Multi-particle event generators for the MSSM

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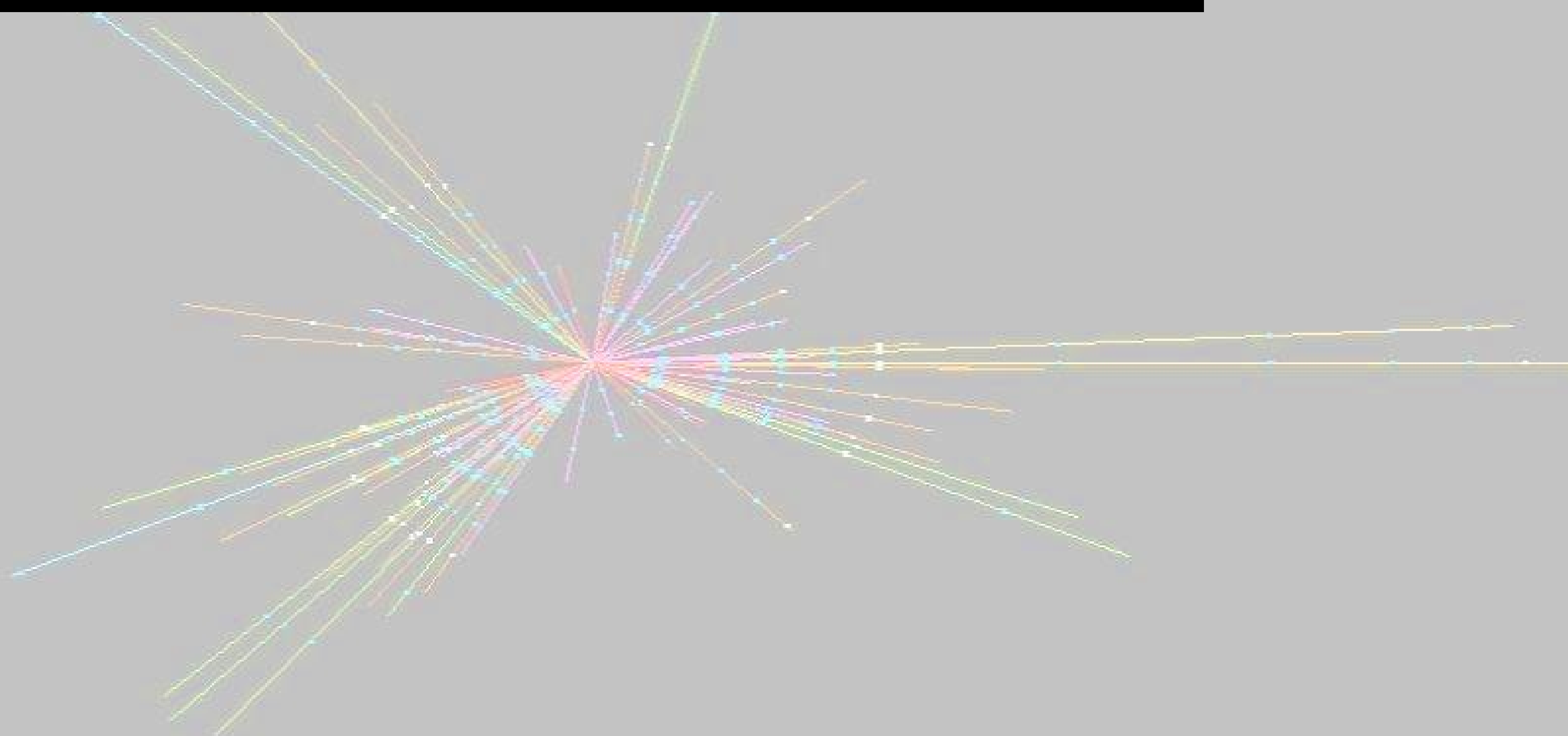
in collaboration with: K. Hagiwara (KEK), W. Kilian (DESY), F. Krauss (TU Dresden), T. Ohl (Univ. Würzburg), T. Plehn (MPI München), D. Rainwater (Rochester), S. Schumann (TU Dresden)

Snowmass, August 24, 2005

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



Precision measurements

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- The spin of all new particles (difficult at LHC!, cf. Barr et al.)
- Mass measurements to get the spectrum. Cascade decays: endpoints of energy spectra provide mass differences
- Coupling measurements: verify SUSY by the structure of couplings

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- Mass measurements to get the spectrum. Cascade decays: endpoints of energy spectra provide mass differences
- 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 evaluation and get a handle on GUT parameters (⇒ P. Zerwas' talk)
  ⇒ **SPA project** `http://spa.desy.de/spa`

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Approximations vs. Accuracy

- 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!

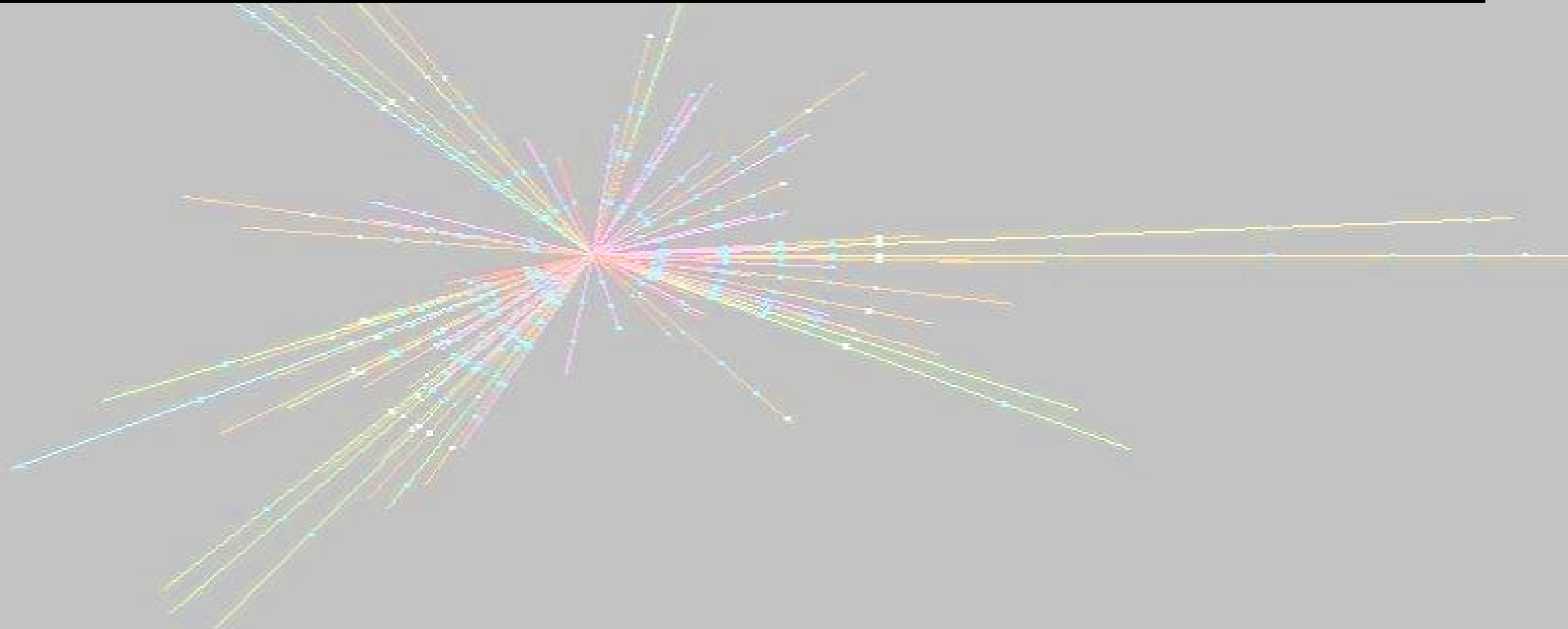
- Spin correlations: information about the spin of particles in cascades (0 vs. $1/2$, $3/2$?, ...)

Traditional MC generators PYTHIA, HERWIG, SUSYGEN limited

Complexity of Multi-(SUSY)-particle event generators

Some generic SUSY process:

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



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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)
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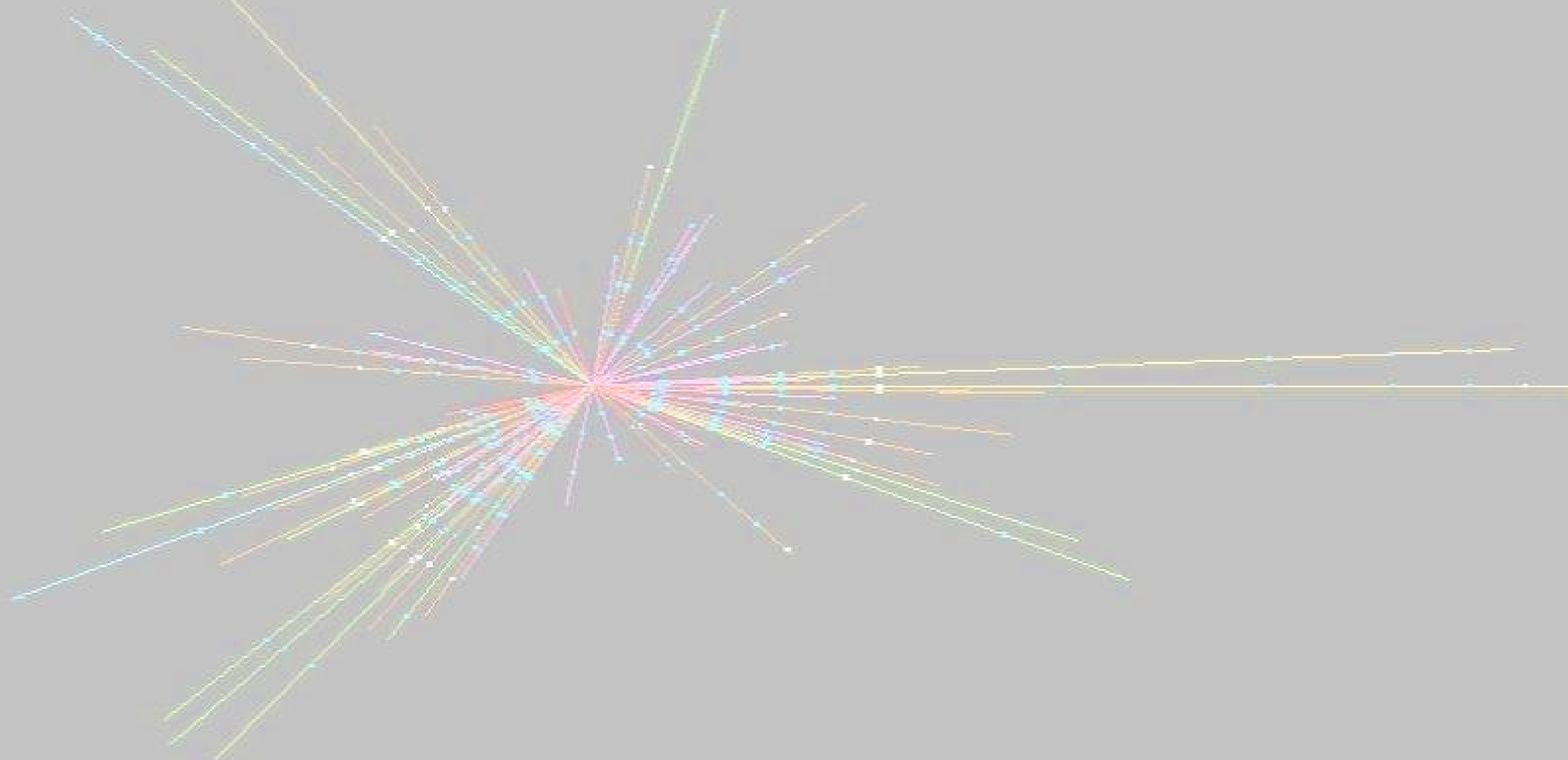
- Efficiency: Matrix element is evaluated some $10^5 - 10^6$ times (flavor, helicity sums)

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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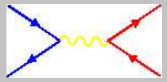
-  **Helas/(S)Madgraph/MadEvent**
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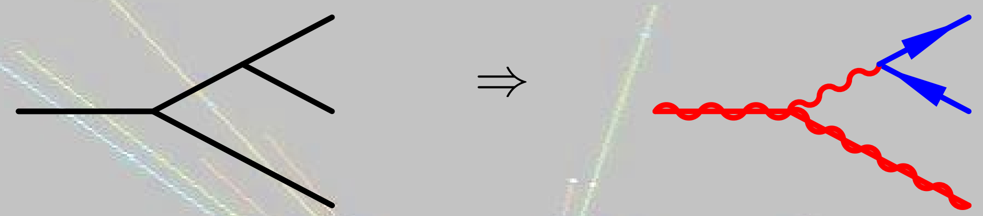
- **Amegic++/Sherpa**
  T. Gleisberg, S. Hoeche, F. Krauss, T. Laubrich, S. Schumann, C. Semmling, J. Winter

Matrix element generation

Three different approaches:

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



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

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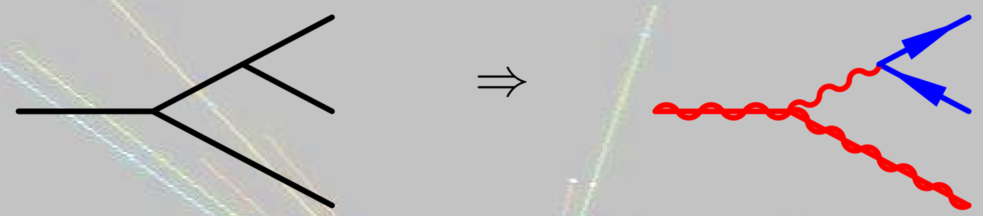

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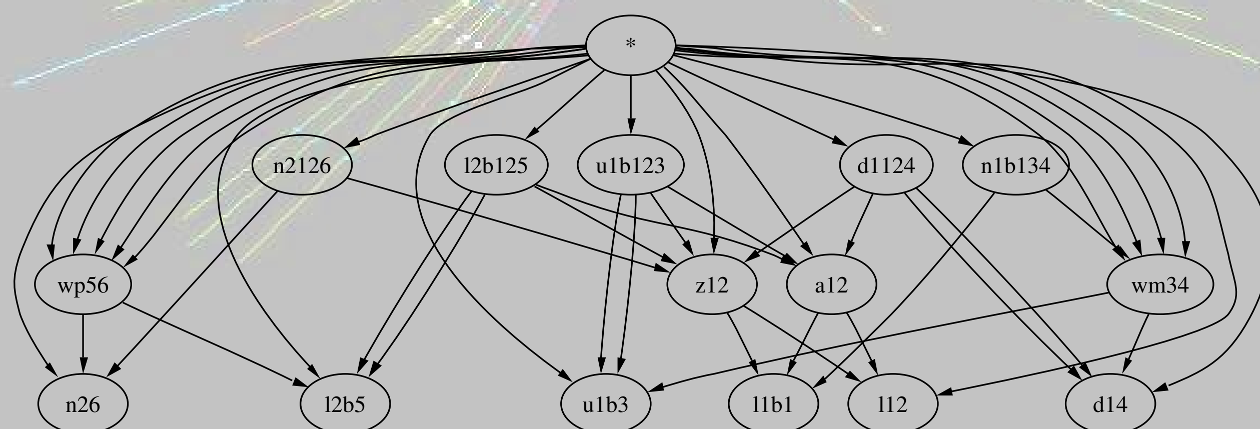
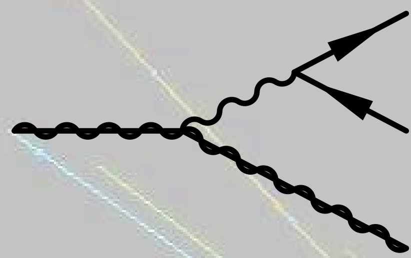
O'Mega: Combine sums of subgraphs into wave functions and thus don't evaluate *anything* twice (DAG = directed acyclical graph)

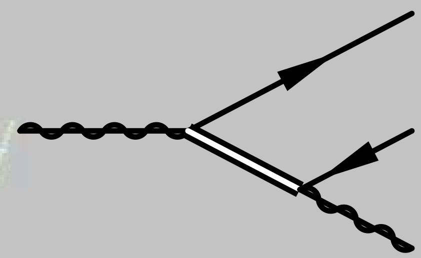


Phase Space Parameterization

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



vs.



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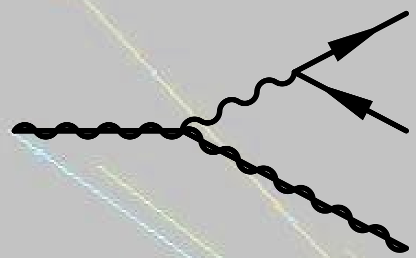

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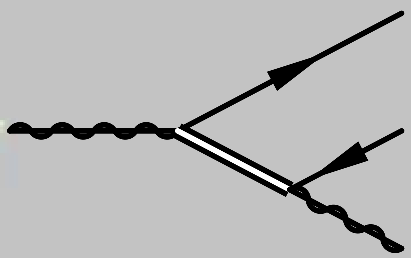

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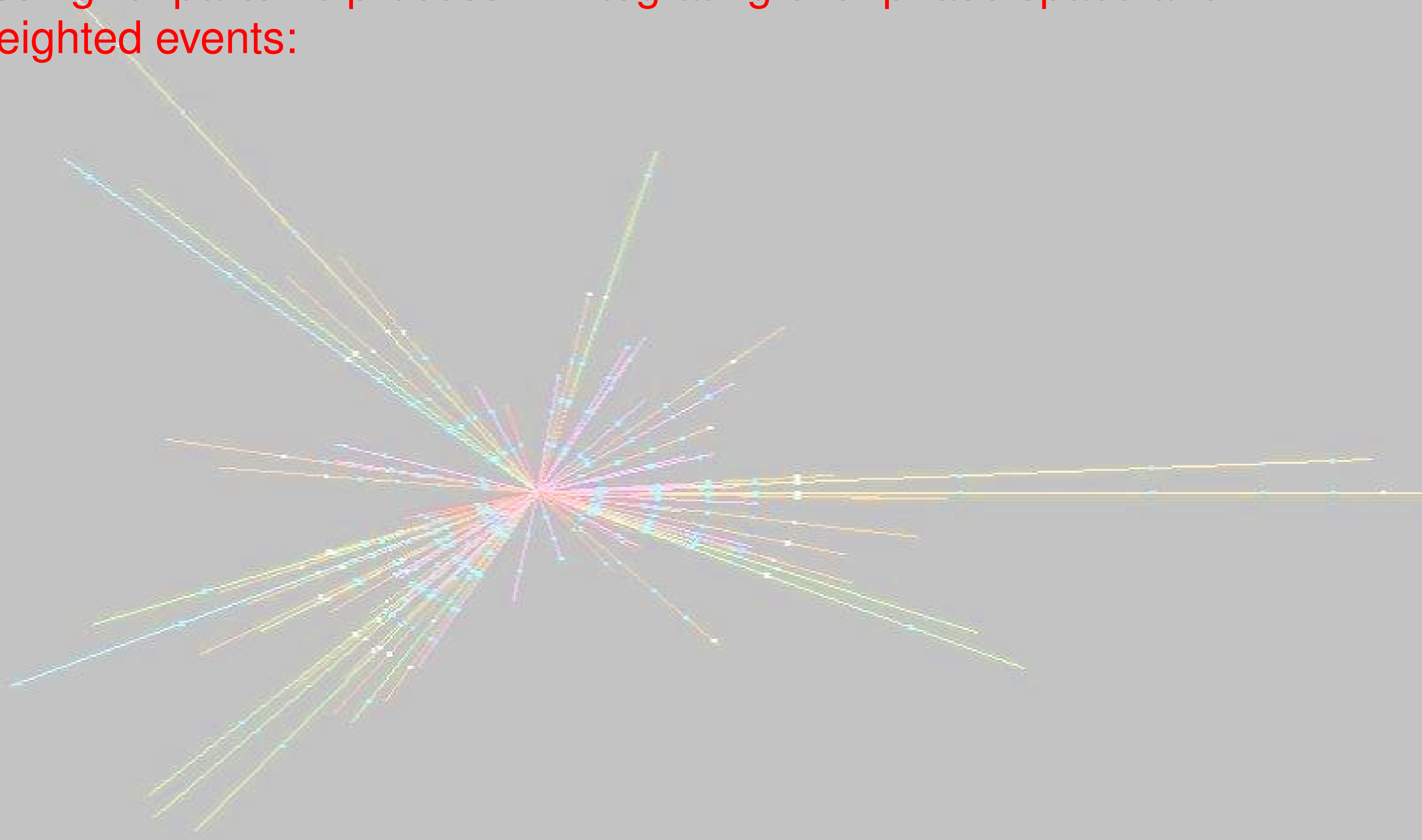
MadEvent: Integrand separated into diagrams squared (as if there were no interferences). Correction factor for interferences applied afterwards.

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

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



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- 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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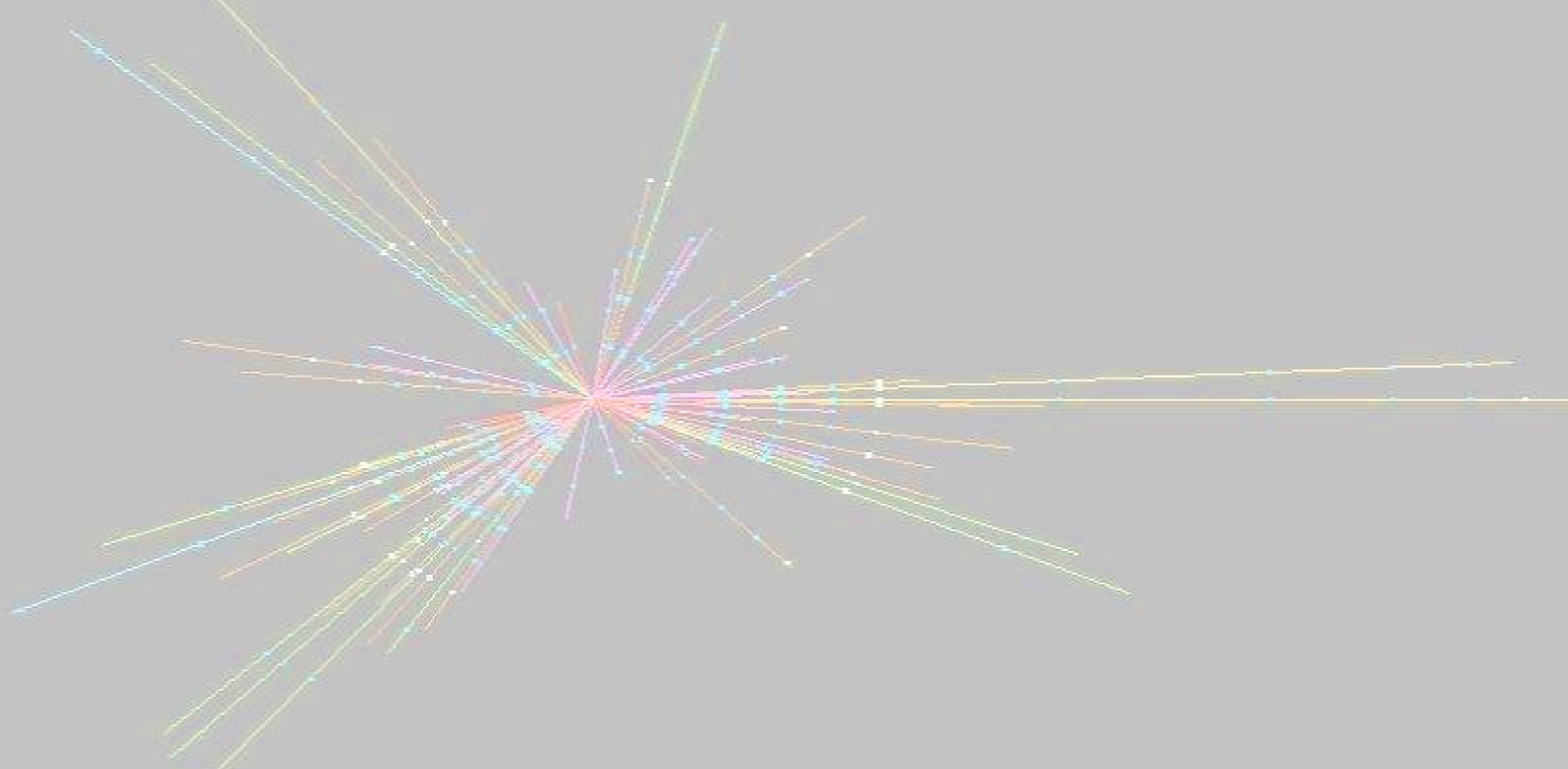
- Finally: hadronization
  MadEvent and WHiZard take care of this by standard interfaces to PYTHIA etc.

  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		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde\chi^0_1\tilde\chi^0_1$	●	240.631(4)	26.3082(2)	240.636(7)	26.3087(9)	240.638(2)	26.3086(3)
$\tilde\chi^0_1\tilde\chi^0_2$	●	62.377(1)	9.9475(1)	62.374(2)	9.9475(4)	62.3785(6)	9.94778(1)
$\tilde\chi^0_1\tilde\chi^0_3$	●	7.78117(2)	0.64795(1)	7.78131(4)	0.64796(1)	7.78121(8)	0.647969(6)
$\tilde\chi^0_1\tilde\chi^0_4$	●	1.03457(3)	1.36561(1)	1.03460(3)	1.36564(5)	1.03460(1)	1.36568(1)
$\tilde\chi^0_2\tilde\chi^0_2$	●	70.730(2)	18.6841(3)	70.730(3)	18.6845(8)	70.7310(7)	18.6843(2)
$\tilde\chi^0_2\tilde\chi^0_3$	●	—	1.85588(2)	—	1.85590(4)	—	1.85594(2)
$\tilde\chi^0_2\tilde\chi^0_4$	●	—	3.03946(4)	—	3.03951(9)	—	3.03949(3)
$\tilde\chi^0_3\tilde\chi^0_3$	●	—	0.0042214(1)	—	0.0042214(2)	—	0.00422147(4)
$\tilde\chi^0_3\tilde\chi^0_4$	●	—	9.93621(8)	—	9.9362(3)	—	9.93637(1)
$\tilde\chi^0_4\tilde\chi^0_4$	●	—	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)

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
$W^+W^- \to X$ (II)							
$\tilde\chi_1^0\tilde\chi_1^0$	●	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)

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
$u\bar{u} \to X$							
$\tilde{g}\,\tilde{g}$	●	—	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 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
$\tilde{e}_L\,\tilde{e}_L^*$	●	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)

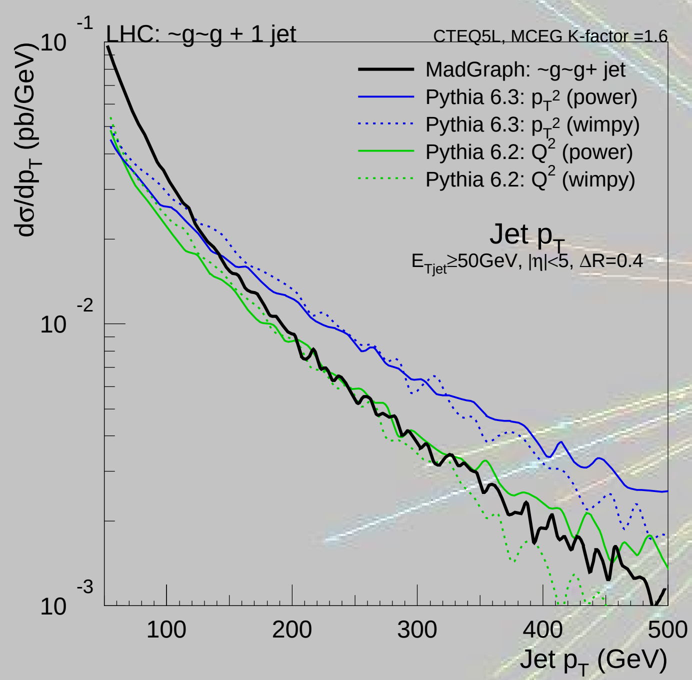
$\tau^+\tau^-$ processes

$\tau^+\tau^- \to X$							
Process	status	Madgraph/Helas 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
$\tilde\tau_1\tilde\tau_1^*$	●	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, $g\gamma$, gZ, gW^-

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



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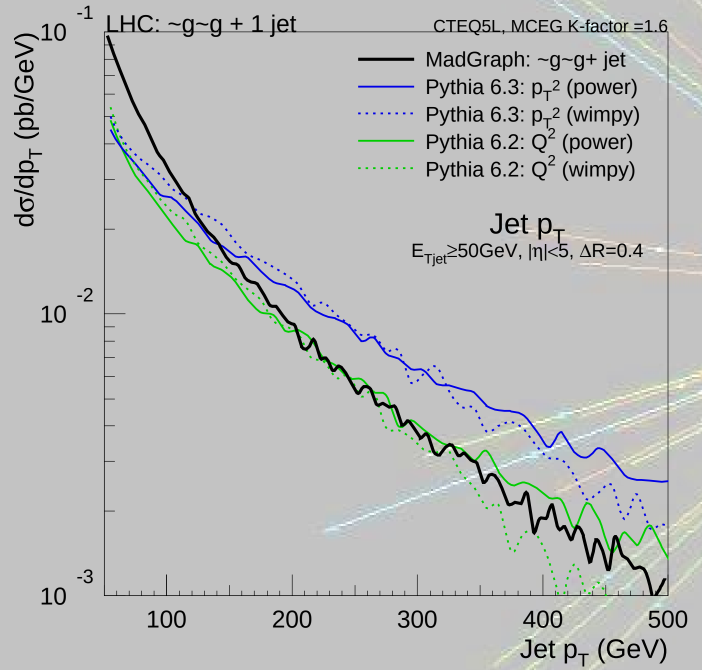
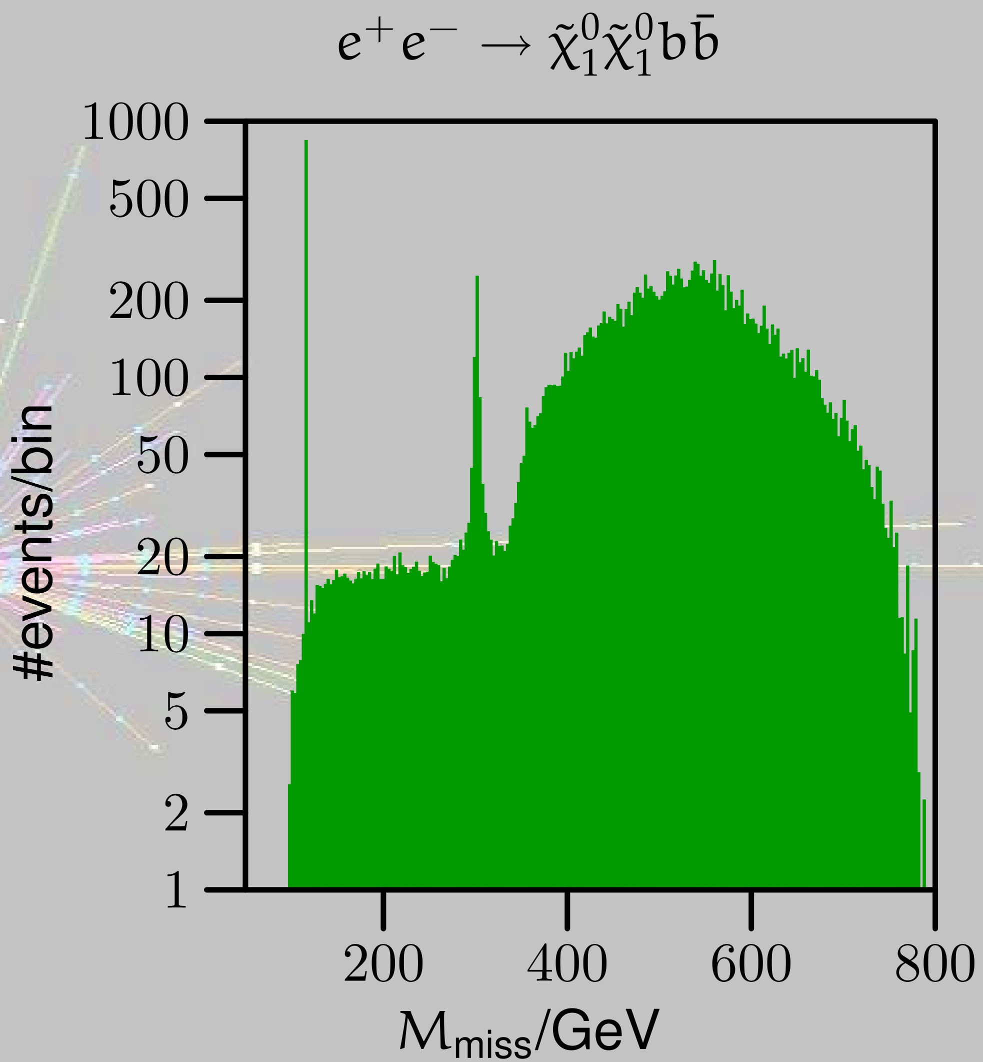


ILC:



(Work in Progress)

Summary & Outlook

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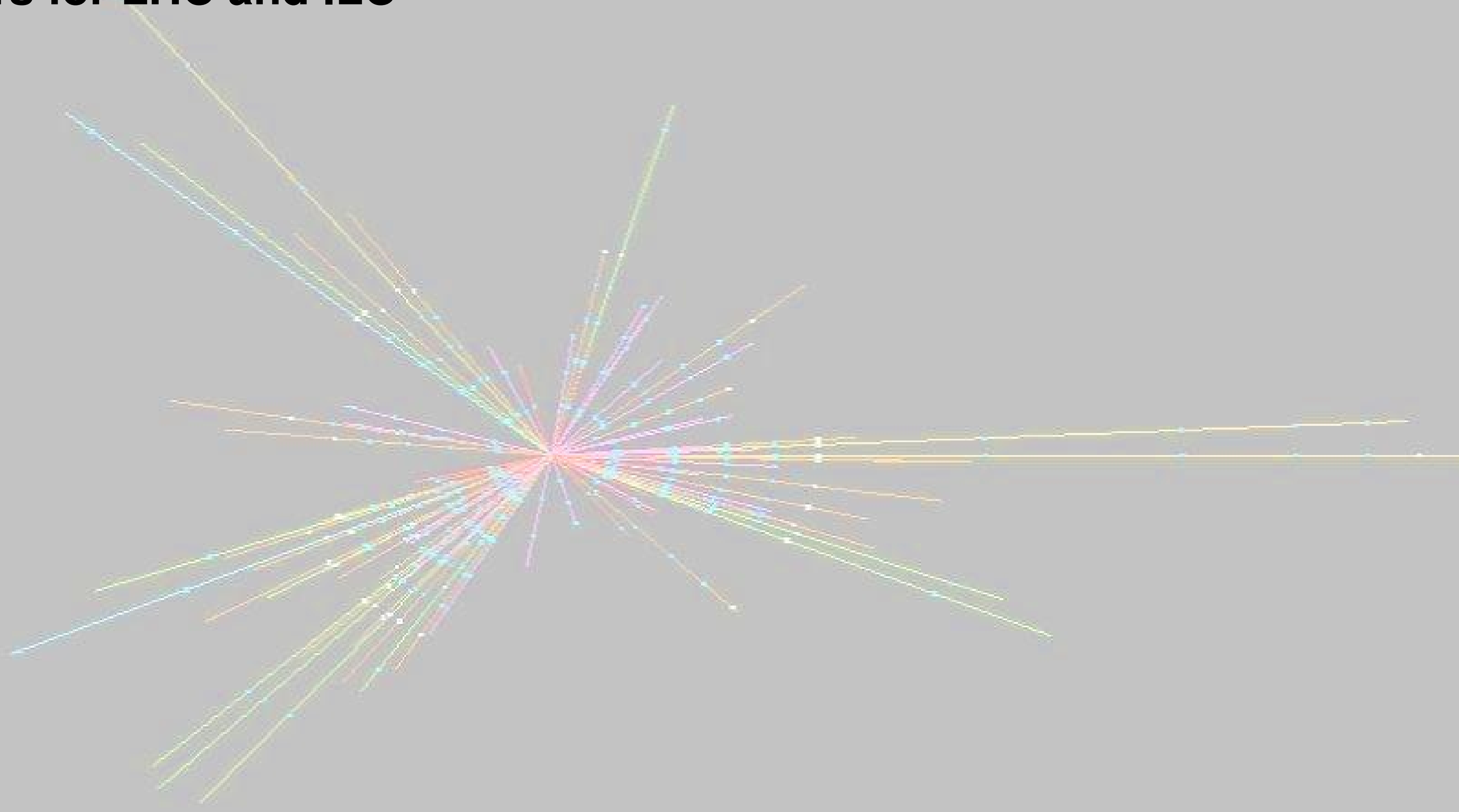

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- Special tasks MadGraph: QCD backgrounds, WhiZard/O'Mega ideal for new models (CP-viol. MSSM $\surd$; NMSSM, UED, E_6 upcoming!), Sherpa: ME+PS

- http://theorie.physik.uni-wuerzburg.de/~ohl/omega/
  http://www-ttp.physik.uni-karlsruhe.de/whizard/
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- Full analyses with spin corr., bkgd., hadronic environment for all processes (e.g. WW →SUSY)

- Next step: Match higher-order corrections with multi-particle final states (Frixione, Webber: MC@NLO, Kilian/Reuter/Robens)