GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

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Soft Physics and tuning in Sherpa

Available models and current status

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MCnet

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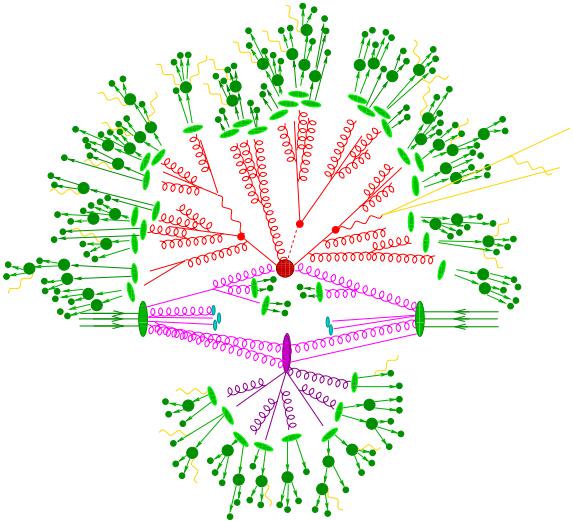
The Sherpa event generator [Bothmann et al. arXiv:1905.09127]

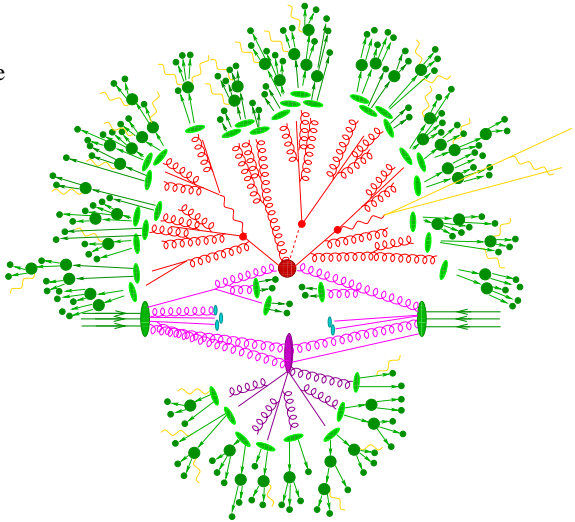
- Hard Interaction
  - LO, NLO QCD/EW*, NNLO QCD
  - ME generators Amegic & Comix
- Radiative corrections
  - Catani-Seymour based PS
  - Dire, Yennie-Frautschi-Suura QED resummation
  - EW Sudakovs
- Multiple interactions
  - Sjöstrand-Zijl model
- Hadronisation
  - Cluster hadronisation model
  - Interface to Pythia's Lund String Fragmentation
- Hadron Decays
  - Phase space or EFTs
  - YFS QED corrections



The Sherpa event generator [Bothmann et al. arXiv:1905.09127]

Sherpa's traditional strength is the perturbative part of the event

- Two multi-purpose matrix element generators
  → Amegic [JHEP02(2002)044, EPJC53(2008)501]
  → Comix [JHEP12(2008)039, PRL109(2012)042001]
- Multiple modes of combining ME & PS
  → LO, NLO, NNLO
  → LOPS, NLOPS, NNLOPS, MEPS, MENLOPS
  → MEPS@NLO
- Renewed interest in soft physics modelling etc..

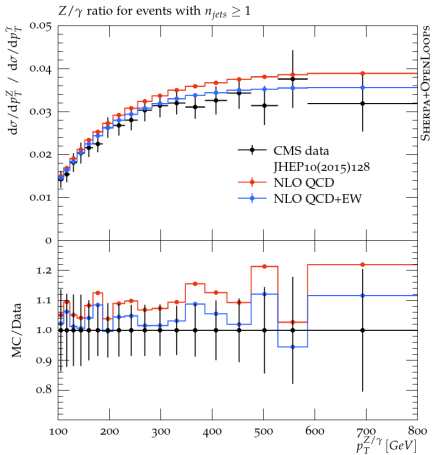


Outline

- Recent developments towards Sherpa 3.0
- Overview of soft physics in Sherpa (hadronisation, UE, MinBias, instanton production)
- Tuning methodology and ideas
- Model and tuning uncertainties
- Outlook

Recent developments towards Sherpa 3.0

- EW Physics
  - Consistent treatment of NLO EW and subleading orders [1712.07975]
  - Automated evaluation of electroweak Sudakov logarithms [2111.13453,2006.14635]
- Computing performance
  - Accelerated clustering procedure for MEPS@NLO merging
  - Improved HPC support (hdf5 I/O, pilot-run technology,...) [1905.05120, 2209.00843]
- Soft Physics / non perturbative
  - Rewritten hadronisation module, improved performance for multiple observables, DIS,...
  - Addition of min-bias, instanton production
  - Update Pythia interface: Pythia6→Pythia8
- Misc
  - Dire parton shower, full fledged implementation [1705.00982]
  - Alaric parton shower (formal NLL accuracy) [2208.06057]
  - NLO merging for loop-induced processes [1509.01597]
- "a lot of genuine and original research work by other people"

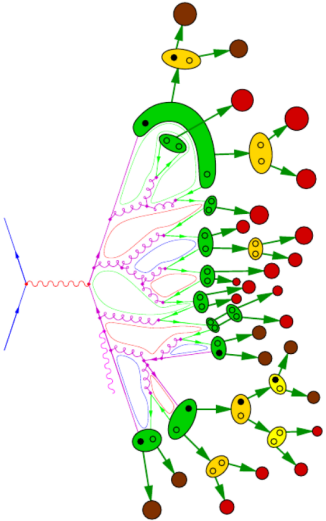


[Ciulli, Kallweit, JML, Pozzorini, Schönherr for LH15]

Soft Physics in Sherpa

Hadronisation: Ahadic [Chahal, Krauss 2203.11385]

- Sherpa 3.0 comes with a major re-write of the hadronisation module
  → Careful analysis of problematic kinematic configuration
- Beam Fragmentation seems to help quite a lot in DIS
- Re-written color reconnections, invoked at the end of the parton shower
- Overall good agreement with LEP data
  → In the process of checking energy dependence
- Will probably need a re-tune, once Sherpa 3.0 is ready



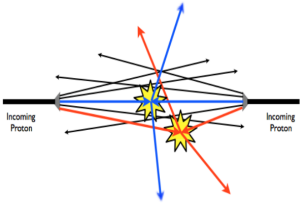
Underlying Event (MPI)

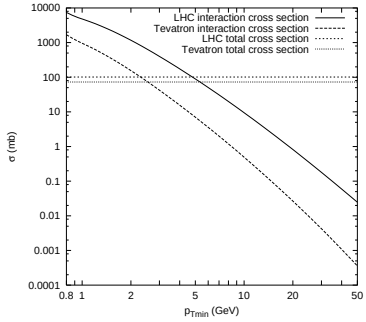
- Sherpa UE based on Sjöstrand-Zijl model
  [Sjöstrand,Zijl Phys. Rev. D36 (1987)]
- Observation: For small p_T, scatting cross-section larger than total
  $\rightarrow$ Interpretation: Multiple scatterings per pp collision

$$\sigma_{\mathrm{int}}(p_{\perp\, min}) = \int_{p^2_{\perp\, min}}^{s/4} \frac{d\sigma}{dp_\perp} dp_\perp$$

$$\langle n_{\mathrm{MPI}}(p_{\perp\, min})\rangle = \frac{\sigma_{\mathrm{int}}(p_{\perp\,\mathrm{min}})}{\sigma_{\mathrm{nd}}}$$

- In Sherpa: Hardest scattering is given by hard process
  $\rightarrow$ remaining xs distributed among additional 2->2 scatterings
  $\rightarrow$ Many more details, impact parameters, ...
  $\rightarrow$ The method is established, currently being re-tuned for the 3.0 release

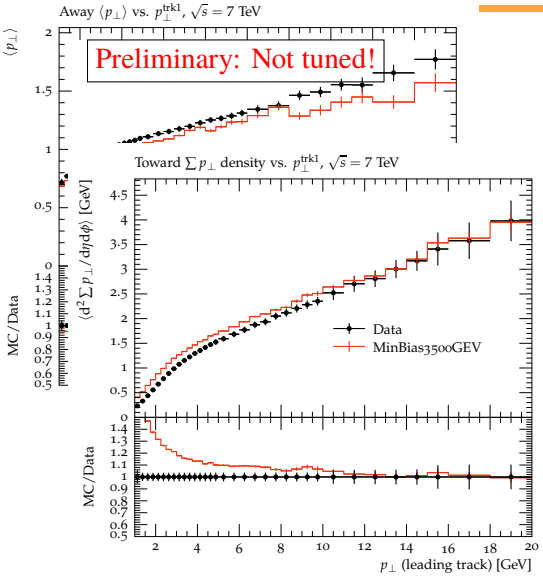




[figures taken from: hep-ph/0402078, 1810.02386]

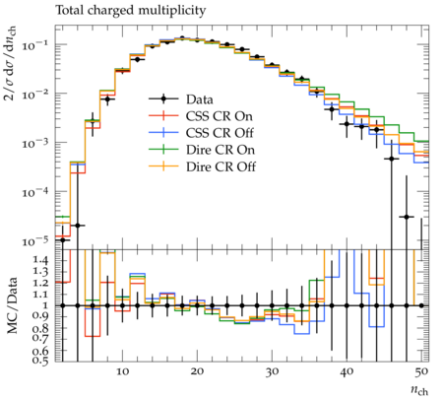
Min Bias

- Natural generalisation from UE to min-bias
- Sjöstrand-Zijl model originally already extended do describe Min-Bias events
  → Recently also realised in Sherpa
- Largest difference from UE, start scale needs to be diced
- Renewed interest due to newly added instanton production
- Current Status: Usable but untuned; WIP
- Used for instanton production searches
  → Reimplementation from recent paper: [1911.09726]
  → Expect a high multiplicity of low energetic partons (soft bomb)
  → Soft physics modelling crucial!



A word on Tuning [Slide adapted from Steffen Schumann]

- Modelling of non-perturbative phenomena corner stone of HEP MCs
  → lack of first-principle ansatz, e.g. Lund- & Cluster models, MPI etc
- Need to calibrate $\mathcal{O}(10-100)$ model parameters with experimental data
- very costly to evaluate for different energies, colliders, lots of measurements
  → grid search not feasible, parametrize/model MC response
  → Professor [Hoeth et al.] & Apprentice [Krishnamoorthy et al.] tools
  → Based on analyses available in RIVET
- fast turn-overs desirable, less resource intense, uncertainty estimates



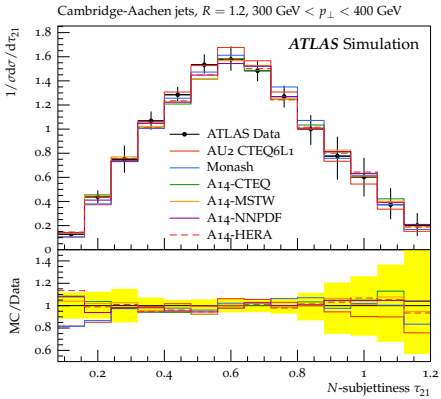
[Chahal and Krauss, SciPost Phys. 13 (2022) no.2]

Tuning uncertainties

- Tune generates set of parameters, varying these creates variations / uncertainties
  → How to vary parameters to obtain meaningful uncertainties?
- Loosely inspired by PDF uncertainties, two different approaches
  → Eigentunes & Replicas
- Unlike e.g. PDF variations, varying model parameter not just a weight
  → Parameters change kinematics and (currently) require separate run

The eigentunes approach: [used e.g. in ATL-PHYS-PUB-2014-021]

- Realised in PROFESSOR, here implemented in Apprentice
- Basic idea: diagonalize $\chi 2$ covariance-matrix
  → Move along principal axis until certain $\Delta\chi^2$ is reached
  → Results in $2N_{\mathrm{param}}$ variations
  → Key point: Choose suitable $\Delta\chi^2$

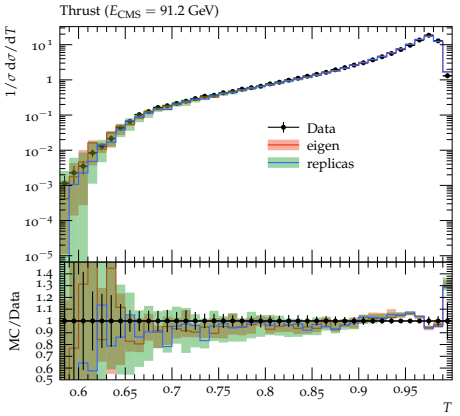


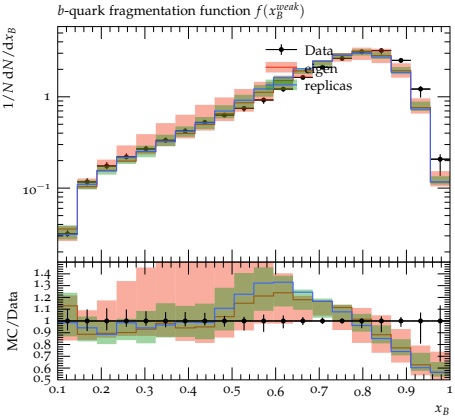
[figure taken from ATL-PHYS-PUB-2014-021]

Tuning uncertainties

- Alternative approach: Re-tune with different sub-sets of the date
  → potentially requires more replica tunes

- Creating subset of variations
  → Only vary the relevant parameters
  → reduces the number of MC runs necessary
- Potential work-flow: making use of new hdf5 I/O
  → re-run only the non-perturbative phases





Conclusion / Outlook

- Sherpa 3.0 comes with major new Physics modules
- More soft physics functionality, Tuning WIP
- Will also come with possibilities for tuning uncertainties
  $\rightarrow$ Working on simplified procedure for the inclusion