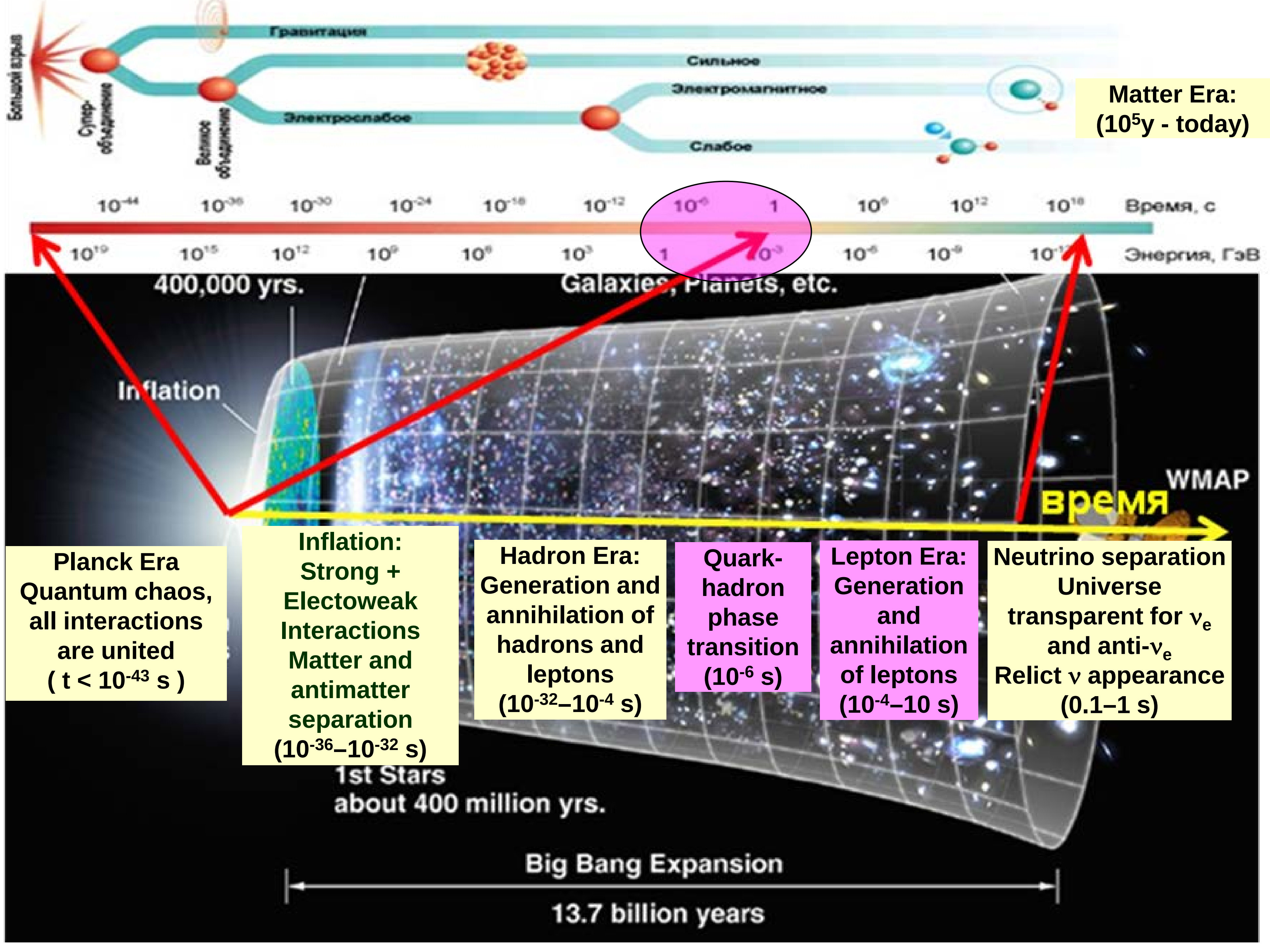
NICA project at JINR

G.Trubnikov
JINR Dubna, on behalf of the team

BLTP, Dubna,
26 August 2014



Гравитация
Сильное
Электромагнитное
Электрослабое
Слабое
Время, с
Энергия, ГэВ
Matter Era:
(10^5y - today)
400,000 yrs.
Galaxies, Planets, etc.
Inflation
WMAP
время
Planck Era
Quantum chaos,
all interactions
are united
(t < 10^-43 s)
Inflation:
Strong +
Electoweak
Interactions
Matter and
antimatter
separation
(10^-36–10^-32 s)
Hadron Era:
Generation and
annihilation of
hadrons and
leptons
(10^-32–10^-4 s)
Quark-
hadron
phase
transition
(10^-6 s)
Lepton Era:
Generation
and
annihilation
of leptons
(10^-4–10 s)
Neutrino separation
Universe
transparent for νe
and anti-νe
Relict ν appearance
(0.1–1 s)
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

Evolution of collision region in Nucleus-Nucleus Interaction

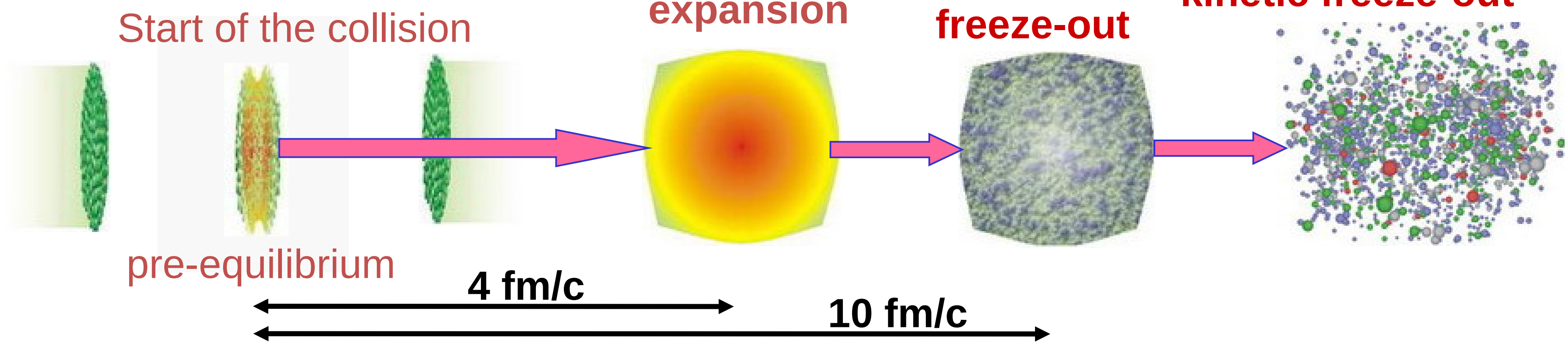
Deconfinement!

QGP – Quark-gluon plasma

QGP and hydrodynamic expansion

Hadronisation, hadronic phase & **chemical freeze-out**

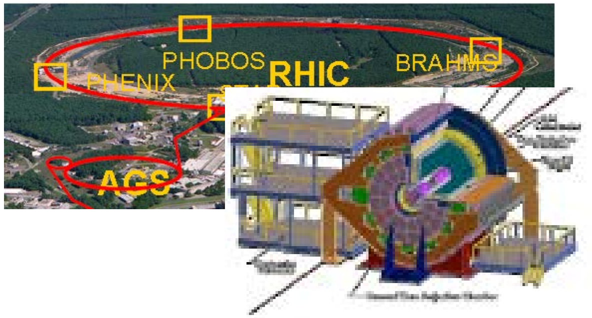
Hadronic phase & **kinetic freeze-out**



$1\ fm/c = 1{\cdot}10^{-13} / 3{\cdot}10^{10} = 3.33{\cdot}10^{-23}$ sec

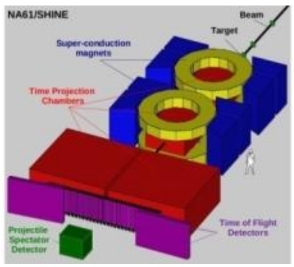
“Chemical freeze-out” – finish of inelastic interactions;
“Kinetic freeze-out” – finish of elastic interactions.

*) freeze-out – here means “to get rid” (phys. slang)



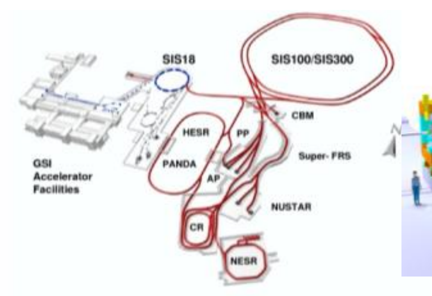
2^{nd} generation HI experiments

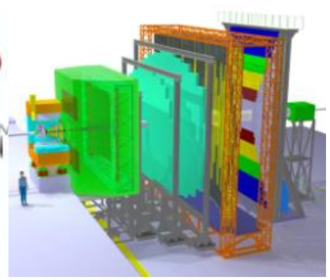
STAR/PHENIX @ BNL/RHIC.
designed for high energy researches ($\sqrt{s_{NN}}$ > 20 GeV),
low luminosity for LES program $L<10^{26}\ cm^{-2}s^{-1}$ for Au^{79+}



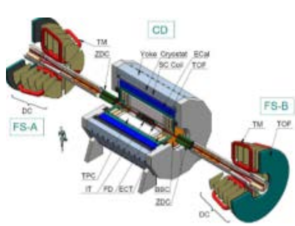
NA61 @ CERN/SPS.
Fixed target, non-uniform acceptance, few energies (10,20,30,40,80,160A GeV), poor nomenclature of beam species

3^{nd} generation HI experiments





CBM @ FAIR/SIS-100/300
Fixed target, E/A=10-40 GeV, high luminosity



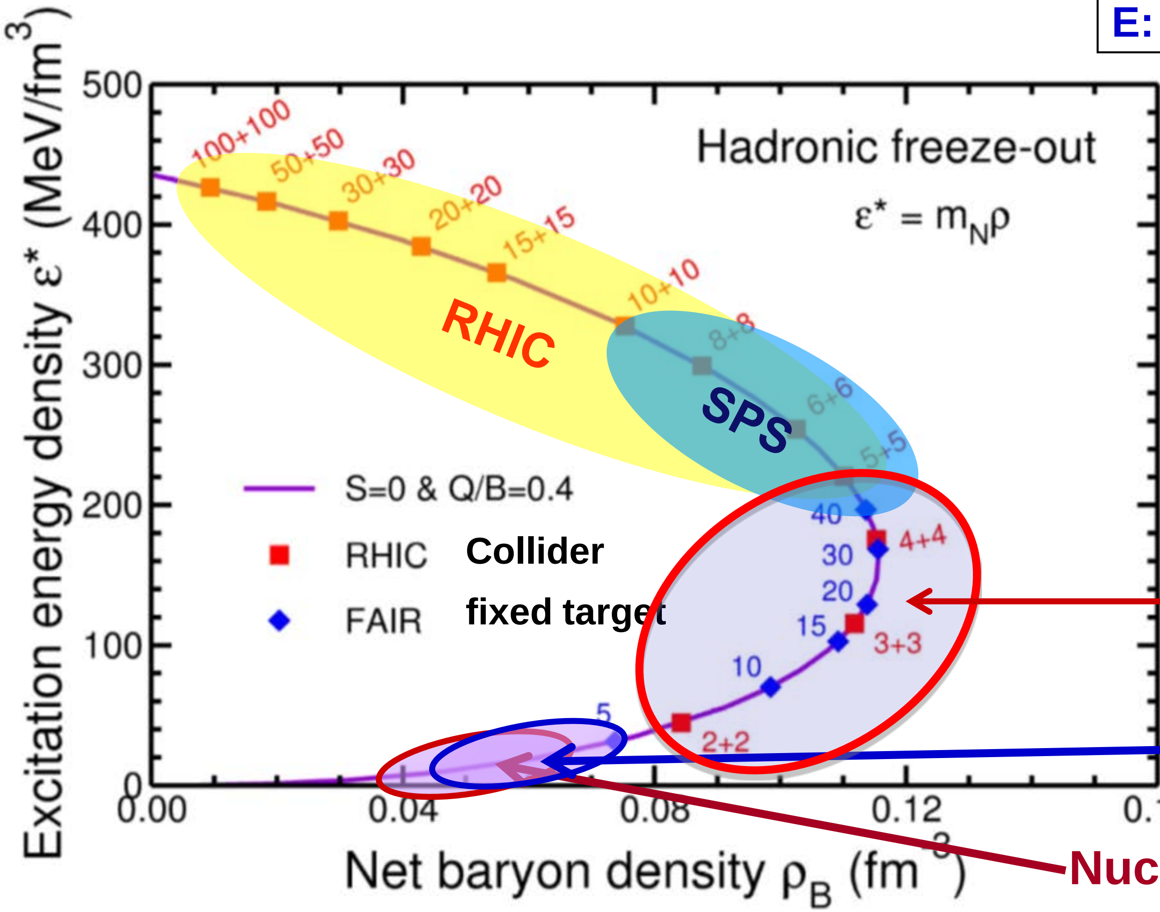
MPD & SPD @ JINR/NICA.
Collider, small enough energy steps in the range $\sqrt{s_{NN}}$ = 4-11 GeV, a variety of colliding systems,
$L\sim10^{27}\ cm^{-2}s^{-1}$ for Au^{79+}

Colliders and fixed target experiments

Baryon density in Au + Au collisions
at $\sqrt{S_{NN}}$ = 4 - 11 GeV/u

E1+E2: collider
E: Fixed Target

J.Randrup, J.Cleymans PR C74 (2006) 047901



NICA/MPD
SIS-300 (FAIR)

SIS-100

Nuclotron / BMN

Colliders and fixed target experiments

u - "unit" => from "amu" -
- atomic mass unit

An example:

Fixed target, ions, E_1 = 100 GeV/u

$$E_1^{total} = 100 + 0.938\ GeV/u, \quad E_2^{total} = 0.938\ MeV/u,$$

$$\sqrt{s} \approx 13.76\ GeV/u, \quad E_1^{total} >> m_u c^2$$

Colliding beams:

the same √s at $(E_1)_{kin} = (E_{kin})_2 \approx 6$ GeV/u

What is a problem?

Luminosity!

Luminosity

Luminosity is a parameter of an experiment with particle beams equal to event number per time unit (**rate**) if the process under study has cross section of $\sigma = 1$.

Luminosity is measured in $cm^{-2} \cdot s^{-1}$.

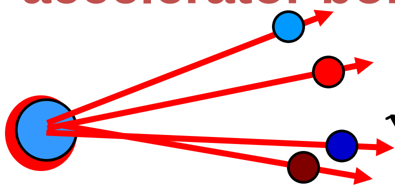
$$L = \begin{cases} \dfrac{N_1 N_2}{S} \cdot f & \text{for colliding beams} \\ (n_0 l)_{target} \cdot \dfrac{dN}{dt} & \text{for fixed target experiment} \end{cases}$$

N_1, N_2 – particle number in colliding beams, S – maximal cross-section of two beams, f – frequency of collisions (for collider - particle rvolution frequency in the ring);

n_0 – target density (cm^{-3}), l – target thickness, dN/dt – particle flux bombarding the target.

Colliders and fixed target experiments

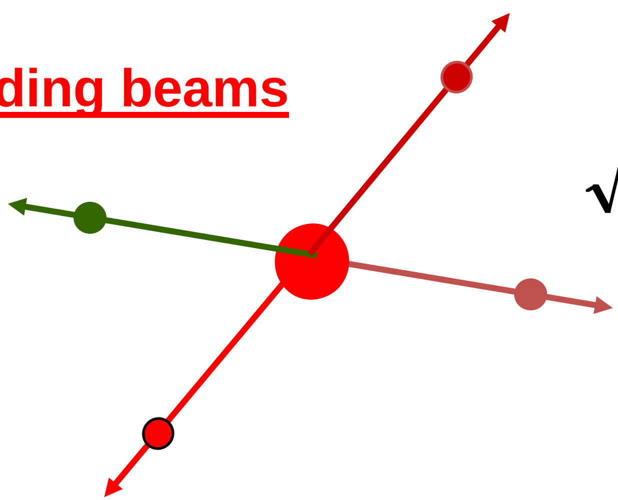
Fixed target experiment: a particle beam extracted from an accelerator bombards an immovable ("fixed") target



$$\sqrt{s} \approx E_{total}^{cms} \approx \begin{cases} \sqrt{2Mc^2 E_{ion\_total}^{lab}}, & E_{ion\_total}^{lab} >> Mc^2 \\ (m+M)c^2 + \dfrac{M}{m+M} \cdot E_{ion\_kin}^{Lab}, & E_{ion\_kin}^{Lab} << mc^2, Mc^2 \end{cases}$$

Both primary particles and generated in collision with fixed target move with the speed of the center of the mass in direction of primary (bombarding) particle!

Colliding beams



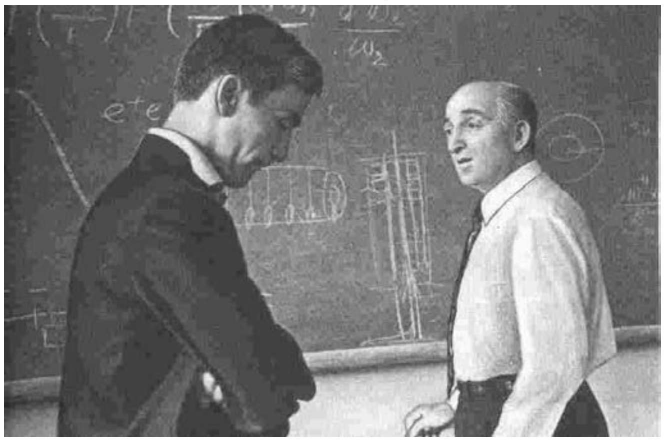
$$\sqrt{s} = E_{total}^{cms} = E_{1total} + E_{2total}, \quad p_1 = p_2\ (!)$$

Colliders and fixed target experiments

History of colliding beams

1956, D.W.Kerst et al., – **First proposal, pp collider**

1958 - 1965 VEP, INP at Novosibirsk



G.Budker, A.Naumov, A.Skrinsky, S.Popov, V.Sidorov, G.Tumaikin et al.

e^-e^-, 2 x 160 MeV,

$L = 3 \cdot 10^{27}\ cm^{-2} \cdot s^{-1}$

G.K.O'Neill

1958 - 1965 SLAC

Princeton-Stanford group:
G. K. O'Neill, B.Richter et al.

e^-e^- collider 2 x 500 MeV

Wolfgang ("Pief") Panofsky

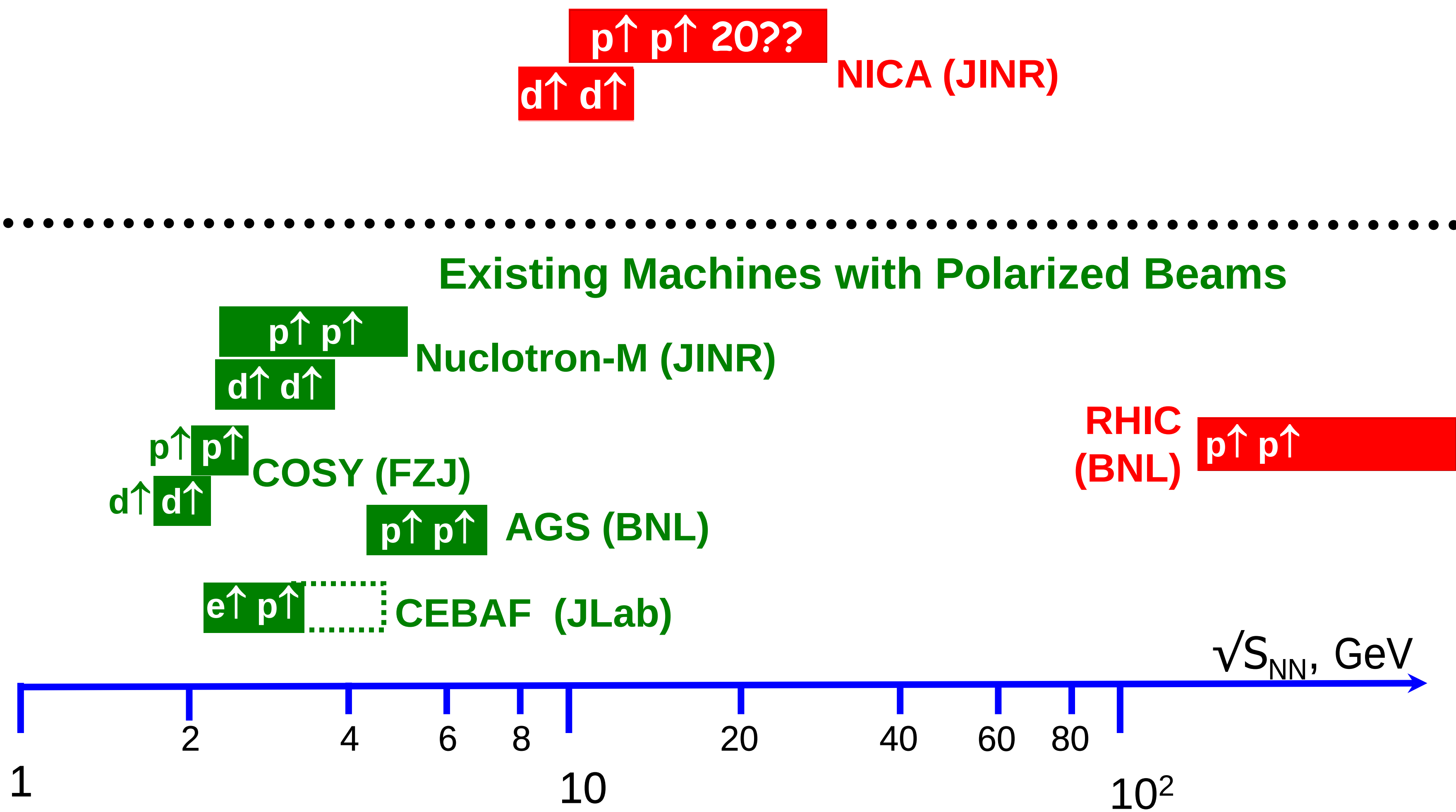
Motivation:

“Experiments with spin have killed more theories than any other single physical parameter.” (J.D.Bjorken)

[Cited by Elliot Leader, “Spin in Particle Physics”, Cambridge Univ. Press, 2001]

1. NICA Physics Case
B. Spin Physics

Future Machines with Polarized Beams



NICA White Paper – International Effort

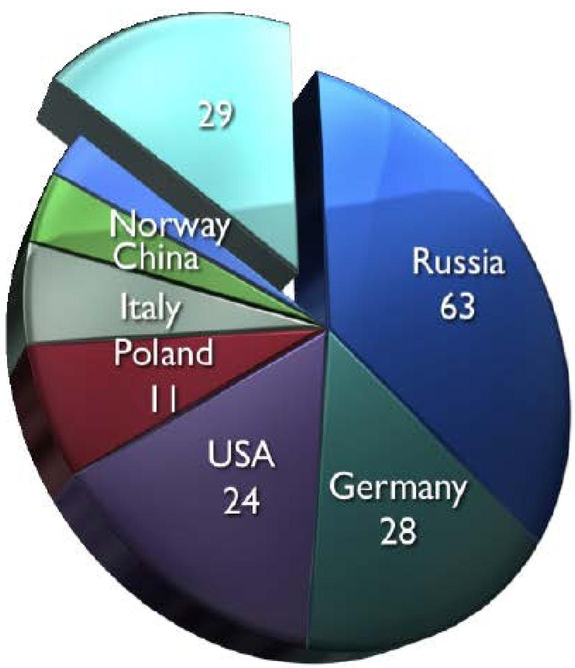
Draft v 10.01
January 24, 2014

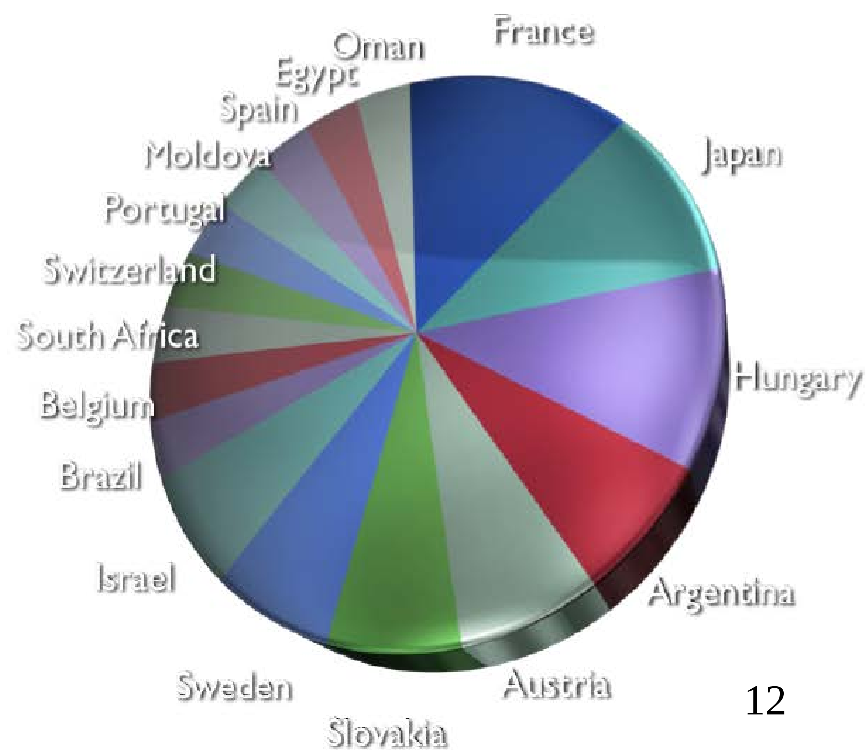
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

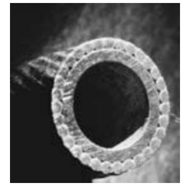
Statistics of White Paper Contributions

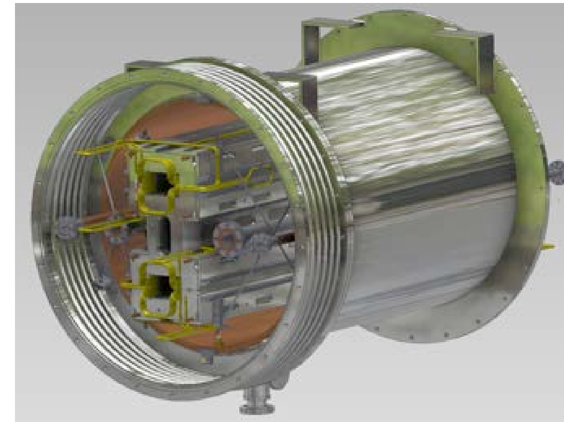
111 contributions:
188 authors from 70 centers in 24 countries

Indicates the activity of scientific community







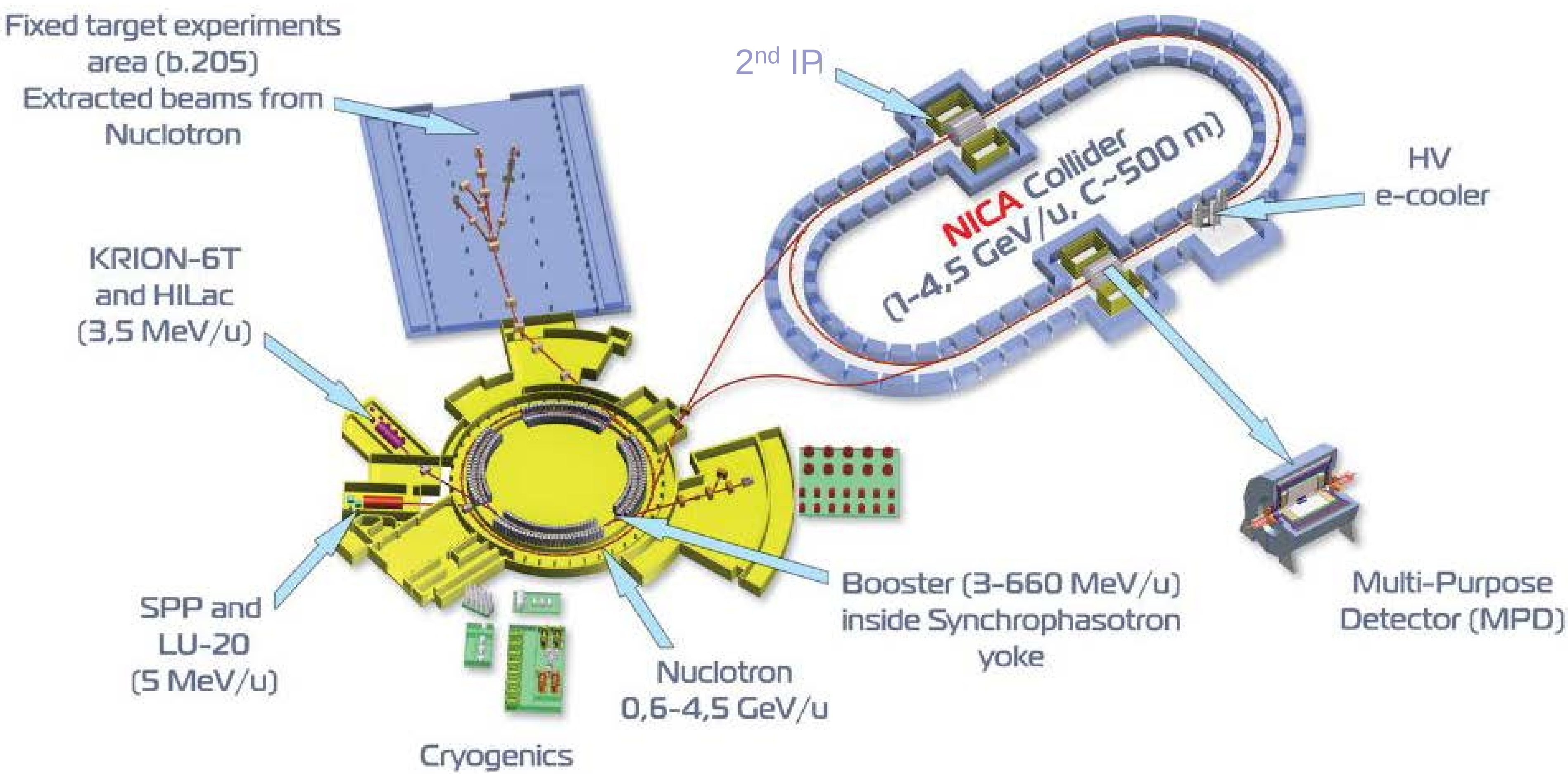


Unique Dubna technologies of fast-cycling superconducting magnets tested during several tens of Nuclotron runs and chosen as basic for accelerator complexes NICA and FAIR

Common European Research infrastructure for Heavy Ion High Energy Physics: NICA + FAIR

Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)



NICA goals

1a) Heavy ion colliding beams 197Au79+ x 197Au79+ at

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

at $L_{average}$= $1\text{x}10^{27}$ $cm^{-2}\cdot s^{-1}$ (at $\sqrt{s_{NN}}$ = 9 GeV)

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

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)

$L_{average}$ ≥ $1\text{x}10^{31}$ $cm^{-2}\cdot s^{-1}$ (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)

Here must be Movie…

NICA: Nuclotron based Ion Collider fAcility

B = 2T

$_{42+}Xe_{124}$

Status of the Nuclotron

Perfect test-bench for NICA booster/collider modes

Energy:

5.15 GeV/u (~ 1.8 T) – routine operation (At higher field the routine operation after 2015)

Intensity:

Deuterons - 3e10 (maximum achieved 5e10)
Light ions – 5e9 ppp (new Laser Source for ions)
Heavy ions – 1e6, after the Booster commissioning – 1e9 (2016)
Polarized deuterons – 1e10 starting from 2015

Slow extraction:

K_dc = 0.8 – 0.9

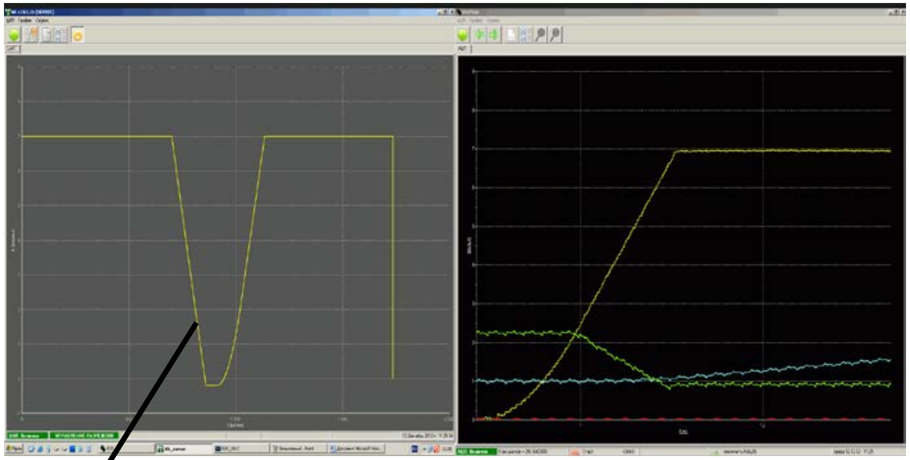
Duty factor:

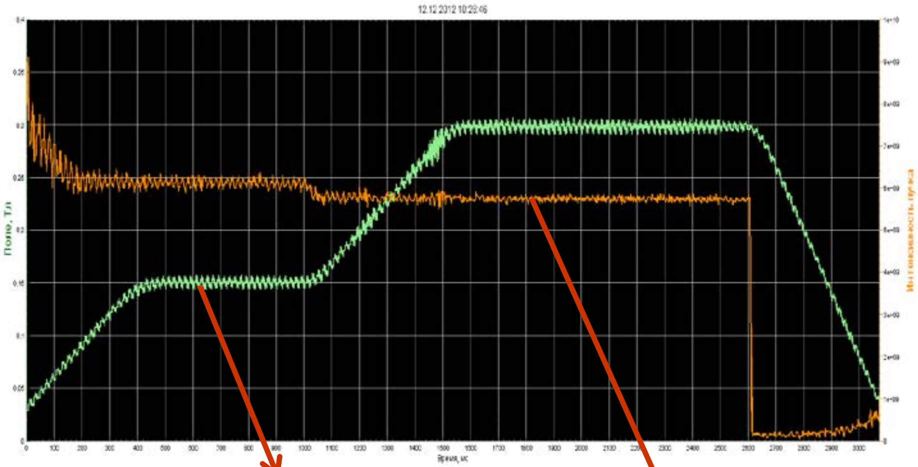
50% (the beam lines in bld. #205 have to be tested and recertified)

- Stochastic cooling of coasting and bunched carbon (C6+) beam
- **Beam acceleration up to maximum design field – 2 T**
- Coasting beam at two plateau
- Demonstration of slow extraction at spill duration of 20 s

Two (three) plateaus

Adiabatic debunching and recapture at efficiency of about 95% was demonstrated





RF amplitude

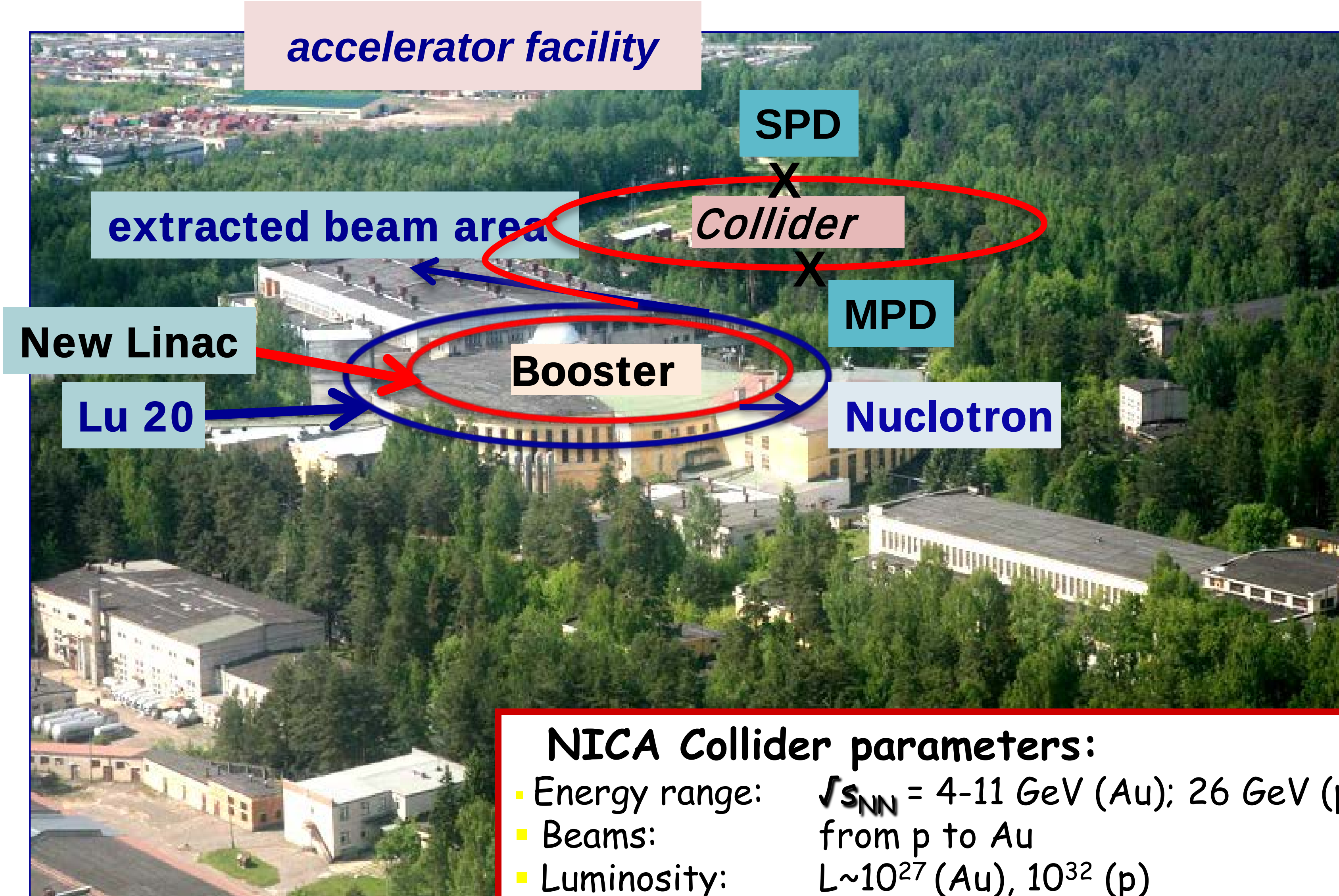
Magnetic field

Beam current

Technical limit of the intermediate plateau duration is about 0.5 s now.

During 2013 (it is a question to the RF station control system)
iwill be realized possibility to operate with 3 flattops:
1^{st}–on the arising front, 2^{nd}–main plateau, 3^{rd}–on the back front (useful for polarimetry).

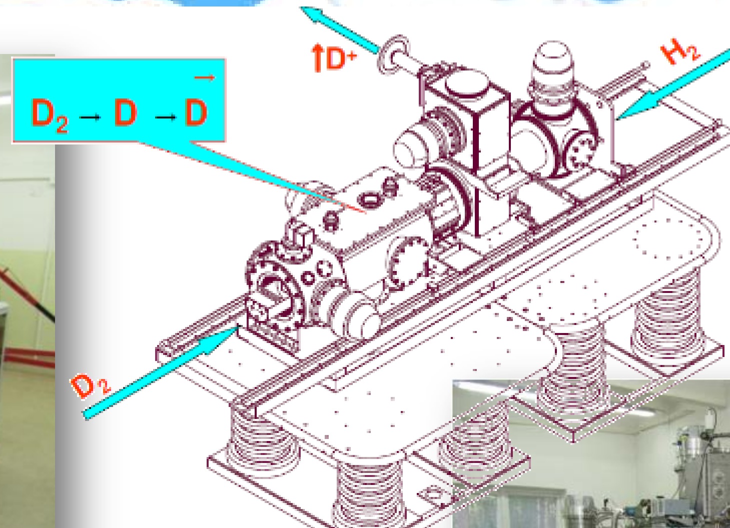
Veksler & Baldin Laboratory of High Energy Physics, JINR



NICA Collider parameters:

- Energy range: $\sqrt{s_{NN}}$ = 4-11 GeV (Au); 26 GeV (p)
- Beams: from p to Au
- Luminosity: $L \sim 10^{27}$ (Au), 10^{32} (p)
- Detectors: MPD; SPD-> Waiting for Proposals

Source of polarized ions (p, d, H) JINR+INR RAS



The main purpose of the SPI-project is to increase the intensity of the accelerated polarized beams (D+,H+) at the JINR Accelerator Complex up to **10^{10} p/pulse**

Results of the test to the end of 2013: **polarized protons and deutrons up to 10^{11} ppp**.

We plan to assemble and TEST SPI at Nuclotron with ↑d in 2015 year
After commissioning of the new RFQ foreinjector for LU-20

Progress in ion sources development and commissioning

Source for polarized particles (SPP)

Source is assembled in 2013 and works on its commissioning had been started in June 2013. The goal is to get 10^{10} deuterons per pulse.

Heavy ion source: Krion-6T ESIS

B= 5.4 Tesla magnetic field reached in a robust regime. Full-scale tests of new ESIS in reflex mode of operation was started in spring 2013.

Test gold ion beams have been produced:

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

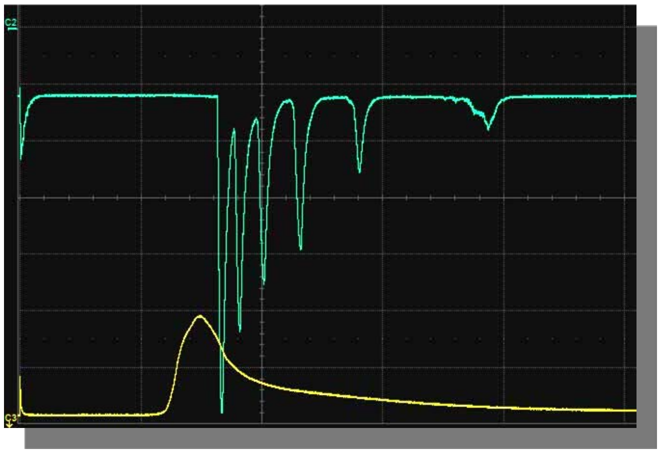
Now the goal is: production of $Au^{65+} \div Au^{69+}$ ion beams for their possible injection into LU-20 -> Nuclotron in spring 2014.

Injection complex

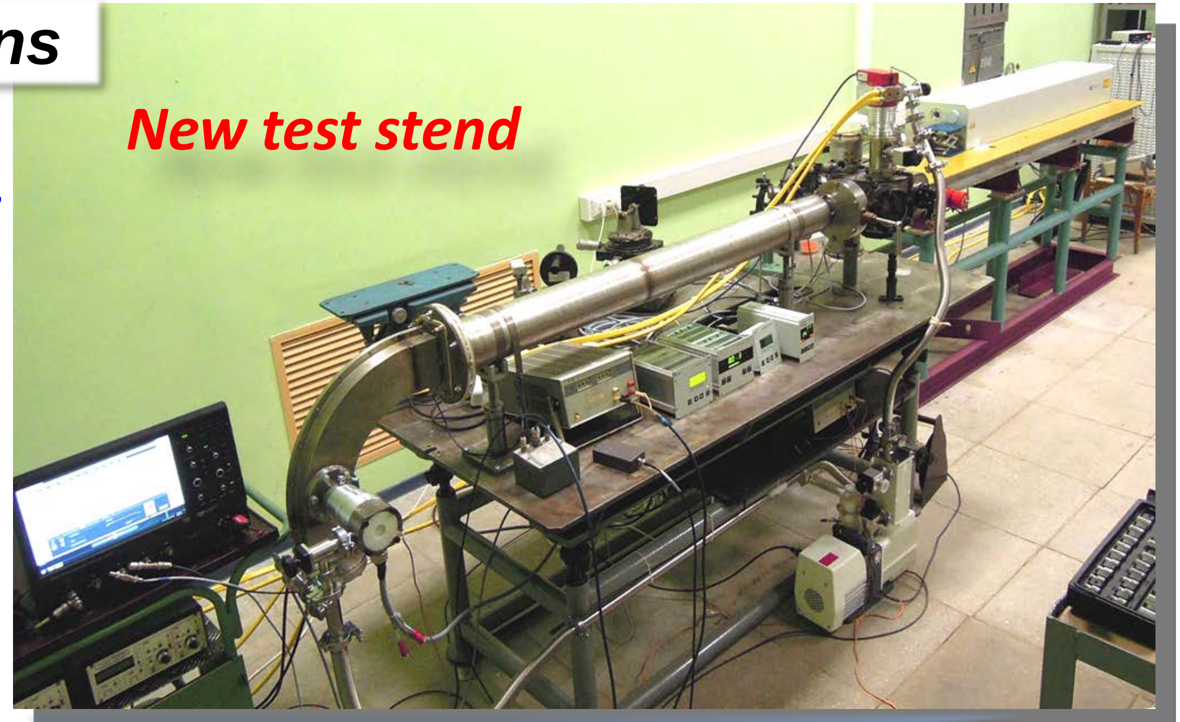
New laser source for ions

New Nd-YAG laser ,

E ≥ 2 J , τ≈ 7-8 ns, ~ $5 \cdot 10^{12}$ W/cm²

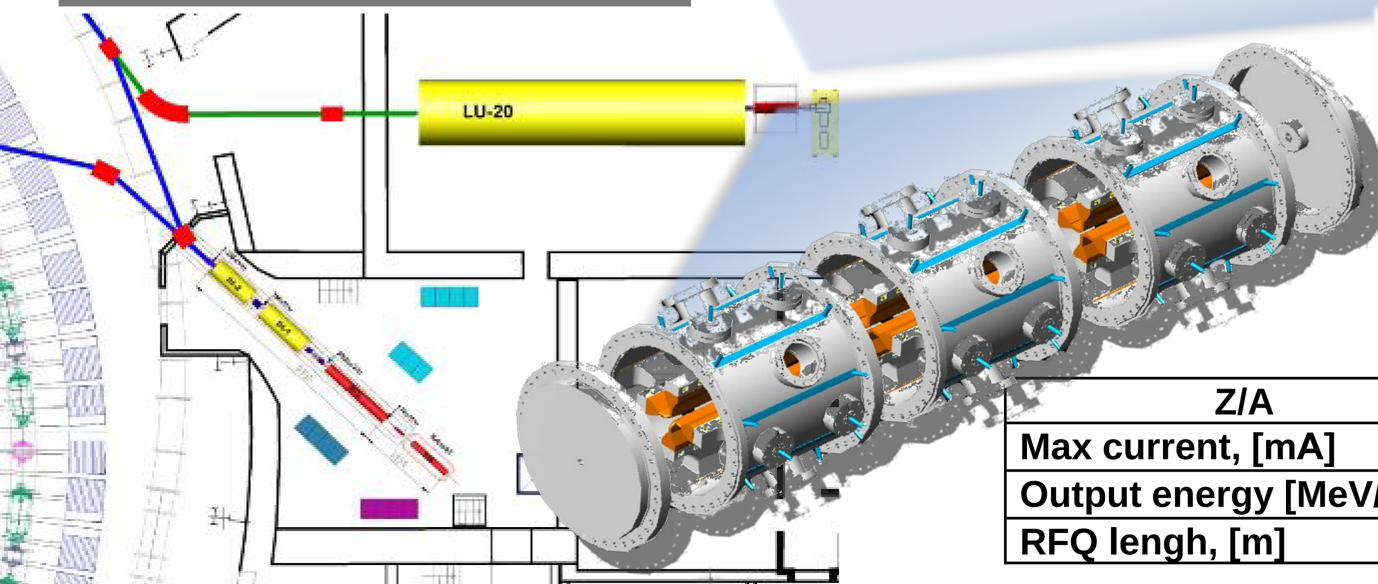


New test stend



New foreinjector for LU-20

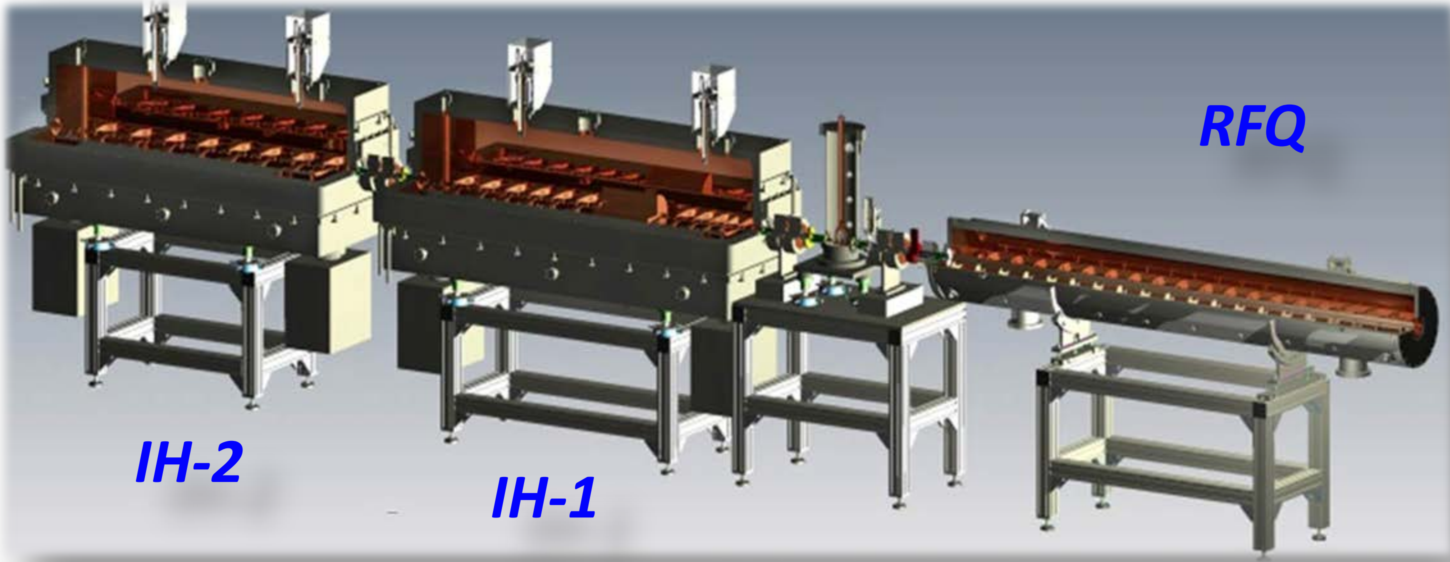
Production in Russia

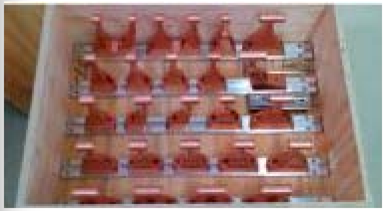


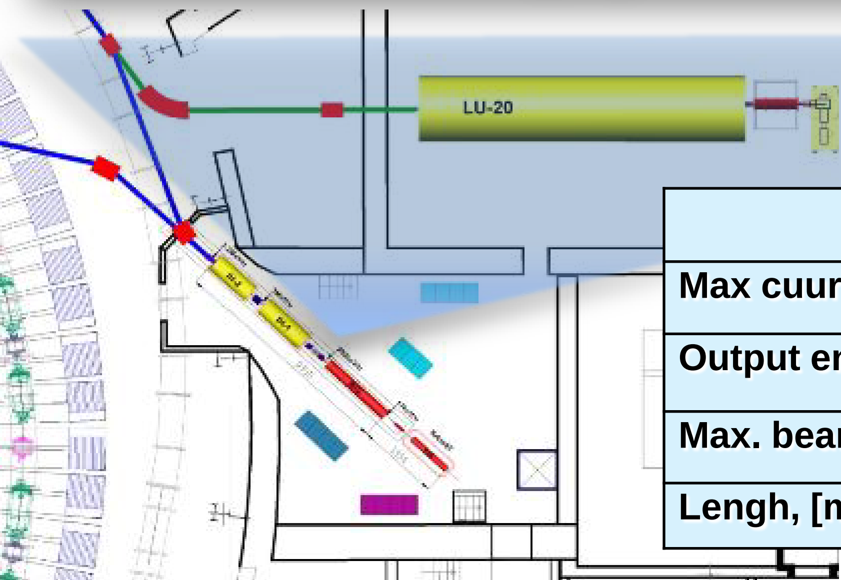
Z/A	1.0- 0.3
Max current, [mA]	≤20
Output energy [MeV/u]	0.156
RFQ lengh, [m]	≤ 3

Injection complex. Development

New Heavy Ion Linac (HILac) – under completion







Z/A	≥ 1/6
Max cuurent, [mA]	≤ 10
Output energy [MeV/u]	3.2
Max. beam puls length [μs]	30
Lengh, [m]	9

LHEP JINR in collaboration with:

BEVATECH

IH Tanks, RFQ Tank:

REUTER TECHNOLOGIE

Kreß GmbH Sondermaschinenbau

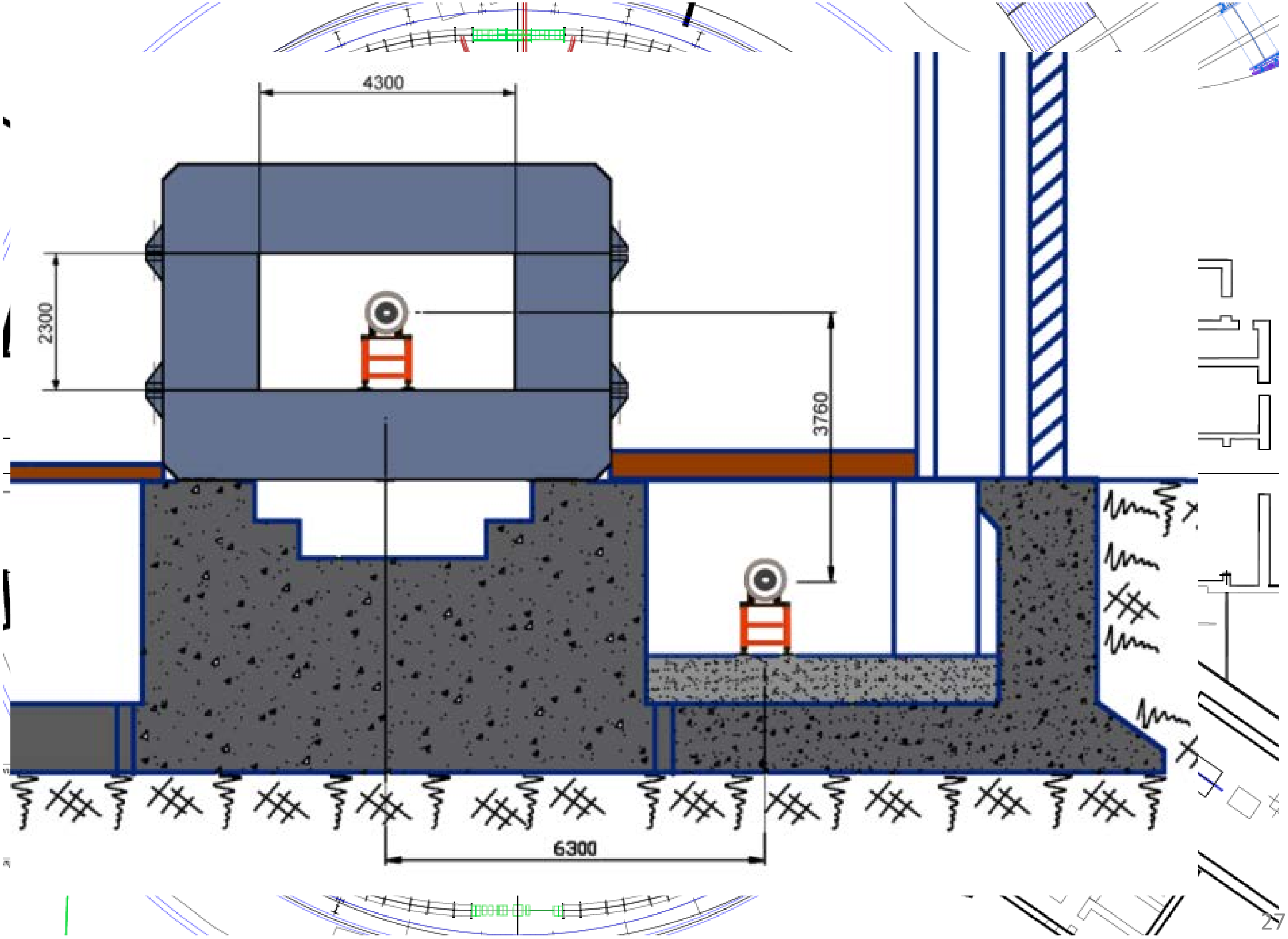
Diagnostics:
NTG

RFQ Tank

2013 October (70% readiness)

2013 Summer

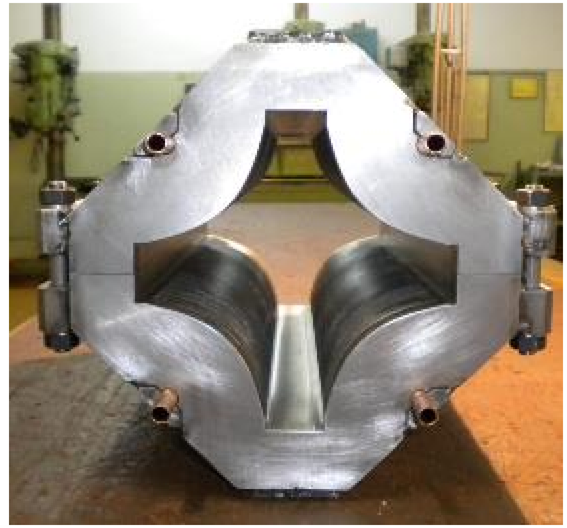
Booster



Booster

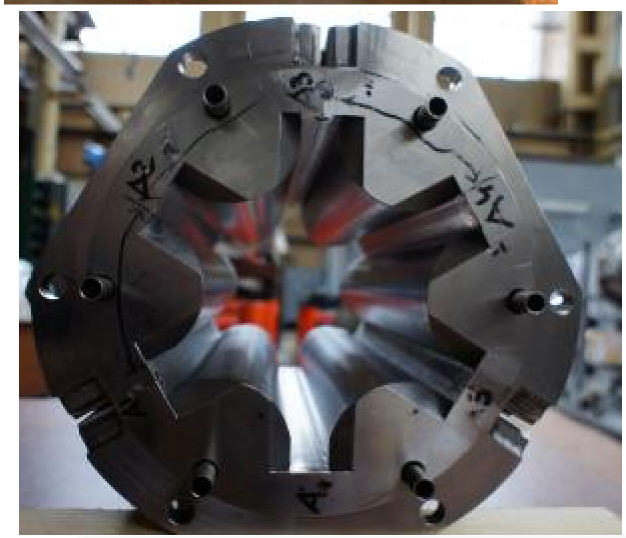
Magnets for the Booster

Booster dipole at cryo-test (9690A) and magnetic measurements



Quadrupole lense at assembly for test

Cryogenic test-bench @ LHEP



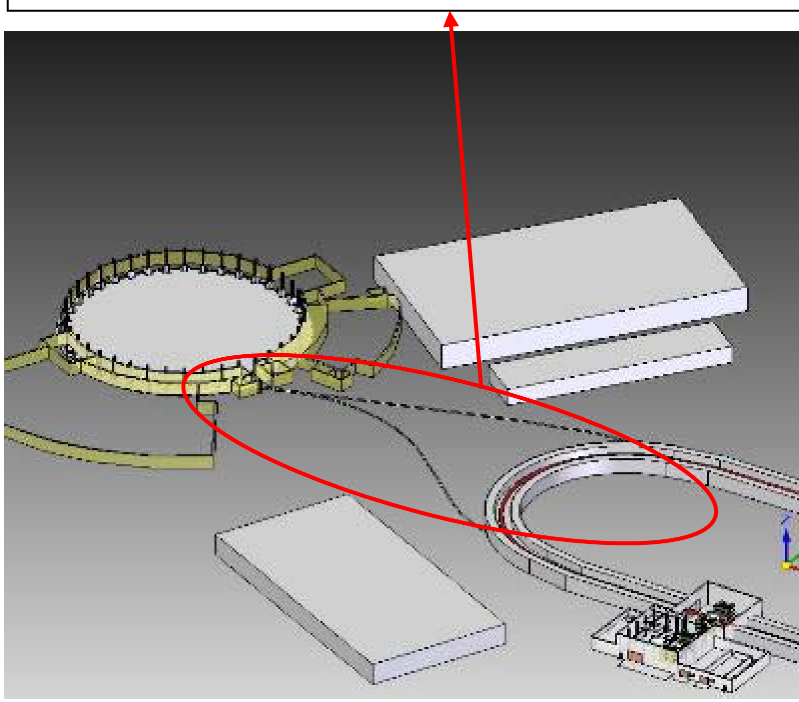
Sextupole corrector prototype (for SIS100 and NICA booster) at assembly

Nuclotron – Collider beam line

Goals of the beam line

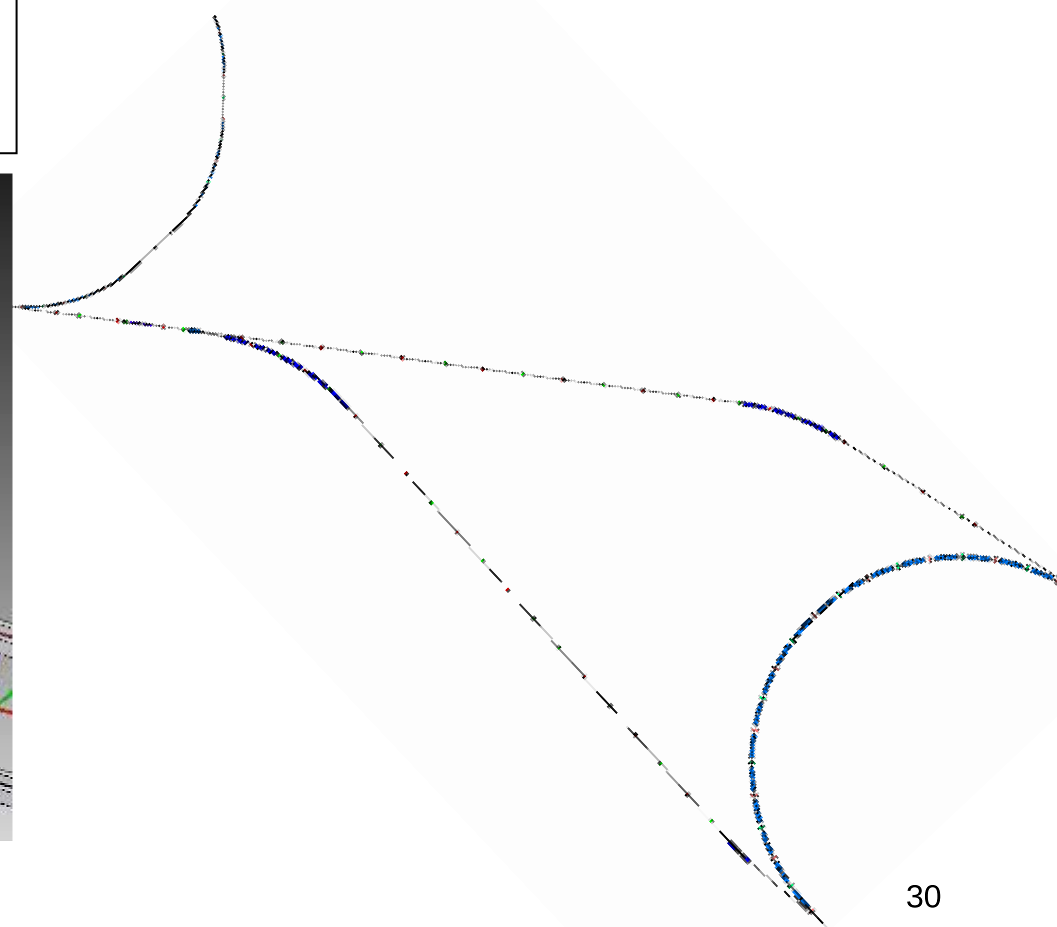
- The beam transport with minimal ion losses.
- The beam matching with lattice functions of Collider rings*.

* except vertical dispersion which suppression is required.



Beam Parameters

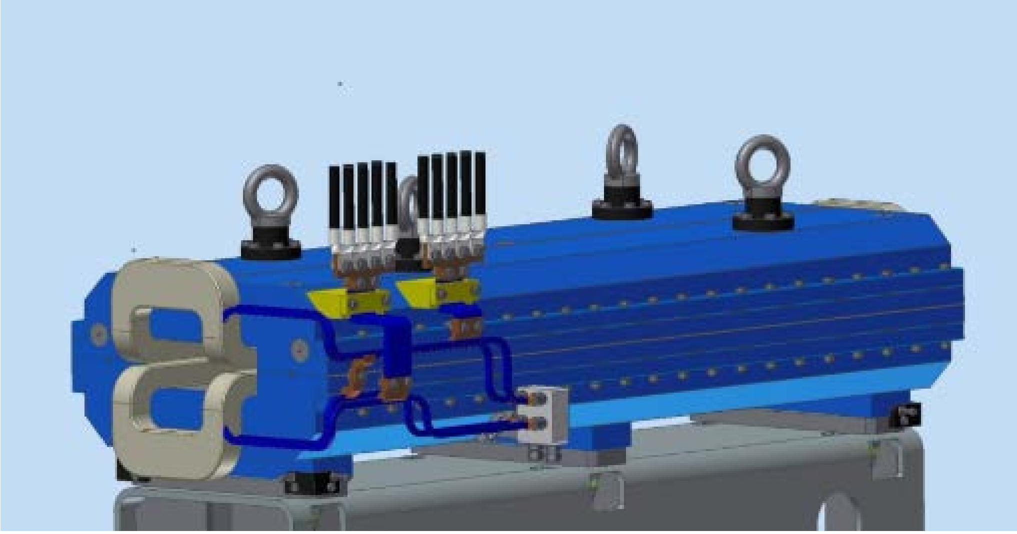
Sort of ions	Au^{79+}
Energy of ions, GeV/u	$1 \div 4.5$
Magnetic rigidity of ions, T m	$14 \div 45$
Ion number	$1 \cdot 10^9$

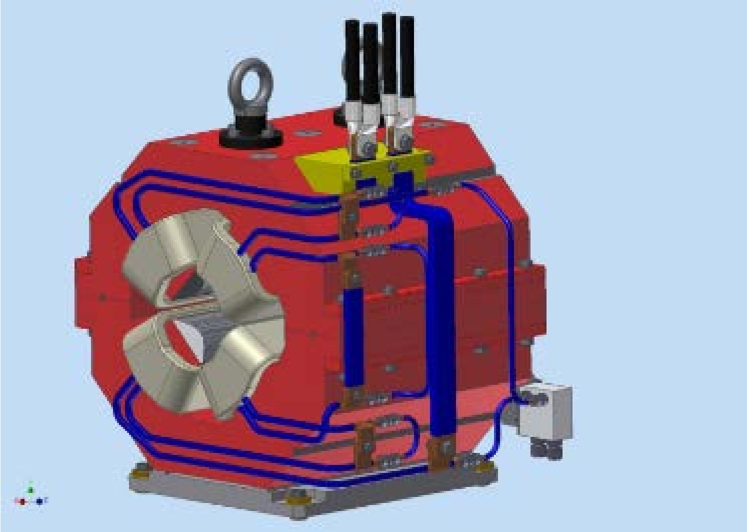


Nuclotron – Collider beam line

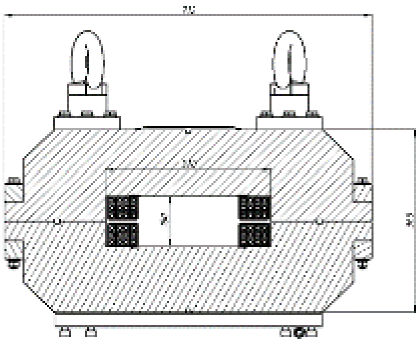
Parameters of magnetic elements

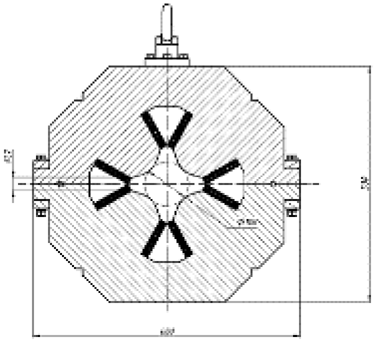
Magnetic element	Number	Effective length, m	Max. magnetic field (gradient), T (T/m)
Horizontal bending magnet	19	2	1.5
Vertical bending magnet	6	2	1.5
Switch bending magnet	1	2	1.5
Quadrupole	45 ÷ 50	0.5	20





Designed by
BINP team





Collider NICA

Collider parameters

Parameter	Value
Circumference, m	503.04
Max. magnetic rigidity, T·m	45.0
Max. magnetic field, T	1.8
Acceptance, π·mm·mrad	40.0
Longitudinal acceptance ($\Delta p/p$)	± 0.01
Number of dipole magnets	80

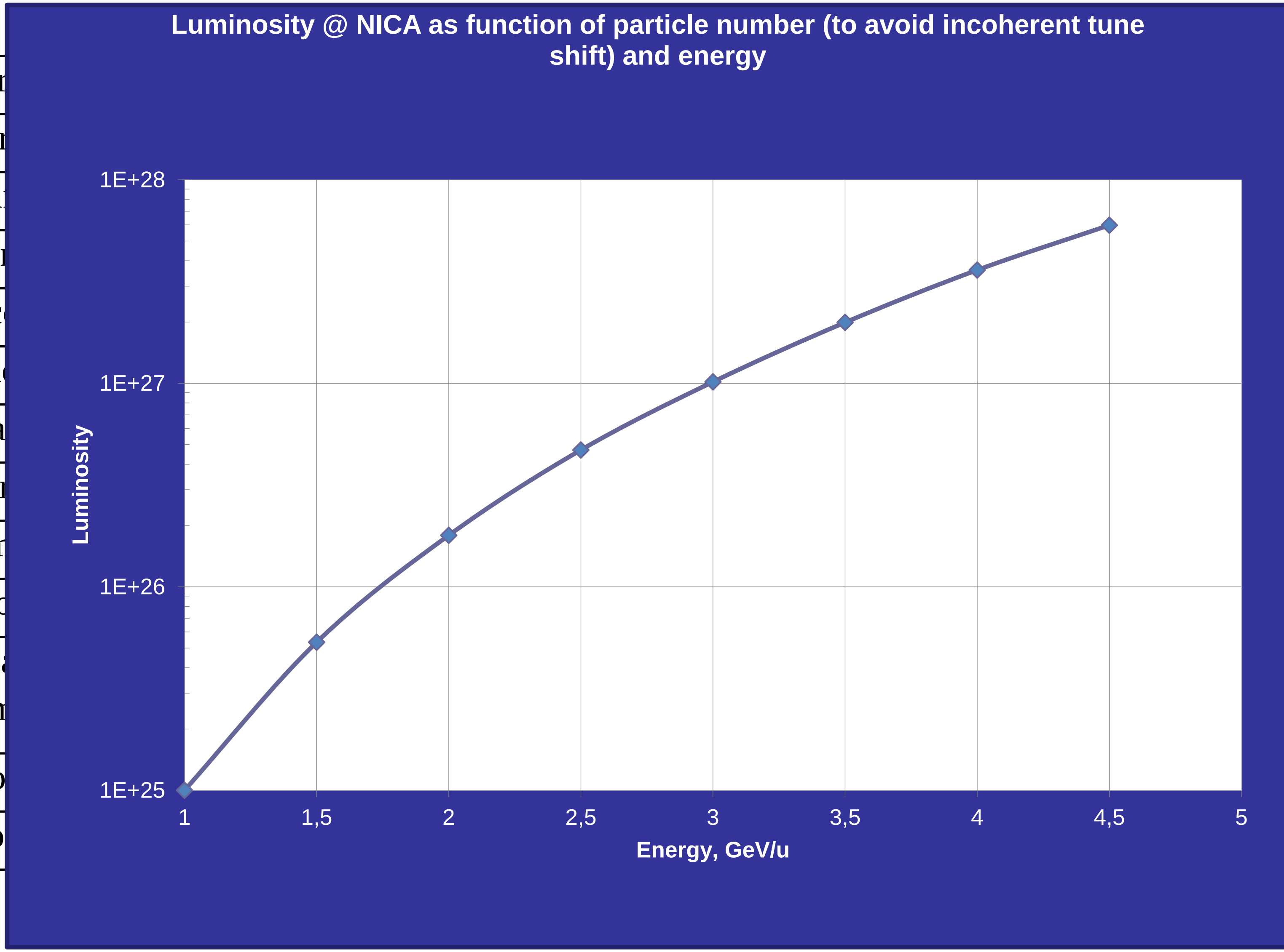
Collider

FODO, 12 cells x 90^o each arc,

$\gamma_{tr} = 7.091$, $\beta^* = 0.35$ m (variable)

Collider parameters

Ring ci
Numbe
Rms bu
Beta-fu
Ring ac
Long. a
Gamma
Ion ene
Ion num
Rms mo
Rms be (unnorn
Lumino
IBS gro



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Maximal achievable luminosity, average

$$L = \frac{dN}{dt}_{reaction} / \sigma_{reaction} \le \frac{dN}{dt}_{production} / \sigma_{loss}$$

Examples:

NICA: Ion generation rate: 10^9 per 4 seconds, reaction cross-section = 7 barn

$$L \le \frac{10^9}{4c \cdot 7 \cdot 10^{-24} см^2} = 3.6 \cdot 10^{31} см^{-2} c^{-1}$$

RHIC (100 GeV/u), cross-section ~ 219 barn **L_{max} ~ $5 \cdot 10^{29}$ cm^{-2} s^{-1}**

CBM (FAIR) Acceleration at SIS300 up to 10^{10} U ions, extraction during 10 sec

L_{max} ~ 10^{32} cm^{-2} s^{-1}

PANDA (FAIR) Antiproton production rate 10^7 / sec, cross-section 0.05 barn

$L_{max} = 10^7/5 \cdot 10^{-26} = 2 \cdot 10^{32}$ cm^{-2} s^{-1}

Cycle parameters limitations

RHIC: Filling of both rings and acceleration up to E_exp ~ 15 min
Experiment duration (L_lifetime) ~ 4 hours

L_{max} ~ $1.2 \cdot 10^{30}$ $см^{-2}$ $с^{-1}$ *1/4 /4 ~ $8 \cdot 10^{28}$ cm^{-2} s^{-1}

Average luminosity RHIC 10^{28} cm^{-2} s^{-1} – During experiment decreases by 20-30%
This will require more intensive collider filling (more often)

NICA

It is planned to fill both rings during 200 sec, "Luminosity lifetime ~ 2000 sec

L_{max} ~ $3.6 \cdot 10^{31}$ cm^{-2} s^{-1} *2 /20 ~ $3.6 \cdot 10^{30}$ cm^{-2} s^{-1}

At designed luminosity 10^{27} cm^{-2} s^{-1} and stabilization of beam emittances due to beam cooling, the luminosity of experiment is practically constant (if main loss mechanism is defined by interaction at Collision Point). Limitation to the experiment characteristical time is connected to losses due to interaction with residual gas

NICA Injection chain is designed with reserve of k~ 50

Limitations caused by Detector possibilities (event count)

Each detector sub-system has technical limitations on event count and registration

$$L_{\max,\det ector} = \frac{dN}{dt}_{count} \Big/ \sigma_{reaction}$$

Rate of MPD is 7 kHz

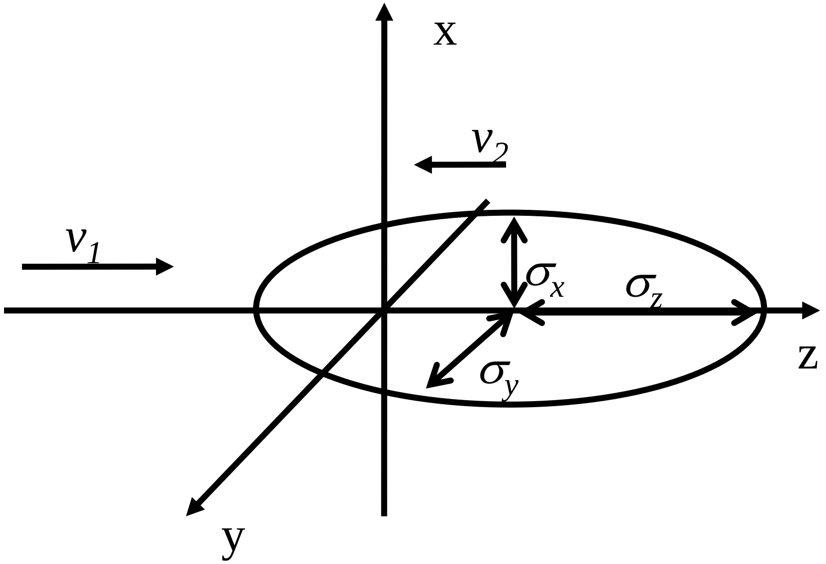
$$L \leq \frac{7 \cdot 10^{3}\,Hz}{7 \cdot 10^{-24}\,cm^{2}} = 10^{27}\,cm^{-2}s^{-1}$$

In the fixed target experiment we can control optimal detector load by varying width of the target. But during energy scan the geometry of the reaction products changes

Collider luminosity

$$L = n_b f_{rev} \int_V \int_t \sqrt{\left(\vec{v}_1 - \vec{v}_2\right)^2 - \frac{\left[\vec{v}_1 \times \vec{v}_2\right]^2}{c^2}}\, \rho_1 \rho_2 \, dV dt$$

For colliding bunches



$$\rho\left[x(t), y(t), z(t)\right] = \frac{N}{\sqrt{2\pi}^{3} \sigma_x(t) \sigma_y(t) \sigma_z(t)} \exp\left[-\frac{x^2(t)}{2\sigma_x(t)} - \frac{y^2(t)}{2\sigma_y(t)} - \frac{z^2(t)}{2\sigma_z(t)}\right]$$

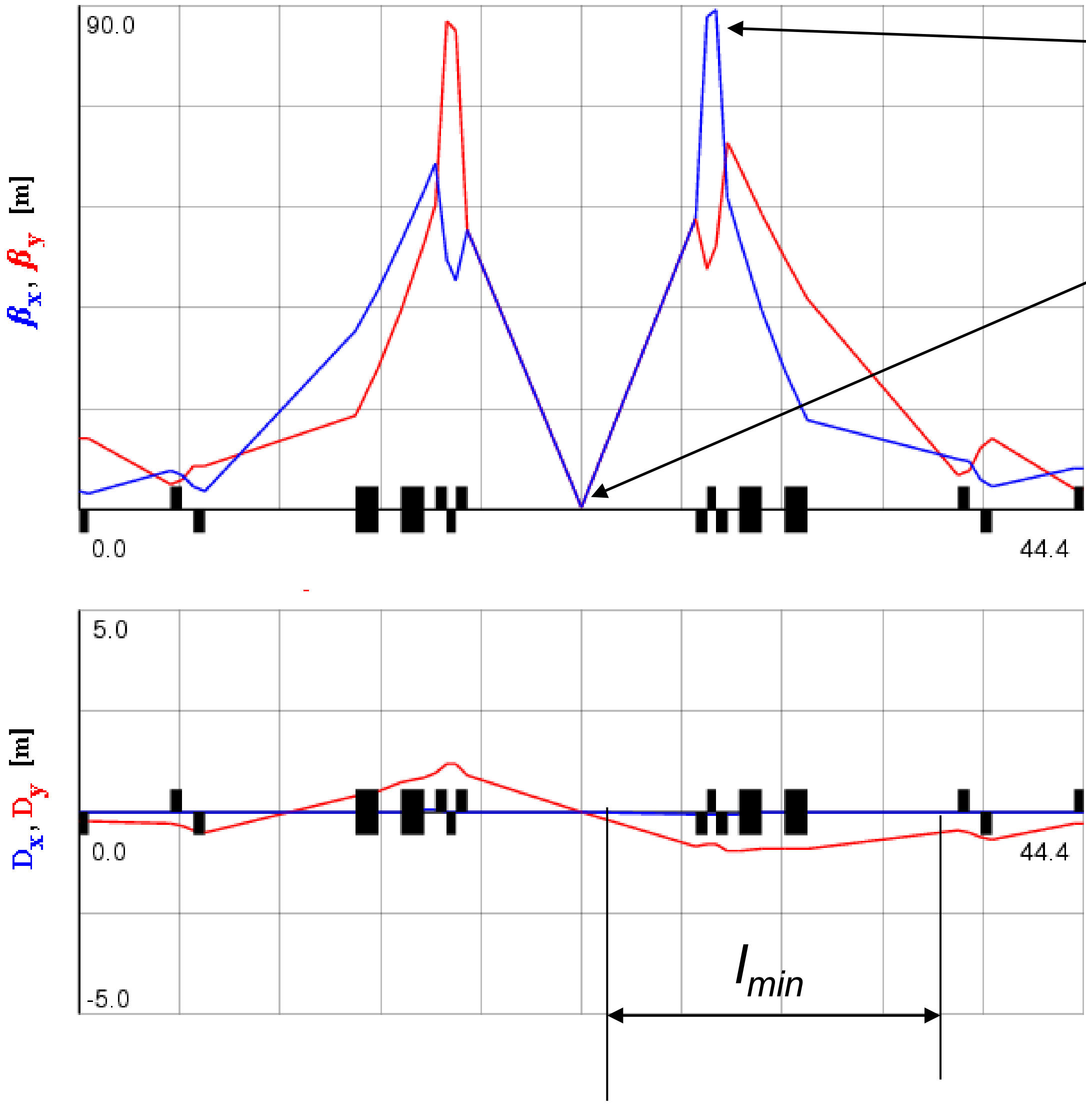
For similar round-shape bunches colliding at zero angle:

$$L = \frac{n_b N_b^2}{4\pi\varepsilon\beta^*} f_{rev} f\left(\frac{\sigma_s}{\beta^*}\right)$$

$$f\left(\frac{\sigma_s}{\beta^*}\right) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{\exp(-u^2)du}{\left[1+\left(\frac{u\sigma_s}{\beta^*}\right)^2\right]}$$

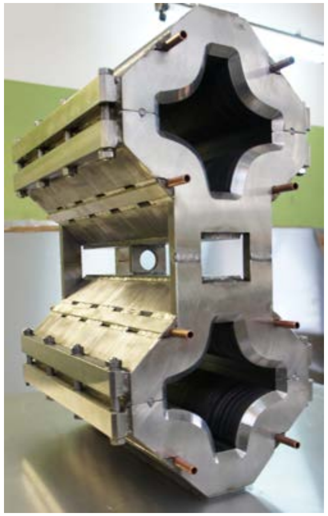
- to increase number of bunches -> parasitic collisions;
- to increase bunch current -> coherent instability;
- to decrease emittance (bunch size) –> incoherent tune shift -> resonanses;
- to decrease IP beta-function -> severe demands to FF QL, chromaticity;
- to increase rev. frequency -> to decrease circumference (no space for equipment)
- to have optimal bunch length (“hour-glass” effect).

Example of the optic structure in the IP region



Max.beam size

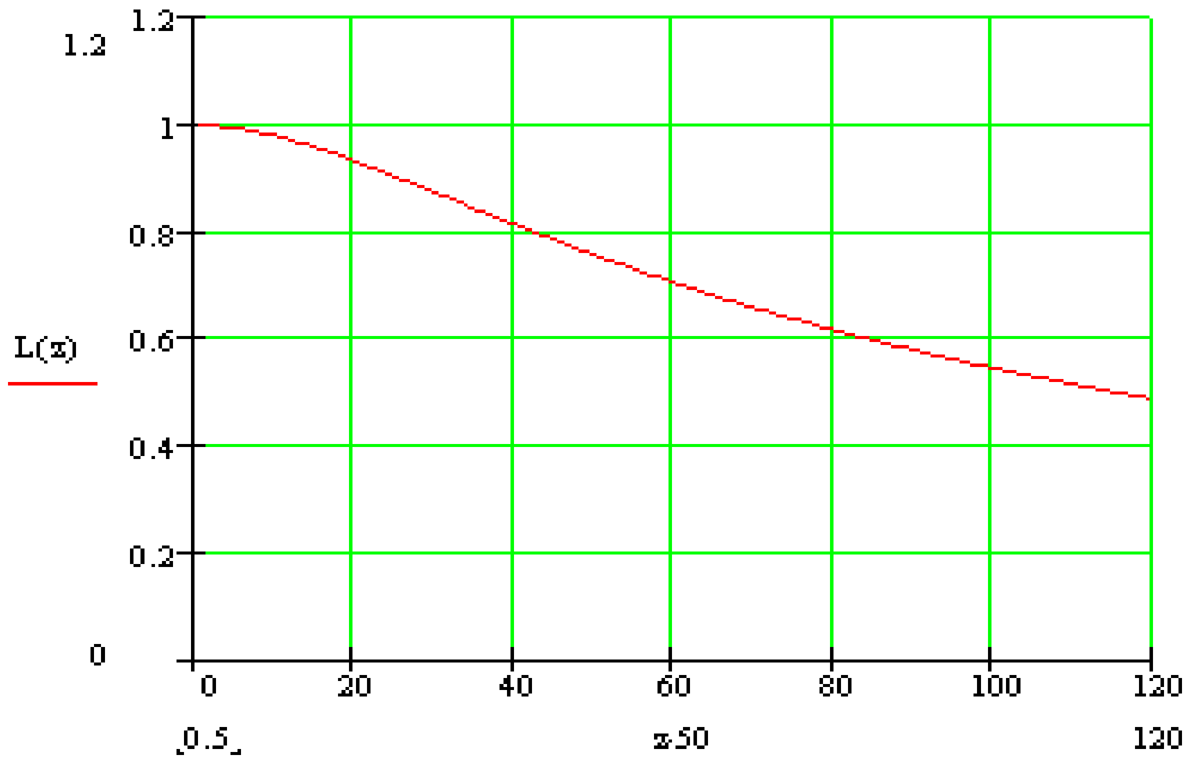
$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$



Another limitation: «electron clouds» effect: ion beam losses due to interaction with secondary electron avalanches from vacuum chambers walls

Bunch length

Hour-glass effect



β* = 0.5 m

	RHIC	NICA
Circumference, m	**3800**	**503**
Bunch spacing, m	**3800/120 = 32** (electron clouds, injection, parasitic collisions)	**15** (distance between dipoles)
Beta-function at IP	**5**	**0.35**
Distance from IP to FFL	**50**	**5**

$$\frac{L_{NICA}}{L_{RHIC}} = \frac{3800}{500}\frac{32}{15}\frac{5}{0.35} \approx 230$$

3.5 GeV/u

RHIC < 10^{25} $cm^{-2}s^{-1}$
NICA ≥ 10^{27} $cm^{-2}s^{-1}$

Luminosity life-time

Without beam cooling - beam emittance grows due to intra-beam scattering

Characteristic time of the luminosity decrease rate
~ several minutes (at RHIC operating with 100 GeV/u ~ 4 hours)

RHIC:
Construction of the Electron cooling system at low energy ions (< 5 GeV/u),
Stochastic cooling is used at maximal energy.

NICA:
Electron + stochastic cooling during beam stacking,
Electron + stochastic cooling during the experiment (collision mode)

IntraBeam scattering (IBS)

Single scattering on large angles – Touschek effect

IBS leads to 3 independent effects:
-“Maxwellisation” of the distribution fuction;
- Equal energy swaping between all 3 degrees of freedom
- Increasing of the 6D phase volume

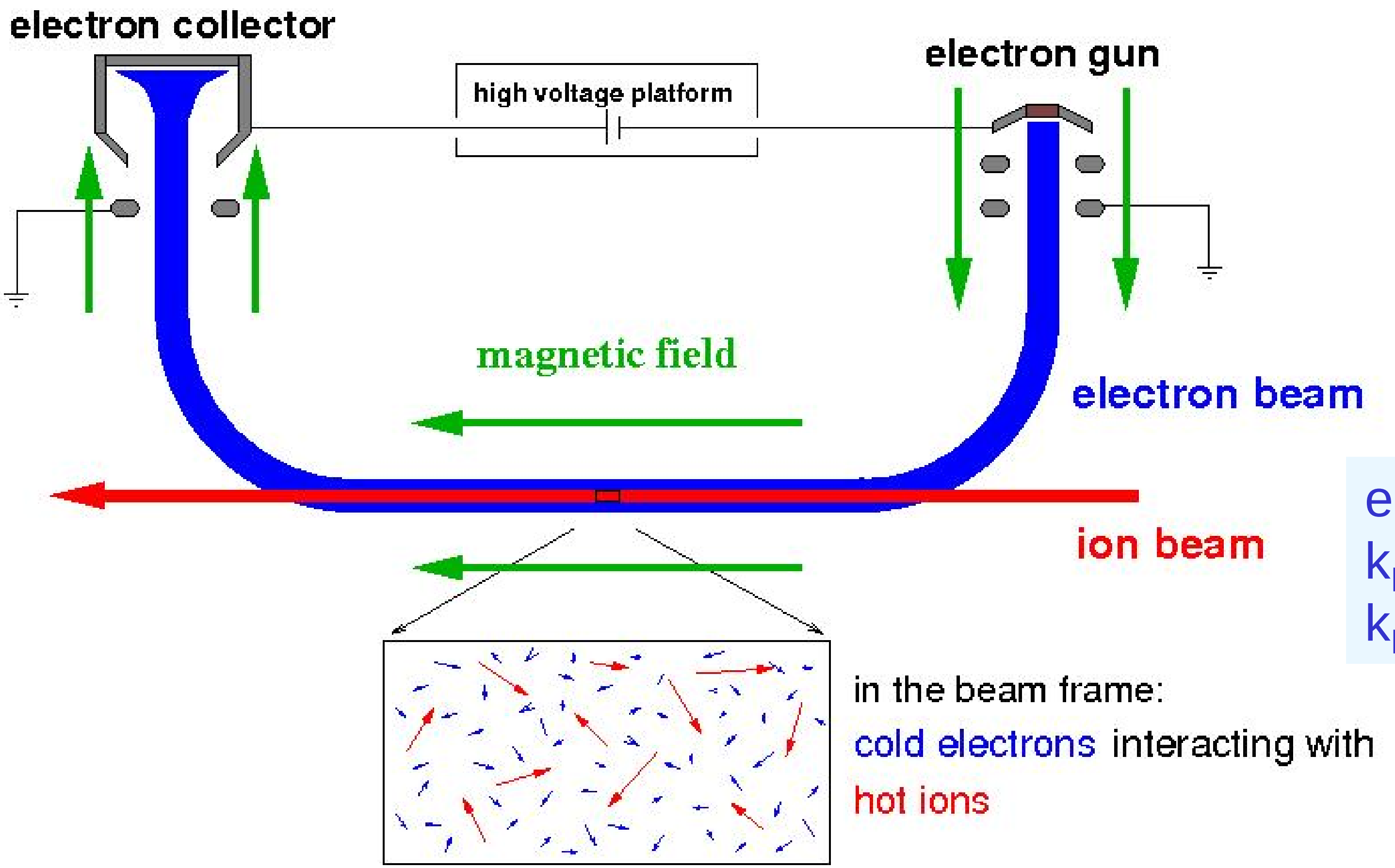
Why IBS differs from situation when molecules interact? -

Cyclic accelerators because of curvature sections (arcs, etc) have Dispersion.
Due to Dispersion the variation of the longitudinal coordinate leads to
The variation of transverse oscillation amplitude.

By other words transverse and longitudinal motion are coupled.

There is no way to keep Luminosity without beam cooling !!!

Electron Cooling



$v_{e//} = v_{i//}$

$E_e = m_e/M_i \cdot E_i$

e.g. :220 keV electrons
cool 400 MeV/u ions

electron temperature
$k_B T_\perp \approx 0.1$ eV
$k_B T_{//} \approx 0.1 - 1$ meV

superposition of a cold intense electron beam with the same velocity

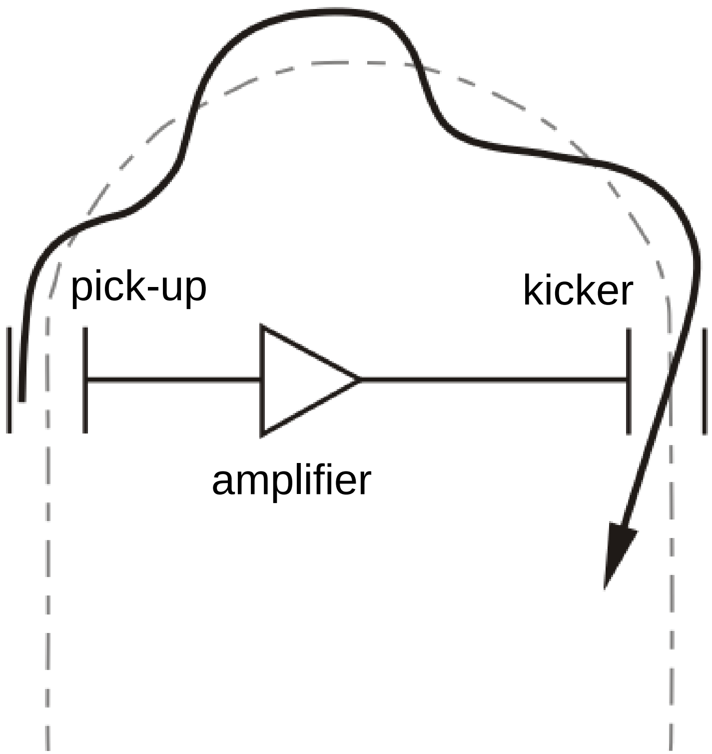
momentum transfer by Coulomb collisions

cooling force results from energy loss in the co-moving gas of free electrons

Courtesy to M.Steck

Stochastic Cooling

First cooling method which was successfully used for beam preparation



S. van der Meer, D. Möhl, L. Thorndahl et al.

Conditions:
Betatron phase advance
(pick-up to kicker): (n + ½) π

Signal travel time = time of flight of particle
(between pick-up and kicker)

Sampling of sub-ensemble of total beam

Principle of transverse cooling:
measurement of deviation from ideal orbit
is used for correction kick (feedback)

Courtesy to M.Steck

Two regimes and cooling methods: injection & storage

Questions:

1. What kind of storage method?

- ✓ **Barrier Bucket method with electron cooling application!**

2. What about storage with stochastic cooling application?

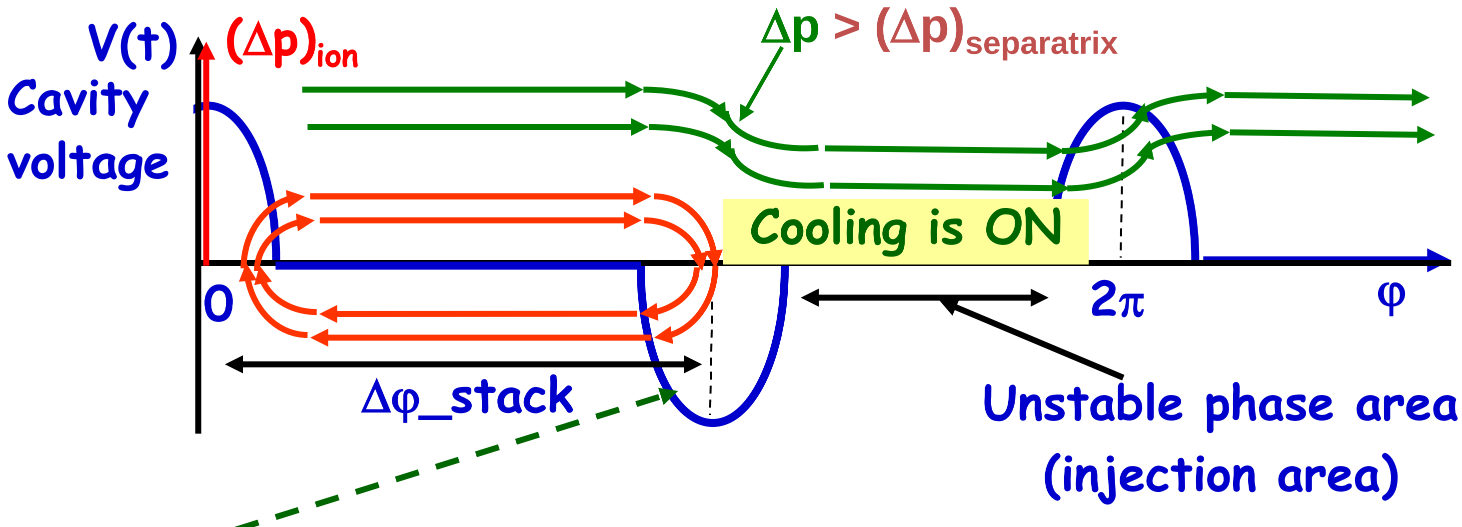
- ✓ **Problems below 2.5 GeV/u $\Rightarrow$ studies in progress…**

3. What kind of acceleration system is proposed?

- ✓ **Barrier Bucket system.**

Barrier Bucket Method

Ion trajectory in the phase space (Δp, φ)



In reality RF voltage pulses can be (and are actually) of nonrectangular shape

The first proposal: Fermilab, J. Griffin et.al., IEEE Trans. on Nuclear Science, v.NS30 No.4, 3502 (1983)

The particle storage with barrier buckets method was tested at ESR (GSI) with electron cooling (2008).

NICA: $T_{revolution}$ = 0.85 ÷ 0.96 μs, $V_{BB} \leq 5$ kV

The problems we have met and the solutions

The problems:

- ✓ Beam space charge effects
- ✓ Beam-beam effects
- ✓ IntraBeam scattering (IBS) ⇒ luminosity degradation

- ✓ Recombination in e-cooler

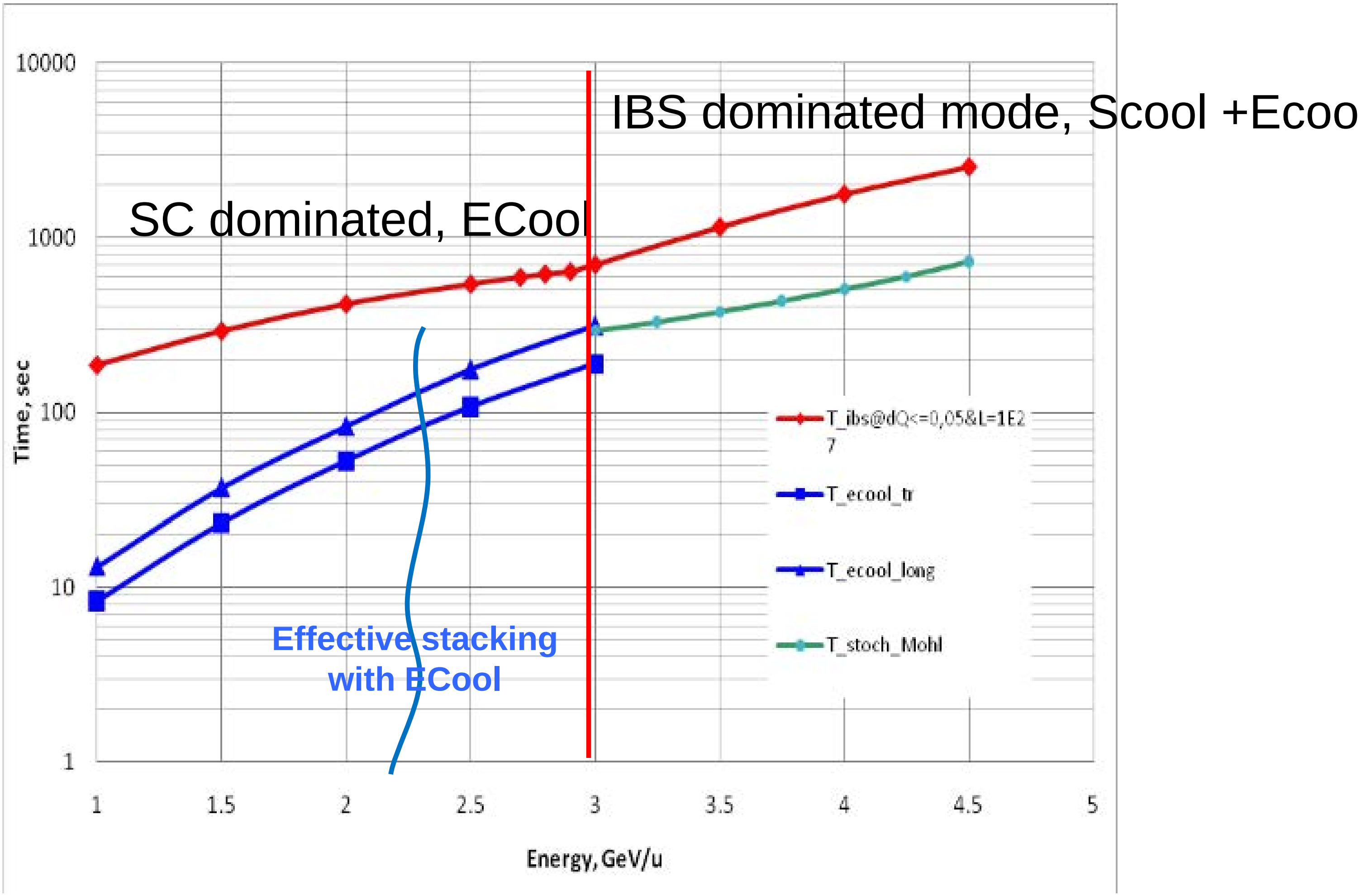
- ✓ Bunch halo formation ⇒ ⇒ parasitic collisions, background growth

The solutions:

- ➢ Electron cooling application
- ➢ Stochastic cooling application
- ➢ Beam parameters choice
- ➢ Operation scenario optimisation

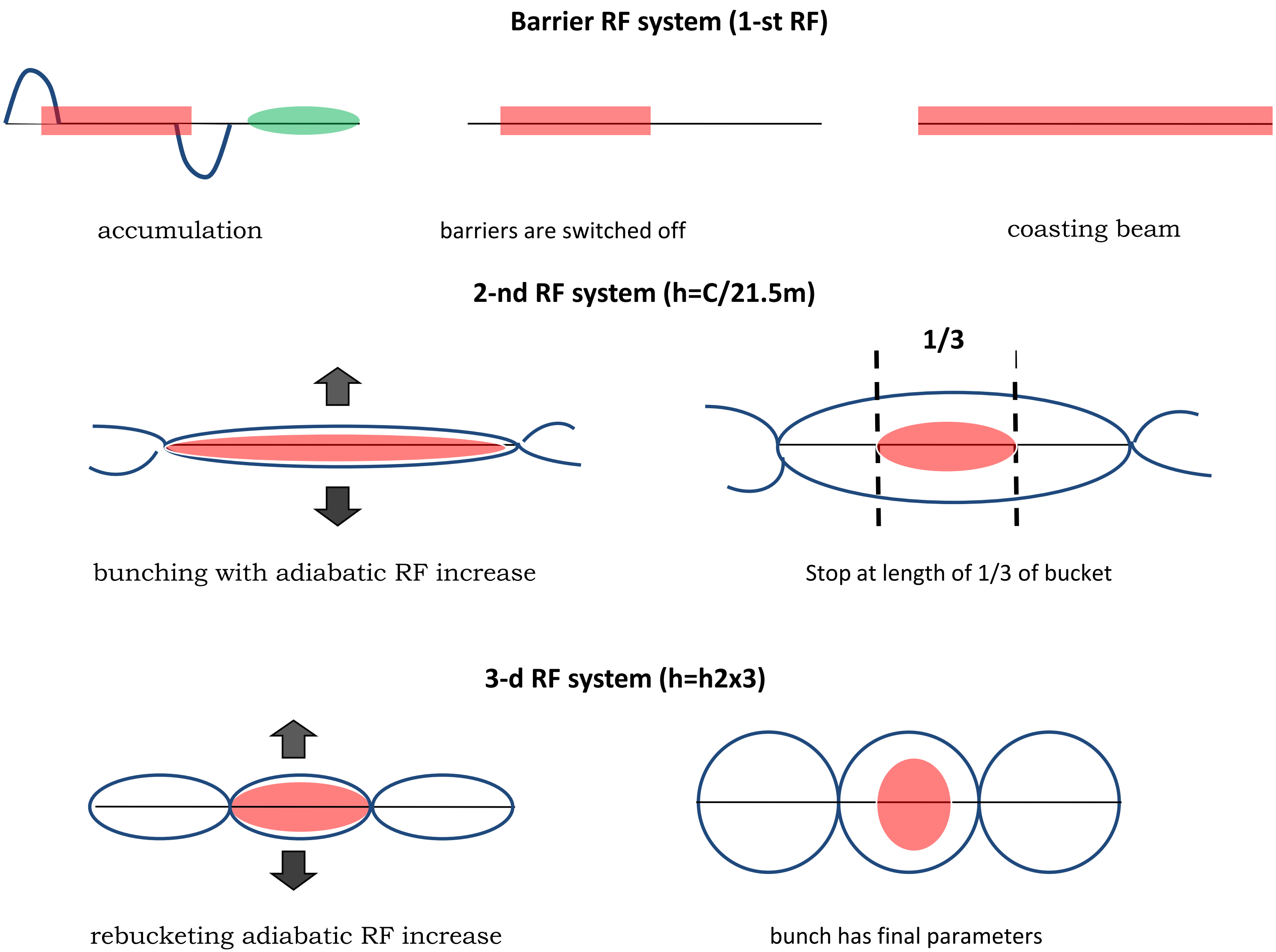
- ➢ Scrappers and collimators

Strategy of the cooling at experiment



IBS is calculated for equal rates in 3 degrees of freedom, $\mathbf{I_e = 0.5\ A}$

Proposed Scheme of Ion Stacking and Bunch Formation in The Collider

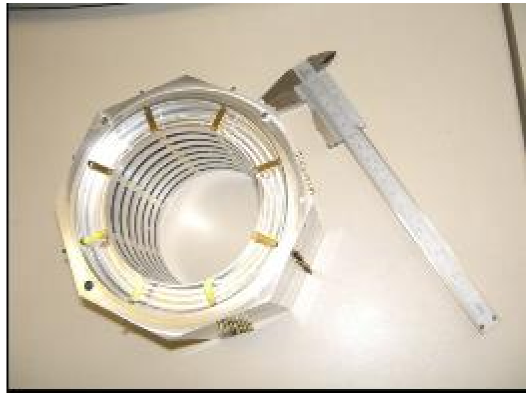


All stages are provided with cooling

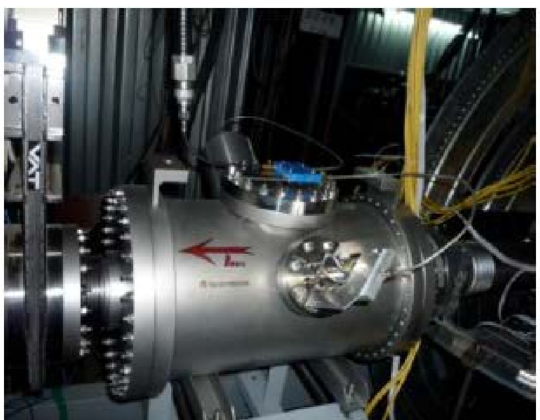
NICA

Stochastic Cooling System

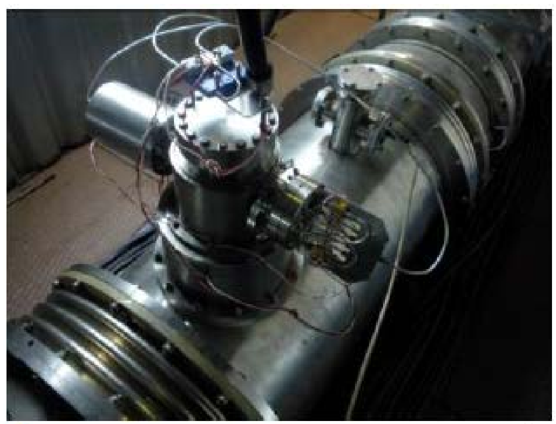
Stochastic Cooling System installed at Nuclotron - is a prototype for the NICA Collider:
W=2-4 HGz, P = up to 60 W
Collaboration: JINR-IKP FZJ-CERN



Ring slot-coupler RF structure (design FZJ)



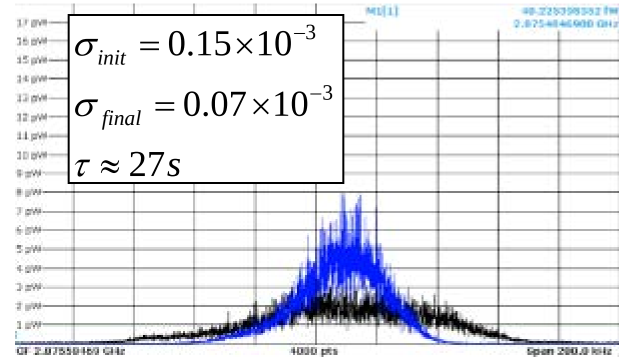
Kicker station



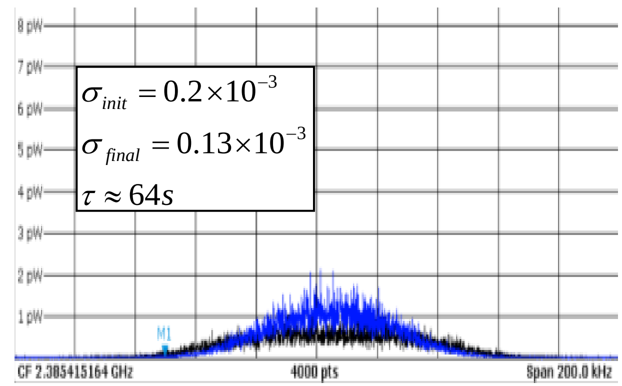
Pick-Up station

Spectrum analyzer

Coasting beam

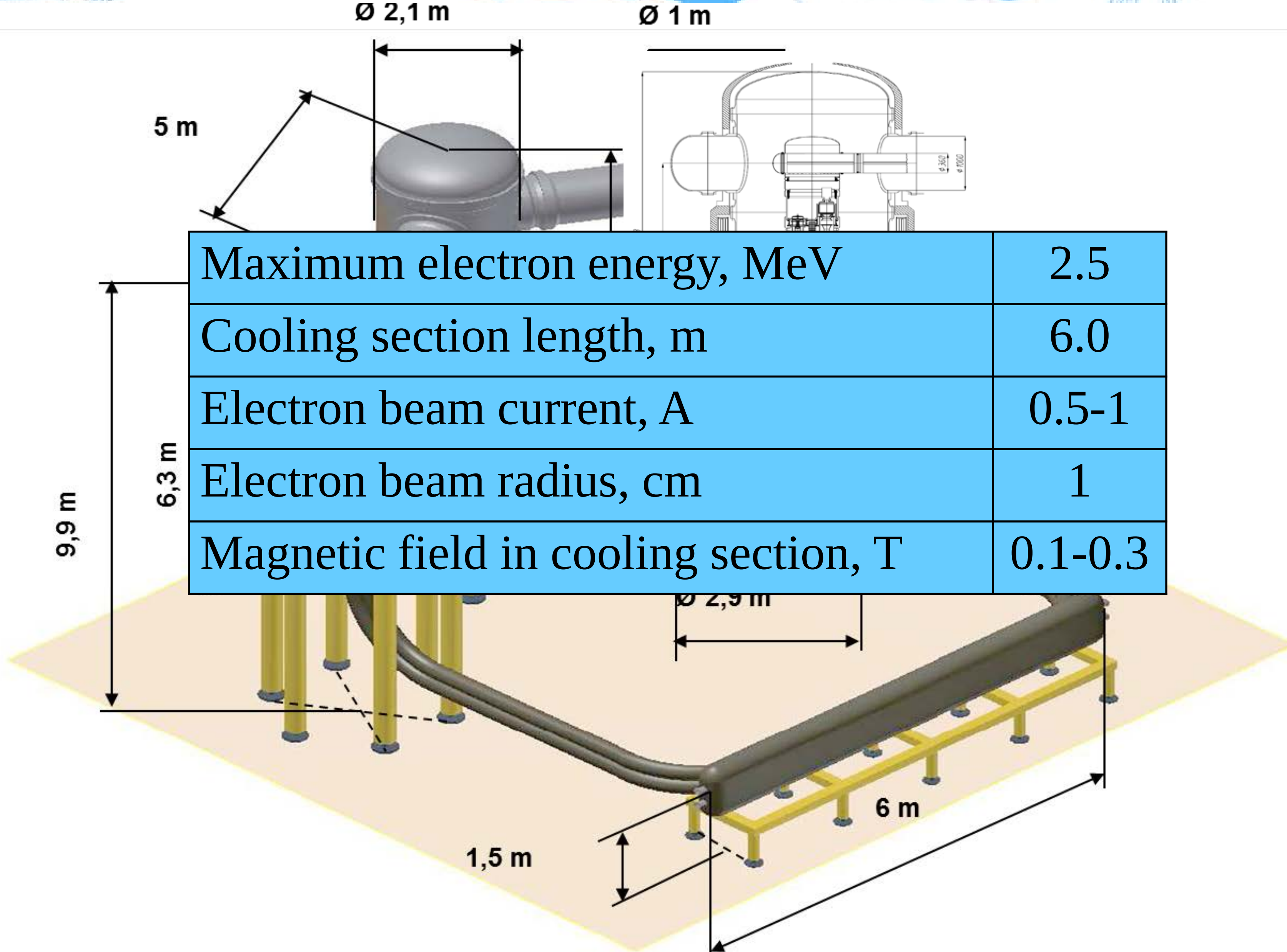


Bunched beam



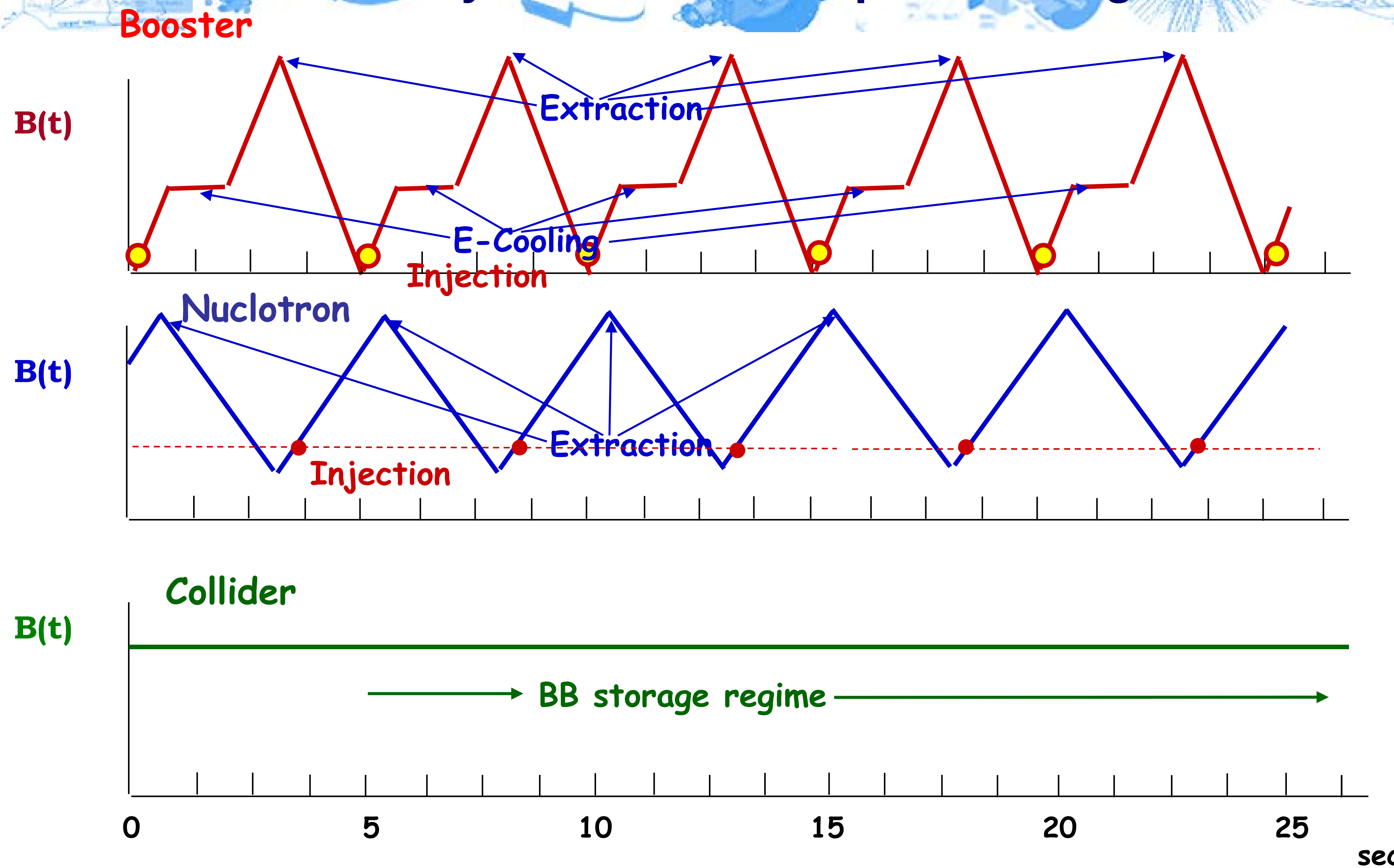
Experimental results (2013): stochastic cooling of the carbon (C6+) beam, E = 2.5 GeV/u

Collider Electron cooling

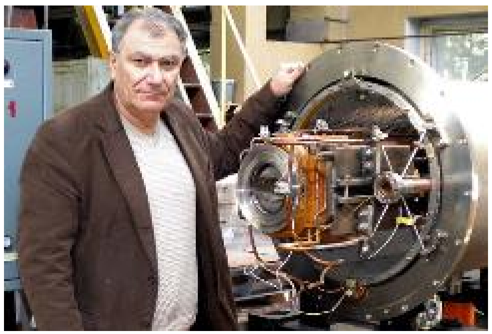


Maximum electron energy, MeV	2.5
Cooling section length, m	6.0
Electron beam current, A	0.5-1
Electron beam radius, cm	1
Magnetic field in cooling section, T	0.1-0.3

1. Facility structure and operation regimes



Full-scale Nuclotron–type superconducting model dipole and quadrupole magnets for the NICA booster and collider were manufactured at Laboratory of High Energy Physics JINR. **First dipole and quadrupole magnets for the NICA booster have successfully passed the cryogenic test on the bench.** 3 pre-serial dipole magnets for the NICA booster will be manufactured and tested this year. **Serial production of the magnets for the booster is scheduled for 2014.** Cryogenic tests of the model twin aperture dipole and quadrupole magnets for the NICA collider are scheduled for the first half of this year.



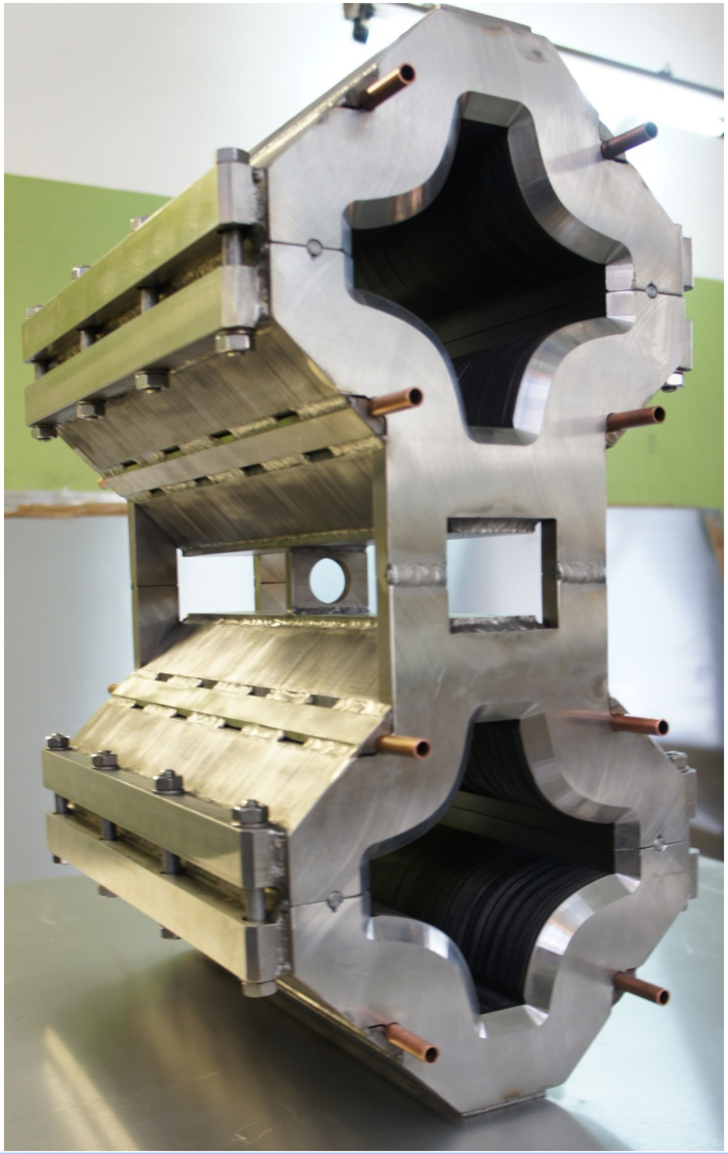
Sextupole corrector prototype (for SIS100 and NICA booster) at assembly

Booster dipole at cryo-test (9690A) and magnetic measurements

Twin aperture dipole magnet for Collider was tested June 2013 up to 11 kA

Collider magnets construction

Test on vacuum tightness of the tubes
for cooling the yoke



High-temperature current leads (LN temp.)

Collaboration with China (ASIPP): Power (high-current) HTSC current-leads up to 17 kA for NICA. Liquid N2 temperature

The first of four pair of HTS current leads on 18 kA before acceptance test in Dubna

<u>Strategy</u>: to exchange all LHe powerful current leads at Nuclotron to HTSC and to use such HTSC in booster and Collider in order to minimize operational costs (~several times). China – is our excellent partner.

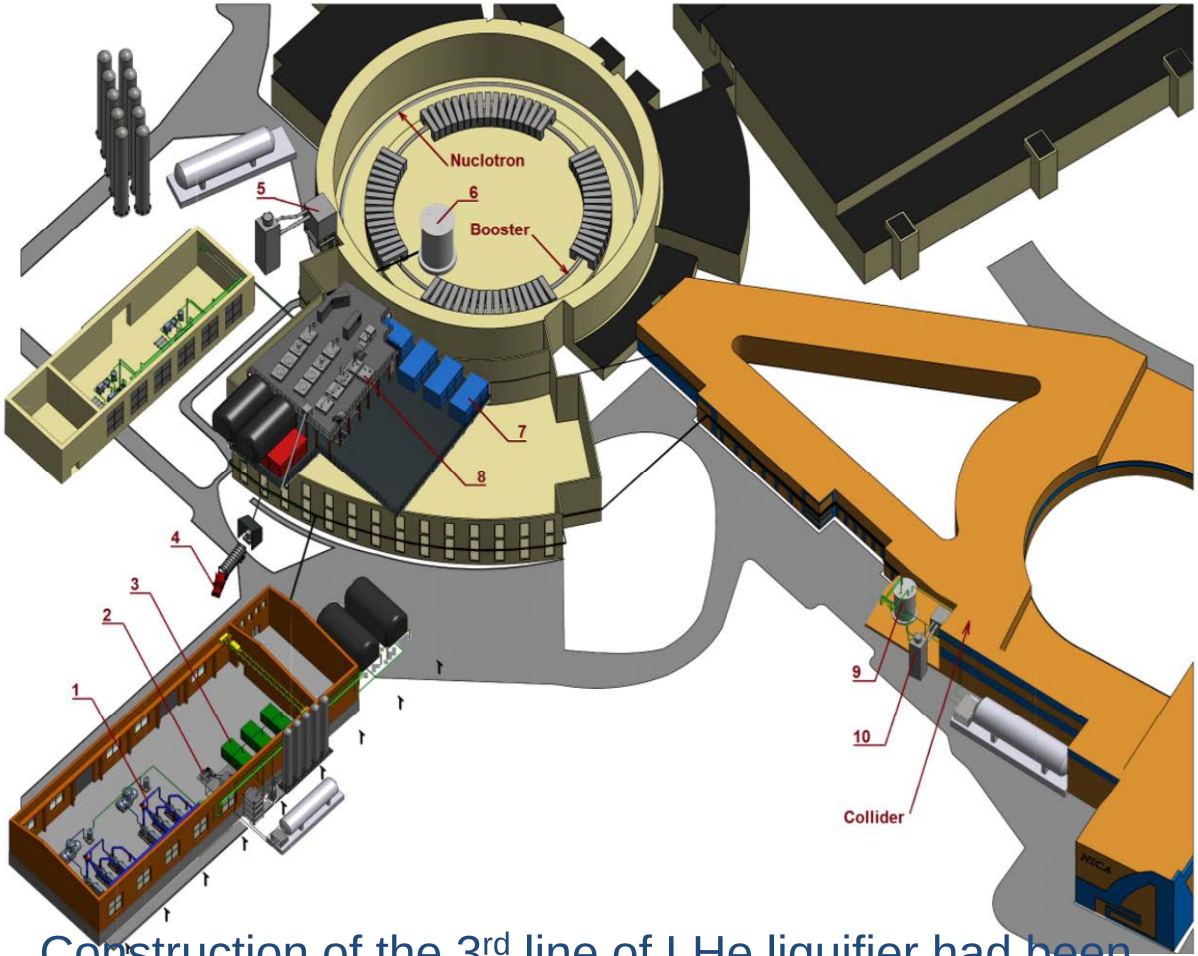
SC magnets assembly and test area (b.217):
cooperation with German centers

Satellite helium refrigerators

Satellite helium refrigerator during assembly on-site in October 2013.

Satellite helium refrigerator in b.217.

Cryogenic system for the NICA complex



Construction of the 3rd line of LHe liquifier had been started in 2013

Commissioning – 2014:
Start in June, December – tech. run

New units for the NICA accelerators:

1 – 6600 Nm^3/h screw compressors Kaskad-110/30;
2 – 1300 kg/h nitrogen liquefier OA-1,3;
3 – nitrogen turbo compressors Samsung Techwin SM – 5000;
4 – liquid helium tank;
5 – 500 kg/h nitrogen re-condenser RA-0,5 of the booster;
6 – satellite refrigerator of the booster;
7 – draining and oil-purification units;
8 – 1000 l/h helium liquefier OG-1000;
9 – satellite refrigerator of the collider;
10 – 500 kg/h nitrogen re-condenser RA-0,5 of the collider.

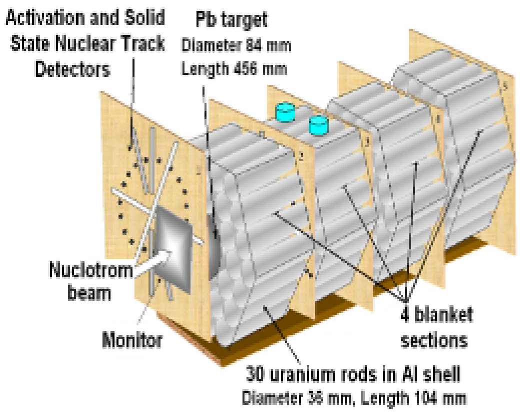
Already signed agreements in cooperation with:

- CERN
- GSI
- State committee in science & technology of Belarus
- Kurchatov Federal Center
- Institute for Nuclear Research RAS
- Moscow State University
- Budker Institute of Nuclear Physics RAN
- Tsinghua University, China
- Institute of Plasma Physics CAS, China
- University of Science and Technology of China
- and others

On-line web-camera
http://betacool.jinr.ru/b/

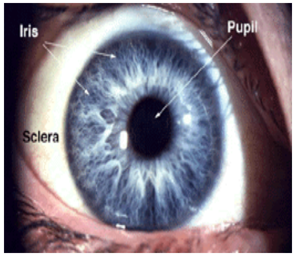
Innovations based on Accelerator technologies

Transmutaion of nuclear fuel waste



Obtaining the basic data for design of set-ups for nuclear waste processing

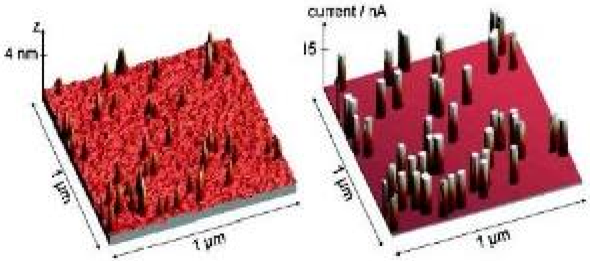
Radiobiology and medicine



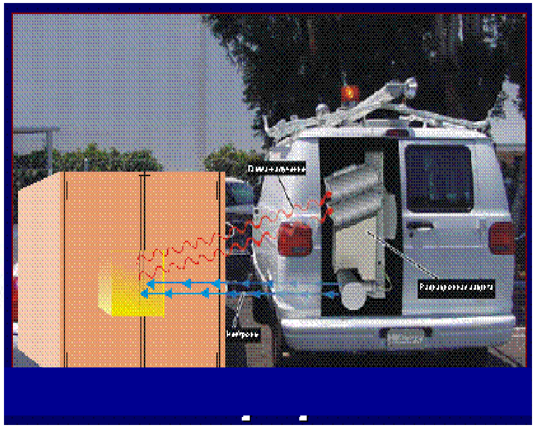
Study of molecular mechanisms of genetic influence on human & mammal

Irradiation treatment of space craft elements and electronics

Ion tracking technologies:

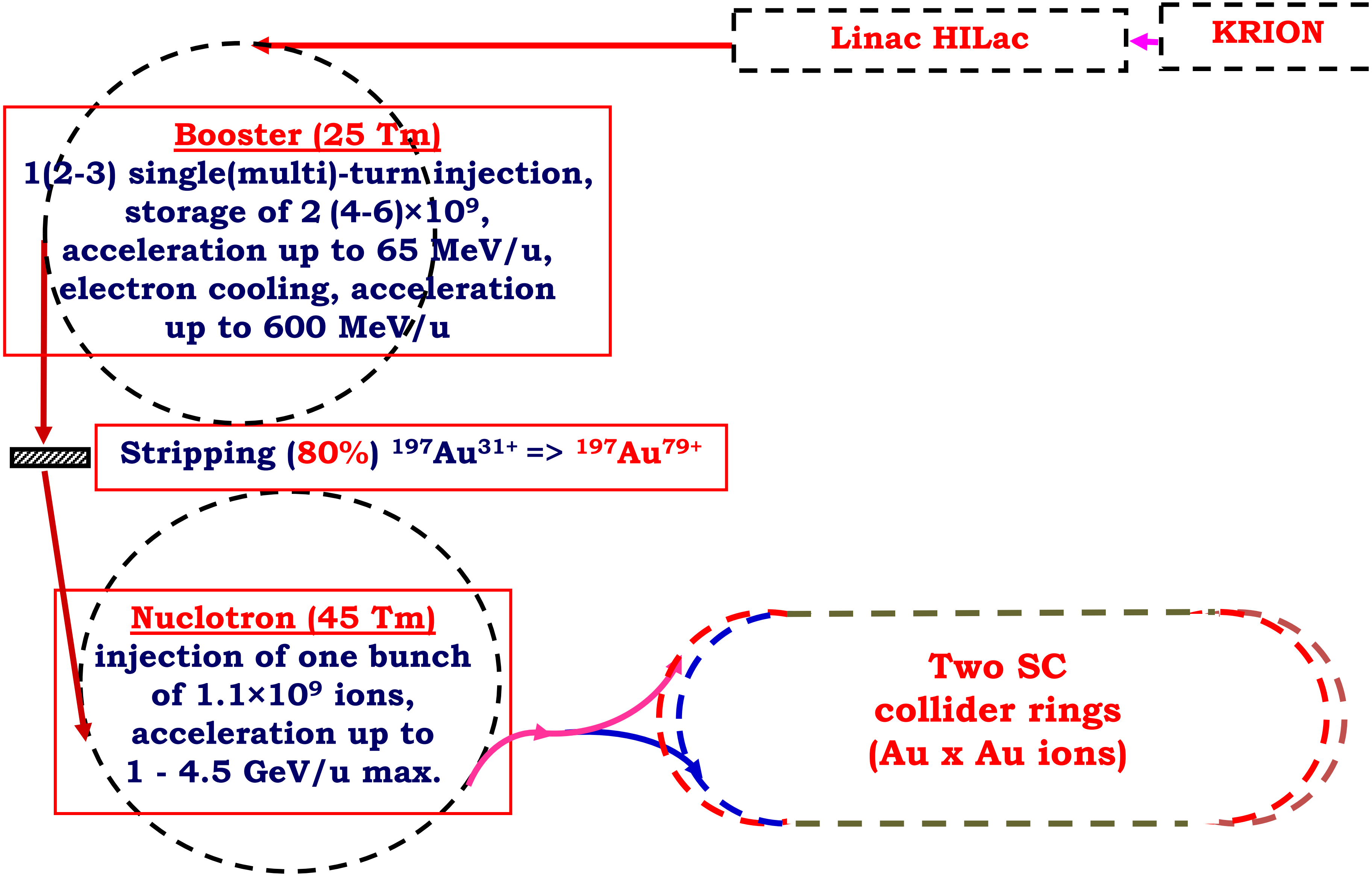


Safety systems



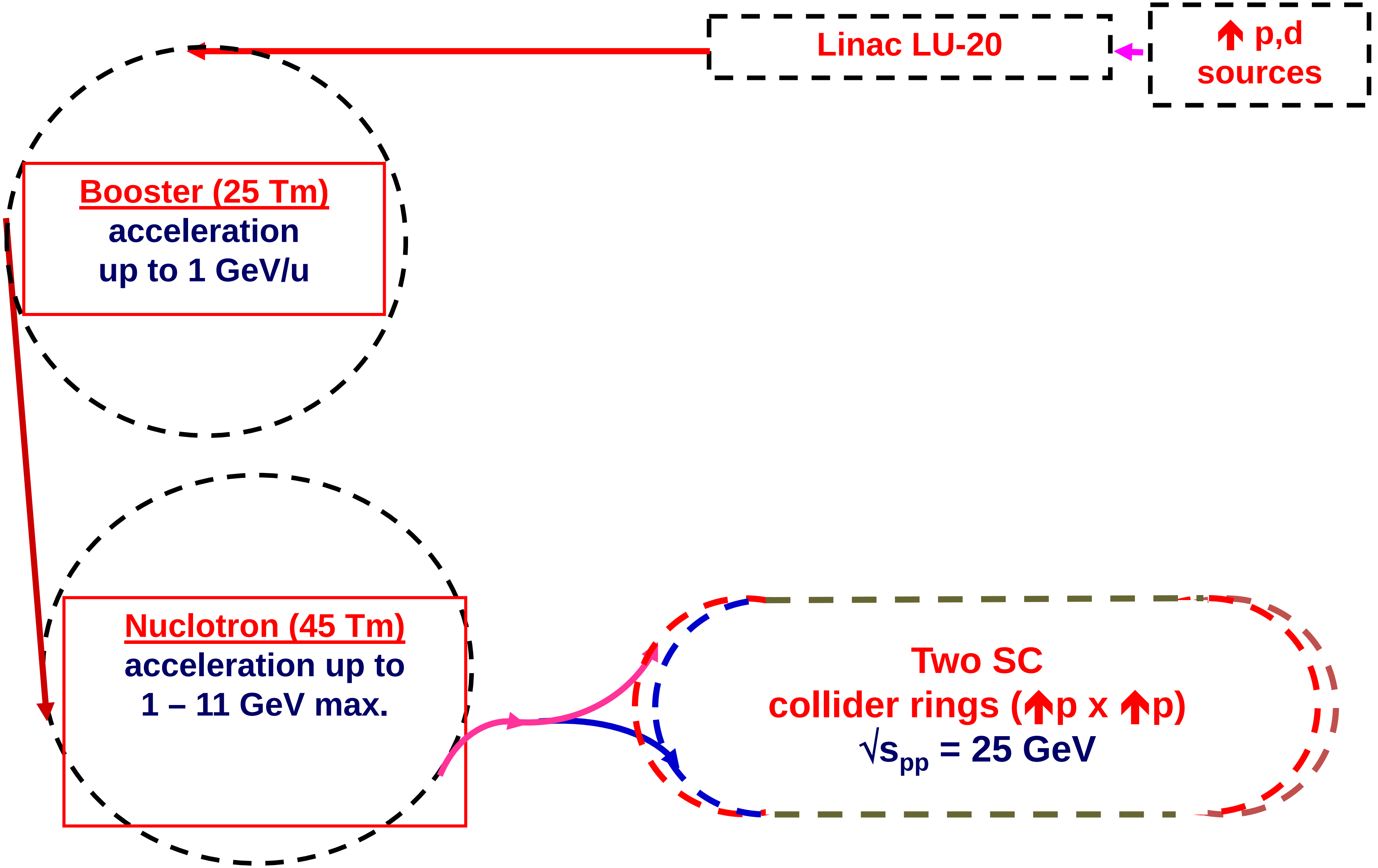
Design and Development of accelerator and detector technologies for medicine

NICA accelerator complex – I (2019)

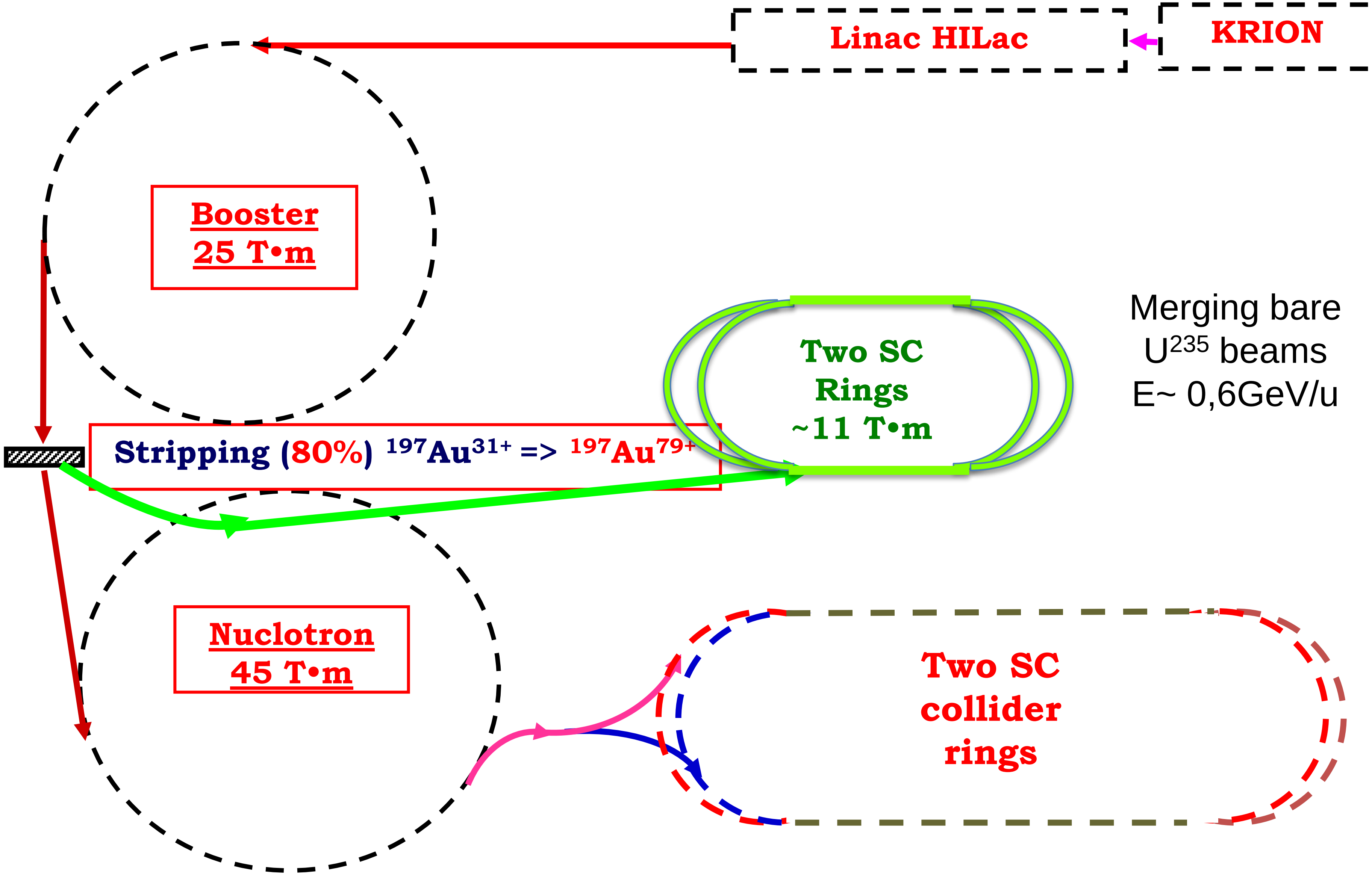


…What NEXT ?…

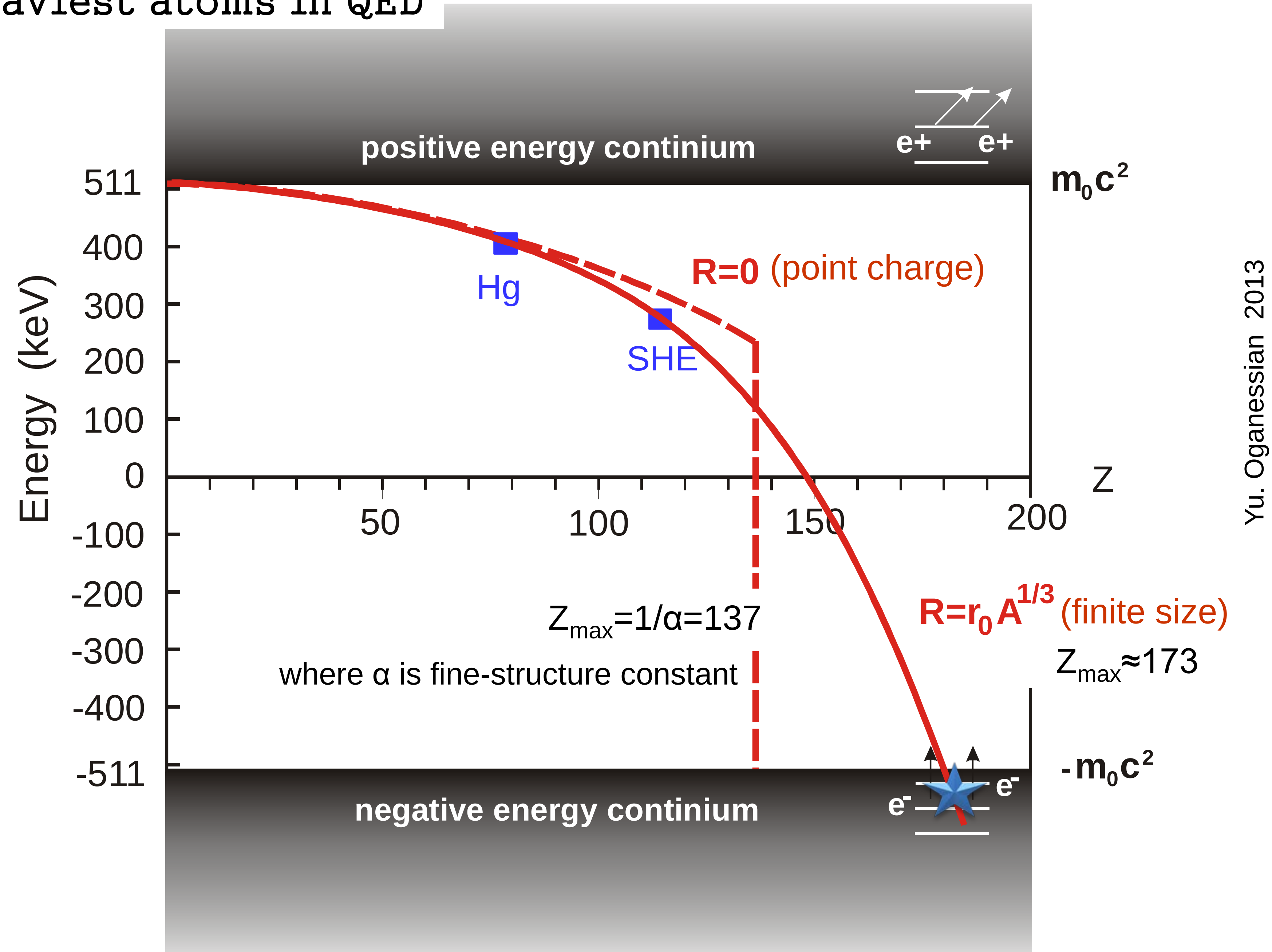
NICA – II accelerator complex

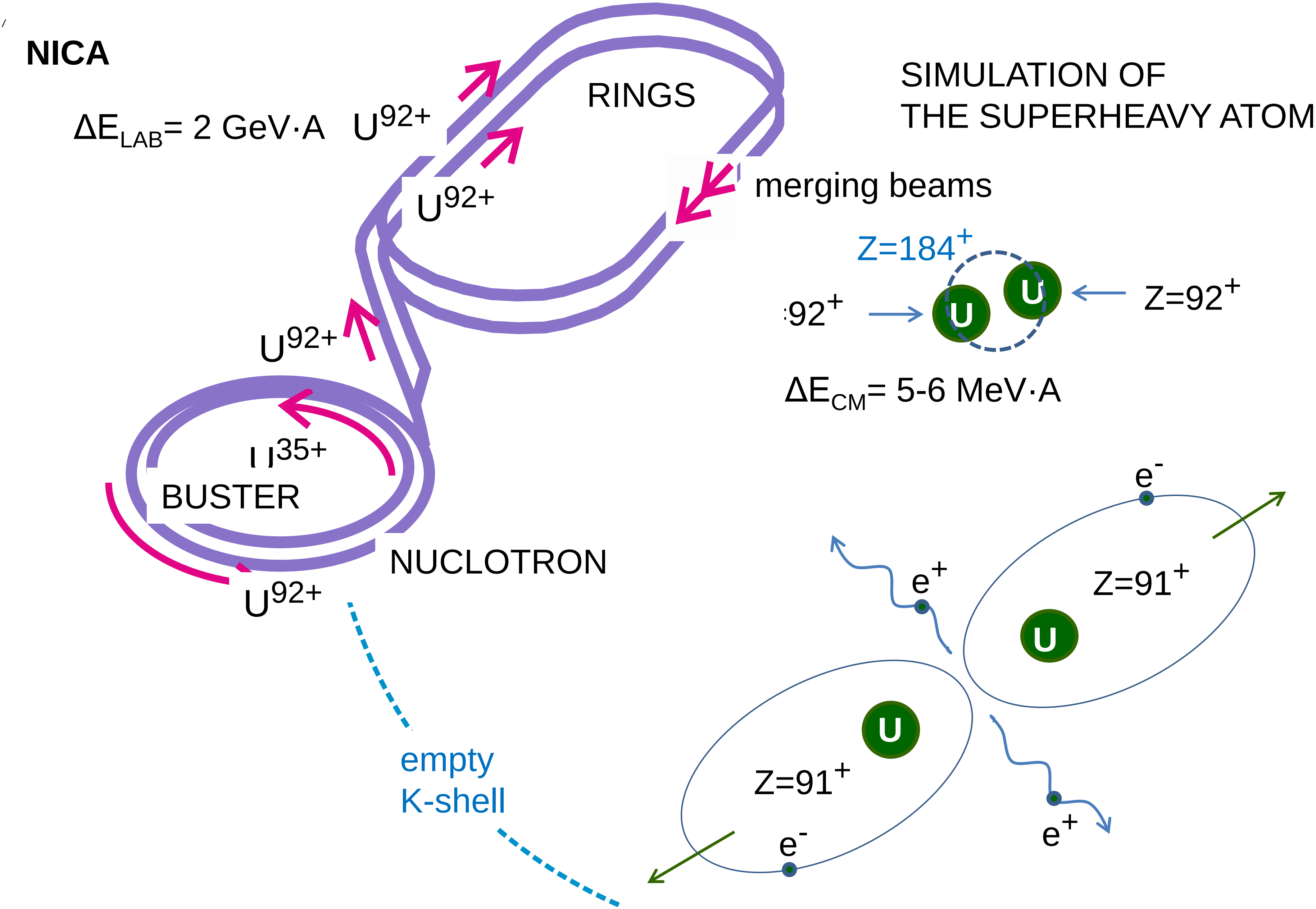


NICA - III accelerator complex



Heaviest atoms in QED

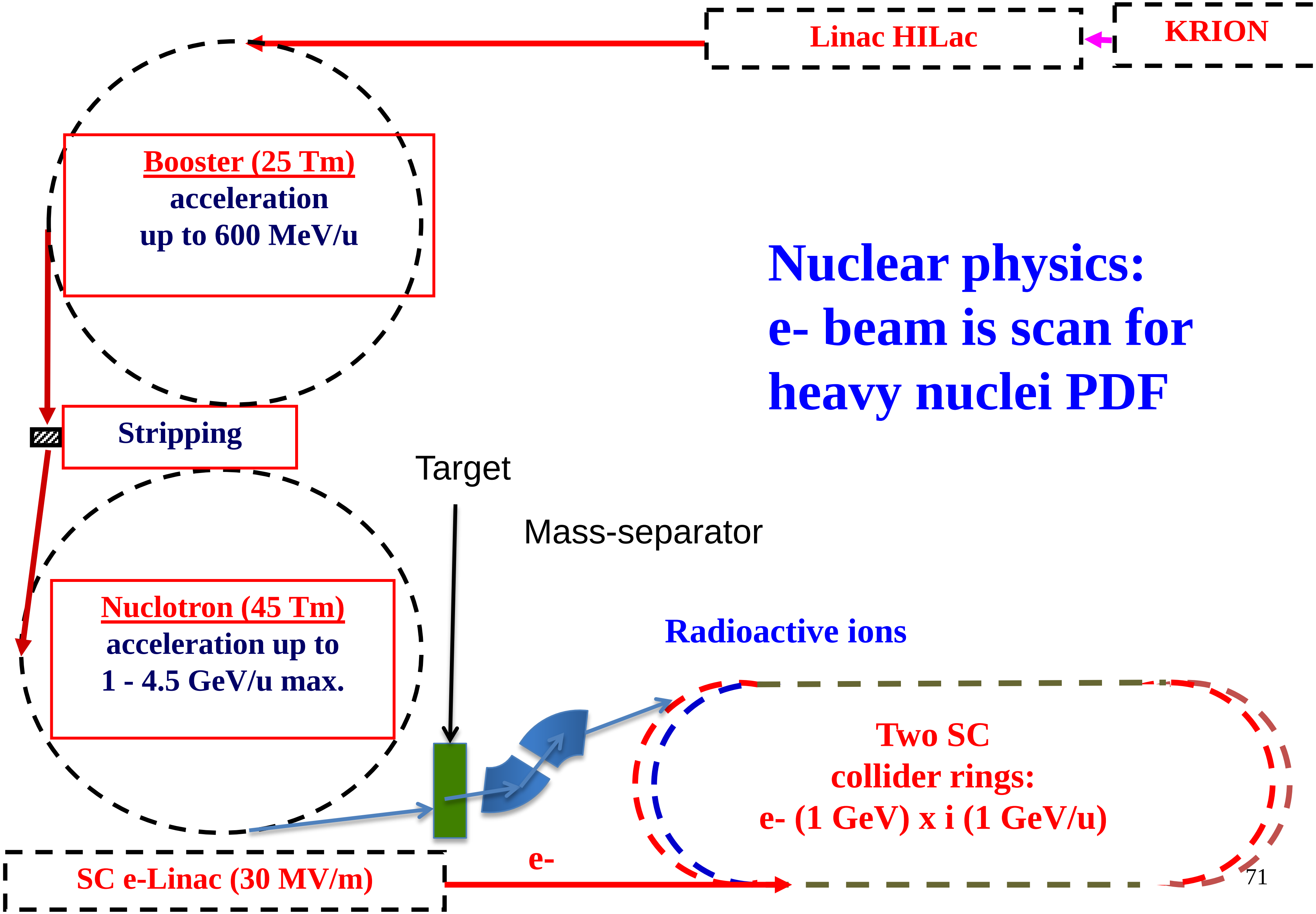


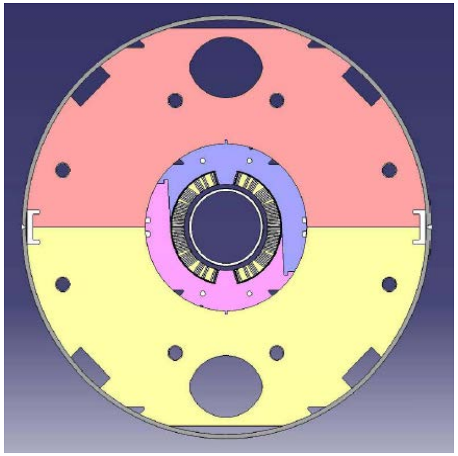


Yu. Oganessian 113-th Session of the Scientific Council of JINR, Feb.21, 2013, Dubna

NICA - IV accelerator complex

Nuclear physics:
e- beam is scan for
heavy nuclei PDF





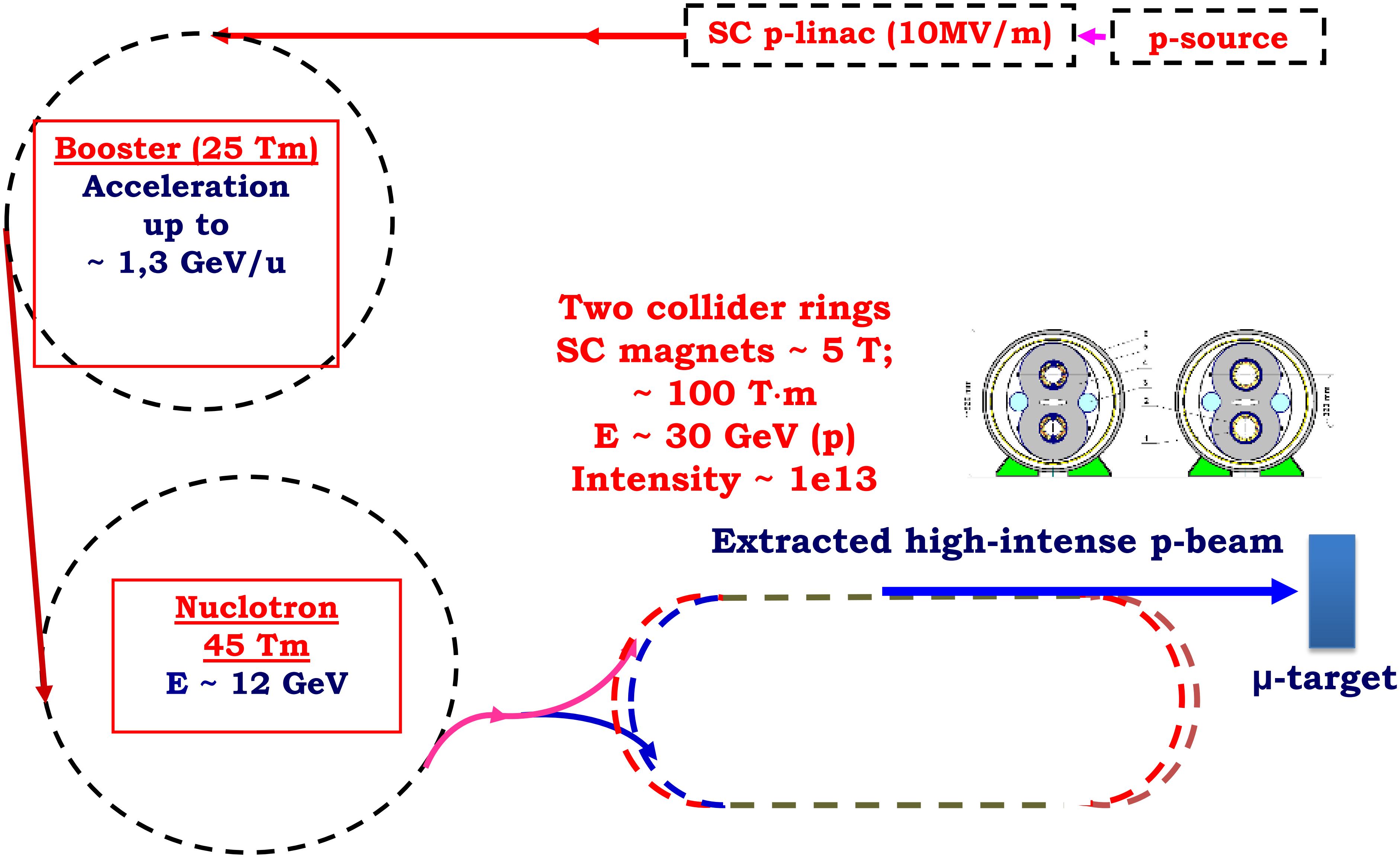
Cos-φ Dipoles

UNK project

Block number	5
Turn number/quadrant	34 (17+9+4+2+2)
Operating current	8924 A
Yoke inner radius	98 mm
Peak field on conductor (with self field)	4.90 T
Bpeak / Bo	1.09
Working point on load line	69%
Current sharing temperature	5.69 K
Inductance/length	2.9 mH/m
Stored energy/length	116.8 kJ/m

Discorap-Project by INFN
Magnet finished in 2010

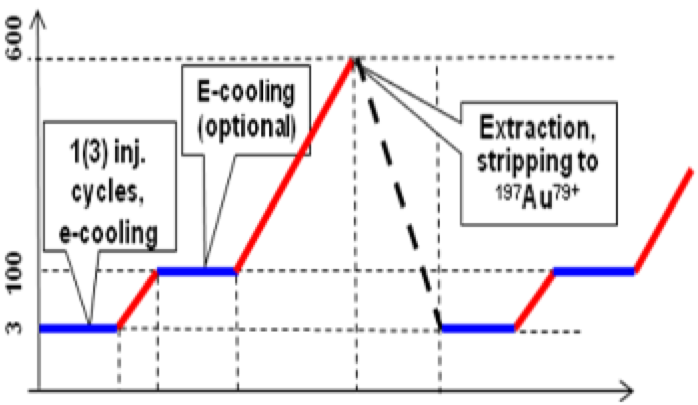
NICA-V accelerator complex



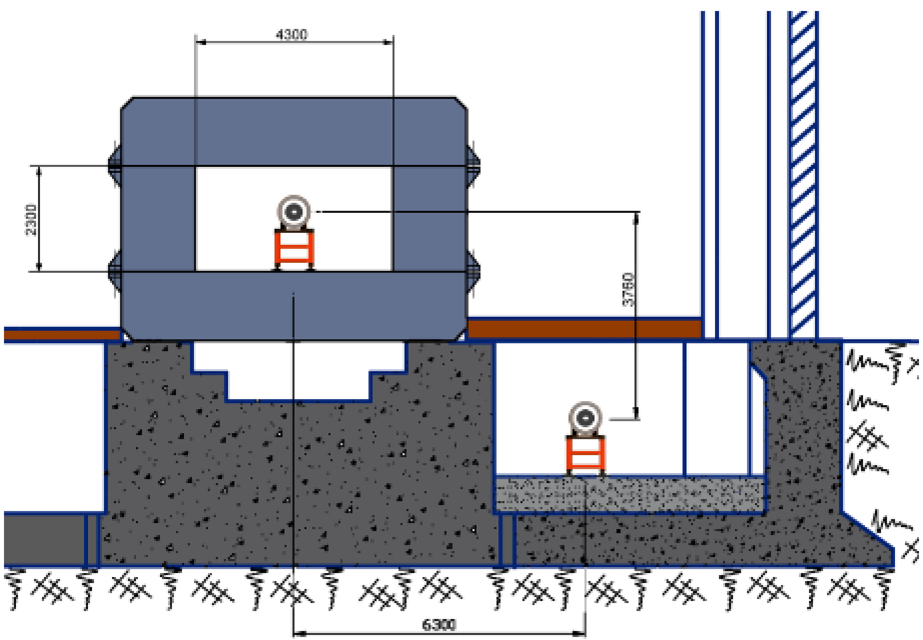
Goal: MW proton beam to the target

Dubna
$\nu_e \to \nu_\mu \to \nu_\tau$
~ 4500 km
Baikal

Thank you for your attention !



Fold symmetry	4
Number of the FODO lattice cells per arc	6
Number of large straight sections	4
Length of large straight sections, m	2×4
Length of small straight sections, m	1.2/0.6
Betatron tunes	5.8/5.85
Amplitude of β-functions, m	14.3
Maximum dispersion function, m	2.9
Momentum compaction factor	0.039
Gamma-transition	5.064
Chromaticity	-6.5/-6.9
Horizontal acceptance, π·mm·mrad	138
Vertical acceptance, π·mm·mrad	40



Sort of ions: before stripping station after stripping station	 Au^{31+}, Au^{52+}, Au^{65+} Au^{79+}
Maximum energy of ions, MeV/u	685
Maximum magnetic rigidity of ions, T m: before stripping station after stripping station	 25 11
Ion number	$2 \cdot 10^9$

Startup version of the collider

Energy range from 3 to 4.5 GeV/u (optimum ~ 3.5 GeV/u)

Operation scenario:

- Stacking with BB + Stoch. longitudinal cooling
- Bunching at h = 22 and Stoch. longitudinal cooling

Parameters

Bunch length is about 1.2 m (instead of 0.6 m)

Momentum spread of $4.2 \cdot 10^{-4}$ (instead of $1 \cdot 10^{-3}$)

Bunch intensity $5 \cdot 10^{8}$ (instead of $2 \cdot 10^{9}$)

Luminosity $(1 \div 7) \cdot 10^{25}$ $cm^{-2}s^{-1}$

Startup version of the collider: goals

-Test of the beam stacking procedure:

stacking efficiency, evolution of transverse emittance

- Test and optimization of Stoch. cooling system

-Test of the beam bunching with cooling

-Investigation of IBS, ring tune ability, beam life-time…

-Test of MPD systems at L ~ $5 \cdot 10^{25}$ $cm^{-2}s^{-1}$

Introduction

Big Bang & Hot Universe

The Planck Era:

Newton potential + dimension consideration

$$\left.\begin{aligned} U &= \frac{Gm^2}{l} \\ l &= ct \\ mc^2 &= \frac{\hbar}{t} \end{aligned}\right\} \Rightarrow$$

The Planck Parameters

$$m_{Planck} = \sqrt{\frac{\hbar c}{G}} \approx 2.2 \cdot 10^{-5}\, g = 10^{19}\, GeV / c^2$$

$$t_{Planck} = \sqrt{\frac{G\hbar}{c^5}} = 5.4 \cdot 10^{-44}\, s$$

$$l_{Planck} = ct_{Planck} = \sqrt{\frac{G\hbar}{c^3}} = 10^{-33}\, cm = 10^{-20}\, fm$$

Introduction

Big Bang and Hot Universe

The Planck Era:

$X \geq X_{Planck}$

$$T_{Planck} = \frac{m_{Planck} c^2}{k} = 1.41679 \cdot 10^{32} K \approx 1.5 \cdot 10^{19} GeV$$

The Planck Parameters

$$\rho_{Planck} = \frac{m_{Planck}}{l^3_{Planck}} = \frac{c^5}{G^2 \hbar} \sim 10^{94} \ g / cm^3$$

$1 \ fm = 10^{-13} \ cm$

$$n_{Planck} = l^{-3}_{Planck} \sim 10^{60} \ fm^{-3},$$

$$n_{proton} \sim \left[\frac{4\pi (0.876 \ fm)^3}{3} \right]^{-1} = 0.354 \ fm^{-3}, \quad n_{nucl} = 0.16 \ fm^{-3}$$

Planck Parameters are criteria for beginning of The Modern Era:

$\rho < \rho_{Planck}$, $T < T_{Planck}$