Electroweak Measurements and Top Quark Properties at the Tevatron

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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 $L = 4.0 \times 10^{32}/\text{cm}^2$ 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
- $W \rightarrow e\nu$ mode in 1 fb$^{-1}$
  - 499,830 W’s
  - 18,725 $Z \rightarrow ee$’s for calibration
- Blind analysis
  - Arbitrary scale factor applied to all three measurements simultaneously
  - Analysis finished, then blinding removed
- Analysis in $p_T^e$, $E_T^{\text{miss}}$ 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 $\Gamma_w$
  - 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 $\Gamma_W$

Mass of the W Boson

- CDF Run 0/I: $80.436 \pm 0.081$ GeV
- D0 Run I: $80.478 \pm 0.083$ GeV
- CDF Run II: $80.413 \pm 0.048$ GeV
- Tevatron 2007: $80.432 \pm 0.039$ GeV
- D0 Run II: $80.402 \pm 0.043$ GeV
- Tevatron 2009: $80.420 \pm 0.031$ GeV
- LEP2 average: $80.376 \pm 0.033$ GeV
- World average: $80.399 \pm 0.023$ GeV

Width of the W Boson

- CDF-Ia: $2.032 \pm 0.329$ MeV
- CDF-Ib: $2.043 \pm 0.138$ MeV
- DØ-I: $2.242 \pm 0.172$ MeV
- CDF-II: $2.033 \pm 0.72$ MeV
- DØ-II: $2.034 \pm 0.72$ MeV
- Tevatron Run-I/II: $2.046 \pm 0.49$ MeV
- LEP-2*: $2.196 \pm 0.83$ MeV

$\Gamma_W = 2.093 \pm 0.002$ GeV (SM)

Correct for
- Use consistent PDFs: CTEQ6M
- Use new world avg. $M_w$
Observing the Top Quark

- Production:

- Decays (BR(\(t \rightarrow Wb\)) \(\sim\) 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

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

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

CDF-CONF-9988

- **Lepton+jets**
  - 4.6 fb\(^{-1}\)
  - Topological and b-tag
  - Normalize to known Z/\(\gamma^*\) cross section

  - Removes lumi. uncertainty

\[ \sigma_{tt} = 7.70 \pm 0.52 \text{ pb} \]

arXiv:1004.3224

CDF Run II Preliminary L=2.2fb\(^{-1}\)

CDF Run II Preliminary L=4.3fb\(^{-1}\)
• **dilepton channel**
  - Main background: Z+jets, diboson+jets, instrumental
  - 5.3 fb⁻¹ total data
  - Boosted decision tree discriminant, ee and \(\mu\mu\) channels

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

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 \( \geq 1 \) 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

To improve this summer
ElectroWeak Fits

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

\[ m_H = 87^{+35}_{-26} \text{ GeV} \]
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
- 5.0\(\sigma\) excess observed for each experiment
**Inputs**
- Utilize D0 and CDF distributions of multivariate discriminants
- Consistent top quark mass
  - $M_t = 170$ GeV
- Consistent cross section
  - To obtain $V_{tb}$

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

1-tag Lepton+Jets

- 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:
  - $\Gamma_{\text{top}} < 7.5$ GeV (95% c.l.)
  - $0.4 < \Gamma_{\text{top}} < 4.4$ 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

$$\Gamma_{top} = 2.05^{+0.57}_{-0.52} \text{ GeV}$$
$$\tau_{top} = 3.2^{+1.1}_{-0.7} \times 10^{-25} \text{ s}$$

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

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

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

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

D0-CONF-5882

- CDF search
  - all-jets channel
  - 2.8 fb⁻¹
  - Matrix-element based discriminant

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

CDF-CONF-9844
Flavor Changing Neutral Currents

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

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

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→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 $p_T^{\text{top}}$, 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:
  \[ m_H = 87^{+35}_{-26} \text{ GeV} \]
  \[ < 157 \text{ GeV @ 95\% c.l.} \]