ALICE data in the framework of the Color String Percolation Model

Aditya N Mishra, Eleazar Cuautle, Guy Paic, Carlos Pajares, Rolf P Scharenberg and Brijesh K Srivastava

Instituto de Ciencias Nucleares, UNAM, Mexico City, Mexico

Departamento de Fisica de Particulas, Universidale de Santiago de Compostela and IGFAE, Spain

Department of Physics and Astronomy, Purdue University, USA

Introduction

- ❑ The color string percolation model (CSPM) describes the initial collision of two heavy ions in terms of color strings stretched between the projectile and target. Color strings may be viewed as small discs in the transverse space filled with the color field created by colliding partons.
- ❑ Particles are produced by the Schwinger mechanism, emitting *qqbar* pairs in this field.
- ❑ With the growing energy and size of the colliding nuclei the number of strings grow and start to overlap to form clusters in the transverse plane.
- ❑ At a certain critical string density a macroscopic cluster appears, which defines the percolation phase transition.
- ❑ The critical density of percolation is related to the effective critical temperature and thus percolation may provide the information of the deconfinement in the heavy-ion collisions.
- ❑ The CSPM has been successfully used to describe the initial stages in the soft region of the high energy heavy-ion collisions.

Color Strings:

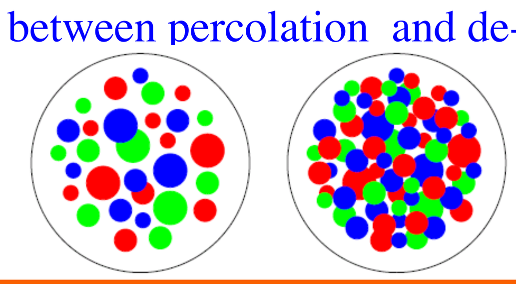
- Multiparticle production at high energies is currently described in terms of color strings stretched between the projectile and target.
- These strings decay into new ones by $q-\bar{q}$ production and subsequently hadronize to produce the observed hadrons. Particles are produced by the Schwinger 2D mechanism.
- As the no. of strings grow with energy and or no. of participating nuclei they start to interact and overlap in transverse space as it happens for disks in the 2-D percolation theory
- ❑ In the case of a nuclear collisions, the density of disks-elementary strings

$$\xi = \frac{N^s S_1}{S_N}$$

N^s = # of strings
S_1 = Single string area
S_N = total nuclear overlap area

Clustering of Color Sources:

- ❑ De-confinement is expected when the density of quarks and gluons becomes so high that it no longer makes sense to partition them into color-neutral hadrons, since these would overlap strongly.
- ❑ We have clusters within which color is not confined : De-confinement is thus related to cluster formation very much similar to cluster formation in percolation theory and hence a connection between percolation and de-confinement seems very likely.



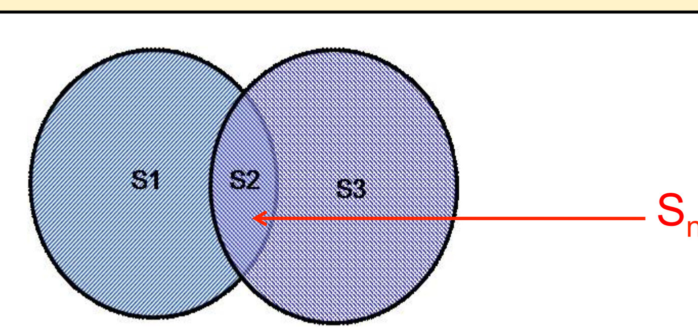
Parton distributions in the transverse plane of nucleus-nucleus collisions

In two dimensions, for uniform string density, the percolation threshold for overlapping discs is:

$\xi_c = 1.18$ Critical Percolation Density

Color Sources:

- ❑ The transverse space occupied by a cluster of overlapping strings split into a number of areas in which different no of strings overlap, including areas where no overlapping takes place.
- ❑ A cluster of n strings that occupies an area S_n behaves as a single color source $\vec{Q}_n$ with a higher color field corresponding to vectorial sum of color charges of each individual string $\vec{Q}_1$



$\vec{Q}_n^2 = n\vec{Q}_1^2$ If strings are fully overlap

$\vec{Q}_n^2 = n\frac{S_n}{S_1}\vec{Q}_1^2$ Partially overlap

Schwinger mechanism for the Fragmentation:

Multiplicity and $<p_T^2>$ of particles produced by a cluster of n strings

Multiplicity (m_n)

$$\mu_n = F(\xi) N^s \mu_1$$

Average Transverse Momentum

$$<p_T^2>_n = <p_T^2>_1 / F(\xi)$$

Color suppression factor can be defined as

$$F(\xi) = \sqrt{\frac{1-e^{-\xi}}{\xi}}$$

(due to overlapping of discs).

Here, ξ is the string density parameter defined as

$$\xi = \frac{N^s S_1}{S_N}$$

N^s = # of strings
S_1 = disc area
S_N = total nuclear overlap area

Methodology

Experimental pT spectra are used to extract F(ξ) by fitting spectra with following function

$$\frac{d^2N}{dpt^2} = \frac{a}{(p_0 + pt)^n}$$

a, p_0 and n are parameters fit to the data.

Parameterization is done using (pp collisions data):
- UA1 data from 200, 500 and 900 GeV
- ISR 53 and 23 GeV

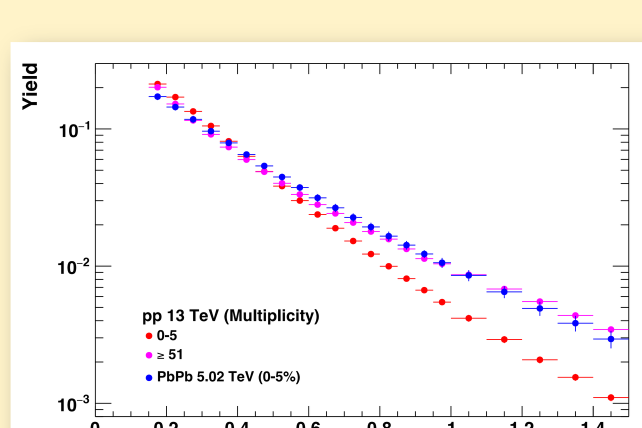
p_0 = 1.71 and n = 12.42 (Nucl. Phys. A698, 331 (2002))

This parameterization can be used for high-multiplicity pp and nucleus-nucleus collisions to account for the clustering.

$$\frac{d^2N}{dpt^2} = \frac{b}{\left(p_0\sqrt{\frac{F(\xi_{pp})}{F(\xi_{AuAu})}} + pt\right)^n}$$

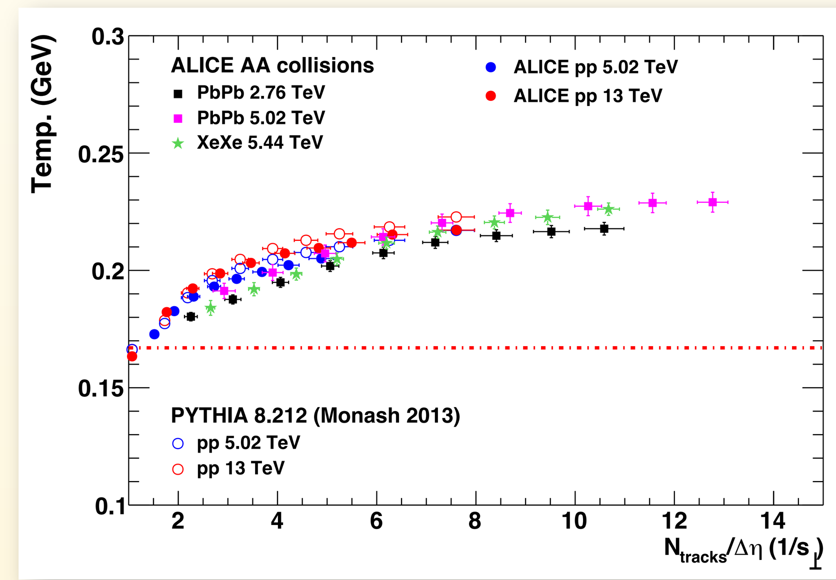
$$F(\xi)_{pp} = 1$$

(No percolation at low energy pp collisions)



Results

Temperature: $T = \sqrt{\frac{\langle p_T^2 \rangle_1}{2F(\xi)}}$

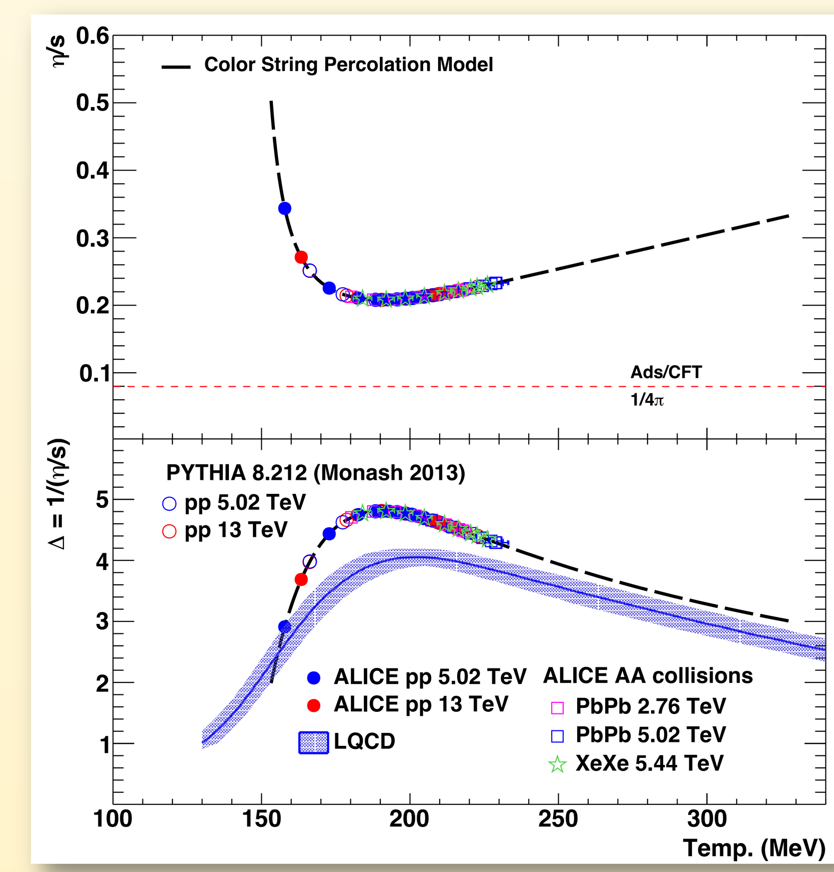


For Au+Au@ 200 GeV (0-10%)
T = 193±3.5 MeV (from CSPM)
T = 220 ± 20 MeV (Direct Photon Measurement)
Phys. Rev. Lett. 104, 132301 (2010)

For Pb+Pb@ 2.76 GeV (0-5%)
T = 218 ± 15 (our calculation from CSPM)
T = 297 ± 12 ± 41MeV (Direct Photon Measurement)
Phys. Lett. B 754 , 235 (2016)

η/s and Trace Anomaly (Δ):

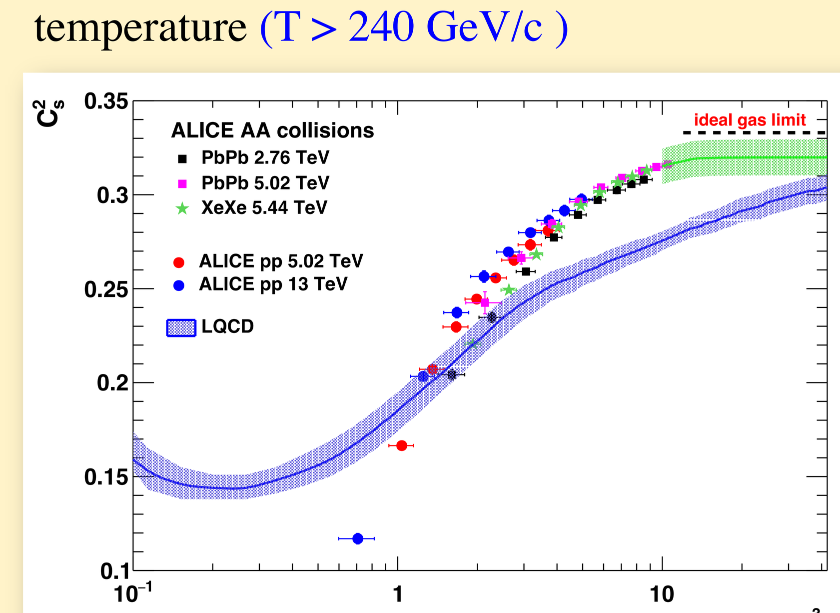
- ❑ This behaviour of η/s is consistent with the formation of a fluid with a low η/s ratio.
- ❑ The trace anomaly (Δ) is the expectation value of the trace of the energy-momentum tensor.
- ❑ We consider the ansatz that inverse of η/s is equal to trace anomaly.
- ❑ The minimum in η/s ~ 0.20 determines the peak of the interaction measure ~ 5 in agreement with the recent HotQCD values (*at the critical temperature of T_c ~ 175 MeV*).

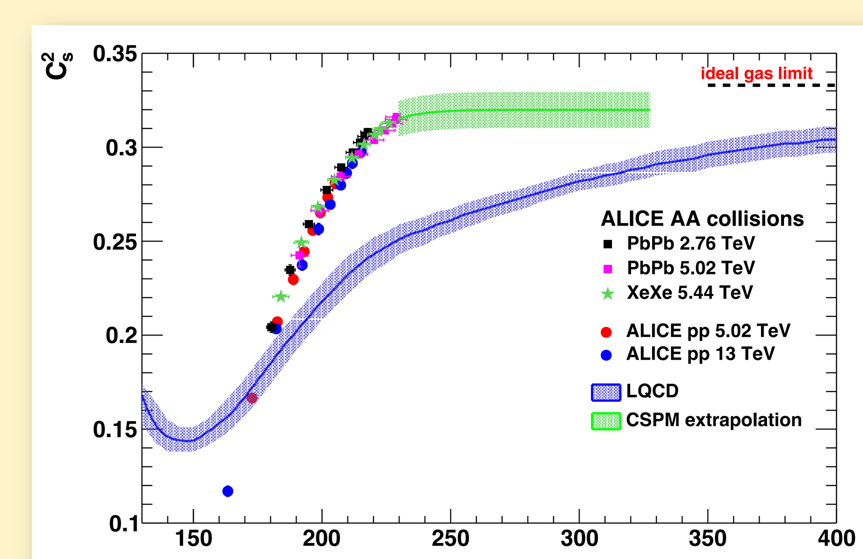


Equation of state (C_s^2): Bjorken 1D expansion gives the sound velocity

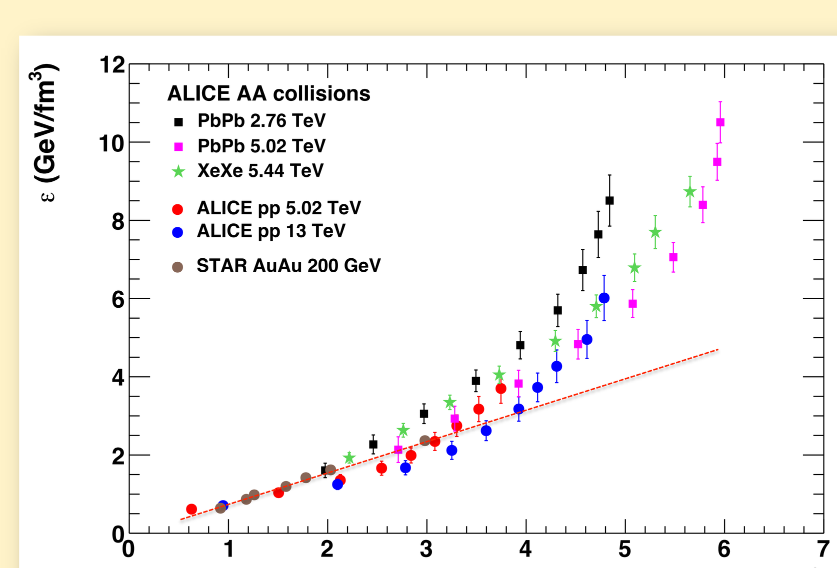
$$c_s^2 = \left(\frac{\xi e^{-\xi}}{1-e^{-\xi}} - 1\right)\left(-\frac{1}{3} + \frac{\Delta}{12}\frac{1}{N}\right)$$

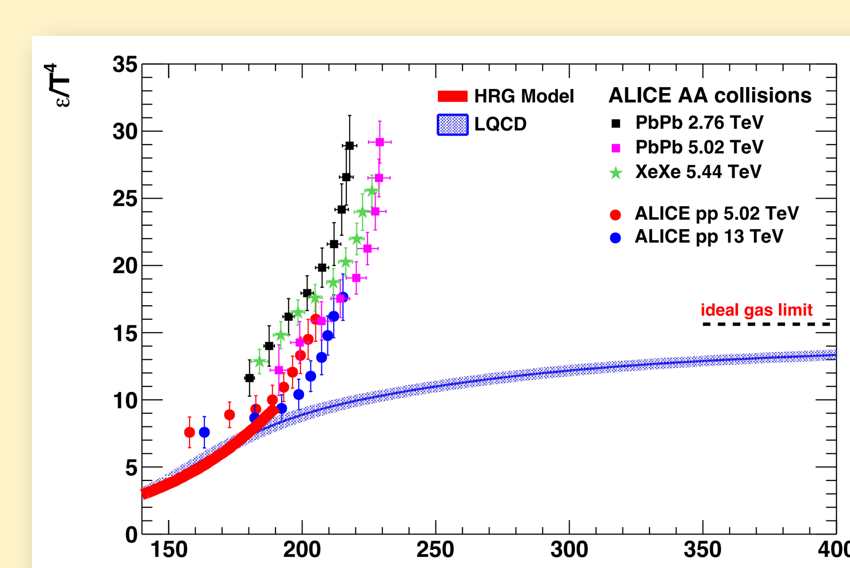
Speed of sound shows saturation behaviour at high energy density (ε > 10 GeV/fm^3) and high temperature (T > 240 GeV/c)





Energy Density (ε):





- ❑ Energy density show a linear behaviour till ξ ~ 3.
- ❑ For ξ > 3, Energy density has non-linear behaviour.
- ❑ Thermal model as well as Lattice QCD calculations agrees CSPM at low Temperature .
- ❑ ε/T^4 shows a continues increase with Temperature which is contrary to the saturation behaviour predicted by Lattice QCD.

Conclusion

- ☑ ALICE pp, PbPb and XeXe data are studied under CSPM approach.
- ☑ The color suppression factor F(ξ) is obtained from the transverse momentum spectra of charged particles in order to obtain various observables.
- ☑ The trace anomaly as a function of temperature shows similar trend as the results obtained in HotQCD collaboration.

References:
[1] M. A. Braun, C. Pajares, Eur. Phys. J. C 16, 349 (2000).
[2] M.A. Braun, F. del Moral, C. Pajares, Phys. Rev. C 65, 024907 (2002).