

A new model for soft interactions in Herwig 7

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(with Stefan Gieseke and Frashër Loshaj)



Multiple parton interactions

- Hadrons are composite objects → Probability of having more than one interaction.
- Default from Herwig++2.1.
- Interactions above a certain value p_{\perp}^{\min} simulated as QCD $2 \rightarrow 2$ processes (*semi-hard* interactions). [Bähr, Gieseke, Seymour, JHEP 0807:076]
- Interactions below p_{\perp}^{\min} modelled as an elastic scattering among gluons (*soft* interactions).[Bähr, Butterworth, Seymour, JHEP 0901:065] [Bähr, Butterworth, Gieseke, Seymour, 0905.4671]

Multiple parton interactions

- In Herwig based on the eikonal model.

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

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

- Parameters of the soft model fixed to describe σ_{tot} and b_{el} .
- p_{\perp} sampled from a distribution that is parameterised with a Gaussian distribution

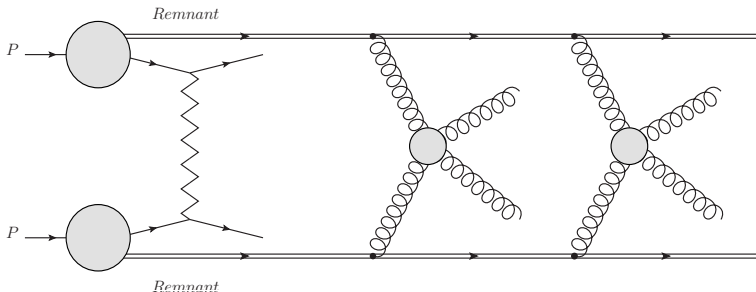
$$\frac{d\sigma_{\text{soft}}^{\text{inc}}}{dp_{\perp}^2} = A e^{-\beta p_{\perp}^2}.$$

Old model for soft interactions

- Number of soft interactions N_{soft} calculated in the eikonal model.

$$\sigma_{\text{tot}} = \sigma_{\text{hard}} + \sigma_{\text{soft}} + (\sigma_{\text{diffraction}})$$

- Modelled as elastic $2 \rightarrow 2$ gluon scattering with $p_{\perp} < p_{\perp}^{\text{min}}$.

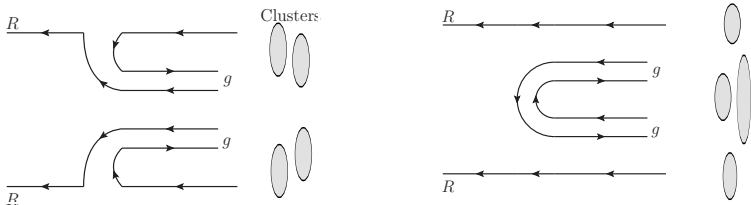


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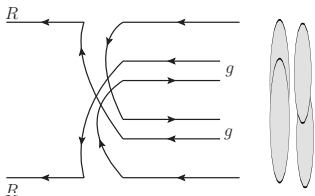


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- No real control over colour connections \rightarrow events with large rapidity gaps.

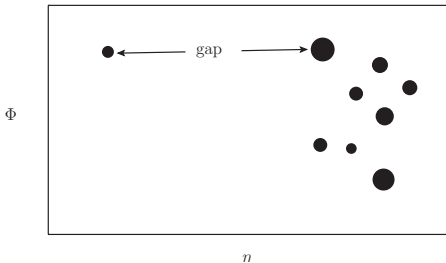
Rapidity Gap

- Total cross section for hadronic collisions.

$$\sigma_{\text{tot}} = \sigma_{\text{el}} + \sigma_{\text{inel}}$$
$$\sigma_{\text{inel}} = \sigma_{\text{ND}} + \underbrace{\sigma_{\text{SD}} + \sigma_{\text{DD}}}_{\text{Diffraction}}$$

Diffraction events associated with colourless exchange
→ large rapidity interval without any hadronic activity.

(Pseudo-)rapidity gap $\Delta\eta$



Behaviour

- ND contributions characterised by experimental observation that $\langle \Delta\eta \rangle \approx 0.15 + \text{fluctuations due to hadronisation. (for a low } p_{\perp} \text{ cut)}$

$$\rightarrow \frac{d\sigma_{\text{ND}}}{d\Delta\eta} \sim e^{-a\Delta\eta}$$

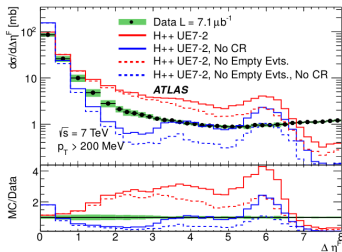
- D contributions dominated by events with large $\Delta\eta$.

$$\rightarrow \frac{d\sigma_{\text{D}}}{d\Delta\eta} \approx \text{const. (w.r.t } \Delta\eta)$$

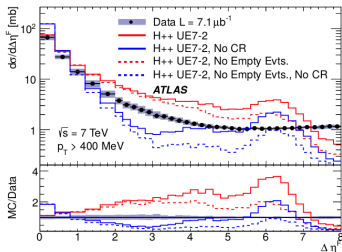
- Cross section measured differential to rapidity gap with different cuts on p_{\perp} by ATLAS and CMS.
- e.g $p_{\perp} > 200 \text{ MeV}$, $p_{\perp} > 500 \text{ MeV} \rightarrow$ minimum bias analyses.
- At high centre-of-mass energies dominated by MPI.

The “Bump” problem

- $\Delta\eta^F$ is defined as the larger of two pseudorapidity regions without any hadronic activity.



(a)



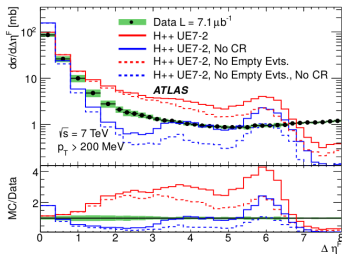
(b)

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

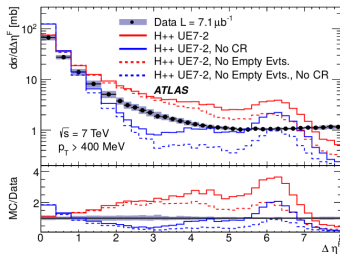
- Herwig++: no model for diffraction $\rightarrow \sim \exp(-a\Delta\eta)$ for low p_\perp cut.
- Extremely sensitive to colour connections in soft MPI.
- No connection topology could produce the required fall off [arXiv:1602.04690 [hep-ph]].

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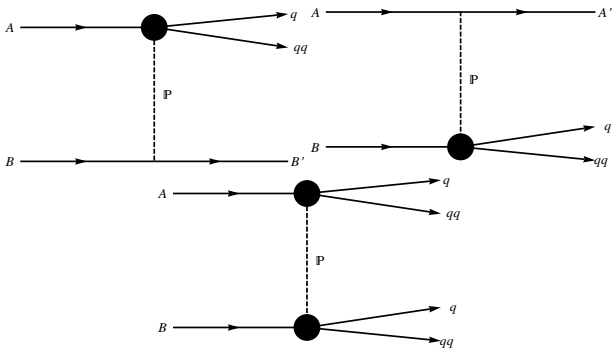
(b)

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

- Need model for diffraction.
- Investigate model for soft MPI.

Diffraction

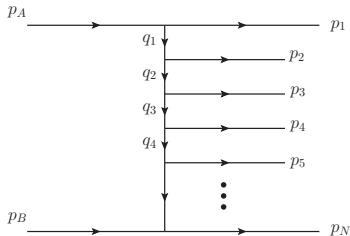
- Implemented by Frashër Loshaj for soft diffraction in Herwig by modelling it with the following matrix elements.



- Final state treated fully nonperturbatively - Quark (q) and diquark (qq) form a cluster with diffractive mass M and stretched along the direction of the dissociated proton.
- For masses M below $m_p + m_q + m_{qq}$, we consider $p p \rightarrow \Delta p$.

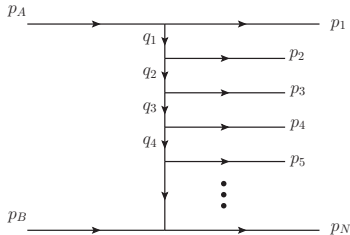
New model for soft interactions

- Two constraints:
 - i) From MB data: Distribution should be approximately uniform in rapidity.
 - ii) Non-diffractive part of the cross section $\sim e^{-a\Delta\eta}$.
- Based on multiperipheral kinematics motivated by cut Pomerons [**Baker, Ter-Martirosyan, Phys.Rept. 28 (1976) 1-143**]
- Idea: Number of soft interactions from MPI model = cut pomerons = particle ladders

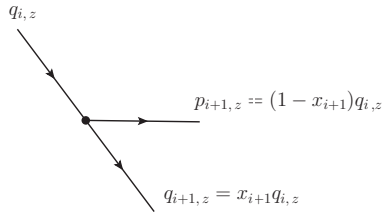


Kinematics

■ Multiperipheral ladder:



$$\langle N \rangle \simeq \ln \frac{s}{m^2}$$

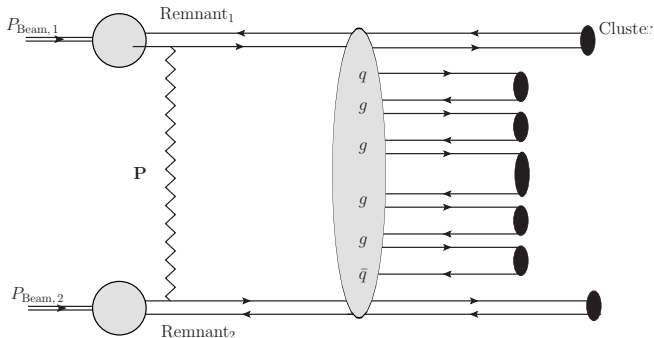


$$\Delta y \sim \ln \frac{1}{x}$$

■ $x_j \simeq x$ such that it gives uniform distribution in rapidity.

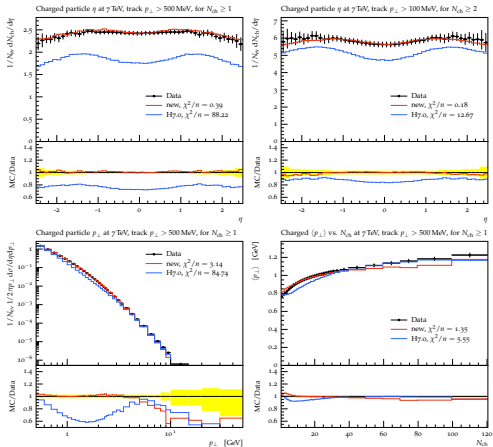
Colour connections

- Particles in the ladder modeled as gluons.
- Emit one $q\bar{q}$ pair in order to get the correct colour connections between the neighbours \rightarrow new model produces clusters ordered in rapidity.



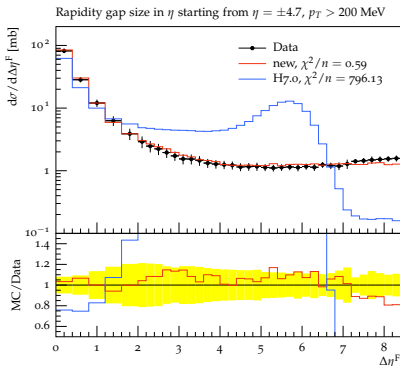
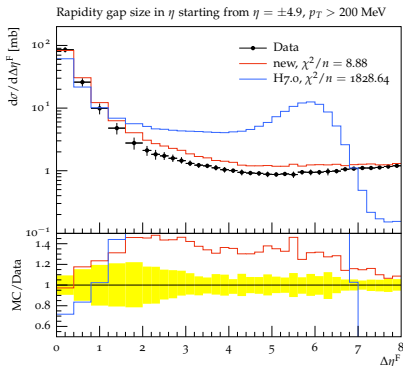
Minimum Bias

- Tuned to MB data from ATLAS [New J.Phys.13:053033,2011] with PROFESSOR(2) [Eur.Phys.J. C65 (2010) 331-357].
- In combination with the model for diffraction Herwig7 is for the first time able to cover all aspects of MB analyses.



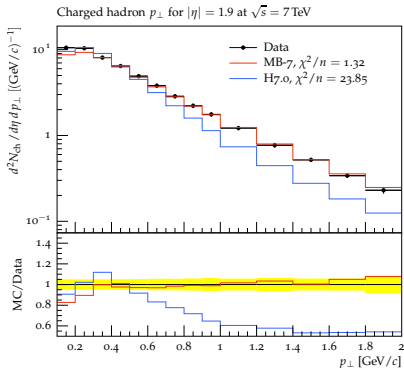
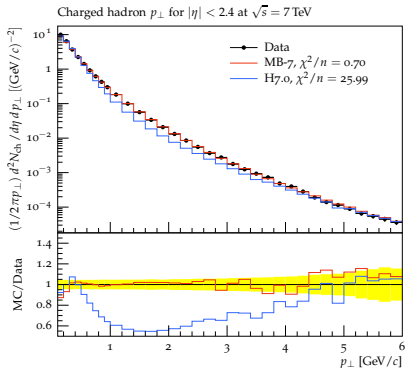
Rapidity Gap

- Satisfying description of ATLAS [Eur.Phys.J. C72 (2012) 1926] and CMS [Phys.Rev. D92 (2015) no.1, 012003] data.



Non-single-diffractive analyses

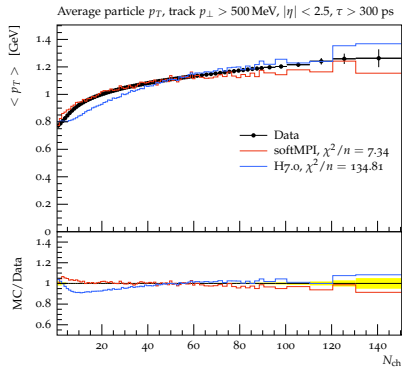
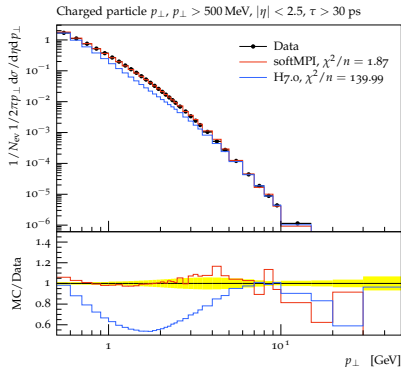
■ CMS: [Phys.Rev.Lett.105:022002,2010]



- Overall good description.
- For transverse momenta $p_{\perp} < 0.3$ GeV difficult.

Extrapolation to 13 TeV

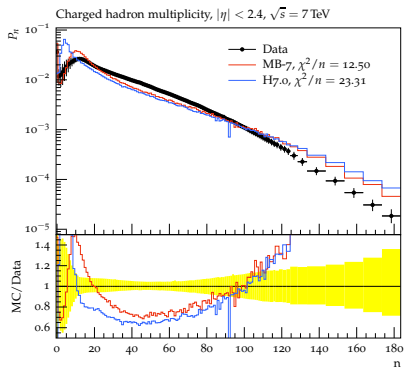
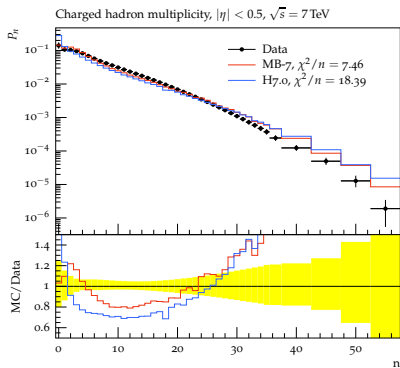
- ATLAS: [Physics Letters B (2016), Vol. 758, pp. 67-88]



- Need more 13 TeV MB/UE analyses!
- Supports 7 TeV tune.

Non-single-diffractive analyses

■ CMS: [J. High Energy Phys. 01 (2011) 079]



■ Overestimation of the high n region \rightarrow new model for CR.

Summary and Outlook

- Replaced old model for soft interactions.
- General improvement of all observables considered.
- Resolved the "bump" problem. Gives the correct behaviour.
- Studies of underlying event analyses with the new model.

Effect of CR on the new model

- Distribution of invariant cluster masses.
- Notion of preconfinement already satisfied fairly well.

