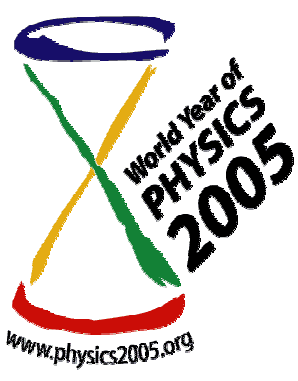


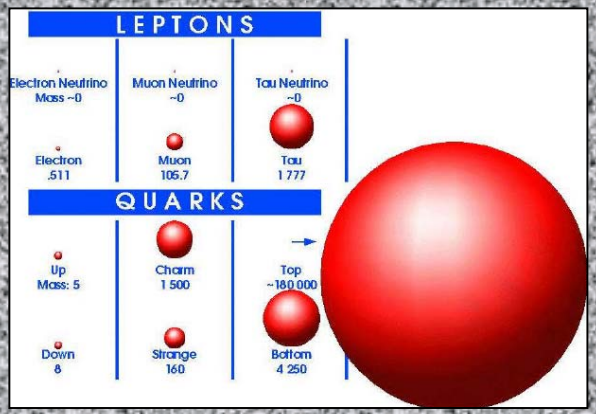
Top quark physics review (results from the Tevatron)

M.Weber, FNAL

Outline

- The top quark
- The detectors and collected data
- Top quark production cross sections
- Is there more than the top quark?
- Top quark properties

The top quark



$y_t = \cong 1$

The top quark decays before it can hadronize

Top Mass

Top Width

Top Spin

Top Charge

Resonance production

Production kinematics

Top Spin Polarization

Rare/non SM Decays

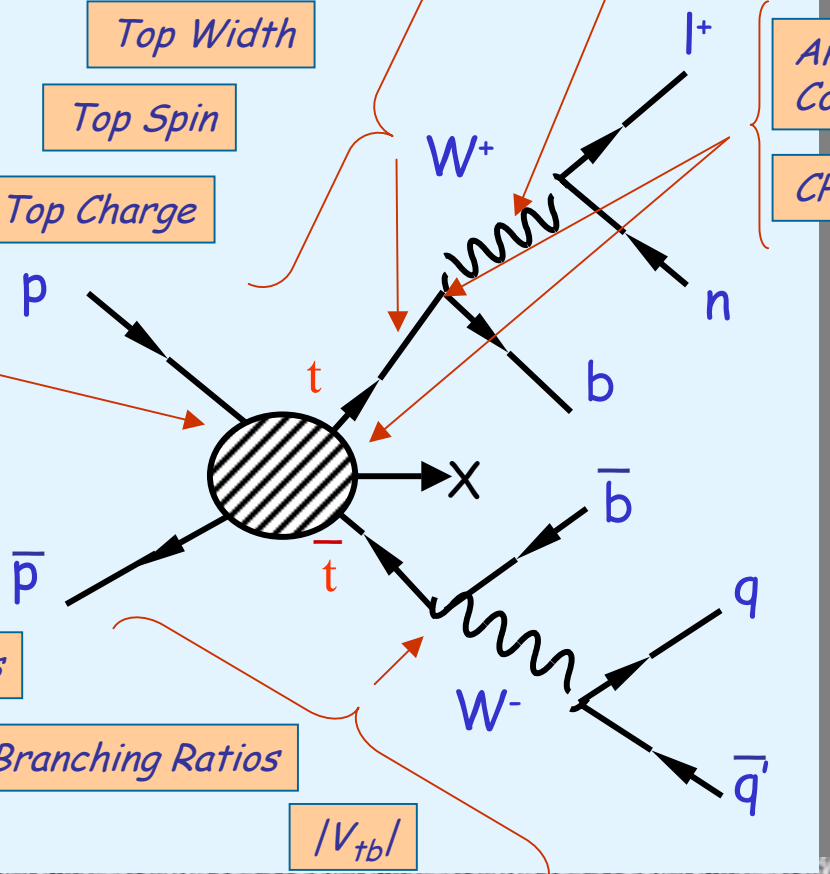
Branching Ratios

$|V_{tb}|$

W helicity

Anomalous Couplings

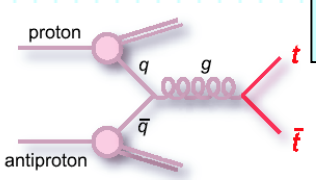
CP violation



New Physics

Top Quark Production

Top quark pair production via strong interaction

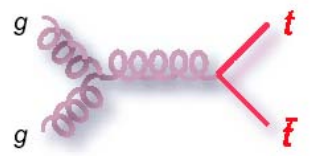


85%

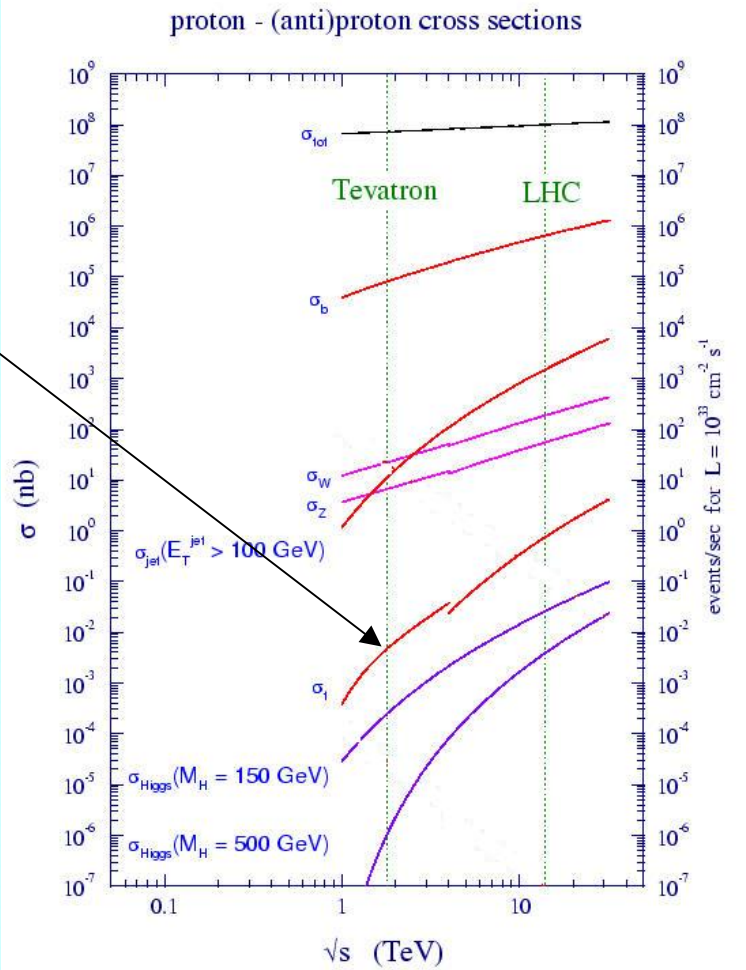
Cacciari etal, JHEP 0404:068,2004

6.7 pb (1.96TeV, m_t=175GeV/c^2)

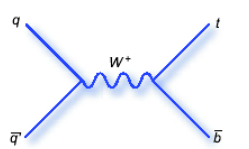
RunII 30% higher than RunI



15%

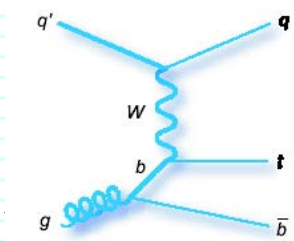


Single top quark production via weak interaction



s-channel: 0.88pb

Sullivan, Phys.Rev.D70:114012,2004

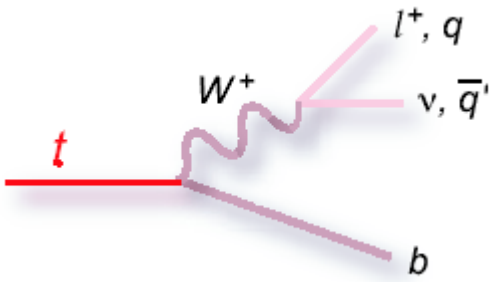


t-channel: 1.98pb

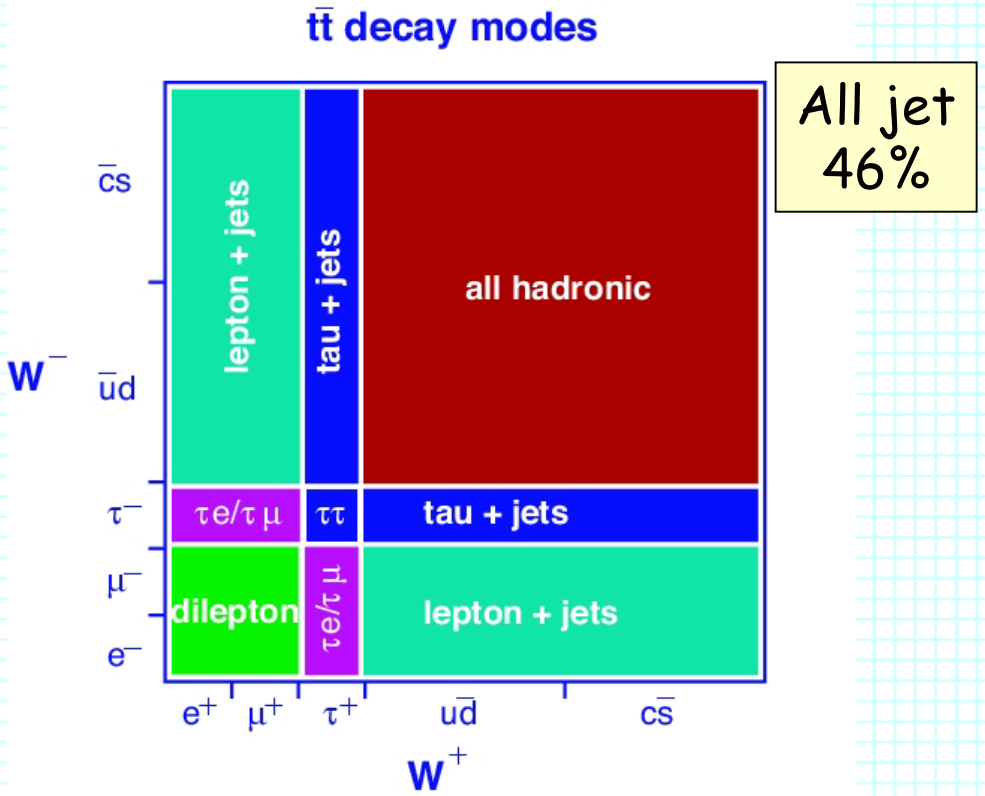
Top quark identification

decay product have:

- good angular separation in the lab frame
- high transverse momentum



$t \rightarrow Wb \cong 100\%$



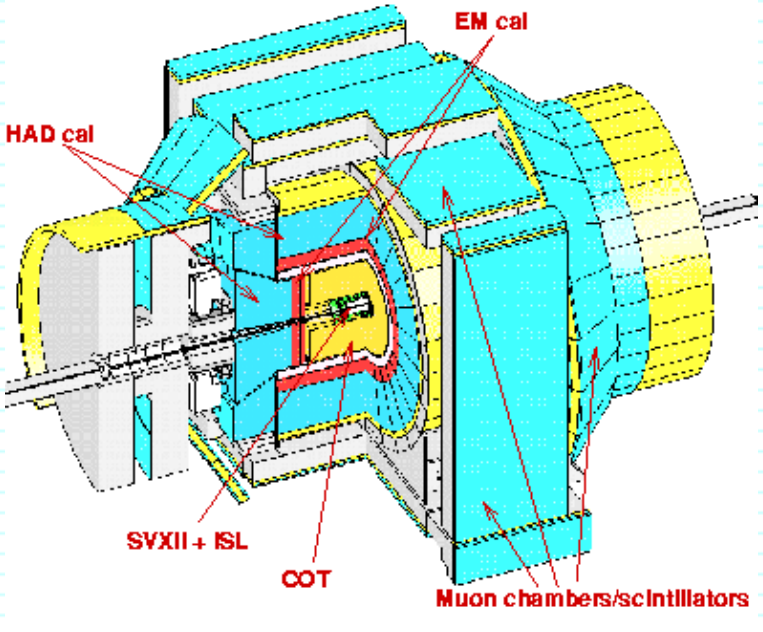
All jet 46%

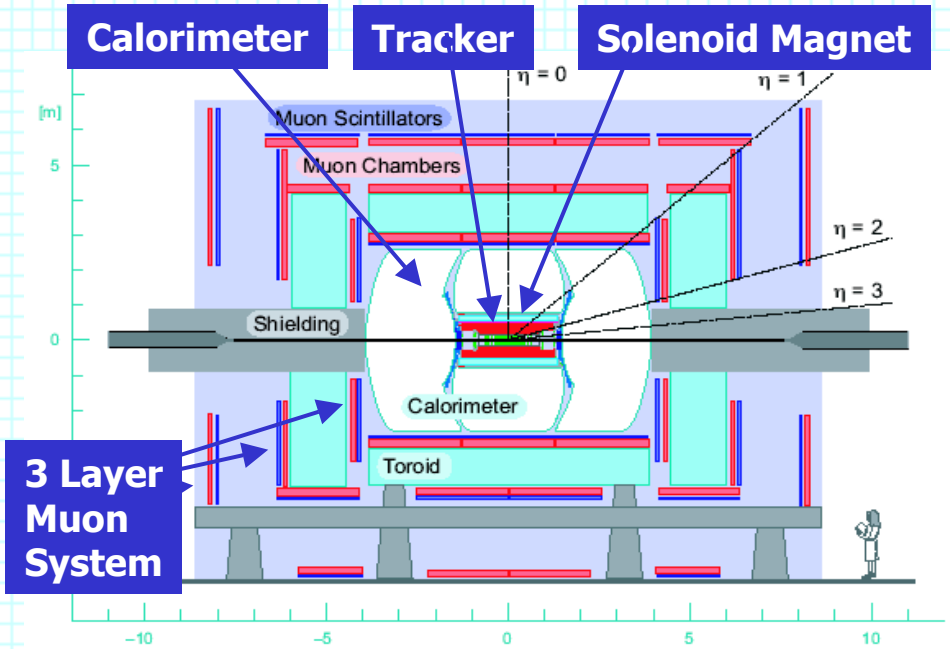
dilepton (e+μ) 4.5%

Lepton + jet 29%

Need to reconstruct and identify Electrons, muons, jets, b-jets and missing transverse energy

CDF and DO in Run II

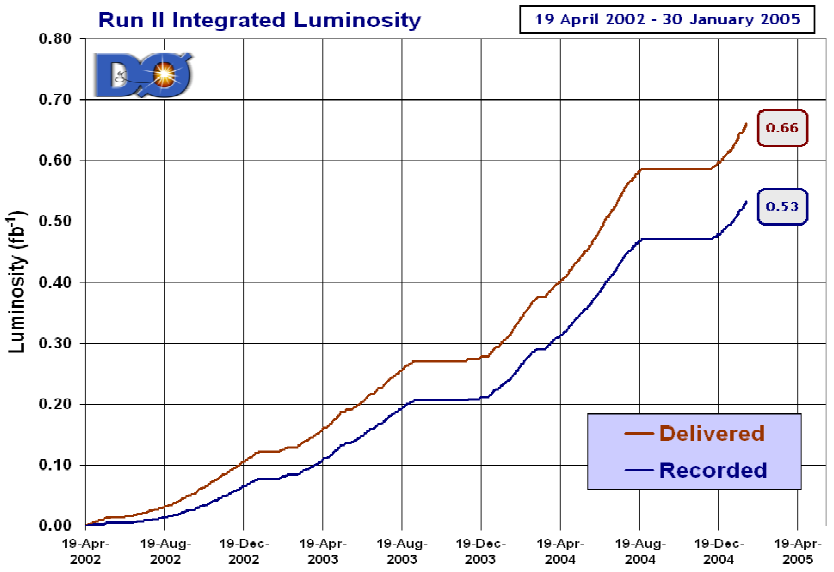




New Silicon Detector
New Central Drift Chamber
New End Plug Calorimetry
Extended muon coverage
New trigger and electronics

Silicon Detector and central fiber tracker in a 2 T solenoid
Substantially upgraded muon system
New trigger and electronics

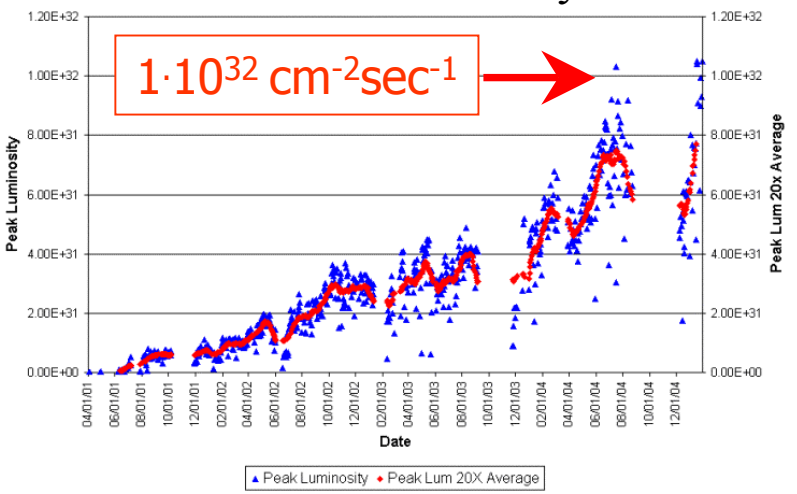
Luminosity

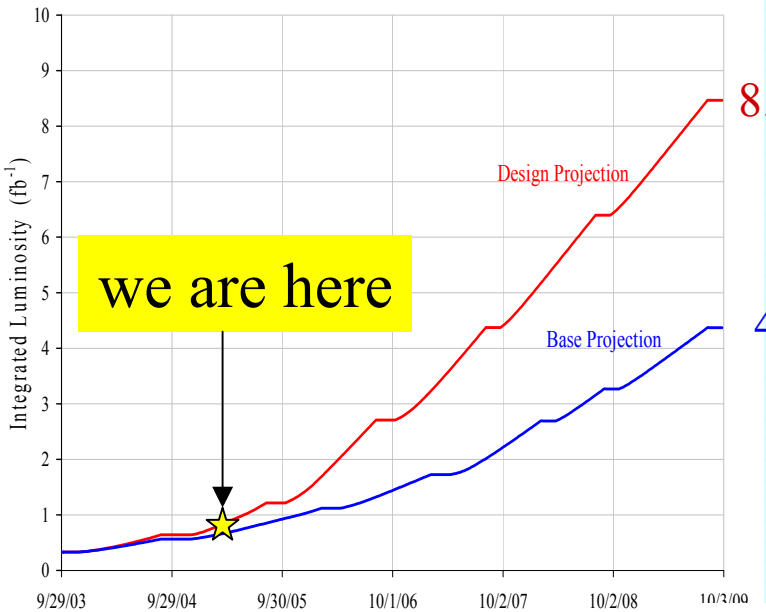


D0: recorded 0.53 fb^{-1}

CDF recorded 0.61 fb^{-1}

instantaneous luminosity





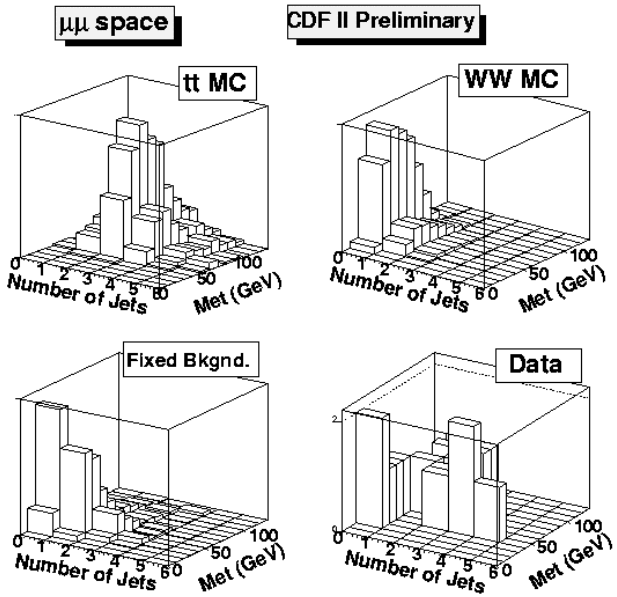
2009

Production Cross section

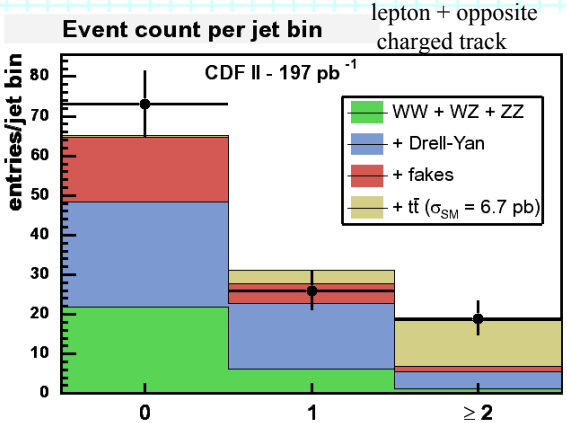
- many results:
  different decay channels,
  different methods,
  with/without b-tagging
- Is there more than the top quark ?
- single top (weak top production)

Di-lepton

Both W decay into lepton and neutrino:
2 jets (b), 2leptons, high missing Et
low BG but low yield



$$\sigma(t\bar{t}) = 8.6^{+2.5}_{-2.4}(stat) \pm 1.1(syst)\ \text{pb}$$

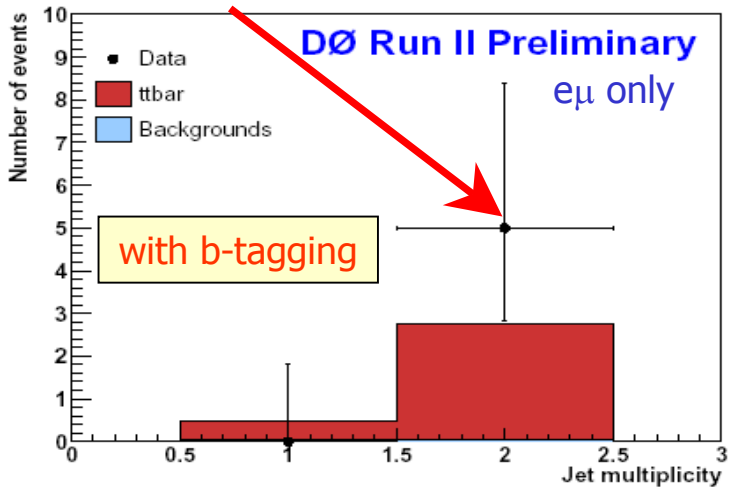


combined di-lepton and lepton + opposite charge track:

$$\sigma(t\bar{t}) = 7.0^{+2.7}_{-2.3}(stat)^{+1.5}_{-1.4}(syst)\ \text{pb}$$

PRL 93, 142001 (2004)

Ultra-pure sample of top quark events: S/N>50

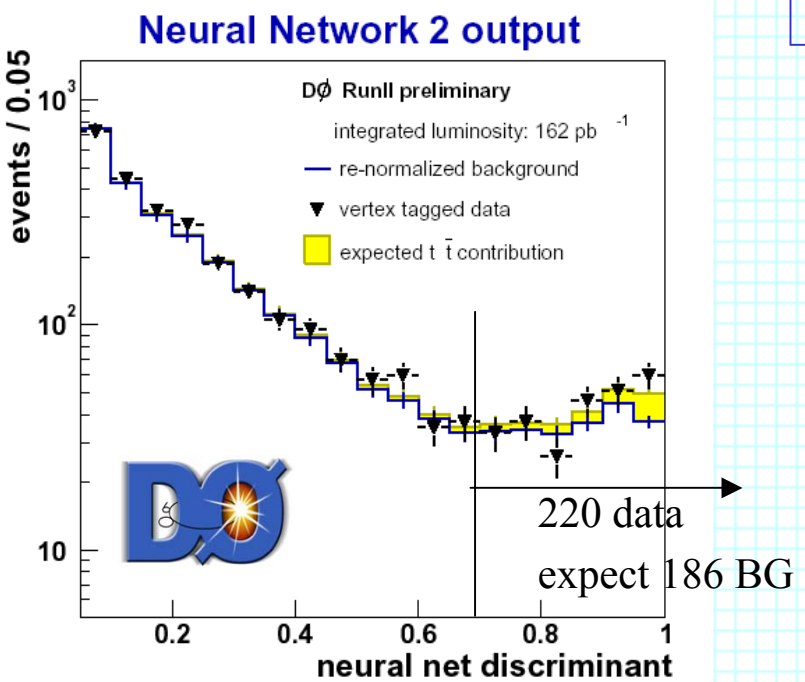


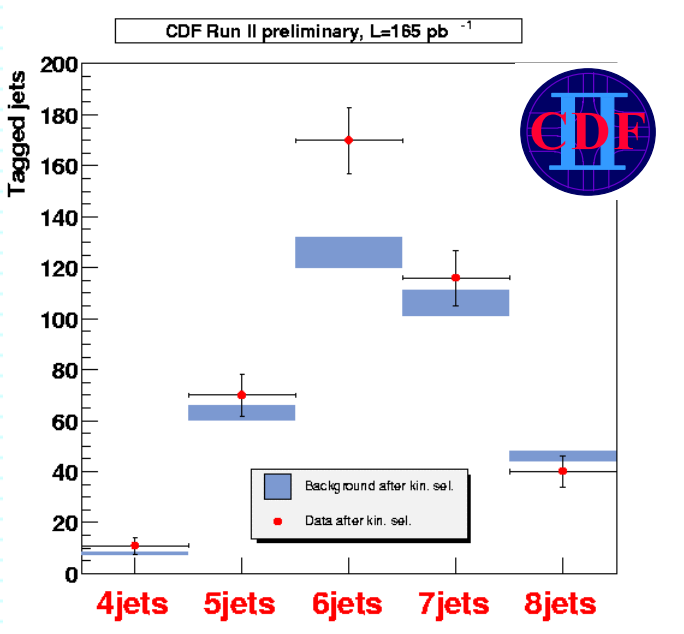
$$\sigma(t\bar{t}) = 11.1^{+5.8}_{-4.3}(stat)^{+1.4}_{-1.4}(syst)\ \text{pb}$$

All jets cross section

requires b-tagging

Both W decay in q-qbar
4jets + 2 bjets, high transverse energy
High yield, high BG

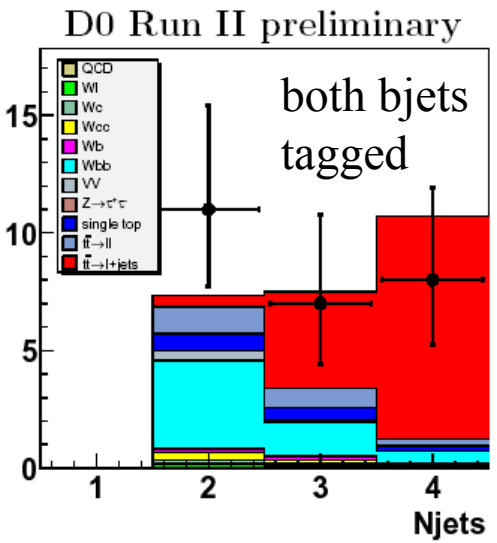




$$\sigma(t\bar{t}) = 7.7^{+3.4}_{-3.3}(stat)^{+4.7}_{-3.8}(syst) \pm 0.5(lumi)\ \text{pb}$$

$$\sigma(t\bar{t}) = 7.8 \pm 2.5(stat)^{+4.7}_{-2.3}(syst)\ \text{pb}$$

Lepton+jets

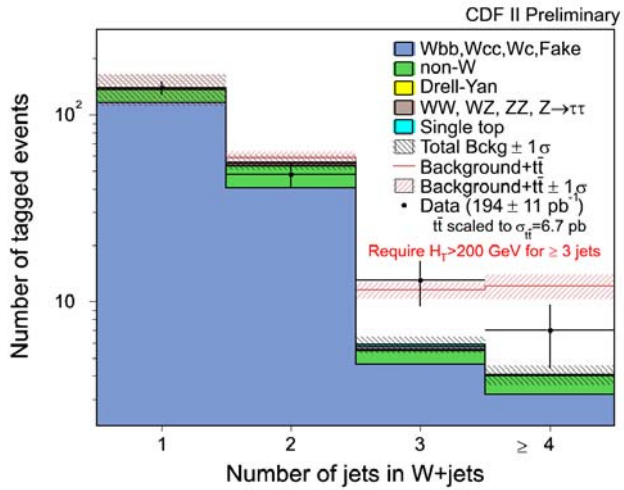


$$\sigma(t\bar{t}) = 7.2^{+1.3}_{-1.2}(stat)^{+1.9}_{-1.4}(syst)\ \text{pb}$$

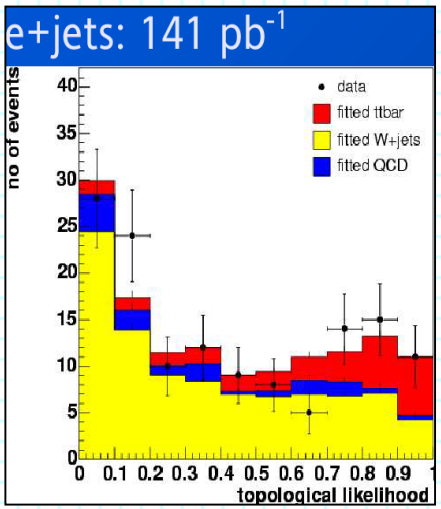
One W decay in q-qbar,
one in lepton + neutrino
2jets + 2 bjets + lepton +missing Et
medium yield, medium BG

l+jets with soft lepton tagging

new



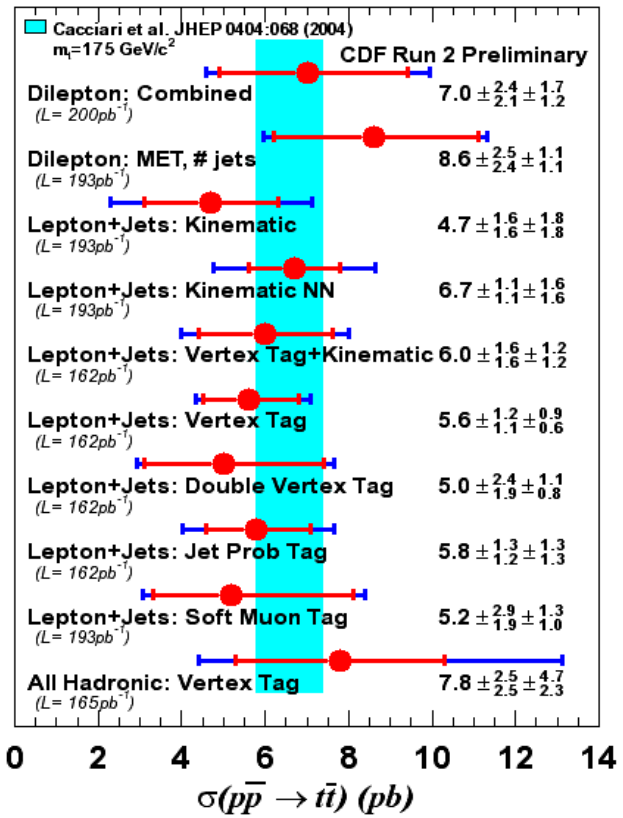
$$\sigma(t\bar{t}) = 5.2^{+2.9}_{-1.9}(stat)^{+1.3}_{-1.0}(syst)\ \text{pb}$$

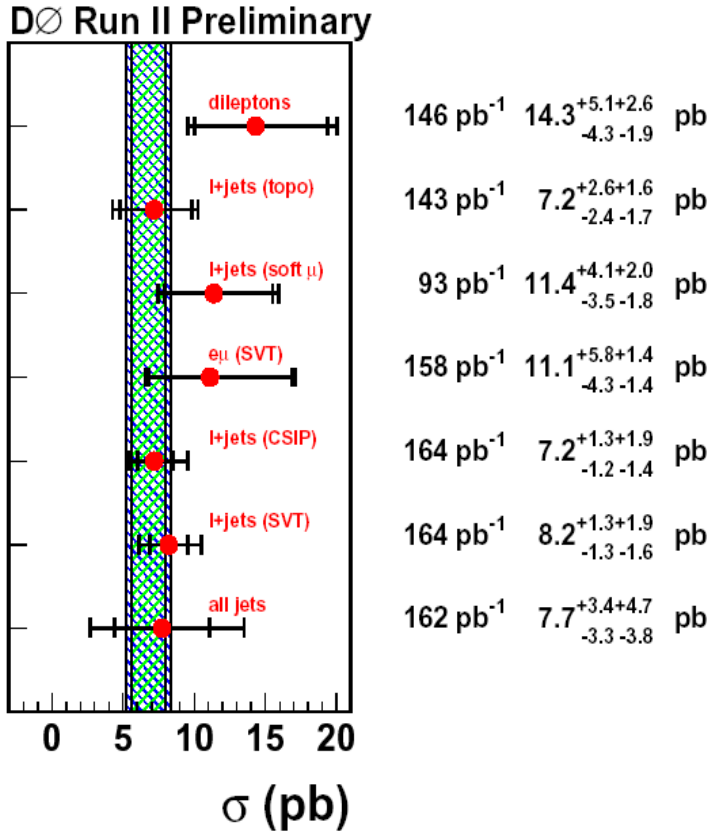


$$\sigma(t\bar{t}) = 7.2^{+2.6}_{-2.4}(stat)^{+1.6}_{-1.7}(syst)\ \text{pb}$$

e and mu

Cross section summary





many measurements with 30-40% precision
compatible with SM, compatible with NP
Aiming for 10% with 2fb^{-1}

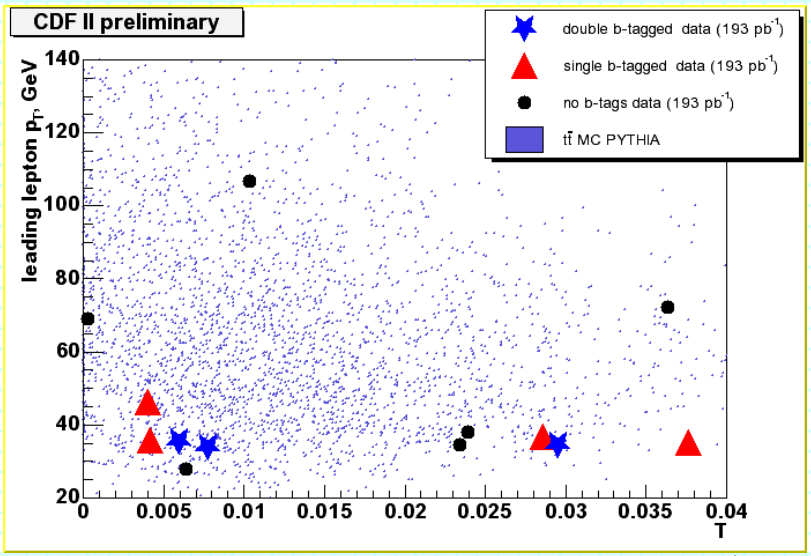
Anomalous Top kinematics

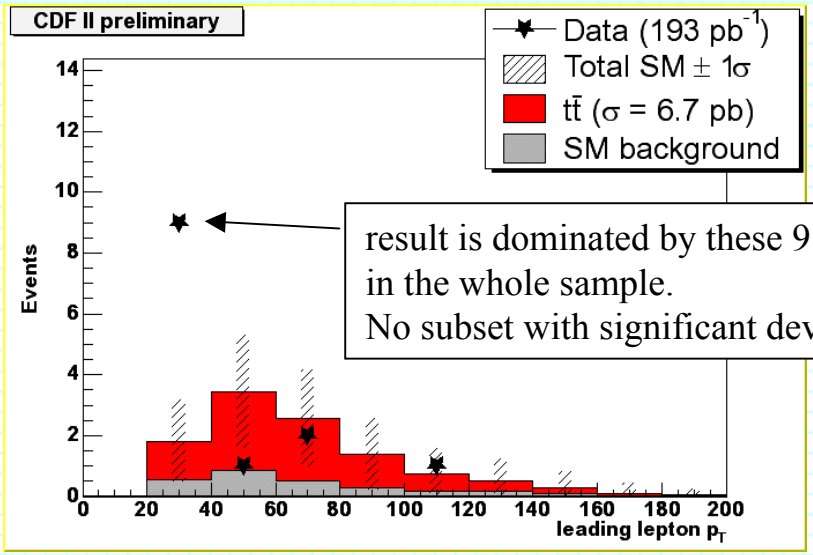
RunII dilepton 193pb-1

probability to measure a sample less consistent with SM is 1%-4.5%

Submitted to PRL

use the cross section analysis preselection and look for events with topology inconsistent with a t-tbar dilepton event

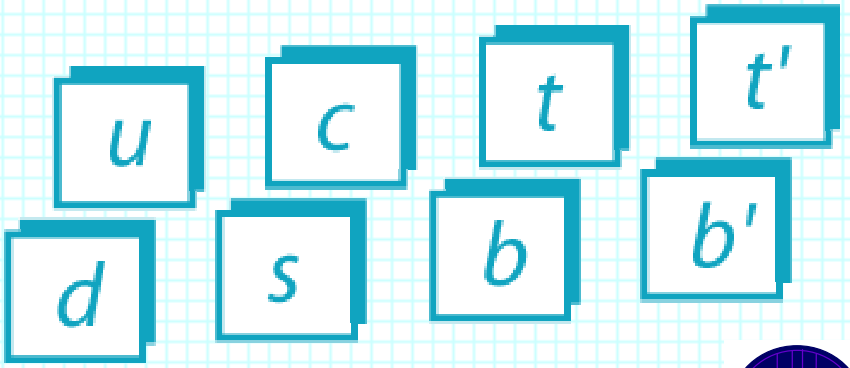




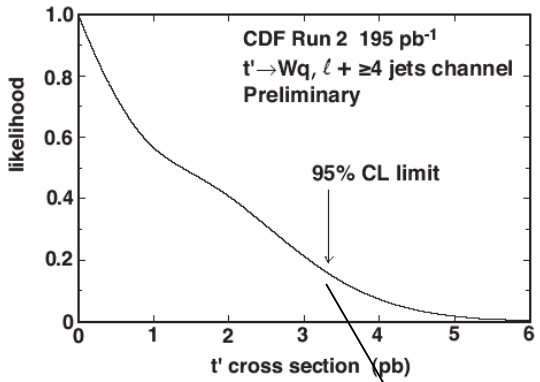
result is dominated by these 9 events in the whole sample.
No subset with significant deviations

more top like

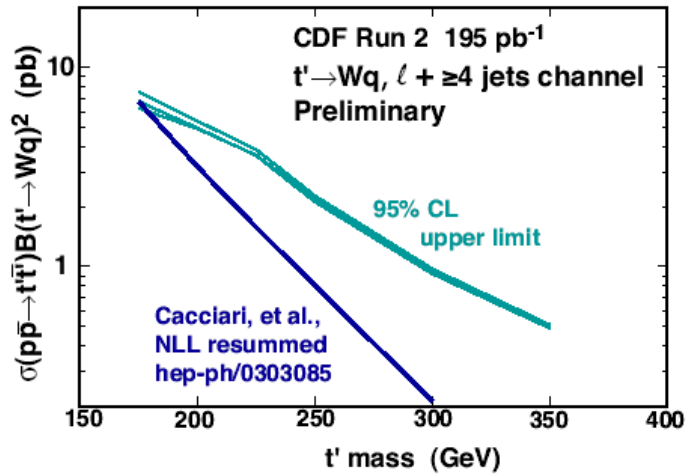
no excess of events with high missing Et and lepton pt seen in RunII

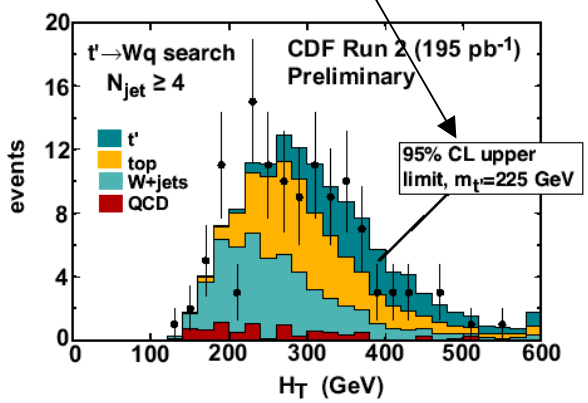


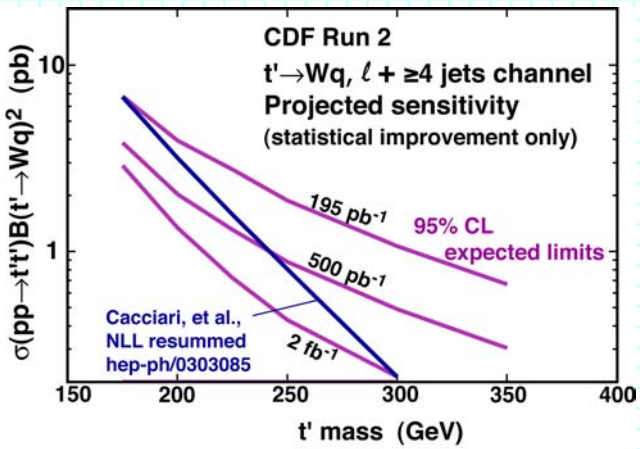
lepton+jets event selection
discriminate between t and t' with Ht



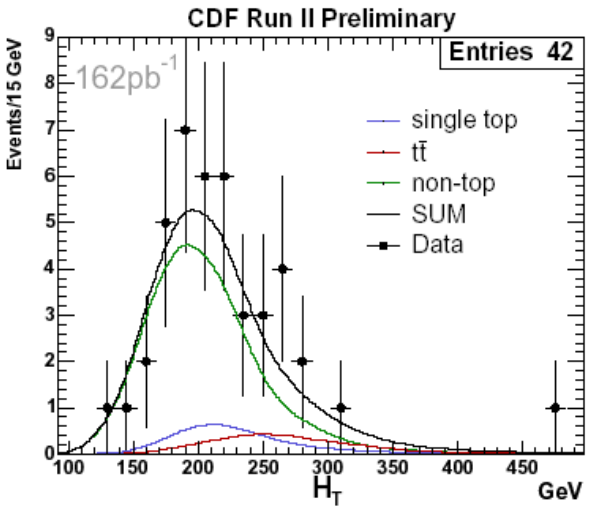
Example
likelihood fit
for m=225GeV/c²



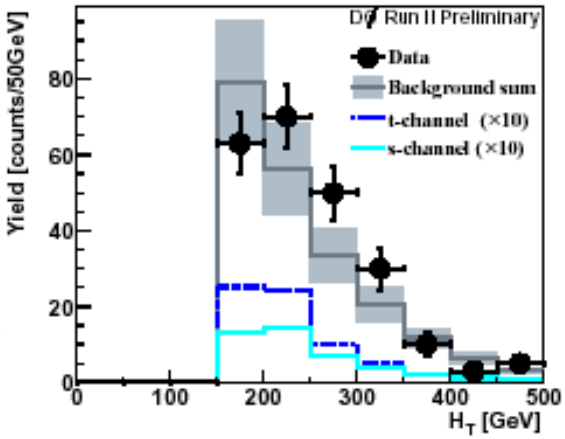




Single top quark limits



high pt lepton
high missEt
two bjets
(+1 light q)

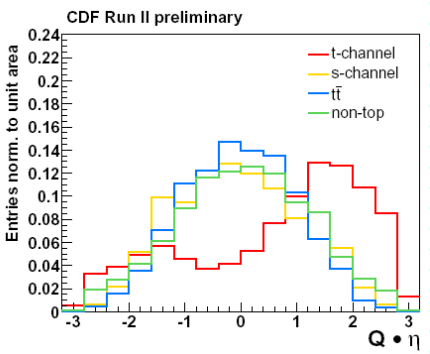


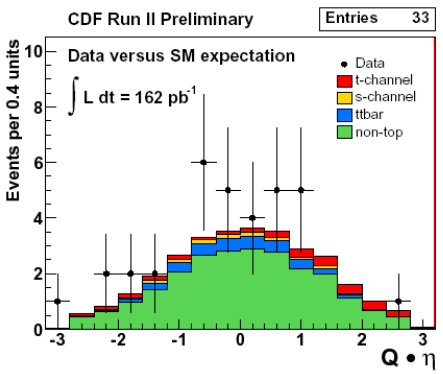
combined s+t limit: <17.8pb (95%CL)

PRD 71 (2005) 012005

s-channel < 19pb
t-channel < 25pb (95%CL)
combined < 23pb

and update from D0
is about to be released





Q: charge of the lepton
η: pseudorapidity of the non b jet

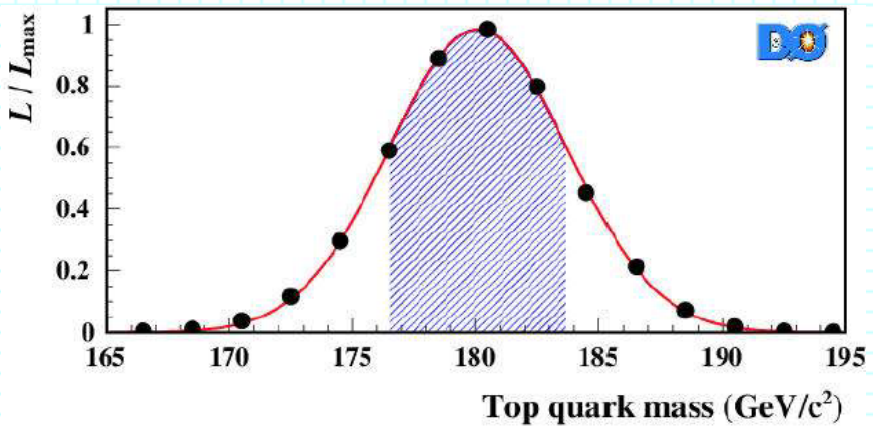
s-channel: <13.6pb (95%CL)
t-channel: <10.1 pb

Top quark Properties

- Mass
- R=B(t->Wb)/B(t->Wq)
- W helicity

Top Mass

- 10 years of top quark mass measurement: from kinematical fit and template comparison, to likelihood calculations using maximum information
- RunI has a 2.5% uncertainty
  RunII 5%, aim for 1% (~2GeV/c^2).

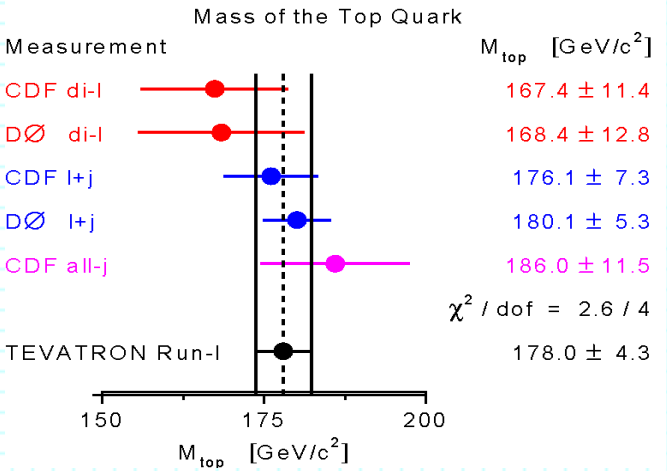


New Mass measurement with RunI data from D0.
Single most precise top mass measurement

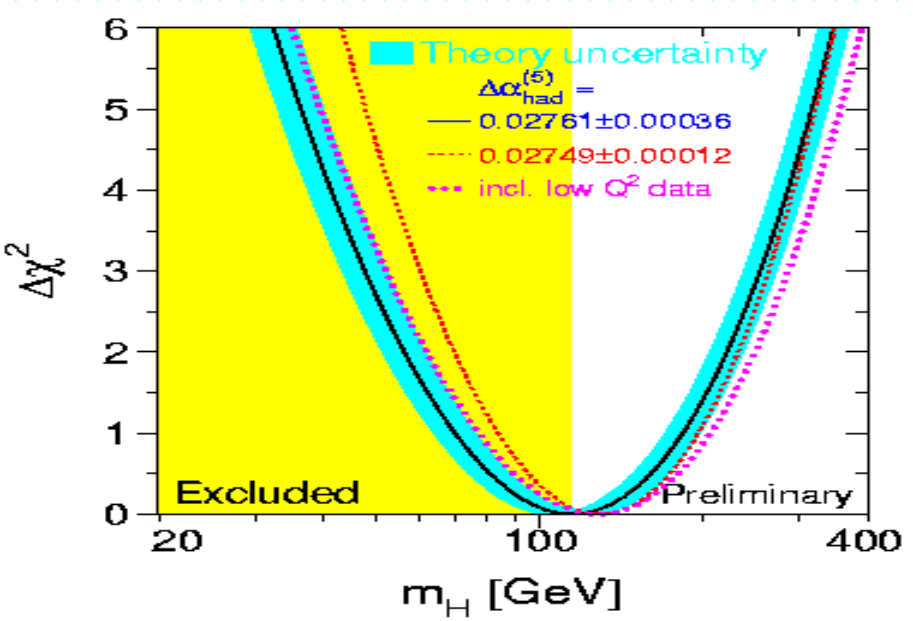
$m_t = 180.1 \pm 3.6(stat) \pm 3.9(syst)$ GeV/c^2

Published in Nature, June 2004

New Top Mass World Average (Run I)

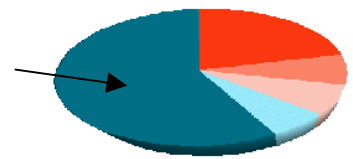


$m_{top} = 178.0 \pm 4.3$ GeV/c^2



Relative weight in top mass average

D0 weight



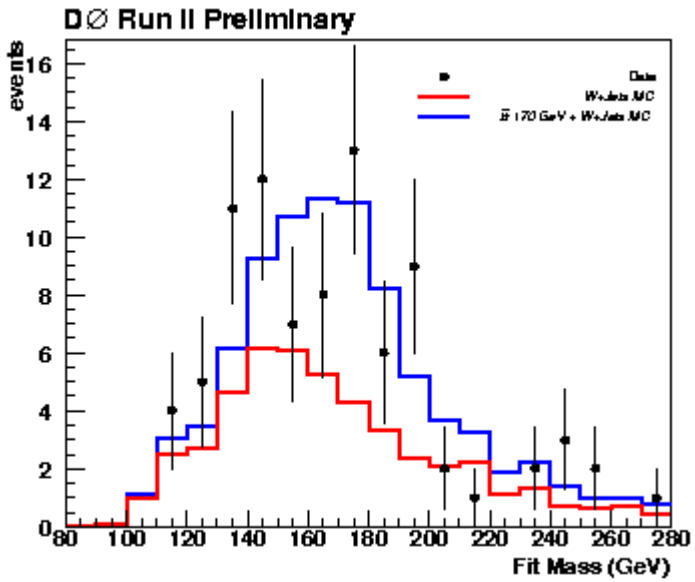
mH $= 114^{+69}_{-45}$ GeV/cc
mH < 260 GeV @ 95% C.L.

Mass in Run II, D0

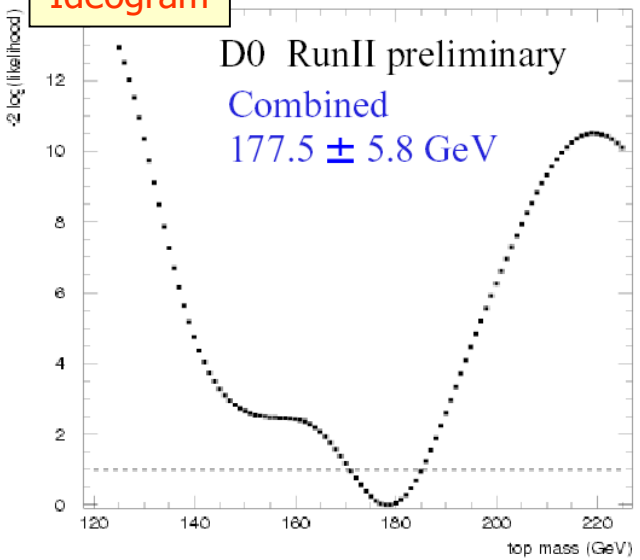
Measurements in lepton+jets channel (~150 pb^{-1})

→ template method uses templates for signal and background mass spectra
→ ideogram method uses analytical likelihood for event to be signal or background

Template



Ideogram



$$m_t = 170.0 \pm 6.5(stat)^{+10.2}_{-5.7}(syst)\ \mathrm{GeV/c^2}$$

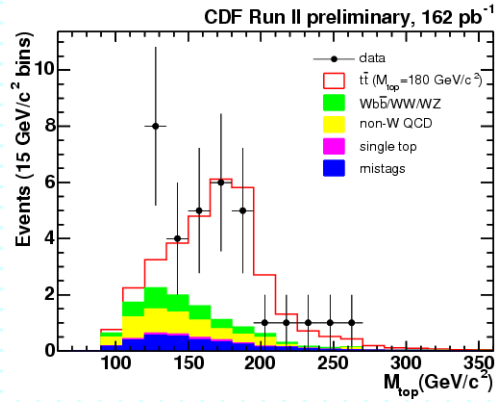
$$m_t = 177.5 \pm 5.8(stat) \pm 7.1(syst)\ \mathrm{GeV/c^2}$$

Systematical error dominated by the (un)knowledge of the jet energy scale

→ Will improve very soon !

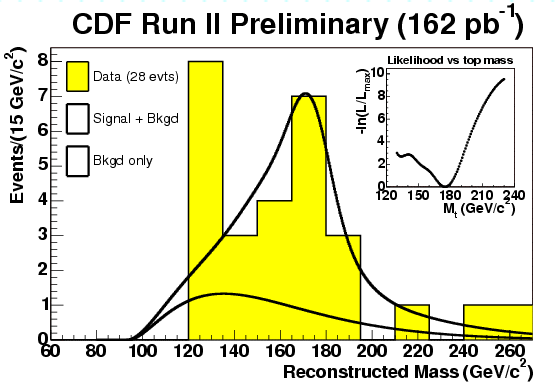
Mass in RunII, CDF

l+jets, multivariate



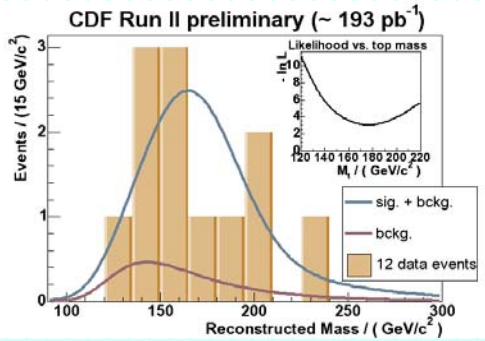
$m_t = 179.6^{+6.4}_{-6.3}(stat) \pm 6.8(syst)\ \mathrm{GeV/c^2}$

l+jets, b tagged



$m_t = 174.9^{+7.1}_{-7.7}(stat) \pm 6.5(syst)\ \mathrm{GeV/c^2}$

di-leptons

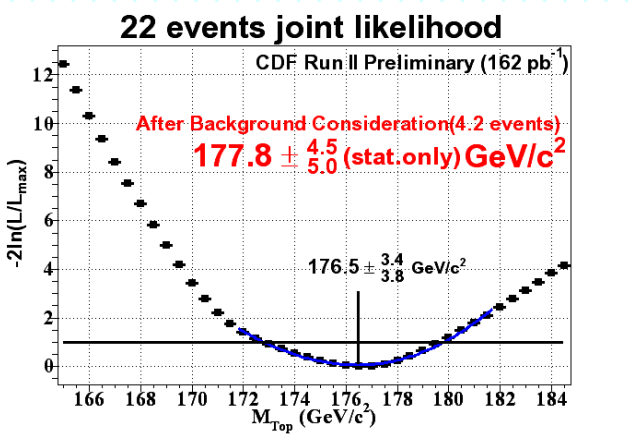


$m_t = 176.5^{+17.2}_{-16.0}(stat) \pm 6.9(syst)\ \mathrm{GeV/c^2}$

Dynamical Likelihood Method
similar to D0 "matrix element method"

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

Single most precise Run II measurement



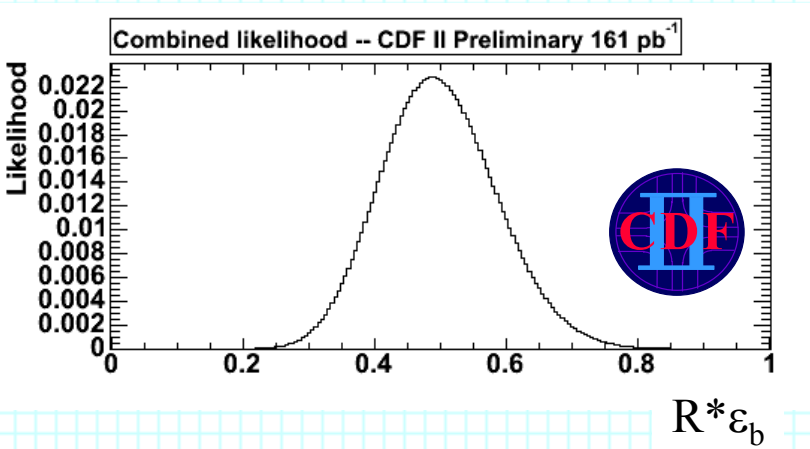
Branching ratio

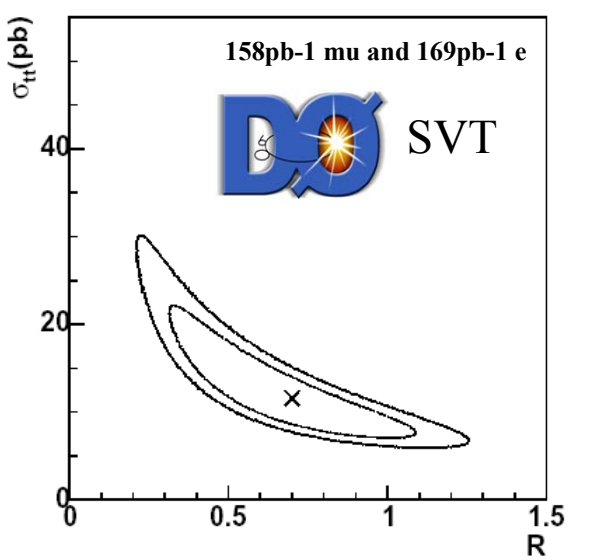
R=B(t->Wb)/B(t->Wq)

SM: R=0.998

$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2$$

Ratios of number of events in b-tag bins
2D fit to the cross section and R for tagged events
Measure R* ε_b (ε_b = tagging efficiency)

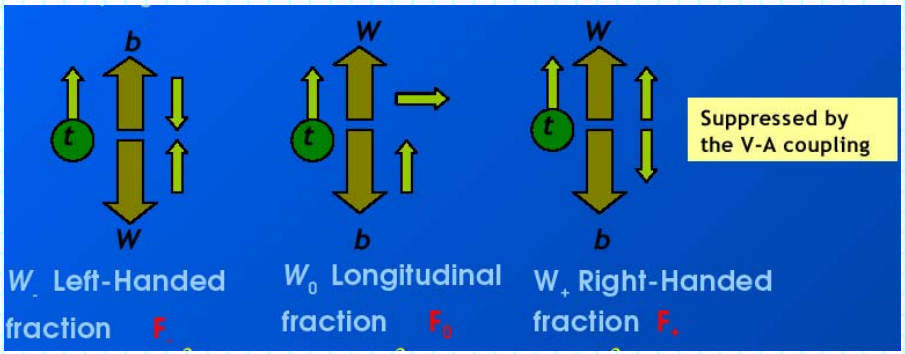


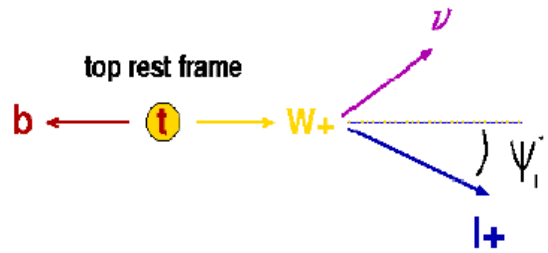


$R = 1.11^{+0.21}_{-0.19}$ (stat+syst)
> 0.62 @ 95% C.L.

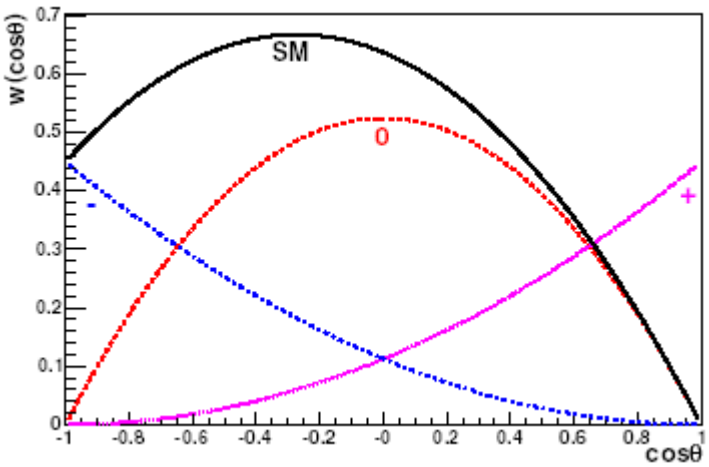
SVT: $R = 0.70^{+0.27}_{-0.24}$ (stat) $^{+0.11}_{-0.10}$ (syst)
CSIP: $R = 0.65^{+0.34}_{-0.30}$ (stat) $^{+0.17}_{-0.12}$ (syst)

W helicity

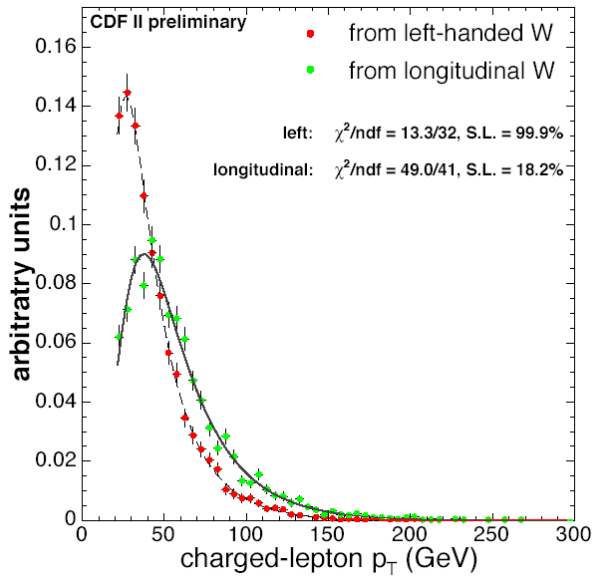




In SM F-=0.30, F_0 =0.70, F_+ =0

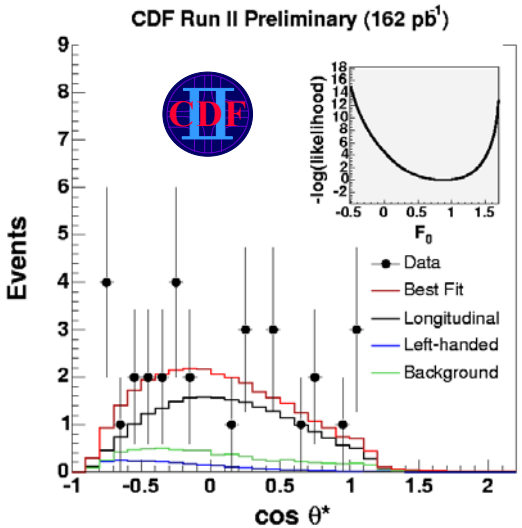


$$M^2_{l+b} = 1/2 \cdot (M^2_T - M^2_W)(1 + cos\psi^\star_l)$$

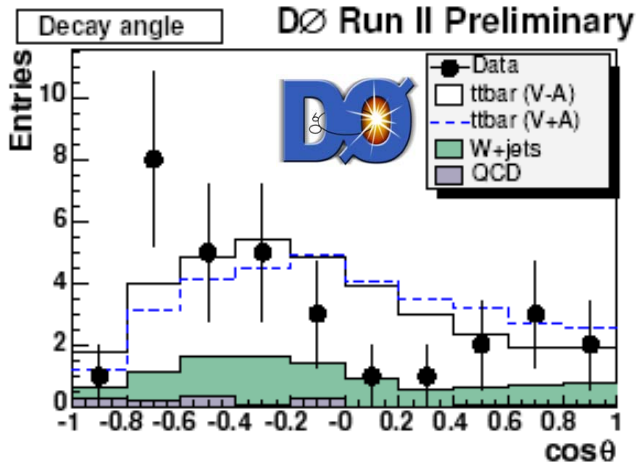


W helicity

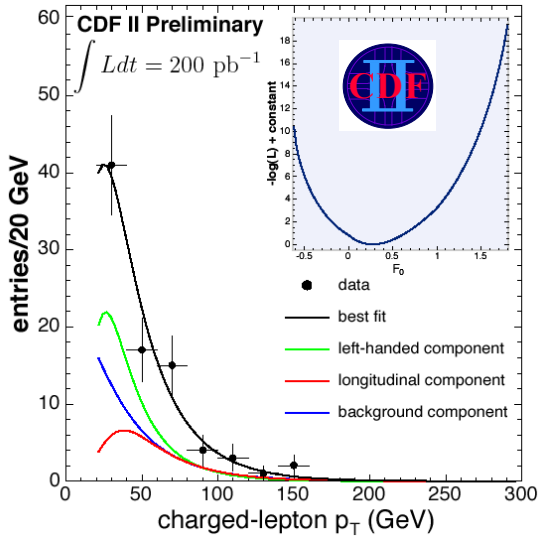
CDF RunI result:
F+<0.18(95%CL)



F0=$0.89^{+0.30}_{-0.34}$ (stat) ±0.17 (syst)
F0>0.25 (95%CL)
lep+jets



F+ <0.24 (90% CL) with tag
F+ <0.24 (90% CL)
dilepton



F0=$0.27^{+0.35}_{-0.24}$
F0 < 0.88 (95% CL)
lep+jets & dilepton

Conclusion

- The top quark is very heavy = very interesting.
- With the Tevatron running really well, we are at the door-step of learning much more, in more detail about the top quark and what it can tell us about undisclosed physics.
- Cross section measurements at the Tevatron RunII are consistent with SM, but also with new physics. More expected soon and aim for 10% with RunII.
- New Mass average from RunI. Measurements from RunII. More statistics and better jet energy scale should reduce the uncertainty very soon.
- Still only limits on single top quark production, should be seen in $1fb^{-1}$ to $2fb^{-1}$
- Analyses with double statistics almost ready, double again next year.
- More results to come (new physics ?).