Recent developments in Sherpa

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GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

FULBRIGHT

The SHERPA 2.2 event generator framework

User Inputs

Initial Beams

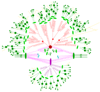
- collider setup
- PDFs (built-in, LHAPDF)
- beam spectra

Parameters/Models

- FeynRules/UFO
- couplings
- masses
- variations
- shower settings
- non-perturbative parameters

Physics Process

- parton level
- perturbative order (QCD/EW)
- selectors
- matching/merging
- partonic decays



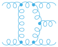
Matrix Elements

Matrix Element Generators

- AMEGIC
- COMIX
- CS subtraction

1-loop Amplitudes

- OpenLoops
- Recola
- GoSam
- BLHA



Parton Showers

CS-Shower (default)

- dipole shower
- fully massive
- QED splittings

DIRE

- hybrid dipole-parton shower algorithm
- fully massive

Matching and Merging

Automated MC@NLO style matching

Multijet-merging algorithms

- based on truncated showers
- tree-level and one-loop matrix elements: MEPS@LO and MEPS@NLO
- approximate electroweak corrections

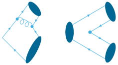
NNLO QCD with parton showers

- selected processes only

Soft Physics

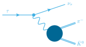
Hadronisation

- AHADIC: a cluster fragmentation model
- interface to Pythia string fragmentation



Hadron Decays

- decay tables for hadronic resonances
- dedicated form-factor models, e.g. τ, B, Λ
- spin correlations
- YFS QED corrections
- partonic channels



Underlying Event

- multiple parton interactions
- beam-remnant colours
- intrinsic transverse momentum

Interfaces/Outputs

Output Formats

- HepMC
- LHEF
- Root Ntuple

Interfaces

- RIVET analyses
- C++/Python ME access
- MCgrid
- integration into ATLAS/CMS

Code/Docu

- HepForge
- GitLab
- online documentation

sherpa.hepforge.org

gitlab.com/sherpa-team/sherpa

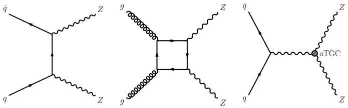
latest release: SHERPA-2.2.8, new write-up: arXiv:1905.09127 [hep-ph]

Precision Pheno: $ZZ \to ll\nu\nu$ production

Signals and backgrounds for SM measurements and BSM searches

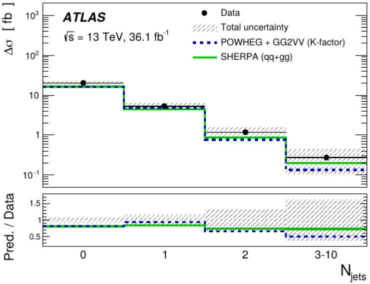
[Aaboud et al.: arXiv:1905.07163 [hep-ex]]

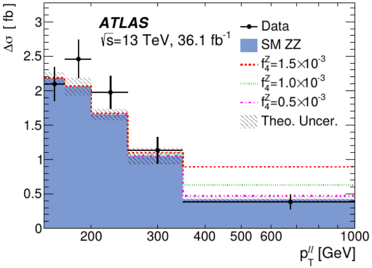
- direct & loop-induced channels
- sensitivity to aTGC



$\hookrightarrow$ uncertainty estimates needed

Process	Generator	Simulation accuracy	Cross-section accuracy
$qqZZ$	Powheg-Box v2 + Pythia8.186	NLO QCD	NNLO QCD + NLO EW
	Sherpa2.2.2	NLO QCD 0-1p, LO QCD 2-3p	
$ggZZ$	gg2vv3.1.6 + Pythia8.186	LO QCD	NLO QCD
	Sherpa2.1.1	LO QCD 0-1p	
$qqZZ$ (aTGCs)	Sherpa2.1.1	NLO QCD 0-1p, LO QCD 2-3p	
WZ	Powheg-Box v2 + Pythia8.186	NLO QCD	
	Powheg-Box v2 + Herwig++		
WW	Powheg-Box v2 + Pythia8.186	NLO QCD	
$qqZZ \to 4\ell$	Powheg-Box v2 + Pythia8.186	NLO QCD	NNLO QCD + NLO EW
$ggZZ \to 4\ell$	gg2vv3.1.6 + Pythia8.186	LO QCD	NLO QCD
Z + jets	Sherpa2.2.1	NLO QCD 0-2p, LO QCD 3-5p	NNLO QCD
$t\bar{t}$	Powheg-Box v2 + Pythia6.428	NLO QCD	NNLO QCD
Wt	Powheg-Box v2 + Pythia6.428	NLO QCD	NNLO QCD
VVV	Sherpa2.1.1	NLO QCD	
$t\bar{t}V$	MadGraph5_aMC@NLO + Pythia8.186	LO QCD	NLO QCD





Pushing Frontiers

Fixed-order & Merging calculations

- automation of NLO EW corrections [Schönherr et al., Reyer et al.]
- resonance-aware NLO QCD subtraction [Liebschner et al.]
- massive parallelisation for high-multi MEPS@LO calculations [Höche et al.]
- multi-jet merging in variable flavour number scheme [Krause et al.]
- approximate NLO EW in MEPS@NLO simulations [Kallweit et al.]

QCD Shower Improvements

- new shower-development platform: DIRE [Höche, Prestel]
- shower logarithmic accuracy [Dreyer et al.; Richardson et al.; Reichelt et al.]
- higher-order corrections [Dulat et al.]

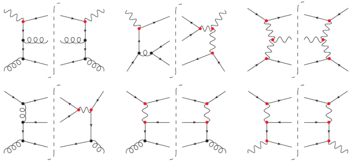
spin-offs

- framework for automated soft-gluon resummation [Reichelt et al.]

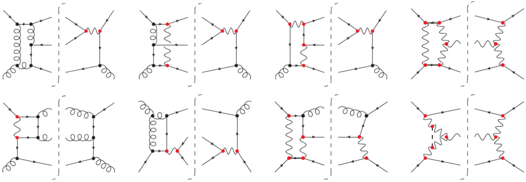
Electroweak Corrections

parametrically $\alpha_s^n \alpha \approx \alpha_s^{n+2}$, Sudakov enhancements

$\hookrightarrow$ photonic initial states, EW Born & Loop corrections, QED reals



$\mathcal{O}(\alpha_s^2\alpha)$ $\mathcal{O}(\alpha_s\alpha^2)$ $\mathcal{O}(\alpha^3)$



$\mathcal{O}(\alpha_s^3\alpha)$ $\mathcal{O}(\alpha_s^2\alpha^2)$ $\mathcal{O}(\alpha_s\alpha^3)$ $\mathcal{O}(\alpha^4)$

Pushing Frontiers: 3-jet production at full SM NLO

Full NLO corrections to hadronic 3-jet production

[Reyer, Schönherr, S.: Eur. Phys. J. C **79** (2019) no.4, 321]

- QCD & QED dipole subtraction [Schönherr]
- virtuals from RECOLA [Actis et al.]

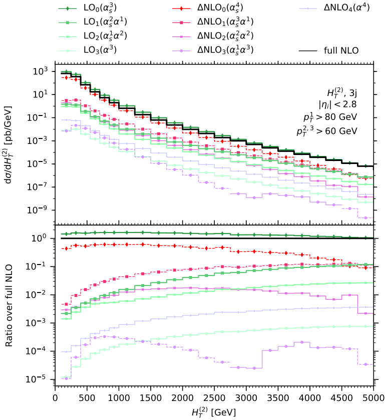
$$\sigma_{nj} = \sum_{i=0}^{n} \sigma_{nj}^{\mathrm{LO}_i} \quad + \quad \sum_{i=0}^{n+1} \sigma_{nj}^{\Delta\mathrm{NLO}_i}$$

$$\mathcal{O}\left(\sigma_{nj}^{\mathrm{LO}_i}\right) \quad = \quad \alpha_{\mathrm{s}}^{n-i}\alpha^{i}$$

$$\mathcal{O}\left(\sigma_{nj}^{\Delta\mathrm{NLO}_i}\right) \quad = \quad \alpha_{\mathrm{s}}^{n+1-i}\alpha^{i}$$

↪ subleading EW tree-level and one-loop contributions sizeable

↪ challenge for matching & merging



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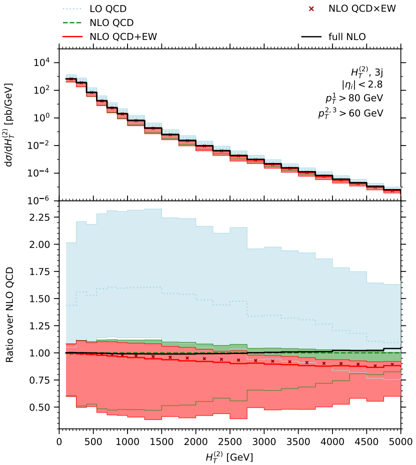

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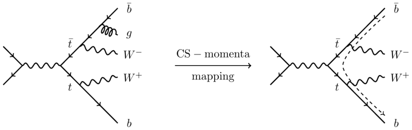
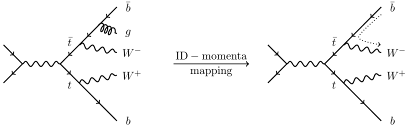
Resonance-virtuality preserving NLO QCD subtraction

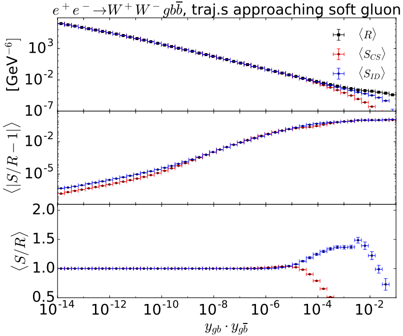
[Höche, Liebschner, Siegert: arXiv:1807.04348 [hep-ph]]

- need efficient subtraction method: map real-emission on Born config, can affect resonance virtuality



- use CS identified-particle formalism





- better MC integration convergence
- improved sampling efficiency

Pushing Frontiers: Resonance-aware dipole subtraction

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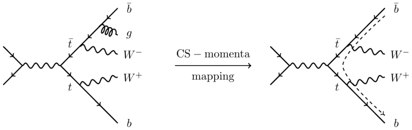

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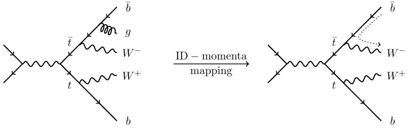

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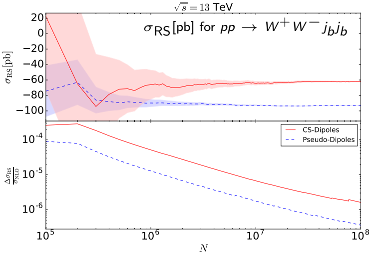


σ[pb]	$\sqrt{s} = 13$ TeV CS	ID
RS	−62.03(59)	−93.21(13)
BVI	360.02(39)	391.53(39)
$\sum$	297.99(71)	298.32(41)

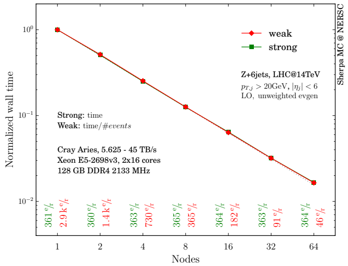
Pushing Frontiers: High-multiplicity multi-jet merging

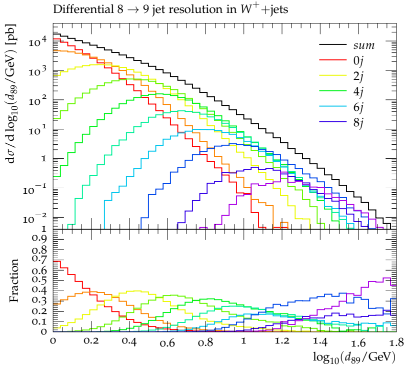
Optimisations for massive parallelisation

[Höche, Prestel, Schulz: Phys. Rev. D **100** (2019) no.1, 014024]

$pp \to X + n$ jets	LO cross section @ 14 TeV [pb]									
X / n	0	1	2	3	4	5	6	7	8	9
W^+	9908(29)	2523(8)	1067(7)	404(4)	148(1)	49.3(5)	15.8(2)	5.2(2)	1.30(8)	0.330(6)
W^-	7496(21)	1898(6)	760(4)	278(2)	94(1)	29.8(3)	9.29(9)	2.71(7)	0.63(2)	0.170(3)
Z	1661(3)	464(1)	193.6(8)	72.2(3)	25.7(2)	8.61(8)	2.74(3)	0.82(2)	0.211(3)	0.057(1)

- separate ME and PS generation
- HDF5 format for ME events
- almost perfect resource scaling



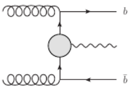


Pushing Frontiers: Multi-jet merging in VFNS

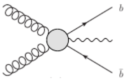
Fusing Z+jets (5F) and Zbb (4F) samples

[Höche, Krause, Siegert: Phys. Rev. D **100** (2019) no.1, 014011]

- 5F (massless) MEPS@NLO
  (mass effects in PS)



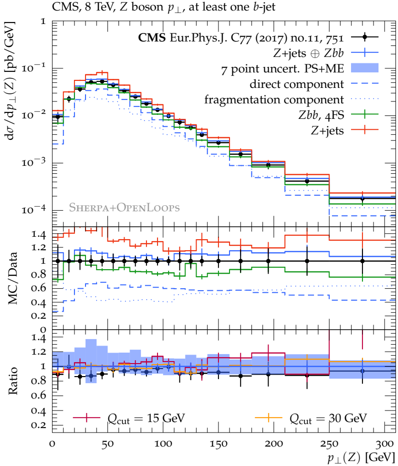
- 4F (massive) MC@NLO
  (mass effects also in ME)



$\hookrightarrow$ consistently combined sample
[heavy-flavour overlap removal]

$\hookrightarrow$ relevant for realistic b-tagging

$Zb + X$ – boson $p_\perp$



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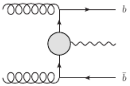

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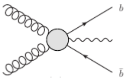

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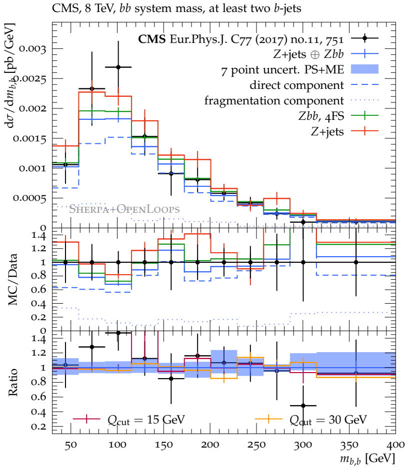
$Zbb + X$ – bb invariant mass



Conclusions

- NLO QCD matching/merging prescriptions routinely used for LHC pheno

  ↪ adjust to rare cases: loop-induced channels, heavy-flavour production
- automation of NLO EW achieved

  ↪ towards EW corrections in MEPS simulations
- focus moving towards improvements of shower algorithms

  ↪ sophisticated reweighting techniques for applying corrections (SVA)
  - uncertainty evaluations
  - approximate NLO EW contributions
  - NLO QCD splitting functions
  - ...
- updated NP models: beam remnants, colour reconnection, hadronisation
- change to `YAML` run card format
- ...

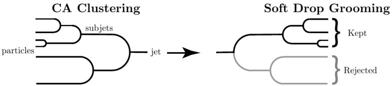
Addendum: shortterm studentship Jeremy Baron

Soft-drop grooming in hadronic event shapes – UE mitigation

- final-year theory PhD U Buffalo
- SD groomed e^+e^- event shapes [Baron et al. JHEP **1808** (2018) 105]

Work accomplished 04-08/19 UGOE

$\hookrightarrow$ extend SD to *pp* event shapes



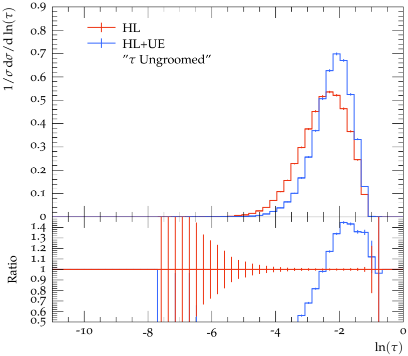
$$\frac{\min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} \geq z_{cut} \left(\frac{\Delta R}{R_0}\right)^{\beta}$$

$\hookrightarrow$ devise observable definitions

$\hookrightarrow$ potential to reduce UE impact

$\hookrightarrow$ towards NLL resum for SD thrust

hadronic thrust (ungroomed)



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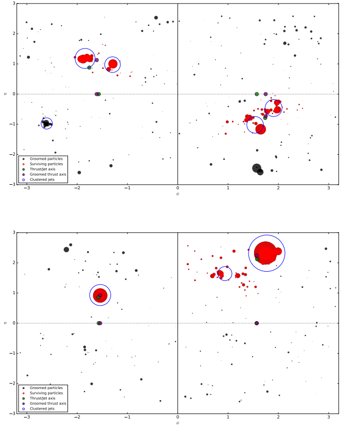
event displays



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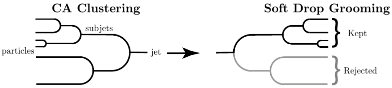

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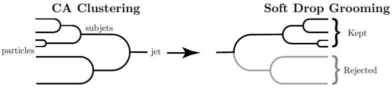

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