LUND UNIVERSITY

DIPSY: a Dipole Event Generator

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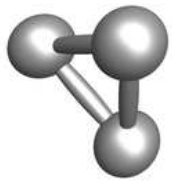
Work done with Gösta Gustafson and Leif Lönnblad.

Contents

- Model description.
  - Virtual initial state cascade.
  - The Interaction.
    - Inclusive observables.
  - The real gluons, FSR and hadronisation.
    - Exclusive observables.
- Results in *pp*.
- Heavy ions (and other 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 probabilities.



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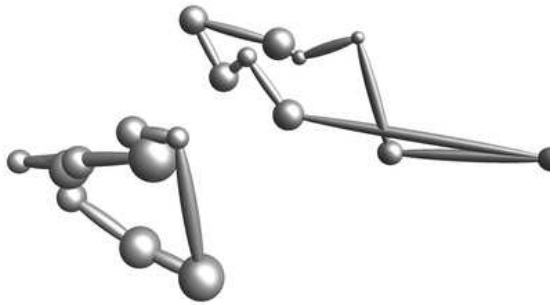

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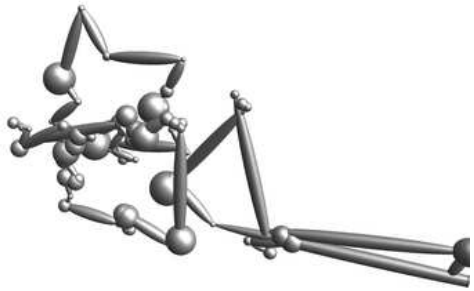
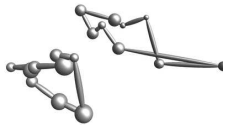
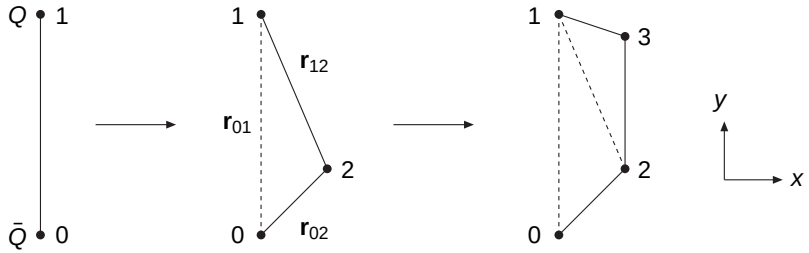


Evolution



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

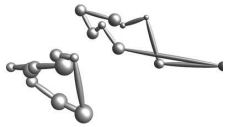
$$\frac{dP}{dy} = \frac{\bar{\alpha}}{2\pi} d^2 r_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$$



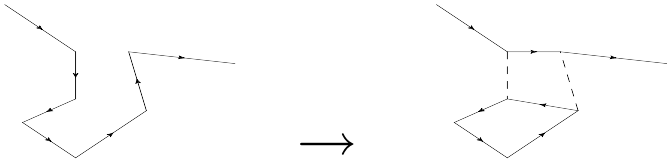
Corrected for the essential parts of NLL BFKL.

- 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_-).

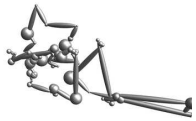
Evolution



- 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}:

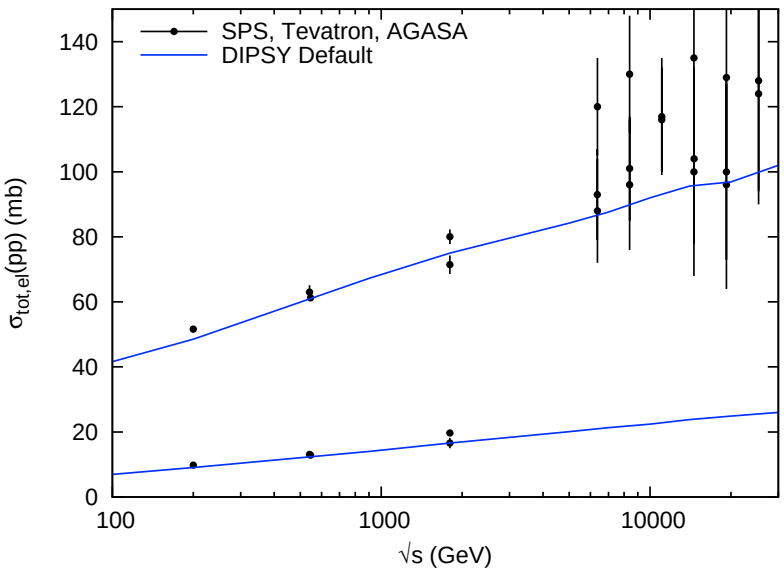
$$F = \sum_{ij} f_{ij} \qquad f_{ij} = \frac{\alpha_s^2}{2} \ln^2 \left(\frac{r_{13} r_{24}}{r_{14} r_{23}} \right)$$

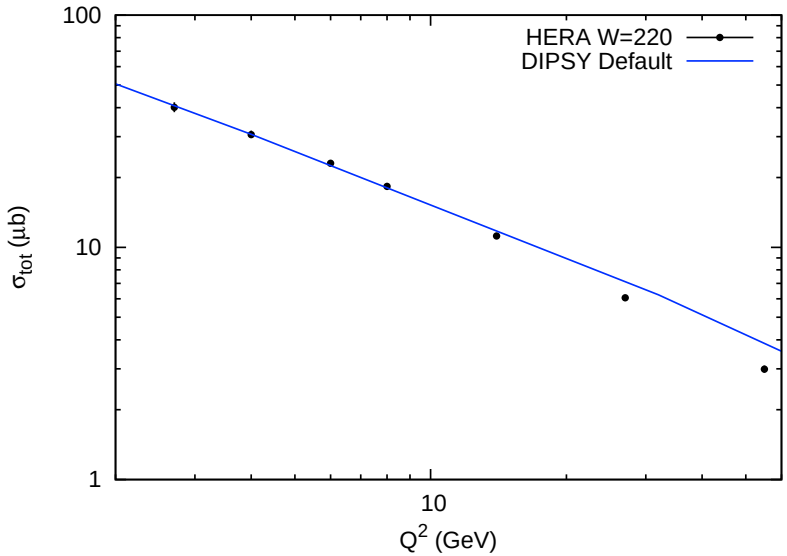
Cross sections from the eikonal formalism (average over cascades):

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

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

Some total cross sections.

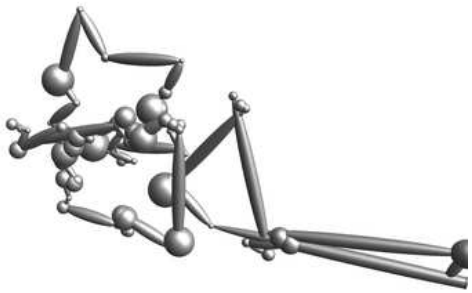




Used to tune many parameters that affects exclusive observables.

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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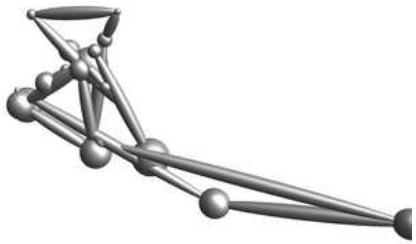

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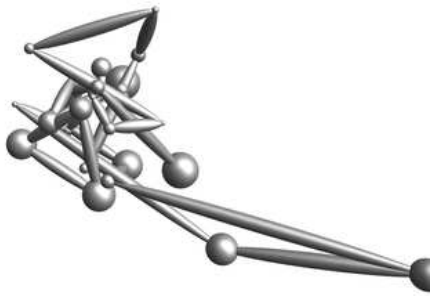

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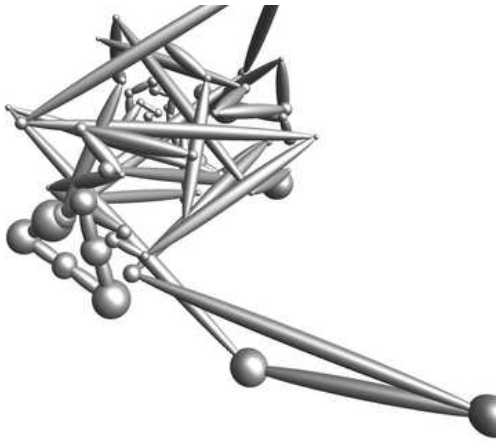
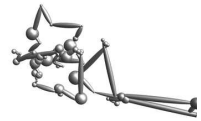




Non-diffractive interaction probability

- Non-diffractive interaction probability is total - diffractive:

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

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

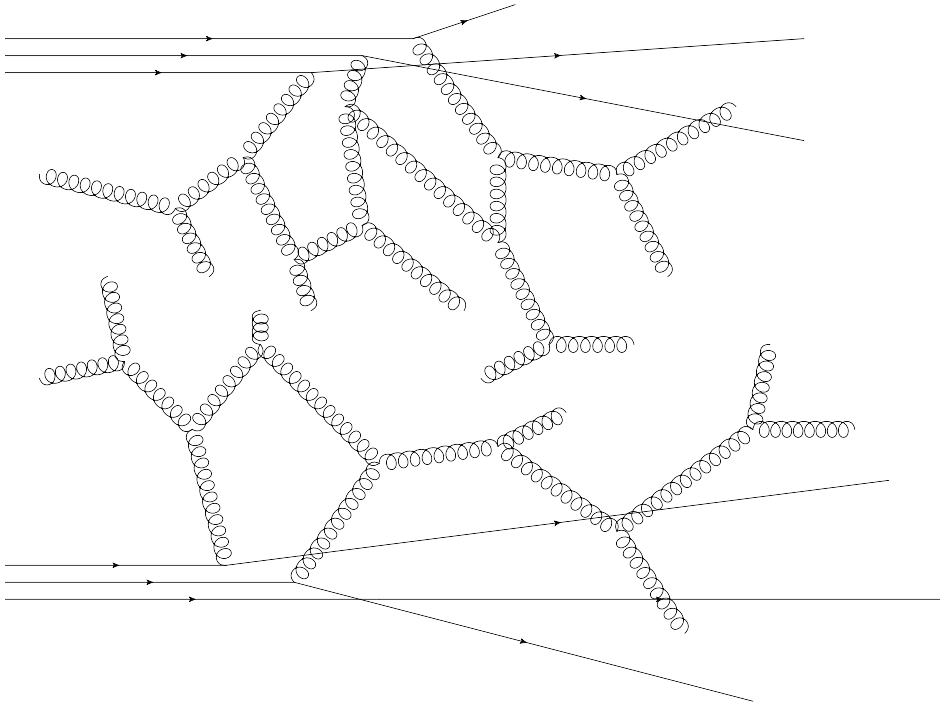
$$1-e^{-2\sum f_{ij}} = 1-\prod e^{-2f_{ij}}$$

- 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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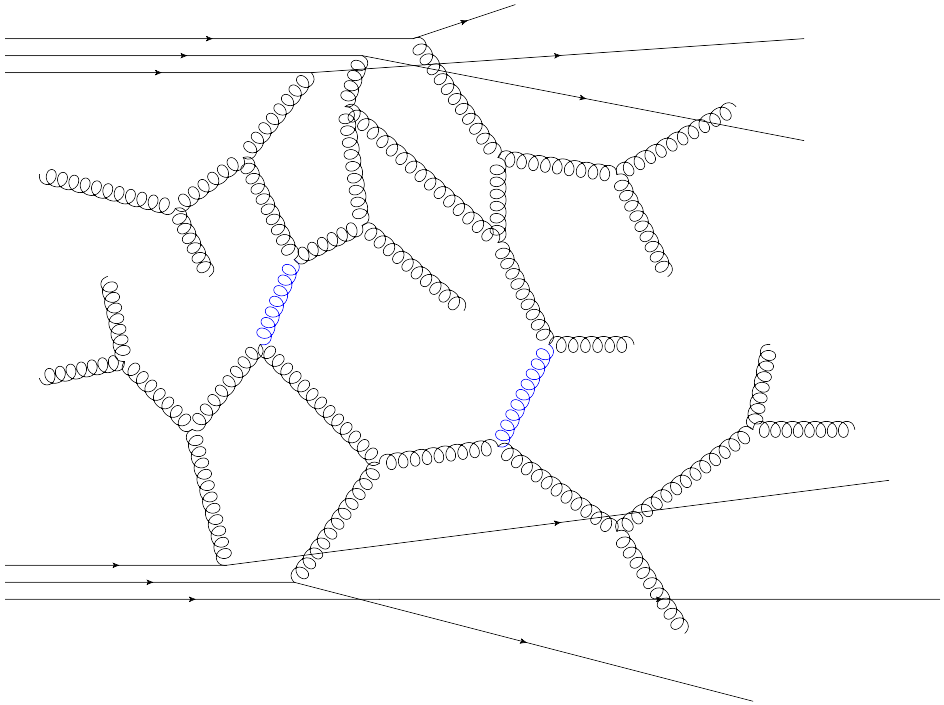

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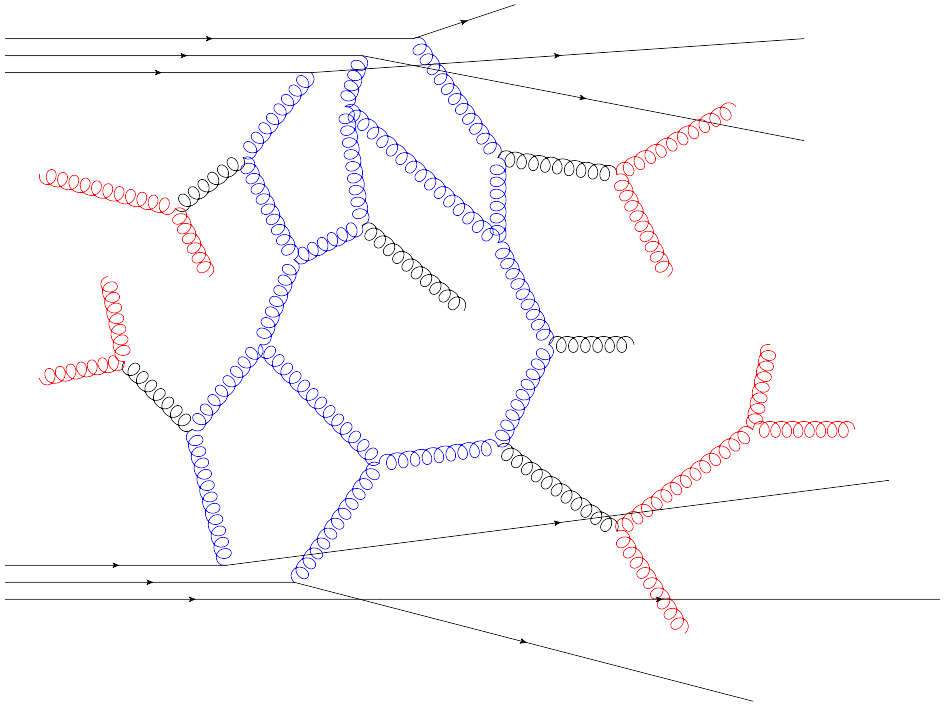
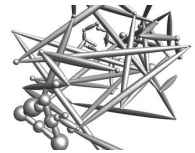


Details...

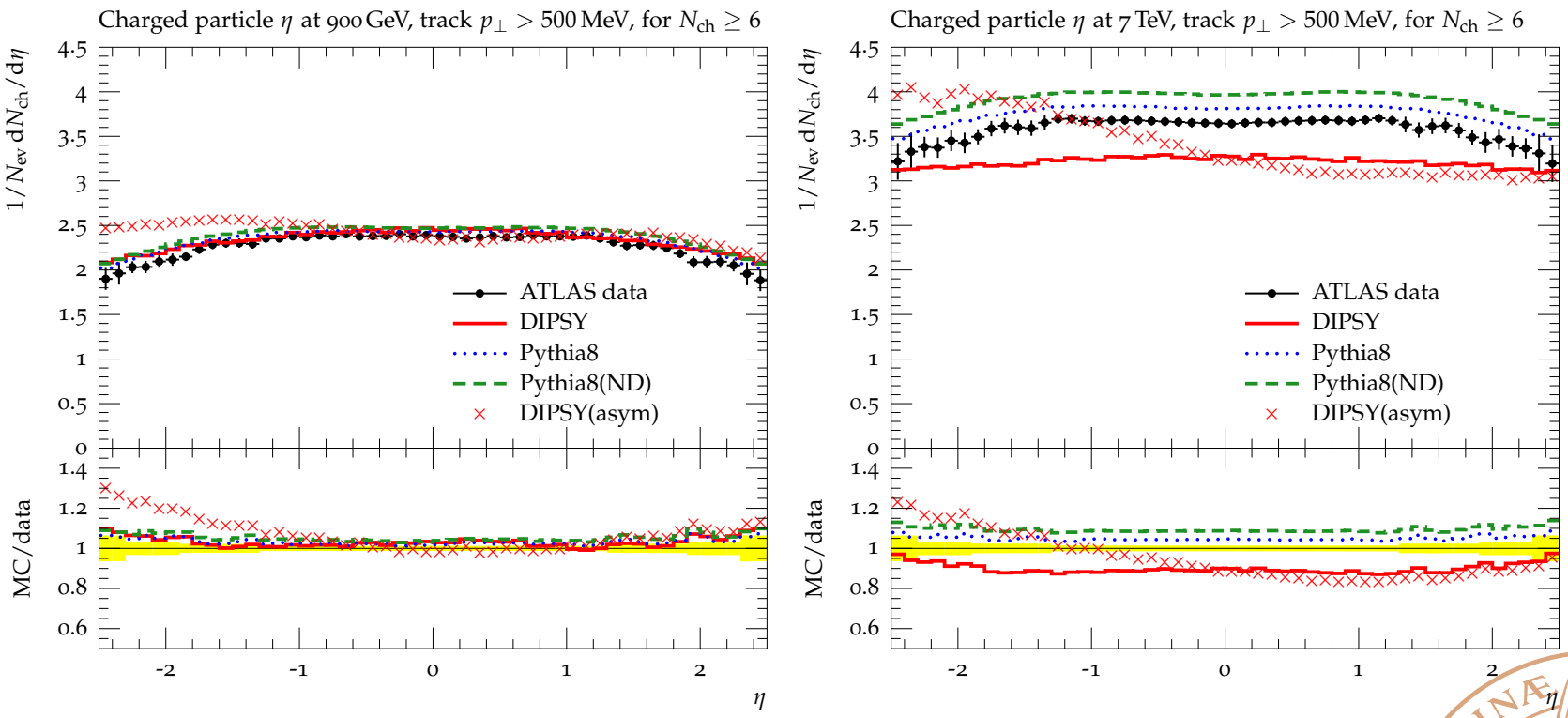
- There are plenty of subtleties where perturbative QCD gives little guidance, but that still affects observables. See `arXiv:1103:4321` for further details.
  - reweighting of some $k_\perp$-max in evolution.
  - deciding what parents to put on shell.
  - formulation of ordering and coherence.
  - and 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

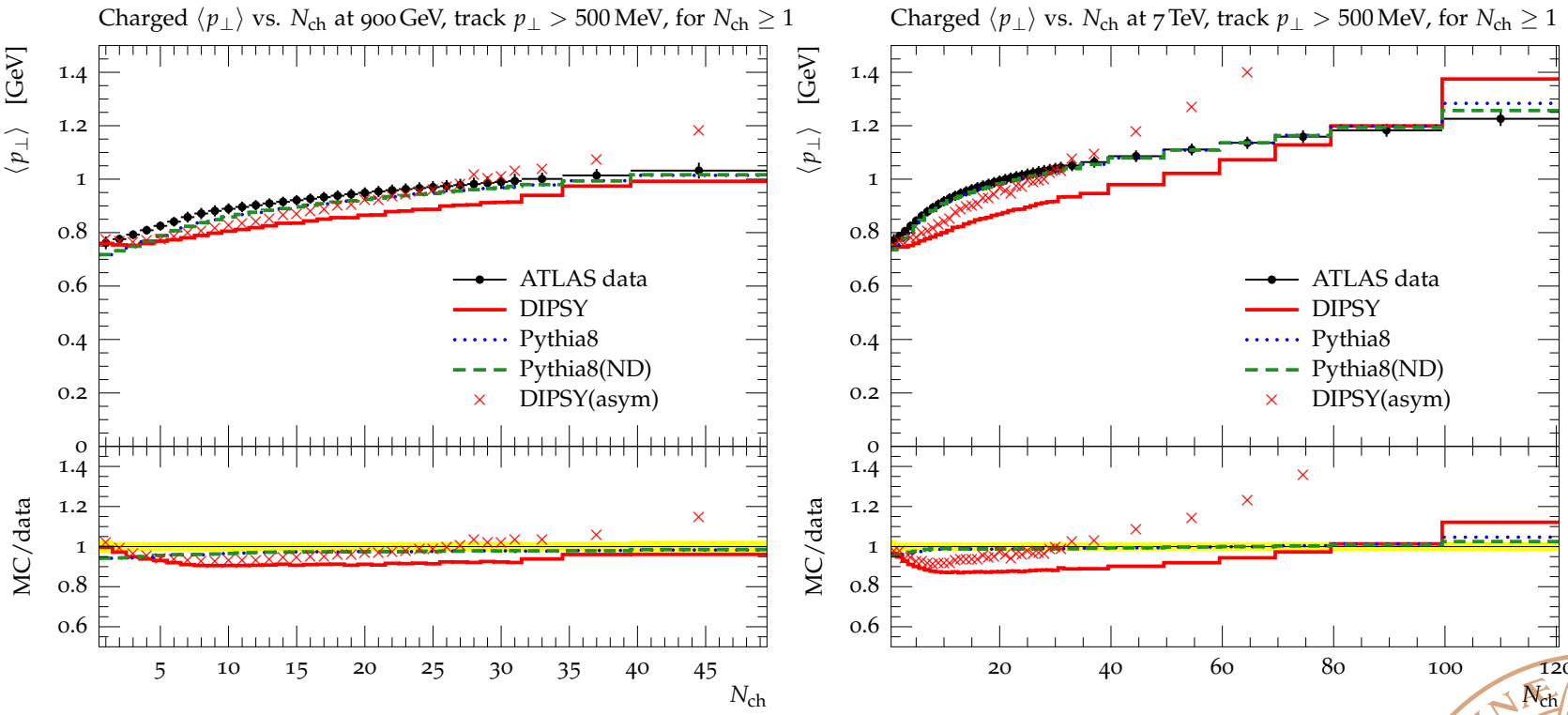
- FSR fills up the remaining phase space (emissions that are unordered in $p_{\pm}$).
- FSR with the ARIADNE Monte Carlo, based on the Linked Dipole Chain model.
- Hadronisation with the Lund String Model using PYTHIA 8.

ATLAS data



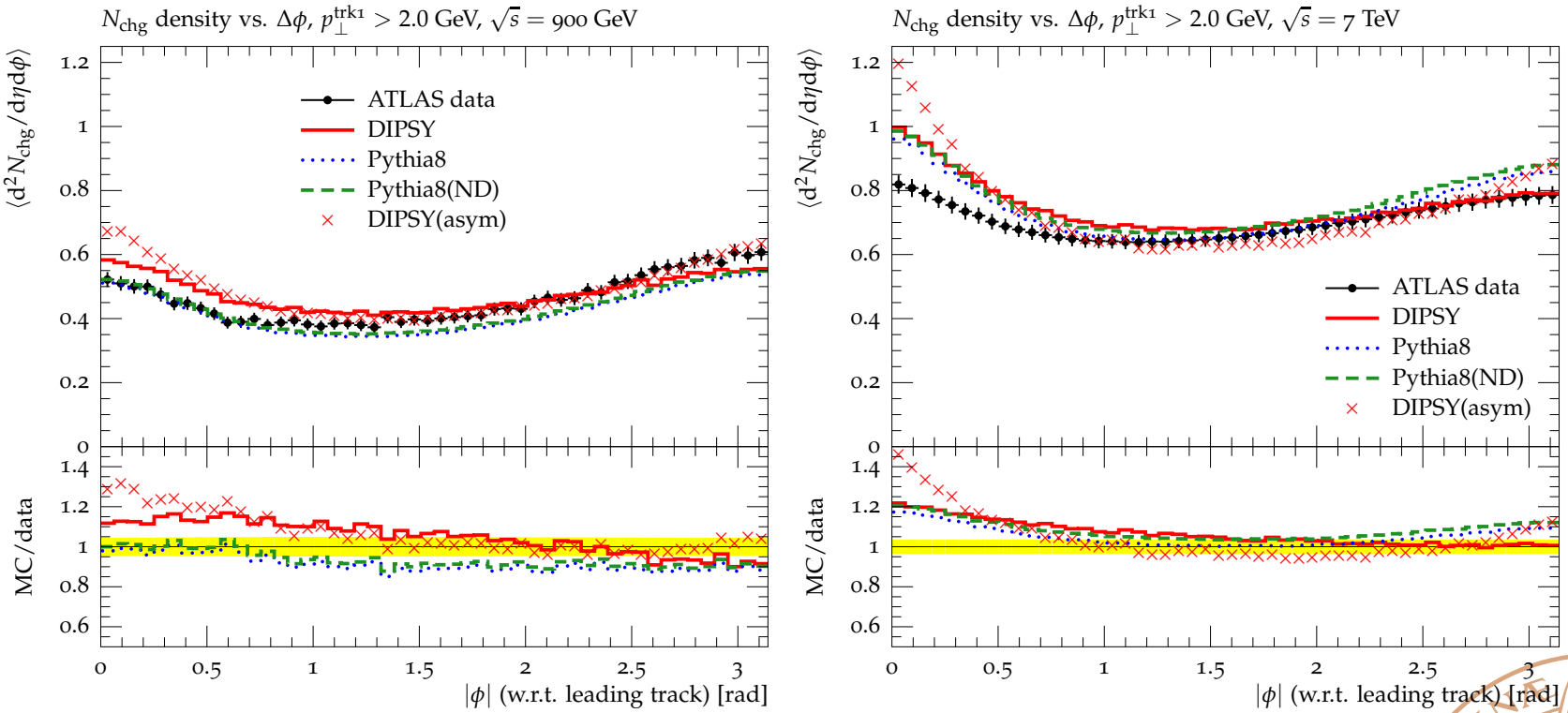
Pseudorapidity distributions of charged particles at 0.9 and 7 TeV.

ATLAS data



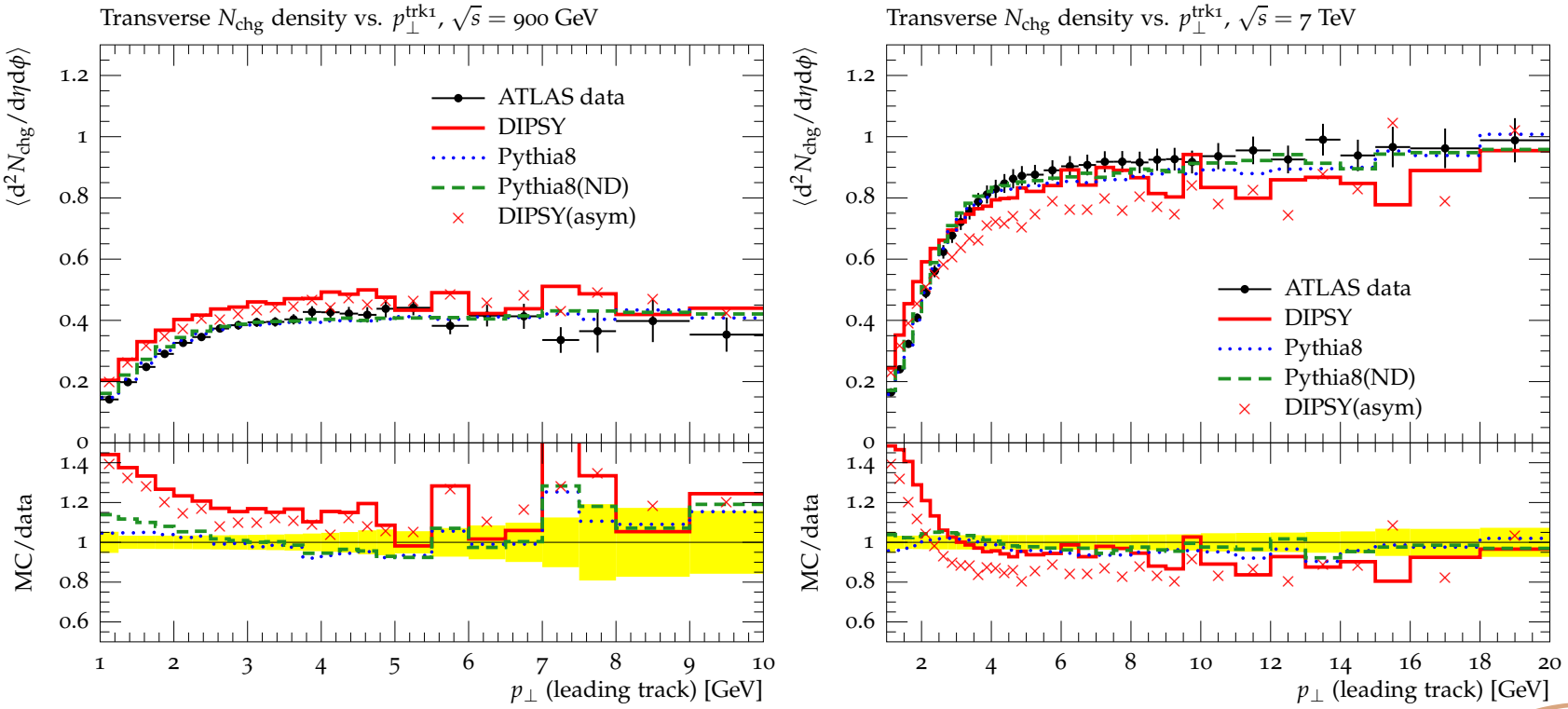
Average transverse momentum as function of charged multiplicity at 0.9 and 7 TeV.

ATLAS data



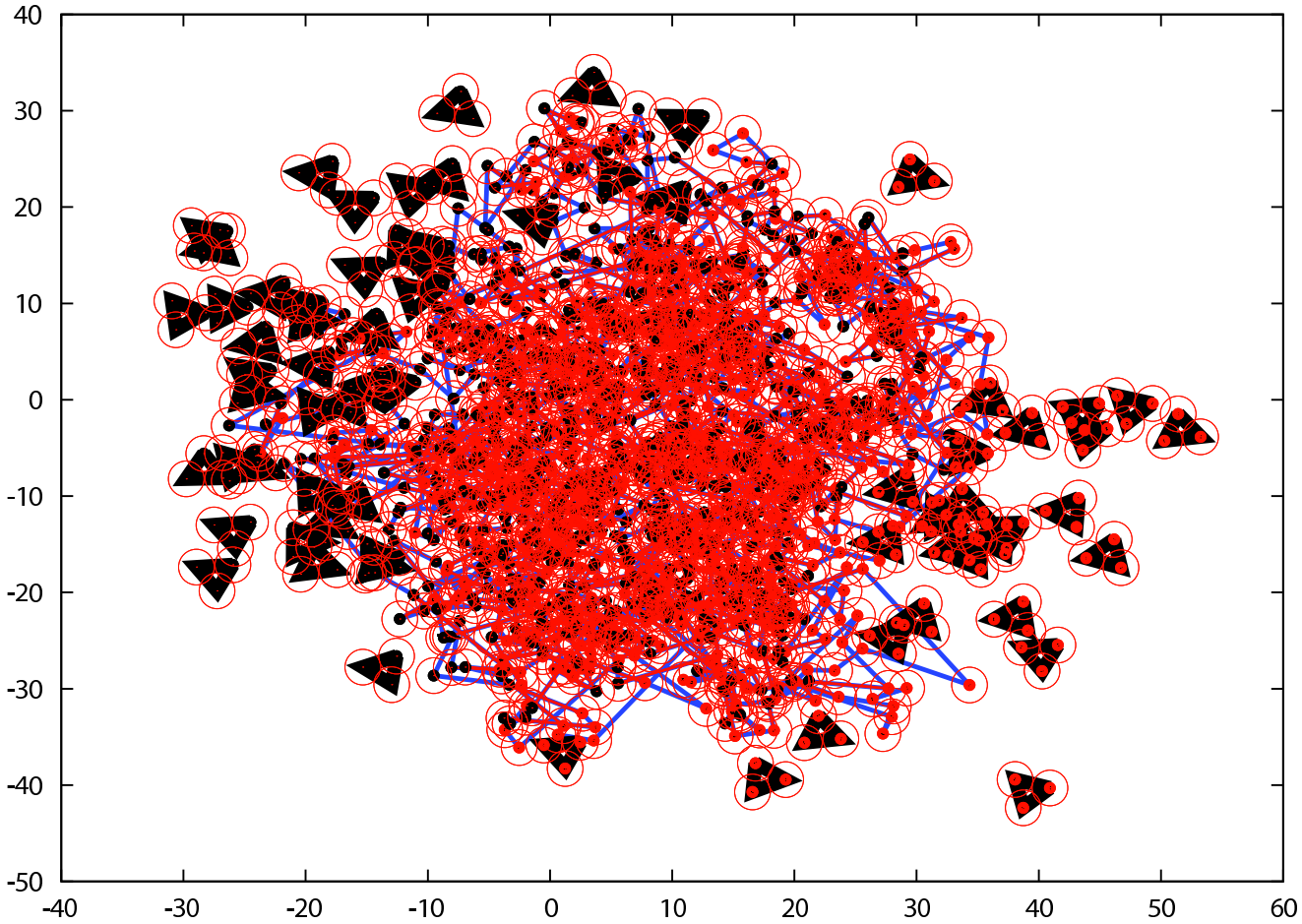
Multiplicity as function of azimutal angle w.r.t. a leading charged particle of at least 2 GeV.

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`.

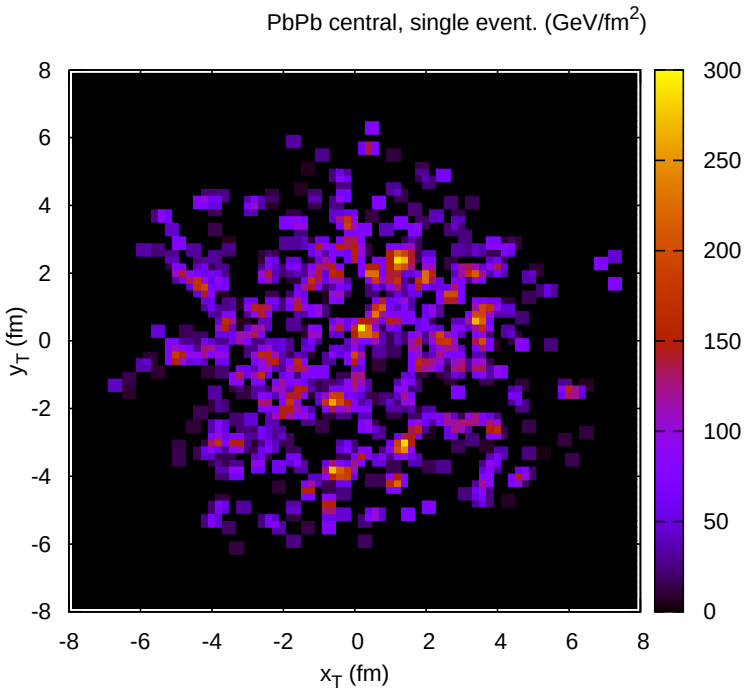
AA

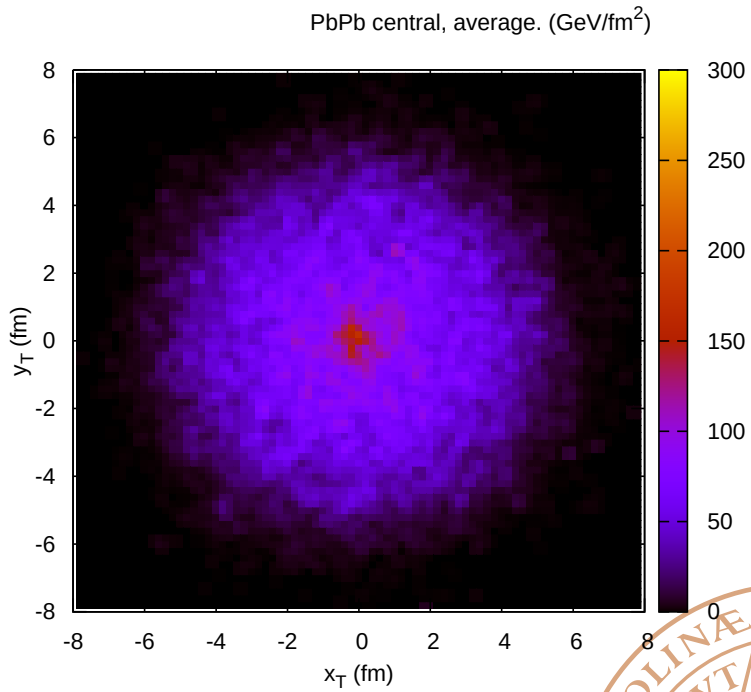


AA

- 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)

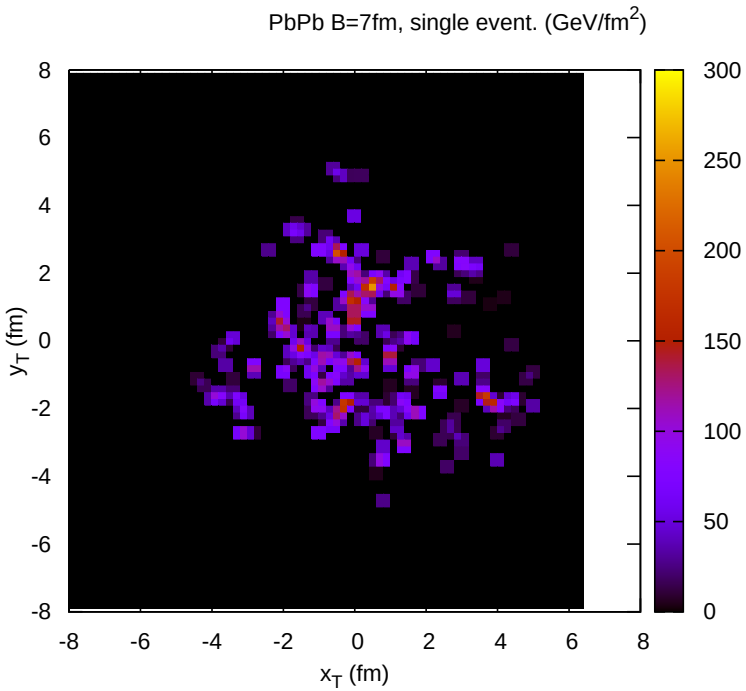
Energy density, Central Pb-Pb at LHC, Preliminary!

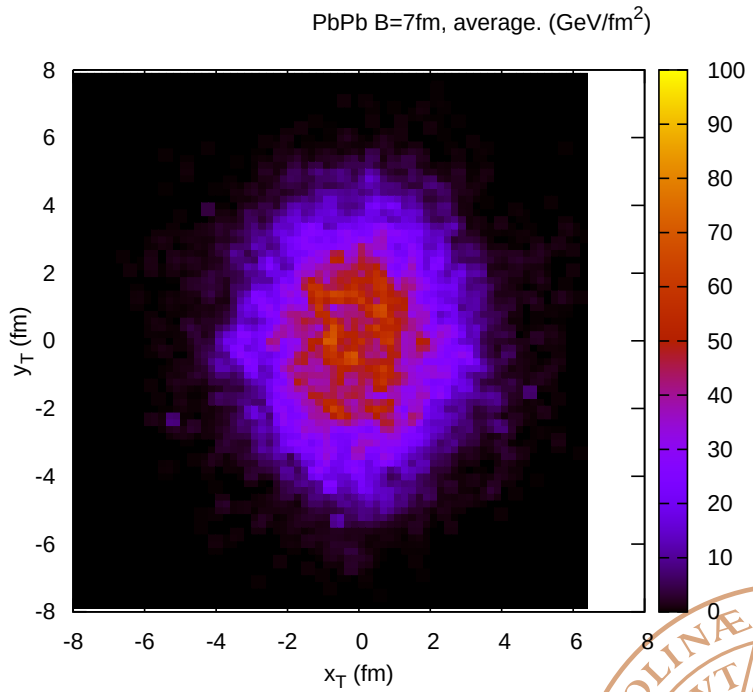




Summed over t=0 gluons with rapidity -1 to 1.

Energy density, b = 7fm Pb-Pb at LHC, Preliminary!





Summed over t=0 gluons with rapidity -1 to 1.

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 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, $\gamma^* p$, $\gamma^* A$.

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