Finding Unexpected Gluinos at the Tevatron

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SLAC

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

arXiv:0803.0019

Cornell, April 23, 2008

Outline

At the frontier

This year...

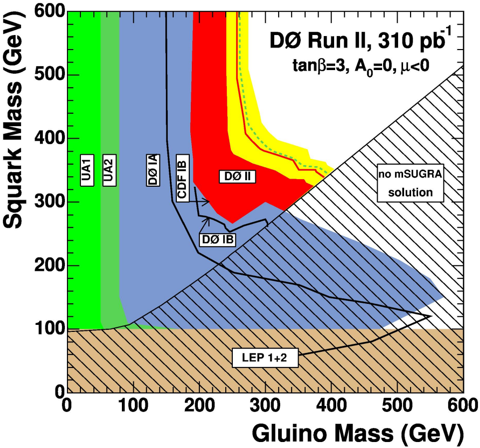
The LHC will open a new energy frontier

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



(cf. hep-ex/0712.3805)

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 $\Longrightarrow$ 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
$\Longrightarrow$ Large missing energy and hard jets

Not representative of general new physics
(or even the MSSM)

Jets + $\not{E}_T$ searches at DØ

	$1j+\not{E}_T$	$2j+\not{E}_T$	$3j+\not{E}_T$	Multijet
E_{T,j_1}	≥ 150	≥ 35	≥ 35	≥ 35
E_{T,j_2}	< 35	≥ 35	≥ 35	≥ 35
E_{T,j_3}			≥ 35	≥ 35
E_{T,j_4}				≥ 20
$\not{E}_T$	≥ 150	≥ 225	≥ 150	≥ 100
H_T	≥ 150	≥ 300	≥ 400	≥ 300
Search:	Gg	$\tilde{q}\tilde{q}$	$\tilde{q}\tilde{g}$	$\tilde{g}\tilde{g}$
Lepton veto in all searches				

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?

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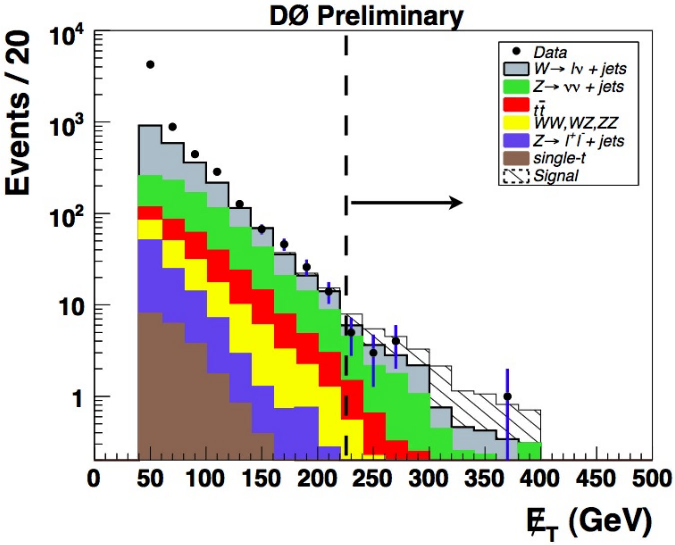
Jets + $\not\!\!E_T$ searches at DØ

Dijet analysis (before H_T and $\not\!\!E_T$ cuts)



Model-independent gluinos

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

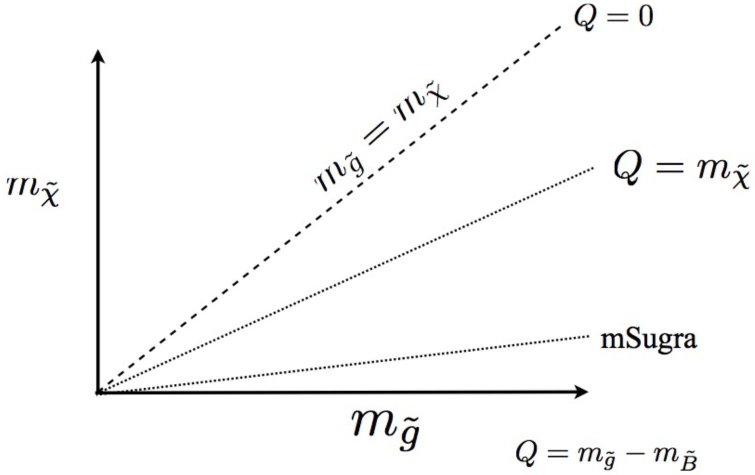
Deviations from mass ratio $m_{\tilde{g}} : m_{\chi_1^0} = 6 : 1$

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

Alternative way of parametrizing searches:

- Color octet ("gluino") decaying to two jets plus $\not{E}_T$
- Assume squarks inaccessible
- Parametrization using only $m_{\tilde{g}}$, $m_{\chi_1^0}$ and $\sigma(pp \to \tilde{g}\tilde{g} + X) \Longrightarrow$ small parameter space

Where has the Tevatron probed gluinos?



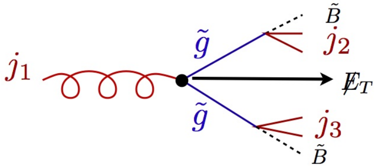
The degenerate limit

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

$\Longrightarrow$ Gluinos effectively "disappear"

Need recoil against jets to get visible signature



Proper simulation of jet production in association with gluino pairs necessary $\Longrightarrow$ Use jet matching!

Jet matching in signal & backgrounds

Matrix elements

1. Fixed order calculation
2. Computationally expensive
3. Limited number of particles
4. Valid when partons are hard and well separated
5. Quantum interference correct
6. Needed for multi-jet description

Parton showers

1. Resums logs to all orders
2. Computationally cheap
3. No limit on particle multiplicity
4. Valid when partons are collinear and/or soft
5. Partial quantum interference through angular ordering
6. Needed for hadronization/ detector simulation

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

$\Longrightarrow$ 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

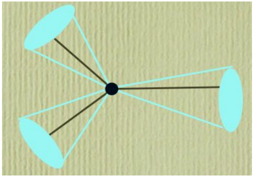
- CKKW matching (Catani, Krauss, Kuhn, Webber)
- MLM matching $\longleftarrow$ Used in this study

MLM matching in MadGraph / MadEvent

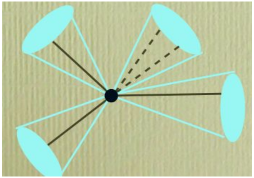
J.A. et al. [arXiv:0706.2569],
cf. M.L. Mangano [2002, Alpgen home page]

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 α_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 $k_{T\text{min}}$

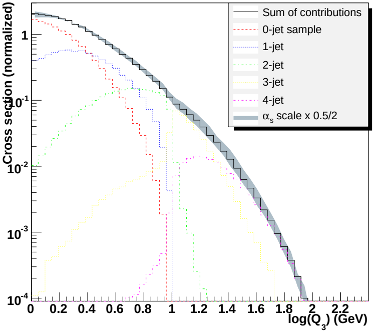


Keep



Discard unless highest multiplicity

Matching example: W+jets at the Tevatron

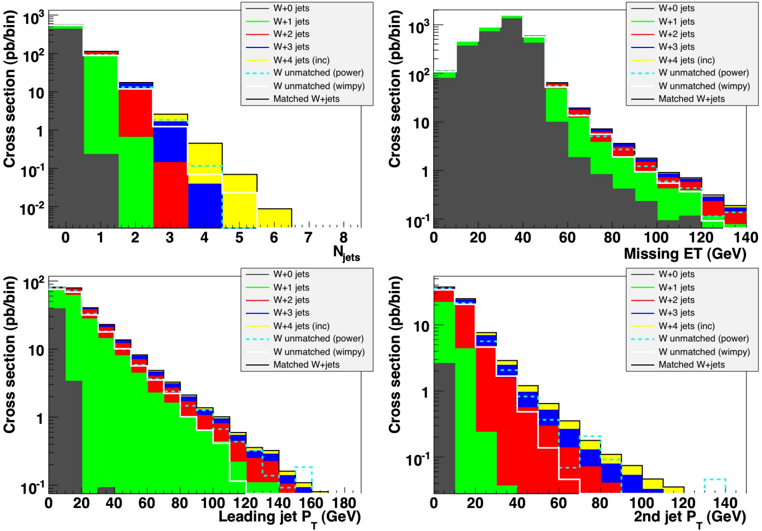


Differential 2 $\rightarrow$ 3 jet rates at parton level by MadEvent + Pythia in $p\bar{p} \rightarrow W$ + jets at the Tevatron, $d_{\rm cut} = 10$ GeV (left), $d_{\rm cut} = 30$ GeV (right).

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



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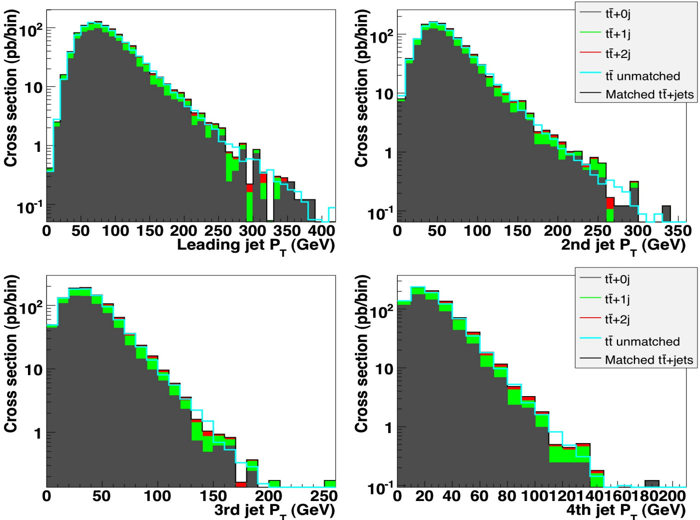
$t\bar{t}$ + **jets**: Small effect of matching (in this study)

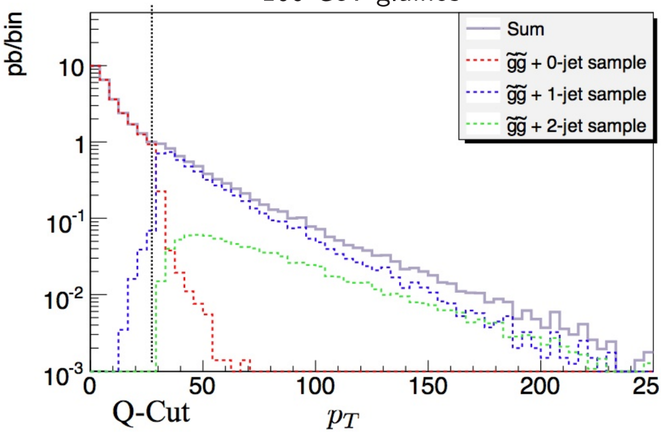


Semileptonic decay dominating over dileptonic decay: 4 hard jets from top decay (untouched by matching of ISR jets)

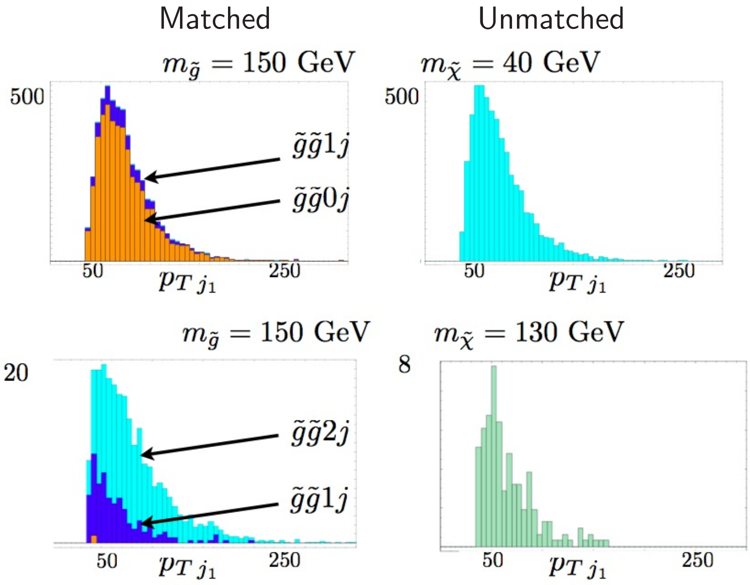
Effects of matching on signal

- MadGraph/MadEvent can do jet matching also in BSM signals
- Crucial in limit of degenerate $\tilde{g}$ and $\not{E}_T$ masses

160 GeV gluinos



Effects of matching on signal



Where can we see them, and how?

Now that we have all the tools, let's redo the analysis by DØ to find the region of visibility for our model-independent gluinos!

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

Perform all simulations with MadEvent – Pythia – PGS

(DØ 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 + 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.

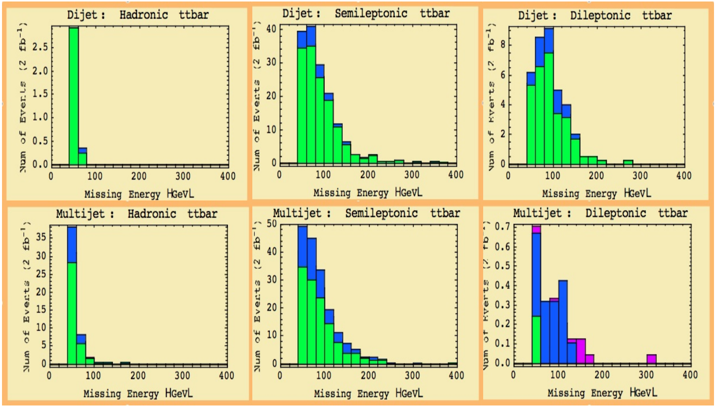
Background validation – W/Z + jets

- $Z \to \nu\bar{\nu}$+jets: Simplest background (only $\not{E}_T$+jets)
- $W \to l^\pm\nu$+jets: Need to miss one lepton
  $\Longrightarrow$ Dependence on efficiencies and isolation criteria
- Hadronic tau decays counted as jets
- All (real) jets by QCD
  $\Longrightarrow$ QCD scale uncertainties for high jet multiplicities

Background validation – $t\bar{t}$

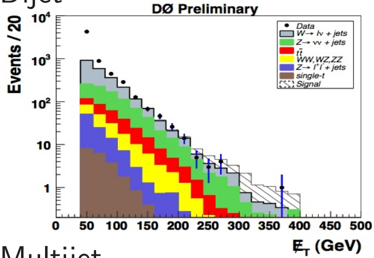
Most important and most complicated background

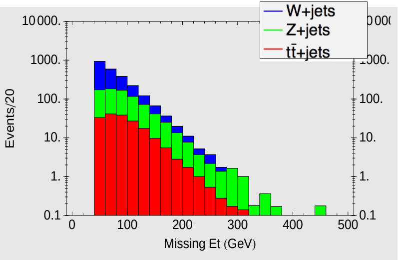
- Semileptonic and fully leptonic decays: lepton efficiencies in active hadronic environment
- Many jets $\Longrightarrow$ large effect of jet veto
- Different decay channels contribute to different searches $\Longrightarrow$ different systematics



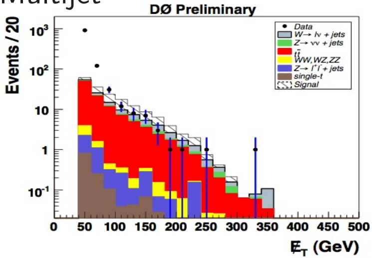
Comparison with DØ

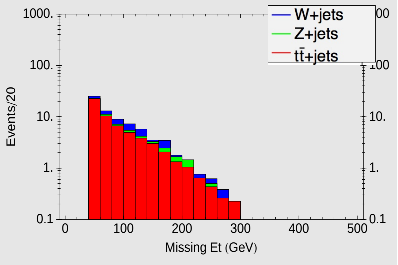
Dijet





Multijet





- Background diffs within 20-50%
- PGS great – differences accounted for by norm factors

Searches

Model on the DØ searches
(gives confidence for backgrounds)

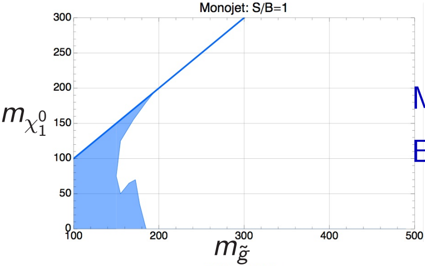
But: Use exclusive searches $\Longrightarrow$ combinable limits

	$1j+\not{E}_T$	$2j+\not{E}_T$	$3j+\not{E}_T$	Multijet
E_{T,j_1}	≥ 150	≥ 35	≥ 35	≥ 35
E_{T,j_2}	< 35	≥ 35	≥ 35	≥ 35
E_{T,j_3}	< 35	< 35	≥ 35	≥ 35
E_{T,j_4}	< 20	< 20	< 20	≥ 20
$\not{E}_T$	Optimized for each $m_{\tilde{g}}, m_{\chi_1^0}$ point			
H_T	Optimized for each $m_{\tilde{g}}, m_{\chi_1^0}$ point			
Lepton veto in all searches				

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

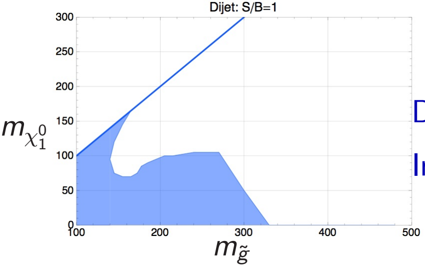
Reach of different searches

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



Monojet seach:

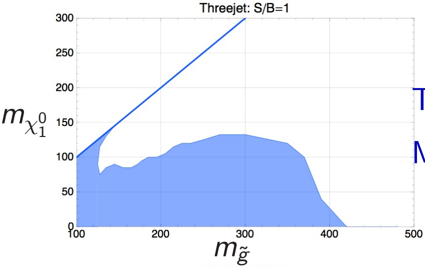
Effective in degenerate region



Dijet seach:

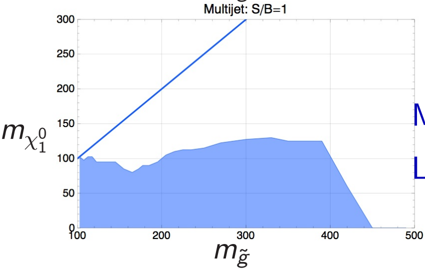
Intermediate region

Reach of different searches



Threejet seach:

Mainly large-Δm region



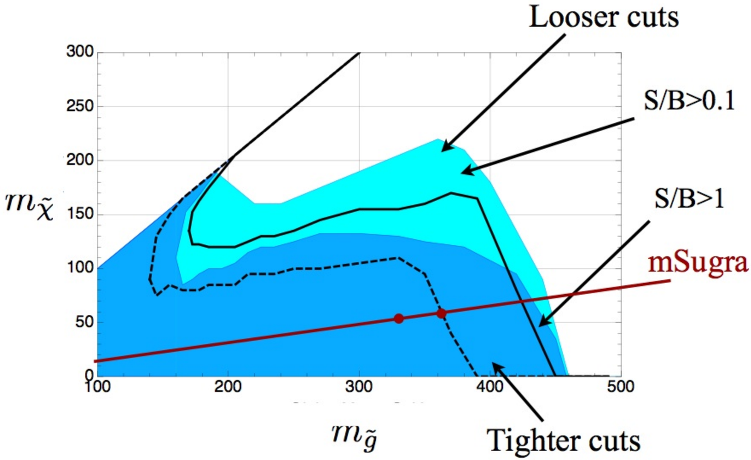
Multijet seach:

Large-Δm region

Mirrors jet structure of gluino decays

Combined exclusion region

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



Outlook

Focused here on the "gluino module": $\tilde{g} \to q\bar{q}\chi$

Could do similar studies for other "modules":

- squarks: $\tilde{q} \to q\chi$ (≤ 2 jets from decay)
- associated $\tilde{q}\tilde{g}$ (≤ 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 σ's (compare OSET approach)

Wino module

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

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

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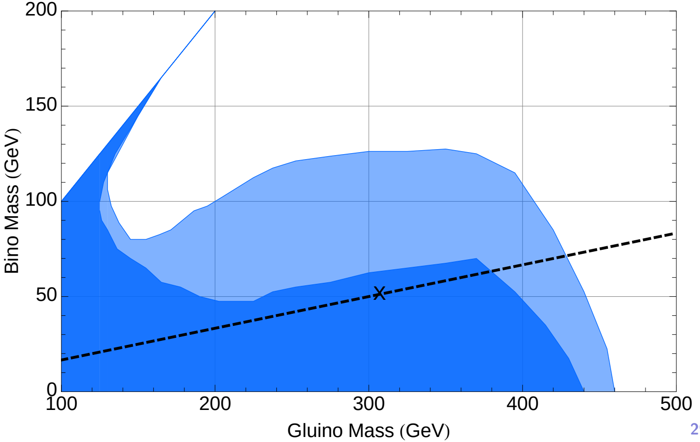

Presentation / Communication

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

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

4 jets

H_T \ $\not{E}_T$	100–200	200–300	300–400
600–800	<5fb	5^{+2}_{-2}fb	<2fb
400–600	<10fb	10^{+3}_{-3}fb	<3fb
200–400	<20fb	10^{+8}_{-8}fb	<5fb

+ 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)