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- Madgraph/Madevent approach
- proof of power by LHC examples
- all under rapid development

in name of:
Advanced user’s tool: Madgraph  

– problem: (differential) tree–level cross sections for ILC, LHC
– usually more complex than $2 \to 2$, otherwise talk $N^m\text{LO}$  
– perfect tool for numerical helicity amplitudes: HELAS  

$\Rightarrow$ interface initial/final states $a, b \to A, B, C, D, \ldots \leftrightarrow |M|^2$ in Fortran

What is and what is not included

– user-defined: particles, interactions in simple syntax
– user-defined: couplings in Fortran, unless Standard Model default
– included: Feynman diagram calculator
– included: Fortran function $|M|^2$  
– only in Madevent: phase space integrator/generator
– only in Madevent: plotting routine, fast detector simulation...

$\Rightarrow$ Madgraph for experts/pheno students  

[Stelzer & Long]

[this is legfest?]

[Hagiwara, Murayama, Watanabe]

[established for many years]
Experimental style or careful hackers: Madevent  [Maltoni, Stelzer, Alwall,...]
- no need to rewrite phase space for \(W + \text{jets}\) every time
- no need to link PAW locally every time
- no need to write Pythia/PGS interface every time
- certainly no need to debug your own code every time...
⇒ highly complex public computer code  [great if someone else maintains it]
⇒ web–based tool, running in Urbana-Champaign, Louvain-la-Neuve

Smadgraph/Madevent  [SUSY release paper: hep-ph/0601063; similar for 2HDM, Higgs–ET, UED, etc.]
- Madgraph: BSM particles, interactions files
  model parameter interface, couplings definition, HELAS interface
- Madevent: same by Perl script
⇒ BSM–Madevent the future

Reference processes on the web  [Smadgraph + Sherpa + Whizard]
Comparison of Automated Tools for Phenomenological Investigations of SuSy
2HDM in MADEVENT

\[ V = \mu_1 H_1^1 H_1^2 + \mu_2 H_2^1 H_2^2 - \left( \mu_3 H_1^1 H_2^1 + \text{h.c.} \right) \]
\[ + \lambda_1 (H_1^1 H_1^2)^2 + \lambda_2 (H_2^1 H_2^2)^2 \]
\[ + \lambda_3 (H_1^1 H_1^2) (H_2^1 H_2^2) + \lambda_4 (H_1^1 H_2^2) (H_2^1 H_2^1) \]
\[ + \left[ \left( \lambda_5 H_1^2 H_2 + \lambda_6 H_1^1 H_1 + \lambda_7 H_2^1 H_2 \right) (H_1^1 H_2^2) + \text{h.c.} \right] \]

\[ V = \mu_1 \phi_1^1 \phi_1^2 + \mu_2 \phi_2^1 \phi_2^2 - \left( \mu_3 \phi_1^1 \phi_2^1 + \text{h.c.} \right) \]
\[ + \frac{1}{2} \lambda_1 (\phi_1^1 \phi_1^2)^2 + \frac{1}{2} \lambda_2 (\phi_2^1 \phi_2^2)^2 \]
\[ + \lambda_3 (\phi_1^1 \phi_1^2) (\phi_2^1 \phi_2^2) + \lambda_4 (\phi_1^1 \phi_2^2) (\phi_2^1 \phi_1^1) \]
\[ + \left[ \left( \frac{1}{2} \lambda_5 \phi_1^1 \phi_2 + \lambda_6 \phi_1^1 \phi_1 + \lambda_7 \phi_2^1 \phi_2 \right) (\phi_1^1 \phi_2^2) + \text{h.c.} \right] \]

[TwoHiggsCalc: Herquet, DeVisscher, Ovyn]
Inclusive and exclusive squark–gluino signatures

- decays to jets, missing energy, possibly leptons
- inclusive: jet multiplicity 1 for $\tilde{q}$, 2 for $\tilde{g}$
- exclusive: SUSY masses from thresholds & edges

$\Rightarrow$ effects of additional hard jets on analyses?

Comparison Pythia — Smadevent

- matrix element $\tilde{g}\tilde{g}+2j$ and $\tilde{u}_L\tilde{g}+2j$  \([p_T,j > 100 \text{ GeV}]\)
- normalized $p_T,j$ distributions
- Pythia shower tuned at Tevatron

$\Rightarrow$ SUSY easier than tops  \([\text{QCD}: \text{the heavier the better}]\)
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SUSY easier than tops [QCD: the heavier the better]
Weakly interacting particles in weak boson fusion

- works great for Higgs (Standard Model or MSSM)
- $W, Z$ background the problem for DY-type $pp \rightarrow \tilde{\chi}\tilde{\chi}, \tilde{\ell}\tilde{\ell}$
- trigger difficult for (neutral) stable sleptons

$\Rightarrow$ give it a try: $qq' \rightarrow q'q\tilde{\ell}\tilde{\ell}^* \quad [\text{cancellations deadly}]$

<table>
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<th>SPS 1a</th>
<th>SPS8</th>
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<td>$\tilde{\tau}_2^+ \tilde{\tau}_2^-$</td>
<td>18.3</td>
<td>0.032</td>
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Weakly interacting particles in weak boson fusion  
[Cho, Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

- works great for Higgs (Standard Model or MSSM)
- $W, Z$ background the problem for DY-type $pp \rightarrow \tilde{\chi}\tilde{\chi}, \ell\ell$
- trigger difficult for (neutral) stable sleptons

$\Rightarrow$ WBF great, but really only for Higgs

Theoretical side remark

- unitarity in $WW \rightarrow \tilde{\chi}\tilde{\chi}$  
  [s and t channel, like $WW \rightarrow \tilde{t}\tilde{t}$]
- e.g. parameter $m_Z$ in s-channel propagator and $\tilde{\chi}\tilde{\chi}\Phi$ Yukawa coupling
  [test of SUSY-protected coupling: Kilian, TP, Richardson, Schmidt]
- mismatch in renormalization fixed by ripping scheme
- similar for mixing scalars, mass matrix and $\tilde{f}\tilde{f}\Phi$ coupling  
  [unitarity fine, F and D terms]
- general problem: widths and couplings for Higgs and SUSY  
  [Sdecay: Mühlleitner et al.]

$\Rightarrow$ all fixed for Smadevent users
Show it is SUSY–QCD  [many ideas: Smillie & Webber]

– straw-man ‘bosonic SUSY’: universal extra dimensions
– compare entire cascade  [use e.g. \( m_{\ell b} \) instead of angles]
– only normalized distributions  [masses from endpoints]
⇒ if fermionic gluino, then Majorana  [like–sign dileptons]

Cascade decays — Smadevent + UED–Madgraph  [Alves, Eboli, TP]

– gluino decay chain as for mass measurement
– compare with first KK \( g, q, Z, \text{ and } \ell \)
– decay asymmetry \( b \) vs. \( \bar{b} \)  [instead of near/far \( b \)]
  \[ \mathcal{A} = \frac{\sigma(b\ell^+) - \sigma(b\ell^-)}{\sigma(b\ell^+) + \sigma(b\ell^-)} \]
– complication: \( \bar{\ell}_{LR} \) or \( \bar{\tau}_{LR} \) tied in with spin
– pure jet observables which work: \( \phi_{bb} \)
⇒ gluino spin sits in decay kinematics
3 – GLUINO SPIN DETERMINATION

Show it is SUSY–QCD [many ideas: Smillie & Webber]

– straw-man ‘bosonic SUSY’: universal extra dimensions
– compare entire cascade [use e.g. $m_{\ell_b}$ instead of angles]
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Cascade decays — Smadevent + UED–Madgraph [Alves, Eboli, TP]

– gluino decay chain as for mass measurement
– compare with first KK $g, q, Z, \ell$
– decay asymmetry $b$ vs. $\bar{b}$ [instead of near/far $b$]
  $A = \frac{\sigma(b\ell^+) - \sigma(b\ell^-)}{\sigma(b\ell^+) + \sigma(b\ell^-)}$
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– gluino decay chain as for mass measurement
– compare with first KK g, q, Z, and $\ell$
– decay asymmetry $b$ vs. $\bar{b}$  [instead of near/far $b$]

$$\mathcal{A} = \frac{\left\{ \sigma(b\ell^+) - \sigma(b\ell^-) \right\}}{\left\{ \sigma(b\ell^+) + \sigma(b\ell^-) \right\}}$$

– complication: $\bar{\ell}_{LR}$ or $\bar{\ell}_{\tilde{L}R}$ tied in with spin
– pure jet observables which work: $\phi_{bb}$

⇒ gluino spin sits in decay kinematics
Example 1: \( pp \to \bar{g}g \to \bar{b}_1b\bar{b}_1^* \) [Berdine, Rainwater, ...]

- naive expectations: corrections \( \sim \Gamma_{\bar{g}}/m_{\bar{g}} \)
- rate up 16% \([\sigma_{\text{pole}}=108 \text{ fb}; \sigma_{\text{all}}=125 \text{ fb}]\)
- compare to NLO uncertainty \( \sim 15\% \)

⇒ detailed discussion in paper...

![Diagrams](image-url)
4 – Off-Shell Squarks and Gluinos at LHC

Example 1: $pp \rightarrow \bar{g}g \rightarrow \bar{b}_1b_1^*$  [Berdine, Rainwater,...]

- naive expectations: corrections $\sim \Gamma_{\bar{g}}/m_{\bar{g}}$
- rate up 16%  [$\sigma_{pole}=108$ fb; $\sigma_{all}=125$ fb]
- compare to NLO uncertainty $\sim 15%$

$\Rightarrow$ detailed discussion in paper...

Example 2: $pp \rightarrow \bar{g}\chi_1^0 \rightarrow \bar{b}_1\chi_1^0$

- rate up 50%!
- distributions spread...
- no interference, but new pole
- separable by jet/lepton edges?
- just a start as well...
Automatic matching of hard jets with parton shower

- writing talk in Caffe Strada — guess Frank will explain right before me?
- Madevent with new $p_T$-ordered Pythia shower [ask Johan Alwall for details]
- Madevent process definition $pp > Wj$, $pp > Wjj$, $pp > Wjjj$, ...
- $e^+e^- \rightarrow Z+jets$ testing ground
Outlook

Madgraph/Madevent progress all over the place  [mostly Louvain-la-Neuve]

- SUSY available in Madgraph, tested in Madevent  [used for several papers]
- 2HDM available in Madevent
- higher-dimension Higgs couplings available in Madevent
- UED tested in Madgraph  [used for SUSY-UED comparison]

- PGS included in Madevent
- jet matching next task for Madevent

- http://madgraph.roma2.infn.it
  http://madgraph.phys.ucl.ac.be
Weak squark vertices [Berdine, Rainwater]

- consider $pp \rightarrow \tilde{t}\tilde{b}^*$, phenomenologically function of $m_{\tilde{t}_1,\tilde{t}_2, \theta_t, m_{\tilde{b}_1,\tilde{b}_2, \theta_b, \tilde{V}_{ij}}$
- all channels $\tilde{t}_1\tilde{b}_i^*, \tilde{t}_1\tilde{b}_2^*, \tilde{t}_2\tilde{b}_1^*, \tilde{t}_2\tilde{b}_2^* \Rightarrow g_{t_1b_1} + g_{t_1b_2} + g_{t_2b_1} + g_{t_2b_2} = g_{tb} = \tilde{V}_{tb}g_W$
- backgrounds: $t\bar{t}W^{\pm}, \tilde{b}_i\tilde{b}_i^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{q}$
- kinematic separation
Weak squark vertices  [Berdine, Rainwater]

- consider pp → \( \tilde{t} \tilde{b}^* \), phenomenologically function of \( m_{\tilde{t}_1, \tilde{t}_2}, \theta_t, m_{\tilde{b}_1, \tilde{b}_2}, \theta_b, \tilde{V}_{ij} \)
- all channels \( \tilde{t}_1 \tilde{b}_1^*, \tilde{t}_1 \tilde{b}_2^*, \tilde{t}_2 \tilde{b}_1^*, \tilde{t}_2 \tilde{b}_2^* \) \( \Rightarrow g_{t_1 b_1}^2 + g_{t_1 b_2}^2 + g_{t_2 b_1}^2 + g_{t_2 b_2}^2 = g_{tb}^2 = \tilde{V}_{tb}^2 g_W^2 \)
- backgrounds: tW±, \( \tilde{b}_1 \tilde{b}_1^* \), \( \tilde{g} \tilde{g} \)
- kinematic separation
- observation at SLHC  [including BRs & efficiencies]

<table>
<thead>
<tr>
<th>SPS</th>
<th>forward jet tag analysis</th>
<th>jet veto analysis</th>
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