Strangeness enhancement across systems in Pythia8/Angantyr

Rope hadronization in Lund strings

Smita Chakraborty
smita.chakraborty@thep.lu.se

15th November 2022

13th International Workshop on Multiple Partonic Interactions at the LHC
IFT - UAM/CSIC, Madrid

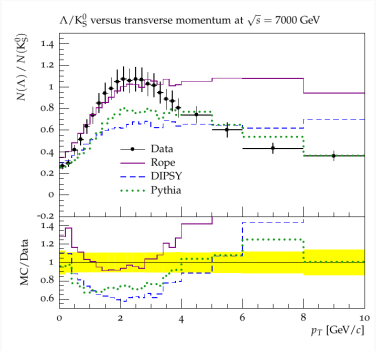
LUNDS UNIVERSITET

Motivation for exploring Lund string interactions

- **Observing Quark Gluon Plasma-like signatures within the Lund string model**
- Observations such as:
  - Imprint of initial geometric anisotropy in the final state particles
    $\implies$ correlation between particles separated in large units of rapidity
  - Modification of large Q^2 processes in small and large systems
    $\implies$ Jet quenching &
    $\implies$ **Change in production yields of heavy flavours, e.g. strange hadrons**

Builds up on the **Angantyr** framework for heavy-ions (*See L Lönnblad's talk,* $15^{th}Nov, 17:00$)

Previous and current developments in the Lund class of MCEGs



Λ/K^0_s ratio in DIPSY compared to CMS data for p-p at $\sqrt{s} = 7$ TeV (JHEP 2015, 148 (2015))

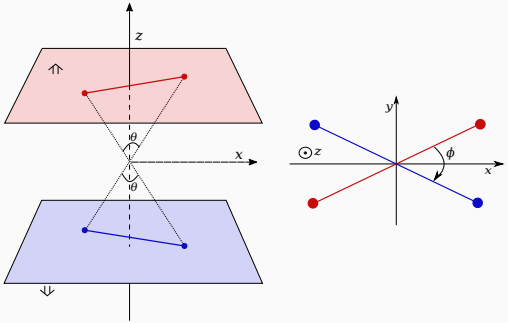
What's new:

- **GLEIPNIR**: ropes (**SciPost Phys. 13 (2022) 2, 023**, Physics Letters B, 137571(2022) 0370-2693), shoving (**JHEP 03 (2021) 270**) & colour reconnection for **all** systems

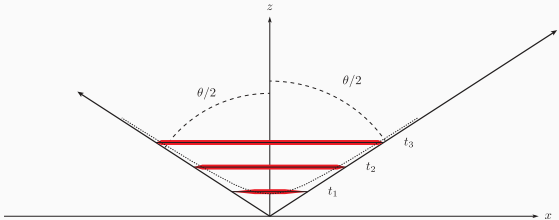
- Interplay of string shoving, rope hadronization: work in progress

SC & L. Lönnblad, *Impact of string interactions on the space-time evolution of hadronic vertices*, **2207.14186**

A pair of string pieces in the *parallel* frame



The parallel frame



String radius evolves to equilibrium radius R in the parallel frame

---

* z axis is transverse to the strings, and is not the beam axis.

†Construction of the parallel frame: C. Bierlich, SC, G. Gustafson and L. Lönnblad, *Setting the string shoving picture in a new frame*, JHEP **03** (2021), 270

Formulation of rope hadronization

- **Wider colour flux tubes when two strings overlap** in co-ordinate space
  $\implies$ **Higher colour multiplets** $\{p, q\}$ form at the ends of colour ropes
  $\implies$ **Resultant higher effective string tension** κ_{eff}

- When a string in a rope breaks $\rightarrow$ transition to a lower colour multiplet
  $\rightarrow$ higher energy is **released**

- During breakup of individual string in the rope, this energy is available for tunnelling
  $\rightarrow$ higher yield of strange quarks a.k.a. **strangeness enhancement**

[†] C. Bierlich, G. Gustafson, L. Lönnblad, et al., J. High Energ. Phys. 2015, 148 (2015).

Resultant higher effective string tension κ_{eff}

◦ From lattice calculations:

Tension in an isolated static rope is proportional to the quadratic Casimir operator C_2

$\implies$ Relative strength of the "rope tension": $C_2(p,q)/C_2(1,0) = \frac{1}{4}(p^2+pq+q^2+3p+3q)$

◦ For breakup via the transition $\{p+1,q\} \mapsto \{p,q\}$: $\kappa_{\text{eff}} = \frac{2p+q+4}{4}\kappa$

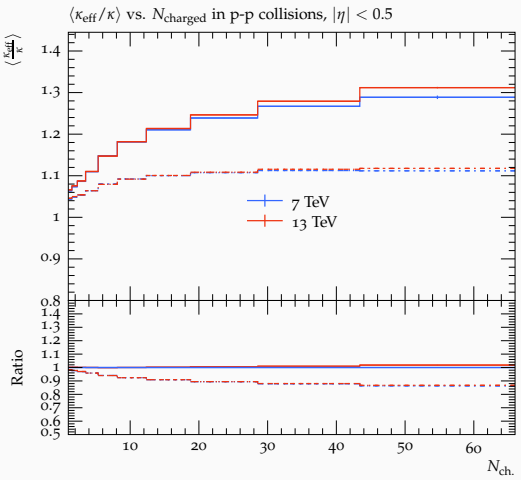
◦ For strange flavour, the suppression factor ρ from tunnelling probability in Lund model is given by:

$$\rho = \exp\left(-\frac{\pi(\mathbf{m_s^2}-\mathbf{m_u^2})}{\kappa_{\text{eff}}}\right)$$

[1] C. Bierlich, SC, G. Gustafson, L. Lönnblad, SciPost Phys. 13 (2022) 2, 023.
[2] J. High Energ. Phys. 2015, 148 (2015).

$\kappa_{\text{eff}}/\kappa$ variation with average charged multiplicity $\langle dN_{ch}/d\eta \rangle$

- R = 0.5 fm (dotted line)
- R = 1 fm (solid line) at $\sqrt{s} = 7$ & 13 TeV, $|\eta| < 0.5$.



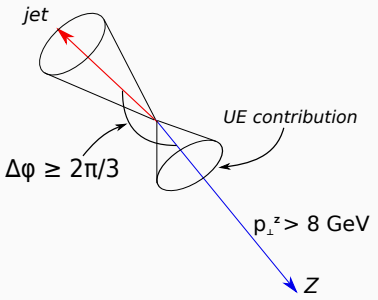
✓ κ_{eff} grows with the number of strings

✓ $\langle dN_{ch}/d\eta \rangle|_{\eta<0.5} \propto$ number of strings

[†] C. Bierlich, SC, G. Gustafson, L. Lönnblad, *Jet modifications from colour rope formation in dense systems of non-parallel strings*, SciPost Phys. 13 (2022) 2, 023.

Advantages of the parallel frame: strangeness yields in jets

- Generate Z + jet events with $|\eta| < 1.9$
- Reconstruct the associated charged particle jet using the anti-k$_T$ algorithm, with $R_j = 0.4$, $|\eta| < 2.1$
  $\rightarrow$ **pseudojet**
- Subtract the UE contribution from the pseudojet cone, for both $p_\perp$ and yields

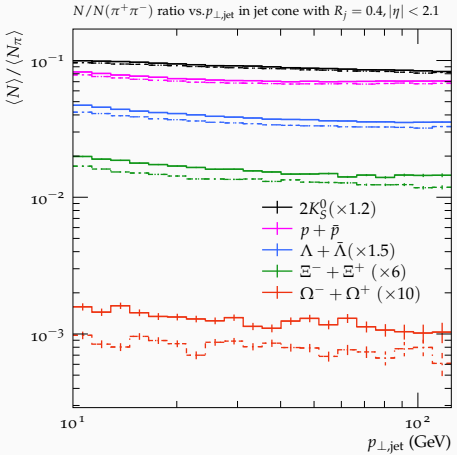


$$p_{\perp,\text{jet}} = p_{\perp,\text{pseudojet}} - 0.5 \times \Sigma p_{\perp,\text{UE}}$$

$$\text{yield}_{\text{jet}} = \text{yield}_{\text{pseudojet}} - 0.5 \times \text{yield}_{\text{UE}}$$

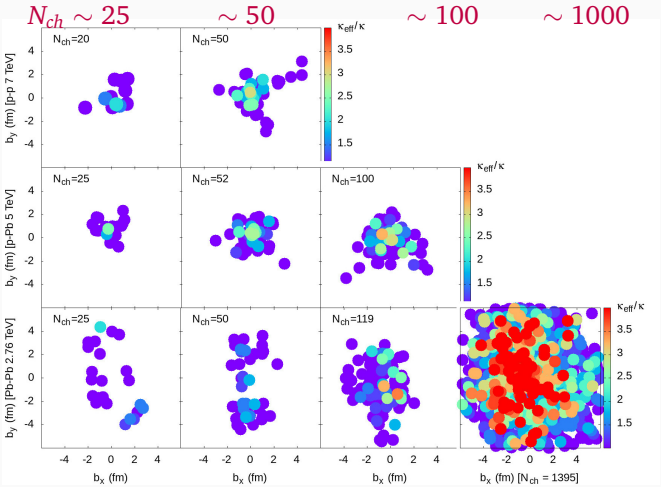
Strangeness yields in jets for p-p at $\sqrt{s} = 13$ TeV

Strange hadrons and protons to $\pi^+\pi^-$ yield ratio in the jet cone with $R_j = 0.4$ vs. $p_{\perp,\text{jet}}$.



†C. Bierlich, SC, G. Gustafson, L. Lönnblad, *Jet modifications from colour rope formation in dense systems of non-parallel strings*, SciPost Phys. 13 (2022) 2, 023.

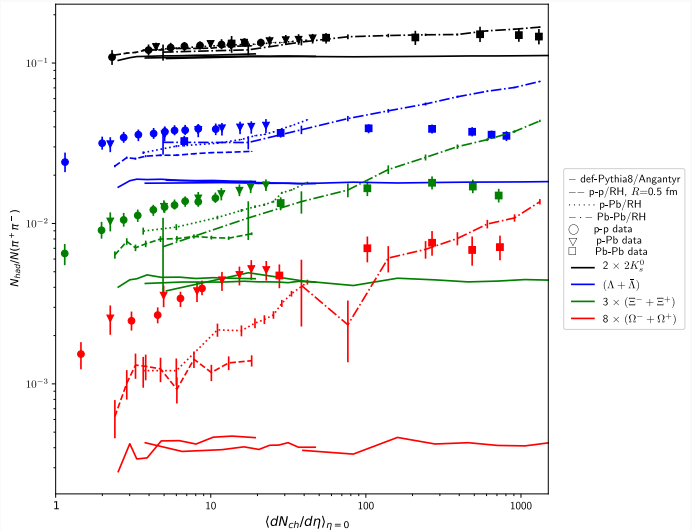
κ_{eff} of primary hadrons in impact parameter space



† C. Bierlich, SC, G. Gustafson, L. Lönnblad, *Strangeness enhancement across collision systems without a plasma*, Physics Letters B, 137571(2022) 0370-2693.

Strangeness yields in pp $\sqrt{s} = 7$ TeV, pPb $\sqrt{s_{NN}} = 5.02$ TeV, PbPb $\sqrt{s_{NN}} = 2.76$ TeV

Strange hadron to $\pi^+\pi^-$ yield ratios vs. $\langle dN_{ch}/d\eta \rangle_{\eta=0}$.



Summary

Conclusions:

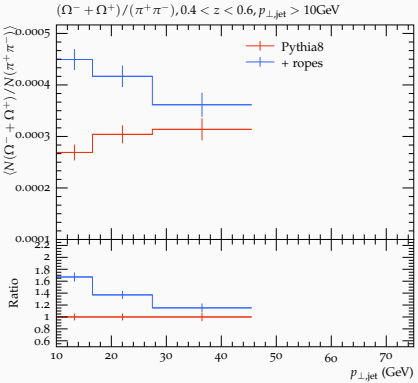
- ✓ **Parallel frame formalism** includes all strings, regardless of the system
- ✓ **Rope hadronization** gives rise to **strangeness and baryon enhancement** across *all* systems, as well as in jets in p-p collisions
- ✓ **String shoving might solve high enhancement of strange baryons** in central A-A collisions

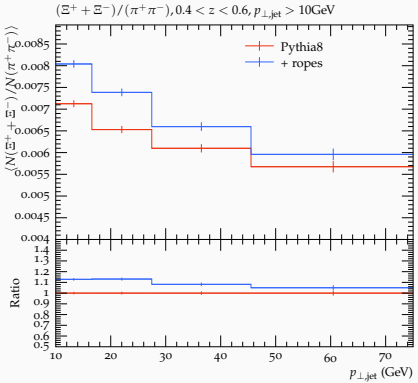
Outlook:

- Merging of rope hadronization and string shoving for **all systems**
- GLEIPNIR: Code to be published with further improvements on string interactions' implementation

Backup

Multi-strange baryon yields in jets for p-p collisions at $\sqrt{s} = 13$ TeV





Yield ratios of $(\Omega^- + \Omega^+)/(\pi^+\pi^-)$ (left) and $(\Xi^- + \Xi^+)/(\pi^+\pi^-)$ (right) with $0.4 < z = p_{\perp,\text{particle}}/p_{\perp,\text{jet}} < 0.6$, as a function of $p_{\perp,\text{jet}}$ for p-p collisions.

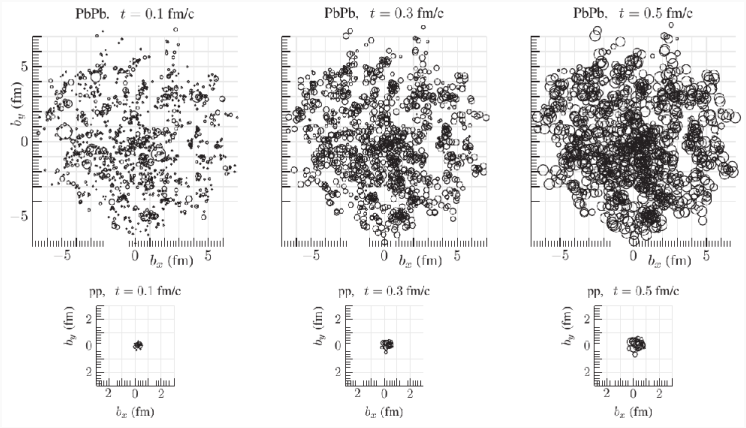
Steps in event generation in Gleipnir in Pythia/Angantyr

$\tau \approx 0$ fm $\rightarrow$	No transverse extension of strings
$\tau \approx 0.5$ fm $\rightarrow$	Parton showers and colour reconnection end, string shoving sets in
$\tau \approx 1$ fm $\rightarrow$	Strings are at maximum radius, maximum shoving force between overlapping strings
$\tau \approx 2$ fm $\rightarrow$	Hadronization via ropes
$\tau > 2$ fm $\rightarrow$	Hadronic rescattering

Dynamic evolution of the colour fields in strings

Pb-Pb@2.76 TeV

p-p@2.76 TeV

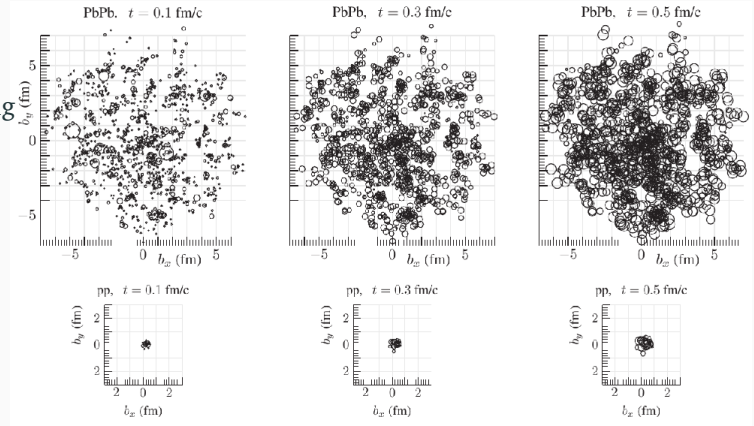


String interactions → primary hadron production vertices[†] → hadronic rescattering

[†]S. Ferreres-Solé and T. Sjöstrand, Eur.Phys.J.C 78 (2018) 11, 983.

Dynamic evolution of the colour fields in strings

Aim: Adding string interactions together with hadronic rescattering



Shift in primary hadronic vertices → string shoving, & κ_{eff} via rope formation.

[†]S. Ferreres-Solé and T. Sjöstrand, Eur.Phys.J.C 78 (2018) 11, 983.