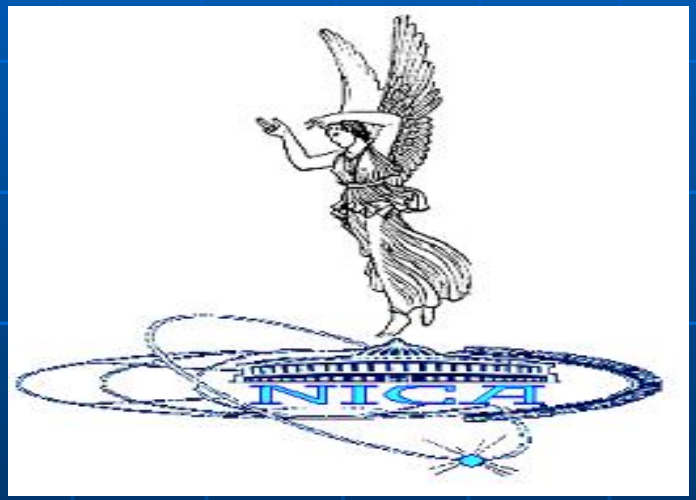
Joint Institute for Nuclear Research
International Intergovernmental Organization

Nuclotron-based Ion Collider fAcility (NICA) at JINR: New Prospect for Heavy Ion Collisions and Spin Physics

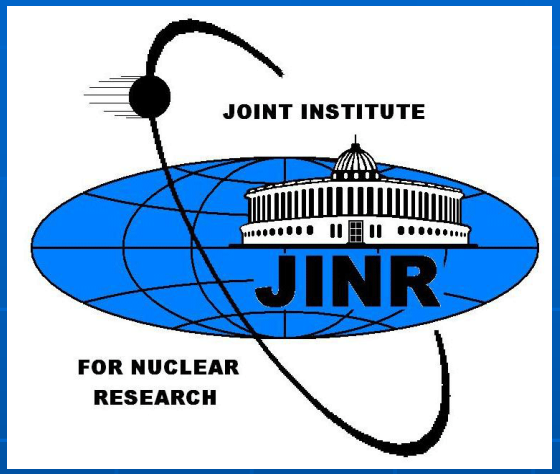
A.N.Sissakian, A.S.Sorin



XIX INTERNATIONAL BALDIN SEMINAR
ON HIGH ENERGY PHYSICS PROBLEMS
"RELATIVISTIC NUCLEAR PHYSICS & QUANTUM CHROMODYNAMICS"

Dubna, September 29 - October 4, 2008

The NICA Project and Research Program



I. The **N**uclotron-based **I**on Collider f**A**cility (NICA)

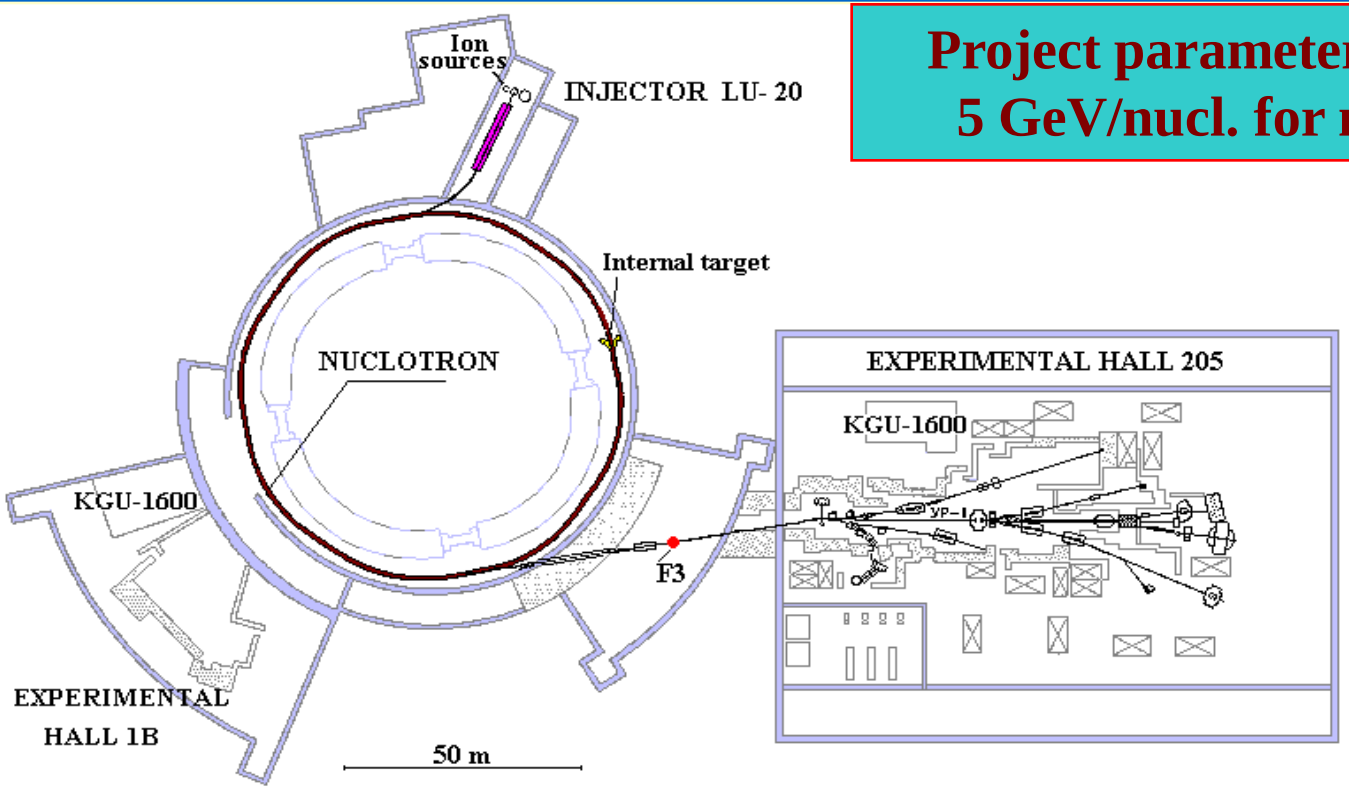
II. Physics of relativistic heavy ion collision (MPD)

III. Spin physics (SPD)

IV. Applied research

JINR NUCLOTRON

Project parameters: maximum energy 5 GeV/nucl. for nuclei with A ~ 200.



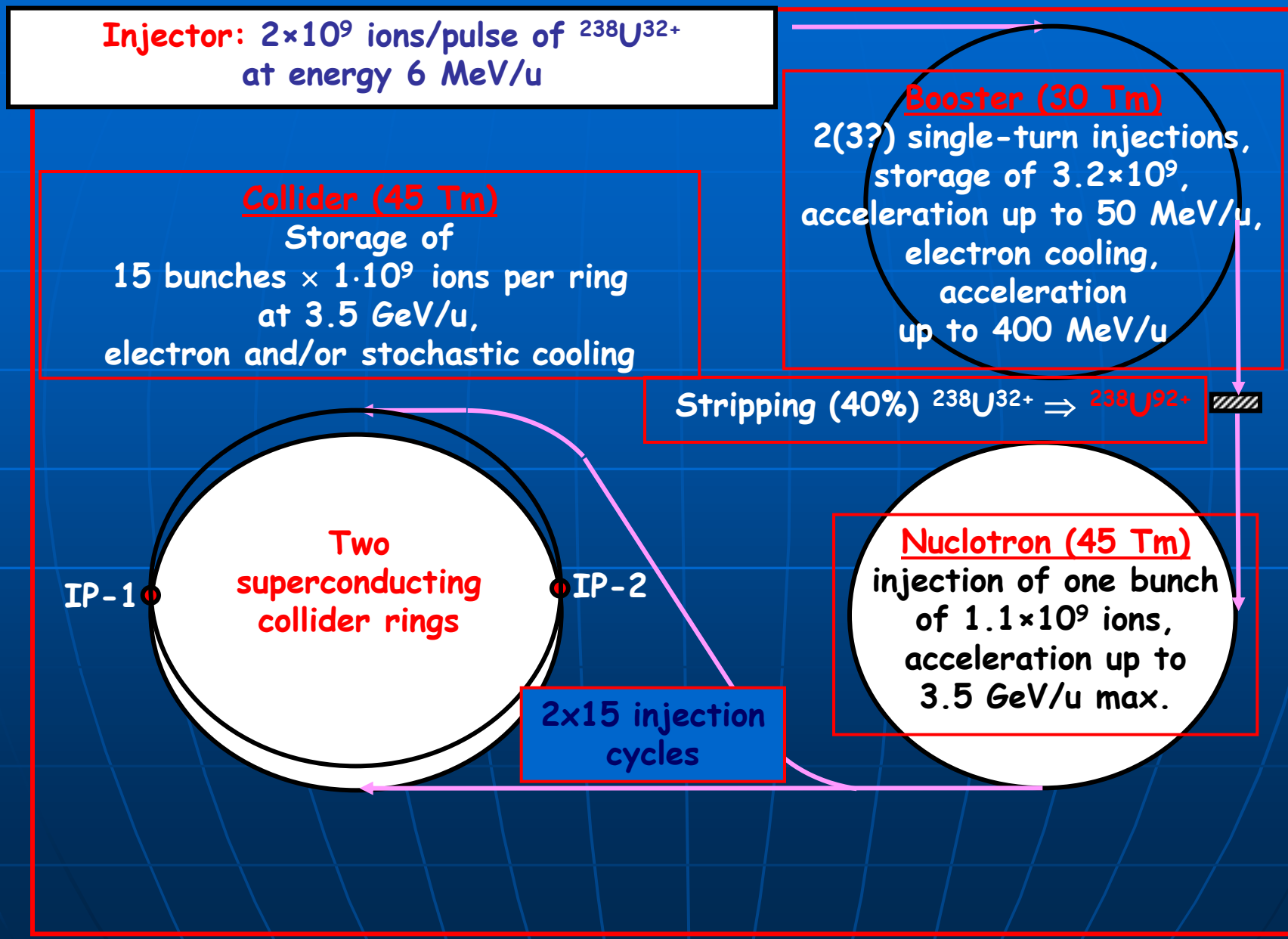
Nuclotron-based Ion Collider fAcility and MultiPurpose Detector (NICA / MPD)

The main goal of the project is an experimental study of hot and dense nuclear matter and spin physics

These goals are proposed to be reached by:

- development of the existing accelerator facility (1st stage of the NICA accelerator programme: Nuclotron-M subproject) as a basis for generation of intense beams over atomic mass range from protons to uranium and light polarized ions;
- design and construction of heavy ion collider with maximum collision energy of $\sqrt{s_{NN}}$ = 9 GeV and average luminosity 10^{27} cm^{-2} s^{-1} (for U^{92+}), and polarized proton beams with energy $\sqrt{s}$ ~ 25 GeV and average luminosity > 10^{30} cm^{-2} s^{-1}
- design and construction of the MultiPurpose Detector (MPD).

Scheme of the NICA compex



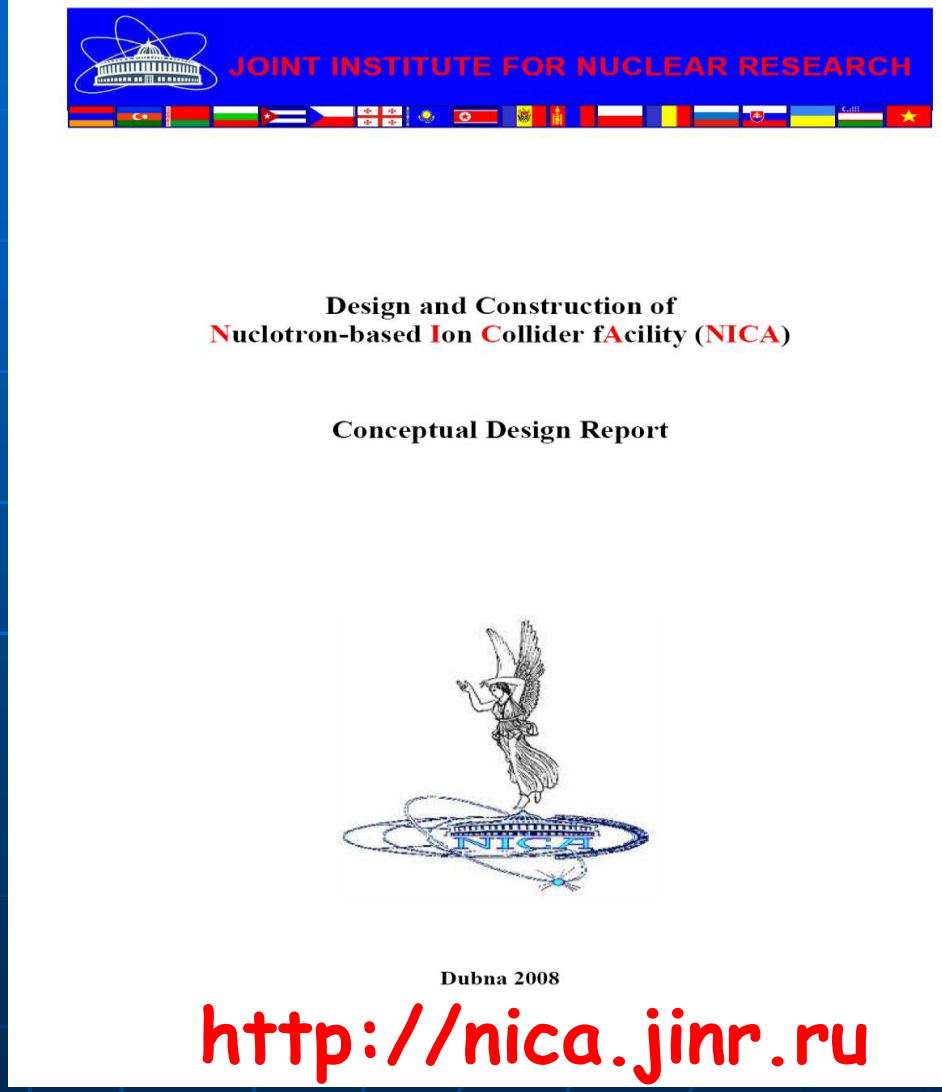
NICA parameters

Circumference	m	225
Number of collision points		2
Beta function in the collision point	m	0.5
Rms momentum spread		0.001
Rms bunch length	m	0.3
Number of ions in the bunch		10^9
Number of bunches		15
Incoherent tune shift		0.05
Rms beam emittance at 1 GeV/u / at 3.5 GeV/u	π mm mrad	3.8 / 0.26
Luminosity per one interaction point at 1 GeV/u at 3.5 GeV/u	$cm^{-2}s^{-1}$	$6.6 \cdot 10^{25}$ $1.1 \cdot 10^{27}$

1. Circumference, m	224
2. β^*, m	0.5
3. $\Delta p/p$ (one σ)	$1 \cdot 10^{-3}$
4. Bunch length (σ), m	0.3
5. Beam emittance (σ), $\pi \cdot$mm$\cdot$mrad	0.26
6. Bunch intensity	$(1-2) \cdot 10^9$
7. Bunch number per ring	15
8.Average luminosity forUU at 3.5 GeV/u	$1.1 \cdot 10^{27}$ $cm^{-2} \cdot s^{-1}$
for pp at 12.5 GeV	$3 \cdot 10^{31}$ $cm^{-2} \cdot s^{-1}$

NICA – Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Institute for High Energy Physics, Protvino
- Budker Institute of Nuclear Physics, Novosibirsk
- MoU with FAIR is under preparation
- *Open for extension …*



The NICA Project Milestones

- **Stage 1: years 2007 – 2009**
  - Upgrate and Development of the Nuclotron facility
  - Preparation of Technical Design Report of the NICA and MPD
  - Start prototyping of the MPD and NICA elements
- **Stage 2: years 2008 – 2012**
  - Design and Construction of NICA and MPD
- **Stage 3: years 2010 – 2013**
  - Assembling
- **Stage 4: year 2013 - 2014**
  - Commissioning

NICA provides unique possibility for the heavy ion physics program:

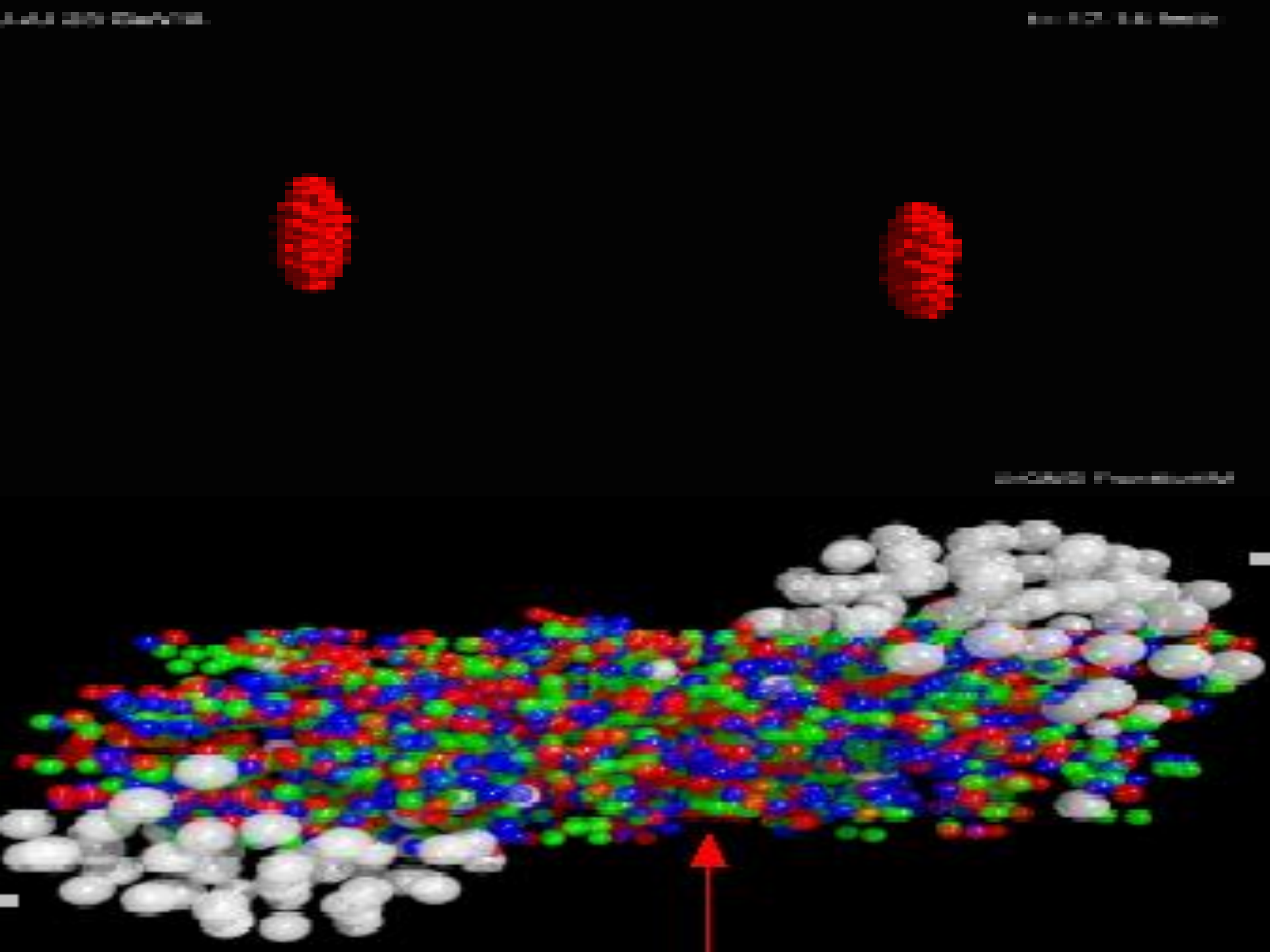
1. Heavy ion beams in **wide** energy range:

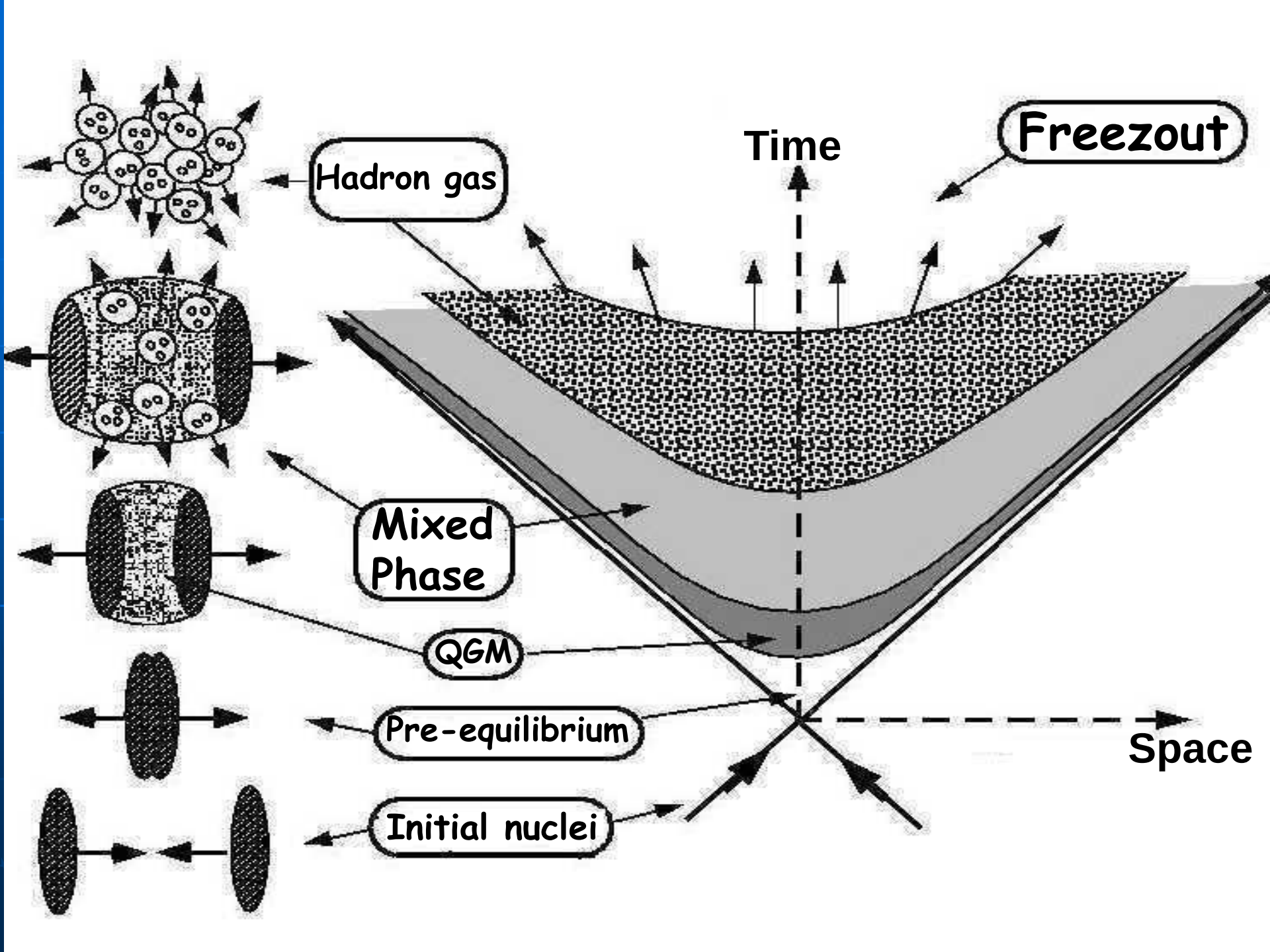
$$\sqrt{s} = 4 - 9 A\mathrm{GeV}$$

2. Possibility to perform atomic number and centrality **scan**

3. Few intersection points for detectors with large energy-independent acceptance

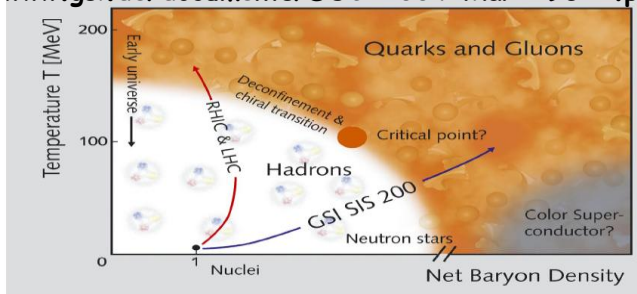
4. High luminosity $L \sim 10^{27}$ см$^{-2}$с$^{-1}$

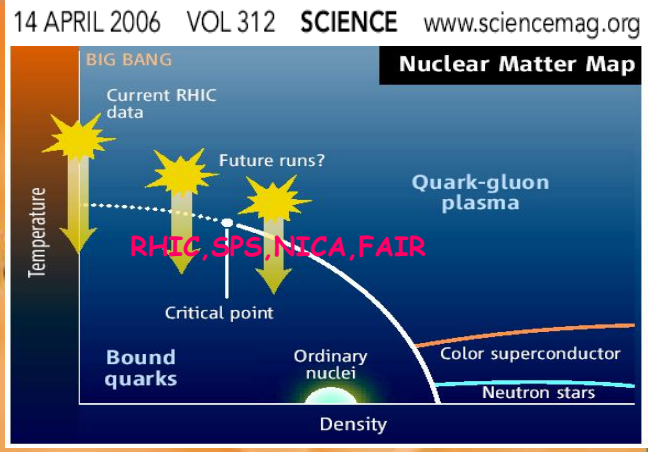



Hadron gas
Time
Freezout
Mixed
Phase
QGM
Pre-equilibrium
Space
Initial nuclei

T

www.gsi.de/documents/DOC-2004-Mar-196-2.pdf





Early universe

Quarks and Gluons

Critical point?

Deconfinement and chiral transition

Hadrons

RHIC, LHC

FAIR SIS 300

NICA

Mixed phase

Neutron stars

Color Super-conductor?

N_B

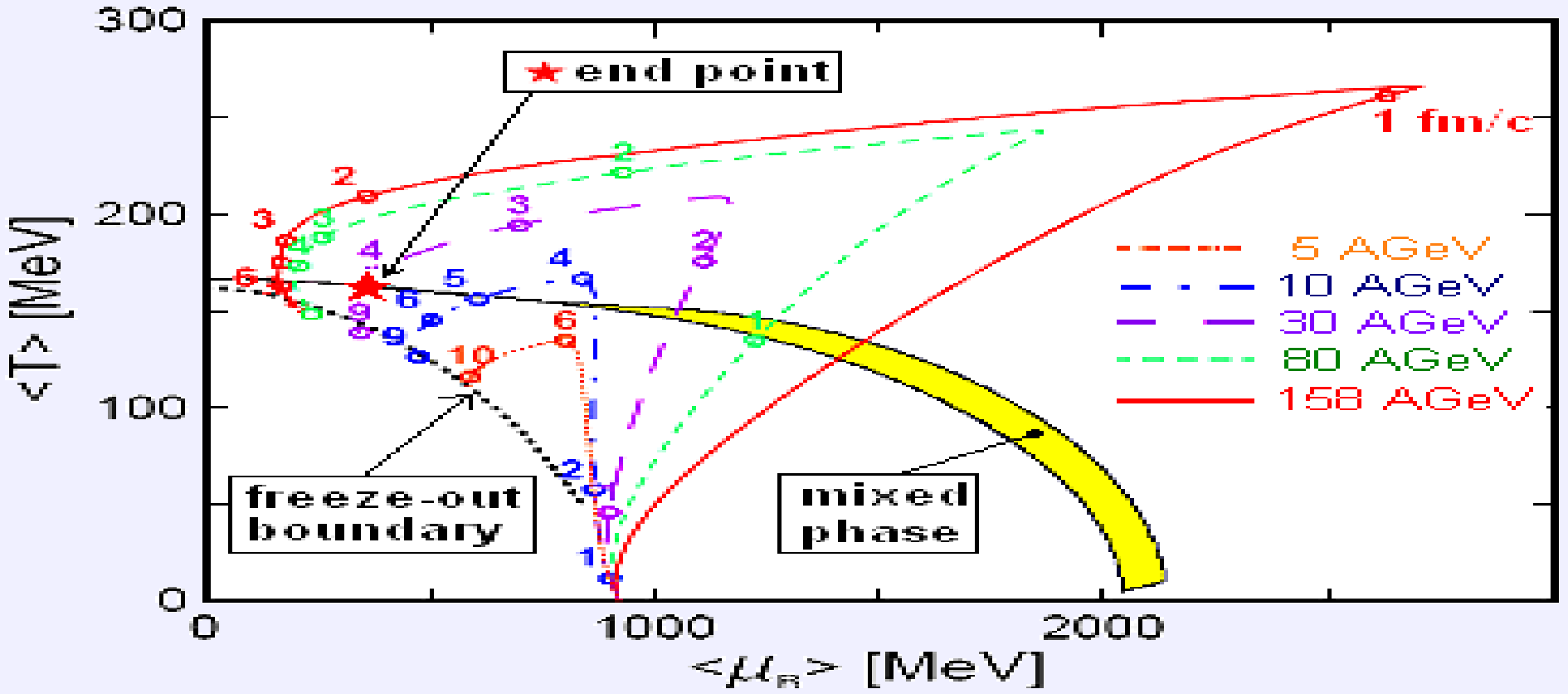
Round Table Discussion

Dubna, July 7-9, 2005

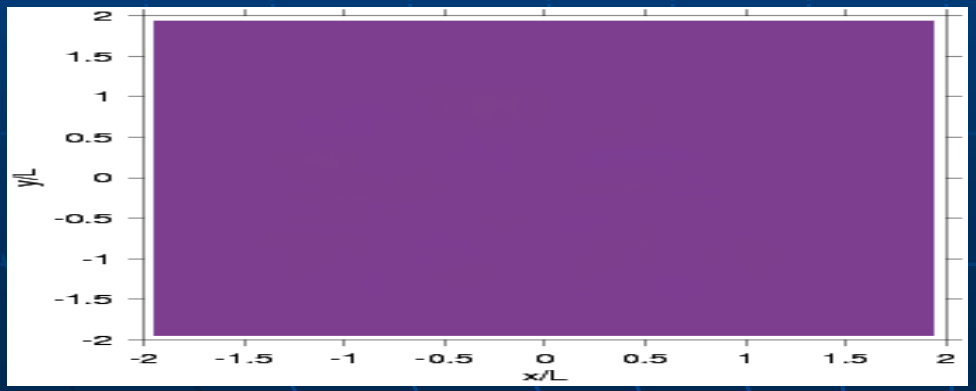
http://theor.jinr.ru/meetings/2005/roundtable/

A.N.Sissakian
A.S.Sorin
M.K.Suleymanov
V.D.Toneev
G.M.Zinovjev
nucl-ex/0511018
nucl-ex/0601034
nucl-th/0608032

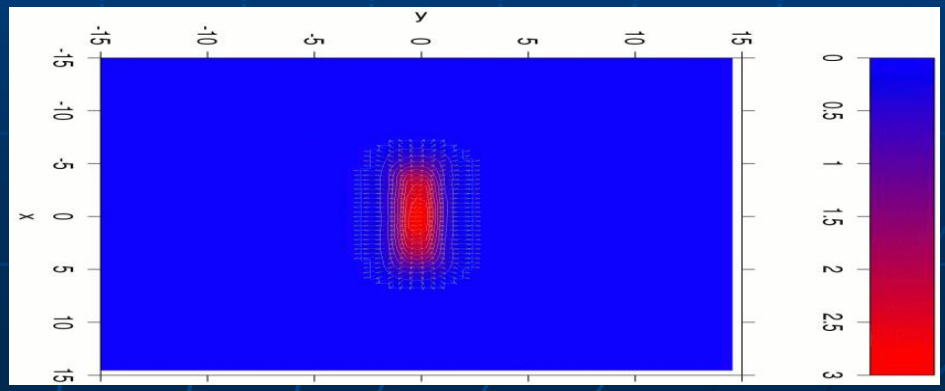
Dynamical trajectories



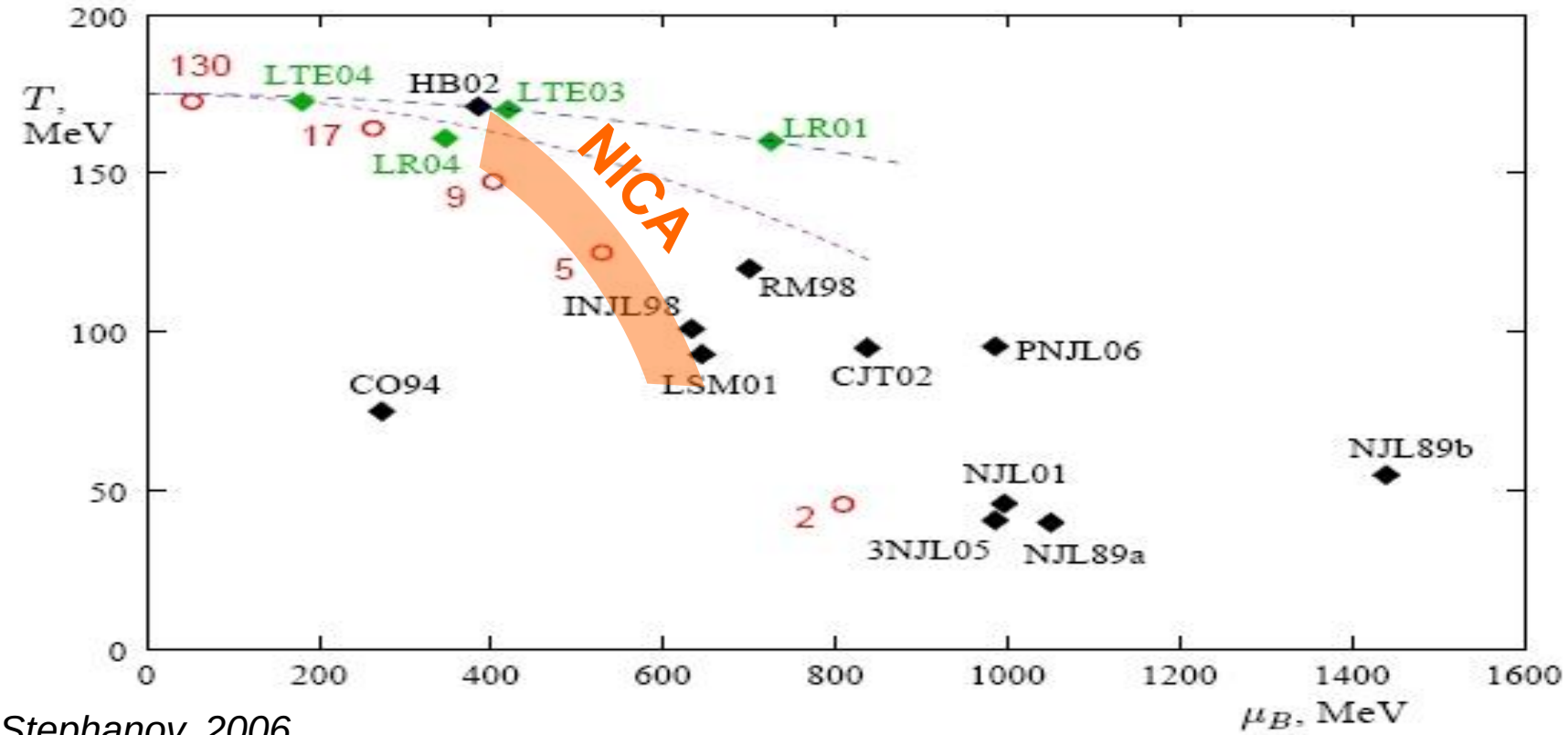
Skokov V., 2008



Ivanov Yu., Russkikh V.,Toneev V., 2005



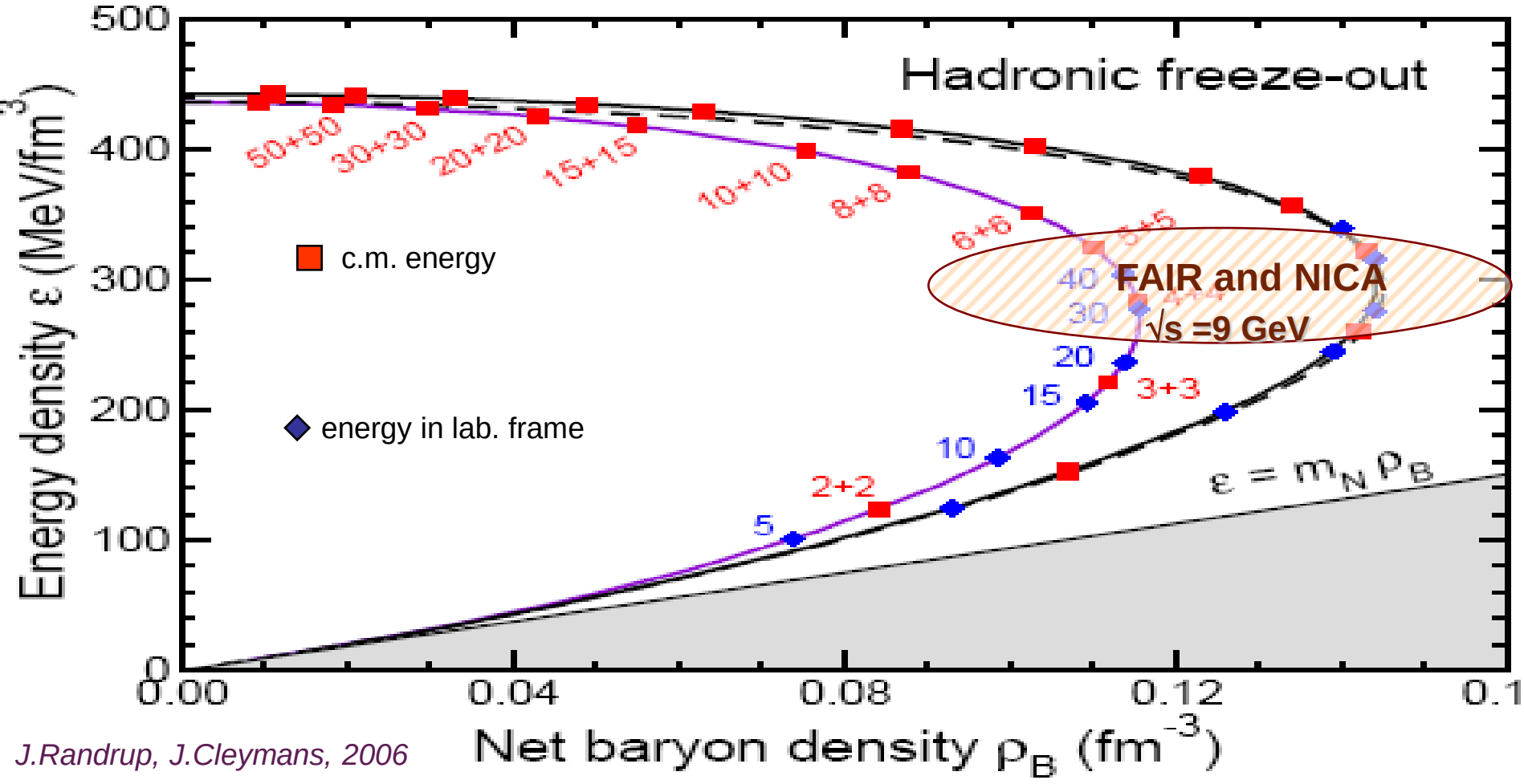
Critical points



M. Stephanov, 2006

- **Models**
- **Lattice QCD**
- **Chemical freeze-out for different energies** $\sqrt{s}$

High baryonic densities



J.Randrup, J.Cleymans, 2006

Maximal baryonic densities on freeze-out curve! ⇨ High densities on interaction stage!?

NICA/MPD physics problems

Study of in-medium properties of hadrons and nuclear matter equation of state including a search for possible signs of deconfinement and/or chiral symmetry restoration phase transitions and QCD critical endpoint

Experimental observables:

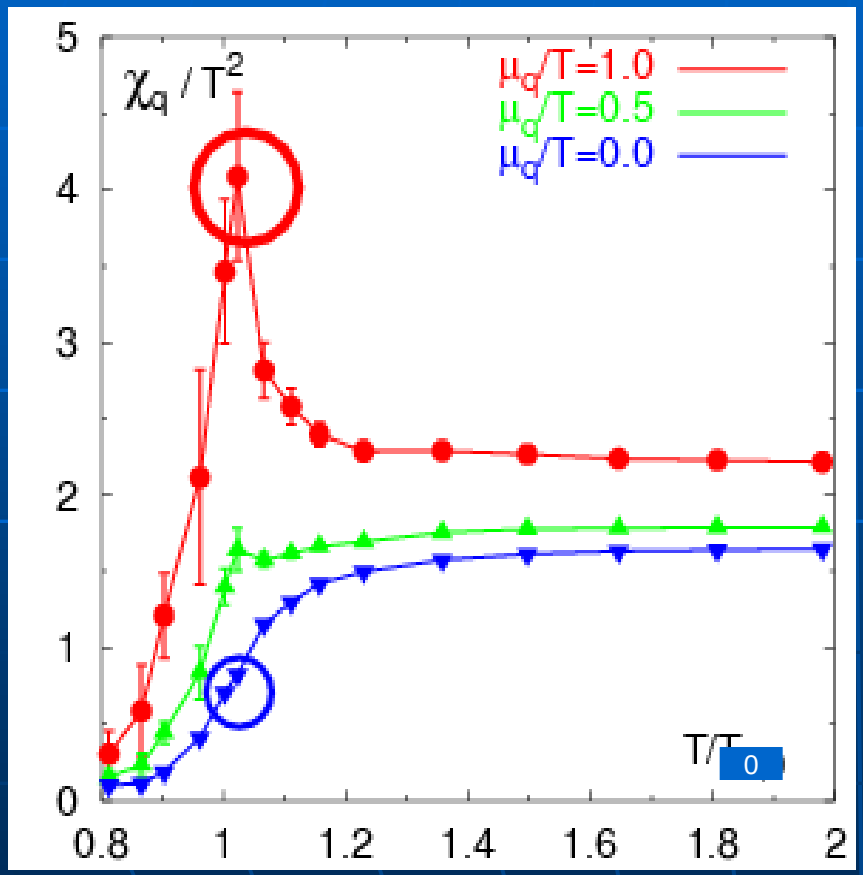
Scanning in beam energy and centrality of excitation functions for

Multiplicity and global characteristics of identified hadrons including multi-strange particles

- Fluctuations in multiplicity and transverse momenta
- Directed and elliptic flows for various indentified hadrons
- particle correlations
- Dileptons and photons

Fluctuations: theoretical status

Lattice QCD predictions: Fluctuations of the quark number density (susceptibility) at μ_B >0 (C.Allton et al., 2003)



$$\frac{\chi_q}{T^2} = \left[\frac{\partial^2}{\partial(\mu_q / T)^2} \frac{P}{T^4} \right]_{T_{fixed}}$$

χ_q (quark number density fluctuations) will diverge at the critical end point

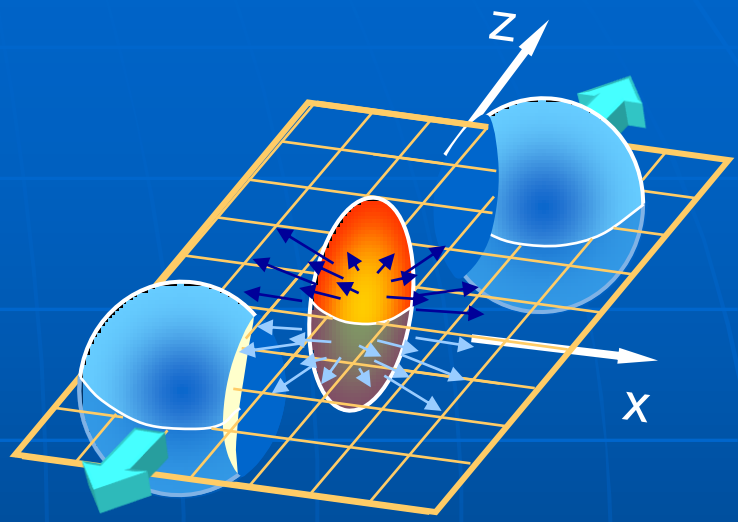
Experimental observation:

- Baryon number fluctuations
- Charge number fluctuations

Collective flows

Non-central collisions

Interactions between constituents lead to a pressure gradients => spatial asymmetry is converted in asymmetry in momentum space => collective flows



$$\frac{dN}{dyp_T dp_T d\varphi} = \frac{dN}{dyp_T dp_T}\frac{1}{2\pi}\left(1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + \ldots\right)$$

directed flow

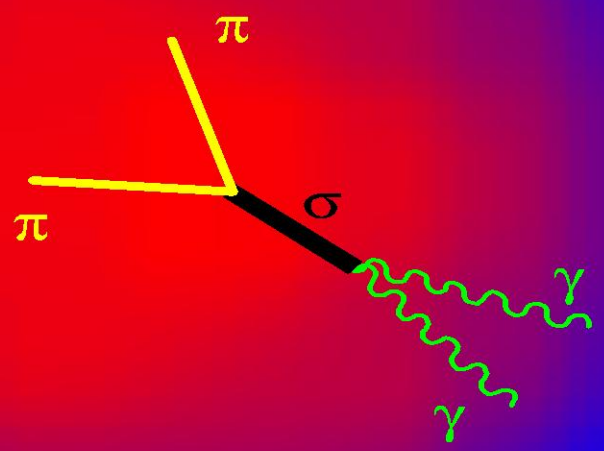
elliptic flow

Correlation femtoscopy of identical particles

$q = p_1 - p_2$, $\Delta x = x_1 - x_2$

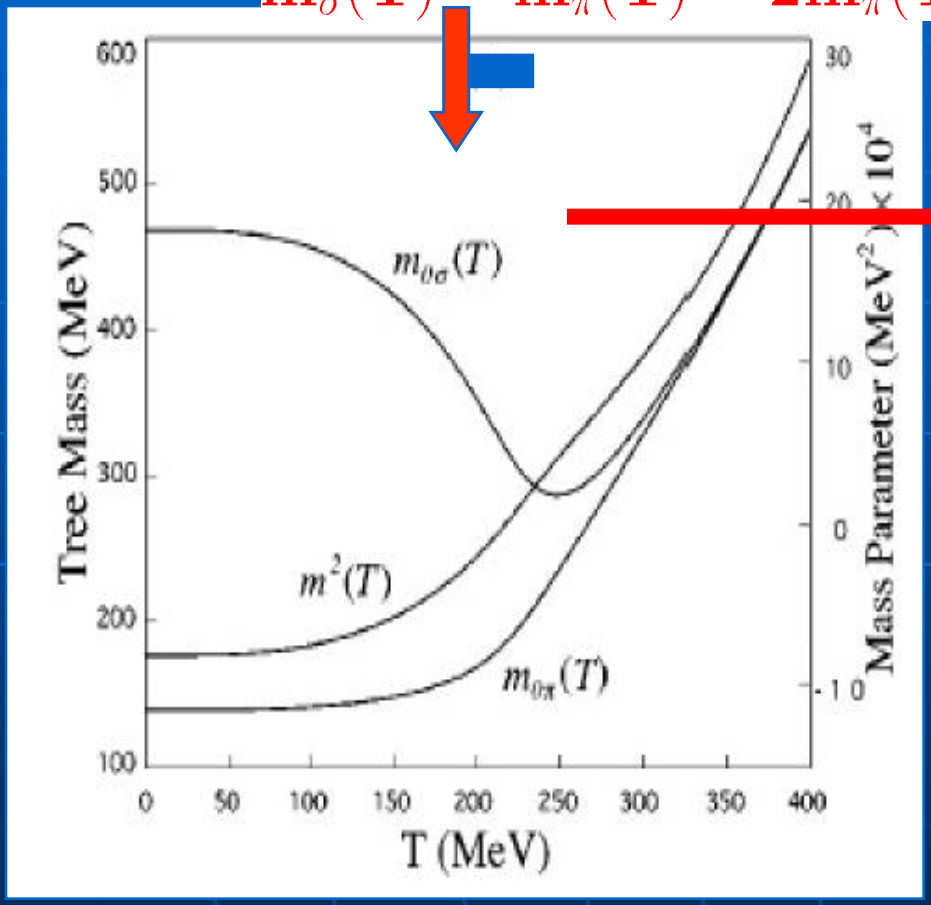
$$C_2 = 1 + (-1)^S < Cos\ q\Delta x > \rightarrow 1 + \lambda \exp(-R^2_{long} q^2_{long} - R^2_{side} q^2_{side} - R^2_{out} q^2_{out} - 2R^2_{out} q_{out} q_{long})$$

Signals of chiral symmetry restoration



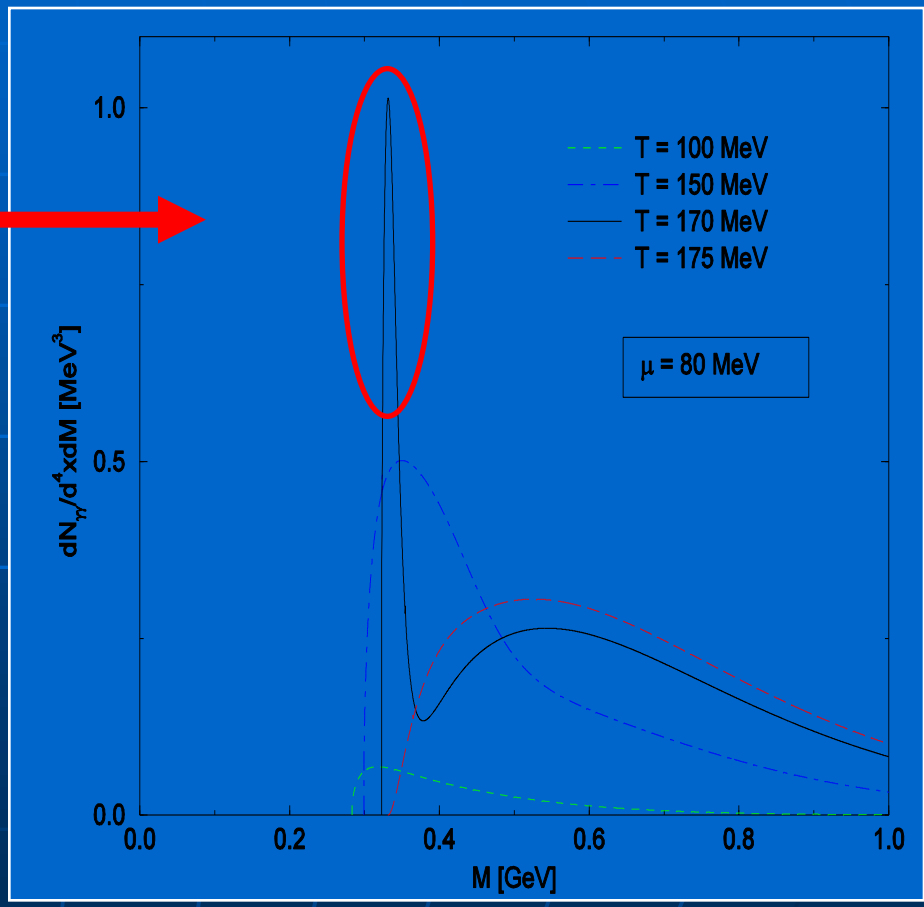
Signals of chiral symmetry restoration

$$m_\sigma(T) - m_\pi(T) = 2m_\pi(T)$$



S.Chiki, T.Hatsuda, 1998

Invariant mass distribution for $\sigma \to \gamma\gamma$



M.Volkov et al., 1998

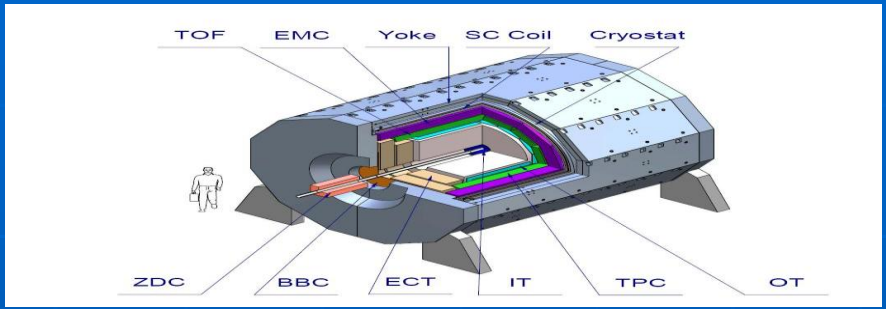
MPD – Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Bogolyubov Institute of Theoretical Physics, NASUk
- Skobeltsyn Institute of Nuclear Physics of Lomonosov MSU, RF
- Institute of Apllied Physics, Academy of Science Moldova
- *Open for extension …*

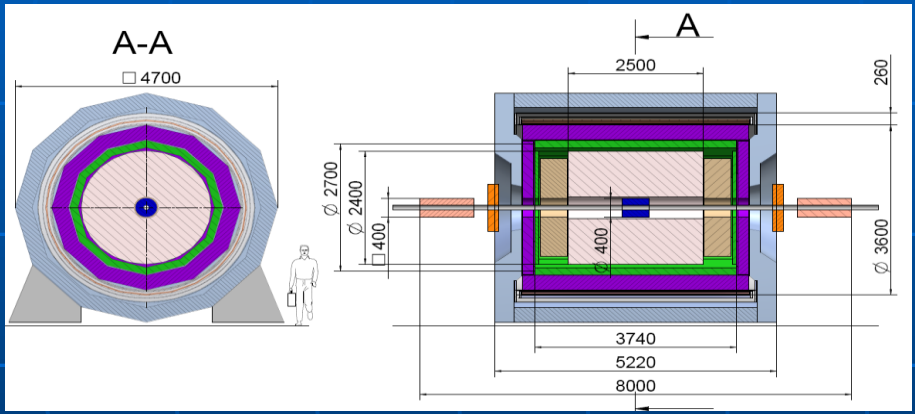
A consortium involving GSI, JINR & other centers for IT module development & production is at the organizational stage

http://nica.jinr.ru

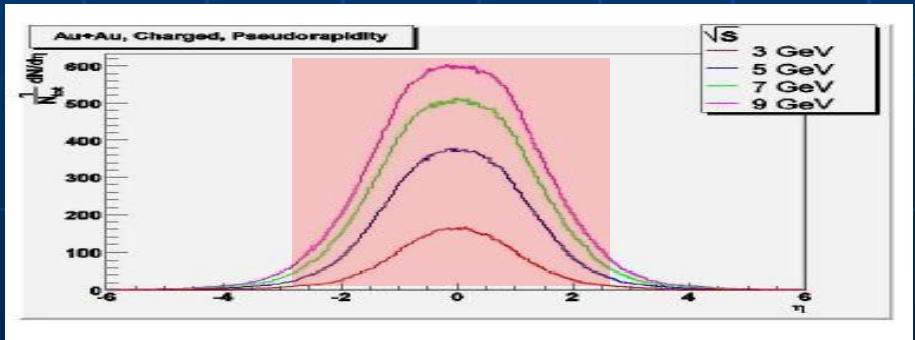
MPD conceptual design



MPD basic geometry



Acceptances for MPD



Inner Tracker (IT) silicon strip detector / micromegas for tracking close to the interaction region.

Barrel Tracker (BT) - TPC + Straw (for tagging) for tracking & precise momentum measurement in the region $-1 < \eta < 1$

End Cap Tracker (ECT) - Straw (radial) for tracking & p-measurement at $|\eta| > 1$

Time of Flight (TOF) - RPC (+ start/stop sys.) to measure Time of Flight for charged particle identification.

Electromagnetic Calorimeter (EMC) for π^0 reconstruction & electron/positron identification.

Beam-Beam Counters (BBC) to define centrality (& interaction point).

Zero Degree Calorimeter (ZDC) for centrality definition.

Experimental programs

Facility	SPS	RHIC	**NICA**	SIS-300
Detector	NA61	STAR PHENIX BRAHMS	**MPD**	CBM
Start (year)	2010	2010	**2013-2014**	2015
Energy (for Pb-ions) c.m. GeV	4.9-17.3	4.9-50	**≤ 9**	≤ 8.5
Event rate (for c.m. 8 GeV)	100 Hz	~10 Hz	**≤ 10 KHz**	≤ 10 MHz
Acceptance	**$0<\eta<4$** $\Delta\varphi<2\pi$	different acceptances	**$-2.5<\eta<2.5$** $\Delta\varphi= 2\pi$	**$0<\eta<4$** $\Delta\varphi<2\pi$
Physics	CP,OD	CP,OD	**CP,OD,HDM**	CP,OD,HDM

CP – critical endpoint

OD – onset of deconfinement

HDM – hadronic dense matter

NICA could provide unique possibilities for the spin program :

1. Accelerate at NUCLOTRON polarized high energy proton and deuterons

2. Have high luminosity (> 10^{30} $см^{-2}с^{-1}$)

3. Have high polarization (> 50%)

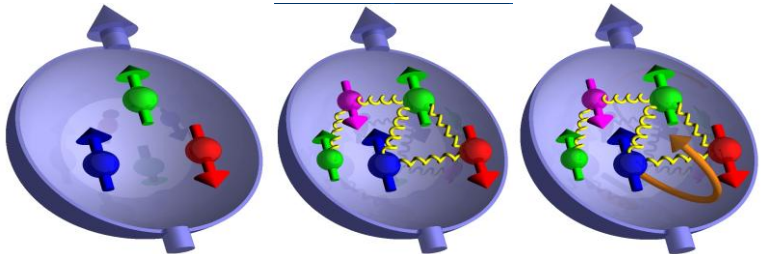
4. Rotate spin L/T

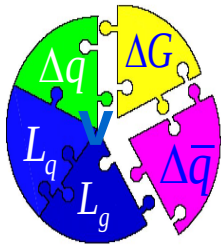
5. Polarization measure ~ 3%

6. Construct adequate (4π geometry) detector

Polarization data has often been the graveyard for fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

J.D. Bjorken, 1987

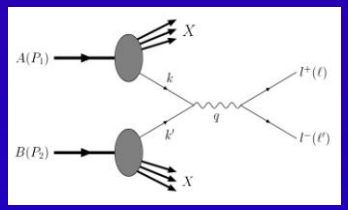




Spin Program at NICA

Studies of the MMT-DY processes with polarized p and D beams.

Extraction of unknown PDFs from J/ψ production processes



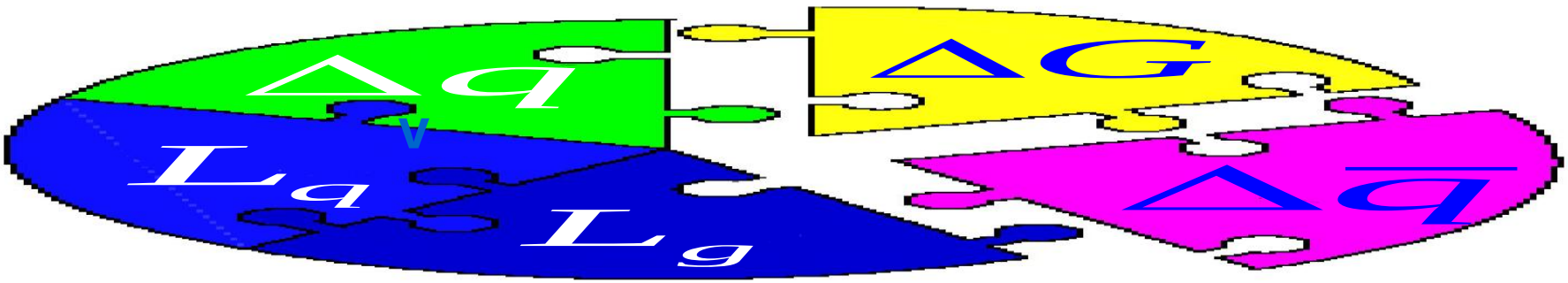
Spin effects in baryon and meson productions.

Studies of spin effects in various exclusive reactions

Diffractive processes studies

Cross sections and double spin asymmetries in elastic reactions

Spectroscopy of quarkoniums with any available decay modes



Experiments on MMT-DY measurements

Experiment	Status	Remarks
E615	Finished	Only unpolarized MMT-DY
NA10	Finished	Only unpolarized MMT-DY
E886	Running	Only unpolarized MMT-DY
RHIC	Running	Detector upgrade for MMT-DY measurements (collider)
PAX	Plan > 2016	Problem with $\bar{p}$ polarization (collider)
COMPASS	Plan > 2010	Only valence PDFs
J-PARC	Plan > 2011	low s (60-100 GeV^2), only unpolarized proton beam
SPASCHARM	Plan?	s ~ 140 GeV^2 for unpolarized proton beam
NICA	Plan 2014	s ~ 670 GeV^2 for polarized proton beams, high luminosity (collider)

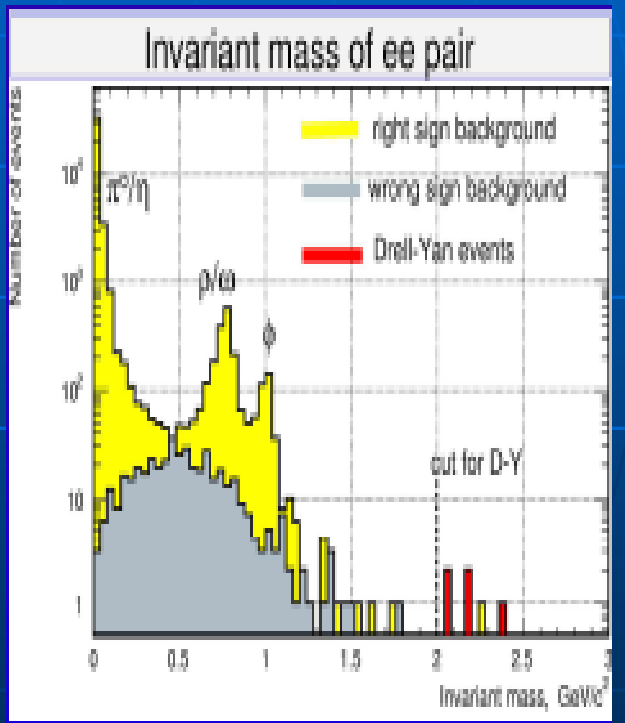
On the Spin Program at NICA

Preliminary estimations of the MMT-DY processes feasibility (first stage)

MMT-DY cross sections (nb) in comparison with PAX (GSI,FAIR) and possibility to increase the statistics (month of data taking)

	σ_{DY} total, nb	$L, cm^{-2}s^{-1}$	K events
PAX, $\sqrt{s} = 14.6 GeV$	~ 2	$\sim 10^{30}$	~ 10
NICA, $\sqrt{s} = 20 GeV$	~ 1	$\sim 10^{30}$	~ 5
NICA, $\sqrt{s} = 26 GeV$	~ 1.3	$\sim 10^{30}$	~ 7

cut on Q, GeV	1.5	1.6	1.7	1.8	1.9	2.0
NICA, $\sqrt{s} = 20\,GeV$						
σ_{DY} total,nb	2.54	1.94	1.59	1.32	1.1	0.9
N events for a month, K	14.1	10.5	8.8	7.3	6.1	5
NICA, $\sqrt{s} = 26\,GeV$						
σ_{DY} total,nb	3.3	2.7	2.3	1.9	1.6	1.3
N events for a month, K	18	15	13	10	9	7
PAX, $\sqrt{s} = 14.6\,GeV$						
σ_{DY} total,nb	5.1	4.33	3.5	2.9	2.46	2.09
N events for a month, K	24.4	20.7	16.7	13.9	11.8	10



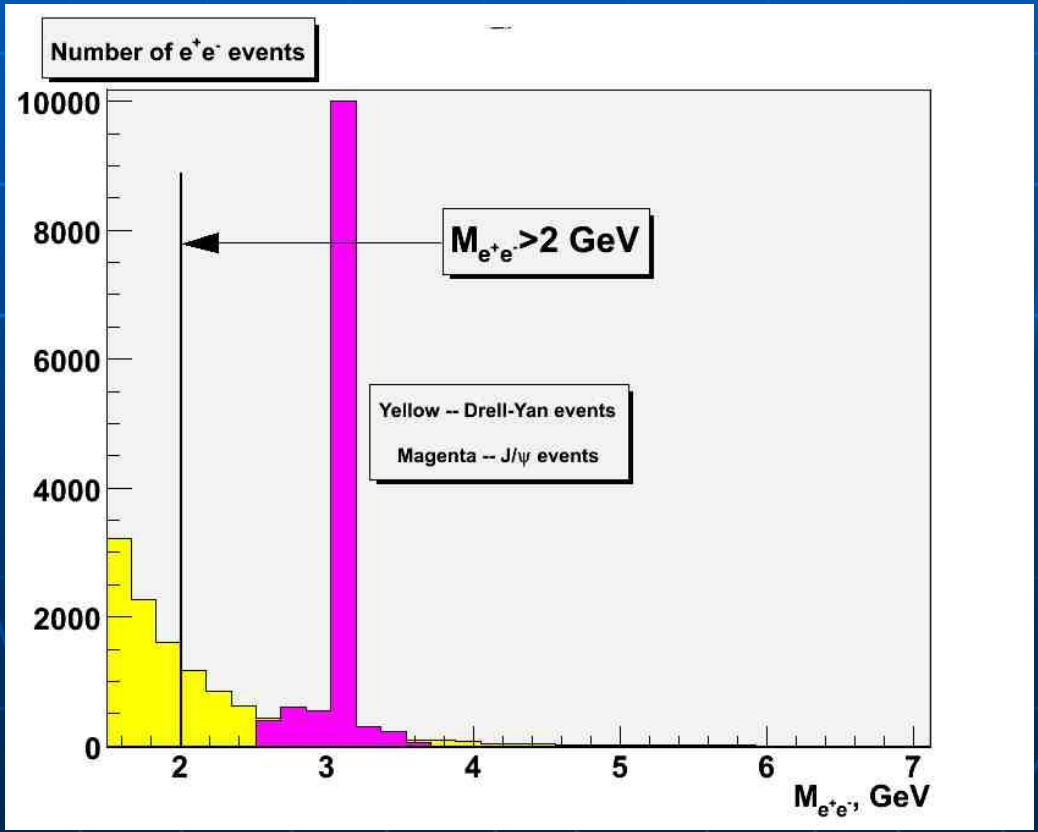
PAX background estimations

On the Spin Program at NICA

Preliminary estimations of J/Ψ statistics in comparison with MMT-DY statistics

$\sqrt{s}$, GeV	20	26
$\sigma_{J/\psi} \cdot B_{e^+e^-}$, nb	10	16
N events for a month, K	55	88

$\sqrt{s}$, GeV	20	26
σ_{DY}, nb	0.9	1.3
N events for a month, K	5	7



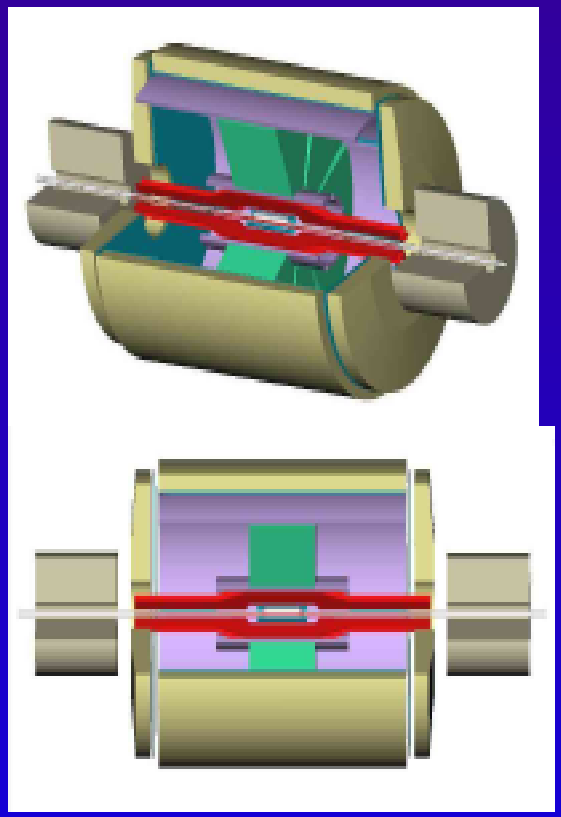
Preliminary scheme ot the experimental set-up for MMT-DY and J/Ψ measurements

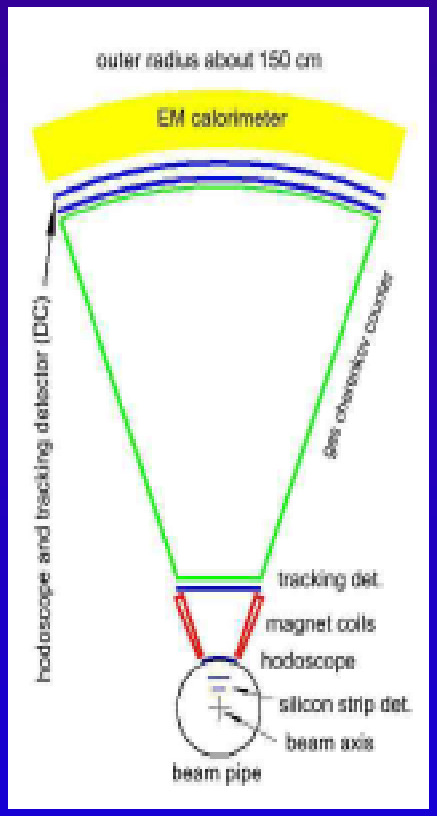
Important advantages of the detector :

2) 4 π geometry – increase of DY statistics

3) Minimal X_0 – effective detection of e+e- pairs

3) Good angular resolution – very important for azimuthal spin asymmetries measurements in the wide kinematical region



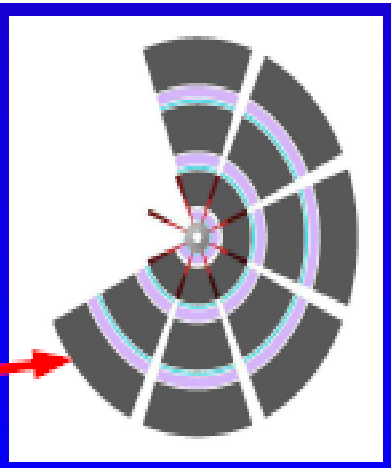


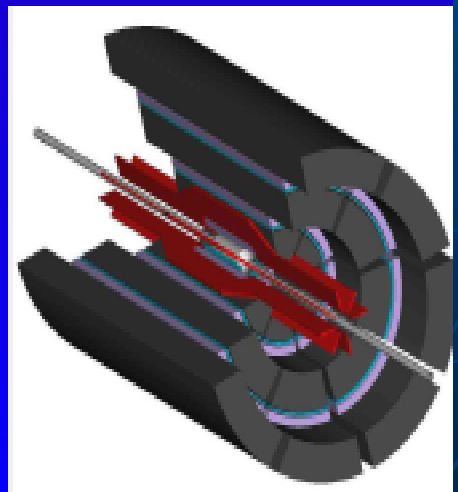
Main parts of the detector (preliminarily):

- Silicon or MicroMega (inner tracking)
- Drift chambers or straw (for tracking)
- Cherenkov counter (for PID and trigger)
- EM calorimeter
- Trigger counters
- EndCap detectors

Similarily to the PAX set-up (hep-ex/0505054)

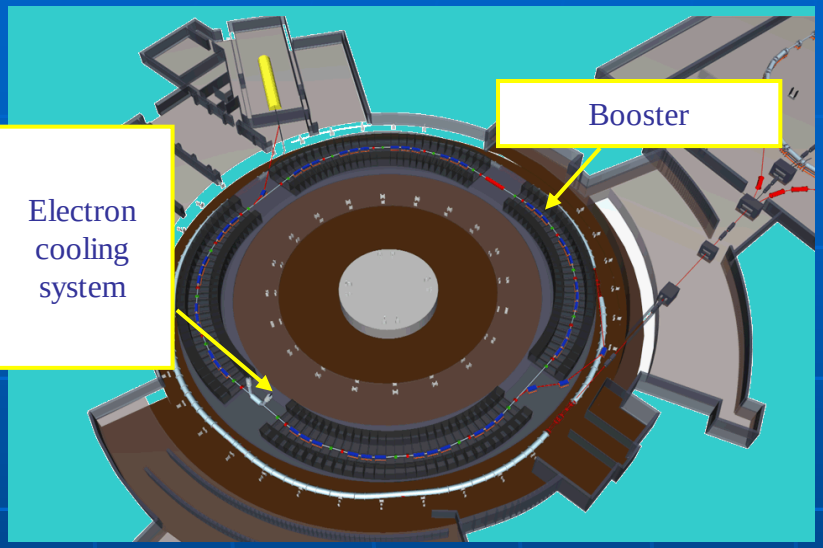
Set-up for muon pairs detection is also under consideration





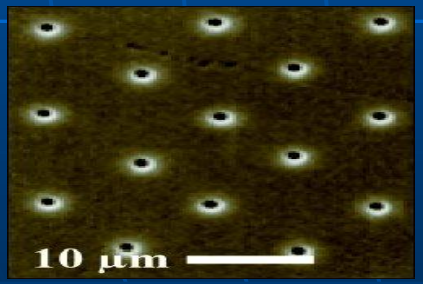
Applied research at NICA

Booster-sinhrotron appliction to nanostructures creations:

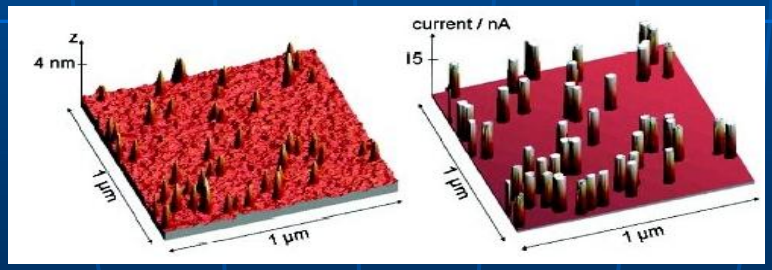


Design and parameters of booster, including wide accessible energy range, possibility of the electron cooling, allow to form dense and sharp ion beams. System of slow extraction provides slow, prolongated in time ion extraction to the target with space scanning of ions on the target surface and guaranty **high controllability** of experimental conditions.

Ion-track technologies:



Ion tracks in a polymer matrix (GSI, Darmstadt)



Topography and current of a diamond-like carbon (DLC) film.The 50 nm thick DLC film was irradiated with 1 GeV Uranium ions.

Production of nanowires, filters, nanotransistors, ...

Round Table Discussions

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/MPD
JINR (Dubna), end 2008
http://nica.jinr.ru

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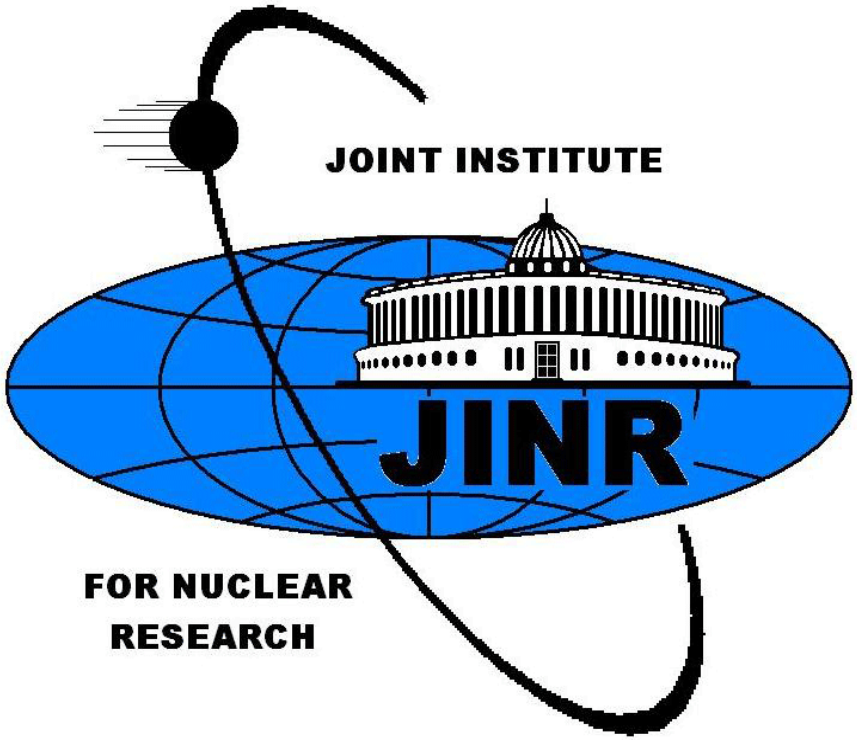
I.Savin, O.Shevchenko, V.Skokov,
O.Teryaev, V.Toneev,
NICA/MPD (SPD) working group

Welcome to the collaboration!



Thank you for attention!