1. Motivation

- Weakly Interacting Massive Particles are good candidates
- Neutralino in supersymmetric extensions of the SM
- 1st Kaluza-Klein (KK) photon in universal extra dimensions (UEDs)
- etc.

UEDs have many degenerate particles

This talk

Computing UED processes is tedious and error-prone

Public tools play a crucial role in obtaining reliable results

Goal of this work

- Automated computations of DM observables in the 5D UED

2. 5D UED

- Universal: All SM particles propagate in flat compact spatial extra dimensions

  [Appelquist, Cheng, Dobrescu, PRD64, 035002 (2001)]

- Minimal universal extra dimension (MUED):

  - All the SM particles propagate in the orbifold: \( S^1 / \mathbb{Z}_2 \)

  - Only two new parameters in the MUED:

    - \( R \): size of the extra dimension
    - \( \Lambda \): cutoff

  - Radiative corrections generate KK mass shift

  - The 1st KK mode of the photon is the LKP

3. Implementation of the 5D UED

3.1 Vertices

- Define 5D fields:

  Hypercharge B-boson
  [www.physics.gla.ac.uk]

- Define 5D vertices:

  EW interactions of LH fermions
  LanHEP

- 4D vertices:

  \[ p_{k_1} = n / R(n = 0, \pm 1, \pm 2, \cdots) \]

3.2 Goldstone boson/ghost

- Define 5D Goldstone/ghosts:

  \( \text{KK modes of gauge scalars} \)
  \( = \text{Goldstone modes} \)

- Define 5D Goldstone/ghost int.:

  \[ \text{Goldstone modes of gluons} \]
  LanHEP

- 4D Goldstone/ghost int.:

- Auxiliary fields needed to reconstruct 4-point gluon vertices

- Auxiliary fields and their int.

4. Describing KK mass shifts

- 5D Lorentz violating effects induce mass shifts from

  \[ \text{Vector} \]

  \[ \text{Fermion} \]

  \[ \text{Scalar} \]

  - The \( Z \)-factors are properly introduced in the Goldstone/ghost sector to retain gauge invariance

  - The MUED spectrum is obtained by adjusting the \( Z \)-factors

  - Covariant derivatives for the 5D Higgs doublet:

    - Zero mode Higgs vev
      \[ \text{Mixing between the KK Higgs bosons and KK gauge scalars} \]

    - CP even KK Higgs:
      \[ \text{Charged KK scalar} \]
      \[ \text{CP odd KK scalar} \]

5. 1st KK photon abundance

- Process overlooked in earlier works:

- All 1st and 2nd KK particles of 5-dimensional universal extra dimension model implemented in micrOMEGAs

  - Wave function factors violating 5D Lorentz invariance \( \rightarrow \) KK mass shifts are described in a gauge invariant manner

  - Finite Higgs vacuum expectation value in the Higgs sector \( \rightarrow \) Correct KK Higgs masses and interactions obtained

  - Precise computation of the relic abundance

6. Summary

[Belanger,MK,Pukhov,JCAP02(2011)009]

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