Electroweak and Top physics at the Tevatron and indirect Higgs Limits

Sandra Leone (INFN Pisa) for the CDF and DØ Collaborations

SUSY07 Karlsruhe, July 28th 2007
Outline

- The Tevatron & the experiments
- $W$ and $Z$ boson physics:
  - $W$ & $Z$ Cross section
  - $W$ Mass and Width
  - inputs to PDF from $W/Z$ data
  - Diboson production
- Top quark physics:
  - Pair production cross section
  - Top mass measurements
  - Single top production
- A global look at the Standard Model:
  - Indirect limit on the Higgs Mass from EWK data
The Tevatron Collider

Run II: $\sqrt{s} = 1.96$ TeV

Performances have kept improving since the start of Run II. So far, 3 fb$^{-1}$ collisions have been delivered to CDF and D0

Peak Luminosities above $2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$ now common

Current Record initial lum: $2.92 \times 10^{32}$ cm$^{-2}$ s$^{-1}$

Record Integrated luminosity per week $\sim 45$ pb$^{-1}$
2 General purpose detectors capable of many different physics measurements

- 13 countries
- 62 institutions
- >600 authors

- 18 countries
- 89 institutions
- >600 authors
Integrated Luminosity

Start of physics-quality data on tape ~2.5 fb⁻¹
delivered: ~ 3 fb⁻¹

Detectors running stably since Feb. '02
Data taking efficiency L(recorded)/L(delivered) commonly > 85%

All results shown in the following based on datasets ranging from ~200 pb⁻¹ to ~1.7 fb⁻¹
W/Z Gauge Bosons Identification

- At Tevatron W and Z hadronic decays are overwhelmed by QCD bckg
  ⇒ Identification through leptonic decays
- W/Z identification is a key ingredient for top physics and searches
  ⇒ Often background for rare processes
  ⇒ Fundamental tools for calibrations and detector checks
- CDF and D0 are using the millions of W and Z boson decays collected, to produce excellent measurements of electroweak observables

CDF and D0 are using the millions of W and Z boson decays collected, to produce excellent measurements of electroweak observables.
Inclusive W/Z Cross Sections

The cross section for inclusive W and Z boson production measured in all leptonic final states ($W \rightarrow e\nu$, $\mu\nu$, $\tau\nu$; $Z \rightarrow ee$, $\mu\mu$, $\tau\tau$) by CDF and D0

- Overall good agreement with the NNLO calculations (Stirling, Van Neerven)
- Accuracy limited by the systematic effects: dominated by the luminosity error (~6%), followed by PDF uncertainties (~2%) in $e/\mu$, and tau algo in $\tau$ channels
\[\frac{d\sigma}{dy}\] distribution of Drell-Yan \(Z/\gamma^* \rightarrow e^+e^-\)

- Measurement of the rapidity distribution and differential cross section of Drell Yan pairs can provide a stringent test of QCD.

- NNLO calculation with NLO CTEQ6.1 PDF theory prediction compared to data.

- Theory prediction scaled to measured \(\sigma(Z)\)

- \(\sigma = 263.34 \pm 0.93\) (stat.) \(\pm 3.79\) (sys.) pb.

- The agreement with theory is good,
- this measurement -with increasing statistics- can be used to constrain PDFs.
CDF published the first attempt to constrain PDFs using the ratio of $W$ boson cross sections measured with central and forward electrons.

$\Rightarrow$ provide sensitivity to the $W$ rapidity

- The largest experimental uncertainty, (luminosity), cancels in this ratio.
- Experimental ratio can be compared with acceptance ratios predicted by any set of PDFs.

- $R_{\text{exp}} = 0.925 \pm 0.033$
- The theoretical NLO predictions are:
  - $R_{\text{CTEQ}} = 0.924 \pm 0.031$
  - $R_{\text{MRST01E}} = 0.941 \pm 0.012$

PRL 98, 251801 (2007)
$W^\pm$ mass fundamental parameter of SM

- Radiative corrections: depends on $M_{\text{top}}$ and $M_{\text{Higgs}}$
  - $W$ propagator includes $H$, $tb$, hypothetical new particle loops

$$\Delta m_W \propto m_t^2$$

$$\Delta m_W \propto \ln m_H^2$$

- $W$ mass obtained from fit of transverse mass $M_T(l\nu)$:

$$M_T = \sqrt{2p_T^l p_T^{l'}} (1 - \cos \phi_{l\nu})$$

- Lepton Momentum
  - calibrate from $J/\psi$ and upsilons
  - cross check with $Z \rightarrow \mu\mu$
$M_W = 80413 \pm 48$ MeV

the best single-experiment result, now statistically limited

Submitted to PRL hep-ex/0707.0085

SUSY07 Karlsruhe, July 28th 2007

Sandra Leone INFN Pisa
Direct measurement of $\Gamma_W$

- Determine $W$ width using the tail of $M_T(l\nu)$ distribution
  - D0 finds $\Gamma_W = 2011 \pm 142$ MeV (177 pb$^{-1}$, e)
  - CDF finds $\Gamma_W = 2032 \pm 71$ MeV (350 pb$^{-1}$, e, $\mu$)

CDF result is the world's most precise single direct measurement

SUSY07 Karlsruhe, July 28th 2007
Summary for $M_W$ and $\Gamma_W$

- CDF has most precise single experiment measurements of the W boson mass and width.

Reduces uncertainty on world average by 15%:

- $29 \rightarrow 25$ MeV

Reduces uncertainty on world average by 22%:

- $60 \rightarrow 47$ MeV
Study of diboson production:

- Test Gauge Boson Self Interactions
- Intermediate step towards SM Higgs searches

Both experiments measured inclusive cross sections for:

- $WW$ (PRL 94, 151801(2005), hep-ex/0605066)
- $WZ$ -$ZZ$
- $W\gamma$
- $Z\gamma$ (hep-ex/0705.1550)
The interference among the tree-level diagrams below creates a zero amplitude for \( \cos(\theta^*) = -(1 + 2Q_d) \) (measure \( \eta_\gamma - \eta_{\text{lepton}} \), not \( \theta^* \)).

Observing the (destructive) interference in \( W\gamma \) (trilinear vertex) is a test of the SM gauge structure.

\[ CDF \Rightarrow \sigma(W+\gamma) = 18.0 \pm 2.8 \text{ pb} \ (1.1 \text{ fb}^{-1}) \]

\[ D0(E_T\gamma > 7\text{GeV}, M_T(l,\gamma,\text{MET}) > 90) \Rightarrow \sigma(W+\gamma) = 3.2 \pm 0.5 \pm 0.2(\text{lum})\text{pb} \]
WZ Cross Section Measurement

Require 3 e,μ leptons and missing tranverse energy

NLO:
\[ \sigma = 3.7 \pm 0.1 \text{ pb} \]

CDF: Significant improvements in lepton acceptance by forming leptons from all the available information

CDF Run II Preliminary

DO: 12 events (BG ~ 3.6)

Significance: \(3.3 \sigma \) (summer 06)

\[ \sigma(p\bar{p} \rightarrow WZ) = 3.98^{+1.91}_{-1.53} \text{ pb}\text{(stat + syst)} \]

Observation: \( \sim 6 \sigma \)

\[ \sigma(p\bar{p} \rightarrow WZ) = 5.0^{+1.8}_{-1.6} \text{ pb} \]

16 candidates, (BG ~ 2.7) expected 12.5

PRL 98, 161801 (2007)
First hints of ZZ

- $pp \rightarrow ZZ$ is the smallest $\sigma$ measured at the Tevatron: $\sigma_{\text{NLO}} = 1.4 \text{ pb}$
- D0: 1 $ee\mu\mu$ candidate, expected $\sim 1.5$: $\sigma < 4.3 \text{ pb (95\%CL)}$
- CDF has combined $41 \& 11\nu\nu$ channel:
  - $1 e\mu\mu$ candidate; expected $\sim 2.5$
  - For $\nu\nu$ use an event-by-event probability and construct a discriminant which is fit to extract the signal

$$\sigma(pp \rightarrow ZZ) = 0.75^{+0.71}_{-0.54} \text{ pb}$$

- Significance : $3.0 \sigma$
- CDF is updating the WZ and ZZ results soon with 2 $\text{fb}^{-1}$ “stay tuned ...”
The top quark is a very special particle:
- Heavier than all known particles
- Decays before hadronizing: $\Gamma_{\text{top}} \approx 1.5 \text{ GeV} > \Lambda_{\text{QCD}}$

Top discovery 12 years ago, since then many top studies performed to answer the question: is what we call “top quark” adequately described by the Standard Model?

Still many open questions:
- Why is the top mass so large?
- Why is its Yukawa coupling ~ 1?
- Does top play a special role in EWSB?

(see S. Cabrera talk for a review of top properties studies and search for new physics in the top samples)
Top Quark Production at Tevatron

- **QCD pair production**
  \[\sigma_{NLO} = 6.7 \text{ pb} \]
  (for \(m_{\text{Top}} = 175 \text{ GeV}\))

- **EWK single-top production**
  - **s-channel**
    \[\sigma_{NLO} = 0.9 \text{ pb}\]
  - **t-channel**
    \[\sigma_{NLO} = 2.0 \text{ pb}\]
  (Both for \(m_{\text{Top}} = 175 \text{ GeV}\))
  - First evidence in Dec. 2006

- \(\sigma\) smaller than top pair production, but allows direct access to \(V_{tb}\) CKM matrix element: cross section \(\propto |V_{tb}|\)
- Single top identification is challenging \(\Rightarrow\) huge background

SUSY07 Karlsruhe, July 28th 2007

Sandra Leone  INFN Pisa
**Top Quark Decay**

**SM predicts:** \( BR(t \rightarrow Wb) \approx 100\% \)

- e-e (1/81)
- mu-mu (1/81)
- tau-tau (1/81)
- e-mu (2/81)
- e-tau (2/81)
- mu-tau (2/81)
- e+jets (12/81)
- mu+jets (12/81)
- tau+jets (12/81)
- jets (36/81)

For \( \bar{t}t \) pairs decay:

- **Dilepton (ee, \( \mu\mu \), e\( \tau \))**
  \( \Rightarrow BR = 5\%, 2 \) high-\( P_T \) leptons + 2 b-jets + large missing-\( E_T \)

- **Lepton (e or \( \mu \)) + jets**
  \( \Rightarrow BR = 30\%, single lepton + 4 \) jets (2 from b’s) + missing-\( E_T \)

- **All Hadronic:**
  \( \Rightarrow BR = 44\%, six jets, no missing-ET \)

- \( \tau_{had} + X \)
  \( \Rightarrow BR = 21\% \)
Measurements of $\sigma_{tt}$

The top pair production cross section error $\sim 12\%$ similar to the theoretical one

$\rightarrow$ high-precision test of perturbative QCD calculations (now at NNLO - Cacciari, Kidonakis)

The cross section is measured in all final states: it is the first step of any analysis studying the top quark properties.

$$\sigma_{tt} = \frac{N_{\text{Data}} - N_{\text{Background}}}{\text{Acc} \int L dt}$$
Lepton + jets $\sigma_{tt}$ & $R$

- **Signature:** isolated high $p_T$ lepton, $E_T \geq 3$ jets
- $b$-jet identification technique based on a neural network, to count the number of events with 0, 1 and at least 2 $b$-jets.
- $R = \frac{B(t\rightarrow Wb)}{B(t\rightarrow Wq)}$ can be extracted simultaneously from the distribution of the observed events between the three categories.
- Likelihood discriminant based on the kinematic properties of $tt$ events is used to further constrain the number of $tt$ events without tagged jets.

$$R = 0.991^{+0.094}_{-0.085}(stat + syst),$$

$$\sigma(tt) = 8.10^{+0.87}_{-0.82}(stat + syst) \pm 0.49(lum) pb.$$

$R > 0.812 \ @ 95\%$

$|V_{tb}| > 0.901 \ @ 95\% \ CL \ assuming \ CKM \ unitarity$

$|V_{tb}| > 0.096 \ @ 95\% \ CL \ without \ CKM \ unitarity$
Lepton +jets $\sigma_{tt}$ & $R$

Predicted and observed number of events in the 0, 1 and 2 b-tag samples, for events with at least 4 jets

Zero-tag sample in bins of topological discriminant

Summary of $R$ at the Tevatron
Top Quark Mass Measurements

- Top mass is a fundamental SM parameter
- Measured by kinematic reconstruction, fit to invariant mass distribution
- Need to relate the reconstructed jets back to parton level:
  \[ \Rightarrow \text{Jet Energy Scale is crucial!} \]

- Many Methods exist, most precise top mass from Matrix Element Method in $\ell^+\text{jets}$:
  \[ \Rightarrow \text{Use four-vectors of reconstructed objects} \]
  \[ \Rightarrow \text{Calculate a probability per event to be signal or background as a function of the top mass} \]
  \[ \Rightarrow \text{Product of event probabilities used to extract the most likely mass} \]

- The mass of the jet pair from $W \rightarrow \text{jj}$ is used to obtain an internal constraint to the jet energy scale (JES).
Top quark mass measurement: $l + jets$

166 $W + 4$ jets ($\geq 1$ b-tag)

$tt$ candidates

$$M_{\text{top}} = 170.9 \pm 2.2(\text{stat.} + \text{JES}) \pm 1.4(\text{syst.}) \text{ GeV} = 170.9 \pm 2.6 \text{ GeV}$$

**Dominant Systematics**

- ISR/FSR Radiation $\pm 1.05$ GeV
- $b$ JES $\pm 0.60$ GeV
- JES Residual $\pm 0.42$ GeV
- $b$ tagging $\pm 0.31$ GeV
Top quark mass measurement: $\ell + \text{jets}$

- $\ell + \vec{E}_T 4 \text{ jets}$
- $P_{\text{sig}} = \text{sum over all 24 possible object-parton assignments, weighted with b-tagging event probabilities}$

$M_{\text{top}} = 170.5 \pm 2.4(\text{stat.} + \text{JES}) \pm 1.2(\text{syst.}) \text{ GeV} = 170.5 \pm 2.7 \text{ GeV}$

Dominant Systematics

- Relative $b$/light JES $\pm 0.57 \text{ GeV}$
- $b$ fragmentation $\pm 0.54 \text{ GeV}$
- Signal Fraction $\pm 0.58 \text{ GeV}$
- Signal Modeling $\pm 0.45 \text{ GeV}$
The top quark mass is known with a precision that was thought unreachable at the Tevatron only a few years ago:

\[ \Delta M / M \sim 1.1\% \]

of the order of the top natural width

 ⇒ be careful in interpreting the meaning of the measurement

⇒ both exp.s are addressing a number of effects that, too small to have an impact in the first measurements, can now become important.

⇒ reconsider which theoretical aspects are relevant, at the 1 GeV level, and whether they are sufficiently well under control.
W helicity in top decays is fixed by $M_{\text{top}}$, $M_W$, and V-A structure of the $tWb$ vertex. It is reflected in kinematics of $W$ decay products.

$W$ helicity states:

- Left-handed fraction: $f_-$
  - ~30%
- Longitudinal fraction: $f_0$
  - ~70%
- Right-handed fraction: $f_+$
  - ~0.036%

$⇒$ Measure angular distribution of charged lepton wrt. top in $W$ rest frame: $\cos\theta^*$

SUSY07 Karlsruhe, July 28th 2007

Sandra Leone INFN Pisa
W Helicity Measurement

- **DO** uses $\ell+$jets and $\ell\ell$ events
  
  With $F_0$ fixed to the SM value (1par):
  
  $F_+ = 0.017 \pm 0.048\,\text{(stat)} \pm 0.047\,\text{(syst)}$
  
  $F_+ < 0.14$ @ 95% CL

- **CDF** uses $\ell+ \geq 4$ jets, $\geq 1b$ tag
  
  1 parameter fit:
  
  $F_+ (F_0=0.7) = 0.01 \pm 0.05 \pm 0.03$
  
  $F_0 (F_+=0) = 0.65 \pm 0.10 \pm 0.06$
  
  $F_+ < 0.12$ @ 95% CL

  2 parameter fit:
  
  $F_0 = 0.38 \pm 0.22 \pm 0.07$
  
  $F_+ = 0.15 \pm 0.10 \pm 0.04$
Evidence for single top production

DO searched for single top with three methods: decision trees (DT), matrix element (ME), and a neural network (NN).

Discriminants are constructed with a large number of kinematic observables (DT, NN) or by evaluating the differential probability of signal with single top ME.

A product over all bins ($N_{\text{jets}}, N_{\text{tags}},$ lepton type) of the discriminant outputs is fit with a likelihood.
First direct limit on $|V_{tb}|$: $0.68 < |V_{tb}| < 1$ at 95%CL

DØ Combination: 3.6σ

Expected significance: 2.3σ

Decision Trees: $3.4σ$
Matrix Elements*: $3.2σ$
Bayesian NNs*: $3.1σ$
Combination*: $3.6σ$

CDF Run II Preliminary

DØ Run II * = preliminary

0.9 fb⁻¹

0.0 ± 1.2

2.7 ± 1.5

0.3 ± 1.2

Single Top Production Cross Section (pb)
Future Prospects

- For $M_w$ & $M_{top}$ Tevatron has done better than expected
  - with $>4$ fb$^{-1}$ and CDF+D0 together may get to:
    - $\sigma_{M_{top}} = 1.0$-1.2 GeV.
- By the end of Run II, $M_w$ will be known with close to 0.02%
  - ($\sigma_{M_W} = 20$-25 MeV) precision!
Indirect bounds on the Higgs

- the $\Delta \chi^2$ curve is derived from precision ewk measurements, as a function of the Higgs-boson mass, assuming the SM to be the correct theory of nature.
- The recent improvements in top and $W$ push the most likely value of the Higgs boson mass deep down into the excluded region.

Taking the LEP bound into account:

- Preferred $m_H: 76^{+33}_{-24}$ GeV
- $114 \text{ GeV} < m_H < 182 \text{ GeV} @ 95\% \text{ C.L.}$

SUSY07 Karlsruhe, July 28th 2007

Sandra Leone  INFN Pisa
Indirect bounds on the Higgs: SM vs MSSM

- Prediction for $M_W$ in the SM and the MSSM as a function of $M_{\text{top}}$

**MSSM band:**
- scan over SUSY mass parameters
- overlap:
  - SM is MSSM-like
- SM band:
  - variation of $M_H$ in SM


slight preference for non-zero SUSY contributions

SUSY07 Karlsruhe, July 28th 2007

Sandra Leone INFN Pisa
Conclusions

- Tevatron experiments have in their hands a gold mine of more than 2 fb\(^{-1}\) of data
  - The accelerator is performing well and the two detectors are well-understood
- CDF and D0 are bringing the tests of the Standard Model at a level of precision which meets or exceeds that of electron-positron colliders
  - The top mass is known with 1.1% precision, the W mass with 0.04% precision
- CDF and D0 will continue to produce excellent physics through 2009, and possibly after that
  - Expect 6-8 fb\(^{-1}\) by the end of Run II
  - Expect 0.7% precision on top mass, 0.02% on W mass
  - The Higgs boson hunt is under way
  - Surprises may be just around the corner
Tevatron Collisions & Cross Sections

- Cross sections for various physics processes vary over many orders of magnitude:
  - processes of interest are often buried under heavy background
  - need good rejection factors, selection and analysis strategies

- As luminosity increases, experiments are forced to deal with new challenges
  - Trigger and analyses being retuned to match the changes
Electroweak physics with $\tau$

$Z \rightarrow \tau \tau$ is irreducible background to $Higgs \rightarrow \tau \tau$ search

$D\bar{O}$ separates taus into 3 categories based on final state particles, $\tau$ identified with Neural Network

Type 1: 1 track
Type 2: 1 track with EM en.
Type 3: more than 1 track

CDF uses cut based tau identification

defines signal and isolation cone around seed track direction

$\pi^0$ information is added

Require track & $\pi^0$ isolated
$Z \rightarrow \tau_e \tau_h$

- Use channel $\tau_1 \rightarrow e + \tau_2 \rightarrow \text{had}$: isolated electron ($E_T > 10$ GeV/c) and hadronic tau ($p_T > 15$ GeV/c)
- Event topology cuts to reject QCD and W+jet backgrounds
- Cross section consistent with SM expectation

$L = 350 \text{ pb}^{-1}$
W boson exhibit a production asymmetry due to the different PDF of u and d quarks in the proton:

\[ A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W} \]

We measure a lepton charge asymmetry (convolution of production and V-A decay).

CDF presented a new analysis method which reconstructs the W rapidity (using a weighted iterative estimate). To be updated soon with 1 fb⁻¹.
Statistics limited but ultimately sensitivity to $Z'$ beyond SM

Distributions consistent with SM predictions
Dilepton $\sigma_{t\bar{t}}$

- **Signature**: events with $ee+\geq 2$ jets, $\mu\mu+\geq 2$ jets, $e\mu+\geq 1$ jet
- **Observed data events**: 73
  - $16$ ee, $9$ $\mu\mu$
  - $32$ $e\mu+\geq 2$ jets, $16$ $e\mu+1$ jet
- **Expected background**: 23.5
  - No requirement on b-jet identification

$$
\begin{align*}
  ee & : \sigma_{t\bar{t}} = 9.6^{+3.2}_{-2.7} \, (\text{stat}) \, ^{+1.9}_{-1.6} \, (\text{syst}) \, \pm 0.6 \, (\text{lumi}) \, \text{pb} \\
  e\mu & : \sigma_{t\bar{t}} = 6.1^{+1.4}_{-1.2} \, (\text{stat}) \, ^{+0.8}_{-0.7} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb} \\
  \mu\mu & : \sigma_{t\bar{t}} = 6.5^{+4.0}_{-3.2} \, (\text{stat}) \, ^{+1.1}_{-0.9} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb} \\
  \text{dilepton} & : \sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1} \, (\text{stat}) \, ^{+0.0}_{-0.8} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb}
\end{align*}
$$
Dilepton $\sigma_{tt}$

- **Signature:** isolated high $p_T$ $ee, \mu\mu, e\mu, \sum E_T \geq 2$ jets
- **Observed data events:** 77: 16 $ee$, 26 $\mu\mu$, 35 $e\mu$

- **Main Backgrounds:** $WW(\rightarrow ee,\mu\mu,em) +$ jets, $Z/\gamma^* (\rightarrow \tau\tau \rightarrow e\mu) +$ jets, $Z/g^* (\rightarrow ee,\mu\mu) +$ jets, $W +$ jets (jet fakes isolated $e,\mu$) (~ 25.6 events)

$\sigma_{tt} = 6.2 \pm 1.1$ (stat.) $\pm 0.7$ (syst.) $\pm 0.4$ (lumi) pb
Lepton + jets $\sigma_{\tt}$

- **Signature:** isolated high $p_T$ lepton, $E_T \geq 3$ jets
- **Event Samples:**
  - $\Rightarrow \geq 1$ b-tags Signal fraction $\sim 80\%$
  - $\Rightarrow \geq 2$ b-tags Signal fraction $\sim 90\%$
- **Main Backgrounds:**
  - Multijet production with fake lepton,
  - $W$ production $+ \geq 3$ jets
- **Most top properties measurements use $\geq 4$ jets events. Yields:** 231 ($\geq 1$ b-tag), 101 ($\geq 2$ b-tags)

\[
\begin{align*}
&\geq 1 \text{ b-tag: } 8.2 \pm 0.5(\text{stat}) \pm 0.8(\text{syst}) \pm 0.5(\text{lum}) \text{ pb} \\
&\geq 2 \text{ b-tag: } 8.8^{+0.8}_{-0.7}(\text{stat}) \pm 1.2(\text{syst}) \pm 0.5(\text{lum}) \text{ pb}
\end{align*}
\]
Lepton + jets $\sigma_{tt}$

- **Signature**: isolated high pT lepton, $\geq$3 jets
- $\geq$1 jet is required to be b-tagged by a very performant Neural Network b-tagging algorithm ($\varepsilon = 54\%$, fake rate = $1\%$)
- Event yields are fit in 8 categories ($e/\mu$; $3/\geq4$ jets; $1/\geq2$ b-tags) to derive the final result:

$$\ell + \text{jets} : \sigma_{pp\to t\bar{t}+X} = 8.3^{+0.6}_{-0.5} \text{(stat)} ^{+0.9}_{-1.0} \text{(syst)} \pm 0.5 \text{(lumi)} \text{ pb}$$
Top Quark Mass: Matrix Element Method

- Use four-vectors of reconstructed objects
- Calculate a probability per event to be signal or background as a function of the top mass
- Product of event probabilities used to extract the most likely mass
- The mass of the jet pair from $W \rightarrow jj$ is used to obtain an internal constraint to the error on the jet energy scale (JES).

\[ P_{\tilde{t} \tilde{t}}(x, m_t, JES) = \frac{\text{Acc}(x)}{\sigma_{\tilde{t} \tilde{t}}(m_t)} \int dq_1 dq_2 f(q_1) f(q_2) d\sigma(y, m_t) T(x, y, JES) \]

- Acceptance
- Normalisation
- Partonic differential Cross Section, based on LO Matrix Element
- Initial state
- Transfer Function: Prob. to measure $x$ from parton-level $y$
Top quark mass measurement: $ll + jets$

- Measurement sensitive to the kinematics of the events and observed number of events. The unconstrained system of dilepton events is solved using the top-antitop longitudinal momentum, and the top quark mass is reconstructed for each event.

70 dilepton events passing event selection and mass reconstruction

The hatched areas mark the dilepton $ttbar$ $\sigma$ and the template top mass measurement using $Pz^{ttbar}$(without cross section dependence).

$M_{top} = 170.7^{+4.2}_{-3.9}(stat.) \pm 2.6(syst.) \pm 2.4(theory)$ GeV
Forward-backward charge asymmetry in top pair production

- NLO calculations predict forward-backward asymmetries of 5-10% but recent NNLO calculations predict large corrections.
- Asymmetry arises from interference between contributions symmetric and antisymmetric under the exchange top -> anti-top, and depends strongly on the region of phase space being probed.
- The low asymmetries expected in the SM makes this a sensitive probe for new physics.

\[ A_{fb} = \frac{N \Delta y^0 - N \Delta y^0}{N \Delta y^0 + N \Delta y^0} = (12 \pm 8(\text{stat}) \pm 1(\text{syst}))\% \]

Where: \( \Delta y = y_t - y_{\bar{t}} \)

SUSY07 Karlsruhe, July 28th 2007
Sandra Leone  INFN Pisa
BKP - Upgrades at Tevatron

- Graph displaying total luminosity (fb⁻¹) with Design and Base curves.
- Graph illustrating Pbars available to the Collider, with max 430.0 and most recent 365.0.
the combination of a dynamical likelihood and LO matrix elements allows a precise measurement.

The selection requires 6 jets ($E_T > 15$ GeV, $|\eta| < 2$) and uses kinematical cuts now “standard” on aplanarity: $\sum E_T^3$, centrality $C > 0.78$, $\sum E_T > 280$ GeV, and a cut on the matrix element–based “top likelihood” $L < 10$.

Templates of $M_{top}$ and $M_{jj}$ are then used in a combined fit to $M_{top}$ and the jet energy scale. The result is:

$$M_{top} = 171.1 \pm 3.7 \text{ (stat.} + \text{JES)} \pm 2.1 \text{ (syst.) GeV/c}^2$$

$$= 171.1 \pm 4.3 \text{ GeV/c}^2$$
Consistency check of CDF single top analyses

Matrix element:
\[ \sigma_{(t\text{-chan.})} = 2.7 \pm 1.5 -1.3 \text{ pb} \]

Neural Network:
\[ \sigma_{(t\text{-chan.})} = 0.2 \pm 1.1 -0.2 \text{ pb} \]
\[ \sigma_{(s\text{-chan.})} = 0.7 \pm 1.5 -0.7 \text{ pb} \]

2-D Likelihood discriminant:
\[ \sigma_{(t\text{-chan.})} = 0.2 \pm 0.9 -0.2 \text{ pb} \]
\[ \sigma_{(s\text{-chan.})} = 0.1 \pm 0.7 -0.1 \text{ pb} \]

Consistency at 1%
CDF expects to observe at 5\( \sigma \) single top production with 4/fb

<table>
<thead>
<tr>
<th>Method</th>
<th>Neural Networks</th>
<th>Matrix Elements</th>
<th>Likelihood Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1D</td>
<td>2D</td>
<td>1D</td>
</tr>
<tr>
<td>Expected p-value</td>
<td>0.5% ( \equiv 2.6 \sigma )</td>
<td>0.4% ( \equiv 2.6 \sigma )</td>
<td>0.6% ( \equiv 2.5 \sigma )</td>
</tr>
<tr>
<td>Observed p-value</td>
<td>54.6%</td>
<td>21.9%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>
Ongoing effort

- Last update in mid March (new CDF result on WW, ZH and from D0 on WH, ZH→new)

Data used: less than 50% of what on tape by now!
Non SM Higgs

- Non SM Higgs(es) have sizeable decay rate to $\tau\tau$ pairs
  \[ \Rightarrow \text{Large efforts to bring up efficiency to trigger on tau events} \]
  (and to detect tau)