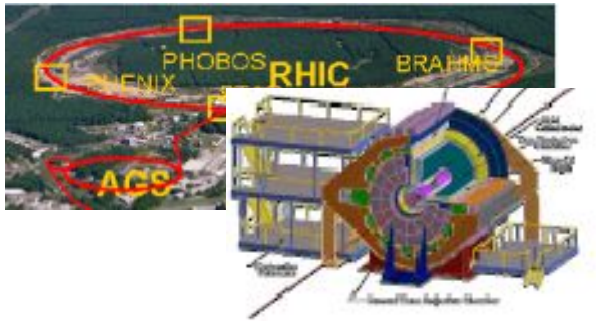
Joint Institute for Nuclear Research
International Intergovernmental Organization

Status of the NICA Project at JINR

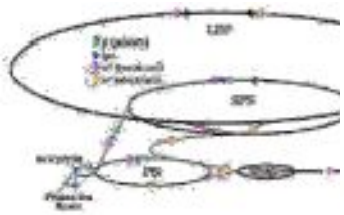
V. Kekelidze, A. Kovalenko, R. Lednicky, V. Matveev,
I. Meshkov, A. Sorin, G. Trubnikov
(for the NICA/MPD collaboration)

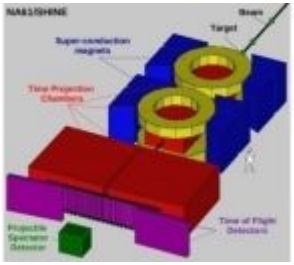
Ginzburg Conference on Physics
Lebedev Institute RAS, Moscow, May 28, 2012

2nd generation HI experiments



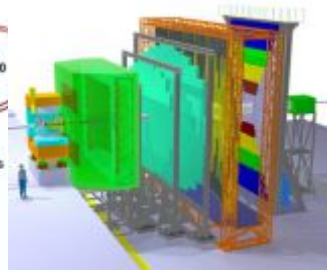
BES STAR/PHENIX@BNL/RHIC





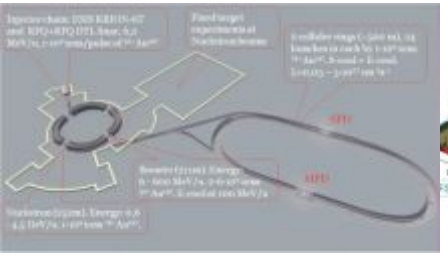
NA61@CERN/SPS

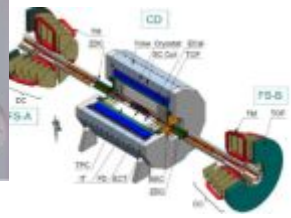
3nd generation HI experiments



CBM@FAIR/SIS-100/300

Fixed target, E/A=10-40 GeV, highest intensity



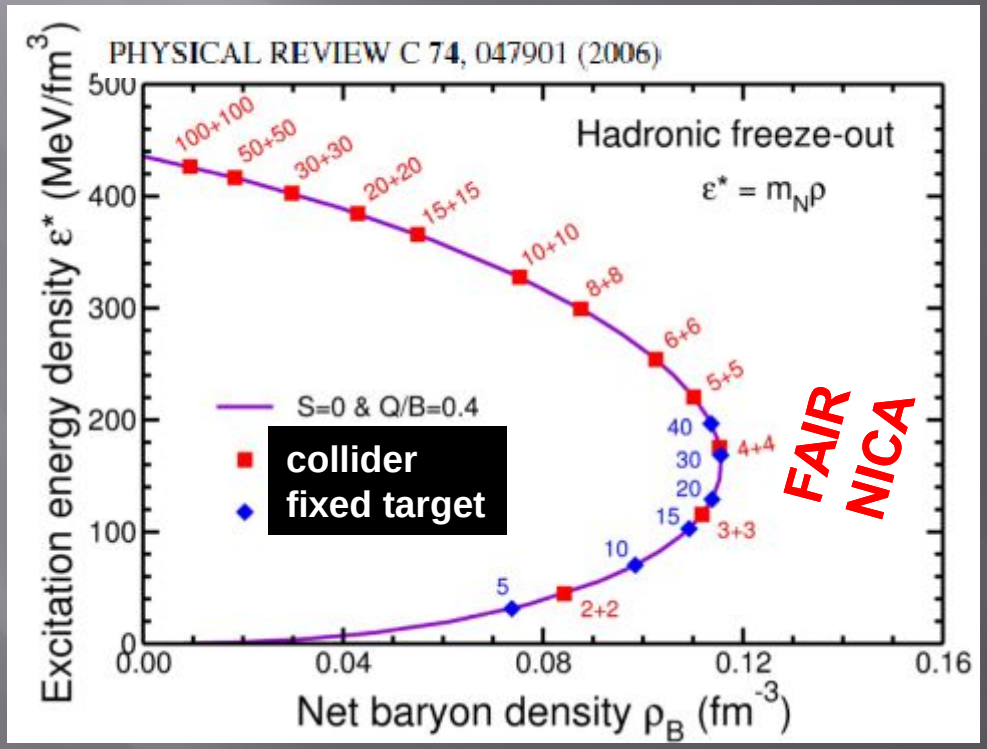


MPD@JINR/NICA

Collider, $\sqrt{s_{NN}}$ = 4-11 GeV, L~10^{27} $cm^{-2}s^{-1}$ for Au^{79+}

Highest baryon density at Lab

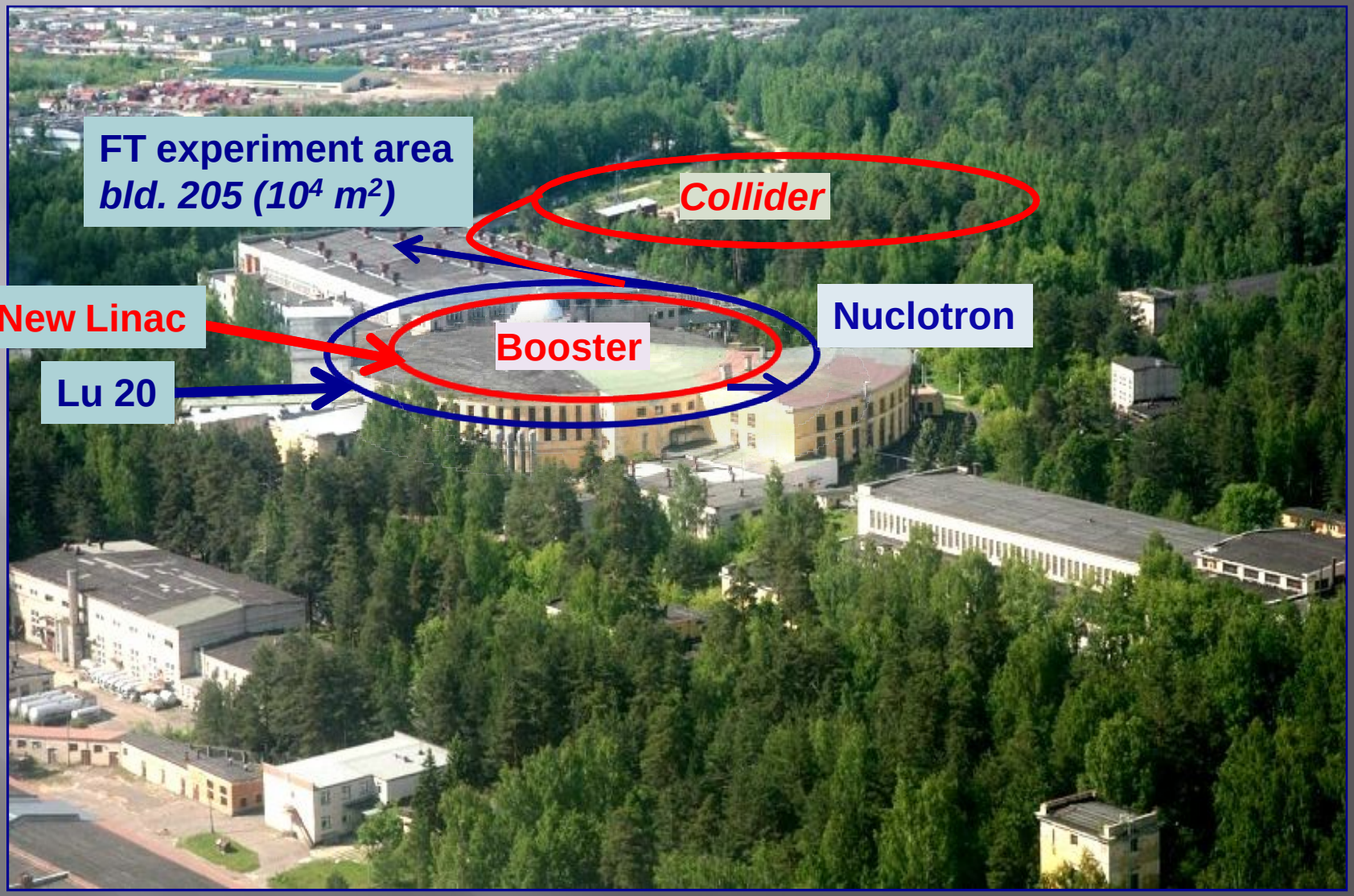
System of maximal net baryon (freeze-out) density is created in A+A collisions at NICA energies → optimum for the compressed nuclear matter exploration



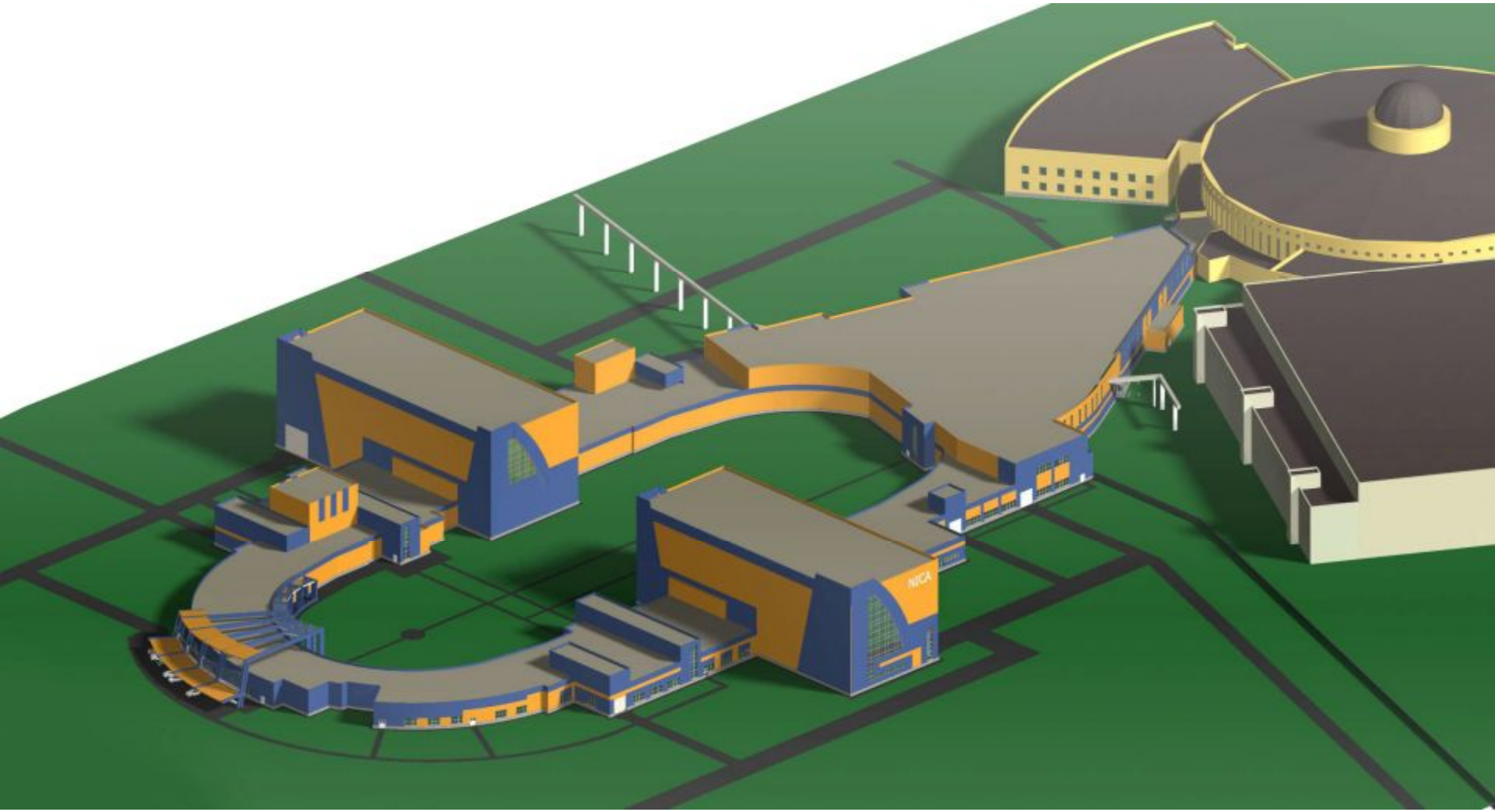
J.Randrup, J.Cleymans, 2006

NICA site

NICA


FT experiment area
bld. 205 (10⁴ m²)
Collider
New Linac
Booster
Nuclotron
Lu 20

Nuclotron-based Ion Collider fAcility (NICA)



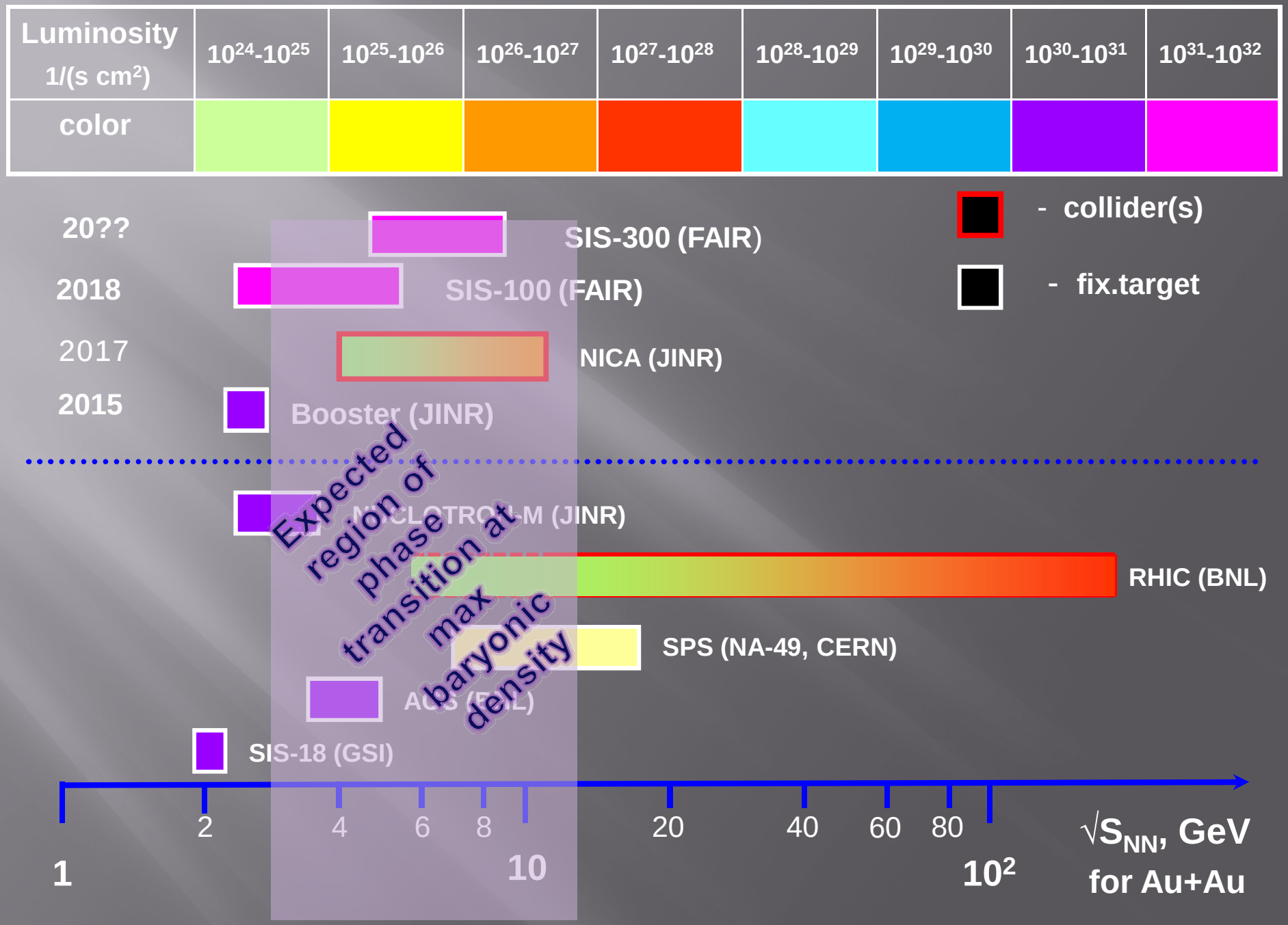
1a) Heavy ion colliding beams $^{197}Au^{79+}$ x $^{197}Au^{79+}$ at
$\sqrt{s_{NN}}$ = 4 ÷ 11 GeV (1 ÷ 4.5 GeV/u ion kinetic energy)
at Laverage= 1E27 $cm^{-2}\cdot s^{-1}$ (at √sNN = 9 GeV)

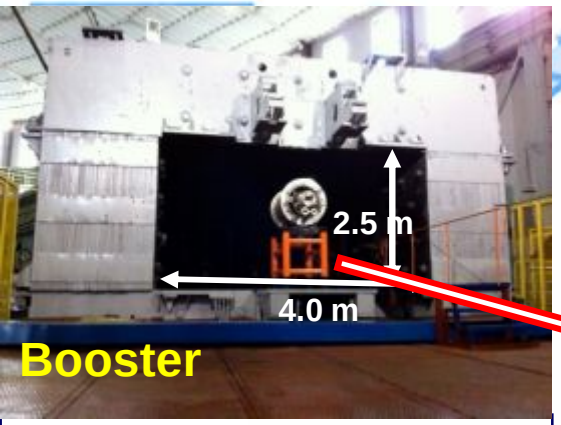
1b) Light-Heavy ion colliding beams of the same energy range and luminosity

2) Polarized beams of protons and deuterons in collider mode:
p↑p↑ √spp = 12 ÷ 27 GeV (5 ÷ 12.6 GeV kinetic energy)
d↑d↑ √sNN = 4 ÷ 13.8 GeV (2 ÷ 5.9 GeV/u ion kinetic energy
Laverage ≥ 1E30 $cm^{-2}\cdot s^{-1}$ (at √s_pp = 27 GeV)

3) The beams of light ions and polarized protons and deuterons for fixed target experiments:
Li ÷ Au = 1 ÷ 4.5 GeV /u ion kinetic energy
p, p↑ = 5 ÷ 12.6 GeV kinetic energy
d, d↑ = 2 ÷ 5.9 GeV/u ion kinetic energy

4) Applied research with ion beams at kinetic energy from 0.5 GeV/u up to 12.6 GeV (p) and 4.5 GeV /u (Au)


Luminosity 1/(s cm²)
10²⁴-10²⁵
10²⁵-10²⁶
10²⁶-10²⁷
10²⁷-10²⁸
10²⁸-10²⁹
10²⁹-10³⁰
10³⁰-10³¹
10³¹-10³²
color
- collider(s)
- fix.target
20??
SIS-300 (FAIR)
2018
SIS-100 (FAIR)
2017
NICA (JINR)
2015
Booster (JINR)
NUCLOTRON-M (JINR)
RHIC (BNL)
SPS (NA-49, CERN)
AGS (BNL)
SIS-18 (GSI)
Expected region of phase transition at max baryonic density
1
2
4
6
8
10
20
40
60
80
10²
√S_NN, GeV
for Au+Au



Synchrophasotron yoke

SPI & LU-20
("Old" linac)

KRION-6T
& HILac

Bldg
#1

Nuclotron

Fixed target
experiments

Bldg
#205

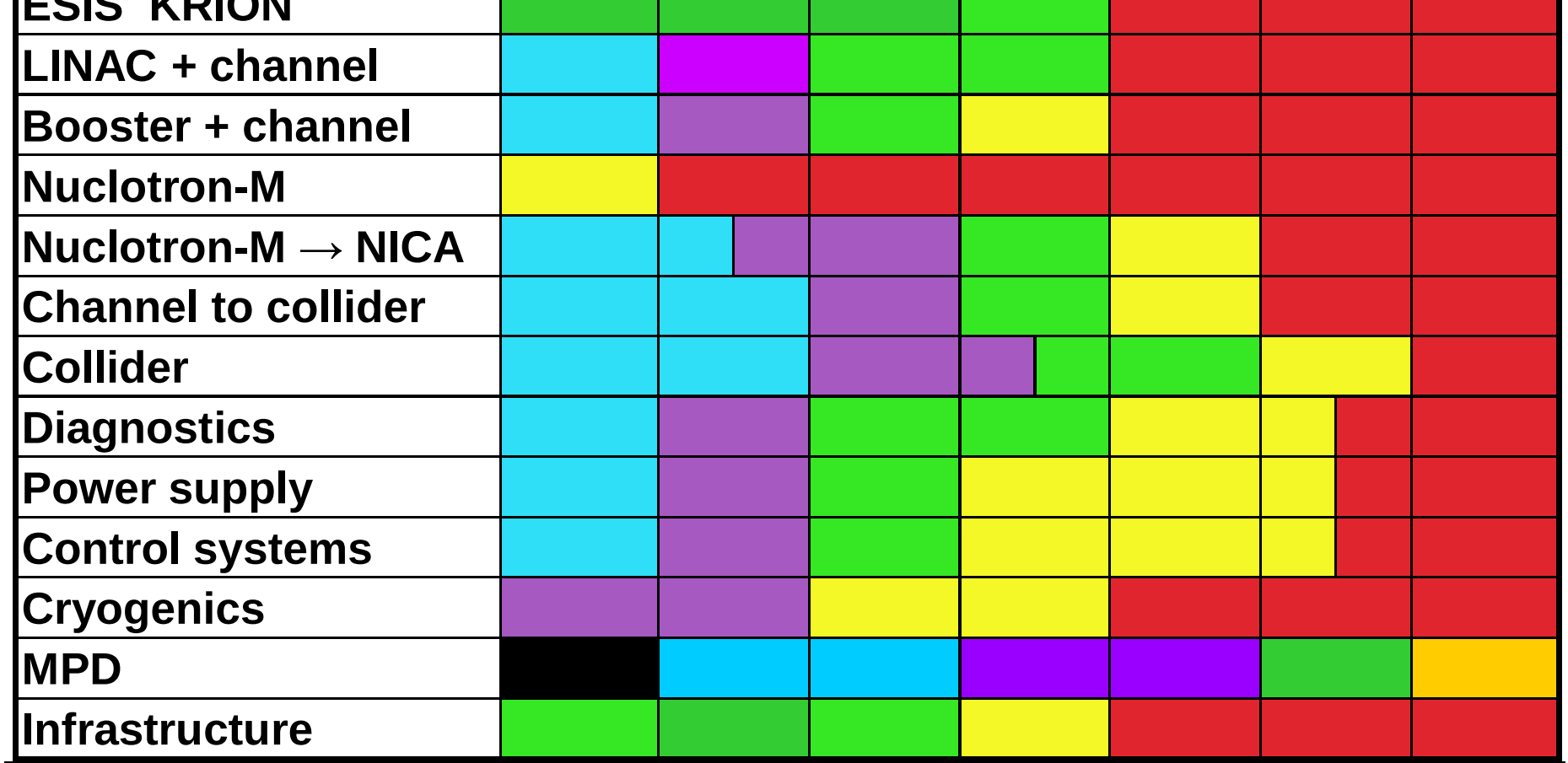
MPD

Collider
C = 503 m

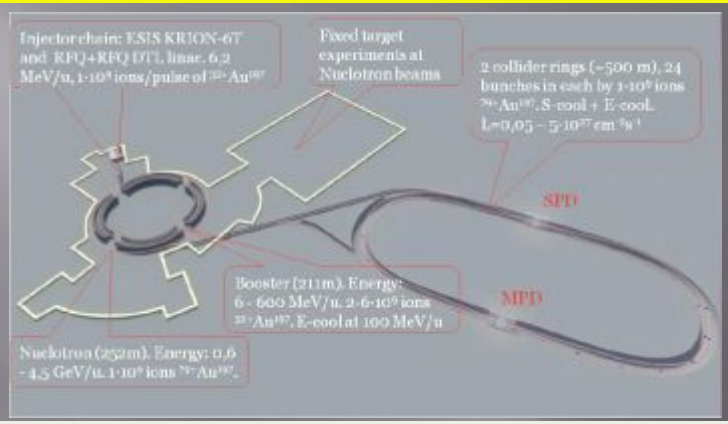
SPD

NICA structure and operation regimes

NICA construction schedule

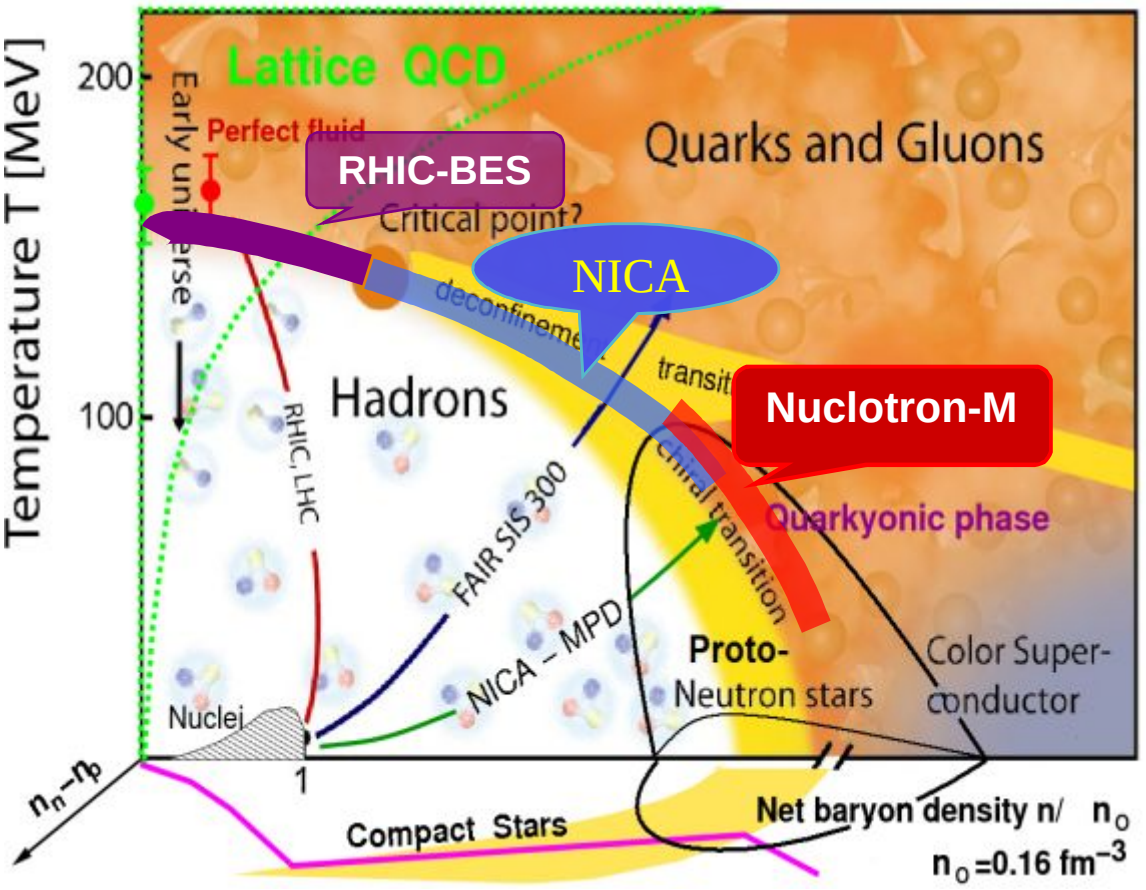


NICA Physics tasks *and challenges*



- **Exploration of the QCD phase diagram**
  - *in-medium properties of hadrons & nuclear matter equation of state*
  - *onset of deconfinement & chiral symmetry restoration*
  - *phase transitions, mixed phase & critical phenomena*
  - *local parity violation (P-odd effects)*
- **Spin physics**
  - *origin of spin*
  - *nucleon spin structure*

QCD phase diagram: prospects for NICA



Energy Range of NICA

The most intriguing and unexplored region of the QCD phase diagram:

- **Highest net baryon density**
- **Onset of deconfinement phase transition**
- **Discovery potential:**
  a) Critical End Point (CEP)
  b) Chiral Symmetry Restoration
  c) Hypothetic Quarkyonic phase
- **Complementary to the RHIC/BES, NA61/CERN, CBM\FAIR and Nuclotron-M experimental programs**

Comprehensive experimental program requires scan over the QCD phase diagram by varying collision parameters: system size, beam energy and collision centrality

MPD: tasks and challenges

- ***bulk observables (hadrons): 4p particle yields (OD, EOS)***
- ***event-by-event fluctuation in hadron productions (CEP)***
- ***femtoscopic correlations involving π, K, p, Λ (OD)***
- ***flows (directed, elliptic,…) for identified hadron species (EOS,OD)***
- ***multistrange hyperon production: yields & spectra (OD, EOS)***
- ***electromagnetic probes (CSR, OD)***
- ***hypernuclei (DM)***
- ***local parity violation (P-odd effects)***

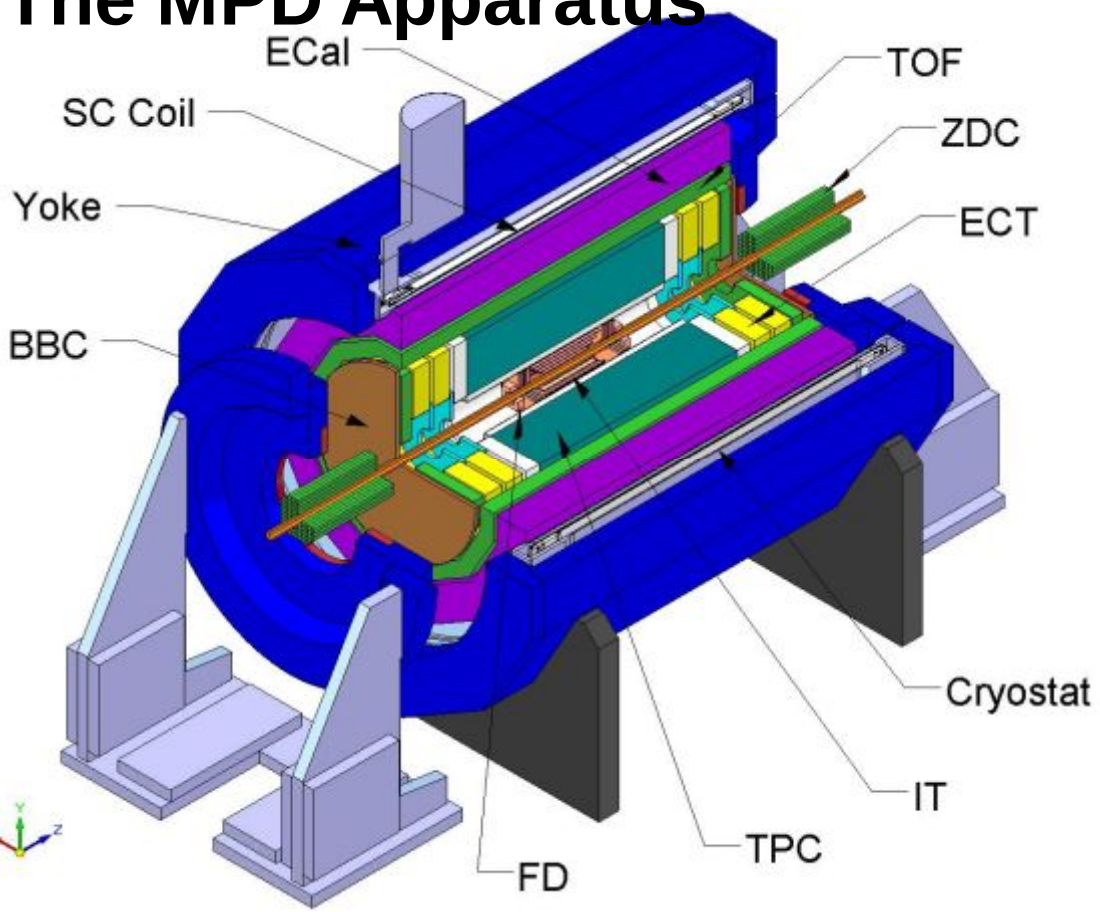
OD – Onset of Deconfinement
CEP – Critical End Point
DM – Dense Matter

CSR – Chiral Symmetry Restoration
EOS – Equation Of State

Challenges:

- **Vast nomenclature of colliding systems – from p+p to Au+Au**
- **Simultaneous observation of a variety of phenomena**
- **Small effects over large kinematical range, sensitivity to acceptance constrains (‘correlations & fluctuations’ studies)**
- **Pattern recognition in high track multiplicity environment**

The MPD Apparatus

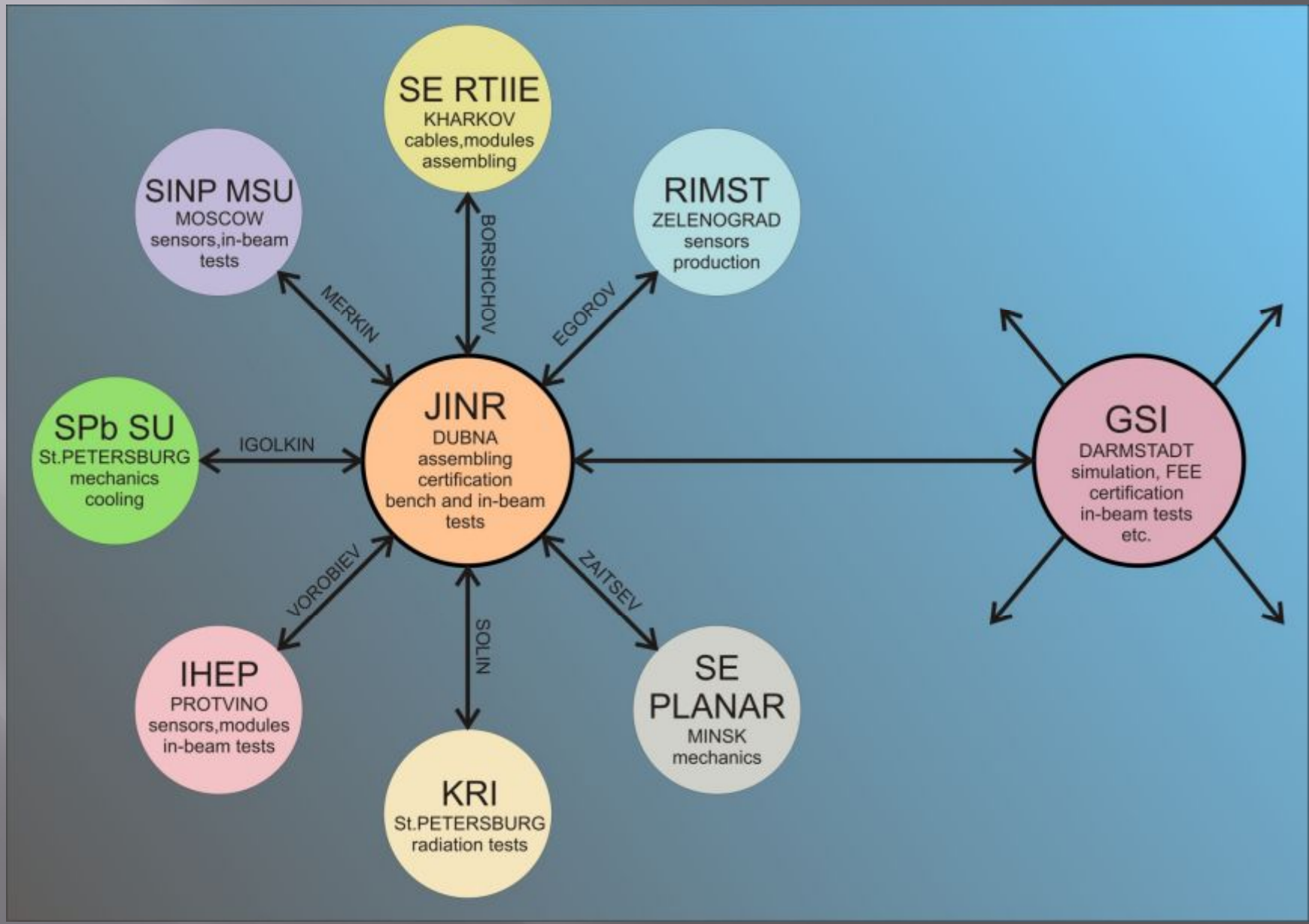


- **Active volume**
  5 m (length) x 4 m (diameter)
- **Magnet**
  0.5 T superconductor
- **Tracking**
  TPC & straw EndCapTracker & silicon pixels (IT) for vertexing
- **ParticleID**
  hadrons(TPC+TOF), π^0,γ (ECAL), e^+e^-(TPC+TOF+ECAL)
- **Centrality & T0 timing**
  ZDC FD

MPD Advantages:

- **Hermeticity, homogenous acceptance (2π in azimuth), low material budget**
- **Excellent tracking performance and powerful PID**
- **High event rate capability and careful event characterization**

The CBM-MPD Consortium Structure



Beam	Nuclotron beam intensity (particle per cycle)		
	Current	Ion source type	New ion source + booster
p	$3 \cdot 10^{10}$	Duoplasmotron	$5 \cdot 10^{12}$
d	$3 \cdot 10^{10}$	--- ,, ---	$5 \cdot 10^{12}$
^{4}He	$8 \cdot 10^{8}$	--- ,, ---	$1 \cdot 10^{12}$
d↑	$2 \cdot 10^{8}$	SPI	$1 \cdot 10^{10}$
^{7}Li	$8 \cdot 10^{8}$	Laser	$5 \cdot 10^{11}$
^{11,10}B	$1 \cdot 10^{9,8}$	--- ,, ---	
^{12}C	$1 \cdot 10^{9}$	--- ,, ---	$2 \cdot 10^{11}$
^{24}Mg	$2 \cdot 10^{7}$	--- ,, ---	
^{14}N	$1 \cdot 10^{7}$	ESIS (“Krion-6T”)	$5 \cdot 10^{10}$
^{24}Ar	$1 \cdot 10^{9}$	--- ,, ---	$2 \cdot 10^{11}$
^{56}Fe	$2 \cdot 10^{6}$	--- ,, ---	$5 \cdot 10^{10}$
^{84}Kr	$1 \cdot 10^{4}$	--- ,, ---	$1 \cdot 10^{9}$
^{124}Xe	$1 \cdot 10^{4}$	--- ,, ---	$1 \cdot 10^{9}$
^{197}Au	-	--- ,, ---	$1 \cdot 10^{9}$

Energy of beams extracted from Nuclotron

covers the gap between SIS-18 and AGS *(with some overlaps)*

	Z/A	***max*** $\sqrt{s_{NN}}$ *(GeV/n)*	***max.*** T_{kin} *(GeV/n)*
p	***1***	***≈ 5.2***	***≈ 12***
d	***1/2***	***≈ 3.8***	***≈ 5.7***
			(including polarized deuterons)
Au	***0.4***	***≈ 3.5***	***≈ 4.5***
			*(at **2T** in dipoles)*

It allows:

- *study of dense baryonic matter at temperatures up to **100** MeV,*
- *(multi)strangeness (open & hidden) production in dense baryonic matter,*
- *modification of particle properties in dense nuclear matter*

The corresponding multi-purpose setup

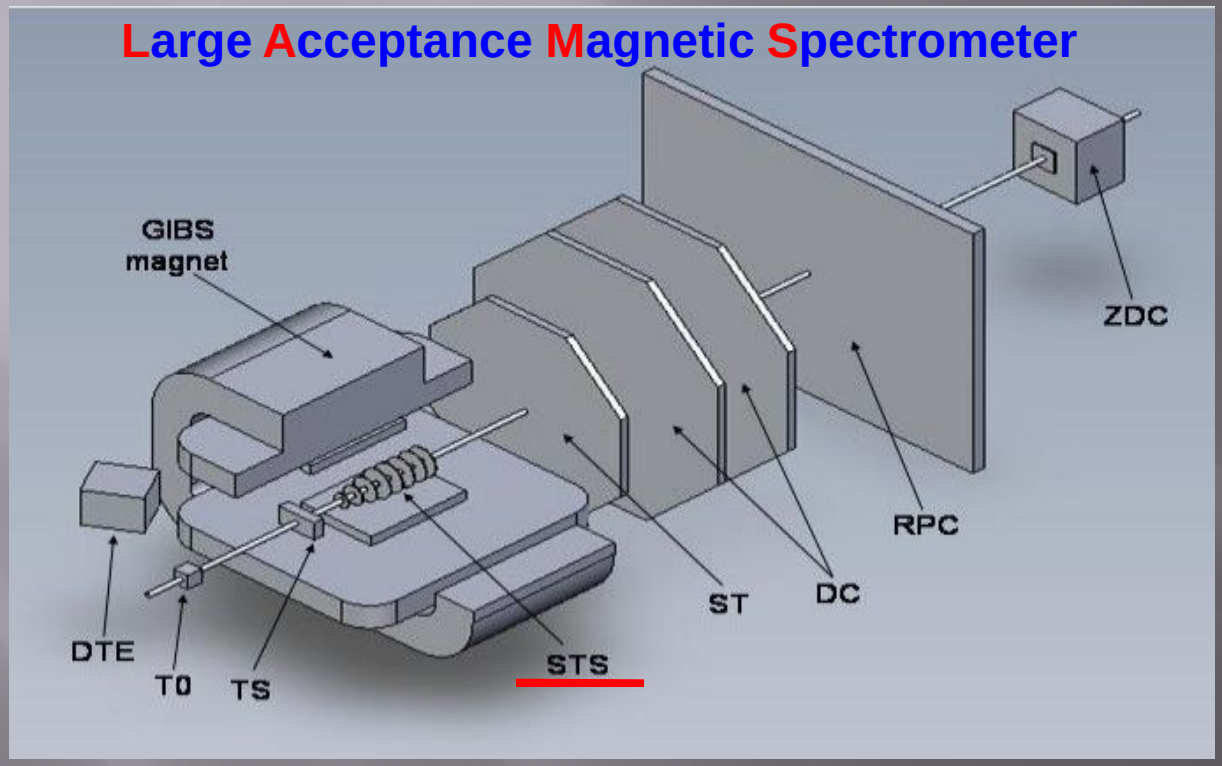
Baryonic Matter at Nuclotron (BM@N)

Strange matter production in heavy ion collisions at the Nuclotron extracted beam: Baryonic Matter at Nuclotron (BM@N)

- Collaboration **GSI-JINR** (preparation of the joint experiment has started)
- The goal of the experiment is the systematic measurements of the observables for multistrange objects (Ξ^-, Ω^-, exotics) in Au-Au collisions in the energy domain of the Nuclotron extracted beam (up to 5 A GeV)

Baryonic Matter at Nuclotron (BM@N)

- measurements of the multi-strange (Ξ, Ω, exotics) & hypernuclei in HI collisions
- close to the threshold production in the region of high sensitivity to the models prediction



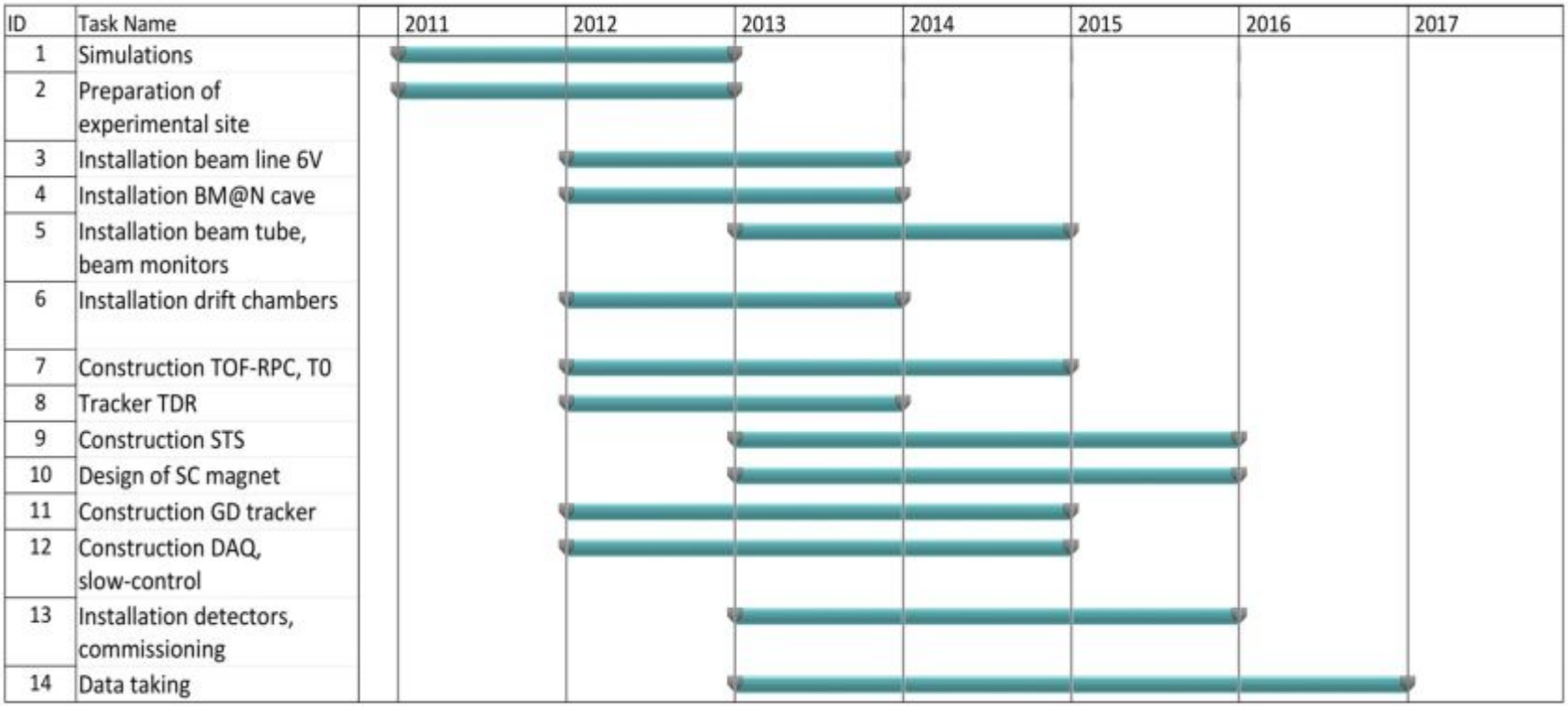
GIBS magnet (SP-41)

TS-target station,
T0- start diamond detector,
STS - silicon tracker,
ST- straw tracker,
DC- drift chambers,
RPC- resistive plate chambers,
ZDC- zero degree calorimeter,
DTE – detector of tr. energy.

▣ the detector based on the sub-detectors developed for CBM, MPD & SPD

Preparation of the joint GSI - JINR experiment Baryonic Matter at Nuclotron (**BM@N**) has started. **The planned data taking - 2015**

Time table of the BM@N experiment



Phase0 (2011) – The site preparation and simulation
Phase1 (2012-2014)–The detector construction and commissioning
Phase2 (2015-.....) - The data taking at 3.5, 4 and 4.65 A GeV

SPD EXPERIMENT AT NICA

The purpose is study of the nucleon spin structure with high intensity polarized light nuclear beams:

- **high collision proton (deuteron) energy up to $\sqrt{s}$ ~ 26(12) GeV**
- **the average luminosity up to 10^{30}-10^{31} cm^2/s**
- **both proton and deuteron beams can be effectively polarized.**

The main topics are:

1. Studies of MMT-DY processes with longitudinaly and transversely polarized p and D beams. Extraction of unknown (poorly known) parton distribution functions (PDFs).
2. PDFs from J/Ψ production processes.
3.Spin effects in baryon, meson and photon productions.
4. Studies of spin effects in various exclusive reactions.
5. Diffractive processes studies.
6. Cross sections, helicity amplidudes and double spin asymmetries (Krisch effect). in elastic reactions.
7. Spectroscopy of quarkoniums.

<u>NICA Spin program plans:</u>

2012-2014 – CDR and TRD preparation, SPD collaboration, R&D

2015-2018 – R&D, Detectors production

First version of SPD CDR (June 2010) at http://nica.jinr.ru/files/Spin_program/spd_cdr.htm

Editorial board:
D. Blaschke
D. Kharzeev
V. Matveev
A. Sorin
H. Stoecker
O. Teryaev
I. Tserruya
N. Xu

NICA

Draft v 6.02
January 20, 2012

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

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

NICA White Paper

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

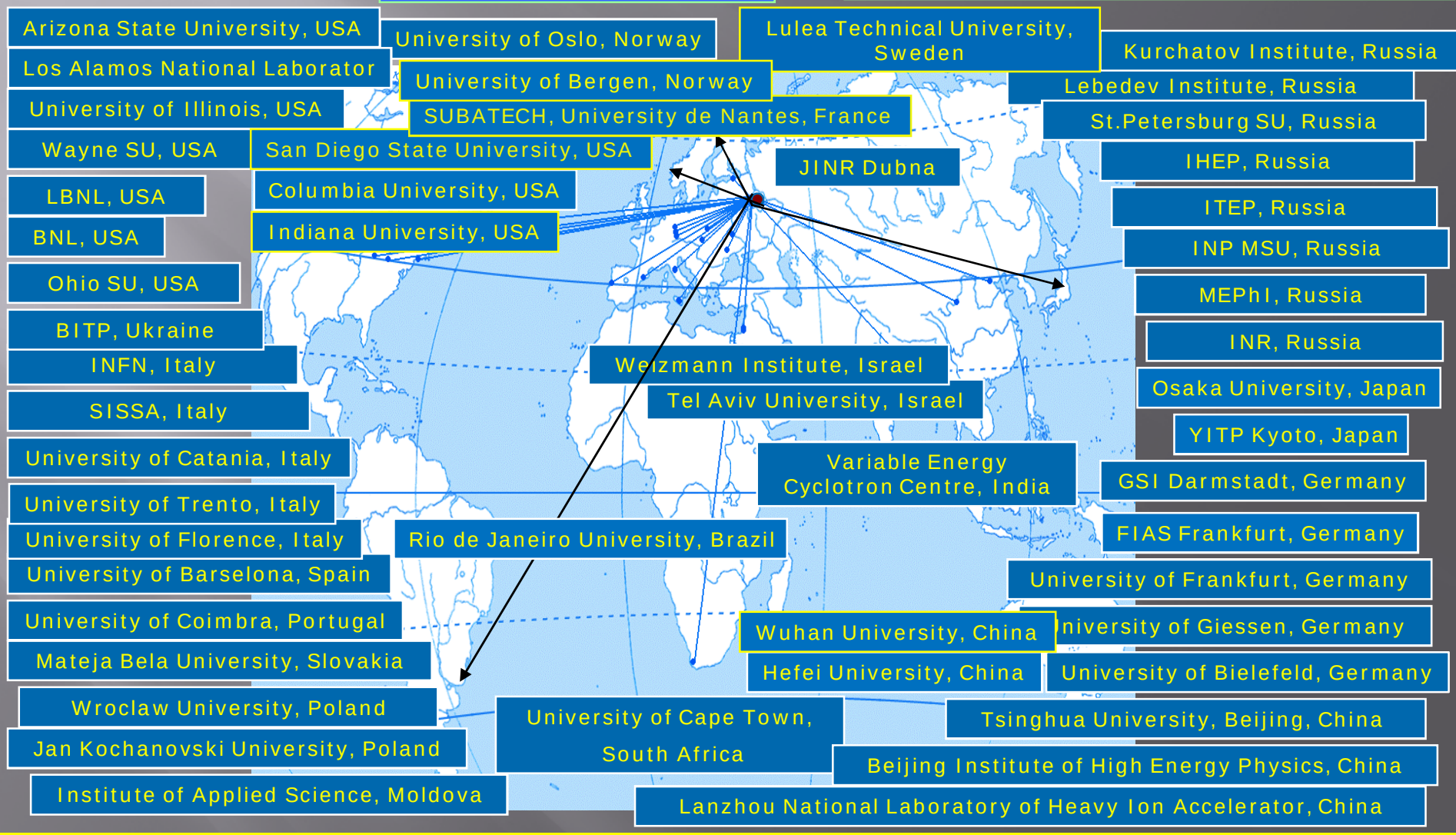
The final goal of the NICA White Paper is to address the following key topics:

- 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

Contents

The NICA White Paper

140 authors *from* **59 scientific centers** *in* **21 Countries (8 JINR members)**



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

List of authors (140)

Kh.Abraamyan, J.Aichelin, A.Andrianov, V.Andrianov, A.Andronic, M.Asakawa, V.Avdeichikov, F.Becattini, R.Bellwied, D.Blaschke, M.Bleicher, H.Blume, E.Bratkovskaya, L.Bravina, P.Braun-Munzinger, A.Bzdak, K.Bugaev, P.Buividovich, X.Cai, W.Cassing, Y.Cheng, L.Csernai, M.Chernodub, J.Cleymans, M.Colonna, P.Costa, O.Denisovskaya, D.E.Donets, E.D.Donets, E.E.Donets, M. DiToro, I.Dremin, A.Efremov, D.Espriu, S.Fantoni, V.Friese, A.Friesen, K.Fukushima, S.Gandolfi, M.Gazdzicki, M.Gorenstein, V.Greco, K.Gudima, C.Hartnack, P.Huovinen, A.Illarionov, Yu.Ivanov, A.Jerusalimov A.Kaidalov, Yu.Kalinovsky, F. Karsch, D.Kharzeev, T. Klähn, T.Kodama, V.Koch, E.Kolomeitsev, E.Kokoulina,V.Korotkikh, A.Kovalenko, A.Kurepin, A.Kutov,V.Ladygin, N.Ladygina, R.Lednicky, A.Leonidov, E.Levin, J.Liao, M.Lisa, B.Liu, Y. Liu , I. Lokhtin, X.Luo, G.Lykasov, V.L.Lyuboshitz, V.V.Lyuboshitz, E.Luschevskaya, L.Malinina, C.Markert, L.McLerran, K.Mikhailov, B.Mohanty, S.Mrowczynski, A.Nagaytsev, V.Nikitin,V.Okorokov, F.Pederiva, S. Petrushanko, S.Plumari, M.Polikarpov, P.Polozov, M.Prokudin, J.Randrup, P.Rau, K.Redlich, H.G.Ritter, O.Rogachevsky, I.Rufanov, V.Salnikov, F.Sandin, L.Sarycheva, H.Satz, I.Savin, P.Senger, G. Shao, G.Sharkov, O.Shevchenko, V.Shutov, K.Schmidt, Yu.Sinyukov, A.Sissakian, V.Skokov, A.Snigirev, A.Sorin, A.Stavinskiy, J.Steinheimer, M.Stephanov, H.Stoecker,V.Stolin, O.Teryaev, R.Tolochek, S.Tolstoukhov, B.Tomasik, V.Toneev, N.Topilskaya, G.Torrieri, S.Troshin, I.Tserruya, L. Turko, S.Typel, Yu. Usikov, S.Voloshin, D.Voskresensky, S. Weber, D.Wang, N.Xu, Yu.Zaitsev, E.Zabrodin, P.Zhuang, D.Zhou, …

NICA White Paper - Contents

75 contributions

Physical phenomena and relevant observables:

- in-medium modification of hadron properties (MMH)
- the nuclear matter equation of state (EoS)
- the onset of deconfinement (OD) and/or
- chiral symmetry restoration (CSR)
- signals of a phase transition (PT)
- the mixed phase and the critical end-point (CEP)
- possible local parity violation in strong interactions (LPV)

The correlations between observables and physical phenomena:

Observables	Physical Phenomena							Detectors	Reference in the White Paper
	MMH	EoS	OD	CSR	PT	CEP	LPV		
yields of hadrons, normal and exotic light nuclei	x	x	x					tracking, TOF	3.6, 3.9, 4.3, 3.11, 4.12, 6.7
yields and spectra of multistrange hyperons	x	x	x					precision tracking (seconday vertices)	2.6, 5.3, 6.4, 12.3, 12.5, 12.6
electromagnetic probes			x	x				tracking, electron identifiers (e.g. RICH)	7.1, 7.2, 7.3, 7.7
azimuthal charged particle correlations					x		x	tracking	8.1 - 8.7, 10.4
event-by-event (EBE) fluctuations						x		tracking, TOF	2.1, 2.6, 3.10, 5.4
Radial, elliptic and triangular flow of hadrons		x	x		x			tracking, TOF	4.4, 4.8, 4.14, 5.8
higher moments of hadron distributions			x		x	x		tracking, TOF	3.10, 4.1, 4.5, 4.6, 4.10, 4.12-4.15
interferometric parameters		x			x			tracking	3.5, 5.1, 5.2, 5.5

Round Table Discussions on NICA/MPD@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 (White Paper)* JINR (Dubna), August 28, 2010
http://theor.jinr.ru/~cpod/Dubna_2010_program2.htm

NICA/JINR-FAIR Bilateral Workshop

Matter at Highest Baryon Densities in the Laboratory and in Space

Frankfurt Institute for Advanced Studies, April 2 - 4, 2012

http://theor.jinr.ru/~nica_fair/

Topics:

- Phases of QCD at high baryon densities
- Effects signalling phase transitions
- Observables in heavy-ion collisions and in astrophysics
- Simulations of ion collisions and supernovae

Aims:

- identify discovery potential of Nuclotron-NICA and FAIR in the canon of current and future HIC experiments
- chiral symmetry restoration
- onset of deconfinement
- in-medium modification of hadron properties
- color superconductivity, multiquark states, etc.

Results:

- Most promising and feasible suggestions for experiments at Nuclotron-NICA and CBM/FAIR
- Priorities for detectors and formation of international collaborations

*** German-Russian Year of Science 2011/2012**

Conclusion

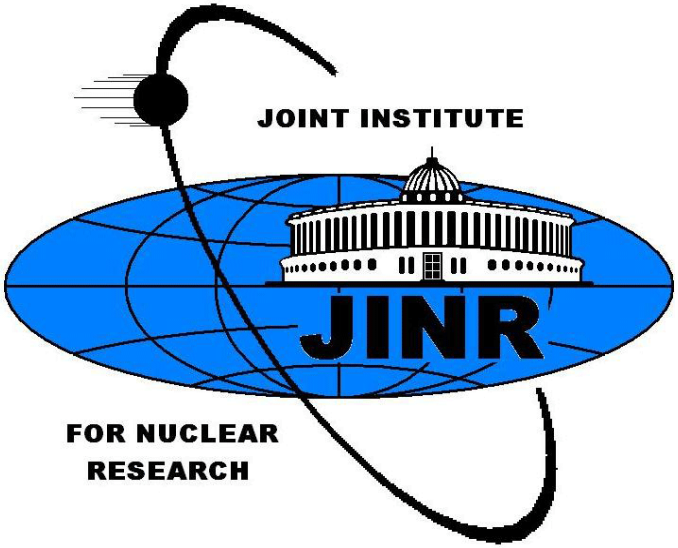
The combination of **NICA collider and Nuclotron-NICA fixed target** energy ranges is perfectly suited for the investigation of:

Observables	Physical Phenomena							Detectors	Reference in the White Paper
	MMH	EoS	OD	CSR	PT	CEP	LPV		
yields of hadrons, normal and exotic light nuclei	x	x	x					tracking, TOF	3.6, 3.9, 4.3, 3.11, 4.12, 6.7
yields and spectra of multistrange hyperons	x	x	x					precision tracking (seconday vertices)	2.6, 5.3, 6.4, 12.3, 12.5, 12.6
electromagnetic probes			x	x				tracking, electron identifiers (e.g. RICH)	7.1, 7.2, 7.3, 7.7
azimuthal charged particle correlations					x		x	tracking	8.1 - 8.7, 10.4
event-by-event (EBE) fluctuations						x		tracking, TOF	2.1, 2.6, 3.10, 5.4
Radial, elliptic and triangular flow of hadrons		x	x		x			tracking, TOF	4.4, 4.8, 4.14, 5.8
higher moments of hadron distributions			x		x	x		tracking, TOF	3.10, 4.1, 4.5, 4.6, 4.10, 4.12-4.15
interferometric parameters		x			x			tracking	3.5, 5.1, 5.2, 5.5

The White Paper demonstrates the unique physics potential of the NICA/MPD Complex. Broad international resonance to the NICA White Paper is an important step towards an international collaboration for the creation of the NICA/MPD and BM@N experiments.

Physics in the NICA energy range is rich and attractive!

Welcome to the collaboration!



Thank you for attention!