Herwig 7.1

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at the
Tools Workshop 9th September CERN

(thanks to Simon Plätzer for the slides)

The Herwig Event Generator

Herwig++ has seen ten years of development to meet a milestone intended to succeed the FORTRAN HERWIG program.

This milestone evolved over time as the experimental and phenomenological needs did.

On top of its first definition (= at least as good as HERWIG), precision has become the key goal

Herwig++ 3.0 → Herwig 7.0

Herwig 7 – Core Features

[Bellm, Gieseke, Grellscheid, Plätzer, M. Rauch, Reuschle, Richardson, Schichtel, Seymour, Siodmok, Wilcock, Fischer, Harrendorf, Nail, Papaefstathiou, D. Rauch – EPJ C 76 (2016) 196]

NLO matched to parton showers as default for the hard process.

→ Fully automated setup of NLO calculation and matching,
  (only links external codes to calculate amplitudes)
→ diagram based phase-space sampling with adaptive integration
→ Run in a single program, no event files to move around.
→ Subtractive (MC@NLO-type) and multiplicative (POWHEG-type) matching.

Two showers: Angular-ordered and dipole shower.

Spin correlations and QED radiation in angular ordered shower.

Facilities for parton shower uncertainties.
Improved kinematics reconstruction.

Vastly improved documentation, usage and installation.

New tunes taking NLO matching into account + much, much more …

Shower Algorithms

Need to have two systematically different algorithms to validate uncertainties

“QTilde” [Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]

→ “Traditional” angular-ordered shower: default shower
→ QED, spin correlations, shower variations, decays
→ Truncated showering for Powheg-type matching

“Dipole” [Plätzer, Gieseke – JHEP 1101 (2011) 024]

→ Dipole-type evolution, ordered in dipole p_T
→ Extensive shower variations, decays soon (7.1)
→ Work horse for NLO multijet merging

Uncertainties

[Bellm, Nail, Plätzer, Schichtel, Siodmok – Eur.Phys.J. C76 (2016) 665]

Aim at evaluating event generator uncertainties in a global prescription

→ Need to evaluate uncertainties of building blocks one at a time.
→ Then pin down cross feed, making minimal assumptions.

Start with the perturbative part: Parton showers – at leading order!
Then check if matching algorithms exhibit the expected improvement.

Shower scale variations not a priori clear to serve as estimating an order one term in the next (logarithmic) order – logarithmic accuracy mostly unclear.

Rather constrain by demanding controllable uncertainties:

→ Small/large where showers are expected to be reliable/unreliable.
→ Consistent between two systematically different algorithms.
→ Not to mess around with hard process input.

Logarithmic structure

[Bellm, Nail, Plätzer, Schichtel, Siodmok – Eur.Phys.J. C76 (2016) 665]

Look at generic Sudakov exponent:

KINEMATIC LIMIT $\sim S$

HARD SCALE $\sim \mu^2$

HARD SCALE IN z PHASE SPACE

$$-\ln \Delta \sim \int_{p_\perp^2}^{R_\perp^2} \frac{dq_\perp^2}{q_\perp^2} \underbrace{K(Q_\perp^2, q_\perp^2)}_{\text{CUTOFF ON RESUMMATION}} \ln\left(\frac{K_\perp^2}{q_\perp^2}\right)$$

α_s running on top, also PDF arguments.

Uncertainty Benchmarks with Herwig 7

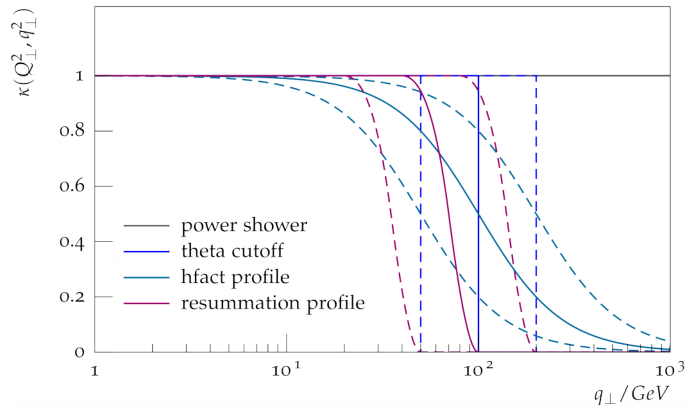
[Bellm, Nail, Plätzer, Schichtel, Siodmok – Eur.Phys.J. C76 (2016) 665]

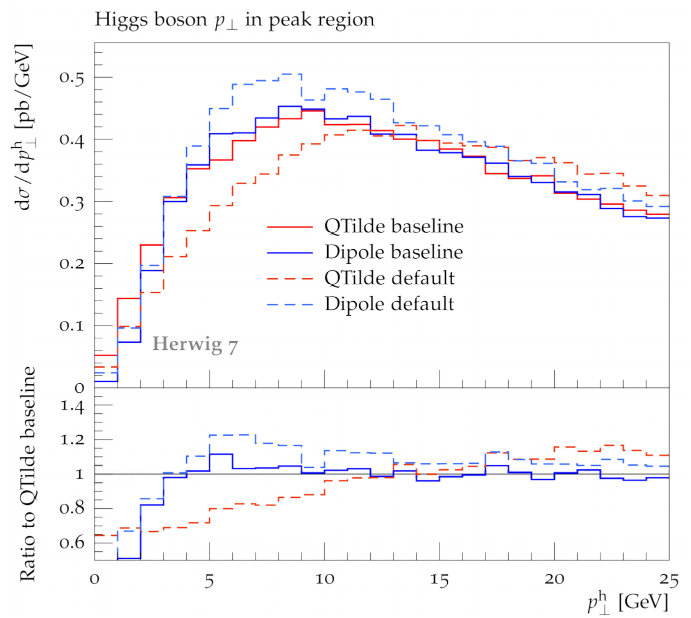
Resummation needs to be cut off at a typical hard scale → veto on hard emissions, region to be filled by matching.

Resummation properties are heavily influenced by the way resummation is being switched off.

Study scale variations in angular ordered and Dipole showers at a benchmark setting where we observe absolutely comparable resummation properties:

Hard veto scales, factorization/renormalization scales in the shower and hard process.





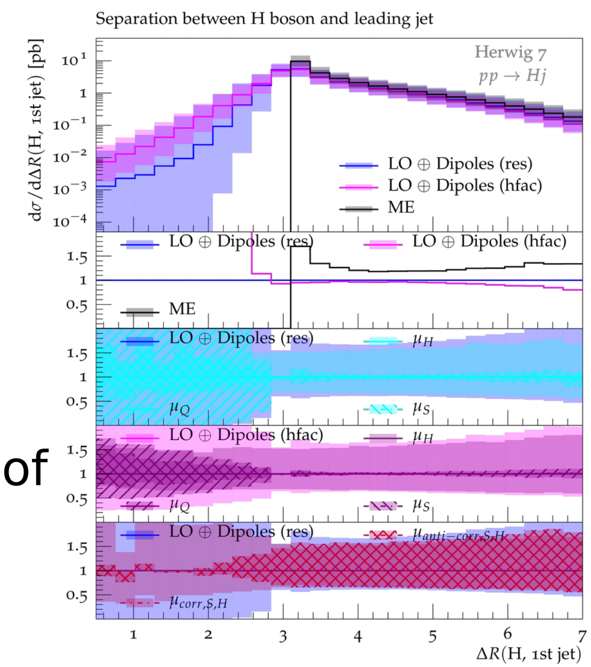
Uncertainty Benchmarks with Herwig 7

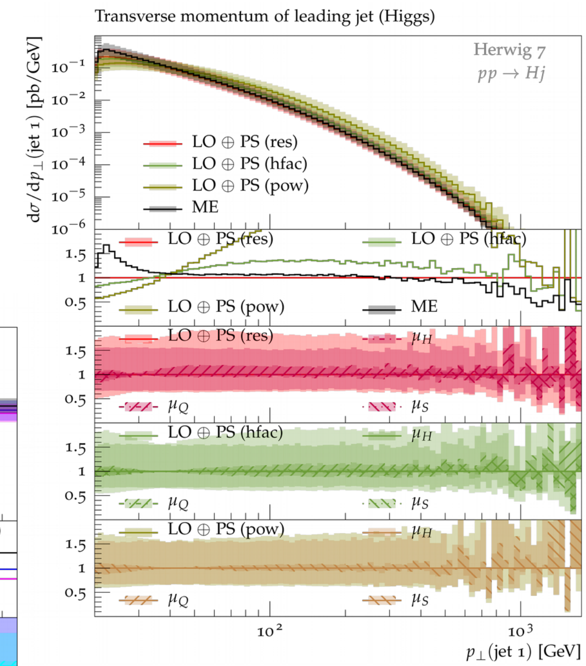
[Bellm, Nail, Plätzer, Schichtel, Siodmok – Eur.Phys.J. C76 (2016) 665]

Choice of the hard veto scale is crucial to reproduce hard process input: typically average transverse momenta of hard objects.

Controllable uncertainties can only be established by narrow, smeared versions of a theta function, confirming simple LL arguments.

We can now check the impact of higher order improvements.





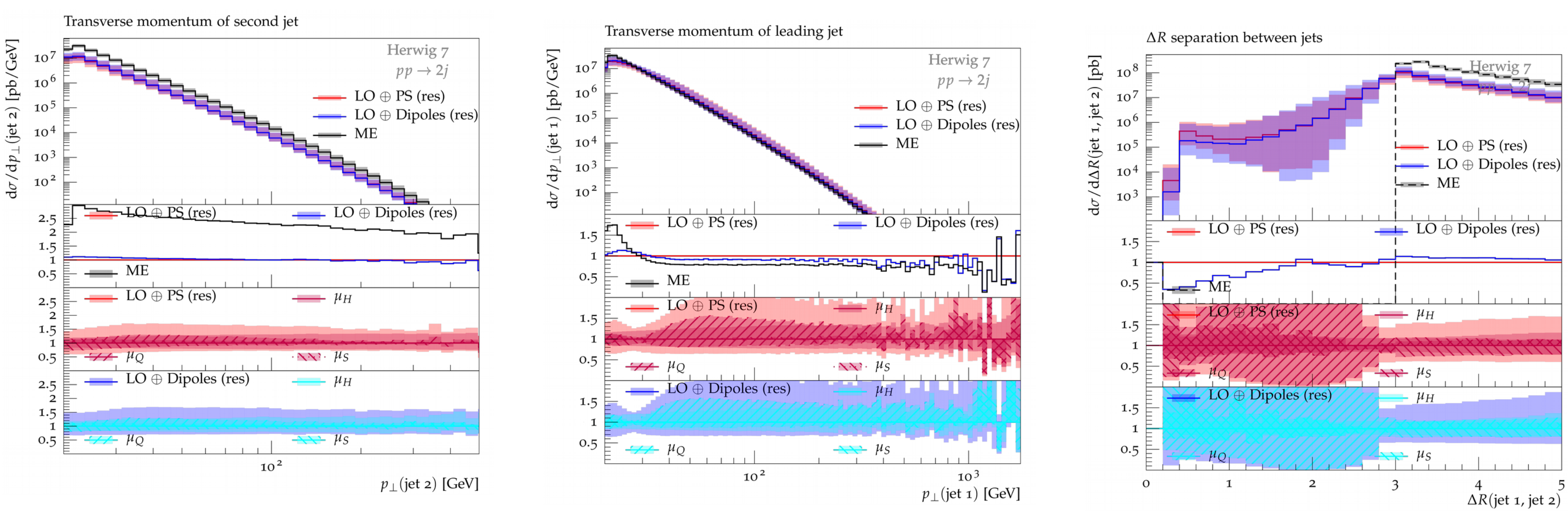
Still “qualitative” procedure unless showers get higher order corrections.

Uncertainty Benchmarks – Jets

[Bellm, Nail, Plätzer, Schichtel, Siodmok – Eur.Phys.J. C76 (2016) 665]

Choice of hard shower scale is crucial.

Again reliable and comparable results across showers:
→ Variations are reasonable, resummation profile as default.



[Amplitudes provided by MG5_aMC + ColorFull]

Shower reweighting

[Bellm, Plätzer, Richardson, Siodmok, Webster – Phys.Rev. D94 (2016) no.3]

On-the fly shower reweighting available
for both shower's scale variations.

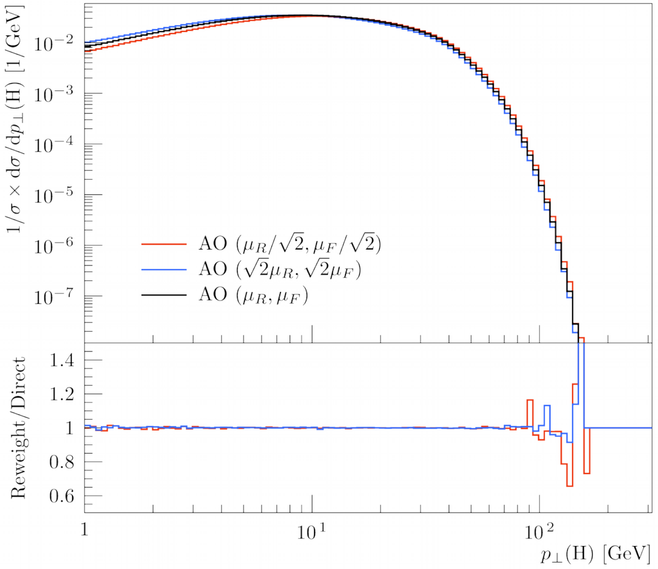
Fills HepMC multi-weight vectors, dedicated
validation and performance studied.

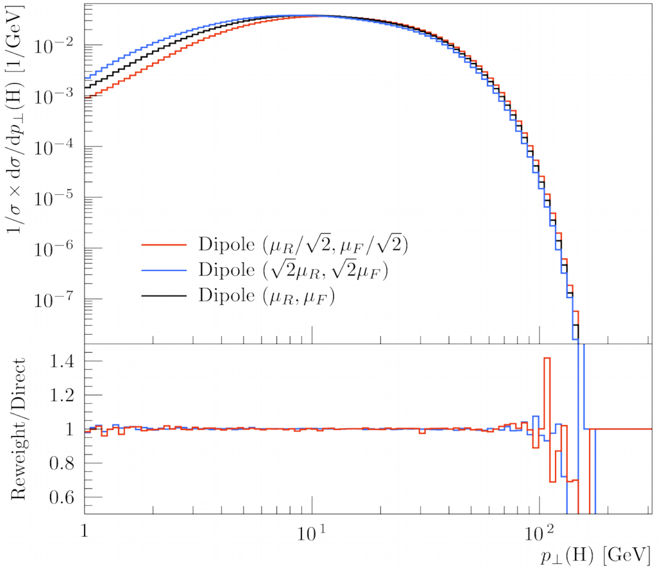
Tested with Rivet 3 beta.

Workhorse:

Weighted version of the “Sudakov veto algorithm”
allowing for an unprecedented shower flexibility.

More applications to follow, can also
deal with negative “probabilities”.





Herwig 7 – Usage Example

Old-style input files still work but will become deprecated.
New NLO input files much easier to handle.

Essentials of a new-style input file:

```
read snippets/Matchbox.in
read snippets/PPCollider.in
```
← Choose ME & collider setup.

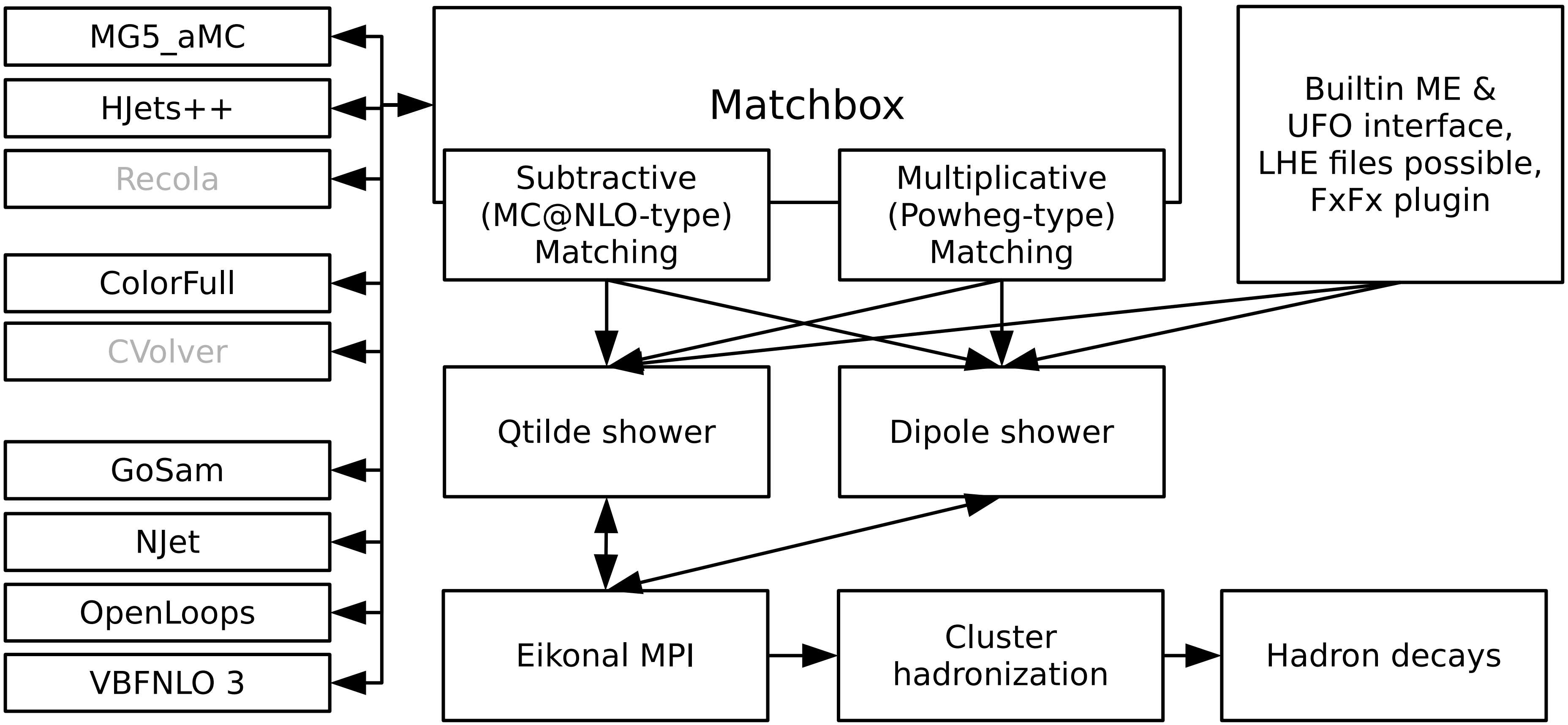
```
set Factory:OrderInAlphaS 1
set Factory:OrderInAlphaEW 2
do Factory:Process p p -> e+ e- j
```
← Choose process.

```
read Matchbox/MadGraph-OpenLoops.in
```
← Choose amplitude providers.

```
read Matchbox/MCatNLO-DefaultShower.in
```
← Choose shower and matching.

Herwig 7 – Under the Hood

Use run-time interfaces to external codes to evaluate amplitudes.
Automatically build up fixed-order or matched NLO cross sections.

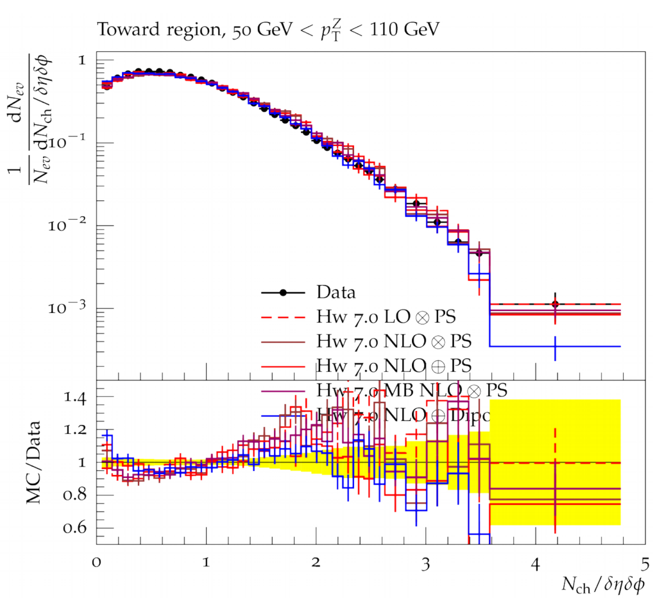


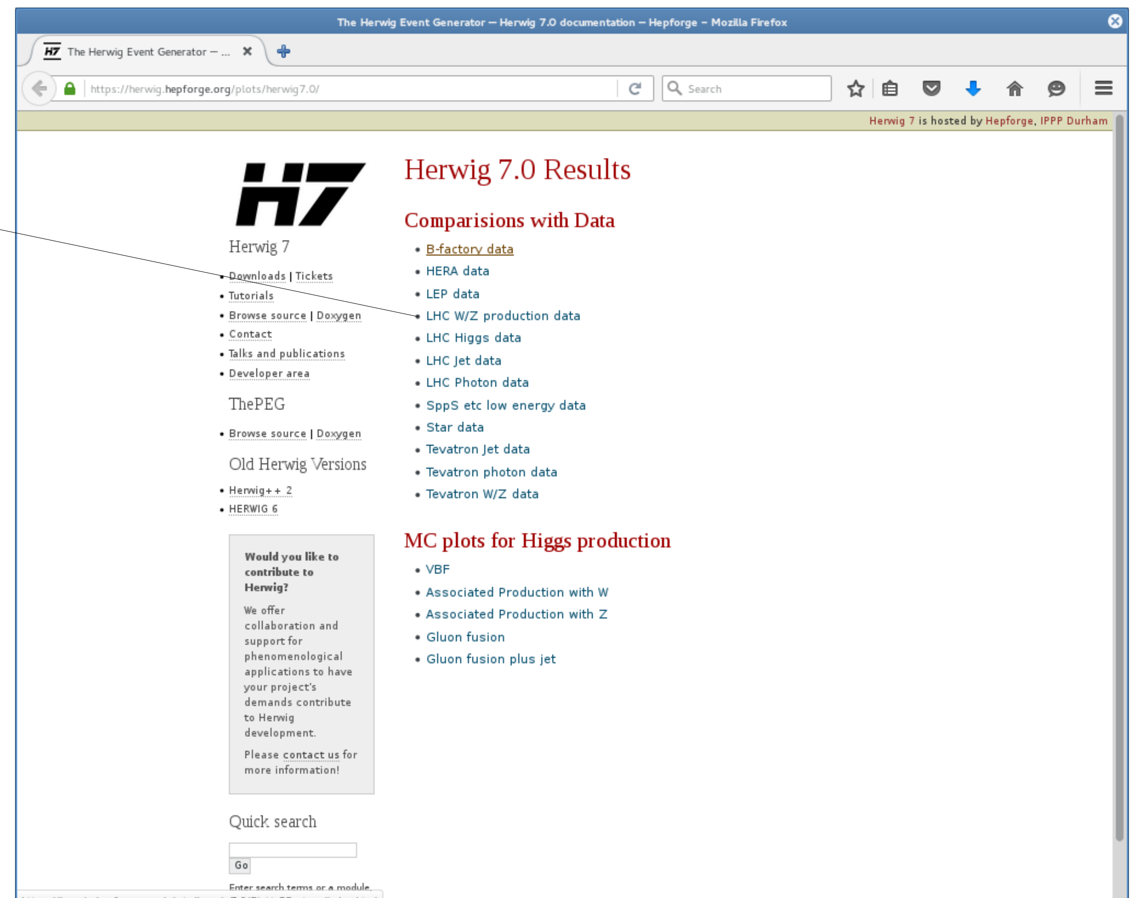
Output: HepMC, Rivet, built-in analyses.

Herwig 7 – Extensive Validation against Data

[amplitudes built-in or from MG5aMC and OpenLoops]

Routinely run all available Rivet analyses.
All processes simulated at NLO using the available options.
Stability and data description crucial for release quality standards.





Herwig 7.1

A number of new features

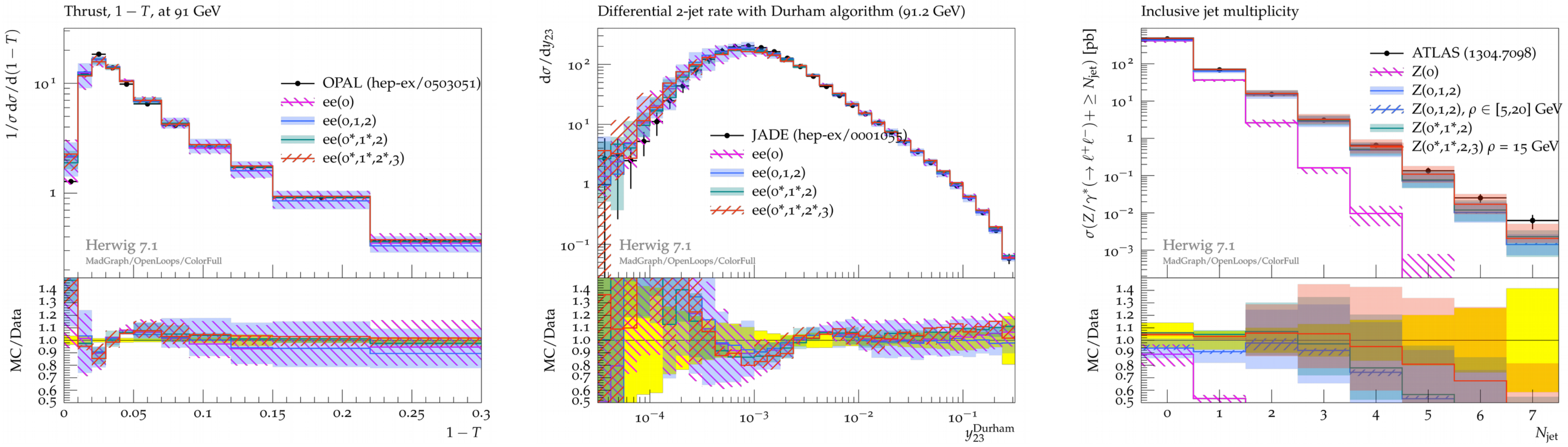
- Merging of multiple emissions at NLO
- Top decays in the dipole shower
- Improved treatment of radiation from heavy quarks
- Improved soft physics
- More options for loop induced processes
- Simplification of input files and interfaces

Herwig 7.1 preview – NLO Multijet Merging

[Bellm, Gieseke, Plätzer]

NLO multijet merging with the dipole shower, inspired by “unitary” merging algorithms. [Plätzer '12 and Lönnblad, Prestel '12]

→ Based on Matchbox infrastructure as outlined before
→ No strict unitarization, only cancel log-enhanced contributions
→ Catching cross section changes due to finite real emission contributions
→ Standard subtractive matching below merging scale

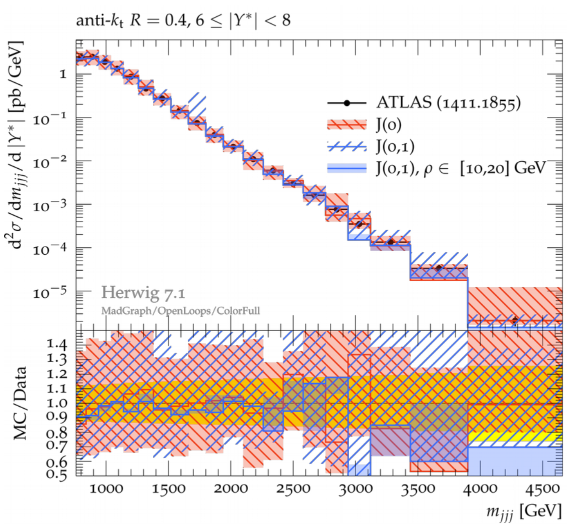


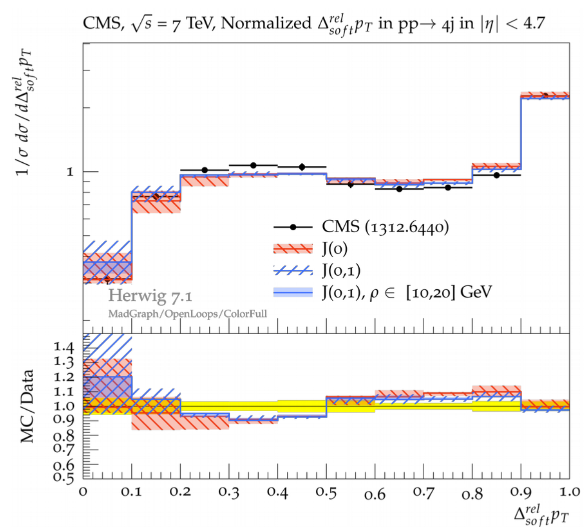
Herwig 7.1 Merging for Jets

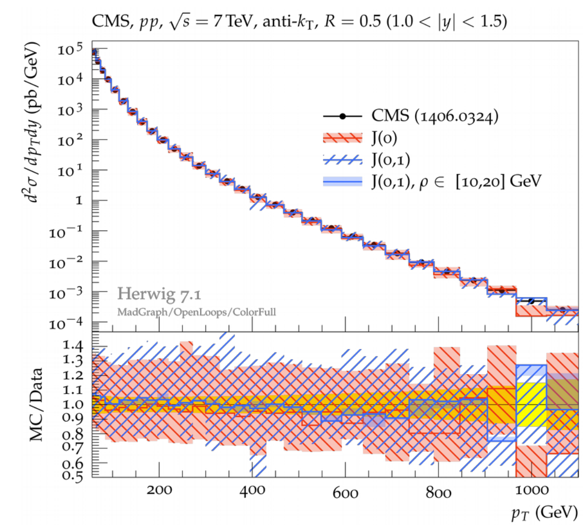
[Bellm, Gieseke, Plätzer]

Leading order two and three jets merged.

→ Identification of hard object (jet) and appropriate cuts crucial.
→ Unitary merging algorithm provides unique key to trace contributions.





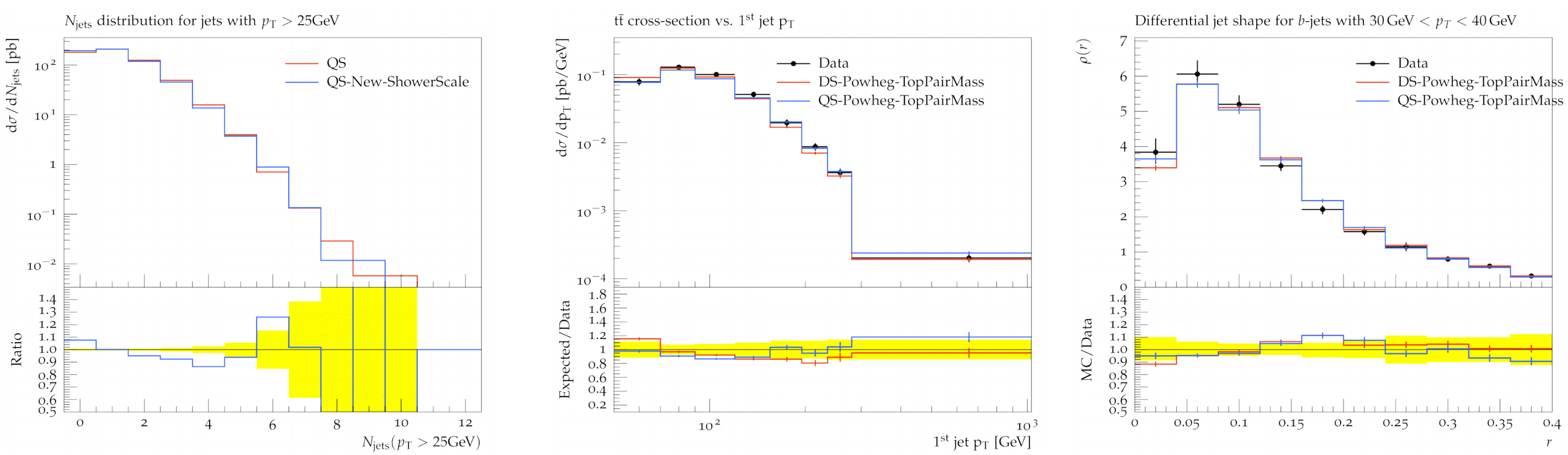


Herwig 7.1 – Tops

[Plätzer, Richardson, Webster – in progress]

Top decays are available at NLO, for both showers, comparable performance.

→ Basis to systematically address uncertainties.



Shower scale setting is again a lesson learned .

Herwig 7.1 preview – Soft physics

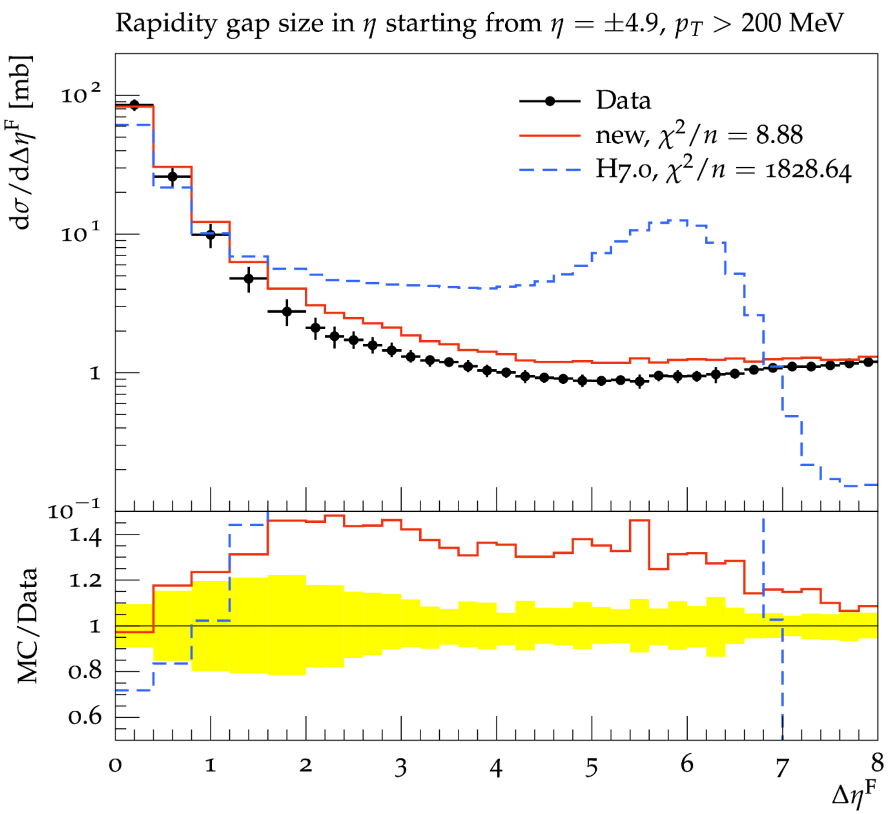
[Gieseke, Kirchgaesser, Loshaj – arXiv:1612.04701]

Improvements in soft physics modeling:

→ Soft diffraction included

→ New model for soft MPI based on multiperipheral kinematics

Color reconnection developments ongoing, stay tuned!



Summary

Herwig 7.0 series

→ NLO matching via two paradigms and two showers
→ Shower variations for both showers
→ Shower on-the-fly reweighting for both showers

Herwig 7.1 series

→ Operates just as 7.0 series
→ NLO multijet merging with dipole shower
→ Top decays with NLO corrections for dipole shower
→ Improved soft physics
→ More options for loop induced processes

Code and Documentation available from https://herwig.hepforge.org