Herwig++

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Outline

- Quick tour with highlights of Herwig++.
- NLO matching.
- Underlying event model.

Herwig collaboration

- Cambridge
  - Bryan Webber, Andreas Papaefstathiou*, ...
- Durham
  - Peter Richardson, David Grellscheid, Jon Tully*, ...
- Karlsruhe
  - SG, Simon Plätzer*, Andrzej Sziodmok•, ...
- Manchester
  - Mike Seymour, ...
- Milano
  - Keith Hamilton•

• Postdoc ($\leq$3yr contract)
* PhD Student
Authors $\subset$ collaboration members.

Herwig++ Project

- Hadron Emission Reactions With Interfering Gluons.
- Completely new development, goal: successor of `HERWIG` (current version 6.5).
- Start: Cambridge/Manchester 2001.
- First version for e^+e^- 2003

SG, P. Stephens and B. Webber, JHEP **0312** (2003) 045 [hep-ph/0310083]

SG, A. Ribon, M. H. Seymour, P. Stephens and B. Webber,JHEP **0402** (2004) 005 [hep-ph/0311208]

- Further development in Cambridge, CERN, Durham, Karlsruhe.
- Beginning of 2006 first version for hadronic collisions (2.0β). Continous development:

SG *et.al.*, Herwig++ 2.0β Release Note, hep-ph/0602069
SG *et al.*, Herwig++ 2.0 Release Note, hep-ph/0609306
M. Bähr *et al.*, Herwig++ 2.1 Release Note. arXiv:0711.3137
M. Bähr *et al.*, Herwig++ 2.2 Release Note. arXiv:0804.3053

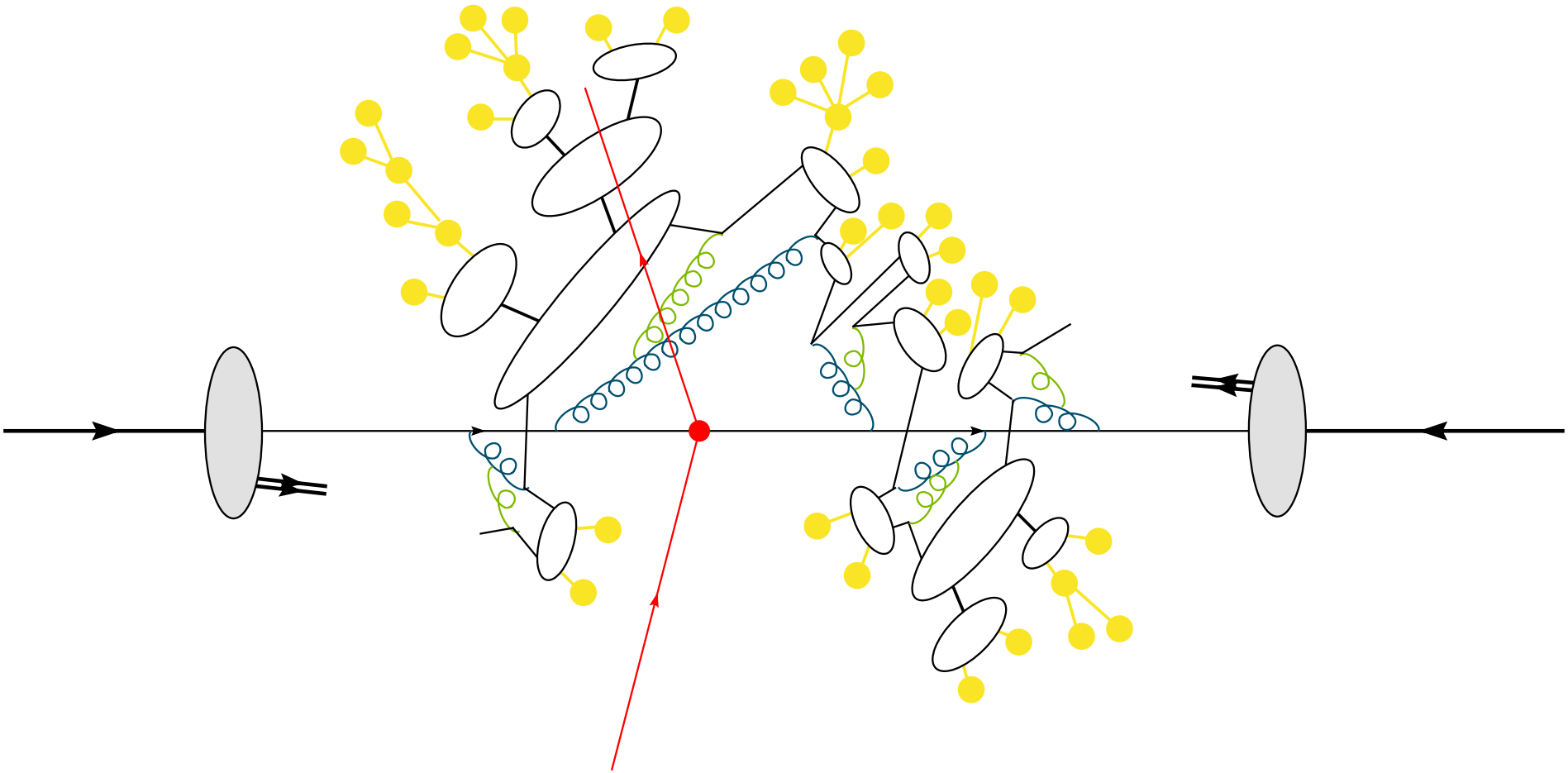
- Physics and Manual.

M. Bähr *et al.*, Herwig++ Physics and Manual, Eur. Phys. J. C **58** (2008) 639

- Current version 2.4 — complete simulation of hadronic collisions.

M. Bähr *et al.*, Herwig++ 2.3 Release Note. arXiv:0812.0529

pp Event Generator



Hard processes

Processes at Born level (out of the box)

- Hadron collider
  QCD $2 \to 2$, $t\bar{t}$, MinBias
  $(\gamma, Z^0) \to \ell^+\ell^-$, $W^\pm \to \ell^\pm \nu_\ell$, $(Z^0, W^\pm) + \text{jet}$
  W^+W^-, $W^\pm Z^0$, Z^0Z^0, $W^\pm\gamma$, $Z^0\gamma$
  h^0, $h^0 + W^\pm$, $h^0 + Z^0$, $h^0 + \text{jet}$, qqh^0 (VBF), $t\bar{t}h^0$
  $\gamma + \text{jet}$, $\gamma\gamma$
- DIS
  NC/CC/Photoproduction
- $e^+e^-/\gamma\gamma$
  $e^+e^- \to Z^0$, $e^+e^- \to q\bar{q}$, $e^+e^- \to \ell^+\ell^-$, $e^+e^- \to W^+W^-$,
  $e^+e^- \to Z^0h^0$, $e^+e^- \to h^0e^+e^-$, $e^+e^- \to h^0\nu_e\bar{\nu}_e$.
  $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to f\bar{f}$.

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  W^+W^-, $W^\pm Z^0$, Z^0Z^0, $W^\pm\gamma$, $Z^0\gamma$
  h^0, $h^0 + W^\pm$, $h^0 + Z^0$, h^0 + jet, qqh^0 (VBF), $t\bar{t}h^0$
  γ + jet, $\gamma\gamma$
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  $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to f\bar{f}$.

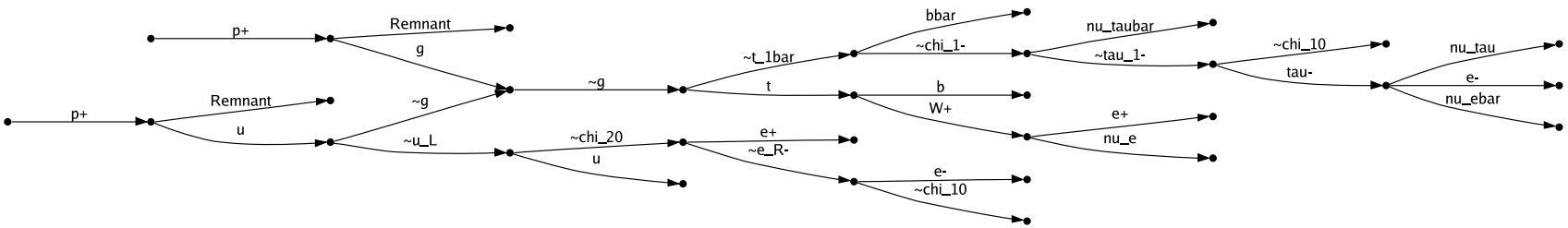
Also at NLO with POWHEG matching (more details later).

Hard processes

- BSM processes
  - MSSM.
  - Extra Dimensions.
  - More under construction.
  - Hard process and up to 3 body decays created automatically from model file.
  - Allows for simulation of full spin correlations.
- Anything else via `LesHouchesFileReader`.

Hard processes

Example event, only MSSM hard process.
Full cascade decay chain w/ spin correlations



MSSM, UED, RS included in Herwig++ (since 2.1).

[Martyn Gigg, Peter Richardson, EPJC **51** (2007) 989]

Finite width effects and 3 body decays (since 2.3)

[M.A. Gigg, P. Richardson, arXiv:0805.3037]

All automatically built.
Inclusive or exclusive process specification.

Parton showers

- New parton shower variables introduced for Herwig++

  [SG, P. Stephens and B. Webber, JHEP **0312** (2003) 045 [hep-ph/0310083]]

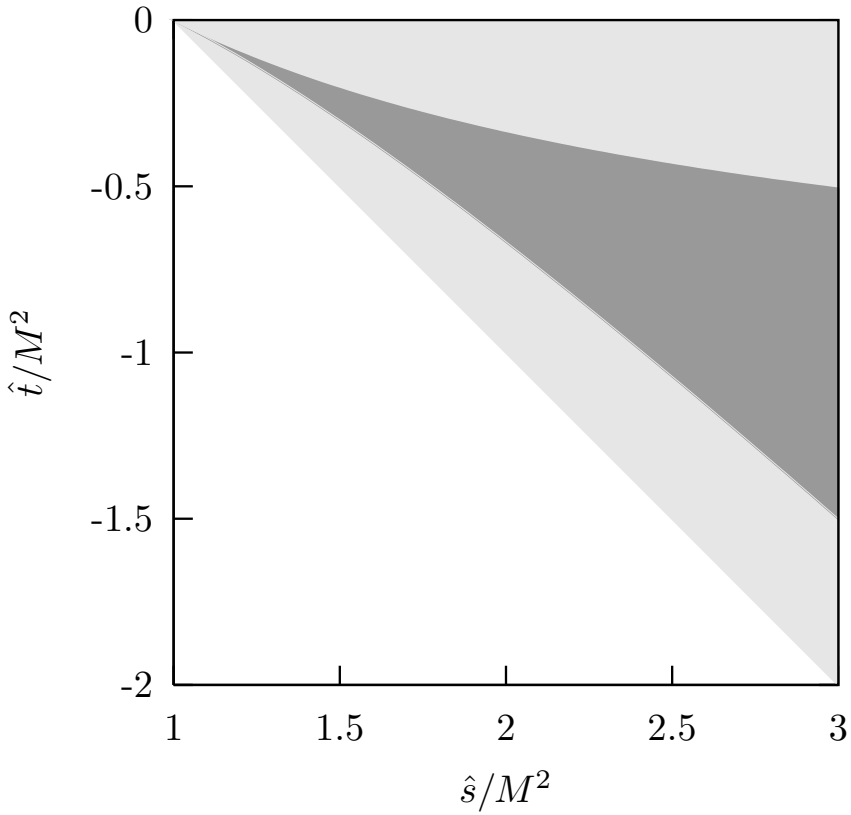
- Default shower.
- More under development → dipole shower, based upon Catani–Seymour dipoles.

  [SG, S. Plätzer, 0909.5593]]

Hard ME correction in DY

- Light: collinear/soft regions.
- Dark: Dead region, filled with extra hard emissions — not accessable by parton shower.
- To be complemented by soft matrix element corrections.

Also for $V^* \to q\bar{q}$, t–decay (2.0)
$gg \to h^0$ (2.2),



MC@NLO (in Herwig++)

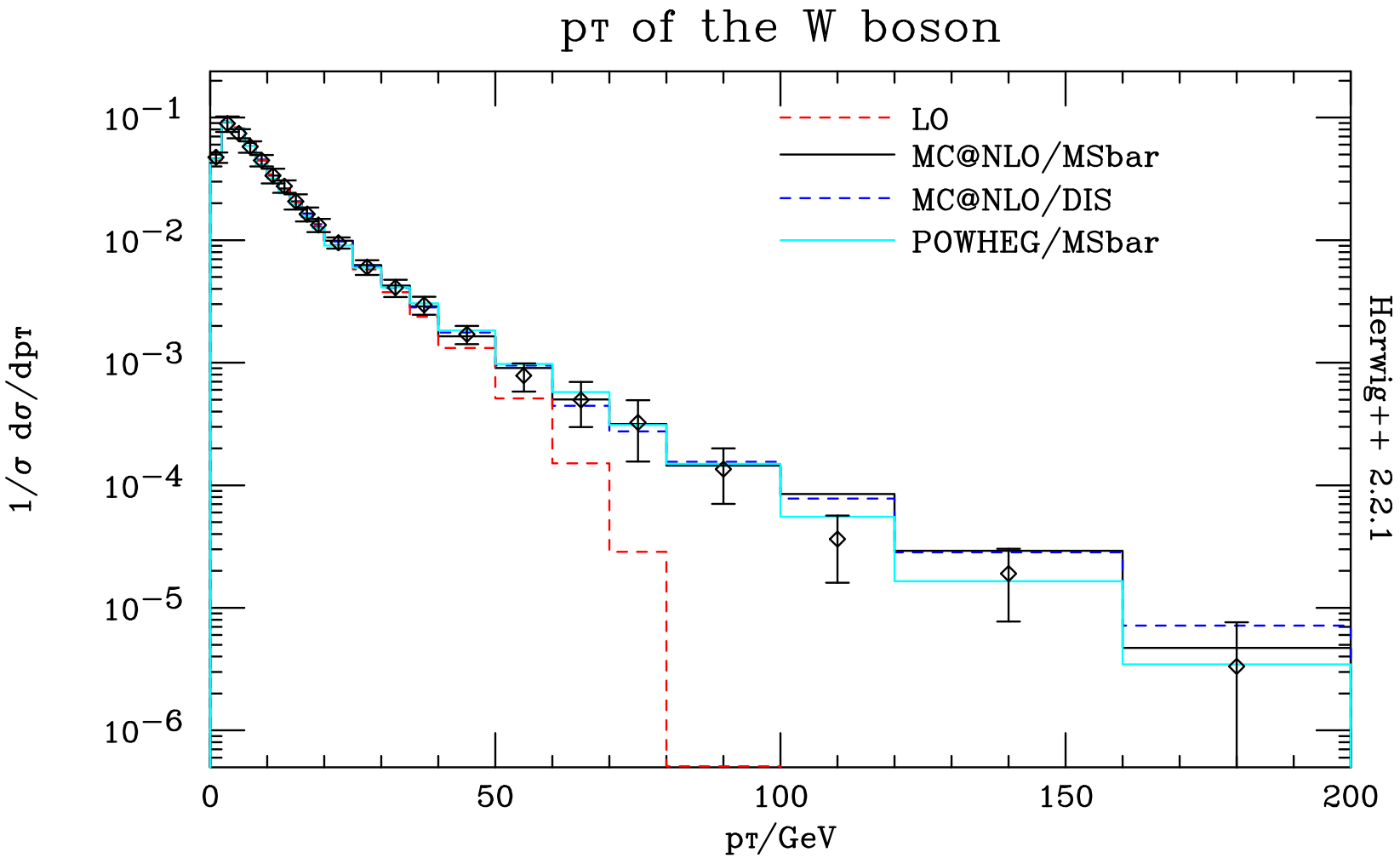
- Introduced 2002 Frixione, Webber, JHEP 0206:029,2002 [hep-ph/0204244].
- Extended to heavy quarks

  Frixione, Nason, Webber, JHEP 0308:007,2003 [hep-ph/0305252].
- further extensions to many processes (single top etc.)
- MC@NLO customised to use with HERWIG.
- Some processes in Herwig++ as well
  $e^+e^- \to$ jets, DY, W', h^0 decay

  Latunde–Dada 0708.4390, 0903.4135, Latunde–Dada, Papaefstatiou, 0901.3685.

MC@NLO (in Herwig++)

Drell–Yan example



Latunde–Dada 0708.4390, 0903.4135, Latunde–Dada, Papaefstathiou, 0901.3685.

POWHEG

- Alternative proposed by P. Nason.
- Modified Sudakov FF for first emission.
- Angular ordered Parton Shower tricky (see below).
- *Truncated Shower* adds in missing radiation afterwards.
- Finally evolution with 'ordinary' Parton Shower.

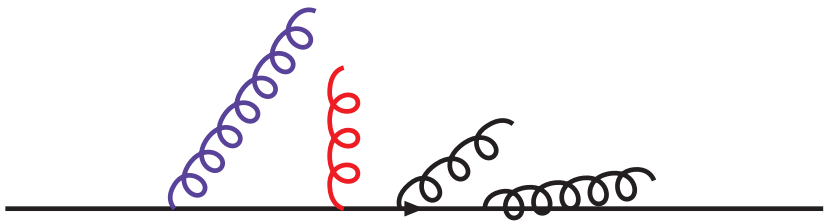
[Nason, hep-ph/0409146; Nason, Ridolfi hep-ph/0606275]

Recently systematically extended.

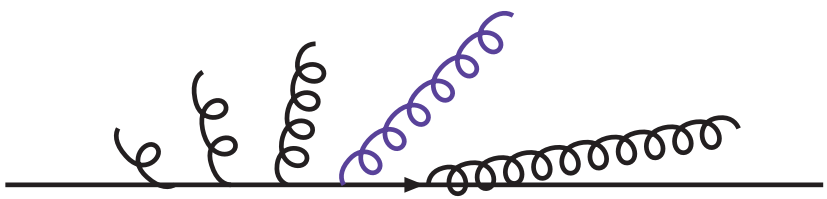
- `POWHEG` formulation independent of the event generator implementation.
- Worked out for different subtraction schemes.

[Frixione, Nason, Ridolfi, 0707.3081, 0707.3088; Frixione, Nason, Oleari, 0709.2092]

Angular ordered showers and POWHEG



$p_\perp$ ordered shower. Angular ordering from additional vetos.



Angular ordered shower. Some softer emissions before hardest one.

Need truncated showers.

POWHEG in Herwig++

- First implementation of method for e^+e^- annihilation

  [O. Latunde–Dada, SG, B. Webber, hep-ph/0612281]

- Many more processes now available with release:
  DY $(\gamma^*/Z^0/W^\pm), h^0, h^0Z^0, h^0W^\pm$

  [K. Hamilton, P. Richardson and J. Tully, 0806.0290, 0903.4345]

- and with contributed code:
  $e^+e^- \to$ jets, $e^+e^- \to t\bar{t}$, $t-$decay, W', h^0-decay

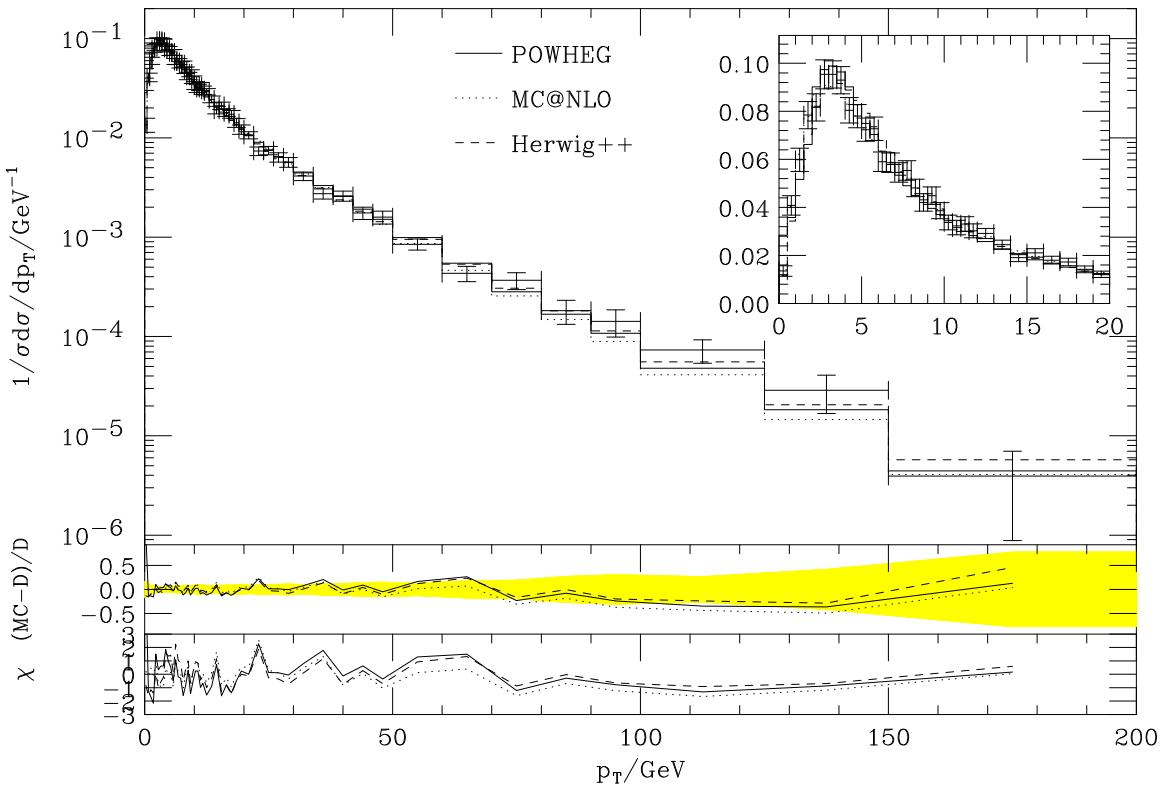
  [O. Latunde-Dada, 0812.3297, Eur. Phys. J. C **58**, 543 (2008)]

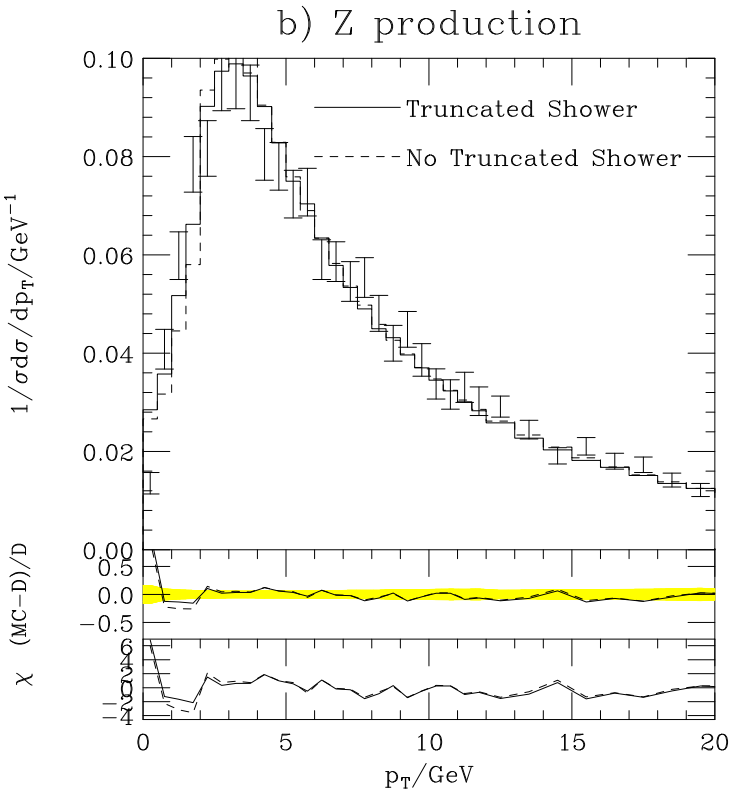
  [A. Papaefstathiou and O. Latunde-Dada, JHEP **0907**, 044]

- includes full truncated showers.
- Interface to work of Nason *et.al.* straightforward.
- More processes underway.

POWHEG in Herwig++

POWHEG in Herwig++ with full truncated shower.
DY γ^*/Z^0 production vs CDF Run I.

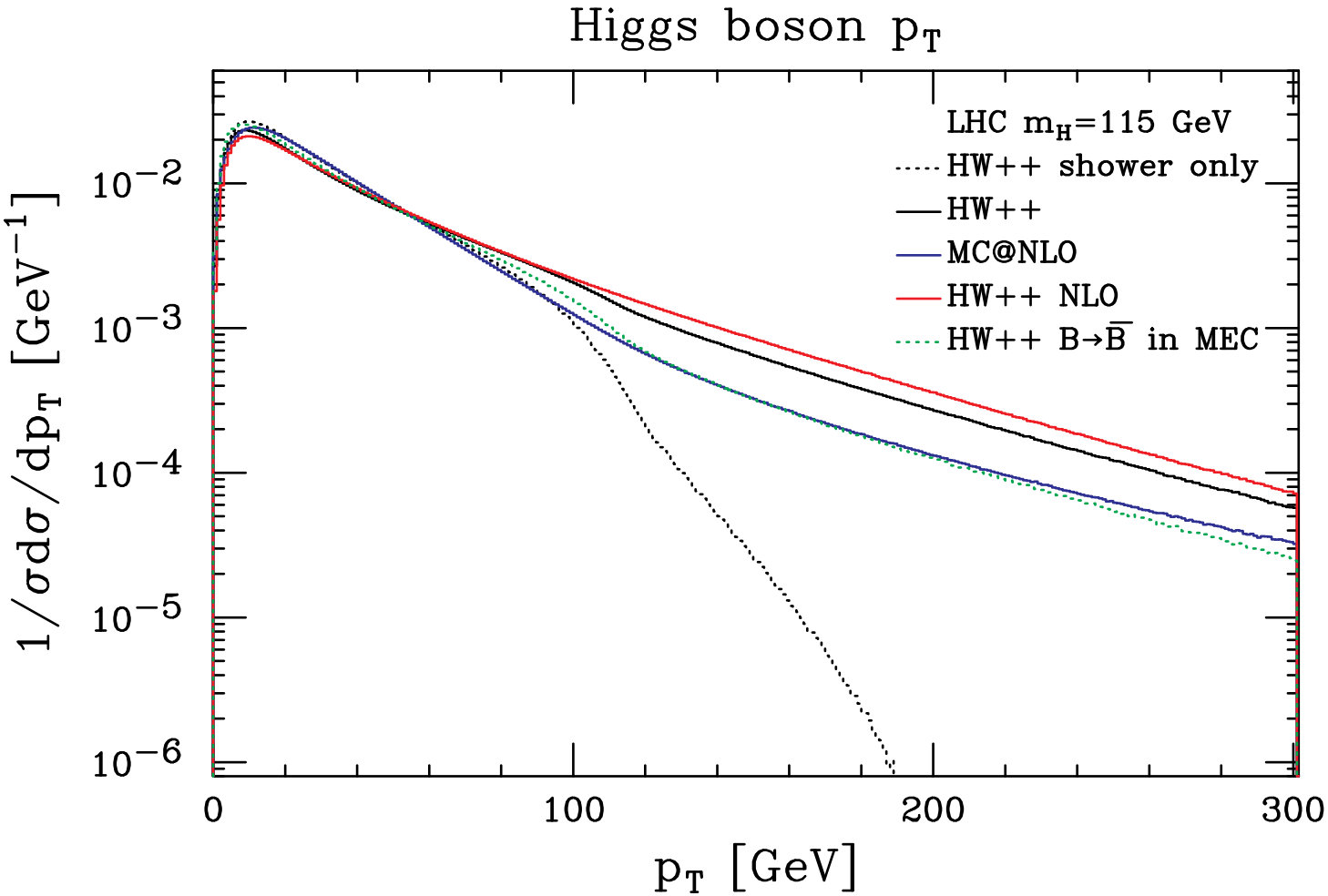




[K. Hamilton, P. Richardson, J. Tully, JHEP 0810:015 [0806.0290]]

POWHEG in Herwig++ with full truncated shower.

$gg \to h^0$



[K. Hamilton, P. Richardson, J. Tully, JHEP 0904:116, [0903.4345]]

NLO in Herwig++

- MC@NLO, some processes, via external package.
- POWHEG, already many processes in release.
  More to come.
- More Matching (both variants possible) with new Catani–Seymour dipole showers in progress
  ($\rightarrow$ talk of S. Plätzer in QCD session).

Hadronization and decays

- Cluster hadronization, similar to HERWIGs. Works.
- Decays much more sophisticated
  - Specialized decayers for majority of channels. Mesons *and* baryons.
  - Up to 5-body decays.
  - Spin correlations.
  - Running widths.
  - Photon radiation off charged hadrons.

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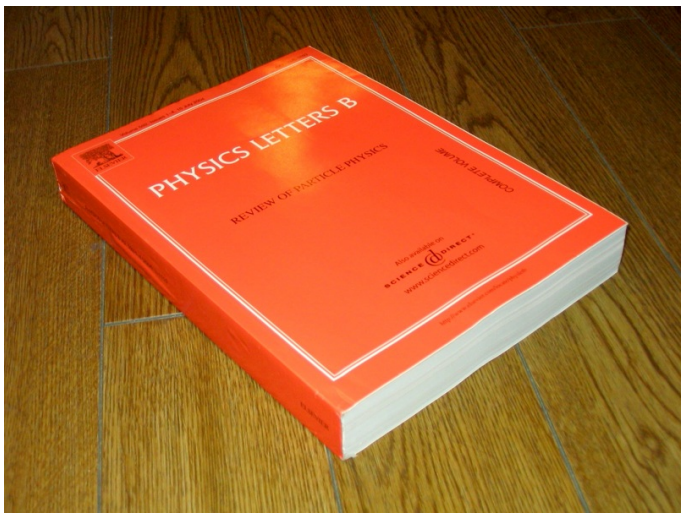
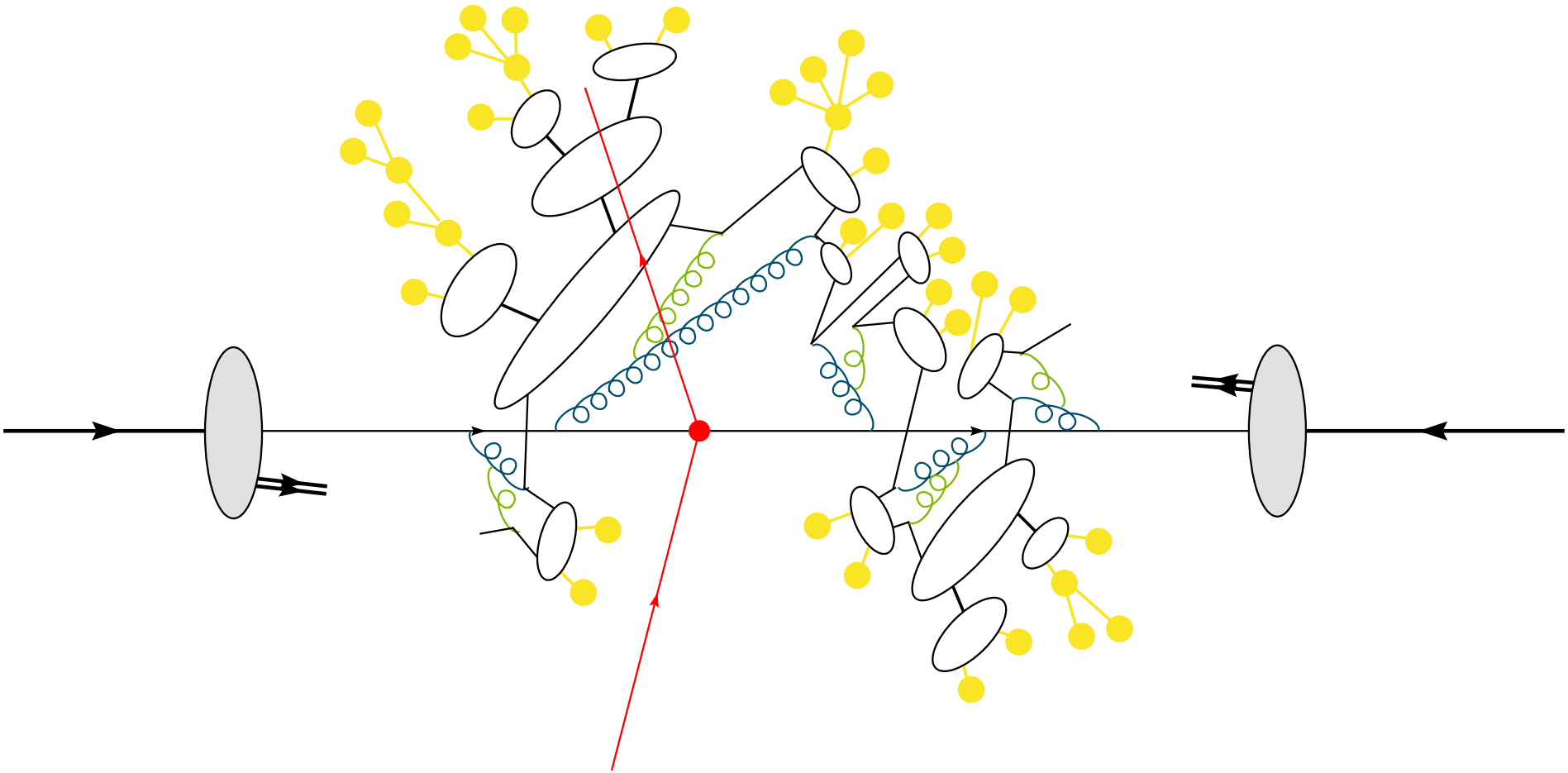


$\sim$ 500 particles and $\sim$ 6500 decay modes included.

pp Event Generator



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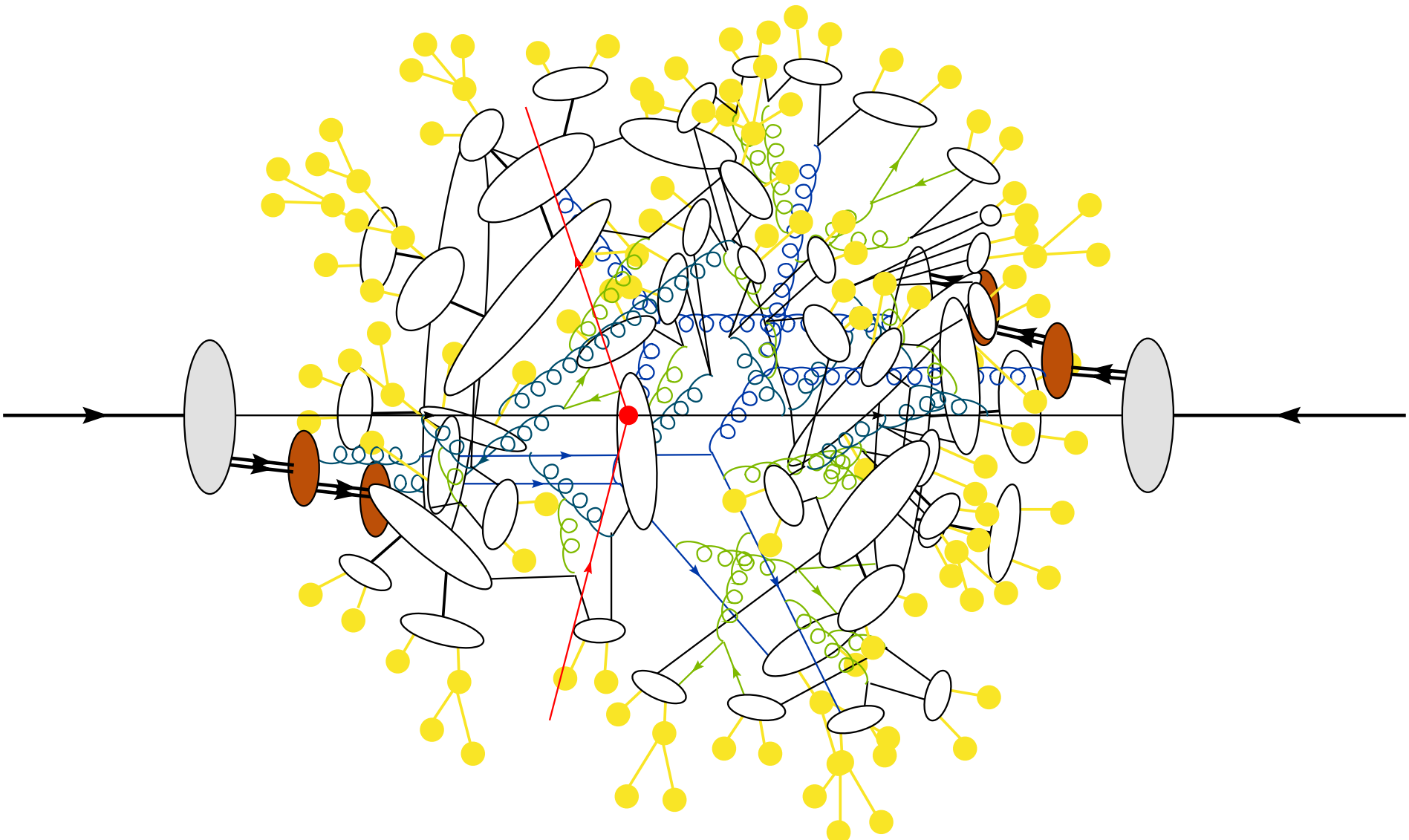


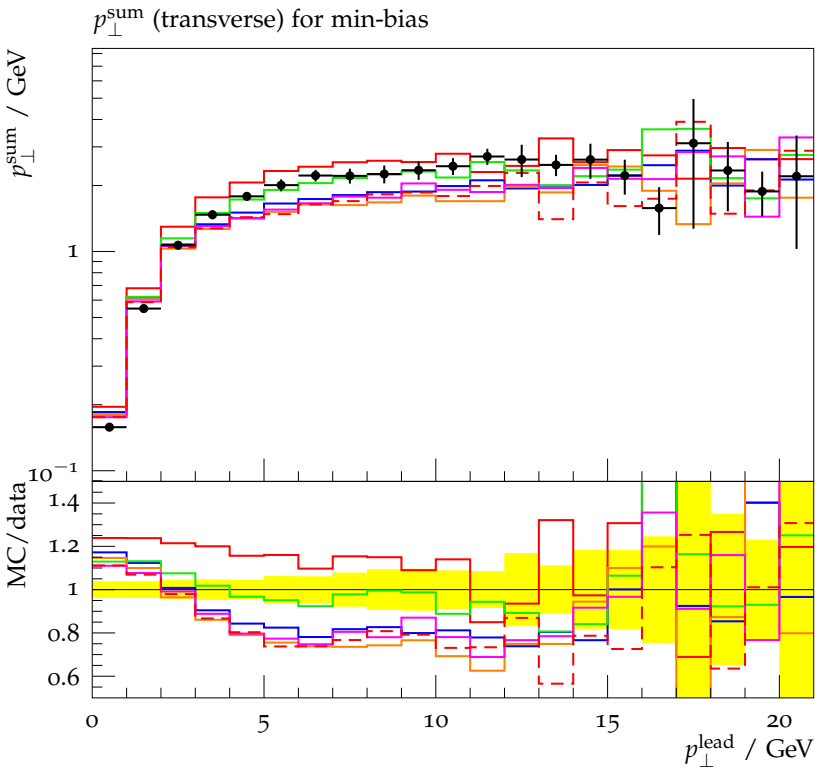
MPI model in Herwig++

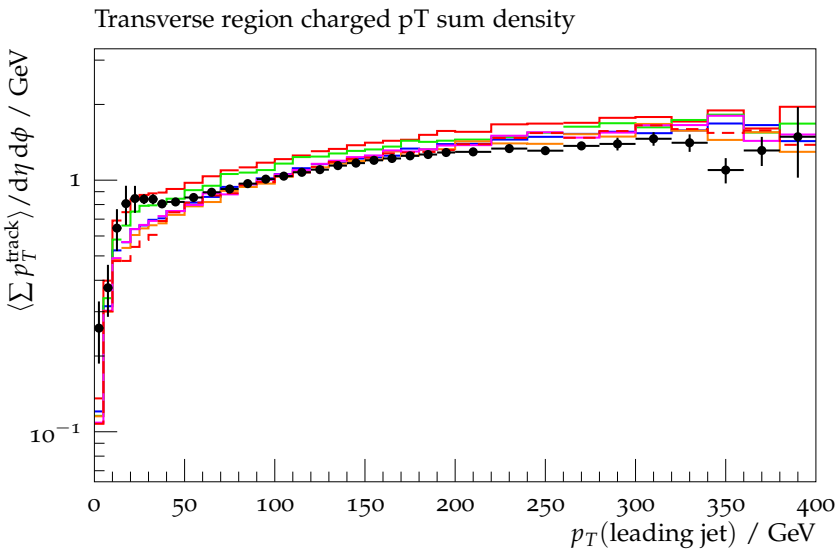
- MPI = Mulitple partonic interactions.
- Hard and soft components.
- Main parameters: μ^2 (inv radius), $p_t^{\min}$.
- Soft parameters fixed from σ_{tot} and b_{el}.
- Try to fit μ^2, $p_t^{\min}$ with Run I/II data.
- MRST LO** pdf as default!

Note: can also demand multiple parton scattering as signal, e.g. double $W^{\pm}$ production, double $b\bar{b}$.

MPI model in Herwig++

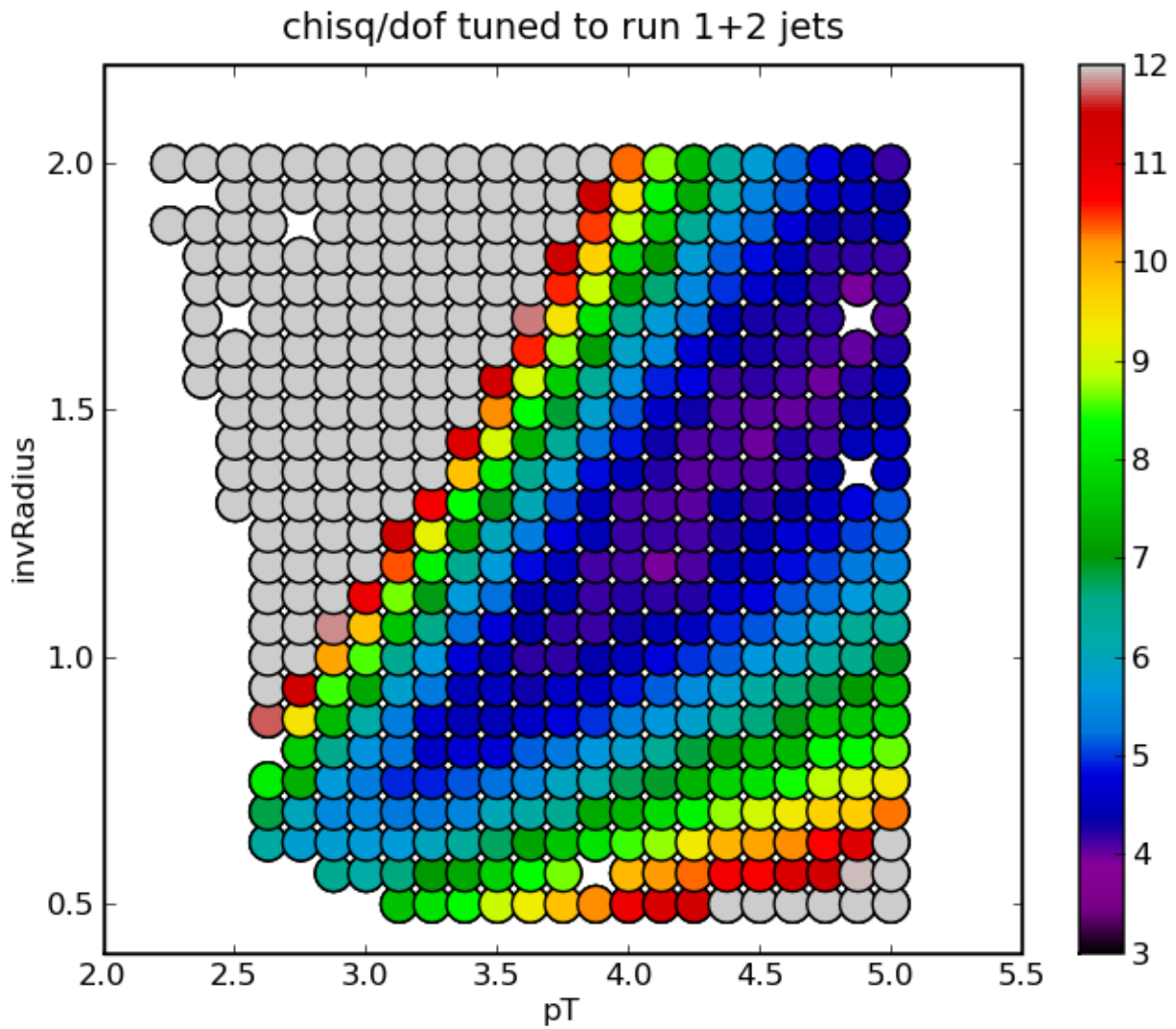
Transverse p_t^{sum} for Run I (left) Run II (right).





Tuned to several UE analysis. Some tension visible.

MPI model in Herwig++



http://projects.hepforge.org/herwig/
mailto: herwig@projects.hepforge.org

Full manual.
Detailed documentation and many examples on wiki pages.

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DOI 10.1140/epjc/s10052-008-0798-9

THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

Herwig++ physics and manual

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Abstract In this paper we describe Herwig++ version 2.2,

Conclusions

- Latest Herwig++ version 2.4.0.
- Quite mature.
- Tuned.
- Everything for LHC.
- Many aspects better than fHerwig.

- Much progress with NLO.
- Underlying Event tunes with early data.