Sherpa

Overview and Recent Developments

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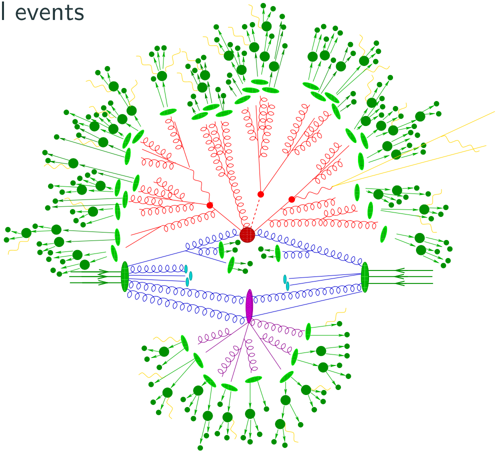
Overview

What is Sherpa? [Gleisberg et al.: JHEP 0902 (2009)]

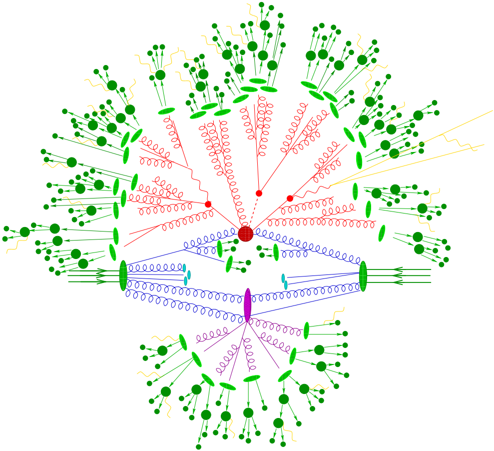
- Multi-purpose MC event generator for high-energy collider physics
- From hard process to hadron-level events
- Focus on perturbative aspects



Overview

Hard Process

- Two tree-level ME generators
  - Comix [Gleisberg et al.: JHEP 0812 (2008)]
  - Amegic++ [Krauss et al.: JHEP 0202 (2002)]
- Interfaces to loop-ME generators
  - NLO QCD
  - NLO EW
- Multijet-merging @ LO and NLO
- NNLO plugins for few processes
  - Drell-Yan
  - Higgs production

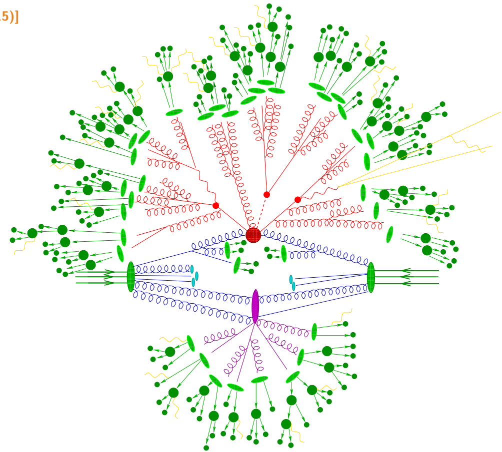


Overview

Dipole Parton Showers

CS shower [Schumann et al.: JHEP 0803 (2008)]

Dire shower [Höche et al.: Eur.Phys.J. C75 (2015)]

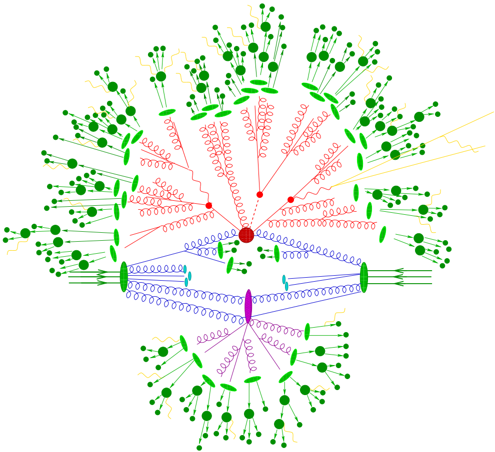


Overview

Non-Perturbative Aspects

Cluster Fragmentation model

Multi-Parton interaction model



BSM Physics with Sherpa

BSM Toolchain

Lagrangian

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{c_G}{\Lambda^2} G^3 + \dots$$

FeynRules

[Alloul et al., CPC 185 (2014)]

UFO Output

[Degrande et al., CPC 183 (2012)]

Input parameters
Particle spectrum
Vertices
Color structures
Lorentz Structures

Monte Carlo

Sherpa
Herwig
MadGraph
...

BSM Capabilities of Sherpa

BSM model input via universal UFO format

Support for spin $0/\frac{1}{2}/1$ particles

Arbitrary Lorentz- and color structures $\rightarrow$ EFTs

ME generation with Comix

Spin-correlated decay chains

Model	number of processes tested	max. rel. deviation Comix $\leftrightarrow$ 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	$5.9 \cdot 10^{-12}$
...		

D-6 Effective Gluon Interactions

$$\mathcal{O}_G = \frac{c_G}{\Lambda^2} f_{abc} G^{\mu}_{a,\nu} G^{\nu}_{b,\kappa} G^{\kappa}_{c,\mu}$$

Collider Constraints from $t\bar{t}$ production

Bound from global top analysis: $\Lambda/\sqrt{c_G} > 850\,\mathrm{GeV}$

[Buckley et al., JHEP 04 (2016)]

Idea: use Multijet Events

Two-jet events insensitive to $\mathcal{O}_G$

$N_{\mathrm{jet}} \geq 4$ not considered before

Need to model high-multiplicity signal (5 jets)

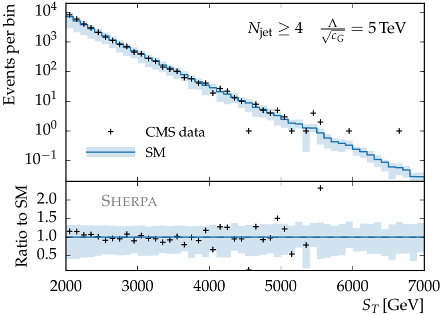
NLO not feasible / relevant $\rightarrow$ use multijet merging

Need very efficient tree-level ME generator (Comix)

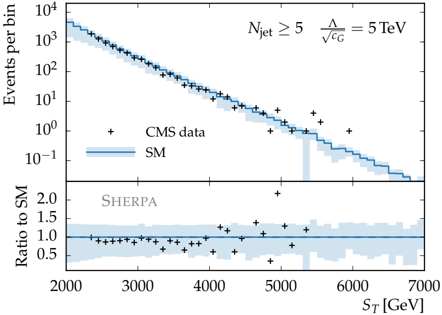
[Krauss, SK, Plehn: Phys.Rev. D95 (2017)]

D-6 Effective Gluon Interactions

Describe data well using MEPS@NLO merging

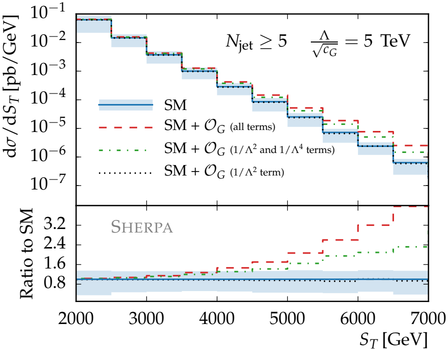


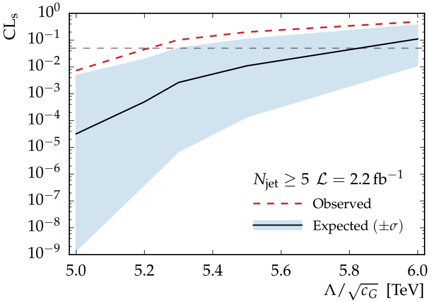
$N_{\text{jet}} \geq 4$



$N_{\text{jet}} \geq 5$

D-6 Effective Gluon Interactions

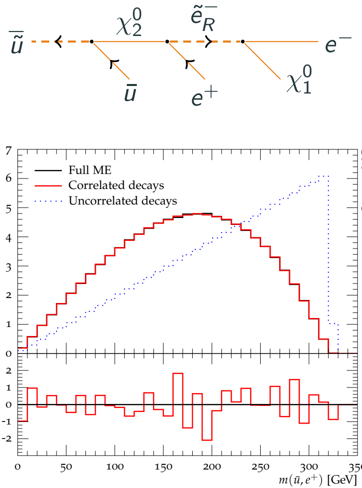


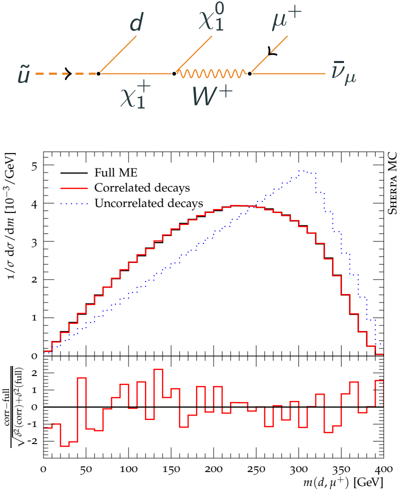


$$\frac{\Lambda}{\sqrt{c_G}} > \mathbf{5.2\,TeV\ at\ 95\,\%\ CL}$$

Based on MC for background, potential for improved using data-driven methods

Spin-Correlated Decays in the MSSM





[Höche et al.: Eur.Phys.J. C75 (2015)]

Recent Developments: NLO EW

NLO EW: Motivation

NNLO QCD → %-level accuracy for many processes $\alpha_s^2 \approx \alpha$

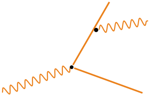
Differentially, EW effects can be much larger

Photon radiation off final state leptons

→ Precision Z and W physics

Large corrections at high p_T: EW Sudakovs

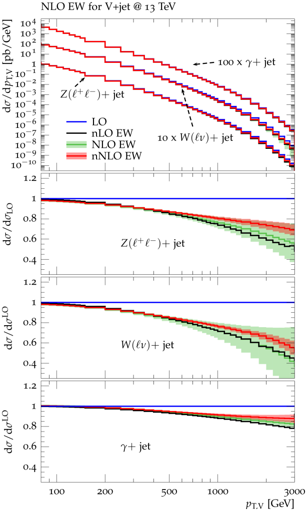
→ Dark matter backgrounds



Automation in Sherpa

Adapt QCD technology

[Schönherr: Eur.Phys.J. C78 (2018)]



[Lindert et al.: Eur.Phys.J. C77 (2017)]

NLO EW: Sherpa Results

Sherpa+OpenLoops

V+0,1,2,3 jets [1607.01831/1606.02330/1605.04692]

$Z + j/\gamma + j$ ratio [1605.04692/1505.05704]

$ll + j/l\nu + j/\nu\nu + j/\gamma + j$ [1705.04664]

$V + H$ [1607.01831]

$ll\nu\nu$ [1705.00598]

$t\bar{t}H$ [1605.04692]

$t\bar{t}$+0,1 jet [1803.00950]

Sherpa+Recola

V jets, $llll$, $t\bar{t}H$ [1704.05783]

Sherpa+GoSam

$\gamma\gamma$+0,1,2 jets [1706.09022]

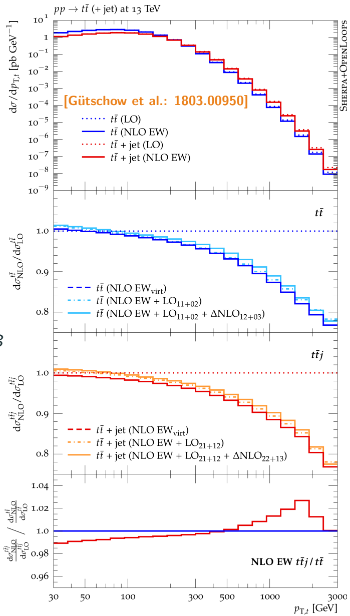
$\gamma\gamma\gamma/\gamma\gamma\nu l/\gamma\gamma ll$ [1710.11514]

EW Corrections for Top Pairs with Jets

$\mathrm{EW_{virt}}$ Approximation

- Captures leading EW Sudakovs
- QED real radiation integrated over
- Can be combined with QCD PS
- Can be used in multijet merging

$$d\sigma^{\text{NLO EW}_{\text{virt}}} = \left[B_{\text{QCD}} + V_{\text{EW}} + \int R^{\text{soft}}\, d\phi_1\right] d\phi_B$$



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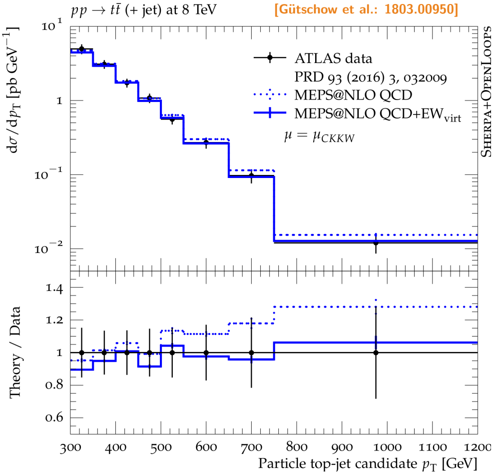
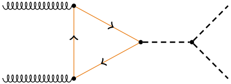
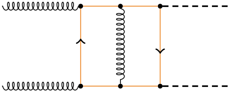
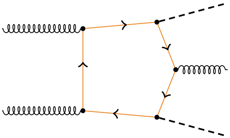


Recent Developments:
NLO for Loop Induced Processes

Loop-Induced Processes at NLO







General Treatment

Born and real corrections: Automated one-loop tools

IR-subtraction: standard techniques, e.g. Catani-Seymour

Parton shower matching: standard techniques, e.g. MC@NLO/Powheg

Availability of two-loop virtual amplitudes

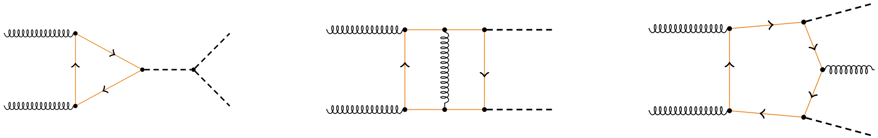
$gg \to \gamma\gamma$ **[Bern et al.: hep-ph/0109078]**

$gg \to VV \to llll$ **[Gehrmann et al.: 1503.04812, Manteuffel et al.: 1503.08835]**

$gg \to HH$ **[Borowka et al.: 1608.04798]**

$gg \to Hj$ **[Jones et al.: 1802.00349]**

Loop-Induced Processes at NLO

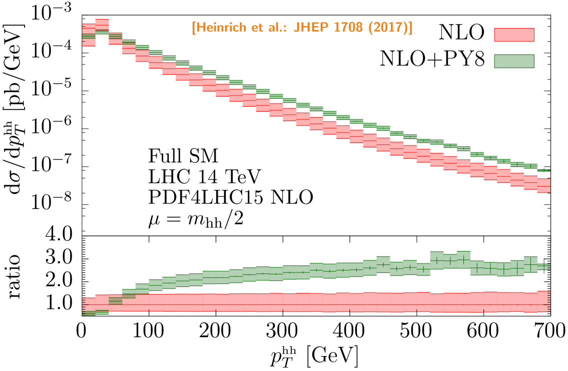


Implementation in Sherpa

- Use Catani-Seymour for IR subtraction
- External 1-loop building blocks (OpenLoops . . .)
- Match to parton showers via MC@NLO (CS shower/Dire shower)

[Jones, SK: JHEP 1802 (2018)]

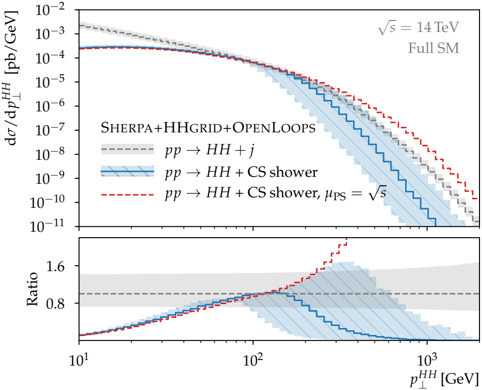
Example: Higgs Pair Production



Indications for large uncertainties

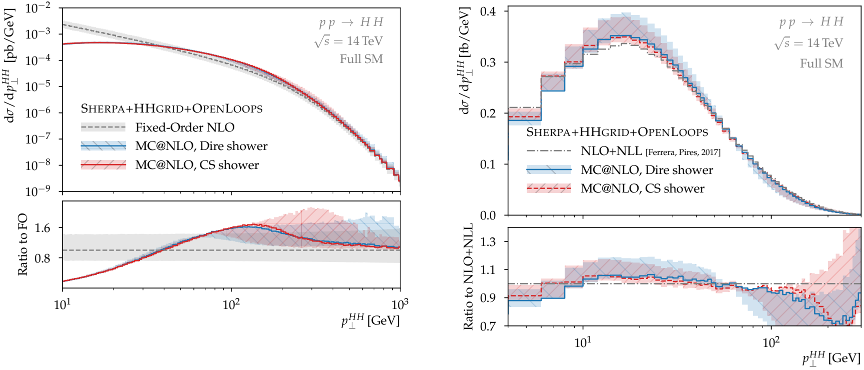
Higgs Pair Production at LO

[Jones, SK: 1711.03319]



Sharply falling fixed-order spectrum → PS overshoots tail

Higgs Pair Production at NLO



In MC@NLO, PS contributions to tail subtracted to $\mathcal{O}(\alpha_s)$

Remainder large, control through judicious choice of shower scale

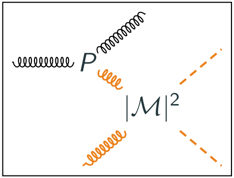
Match to fixed-order in high $p_\perp$ tail

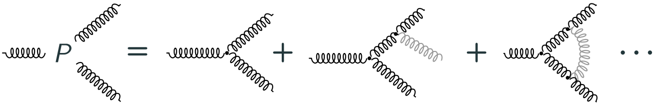
Good agreement with analytic resummation in low $p_\perp$ region

[Jones, SK: JHEP 1802 (2018)]

Recent Developments: NLO PS

Towards NLO Parton Showers





So far only LO kernels in parton showers

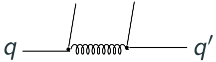
First steps: Adapt NLO DGLAP for PS evolution

Formally connect PDF evolution to parton shower framework

Genuine $1 \to 3$ splittings for $q \to q'$

Soft evolution: treat at LO for now

[Höche et al.: Phys.Rev. D96 (2017)]



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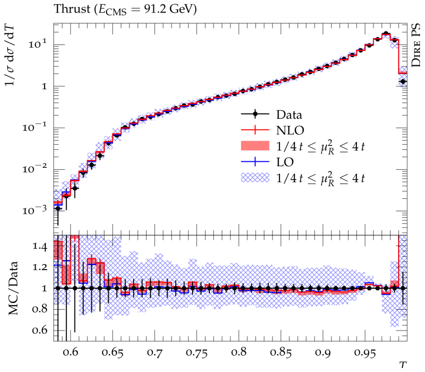

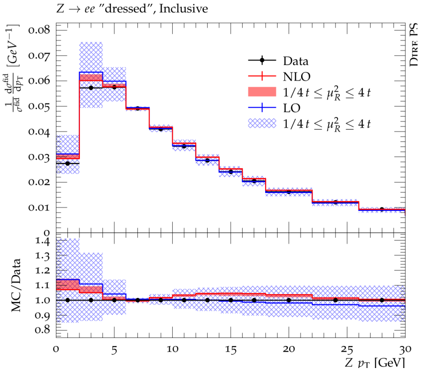

[Höche et al.: JHEP 1710 (2017)]

Summary

Sherpa: general-purpose complete event generation framework

BSM physics via universal UFO format

Arbitrary models of spin $0/\frac{1}{2}/1$ particles supported (EFTs)

Recent developments:

- NLO electroweak corrections
- NLO parton shower
- NLO loop-induced processes

Performance