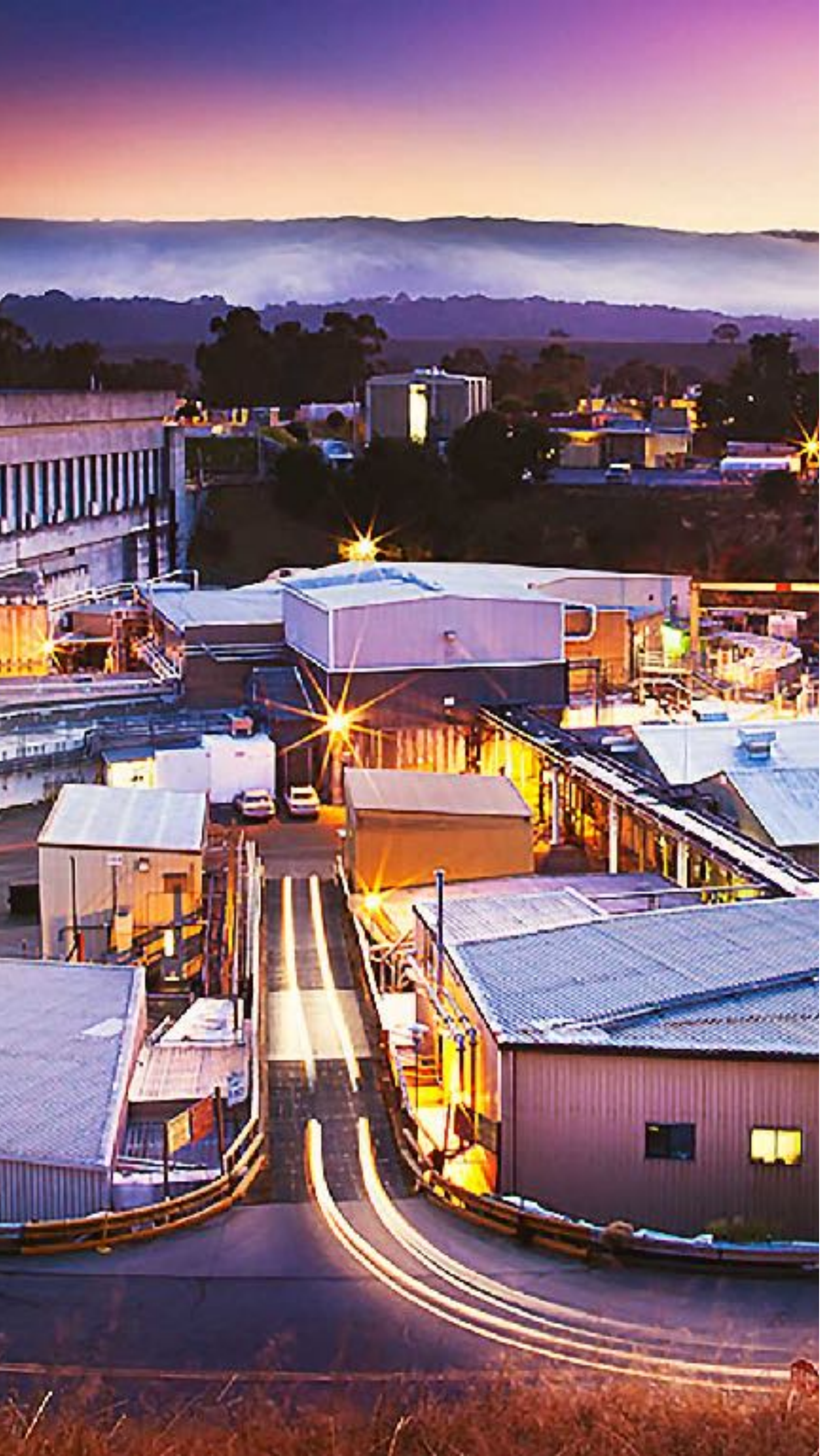

MC4BSM 2017
May 11-13; SLAC

BSM with Pythia 8

Nishita Desai (for the Pythia8 Collaboration)

Computer Physics Communications 191 (2015) 159–177

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An introduction to PYTHIA 8.2[☆]

Torbjörn Sjöstrand[a,*], Stefan Ask[b,1], Jesper R. Christiansen[a], Richard Corke[a,2], Nishita Desai[c], Philip Ilten[d], Stephen Mrenna[e], Stefan Prestel[f,g], Christine O. Rasmussen[a], Peter Z. Skands[h,i]

- 4 public versions (current 8.226) + 3 new authors (Ilkka Helenius, Leif Lönnblad, Nadine Fischer) since 8.200.
- Addition of gamma gamma, gamma hadron processes
- New UserHooks, possible for user to write own ME+PS plugins
- New Python interface, interface to MG5_aMC@NLO
- Automated parton-shower uncertainty bands

The challenge of BSM searches @ LHC

- How does the BSM physics behave? Produce new particles, distribution shape changes, …
  - Leading order (often tree-level) is enough for a smoking gun, NLO to follow if needed.

- What does SM look like?
  - Since much larger cross sections than BSM, high precision needed, i.e. N(N)LO calculations are needed.
  - Specialised generators + merging techniques needed

In Pythia 8, we have a large number of BSM processes + interfaces to external generators + sophisticated LO/NLO merging

A LARGE LIST OF BSM PROCESSES

Process Selection
-- QCD
-- Electroweak
-- Onia
-- Top
-- Fourth Generation
-- Higgs
-- SUSY
-- New Gauge Bosons
-- Left-Right Symmetry
-- Leptoquark
-- Compositeness
-- Hidden Valleys
-- Extra Dimensions
-- Dark Matter

- BSM Higgs: Generic 2 Higgs doublet model
  - Flexible Yukawa assignments to get type I/II/III/IV models
  - EFT operators for anomalous couplings to gauge bosons
  - CP violation possible
- New Gauge bosons
  - Z′ with full interference with gamma
  - W′
  - Horizontal gauge boson R
- L-R symmetry
  - Z_R and W_R bosons corresponding to right-handed SU(2)

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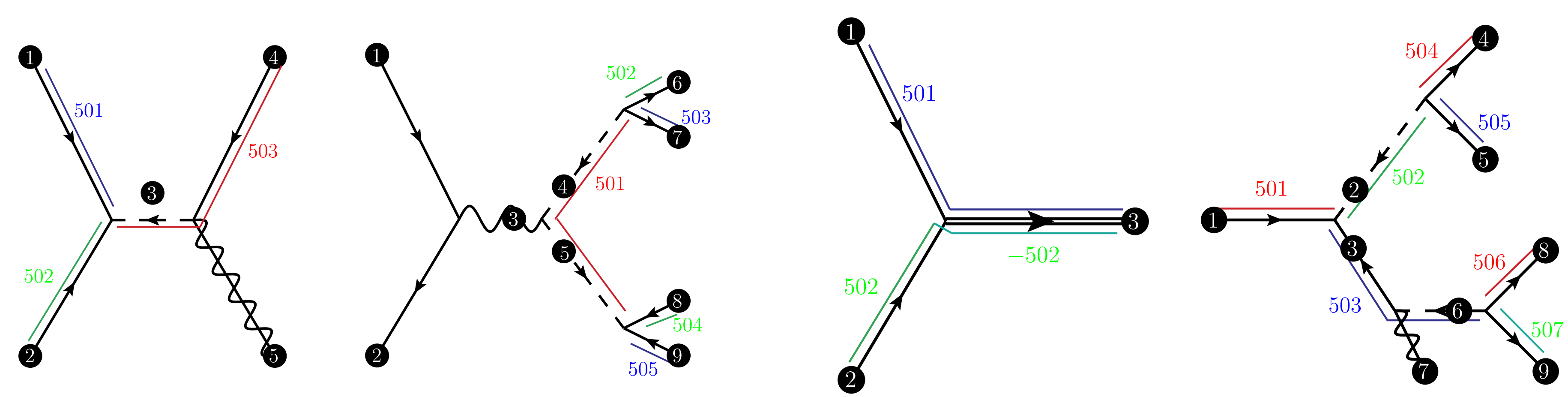
- 6x6 squark/slepton matrices allow processes with: CP/Flavour/R-parity violation
- All pair-production, RPV resonant production, and two-body decays
- Up to four body decays of staus (long-lived)
- Can handle extra Higgses/higgsinos from NMSSM
- Capable of hadronising exotic states i.e. baryon-number violating RPV, R-hadrons, (and also sextets, though not really SUSY)



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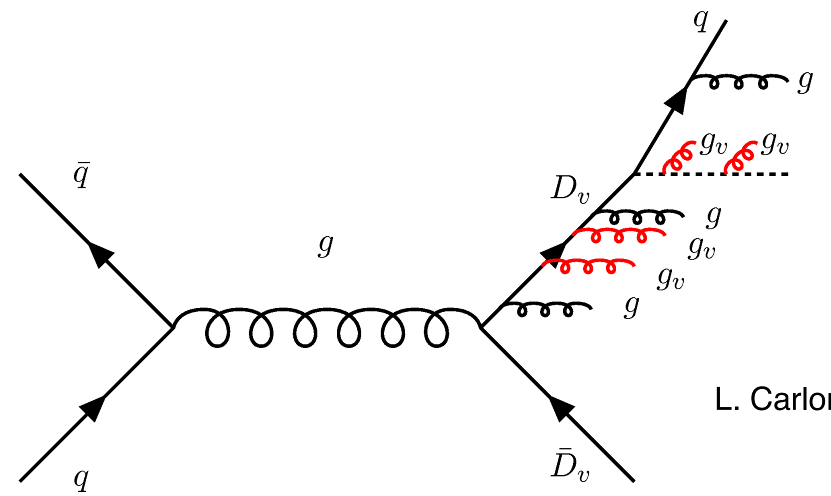
Showering and hadronisation in the presence of hidden gauge group



L. Carloni and T. Sjöstrand, JHEP 1009 (2010) 105

L. Carloni, J. Rathsman and T. Sjöstrand, JHEP 1104 (2011) 091

- Mediator particles charged under both groups
- Normal QCD, QED radiation
- Radiation into hidden valley photons (which then decay to SM via mixing with SM gauge bosons)
- Radiation into hidden valley gluons which forms hidden sector mesons

Possible to use this implementation to study exotic signatures See e.g. “Emerging Jets” documented in Schwaller et al. JHEP 1505 (2015) 059 including modified running of dark sector couplings.

A LARGE LIST OF BSM PROCESSES

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- -- Hidden Valleys
- -- Extra Dimensions
- -- Dark Matter

- Extra dimensions
  - Randall-Sundrum
  - Large Extra-dim
  - Unparticles
- Dark Matter PRELIMINARY
  - DM searches at the LHC are essentially mono-X searches
  - Currently, we have one mono-jet production mechanism for Dirac DM with vector mediator
  - New Dark matter mono-X processes in progress

Links to external programs

- Les Houches Accord
- SUSY Les Houches Accord
- HepMC Interface
- ProMC Files
- Semi-Internal Processes
- Semi-Internal Resonances
- MadGraph5 Processes
- HelacOnia Processes
- Alpgen Event Interface
- Matching and Merging
  - POWHEG Merging
  - aMC@NLO Matching
  - CKKW-L Merging
  - Jet Matching
  - UMEPS Merging
  - NLO Merging
- User Hooks
- Hadron-Level Standalone
- External Decays
- Beam Shape
- Parton Distributions
- Jet Finders
- Random Numbers
- Implement New Showers
- RIVET usage
- ROOT usage
- A Python Interface

- Interface to LHAPDF or other external PDF libraries.
- External showers (e.g. VINCIA, DIRE)
- Les Houches Accord files for reading events (LHEF) or runtime LHA interface.
- Semi-internal processes*
- HepMC output for programs like RIVET, Delphes etc.
- Can be compiled as a plugin to ROOT.
- Generalised SLHA input for any BSM model.*
- Python interface
- Plugin to generate events using MG5_aMC@NLO from within Pythia8 (using gridpack)

Change default behaviour with UserHooks

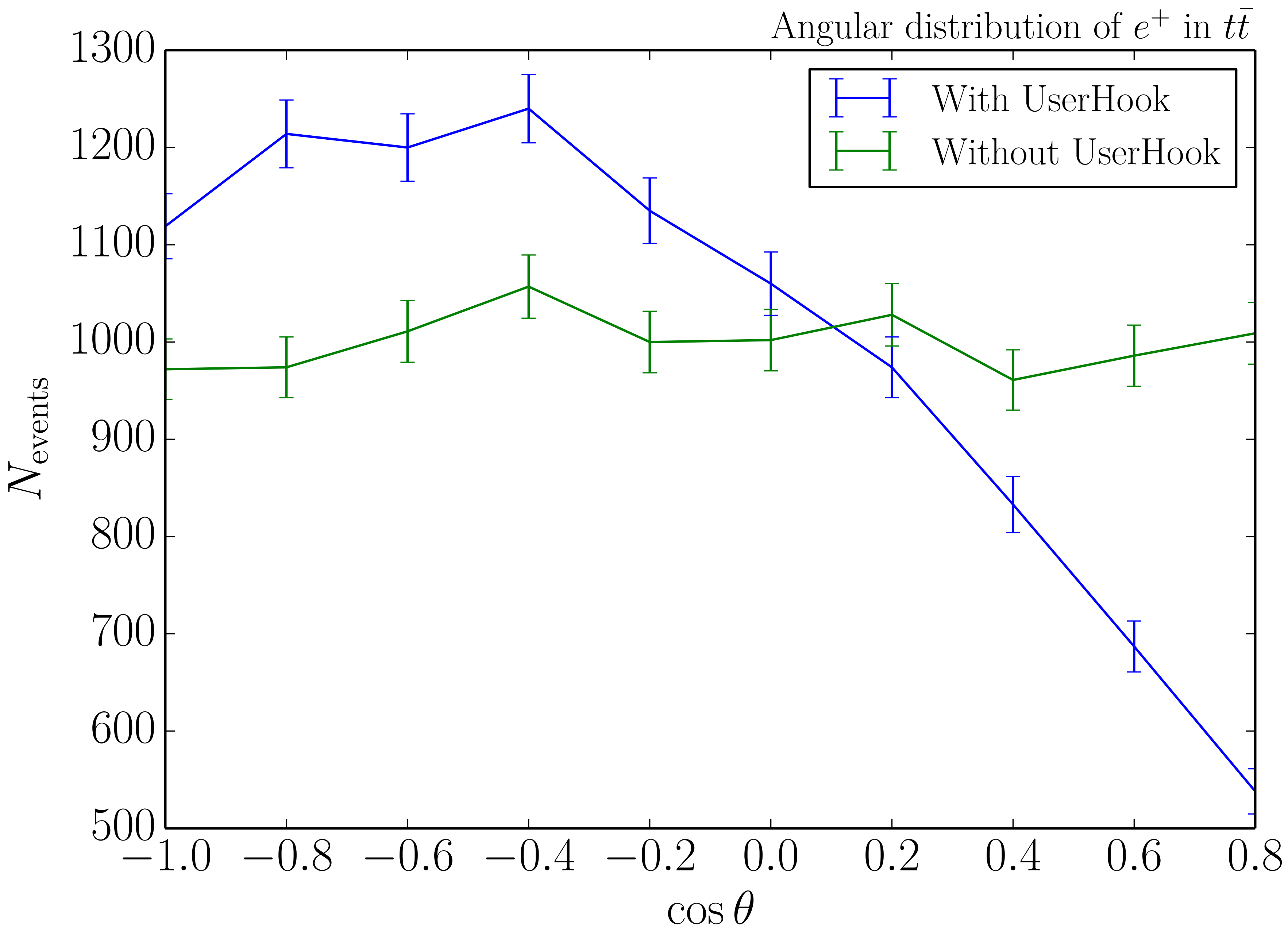
UserHooks allow interruption of event generation at different stages.

- After setting up beams
- After generating hard process
- During showers (veto emissions etc.)
- After showers (but before hadronisation)
- During hadronisation
- Modify cross section
- Reject certain decays (or decay chains)
- Add vertex information (e.g. for particles produced during showers)
- …

USERHOOK EXAMPLE: ANGULAR DISTRIBUTION IN DECAY

Change angular distribution of products of W based on polarisation from flat to $(1 \pm \cos\theta)^2$ or $\sin^2\theta$ for (+, –, 0)

(see example main62)



Add your own hard process using semi-internal processes

You can use the entire Pythia internal machinery by supplying only the matrix-element-squared for your process in terms of Pythia's kinematic variables.

see example main22

- In-built classes for $2\to1, 2, 3$ processes that the user can inherit from to write own ME using standard kinematic variables
- Possible to use your own phase space generator if desired
- New resonances can be added similarly for using "semi-internal resonance" for automatic calculation of width
- Any new parameters needed by your theory can be provided using the extended SLHA interface.

GIVE EXTERNAL PARAMETERS WITH YOUR OWN SLHA BLOCKS

LHE files already allow a lot of flexibility; new particles can be specified with quantum numbers

particle ID   particle name

```
BLOCK QNUMBERS 7654321 # balleron
      1     0  # 3 times electric charge
      2     2  # number of spin states (2S+1)
      3     8  # colour rep (1: singlet, 3: triplet, 6: sextet, 8: octet)
      4     0  # Particle/Antiparticle distinction (0=own anti)
```

particle name   anti-particle name

```
BLOCK QNUMBERS 8765432 # yup yupbar
      1     2  # 3 times electric charge
      2     2  # number of spin states (2S+1)
      3     3  # colour rep (1: singlet, 3: triplet, 6: sextet, 8: octet)
      4     1  # Particle/Antiparticle distinction (0=own anti)

 BLOCK MASS
 #      ID code   pole mass in GeV
        7654321    800.0   # m(balleron)
        8765432    600.0   # m(yup)

 #           ID       WIDTH in GeV
 DECAY    7654321   2.034369169E+00   # balleron decays
 #     BR                  NDA        ID1        ID2        ID3
       9.900000000E-01     3          6          5          3    # BR( -> t b s )
       1.000000000E-02     3          4          5          3    # BR( -> c b s )
```

GIVE EXTERNAL PARAMETERS WITH YOUR OWN SLHA BLOCKS

```
BLOCK MYPARAMS
# Parameters for my BSM theory
#   No     Value
      1     1.0e-2  # some small parameter
      2     2000    # some large parameter

BLOCK NEWMIXING
# Mixing for new particles
  1       1    0.50
  1       2    0.87
  1       3    0.00
  2       1    0.87
  2       2    0.50
  2       3    0.00
  3       1    0.00
  3       2    0.00
  3       3    1.00
```

These can be accessed from your process via the extended SLHA interface

```
bool slhaPtr->getEntry(string blockName, double& val);
bool slhaPtr->getEntry(string blockName, int indx, double& val);
bool slhaPtr->getEntry(string blockName, int indx, int jndx, double& val);
bool slhaPtr->getEntry(string blockName, int indx, int jndx, double& val);
```

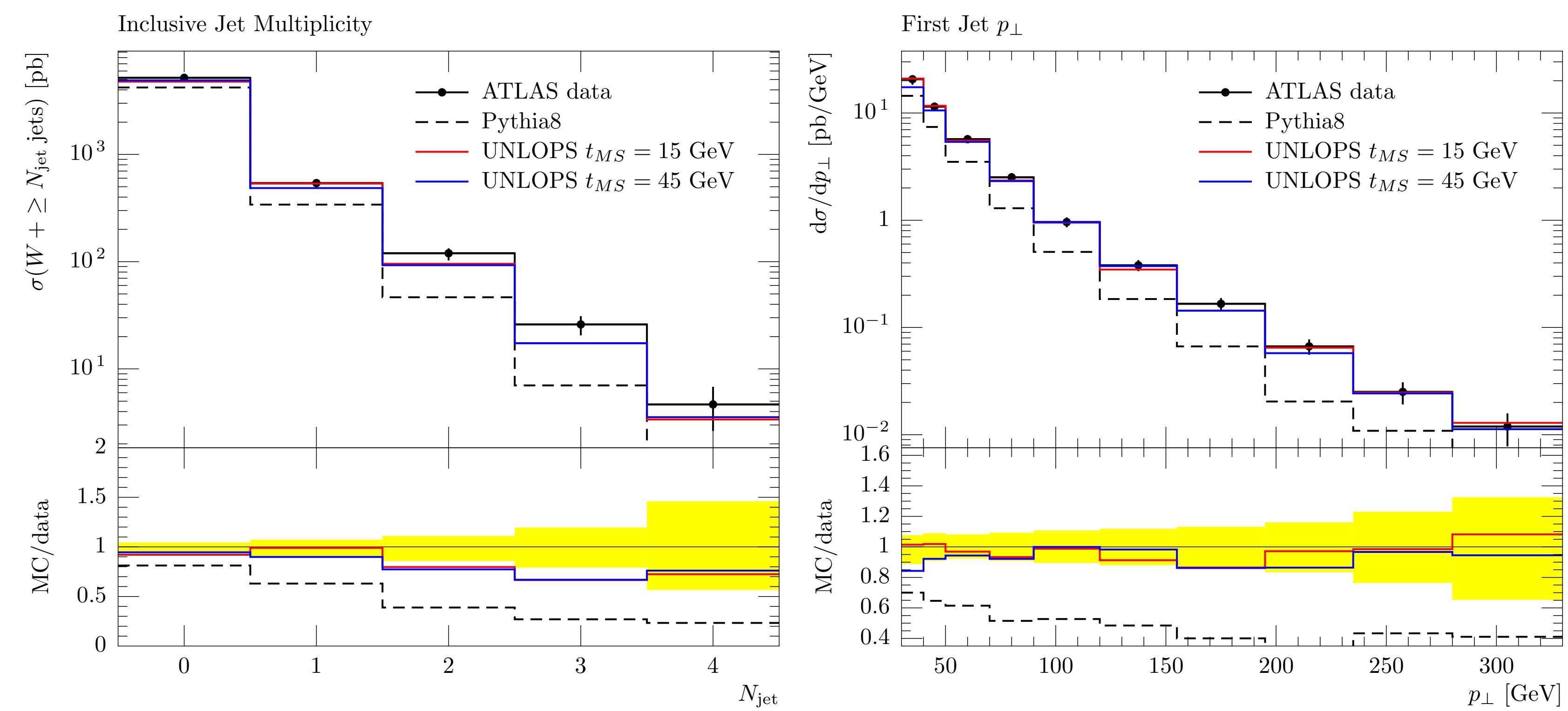
Matching and Merging

Matching and Merging
- -- POWHEG Merging
- -- aMC@NLO Matching
- -- CKKW-L Merging
- -- Jet Matching
- -- UMEPS Merging
- -- NLO Merging

A range of matching and merging algorithms are available as plugins

- At tree-level: MLM, CKKW-L, UMEPS
- At NLO: FxFx, UNLOPS, NL^3

See examples main80-89 for details



Lonnblad and Prestel; JHEP(2013) 2013:166

NEW: User can write own ME+PS plugin using classes Merging() and MergingHook()

Talk to Stefan Prestel to know more

Automated Shower Uncertainty Bands/Weights

Mrenna, Skands Phys.Rev. D94 (2016) 074005

Idea: perform a shower with nominal settings

Ask: what would the probability of obtaining this event have been with **different choices** of μ_R, radiation kernels, … ?

Easy to calculate **reweighting factors**

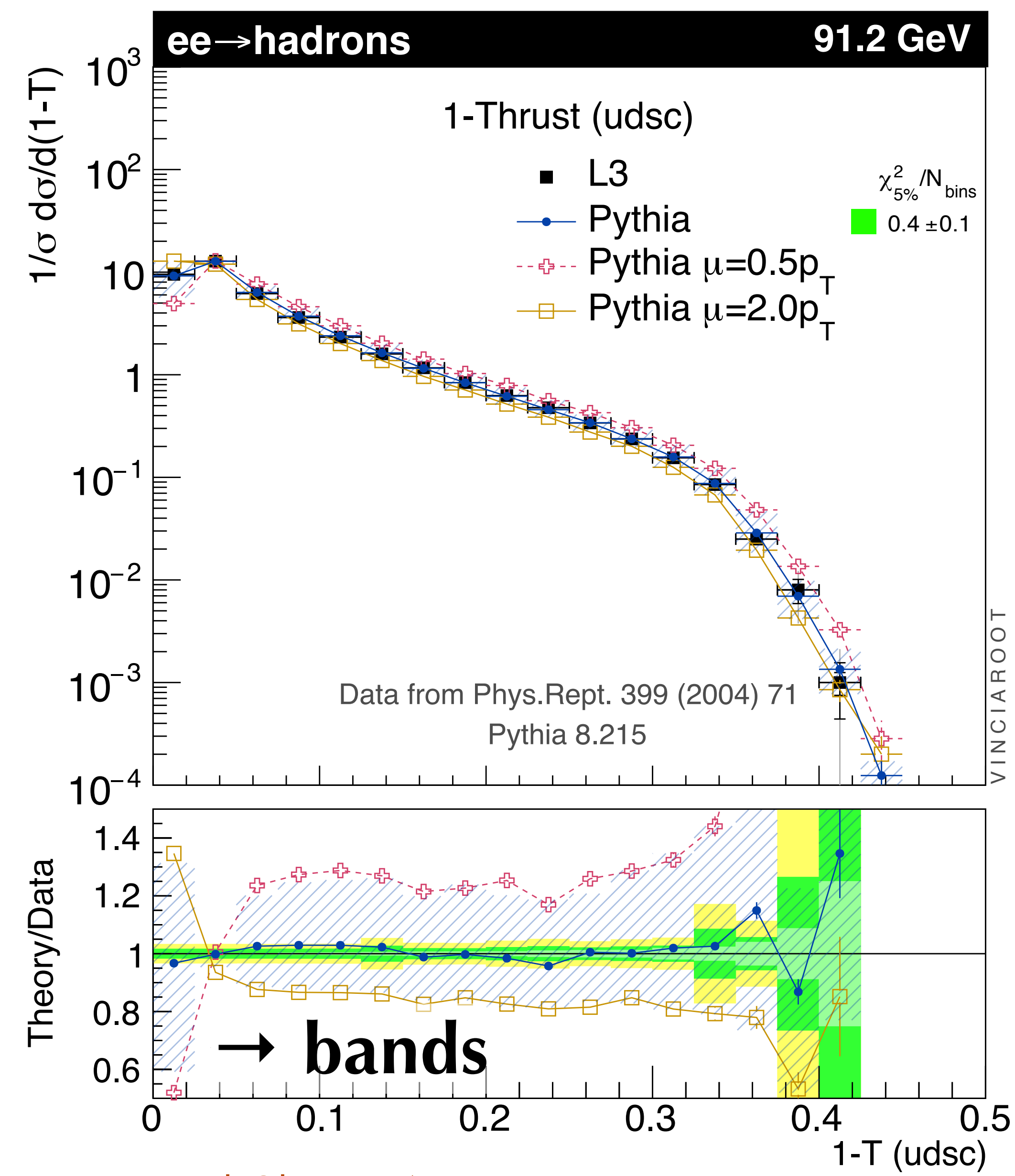
In MC accept/reject algorithm:

for **all** branchings

∀ *Accepted Branchings:* $$R'_{\rm acc}(t) = \frac{P'_{\rm acc}(t)}{P_{\rm acc}(t)}$$

∀ *Rejected Branchings:* $$R'_{\rm rej}(t) = \frac{1 - P'_{\rm acc}(t)}{1 - P_{\rm acc}(t)}$$

Giele, Kosower, Skands PRD84 (2011) 054003



Output: **vector of weights** for each event

One for the nominal settings (unity)

+ Alternative weight for each variation

(Note: similar functionality also recently implemented in Herwig++ and Sherpa)

SUMMARY

- Hundreds of BSM production processes already available
- Links to external ME generators via LHE, or via “semi-internal processes”
- Modular, very versatile: you can modify/overload cross sections, decays, showers, phase space, hadronisation.
- Sophisticated matching/merging machinery

- For more information, go to the online manual at: http://home.thep.lu.se/~torbjorn/pythia82html/Welcome.html
- Capabilities of Pythia8 demonstrated in ~90 examples