Searches for New Physics in Top Events at the Tevatron

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Tevatron’s legacy
Top quark at Tevatron

- Observed and studied at Tevatron
- Strikingly large mass
  - $m_t = 173.18 \pm 0.94$ GeV/$c^2$
  - Strongest coupling to Higgs field
- $\sigma_{t\bar{t}} = 7.65 \pm 0.42$ pb (Tevatron 2012)
- Search for new physics in top quark properties.
  - Look for deviation from SM
  - Observed large $A_{FB}$?
- Direct searches for new physics:
  - Many BSM models predict particles couple preferably to $t\bar{t}$
  - $Z'$, $W'$, $b'$, $t'$, $t \rightarrow Zq$, anomalous coupling, dark matter...
Why study top at Tevatron?

- Tevatron is the $p\bar{p}$ collider
- Still competitive sensitivity to $q\bar{q}$ initiated new physics models, like $q\bar{q} \rightarrow Z' \rightarrow t\bar{t}$
Why study top at Tevatron?

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**SM:**

\[
\frac{\sigma_{\text{LHC}}^{\ell\ell}}{\sigma_{\text{Tevatron}}^{\ell\ell}} \approx 25
\]

**Z':**

\[
\frac{\sigma_{\text{LHC}}^{Z' \rightarrow \ell\ell}}{\sigma_{\text{Tevatron}}^{Z' \rightarrow \ell\ell}} \approx 5-10 \text{, } M_{Z'} < 800 \text{ GeV}
\]

**Graph:**

- \( Z' \rightarrow \ell\ell \)
- \( M_{Z'} \text{ [GeV/c}^2\text{]} \)
- \( \sigma_{\text{LHC}}^{Z' \times B} / \sigma_{\text{Tevatron}}^{Z' \times B} \)

**Referenced Resources:**

- arXiv:1112.4928, R. Harris, S. Jain
Motivation for \( Z' \) search

- Top is very heavy, maybe indication of coupling to new physics
- Various theoretical models predict \( \bar{t}t \) resonant states: \( Z' \) in extended gauge theories, axigluons, KK states of gluon/Z, Topcolor
- Tevatron \( \bar{t}t \) forward-backward asymmetry
- 2\( \sigma \) excess of events at masses around 950 GeV at D0
Most of the searches in $t\bar{t}$ final state are done in lepton+jets final state

- Clean signature, large statistics, only one neutrino is missing

Search technique:

- $M_{t\bar{t}}$ spectrum is reconstructed by taking invariant mass of all objects (lepton, jets, missing $E_T$)
- ME, kinematic fitter, no kinematic constraint.

Search for a peak in $M_{t\bar{t}}$ spectrum

- Understand SM fluctuation probabilities
- Calculate Upper Limits
- Compare data with our expectations (SM or with new physics)

Top Pair Branching Fractions

- "alljets" 46%
- $\tau$+jets 15%
- $\mu$+jets 15%
- $e$+jets 15%
- "dileptons"
- "lepton+jets"

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History of $Z'$ searches
CDF analyzed full Tevatron dataset of 9.4 fb\(^{-1}\) for resonance search in lepton plus jets final state

- Require at least 3 jets, 1 lepton, missing \(E_T\) and 1 or 2 b-jets
- Reconstruct \(t\bar{t}\) invariant mass:
  - All objects in final
  - No constraint on top quark presence
- Leptophobic \(M_{Z'} > 915\) GeV

\[\text{Observed limit} \quad \text{Expected limit} \quad \text{Median expected} \quad \text{Median expected} = 1.2\%\]

\[\text{Z'}/M_K \quad \text{Topcolor Z'}\]

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\[\text{Leptophobic } M_{Z'} > 915\text{ GeV}\]
- LHC searches for the same benchmark narrow leptophobic $Z'$ model
- LHC is more sensitive for the mass region above TeV
  - LHC excludes $M_{Z'} > 1.5$ TeV
- However, Tevatron is still more sensitive in the region below 750 GeV
- Increased colliding energies and instantaneous luminosity at LHC makes this mass region even harder to probe

![Graph showing comparison to LHC](image)
One of the many models to explain $A_{\text{fb}}$ predicts $pp \rightarrow Xt \rightarrow \bar{t} j t$

Default L+J event selection, but at least 5 jets in final state

Identify the jets from $tt\bar{t}$ decay using kinematic fitter

Select the jet with the largest $m_{tj}$

Data consistent with SM

0.61 pb to 0.02 pb for $X$ masses ranging 200-800 GeV
4th generation t’

- Heavier than SM top quark
  - Same production and decay mechanism as in SM
- Reconstruct t’ mass using kinematic fitter
  - Simultaneous fit to reconstructed t’ mass and H_t
- Data consistent with SM at 2σ
- Set the UL on $\sigma_{t't'}$
  - D0: $M_{t'} > 296$ GeV; CDF: $M_{t'} > 358$ GeV
- Dark matter interacts with SM via \( T' \) carrying both dark matter and SM charges
- Decays: \( T'T' \rightarrow tt + XX \), \( X \) is dark matter candidate
- Signature: \( t\bar{t} \) plus large missing energy
- Search discriminant:
  - All hadronic: missing \( E_T \) significance
  - Lepton+jets: \( m_{T'} \) is \( W \) transverse mass
- Data consistent with SM
  - Limits set on \( m_{T'} \) vs \( m_X \)
In one of SM extensions Lorentz-Violating term is introduced

Lorentz violation predicts $\sigma_{tt}$ dependence on time of a day

For each block of data
  ‣ Sidereal time is extracted
  ‣ $\sigma_{tt}$ is measured

R+1 is the ratio of measured $\sigma_{tt}$ divided on SM predcition

Data is consistent with SM
Rare $Z$ Decays into Two Reconstructed Photons

- LEP set UL on $\text{BR}(Z \rightarrow \gamma\gamma)$ and $\text{BR}(Z \rightarrow \pi^0\gamma)$ at $5 \times 10^{-5}$
- At Tevatron $\sigma_Z \text{B}(Z \rightarrow ee) = 250$ pb. $2.5 \times 10^6$ $Z \rightarrow ee$ events
- Signal modeled by Pythia
- Main backgrounds:
  - Drell-Yan estimated from MC ($54 \pm 5$)
  - $\gamma\gamma$, $\gamma j$, and $jj$ estimated from data sidebands fit ($2251 \pm 61$)
- Results:
  - No excess observed
  - Best limits to date
Summary

- Tevatron has delivered unique data for top quark physics
- Wide range of property measurements and searches have been performed
  - Providing complementary results to LHC data
- CDF and D0 continue studies in top quark
- Many analyses have incorporated the full Tevatron dataset
- More information on the Tevatron results:
  - D0: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

- Thank you!