Search for Gauge-Mediated Supersymmetry

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Tevatron Collider

1992-95
Run 1: 100 pb\(^{-1}\), 1.8 TeV

2001-2009 Run 2: major upgrades
higher \(E_{\text{CM}}\) = 1.96 TeV
\(~3\) fb\(^{-1}\) recorded, expect \(~8\) fb\(^{-1}\) in 2009

Collider Peak Luminosity

\[3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}\]
**DØ Detector**

- **Tracker**
- **Solenoid Magnet**
- **Muon Scintillators**
- **Muon Chambers**
- **Calorimeter**
- **Toroid**
- **Electronics**
- **Preshowers**

**Components:**
- **3 Layer Muon System**
- **Shielding**
- **protons**
Gauge-Mediated SUSY Breaking

Alternative to gravity mediated SUSY breaking
- SUSY breaking occurs at scale $\Lambda$ much lower than GUT (10 – 100 TeV)
- Mediated by new gauge fields – “messengers”
- Gravitino is very light (<keV) and is LSP
- Dark Matter is a mix of the gravitino and the lightest “messenger”

Lifetime of NLSP is a free parameter
- All SUSY particles cascade to NLSP, so if R-parity is conserved all final states have two NLSPs

NLSP can be neutralino or stau:
$\chi_1^0 \rightarrow \gamma G$ or $\tau_1^+ \rightarrow \tau^+ G$
- If neutralino is higgsino-like then it can also decay to hG and ZG
- Gravitino is weakly interacting and is registered as missing transverse energy (MET)
## Typical Final States

<table>
<thead>
<tr>
<th></th>
<th>prompt decays</th>
<th>inside detector</th>
<th>outside detector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stau</strong></td>
<td>multiple τ + MET</td>
<td>tracks with kinks</td>
<td>muon-like highly ionising slow moving particles</td>
</tr>
<tr>
<td><strong>Neutralino</strong></td>
<td>γγ + MET</td>
<td>non-pointing photon(s)</td>
<td>mSUGRA-like</td>
</tr>
<tr>
<td><strong>Higgsino</strong></td>
<td>γ bb + MET, γ Z+MET</td>
<td>Non-pointing b-jets, detached Z</td>
<td>mSUGRA-like</td>
</tr>
</tbody>
</table>

- Many of the final states are predicted by other models (extra dimensions, 4th generation quarks, etc...)

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mGMSB

Model Parameters:
- $\Lambda$ - mass parameter (effective scale of SUSY breaking)
- $M_m$ - messenger mass scale
- $N_5$ - number of messenger fields
- $\tan \beta = \langle \phi_1 \rangle / \langle \phi_2 \rangle$
- $\text{sign } \mu = \pm 1$ - sign of higgsino mass term
- $C_{\text{grav}}$ - determines NLSP lifetime

Gaugino masses proportional to $N_5$, scalar masses proportional to $\sqrt{N_5}$

Snowmass slope E:
- $\Lambda$ - varies
- $M_m = 2 \cdot \Lambda$
- $N_5 = 1$
- $\tan \beta = 15$
- $\text{sign } \mu = +1$

Neutralino NLSP

Snowmass slope D:
- $\Lambda$ - varies
- $M_m = 2 \cdot \Lambda$
- $N_5 = 3$
- $\tan \beta = 15$
- $\text{sign } \mu = +1$

Stau NLSP
Charged Massive “Stable” Particles

“Old” analysis - 0.35 fb\(^{-1}\), update is in the works...

Exist in many models in addition to GMSB: AMSB, stable stop, R-hadrons...

Appear in the detector as a “slow muons”

Study exclusive pair production of CMSP’s

- require two muons in event
- measure muon speed with scintillator counters (counter resolution ~ 2 to 4 ns)
- speed resolution depends on detector region and number of reconstructed hits -> construct “speed significance”

Main background: Drell-Yan

Use low-mass di-muons (<120 GeV) to calibrate speed significance

Look for excess in high mass di-muons

Data agrees with SM expectation...
Charged Massive “Stable” Particles

- **No excess, set limits**
  - GMSB line (Snowmass slope D): $M=2\Lambda$, $N_5=3$, $\tan\beta=15$, $\text{sign } \mu > 0$
  - AMSB Gauginos: $M_1=3M_2$, $M_3=500$, $\mu=10$ TeV
  - $\tan \beta = 15$, $M(\text{squark}) = 800$ GeV
Di-photon Data Analysis

Data collected in the Run IIa: 1.1 fb\(^{-1}\)

Photon and electron identification:
- Calorimeter cluster with > 95% energy in EM calorimeter
- Isolated in calorimeter \((E_{\text{TOT}}^{R=0.4} - E_{\text{EM}}^{R=0.2})/E_{\text{EM}}^{R=0.2} < 0.07\)
- Scalar sum of track \(p_T\) in \(0.05 < R < 0.4\) annulus around the direction of the cluster is less than 2 GeV
- Shower shape is consistent with photon
- Cluster is electron if there is a central track match (or an electron-like hit pattern in the tracker) and is a photon otherwise

Event selection
- Two photons, \(E_T > 25\) GeV and \(|\eta| < 1.1\)
- \(\Delta\phi (\text{jet, MET}) < 2.5\) – for leading jet (if present) - to remove events with mismeasured missing \(E_T\)
- use photon pointing to eliminate mis-vertexing
Photon Pointing & Vertex Selection

- There can be several interactions per event
- Vertex distribution RMS $\sim 28$ cm
- MET is significantly affected if the vertex is shifted by $>10$ cm
- Which vertex did the photons come from?

DØ has four longitudinal EM layers and a preshower

Fit a straight line through the five points (obtain resolution of each layer using $Z \rightarrow ee$ events)

$Z_{VTX}$ resolution $\sim 2$ cm (verified with $Z \rightarrow ll\gamma$ events)

In the analysis require at least one photon to have CPS cluster
Backgrounds

- Physics backgrounds are small: \( W\gamma\gamma, Z\gamma\gamma \) - COMPHEP MC
- All instrumental backgrounds can be determined from data

**without true MET**  -fake MET
- QCD: \( \gamma\gamma, \gamma+j, j+j \)  (jet is faking \( \gamma \))
- Drell-Yan  (lost tracks)

**largest**

**with true MET**  -fake \( \gamma \)
- \( W\gamma \rightarrow e\nu\gamma \)  (lost track)
- \( Wj \rightarrow e\nu j \)  (lost track, fake \( \gamma \))
- \( Z \rightarrow \tau\tau \rightarrow ee +X \)  (lost tracks)
- \( tt \rightarrow ee + X \)  (lost tracks)
- \( WW, WZ, ... \)  (lost tracks)
Backgrounds with No Genuine MET

Need to know the shape of MET distribution for them
- and normalize to data with low MET

MET resolution is dominated by the energy resolution of the photons
- to first order, the shape does not depend on whether the photons are real or faked by jets
- still, there is a small difference due to the fact that when jet fakes a photon, the photon’s energy is less than original parton’s energy

Take $\gamma\gamma$ shape from $Z\rightarrow ee$
Take fake shape from a sample that is the same as signal sample except both photons fail shower shape cut (hh sample)
Take relative contribution that fits data best
- $60\pm20\%$ of real $\gamma\gamma$
- agrees with MC expectation for $\gamma\gamma$
- purity cross-checked by looking at shower shape in the preshower (not used for photon ID)

fluctuated jet: most energy is carried by $\pi^0$
Backgrounds with Genuine MET

- Always involve electron - photon mis-identification
  - can determine using $e\gamma$ events and known mis-identification rate
- Select $e\gamma$ events using the same kinematical cuts as $\gamma\gamma$
  - Contributions from
    - $Z\rightarrow ee$ (one lost track) - get contribution from di-EM mass fit
    - QCD (jets faking electron and photon) - subtract using shape of $hh$ sample
    - the processes we want to measure ($W\gamma$, $Wj$, $WZ$, $tt$, etc)

also serves as a cross-check of QCD subtraction method:

grey area is $Z+QCD+W\gamma$ MC + $Wj$ obtained from data
error is dominated by $j\rightarrow \gamma$ fake rate (correlated between bins)
Signal MC: ISAJET for masses and branchings, PYTHIA for event generation, full detector simulation plus real zero-bias events overlay to simulate multiple interactions per crossing.
Two Highest MET Events

\[ \text{ME}_T = 63 \text{ GeV}, \ E_T(\gamma) = 69, \ 27 \text{ GeV} \]
plus electron with \( E_T = 23 \text{ GeV} \)

\[ \text{ME}_T = 105 \text{ GeV}, \ E_T(\gamma) = 82, \ 33 \text{ GeV} \]

Expect \( \sim 0.15 \) events from \( W_{\gamma\gamma} \)
with \( E_T(\gamma) > 25 \text{ GeV} \)

Expect \( \sim 0.1 \) event from \( Z_{\gamma\gamma} \)
with \( E_T(\gamma) > 25 \text{ GeV} \)
Limit Setting

- Since data agrees with the MC proceed to limit-setting
- Use CLS method - takes into account shape of the distributions

@ 95% CL:
\[ \Lambda > 92 \text{ TeV} \]
\[ m(\chi_1^0) > 126 \text{ GeV} \]
\[ m(\chi_1^+) > 230 \text{ GeV} \]
Summary and Outlook

Still no sign of SUSY, although some interesting events are showing up...

Not the end of the story - have more than twice the data on tape, will get ~8 fb$^{-1}$ by the end of 2009

Stay tuned!