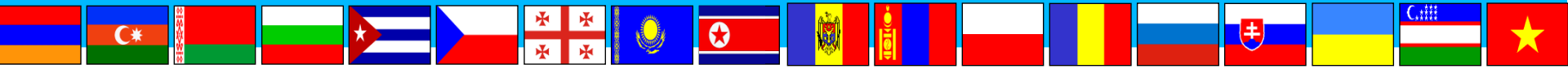
Joint Institute for Nuclear Research
International Intergovernmental Organization



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)

International Conference on New Frontiers in Physics
FAIR Workshop
Conference Center of the Orthodox Academy of Crete
Kolymbari, Greece, July 29, 2014

NICA
Volga
river

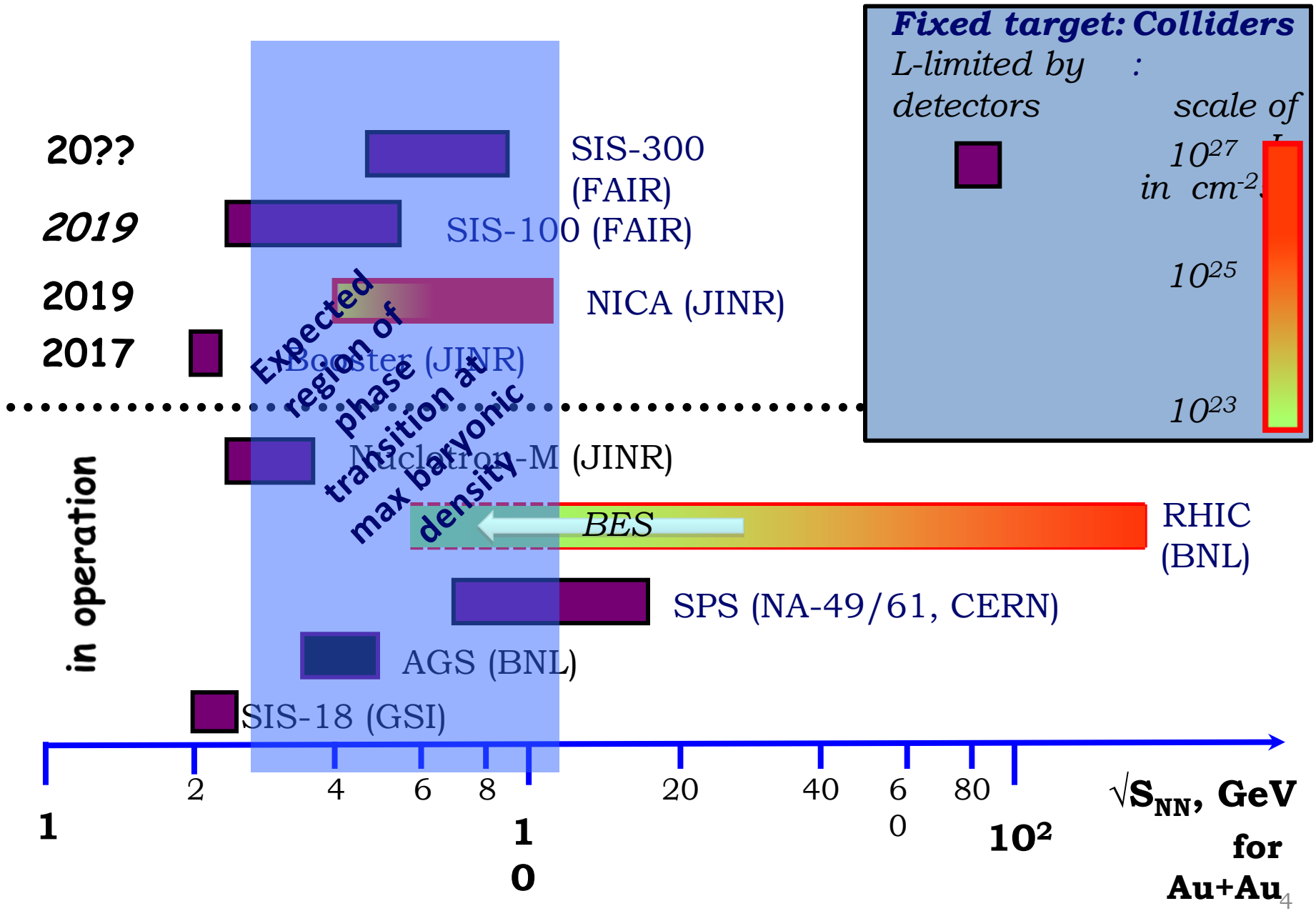
NICA (Nuclotron based Ion Colider fAcility) – the flagship project in HEP of Joint Institute for Nuclear Research (JINR)

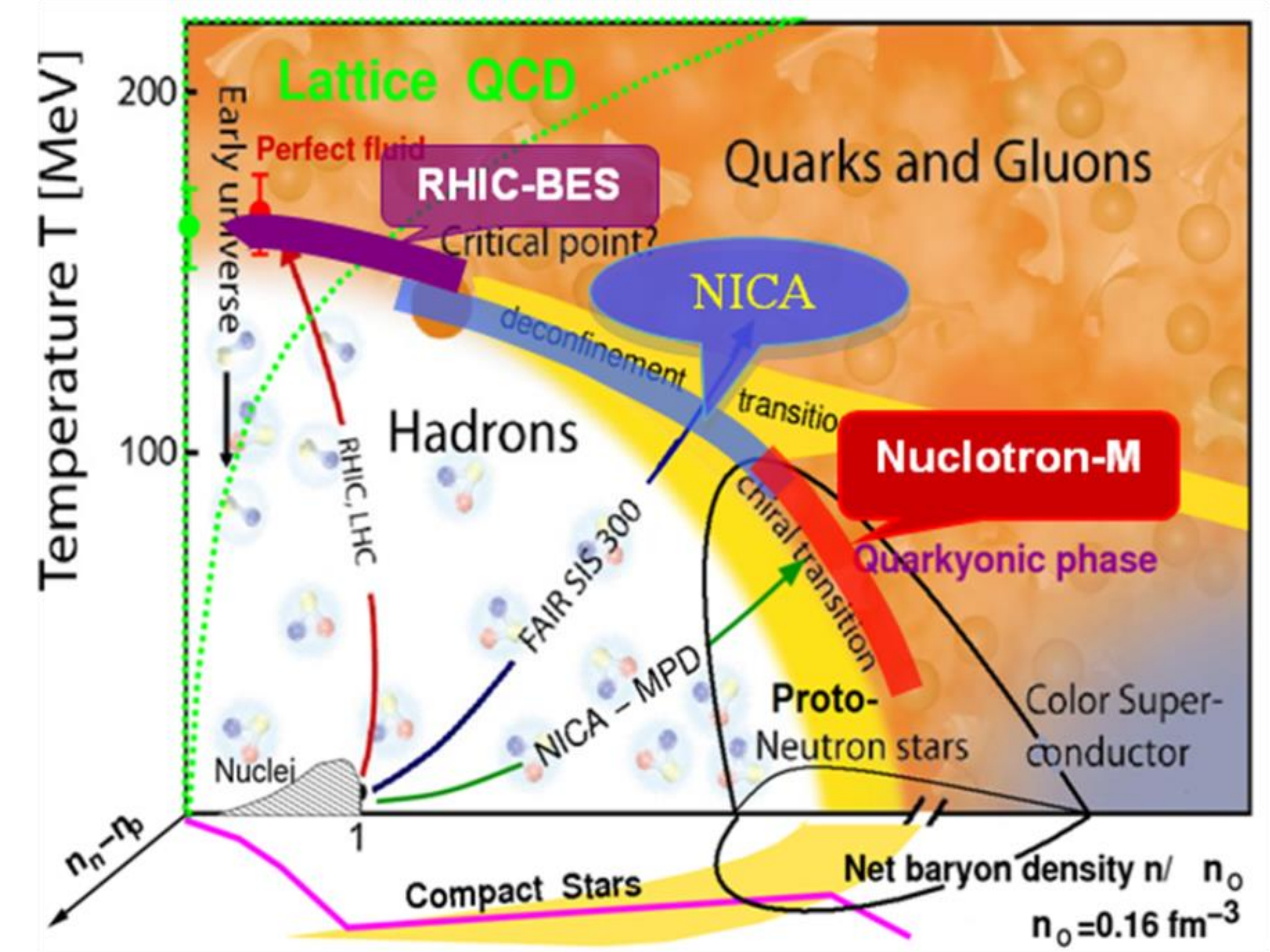
Main targets of "NICA Complex":

- ***study of hot and dense baryonic matter***
- *investigation of nucleon spin structure, polarization phenomena*

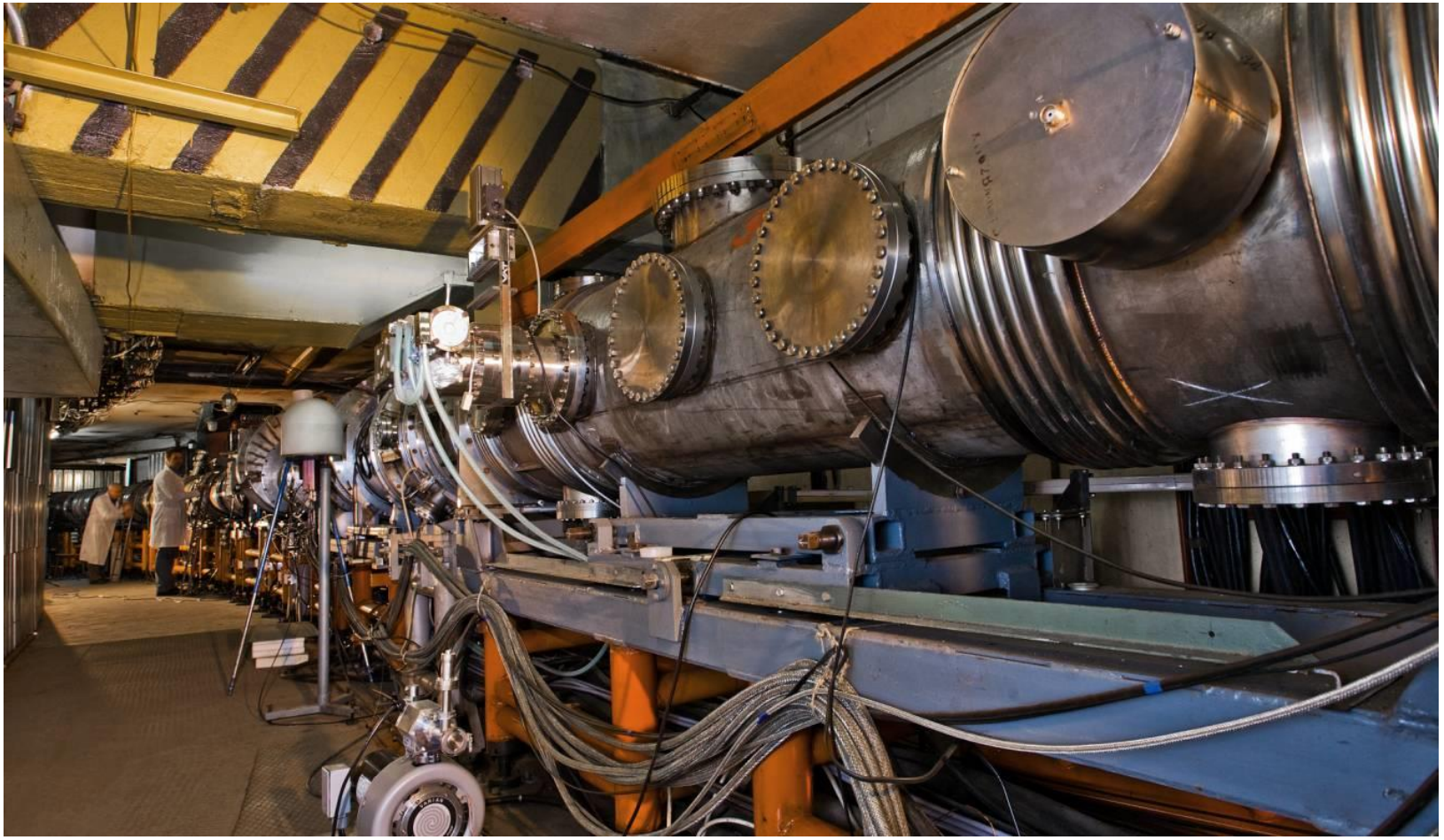
- *development of accelerator facility for HEP @ JINR providing intensive beams of relativistic ions from p to Au polarized protons and deuterons with max energy up to* $\sqrt{S_{NN}}$ = *11 GeV (Au^{79+}) and =27 GeV (p)*

Present and future HI machines




Lattice QCD
Quarks and Gluons
Perfect fluid
RHIC-BES
Critical point?
NICA
deconfinement
transitio
Hadrons
Nuclotron-M
Quarkyonic phase
chiral transition
RHIC, LHC
FAIR SIS 300
NICA – MPD
Proto-
Neutron stars
Color Super-
conductor
Nuclei
Compact Stars
Temperature T [MeV]
200
100
1
$n_n - n_p$
Net baryon density n/ n_0
n_0=0.16 fm^{-3}

Synchrotron **Nuclotron,** in operation since 1993
– *based on superconducting magnets developed in Dubna*

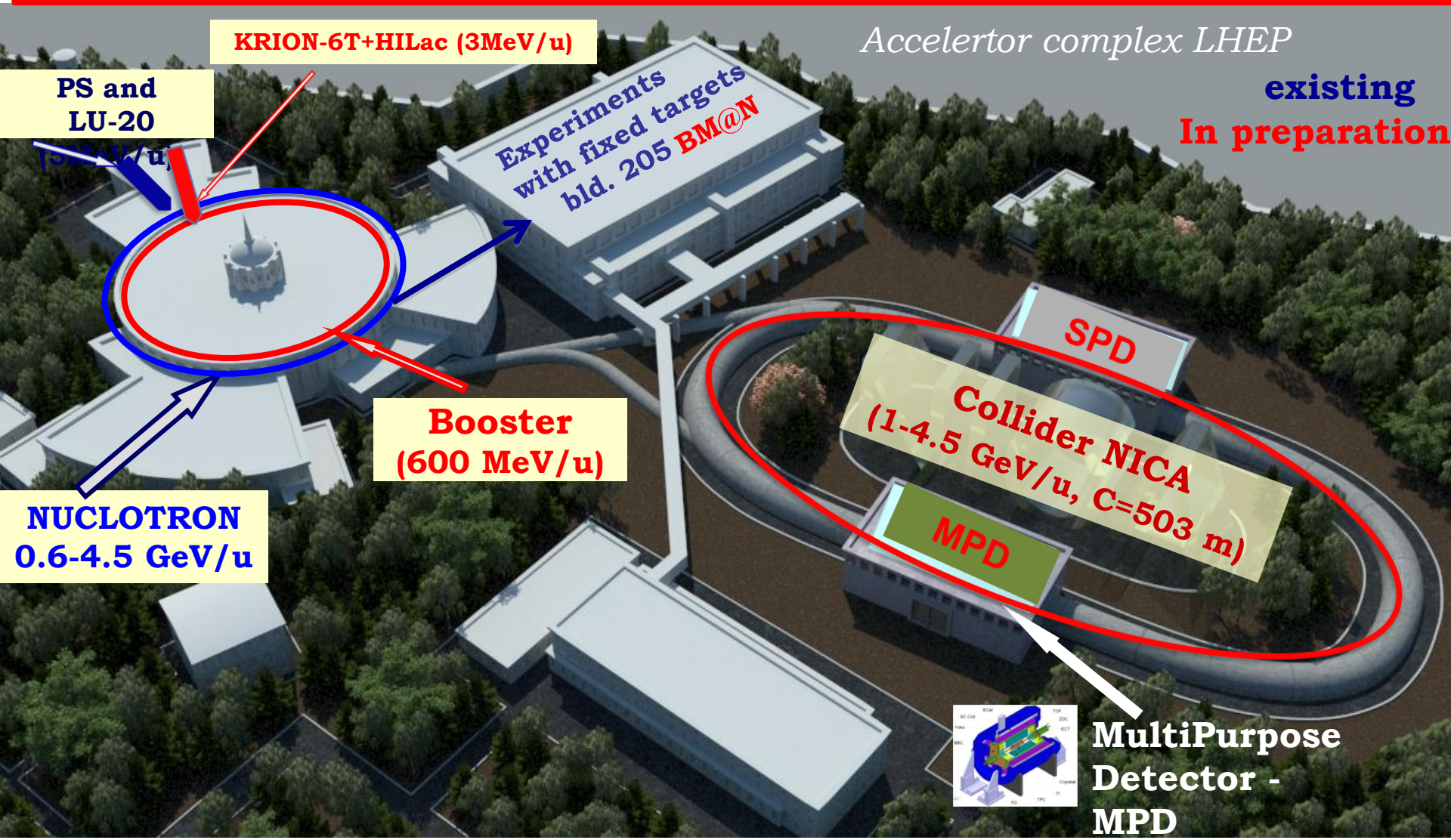


Nuclotron provides accelerated proton and ion beams (up to *Xe42+*, *A=124*) with energies up to 6 AGeV (Z/A = 1/2)

Complex NICA

Collider basic parameters:

$\sqrt{s_{NN}}$ = **4-11** GeV; ***beams***: *from* **p** to **Au**; **L~10^{27}** cm^{-2} c^{-1} (Au), ~**10^{32}** cm^{-2} c^{-1} (p)



NICA – basic milestones

- The project of **NICA complex** is approved **2010**
- The 1-st stage of **Nuclotron** modernization is completed **2010**

  10 runs have been carried out are in

  2010 – 2014

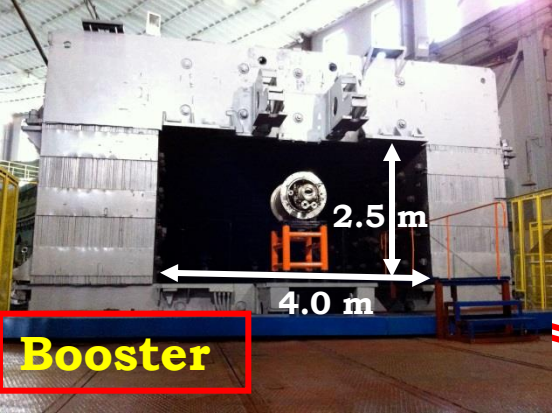
- <u>The projects</u>: <u>approval – completion</u>
  - ✓ **accelerator complex** **2010 – 2019**
  - ✓ **MPD (MultiPurpose Detector)** **2010 – 2019**
  - ✓ **experiment with fixed target BM@N (I stage)** **2012 - 2017**

- The project preparation for **Spin Physics Detector (SPD)**

  is in progress

Status of the accelerator complex

NICA – Stage I



SPI & ΛУ-20 ("Od" linac)

KRION-6T & «New» linac

Synchrophasotron yoke

Nuclotron

Fixed target experiments 2014

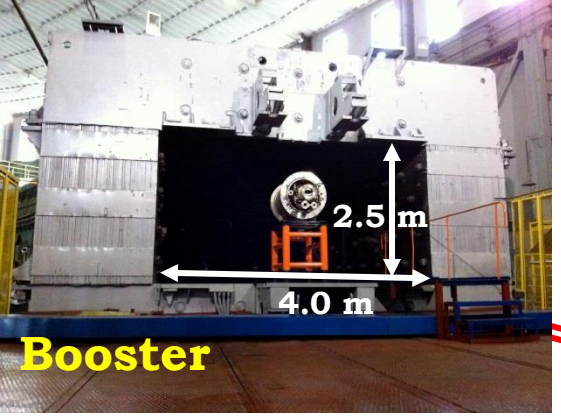
Nuclotron facility today

2017 NICA – Stage I

Nuclotron Beams

Parameter	Project (2017)		Achieved	
Magnetic field, T	2.0 (Bρ = 42.8 T·m)		2.0	
Field ramp, T/s	1.0		0.8	
Repetition period, s	5.0		8.0	
	Energy, GeV/u	Ions/ cycle	Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	6.0	$5 \cdot 10^{10}$	5.6	$1 \cdot 10^{10}$
Heavy ions	*With KRION-6T & Booster*		*Without KRION-2*	
$^{40}Ar^{18+}$	4.9	$2 \cdot 10^{10}$	3.5	$5 \cdot 10^{6}$
$^{56}Fe^{26+}$	5.4	$1 \cdot 10^{10}$	2.5	$2 \cdot 10^{6}$
$^{124}Xe^{48/42+}$	4.0	$2 \cdot 10^{9}$	1.5	$1 \cdot 10^{3}$
$^{197}Au^{79+}$	4.5	$2 \cdot 10^{9}$	---	---
Polarized beams	*With SPI & Siberian snake*		*With POLARIS*	
p↑	11.9	$1 \cdot 10^{10}$	---	---
d↑	5.6	$1 \cdot 10^{10}$	2.0	$5 \cdot 10^{8}$

NICA – Stage II



SPI & ΛУ-20 ("Od" linac)

KRION-6T & «New» linac

Synchrophasotron yoke

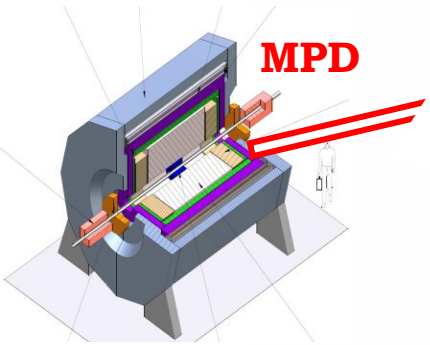
Bldg #1

Nuclotron

Fixed target experiments

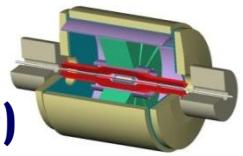
Bldg #205

BM@N 2017



2019 NICA – Stage II

Spin Physics Detector (SPD)



Stage III

NICA – Stage II
(Heavy Ion Mode)

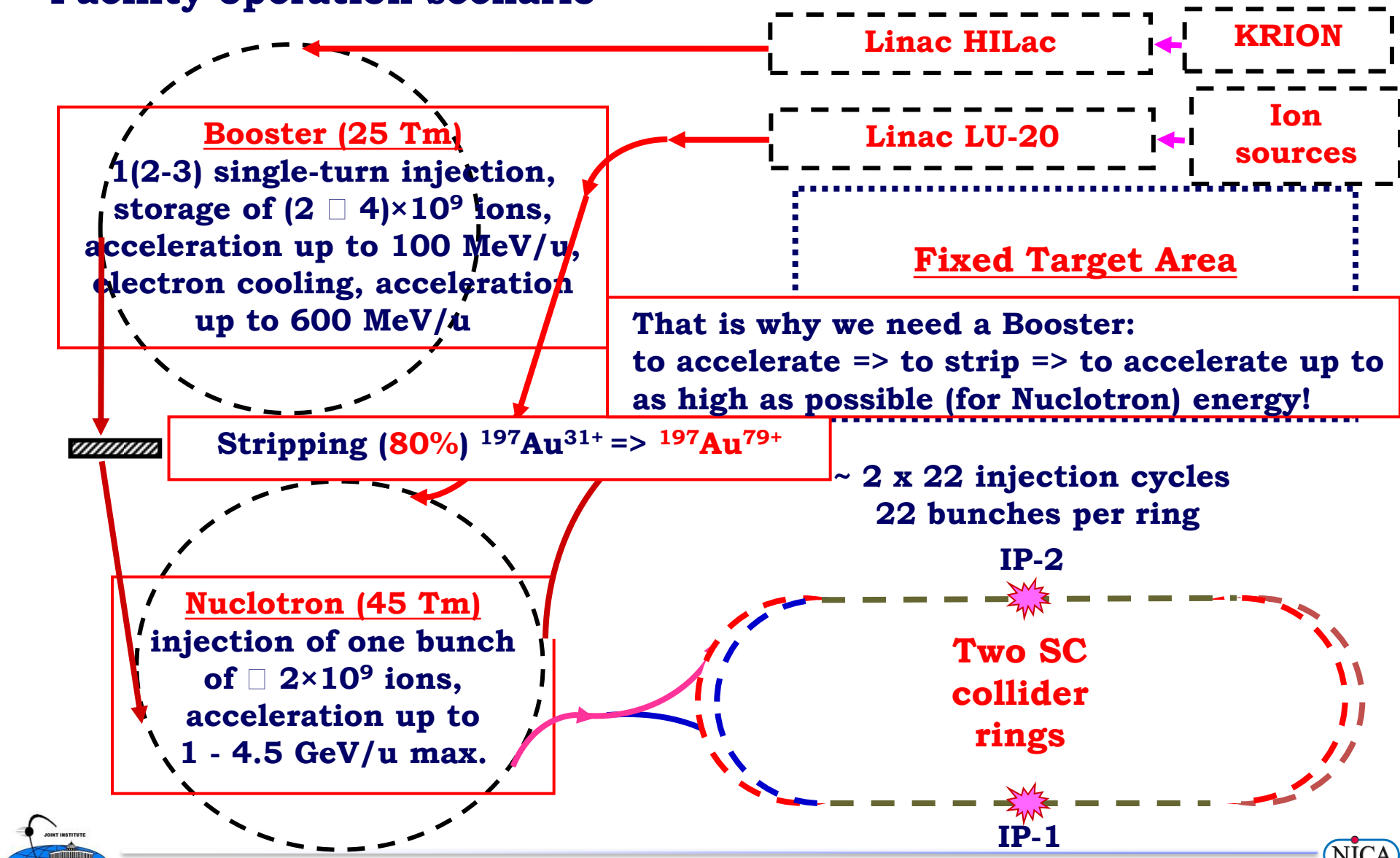
Key Parameters of The NICA Collider

Collider lattice: FODO, 12 cells x 90⁰ each arc,

Ring circumference, m	503,04		
Number of bunches	22		
R.m.s. bunch length, m	0.6		
Ring acceptance, π·mm·mrad	40.0		
Long. Acceptance, Δp/p	≤ 0.01		
$\gamma_{transition}$ ($E_{transition}$, GeV/u)	7.091 (5.72)		
β*, m	0.35		
Ion Energy, GeV/u	1.0	3.0	4.5
Ion number/bunch, 1e9	0.275	2.4	2.2
R.m.s. emittance, h/v π·mm·mrad	1.1/1.0	1.1/0.9	1.1/0.76
R.m.s. Δp/p, 1e-3	0.62	1.25	1.65
IBS growth time, s	190	700	2500
Peak luminosity, $cm^{-2}·s^{-1}$	1.1e25	1e27	1e27

NICA – Stage II: Structure and Operation Regimes (Heavy Ion Mode)

Facility operation scenario



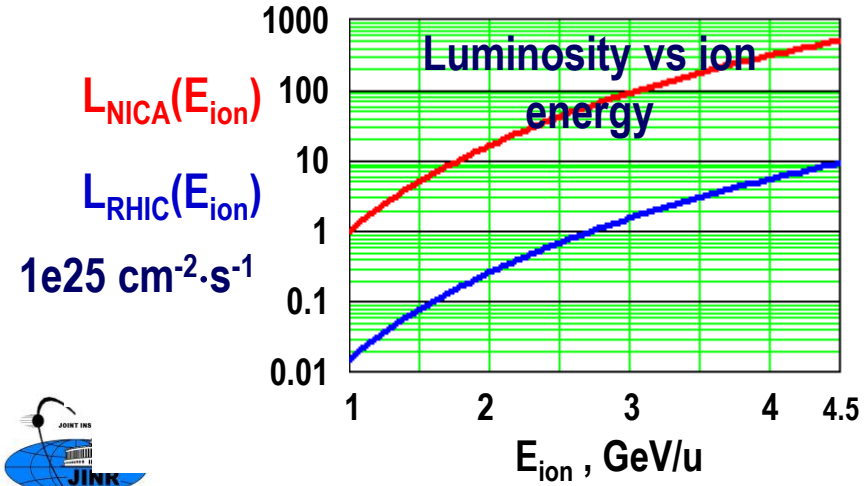
NICA – Stage II: Structure and Operation Regimes (Heavy Ion Mode)

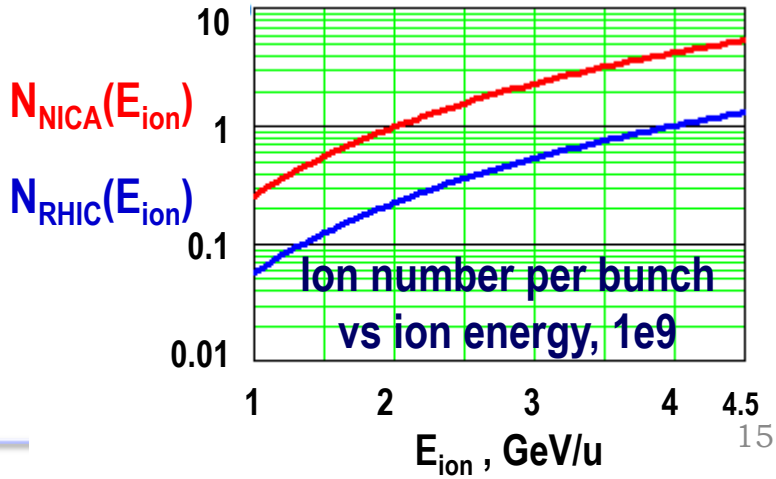
Why RHIC has low luminosity at the energy where luminosity of NICA is relatively high? The reason is the beam space charge:

$$N_{bunch} \propto 1/C_{ring}\,, \quad L \propto (N_{bunch})^2 \propto 1/(C_{ring})^2\ !$$

$$C_{RHIC}/C_{NICA} = 7.62\,, \quad L_{NICA} / L_{RHIC} = (C_{RHIC}/C_{NICA})^2 \leq 58.1$$

Parameter	RHIC	NICA
C_{Ring}, m	3834	503
Bunch length, m	1.0	0.6
Beam emittance, π·mm·mrad	1.0	1.0
Number of intersections	6	2
β^*, m	1.0	0.35
Hour-glass factor	0.8	0.6





NICA – Stage III : Collider of polarized beams

1st concept of the collider beams has been developed

It assumes acceleration of polarized protons and deuterons in Nuclotron avoiding the Booster.

Concept of polarized protons in Nuclotron has been developed, but its realization requires significant upgrade of Nuclotron.

New concept with polarized particles acceleration in the Booster and storage in the Collider rings is under preliminary consideration.

Analysis of depolarization effects in the Collider is in progress.

NICA – Stage III : Collider of polarized beams

Source of Polarized p↑ & d↑ Ions SPI

Collaboration of INR (Troitsk) & JINR

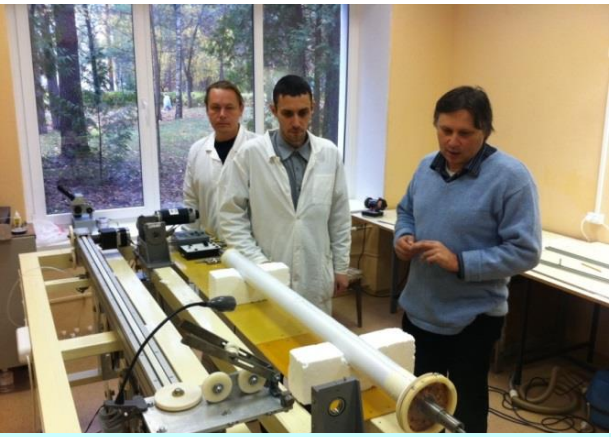
SPI at JINR, May 2013

SPI test at Nuclotron with d↑ is planned for winter 2015.

It will be beginning of new stage of experiments with polarized beams at Nuclotron.

NICA Elements Fabrication

Heavy Ion Source KRION-6T/ESIS
(Electron String Ion Source modification)



6T solenoid fabrication (2012)

KRION-6T/ESIS has been assembled and being tested (March 2014)

Test results (April 2014) : B= 5.4T magnetic field reached in a working regime.

Test of gold ion beams has been produced:

- $Au^{30+} \div Au32^{32+}$, $6 \cdot 10^8$, T_{ioniz}= 20 ms for
- Au^{32+} -> repetition rate 50 Hz.
- ion beams $Au^{51+} \div Au^{54+}$ are produced.

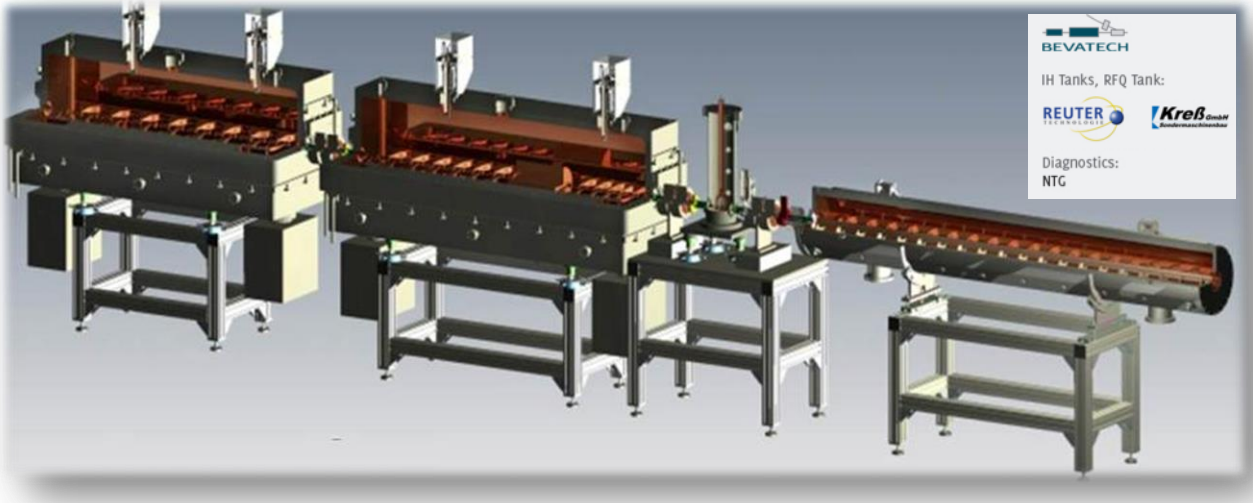
NICA Elements Fabrication

Heavy Ion Linear Accelerator (HILAC, 3 MeV/u)

-under construction at BEVATECH (Frankfurt)

- first section delivery - October 2014

- final delivery - June 2015



SC Magnets for Booster, Collider & SIS-100 (FAIR)

1st pre-production magnet prototype (Booster dipole) – September 2014

1st production magnet sample ("serial" Booster dipole) –
– December 2014

Magnet assembly workshop at LHEP JINR

~ 450 SC magnets will be assembled & tested in the workshop for ***NICA*** *&* *SIS-100* ***FAIR***

Starts production in 2014

the cable machine

area for SC coil fabrication

NICA Elements Fabrication

SC Magnets for Booster, Collider & SIS-100 (FAIR)

The Booster Magnets

Booster dipole and quadrupole lens

UH vacuum beam chamber (curved)

HTSC current leads 17 kA

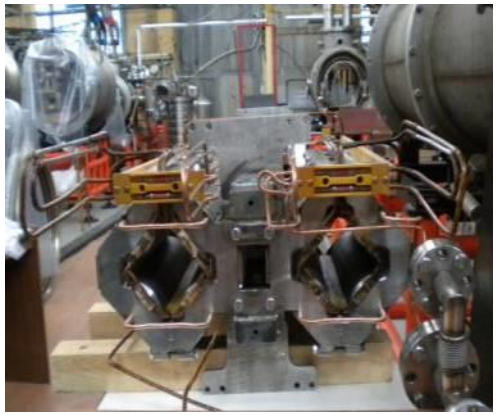
The Collider "twin" dipole

Full-scale Nuclotron–type superconducting prototypes of dipole and quadrupole magnets for the NICA Booster and Collider were manufactured at LHEP JINR, have successfully passed the cryogenic test on the bench. Serial production of the magnets for the Booster will be started in December 2014.

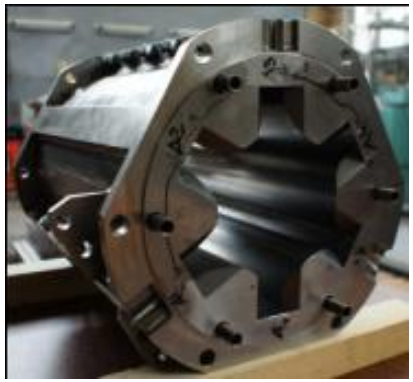
SC Magnets for Booster, Collider & SIS-100 (FAIR)

The SIS 100 & NICA Magnets

Dipole & quadrupole prototypes for SIS100 (FAIR)



The Collider quadrupole lens



Sextupole corrector prototype for SIS100 and NICA Booster and its assembly

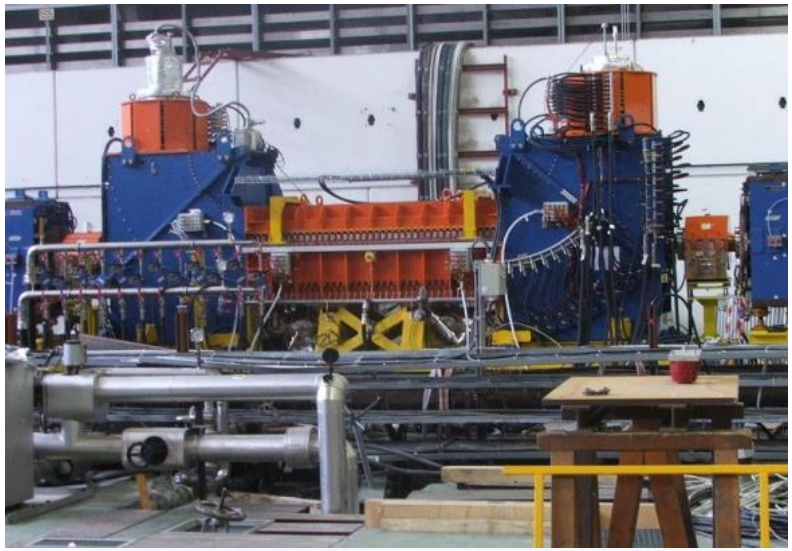
Budker INP (Novosibirsk) - design and fabrication

RF acceleration systems for Booster

BINP, RF for Booster (June 2013)
Will be delivered to JINR in 2014

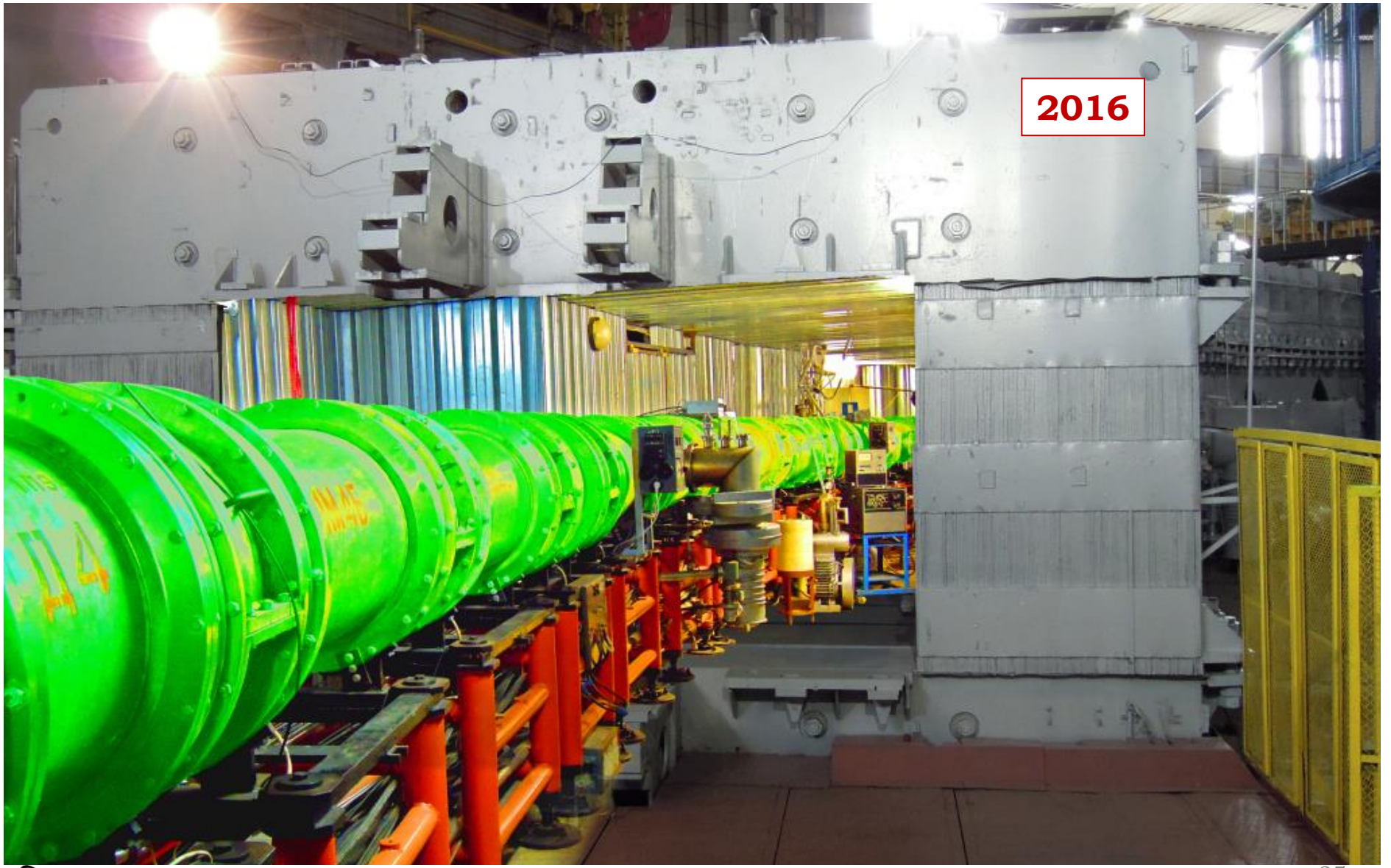
Electron cooler for Booster

(stage of working design)

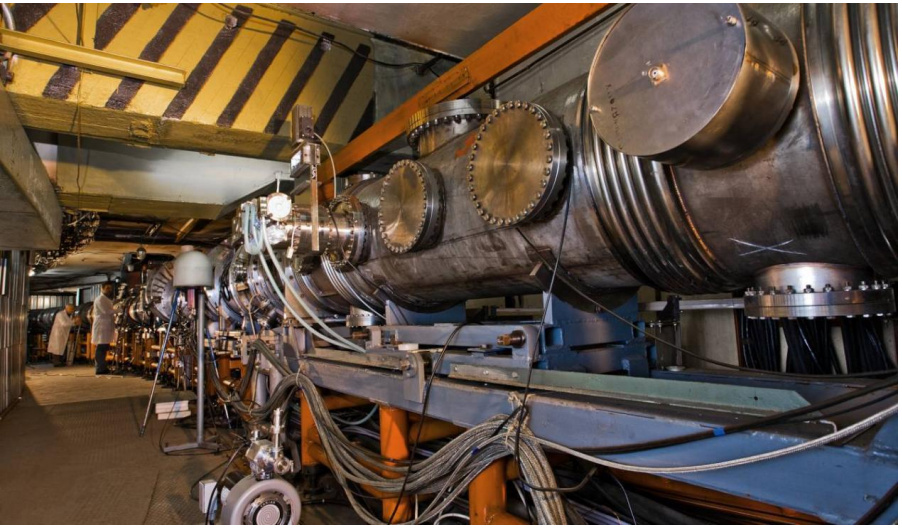


Electron cooler for Booster (prototype)

Booster Synchrotron Construction



Nuclotron Upgrade



Nuclotron is SC synchrotron accelerating ions and delivering presently ion beams:

deuterons E_{max} = 4.8 GeV/u (B = 1.7 T)

$^{124}Xe^{42+}$ E_{max} = 3.0 GeV/u (B = 1.7 T).

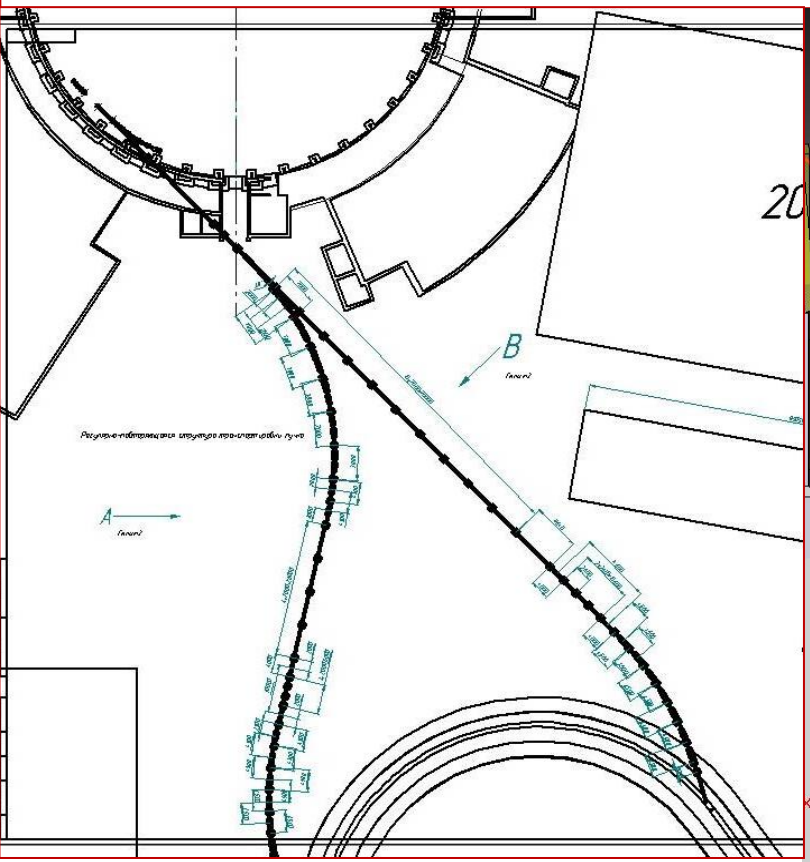
The Nuclotron upgrade tasks for collider mode:

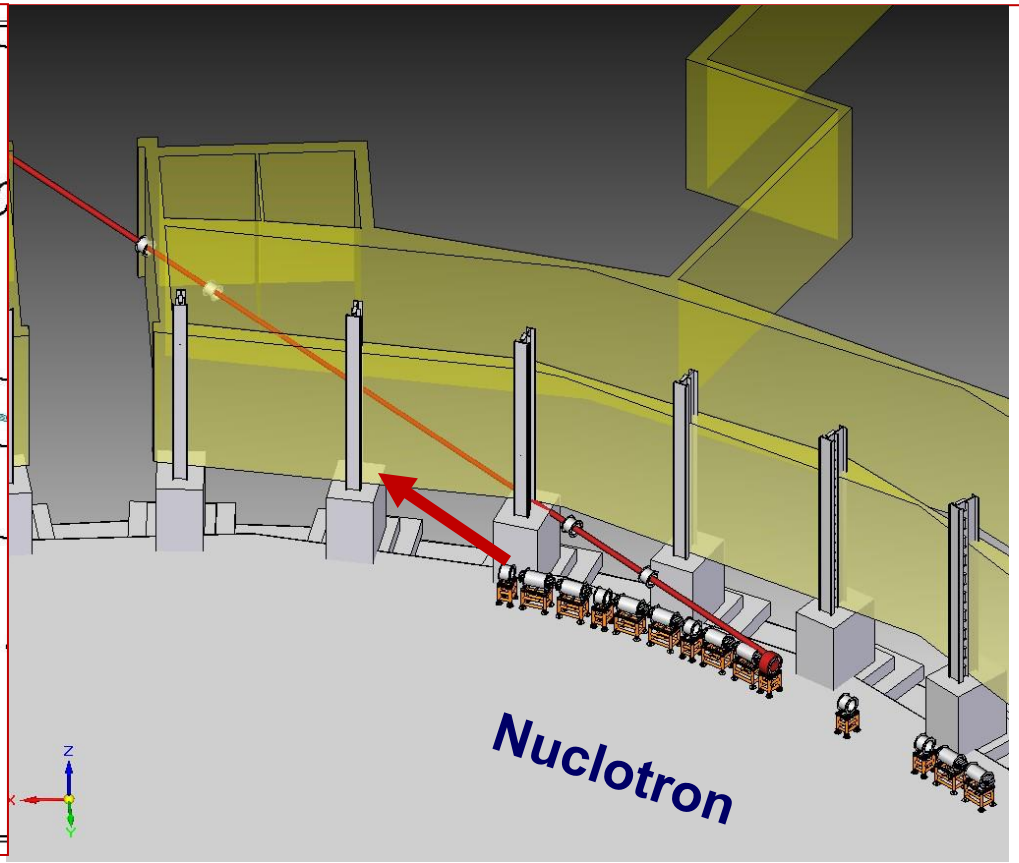
- Acceleration of $^{197}Au^{79+}$ up to 4.5 GeV/u
- Injection system for 197Au79+ at 600 MeV/u
- Upgrade of RF system
- Extraction system for 197Au79+ at 1 ÷ 4.5 GeV/u
- Upgrade of control system (synchronization)

The work is in steady progress

NICA Elements Fabrication

JINR + BINP Beam transfer channel Nuclotron - Collider
(stage of working design)





Channel lattice:

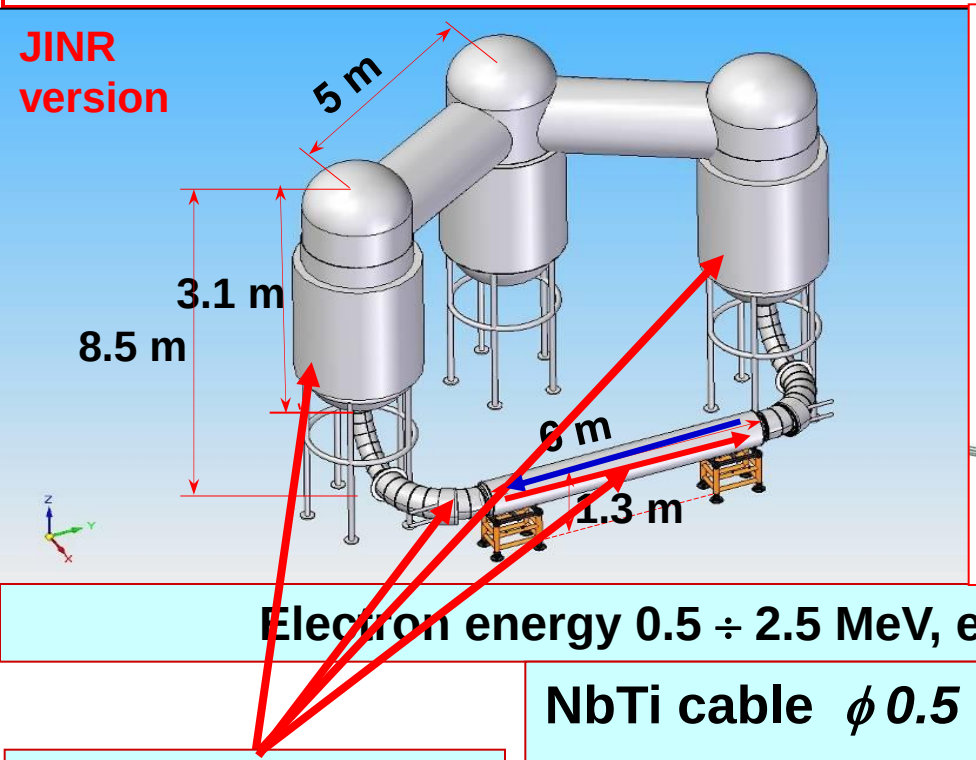
pulsed magnets, 35 dipoles, 56 quadrupoles, $P_{average}$ ~ 200 kW

NICA Elements Fabrication

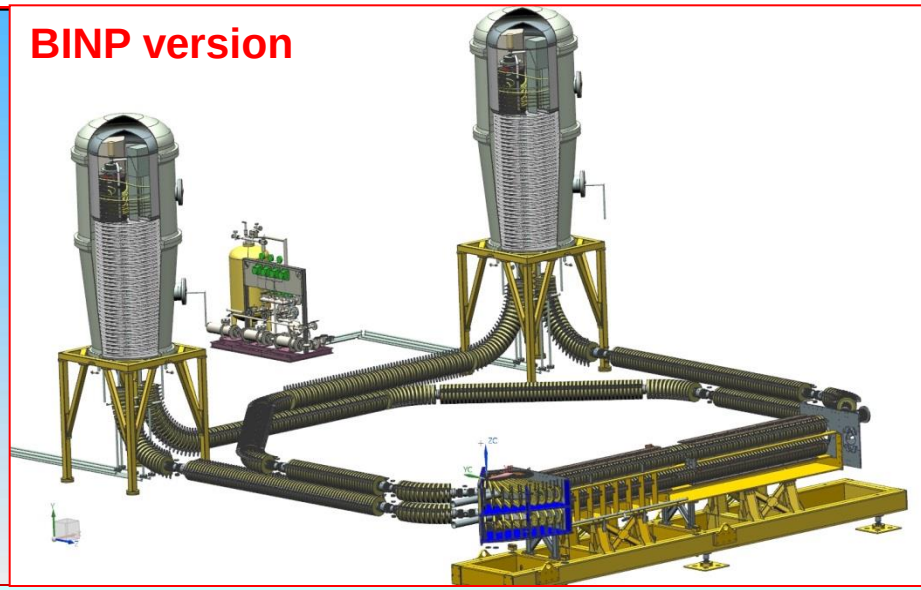
JINR + BINP + AREI + Fermilab + NEC + Geliymash (Moscow)

Electron Cooler for NICA Collider – Two Versions

JINR version



BINP version



Electron energy 0.5 ÷ 2.5 MeV, electron beam current 0.1 ÷ 1 A

SC solenoids

(JINR version)

NbTi cable ϕ *0.5* **мм** **L = 275 km** **$ 250,000**

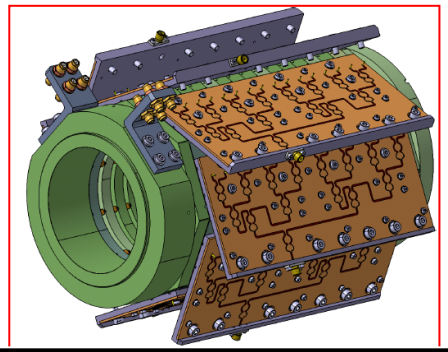
HTSC band 12 x 0.5 мм^2 **L = 11.5 km** **$ 350,000**

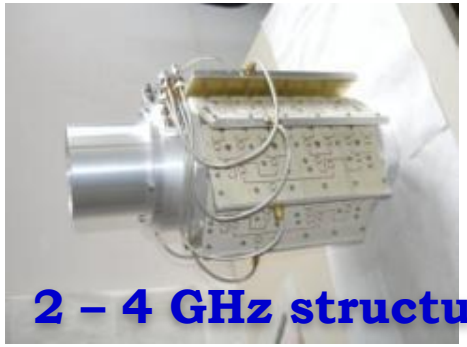
Maximum electron energy, MeV	2.5
Electron beam current, A	0.1 – 1.0
Solenoids' magnetic field, T	0.2

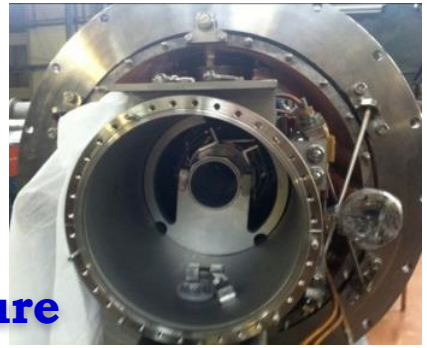
NICA Elements Fabrication

JINR + FZ Jülich Stochastic Cooling for NICA Collider

Pick-Up/Kicker Station (FZJ)



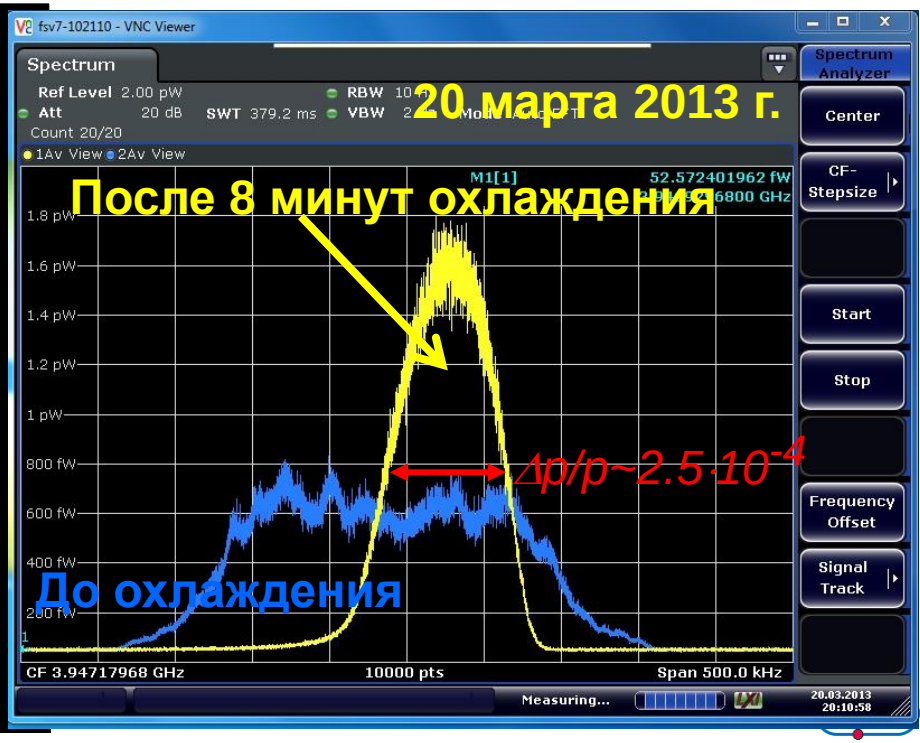




Stochastic Cooling
Test experiment at Nuclotron

<u>March 2013</u> Schottky-signal spectrum
Before (blue) and after (yellow) cooling
Deuterons, 3 GeV/u, h = 3500, N_{ion} = 2e9

<u>December 2013</u> Carbon ions $^{12}C^{6+}$
3 GeV/u, N_{ion} = 5e8
Coasting beam τ_{cool} = 27 sec (h = 2500)
Bunched beam τ_{cool} = 50 sec (h =2000)



Summary: The NICA Beams

Heavy ion colliding beams up to $^{197}Au^{79+}$ + $^{197}Au^{79+}$

at $\sqrt{s_{NN}}$ = 4 ÷ 11 GeV , $L_{average}$= 1x10^{27} cm^{-2}·s^{-1}

Light-Heavy ion colliding beams of the same $\sqrt{s_{NN}}$ and the same or higher $L_{average}$

Polarized beams of protons and deuterons in collider mode:

$p\uparrow p\uparrow$ $\sqrt{s_{pp}}$ = 12 ÷ 26 GeV L_{max} ≈ 1x10^{32} cm^{-2}·s^{-1}

$d\uparrow d\uparrow$ $\sqrt{s_{NN}}$ = 4 ÷ 13.8 GeV

Extracted beams of light ions and polarized protons and deuterons for fixed target experiments:

Li ÷ Au = 1 ÷ 4.5 GeV /u ion kinetic energy

$p\uparrow$, $p\uparrow$ = 5 ÷ 12.6 GeV kinetic energy

$d\uparrow$, $d\uparrow$ = 2 ÷ 5.9 GeV/u ion kinetic energy

The set of NICA beams provides unique possibility both for basic and applied researches in the forthcoming decades

Experiments at NICA:

MultiPurpose Detector (MPD)

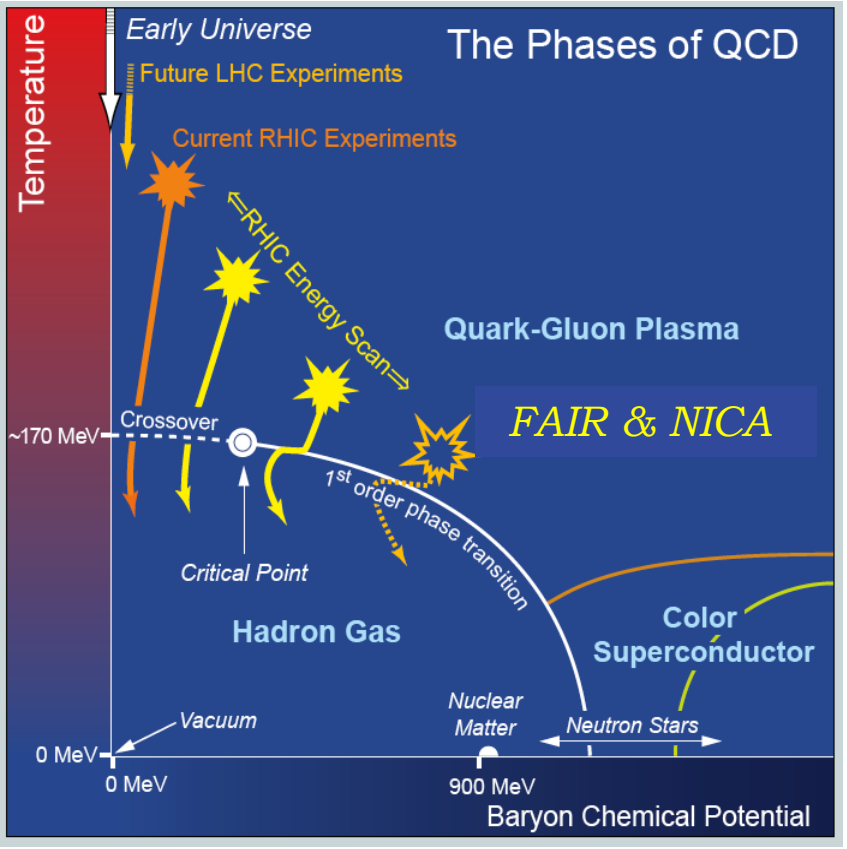
at the Collider

and

Baryonic Matter at Nuclotron (BM@N)

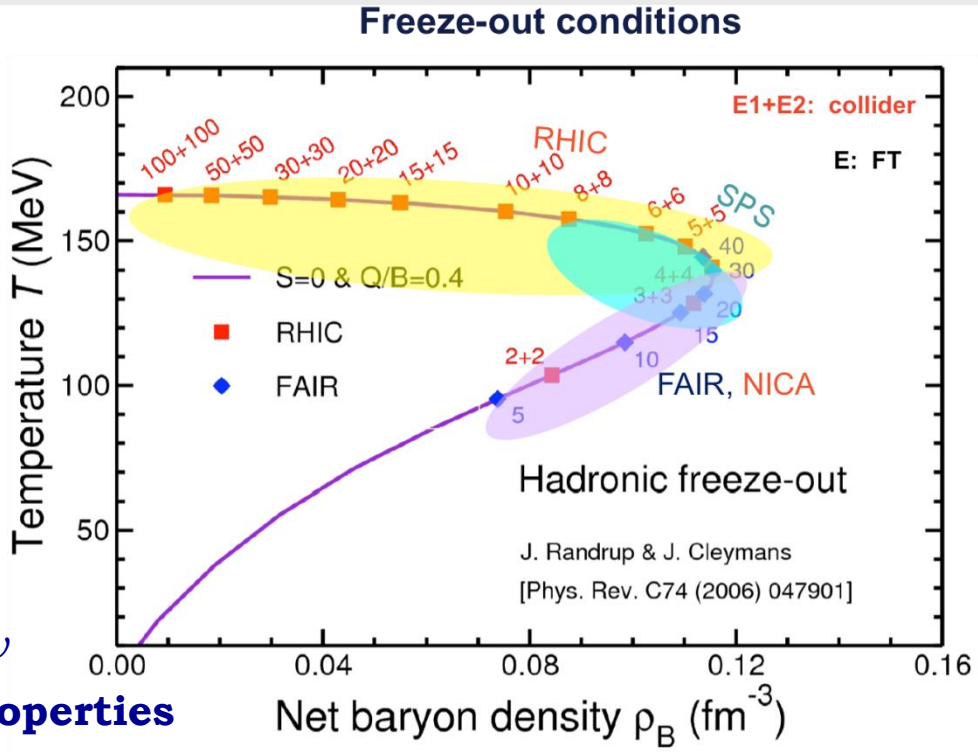
at extracted Nuclotron beam

Physics



QCD matter at NICA :

- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*



- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** - *enhanced strangeness production*
- **QCD Critical Point** - *event-by-event fluctuations & correlations*
- **Strangeness in nuclear matter** - *hypernuclei*

NICA White Paper

NICA

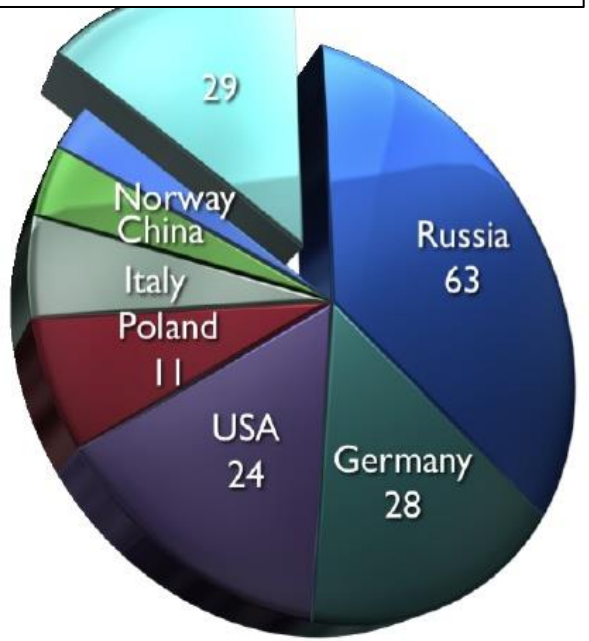
Draft v 8.03
January 24, 2013

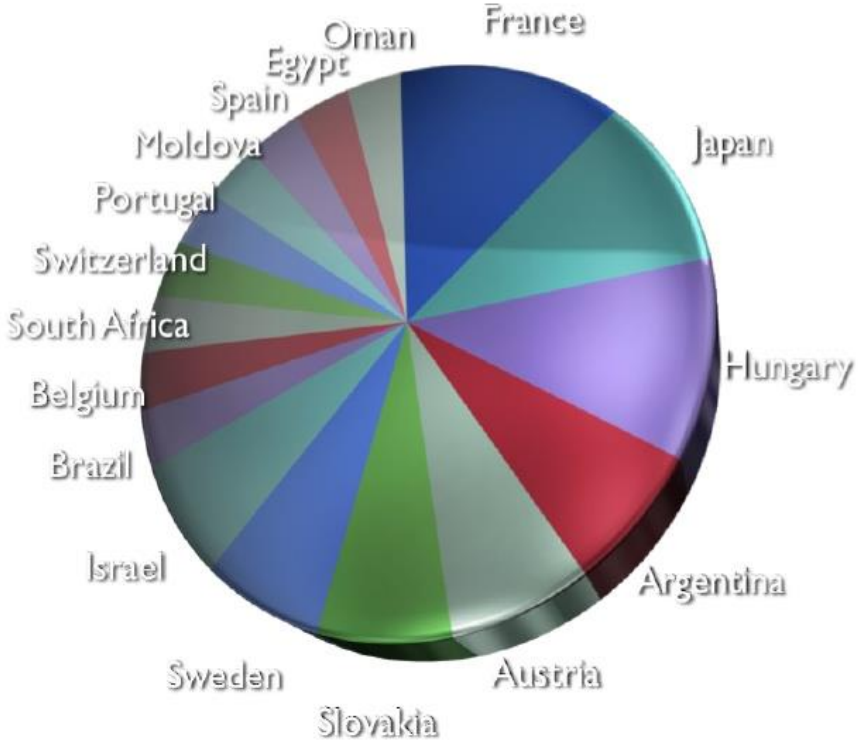
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

Statistics of White Paper Contributions

111 *contributions:*
188 *authors from* **70** *centers in* **24**

Indicates wide international interest to the physics at MPD & BM@N



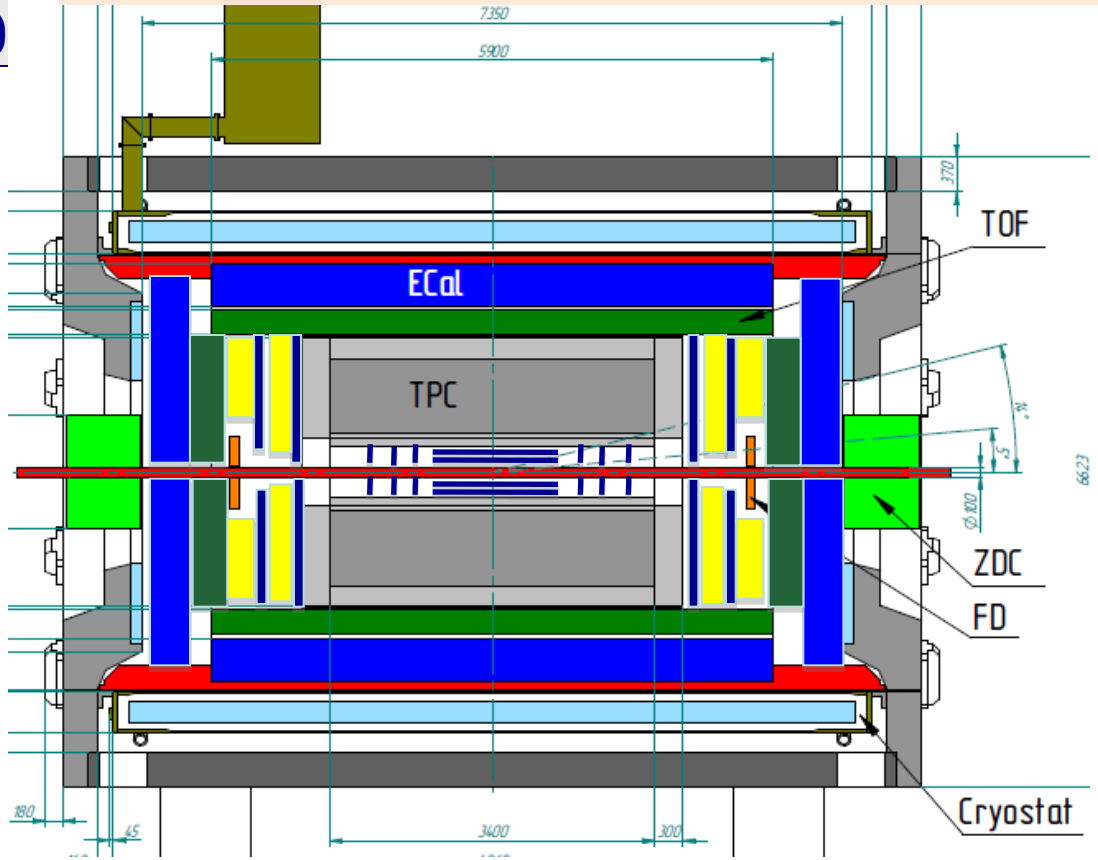


MPD detector for Heavy-Ion Collisions @ NICA

Tracking: up to $|\eta|<2$ (TPC)
PID: hadrons, e, γ (TOF, TPC, ECAL)
Event characterization:
centrality & event plane (ZDC)

Stage 1: TPC, TOF, ECAL, ZDC, FD

Stage 2: IT + Endcaps (tracker, TOF, ECAL)

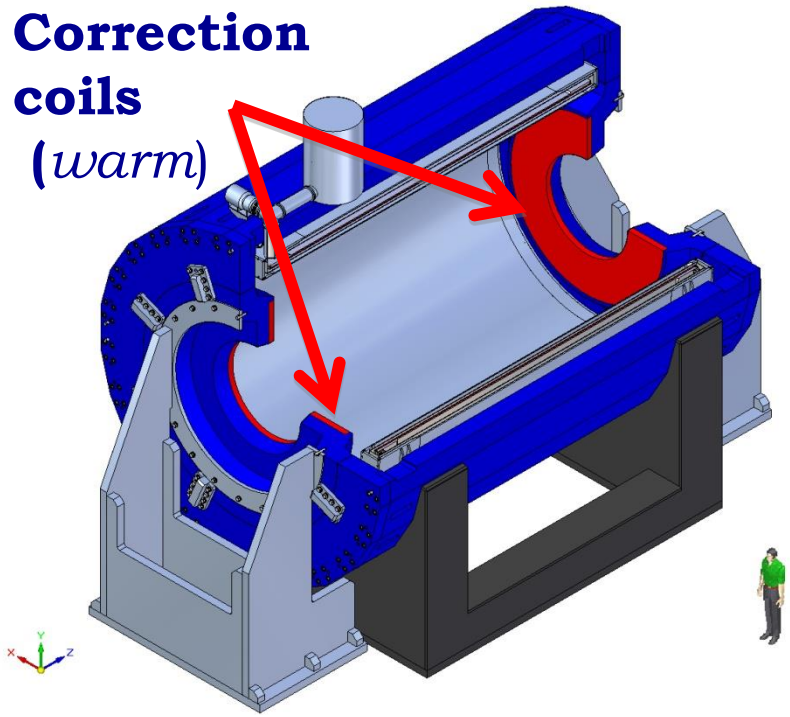


Superconducting solenoid:

high level (~ 10^{-4}) of magnetic field homogeneity

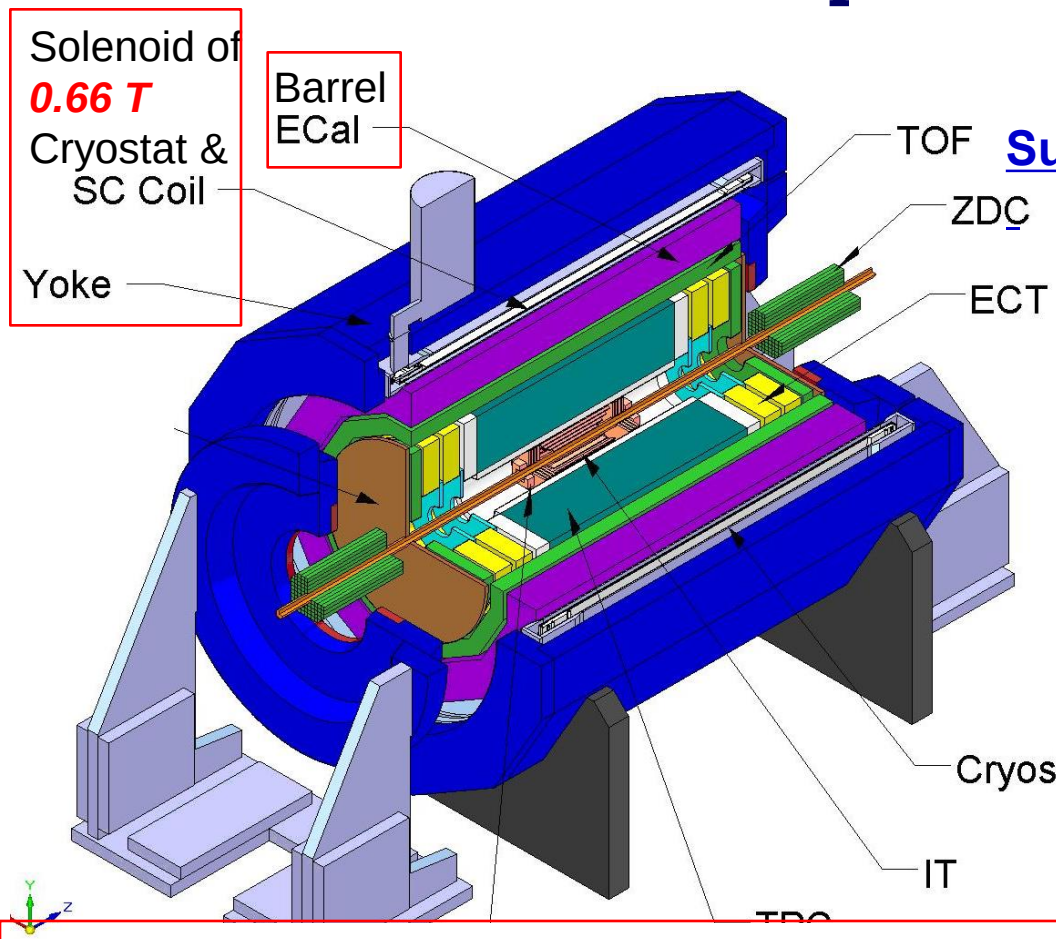
B_0=0.66 T

Correction coils (*warm*)



Status:
technical design – completed;
survey for producers

MultiPurpose Detector (MPD)



Subdetectors & probes' identification:

Particle Tracking:

- *Time projection chamber (TPC)*
- *Inner tracker (IT)*
- *End Cap Tracker (ECT)*

Particle identification:

- *Time-of-flight detector (TOF)*
- *Electromagnetic calorimeter (Ecal)*
- *Time projection chamber (TPC)*

Triggering (T0)

- *Fast Forward Detector (FFD)*

Identification of centrality and event plane:

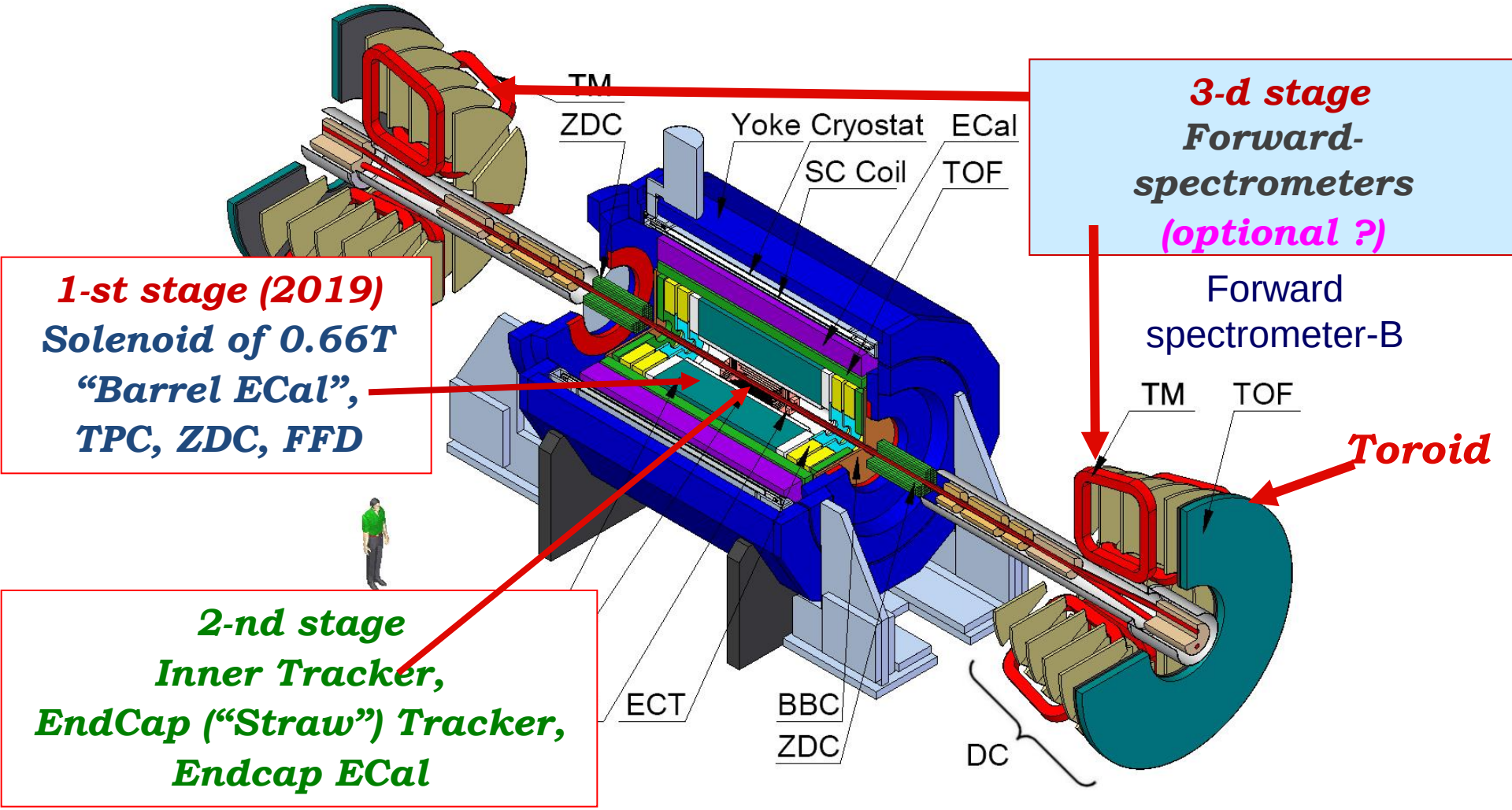
MPD advantages:

- ✓ *maximum and homogeneous detection efficiency (2π symmetry),*
- ✓ *high "transparency" for particles (small amount of matter;*
- ✓ *high quality of trajectories' reconstruction and particle identification*
- ✓ *high detection rate (~ 7 kHz)*

Disadvantage: weight ≈ 1200 tons

MultiPurpose Detector (MPD)

3 stages of MPD commissioning



3-d stage
Forward-spectrometers
(optional ?)

1-st stage (2019)
Solenoid of 0.66T
"Barrel ECal",
TPC, ZDC, FFD

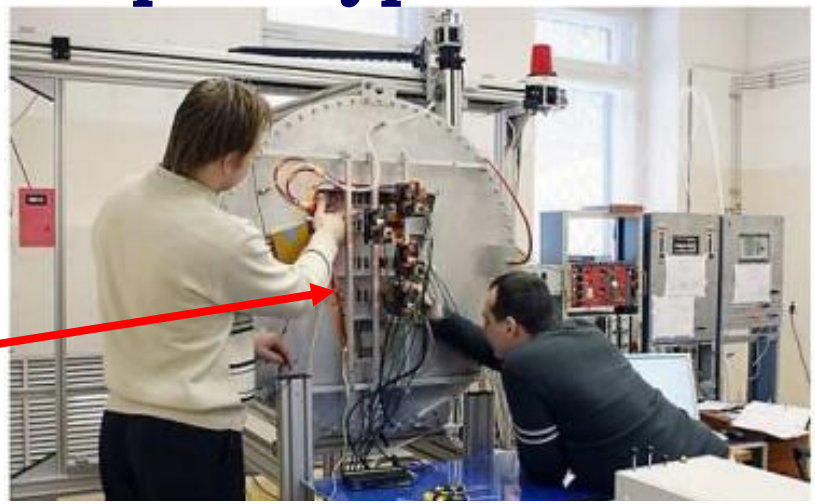
2-nd stage
Inner Tracker,
EndCap ("Straw") Tracker,
Endcap ECal

MPD Subdetectors' Development

Time Projection Chamber - prototype 1

Field Cage prototype

The general view of the TPC Prototype-1

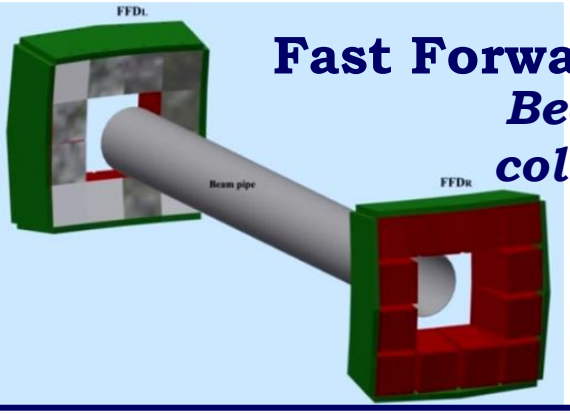


Preparation for test with UV laser.

Cylinder C3 (Dec. 2013) (carbon-filled plastic)

MultiPurpose Detector (MPD)

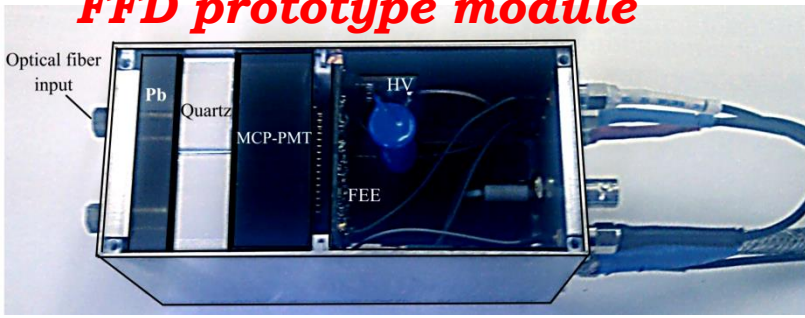
MPD Subdetectors' Development



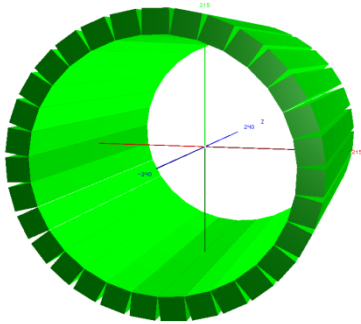
Fast Forward Detector (FFD)

Beam adjustment and collision trigger (30 ps)

FFD prototype module



JINR (VBLHEP) + Radium Institute (St.Petersburg).)



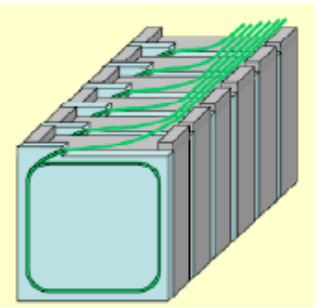
Electromagnetic Calorimeter (ECAL "Shashlyk")

JINR (VBLHEP & DLNP) + ISM (Kharkov)

Zero Degree Calorimeter (ZDC)

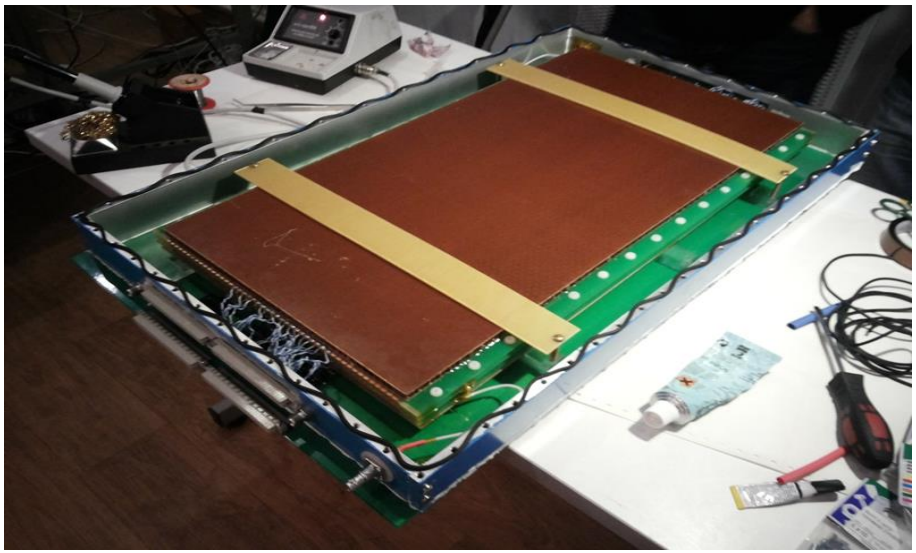
INR (Troisk) + JINR (VBLHEP)

Pb + scintillator sampling (51)
Read-out: fibers+ Avalanche PDs
ZDC coverage: 2.2<|h|<4.8



MultiPurpose Detector (MPD)

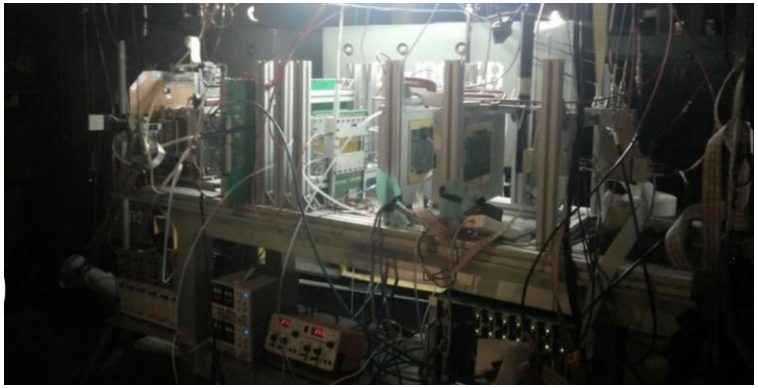
MPD Subdetectors' Development



A full-scale double-stack mRPC prototype

MultiResistive Plate Counter (mRPC)

JINR (VBLHEP) + Hefei, Beijing (China)

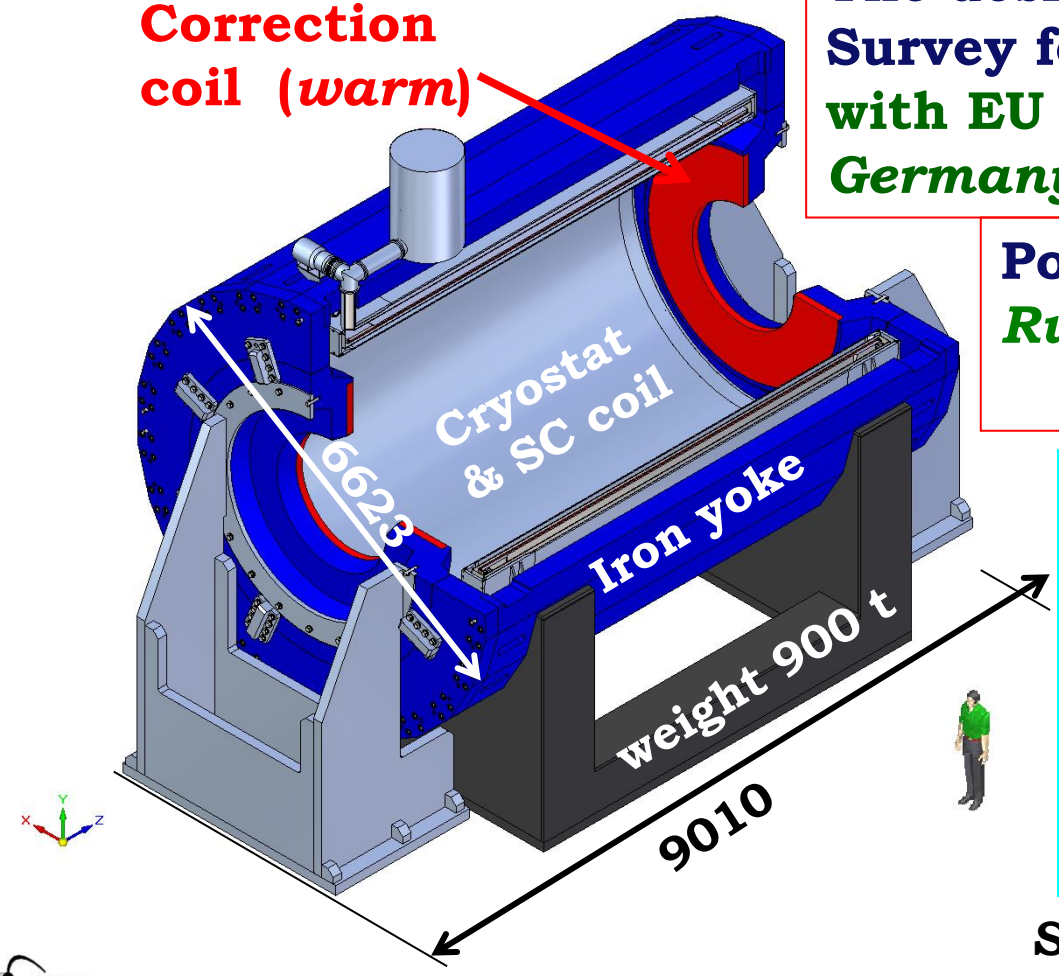


Experimental setup for mRPC tests at Nuclotron (March 2013)

MultiPurpose Detector (MPD)

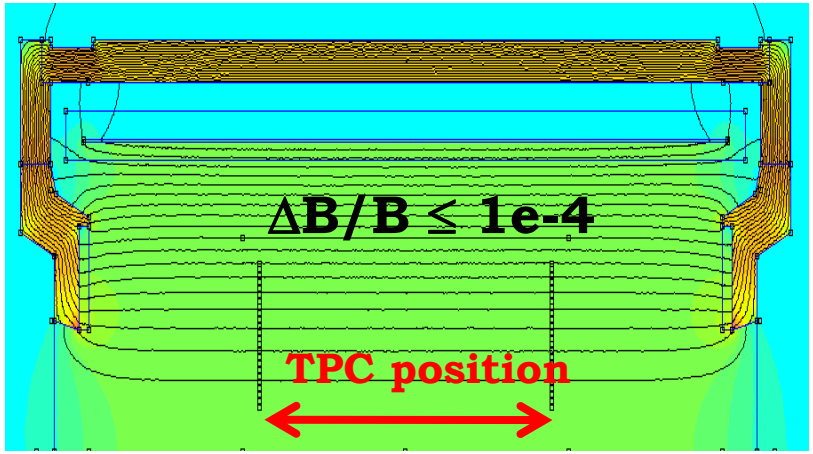
MPD SC solenoid, B_0=0.66 T

Design: Scientific Prodctn Association "Neva - Magnet" (St.Petersburg)



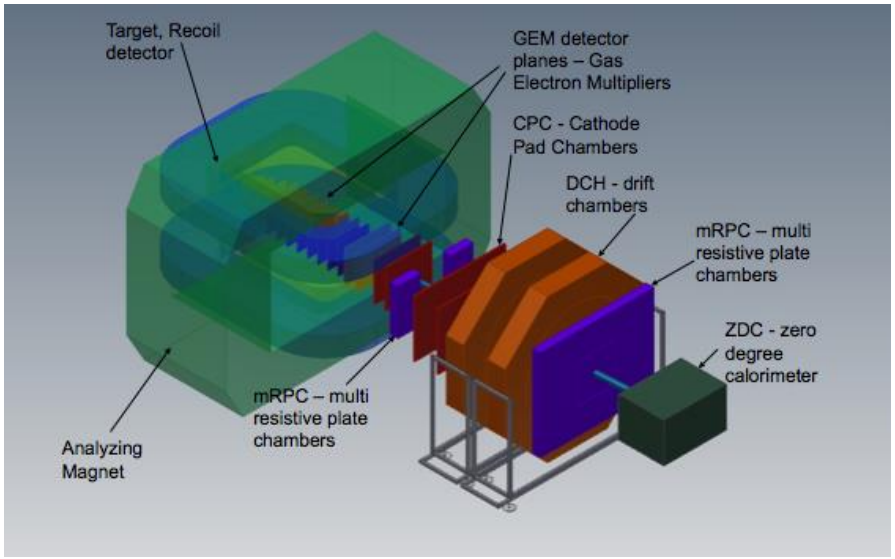
The design – close to completion;
Survey for contractors – negotiations with EU companies *(ASG, Genova, Germany) & Toshiba (Japan)*

Possible subcontractors:
Russian & Ukrainian companies



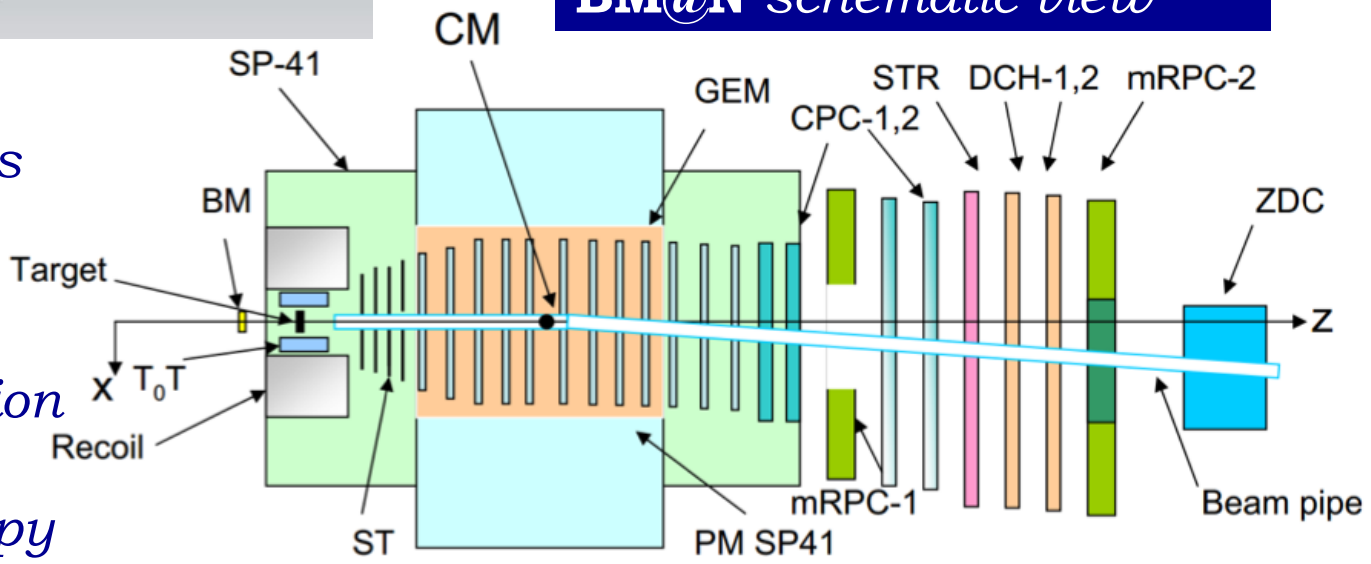
Simulated map of magnetic field

BM@N (**B**aryonic **M**atter at **N**uclotron): *the 1st stage*



Collaboration of scientific centers:
INR, SINP MSU, IHEP + S-PSUniversity (Russia);
GSI, Frankfurt U., Gissen U. (Germany): + CBM-MPD IT-Consortium,

BM@N *schematic view*

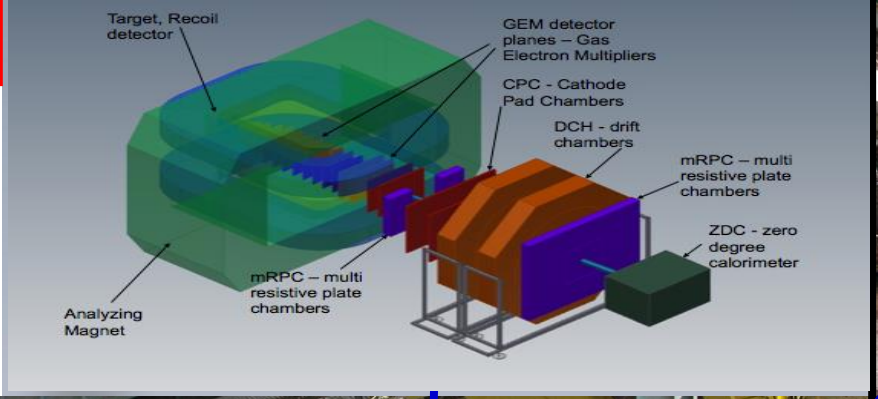


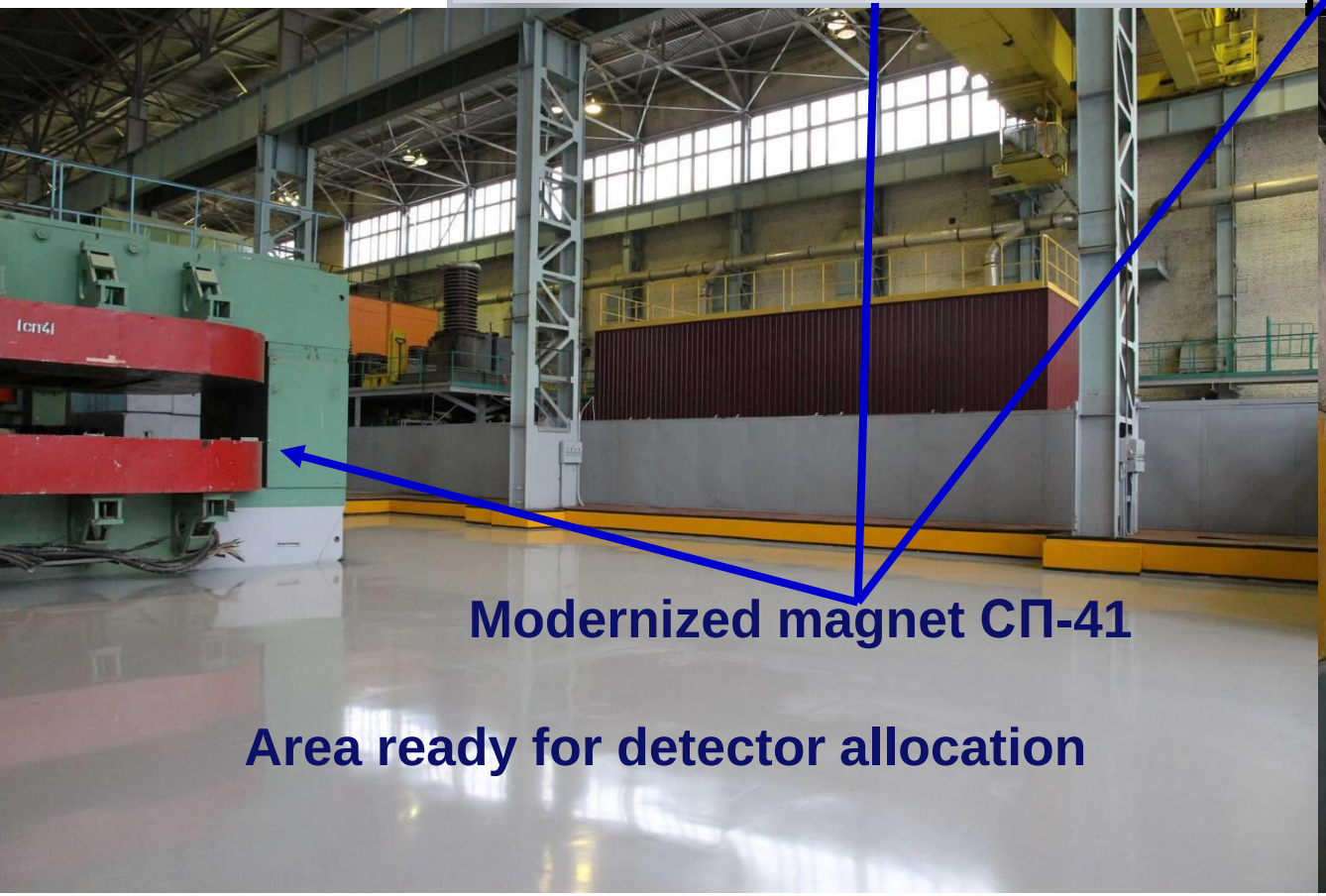
Physics:

- ✓ *in-medium effects for strangeness & vector mesons*
- ✓ *hyperon production*
- ✓ *hadron femtoscopy*
- ✓ *electromagnetic probes (optional)*

NICA – Stage I

Project BM@N, Preparation in Bld. 205





Modernized magnet СП-41

Area ready for detector allocation

SPD (Spin Physics Detector) at NICA

Collider provides both:
transversally & longitudinally polarized ***p*** & ***d***
with energy up to $\sqrt{S}$ = ***27 GeV***

The issues to be studied:

- *MMT-DY processes*
- *J/Ψ production processes*
- *Spin effects in inclusive high-p_T reactions*
- *Spin effects in one and two hadron production processes*
- *Polarization effects in heavy ion collisions*

The Collaboration is forming

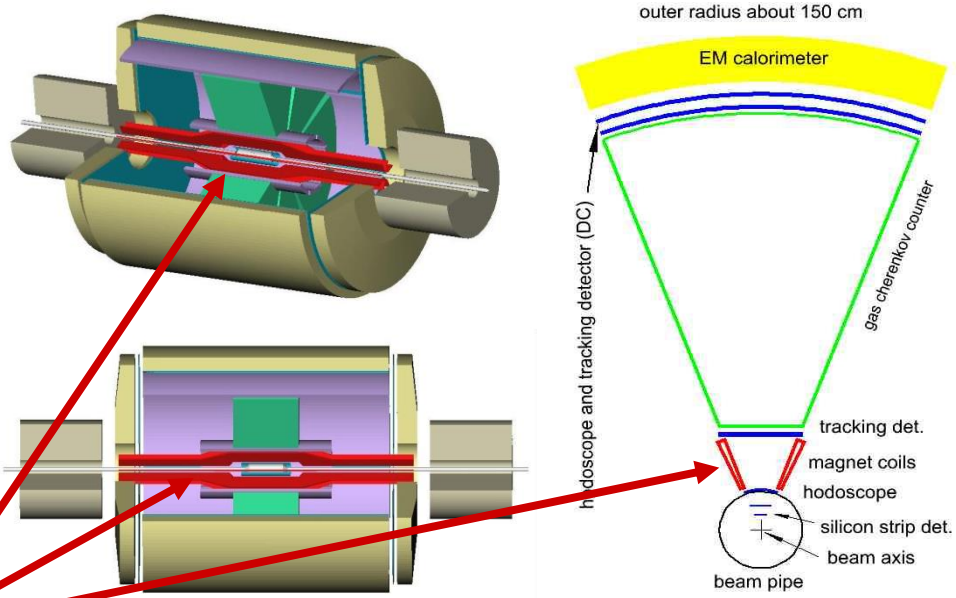
Project is under preparation

NICA – Stage III : Collider of polarized beams

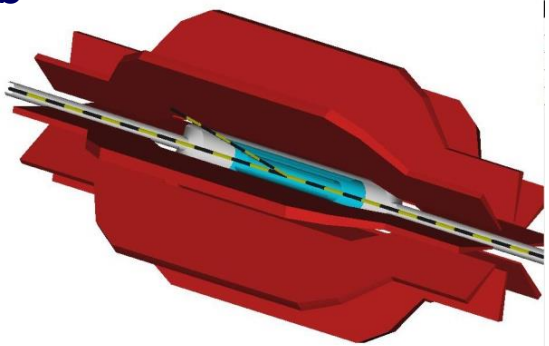
Spin Physics Detector (SPD) – Very First Concept

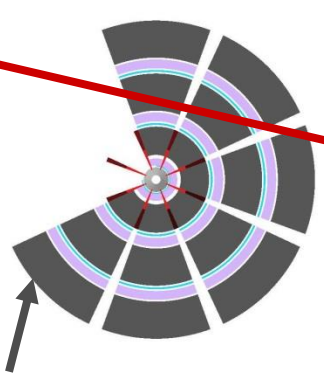
Main elements of the detector:

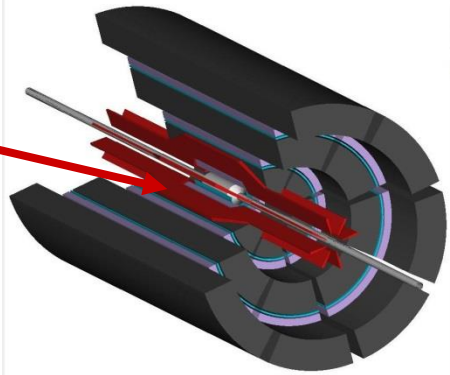
- Silicon or MicroMega (inner tracking)
- Drift chambers or straw (for tracking)
- Cherenkov counter (for PID and trigger)
- EM calorimeter
- Trigger counters
- EndCap detectors



Toroidal magnet





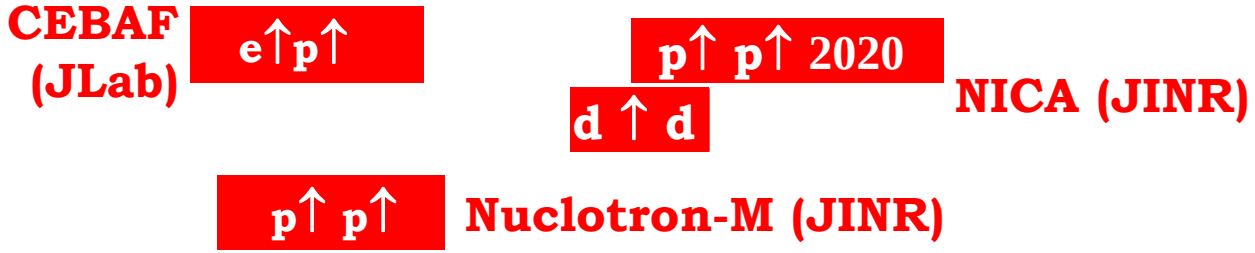


Subdetector for muon pairs

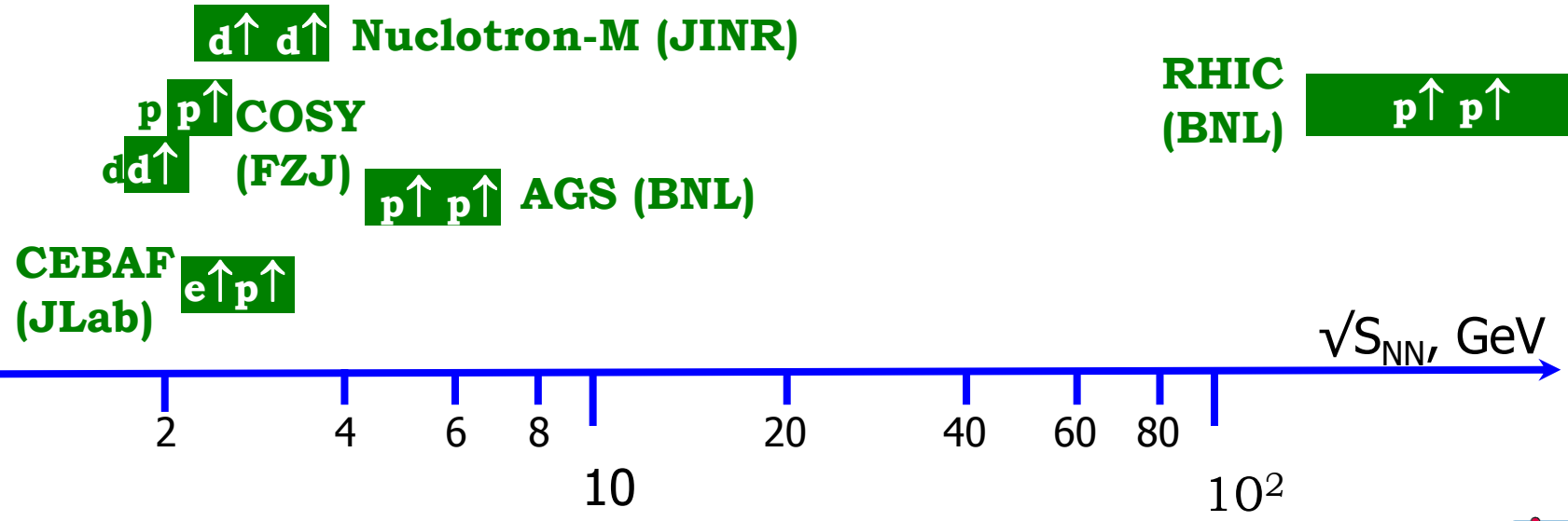
First proposal of SPD concept is expected at the end of 2015

NICA Research Program
Spin Physics

Future Machines with Polarized Beams

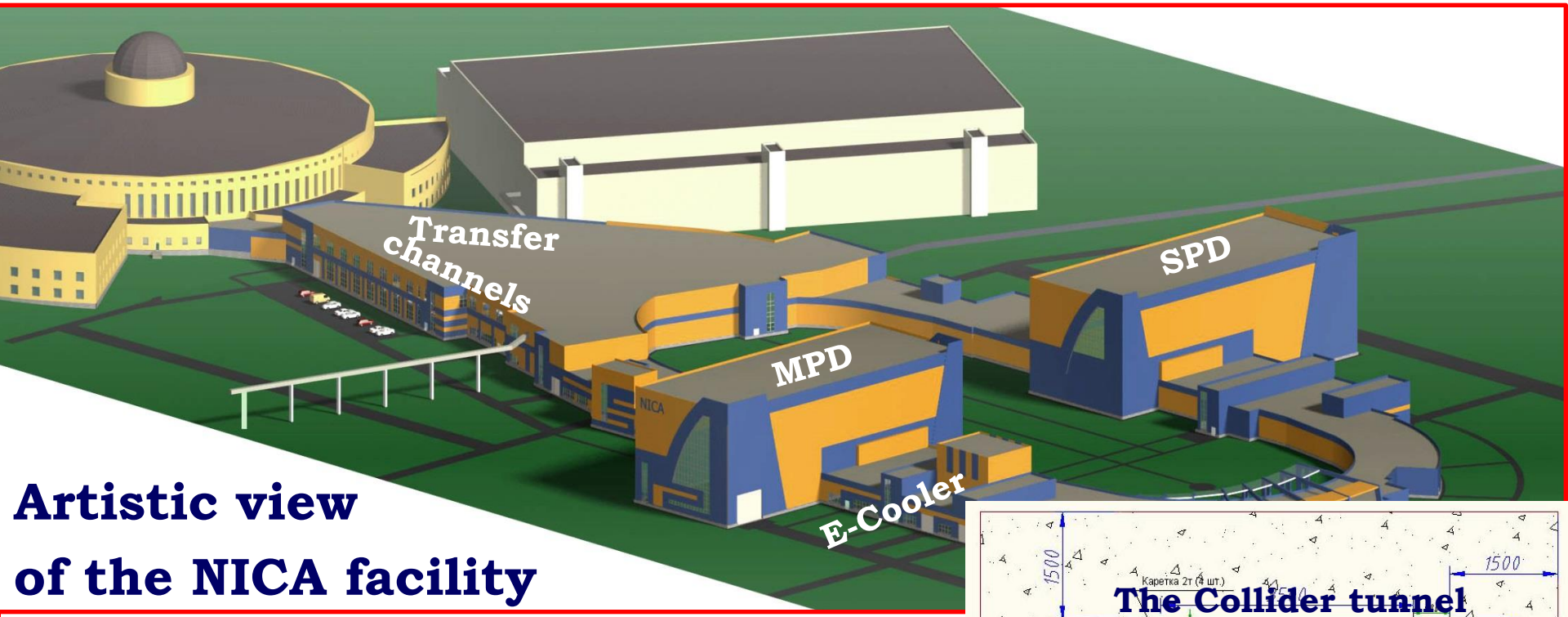


Existing Machines with Polarized Beams



NICA Collaboration

Civil engineering – Status and Plans

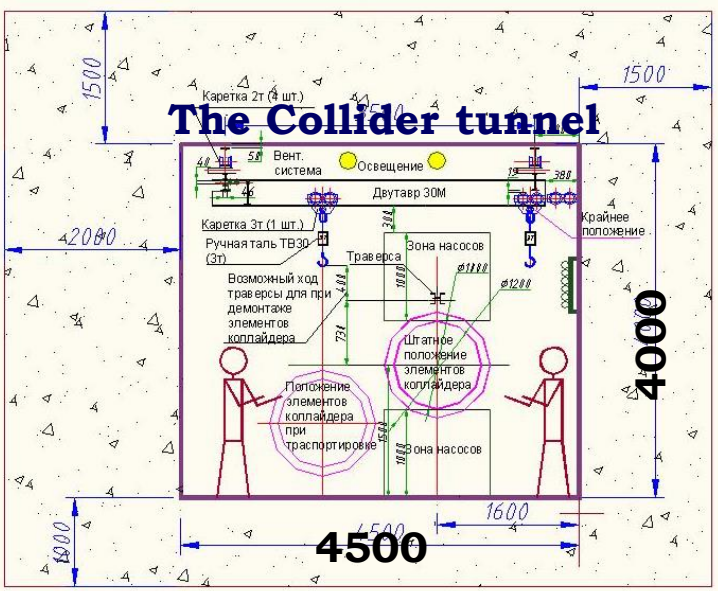


Artistic view of the NICA facility

The technical project of NICA **(civil e**

description and disposition) has been

has passed State Expertise (

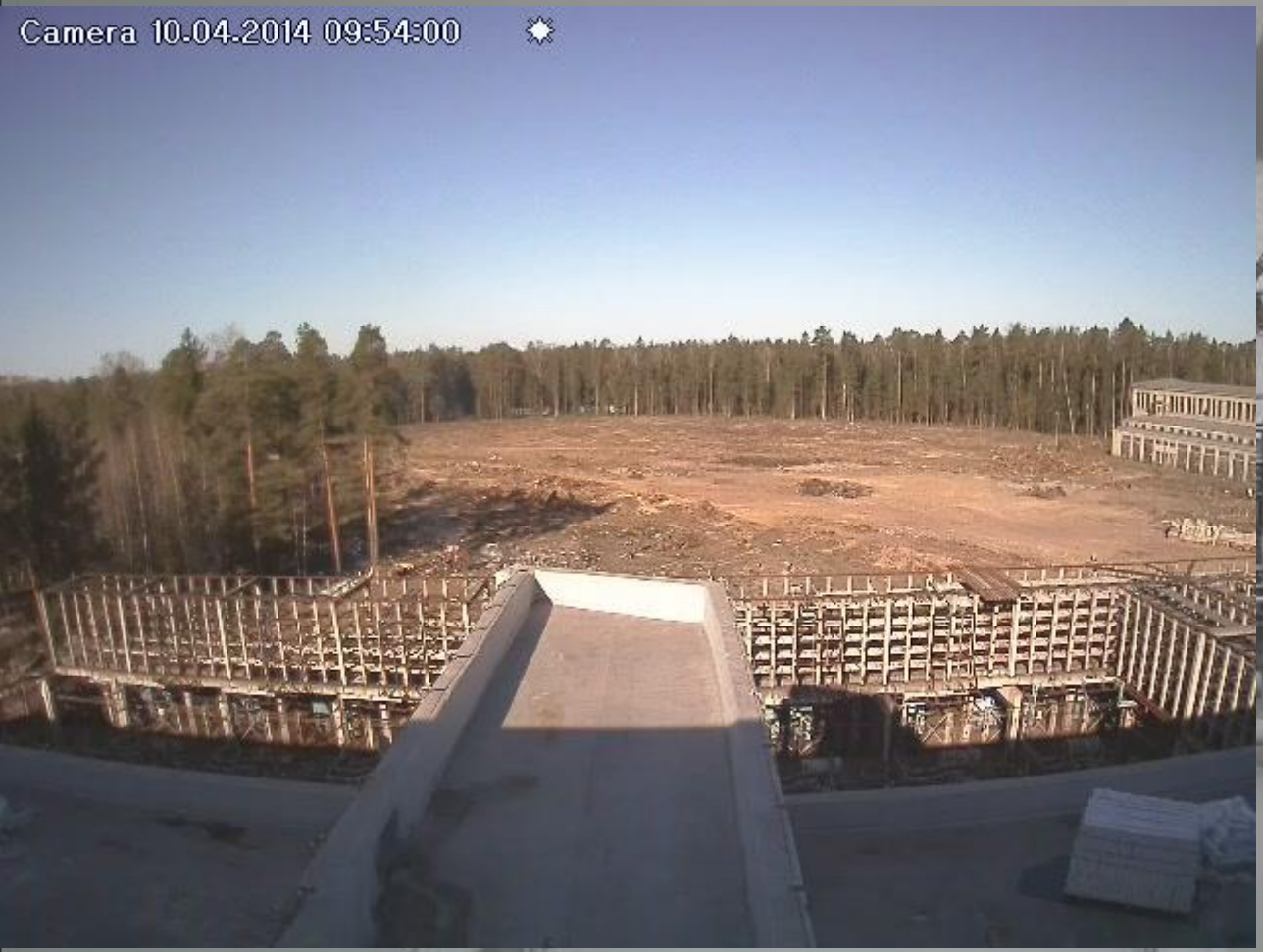


Civil engineering – Status and Plans

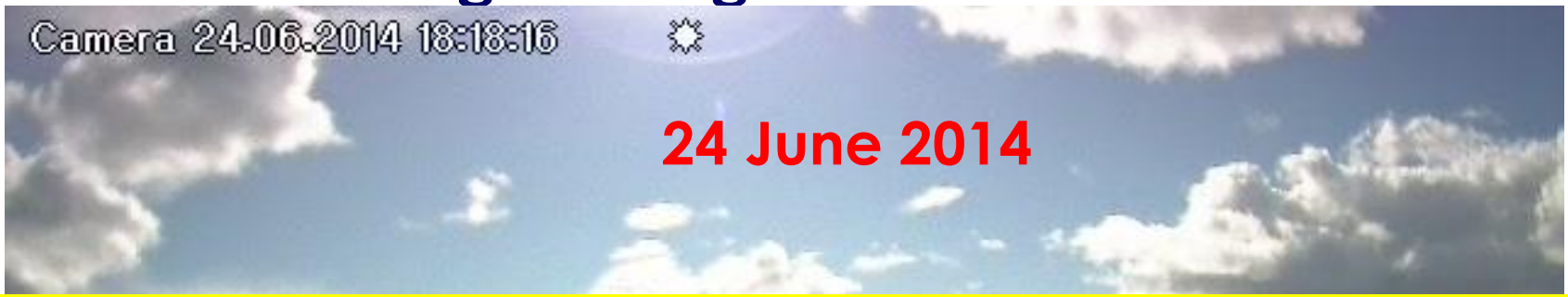
Civil construction is started

On-line web-camera (Feb.2014)

http://nucloweb.jinr.ru/nucloserv/205corp.htm



Civil engineering – Status and Plans



Signing of the contract with the building company "Strabag", Austria (the winner of the tender) is close to completion.

Presently => stage of requirement specification based on NICA Technical Project

Civil construction duration is estimated as 36 months!

Beginning of Collider mounting – September 2017

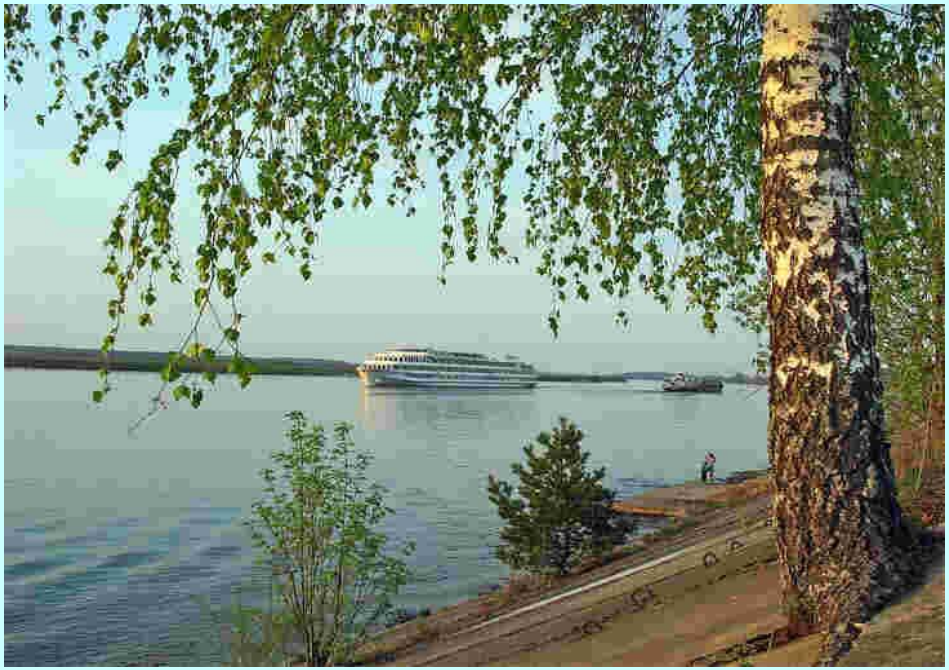
Start up version of NICA commissioning is planned for 2019

Concluding remarks

- **NICA complex has a potential for competitive research** ***in the fields of dense baryonic matter and spin physics***
- **Construction of the** ***accelerator complex and its elements are in progress***
- **Constructions of both detectors BM@N & MPD** ***are progressing as well***
- **The SPD project is in preparation**
- **The international collaboration around the NICA is growing**
- **New partners are invited to join NICA**

Strangeness in Quark Matter 2015

Dubna, 6.-11. July 2015



Official Logo:

SQM DUBNA 2015

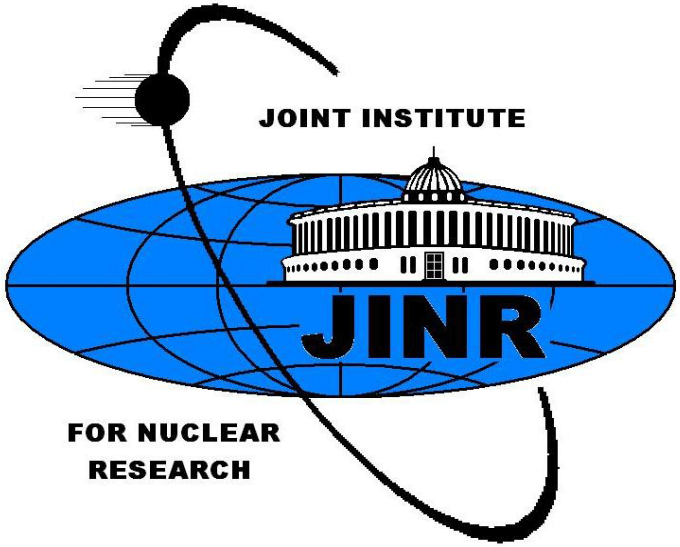
Email: sqm@jinr.ru

Website: http://sqm.jinr.ru

Satellite Meetings:

- Summer School “Dense Matter”, Dubna, June 29 – July 4, 2015
- Roundtable “Physics at NICA”, Dubna, 5. July 2015

Welcome to the collaboration!



Thank you for attention!