Soft interactions in Herwig

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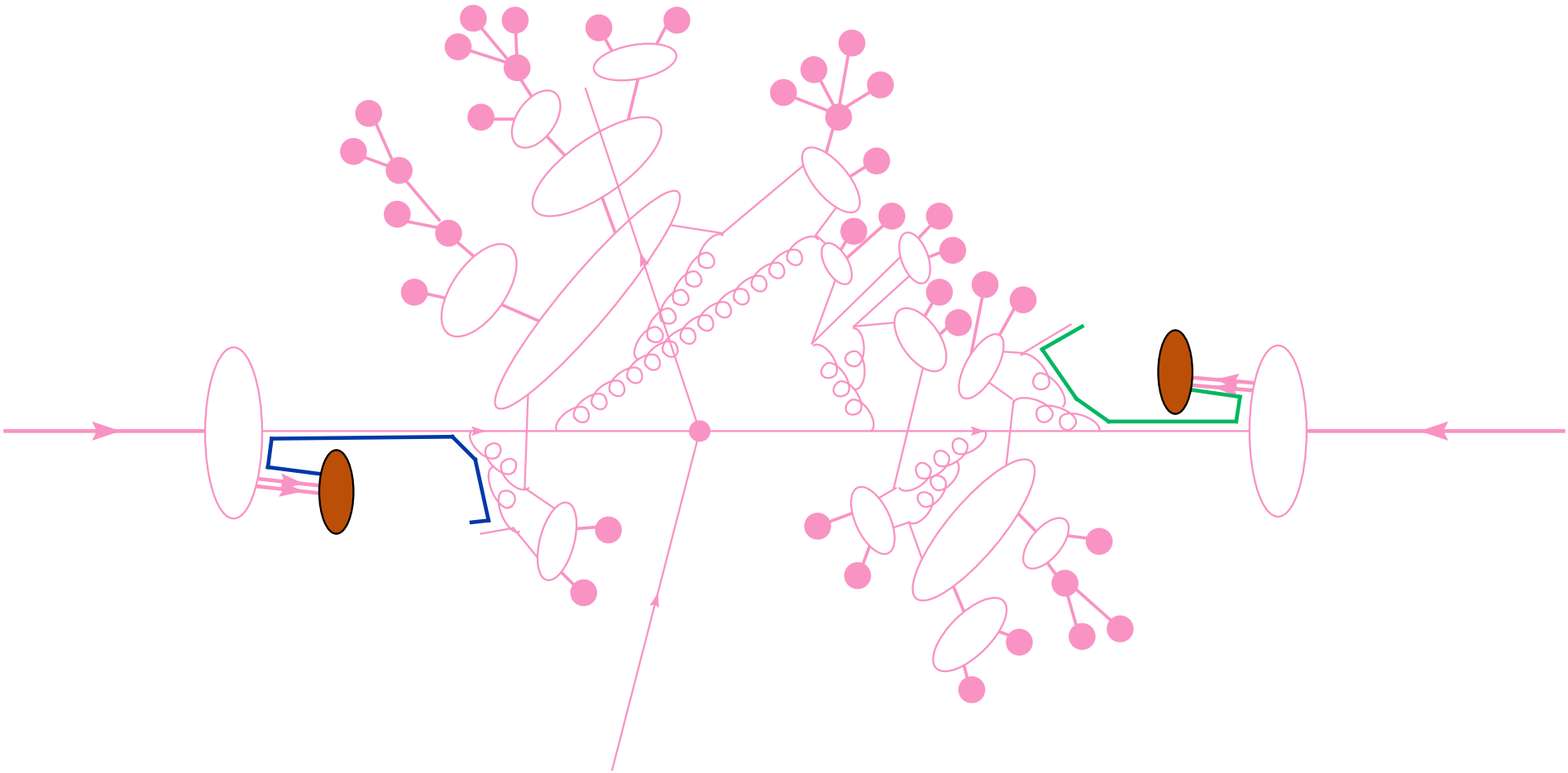
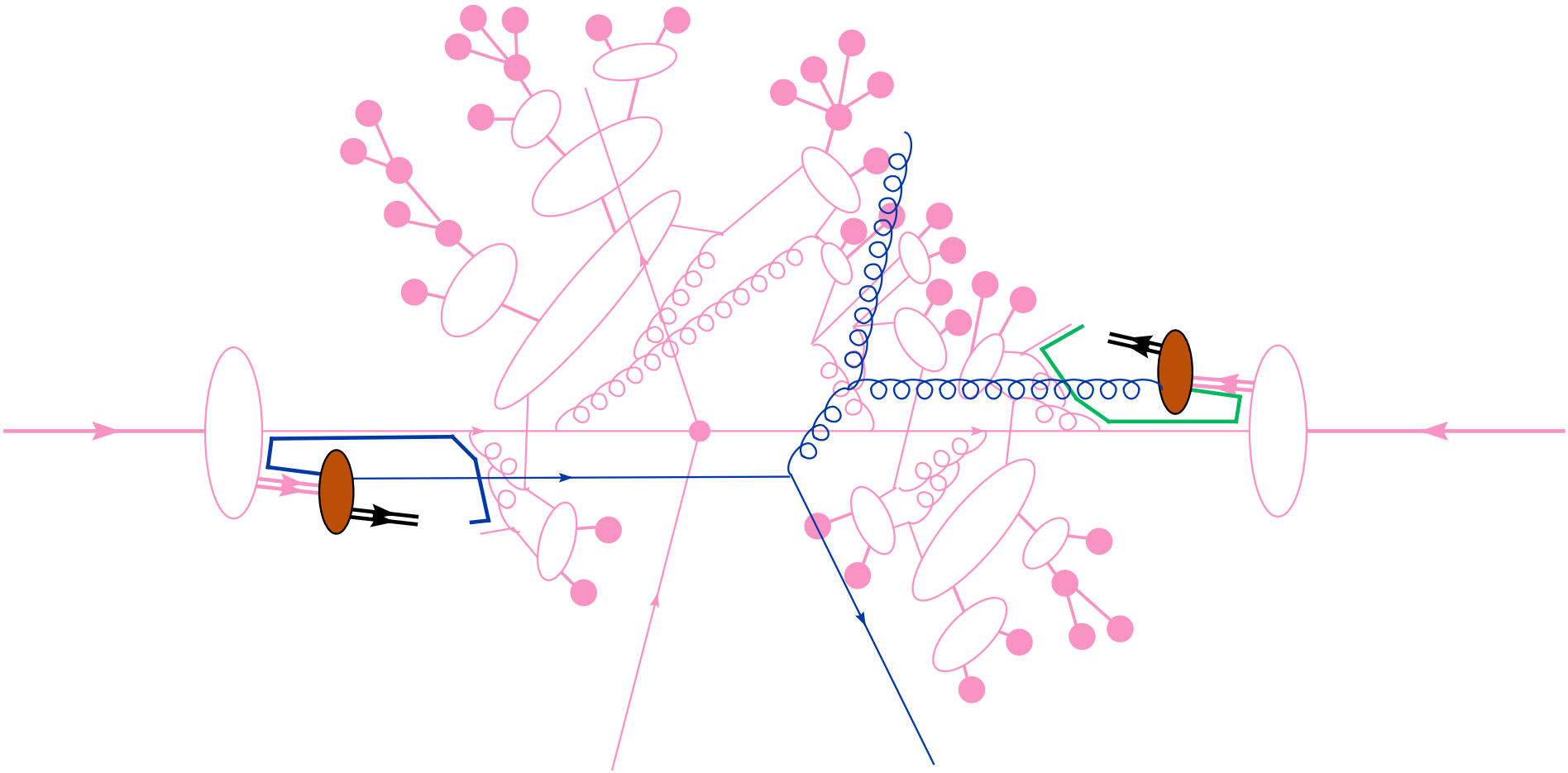
pp Event Generator



pp Event Generator



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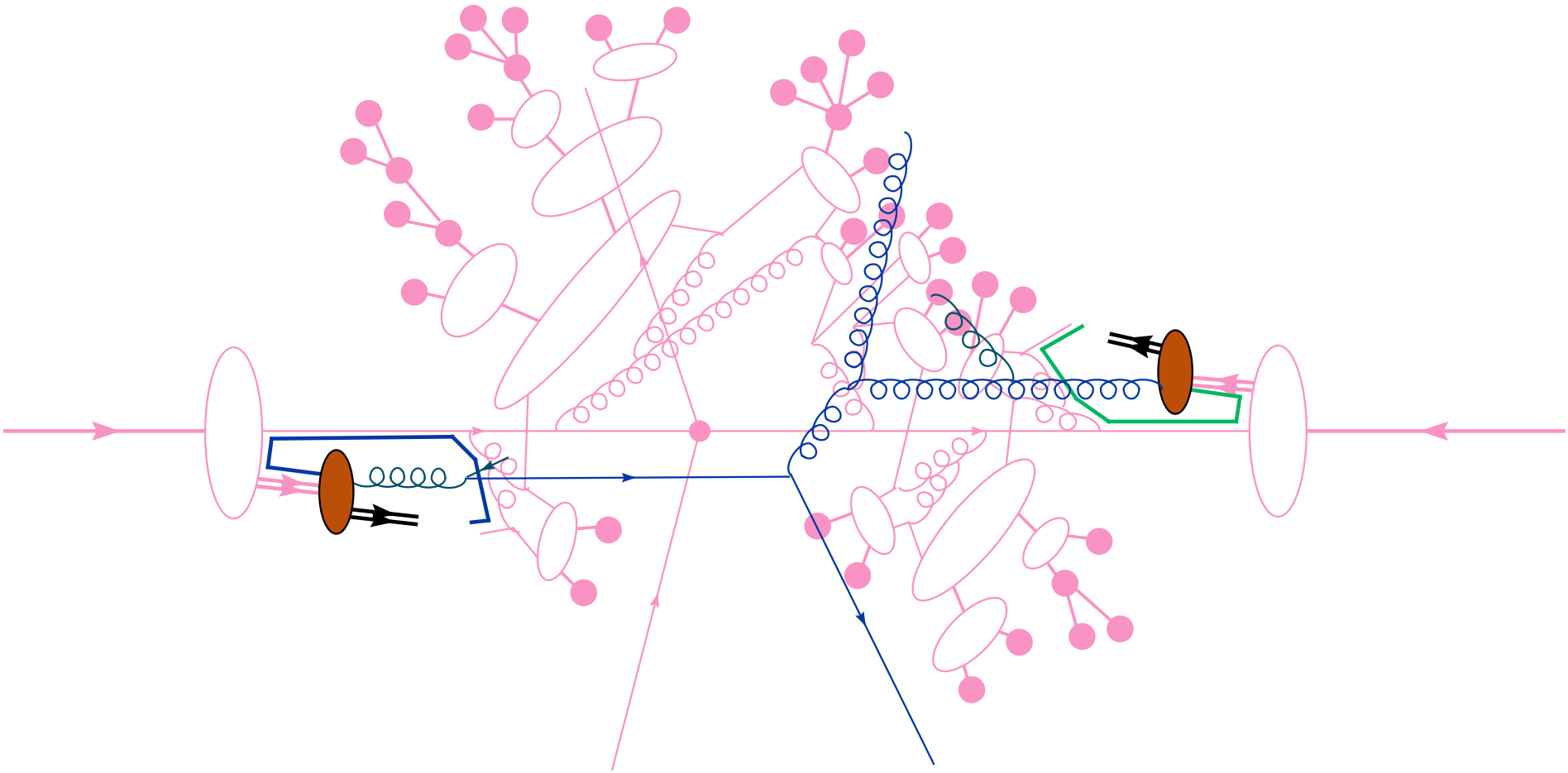

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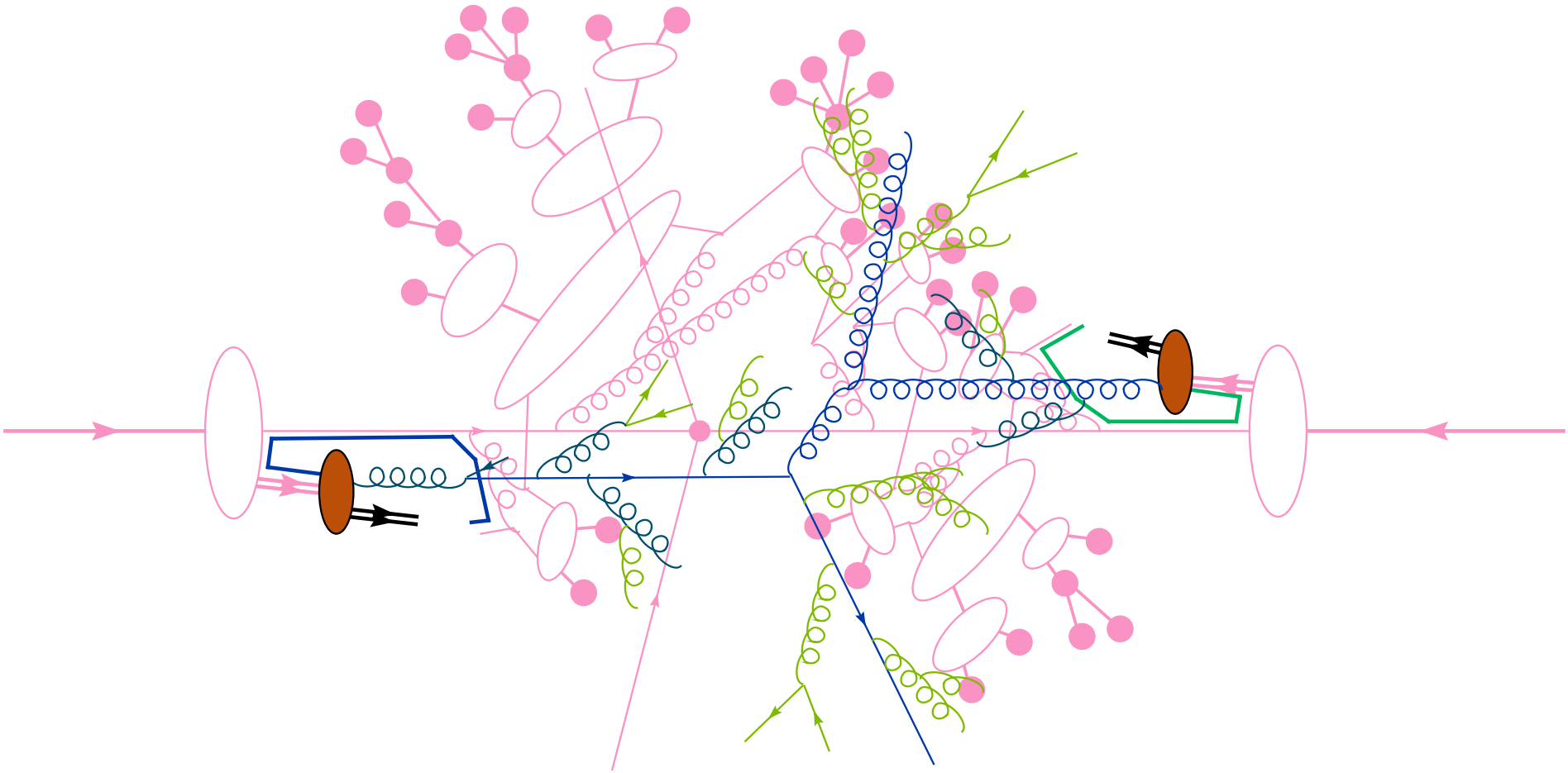

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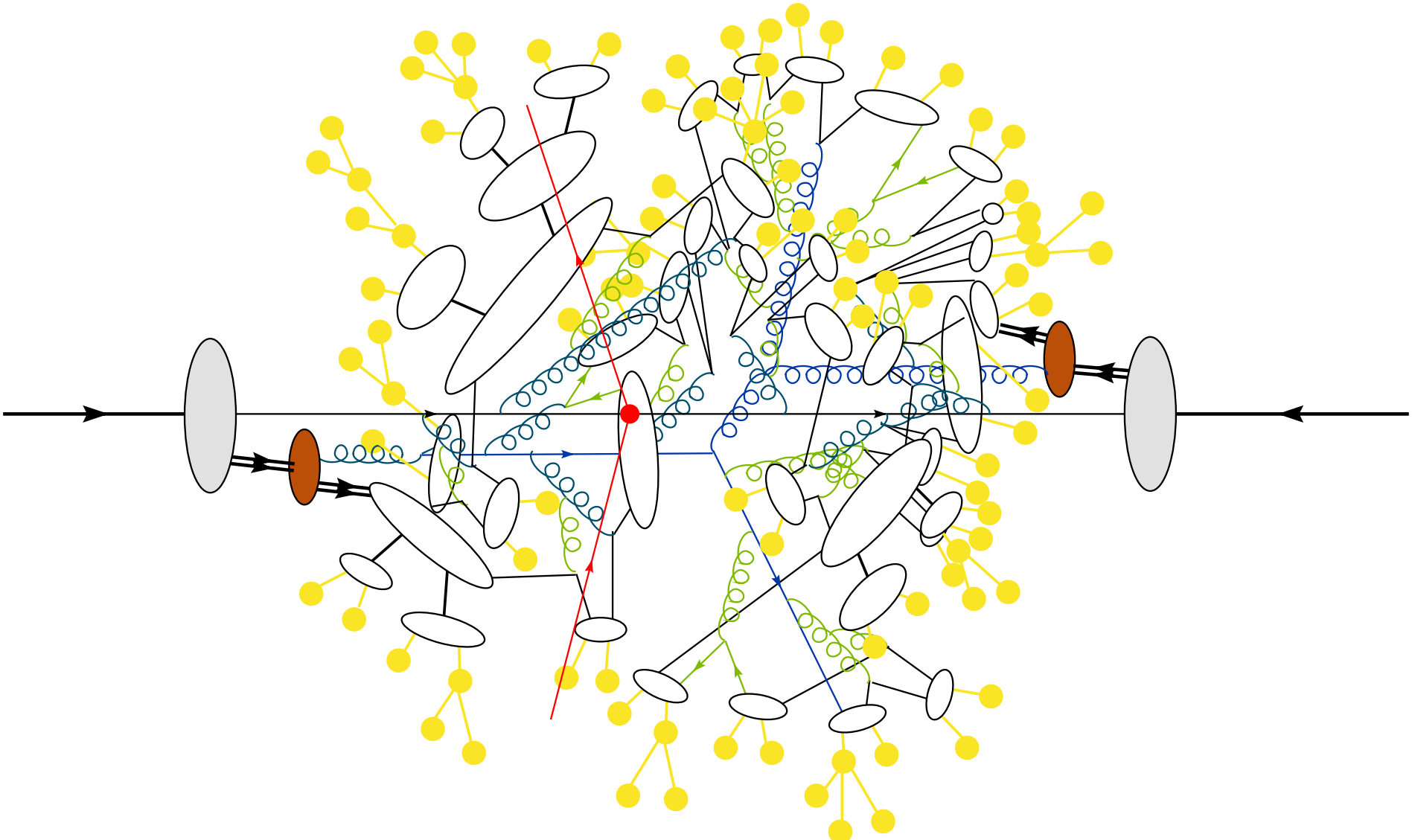

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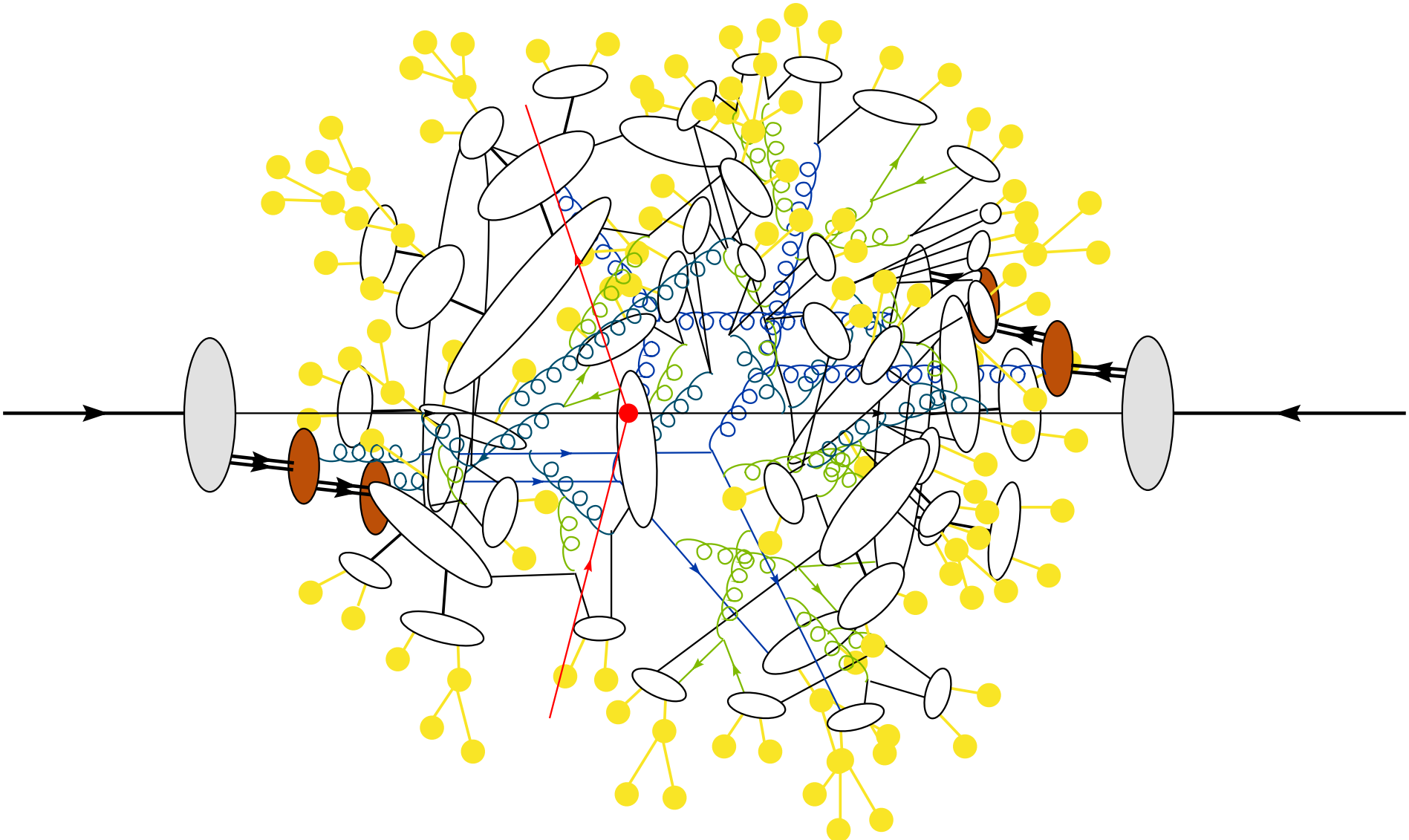


Underlying event in Herwig++

Semihard UE

- Default from Herwig++ 2.1. [Herwig++, 0711.3137]
- Multiple hard interactions, $p_t \geq p_t^{\min}$. [Bähr, SG, Seymour, JHEP 0807:076]
- pQCD $2 \to 2$.
- Similar to `JIMMY`.
- Good description of harder UE data ("plateau").

Underlying event in Herwig++

Soft UE

- Default from Herwig++ 2.3. [Herwig++, 0812.0529]
- Extension to soft interactions $p_t < p_t^{\min}$.
- Theoretical work with simplest possible extension.

  [Bähr, Butterworth, Seymour, JHEP 0901:065]

- "Hot Spot" model. [Bähr, Butterworth, SG, Seymour, 0905.4671]

Hot Spot model

Fix the two parameters μ_{soft} and $\sigma_{\text{soft}}^{\text{inc}}$ in

$$\chi_{\text{tot}}(\vec{b},s) = \frac{1}{2}\left(A(\vec{b};\mu)\sigma_{\text{hard}}^{\text{inc}}(s;p_t^{\text{min}}) + A(\vec{b};\mu_{\text{soft}})\sigma_{\text{soft}}^{\text{inc}}\right)$$

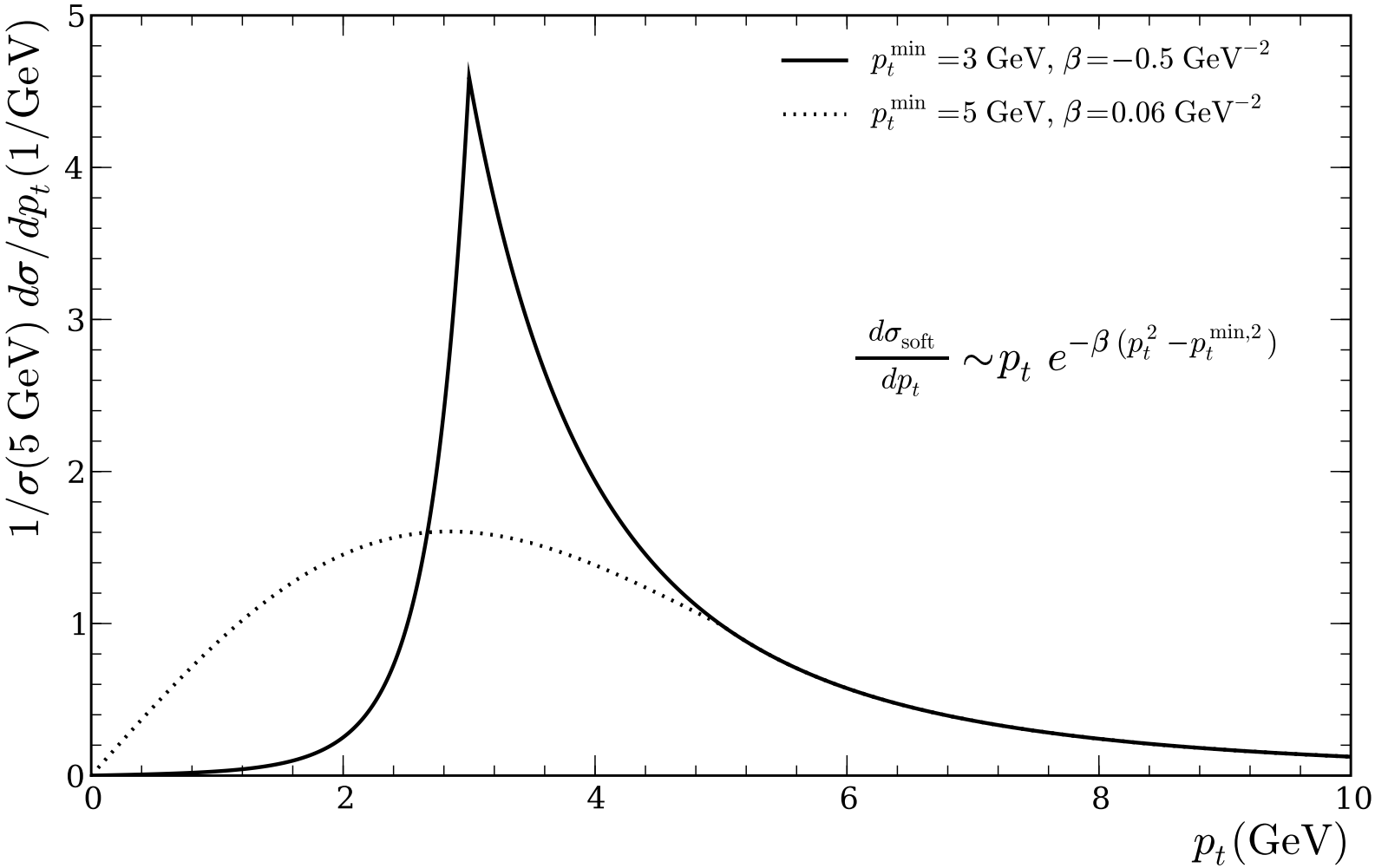
from two constraints. Require simultaneous description of σ_{tot} and b_{el} (measured/well predicted),

$$\sigma_{\text{tot}}(s) \stackrel{!}{=} 2\int \mathrm{d}^2\vec{b}\left(1-\mathrm{e}^{-\chi_{\text{tot}}(\vec{b},s)}\right) ,$$

$$b_{\text{el}}(s) \stackrel{!}{=} \int \mathrm{d}^2\vec{b}\frac{b^2}{\sigma_{\text{tot}}}\left(1-\mathrm{e}^{-\chi_{\text{tot}}(\vec{b},s)}\right) .$$

Extending into the soft region

Continuation of the differential cross section into the soft region $p_t < p_t^{\min}$ (here: p_t integral kept fixed)



Implementation of soft scattering

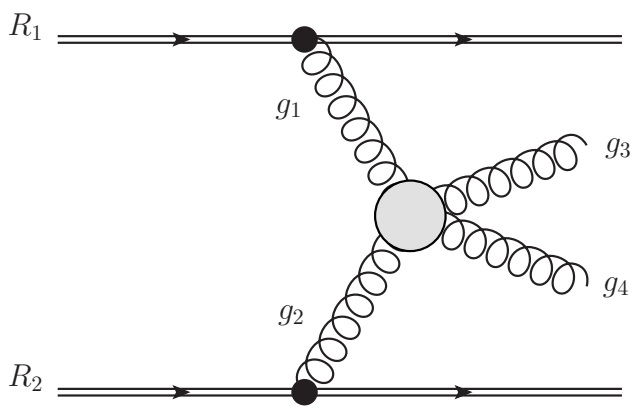
Soft gluon production with soft $p_t < p_t^{\min}$ spectrum.

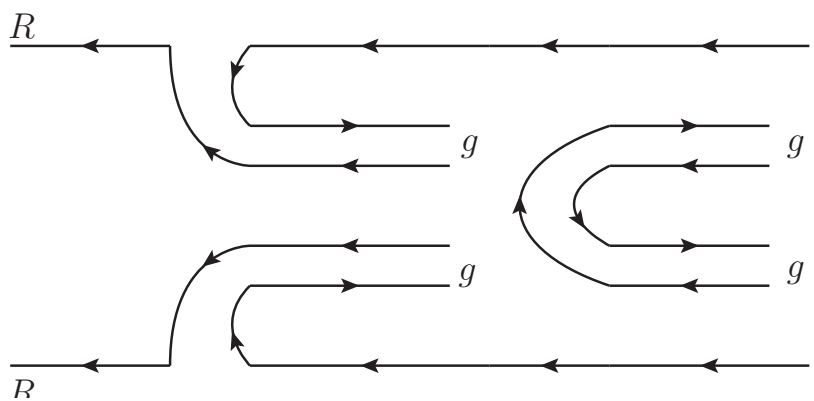
Colour structure important. Two extreme cases possible.

Sensitivity to parameter

$$\texttt{colourDisrupt} = P(\text{disrupt colour lines})$$

Long colour lines appear when swapping outgoing gluons.



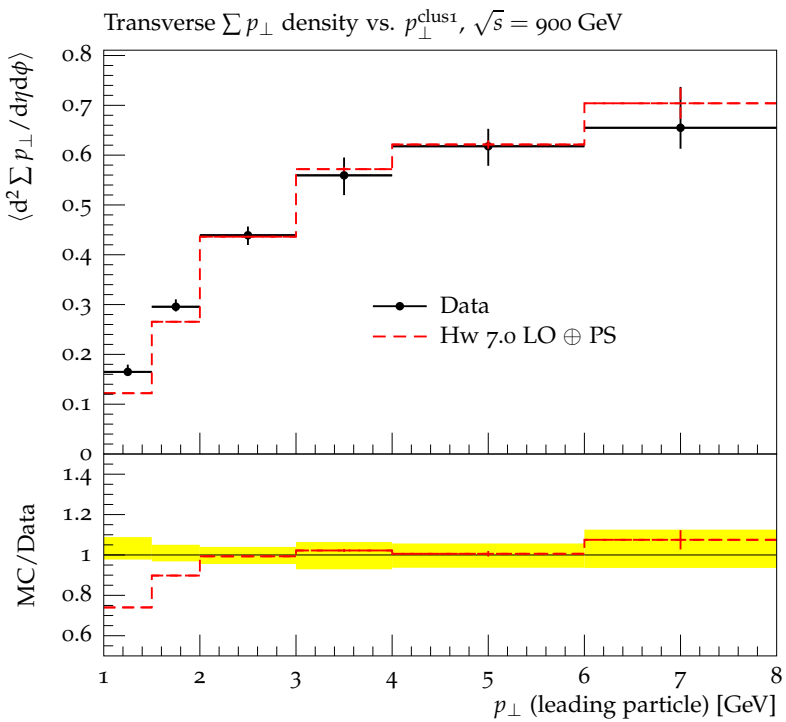


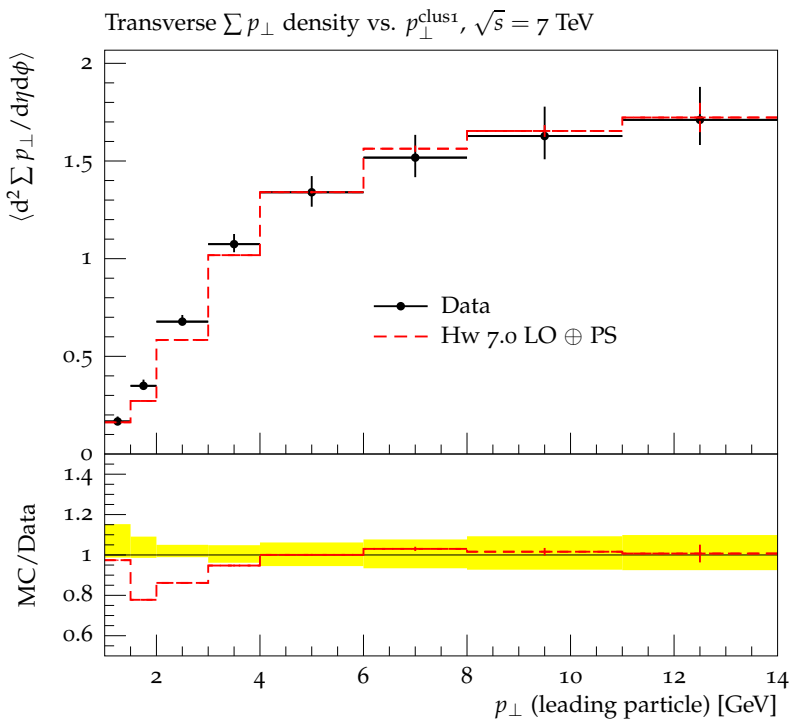
Colour reconnections applied!

So far at the LHC

Soft model is extension of MPI model for Underlying Event and *harder* aspects of Min Bias events.
Herwig 7.0 at 900 GeV and 7 TeV:

[ATLAS, Eur.Phys.J. C71 (2011) 1636]





Still reasonably well for moderately soft particles.

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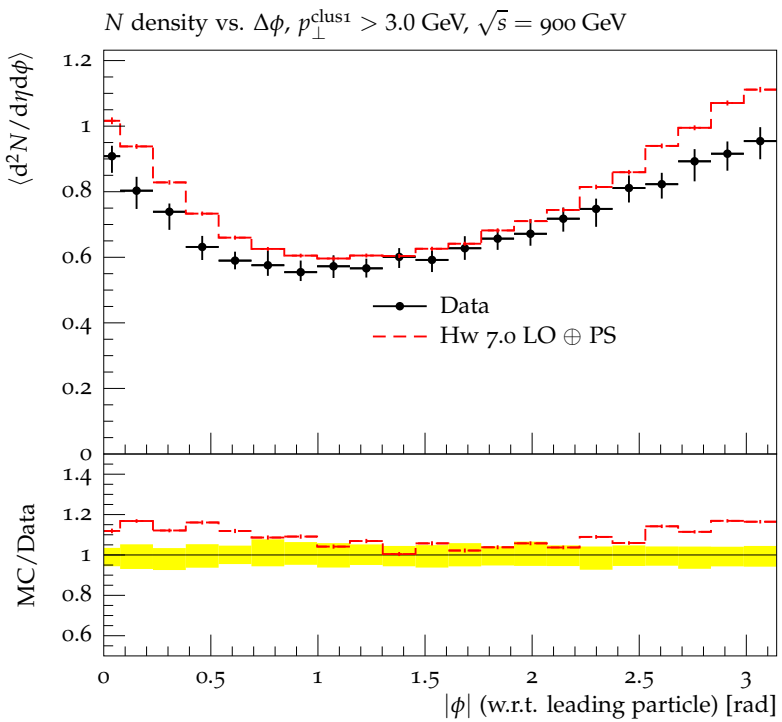
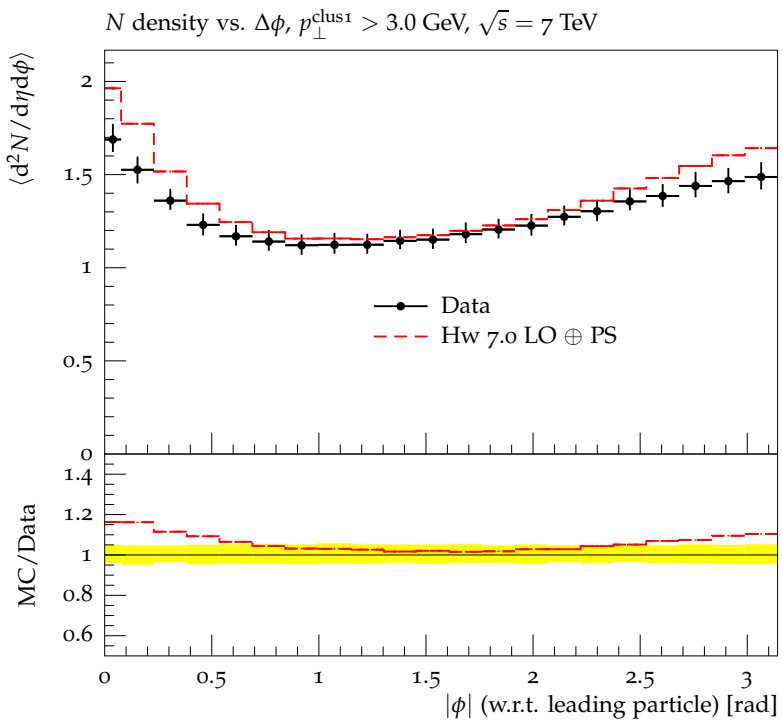


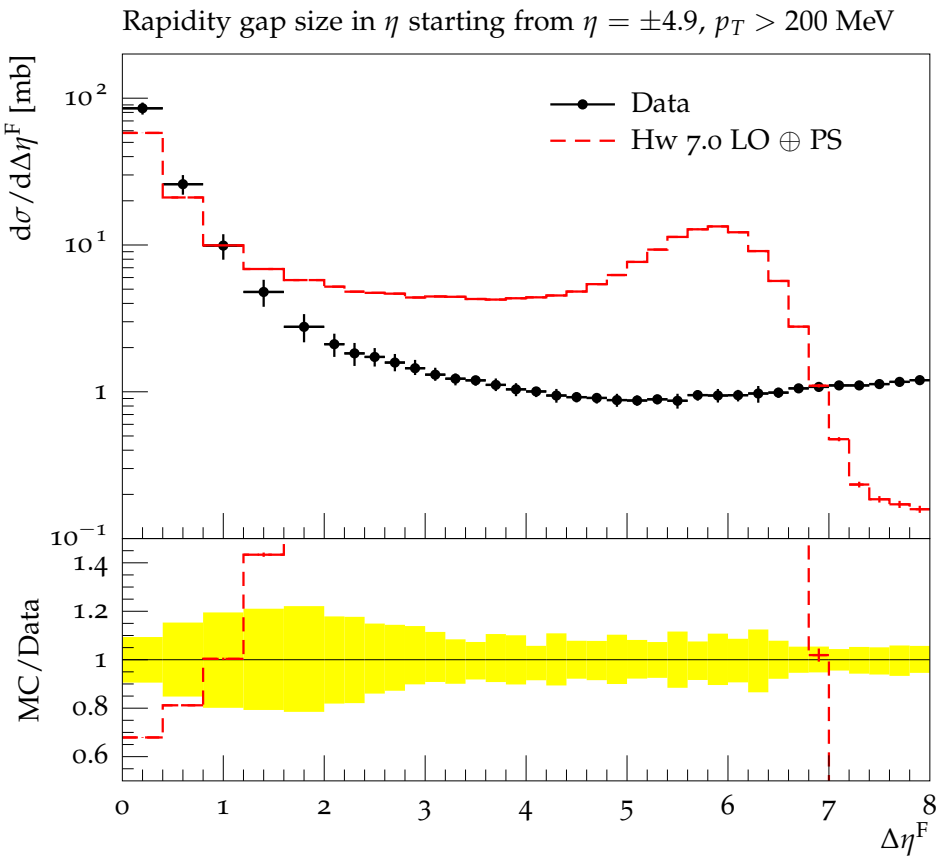


Still reasonably well for moderately soft particles.

The bump

A clear case of abusing a model for the hard UE in forward/diffractive final states…

[ATLAS, Eur.Phys.J. C72 (2012) 1926]



Bump is artefact. No Diffraction. Poor modeling of soft interactions. Colour assignment ad hoc.

Outline

Challenge accepted.

- Model for diffractive final states.
- Model for soft particle production.
- Results.

Diffraction as part of minimum bias simulation

Diffractive final states directly modeled.

Not embedded in MPI approach via cuts through triple pomeron vertices. Therefore change in constraint

$$x\sigma_{\text{tot}}(s) \stackrel{!}{=} 2\int \mathrm{d}^2\vec{b}\left(1-\mathrm{e}^{-\chi_{\text{tot}}(\vec{b},s)}\right) \ ,$$

where

$$x \approx 1-\frac{\sigma_{\text{diff}}}{\sigma_{\text{tot}}} \sim 20-25\% \ .$$

In min-bias simulation: every event is either

- diffractive, directly modeled from pp initial state.
- non-diffractive, modeled in the MPI picture, parton level.

Diffractive final states

Strictly low mass diffraction only. Allow M^2 large nonetheless.

M^2 power-like, t exponential (Regge).

$$pp \to \text{(baryonic cluster)} + p \ .$$

Hadronic content from cluster fission/decay $C \to hh \ldots$
Cluster may be quite light. If very light, use directly

$$pp \to \Delta + p \ .$$

Also double diffraction implemented.

$$pp \to (\text{cluster}) + (\text{cluster}) \qquad pp \to \Delta + \Delta \ .$$

Technically: new MEs for diffractive processes set up.

Model for soft particle production in Herwig

Reproduce core properties of soft particle production.

"flat in rapidity", "narrow in p_t".

Main idea: "soft interaction = cut pomeron = particle ladder".

N_{soft} from MPI model = #ladders.

Clusters produced via colour connected quarks and gluons.

Adopt to soft interactions in Herwig via remnant decays.

Multiperipheral kinematics

[Baker, Ter-Martirosyan 1976]

Average relative momentum fraction $\langle x \rangle$. Leads to flat rapidity distribution of emissions in a single ladder.

$$\Delta y \sim \ln \frac{1}{x} \, .$$

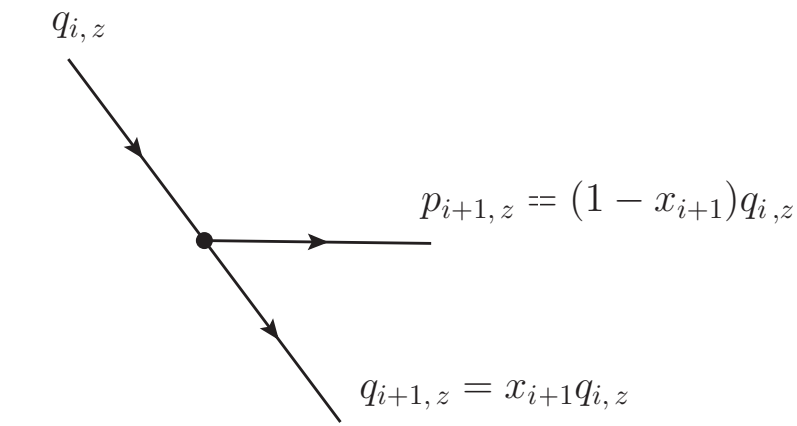
Choose some constant C, then

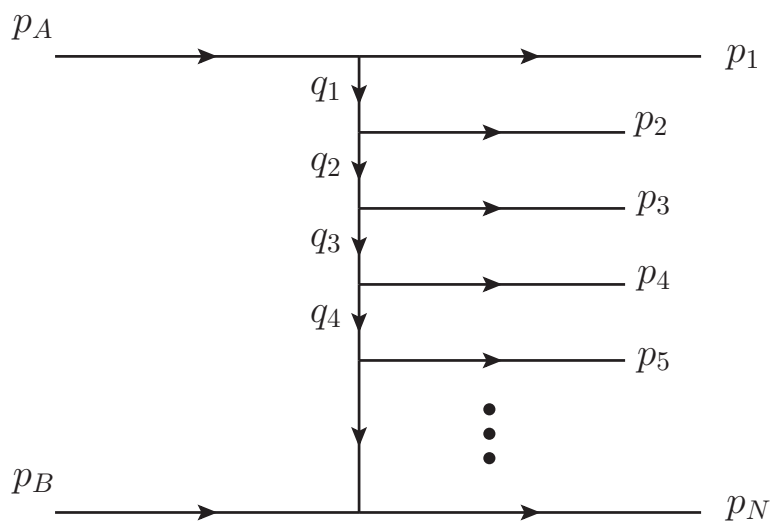
$$\langle x \rangle \sim 1/C \, .$$

$\langle N \rangle$ average number of emitted particles.

$$\langle N \rangle = \frac{1}{\ln C} \ln \frac{s}{m^2}$$

$p_\perp$ or $m_\perp$ moderate, unordered.



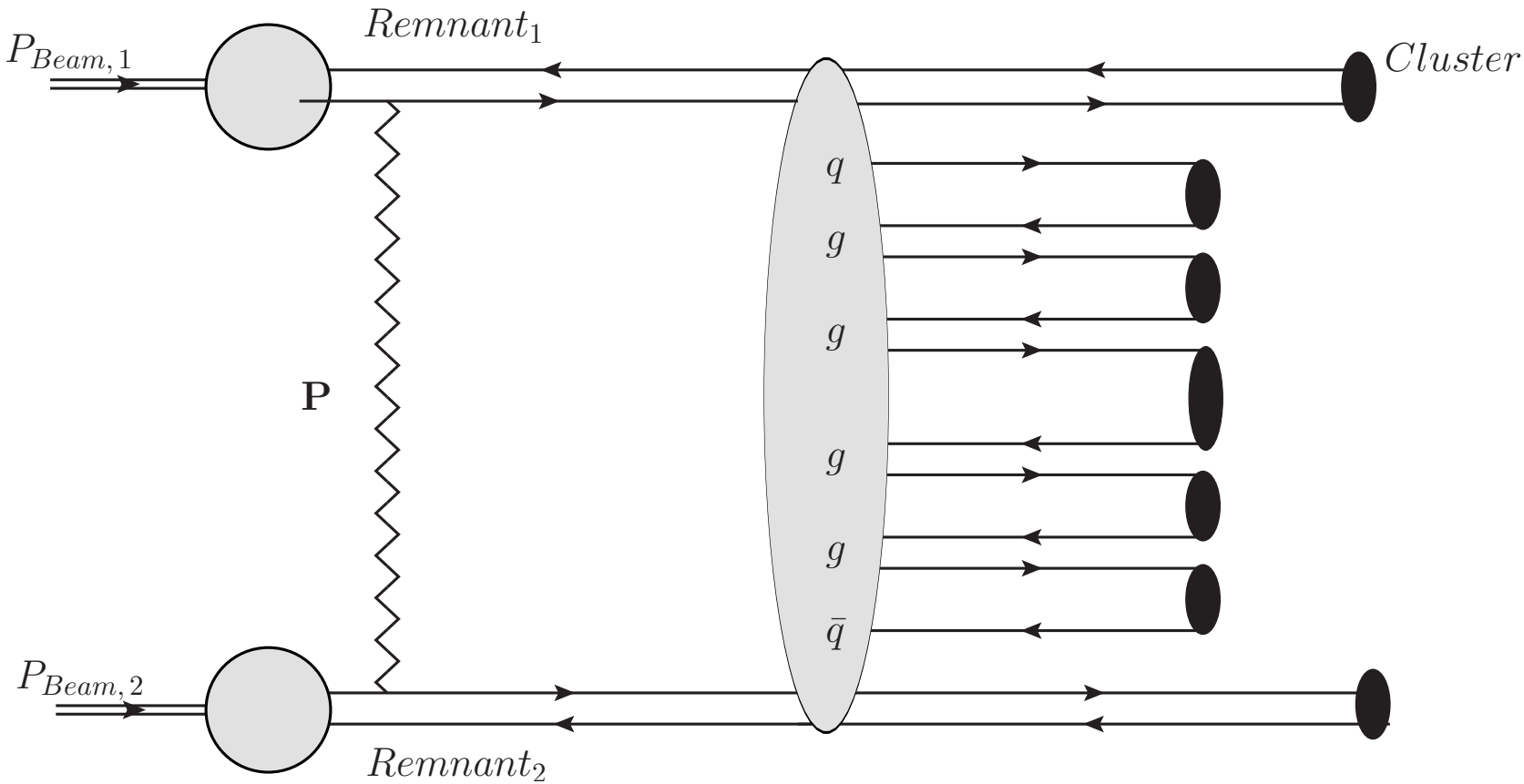


Soft particle production model in Herwig

- #ladders = N_{soft}.
- N particles from Poissonian, width $\langle N \rangle$.
  Model parameter $1/\ln C \equiv n_{\text{ladder}} \rightarrow$ tuned.
- x_i smeared around $\langle x \rangle$ (calculated).
- $p_\perp$ from Gaussian acc to soft MPI model.
- particles are q, g, see figure.
  Symmetrically produced from both remnants.
- Colour connections between neighboured particles.

Soft particle production model in Herwig

Single soft ladder with MinBias initiating process.



Further hard/soft MPI scatters possible.

Parameters and tuning

Diffraction plus MPI incl new soft model.

Diffractive cross sections adjusted to data.

Tuning to Min Bias data: $\eta, p_\perp$ for various N_{ch}, $\langle p_\perp \rangle (N_{\text{ch}})$.

Usual MPI parameters

$$(p_{\perp,0}^{\text{min}}, b) \to p_\perp^{\text{min}}(\sqrt{s}), \quad \mu^2, \quad p_{\text{reco}} \ .$$

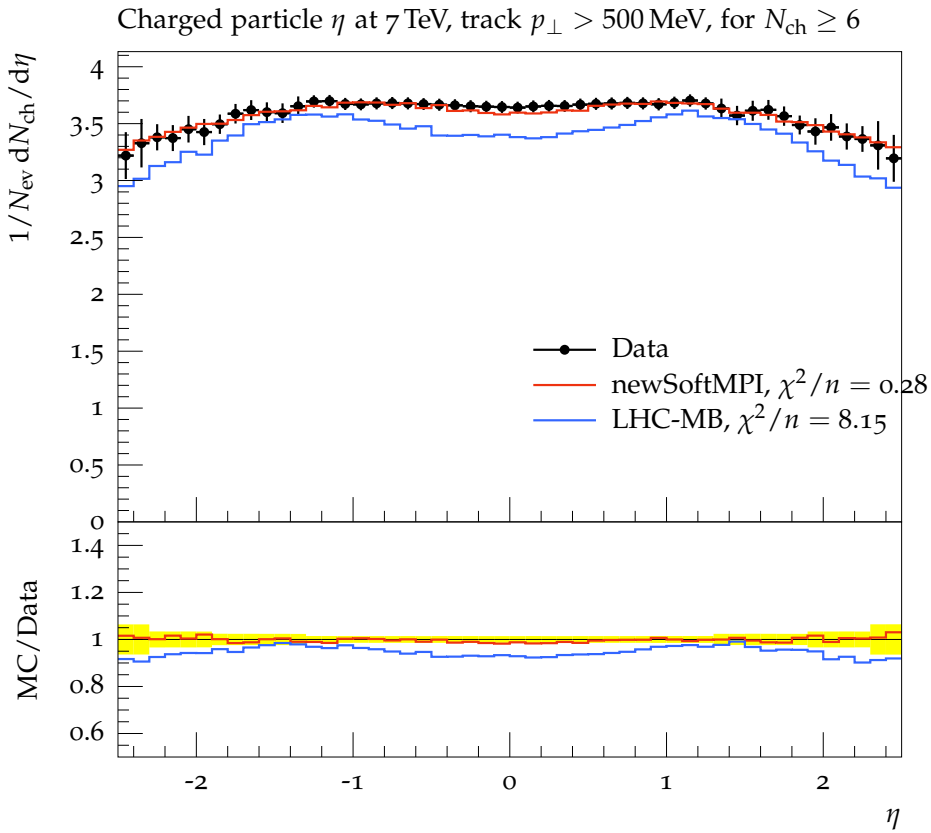
One additional parameter

$$n_{\text{ladder}} \ .$$

Tuned results

ATLAS Min Bias 7 TeV.

[ATLAS, New.J.Phys. 13 (2011) 053033]

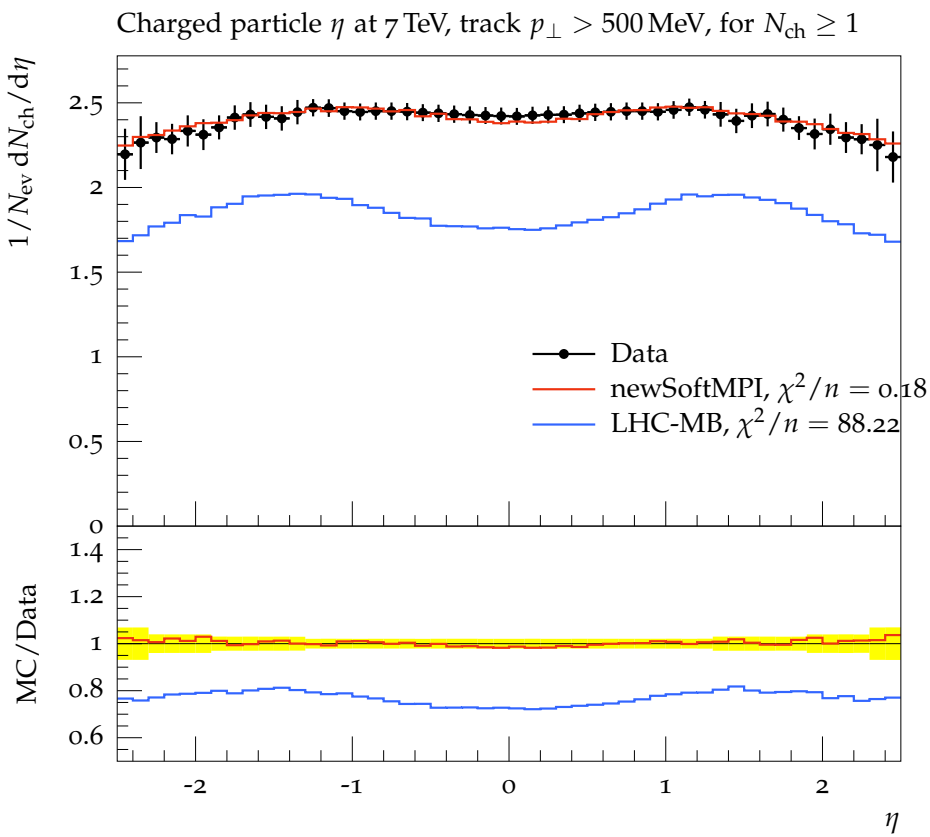


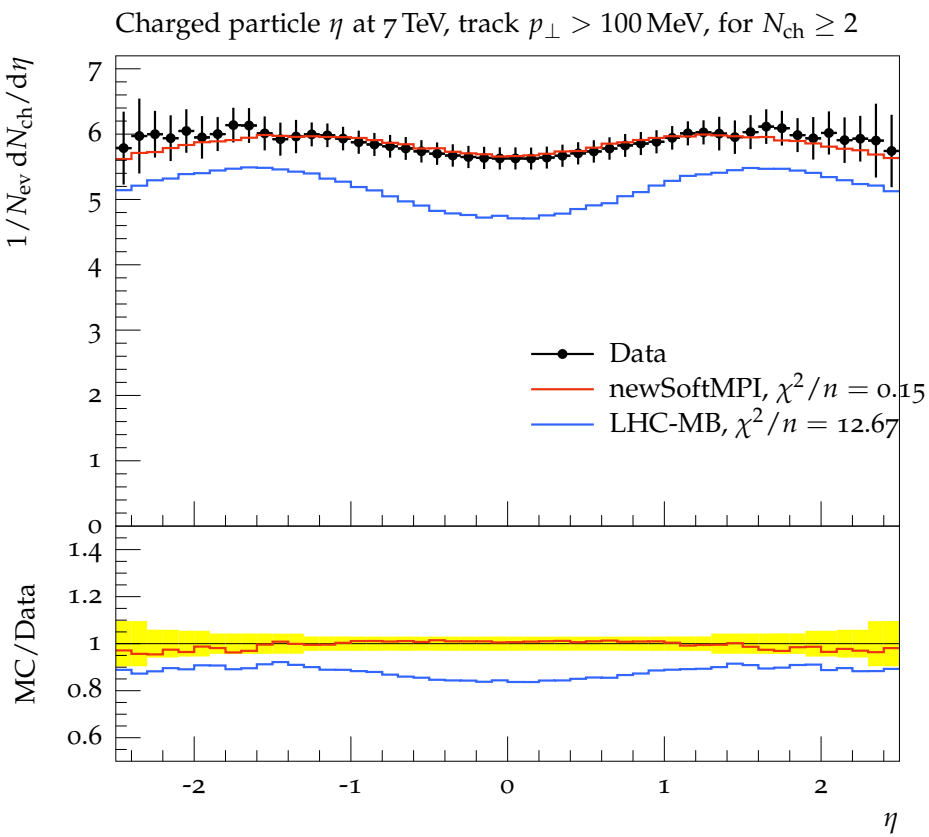
Similar to previous results, "harder part of Min Bias".

Tuned results

ATLAS Min Bias 7 TeV.

[ATLAS, New.J.Phys. 13 (2011) 053033]



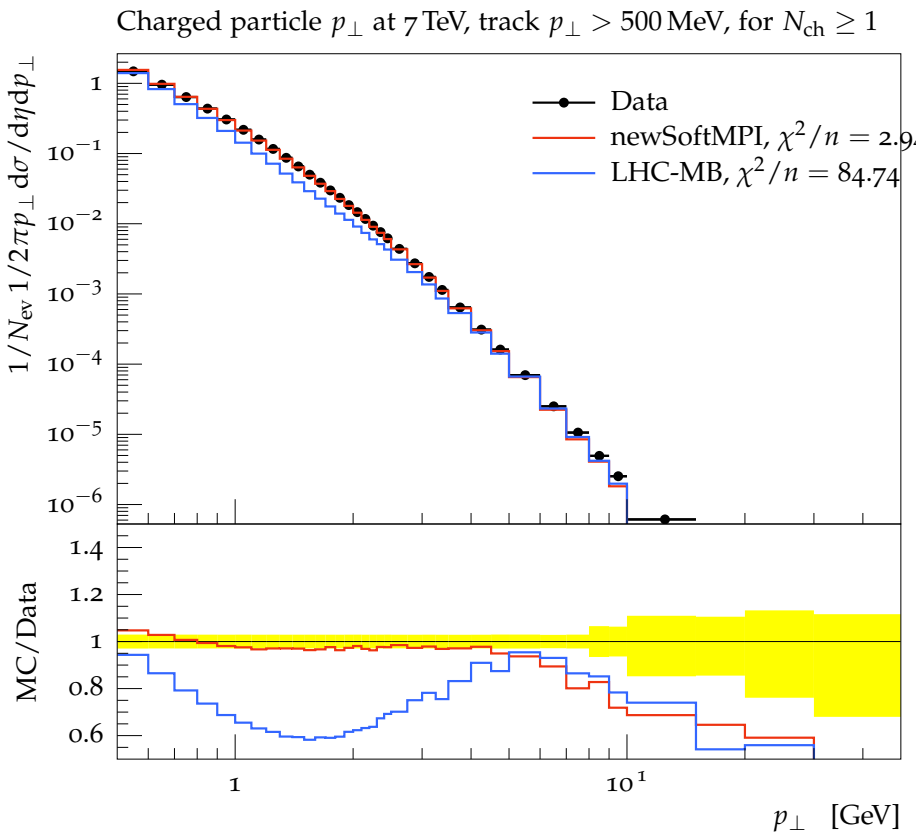


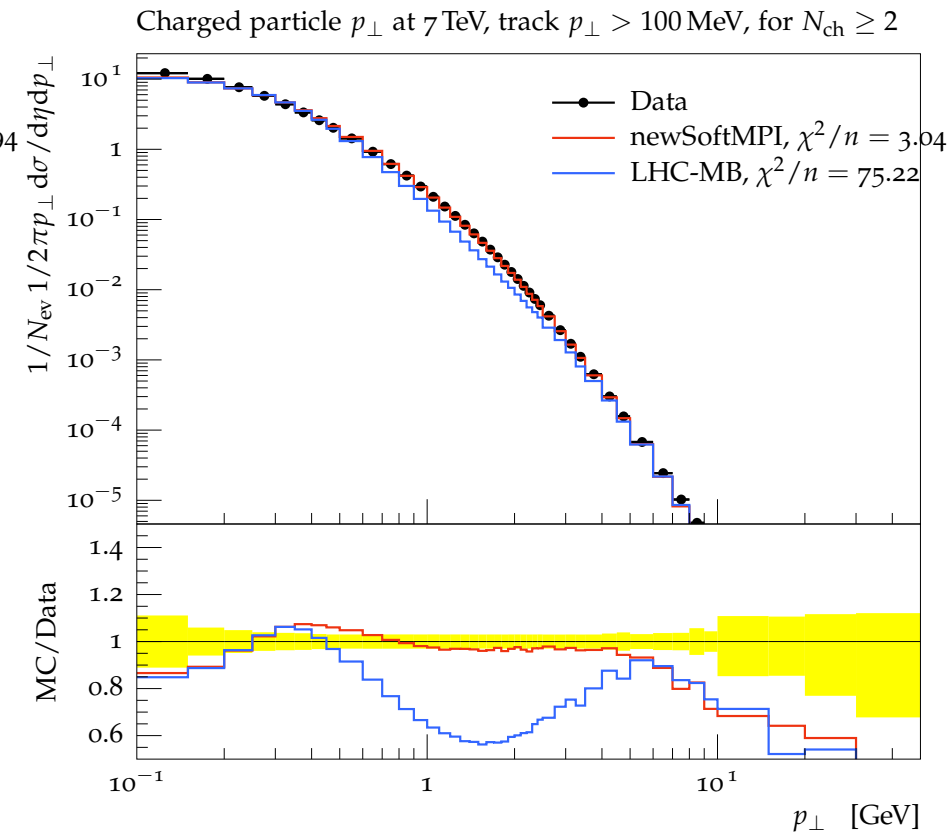
Also soft rates well described.

Tuned results

ATLAS Min Bias 7 TeV.

[ATLAS, New.J.Phys. 13 (2011) 053033]



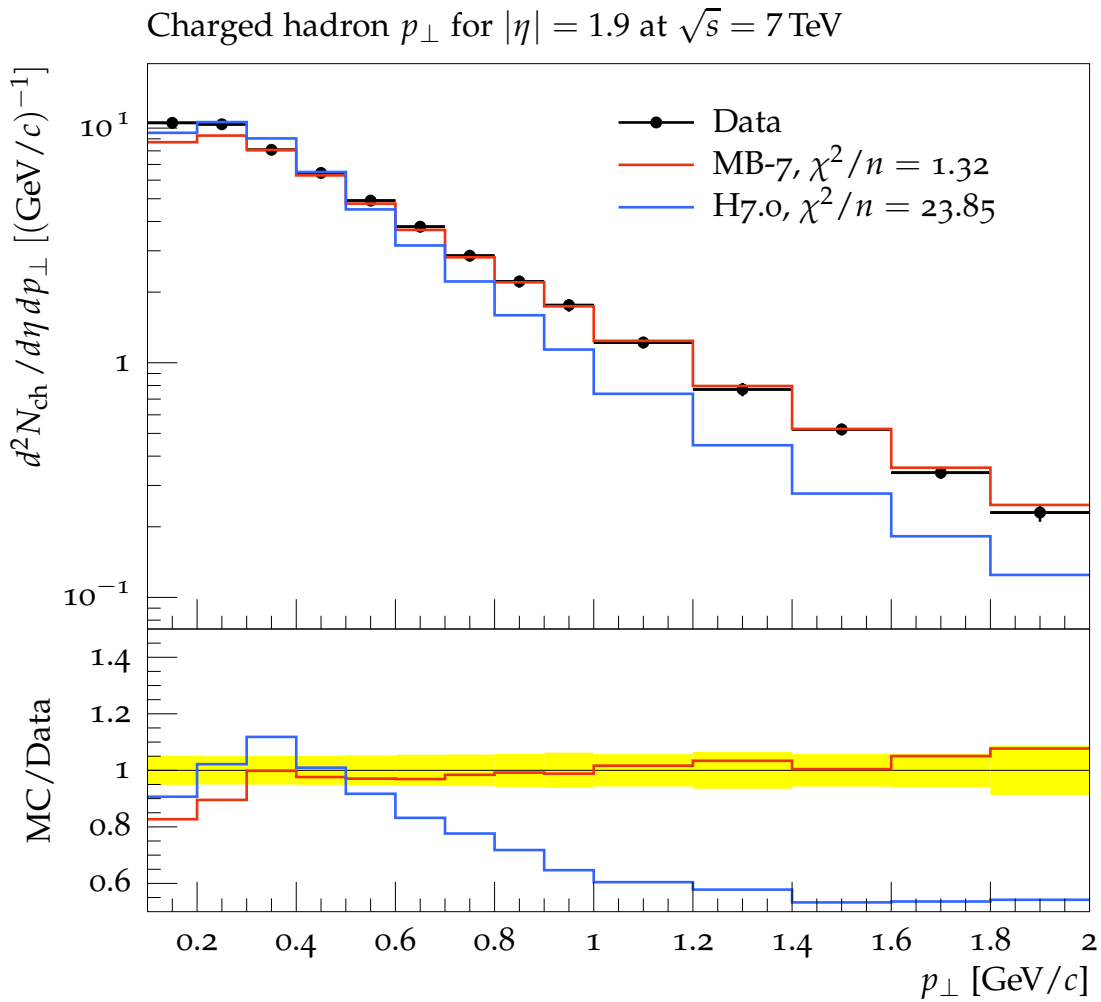


Tails? Still within 1σ.

More results

CMS, NSD analysis 7 TeV

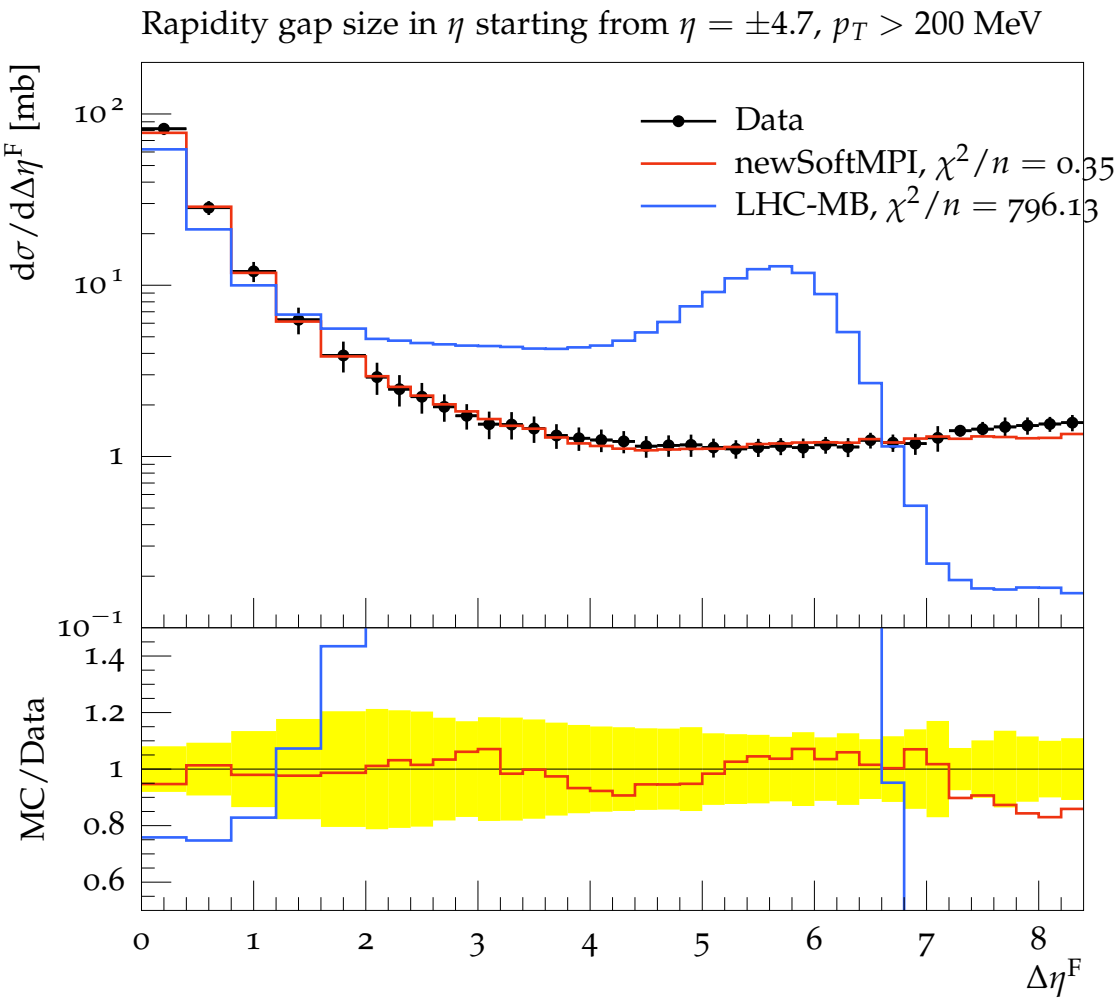
[CMS, PRL 105 (2010) 022002]



Lowest bin → potential to be tunable.

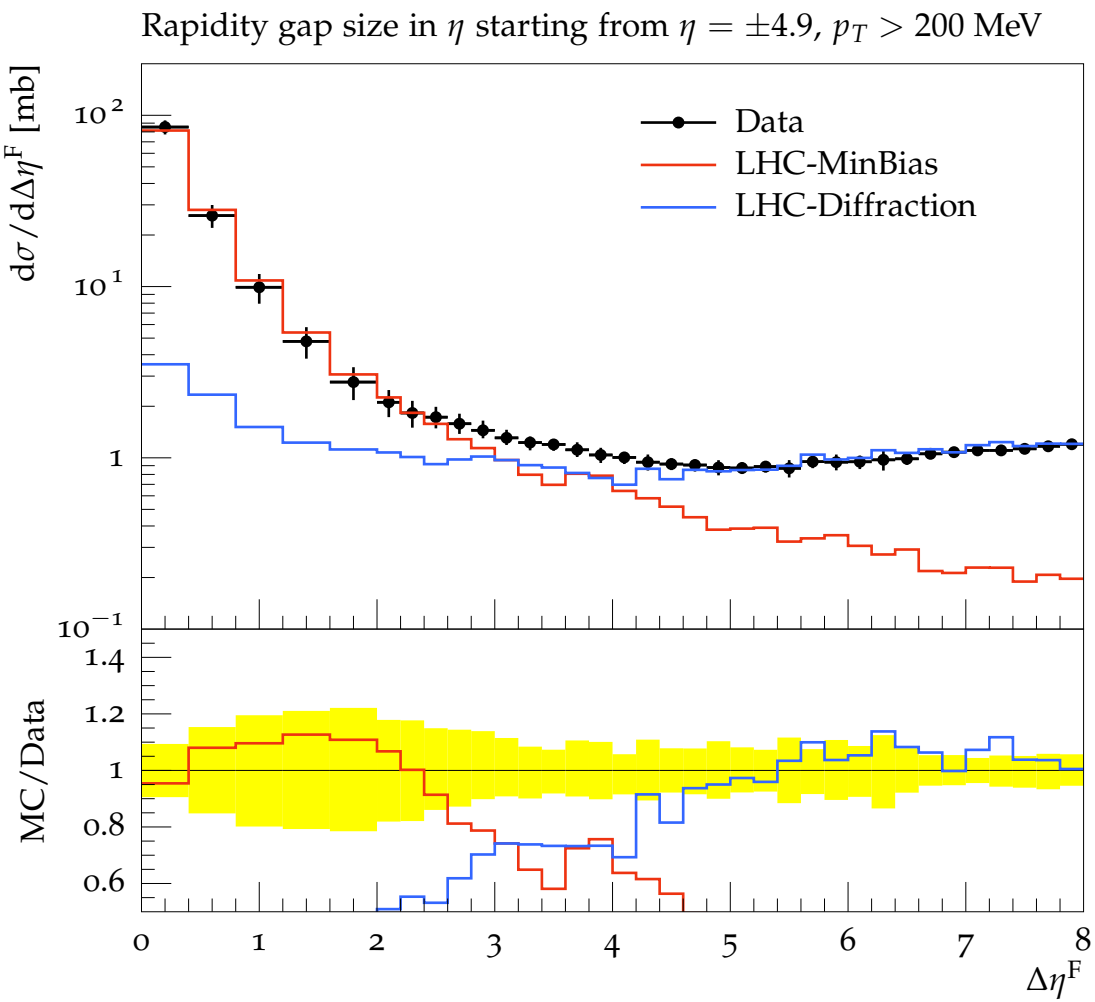
The bump plot, $\Delta\eta_F$

[CMS, PRD 92 (2015) 012003]



Individual contributions to $\Delta\eta_F$

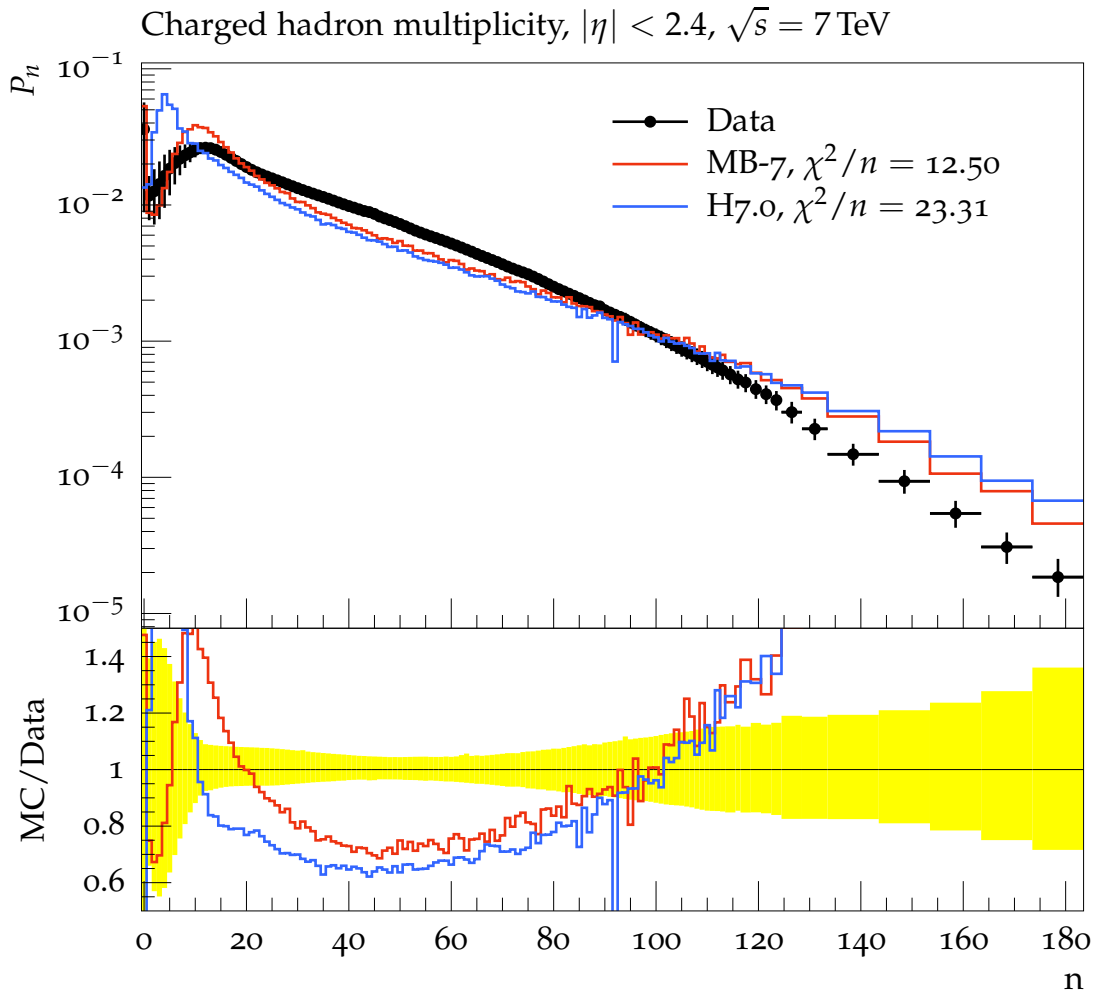
[ATLAS, Eur.Phys.J. C72 (2012) 1926]



Charged particle multiplicity

CMS, NSD analysis 7 TeV

[CMS, PRL 105 (2010) 022002]

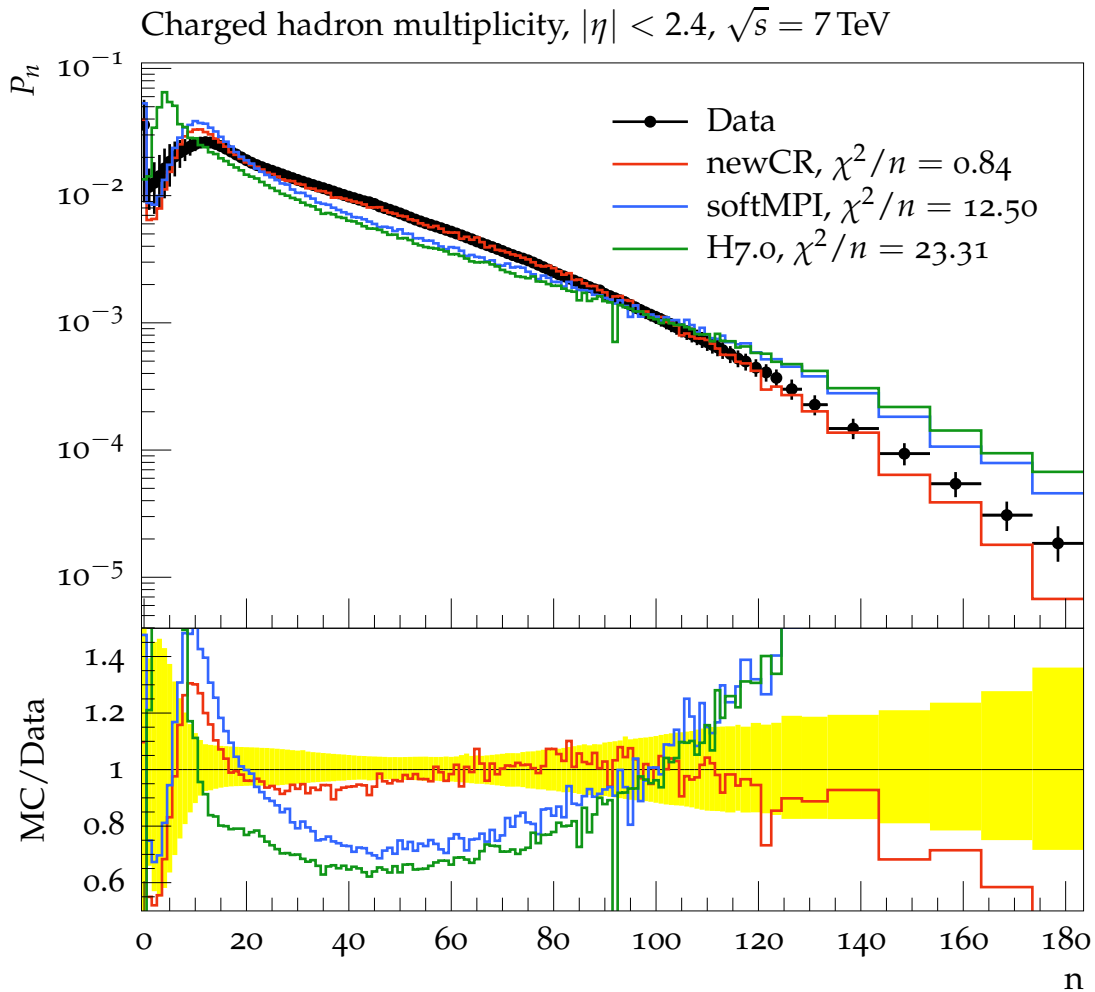


Large discrepancies, tail in particular. Low $n \rightarrow$ "NSD"?

Charged particle multiplicity

CMS, NSD analysis 7 TeV

[CMS, PRL 105 (2010) 022002]



CR model with Baryons (preliminary teaser).

Conclusions

- GIGO ...
- Completely new Min Bias scattering with diffraction and soft particle production.
- Data well described.
- N_{ch} distributions tricky $\rightarrow$ outlook colour reconnection.