Top Quark Mass Measurements
at the D0 Experiment

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Motivation

- The top quark is the heaviest of all known fundamental particles and its mass is not predicted by the Standard Model.

- Measurements of the top quark mass and the W boson mass constrain the mass of the yet unobserved Higgs boson.

- As the Yukawa coupling of the top quark is close to one, it may play a special role in the electroweak-symmetry breaking.
D0 is one of the two general purpose detectors at the Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.96$ TeV.

The D0 detector is composed of three main sub-systems:
- tracking system
- calorimeter
- muon system.

Up to now, 5.3 fb$^{-1}$ of data recorded by the D0 detector.

Analyses shown here are based on up to 2.8 fb$^{-1}$ of data.
Top Quark Production and Decay

- At the Tevatron, top pairs are mainly produced via $q\bar{q}$ annihilation (85%).

- Decay channels are classified according to the W boson decay as $\text{Br}(t \rightarrow Wb) \equiv 100\%$.

- The dilepton channel is characterized by 2 b jets, 2 leptons (e, mu) and missing transverse energy due to the 2 undetected neutrinos.

$\Rightarrow$ The reconstruction of the top mass is under-constrained.

- Lepton+Jets decay is characterized by 4 jets, 1 lepton and missing transverse energy from the undetected neutrino.
Neutrino Weighting Method

- dilepton channel

Matrix Element Method

- dilepton channel
- lepton+jets channel

Top Quark Mass from Cross Section
Neutrino Weighting Method

- Neutrino Weighting method is based on templates.
- Besides top and W mass, different hypotheses of neutrino rapidities are used to calculate the neutrino momenta.
- Comparing the measured missing transverse energy to the neutrino momenta, each event can be assigned a weight:

\[
w(m_{\text{top}}) = \frac{1}{n_{\text{sol}} \sum_{i=0}^{n_{\text{sol}}}} \exp\left(\frac{-\left(\vec{E}_T - \vec{p}_T^{\nu_1}(m_{\text{top}}) - \vec{p}_T^{\nu_2}(m_{\text{top}})\right)^2}{2\sigma^2_{\vec{p}_T}}\right)
\]

- The top mass is extracted from a maximum likelihood fit to templates based on the fitted mean and rms of these weight distributions.
Neutrino Weighting Result

- Method calibrated with simulated top pair events and main background (Z+jets, WW, WZ, ZZ).
- Measurement is based on 83 dilepton candidate events of D0 Run IIa (1.0 fb⁻¹) data.
- Top mass is measured to be:
  \[176.0 \pm 5.3 \text{ (stat.)} \pm 2.0 \text{ (syst.) GeV}.\]
- Systematic uncertainties dominated by the jet energy scale (1.7 GeV).
Neutrino Weighting Method
- dilepton channel

Matrix Element Method
- dilepton channel
- lepton+jets channel

Top Quark Mass from Cross Section
Matrix Element Method

- Matrix Element method makes use of maximum kinematic information.
- Assuming a certain top mass the signal likelihood is

\[
P_{\text{sgn}}(x; m_{\text{top}}) = \frac{1}{\sigma_{\text{obs}}} \int \sum_{\text{flavors}} dq_1 dq_2 dy f(q_1) f(q_2) \frac{(2\pi)^4 |M|^2}{\sqrt{(q_1 \cdot q_2)^2}} W(x, y)
\]

with the PDFs, \( f(q) \), the matrix element, \( M \), transfer functions, \( W(x, y) \), mapping true four-momenta \( y \) to measured \( x \).
- Top mass extracted from likelihood fit of the event probabilities:

\[
P_{\text{evt}}(x; m_{\text{top}}) = f_{\text{top}} \cdot P_{\text{sgn}}(x; m_{\text{top}}) + \sum_{\text{bkg}} f_{\text{bkg}} \cdot P_{\text{bkg}}(x)
\]
- Method calibrated with simulated top pair events and main background (Z+jets, WW, WZ, ZZ).
- Measurement is based on 107 electron+muon candidate events of D0 Run II (2.8 fb⁻¹) data.
- Top mass is measured to be: 172.9 ± 3.6 (stat.) ± 2.3 (syst.) GeV.
- Systematic uncertainties dominated by the jet energy scale (2.0 GeV).
Measurements

Neutrino Weighting Method

♦ dilepton channel

Matrix Element Method

♦ dilepton channel

♦ lepton+jets channel

Top Quark Mass from Cross Section
Simultaneous Measurement of $m_{\text{top}}$ vs. JES

- **Largest systematic uncertainty** on the top quark mass from the uncertainty on the jet energy scale.
- Measurement of an overall jet energy scale factor on top of the nominal correction possible in the lepton+jets channel due to the **W mass constraint**.

$\Rightarrow$ Systematic uncertainty can be significantly reduced in the lepton+jets channel by a simultaneously fit of $m_{\text{top}}$ and JES.
Measurement using Lepton+Jets Events

- Method calibrated with simulated top pair events and main background (W+jets, Z+jets).
- Run II (2.2 fb\(^{-1}\)) measurement based on 491 lepton+jets events requiring one jet to be b tagged.
- In Run IIb, JES measured to be:
  \[1.040 \pm 0.015 \text{ (stat.+m}_{\text{top}})\].
- Top mass measured with 2.2 fb\(^{-1}\) to be:
  \[172.2 \pm 1.0 \text{ (stat.+JES)} \pm 1.4 \text{ (syst.) GeV}.\]
Measurements

Neutrino Weighting Method
- dilepton channel

Matrix Element Method
- dilepton channel
- lepton+jets channel

Top Quark Mass from Cross Section
Top Quark Mass from Cross Section

- The definition of the top quark mass is convention-dependent.
- Implementation in Monte Carlo only close to the pole mass.
- Extraction of the top quark mass from the top pair production cross section allows for an unambiguous interpretation in the pole mass definition.
- Comparison of the measured cross section to the theoretical $\text{NNLO}_{\text{approx}}$ prediction yields: $m_{\text{top}} = 169.6 \pm 5.5 \text{ (stat.+syst.) GeV}$.
- Result consistent with direct measurements.
**Summary**

- **Current world average of the top quark mass including up to 2.8 fb\(^{-1}\) of Tevatron data:**
  
  \[ 172.4 \pm 0.7 \text{ (stat.)} \pm 1.0 \text{ (syst.) GeV} \]

- **New combination and new results expected end of next week!**