SUSY AT THE LHC WITH SMADGRAPH

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- SUSY MadGraph
- WBF SUSY pairs
- mixed-flavor squark pairs

New MadGraph & MadEvent

MadGraph: [Stelzer, Long, Maltoni]

Tool for generating Fortran code to calculate matrix elements.

Recent additions:

- Denner scheme for handling Majorana fermions
- color subamps match PSMC color flows (QCD L.H. accord)
- up to 12 external particles
- can specify inclusion/exclusion of intermediate states

MadEvent:

Web-based, CompHEP-like front end: calculates collider cross sections w/ kinematic cuts, makes plots.

Parallelized! 22 nodes (64 nodes at Rome soon)

SUSY MadGraph & MadEvent

Package is standard MadGraph plus:

1. MSSM model input files (particles, interactions)
2. routine to read SUSY Les Houches Accord spectrum input
3. routine to calculate MSSM couplings

Improvements over previously available tools:

- full spin correlations to final state
- higher-order SUSY processes trivial
- consistent theoretical treatment of couplings

Testing SUSY MadGraph:

$\longrightarrow$ all $e^+e^- \to$ SUSY pairs checked with literature

$\longrightarrow$ all $pp \to$ SUSY pairs in Prospino checked

$\longrightarrow$ all possible $VV, VH \to$ SUSY pairs checked for unitarity

$\longrightarrow$ >300-process comparison with Whizard & Sherpa

SUSY MadGraph sundry technical details

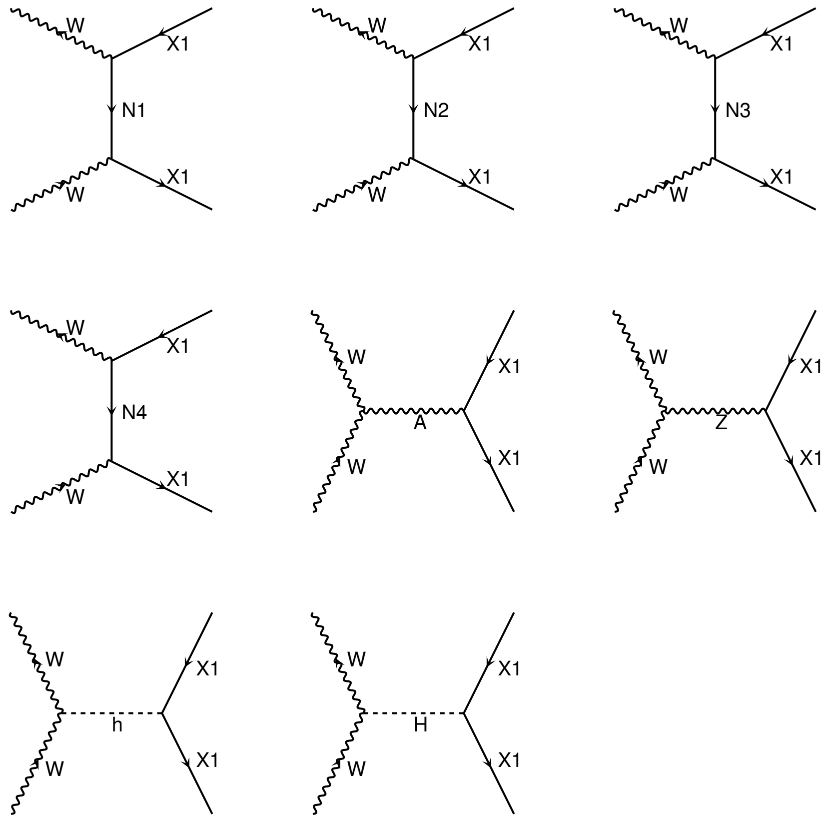
- R-parity conserving MSSM
- no CP violation (but user could easily add)
- no SUSY breaking scheme assumed, because:
- spectrum taken strictly from SLHA input files,
  so order of masses/mixings externally governed;
  sparticle widths taken from Sdecay SLHA files
- ino mixing matrices taken to be real
  $\longrightarrow$ negative ino masses OK in matrix elements

EW parameters and SUSY scattering

Warning! – blind use of SUSY spectrum generator input will yield unitarity violation for $VV \longrightarrow \chi_i \chi_j$ (discovered in testing)

Reason: for unitarity cancellation, need exact match between g_w at interactions vertices with $g_w v$ (M_V) in weak ino fermion masses.

$\longrightarrow$ extract EW info from ino mixings



Effective EW parameters from ino mixing matrices

SUSY spectrum generators run EW parameters to SUSY scale to compute ino mixing matrices - mismatch with weak-scale values.

Assume the LO form for the matrices:

$$\begin{pmatrix} m_{\tilde{B}} & 0 & -m_Z s_w c_\beta & m_Z s_w s_\beta \\ 0 & m_{\tilde{W}} & m_Z c_w c_\beta & -m_Z c_w s_\beta \\ -m_Z s_w c_\beta & m_Z c_w c_\beta & 0 & -\mu \\ m_Z s_w s_\beta & -m_Z c_w s_\beta & -\mu & 0 \end{pmatrix} , \quad \begin{pmatrix} m_{\tilde{W}} & \sqrt{2}\, m_W s_\beta \\ \sqrt{2}\, m_W c_\beta & -\mu \end{pmatrix}$$

1. knowing μ, $\tan\beta$, $m_{\tilde{W}}$ and $m_{\tilde{B}}$, extract m_Z, m_W and $\sin^2_W$ in the on-shell scheme

2. then choose G_F as the 3rd EW input parameter and go on

$\longrightarrow$ preserves unitarity of $VV \to XX$ scattering

· don't know if this is necessary for LHC calc's - 10% diffs?

WBF SUSY PAIRS AT LHC

[Cho, Hagiwara, Kanzaki, Plehn, DR, Stelzer (preliminary)]

Idea: weak boson fusion production of weakly-interacting particles (Higgs) can reduce backgrounds - works for SUSY?

[charginos: Datta, Konar, Mukhopadhyaya, 2001; sleptons: D. Choudhury et al., 2003]

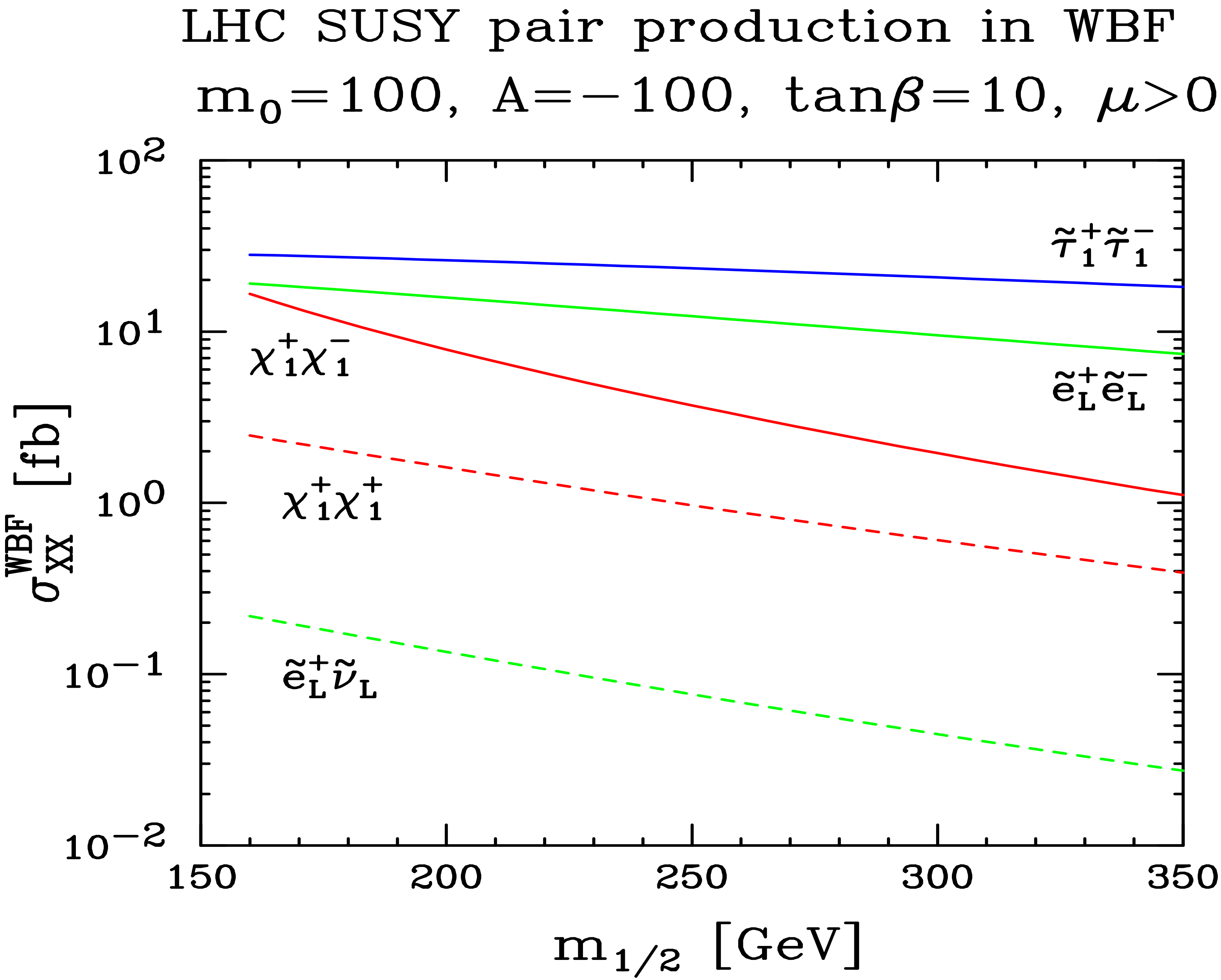
Previous studies reported mixed results for chargino visibility, positive results for sleptons.

Examine $\chi_i^0\chi_j^0$, $\chi_i^0\chi_j^\pm$, $\chi_i^+\chi_j^-$, $\chi_i^\pm\chi_j^\pm$, $\tilde{\ell}^\pm\tilde{\nu}$, $\tilde{\ell}^+\tilde{\ell}^-$ in WBF

Comparison with previous analyses:

mostly agreement, huge difference for $\tilde{\ell}^\pm\tilde{\nu}$

(previous calculations were not gauge-invariant)



$\sim 10\%$ difference w/wout EW ripping scheme;

particle widths $< 1\%$ effect.

Mixed-flavor squark pairs

[Berdine, DR, using SMADGRAPH, submitted to PRD]

Measuring BRs of SUSY pairs in QCD production says very little about the weak vertices in cascade decays (as with top quarks)

$\longrightarrow$ Could LHC produce squark pairs weakly? (W-$\tilde{q}_L$-$\tilde{q}'_L$ vertex)

Sure, but $\sigma_{EW} \ll \sigma_{QCD}$ (~ 2 orders of magnitude)

► Notice: EW pairs often give same-sign leptons in final state

(consider "typical" case of light $\chi_1^\pm$, lighter $\tilde{\tau}_1$)

$\longrightarrow$ LHC can flavor-tag b jets well, c only marginally,

so take advantage and consider $\tilde{t}_i \tilde{b}_j^*$ / $\tilde{t}_i^* \tilde{b}_j$ production

► phenomenologically, xsec's reduce to m_{q_1}, m_{q_2}, θ_q

What about super-CKM?

If SUSY is exact, $\boxed{\widetilde{V}_{ij} = V_{ij}}$ – but this isn't the case.

If SUSY breaking is flavor-blind, the same holds, UP TO evolution effects from breaking scale to EW scale, which should be small.

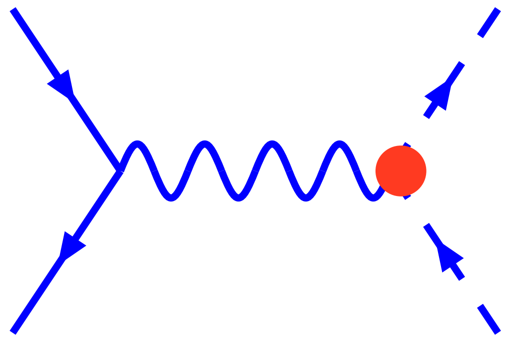
If SUSY breaking is not flavor-blind, $\widetilde{V}_{ij} \neq V_{ij}$

So what do we know?

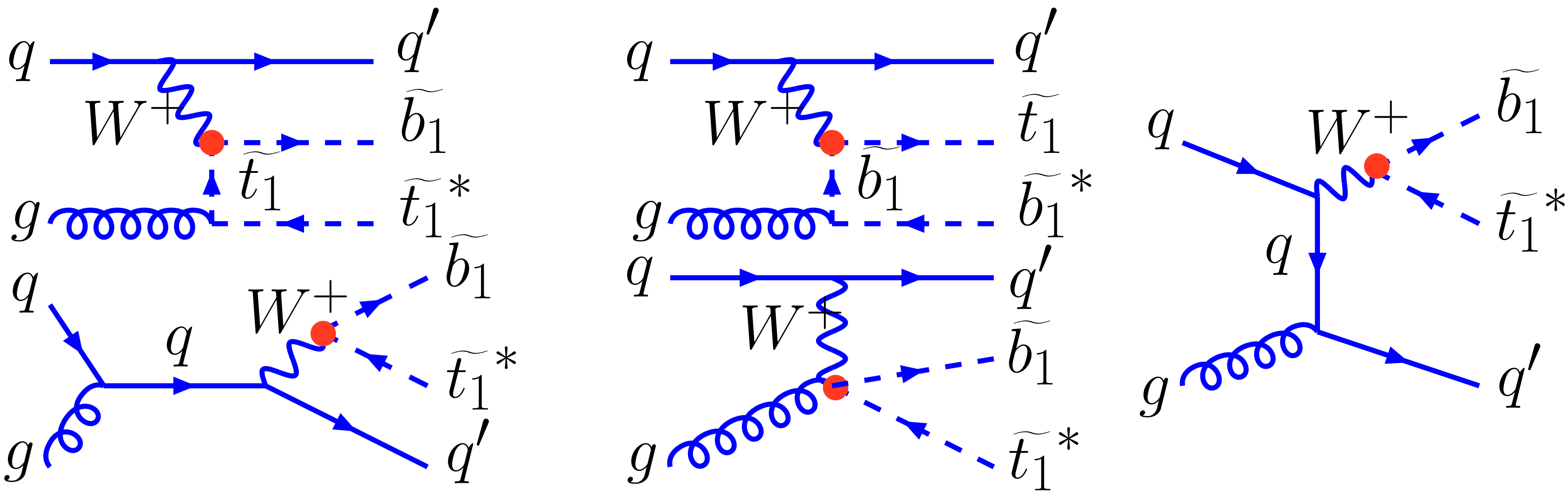
$\longrightarrow$ absolutely nothing!

Processes analagous to single-top production

s-channel:



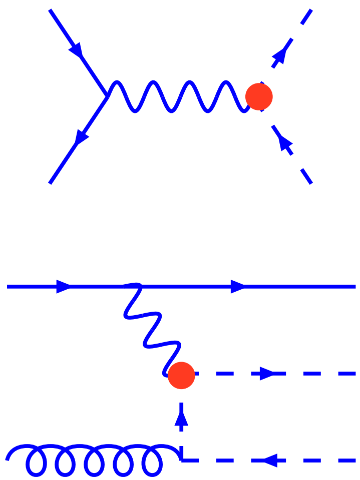
t-channel:



· Due to mixing, must consider $\tilde{t}_1\tilde{b}_1^*$, $\tilde{t}_1\tilde{b}_2^*$, $\tilde{t}_2\tilde{b}_1^*$, $\tilde{t}_2\tilde{b}_2^*$ separately.

SPS1a as benchmark; $\sigma_{\tilde{t}_i\tilde{b}_j}$ driven by masses & mixings.

Here, $m_{\tilde{t}_1,\tilde{t}_2} = 396, 587$ GeV and $m_{\tilde{b}_1,\tilde{b}_2} = 517, 547$ GeV.



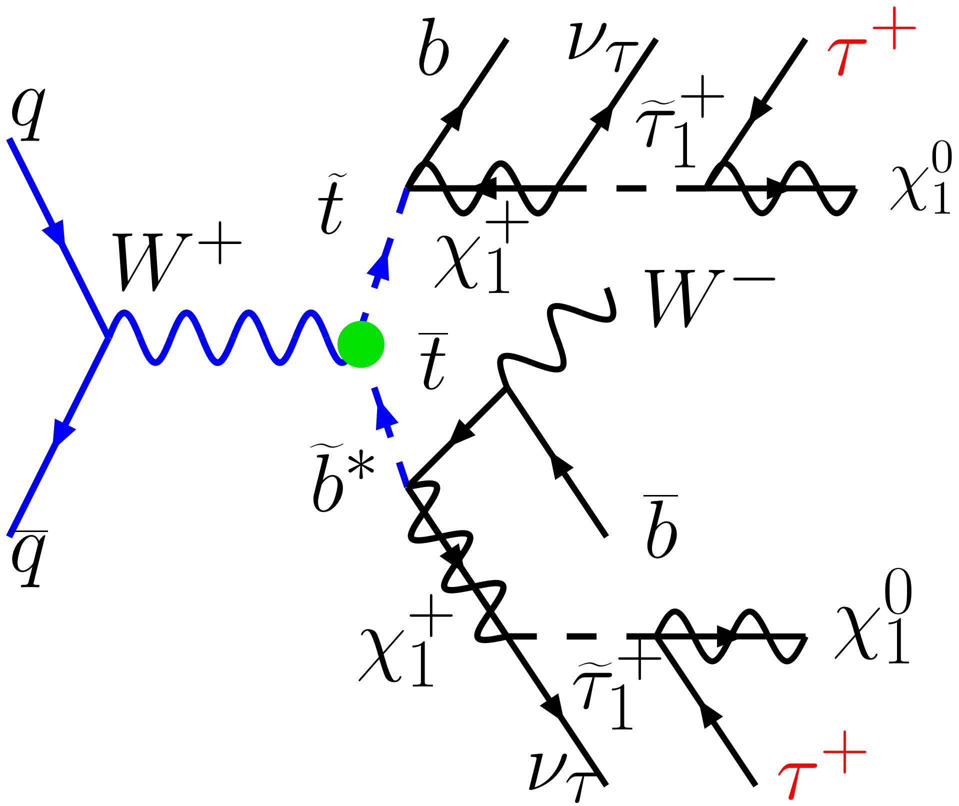
σ [fb]	$\sigma_{\tilde{t}_1\tilde{b}_1}$	$\sigma_{\tilde{t}_1\tilde{b}_2}$	$\sigma_{\tilde{t}_2\tilde{b}_1}$	$\sigma_{\tilde{t}_2\tilde{b}_2}$
$0j,\ \tilde{t}\,\tilde{b}^*$	1.3	.18	1.4	.20
$0j,\ \tilde{t}^*\,\tilde{b}$	.51	.07	.51	.07
$1j,\ \tilde{t}\,\tilde{b}^*$	4.7	.73	3.6	.47
$1j,\ \tilde{t}^*\,\tilde{b}$	2.2	.34	1.6	.21

· If all 4 rates measureable, then:

$$\hat{g}^2_{t_1b_1} + \hat{g}^2_{t_1b_2} + \hat{g}^2_{t_2b_1} + \hat{g}^2_{t_2b_2} \;=\; \hat{g}^2_{tb} \;=\; \widetilde{V}^2_{tb}\, g^2_W$$

but we'd need all 4 masses & dom. BRs to extract...

Many possible decay chains; dominant for $\tilde{t}_1 \tilde{b}_1^*$ is:



One spectacular final state is $b\bar{t}\tau^+\tau^+$: (BR $\sim 41\%$)

- let $t \to bjj$ and reconstruct $m_{bjj} = m_t$ (BR $\sim 68\%$)
- let $\tau\tau \to \ell\ell, \ell h, hh$ (more complicated)

Backgrounds

$\longrightarrow$ 2 b jets, 2 same-sign leptons, and 2 light jets; reconstruct t.

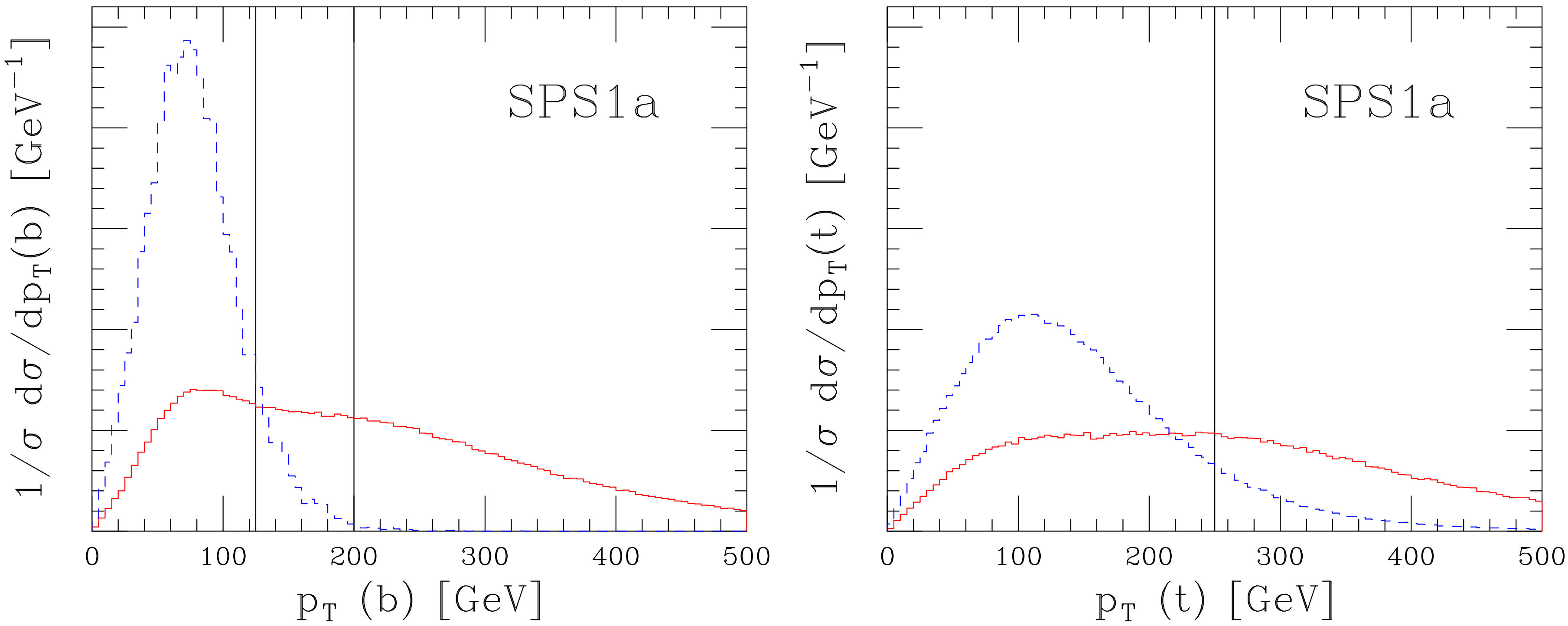
1. $t\bar{t}W^{\pm}$: 290(136) fb, but low-p_T leptons
2. $\tilde{b}_i\tilde{b}_i^*$ pairs: lose a W - high rejection efficiency
3. $\tilde{g}\tilde{g}$ & $\tilde{q}\tilde{g}$ pairs: $\tilde{q} \longrightarrow q\chi_1^+$, $\tilde{g} \longrightarrow \bar{t}\tilde{t}_1, b\tilde{b}_1$
   - ▶ typically 1 more hard jet than signal

Cross sections in [fb] (Assume $t\bar{t}W$ is totally eliminated.)

SPS	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$\tilde{t}\tilde{b}^*$	$\tilde{t}^*\tilde{b}$	$\tilde{t}\tilde{t}^*$	$\tilde{b}\tilde{b}^*$	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$	$\tilde{d}_L\tilde{g}$
1a	396	587	517	547	12.6	5.49	1630	560	4900	7370	3740
4	540	696	619	691	3.74	1.52	306	168	1350	1890	897
5	248	648	563	651	26.4	12.0	14200	280	1560	2780	1340
6	476	704	640	662	3.90	1.59	575	164	1570	2510	1210

Two strategies: (1) hard jet veto; (2) hard forward jet tag

Additional tricks for SPS1a



b and t spectra are very different for signal v. $\tilde{g} \longrightarrow \bar{t}\tilde{t}_1, b\tilde{b}_1$

Rejection factor of >100 possible for background.

The bottom line for SPS1a/5

Assumptions:

- 2×3000 fb^{-1} at SLHC
- kinematic cuts 100% efficient
- $\epsilon_{bb} = 25\%, \quad \epsilon_{\tau\tau} = 23\%$
- $t\bar{t}W$ bkg eliminated

SPS	forward jet tag analysis				jet veto analysis			
	N_S	N_B	S/B	S.S.	N_S	N_B	S/B	S.S.
1a	32	210	1/7	2.2σ	78	105	1/1.3	7.6σ
5	160	2350	1/15	3.3σ	320	1035	1/3.3	10σ

General MSSM scenarios

- Lighter $\tilde{t}, \tilde{b}$ via increased mixing

  $A_0 \to -500$ GeV: $3\times$ signal rate and BR($\tilde{g} \to \bar{t}\tilde{t}$)

- Heavier stop via increased M_3

  start with SPS1a, set $M_{1,2,3} = 100, 200, 500$ GeV

  results similar to SPS1a

- Gluino lighter than sbottoms

  often find chargino NLSP, similar ID efficiencies to stau

  extremely promising due to ultra-low background

- Stau coannihilation scenario

  stau mass ~ 100 MeV above LSP; long-lived; 100% ID

  could measure already at LHC for SPS1a/5-like rates

SUMMARY

- SUSY MadGraph/MadEvent: new tools for complete calculations of MSSM processes at colliders
- some interesting theory issues on consistent treatment of couplings, but does not appear to affect LHC pheno
- WBF colorless SUSY pairs xsec's small, but some may be interesting - needs further study
- mixed-flavor production promising for extracting SUSY parameters (but difficult)