BSM Physics with Sherpa

[arXiv:1412.6478]

MC4BSM 9, Fermilab

Silvan Kuttimalai

Institute for Particle Physics Phenomenology, Durham

May 18, 2015

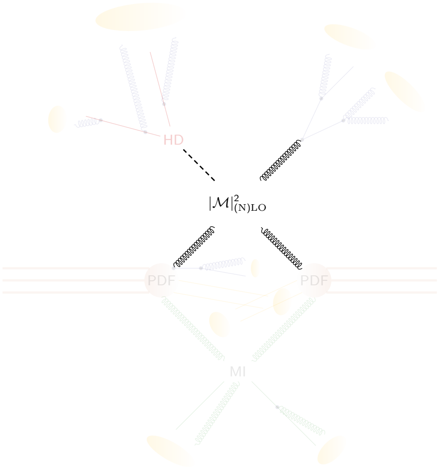
Outline

1. Overview

2. Simulating BSM Physics with Sherpa

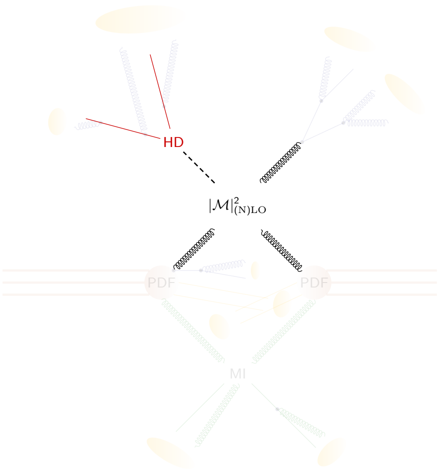
Outline

The Hard Process: LO and NLO Matrix Elements



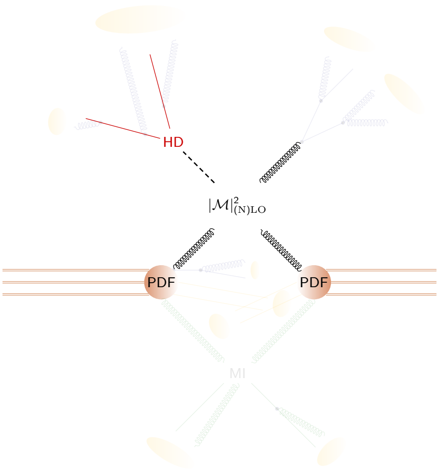
- Automated tree-level ME generators: Comix/Amegic
- Fully automated phase space integration
- Fully automated Catani-Seymour dipole subtraction
- Library of hard-coded 1-loop MEs
- Interfaces to external 1-loop providers
  - OpenLoops/Collier
    [Phys.Rev.Let. 108 (2012) 111601, arXiv:1111.5206]
  - BlackHat
    [arXiv:1001.1307]
  - MCFM
    [Nucl.Phys.Proc.Suppl. 205-206 (2010) 10, arXiv:1007.3492]
  - GoSam via BLHA
    [Eur.Phys.J. C72 (2012) 1889, arXiv:1111.2034]
    [Comput.Phys.Commun. 181 (2010), arXiv:1001.1307]
- NNLO accuracy for selected processes

Decays of Heavy Resonances: NWA



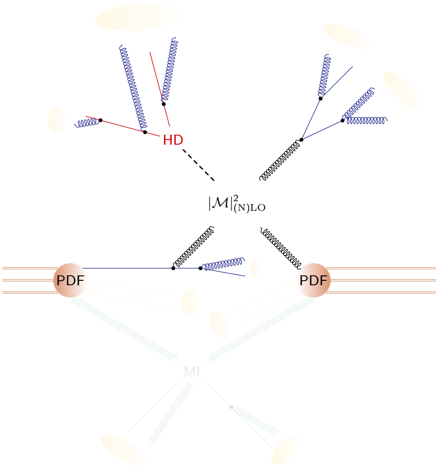
- Factorized decays in narrow-width approximation
- Automatic calculation of LO branching ratios
- On-shell production of heavy resonances
- Subsequent fully spin-correlated simulation of decay chains
- LO decays on top of NLO processes

Beams and PDFs



- PP collisions
- $\bar{P}P$ collisions
- e^+e^- collisions
- DIS (e^-P)
- Various built-in PDFs
- Interface to LHAPDF

Adding the Parton Shower



- Parton shower based on Catani-Seymour dipole subtraction

  [Schumann, Krauss, JHEP 03 (2008) 038, arXiv:0709.1027]
- Seamlessly integrated with NLO subtraction scheme
- Automated matching to fixed order NLO matrix Elements: S-MC@NLO
- Fully automated LO and NLO matrix element corrections can be employed (CKKW merging)

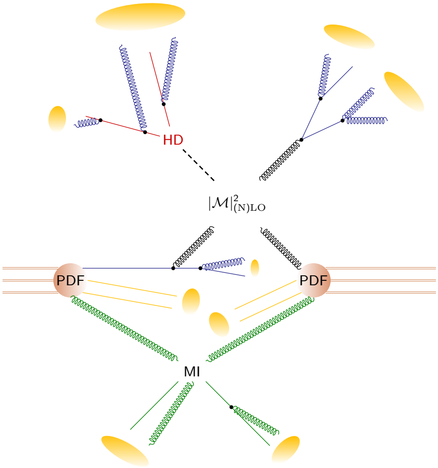
  [Hoeche et al., JHEP 1304 (2013) 027, arXiv:1207.5030]

  [Gehrmann et al., JHEP 1301 (2013) 144, arXiv:1207.5031]
- NNLO matching in UNLOPS scheme (DY, H inclusive)

  [Hoeche et al., Phys. Rev. D91 (2015) 74015, arXiv:1405.3607]

  [Hoeche et al., Phys. Rev. D90 (2014) 54011, arXiv:1407.3773]

Non-Perturbative Aspects

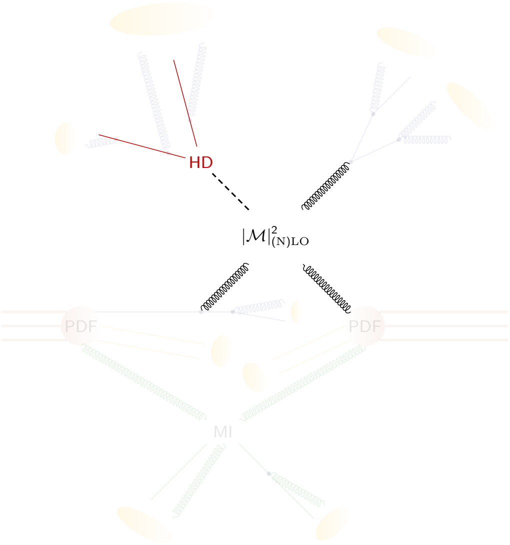


- Multi-parton interactions
  [Sjostrand, van Zijl, Phys. Rev. D36 (1987) 2019]
- Built-in cluster fragmentation module
- Interface to Pythia's string fragmentation
- Hadron decay module with full spin-correlations
- Tau decays: either as hard decay or hadron decay

Outline

Hard Processes in BSM Scenarios

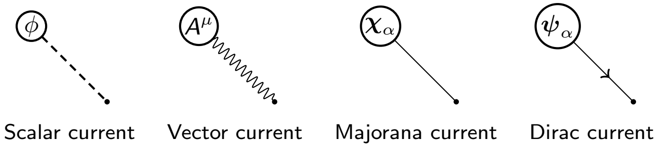
- Collider searches:
  look for new physics at
  high energy scales
- Need scattering amplitudes
  for BSM models
- Ingredients:
  - Particles/fields
  - Interactions
  - Consistent parametrization



Scattering Amplitudes with Comix: Building Blocks

Matrix Elements with Comix

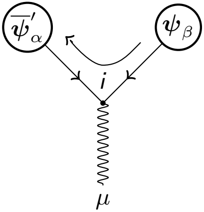
- Non-diagrammatic approach: Berends-Giele type recursions
- Highly efficient for multi-leg amplitudes
- Generates amplitudes on the fly
- Computes amplitudes in terms of *currents*



Scattering Amplitudes with Comix: Building Blocks

Matrix Elements with Comix

- Non-diagrammatic approach: Berends-Giele type recursions
- Highly efficient for multi-leg amplitudes
- Generates amplitudes on the fly
- Computes amplitudes in terms of *currents*



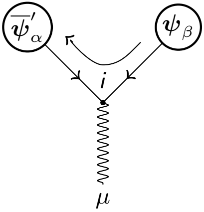
$$= \sum_{\alpha,\beta} \overline{\psi}'_\alpha \Gamma^\mu_{\alpha\beta} \psi_\beta = e\overline{\psi}_a(\gamma^\mu)_{ab}\psi_b$$

- Couplings
- Lorentz structure
- Color structure

From the Lagrangian to Events: the Old-Fashioned Way

Parametrization
Particle Spectrum
Vertices
Lorentz Structures
Colour Structures
Coupling Constants

$\xrightarrow[\text{by hand}]{\text{Hard-wire}}$ Sherpa $\xrightarrow{\text{Generate}}$ Events



$$= \sum_{\alpha,\beta} \overline{\boldsymbol{\psi}}'_\alpha \Gamma^\mu_{\alpha\beta} \boldsymbol{\psi}_\beta = e\overline{\boldsymbol{\psi}}_a (\gamma^\mu)_{ab} \boldsymbol{\psi}_b$$

- Couplings
- Lorentz structure
- Color structure

From the Lagrangian to Events: the FeynRules/UFO Way

Lagrangian —User Implementation→ FeynRules —UFO Output (Python)→

- Parametrization
- Particle Spectrum
- Vertices
- Lorentz Structures
- Colour Structures
- Coupling Constants

Universal FeynRules Output (UFO)

- Very generic
- Generator independent
- Easy validation and cross checks between generators
- Use same parameter card for different generators
- Allows for full automatization from Lagrangian to MC events

From the Lagrangian to Events: the FeynRules/UFO Way

UFO Output (Python) ⟶

Parametrization	✓
Particle Spectrum	✓
Vertices	✓
Lorentz Structures	✗
Colour Structures	✗
Coupling Constants	✓

Read in ⟶ Sherpa Generate ⟶ Events

Universal FeynRules Output (UFO)

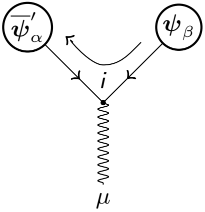
- Very generic
- Generator independent
- Easy validation and cross checks between generators
- Use same parameter card for different generators
- Allows for full automatization from Lagrangian to MC events

From the Lagrangian to Events: the FeynRules/UFO Way

$\xrightarrow{\text{UFO Output (Python)}}$

Parametrization	✓
Particle Spectrum	✓
Vertices	✓
Lorentz Structures	✗
Colour Structures	✗
Coupling Constants	✓

$\xrightarrow{\text{Read in}}$ Sherpa $\xrightarrow{\text{Generate}}$ Events



$$= \sum_{\alpha,\beta} \overline{\psi}'_\alpha \Gamma^\mu_{\alpha\beta} \psi_\beta$$

- Lorentz structures must be highly efficient
- Hard coding routines is neither flexible nor general

⇒ Auto-generate C++ routines, load at runtime
  - ⇒ Fully generic
  - ⇒ Automatic optimization
  - ⇒ Automatic fermion flow treatment

From the Lagrangian to Events: the FeynRules/UFO Way

UFO Output (Python) →

- Parametrization ✓
- Particle Spectrum ✓
- Vertices ✓
- Lorentz Structures ✓
- Colour Structures ✓
- Coupling Constants ✓

Read in / Generate lib. → Sherpa → Generate → Events

Making the Model Available to Sherpa: Python Extension

- Load model
- Write a C++ model:
  parameter input, particle spectrum, vertices, coupling constants
- Compute and write out numerical routines for Lorentz structures
- Map colour structures to existing implementations
- Compile model and install library to be loaded at runtime
- Once installed, model is available for event generation

From the Lagrangian to Events: the FeynRules/UFO Way

UFO Output (Python) $\longrightarrow$

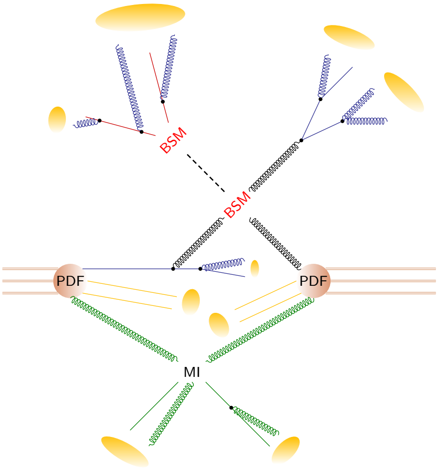
- Parametrization ✓
- Particle Spectrum ✓
- Vertices ✓
- Lorentz Structures ✓
- Colour Structures ✓
- Coupling Constants ✓

$\xrightarrow[\text{Generate lib.}]{\text{Read in}}$ Sherpa $\xrightarrow{\text{Generate}}$ Events

Current Limitations

- Lorentz structures completely general $\rightarrow$ arbitrary higher-dimensional operators
- Tensor particles not yet supported as external particles
- Colour structures restricted to hard-wired available implementations (quite comprehensive)
- NLO not yet fully supported

Validation



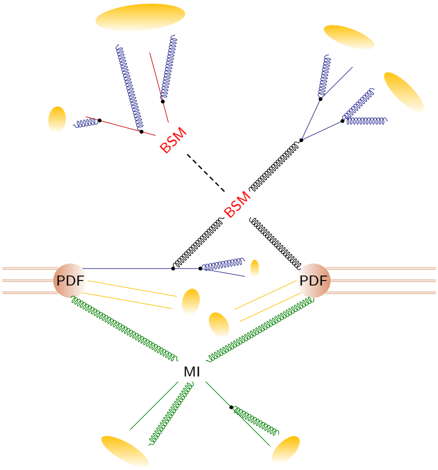
ME comparisons vs MadGraph5

[arXiv:1405.0301]

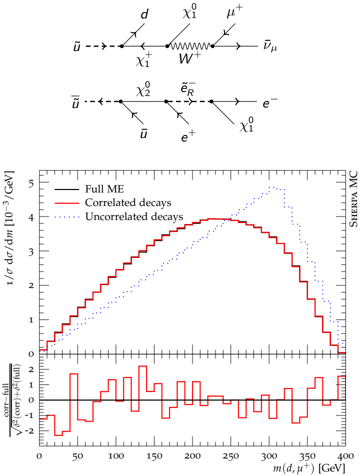
- Five models
- Several hundreds of processes
- $2 \rightarrow 1, 2, 3, 4$ processes
- 6-point Lorentz structures
- Individual phase space points
- 1000 points per process

Model	number of processes tested	max. rel. deviation Comix ↔ MadGraph5
Standard Model	60	$2.3 \cdot 10^{-10}$
Higgs Effective Field Theory	13	$4.3 \cdot 10^{-13}$
MSSM	401	$1.0 \cdot 10^{-10}$
Minimal Universal Extra Dimensions	51	$2.8 \cdot 10^{-12}$
Anomalous Quartic Gauge Couplings	16	$5.9 \cdot 10^{-12}$

Validation



Decay Chains in the MSSM



Conclusions

- Sherpa provides extensive toolkit for simulating collider physics
  - LO/NLO matrix elements
  - Parton shower matching (LO and NLO)
  - CKKW merging (LO and NLO)
  - Management of all non-perturbative aspects
- BSM support completely re-written
  - Hard-coded in-house implementation of BSM models discontinued...
  - ... in favour of the generic UFO standard
  - Model input fully compatible with other generators
  - Automatic generation of arbitrary Lorentz structures
  - Available in Sherpa-2.2.0 (few weeks)
  - Main reference [arXiv:1412.6478]
- Try it out in the tutorials!