Introduction to Herwig 7

Simon Plätzer
Particle Physics — University of Vienna

at the
EIC Software Tutorials
Remote | 19 August 2020

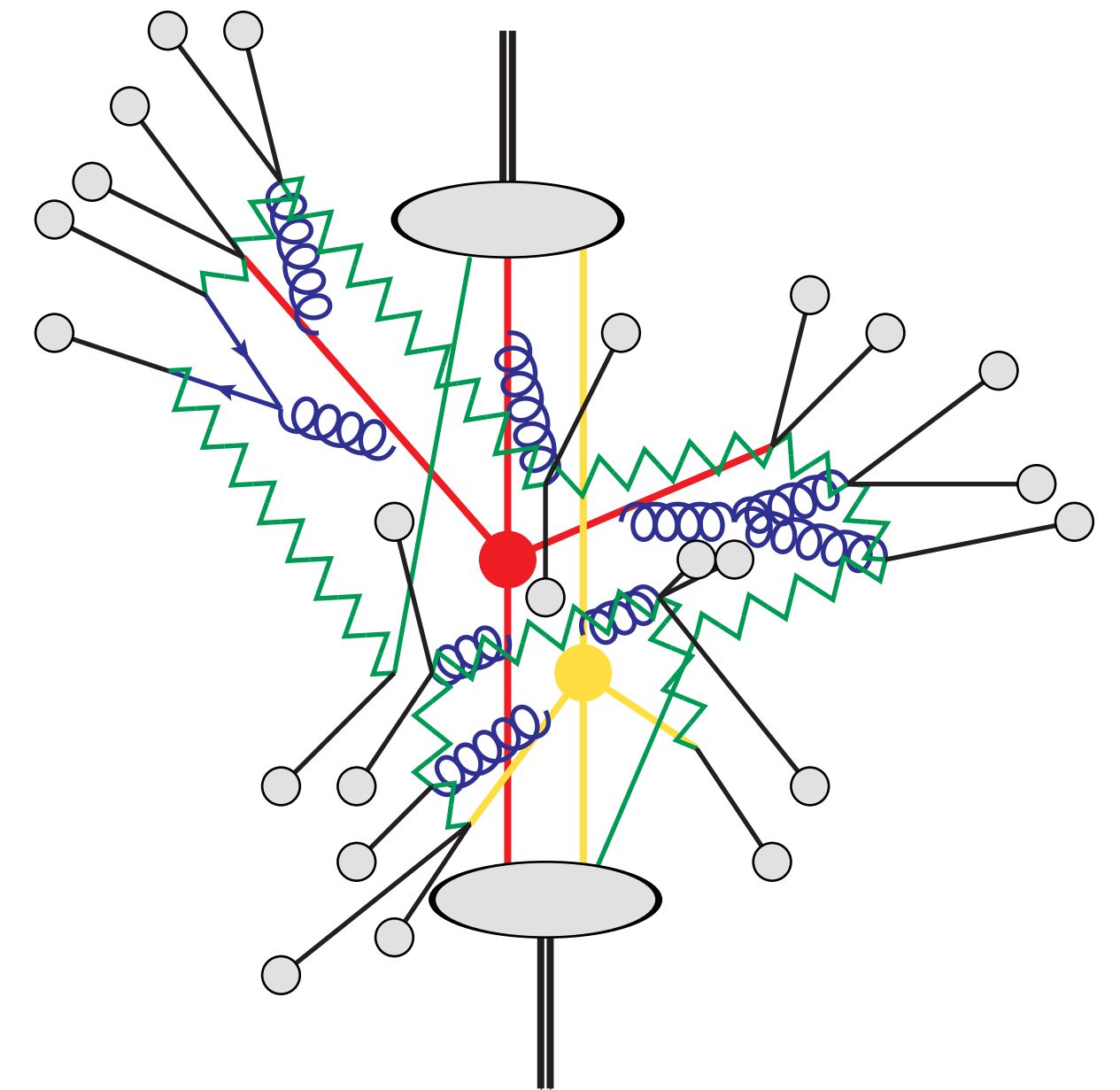Rooted in accurate description of QCD effects.
Fully detailed description of ee, ep and pp collisions.

Hard partonic scattering — NLO QCD, routinely
Parton showers — angular ordered & dipole-like
Multi-parton interactions — Eikonal model
Hadronization — Cluster hadronization

$$\mathrm{d}\sigma \sim \mathrm{d}\sigma_{\mathrm{hard}}(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

Outline

The Physics of Herwig 7

Documentation & installation

Operating Herwig 7 & some technical details

Setups and runs for simple processes using Herwig 7 & Rivet

ZOOM meeting chat can be used for discussions and questions,
Stefan Gieseke, Patrick Kirchgaesser and Graeme Nail have joined me for support!

Herwig 7 Overview

[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]
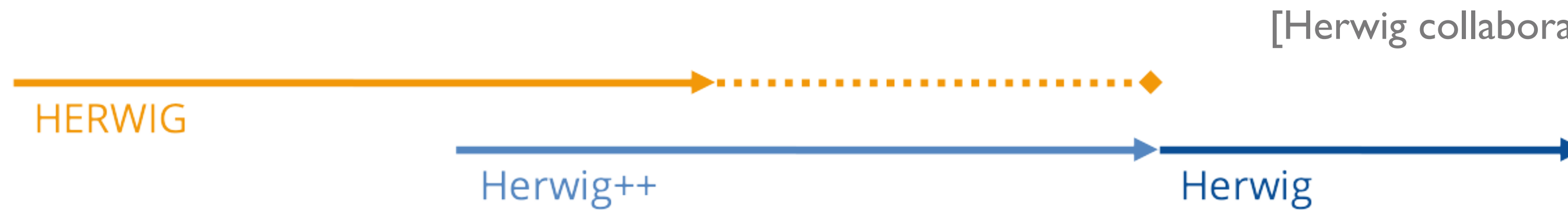
Two shower modules: angular ordered and dipole-type, both including parton shower uncertainty estimates.

[Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]
[Plätzer, Gieseke – JHEP 1101 (2011) 024]
[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

[Plätzer, Gieseke – EPJ C72 (2012) 2187]
[Plätzer — JHEP 1308 (2013) 114]
[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]

Automated NLO matching and multi jet merging.
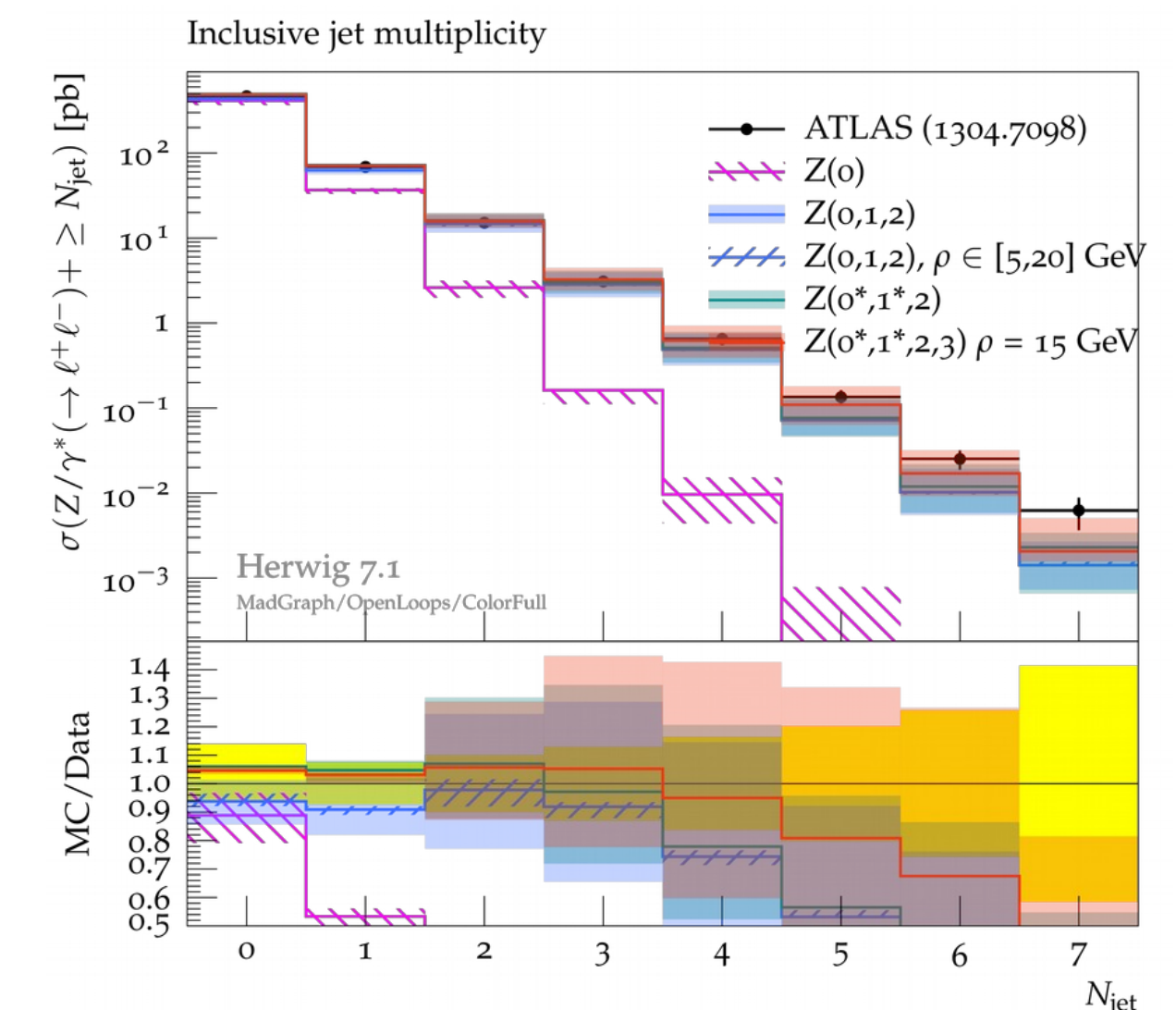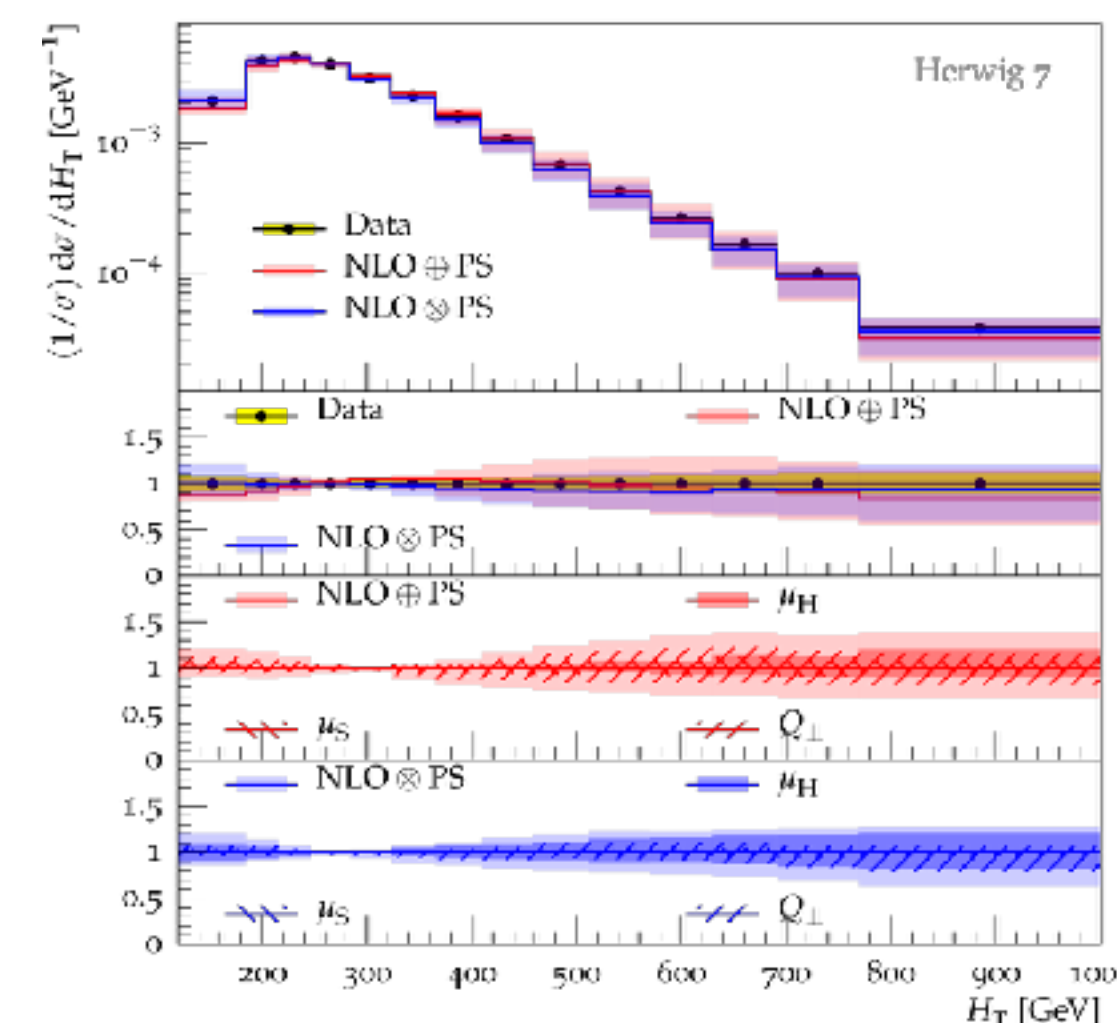
Automated BSM simulations using UFO model files.

[Gigg, Richardson — EPJ C51 (2007) 989]
[Richardson, Wilcock — EPJ C74 (2014) 2713]

Cluster hadronization model

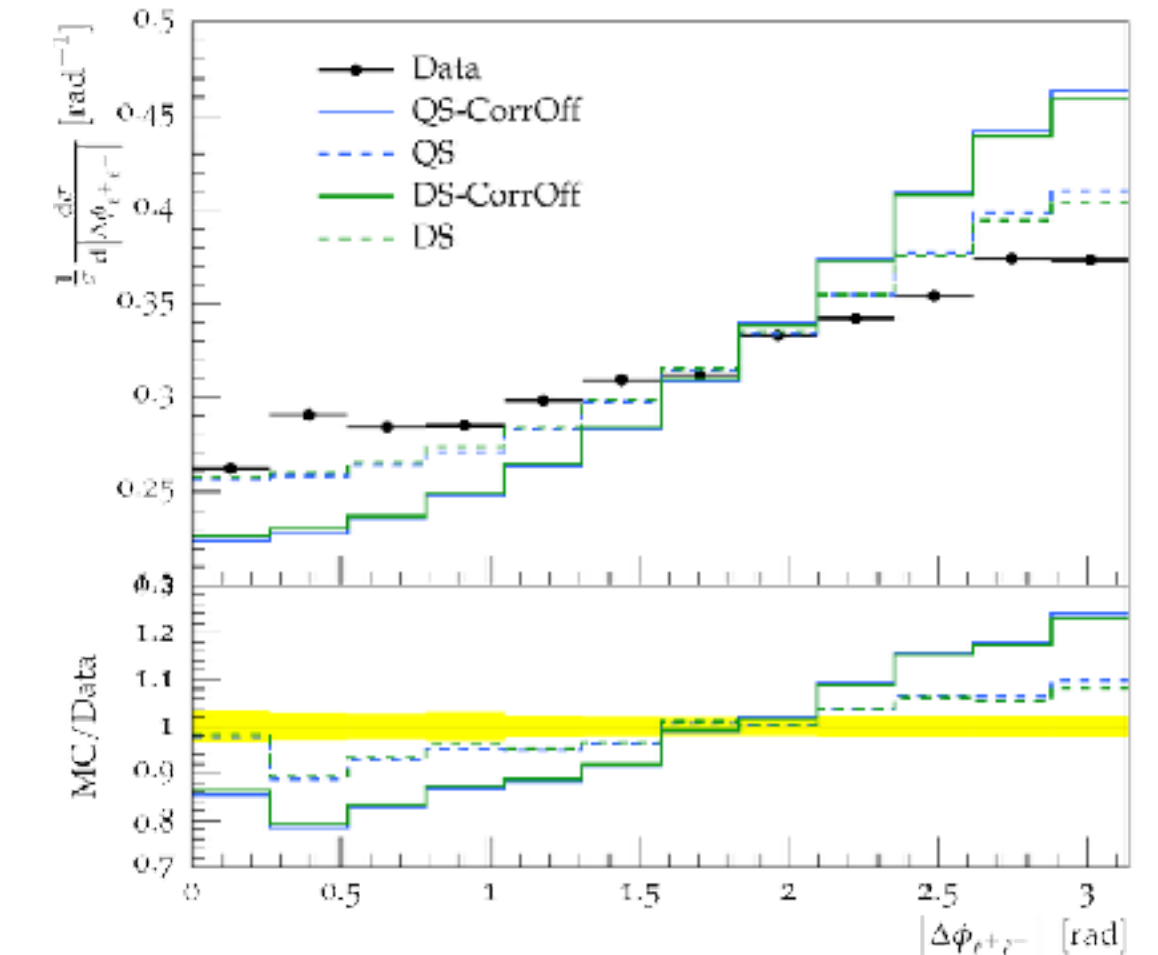Eikonal MPI model

Colour Reconnection

Several improvements on existing shower algorithms

- Spin correlations in both shower modules

  [Webster, Richardson - Eur.Phys.J.C 80 (2020) 2]

- QED radiation in angular ordered shower
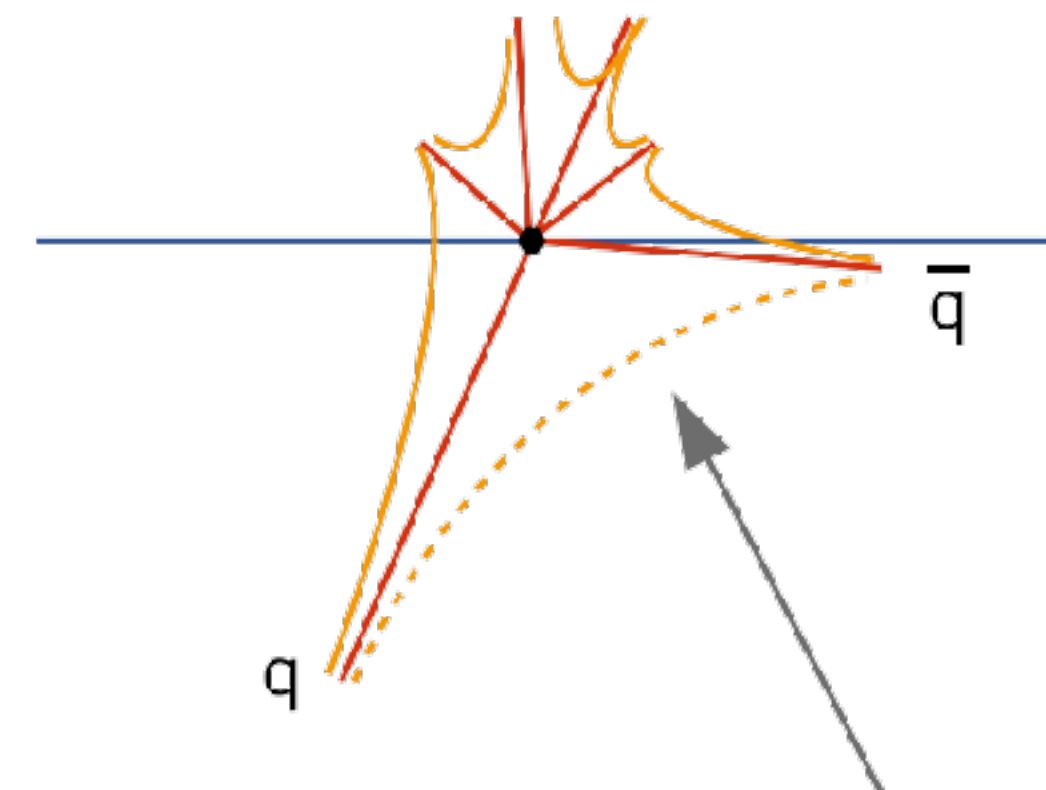- Shower reweighting algorithms encode some variations on-the-fly   [Bellm, Plätzer, Richardson, Siodmok, Webster – PRD 94 (2016) 3]
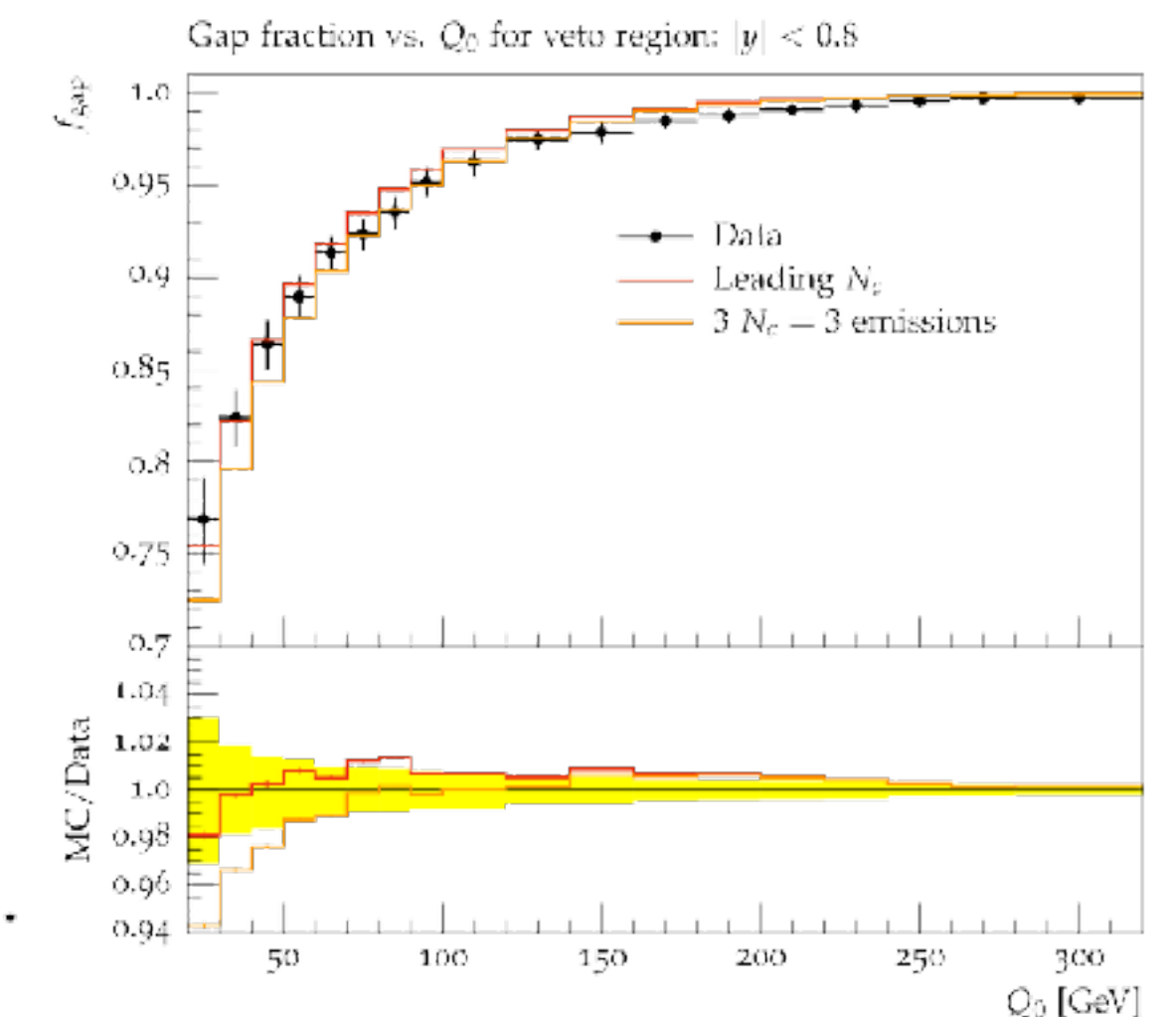
Colour matrix element corrections available in the dipole shower evolution

[Plätzer, Sjödahl – JHEP 1207 (2012) 042]
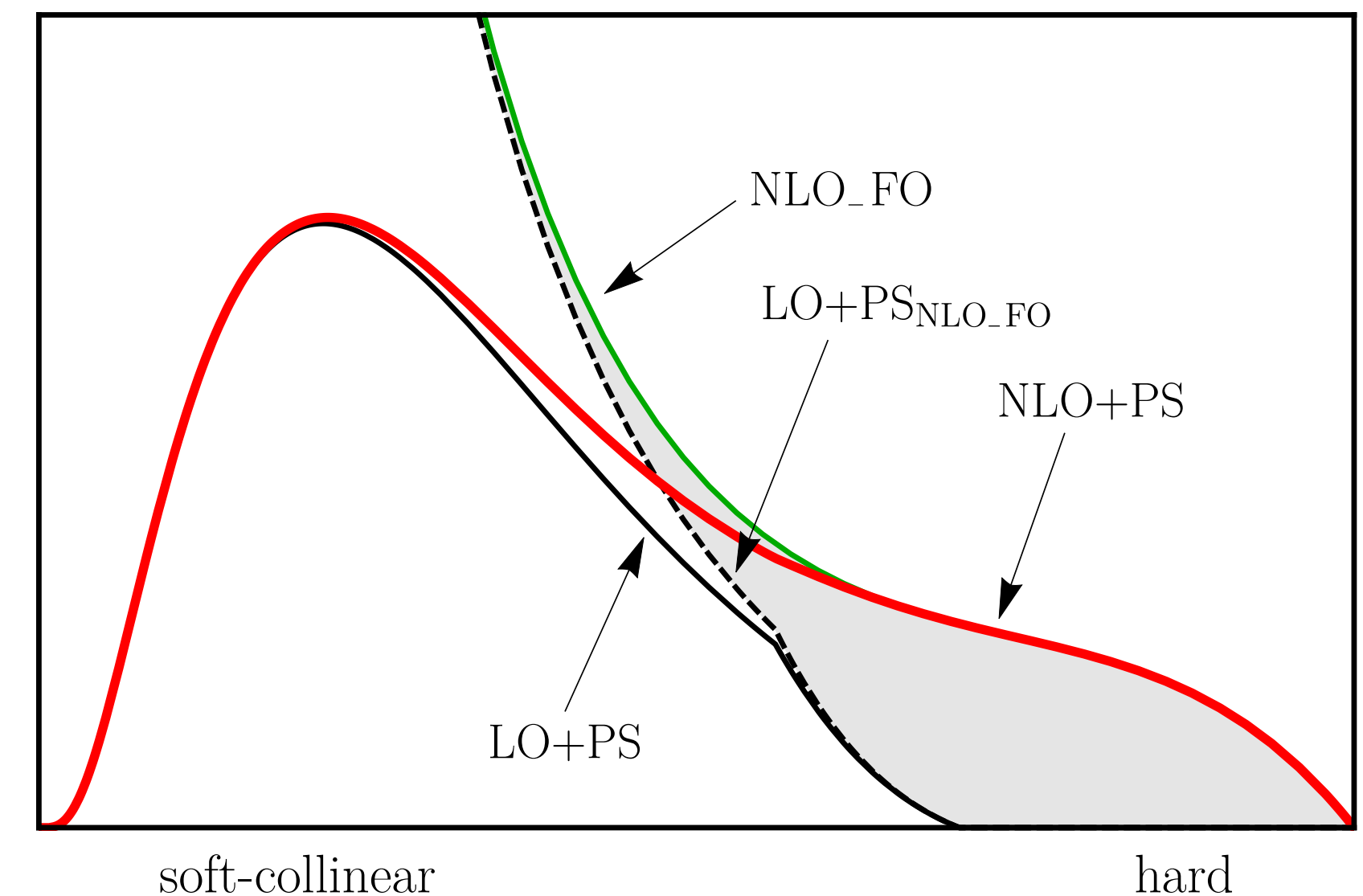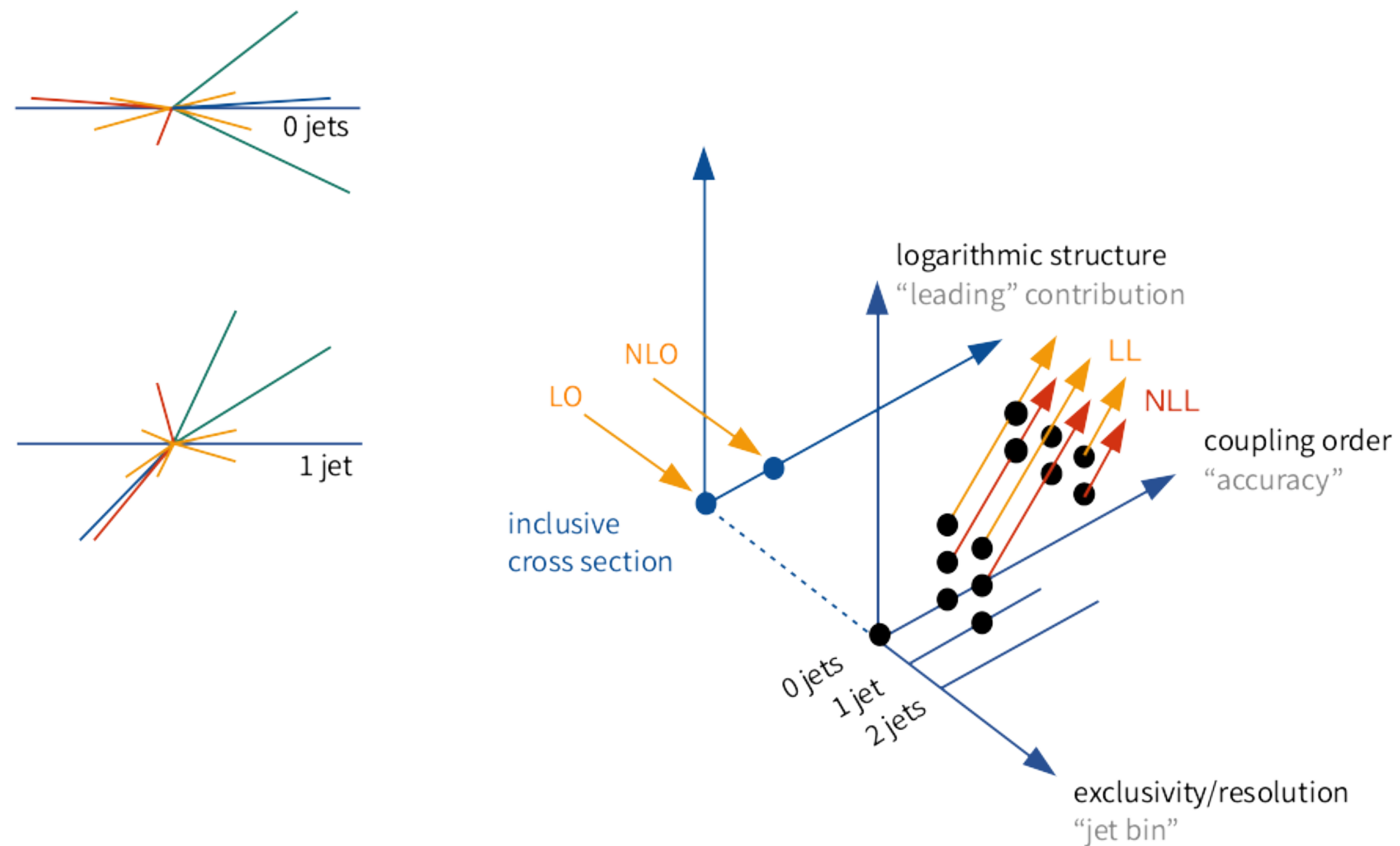[Plätzer, Sjödahl, Thoren – JHEP 11 (2018) 009]

Some subleading-N corrections can be restored.

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Expand shower to NLO in strong coupling, then subtract from fixed-order.
Will improve hardest emission from shower approximation to LO, normalisation at NLO.


NLO QCD default accuracy for hard processes in Herwig 7 using Matchbox

[Bellm, Plätzer, Rauch, Reuschle, Wilcock – 2011-2015]

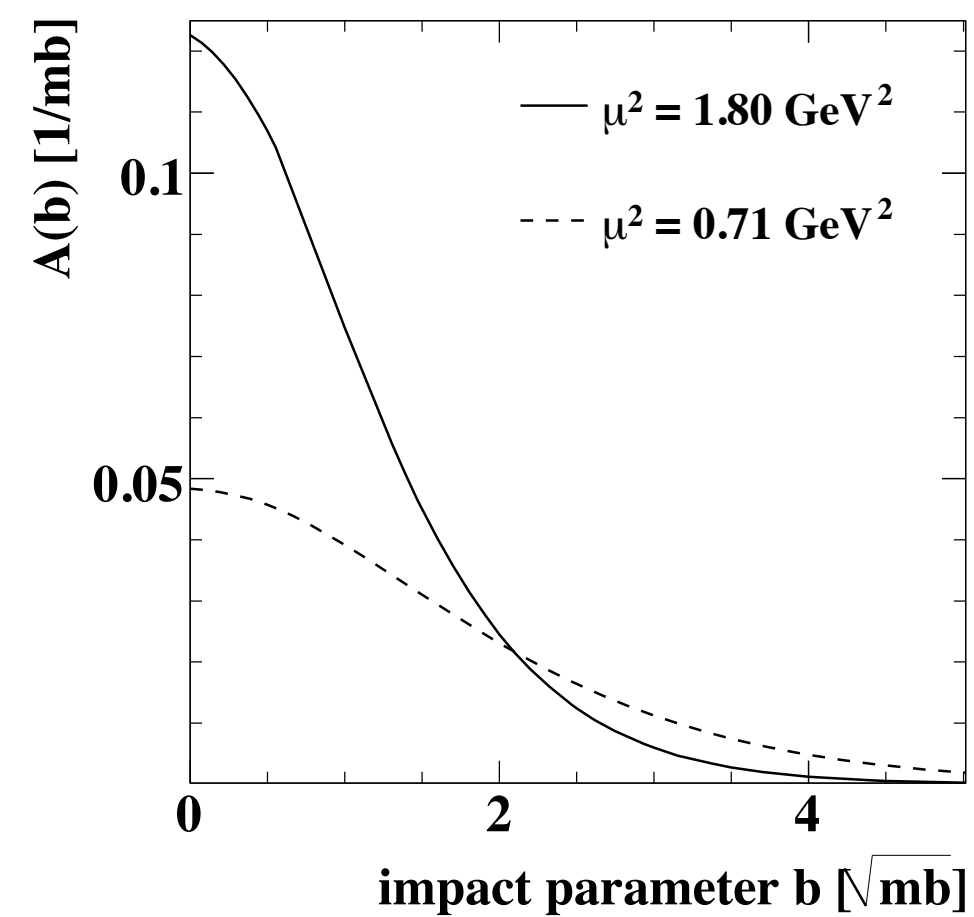Combine multijets at NLO with parton showers into one inclusive sample.

Available in all multipurpose event generators,
mainly based on unitarized schemes

[Plätzer — JHEP 1308 (2013) 114]
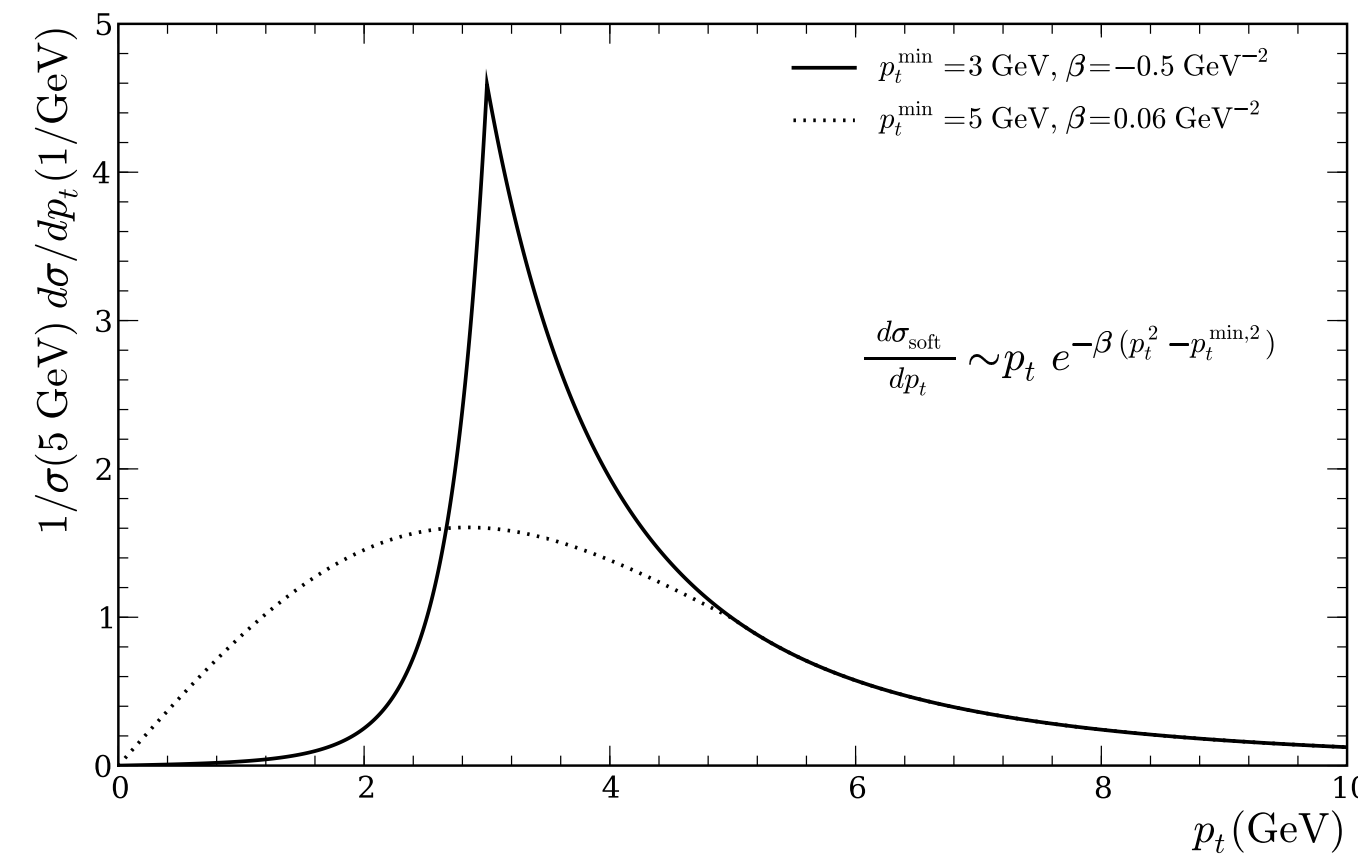[Prestel, Lönnblad — JHEP 03 (2013) 166]

[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]

Multiparton Interactions
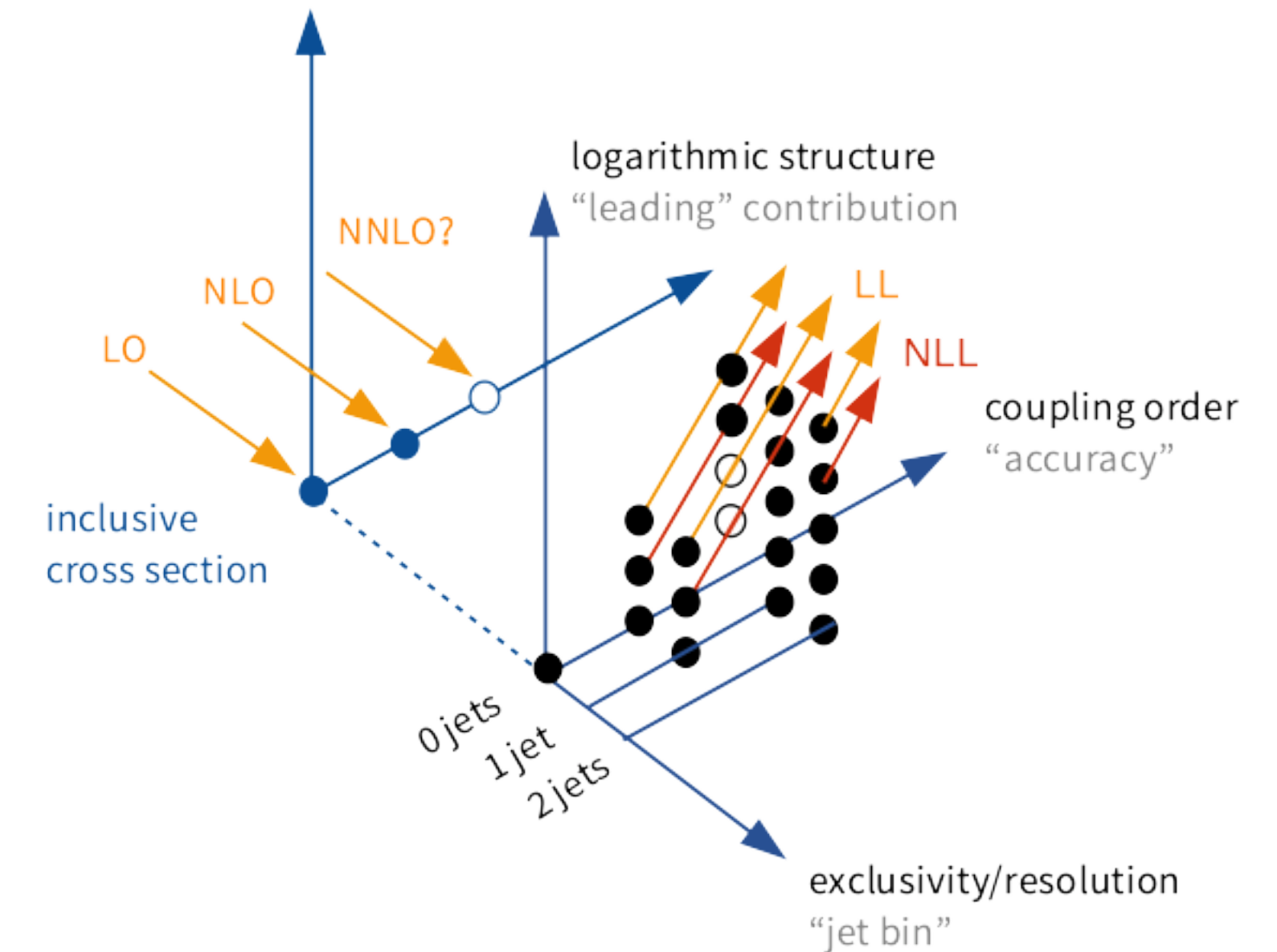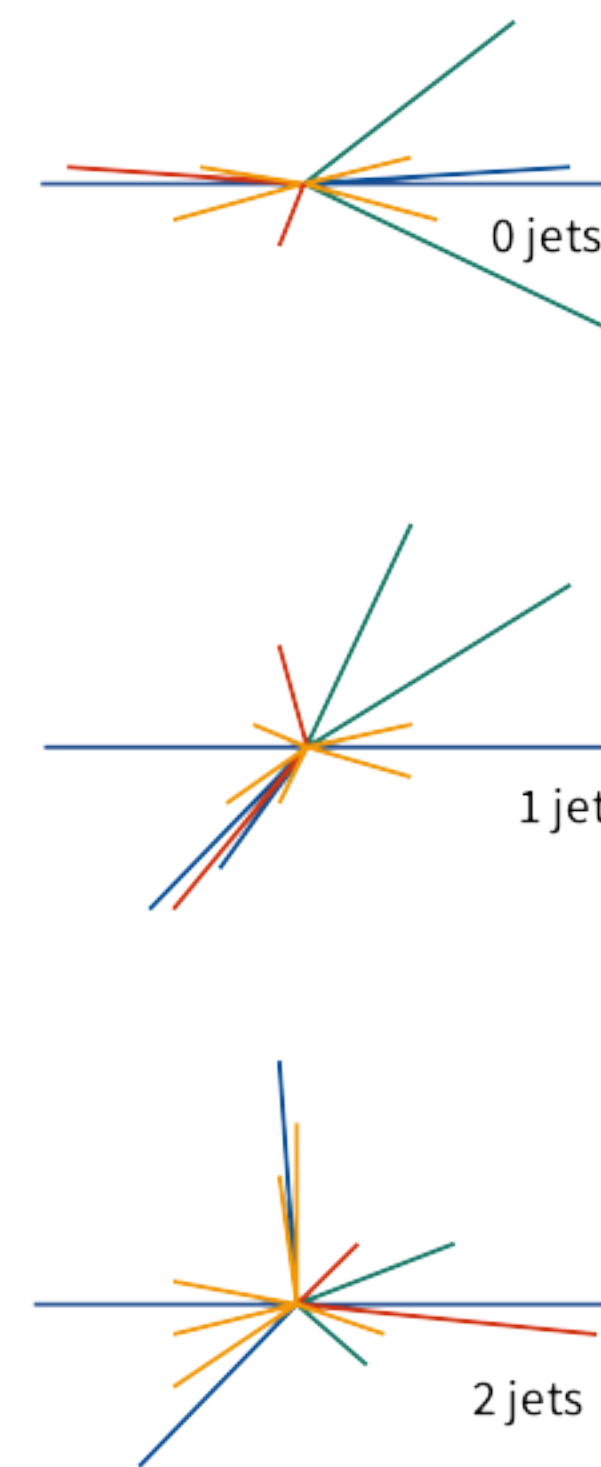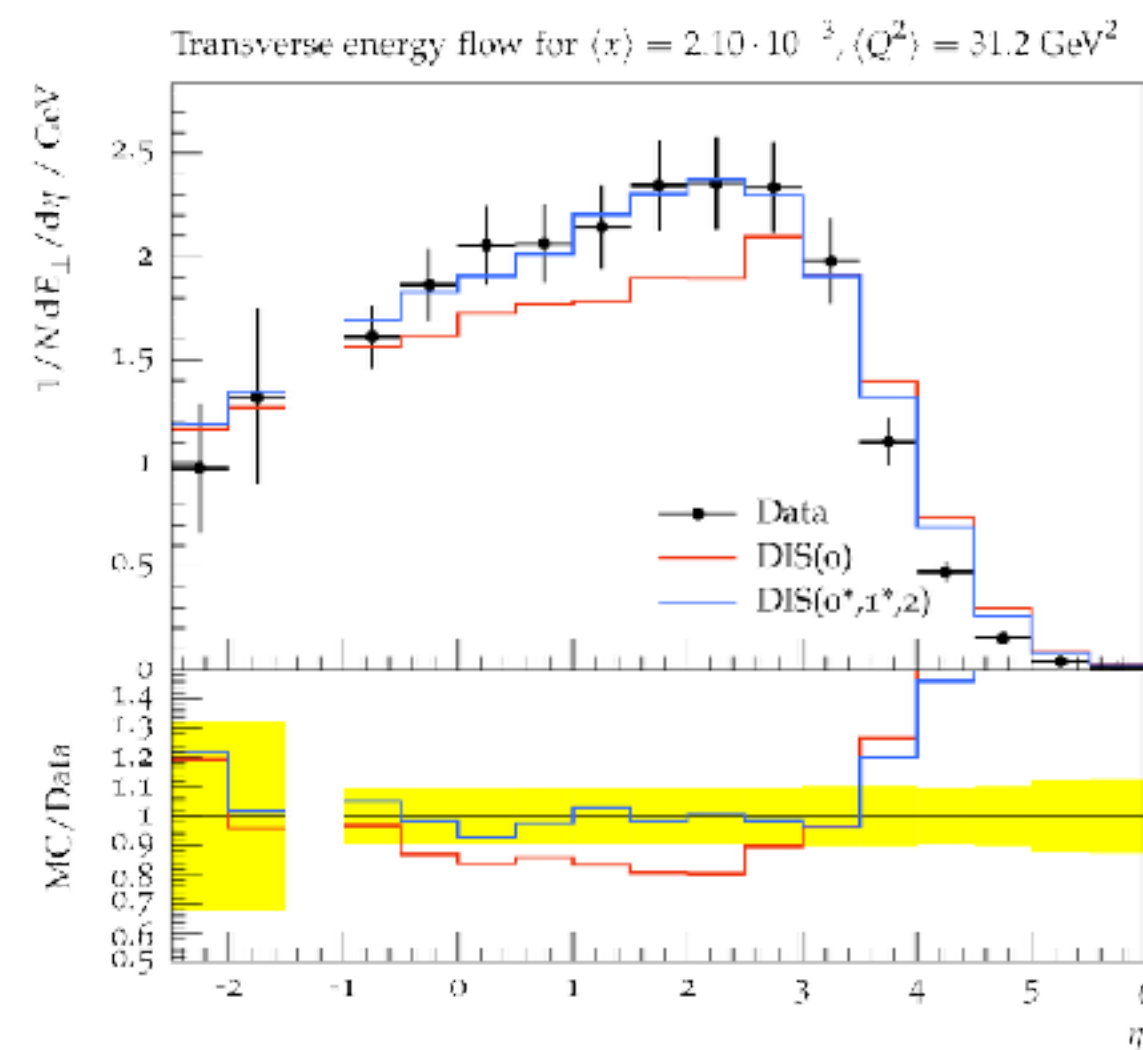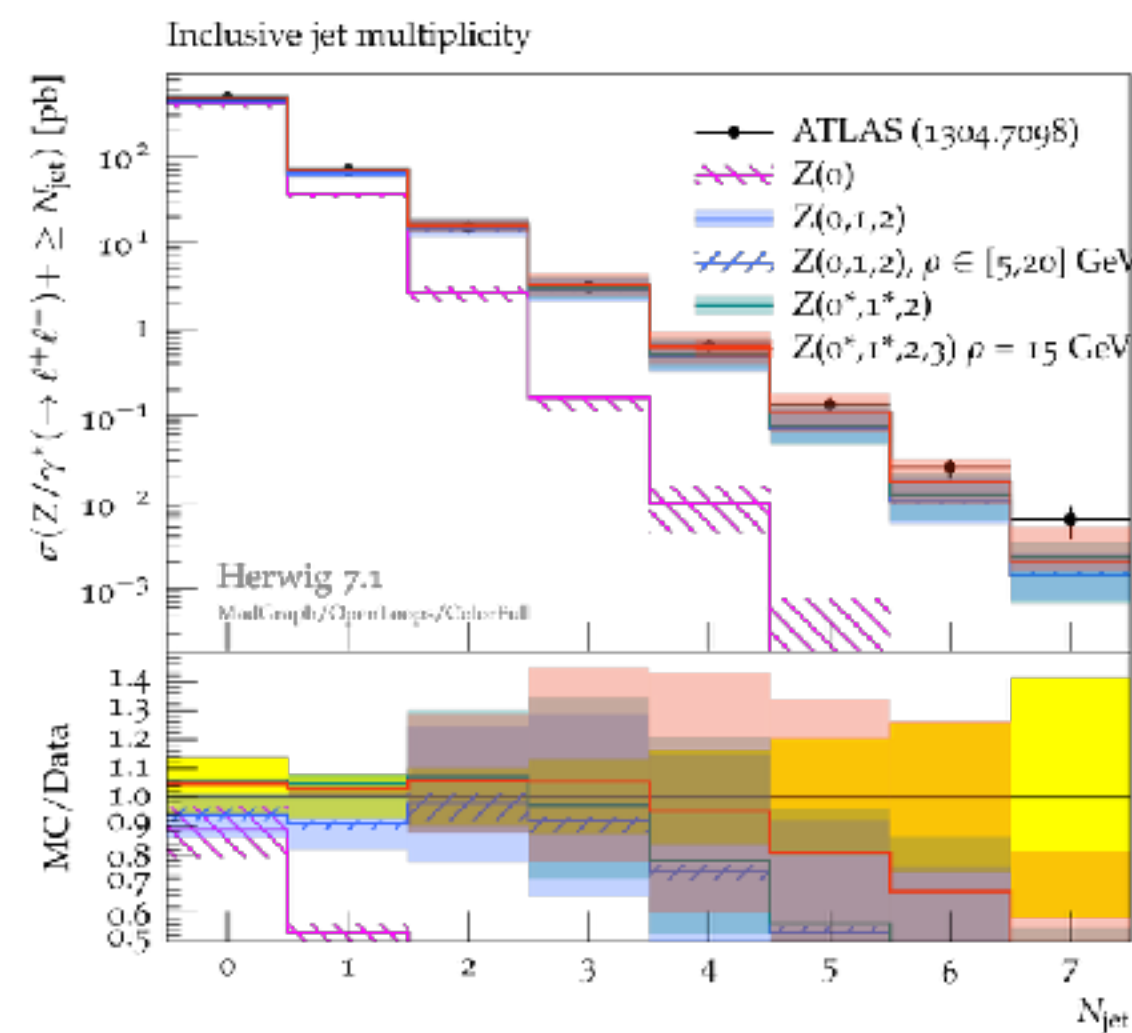
Key ingredients for MPI
modelling in Herwig 7

$$\frac{d\sigma_{\text{soft}}}{dp_t} \sim p_t \, e^{-\beta \, (p_t^2 - p_t^{\min,2})}$$

soft & hard scatters
+ diffraction

matter distribution

colour reconnection
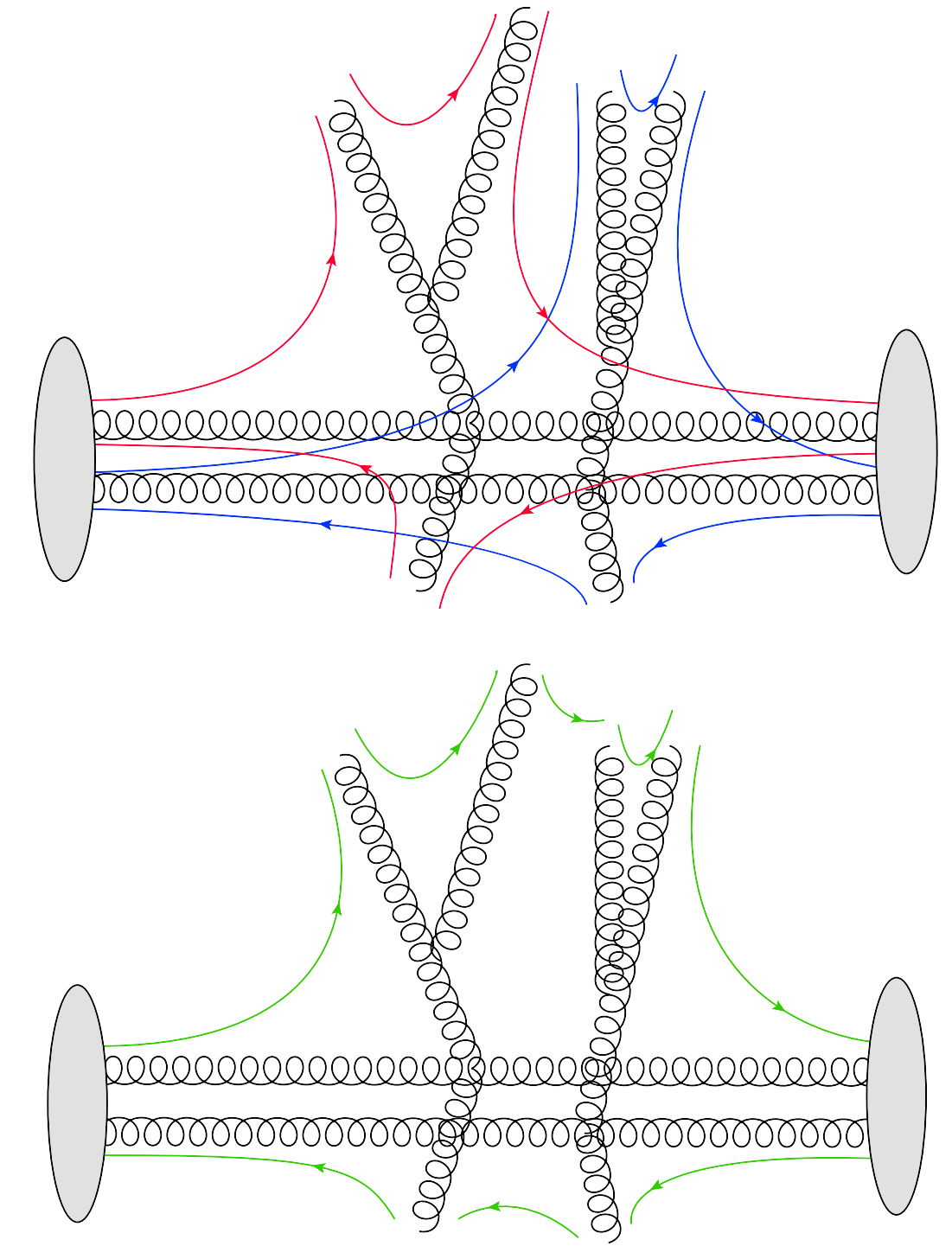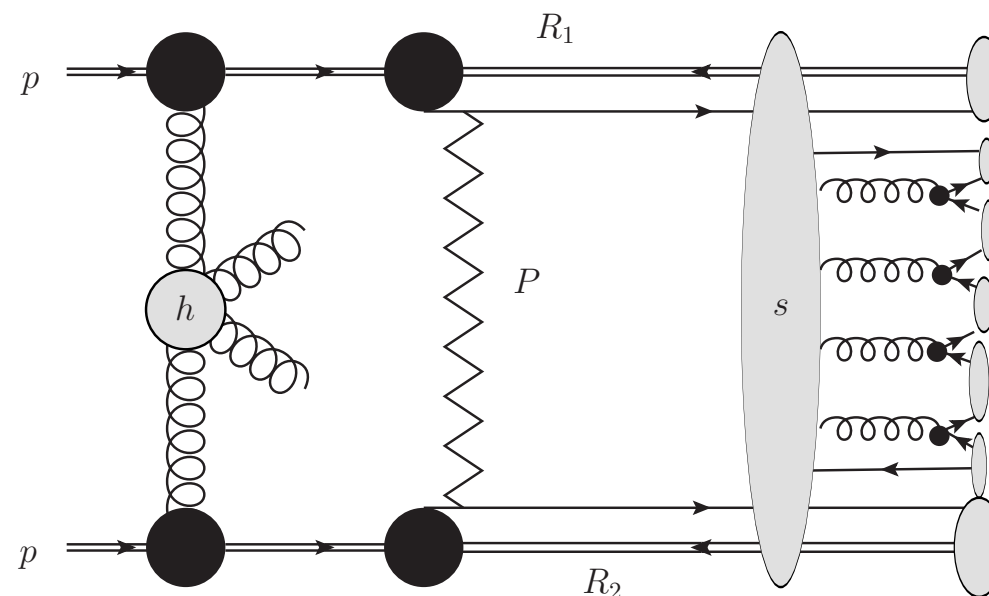
[Figure by Stefan Gieseke]

Work ongoing to apply to heavy ion physics.

[Gieseke, Loshaj, Kirchgasser — EPJ C77 (2017) 156]
[Bellm, Gieseke, Kirchgasser — arXiv:1911.13149]

['Stacking' MPI already available — Bellm, Bierlich 2018]

Cluster Hadronization
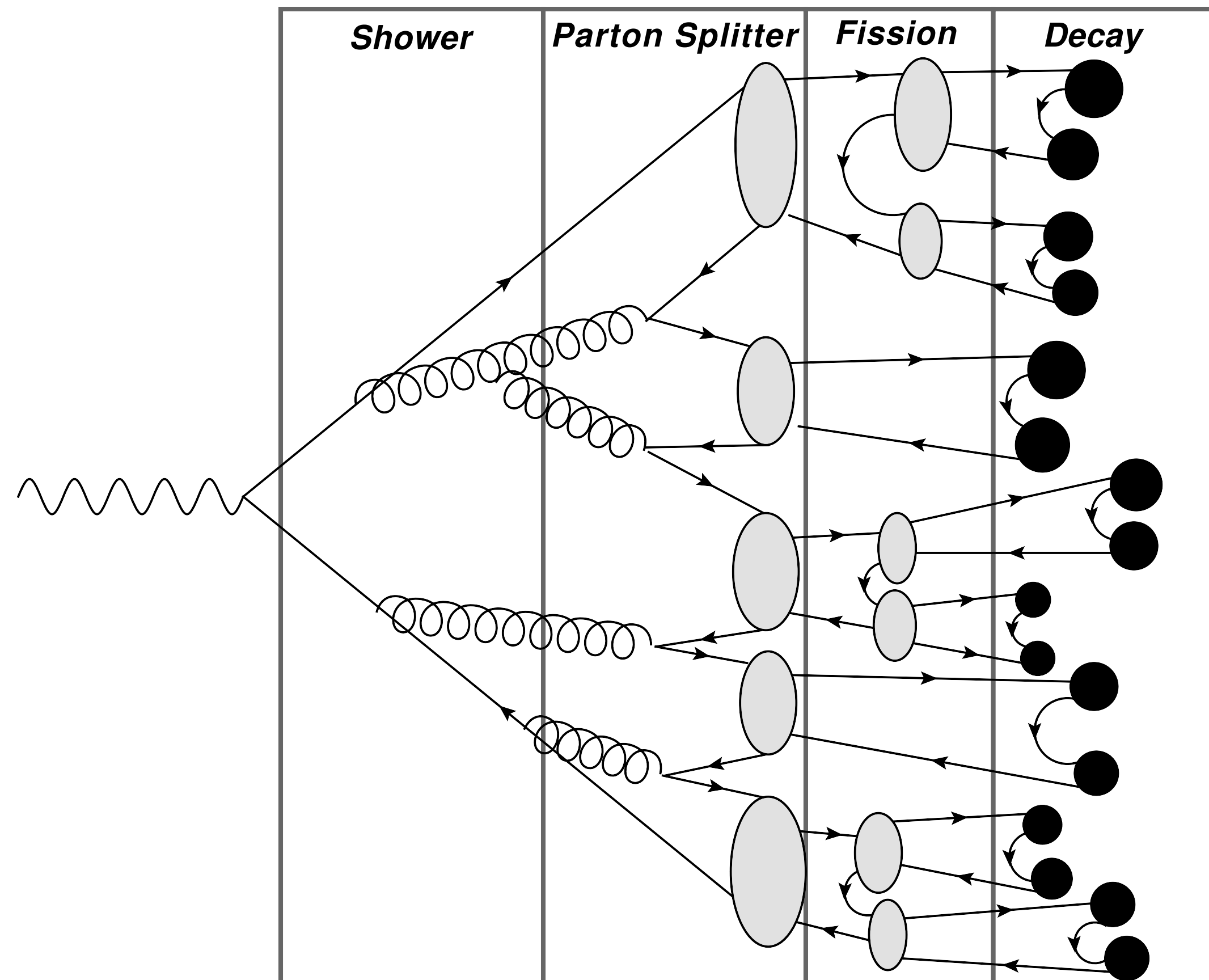
Clusters formed by splitting gluons after shower evolution

Different weights for light flavours

Clusters fission if too heavy:

$$M^p \geq q^p + (m_1 + m_2)^p$$

Fission parameters different for uds, c and b, but only uds produced

Lighter clusters decay into hadrons

[Figure by Patrick Kirchgaesser]

Shower *Parton Splitter* *Fiss* *Decay*

Colour Reconnection
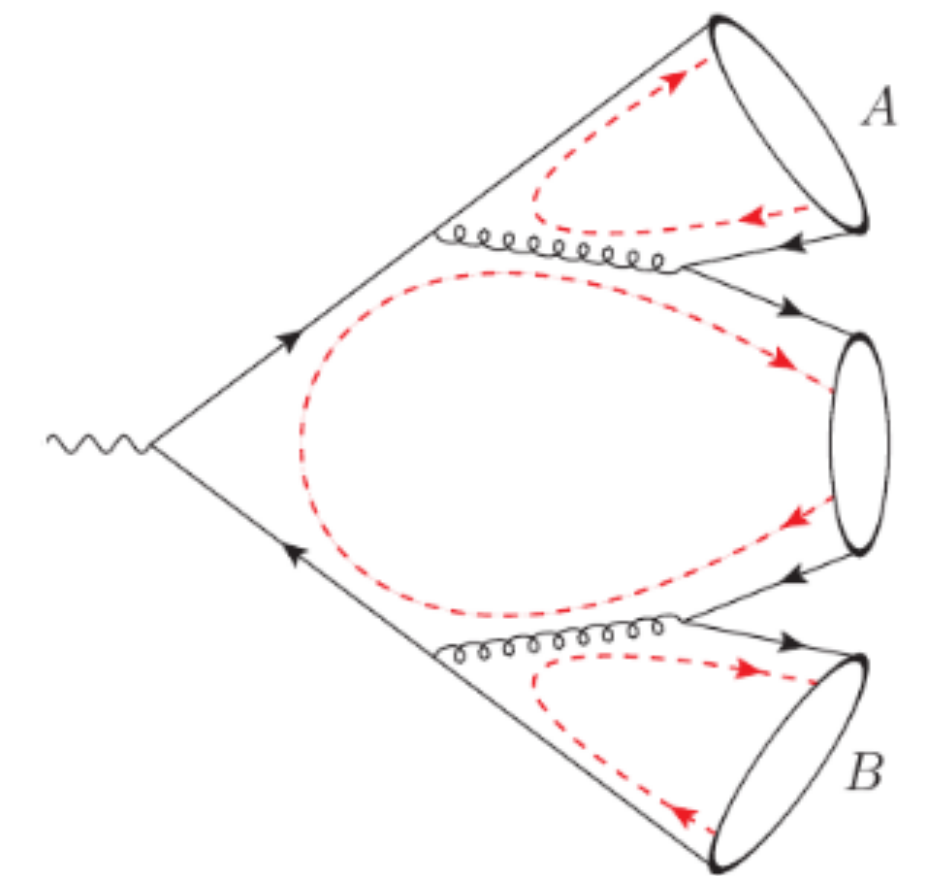
Preconfinement assumption violated in hadronic environments: colour reconnection crucial.

[Gieseke, Röhr, Siodmok — EPJ C72 (2012) 2225]
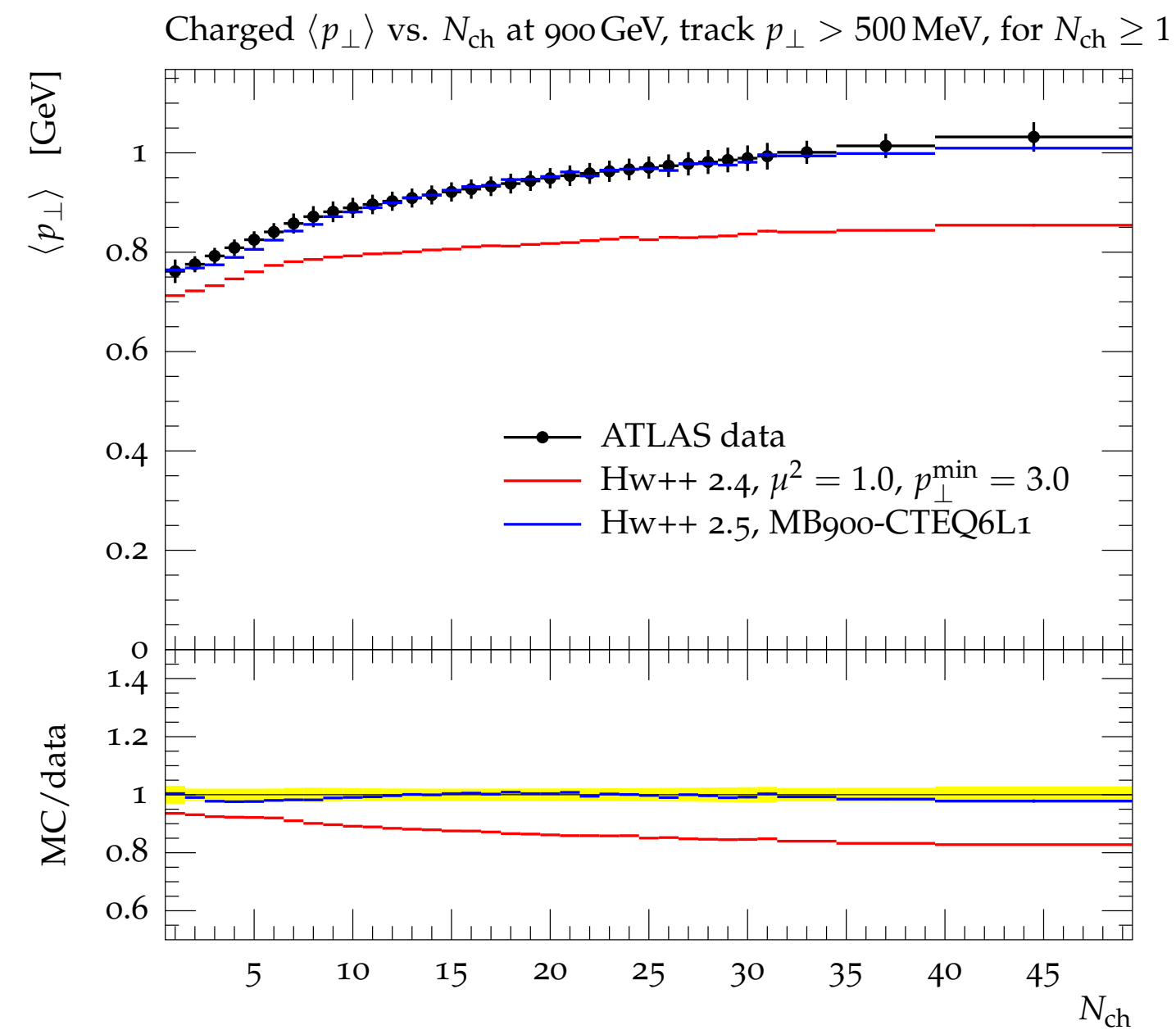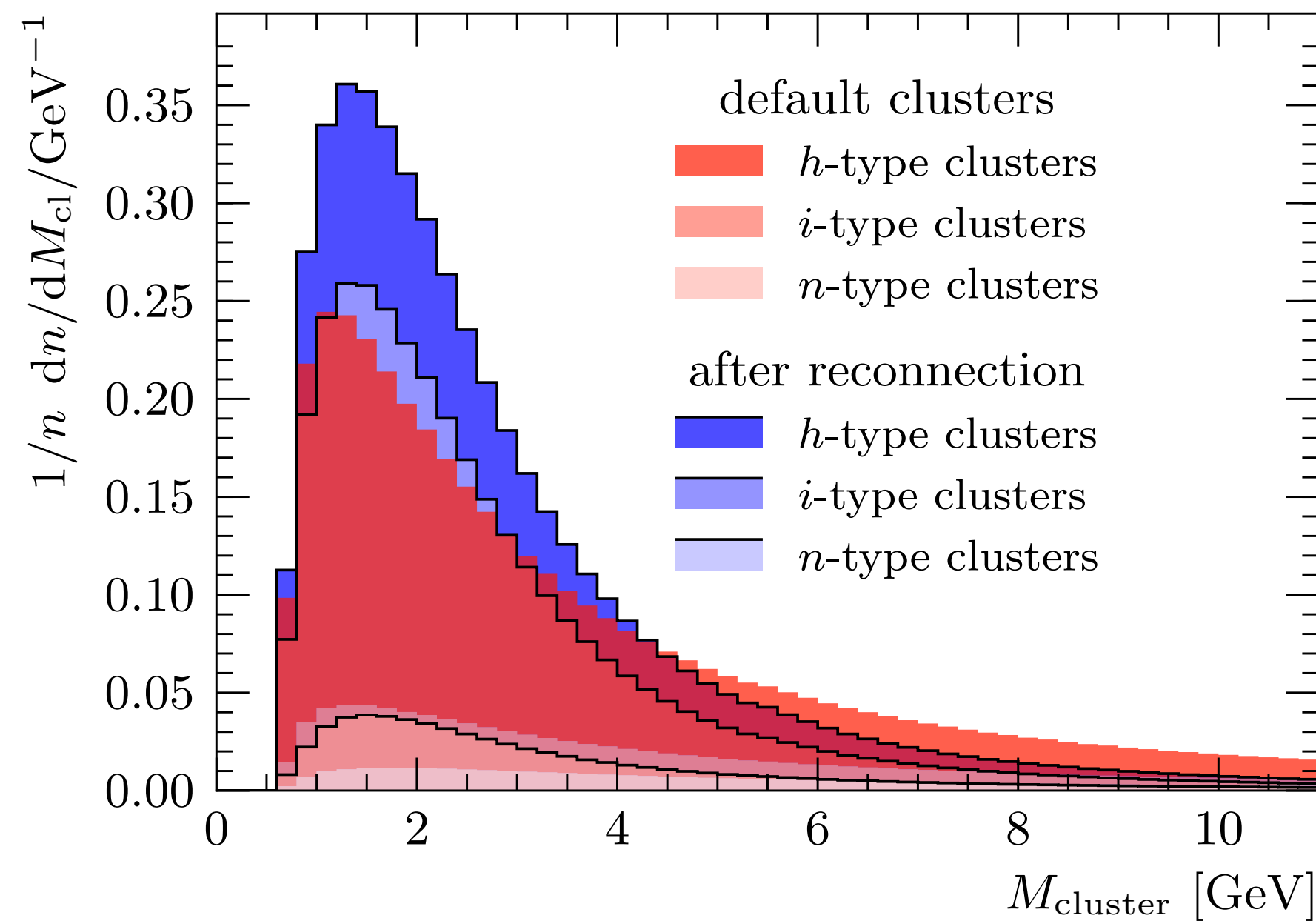
Geometric & Baryonic Reconnection

New model uses geometric measure instead of 'string length' and introduces baryonic degrees of freedom
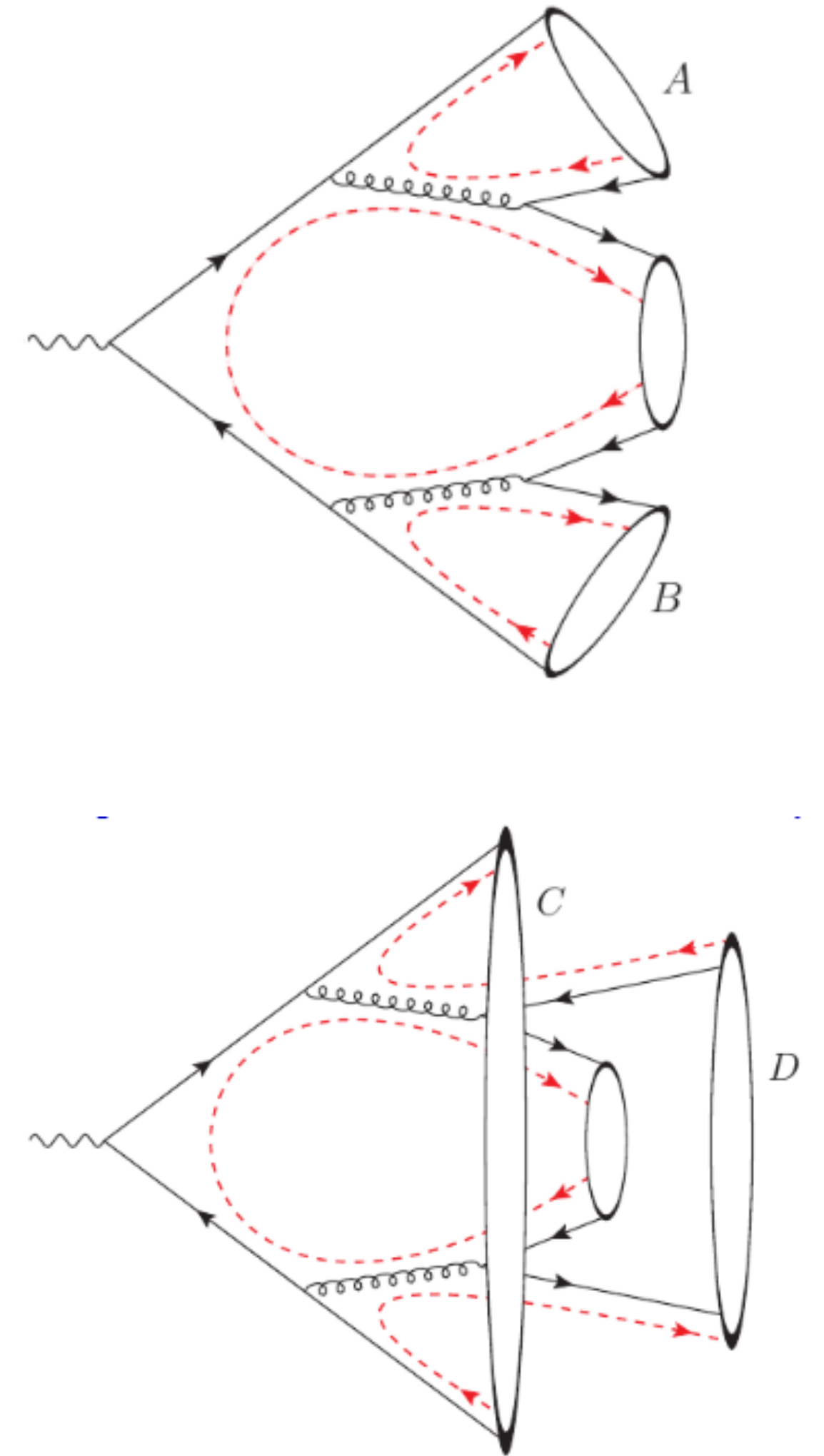

$$R_{q,qq} + R_{\bar{q},\bar{q}\bar{q}} < R_{q,\bar{q}} + R_{qq,\bar{q}\bar{q}}$$

[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]
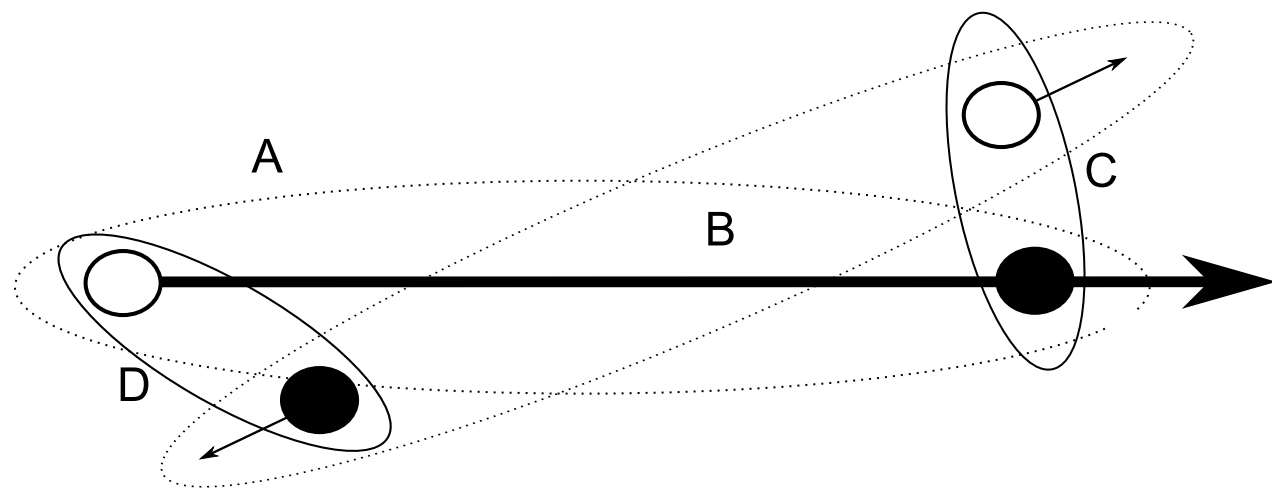
Combination with globally enhanced strange production.

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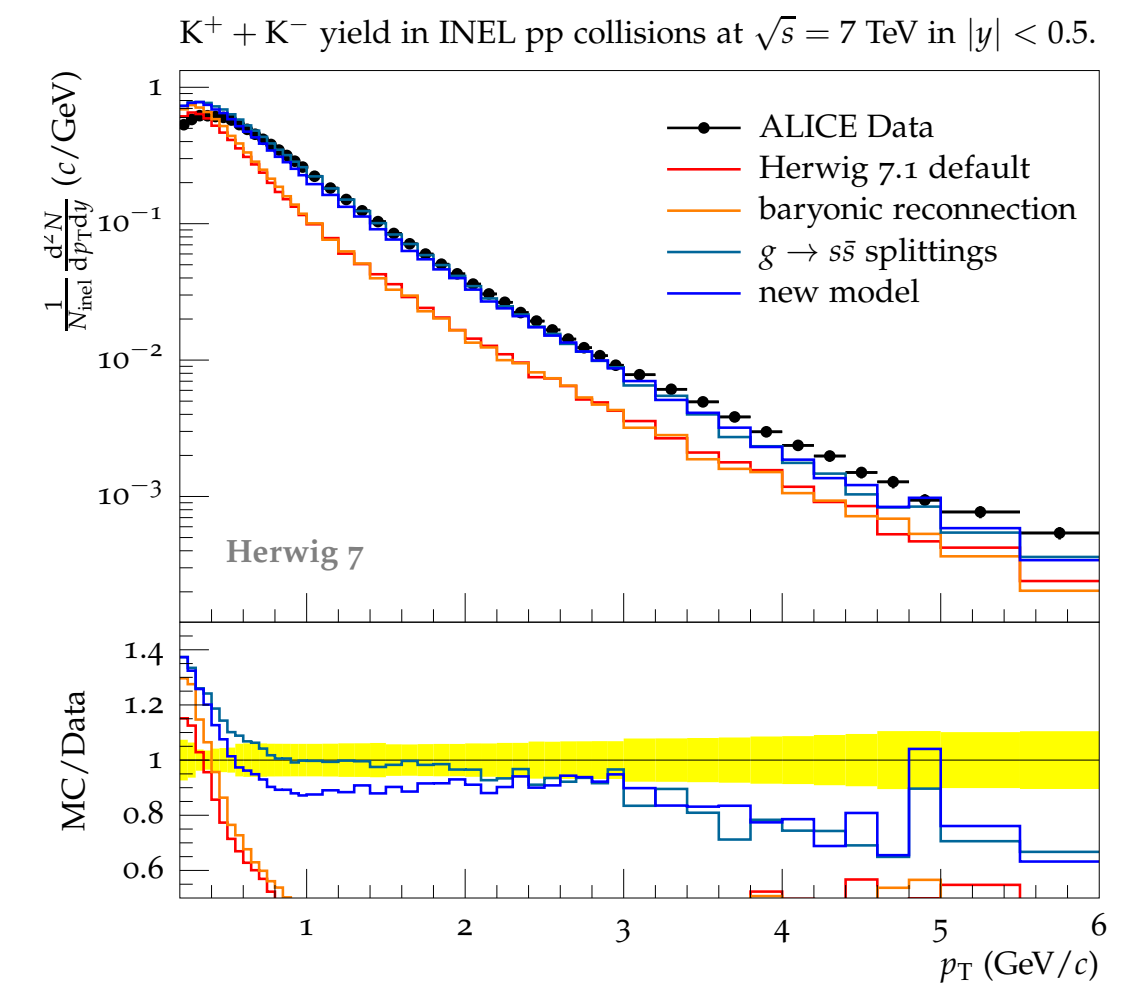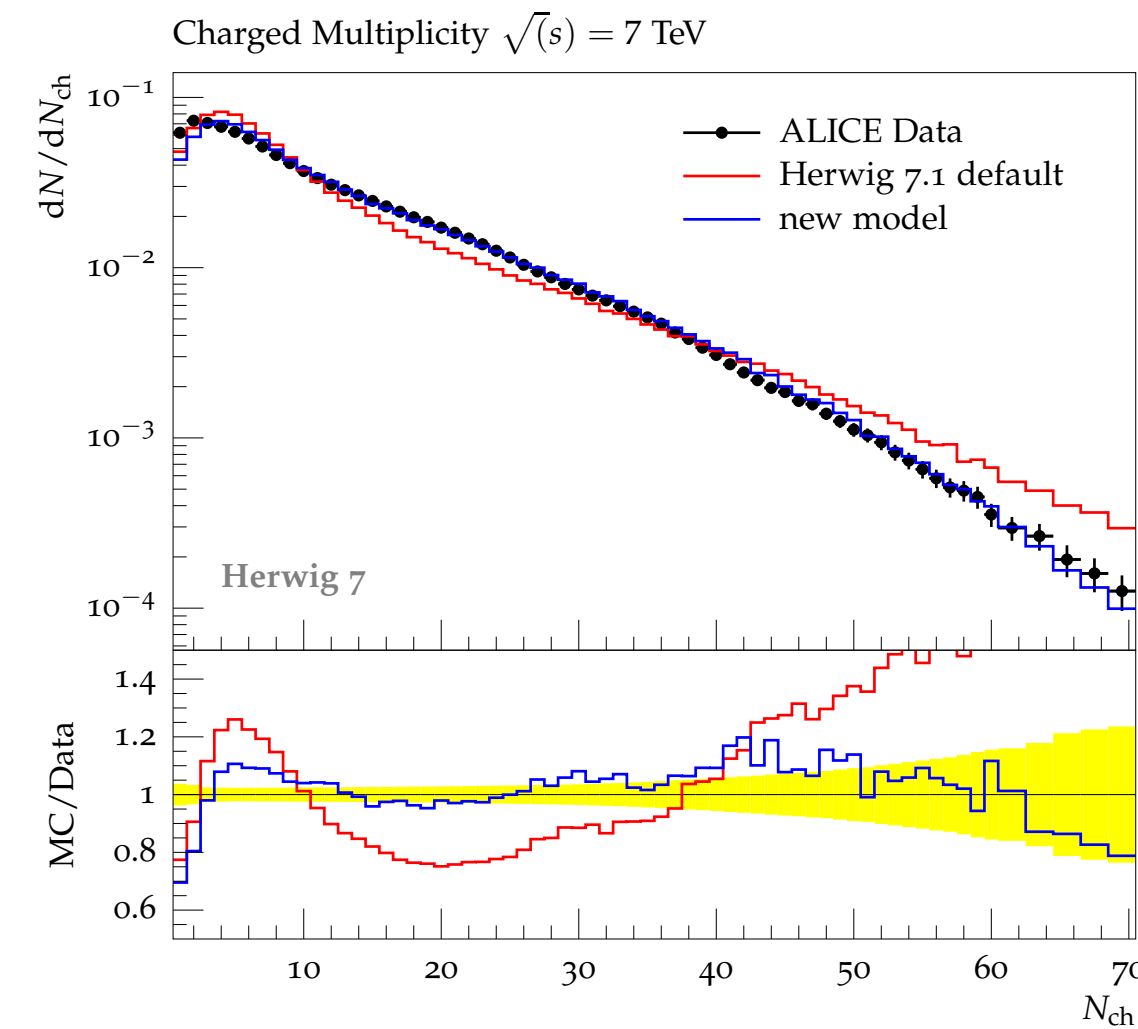
Strange production in gluon splitting and fission dependent on environment.

[Duncan, Kirchgaesser – EPJ C79 (2019) 61]

$$w_s(m)^2 = \exp\left(\frac{-m_0^2}{m^2}\right)$$
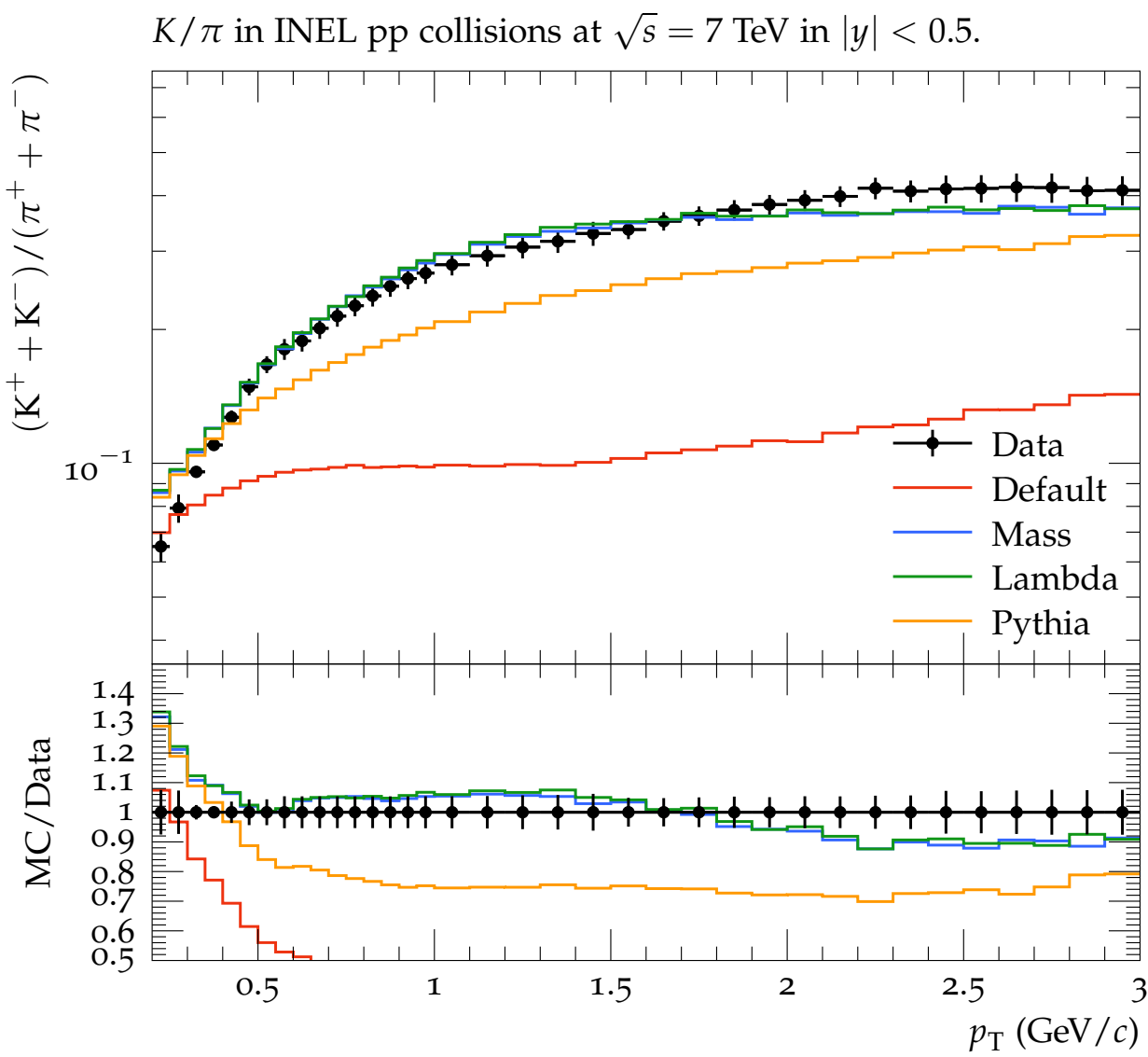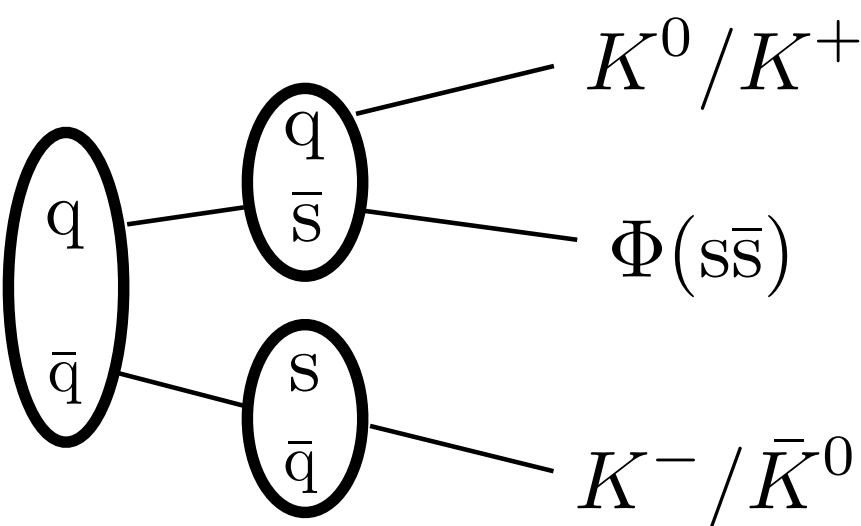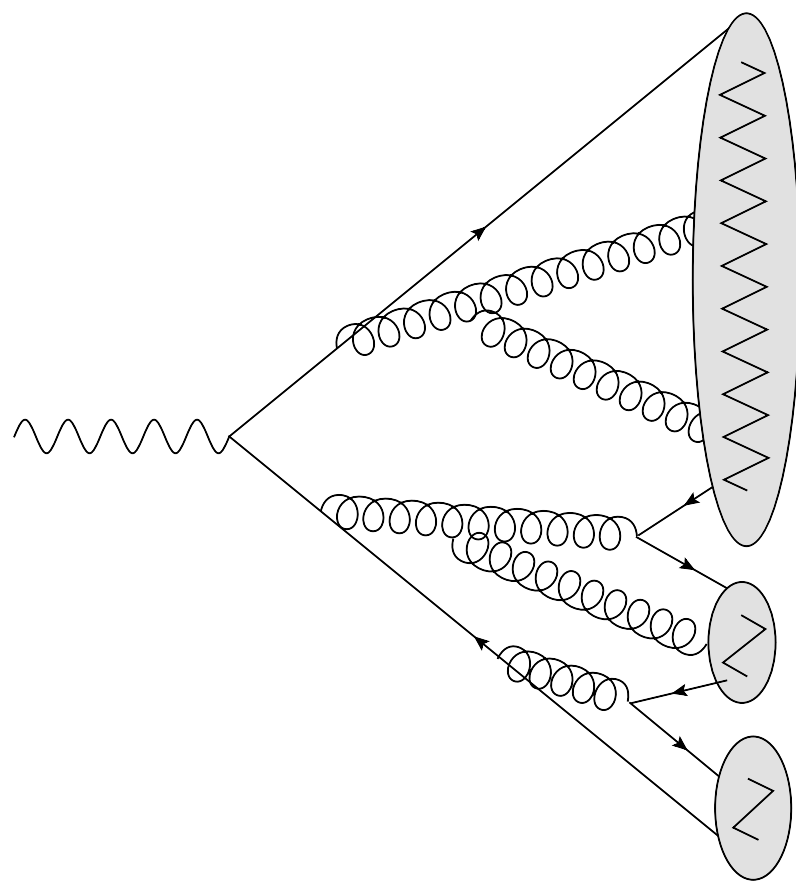
Spacetime information in colour reconnection possibly relevant in dense environments

K^0/K^+

$q/\bar{s}$

$\Phi(s\bar{s})$

q

$\bar{q}$

$s/\bar{q}$
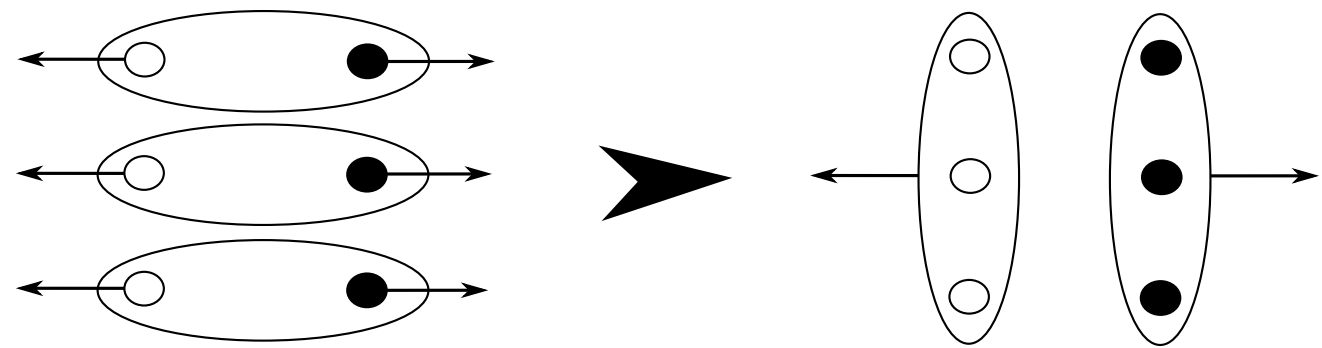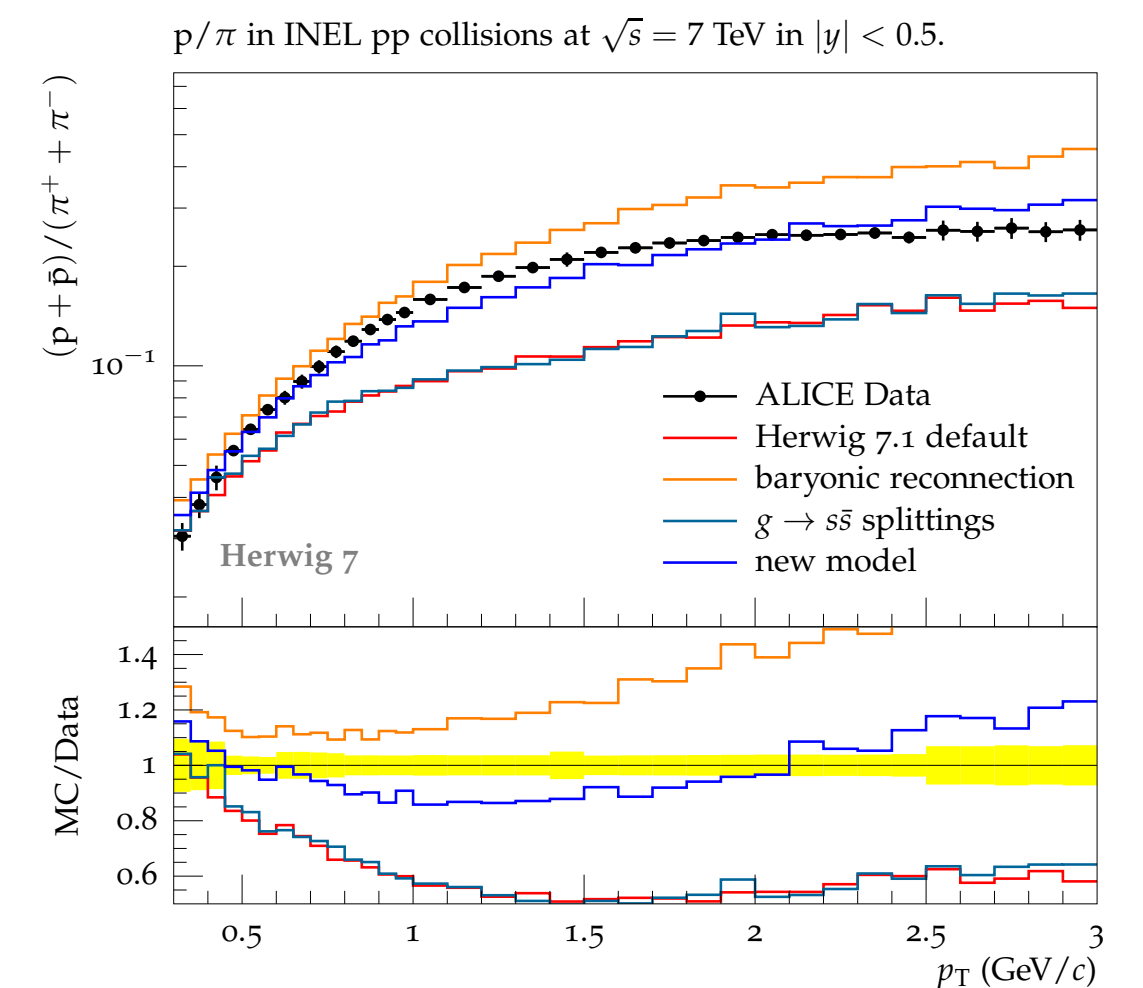
$K^-/\bar{K}^0$

$\Phi(s\bar{s})$

K/π in INEL pp collisions at $\sqrt{s} = 7$ TeV in $|y| < 0.5$.

Legend:
- Data
- Default
- Mass
- Lambda
- Pythia

$(K^+ + K^-)/(\pi^+ + \pi^-)$

MC/Data

p_T (GeV/c)

Legend:
- Cluster before CR
- Quarks
- Antiquarks

Legend:
- Baryonic reco.
- Mesonic reco.
- No reco.
- Quarks
- Antiquarks
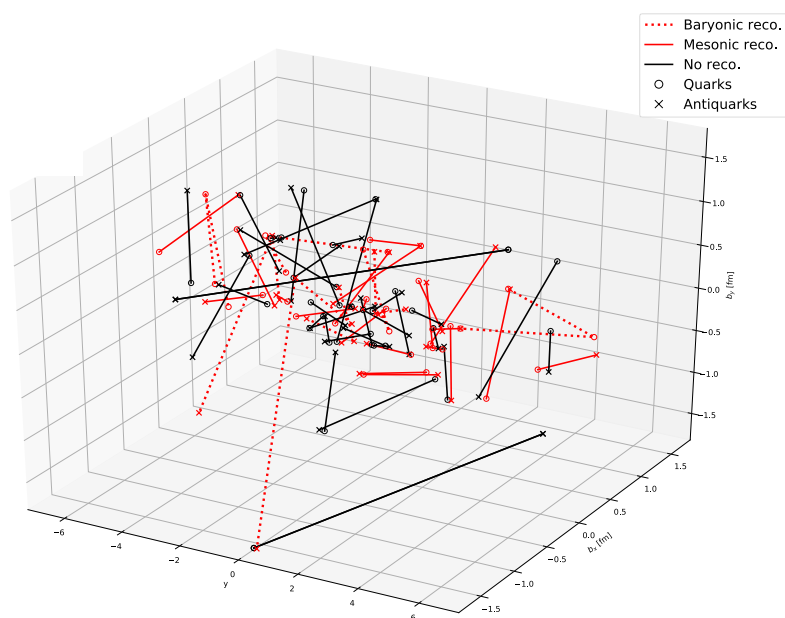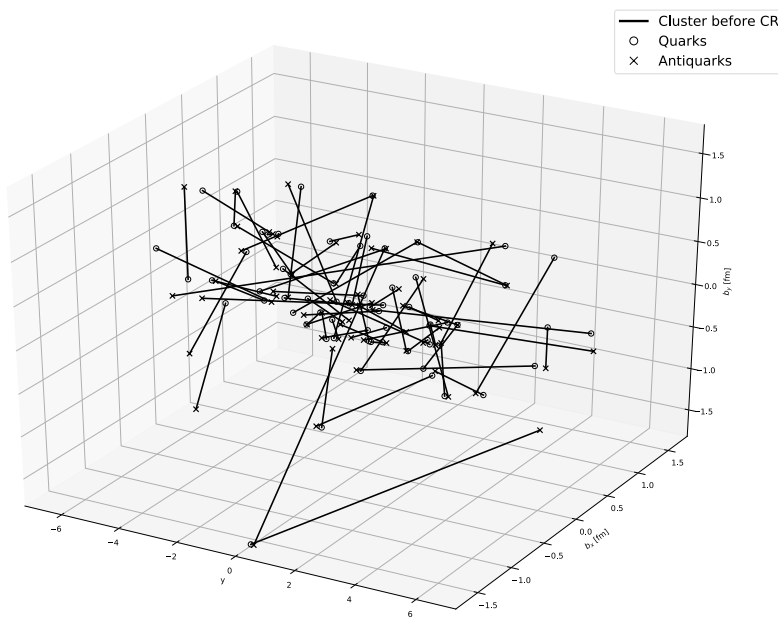
[Bellm, Duncan, Gieseke, Myska, Siodmok – EPJ C79 (2019) 1003]

Documentation & Tutorials

Herwig main website at
`herwig.hepforge.org`

Tutorials

Accompanying resource for this tutorial!

Current release predictions
compared to available Rivet analyses

Herwig 7

- Downloads | Tickets
- Tutorials | Plots
- Browse Source | Doxygen
- Contact
- Talks and publications
- Developer area

ThePEG

- Browse source | Doxygen

Old Herwig Versions

- Herwig++ 2
- HERWIG 6

Would you like to contribute to Herwig?

We offer collaboration and support for phenomenological applications to have your project's demands contribute to Herwig development.

Please contact us for more information!

The Herwig Event Generator

Herwig is a multi-purpose particle physics event generator.

It is built based on the experience gained with both the HERWIG 6 and Herwig++ 2 event generators. Continuing the Herwig++ 2 development, Herwig 7.0 (Herwig++ 3.0) replaces any prior HERWIG or Herwig++ versions.

Herwig provides significantly improved and extended physics capabilities when compared to both its predecessors, HERWIG 6 and Herwig++ 2, while keeping the key model motivations such as coherent parton showers (including angular-ordered and dipole-based evolution), the cluster hadronization model, an eikonal multiple-interaction model, highly flexible BSM capabilities and improved perturbative input using next-to-leading order QCD.

Download and Installation

The current version is Herwig 7.2.1, and is based on ThePEG 2.2.1

For installation we recommend to use our bootstrap script which is available here. See the tutorials for detailed installation instructions.

Documentation

Installing and using the current version is extensively covered in the tutorials. A detailed manual covering all physics developments since Herwig++ 2 is in preparation.

The detailed Herwig++ 2 manual is arXiv:0803.0883. When using Herwig 7, please cite this manual along with the Herwig 7 release note (Eur.Phys.J. C76 (2016) no.4, 196) until the main Herwig 7 manual is available. The release note describes the new features of the latest version, 7.2.

Contact

Any questions or comments should be directed to herwig@projects.hepforge.org.

To receive email updates about new releases, please send a blank message to herwig-announce-join@projects.hepforge.org.
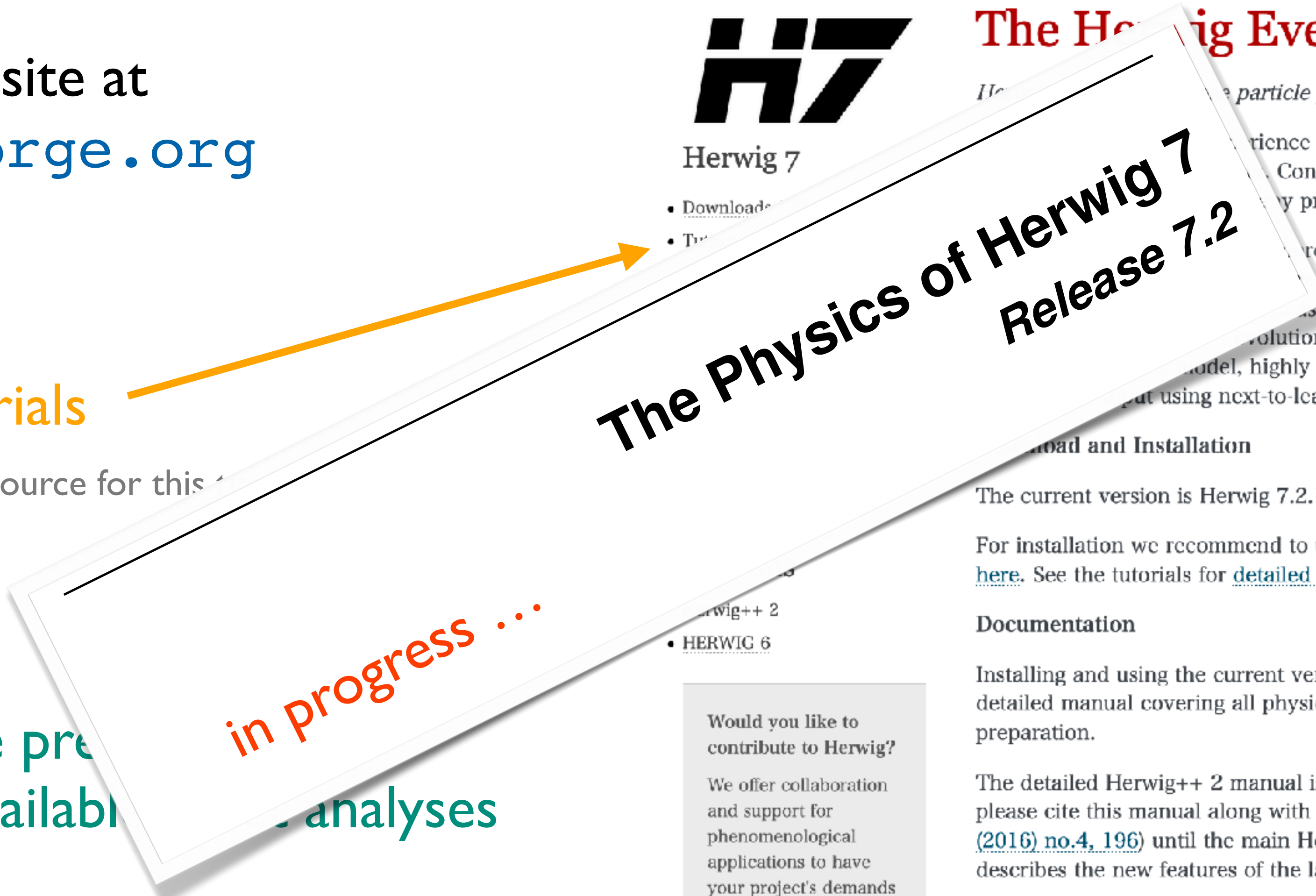
Herwig main website at
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Tutorials

Accompanying resource for this

Current release pre
compared to availabl   analyses

The Physics of Herwig 7
Release 7.2

in progress …

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Documentation & Tutorials

Closely following the Herwig tutorial at the 2019 MCnet school

Conveniently use a docker setup with Graeme's Herwig container

```
docker pull graemenail/herwig-eic

alias Herwig='docker run -i  --rm  -u `id -u $USER`:`id -g`
-v $PWD:$PWD -w $PWD  graemenail/herwig-eic Herwig'


alias rivet-mkhtml='docker run -i  --rm  -u `id -u $USER`:`id -g`
-v $PWD:$PWD -w $PWD  graemenail/herwig-eic rivet-mkhtml'
```

Generate a workspace for Herwig runs, copy input files and pre-adapted grids:

```
mkdir herwig-tutorials && cd herwig-tutorials && wget …
tar xzf Herwig.tar.gz
```

Workflow

Input File

manipulates

Repository

virtual file system of objects

Herwig read

Herwig build
Herwig integrate

adapts integrating grids in parallel

.run file

Herwig run

HepMC, Rivet, builtin analyses, cross section information & log

ME providers → Matchbox hard process

Builtin ME

ufo2herwig

LHE files

Subtractive matching

Multiplicative matching

Multijet merging

Angular ordered shower

Dipole shower

Multi Parton Interactions

(Cluster) hadronization

$$\mathrm{d}\sigma \sim \mathrm{d}\sigma_{\mathrm{hard}}(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

Take a look at LEP-Matchbox.in — what's going on?

Build an event generator, run a few 1000 events:

```
Herwig read LEP-Matchbox.in
Herwig run -N 10000 LEP-Matchbox.run
```

Take a look at the .log file and the .out file. Enable Rivet in the run:

```
cd /Herwig/Analysis
insert Rivet:Analyses 0 ALEPH_1996_S3486095
insert /Herwig/Generators/EventGenerator:AnalysisHandlers 0 Rivet
```

Switch between showers and orders, switch off the parton shower and/or hadronization:

When showers, process or (N)LO change, use a different event generator name, e.g.:

```
saverun LEP-LO EvenGenerator
```

```
# read Matchbox/MCatNLO-DefaultShower.in
read Matchbox/LO-DipoleShower.in

cd /Herwig/EventHandlers
set EventHandler:CascadeHandler NULL
set EventHandler:HadronizationHandler NULL
```

NLO Matching and QCD Effects in Drell-Yan

We will start from LHC-Matchbox.in, with some modifications:

```
set /Herwig/Shower/ShowerHandler:DoFSR No # switches off final state radiation
set /Herwig/Shower/ShowerHandler:DoISR No # switches off initial state radiation

cd /Herwig/EventHandlers
#set EventHandler:CascadeHandler NULL
set EventHandler:CascadeHandler:MPIHandler NULL # switches off MPI
set EventHandler:DecayHandler NULL # switches off particle decays
set EventHandler:HadronizationHandler NULL # switches off hadronization
```

Gradually switch on the different physics models; also have a look at the effect of the intrinsic transverse momentum, which can be changed with

```
set /Herwig/Shower/ShowerHandler:IntrinsicPtGaussian 2.2*GeV
set /Herwig/DipoleShower/IntrinsicPtGenerator:ValenceIntrinsicPtScale 2.0*GeV
set /Herwig/DipoleShower/IntrinsicPtGenerator:SeaIntrinsicPtScale 2.0*GeV
```

More processes and DIS

More processes are available via external matrix element providers, choose leading order to improve on the adaption of integration grids.

```
set Factory:OrderInAlphaS 1
set Factory:OrderInAlphaEW 1
do Factory:Process p p -> Z0 j

read Matchbox/DefaultPPJets.in
insert JetCuts:JetRegions 0 FirstJet

read Matchbox/LO-DefaultShower.in
read Matchbox/MadGraph-OpenLoops.in
```

Jets identified by fastjet

Take a look at DIS-Matchbox.in and try it out — you will see a familiar setup. Everything works just as for LEP and LHC.

One-loop ME provider (if needed)

Tree-level ME provider

Outlook: Multi-jet Merging

Input files are provided for the multi jet merging, as well, take a look in share/Herwig/

```
read snippets/DipoleMerging.in

[...]

## Set the order of the couplings
cd /Herwig/Merging
set MergingFactory:OrderInAlphaS 2
set MergingFactory:OrderInAlphaEW 0

## Select the process
do MergingFactory:Process p p -> j j [ j ]

set MergingFactory:NLOProcesses 1

set Merger:MergingScale 20.*GeV
set Merger:MergingScaleSmearing 0.1
```

Processes with jets at the level of the hard process as well as DIS are handled without any problems.

Thank you!

herwig@hepforge.org