How can we discriminate between a (cold) dense colour field or overlapping strings and a (hot) quark-gluon plasma

Gösta Gustafson

gosta@thep.lu.se

In coll. with L. Lönnblad, C. Bierlich, H. Shah, and S. Chakraborty

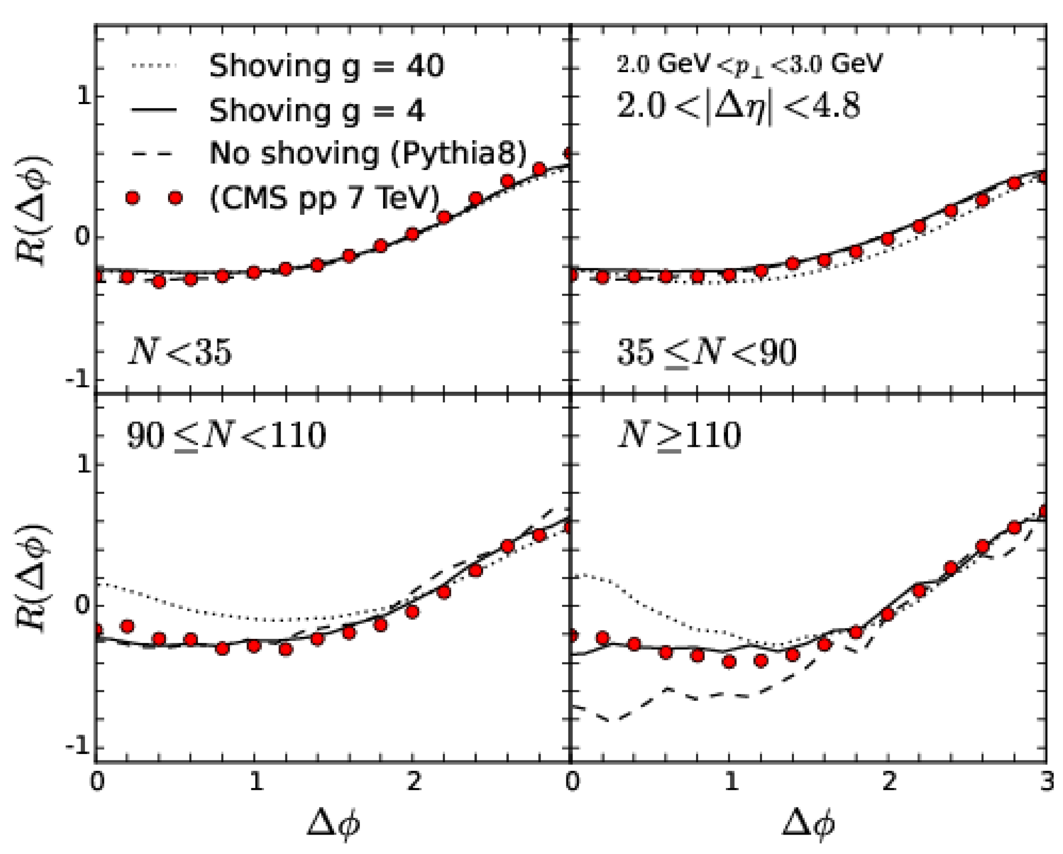
LUNDS UNIVERSITET

Are QGP-like effects just an effect of high energy density?

Overlapping strings/ropes and a hot plasma give very similar results for standard observables. In a series of papers we have investigated the effects of string-string interaction and strong colour fields.

Long range correlations - ridge

Overlapping strings give higher energy density. A large energy density gradient gives a high transverse pressure, and long range angular correlations, see ref. [1].



The figure shows angular correlations for pp collisions at 7 TeV from ref. [1] in four centrality intervals. The model has a tunable parameter, g, and for (the reasonable) value g = 4, the model gives a ridge similar to data from CMS [2].

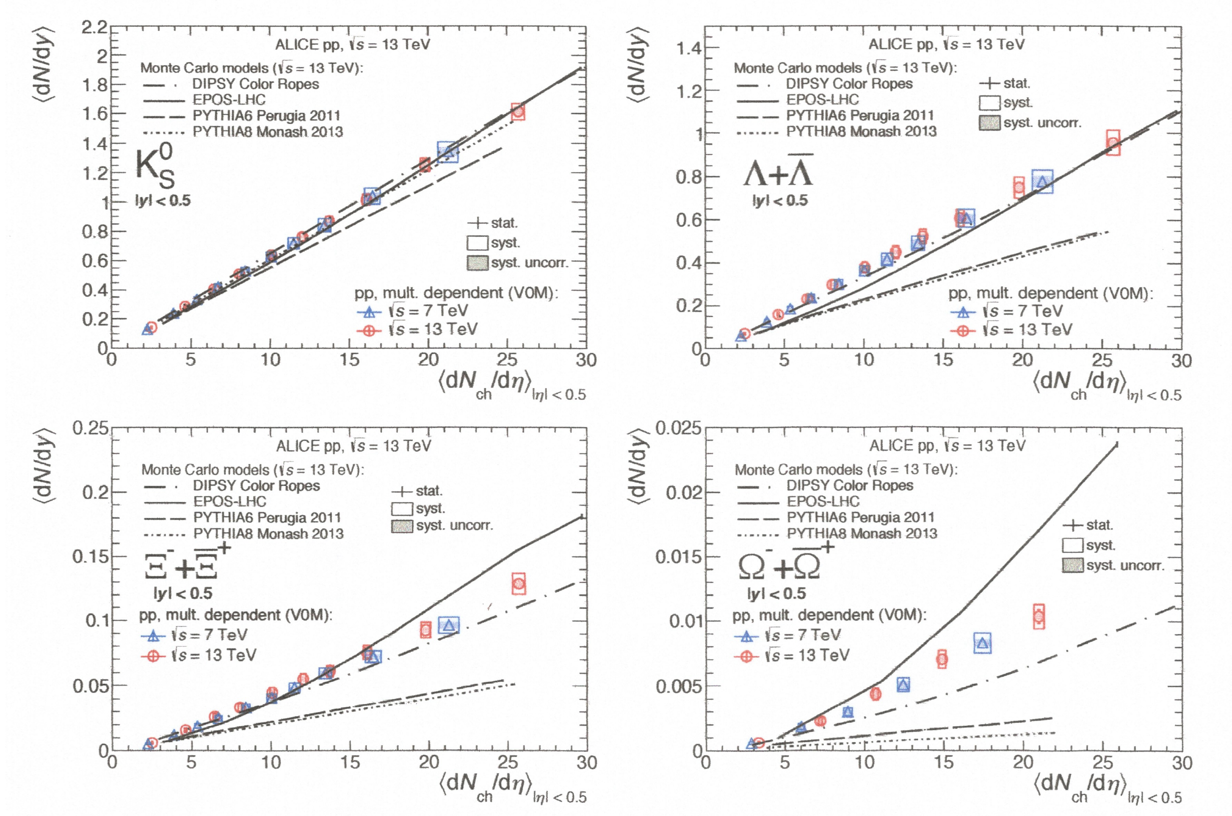
What is very essential is boost invariance. The strings and the glasma are stretched between the projectile and target remnants. They are naturally approximately boost invariant.

Models assuming a boost invariant hot plasma often refer to Bjorken [3] and/or Kajantie–McLerran [4]. Bjorken does not give a dynamical motivation for boost invariance. He only says that since the observed hadron distribution is boost invariant, this must also be the case for the initial conditions. Kajantie–McLerran actually obtain a result which is *not* boost invariant.

The glasma is often assumed to be transformed into a (boost invariant) plasma. It is, however, not obvious, what mechanism can cause such a transformation.

Strangeness enhancement

Overlapping strings forming stronger colour fields (ropes) give an enhanced s/u ratio, see ref. [5]. The effect is similar to the one in a hot plasma. (Baryon enhancement is, however, more model dependent for both ropes and plasma.)



The figure shows data for strange hadron production *vs* central multiplicity from ALICE [6], compared with results from the rope model in ref. [5].

Jet quenching

Weizsäcker–Williams formulation of bremsstrahlung:
A boosted electromagnetic field acts as a flow of virtul quanta: photons. In QCD this formalism gives BFKL evolution in transverse coordinate space.

A high-energy parton moving through a dense field (a glasma or a collection of ropes) will scatter in a way similar to scattering against gluons in a plasma. Jet quenching will probably also be affected by the type of string interaction causing the ridge.
Quantitative estimates are not yet ready.

Some questions to be answered

i) What observable can distinguish between cold strings/ropes and a hot plasma?

ii) What is the relation between dense strings/ropes and glasma?
Is a rope just a quantized version of the classical glasma field?
The strings are due to colour exchange between colliding partons, while the glasma is caused by the non-Abelian feature of colliding colour fields.
Are these two features different views of the same phenomenon?

iii) What is the motivation for boost invariant initial conditions in the formation of a quark-gluon plasma?
Is there a natural mechanism turning a glasma into a plasma?

1. C Bierlich, G. Gustafson, and L. Lönnblad, Phys.Lett. B779 (2018) 58
2. V. Khachatryan *et al.* (CMS), JHEP 09, 091 (2010), arXiv:1009.4122
3. J. Bjorken, Phys.Rev. D27 (1983) 140
4. K. Kajantie and L D. McLerran, Nucl.Phys. B214 (1983) 261-284
5. C. Bierlich, G. Gustafson, L. Lönnblad, and A. Tarasov, JHEP 1503 (2015) 148, arXiv:1412.6259
6. S. Acharya et al. (ALICE), arXiv:1908.01861