Finding Unexpected Gluinos at the Tevatron

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SLAC

With M.-P. Le, M. Lisanti and J. Wacker

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Outline

1. At the frontier
2. Model-independent gluinos
3. Jet matching in signal & backgrounds
4. Where can we see them, and how?
5. Outlook
At the frontier

This year...

The LHC will open a new energy frontier

Don’t know what will be found

- Supersymmetry?
- Extra dimensions?
- New global symmetries?
- Completely unexpected stuff?

But are we sure that there is no new physics already in the Tevatron data?
The problem with benchmarks

Searches don’t cover the full imaginable parameter space
The problem with benchmarks

mSUGRA very special scenario:

- Running of unified gaugino masses from high scale
  \[ \implies \text{Mass ratio} \ m_{\tilde{g}} : m_{\tilde{B}} = 6 : 1 \]
- \[ m_{\tilde{q}} \gtrsim m_{\tilde{g}} \]
- Long decay chains through winos common

Effectively massless LSP
\[ \implies \text{Large missing energy and hard jets} \]

Not representative of general new physics
(or even the MSSM)
### Jets + $\not{E}_T$ searches at DØ

#### Table:

<table>
<thead>
<tr>
<th></th>
<th>$1j + \not{E}_T$</th>
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<td>$\not{E}_T$</td>
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<td>$\geq 225$</td>
<td>$\geq 150$</td>
<td>$\geq 100$</td>
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<tr>
<td>$H_T$</td>
<td>$\geq 150$</td>
<td>$\geq 300$</td>
<td>$\geq 400$</td>
<td>$\geq 300$</td>
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<tr>
<td>Search:</td>
<td>$Gg$</td>
<td>$\tilde{q}\tilde{q}$</td>
<td>$\tilde{q}\tilde{g}$</td>
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Jets + $\not{E}_T$ very general signal, but searches mSUGRA signature-based (large $H_T$ and $\not{E}_T$ cuts)

Could these searches actually cut out new physics?
Jets + $E_T$ searches at DØ

Dijet analysis (before $H_T$ and $E_T$ cuts)
Model-independent gluinos

Very common scenario in new physics models:
Color octets decaying to jets and missing energy

Deviations from mass ratio $m_{\tilde{g}} : m_{\chi_1^0} = 6 : 1$

- Anomaly mediation
- Mirage mediation
- Non-minimal gauge mediation
- UED

Alternative way of parametrizing searches:

- Color octet (“gluino”) decaying to two jets plus $E_T$
- Assume squarks inaccessible
- Parametrization using only $m_{\tilde{g}}$, $m_{\chi_1^0}$ and
  $\sigma(pp \rightarrow \tilde{g} \tilde{g} + X) \Rightarrow$ small parameter space
Where has the Tevatron probed gluinos?

At the frontier
Model-independent gluinos
Jet matching in signal & backgrounds
Outlook
The degenerate limit

Special difficulties in the limit \( m_{\tilde{g}} \sim m_{\chi_1^0} \):

- Jets from the decay are soft
- LSP carries away energy but not momentum

\[ \implies \text{Gluinos effectively “disappear”} \]

Need recoil against jets to get visible signature

Proper simulation of jet production in association with gluino pairs necessary \( \implies \) Use jet matching!
### Jet matching in signal & backgrounds

<table>
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<tr>
<th><strong>Matrix elements</strong></th>
<th><strong>Parton showers</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fixed order calculation</td>
<td>1. Resums logs to all orders</td>
</tr>
<tr>
<td>2. Computationally expensive</td>
<td>2. Computationally cheap</td>
</tr>
<tr>
<td>3. Limited number of particles</td>
<td>3. No limit on particle multiplicity</td>
</tr>
<tr>
<td>4. Valid when partons are hard and well separated</td>
<td>4. Valid when partons are collinear and/or soft</td>
</tr>
<tr>
<td>5. Quantum interference correct</td>
<td>5. Partial quantum interference through angular ordering</td>
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</table>

Matrix element and Parton showers complementary approaches

Both necessary in high-precision studies of multijet processes

Need to combine without double-counting
Jet matching schemes

The simple idea behind matching

- Use matrix element description for well separated jets, and parton showers for collinear jets
- Phase-space cutoff to separate regions

⇒ No double-counting between jet multiplicities

Difficulties

- Get smooth transition between regions
- No/small dependence from precise cutoff
- No/small dependence from largest multiplicity sample

How to accomplish this

- CKKW matching (Catani, Krauss, Kuhn, Webber)
- MLM matching ← Used in this study
MLM matching in MadGraph / MadEvent

J.A. et al. [arXiv:0706.2569],

Use shower hardness to separate ME/PS

1. Generate multiparton event with cut on jet $k_T$
2. Cluster event and use $k_T^2$ for $\alpha_s$ scale
3. Shower event (using Pythia) starting from hard scale
4. Collect showered partons in $k_T$ jets with $k_{T\text{cut}} > k_{T\text{min}}$
5. Keep event only if each jet matched to one parton
6. For highest multiplicity sample, allow extra jets softer than $k_{T\text{min}}$

---

1. Keep
2. Discard unless highest multiplicity
Matching example: $W+$jets at the Tevatron

Differential $2 \rightarrow 3$ jet rates at parton level by MadEvent + Pythia in $p\bar{p} \rightarrow W +$ jets at the Tevatron, $d_{\text{cut}} = 10 \text{ GeV}$ (left), $d_{\text{cut}} = 30 \text{ GeV}$ (right).

Comparison between different implementations done: Alpgen, Ariadne, Helac, MadEvent, Sherpa [arXiv:0706.2569]
Effects of matching on backgrounds

**W/Z + jets**: Large effect of matching

- **Cross section (pb/bin)**
  - Multiple plots showing the cross section for different jet numbers and missing ET for W/Z + jets at the Tevatron.
  - The plots demonstrate the impact of matching on both backgrounds and signal.
  - Effects of matching on backgrounds and signal are highlighted.

- **Where can we see them, and how?**
  - Outlook on gluinos at the Tevatron.
  - Model-independent gluinos.
  - Jet matching in signal & backgrounds.
  - Jet matching schemes.
  - MLM matching in MadGraph / MadEvent.
  - Matching example: W+jets at the Tevatron.

- **Effects of matching on backgrounds**
  - Large effect of matching.

- **Effects of matching on signal**
  - Details on how matching affects signal events.

- **Outlook**
  - Future prospects and research directions.
**t\bar{t} + jets:** Small effect of matching (in this study)

Semileptonic decay dominating over dileptonic decay: 4 hard jets from top decay (untouched by matching of ISR jets)
Effects of matching on signal

- MadGraph/MadEvent can do jet matching also in BSM signals
- Crucial in limit of degenerate $\tilde{g}$ and $E_T$ masses

160 GeV gluinos
Effects of matching on signal

\[ m_{\tilde{g}} = 150 \text{ GeV} \]

\[ m_{\tilde{\chi}} = 40 \text{ GeV} \]

\[ m_{\tilde{g}} = 150 \text{ GeV} \]

\[ m_{\tilde{\chi}} = 130 \text{ GeV} \]
Where can we see them, and how?

Now that we have all the tools, let’s redo the analysis by \( D\bar{\emptyset} \) to find the region of visibility for our model-independent gluinos!

1. Simulate background and validate by comparison with \( D\bar{\emptyset} \)
2. Simulate the signal for different mass combinations \((m_{\tilde{g}}, m_{\tilde{B}})\)
3. Decide on search strategies
4. Optimize cuts point-by-point in \((m_{\tilde{g}}, m_{\tilde{B}})\) space
5. Plot the projected exclusion region for the Tevatron

Perform all simulations with MadEvent – Pythia – PGS

(D\( \bar{\emptyset} \) used AlpGen – Pythia – Full sim)
Background validation

Compared backgrounds to the DØ searches:
Dijet, Threejet, Multijet

Get validation for issues like:
- Lepton and jet efficiencies
- Jet energy scale
- Generation details (scale choices, Pythia parameters)

Most important backgrounds:
- $W/Z + \text{jets}$
- $t\bar{t}$
- QCD (avoided by $\not{E}_T$ cut at 100 GeV)

(Subdominant backgrounds: Diboson, Single top)

Different issues for each search and each background.
Background validation – $W/Z + \text{ jets}$

- $Z \rightarrow \nu\bar{\nu}+\text{jets}$: Simplest background (only $E_T+\text{jets}$)
- $W \rightarrow l^{\pm}\nu+\text{jets}$: Need to miss one lepton
  $\implies$ Dependence on efficiencies and isolation criteria
- Hadronic tau decays counted as jets
- All (real) jets by QCD
  $\implies$ QCD scale uncertainties for high jet multiplicities
Background validation – $t\bar{t}$

Most important and most complicated background
- Semileptonic and fully leptonic decays: lepton efficiencies in active hadronic environment
- Many jets $\rightarrow$ large effect of jet veto
- Different decay channels contribute to different searches $\rightarrow$ different systematics
Comparison with DØ

Dijet

Multijet

- Background diffs within 20-50%
- PGS great – differences accounted for by norm factors
Unexpected gluinos at the Tevatron

Johan Alwall

At the frontier

Model-independent gluinos

Jet matching in signal & backgrounds

Where can we see them, and how?

Background validation

Comparison with $D\phi$ searches

Reach of different searches

Combined exclusion region

Outlook

Searches

Model on the $D\phi$ searches
(gives confidence for backgrounds)

But: Use exclusive searches $\implies$ combinable limits

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Optimize $\not{E}_T$ and $H_T$ for maximum significance given limit on $S/B$
Reach of different searches

Different searches cover different parts of \((m_{\tilde{g}}, m_{\chi_1^0})\) space:

- **Monojet search:** Effective in degenerate region
- **Dijet search:** Intermediate region
Reach of different searches

Threejet: S/B=1

\[ m_{\tilde{g}} \]

\[ m_{\chi^0_1} \]

Threejet search:
Mainly large-\(\Delta m\) region

Multijet: S/B=1

\[ m_{\tilde{g}} \]

\[ m_{\chi^0_1} \]

Multijet search:
Large-\(\Delta m\) region

Mirrors jet structure of gluino decays
Combined exclusion region

Projected exclusion region for 2 fb$^{-1}$ at the Tevatron

Looser cuts

S/B > 0.1

S/B > 1

mSugra

Tighter cuts

Outlook
Outlook

Focused here on the “gluino module”: \( \tilde{g} \rightarrow q\bar{q}\chi \)

Could do similar studies for other “modules”:

- squarks: \( \tilde{q} \rightarrow q\chi \) \((\leq 2\) jets from decay\)
- associated \( \tilde{q}\tilde{g} \) \((\leq 3\) jets from decay\)
- decay chains: 1 lepton, 2 leptons, additional hard jets, ...
- decay to heavy quarks: \( b \) tags

Each module readily parameterized by masses and \( \sigma \)’s (compare OSET approach)
Wino module

Example: Take worst-case scenario with 100% BR into wino with subsequent decay to bino \((m_{\tilde{W}} \sim m_{\tilde{B}} + m_{Z/W})\)

Projected exclusion region for 2 fb\(^{-1}\) at the Tevatron
Presentation / Communication

Better way of presenting limits/discoveries needed

- Model independent
- Informative – compare with different models
- Reproducible – background and signal generation

An (even more model-independent) suggestion:
For each “search” (number of jets, leptons), give limit on

\[
\frac{d^2\sigma}{dH_T d\not{E}_T} \Delta H_T \Delta \not{E}_T
\]

+ Fast sim tool for detector simulation
Conclusions

- We’re living in exciting times
- Don’t know what we’ll find / what to look for
- Benchmark searches possibly useful but dangerous
- Worst scenario: Cutting out new physics from data
- Need better / more model-independent / more useful way to search / communicate results
  → Limits on model-independent “modules”?  
  → Search/Signature based “limit grids”?  
- Theorists will need to simulate their models 
  (our experimental friends won’t have time for everything)