MPI, Hadronization and Colour Reconnection ~~Effects~~ in CJV in Herwig

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Overview

Herwig 7 - Released in December 2015

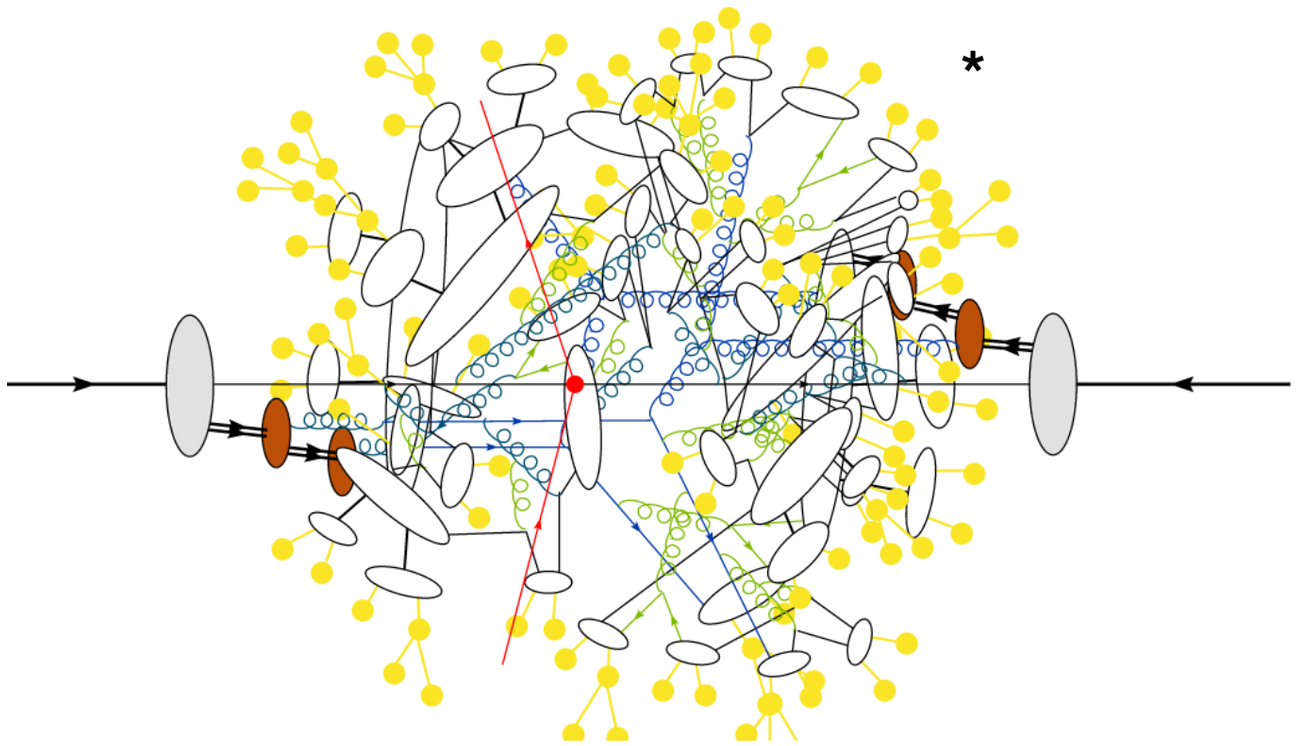
[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]

…a multi purpose particle physics event generator

Successor of Herwig ++

A collaborative effort

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



Components

- PDF
- Initial State Radiation
- Hard interaction
- **Multi Parton Interactions**
- Final State Radiation
- **Diffraction**
- Parton Shower
- **Hadronization**
- **Colour Reconnection**
- Decay

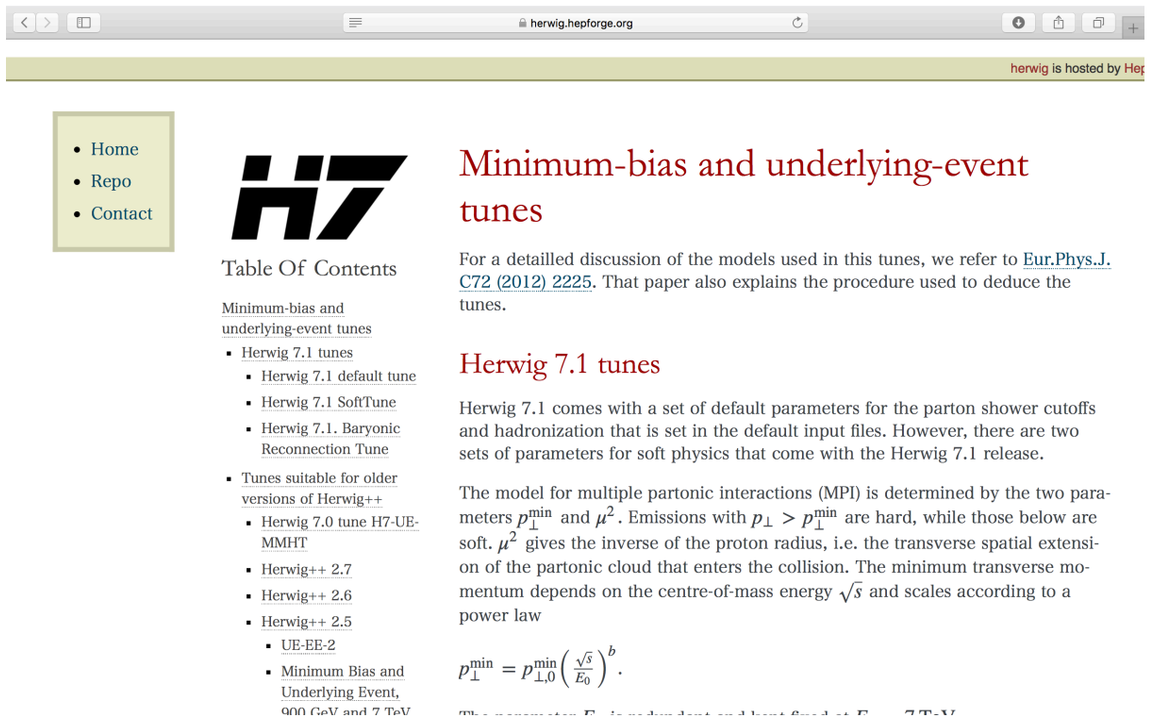
***Not really a VBF/VBS event**

Herwig 7 - Website

Herwig 7 online documentation

https://herwig.hepforge.org/index.html

- Many **tutorials** and recommendations for different tunes online
- Explanation of **new features** and link to relevant papers
- Example **input files** etc…
- Usually kept up to date (in doubt, ask us!)



Installation of Herwig 7

- Manual installation
- Bootstrapscript
- All explained in detail

Using the Herwig bootstrap script

Installation of Herwig 7.1.4 (current version) including all dependencies

Herwig 7 - core features

Herwig 7.0

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

- NLO Matching for angular ordered and dipole shower
- MC@NLO-type and Powheg type algorithms
- Matchbox

[Plätzer, Bellm, Rauch, Reuschle, Wilcock – unpublished]

Herwig 7.1

[Herwig collaboration – arXiv:1705.06919]

- Shower variations and **reweighting**

[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

[Bellm, Plätzer, Richardson, Siodmok, Webster – PhysRev D94 (2016) 4028]

- NLO **multijet merging** with the dipole shower

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

- New **soft mpi** model and **colour reconnection** improvements

[Gieseke, Loshaj, PK – EPJ C77 (2017) 156] [Gieseke, PK, Plätzer – EPJ C78 (2018) 99]

Current version Herwig 7.1.4 **New release (Herwig 7.1.5) in the next weeks**

Get it right here! https://herwig.hepforge.org/tutorials/index.html

Recent developments

Matching

- Parton Shower and Matching uncertainties in **Top Quark Pair Production** with Herwig 7
  [Cormier, Plätzer, Reuschle, Richardson, Webster -1810.05493]
- Stress testing the **vector boson approximation** in multi jet final states
  [Campanario, Figy, Plätzer, Rauch, Schichtel, Sjödahl - Phys. Rev. D98(2018)no. 3,033003]
- **Precision comparison** of predictions for Higgs boson + jet production at the LHC as a function of jet size
  [LH 17 study, awaiting publication]

Spin and (sub)leading N

- **Colour Rearrangement** for Dipole Showers
  [Bellm - Eur. Phys. J C78(2018) no.7,601]
- **Spin Correlations** in Parton Shower Simulations
  [Richardson, Webster -1807.01955]
- **Soft Gluon evolution** and non global logarithms
  [Martínez, de Angelis, Forshaw, Plätzer, Seymour]
- **Colour matrix element corrections** for Parton showers
  [Plätzer, Sjodahl, Thorén - JHEP11(2018)009]

Hadronization

- **Baryon production** from cluster hadronization
  [Gieseke, PK, Plätzer - Eur. Phys. J C(2018) no. 2, 99]
- Kinematic **strangeness production**
  [Duncan, PK - Eur. Phys. J. C79 no. 1 (2019) 61]

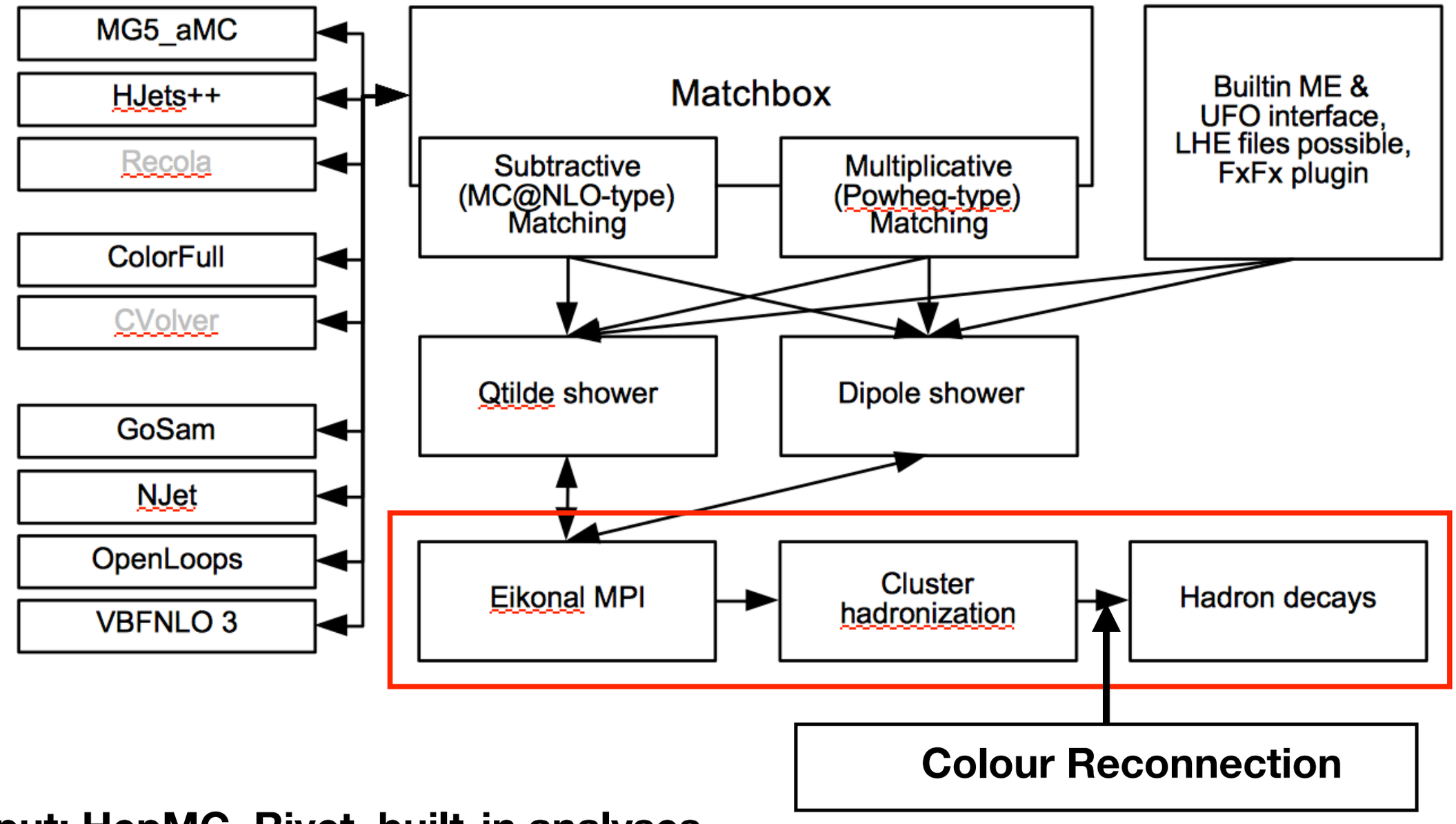
Heavy Ion modeling

- **Pista**: Posterior Ion STAcking
  [Bellm, Bierlich - 1807,01291]

The inner workings of Herwig 7

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.

Cluster hadronization - basics

Cluster hadronization model

[Webber - Nucl. Phys. B238, 492 (1984)]

- Based on **colour pre-confinement** and planar diagram theory

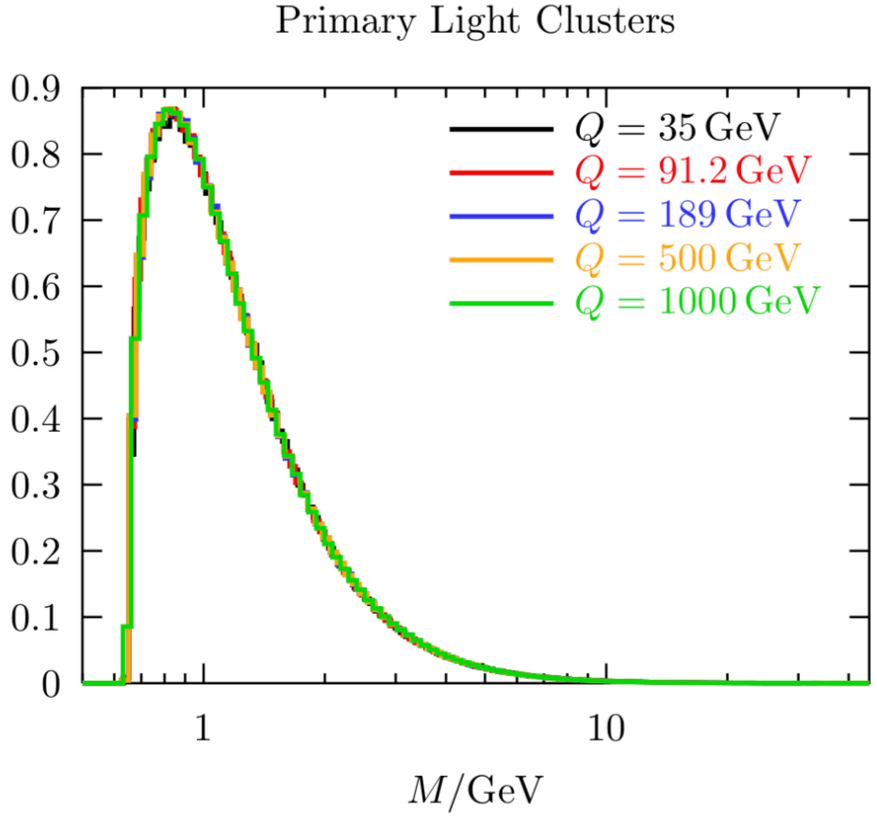
[Amati, Veneziano - Phys.Lett. 83B (1979) 87-92]

- Highly primordial, **excited colour singlet** q-qbar pair

[t'Hooft - Nuclear Physics B 72(3):461-473]

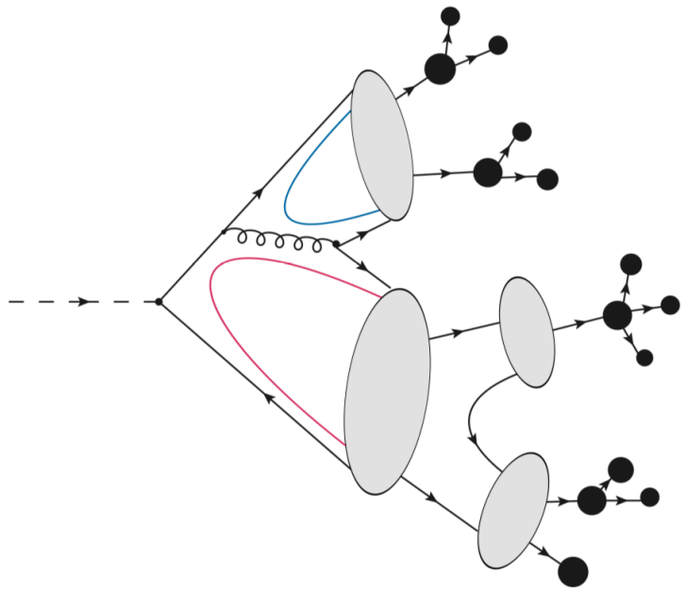
- Universal invariant mass distribution
- Properties of cluster determined by its **invariant mass**

$$M_{i\bar{i}}^2 = (p_i + p_{\bar{i}})^2$$



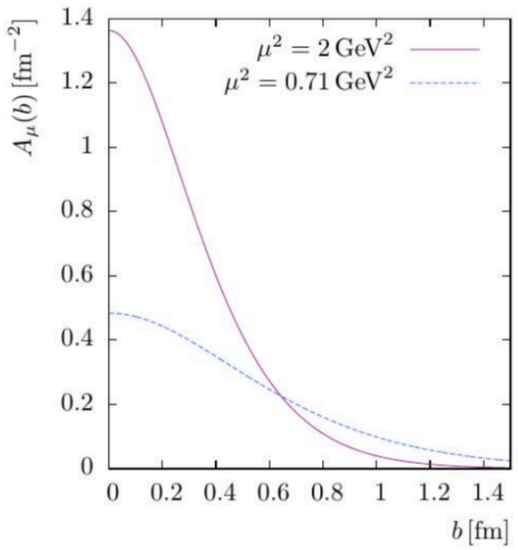
Independent of collision energy

If too heavy it fissions



The MPI model - basics

Matter distribution

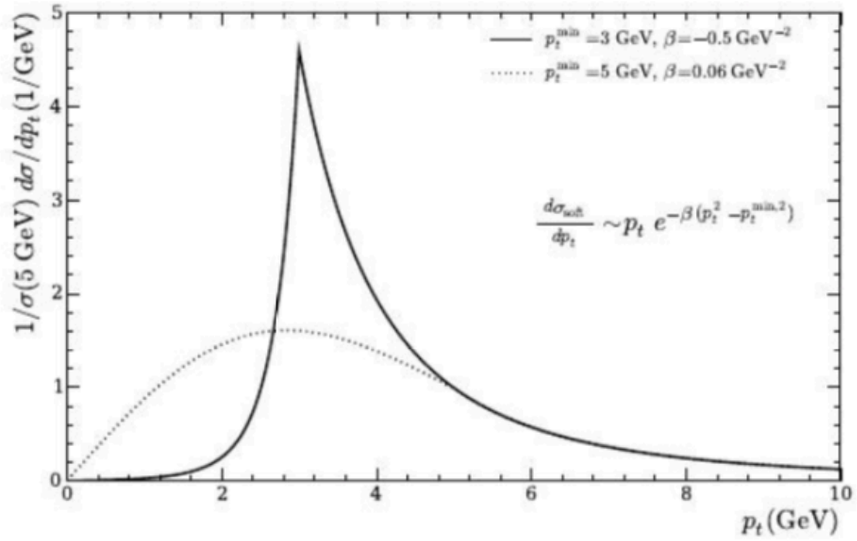


- Based on the Eikonal model
- Parameters fixed to describe σ_{tot}

$$\mathcal{P}_{h,s} = \frac{2\chi_{\mathrm{hard}}(b,s)^h}{h!}\frac{2\chi_{\mathrm{soft}}(b,s)^n}{n!}e^{-2\chi_{\mathrm{tot}}(b,s)}$$

$$\chi_{\mathrm{tot}}(b,s) = \frac{1}{2}(A(b,\mu)\sigma_{\mathrm{hard}}(s,p_\perp^{\mathrm{min}}) + A(b,\mu_{\mathrm{soft}})\sigma_{\mathrm{soft}})$$

Extension to soft region



- Interactions above $p_\perp^{\mathrm{min}}$ simulated as QCD 2 to 2 processes (semi-hard interactions)
- Interactions below $p_\perp^{\mathrm{min}}$ simulated as soft gluon ladders with *multiperipheral* kinematics (soft interactions)

Different matter distribution for soft interactions

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

Main parameters

- set /Herwig/UnderlyingEvent/MPIHandler:pTmin0 3.5
- set /Herwig/UnderlyingEvent/MPIHandler:InvRadius 1.4
- set /Herwig/UnderlyingEvent/MPIHandler:Power 0.4
- set /Herwig/Hadronization/ColourReconnector:ReconnectionProbability 0.5

MPI - soft interactions

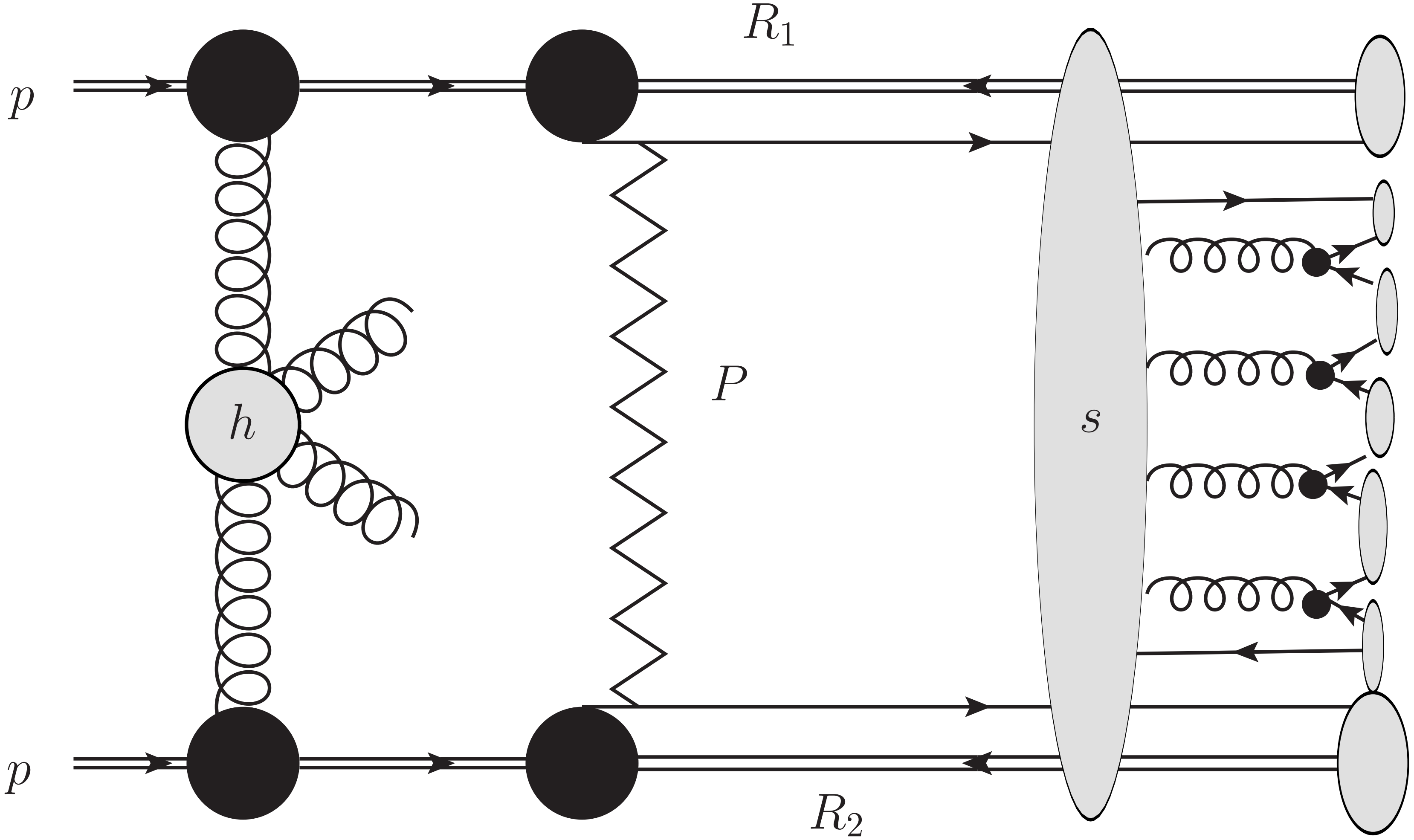
New model for soft interactions

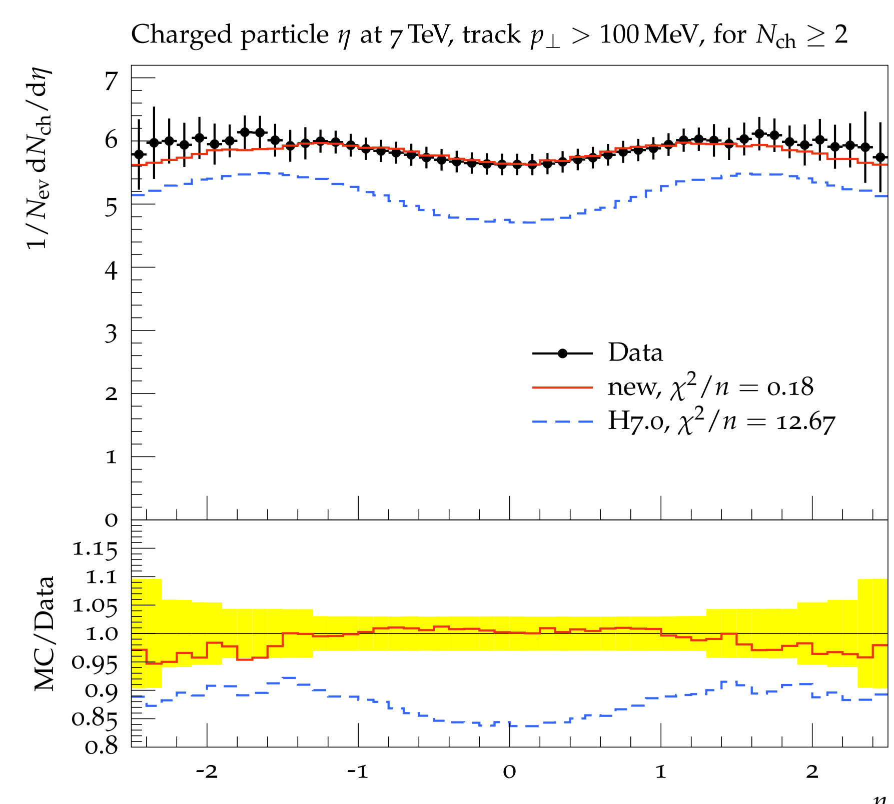
[Gieseke, Loshaj, Kirchgaesser – EPJ C77 (2017) 156]

- Multiperipheral gluon ladder
- Gluons treated non-perturbatively
- Paramaters of the model parametrized to describe 0.9, 7 and 13 TeV MB data

$$\langle N \rangle \approx N_{\text{ladder}} \times \ln \frac{s}{m^2}$$

$$N_{\text{ladder}} = N_0 \left(\frac{s}{\text{TeV}^2} \right)^{-0.08}$$





Radiates in inter jet region but pT cut > 4 GeV gets rid of soft mpi contributions

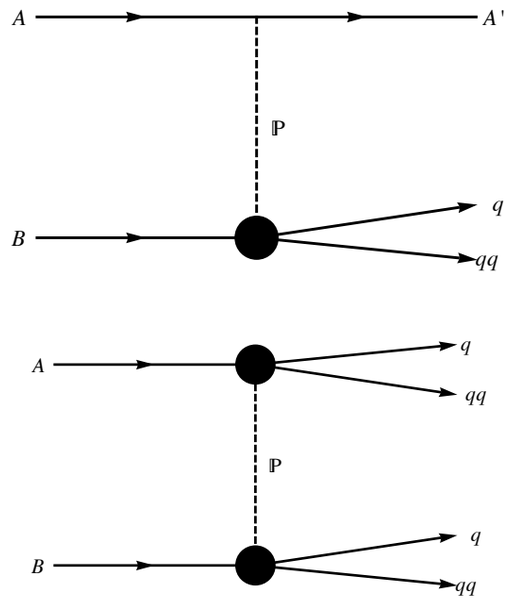
[ATLAS [New J.Phys. ... ,2011]

Diffraction

[Gieseke, Loshaj, Kirchgaesser – EPJ C77 (2017) 156]

Inclusion of diffractive topologies

- Single and double diffraction
- Final state treated fully non-perturbatively
- Small pT but tail towards high diffractive masses
- Characterized through large rapidity gaps



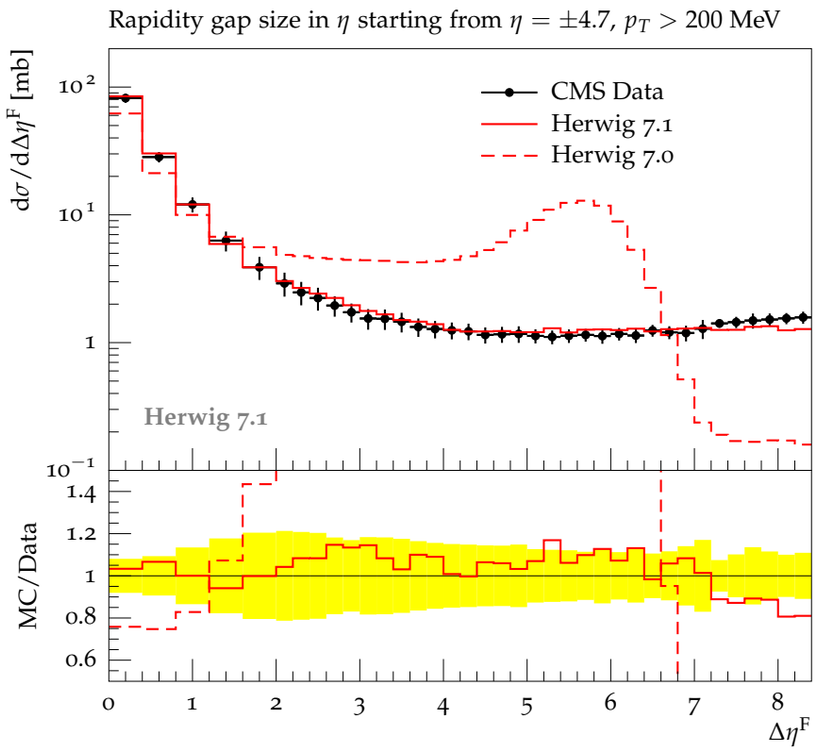
Combination with UE model

- Either diffractive or MPI event
- Cross sections tuned to data
- Rapidity gap survival similar to CJV?

```
# Needed to get the correct fraction of diffractive events
set /Herwig/MatrixElements/MEMinBias:csNorm 4.5584

 # Set weight for Diffraction
 set MEDiffractionLeft:DiffractionAmplitude 12
 set MEDiffractionRight:DiffractionAmplitude 12
 set MEDiffractionDouble:DiffractionAmplitude 8

 set MEDiffractionDeltaLeft:DiffractionAmplitude 4
 set MEDiffractionDeltaRight:DiffractionAmplitude 4
 set MEDiffractionDeltaDouble:DiffractionAmplitude 2
```



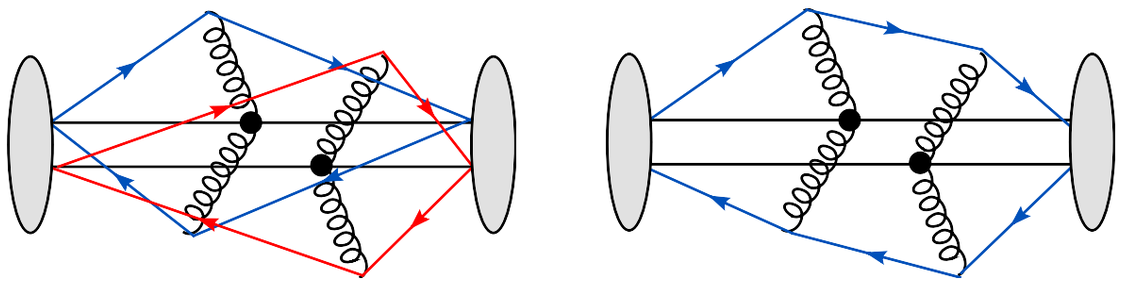
CMS [Phys.Rev. D92 (2015) no.1, 012003]

Colour Reconnection - basics

[S.Gieseke, C.Röhr, A.Siodmok, Eur.Phys.J. C72 (2012) 2225]
[S. Gieseke, PK, S. Plätzer – EPJ C78 (2018) 99]

Algorithms

- **Plain** Colour Reconnection
- **Statistical** Colour Reconnection
- **Baryonic** Colour Reconnection



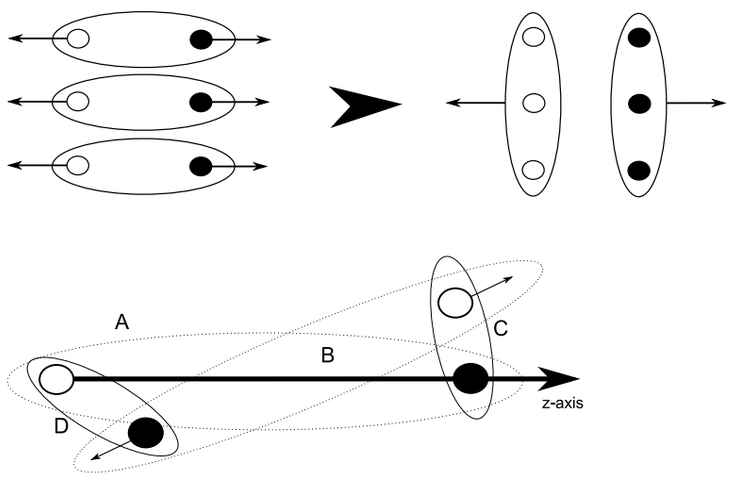
Plain and Stat CR based on reduction of invariant cluster mass

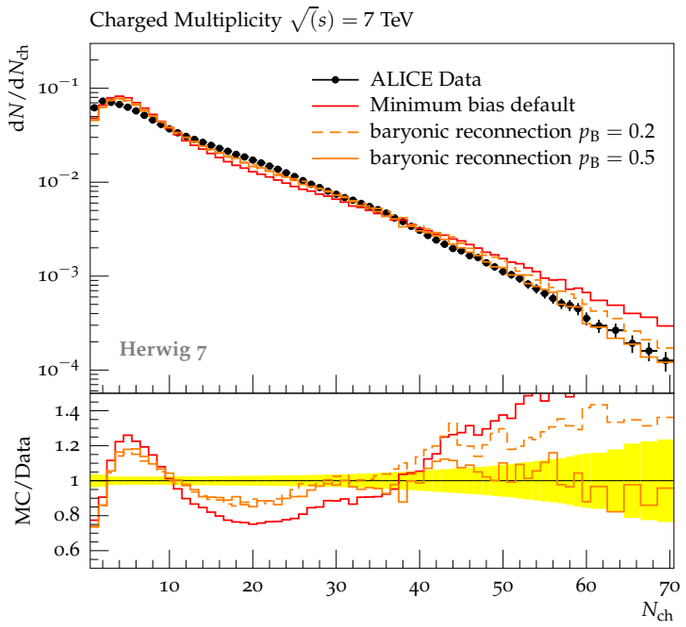
$$\lambda = \sum_{i=1}^{N_{\mathrm{cl}}} M_i^2$$

Important for the description of MB and UE data

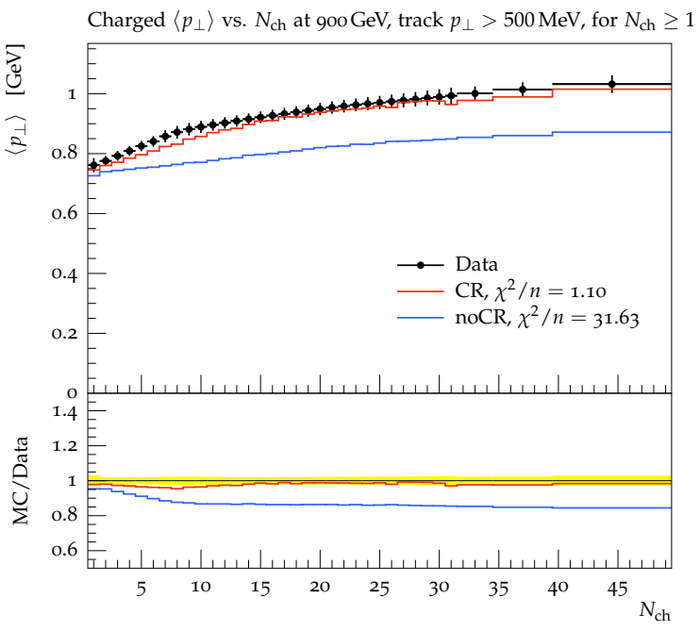
Baryonic CR

- Allow baryonic cluster during CR
- Geometrical model





[Eur.Phys.J. C68 (2010) 345-354]



[New J.Phys.13:053033,2011]

Can CR ‚destory' one jet? 3->2? / Activity in inter jet region? (Code wise)