Elementary Particle and Relativistic Heavy-Ion Physics at JINR

R.Lednicky

Brazil-JINR FORUM
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Research is focused on the following topics:

1. Particle physics research, including neutrino physics and rare phenomena studies (covering the Energy, Intensity, Accuracy, and Cosmic Borders), aimed at extending the Standard Model and discovering new fundamental laws of Nature.

2. High-energy heavy-ion physics research (Energy and Intensity Borders) aimed at establishing unique properties of hadronic matter under conditions of phase transitions between quark and hadronic states of matter.

3. Development of new-generation detector systems and accelerator complexes, theoretical support of current and planned experimental investigations, development and maintenance of high-performance telecommunication links and computing facilities at JINR.

JINR Activities in HEP

are carried out in four JINR laboratories:
VBLHEP, DLNP, BLTP and LIT in the following main directions:

- physics of new states of nuclear matter;
- nucleon structure and its spin dependence;
- non-perturbative QCD;
- physics of rare processes;
- tests of fundamental symmetries;
- Standard Model and beyond;
- neutrino physics.

Talks: VBLHEP - A. Sorin, E. Strokovsky, A. Vodopianov
DLNP - G. Chelkov, V. Glagolev, D. Naumov
BLTP - V. Voronov, I. Anikin, A. Dorokhov, A. Bednyakov, M. Deka, E. Ilgenfritz, L. Jenkovszky, Ya. Klopot, S. Nedelko, D. Shkirmanov, V. Toneev
LIT - I. Bogolyubsky

Home activities

Synchrophasotron – Nuclotron – NICA

1957 – 2002 Synchrophasotron	1993 – Nuclotron	2019 – NICA

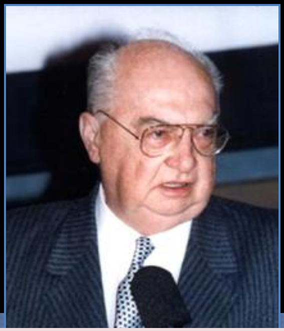
10 GeV proton accelerator – world leader in energy.

Beginning of era of high-energy physics

V.Veksler – phase stability principle discovery

First in the world

Superconducting Synchrotron of heavy ions



A.Baldin –start of relativistic nuclear physics era

Superconducting collider of heavy ions & polarized particles

Study of baryonic matter at extreme conditions (max net baryon density)

The JINR 7-year plan for 2010-2016 approved by CPP in 2009:

NICA – the JINR flagship project in HEP

The JINR 7-year plan for 2010-2016 approved by the CPP in 2009:

NICA (Nuclotron based Ion Collider fAcility) – the JINR flagship project in HEP

Main targets of "NICA Complex":

- *study of hot and dense baryonic matter at max baryonic density*
- *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 deutrons with max energy up to

$\sqrt{S_{NN}}$= **11 GeV (Au+Au)** and **26 GeV (p+p)**

$L \sim$ $\mathbf{10^{27}\ cm^{-2}s^{-1}}$ $\mathbf{10^{32}\ cm^{-2}s^{-1}}$

Spin Physics Tasks

→ MMT-DY (dilepton) and J/ψ production processes with transversely and longitudinally polarized p and d beams:
- measurement of unknown or poorly known PDF's

→ Spin effects in baryon, meson and photon production

contributing to solution of spin crisis

→ Spin effects in various exclusive reactions & diffractive processes

→ Spin-dependent cross sections, helicity amplitudes and double spin asymmetries (Krish effect) in elastic reactions

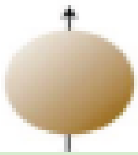
→ Spectroscopy of quarkonia

→ Polarimetry

The Present: Proton Spin

- The sum rule: $S(\mu) = \sum_f \langle P,S|\hat{J}^z_f(\mu)|P,S\rangle = \frac{1}{2} \equiv J_q(\mu) + J_g(\mu)$
  - Infinite possibilities of decompositions – connection to observables?
  - Intrinsic properties + dynamical motion and interactions
- An incomplete story:

Jaffe-Manohar, 90
Ji, 96, ...



Proton Spin

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + (L_q + L_g)$$

Quark helicity
Best known

$$\frac{1}{2}\int dx\left(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}\right)$$

$\sim 30\%$

Gluon helicity
Start to know

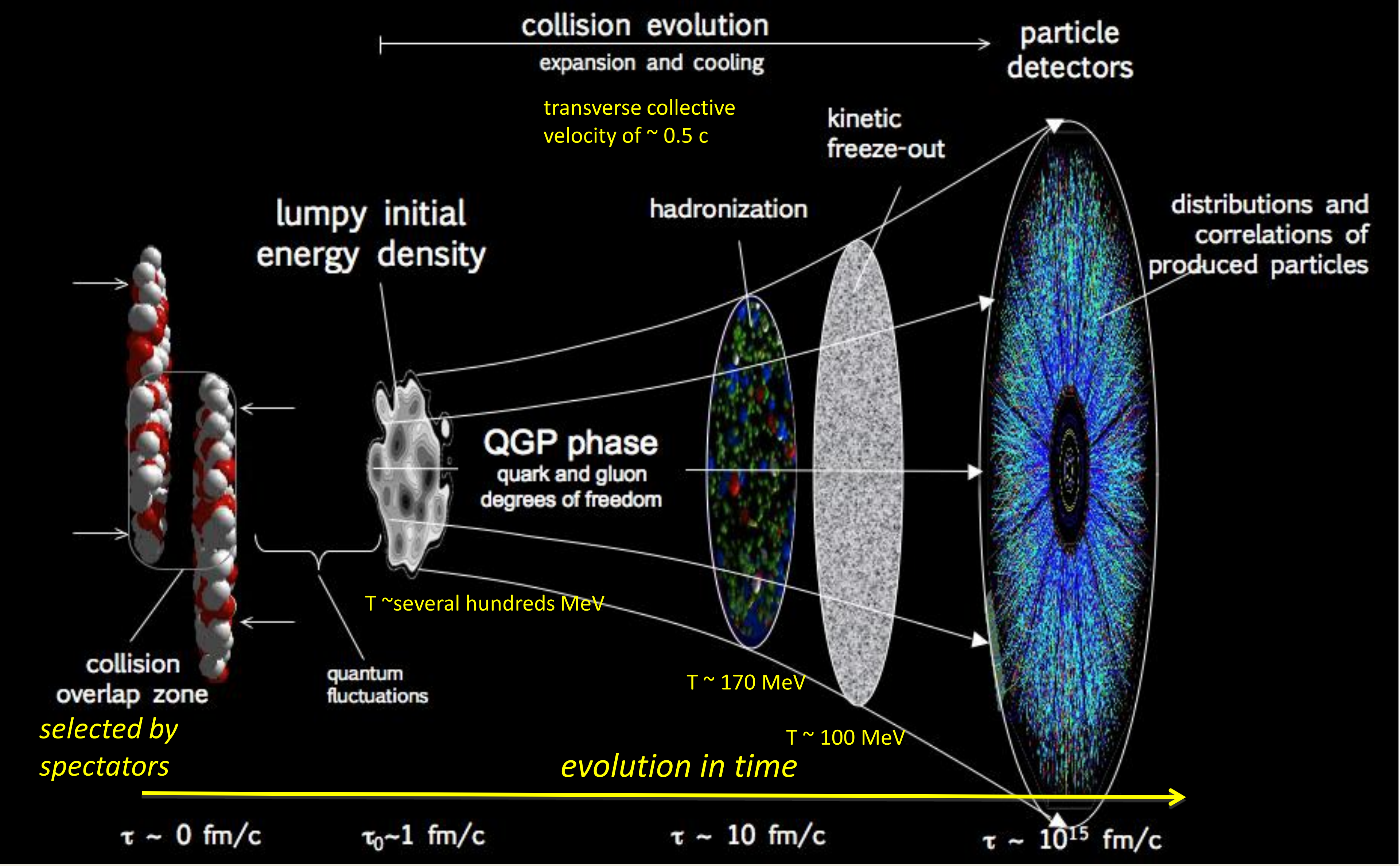
$$\Delta G = \int dx \Delta g(x)$$

$\sim 20\%$(STAR Data)

Orbital Angular Momentum of quarks and gluons
Little known

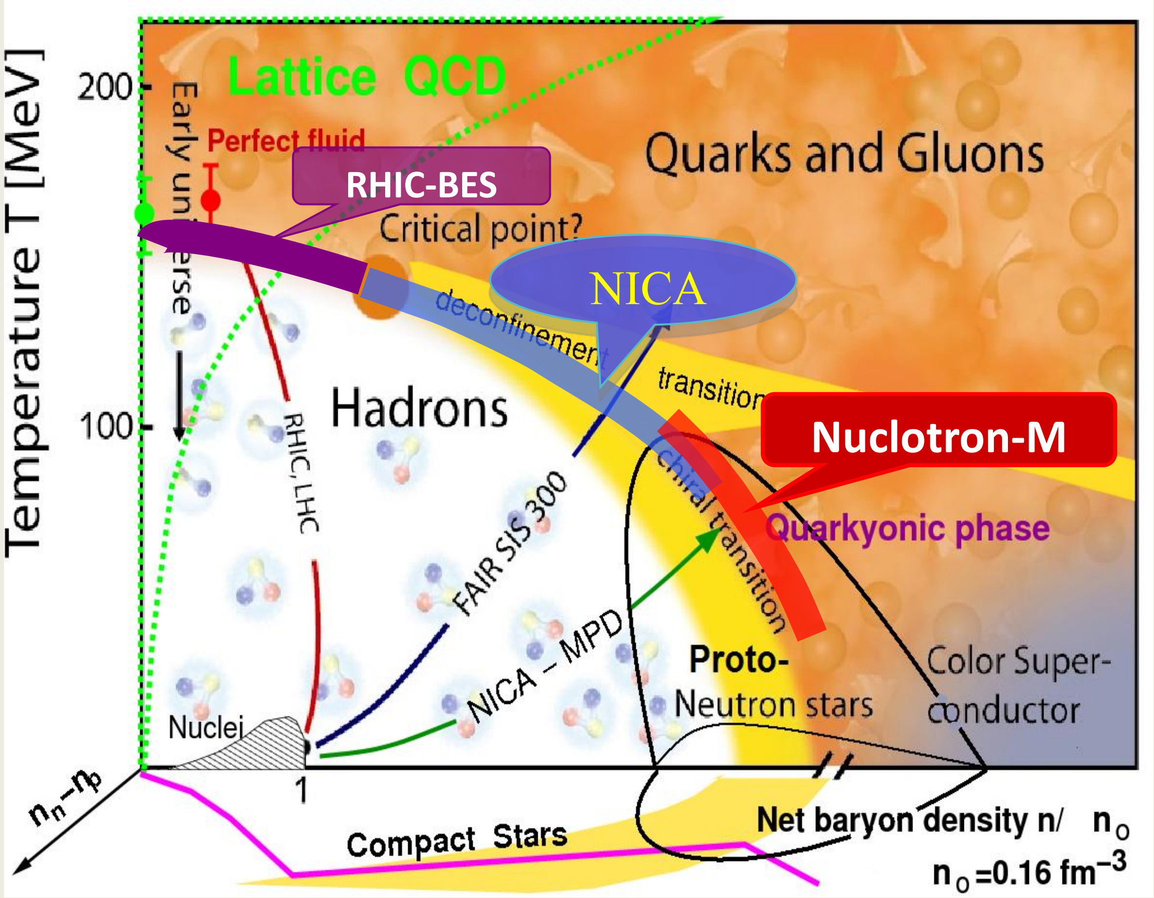
Net effect of partons' transverse motion?

Nuclear collisions and the QGP expansion



QCD phase diagram

Deconfined matter (high ε,T,n_B):
ε >1 GeV/fm^3, T>150 MeV or n_B>(3-5)n_0



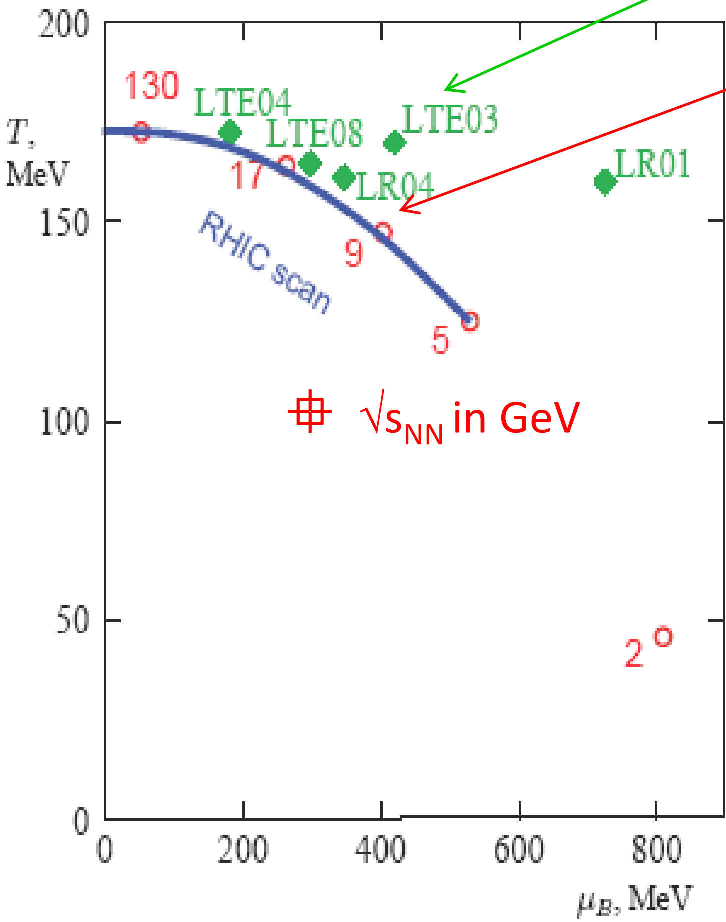
Energy Range of NICA

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

- **Highest net baryon density**
- **Onset of deconfinement phase transition**
- **Strong discovery potential:**
  a) Critical End Point (CEP)
  b) Chiral Symmetry Restoration
  c) Hypothetic Quarkyonic phase
- **Complementary to the RHIC/BES, CERN, 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

Location of the critical point vs freeze-out



Needed:

- Experiments:
  - RHIC,
  - NA61(SHINE) @ SPS,
  - CBM @ FAIR/GSI & MPD @ NICA/JINR
- Improve lattice predictions, understand systematic errors.
- Understand critical phenomena in the dynamical environment of a h.i.c. (understand background) – develop optimal signatures

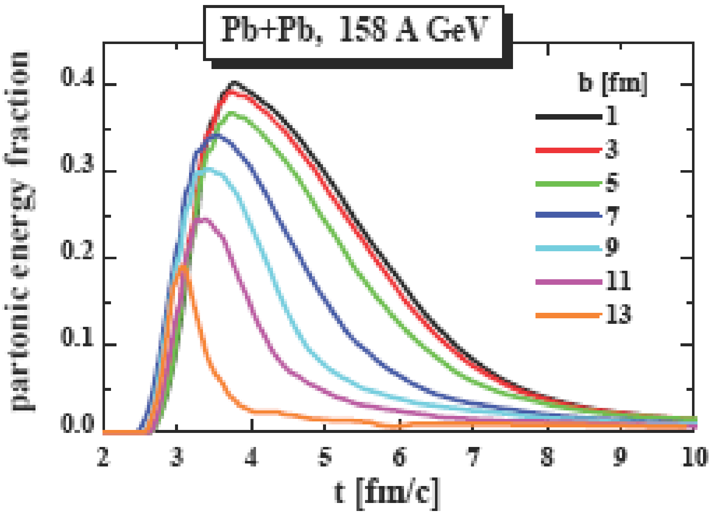
Lattice says:

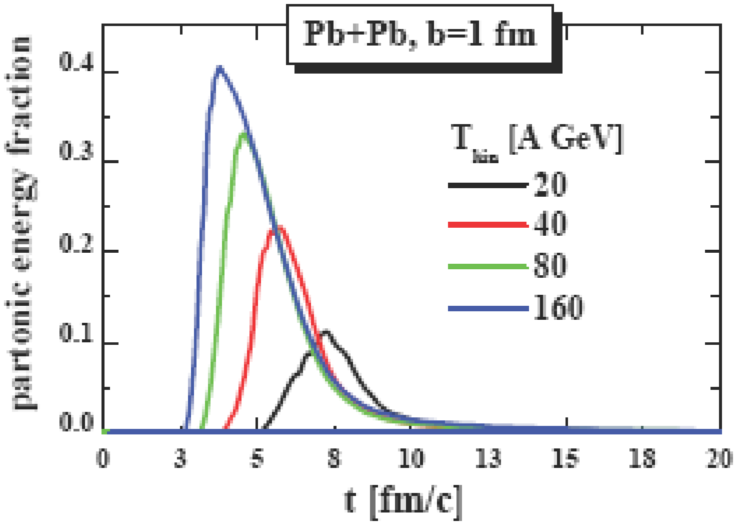
crossover at $\mu_B = 0$ but CEP location is not clear

CEP: T ~ 160-170 MeV, μ_B > 200 MeV

Perspectives at FAIR/NICA energies

partonic energy fraction vs centrality and energy





→Dramatic decrease of partonic phase with decreasing energy and centrality !

Motivation for the next generation of HI experiments (such as @ NICA)

A dramatic decrease of partonic phase with decreasing energy

⇓

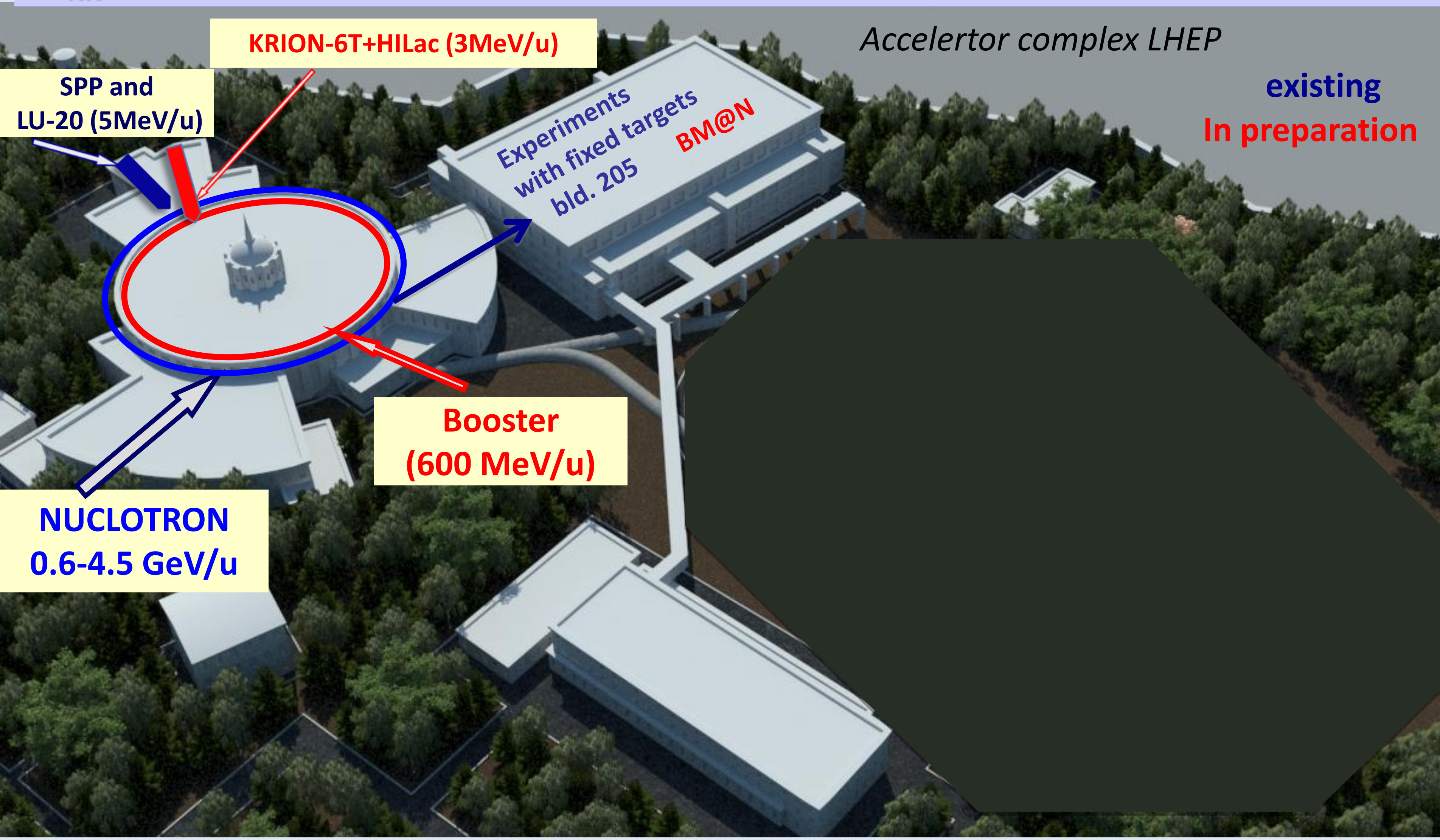
3rd generation experiment with dedicated detectors are required for more sensitive and detailed study of PT's and search for CEP

- requirements for 3rd generation experiments
  - energy range which brackets onset of deconfinement
  - small enough energy steps
  - choice of projectile nuclei
  - large uniform acceptance and PID
  - sufficient statistics

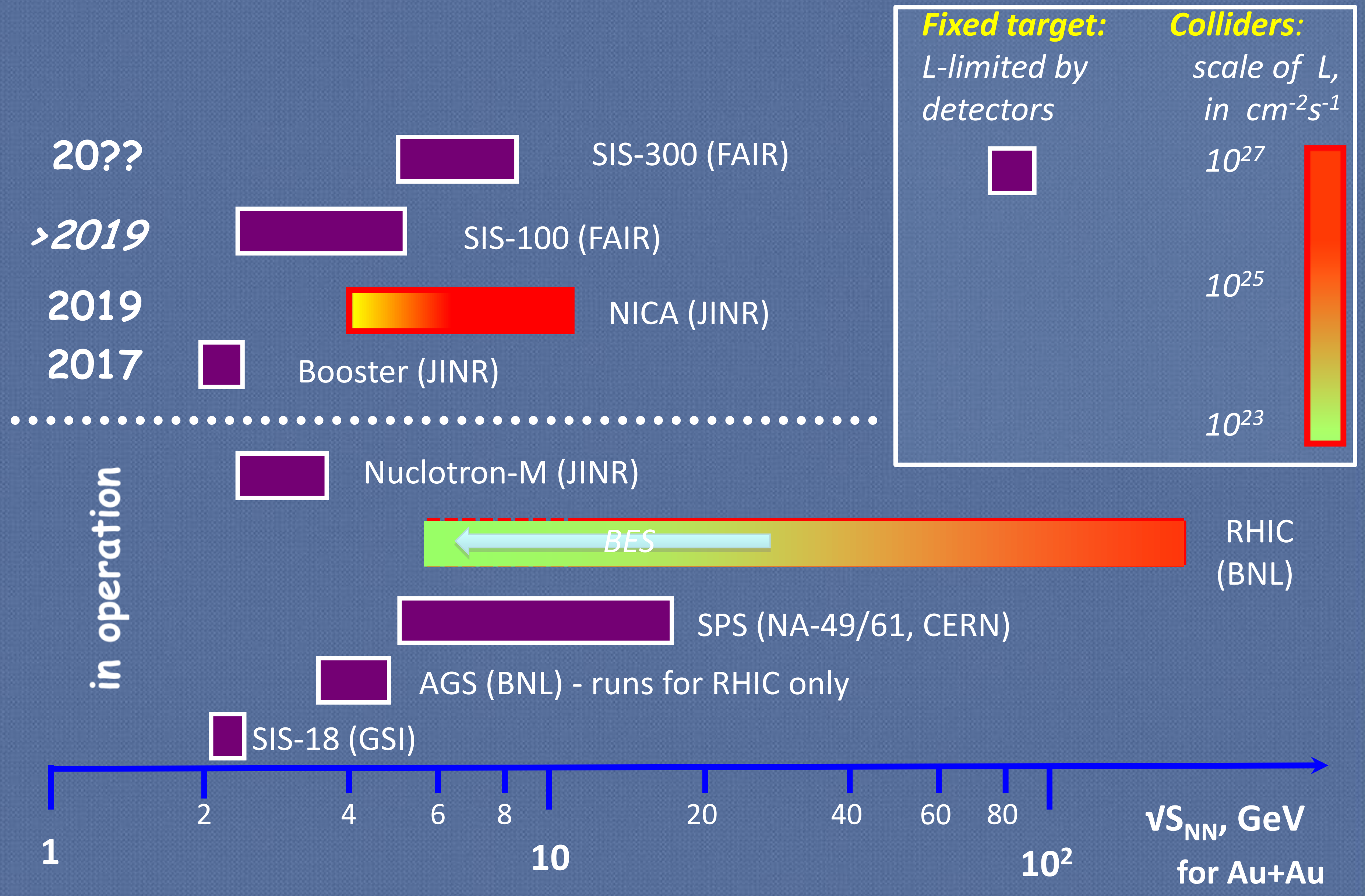
Complex **NICA**, JINR *Dubna*

Collider basic parameters:

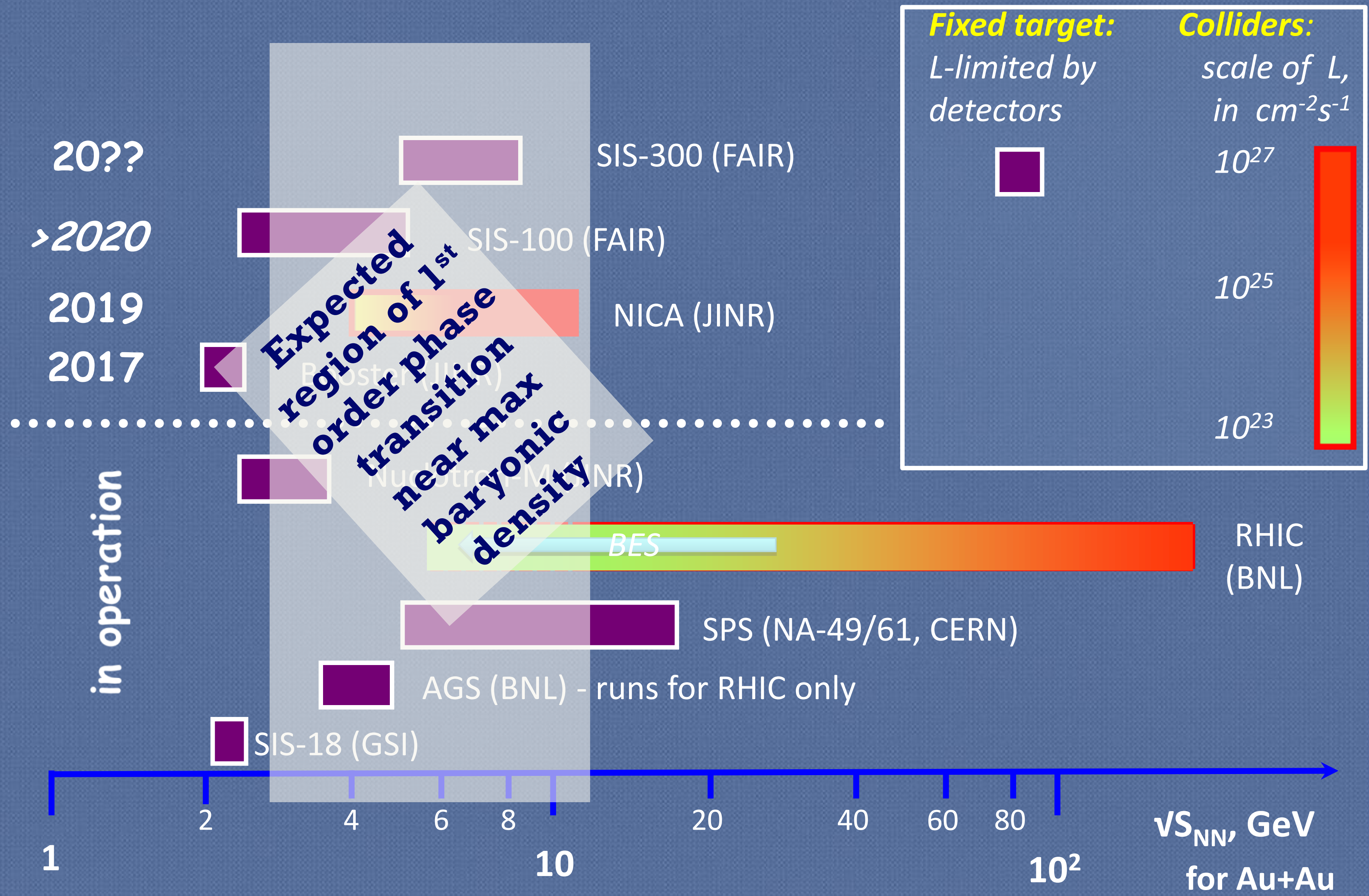
$\sqrt{s_{NN}}$ = **4-11** GeV; ***beams***: *from* **p** to **Au**; **L**~10^{27} cm^{-2} c^{-1} (Au), ~10^{32} cm^{-2} c^{-1} (p)



NICA among present and future HI machines



NICA among present and future HI machines



Complex NICA – civil construction

The project has passed through the State Expertise in 2013

For the first time at JINR an international tendering has been organized

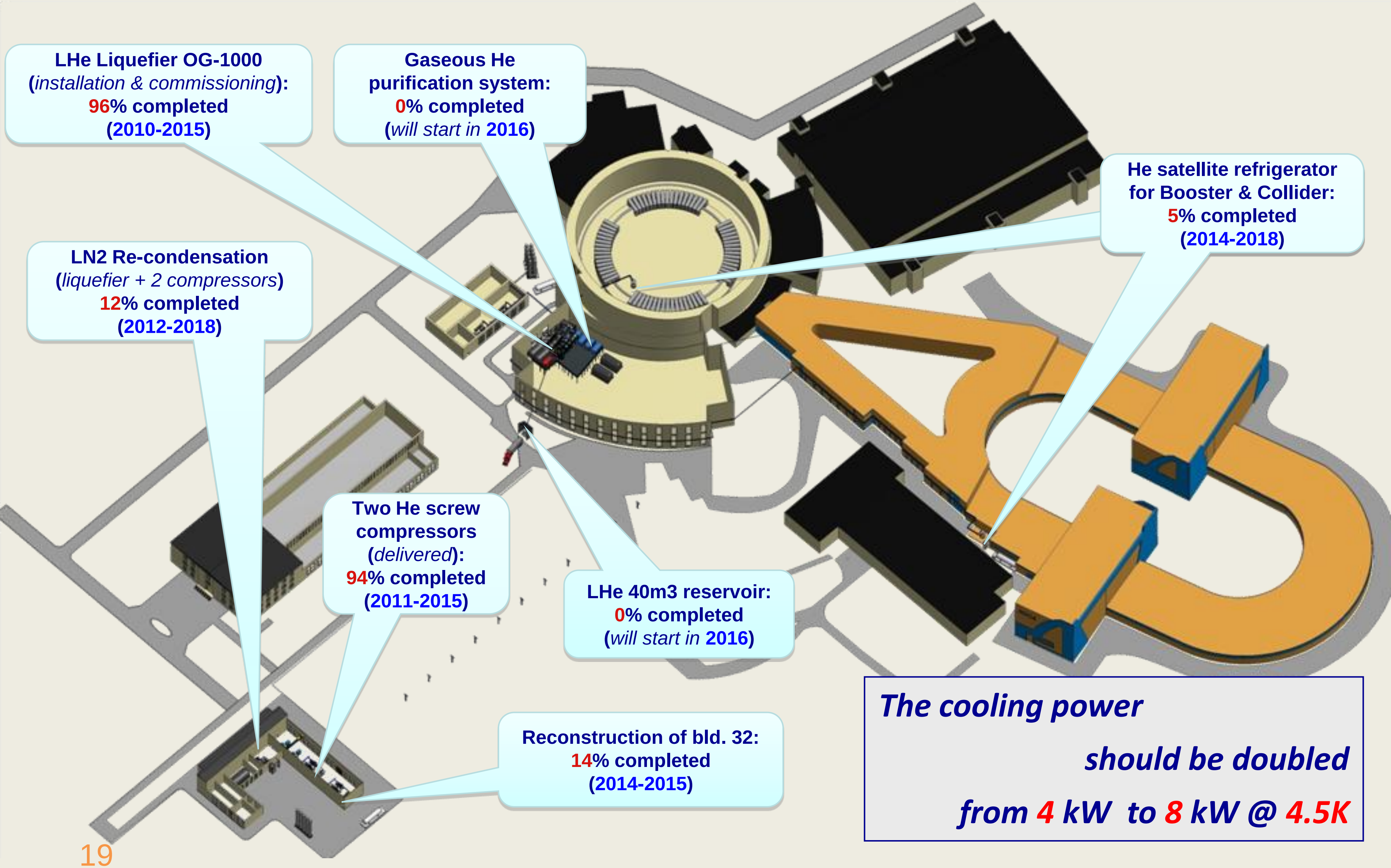
Facility for assembling and serial tests of SC-magnets

Status
ration
ration
ration
development
development
construction

Cryogenic test hall	t bench in operation, 2nd test bench– now testing
Power converters hall	In operation

quadrupoles																	
multipole correctors																	
nonstructurals																	

Development of the NICA Cryogenics



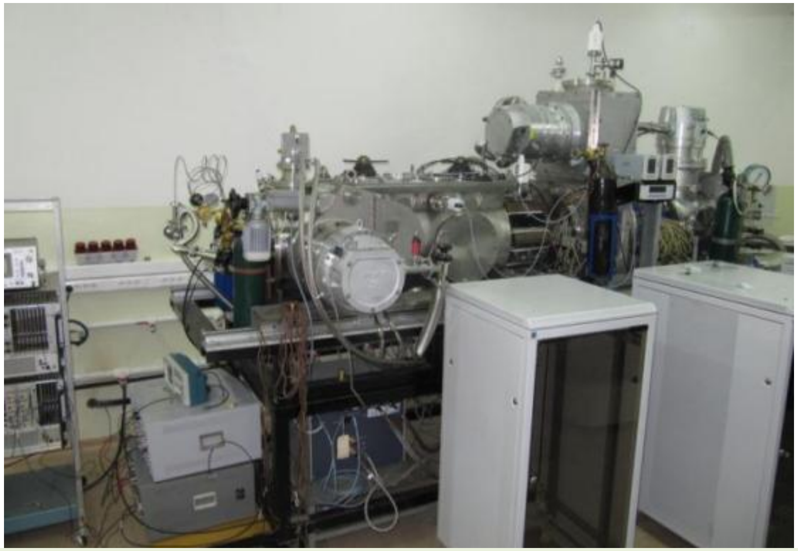
The cooling power

should be doubled

from 4 kW to 8 kW @ 4.5K

Progress in NICA injection complex: *ion sources*

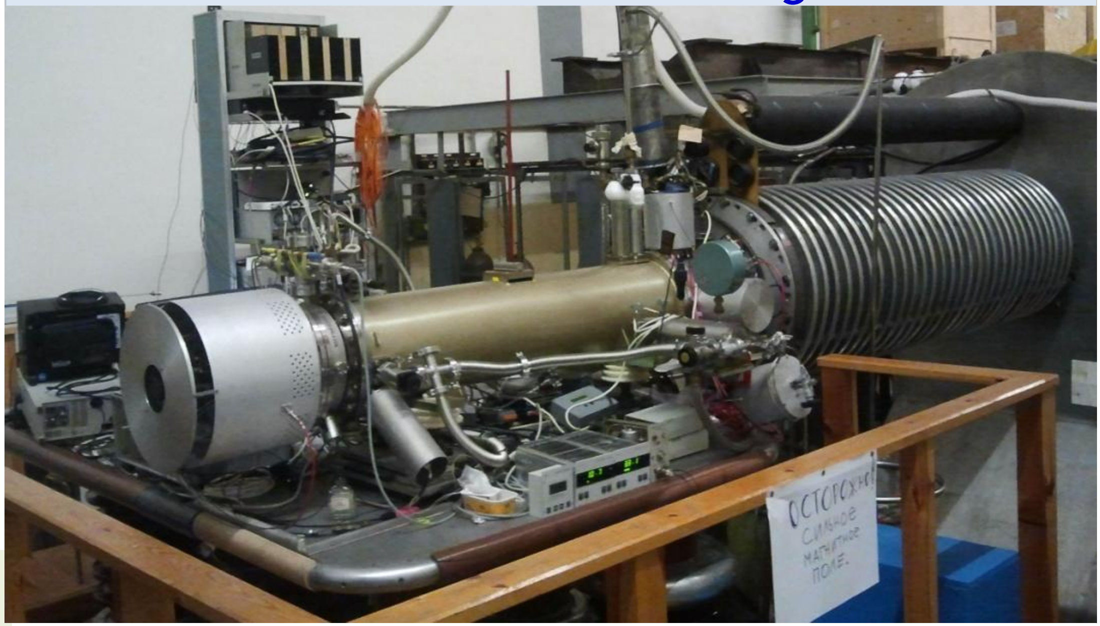
Source of polarized particles (SPP)



SPP is now commissioned to provide 10^{10} polarized deuterons/pulse

Heavy ion source: Krion-6T ESIS @ LU-20

Electron **S**tring **I**on **S**ource



5.4T magnetic field reached in a robust regime. Test gold ion beams have been produced:

- $Au^{30+} \div Au^{32+}$, 6 **x**10^8 ions/pulse,
  20 ms ionization time
- $Au^{51+} \div Au^{54+}$, 1.3×10^8 ions/pulse

*The achieved electron string current density J ~**1400** A/cm^2*
fits to the NICA-MPD requirements

NICA Heavy ion injector

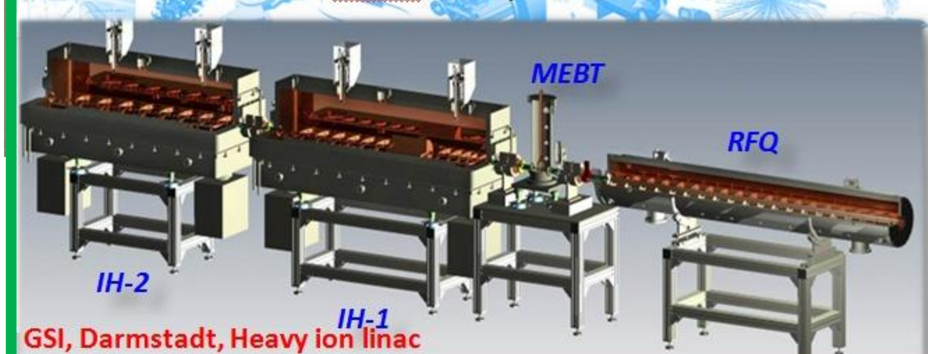
High current (10 mA) HI Linac (HILAC)

"BEVATECH OHG" in Offenbach/Mainz

HILAC delivered to Dubna, start of commissioning in July 2015

RFQ section in new HILINAC hall

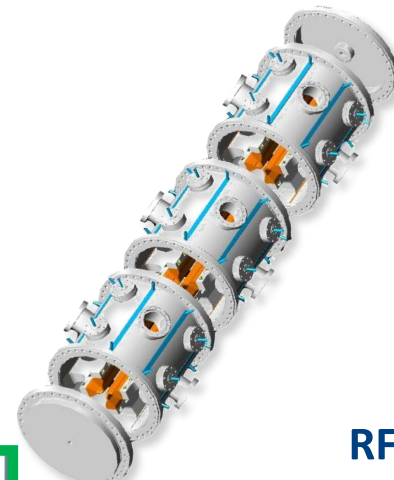
NICA HILac: RFQ + IH1 + IH2



	Type	Weight	Length	RF power	Exit energy
RFQ	4 - rod	2000 kg	3.16 m	120 kW	0.3 MeV/u
MEBT	Two QD + buncher	500 kg	1.4 m	3 kW (buncher)	0.3 MeV/u
IH1	DTL + QT	4000 kg	2.3 m	296 kW	2 MeV/u
IH2	DTL	3900 kg	2.1 m	278 kW	3.2 MeV/u

NICA light ion injector (LU-20)

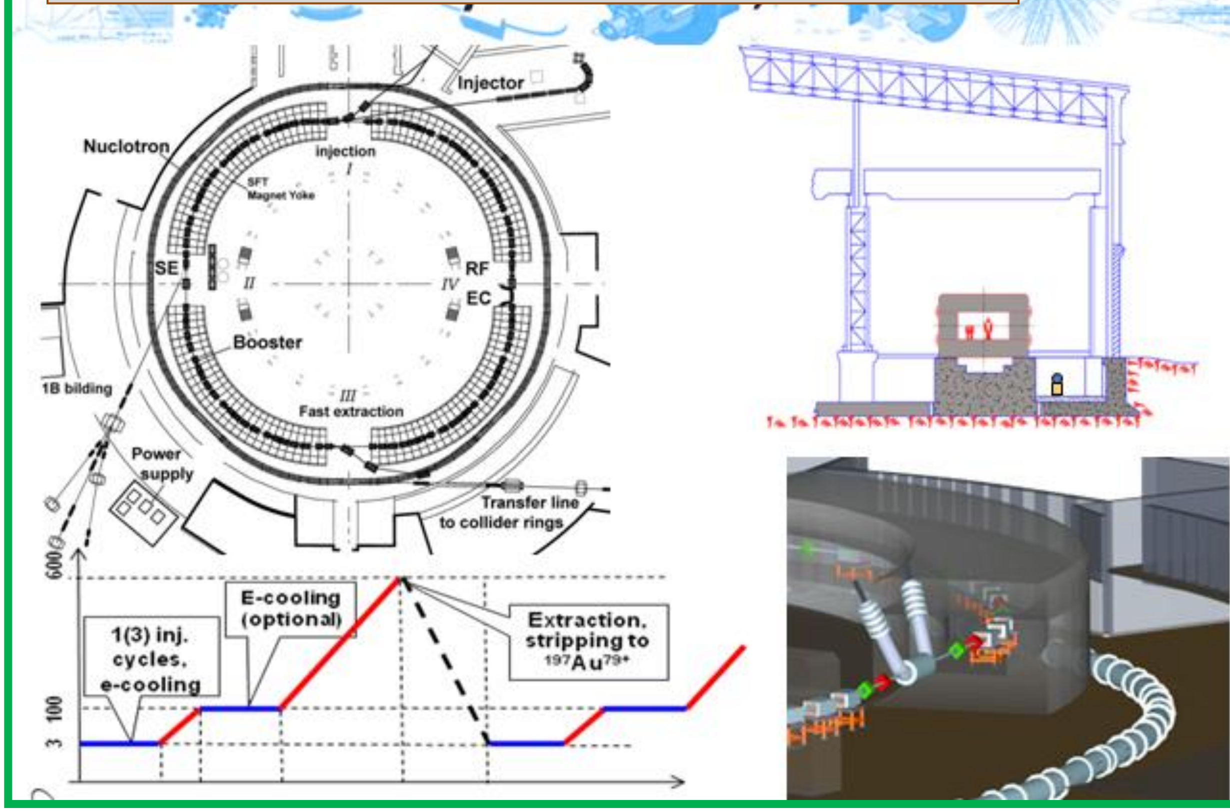
RFQ resonator. Production started in 2013 (ITEP, MEPHI, VNIITP Snezhinsk)



RFQ resonator:
copper plating finished. Delivered to ITEP for commissioning in Sept. 2015

The Booster – commissioning in 2017

Booster synchrotron: C = 211 m
ultra high vacuum
electron cooling



40 Dipole SC magnets

48 Quadruple SC magnets

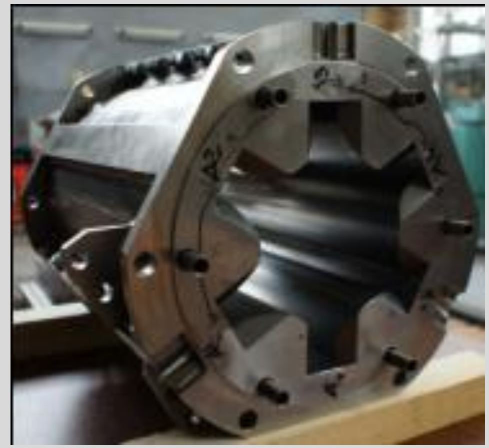
Full-scale Nuclotron–type superconducting prototypes of dipole and quadrupole magnets for the NICA booster and collider were manufactured at LHEP JINR, **have successfully passed the cryogenic test on the bench.**

Serial production of the magnets: for the booster started in Dec. 2014

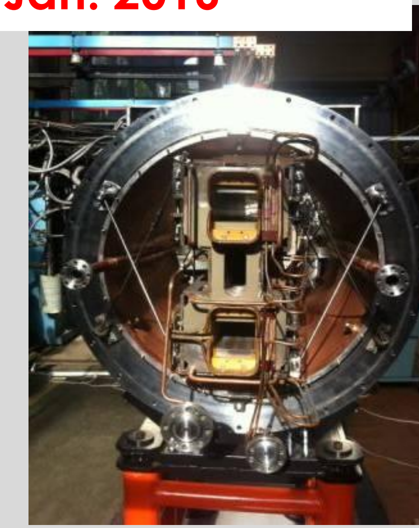
for the collider will start in Jan. 2016

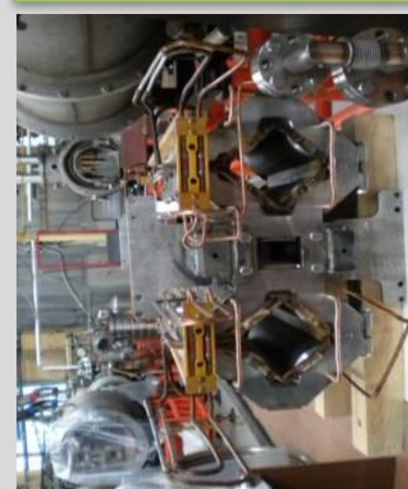
Booster dipole (up) and quadrupole lense and Q-doublet (down)

Booster UHV beam chamber (curved)



Sextupole corrector prototype for booster and SIS100 at assembly





Collider dipole (up) and quadrupole lense (down)

Magnets (booster+ collider+SIS-100) production plan

		2015				2016				2017				2018				2019				2020			
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Booster																									
dipoles	**40+3**																								
quadrupoles	**48+6**																								
multipole correctors	**40+4**																								
Collider																									
dipoles	**80+5**																								
quadrupoles	**86+5**																								
multipole correctors																									
nonstructurals																									
SIS-100																									
pre-series quadrupole	**2**																								
pre-series sextupole correctors	**1**																								
pre-series dipole correctors	**2**																								
pre-series multipole correctors	**2**																								
quadrupole	**166**																								
sextupole correctors	**48**																								
dipole correctors	**83**																								
multipole correctors	**12**																								

Booster magnets in 2015:
- **16** *dipoles*
- **24** *quadrupoles*

NICA fixed target mode @ Nuclotron beams

Intensities, particles per cycle

Beam	Energy	GSI (SIS18)	Nuclotron-M (2011)	Planned with Nuclotron-N (2015)	Planned with new ion source and booster (2017)
p	4,5 GeV	$2\cdot10^{10}$	-	$5\cdot10^{11}$	$5\cdot10^{12}$
d	2,2 GeV	$5\cdot10^{11}$	$6\cdot10^{10}$	$5\cdot10^{11}$	$5\cdot10^{12}$
^{4}He			$2\cdot10^{9}$	$3\cdot10^{10}$	$1\cdot10^{12}$
d↑			$2\cdot10^{8}$	$7\cdot10^{10}$ *(SPP)*	$7\cdot10^{10}$ *(SPP)*
$^{7}Li^{6+}$			$7\cdot10^{9}$	$3\cdot10^{10}$	$5\cdot10^{11}$
$^{12}C^{6+}$	300 MeV	$7\cdot10^{10}$	$6\cdot10^{9}$	$3\cdot10^{10}$	$3\cdot10^{11}$
$^{24}Mg^{12+}$	300 MeV	$5\cdot10^{10}$	$7\cdot10^{8}$	$4\cdot10^{9}$	$5\cdot10^{10}$
$^{40}Ar^{18+}$	300 MeV	$6\cdot10^{10}$	$8\cdot10^{6}$	$2\cdot10^{9}$	$2\cdot10^{10}$
$^{56}Fe^{28+}$			$4\cdot10^{6}$	$2\cdot10^{9}$	$5\cdot10^{10}$
$^{58}Ni^{26+}$	300 MeV	$8\cdot10^{9}$			
$^{84}Kr^{34+}$	0,3 -1 GeV	$2\cdot10^{10}$	$2\cdot10^{5}$	$1\cdot10^{8}$	$1\cdot10^{9}$
$^{124}Xe^{48/42+}$	0,3 -1 GeV	$1\cdot10^{10}$	$1\cdot10^{5}$	$7\cdot10^{7}$	$1\cdot10^{9}$
$^{181}Ta^{61+}$	1 GeV	$2\cdot10^{9}$			
$^{197}Au^{65/79+}$		$3\cdot10^{9}$		$1\cdot10^{8}$	$1\cdot10^{9}$
$^{238}U^{28+/73+}$	0,05-1 GeV	$6\cdot10^{9}/2\cdot10^{10}$			

Experiments & activities at Nuclotron

- ALPOM-2
- DSS

✓ Cross-section measurements in elastic & inelastic scatterings of polarized & unpolarized beams on polarized & unpolarized targets, measurements of polarization analyzing power

✓ Study of 3-nucleon forces

- HyperNIS

✓ Study of properties of lightest hypernuclei and search for the effects of hidden strangeness

- PHASA-3

✓ Study of phase transitions in nuclear matter

- BM@N

✓ Study of baryonic matter with strangeness

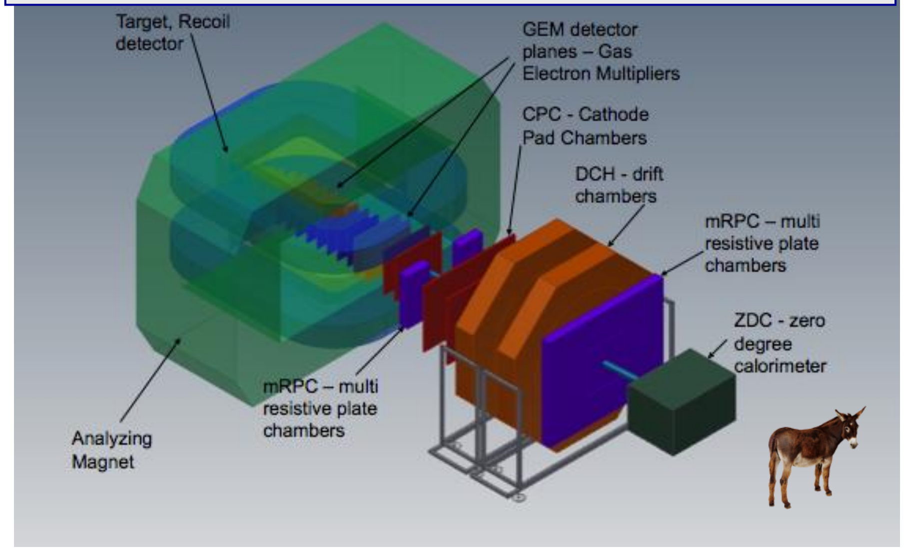
- Energy & transmutation
- Compact electron & ion accelerators
- ….

BM@N (2016) : Study of dense baryonic matter at < 6 GeV/n

Physics is complementary to the MPD (2019) program & will be up-to-date even after MPD start-up

BM@N: *the 1st stage*

approved in 2012



Collaboration of 19 scientific centers:

INR, SINP MSU, IHEP + S-Ptr Univ. (RF);

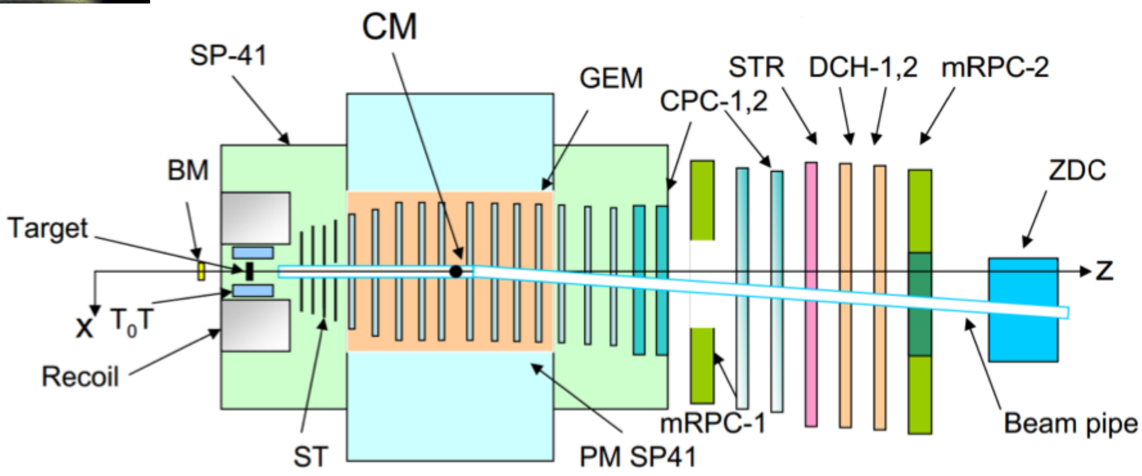
GSI, Frankfurt U., Gissen U. (Germany):

+ CBM-MPD IT-Consortium, …

Physics:

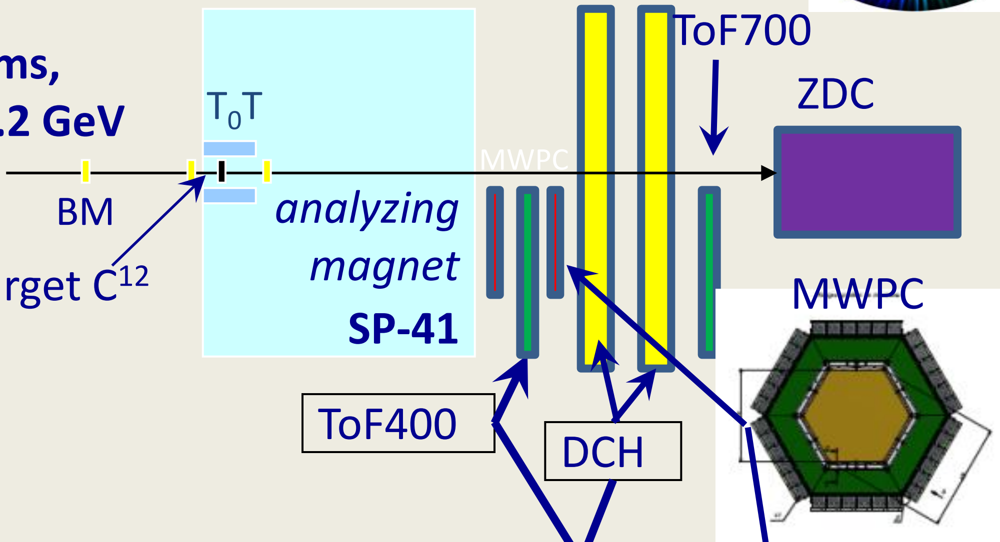
- ✓ *hyperon & hypernuclei production*
- ✓ *hadron femtoscopy*
- ✓ *in-medium effects for strange & vector mesons*
- ✓ *electromagnetic probes (optional)*

BM@N *schematic view*



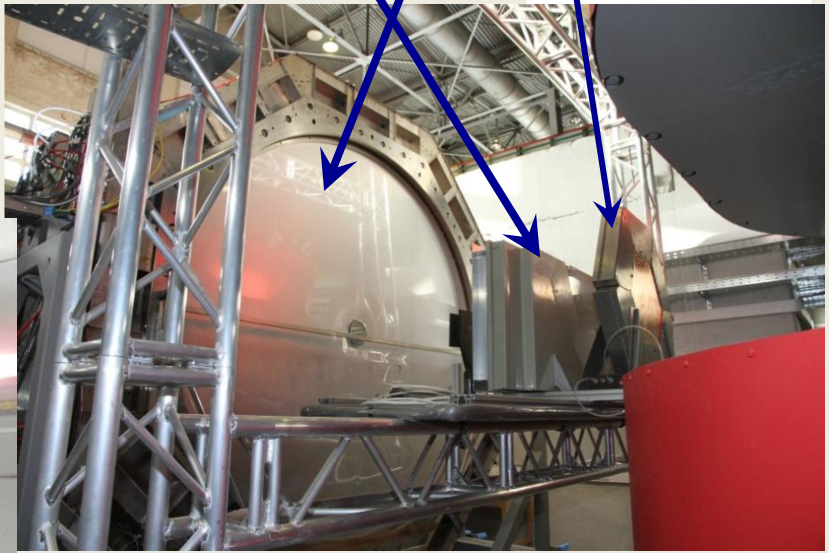
BM@N technical run in February-March 2015

d, C^{12} beams,
T_0= 3.5– 4.2 GeV



<u>**Tasks for test run**</u>:

- *trace d, C^{12}; beam profile/structure*
- *test detector response: ToF400/700 (part), DCH-1,2 (part), ZDC (part),T_0T, BM*
- *test integrated DAQ / trigger based on T_0T in magnet*



ZDC on movable platform

NICA collider mode

MPD (2019) & SPD (>2019)

The MultiPurpose Detector (MPD) project

- approved in 2010

The goal:

Search for the mixed phase and phase transition of strongly interacting matter in processes:

AA, pA and pp interactions

using variety of nuclei A (from p to Au)

scanning over energy range: $\sqrt{S_{NN}}$ = 4 – 11 GeV with a fine steps

Strategy: detailed energy & system size scan *with a step ~ 10 MeV/u in selected regions*

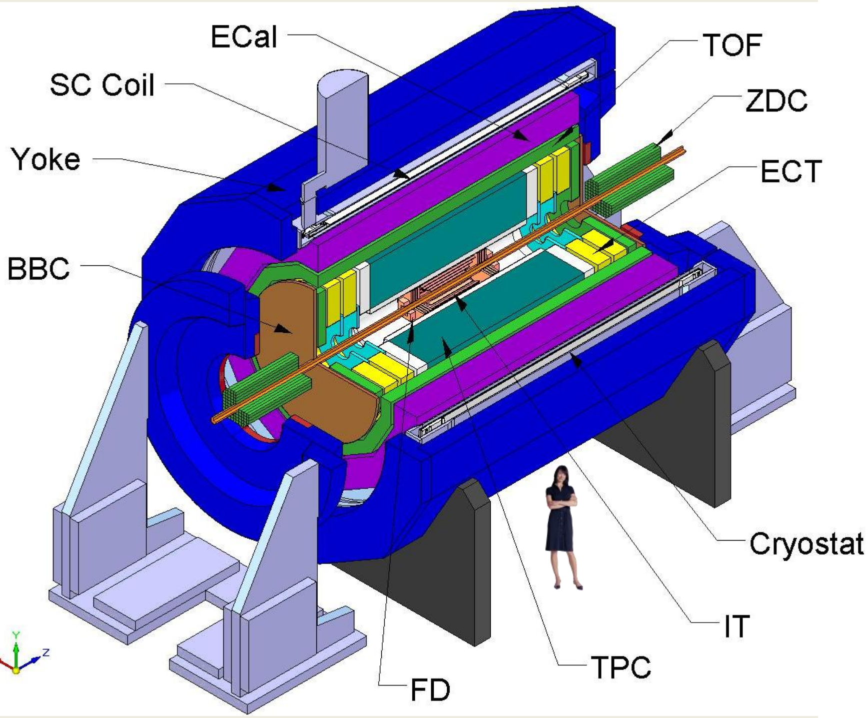
at high **L** allowing the high statistic (*precision*) studies

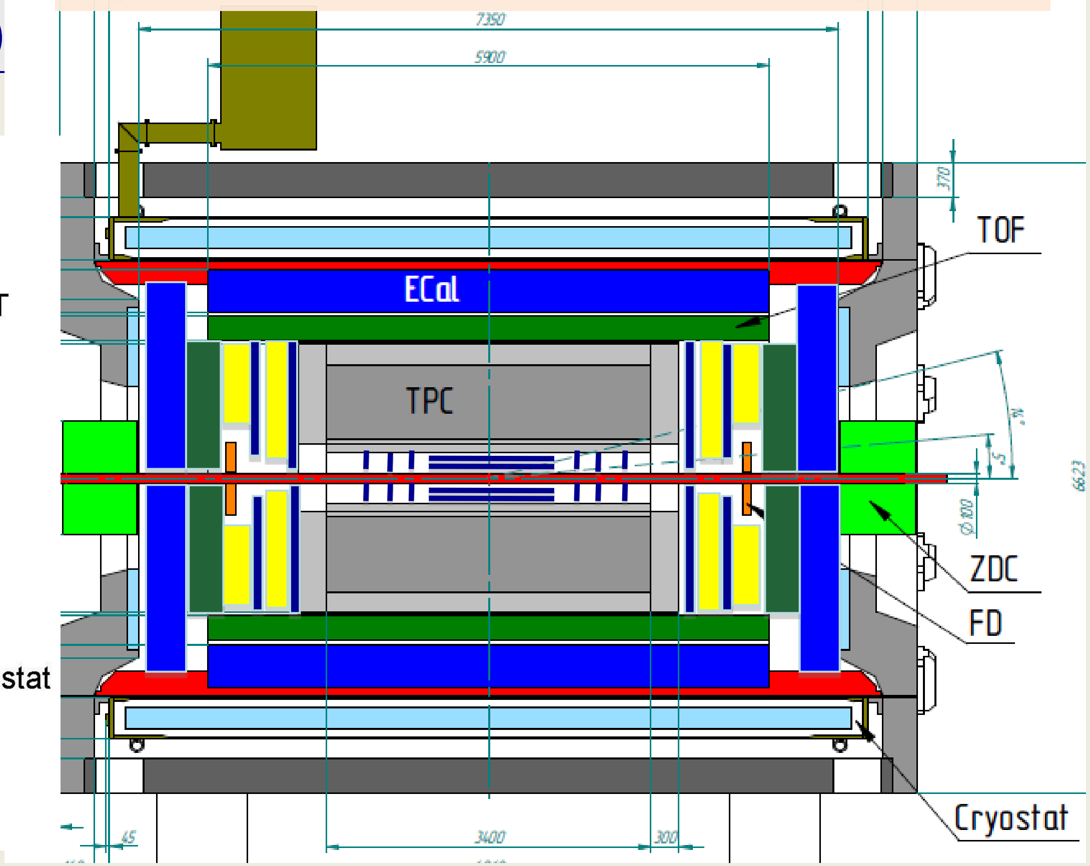
MPD detector for Heavy-Ion Collisions @ NICA

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)





Status: *technical design and detector R&D – completed;*
Preparation for the mass production
Contracts for the production of MPD SC Solenoid – to be signed in 2015

SPD status

LoI-02.06.14 (17 institutions):

SPIN PHYSICS EXPERIMENTS AT NICA-SPD WITH POLARIZED PROTON AND DEUTERON BEAMS

18.02.2015 JINR SPD working group formed:

- to start the work on SPD TDR
- to organize the work related to the acceleration of polarized particles and beam polarization measurements
- to organize formation of the international collaboration

The proposed measurements:

► DY processes
► Direct (prompt) photons

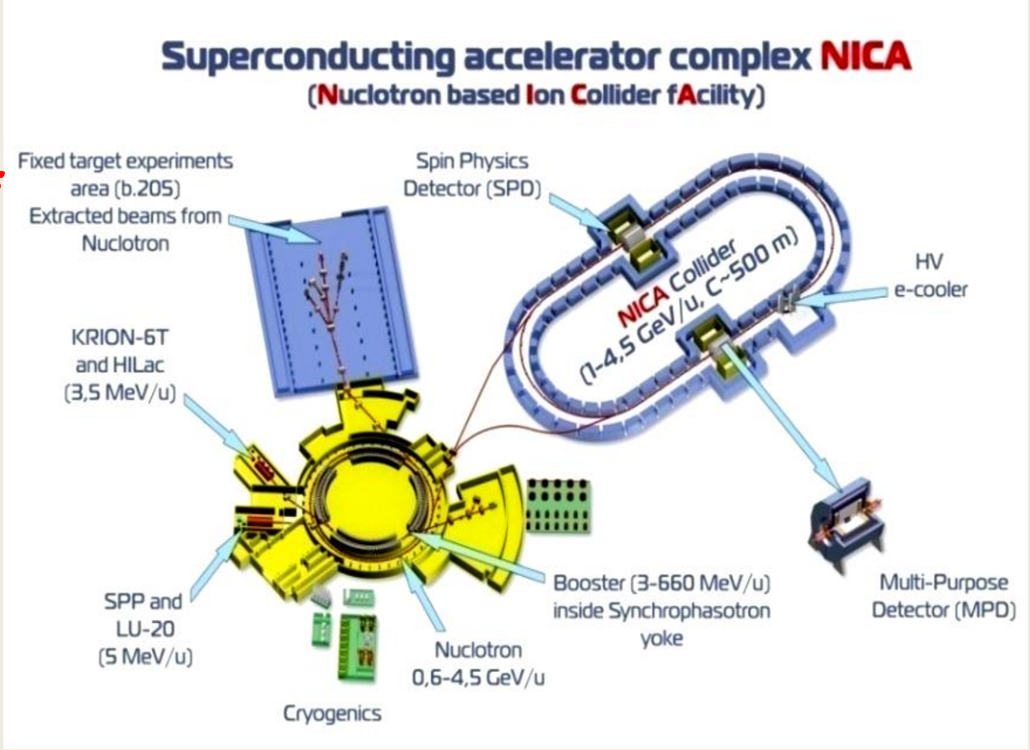
} *to solve spin crisis*

► J/Ψ production processes

► Spin effects in inclusive high-p_T reactions.

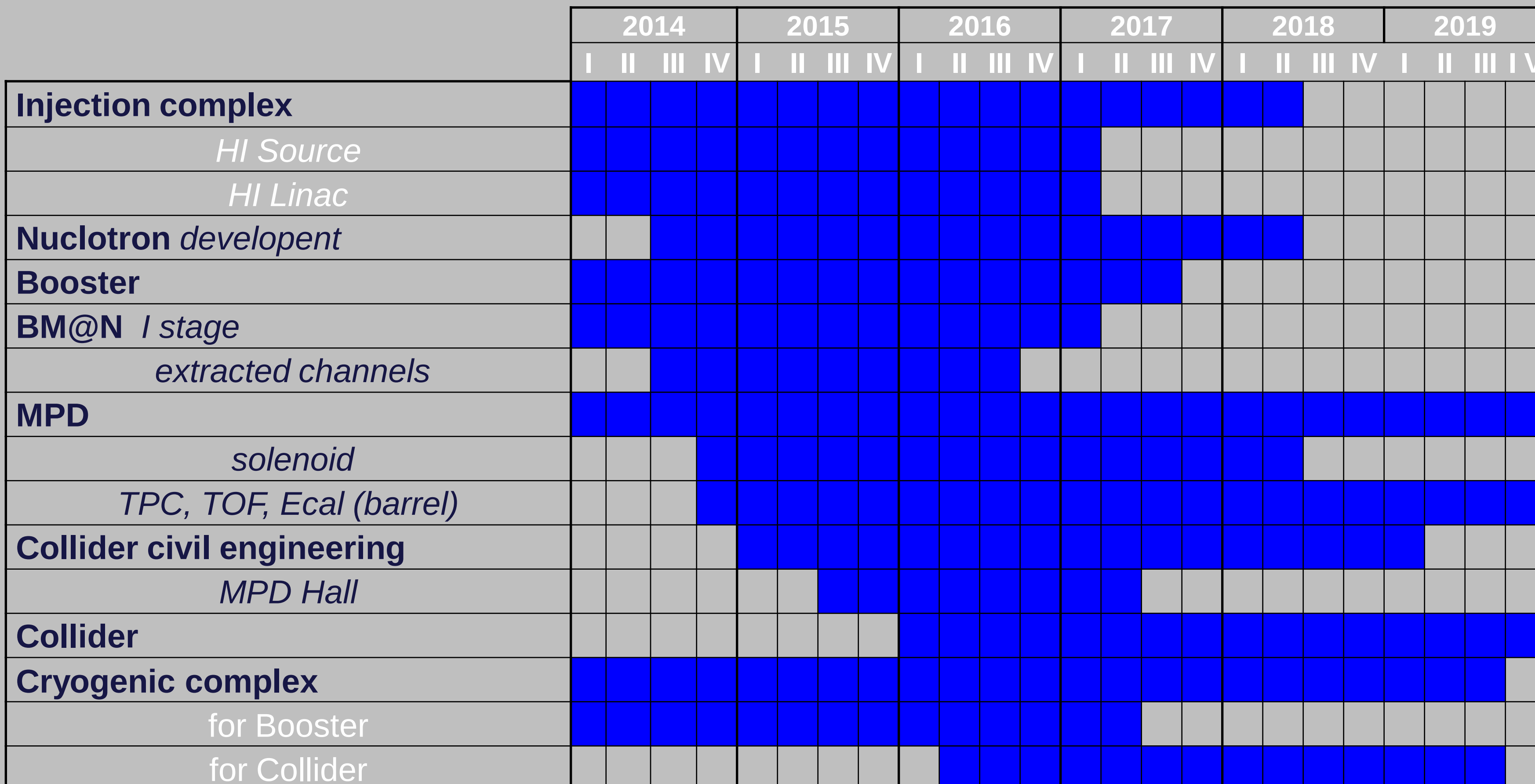
► Polarization effects in heavy ion collisions.

► Spin-dependent effects in elastic pp, dp, dd scattering



Tentative schedule for NICA

(to be updated after the major contracts are signed)



NICA as one of the 6 mega-science projects in RF

08 Aug'13: Representatives of 13 countries, 6 signed to join the mega-science project NICA

08 Aug'13: Representatives of 13 countries, 6 signed: **Belarus, Bulgaria, Germany, Kazakhstan, RF, Ukraine**. Ready to join: **China and South Africa .**

The Parties have agreed to inform their Governments about the Meeting on Prospects for Collaboration in the Mega-Science Project "NICA Complex" and to express their interest in preparing corresponding multilateral Agreement and in taking steps for approval by their countries

Germany (BMBF, GSI) – to the Test Facility for SC magnets and Si tracker Lab; **MoU**

China (ASIPP) – to the HTSC current leads, SC magnets, vacuum systems; **MoU**

USA (FNAL) – to the NICA collider stochastic and electron cooling systems; **MoU**

CERN – to the BM@N and MPD elements (drift chambers, MM systems…); **MoU**

Rep. of South Africa – cryostats, diagnostics for SC ion source, cryogenics. **MoU**

Extension of the International Cooperation

NICA & FAIR became the part *(Work Package 3)* of **CREMLIN** project (Connecting Russian & European Measures for Large-scale Research Infrastructures) in the framework of **HORIZON 2020**

Signed by 19 European Institutes (including JINR + 5 Russian Institutes)

Project kick-off:
Moscow, Oct. 5-8, 2015

Bulgarian authorities (Nuclear Regulatory Agency, as a representative in JINR CPP and Ministry of Education) take a decision about submission of the NICA project to ESFRI Roadmap. Special letter of Commitment prepared and Letter of support for the submission of the NICA project.

Authorities of **Czech Republic**, **Romania** and **Slovakia** kindly considered favorably the support to this submission.

CREMLIN objectives for NICA & FAIR:

- *exchange of know-how on designing and constructing detector and accelerator components*
- *involvement in common activities to bundle resources and create additional synergies*
- *providing support in coordination, reviewing and training*

European Commission
RESEARCH & INNOVATION
Infrastructures

The ESFRI Roadmap identifies new Research Infrastructures (RI) of pan-European interest corresponding to the long term needs of the European research communities, covering all scientific areas, regardless of possible location.
Project descriptions highlight the manner in which they would impact on science and technology development at international level, how they would support new ways of doing science in Europe, and how they would contribute to the enhancement of the European Research Area.

External activities

@

CERN, BNL, Fermilab, GSI/FAIR, Japan, China, Italy

- **I. CERN (LHC):** LHC development – consolidation of SC magnets;
  CMS, ALICE and ATLAS – data taking & analysis & ***upgrade***;
- **II. CERN (SPS):**
  COMPASS – finished 1st phase. Detector modification to measure GPD (DVCS) and polarized/unpolarized D-Y;
  NA61 – neutrino and heavy-ion programs;
  NA62 – measurement of extremely rare decays **($K^+ \to \pi^+ \nu\nu$)** ;
  DIRAC – lifetime measurement of $\pi\pi$ and πK atoms completed at PS; collaboration formed to continue at SPS (20-40 gain in stat.)
- **III. BNL (RHIC):**
  STAR - energy scan HI program and physics with polarized beams (important experience for future research at NICA)
- **IV. Fermilab:**
  CDF, D0 – data analysis: the most precise masses of W и t-quark
  Mu2e **($\mu \to e$),** ORKA **($K^+ \to \pi^+ \nu\nu$)** – in discussion
- **V. GSI, FAIR (SIS-18/100/300):**
  HADES – data analysis, CBM, PANDA – in preparation
- **VI. J-PARC & KEK:** COMET ($\mu \to e$) – in discussion
- **VII. BEPCII:** BESIII – new narrow mesons around 4 GeV with hidden charm
- **VIII. ν-oscillations:** OPERA (direct $\nu_\mu \to \nu_\tau$) - data analysis
  BOREXINO (Solar ν) – confirmed MSW theory of oscill. in matter
  Daya Bay (Reactor ν) – measured nonzero $\theta_{13} \Rightarrow$ open a way to solve ν mass hierarchy in long base projects Daya Bay II (JUNO), NOVA …

Supporting activities

- Detector systems and Accelerator complexes, e.g. ADVANCED STUDIES ON NEW GENERATION OF ELECTRON-POSITRON ACCELERATORS AND COLLIDERS
- IT & Telecommunications
  JINR Central Information and Computing Complex
- Theoretical physics

ADVANCED STUDIES ON NEW GENERATION OF ELECTRON-POSITRON ACCELERATORS AND COLLIDERS

Scopes of the Project :

- **Optimization of the allocation of ILC complex in Dubna region;**
- **R&D on: CLIC elements;**
  DC photoinjector prototype;
  electron linear accelerator test bench;
- **Reproduction of SC niobium cavities;**
- **Nb explosion welding with stainless steel;**
- **Precise laser metrology;**
- **Investigation on intense electron beams and FEL ;**
- **Low Energy Particle Toroidal Accumulator LEPTA**

IT & Telecommunications

JINR Central Information and Computing Complex

2012 –Tier1 prototype created

1200 cores, 720 TB disk storage, 72 TB tape storage

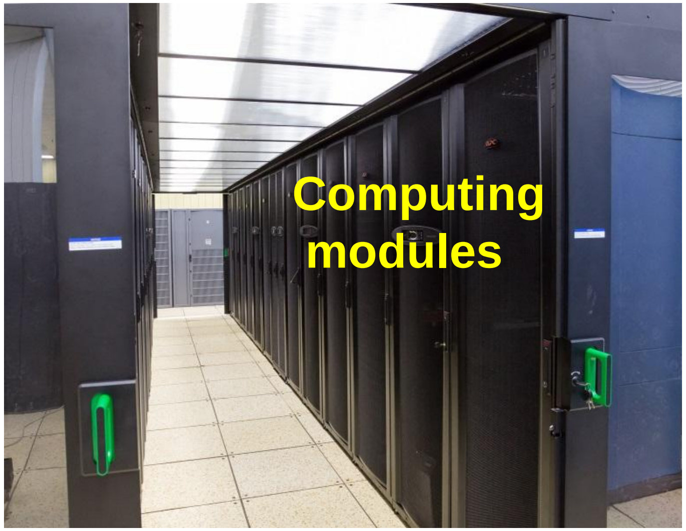
2014 - Russia Tier 1 full scope start-up in WLCG

NRC “Kurchatov Institute” supports ATLAS, ALICE and LHCb

JINR supports CMS

JINR Multifunctional Centre for Data Storage, Processing and Analysis

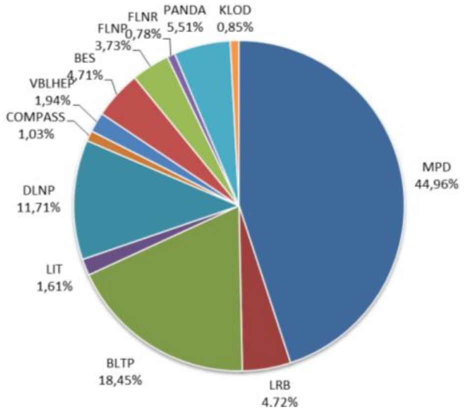
- **Grid-Infrastructure at Tier1 and Tier2 Levels**
- **General Purpose Computing Cluster**
- **Cloud Computing Infrastructure**
- **Heterogeneous Computing Cluster HybriLIT**
- **Education and Research Infrastructure for Distributed and Parallel Computing**



JINR Multifunctional Centre for Data Storage, Processing and Analysis

General Purpose Computing Cluster
Local users (no grid)

Sharing of the resources of the computing cluster according to the processing time among the divisions of the Institute and user groups in 2014.

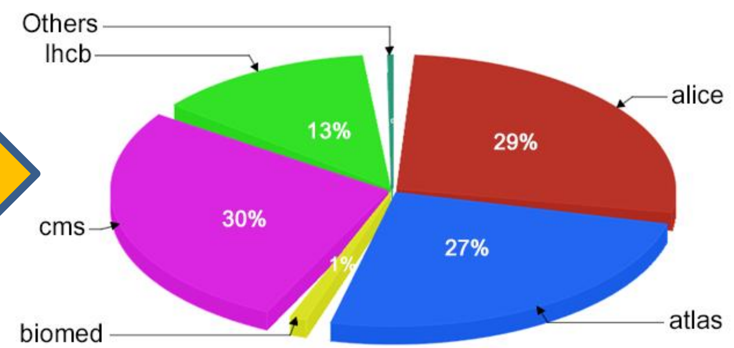


Grid-Infrastructure :
JINR-LCG2 Tier2 Site
JINR-CMS Tier1 Site

Summary of the use of JINR Tier2 grid-infrastructure by virtual organizations of RDIG/WLCG/EGI.

~ 5 million Jobs

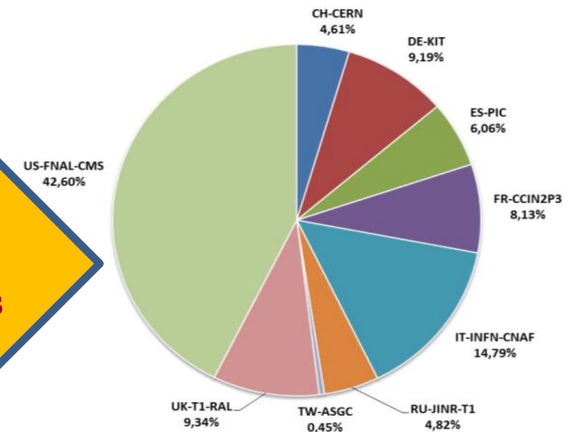
~166 million hours



Usage of Tier1 centers by CMS experiment

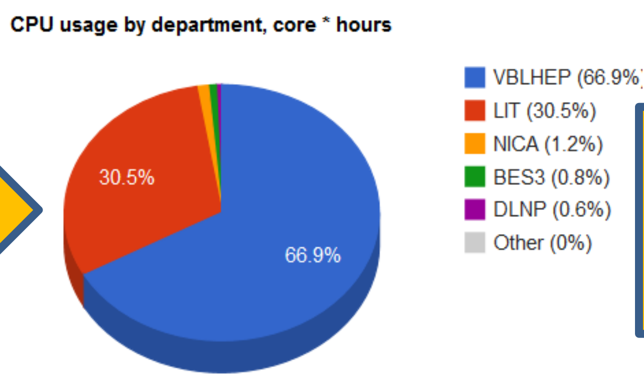
~ 1 million Jobs

~65 million hours



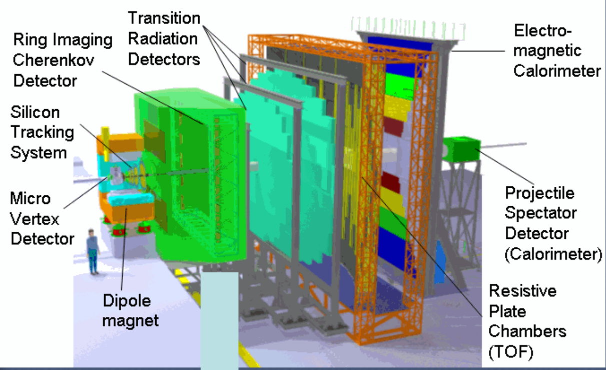
Cloud Infrastructure

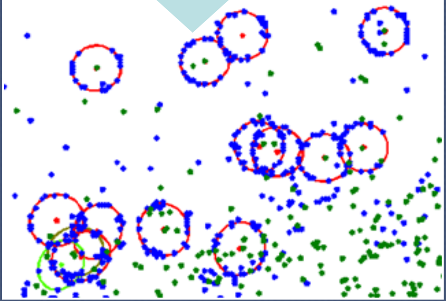
Distribution of cloud resources among the Laboratories and JINR groups in 2014.



CBM (GSI) – Methods, Algorithms & Software for Fast Event Reconstruction

Fast parallel algorithms were developed for event reconstruction in the CBM





Event reconstruction algorithms:

1)Tracking: Kalman filter and track following;
2)Ring reconstruction: Hough Transform, COP, ellipse fitting;
3)Electron identification in RICH: ANN and cuts.

Modern technologies for parallelization:

1) Vectorization (SIMD - Single Instruction Multiple Data);
2) Multithreading (many cores CPU).

Results:

1)High efficiency of track and ring reconstruction (93-95%);
2)Very fast algorithms.

TASK:

1) Development of methods, algorithms and software for:
 - global track reconstruction;
 - event reconstruction in RICH;
 - electron identification in TRD;
 - momentum reconstruction;
2) Magnetic field calculations;
3) Contribution to the CBMROOT.

Task	Initial Time [ms/event]	Parallel Time [ms/event]	Speedup
Tracking	730	1.5	487
Ring reconstruct.	375	2.5	143

The work was awarded with a prize of Governor of the Moscow region for 2012

Theoretical Physics

During last years research at BLTP has been carried out along the following main directions in the field of PP and RHIP:

The Standard Model and Its Extensions
Spin and Hadron Physics
Hadronic Matter under Extreme Conditions
Neutrino Physics

Studies were focused on both:
- purely theoretical problems of PP &
- theoretical support of JINR experimental programs

~ 300 journal articles, reviews and monographs are published per year

~ 15 international conferences, workshops and schools are organized per year with ~ 1000 participants from the JINR member states and other countries

The Standard Model and Its Extensions

For the first time the calculation of the full set of 3-loop Standard Model beta functions was performed. This allows one to relate the SM physics at the TeV and Planckian scales. The analysis proves that the SM is a self-consistent model at least up to the energy of order 10^{10} GeV.

A systematic analysis based on combined LHC data (LHCb experiment), the relic density (WMAP and other cosmological data) and upper limits on the dark matter scattering cross sections on nuclei (XENON100 data) has been performed and indicated that gluinos below 1 TeV and the lightest supersymmetric particle with the mass below 160 GeV are excluded.

Hadron and Spin Physics

Models for transverse momentum and spin-dependent parton distribution were constructed, and new relations between them were derived.

The generalized parton distributions were applied for QCD description of cross-sections and spin asymmetries of exclusive meson leptoproduction.

Neutrino Physics

The field-theoretical approach to neutrino oscillations was developed. The higher-order corrections to the large-distance asymptotic behavior of the wave-packet modified neutrino propagator were derived. The corrections can be relevant to explanation of the reactor antineutrino anomaly.

Hadronic Matter under Extreme Conditions

The kinetic model of AA collisions was generalized to include formation and evolution of electromagnetic fields during a collision as well their influence on the quasi-particle transport. It was shown that the electric field, besides the magnetic one, plays an important role in Chiral Magnetic Effect (CME).

The new source of the P-odd effects in heavy ion collisions due to the medium vorticity was suggested and investigated, and the new mechanism of hyperons polarization was found and explored.

It has been demonstrated that the strong electromagnetic field can trigger the quark deconfinement in QCD and generate additional azimuthal asymmetries in HIC.

Conclusions

- Some important JINR goals achieved:
  - substantial progress in realization of the NICA project
  - top level physics results obtained with the active JINR participation in external experiments at the best world facilities

- The timely and full-scale realization of our plans requires:
  - integration of JINR basic facilities in the international science infrastructure
  - attraction of additional financial and human resources

    (such as support of NICA as one of six international mega-science projects on the territory of RF)

Thank you for your attention!

Welcome to JINR in Dubna

www.jinr.ru