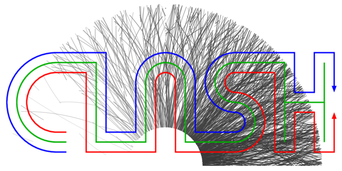


LUNDS UNIVERSITET

Herwig 7 - status report

Patrick Kirchgaeßer | December 21
Department of Astronomy and Theoretical Physics - Lund University
23rd MCnet Meeting, Manchester

MCnet

Outline

- Overview
- Parton Shower developments
- Soft QCD developments
- Additional studies and developments

Overview

Herwig 7 - Released in December 2015

… a multi purpose particle physics generator

[Herwig collaboration - EPJC 76 (2016) 665]

Current active contributors

Gavin Bewick, Cody B. Duncan, Silvia Ferrario Ravasio, Stefan Gieseke, Patrick Kirchgaeßer,
Mohammad R. Masouminia, Andreas Papaefstathiou, Simon Plätzer, Peter Richardson, Michael H. Seymour and Andrzej Siódmok
+ Many Master and Bachelor students

Current release

[Herwig 7.2 release note, Bellm et al. - EPJC 80 (2020)]

Overview

Online documentation

- Tutorials and tune recommendations
- Explanation of new features and link to papers
- Example input files

Installation

- Manual
- Bootstrap script, installs all dependencies

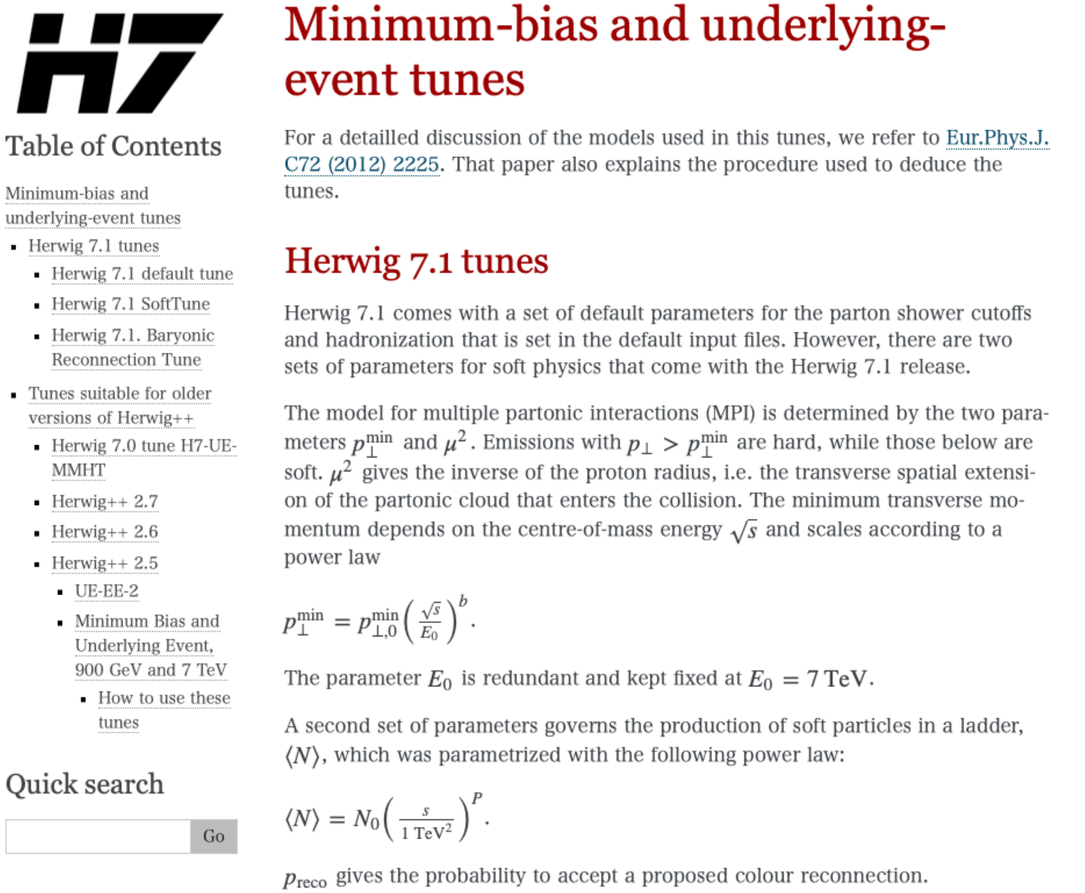


Table of Contents

Quick search

Go

Minimum-bias and underlying-event tunes

For a detailled discussion of the models used in this tunes, we refer to Eur.Phys.J. C72 (2012) 2225. That paper also explains the procedure used to deduce the tunes.

Herwig 7.1 tunes

Herwig 7.1 comes with a set of default parameters for the parton shower cutoffs and hadronization that is set in the default input files. However, there are two sets of parameters for soft physics that come with the Herwig 7.1 release.

The model for multiple partonic interactions (MPI) is determined by the two parameters $p_\perp^{\min}$ and μ^2. Emissions with $p_\perp > p_\perp^{\min}$ are hard, while those below are soft. μ^2 gives the inverse of the proton radius, i.e. the transverse spatial extension of the partonic cloud that enters the collision. The minimum transverse momentum depends on the centre-of-mass energy $\sqrt{s}$ and scales according to a power law

$$p_\perp^{\min} = p_{\perp,0}^{\min}\left(\frac{\sqrt{s}}{E_0}\right)^b.$$

The parameter E_0 is redundant and kept fixed at $E_0 = 7\,\text{TeV}$.

A second set of parameters governs the production of soft particles in a ladder, $\langle N\rangle$, which was parametrized with the following power law:

$$\langle N\rangle = N_0\left(\frac{s}{1\,\text{TeV}^2}\right)^P.$$

p_{reco} gives the probability to accept a proposed colour reconnection.

Link to the bootstrap script

https://herwig.hepforge.org

Overview

Herwig 7.2 Release Note (2019)

[Herwig collaboration – Eur.Phys.J. C80 (2020) 452]

Johannes Bellm, Gavin Bewick, Silvia Ferrario Ravasio, Stefan Gieseke, David Grellscheid, Patrick Kirchgaeßer, Mohammad R. Masouminia, Graeme Nail, Andreas Papaefstathiou, Simon Plätzer, Michael Rauch, Christian Reuschle, Peter Richardson, Michael H. Seymour, Andrzej Siódmok and Stephen Webster

Herwig 7.1 Release Note (2017)

[Herwig collaboration – 1705.06919]

Johannes Bellm, Stefan Gieseke, David Grellscheid, Patrick Kirchgaeßer, Frashër Loshaj, Graeme Nail, Andreas Papaefstathiou, Simon Plätzer, Radek Podskubka, Michael Rauch, Christian Reuschle, Peter Richardson, Peter Schichtel, Michael H. Seymour, Andrzej Siódmok, Stephen Webster

Herwig 7.0 Release Note (2016)

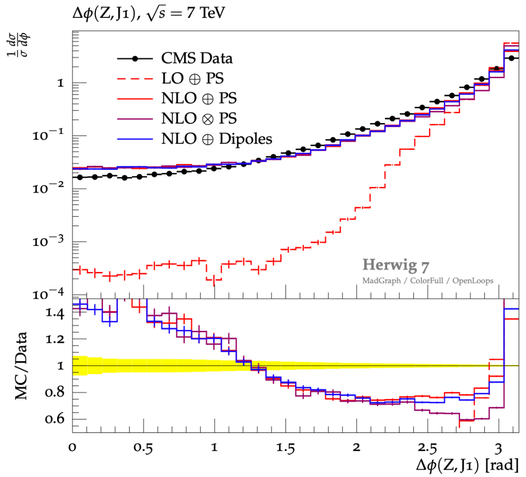
[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]

Johannes Bellm, Stefan Gieseke, David Grellscheid, Simon Plätzer, Michael Rauch, Christian Reuschle, Peter Richardson, Peter Schichtel, Michael H. Seymour, Andrzej Siódmok, Alexandra Wilcock, Nadine Fischer, Marco Harrendorf, Graeme Nail, Andreas Papaefstathiou, Daniel Rauch

Milestones in the past ~4 years

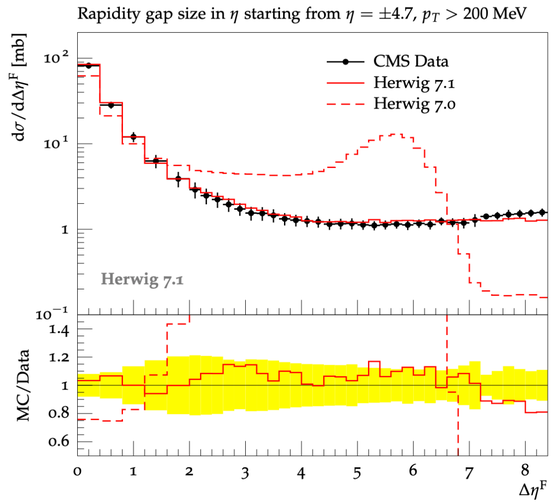
Herwig 7.0

- Major rewrite
- Built in NLO hard processes
- Matchbox module
- Matching to both showers
- QED radiation and spin correlations in the angular ordered shower



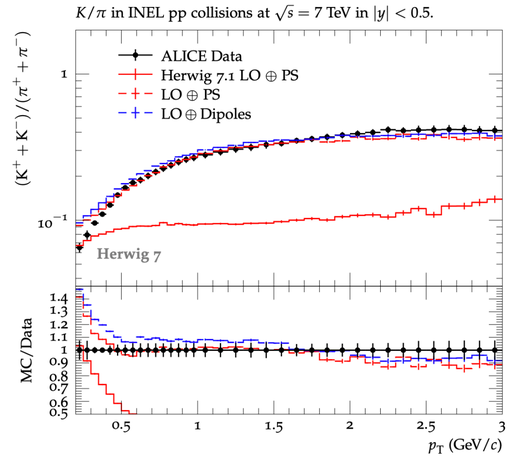
Herwig 7.1

- Multijet merging with the dipole shower
- New model for soft interactions
- New model for diffraction
- New tune of hadronization model



Herwig 7.2

- Colour matrix element corrections
- Baryonic colour reconnection & MPI improvements
- Spin correlation in both showers
- Better support for BSM models



Herwig 7 under the hood

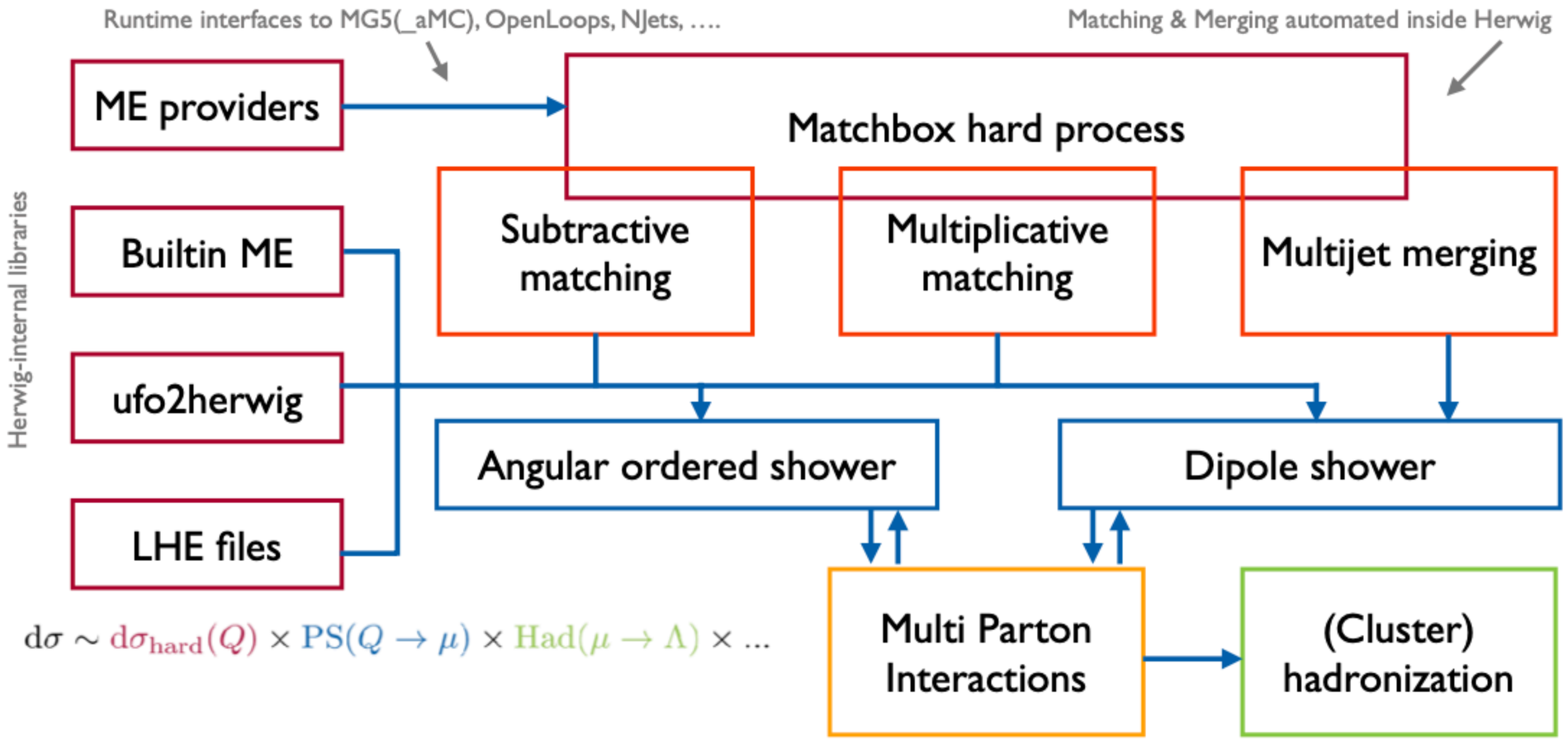


Figure from Simon Plätzer

Parton Shower Developments

Theory and phenomenology

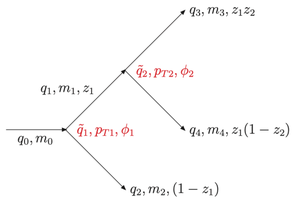
- Parton Shower Variations — [Bellm, Nail, Plätzer, Schichtel, Siódmok – Eur.Phys.J.C 76 (2016)]
- Parton Shower Reweighting — [Bellm, Plätzer, Richardson, Siódmok, Webster – PRD 94 (2016)]
- Improved simulation of quark/gluon jets — [Reichelt, Richardson, Siódmok - Eur.Phys.J.C 77 (2017)]
- Colour matrix element corrections in dipole shower — [Plätzer, Sjödahl, Thoren – JHEP 11 (2018)]
- Mass effects in dipole shower — [Cormier, Plätzer, Reuschle, Richardson, Webster – Eur.Phys.J.C 79 (2019) 915]
- Spin correlations in both shower modules — [Webster, Richardson - Eur.Phys.J.C 80 (2020)]
- Accuracy of Parton showers — FSR [Bewick, Ferrario Ravasio, Richardson, Seymour, JHEP 04 (2020) 019]; ISR [Bewick, Ferrario Ravasio, Richardson, Seymour, arXiv:2107.04051]
- Angular ordered EW parton shower — [Masouminia, Richardson — arXiv:2108.10817]

Parton Shower Developments

[Bewick, Ferrario Ravasio, Richardson, Seymour, JHEP 04 (2020) 019 & arXiv:2107.04051]

Logarithmic Accuracy of Angular-Ordered Parton Showers

- Motivation: “Logarithmic accuracy of parton showers: a fixed-order study”, by M. Dasgupta, F. Dreyer, K. Hamilton, P.F. Monni and G. Salam (1805.09327)
- Study how well the angular ordered Parton shower reproduces the double-emission probability when both emissions are soft and well separated in rapidity
- Three interpretations of the ordering variable $\tilde{q}$

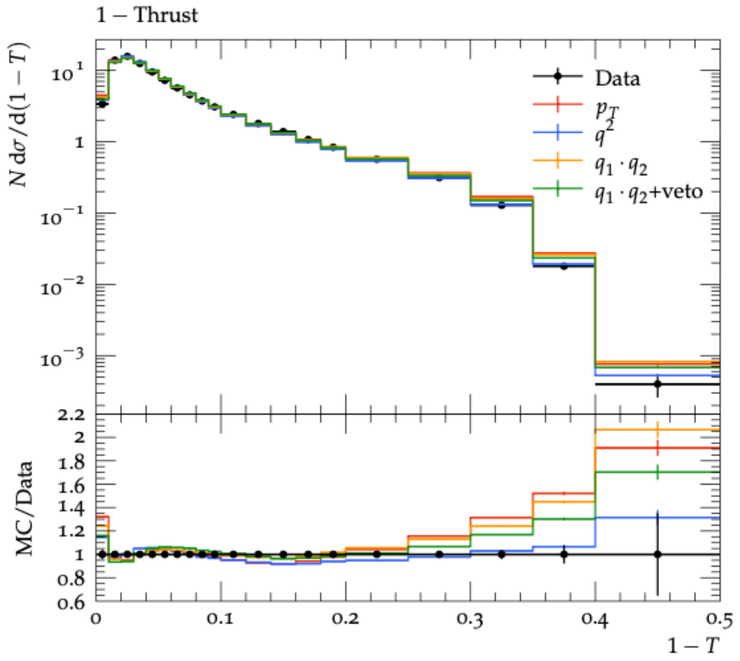


$\mathbf{p_T}$ preserving	$\mathbf{q^2}$ preserving	(new) **dot-product** preserving
$\tilde{q}^2 = \frac{p_T^2 + (1-z)m_1^2 + zm_2^2 - z(1-z)m_0^2}{z^2(1-z)^2}$	$\tilde{q}^2 = \frac{q_0^2 - m_0^2}{z(1-z)}$	$\tilde{q}^2 = \frac{2q_1 \cdot q_2 + m_1^2 + m_2^2 - m_0^2}{z(1-z)}$

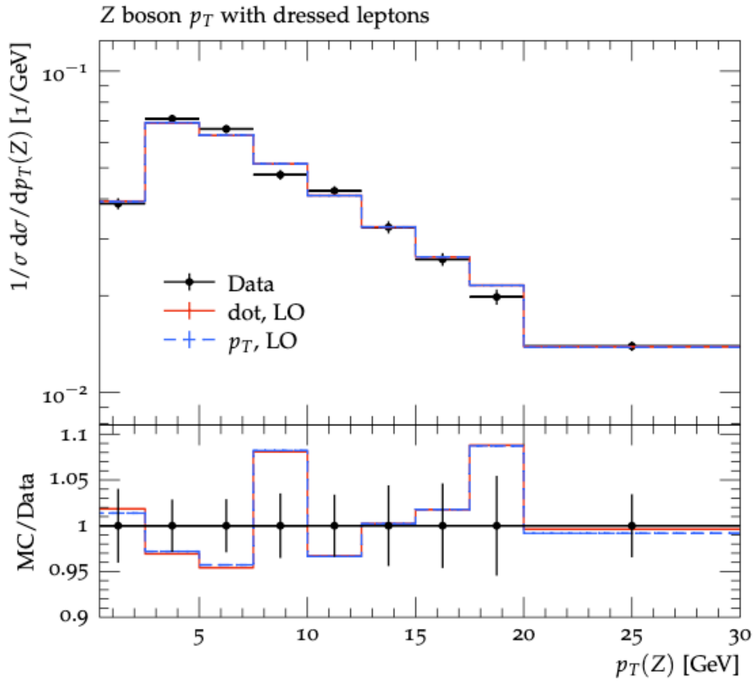
- p_T and dot-product preserving schemes correctly reproduce the double-emission probability, q^2 scheme does not

Parton Shower Developments

LEP



LHC Drell-Yan



q^2 preserving scheme might be preferred for this LEP observable but **dot-product** scheme gives best overall description of data. **Dot-product** scheme new default for ISR and FSR. Also correctly reproduces the double emission probability.

More developments

- Building a consistent Parton Shower
  [Forshaw, Holguin, Plätzer JHEP 09 (2020) 014]
- Dipole shower colour improvements
  [Forshaw, Holguin, Plätzer EPJC 81 (2021) 364]
- Ongoing work to implement new recoil scheme and partitioning functions in Herwig
  [Duncan, Plätzer, Simpson Dore - in preparation]

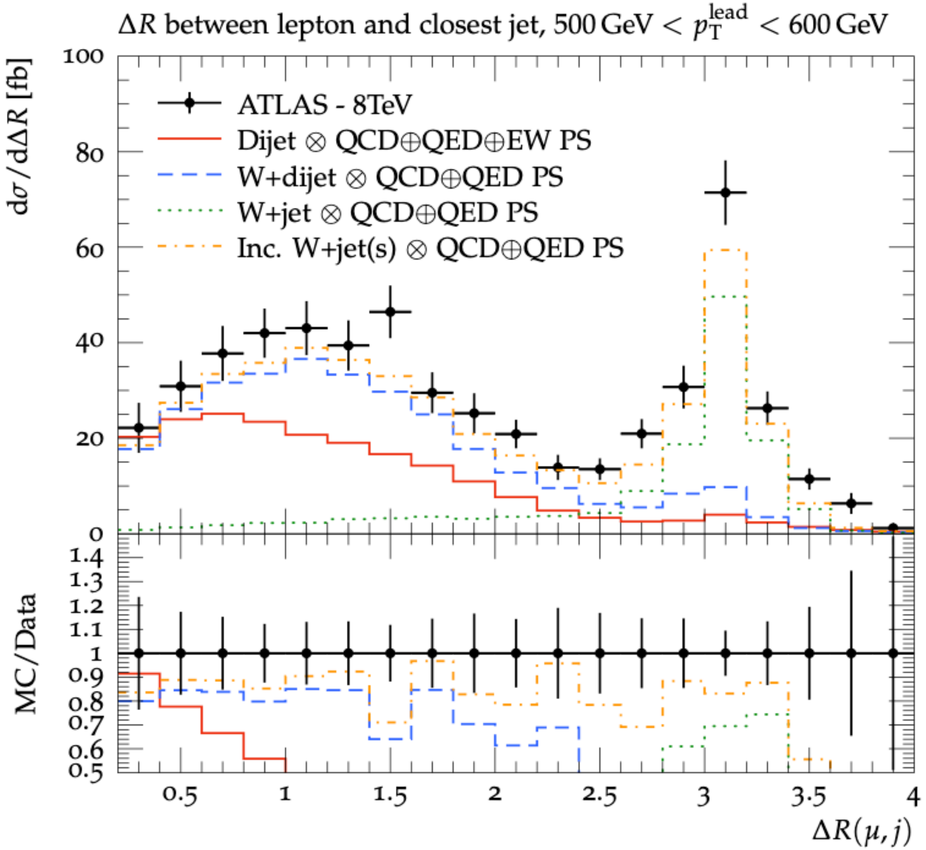
Parton Shower Developments

[Masouminia, Richardson — arXiv:2108.10817]

Angular ordered EW parton shower

QCD+QED ⟶ QCD+QED+EW

- Quasi-collinear EW branching functions implemented in Herwig 7
- IS EW Rad. & FS EW AO PS
- EW shower describes successive EW radiations within the confinenemtns of collinear factorisation
- Can describe W+2jets distribution
- **Coming with Herwig 7.3**



Angular distribution of W boson with high pT jets

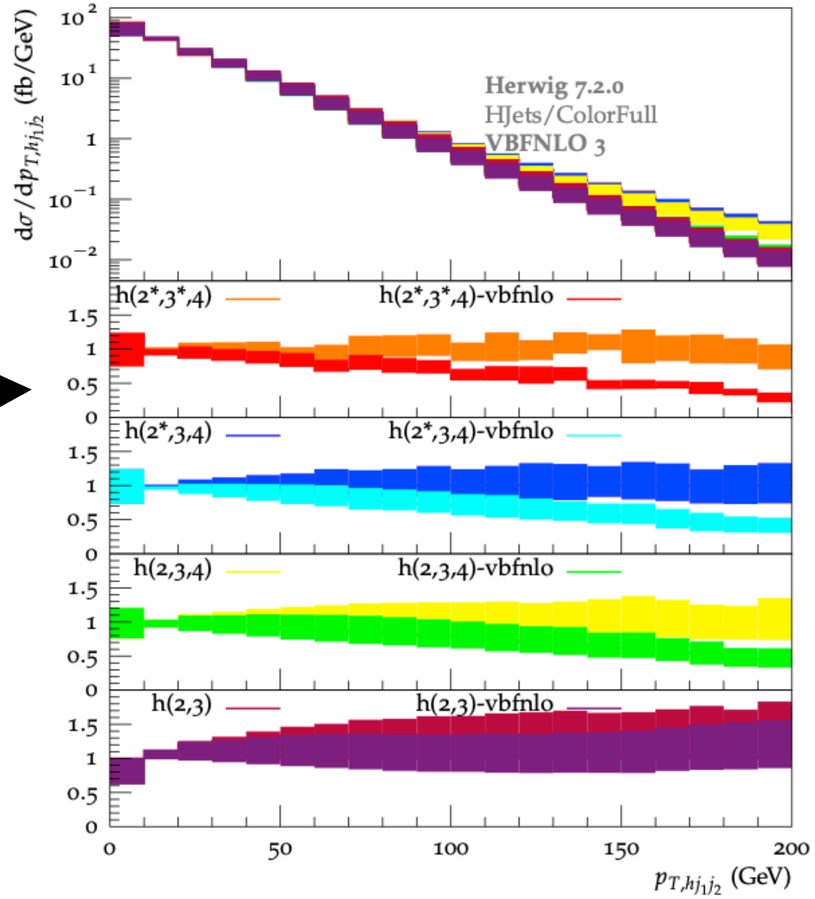
Matching and Merging

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

NLO multijet merging

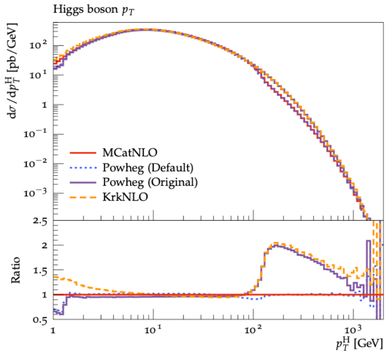
- NLO matched to parton showers as new default.
- Fully automated for two matching schemes (MC@NLO and Powheg)
- Performed by Matchbox module
- MEs from external providers
- Works for (ee/ep/pp) - recent application VBF+jets

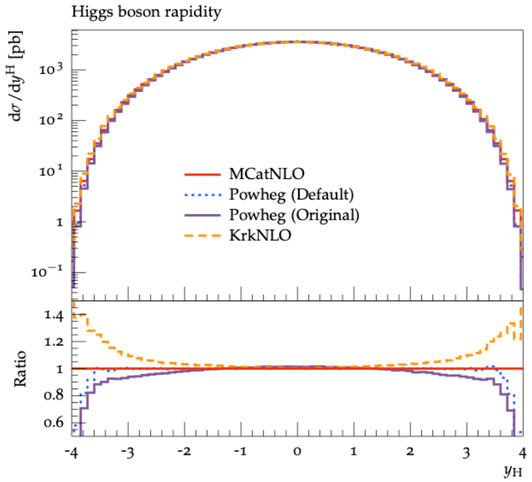
[Chen, Figy, Plätzer — arXiv:2109.03730]



KrkNLO matched to dipole shower

- Available in Herwig 7
- New pdf sets needed
- Implemented for Z/H





[Jadach, Nail, Placzek, Sapeta, Siódmok, Skrzypek, Eur.Phys.J. C77 (2017) no.3, 164]

Developments in the soft QCD sector

Hadronization

- Baryon production from cluster hadronization [Gieseke, PK, Plätzer - EPJC 78 (2018) 224]
- Kinematic strangeness production [Duncan, PK - EPJC 79 (2019) 61]

Multiple parton interactions

- Soft and diffractive scattering [Gieseke, PK, Loshaj - EPJC 77 (2017)]
- Improving the simulation of MPI and diffraction [Bellm, Gieseke, PK - EPJC 80 (2020) 5]
- Space-time model [Bellm, Duncan, Gieseke, Myska, Siódmok - EPJC 79 (2019) 12]

Heavy Ion modeling

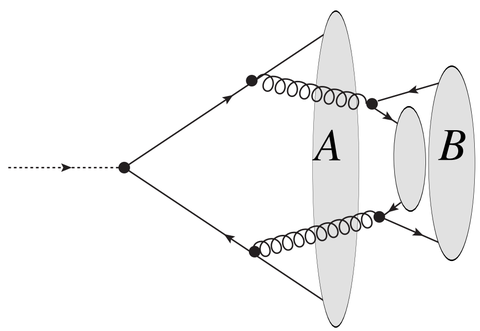
- PISTA: Posterior Ion STAcking [Bellm, Bierlich - arXiv:1807.01291]
- Heavy Ion collisions with Herwig [Duncan, Gieseke, Lukwata - in preparation]

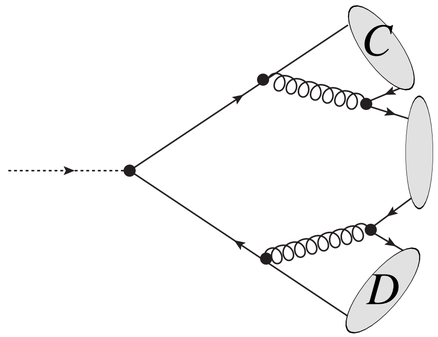
Developments in the soft QCD sector

[Gieseke, Röhr, Siódmok - EPJC 72 (2012) 2225]

[Gieseke, PK, Plätzer - EPJC 78 (2018) 99]

Plain Colour Reconnection



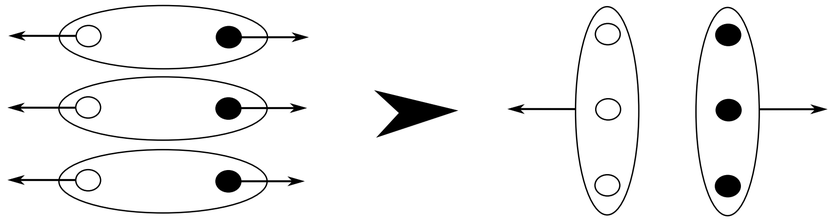


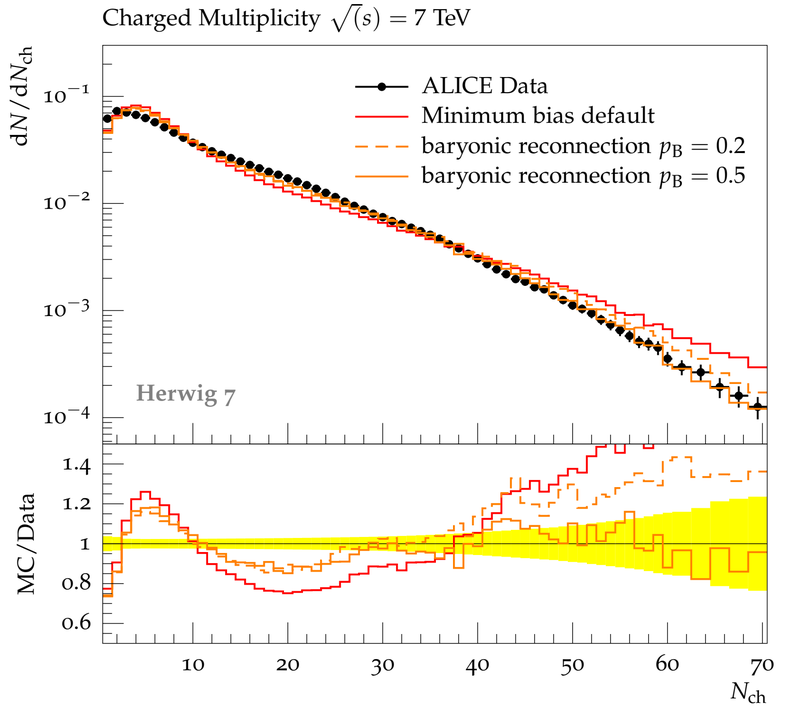
Reduces

$$\lambda = \sum_{i=1}^{N_{\mathrm{cl}}} M_i^2$$

Baryonic Colour Reconnection

- Generalize to geometric model, based on rapidity
- Allow reconnection into baryonic clusters



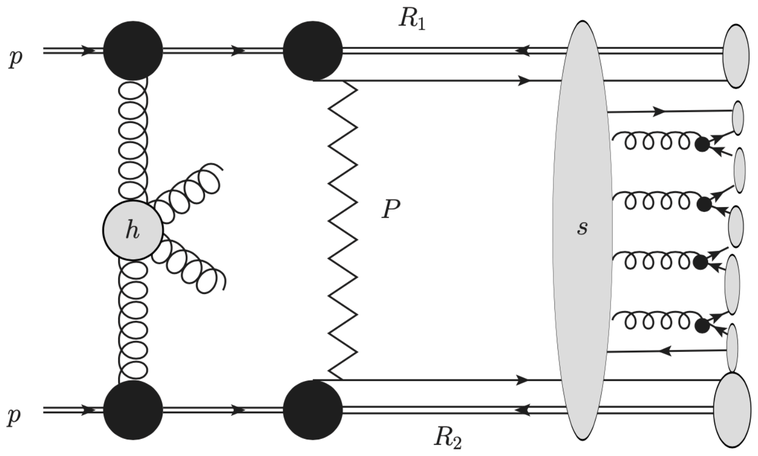


Developments in the soft QCD sector

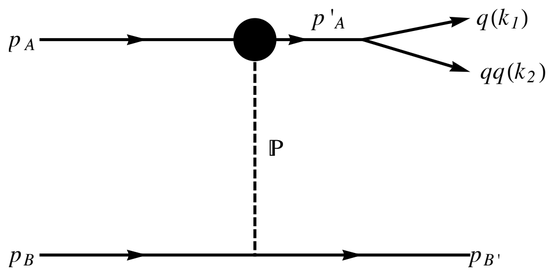
[Gieseke, PK, Loshaj - EPJC 77 (2017) 156]

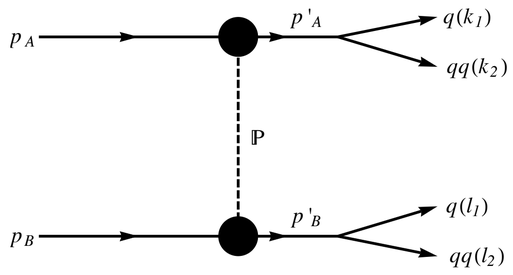
[Bellm, Gieseke, PK - EPJC 80 (2020) 5]

Soft interactions = multiple soft gluon ladders



Single and Double diffractive processes

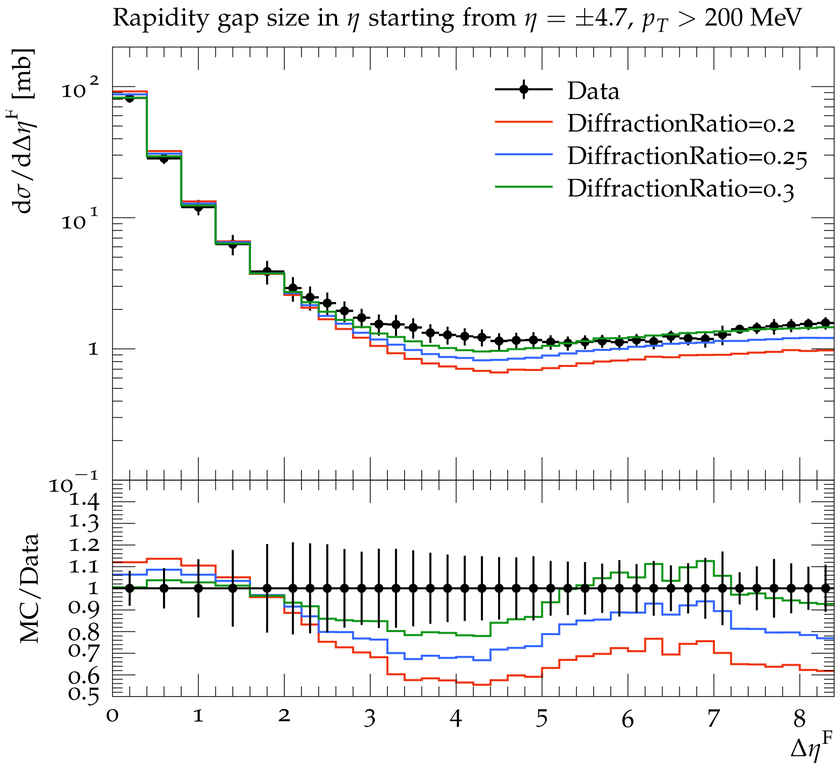




Tuning of diffractive cross-section

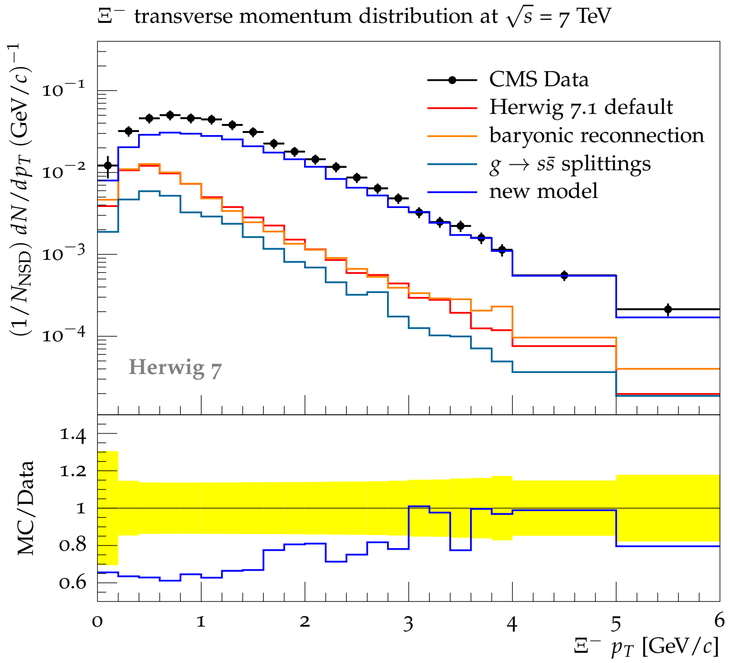
$$\sigma_{\text{inel}}(s) = \sigma_{\text{tot}}(s) - \sigma_{\text{el}}(s)$$

$$\sigma_{\text{diff}}(s) = R_{\text{diff}}\sigma_{\text{inel}}(s)$$

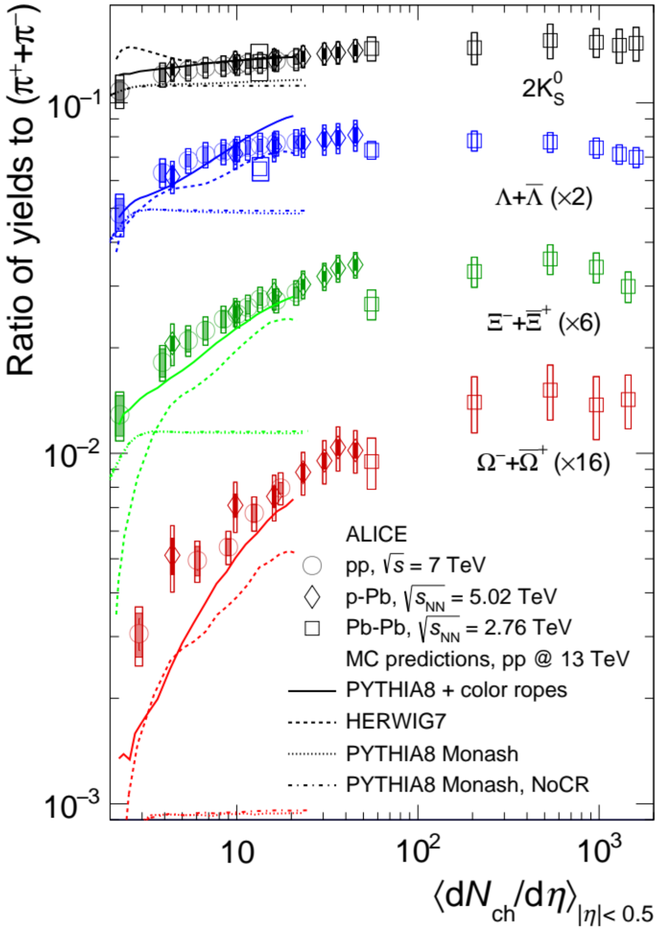


Developments in the soft QCD sector

- Good description of MB+UE data
- Good description of diffraction
- At least qualitative description of ALICE strangeness data



[From Vytautas Vislavicius, **MPI at LHC 2019**]

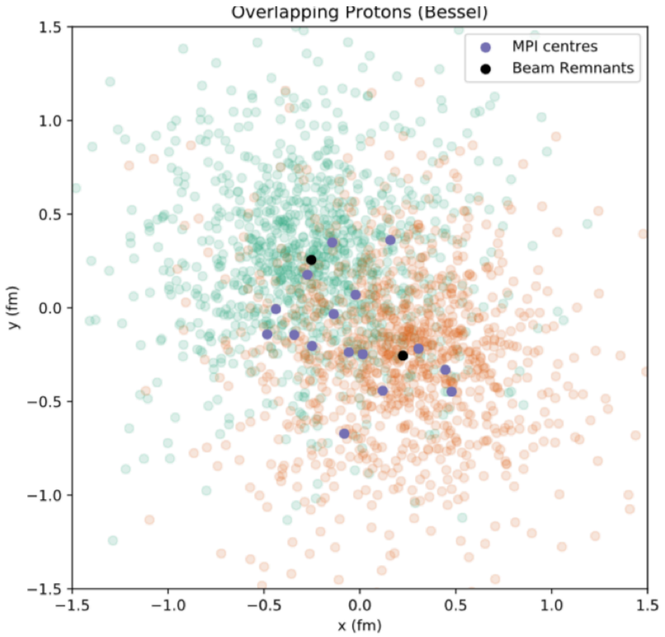


Additional studies and developments

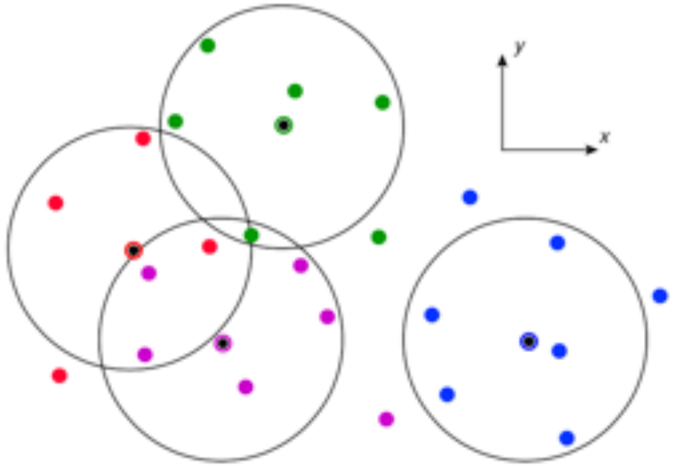
[Bellm, Duncan, Gieseke, Myska, Siódmok - EPJC 79 (2019) 12]

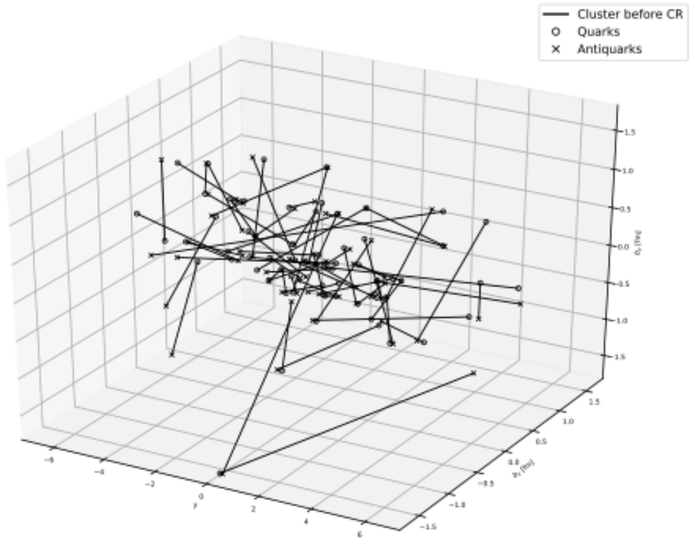
Space-time colour reconnection

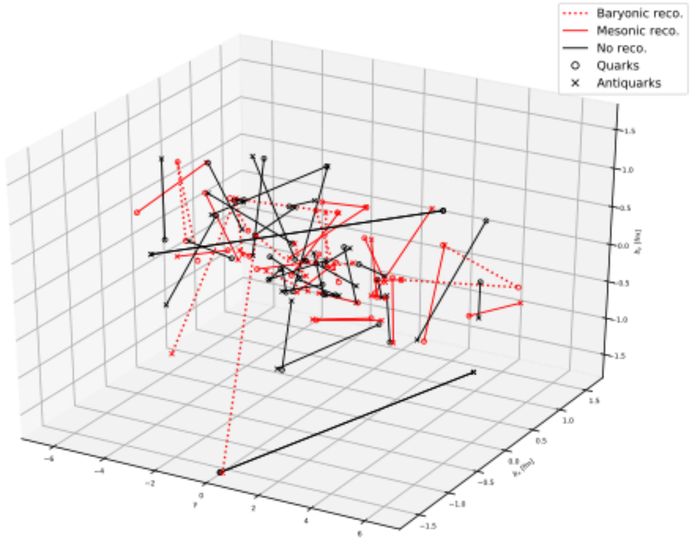
MPI centers from overlap function



PS propagation in transverse plane





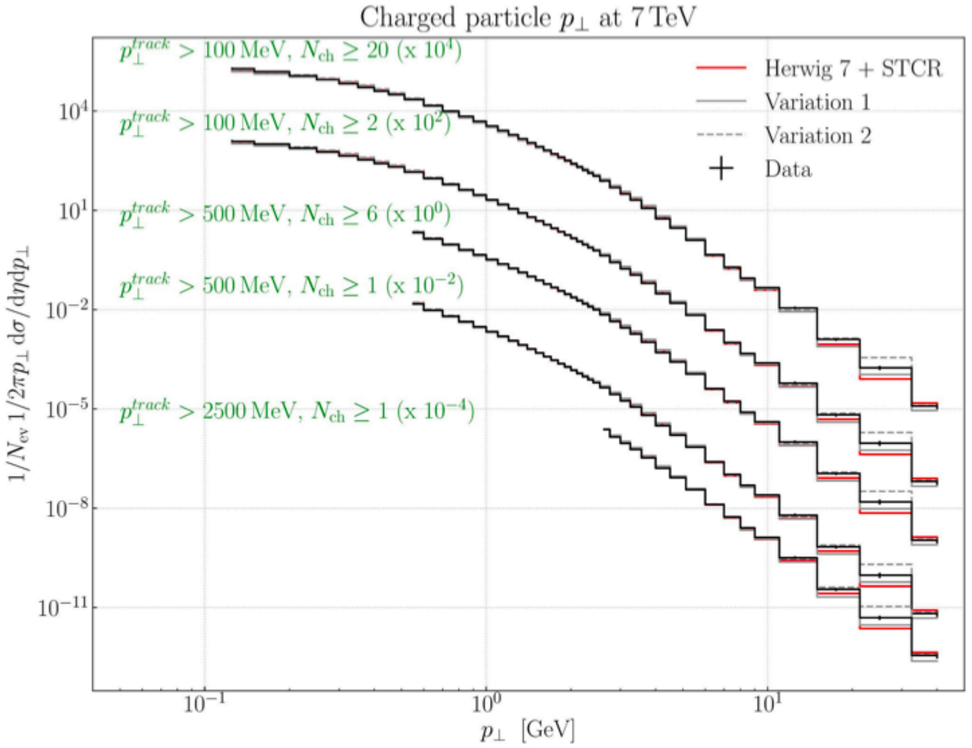


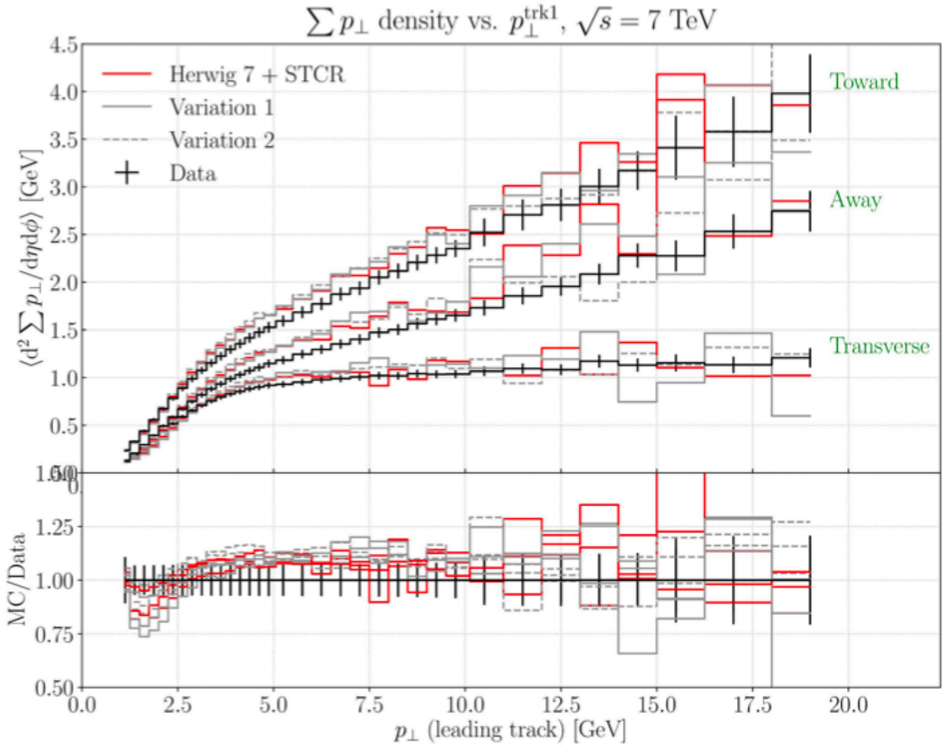
Reconnection based on ST measure

$$R_{ij}^2 = \frac{\Delta d_{\perp ij}^2}{d_0^2} + \Delta y_{ij}^2$$

$$P_{M,reco} = \exp\left(-\frac{R_{14}+R_{23}}{R_{12}+R_{34}}\right) = \exp\left(-\frac{\sum R_{new}}{\sum R_{old}}\right)$$

Additional studies and developments

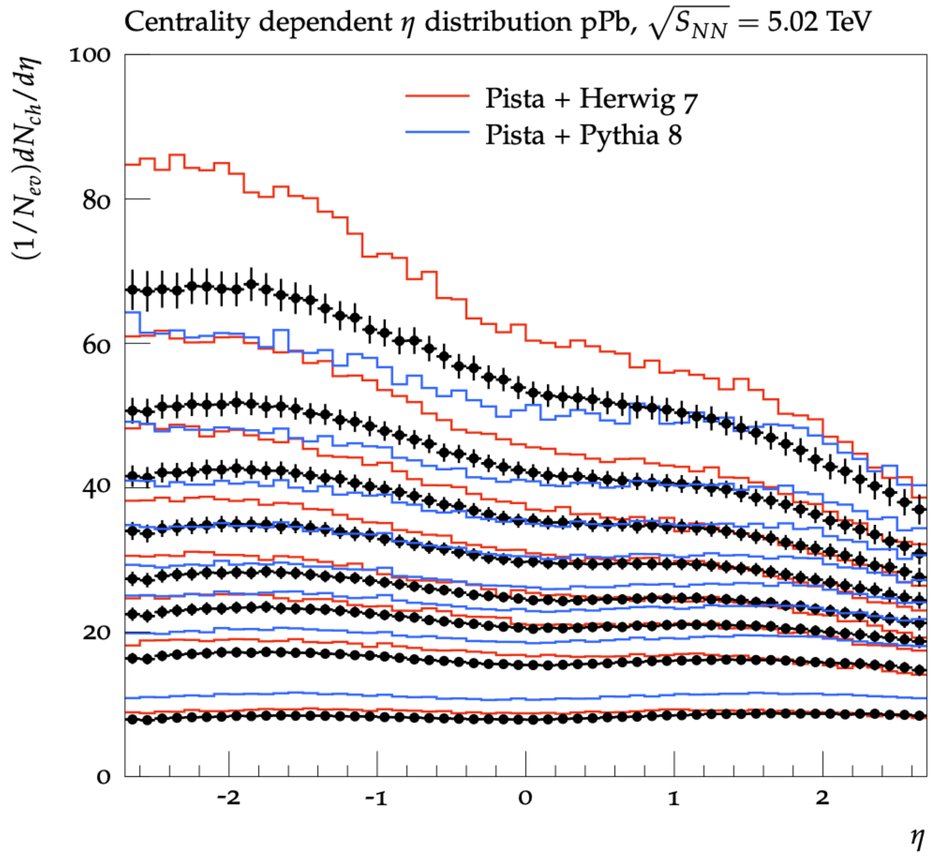




- Good description of data
- Basis for Heavy Ion collision model and rescattering

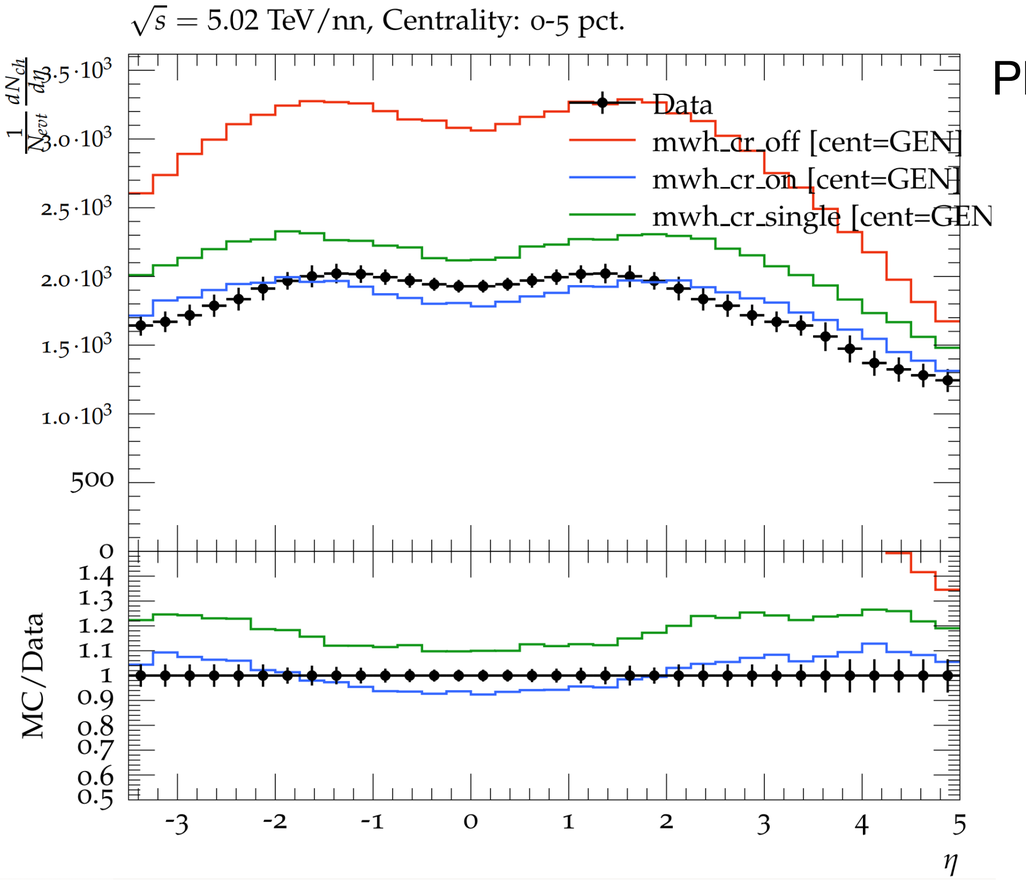
Additional studies and developments

PISTA: Glauber calculation then stacking of events



„pre-burner“ for MC generators

Glauber+Herwig->Single Heavy Ion event at Parton Level



PbPb

[Bellm, Bierlich - 1807.01291]

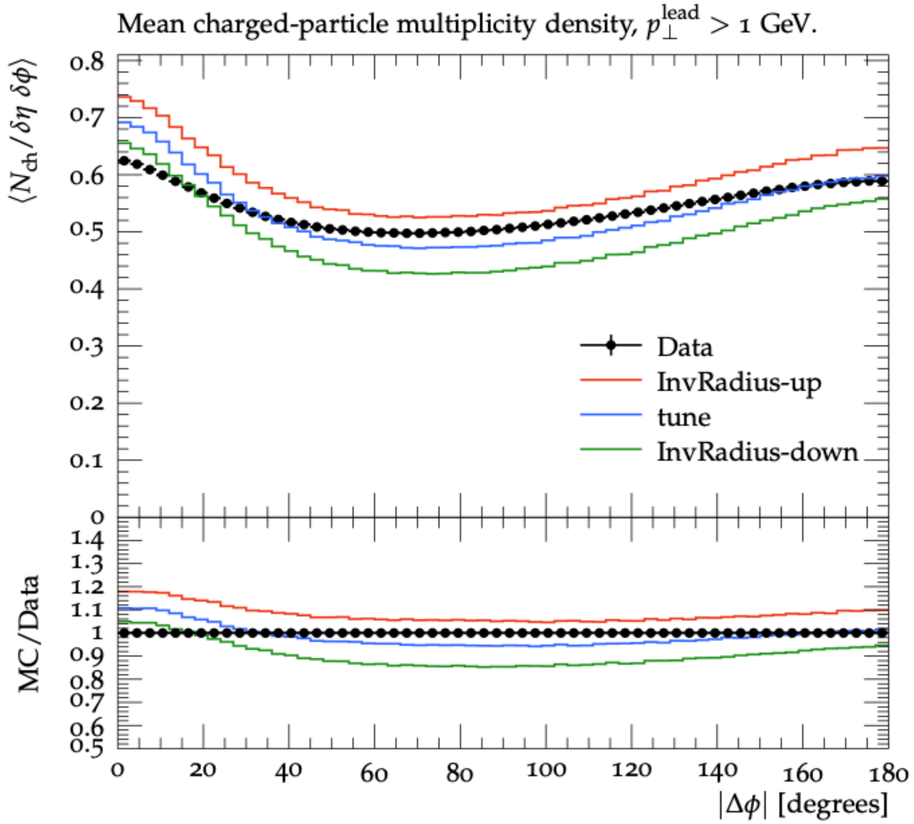
[Lukwata - Master Thesis (KIT)]

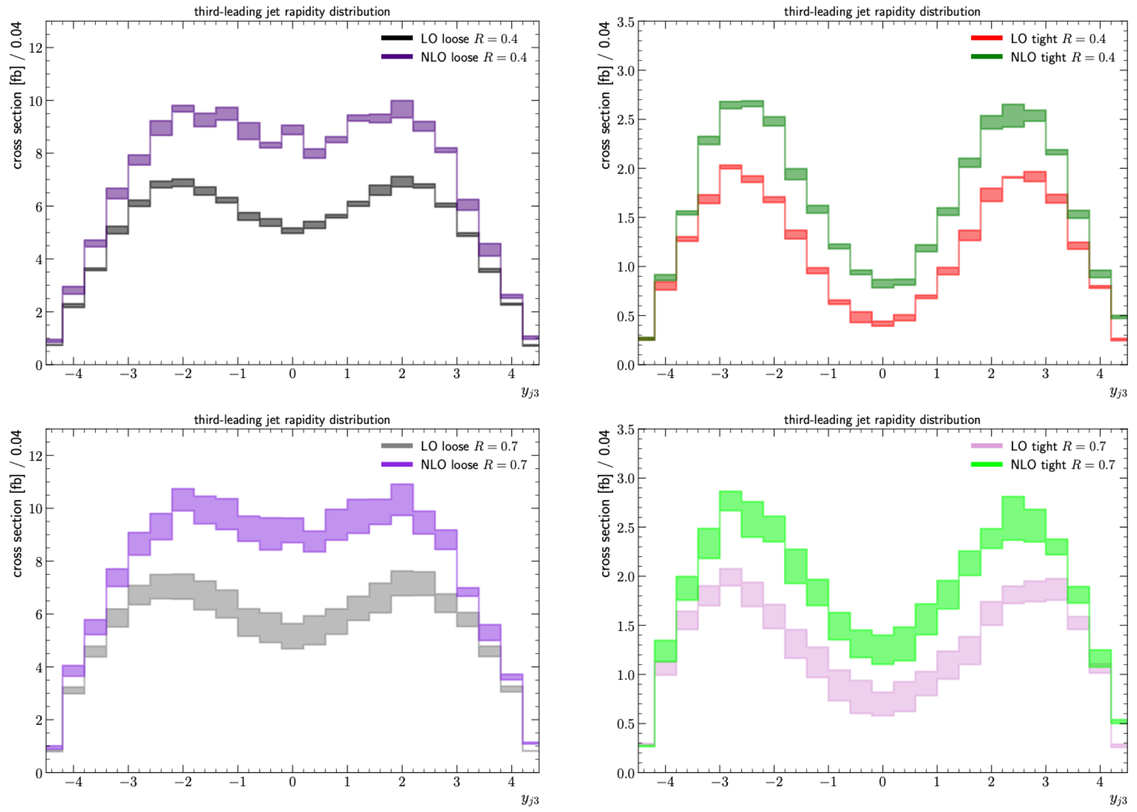
[Duncan, Gieseke, Lukwata - in preparation]

Additional studies and developments

[Bittrich, PK, Papaefstathiou, Plätzer, Todt, arXiv:2110.01623]

Soft QCD effects in VBS/VBF



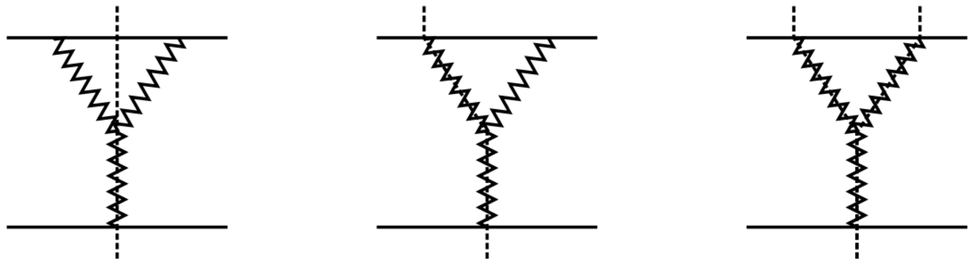


Additional studies and developments

Diffractive cross-sections

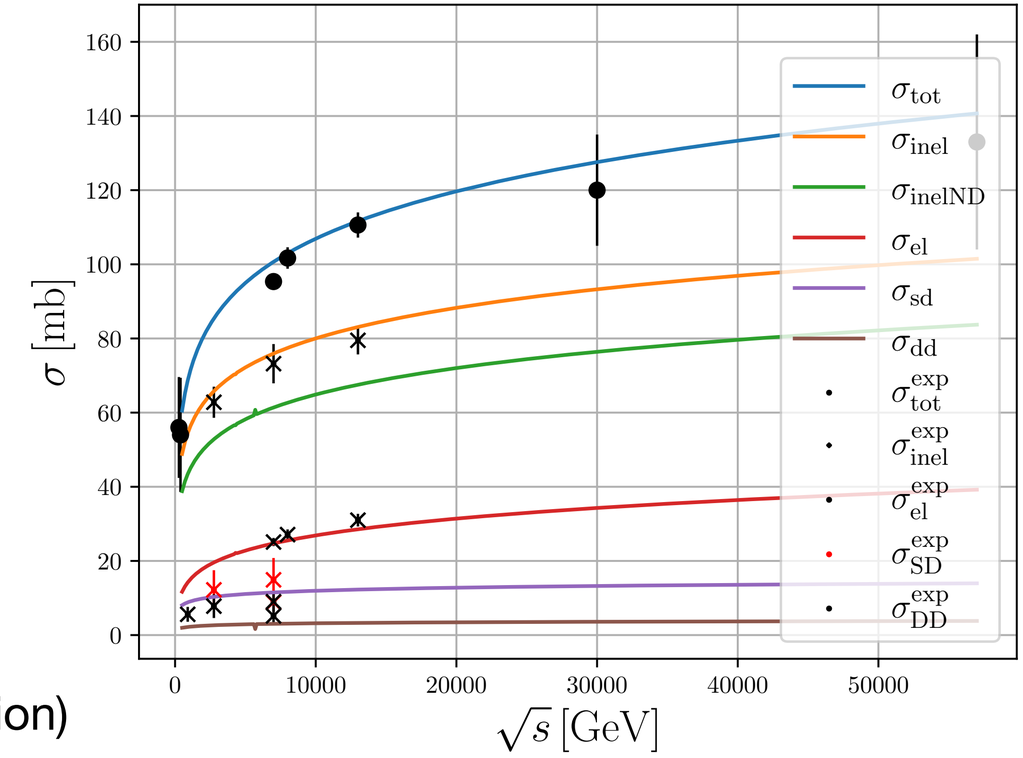
[Gieseke, PK, Röhr, Seymour, in preparation]

Multi-channel eikonal model with enhanced pomeron diagrams



High-mass diffraction

Multiperipheral particle production



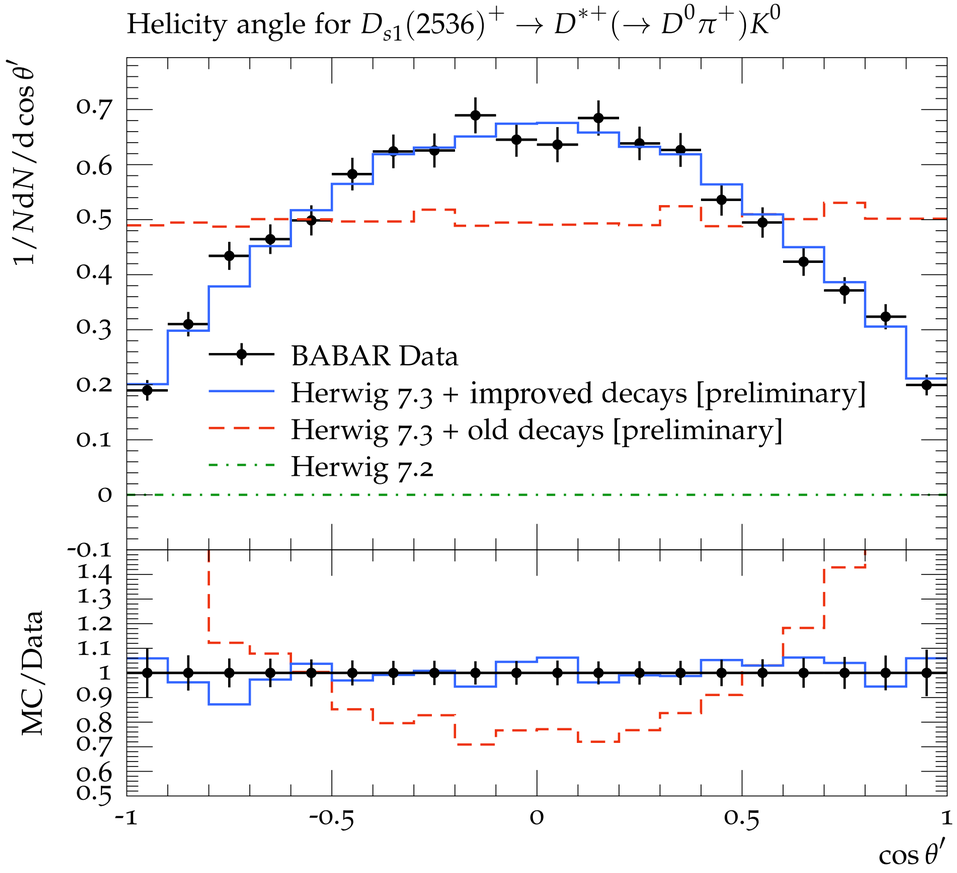
- Cross-sections as predictions of the model (no DL parametrisation)
- Good extrapolation of energy dependence

Additional studies and developments

Improved heavy hadron decay

[Masouminia, Richardson - in preparation]

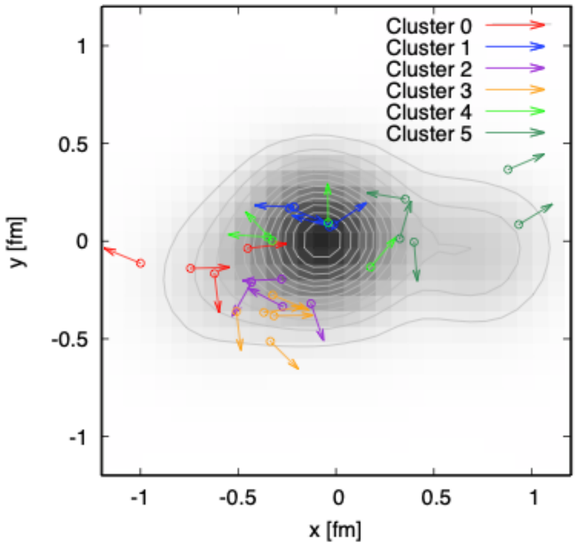
- Heavy quark effective field theory (HQEFT) produces non-zero contributions
- Improved hadronization and decay of heavy quarks
- **Coming with Herwig 7.3**

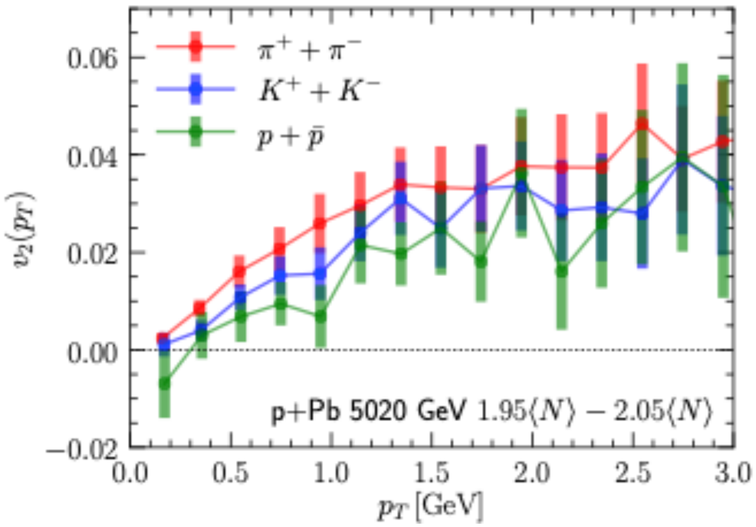


Additional studies and developments

Hadronization

- CGC + Herwig 7

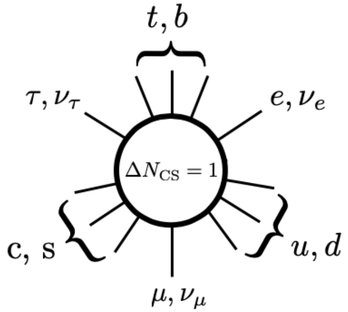


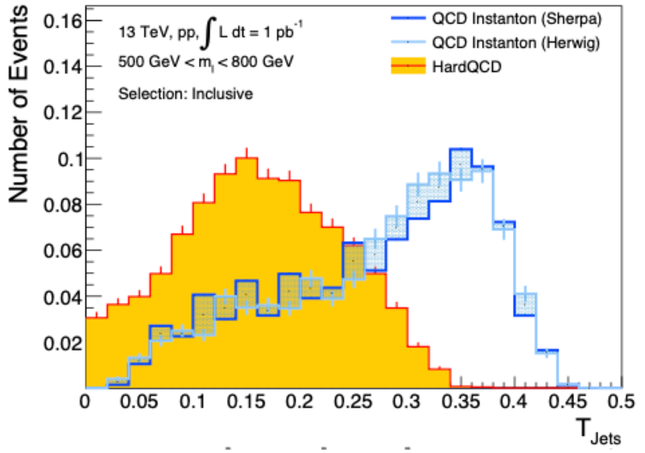


[Greif, Greiner, Plätzer, Schenke, Schlichting — Phys.Rev.D 103 (2021) 5]

Instantons/Sphalerons

- Framework for “blob” type processes



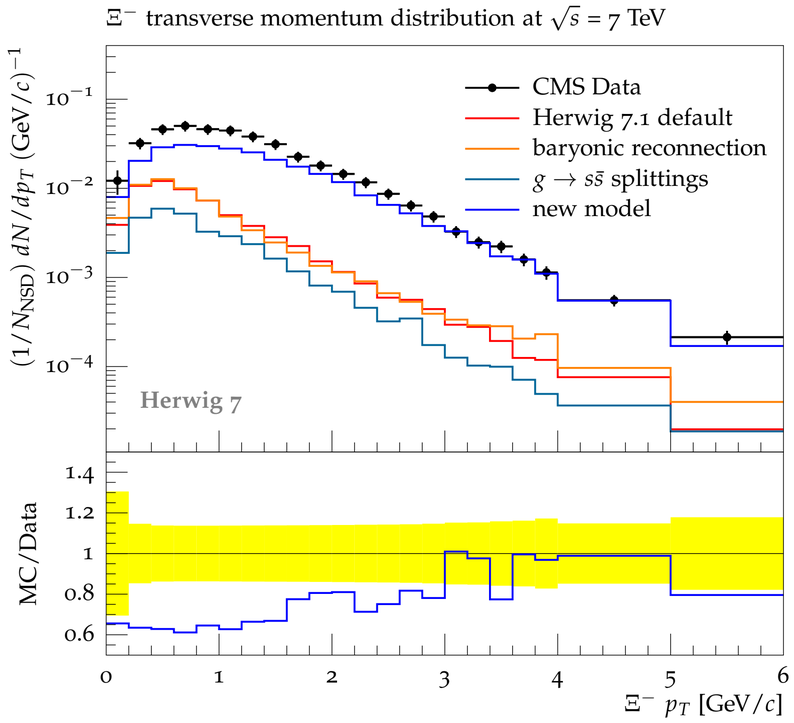


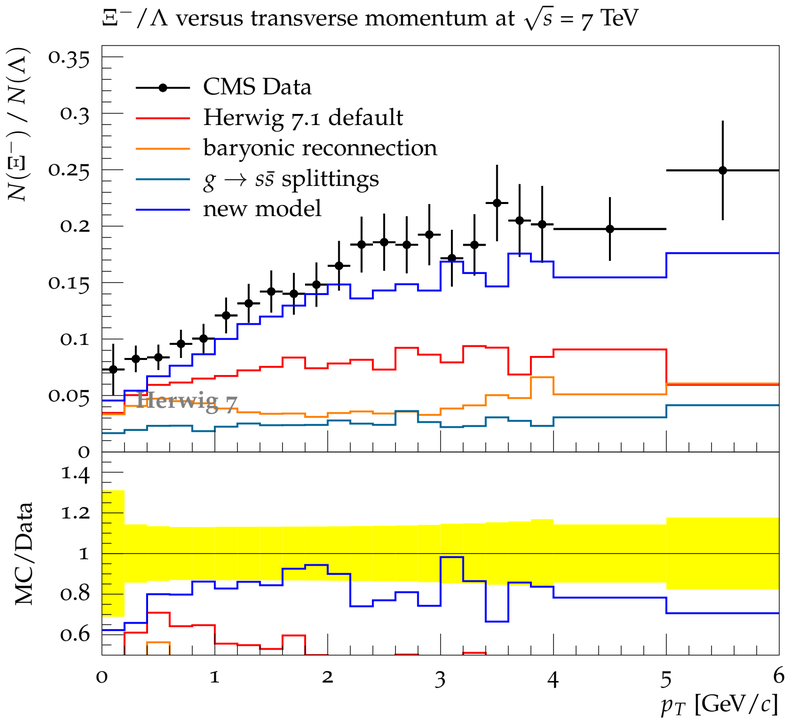
[Amoroso — based on Instanton simulation in Herwig 7]

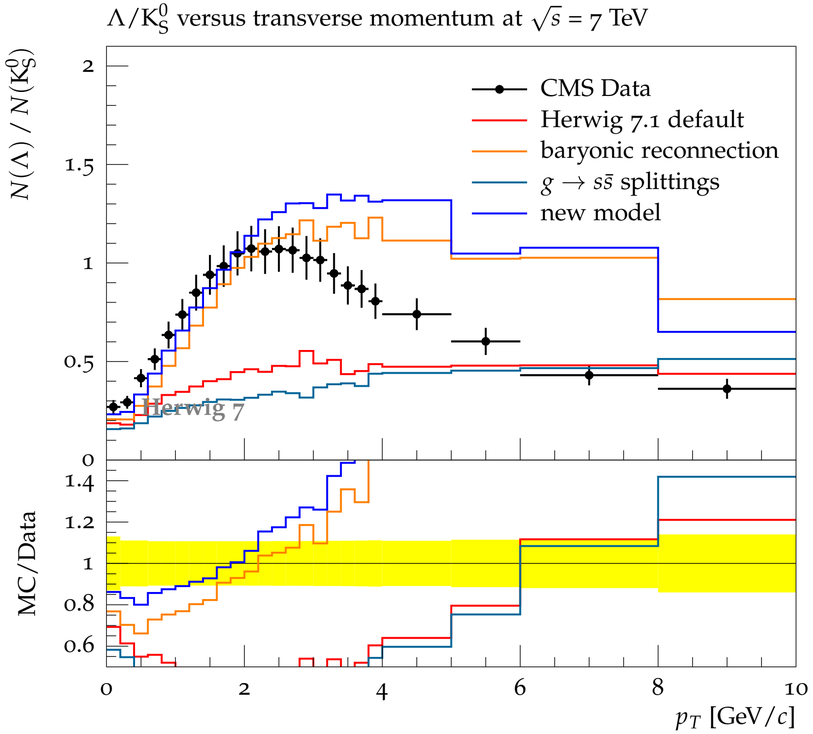
[Papaefstathiou, Plätzer, Sakurai — JHEP 1912 (2019) 017]

Thanks

Backup

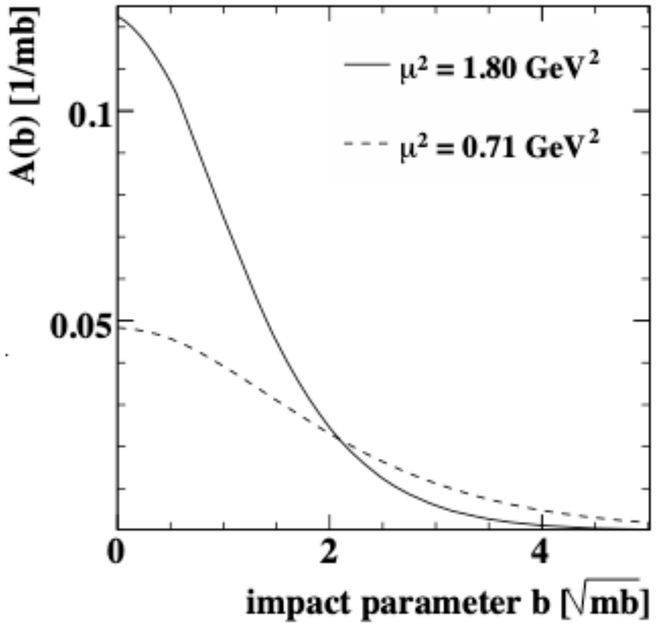

Ξ^- transverse momentum distribution at $\sqrt{s}$ = 7 TeV
$(1/N_{NSD})\, dN/dp_T$ (GeV/c)$^{-1}$
CMS Data
Herwig 7.1 default
baryonic reconnection
$g \to s\bar{s}$ splittings
new model
Herwig 7
MC/Data
Ξ^- p_T [GeV/c]


Ξ^-/Λ versus transverse momentum at $\sqrt{s}$ = 7 TeV
$N(\Xi^-)$ / $N(\Lambda)$
CMS Data
Herwig 7.1 default
baryonic reconnection
$g \to s\bar{s}$ splittings
new model
Herwig 7
MC/Data
p_T [GeV/c]

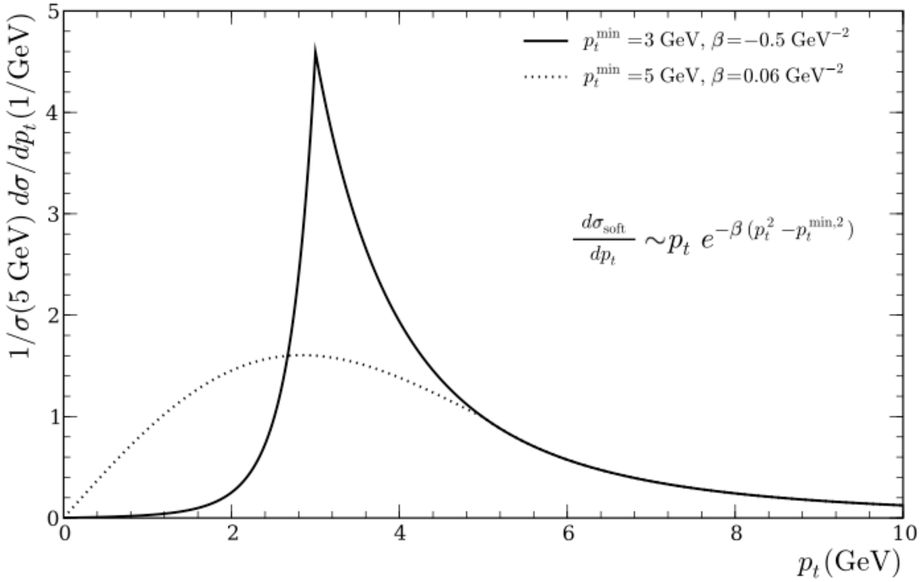

Λ/K^0_S versus transverse momentum at $\sqrt{s}$ = 7 TeV
$N(\Lambda)$ / $N(K^0_S)$
CMS Data
Herwig 7.1 default
baryonic reconnection
$g \to s\bar{s}$ splittings
new model
Herwig 7
MC/Data
p_T [GeV/c]

Multiple Parton Interaction Model

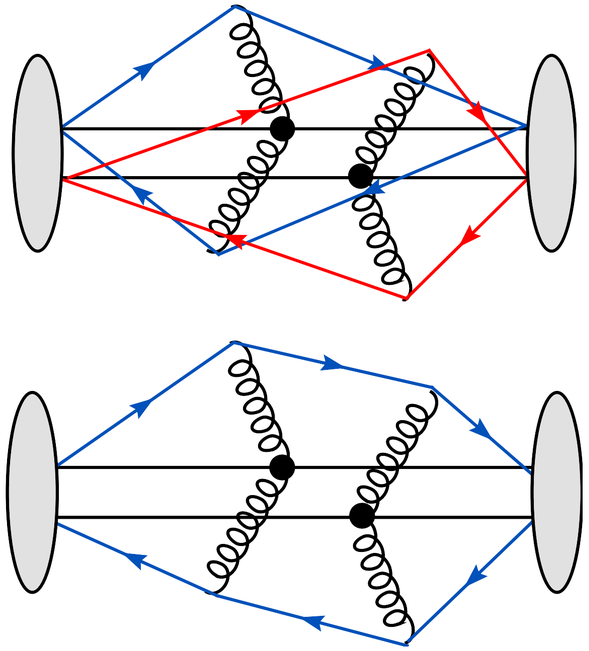
Matter distribution



Soft & hard scatters



Colour Reconnection



Main parameters:

- μ^2 - inverse hadron radius squared -> overlap function
- $p_t^{\min}$ - cutoff scale between soft and hard model components
- p_{reco} - colour reconnection

- Herwig Webpage
- Tutorials
- Docker container (Herwig 7.2.2)

  docker pull patrickkirchgaesser/herwig

- Installation with bootstrapscript

Herwig read LHC-MB.in

Herwig run LHC-MB.run -N 10000

rivet-mkhtml LHC-MB.yoda …

Table of Contents

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Minimum-bias and underlying-event tunes

For a detailled discussion of the models used in this tunes, we refer to Eur.Phys.J. C72 (2012) 2225. That paper also explains the procedure used to deduce the tunes.

Herwig 7.1 tunes

Herwig 7.1 comes with a set of default parameters for the parton shower cutoffs and hadronization that is set in the default input files. However, there are two sets of parameters for soft physics that come with the Herwig 7.1 release.

The model for multiple partonic interactions (MPI) is determined by the two parameters $p_\perp^{\min}$ and μ^2. Emissions with $p_\perp > p_\perp^{\min}$ are hard, while those below are soft. μ^2 gives the inverse of the proton radius, i.e. the transverse spatial extension of the partonic cloud that enters the collision. The minimum transverse momentum depends on the centre-of-mass energy $\sqrt{s}$ and scales according to a power law

$$p_\perp^{\min} = p_{\perp,0}^{\min}\left(\frac{\sqrt{s}}{E_0}\right)^b.$$

The parameter E_0 is redundant and kept fixed at $E_0 = 7\,\text{TeV}$.

A second set of parameters governs the production of soft particles in a ladder, $\langle N\rangle$, which was parametrized with the following power law:

$$\langle N\rangle = N_0\left(\frac{s}{1\,\text{TeV}^2}\right)^P.$$

p_{reco} gives the probability to accept a proposed colour reconnection.

[Herwig collaboration - EPJC 76 (2016) 665]