STRING and PARTON PERCOLATION

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INTRODUCTION

PARTON PERCOLATION

J/ψ SUPPRESSION

STRING PERCOLATION

(p_T fluctuations, p_T distributions,

F-B correlations, B-E correlations)

CONCLUSIONS

2 D PERCOLATION

circular surface of radious R (transverse nuclear area)

N small disc of radious r_0 (transverse partonic or string size)

With increasing density $n = \frac{N}{\pi R^2}$, clusters of increasing size appear

Cluster formation shows critical behaviour, $N \to \infty$, $R \to \infty$ n finite the cluster size diverges at the critical value

$$\eta_c = \pi r_0^2 \; N/\pi R^2 \approx 1.13$$

For finite N and R percolation sets in when the largest cluster spans through the entire surface

Fraction of the surface covered by the discs is $1-e^{-\eta}$

which is 2/3 at $\eta = \eta_C = 1.13$

In A-A collisions the incident nucleons (therefore the subsequent partons or strings) are not distribute in a uniform way. (More in the center than towards the edge). This does that η_C becomes larger.

PARTON PERCOLATION

Hard probes (such as quarqonia) probes the medium locally and this tests only if it has reached the percolation (deconfinement) threshold at their location.

In Local percolation the disc density in the percolating cluster is greater than $\frac{3}{2}\eta_C / \pi r_0^2 \approx 1.72 / \pi r_0^2$

In A-A collisions at $\sqrt{s}$, $n_s(A)$ the density of nucleons in the transverse plane

$\frac{dN_q(x,Q^2)}{dy}$ is PDF (at y=0 $x = k_T / \sqrt{s}$)

$$k_T \approx Q$$

$$n_s(A)\frac{dN_q(x,Q_c^2)}{dy}\bigg|_{x=Q_c/\sqrt{s}} = \frac{1.72}{\pi / Q_c^2}$$

J/ψ SUPPRESSION

A-A $\longrightarrow$ $\chi_c(\psi')$ + x

$\quad\quad\quad\quad\quad\quad\hookrightarrow$ J/ψ + x

$\quad\quad\quad\quad\quad J/\psi$ + x

$\chi_c \quad Q = \frac{1}{r} = 0.6\ GeV$

$\psi' \quad Q = \frac{1}{r} = 0.5\ GeV$

$J/\psi \quad Q = \frac{1}{r_{J/\psi}} \quad 1\ GeV$

SPS

Pb-Pb $\sqrt{s} = 17.4$ —— N_{part}=125 $Q_c \approx 0.7\ GeV$
(χ_c and ψ′ are resolved but not J/ψ)

—— N_{part}=320 $Q_c \approx 1\ GeV$
(all are resolved)

RHIC

Au-Au $\sqrt{s} = 200 \quad N_{part} = 90 \quad Q = 1\ GeV$

one step pattern.

see

S. Digal, S. Fortunato and H. Satz
hep-ph /0310354 Eur. Phys. J C 543 (2004)

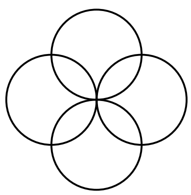
STRING PERCOLATION

$$\eta = \pi r_0^2 \ \frac{N_s}{\pi R^2}$$

$r_0 \approx 0.2 - 0.25\ fm$ string transverse size

N_s number of strings

Color field of a cluster



$$\vec{Q}_n^2 = \left(\sum \vec{Q}_1\right)^2$$

$$Q_n^2 = nQ_1^2$$

Multiplicity $$\mu_n = \sqrt{\frac{nS_n}{S_1}}\mu_1$$

Transverse momentum $$< p_T^2 > = \sqrt{\frac{nS_n}{S_1}} < p_T^2 >_1$$

If just touching $$S_n = nS_1 \begin{cases} \mu_n = n\mu_1 \\ < p_T^2 >=< p_T^2 >_1 \end{cases}$$

In full overlapping $$S_n = S_1 \begin{cases} \mu_n = \sqrt{n}\mu_1 \\ < p_T^2 >= \sqrt{n} < p_T^2 >_1 \end{cases}$$

At high density

$$< nS_1 / S_n > \longrightarrow \frac{\eta}{1-\exp(-\eta)} \equiv \frac{1}{F(\eta)^2}$$

Thus

$$\mu = N_s F(\eta) \mu_1$$

$$< p_T^2 >= \frac{1}{F(\eta)} < p_T^2 >_1$$

Notice that $N_s \sim N_{coll} = N_A^{4/3}$ (y=0)

as $F(\eta) \sim N_A^{-1/3}$

$\mu \sim N_A$ (saturation of the multiplicity per participant)

Also

$$\mu < p_T^2 >= N_s \mu_1 < p_T^2 >_1$$

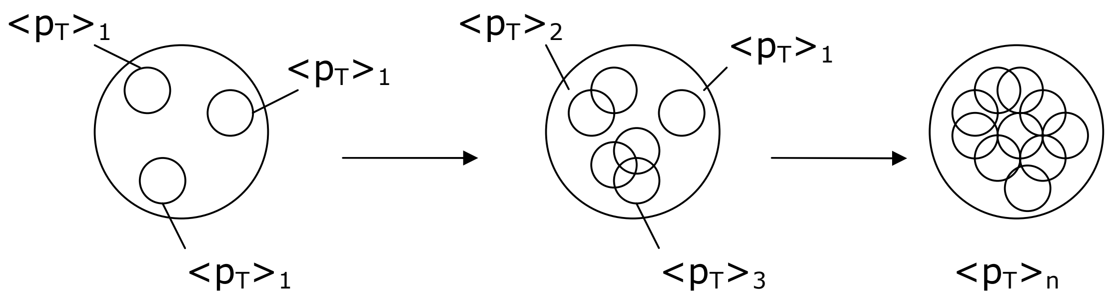
and

$$< p_T^2 >= \mu \left(\frac{r_0}{R} \right)^2 \frac{< p_T^2 >_1}{\mu_1}$$

J. Dias de Deus et al. Phys. Lett. B581 156 (2004)

L. McLerran et al. Phys. Lett. B514 29 (2001) and Nucl. Phys. A705 494 (2002)

TRANSVERSE MOMENTUM FLUCTUATIONS



No fluctuations   No fluctuations

fluctuations related to the behaviour of the number of clusters as a function of centrality

PHENIX

$$F_{p_T} \equiv \frac{\omega_{DATA} - \omega_{random}}{\omega_{random}}$$

$$\omega = \frac{\sqrt{< p_T^2 > - < p_T >^2}}{< p_T >}$$

J. Dias de Deus and A. Rodrigues hep-ph/0308011
E. Ferreiro, F. del Moral and C. Pajares PRC69 034901 (2004)

This effect explains also $\frac{< n_-^2 > - < n_- >^2}{< n_- >}$

Behaviour seen at SPS NA49 Collaboration?

TRANSVERSE MOMENTUM DISTRIBUTIONS

Higher centrality → Change in the cluster size distribution

$$P(m) \rightarrow \frac{m\,P(m)}{<m>} \rightarrow \ldots \frac{m^k}{<m^k>} P(m)$$

G. Jona Lasinio   The renormalization group: a probabilistic view
Nuovo Cimento 26 B 99 (1975)

J. Dias de Deus, C. Pajares and C.A. Salgado   PL 408 417 (1997)
PL 409 474 (1997)

Changes a block (cluster) → single

many strings $<p_T^2>_1$ → $<p_T^2>_n$

$<\mu>_1$ → μ_n

$$P(m) \sim m^k \exp(-\gamma m)$$

$$\frac{A}{\left(1+\frac{F(\eta)p_T^2}{k<p_T^2>_{1i}}\right)^k} = \int dx\; e^{-p_T^2 x} \left(\frac{kx}{<x>}\right)^{k-1} \exp\left(\frac{-kx}{<x>}\right)$$

Scaling law

$$\left.\begin{aligned} \frac{1}{k} &= \frac{<x^2> - <x>^2}{<x>^2} \\ <x> &= \frac{1}{<p_T^2>_\eta} = \frac{F(\eta)}{<p_T^2>_{1i}} \end{aligned}\right\}$$

Notice

- Minimum of k related to Maximum of p_T fluctuations
- Above such k_{min}, p_T suppression
- At low η, only single strings, no fluctuations,

  $k \to \infty$
- At very high η, only one cluster, no fluctuations,

  $k \to \infty$
- (J. Dias de Deus talk for details)
- Some scaling law obtained in many networks phenomena where clustering occurs. Also in non-extensive thermodynamics (Tsallis)

$$\frac{d\ \ln f}{d\ \ln p_T} \xrightarrow[low\ p_T]{} \frac{-2F(\eta)p_T^2}{< p_2^T >_{1i}}$$

$$< p_T^2 >_{1p} \quad > \quad < p_T^2 >_{1k} \quad > \quad < p_T^2 >_{\pi}$$

$$\frac{R_{CP}^P(p_T)}{R_{CP}^{\pi}(p_T)} \quad at\ higher\ p_T \quad \sim \left(\frac{< p_T^2 >_{1p}}{< p_T^2 >_{1\pi}}\right)^{k_c - k_p} > 1$$

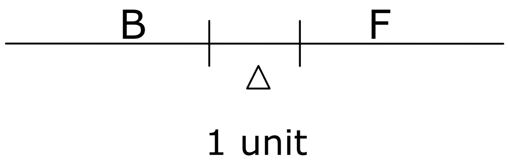
as $k_c > k_p$ because $\eta_c > \eta_p$

(high density branch)

This low p_T and intermediate p_T behaviour same physical origin

FORWARD-BACKWARD CORRELATIONS

$$D_{BF} \equiv \; < \mu_B \mu_F > - < \mu_B > \; < \mu_F >$$



D_{BF} □ number of independent sources

(number of clusters)

Experimental Data up to now

$$< \mu_B >_F = a + b\mu_F$$

$$b \equiv \frac{D_{BF}}{D_{FF}}$$

In *pp* *b* increases with *s*

pA *b* increases with *A*

Prediction D_{BF} and b should decrease after some critical centrality

N.S. Amelin, N.S. Armesto, M.A. Braun, E. Ferreiro, C. Pajares PRL 73 2813 (1994)
M.A. Braun et al Eur. Phys. J C32 535 (2004)

BOSE-EINSTEIN CORRELATIONS

$$C_2(p_1, p_2) = 1 + \lambda e^{-r^{\mu} Q_{\mu}}$$

$\lambda \equiv C_2(0,0) - 1$ is the chaoticity parameter

For a single string (LUND) $\lambda = 1$ (chaotic)

ASSUMING INCOHERENT SUPERPOSITION OF CHAOTIC CLUSTERS

$$\lambda = \frac{n_s}{n_T} = \frac{\text{number of pairs from the same clusters}}{\text{total number of pairs}}$$

Exp data

	λ		
O-C	0.92	$\langle N_{part} \rangle$ =	19.2
O-Cu	0.29		29.5
O-Ag	0.22		47
O-Au	0.16		53

S-Pb	0.46		
Pb-Pb	0.59		
NA44	$3.1 < y < 4.3$	15% centrality	
Pb-Pb	0.42	$2.9<y<5.5$, $p_T<0.6$	central
NA49			
Au-Au	0.66		central

TREND: At low density $\lambda \propto \frac{1}{N_{part}}$

At high density λ grows with N_{part}

CONCLUSIONS

- The pattern of χ, ψ' and direct J/ψ threshold for parton percolation describes naturally the SPS data (the thresholds are different from thermal suppression)

- String percolation describes rightly the data of RHIC
  a) multiplicities
  b) low and intermediate p_T
  c) p_T fluctuations
  d) 2-body and 3-body B-E strength

- Most of the data are related to the behaviour of the number of clusters on the density