SUSY–MADGRAPH, MADEVENT

Tilman Plehn

MPI München & University of Edinburgh

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

in name of:

J. Alwall, K. Hagiwara, F. Maltoni, D. Rainwater, T. Stelzer, R. Frederix, M. Herquet, S. DeVisscher,...

MADGRAPH VS. MADEVENT

Advanced user's tool: Madgraph [Stelzer & Long]

- problem: (differential) tree–level cross sections for ILC, LHC
- usually more complex than $2 \to 2$, otherwise talk N^{m}LO [this is legfest?]
- perfect tool for numerical helicity amplitudes: HELAS [Hagiwara, Murayama, Watanabe]

$\Rightarrow$ interface initial/final states $a, b \to A, B, C, D, ... \leftrightarrow \overline{|\mathcal{M}|^2}$ 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 $\overline{|\mathcal{M}|^2}$ [plus HELAS library]
- only in Madevent: phase space integrator/generator
- only in Madevent: plotting routine, fast detector simulation...

$\Rightarrow$ Madgraph for experts/pheno students [established for many years]

MADGRAPH VS. MADEVENT

Experimental style or careful hackers: Madevent [Maltoni, Stelzer, Alwall,...]

– no need to rewrite phase space for W + 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

Higgs Basis (more info)

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

lambda1	1
lambda2	1
lambda3	1
lambda4	0
lambda5	0
Norm of lambda6	0
Norm of lambda7	0
Phase of lambda6	0
Phase of lambda7	0
Mass of Charged Higgs (GeV)	300

Generic Basis (more info)

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

Tan(beta)=v2/v1	1
Phase of v2	0
Norm of mu3	0
lambda1	1
lambda2	1
lambda3	1
lambda4	0
Norm of lambda5	0
Norm of lambda6	0
Norm of lambda7	0
Phase of lambda5	0
Phase of lambda6	0
Phase of lambda7	0

Yukawa parameters

Higgs basis (more info)

$$\mathcal{L}_Y = \frac{\overline{Q_L}\sqrt{2}}{v}\left[(M_d H_1 + Y_d H_2) d_R + (M_u \tilde{H}_1 + Y_u \tilde{H}_2) u_R\right] + \frac{\overline{E_L}\sqrt{2}}{v}\left[(M_e H_1 + Y_e H_2) e_R\right]$$

Generic Basis (more info)

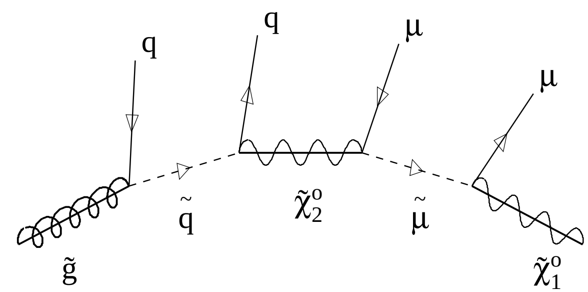
$$\mathcal{L}_Y = \frac{\overline{Q_L}\sqrt{2}}{v}\left[(\Delta_d \phi_1 + \Gamma_d \phi_2) d_R + (\Delta_u \tilde{\phi}_1 + \Gamma_u \tilde{\phi}_2) u_R\right] + \frac{\overline{E_L}\sqrt{2}}{v}\left[(\Delta_e \phi_1 + \Gamma_e \phi_2) e_R\right]$$

Yukawa couplings to the second Higgs doublet of the down type quarks (norm and phase)

Y1D/G1D	0	0	Y1S/G1S	0	0	Y1B/G1B	0	0
Y2D/G2D	0	0	Y2S/G2S	0	0	Y2B/G2B	0	0
Y3D/G3D	0	0	Y3S/G3S	0	0	Y3B/G3B	0	0

[TwoHiggsCalc: Herquet, DeVisscher, Ovyn]

1 – SQUARKS AND GLUINOS WITH JETS



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

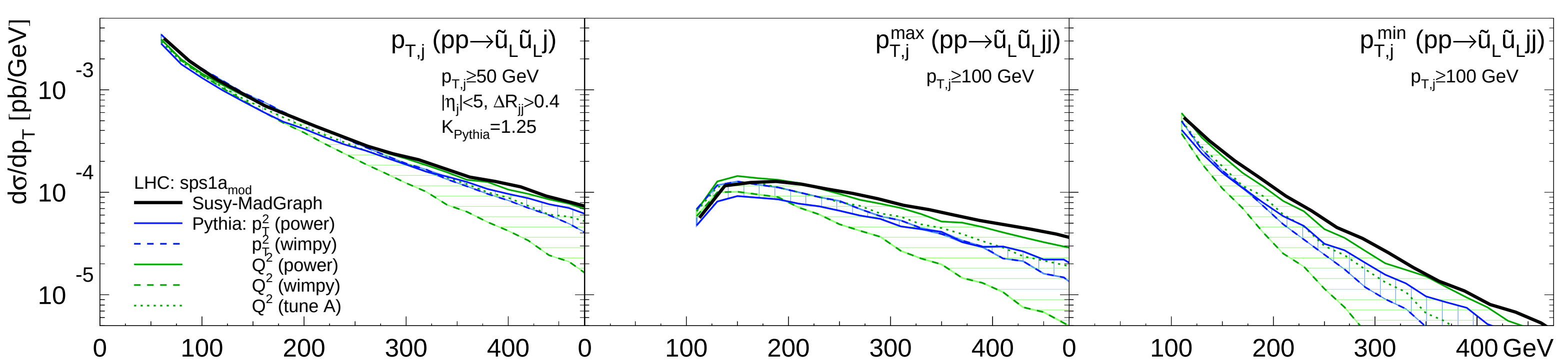
⇒ effects of additional hard jets on analyses?

Comparison Pythia — Smadevent [TP, Rainwater, Skands]

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

⇒ SUSY easier than tops [QCD: the heavier the better]

σ [pb]	$t\bar{t}_{600}$	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$
σ_{0j}	1.30	4.83	5.65
σ_{1j}	0.73	2.89	2.74
σ_{2j}	0.26	1.09	0.85



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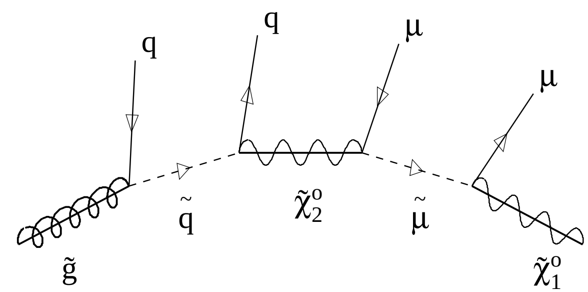

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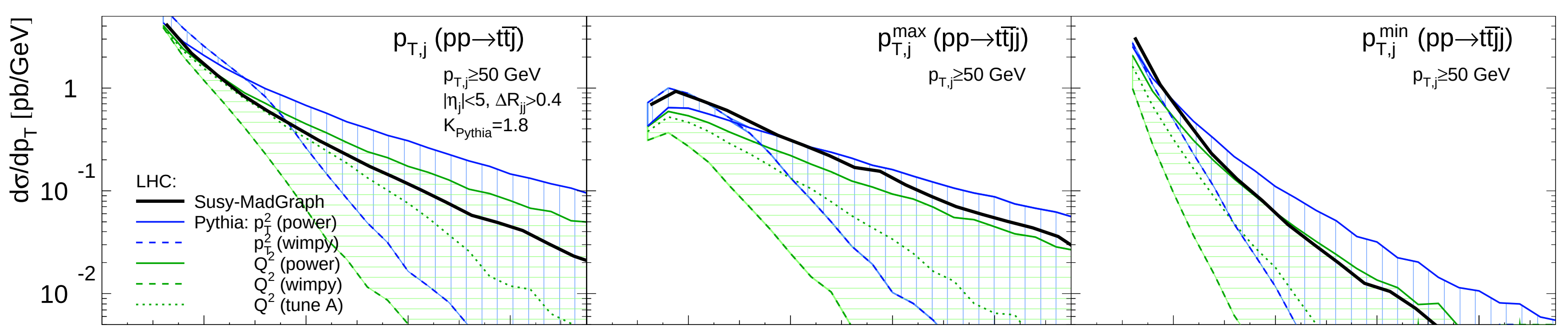

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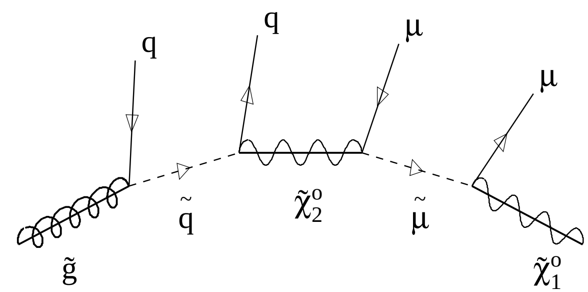

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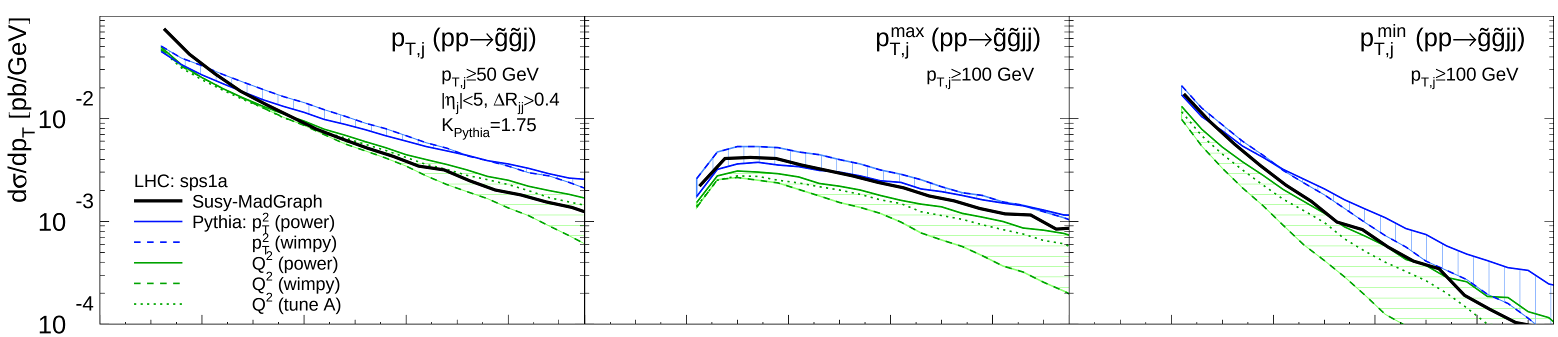

Weakly interacting particles in weak boson fusion [Cho, Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

– works great for Higgs (Standard Model or MSSM)

– W, Z background the problem for DY-type pp $\to \tilde{\chi}\tilde{\chi}, \tilde{\ell}\tilde{\ell}$

– trigger difficult for (neutral) stable sleptons

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

	SPS 1a		SPS8	
process	DY	WBF	DY	WBF
$\tilde{e}_L^+ \tilde{e}_L^-$	22.5	0.036	2.49	0.004
$\tilde{e}_R^+ \tilde{e}_R^-$	29.0	0.029	14.3	0.014
$\tilde{\tau}_1^+ \tilde{\tau}_1^-$	34.4	0.033	16.0	0.015
$\tilde{\tau}_2^+ \tilde{\tau}_2^-$	18.3	0.032	2.40	0.004

2 – SUSY IN WEAK BOSON FUSION

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– W, Z background the problem for DY-type pp $\to \tilde{\chi}\tilde{\chi}, \tilde{\ell}\tilde{\ell}$

– trigger difficult for (neutral) stable sleptons

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

Theoretical side remark

– unitarity in WW $\to \tilde{\chi}\tilde{\chi}$ [s and t channel, like WW $\to t\bar{t}$]

– 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]

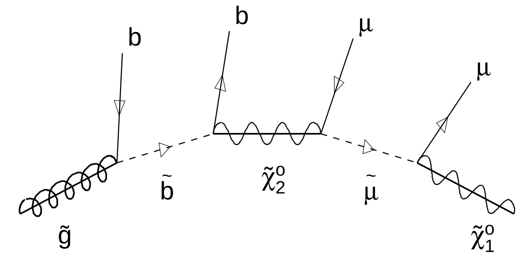
– mismatch in renormalization fixed by ripping scheme

– similar for mixing scalars, mass matrix and $\tilde{f}\tilde{f}\Phi$ coupling [unitarity fi ne, F and D terms]

– general problem: widths and couplings for Higgs and SUSY [Sdecay: Mühlleitner et al.]

$\Rightarrow$ all fixed for Smadevent users

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]

– 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, and ℓ

– decay asymmetry b vs. $\bar{b}$ [instead of near/far b]

$$\mathcal{A} = [\sigma(b\ell^+) - \sigma(b\ell^-)]/[\sigma(b\ell^+) + \sigma(b\ell^-)]$$

– complication: $\tilde{\ell}_{LR}$ or $\tilde{\tau}_{LR}$ tied in with spin

– pure jet observables which work: ϕ_{bb}

⇒ gluino spin sits in decay kinematics

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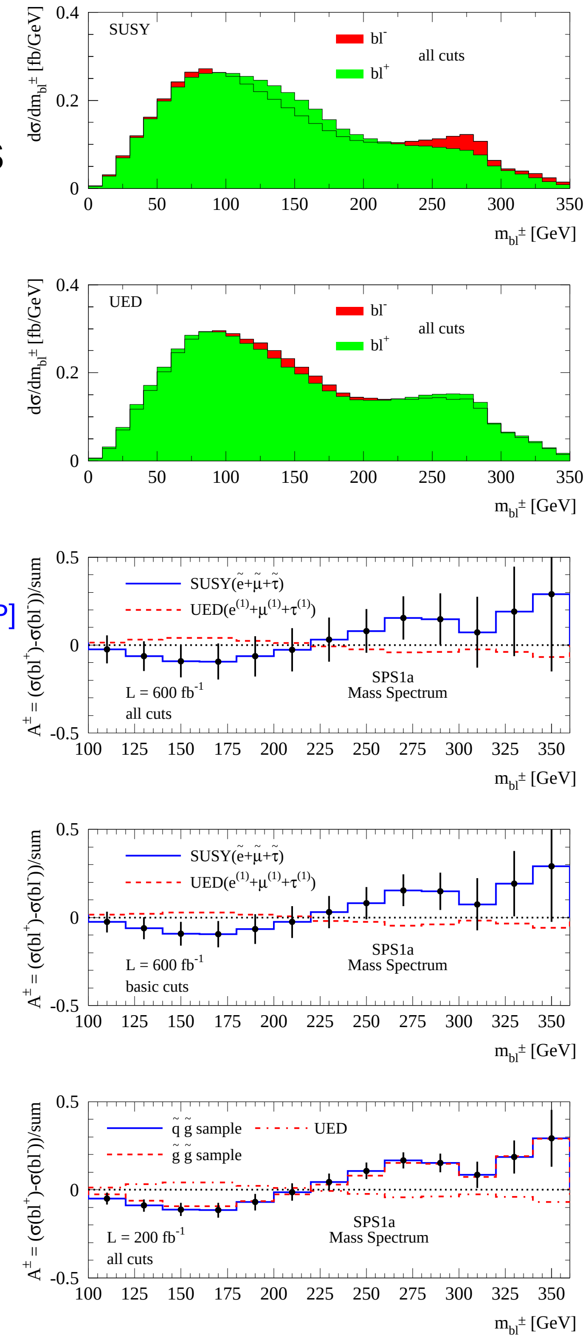

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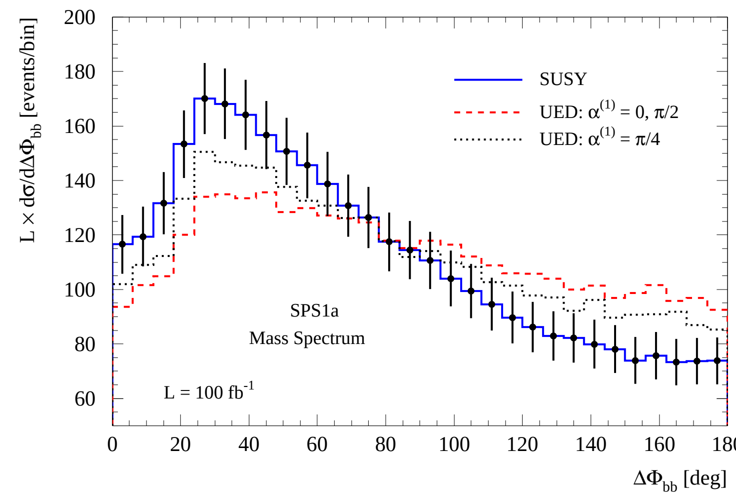


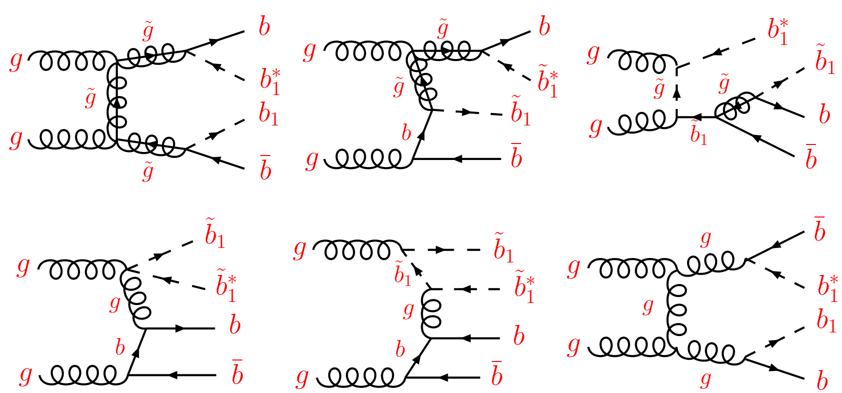
Example 1: $pp \to \tilde{g}\tilde{g} \to \bar{b}\tilde{b}_1 b\tilde{b}_1^*$ [Berdine, Rainwater,...]

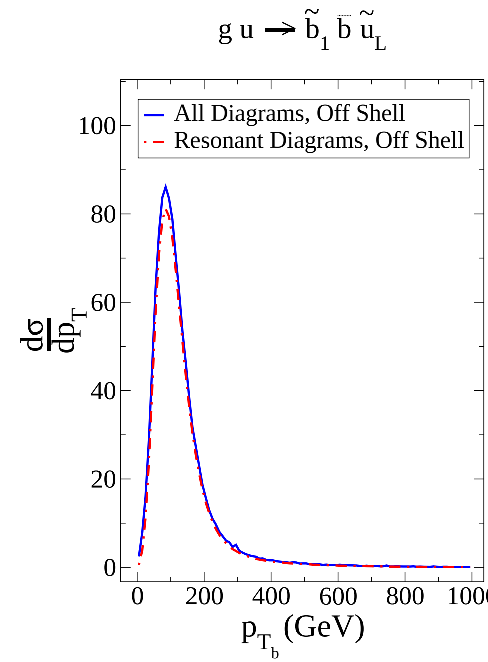
– naive expectations: corrections $\sim \Gamma_{\tilde{g}}/m_{\tilde{g}}$

– rate up 16% [σ_{pole}=108 fb; σ_{all}=125 fb]

– compare to NLO uncertainty $\sim$ 15%

$\Rightarrow$ detailed discussion in paper...





4 – Off-Shell Squarks and Gluinos at LHC

Example 1: pp $\rightarrow \tilde{g}\tilde{g} \rightarrow \bar{b}\tilde{b}_1 b\tilde{b}_1^*$ [Berdine, Rainwater,...]

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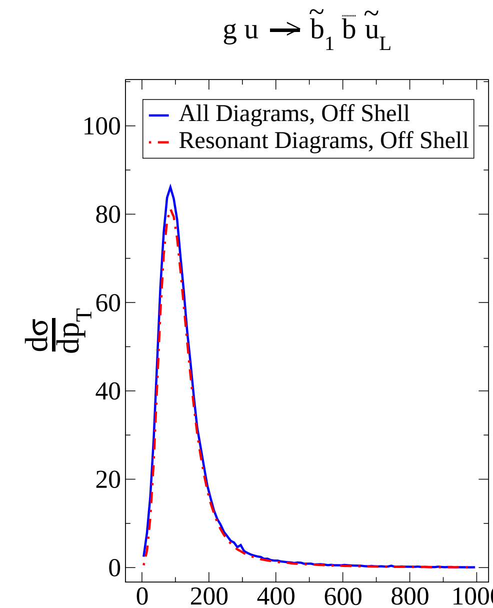


Example 2: pp $\rightarrow \tilde{g}\tilde{\chi}_1^0 \rightarrow \bar{b}\tilde{b}_1\tilde{\chi}_1^0$

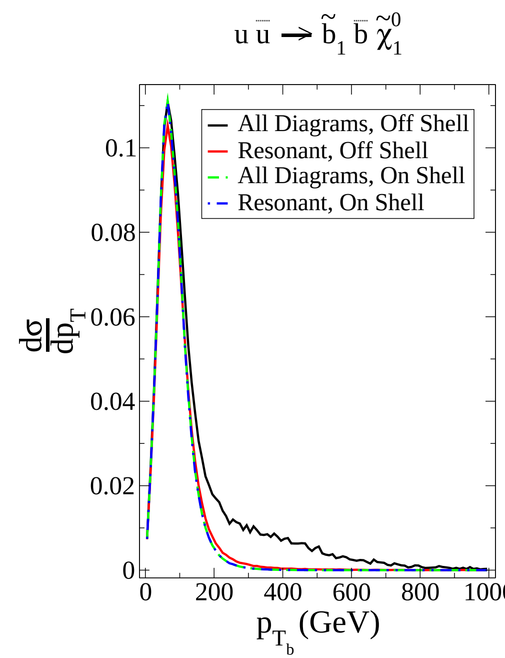
– rate up 50%!

– distributions spread...

– no interference, but new pole

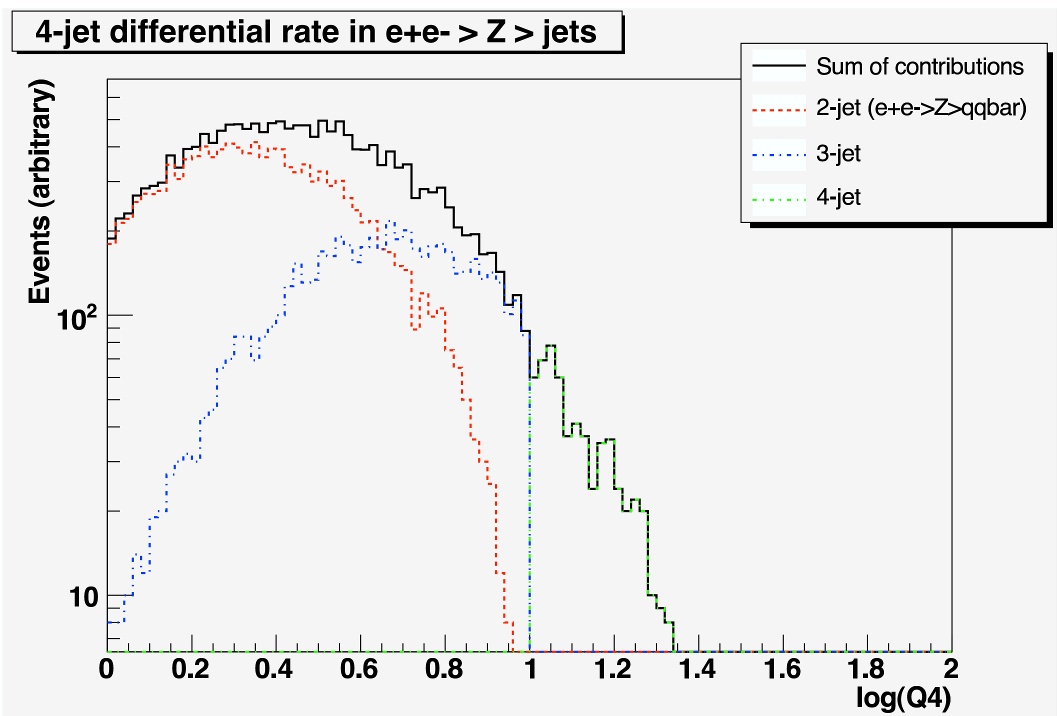
– separable by jet/lepton edges?

– 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, ...
- $e^+e^- \to$ 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]

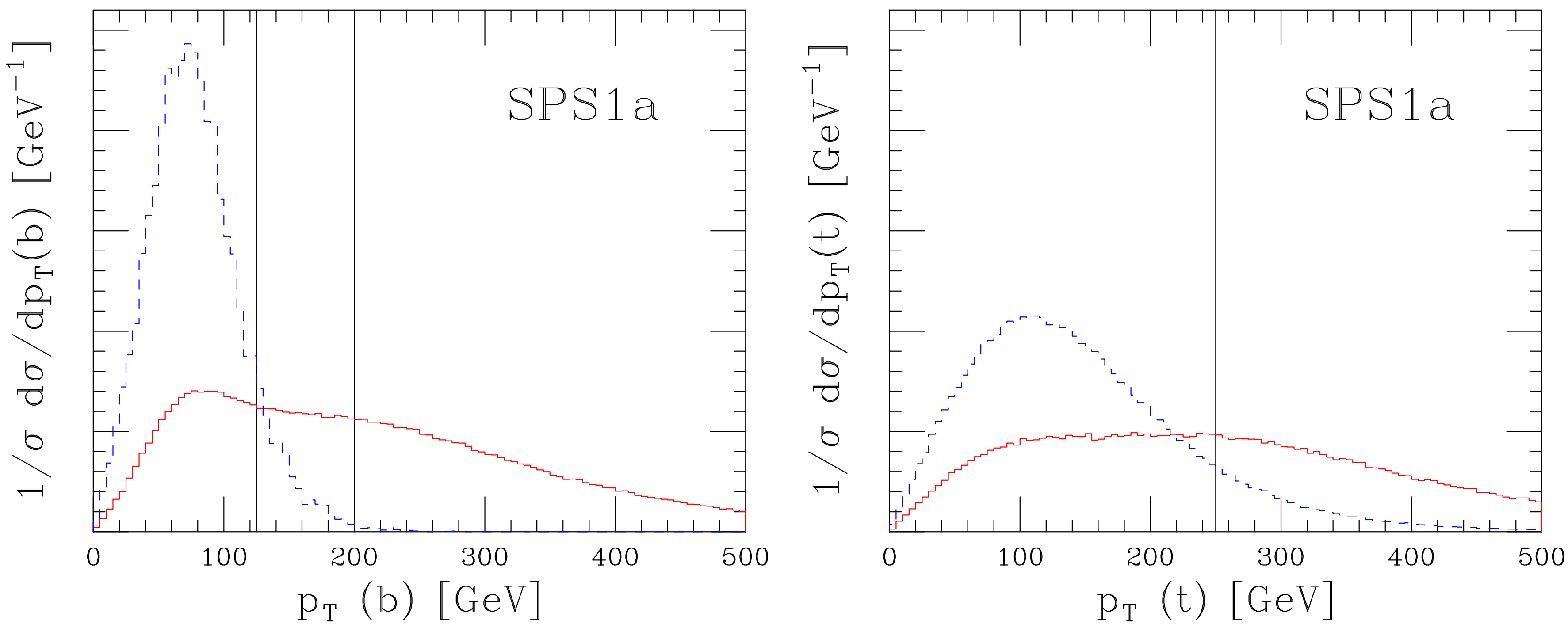
- PGS included in Madevent
- jet matching next task for Madevent

- http://madgraph.roma2.infn.it
  http://madgraph.phys.ucl.ac.be

Backup: Mixed-flavor Squark Pairs

Weak squark vertices [Berdine, Rainwater]

- consider pp $\to \tilde{t}\,\tilde{b}^*$, phenomenologically function of $m_{\tilde{t}_1,\tilde{t}_2}$, θ_t, $m_{\tilde{b}_1,\tilde{b}_2}$, θ_b, $\widetilde{V}_{ij}$
- all channels $\tilde{t}_1\tilde{b}_1^*, \tilde{t}_1\tilde{b}_2^*, \tilde{t}_2\tilde{b}_1^*, \tilde{t}_2\tilde{b}_2^* \Rightarrow g^2_{t_1 b_1} + g^2_{t_1 b_2} + g^2_{t_2 b_1} + g^2_{t_2 b_2} = g^2_{tb} = \widetilde{V}^2_{tb} g^2_W$
- backgrounds: $t\bar{t}W^\pm$, $\tilde{b}_i\tilde{b}_i^*$, $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$
- kinematic separation



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– backgrounds: $t\bar{t}W^\pm$, $\tilde{b}_i\tilde{b}_i^*$, $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$

– kinematic separation

– observation at SLHC [including BRs & efficiencies]

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