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Colour Particle States Behaviour in the QCD Vacuum

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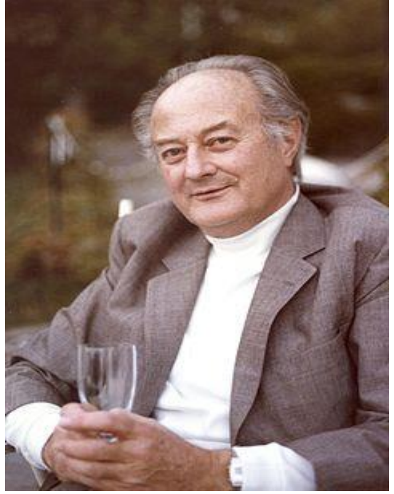

50th Anniversary of Hagedorn's Statistical Bootstrap Model

Rolf Hagedorn (1981)

1984-1994 we collaborated with R.H. intensively at CERN.

My interest in SBM was:

1) How multiplicity distribution of SBM where fireball gives fireballs,… is connected with other multicluster (clan) D, ex. NBD? We've calculated P_n of SBM and shown that after finding the connection of important parameters (<N>, T) for SBM and (k,<n>) for NBD D's become almost identical distributions!

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2) What is the cardinal of the set of fireballs, as a result of bootstrap equation? F. consists of F's consisted of F's! In mathematics: cardinal of set of all sets is cardinal of set! Bootstrap equation?! (Rassel paradox).

$$2^{\aleph_0} = 3^{\aleph_0} = \ldots = \aleph_0^{\aleph_0} = \aleph_1^{\aleph_0} = c^{\aleph_0} = c.$$

Power of Continuum?

3) The role of Hagedorn limiting temperature in phase transition to quark-gluon matter (QGP)?

A lot of points for understanding!

He was a great man! He knew everything about his subject, based on statistical physics and thermodynamics and it was not possible to move him from this positions. The tale of Hagedors ideas is very important in the modern physics of QGP (or new quark –gluon) matter.

He liked his house,

his horse, his wife,

his physics,…

We liked him and have great respect for R.H. …

Quantum system and Environment, Decoherence

- **Interactions of some quantum system with the environment can be effectively represented by additional stochastic terms in the Hamiltonian of the system.**
- **The density matrix of the system is obtained by averaging with respect to degrees of freedom of environment**
- **Interactions with the environment result in decoherence and relaxation of quantum superpositions. Information on the initial state of the quantum system is lost after suficiently large time** (**Haken; Haake; Peres [4-7]**)
- **Quantum decoherence** is the loss of coherence or ordering of the phase angles between the components of a system in a quantum superposition.
- **D.**occurs when a system interacts with its environment in a thermodynamically irreversible way
- **D.** can be viewed as the loss of information from a system due to the environment (often modeled as a heat bath)
- **Dissipation** is a decohering process by which the populations of quantum states are changed due to entanglement with a bath
- **Relaxation** usually means the return of a perturbed system into equilibrium. Each relaxation process can be characterized by a **relaxation time** τ.

Stochastic QCD vacuum

- The model of QCD stochastic vacuum is one of the popular phenomenological models which explains quark confinement (WL decreasing) , string tensions and field congurations around static charges (Ambjorn; Simonov; Dosch [10-13])
- Only the second correlators are important and the other are negligible (which are important in coherent vacuum where all correlators are important) (Simonov [11]) (Gauss domination) It has been conrmed by lattice calculation Shevchenko, Simonov [43]. The most important evidence for this is Casimir scaling [39].
- It is based on the assumption that one can calculate vacuum expectation values of gauge invariant quantities as expectation values with respect to some well-behaved stochastic gauge field
- It is known that such vacuum provides confining properties, giving rise to QCD strings with constant tension at large distances

Stochastic QCD vacuum as environment

- We consider QCD stochastic vacuum as the environment for colour quantum particles and average over external QCD stochastic vacuum implementations.
- Instead of considering nonperturbative dynamics of Yang-Mills fields one introduces external external environment and average over its implementations

As a consequence we obtain:

- decoherence, relaxation of quantum superpositions
- information lost and confinement of colour states phenomenon
- White objects can be obtained as white mixtures of states described by the density matrix as a result of evolution in the QCD stochastic vacuum as environment (Kuvshinov, Kuzmin, Buividovich [1-3])

Colour decoherence

Consider propagation of heavy spinless colour particle along some fixed path γ. The amplitude is obtained by parallel transport (Kuvshinov, Kuzmin, Buividovich [1-3])

$$\partial_\mu|\phi\rangle = i\hat{A}_\mu|\phi\rangle$$

$$|\phi(\gamma)\rangle = \hat{P}\exp\left(i\int_\gamma \hat{A}_\mu dx^\mu\right)|\phi_{in}\rangle \qquad (1)$$

In order to consider mixed states we introduce the colour density matrix taking into account both colour particle and QCD stochastic vacuum (environment)

$$\rho(loop,\gamma\bar{\gamma}) = \langle\phi(\gamma)\rangle\langle\phi(\gamma)|\rangle \qquad (2)$$

Here we average over all implementations of stochastic gauge field (environment degrees of freedom) – decoherence due to interaction with environment. In the model of QCD stochastic vacuum only expectation values of path ordered exponents over closed paths are defined.

Closed path corresponds to a process in which the particle-antiparticle pair is created, propagate and finally annihilated. With the help of (1) and (2) we can obtain expression for density matrix [1,3]:

$$\rho(loop,\gamma\bar{\gamma}) = N_c^{-1} + (|\phi_{in}\rangle\langle\phi_{in}| - N_c^{-1})W_{adj}(loop,\gamma\bar{\gamma}) \qquad (3)$$

Colour density matrix in colour neutral stochastic vacuum can be decomposed into the pieces transform under trivial and adjoint representations [1,3, 37,38] $\hat{\rho}_1 = N_c^{-1}\hat{I} + \rho_1^a \hat{T}_a$

and Wilson loop in fundamental representation is [3]

$$W_{fund}(loop, \gamma\bar{\gamma}) = \langle T_r \hat{P} \exp\left(\int_{loop,\gamma\bar{\gamma}} i\hat{A}_\mu dx^\mu\right)\rangle \qquad (4)$$

(non-abelian Stocks theorem)

- $=\exp \sum_{n=2}^{\infty} (i)(n)(\Delta)(n)[S] \approx$ **expΔ(2)[S=RxT] = exp(-const RxT)** $\gg$ exp(Δ)(n)[S]; (Δ(n)-correlators [13]
- **WL decays exponentially with the area spanned on loop (In terms of time T and distance R) (G,S,C)**
- $$\rho(loop, \gamma\bar{\gamma}) = N_c^{-1} + (\rho_{in} - N_c^{-1})\exp(-\sigma_{adj} RT) \qquad (5)$$ $$\hat{\rho}(L : RT \to \infty) = N_c^{-1}\hat{I}$$

where $\sigma_{adj} = \sigma_{fund} G_{adj} G_{fund}^{-1}$ **is string tension in the adjoint representation,**

G_{adj}, G_{fund} **- eigenvalues of quadratic Casimir operators String tension** $\sigma_{fund} = \frac{g^2}{2} l_{corr}^2 F^2 \qquad (6)$

- **g is coupling constant, lcorr – correlation length in the QCD stochastic vacuum, F - average of the second cumulant of curvature tensor (Dosch; Simonov[12,13]).**
- **Here all colour states are mixed with equal probabilities and all information on initial color state is lost. The stronger are the color states connected the stronger their states transform into the white mixture**

Decoherence rate, Purity, Von Neumann entropy

The decoherence rate of transition from pure colour states to white mixture can be estimated on the base of purity (Haake[8])

P=Tr ρ ²

$$P = N_c^{-1} + (1 - N_c^{-1}) \exp(-2\sigma_{fund} G_{adj} G_{fund}^{-1} RT) \qquad (7)$$

When RT tends to 0, P → 1, that corresponds to pure state. When composition RT tends to infinity the purity tends to 1/Nc, that corresponds to the white mixture

The rate of purity decrease is $T_{dec}^{-1} = -2\sigma_{fund} G_{adj} G_{fund}^{-1}$

Left side of the equation is the characteristic time of decoherence proportional to QCD string tension and distance R

The information of quark colour states is lost due to interactions between quarks and confining non-Abelian gauge fields

Von Neumann entropy: $S = -\mathrm{Tr}\,(\hat{\rho} \ln \hat{\rho})$ S = 0 for the initial state and S = ln Nc for large RT-increases

It can inferred from (3) and (7) that the stronger is particle-antiparticle pair coupled by QCD string or the larger is the distance between particle and antiparticle the quicker information about colour state is lost as a result of interaction with the QCD stochastic vacuum. Thus white states can be obtained as a result of decoherence process

Colour confinement and instability of colour particle motion

- The stability of quantum motion of the particles is described by fidelity f (Peres[40], Prosen[41], Cheng[42]). The definition of fidelity is similar with Wilson loop definition in QCD (Kuvshinov, Kuzmin [14]). Using the analogy between the theory of gauge fields and the theory of holonomic quantum computation (Reineke ; Kuvshinov,Kuzmin, Buividovich [9,14,15]) We can define the fidelity of quark (the scalar product of state vectors for perturbed and unperturbated motion) as an integral over the closed loop, with particle traveling from point x to th

$$f = \langle \left(\langle \phi_{in} | \hat{P} \exp \left(\int i \hat{A}_\mu dx^\mu \right) | \phi_{in} \rangle \right) \rangle \qquad (8)$$

The final expression for the fi ... ic vacuum is

$$f = \exp \left(-\frac{1}{2} g^2 l_{corr}^2 F^2 S_\gamma \right) \qquad (9)$$

Thus fidelity for colour particle moving along contour decays exponentially with the surface spanned over the contour, the decay rate being equal to the string tension (6) Motion becomes more and more instable

❖ Sometimes fidelity is defined in another way (Hubner [34], Uhlmann [35], Kuvshinov, Bagashov [33])

$$F(\omega,\tau) = \mathrm{Tr}\,\left(\sqrt{\sqrt{\omega}\tau\sqrt{\omega}}\right) \quad \rightarrow \quad F = \mathrm{Tr}\,\left(\hat{\rho}_{in}\sqrt{N_c^{-1} + (1 - N_c^{-1})W_{adj}(L)}\right)$$

(Square root of probability of transition from the state with density matrix ω to state with d.m. τ; ϱ_{in} to ϱ_{out}) The fidelity decreases For two random paths in Minkowski space, which are close to each other, the expression for the fidelity is similar, but now the averaging is performed with respect to all random paths which are close enough. And the final expression is

$$f = \exp\left(-\frac{1}{2}g^2 l_{corr}\int_{\gamma_1} dx^{\upsilon} F_{\chi\alpha}\widetilde{F}_{\upsilon\beta}\upsilon^{\chi}\langle\delta\chi^{\alpha}\delta\chi^{\beta}\rangle\right) \qquad (10)$$

where δχ - is the deviation of the path γ_2 from the path γ_1, υ is the four-dimensional velocity and l_{corr} is the correlation length of perturbation of the particle path expressed in units of world line length. If unperturbed path is parallel to the time axis in Minkowski space, the particle moves randomly around some point in three dimensional space. The fidelity in this case decays exponentially with time.

❖ Thus we have connection between confinement and instability of colour particle motion and could be related to possible mechanisms of colour particle confinement

Order-chaos transition, critical energy of and mass of Higgs boson

The increasing of instability of motion in the confinement region is also connected with existence of chaotic solutions of Yang-Mills field [Savvidy; Kuvshinov, Kuzmin 1,16], possible chaos onset (Kawabe [17]. Yang-Mills fields already on classical level show inherent chaotic dynamics and have chaotic solutions [16, 17] The same is true quarks (Kuvshinov, Kazitscky [NPCS 2015] .

It was shown that Higgs bosons and its vacuum quantum fluctuations regularize the system and lead to the emergence of order-chaos transition at some critical energy (Matinyan Kuvshinov, Kuzmin [18-21])

$$E_c = \frac{3\mu^4}{64\pi^2}\exp\left(1 - \frac{\lambda}{g^4}\right)$$

$$E_C = \frac{3\mu^4}{32\pi^2}\exp\left(2\alpha_w - \frac{2\lambda}{g^4}\beta_w\right)\left(1 + \frac{1}{2\cos^4\theta_w}\right)\left(1 - 7e^{-2}\right)$$

$$\alpha_w = \frac{2\ln\cos\theta_w}{1 + 2\cos^4\theta_w}; \quad \beta_w = \frac{32\pi^2\cos^4\theta_w}{9\left(1 + 2\cos^4\theta_w\right)}$$

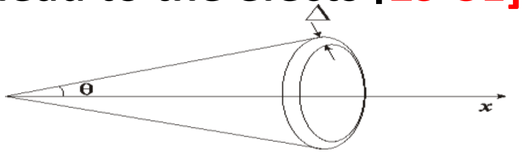
Here μ is mass of Higgs boson, λ is its self interaction coupling constant, g is coupling constant gauge and Higgs fields

In the region of confinement there exists the point of order -chaos transition where the fidelity decreased exponentially and which is equal to string tension (6). This connects the properties of stochastic QCD vacuum and Higgs boson mass and self interaction coupling constant

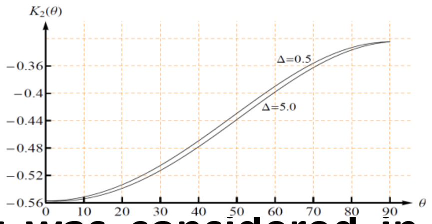
Squeezed and entangled colour states

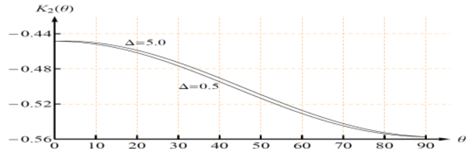
The increasing of instability of motion in the confinement region is also connected with possible quantum entanglement as a probe of confinement and quantum squeezing of colour states (Kuvshinov, Shaparau, Kokoulina, Marmysh, Buividovich; Nashioka; Klebanov [23-26,35]) The emergence of entagled and squeezed states in QCD becomes possible due to the four-gluon self-interaction, the three-gluon self-interaction does

- **not lead to the efects [29-31]**



$$K_{(2)}(\theta_1,\theta_2) = \frac{C_{(2)}(\theta_1,\theta_2)}{\rho_1(\theta_1)\rho_1(\theta_2)},$$





Quantum entanglement existence in Yang-Mills-Higgs theory was considered in [23] on the base of original quasiclassical formalism developed in [26]. The concept of quantum entanglement was found to be very useful as a model-independent characteristic of the structure of the ground state of quantum field theories which exhibit strong long range correlations, most notably lattice spin systems at and near the critical points and the corresponding conformal field theories (Calabrese [32])

Quantum entanglement was also considered as an alternative way to probe the confining properties of large-N gauge theories (Nashioka; Klebanov [24,25]) Quantum entanglement between the states of static quarks in the vacuum of pure Yang-Mills theory was analyzed in [24].

Hilbert space of physical states of the fields and the charges is endowed with a direct product structure by attaching an infinite Dirac string to each charge. Tracing out the gauge degrees of freedom gives the density matrix which depends on the ratio of Polyakov and Wilson loops spanned on quark world lines (Kuvshinov, Buividovich [34].

- **Question: what is the result of interaction of Superpositions, Multiparticle States (pure separable, mixed separable and nonsepaparable (entangled) colour states with Stochastic QCD Vacuum ?**

Interaction of Colour Superposition with QCD Vacuum

When the initial (pure) colour state is a **superposition of colour states (Kuvshinov, Bagashov [33])**

$$|\phi_{in}\rangle = \alpha|1\rangle + \beta|2\rangle + \gamma|3\rangle \qquad |\alpha|^2 + |\beta|^2 + |\gamma|^2 = 1$$

The corresponding **density matrix** is

$$\hat{\rho}_{in} = |\phi_{in}\rangle\langle\phi_{in}| \qquad \hat{\rho}_{in} = \begin{pmatrix} |\alpha|^2 & \alpha\beta^* & \alpha\gamma^* \\ \alpha^*\beta & |\beta|^2 & \beta\gamma^* \\ \alpha^*\gamma & \beta^*\gamma & |\gamma|^2 \end{pmatrix}$$

After integration and averaging

$$\hat{\rho}(y) = \langle\langle\hat{\rho}_1(y)\rangle\rangle = N_c^{-1}\hat{I} + (\hat{\rho}_{in} - N_c^{-1}\hat{I})W_{adj}(L)$$

When RT→∞ $\quad W_{adj}(L) = \exp(-\sigma_{adj}RT)$

$$\begin{pmatrix} |\alpha|^2 & \alpha\beta^* & \alpha\gamma^* \\ \alpha^*\beta & |\beta|^2 & \beta\gamma^* \\ \alpha^*\gamma & \beta^*\gamma & |\gamma|^2 \end{pmatrix} \to \begin{pmatrix} N_c^{-1} & 0 & 0 \\ 0 & N_c^{-1} & 0 \\ 0 & 0 & N_c^{-1} \end{pmatrix}$$

Density **matrix is diagonal ρout=diag (1/Nc)**

Purity, Von Neumann Entropy(S)

$$P = N_c^{-1} + (1 - N_c^{-1}) W_{adj}^2(L)$$

$$S=(1-N^{-1}_C)(1-\ln\frac{Wadj(L)}{Nc})$$

- For the initial stateRT →0: purity P → 1 -pure state, entropy S→O
- Asymptotically RT→∞: $P=N_C^{-1}$-fully mixed state,entropy S=lNc

-Interaction of an arbitrary colour superposition with the QCD stochastic vacuum at large distances leads to an emergence of a mixed state
-With equal probabilities for different colours
-Without any non-diagonal terms in the corresponding density matrix
ρ_{out}=diag (1/Nc)

Interaction of two-particle states with QCDV

- *Consider a system of two quarks: subsystems A and B.*
- *Assume that there are only two possible states: |A>, |B>and $|\bar{A}>; |\bar{B}>$.*
- *Thus here we have $N_c = 2$.*
- *Pure separable* $$|\phi\rangle = |a\rangle|b\rangle$$
- *Mixed Separable* $$\rho_{AB} = \rho_A \rho_B$$
- *Pure nonseparable(entangled)* $$|\phi\rangle = \alpha|A\rangle|\bar{B}\rangle + \beta|\bar{A}\rangle|B\rangle$$

(Density matrix cannot be represented as $\hat{\varrho} = \sum_i \rho_i \varrho_i^A \otimes \varrho_i^{\mathrm{B}}$*)*

$$\rho_{AB} = |\phi\rangle\langle\phi| = |\alpha|^2|A\bar{B}\rangle\langle\bar{B}A| + \alpha\beta^*|A\bar{B}\rangle\langle B\bar{A}| + \alpha^*\beta|\bar{A}B\rangle\langle\bar{B}A| + \\ + |\beta|^2|\bar{A}B\rangle\langle B\bar{A}|$$

Density matrix, Purity, Von Neumann Entropy(TwPS)

Initial state

$$\rho_{AB} = \begin{array}{c} \\ |AB\rangle \\ |\bar{A}B\rangle \\ |A\bar{B}\rangle \\ |\bar{A}\bar{B}\rangle \end{array} \begin{array}{c} \begin{array}{cccc} \langle BA| & \langle B\bar{A}| & \langle \bar{B}A| & \langle \bar{B}\bar{A}| \end{array} \\ \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & |\beta|^2 & \alpha^*\beta & 0 \\ 0 & \alpha\beta^* & |\alpha|^2 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \end{array}$$

State:	pure separable	mixed separable	pure entangled
P (purity)	1	$\frac{1}{4} \leq P < 1$	1
S (entropy)	0	$0 < S \leq 2 \ln 2$	0

→
Diagonalization

$\rightarrow$
RT→∞

Purity decreases
Entropy increases

Final state

$$\rho_{AB_{W(L)\to 0}} = \begin{array}{c} \\ |AB\rangle \\ |\bar{A}B\rangle \\ |A\bar{B}\rangle \\ |\bar{A}\bar{B}\rangle \end{array} \begin{array}{c} \begin{array}{cccc} \langle BA| & \langle B\bar{A}| & \langle \bar{B}A| & \langle \bar{B}\bar{A}| \end{array} \\ \begin{pmatrix} 1/4 & 0 & 0 & 0 \\ 0 & 1/4 & 0 & 0 \\ 0 & 0 & 1/4 & 0 \\ 0 & 0 & 0 & 1/4 \end{pmatrix} \end{array}$$

State:	pure separable	mixed separable	pure entangled
P (purity)	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
S (entropy)	$2 \ln 2$	$2 \ln 2$	$2 \ln 2$

Interaction of three Particle States with QCDV

$$|\phi\rangle = |a\rangle|b\rangle|c\rangle \qquad \rho_{AB} = \rho_A\rho_B\rho_C \qquad |\phi\rangle = a|A_1B_2C_3\rangle + b|A_1B_3C_2\rangle + c|A_2B_1C_3\rangle + d|A_2B_3C_1\rangle + e|A_3B_1C_2\rangle + f|A_3B_2C_1\rangle$$

$$|a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2 + |f|^2 = 1$$

$$\rho_{ABC} = \begin{array}{c} \\ |A_1B_2C_3\rangle \\ |A_1B_3C_2\rangle \\ |A_2B_1C_3\rangle \\ |A_2B_3C_1\rangle \\ |A_3B_1C_2\rangle \\ |A_3B_2C_1\rangle \end{array} \begin{array}{c} \begin{array}{cccccc} \langle C_3B_2A_1| & \langle C_2B_3A_1| & \langle C_3B_1A_2| & \langle C_1B_3A_2| & \langle C_2B_1A_3| & \langle C_1B_2A_3| \end{array} \\ \begin{pmatrix} |a|^2 & ab^* & ac^* & ad^* & ae^* & af^* \\ ba^* & |b|^2 & bc^* & bd^* & be^* & bf^* \\ ca^* & cb^* & |c|^2 & cd^* & ce^* & cf^* \\ da^* & db^* & dc^* & |d|^2 & de^* & df^* \\ ea^* & eb^* & ec^* & ed^* & |e|^2 & ef^* \\ fa^* & fb^* & fc^* & fd^* & fe^* & |f|^2 \end{pmatrix} \end{array}$$

↓**Diagonalization**

$$\rho_{ABC} = \begin{array}{c} \\ |A_1B_2C_3\rangle \\ |A_1B_3C_2\rangle \\ |A_2B_1C_3\rangle \\ |A_2B_3C_1\rangle \\ |A_3B_1C_2\rangle \\ |A_3B_2C_1\rangle \end{array} \begin{array}{c} \begin{array}{cccccc} \langle C_3B_2A_1| & \langle C_2B_3A_1| & \langle C_3B_1A_2| & \langle C_1B_3A_2| & \langle C_2B_1A_3| & \langle C_1B_2A_3| \end{array} \\ \begin{pmatrix} 1/27 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/27 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/27 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/27 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/27 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/27 \end{pmatrix} \end{array}$$

Purity, Von Neumann Entropy (ThPS)

State:	pure separable	mixed separable	pure entangled
P (purity)	1	$\frac{1}{27} \leq P < 1$	1
S (entropy)	0	$0 < S \leq 3 \ln 3$	0

$\downarrow$

$RT \rightarrow \infty$
Purity decreases
Entropy increases

State:	pure separable	mixed separable	pure entangled
P (purity)	$\frac{1}{27}$	$\frac{1}{27}$	$\frac{1}{27}$
S (entropy)	$3 \ln 3$	$3 \ln 3$	$3 \ln 3$

Interaction of N_p multiparticle states with QCDV Density matrix, Purity, Von Neumann Entropy (TPS)

$$\hat{\rho}(y) = N_c^{-N_p}\hat{I} + (\hat{\rho}_{in} - N_c^{-N_p}\hat{I})W_{adj}(L)$$

$$\hat{\rho}(L : RT \to \infty) = N_c^{-N_p}\hat{I}$$

$$\mathrm{P} = N_c^{-N_p} + (1 - N_c^{-N_p})W_{adj}^2(L)$$

$$S = -\mathrm{Tr}\,(N_c^{-N_p}\hat{I}\ \ln(N_c^{-N_p}\hat{I})) = \mathrm{Tr}\,(N_c^{-N_p}\hat{I}N_p\ln N_c) = N_c^{N_p}N_c^{-N_p}N_p\ln N_c = \\ = N_p\ln N_c$$

Purity, Von Neumann Entropy

State:	pure separable	mixed separable	pure entangled
P (purity)	1	$\frac{1}{N_c^{N_p}} \leq$P< 1	1
S (entropy)	0	$0<$S$\leq N_p \ln N_c$	0

$\downarrow$ **RT$\longrightarrow\infty$**

State:	pure separable	mixed separable	pure entangled
P (purity)	$\frac{1}{N_c^{N_p}}$	$\frac{1}{N_c^{N_p}}$	$\frac{1}{N_c^{N_p}}$
S (entropy)	$N_p \ln N_c$	$N_p \ln N_c$	$N_p \ln N_c$

Purity decreases, Entropy increases

ОИЭЯИ СОСНЫ

Conclusion

- Vacuum of quantum chromodynamics can be considered as environment (in the sense of quantum optics) for colour particles
- Density matrix, Purity and Fidelity for colour particles are depended on Wilson loop averaged through QCD vacuum degrees of freedom
- In the case of of stochastic (not coherent) QCD vacuum (only correlators of the second order are important) in confinement region (Wilson loop decays exponentially) we have decoherence of pure colour states into a mixed white states and instability (chaoticity) of their motion, fidelity and purity decay exponentially (decay rate =string tension)
- Dynamics of Yang-Mills fields can be regularized by Higgs fields and quantum fields fluctuations. Critical point of order-chaos transition appears which corresponds to the point, where fidelity and purity drop exponentially
- Quantum squeezinq and entanglement accompany nonperturbative (A^4) evolution of colour particles in QCD vacuum, confinement, decoherence and instability
- For multiparticles (pure separable, mixed separable and nonsepaparable (entangled) when $RT \to \infty$ we obtain diagonalization of density matrix, decreasing of purity and fidelity, increasing of Von Neumann entropy

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