Final States in DIPSY

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Work done with Gösta Gustafson and Leif Lönnblad.

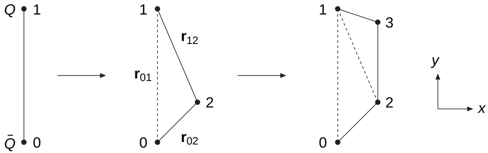
Content

- Inclusive cross sections review.
- Exclusive final states: ISR, interaction, FSR and hadronisation.
- Comparison to experiments: CDF and ALICE.
- Comments on other possible reaction: γ^* and Heavy Ions.

Evolution in rapidity

A colour dipole emits a gluon in transverse space with probability

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



Equivalent to LL BFKL.

Interaction

A Born level calculation gives the collision amplitude for a pair of dipoles from different states:

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

With the eikonal approximation, the total unitarised probability then becomes

$$t \equiv 1 - e^{-\sum f_{ij}}.$$

See Gösta Gustafsons talk for more information.

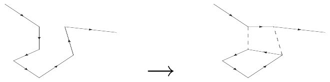
Modifications in DIPSY

Energy conservation

- Keep track of p_μ for all partons.
- Small dipoles $\leftrightarrow$ high p_T.
- Gives dynamic cutoff for small emissions.

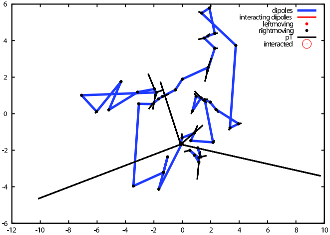
Non-linear 2 $\rightarrow$ 2 swing:

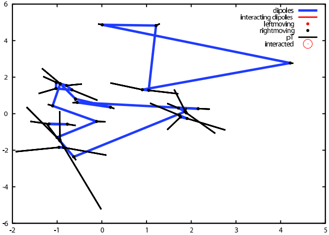
- Saturation in evolution.



Confinement

- Supression of too large dipoles.


dipoles
interacting dipoles
leftmoving
rightmoving
pT
interacted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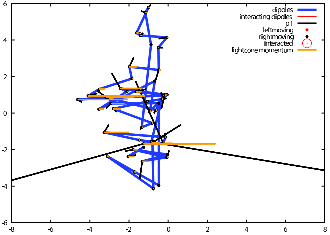
dipoles
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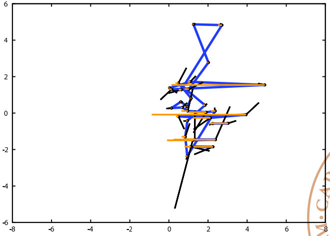
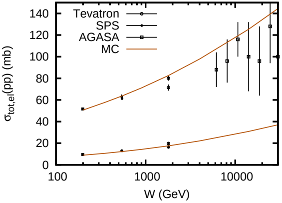
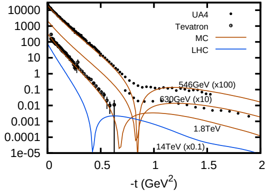
lightcone momentum

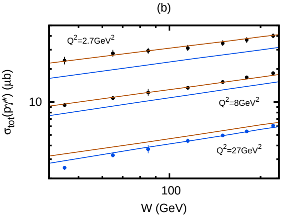


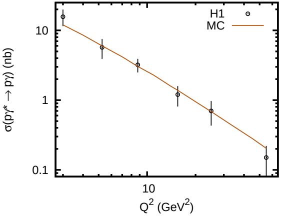
Some sample results

pp and $\gamma^{\star}$p: total, elastic and diffractive cross section.









Final States

Want to use the information about the particles in the virtual cascades to generate real final states.

Problems to solve:

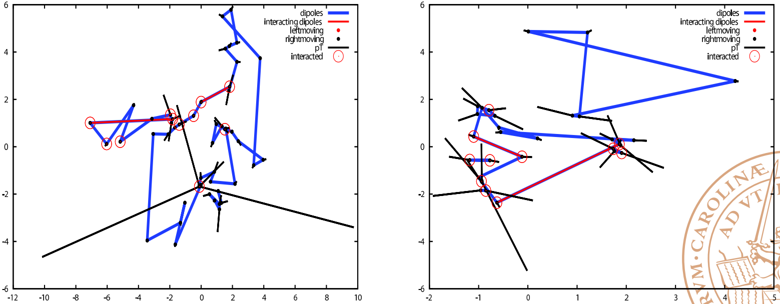
- Which dipoles interact?
- Which gluons are part of the interacting chain?
- what p_μ should the gluons have?
- Which emissions are virtual and will be reabsorbed?

No new parameters will be introduced in answering these questions! Many constraints from self consistency.

Selecting Interactions

Independent interactions $\rightarrow$ Poissonian distribution.

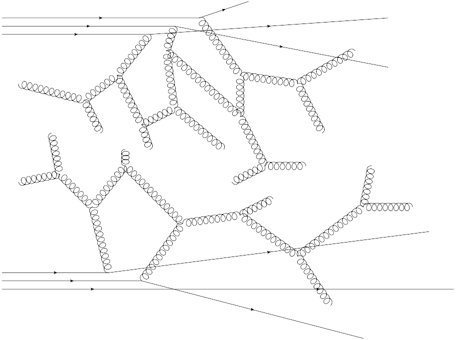
Non-diffractive = total - diffractive:
$2(1 - e^{-\sum f_{ij}}) - (1 - e^{-\sum f_{ij}})^2 = 1 - e^{-2\sum f_{ij}}$ interpreted as interaction probability $1 - e^{-2f_{ij}}$ for each dipole pair ij.



Interacting gluon chain

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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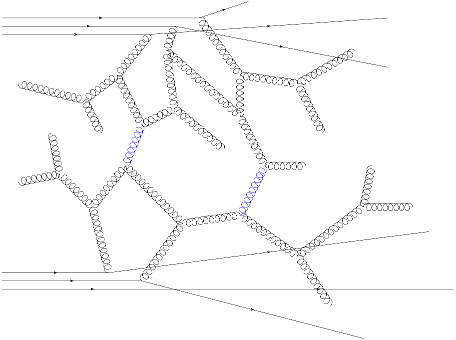

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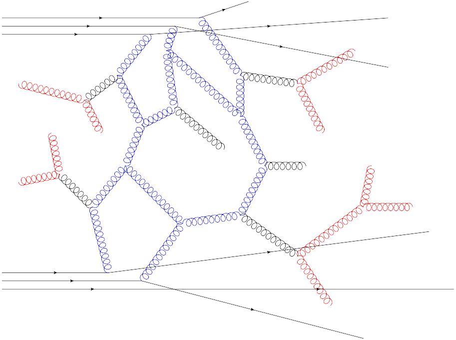


Determining p_μ

- The two parents at transverse distance $\mathbf{r_1}$ and $\mathbf{r_2}$ give the $p_T = \mathbf{r_1}/\mathbf{r_1^2} + \mathbf{r_2}/\mathbf{r_2^2}$. Parents take the recoil to conserve p_T.
- Rapidity y is given from the emission, which gives $p_+ = p_T e^{-y}$. Parents provide p_+ if they have enough, giving a dynamic cut off for high p_T.
- The outgoing gluons will be massless: $p_- = p_T e^y$. For the main chain (spacelike) gluons, this should be interpreted as the negative p_- carried to cancel with the p_- from the colliding particle.
- The p_- needed for all the outgoing gluons is summed up and has to be provided by the colliding gluon from the other state, to conserve p_-, providing a dynamic cut off for interactions with high p_T.

Virtual fluctuations: non-DGLAP suppression

Dipoles are emitted with weights d^2p_T/p_T^2 in the cascade.

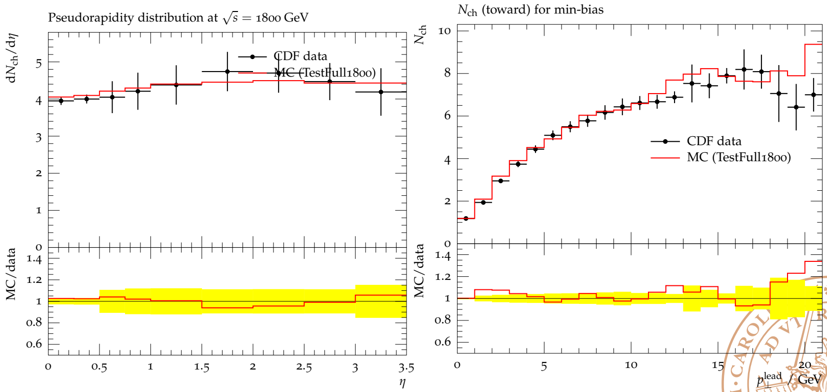
- Correct for interacting dipoles and DGLAP-like chains.
- A local maxima in p_T should have a weight d^2p_T/p_T^4 according to BFKL.
- This extra suppression of small dipoles is made by keeping local maxima with a probability $p_{T<}^2/p_{T\max}^2$ where $p_{T<}$ is the neighboring gluons momentum. Other small dipoles are reabsorbed.
- It is not known if a parton is a p_T maximum until after the emissions are decided, giving catch-22 like situations.
- This problem is solved by enforcing causality in the sence that an emission cannot be blocked by a future emission.

FSR and hadronisation

- The real gluons from DIPSY are sent to Ariadne.
- Ariadne does FSR using the colour couplings of the gluons. Covers the phase space of the removed non-main chain gluons removed in DIPSY.
- Ariadne passes the new state to PYTHIA.
- PYTHIA makes strings of the colour dipoles and do string fragmentation into hadrons.
- The hadrons decay into the final state.

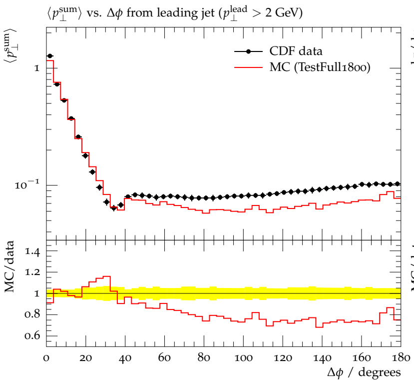
CDF

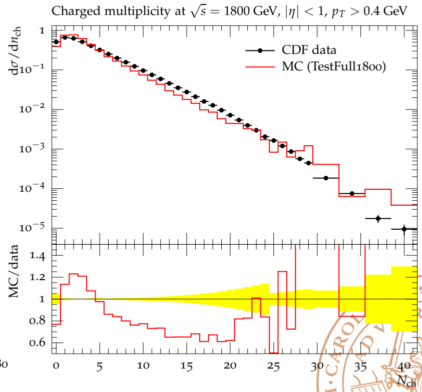
Pseudorapidity distribution and N_{ch} in towards region.



CDF

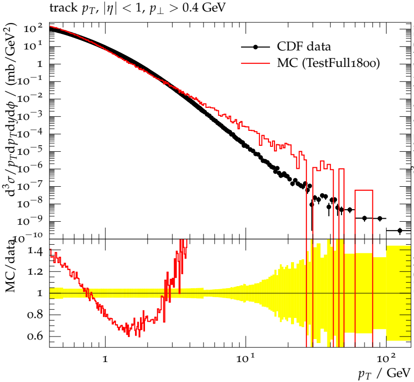
Angular distribution and multiplicity frequency.

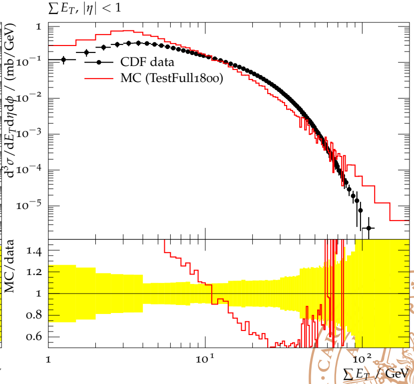




CDF

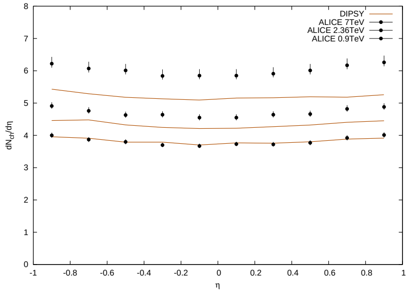
Track p_T and $\sum E_T$ distributions.

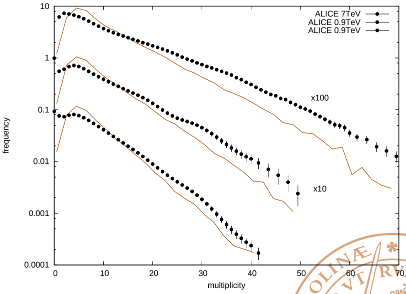




ALICE

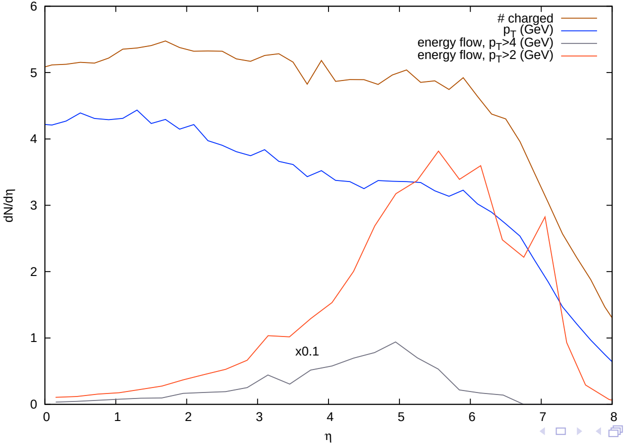
Rapidity distribution and Multiplicity frequency.





Forward

p_T, multiplicity and energy flow over a wide η range. Thanks to Grzegorz Brona for trigger and cutoff help.

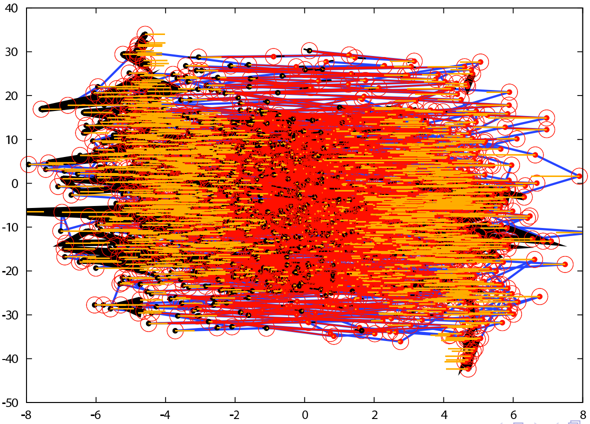


Heavy Ions

- Distribution of nucleons from collaborators András Ster and Tamás Csörgő.
- Then evolve, collide and absorb as normal. Will be very swing-heavy.
- Similar to Colour glass condensate.
- DIPSY uses finite size nucleus and works at limited energies, for example at RHIC and LHC.
- Have p_μ, x_T and colour flow for every parton after collision to plugg into final state models, such as hydrodynamics.

Heavy Ions

Central Au-Au collision in y-x_T space.



DIS

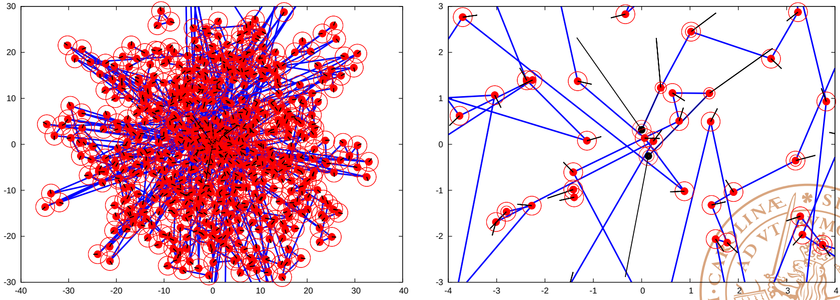
Can exchange one of the protons with a single dipole.

- Size of dipole is $1/Q$ so that the recoil on the quarks is Q.
- Will have high p_T on one end, low p_T on the other.
- Not yet done with final states, but we expect good results since total cross sections worked very well.

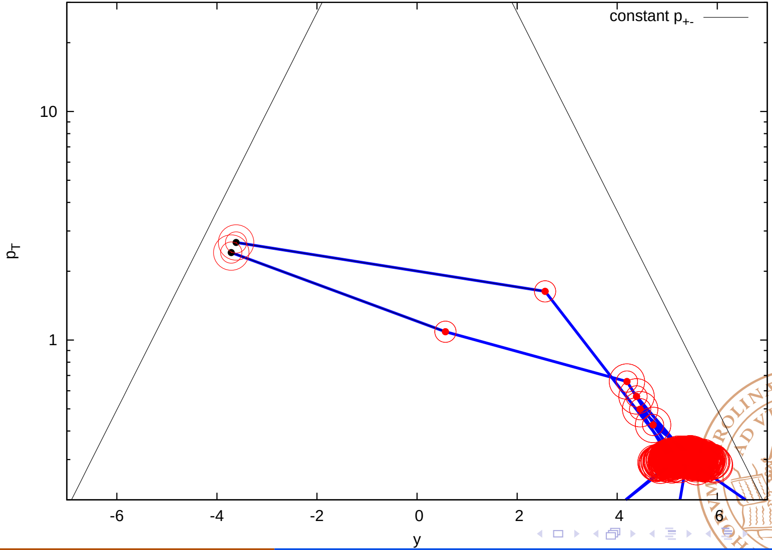
e^-A

Collide a single dipole with a cascade of nucleons. Can again use same tools as for *pp*.

Here follows a sample event just as proof of concept:



Or better seen in a y-p_T plot:



Summary

- Uses a dipole model in space and rapidity, implemented in DIPSY, to create virtual initial state casades.
- Cascades can be used to calculate interaction probability and cross sections.
- By selecting interaction it is possible to pick out the real main chain gluons, that can be sent to FSR and hadronisation to produce final states.
- This is done with only two tunable parameters, that are fixed from total *pp* cross sections.
- Reproduces data from CDF and ALICE decently or better.
- Applications in Heavy Ions, DIS and eA.

DIS and the proton cascade

The proton cascade is done independently of the photon, but the final state will still feel the photon a little:

- Large dipoles will not resolve the photon, so a small dipole (high p_T) will interact.
- The gluon chain in the proton will be steeper in p_T to reach up to the iteracting dipole.
- The non-DGLAP suppression will be less likely to trigger, and there will be more p_T also on the proton side.

small dipole absorb

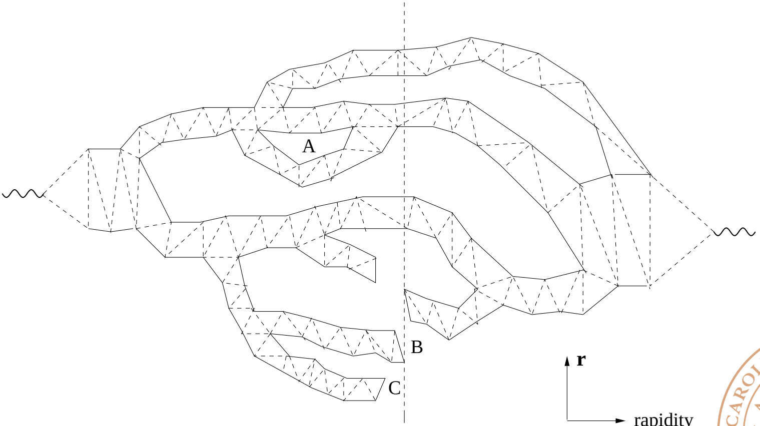
Dipoles come with relative weight of $1/r^2$ in evolution as seen from emission amplitude.

high p_T events should come with weight of $d^2p_T/p_T^4 = d^2r$.

So small dipoles in evolution (giving large p_T) are too frequent.

Solution: Absorb small dipoles. Keep with a propbability $p \propto r_{small}^2$. Then final weight for small dipoles will be d^2r as we want.

Virtual Partons



Divergent mueller evolution

No problem since small dipoles are unlikely to interact.

Infinitely many small dipoles, but finite total interaction probability.

Inconvenient for monte carlos though.