The Abdus Salam International Centre for Theoretical Physics (ICTP), in collaboration with the Italian Institute for Nuclear Physics (INFN), will hold the

7th International Workshop on Multiple Partonic Interactions at the LHC

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Towards diffraction in Herwig

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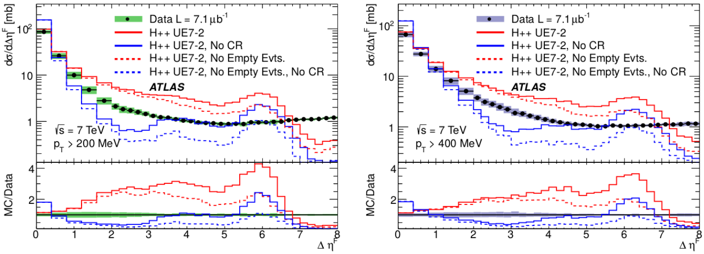
Motivation - the “Bump” problem

Forward pseudorapidity gap $\Delta\eta^F$. Defined as the larger of two pseudorapidities from the last particle to the edge of detector.

Eur.Phys.J. C72 (2012) 1926



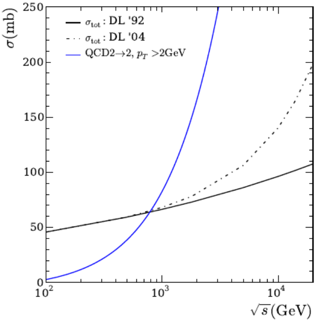
(a) (b)

- Large pseudorapidity gaps due to soft interactions and colour (re)connection.
- To address the problem we: modify colour (re)connection model to remove (quasi) diffractive events and add diffraction properly (see also M. Myska et al., MPI@LHC 2014 proceedings).

Multiple parton interactions (MPI) - quick review

- Inclusive jet cross section above transverse momentum p_T

$$\sigma_{\mathrm{H}}^{inc}(s, p_T^{\min}) = \int dx_1 dx_2 d\hat{t}\, \Theta\left(p_T - p_T^{\min}\right) \sum_{i,j,k,l} \frac{1}{1+\delta_{kl}} \times \left(f_{i|h1}(x_1, \mu^2) f_{i|h2}(x_2, \mu^2) \frac{d\hat{\sigma}_{ij\to kl}}{d\hat{t}}(x_1 x_2 s, t) \right)$$



- Cross section increases with s.
- At moderate values of s, exceeds total cross section.
- A way to resolve this contradiction is using MPI.

(see M. Bähr et al., 2009,I. Borozan and M. H. Seymour, 2002)

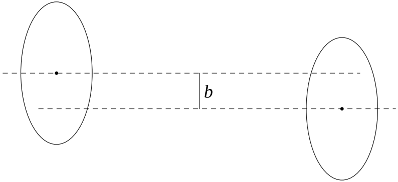
(Semi) Hard interactions

- $\sigma_{\mathrm{H}}^{\mathrm{inc}}$ can be understood as jet production cross section in respect of the luminosity of incoming partons - Multiple parton interactions (MPI) unitarize jet cross section.
- MPI cross sections are calculated using the eikonal model. Average multiplicity at fixed impact parameter b:

$$\langle n \rangle (s, b) = A(b) \sigma_{\mathrm{H}}^{\mathrm{inc}}(s, p_T^{\min}),$$

where overlap function $A(b)$ satisfies

$$\int d^2 b A(b) = 1.$$



Ekonal model

Eikonal model n pomeron amplitude

$$\mathcal{A}^{(n)}(s,b) = \frac{1}{2i}\frac{(-\chi(s,b))^n}{n!}, \quad \text{with } \chi(s,b) = -2i\mathcal{A}^{(1)}(s,b)$$

Using AGK rules, the k cut pomeron cross section is

$$\sigma_k(s) = \int d^2b \frac{(2\chi)^k}{k!} \exp(-2\chi)$$

Jet production cross section due to k uncorrelated hard interactions

$$\sigma_k(s) = \int d^2b \frac{\left(A\sigma_{\mathrm{H}}^{\mathrm{inc}}\right)^k}{k!} \exp\left(-A\sigma_{\mathrm{H}}^{\mathrm{inc}}\right)$$

Like eikonal model if $\chi_{\mathrm{H}}(s,b) = \frac{1}{2}A(b,\mu)\sigma_{\mathrm{H}}^{\mathrm{inc}}(s,p_T^{\mathrm{min}})$.
Describes well the underlying event (see for example M. Bähr, S. Gieseke, and M. H. Seymour JHEP 07 (2008), 076).

Soft interactions

- Extend the model to include interactions with $p_T < p_T^{\min}$.
- Add to the eikonal function the soft contribution (I. Borozan and M. H. Seymour JHEP 09 (2002), p. 015):

$$\chi(s,b) = \chi_H(s,b) + \chi_S(s,b) = \frac{1}{2}\left[A(b,\mu)\sigma_H^{\mathrm{inc}}(s,p_T^{\min}) + A(b,\mu_s)\sigma_s^{\mathrm{inc}}\right]$$

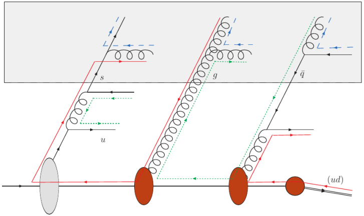
- The cross section for j soft and k hard uncorrelated interactions

$$\sigma_{jk} = \int d^2b \frac{(2\chi_S)^j}{j!}\frac{(2\chi_H)^k}{k!}\exp\left[-2(\chi_S + \chi_H)\right]$$

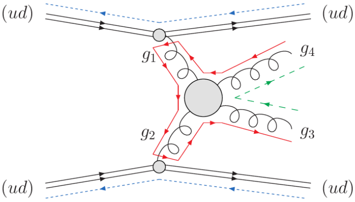
- σ_s^{inc} and μ_s are obtained by fitting to experimental data. This is done by requiring the total cross section and elastic slope, that depend on χ, fit the data.
- Generic gluon-gluon interactions are generated at $p_T < p_T^{\min}$, since perturbation theory doesn't apply. We require $d\sigma_{\mathrm{H}}^{\mathrm{inc}}/dp_T^2$ to match the soft counterpart at $p_T = p_T^{\min}$.

Colour connections

- Event with multiple hard subprocesses

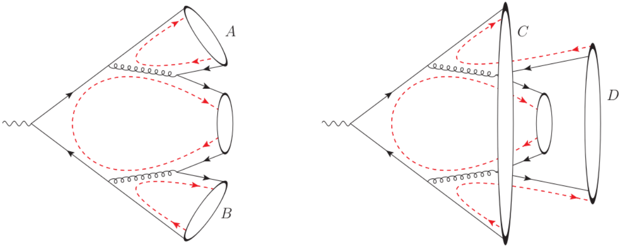


- Soft subprocess with disrupted colour lines (exceptional case)



Colour reconnection

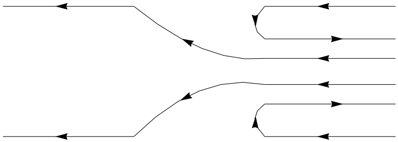
- Partons are connected via colour lines to create clusters. Bare MPI model with colour topologies shown above needs to be modified to include other correlations.
- Colour reconnection model creates lower mass clusters from the original ones (S. Gieseke, C. Röhr, and A. Siodmok Eur.Phys.J.C72 (2012) 2225).



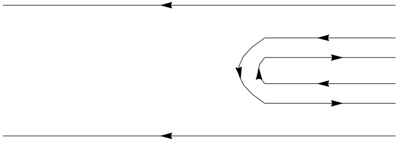
- Despite the success, the model leads to rapidity gaps as shown above.
- We need to introduce other colour topologies explicitly.

Colour connections of soft scatters in Herwig

The current connections are



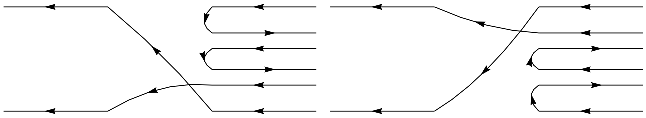
and



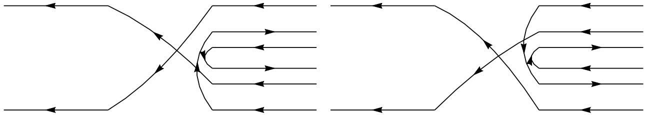
- Both produce gaps even after disallowing remnant clusters from reconnecting.
- To address the issue we consider other colour connections.

Colour connections 1

Connections that seem to give the least rapidity gaps after colour reconnection



A

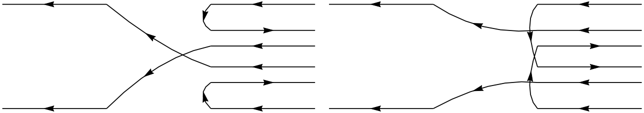


H

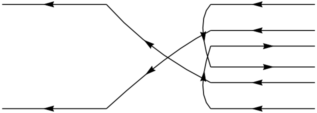
(work done together with M. Myska)

Colour connections 2

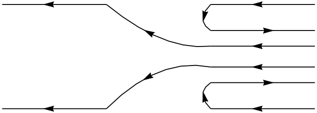
Connections with intermediate contribution



B



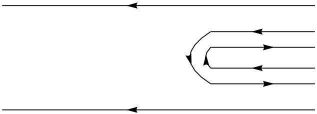
C



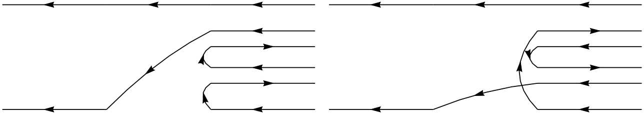
E

Colour connections 3

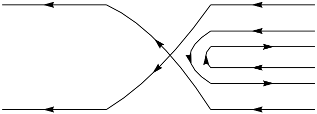
Connections with most gaps



D

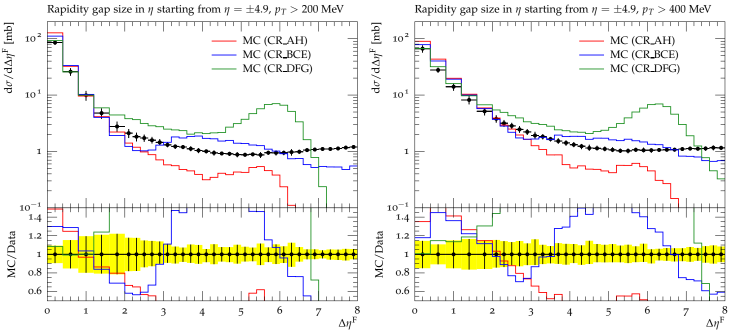


F



G

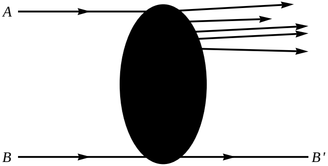
Rapidity gaps

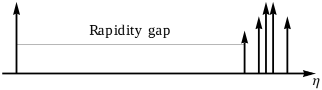


- Connections A and H give the most suppression.
- The distribution in $\Delta\eta^F$ for these connections is not exponential. Large tail comes from soft interactions.
- Events with large $\Delta\eta^F$ have to come from diffraction.

Diffraction in hadron collisions

Events with rapidity gaps





Cross section behaves as

$$\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{-B|t|} \simeq \left.\frac{d\sigma}{dt}\right|_{t=0} (1 - B|t|)\,,$$

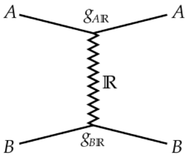
in analogy with diffraction in optics

$$I(\theta) \simeq I(0)\left(1 - Bk^2\theta^2\right).$$

A definition: diffraction is a high energy process in which no quantum numbers are exchanged between colliding particles.

Regge theory

Consider the process $A + B \rightarrow A + B$.



Entire families of particles are exchanged between hadrons, which are called reggeons $\mathbb{R}$, with amplitude

$$A(s,t) = \beta(t)\eta(t)s^{\alpha(t)},$$

$$\eta(t) \equiv -\frac{1 + \xi e^{-i\pi\alpha(t)}}{\sin \pi\alpha(t)}, \quad \beta(t) = g_{A\mathbb{R}}(t) g_{B\mathbb{R}}(t)$$

In studying diffraction we are interested in a reggeon with vacuum quantum numbers - the pomeron $\mathbb{P}$.

Soft diffraction cross section

Single diffraction:

$$\frac{d^2\sigma^{SD}}{dM^2dt} = \frac{1}{16\pi^2 s}|g_{\mathbb{P}}(t)|^2 g_{\mathbb{P}}(0) g_{\mathbb{PPP}}(0) \left(\frac{s}{M^2}\right)^{2\alpha_{\mathbb{P}}(t)-1} \left(M^2\right)^{\alpha_{\mathbb{P}}(0)-1} .$$

and double diffraction

$$\frac{d^3\sigma^{DD}}{dM_1^2 dM_2^2 dt} = \frac{1}{16\pi^3 s} g_{\mathbb{P}}^2(0) g_{\mathbb{PPP}}^2(0) \left(\frac{s}{M_1^2 M_2^2}\right)^{2\alpha_{\mathbb{P}}(t)-1} \times \left(M_1^2\right)^{\alpha_{\mathbb{P}}(0)-1} \left(M_2^2\right)^{\alpha_{\mathbb{P}}(0)-1} .$$

where $\alpha(t) = \alpha(0) + \alpha' t$, $g_{\mathbb{P}} = g_{p\mathbb{P}}$ is the pomeron-proton coupling and $g_{\mathbb{PPP}}$ is the triple pomeron coupling.

Generating diffractive events

- We write as usual $|g_{\mathbb{P}}(t)|^2 = e^{B_0 t}$. We then generate single diffractive events from the distribution

$$\frac{d^2\sigma^{SD}}{dM^2 dt} \sim \left(\frac{s}{M^2}\right)^{\alpha_{\mathbb{P}}(0)} e^{\left(B_0 + 2\alpha' \ln\left(\frac{s}{M^2}\right)\right)t}$$

- Similarly, double diffraction is generated by

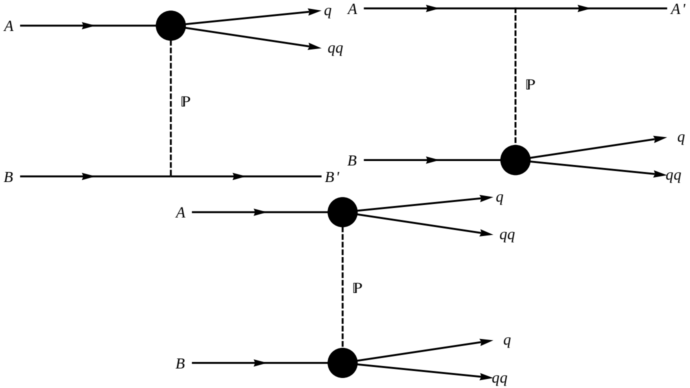
$$\frac{d^2\sigma^{DD}}{dM_1^2 dM_2^2 dt} \sim \left(\frac{s}{M_1^2}\right)^{\alpha_{\mathbb{P}}(0)} \left(\frac{s_0}{M_2^2}\right)^{\alpha_{\mathbb{P}}(0)} e^{\left(b + 2\alpha' \ln\left(\frac{ss_0}{M_1^2 M_2^2}\right)\right)t}.$$

where b is very small and $s_0 \simeq 1/\alpha'$. Overall constant is fitted to data. We also use the following values of parameters: $\alpha_{\mathbb{P}}(0) = 1.08$, $B_0 = 10.1\ \mathrm{GeV}^{-2}$, $\alpha' = 0.25\ \mathrm{GeV}^{-2}$.

Damping factor $(1 - M^2/s)$ was used to include points in phase space not covered by Regge theory.

Diffractive events in Herwig

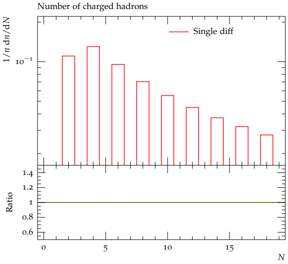
- We implement soft diffraction in Herwig by modelling it with the following matrix element

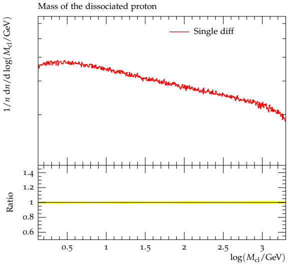


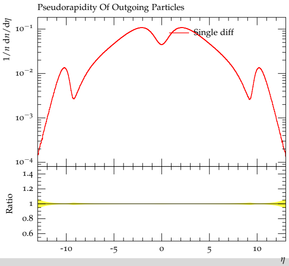
- Quark (q) and diquark (qq) form a cluster with diffractive mass. The cluster then is handled by the rest of the event generator.

Model features

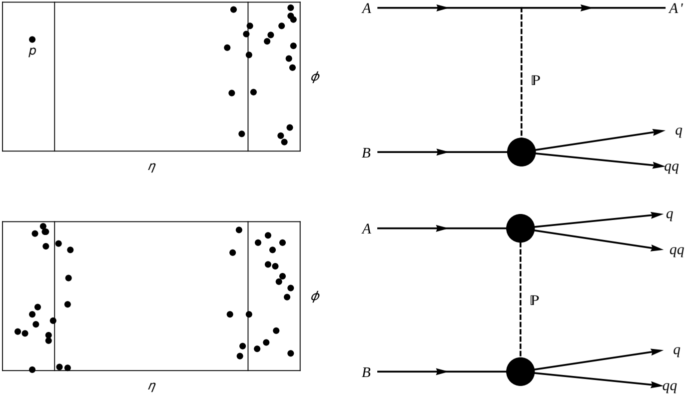
- The model shows features expected from diffraction, e.g., small number of final charged particles and rapidity gap:





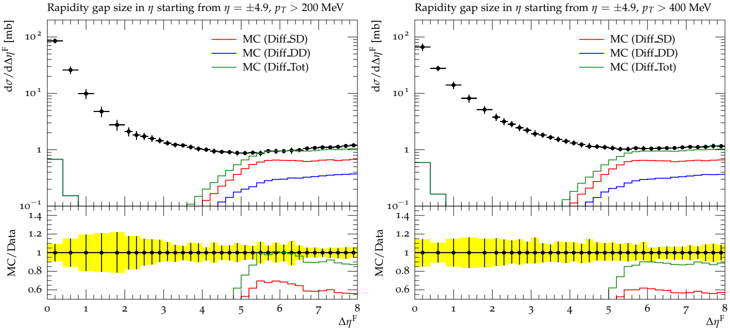


Pseudorapidity gap



- Single diffraction contributes at large $\Delta\eta^F$.
- Double diffraction with one of the masses much smaller contributes around $\Delta\eta^F \sim 0$ and large $\Delta\eta^F$.

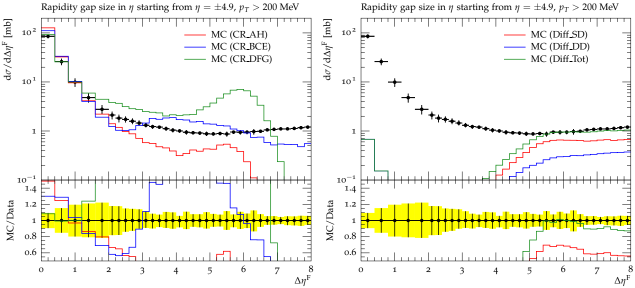
Diffraction (preliminary) results



- For large $\Delta\eta^F$ we reproduce $d\sigma/d\Delta\eta^F \approx \mathrm{const.}$
- We have to modify the fragmentation of the cluster to cover the whole $\Delta\eta^F$ range.

Combining minbias and diffractive runs

- It remains to be implemented:
  - Combine different colour connections to get the proper nondiffractive cross section and add diffractive events.



  - MPI model has to be added to diffractive events as well.

Summary and outlook

- The soft MPI model of Herwig produces large rapidity gaps in the colour reconnection model.
- These gaps can be suppressed by:
  - Introducing new colour connections between soft gluons and remnants and
  - Modifying the colour reconnection model to exclude remnant clusters from reconnecting.
- Events with large rapidity gaps have to come from diffraction. We have shown how diffraction can be implemented in Herwig.

- Appropriate soft colour connections have to be chosen to get the proper non-diffractive events.
- Diffraction has to be integrated into the MPI model.