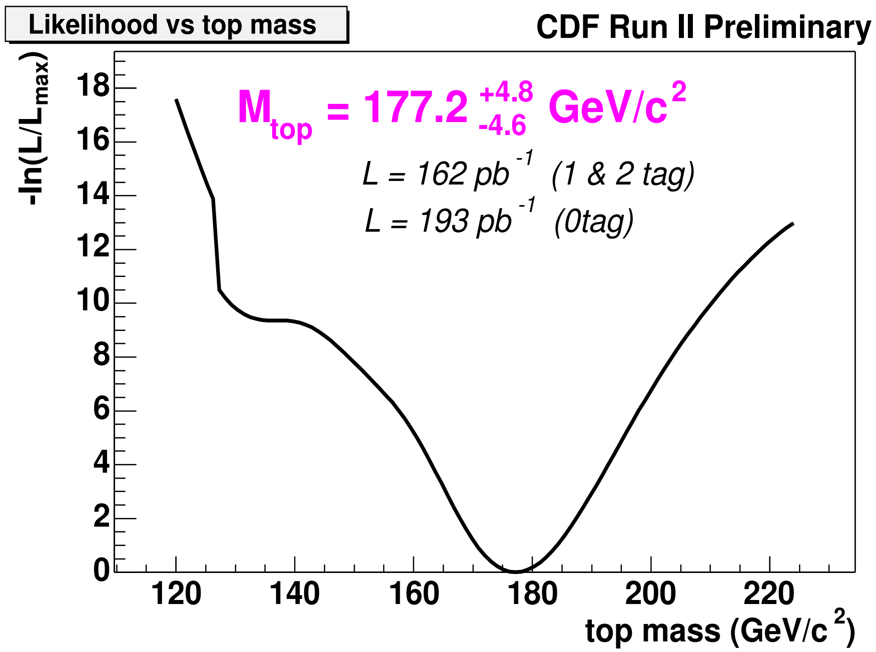
Likelihood fit with m_{top} and background frac as free parameter.

sample	$\mathcal{L}$ (pb^{-1})	# of Candidates
2 tag	162	11
1 tag	162	17
0 tag	193	40

2 tag sample



0, 1 and 2 tag samples combined



Results :

2 tag sample	$180.9\ ^{+6.4}_{-5.8}$ (stat) $\pm$ 5.8 (syst) GeV/c^2
combined	$177.2\ ^{+4.9}_{-4.7}$ (stat) $\pm$ 6.6 (syst) GeV/c^2

Top Mass in $l + jets$ - DLM (CDF) 1

Event Selection :

- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- $\not{E}_T > 20$ GeV.
- Exactly 4 jets with $E_T > 15$ GeV.
- ≥ 1 of the 4 jets SECVTX tagged.

"Dynamical Likelihood Method"

Calculate likelihood as a function of m_{top} according to Matrix Element for each event.

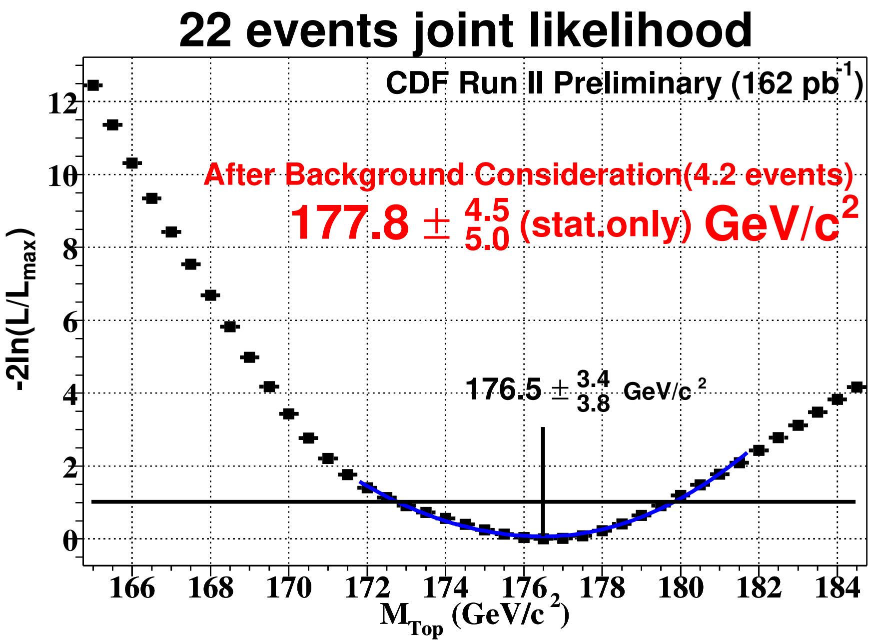
$$L^i(m_{top}) = \sum_{comb.} \int \frac{(2\pi^4)}{flux} PDF(z_a, z_b) f(p_T) |\mathcal{M}(z_a, z_b, \mathbf{x}; m_{top})|^2 w(\mathbf{x}, \mathbf{y}; m_{top})\, d\mathbf{x}$$

$\mathbf{y}$	Observables
$\mathbf{x}$	Partons
$PDF(z_a, z_b)$	Parton Distribution Function
$f(p_T)$	Probability for p_T of $t\bar{t}$ system
$\mathcal{M}(z_a, z_b, \mathbf{x}; m_{top})$	Matrix element
$w(\mathbf{x}, \mathbf{y}; m_{top})$	Transfer function

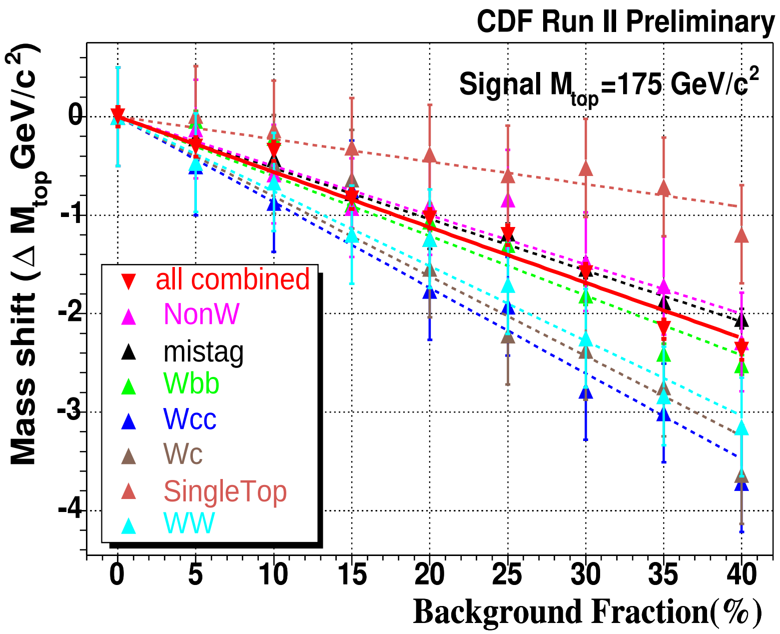
Top Mass in $l + jets$ - DLM (CDF) 2

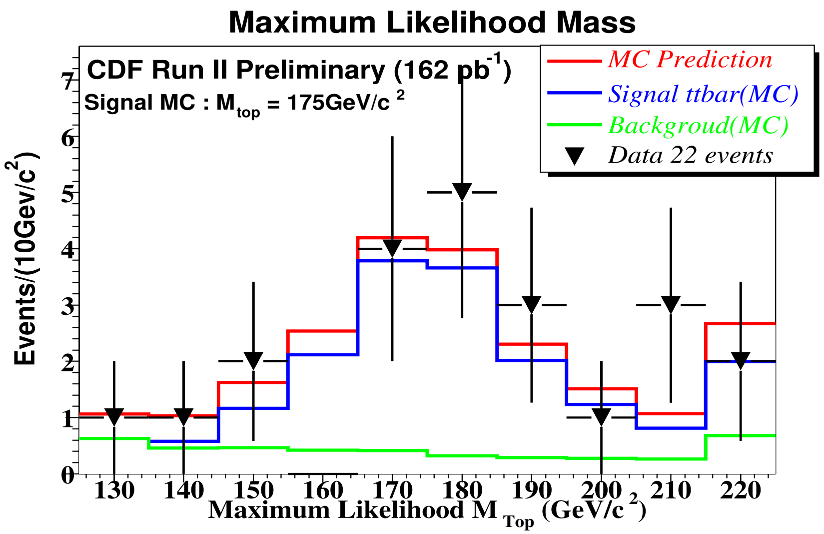
22 Candidates with 19% background. $\mathcal{L} = 162\ \mathrm{pb}^{-1}$.

multiplied likelihood



mapping functions



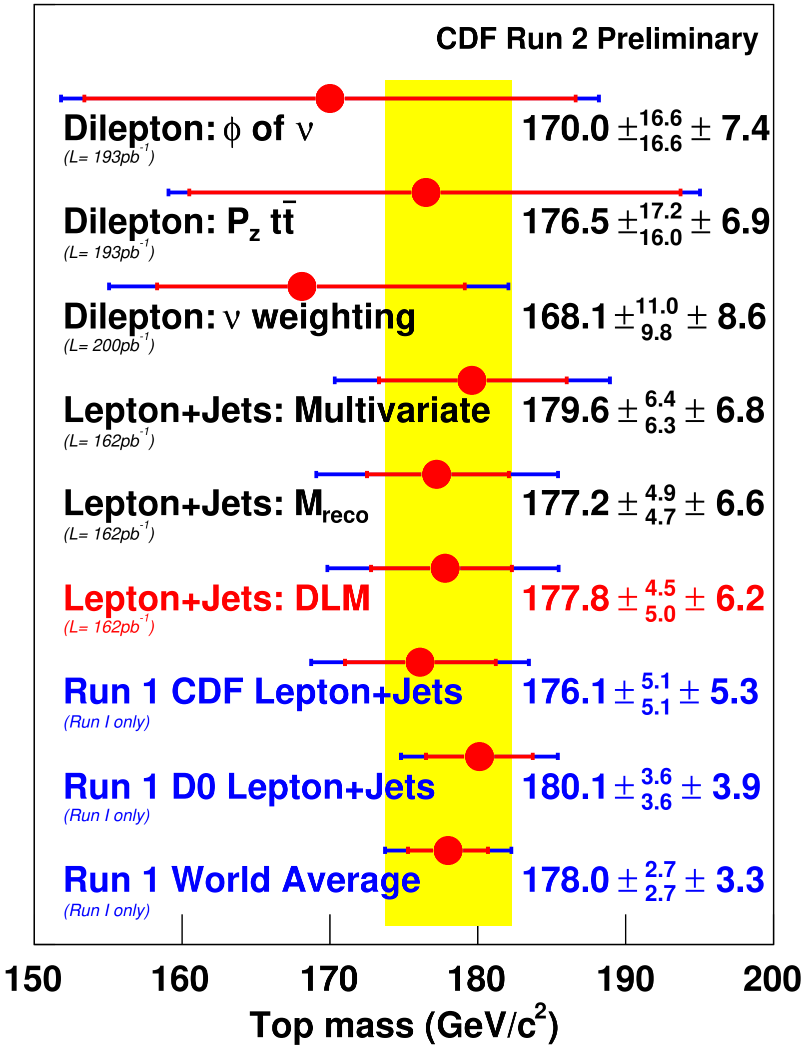


Result :

$177.8\ ^{+4.5}_{-5.0}\ (\mathrm{stat})\ \pm 6.2\ (\mathrm{syst})\ \mathrm{GeV/c^2}$

Top Mass Measurements - Summary

CDF Run II results



D0 Run II results

Lepton+Jets $(160\ pb^{-1})$:

$$170.0\ \pm 6.5\ (\mathrm{stat})\ ^{+10.5}_{-6.1}\ (\mathrm{syst})$$

Dilepton $(260\ pb^{-1})$:

$$155\ ^{+14}_{-13}\ (\mathrm{stat})\ \pm 7\ (\mathrm{syst})$$

Top Mass Measurements (CDF) - Prospects

We are updating the measurements with $320\ \mathrm{pb}^{-1}$ of data in CDF double stat..

Current systematic uncertainty dominated by Jet Energy Scale (JES).

$l + jets$ template

CDF Run II Preliminary

source	combined (GeV/c^2)	2 tag (GeV/c^2)
ISR	0.61	0.69
FSR	1.00	1.20
PDF	0.19	0.15
b-tagging	0.20	0.27
bkgd shape	0.68	0.17
jet resolution	0.71	0.54
jet energy scale	6.37	5.56
generator	0.11	0.03
total	6.56	5.77

$l + jets$ DLM

Source	$\Delta\ M_{top}\ \mathrm{GeV}/c^2$
Jet Energy Corrections	5.3
ISR	0.5
FSR	0.5
PDFs	2.0
Generator	0.6
Spin correlation	0.4
NLO effect	0.4
Transfer Function	2.0
Background fraction($\pm 5\%$)	0.5
Background modeling	0.5
Monte Carlo modeling	0.6
Total	6.2

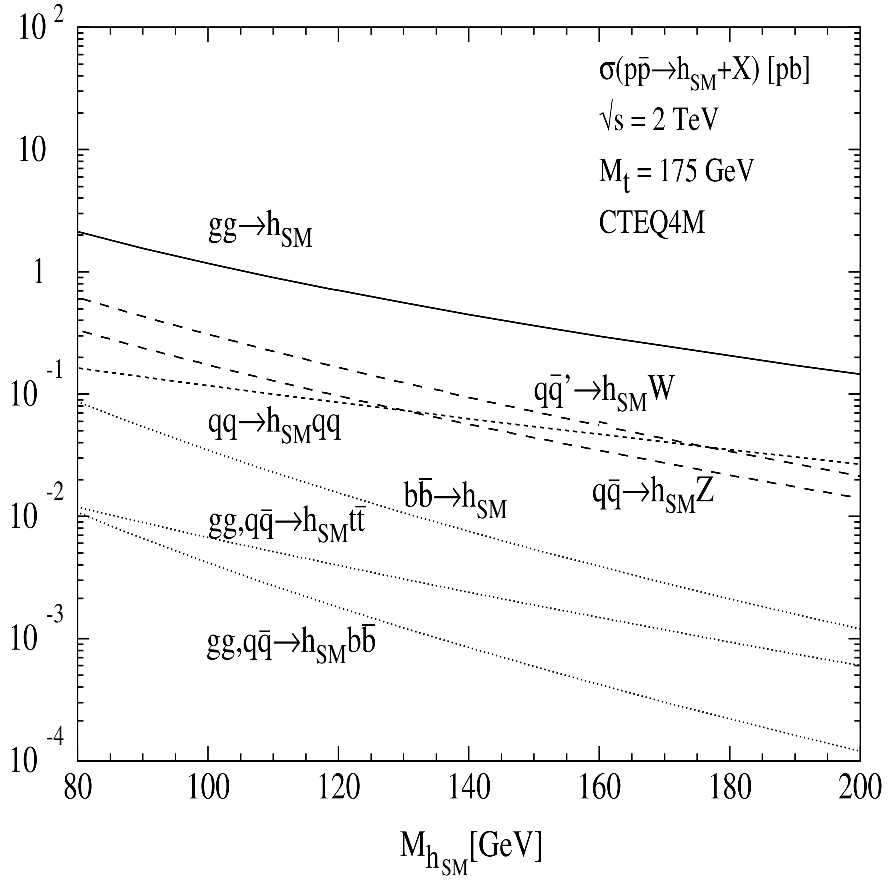
Lots of work done to reduce JES in CDF.

Expect JES to scale down to $\sim 3\ \mathrm{GeV}/c^2$ level this Spring.

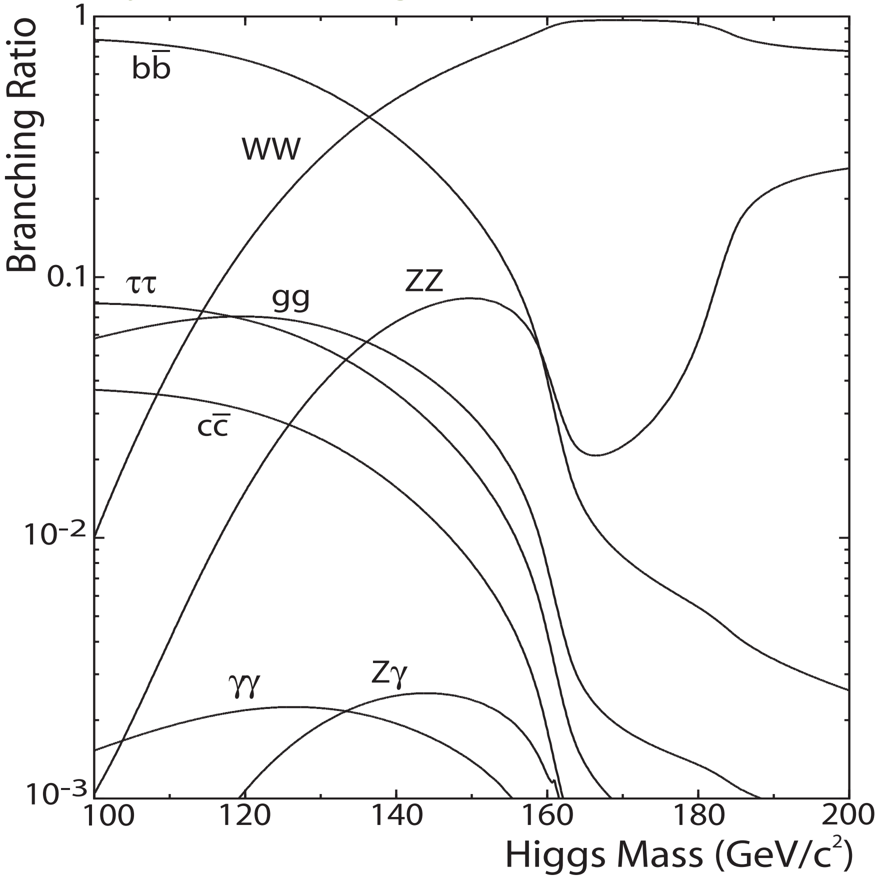
SM Higgs Production and Decay at Tevatron

Tevatron has a sensitivity to Higgs with mass $\leq 180\ \mathrm{GeV}/c^2$.

Decay branching ratios



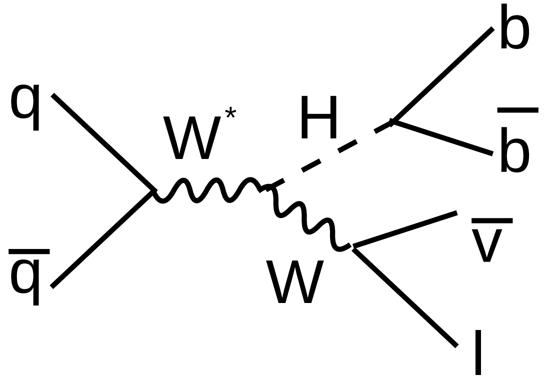
Decay branching ratios



$WH \to l\nu bb$ Search (CDF)

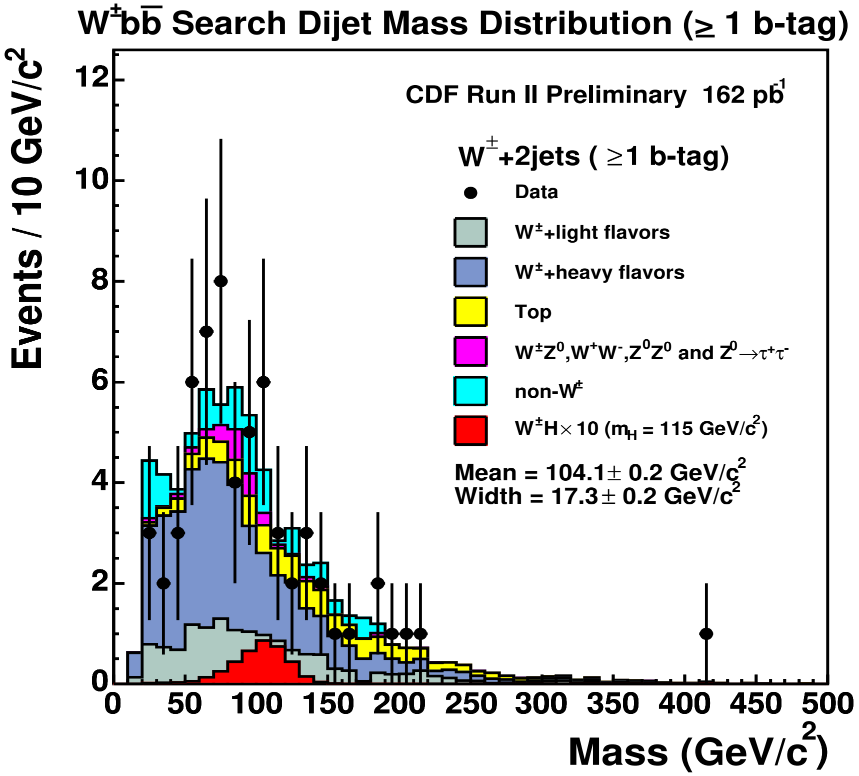
Event Selection :

- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- $\not{E}_T > 20$ GeV.
- 2 jets with $E_T > 15$ GeV, $\eta < 2$.
- ≥ 1 of the 2 jets SECVTX tagged.

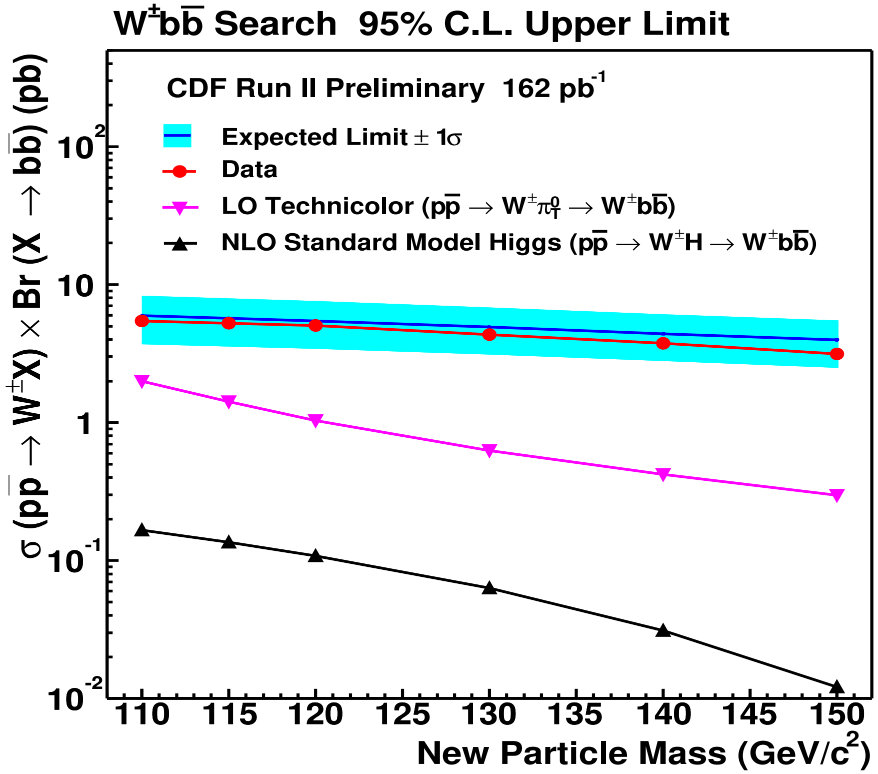


162 pb^{-1}.

di-jet mass



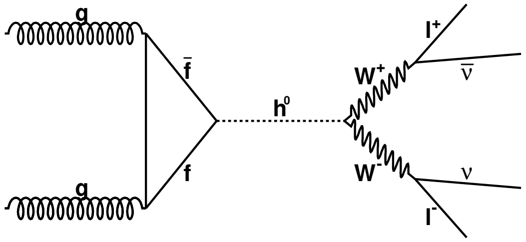
limit on $\sigma \times br$.



$H \to WW \to l\nu l\nu$ Search (CDF)

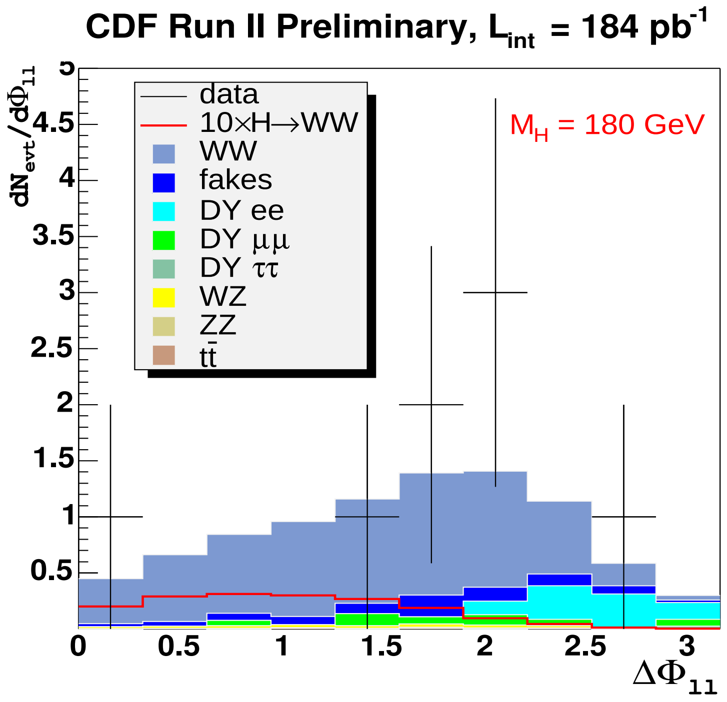
Event Selection :

- 2 leptons ($p_T > 20$ GeV, $|\eta_e| < 2$ or $|\eta_\mu| < 1$).
- $\not{E}_T > 25$ GeV.
- No jets with $E_T > 15$ GeV, $|\eta| < 2.5$.
- Opposite signed leptons.
- $m_{ll} < m_H/2$

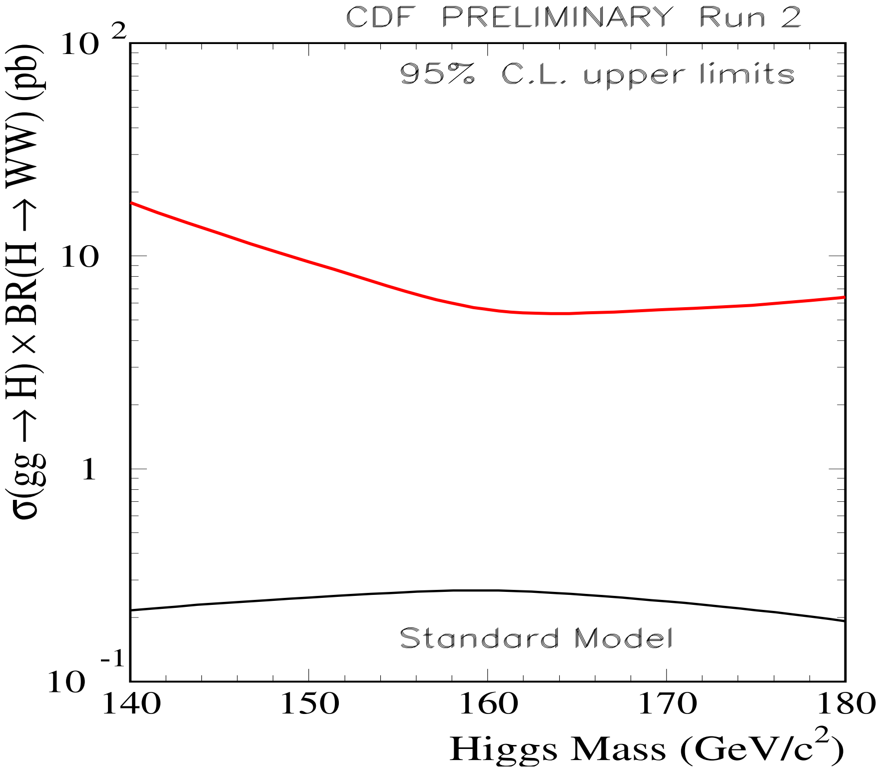


184 pb^{-1}.

$\Delta\phi_{ll}$.



limit on $\sigma \times br$.

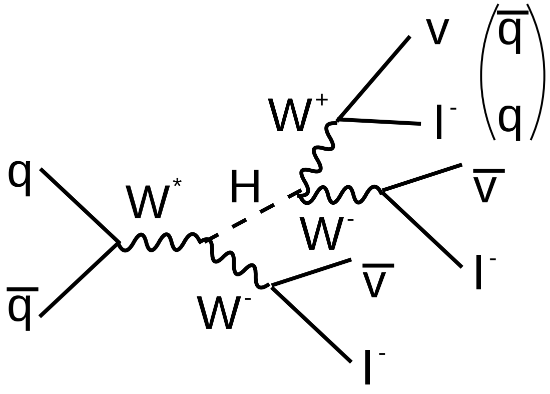


$WH \to WWW \to l\nu l\nu + X$ Search (CDF)

Event Selection :

- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- 2nd lepton ($p_T > 18$ GeV).
- Same signed 2 leptons.
- $|\vec{p}_T^{\,l1} + \vec{p}_T^{\,l2}| > 35$ GeV$/c^2$.

193 pb^{-1}.



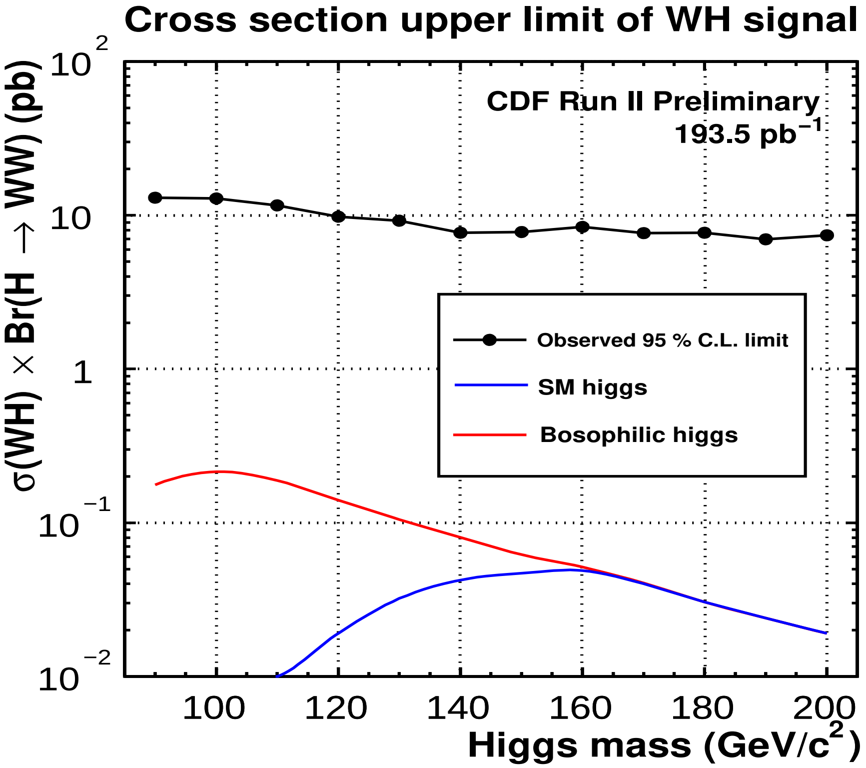
sensitive to bosophilic Higgs.

background vs observed # events.

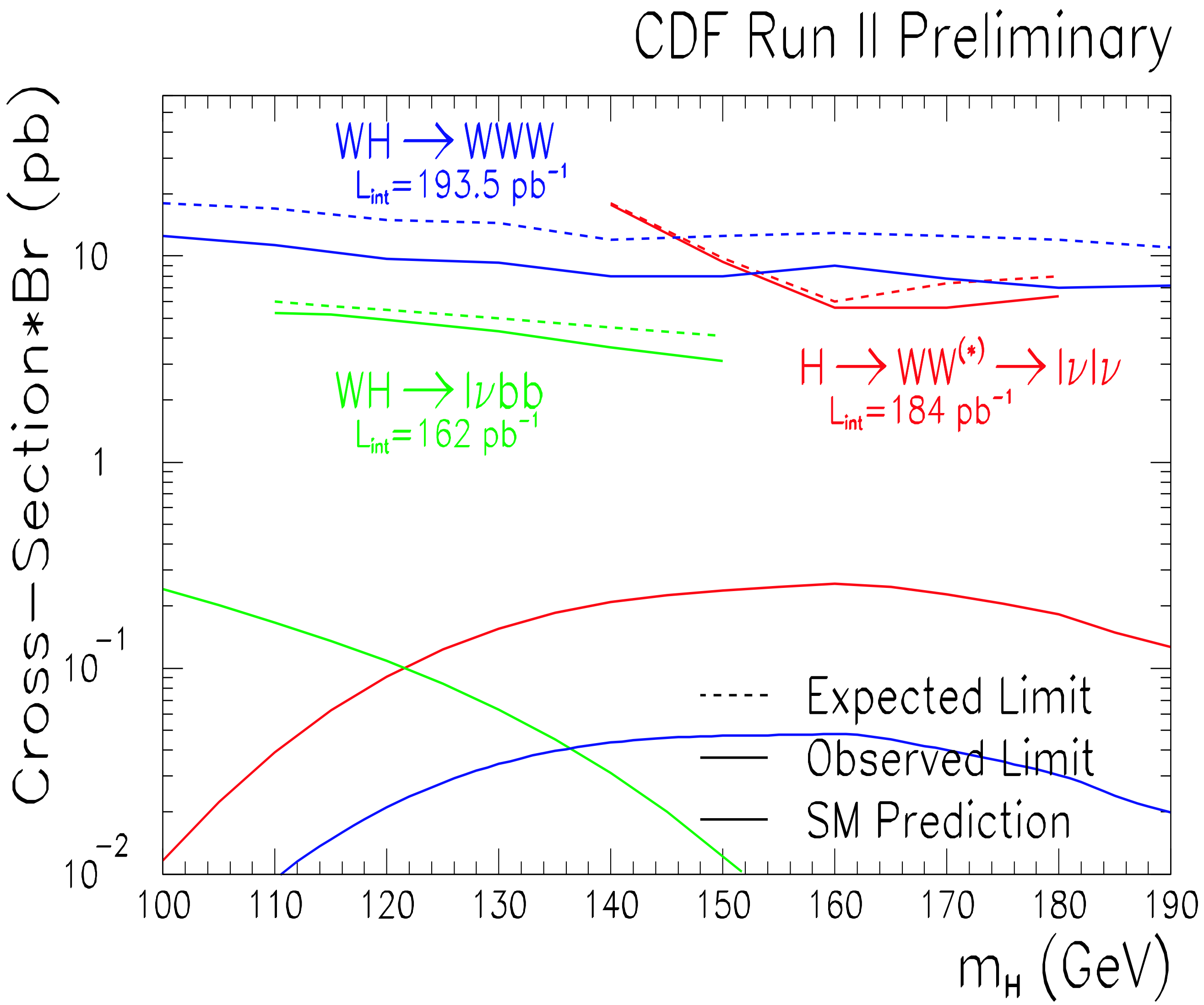
CDF Run II Preliminary (193.5 pb^{-1})

Process	Expected events ($\pm$ stat)
Bosophilic $WH(110)$	0.056 ± 0.004
SM $WH(160)$	0.034 ± 0.002
WZ	0.14 ± 0.09
ZZ	0.013 ± 0.010
$t\bar{t}$	0.0097 ± 0.0075
$WQ\bar{Q}$	0.0033 ± 0.0032
WW	0.0034 ± 0.0033
Z/γ^*	0.051 ± 0.037
Fake Lep.	0.12 ± 0.01
Residual photon conversion	0.61 ± 0.61
Total	$0.95 \pm 0.61(\text{stat}) \pm 0.18(\text{syst})$
Observed event	0

limit on $\sigma \times br$.



Higgs Search - summary



Summary

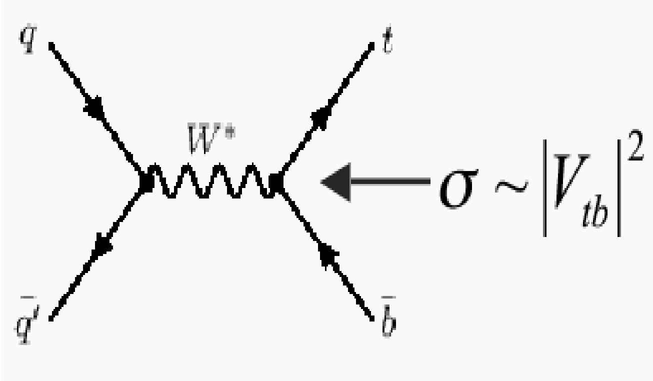
- Tevatron, CDF and D0 are operating well.
- $m_{top} = 177.8\ ^{+4.5}_{-5.0}\ (\mathrm{stat})\ \pm 6.2\ (\mathrm{syst})\ \mathrm{GeV/c^2}$ (DLM in $l + jets$).
- Updated results are coming up with double amount of data ($\sim 320\ \mathrm{pb}^{-1}$).
  - First measurement of m_W with $\delta m_W \sim 76\ \mathrm{MeV}/c^2$ in Run II.
  - $\delta m_{top} \sim 5\ \mathrm{GeV}/c^2$ by template/DLM. $\rightarrow$ to be combined with other methods.
- Limits on SM Higgs Cross Section $\sim$ few dozen $\times$ SM prediction.
  - Consistent with our expectation.
  - Work in progress on new channels ($ZH \rightarrow l\nu bb$, $ZH \rightarrow \nu\nu bb$).

backup

Single Top Search (CDF) 1

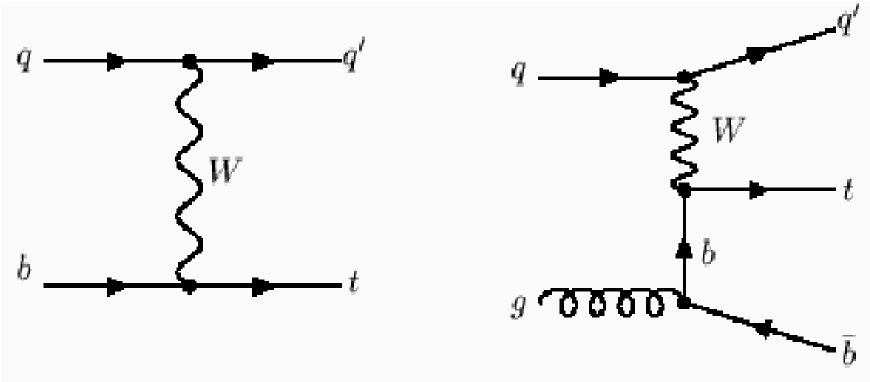
s-channel

$\sigma_{NLO} = 0.88 \pm 0.07$ pb



t-channel

$\sigma_{NLO} = 1.98 \pm 0.21$ pb



- Direct measurement of $|V_{tb}|^2$.
- Sensitive to new physics
  - W', anomalous coupling, FCNC.
- Challenging :
  - small cross section.
  - $t\bar{t}$ signature similar.
  - large additional backgrounds.

Event Selection :

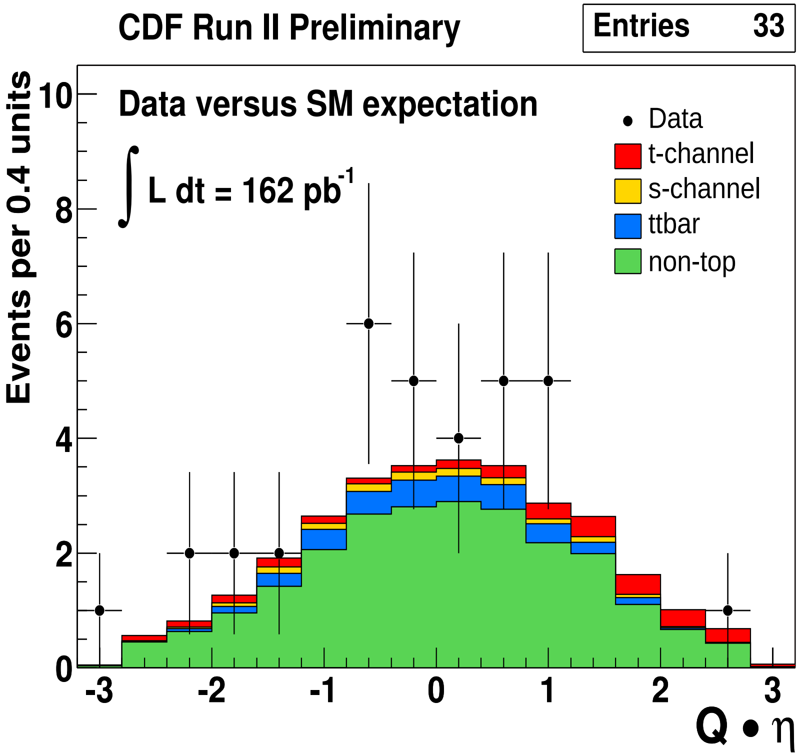
- 1 lepton ($p_T > 20$ GeV, $|\eta| < 1$).
- $\not{E}_T > 20$ GeV.
- 2 jets with $E_T > 15$ GeV.
- ≥ 1 of the 2 jets SECVTX tagged.

Single Top Search (CDF) 2

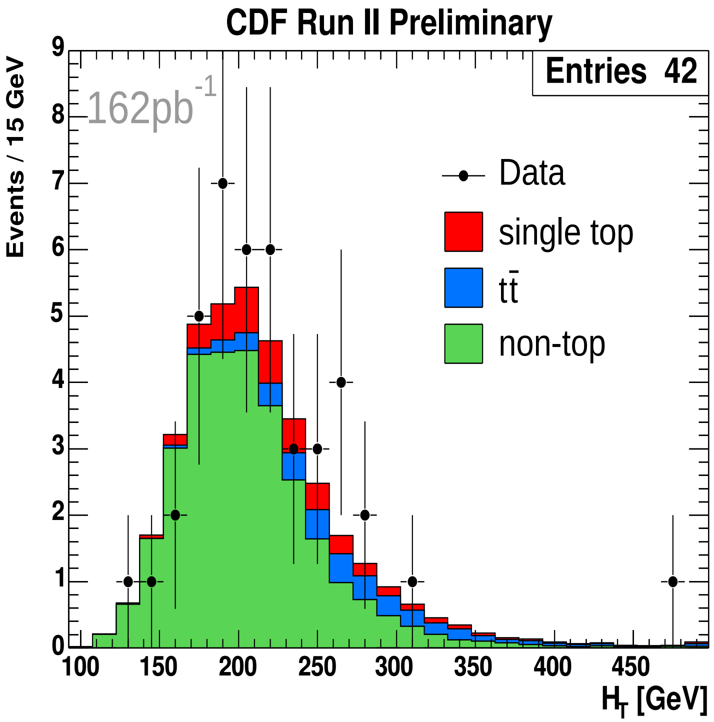
separate search

combined search

Data Distribution vs Expectation



Data Distribution vs Expectation



Results :

$\sigma_{t-chan.} < 13.6$ pb (95% C.L.)

$\sigma_{s-chan.} < 10.1$ pb (95% C.L.)

Results :

$\sigma_{t-chan.} + \sigma_{s-chan.} < 17.8$ pb (95% C.L.)

Web Pages

CDF public resuls web page :
http://www-cdf.fnal.gov/physics/physics.html

D0 public resuls web page :
http://www-d0.fnal.gov/Run2Physics/