SUSY Results from the Tevatron

**SUSY 2011**
28 Aug – 2 Sept, Fermilab

*Leo Bellantoni, FNAL*
The Tevatron

11~12 fb\(^{-1}\) delivered per experiment

Both CDF & D0 detectors measure \(e, \mu, \gamma, \text{jets, } \tau\) well and tag \(b, c\) with vertex detectors

After so many years, these are well-understood detectors

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
A Glance Back

squarks and gluinos in jets + Missing $E_T$
$25.3 \text{ nb}^{-1}$

$W \rightarrow \tau \nu$, $Z \rightarrow \nu\nu$
HF production backgrounds estimated from Monte Carlo alone
A Glance Back

\[10^2\] as much data
Background models now include diboson production, top pair production, and QCD rates from data, not MC

Analysis techniques now much more advanced:
- Combined selection criteria
- Multivariate discriminant
- Limit setting procedures

Table of Contents

• Recent results
  • stop & sneutrino in $e\mu$
  • like sign dileptons
  • $B_S \rightarrow \mu\mu$
  • GMSB in $\gamma\gamma$
  • SUSY & Dark Photons

• Looking forward
  • charm tagging
  • tau tagging
  • a few words about $pp$ vs $p\bar{p}$
\( \tilde{t} \) pairs in \( e \mu \slashed{E}_T \)

**Backgrounds are**

\[
p\bar{p} \rightarrow Z/\gamma^* \rightarrow \tau^+\tau^- \rightarrow e^+\mu^- 4\nu
\]

occurs at relatively low \( \slashed{E}_T, p_T(\ell^\pm) \)
(< 20 GeV) and large opening angle (\( \Delta\phi > 2.8 \)) in the transverse plane

\( p\bar{p} \rightarrow t\bar{t} \) is basically the same thing without the SUSY; it can be suppressed with MVA methods

**WW likewise**


**Other stop searches:**

- top–like \( \ell\ell \)
$\tilde{\nu}$ in $e\mu$

A search for $e\mu$ resonances

Parameterized in terms of R-Parity violating sneutrino:

$$L = -\lambda_{312} (\tilde{\nu}_L)[\bar{u}_R e_L + \bar{e}_R \mu_L] - \lambda_{311} (\tilde{\nu}_L)[\bar{d}_R d_L] + h.c.$$

Similar to the $\tilde{t}$ search, but select low-$E_T$ events:

$20$ GeV $< E_T < 0.7 < \phi(\mu, E_T) < 2.3$

Jet veto reduces $t\bar{t}$

Abazov et al.,
\( \tilde{\nu} \) in \( e\mu, e\tau \) and \( \mu\tau \)

*Figures showing distributions of invariant mass for different channels.*


\( M(\tilde{\nu}) \text{ GeV} \)
Like Sign Dileptons I

2 high $p_T$ leptons of same (non-zero) charge is rare in $p\bar{p}$ collisions: $\sigma(p\bar{p} \rightarrow WZ/ZZ \rightarrow \ell^+\ell^-) \sim$ few pb

This makes an excellent signature for many BSM extensions: SUSY, Universal Extra Dimensions, heavy Majorana $\nu$, 4th generation fermions, $H^{++}$

1st step: model-independent search for isolated same-charge same-vertex $e^\pm$ or $\mu^\pm$

- $p_T^{(1)} > 20$ GeV \hspace{1mm} $|\eta| < 1.1$
- $p_T^{(2)} > 10$ GeV \hspace{1mm} $|\eta| < 1.1$
- Veto $86$ GeV $<$ $m(\ell^+\ell^-)$ $<$ $96$ GeV
- Veto $86$ GeV $<$ $m(e^+e^-)$ $<$ $96$ GeV

CONF Note 10464
Like Sign Dileptons II

2nd step: Require 1 or more jets in addition to the model-independent selection

Set limits on production cross-sections times decay branching ratios as function of $m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_2^0)$ and $m(\tilde{q}), m(\tilde{g})$

Using $Br(\tilde{q} \rightarrow q\tilde{\chi}_1^\pm) = Br(\tilde{q} \rightarrow q\tilde{\chi}_2^0) = 1/2$


CDF RunII Preliminary \[ \int L = 6.1 \text{ fb}^{-1} \]

CDF Note 10465
Like Sign Dileptons III

Minimal Supersymmetry has 5 Higgs bosons; lightest is CP-even scalar $h$

With radiative corrections $m_h \leq 135\text{GeV}$ for all $\tan \beta$ (lower for $\tan \beta \approx 1$)

Existing limit is close to this bound!

In mSUGRA, the SM Higgs bound $m_h \leq 114\text{GeV}$ applies

Favors high $\tan \beta$ - which means, processes that decay to $\tau$ are of particular interest

3rd step: look for $\tau e$, $\tau \mu$ events in same-sign sample

Like Sign Dileptons III

Look for a hadronically decaying $\tau$ with $\mu$ or $e$ of the same charge

"Simplified gravity" model 1:

$Br(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}^+ \tilde{\tau}^-) = Br(\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}^\pm \nu) = 1$

$Br(\tilde{\ell}^\pm \rightarrow \ell \tilde{\chi}_1^0) = 1$

$m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^\pm)$

"Simplified gravity" model 2:

Similar, but

$Br(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}^+ \tilde{\tau}^-) = Br(\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}^\pm \nu) = 1/3$

$Br(\tilde{\ell}^\pm \rightarrow \ell \tilde{\chi}_1^0) = 1$, flavor conserving

"Simplified gauge" model:

$Br(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}^\pm \tilde{\tau}^\mp) = 1/3$

$Br(\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}^\pm \nu) = 1$ \quad $m(\tilde{\chi}_1^0) \approx 0$

$Br(\tilde{\ell}^\pm \rightarrow \ell \tilde{\chi}_1^0) = 1$, flavor conserving

CDF Note 10611
B_S \rightarrow \mu \mu

Br(B_s \rightarrow \mu^+\mu^-) = (3.2\pm0.2) \times 10^{-9}
Br(B_d \rightarrow \mu^+\mu^-) = (1.0\pm0.1) \times 10^{-10}
A. J. Buras et al., JHEP 1010:009, 2010

In MSSM \quad Br(B_s \rightarrow \mu^+\mu^-) \propto \tan^6(\beta)

Continuum backgrounds are:
- b \rightarrow c \mu^- X; c \rightarrow (s,d) \mu^+ X
- Z/\gamma^* \rightarrow \mu^+\mu^- and (wrong) large impact parameter
- pp \rightarrow b\bar{b} \rightarrow \mu^+\mu^- X
- Fake muons

Fit \(M(\mu\mu)\) to a line outside signal region

Non-continuum background:
\(B_s \rightarrow 2\) hadrons which are mis-identified as muons

Estimated in D^{*+} tagged
\(D^0 \rightarrow K^-\pi^+\) data

For 0.995 < NNet < 1 (most pure sample)

0.92 \pm 0.21 events in B_d window
0.11 \pm 0.11 events in B_s window
**$B_S \rightarrow \mu \mu$**

Likelihood fit includes all bins in $M(\mu \mu)$, NN

Systematic uncertainties included as nuisance parameters, modeled as Gaussian

Including S.M. contribution as background, p-value is 1.9% for $B_S$ box, >23% for $B_d$ box.

\[
Br(B_d \rightarrow \mu^+\mu^-) < 5.0 \times 10^{-9} \quad 90\% \ C.L.
\]
\[
4.6 \times 10^{-9} < Br(B_s \rightarrow \mu^+\mu^-) < 39 \times 10^{-9}
\]

Central value for $S$ corresponds to 5.6 times SM rate

7 fb$^{-1}$  \hspace{1cm} \textbf{arXiv:1107.2304}

**But** later CMS result on 1.14fb$^{-1}$ (arXiv:1107.5834) was

$Br(B_S \rightarrow \mu^+\mu^-) < 19 \times 10^{-9}$
GMSB in $\gamma\gamma E_T$

In Gauge Mediated Supersymmetry Breaking, gravitino is LSP. Gravitino is dark matter candidate if $m_G < \text{few keV}$

$p\bar{p}$ collisions produce SUSY particles. Cascade down to NLSP & then to gravitino. Phenomenology determined by NLSP.

One clean signature is when last decay in the chain is $\tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \gamma \tilde{G} \gamma \tilde{G}$

UED limits also found:
Abazov et al. PRL 105, 221802 (2010)

Using SPS8:

$$\Lambda_{\text{GMSB}} > 124 \text{ TeV}$$

$$m(\tilde{\chi}_1^0) > 175 \text{ GeV}, \; m(\tilde{\chi}_1^\pm) > 331 \text{ GeV}$$
SUSY & Dark Photons

PAMELA, ATIC, Fermi LAT, INTEGRAL, HEAT, AMS-01, WMAP (‘haze’) all have results that could be interpreted as dark matter annihilation to $e^+e^-$ near the center of the Milky Way


⇒ try to fit them all into 1 model (along with DAMA results)

- Dark matter is on 0.5 - 0.8 TeV mass scale and annihilates to SM particles with sizeable cross sections
- Perhaps some new symmetry prevents the decay of these states
- These massive states might couple to $\mathcal{O}[1\text{GeV}]$ “dark photons” which is part of a new sector of matter (a Hidden-Valley model)
- This picture of dark matter can be implemented with GMSB SUSY
SUSY & Dark Photons

Look for $2\ e^+e^-$, $\mu^+\mu^-$ pairs with small opening angles – need to develop new isolation cuts

Don’t require $\ell^+\ell^-$ pairs to come from primary $p\bar{p}$ vertex to allow up to $\mathcal{O}[1\text{cm}]$ decay length

\[ E_T > 30 \text{ GeV} \]

Looking Forward: charm tagging

**Charm is hard to find with just vertex detectors**

Typically $\tau(b\ hadrons) > \tau(c\ hadrons)$

$\Rightarrow$ no high-purity selection

2 output, 22 input

Neural Net

CDF Run II Preliminary

CDF CONF Note 9834
Looking Forward: tau tagging

τ is a long lived particle

Use impact parameter to remove jets faking τ more efficiently.
(large $c\tau_{\text{life}} \Rightarrow$ large $d_0$)

After adding these variables in the NN clear improvement was observed:
~ 10% more signal for the same bkg

3 prong $\tau_{\text{had}}$
“Overall, this search complements the Tevatron searches, which are mostly sensitive to electroweak gaugino production, while this search is mostly sensitive to squark-gluino production.”
This Just In

New result in SUSY search in trileptons from CDF:

![CDF Run II Preliminary (L=5.8 fb^{-1})](image)

Marcel Vogel presentation 235 in Room F (Wilson Hall 3NE)
Monday 29 Aug 11:35 AM

CDF Note 10636
Closing

![Graph showing regions of parameter space for supersymmetry (SUSY)](image)

- CDF Excluded Range
- UA1 Upper Limit

Parameters:
- $M_{\tilde{g}}$ (GeV)
- $M_{\tilde{q}}$ (GeV)
Closing

\[ D\bar{0}, \ L=2.1 \ \text{fb}^{-1} \]
\[ \tan\beta=3, \ \ A_0=0, \ \mu<0 \]
Closing

Squark-gluino-neutralino model (massless $\tilde{\chi}_1^0$)

ATLAS Preliminary
0 lepton 2011 combined
- Observed 95% C.L. limit
- Median expected limit
- $CL_s$ Observed 95% C.L. limit
- $CL_s$ Median expected limit
- 2010 data PCL 95% C.L. limit

LEP 2 $\tilde{q}$
Tevatron, Run I
D0, Run II
CDF, Run II

$\chi^2 = 165 \text{ pb}^{-1}, s = 7 \text{ TeV}$

$\sigma_{\text{SUSY}} = 0.1 \text{ pb}$

$\sigma_{\text{SUSY}} = 1 \text{ pb}$

$\sigma_{\text{SUSY}} = 10 \text{ pb}$

L. Bellantoni (FNAL)  SUSY '11  28 Aug 2011
Closing
Many thanks: Oscar Gonzalez, Mike Eads, Michel Jaffre, Rob Forrest, & Our Conference Organizers
Another Slide

sparticle masses ≠ SM particle masses

Few constraints on Lagrangian terms that could create this asymmetry ⇒ 105 “L_{SOFT}” terms

Different SUSY-breaking models simplify these 105 terms with various parameterizations

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<thead>
<tr>
<th>mSUGRA</th>
<th>GMSB</th>
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<tbody>
<tr>
<td>m_0</td>
<td>Λ</td>
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<tr>
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<td>tan β</td>
<td>M_m</td>
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<td>Messenger mass scale</td>
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<td>tan β</td>
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<td>Ratio of Higgs vev</td>
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<td>Higgsino parameter</td>
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<td>C_{grav}</td>
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<td>Sets the NLSP lifetime</td>
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Just 2 of many possibilities