Underlying Event and Hadronization in DIPSY and Pythia8

Christian Bierlich

bierlich@thep.lu.se

with: Jesper Christiansen, Gösta Gustafson, Leif Lönnblad, Harsh Shah, Andrey Tarasov

Lund University

May 4, 2017

Quark Gluon Plasma in the Underlying Event?

- Two uses of the UE, complements each other:
    1. Background for searches etc.
    2. Understanding of proton structure $\rightarrow$ soft QCD.
- Usual picture of UE:
    1. Several (almost) uncorrelated partonic interactions.
    2. Apply parton shower, correct final configuration with CR.
    3. Hadronize with strings or clusters.
- Picture being questioned by Quark Gluon Plasma behaviour in pp and pA.
    - $\rightarrow$ The end for jet universality?
    - $\rightarrow$ Or a new beginning for soft physics models?
    - $\rightarrow$ And what about QGP formation in AA?
- This talk:
    1. DIPSY – an alternative description of the UE.
    2. Rope hadronization, final state interactions of strings.
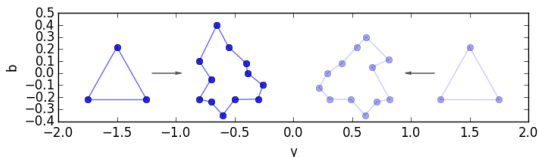   3. Hadron flavours and the ridge.

The DIPSY formalism (Flensburg et al. arXiv:1103.4321 [hep-ph])

- DIPSY is an initial state model:

    Dipole evolution in **I**mpact **P**arameter **S**pace and rapidit**Y**.

- DIPSY replaces PDFs and ISR with dipole evolution:

$$\frac{dP}{dY} = \frac{3\alpha_s}{2\pi^2} d^2\vec{z} \frac{(\vec{x} - \vec{y})^2}{(\vec{x} - \vec{z})^2(\vec{z} - \vec{y})^2}$$

- Evolution in real space and rapidity $\rightarrow$ provides $b_\perp$ picture of proton.
- Built on Mueller dipole model, equivalent to LL-BFKL.

(Mueller and Patel: arXiv:hep-ph/9403256)

Multiparton Interactions in DIPSY

- Gluon-gluon interactions ⇔ Dipole-dipole interactions:

$$f_{ij} = \frac{\alpha_s^2}{8} \left[\log \left(\frac{(\vec{x}_i - \vec{y}_j)^2 (\vec{y}_i - \vec{x}_j)^2}{(\vec{x}_i - \vec{x}_j)^2 (\vec{y}_i - \vec{y}_j)^2} \right) \right]^2$$

- No resonance production or jet trigger – only fluctuations.
- MPIs and total amplitude linked through optical theorem:

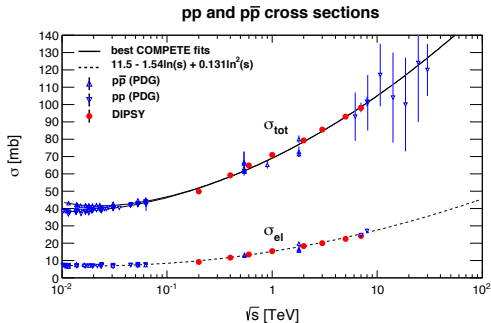$$\Im(A_{el}) = \frac{1}{2}(|A_{el}|^2 + P_{abs}); -iA_{el} = 1 - \exp\left(-\sum_{ij} f_{ij}\right).$$

- Vanilla version: linked to Ariadne FSR and Pythia 8 string hadronization.

(Lönnblad: Comput.Phys.Commun. 71 (1992) 15-31)

(Sjöstrand et al.: arXiv:1410.3012 [hep-ph])

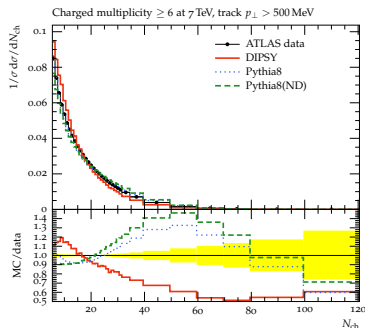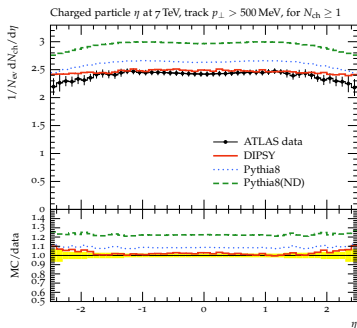# Description of UE observables

- Total amplitude gives cross sections.
- Energy dependence of $pp(\bar{p})$ reproduced nicely.

- Diffraction from fluctuations, Good–Walker formalism.

Exclusive observables I (Data: ATLAS arXiv:1012.5104 [hep-ex])

- Some energy dependence on ≈ 5 tuning parameters.
- Currently tunes exist for 0.9, 2.76 and 7 TeV.
 - $\rightarrow$ Further energies upon request.

Exclusive observables II

- Further observables available on http://home.thep.lu.se/DIPSY.
- Code available upon request.
- Interesting: Rising $\langle p_\perp \rangle (N_{ch})$ without CR.
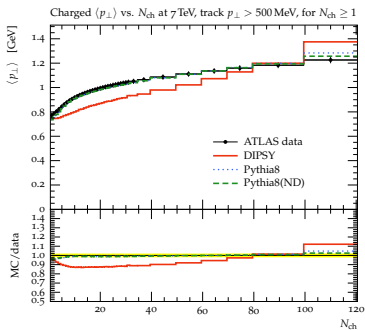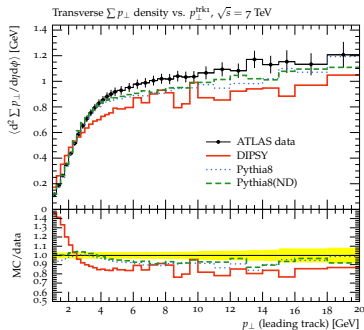
# Rope hadronization (CB et al: arXiv:1412.6259 [hep-ph])

- Strings overlapping in final state – coherence effects.
  - $\rightarrow$ Rope formation and -hadronization.
  - $\rightarrow$ Affects final state hadrochemistry.
  - $\rightarrow$ Dynamical build-up of "flow".
- Overlapping strings $\Rightarrow$ Colour multiplets.

(Biro et al: Nucl.Phys. B245 (1984) 449-468)
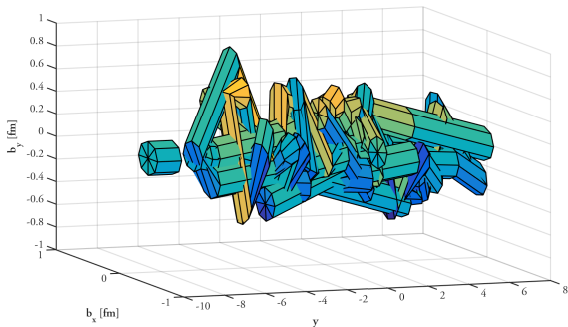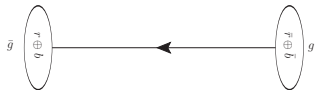
Multiplet formation

- Two strings overlapping completely.
    - → Colour charges acting coherently.
    - → Several options – random walk.
- Recursion relations combining a triplet with a multiplet.
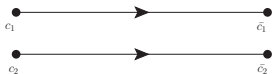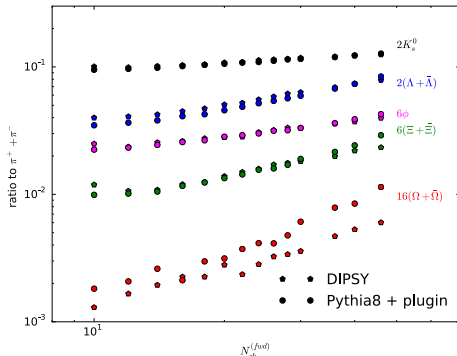

Case (a), $c_1 = c_2$:

Case (b), $c_1 \neq c_2$:

$$\{p, q\} \otimes \{1, 0\} = \{p, q - 1\} \oplus \{p - 1, q + 1\} \oplus \{p + 1, q\},$$

$$\{p, q\} \otimes \{0, 1\} = \{p - 1, q\} \oplus \{p, q + 1\} \oplus \{p + 1, q - 1\}.$$

Flavour composition – more strange quarks

- Result from lattice QCD: Sting tension scales with C_2(multiplet).
- Strange quarks suppressed by: $\exp\left(-\frac{\pi(m_s^2 - m_u^2)}{\kappa}\right)$
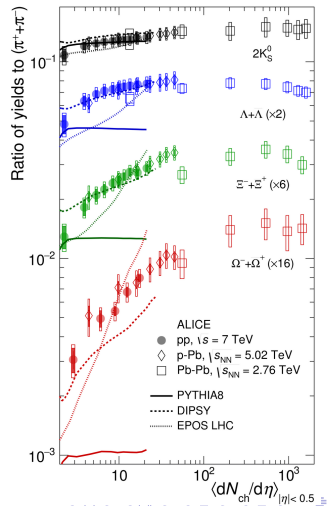

Implemented in DIPSY;

(CB and Christiansen: arXiv:1507.02091 [hep-ph])

Pythia8 by plugin: http://home.thep.lu.se/DIPSY#ropes;

(CB: arXiv:1606.09456 [hep-ph])

# Shoving – latest development, not production code

- Pressure in transverse plane from overlaps.
- Shoving resolved pair-wise, $p_\perp$ conservation.
- Practically done by adding a small excitation (gluon) to the string in each slice. (CB et al: arXiv:1612.05132 [hep-ph])
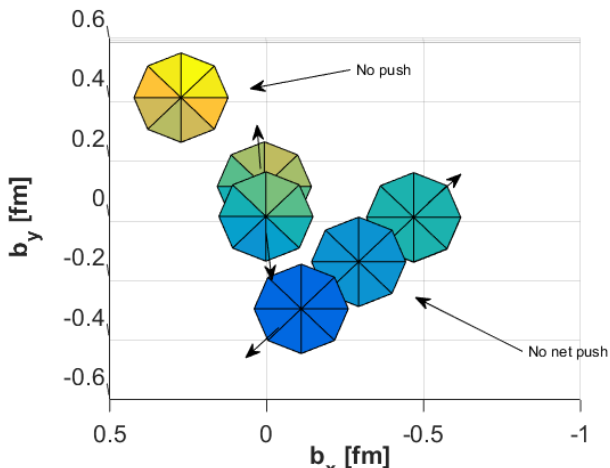
Shoving: An experimental motivation

- Ridges linked to flow seen in AA, pA and pp.
- Very well described by hydrodynamics.
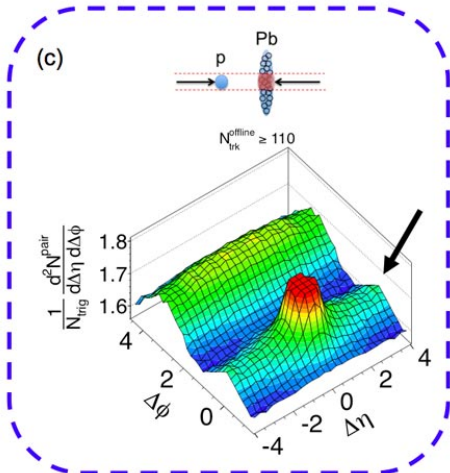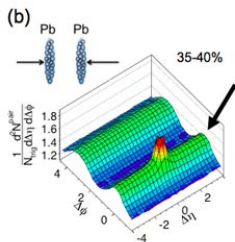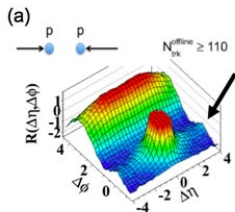
Two–particle correlations

- Shoving produces a "ridge".
- Currently for events consisting of long, soft strings only.
- Working towards a complete description.
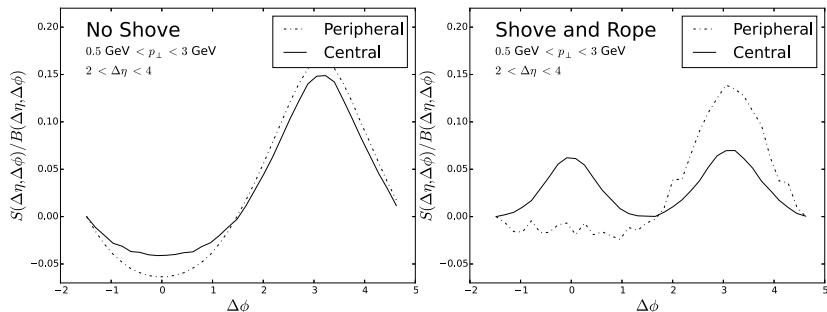
Future: extending to heavy ions (CB et al. arXiv:1607.04434 [hep-ph])

- Build up HI collisions from pp – whole new playing field!
- FritiofP8 built on Pythia, but extrapolation method is general.
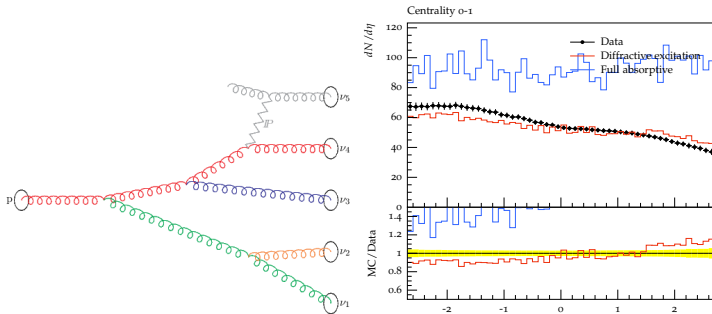
- First step: Establish good baseline.
- Can pp models explain collective effects and restore jet universality?
- Or will we ultimately need a thermalized plasma description?

Conclusions

- DIPSY: Initial state model, no PDFs, different MPI picture.
    - $\rightarrow$ Provides a very different picture of underlying events.
    - $\rightarrow$ Serves as inspiration for further studies.
- Ropes: Work on the non-perturbative phase of the final state.
    - $\rightarrow$ Good description of flavours in DIPSY and Pythia8 (as plugin).
    - $\rightarrow$ Promising description of ridge.
- Future: Plans for taking Pythia+Rope model to heavy ion collisions.
    - $\rightarrow$ FritiofP8 extrapolation model.
    - $\rightarrow$ Already pA "underlying event" description.

Backup: The shoving pressure

- $p_\perp$ push on string segment, length δl, time interval δt.
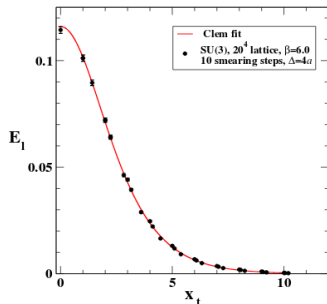- If everything starts in a point at $t = 0$ then $\delta l = t\delta y$.

$$\delta p_{\perp 12} = f_{12} \cdot \delta l \delta t = f_{12} \cdot t\delta y \delta t$$

- The force is f; chromoelectric field of effective dual s.c. (lattice).
- Approximate with Gaussian:

$$E_l = C_0 \exp\left(-\frac{x_\perp^2}{2R^2}\right)$$

- Interaction energy between two vortex lines:

$$U_{12} \propto E_l \Rightarrow f_{12} = -\frac{\partial U_{12}}{\partial x_{\perp 12}}$$

$$= Cx_{\perp 12} \exp\left(-\frac{x_{\perp 12}^2}{2R^2}\right)$$

Cea et al. arXiv:1404.1172 [hep-lat]