New Physics Searches

Volker Büscher
Universität Mainz

Selection of results from the ATLAS, CDF, CMS and DØ Collaborations

EPS 2009, July 20, 2009

- Supersymmetry
- New high-mass states
- Exotic Signals
Tevatron: 2 TeV
Proton-Antiproton
In operation since 2001
7 fb$^{-1}$ delivered, expect 12 fb$^{-1}$ by 2011

LHC: 14 TeV
Proton-Proton
Scheduled to restart in Fall 2009
expect 200 pb$^{-1}$ at $\sqrt{s}=10$ TeV in 2010
Run II Integrated Luminosity

Most recent results: 4.2 fb$^{-1}$

6.10

6.90
Supersymmetry

The idea: particle physics is symmetric under transformation of Fermion ↔ Boson
→ one supersymmetric partner for each SM particle
→ stabilizes Higgs mass, unification of coupling constants, dark matter candidate

Superpartners are heavy → SUSY is broken → masses unknown

Prediction:
– Extended Higgs sector: 5 Higgs bosons h,H,A,H±
– Many new particles: Charginos/Neutralinos/Gluinos, Squarks, Sleptons

<table>
<thead>
<tr>
<th>Names</th>
<th>spin 0</th>
<th>spin 1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>squarks, quarks (×3 families)</td>
<td>Q, τ, d</td>
<td>(\tilde{u}_L \tilde{d}_L), \tilde{u}_R^<em>, \tilde{d}_R^</em></td>
</tr>
<tr>
<td>sleptons, leptons (×3 families)</td>
<td>L, \bar{e}</td>
<td>(\tilde{\nu} \tilde{e}_L), \tilde{\nu}_R^* \tilde{e}_R^*</td>
</tr>
<tr>
<td>Higgs, higgsinos</td>
<td>H_u, H_d</td>
<td>(H_u^+, H_u^0), (\tilde{H}_u^+, \tilde{H}_u^0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Names</th>
<th>spin 1/2</th>
<th>spin 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>gluino, gluon</td>
<td>\tilde{g}</td>
<td>g</td>
</tr>
<tr>
<td>winos, W bosons</td>
<td>\tilde{W}^\pm, \tilde{W}^0</td>
<td>W^\pm, W^0</td>
</tr>
<tr>
<td>bino, B boson</td>
<td>\tilde{B}^0</td>
<td>B^0</td>
</tr>
</tbody>
</table>
A typical Mass Spectrum

Particle Spectrum

Mass (eV)

$10^{12}$

$10^{11}$

$H^+$

$H, A$

$\chi^+, \chi^0$

$\chi_2, \chi_4$

$\chi_1, \chi_2$

$\chi_1$

$\chi_0$

$\bar{q}$

$\bar{b}_{2}\tilde{t}_2$

$\bar{b}_1$

$\tilde{t}_1$

$\bar{q}_L, \bar{q}_R$

$\nu_L$

$\nu_R$

$\tau_1$

$\tau_2$
A typical Mass Spectrum

Particle Spectrum

Mass (eV)

$10^{11}$

$10^{12}$

Squarks/Gluinos

$\tilde{g}$

$\tilde{q}_L, \tilde{q}_R$

$\tilde{b}_2$

$\tilde{t}_1$

$\tilde{\tau}_2$

$\nu_L, \tau_1$

$\chi_1, \chi_2$

$\chi_3, \chi_4$

$H^+ / H, A$

$h$

$\chi_1^0$
Inclusive Search for generic Squarks/Gluinos

Squarks/Gluinos produced via strong interaction
→ large cross sections at hadron colliders

Decays: jets + LSP
  – LSP assumed to be stable ($R_p$ conserved)
→ Signature: jets + $E_T$

$qq\bar{q}\bar{q}$ candidate event in DØ

Multijet Background

Background:
$Z \rightarrow \nu\nu + \text{jets}$
Inclusive Search for generic Squarks/Gluinos

- No evidence for squark/gluino production at the Tevatron
- Limits in squark/gluino mass plane, probing squark/gluino masses up to 400/320 GeV
- Starting to be limited by parton luminosities
- No evidence for squark/gluino production at the Tevatron
- Limits in squark/gluino mass plane, probing squark/gluino masses up to 400/320 GeV
- starting to be limited by parton luminosities
What SUSY particles to look for?

- Stop/sbottom expected to be light

<table>
<thead>
<tr>
<th>Mass (eV)</th>
<th>Particle Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{11}$</td>
<td>$\chi_1^0$</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>$\chi_3^0$</td>
</tr>
<tr>
<td></td>
<td>$\chi_1$, $\chi_2$</td>
</tr>
<tr>
<td></td>
<td>$\tilde{t}_1$</td>
</tr>
<tr>
<td></td>
<td>$\tilde{b}_1$</td>
</tr>
<tr>
<td></td>
<td>$\tilde{g}$</td>
</tr>
<tr>
<td></td>
<td>$H^\pm$, $H, A$</td>
</tr>
</tbody>
</table>
Search for Supersymmetry – Sbottom Quarks

Decay: $\tilde{b} \rightarrow b + \tilde{\chi}_1^0$

$\rightarrow$ jets+$E_T$ analysis with b-tagging

D0 Run II Preliminary (4 fb$^{-1}$)

before b-tagging

after b-tagging
Visible energy in event depends on $\tilde{b}-\tilde{\chi}_1^0$ mass difference $\Delta m$

Low $\Delta m$ analysis: 483 events observed, $493 \pm 12$ events expected
- No reach for $\tilde{b}-\tilde{\chi}_1^0$ mass differences below 30 GeV (trigger)

High $\Delta m$ analysis: 7 events observed, $7.1 \pm 0.4$ events expected
- Probing sbottom masses up to 250 GeV
Search for Supersymmetry – Stop Quarks

For light stop, $\tilde{t} \rightarrow t + \tilde{\chi}_1^0$ not allowed

Dominant decay mode depends on other SUSY masses:
- If stop is next-to-lightest SUSY particle: loop-induced decay $\tilde{t} \rightarrow c + \tilde{\chi}_1^0$

Prompt decays: $2\ c$-jets + $E_T$

Long-lived Stop Quark

CDF Run II Preliminary

\[ \int L \ dt = 2.6 \text{ fb}^{-1} \]

Observed Limit (95% CL)
Expected Limit ($\pm 1\sigma$)

CDF Run II Preliminary

\[ \int L \ dt = 1.03 \text{ fb}^{-1} \]

Stop Production cross section (NLO)

Cross section limit from central $\mu$

CDF 295 pb$^{-1}$

DØ 995 pb$^{-1}$

LEP $\theta = 56^\circ$

LEP $\theta = 0^\circ$

Stop Mass [GeV/c$^2$]

Neutralino Mass [GeV/c$^2$]

Cross section (pb)
Search for Stop Quarks: $\tilde{t} \rightarrow b + \tilde{\chi}^\pm_1$

If Chargino light enough: $\tilde{t} \rightarrow b + \tilde{\chi}^\pm_1$

With $\tilde{\chi}^\pm_1 \rightarrow \ell \nu \tilde{\chi}^0_1$, final state very similar to dileptonic top decays

$\rightarrow$ search top dilepton sample for hints of stop quarks

Reconstruct stop quark mass to distinguish from top:

- build a “heavy neutrino” from LSP+neutrino, then use neutrino weighting technique
- extract limits in 3d space of $m_\tilde{t}$, $m_{\tilde{\chi}^\pm_1}$, $m_{\tilde{\chi}^0_1}$
Search for Stop Quarks: $\tilde{t} \rightarrow b + \tilde{\chi}_1^{\pm}$

If Chargino light enough: $\tilde{t} \rightarrow b + \tilde{\chi}_1^{\pm}$

With $\tilde{\chi}_1^{\pm} \rightarrow \ell \nu \tilde{\chi}_1^{0}$, final state very similar to dileptonic top decays
→ search top dilepton sample for hints of stop quarks

Reconstruct stop quark mass to distinguish from top:
– build a “heavy neutrino” from LSP+neutrino, then use neutrino weighting technique
– extract limits in 3d space of $m_\tilde{t}$, $m_{\tilde{\chi}_1^{\pm}}$, $m_{\tilde{\chi}_1^{0}}$
Search for Stop Quarks: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$

If Sneutrino light enough: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$ with $\tilde{\nu} \rightarrow \nu + \tilde{\chi}^0_1$

Most sensitive channel: $2b + e + \mu + E_T$

Mass difference between stop and sneutrino determines transverse energy in event

→ analysis split into several transverse energy bins

Low energy
Background: $Z \rightarrow \tau \tau \rightarrow e\mu + E_T$

High energy
Background: $t\bar{t} \rightarrow 2b + e\mu + E_T$

DØ Run II Preliminary, 3.1 fb$^{-1}$

$S_T < 80$

$220 < S_T$
Search for Stop Quarks: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$

If Sneutrino light enough: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$ with $\tilde{\nu} \rightarrow \nu + \tilde{\chi}_1^0$

Most sensitive channel: $2b + e + \mu + E_T$

Mass difference between stop and sneutrino determines transverse energy in event
→ analysis split into several transverse energy bins

![Graph showing excluded regions in the 2D mass plane of stop and sneutrino masses, with LEP I and LEP II excluded regions, and CDF 1 fb$^{-1}$ results.](image-url)
What other SUSY particles to look for?

Particle Spectrum

<table>
<thead>
<tr>
<th>Mass (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{12}$</td>
</tr>
<tr>
<td>$10^{11}$</td>
</tr>
<tr>
<td>$10^{10}$</td>
</tr>
<tr>
<td>$10^{9}$</td>
</tr>
<tr>
<td>$10^{8}$</td>
</tr>
<tr>
<td>$10^{7}$</td>
</tr>
<tr>
<td>$10^{6}$</td>
</tr>
<tr>
<td>$10^{5}$</td>
</tr>
<tr>
<td>$10^{4}$</td>
</tr>
<tr>
<td>$10^{3}$</td>
</tr>
<tr>
<td>$10^{2}$</td>
</tr>
<tr>
<td>$10^{1}$</td>
</tr>
<tr>
<td>$10^{0}$</td>
</tr>
</tbody>
</table>

- $h$
- $H^\pm/H_A$
- $\tilde{g}$
- $\tilde{b}_2$, $\tilde{b}_1$
- $\tilde{t}_1$
- $\tilde{q}_L$, $\tilde{q}_R$
- $\chi^\pm$, $\chi^0$
- $\tilde{\chi}_1$, $\tilde{\chi}_2$
- $\tilde{\chi}_3$, $\tilde{\chi}_4$
- $\tau_1$, $\nu_L$

- potentially too heavy
- too rare to observe
- invisible
Search for Charginos and Neutralinos

Golden channel: $\tilde{\chi}^\pm \tilde{\chi}_2^0 \rightarrow 3\ell + E_T$

Challenges:
- production cross section (electroweak) relatively small
- low-$p_T$ leptons

Large number of trilepton and dilepton plus track analyses from CDF and DØ
- $p_T$ cuts as low as 3 GeV

![Diagram of SUSY processes](image)
Search for Charginos and Neutralinos

requiring 2 leptons

![Graph showing data analysis for 2 lepton selection.]  

requiring 3 leptons

![Graph showing data analysis for 3 lepton selection.]  

Observed number of events is consistent with expected background

→ No evidence for chargino/neutralino production
Candidate Event

Run 231775 Evt 20290595 Sat Mar 31 11:05:15 2007
ET scale: 17 GeV

SUSY: WZ + 2 LSP

Standard Model: WZ
Search for Charginos and Neutralinos: Results

- Analyses probing chargino masses up to 176 GeV
- Reach degrades with increasing $\tan\beta$
Search for Supersymmetry at the LHC

Particle Spectrum

Mass (eV)

- $\tilde{g}$
- $\tilde{t}_1$
- $\tilde{b}_2$
- $\tilde{b}_1$
- $\tilde{t}_2$
- $\tilde{H}_1$
- $\tilde{H}_2$
- $\tilde{H}_3$
- $\tilde{H}_4$
- $\tilde{\nu}_L$
- $\tilde{\tau}_1$
- $\tilde{\tau}_2$
- $\tilde{\chi}^0_1$
- $\tilde{\chi}^0_2$
- $\tilde{\chi}^0_3$
- $\tilde{\chi}^0_4$
- $\tilde{\chi}^+_1$
- $\tilde{\chi}^+_2$
- $\tilde{\chi}^+_3$
- $\tilde{\chi}^+_4$

Potential too heavy

Too rare to observe

Invisible

All particles accessible
- Strong production will dominate
- Potentially long decay cascades
Search for Supersymmetry at the LHC

CMS: updated study of jets+2l+$E_T$ analysis ($\sqrt{s}=10$ TeV, $\int L dt=200$ pb$^{-1}$)

- excellent discovery potential for “light” SUSY
- for $\tilde{\chi}_2^0 \rightarrow \ell\ell\tilde{\chi}_1^0$ in cascade decays: $m_{\ell\ell} \leq m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$
- observation of signal would allow fit of dilepton endpoint with 4% accuracy
CMS: updated study of jets+2l+$E_T$ analysis ($\sqrt{s}=10$ TeV, $\int Ldt=200$ pb$^{-1}$)

- excellent discovery potential for “light” SUSY
- for $\tilde{\chi}^0_2 \rightarrow \ell\ell\tilde{\chi}^0_1$ in cascade decays: $m_{\ell\ell} \leq m_{\tilde{\chi}^0_2}-m_{\tilde{\chi}^0_1}$
- observation of signal would allow fit of dilepton endpoint with 4% accuracy

![Graph showing CMS preliminary 10 TeV data with significant values: $m_{\text{cut}} = 52.8 \pm 1.1$, $n_{\text{Sig}} = 97 \pm 17$, $n_z = 0.0 \pm 1.8$, $n_{\text{Bkg,0-80}} = 130.1 \pm 11.4$ ($\chi^2/\text{ndf} = 0.74$).]
ATLAS: updated study of all inclusive search channels ($\sqrt{s}=10$ TeV, $\int L dt = 200 \text{ pb}^{-1}$)

- excellent discovery potential for “light” SUSY
New High-Mass States

Most models predict high-mass states $X$ that fit 2 generic classes:

- resonant production of $X \rightarrow f \bar{f}, \gamma \gamma, VV$ (e.g. $W', Z',$ RS-Gravitons etc.)
- $X$ pair production (e.g. Leptoquarks, $b'$, $t'$ etc.)

Mass reach ultimately limited by parton luminosities: $\sim 1$ TeV for $X$, $\sim 500$ GeV for $XX$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>Sequential $V'$</th>
<th>RS-G. $k/M_{Pl}=0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma \gamma$</td>
<td>$WW/WZ$</td>
</tr>
<tr>
<td>Limit (GeV)</td>
<td>$\gamma \gamma$</td>
<td>$WW/WZ$</td>
</tr>
<tr>
<td>$e\nu$</td>
<td>1000</td>
<td>966</td>
</tr>
<tr>
<td>$ee$</td>
<td>910*</td>
<td>399</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>1030</td>
<td>820</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>910*</td>
<td>399</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>840</td>
<td>820</td>
</tr>
<tr>
<td>$qq$</td>
<td>840</td>
<td>820</td>
</tr>
<tr>
<td>$tt$</td>
<td>900</td>
<td>606</td>
</tr>
<tr>
<td>$tb$</td>
<td>900</td>
<td>606</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>Leptoquarks $\beta=1$</th>
<th>Sequential $f'$</th>
<th>Excited $f^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e\gamma$</td>
<td>$\mu\gamma$</td>
<td></td>
</tr>
<tr>
<td>$eq$</td>
<td>256</td>
<td>325</td>
<td></td>
</tr>
<tr>
<td>$\mu q$</td>
<td>316</td>
<td>311</td>
<td></td>
</tr>
<tr>
<td>$b\tau$</td>
<td>210</td>
<td>796</td>
<td></td>
</tr>
<tr>
<td>$q\nu$</td>
<td>205</td>
<td>853</td>
<td></td>
</tr>
<tr>
<td>$b\nu$</td>
<td>252</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b' \rightarrow tW$</td>
<td>325</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t' \rightarrow qW$</td>
<td>311</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* reviewers extrapolation
New High-Mass States: $b'b' \rightarrow 2b + 4W$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>ee</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>qq</th>
<th>$t\bar{t}$</th>
<th>tb</th>
<th>RS-G. $k/M_{Pl}=0.1$</th>
<th>$\gamma\gamma$</th>
<th>WW/WZ</th>
<th>ZZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td>1030</td>
<td>910*</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
<td>606</td>
<td>490</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>eq</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>q$\nu$</th>
<th>b$\nu$</th>
<th>$b' \rightarrow tW$</th>
<th>$t' \rightarrow qW$</th>
<th>$e\gamma$</th>
<th>$\mu\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
<td>853</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

CDF Run II Preliminary (2.7 fb$^{-1}$)
**New High-Mass States: X→WV→ eν + 2j**

<table>
<thead>
<tr>
<th>Sequential V'</th>
<th>RS-G. k/M_{Pl} = 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>X→</td>
<td>eν</td>
</tr>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Leptoquarks β = 1**

<table>
<thead>
<tr>
<th>Sequential f'</th>
<th>Excited f*</th>
</tr>
</thead>
<tbody>
<tr>
<td>X→</td>
<td>eq</td>
</tr>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

---

**CDF run II Preliminary 2.9fb⁻¹**

**Et cuts optimized for 400-700GeV Z'**

- Data
- Bkgd ±1σ
- Z' signal
- W+Jets
- tt̅
- WW
- QCD
- Others

**600GeV Z'**

**WW Invariant Mass (GeV)**

**Et cuts optimized for 400-700GeV W'**

- Data
- Bkgd ±1σ
- W' signal
- W+Jets
- tt̅
- WW
- QCD
- Others

**600GeV W'**

**WZ Invariant Mass (GeV)**
### New High-Mass States: $X \rightarrow ZZ \rightarrow 4\ell$ or $2\ell + 2j$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>ee</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>qq</th>
<th>$t\bar{t}$</th>
<th>tb</th>
<th>RS-G. $k/M_{\text{Pl}} = 0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td>1030</td>
<td>910*</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>WW/WZ</td>
<td></td>
<td>ZZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$eq$</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>$q\nu$</th>
<th>$b\nu$</th>
<th>$b' \rightarrow tW$</th>
<th>$t' \rightarrow qW$</th>
<th>Excited $f^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

### COMBINED DIJET CHANNELS

CDF RUN II PRELIMINARY

$\mathcal{L} = 2.5-2.9$ FB$^{-1}$

![Graph showing event distribution (bin vs. $M_{lljj}$ (GeV))](#)

**DATA**

**BACKGROUND**
New High-Mass States: $X \rightarrow ee$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>$qq$</th>
<th>$t\bar{t}$</th>
<th>$tb$</th>
<th>$\gamma\gamma$</th>
<th>$WW/WZ$</th>
<th>$ZZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td>1030</td>
<td>910*</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
<td>606</td>
<td>490</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$eq$</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>$\mu \nu$</th>
<th>$b\nu$</th>
<th>$b' \rightarrow tW$</th>
<th>$t' \rightarrow qW$</th>
<th>$e\gamma$</th>
<th>$\mu\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
<td>853</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

![Graph](image-url)
New High-Mass States: $X \rightarrow \mu\mu$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>$qq$</th>
<th>$t\bar{t}$</th>
<th>$tb$</th>
<th>$\gamma\gamma$</th>
<th>$WW/WZ$</th>
<th>$ZZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td><strong>1030</strong></td>
<td>910*</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
<td>606</td>
<td>490</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$eq$</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>$q\nu$</th>
<th>$b\nu$</th>
<th>$b'\rightarrow tW$</th>
<th>$t'\rightarrow qW$</th>
<th>$e\gamma$</th>
<th>$\mu\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
<td>853</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

CDF II preliminary \[\int L \, dt = 2.3 \, \text{fb}^{-1}\]
New High-Mass States: $X \rightarrow qq$

### Sequential $V'$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>$qq$</th>
<th>$t\bar{t}$</th>
<th>$tb$</th>
<th>$\gamma\gamma$</th>
<th>WW/WZ</th>
<th>ZZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td>1030</td>
<td>910</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
<td>606</td>
<td>490</td>
</tr>
</tbody>
</table>

### Leptoquarks $\beta=1$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$eq$</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>$q\nu$</th>
<th>$b\nu$</th>
<th>$b'\rightarrow tW$</th>
<th>$t'\rightarrow qW$</th>
<th>$e\gamma$</th>
<th>$\mu\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
<td>853</td>
</tr>
</tbody>
</table>

* reviewers extrapolation

---

**Figure:**

- **(a)**: Graph showing $d\sigma/dm_{jj}$ [pb/(GeV/c$^2$)] for various masses: 300, 500, 700, 900, and 1100 GeV/c$^2$.
- **(b)**: Graph showing the ratio $(\text{Data} - \text{Fit})/\text{Fit}$ versus $m_{jj}$ [GeV/c$^2$] for masses ranging from 200 to 1400 GeV/c$^2$. The data points are compared to the fit from the CDF Run II experiment (1.13 fb$^{-1}$).
New High-Mass States: $X \rightarrow t\bar{t}$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$e\nu$</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$\tau\tau$</th>
<th>$qq$</th>
<th>$t\bar{t}$</th>
<th>$tb$</th>
<th>$\gamma\gamma$</th>
<th>$WW/WZ$</th>
<th>$ZZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>1000</td>
<td>966</td>
<td>1030</td>
<td>910*</td>
<td>399</td>
<td>840</td>
<td>820</td>
<td>800</td>
<td>900</td>
<td>606</td>
<td>490</td>
</tr>
</tbody>
</table>

Sequential $V'$

<table>
<thead>
<tr>
<th>$X \rightarrow$</th>
<th>$eq$</th>
<th>$\mu q$</th>
<th>$b\tau$</th>
<th>$q\nu$</th>
<th>$b\nu$</th>
<th>$b' \rightarrow tW$</th>
<th>$t' \rightarrow qW$</th>
<th>$e\gamma$</th>
<th>$\mu\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit (GeV)</td>
<td>256</td>
<td>316</td>
<td>210</td>
<td>205</td>
<td>252</td>
<td>325</td>
<td>311</td>
<td>796</td>
<td>853</td>
</tr>
</tbody>
</table>

Leptoquarks $\beta = 1$

Excited $f^*$

*R reviewers extrapolation

**CDF Run II preliminary, $L=2.8fb^{-1}$**

- **Data**
- **Z' (650 GeV)**
- **$t\bar{t}$**
- **$W+jets$**
- **Other MC**
- **Multijet**

lepton+jets channel

all-hadronic channel
New High-Mass States at the LHC

Searches in all channels will be repeated at the LHC with much higher mass reach

Interesting experimental detail: top mass small compared to 7 TeV

→ top decay products in single jet → t-tagging!

Top-Jet Tagging Efficiency

CMS Preliminary
New High-Mass States at the LHC

Searches in all channels will be repeated at the LHC with much higher mass reach

Interesting experimental detail: top mass small compared to 7 TeV

→ top decay products in single jet → t-tagging!

Background, Dijet Mass

CMS Preliminary

Dijet Mass, $M = 2000$ GeV/c$^2$, $w = 20$ GeV

CMS Preliminary

<table>
<thead>
<tr>
<th>Constant</th>
<th>Mean</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>2367</td>
<td>1827</td>
<td>139.1</td>
</tr>
</tbody>
</table>

Z’ Signal
Dijet production has large cross section

→ can probe for deviations at very high energy scales

Observable: \( \chi_{\text{dijet}} = \exp(|y_1 - y_2|) \)

- roughly flat in QCD
- new physics detectable as deformation at high dijet mass

Models tested:

- composite quarks: \( \Lambda_C > 2.9 \text{ TeV} \)
- Large extra dimensions (ADD): \( M_S > 1.66 \text{ TeV} \) (GRW)
Exotic Signatures

“Actually, did you ever search for ...?”
Supersymmetric hidden valley model motivated by various hints of dark matter signals

- Photon in hidden sector: dark photon $\gamma_D$ with SUSY partner darkino $\tilde{X}$
- Dark Photon mass $\lesssim O(1)$ GeV to explain Pamela positron excess
Production of supersymmetric particles results in decays $\tilde{\chi}_1^0 \rightarrow \gamma_D \tilde{X}$ or $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{X}$

→ look for events with $\gamma + \gamma_D + E_T$ with $\gamma_D \rightarrow ee, \mu\mu$ (small lepton opening angle)
Production of supersymmetric particles results in decays $\tilde{\chi}^0_1 \rightarrow \gamma \tilde{X}$ or $\tilde{\chi}^0_1 \rightarrow \gamma \tilde{X}$

→ look for events with $\gamma + \gamma_D + E_T$ with $\gamma_D \rightarrow e\bar{e}, \mu\mu$ (small lepton opening angle)
Production of supersymmetric particles results in decays $\tilde{\chi}_1^0 \rightarrow \gamma D \tilde{X}$ or $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{X}$

$\rightarrow$ look for events with $\gamma + \gamma_D + E_T$ with $\gamma_D \rightarrow e e, \mu \mu$ (small lepton opening angle)
Preparing for exotic signals at the LHC

Many models predict long-lived charged or neutral particles

Many signatures to be explored: displaced vertices, kinks, disappearing tracks, high ionisation, non-pointing photons, out-of-time energy...

→ need to make sure none of them are discarded by ATLAS and CMS trigger systems

Example: stopped gluinos in CMS

- will run trigger on low-$p_T$ jet in buckets/periods without beam
- sensitivity to stopped gluinos for large range of gluino lifetime

\[
\begin{align*}
\text{Gluino lifetime} & \quad \text{discovery} \\
1\text{s} & \quad 5\text{ days} \\
1\text{ms} & \quad 30\text{ days} \\
1\text{h} & \quad 30\text{ days} \\
12\text{h} & \quad 30\text{ days} \\
1\text{d} & \quad 30\text{ days} \\
1\text{w} & \quad 30\text{ days}
\end{align*}
\]

\[
\begin{align*}
\text{Significance} & \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \\
\text{m}_g \text{ (GeV)} & \quad 200 \quad 250 \quad 300 \quad 350 \quad 400 \quad 450 \quad 500 \quad 550 \quad 600 \quad 650 \quad 700
\end{align*}
\]
Preparing for exotic signals at the LHC

Example: Higgs $h \rightarrow \pi^0_\nu \pi^0_\nu$ with long-lived $\pi^0_\nu \rightarrow b\bar{b}$ in ATLAS

Implemented three dedicated triggers:

– Decays in tracker: “trackless jets” with a muon
Preparing for exotic signals at the LHC

Example: Higgs $h \rightarrow \pi^0_v \pi^0_v$ with long-lived $\pi^0_v \rightarrow b \bar{b}$ in ATLAS

Implemented three dedicated triggers:

- Decays in tracker: “trackless jets” with a muon
- Decays in calorimeter: tau-like jet, distorted longitudinal profile, no tracks
- Decays in the muon system: several muons without jets or tracks
Preparing for exotic signals at the LHC

Example: Higgs $h \rightarrow \pi^0_v \pi^0_v$ with long-lived $\pi^0_v \rightarrow b\bar{b}$ in ATLAS

Implemented three dedicated triggers:

- Decays in tracker: “trackless jets” with a muon
- Decays in calorimeter: tau-like jet, distorted longitudinal profile, no tracks
- Decays in the muon system: several muons without jets or tracks

Combination of triggers: efficiency > 15% for decay length 1-20 m
Conclusions

- Tevatron is running very well: 6 fb$^{-1}$ on tape, good prospects for up to 12 fb$^{-1}$ by 2011
- Huge number of signatures explored, still adding new ones
- ATLAS and CMS ready for analysis of first LHC data
- Excellent prospects for early discovery: no more limits, please!

Thanks to:
Todd Adams, Oliver Buchmüller, Arnaud Duperrin, Paul de Jong, Greg Landsberg, Monica D’Onofrio, Giacomo Polesello, Jeffrey Richman, Albert de Roeck, Eduardo Ros, Pierre Savard, Tom Wright

Full set of results available at:
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm
https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults
BACKUP
Search for Charginos and Neutralinos: Results

Probing chargino masses up to 176 GeV

Reach degrades with increasing \( \tan\beta \)
Production of supersymmetric particles results in decays $\tilde{\chi}_1^0 \to \gamma_D \tilde{X}$ or $\tilde{\chi}_1^0 \to \gamma \tilde{X}$

→ look for events with $\gamma + \gamma_D + E_T$ with $\gamma_D \to ee, \mu\mu$ (small lepton opening angle)

![Graph showing the production cross-section as a function of $m_{d\gamma}$](image-url)
Production of supersymmetric particles results in decays $\tilde{\chi}_1^0 \to \gamma D \tilde{X}$ or $\tilde{\chi}_1^0 \to \gamma \tilde{X}$

→ look for events with $\gamma + \gamma_D + E_T$ with $\gamma_D \to \text{ee, } \mu \mu$ (small lepton opening angle)