# New Developments in FeynRules

arxiv:1310.1921

A. Alloul

with N.D. Christensen, C. Degrande, C. Duhr, B. Fuks

GRPHE - Université de Haute-Alsace

October 28-30, 2013

# Outline

1. Basic features of FeynRules
2. New developments in version 2.0
3. Conclusion

# Need for automatization

- ⋇ Standard Model ≡ effective theory.
  - ⇨ **Hierarchy** problem
  - ⇨ **Neutrino** oscillations
  - ⇨ **Dark** matter and energy
  - ⇨ . . .
- ⋇ LHC is running
  - ⇨ Deviations from Standard Model?
  - ⇨ New signatures?
  - ⇨ Properties of the Higgs-like boson
  - ⇨ . . .

⇓

**Need for theoretical predictions**

- ⋇ Develop **new** models
  - ⇨ Write Lagrangian
  - ⇨ Compute several quantities (decay widths, mass and mixing matrices . . . )
- ⋇ **Implement** in Monte Carlo (MC) tools
  - ⇨ Many available tools (CalcHep, MadGraph, Pythia, Sherpa. . . )
  - ⇨ Every tool has its **dedicated** file format
  - ⇨ Every tool has its **advantages / disadvantages**

Starting from a **model**, FeynRules provides all the **necessary** ingredients to generate the **model file** for the beloved MC tool(s)

# A simple example: The Higgs Effective Lagrangian

[AA, B. Fuks, V. Sanz arXiv:1310.5150]

## Model implementation

- Consider the dimension-six $\mathcal{CP}$-conserving coupling

$$i g_1 \frac{\bar{c}_{HB}}{M_W^2} B_{\mu\nu} D^\mu \Phi^\dagger D^\nu \Phi$$

  - First declare the gauge symmetries `M$GaugeGroups = {U1Y == {...}, SU2L == {...}}`
  - The fields `M$ClassesDescription = {V[1] == {....}, S[1] == {....}}`
    - ⇨ Other types of fields supported U, F, W, CSF, VSF, R, RW
  - The parameters `M$Parameters = {cHB == {...}, g1 == {....}, MW == {...}}`
- Finally, the Lagrangian

```
Lagr = I cHB g1/ MW^2 FS[B,mu,nu] DC[Phibar[ii],mu] DC[Phi[ii],nu]
```

⇨ Several commands to compute (non-)supersymmetric Lagrangians.

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## Passing the information to Monte Carlo tools

- **Several** interfaces to pass the information
  - CalcHep ▪ FeynArts ▪ MadGraph ▪ Sherpa ▪ Whizard
- "Home-made" interface
  - ⇨ Python based
  - ⇨ **No restrictions** with respect to Lorentz/Colour structure
  - ⇨ Supported by Aloha, MadAnalysis 5 and MadGraph 5
  - ⇨ Will be used in the future by GoSam and Herwig++

```
WriteUFO[lagr]
```

## For further details


☞ **FeynRules - Feynman rules made easy**, *Christensen, Duhr, CPC'09*

☞ **A superspace module for the FeynRules package**, *Duhr, Fuks, CPC'11*

☞ **A Comprehensive approach to new physics simulations**, *Christensen, de Aquino, Degrande, Duhr, Fuks, Herquet, Maltoni, Schumann, E.P.J C71 '11*

☞ **UFO - The Universal FeynRules Output**, *Degrande, Duhr, Fuks, Grellscheid, Mattelaer, Reiter, CPC '12*

☞ **Introducing an interface between WHIZARD and FeynRules**, *Christensen, Duhr, Fuks, Reuter, Speckner, E.P.J. C72 '12*

☞ **Beyond the Minimal Supersymmetric Standard Model: from theory to phenomenology**, *Fuks, Int.J.Mod.Phys. A27 '12*

☞ **Spin-3/2 particles at colliders**, *Christensen, de Aquino, Deutschmann, Duhr, Fuks, Garcia-Cely, Mattelaer, Mawatari, Oexl, Takaesu, Eur. Phys. J. C73 (2013) 2580*

☞ **New developments in FeynRules**, *AA, Christensen, Degrande, Duhr, Fuks, arXiv:1309.7806*

☞ **FeynRules 2.0 - A complete toolbox for tree-level phenomenology**, *AA, Christensen, Degrande, Duhr, Fuks, arXiv:1310.1921*

# Spin-3/2 Rarita-Schwinger fields

## Implementing the field

- Spin-3/2 fields
  - ⇨ Described first by Rarita & Schwinger in 1941.
  - ⇨ Appears in some BSM theories (Gravitino in SUSY, e.g)
- In FeynRules { Lagrangian's dimensionality **unrestricted**. **Complete** superspace module. } **Everything is there !**
- Two **new classes** for field decalaration
  - ⇨ For two-component fermions `RW`
  - ⇨ For four-component fermions `R`

## In the case of supersymmetry

- Goldstino / Gravitino
  - ⇨ Spontaneous supersymmetry breaking ⇨ massless fermion.
  - ⇨ Its interactions given by supercurrent $\epsilon \cdot J^\mu + \bar\epsilon \cdot \bar J^\mu = \frac{\partial \mathcal{L}}{\partial(\partial_\mu X)} \delta_\epsilon X - K^\mu$
  - ⇨ FeynRules dedicated command `Supercurrent[lc,lv,lw,sp,mu]`

    `lc`: Chiral Lagrangian, `lv`: Vector Lagrangian, `lw`: Superpotential, `sp,mu`: Spin & Lorentz indices.
- UFO and CalcHEP interfaces **adapted**

☞ **Simulating spin-3/2 particle production at colliders**,
*Christensen, de Aquino, Deutschmann, Duhr, Fuks, Garcia-Cely, Mattelaer, Mawatari, Oexl, Takaesu*,
*Eur. Phys. J. C73 (2013) 2580*

# Decays package

- ⁂ Tree-Level two-body decay widths
  - ⇨ Are now **automatically** computed for any model

```
verts = FeynmanRules[LQCD];
results = ComputeWidths[verts];
```

  - ⇨ Everything is **analytical**

- ⁂ Phase-space closed channels included
  - ⇨ No information on the (numerical values of the) spectrum at this level
  - ⇨ Benchmark scenario **independent**

- ⁂ Information passed to the UFO `WriteUFO[LQCD, AddDecays -> True]`
  - ⇨ **Flexible**: closed formulas (NLO, n-body) can be included.

- ⁂ MadGraph 5[1]
  - ⇨ **checks** numerically open channels.
  - ⇨ compute **automatically** n-body decay widths

☞ **Computing decay rates for new physics theories with** FeynRules **and** MadGraph,
*Alwall, Duhr, Fuks, Mattelaer, Oeztürk*,
*In preparation*

[1] CalcHep calculates also **automatically** widths

# Spectrum generator

## Problem

- After generating the model file for the MC-generator, we need
  - ⇨ To calculate the mass matrices: Lengthy and error-prone
  - ⇨ Diagonalize them: No analytical solution for matrices bigger than $4 \times 4$
  - ⇨ Update the model file: Lengthy (several scenarios) and error-prone

## Solution

- FeynRules will
  - ⇨ extract automatically analytical expressions for mass matrices
  - ⇨ generate automatically a numerical code for the diagonalization
- The numerical code:
  - ⇨ produces a SLHA-like output

# Mass matrices generation with FeynRules

## Model file simplified

- Two new global variables `M$MixingDescription, M$vevs`
- Mass matrices, mixing matrices declared **automatically as complex**

## Commands available in FeynRules

- Compute mass matrices: `ComputeMassMatrix[lagr]`
- Summary of all results `MixingSummary[]`
- ...

## Towards a numerical code

- Write the C++ package: `WriteASperGe[Lagrangian]`
- Run the package and **import** results: `RunASperGe[]`

```
Block MASS
# pdg code mass particle
  22 0.000000e+00 # A
  23 9.180401e+01 # Z
```

☞ **Automated mass spectrum generation for new physics**,
*AA, D'Hondt, De Causmaecker, Fuks, Rausch de Traubenberg, E.P.J C73 '13*

# Conclusion

**Features of FeynRules 2.0**

- Model implementation minimal
- **Superspace** package
- Many interfaces to Monte Carlo tools
- Universal FeynRules Output
- Spectrum generator (with ASperGe).
- Decay package for $1 \to 2$ processes.
- Rarita-Schwinger spin-3/2 field implemented.
- LaTeX interface
- Major speed improvement and bug corrections.

`feynrules.irmp.ucl.ac.be`

**Thank you for your attention**

# The LaTeX interface

```
WriteLaTeXOutput[L1, L2, ... , V1, V2, ...]
```

`L1, L2,...` are Lagrangians
`V1, V2,...` are list of vertices

- The output
  - **title.tex**: Contains the title.
  - **abstract.tex**: Contains the abstract.
  - **introduction.tex**: Contains the introduction.
  - **symmetries.tex**: Contains information about the gauge symmetries and indices.
  - **fields.tex**: Contains information about the fields.
  - **lagrangians.tex**: Contains the Lagrangians.
  - **parameters.tex**: Contains information about the parameters.
  - **vertices.tex**: Contains the vertices.
  - **bibliography.tex**: Contains the bibliography.

$$\begin{pmatrix} \gamma & 1 \\ \phi^{++} & 2 \\ \phi^{--} & 3 \end{pmatrix} \qquad 2ie({p_2}^{\mu_1} - {p_3}^{\mu_1})$$