The Third Annual Large Hadron Collider Physics Conference

NICA Plans

Three Stages of The NICA Project

Nuclotron-based Ion Collider fAcility

I.Meshkov for NICA Team

JINR, Dubna

St. Petersburg, August 31 – September 5, 2015

Outline

Introduction: The NICA Project at JINR

The NICA project is aimed to develop, construct and commission at Joint Institute for Nuclear Research (Dubna, Russia) a modern accelerator complex

Nuclotron-based Ion Collider fAcility (NICA)

equipped with two detectors

MultiPurpose Detector (MPD)

&

Spin Physics Detector (SPD)

and perform experiments on search of the mixed phase of baryonic matter state and nature of nucleon/particle spin

Introduction: The NICA Project at JINR

The NICA project is planned to be commissioned in three stages:

I. Fixed target experiments on Nuclotron ion beams:

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

$\sqrt{s}$ *(Au × Au) = 2.33 – 3.47 GeV/u*

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

1 ÷ 4.5 GeV /u   ion kinetic energy

$\sqrt{s_{NN}} = 4 – 11$ *GeV*, $L_{average} = 1 \times 10^{27}\ cm^{-2} \cdot s^{-1}$

Light × Heavy ion colliding beams of the same $\sqrt{s_{NN}}$

and the same or higher $L_{average}$

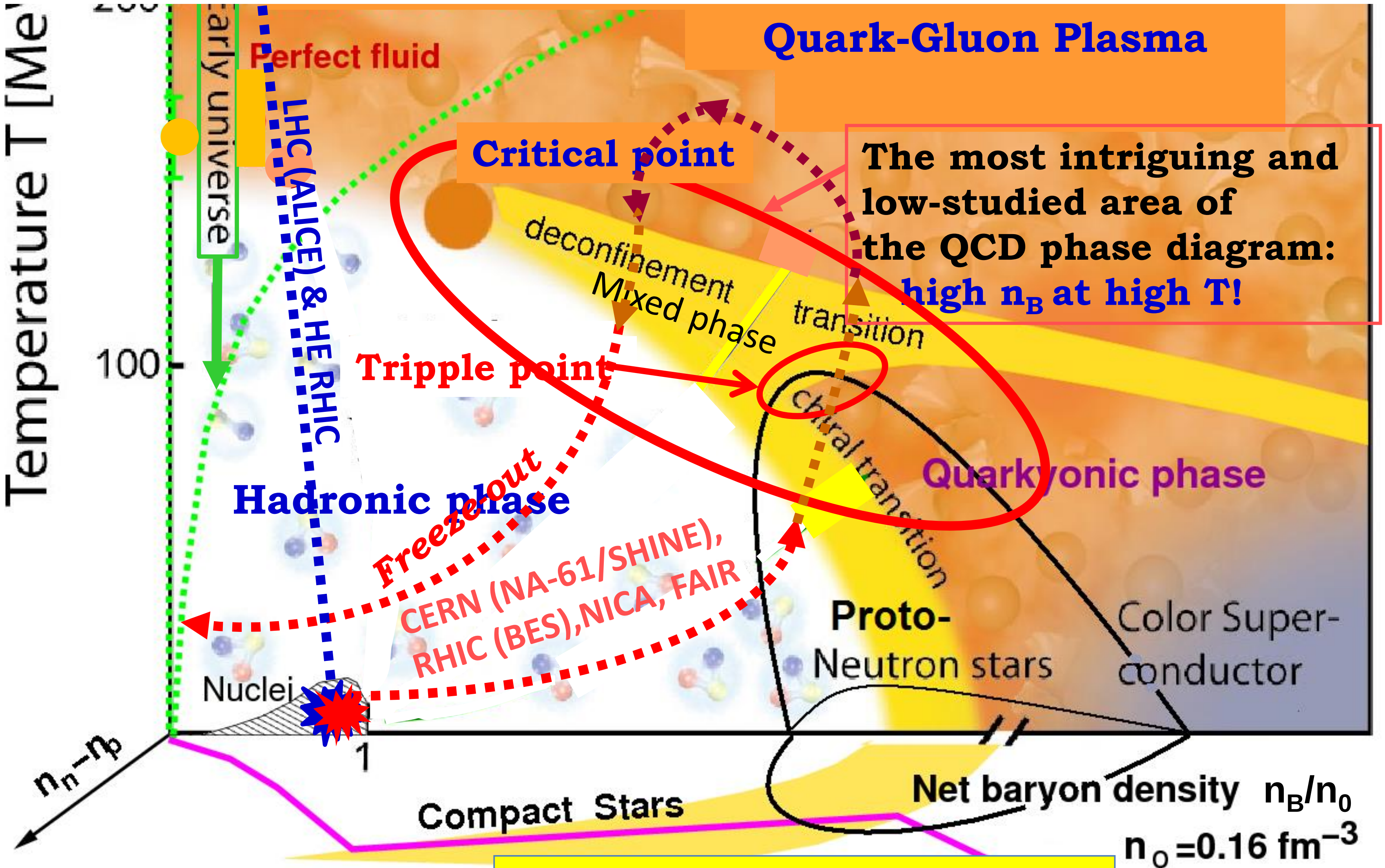
III. *Polarized protons and deuterons*

p↑, p↑ = 5 – 12.6 GeV kinetic energy ($\sqrt{s}$ = 12 – 27 GeV)

d↑, d↑ = 2 – 5.9 GeV/u kinetic energy ($\sqrt{s}$ = 4 – 13.8GeV/u)

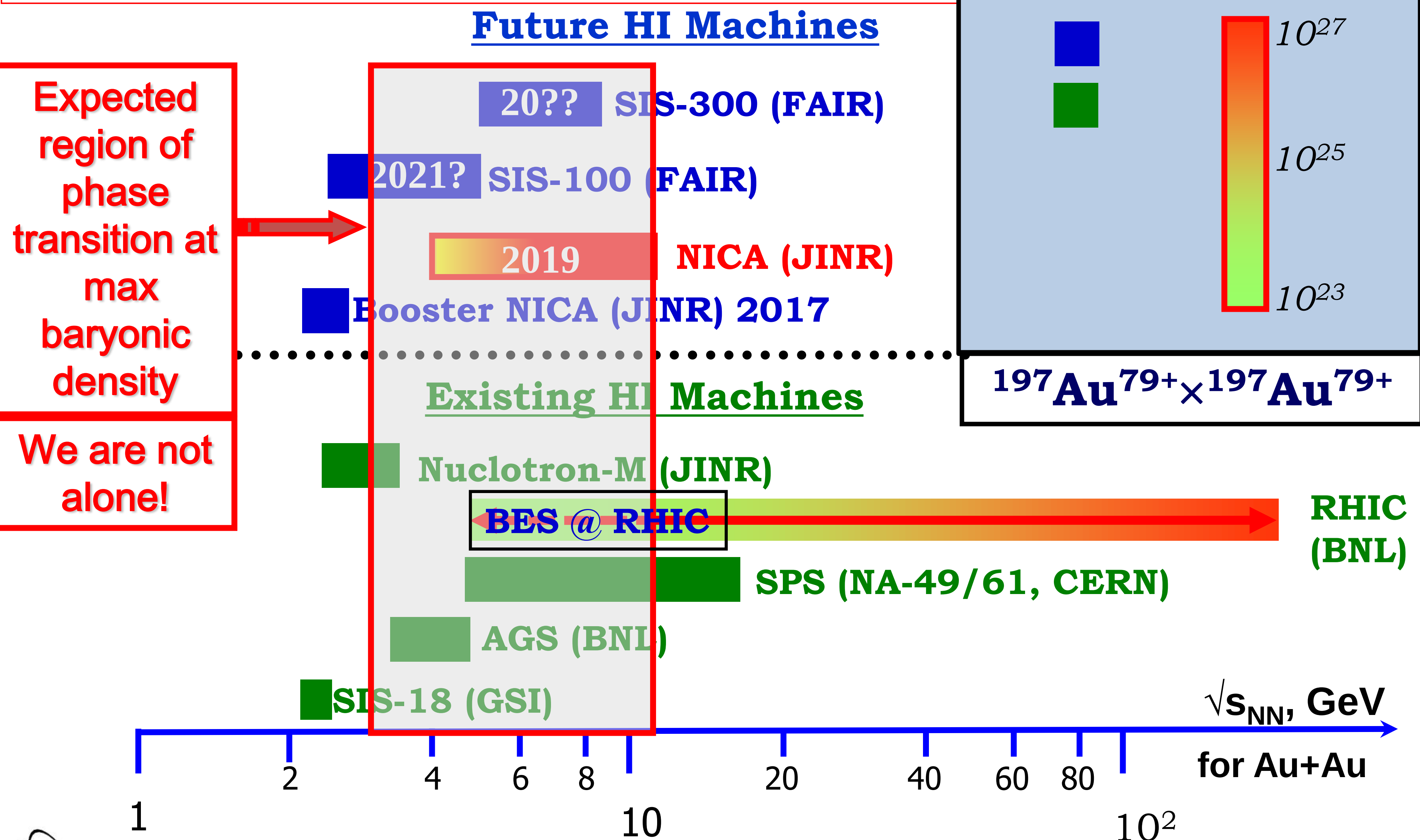
$L_{max} \approx 1x10^{32}\ cm^{-2} \cdot s^{-1}$

Introduction: Physics Case of the NICA project

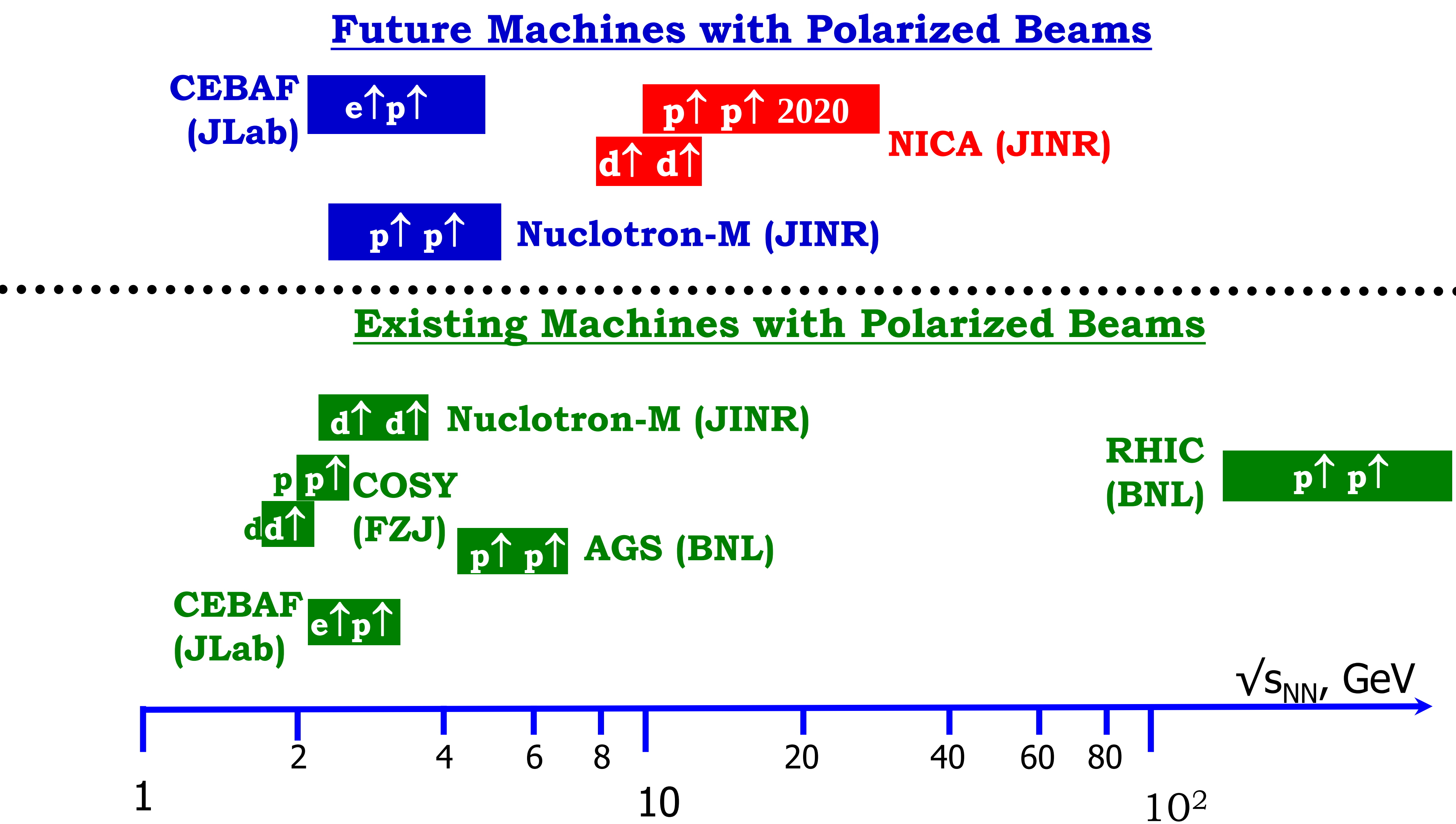


n_B = n_baryon - n_antibaryon

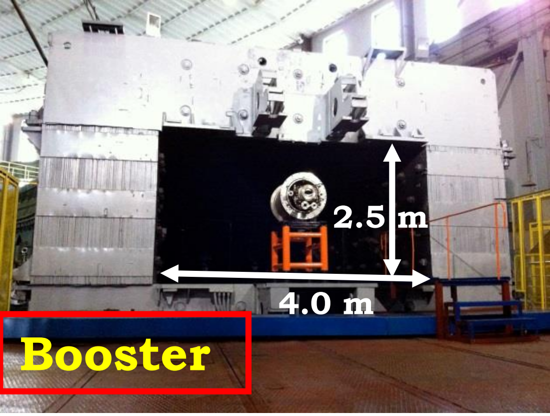
1a.Heavy Ion Accelerators & Colliders in NICA Energy Range



1b. Accelerators & Colliders for Spin Physics Today

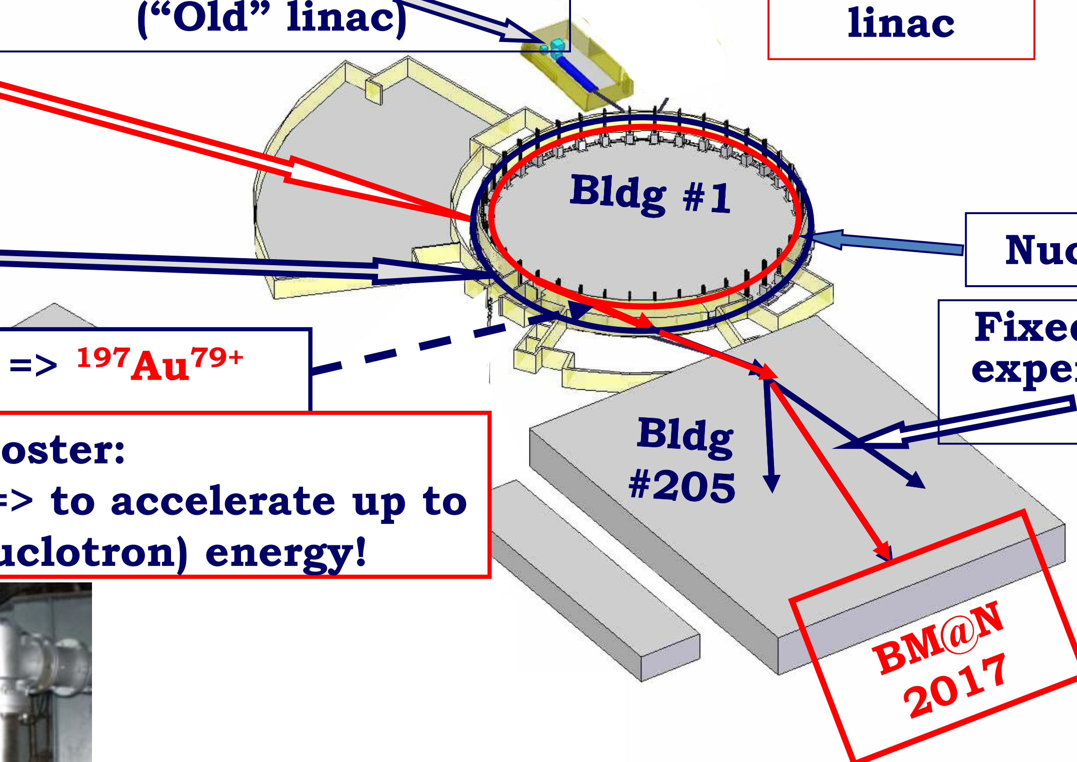


2. NICA – Stage I



SPI and others @ LU-20 (“Old” linac)

KRION-6T & «New» linac



Synchrophasotron yoke

Nuclotron

Fixed target experiments 2014

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$

That is why we need a Booster:
to accelerate => to strip => to accelerate up to as high as possible (for Nuclotron) energy!

Nuclotron facility today

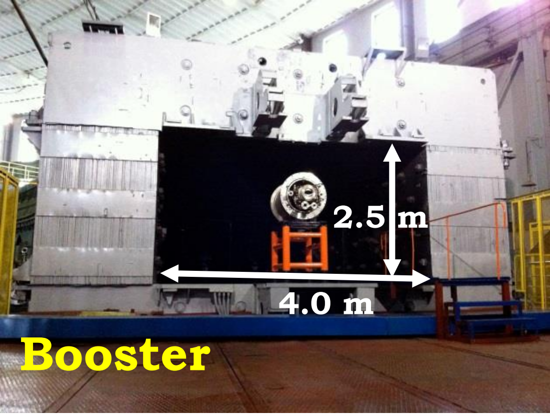
2017 NICA – Stage I
Baryonic Matter @ Nuclotron

Nuclotron Beams

Parameter	*Achieved*		*Project (2017)*	
Magnetic field, T	2.0		2.0 (Bρ = 42.8 T·m)	
Field ramp, T/s	0.8		1.0	
Repetition period, s	8.0		5.0	
	Energy, GeV/u		Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	5.6		6.0	$5{\cdot}10^{10}$
Heavy ions	*Without KRION-2*		*With KRION-6T & Booster*	
$^{40}Ar^{13+}$ => $^{40}Ar^{18+}$	3.5	$5{\cdot}10^{6}$	5.2	$2{\cdot}10^{10}$
$^{56}Fe^{14+}$ => $^{56}Fe^{26+}$	2.5	$2{\cdot}10^{6}$	5.4	$1{\cdot}10^{10}$
$^{131}Xe^{21+}$ => $^{131}Xe^{54+}$	1.5	$1{\cdot}10^{3}$	4.7	$2{\cdot}10^{9}$
$^{197}Au^{31+}$ => $^{131}Au^{79+}$	[1.37]	---	4.5	$2{\cdot}10^{9}$
Polarized beams	*With Polaris*		*With SPI*	
p↑	---	---	11.9	$1{\cdot}10^{10}$ *)
d↑	2.0	$5{\cdot}10^{8}$	5.6	$1{\cdot}10^{10}$

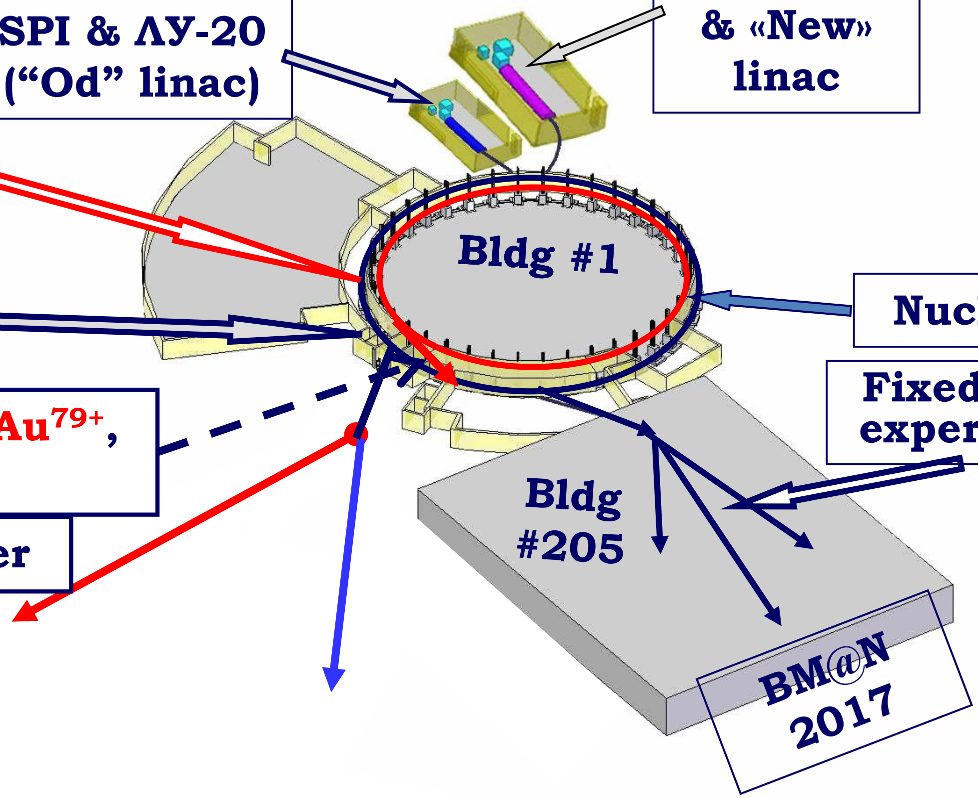
) With the Siberian snake in Nuclotron

3. NICA – Stage II



SPI & ΛУ-20 (“Od” linac)

KRION-6T & «New» linac



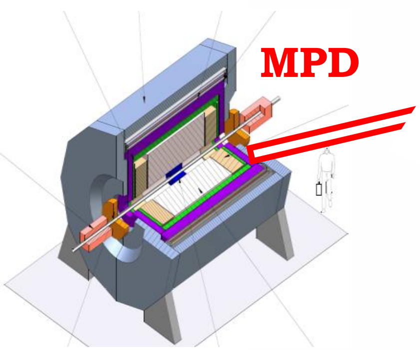
Synchrophasotron yoke

Nuclotron

Fixed target experiments

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$,
Acceleration in Nuclotron

Injection and storage in Collider



≥ 2 x 22 injection cycles
22 bunches per ring,
1e9 ions/bunch

2019 NICA – Stage II

3. NICA – Stage II (Heavy Ion Mode)

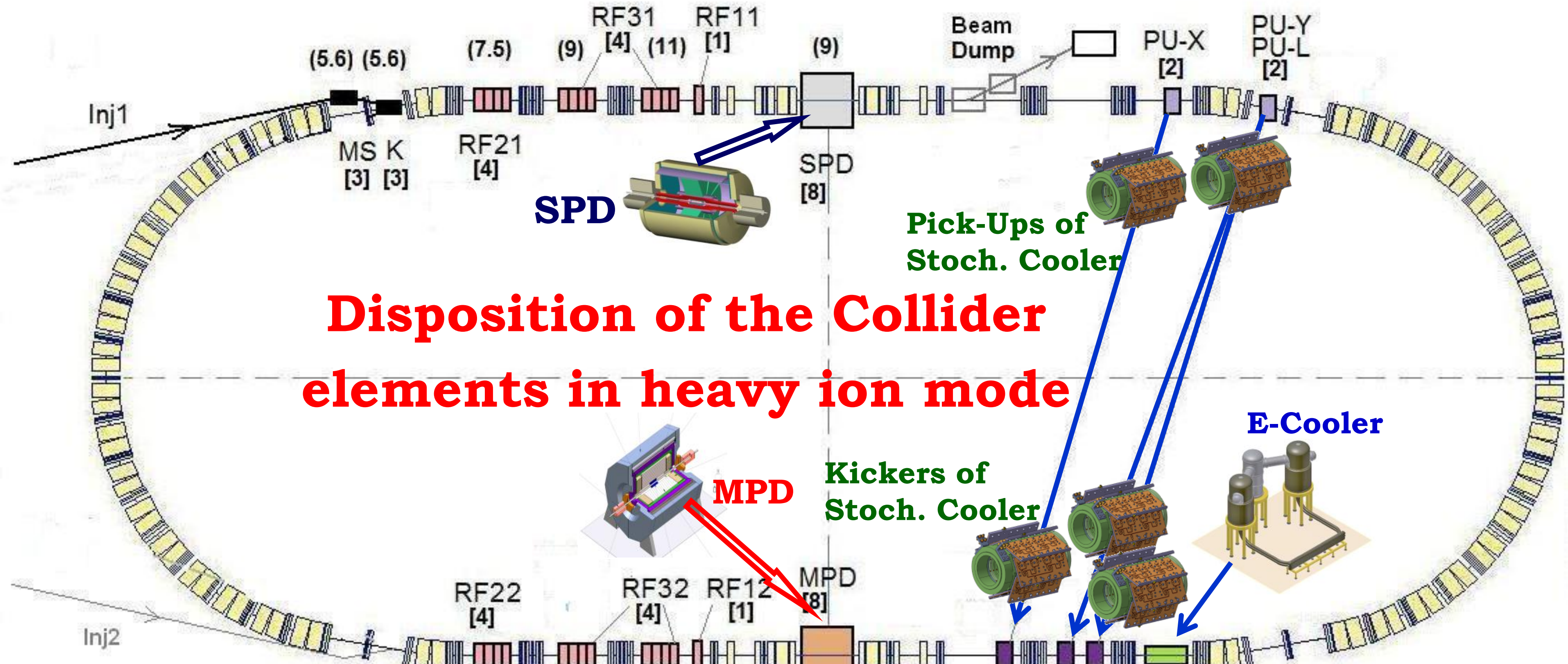
Key Parameters of The NICA Collider

Collider lattice: FODO, 12 cells x 90^0 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 Kin. Energy, GeV/u √s, GeV/u	1.0 4.0	3.0 5.0	4.5 11.0
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, $cm^{-2}\cdot s^{-1}$	1.1e25	1e27	1e27

Cooling is mandatory → IBS growth time

3. NICA – Stage II:
Structure in Heavy Ion Mode



[ ] - element length

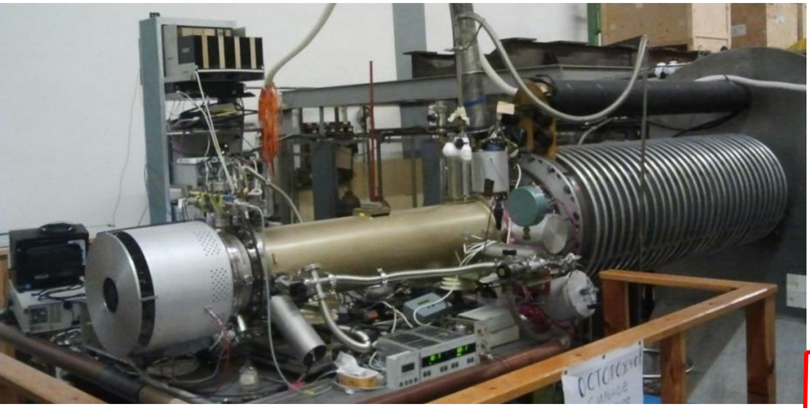
( ) - distance between elements

Au(+79) ion mode

4. NICA Elements Fabrication in Collaboration …

4.1. Heavy Ion Source KRION-6T/ESIS

(Electron String Ion Source modification)



KRION-6T at the LU-20 linac (May 2014)

Test results (April 2014) :

B= 5.4T magnetic field

- $Au^{30+} \div Au^{32+}$, $6 \cdot 10^{8}$ per cycle, rep. rate 50 Hz
- $Au^{51+} \div Au^{54+}$, $1 \cdot 10^{8}$ per cycle, rep. rate 30 Hz

Test at Nuclotron with new RFQ injector of LU-20 is scheduled for spring 2016.

4.2. Heavy Ion Linear Accelerator

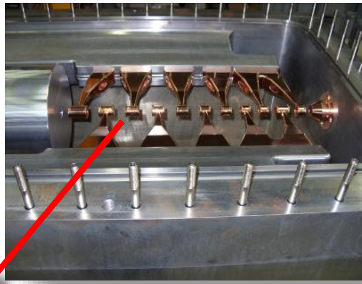
(HILAc, 3 MeV/u)

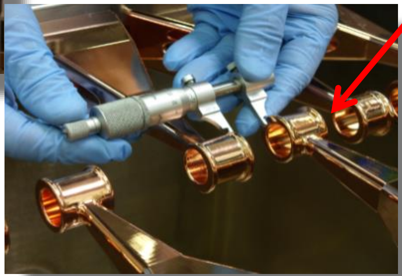
HILAc is under delivery from BEVATECH C° (Frankfurt):
Two sections have been transported to JINR;

Final assembling and test at JINR is scheduled for September 2015.

Resonator # 1 of RFQ section

2nd resonator of RFQ DTL section





Drift tubes and gaps of the 3rd resonator of RFQ DTL

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

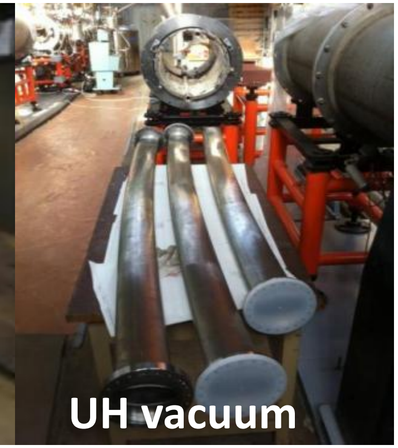
SC Magnet Plant at VBLHEP

Co-investments from JINR and BMBF (GSI, Germany)

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

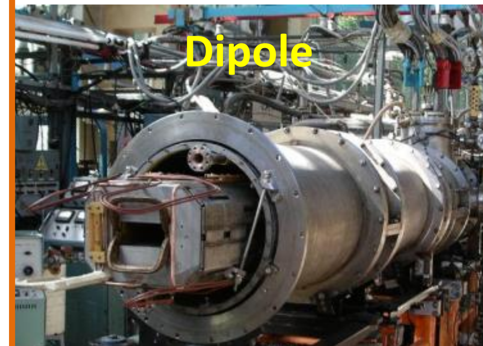
The Booster Elements

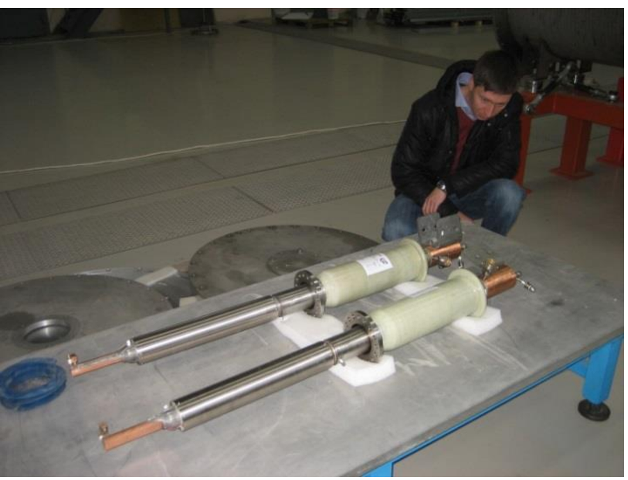
Booster dipole and quadrupole lens



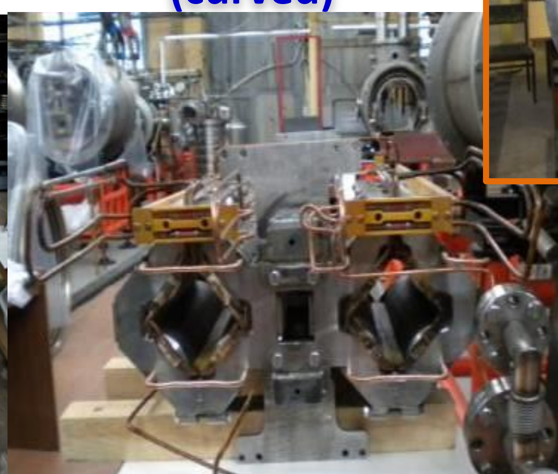
UH vacuum chambers (curved)

SIS-100

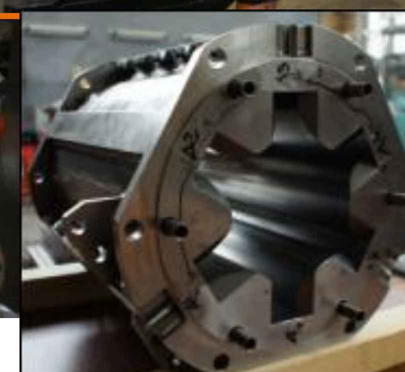




HTSC current leads 17 kA



The Collider "twin" dipole and lens



Sextupole corrector prototype for SIS100 and NICA Booster

4.4 & 4.5. Budker INP (Novosibirsk) - design and fabrication

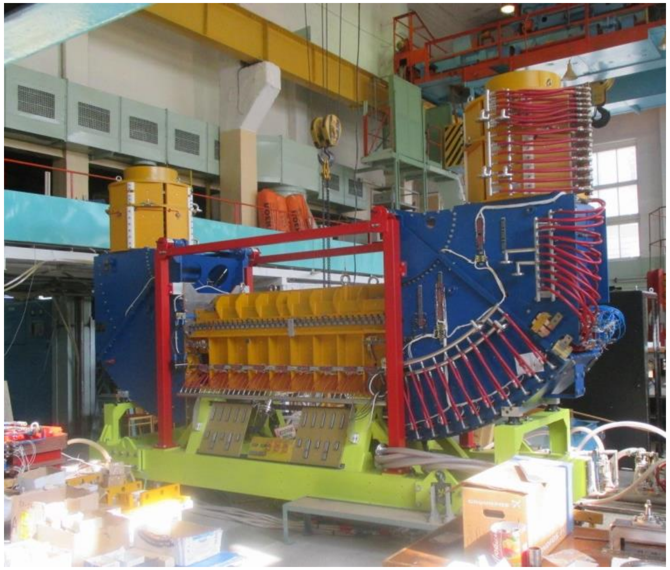
4.4. RF acceleration systems for Booster

RF for Booster (June 2013) has been delivered to JINR in September 2014

BINP-JINR team at 1st RF station: test at test-bench at JINR, November 2014

4.5. Electron cooler for the Booster

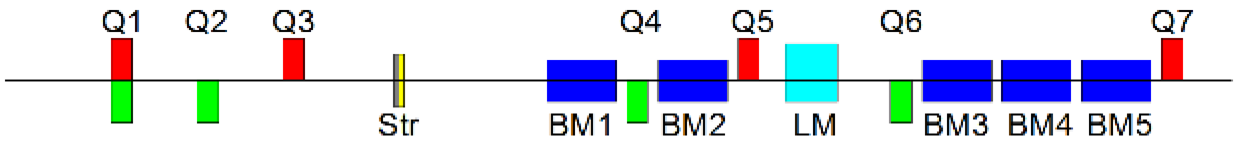
(stage of fabrication)



Electron cooler for NICA Booster assembled at BINP 03.09.2015

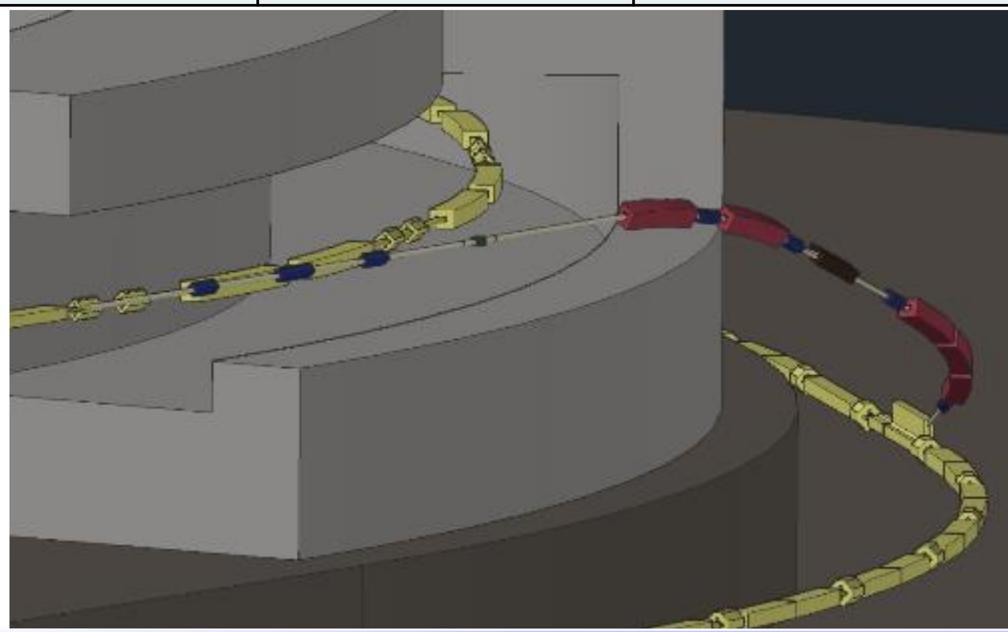
5. Booster Synchrotron Construction

5. Beam Transfer Channel Booster - Nuclotron

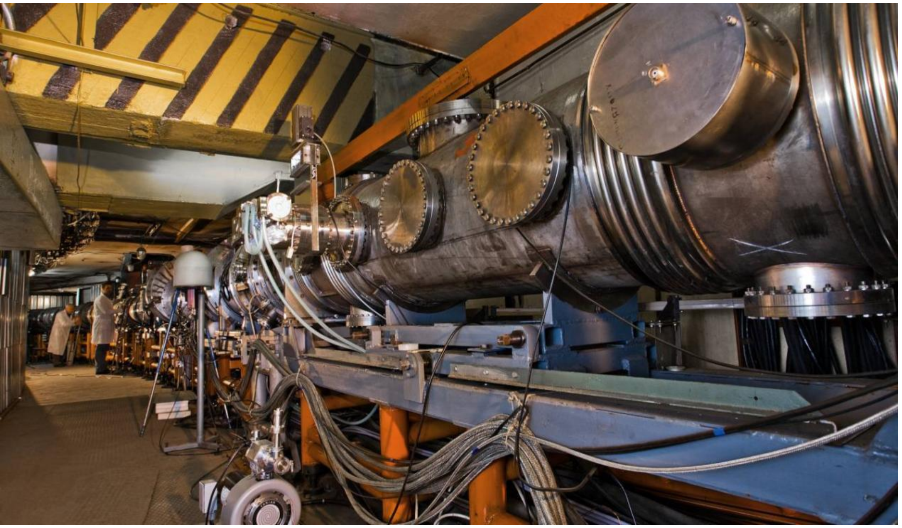


Parameters of The Stationary NC Magnets of The Channel

Magnetic element	Type	Effective length, m	Max. magn. field, T	Max. gradient, T/m
BM1 – BM5	Dipole	1,312	1,8	
LM	Lambertson magnet	1	1,5	
Q1, Q3	Quadrupole	0,4		27
Q2	quadrupole	0,6		27
Q4 –	quadrupole	0,4		12



6. 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:

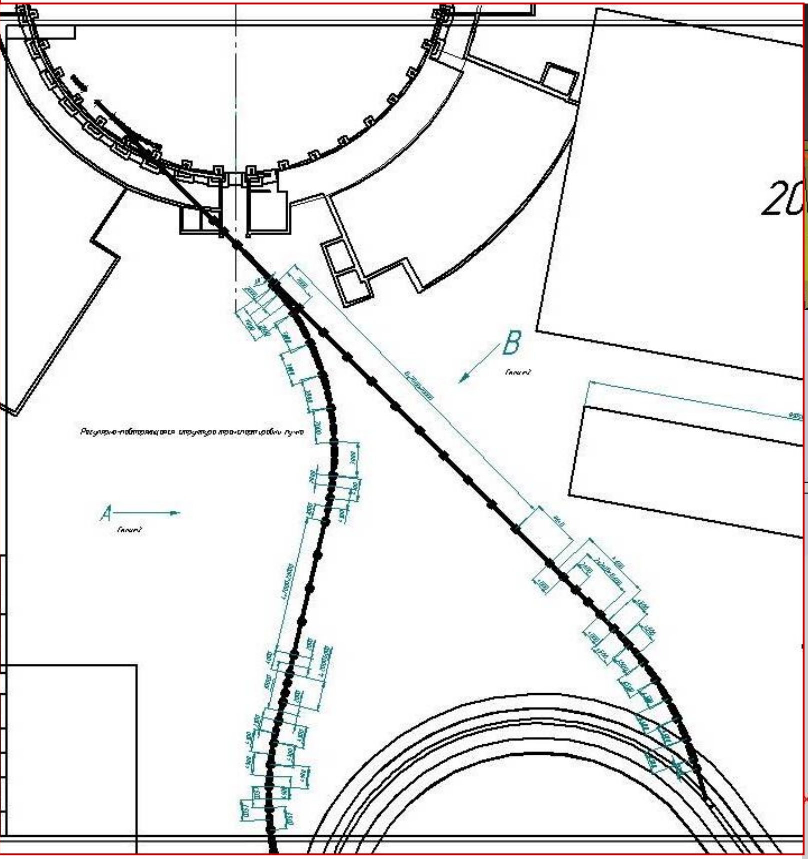
- **Acceleration of $^{197}Au^{79+}$ up to 4.5 GeV/u**
- **Injection system for $^{197}Au^{79+}$ at 600 MeV/u**
- **Upgrade of RF system**
- **Extraction system for $^{197}Au^{79+}$ at 1 ÷ 4.5 GeV/u**
- **Upgrade of control system (synchronization!)**

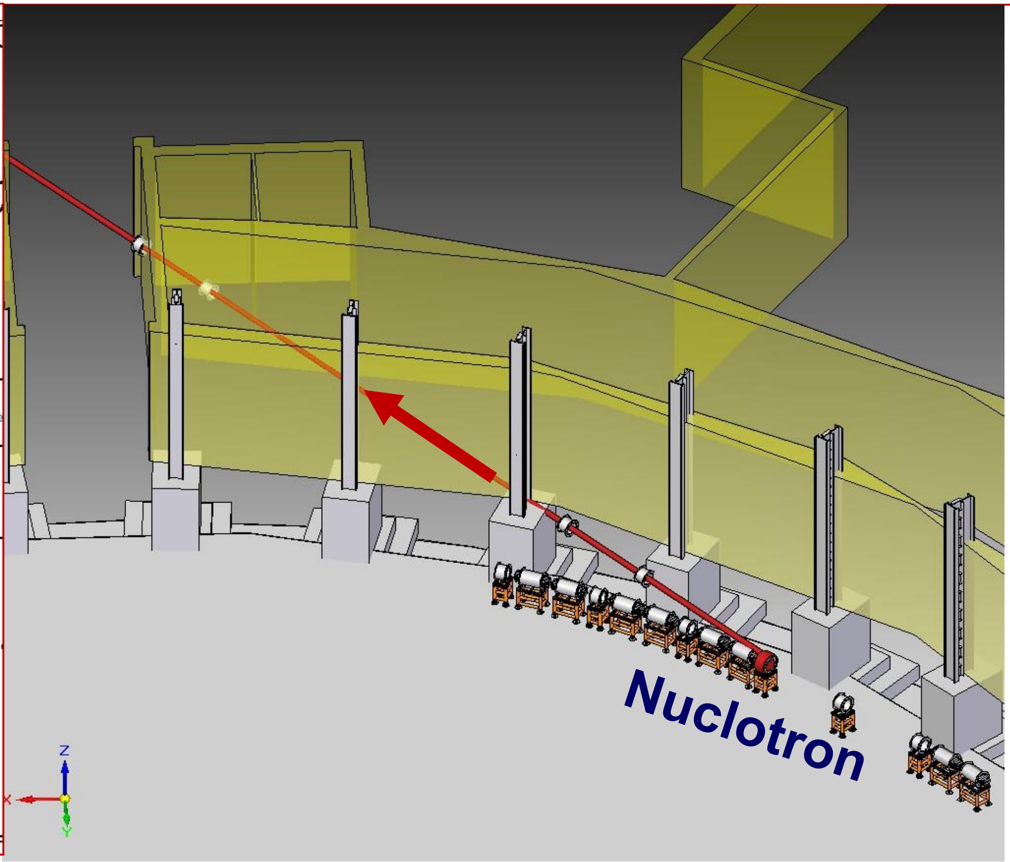
The work is in the steady progress…

7. NICA Elements Fabrication in Collaboration … (Contnd)

JINR + BINP 7.1. Beam transfer channel Nuclotron - Collider

(stage of working design)



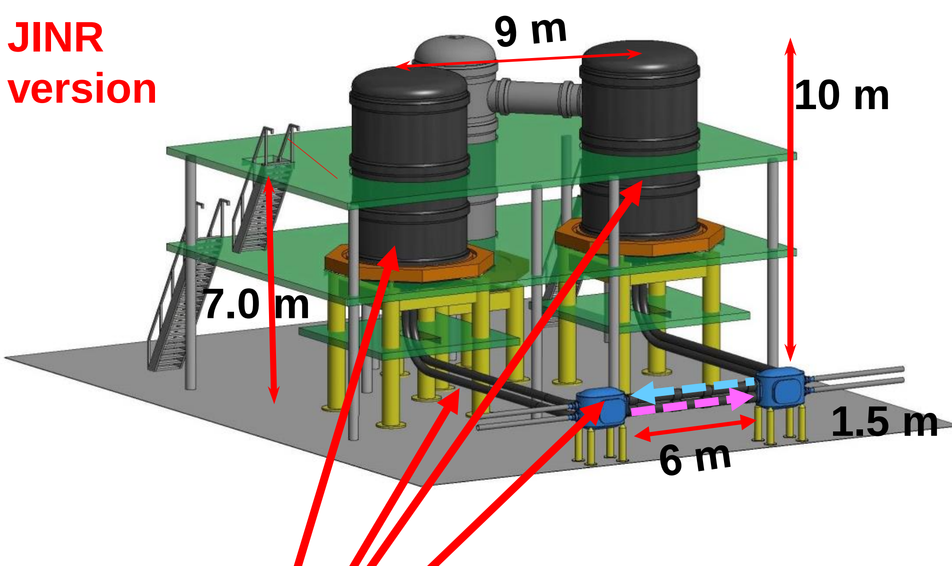


Channel lattice:

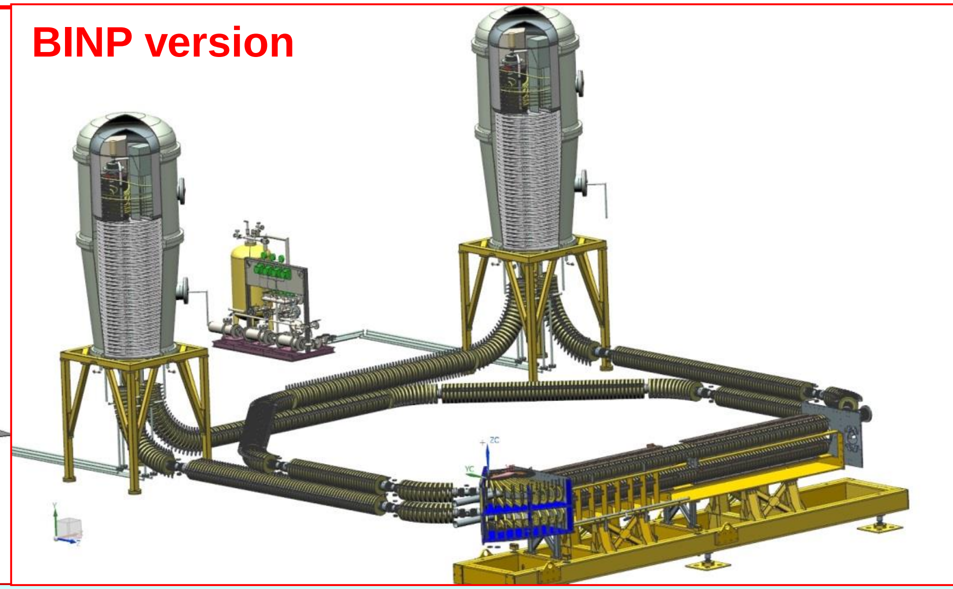
pulsed magnets, 35 dipoles, 56 quadrupoles, $P_{average}$ ~ 200 kW

7.2. 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

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

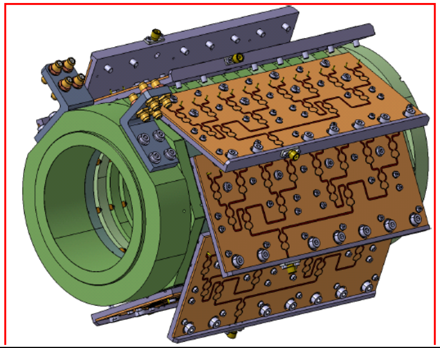
SC solenoids

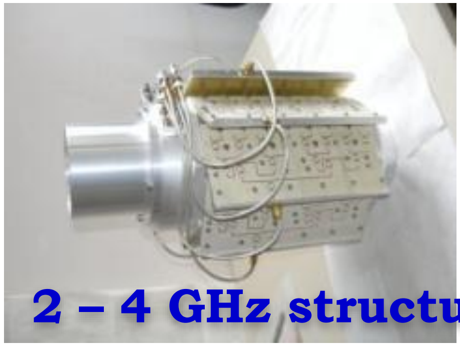
(JINR version)

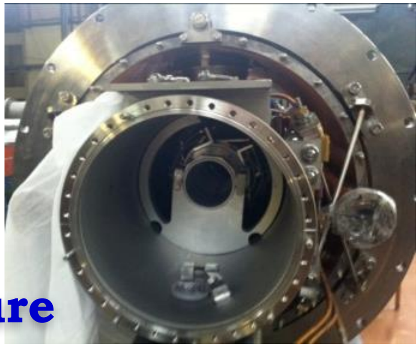
Maximum electron energy, MeV	2.5
Electron beam current, A	0.1 – 1.0
Solenoids’ magnetic field, T	0.2

JINR + FZ Jülich 7.3. Stochastic Cooling for NICA Collider

Pick-Up/Kicker Station (FZJ)



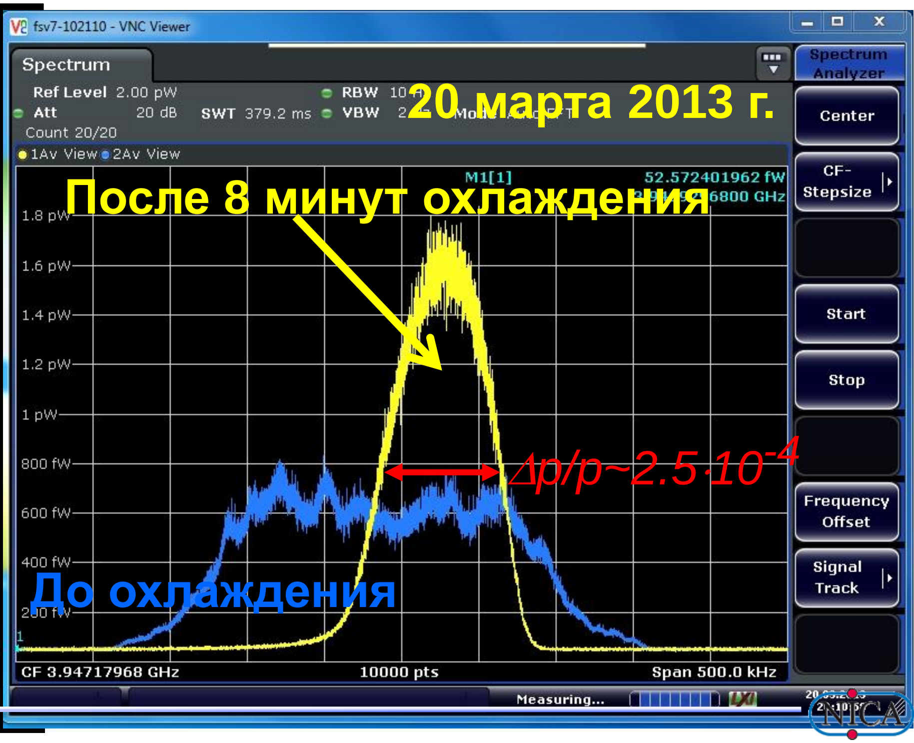




Stochastic Cooling
Test experiment at Nuclotron

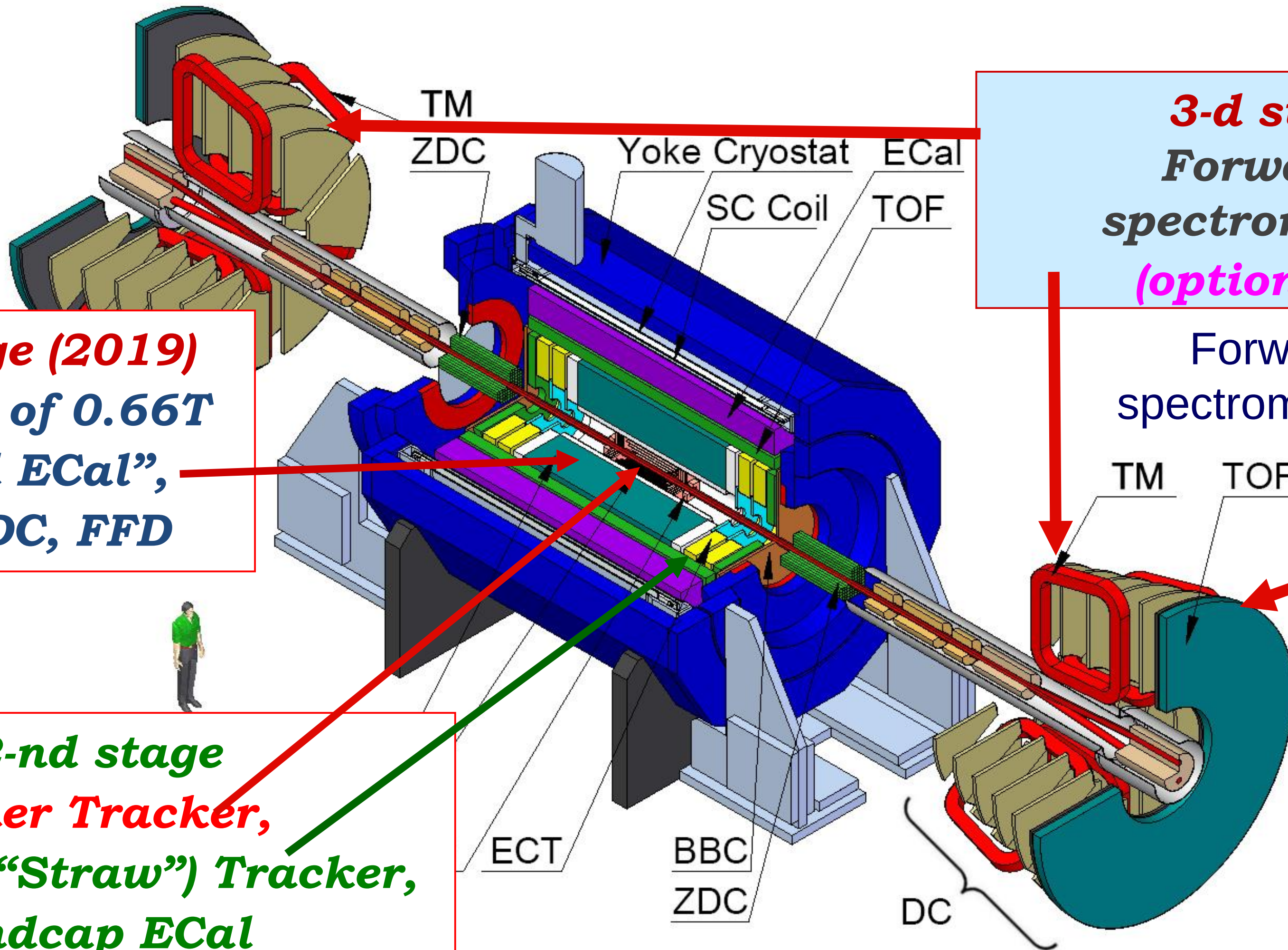
March 2013 Schottky-signal spectrum
Before (blue) and after (yellow) cooling
Deuterons, 3 GeV/u, h = 3500, N_{ion} = 2e9

December 2013 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)



8. MultiPurpose Detector (MPD)

3 stages of MPD commissioning



3-d stage
Forward-spectrometers
(optional ?)

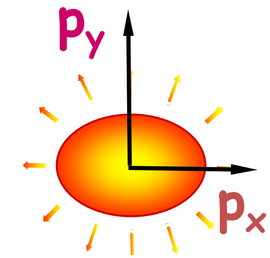
1-st stage (2019)
Solenoid of 0.66T
"Barrel ECal",
TPC, ZDC, FFD

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

8. MultiPurpose Detector (MPD)

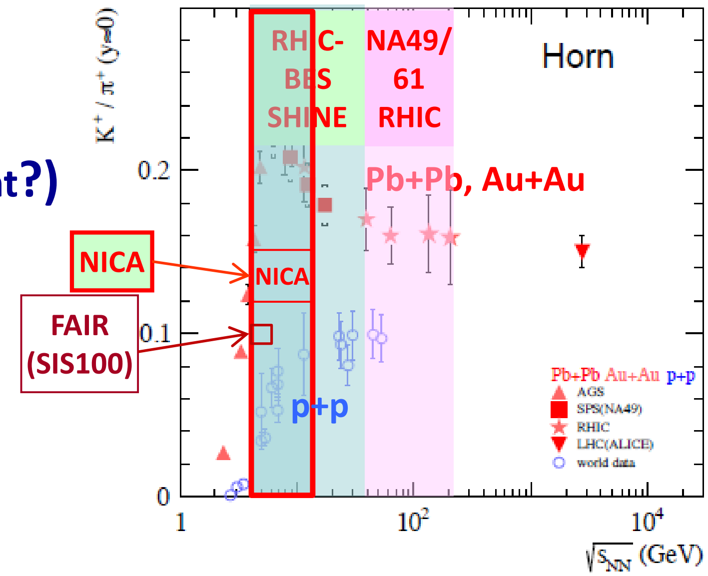
The Signatures of The Cumulative effects and The Mixed Phase Formation

What is to look for ?



- ✓ Ellipticity parameters of the flow of the central fireball matter in momentum space;

- ✓ The famous "Horn" (Indication to Onset of Deconfinement?)



- ✓ Registration of leptons => they carry information about QGP-phase structure!

- ✓ Registration of photons => that gives us the temperature of QGP

- ✓ Fluctuations of the reaction parameters! They are "a sign" of the mixed phase: system becomes unstable at the two-phases stage!

8. MultiPurpose & BM@N Detectors

Workshop for The Microstrip Subdetector Assembly & Tests

Clean room for Silicon Vertex Detector assembly is ready;

The workshop will start operation in 2015.

Project status:

in accordance with plans

CBM-MPD Consortium

***CERN & JINR signed MoU** for Collaboration in manufacturing of the carbon fiber spaceframes for the (SiTS) for BM@N & MPD at NICA & CBM at FAIR*

8. MultiPurpose & BM@N Detectors

Workshop for Assembly and Tests of the TOF Subdetectors

The detector assembly has been started in Dec. 2014; will be fully completed in 2015

The bench for ultrasonic cleaning of glass, in operation

The glass drying bench

The detector assembly bench, in operation

Test at the Nuclotron beam of the prototype of the full-scale of the Multi-Resistive Plate Counter (mRPC)

8. MultiPurpose & BM@N Detectors

Workshop for the TPC Assembly & Tests
(*under preparation*)

Prototype of the "cage" forming TPC electric field

The main framework of carbon fiber composite for the TPC (Dec. 2013)

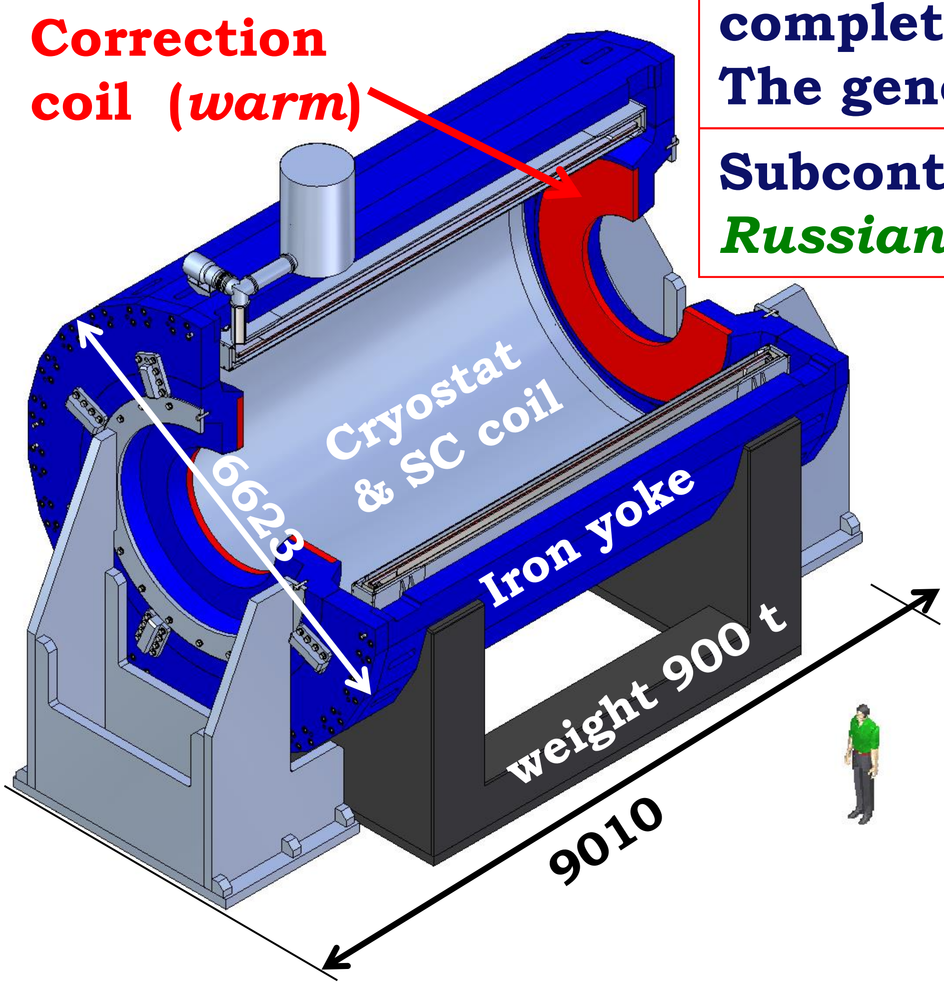
8. MultiPurpose & BM@N Detectors

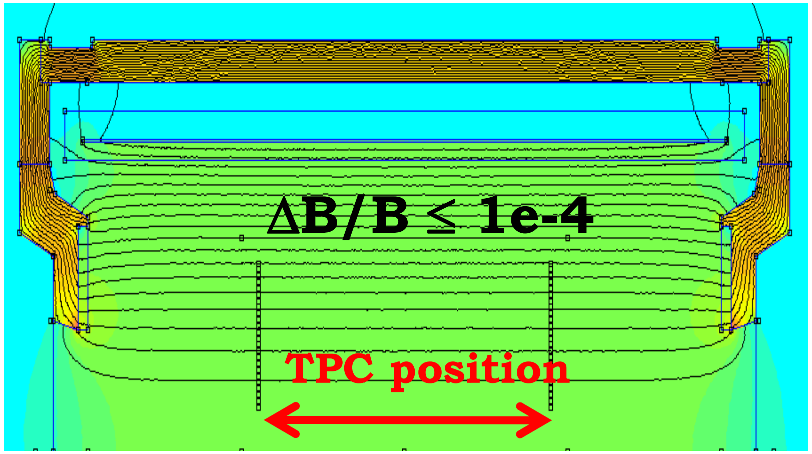
SC Solenoid of the MPD, B = 0.66 T

Project: "Neva-Magnit" C° (St. Petersburg)

The solenoid project is close to the completion;
The general producer - *ASG (Genova)*

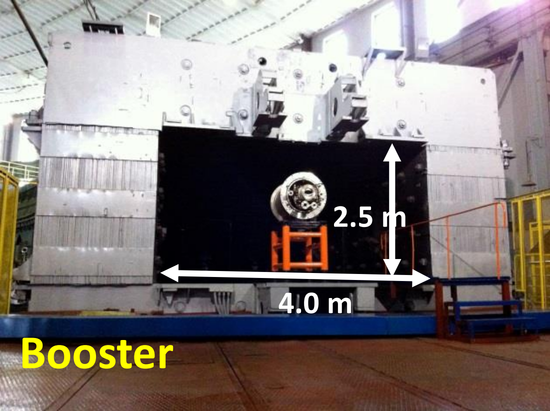
Subcontractors:
Russian & Czech companies





Численное моделирование B - поля

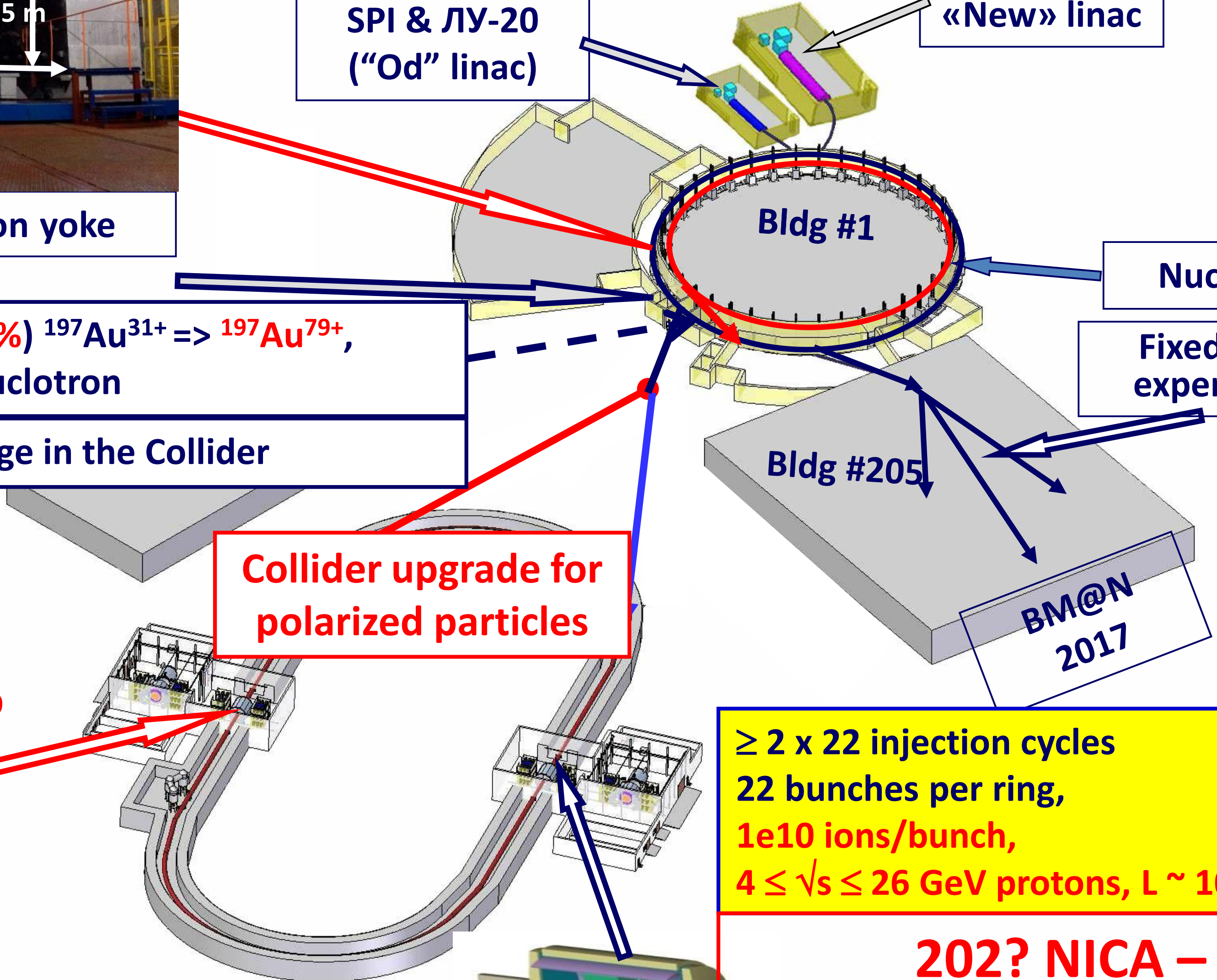
9. NICA – Stage III



Synchrophasotron yoke

SPI & ЛУ-20 (“Od” linac)

KRION-6T & «New» linac



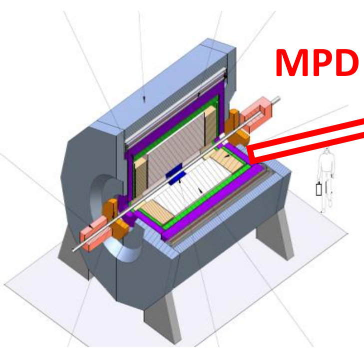
Nuclotron

Fixed target experiments

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$,
Acceleration in Nuclotron

Injection and storage in the Collider

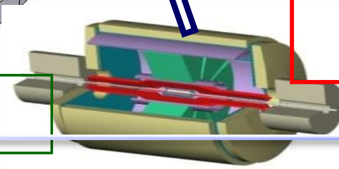
Collider upgrade for polarized particles



MPD

≥ 2 x 22 injection cycles
22 bunches per ring,
1e10 ions/bunch,
$4 \leq \sqrt{s} \leq 26$ GeV protons, L ~ 10^{32}

202? NICA – Stage III

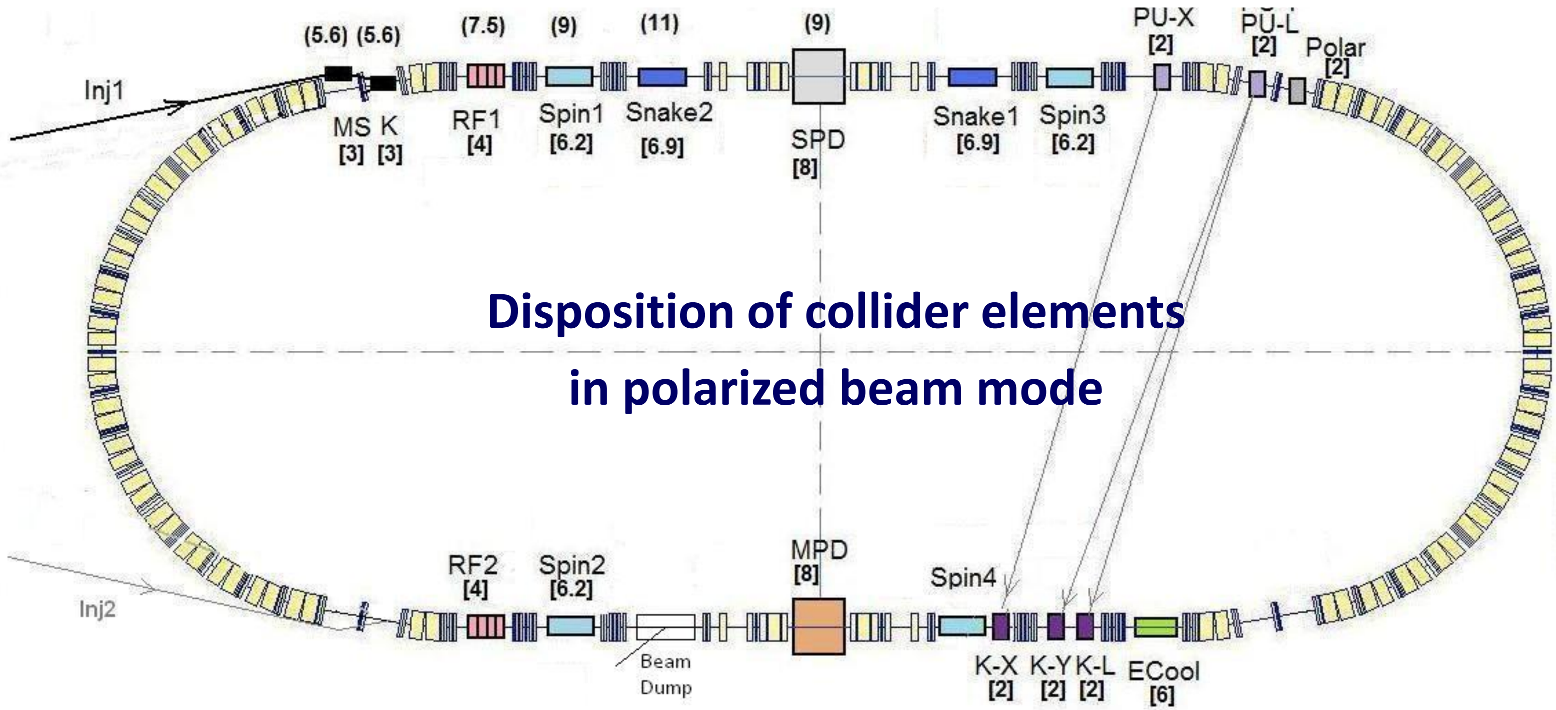


Spin Physics Detector (SPD)

9. NICA – Stage III : Collider of polarized beams

Accelerators:

- 1st concept of the collider beams has been developed. It assumes acceleration of polarized protons (!) and deuterons in Nuclotron avoiding the Booster.
- Concept of the acceleration of the polarized protons in Nuclotron has been developed, but its realization *requires a significant upgrade of the 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.



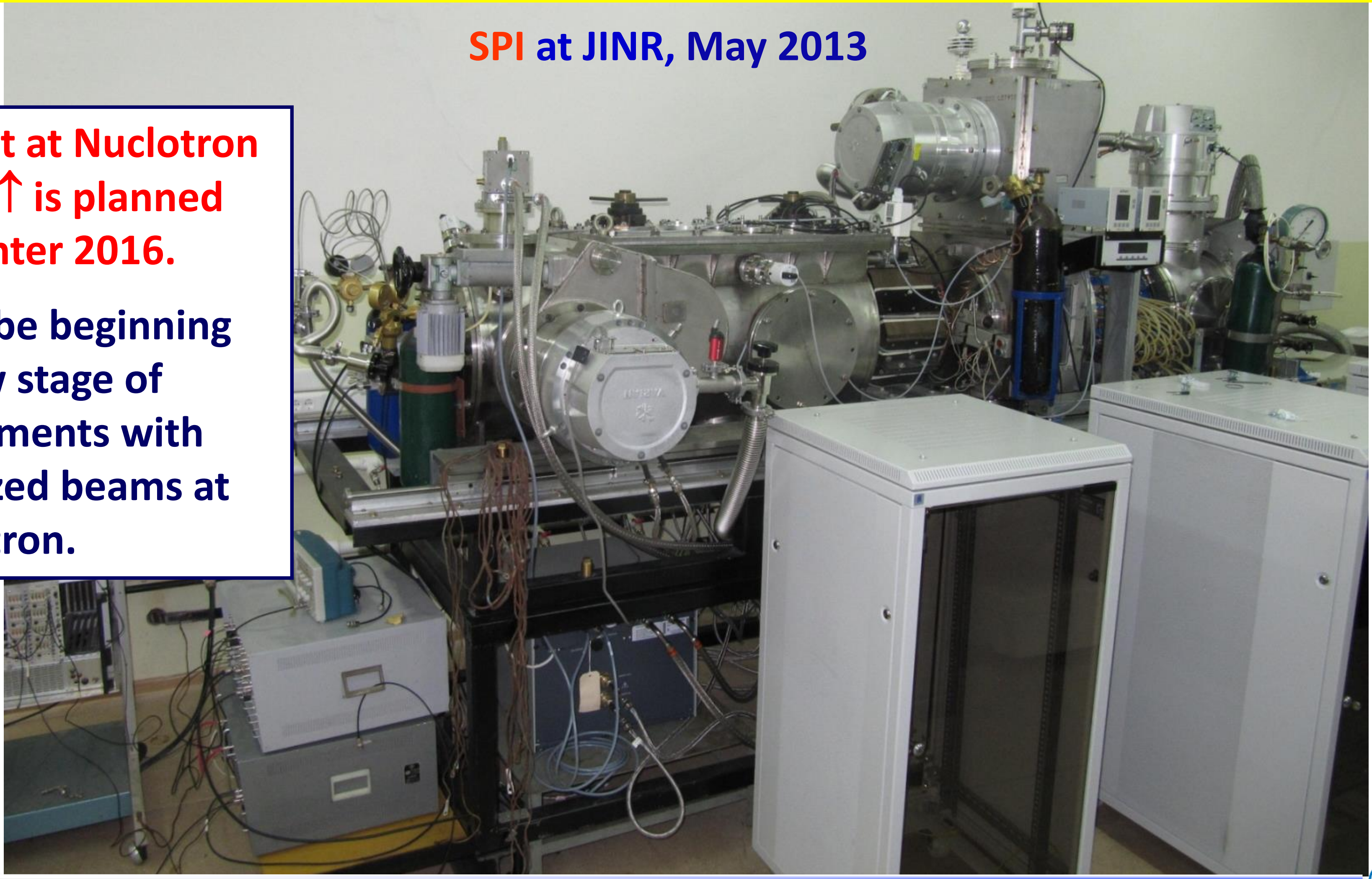
9. NICA – Stage III : Collider of polarized beams

Source of Polarized (p↑ & d↑) Ions SPI

Accelerators:

Collaboration of INR (Troitsk) & JINR

SPI at JINR, May 2013



SPI test at Nuclotron with d↑ is planned for winter 2016.

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

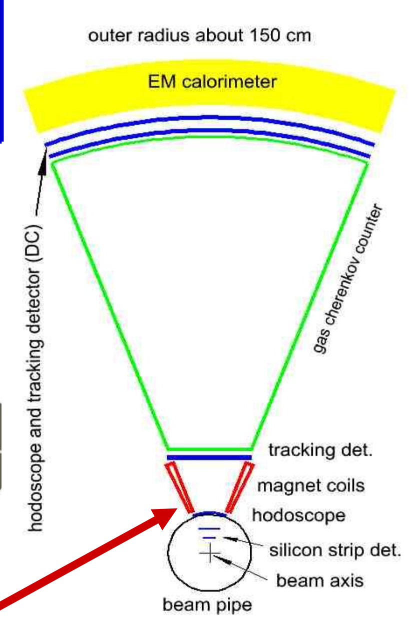
9. NICA – Stage III : Collider of polarized beams

SPD status:

02.06.14 LoI formulated and distributed (17 institutions):
"SPIN PHYSICS EXPERIMENTS AT NICA-SPD WITH POLARIZED PROTON AND DEUTERON BEAMS"

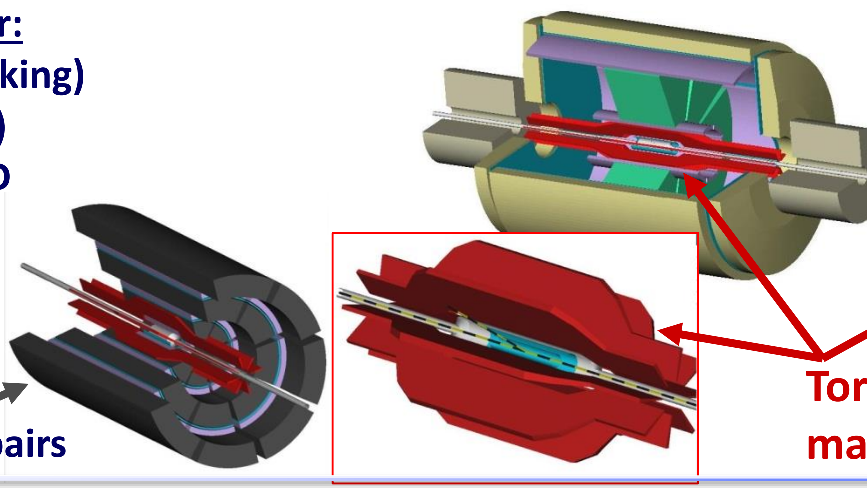
18.02.2015 JINR SPD working group formed:
- to start the work on SPD TDR
- to organize the work related to the acceleration of polarized particles and beam polarization measurements
- to organize formation of the international collaboration

- Application of MPD to the stage III is under consideration



Spin Physics Detector (SPD) – Very First Concept (2012)

Main elements of the detector:
- Silicon or MicroMega (inner tracking)
- Drift chambers or straw (tracking)
- Cherenkov counter (for particle ID and trigger)
- EM calorimeter
- Trigger counters
- EndCap detectors



Subdetector for muon pairs

Toroidal magnet

10. NICA Collaboration

Belarus
NC PHEP BSU (Minsk)
GSU (Gomel)
...
...

Germany
GSI (Darmstadt)
JLU (Giessen)
UR (Regensburk)
Frankfurt/Main Univ.
FIAS
FZJ (Julich)
FAU(Erlangen)

Bulgaria
INRNE BAS (Sofia)
TU-Sofia
SU
ISSP BAS
LTD BAS
SWU
PU (Plovdiv)
TUL (Blagoevgrad)

Ukraine
BITP NASU, KSU (Kiev)
KhNU, KFTI NASU (Kharkiv)

Russia
INR RAS (Moscow)
NRC KI (Moscow)
BINP RAS (Novosibirsk)
MSU (Mscow)
LPI RAS (Moscow)
St.Pet. Univ ersity
RI (St.Petersburg)
...
...

Poland
Tech.University (Warsaw)
Warsaw University
Fracoterm (Krakow)
Wroclaw University
INP (Krakow)

Czech Republic
TUL (Liberec)
CU (Prague)
Rzezh, ...

RSA
UCT (Cape Town)
UJ (Johannesburg)
iThemba Labs

Australia
Azerbaijan
CERN
China
France
Georgia
Greece
India

Italy
Japan
Moldova
Mongolia
Romania
Serbia
Slovakia
USA

10. NICA Collaboration

Budker INP

Budker INP Novosibirsk

Booster RF system, e-cooler
- ✓ Collider RF system
- ✓ HV e-cooler for collider
- ✓ Electronics

INP RAS, Troitsk

Polarised ion source,
Beam diagnostics

НПО ГЕЛИЙМАШ

КРИОГЕНМАШ

Alikhanov ITEP

Beam dynamics, RFQ linac

ВЭИ

Institute for Electrotechnique

HV Electron cooler

IHEP, Protvino

Beam dynamics,
Feed-back systems

GSI/FAIR

SC magnets for
Booster/Collider/SIS-100,
RF, UHV, beam cooling, diagnostics

FZ Juelich (IKP)

HV Electron cooler
Stochastic cooling

Fermilab

HV Electron cooler
Beam dynamics, stoch.cooling

CERN

SC technologies,
Rad.safety, energetics,
Beam cooling and dynamics,
Metrology

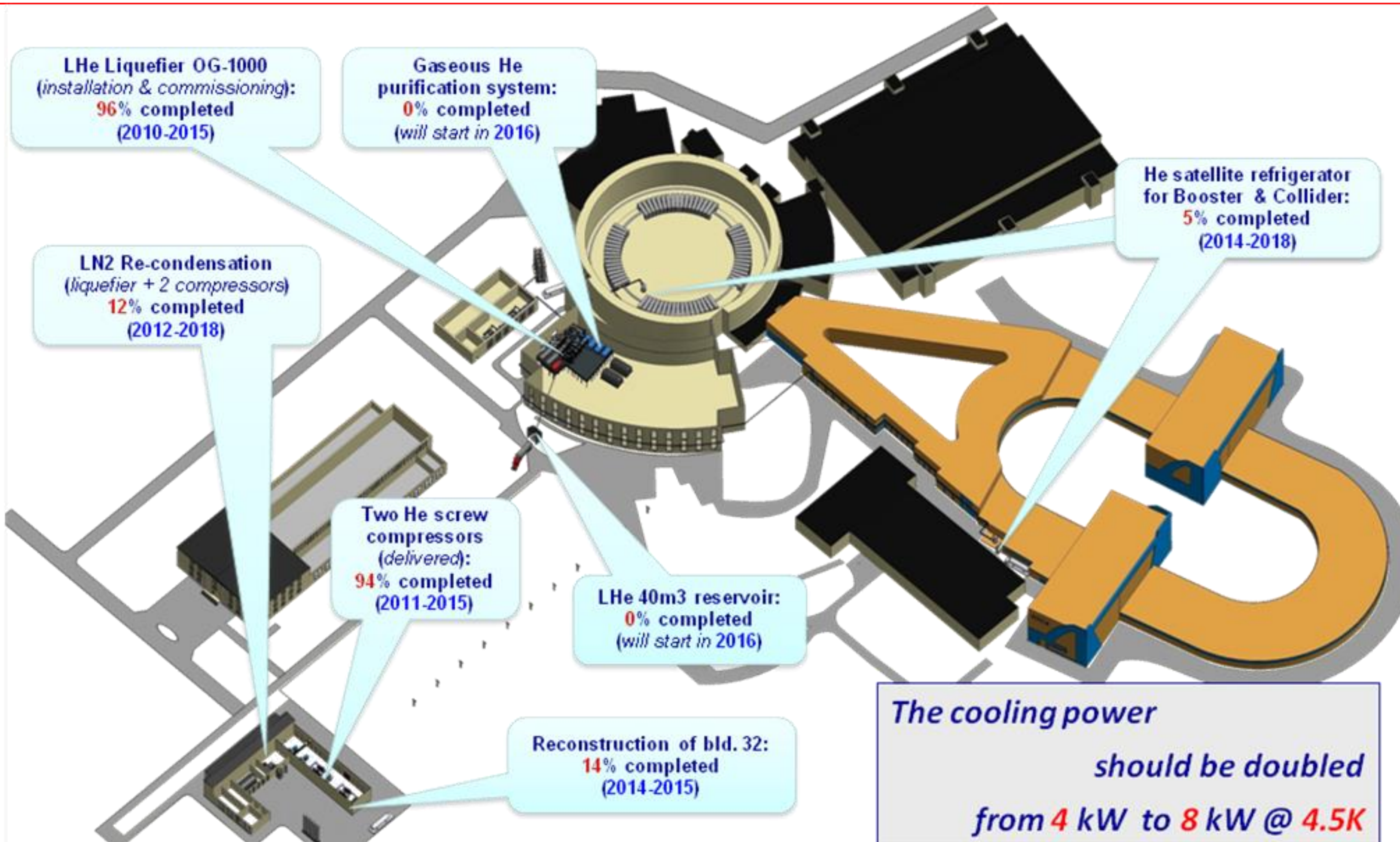
BNL (RHIC)

Beam dynamics,
Stochastic cooling

iThemba Labs & 6 others (RSA)

Elements of the NICA accelerators

Cryogenics (Infrastructure Engineering)



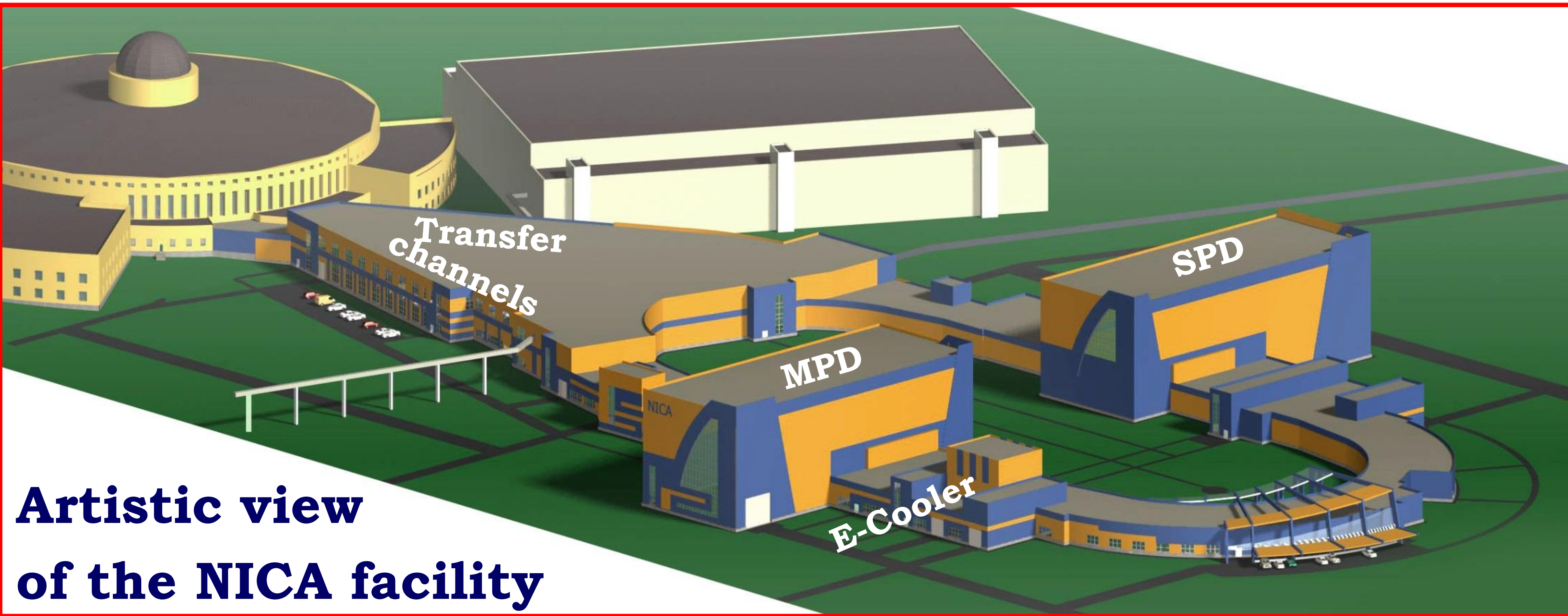
The cooling power

should be doubled

from 4 kW to 8 kW @ 4.5K

The productivity of the LHe cold-productivity of the cryogenic system will be increased from 4 kW up to 8 kW at 4.5 K

11. Infrastructure and civil engineering



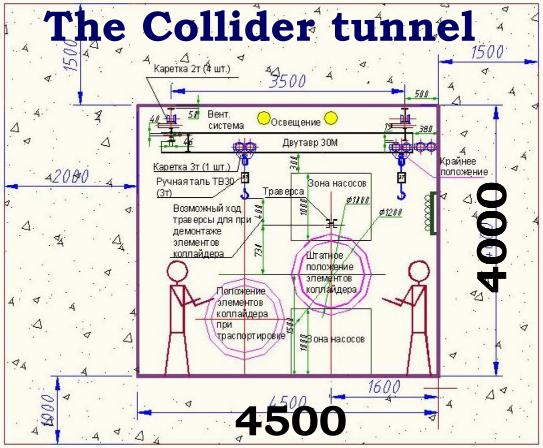
Artistic view of the NICA facility

The technical project of NICA

(civil engineering, equipment description and disposition) has been completed in

2013

and has passed State Expertise (Sept. 2013).



11. Infrastructure and civil engineering

Phase 1 of Civil construction has been started

21 November 2013. The cutting of the trees for clearance the NICA collider site:

11. Civil engineering – Status and Plans

Contract for the 1st phase of the Collider building construction will be signed soon (stage of *final coordination*) with the building company "Strabag", Austria (*the winner of the tender*). The 1st phase assumes preparatory work on NICA site analysis and infrastructure for construction work preparation. Then the 2nd phase – the building construction works – begins. Civil construction duration is estimated by Strabag C° as

42 months!

Beginning of the Collider mounting is planned for <u>September 2018</u>

Start up version of NICA commissioning is scheduled for the end of 2019.

12. Start up mode of NICA operation

The NICA accelerator complex commissioning is scheduled for

the end of 2019

The complex will be commissioned with

- Injectors chain
- Transfer channels
- Collider in start up version, i.e:
  - with RF-1 and RF-2, biu without RF-3
  - with SC system - one channel per ring (longitudinal cooling)
  - without El-Cooler
  - without feed-back system

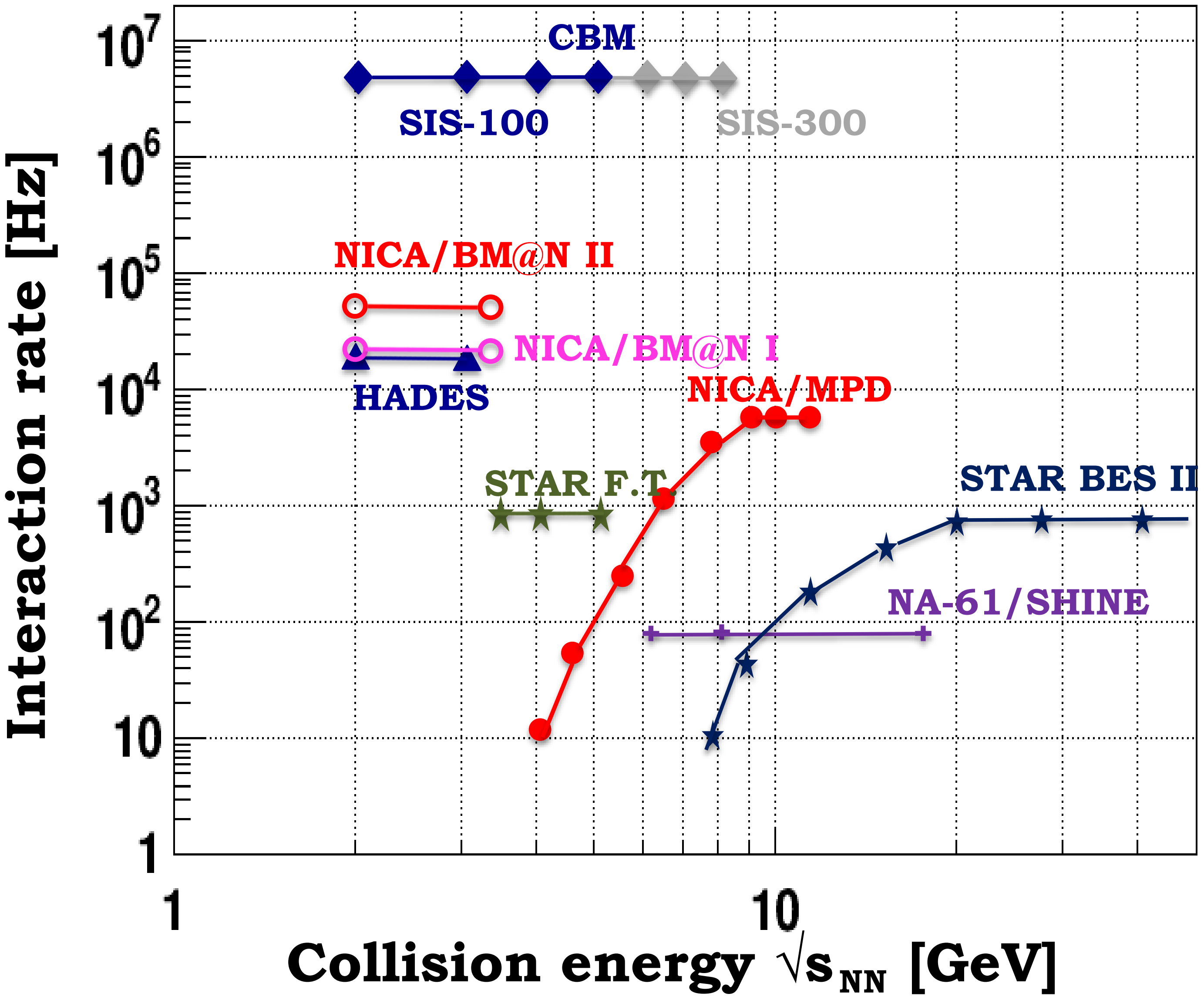
It will allow us to provide collider operation in the energy range of

3 - 4 GeV/u ($\sqrt{s}$ = 8 – 10 GeV/u) $^{197}Au^{79+}$ ions

at the luminosity of

5×10^{25} $cm^{-2} \cdot s^{-1}$

13. Where are we going…



Concluding remarks

- The NICA accelerators are in the stage of fabrication and/or assembling/mounting
- BM@N and MPD sub-detectors are in the stage of the fabrication
- the civil construction of NICA complex was started
- SPD LoI has been prepared and SPD working group has been formed
- International cooperation around NICA is growing
- The commissioning of the start-up mode of the NICA is scheduled for the end of 2019

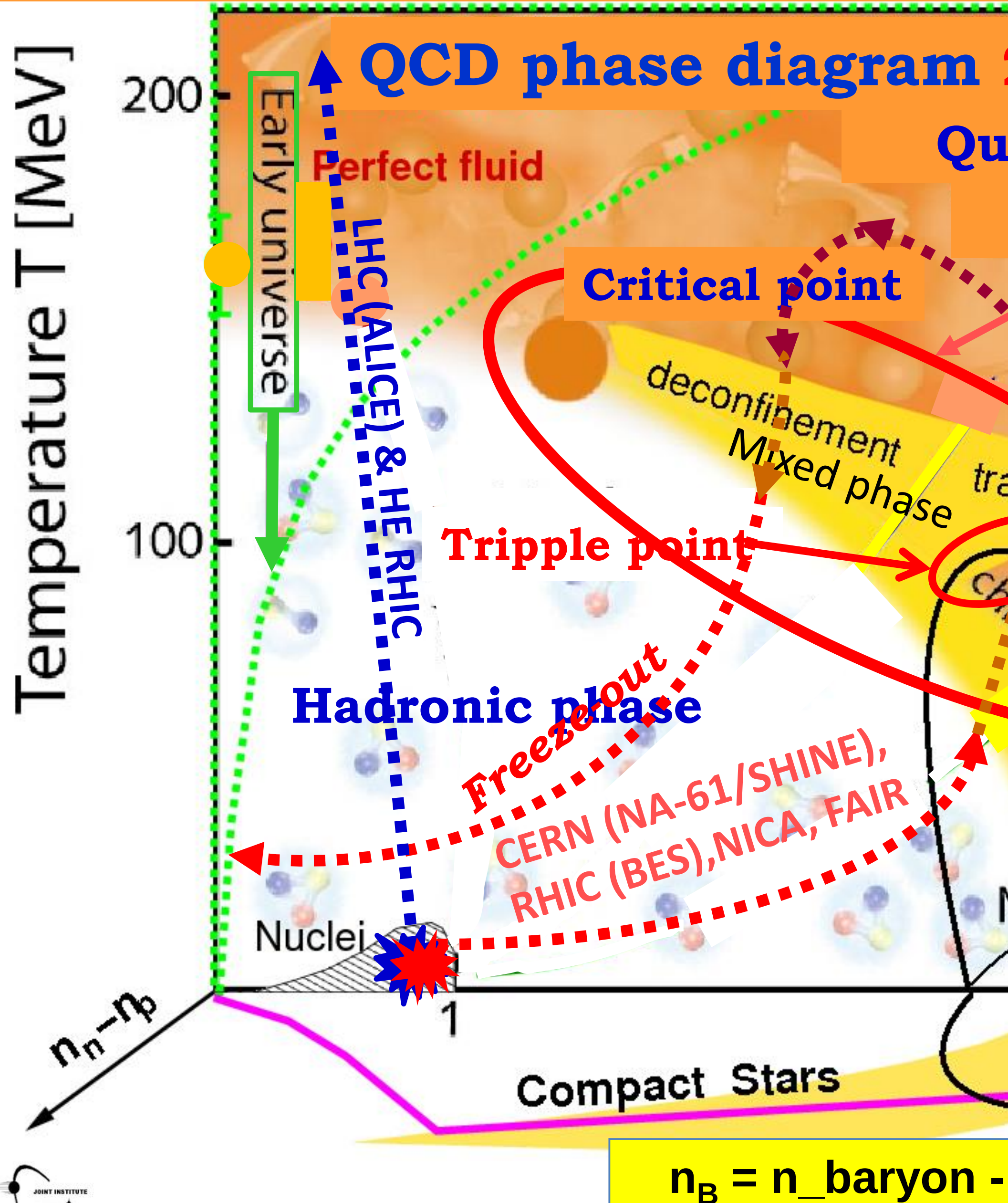
The set of NICA beams provides unique possibility both for basic and applied researches in the forthcoming decades.

In Greek Nικε is the name of Goddess of Victory,
And "Nικα!" means "Go and win!"

Thank you for your attention!

Backups

Nuclei Collisions and Phase Trajectories in T-n_B space



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/SHINE/ALICE, FAIR and Nuclotron-M experimental programs**

8. NICA – Stage III : Collider of polarized beams

SPD:

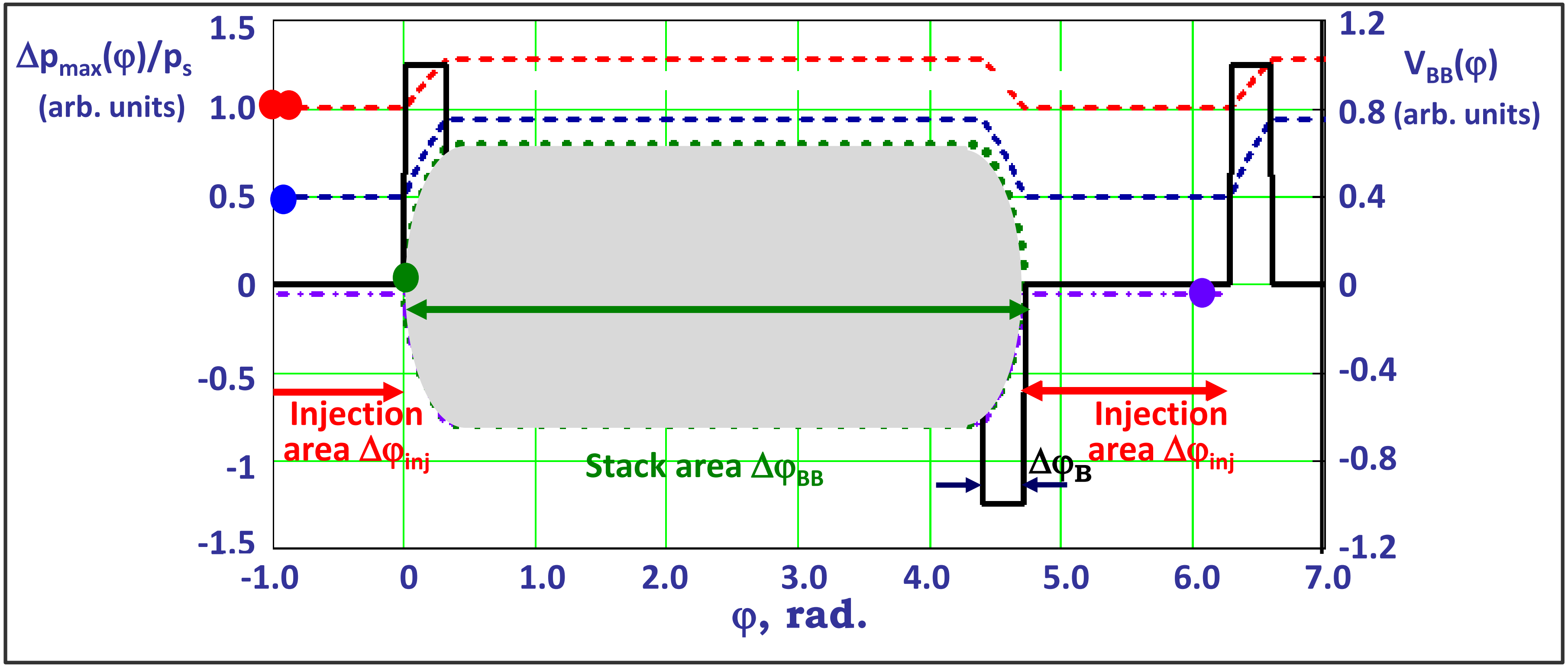
The proposed measurements:

- DY processes
- Direct (prompt) photons
- 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

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

Facility operation scenario: Three Steps of Beam Formation in NICA Collider

Step 1. Cooling and stacking with barrier voltage



Sufficient condition for ion stacking: $\tau_{cool} \le T_{injection}$ (injection period)

Necessary condition for ion stacking: $T_{synchr.\ oscillation} < T_{injection}$

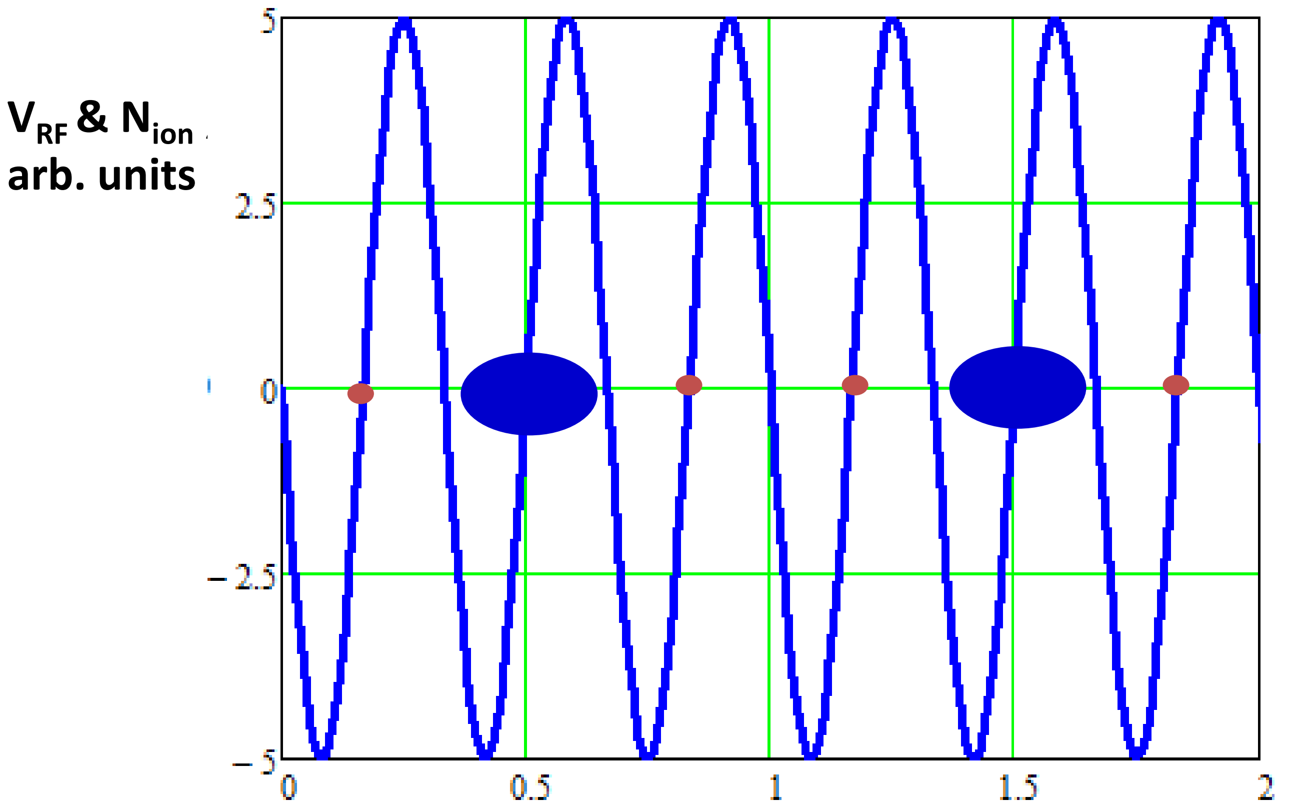
RF-1 acceleration station of "barrier voltage"

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

Facility operation scenario: Three Steps of Beam Formation in NICA Collider

Steps 2-3. **Formation of the short ion bunches in presence of cooling, RF-2 & RF-3 acceleration station of harmonic voltage**

From coasting beam => to 22nd harmonics = > 66th harmonics



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

Intriguing question: Why RHIC has low luminosity at the energy where luminosity of NICA is relatively high?

The reason is the beam space charge (single bunch problem!):

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

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

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

!!