Workshop on Beam Cooling and Related Topics
COOL'11

NICA Project at JINR

Nuclotron-based Ion Collider fAcility

I.Meshkov for NICA team

September 12 - 16, 2011, Alushta, Ukraine
hosted by JINR, Dubna

Contents

Introduction: The goal of the project

The goal of the project is

construction at JINR of a new accelerator facility that provides

1a) Heavy ion colliding beams $^{197}Au^{79+} \times {}^{197}Au^{79+}$ at

$\sqrt{s_{NN}}$ = 4 ÷ 11 GeV (1 ÷ 4.5 GeV/u ion kinetic energy)

at $L_{average}$ = 1E27 $cm^{-2} \cdot s^{-1}$ (at $\sqrt{s_{NN}}$ = 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↑ $\sqrt{s_{pp}}$ = 12 ÷ 27 GeV (5 ÷ 12.6 GeV kinetic energy)

d↑d↑ $\sqrt{s_{NN}}$ = 4 ÷ 13.8 GeV (2 ÷ 5.9 GeV/u ion kinetic energy)

$L_{average} \geq$ 1E30 $cm^{-2} \cdot s^{-1}$ (at $\sqrt{s_{pp}}$ = 27 GeV)

3) The beams of light ions and polarized protons and deuterons for fixed target experiments:

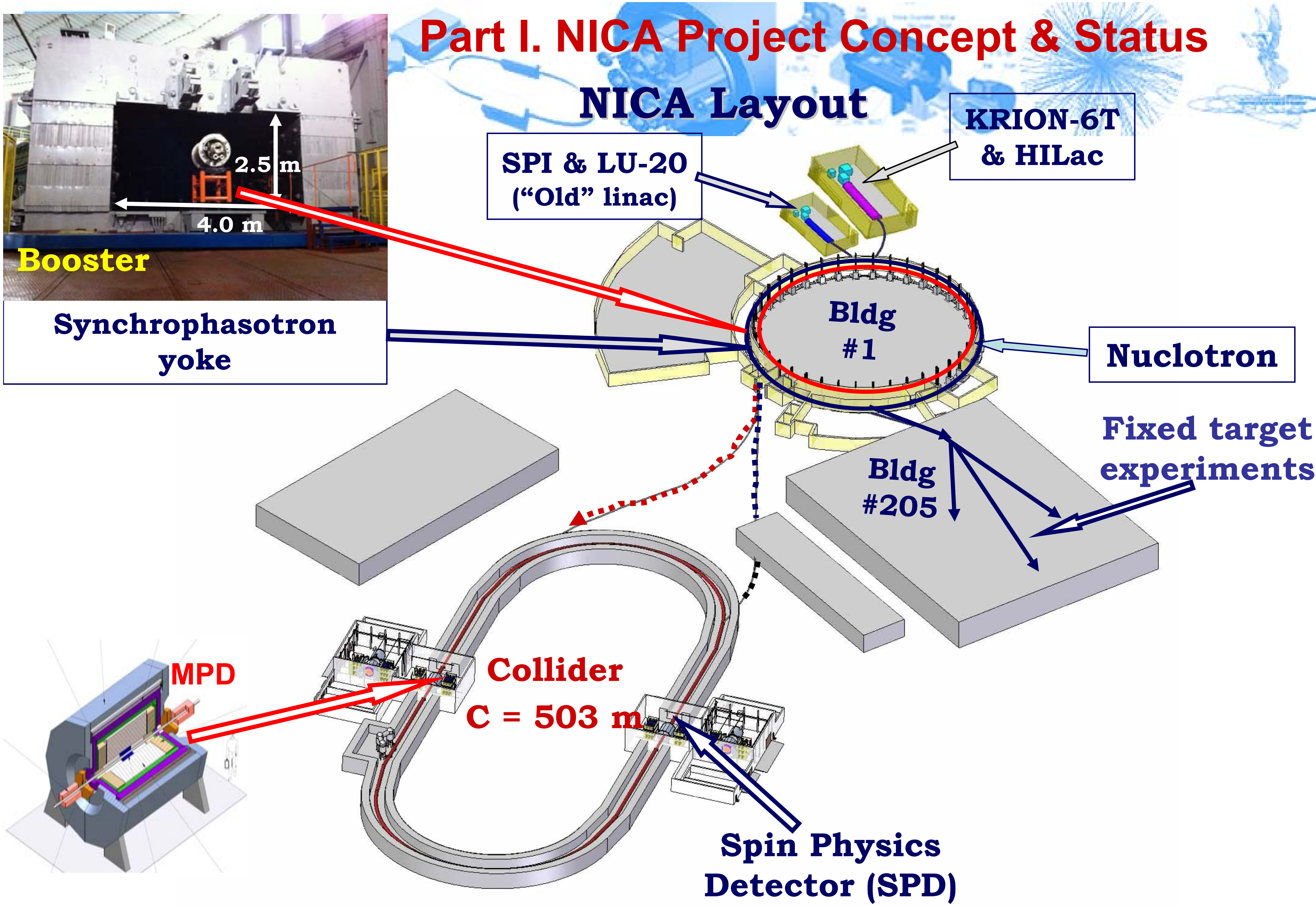
Li ÷ Au = 1 ÷ 4.5 GeV /u ion kinetic energy
p, p↑ = 5 ÷ 12.6 GeV kinetic energy
d, d↑ = 2 ÷ 5.9 GeV/u ion kinetic energy

4) Applied research on ion beams at kinetic energy

from 0.5 GeV/u up to 12.6 GeV (p) and 4.5 GeV /u (Au)

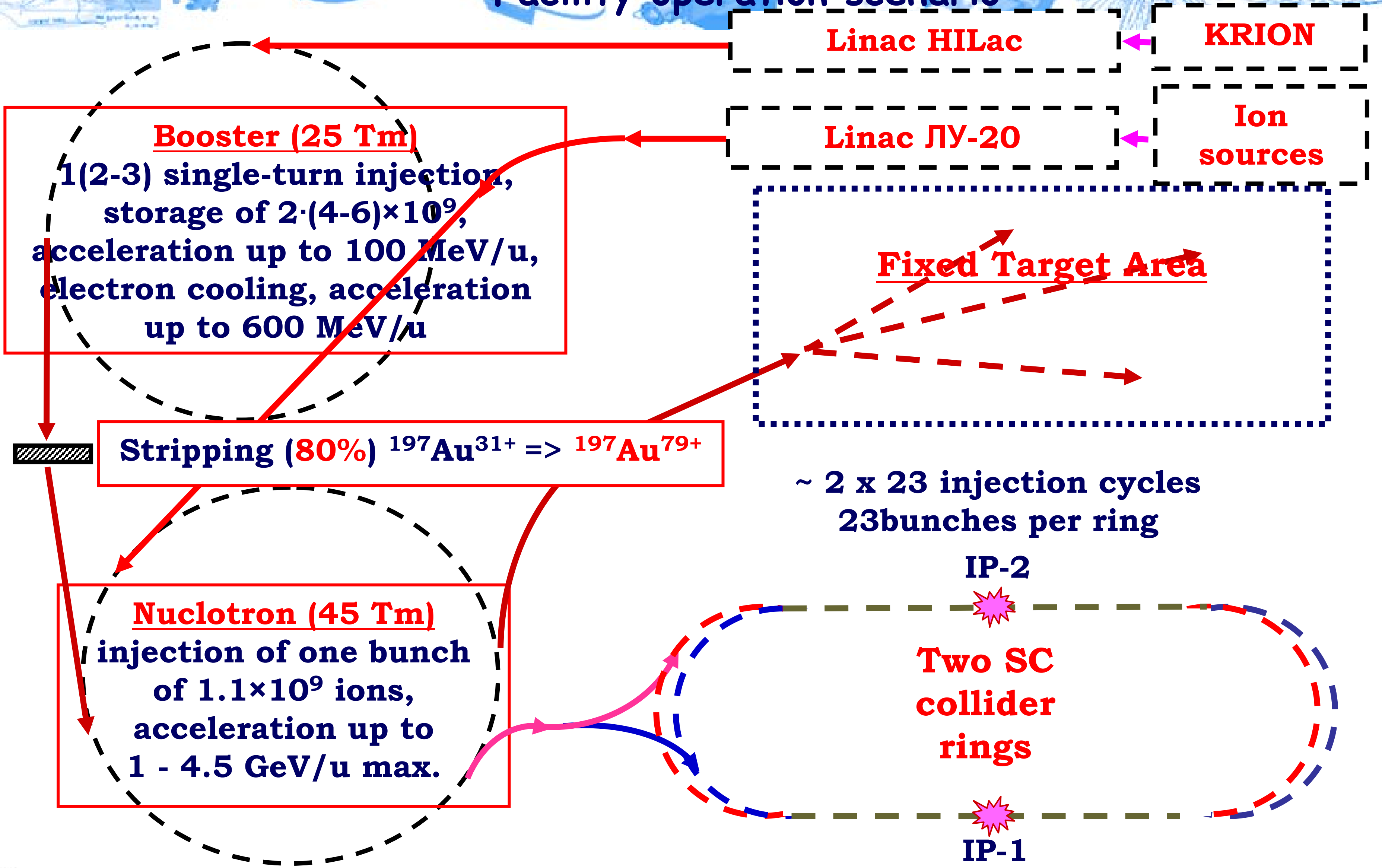
Part I. NICA Project Concept & Status

NICA Layout

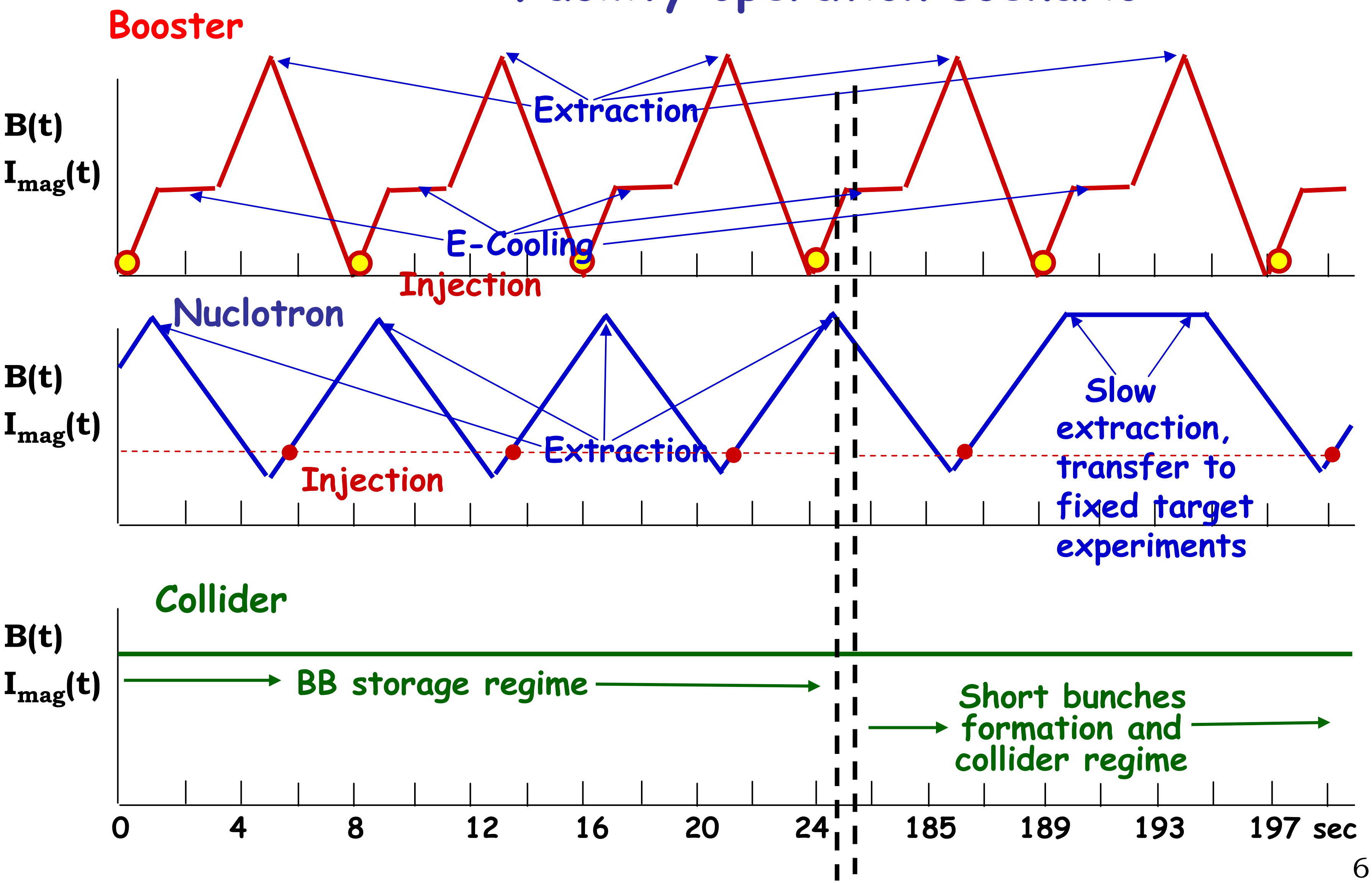


Part I. NICA Project Concept & Status

Facility operation scenario



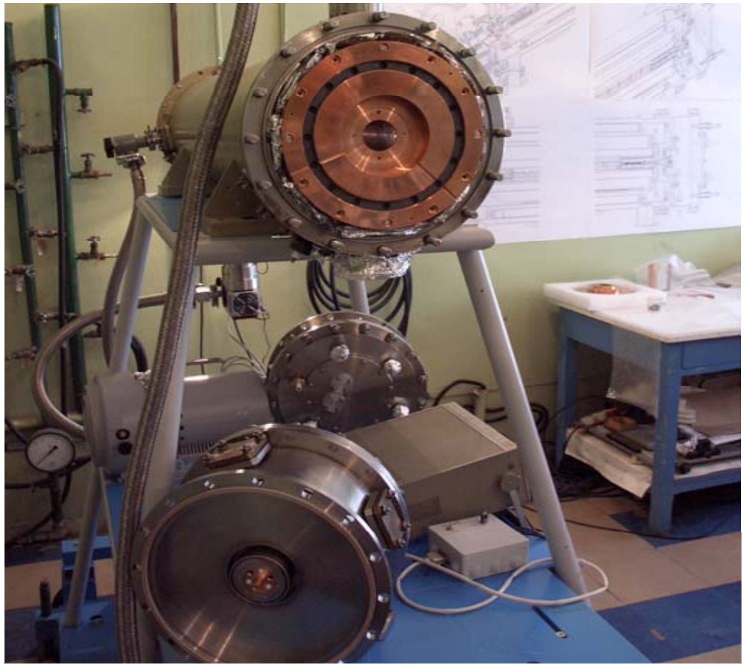
Facility operation scenario



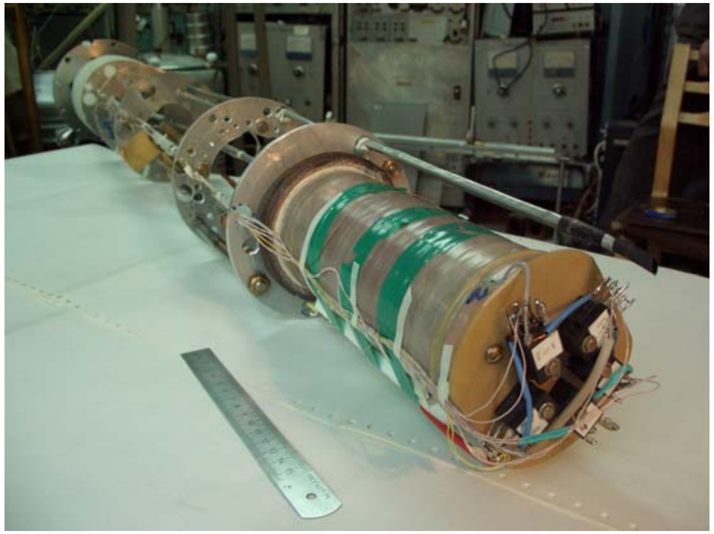
I.1. Injection complex

Cryogenic Ion Source KRION-6T ("EBIS type")

(2÷4)E9 $^{197}Au^{31+}$ ions per pulse at repetition frequency up to 20 Hz



Assembling of electron/ion optics system (view from the "ion extraction" side



Superconducting test coil (L=19 cm, 32 layers of SC wire) : preparation for testing in a liquid helium.

September 2011 –beginning of test

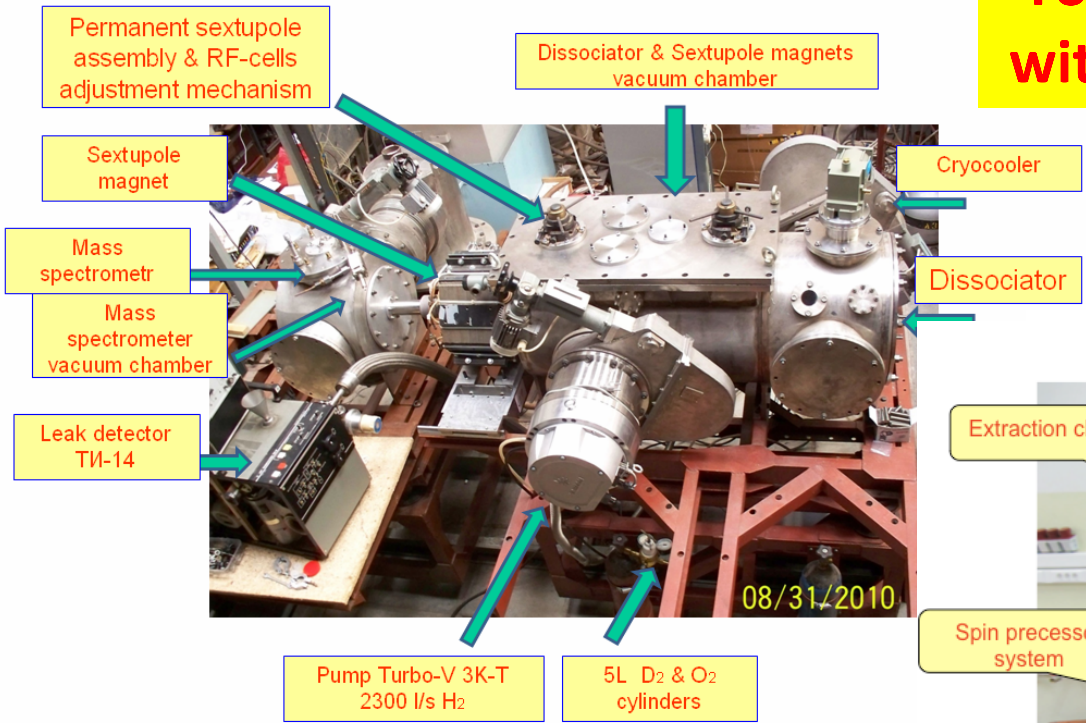
Part I. NICA Project Concept & Status

I.1. Injection complex

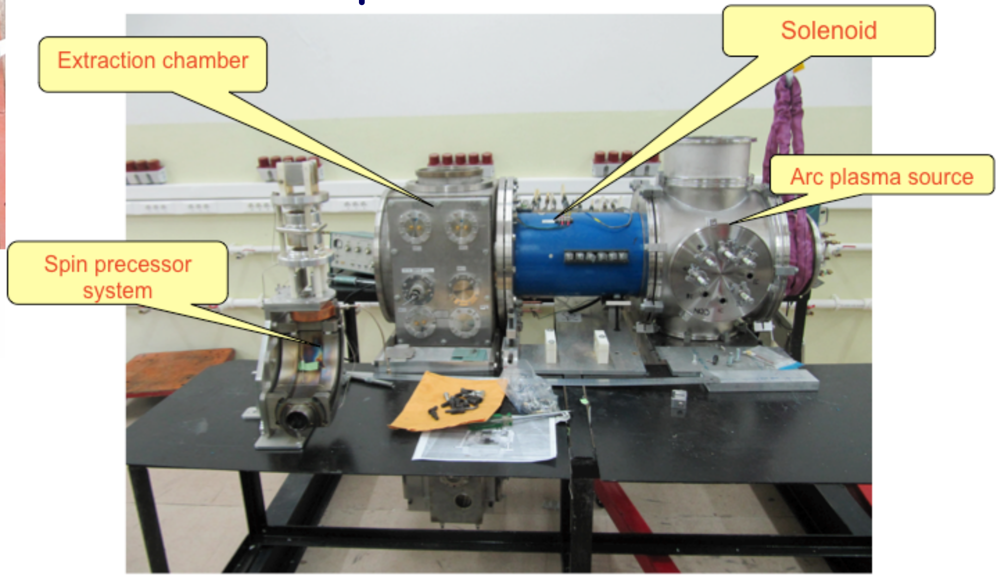
Source of polarized protons/deuterons (JINR/INR RAS)

To be tested at Nuclotron with ↑d at the end of 2012

The source general view

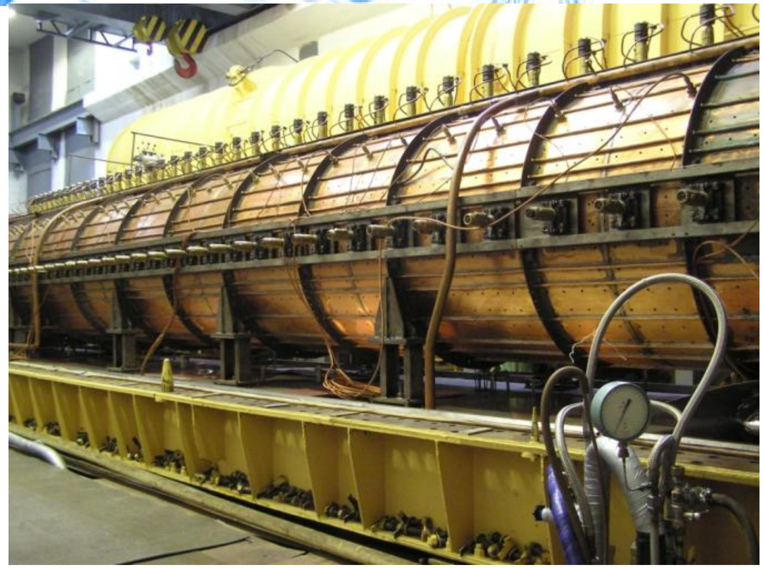


Assembled charge-exchange plasma ionizer



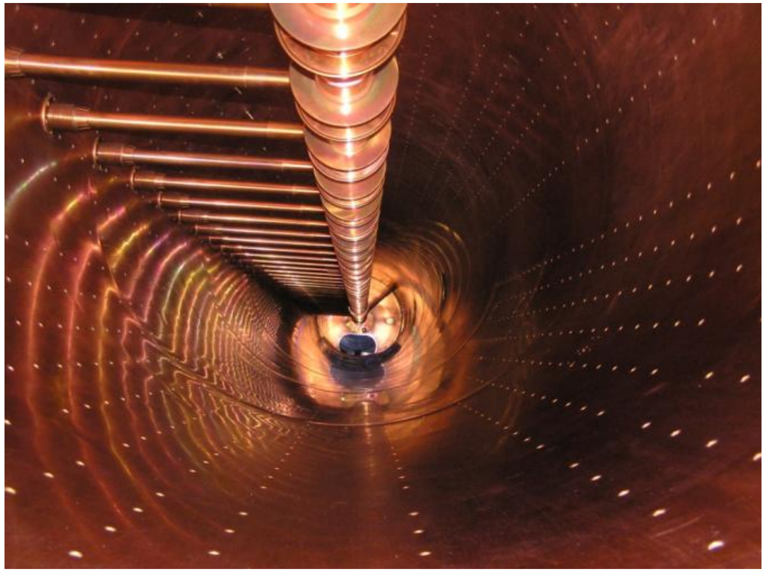
I.1. Injection complex

Linac LU-20



Presently under modernization:

- Upgrade of the power supply system for injection channel;
- Upgrade of vacuum system for fore-injector.



I.1. Injection complex

Heavy Ion Linac (HILAc)

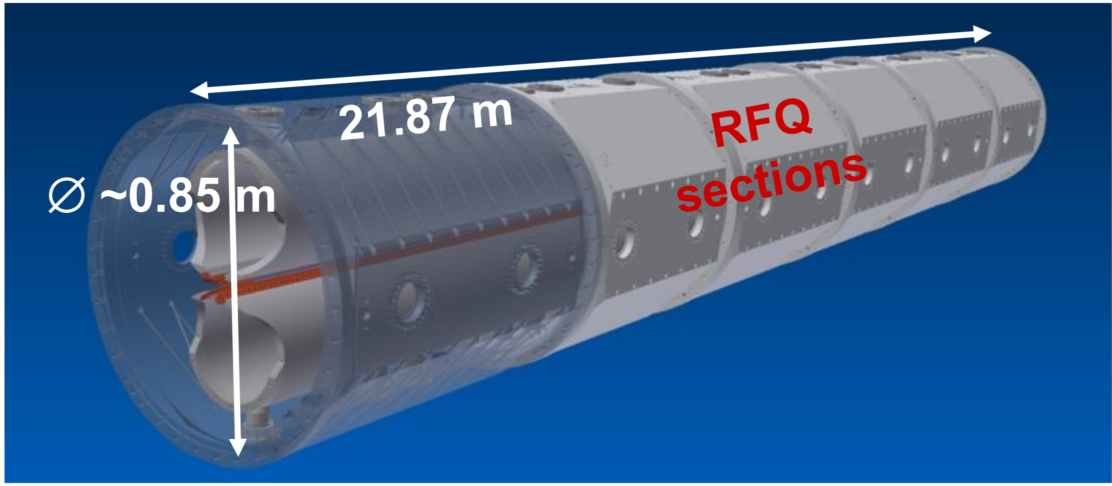
Maximum energy of 3.2 MeV/u for $^{197}Au^{31+}$ ions

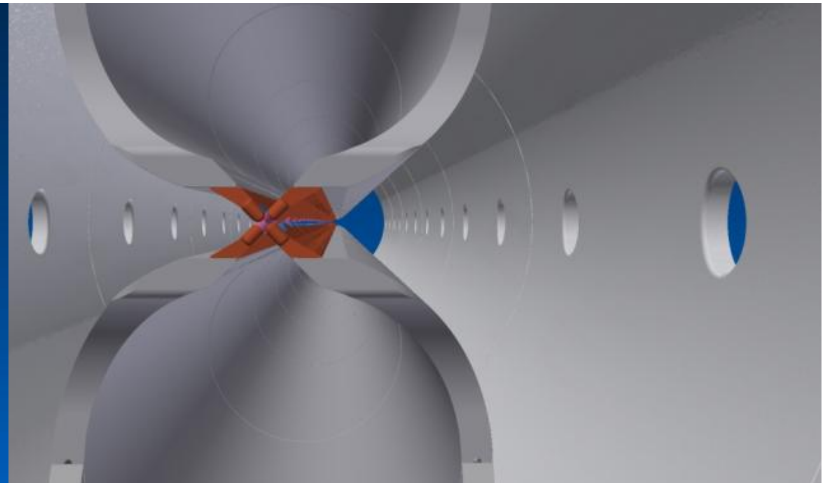
Three options of HILAc design and construction:

1) IHEP (project) + JINR (design) + Rus. Fed. Center VNIIEF (Sarov)

2) ITEP 3) Institute of Appl. Physics (Goethe Univ., Frankfurt)

HILAc design at JINR: 2 RFQ sections + 2 DTL sections (Drift Tube Linac)



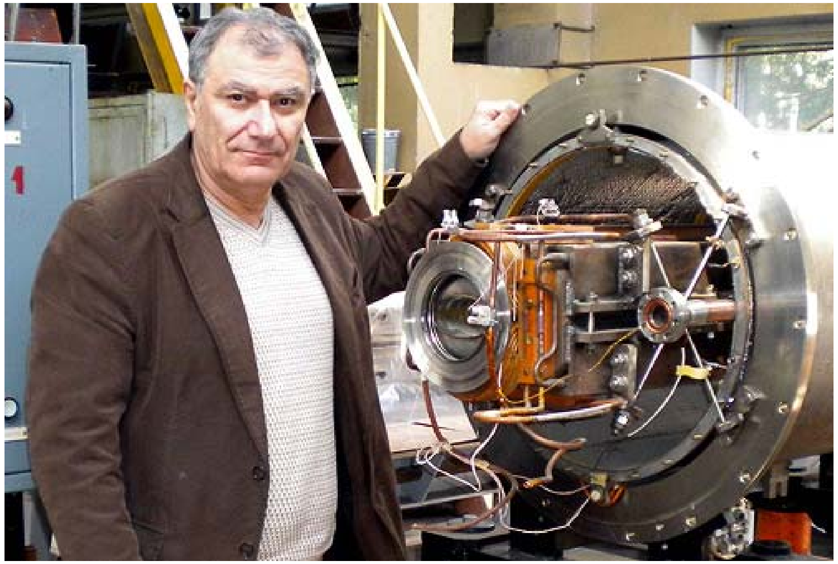


I.2. Booster-Synchrotron

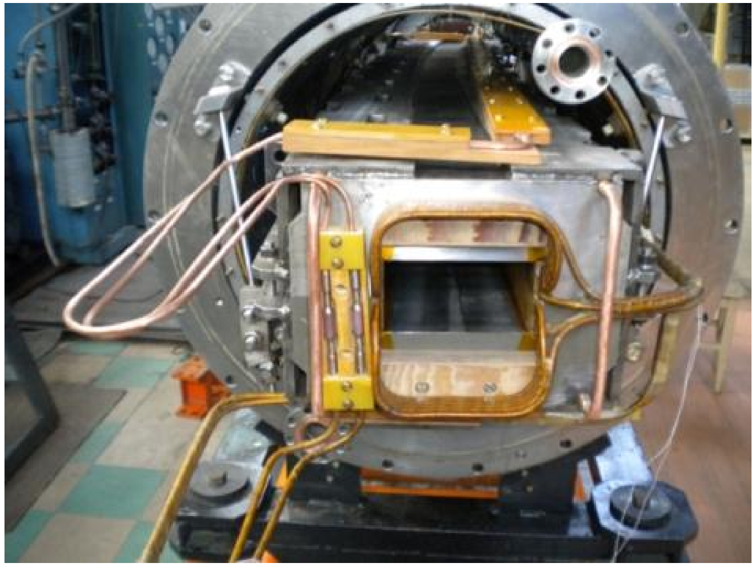
Vladimir I. Veksler

Dismounted presently

SC Dipole of The Booster-Synchrotron



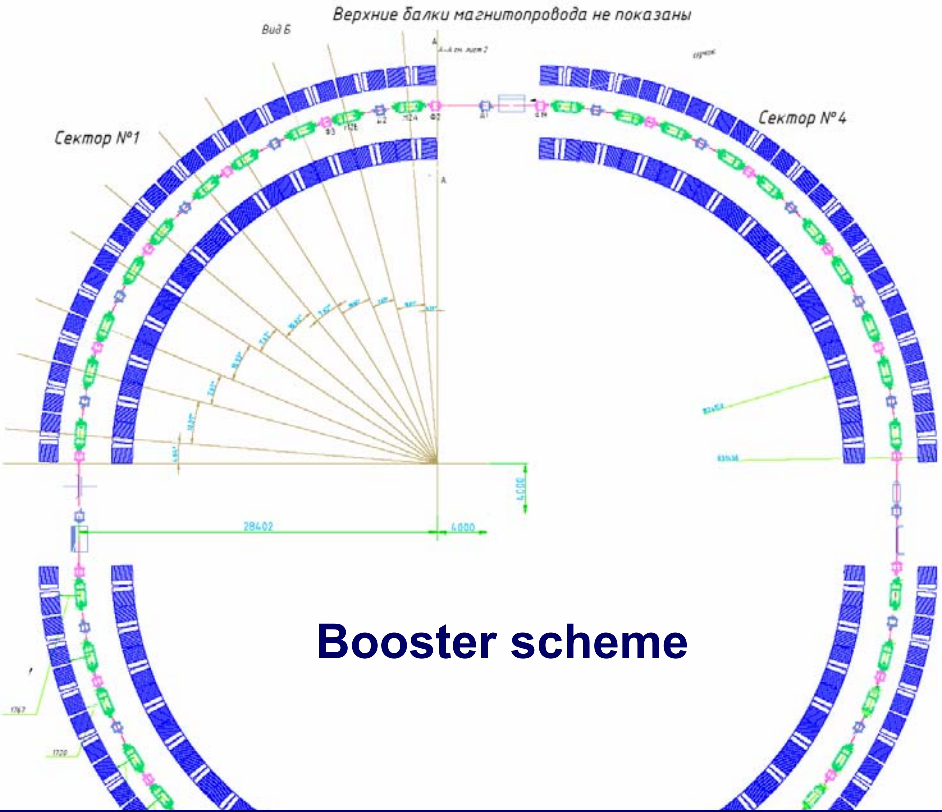
Dr.Hamlet Khodjibagiyan –
father of NICA SC magnets



June 2011
SC dipole preparation
for the cryogenic test

Part I. NICA Project Concept & Status

I.2. SC Booster-Synchrotron (Contnd)



Booster scheme

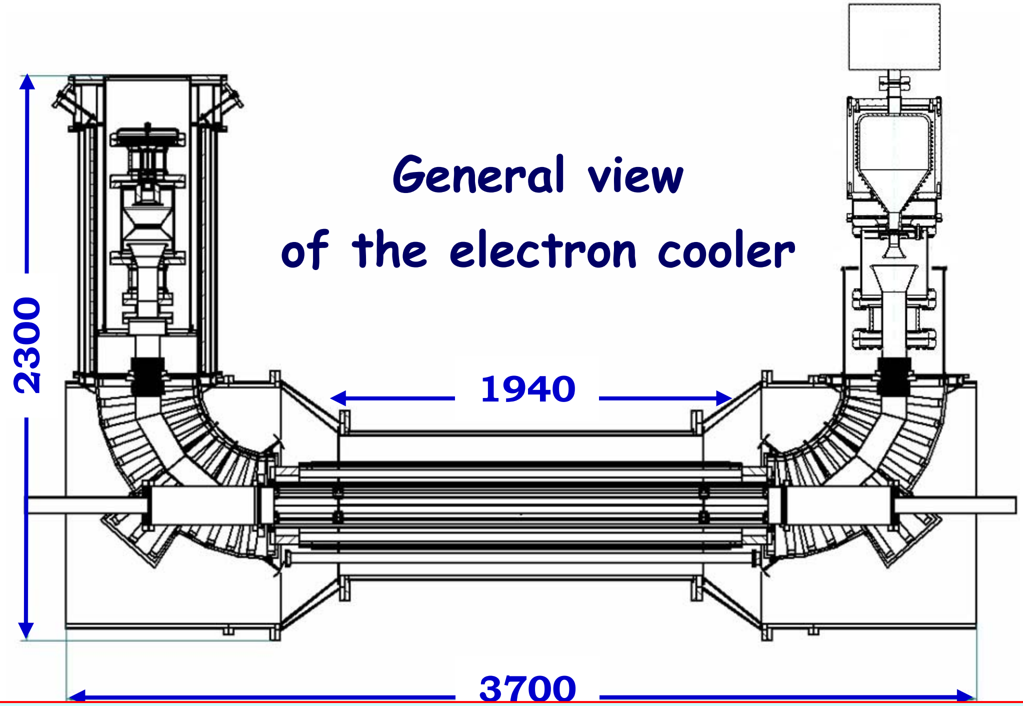
Booster Parameters

Particles	ions A/Z≤3
Injection energy, MeV/u	3
Maximum energy, GeV/u	0.6
Magnetic rigidity, T·m	1.55 ÷ 25.0
Circumference, m	211.2
Fold symmetry	4
Quadrupole periodicity	24
Betatron tune	5.8/5.85

Design and construction of the Booster RF System is under development at Budker INP (G.Kurkin and team) (to be ready April 2012)

I.2. Booster-Synchrotron (Contnd)

Booster electron cooler:
working design of e-cooler elements



See poster A.Rudakov et al., Booster electron cooling system of NICA project

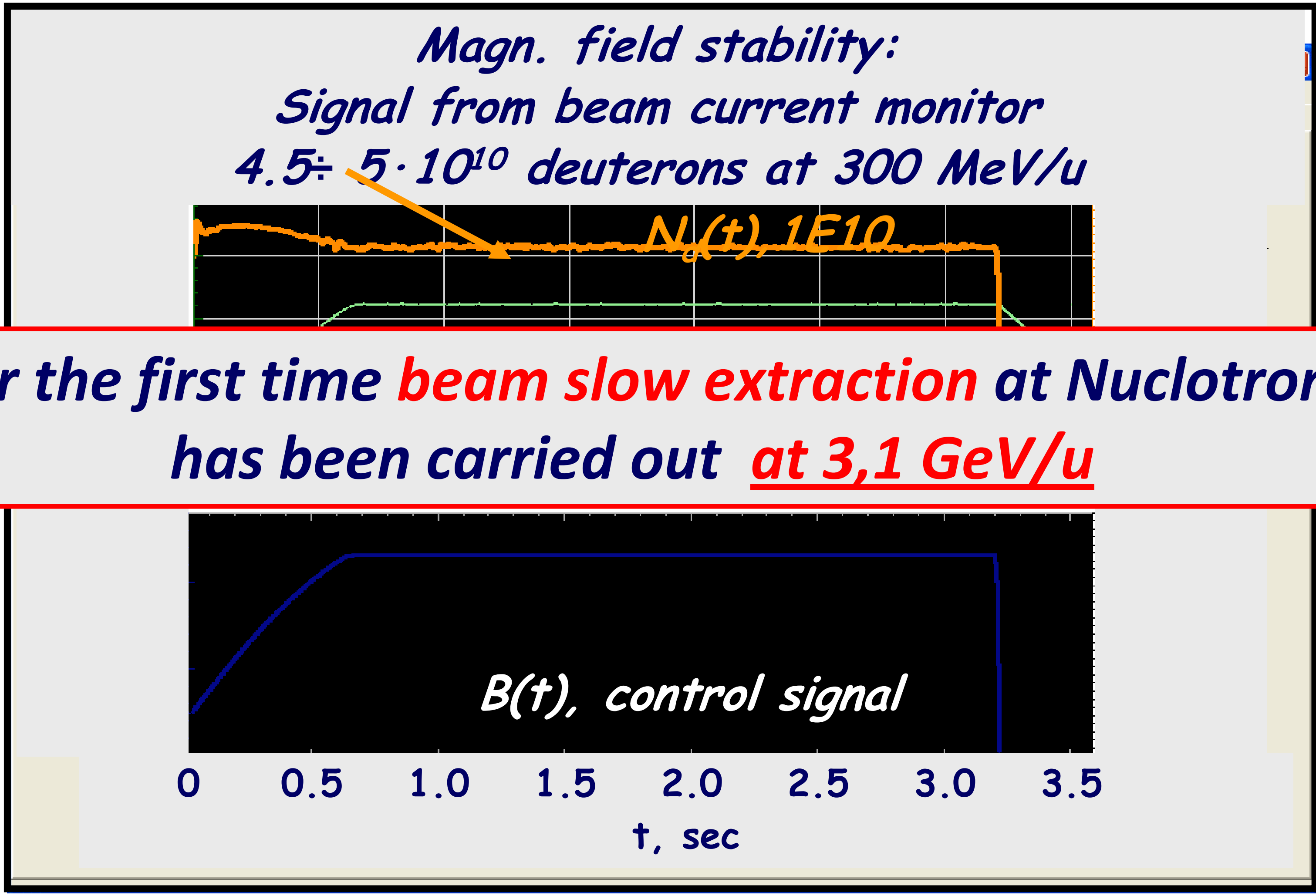
Agreement with Budker INP: common design,
the main part will be constructed at BINP
(V.Parkhomchuk and team)

Part I. NICA Project Concept & Status

I.3. SC Synchrotron Nuclotron

Parameter	Project	Status (April 2011)
Max. magn. field, T	2.05	2.05
Magn. rigidity, T·m	45	45
Cycle duration, s	2.0	5.0
B-field ramp, T/s	2.0	1.0
Accelerated particles	p–U, p↑, d↑	p-Xe, d↑
Max. energy, GeV/u	12.6(p), 5.87(d) 4.5($^{197}Au^{79+}$)	3.5 (d), 1.5 ($^{124}Xe^{42+}$)
Intensity, ions/cycle	1E11(p,d), 1E9 (A > 100)	5E10 (p,d), 1E10 (d↑) 1E5 ($^{124}Xe^{24+}$)

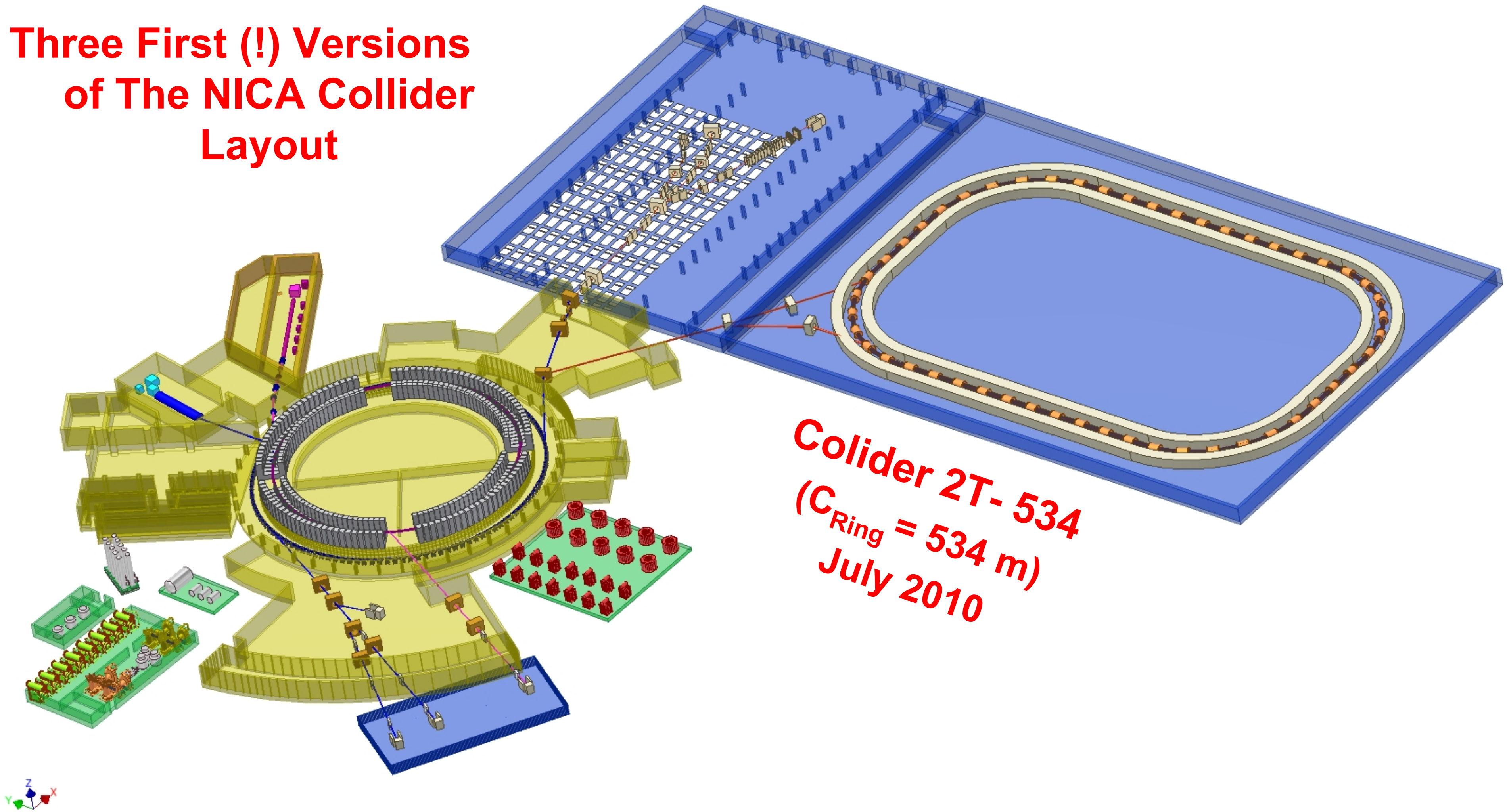
Machine performance improvement



For the first time beam slow extraction at Nuclotron has been carried out at 3,1 GeV/u

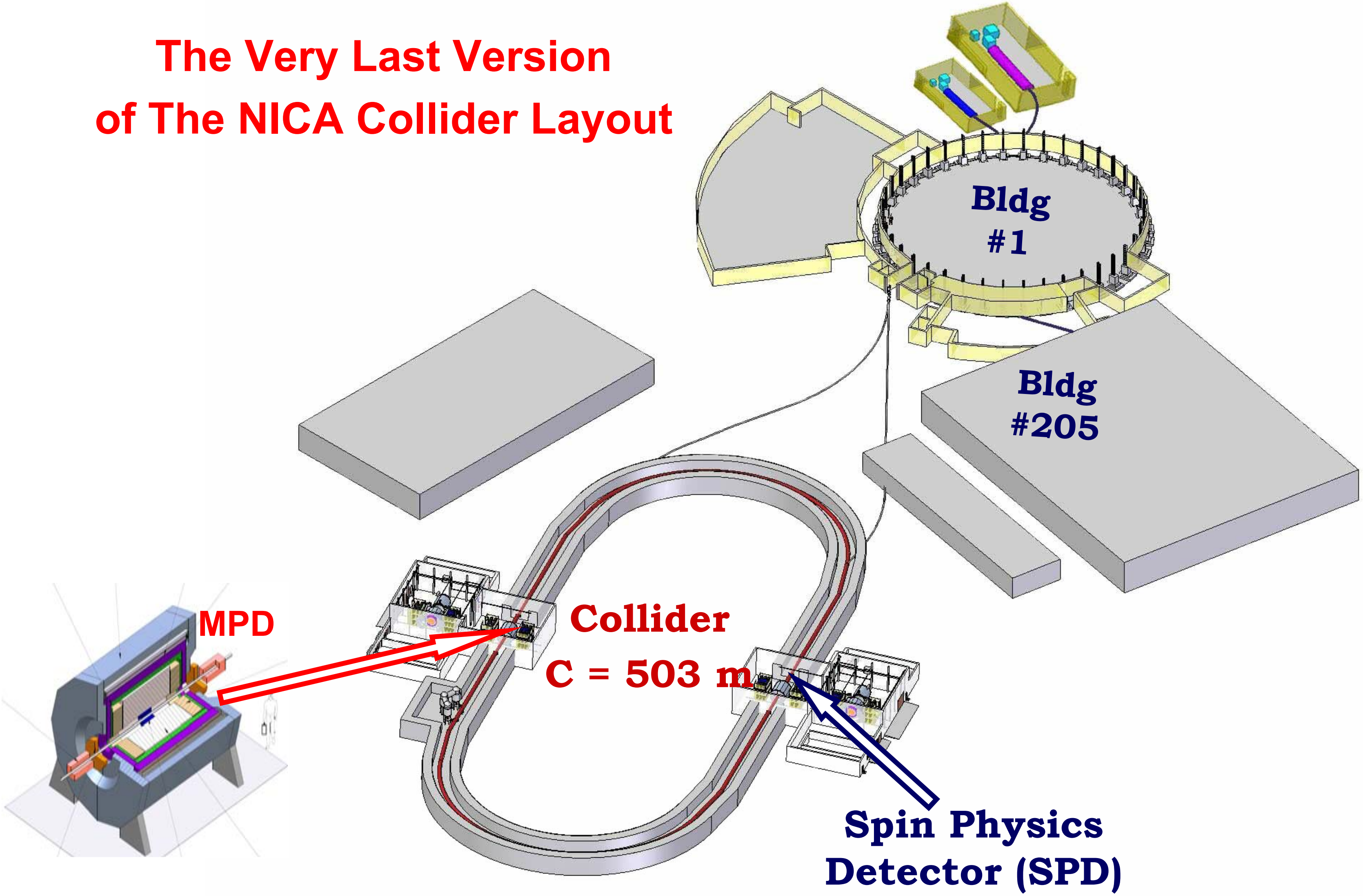
I.4. SC Collider

Three First (!) Versions of The NICA Collider Layout



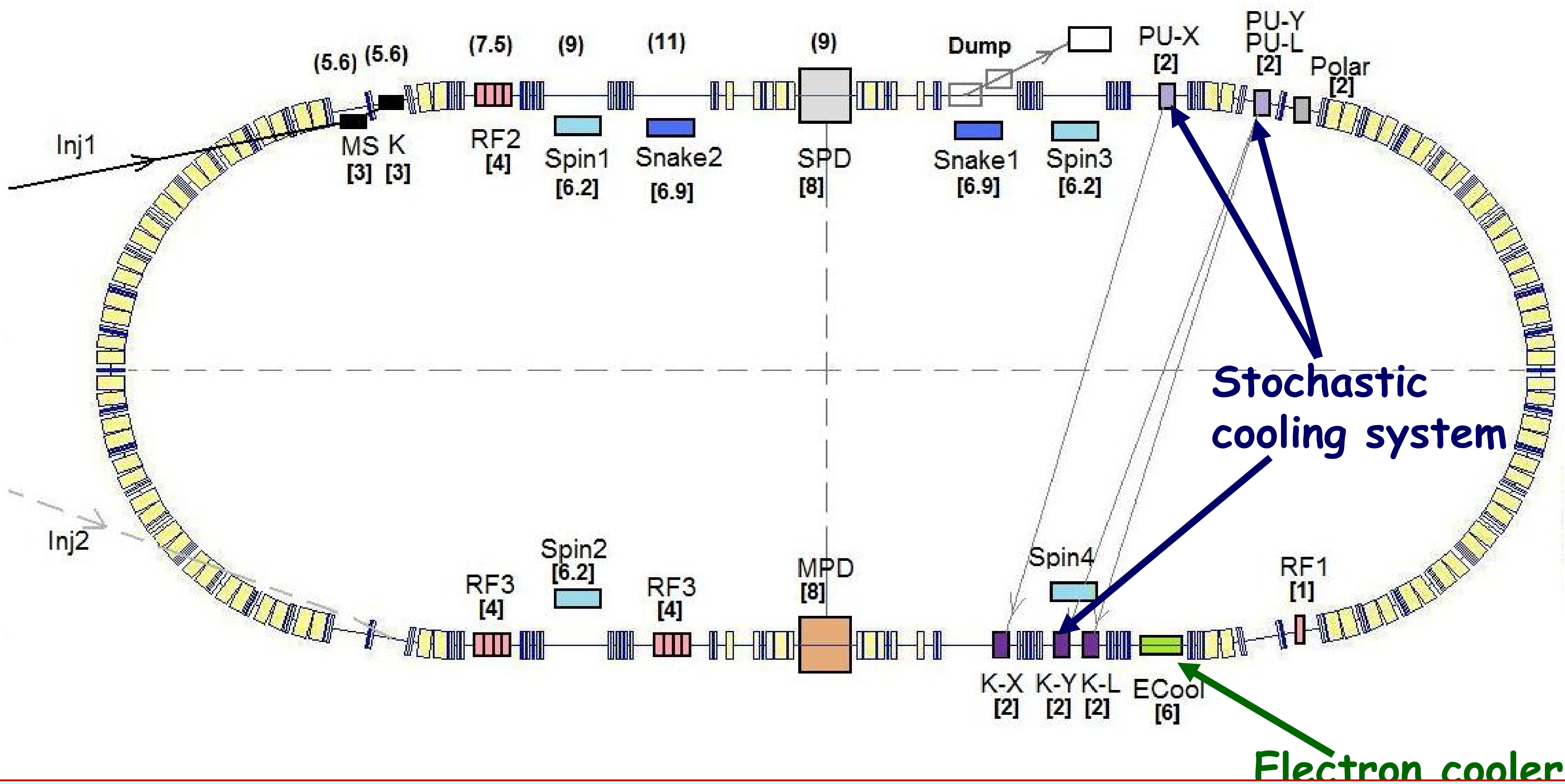
I.4. SC Collider

The Very Last Version of The NICA Collider Layout



Part I. NICA Project Concept & Status
I.4. SC Collider

Collider ring principle scheme

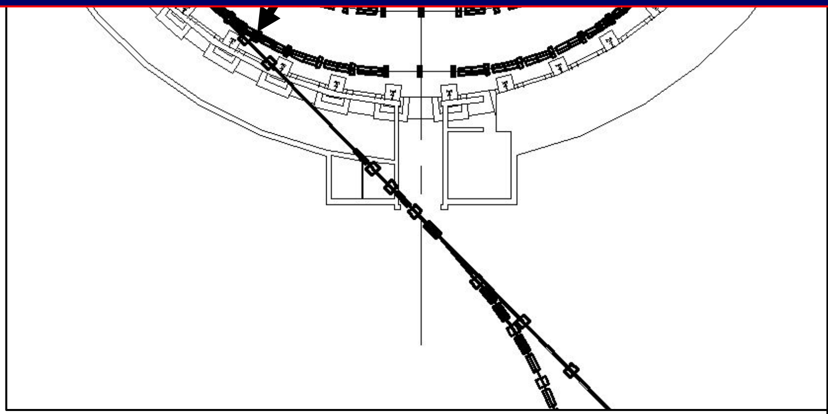


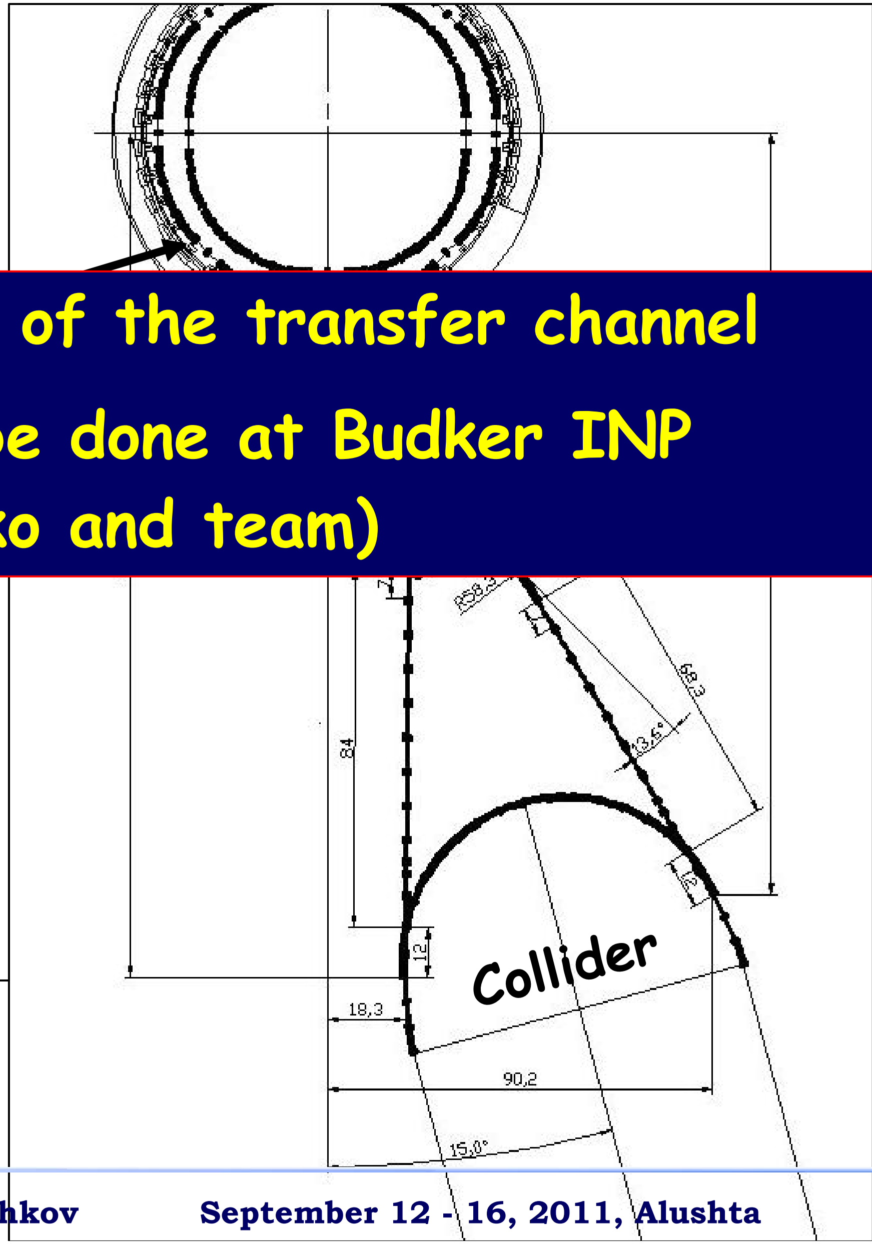
S-Cooling system is presented in the talks of G.Trubnikov (the next after myself) and T.Katayama (Tue, 11-10)

Collider general parameters

Ring circumference, m	503
Focusing structure	FODO (12 cell x 90^0 each arc)
Number of dipole magnets	80
Number of bunches per ring	23
Ring acceptance, π·mm·mrad	40.0
RMS momentum spread, 1e-3	1.8
Max. Ion number per bunch, 1e9	2.0

Transfer channel Nuclotron - Collider





Design and construction of the transfer channel focusing system will be done at Budker INP (A.Medvedko and team)

Collider SC magnets

RF Systems

Parameter \ RF system	RF1 (BB*))	RF2	RF3
Frequency, MHz*)	0.529÷0.59	11.4÷12.8	34.2÷38.4
Number of cavities	5	4	8
Total power, kW	-	100	400
Cavity length, m	-	1.1	1.1
Total length, m	-	4.4	8.8

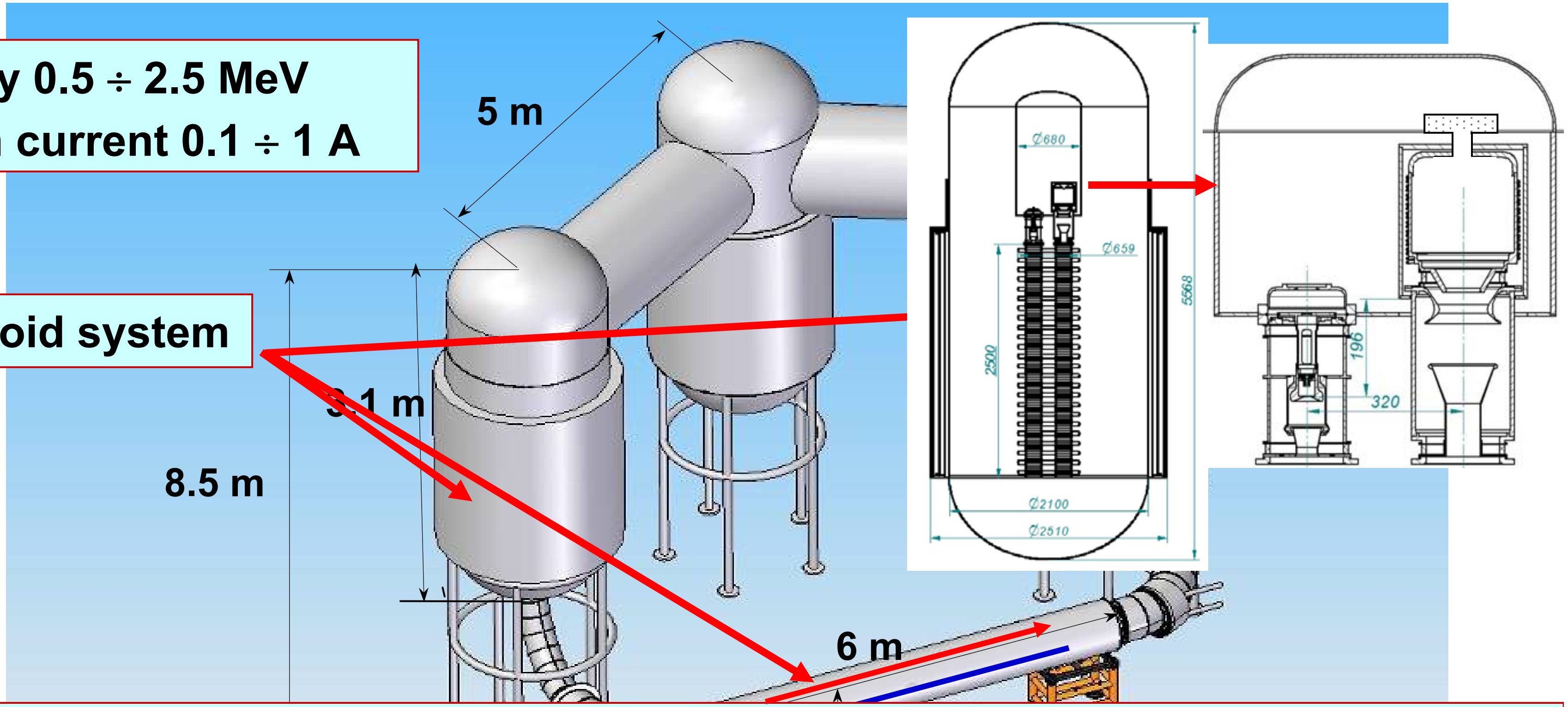
Project of the Collider RF Systems is under development at Budker INP (G.Kurkin and team)

*) Frequency of pulses of the same polarity in RF system of BB type. Rectangular pulses of phase duration π/6, phase distance between the pulses of opposite polarity is equal to π.

HV Electron cooler: working design

El. energy 0.5 ÷ 2.5 MeV
El. beam current 0.1 ÷ 1 A

SC solenoid system



See posters: S.Yakovenko et al., Electron Cooler for NICA Collider
R. Pivin Superconducting Solenoid for Electron Cooling System

Cooperation with V.I.Lenin All-Russian Electrotechnical Institute

Stochastic cooling system:

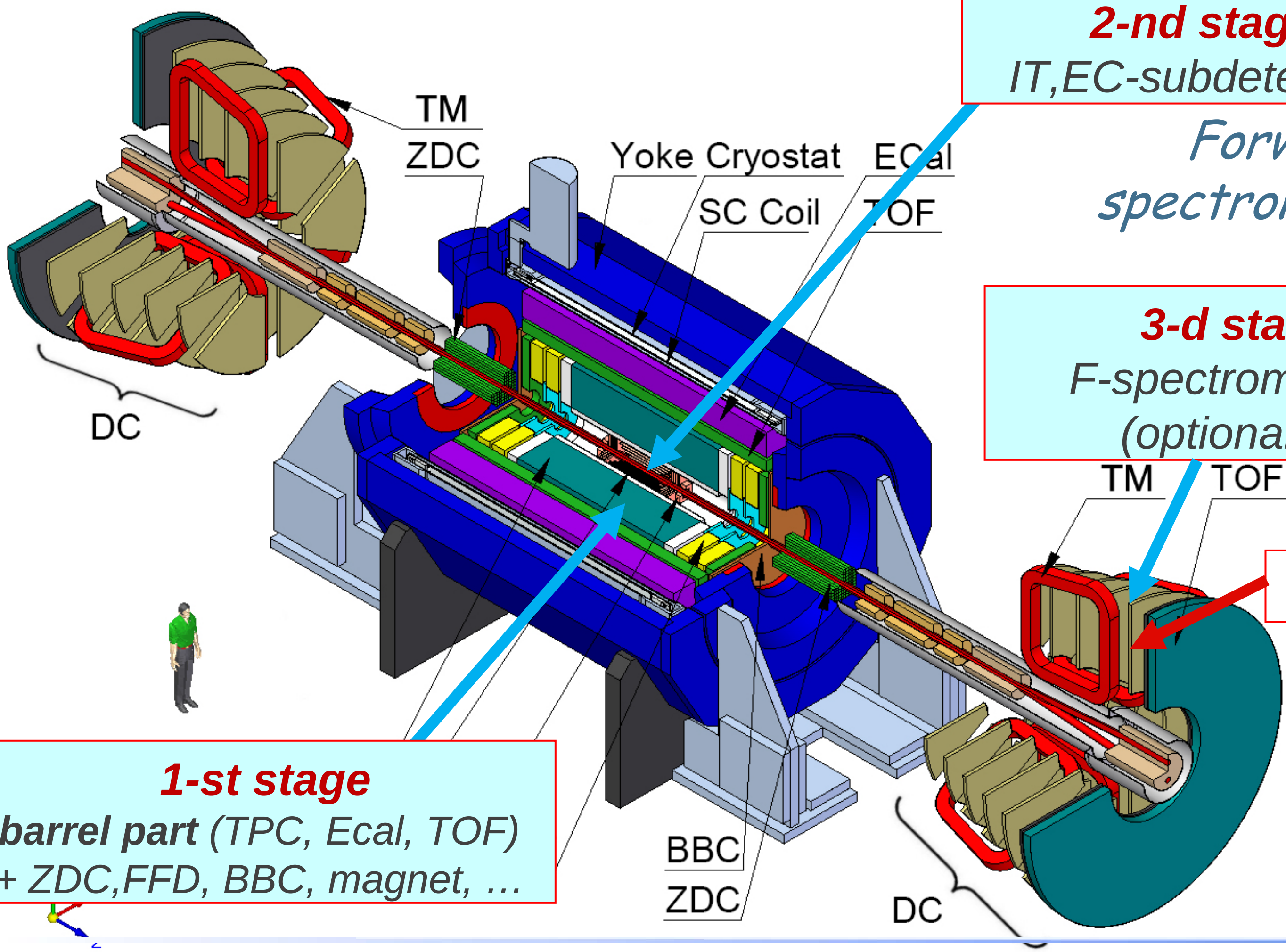
- ✓ conceptual design
- ✓ test experiment at Nuclotron

Common work with T.Katayama (GSI), R.Stassen (FZJ), L.Thorndahl, D.Möhl (CERN)

NICA S-Cooling system and the procedures are presented in the talks of G.Trubnikov (the next after myself) and T.Katayama (Tue, 11-10)

I.5. MultiPurpose Detector (MPD)

3 stages of putting into operation



2-nd stage
IT,EC-subdetectors

Forward spectrometer-B

3-d stage
F-spectrometers (optional ?)

Toroid

1-st stage
***barrel part** (TPC, Ecal, TOF)*
+ ZDC,FFD, BBC, magnet, …

Part II. Collider Luminosity and Cooling Issues

II.1. Boundary conditions for NICA Collider

1) Beam emittance (unnormalized) $\varepsilon_b \le 1\ \pi\cdot$mm$\cdot$mrad –

– limited by the ring acceptance

2) $L(E_i) \ge$ 1E27 cm$^{-2}\cdot$s^{-1} at $3.5 < E_i < 4.5$ GeV/u – physics requirement

3) Ion number per bunch is limited by injection chain and ion storage time duration:

$N_b \le$ 2E9 per bunch

II.2. Trivial consideration and nontrivial conclusion

$$\left.\begin{aligned} L &\propto \frac{N_{ion}^2}{\varepsilon}\cdot f_1(E_{ion})\cdot f_{HG}(\beta^*,\sigma_s) \\ \Delta Q &\propto \frac{N_{ion}}{\varepsilon}\cdot f_2(E_{ion}) \end{aligned}\right\} \Rightarrow L \propto \Delta Q^2\cdot\varepsilon\cdot f_3(E_{ion})\cdot f_{HG}(\beta^*,\sigma_s),\quad N_{ion}\propto \Delta Q\cdot\varepsilon\cdot f_4(E_{ion})$$

At fixed $\Delta Q = \Delta Q_{max} \approx 0.05$ maximum luminosity is achieved when all acceptance is filled with ions!

"Space Charge Dominated Regime" (SCD Regime)

II.4. Trivial consideration and nontrivial conclusion (Contnd)

$$\left.\begin{aligned} L &\propto \frac{N_{ion}^{2}}{\varepsilon}\cdot f_1(E_{ion})\cdot f_{HG}(\beta^*,\sigma_s) \\ \Delta Q &\propto \frac{N_{ion}}{\varepsilon}\cdot f_2(E_{ion}) \end{aligned}\right\} \Rightarrow \quad if\ \ L = const = 1E27\ we\ have$$

$$N_{ion} \propto \sqrt{L\cdot\varepsilon}\cdot f_4(E_{ion},\beta^*,\sigma_s), \quad \Delta Q \propto \sqrt{\frac{L}{\varepsilon}}\cdot f_5(E_{ion},\beta^*,\sigma_s) < \Delta Q_{max} = 0.05$$

If luminosity can be limited (for some “not beam rerlated” reasons – e.g., detector performance) one can have *IBS Dominated Regime*:

$$\tau_{IBS} = \tau_{cooling}$$

II.3. Space Charge Dominated Regime (SCDR)

Approaching equilibrium at beam cooling:

☺ $\Delta Q_{total} \le \Delta Q_{res} \Rightarrow$ **cooling shrinks ion beam to equilibrium state**

☹ $\Delta Q_{total} > \Delta Q_{res} \Rightarrow$ **nonlinear resonance expands ion beam until it reaches equality** $\Delta Q_{total} = \Delta Q_{res}$ **(*satisfactory condition*)**

Necessary condition: $\tau_{cool} < \tau_{IBS}$.

$$\Delta Q_{total} = \Delta Q_{bet} + n_{\xi}\xi = \frac{Z^2}{A} \cdot \frac{r_p N_b}{\beta^2 \gamma 4\pi\varepsilon_{beam}} \cdot \left(\frac{k_{bunch}}{\gamma^2} + n_{\xi}(1+\beta^2) \right) \le \Delta Q_{res},$$

$$k_{bunch} = \frac{C_{Ring}}{\sqrt{2\pi} \cdot \sigma_s}$$

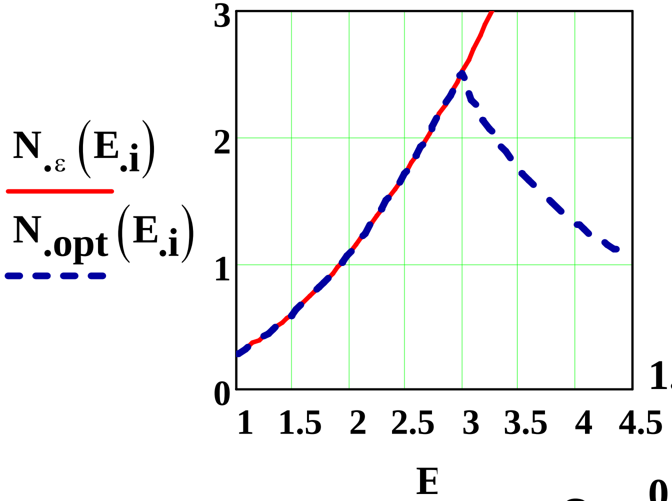
n_{ξ} *= 2 – number of IPs*

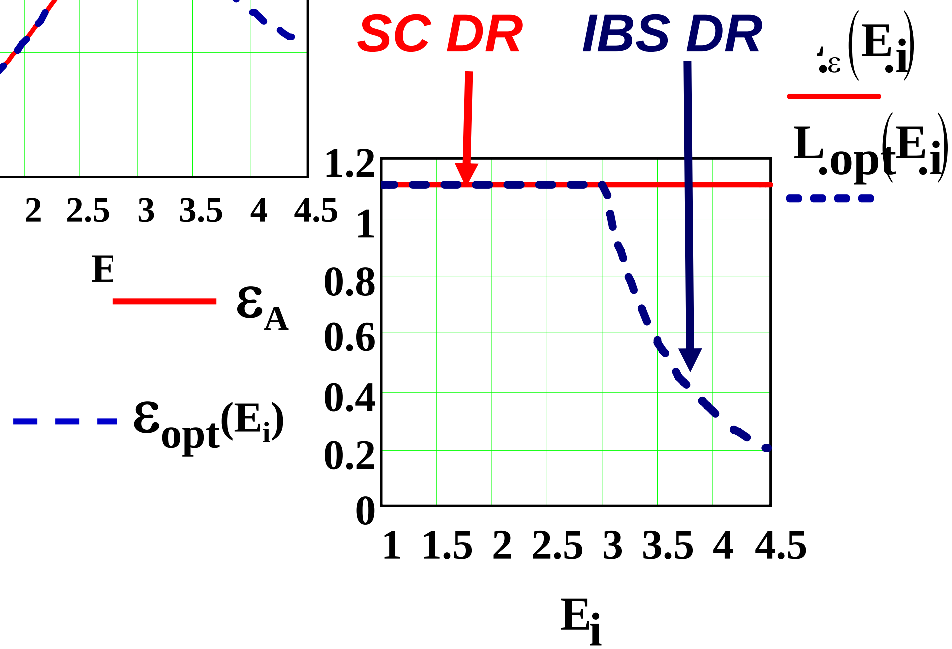
How can we obtain such a regime? We vary N_{ion} per bunch!

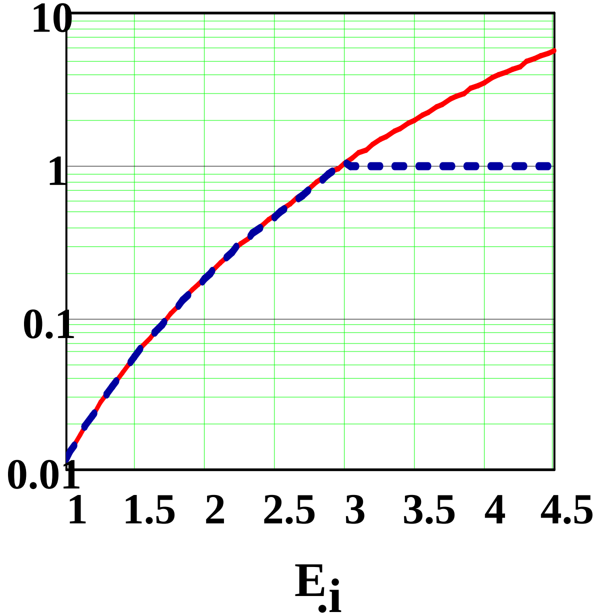
(e.g., by number of injection cycles)

A) Acceptance is filled with ions up to $\Delta Q = \Delta Q_{max} = 0.05$, $L = L_{max}$

B) Optimal regime: $L = \begin{cases} L_{max} \text{ at } 1 \le E_i \le 3 \text{ GeV/u}, \\ 1E27 = \text{const at } 3 \le E_i \le 4.5 \text{ GeV/u}. \end{cases}$







II.5. Several remarks on cooling application

1. The luminosity limitation considered here is not absolute: there are several options which allow us to increase luminosity by several times in low energy range;

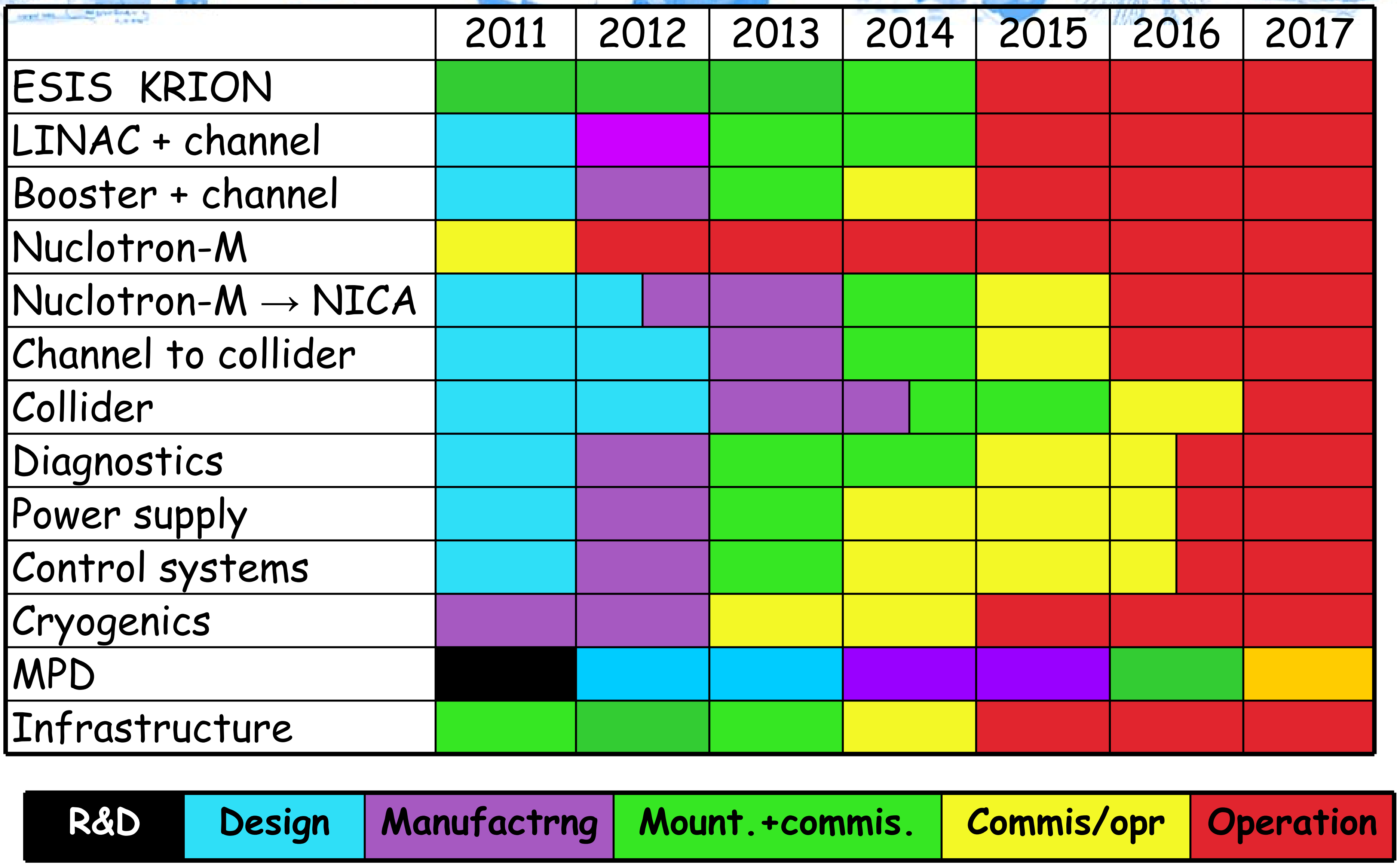
   (see next talk of G.Trubnikov)

2. Application of electron cooling of bare nuclei is accompanied by recombination of nuclei with cooling electrons that can diminish significantly beam life time. Special measure should be taken to avoid this restriction;

   (see talk of A.Philippov, Thursday, 12-00)

3. Stochastic cooling of an intense bunched beam is very challenging and not well developed yet.

NICA Time Table



Conclusion

Project NICA Passed the stage of concept formation and is presently in the stage of

- ✓ Detailed simulation of ion beam dynamics,
- ✓ Constru … pes,
- ✓ Beginni…
- ✓ Workin…
- ✓ Preparation of documentation for the State Expertise.

Tnank you for you attention!

Staged commissioning of NICA accelerators is foreseen and beginning of experiments on colliding ion beams (Ist phase of the project) is planned for 2017 year.