Impact of parton shower and underlying event model on observables related to pTW/Z: HERWIG 7

on behalf of the Herwig 7 team

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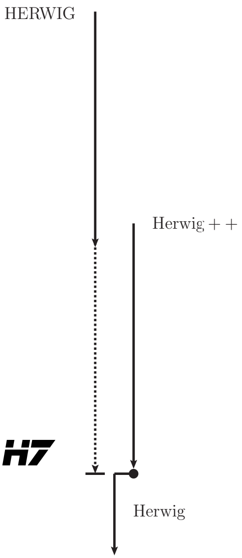
INSTITUTE OF NUCLEAR PHYSICS PAN, KRAKOW, POLAND (NCN, POLAND GRANT NO. 2016/23/D/ST2/02605)

ElectroWeak Workshop

Outline

- Introduction
- Parton Shower (Shower Variations and the recent progress)
- Underlying Event (Main parameters and the recent progress)
- QED/EW corrections and Parton Shower
  - Yennie–Frautshi–Suura (YFS) exclusive exponentiation for FSR - SOFTY
  - ISR/FSR QED in Parton Shower
  - QCD parton showers and NLO EW corrections to Drell-Yan
- Conclusions & Future Plans

Herwig Evolution



HERWIG (Hadron Emission Reactions With Interfering Gluons):
Fortran code, last version 6.521
(1992-2002)
[Marchesini, Webber, Abbiendi, Corcella, Knowles, Moretti, Odagiri, Richardson, Seymour, Stanco]

Herwig++ (C++, improved physics, 2004):
[Bähr, Gieseke, Gigg, Grellscheid, Hamilton, Latunde-Dada, Plätzer, Richardson, Seymour, Sherstnev, Tully, Webber]
last version 2.7.1 (2014)
[Bellm, Gieseke, Grellscheid, Papaefstathiou, Plätzer, Richardson, Rohr, Schuh, Seymour, AS, Wilcock, Zimmermann]
intended to fully replace Fortran version

experimental and phenomenological evolution over time
$\Rightarrow$ precision as key goal

Herwig 7.0

[Bellm, Gieseke, Grellscheid, Plätzer, Rauch, Reuschle, Richardson, Schichtel, Seymour, AS, Wilcock, Fischer, Harrendorf, Nail, Papaefstathiou, D. Rauch]

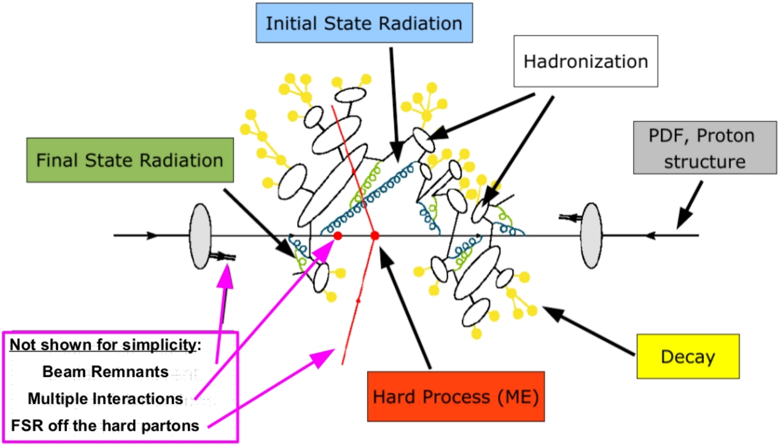
τ(HERWIG) $\sim$ τ(Herwig++) $\gtrsim$ 15 years.

Herwig 7

- New major release Herwig++ 3.0 $\rightarrow$ Herwig 7.0
- Evolution of fHERWIG/Herwig++ subsumed as “7 $>$ 6.5”.
  “Better than fHERWIG in any aspect plus more”.
- “NLO for all hard processes.”

[J. Bellm et.al., Eur.Phys.J. C76 (2016), 196]

Building blocks



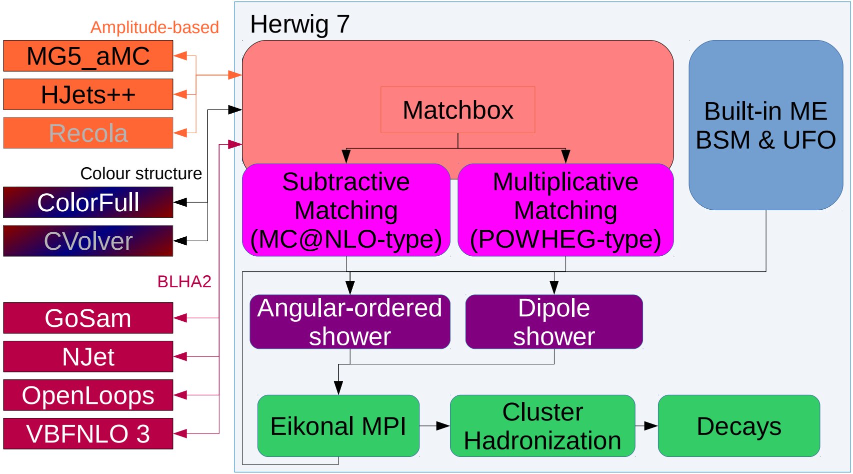
taken from Stefan Gieseke ©

Features

Main features of Herwig 7:

- Two parton-shower implementations
  - Angular-ordered shower
  - Dipole shower
- NLO matched to parton showers as new default
  - Matching/merging mechanism fully generic, fully automated
  - Two matching schemes implemented
    - subtractive (MC@NLO-type)
    - multiplicative (Powheg-type)
  - performed by Matchbox module
    [work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]
  - matrix elements in general from external providers via linked library
- NLO merging with the dipole shower [Bellm, Gieseke , Plätzer]
- Spin correlations and QED radiation in angular-ordered shower [Richardson]
  last missing feature from Fortran HERWIG
- Simulation of QED Radiation in Particle decays using the YFS Formalism [Hamilton, Richardson]
- Parton-shower variations [Bellm, Nail, Plätzer, Schichtel, AS]
- Parton-shower reweighting [Bellm, Plätzer, Richardson, AS, Webster]
- Developments at the soft front [Gieseke, Kirchgaeßer, Plätzer, Seymour, AS]
- Third matching scheme: KrkNLO [Jadach, Nail, Placzek, Sapeta, AS, Skrzypek]
- Improved documentation, much more user-friendly input files
- Many many more...

Structure



Fully automated, so that users can choose their process and everything is set up for them!

Input

New-style input files

- common code fragments separated into snippets
- include with simple `read <file>` statement
- small complete input file example:

```
read Matchbox/PPCollider.in                                  ← collider setup

cd /Herwig/MatrixElements/Matchbox                           ← process setup
set Factory:OrderInAlphaS 0
set Factory:OrderInAlphaEW 2
do Factory:Process p p -> e+ e-
read Matchbox/MadGraph-OpenLoops.in                          ← amplitude provider

read Matchbox/FiveFlavourScheme.in                           ← additional options
read Matchbox/MCatNLO-DefaultShower.in                       ← e.g. shower and matching

do /Herwig/MatrixElements/Matchbox/Factory:ProductionMode
cd /Herwig/Generators
saverun LHC EventGenerator
```

Installation and Usage

- Simple installation via bootstrap script

  `./herwig-bootstrap <installation directory>`

  by default also installs external matrix providers
  (GoSam, HJets++, MadGraph5_aMC@NLO, NJet, OpenLoops, VBFNLO) simultaneously

- Simple running

```
Herwig build LHC.in
Herwig integrate LHC.run
Herwig run LHC.run
```

- lots of parallelization
  - grid adaption parallel with separate jobs (no IPC)

    ```
    Herwig build LHC.in -z1
    for i in `seq 0 <maxjobs>`; do
      <qsub> Herwig integrate LHC.run --jobid=$i; done
    ```

  - parallel running on multi-core machines

    ```
    Herwig run --jobs=8 LHC.run
    ```

- live documentation via sphinx sites at

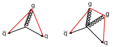
  https://herwig.hepforge.org

Parton-showers in Herwig 7

Angular-ordered Parton Shower (PS)

- Angular-ordered
- Colour coherence by construction
- No full coverage of phase-space

Dipole Shower



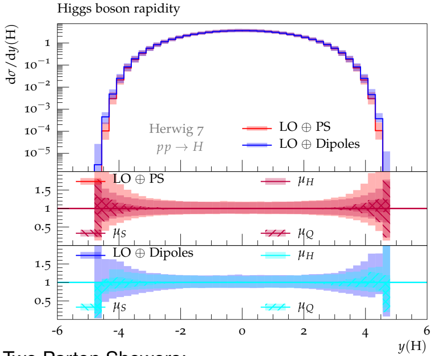
- p_T-ordered
- Colour coherence
- Full phase space
- Catani-Seymour dipoles

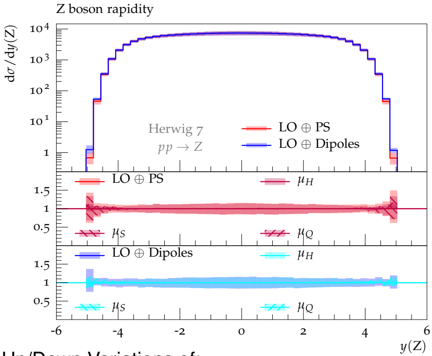
Main parameters:

- q_{min} the cut-off in the parton shower (in general phase-space limits for PS)
- $\alpha_s(M_Z)$
- kinematic reconstruction (formally subleading but important!)

For a recent tuning strategy of PS, see for example: [Reichelt, Richardson, AS, Eur.Phys.J. C77 (2017) no.12, 876]

[Bellm, Nail, Plätzer, Schichtel, AS Eur.Phys.J. C76 (2016) no.12, 665]





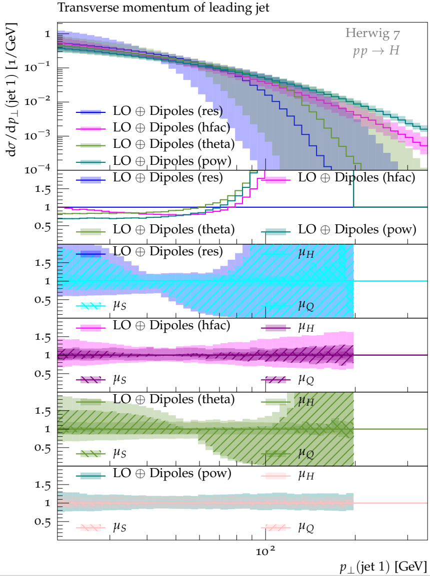
Two Parton Showers:

- Angular-ordered Parton Shower (PS)
- p_T-ordered Dipole Shower

Up/Down Variations of:

- μ_H - argument of PDF, α_S in hard matrix element
- μ_S - argument of PDF, α_S in the shower
- μ_Q - shower starting/veto scale
- μ_{IR} - shower cutoff

Parton-shower Variations: Profile scales



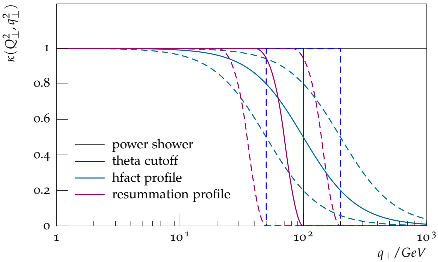


Figure: Profile Scales with $Q_\perp = 100$ GeV

Power

$$\kappa(Q, q) = 1$$

Theta

$$\kappa(Q_\perp^2, q_\perp^2) = \theta(Q^2 - q^2)$$

HFact

$$\kappa(Q_\perp^2, q_\perp^2) = \left(1 + \frac{q^2}{Q^2}\right)^{-1}$$

Resummation

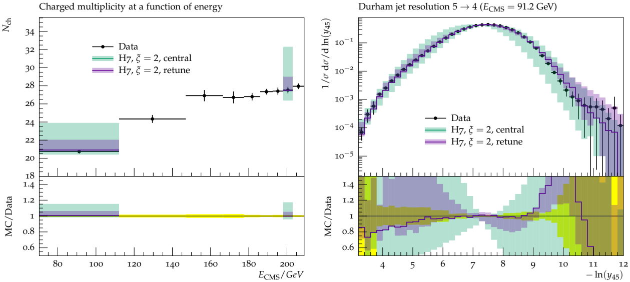
Tuning vs. Variations

[Part of Les Houches proceedings, Bellm, Hoang, Lonnblad, Plaetzer, Prestel, Samitz, AS]

To assess the effect of the correlation between infrared cut-offs and hadronization parameters with variations of α_s:

1. The central tune. This is simply chosen to be the default value. Its scale variation band (the envelope of the tune) is estimated by shifting $\alpha_s(M_z) \to \alpha_s(\{\frac{1}{\xi}, 1, \xi\}M_z) \to \alpha'_s(M_z)$, with $\xi = 2$ without additional retuning for each $\alpha'_s(M_z)$ variation.
2. Two more tunes, called "retune" and the corresponding scale variation band, are obtained by the same $\alpha_s(M_z)$ variation as for "central" tune but this time we also retune to ALEPH data for each $\alpha'_s(M_z)$ variation.

For some observables it seems like the uncertainties shrink dramatically.



Using retuned scale variations gives a better estimate of the uncertainties

Tuning vs. Variations

[Part of Les Houches, Bellm, Hoang, Lonnblad, Plaetzer, Prestel, Samitz, AS]

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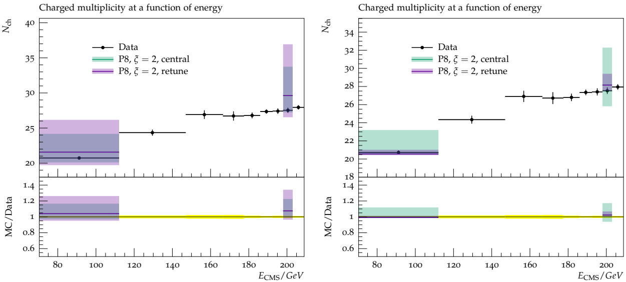
Strongly depends, which observables are tuned to.

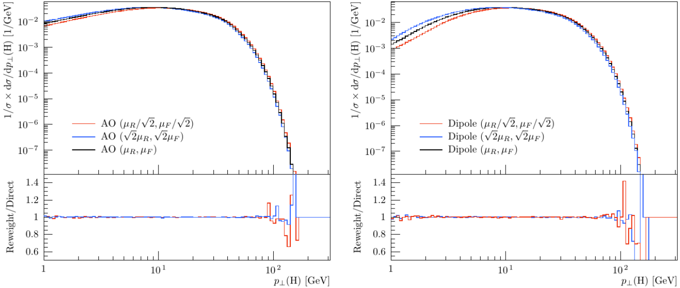


Parton-Shower Reweighting

Run-time improvement via parton-shower reweighting

[Bellm, Plätzer, Richardson, AS, Webster, Phys.Rev. D94 (2016)]

Transverse momentum of Higgs boson in $pp \to gg \to H$, $\sqrt{S} = 13$ TeV



- excellent agreement between individual runs for different scales and reweighting
- significant speed improvements: time in seconds for 10 000 events

Shower	Hadron-ization & Decays	No MPI Direct	No MPI Reweight	No MPI Frac. Diff.	MPI Primary Direct	MPI Primary Reweight	MPI Primary Frac. Diff.	MPI All Direct	MPI All Reweight	MPI All Frac. Diff.
AO	Off	79.8	94.2	-0.18	384.4	249.1	0.35	416.7	375.1	0.09
	On	183.2	128.3	0.30	738.7	364.3	0.51	751.4	482.3	0.35
Dipole	Off	99.6	52.8	0.47	435.4	161.9	0.63	462.7	213.6	0.54
	On	271.8	108.2	0.60	831.7	286.6	0.65	859.2	340.1	0.60

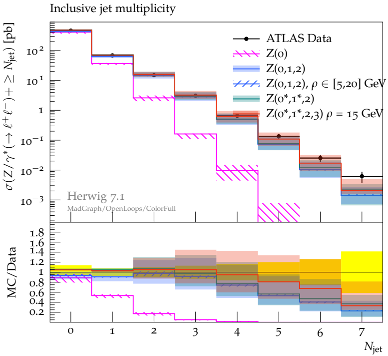
Herwig 7 recent developments

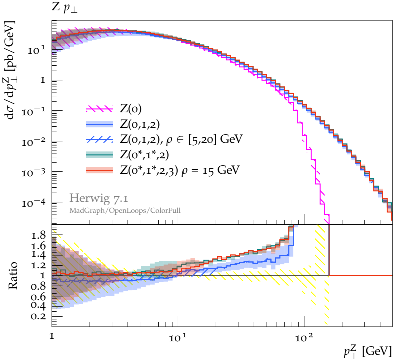
NLO Merging to Parton Shower Combination of different jet multiplicities.

Modified unitarized merging algorithm with the dipole shower

[Bellm, Gieseke, Plätzer EPJC 78 (2018)no.3,244] based on [Plätzer & Lönnblad, Prestel – 2012]

Example:

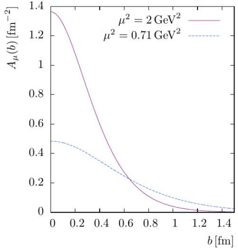




The uncertainty bands are produced by synchronized variation of the renormalization and factorization scale in the shower and ME calculation

Underlying event in Herwig++ - key components

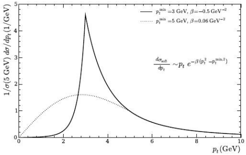
Matter distribution (μ^2)



Based on electromagnetic form factor

(radius of the proton free parameter)

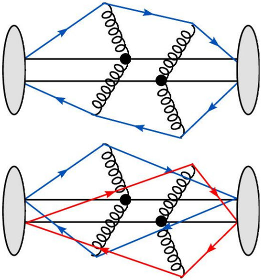
Extension to soft MPI ($p_t < p_t^{\min}$)



Gaussian extension below $p_t^{\min}$

Energy dependent $p_t^{\min}$

Colour structure (p_{reco}, p_{CD})



Possibility of change of color structure (color reconnection)

The least understood part of modeling

Main parameters:

- μ^2 - inverse hadron radius squared (parametrization of overlap function)
- $p_t^{\min}$ - transition scale between soft and hard components $\Rightarrow p_t^{\min} = p_{t,0}^{\min}\left(\frac{\sqrt{s}}{E_0}\right)^b$
- p_{reco} - colour reconnection
- p_{CD} - colour structure of the Soft UE

Herwig 7 recent developments

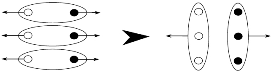
Baryonic Colour Reconnection

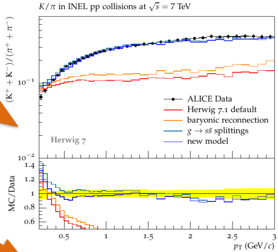
[Gieseke, Kirchgaeßer, Plätzer EPJC 78 (2018) no.2, 99]

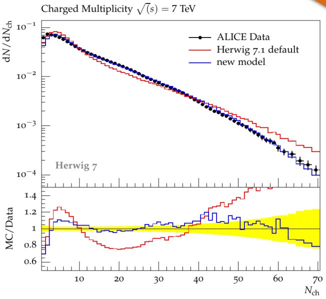
Idea:

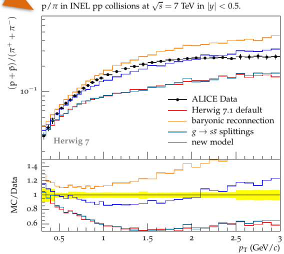
– Allow gluon to strange-pairs

– Allow recombination of mesonic to baryonic clusters with probability derived in proximity in momentum space.







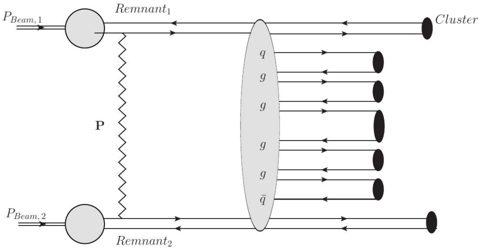


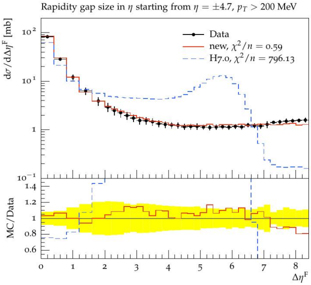
[ALICE, EPJ C75 (2015) 226]

Herwig 7 recent developments

Soft Physics

- Inclusion of diffractive topologies
- New soft peripheral MPI model
- The rapidity bump disappears

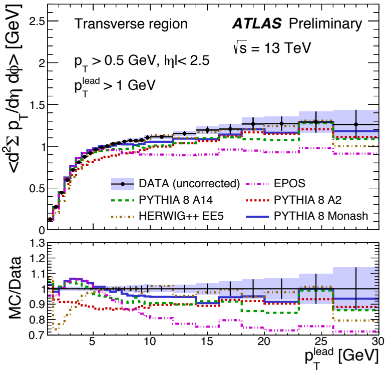


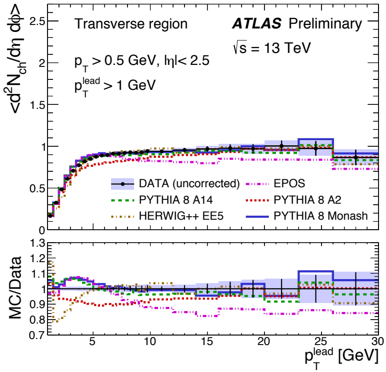


[S. Gieseke, F. Loshaj, P. Kirchgaeßer Eur.Phys.J. C78 (2018) no.2, 99]

Data Comparisons: Soft QCD

Underlying event@13TeV
This is prediction since the model was not tuned to 13 TeV data sets



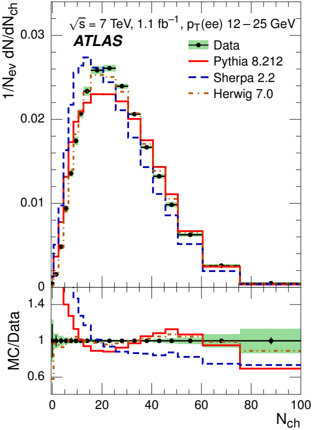


A lot of progress in Soft Physics → important to use up-to-date models and tunes!

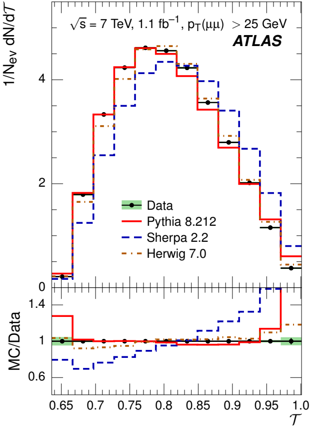
Data Comparisons: Soft QCD Underlying Event

Collaborations starts to use H7. The first time in Measurement of event-shape observables in $Z \to e^+e^-$ by ATLAS

[Eur.Phys.J. C76, (2016), 375]



Distribution of charged-particle multiplicity for $Z \to e^+e^-$.

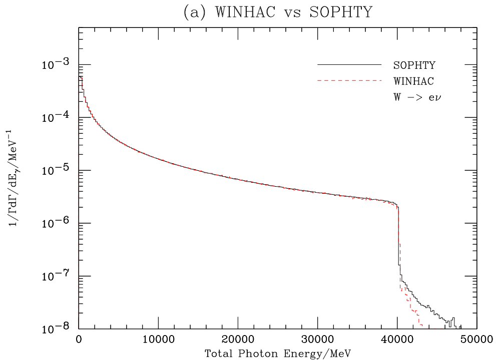


Transverse thrust $\mathcal{T}$ distribution of charged particles for $Z \to e^+e^-$.

Yennie–Frautshi–Suura (YFS) exclusive exponentiation for FSR - SOFTY

[K. Hamilton and P. Richardson, JHEP 0607 (2006) 010]

The total energy of the photons radiated in $W^{\pm} \to e^{\pm}\nu$

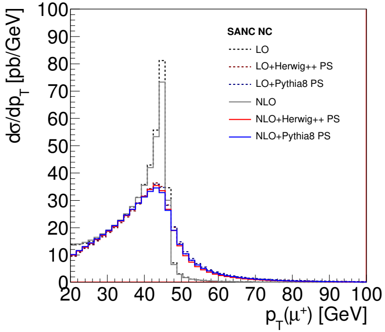


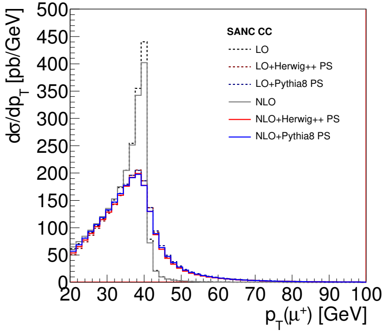
This approach is based on the YFS formalism which takes into account large soft photon logarithms to all orders. In addition, the leading collinear logarithms are included to $O(\alpha)$ by using the dipole splitting functions. The disagreement about 40 GeV is due to events with at least two hard photons.

QCD parton showers and NLO EW corrections to Drell-Yan

[P. Richardson, Sadykov, Sapronov, Seymour, Skands, arXiv:1011.5444]

- The EW NLO calculation of SANC has been implemented in the LO PS HERWIG++ and PYTHIA8





The difference between shower algorithms leads to residual differences in the relative corrections of $2-3\%$ in the $p_T(mu)$ distributions at $p_T(mu) >$ 50 GeV (where the NLO EW correction itself is of order 10%)

ISR/FSR QED in Parton Shower

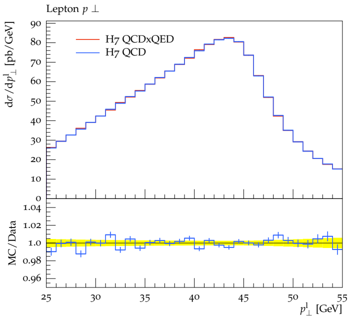
New in Herwig 7.

Trial QCD and QED emissions are generated and the one with the higher scale selected, as required by the competition algorithm.

Example:

Rivet (pleas use it:)): MC_ZINC - Monte Carlo validation observables for Z[e+e-] production ($pTl > 25GeV$, 65 GeV $< M_{ll} <$ 115 GeV)

Only ISR effects below (FSR switched off):



QED radiation from quarks is by factor 100 weaker than QCD radiation!

[T. Sjöstrand, Yellow Report CERN 92-04 (1992) 89]

Possible development in Cracow?

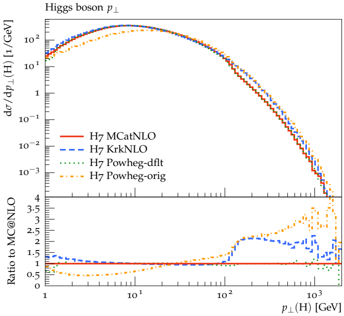
- Dedicated work on Drell-Yan W/Z:
  W(Z)INHAC (W.Placzek talk)/KKMC(Z. Was talk) + Herwig 7 (this talk) + KrkNLO (next slide)
- Difficult task...
- We need to understand if this is really worth/needed.

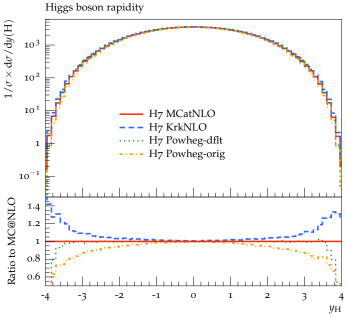
Matching: MC@NLO, Powheg and KrkNLO

- NLO matched to parton showers as new default. Matching mechanism fully generic, fully automated for two showers and two matching schemes [subtractive (MC@NLO-type) multiplicative (Powheg-type)
  - performed by Matchbox module

    [work led by S. Plätzer with substantial contributions by J. Bellm, A. Wilcock, M. Rauch, C. Reuschle]
  - matrix elements in general from external providers via linked library
- Also a new matching method KrkNLO matched to the Dipole Shower is available in H7
  - Very simple.
  - Price to pay: new pdf sets in MC scheme, we provide them based on standard MSbar sets.
  - So far implemented in Herwig for Z/H.

[Jadach, Nail, Placzek, Sapeta, AS, Skrzypek, arXiv:1607.06799]



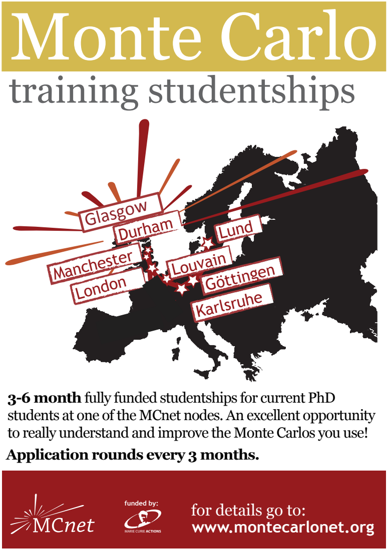


Summary & Outlook

- Fully automated NLO plus parton-shower calculations by default
  - Two matching algorithms
  - Two parton showers
- NLO multi-jet merging
- Flexible, easy-to-use tool for both SM and BSM simulations
- QED/EW correction (SOFTY, QED PS, NLO EW SANC)
- Further development:
  - more on NLO EW corrections (Recola together with an extension to mixed QCD+QED corrections in the Matchbox), QED radiation in the Dipole Shower...
  - Loop-induced processes
  - work on soft QCD: new colour re-connection models, ...
  - fully exploit phenomenology potential (for example q/g discrimination) and continue on uncertainties.
  - . . .

herwig@projects.hepforge.org

https://herwig.hepforge.org/



MC*net* projects

Pythia+Vincia

Herwig

Sherpa

MadGraph

“Plugin” – Ariadne+HEJ

CEDAR – Rivet+Professor

+Contur+hepforge+…

Thank you for your attention!