New models and Supersymmetry in FeynRules.

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Outline

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Validation procedure - the four-star system (LH2009)

One whiteboard at Les Houches 2009

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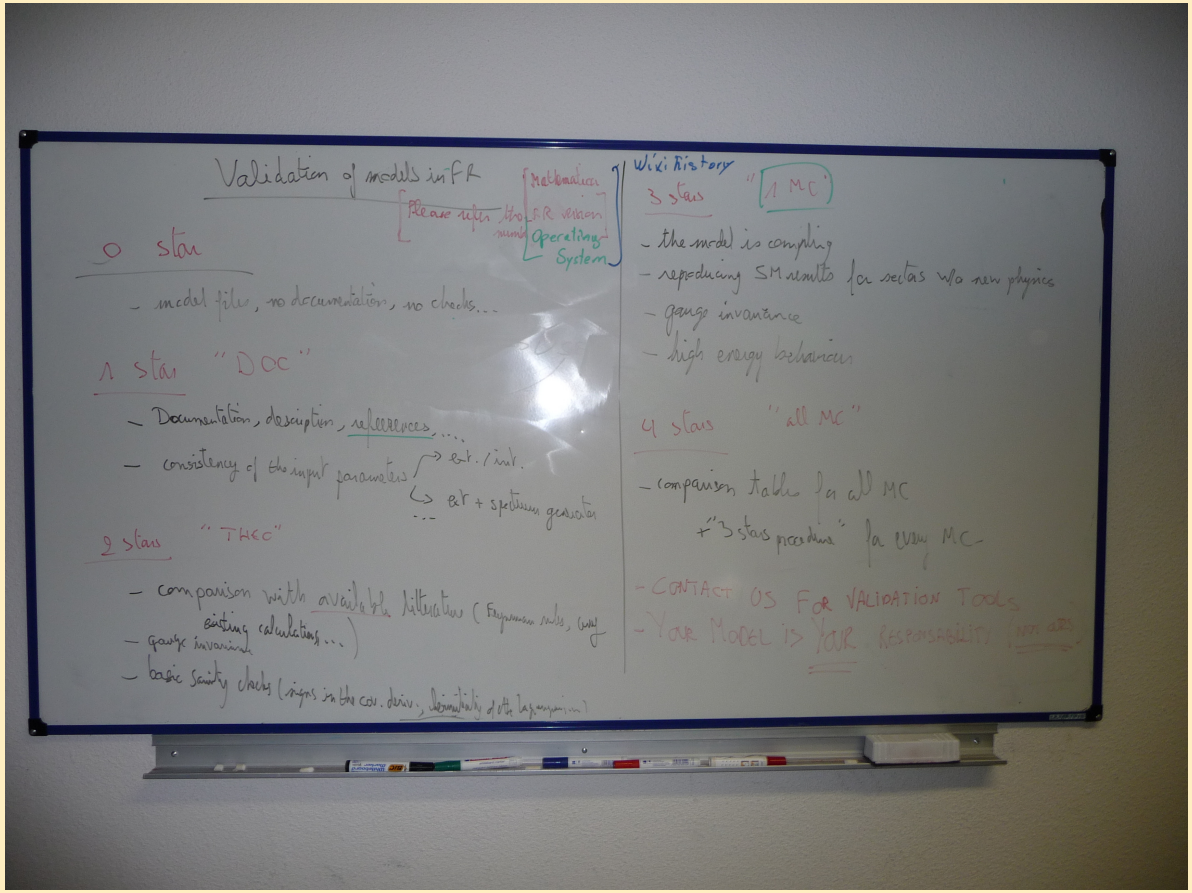

Validation procedure - the four-star system (LH2009)

- **Any model can be put on the FeynRules website.**
- **First star [DOC]:**
  * **Documentation**: description, references, ...
  * Complete model or theory fragment.
  * Consistency of the input parameters.
- **Second star [THEO]:**
  * **Basic sanity checks**: hermiticity, signs, ...
  * **Comparison with literature**.
  * Use of `FeynArts/FormCalc` possible.
- **Third star [1MC]:**
  * The MC is producing **reliable results for basic processes**.
  * Reproduction of the SM results for sectors independent on new physics.
  * Gauge invariance, behaviour at high energy.
  * **Numerical tables for cross sections (future references).**
- **Fourth star [nMC]:**
  * Reproduce the [1MC] step for more than one MC generator.
  * **Comparison tables for future references**.

Outline

The (almost) most general MSSM - model [BenjF]

- **A general version of the MSSM** (any usual limit easily taken).
  - **Sfermion sector.**
    - 6×6 and 3×3 CP and flavour violating mixing matrices.
    - *e.g.* $\left(\tilde{u}_1, \tilde{u}_2, \tilde{u}_3, \tilde{u}_4, \tilde{u}_5, \tilde{u}_6\right)^T = R^{\tilde{u}}\left(\tilde{u}_L, \tilde{c}_L, \tilde{t}_L, \tilde{u}_R, \tilde{c}_R, \tilde{t}_R\right)^T,$

      $\left(\tilde{d}_1, \tilde{d}_2, \tilde{d}_3, \tilde{d}_4, \tilde{d}_5, \tilde{d}_6\right)^T = R^{\tilde{d}}\left(\tilde{d}_L, \tilde{s}_L, \tilde{b}_L, \tilde{d}_R, \tilde{s}_R, \tilde{b}_R\right)^T.$
  - **Higgs sector.**
    - Only 2×2 mixing considered for the moment.
    - **To be generalized in version 1.0.2**.

      $$\left(\tilde{h}_1, \tilde{h}_2, \tilde{h}_3\right)^T = R^h\left(\sqrt{2}\mathrm{Re}\{H_1^0\}, \sqrt{2}\mathrm{Re}\{H_2^0\}, A^0_{\mathrm{tree}}\right)^T$$
  - **Gaugino/higgsino sector.**
    - Written in the mass basis (contrary to the rest of the Lagrangian).
    - **To be changed in version 1.0.2** (generalization purposes).
- **105 free parameters.**
  - The **SLHA-FR format** (SLHA2-like format).
  - C++ translator SLHA1/2 $\Leftrightarrow$ SLHA-FR **(v1.2.1 is coming)**.

The (almost) most general MSSM - validation [BenjF]

- **Handmade vs. automated implementation.**
  - * 2522 vertices, without the four-scalar interactions.
  - * **More that 10000 vertices, with the four-scalar interactions !!!**
- FeynArts/FormCalc.
  - ✔ All $2 \to 2$ SUSY hadroproduction processes checked with litterature. [Bozzi, BenjF, Herrmann, Klasen (2007); BenjF, Herrmann, Klasen (2009; in prep.)].
- MadGraph/MadEvent (in the cMSSM limit):
  - * MG-Stock was validated by the CATPISS collaboration [Hagiwara *et al.* (2006)].
  - ✔ **320 decay widths.**
  - ✔ **626** $2 \to 2$ **SUSY processes.**
  - ✔ **2708** $2 \to 3$ **SUSY processes.**
  - ◉ **TO DO**: check with XSusy for the general MSSM [BenjF, Herrmann (in prep.)].

The signs and absolute values of all the vertices have been checked.

- CalcHep/CompHep (in the cMSSM):
  - ✘ **626** $2 \to 2$ **SUSY processes** $\Rightarrow$ **Bugs found in the stock version!**

The (almost) most general MSSM - validation [BenjF]

Some MadGraph/MadEvent and CalcHep results

Process	MG-FR	MG-ST	CH-FR	CH-ST	Comparison
b,b~>mu+,mu-	7.01173×10^{-3}	7.00622×10^{-3}	7.0113×10^{-3}	7.0114×10^{-3}	δ = 0.0786383 %
b,b~>e+,e-	7.01047×10^{-3}	7.00913×10^{-3}	7.0113×10^{-3}	7.0114×10^{-3}	δ = 0.0323792 %
b,b~>tau+,tau-	7.23656×10^{-3}	7.2231×10^{-3}	7.2351×10^{-3}	7.2352×10^{-3}	δ = 0.186166 %
b,b~>ve,ve~	8.38141×10^{-3}	8.38607×10^{-3}	8.3842×10^{-3}	8.3843×10^{-3}	δ = 0.0556675 %
b,b~>vm,vm~	8.3868×10^{-3}	8.38046×10^{-3}	8.3842×10^{-3}	8.3843×10^{-3}	δ = 0.0756488 %
b,b~>vt,vt~	8.38227×10^{-3}	8.38318×10^{-3}	8.3842×10^{-3}	8.3843×10^{-3}	δ = 0.0242298 %
b,b~>u,u~	2.19296	2.19098	2.1931	2.1931	δ = 0.0966848 %
b,b~>t,t~	4.74685×10^{1}	4.74541×10^{1}	4.7307×10^{1}	4.7308×10^{1}	δ = 0.340907 %
b,b~>d,d~	2.19374	2.19428	2.1944	2.1944	δ = 0.0301166 %
b,b~>b,b~	2.34515×10^{4}	2.34471×10^{4}	2.3448×10^{4}	2.3448×10^{4}	δ = 0.0188769 %
b,b~>W+,W-	1.33248	1.33234	1.3331	1.3331	δ = 0.0573475 %
b,b~>Z,Z	1.39592×10^{-1}	1.39525×10^{-1}	1.3982×10^{-1}	1.3982×10^{-1}	δ = 0.210885 %
b,b~>Z,a	2.8492×10^{-2}	2.85038×10^{-2}	2.8503×10^{-2}	2.8504×10^{-2}	δ = 0.0420335 %
b,b~>g,g	5.55219×10^{1}	5.54535×10^{1}	5.5504×10^{1}	5.5504×10^{1}	δ = 0.12333 %
b,b~>sd1,sd1~	3.40163×10^{-1}	3.40348×10^{-1}	3.401×10^{-1}	3.4009×10^{-1}	δ = 0.0759557 %
b,b~>sd2,sd2~	2.58964×10^{-1}	2.59026×10^{-1}	2.5914×10^{-1}	2.5915×10^{-1}	δ = 0.0716753 %
b,b~>sd1,sd2~	6.07283×10^{-1}	6.07465×10^{-1}	6.0701×10^{-1}	6.0701×10^{-1}	δ = 0.0749837 %
b,b~>su1,su1~	2.88616×10^{-1}	2.89041×10^{-1}	2.8884×10^{-1}	2.8625×10^{-1}	δ = 0.97026 %
b,b~>su6,su6~	5.91346×10^{-3}	5.91497×10^{-3}	5.9124×10^{-3}	5.2701×10^{-3}	δ = 11.5309 %
b,b~>su1,su6~	1.15552×10^{-2}	1.15752×10^{-2}	1.1567×10^{-2}	8.7247×10^{-3}	δ = 28.0835 %
b,b~>n1,n1	1.73348×10^{-4}	1.73503×10^{-4}	1.7329×10^{-4}	1.7329×10^{-4}	δ = 0.12272 %
b,b~>n1,n2	7.25698×10^{-4}	7.25803×10^{-4}	7.2617×10^{-4}	7.2618×10^{-4}	δ = 0.0664021 %
b,b~>n1,n3	4.87872×10^{-4}	4.89162×10^{-4}	4.8893×10^{-4}	4.8893×10^{-4}	δ = 0.26393 %
b,b~>n1,n4	2.90254×10^{-4}	2.89831×10^{-4}	2.8994×10^{-4}	2.8994×10^{-4}	δ = 0.146048 %
b,b~>n2,n2	5.74033×10^{-3}	5.74407×10^{-3}	5.7423×10^{-3}	5.7424×10^{-3}	δ = 0.0651865 %
b,b~>n2,n3	2.73662×10^{-3}	2.73514×10^{-3}	2.7398×10^{-3}	2.7399×10^{-3}	δ = 0.173711 %
b,b~>n2,n4	2.0141×10^{-3}	2.01493×10^{-3}	2.0149×10^{-3}	2.015×10^{-3}	δ = 0.0448974 %
b,b~>n3,n3	4.54157×10^{-5}	4.54171×10^{-5}	4.5409×10^{-5}	4.5409×10^{-5}	δ = 0.0178662 %
b,b~>n3,n4	1.08667×10^{-2}	1.08477×10^{-2}	1.0845×10^{-2}	1.0845×10^{-2}	δ = 0.199685 %
b,b~>n4,n4	2.16226×10^{-4}	2.15906×10^{-4}	2.1573×10^{-4}	2.1574×10^{-4}	δ = 0.229686 %

The (almost) most general MSSM - to do list [BenjF]

- **From an almost most general model to the most general one.**
  * Generalization of the **Higgs sector**.
  * Switch to the gauge basis for the **gaugino/higgsino sector**.
- MadGraph/MadEvent and CalcHep/CompHep.
  * **Check with** XSusy for the general model case.
- Sherpa:
  * **Ongoing validation**: one issue related to Majorana particles remaining. [+ possible hidden stuff].
- Whizard:
  * **Starting validation**: compiling issue (too huge model file).

R-parity violating MSSM [BenjF]

- **Implementation in FeynRules** (not public).
  - * **General mixings.**
    - ◇ Neutrinos/neutralinos & charged leptons/charginos.
    - ◇ Neutral Higgses/sneutrinos & charged Higgses/charged sleptons.
    - ◇ **The neutralino/chargino sector will be rewritten**.
  - * **105 + 192 free parameters.**
    - ◇ The **SLHA-FR format** (SLHA2-like format).
    - ◇ C++ translator SLHA1/2 $\Leftrightarrow$ SLHA-FR **(not yet there)**.
- **FeynArts model file**.
  - * Weird stuff seen (06.09.09) $\Rightarrow$ **under investigations**.
  - * ε_{ijk} colour structure not hardcoded in FeynArts/FormCalc.
  - * **The model ~~works~~ seems to work!**
- **MadGraph model files** [with J. Andrea].
  - * Created with one single R-parity violating parameter (λ''_{ijk})
    [8 hours with a 8GB RAM machine $\Rightarrow$ LHCGRID?].
  - * **The model files are compiling** [with normal machines].
  - * ε_{ijk} colour structure: **the validation will soon start**.
  - * **To do**: validation against (Pythia)/Herwig/SusyGen.

The Next-to-Minimal Supersymmetric Standard Model [BenjF]

- **Implementation in** FeynRules (not public).
  - * **General mixings.**
    - ◇ Extended neutralino sector.
    - ◇ Extended Higgs sector.
    - ◇ **The neutralino/chargino sector will be rewritten**.
  - * **105 + 10 free parameters.**
    - ◇ The **SLHA-FR format** (SLHA2-like format).
    - ◇ C++ translator SLHA1/2 $\Leftrightarrow$ SLHA-FR **(seems to work)**.
- MadGraph **and** CalcHep **model files** [with F. Braam, J. Reuter].
  - * **Validation against the stock version of** Whizard.
  - * ≈ 60 e^+e^- processes checked.
  - * $\tau^+\tau^-$ **processes: issues with the neutralinos and the Higgses.**

Outline

The Standard Model [N. Christensen, C. Duhr]

- **Best complete results (with some SHERPA and WHIZARD issues)**:

CALCHEP, COMPHEP, MADGRAPH/MADEVENT, SHERPA and WHIZARD results

Process	CalcHEP Stock	CalcHEP Feynman	CalcHEP Unitary	CompHEP Feynman	MadGraph Stock	MadGraph Unitary	Sherpa Unitary	Whizard Stock	Whizard Feynman	Whizard Unitary	
gg->gg	116490.	116490.	116490.	116490.	116680.	116120.	116490	115031.	116585.	116642.	Discrpency!
uū->gg	199.95	199.95	199.95	199.94	200.21	199.77	199.963	199.693	199.693	199.693	
tt̄->gg	64.595	64.595	64.595	64.592	64.467	64.537	64.5856	64.623	64.5601	64.5601	
$e^+e^-\to\mu^+\mu^-$	0.37194	0.37195	0.37195	0.37194	0.37202	0.37148	0.372011	0.372034	0.372028	0.372028	
$e^+e^-\to e^+e^-$	734.15	734.15	734.15	734.16	733.96	734.47	734.314	734.622	734.609	734.609	
$e^+e^-\to\nu_e\bar{\nu}_e$	49.143	49.145	49.145	49.145	results	results	49.1361	49.1139	49.1184	49.1184	
tt̄->uū	16.018	16.018	16.018	16.018	16.012	16.022	16.0204	16.0214	16.0214	16.0214	
uū->ss̄	9.7634	9.7634	9.7634	9.7631	9.7631	9.7692	9.76376	9.76348	9.76346	9.76348	
$u\bar{d}\to c\bar{s}$	0.3531	0.35311	0.35311	0.35312	0.35274	0.35318	0.353149	0.353212	0.353215	0.353215	
$u\bar{s}\to c\bar{d}$	0.0010187	0.0010187	0.0010187	0.0010187	0.0010186	0.0010182	0.00101879	0.00101897	0.00101898	0.00101898	
$W^+W^-\to t\bar{t}$	44.534	44.535	44.535	44.534	44.647	44.485	44.5503	44.4991	44.4992	44.4992	
tt̄->ZZ	1.2534	1.2534	1.2534	1.2534	1.254	1.2559	1.25321	1.25431	1.25432	1.25432	
tt̄->Zγ	1.3119	1.3119	1.3119	1.312	1.3139	1.3113	1.31197	1.31261	1.31202	1.31202	
tt̄->γγ	0.088486	0.088486	0.088486	0.088485	0.088527	0.088462	0.0884835	0.0884519	0.0884983	0.0884983	
uū->W^+W^-	1.7736	1.7737	1.7737	1.7737	1.7698	1.776	1.77424	1.77412	1.77413	1.77413	
uū->ZZ	0.19345	0.19347	0.19347	0.19346	0.19357	0.19318	0.193462	0.192923	0.192927	0.192927	
uū->Zγ	0.33811	0.33812	0.33812	0.33811	0.3381	0.3384	0.334504	0.338125	0.338124	0.338124	Discrpency!
uū->γγ	0.18322	0.18322	0.18322	0.18323	0.18332	0.18329	0.183224	0.183377	0.183373	0.183373	
$\tau^+\tau^-\to W^+W^-$	5.3681	5.3684	5.3684	5.3686	5.3517	5.3637	5.36799	5.36556	5.3656	5.3656	
$\tau^+\tau^-\to ZZ$	0.31816	0.31817	0.31817	0.31816	0.31852	0.31805	0.318256	0.31799	0.317993	0.317993	
$\tau^+\tau^-\to Z\gamma$	2.0057	2.0057	2.0057	2.0057	2.0083	2.0044	1.98453	1.99948	2.00799	2.00799	Discrpency!
$\tau^+\tau^-\to\gamma\gamma$	2.7791	2.7791	2.7791	2.779	2.7773	2.7756	2.77911	2.77248	2.77711	2.77711	
ZZ->ZZ	1.9606	1.9606	1.9606	1.9606	1.9565	1.9555	1.96071	1.96046	1.96046	1.96046	
$W^+W^-\to\gamma\gamma$	20.825	20.825	20.825	20.824	20.827	20.804	20.8182	20.8527	20.8171	20.8171	
$W^+W^-\to ZZ$	272.62	272.63	272.63	272.62	272.36	272.11	272.694	272.422	272.425	272.425	
$W^+W^-\to W^+W^-$	1318.1	1318.2	1318.2	1318.2	1317.2	1318.8	1318.45	1320.05	1320.03	1320.03	
hh->hh	1.8569	1.857	1.857	1.857	-	1.8567	1.85587	1.86179	1.86179	1.86179	
ZZ→hh	6.3027	6.3029	6.3029	6.3029	6.311	6.3137	6.30265	6.29227	6.31003	6.31003	
hh->W^+W^-	94.47	94.473	94.473	94.473	94.815	94.833	94.5793	94.5073	94.5077	94.5077	

Model database (FeynRules v1.4.0)

- **New public models interfaced to Monte Carlo tools.**

  [Christensen, de Aquino, Degrande, Duhr, BenjF, Herquet, Maltoni, Schumann, arXiv:0906.2474].

  * The most general two-Higgs-doublet model [C. Duhr, M. Herquet].
  * Universal extra dimensional models [P. Aquino].
  * The Minimal Higgsless Model [N. Christensen].
  * **Full agreement has been obtained after comparing**:
    - FeynRules-generated CalcHep, MadGraph, Sherpa versions.
    - Existing MadGraph and/or CalcHep (stock) versions.

- **New public models not interfaced to Monte Carlo tools.**

  [Christensen, de Aquino, Degrande, Duhr, BenjF, Herquet, Maltoni, Schumann, arXiv:0906.2474].

  * Large extra dimensional models [P. Aquino].
  * Chiral pertubation theory [C. Degrande].
  * Strongly interacting Light Higgs models [C. Degrande].
  * FeynArts **investigations have been performed**.

The Two-Higgs-Doublet model [C. Duhr, M. Herquet]

- **Model description**: [Branco, Lavoura, Silva, (1999)].
  - Two $SU(2)$ Higgs doublets with the same hypercharge ($Y = +1$).
  - Contains the most general Higgs potential: 14 new free parameters.
  - Contains the most general Yukawa interactions with all the Higgses.
- ✔ CalcHep/MadGraph: **185** $2 \to 2$ processes.
  - Matrix elements evaluated at given phase space points.

Some CalcHep/MadGraphresults

Process	MG-FR	MG-ST	CH-FR	Comparison
w+,w->w+,w-	1.34717531×10^{3}	1.34627829×10^{3}	1.347×10^{3}	δ = 0.06660742178741162 %
w+,w->z,z	2.78702715×10^{2}	2.77367422×10^{2}	2.7818×10^{2}	δ = 0.4802606402149 %
w+,w->z,a	1.50968136×10^{2}	1.51275733×10^{2}	1.5113×10^{2}	δ = 0.2035422594461398 %
w+,w->a,a	2.01614354×10^{1}	2.01958656×10^{1}	2.0179×10^{1}	δ = 0.17062687120728287 %
z,z>z,z	1.61575084×10^{1}	1.61491479×10^{1}	1.6155×10^{1}	δ = 0.05175713588163559 %
w+,w->h1,h1	$6.61659297 \times 10^{-1}$	$6.61999966 \times 10^{-1}$	6.6177×10^{-1}	δ = 0.05147382102367535 %
w+,w->h1,h2	$3.85088652 \times 10^{-3}$	$3.84459982 \times 10^{-3}$	3.8473×10^{-3}	δ = 0.16338668466794046 %
w+,w->h1,h3	$1.23289791 \times 10^{-2}$	$1.23475665 \times 10^{-2}$	1.2341×10^{-2}	δ = 0.15064831440589155 %
w+,w->h2,h2	$4.45495546 \times 10^{-1}$	$4.44850359 \times 10^{-1}$	4.4527×10^{-1}	δ = 0.14492951478224567 %
w+,w->h2,h3	1.0768492	1.07589008	1.0763	δ = 0.08910693542044637 %
w+,w->h3,h3	$8.99279261 \times 10^{-2}$	$9.00391927 \times 10^{-2}$	8.9963×10^{-2}	δ = 0.12365214350479091 %
w+,w->h+,h-	2.44619153	2.44427043	2.4433	δ = 0.11827528413778879 %
w+,z>h+,h1	2.8883921×10^{-1}	$2.88845981 \times 10^{-1}$	2.8874×10^{-1}	δ = 0.03669791286017285 %
w-,z>h-,h1	2.8868384×10^{-1}	$2.88863872 \times 10^{-1}$	2.8874×10^{-1}	δ = 0.06234359387436951 %
w-,z>h-,h2	$1.48403232 \times 10^{-2}$	$1.48740076 \times 10^{-2}$	1.4853×10^{-2}	δ = 0.226721579070522 %
w-,z>h-,h3	$3.00889891 \times 10^{-2}$	$3.01168338 \times 10^{-2}$	3.0116×10^{-2}	δ = 0.09249836198152199 %
w+,a>h+,h1	$1.97049566 \times 10^{-2}$	$1.96942436 \times 10^{-2}$	1.9692×10^{-2}	δ = 0.06577462381954177 %
w+,a>h+,h2	7.9249421×10^{-3}	$7.92658436 \times 10^{-3}$	7.9263×10^{-3}	δ = 0.02072052813518518 %
w-,a>h-,h3	1.6921328×10^{-4}	$1.69340468 \times 10^{-4}$	1.6934×10^{-4}	δ = 0.07513607558704156 %
z,z>h1,h1	2.33325979	2.333422	2.3345	δ = 0.053139409729554304 %
z,z>h1,h2	NAN	NAN	NAN	δ = 0 %
z,z>h1,h3	NAN	NAN	NAN	δ = 0 %
z,z>h2,h2	$6.63619749 \times 10^{-1}$	$6.62745315 \times 10^{-1}$	6.6299×10^{-1}	δ = 0.13185419666632286 %
z,z>h2,h3	1.06543437	1.06612196	1.0656	δ = 0.06451530183113398 %
z,z>h3,h3	$7.78513157 \times 10^{-2}$	$7.79162284 \times 10^{-2}$	7.792×10^{-2}	δ = 0.08818606903504053 %
z,z>h+,h-	1.35644808	1.35571884	1.3558	δ = 0.0537754512543111 %

Minimal Universal Extra Dimensions [P. de Aquino]

- **Model description**.
  - * Five-dimensional model with a spatial and compact fifth dimension.
  - * All Standard Model particles can propagate in the fifth dimension.
  - * Kaluza-Klein towers of new particles for each Standard Model particle.

✔ CalcHep/MadGraph: **118** $2 \to 2$ processes.

Some CalcHep/MadGraphresults

Process	MG-FR	CH-FR	CH-Stock	Result
e1R-,e1R+>u,u~	1.107×10^{-1}	1.1094×10^{-1}	1.1094×10^{-1}	OK: 0.216567%
e1R-,e1R+>d,d~	3.277×10^{-2}	3.2795×10^{-2}	3.2795×10^{-2}	OK: 0.0762602%
e1R-,e1R+>e-,e+	2.5553×10^{-1}	2.5537×10^{-1}	2.5537×10^{-1}	OK: 0.0626346%
e1R-,e1R->e-,e-	1.0714	1.0714	1.0714	OK: 0.%
e1R-,m1R->e-,m-	6.5807×10^{-1}	6.5818×10^{-1}	6.5818×10^{-1}	OK: 0.0167142%
e1R-,m1R+>e-,m+	4.7857×10^{-1}	4.7682×10^{-1}	4.7682×10^{-1}	OK: 0.366343%
e1R-,e1R+>A,A	2.0803×10^{-1}	2.0788×10^{-1}	2.0788×10^{-1}	OK: 0.072131%
n11,n11~>u,u~	1.6364×10^{-1}	1.6354×10^{-1}	1.6354×10^{-1}	OK: 0.0611284%
n11,n11~>Z,Z	4.1402×10^{-1}	4.1349×10^{-1}	4.1349×10^{-1}	OK: 0.128095%
n11,n11~>W+,W-	5.9018×10^{-1}	5.9009×10^{-1}	5.901×10^{-1}	OK: 0.0152507%
e1L-,e1L+>u,u~	2.3023×10^{-1}	2.2977×10^{-1}	2.2977×10^{-1}	OK: 0.2%
e1L-,e1L+>d,d~	1.4289×10^{-1}	1.4274×10^{-1}	1.4275×10^{-1}	OK: 0.105031%
e1L-,e1L+>e-,e+	2.5×10^{-1}	2.4978×10^{-1}	2.4978×10^{-1}	OK: 0.0880387%
e1L-,n11~>d,u~	6.3986×10^{-1}	6.3998×10^{-1}	6.3999×10^{-1}	OK: 0.0203149%
e1L-,n11~>e-,n1~	6.3118×10^{-1}	6.3132×10^{-1}	6.3133×10^{-1}	OK: 0.0237622%
e1L-,n11>e-,n1	1.0519	1.0519	1.0519	OK: 0.%
B1,B1>u,u~	9.2638×10^{-2}	9.2548×10^{-2}	9.2548×10^{-2}	OK: 0.0971996%
B1,B1>d,d~	6.1392×10^{-3}	6.1347×10^{-3}	6.1347×10^{-3}	OK: 0.0733263%
B1,B1>e+,e-	1.8444×10^{-1}	1.8411×10^{-1}	1.8411×10^{-1}	OK: 0.17908%
Z1,Z1>u,u~	3.5574×10^{-1}	3.5556×10^{-1}	3.5556×10^{-1}	OK: 0.0506116%
Z1,Z1>d,d~	3.566×10^{-1}	3.5556×10^{-1}	3.5556×10^{-1}	OK: 0.292069%
Z1,Z1>e+,e-	1.3429×10^{-1}	1.3409×10^{-1}	1.3409×10^{-1}	OK: 0.149042%
Z1,Z1>W-,W+	2.8571×10^{1}	2.8573×10^{1}	2.8573×10^{1}	OK: 0.00699986%

The Minimal Higgsless model [N. Christensen]

- **Model description**: [Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi, Tanabashi (2006)]
  - 5D $SU(2) \times SU(2) \times U(1)$ theory in a slice of Anti-deSitter space.
  - Gauge invariant higgsless model with delocalized fermions.
  - New extra gauge bosons and fermions.

✔ CalcHep, CompHep, MadGraph, Sherpa, Whizard: **224** $2 \to 2$ processes.

CalcHep, CompHep, MadGraph, Sherpa and Whizard results

	Lanhep CalcHEP Feynman	Lanhep CalcHEP Unitary	FeynRules CalcHEP Feynman	FeynRules CalcHEP Unitary	FeynRules CompHEP Feynman	FeynRules Sherpa Unitary	FeynRules MadGraph Unitary	Speckner Whizard	FeynRules Whizard Feynman	FeynRules Whizard Unitary
W+W-->γγ	20.362	20.362	20.362	20.362	20.369	20.3683	20.363	20.3725	20.3725	20.3725
W+W-'->γγ	0	0	0	0	0	0	0	0	0	0
W+'W-'->γγ	0.94225	0.94225	0.94225	0.94225	0.94227	0.942253	0.94151	0.944174	0.944174	0.944174
W+W-->γZ	164.64	164.64	164.64	164.64	164.67	164.565	164.86	164.608	164.608	164.608
W+W-->γZ'	1.3394	1.3394	1.3394	1.3394	1.3394	1.33908	1.3384	1.33858	1.33858	1.33858
W+W-'->γZ	4.0308	4.0308	4.0308	4.0308	4.0307	4.02947	4.0427	4.03546	4.02545	4.02545
W+W-'->γZ'	5.4937	5.4937	5.4937	5.4937	5.4938	5.49029	5.4947	5.49719	5.49914	5.49914
W+'W-'->γZ	1.0733	1.0733	1.0733	1.0733	1.0733	1.07322	1.0748	1.07478	1.07478	1.07478
W+'W-'->γZ'	59.388	59.388	59.388	59.388	59.388	59.3934	59.406	59.459	59.413	59.413
W+W-->ZZ	364.06	364.06	364.06	364.06	364.06	364.04	363.45	363.995	363.995	363.995
W+W-->ZZ'	7.4509	7.4509	7.4509	7.4509	7.4505	7.45122	7.4295	7.4451	7.4451	7.4451
W+W-'->ZZ	4.9438	4.9438	4.9438	4.9438	4.9438	4.94435	4.9594	4.94245	4.94245	4.94245
W+W-->Z'Z'	8.9045	8.9045	8.9045	8.9045	8.9045	8.90348	8.8912	8.90598	8.90598	8.90598
W+W-'->ZZ'	133.67	133.67	133.67	133.67	133.67	133.628	133.81	133.497	133.497	133.497
W+'W-'->ZZ	37.589	37.589	37.589	37.589	37.589	37.5893	37.555	37.5978	37.5978	37.5978
W+'W-'->ZZ'	28.081	28.081	28.081	28.081	28.081	28.077	28.061	28.0743	28.0743	28.0743
W+W-'->Z'Z'	12.427	12.427	12.427	12.427	12.427	12.4257	12.418	12.4318	12.4318	12.4318
W+'W-'->Z'Z'	1148.1	1148.1	1148.1	1148.1	1148.1	1147.97	1147.2	1147.7	1147.7	1147.7
W+W-->W+W-	1406.6	1406.6	1406.6	1406.6	1406.6	1407.02	1405.3	1403.19	1403.15	1403.15
W+W-->W+W-'	2.9169	2.9169	2.9169	2.9169	2.9171	-	2.9211	2.9198	2.91908	2.91908
W+W-'->W+W-	5.3129	5.3129	5.3129	5.3129	5.3131	5.31253	5.3143	5.31128	5.31569	5.31569
W+W-->W+'W-'	7.0778	7.0778	7.0778	7.0778	7.0779	7.07395	7.078	7.08119	7.07527	7.07527
W+W-'->W+W-'	140.62	140.62	140.62	140.62	140.63	140.528	140.63	140.71	140.742	140.742
W+'W-'->W+W-	31.233	31.233	31.233	31.233	31.233	31.2264	31.278	31.2146	31.219	31.219
W+'W-'->W+W-'	19.48	19.48	19.48	19.48	19.481	-	19.488	19.5127	19.4806	19.4801
W+W-'->W+'W-'	6.9908	6.9908	6.9908	6.9908	6.9908	-	6.9808	7.00147	6.98348	6.98348
W+'W-'->W+'W-'	724.47	724.47	724.47	724.47	724.44	724.147	724.9	725.104	724.761	724.761

- **No remaining issues here!**

Outline

Future developments with new models

- **The validation and implementation of models are ongoing!**
- **SUSY models**.
  * **MSSM, RPV MSSM, NMSSM**: ongoing work.
  * **Dirac gauginos** [C. Duhr, P. Fox, BenjF, G. Kribbs, A. Martin].
    - Private MadGraph and CalcHep versions are existing.
    - `http://www.lpthe.jussieu.fr/LesHouches09Wiki/index.php/Dirac_Gauginos`.
  * **Left-Right symmetric MSSM** [M. Frank, BenjF, I. Turan].
    - One private CalcHep version is existing.
- **6D Universal Extra Dimensions.** [Cacciapaglia, Deandrea, Llodra-Perez (2009)].
  "...The model is being implemented in the FeynRules package [20] and it will be made publicly available [...]"
- **Inclusion of two (or more than 50 excitations) in the 5D UED model** [I. Turan].
- **Various CMS analyses based on FeynRules models** [R. Plestina, P. Sellers, S. Fonseca, P. Ribeiro].
- **Standard Model with Excited Leptons (ATLAS)** [G. Azuelos, BenjF].
- $U(1)_{B-L}$ [L. Basso].