Searches for Squark and Gluino Production at the Tevatron

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On behalf of the CDF and DØ Collaborations
Outline

• Tevatron and the collider experiments
• SUSY searches at the Tevatron
• Results from squark and gluino searches in
  • Inclusive Missing Transverse Energy (MET) + jets signature
  • MET + jets + tau
  • Model independent MET + di-jet signature
• Summary
• Tevatron delivered $L = \sim 4.3 \text{ fb}^{-1}$
• CDF and DØ collected $\sim 3.5 \text{ fb}^{-1}$
The Tevatron Experiments

Multipurpose detectors:

- Electron, muon, tau identification
- Jet and missing energy measurement
- Heavy-flavor tagging through displaced vertices and soft leptons
SUSY at the Tevatron

- Predicted rates for SUSY are LOW !!!

- Need to look for distinctive signature to distinguish from SM background

- Present results using data samples: $\sim 1 - 2 \text{ fb}^{-1}$
Searches for Squarks and Gluinos

• Cover on inclusive searches for squarks and gluinos pair production
• Searches for Stop and Sbottom will be covered by Philippe Calfayan
• In these searches, we assume R-parity is conserved
  ⇒ Lightest SUSY particle (LSP) is stable
  ⇒ SUSY particles are pair produced
• LSP is neutral and interacts weakly
  ⇒ escapes detection
  ⇒ missing energy signature
 Searches for Squarks/Gluinos in MET+Jets

- $\tilde{q}, \tilde{g}$ can be copiously pair produced at Tevatron if sufficiently light

$\tilde{q}\tilde{g}$

Signature:
- multiple jets and large MET

100 events per fb$^{-1}$
Search for Squarks/Gluino in Different Topology

Relative Contribution from each Production

\[ M(\tilde{q}) = M(\tilde{g}) \]

- Contributions from each final state signature depends on the masses of squarks and gluino
Backgrounds in MET+jets Signature

Real MET

• $W(\rightarrow l\nu) + \text{jets}$
• $Z(\rightarrow \nu\nu) + \text{jets}$
• $t\bar{t}$-bar, single top
  • $(t\rightarrow Wb, W\rightarrow l\nu)$
• $WW, WZ, ZZ$

Fake MET

• Mis-measurement of jets’ energy
  • energy resolution, particles entering non-instrumented region
  • MET align with mis-measured jet’s direction
  • Can have large contribution from QCD multi-jet due to its large cross section

• Non-collision background
  • Beam halo
  • Cosmic muon
  • Noise/dead-channels in detector
Non-Collision MET Background

• Cleaning up non-collision background
  • Lots of effort from CDF and DØ at the beginning of Run 2 to understand the non-collision background
    • Fix any instrumental issues, or remove runs/events if not fixed
    • Require events with good primary vertex (PV)
    • Sufficient tracks in jets originate from PV
    • ….
Event Selection

- CDF,DØ search in \( \sim 2 \) fb\(^{-1} \) data sample
- Separate searches in the MET +2 jets, +3 jets, and +4 jets final states
- Remove non-collision background
- MET direction not align with jets (reduce QCD)
- Lepton veto (reduce W/Z+jets, top, diboson)
- Optimize cuts on leading jets’ \( E_T \), MET and \( H_T \) (scalar sum of jets’ \( E_T \))

<table>
<thead>
<tr>
<th>Analysis</th>
<th>CDF</th>
<th>DØ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>( H_T ) (GeV)</td>
<td>MET (GeV)</td>
</tr>
<tr>
<td>2-jets</td>
<td>330</td>
<td>180</td>
</tr>
<tr>
<td>3-jets</td>
<td>330</td>
<td>120</td>
</tr>
<tr>
<td>4-jets</td>
<td>280</td>
<td>90</td>
</tr>
</tbody>
</table>
Events in Control Regions

• Test background prediction in kinematic control regions:

  QCD multijet Control Region
  • Require at least one jet aligned with MET

  W/Z+jets, top Control Region
  • At least one electron candidate
Events in Signal Regions

CDF Run II Preliminary

N_{jet} \geq 4 \quad \text{MET} > 90 \quad \text{HT} > 280

<table>
<thead>
<tr>
<th>Analyses</th>
<th># Expected</th>
<th># Observed</th>
<th># Expected</th>
<th># Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-jets</td>
<td>16 ± 5</td>
<td>18</td>
<td>11 ±1^{+3}_{-2}</td>
<td>11</td>
</tr>
<tr>
<td>3-jets</td>
<td>37 ± 12</td>
<td>38</td>
<td>11 ±1^{+3}_{-2}</td>
<td>9</td>
</tr>
<tr>
<td>4-jets</td>
<td>48 ± 17</td>
<td>45</td>
<td>18 ±1^{+6}_{-3}</td>
<td>20</td>
</tr>
</tbody>
</table>

CDF (2 fb^{-1})

DØ, L=2.1 fb^{-1}

DØ, L=2.1 fb^{-1}

- Data
- SM Background
- Fitted QCD
- SUSY

m(\tilde{g}) = 439 GeV
m(\tilde{q}) = 396 GeV

Events / 20 GeV

Events / 30 GeV

missing-\text{E}_T[\text{GeV}]

\text{E}_T(\text{GeV})

Analyses

Preliminary

PLB 660, 449 (2008)
Exclusion Limit in Msquark vs Mglunino Plane

- Determine limits in mSUGRA framework
- Mass limit (taking into account theory uncertainties from PDF, renormalization and factorization scale)
  - $M(\tilde{g}) < 280$ GeV (CDF), $< 308$ GeV (DØ), for all squark mass
  - $M(\tilde{q}) < 380$ GeV (CDF, DØ), for all gluino mass
Exclusion Limit in $m_0$ vs $m_{1/2}$ Plane

- Results from both experiments also constrain the mSUGRA parameters ($m_0$: universal scalar mass, $m_{1/2}$: universal gaugino mass)
- Extend limits beyond LEP
Squarks in MET+Jets+Tau Channel

• Large mixing between L- and R-handed superpartners of 3rd generation fermions

• For stau ($\tilde{\tau}$), large mixing may occur at high tan$\beta$

  ⇒ lightest stau ($\tilde{\tau}_1$) might be the lightest slepton

  ⇒ can be produced in cascade decays of squark pair production

• stau decays directly: $\tilde{\tau}_1 \rightarrow \tau\tilde{\chi}_1^0$

• Final state signature: $\geq 2$ jets + large MET + tau lepton
Squarks in MET+Jets+Tau Channel

- Selection cuts are similar to the inclusive MET+jets channel
- ≥1 hadronic tau (E_T > 15 GeV)
  - Hadronic tau: narrow isolated jet with low track multiplicity
- Optimize the MET and JJTHT(ET_{jet1} + ET_{jet2} + ET_T) cut

![Graph showing the distribution of JJTHT (GeV) vs. Events / 30](image)

(before final JJTHT and MET cuts)

- After all selection cuts:
  - Nobs=2, Nexpt=1.7±0.2^{+0.6}_{-0.3}
  - Interpret results in mSUGRA model (tanβ=15, A_0=-2m_0, μ<0)
  - Exclude mass m(squark)<366 GeV
Signature Based Search in the MET+dijet Channel

• In many new physics models their predictions have MET +2 jets signature in the final state:
  • SUSY, Leptoquarks, Universal Extra Dimensions …

• Perform a generic search in MET +2 jets signature w/o optimizing to a specific model

• Event Selection:
  • Similar pre-selection cuts as inclusive squark/gluino search
    • But requires only 2 jets in final state
  • Choose two kinematic regions to have sensitivity to a wide range of new physics
    • Low kinematic region: \( H_T (E_{T(J1)} + E_{T(J2)}) > 125 \text{ GeV}, \text{MET} > 80 \text{ GeV} \)
    • High kinematic region: \( H_T > 225 \text{ GeV}, \text{MET} > 100 \text{ GeV} \)
### Selected Events in $L=2$ fb$^{-1}$ Data Sample

CDF Run II Preliminary

<table>
<thead>
<tr>
<th>Background</th>
<th>(Low) $H_T&gt;125$, $MET&gt;80$ (GeV)</th>
<th>(High) $H_T&gt;225$, $MET&gt;100$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z\rightarrow\nu\nu$</td>
<td>$777 \pm 49$</td>
<td>$71 \pm 12$</td>
</tr>
<tr>
<td>$W\rightarrow\tau\nu$</td>
<td>$669 \pm 42$</td>
<td>$50 \pm 8$</td>
</tr>
<tr>
<td>$W\rightarrow\mu\nu$</td>
<td>$399 \pm 25$</td>
<td>$33 \pm 5$</td>
</tr>
<tr>
<td>$W\rightarrow e\nu$</td>
<td>$256 \pm 16$</td>
<td>$14 \pm 2$</td>
</tr>
<tr>
<td>$Z\rightarrow ll$</td>
<td>$29 \pm 4$</td>
<td>$2 \pm 0$</td>
</tr>
<tr>
<td>Top Production</td>
<td>$74 \pm 9$</td>
<td>$11 \pm 2$</td>
</tr>
<tr>
<td>QCD</td>
<td>$49 \pm 30$</td>
<td>$9 \pm 9$</td>
</tr>
<tr>
<td>$\gamma +$jets</td>
<td>$55 \pm 13$</td>
<td>$5 \pm 3$</td>
</tr>
<tr>
<td>Non-collision</td>
<td>$4 \pm 4$</td>
<td>$1 \pm 1$</td>
</tr>
<tr>
<td><strong>Total predicted</strong></td>
<td><strong>2312 ± 140</strong></td>
<td><strong>196 ± 29</strong></td>
</tr>
<tr>
<td>Data observed</td>
<td>2506</td>
<td>186</td>
</tr>
</tbody>
</table>

CDF II Preliminary (2.0 fb$^{-1}$)

H$_T$ distribution from low kinematic region
Interpretation of Results in MSSM SUSY Model

- Choosen MSSM model:
  - \( \tilde{\chi}_1^0 \) is the LSP
  - \( \tilde{u}, \tilde{d}, \tilde{c}, \tilde{s} \) are degenerate in mass
  - \( m(\tilde{g})/m(\tilde{q}) > 1.2 \)
    - No mSUGRA solution
    - Squark pair production dominates
  - \( \tan \beta = 3, A_T = -500, \mu = -800 \)
- Decide the kinematic region cuts to be applied on which SUSY points based on lowest (best) a priori cross section upper limit:
  - Low kinematic (125/80): point 4
  - High kinematic (225/100): points 1,2,3

<table>
<thead>
<tr>
<th>SUSY spectrum</th>
<th>( \tilde{q} ) mass (GeV)</th>
<th>( \tilde{g} ) mass (GeV)</th>
<th>( \tilde{\chi}_1^0 ) mass (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>320</td>
<td>390</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>450</td>
<td>72</td>
</tr>
<tr>
<td>3</td>
<td>220</td>
<td>520</td>
<td>85</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>550</td>
<td>89</td>
</tr>
</tbody>
</table>
### Cross Section Limit

<table>
<thead>
<tr>
<th>SUSY spectrum</th>
<th>A priori limit (pb)</th>
<th>Observed limit (pb)</th>
<th>Pythia LO cross section (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.52</td>
<td>0.46</td>
<td>0.36</td>
</tr>
<tr>
<td>2</td>
<td>0.88</td>
<td>0.77</td>
<td>1.73</td>
</tr>
<tr>
<td>3</td>
<td>1.82</td>
<td>1.60</td>
<td>3.21</td>
</tr>
<tr>
<td>4</td>
<td>75.9</td>
<td>122.3</td>
<td>57.4</td>
</tr>
</tbody>
</table>

- SUSY points 2, 3 excluded at LO using Pythia’s cross section

![CDF Run II Preliminary](image)

- **SUSY point #2**
A MET+dijet Event Candidate

- Highest $H_T$ event
  - $H_T = 452$ GeV
- MET = 116 GeV
- Could be a QCD di-jet event with a mis-measured jet

$E_T = 280$ GeV

$E_T = 173$ GeV
Summary

• Tevatron experiments have searched for squarks and gluinos in MET+jets final states on 2 fb\(^{-1}\) data sample

• No evidence of SUSY yet

• Expect ~2-3X more data by end of Run II (& 2X more by combining CDF+DØ)

• Keep our eyes open for any tantalizing hints !!!

• If nothing found, will provide further important constraints!

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.html
Back Up
Upper Limit Cross Section in MET + Jets Search

• For $m(\text{squark})=460$ GeV

• $m(\text{squark})=m(\text{gluino})$
MET + Jets + Tau : After All Section Cuts