Multi-particle event generators for the MSSM

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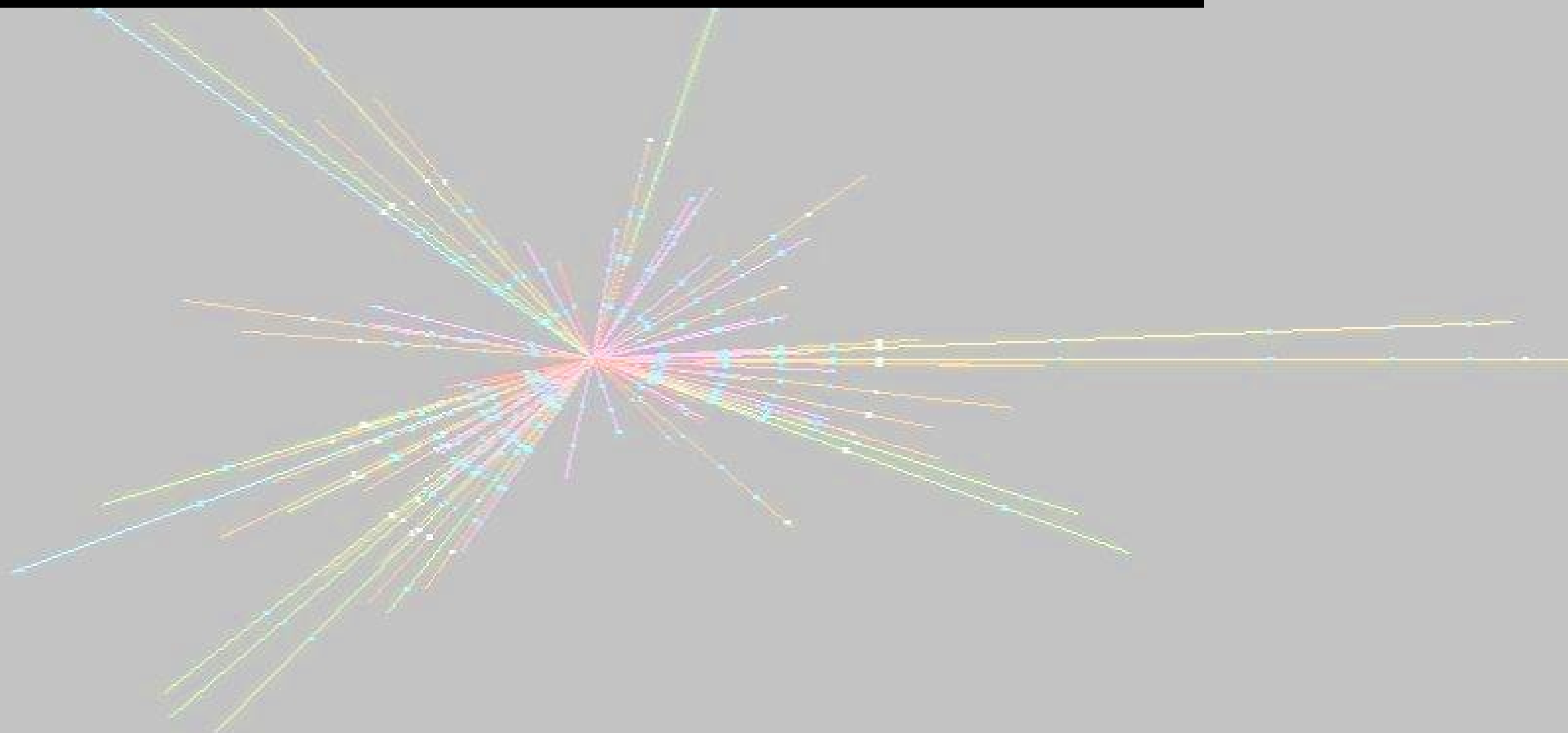
Snowmass, August xx, 2005

Precision measurements

Hopefully: New physics signals at LHC!
but: need to prove SUSY



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- The spin of all new particles (difficult at LHC!, cf. Barr et al.)
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- Coupling measurements: verify SUSY by the structure of couplings
- Precise predictions for SUSY processes: , these are background to other (more difficult) SUSY processes
- Precise parameter values: Reverse the renormalization-group calculation and get a handle on GUT parameters (⇒ P. Zerwas' talk)
  ⇒ **SPA project** `http://spa.desy.de/spa`

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- Radiative corrections have to be included (not only K-factors, cf. later) BUT also
- **Non-factorization of processes** into $2 \to 2$ production processes and decays *is not* sufficient. $\Rightarrow$ Include *off-shell intermediate states* and *full gauge-invariant diagram classes*
- SM *and* SUSY backgrounds (for LHC, *but also* for ILC; in general: no factorization for signal/background!
- Spin correlations: information about the spin of particles in cascades (0 vs. $1/2$, $3/2$?, . . .)

Traditional MC generators PYTHIA, HERWIG, SUSYGEN limited

Complexity of Multi-(SUSY)-particle event generators

Some generic SUSY process:

$e^+e^- \to b\bar{b}e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ 66478 diagrams. (It's just $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0$!)

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- Entanglement of different signal diagrams ($e^+e^- \to \tilde{\chi}^0_i\tilde{\chi}^0_j, \tilde{b}_i\tilde{b}_j, \tilde{e}_i\tilde{e}_j$)
- Need for cuts to disentangle those (experimentally and in the simulation)
- Add SM backgrounds ($e^+e^- \to b\bar{b}e^+e^-\nu_i\bar{\nu}_i$)
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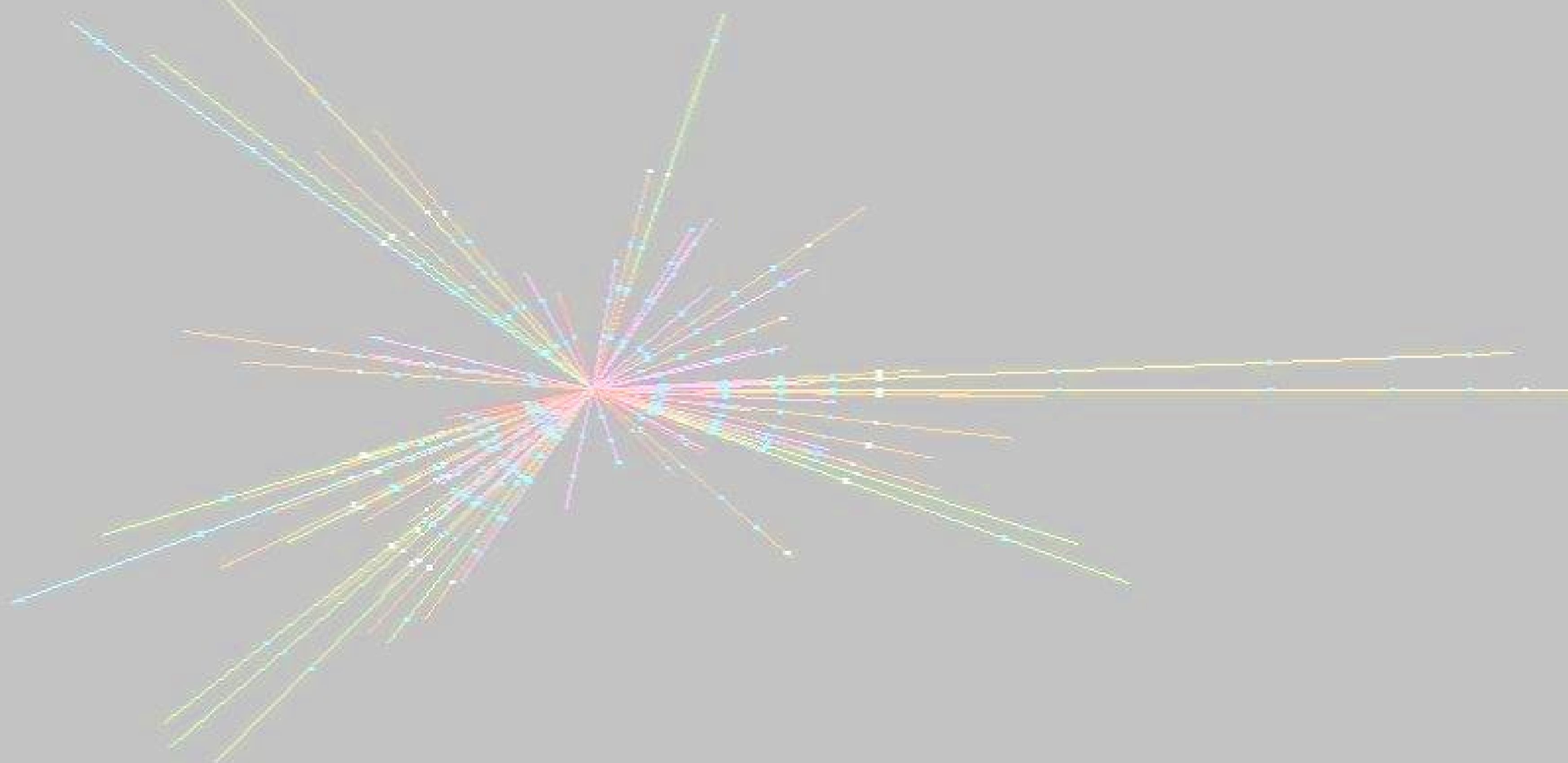
- Much more complicated processes for LHC, and even also for ILC
- Efficiency: Matrix element is evaluated some $10^5 - 10^6$ times (flavor, helicity sums)

Overview over the Tools

New generator generation which includes *all issues* above and can handle the complexity mentioned:

DESY Monte Carlo workshop: 27/06/2005 - 14/07/2005



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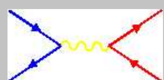
-  **Helas/(S)Madgraph/MadEvent**
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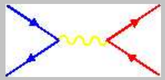
-  **Helas/(S)Madgraph/MadEvent**
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- Ω **WHiZard/O'Mega**
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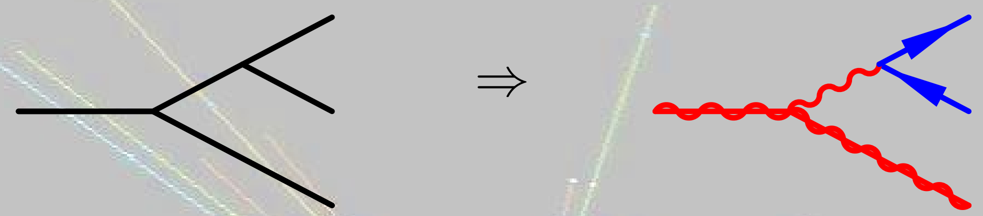
-  **Amegic++/Sherpa**
  T. Gleisberg, S. Hoeche, F. Krauss, T. Laubrich, S. Schumann, C. Semmling, J. Winter

Three different approaches:

Sherpa: Topologies generated and filled with particles and vertices $\Rightarrow$ full set of Feynman graphs $\Rightarrow$ chain of subroutine calls.



MadGraph: Similar, but duplicate HELAS calls (corresponding to identical subdiagrams) are eliminated.

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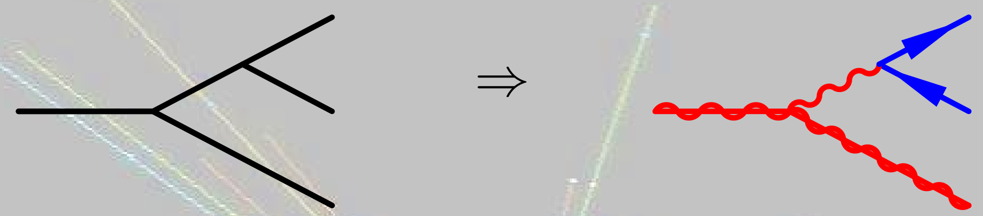
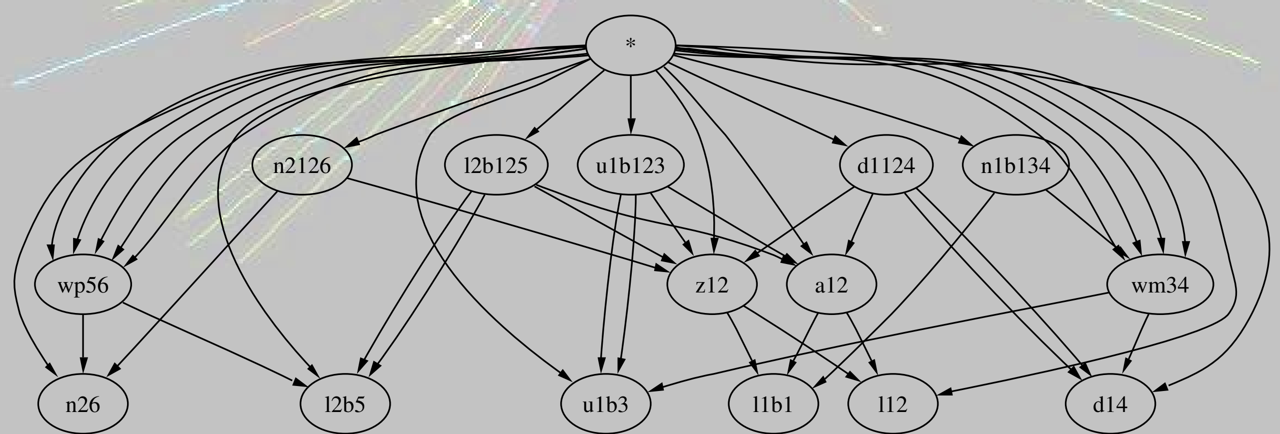


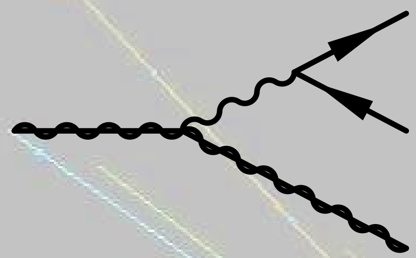
MadGraph: Similar, but duplicate HELAS calls (corresponding to identical subdiagrams) are eliminated.

O'Mega: Combine sums of subgraphs into wave functions and thus don't evaluate *anything* twice (DAG = directed acyclical graph)

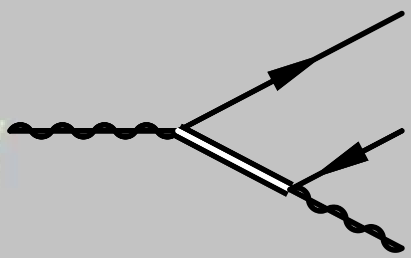


Phase Space Parameterization

Difficult task: The set of 'good' integration variables is different for each graph.



vs.



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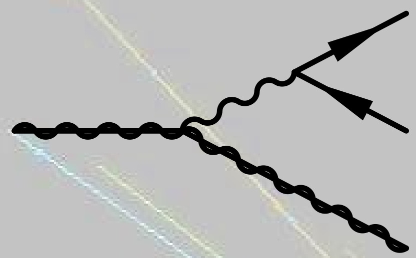

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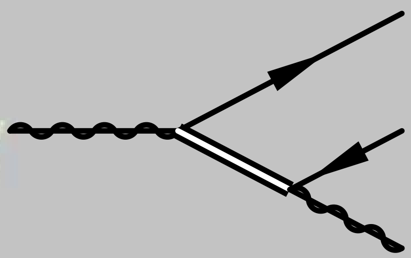

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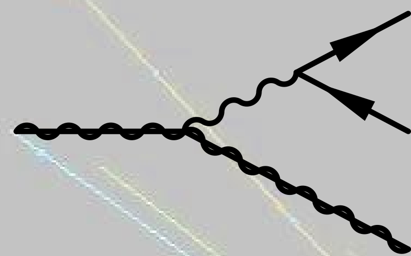

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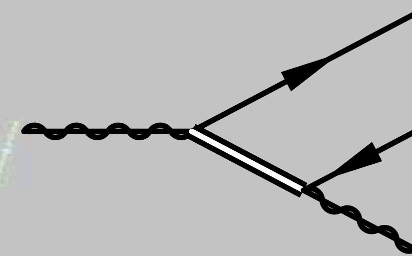

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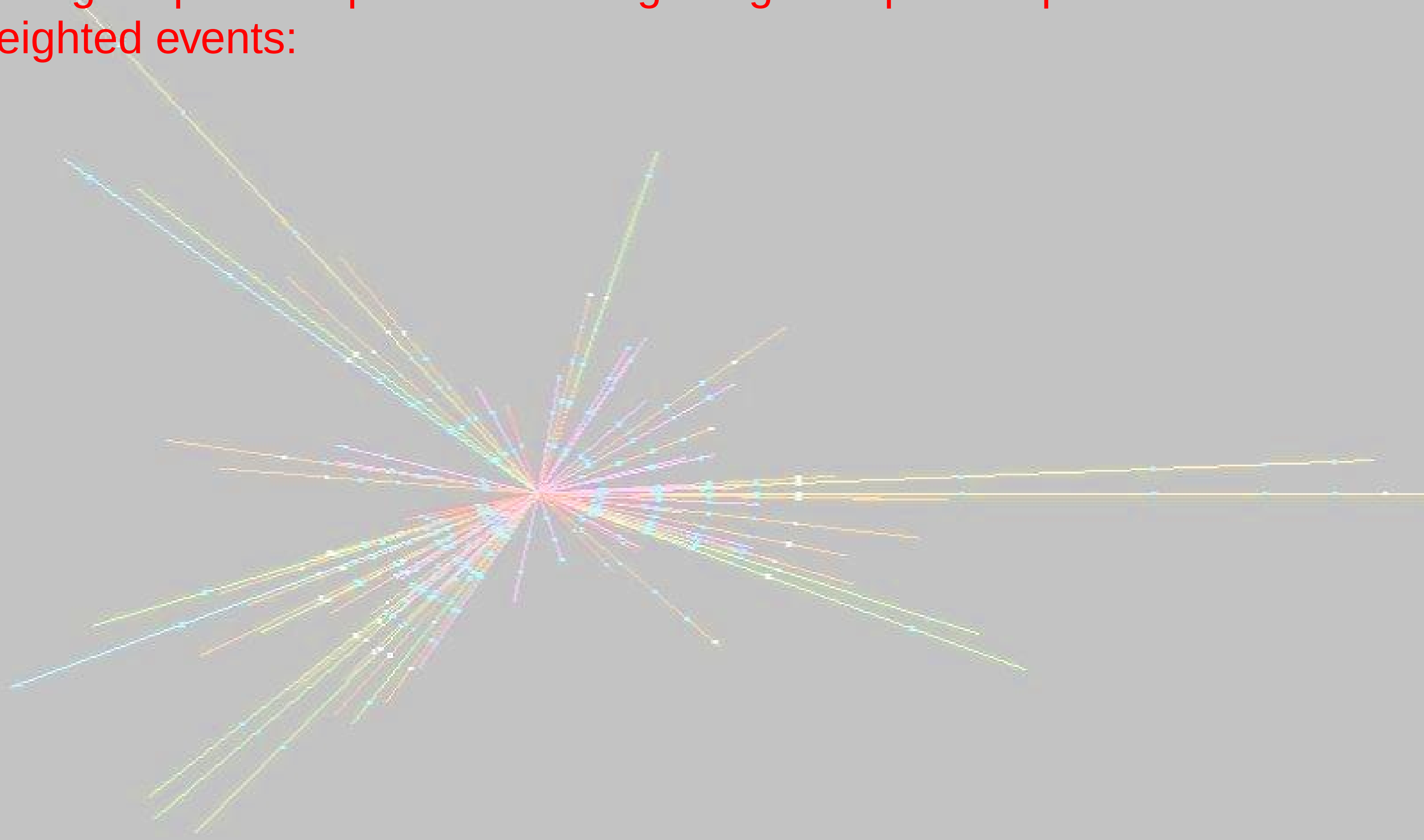
MadEvent: Integrand separated into diagrams squared (as if there were no interferences). Correction factor for interferences applied afterwards.

In the final step, we have to generate unweighted events $\Rightarrow$the adapted 'grids' should map the integrand as close to a constant as possible.

<u>Moreover:</u> ”Dressing” of partonic process in integrating over phase space and generating unweighted events:



Events

Moreover: "Dressing" of partonic process in integrating over phase space and generating unweighted events:

- Structure functions for incoming partons. Need to integrate over x_1 and x_2. Kills efficiency drastically!
- e^+e^- collisions: account for beamstrahlung, beam energy spread
- e^+e^- collisions: longitudinal and transversal polarization (⇒spin density matrices): `WHiZard`
- Initial-state radiation (ISR) of multiple gluons and/or photons

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- Complicated parton shower for colored (and charged) particles in final state
- Finally: hadronization

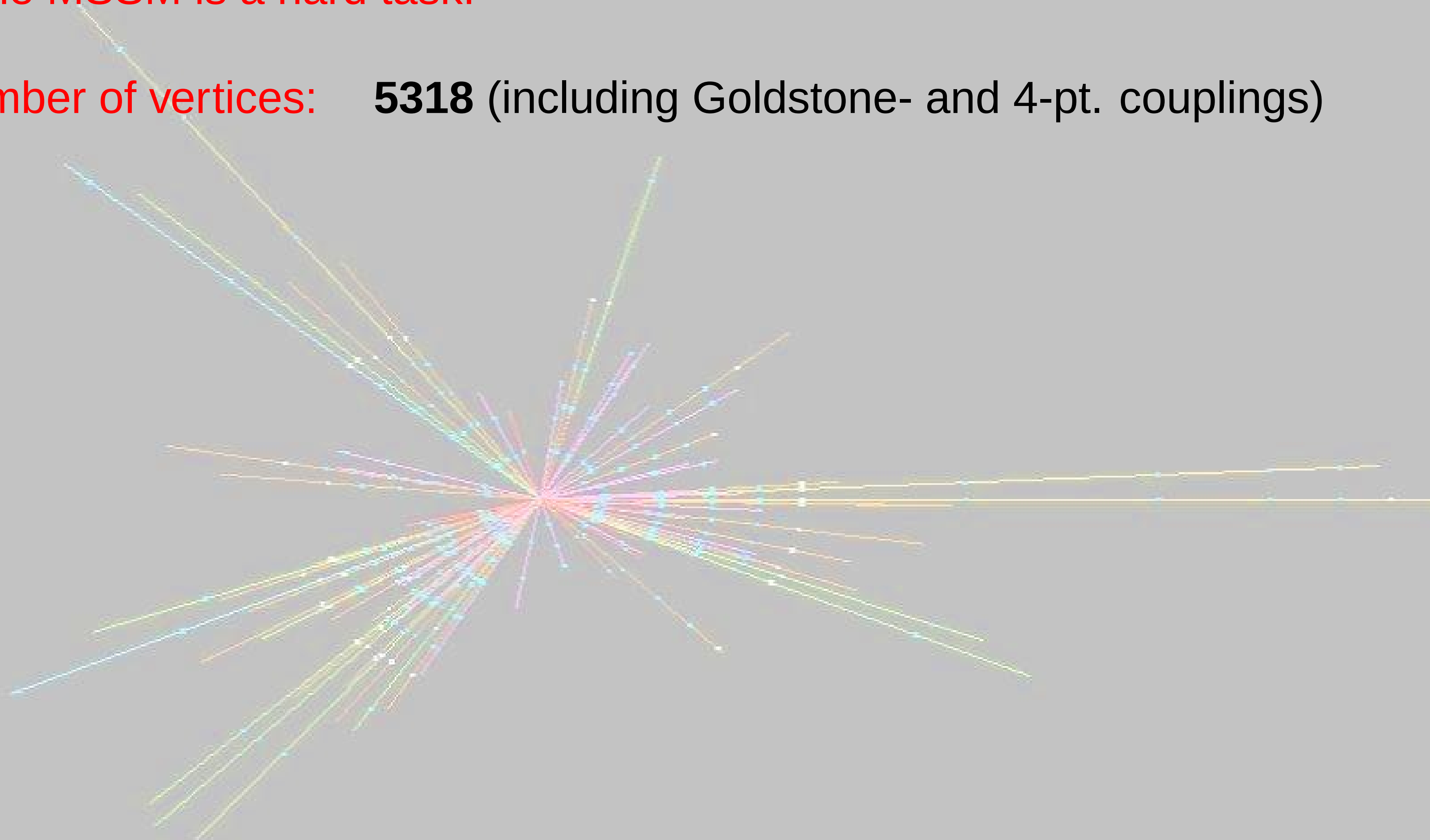
  `MadEvent` and `WHiZard` take care of this by standard interfaces to PYTHIA etc.

  `Sherpa` has its own code for QCD effects

Tests, Difficulties and Stumbling blocks

Implementing the MSSM is a hard task!

- Sheer number of vertices: **5318** (including Goldstone- and 4-pt. couplings)



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TESTS:

- Unitarity
- Ward- and Slavnov-Tayler identities for gauge groups and SUSY
- Comparison of the different programs

e^+e^- processes

$e^+e^- \to X$ (I)							
Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{e}_L \tilde{e}_L^*$	●	54.687(2)	78.864(6)	54.687(3)	78.866(4)	54.6890(7)	78.8670(8)
$\tilde{e}_R \tilde{e}_R^*$	●	274.69(2)	91.776(8)	274.682(1)	91.776(5)	274.695(3)	91.778(1)
$\tilde{e}_L \tilde{e}_R^*$	●	75.168(5)	7.237(1)	75.167(3)	7.2372(4)	75.1693(7)	7.23744(7)
$\tilde{\mu}_L \tilde{\mu}_L^*$	●	22.5471(7)	6.8263(2)	22.5478(9)	6.8265(3)	22.5482(2)	6.82638(7)
$\tilde{\mu}_R \tilde{\mu}_R^*$	●	51.839(2)	5.8107(2)	51.837(2)	5.8105(2)	51.8401(5)	5.81085(6)
$\tilde{\tau}_1 \tilde{\tau}_1^*$	●	55.582(2)	5.7139(2)	55.580(2)	5.7141(2)	55.5835(6)	5.71399(6)
$\tilde{\tau}_2 \tilde{\tau}_2^*$	●	19.0161(6)	6.5047(2)	19.0174(7)	6.5045(3)	19.0163(2)	6.50473(7)
$\tilde{\tau}_1 \tilde{\tau}_2^*$	●	1.4118(4)	0.21406(1)	1.41191(5)	0.214058(8)	1.41187(1)	0.214067(2)
$\tilde{\nu}_e \tilde{\nu}_e^*$	●	493.35(2)	272.15(2)	493.38(2)	272.15(1)	493.358(5)	272.155(3)
$\tilde{\nu}_\mu \tilde{\nu}_\mu^*$	●	14.8632(4)	2.9231(1)	14.8638(6)	2.9232(1)	14.8633(1)	2.92309(3)
$\tilde{\nu}_\tau \tilde{\nu}_\tau^*$	●	15.1399(5)	2.9246(1)	15.1394(8)	2.9245(1)	15.1403(2)	2.92465(3)
$\tilde{u}_L \tilde{u}_L^*$	●	—	7.6185(2)	—	7.6188(3)	—	7.61859(8)
$\tilde{u}_R \tilde{u}_R^*$	●	—	4.6933(1)	—	4.6935(2)	—	4.69342(5)
$\tilde{c}_L \tilde{c}_L^*$	●	—	7.6185(2)	—	7.6182(3)	—	7.61859(8)
$\tilde{c}_R \tilde{c}_R^*$	●	—	4.6933(1)	—	4.6933(2)	—	4.69342(5)
$\tilde{t}_1 \tilde{t}_1^*$	●	—	5.9845(4)	—	5.9847(2)	—	5.98459(6)
$\tilde{t}_2 \tilde{t}_2^*$	●	—	5.3794(3)	—	5.3792(2)	—	5.37951(6)
$\tilde{t}_1 \tilde{t}_2^*$	●	—	1.2427(1)	—	1.24264(5)	—	1.24270(1)
$\tilde{d}_L \tilde{d}_L^*$	●	—	5.2055(1)	—	5.2059(2)	—	5.20563(2)
$\tilde{d}_R \tilde{d}_R^*$	●	—	1.17588(2)	—	1.17595(5)	—	1.17591(1)
$\tilde{s}_L \tilde{s}_L^*$	●	—	5.2055(1)	—	5.2058(2)	—	5.20563(2)
$\tilde{s}_R \tilde{s}_R^*$	●	—	1.17588(2)	—	1.17585(5)	—	1.17591(1)
$\tilde{b}_1 \tilde{b}_1^*$	●	—	4.9388(3)	—	4.9387(2)	—	4.93883(5)
$\tilde{b}_2 \tilde{b}_2^*$	●	—	1.1295(1)	—	1.12946(4)	—	1.12953(1)
$\tilde{b}_1 \tilde{b}_2^*$	●	—	0.51644(3)	—	0.516432(9)	—	0.516447(6)

e^+e^- processes

$e^+e^- \to X$ (II)

Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	●	240.631(4)	26.3082(2)	240.636(7)	26.3087(9)	240.638(2)	26.3086(3)
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	●	62.377(1)	9.9475(1)	62.374(2)	9.9475(4)	62.3785(6)	9.94778(1)
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	●	7.78117(2)	0.64795(1)	7.78131(4)	0.64796(1)	7.78121(8)	0.647969(6)
$\tilde{\chi}_1^0\tilde{\chi}_4^0$	●	1.03457(3)	1.36561(1)	1.03460(3)	1.36564(5)	1.03460(1)	1.36568(1)
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	●	70.730(2)	18.6841(3)	70.730(3)	18.6845(8)	70.7310(7)	18.6843(2)
$\tilde{\chi}_2^0\tilde{\chi}_3^0$	●	—	1.85588(2)	—	1.85590(4)	—	1.85594(2)
$\tilde{\chi}_2^0\tilde{\chi}_4^0$	●	—	3.03946(4)	—	3.03951(9)	—	3.03949(3)
$\tilde{\chi}_3^0\tilde{\chi}_3^0$	●	—	0.0042214(1)	—	0.0042214(2)	—	0.00422147(4)
$\tilde{\chi}_3^0\tilde{\chi}_4^0$	●	—	9.93621(8)	—	9.9362(3)	—	9.93637(1)
$\tilde{\chi}_4^0\tilde{\chi}_4^0$	●	—	0.135479(1)	—	0.135482(5)	—	0.135479(1)
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	●	162.786(6)	45.079(2)	162.788(7)	45.080(2)	162.786(2)	45.0808(5)
$\tilde{\chi}_2^+\tilde{\chi}_2^-$	●	—	26.9854(3)	—	26.9864(6)	—	26.9857(3)
$\tilde{\chi}_1^+\tilde{\chi}_2^-$	●	—	4.01053(5)	—	4.01053(9)	—	4.01066(4)
$Z h^0$	●	59.377(2)	3.1148(2)	59.376(1)	3.11492(9)	59.3789(6)	3.11491(3)
$Z H^0$	●	0.000617904(1)	0.00055060(3)	0.0006179180(5)	0.00055058(2)	0.000617919(6)	0.000550607(6)
$A^0 h^0$	●	—	0.00053434(2)	—	0.00053433(2)	—	0.000534350(5)
$A^0 H^0$	●	—	2.37418(7)	—	2.37434(9)	—	2.37422(2)
H^+H^-	●	—	5.5335(2)	—	5.5339(2)	—	5.53374(6)

W^+W^- processes

$W^+W^- \to X$ (I)

Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{e}_L \tilde{e}_L^*$	●	192.14(2)	26.538(4)	192.145(1)	26.5380(6)	192.151(9)	26.538(1)
$\tilde{e}_R \tilde{e}_R^*$	●	14.215(3)	1.0297(3)	14.2151(4)	1.02966(4)	14.2153(7)	1.02968(5)
$\tilde{\mu}_L \tilde{\mu}_L^*$	●	192.14(2)	26.538(4)	192.146(1)	26.5380(6)	192.139(9)	26.540(1)
$\tilde{\mu}_R \tilde{\mu}_R^*$	●	14.215(3)	1.0297(3)	14.2145(4)	1.02972(4)	14.2153(7)	1.02975(5)
$\tilde{\tau}_1 \tilde{\tau}_1^*$	●	7.926(2)	0.8328(3)	7.9266(2)	0.83284(3)	7.9269(4)	0.83286(4)
$\tilde{\tau}_2 \tilde{\tau}_2^*$	●	168.05(2)	22.419(4)	168.046(1)	22.4195(5)	168.046(8)	22.419(1)
$\tilde{\tau}_1 \tilde{\tau}_2^*$	●	17.852(3)	2.3294(4)	17.8521(1)	2.32935(5)	17.8518(9)	2.3293(1)
$\tilde{\nu}_e \tilde{\nu}_e^*$	●	157.80(4)	23.487(6)	157.809(3)	23.486(1)	157.803(8)	23.489(1)
$\tilde{\nu}_\mu \tilde{\nu}_\mu^*$	●	157.80(4)	23.487(6)	157.806(3)	23.487(1)	157.807(8)	23.488(1)
$\tilde{\nu}_\tau \tilde{\nu}_\tau^*$	●	152.51(4)	23.427(6)	152.509(3)	23.429(1)	152.520(8)	23.429(1)
$\tilde{u}_L \tilde{u}_L^*$	●	—	41.59(1)	—	41.590(1)	—	41.588(2)
$\tilde{u}_R \tilde{u}_R^*$	●	—	1.0761(3)	—	1.07608(3)	—	1.07605(5)
$\tilde{c}_L \tilde{c}_L^*$	●	—	41.59(1)	—	41.588(1)	—	41.599(2)
$\tilde{c}_R \tilde{c}_R^*$	●	—	1.0761(3)	—	1.07603(3)	—	1.07603(5)
$\tilde{t}_1 \tilde{t}_1^*$	●	—	180.64(1)	—	180.637(4)	—	180.637(9)
$\tilde{t}_2 \tilde{t}_2^*$	●	—	204.46(1)	—	204.461(3)	—	204.47(1)
$\tilde{t}_1 \tilde{t}_2^*$	●	—	85.176(3)	—	85.178(2)	—	85.187(4)
$\tilde{d}_L \tilde{d}_L^*$	●	—	39.006(7)	—	39.0067(4)	—	39.007(2)
$\tilde{d}_R \tilde{d}_R^*$	●	—	0.26929(7)	—	0.269305(8)	—	0.26930(1)
$\tilde{s}_L \tilde{s}_L^*$	●	—	39.006(7)	—	39.0062(4)	—	39.007(2)
$\tilde{s}_R \tilde{s}_R^*$	●	—	0.26929(7)	—	0.269291(8)	—	0.26930(1)
$\tilde{b}_1 \tilde{b}_1^*$	●	—	141.456(8)	—	141.457(2)	—	141.467(7)
$\tilde{b}_2 \tilde{b}_2^*$	●	—	19.714(1)	—	19.7133(4)	—	19.715(1)
$\tilde{b}_1 \tilde{b}_2^*$	●	—	61.090(4)	—	61.090(1)	—	61.093(3)

W^+W^- processes

$W^+W^- \to X$ (II)							
Final state	status	Madgraph/Helas		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde\chi_1^0\tilde\chi_1^0$	●	3.8822(2)	1.2741(4)	3.8824(1)	1.27423(8)	3.8821(2)	1.2741(1)
$\tilde\chi_1^0\tilde\chi_2^0$	●	121.29(1)	24.47(1)	121.2925(7)	24.472(3)	121.296(6)	24.477(1)
$\tilde\chi_1^0\tilde\chi_3^0$	●	6.8936(7)	12.880(7)	6.8934(2)	12.8790(8)	6.8938(3)	12.8793(6)
$\tilde\chi_1^0\tilde\chi_4^0$	●	1.4974(1)	9.707(5)	1.4973(6)	9.7064(7)	1.49735(7)	9.7078(4)
$\tilde\chi_2^0\tilde\chi_2^0$	●	5996.5(4)	1041.5(6)	5996.57(2)	1041.50(5)	5996.4(3)	1041.48(5)
$\tilde\chi_2^0\tilde\chi_3^0$	●	—	365.6(2)	—	365.615(6)	—	365.63(2)
$\tilde\chi_2^0\tilde\chi_4^0$	●	—	467.8(2)	—	467.775(8)	—	467.77(2)
$\tilde\chi_3^0\tilde\chi_3^0$	●	—	82.35(3)	—	82.347(8)	—	82.352(4)
$\tilde\chi_3^0\tilde\chi_4^0$	●	—	138.20(5)	—	138.18(1)	—	138.205(7)
$\tilde\chi_4^0\tilde\chi_4^0$	●	—	117.78(4)	—	117.80(1)	—	117.786(6)
$\tilde\chi_1^+\tilde\chi_1^-$	●	3772(1)	944.3(8)	3771.6(4)	944.2(1)	3771.8(2)	944.32(5)
$\tilde\chi_2^+\tilde\chi_2^-$	●	—	258.3(2)	—	258.37(4)	—	258.36(1)
$\tilde\chi_1^+\tilde\chi_2^-$	●	—	131.0(1)	—	130.98(2)	—	130.966(7)
h^0h^0	●	6023.6(9)	6057(3)	6024.7(4)	6061.3(1.3)	6025.0(3)	6058.7(3)
h^0H^0	●	—	2.174(1)	—	2.1752(6)	—	2.1752(1)
H^0H^0	●	—	6.7515(1)	—	6.7509(11)	—	6.7517(3)
A^0A^0	●	—	6.7270(1)	—	6.7273(4)	—	6.7274(3)
Zh^0	●	75520(13)	86174(42)	75539(7)	86198(20)	75528(4)	86181(4)
ZH^0	●	1.70948(2)	16.390(8)	1.70944(8)	16.3939(37)	1.70971(9)	16.3933(8)
A^0h^0	●	—	0.0060126(3)	—	0.0060123(7)	—	0.0060130(3)
A^0H^0	●	—	3.4709(3)	—	3.4708(7)	—	3.4710(2)
H^+H^-	●	—	19.605(1)	—	19.6060(23)	—	19.605(1)

WZ processes

$W^- Z \to X^-$							
Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{e}_L \tilde{\nu}_e^*$	●	96.635(6)	15.726(1)	96.639(2)	15.728(2)	96.632(5)	15.7249(8)
$\tilde{\mu}_L \tilde{\nu}_\mu^*$	●	96.635(6)	15.726(1)	96.638(2)	15.727(2)	96.631(5)	15.7264(8)
$\tilde{\tau}_1 \tilde{\nu}_\tau^*$	●	14.9542(8)	1.427(1)	14.952(1)	1.4268(2)	14.953(1)	1.42747(7)
$\tilde{\tau}_2 \tilde{\nu}_\tau^*$	●	85.875(5)	14.479(1)	85.875(2)	14.478(2)	85.870(4)	14.4780(7)
$\tilde{d}_L \tilde{u}_L^*$	●	—	24.220(3)	—	24.220(1)	—	24.219(1)
$\tilde{s}_L \tilde{c}_L^*$	●	—	24.220(3)	—	24.221(1)	—	24.220(1)
$\tilde{b}_1 \tilde{t}_1^*$	●	—	40.676(2)	—	40.676(4)	—	40.677(2)
$\tilde{b}_2 \tilde{t}_2^*$	●	—	8.3717(5)	—	8.3706(7)	—	8.3722(4)
$\tilde{b}_1 \tilde{t}_2^*$	●	—	63.596(3)	—	63.592(6)	—	63.591(3)
$\tilde{b}_2 \tilde{t}_1^*$	●	—	3.9242(2)	—	3.9236(5)	—	3.9244(2)
$\tilde{\chi}_1^0 \tilde{\chi}_1^-$	●	61.634(6)	16.389(5)	61.626(3)	16.389(1)	61.633(3)	16.391(1)
$\tilde{\chi}_2^0 \tilde{\chi}_1^-$	●	2835.5(7)	668.2(4)	2835.0(3)	668.1(1)	2835.6(2)	668.34(3)
$\tilde{\chi}_3^0 \tilde{\chi}_1^-$	●	—	278.5(1)	—	278.53(1)	—	278.58(2)
$\tilde{\chi}_4^0 \tilde{\chi}_1^-$	●	—	270.9(1)	—	270.97(2)	—	271.02(2)
$\tilde{\chi}_1^0 \tilde{\chi}_2^-$	●	11.7607(3)	12.379(4)	11.7619(7)	12.380(1)	11.7602(6)	12.380(1)
$\tilde{\chi}_2^0 \tilde{\chi}_2^-$	●	—	218.3(1)	—	218.38(2)	—	218.40(1)
$\tilde{\chi}_3^0 \tilde{\chi}_2^-$	●	—	76.50(3)	—	76.494(5)	—	76.497(4)
$\tilde{\chi}_4^0 \tilde{\chi}_2^-$	●	—	97.70(4)	—	97.693(7)	—	97.693(4)
$h^0 H^-$	●	—	0.0004439(6)	—	0.0044399(5)	—	0.0044395(2)
$H^0 H^-$	●	—	6.1592(6)	—	6.1592(2)	—	6.1589(3)
$A^0 H^-$	●	—	5.9728(6)	—	5.9726(5)	—	5.9723(3)
$W^- h^0$	●	76200(30)	82900(110)	76213(6)	82886(16)	76209(4)	82909(4)
$W^- H^0$	●	4.2446(2)	15.78(2)	4.2446(2)	15.783(3)	4.2445(2)	15.7848(8)
$W^- A^0$	●	1.07034(3)	0.24799(1)	1.07037(1)	0.24815(7)	1.07017(6)	0.24801(1)
$Z H^-$	●	0.17724	0.25404	0.17723(2)	0.25403(7)	0.17714(4)	0.25404(1)

$W\gamma$ processes

$W^-\gamma \to X^-$

Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{e}_L \tilde{\nu}_e^*$	●	92.93(2)	14.478(3)	92.927(7)	14.477(3)	92.933(5)	14.4789(7)
$\tilde{\mu}_L \tilde{\nu}_\mu^*$	●	92.93(2)	14.478(3)	92.942(7)	14.479(3)	92.934(5)	14.4782(7)
$\tilde{\tau}_1 \tilde{\nu}_\tau^*$	●	12.098(2)	1.2566(2)	12.100(1)	1.2566(3)	12.1035(6)	1.25669(6)
$\tilde{\tau}_2 \tilde{\nu}_\tau^*$	●	85.17(1)	13.373(2)	85.167(7)	13.372(3)	85.174(4)	13.3731(7)
$\tilde{d}_L \tilde{u}_R^*$	●	—	6.260(2)	—	6.260(1)	—	6.2605(3)
$\tilde{s}_L \tilde{c}_R^*$	●	—	6.260(2)	—	6.262(1)	—	6.2605(3)
$\tilde{b}_1 \tilde{t}_1^*$	●	—	5.527(1)	—	5.528(1)	—	5.5279(3)
$\tilde{b}_2 \tilde{t}_2^*$	●	—	0.5418(1)	—	0.5417(1)	—	0.54182(3)
$\tilde{b}_1 \tilde{t}_2^*$	●	—	6.267(1)	—	6.267(1)	—	6.2680(3)
$\tilde{b}_2 \tilde{t}_1^*$	●	—	0.8593(2)	—	0.8595(2)	—	0.85928(4)
$\tilde{\chi}_1^0 \tilde{\chi}_1^-$	●	15.824(4)	3.834(2)	15.821(2)	3.8332(6)	15.823(1)	3.8338(2)
$\tilde{\chi}_2^0 \tilde{\chi}_1^-$	●	1223.5(2)	303.1(1)	1223.5(1)	303.04(5)	1223.35(6)	303.11(2)
$\tilde{\chi}_3^0 \tilde{\chi}_1^-$	●	—	50.91(2)	—	50.902(8)	—	50.909(3)
$\tilde{\chi}_4^0 \tilde{\chi}_1^-$	●	—	52.64(2)	—	52.648(8)	—	52.643(3)
$\tilde{\chi}_1^0 \tilde{\chi}_2^-$	●	3.0373(3)	6.574(2)	3.03742(7)	6.5764(9)	3.0373(2)	6.5749(3)
$\tilde{\chi}_2^0 \tilde{\chi}_2^-$	●	—	34.00(1)	—	34.003(5)	—	34.000(2)
$\tilde{\chi}_3^0 \tilde{\chi}_2^-$	●	—	47.72(1)	—	47.719(7)	—	47.720(2)
$\tilde{\chi}_4^0 \tilde{\chi}_2^-$	●	—	59.64(2)	—	59.636(8)	—	59.639(3)
$h^0 H^-$	●	—	0.004519(1)	—	0.0045192(8)	—	0.0045194(3)
$H^0 H^-$	●	—	4.961(1)	—	4.9610(9)	—	4.9611(2)
$A^0 H^-$	●	—	4.966(1)	—	4.9671(9)	—	4.9668(2)
$W^- h^0$	●	12848(6)	15800(20)	12855(3)	15811(4)	12851.2(7)	15801(1)
$W^- H^0$	●	0.5401(1)	3.016(4)	0.54011(6)	3.0172(7)	0.54016(3)	3.0170(2)

$u\bar{u}$ processes

$u\,\bar{u} \to X$

Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{g}\,\tilde{g}$	●	—	1137.7(2)	—	1137.8(2)	—	1137.7(1)
$\tilde{e}_L\,\tilde{e}_L^*$	●	5.169(1)	1.5467(3)	5.1698(9)	1.5469(2)	5.1700(3)	1.54698(8)
$\tilde{e}_R\,\tilde{e}_R^*$	●	6.538(1)	0.7318(1)	6.538(1)	0.7318(1)	6.5379(3)	0.73179(4)
$\tilde{\mu}_L\,\tilde{\mu}_L^*$	●	5.169(1)	1.5467(3)	5.1687(9)	1.5466(3)	5.1693(3)	1.54679(8)
$\tilde{\mu}_R\,\tilde{\mu}_R^*$	●	6.538(1)	0.7318(1)	6.536(1)	0.7316(1)	6.5387(3)	0.73189(4)
$\tilde{\tau}_1\,\tilde{\tau}_1^*$	●	6.993(1)	0.7195(1)	6.992(1)	0.7194(1)	6.9935(3)	0.71949(4)
$\tilde{\tau}_2\,\tilde{\tau}_2^*$	●	4.1263(7)	1.3962(2)	4.1246(7)	1.3957(2)	4.1269(2)	1.39617(7)
$\tilde{\tau}_1\,\tilde{\tau}_2^*$	●	0.5420(1)	0.08218(1)	0.54193(9)	0.08217(1)	0.54199(3)	0.082184(4)
$\tilde{\nu}_e\,\tilde{\nu}_e^*$	●	5.7063(5)	1.1222(2)	5.706(1)	1.1222(2)	5.7064(3)	1.12224(6)
$\tilde{\nu}_\mu\,\tilde{\nu}_\mu^*$	●	5.7063(5)	1.1222(2)	5.704(1)	1.1217(2)	5.7070(3)	1.12237(6)
$\tilde{\nu}_\tau\,\tilde{\nu}_\tau^*$	●	5.812(1)	1.1228(2)	5.813(1)	1.1229(2)	5.8126(3)	1.12282(6)
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	●	2.2483(1)	1.2164(1)	2.24829(2)	1.2165(1)	2.2483(1)	1.2165(2)
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	●	0.053855(3)	0.10850(1)	0.0538560(9)	0.10850(1)	0.053855(3)	0.108493(5)
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	●	0.524518(4)	0.096758(1)	0.524526(3)	0.096752(5)	0.52450(3)	0.096763(5)
$\tilde{\chi}_1^0\tilde{\chi}_4^0$	●	0.0098233(3)	0.067303(3)	0.00982339(8)	0.067293(6)	0.0098238(5)	0.067308(3)
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	●	3.66463(5)	4.2298(3)	3.66472(3)	4.2296(4)	3.6646(2)	4.2298(3)
$\tilde{\chi}_2^0\tilde{\chi}_3^0$	●	—	0.21148(3)	—	0.211458(8)	—	0.21147(1)
$\tilde{\chi}_2^0\tilde{\chi}_4^0$	●	—	0.55025(5)	—	0.55025(8)	—	0.55028(3)
$\tilde{\chi}_3^0\tilde{\chi}_3^0$	●	—	0.00033843(1)	—	0.00033843(1)	—	0.00033844(2)
$\tilde{\chi}_3^0\tilde{\chi}_4^0$	●	—	4.4435(3)	—	4.4433(2)	—	4.4436(2)
$\tilde{\chi}_4^0\tilde{\chi}_4^0$	●	—	0.016385(3)	—	0.016389(3)	—	0.016386(1)
$\tilde{\chi}_1^+\,\tilde{\chi}_1^-$	●	153.97(2)	10.732(5)	153.977(2)	10.734(2)	153.964(8)	10.7329(5)
$\tilde{\chi}_2^+\,\tilde{\chi}_2^-$	●	—	5.0402(5)	—	5.0401(2)	—	5.0400(3)
$\tilde{\chi}_1^+\,\tilde{\chi}_2^-$	●	—	1.5363(2)	—	1.5362(2)	—	1.5363(1)
$Z\,h^0$	●	22.795(2)	1.1958(1)	22.797(2)	1.1960(2)	22.798(1)	1.19582(6)
$Z\,H^0$	●	0.000237220(1)	0.00021138(2)	0.000237224(1)	0.00021142(4)	0.00023723(1)	0.00021141(1)

$d\bar{d}$ processes

$d\bar{d} \to X$							
Final state	status	Madgraph/Helas		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde{e}_L \tilde{e}_L^*$	●	3.3467(6)	0.9844(2)	3.3472(6)	0.9845(2)	3.3473(2)	0.98453(5)
$\tilde{e}_R \tilde{e}_R^*$	●	2.0046(3)	0.21577(4)	2.0047(3)	0.21578(4)	2.0047(1)	0.21577(1)
$\tilde{\mu}_L \tilde{\mu}_L^*$	●	3.3467(6)	0.9844(2)	3.3465(6)	0.9843(2)	3.3469(2)	0.98435(5)
$\tilde{\mu}_R \tilde{\mu}_R^*$	●	2.0046(3)	0.21577(4)	2.0041(3)	0.21572(4)	2.0049(1)	0.21578(1)
$\tilde{\tau}_1 \tilde{\tau}_1^*$	●	1.7274(3)	0.17266(3)	1.7271(3)	0.17264(3)	1.7273(1)	0.17265(1)
$\tilde{\tau}_2 \tilde{\tau}_2^*$	●	2.4580(4)	0.8175(1)	2.4570(4)	0.8171(1)	2.4582(1)	0.81753(4)
$\tilde{\tau}_1 \tilde{\tau}_2^*$	●	0.6951(1)	0.10539(2)	0.6950(1)	0.10538(2)	0.69505(4)	0.105383(5)
$\tilde{\nu}_e \tilde{\nu}_e^*$	●	7.3174(1)	1.4391(2)	7.318(1)	1.4391(2)	7.3177(4)	1.43913(7)
$\tilde{\nu}_\mu \tilde{\nu}_\mu^*$	●	7.3174(1)	1.4391(2)	7.314(1)	1.4385(3)	7.3186(4)	1.43930(7)
$\tilde{\nu}_\tau \tilde{\nu}_\tau^*$	●	7.454(1)	1.4398(2)	7.454(1)	1.4400(2)	7.4539(4)	1.43987(7)
$\tilde{\chi}_1^0 \tilde{\chi}_1^0$	●	0.118931(1)	0.079120(5)	0.1189331(7)	0.079125(4)	0.118938(5)	0.079118(5)
$\tilde{\chi}_1^0 \tilde{\chi}_2^0$	●	0.249928(5)	0.34310(3)	0.249935(1)	0.34310(2)	0.24992(1)	0.34309(2)
$\tilde{\chi}_1^0 \tilde{\chi}_3^0$	●	0.81721(1)	0.17387(1)	0.817225(4)	0.173875(3)	0.81722(5)	0.17387(1)
$\tilde{\chi}_1^0 \tilde{\chi}_4^0$	●	0.0212680(5)	0.140018(3)	0.0212673(2)	0.140020(3)	0.021268(1)	0.14003(1)
$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	●	1.93986(1)	3.1013(3)	1.939907(9)	3.1011(2)	1.9399(1)	3.1012(2)
$\tilde{\chi}_2^0 \tilde{\chi}_3^0$	●	—	1.07903(5)	—	1.07909(2)	—	1.07910(5)
$\tilde{\chi}_2^0 \tilde{\chi}_4^0$	●	—	1.1685(1)	—	1.16852(6)	—	1.16868(5)
$\tilde{\chi}_3^0 \tilde{\chi}_3^0$	●	—	0.00266293(3)	—	0.00266298(4)	—	0.0026631(1)
$\tilde{\chi}_3^0 \tilde{\chi}_4^0$	●	—	4.7678(5)	—	4.76810(9)	—	4.7678(3)
$\tilde{\chi}_4^0 \tilde{\chi}_4^0$	●	—	0.08799(1)	—	0.087994(6)	—	0.087993(5)
$\tilde{\chi}_1^+ \tilde{\chi}_1^-$	●	137.16(2)	10.508(5)	137.161(3)	10.504(2)	137.17(1)	10.5073(5)
$\tilde{\chi}_2^+ \tilde{\chi}_2^-$	●	—	4.4960(5)	—	4.4954(1)	—	4.49605(5)
$\tilde{\chi}_1^+ \tilde{\chi}_2^-$	●	—	0.7742(2)	—	0.77407(5)	—	0.77420(5)
$Z h^0$	●	29.232(2)	1.5335(2)	29.235(3)	1.5337(3)	29.235(1)	1.53363(8)
$Z H^0$	●	0.000304205(1)	0.00027107(3)	0.00030421(2)	0.00027112(5)	0.00030421(1)	0.00027109(1)

gg, qg, ee processes

$g\,g \to X$

Final state	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$\tilde{g}\,\tilde{g}$	●	—	13575(2)	—	13575.6(1)	—	13575.8(7)
$\tilde{u}_L\,\tilde{u}_L^*$	●	—	185.60(2)	—	185.615(3)	—	185.61(1)
$\tilde{u}_R\,\tilde{u}_R^*$	●	—	191.58(2)	—	191.590(3)	—	191.59(1)
$\tilde{c}_L\,\tilde{c}_L^*$	●	—	185.60(2)	—	185.612(3)	—	185.61(1)
$\tilde{c}_R\,\tilde{c}_R^*$	●	—	191.58(2)	—	191.588(3)	—	191.59(1)
$\tilde{t}_1\,\tilde{t}_1^*$	●	—	250.70(2)	—	250.71(1)	—	250.70(1)
$\tilde{t}_2\,\tilde{t}_2^*$	●	—	180.54(2)	—	180.541(3)	—	180.54(1)
$\tilde{d}_L\,\tilde{d}_L^*$	●	—	184.07(2)	—	184.081(3)	—	184.09(1)
$\tilde{d}_R\,\tilde{d}_R^*$	●	—	191.87(2)	—	191.875(3)	—	191.87(1)
$\tilde{s}_L\,\tilde{s}_L^*$	●	—	184.07(2)	—	184.079(3)	—	184.08(1)
$\tilde{s}_R\,\tilde{s}_R^*$	●	—	191.87(2)	—	191.873(3)	—	191.86(1)
$\tilde{b}_1\,\tilde{b}_1^*$	●	—	201.88(2)	—	201.884(4)	—	201.90(1)
$\tilde{b}_2\,\tilde{b}_2^*$	●	—	192.52(2)	—	192.516(3)	—	192.53(1)

$q\,g \to X$

Process	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$u\,g \to \tilde{u}_L\,\tilde{g}$	●	—	3405.0(5)	—	3405.2(3)	—	3404.8(2)
$u\,g \to \tilde{u}_R\,\tilde{g}$	●	—	3460.0(5)	—	3460.0(3)	—	3460.4(2)
$d\,g \to \tilde{d}_L\,\tilde{g}$	●	—	3390.0(5)	—	3390.5(3)	—	3390.0(2)
$d\,g \to \tilde{d}_R\,\tilde{g}$	●	—	3462.5(5)	—	3462.5(3)	—	3462.0(2)

$e^-\,e^- \to X$

Process	status	Madgraph/Helas 0.5 TeV	Madgraph/Helas 2 TeV	Whizard/O'Mega 0.5 TeV	Whizard/O'Mega 2 TeV	Sherpa/A'Megic 0.5 TeV	Sherpa/A'Megic 2 TeV
$e^-\,e^- \to \tilde{e}_L\,\tilde{e}_L$	●	520.30(4)	36.83(3)	520.31(3)	36.836(2)	520.32(3)	36.832(2)
$e^-\,e^- \to \tilde{e}_R\,\tilde{e}_R$	●	459.6(1)	28.65(3)	459.59(1)	28.650(3)	459.63(3)	28.651(2)
$e^-\,e^- \to \tilde{e}_L\,\tilde{e}_R$	●	160.04(1)	56.55(2)	159.96(2)	56.522(8)	160.04(2)	56.545(3)

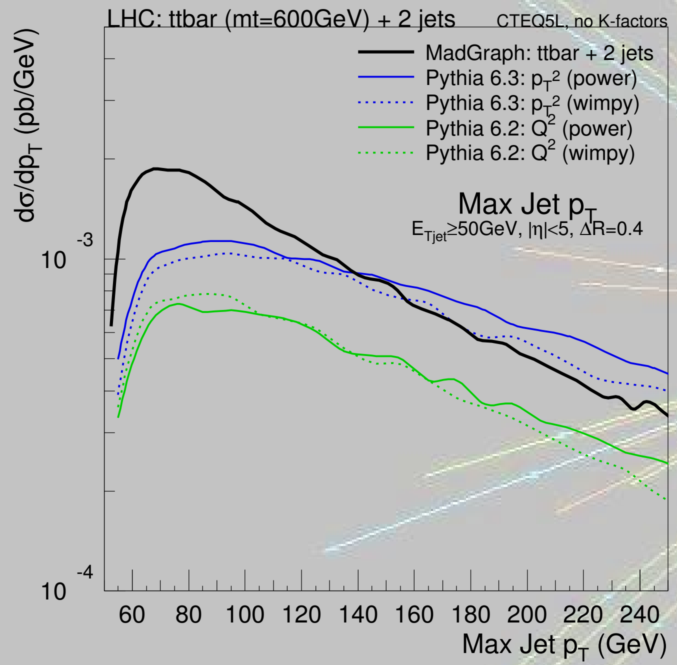
$\tau^+\tau^-$ processes

$\tau^+\tau^- \to X$							
Process	status	Madgraph/Helas		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde\tau_1\tilde\tau_1^*$	●	257.57(7)	79.63(4)	257.32(1)	79.636(4)	257.30(1)	79.638(4)
$\tilde\tau_2\tilde\tau_2^*$	●	46.55(1)	66.86(2)	46.368(2)	66.862(3)	46.372(2)	66.862(3)
$\tilde\tau_1\tilde\tau_2^*$	●	95.50(3)	19.00(1)	94.637(3)	19.0015(8)	94.645(5)	19.000(1)
$\tilde\nu_\tau\tilde\nu_\tau^*$	●	502.26(7)	272.01(8)	502.27(2)	272.01(1)	502.30(3)	272.01(1)
$\tilde\chi_1^0\tilde\chi_1^0$	●	249.94(2)	26.431(1)	249.954(9)	26.431(1)	249.96(1)	26.431(1)
$\tilde\chi_1^0\tilde\chi_2^0$	●	69.967(3)	9.8940(3)	69.969(2)	9.8940(4)	69.968(3)	9.8937(5)
$\tilde\chi_1^0\tilde\chi_3^0$	●	17.0387(3)	0.7913(1)	17.0394(1)	0.79136(2)	17.040(1)	0.79137(5)
$\tilde\chi_1^0\tilde\chi_4^0$	●	7.01378(4)	1.50743(3)	7.01414(6)	1.5075(5)	7.0141(4)	1.50740(8)
$\tilde\chi_2^0\tilde\chi_2^0$	●	82.351(7)	18.887(1)	82.353(3)	18.8879(9)	82.357(4)	18.8896(1)
$\tilde\chi_2^0\tilde\chi_3^0$	●	—	1.7588(1)	—	1.75884(5)	—	1.7588(1)
$\tilde\chi_2^0\tilde\chi_4^0$	●	—	2.96384(7)	—	2.9640(1)	—	2.9639(1)
$\tilde\chi_3^0\tilde\chi_3^0$	●	—	0.046995(4)	—	0.0469966(9)	—	0.046999(2)
$\tilde\chi_3^0\tilde\chi_4^0$	●	—	8.5852(4)	—	8.55857(3)	—	8.5856(4)
$\tilde\chi_4^0\tilde\chi_4^0$	●	—	0.26438(2)	—	0.264389(5)	—	0.26437(1)
$\tilde\chi_1^+\tilde\chi_1^-$	●	185.09(3)	45.15(1)	185.093(6)	45.147(2)	185.10(1)	45.151(2)
$\tilde\chi_2^+\tilde\chi_2^-$	●	—	26.515(1)	—	26.5162(6)	—	26.515(1)
$\tilde\chi_1^+\tilde\chi_2^-$	●	—	4.2127(4)	—	4.21267(9)	—	4.2125(2)
h^0h^0	●	0.3533827(3)	0.0001242(2)	0.35339(2)	0.00012422(3)	0.35340(2)	0.000124218(6)
h^0H^0	●	—	0.005167(4)	—	0.0051669(3)	—	0.0051671(3)
H^0H^0	●	—	0.07931(3)	—	0.079301(6)	—	0.079311(4)
A^0A^0	●	—	0.07975(3)	—	0.079758(6)	—	0.079744(4)
Zh^0	●	59.591(3)	3.1803(8)	59.589(3)	3.1802(1)	59.602(3)	3.1829(2)
ZH^0	●	2.8316(3)	4.671(5)	2.83169(9)	4.6706(3)	2.8318(1)	4.6706(2)
ZA^0	●	2.9915(4)	4.682(5)	2.99162(9)	4.6821(3)	2.9917(2)	4.6817(2)
A^0h^0	●	—	0.005143(4)	—	0.0051434(3)	—	0.0051440(3)
A^0H^0	●	—	1.4880(2)	—	1.48793(9)	—	1.48802(8)
H^+H^-	●	—	5.2344(6)	—	5.2344(2)	—	5.2345(3)

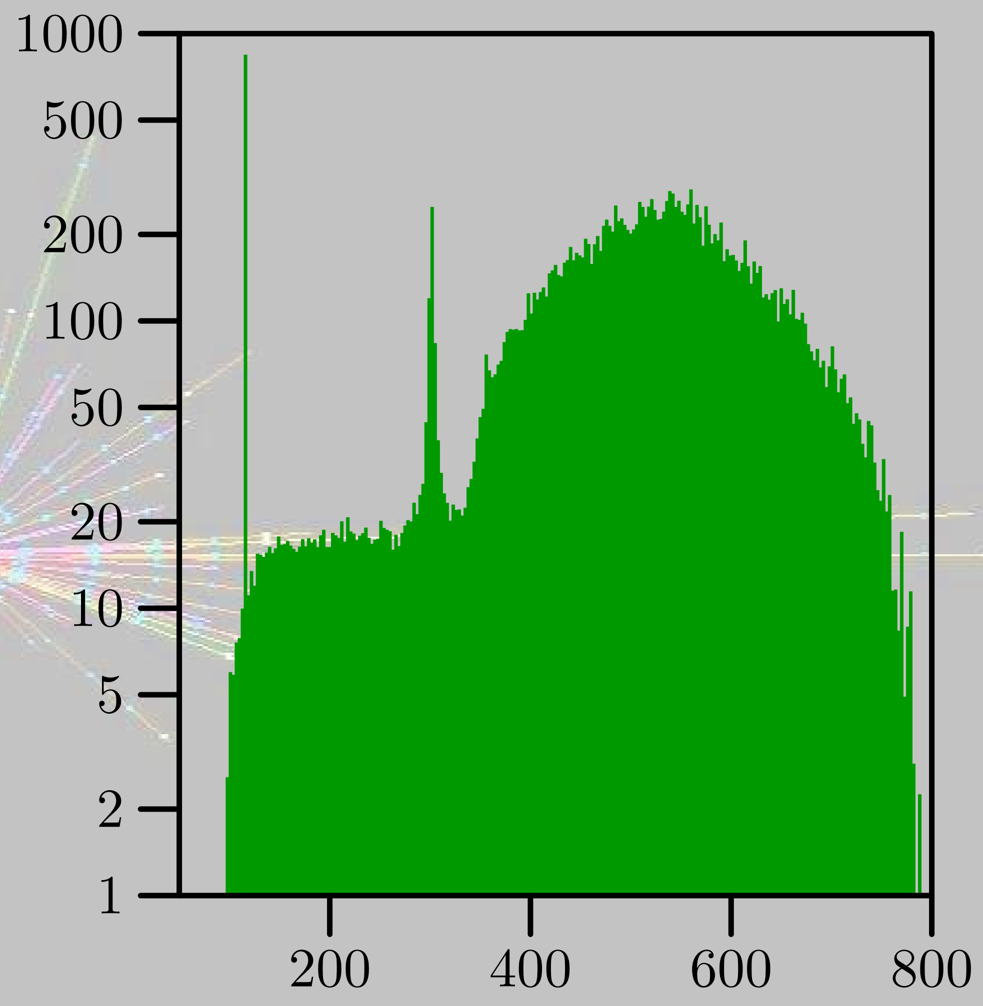
$\gamma\gamma \to X$							
Process	status	Madgraph/Helas		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde{e}_L \tilde{e}_L^*$	●	210.00(1)	29.058(1)	210.005(7)	20.056(5)	210.00(1)	29.060(2)
$\tilde{e}_R \tilde{e}_R^*$	●	250.32(1)	31.376(1)	250.321(11)	31.381(6)	250.32(1)	31.379(2)
$\tilde{\mu}_L \tilde{\mu}_L^*$	●	210.00(1)	29.058(1)	209.979(7)	29.041(5)	210.01(1)	29.058(2)
$\tilde{\mu}_R \tilde{\mu}_R^*$	●	250.32(1)	31.376(1)	250.322(11)	31.379(6)	250.31(1)	31.376(2)
$\tilde{\tau}_1 \tilde{\tau}_1^*$	●	263.35(1)	31.715(1)	263.362(13)	31.714(6)	263.36(1)	31.719(2)
$\tilde{\tau}_2 \tilde{\tau}_2^*$	●	207.62(1)	28.895(1)	207.618(7)	28.897(5)	207.63(1)	28.896(2)
$\tilde{u}_L \tilde{u}_L^*$	●	—	9.4531(3)	—	9.4536(4)	—	9.4530(4)
$\tilde{u}_R \tilde{u}_R^*$	●	—	9.7241(3)	—	9.7244(5)	—	9.7236(5)
$\tilde{c}_L \tilde{c}_L^*$	●	—	9.4531(3)	—	9.4534(4)	—	9.4531(4)
$\tilde{c}_R \tilde{c}_R^*$	●	—	9.7241(3)	—	9.7230(5)	—	9.7244(5)
$\tilde{t}_1 \tilde{t}_1^*$	●	—	12.5135(5)	—	12.5159(9)	—	12.5157(6)
$\tilde{t}_2 \tilde{t}_2^*$	●	—	9.2289(3)	—	9.2298(4)	—	9.2287(5)
$\tilde{d}_L \tilde{d}_L^*$	●	—	0.58654(2)	—	0.58655(3)	—	0.58655(x)
$\tilde{d}_R \tilde{d}_R^*$	●	—	0.60857(2)	—	0.60853(3)	—	0.60857(3)
$\tilde{s}_L \tilde{s}_L^*$	●	—	0.58654(2)	—	0.58656(3)	—	0.58656(3)
$\tilde{s}_R \tilde{s}_R^*$	●	—	0.60857(2)	—	0.60863(3)	—	0.60860(3)
$\tilde{b}_1 \tilde{b}_1^*$	●	—	0.63761(2)	—	0.63761(3)	—	0.63759(3)
$\tilde{b}_2 \tilde{b}_2^*$	●	—	0.61043(2)	—	0.61045(3)	—	0.61049(3)
$\tilde{\chi}_1^+ \tilde{\chi}_1^-$	●	1458.99(6)	274.0(1)	1459.04(6)	274.020(9)	1458.96(7)	274.01(1)
$\tilde{\chi}_2^+ \tilde{\chi}_2^-$	●	—	181.54(3)	—	181.542(6)	—	181.549(9)
$H^+ H^-$	●	—	20.650(1)	—	20.644(2)	—	20.649(1)

And more processes: uu, dd, $\tau^-\bar{\nu}_\tau$, $b\bar{b}$, $b\bar{t}$, γZ, ZZ

T. Plehn, P. Skands:
Adapt PYTHIA showers to exact results on jet radiation



ILC:



(Work in Progress)

Summary & Outlook

- ◊ `MadGraph, WHiZard/O'Mega, Sherpa` agree ⇒**next generation event generators for LHC and ILC**
- Special tasks `MadGraph`: QCD backgrounds, `WhiZard/O'Mega` ideal for new models (CP-viol. MSSM $\surd$; NMSSM, UED, E_6 upcoming!), `Sherpa`: ME+PS
- `http://theorie.physik.uni-wuerzburg.de/õhl/omega/`
  `http://www-ttp.physik.uni-karlsruhe.de/whizard/`
  `http://madgraph.hep.uiuc.edu/` (no Smadgraph yet)
  `http://141.30.17.245/hep/hep/index.html`
- First step is done, but still a lot of work to do:
- Full analyses with spin corr., bkgd., hadronic environment for all processes (e.g. $WW \to$SUSY)
- Next step: Match higher-order corrections with multi-particle final states (Frixione, Webber: `MC NLO`, Kilian/Reuter/Robens)

Summary & Outlook