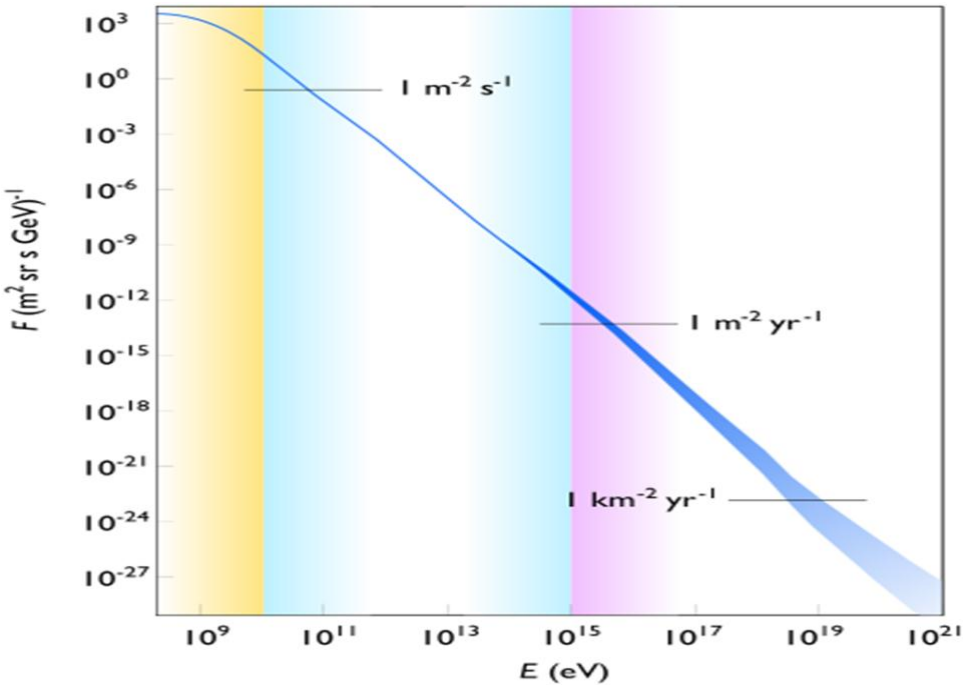

ISMD2011
Could dense quark matter be a source of super high energy cosmic rays?
COMSATS
Institute of Information Technology , Islamabad
Dr.Sc. Mais Suleymanov

the talk focuses on one of the possible sources of the high energy cosmic particles ~ 10^{15}eV and more

it was proposed that the dense (and/or hot) quark matter could be a source of the super high-energy secondary hadrons

cosmic rays are a main component of the Universe ; they could solve an important information on appearance and evaluation of the Universe



a source of cosmic rays with super high energies (10^{15}eV) stays unknown *[V.L. Ginzburg "The origin of cosmic rays (Forty years later)" Phys. Usp. 36 (7) 587–591 (1993)]* , even whether galactic or extragalactic origin of the super high energy cosmic rays is not clean steel

the flux of cosmic ray particles as a function of their energy.

the lowest energies (yellow zone) are mainly attributed to solar cosmic rays, intermediate energies (blue) to galactic cosmic rays, and highest energies (purple) to extragalactic cosmic rays *[S. Swordy, The energy spectra and anisotropies of cosmic rays, 2001, Space Science Reviews 99, pp.85–94]*

The huge magnetic fields which are generated by some massive stars could be sources of the super high energy cosmic rays

[K.V. Ptitsina,S.V.Troitsky. Phys. Usp. 187 (7) 587–591 (2010)]

the energy is not enough to accelerate the particles to energies great than 10^{15}eV

Could dense quark matter be a source of super high energy cosmic rays?

New source of super high energy cosmic rays , without acceleration …

Conditions

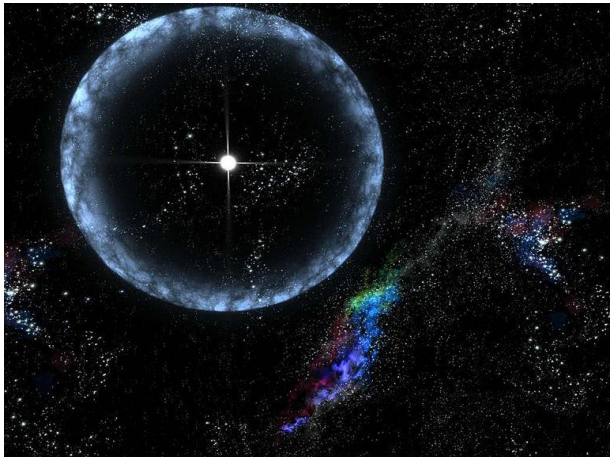
1. Dense and/or hot quark matter ($\rho \sim> \rho_c$, $T \sim> T_c$);
2. Collective behavior of partons and formation of coherent parton group;
3. Coherent interaction of the grouped partons-system

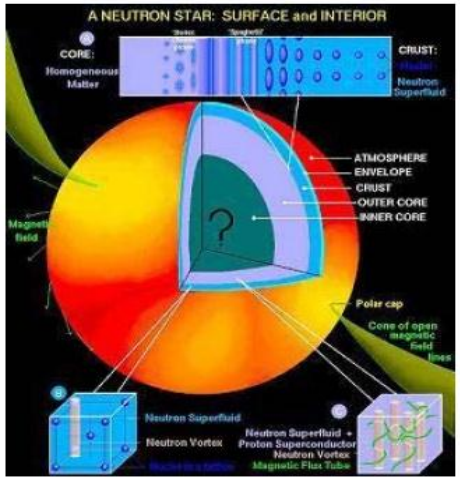
the maximum energy of cosmic particles might be limited only by the values of the total energy of the system, the values of energy will depend on the parameters of the system too - high energy particles without acceleration

Could dense quark matter be a source of super high energy cosmic rays?

I Condition: Dense and/or hot quark matter ($\rho \sim> \rho_c$, $T \sim> T_c$)

The matter can be formed in the center of some massive stars (in center of supernova stars; the process of neutron stars formation [A. G. Lyne and F. G. Smith. *Pulsar Astronomy*. Cambridge University Press, 1990.]) due to high density of matter the deconfinement and parton structure could appear in these mediums





Could dense quark matter be a source of super high energy cosmic rays?

Second condition: Collective behavior of partons

What we have had?

At relativistic energies: JINR Cumulative effect -

production of the particles with energies beyond the kinematic limit of free nucleon collisions - A.M. Baldin (et al. Sov.J. Nucl.Phys.18,41 (1973); Journal of PEPAN, v.8 (1977), p.429- 477)

A.V. Efremov. PEPAN, v.13, p.613 (1982)

M.I. Stricman, L.L. Francfurt PEPAN, v.11, p.571 (1980)

D+A → reactions at 5 AGeV the pions were produced with energies ~ 8 GeV

Could dense quark matter be a source of super high energy cosmic rays?

Second condition: Collective behavior of partons

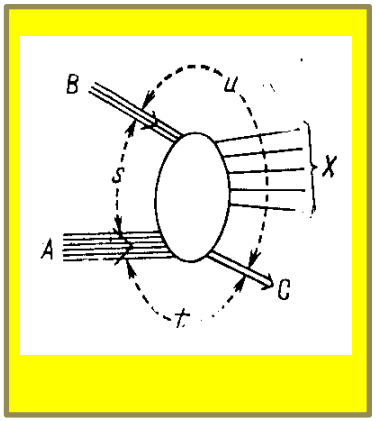
At relativistic energies: JINR Cumulative effect

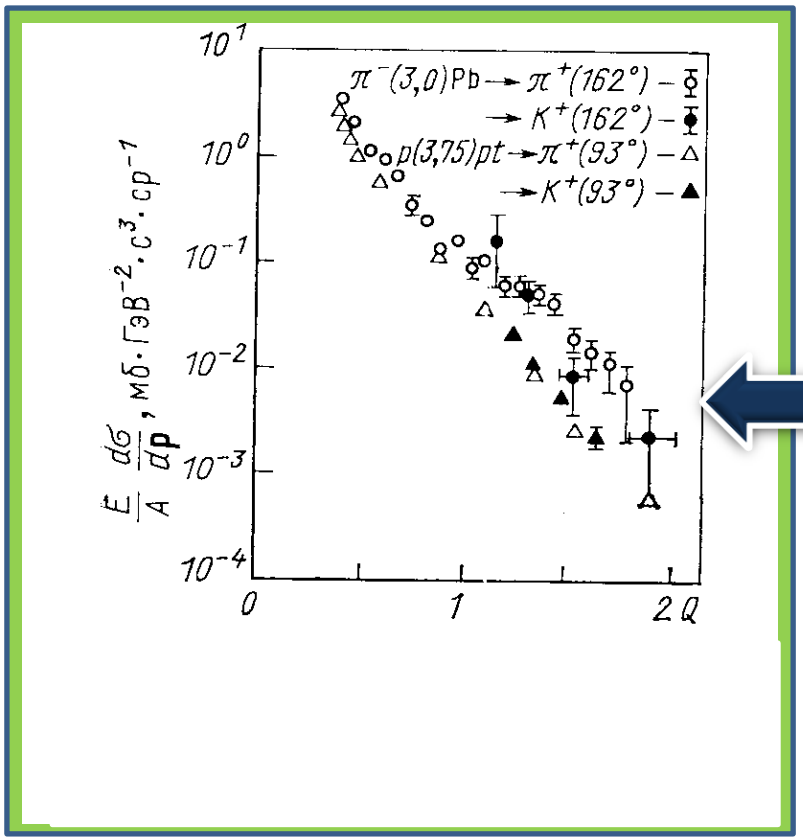
What we have had?

B+A →C+X reactions , particles C were emitted with x > 1 ,

$x=u/s \approx (1/m)(\varepsilon - p\cos\theta)$

h+N → x ≤ 1





V.S . Stavinski.
Journal of PEPAN, v.10 (1979), p.949-995

Second condition: Collective behavior of partons What we have had?

1. For photon-nuclear;
   lepton-nuclear;
   hadron-nuclear ;
   nuclear-nuclear

2. Strong A-dependences for the invariant inclusive cross sections $f(\mathbf{p})= \varepsilon\, d\sigma/d\mathbf{p}$ of cumulative particles :

A	$\gamma, e, \mu + A \rightarrow$
A	$h + A$ (heavy) $\rightarrow$
$A^{n>1}$	$h + A$ (light) $\rightarrow$
$A^{5/3}$	$h + A \rightarrow d+X$
A^{2}	$h + A \rightarrow t+X$
$A^{2/3}$	$\pi + A \rightarrow$

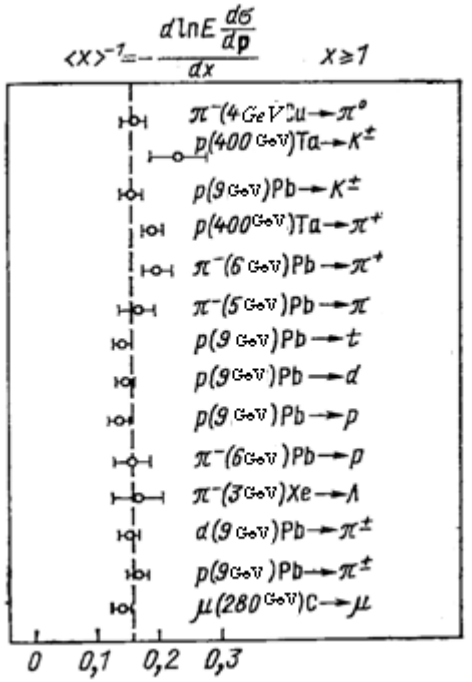
At relativistic energies: JINR Cumulative effect

3. **Universal parameter**

$$\varepsilon \frac{d\sigma}{d\mathbf{p}} \sim \exp\left(-x/\langle x\rangle\right)$$

inverse of slope

$$\langle x \rangle \simeq 0{,}16$$



Second condition: Collective behavior of partons What we have had?

At relativistic energies: JINR Cumulative effect

The theoretical interpretation :

- a result of nucleon collective phenomena where the parton degrees of freedom could appear ;

- the cumulative particles could be produced on the system of collected (groped) nucleons

The system could be formed as a result of :

- fluctuation of nuclear density (D.I. Blokhintsev);

- interaction of the projectile with target nucleons;

- percolation

very small probability because of the cumulative particles have been observed for $\gamma, e, \mu + A \rightarrow$ reactions too

H. Satz. hep-ph/0212046;
Janusz Brzychczyk. nucl-th/0407008;
C. Pajares. hep-ph/0501125

Second condition : Collective behavior of partons

At relativistic energies: CERN EMC effect

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/83-14
January 24th, 1983

THE RATIO OF THE NUCLEON STRUCTURE FUNCTIONS F_2^N FOR IRON AND DEUTERIUM

The European Muon Collaboration

CERN[1]-DESY(Hamburg)[2]-Freiburg[3]-Kiel[4]-Lancaster[5]-LAPP(Annecy)[6]-
Liverpool[7]-Marseille[8]-Oxford[9]-Rutherford[10]-Sheffield[11]-Turin[12] and Wuppertal[13]

J.J. Aubert[8], G. Bassompierre[6], K.H. Becks[13], C. Best[10a)], E. Böhm[4],
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J.H. Cobb[5c)], G. Coignet[6], F. Combley[11], G.R. Court[7], G. D'Agostini[8], W.D. Dau[4],
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R.P. Mount[9j)], P.R. Norton[10], J. McNicholas[9k)], A.M. Osborne[1], P. Payre[6],
C. Peroni[12], H. Pessard[6], U. Pietrzyk[13], K. Rith[3], M. Schneegans[6], T. Sloan[5],
H.E. Stier[3], W. Stockhausen[13], J.M. Thénard[6], J.C. Thompson[10], L. Urban[6l)],
M. Villers[9], H. Wahlen[13], M. Whalley[11m)], D. Williams[7], W.S.C. Williams[9],
J. Williamson[11], S.J. Wimpenny[7].

J.J. Aubert et al., Phys. Lett. 123B, 275 (1983)

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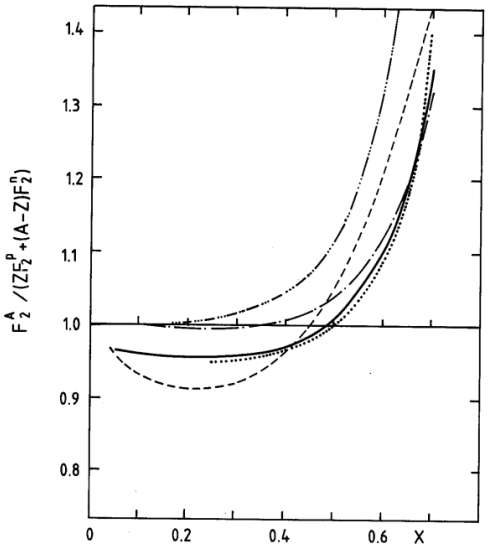
Second condition : Collective behavior of partons

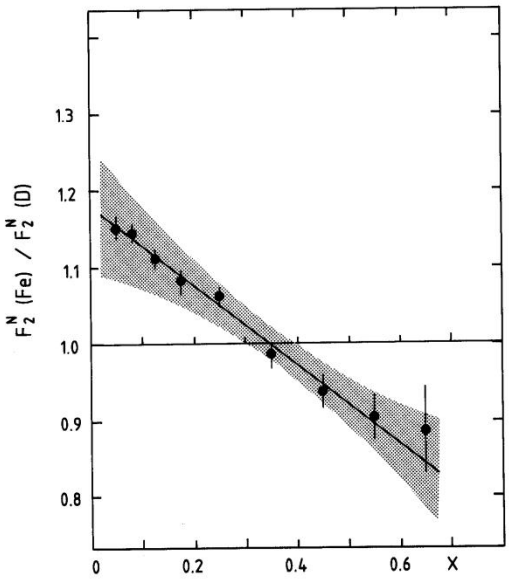
Deep inelastic muon scattering on iron and deuterium

the F_2 and hence the quark and gluon distributions of a nucleon bound in a nucleus differ from those of a free nucleon

Experiment



The existing theoretical predictions



Ratio of the structure functions $F_2^N(Fe)/F_2^N(D)$

a result of nucleon collective phenomena ; the parton degrees of freedom appear

Disagreement

Second condition : Collective behavior of partons

the results - RHIC&LHC

azimuthal anisotropy at RHIC&LHC show a collective behavior, which is likely to be formed at an early, parton, stage of the spacetime evolution of product hot and dense matter *[. V. A. Okorokov. Physics of Atomic Nuclei, 2009, Vol. 72, No. 1, pp. 147–160.; J.Adamset al., Phys.Rev.Lett. 95, 122301 (2005);A.Adareet al., Phys.Rev.Lett. 98, 162301 (2007)].*

anisotropy indicates that matter under extreme conditions behaves as a nearly **ideal liquid** rather than an ideal gas of quarks and gluons.

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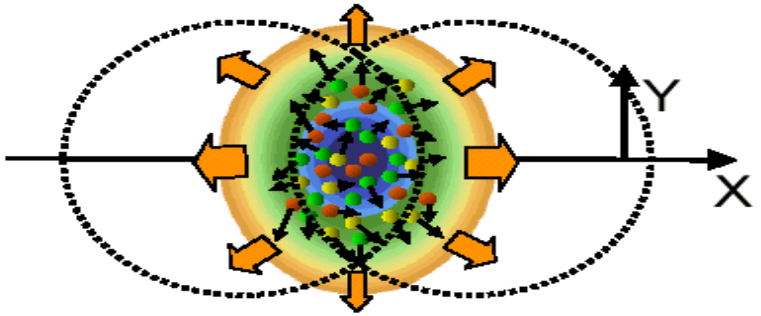
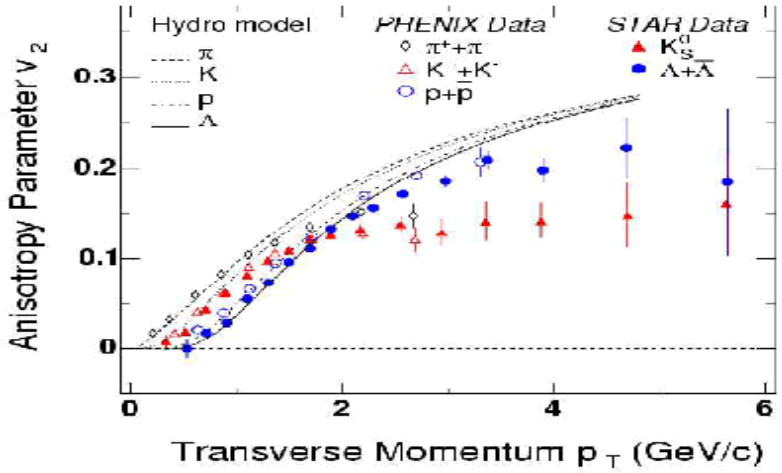
Second condition : Collective behavior of partons : RHIC Energies

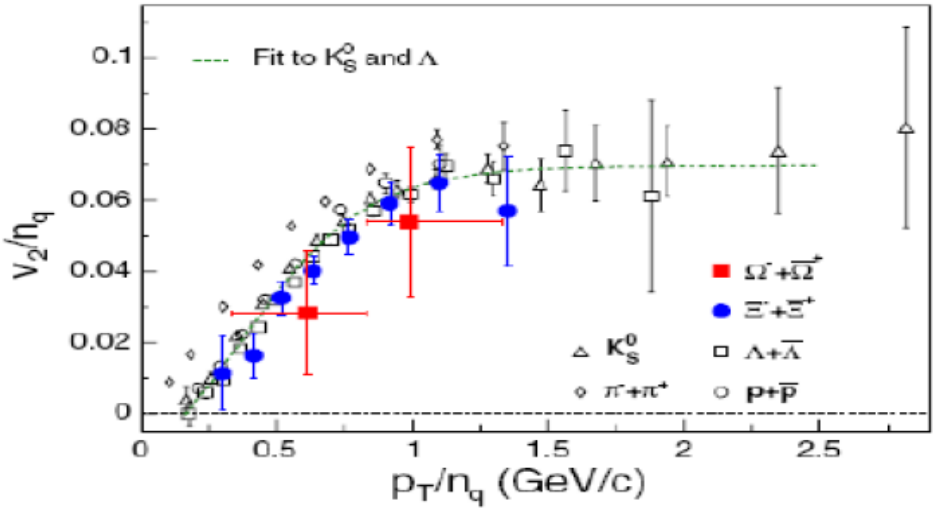
elliptic flow --- `early signature´ of QGP

$$\frac{dN_h}{dp_T^2\,dy\,d\varphi} = \frac{dN_h}{dp_T^2\,dy}\frac{1}{\pi}(1 + 2v_1\cos\varphi + 2v_2\cos 2\varphi + \ldots)$$





evidence for an early buildup of pressure and a fast thermalization of the quark-gluon system



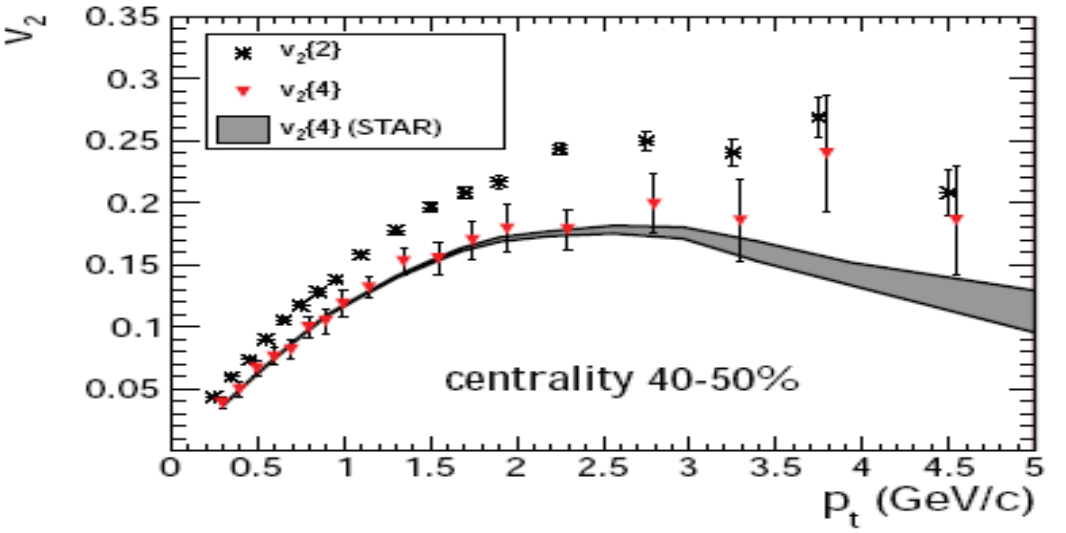
Scaling behavior of v_2 vs P_T

[*J.Adamset al., Phys.Rev.Lett. 95, 122301 (2005); A.Adareet al., Phys.Rev.Lett. 98, 162301 (2007)*]

gives possibility to assume that the collective behavior of the partons defines the dynamic of the expansion in the longitudinal plane namely

number of quark (n_q) scaled v_2 as a function of scaled p_T . All data are from 200 GeV Au+Au minimum bias collisions. The dot-dashed-line is the scaled result of the fit to K_0^S and Λ.

Second condition :
Collective behavior of partons



At ultrarelativistic energies: v_2 vs p_T LHC

The first measurement of elliptic flow of charged particles in Pb-Pb collisions at the center of mass energy per nucleor pair $\sqrt{s_{NN}} = 2.76TeV$,with the ALICE detecto

$v_2(p_t)$ does not change within uncertainties from

$\sqrt{s_{NN}}$ = 200 GeV to 2.76 TeV

V_2 (p_t) for the central bin 40-50% from the 2- and 4-particle cumulant methods for the measurement and for the *Au-Au* collisions (STAR RHIC) at $\sqrt{s_{NN}} = 200GeV$

K. Aamodt et al.
arXiv:1011.3914v1 [nucl-ex]
17 Nov 2010

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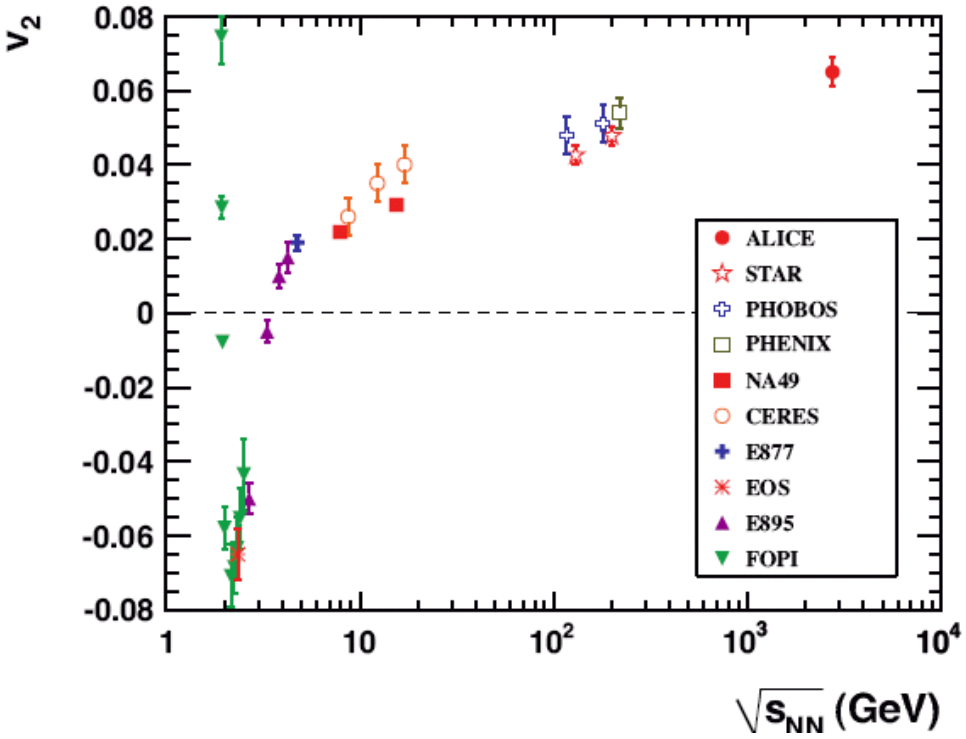
v_2 increases with energy



relativistic&ultrararelativistic hadron-nuclear and nucleaer-nuclear interactions show the **collective behavior** which is likely to be formed at an early, parton, stage of the spacetime evolution of product hot and dense matter

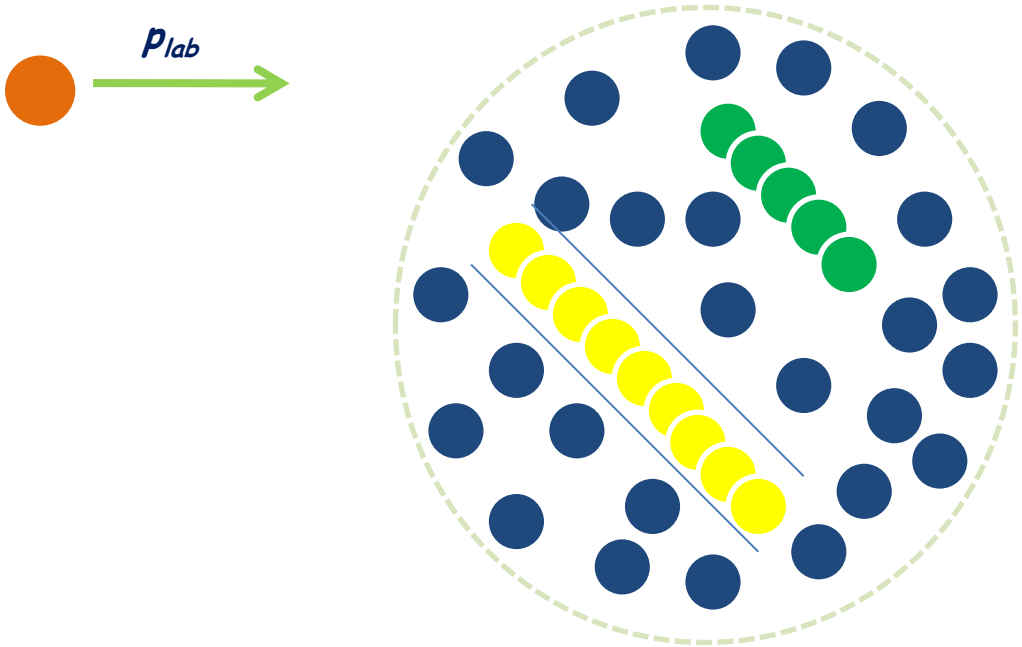
Third condition: Coherent interaction of the grouped partons.

Coherent "Tube" Model (CTM) widely discussed – for quantitative results

G. Berlad et al., *Phys. Rev.* **D13**, 161 (1976).
S. Frederiksson, *Nucl. Phys.* **B111**, 167 (1976).
L. Bergström, S. Frederiksson, *Phys. Lett.* **68B**, 177 (1977).
Y. Afek et al., Technikon Haifa preprint TECHNION-PH-77-22, 1978.
B. Andersson, Invited talk at the VII Int. Colloquium on Multiparticle Reactions, Tutzing 1976.

the interaction of a hadron with a target nucleus results from its simultaneous collision with the tube of nucleons of cross section σ that lie along its path in the target nucleus

cumulative square of the center-of-mass energy, $s_i \cong 2imp_{lab}$, i – a number of nucleons ;m - the nucleon mass; p_{lab} - lab. momentum of the incident hadron.



Third condition: Coherent interaction of the grouped partons.

What we have had?

Y. Afek, t G. Berlad, and G. Eilam and A. Darf. PHYS. REV. LET. 37, 14(1976) pp.947-951.Cumulative Enhancement of J/Ψ Production in Hadron-Nucleus Collisions.

unusually strong A dependence for cross section of the inclusive J/Ψ production in *hA* collisions at incident energies below 30 GeV was discribed quantitatively

cumulative effects (via energy rescaling) led to an A dependence of the cross section that was much stronger than the commonly assumed A or $A^{2/3}$

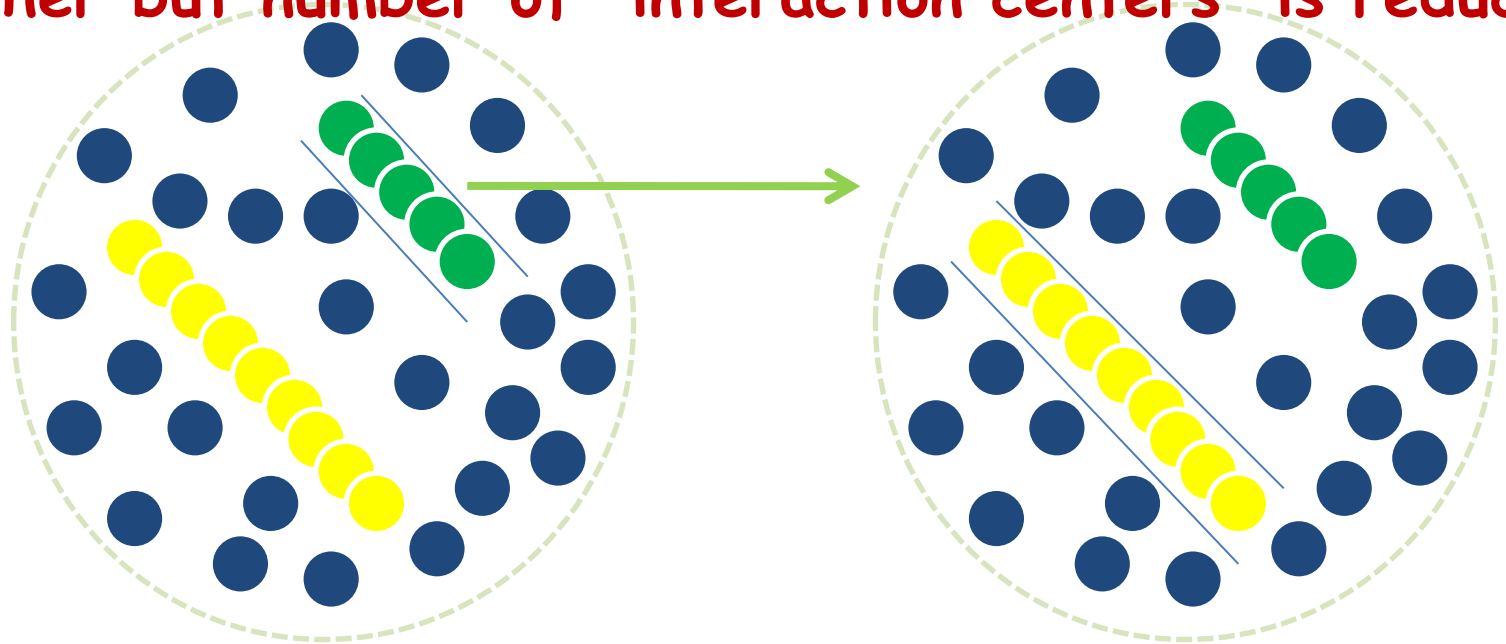
Third condition: Coherent interaction of the grouped partons.

What we have had?

in this model /Afek et al. , 1978/ , a substitution has been proposed replacing interaction of n_1 nucleons of the incident nucleus with n_2 nucleons of the target nucleus belonging to "colliding tubes" by **interaction of two fictitious "nucleons" with the momentum n_1p_1 and n_2p_2** , respectively. Then the corresponding relativistic invariant

$$S=(n_1p_1+n_2p_2)^2$$

i.e. the interaction proceeds in such a way as if **the energies were higher but number of "interaction centers" is reduced.**



Physical Picture

in the high density (and/or high temperature) nuclear matter the collective behaviour of partons could lead to formation of the coherent groups of the partons ("coherent tube")

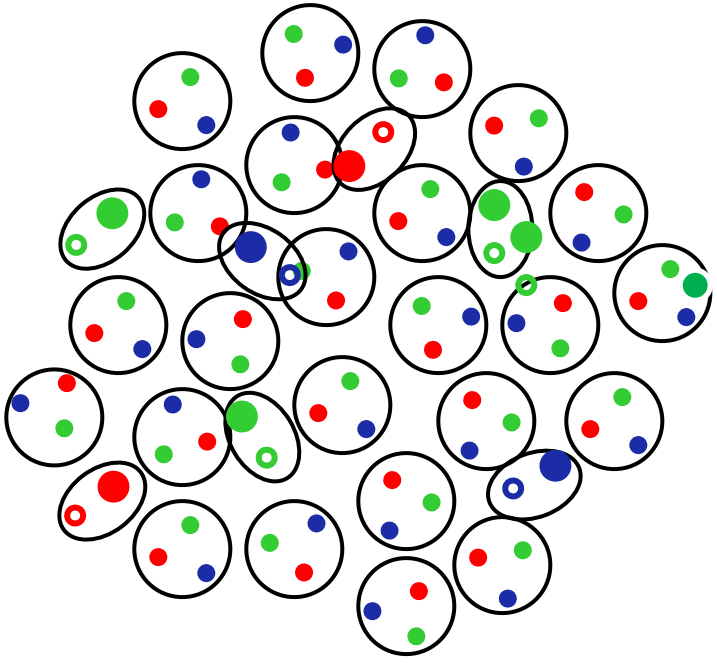
as a results of the coherent interactions the parton(s) could be produced with limited large values of $x \to 1$ and hardonize to super high-energy particle(s), since in this case the resulting energy will depend on the parameters of the system too- the energy of energetic particle could be limited by values of the total energy of the system only

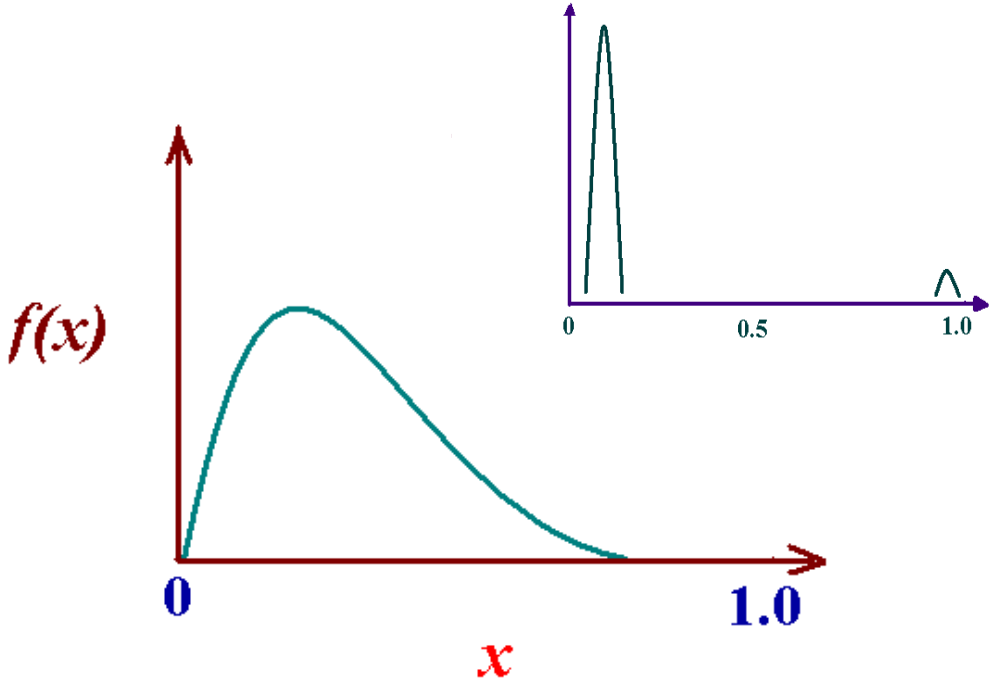
for example in framework of Coherent "Tube Model" the cumulative square of the center-of-mass energy s will depend on a number i of the partons, grouped in the tube(s), and increase with i . So if we consider a system with temperature around *150-170 MeV* (hot matter) and density 7-10 times greater than normal nucleus one (dense matter), then in this system the particle(s) with energy ~ 10^{15} *eV* could be produced as a result of coherent interactions with system of groped partons (or tube(s)) containing ~ 10^{7} partons and more.

Could dense quark matter be a source of super high energy cosmic rays?

Physical Picture

the coherent interactions and super high energy parton(s) production can change the x distribution of the partons





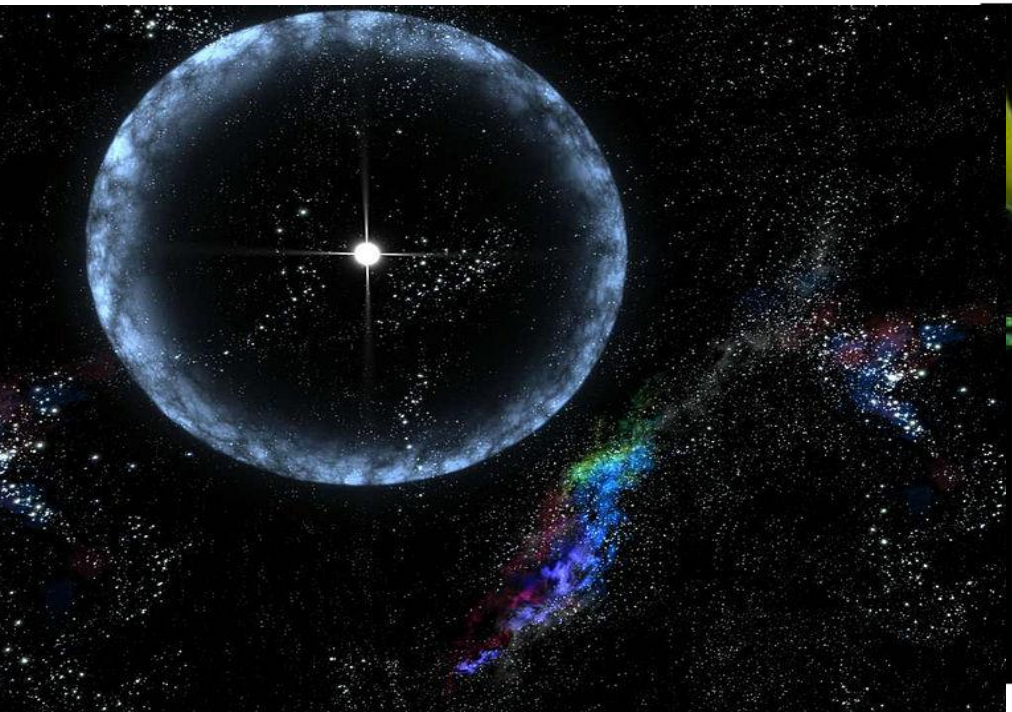
Could dense quark matter be a source of super high energy cosmic rays?

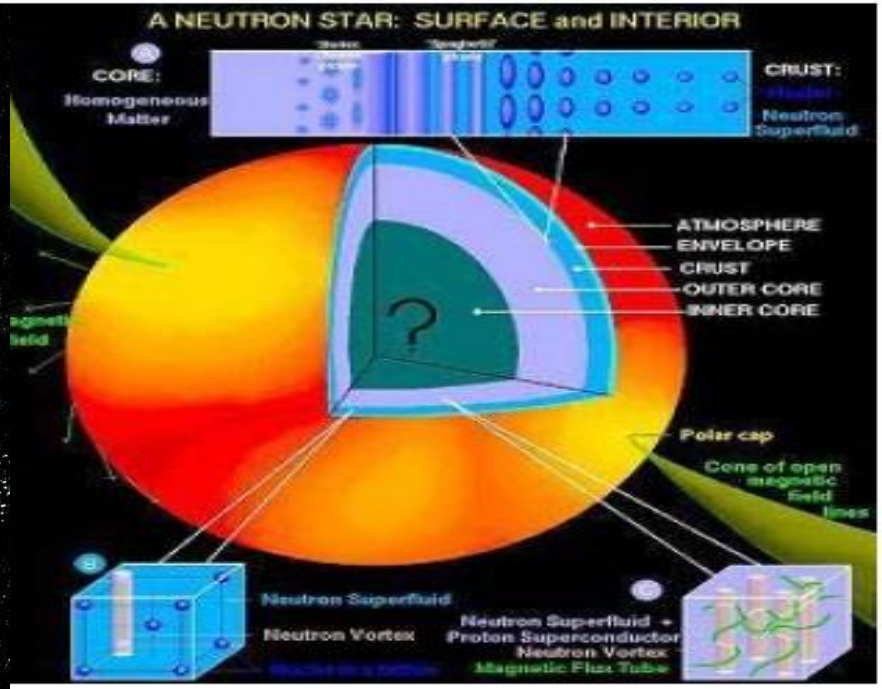
Physical Picture

a medium with high density (and/ or high temperature) close to the *QCD* critical one could be a source of cosmic particles with super high energies

the medium can be created in the center of some massive star and parton(s) with large values of x or energy can be formed in this system as a result of collective phenomenon and coherent interactions, they hadronize and appear as super high-energy cosmic particles.

the maximum energy of cosmic particles is limited only by the values of the total energy of the grouped partons.

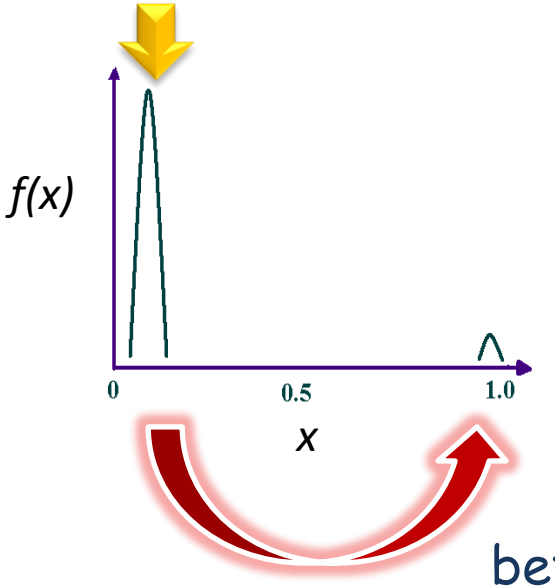




Expectation: correlations

the physical picture assume the existing of two types strong correlations (R>>1) between the partons in the hot and dense matter

between the partons
with limited low values of $x \to 0$

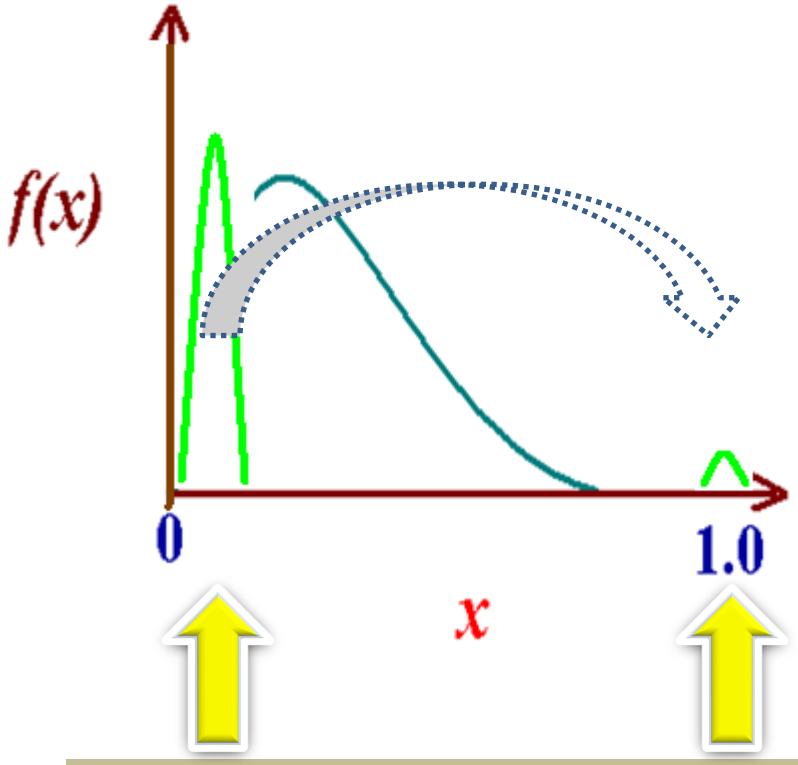


between the particles : $x \to 1$

& $x \to 0$

Could dense quark matter be a source of super high energy cosmic rays?

in hot and dense matter the x distribution of partons could be changed and get the structure with two additional maximums due to collective behaviors of partons and their coherent interactions



enhancement for the lowest energy and highest energy secondary particles

Could dense quark matter be a source of super high energy cosmic rays?

these correlations could be study in the hadron-nuclear and nuclear-nuclear interactions at relativistic and ultrarelativistic energies

the centrality dependences of the correlations could give essential information on the physical picture.

Summary

experimental results on relativistic and ultrarelativistic hA- & AA-interactions point out the collective behavior of the partons

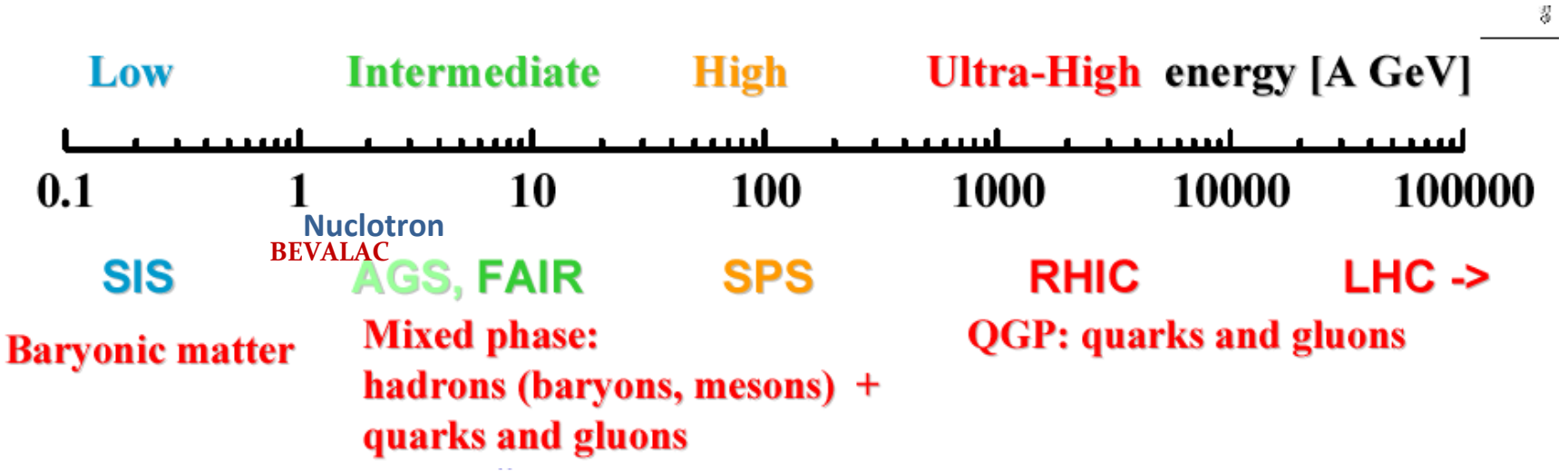
the behavior could lead to: coherent interactions of grouped partons; partons production with limited long values of x ; formation on super high energy particles

the observation of these particles could be a signal on the hot and dense states of strongly interacting matter (as well as for the QGP)

the system could be created in the center of some massive starts

the physical picture: can explain quantitatively existing of some new source for the super high energy particles without any acceleration; assumes the existing of some correlations in dense (and/or hot) matter


Thank you


Low
Intermediate
High
Ultra-High
energy [A GeV]
0.1
1
10
100
1000
10000
100000
Nuclotron
BEVALAC
SIS
AGS, FAIR
SPS
RHIC
LHC ->
Baryonic matter
Mixed phase:
hadrons (baryons, mesons) +
quarks and gluons
QGP: quarks and gluons