Low x, final states and diffraction with dipoles in transverse space

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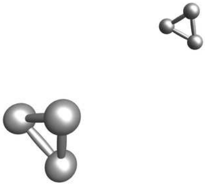
Work done with Gösta Gustafson and Leif Lönnblad.

Contents

- Describe our model for inclusive observables.
  - Show some results from a paper.
- Describe our extended model for exclusive observables.
  - Show some results from another paper.
  - Future applications.

A Colour Dipole Model

1. Model incoming particles with colour dipoles in transverse space and rapidity (eg γ^* = single dipole, proton = )
2. Evolve states in rapidity until they meet.
3. Collide at interaction rapidity y_0. Calculate interaction probability.



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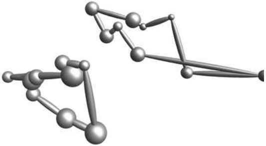

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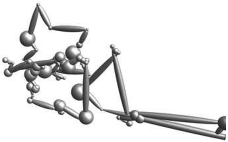
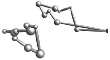
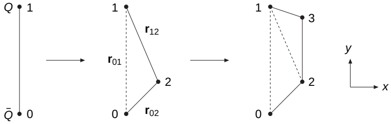


Evolution



Based on LL BFKL model by Mueller (low x, only gluons).

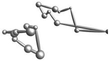
$$\frac{dP}{dy} = \frac{\bar{\alpha}}{2\pi} d^2 r_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$$



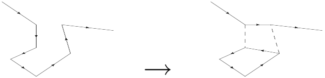
Corrected for the essential parts of NLL BFKL.

- energy conservation. Keeps track of p_+, p_- and $p_\perp$ for all partons. $p_\perp$ set from dipole size: transverse recoil $p_\perp = 1/r$ on emission and parents.
- running α_s
- projectile-target symmetry (ordering in p_+ and p_-).

Evolution

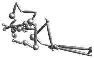


- Confinement from a gluon mass. Suppresses emissions at large transverse distance. Fullfills Froissart bound.
- Saturation, dipole swing: (N_C^2 suppressed)



  - Each dipole has colour index, only dipoles of same colour can swing: quadrupoles.
  - Swings happen often between emission, but favours smaller dipoles over larger dipoles.

Interaction



Born amplitude, with dipole-dipole interaction amplitude f_{ij}:

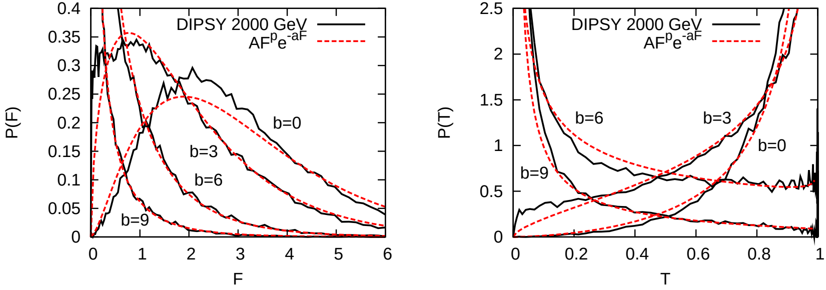
$$F = \sum_{ij} f_{ij} \qquad f_{ij} = \frac{\alpha_s^2}{2} \ln^2 \left(\frac{r_{13} r_{24}}{r_{14} r_{23}} \right)$$

Cross sections from the eikonal formalism (average over cascades):

- $\sigma_{\text{tot}} = 2 \int d^2b \langle 1 - e^{-F} \rangle$
- $\sigma_{\text{el}} = \int d^2b \langle 1 - e^{-F} \rangle^2$
- $\sigma_{\text{diff ex}} = \int d^2b \left(\langle (1 - e^{-F})^2 \rangle - \langle 1 - e^{-F} \rangle^2 \right)$

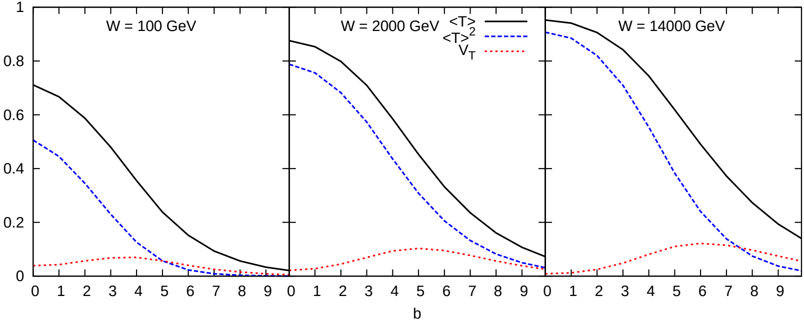
Same corrections as in evolution: energy conservation, running α_s, $p_\pm$ordering, saturation, confinement.

fluctuations and saturation



- Diffractive excitation comes from the fluctuations in interaction probability over different cascades.
- Unitarisation puts all large interaction probabilities close to 1, ie small fluctuations!
- seen in high energy *pp* at central collisions. ($T = 1 - e^{-F}$)

pp Impact parameter profile

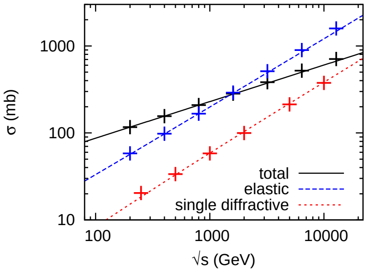


- V_T is the fluctuations, giving the diffractive excitation.
- Low b have low fluctuations due to saturation.
- Diff excitation comes from a ring in transverse space.
- This effect is not present in $\gamma^* p$, as F is much smaller than 1, giving comparably large $\sigma_{\text{diff ex}}$ in $\gamma^* p$.

Our model: Good–Walker

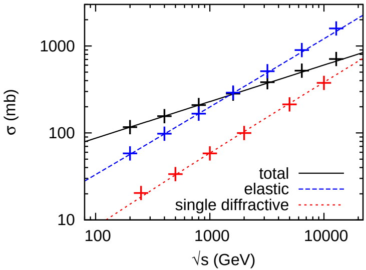
- Our model is in the Good–Walker formalism, which normally is only used at low excited masses M_X.
- Since we include fluctuations in the cascade, we can extend to any masses.
- can compare Good–Walker formalism to triple-Regge over a large range of M_X.
- See `arXiv:1004:5502` for furth details.

Comparison to Triple-Regge



- Unsaturated models (both triple-Regge and our model).
- Our (unsaturated) model has the same power-like behaviour as expected from triple-Regge.
  - $\sigma_{\text{tot}} = \beta^2(0) s^{\alpha(0)-1} \equiv \sigma_0^{p\bar{p}} s^{\varepsilon}$
  - $\frac{d\sigma_{\text{el}}}{dt} = \frac{1}{16\pi} \beta^4(t) s^{2(\alpha(t)-1)}$
  - $M_X^2 \frac{d\sigma_{\text{SD}}}{dt d(M_X^2)} = \frac{1}{16\pi} \beta^2(t) \beta(0) g_{3P}(t) \left(\frac{s}{M_X^2}\right)^{2(\alpha(t)-1)} (M_X^2)^{\varepsilon}$

Comparison to Triple-Regge



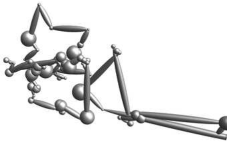
Crosses are our model, lines are triple-Regge with

$$\begin{aligned}\alpha(0) &= 1+\varepsilon = 1.21, \quad \alpha' = 0.2\,\text{GeV}^{-2},\\ \sigma_0^{p\bar{p}} &= \beta^2(0) = 12.6\,\text{mb}, \quad b_{0,\text{el}} = 8\,\text{GeV}^{-2},\\ g_{3P}(t) &= \text{const.} = 0.3\,\text{GeV}^{-1}.\end{aligned}$$

- NLL and confinement important for this result!

To get final states, we need:

- Determine which dipoles interact.
- Determine which of the dipoles in the cascade should be kept, and which should be reabsorbed.
- Add final state radiation.
- Hadronise.



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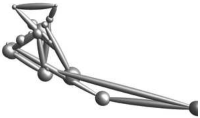

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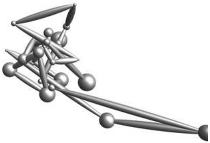

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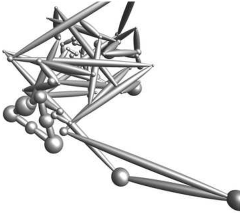


Non-diffractive interaction probability

- Non-diffractive interaction probability is total - diffractive:

$$2(1-e^{-F})-(1-e^{-F})^2=1-e^{-2F}$$

- The non-interaction probability factorise ($F=\sum f_{ij}$)

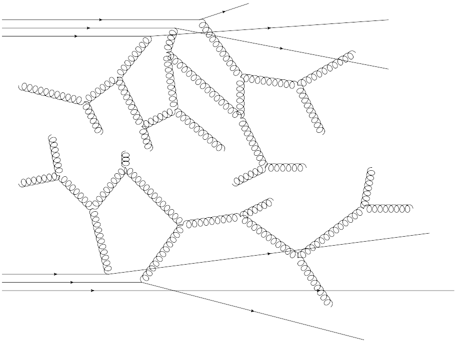
$$1-e^{-2\sum f_{ij}}=1-\prod e^{-2f_{ij}}$$

- assuming independent interactions, the non-diffractive dipole-dipole interaction probability between dipole i and j is $1-e^{-2fij}$.
- This can be used to determine the interacting dipoles in our Monte Carlo implementation: DIPSY.

Virtual vs Real gluons

Once the interactions are in place, it is easy to see the interacting gluon chains.

Emissions not on interacting chains are emitted as final state radiation by ARIADNE, removed in DIPSY to not double count.



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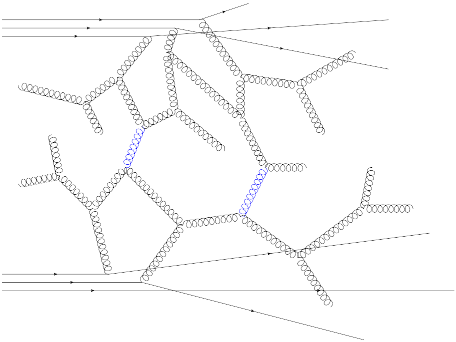

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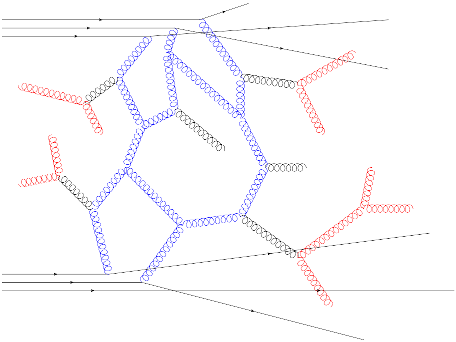


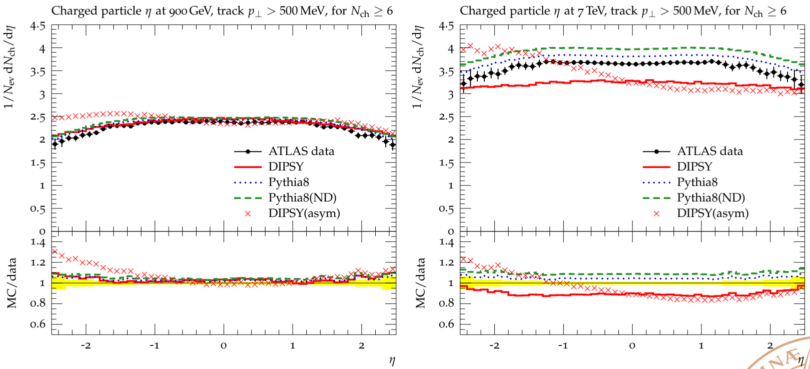
Details...

- There are plenty of subtleties where perturbative QCD gives little guidance, but that still affects observables. See `arXiv:1103:4321` for further details.
  - reweighting of some $k_\perp$-max in evolution.
  - deciding what parents to put on shell.
  - formulation of ordering and coherence.
  - and more.
- These are first decided by self consistency (frame independence) and tuning to inclusive observables.
- Last freedom in model-space is left to be tuned to exclusive obervables such as charged particle distributions.

Final State radiation and Hadronisation

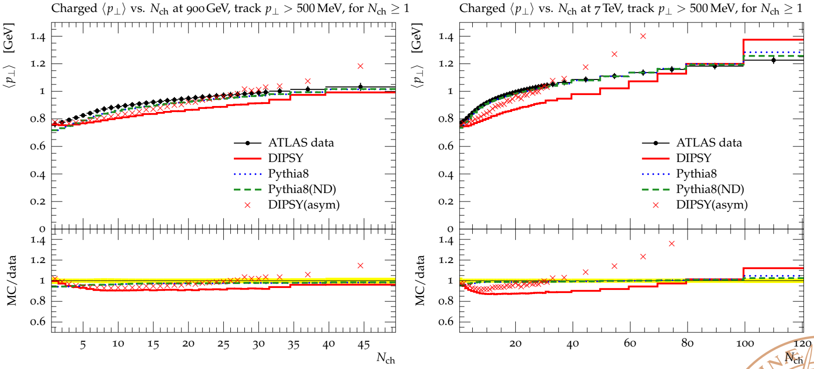
- FSR fills up the remaining phase space (emissions that are unordered in $p_\pm$).
- FSR with the ARIADNE Monte Carlo, based on the Linked Dipole Chain model.
- Hadronisation with the Lund String Model using PYTHIA 8.

ATLAS data



Pseudorapidity distributions of charged particles at 0.9 and 7 TeV.

ATLAS data



Average transverse momentum as function of charged multiplicity at 0.9 and 7 TeV.

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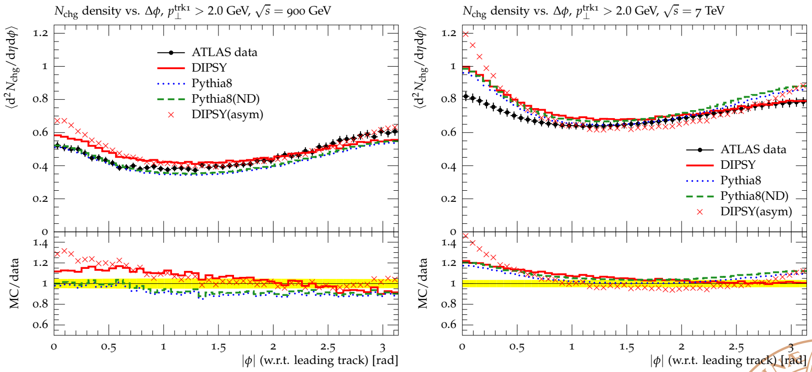
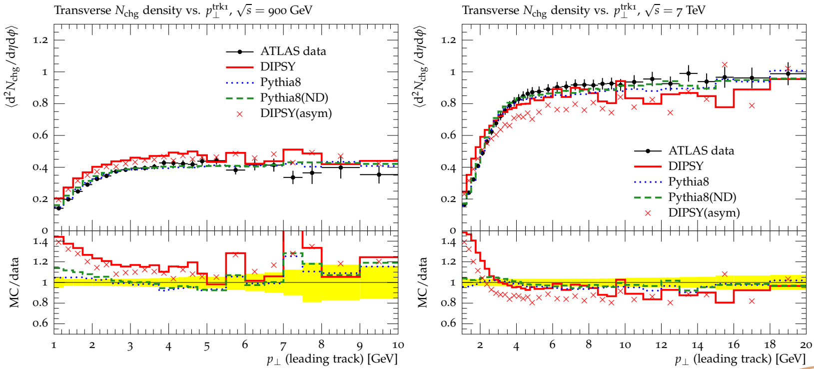


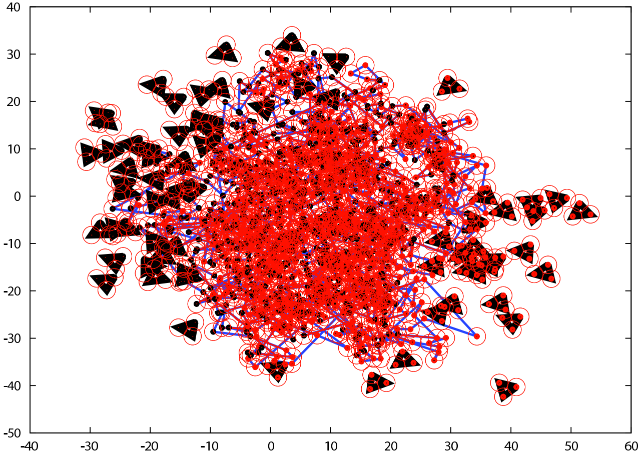
Multiplicity as function of azimutal angle w.r.t. a leading charged particle of at least 2 GeV.

ATLAS data



The multiplicity of charged particles in the transverse region as function of the transverse momentum of the leading charged particle. More plots at `http://home.thep.lu.se/~leif/DIPSY.html`.

AA



AA

- An ion starts as *A* nucleons (dipole triangles) distrubted in transverse space.
  - Red dots from one side, black dots from other.
  - black triangles are spektator nucleons.
- The swings, within and between nucleons, describe the saturated cascade.
- Get a full partonic picture with both momentum and transverse position.
- Dynamically describes all fluctuations. (v_3 for example)
- Can be used as initial condition for other models. (hydrodynamics for example)

More possibilities

- DIS final states.
  - Inclusive and semi-inclusive data is well described.
  - Current version can generate $\gamma^* p$ final states, but have not yet been compared to data.
- $\gamma^* A$ inclusive and exclusive observables.
  - By first tuning AA, pA and $\gamma^* p$ to data, it should be reliable.
- Diffractive final states.
  - Tricky (interactions are not independent), but underway.
  - Hope to return soon with results.

Summary

- BFKL-based dipole model in transverse space, evolved in rapidity.
  - Includes most of NLL, saturation and confinement.
  - Does inclusive observables and now full event generator.
  - Monte Carlo implementation: DIPSY.
- Some inclusive results from `arXiv:1004:5502`.
  - Diffractive excitation suppressed by saturation in *pp*.
  - Can do Good–Walker at large excited mass M_X.
  - Our model with NLL and confinement effect, but without saturation, behaves as bare triple-Regge with reasonable parameters.
- Some exclusive results from `arXiv:1103:4321`.
  - Competetive description of LHC and CDF data.
  - Different approach than other event generators.
  - Can also be used in reactions as AA, γ^*p, γ^*A.

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