SUGRA Results from CDF

- Status of CDF Run II
- Searches with Jets and $E_T$
- Searches with Leptons and $E_T$
- The Search for $B_s \rightarrow \mu^+\mu^-$
- Concluding Remarks

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SUGRA20
Northeastern University
20-March-2003
CDF Run II Upgrades

Improved Detector Capabilities:

- Main Ring is gone!
  ⇒ easier time with acc. bg’s
- plug calorimetry
  ⇒ better $E_T$ coverage
- extended lepton coverage
  ⇒ higher acceptance
- better $E_T$ triggers
  lower thresholds $\rightarrow$ higher eff.
- better timing in HCAL
  ⇒ better non-coll BG rej’n
**Accelerator Performance and Luminosity**

**Tevatron Run II:**

- higher energy $\sqrt{s} = 1.96$ TeV
- higher luminosities...
  - below expectations – *but improving!*
    - record $3.6 \times 10^{31}$ cm$^{-2}$s$^{-1}$
    - 4–7 pb$^{-1}$ / week
    - 180 pb$^{-1}$ delivered,
      130 pb$^{-1}$ recorded
      $\Rightarrow$ typ. op. eff $\sim$ 90%
- real physics data since a year –
  $> 70$ pb$^{-1}$ for most analyses

*This is not enough to surpass the Run I results.*

*However, we are working toward probing new territory in the next year.*
**Relevant Searches**

**SUGRA!**

- Very Parsimonious w/ Parameters...
- main mass param’s $m_0$ & $m_{1/2}$
  
  $M_{\text{gauginos}} \sim m_{1/2}$
  $M_{\text{scalars}}^2 \equiv m_0^2 + m_{1/2}^2$
- 3rd generation ‘edge effects’
  make tan $\beta$ important, too.
  $\rightarrow$ high/low tan $\beta$ dichotomy

Assume R-parity conservation

$\rightarrow \tilde{\chi}_1^0$ is the LSP

Today we emphasize the newest Run I results,
and give some hints of the status of non-SUSY Run II searches...
Multiple Jets and Missing Energy

Intended for $\tilde{q}, \tilde{g}$ signals.

- **2-stage selection**
  - get rid of accel’r bg.
  - $E_T \&$ topology cuts kill QCD
  - QCD, EWK+top bg’s roughly equal

- **The “Blind Box”**
  - define signal / control regions acc:
    - $E_T, H_T \equiv E_{J2} + E_{J3} + \not{E}_T, N_{iso}^{trk}$

  → check normalization and kinematic dist’s in control regions before looking at events in the signal region.
No Signal / No Excess.

74 observed
76 ± 13 expected
(35 EWK + 41 QCD)

Tighten cuts on $E_T^\text{miss}$ and $H_T$ in order to improve sensitivity in four general cases of $M_{\tilde{q}}$ and $M_{\tilde{g}}$.

Again, no excess. → set limits.

Exclusion: World’s Best Limit

$M_{\tilde{g}} > 300$ GeV for $M_{\tilde{q}} \sim M_{\tilde{g}}$

$M_{\tilde{g}} > 195$ GeV for $M_{\tilde{q}} \gg M_{\tilde{g}}$

This results represents a substantial improvement in sensitivity over earlier work. → reason for some optimism?
**Run II Improvements:**

- no MR splash!
- plug calorimeter
- better $E_T$ triggers
- better HCAL timing

$E_T$ measurements sensitive to
- calorimeter uniformity
- em / had calibration
- beam position!

Much work has been done... 

→ understand $E_T$ at a level 
  sufficient for searches.

Results from a Leptoquark search will be ready in the Spring.
Related Work in Run II: Search for Dijet Resonances

New result from Run II!!

- combine several di-jet samples
- di-jet mass calculated from corrected jet energies

→ fit corrected spectrum to empirical smooth function
→ ratio and residuals show no signs of ‘bumps’

Upper limits on $\sigma \cdot B$:

0.3–1.5 pb for masses in the 800-1000 GeV range

→ significantly extends exclusion of axigluons and excited quarks.
Phenomenological Studies of the Reach of Run II

Run II SUGRA Working Group:
(also, Baer et al. PRD64 1996)

Take queues from Run I analyses, and assume $\mathcal{L} = 2 \text{ fb}^{-1}$.

Rough criteria appropriate for discovery.

Results in $(m_0, m_{1/2})$ plane correspond roughly to $M_\tilde{g} > 400$ GeV.

Presumably a ‘real’ analysis will do even better...
**Like-Sign Leptons, Jets and Missing Energy**

Another possibility for \( \tilde{q} \) & \( \tilde{g} \)

If EWK gauginos light enough, they appear in the cascade decays of \( \tilde{q} \) and \( \tilde{g} \), and decay sometimes to leptons.

*Like-Sign* lepton pairs are unusual
⇒ low SM backgrounds.

* complements Jets+\( E_T \) search

Assume no decays to Higgs bosons.
What do we need to know, experimentally speaking?

- What leptons do we have?
  - reconstruction and ID
  - fake, non-prompt sources

- Large opposite-sign sources
  - $Z$'s, $J/\psi$, $b\bar{b} + c\bar{c}$, etc.

- missing energy measurement
  - resolution and tails
  - (non-collision bg)

*OS/LS comparisons are the key.*
**No Excess.**

\[ \begin{align*}
\text{expect} & \quad \text{observe} \\
\text{opposite-sign:} & \quad 14.1 \pm 3.1 \quad 19 \\
\text{like-sign:} & \quad 0.55 \pm 0.26 \quad 0
\end{align*} \]

\[ \rightarrow \text{set limits} \]

\[ M_{\tilde{g}} > 221 \text{ GeV for } M_{\tilde{q}} \sim M_{\tilde{g}} \]

\[ M_{\tilde{g}} > 168 \text{ GeV for } M_{\tilde{q}} \gg M_{\tilde{g}} \]

The multi-jet+\( E_T \) searches appear to be more powerful. 
*In fact* they apply to scenarios differing in the way in which \( \tilde{q} \)'s and \( \tilde{g} \)'s decay. **Both searches are important!**
Related Work in Run II: Leptoquark Searches

New result from Run II!!

\[ e^+e^- JJ \text{ channel} \]

(opposite-sign, no \( E_T \))

- demand tight \( e^+e^- \)
  \( \rightarrow \) testing lepton ID
  \( \rightarrow \) understood

main bg \( Z \rightarrow e^+e^- + \text{ISR} \)

\( \rightarrow \) understood

\begin{align*}
\text{total background} & \quad 3.39 \pm 3.15 \\
\text{observed} & \quad 0
\end{align*}

\[ \sigma \times Br \text{ sensitivity to } \sim 0.1 \text{ pb for } 72 \text{ pb}^{-1} \]
**Tri-leptons**

**Associated Production of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$**

- pertinent to gauginos with significant leptonic BR’s
  
  $\rightarrow M_{\tilde{g}} < M_{\tilde{q}} < 2 M_{\tilde{g}}$

  probe $150 < M_{\tilde{g}} < 340$ GeV

- low backgrounds
  
  dibosons, $tt$, $bb$

  $WW$, Drell-Yan + fake lepton

  expect $6.6 \pm 1.1$, observe 6

- require $E_T > 15$ GeV

  expect $1.1 \pm 0.2$, observe zero

  sensitivity at $\sigma \times B \sim 0.3$ pb

**Not very constraining, needs more luminosity.**

**New result on LSDL available at DPF…**
Related Work: $Z'$ Searches in $e^+e^-$ and $\mu^+\mu^-$ channels

New result from Run II!!

- two tight leptons
  $\longrightarrow$ understand lepton ID

- eliminate QCD and CR backgrounds, leaving DY processes

- define mass region $M_{\ell^+\ell^-} > 150$ GeV
  total expected background $5.2 \pm 0.3$
  observed $4$

sensitivity to $\sim 1$pb ($\mu$) $\sim 0.1$pb (e)

- muons $M_{Z'} > 455$ GeV
- electrons $M_{Z'} > 650$ GeV

Work proceeds with low-$p_T$ multilepton sample – more challenging...
Phenomenological Studies of the Reach of Run II

Several studies showing gains in sensitivity.

* some useful ideas there.

BG from off-shell bosons important

decays to $\tau$’s play important role

→ try to reconstruct them

→ lower $p_T$ thresholds

Trileptons most effective at low $\tan\beta$

→ high $\tan\beta$ scenario is complicated.

Work on $\tau$ identification is intense.

Clean signals seen in $W \to \tau\nu_{\tau}$ and $Z \to \tau^+\tau^-$. 

Barger & Kao, 1998
A Search for $\tilde{t}_1 \rightarrow b\ell\bar{\nu}$

Opposite-Sign Leptons, Jets and $E_T$

Latest published CDF SUSY result!

Careful control of OS-dilepton sample

→ DY large in OS (not LS)
→ HF large in both (not equally)
→ mis-ID significant in both
→ $t\bar{t}$, diboson present OS
  • check high/low $p_T$ and $E_T$
    * good agreement!

Impose (single) $b$-tag

Gain sensitivity with $E_T > 30$ GeV & angle cuts.

Two ‘Blind Analyses’

\[ M_{\tilde{t}} - M_\nu \]

<table>
<thead>
<tr>
<th></th>
<th>obs.</th>
<th>expect.</th>
<th>signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>small</td>
<td>0</td>
<td>1.5 ± 0.5</td>
<td>5.7 ± 2.1</td>
</tr>
<tr>
<td>large</td>
<td>0</td>
<td>2.1 ± 0.5</td>
<td>8.2 ± 3.1</td>
</tr>
</tbody>
</table>

Michael Schmitt, Northwestern University
Stop in the Dilepton Channel, $t \rightarrow l \bar{\nu} b$

CDF Run I Preliminary
$\int L \, dt = 107 \, \text{pb}^{-1}$

- Data
- All Background
- Background Uncertainty

2 Isolated Leptons
$p_T(l_1) > 10 \, \text{GeV/c}$, $p_T(l_2) > 6 \, \text{GeV/c}$
Missing $E_T > 15 \, \text{GeV}$
Jet $E_T > 15 \, \text{GeV}$

Exclusions:

Stop in the Dilepton Channel, $t \rightarrow l \bar{\nu} b$

CDF $\int L \, dt = 107 \, \text{pb}^{-1}$

$\sum \text{Br}(t \rightarrow l \bar{\nu} b) = 100\%_{\text{e,\mu,\tau}}$

CDF excluded at 95\% C.L.
Heavy Flavor Jets & Missing Energy

Intended for \( \tilde{t}_1 \) and \( \tilde{b}_1 \) signals.

- assume prototypical decay modes
  \[ \tilde{t}_1 \rightarrow c\tilde{\chi}^0_1 \quad \tilde{b}_1 \rightarrow b\tilde{\chi}^0_1 \]
- signature is 2 HF jets and \( E_T \)
  use ‘jet probability’
  tighter cut for bottom
  looser cut for charm

Run II Progress –
- Run 1-style algorithms working
- tagging rates measured in data
- simulation compares well to data
  \[\implies\text{HF Jets} + E_T \text{ looking good.}\]
Examples of Studies of Heavy Flavor Tagging

Number of Good Tracks in Tagged Electron Jet

Number of Tagged Tracks in Tagged Electron Jet

Secondary Vertex Pseudo Lxy in Tagged Electron Jet

Secondary Vertex Mass in Tagged Electron Jet

\[ \begin{align*}
\text{Entries} & \quad 1840 \\
\text{Mean} & \quad 4.268 \\
\text{RMS} & \quad 1.543
\end{align*} \]
The Search for $B_s \rightarrow \mu^+ \mu^-$

- This rare decay can be very strongly enhanced for high-$\tan\beta$ SUSY.
  \[ \tan^6 \beta \]

- Complements the tri-lepton search (which is weak due to enhanced $\tau$'s)
  Dedes, Dreiner, Nierste, Richardson
  hep-ph/0207026

- CDF set upper limit in Run I
  \[ B < 2.6 \times 10^{-6} \quad 95\% \text{ C.L.} \]

- Recent studies indicate sensitivity could reach $\sim 10^{-8}$ for 15 fb$^{-1}$.
  Arnowitt, Dutta, Kamon, Tanaka hep-ph/0203069
Related Work in Run II: \[ D^0 \rightarrow \mu^+ \mu^- \quad \text{New!} \quad 69 \text{pb}^{-1} \]

CDF Run II Preliminary

Normalization mode:
1371 ± 53 \( D^0 \rightarrow \pi^+ \pi^- \) in the mass search window
\[ \int L \, dt = 69 \text{pb}^{-1} \]
CMU fiducial

CDF Run II Preliminary

D^0 \rightarrow \mu^+ \mu^- \quad \text{Search}

0 events in the ±2\( \sigma \) search window

expect: 1.7 ± 0.7 events
observe: zero

\[ BF(D^0 \rightarrow \mu^+ \mu^-) < 3.1 \times 10^{-6} \quad 95\% \text{ C.L.} \]

Already 2\( \times \) better than previous limit. \( B_s \rightarrow \mu^+ \mu^- \) results are on the way...
**Higgs Searches**

In mSUGRA, Higgs mass bounds cover more parameter space than TeVATRON squark & gluino searches.

With $\mathcal{L} \sim 10 \text{ fb}^{-1}$ the mass reach for a SM-like Higgs boson was estimated to be about 140 GeV – well beyond the maximum mSUGRA mass of $\sim 122 \text{ GeV}$. (FNAL WS 1998-99)

The CDF and DØ Collaborations are re-examining these estimates in the context of current detector and accelerator performance.

Ellis et al. PL B510 (2001) 236
Summary and Conclusions

- Searches for non-SM particles are ‘turning on’ this year.

- Sensitivity in the mSUGRA scenario should soon surpass that of Run I.
  - thanks to better detector & triggers
  - hope for $L > 200 \text{pb}^{-1}$ by end of year
  - current $L \times \sigma$ roughly the same as Run I
    since $\sigma(2\text{TeV}) > \sigma(1.8\text{TeV})$.

- Some new results should be ready this summer,
  with many more by the next SUSY conference.

- For the next several years, Fermilab is the place for SUSY!

Thanks to the organizers!

Michael Schmitt, Northwestern University