SUSY-MADGRAPH

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LoopFest 2005, Snowmass

- SUSY MadGraph
- WBF SUSY pairs
- QCD SUSY pairs plus jets

NEW MADGRAPH & MADEVENT

MADGRAPH: [Stelzer & Long 1994]

Tool for generating Fortran code to calculate matrix elements.

(Fairly) recent additions: "MADGRAPH II"

- color subamps match PSMC color flows (QCD L.H. accord)
- can define Majorana fermions (uses Denner scheme)
- "arbitrary" number of external particles
- can specify inclusion/exclusion of intermediate states

MADEVENT: [Stelzer & Maltoni 2001]

Web-based, CompHEP-like front end:

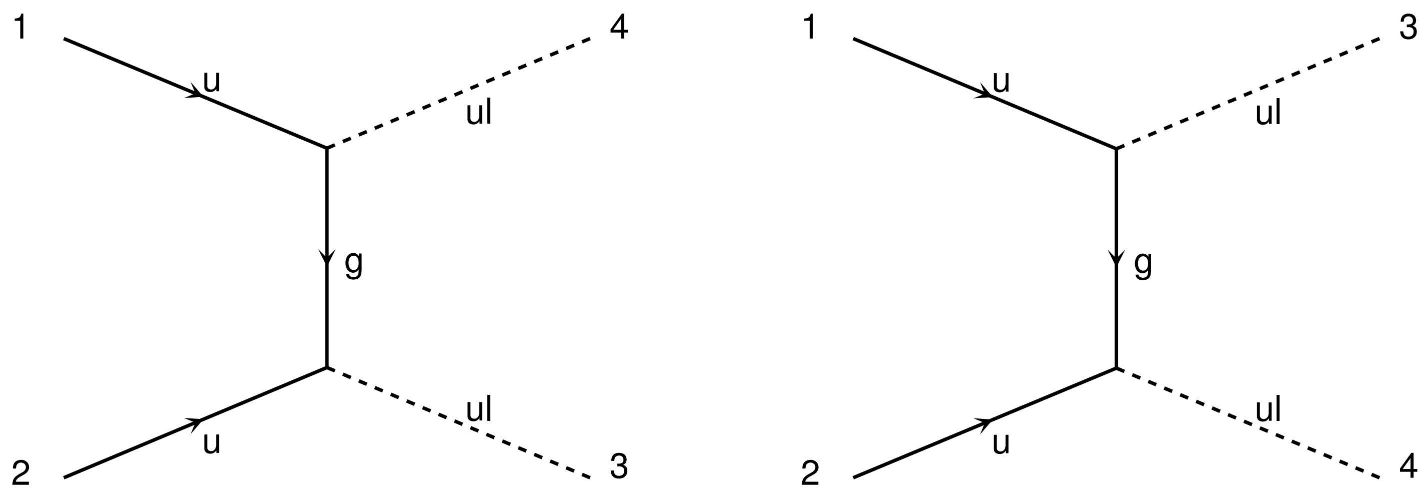
calculates collider σ's w/ kinematic cuts, makes plots.

Parallelized! 22 nodes (64 nodes at Rome soon)

Majorana fermions in MadGraph II

Example of Denner scheme implementation: $uu \longrightarrow u_L u_L$

(t-channel gluino)



Clashing arrows at fermion vertices!

Use charge-conjugate (CC) wave function for $u(p_2)$ and CC vertex at clashing arrows: only 1 overall fermion flow needs to be defined, no ambiguity and no worry over extra (-) signs internally.

SUSY-MadGraph

Package is standard MadGraph II 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 $e^+e^- \rightarrow$ SUSY pairs checked with literature

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

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

$\longrightarrow$ >375-process comparison with Whizard & Sherpa

SUSY MadGraph sundry technical details

- R-parity conserving MSSM
- no CP violation (but user could straightforwardly add)
- diagonal CKM
- no SUSY breaking scheme assumed, because:
- spectrum & parameters taken 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
- no quartic scalar couplings (useless for collider physics)

Particles data file (sample)

```
#Name anti_Name Spin Linetype Mass Width Color Label Model
# Quarks
t t~ F S MT WT T t XXX
# Squarks
dl dl~ S D MDL WDL T dl XXX
# Leptons
e- e+ F S ZERO ZERO S e XXX
# Sleptons
el- el+ S D MEL WEL S el XXX
sve sve~ S D MVE WVE S ve XXX
# Vector Bosons
g g V C ZERO ZERO O _ XXX
z z V W MZ WZ S Z XXX
w- w+ V W MW WW S W XXX
# Higgs
h1 h1 S D MH1 WH1 S h XXX
h- h+ S D MHC WHC S hc XXX
# Inos
go go F S MGO WGO O g XXX
n1 n1 F S MN1 WN1 S N1 XXX
x1- x1+ F S MX1 WX1 S X1 XXX
```

Interactions data file (sample) [>800 lines]

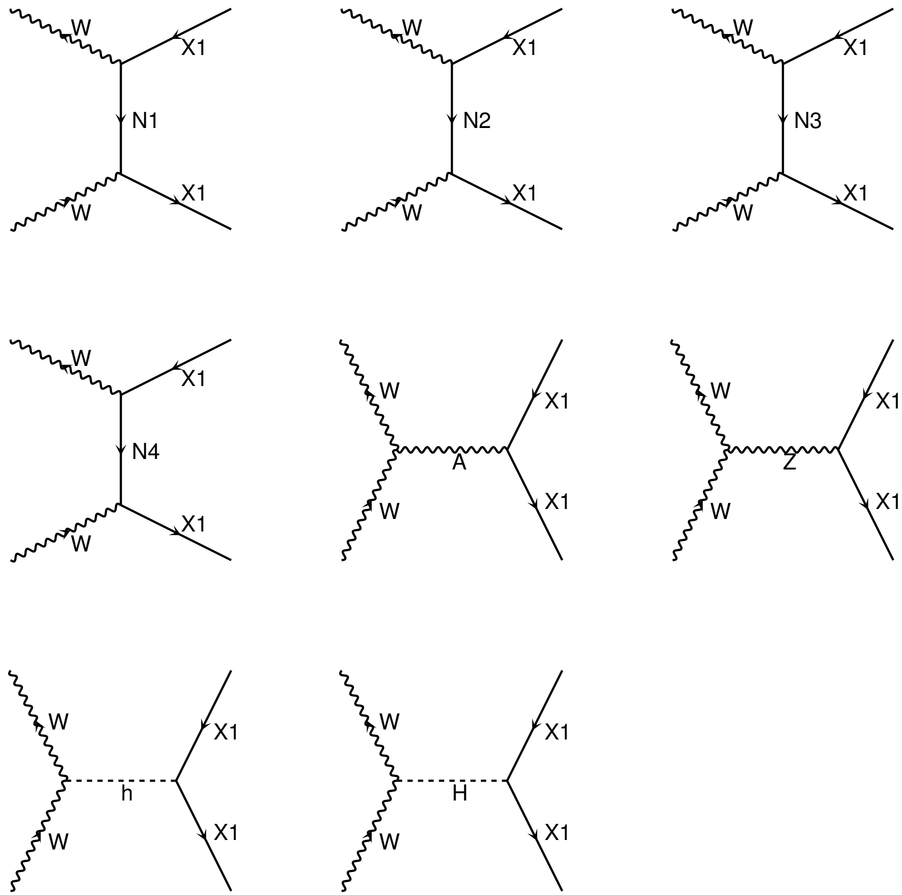
```
# FFV (weak inos)
n1 n3 z GZN13 QED
x1- x2- z GZX12 QED
n1 x1- w+ GWN1X1 QED
# FFS (Yukawa)
b b h2 GH2BB QED
# FFS (gluinos)
d go dl  GQLGOM QCD
go d dl~ GQLGOP QCD
# FFS (Higgs and weak inos)
x1- x2- h1 GH1X12 QED
x2- x1- h1 GH1X21 QED
# VSS QED non-Higgs
z dl dl~ GZDLDL QED
# VSS Higgs
w+ h- h1 GWHCH1 QED
# SSS Higgs-sfermion
h1 t1 t1~ GH1T1T1 QED
# VVSS mixed QCD-QED
g a dl dl~ GGADLDL DUM QCD QED
# VVSS QED Higgs
z z h1 h1 GZZH1H1 DUM QED QED
```

EW parameters and SUSY scattering

Warning! – blind use of SUSY spectrum generator input will yield unitarity violation for $VV \to \chi_i \chi_j$ (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 ($\sin^2\theta_W = 1 - M_W^2/M_Z^2$)
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?

· holds to all EW order? dunno $\longrightarrow$ we will check...

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]

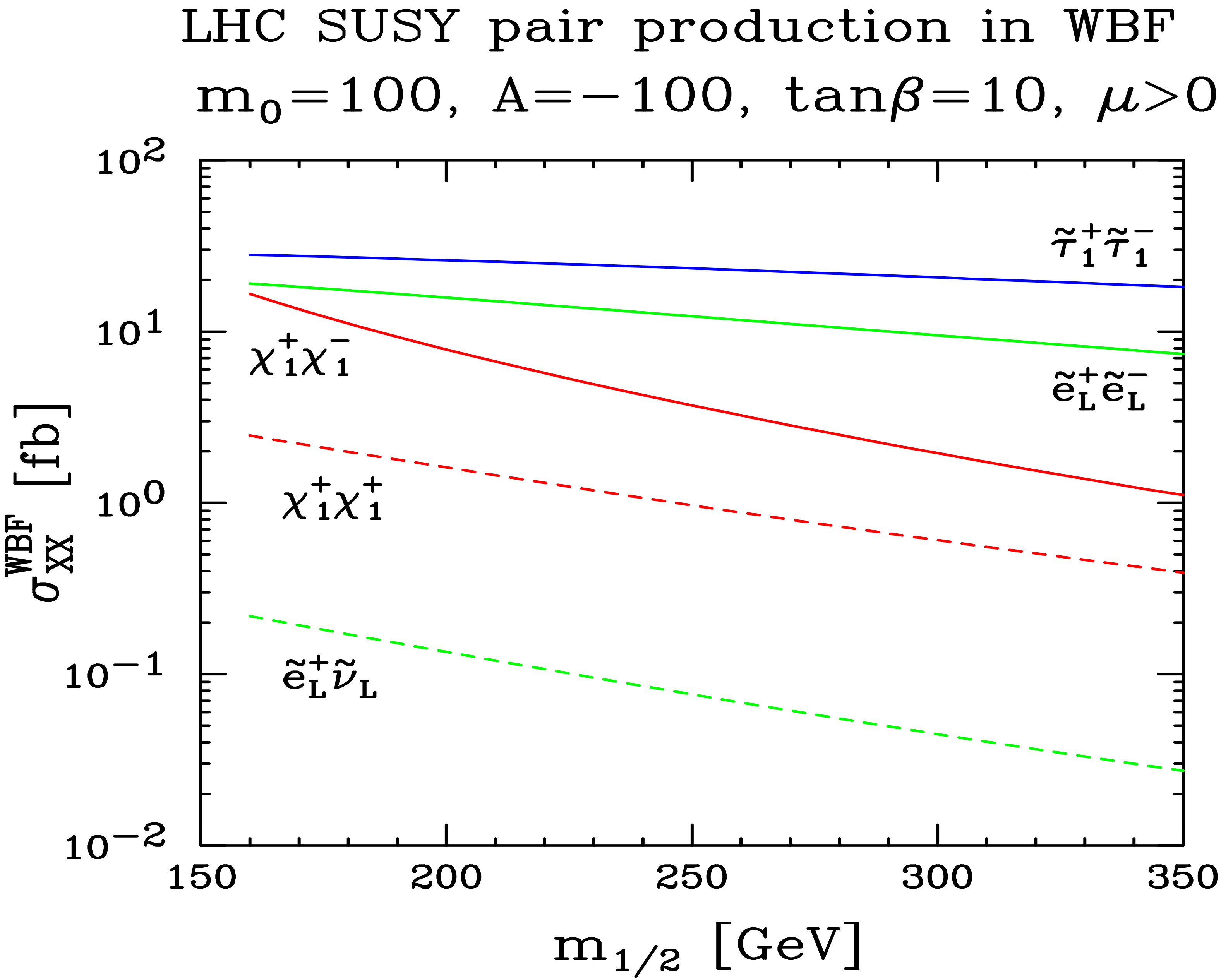
Previous studies reported mixed results for chargino visibility, positive results for sleptons.

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 only WBF, ignored Brem. diagrams)



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

particle widths $< 1\%$ effect.

WBF xsecs shown do not apply "tagging jet" cuts;

cuts would reduce rates by factor $\sim 2-4$

- Note: do NOT need tagging jet cuts for $\chi_1^+\chi_1^+$;

  channel will be difficult, maybe marginal, but worth pursuing

- WBF $\tilde{e}_L\tilde{\nu}$ seems to disagree with literature, but very difficult

  to compare precisely

- WBF stau pairs comparable to DY! could double LHC rate

SPS	1a	1b	2	3	4	5	6	7	8	9
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	26.3	14.9	0.012	18.4	9.0	17.0	11.2	30.0	18.9	4.4
$\tilde{\tau}_1^+\tilde{\tau}_2^-$	0.005	0.002	0	0.001	0.001	0.002	0	0.002	0	0
$\tilde{\tau}_2^+\tilde{\tau}_2^-$	14.2	4.9	0.011	7.3	3.0	9.2	4.4	9.3	4.6	3.3

(these x-secs with rapidity gap: $\triangle R(jj) > 4.2$)

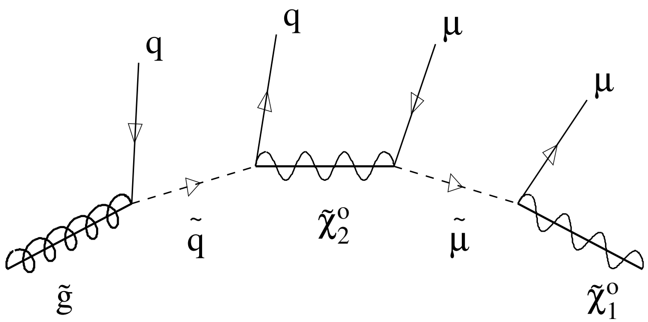
QCD SUSY PAIRS + JETS AT LHC

Squarks and gluinos easily

discovered at LHC:

high-p_T multijets + leptons signal

via cascade decays

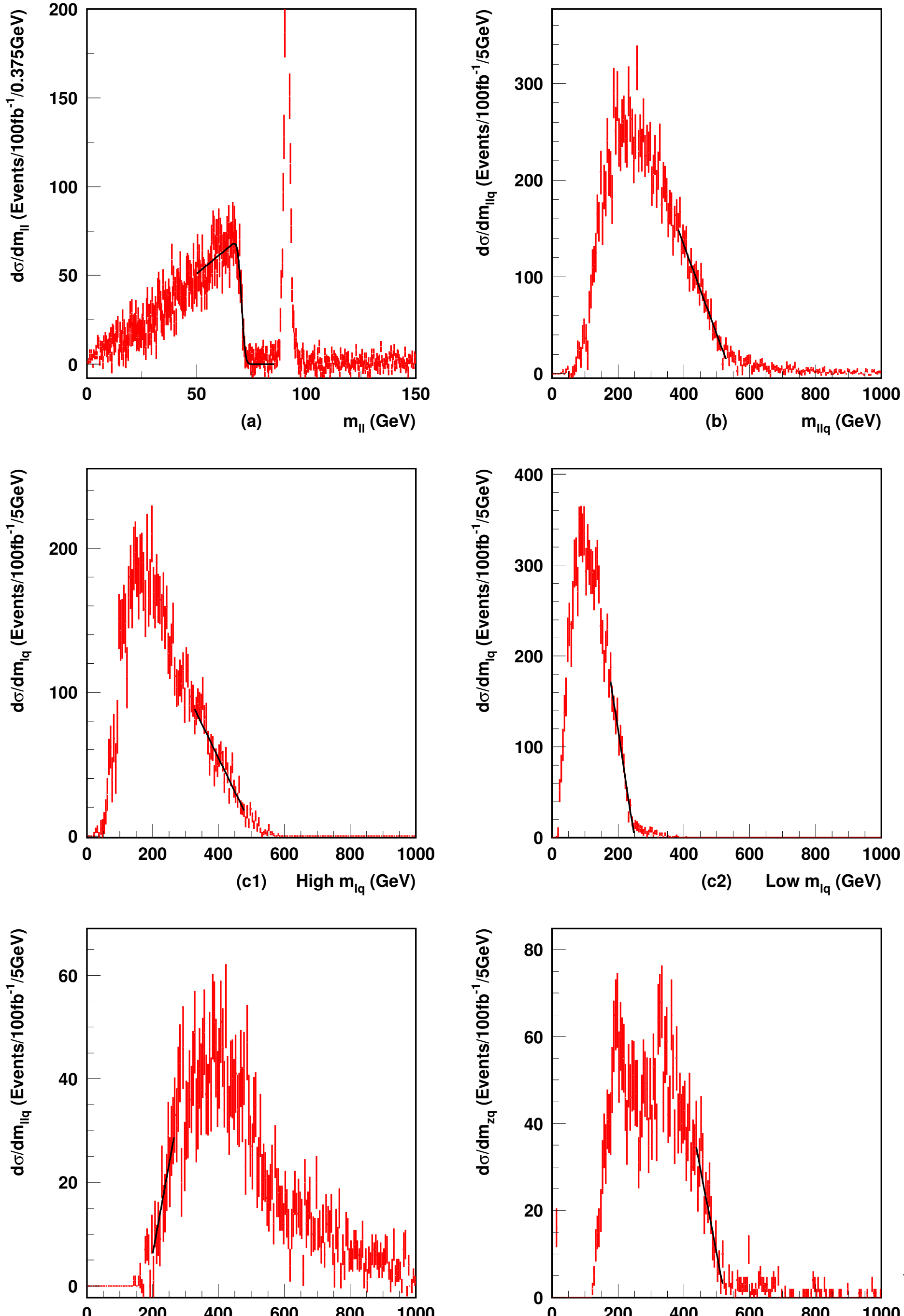


- mass diff.'s via jet/lep "edges"

  [Hinchliffe & Paige; Allanach et al.]

► $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\tilde{q}$ samples separated

by # of hard jets



How many hard jets does QCD give in SUSY events?

[Plehn, DR, using SMADEVENT]

▶ extra hard jets affect cascade studies - how many are there?

NLO $\tilde{g}\tilde{g}j$, $\tilde{q}\tilde{q}^*j$ rates not known, but can calc. hard real emission

Generate events with $p_T(j) > 50(100)$ GeV at LHC:

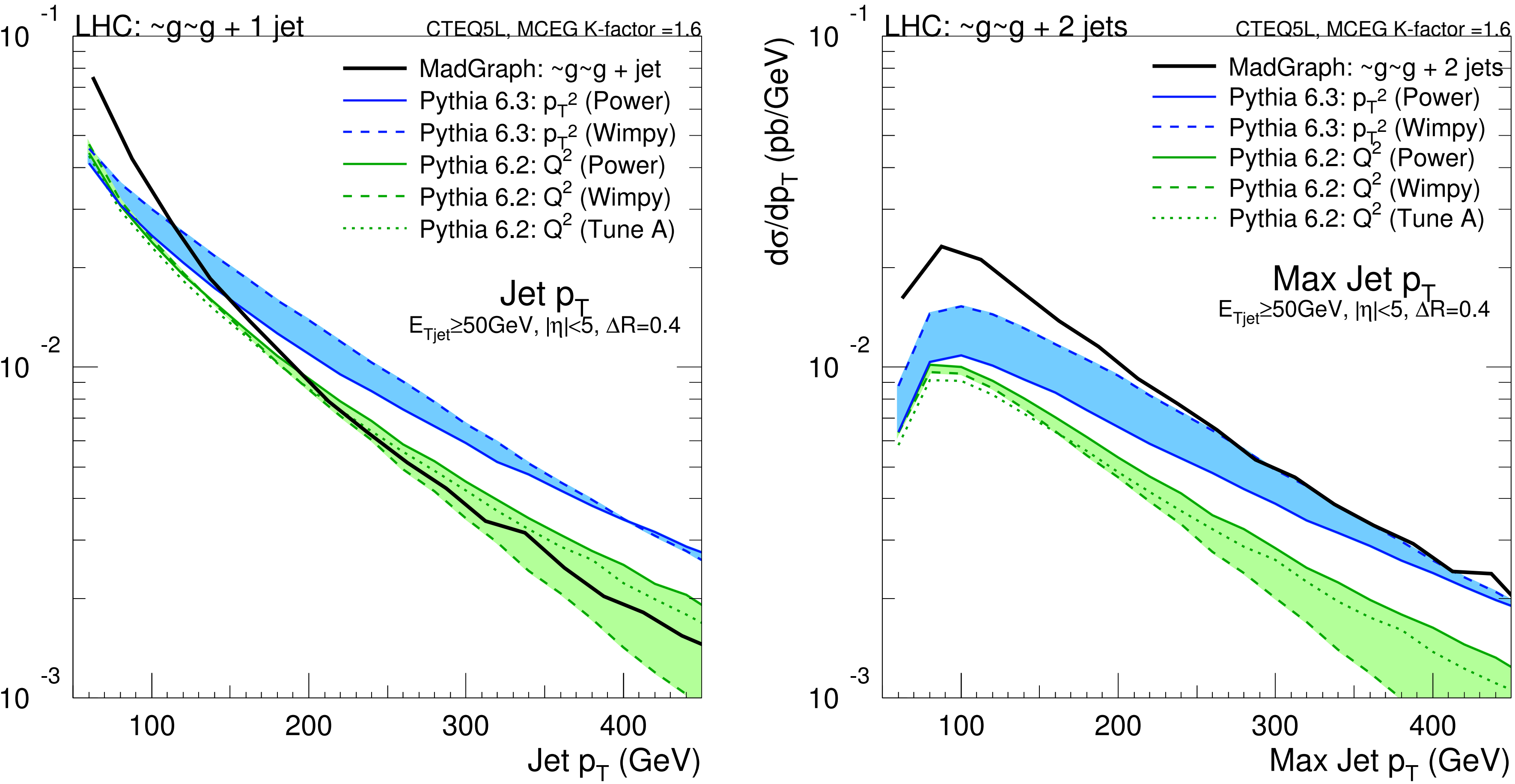
600 GeV top quarks, gluino pairs, $\tilde{u}_L$+$\tilde{g}$ [SPS1a]

	$\sigma_{T\bar{T}}$	$\sigma_{\tilde{g}\tilde{g}}$	$\sigma_{\tilde{q}\tilde{g}}$
0j	1.30 (1.30)	4.83 (4.83)	5.65 (5.65)
1j	1.50 (0.73)	5.91 (2.89)	5.38 (2.74)
2j	1.21 (0.26)	4.16 (1.09)	3.18 (0.85)

- $+1j, 2j$ is so large because of flavor unlocking of initial state
- question: at which p_T is the Sudakov factor important?

$\tilde{g}\tilde{g}$ plus jets for SPS1a [Plehn,DR,Skands, preliminary]

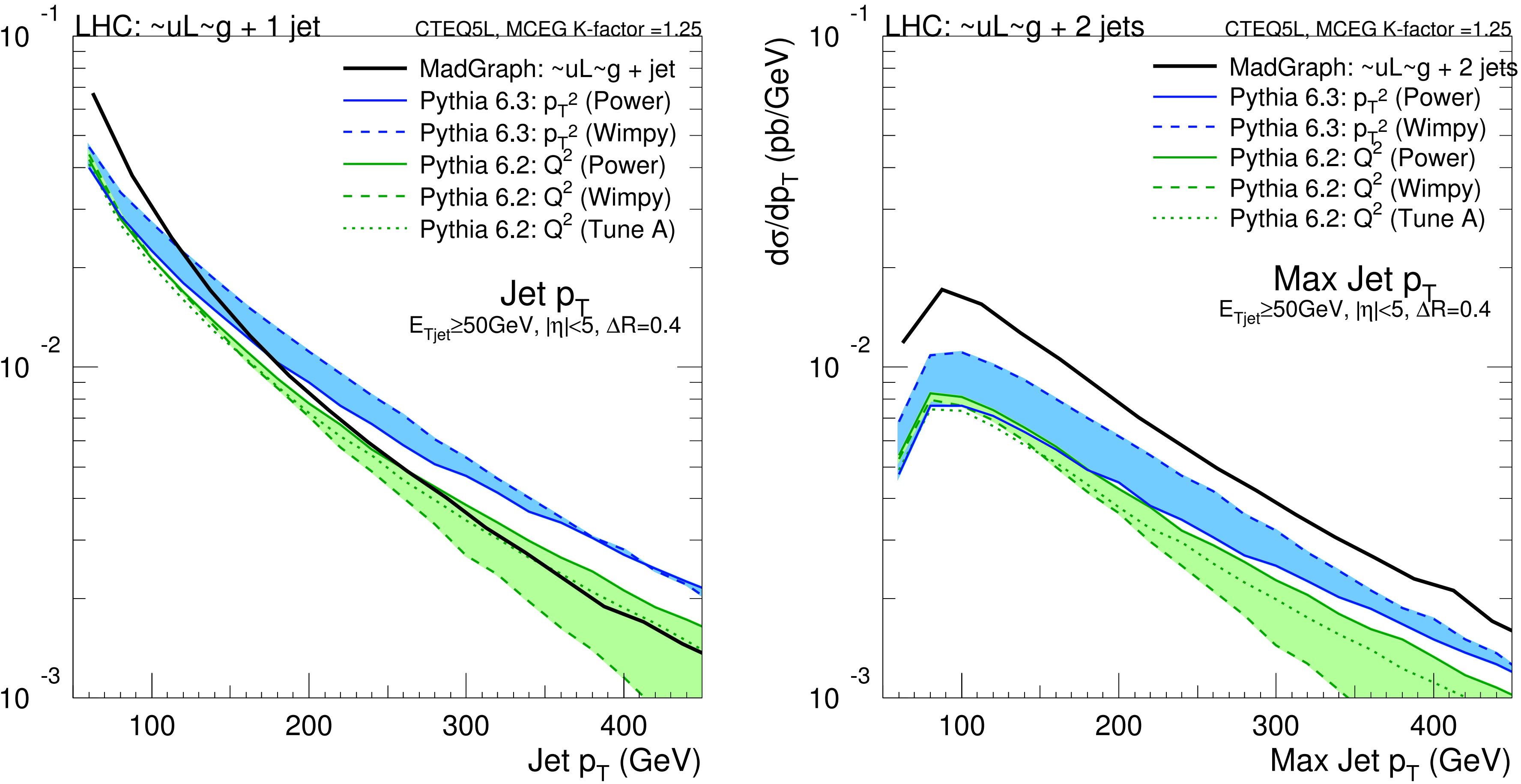
PYTHIA 6.3 normalized to NLO rate (PROSPINO)



- Q^2-ordered shower great for 1j, drastically low for 2j
- p_T^2-ordered shower too hard for 1j, funny shape for 2j
- M.E. valid for $p_T \gtrsim 100$ GeV $\longrightarrow$ due to $\log(\frac{M}{p_T})$

$\tilde{u}_L \tilde{g}$ plus jets for SPS1a [Plehn,DR,Skands, preliminary]

PYTHIA 6.3 normalized to NLO rate (PROSPINO)



- same general conclusions as for $\tilde{g}\tilde{g}$+ jets

Remaining work to be done: [Plehn, DR, Skands]

- compare Pythia & M.E. angular dist'bns – in progress
- understand M.E. matching - future task

Keep in mind: non-trivial uncertainty for both M.E. and Pythia over amount of extra jet radiation.

$\longrightarrow$ need study of $t\bar{t}+$jets @ Tev2 (help tune Pythia)

$\longrightarrow$ need full NLO calculation of $t\bar{t}j$

[in progress: Brandenburg, Dittmaier, Uwer, Weinzierl]

$\longrightarrow$ must include matrix elements for $\tilde{g}\tilde{g}j$, $\tilde{g}\tilde{q}j$, $\tilde{q}\tilde{q}j$ in Pythia (Sherpa can already do this)

$\longrightarrow$ Pythia will have to be tuned!

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
- heavy colored SUSY pairs + jets will affect LHC cascade decay pheno, but investigations still in early stages
- mixed-flavor production promising for extracting SUSY parameters (but difficult)