Underlying Event and Hadronization in DIPSY and Pythia8

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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.

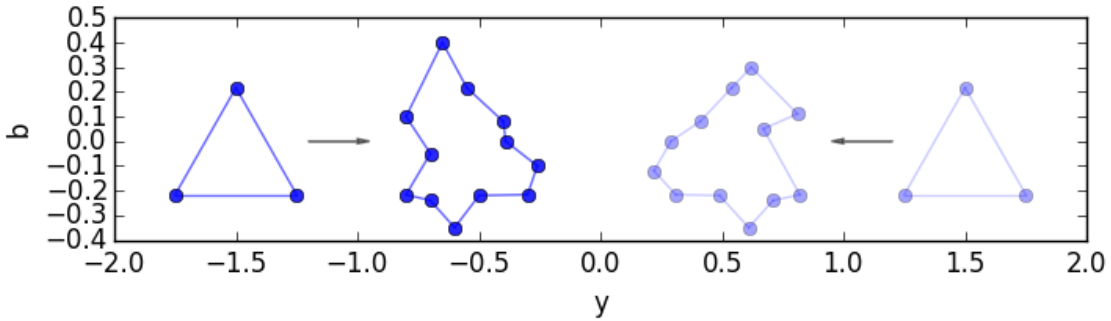
The DIPSY formalism (Flensburg et al. arXiv:1103.4321 [hep-ph])

- 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 $\Leftrightarrow$ 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:

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

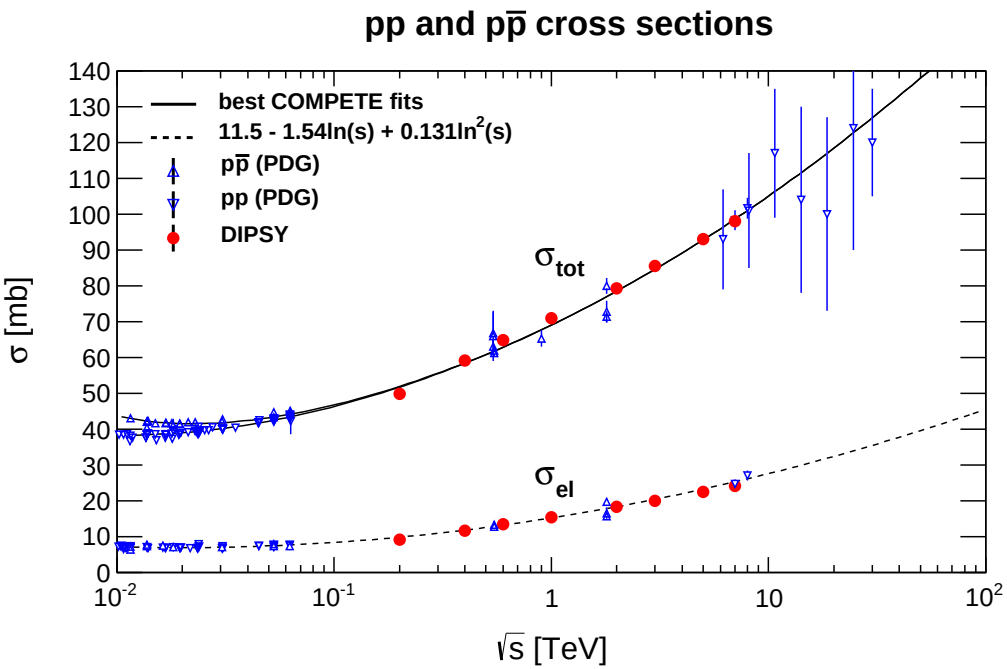
- Vanilla version: linked to Ariadne FSR and Pythia 8 string hadronization.

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

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

Description of UE observables

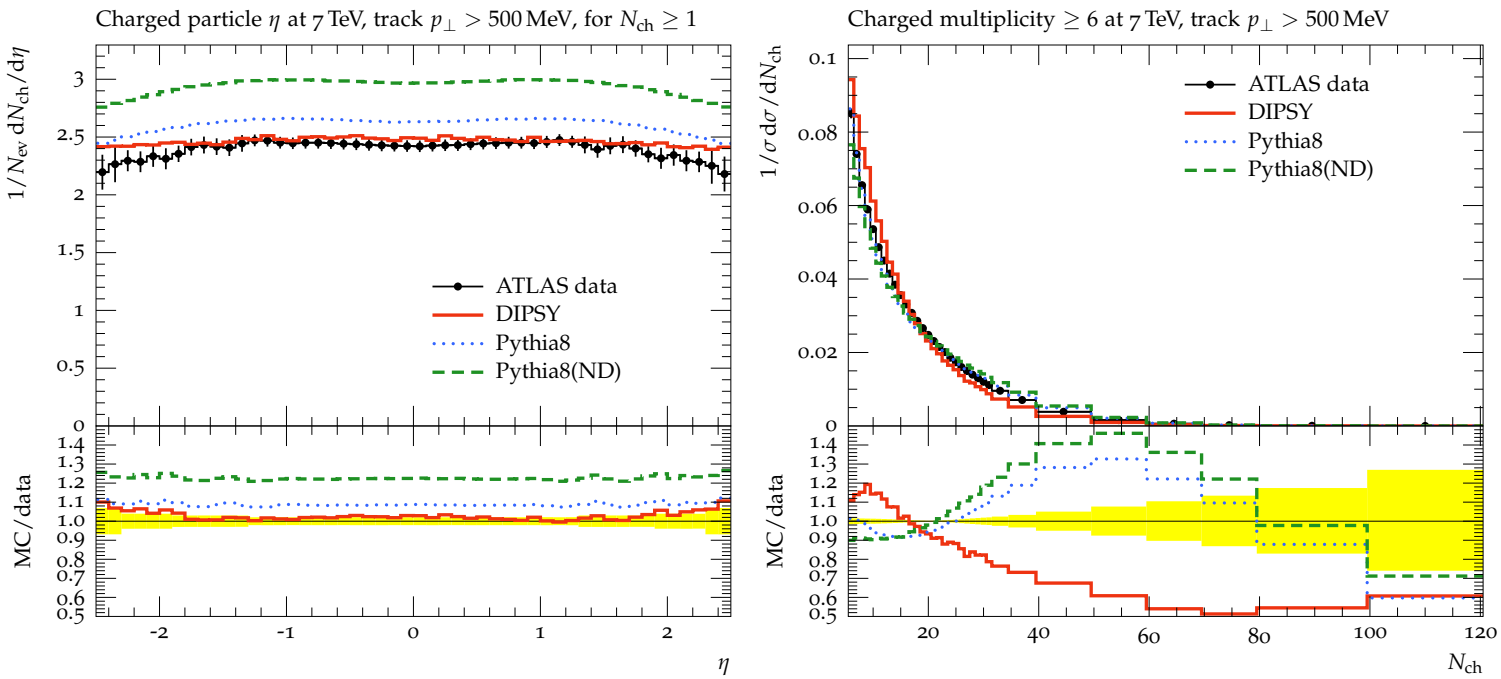
- Total amplitude gives cross sections.
- Energy dependence of $pp(\bar{p})$ reproduced nicely.



- Diffraction from fluctuations, Good–Walker formalism.

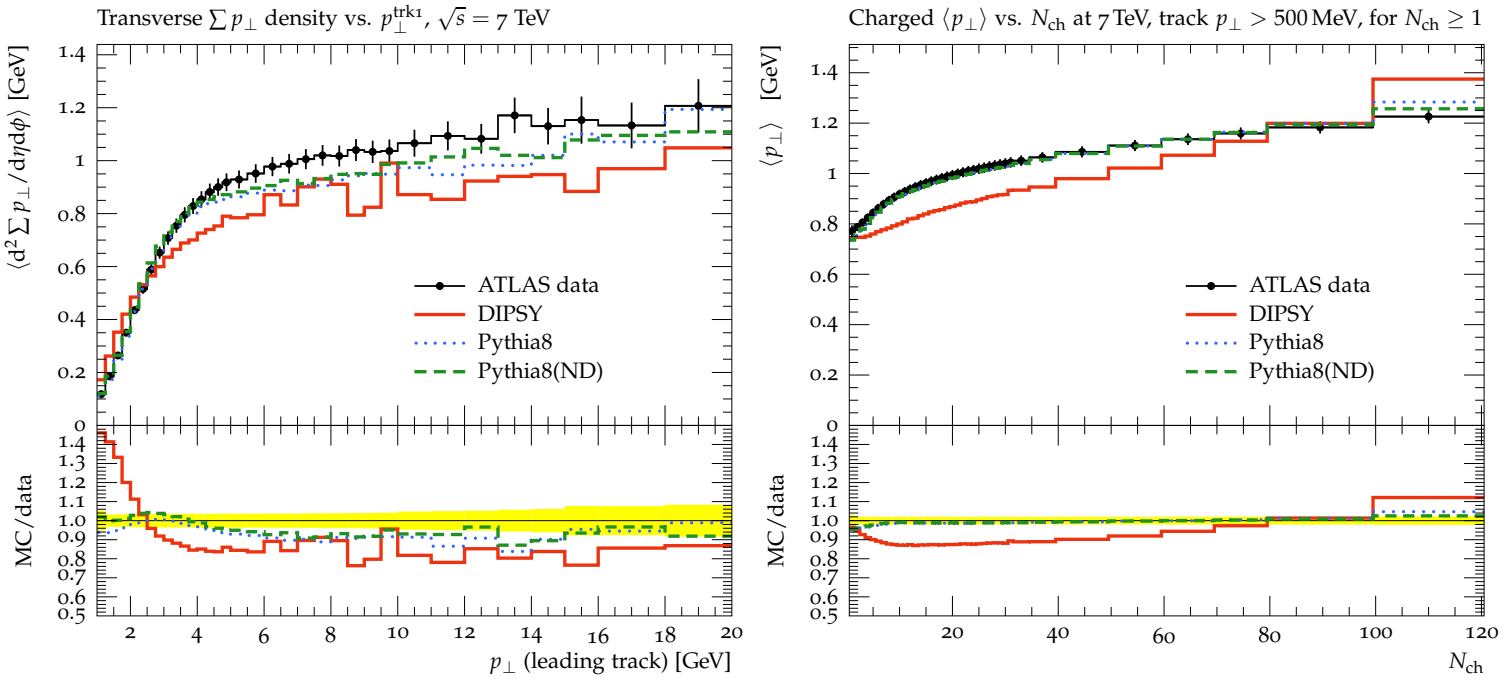
Exclusive observables I (Data: ATLAS arXiv:1012.5104 [hep-ex])

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



Exclusive observables II

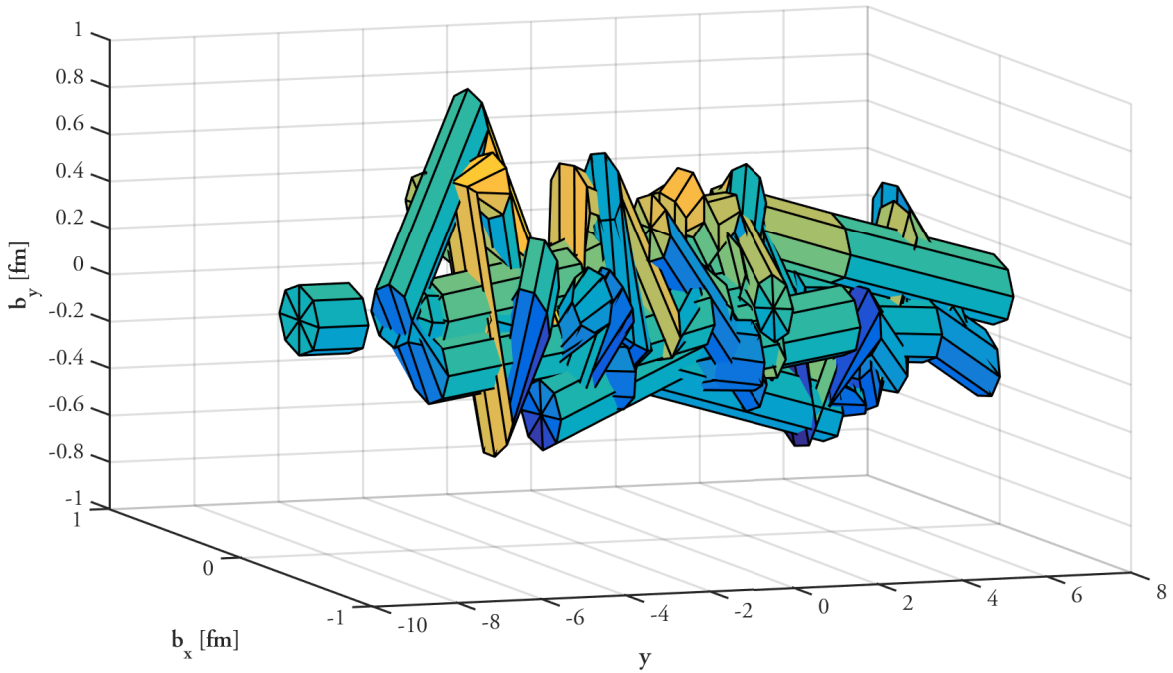
- Further observables available on `http://home.thep.lu.se/DIPSY`.
- Code available upon request.
- Interesting: Rising $\langle p_\perp \rangle (N_{ch})$ without CR.



Rope hadronization (CB et al: arXiv:1412.6259 [hep-ph])

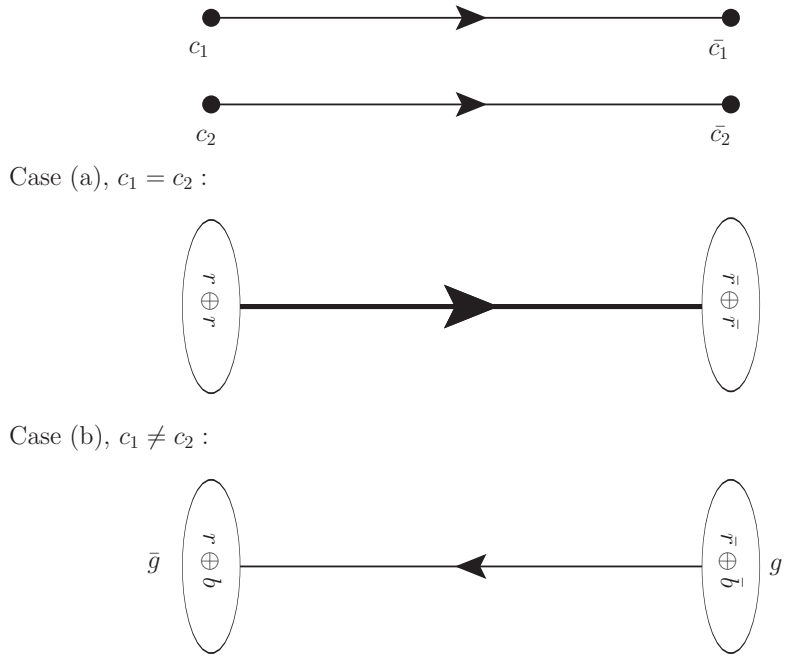
- Strings overlapping in final state – coherence effects.
  - → Rope formation and -hadronization.
  - → Affects final state hadrochemistry.
  - → Dynamical build-up of "flow".
- Overlapping strings ⇒ Colour multiplets.

(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.

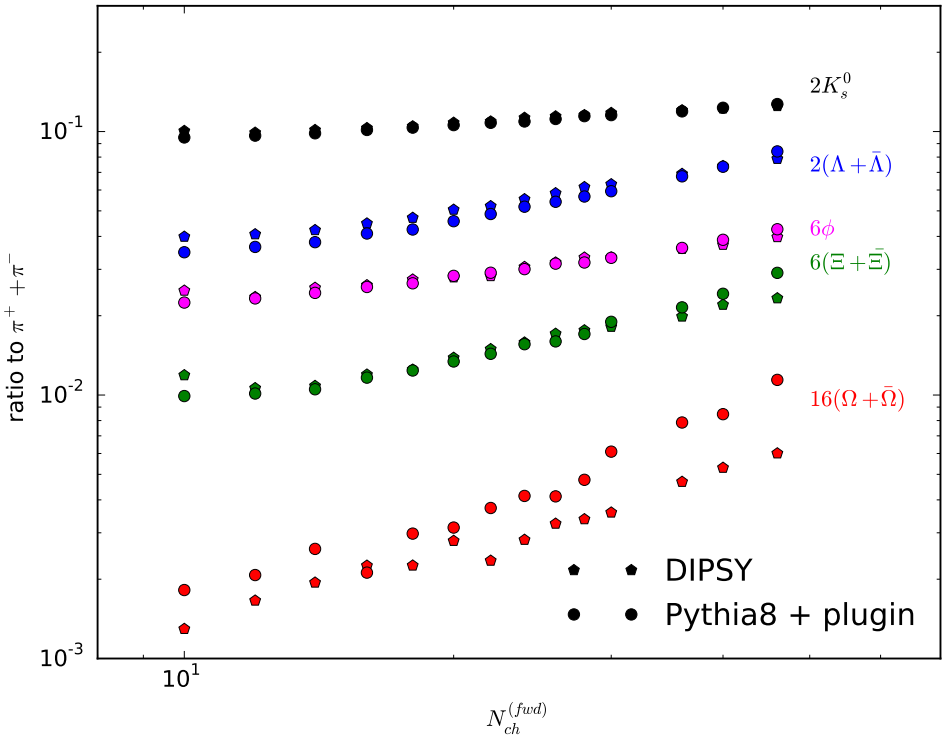


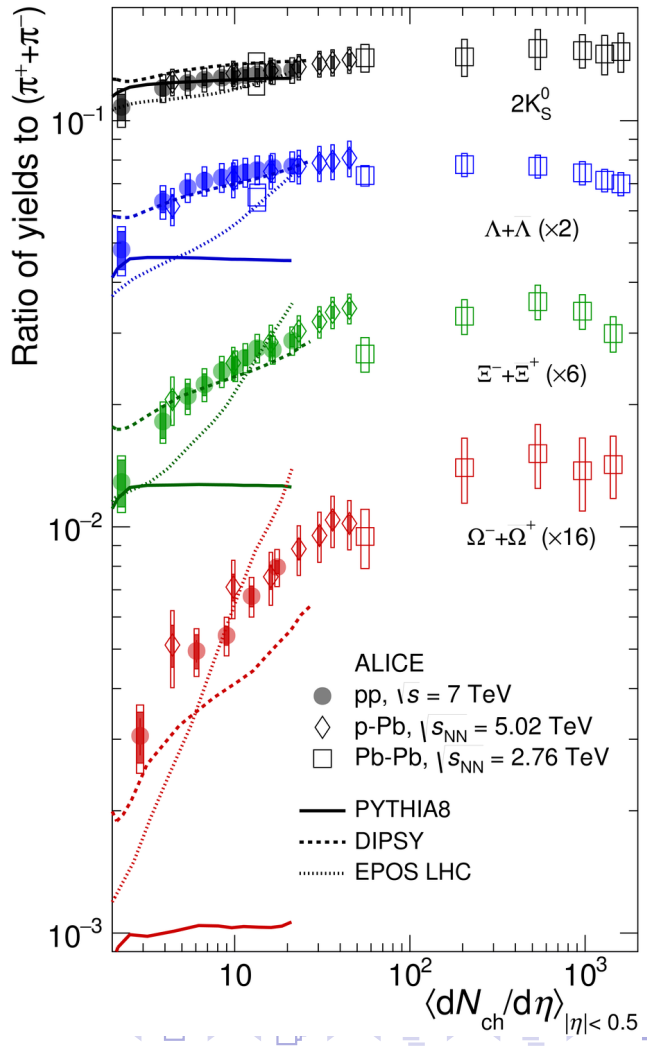
$$\{p,q\} \otimes \{1,0\} = \{p,q-1\} \oplus \{p-1,q+1\} \oplus \{p+1,q\},$$

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

Flavour composition – more strange quarks See also talk by T. Sjöstrand

- 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])

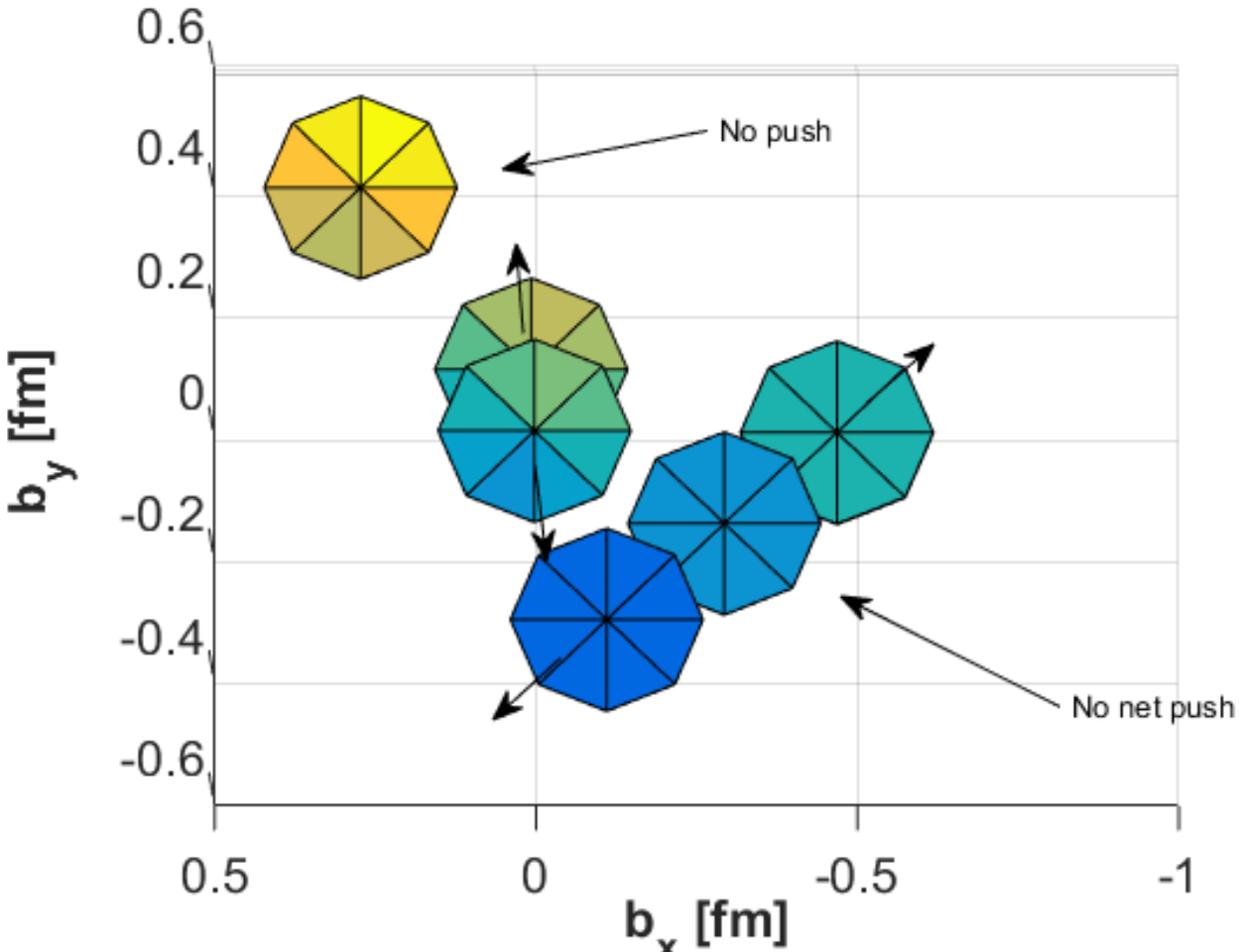
Pythia8 by plugin: `http://home.thep.lu.se/DIPSY#ropes`;

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

Shoving – latest development, not production code

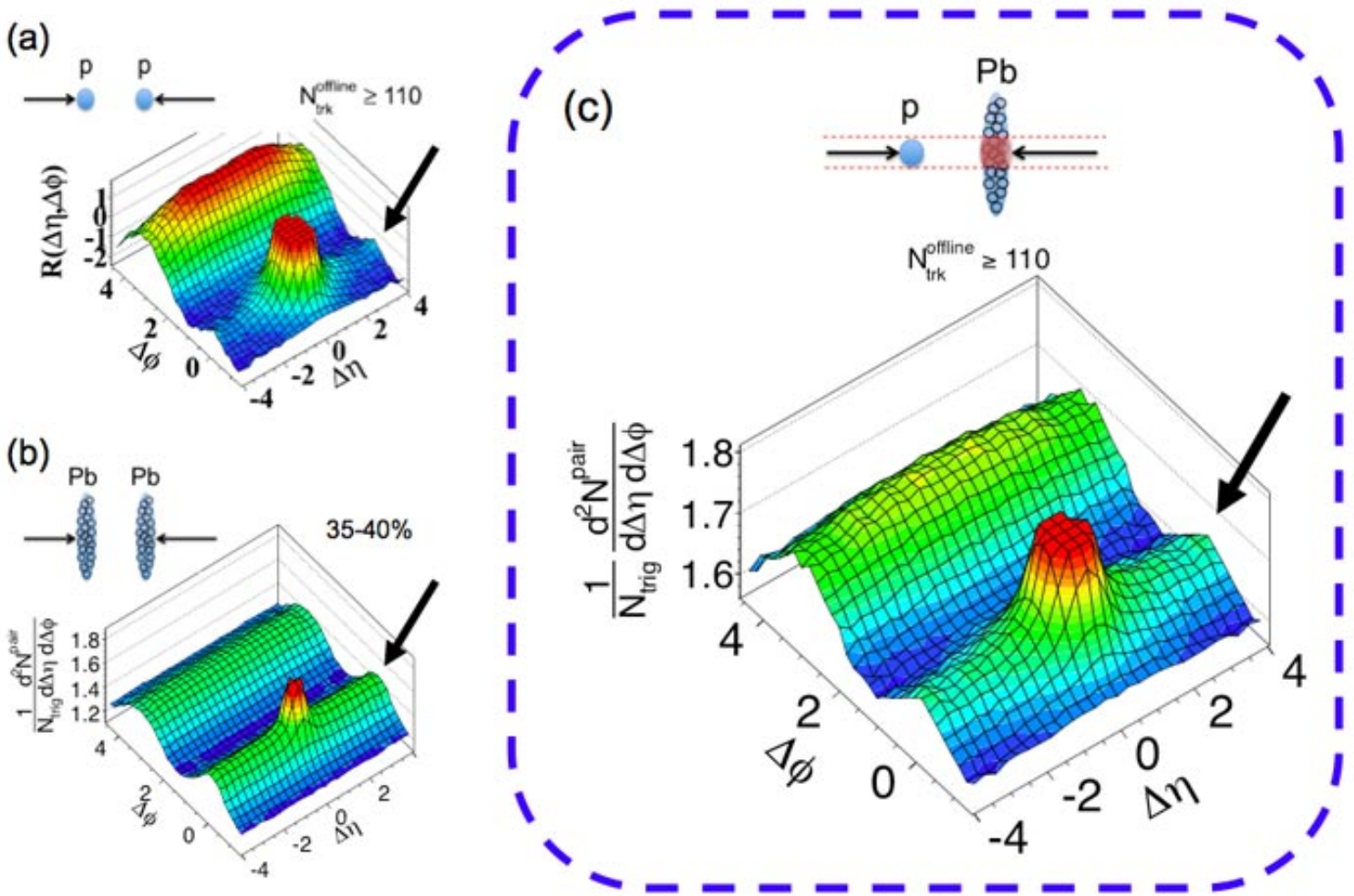
- Pressure in transverse plane from overlaps.
- Shoving resolved pair-wise, $p_\perp$ conservation.
- Practically done by adding a small excitation (gluon) to the string in each slice.

(CB et al: arXiv:1612.05132 [hep-ph])



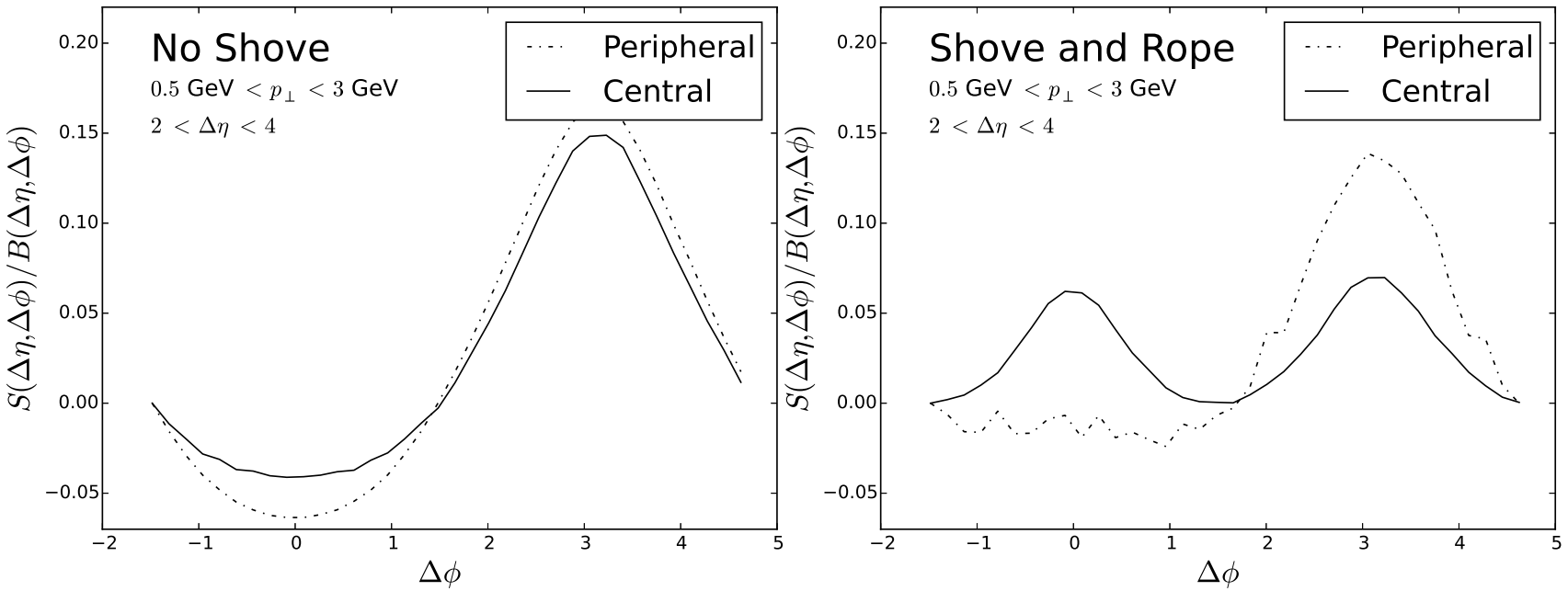
Shoving: An experimental motivation (CMS: arXiv:1009.4122 [hep-ex])

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



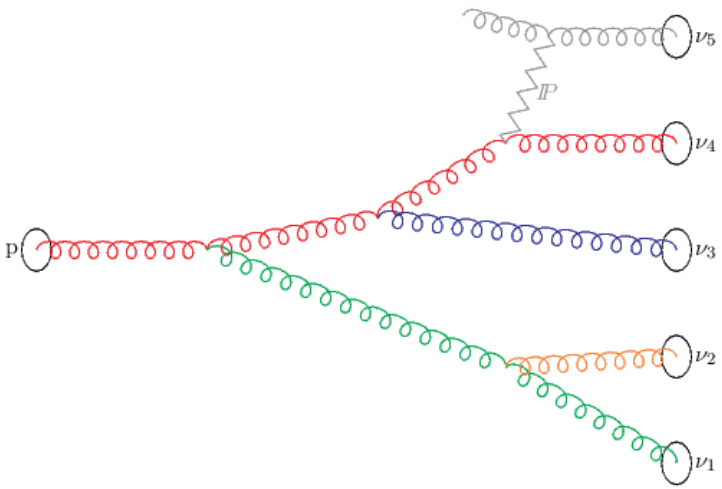
Two–particle correlations

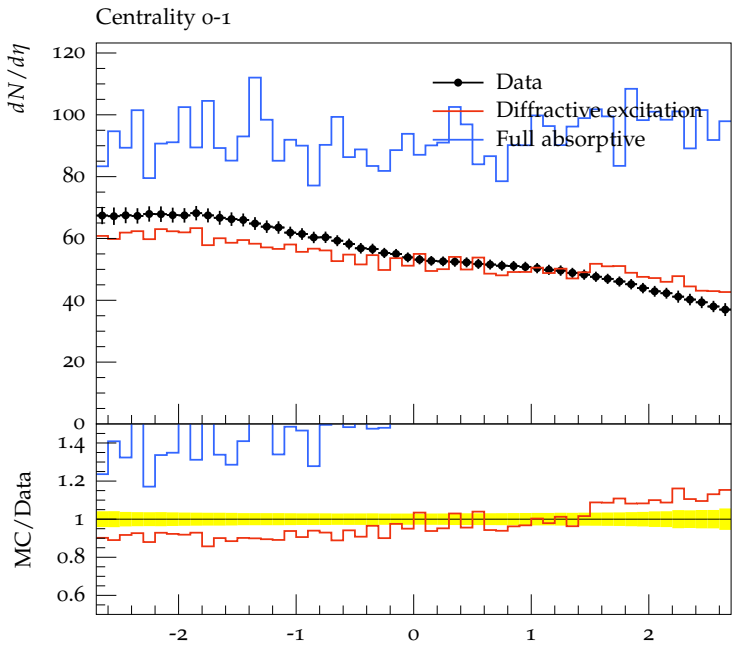
- Shoving produces a "ridge".
- Currently for events consisting of long, soft strings only.
- Working towards a complete description.



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.
  - → Provides a very different picture of underlying events.
  - → Serves as inspiration for further studies.
- Ropes: Work on the non-perturbative phase of the final state.
  - → Good description of flavours in DIPSY and Pythia8 (as plugin).
  - → Promising description of ridge.
- Future: Plans for taking Pythia+Rope model to heavy ion collisions.
  - → FritiofP8 extrapolation model.
  - → 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 $\delta l = t\delta y$.

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

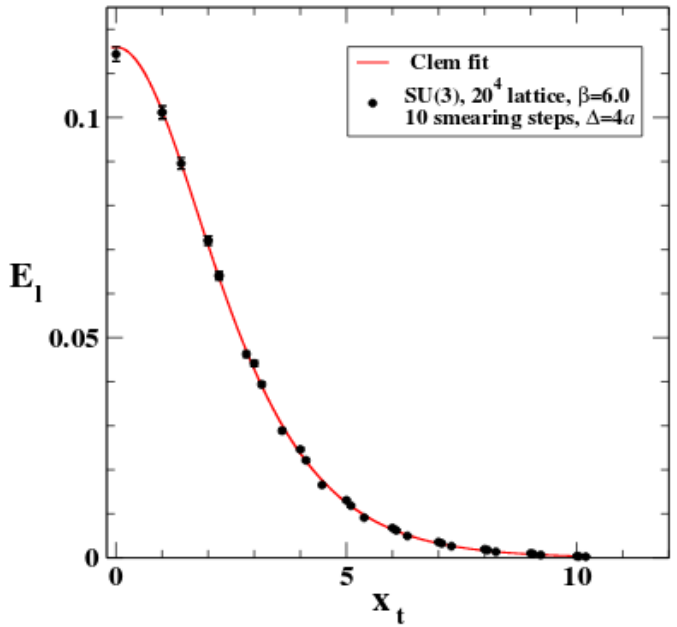
- The force is f; chromoelectric field of effective dual s.c. (lattice).
- Approximate with Gaussian:

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

- Interaction energy between two vortex lines:

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

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



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