DIPSY
a new generator for minimum bias and heavy ion collisions

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Outline

- The modified Mueller dipole model
- Obtaining exclusive final states
- Comparing with data
- Going to Heavy Ions

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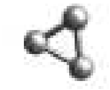
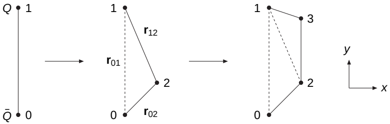
DIPSY (with Christoffer Flensburg and Gösta Gustafson)



The virtual cascade



- Muellers formulation of BFKL
- $\frac{dP}{dy} = \frac{\bar{\alpha}}{2\pi} d^2 r_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$
- Dipoles in impact parameter space, evolved in rapidity
- Builds up virtual Fock-states of the proton

Non-leading effects

- Running α_s
- Introduce $k_\perp \sim 1/r$ to get energy–momentum conservation.
  (Ordering in p_+ and p_- gives a dynamic cutoff)
- Non-perturbative regularization with small gluon mass (confinement effects)

The interaction

- Dipole–dipole interaction:
  $F = \sum_{ij} f_{ij} \qquad f_{(12)(34)} = \frac{\alpha_s^2}{2} \ln^2\left(\frac{r_{13}r_{24}}{r_{14}r_{23}}\right)$
- Unitarize to get saturation effects (pomeron loops):
  $F \to 1 - e^{-F}$
- Without energy conservation we get exponential growth of small dipoles which do not interact
- Non-perturbative regularization with small gluon mass
- Rederive Mueller's expression above in transverse momentum space for final states.

The Swing

- The unitarized interaction probability gives pomeron loops only in the interaction frame.
- To be Lorentz invariant we want them also in the evolution
- Accomplished by the *Swing* (colour reconnection)
- Two dipoles with the same colour may reconnect.
- Does not reduce the number of dipoles, but smaller dipoles are favoured, and these have weaker interactions.
- In the end we get saturation in both evolution and interaction

We now have a model for inclusive and semi-exclusive observables, which includes explicit modeling of fluctuations in the initial state

- pp and ep-DIS total cross section OK
- pp and ep-DIS (quasi) elastic cross section OK including t-dependence
- pp and ep-DIS diffraction OK
- Double parton scattering at the LHC — interesting predictions
  (σ_{eff} depends more on jet $p_{\perp}$ than on x and rapidity)

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But we want fully exclusive hadronic final states

Real gluons

We have generated the gluonic Fock-states of the colliding protons.

Most of the gluons in this state are simply virtual fluctuations, which will not make it to the final state.

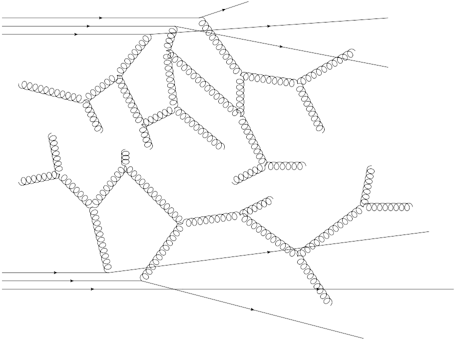
In the momentum picture all gluons in the proton with large p_+ will be off-shell with a negative p_- component.

Only those gluons which actually collides (or have children which collides) with gluons from the proton with large p_- will be able to come on-shell. All others must be reabsorbed.

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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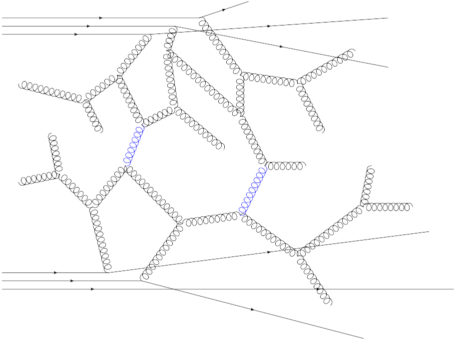

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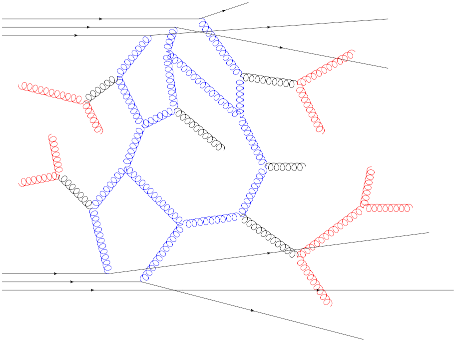


But... energy–momentum conservation effects were taken into account assuming all gluons were real. When some are reabsorbed the kinematics will change.

Also some sequences of emissions in the evolution will correspond to local hard scatterings in some frame, and these will not get the proper $\sim 1/q_\perp^4$ behavior.

In the end we want to just have *primary* (a.k.a. backbone) gluons left, which are ordered in both q_+ and q_- (and hence also in rapidity).

These are the ones we know gives the non-vanishing contributions to the cross section.

- Choose which dipoles interact: $1 - e^{-F_{ij}}$
- Take away non-interacting gluons
- Take away kinematically impossible interactions/gluons
- Take away wrongly distributed sub-scatterings
- Take away non-ordered gluons

Final state radiation and hadronization

The primary gluons are now sent to ARIADNE for final-state showering.

This is a unitary procedure and only emissions which are *unordered* in q_+ and q_- w.r.t. the primary gluons are allowed.

Then we send everything to PYTHIA8 for hadronization.

Frame-independence

We have quite a lot of parameters:

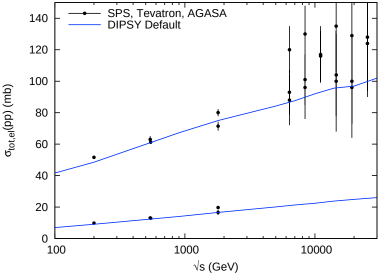
- R_{max}: Non-perturbative regularization
- R_p: Proton size ($\approx R_{\mathrm{max}}$)
- w_p: Fluctuations in the initial proton size (small)
- Λ_{QCD}: in the running α_{s}
- λ_r: Swing parameter (saturated)

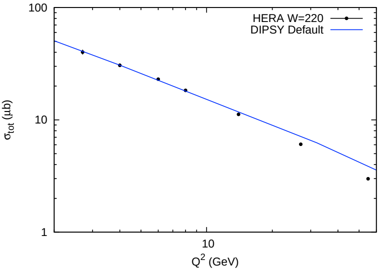
Most of these can be fit to the total and elastic cross sections.

But there are also a lot of choices made for which no guidance can be found in perturbative QCD, especially for the selection of the real gluons.

Most of these can be fixed by requiring frame-independence.

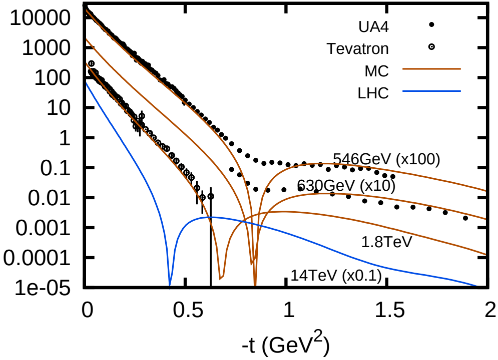
Some inclusive cross sections.



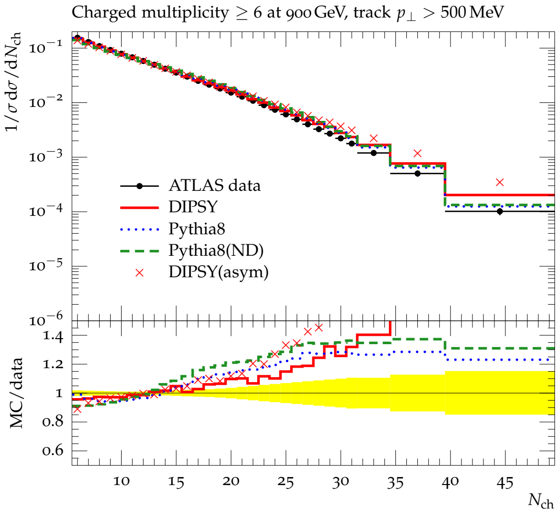


Total and elastic $\sigma_{pp}(\sqrt{s})$ (left) and total $\sigma_{\gamma^* p}(Q^2)$ (right).
(Also hits ATLAS inelastic cross section.)

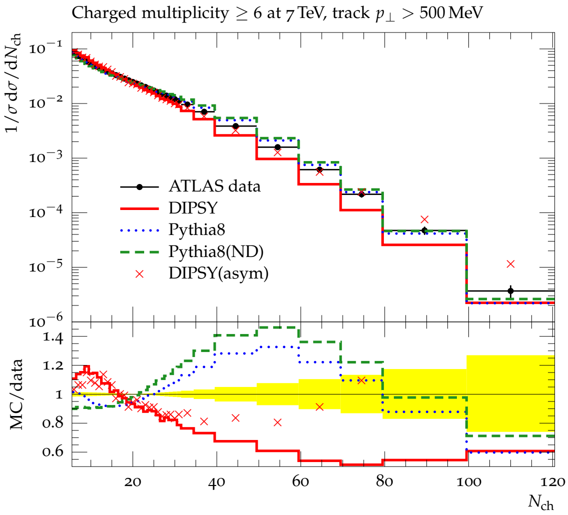
t-dependence of elastic cross section

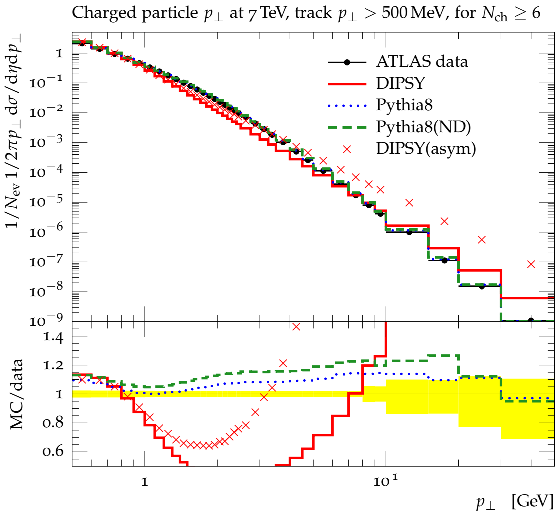


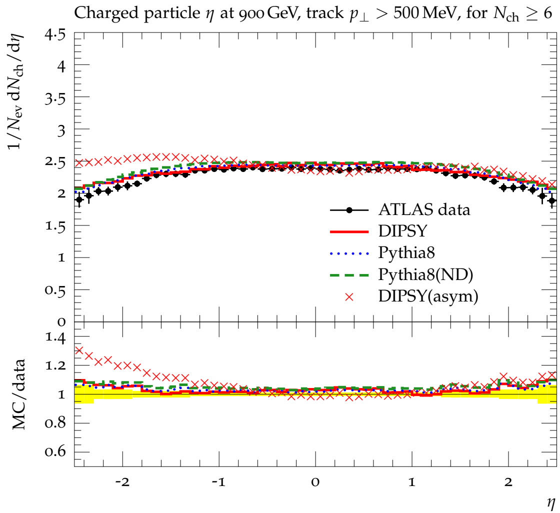
Final-state observables



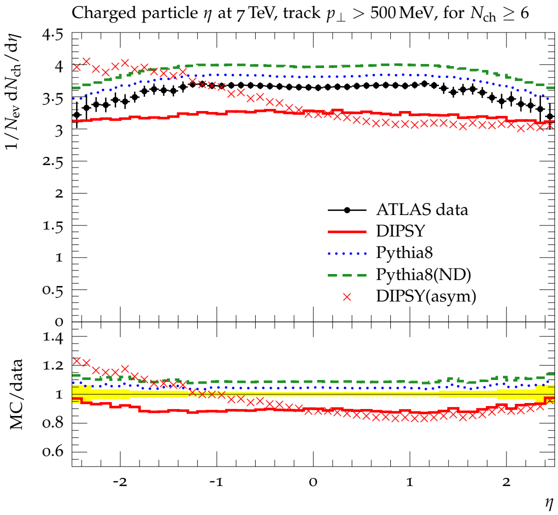
More plots on `http://home.thep.lu.se/~leif/DIPSY.html`


Charged multiplicity ≥ 6 at 7 TeV, track $p_\perp$ > 500 MeV
$1/\sigma\, d\sigma/dN_{ch}$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
ATLAS data
DIPSY
Pythia8
Pythia8(ND)
DIPSY(asym)
MC/data
1.4
1.2
1
0.8
0.6
20
40
60
80
100
120
N_{ch}


Charged particle $p_\perp$ at 7 TeV, track $p_\perp > 500$ MeV, for $N_{ch} \geq 6$
$1/N_{ev}\, 1/2\pi p_\perp\, d\sigma/d\eta dp_\perp$
ATLAS data
DIPSY
Pythia8
Pythia8(ND)
DIPSY(asym)
MC/data
$p_\perp$ [GeV]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
1.4
1.2
1
0.8
0.6
1
10^{1}



Charged particle η at 900 GeV, track $p_\perp > 500$ MeV, for $N_{ch} \geq 6$
$1/N_{ev}\, dN_{ch}/d\eta$
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
ATLAS data
DIPSY
Pythia8
Pythia8(ND)
DIPSY(asym)
MC/data
1.4
1.2
1
0.8
0.6
-2
-1
0
1
2
η



Charged particle η at 7 TeV, track $p_\perp > 500$ MeV, for $N_{ch} \geq 6$
$1/N_{ev}\, dN_{ch}/d\eta$
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
ATLAS data
DIPSY
Pythia8
Pythia8(ND)
DIPSY(asym)
MC/data
1.4
1.2
1
0.8
0.6
-2
-1
0
1
2
η

Valence configuration

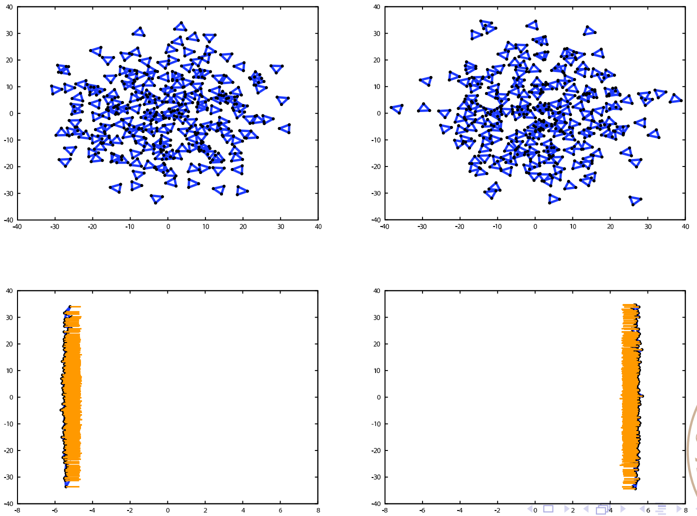
In general the description of data is worse than for PYTHIA8 (Tune 4c), but better than most other generators (c.f. `mcplots.cern.ch`).

One main problem is the naive valence configuration used: we may get very high energy gluons interacting and giving too hard jets in the forward region. (We're working on it).

Heavy Ions

- An ion starts as A nucleons (dipole triangles) distributed in transverse space.
  - Wood-Saxon with hard core.
- The swings, within and between nucleons, describe the saturation in the evolution.
- Get a full partonic picture with both momentum and transverse position.
- Dynamically describes all fluctuations and correlations.
- No new model dependence! (only nucleon distribution) Everything tuned from pp and $\gamma^* p$.
- (DIPSY is a bit too slow right now, $\sim$30 min for an LHC event)

Sample Au-Au event



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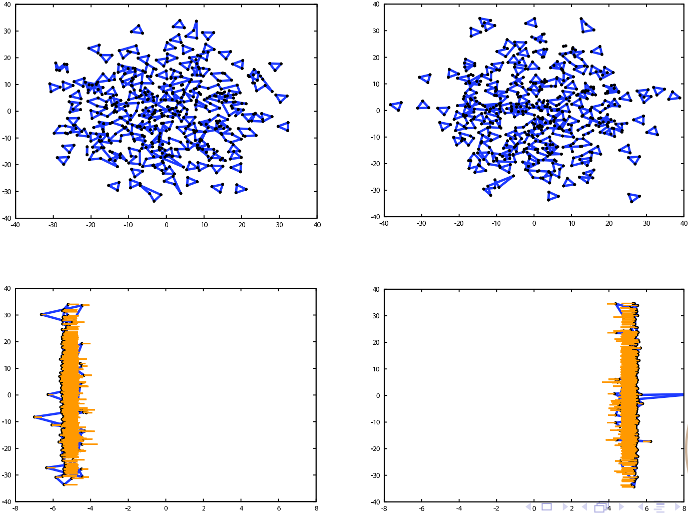

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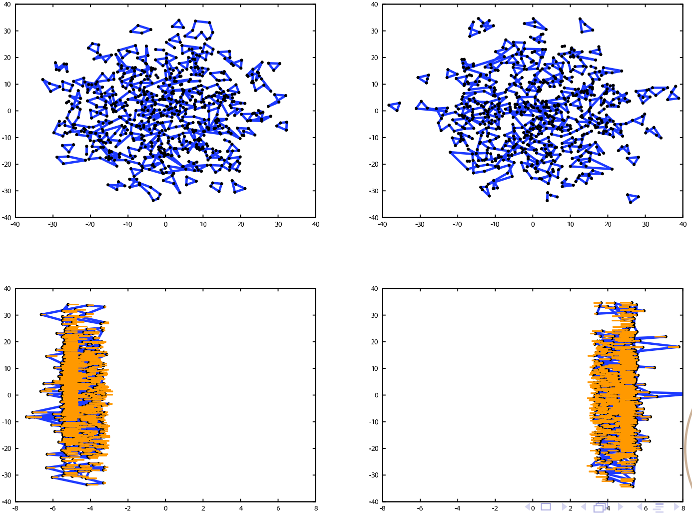

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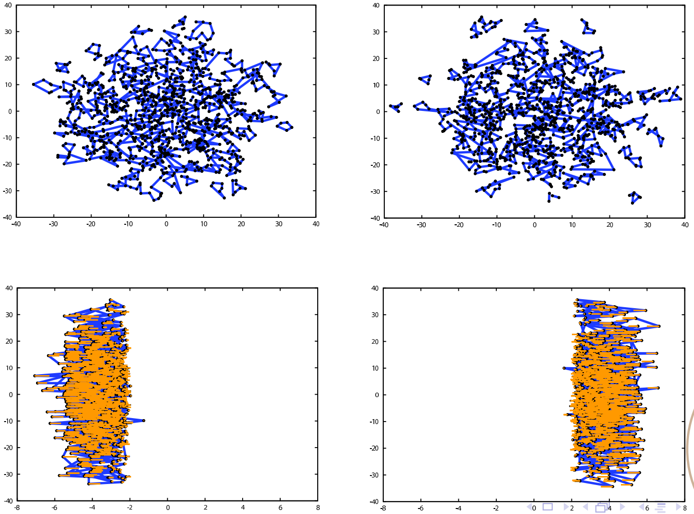

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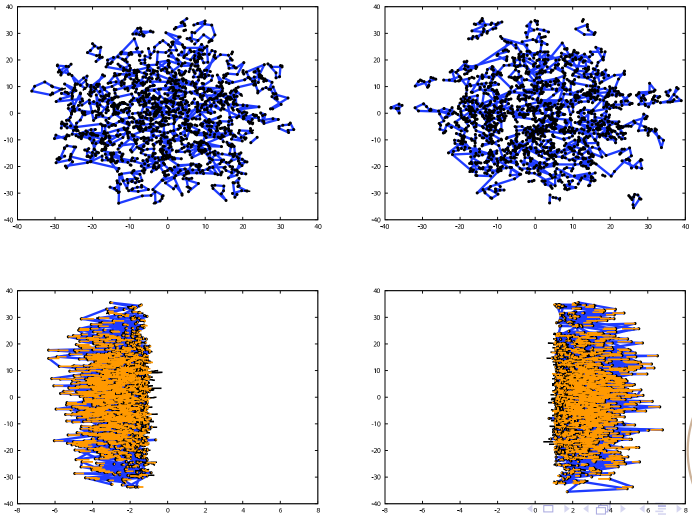

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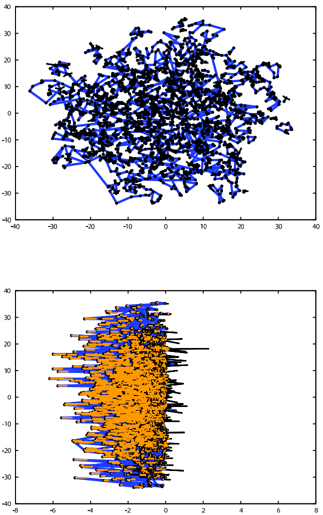

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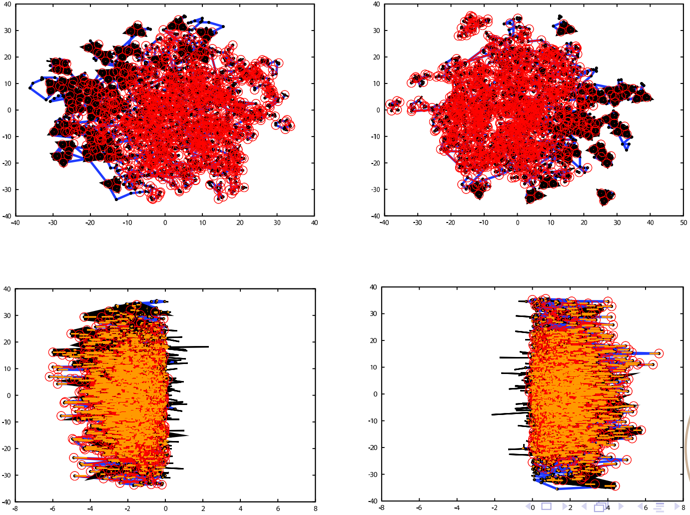

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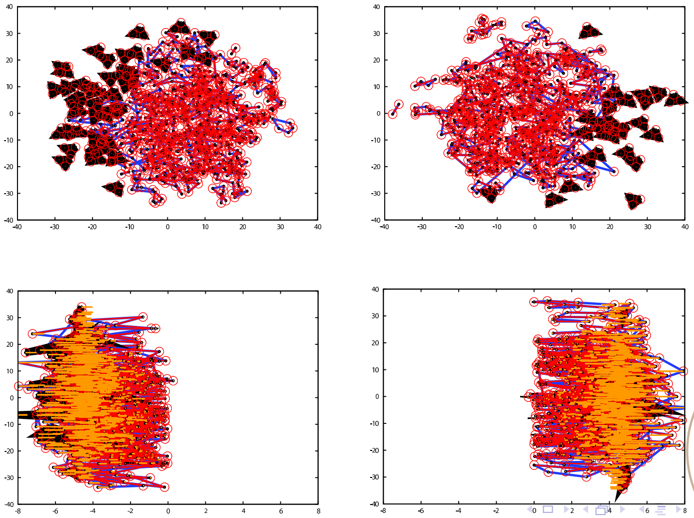

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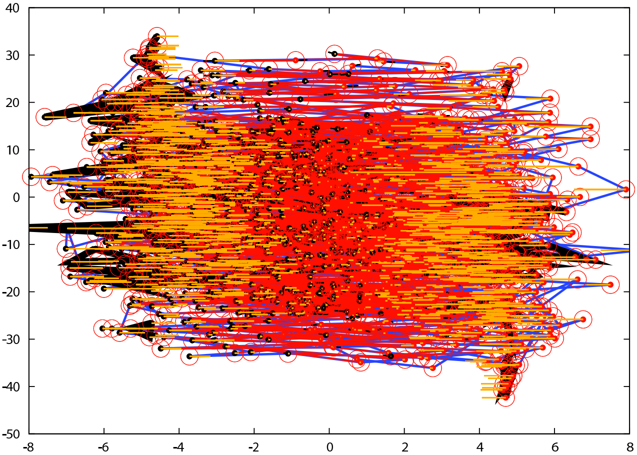

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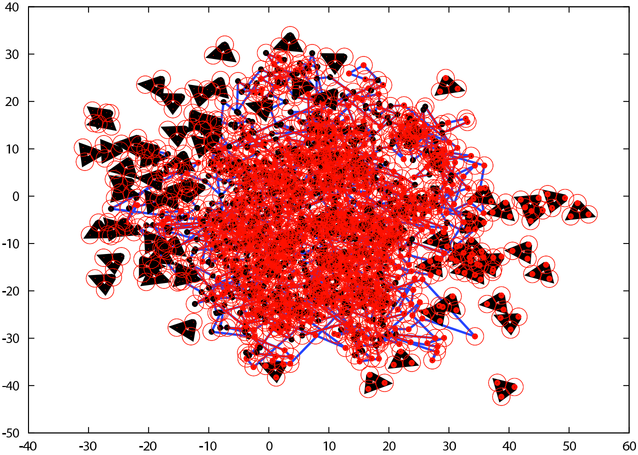

Outlook

DIPSY is working, but there are things to do:

- NLL effects (quarks, non-singular terms)
- ME-corrections for high-$p_\perp$
- Improved valence structure (fuzzy valence)
- Final-state swing (re-tune)
- Diffractive final states
- Speed-up heavy ions
- Final state effects in HI
  (quenching? hydro? rescatterings?)