# Minimal Universal Extra Dimensions (MUED)

## Author

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## Description of the model & references

One popular aproach to solve the Hierarchy Problem of the Standard Model is to extend space-time to higher dimensions. In this framework, the usual four-dimensional space-time is contained in a four-dimensional brane embedded in a large structure with N additional dimensions, the bulk.

Here, we shall focus on the Universal Extra Dimensional theory, in which the usual Standard Model particles are free to propagate in the bulk. As a consequence, these particles will be seem on the effective theory as a tower of N 4-dimensional particles with the same quantum numbers, but with increasing masses. This is called the Kaluza-Klein tower. Momentum conservation in the 5-dimensional space-time generates a conserved Kaluza-Klein number, which implies that different Kaluza-Klein modes can not mix with eachother.

In this implementation, a theory with five dimensions is considered, in which the fifth dimension is spatial and compactified on a S1/Z2 orbifold of radius R. We start from the most general five-dimensional Lagrangian. FeynRules derives the four-dimensional lagrangian automatically by imposing dimensional reduction and integratig out the extra-coordinate y.

The minimal Universal extra dimensional model is given in:

- ?Physical Review D 66 (2002) 056006: H-C. Cheng, K.T. Matchev, M. Schmaltz, *Bosonic Supersymmetry? Getting fooled at the LHC.*

This implementation was based in another existing implementation in *CalcHEP*:

- ?mued.ps: A. Datta, K. Kong, K. T. Matchev, *Minimal Universal Extra Dimensions in* CalcHEP */CompHEP.*

The masses of Kaluza-Klein particles are computed via 1 loop:

- ?Physical Review D 66 (2002) 036005: H.-C. Cheng, K. T. Matchev, M. Schmaltz, *Radiative Corrections to Kaluza-Klein Masses.*

## Model files & extensions

### The MUED implementation:

- Main FeynRules files (as a tar-ball): MUED.tar.gz?.
- Run mued.fr. This is the main file. All the other files are called by this main file.
- Example of a Mathematica® notebook loading the model and the parameters: MUED.nb?.

## Instructions

The MUED is implemented in **unitary gauge**.

- The switch `FeynmanGauge` (future devlopments) must thus be set to `False`,
- To run it in !CalcHEP the switch `FeynmanGauge` must be set to `True` when asking the !CalcHEP output, and then to `False` before any run.
- In MadGraph, the maximal number of particles must be increased to run the model:
  - Increase the value of `max_particles` in `params.inc` in the `MadGraphII` directory from `2**7-1` to `2**8-1`
  - Remove all excecutables in the `MadGraphII` directory (`rm -rf *.o`).
  - recompile MadGraph by typing `make` in the MadGraph main directory.

## Validation

In order to validate our implementation, we have checked 118 processes using a center-of-mass energy of 1400 GeV. It was done the following way:

- **Comparison of the built-in Madgraph Standard-Model and FeynRules generated Madgraph MUED for Standard Model processes.** This comparison was done using squared matrix element at given phase-space points.
- **Comparison of the existing CalcHEP MUED (CH-ST) with the FeynRules generated ones in CalcHEP** *,* **Madgraph and Sherpa: CH-FR, MG-FR and SH-FR,** through the calculation of several **2-to-2** cross-sections. All the checks performed were conclusive.

- Validation Table - SM + Fermions (Cross sections given in pb): ValidationMUED.jpg
- Validation Table - Gauge (Cross sections given in pb): ValidationGauge?.jpg