(B)SM in SHERPA

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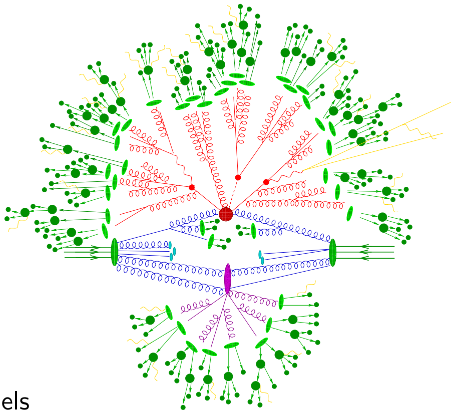
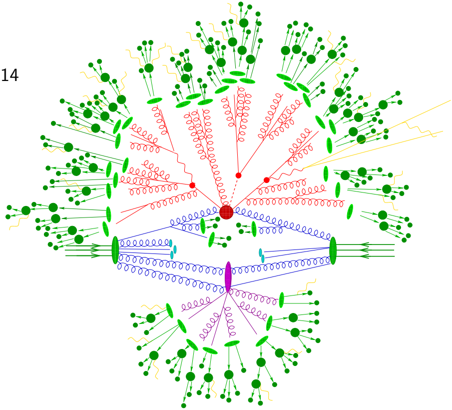
Modules

- Matrix Element generators AMEGIC++ (SM, BSM) and Comix (SM)
- Parton Shower based on Catani-Seymour subtraction
- Multiple interaction model à la Pythia (non-interleaved)
- In-house cluster hadronization and interface to PYTHIA string fragmentation (cross-checks!)
- Built-in hadron decay package $\approx$ 400 hadrons, $\approx$ 2500 decay channels
- Photon emission generator based on YFS formalism



Interfaces

- FeynRules [Christensen,Duhr] CPC180(2009)1614
- LHAPDF [Whalley et al.] hep-ph/0508110
- Binoth Les-Houches Accord
  [Binoth et al.] CPC181(2010)1612
- FastJet [Cacciari,Salam] PLB641(2006)57
- HepMC [Dobbs,Beck-Hansen] CPC134(2001)41
- StdHEP → PGS [Conway et al.]
- Rivet [Buckley et al.] arXiv:1003.0694
- HZTool [Waugh et al.] hep-ph/0605034



New physics models, option 1: DIY

Your Model

Model_Base → Interaction_Model_Base

Model_Base

Particle parameters
Coupling constants

- Standard_Model ↔ Interaction_Model_SM
- MSSM ↔ Interaction_Model_MSSM
- ADD ↔ Interaction_Model_ADD
- AGC ↔ Interaction_Model_AGC
- ... ↔ ...

Interaction_Model_Base

Color & helicity structure
of elementary vertices

Full control over all parameter settings
Possible to recycle underlying model (e.g. SM)

New model can be supplied as external dynamic library at runtime

Built-in models: MSSM

Features

- *R*-parity conserving MSSM
- Feynman rules according to [Rosiek] PRD41(1990)3464
- Majorana fermions according to [Denner et al.] NPB387(1992)467
- Spectra and parameters from SLHA files [Skands et al.] JHEP07(2004)036

Validation

- Comparison of $\mathcal{O}(500)$ cross sections
  with MadGraph/MadEvent & Whizard/O'Mega
- Published in [Hagiwara et al.] PRD73(2006)055005
  Online at http://sherpa.hepforge.org/susy_comparison/

Built-in models

ADD model of extra dimensions [Arkani-Hamed,Dimopoulos,Dvali] PLB429(1998)263

- Incorporates all 3- and 4-point interactions
- Real and virtual graviton production
- $\Rightarrow$ Helicity formalism for spin-2 particles [Gleisberg et al.] JHEP0309(2003)001

Anomalous EW gauge couplings

- Triple and quartic interactions
  [Hagiwara et al.] NPB282(1987)253, [Gangemi et al.] hep-ph/0001065
- Unitarization according to [Baur,Zeppenfeld] NPB308(1988)127

Some others

- Higgs portal [Dedes et al.] JHEP11(2008)063
- Hidden Valley
- Axigluon
- ...

New physics models, option 2: FeynRules

Your Model

↓

FeynRules

Model_Base | Interaction_Model_Base

Particle parameters
Coupling constants

- FeynRules_Model

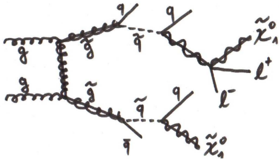
↔

Color & helicity structure
of elementary vertices

- Interaction_Model_FeynRules

Sherpa reads FeynRules' generated output files, sets up model on-the-flight

Caution: Only predefined helicity/color building blocks can be used!
i.e. no automated implementation of helicity amplitudes



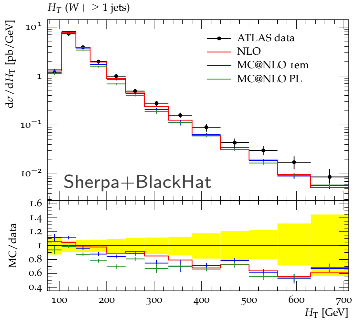
⟶

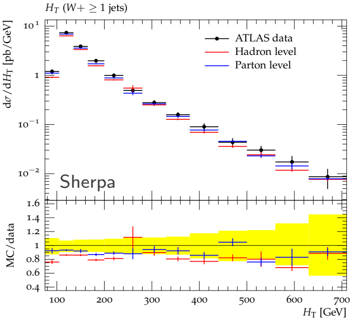
- $t\bar{t}$+jets, single-t
- V+jets, VV+jets
- jets

Dynamics of multi-particle final state depends on new-physics parameters

Precise, fully differential SM background predictions are mandatory!

Example: H_T-spectrum in W+1-jet events, NLO⊕PS vs. ME⊗PS



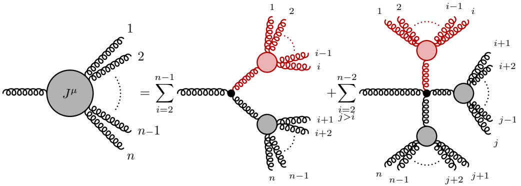


The quest for many jets

Zero'th order approximation: SM background ⇔ event with many jets

Sherpa generates these efficiently with Comix [Gleisberg,SH] JHEP12(2008)039

- Build ME from off-shell currents joined by vertices
- Read from right to left! → maximal recycling



Performance at tree-level

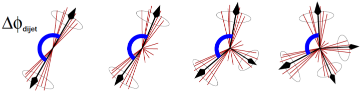
gg → ng	Cross section [pb]				
n $\sqrt{s}$ [GeV]	8 1500	9 2000	10 2500	11 3500	12 5000
Comix	0.755(3)	0.305(2)	0.101(7)	0.057(5)	0.026(1)
PRD67(2003)014026	0.70(4)	0.30(2)	0.097(6)		
NPB539(1999)215	0.719(19)				

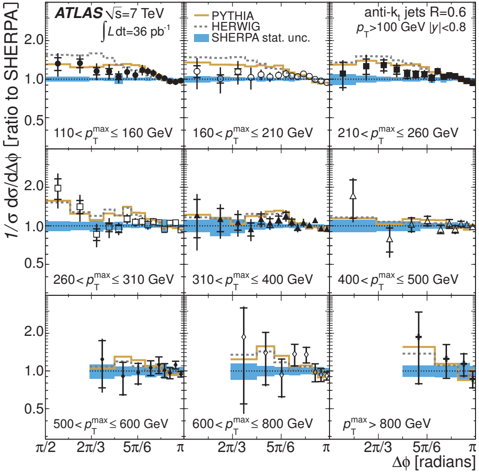
Used e.g. for pp→8j [Kilic,Schumann,Son] JHEP04(2009)128

The quest for many jets

Sherpa's traditional strength:
ME⊗PS merging aka CKKW
[Catani et al.] JHEP11(2001)063
[Krauss et al.] JHEP05(2009)053

- High multiplicity with ME generator Comix
- Low systematics due to truncated showers
- Can be combined with built-in POWHEG or built-in MC@NLO
  → MENLOPS

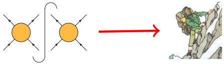
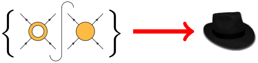
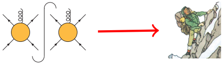




[ATLAS] PRL106(2011)172002

The quest for many jets reloaded

Eventually want to compute high-multiplicity SM backgrounds at NLO

Need
- Born term: $B =$ 
- Virtual terms: $V = \sum 2\,\mathrm{Re}$ 
- Real terms: $R = \sum$ 

Singularities in V & R must be removed before MC-integration $\rightarrow$ subtraction

$$\sigma_{\mathrm{NLO}} = \int \mathrm{d}\Phi_B \left[\mathrm{B} + \tilde{\mathrm{V}}\right] + \int \mathrm{d}\Phi_R\, \mathrm{R} = \int \mathrm{d}\Phi_B \left[\left(\mathrm{B} + \tilde{\mathrm{V}} + \mathrm{I}\right) + \int \mathrm{d}\Phi_{R|B}\, (\mathrm{R} - \mathrm{S})\right]$$

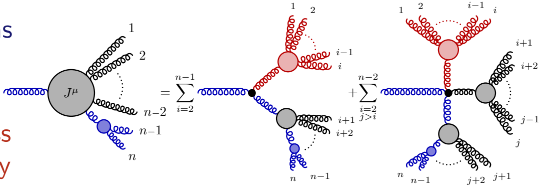
Useful idea: Automate and focus on virtual corrections
$\rightarrow$ Binoth Les-Houches accord [Binoth at al.] CPC181(2010)1612

The quest for many jets reloaded

BlackHat attacks ever higher multiplicity $\rightarrow$ need efficient subtraction

$\Rightarrow$ Comix now extended with Catani-Seymour dipole method [SH]

- Fix CS spectator parton as "final" leg in amplitude
- Recycle subamplitudes from real-radiation process and dipoles simultaneously



Performance for real piece in $pp \rightarrow e^+e^-$+jets (7 TeV)

σ_{R-S} [pb]	Number of jets					
n k_T-jets $p_{Tj} > 30$ GeV, R=0.4	0	1 $\alpha_c = 0.1$	2 $\alpha_c = 0.03$	3 $\alpha_c = 0.01$	4 $\alpha_c = 0.003$	5 $\alpha_c = 0.001$
AMEGIC++/BlackHat **Comix**	30.6(1) 30.7(1)	25.2(3) 25.4(3)	16.7(2) **16.3(2)**	11.5(1) **11.6(1)**	? **5.68(4)**	– **2.00(2)**
Speedup*	0.4	0.5	**1.9**	**1.8**	?	–

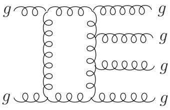
*Timing for complete integration (i.e. matrix-element *and* phase-space)

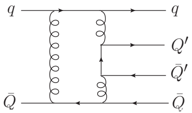
BlackHat⊗Comix is pushing limits:

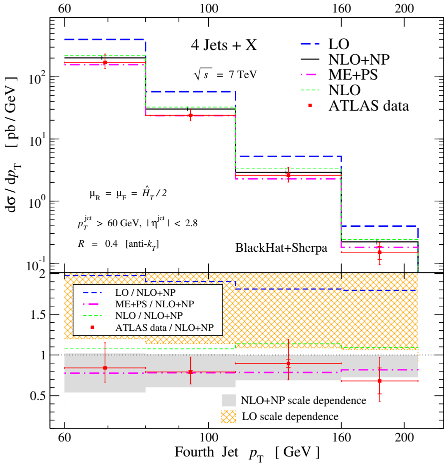
Four-jet production at NLO

[BlackHat] arXiv:1112.3940

- Non-perturbative corrections determined with Sherpa
- Uncertainties from in-house hadronization vs. Lund string





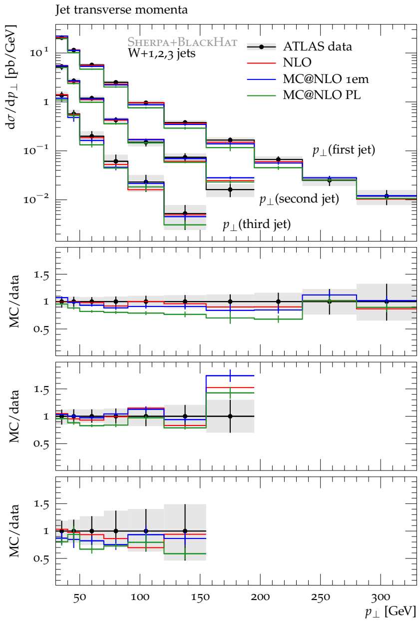


Combining NLO ME with parton showers

Some effort in Sherpa on MC@NLO
$W+n$ **jets, where** $n \leq 3$ **at present**
[SH,Krauss,Schönherr,Siegert] arXiv:1201.5882

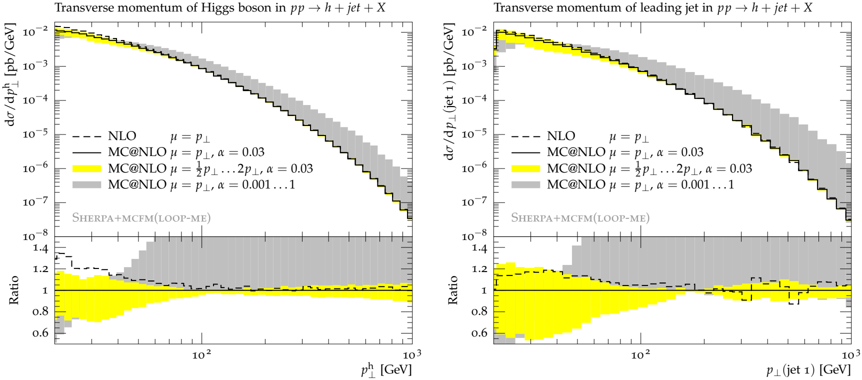
First color-correct implementation of $\mathbb{S}$-terms in generic MC@NLO

Now working towards "CKKW@NLO"



Combining NLO ME with parton showers

Features of NLO matching algorithms exemplified: $pp \to h{+}j$



[SH,Krauss,Schönherr,Siegert] arXiv:1111.1220

Lower edge of gray band $\to$ MC@NLO
Upper edge $\to$ plain POWHEG $(R^f = 0)$

} Both formally NLO correct!

Be careful which prediction you trust!

Summary

Things you can get from Sherpa

- simulation of BSM physics via FeynRules interface
- backgrounds at tree-level with ME$\otimes$PS
- backgrounds at NLO with Mc@Nlo

Try it during the tutorial!