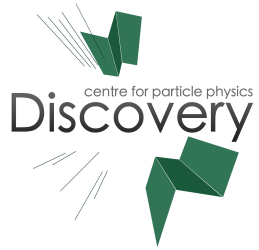
Microscopic collectivity from string interactions in pp

Christian Bierlich
bierlich@thep.lu.se

Lund University / University of Copenhagen
With: J. Christiansen, G. Gustafson, L. Lönnblad, H. Shah, A. Tarasov

Jan 5, 2018
JETSCAPE Winter School and Workshop



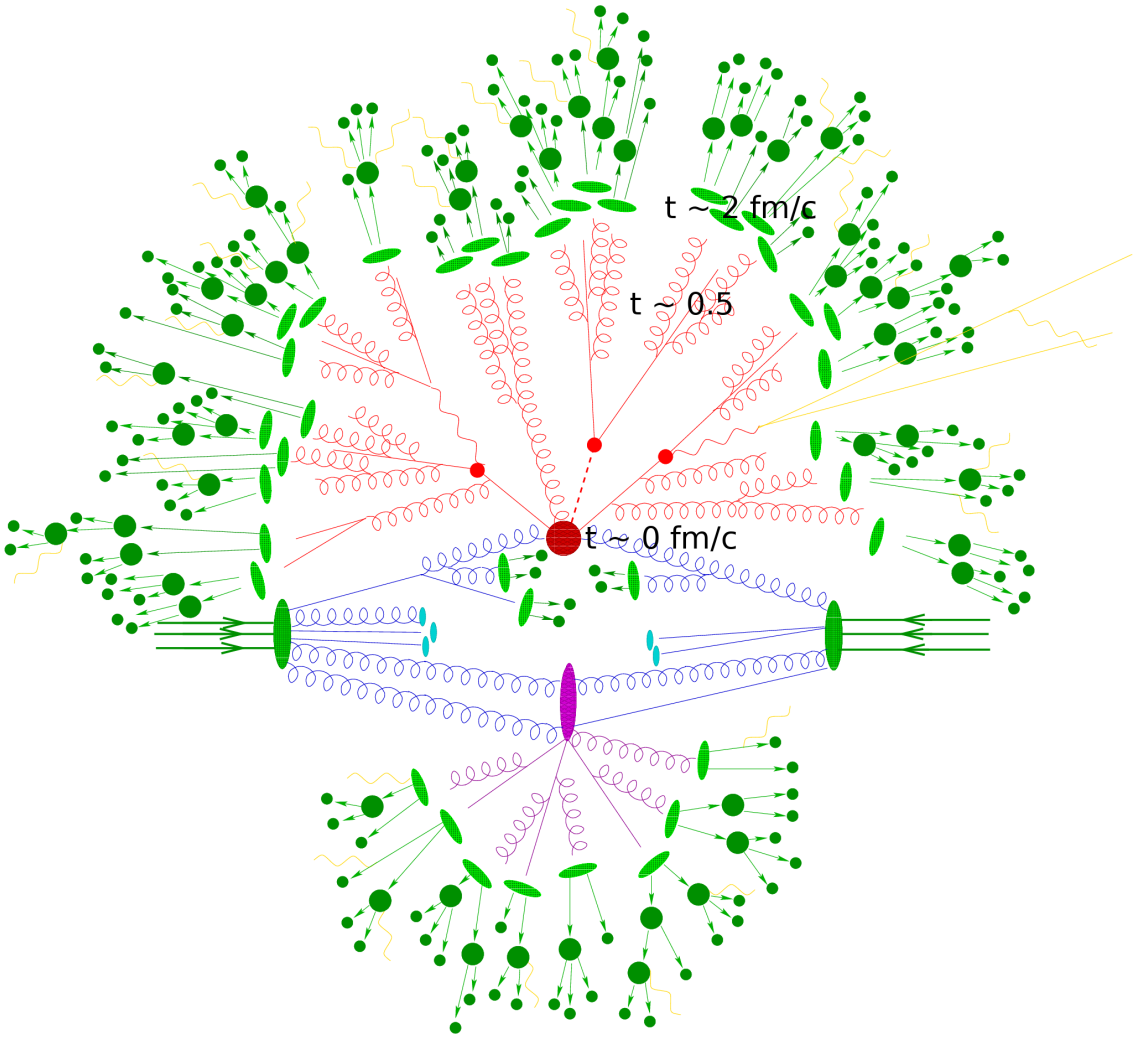
Collectivity in small systems is a game changer

- Heavy ion-like behaviour has been observed in pp collisions.
- This has spurred interest in developing pp models towards HI and collectivity.
- Collectivity in small systems challenges two paradigms at once!
  1. How far down in systems size does the "SM of heavy ions" remain?
  2. Can the standard MC tools for pp remain standard?

Huge potential to learn about non-perturbative QCD.

- This talk:
  1. The microscopic model for collectivity.
  2. String shoving in pp collisions.
  3. Rope hadronization and strangeness.
  4. The road ahead – can we find a common ground for General Purpose MCs and JETSCAPE?

Reminder: A pp event (see School talk Wed.)

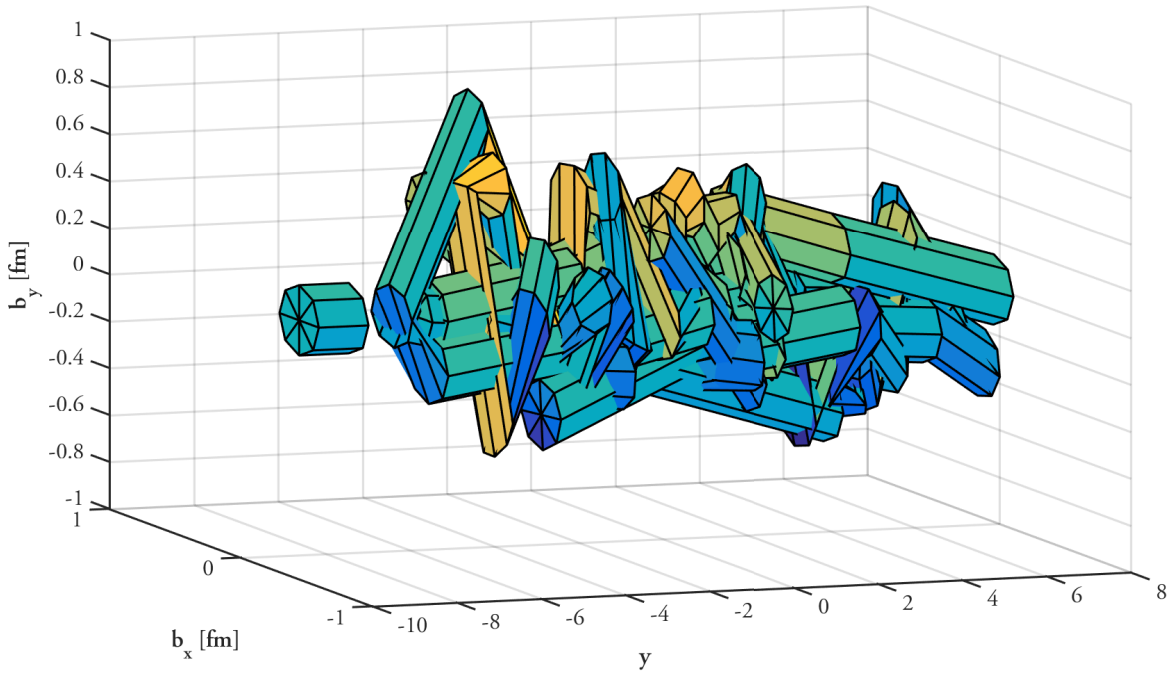


Adapted from S. Hoeche

- Multiple partonic interactions important at LHC.
- Each sub-interaction treated almost independently.
- QGP phase neither expected nor treated.
- Very limited time before hadronization.

Interacting strings instead of a plasma

- Many strings overlapping even in pp.
- New fundamental parameter r_0, taken from lattice QCD.
- Gives orthogonal description of collectivity – no assumption of deconfined nor thermalized plasma.



The "microscopic model" of collectivity at a glance

- Collective effects, based on interacting Lund strings (In PYTHIA8 v. 8.230).
- Additional input fixed or inspired by lattice, few tunable parameters.
- Collectivity without plasma? (CB, Gustafson, Lönnblad: arXiv:1710.09725 [hep-ph])
- Improving strangeness with ropes (CB, Gustafson, Lönnblad, Tarasov: arXiv:1412.6259 [hep-ph])
- (Extendable to pA and AA through Angantyr (CB, Gustafson, Lönnblad, arXiv:1607.04434), covered in school lecture).

The "microscopic model" of collectivity at a glance

- Collective effects, based on interacting Lund strings (In PYTHIA8 v. 8.230).
- Additional input fixed or inspired by lattice, few tunable parameters.
- Collectivity without plasma? (CB, Gustafson, Lönnblad: arXiv:1710.09725 [hep-ph])
- Improving strangeness with ropes (CB, Gustafson, Lönnblad, Tarasov: arXiv:1412.6259 [hep-ph])
- (Extendable to pA and AA through Angantyr (CB, Gustafson, Lönnblad, arXiv:1607.04434), covered in school lecture).

1. $t \approx 0$ fm. Strings no transverse extension. No interactions, partons may propagate.
2. $t \approx 0.6$ fm. Parton shower ends. Depending on "diluteness", strings may shove each other around.
3. $t \approx 1$ fm. Strings reach full transverse extension. Shoving effect maximal.
4. $t \approx 2$ fm. Strings will hadronize. Possibly as a colour multiplet (a "Rope").

Shoving: Prehistoric origins

- 1st law of phenomenology: When you think you have a good idea...

Shoving: Prehistoric origins

- 1st law of phenomenology: When you think you have a good idea...
- ...there is already a Russian paper from the 80'es about it.

Shoving: Prehistoric origins

- 1st law of phenomenology: When you think you have a good idea...
- ...there is already a Russian paper from the 80'es about it.
- Highly underappreciated paper – $\mathcal{O}(10)$ citations.

Long-range azimuthal correlations in multiple-production processes at high energies

V. A. Abramovskiĭ, É. V. Gedalin, E. G. Gurvich, and O. V. Kancheli
Institute of Physics, Academy of Sciences of the Georgian SSR

(Submitted 18 January 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 6, 281–283 (25 March 1988)

The interaction between chromoelectric tubes formed in high-energy hadron reactions leads to an azimuthal asymmetry in the distribution of secondary particles.

Shoving: Prehistoric origins

- 1st law of phenomenology: When you think you have a good idea...
- ...there is already a Russian paper from the 80'es about it.
- Highly underappreciated paper – $\mathcal{O}(10)$ citations.

Long-range azimuthal correlations in multiple-production processes at high energies

V. A. Abramovskiĭ, É. V. Gedalin, E. G. Gurvich, and O. V. Kancheli
Institute of Physics, Academy of Sciences of the Georgian SSR

(Submitted 18 January 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 6, 281–283 (25 March 1988)

The interaction between chromoelectric tubes formed in high-energy hadron reactions leads to an azimuthal asymmetry in the distribution of secondary particles.

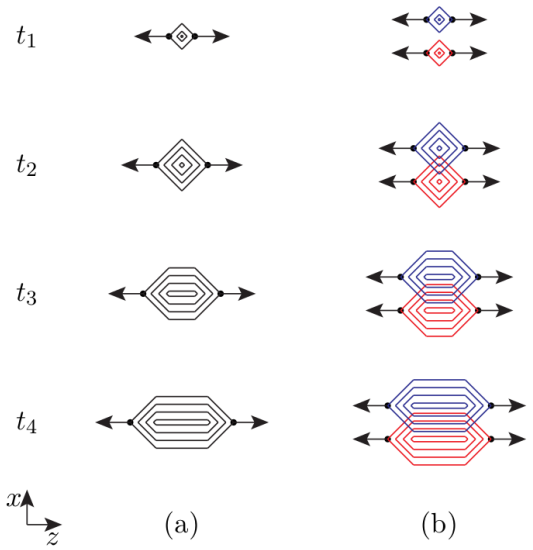
6. In an interaction of heavy nuclei with nuclei, many overlapping quark tubes form, and a large azimuthal asymmetry may be observed.[2)] Furthermore, since an $A \times A$ collision is noncentral on the average, the system of quark tubes fills a transversely anisotropic region. It is clear geometrically that its anisotropy is oriented along the impact parameter of the collision. We might thus expect correlations between the azimuthal distribution of secondary hadrons and the azimuthally anisotropic distribution of the decay products of the nucleus.

Again, we wish to emphasize that data on the azimuthal asymmetry in soft multiple-production processes may contain some very nontrivial information.

String shoving (CB, Gustafson, Lönnblad: arXiv:1710.09725 [hep-ph])

- Strings are vortex lines in S.C.
- For $t \to \infty$, profile known from IQCD (Cea et al. arXiv:1404.1172 [hep-lat]) giving:

$$f(d_\perp) = \frac{g\kappa d_\perp}{R^2} \exp\left(-\frac{d_\perp^2(t)}{4R^2}\right).$$



- Dominated by electric field $\to g = 1$.

- Reality:

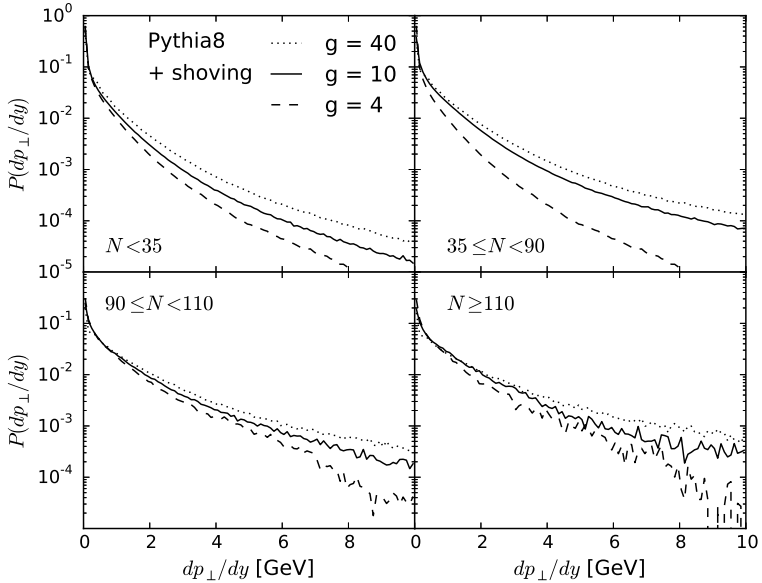
  Type 1 Energy to destroy vacuum.
  Type 2 Energy in current.

- Pairwise, momentum conserving, "kicks".
- Includes "medium recoil" by construction, promise for including jets.

Resolving the kicks

- We resolve kicks as gluons – not best approach.
- When is a gluon free of the string?

$$\lambda_g \approx 2\pi k_\perp, l_{ur} = k_\perp/2\kappa \Rightarrow k_{\perp,0} \gtrsim 1.6\text{GeV}$$



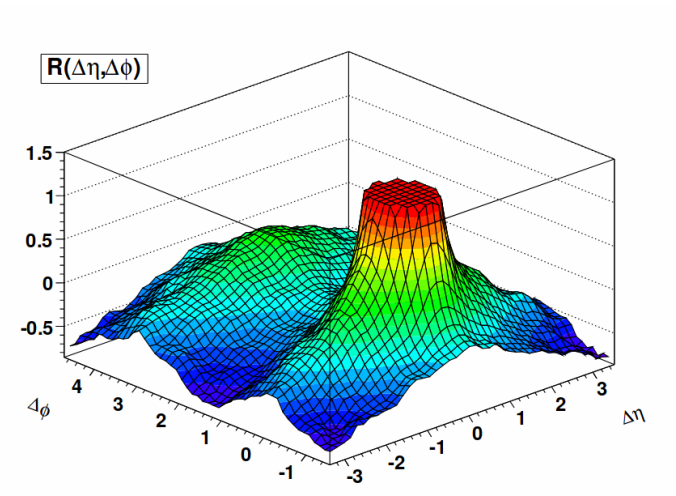
- Better (future improvement):

  Soft Put directly on hadrons.

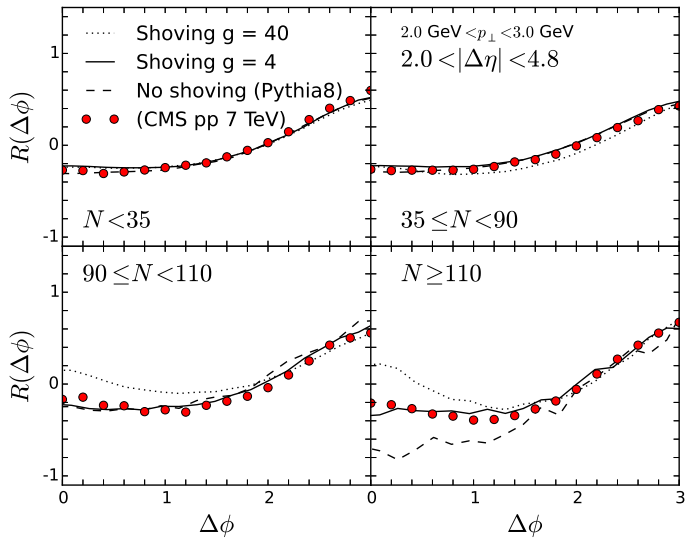
  Hard Resolved gluons (also effects for sub-jet observables).

The ridge from interacting strings

- Ridge produced by string shoving, or hydrodynamical expansion.
- Consequences for the deconfined, thermalized plasma?
- What can we do to discriminate between models?
  1. Better understanding of IS geometry (PYTHIA8 open interface)?
  2. Interplay with FS interactions (particle production + jet quenching)?



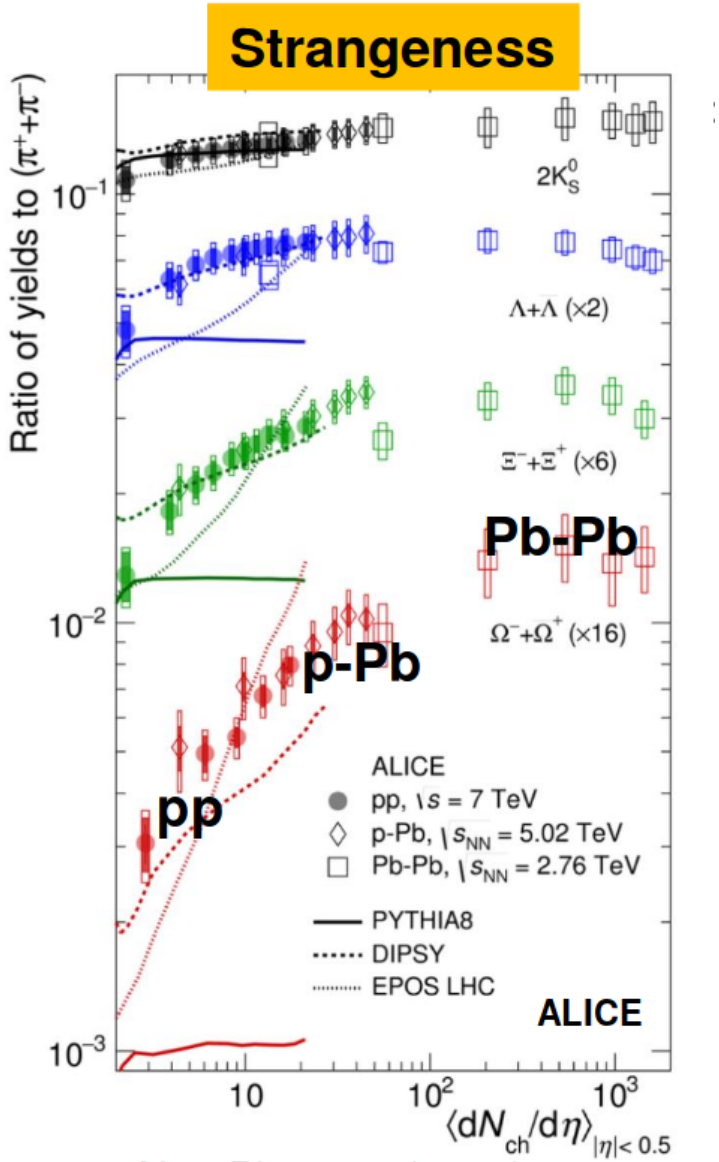
(EPOS with hydro, arXiv:1011.0375)



(PYTHIA8 with shoving)

Hadronization: Modification of string tension

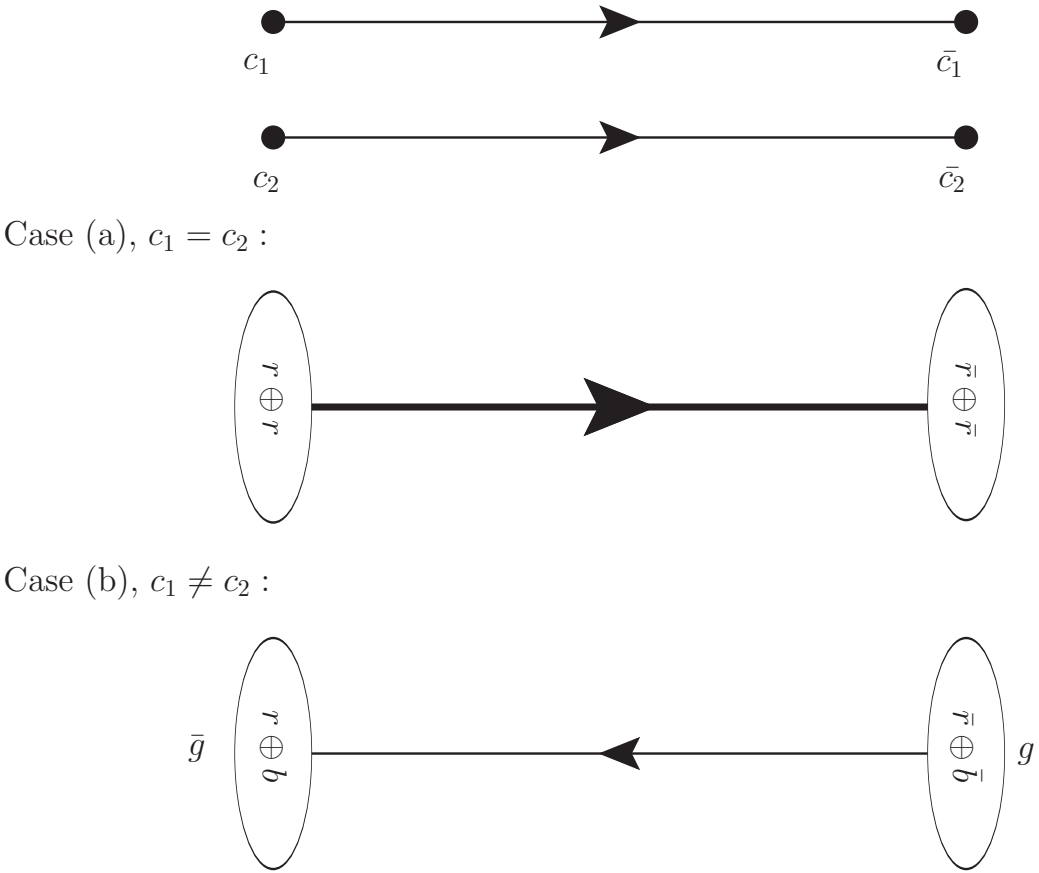
- After shoving, the strings hadronize.
- Now $t \sim 2$fm.
- Strings fragment together in colour multiplets ("Ropes").
- Ropes have higher string tension, giving more strange quarks.
- Here old implementation "DIPSY", now in Pythia.



Nat. Phys. 13 (2017) 535

Higher string tension from overlaps (1412.6259)

- Strings can be close enough that end charges act coherently.
- "Rope formation".



Effect on hadronization parameters

Large effect on hadron flavours

- Strange quark breakup suppression:

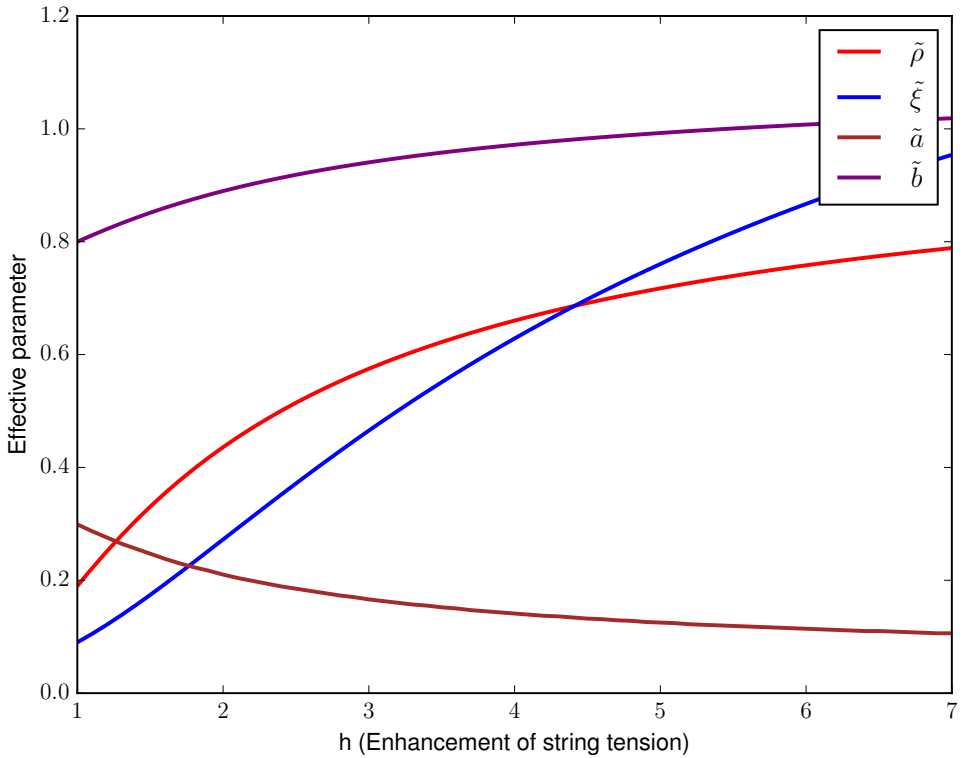
$$\rho_0 = \exp\left(-\frac{\pi(m_s^2 - m_u^2)}{\kappa}\right) \rightarrow \tilde{\rho}(\kappa) = \rho_0^{\frac{\kappa_0}{\kappa}}.$$

Effect on hadronization parameters

Large effect on hadron flavours

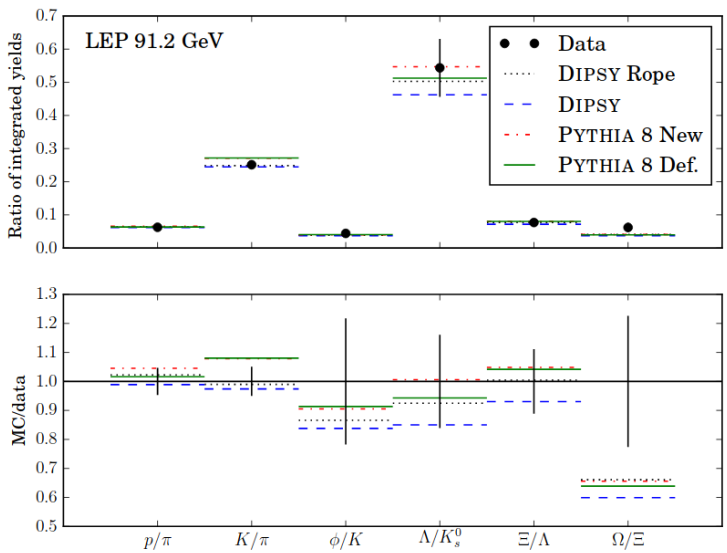
- Strange quark breakup suppression:

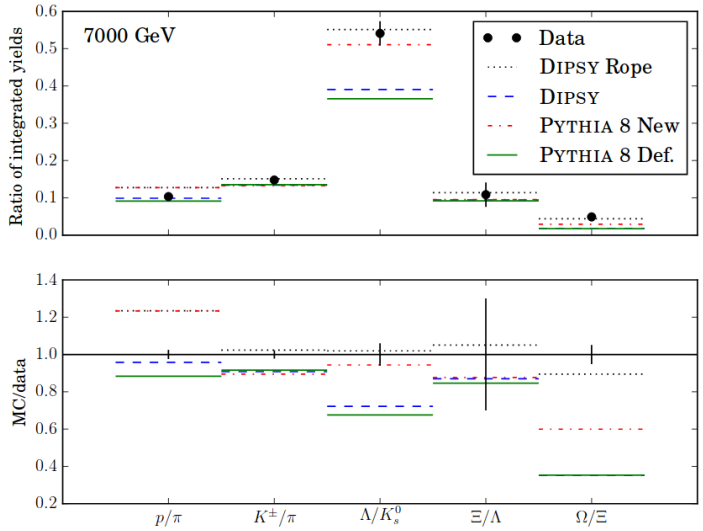
$$\rho_0 = \exp\left(-\frac{\pi(m_s^2 - m_u^2)}{\kappa}\right) \rightarrow \tilde{\rho}(\kappa) = \rho_0^{\frac{\kappa_0}{\kappa}}.$$



Restoration of jet universality (1507.02091)

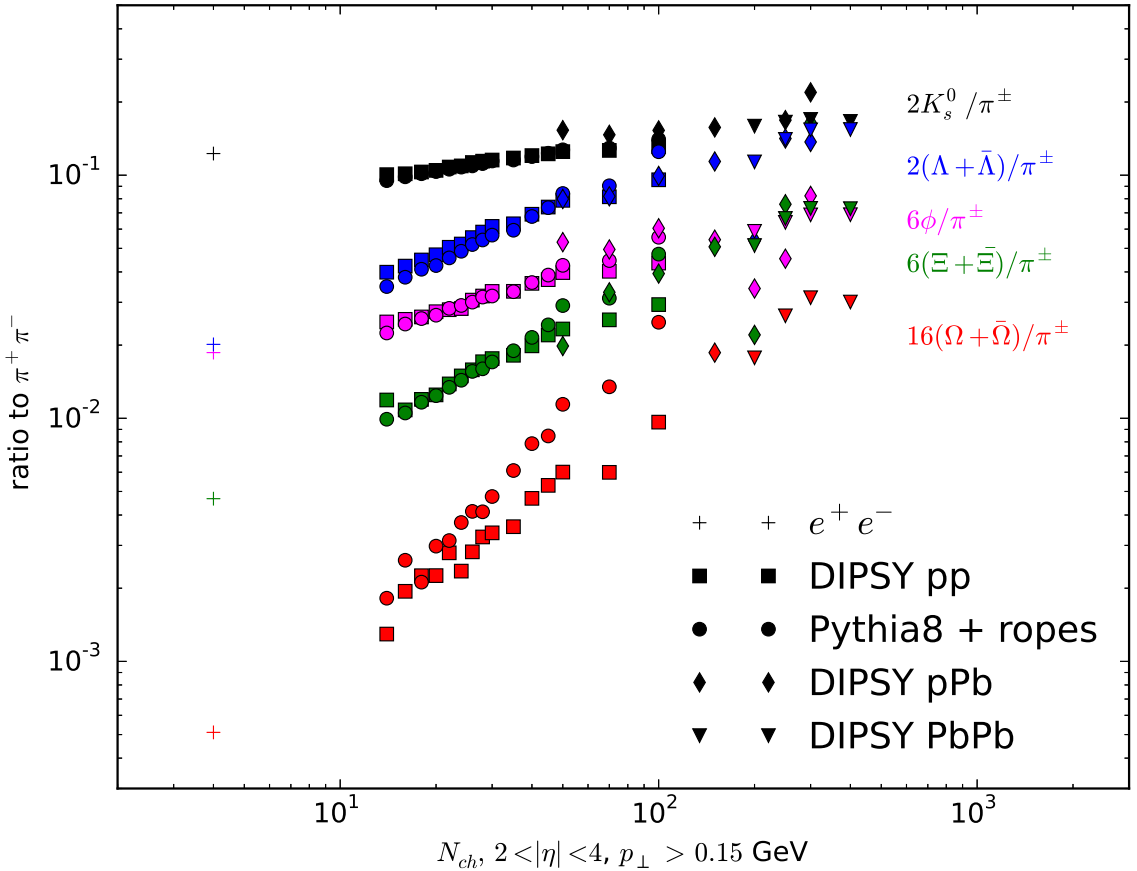
- From MC event generator POW, largest problem was breaking of jet universality.
- Rope Hadronization restores this by through geometry.





Strangeness across systems

- A nice prediction is strangeness across systems.
- Note: HI not Pythia8/Angantyr, but DIPSY – a predecessor program.



Where do we go from here?

- What we want:

Where do we go from here?

- What we want:
  - Use orthogonal approaches to find points of tension.
  - Use tension to identify observables.
  - Learn more about the underlying dynamics: (Non-perturbative) QCD.
  - Establish a common ground for Pythia models and JETSCAPE MCs.

Where do we go from here?

- What we want:
  - Use orthogonal approaches to find points of tension.
  - Use tension to identify observables.
  - Learn more about the underlying dynamics: (Non-perturbative) QCD.
  - Establish a common ground for Pythia models and JETSCAPE MCs.
- What we don't want:

Where do we go from here?

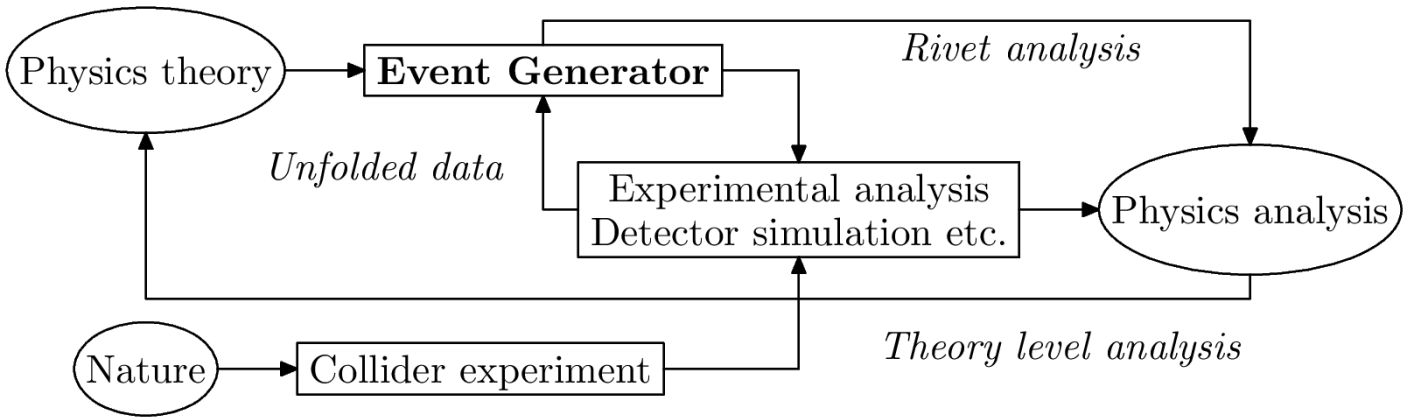
- What we want:
  - Use orthogonal approaches to find points of tension.
  - Use tension to identify observables.
  - Learn more about the underlying dynamics: (Non-perturbative) QCD.
  - Establish a common ground for Pythia models and JETSCAPE MCs.
- What we don't want:
  - Just adding another curve to the figures.

Where do we go from here?

- What we want:
  - Use orthogonal approaches to find points of tension.
  - Use tension to identify observables.
  - Learn more about the underlying dynamics: (Non-perturbative) QCD.
  - Establish a common ground for Pythia models and JETSCAPE MCs.
- What we don't want:
  - Just adding another curve to the figures.
- What we need:
  - Model independent tool(s) for theory/data comparison.
- Remainder of the talk:
  - Rivet – Robust Independent Validation of Experiment and Theory.
  - Open implementation of microscopic model + Angantyr.
  - Example of tension – the ϕ-meson.

Comparison tools: Rivet (1003.0694 and rivet.hepforge.org, see talk by G. Milhano)

- It makes no sense to do comparisons at detector level.
- But! Correcting all the way to "theory level" introduces biases.
  - Impact parameter unmeasurable.
  - Will multi particle correlations remove all non-flow?
  - Is uncorrelated jet background handled correctly by subtraction?
- Rivet combines unfolded data with a particle level analysis.



- Requirements:
  - Experimentalists: Model independent analysis. *Unfolding*.
  - Theorists: Theory should give a particle level prediction.

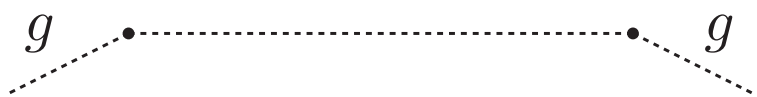
Open implementation in Pythia8

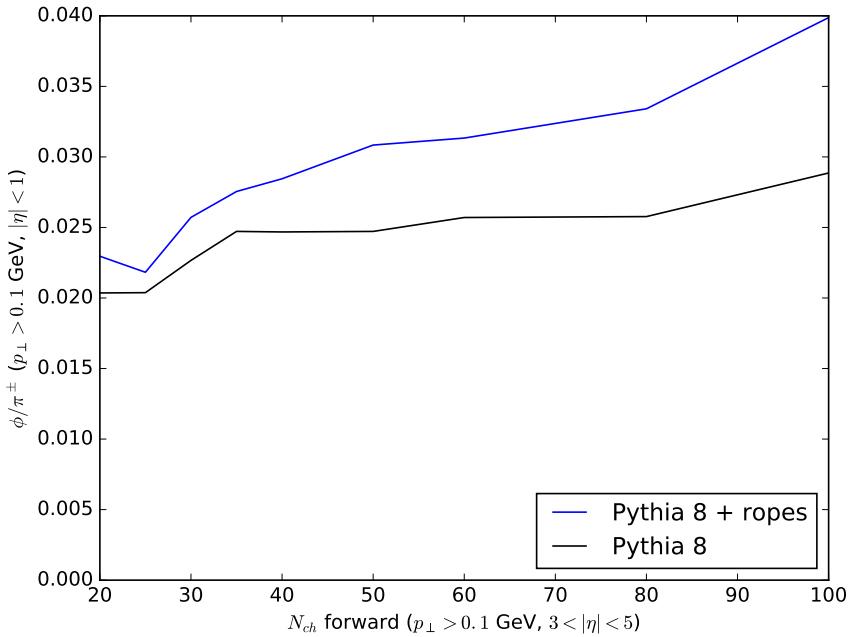
- Everything mentioned here + school talk is implemented in Pythia8.
- Download it and try it for yourself – please report any problems.
  - `home.thep.lu.se/Pythia`
- Angantyr and microscopic collectivity is implemented in a user customizable manner.
- User can interface their own model for initial state geometry, semi-inclusive cross sections or even build-up of exclusive final states.
- If you are interested in using it for advanced purposes (modifying etc.), feel free to get in touch.

What about the ϕ meson?

Double suppression

- The ϕ is an excellent laboratory for strangeness effects.
- Two s-breaks means twice suppression and added sensitivity.

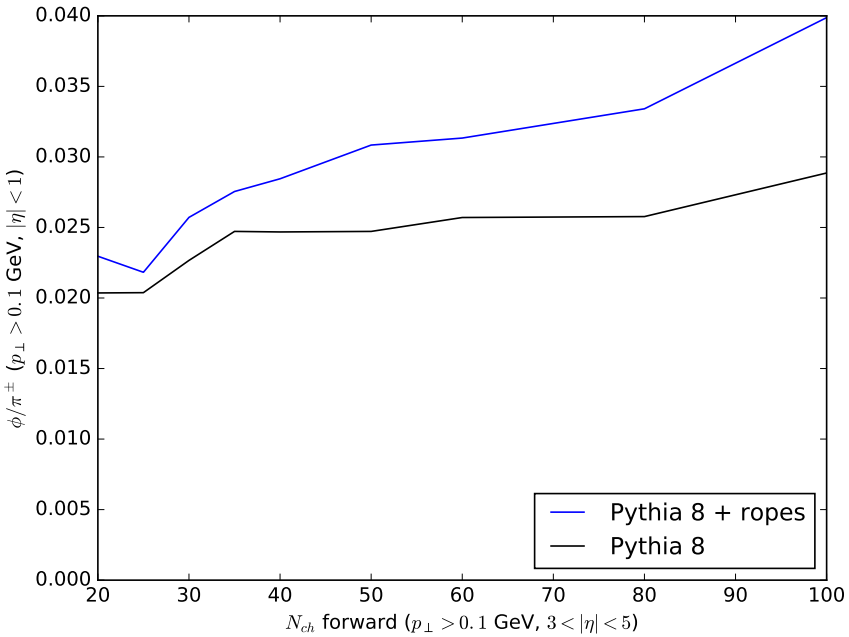




What about the ϕ meson?

Double suppression

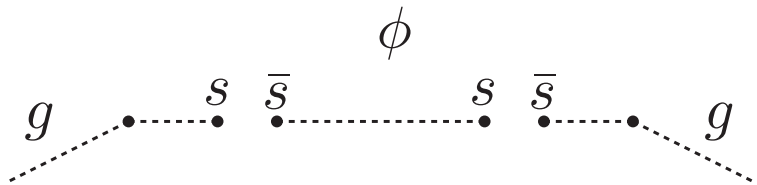
- The ϕ is an excellent laboratory for strangeness effects.
- Two s-breaks means twice suppression and added sensitivity.

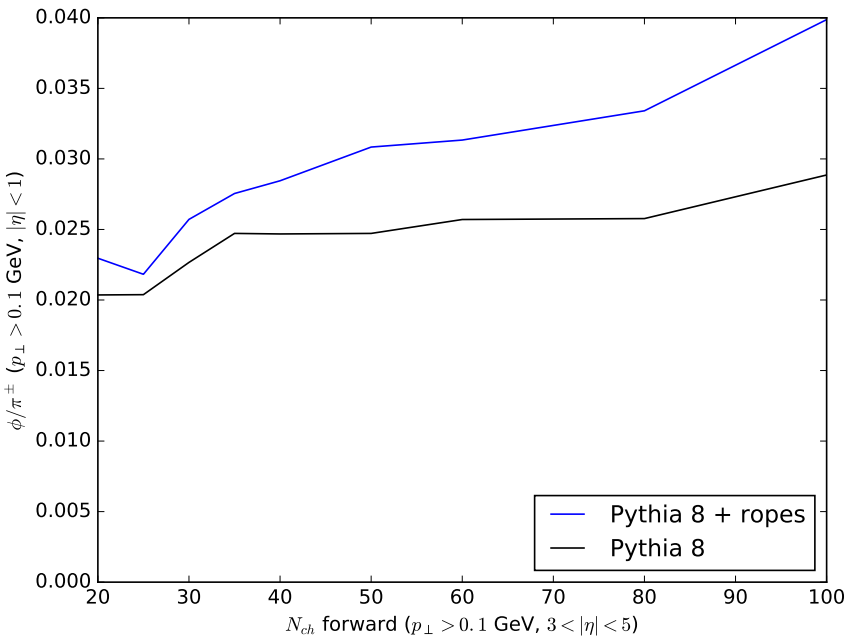


What about the ϕ meson?

Double suppression

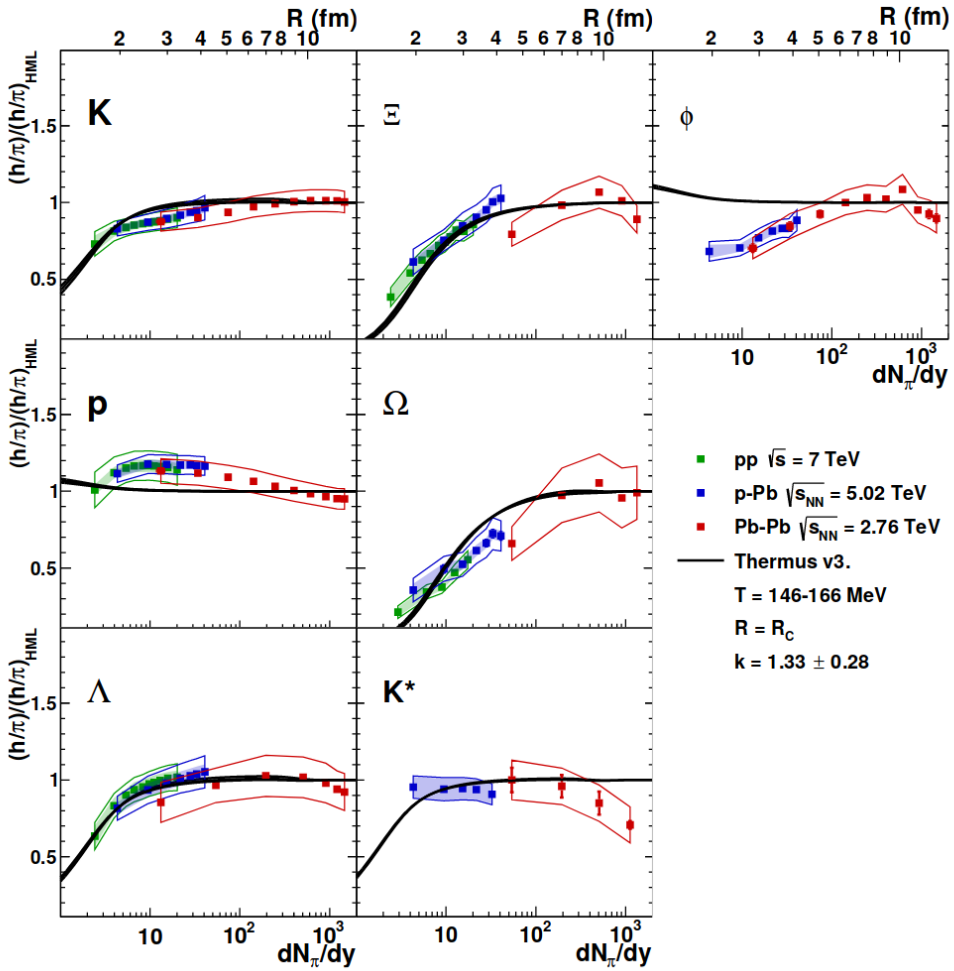
- The ϕ is an excellent laboratory for strangeness effects.
- Two s-breaks means twice suppression and added sensitivity.





Contrasting with thermal models (Vislavicius and Kalweit: arXiv:1610.03001 [hep-ex])

- Thermus gets several features by relating N_{ch} to system size.
- But the ϕ is different. Instead of focusing what we get right, we should go more exclusive in tension regions is different.



Summary

- Presented microscopic model for collectivity, implemented in Pythia.
  - Model so far implemented for pp, while pA and AA is on the way.
  - Strangeness: Good description, few parameters, restores jet universality.
  - The pp ridge: Shoving mechanism is promising.
  - Next step: flow coefficients.
- Establishing a common ground.
  - Theory/Data comparison should be done on equal footing.
  - Our ultimate goal is to learn about dynamics – which means that models should converge or be excluded.
  - Seek out tension regions.
  - Open implementations and tools like Rivet eases the pain.
  - ...but of course come at a cost.
- Thank you for listening!