New Phenomena Searches at the Tevatron

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on behalf of the CDF and DØ collaborations

Rencontres de Moriond
QCD and High Energy Interactions
March 10-17, 2012, La Thuile, Italy
Outline

- SUSY
  - Gauginos
  - 3rd generation squarks
- Non SUSY
  - Resonances
  - UED
  - Dark matter
Unexplained in Standard Model

- No Higgs boson observed yet
- Hierarchy or Naturalness Problem
  - Huge gap between electroweak and Planck scale

\[ \Rightarrow m_H^2 \propto \Lambda^2 \]

- Dark Matter in our universe unaccounted for
- No unification of forces
- Not enough CP violation for baryogenesis
- Gravity
- Flavors
- ...

In general, Standard Model is a “low” energy effective theory
SUperSYmmetry

• An extension to the Standard Model

• Each boson/fermion has its super partner which is fermion/boson

• Mixing:

\[ W^\pm, H^\pm \rightarrow \text{Charginos} \ \tilde{\chi}^\pm_{1,2} (\tilde{W}^\pm, \tilde{H}^\pm) \]
\[ \gamma, Z, H \rightarrow \text{Neutralinos} \ \tilde{\chi}^0_{1,2,3,4} (\tilde{\gamma}, \tilde{Z}, \tilde{H}) \]
SUSY trileptons

- Gaugino (chargino-neutralino) pair production

- Small cross-sections, but spectacular trilepton signatures

- Small SM backgrounds, 3rd lepton can be identified as an isolated track: e, μ, or τ (or track);

- Main background DY+jet, with jet misidentified as lepton or track, is estimated from data

- Interpreted in mSUGRA, benchmark:
  \( m_0 = 60 \text{ GeV}, \tan \beta = 3, A_0 = 0, \text{ and } M_{1/2} = 160 \text{ GeV} \)
  
\[ \mathcal{L} = 5.8 \text{ fb}^{-1} \]

Excluded
\[ M^{\tilde{\chi}^{\pm}} < 168 \text{ GeV} \]

\[ CDF \text{ Note 10636} \]
Same sign leptons with tau

- Simplified SUSY model:
  - Simplified gravity model similar to mSUGRA:
    - Electroweak production of $\tilde{\chi}^0_2\tilde{\chi}_1^\pm$ pairs with subsequent decay to stau+X and $\text{BR}(\tilde{\chi}^0_2,\tilde{\chi}_1^\pm \rightarrow \tilde{\tau} + X)=1, 1/3$
  - Simplified gauge model similar to GMSB:
    - LSP is very light gravitino; charginos don't couple to right handed sleptons, so charginos decay to staus: $\text{BR}(\tilde{\chi}_1^\pm \rightarrow \tilde{\tau} + X)=1$

- Same search for chargino-neutralino, but selecting one e or $\mu$ and one hadronic $\tau$ with the same sign
  - Requiring a hadronic $\tau$ adds sensitivity to high $\tan\beta$ SUSY space.

- Since no excess is observed, we set limits in $M(\tilde{\chi}_1^\pm)$ vs $M(\tilde{l})$ plane

CDF Note 10611

L. Ž. NP at Tevatron 12/3/2012
Search for $Z\gamma+\text{MET}$

- Search for SUSY in the $Z+\gamma+\text{MET}$ final state
  - Predicted by GMSB SUSY models where the lightest neutralino is NLSP produced in pairs
  - They decay to either a $Z$ boson or a photon and to a gravitino that escapes detection.
  - Parametrized by an effective SUSY breaking scale $\Lambda$

- Select a pair of oppositely charged leptons consistent with $Z$, photon and large MET
  $\Rightarrow$ Signal region

- Dominant backgrounds are $Z\gamma$ which is normalized to data, and $Z+$jets which is obtained from control regions from data.

- Analysis is further optimized using BDT

- In the absence of an excess limits are set:
  - Model with $\Lambda < 87$ TeV is excluded
  - Lightest neutralino with $m < 151$ GeV is also excluded

$L = 6.2 \text{ fb}^{-1}$
Stop in $\mu + \tau$ final states

- Superpartners of the top and bottom quarks can be the lightest squarks.

- Search for $\tilde{t}_1 \tilde{t}_1 \rightarrow b b \mu \tau$ MET final state, where muon can come from either stop or tau which comes from stop.
  - MET comes from assumption that either $\tilde{\nu}$ is LSP or it decays invisibly.
  - At least one jet is requested, and events with 1, 2, or more than 2 jets are analyzed separately.

- Two signal points: $[m_{\tilde{t}_1}, m_{\tilde{\nu}}] = [180, 60]$ GeV (Signal A), and $[120, 80]$ GeV (Signal B).
  $\Rightarrow$ High and low $m_{\tilde{t}_1}$ and $\Delta m$.

- Limits are obtained under assumption:
  - wino scenario: $B(\tilde{t}_1 \rightarrow b \mu \tilde{\nu}) = B(\tilde{t}_1 \rightarrow b \tau \tilde{\nu}) = 1/3$
  - higgsino scenario: $B(\tilde{t}_1 \rightarrow b \mu \tilde{\nu}) = 0.1$, $B(\tilde{t}_1 \rightarrow b \tau \tilde{\nu}) = 0.8$

$\mathcal{L} = 7.3$ fb$^{-1}$

arXiv:1202.1978

12/3/2012  L. Ž. NP at Tevatron
Charged Massive Long Lived particles

- Predicted by many models
  ⇒ Implications on cosmology

- CMLLP live long enough to escape detector before it decays
  ⇒ Signature is like heavy, slow, long lived muons

- In SUSY, where LSP is stable, NLSP may be long lived
  Charginos (gaugino-, or higgsino-like)
  Also top squark could be long lived if it is the lightest colored sparticle

- Speed \( \beta \)

- Ionization Energy Loss

- Higgsino:
  \( M < 217 \text{ GeV} \)

- Stop:
  \( M < 285 \text{ GeV} \)

- Gaugino:
  \( M < 267 \text{ GeV} \)

- arXiv:1110.3302

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Non SUSY

- Many new theories predict large spectrum of the new particles
Randall Sundrum Graviton Decaying to ZZ

- In some models, decays of the graviton $G^*$ to leptons or photons can be suppressed ⇒ dominant decays are to pairs of top quarks, Higgs bosons or heavy bosons

- Search for $G^* \rightarrow ZZ \rightarrow llX$, $X=ll$, $jj$, $vv$ is performed with 6 fb$^{-1}$ of data

- No significant excess is observed, and limits on the $G^* \rightarrow ZZ$ cross section are set to be between 0.26 pb and 0.045 pb, for mass range from 300 to 1000 GeV

$\mathcal{L} = 6.0$ fb$^{-1}$
Search for ZZ+MET

- Search for \( pp \rightarrow X_2X_2 \rightarrow ZX_1ZX_1 \rightarrow lljj+MET \)
- Search for events with two leptons from Z and two jets from Z
- Define

\[
\Delta m = \sqrt{\left( \frac{m_{ee} - m_{Z\rightarrow ee}}{g_{ee}} \right)^2 + \left( \frac{m_{jj} - m_{Z\rightarrow jj}}{g_{jj}} \right)^2},
\]

- Results are interpreted as a search for the fourth generation neutrino, which may be a mixture of the Dirac and Majorana, thus leading to the two eigenstates, heavier unstable \( N_2 \) or lighter and stable \( N_1 \)
  - It can be also interpreted as a search for neutralino pair production \( \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0\tilde{\chi}_1^0 \)

No significant excess in data
Upper limits are set

\( \mathcal{L} = 4.2 \text{ fb}^{-1} \)

12/3/2012
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PRD-RC 85, 011104 (2012)
Universal Extra Dimensions with the same sign muons

- Universal extra dimensions - all particles can propagate in the extra dimensions
  - Minimal UED model - only one extra dimension

- Search for the KK pair production in minimal UED
  - Subsequent decays will lead to final states with up to four leptons with low $p_T$
  - Select two same sign muons to suppress backgrounds
  - To further gain sensitivity we use BDT

- Limits set as a function of $R^{-1}$, which corresponds to the mass of KK state, and $R$ is radius of compact dimension

$L = 7.3 \, fb^{-1}$

R$^{-1} < 260$ GeV

arXiv:1112.4092
Dark Matter: Monojet+MET

- Search for dark matter in $pp \rightarrow \chi \bar{\chi} + \text{jet}$ production
- Models in which $\chi$ is a Dirac fermion, and production is mediated by a massive state $M$, in models of axial-vector mediated, vector mediated, and $t$-channel mediator exchange
- Select events with one high $p_T$ jet and high MET
- Multijets background obtained from data, electroweak ($W$ and $Z$) from simulation, but normalized to data in dedicated control region
- Search for excess in events with jet with high $p_T$

$\mathcal{L} = 6.7 \, fb^{-1}$

Submitted to PRL, arXiv:1203.0742
In the absence of a significant excess, upper limits are set.

Limits are converted into constraints on the dark matter-nucleon cross section.

Comparable to the results of direct searches.

$L = 6.7 \text{ fb}^{-1}$
Summary

• Tevatron has ended its 25 years run on September 30th 2011
  - It ran more than 9 years at $\sqrt{s} = 1.96$ TeV
  - It delivered almost 12 fb$^{-1}$ during that period
  - We are grateful for all these data
• Two mature experiments, performed very well
  - New phenomena program was very rich and many searches have been performed over the years
• Our data agrees with Standard Model prediction
  - Many models were constrained

 Preliminary and published results:
http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
http://www-d0.fnal.gov/d0_publications/d0_pubs_list_runII_bytopic.html#np
Backup
Tevatron Data Taking

Run II Integrated Luminosity

10.7 fb\(^{-1}\) on tape

More than 90% efficiency lately

Peak luminosity \(\sim 4.4 \times 10^{32}\)

Today up to 11.9

Run IIa

Run IIb
CDF and DØ experiments in Run II

- Both detectors are upgraded in Run II
- New silicon micro-vertex trackers
- New tracking systems
- Upgraded muon chambers

Angular coverage

<p>|                      | |η|    |
|----------------------|------|
| Muon ID              | ~2   |
| Tracking             | ~2.5 |
| EM / Jet ID          | ~4   |</p>
<table>
<thead>
<tr>
<th>$M_{N1}, M_{N2}$ [GeV/c^2]</th>
<th>$E_T$ cut [GeV]</th>
<th>Acceptance [%]</th>
<th>$\sigma_{N2}$ [fb]</th>
<th>Exp./Obs. Limit</th>
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The standard model of big bang nucleosynthesis (BBN) has difficulties in explaining the observed lithium production. The existence of a CMLLP that decays during or after the time of BBN could resolve this disagreement.

Muons from $Z \rightarrow \mu\mu$ events studied throughout the data sample allow calibration of the time measurement to better than 1 ns, with resolutions between 2-4 ns, and to maintain the mean $dE=dx$ constant to within 2% over the data-taking period.

From a specific muon scintillation counter we calculate a particle's speed from the time recorded and the counter's distance from the production point, and we compute an overall speed from the weighted average of these individual speeds, using measured resolutions.

The ionization loss data from the typically 8-10 individual energy deposits in the SMT are combined using an algorithm that omits the largest deposit to reduce the effect of the Landa tail and corrects for track crossing angle. We normalize the $dE=dx$ measurements by requiring the $dE=dx$ distribution of muons from $Z \rightarrow \mu\mu$ events to have a maximum at 1.
Stop in $\mu+\tau$ final states

N$_{jets}$ = 2

N$_{jets}$ = 1

arXiv:1202.1978 $L = 7.3$ fb$^{-1}$
Search for 3jet resonances

- RPV SUSY gluino pairs, each decaying into three partons: \( gg \rightarrow 3\text{jet} + 3\text{jet} \)
- Similar to all hadronic \( tt \), dominant background multijets
- Selection: \( \text{MET} \leq 50 \text{ GeV}; 1 \leq N_{\text{vert}} \leq 4; N_{\text{jets}} \geq 6; \sum_{\text{6 jets}} p_T \geq 250 \text{ GeV} \)
- Final “diagonal” cut: \( \sum p_T - M_{jjj} > \text{offset} \)
  - offset optimized for different mass points
- \( MJ \) background from data - 5 jets sample
- Fitted with Landau function
- Fit signal with Landau+Gaussian
- No excess observed in data, we set limits

\( \mathcal{L} = 3.2 \text{ fb}^{-1} \)

PRL 107, 042001, 2011

CDF RUN II 3.2 fb\(^{-1}\)

95\% C.L. limit observed

95\% C.L. limit expected

\( \pm 1 \sigma \) on expected limit

\( m = m_g + 10 \text{ GeV/c}^2 \)

\( m = m_g < 0.7 \text{ TeV/c}^2 \)
Introduction to SUSY

- Provides a solution to hierarchy problem:
  - exact cancellation between fermion and boson loops for Higgs
  - But introduces more particles, free parameters
- Susy breaking
- Dark matter candidate
- Unification of forces
- R parity
- Models searched at Tevatron
Search for ZZ resonances

- CDF
- D0
Dielectron resonances

CDF 5.7 fb$^{-1}$

$\text{Data}$
- Drell-Yan
- QCD
- Diboson
- $t\bar{t}$
Dimuon resonances

CDF Run II Preliminary 4.6 fb$^{-1}$

- Data
- $Z/\gamma$
- $t\bar{t}$
- WW
- Fakes
- Cosmics

CDF Run II preliminary (L=5.7 pb$^{-1}$)

- DATA
- Drell-Yan
- Fakes
- Diboson
- $t\bar{t}$

CDF Run II Preliminary, 4.6 fb$^{-1}$

- Med. 95% CL limit
- 68% of PE
- 95% of PE
- $Z_{xx}$ Theory
- 95% CL limit

12/3/2012
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