Introduction

Lepton compositeness: e*

Resonances in $Z+\gamma$

Randall-Sundrum gravitons

Large extra dimensions: single photon

New gauge bosons: $W'$

Leptoquarks: all generations

Conclusions
Beyond SUSY, there are many other possible models of new physics that could easily produce results in 1 fb^{-1}.

While SUSY may be popular, all that is certain is a high probability for some sort of new physics “just around the corner”:

- Radiative corrections to the Higgs mass
- If there is one
- Gravitation?
- Unification of couplings?
- Three generations?
- Dark matter?
- .....
Data Set = “Run Ila”

Results based on Run Ila data set
All limits are at 95% CL
Lepton Compositeness: $e^*$

- Learning from thousands of years of history, quarks and leptons may be made of smaller pieces ("preons")
  - Allows excited states ($e^*$, $\mu^*$, $q^*$)
  - Describe as contact interaction (compositeness scale $\Lambda$)
  - Decay: gauge interaction ($e^* \rightarrow e\gamma$, $\nu W$, $e Z$) or CI ($e^* \rightarrow e\ell\ell$)

- Search in $e\,e\,\gamma$

Two isolated electrons with $E_T > 25$ GeV, 15 GeV
Next: isolated photon with $E_T > 15$ GeV
Excited Fermions: $e^*$

- Observe **259 events with expectation 239 ± 26 events**
- Search for peak in $e^+\gamma$ invariant mass
- Optimize selection criteria
  - Combination $e1^+\gamma$ or $e2^+\gamma$
  - Mass window / single sided cut
  - $|\eta|$ acceptance and separation (for small $m(e^*)$)
- Find 0 or 1 event in data for all $e^*$ masses, with small expected SM background

Limit: $m(e^*) > 756$ GeV for $\Lambda = 1$ TeV

For comparison: $m(e^*) > 989$ GeV when neglecting CI decays, for $\Lambda = m(e^*)$, and using the same theory cross sections as CDF
Resonances in Z+\gamma

- **Scalar or vector narrow resonance decaying into Z+\gamma, with Z \rightarrow ee or \mu\mu**
- Isolated e, \mu, \gamma with p_T > 15 – 25 GeV
- ll\gamma mass resolution 4% – 8% (mass constraint to Z for muon channel)
- M_{ll} > 80 GeV after optimization against background (Z+\gamma and Z+jet dominant)
- **Find 49(50) events in e(\mu) channel, compatible with SM expectation of 42 \pm 7 (46 \pm 7) events**
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- **Scalar or vector narrow resonance decaying into Z+γ, with Z → ee or μμ**
- Isolated e, μ, γ with \( p_T > 15 – 25\text{ GeV} \)
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Randall-Sundrum Gravitons

Use extra dimensions to address hierarchy problem

**RS model:**

One 5\textsuperscript{th} (infinite) ED with warped geometry

Gravity is localized on a brane other than the SM

KK excitations have spacings of order TeV

Signature: **narrow, high mass resonances**

Two model parameters: **Mass and coupling** \( (\kappa/M_{\text{Pl}}) \)

**Combined ee + \gamma\gamma:** (BF in \( \gamma\gamma = 2 \times \text{ee} \))

- 2 central \( (|\eta|<1.1) \) electromagnetic objects with \( E_T > 25 \text{ GeV} \)

- **Background:** DY and di-photon

- QCD background estimated from data

- Sliding mass window

(Previously: 785 GeV based on 260 pb\textsuperscript{-1})

For \( \kappa/M_{\text{Pl}} = 0.1: M_1 > 900 \text{ GeV} \)
Large Extra Dimensions: $\gamma+\text{MET}$

- LED can explain why gravity is weak: 
  \[ \frac{1}{G} \sim M_{\text{Pl}}^2 \sim M_{D}^{n+2} R^n \]

- Can solve the hierarchy problem: 
  \[ M_{D} \sim M_{W} \]

- Here: search in monophoton final state – complementary to “monojets”

- Finely segmented EM calorimeter, central preshower for photon pointing

\[ G_{KK} \]

$q$

$\bar{q}$

$\gamma$

**Diagram:**
- Central Calorimeter
- EM Shower
- Solenoid
- Central Fiber Tracker
- End Calorimeter
- EM1, EM2, EM3, EM4
- Z_{EMVTX}
- EM Calorimeter
- FH Calorimeter
- PS
- Solenoid
- CFT
- SMT

**Legend:**
- GEANT simulation of an electron shower
LED: $\gamma$+MET

- Exactly one photon with $E_T > 90$ GeV and $|\eta| < 1.1$
- MET > 70 GeV
- Backgrounds from fit of templates to dca
- Find 29 events in data (expect $22.4 \pm 2.5$)

Limit better than LEP for $N_D > 4$
New Gauge Bosons: $W' \rightarrow e \nu$

- Predicted in many beyond-SM scenarios, GUT's, e.g. left-right symmetric models $(SU(2)_L \times SU(2)_R)$

- Benchmark: a SM-like $W'$

- **Selection:** isolated central electron with $E_T > 30$ GeV

- MET > 30 GeV, $M_T > 140$ GeV

- Estimate QCD background from low $M_T$ region

\[ M_T = M(p_T(e), \text{MET}) \]
**W' – Result**

- **Data (for M_T > 140 GeV):**
  - **967 events**

- **Standard Model expectation:**
  - **959 ± 21 (stat) ± 90 (syst) events**

- **Use M_T distribution to derive limits**

**M(W') > 1.00 TeV**

*First direct search with sensitivity beyond 1 TeV*

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**Graphical Content:**

- **Graph (a):**
  - **Data distribution**
  - **W → e ν**
  - **QCD (from data)**
  - **Other**
  - **m_W = 500 GeV**
  - **m_W = 1100 GeV (× 200)**

- **Graphical Representation:**
  - **Theory (NNLO)**
  - **95% CL Limit**
  - **Observed**
  - **Expected**
  - **Excluded (Run I)**

- **Equation:**
  - **m_W > 1.00 TeV at 95% CL**

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**Arnd Meyer (RWTH Aachen)**

**June 20, 2008**
Leptoquarks

- Couples directly to a quark and a lepton
- Carry both a baryon number and a lepton number
- Predicted in GUT's, Extended Technicolor, Compositeness
- Spin-0 or spin-1
- Charge $Q = \frac{1}{3}, \frac{2}{3}, \frac{4}{3}$
- Minimal Buchmüller-Rückl-Wyler model: small LQ masses (large cross section) in reach of Tevatron
- Pair production via $qq$ or $gg$
- Scalar LQ production calculated to NLO

$$\beta := BF(LQ \rightarrow lj)$$
$$\sigma \times BF(\nu\nu jj) \propto (1 - \beta)^2$$
$$\sigma \times BF(lljj) \propto \beta^2$$
$$\sigma \times BF(l\nu jj) \propto 2\beta (1 - \beta)$$

![Graph showing cross-section vs LQ mass](image-url)
Leptoquarks: 1st Generation – eejj

- Pair production of LQ1
- At least 2 electrons and 2 jets
  - Electrons: central-central (|\eta| < 1.1) or central-forward (|\eta| < 1.1, 1.5-2.5), E_T > 25 GeV
  - Jets: E_T > 25 GeV, |\eta| < 2.5
- Further cuts to improve sensitivity
  - Limits on scalar and vector LQ
- S_T = E_T(e1) + E_T(e2) + E_T(j1) + E_T(j2)
- Best expected limits (M(LQ) = 290 GeV) for M(ee) > 110 GeV and S_T > 400 GeV
- Use \langle M_{ej} \rangle = (M_{e1} + M_{e2}) / 2 distribution to set limits (M_{e1} and M_{e2} chosen such that LQ and LQ difference minimal)
LQ1 – Results

Vector LQ:

- $M(LQ1) > 350$ GeV \( (Q=1/3, T_3 = -1/2, \kappa_G = 1, \lambda_G = 0) \)
- $M(LQ1) > 410$ GeV \( (Q=1/3, T_3 = -1/2, \kappa_G = 0, \lambda_G = 0) \)
- $M(LQ1) > 458$ GeV \( (Q=1/3, T_3 = -1/2, \kappa_G = -1, \lambda_G = -1) \)

Scalar LQ: $M(LQ1) > 292$ GeV
Leptoquarks: 2nd Generation – $\mu\nu jj$

**Basic selection:**

- Exactly one muon with $p_T>20$ GeV, at least 2 jets with $p_T>25$ GeV, MET > 25 GeV
- MET not aligned with muon to minimize mis-measured MET
- $M_T(\mu, \nu) > 50$ GeV to reject QCD background

**Optimize for $m(LQ) = 200$ GeV:**

- $M_T(\mu, \nu) > 160$ GeV – remove background from W production
- Scalar transverse energy $S_T = p_T(\mu) + p_T(jet1) + p_T(jet2) + MET > 350$ GeV
- $M_T(\nu, jet1) > 150$ GeV – correlated with LQ mass
- $|M(LQ)_{rec} – M(LQ)_{gen}| < 100$ GeV for the $\mu$-jet combination closest to searched LQ
Samples

<table>
<thead>
<tr>
<th>Process</th>
<th>m(LQ)</th>
<th>Others similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W(+jets) \rightarrow l\nu + jets)</td>
<td>3.2 ± 0.6 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>(Z/\gamma^*(+jets) \rightarrow \mu\mu + jets)</td>
<td>0.68 ± 0.19 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>(t\bar{t}) (inclusive)</td>
<td>2.3 ± 0.2 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>QCD</td>
<td>0.22 ± 0.05 ± 0.04</td>
<td></td>
</tr>
</tbody>
</table>

\[\text{Total Background} = 6.4 \pm 0.7 \pm 0.8\]

\[\varepsilon_{\text{signal}} = 0.079 \pm 0.001 \pm 0.007\]

Dominant remaining backgrounds: W+jets, ttbar

(m(LQ) = 200 GeV, others similar)

For publication, update including \(\mu\mujj\) channel underway

\[m(LQ) > 214 \text{ GeV for } \beta = 0.5\]
Leptoquarks: 3rd Generation – \( \tau \tau bb \)

\[
LQ_3 \ ar{LQ}_3 \rightarrow \tau^- b \tau^+ \bar{b}
\]

\( \tau_1 \rightarrow \mu \bar{\nu}, \tau_2 \rightarrow \nu + \text{hadrons} \)

- Pair production of LQ3
- 2 opposite-sign taus and 2 jets
  - Tau 1: \( p_T > 15 \text{ GeV}, |\eta| < 2.0 \)
  - Tau 2: visible \( p_T > 15 – 20 \text{ GeV} \), identified using NN-algorithm based on tracks and calorimeter information
  - Jets: \( E_T > 25, 20 \text{ GeV}, |\eta| < 2.5 \)
  - \( m^* < 60 \text{ GeV} \)
  - Two sub-samples: 1 b-tag or 2 b-tags
  - b-tag based on NN, optimized for sensitivity
- Veto extra muons or electrons

\[
S_T = p_T(\mu) + p_T(\tau) + p_T(\text{jet1}) + p_T(\text{jet2}) + \text{MET}
\]

DØ 1.05 fb\(^{-1}\) Preliminary

\[
m^* = \sqrt{2E^\mu E^\nu (1 - \cos \Delta \phi)}
\]

\[
E^\nu = E_T(E^\mu/p_T^\mu)
\]
LQ3 – Results

Use $S_T$ distribution and both 1 and ≥ 2 b-tagged samples to obtain limits

- Charge = 4/3, 2/3 LQ, $\beta = 1$
- For $Q = 2/3$, $LQ \rightarrow t \nu$ is allowed, only suppressed by phase space
- $BF(LQ \rightarrow t \nu) = (1 - \beta) \times f_{ps}$

<table>
<thead>
<tr>
<th>Source</th>
<th>1b-tag</th>
<th>≥ 2b-tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W + lp$</td>
<td>1.0±0.4</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>$W + c\bar{c}$</td>
<td>0.4±0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>$W + b\bar{b}$</td>
<td>0.4±0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>$Z + lp$</td>
<td>5.0±0.2</td>
<td>0.1±0.0</td>
</tr>
<tr>
<td>$Z + c\bar{c}$</td>
<td>1.7±0.2</td>
<td>0.1±0.1</td>
</tr>
<tr>
<td>$Z + b\bar{b}$</td>
<td>1.8±0.1</td>
<td>0.4±0.1</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>5.2±0.1</td>
<td>3.1±0.1</td>
</tr>
<tr>
<td>Diboson</td>
<td>0.3±0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>MJ</td>
<td>4.0±2.5</td>
<td>0.8±1.0</td>
</tr>
</tbody>
</table>

Sum Bknd 19.6±2.5 4.8±1.0

(Uncertainties in Table are statistical only)

$\sigma \times BR^2$ [pb]

DØ 1.05 fb^{-1}

Preliminary

m(LQ) > 201 GeV for $\beta = 1$
Conclusions

- A vibrant program searching for non-SUSY new phenomena continues – have shown new(er) results in the areas of compositeness and leptoquarks, (large) extra dimensions, and extra gauge bosons.

- Most searches based on 1 fb\(^{-1}\) of integrated luminosity are now completed.

- With almost 4 fb\(^{-1}\) collected, updates promising.

- All results and more available at http://www-d0.fnal.gov/Run2Physics/WWW/results.htm
Backup
Candidate Event II

Run 174429 Evt 13763152

ET scale: 109 GeV

Triggers:

Bins: 156
Mean: 1.69
Rms: 12.1
Min: 0.00916
Max: 107

em particle et: 125.2
em particle et: 24.75
em particle et: 103.7
MET et: 7.573
## Candidate Events

<table>
<thead>
<tr>
<th>Run number</th>
<th>Event number</th>
<th>$m_{e^*} = 200$ GeV</th>
<th>$m_{e^*} = 300$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$: $p_T$, $\eta$, $\phi$, $q$</td>
<td>202101</td>
<td>174429</td>
<td></td>
</tr>
<tr>
<td>$e_2$: $p_T$, $\eta$, $\phi$, $q$</td>
<td>35629781</td>
<td>13763152</td>
<td></td>
</tr>
<tr>
<td>$\gamma$: $p_T$, $\eta$, $\phi$</td>
<td>63.7 GeV, $-0.800$, $3.105$, $+$</td>
<td>124.1 GeV, $0.606$, $-1.334$, $-$</td>
<td></td>
</tr>
<tr>
<td>$m(e^* \text{ candidate})$</td>
<td>94.1 GeV, $0.199$, $-0.675$</td>
<td>24.8 GeV, $0.128$, $3.067$, $+$</td>
<td></td>
</tr>
<tr>
<td>$m(e_1, e_2)$</td>
<td>194.6 GeV</td>
<td>103.1 GeV, $-1.073$, $1.714$</td>
<td></td>
</tr>
<tr>
<td>$m(e_1, \gamma)$</td>
<td>92.8 GeV</td>
<td>310.6 GeV</td>
<td></td>
</tr>
<tr>
<td>$m(e_2, \gamma)$</td>
<td>167.8 GeV</td>
<td>93.6 GeV</td>
<td></td>
</tr>
<tr>
<td>$m(e_1, e_2, \gamma)$</td>
<td>194.6 GeV</td>
<td>310.6 GeV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>273.2 GeV</td>
<td>90.3 GeV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>336.8 GeV</td>
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</table>