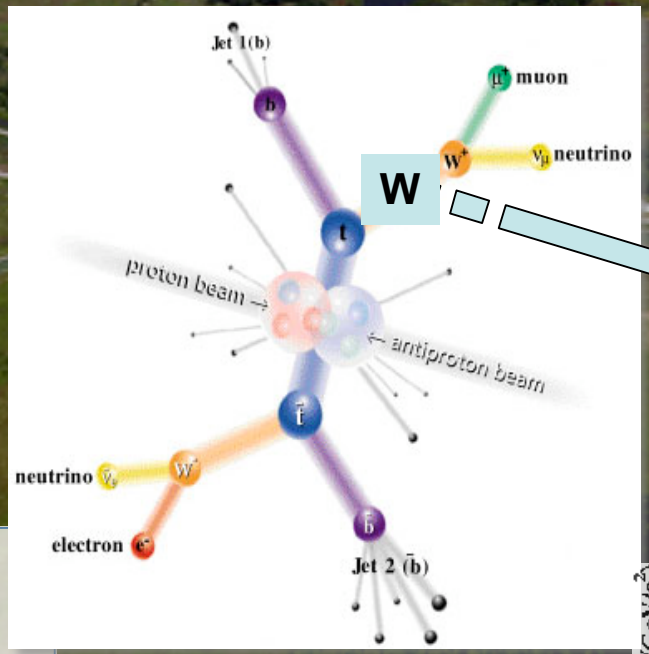
Fermilab User's Meeting
June 2, 2010

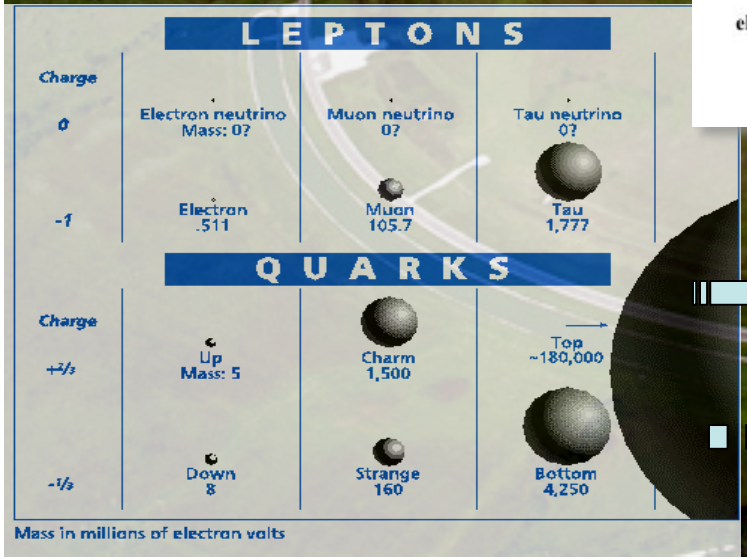
Electroweak Measurements and Top Quark Properties at the Tevatron

Robert Kehoe
Southern Methodist U.
Dept. of Physics

On behalf of the D0 and CDF Collaborations

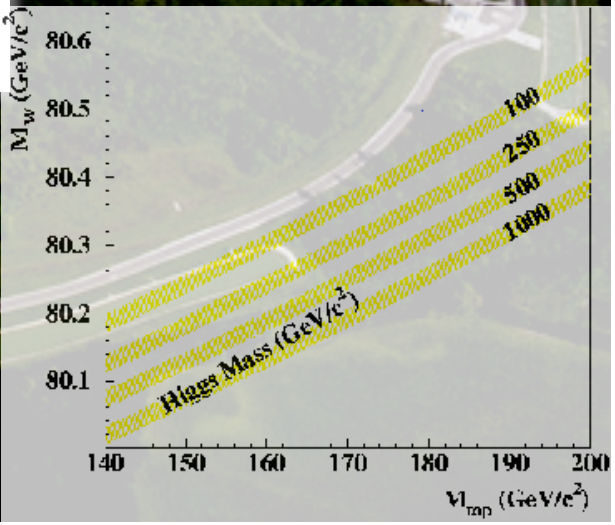


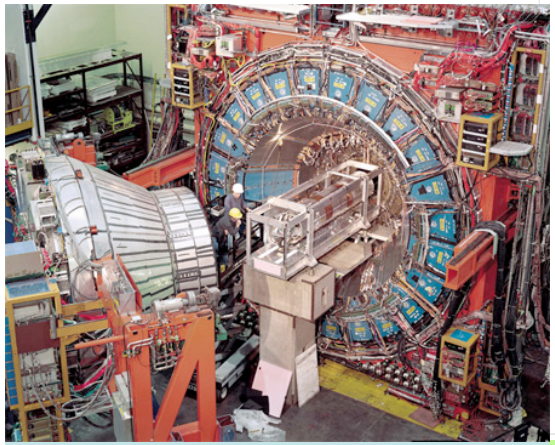
radiative corrections for M_W go as m_t^2, $\log(m_H)$

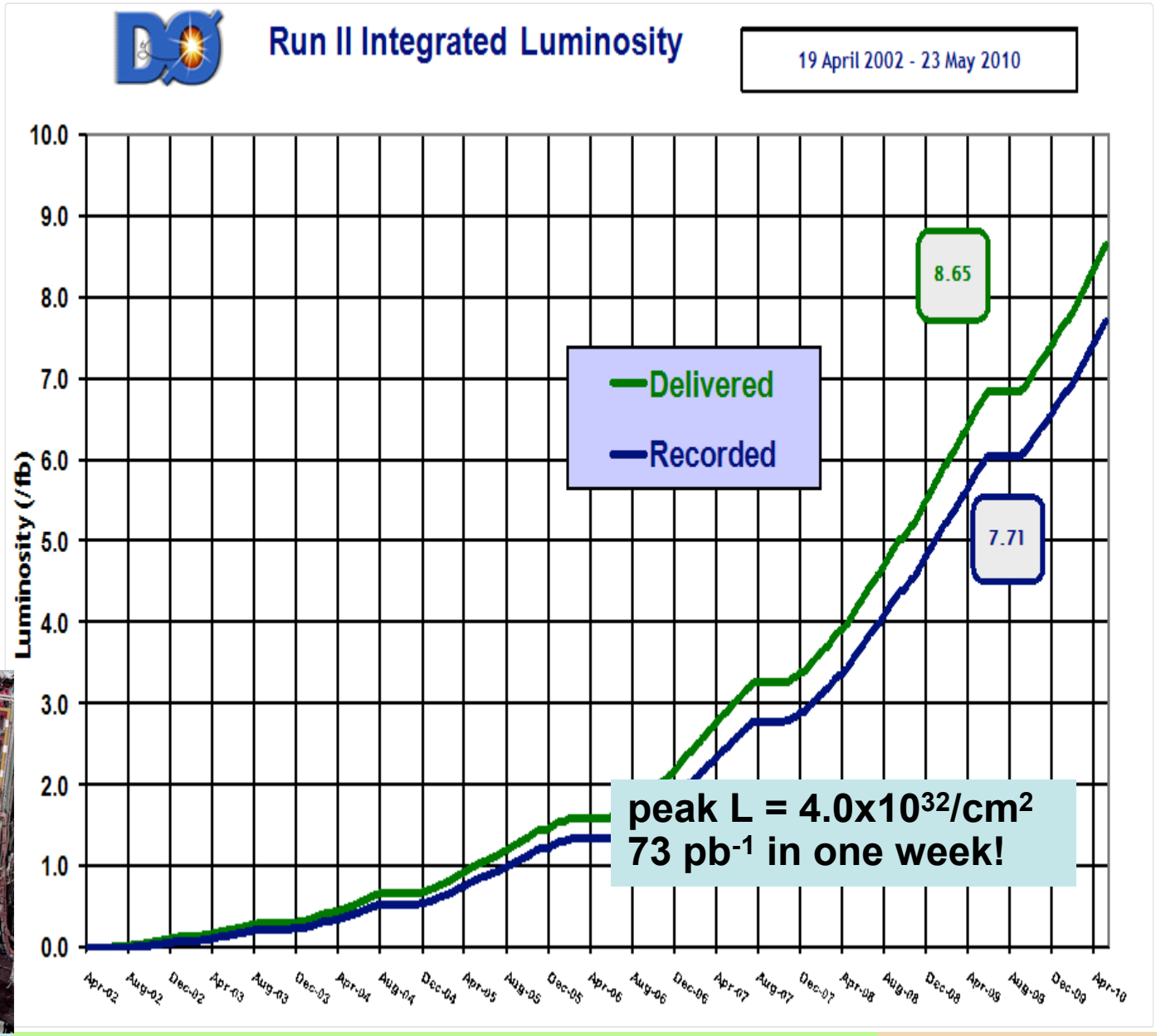


$$Y_t = m_t\sqrt{2}/v \approx 1$$

new physics?

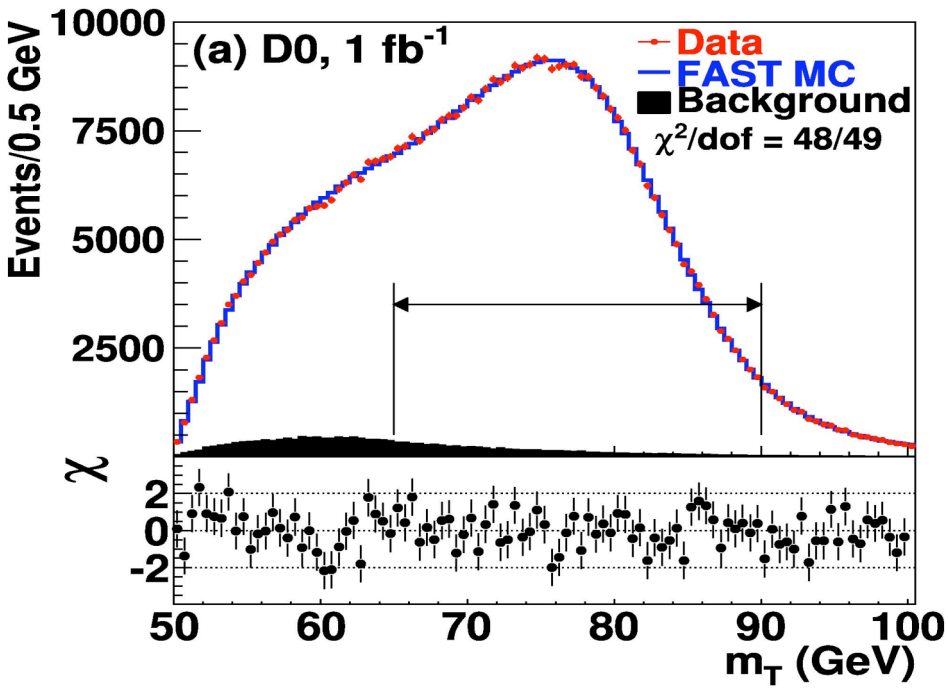





Run II Integrated Luminosity
19 April 2002 - 23 May 2010
Luminosity (/fb)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Delivered
Recorded
8.65
7.71
peak L = 4.0x10^32/cm^2
73 pb^-1 in one week!
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Dec-07
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10

W Mass Measurement

- M_W is sensitive probe of EWSB
- Requirements:
  - Precise EM calorimeter calibration
  - Detailed model of recoiling particle production and detector response
- W→eν mode in 1 fb^{-1}
  - 499,830 W's
  - 18,725 Z→ee's for calibration
- Blind analysis
  - Arbitrary scale factor applied to all three measurements simultaneously
  - Analysis finished, then blinding removed
- Analysis in p_T^e, E_T^{miss} and m_T
  - Systematics: for m_T method 34 MeV for electron calibration out of 37 MeV total
  - Uncorrelated… combination



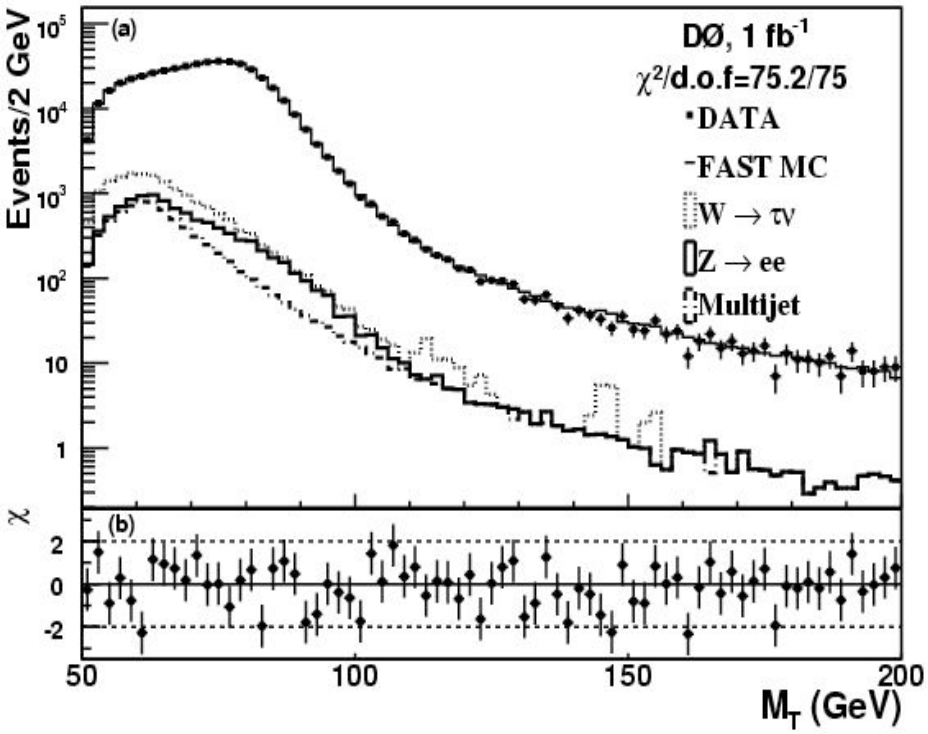
$$M_W = 80.401 \pm 0.021(\text{stat}) \pm 0.038(\text{syst}) \text{ GeV}$$

PRL 103:141801 (2009)

W Width Measurement

- Gauge structure of SM
  - Tight constraint on Γ_w
  - New heavy particles modify radiative corrections

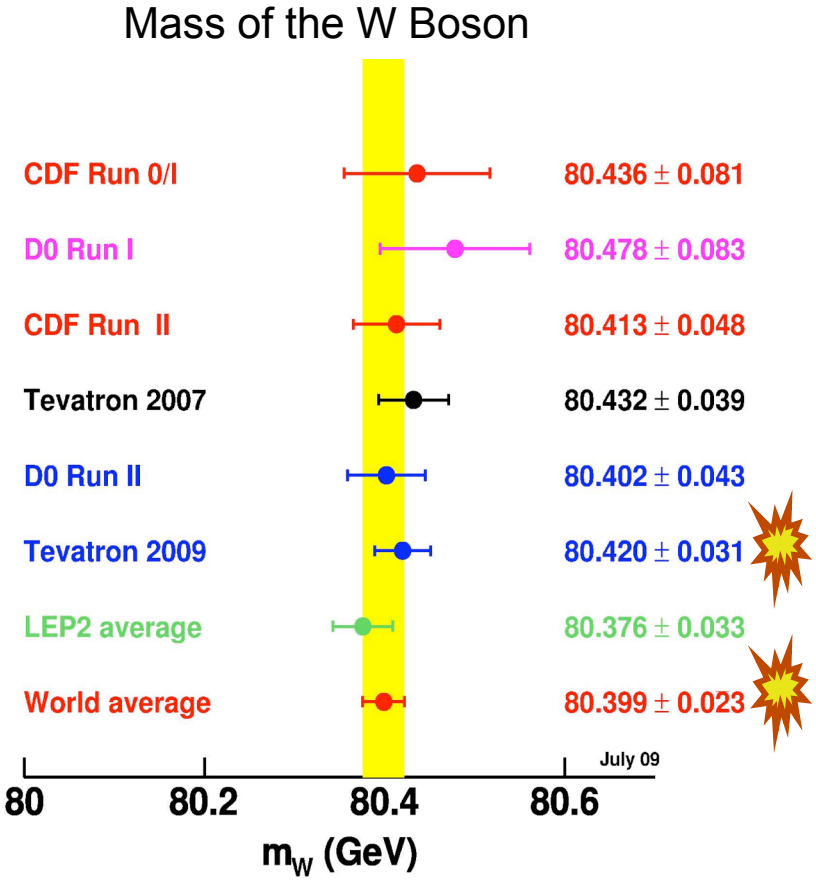
- New D0 measurement
  - 1 fb^{-1} W→eν
  - Method:
    - $100<m_T<200$ GeV
    - Orthogonal sample to M_w
  - Recoil studied using Z→ee data
  - Main systematics: electron calibration, hadronic recoil, PDFs



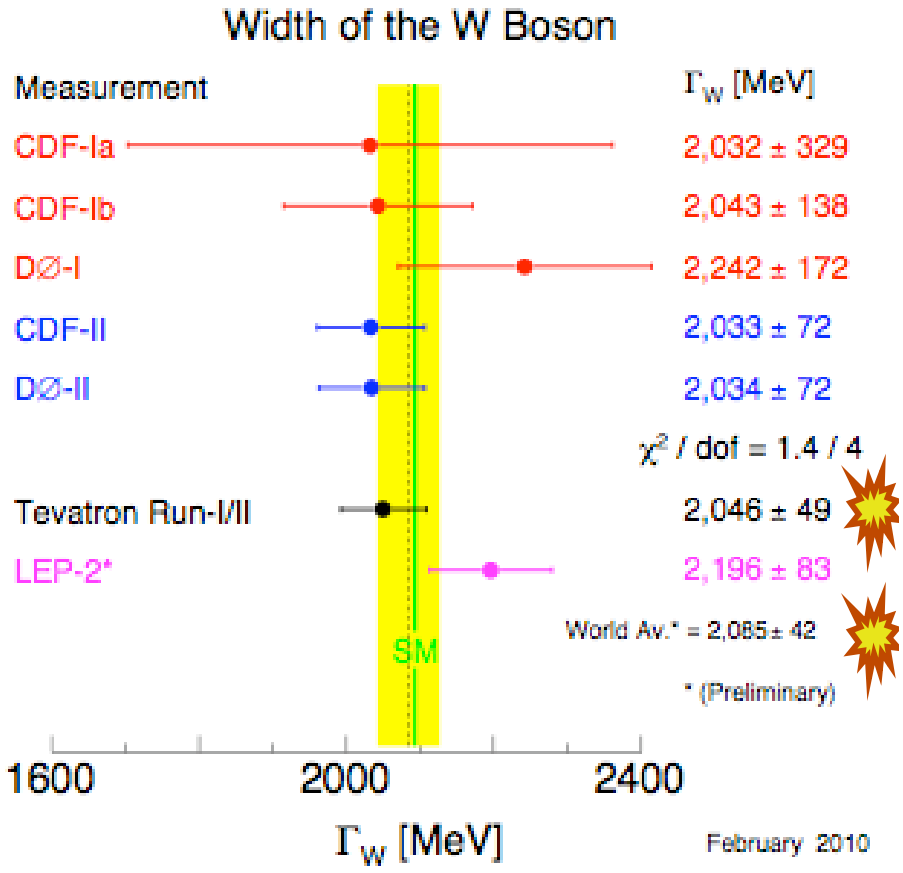
$$\Gamma_W = 2.028 \pm 0.072 \text{ GeV}$$

PRL 103:231802 (2009)

World Averages of M_W and Γ_W



FERMILAB-TM-2439-E



FERMILAB-TM-2490-E

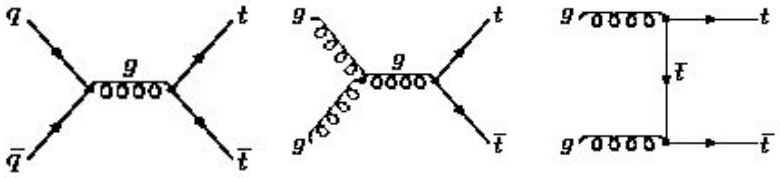
Correct for

- Use consistent PDFs: CTEQ6M
- Use new world avg. Mw

$$\Gamma_W = 2.093 \pm 0.002 \text{ GeV (SM)}$$

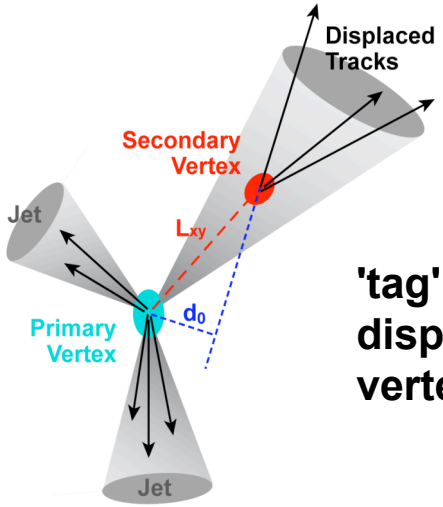
Observing the Top Quark

- Production:

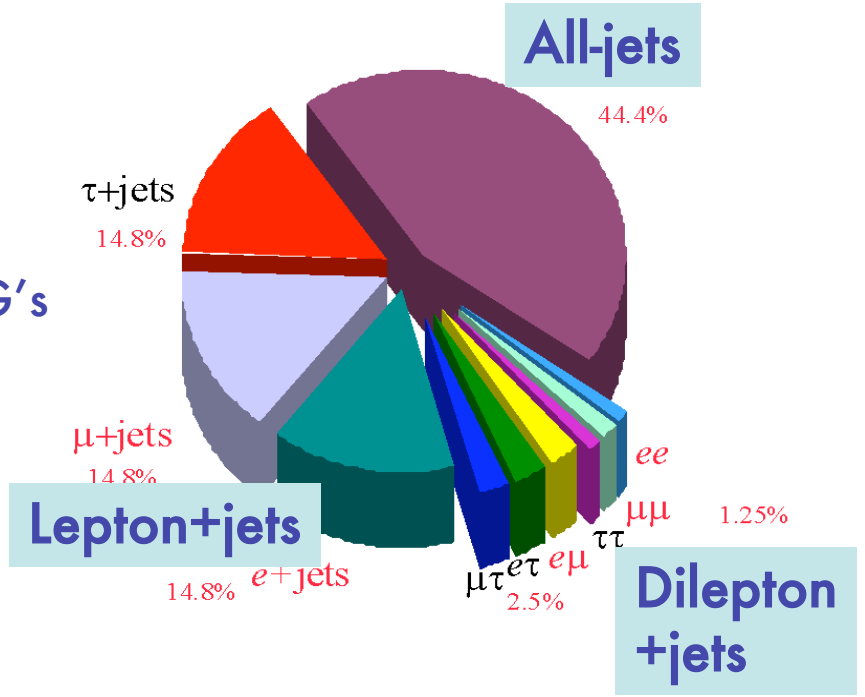


$$\sigma(t\bar{t}) \approx 7\,\text{pb}$$

- Decays (BR(t → Wb) ~ 100%)
  - *W* and *b* decays specify final states
  - Dilepton: two isolated, high P_T leptons
  - L+jets: one lepton from one W
  - Leptonic channels analyzed in tagged and untagged modes
  - All-jets: must be b-tagged to control BG's



'tag' displaced vertex



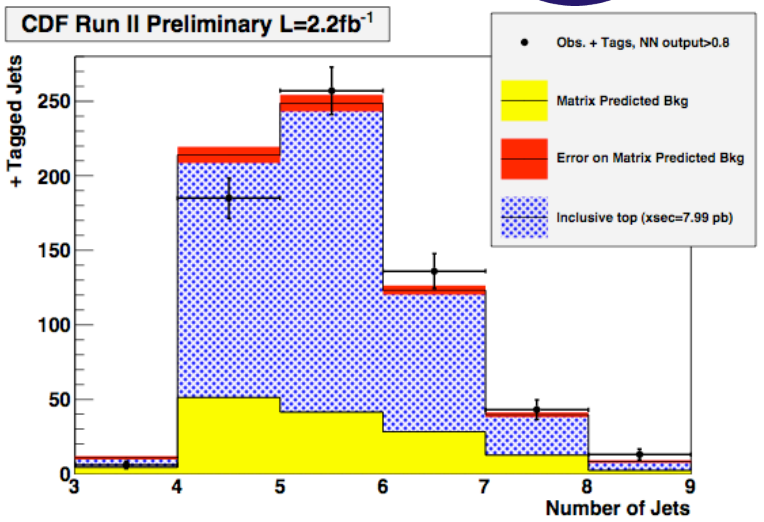
Top Pair Cross Section

$\sigma_{tt} = 7.46^{+0.48}_{-0.67}$ pb (theor.) Moch&Uwer, PRD 78:034003 (2008)

- Missing Et+jets
  - Veto explicit leptons
  - 2.2 fb^{-1}
  - Neural network on event topology

$\sigma_{tt} = 7.99 \pm 0.55(stat) \pm 0.76(sys) \pm 0.46(lum)$ pb

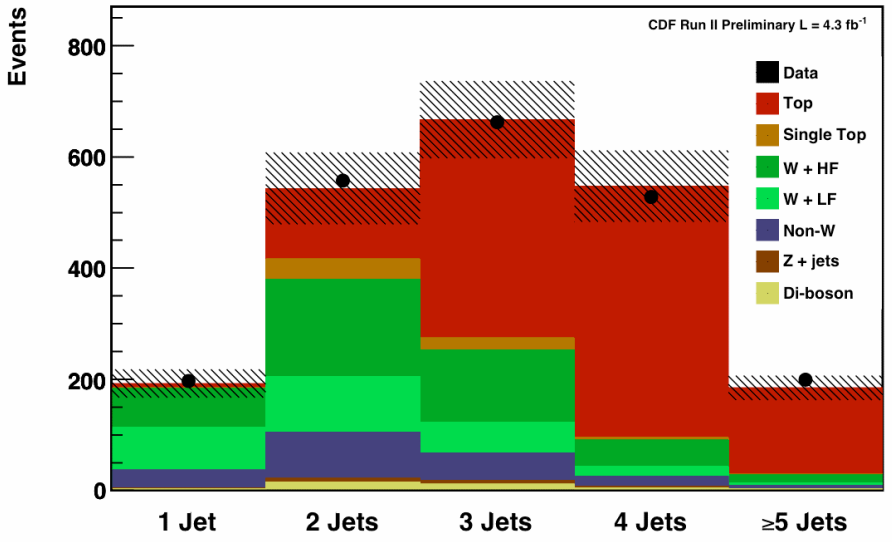
CDF-CONF-9988



- Lepton+jets
  - 4.6 fb^{-1}
  - Topological and b-tag
  - Normalize to known Z/γ* cross section
    - Removes lumi. uncertainty

$\sigma_{tt} = 7.70 \pm 0.52$ pb

arXiv:1004.3224

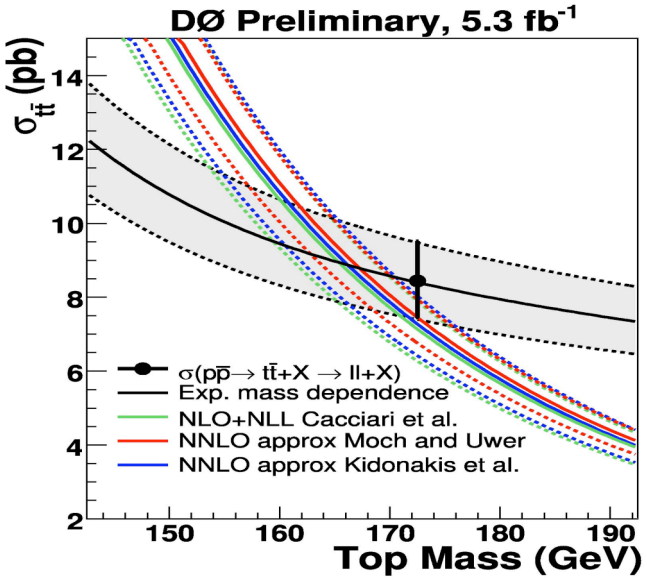


Top Pair Cross Section

- dilepton channel
  - Main background: Z+jets, diboson+jets, instrumental
  - 5.3 fb^{-1} total data
  - Boosted decision tree disciminant, ee and μμ channels

$$\sigma_{tt} = 8.4 \pm 0.5(stat)^{+0.9}_{-0.8}(sys)^{+0.7}_{-0.6}(lum)\ \text{pb}$$

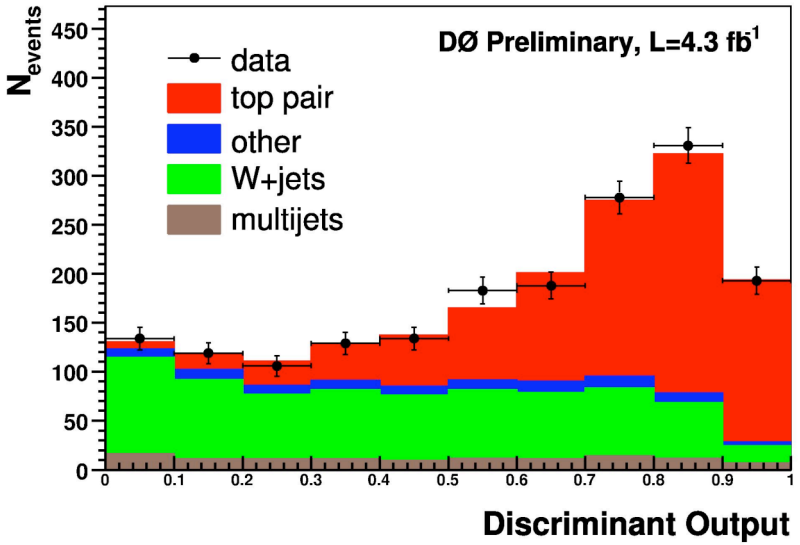
D0-CONF-6038



- Lepton+jets channel
  - 4.3 fb^{-1}
  - Topological and b-tag analyses

$$\sigma_{tt} = 7.70^{+0.79}_{-0.70}\ \text{pb (topological)}$$
$$= 7.93^{+1.04}_{-0.91}\ \text{pb (b-tag)}$$

D0-CONF-6037



Top Mass Analyses

- Dilepton channel
  - Template analyses, 4.8 fb^{-1}
  - Integration over neutrino rapidity
  - Local polynomial smoothing of templates
  - Separate 0 and ≥1 tag events

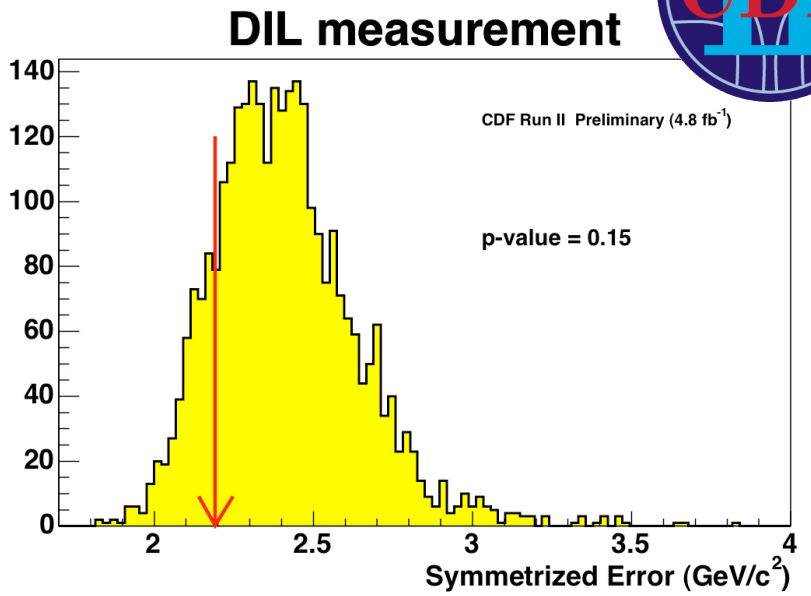
$$m_t = 170.6 \pm 2.2(\text{stat}) \pm 3.1(\text{syst})\ \text{GeV}\ (2\ell)$$

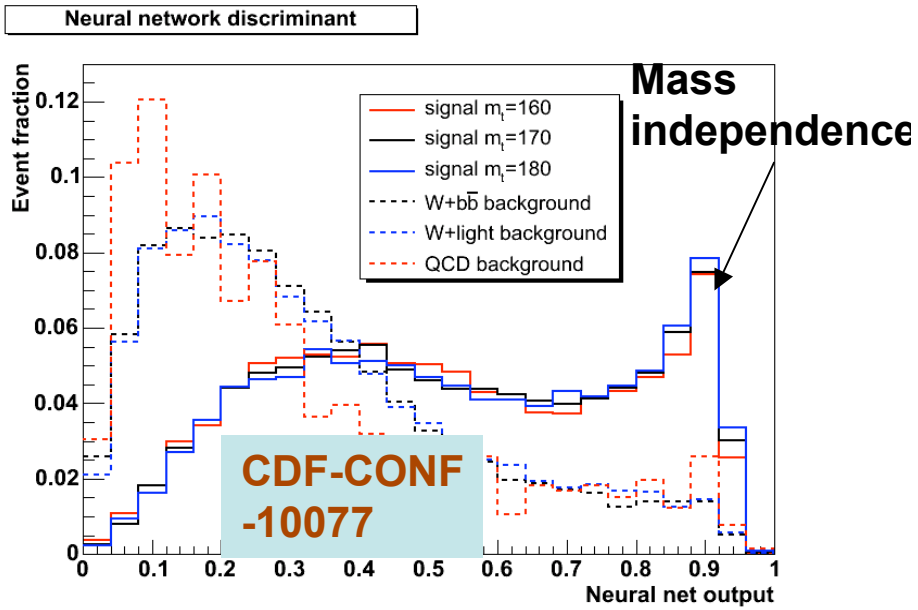
CDF-CONF-10033

- Lepton+4jets exclusive, 4.8 fb^{-1}
  - Matrix element analysis, b-tagging
  - Kinematic NN discriminant
  - Leading systematics
    - largest uncertainties after JES: MC generator, residual JES, background

$$m_t = 172.8 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.8(\text{syst})\ \text{GeV}$$

As precise as 2009 TeV average!





World Average Top Mass

- Combination of all CDF results:
  - Runs I and II
  - Dilepton, l+jets, all-jets

$m_t = 172.6 \pm 0.9(\text{stat}) \pm 1.2(\text{syst})$ GeV (CDF)

CDF-NOTE-9714

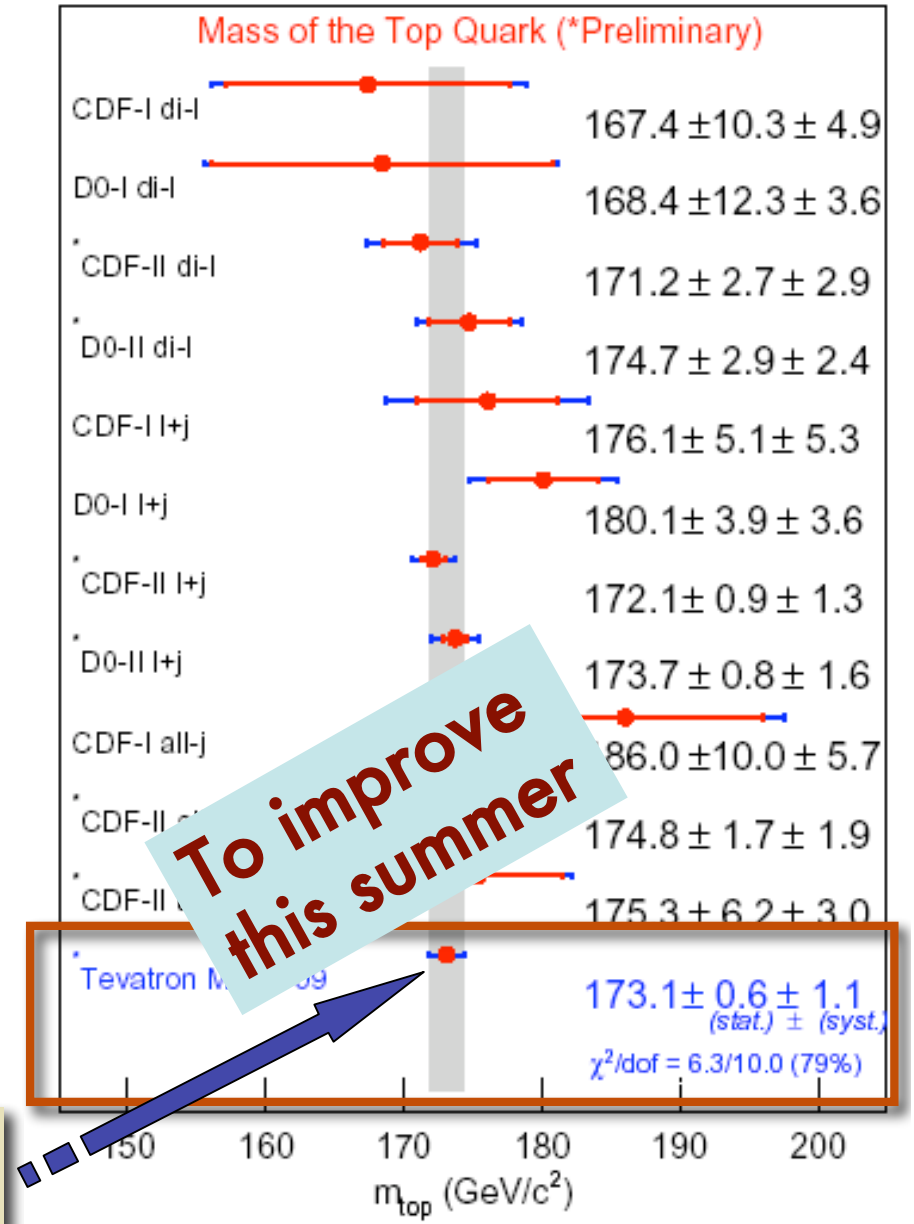
  - Will improve

- Combination of all D0 results
  - Runs I and II
  - Dilepton, l+jets

$m_t = 174.2 \pm 0.9(\text{stat}) \pm 1.5(\text{syst})$ GeV(D0)

D0-CONF-5900

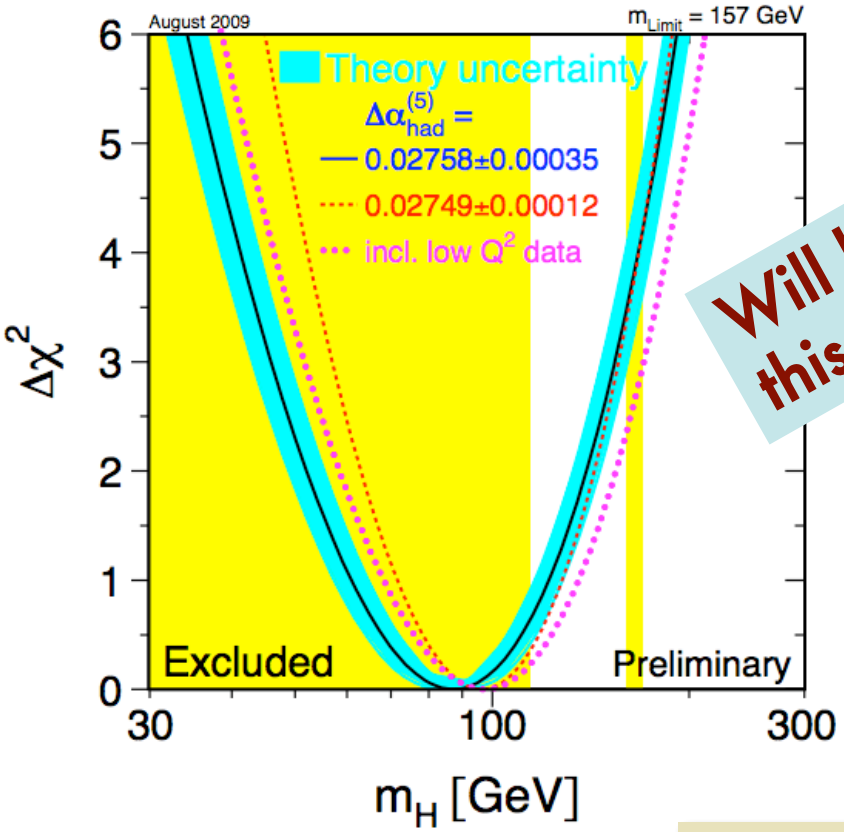
- Should achieve 1 GeV uncertainty from Run II



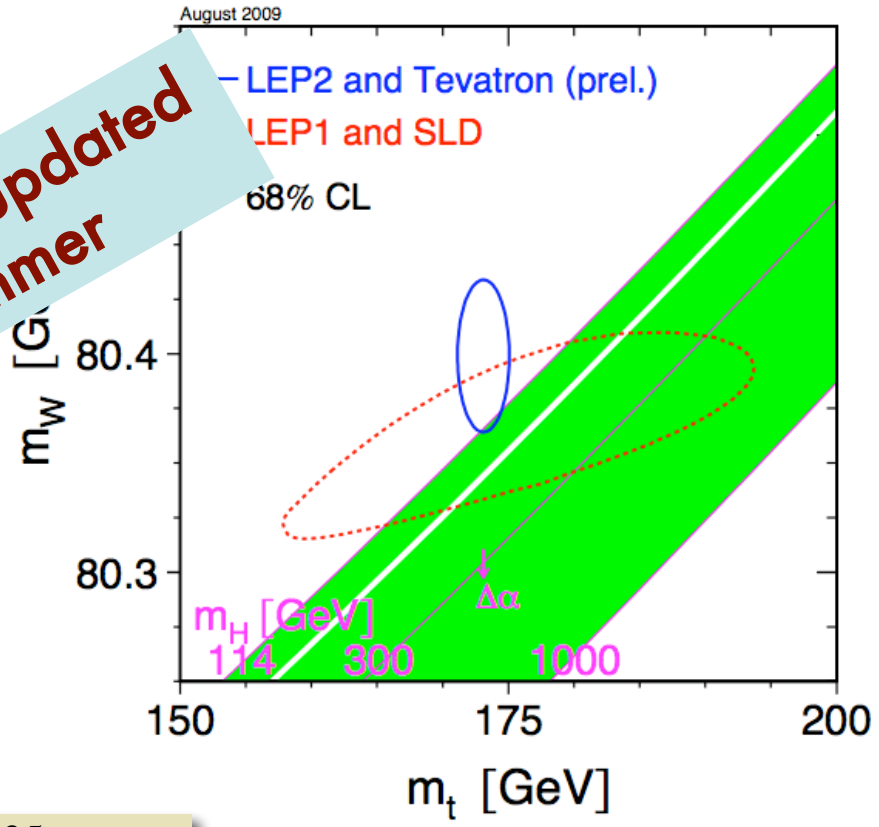
FERMILAB-TM-2427-E
arXiv:0903.2503

ElectroWeak Fits

- Update of Tevatron top mass, W mass (+ Higgs exclusion) incorporated:



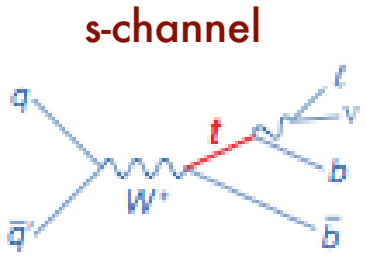
Will be updated this summer



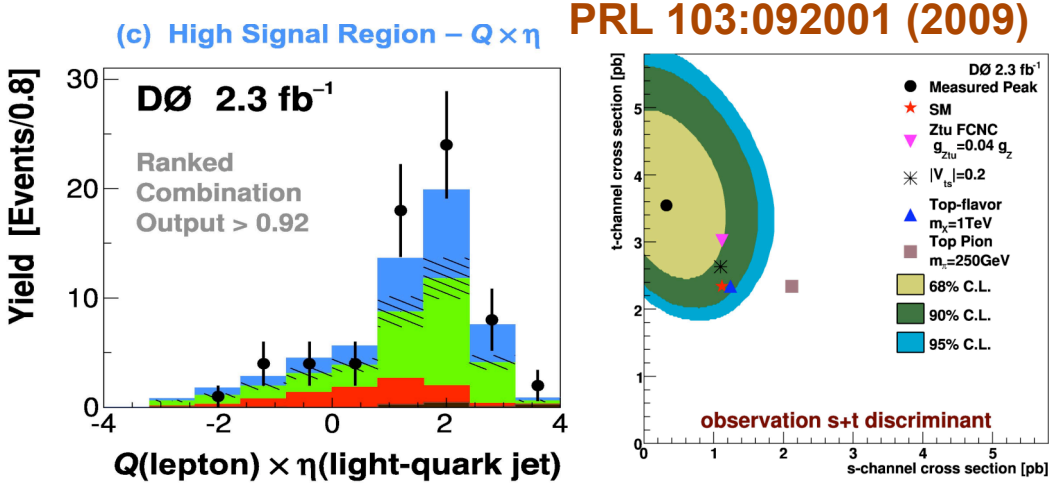
$$m_H = 87^{+35}_{-26}\,\mathrm{GeV}$$

Single Top Production

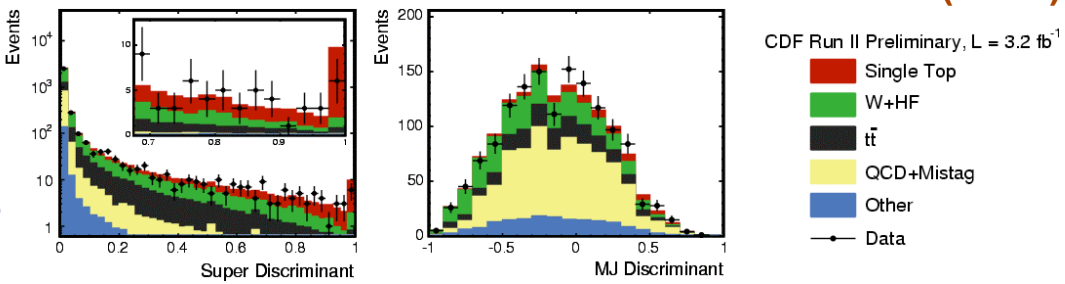
- Electroweak production of top quarks
  - important probe of Wtb vertex
  - Constrains 4th generation models
- D0 used 2.3 fb^{-1} l+jets data
  - combine three discriminant methods
    - Decision tree
    - Neural network
    - Matrix element
- CDF in 3.2 fb^{-1}
  - L+jets+MET: 5 techniques combined
    - 2 likelihoods, one emphasizing s-channel
    - Matrix element
    - Neural network
    - Boosted decision tree
  - Neural network in MET+jets
- 5.0σ excess observed for each experiment



PRL 103:092001 (2009)



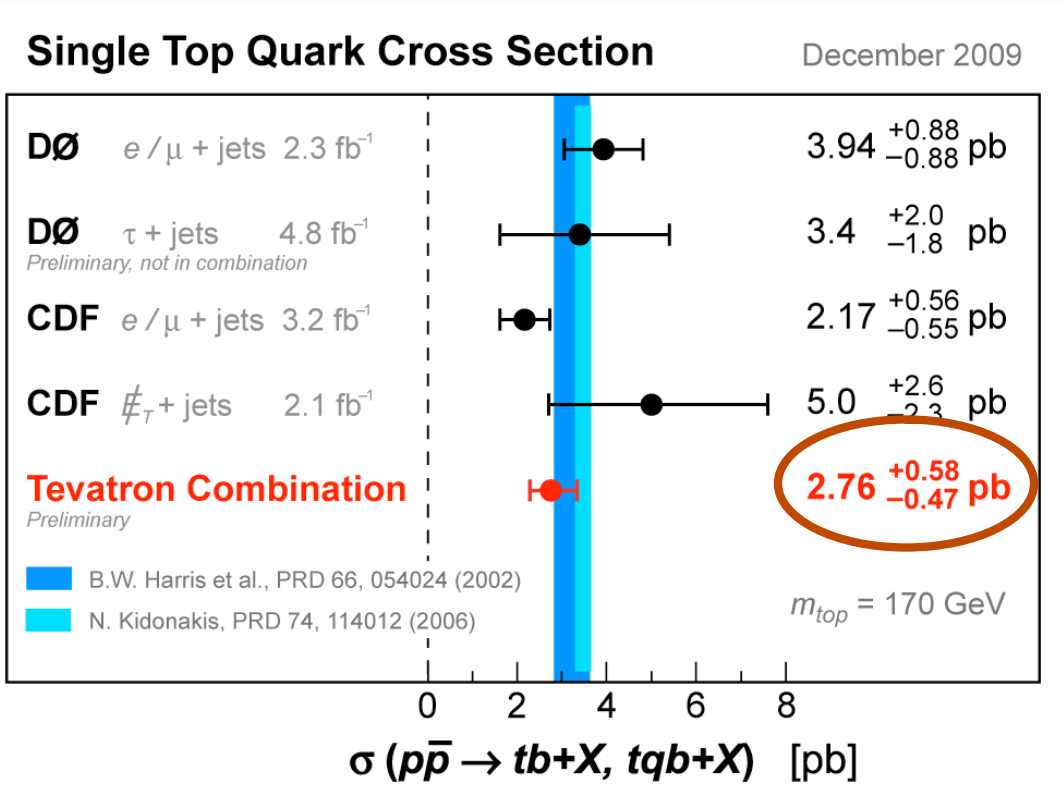
PRL 103:092002 (2009)



World Average

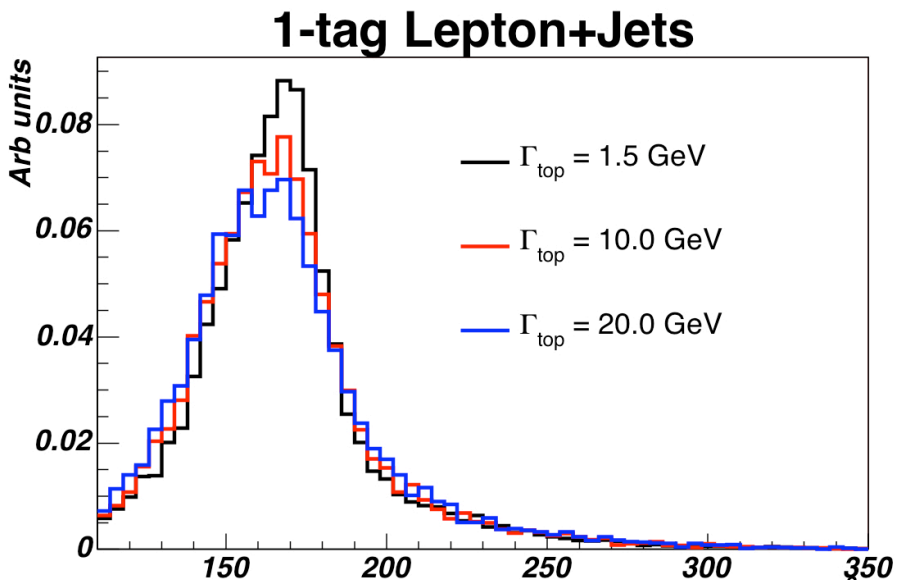
- Inputs
  - Utilize D0 and CDF distributions of multivariate discriminants
  - Consistent top quark mass
    - M_t = 170 GeV
  - Consistent cross section
    - To obtain V_{tb}

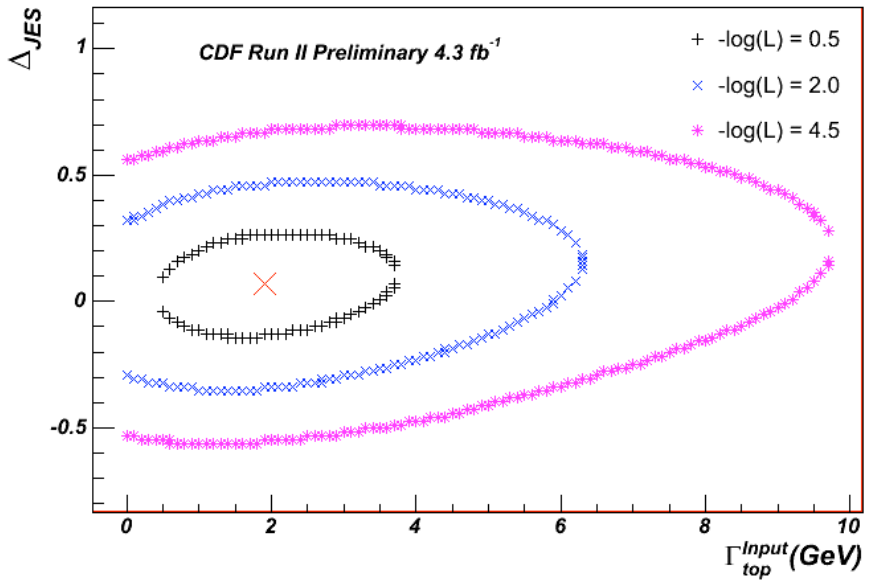
$$|V_{tb}| = 0.88 \pm 0.07 \text{ @ } 95\% \text{ c.l.}$$
$$> 0.77 \text{ @ } 95\% \text{ c.l.}$$



FERMILAB-TM-2440-E

Top Width





- Reconstructed top mass distribution gives top width
- 4.3 fb^{-1}, lepton+jets
  - Use template approach
  - M_t vs. jet energy calibration
  - Compare to PYTHIA MC
- Measurements:

$\Gamma_{top} < 7.5$ GeV (95% c.l.)

$0.4 < \Gamma_{top} < 4.4$ GeV (68% c.l.)

CDF-CONF-10035

Top Width

- Use indirect measure
  - Partial width from single top production, $\Gamma(t \to Wb)$
    - Normalization from data/NLO calculations
  - Branching fraction to Wb from lepton+jets with 0, 1 and 2 b-tags

$$\Gamma_{top} = \Gamma(t \to Wb)/BR(t \to Wb)$$

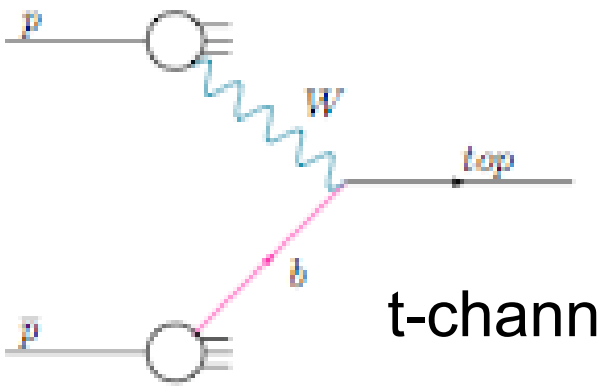
- Assume no flavor changing neutral currents, and V_{ts} and V_{td} small

$$\Gamma_{top} = 2.05^{+0.57}_{-0.52}\ \text{GeV}$$

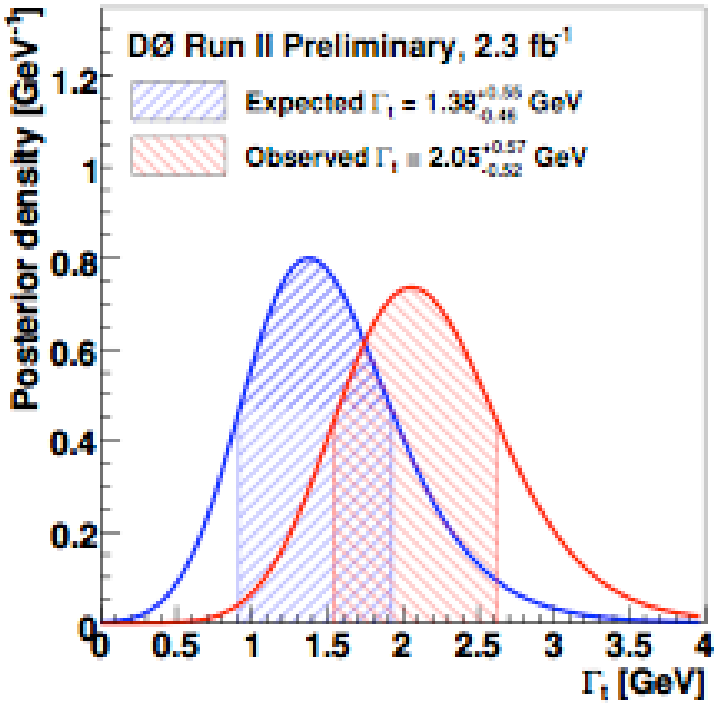
$$\tau_{top} = 3.2^{+1.1}_{-0.7} \times 10^{-25}\ \text{s}$$

D0-CONF-6034

SM:
1.26 GeV
5x10^{-25} s



t-channel

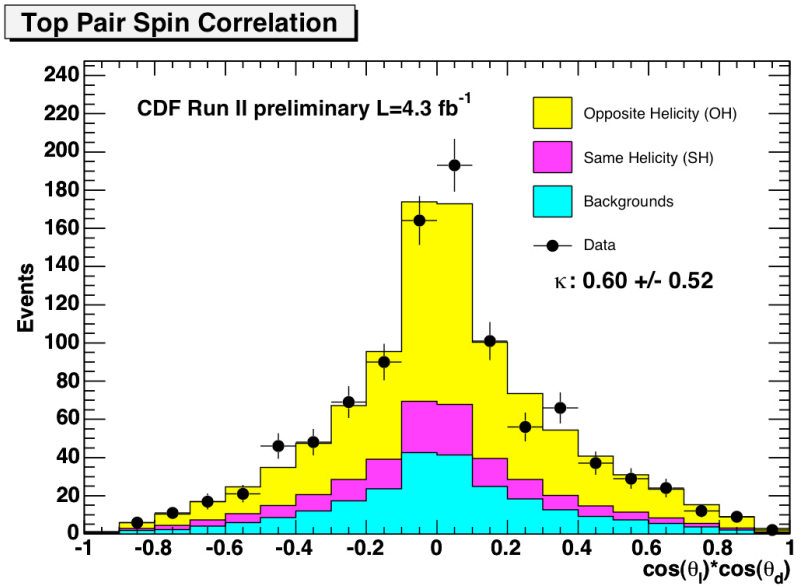


Top Spin Correlations

- In SM: top and antitop spins correlated
  - Modified by new physics: KK or Z′ models
- Top lifetime shorter than characteristic time of hadronization
  - So top decays before it hadronizes
  - Top spin information is carried away by decay products: W and b
- CDF measurement
  - 4.3 fb^{-1}, l+jets events
  - Helicity angle distributions for
    - Lepton, down-quark, b-quark
  - No correlation gives opposite helicity fraction of 0.5
    - Simulation of top with correlation gives ~0.7

$$\kappa = 0.60 \pm 0.50(stat) \pm 0.16(sys)$$

CDF-PUB-10048



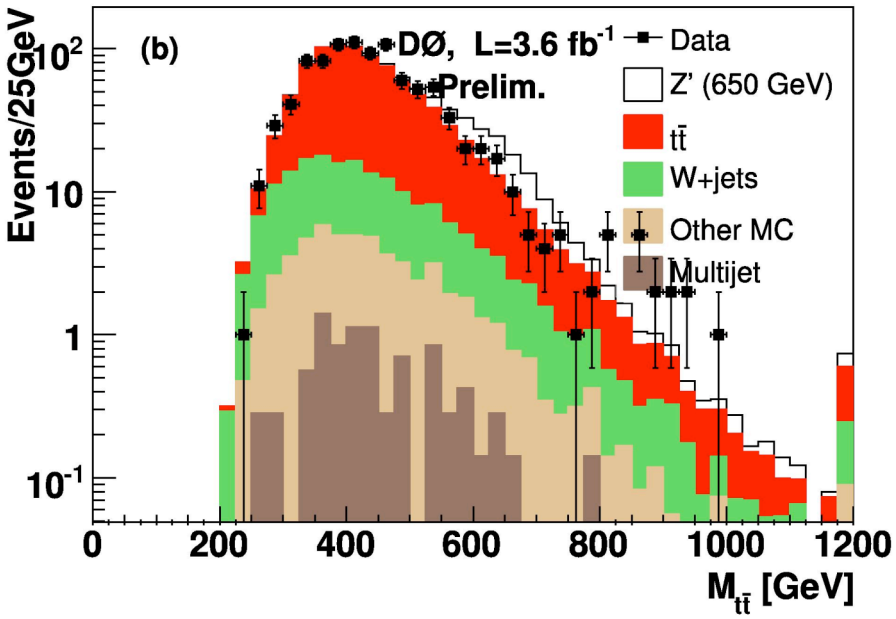
- D0 measurement in dilepton events

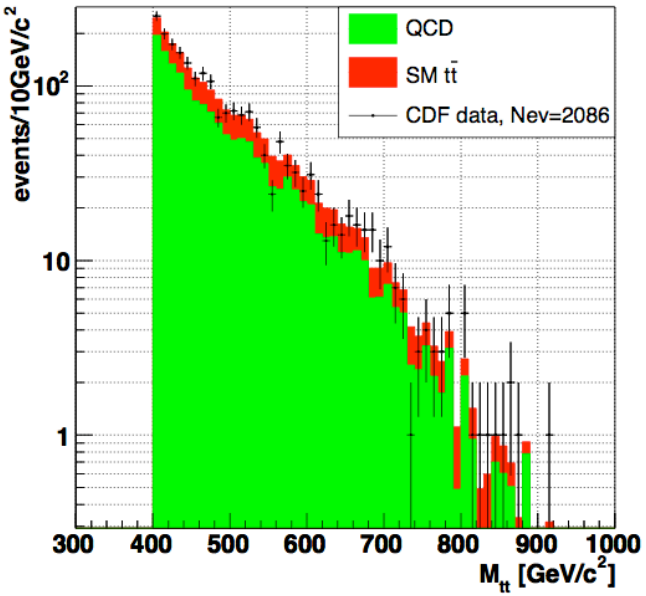
$$\kappa\left(\text{different basis}\right) = -0.17^{+0.64}_{-0.53}$$

D0-CONF-5950

Will be a Tevatron combined results

Ttbar Resonances





- Top Yukawa coupling close to unity
  - Is top special?
  - Look for unexpected ttbar resonance
- D0 search
  - 3.6 fb^{-1}
  - lepton+jets channel
  - Test ttbar invariant mass distribution

$M_{Z'} > 820$ GeV @ 95% c.l.

D0-CONF-5882

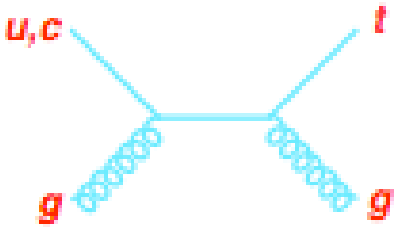
- CDF search
  - all-jets channel
  - 2.8 fb^{-1}
  - Matrix-element based discriminant

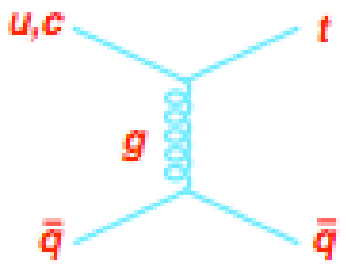
$M_{Z'} > 805$ GeV @ 95% c.l.

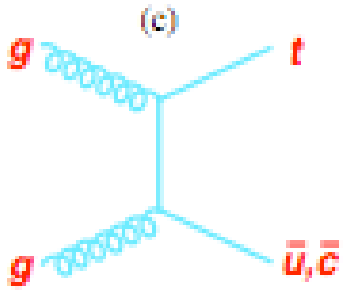
CDF-CONF-9844

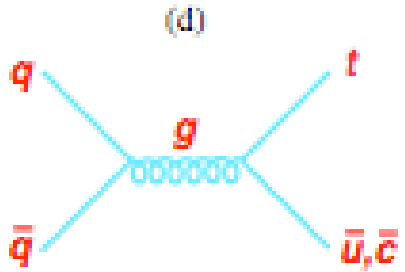
Flavor Changing Neutral Currents

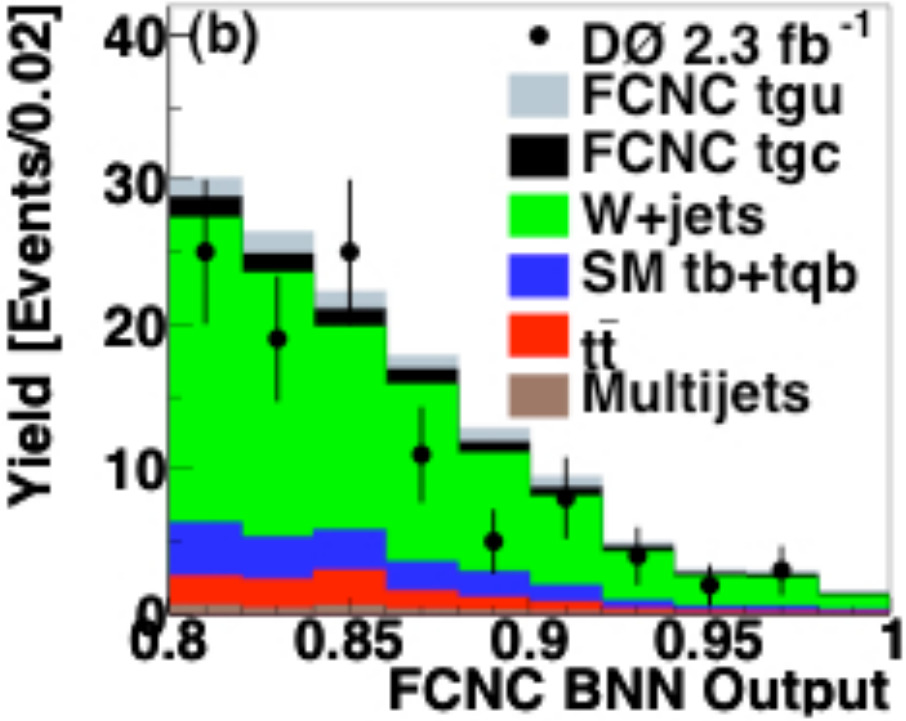
- Single top + additional jet
- 2.3 fb^{-1}











$$BR(t \to gu) < 2.0 \times 10^{-4}$$
$$BR(t \to gc) < 3.9 \times 10^{-3}$$

D0-CONF-5882

Many Other Recent Measurements...

- **Electroweak Results:**
- Charge asymmetry in $W \rightarrow \mu\nu$ decays, D0-CONF-5976 (D0)
- $W \rightarrow e\nu$ charge asymmetry D0 and CDF comparison, PRL 102:181801 (2009)
- $ZZ \rightarrow 4$ lepton cross section, CDF-CONF-9910 (CDF)
- WW/WZ cross section, arXiv:0911.4449 (CDF)
- Measurement of WW cross section, PRL 103:191801 (2009) (D0)

- **Top Quark Results:**
- Dependence of ttbar cross section on p_T^{top}, FERMILAB-PUB-10-008-E (D0)
- Cross Section of ttbar + hard jet, CDF-CONF-9850 (CDF)
- Top mass in dilepton final states, PRD 80:092006 (2009) (D0)
- Mass difference in ttbar decays, PRL 103:132001 (D0)
- Single top t-channel cross section, PLB 682:363 (2010) (D0)
- Search for single top in tau+jets channel, arXiv:0912.1066 (D0)
- ttbar spin correlation in dilepton events, CDF-CONF-9824 (CDF)
- Top quark charge, CDF-PUB-9939 (CDF)
- Search for $t' \rightarrow Wq$, CDF-PUB-10110 (CDF)
- Search for NMSSM Higgs in top quark decays, CDF-PUB-10104 (CDF)

Conclusions

- 7.7 fb^{-1} recorded, up to 5.3 fb^{-1} has been analyzed
- Electroweak measurements
  - New best M_w by a single experiment and world average

$$M_W = 80.399 \pm 0.023(\text{stat} + \text{syst}) \text{ GeV}$$

  - W width determination
- Top quark measurements
  - Common systematics scheme is accepted and being refined
    - CDF and D0 working together
  - Top mass world average:

$$m_t = 173.1 \pm 0.6(\text{stat}) \pm 1.1(\text{syst}) \text{ GeV (CDF + D0)}$$

0.75% precision!

  - CKM matrix element: $|V_{tb}| = 0.88 \pm 0.07 \text{ @ } 95\% \text{ c.l.}$
  - Many other measurements: cross sections, top width, spin correlations, etc.
- Full Run II
  - Valuable, strong constraints on electroweak parameters (W, top, Higgs)
  - Competitive or complementary to LHC program
- Constraints on the Higgs boson:

$$m_H = 87^{+35}_{-26} \text{ GeV}$$
$$< 157 \text{ GeV @ } 95\% \text{ c.l.}$$