

# Joint Institute for Nuclear Research International Intergovernmental Organization



## Status and progress of the NICA White Paper

A.S. Sorin



Round Table 5 “Physics at NICA”  
JINR, Dubna, August 28, 2010

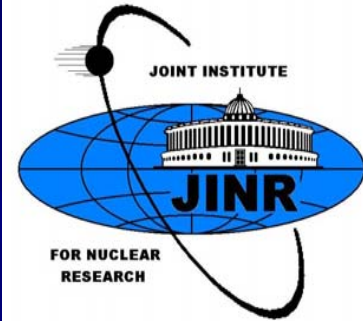
# Round Table Discussions on NICA@JINR

## Round Table Discussion I

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

July 7 - 9, 2005

<http://theor.jinr.ru/meetings/2005/roundtable/>



## Round Table Discussion II

Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron: Nuclotron facility development

JINR, Dubna, October 6 - 7, 2006

<http://theor.jinr.ru/meetings/2006/roundtable/>

## Round Table Discussion III

*Searching for the mixed phase of strongly interacting QCD matter at the NICA: Physics at NICA*

JINR (Dubna), November 5 - 6, 2008

<http://theor.jinr.ru/meetings/2008/roundtable/>

## Round Table Discussion IV

*Searching for the mixed phase of strongly interacting QCD matter at the NICA: Physics at NICA (White Paper)*

JINR (Dubna), September 9 - 12, 2009

<http://theor.jinr.ru/meetings/2009/roundtable/>





## Round Table Discussion V

*Searching for the mixed phase of strongly interacting QCD matter at the NICA: Physics at NICA*

JINR (Dubna), August 28, 2010

<http://theor.jinr.ru/~cpod/program.html>

## TOPICS:

I: Fixed target experiments at Nuclotron-N

II: Status and progress of the NICA White Paper

# NICA White Paper

## SEARCHING for a QCD MIXED PHASE at the NUCLOTRON-BASED ION COLLIDER FACILITY

The final goal of the NICA White Paper is to address the following key topics:

- Phases of dense QCD matter and conditions for their possible realization
- Characteristic processes as indicators of phase transformations
- Estimates of various observables for events
- Comparison to other experiments

<http://theor.jinr.ru/twiki-cgi/view/NICA/WebHome>



Draft v 3.01  
June 17, 2010

SEARCHING for a QCD MIXED PHASE at the  
NUCLOTRON-BASED ION COLLIDER FACILITY  
(NICA White Paper)

**Editorial board:**

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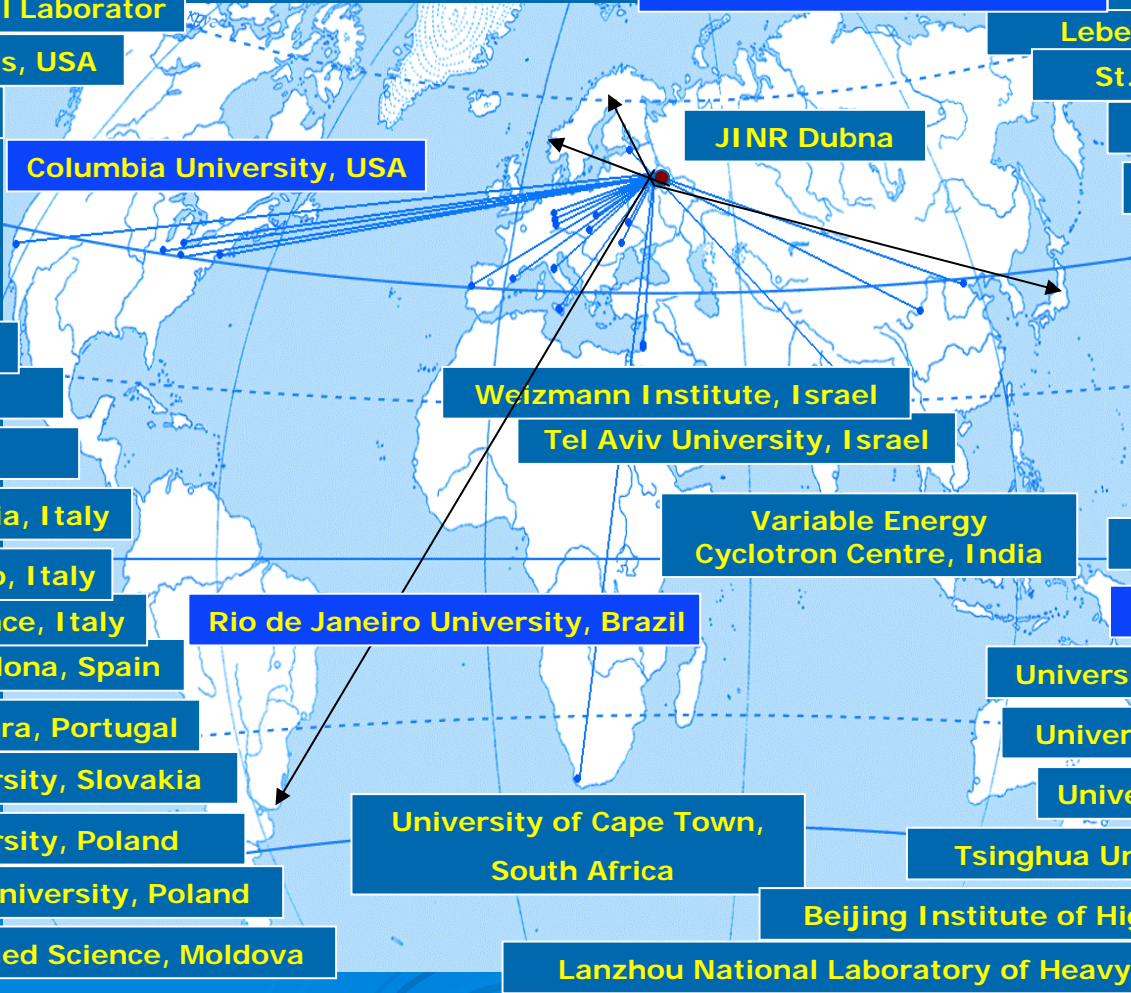
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Almost all experts in the field of heavy ion collisions have contributed  
to the NICA White Paper



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**(55 contributions = 44 + 11, additional 25%)**

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**2 Phases of QCD matter at high baryon density (10 + 6)**

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**4 Mechanisms of multi-particle production (5 + 1)**

**5 Electromagnetic probes and chiral symmetry in dense QCD matter (6)**

**6 Local P and CP violation in hot QCD matter (5 + 1)**

**7 Cumulative processes (2)**

**8 Polarization effects and spin physics (3)**

**9 Related topics (2 + 1)**

**10 References**

# New Contributions to the NICA White Paper Draft v 3.03

(last update: June 20, 2010)

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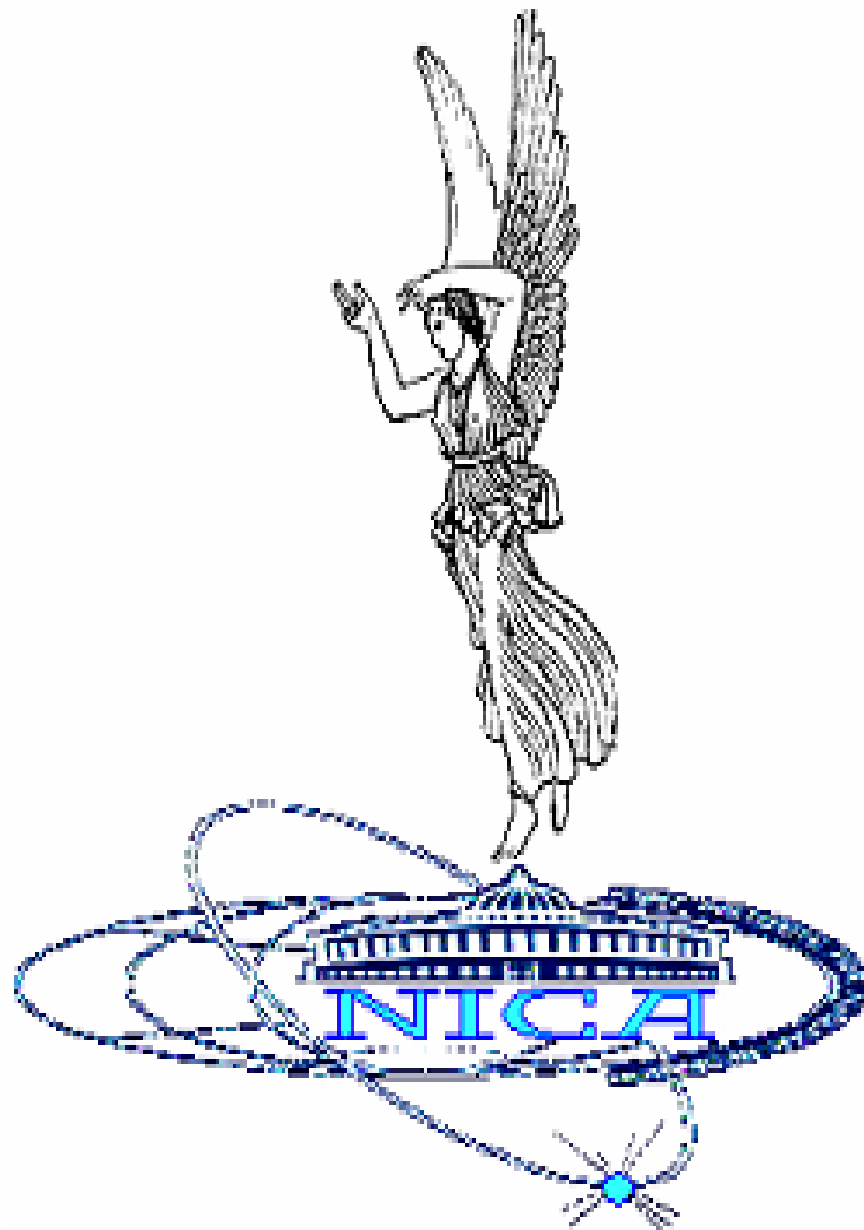
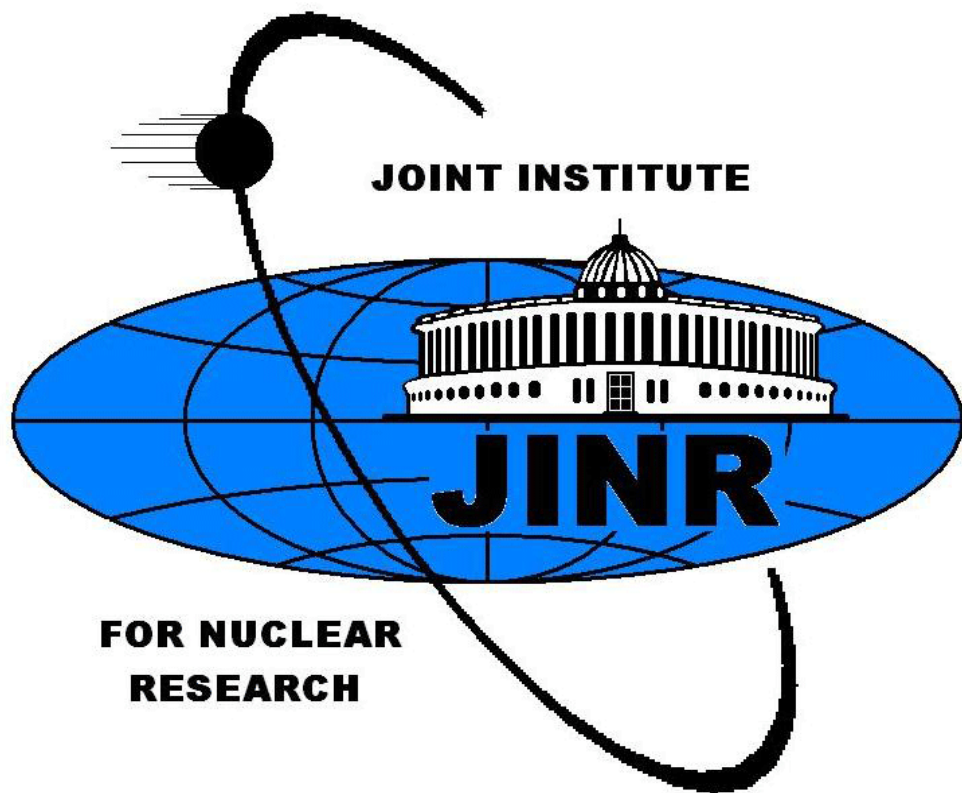
- 1) Peter Senger (GSI): Nuclear matter physics at NICA
- 2) S.M. Troshin (Protvino): Directed flow as signal of liquid state of transient matter
- 3) Kenji Fukushima (YITP Kyoto): Transitional change to baryon-rich QCD matter at NICA energy
- 4) Masayuki Asakawa (U Osaka): Importance of third moments of conserved charges
- 5) Yuri Ivanov (Kurchatov I Moscow and GSI): Baryon stopping in Heavy-Ion Collisions at  $E=2...160$  GeV/nucleon
- 6) Giorgio Torrieri (FIAS & Columbia U): Statistical hadronization phenomenology in a low-energy collider
- 7) Giorgio Torrieri (FIAS & Columbia U): Flow scaling in a low-energy collider: when does the perfect fluid turn on?
- 8) Takeshi Kodama (U Rio de Janeiro): Fluctuations and non-equilibrium processes in collective flow
- 9) Marcus Bleicher & Jan Steinheimer (FIAS): MEMO production at high baryon densities
- 10) Oleg Rogachevsky, A.S. & Oleg Teryaev (JINR): Chiral vortical effect and neutron asymmetries at NICA
- 11) D.E. Donets et al. (JINR): Development of highly charged ion sources for NICA injector and its possible application for nanofabrication and in medicine

## New contributions in preparation:

1. L. McLerran (BNL), K. Redlich (U Wroclaw), et al.  
“Triple point and quarkyonic phase in the QCD phase diagram”
2. L.Turko (Wroclaw University, Poland), “TBA”
3. F.Karsch and Ch.Schmidt (BNL, Uni. Bielefeld, GSI Darmstadt)  
“Lattice results on QCD at finite temperature and baryon density”
4. Joerg Aichelin (Universit´e de Nantes), “TBA”
5. Hans Georg Ritter (BNL), “TBA”

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**Thank you for attention!**



### IHEP-JINR seminar at Protvino, 14.02.08

## MEMORANDUM



### МЕМОРАНДУМ Совместного семинара ИТЭФ-ОИЯИ Институт теоретической и экспериментальной физики 27 мая 2009 года, г. Москва

Участники семинара заслушали доклады:  
А.Н. Сисаки "Ускорительный комплекс NICA: статус и перспективы".  
Б.Ю. Шарков "Новые возможности ускорителей для исследования вещества экстремальных условиях".  
И.Н. Мешков "Коллайдеры тяжелых ионов RHIC и NICA: статус и перспективы".  
В.Д. Тонев "Физика тяжелых ионов на ускорительном комплексе NICA".

Отмечены:  
1) актуальность и возрастающая привлекательность исследований тяжелоионных столкновений в диапазоне энергий  $\sqrt{sNN} = 4 - 11$  ГэВ для фундаментальных проблем поиска новых состояний ядерной материи и изучения процессов экстремально высоких плотностей;  
2) прогресс в развитии проекта NICA, получившего широкую международную известность и высокую оценку авторитетных экспертов мирового уровня;  
3) заинтересованность специалистов ИТЭФ в активном участии в совместных с ОИЯИ работах по проекту NICA;  
4) необходимость более тесной кооперации в решении проблем, представляющих взаимный интерес, включая организацию ассоциации (консорциума, сообщества) по исследованию экстремальных состояний вещества и фазовых превращений в ионных столкновениях.

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### Решение

Общемосковского семинара по релятивистской ядерной физике  
Институт Ядерных Исследований РАН  
27 марта 2008 года

Участники семинара "Проект NICA (тяжелоионный коллайдер: концепции, планы реализации и перспективы совместных работ)" заслушав доклады, представленные разработчиками Проекта NICA/MPD (ОИЯИ):

1. А.Н. Сисакин "Статус проекта NICA/MPD".
2. А.Н. Сисакин, А.С. Сорин "Программа физических исследований на ускорительном комплексе NICA".
3. И.Н. Мешков "Концептуальный проект ускорительного комплекса NICA".
4. В.Д. Кекелидзе "Концептуальный проект многоцелевого детектора MPD".

и обсудив цели и содержание проекта, а также перспективы его осуществления, приняли к следующему заключению.

1. Физическая проблема, инициировавшая разработку Проекта, является одной из наиболее важных среди фундаментальных проблем физики микромира и начальных этапов эволюции Вселенной.
2. Представленные на семинаре концептуальные проекты NICA и MPD выполнены на современном уровне с привлечением передовых технологий и использованием оригинальных идей, предложенных и развитых в России.
3. Осуществление Проекта на базе лабораторий ОИЯИ представляется вполне реальным, а представленные планы работ - выполнимым.
4. Для успешного и быстрого выполнения Проекта целесообразно создание широкой Всероссийской и международной кооперации.
5. Институты России располагают необходимым научным и инженерно-техническим потенциалом.
6. Успешная реализация Проекта позволит всем участникам Проекта занять лидирующие позиции в физике высоких энергий и войти в число самых передовых исследовательских центров мира.

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### Round Table Discussions I, II, III, IV... JINR, Dubna, 2005, 2006, 2008, 2009...

### ITEP-JINR seminar at ITEP, 27.05.09

### All Moscow-JINR seminar at INR, 27.03.08

# Nuclear matter physics at NICA

Peter Senger

*Helmholtzzentrum Heavy Ion Research, GSI Darmstadt, Germany*

Physics case	Observables	Detectors
nuclear EOS at high densities	proton flow, $\Lambda$ , $\Xi$ , $\Omega$	Silicon tracker, TPC, TOF
deconfinement phase transition, phase coexistence	excit. funct. of yield and flow of $K$ , $\Lambda$ , $\Xi$ , $\Omega$ . e-by-e fluctuations	Silicon tracker, TPC, TOF
strange matter	multi-strange short-lived objects (decay into $\Lambda$ , $\Xi$ , $\Omega$ )	Silicon tracker, TPC, TOF
chiral phase transition, hadrons in dense matter	dileptons ( $e^+e^-$ )	HBD, RICH, TPC, TOF, ECAL, (TRD ?)

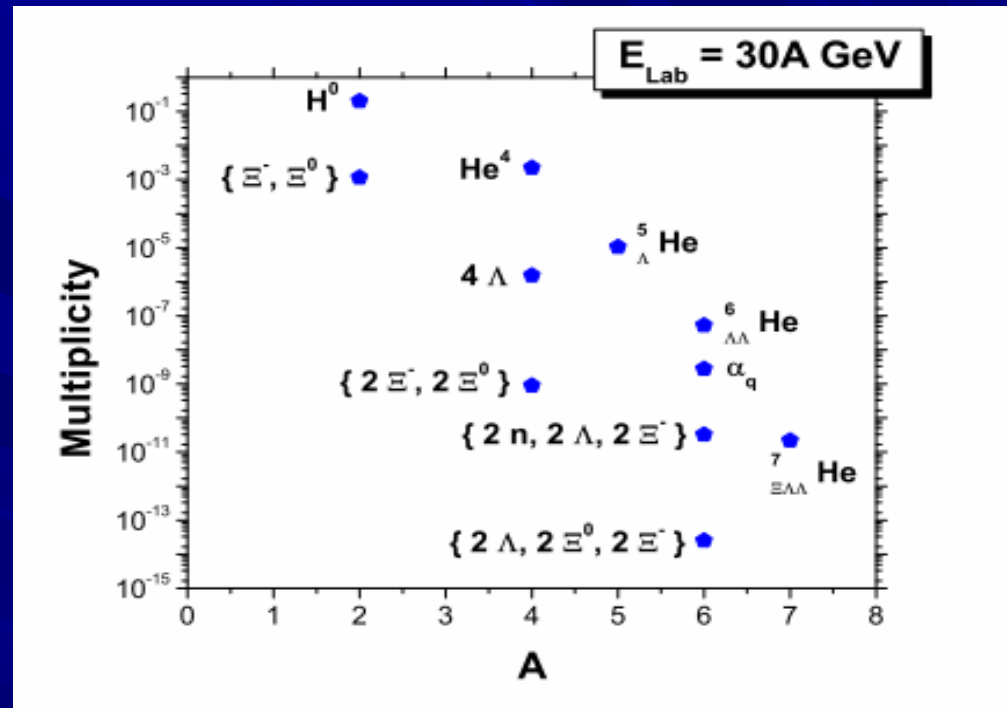
- **Most interesting** scientific questions with a **basic version of the MPD**: magnet, TPC, Silicon tracker and TOF detector; upgrade: electron detectors
- NICA/MPD part of worldwide program exploring the QCD phase diagram at high densities: AGS, SPS, NA61/SHINE, GSI/SIS18 --> RHIC, FAIR, NICA
- **Problem for STAR @ RHIC**: low luminosity, limited beamtime
- **Virtues of NICA**:
  - high luminosity at high baryon density-->**multidifferential observables**
  - collider exp. with **uniform acceptance**, almost independent of energy
- MPD @ NICA and CBM @ FAIR: **complementary measurements, joint R&D**

# MEMO production at high baryon densities

Marcus Bleicher & Jan Steinheimer

*FIAS & J.W.Goethe University Frankfurt (Main), Germany*

Cluster	Mass [GeV]	Quark content
$He^4$	3.750	$12q$
$H^0$	2.020	$4q + 2s$
$\alpha_q$	6.060	$12q + 6s$
$\{\Xi^-, \Xi^0\}$	2.634	$2q + 4s$
$\{4\Lambda\}$	4.464	$8q + 4s$
$\{2\Xi^-, 2\Xi^0\}$	5.268	$4q + 8s$
${}^5_{\Lambda}He$	4.866	$14q + 1s$
${}^6_{\Lambda\Lambda}He$	5.982	$16q + 2s$
${}^7_{\Xi^0\Lambda\Lambda}He$	7.297	$16q + 2s$
$\{2n, 2\Lambda, 2\Xi^-\}$	6.742	$12q + 6s$
$\{2\Lambda, 2\Xi^0, 2\Xi^-\}$	7.500	$8q + 10s$
$\{d, \Xi^-, \Xi^0\}$	4.508	$8q + 4s$
$\{2\Lambda, 2\Xi^-\}$	4.866	$6q + 6s$
$\{2\Lambda, 2\Sigma^-\}$	4.610	$8q + 4s$



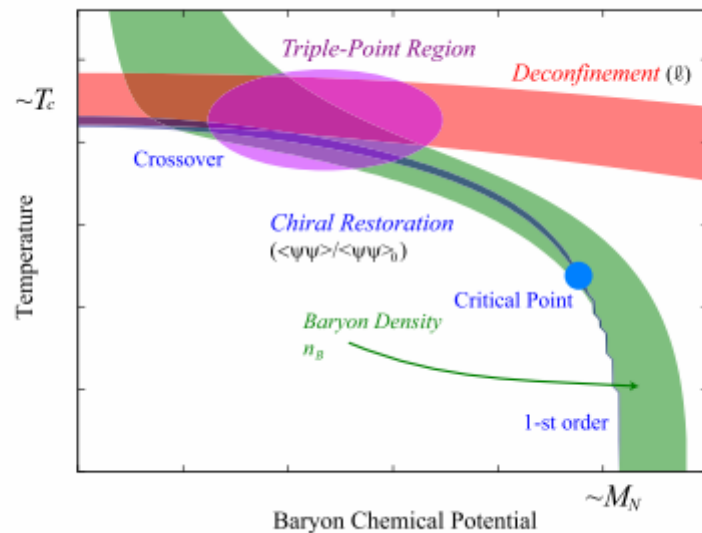
- Production of multi-strange metastable objects (MEMOs) explored in Pb+Pb reactions at 30 AGeV within **coupled transport-hydrodynamics model**
- Predictions for **yields** & particle-dependent **rapidity and momentum distributions**
- Excitation functions show clear maximum in the energy range of **NICA and FAIR** which are therefore **the ideal place to study** the production of these **MEMOs**



# Transitional change to baryon-rich QCD matter at NICA energy

Kenji Fukushima

*Yukawa Institute for Theoretical Physics,  
Kyoto University, Japan*



See also arxiv:1006.2596

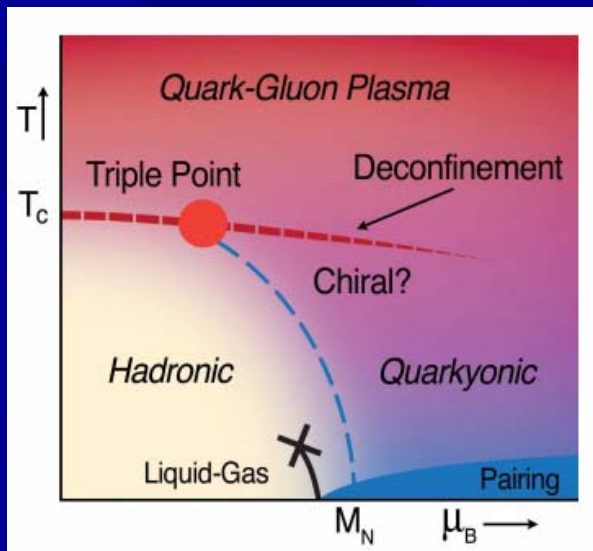
„Phase diagram of hot and dense QCD constrained by the statistical model“

(Polyakov-loop NJL model)

“... the collision energy  $\sqrt{s_{NN}} \approx 8$  GeV is a threshold below which abundant baryons can emerge. Such baryon dominant matter yet below deconfinement could be identified with so-called **Quarkyonic Matter**. **NICA** would be an **ideal facility** to probe such an onset to enter the baryon-rich regime of QCD matter.“

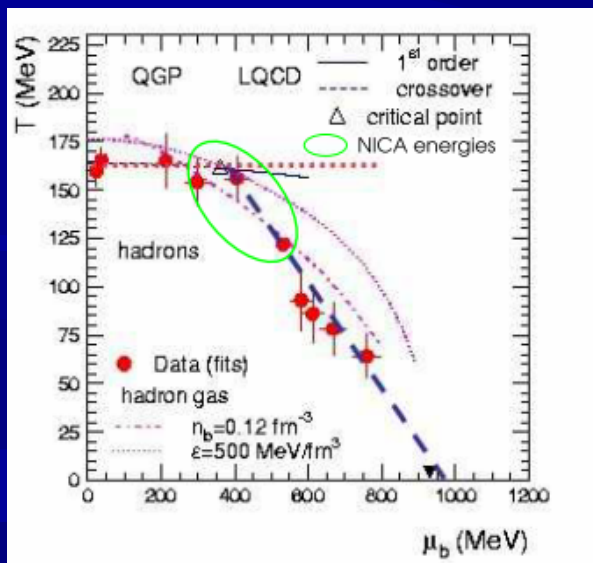
# Triple point and quarkyonic matter in the QCD phase diagram

Larry McLerran, Krzysztof Redlich and David Blaschke,  
*BNL Upton, USA; U Wroclaw, Poland; JINR Dubna, Russia*



Based on A. Andronic et al.  
Nucl. Phys. A 837. 65 (2010)  
[arxiv:0911.4806]

*In preparation*



The NICA (and CBM) energy range (green ellipse) covers chemical freeze-out parameters in the **QCD phase diagram** from the fit of hadron production with the statistical model which lie in the transition from meson-dominated to baryon-dominated freeze-out.

Here we expect the suggested transition from a hadronization out of the Quark-Gluon Plasma to a hadronization out of the „Quarkyonic Phase“, i.e., where three phases meet in a „Triple Point“: **QGP, Hadronic and Quarkyonic Phase!**

# Importance of third moments of conserved charges in HICs

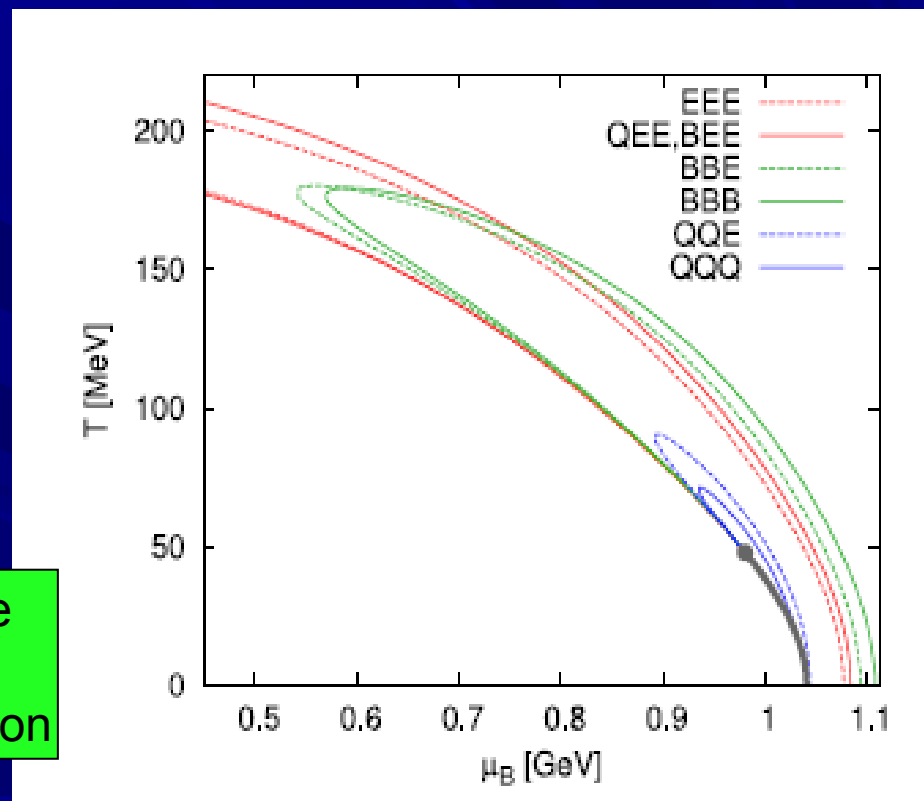
Masayuki Asakawa  
Osaka University, Japan

Third moments of conserved charges  
(derivatives of susceptibilities)

$$m_3(ccc) \equiv \frac{\langle (\delta N_c)^3 \rangle}{VT^2}, \quad m_3(EEE) \equiv \frac{\langle (\delta E)^3 \rangle}{VT^5}$$

where  $N_c$  with  $c=B, Q$  are net baryon and electric charge numbers in a volume  $V$ .  $E$  denotes the total energy,  $dN_c = N_c - \langle N_c \rangle$ ,  $dE = E - \langle E \rangle$ . Mixed moments accordingly.

Regions where third moments take negative values in the  $T$ - $\mu_B$  plane are strongly correlated with the suspected phase transition



Establishing negativeness of third moments in experiment is evidence for:

- (1) existence of peak structure of susceptibilities in the QCD phase diagram
- (2) realization of hot matter beyond the peak, i.e. the QGP, in heavy-ion collisions

# Baryon stopping in heavy-ion collisions at E=2-160 GeV/nucl.

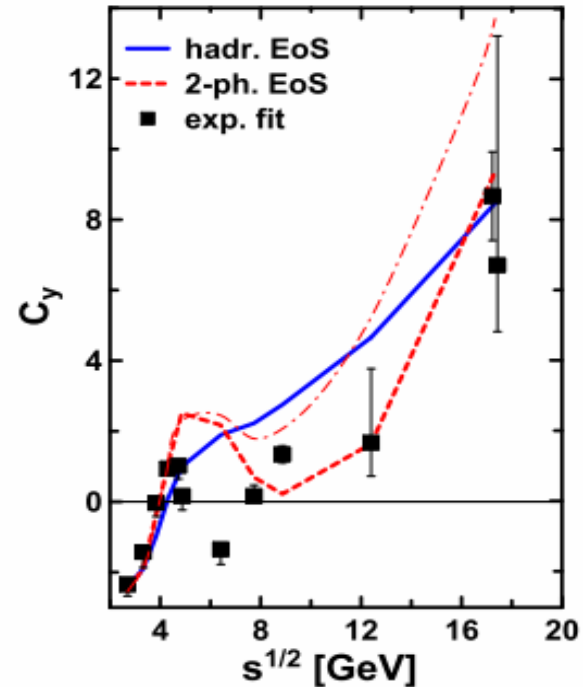
Yuri B. Ivanov

*Kurchatov Institute Moscow, Russia & GSI Darmstadt, Germany*

Irregularity in the energy dependence of the **curvature  $C_y$  of the proton spectrum** as a function of the (dimensionless) rapidity  $(y-y_{cm})/y_{cm}$

$$C_y \equiv \left( \frac{y_{cm}^3}{dy^3} \frac{d^3 N}{dy^3} \right)_{y=y_{cm}} / \left( \frac{y_{cm}}{dy} \frac{dN}{dy} \right)_{y=y_{cm}}$$
$$= (y_{cm}/w_s)^2 (\sinh^2 y_s - w_s \cosh y_s).$$

The „wiggle“ in  $C_y(s)$  is the characteristics of a first order phase transition in the EoS



- The „wiggle“ in energy dependence of the curvature  $C_y$  of the proton spectrum occurs between AGS and low SPS energies
- It is characteristic for a 1<sup>st</sup> order phase transition („mixed phase“) behaviour !
- NICA @ JINR and CBM @ FAIR will cover the relevant energies to confirm or reject this observed trend in the experimental data

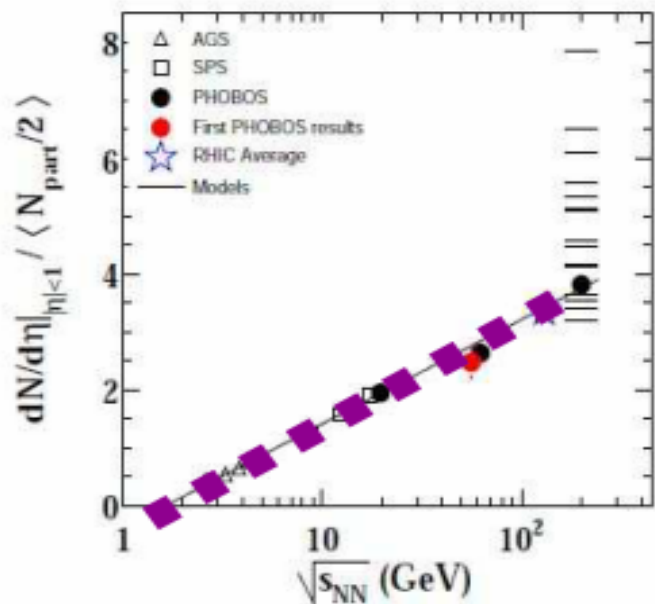
# Flow scaling in a low-energy collider: When does the perfect fluid turn on?

Giorgio Torreri

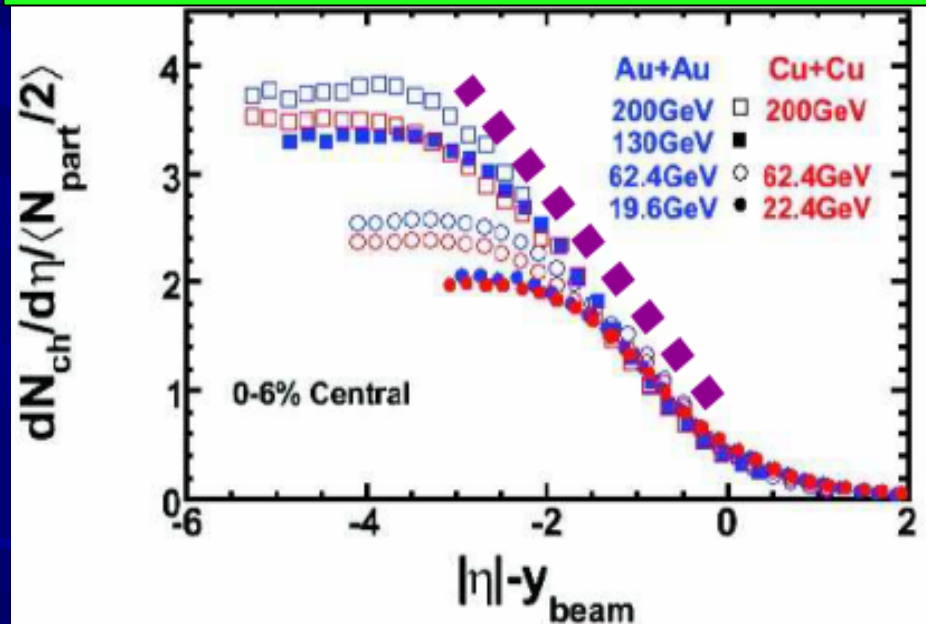
*FIAS and University Frankfurt, Germany; Columbia Univ., USA*

RHIC found remarkable scaling laws indicating „perfect fluid“ - minimal viscosity!

mid-rapidity  $dN/dy$  vs. energy



$dN/dy$  away from  $y_{beam}$  - limiting fragmentation

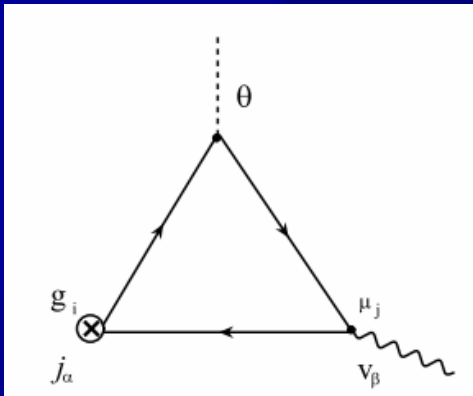


- Establish a lower limit for the onset of the hydro scaling in HIC experiments!
- Collider for scanning energy and rapidity below RHIC energies: NICA optimal!

# Chiral vortaic effect and neutron asymmetries at NICA

Oleg Rogachevsky, Alexander Sorin and Oleg Teryaev  
*JINR Dubna, Russia*

Both, chiral magnetic effect (CME) and chiral vortaic effect (CVE) belong to the class of effects based on the triangle anomaly in QFT. CVE is a generalization to conserved charges other than the electric one. In case of **baryon charge and chemical potential**, it should manifest itself by **neutron asymmetries**, observable at NICA/MPD !



$$e_j A_\alpha J^\alpha \Rightarrow \mu_j V_\alpha J^\alpha$$

$$J_e^\gamma = \frac{N_c}{4\pi^2 N_f} \varepsilon^{\gamma\beta\alpha\rho} \partial_\alpha V_\rho \partial_\beta (\theta \sum_j e_j \mu_j)$$

$$e_j \vec{H} \rightarrow \mu_j \vec{\nabla} \times \vec{V}$$

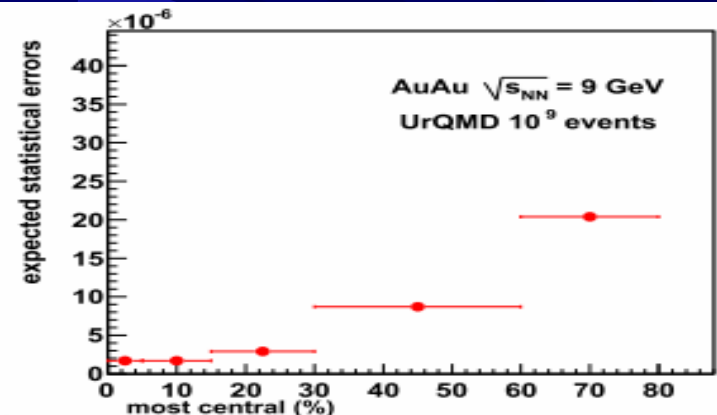
$$J_i^\nu = \frac{\sum_j g_{i(j)} \mu_j}{\sum_j e_j \mu_j} J_e^\nu$$

$$J_i^0 = \frac{|\vec{\nabla} \sum_j g_{i(j)} \mu_j|}{|\vec{\nabla} \sum_j e_j \mu_j|} J_e^0$$

Observable: three-particle correlator:

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle$$

**In CME case at RHIC: 15 M events were sufficient to establish the effect**  
**For demonstrating the CVE, we need 1000 M events, which can be collected at NICA/MPD within a few months of running time!**



# **Development of highly charged ion sources for NICA injector & possible applications for nanofabrication and in medicine**

**D.E. Donets, E.D. Donets, E.E. Donets, V. Salnikov, V. Shutov**  
*Kurchatov Institute Moscow, Russia & GSI Darmstadt, Germany*

Novel type of highly charged ions sources – Electron String Ion Sources (ESIS) is under development in JINR in framework of NICA project. This ion sources produce intense beams of highly charged ions of heavy elements, up to gold. Two major applications of this ion sources: for nanofabrication and for cancer therapy are briefly discussed.

**1 Production of nanostructures by slow highly charged ions for information storage and processing at nanometer range**

**2 Resonant combination cancer therapy – newly proposed method with use of highly charged ion source of highest intensity**

Basic and applied researches with highly charged intense ion beams of heavy elements, produced with ESIS-type ion sources have a very wide area for applications in nano-sciences and medicine. Ion source development program in framework of the NICA project has a great potential for various nonaccelerator applications as well.