Fermilab User's Meeting
June 2, 2010

Electroweak Measurements and Top Quark Properties at the Tevatron

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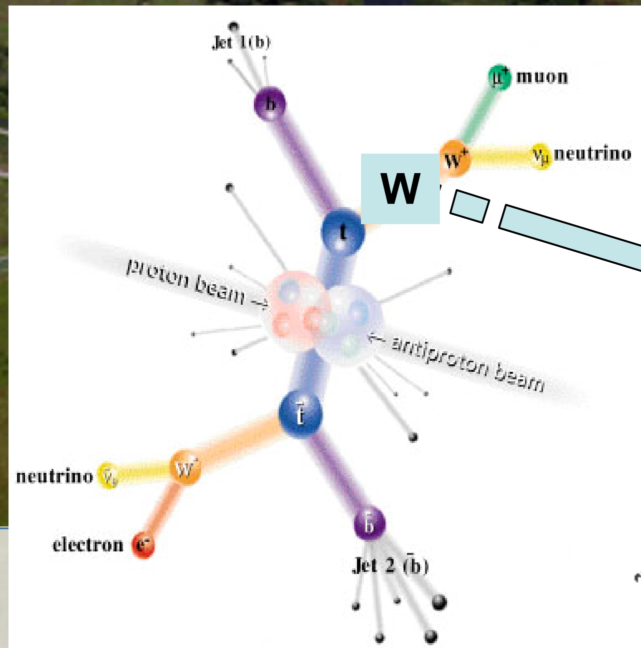
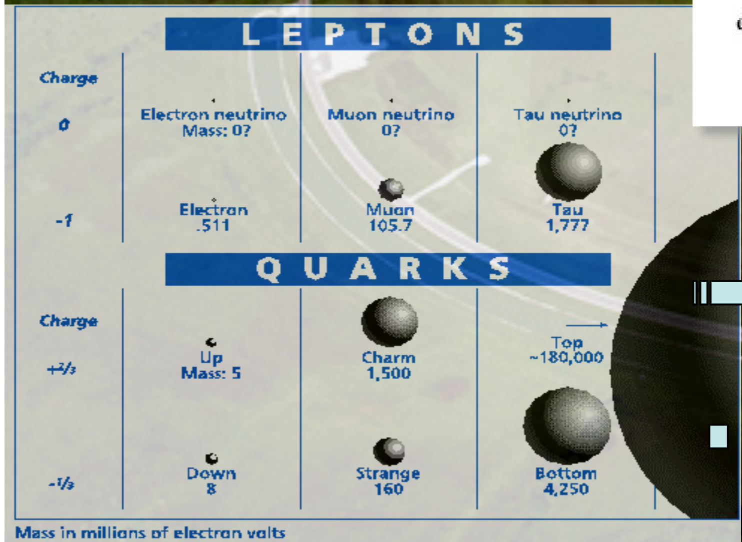
On behalf of the D0 and CDF Collaborations



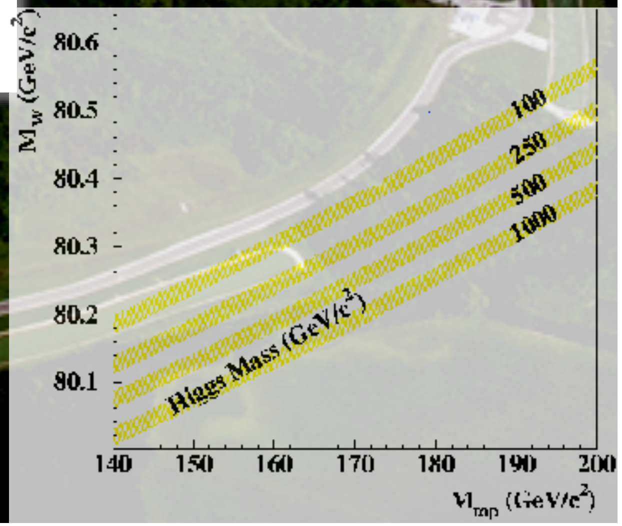
W

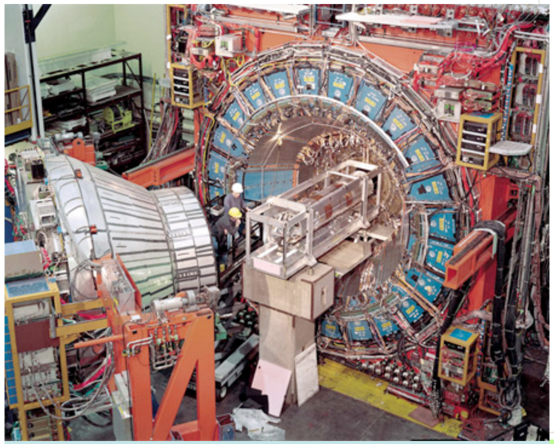
radiative corrections for M_W go as m_t^2, $\log(m_H)$

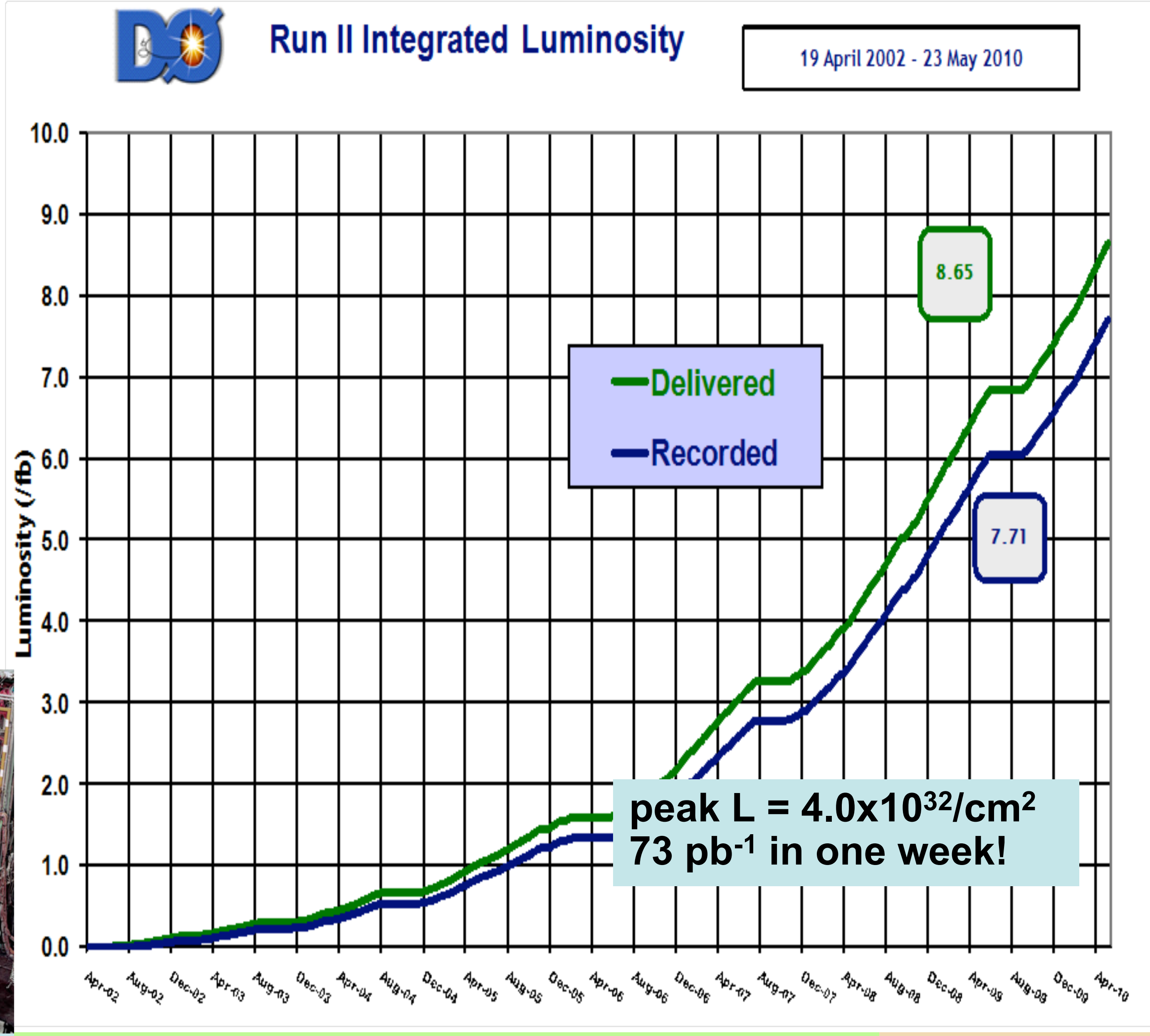


$$Y_t = m_t\sqrt{2}/v \approx 1$$

new physics?



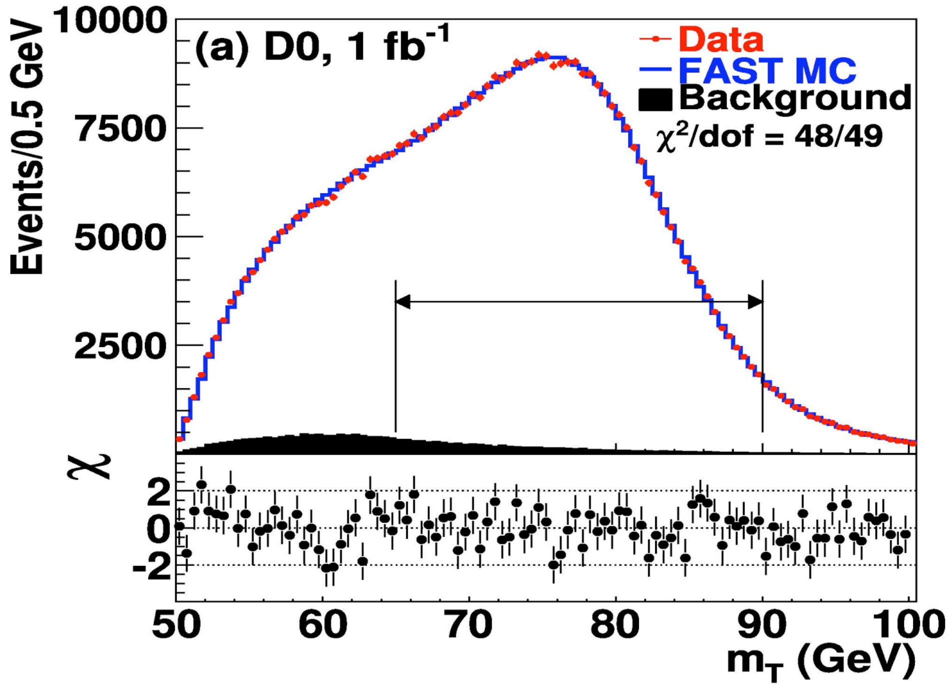




peak L = $4.0\times10^{32}/cm^2$
73 pb^{-1} in one week!

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

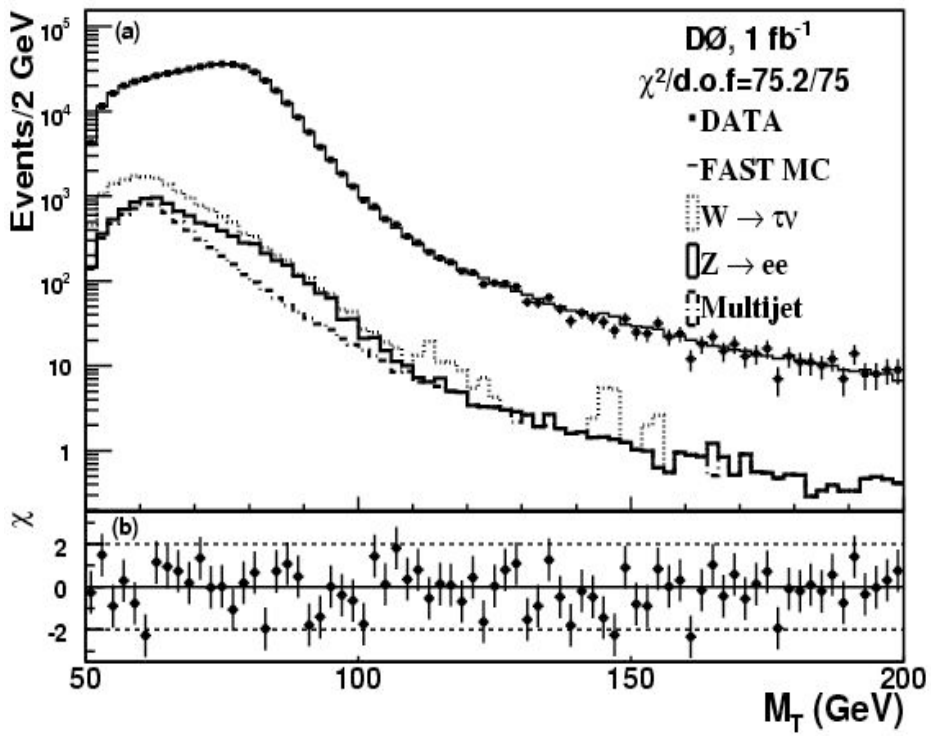


$$M_W = 80.401 \pm 0.021(\text{stat}) \pm 0.038(\text{syst})\ \text{GeV}$$

PRL 103:141801 (2009)

W Width Measurement

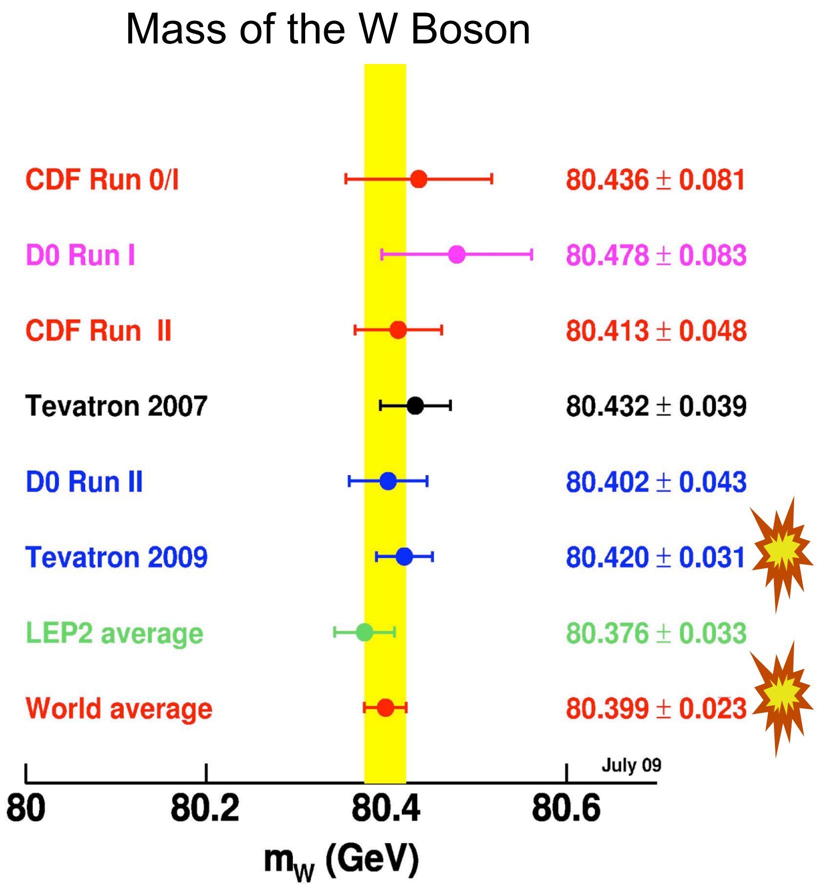
- Gauge structure of SM
  - Tight constraint on Γ_W
  - New heavy particles modify radiative corrections
- New D0 measurement
  - 1 fb^{-1} $W \rightarrow e\nu$
  - Method:
    - $100 < m_T < 200$ GeV
    - Orthogonal sample to M_W
  - Recoil studied using $Z \rightarrow ee$ data
  - Main systematics: 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



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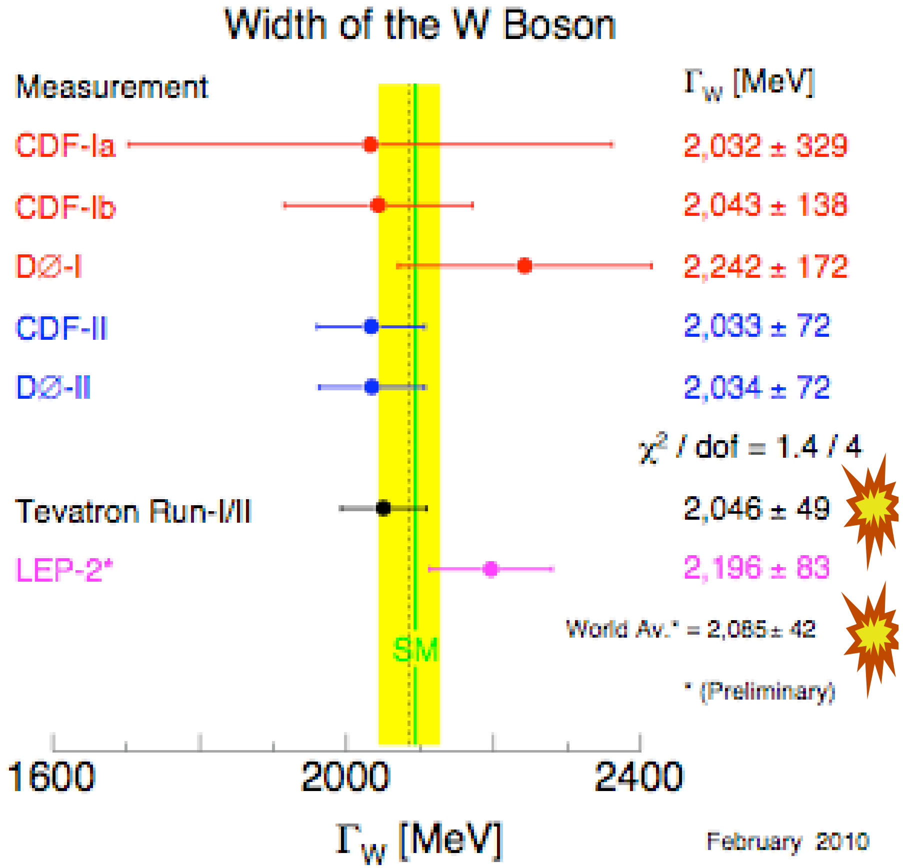


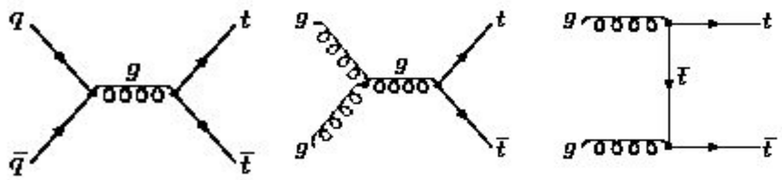
FERMILAB-TM-2490-E

Correct for

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

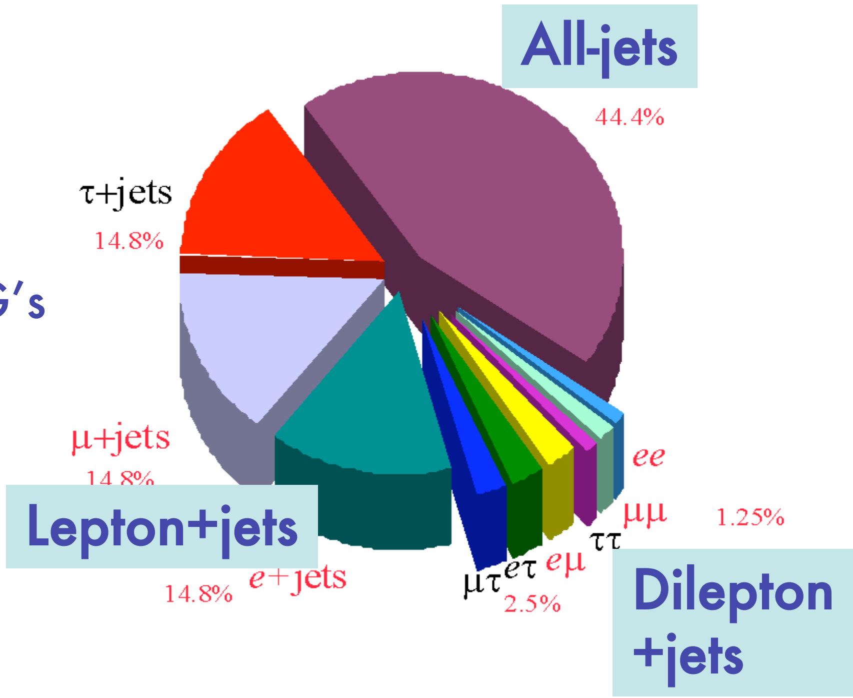
$$\Gamma_W = 2.093 \pm 0.002 \text{ GeV (SM)}$$

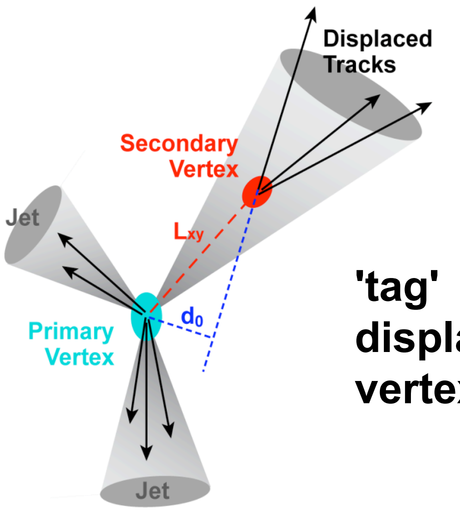
Observing the Top Quark

- 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

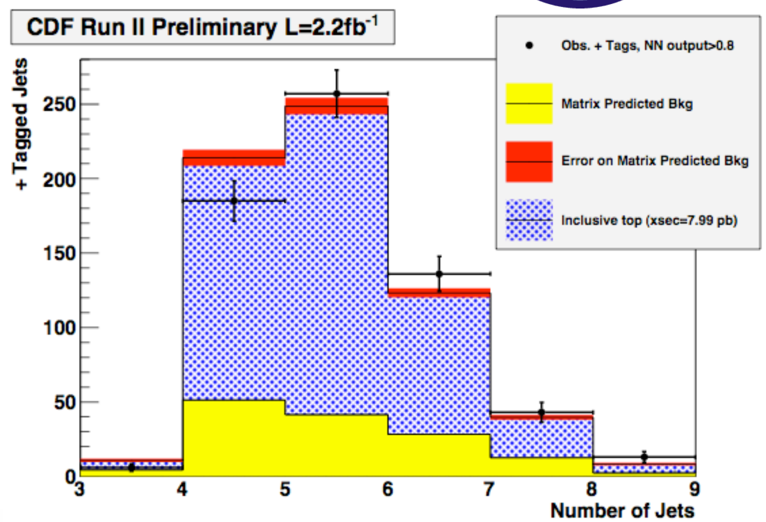
Top Pair Cross Section

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

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

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

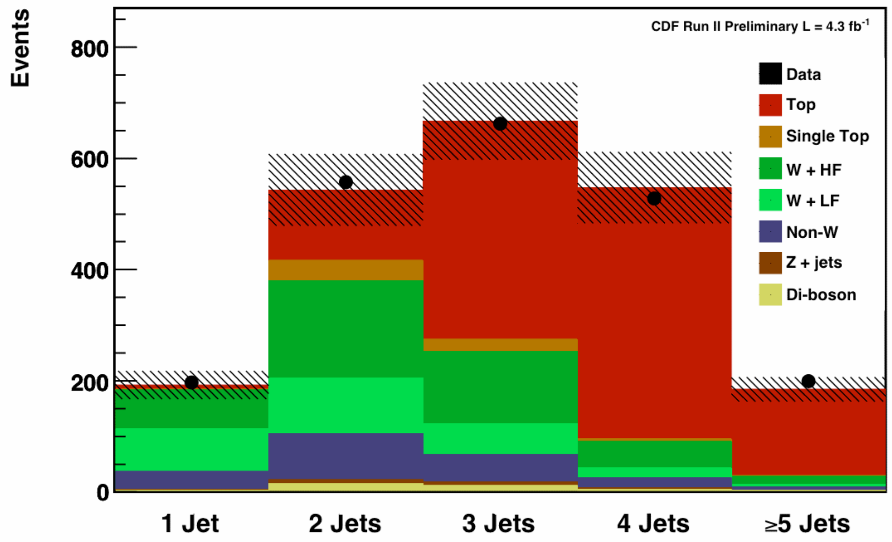
CDF-CONF-9988



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

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

arXiv:1004.3224

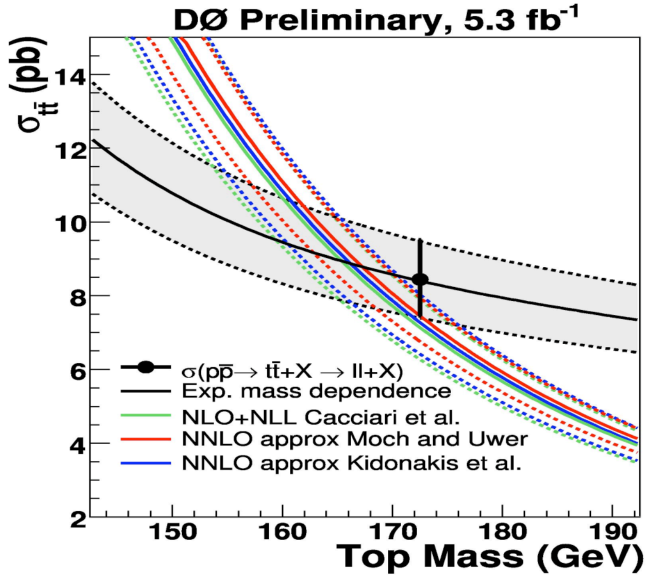


Top Pair Cross Section

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

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

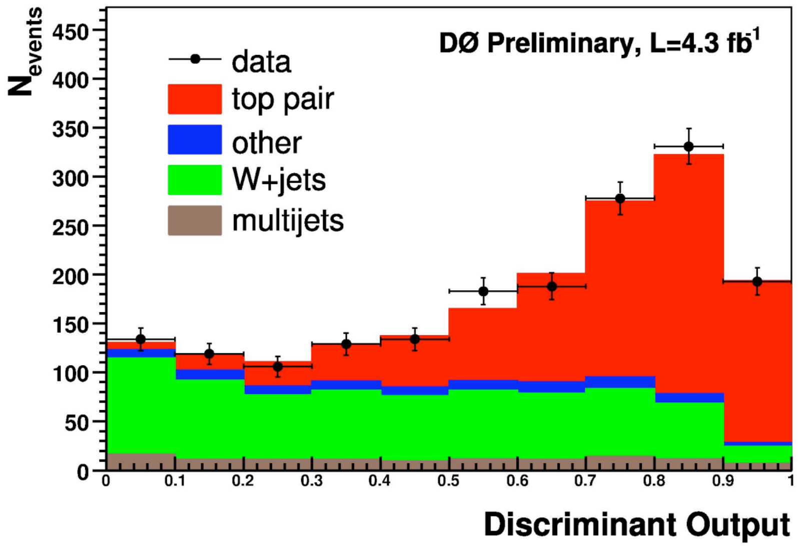
D0-CONF-6038



- 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

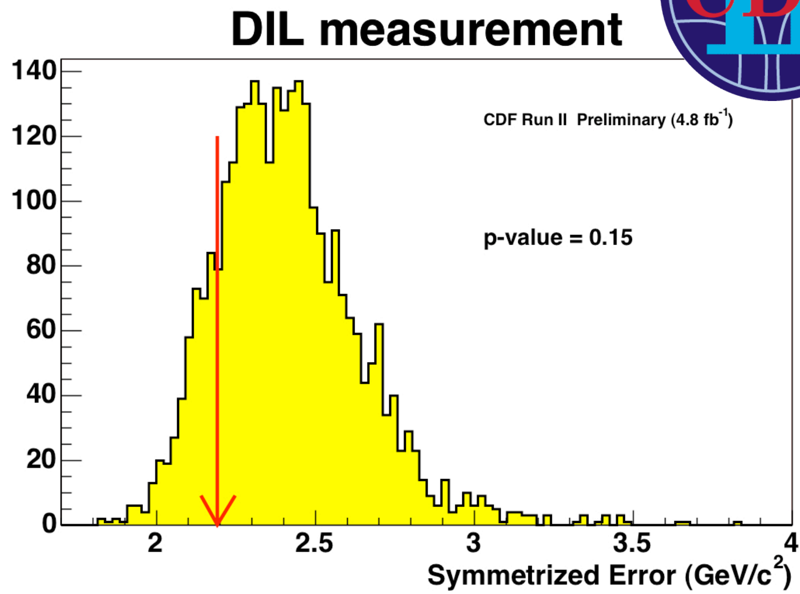


Top Mass Analyses

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

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

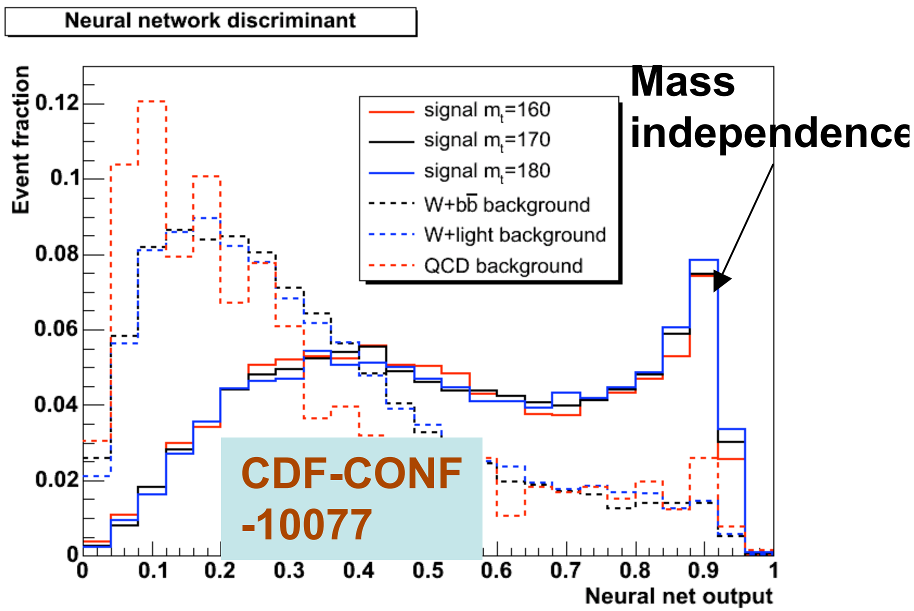
CDF-CONF-10033



- 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

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

CDF-NOTE-9714

  - Will improve

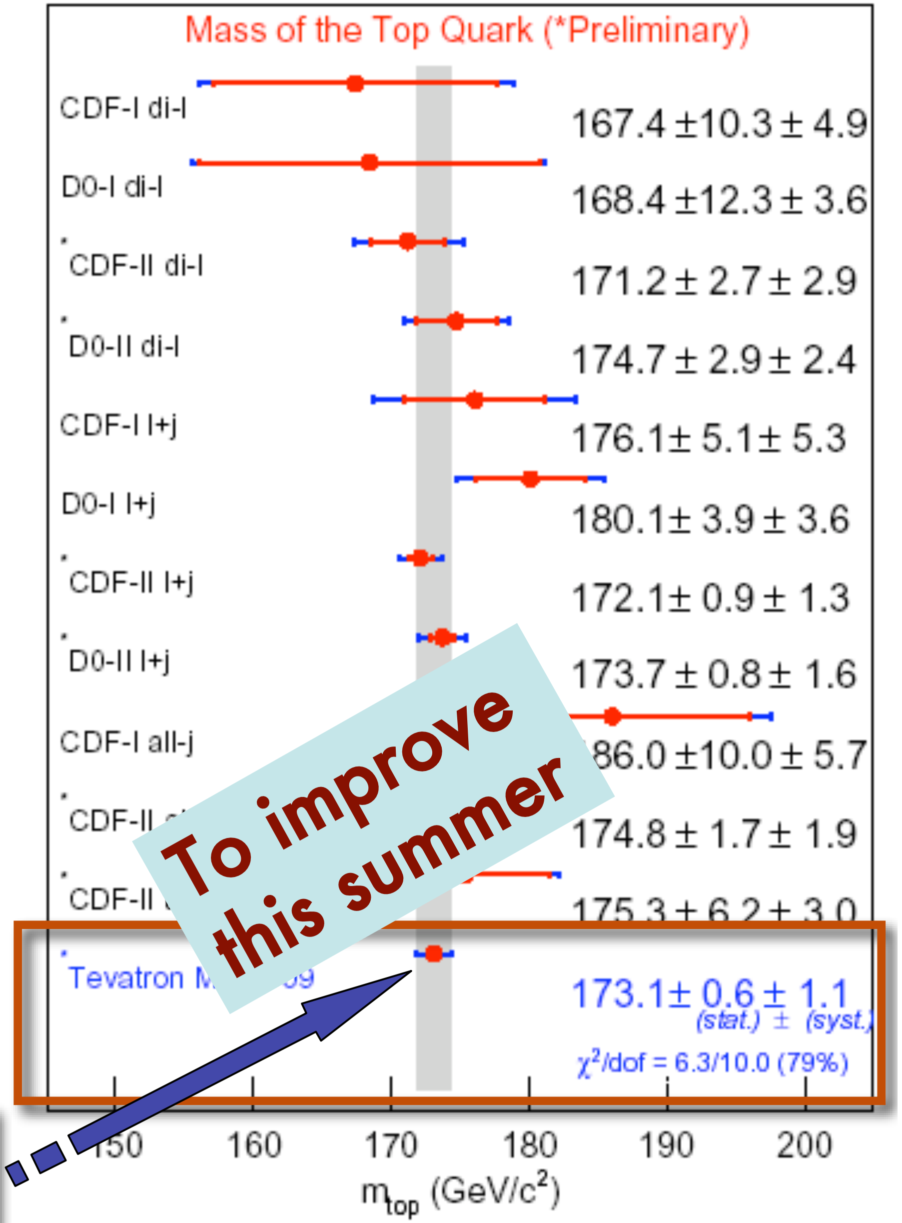
- Combination of all D0 results
  - Runs I and II
  - Dilepton, l+jets

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

D0-CONF-5900

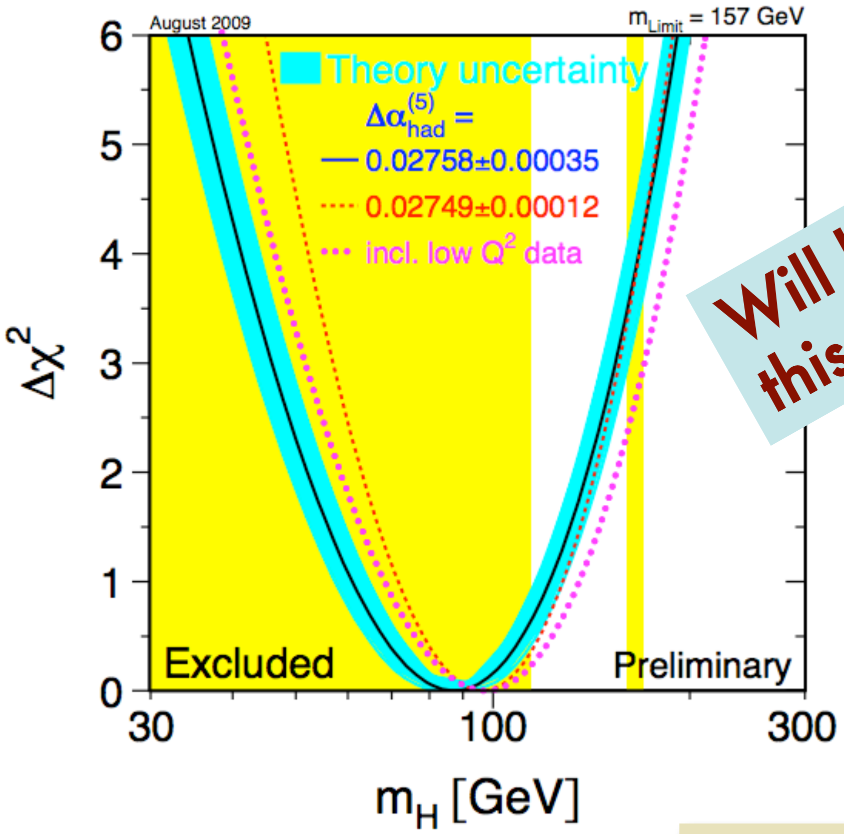
- Should achieve 1 GeV uncertainty from Run II

FERMILAB-TM-2427-E
arXiv:0903.2503

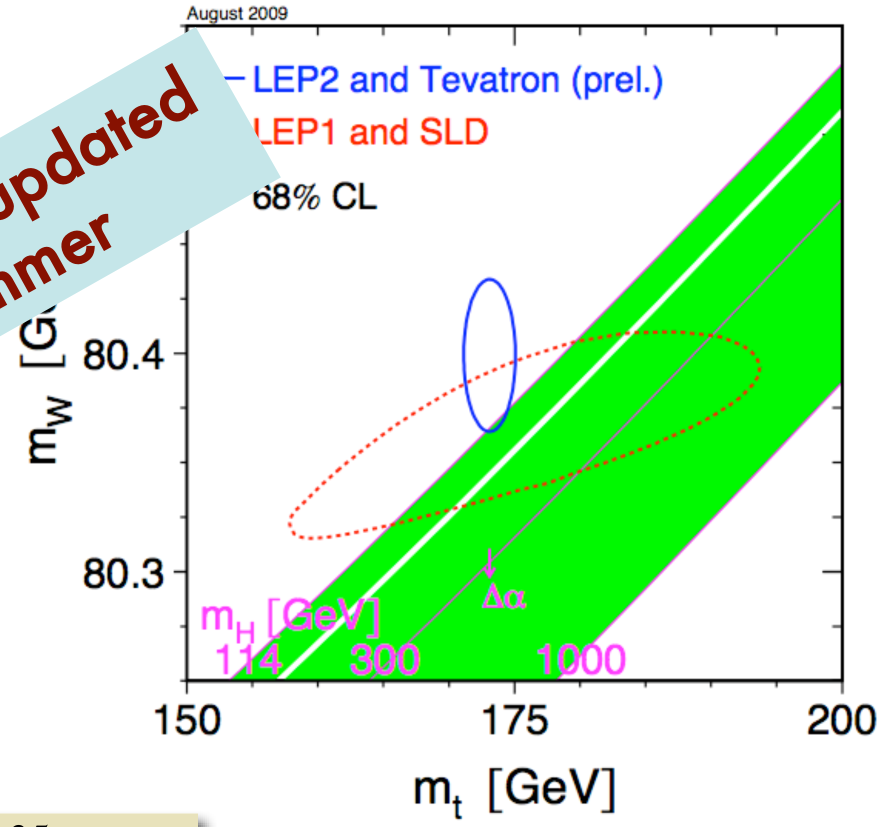


ElectroWeak Fits

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



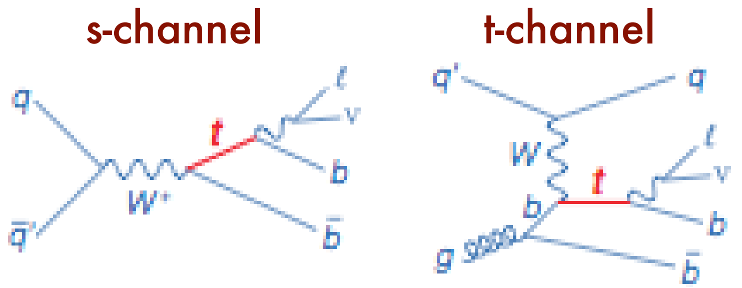
Will be updated this summer



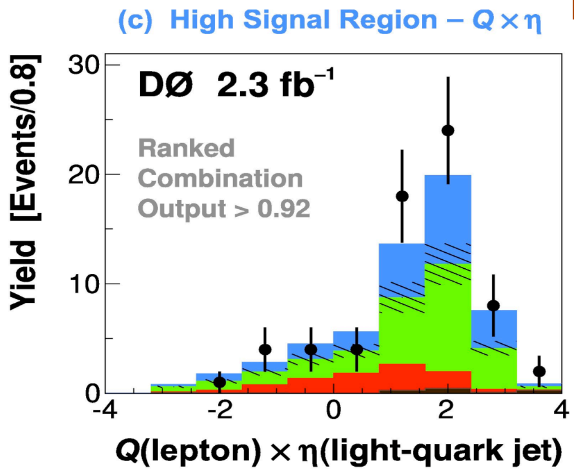
$$m_H = 87^{+35}_{-26}\,\mathrm{GeV}$$

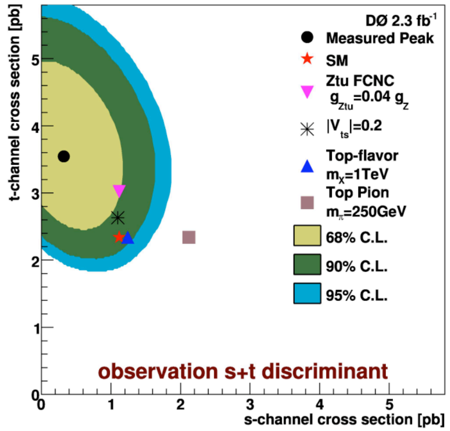
Single Top Production

- 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

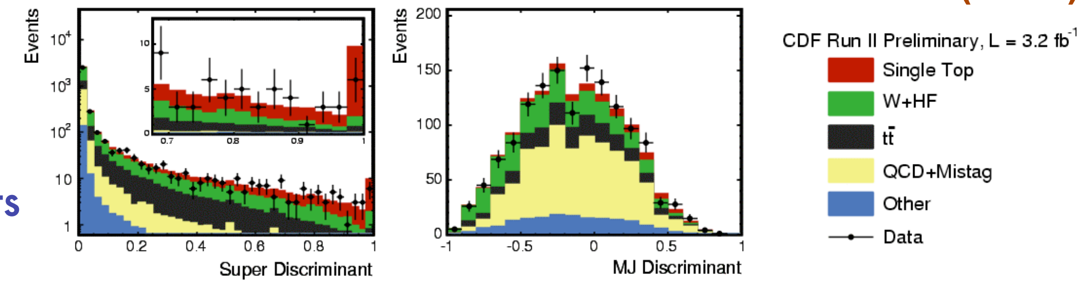


PRL 103:092001 (2009)





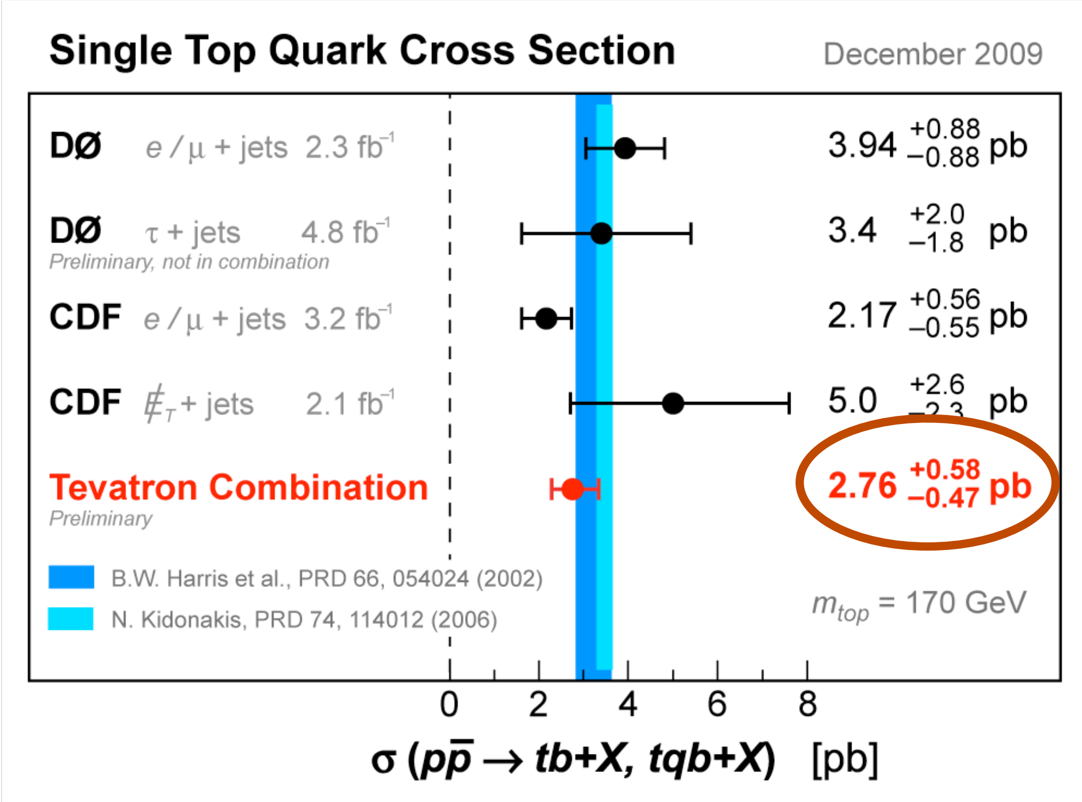
PRL 103:092002 (2009)



World Average

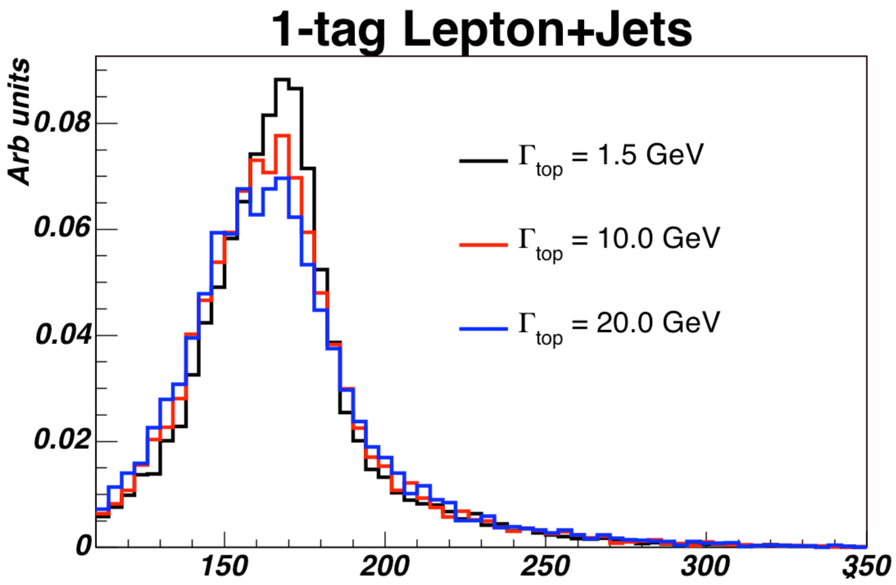
- Inputs
  - Utilize D0 and CDF distributions of multivariate discriminants
  - Consistent top quark mass
    - M_t = 170 GeV
  - Consistent cross section
    - To obtain V_{tb}

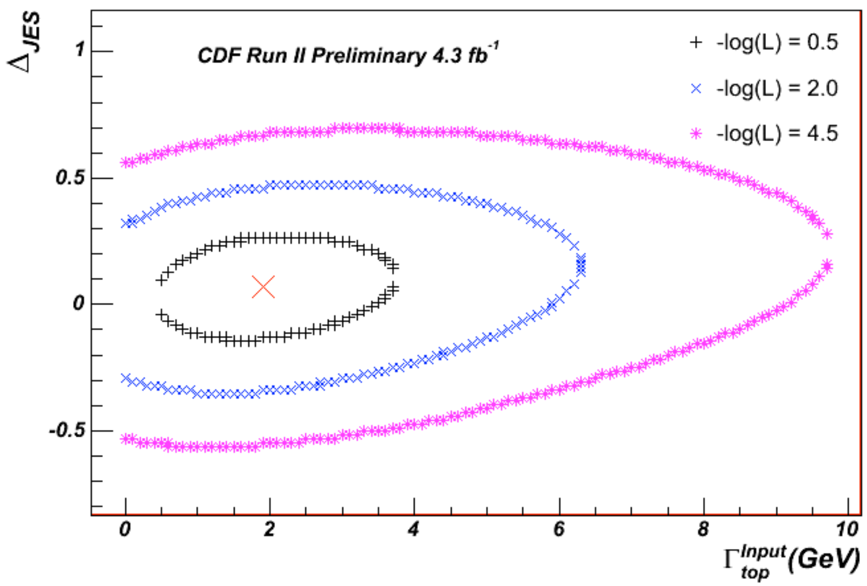
$$|V_{tb}| = 0.88 \pm 0.07 \text{ @ } 95\% \text{ c.l.}$$
$$> 0.77 \text{ @ } 95\% \text{ c.l.}$$



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:

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

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

CDF-CONF-10035

Top Width

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

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

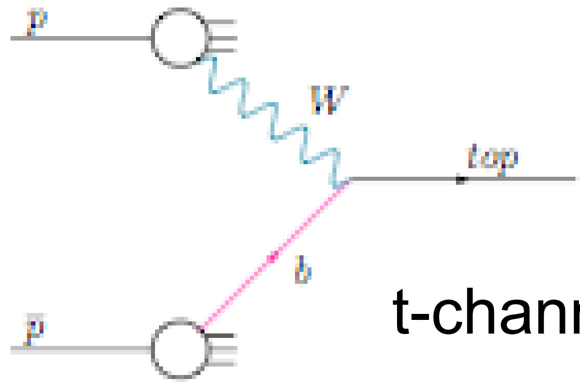
- Assume no flavor changing neutral currents, and V_{ts} and V_{td} small

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

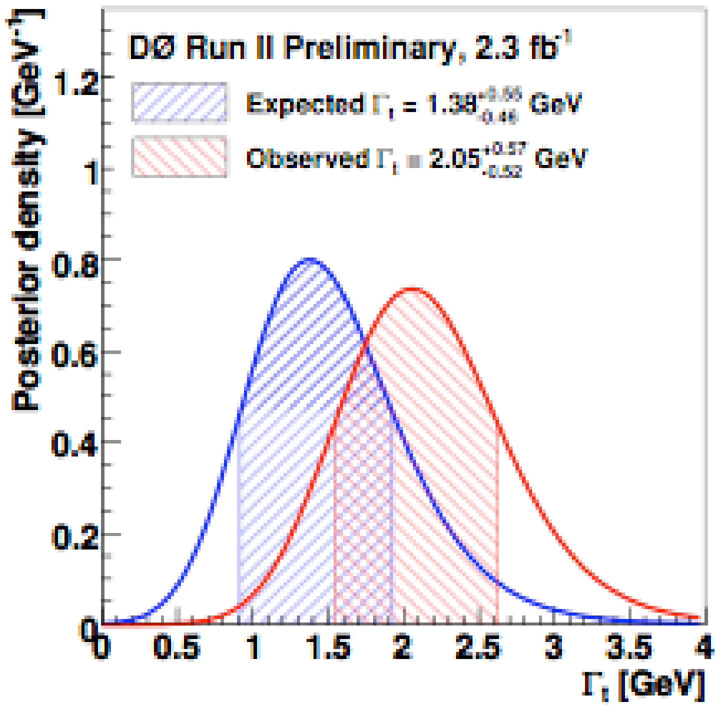
$$\tau_{top} = 3.2^{+1.1}_{-0.7} \times 10^{-25}\ \mathrm{s}$$

D0-CONF-6034

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



t-channel

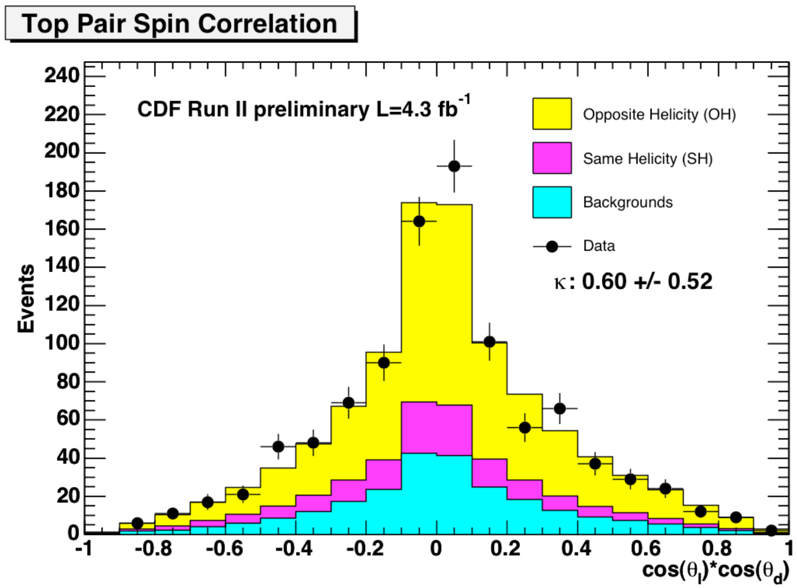


Top Spin Correlations

- 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



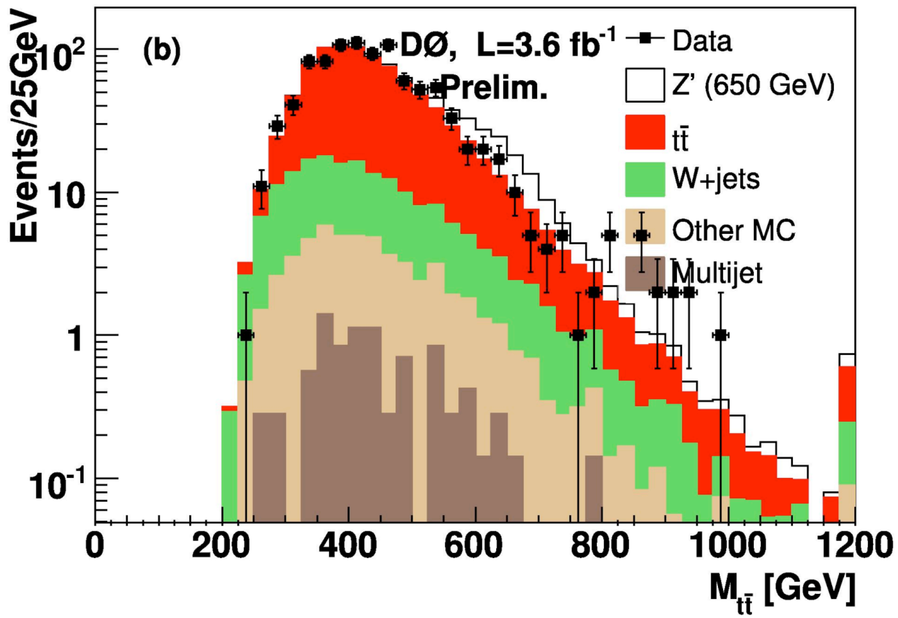
- D0 measurement in dilepton events

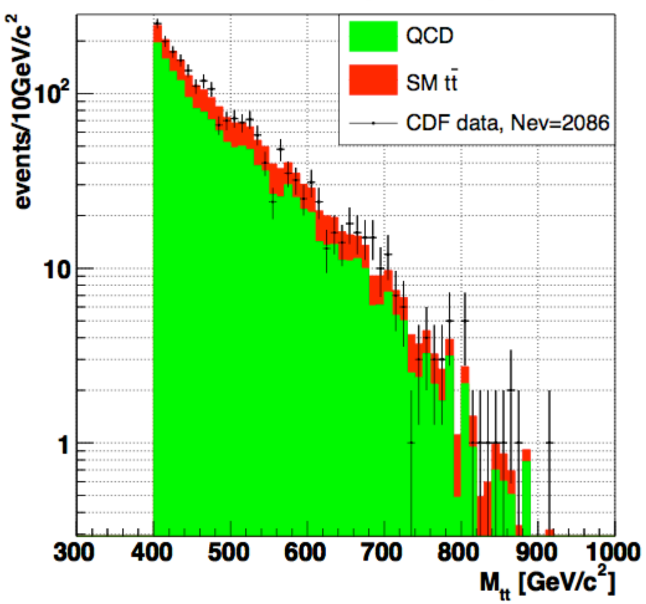
$$\kappa(\text{different basis}) = -0.17^{+0.64}_{-0.53}$$

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

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

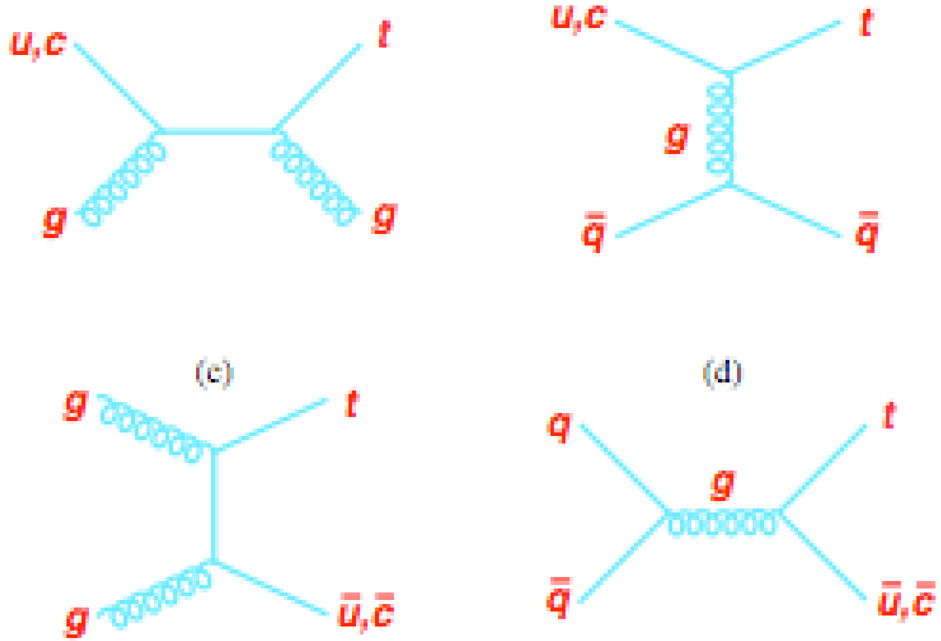
D0-CONF-5882

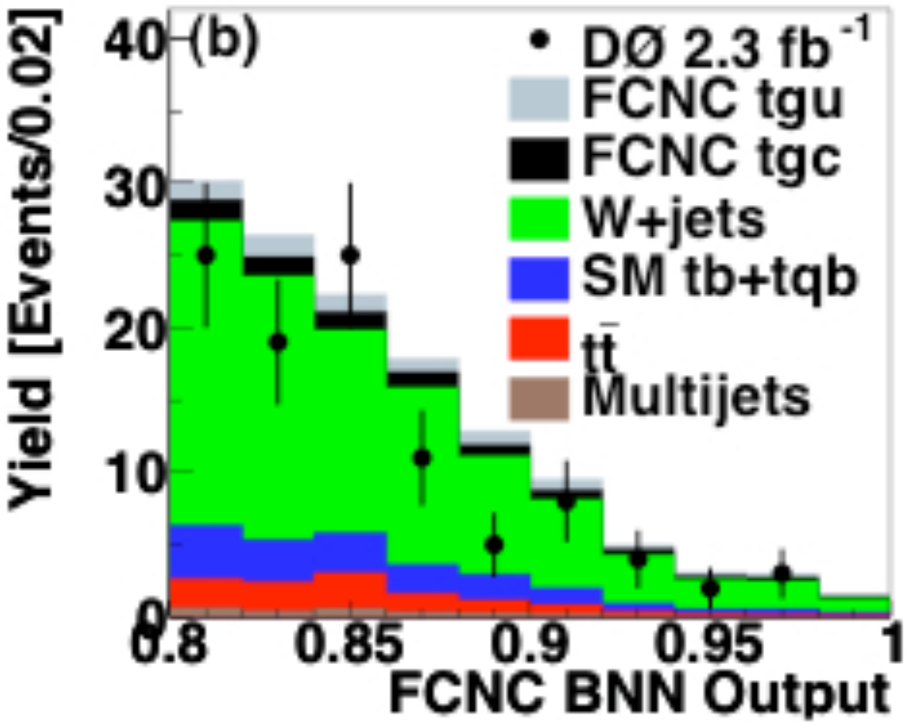
- CDF search
  - all-jets channel
  - 2.8 fb^{-1}
  - Matrix-element based discriminant

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

CDF-CONF-9844

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

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