Joint Institute for Nuclear Research

VERY HIGH MULTIPLICITY PHYSICS

Sixth International Workshop

Dubna, April 16–17, 2005

Proceedings of the Workshop

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Search for the mixed phase of strongly interacting matter at the JINR Nuclotron

A.N.Sissakian, A.S.Sorin, M.K.Suleymanov

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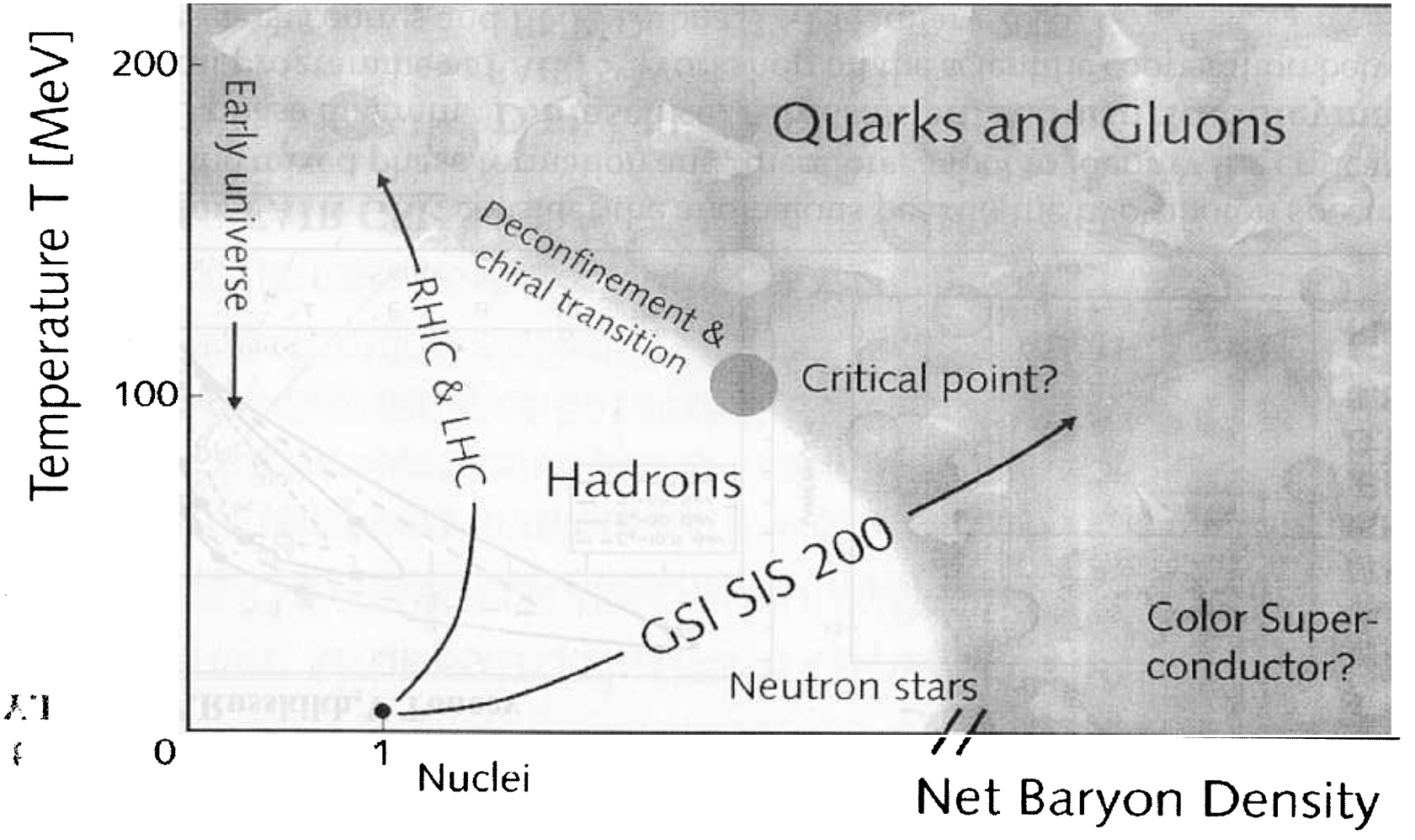
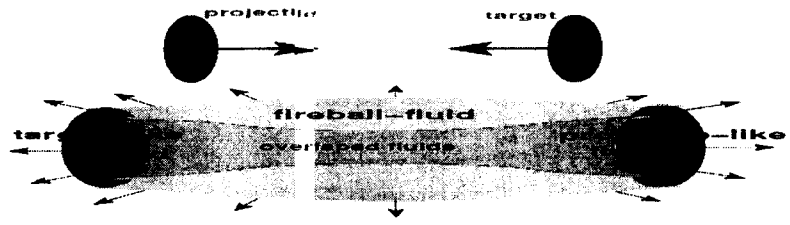
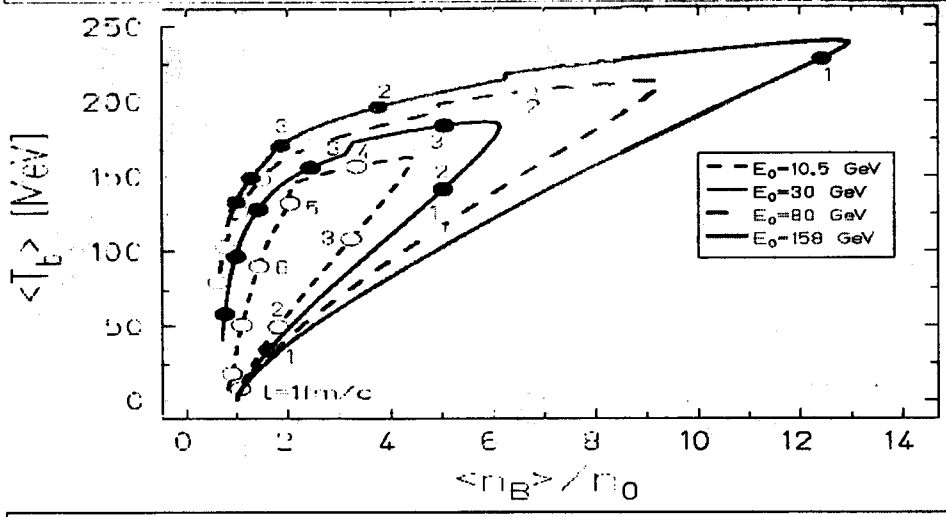
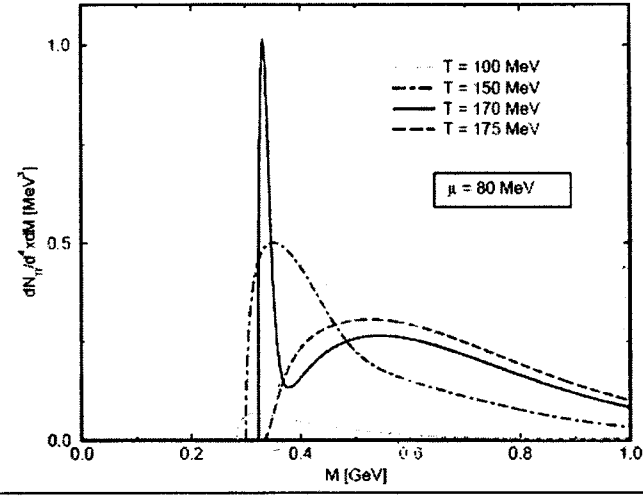
Phases of strongly interacting matter



Simulations of Heavy-Ion Collisions:
Relativistic 3-fluid hydrodynamic model for the energy range: a few to 200 *A GeV*.
Y.Ivanov,V.Russkikh,V.Toneev







$\pi\pi \to \gamma\gamma$

M.Volkov, E.Kuraev,D .Blaschke, G.R¨opke, S.Schmidt,

PLB(1998)

Proposal for FAIR GSI: consider the anomalous peak in the two-photon spectrum as a signal of the mixed phase formation and, therefore, a tool to identify the critical point in the QCD phase diagram. **D.Blaschke, A.Sissakian, A.Sorin, M.Suleymanov** (On physical programme at FAIR, 5thWorkshop on the scientific cooperation between German research centres and JINR, Dubna, 17-19 January 2005, http://cv.jinr.ru/BMBF_05/index.html).

$\sigma \to \pi\pi \; \sigma \to \gamma\gamma$
$\Gamma_\sigma = 600 - 1000 MeV$
$M_\sigma = 400 - 1200 MeV$

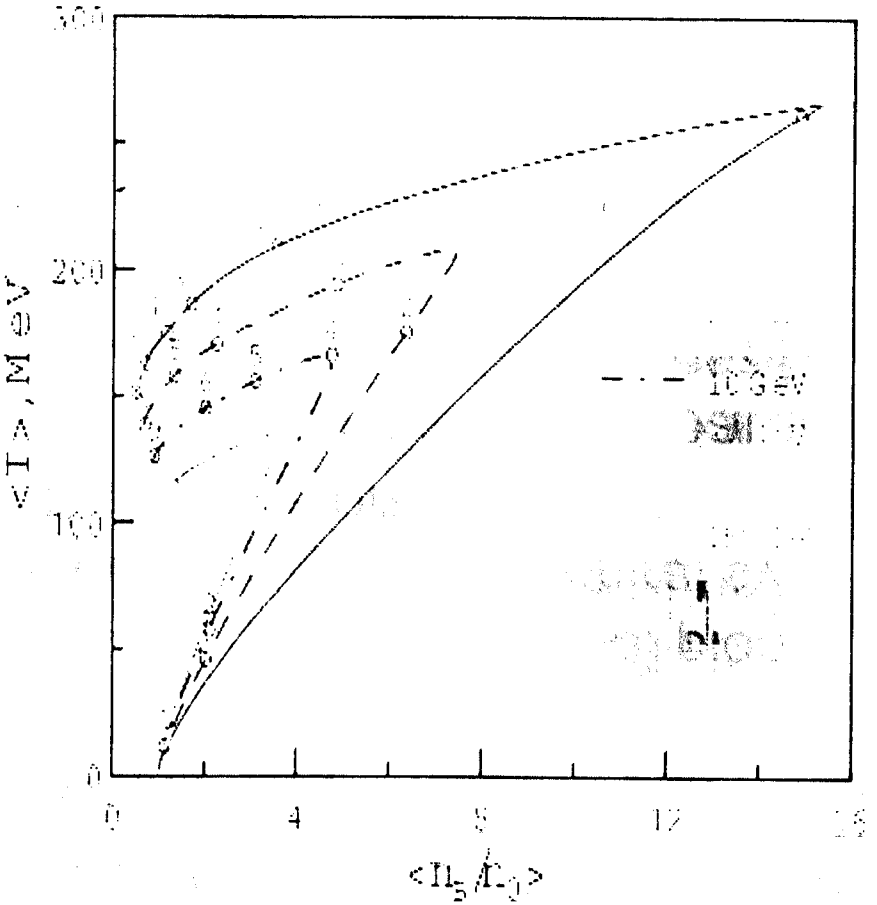
The number of anomalous two-photon events in the narrow invariant mass region M_2gamma ~ M_sigma(mu_c, T_c) can be considered as a "clock" for the duration of the mixed phase.

Problems of SPS and RHIC: huge background from neutral pion decays complicates identification of this signal. Privilege of FAIR: higher densities entail lower critical temperatures → lower background!

What about the JINR Nuclotron?

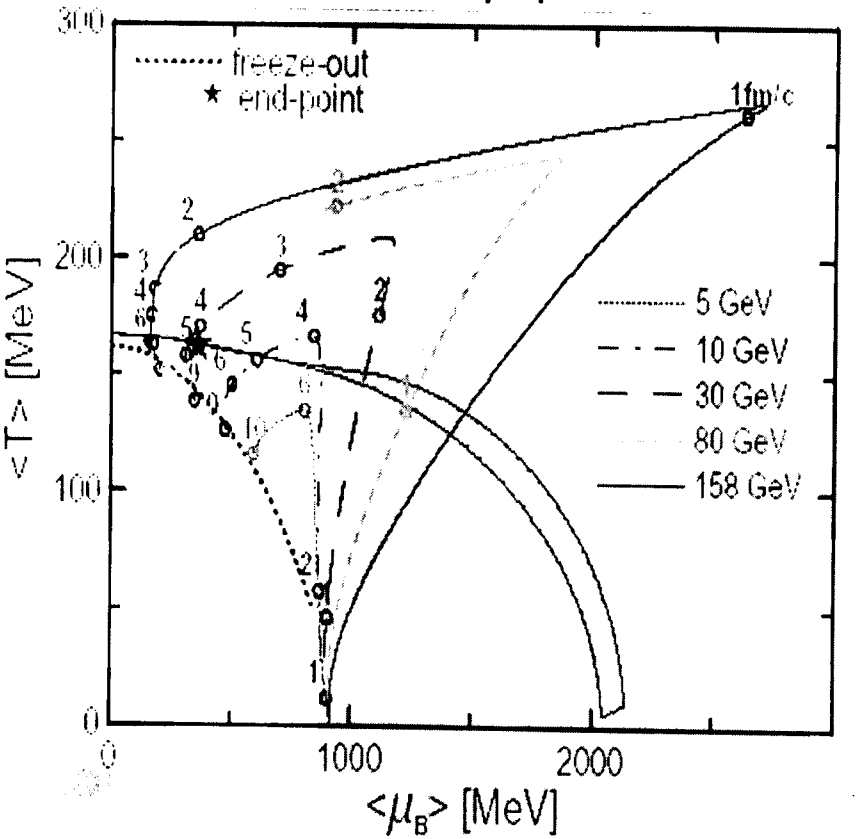
Nuclotron: E ~ 5 GeV/nucleon, heavy nuclei A ~ 200

With light quarks



V.Toneev, Talk at the CBM Collaboration Meeting March 9-12, 2005, GSI,Darmstadt, http://www.gsi.de/documents/DOC-2005-Mar-871.pdf

With heavy quarks



Y.Ivanov,V.Russkikh,V.Toneev, Relativistic Heavy-Ion Collisions within 3-Fluid Hydrodynamics: Hadronic Scenario, nucl-th/0503088 (March 31 2005)

Search for the mixed phase of strongly interacting matter at the JINR Nuclotron

Perspective theoretical and experimental researches

1. Investigation of properties of hadrons in hot and/or dense baryon matter (a change of their masses and widths is expected, first of all of the σ-meson as the partner of pions in the chiral multiplet, which characterizes a degree of chiral symmetry violation and can serve as a "signal" of its restoration as well as the mixed phase formation).

2. Analysis of a role of multiparticle hadron interactions, perfection of available and development of new space-time models of collision of heavy nuclei at high energies as well as "signals" of formation of new phases during the evolution.

3. Analysis of the dependence on energy and centrality of the multiplicity of pions, strange particles, and their ratio, as well as K-meson spectra with respect to transverse momentum (nonmonotonic dependences are expected, which can be due to a manifestation of the mixed phase formation).

4. Analysis of dileptons and slow pion production in collisions of heavy nuclei (their enhancement in comparison with hadron-hadron interactions is expected).

5. Analysis of the behaviour of angular correlations and flows of secondary particles (their abnormal behaviour in comparison with hadron-hadron interactions is expected).

6. Analysis of fluctuations of the multiplicity of secondary particles (their nonmonotonic dependences on energy can give information on the area of the phase transition and, moreover, the matter phase diagram).

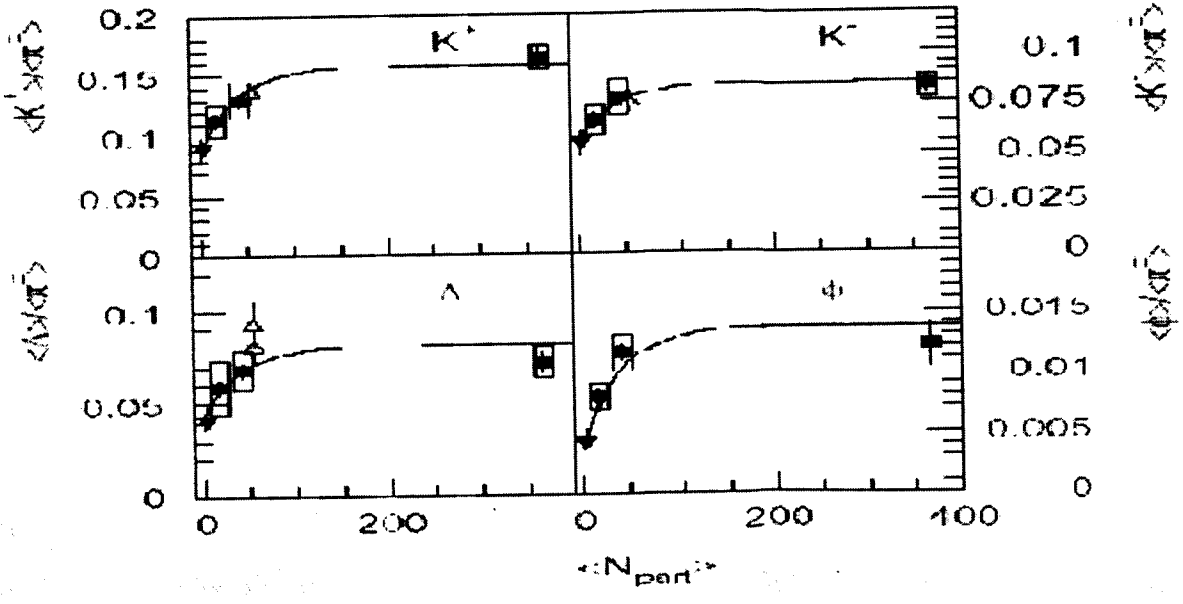
7. Analysis of characteristics of nuclear fragments depending on the centrality (abnormal change of the behaviour in comparison with peripheral collisions is expected).

8. Energy and atomic number scanning for all characteristics of central collisions of heavy nuclei (this might allow one to obtain information on the equation of state of strongly interacting matter in the transition area).

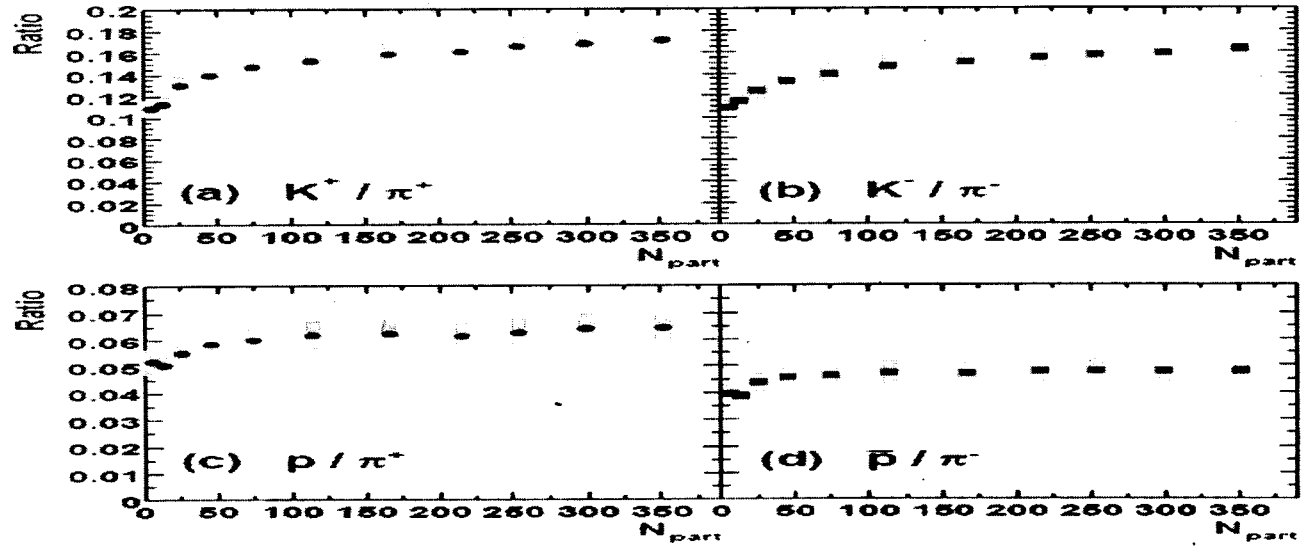
3. Analysis of the dependence on energy and centrality of the multiplicity of pions, strange particles, and their ratio, as well as K-meson spectra with respect to transverse momentum (nonmonotonic dependences are expected, which can be due to a manifestation of the MP formation).

NA49 Collaboration SPS **Strangness production**

C.Alt, et al, System-size dependence of strangeness production in nucleus-nucleus collisions at $\sqrt{s_{NN}}$=17.3 GeV , Phys.Rev.Lett. 94 (2005) 052301



Experimental ratios of $\langle K^+ \rangle$, $\langle K^- \rangle$, φ, and Λ to $\langle \pi^\pm \rangle$ plotted as a function of system size (▼ p+p, C+C and Si+Si, ● S+S, ■ Pb+Pb). Statistical errors are shown as error bars, systematic errors if available as rectangular boxes. The curves are shown to guide the eye and represent a functional form a - b exp(-$\langle N_{part} \rangle$ /40). At $\langle N_{part} \rangle$=60 they rise to about 80% of the difference of the ratios between N_{part} =2 and 400.



Centrality dependence of particle production ratios for
(a) K+/π+,
(b) K−/π−,
(c) p/π+, and
(d) antip/π−
in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
[S. S. Adler, et al., Phys. Rev. Lett. 91 (2003) 182301.].

4. Analysis of dileptons and slow pion production in collisions of heavy nuclei (their enhancement in comparison with hadron-hadron interactions is expected).

Mixed Phase is a state of the compressed nuclear matter.

The π -meson condensate

А. Б. Мигдал, 1971, ЖЭТФ, 61, p. 2210;
1972, ЖЕТФ, 34 p. 1184;
1972, ЖЭТФ, 63, p. 1933;
1973, ЖЭТФ, 1973, 36, p. 1052;
R.F. Sawyer, Phys.Rev.Lett., 1972, 29, p. 382 ;
D. J. Scalapino, Phys.Rev.Lett., 1972, 386;
R. F. Sawyer And D. J. Scalapino, Phys.Rev.D, 1972, 7, p. 953.

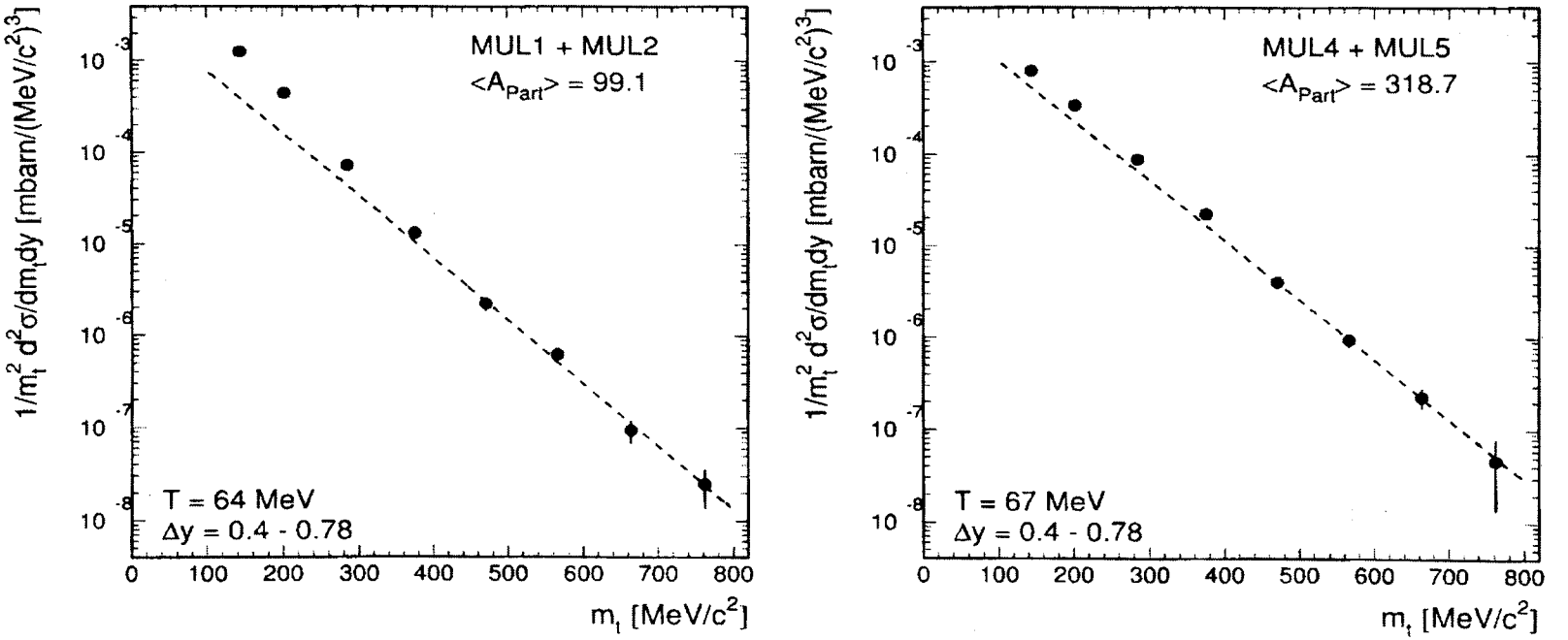
The minimum baryon density for the pion condensation is expected to be

$$\rho_c \cong (2\text{-}3)\,\rho^0$$

(T.Takatsuka and R.Tamagaki, Prog. Theor. Phys 77 (1987), 362).

TAPS Colloboration - *R. Averbeck et al.* Z.Phys.A, 1997, 359, 65;
A.Marin et al., Phys.Lett.B, 1977, 409, 77;
A.R.Wolf et al., Phys. Rev. Lett., 1998, 80, 5281;
A. R. Wolf, geb. Gabler: Doktorarbeit, Gieben 1997.

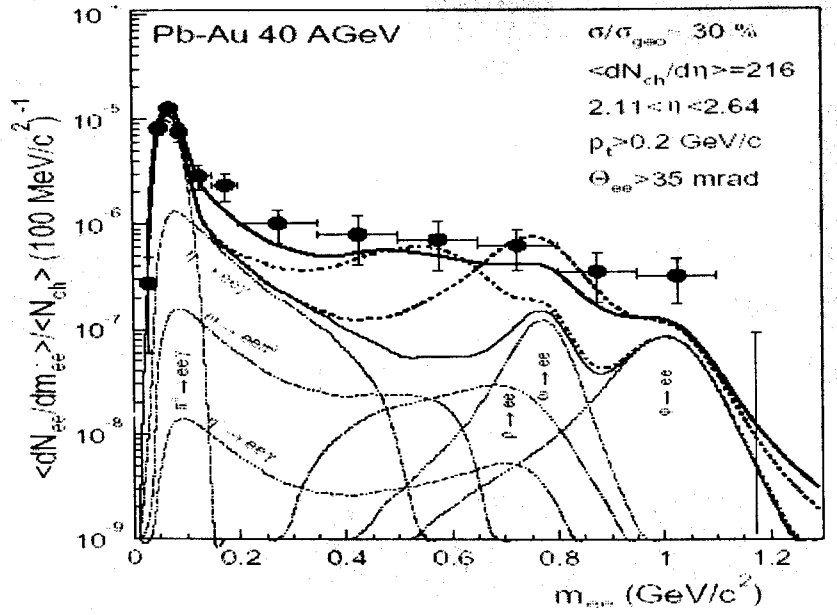
Invariant inclusive specrtum of the $\pi 0$- and η-mesons produced in Au + Au reactions at 0,8 A GeV (left — noncentral collisions, right - central collisions).



1) Two values of the temperature for π^0 –meson - T≅50 and 70 MeV;
2) dependence of the centrality.

CERN SPS Colloboration: D.Adamova´ et al., Enhanced Production of Low-Mass Electron-Positron Pairs in 40 AGeV Pb-Au Collisions at the CERES/NA45 experiment, nucl-ex/0209024.

Measurements of low-mass electron-positron pairs in Pb-Au collisions at the SPS beam energy of 40 AGeV. The pair yield integrated over the range of invariant masses $0.2<m\leq.1$ GeV/c^2 is enhanced over the expectation from neutral meson decays by a factor of 5.9 ± 1.5(stat.) $\pm$ 1.2(syst. data) $\pm$ 1.8(syst. meson decays), somewhat larger than previously observed at the higher energy of 158 AGeV. It may be linked to chiral symmetry restoration and support the notion that the in-medium modifications of the ρ are more driven by baryon density than by temperature.

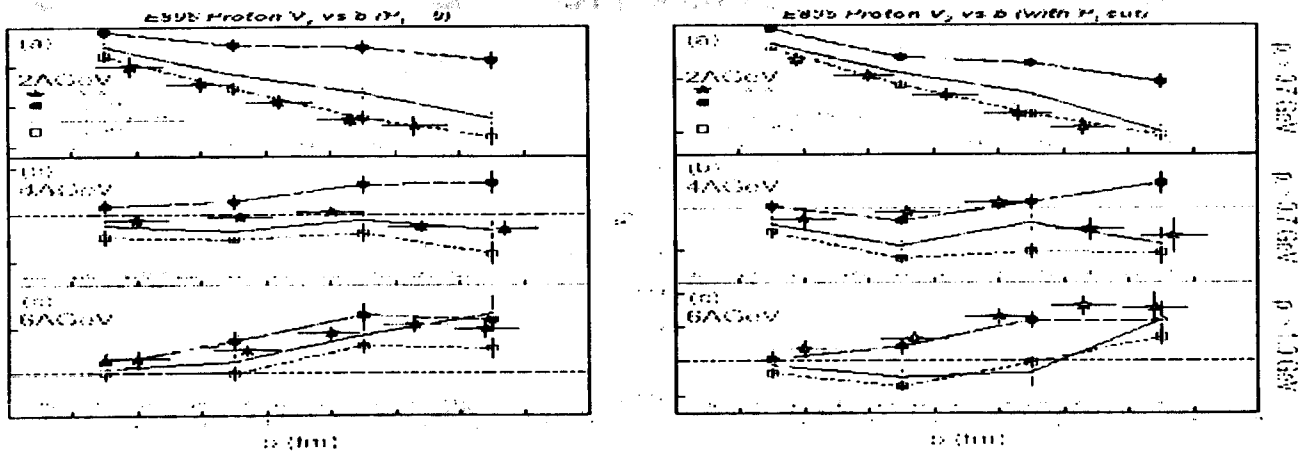


Inclusive e^+e^- mass spectrum, compared to the hadron decay cocktail (thin solid; individual contributions thin dotted) and to theoretical model calculations based on $\pi^+\pi^-$ annihilation with an unmodified ρ (thick dashed), an in-medium dropping mass ρ (thick dashed-dotted) and an in-medium spread ρ width (thick solid). The model calculations contain the cocktail, but without the ρ to avoid double counting. The low-mass tail of the cocktail ρ is due to the inclusion of a $\pi^+\pi^-$phase space correction. The (weaker) tails of the ω and φ are caused by electron bremsstrahlung.

5. Analysis of the behaviour of angular correlations and flows of secondary particles (their abnormal behaviour in comparison with hadron-hadron interactions is expected).

$$dN/d\phi \propto [1+2v_1\cos(\phi)+2v_2\cos(2\phi)]$$

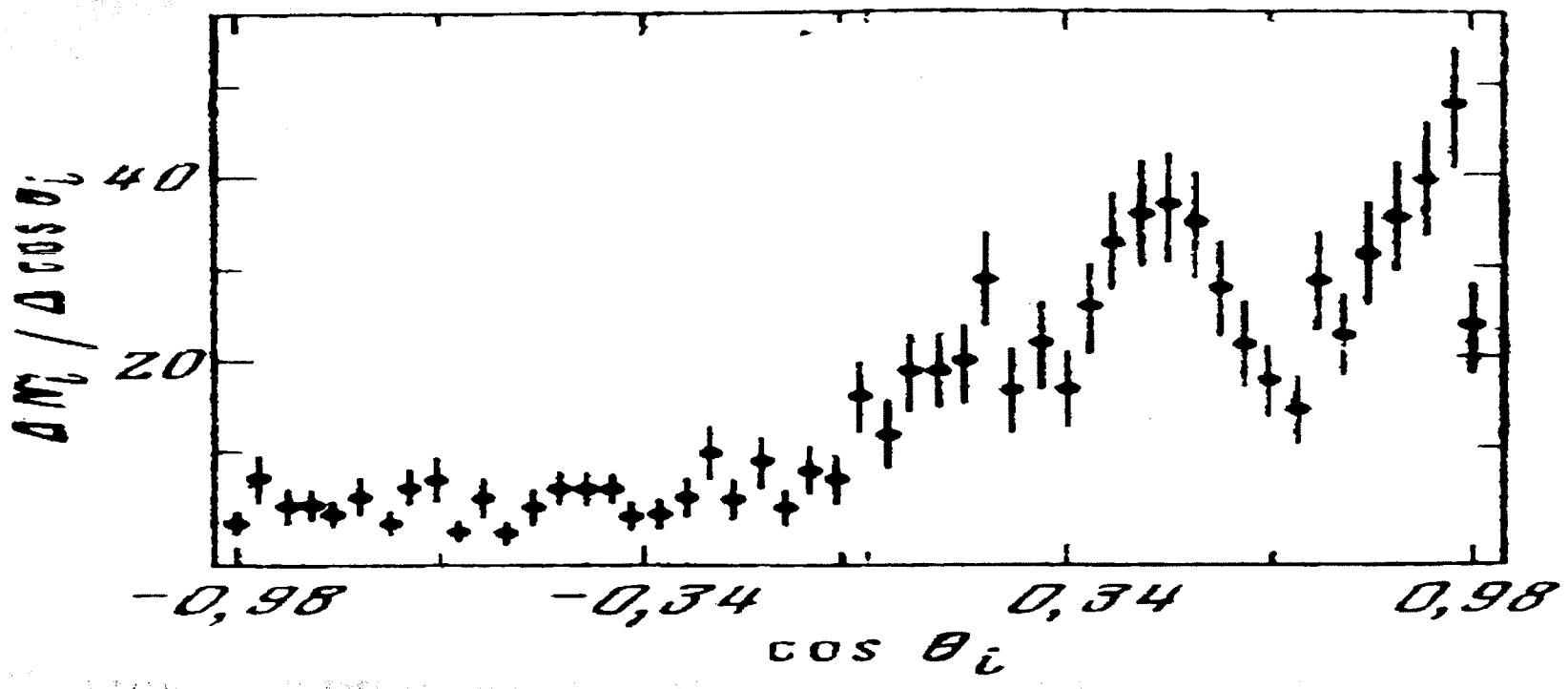
BNL E895 Collaboration has studied the proton elliptic flow as a function of impact-parameter b, for two transverse momentum cuts in 2 - 6 AGeV Au + Au collisions (AGS).



P. Chung et al. Differential Elliptic Flow in 2 - 6 AGeV Au + Au Collisions: A New Constraint for the Nuclear Equation of State, nucl- ex/ 0112002.

The elliptic flow shows an essentially linear dependence on b (for 1.5 < b < 8 fm) with a negative slope at 2 AGeV, a positive slope at 6 AGeV and a near zero slope at 4 AGeV. These dependencies serve as an important constraint for discriminating between various EOS for high density nuclear matter, and they provide important insights on the interplay between collision geometry and the expansion dynamics.

The angular distributions of protons with the momentum less than 1.0 GeV/c in the events of π-^{12}C -interactions at the momentum 40 GeV/c with the total disintegration of nuclei [A.I.Anoshin et al.Yad.Fiz.33:164(1981)]. The anomalous peak is seen in this distribution. The behavior of angular distributions of protons emitted in π-^{12}C -interactions at momentum 5 GeV/c [O.B.Abdinov et al. Preprint JINR,1-80-859,Dubna (1980)] has also an anomalous peak.



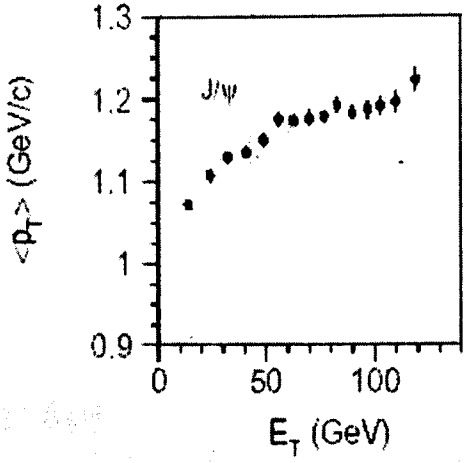
The angular distributions of protons emitted in π^{-12}C -interactions at momentum 40 GeV/c.

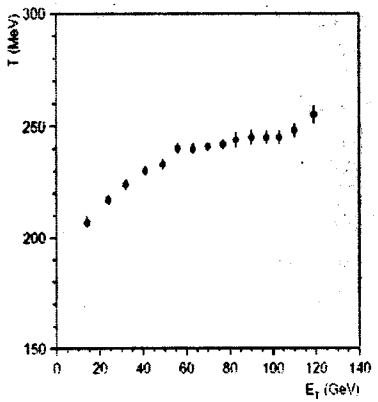
Centrality experiments

Studying a dependence of characteristics of nuclear-nuclear interactions on the centrality is an important experimental way of obtaining information on phases of strongly interacting matter formed during the collision evolution. It is expected that new structures - changes in the behaviour, will show up in these characteristics due to phase transitions.

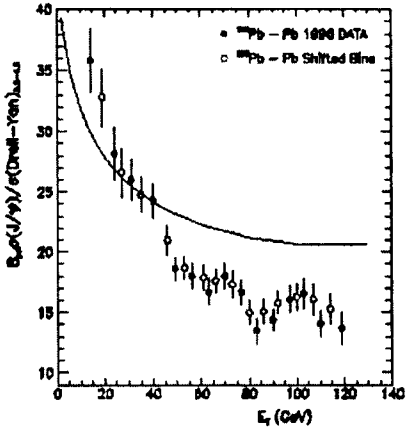
Search for the mixed phase of strongly interacting matter

Experimental results give an evidence of existence of sharp regime changes in event characteristics as a function of the collision centrality.





The behaviour changes at $E_T \approx 40\text{-}50$ GeV



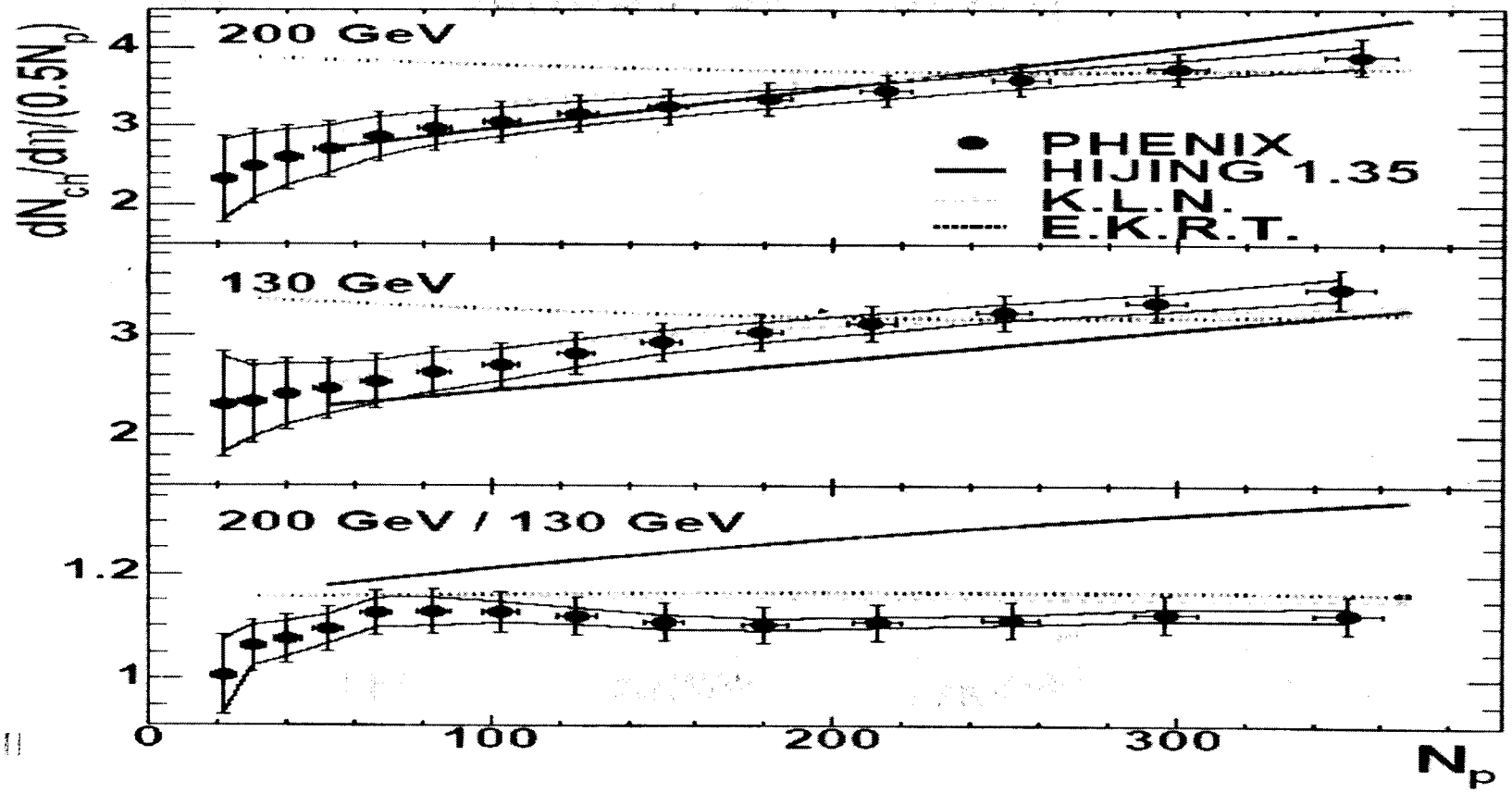
$<P_t>$ of J/Ψ and inverse slope (T) of J/Ψ transverse mass distributions in Pb-Pb interactions at 158 GeV/nucl. as a function of centrality (E_T) (NA38, NA50).

The cross section of J/Ψ production in Pb-Pb interactions at 158 GeV/nucl. as a function of centrality (E_T) (NA38, NA50) normalaized to the cross section of Drell-Yan pairs.

Possible explanation: the regime changes is a manifestation of the Mixed Phase (MP) formation (A.N. Sissakian, A.S. Sorin, M.K. Suleymanov, G.M. Zinovjev).

The experimental information on conditions of MP formation is important to fix the onset stage of the quark deconfiment for its future identification.

Search for MP: anomalous peak in the angular distribution of protons and anomalous angular correlation of secondary particles production and anomaly in the small energy π^0- or (π^+, π^-)-meson (lepton) pairs production, simultaneously, as a function of the centrality.



Multiplicity per participant nucleon pair, as a function of the centrality, for $\sqrt{s_{NN}}$ =130 GeV and 200 GeV Au+Au collisions as measured in PHENIX (A. Bazilevsky, Nucl. Phys. A715 (2003) 486).

Preliminary Collaboration

BLTP JINR:
D. Blaschke, E.Kuraev, A.Radzhabov, *A.Sissakian, A.Sorin,* V.Skokov, V.Toneev, M.Volkov, V.Yudichev, ...

LIT JINR:
Yu.Kalinovsky, ...

VBLHE JINR:
K.Abramyan, N.Amelin, B.Batyunya, A.Kovalenko, V.Krasnov, A.Malakhov, M.Suleymanov, A.Vodopianov, ...

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BITP NAS (Kiev, Ukraine):
V.Begun, M.Gorenstein, S.Konchakovsky, V.Trubnikov, G.Zinovjev, ...

Collaboration, suggestions, and remarks are welcome!