Lund strings in dense environments

Leif Lönnblad

(with Christian Bierlich and Gösta Gustafson)

Department of Astronomy
and Theoretical Physics
Lund University

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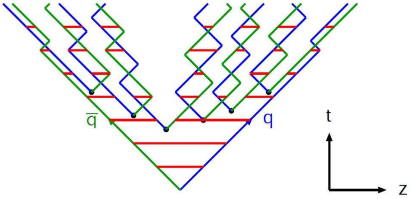
Outline

- String hadronisation
- Rope hadronisation
- String shoving

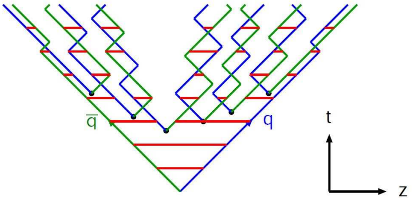
[arXiv:1412.6259, arXiv:1710.09725]

The Lund Model



- The tunnelling mechanism: $\mathcal{P} \propto e^{-\frac{\pi m_{q\perp}^2}{\kappa}} = e^{-\frac{\pi m_q^2}{\kappa}} e^{-\frac{\pi p_\perp^2}{\kappa}}$
- The fragmentation function: $p(z) = N\frac{(1-z)^a}{z} e^{-bm_\perp^2/z}$
- Many parameters depends (implicitly) on κ.

The Lund Model (short version)



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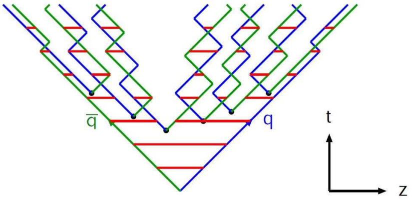

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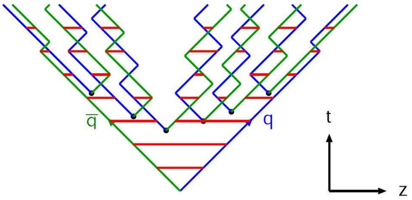

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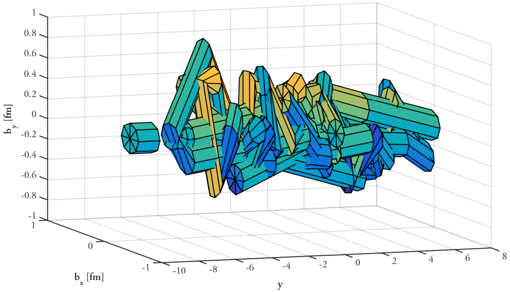
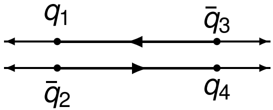
Overlapping strings

- How do we treat strings that overlap in space–time?



Take the simplest case of two simple, un-correlated, completely overlapping strings, with opposite colour flow.



- 1/9: A colour-singlet
- 8/9: A colour-octet

The string tension affects all details in the Lund string fragmentation.
It is proportional to the Casimir operator $C_2^{(8)} = \frac{9}{4} C_2^{(3)}$.

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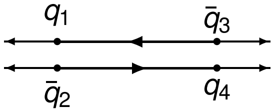

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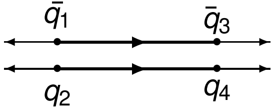

- 1/3: An anti-triplet
- 2/3: A sextet

$$C_2^{(6)} = \frac{5}{2} C_2^{(3)}$$

The anti-triplet case is related to string junctions and baryon production (popcorn mechanism).

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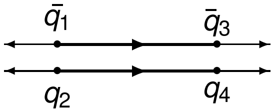

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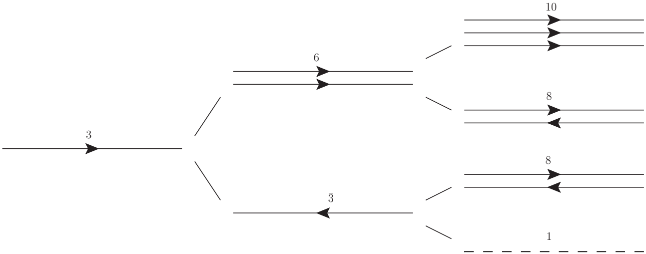
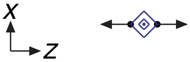
A random walk in colour-space



[Biro, Nielsen, Knoll (1984)]

Time evolution of string-like colour fields



- $<$ 0.2 fm/c; perturbative distances
- $\sim$ 1 fm/c: beginning to reach maximum thickness
- $>$ 1 fm/c: string is formed
- $\sim$ 2 fm/c: string breaking begins in the middle
- strings start to overlap

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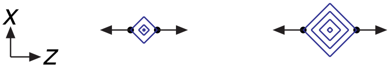

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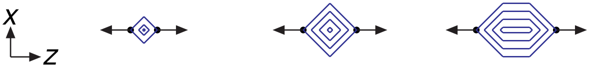

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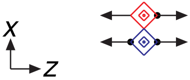

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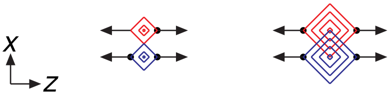

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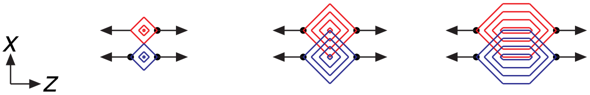

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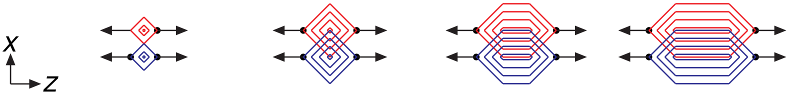

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Effects of increased string tension

- Easier to produce strange quarks in string breaking.
- Effects on multiplicity needs to be tuned away
- Possible effects on diquarks in break-ups (not clear-cut)
- Increased transverse momenta.
- Partially overlapping strings repel each other to minimize energy.

The Rope Model

- Partially overlapping string pieces in impact parameter and rapidity.
- Reconnect to get colour singlets.
- Random walk for the rest to get higher colour multiplets (ropes).
- The rope will break one string at the time.
- Calculate an effective string tension of a break-up, e.g.
  - the first string to break in a sextet has an effective $\kappa_{\text{eff}} \propto C_2^6 - C_2^3 = \frac{3}{2} C_2^3$
  - The second breakup has standard $\kappa \propto C_2^3$
- Rescale the PYTHIA8 parameters accordingly.

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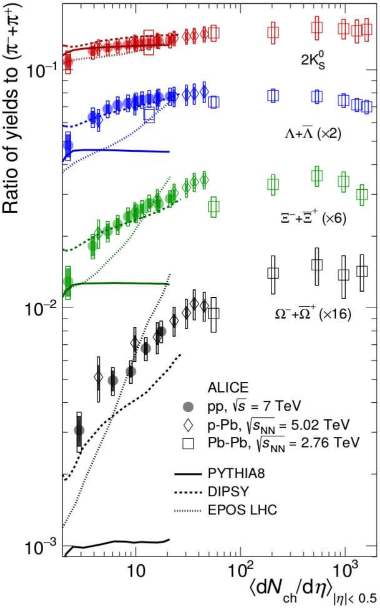

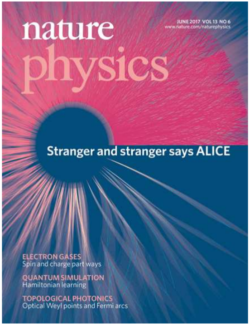

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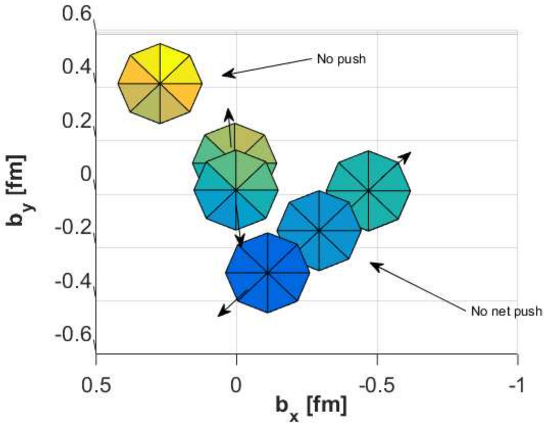
Will overlapping strings in high multiplets generate a transverse pressure?



[Abramovsky, Gedalin, Gurvich, Kancheli (1988)]

String Shoving

- After strings are fully formed ($\sim$ 1 fm/c) until string breaks ($\sim$ 2 fm/c)
- All strings are sliced into δy slices.
- In each (small) time–step $\delta\tau$, each string will get a kick from other strings:

$$\delta p_\perp = \delta\tau\delta y \frac{\tau g \kappa d_\perp}{R^2} e^{-\frac{d_\perp^2}{4R^2}}$$

- Momentum conservation is observed:
  Transverse kicks resolved pairwise,
  Longitudinal recoil absorbed by kicking dipole.
- Note that we are shoving the strings rather than the string ends.

"kick" $\rightarrow$ "kink" $=$ gluon

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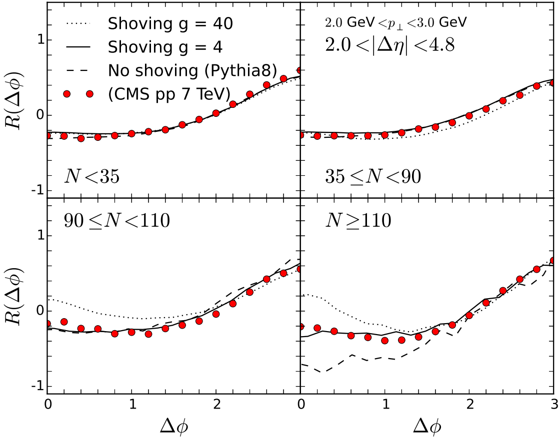
Shoving g = 40
Shoving g = 4
No shoving (Pythia8)
(CMS pp 7 TeV)
2.0 GeV < $p_\perp$ < 3.0 GeV
2.0 < |Δη| < 4.8
N < 35
35 ≤ N < 90
90 ≤ N < 110
N ≥ 110
R(Δφ)
Δφ

Still things to do

- How to handle baryons in ropes
- Shoving has problems with high $p_\perp$ gluons
- Not fully Lorentz invariant
- Shoving produces a lot of soft gluons, which are difficult to handle by PYTHIA8

Tomorrow: Heavy Ions in PYTHIA8

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- What happens in even denser systems?
- Now we heavy ions in PYTHIA8
- not ready for ropes and shoving yet

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