One Universal Extra Dimension in PYTHIA

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Abstract

The Universal Extra Dimensions model has been implemented in the PYTHIA generator from version 6.4.18 onwards, in its minimal formulation with one TeV⁻¹ sized extra dimension. The additional possibility of gravity-mediated decays, through a variable number of eV⁻¹ sized extra dimensions into which only gravity extends, is also available. The implementation covers the lowest-lying Kaluza-Klein (KK) excitations of Standard Model particles, except for the excitations of the Higgs fields, with the mass spectrum calculated at one loop. 2 → 2 tree-level production cross sections and KK number conserving 2-body decays are included. Mixing between iso-doublet and -singlet KK excitations is neglected thus far, and is expected to be negligible for all but the top sector.

1 Introduction

In the Universal Extra Dimensions (UED) model, first formulated in [1], all Standard Model (SM) fields are allowed to propagate into δ TeV⁻¹ sized extra dimensions. In its minimal formulation, the SM lives in 4 + δ(= 1) space-time dimensions. This model can be considered as an effective theory, valid below some cutoff scale Λ > 1/R, where R is the compactification length of the extra dimension. To avoid fine-tuning of the parameters in the Higgs sector, 1/R should also not be much higher than the electroweak scale. Such models can be shown to be consistent with all current low-energy and collider constraints [1–3].

If the UED space is further embedded into a larger space with N extra dimensions into which only gravity spreads [4], gravity mediated decays also become possible. In this case the (4 + N)-dimensional Planck scale MD should not be more than one or two orders of magnitude above 1/R [5].

Phenomenologically, UED models exhibit several interesting properties, often similar to those of supersymmetric (SUSY) models. Every SM field has a Kaluza-Klein (KK) partner (a whole tower of them in fact, but here we consider only the lowest-lying excitations), which carries a conserved quantum number, KK parity. This conserved parity, tracing its origin to extra-dimensional momentum conservation, renders the lightest KK particle (LKP) stable. Heavier KK modes cascade decay to the LKP by emitting relatively soft SM particles. The LKP escapes detection, generally resulting in missing energy signals. If the model is extended to include (N + 4)-dimensional gravity, then the LKP may decay further to its SM partner plus a low-mass graviton excitation, in which case a phenomenology more similar to that of SUSY models with gauge mediated SUSY breaking may arise [6, 7].

In the PYTHIA [8] implementation, the adjustable parameters for the default UED model (i.e., with no modification of the gravitational sector) are 1/R, Λ, and the number of quark flavours in the KK

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excitation spectrum, with default values of $1/R = 1$ TeV, $\Lambda = 20$ TeV, and $n_{f}^{KK} = 5$, respectively, while $\delta$ is fixed to the value of 1. Optionally, one may choose to adjust the value of $\Lambda \times R$ rather than that of $\Lambda$. For the variant of the model with $(4 + N)$-dimensional gravity, the number of $eV^{-1}$-sized extra dimensions, $N = 2, 4, \text{or} 6$, and the scale $M_D$ also enter as adjustable parameters, with default values of $N = 6$ and $M_D = 5$ TeV, respectively.

In Section 2, we give a brief description of the spectroscopy of the minimal UED model and in Section 3 extend it to include gravity mediated decays. In Section 4 the UED implementation in the PYTHIA generator is detailed. We conclude and give an outlook in Section 5.

2 One-dimensional UED spectroscopy

In one-dimensional UED, each SM particle has $n = 1, 2, 3, \ldots$ KK excitations, of squared mass

$$m_n^2 = m_{SM}^2 + n^2/R^2 \quad (1)$$

with the $n = 0$ state corresponding to the SM particle. So far, only the $n = 1$ excitations have been incorporated in PYTHIA. The compactification of the extra dimensions is assumed to conserve the extra-dimensional momentum components at tree level, resulting in conservation of KK number in the effective 4-dimensional model. Hence KK particles are always produced in pairs and there are no vertices involving only one non-zero KK mode.

At tree level, the mass spectrum at each KK level is highly degenerate for all SM particles with $m_{SM} \ll 1/R$, cf. eq. (1). However, first order radiative corrections, calculated in [9] and implemented in PYTHIA using the code from [10], lift this degeneracy by about 20% for strongly interacting particles, the heaviest being the excited gluon, and by less than 10% for leptons and EW bosons, the lightest being the excited photon (the LKP). With these mass splittings, the SM quark and gluon KK excitations cascade decay down to the LKP, which is stable (unless $(N + 4)$-dimensional gravity is switched on, see below). An example of a nondegenerate KK particle mass spectrum obtained with PYTHIA for representative values of the free parameters is shown in Figure 1. These results agree with [9].

![Pythia 6.4.20 UED - First level KK mass spectrum](image)

Figure 1: In the first figure is shown the KK particle mass spectrum of the first level KK states including radiative corrections [9], for $1/R = 500$ GeV, $\Lambda R = 20$ and $\alpha_s = 0.118$. The star (*) denotes a KK particle and the notations $D$ and $S$ indicate respectively the doublet and singlet KK fermions. In the second figure are shown the dominant (solid) and rare (dotted) decays of KK particles. The particles not denoted by a star (*) are SM.
In general, mixing can occur between the doublet and singlet KK states. This effect is strongly suppressed for the light-flavor KK states, but can be phenomenologically relevant for the KK top quark [1]. Nonetheless, since the excited top pair production is small compared to the sum of all KK processes at the LHC [11], neglecting the mixing should still be a reasonable approximation for observables that are not explicitly sensitive to the top flavor. In the current PYTHIA implementation, the effects of doublet-singlet mixing in the KK sector are thus neglected.

3 Gravity mediated UED decay widths

If the (4 + 1)-dimensional UED space (brane) is embedded into a larger space of (4 + N) dimensions (bulk), where N counts the number of eV$^{-1}$ sized extra dimensions into which only gravity propagates (with one of the N being parallel to the UED dimension), then gravity mediated decays also become possible [4]. The phenomenology of these decays then also depends on the (4 + N)-dimensional Planck scale $M_{D}$, introducing two additional free parameters in the model, N and $M_{D}$.

The graviton field appears as a massless particle with a tower of excited modes whose masses differ by order of eV. Most importantly, the graviton modes extending in the UED direction couple to KK particles. Hence KK particles may decay directly to SM particles by emitting such low-mass graviton excitations. While the coupling to each such mode is incredibly small, the modes are sufficiently densely spaced that, after summation (or, in the continuum approximation used for practical calculations, integration) over them, total transition rates relevant for collider phenomenology may occur. In general, the gravity-mediated decays will compete with the non-gravitational (mass-splitting) modes. If

$$\Gamma(\text{mass splitting}) > \Gamma(\text{gravity mediated})$$

then the gluon and quark excitations will cascade down to the excited photon $\gamma^*$ (LKP), which then will decay via $\gamma^* \rightarrow \gamma + G^(*)$. More details can be found in [12]. This decay is the only gravity-mediated mode that appears by default in the PYTHIA implementation when (N + 4)-dimensional gravity is switched on. The branching ratio for $\gamma^* \rightarrow \gamma + G^(*)$ is then 100%.

The remaining gravity mediated decays (of all other KK particles) are foreseen to be included in a future version and are currently available as a standalone add-on routine, $pygrav.f$, which can be downloaded from [14], with width expressions from [5, 13, 15].

The graviton mass in these decays is obtained by integrating the differential width taken from $[5, 13]$. The formulae for the mass splitting decay widths in PYTHIA were extracted from the code [10] and their dependence on $1/R$ is illustrated in Figure $\text{2}$, which is in agreement with [12].

4 PYTHIA implementation

The PYTHIA implementation of the UED particle spectrum, production processes, and decay modes is summarized here, after which we give a brief overview of the relevant user switches, parameters, and subroutines controlling the code.

4.1 PYTHIA UED particle spectrum, production processes and decay modes

In PYTHIA, in order to avoid confusion between chiral and weak eigenstates, the UED KK states are labeled following a slightly different convention than that so far adopted by the PDG. In the PDG, the

\footnote{This corrects a numerical problem in the implementation of [11].}
On the left-hand figure, the mass splitting decay widths are shown versus $1/R$ for the first level KK excitations of vector bosons for the following decays: $g \rightarrow d^* \bar{d}$, $W^{\pm} \rightarrow e^* e^*$, and $Z^* \rightarrow e^* e^-$. On the right-hand figure, the mass splitting decay widths are shown for the first level KK excitations of fermions: $q^* \bar{D}$, $q^* S$ (for up-type quarks; the width for down-type quarks is four times smaller) and $\ell^* D$. These plots were produced using PYTHIA 6.4.20 with $\Lambda_R = 20$.

KK particles are labeled such that for the fermions, the subscripts $L$ and $R$ denote that the fermion is respectively a doublet or a singlet under SU(2) (see Table 1 for first level excitations). However, these doublet and singlet UED excitations are ordinary Dirac fermions, which both have left- and right- handed chiral spinor components.

To avoid any confusion with helicity states, the notations $D$ (for doublet) and $S$ (for singlet) are used here instead of the PDG $L$ and $R$. Furthermore, the superscript (1) is replaced by a star (*) to correspond to the usual PYTHIA notation for extra-dimensional excitations. The relationship between the PYTHIA and PDG particle names is given in Table 1. We emphasize that these are only notational differences, of a purely cosmetic nature. We use the same numbers (particle codes) as the PDG, and our scheme is therefore fully compatible with theirs.

The UED states can be produced through nine new production processes (ISUB=311 to 319), listed in Table 2. These employ tree-level differential cross section expressions [5, 11] and their dependence on $1/R$ is illustrated in the two plots of Figure 3 (for default choices of all other PYTHIA parameters, such as the strong coupling, parton distributions, and renormalization and factorization scales). These can be compared to those in [5, 12]. UED processes generated using an external generator can of course also be interfaced, using the existing LHA [16] and LHEF [17, 18] interfaces, in which case PYTHIA will handle the subsequent decays, radiation, and fragmentation.

Finally, the mass-splitting decay modes as well as their typical branching ratios and widths are given in Table 3. Again, externally calculated branching ratios can also be interfaced, if so desired, using the existing interface to SLHA decay tables [19]. As mentioned previously, in this version of PYTHIA, the excited states of the Higgs are not implemented, and the only available gravity mediated decay is that of the excited photon, $\gamma^* \rightarrow \gamma + \phi^(*)$.
| PDG particle name | Particle code | PYTHIA particle name |
|------------------|---------------|----------------------|
| d$_{(1)}$ | 5100001 | d$_D^+$ |
| u$_{(1)}$ | 5100002 | u$_D^+$ |
| e$_{(1)}^-$ | 5100011 | e$_D^-$ |
| $\nu_{eL}$ | 5100012 | $\nu_{eD}$ |
| g | 5100021 | g |
| $\gamma^{(1)}$ | 5100022 | $\gamma^*$ |
| $Z^{(1)0}$ | 5100023 | $Z^{*0}$ |
| $W^{(1)+}$ | 5100024 | $W^{*+}$ |
| d$_{(1)}$ | 6100001 | d$_S^+$ |
| u$_{(1)}$ | 6100002 | u$_S^+$ |
| e$_{(1)}^-_R$ | 6100011 | e$_S^-$ |

Table 1: PDG and PYTHIA notations and codes for the first level KK excitations.

| ISUB | Production process | Note |
|------|--------------------|------|
| 311 | g + g → g$^*$ + g$^*$ | |
| 312 | g + q → g$^*$ + q$^*_D$; g$^*$ + q$^*_S$ | |
| 313 | q$_i$ + q$_j$ → q$^*_D$ + q$^*_D$; q$^*_S$ + q$^*_S$ | all $i, j$ |
| 314 | g + g → q$^*_D$ + q$^*_D$; q$^*_S$ + q$^*_S$ | |
| 315 | q + q → q$^*_S$ + q$^*_S$; q$^*_S$ + q$^*_S$ | |
| 316 | q$_i$ + q$_j$ → q$^*_D$ + q$^*_D$ | $i \neq j$ |
| 317 | q$_i$ + q$_j$ → q$^*_D$ + q$^*_D$; q$^*_S$ + q$^*_S$ | $i \neq j$ |
| 318 | q$_i$ + q$_j$ → q$^*_D$ + q$^*_D$; q$^*_S$ + q$^*_S$ | all $i, j$ |
| 319 | q$_i$ + q$_j$ → q$^*_D$ + q$^*_D$ | all $i, j$ |

Table 2: UED production processes and their associated PYTHIA ISUB process number.

4.2 PYTHIA user switches and subroutines for UED

The UED parameters which can be modified by the user are:

- the compactification scale or curvature of the extra dimension, $1/R$,
- the cutoff scale of the theory, $\Lambda$ (or, alternatively, $\Lambda \times R$),
- the number of quark flavors,
- whether to use the extension to $(4 + N)$-dimensional gravity and hence allow LKP decay by graviton emission, and if so,
- the number of large extra dimensions where only the graviton propagates, $N$,
- and the $(4 + N)$-dimensional Planck scale, $M_D$.

The Higgs boson mass is also a free parameter in the UED theory but it is set through the usual PYTHIA $\text{pmas}(25,1)$ parameter. In the code, the UED switches and parameters are stored in the new common block:
Figure 3: Cross sections for the production of two stable KK final states in proton-proton collisions at \( E_{cm} = 14 \) TeV (LHC), generated using Pythia 6.4.20. On the left-hand figure are shown the cross sections versus \( 1/R \) for quasi degenerate KK particle masses \( m_{KK} \simeq 1/R \) (user switch IUED(6)=0; see Section 4.2), for the different production sources: \( g g \), \( gq \) and \( qq \), and for the sum of the three. On the right-hand figure are shown the cross sections for the production of two hard photons with missing transverse energy in the final state, where KK particle masses include radiative corrections (IUED(6)=1, the user switch default value), and with the following kinematic cuts: \( p_{T}^{\gamma_1}, p_{T}^{\gamma_2} > 200 \) GeV/\( c \) and \( E_{T}^{miss} > 200 \) GeV, for \( N = 2 \) and 6. For all cases, \( \Lambda R = 20 \).

\[
\text{COMMON/PYPUED/IUED (0:99), RUED (0:99)}
\]

IUED (1) = The main UED ON(=1)/OFF(=0) switch
Default value = 0

IUED (2) = On/Off switch for the extension to \((N + 4)\)-dimensional gravity (switching it on enables gravity-mediated LKP decay): ON(=1)/OFF(=0)
Default value = 0

IUED (3) = The number of KK excitation quark flavors
Default value = 5

IUED (4) = \( N \), the number of large extra dimensions where only the graviton propagates. Only used when IUED (2)=1.
Default value = 6 (can be set to 2, 4 or 6)

IUED (5) = Selects whether the code takes \( \Lambda (=0) \) or \( \Lambda R (=1) \) as input. See also RUED (2:3).
Default value = 0

IUED (6) = Selects whether the KK particle masses include radiative corrections (=1) or are nearly degenerate \( m_{KK} \simeq 1/R (=0) \).
Default value = 1
| Decay mode | Branching ratio | Total Width (GeV) |
|------------|----------------|------------------|
| $l_*^S \rightarrow l + \gamma^*$ | 100% | $1.23 \times 10^{-1}$ |
| $d_*^S \rightarrow q + \gamma^*$ (except for $q = t$) | 100% | $1.39 \times 10^{-2}$ |
| $u_*^S \rightarrow q + \gamma^*$ (except for $q = t$) | 100% | $5.82 \times 10^{-2}$ |
| $\nu_D^s \rightarrow \nu + \gamma^*$ | 100% | $1.16 \times 10^{-3}$ |
| $l_D^s \rightarrow l + \gamma^*$ | 100% | $1.16 \times 10^{-3}$ |
| $q_D^s \rightarrow all$ | 100% | $1.56 \times 10^{-1}$ |
| $q_D^b \rightarrow q + Z^*$ (except for $q = b, t$) | 1/3 |
| $q_D^{b_i} \rightarrow q_j + W^*$ (except for $q = b, t$) | 2/3 |
| $b_D \rightarrow b + Z^*$ | 100% | $5.21 \times 10^{-2}$ |
| $t_D^* \rightarrow b + W^*$ | 100% | $1.04 \times 10^{-1}$ |
| $W^{*\pm} \rightarrow l^{\pm} + \nu_D^*$ (and $\nu + l_D^{*\pm}$) | 1/6 | $3.75 \times 10^{-1}$ |
| $Z^* \rightarrow \nu + \nu_D^*$ (and $\nu + \nu_D^*$) (and $1^+ + l_D^{*\pm}$) | 1/12 | $1.92 \times 10^{-1}$ |
| $g^* \rightarrow all$ | 100% | 53.9 |
| $g^* \rightarrow q + \bar{q}_S$ (and $q_S + \bar{q}$) (down type) | 6.4% |
| $g^* \rightarrow q + \bar{q}_S$ (and $q_S + \bar{q}$) (up type except for $q = t$) | 6.0% |
| $g^* \rightarrow q + \bar{q}_D$ (and $q_D + \bar{q}$) (except for $q = t$) | 3.8% |

Table 3: UED decay modes, branching ratios and widths for $1/R = 500$ GeV and $\Delta R = 20$. Note that certain decays are kinematically suppressed for lower values of $1/R$. This is the case when $1/R = 500$ GeV for $t_D^* \rightarrow t + \gamma^*$, $b_D \rightarrow t + W^*$, $t_D^* \rightarrow t + Z^*$ and $g^* \rightarrow t + \bar{t}_D^*$ or $g^* \rightarrow t + \bar{t}_D^*$. The $q_D^S \rightarrow Z^* + q$ and $Z^* \rightarrow l_D^* + l$ decays have been switched off due to the fact that they are suppressed by a factor $\sin^2 \theta_1$, the level 1 Weinberg angle which is of order $10^{-2} - 10^{-3}$, whereas the $W^* \rightarrow l_D^* + \nu$ decay is forbidden [20].

RUED (1) = $1/R$, the curvature of the extra dimension  
Default value = 1000 GeV

RUED (2) = $M_D$, the ($4 + N$)-dimensional Planck scale. Only used when IUED (2) = 1.  
Default value = 5000 GeV

RUED (3) = $\Lambda$, the cutoff scale. Used when IUED (5) = 0.  
Default value = 20000 GeV

RUED (4) = $\Lambda R$, the cutoff scale times the radius of the extra dimension. Used when IUED (5) = 1.  
Default value = 20

Four new subroutines and two new functions were added to handle UED-specific tasks:

SUBROUTINE PYXDIN to initialize Universal Extra Dimensions

SUBROUTINE PYUEDC to compute UED mass radiative corrections

SUBROUTINE PYXUED to compute UED cross sections

SUBROUTINE PYGRAM to generate the UED KK graviton mass spectrum

FUNCTION PYGRAW to compute UED partial widths to $G^*$

FUNCTION PYWDKK to compute UED differential widths to $G^*$
In addition, several PYTHIA routines were modified to facilitate the UED implementation. These are

- **SUBROUTINE PYGIVE** now accepts input also for IUED and RUED
- **SUBROUTINE PYINIT** added call to PYXDIN to initialize UED
- **SUBROUTINE PYMAXI** small extension for UED overestimates
- **SUBROUTINE PYPTFS** small extension for showering KK gluons
- **SUBROUTINE PYRAND** extended to choose flavors in UED processes
- **SUBROUTINE PYRESD** added call to PYGRAM to choose graviton mass from continuous spectrum in UED decays to gravitons
- **SUBROUTINE PYSCAT** extended to include UED processes
- **SUBROUTINE PYSIGH** small extension to call PYXUED for UED
- **SUBROUTINE PYWIDT** extended to compute KK decay widths

## 5 Conclusion and outlook

The minimal UED (mUED) model with one extra dimension has been implemented in the PYTHIA generator from version 6.4.18 onwards. The additional possibility of gravity mediated decays has also been included. The model uses 1-loop corrected mass formulae and tree-level expressions for cross section and decay width calculations.

The main point of this work is to facilitate complete collider phenomenology studies of UED signatures, by combining the leading-order production and decay matrix elements discussed in the main body of this paper with the more traditional components of the PYTHIA generator: sequential resonance decays, parton showers, hadronization, and modeling of the underlying event. Due to the typically large absolute mass scales and relatively small mass differences in the mUED model, additional QCD jets from initial-state radiation can be an important source of combinatorial error when attempting to identify the jets emitted in decays of colored KK particles. The UED implementation is compatible with both the old ($Q^2$-ordered [23–25]) and new ($p^2_\perp$-ordered [26]) shower and underlying-event models available in PYTHIA 6.4. Hopefully, this will make it easier to evaluate not only the overall impact of the QCD corrections, but also to gain some insight into their uncertainties. Large QCD uncertainties may sometimes be reduced by the application of matrix-element-to-parton-shower matching methods (see, e.g., the reviews in [22, 27–29]), but this was deemed beyond the scope of the present work.

This work was started at the Les Houches Workshop in 2005 [30] first using the CalcHEP and CompHEP event generators [31] and since then ongoing work has been carried out in the ATLAS [32–34], International GDR [35], and MC4BSM [36] contexts.

The next step will be to implement the model in C++ in PYTHIA8 [37]. We furthermore intend to include the whole set of gravity mediated decay widths, but deemed this low priority at present, since only a small region of parameter space is concerned, where the mass splitting and gravity mediated widths are of the same order of magnitude. Likewise, for studies concentrating on the top sector, the doublet-singlet mixing effects in the KK top sector should be included. Finally, it would be interesting

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2 As an alternative to the decays included in this implementation, externally generated decay tables for the UED particles can also be read in, e.g., using the SLHA format [19].

3 For illustration, see, e.g., the corresponding case for SUSY, studied in [21, 22].
to include also the excitations of the SM Higgs fields as well as the effects of potentially resonant KK number violating interactions mediated by the 2nd level KK states [9, 20, 38].

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References

[1] T. Appelquist, H.-C. Cheng, B.A. Dobrescu, Phys. Rev. D64 035002 (2001) [hep-ph/0012100].
[2] T. Appelquist and H. U. Yee, Phys. Rev. D67 (2003) 055002 [hep-ph/0211023].
[3] C. Lin, FERMILAB-THESIS-2005-69, CDF Note 7980 (2005).
[4] A. DeRujula, A. Donini, M.B. Gavela and S. Rigolin, Phys. Lett B482 (2000) 195 [hep-ph/0001335].
[5] C. Macesanu, C.D. McMullen and S. Nandi, Phys. Rev. D66 (2002) 015009 [hep-ph/0201300].
[6] J. L. Feng, A. Rajaraman and F. Takayama, Phys. Rev. D68 (2003) 085018 [hep-ph/0307375].
[7] N. R. Shah and C. E. M. Wagner, Phys. Rev. D74 (2006) 104008 [hep-ph/0608140].
[8] T. Sjöstrand, S. Mrenna and P. Skands, JHEP05 (2006) 026 [hep-ph/0603175].
[9] H. Cheng, K. Matchev and M. Schmaltz, Phys. Rev. D66 (2002) 036005 [hep-ph/0204342].
[10] C. Macesanu, private communication. Routine for calculating radiative corrections to the KK excitation masses and their mass splitting decay widths. See http://wwwlapp.in2p3.fr/~przys/macesanu.f.
[11] P.-H. Beauchemin and G. Azuelos, ATL-PHYS-PUB-2005-003.
[12] C. Macesanu, C.D. McMullen and S. Nandi, Phys. Lett B546 (2002) 253-260 [hep-ph/0207269].
[13] C. Macesanu Int. J. Mod. Phys. A21 (2006) 2259 [hep-ph/0510418].
[14] The pygrav.f subroutine for calculating gravity mediated decay widths is available at http://wwwlapp.in2p3.fr/~przys/pygrav.f.

[15] C. Macesanu, A. Mitov and S. Nandi, Phys. Rev. D68 (2003) 084008 [hep-ph/0305029].

[16] E. Boos et al., hep-ph/0109068.

[17] J. Alwall et al., Comput. Phys. Commun. 176 (2007) 300 [hep-ph/0609017].

[18] J. Alwall et al., arXiv:0712.3311 [hep-ph].

[19] P. Skands et al., JHEP 0407 (2004) 036 [hep-ph/0311123].

[20] H. Cheng, K. Matchev and M. Schmaltz, Phys. Rev. D66 (2002) 056006 [hep-ph/0205314].

[21] T. Plehn, D. Rainwater and P. Skands, Phys. Lett. B 645 (2007) 217 [arXiv:hep-ph/0510144].

[22] J. Alwall, S. de Visscher and F. Maltoni, arXiv:0810.5350 [hep-ph].

[23] T. Sjöstrand, Phys. Lett. B 157, 321 (1985).

[24] M. Bengtsson and T. Sjöstrand, Phys. Lett. B 185 (1987) 435; Nucl. Phys. B 289 (1987) 810.

[25] T. Sjöstrand and M. van Zijl, Phys. Rev. D 36 (1987) 2019.

[26] T. Sjöstrand and P. Z. Skands, Eur. Phys. J. C 39 (2005) 129 [arXiv:hep-ph/0408302].

[27] S. Mrenna and P. Richardson, JHEP 0405 (2004) 040 [arXiv:hep-ph/0312274].

[28] M. A. Dobbs et al., arXiv:hep-ph/0403045.

[29] S. Höche, F. Krauss, N. Lavesson, L. Lönnblad, M. Mangano, A. Schälicke and S. Schumann, arXiv:hep-ph/0602031.

[30] B.C. Allanach et al., FERMILAB-CONF-06-338-T, SLAC-PUB-11770, Feb. 2006 [hep-ph/0602198].

[31] For information on MUED in CalcHEP/CompHEP, see K.C. Kong’s page, http://home.fnal.gov/~kckong/mued

[32] See ATLAS UED Twiki page, https://twiki.cern.ch/twiki/bin/view/Atlas/UniversalExtraDimensions

[33] See talk given by H. Przysiezniak in the ATLAS Exotics Meeting 06.12.2007, “Pythia UED validation with ATLAST”, http://indico.cern.ch/conferenceDisplay.py?confId=24100

[34] See talk given given by H. Przysiezniak in the ATLAS Monte Carlo Generator Meeting 10.12.2007, “Universal Extra Dimensions in Pythia”, http://indico.cern.ch/conferenceDisplay.py?confId=10890

[35] See talk given given by H. Przysiezniak at the EURO-GDR 2007 International Meeting in Brussels 12-14.11.2007, “Tools for Extra-Dimensions”, http://indico.in2p3.fr/conferenceOtherViews.py?view=standard&confId=422
[36] See talk given by H. Przysiezniak at the MC4BSM-3 Workshop 10-11.03.2008, “Minimal and Gravity Mediated Universal Extra Dimensions in Pythia”,
http://indico.cern.ch/contributionDisplay.py?contribId=36&confId=27006

[37] T. Sjöstrand, S. Mrenna and P. Skands, *Comput. Phys. Commun.* **178** (2008) 852 [arXiv:0710.3820 [hep-ph]].

[38] A. Datta, K. Kong and K. T. Matchev, *Phys. Rev. D* **72** (2005) 096006 [Erratum-ibid. D **72** (2005) 119901] [arXiv:hep-ph/0509246].