Experience with NUCLOTRON

FRRC School,
Hirschegg, 15 February, 2011

G. Trubnikov
on behalf of the team

1. Nuclotron – history, reasons, technologies, location…
2. Lattice structure, main parameters
3. Subsystems, beam cooking, requirements
4. Beam dynamics. Particle losses, main problems
5. Injector chain. Modernization.
6. Vacuum system – M
7. RF system – M. Cycle requirements
8. Power supply – M. Cycle requirements
9. Beam control and diagnostics
10. Cryogenics. Goals for upgrade
11. Beam slow extraction. FT program
12. Plans, goals, perspectives. Comparison
13. NICA
14. Conclusion

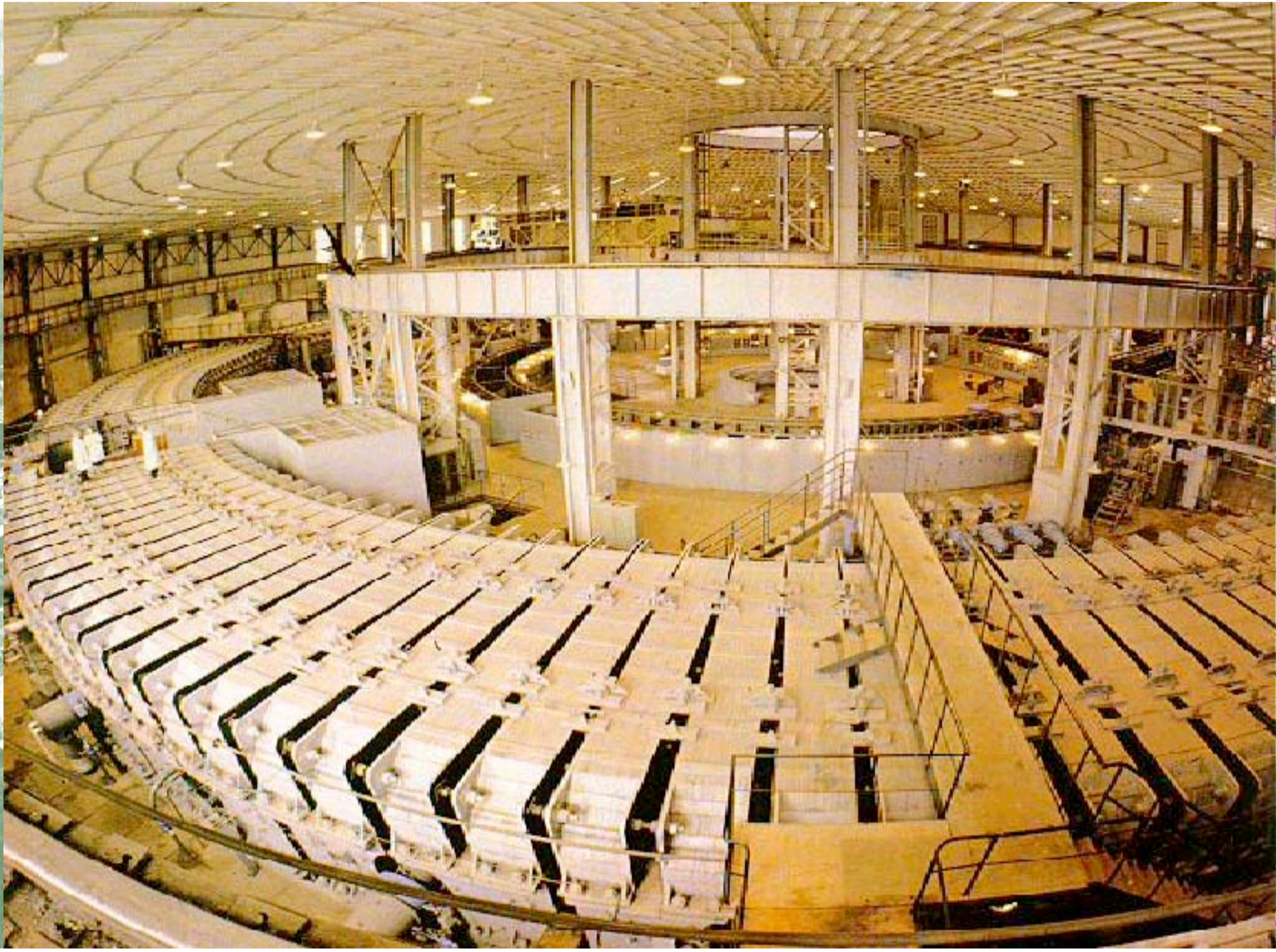
JINR 1956-2006 DUBNA

JOINT INSTITUTE FOR NUCLEAR RESEARCH

The Joint Institute for Nuclear Research (JINR) in Dubna is an international research organization established in accordance with the intergovernmental agreement of 11 countries in 1956. At the present time, 18 countries are the JINR Member States and 5 more countries have the associated member status.

The Synchrophazotron – soft-focusing machine, launched in 1957. Circumference 211 m. 4 quadrants, 36000 tons of steel. Vacuum chamber 110x60 cm.

The first relativistic nuclear beams with the energy of 4.2 AGeV were obtained at the Synchrophasotron in 1971. Since that time the study of relativistic nuclear physics problems has been one of the main directions of the JINR research program.



Precursors and Hints

1970 – Synchrophazotron (JINR): observation of

$dd \Rightarrow \pi$-jet : $\Sigma E_{jet} > 2m_n c^2 \Rightarrow$ first cumulative effect!

(V.Sviridov, V.Stavinsky)

1980th - 2007 AGS, SPS, RHIC

Hypothesis of quark–gluon plasma (QGP*)) –
- a "mirage" never proved been observed

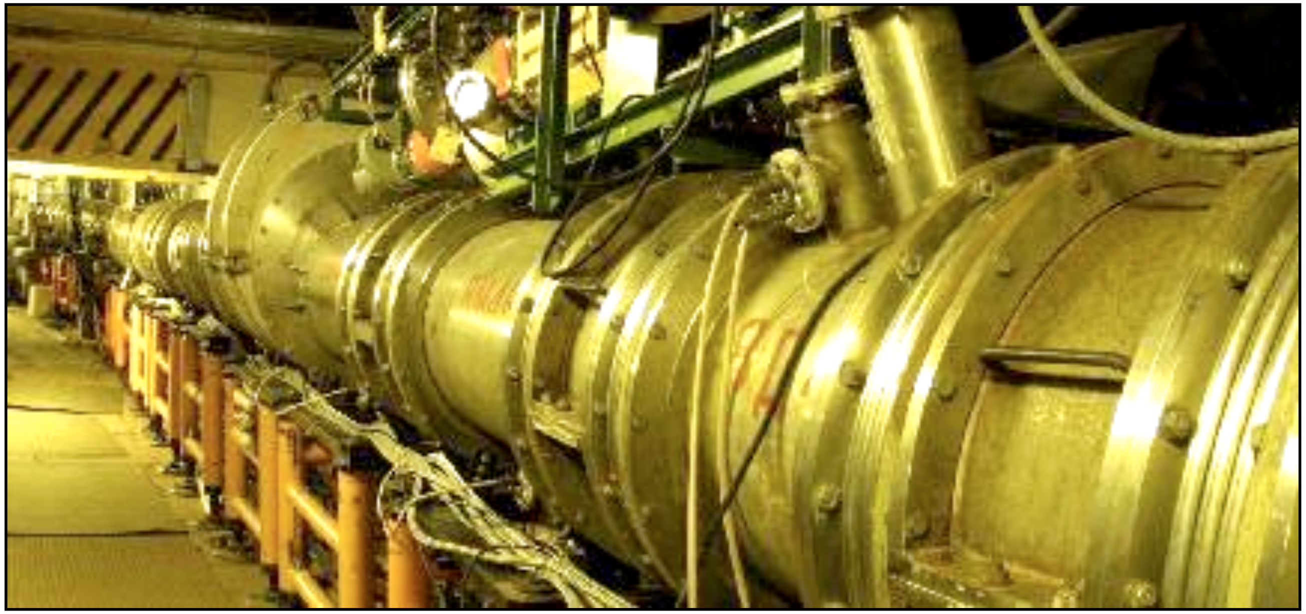
Nevertheless, there are all indications of a qualitatively new form of matter is being produced in central Au x Au collisions at RHIC!

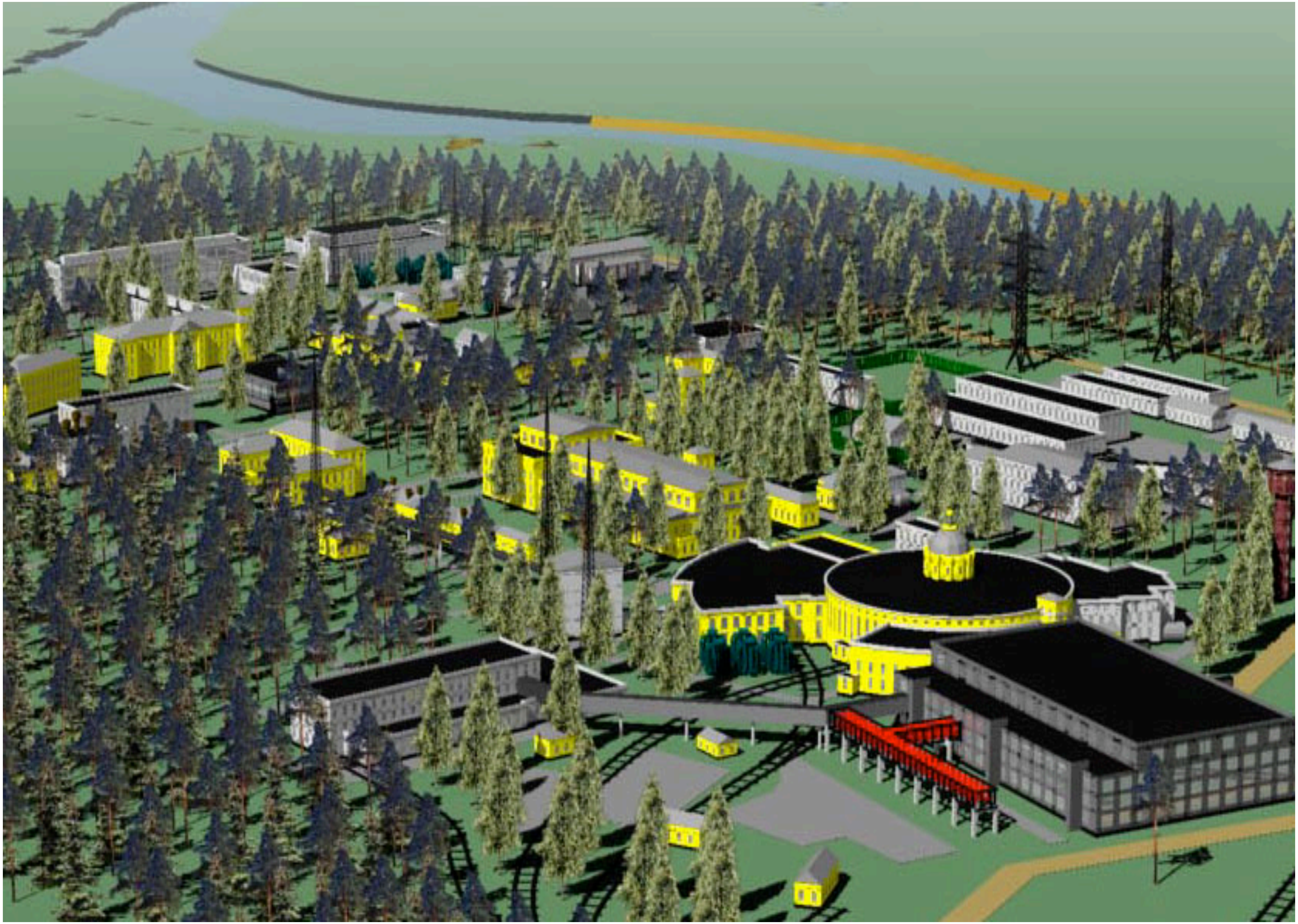
*) QGP ≡ a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes.

Nuclotron – Superconducting Proton Synchrotron operation since 1993

Alexander Baldin

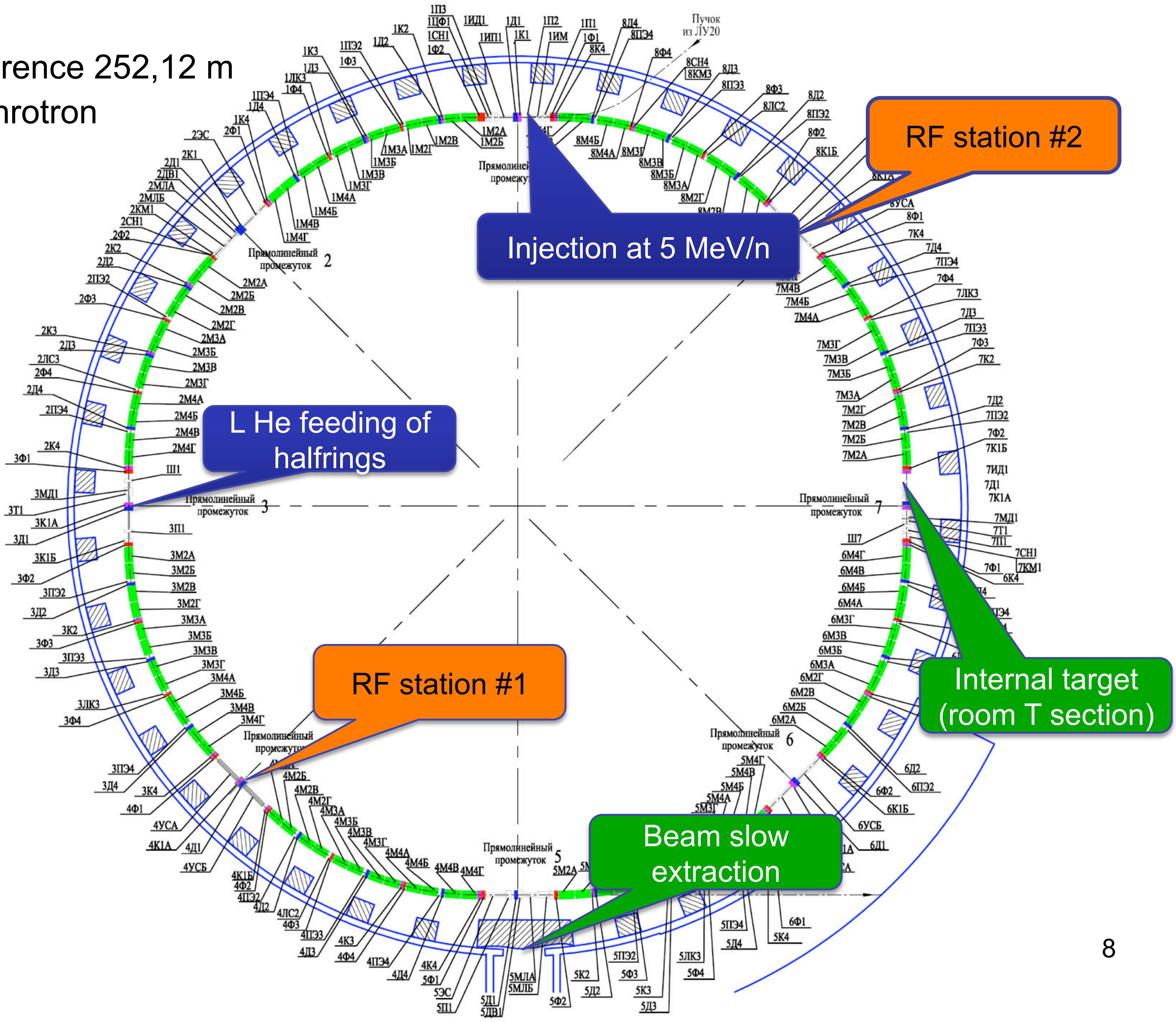
6 A·GeV synchrotron based on unique fast-cycling superferric magnets, was designed and constructed at JINR for five years (1987-1992) and put into operation in March 1993. The annual running time of 2000 hours is provided during the last years.



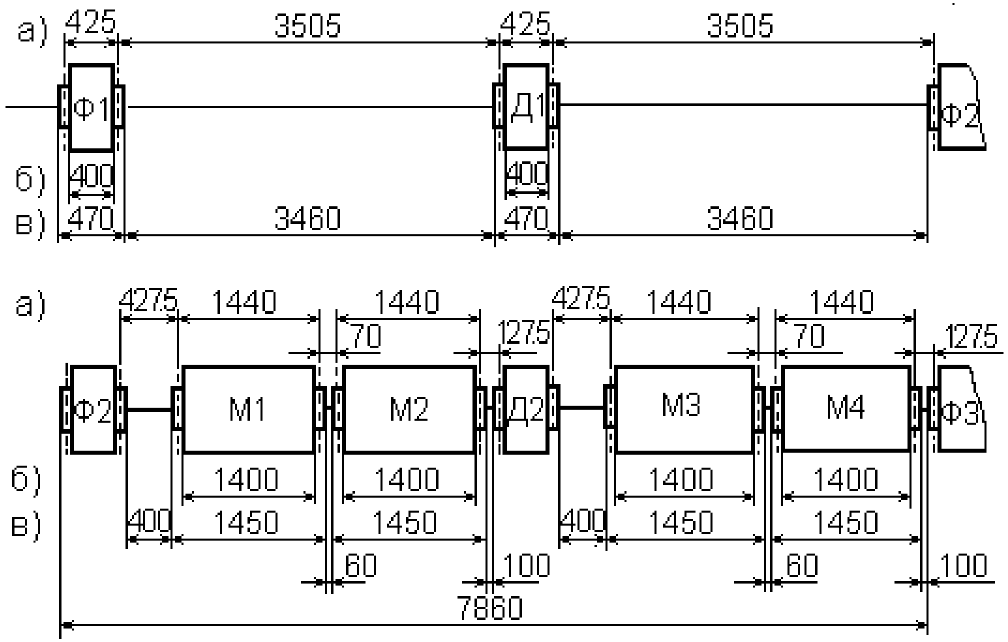


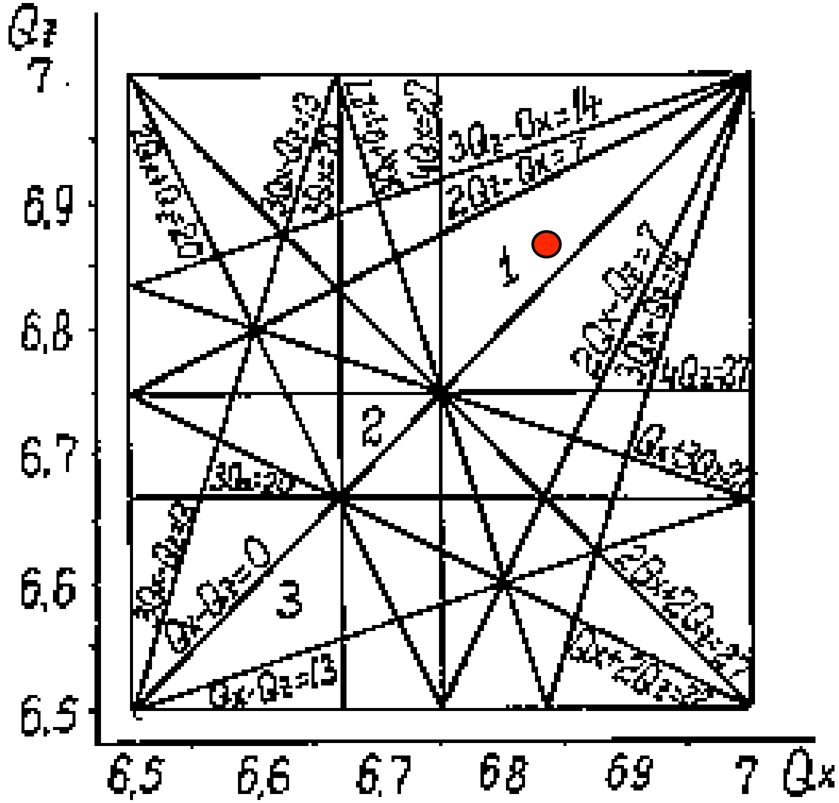
Circumference 252,12 m

SC synchrotron



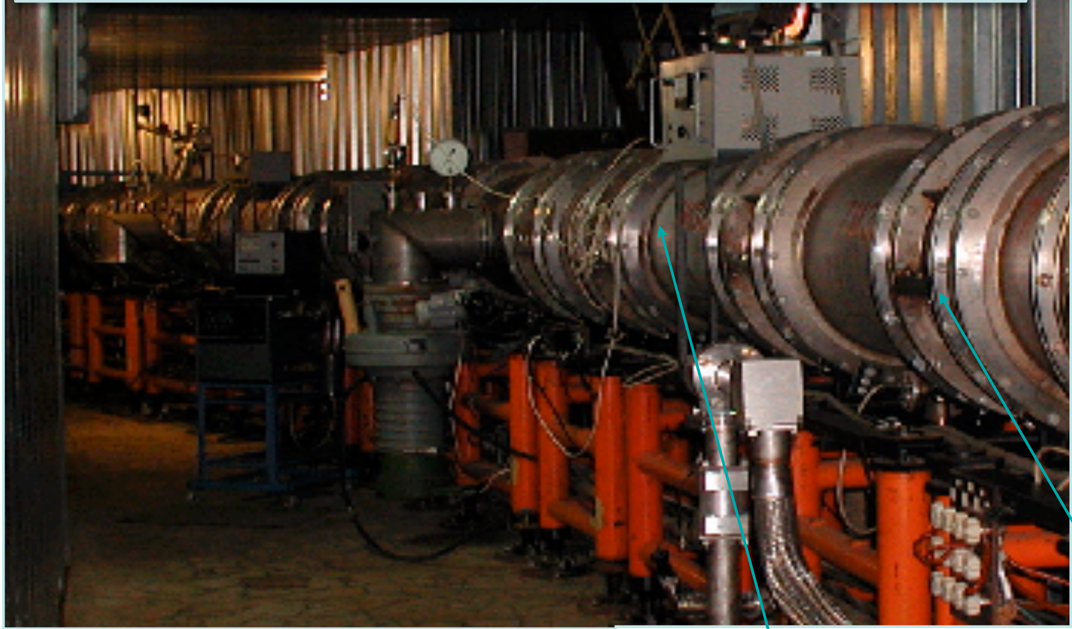
Optic structure of the Nuclotron: 8 super-periods, each contains 3 regular periods and 1 period, which does not contain dipole magnet. Reguar period includes focusing and defocusing quadrupole lenses, 4 dipoles and 2 small stright sections for multipole correctors and diagnostics.





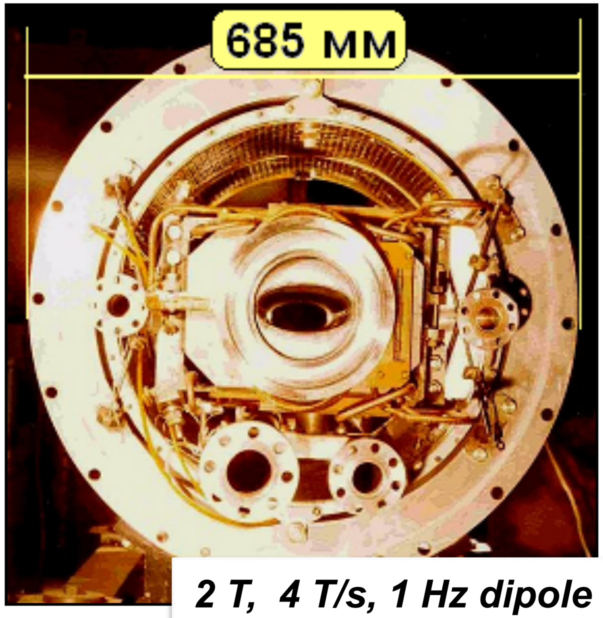
Chromaticity $\Delta Q_x/(\Delta p/p)$ and $\Delta Q_z/(\Delta p/p)$	-7.8 -10.0
Compaction factor	0,012
Corrected orbit amplitude	4 mm
Acceptance horiz/vert [pi mm mrad]	40 / 45
Emittance inj/acc [pi mm mrad]	30 / 1.7_x and 2.0_z
DP/P inj/max/accel	$\pm 10^{-3}$ / $4\cdot 10^{-4}$ / $8\cdot 10^{-3}$

JINR NUCLOTRON

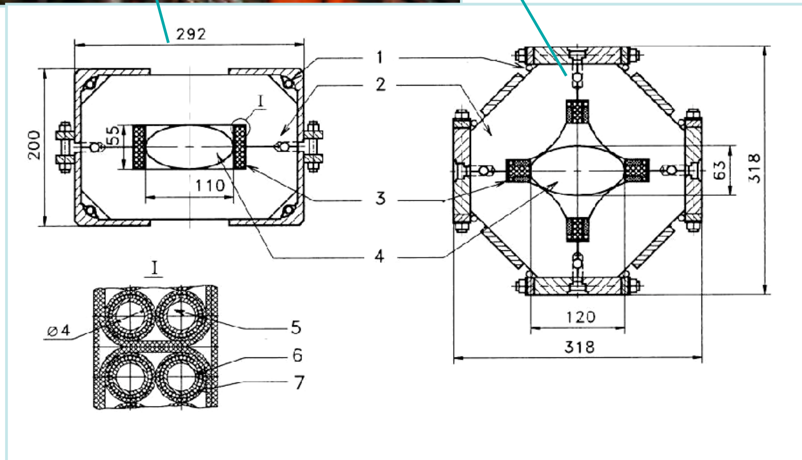


Design and construction of the Nuclotron provided to JINR the unique long-term experience in the technology of superconducting magnets

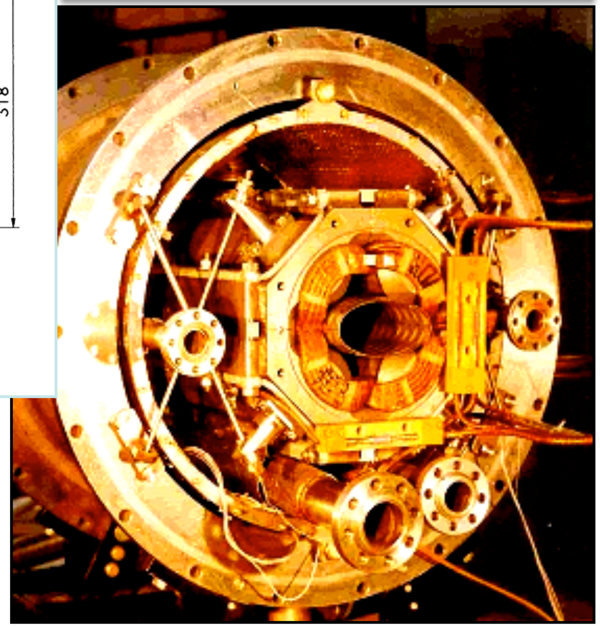
Nuclotron fast-cycled superferric dipole and quadrupole magnets



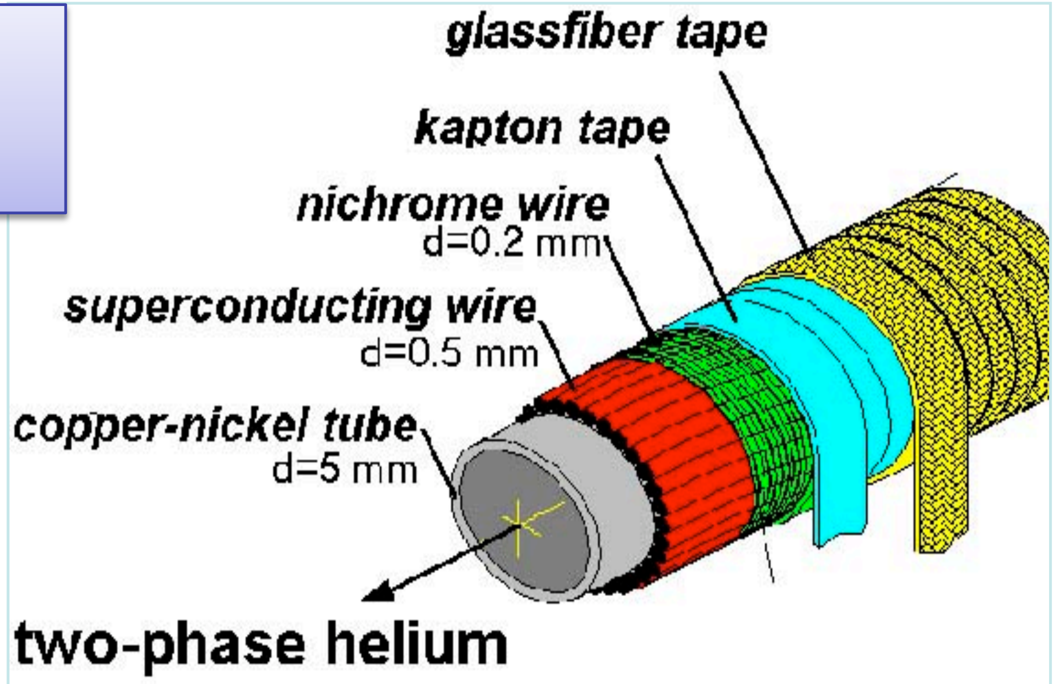
2 T, 4 T/s, 1 Hz dipole

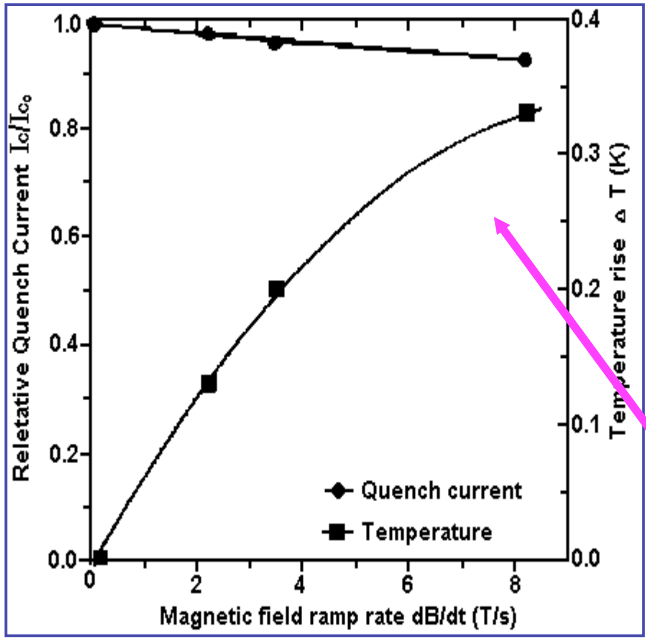


34 T/m, 68 T/m s, quad

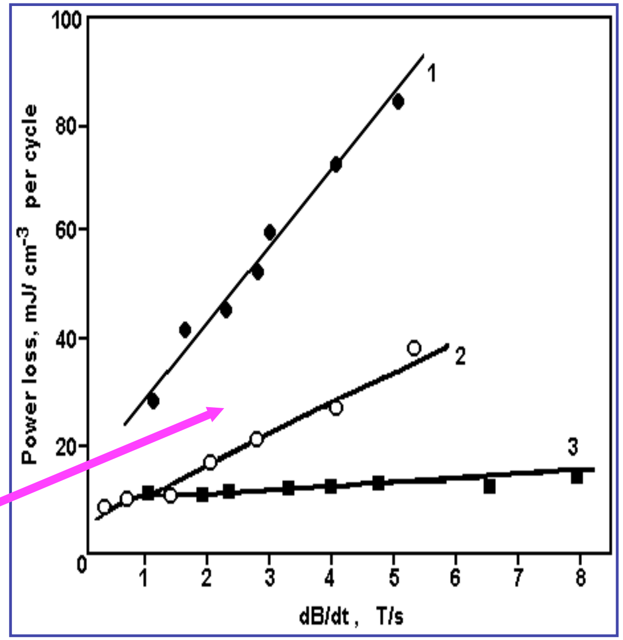


NUCLOTRON: NbTi
composite hollow cable





- Low degradation of the cable critical current in a fast ramping operation (4.8 %. @ dB/dt=4T/s)



- Weak dependence of the eddy current loss on the magnetic field ramp

Nuclotron status

Stable operation 1300 ÷ 2000 hours/year during the past three years.
More than 75% of the total beam time is used for physics,
experiments the beam time allocated for MD ~ 25% of the total one.

The ion beams: p, d, He, Li, B, C, N^{6+}, N^{7+} , Mg , Ar^{16+}, Fe^{24+};
d↑ tested
The energy range 0.35 ÷ 2.2 GeV/u for nuclei,
3,5 GeV/u for deuterons,
5.7 GeV for protons.

The experiments are performed by 14 collaborations.

Collaboration at Nuclotron

Internal target

ETA-NUCLEI, DELTA-2, LNS

Exctracted beams

ALPOM, BECQUEREL, DELTA-SIGMA, ENERGY & TRANSMUTATION, FAZA-3, GAMMA-2, GIBS, MARUSYA, NIS, KRISTAL, TPD, STRELA, Med-Nuclotron, Radiobiological investigations

NUCLOTRON Users

Belarus: The Institute of Radiative Physical-Chemical Problems of NASB, The Academy of Scientific and Engineering Complex 'SOSNY', (Minsk) …

Bulgaria: Institute for Nuclear Research and Nuclear Energy of BAS, University of Chemical Technology and Metallurgy (UCTM) (Sofia) …

Czech Republic: Nuclear Physics Institute (Řež), Charles University, Czech Technical University (Prague) …

Greece: Aristotle University of Thessaloniki (Thessaloniki)

Italy: Istituto Nazionale di Fisica Nucleare. Sezione di Firenze (Florence) …

Germany: Technishe Hochschule Darmstadt – Institut für Kernphysik (Darmstadt), Universität (Siegen, Karlsruhe), Philipps-Universität Marburg (Marburg), Forschungszentrum Jülich GmbH (Jülich) …

Mongolia: Institute of Physics and Technology of MAS, National University of Mongolia (Ulaanbaatar)

Slovak Republic: Institute of Experimental Physics, P.J. Šafárik University (Košiče), Institute of Physics SAS, Comenius University (Bratislava) …

Poland: Niewodniczanski Institute of Nuclear Physics (Cracow), The Andrzej Soltan Institute for Nuclear Studies (Otwock, Warsaw) …

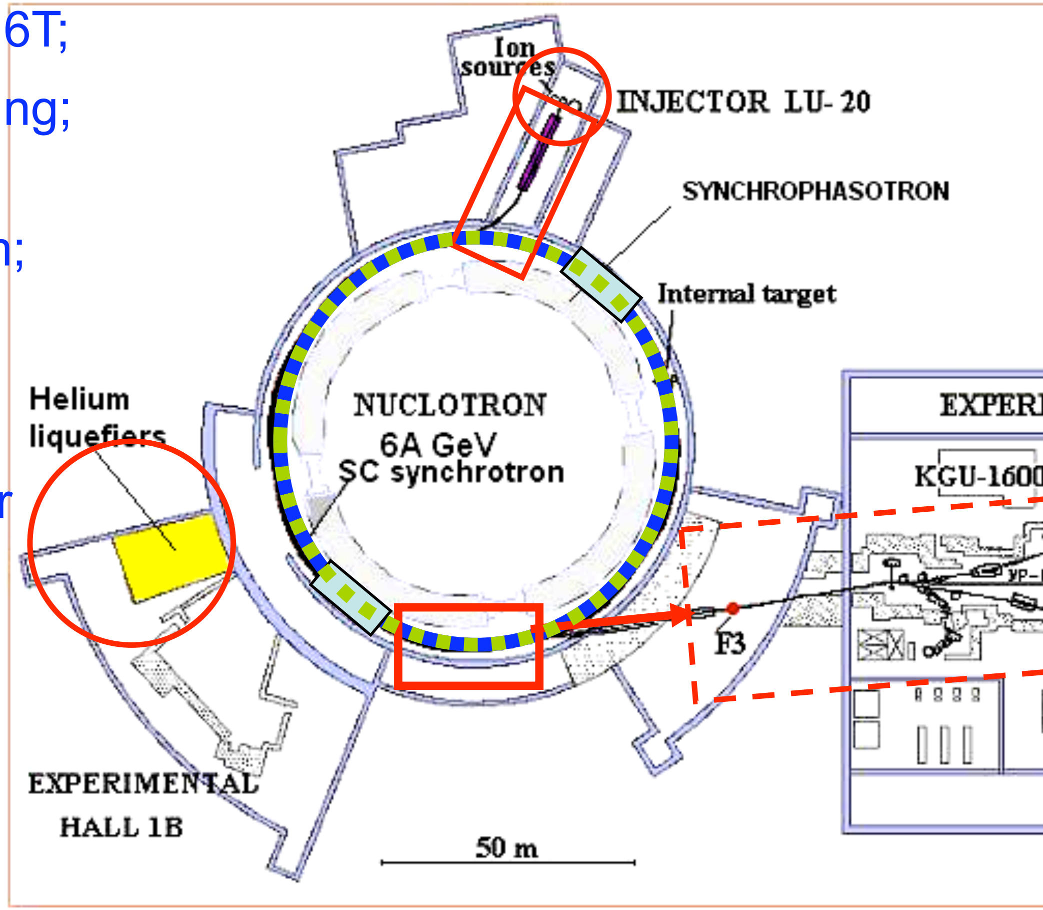
Russia: Institute for Nuclear Research of RAS (Troitsk), Lebedev Physical Institute of RAS (FIAN), Skobeltsyn Research Institute of Nuclear Physics at the Moscow State University, Russian Nuclear Research Institute of Experimental Physics (Sarov), Institute of Atomic Energy (Obninsk) …

And the Scientific Centers in Armenia, Georgia, Egypt, Kazakhstan, Romania, USA, Uzbekistan, Ukraine, France, Japan

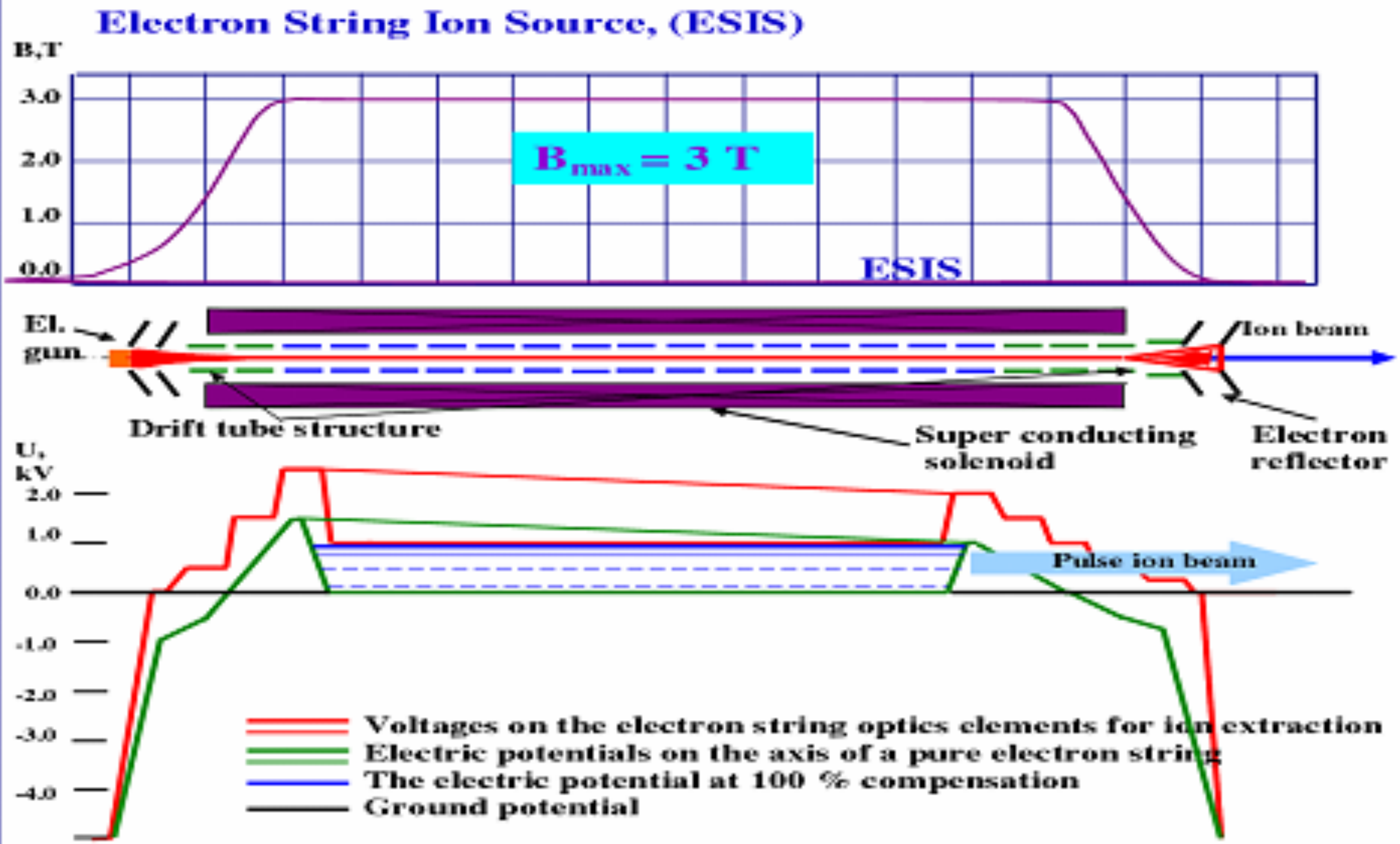
Australia: The University of Sidney

10 stages-subprojects of the Nuclotron-M project

- Modernization of ion source KRION to KRION 6T;
- Improvement of the vacuum in the Nuclotron ring;
- Development of the power supply system, quench detection and energy evacuation system;
- Modernization of the RF system (including trapping & bunching systems, controls and diagnostics);
- Modernization of the slow extraction system for accelerated heavy ions at maximal energies;
- Modernization of automatic control system, diagnostics and beam control system;
- Transportation channel of the extracted beams and radiation safety;
- Improvement of the safety, stability and economical efficiency of the cryogenics;
- Modernization of the injector complex (fore-injector and linac) for acceleration of heavy ions;
- Development and creation of high intensity polarized deutron source



<u>Beam dynamics: minimization of the beam losses at all stages from injection to acceleration and to extraction of the beams (not more then 15-20%, we have about 50-80%).</u>

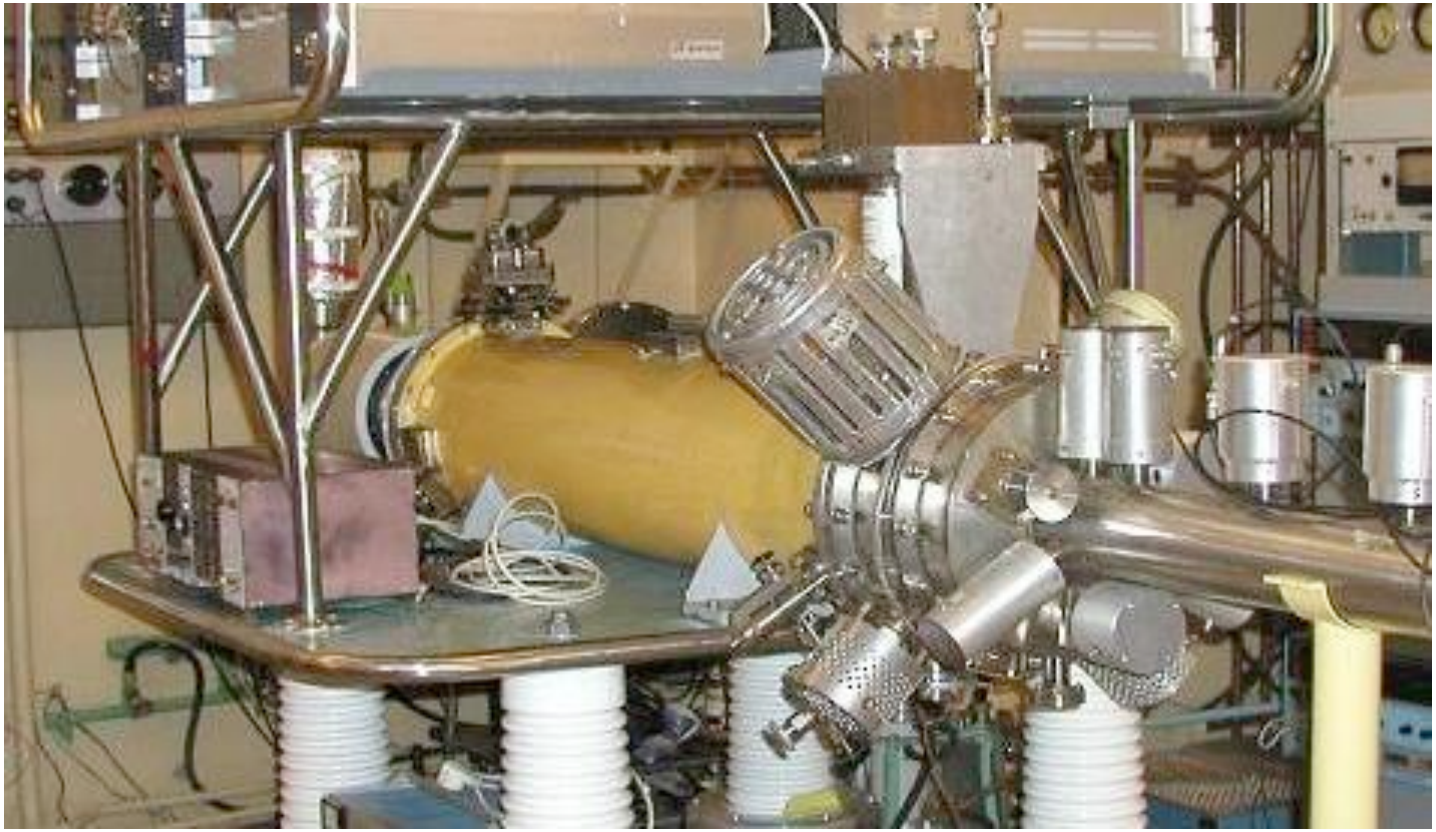


EBIS in the electron reflex mode of operation

EBIS: 300 kW DC electron beam power

ESIS: 200 W

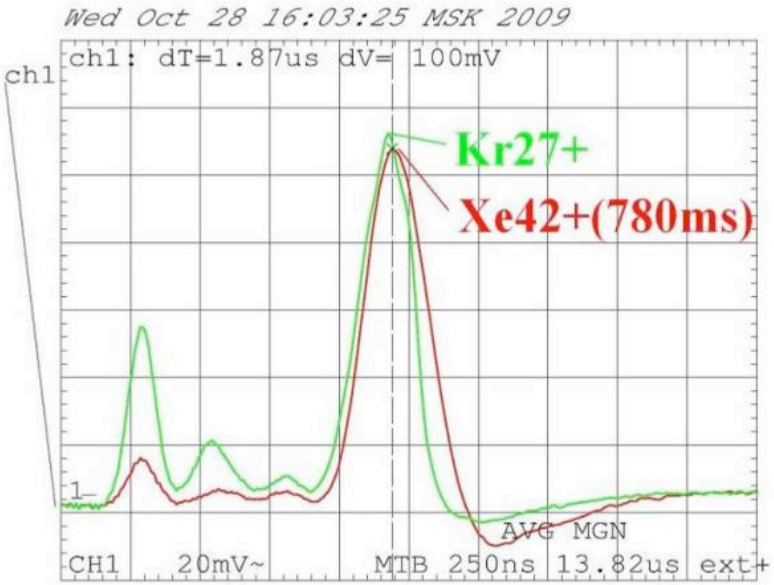
General view of the KRION ion source with 3 T solenoid



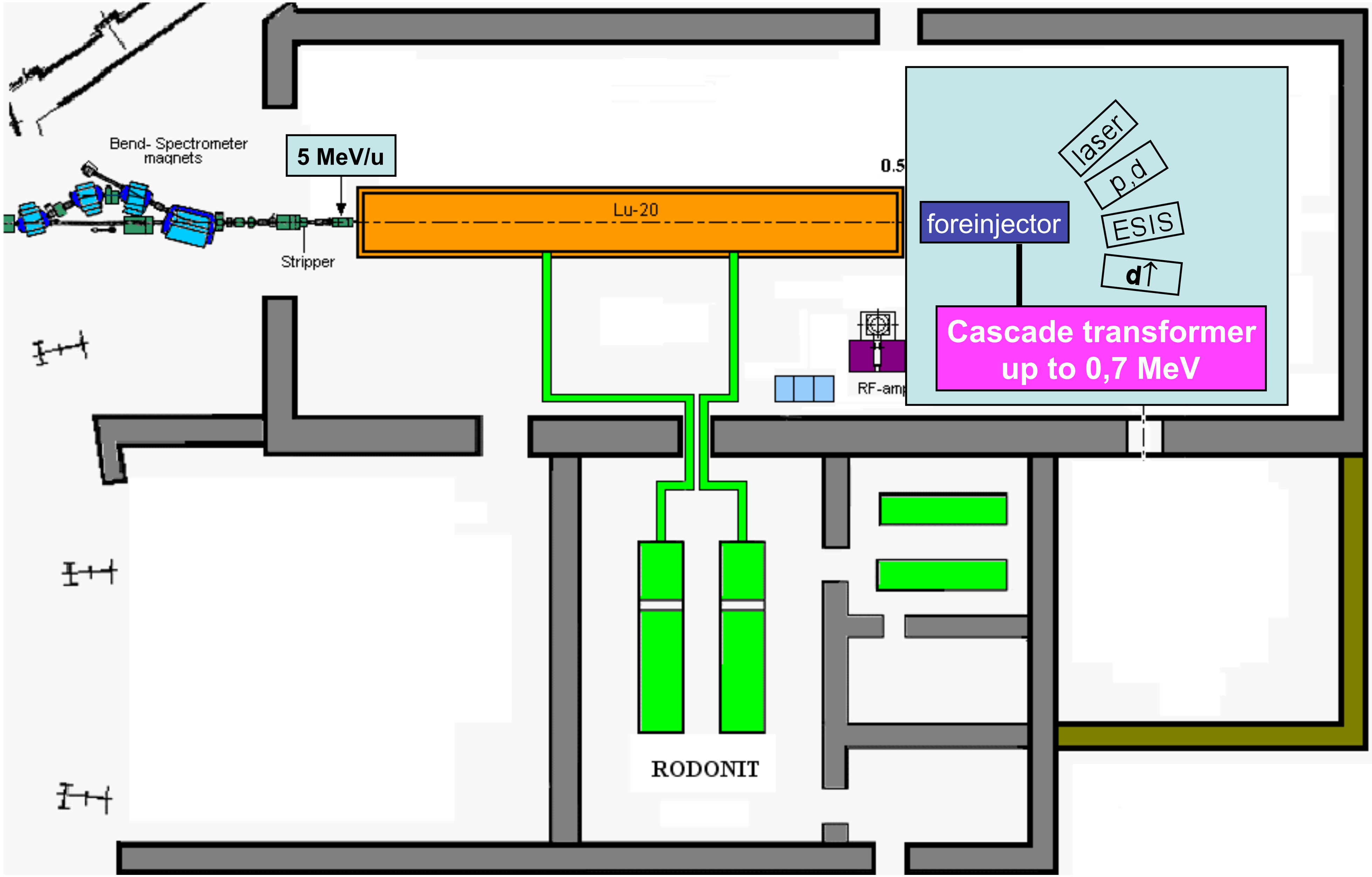
Experimental result — 3 T solenoid: $5 \cdot 10^{8}$ Au^{30+} — E. Donets

Expectation — 6 T solenoid: $2 \cdot 10^{9}$ U^{32+}

E.Donets and team.
KRION source



As LU-20 accepts ions with charge to mass ratio q/M>1/3 one should produce in ion source ^{124}Xe ion beams with the following charge states: ^{124}Xe41+, ^{124}Xe42+, ^{124}Xe43+, ^{124}Xe44+ This was done in October 2009 run with use of KRION-2T Electron String Ion Source. Highly charged Xe ion beams with charge state Xe42+ in the maximum of the charge state spectrum (see picture) has been produced for **780 ms of ionization time**. **A total pulse ion current for highly charged Xe ions was obtained on a level 130 μA** which contains mixture of Xe40+, Xe41+, Xe42+, Xe43+, Xe44+ charge states. In terms of the single chosen charge state Xe42+ in its maximum the extracted ion beam pulse contained about **$3x10^7$ Xe42+ particles per pulse**. Pure separated isotope ^{84}Kr was used for calibration of Time-of-Flight analysis.



Bend- Spectrometer magnets
5 MeV/u
Stripper
Lu-20
0.5
foreinjector
laser
p,d
ESIS
d↑
Cascade transformer up to 0,7 MeV
RF-amp
RODONIT

Injector (LU-20) modernization

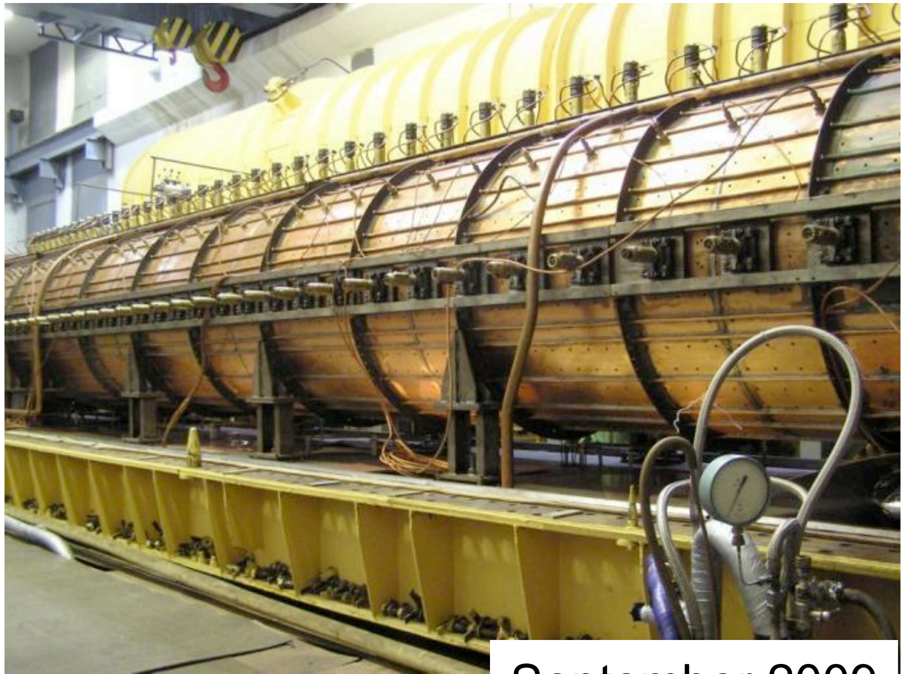
- dismounting of the linac vessel and geodethy of all 59 druft tubes

- new power supplies for corrector magnets

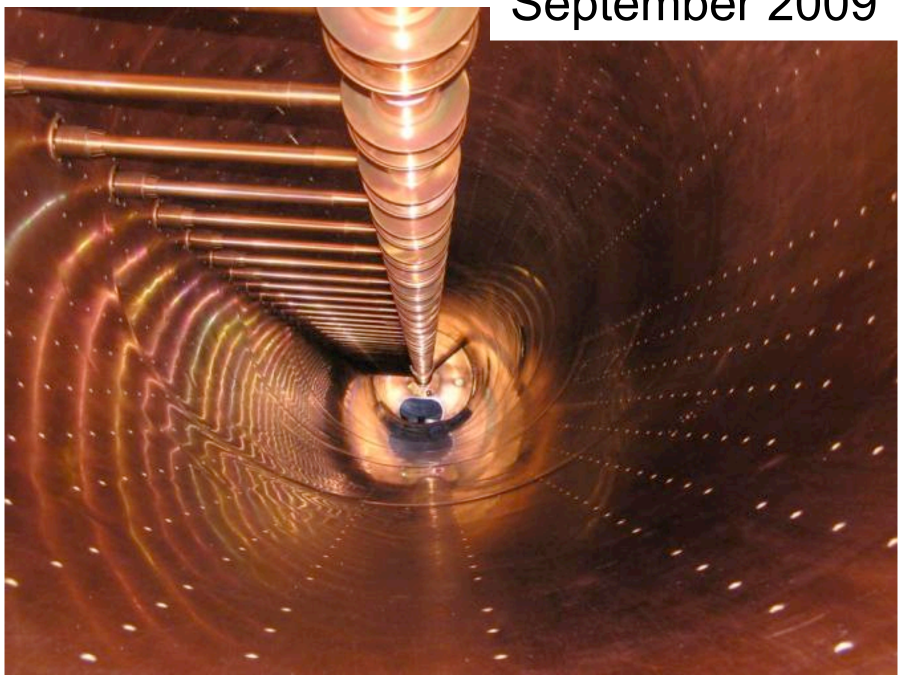
- commissioning of the new synchronization system for all linac control channels

- exchange of some vacuum chamber parts of the injection channel (new fast vacuum shutters)

- 2-3 dedicated beam runs



September 2009

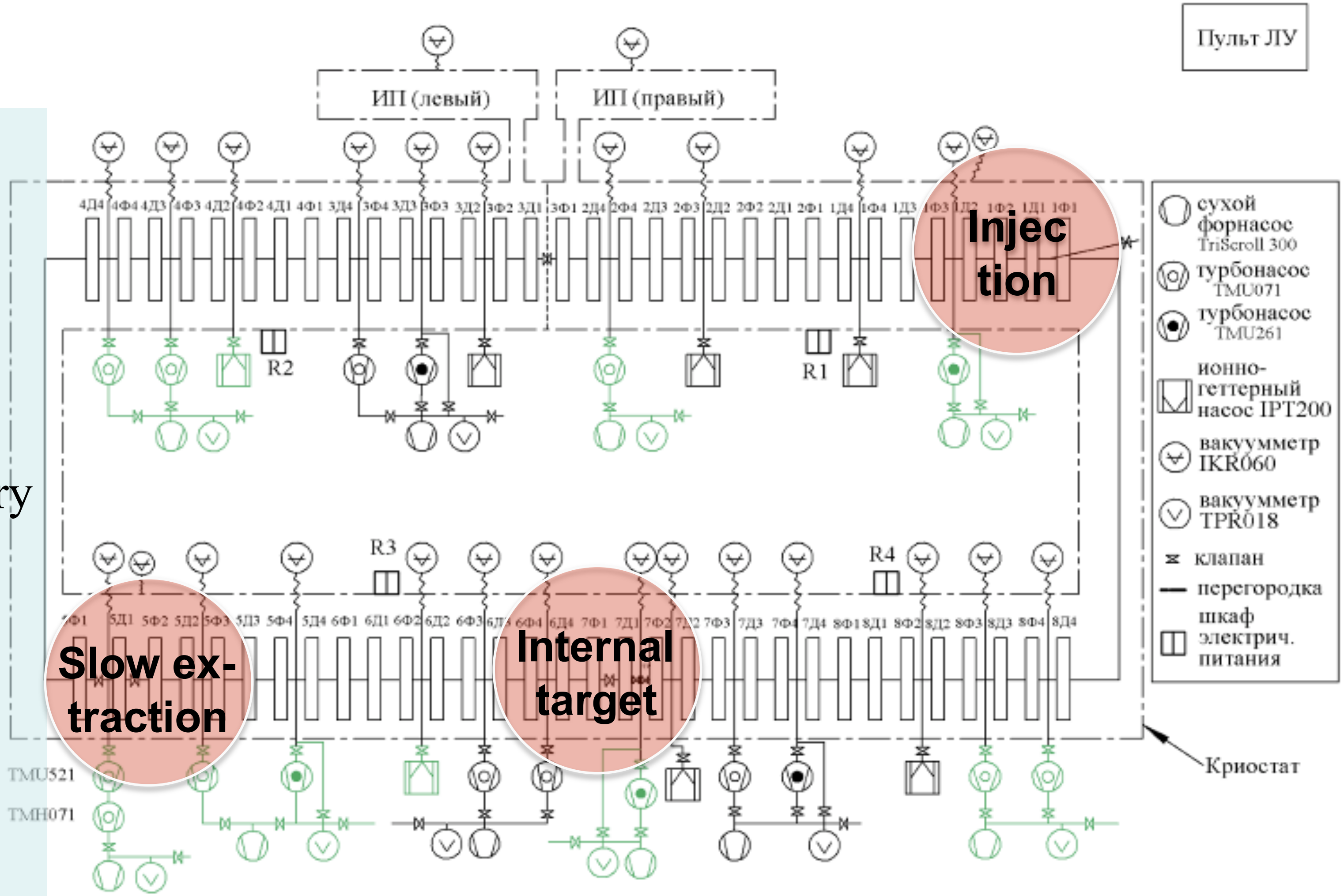


Nuclotron vacuum system modernization

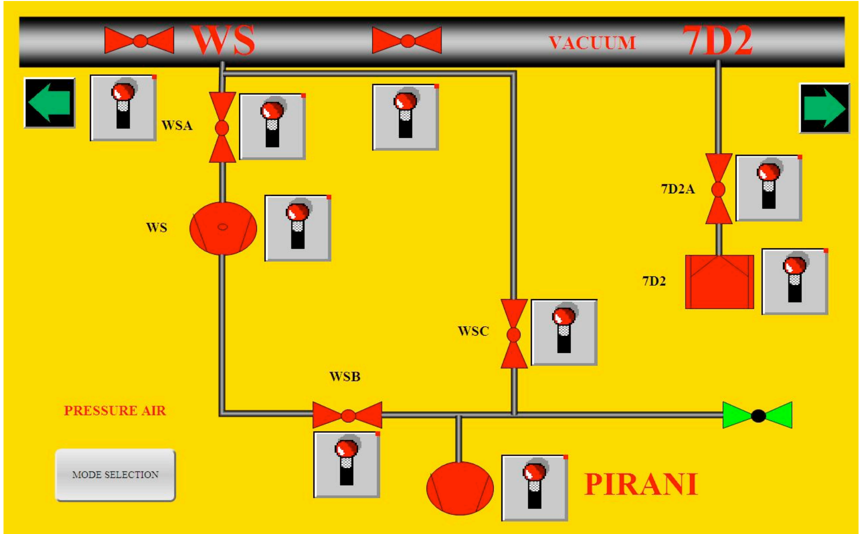
<u>2 stages</u> <u>are planned in the frames of Nuclotron-M project</u>

-1st stage: necessary modernization of Nuclotron

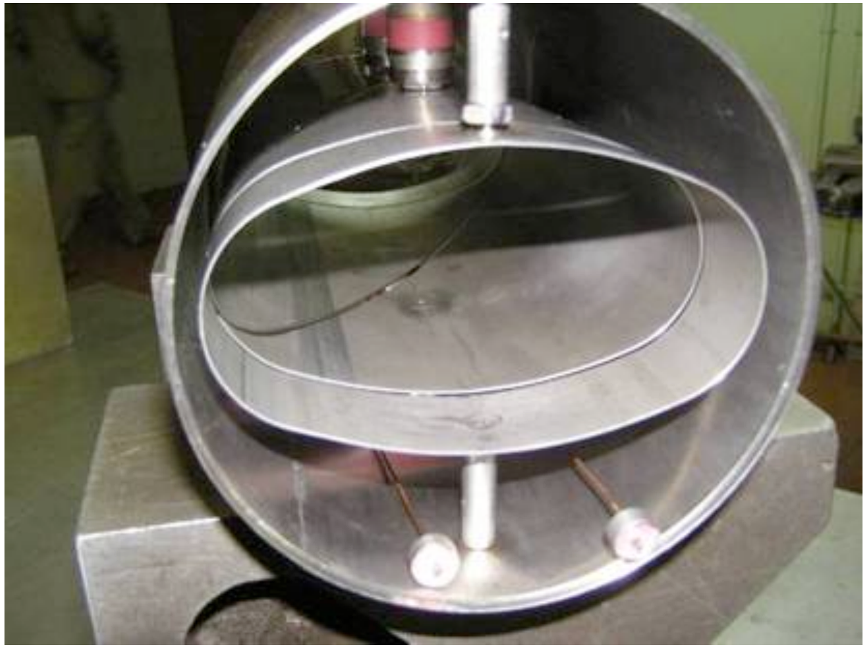
- 2nd stage: modernization for NICA



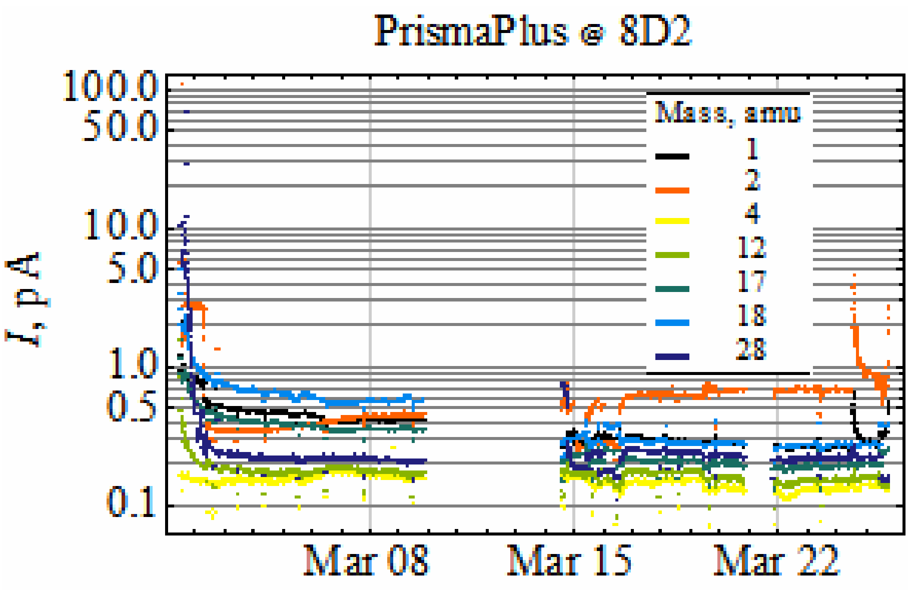
Assembled pick-up station



Touch-screen panel for vacuum system control



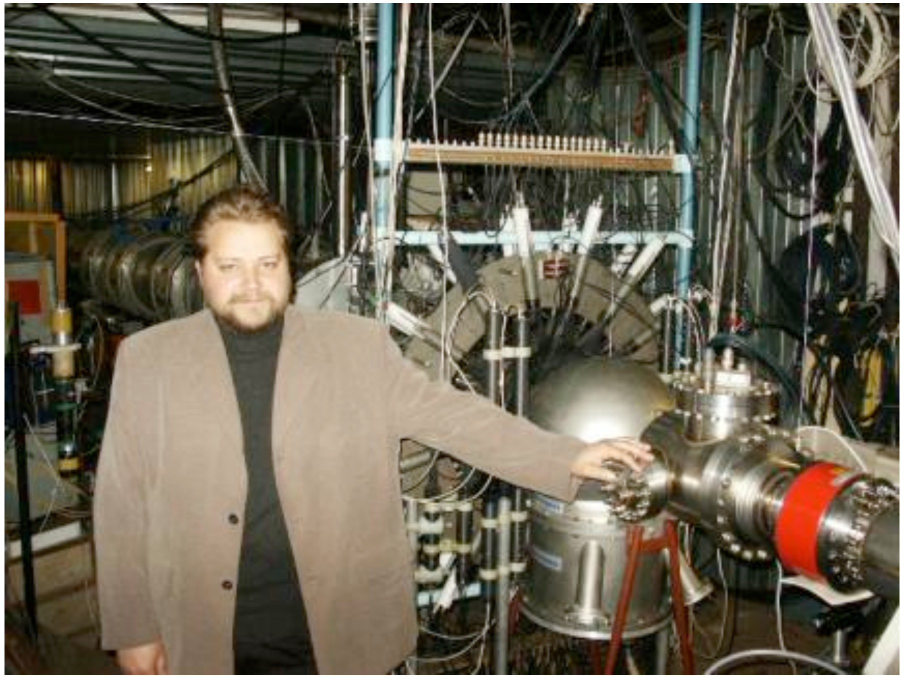
Assembled elliptical pick-up station



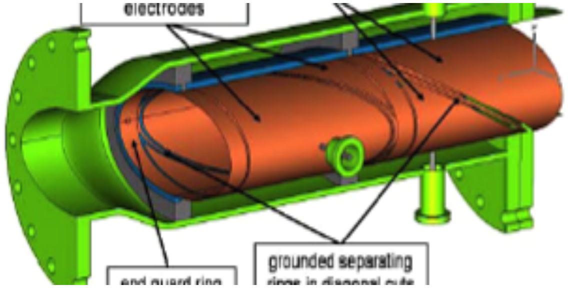
Monitoring of vacuum during run



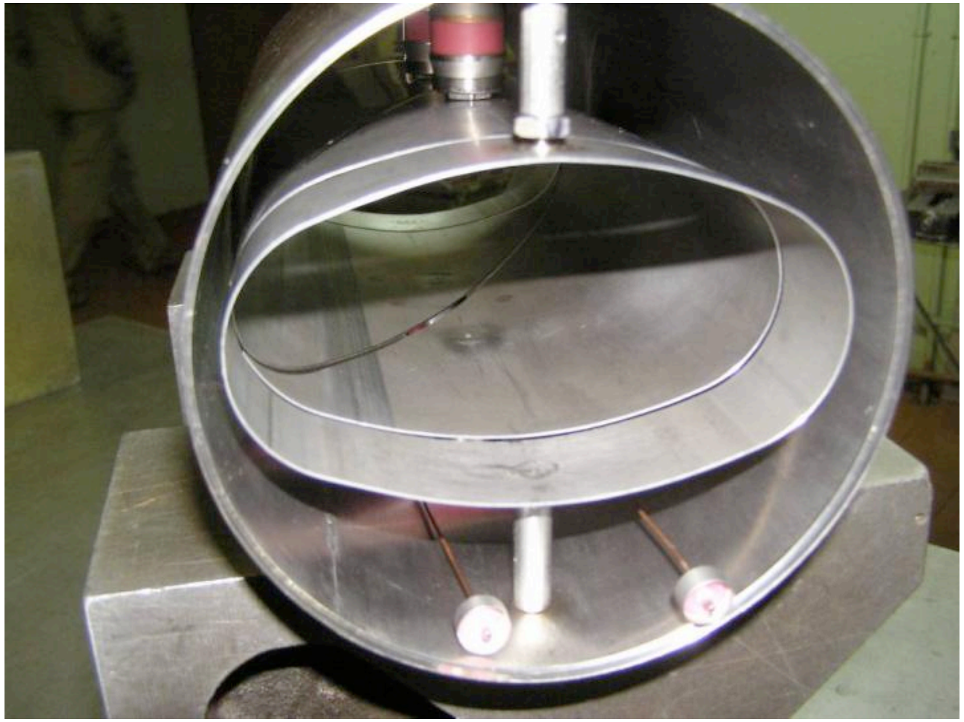


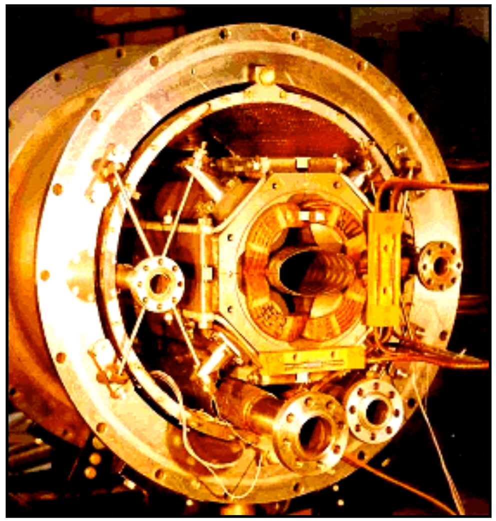




New diagnostics (elliptical pick-up stations)

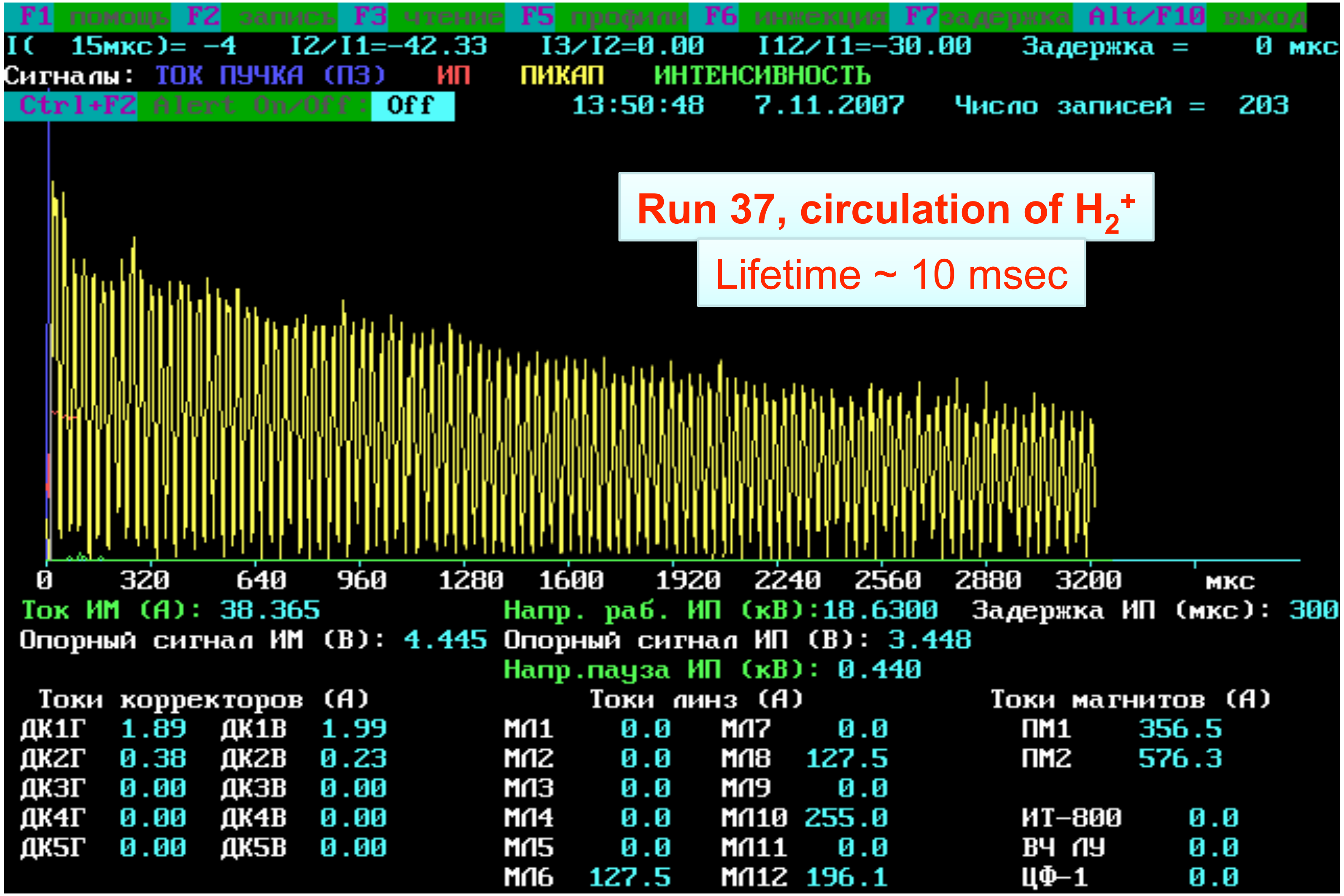


New (elliptical) pick-up station prototype for Nuclotron (GSI design).





Run 39, (circulation of H_2^+) – lifetime 100 msec, Average vacuum ~ 2*10-9 Torr (2009)



Crossection decay of H_2^+ ions on Nitrogen at Energy 5 MeV/n ~ 10^{-16} см^2

Before installation of new pumps av. vacuum at Nuclotron ~ (1-2)*10^{-8} Torr (2008)

Before modernization of the injection channel ~ 5*10-7 Torr (2006)

Since July’07 we performed 6 runs (# 37, 38, 39, 40, 41)

Results of the 41st run at Nuclotron 25 Feb - 25 March 2010:

Generated, accelerated Xe ions
(for the first time at Nuclotron !):
C (A=12, Z=4)
Xe (A=124, Z=42)

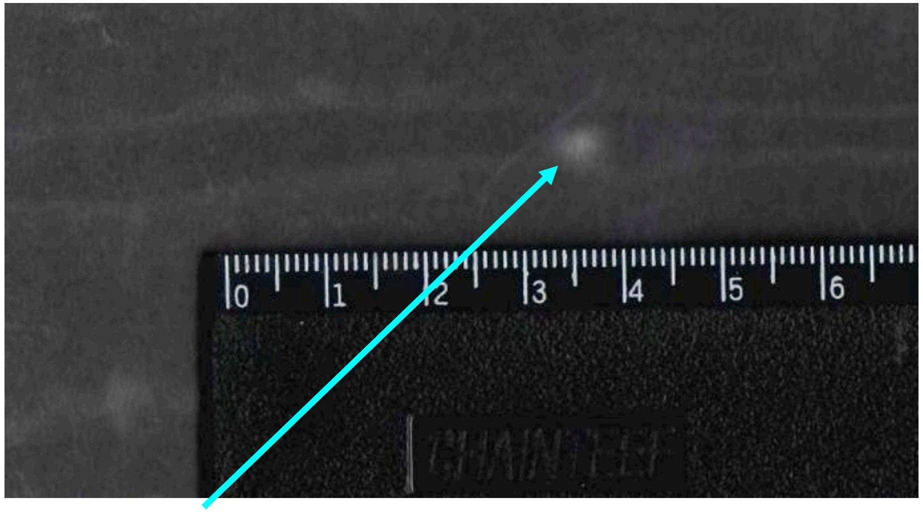
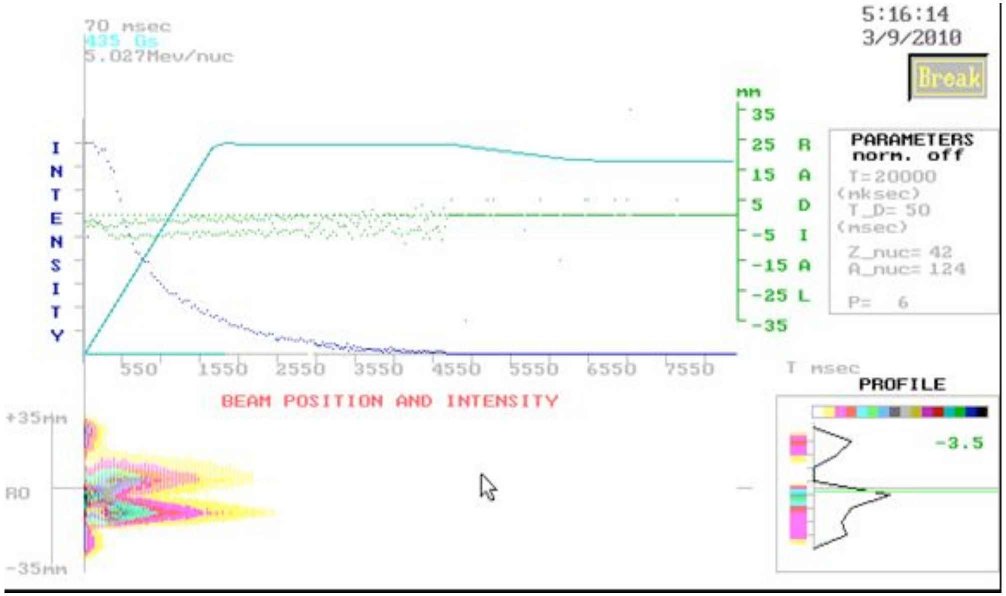


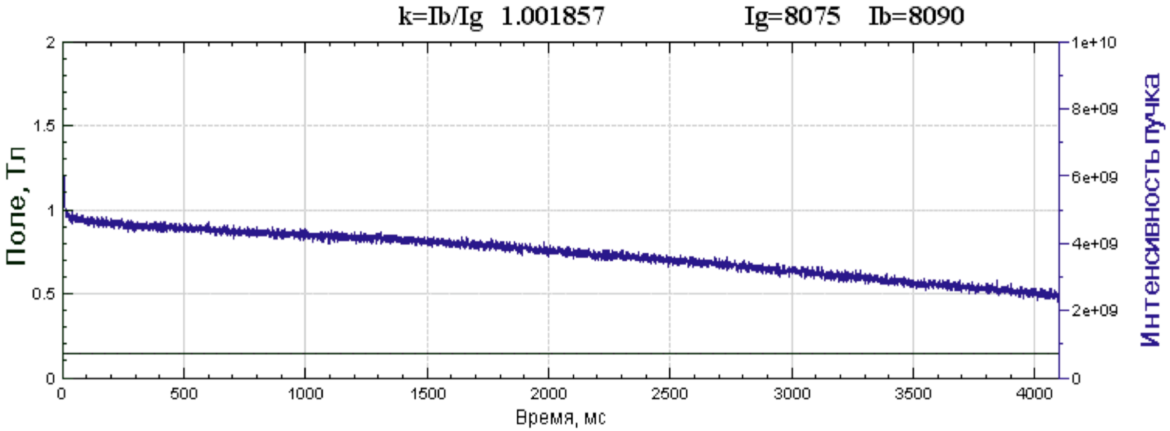
Image of the extracted Xe beam
(E = 0,6 GeV/) on photoplate

Signal of the Xe beam from low-intensity detector at the ring



Xe beam (A=124, Z=42+) was accelerated (10^6 i) up to 570 MeV/n & 1 GeV/n, and succesfully extracted (10^4 i).

Beam losses



$$P = \frac{1}{2.69 \cdot 10^{16} \cdot \sigma_{tot}(E) \cdot 3 \cdot 10^{10} \cdot \beta \cdot \tau_0}$$

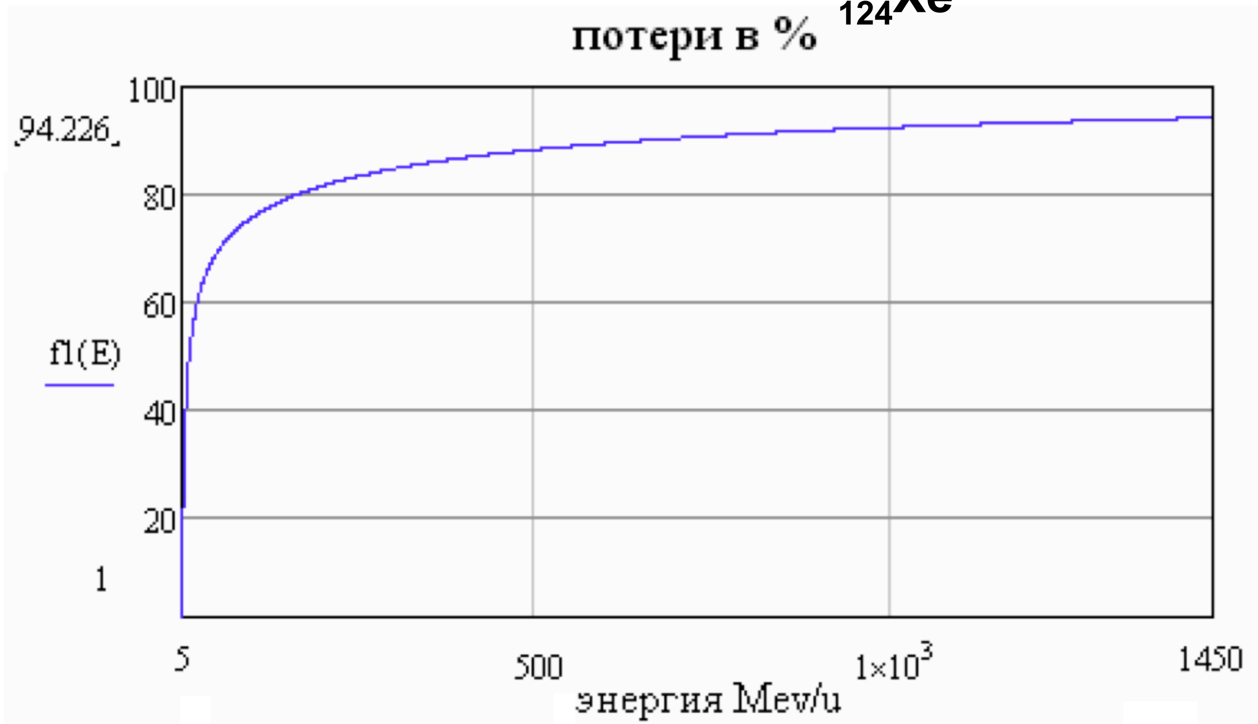
$$\Delta\varepsilon_{k\sigma} \approx 0.14 k^2 \frac{q_p^2}{A_p^2} \overline{\beta}_x \frac{Pt}{\beta_p^3 \gamma_p^2}$$

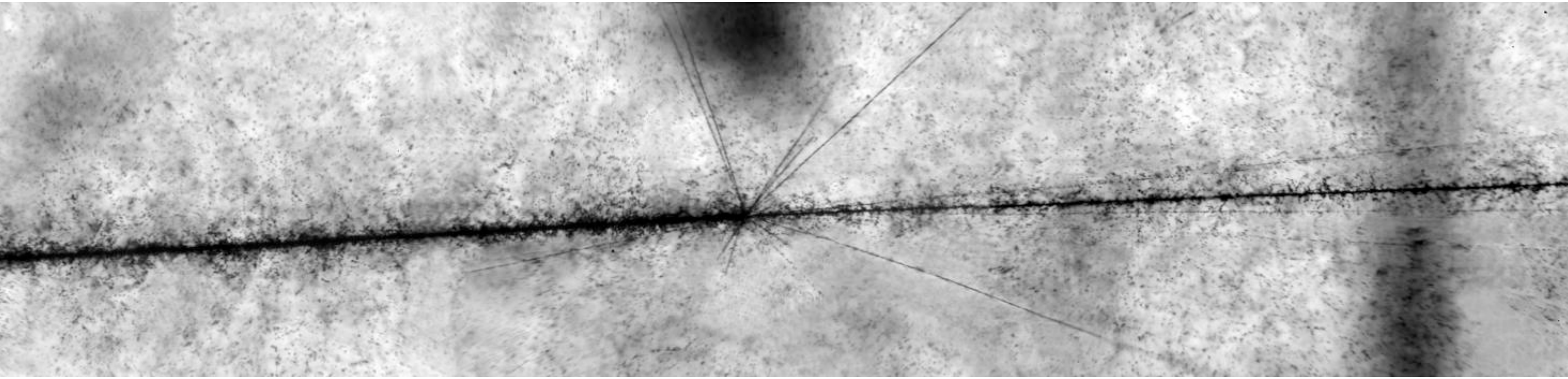
Beam emittance growth on residual gas (multiple scatt.)

$$\sigma = \int_{\Theta_0}^{\Theta_{max}} \frac{d\sigma}{d\Omega} d\Omega = \frac{2\pi r_p^2 (Z_i / A)^2 Z_t}{\beta^3 \gamma^2 \Theta_0^2}$$

losses on residual gas (single scattering)

$^{124}Xe^{42+}$



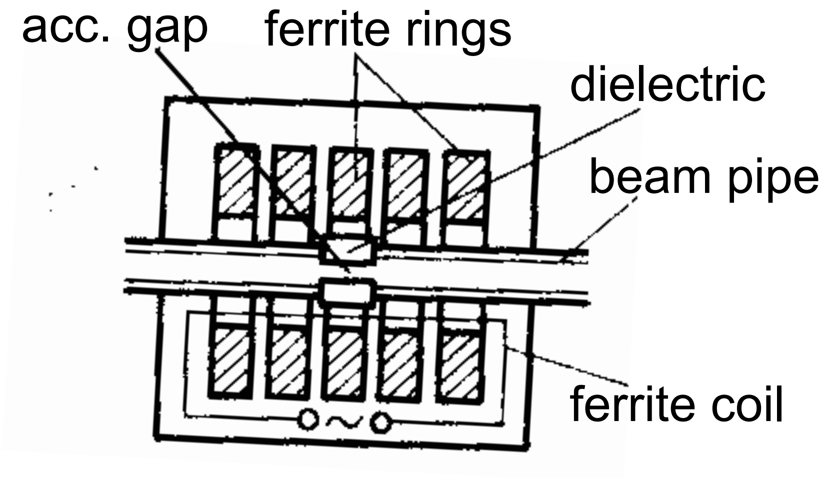


Xe (1 Gev/n) trace on photoemulsion
(experiment “Becquerel”)

RF system modernization

Nuclotron has 2 RF stations. T = 40K.

F0 .. Fmax = 0,5 MHz .. 5 MHz



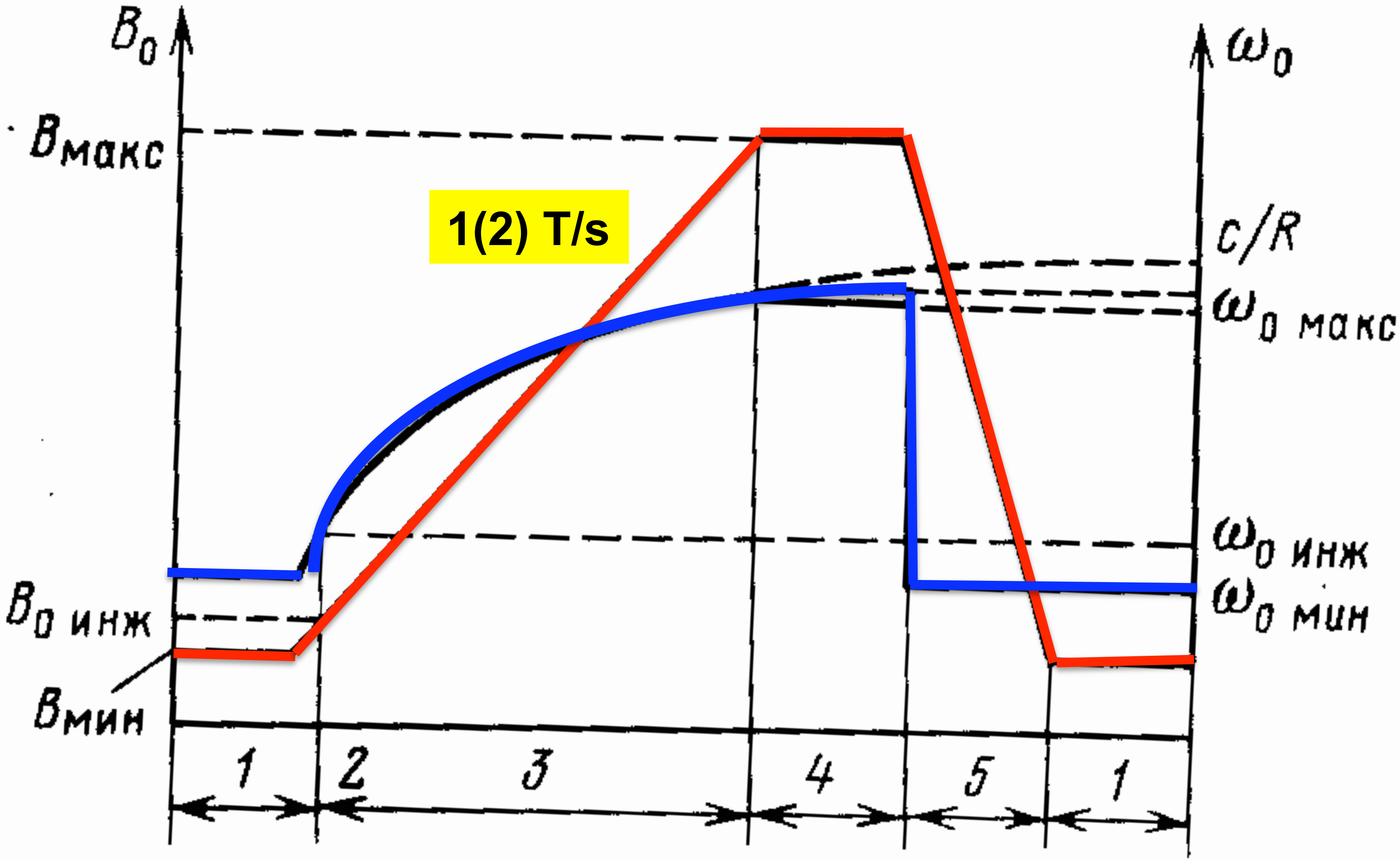
- existing pick-up stations were totally revised and experimentally tested at room and He temperatures.

- Special shielding for the both RF stations and plugs of HV cables to this station were manufactured and installed in a tunnel. This allows to decrease noise from RF on the beam signal by factor of 10-15**;**

- Created the new control system of RF and B (magnetic field) synchronization with new digital synthesizer and accuracy of 0.01 Gauss;

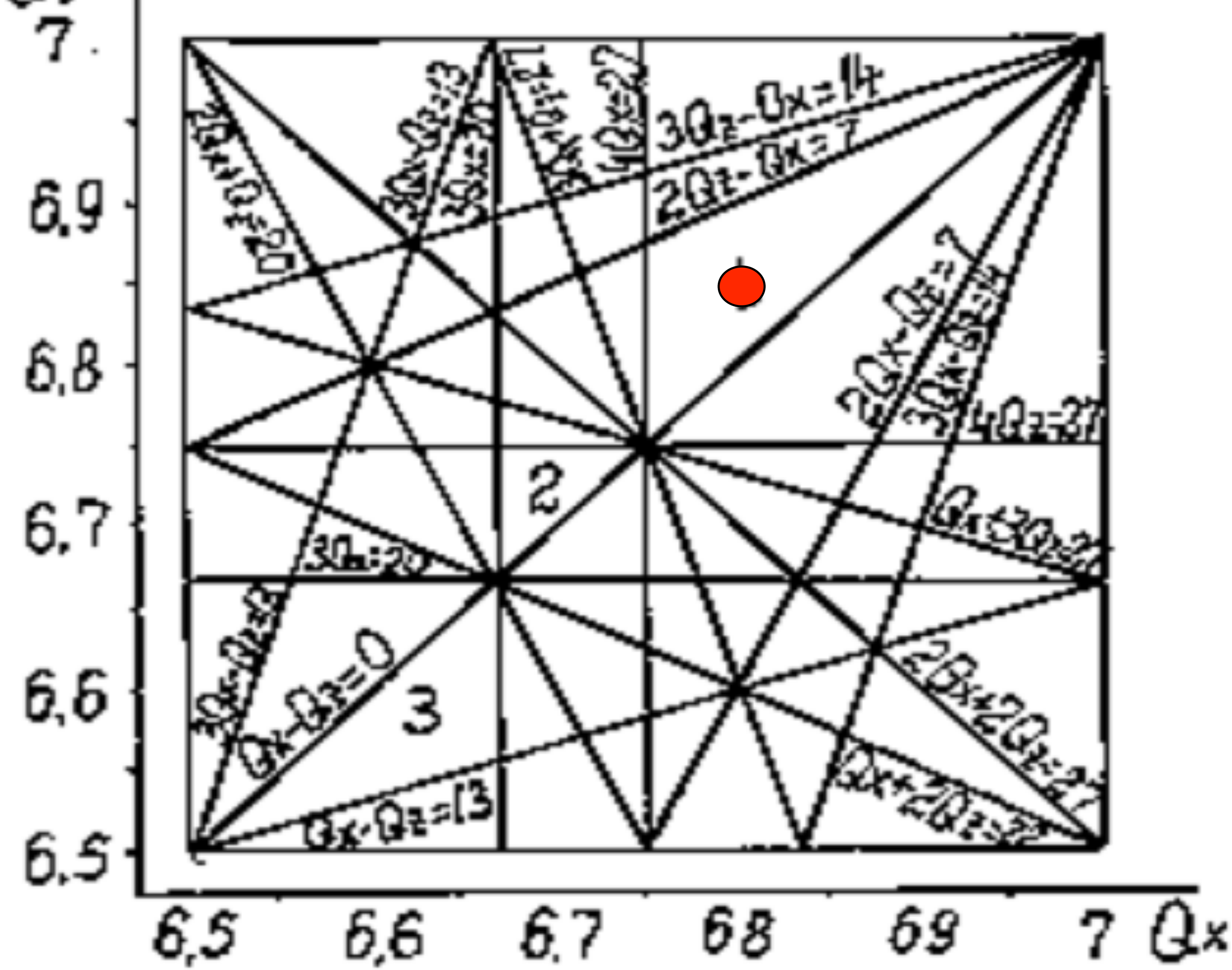
B field from 300 Gs (injection) up to 20000 Gs (max. acc) – **factor of 700**

RF frequency from 0,5 MHz (injection) up to 5 MHz (max. acc) – **factor of 10**

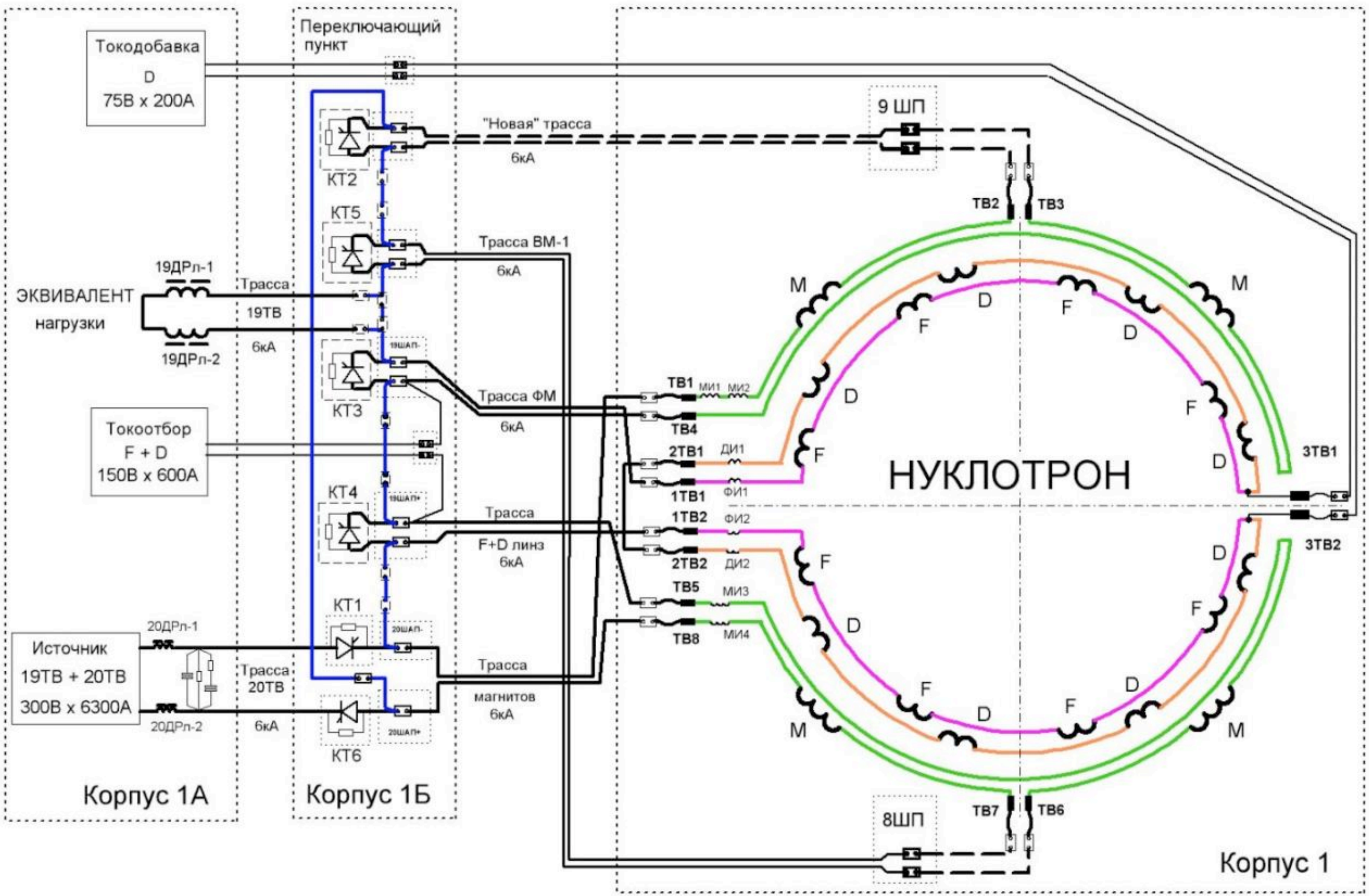


Accuracy for B etalon is - 0,01 Gs
Accuracy for RF (Δf/f) is 10^-5

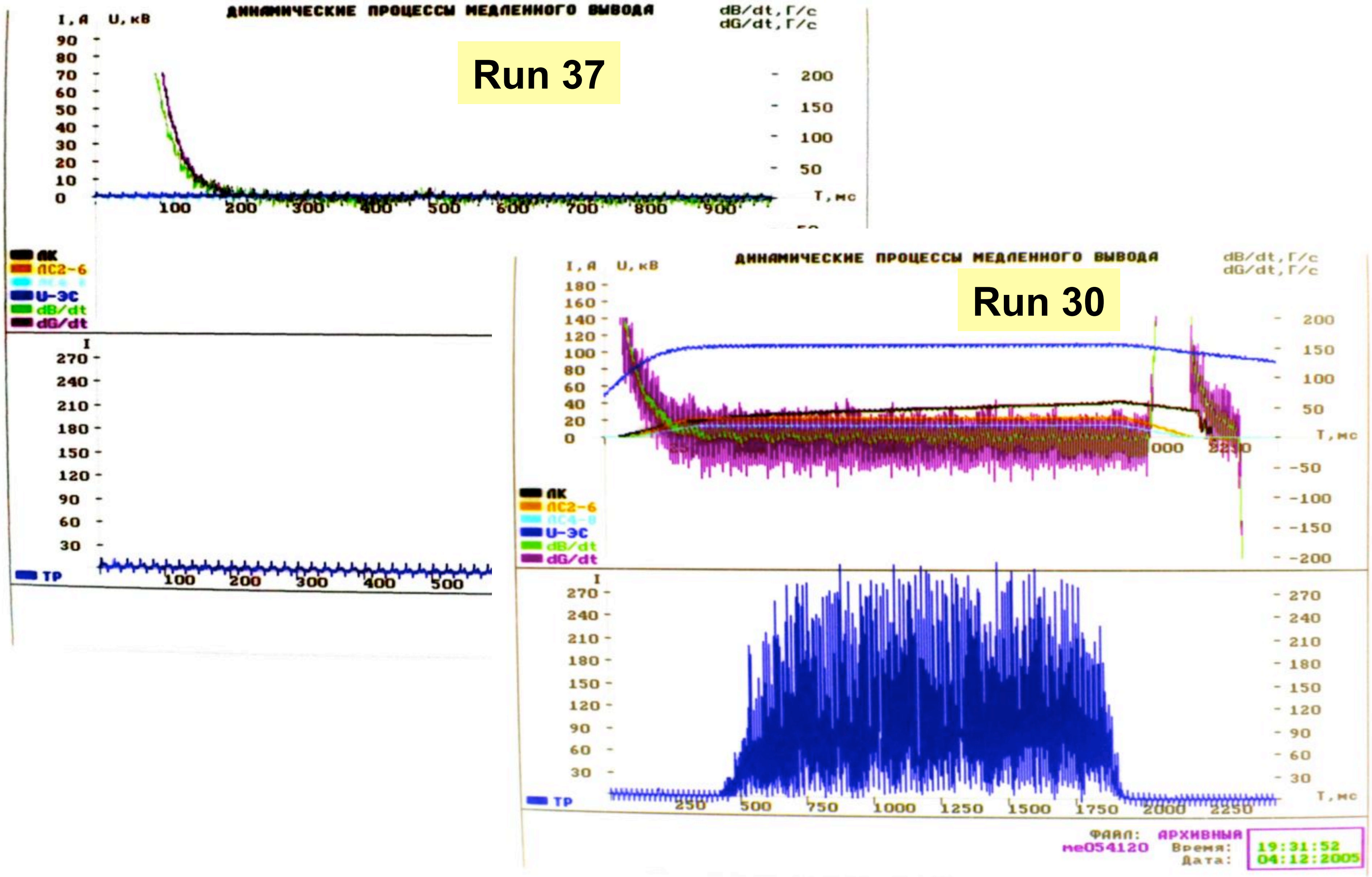
Required accuracy ΔQ is about 0,01 - 0,02



New layout of the power supply system



Decrease of the field ripple by factor of 10–15



Improvement of the power supplies, shielding and energy evacuation system of the magnets and lenses

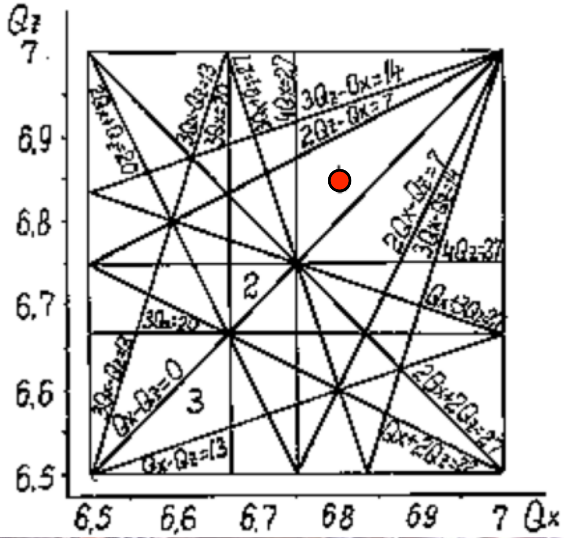
Run 41 (performed):

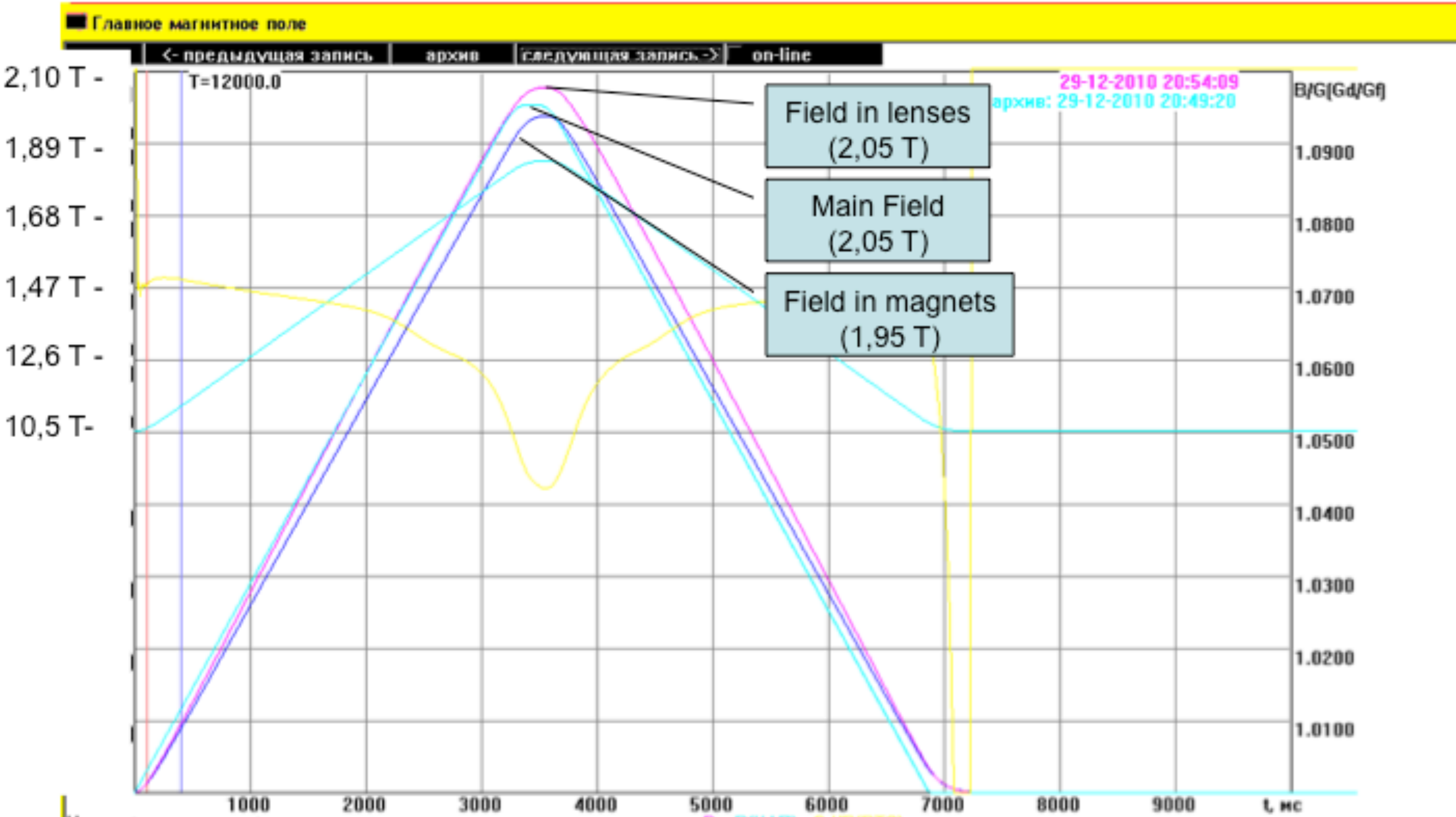
Very important stage – increase of the magnetic field in magnets and lenses from 1.5 up to 1.8 using special prototype of the energy evacuation system;

Next stage – field increase from 1.8 up 1.9 - 2T in the end of 2010 and full-scale commissionig of the new power supply system

- power supply for current increase in the F-lenses is under construction;
- new system for magnet field control;
- beam-bump power supply;

Full-scale modernization of the Nuclotron power supply system

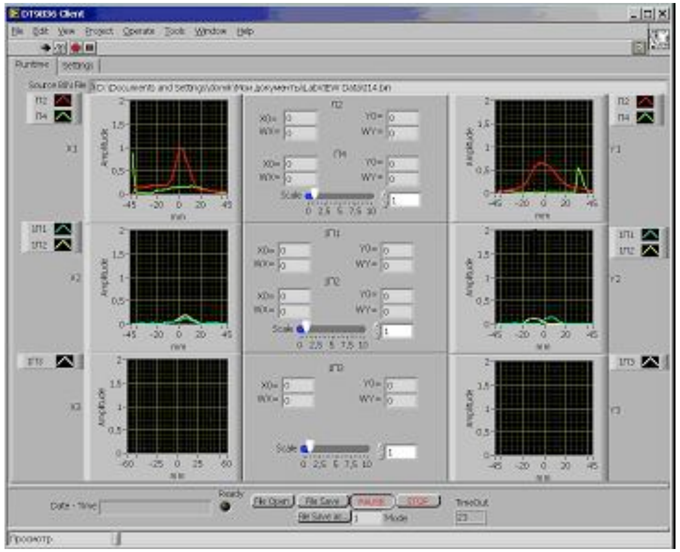




На график выдается: опорная функция реальное поле градиент D B[ЦАП] Gd/B[RTS]

t,мс	Гс - Bo	B	Gd	Gf	Gd-B	Gd-kB	мВ - Ub	Ug	Ib	Ig	Bo	B	G	kB	kB'	k
нюк. 113.2	677.5	289.0	309.4	249.7	20.4	20.4	1332.3	14.3	63.0	1.0	258.7	112.2	9730.3	8425.5	6899.8	1.00000
400.0	2423.6	1850.2	1981.7	0.0	131.5	131.5	1824.0	14.6	405.6	0.0	927.7	707.4	9700.0	8409.6	6905.5	1.00000
6517.0	2165.3	2681.6	2867.0	0.0	185.4	185.4	-1615.3	10.4	578.0	1.7	808.0	1003.9	9712.7	8422.2	6898.2	1.00000

Modernization of the automation system for control, beam diagnostics and monitoring of parameters of the accelerator complex.

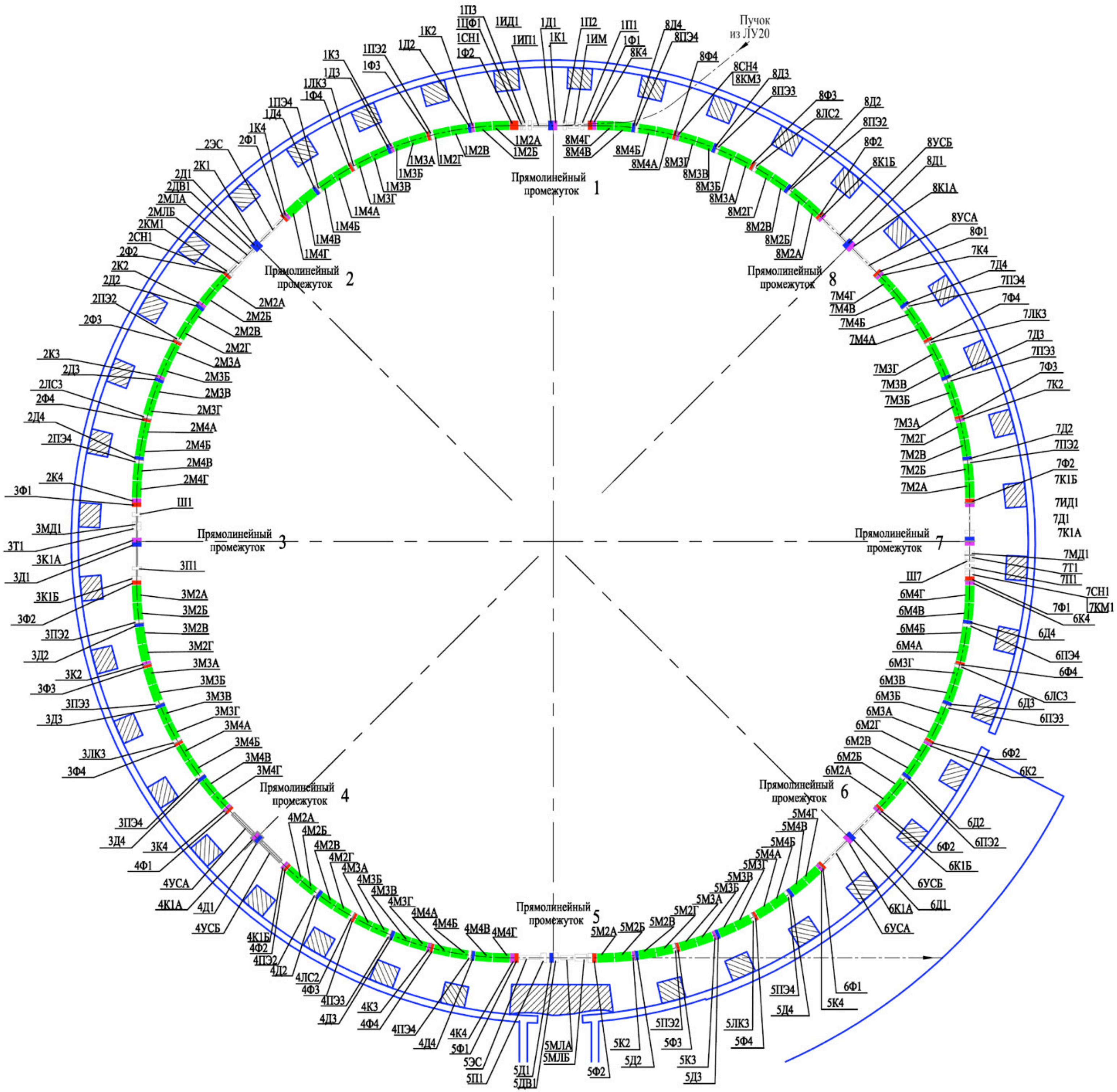


Automatic system “INJECTION”

Kit of new power supplies (130 A) for
Nuclotron correctors
Collaboration with Slovakia

32 correctors in the ring

One of 30 chips (hi-tech) for automatic
System for beam orbit measurement


Пучок из ЛУ20
Прямолинейный промежуток 1
Прямолинейный промежуток 2
Прямолинейный промежуток 3
Прямолинейный промежуток 4
Прямолинейный промежуток 5
Прямолинейный промежуток 6
Прямолинейный промежуток 7
Прямолинейный промежуток 8
1П3
1ЦФ1
1СН1
1Ф2
1ИД1
1ИП1
1Д1
1К1
1П2
1ИМ
1П1
1Ф1
8К4
8Д4
8ПЭ4
8Ф4
8СН4
8КМ3
8Д3
8ПЭ3
8Ф3
8ЛС2
8Д2
8ПЭ2
8Ф2
8К1Б
8УСБ
8Д1
8К1А
8УСА
8Ф1
1К2
1Д2
1ПЭ2
1Ф3
1К3
1Д3
1ЛК3
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2ЭС
2К1
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2ДВ1
2МЛА
2МЛБ
2КМ1
2СН1
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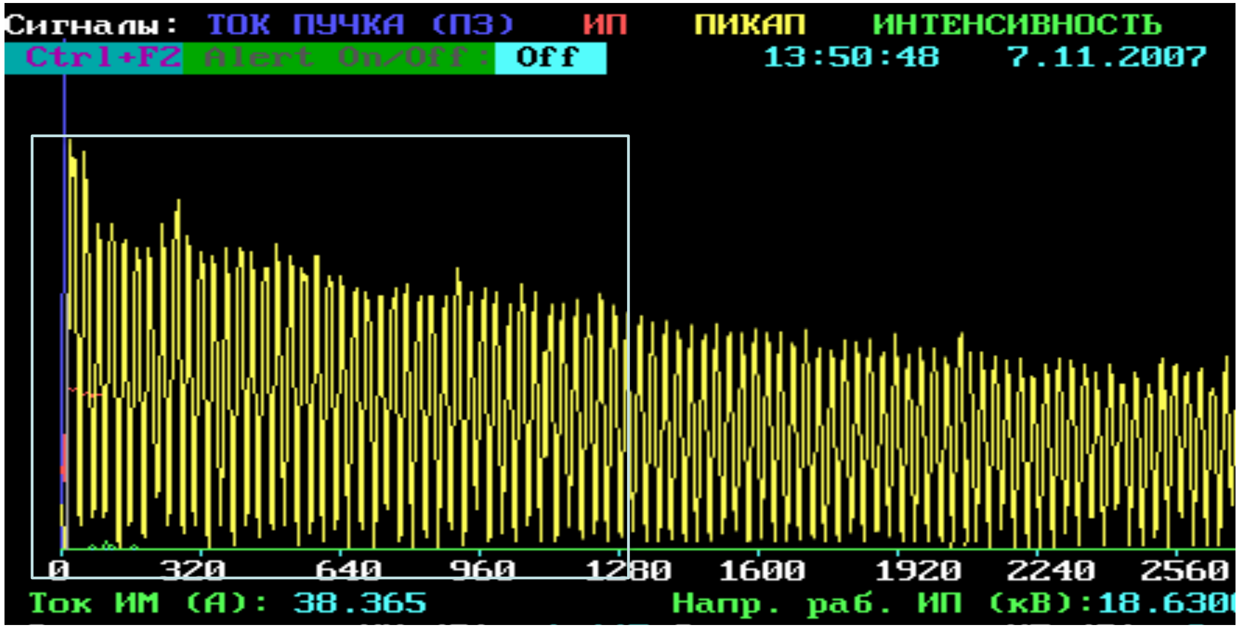
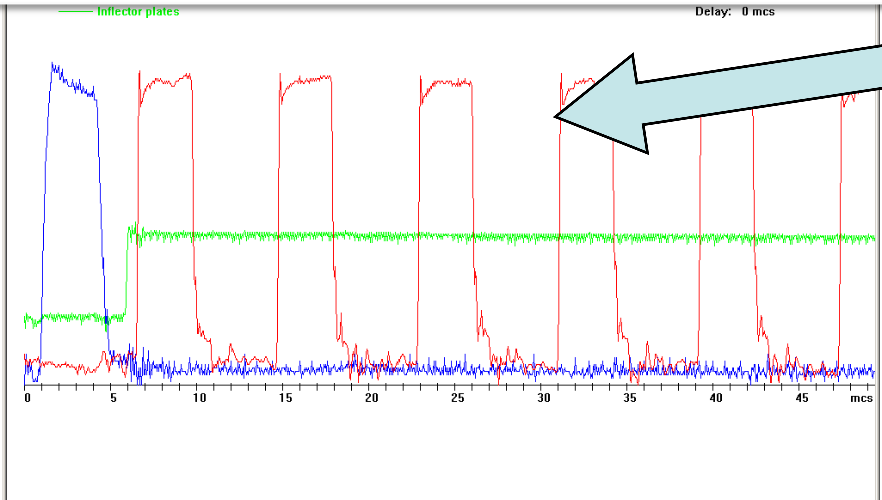
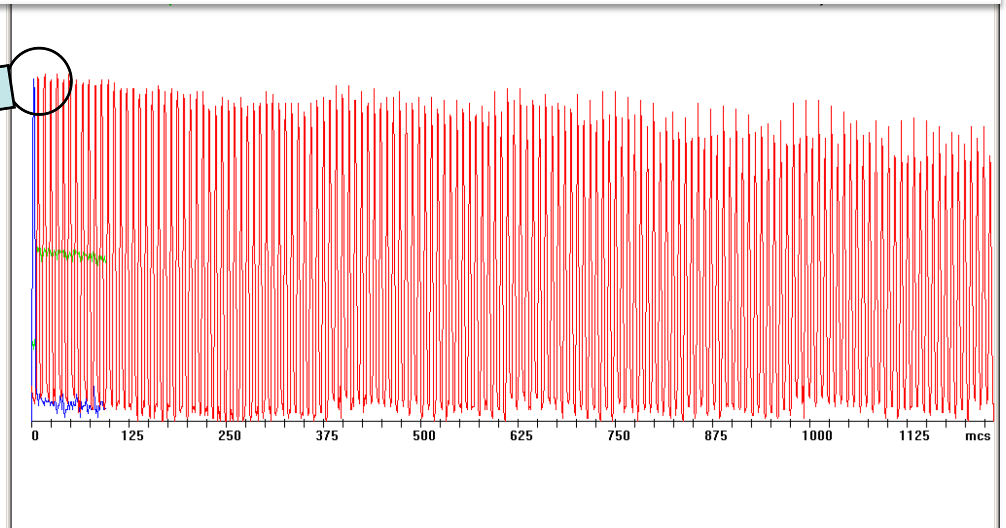


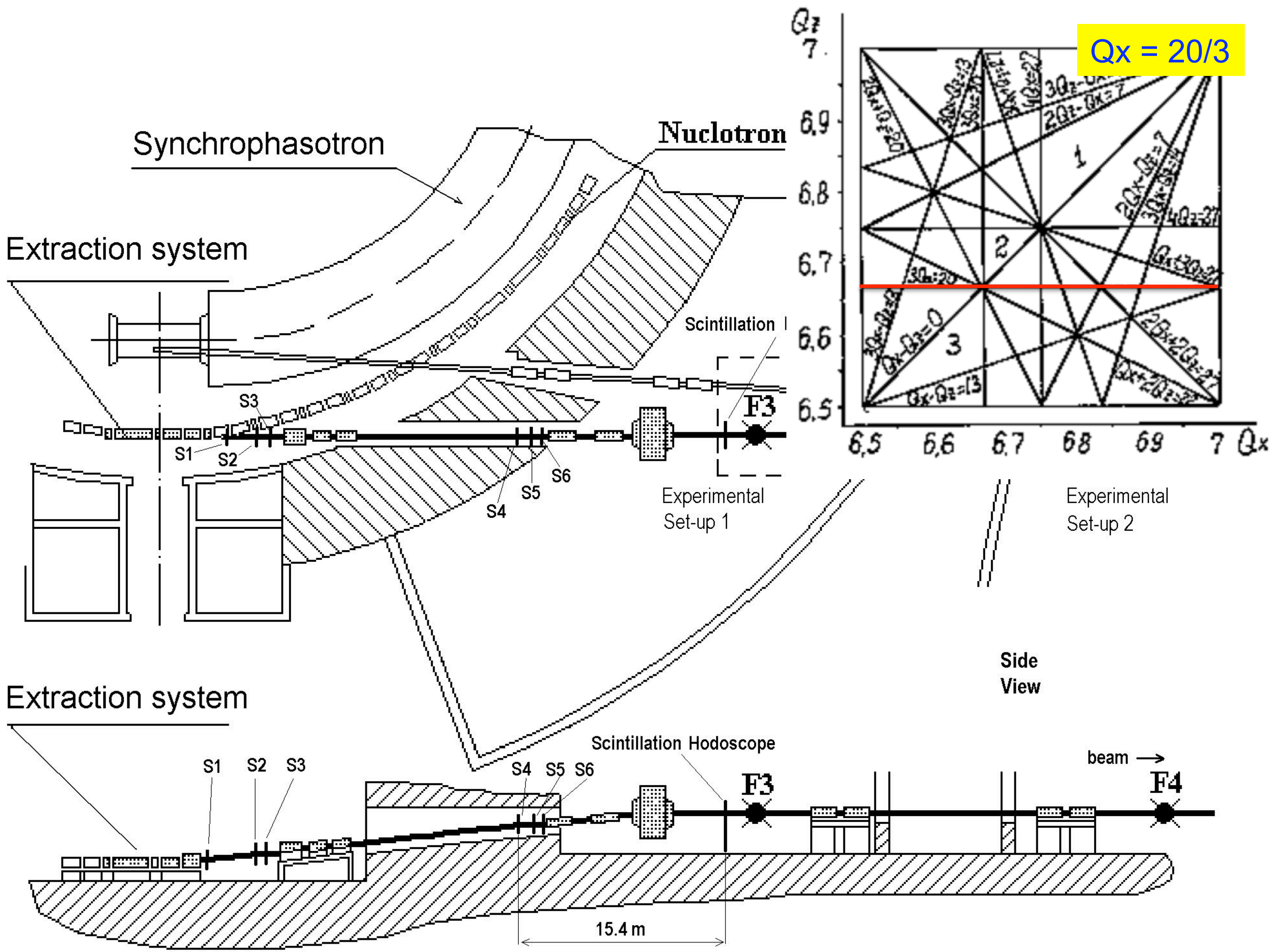
First 6 revolutions (about 50 µs) of the deuteron beam in the ring after the orbit correction: Blue line is the injected beam intensity from LU-20, red line: the pick-up signal



Revolutions (about 50 µs) of the deuteron beam in the ring after the orbit correction: during 1.150 ms. Slight increase of the pick-up signal is related with the beam debunching. **December 2010**



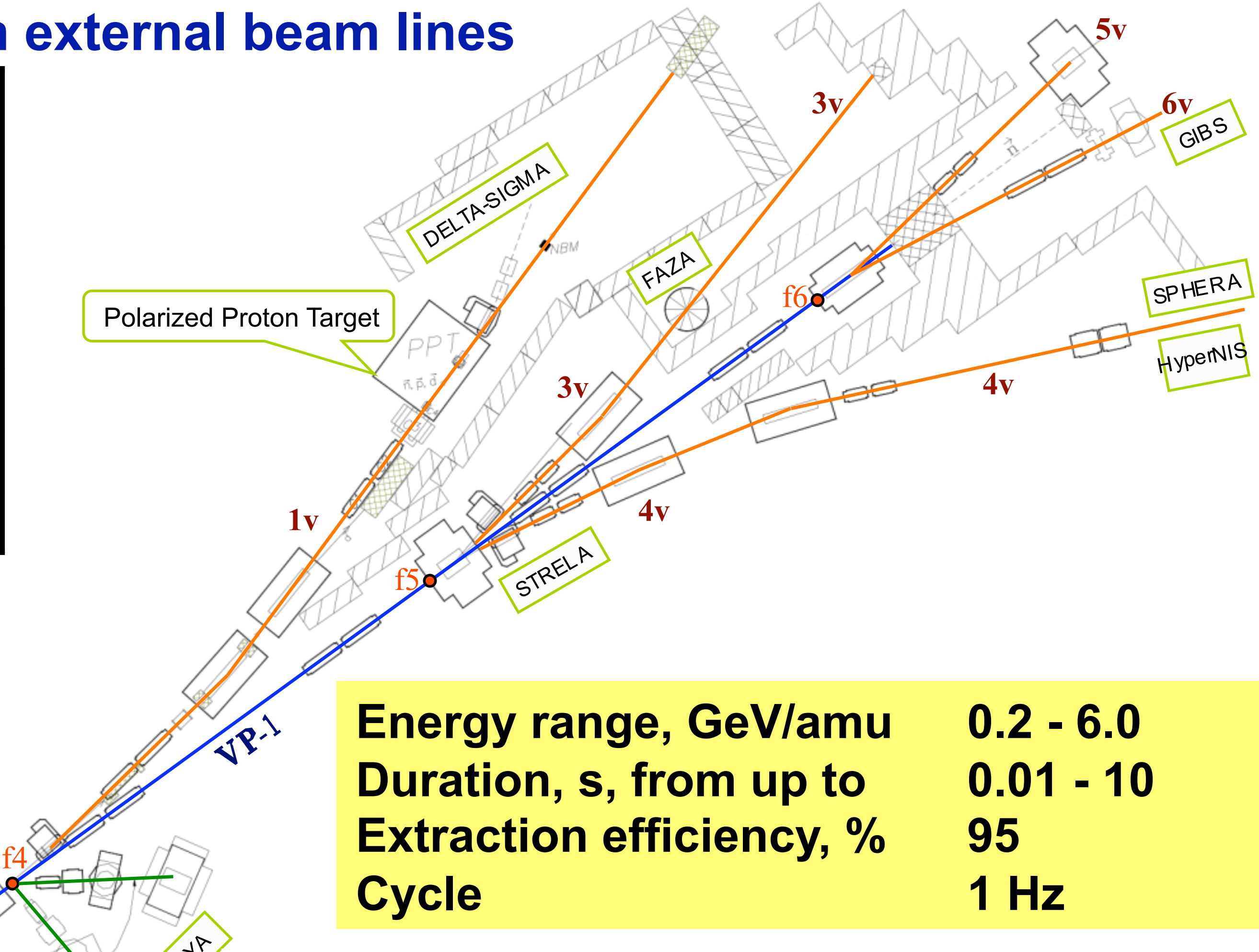
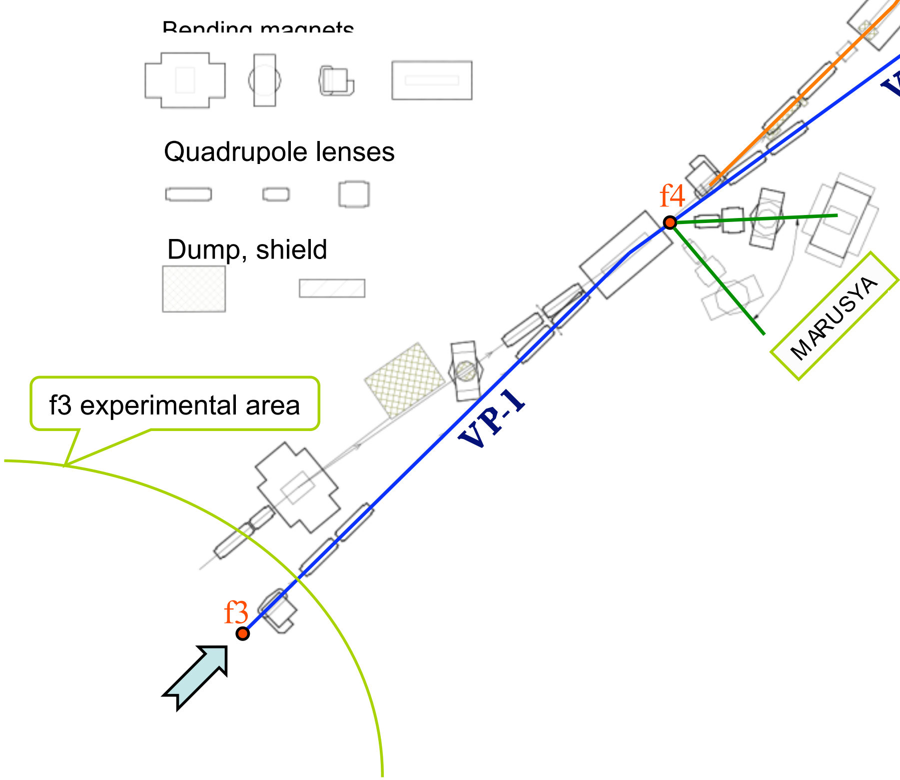
One of the most importatnt results of 42nd run: decrease of particle losses at injection. Now 30%, before 70%



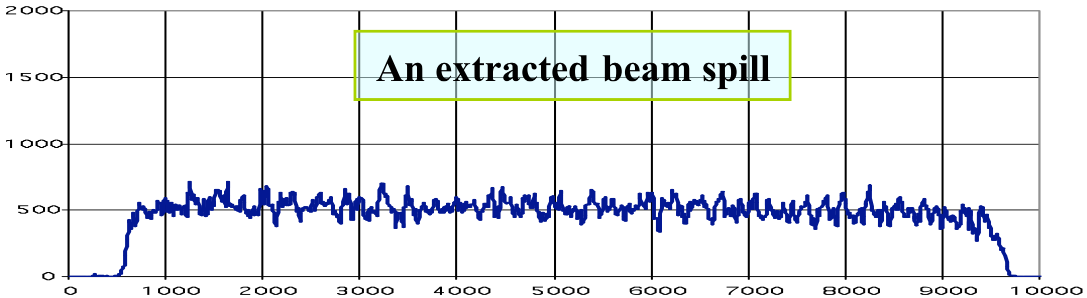
Qx = 20/3
Qz
7
6,9
6,8
6,7
6,6
6,5
6,5
6,6
6,7
6,8
6,9
7
Qx
1
2
3
Synchrophasotron
Nuclotron
Extraction system
Scintillation
F3
S1
S2
S3
S4
S5
S6
Experimental
Set-up 1
Experimental
Set-up 2
Side
View
Extraction system
Scintillation Hodoscope
S1
S2
S3
S4
S5
S6
F3
beam
F4
15.4 m

Nuclotron external beam lines

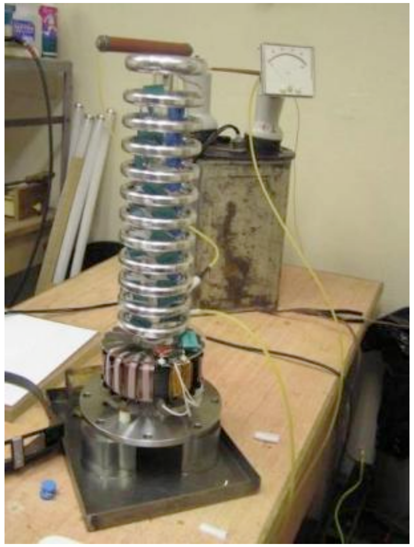
Parameter	Value
Momentum range (z/A=1/2), GeV/c/u	0.6 – 6.8
Momentum spread, σ	0.04 – 0.08
Extraction time ,s	10
Beam emittance (max)	2π
Beam size in a waist, σ	≤ 1
Extraction efficiency,%	> 90

Energy range, GeV/amu	**0.2 - 6.0**
Duration, s, from up to	**0.01 - 10**
Extraction efficiency, %	**95**
Cycle	**1 Hz**



Beam slow extraction system at maximum energy (V. Volkov)



Prototype of new high voltage power supply for the electro-static septum was constructed and successfully tested up to **220 kV** (existing septum power supply allows up to 110 kV only – it corresponds to 2,3 GeV/n extracted beam).

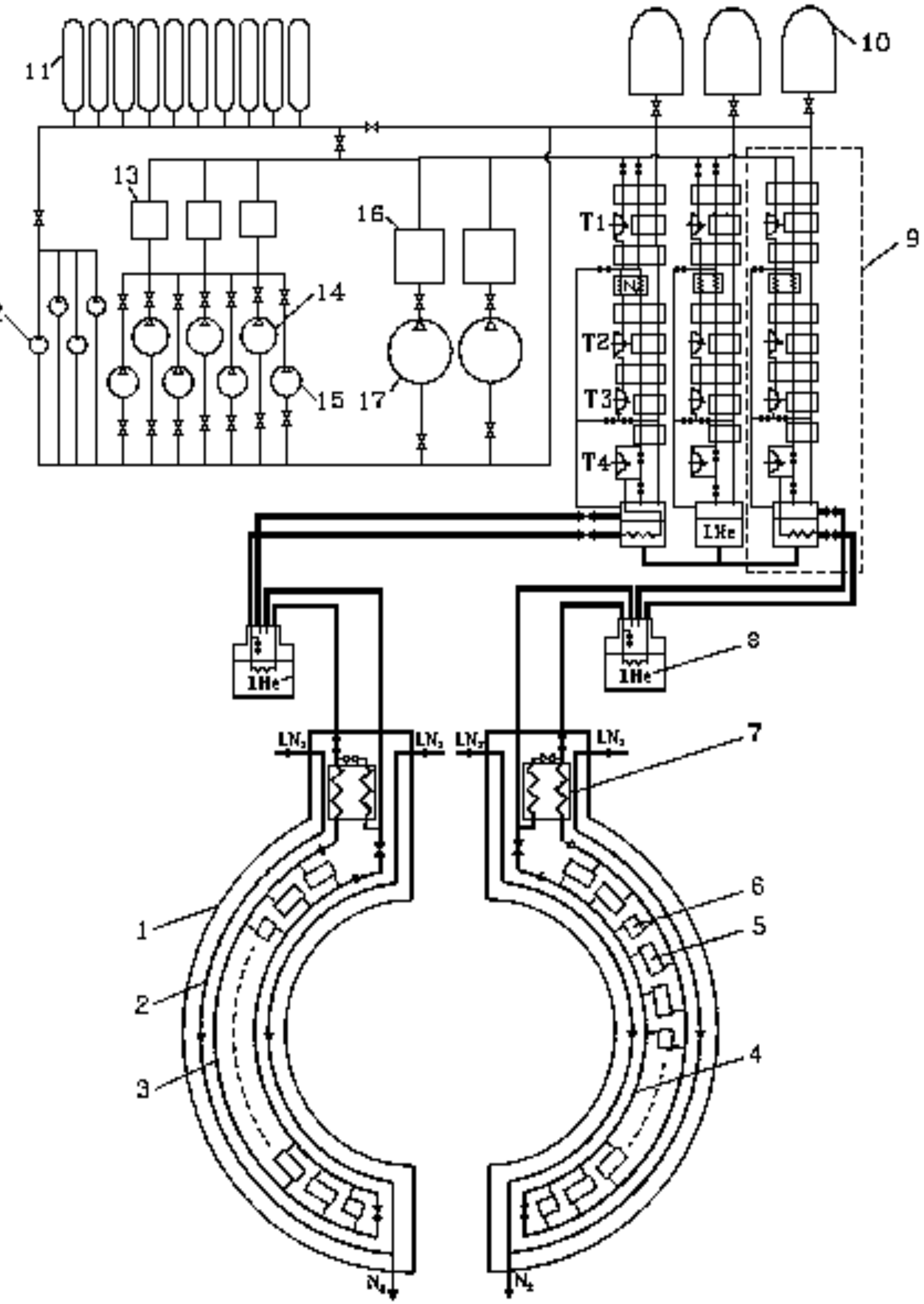
We plan to install it in the slow extraction sector in order to provide experiments on beam extraction at energy 4 GeV/n during next Nuclotron run - **done (tested at 150 kV).**

Modernization of the cryogenic system

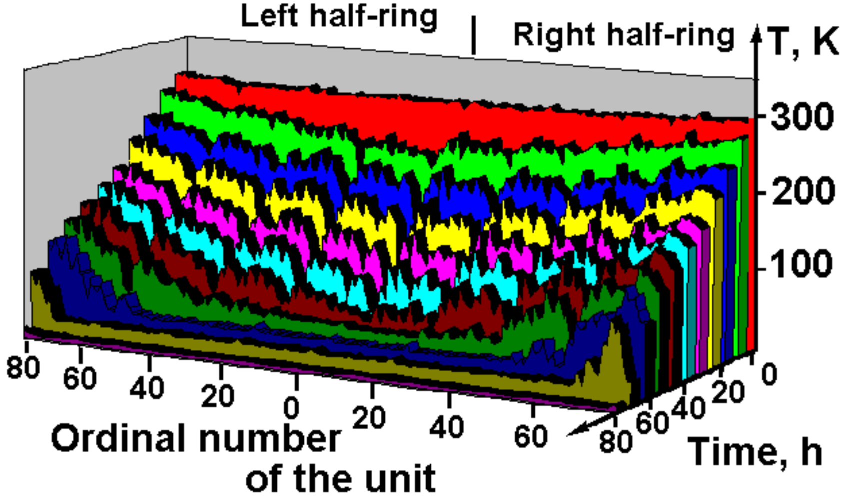
Design and construction of the system for diagnostic and compute control of the existing helium refrigerators KGU-1600/4.5 and all helium circuit;

Design, construction and put into operation the system for re-condensation of a cold gaseous nitrogen evaporated after cooling heat screens of the Nuclotron ring cryogenic modules; - factor 2-3 o economical efficiency

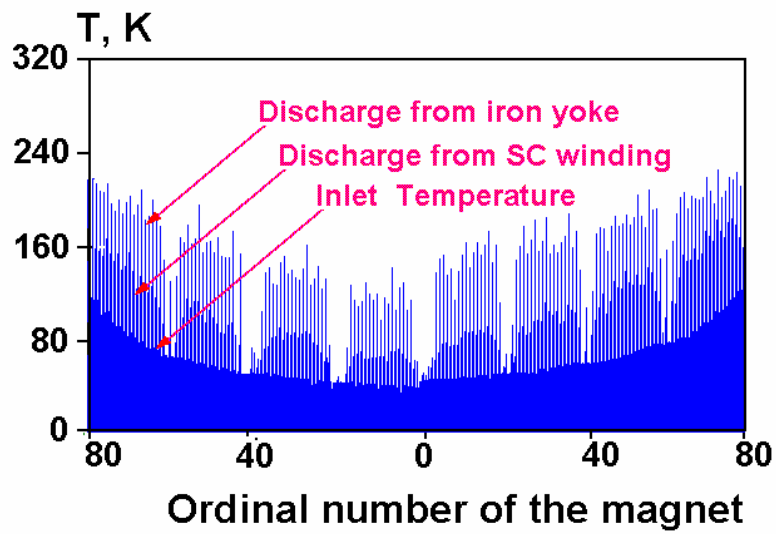
Reparation and partial replacement of the cryogenic equipment that have exceeded tolerable operation period.

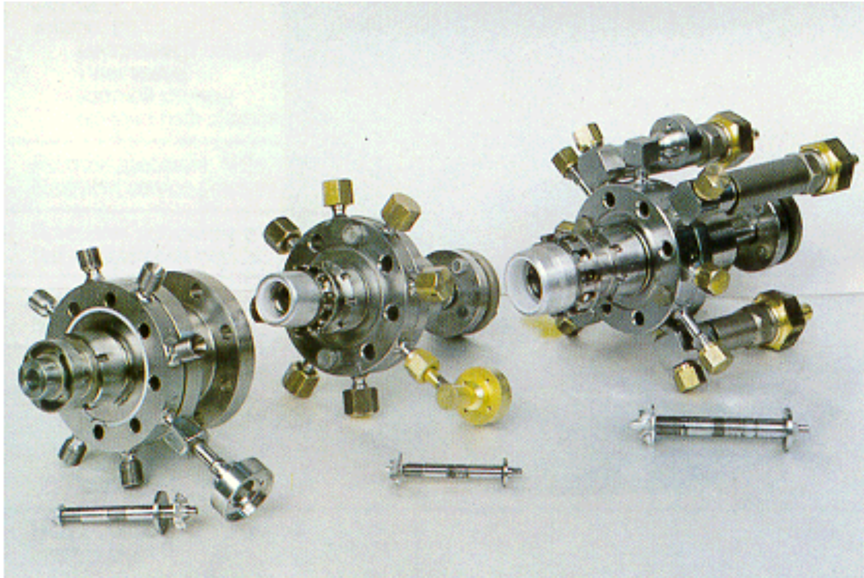


RING COOLING-DOWN EVOLUTION



Temperature distribution of the helium cooling gas (30 hours after starting)





“Wet” turboexpanders (frequency 300000 turns/min)

Total revision and modernization of cryo-plant:
- oil-absorbing filters exchange and refilling
- He tanks and cylinders reconstruction
- cleaning of the pipe-lines
- renovation of turbo-expanders kit

Will sufficiently allow to work stable and to economy liquid Nitrogen and He

Personnel of JINR and HELIIMASH during dismountig works at KGU-1600/4.5

Upgrade of the cryogenic supply system and cryogenics power increasing towards NICA

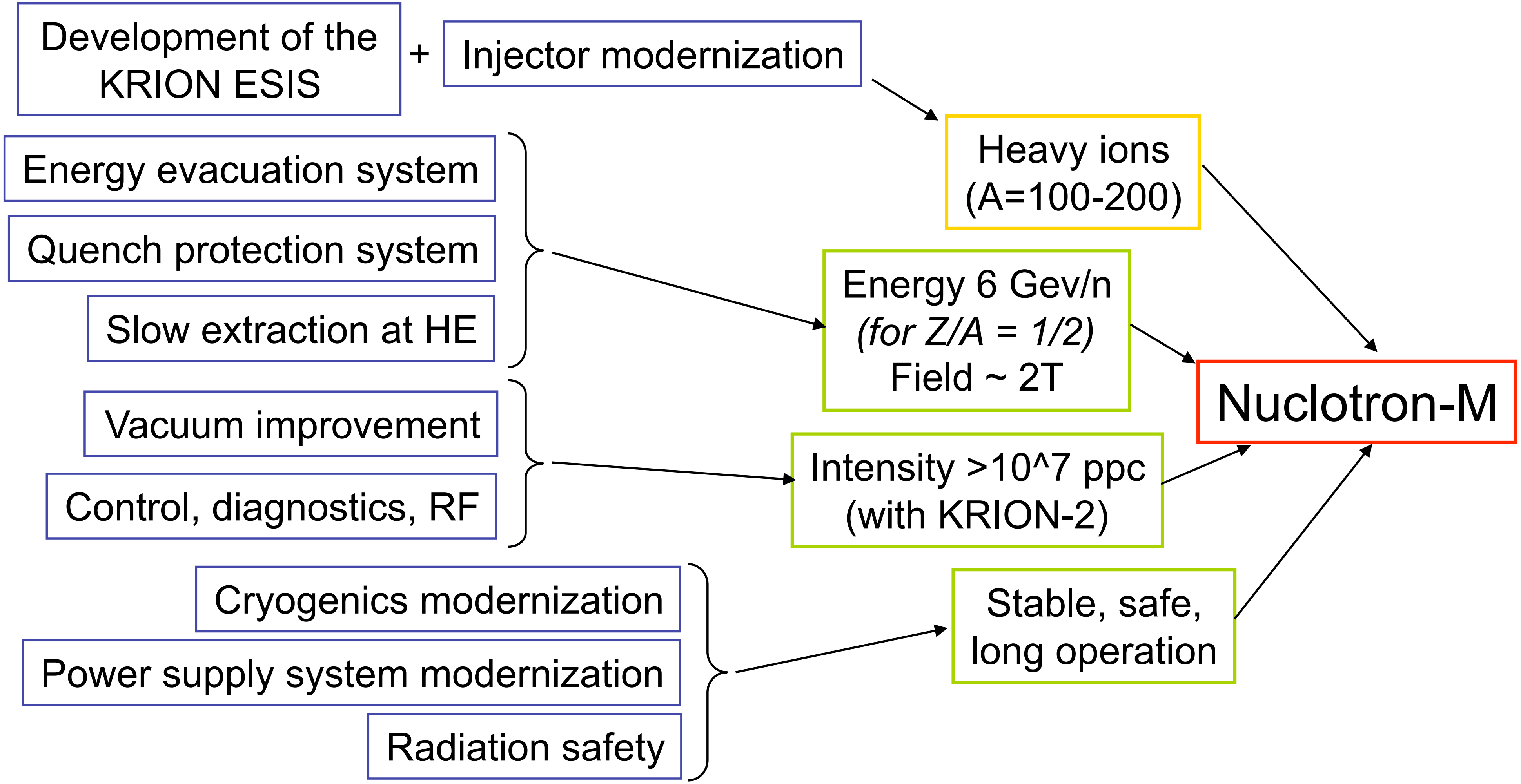
Additional screw compressor for helium (6000m^3/h) - from HELIIMASH
Succesfully commissioned and used during run #41 (step towards NICA)

Resource saving:

In winter 2010 we modernized Nitrogen liquefying plant and decreased cost by 24%

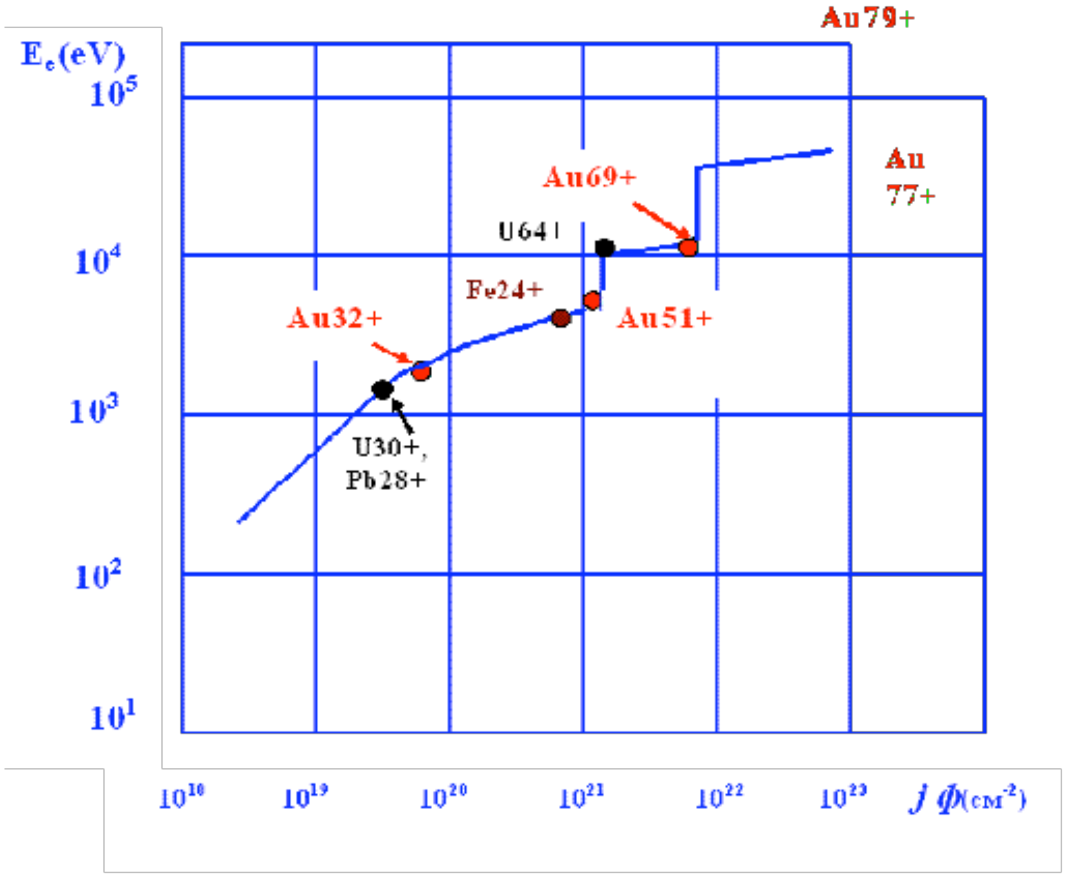
During summer 2010 we continued upgrade of the Plant and have additional 15-20% of LN cost saving.

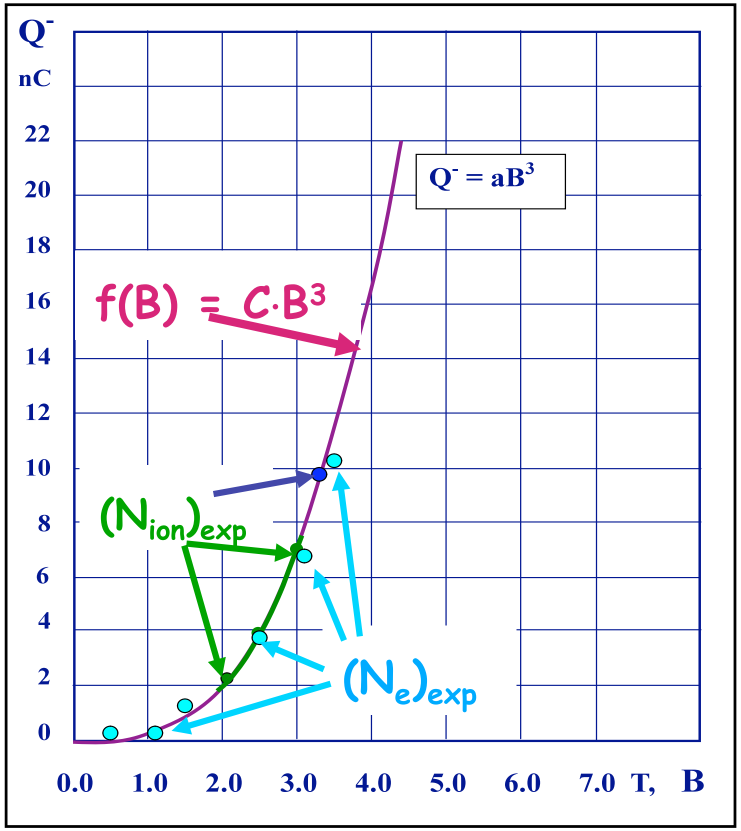
For info: during 1 month run LN consumption of Nuclotron is ~ 250 tons, 1 ton = 10000 rub.



Nuclotron-M beams in 2010 and further (until NICA commissioning):

- Deutrons, protons – development of existing physics program + appl. research
- Light ions – hypernuclei, applied research (medicine, radiobiology, etc)
- Heavy ions – R&D for detector elements, key accelerator technologies for NICA (stripping, fast injection/extraction, cooling, electron clouds effect, etc)
- Polarized deutrons from new intense source (polarimetry, etc.)



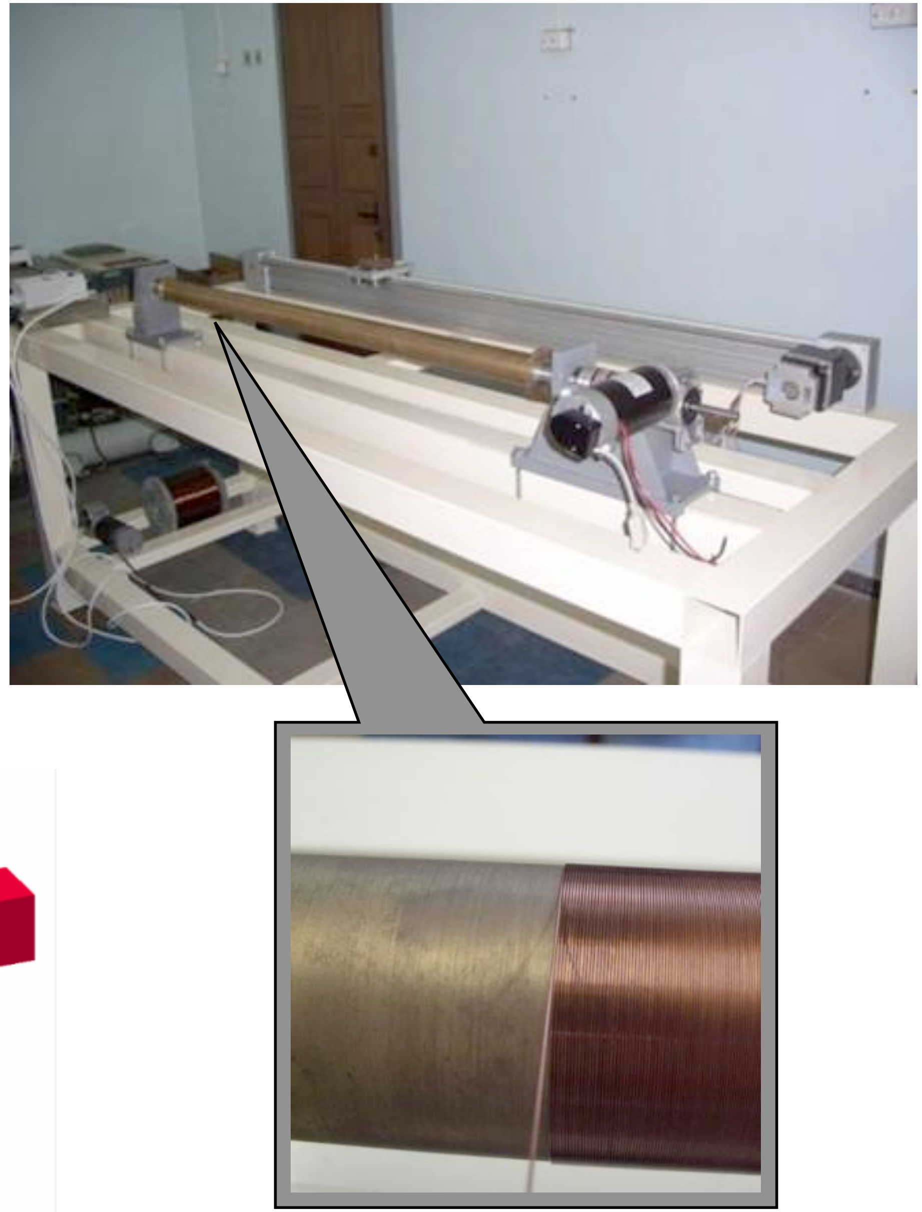


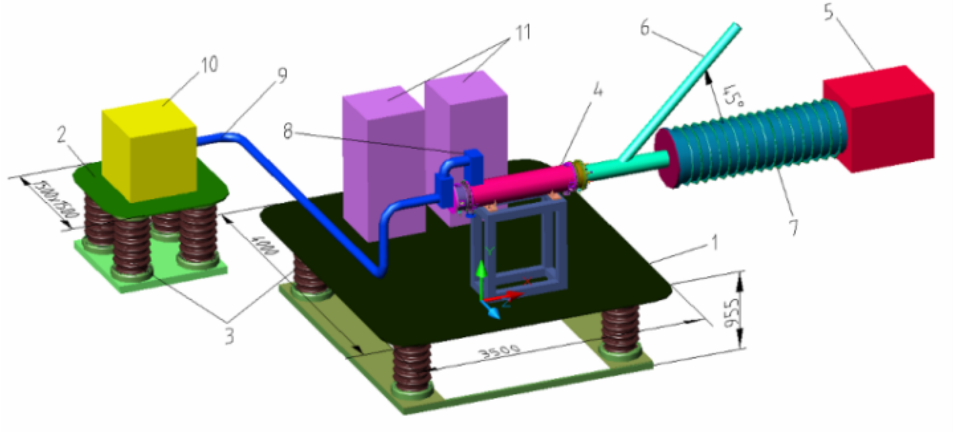
New ESIS "KRION-6T":
$B \leq 6.0$ T,
$E_e \leq 25$ keV

Ions	Au^{32+} (U^{32+})	Au^{51+} (U^{64+}) (with use of ion-ion cooling)	Au^{69+} (with use of ion-ion cooling)
Ionization time, τ, s	0.015	0.75	5.0
Work frequency, Hz	0.5	40	0.2
Total number of ions per pulse (at a given charge states)	$2\cdot10^9$	$5\cdot10^8$	$3\cdot10^8$
Extraction time, µs	6 - 8	6 - 8	6 - 8

E.D. Donets et al.,
Rev. Sci. Instr. 75, (2004)

Assembled vacuum and cryogenic vessels of the new source KRION-6T; New automatic machine tool for solenoid coil spooling.



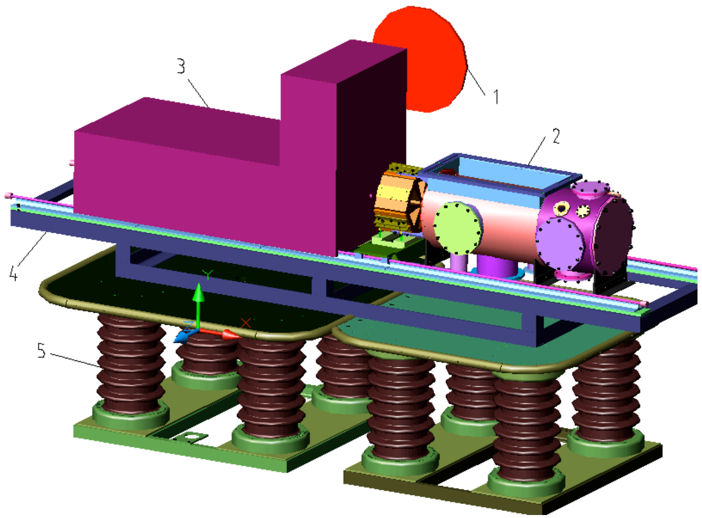


Development and creation of a high-intensity polarized deuteron source (V. Fimushkin)

We continue collaboration works with INR (Troitsk) on the development of the new high-intensity polarized deuteron source, and signed an addendum for work prolongation in 2009. We plan to start commissioning of the source elements in 2010 at JINR.

Simulation, modeling and design of different elements of the future source are in active phase at LHEP. Experimental hall for the future test bench with that source is prepared at LHEP building 203A, preparation electrical and water-cooling works were performed.

It is planned to purchase part of necessary vacuum equipment (TMN pumps) for the SPD realization in 2009 **– done.**



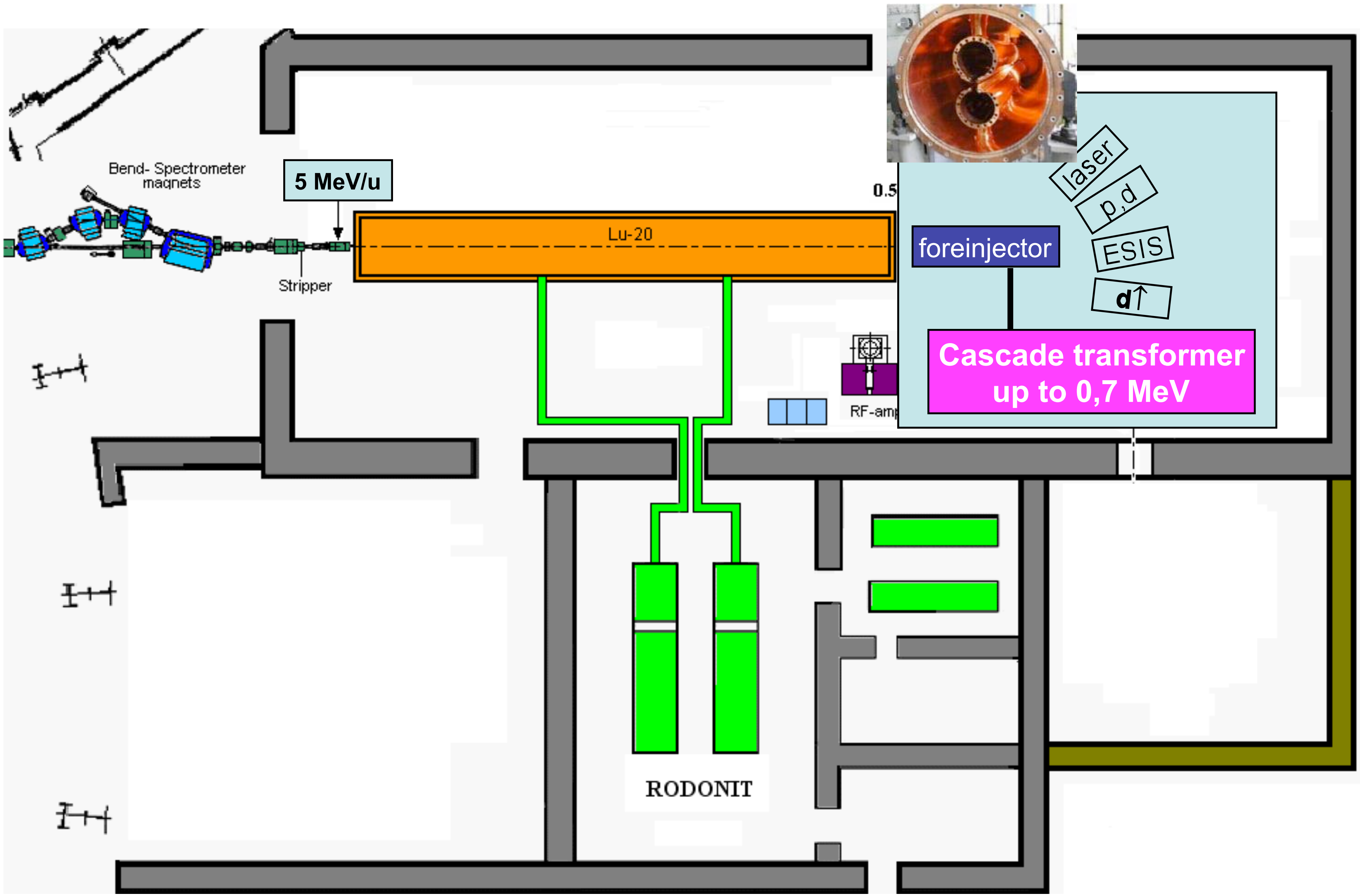
Вакуумная камера диссоциатора и постоянных шестиполюсных магнитов

Вакуумная камера масс-спектрометра

Течеискатель ТИ-14А

Турбомолекулярный насос V3-KT

Баллоны 5л для дейтерия и кислорода

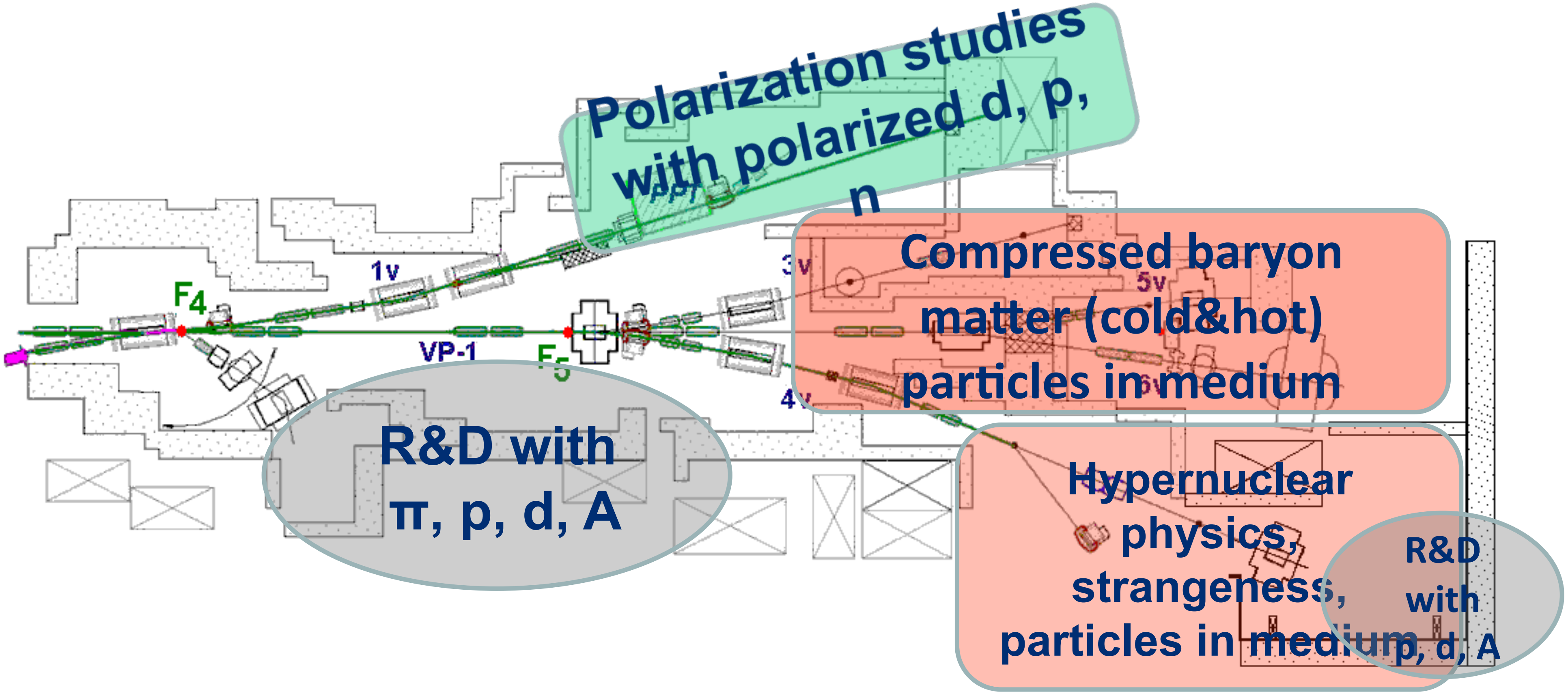

Bend- Spectrometer magnets
5 MeV/u
Lu-20
Stripper
0.5
foreinjector
laser
p,d
ESIS
d↑
Cascade transformer up to 0,7 MeV
RF-amp
RODONIT

Beam	Nuclotron beam intensity, particles per cycle				
	Current	*Ion source type*	*Nuclotron-M (2010)*	*Nuclotron-N (2012)*	*New ion source + booster (2014)*
p	$3 \cdot 10^{10}$	Duoplasmotron	$8 \cdot 10^{10}$	$5 \cdot 10^{11}$	$5 \cdot 10^{12}$
d	$3 \cdot 10^{10}$	--- ,, ---	$8 \cdot 10^{10}$	$5 \cdot 10^{11}$	$5 \cdot 10^{12}$
^{4}He	$6 \cdot 10^{8}$	--- ,, ---	$2 \cdot 10^{9}$	$3 \cdot 10^{10}$	$1 \cdot 10^{12}$
d↑	$2 \cdot 10^{8}$	ABS ("Polaris")	$2 \cdot 10^{8}$	$7 \cdot 10^{10}$ *(SPI)*	$7 \cdot 10^{10}$ *(SPI)*
^{7}Li	$2 \cdot 10^{9}$	Laser	$7 \cdot 10^{9}$	$3 \cdot 10^{10}$	$5 \cdot 10^{11}$
^{10}B	$1 \cdot 10^{9}$	--- ,, ---	$3 \cdot 10^{9}$	$2 \cdot 10^{9}$	$7 \cdot 10^{10}$
^{12}C	$2 \cdot 10^{9}$	--- ,, ---	$6 \cdot 10^{9}$	$3 \cdot 10^{10}$	$3 \cdot 10^{11}$
^{24}Mg	$2 \cdot 10^{8}$	--- ,, ---	$7 \cdot 10^{8}$	$4 \cdot 10^{9}$	$4 \cdot 10^{10}$
^{14}N	$1 \cdot 10^{7}$	ESIS ("Krion-2")	$3 \cdot 10^{7}$	$3 \cdot 10^{8}$	$5 \cdot 10^{10}$
^{24}Ar	$4 \cdot 10^{6}$	--- ,, ---	$8 \cdot 10^{6}$	$2 \cdot 10^{9}$	$2 \cdot 10^{10}$
^{56}Fe	$1 \cdot 10^{6}$	--- ,, ---	$4 \cdot 10^{6}$	$2 \cdot 10^{9}$	$5 \cdot 10^{10}$
^{84}Kr	$1 \cdot 10^{5}$	--- ,, ---	$2 \cdot 10^{5}$	$1 \cdot 10^{8}$	$1 \cdot 10^{9}$
^{124}Xe	$1 \cdot 10^{4}$	--- ,, ---	$1 \cdot 10^{5}$	$7 \cdot 10^{7}$	$1 \cdot 10^{9}$
^{197}Au	-	--- ,, ---		$7 \cdot 10^{7}$	$1 \cdot 10^{9}$

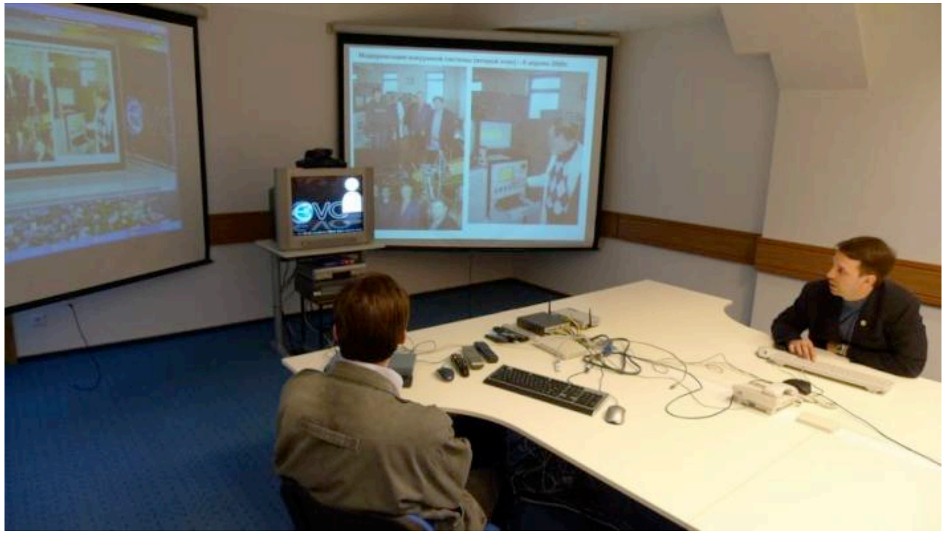
Nuclotron-M (2010): vacuum (↑x100), new power supply system, orbit correction, automatization;
Nuclotron-N (2012): new ESIS (KRION 6T: I ↑x20) + Reconstructed LU-20 (new RFQ + E-resonator: I ↑x2) + Adiabatic RF capture (I ↑x2)

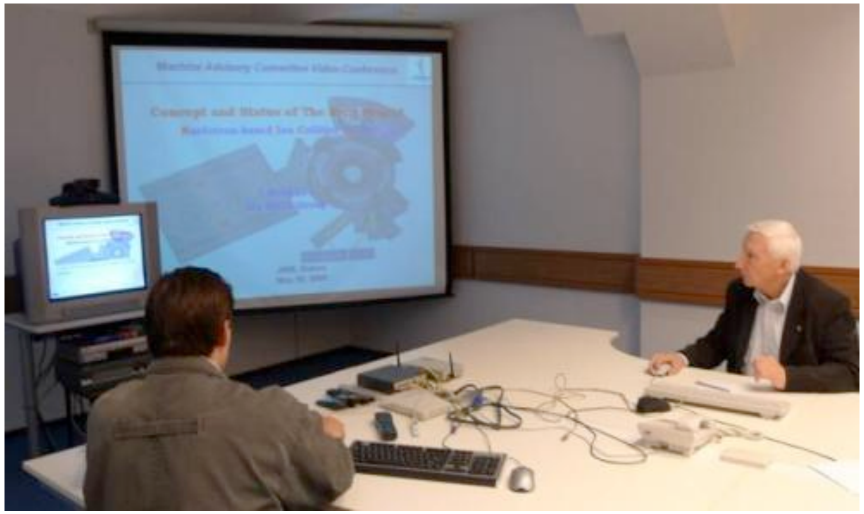
Beam	Comparison, particles per cycle				
	Energy	*GSI (SIS18)*	*Nuclotron-M (2010)*	*Nuclotron-N (2012)*	*New ion source + booster (2014)*
p	4,5 GeV	$5\cdot10^{11}$	$8\cdot10^{10}$	$5\cdot10^{11}$	$5\cdot10^{12}$
d	2,2 GeV	$2\cdot10^{10}$	$8\cdot10^{10}$	$5\cdot10^{11}$	$5\cdot10^{12}$
^{4}He			$2\cdot10^{9}$	$3\cdot10^{10}$	$1\cdot10^{12}$
d↑			$2\cdot10^{8}$	$7\cdot10^{10}$ *(SPI)*	$7\cdot10^{10}$ *(SPI)*
$^{7}Li^{6+}$			$7\cdot10^{9}$	$3\cdot10^{10}$	$5\cdot10^{11}$
$^{12}C^{6+}$	300 MeV	$7\cdot10^{10}$	$6\cdot10^{9}$	$3\cdot10^{10}$	$3\cdot10^{11}$
$^{14}N^{7+}$	300 MeV	$1\cdot10^{11}$	$3\cdot10^{7}$	$3\cdot10^{8}$	$5\cdot10^{10}$
$^{24}Mg^{12+}$	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	$2\cdot10^{9}$			
$^{197}Au^{65/79+}$		$3\cdot10^{9}$		$1\cdot10^{8}$	$1\cdot10^{9}$
$^{238}U^{28+}$	0,05-1 GeV	$5\cdot10^{9}$			

“Fixed target” experiments (2011-2015 - … years) at existing extracted beams



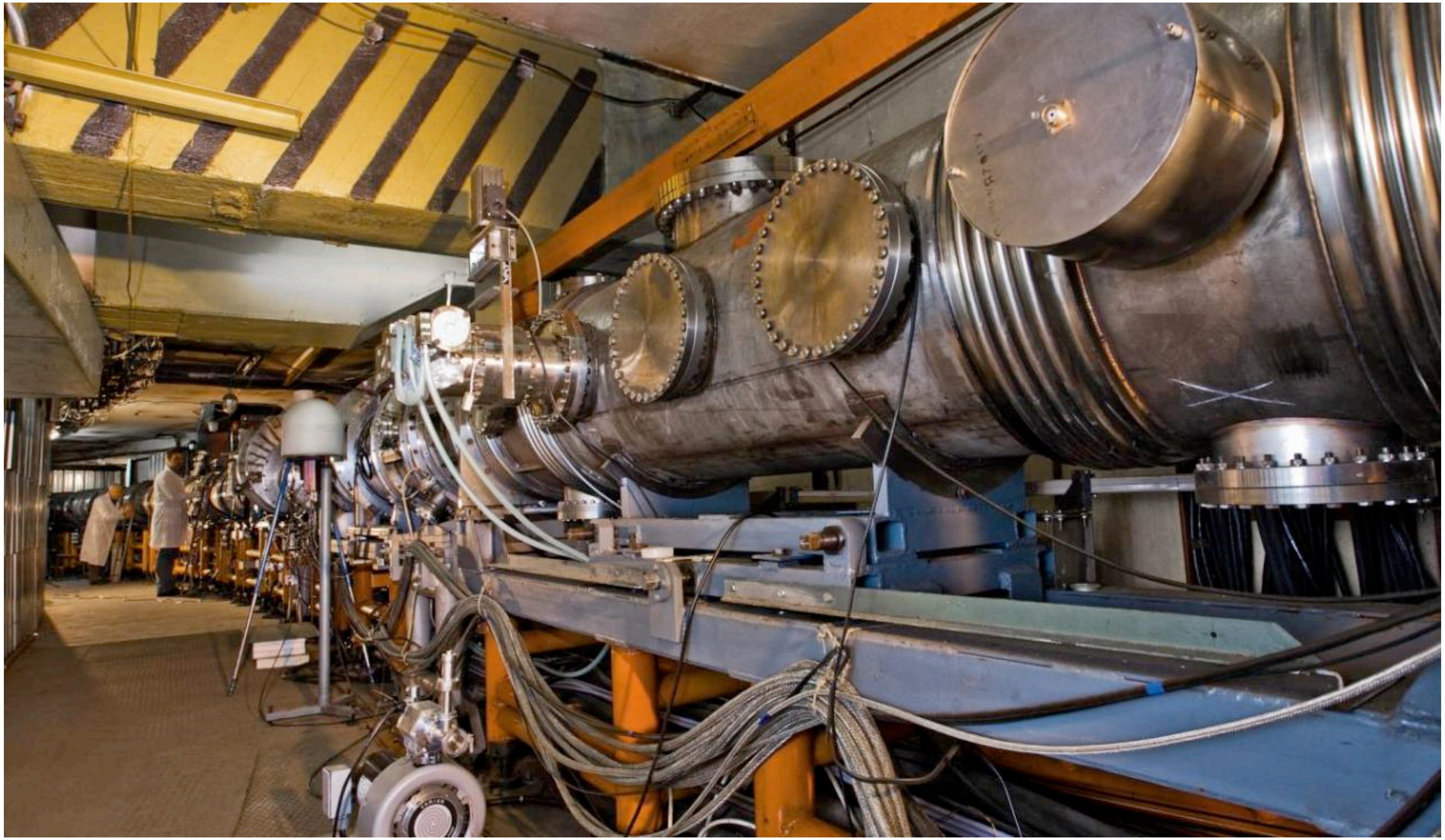
Nuclotron/NICA MAC



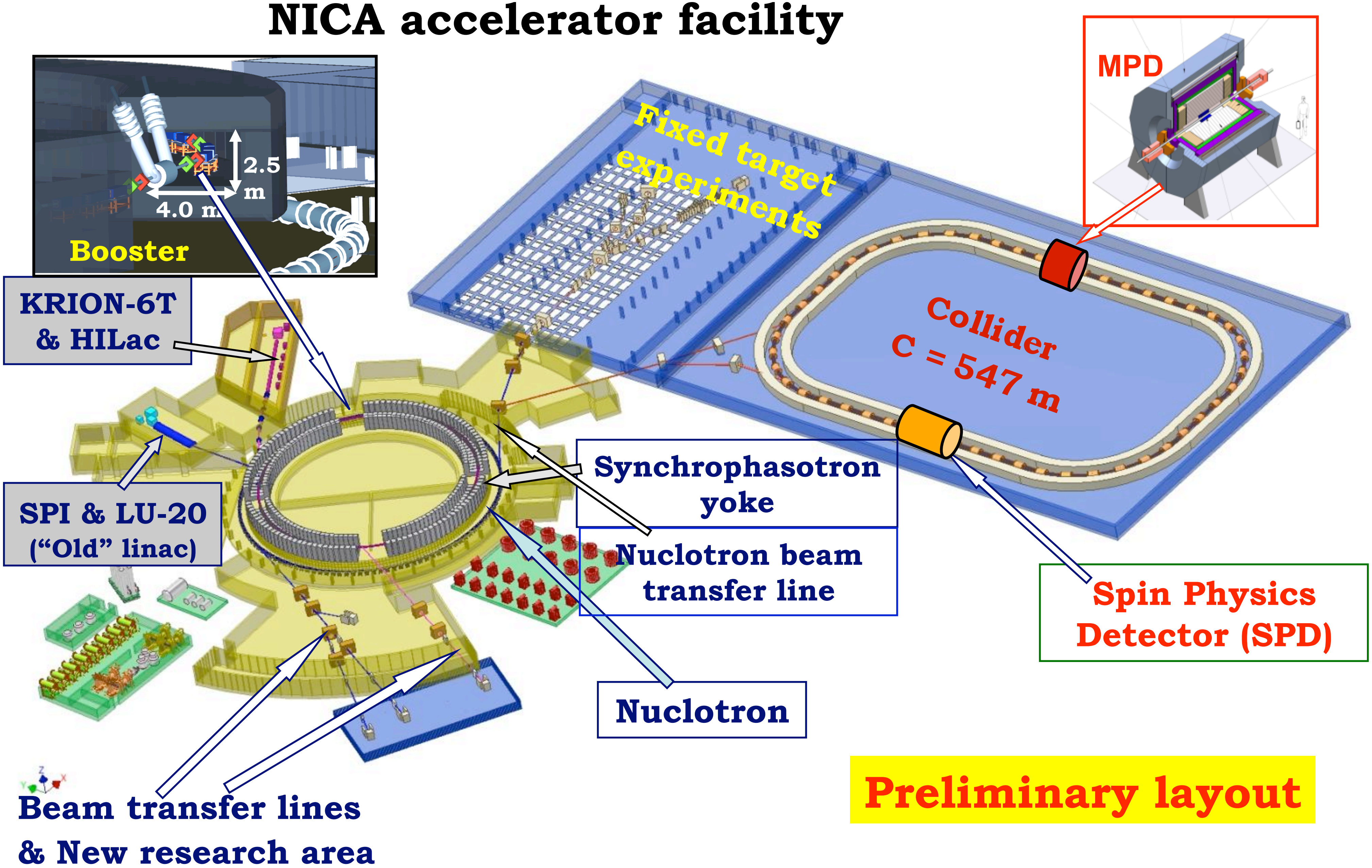


PAC for particle physics
- June 2008
+
Nuclotron-M Machine
Advisory Committee
+
Honorary guests

NICA: Nuclotron based Ion Collider fAcility



NICA accelerator facility



Preliminary layout

NICA

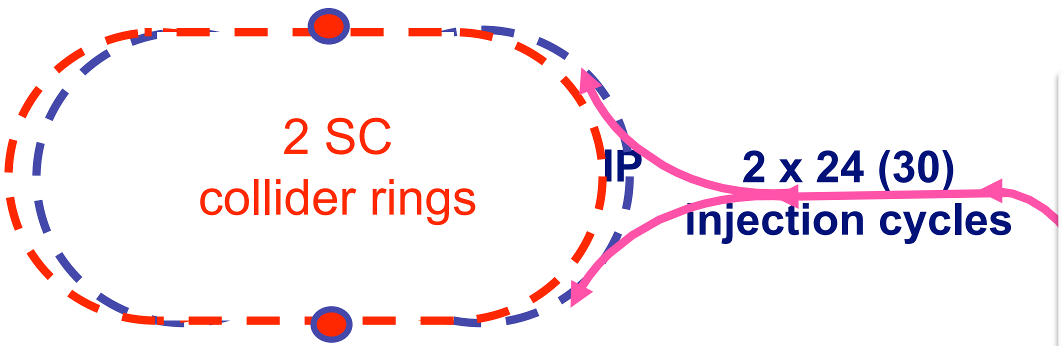
Heavy Ion Mode: Operation Regime and Parameters

Injector: 2×109 ions/pulse of 197Au32+
at energy of 6.2 MeV/u

Collider (45 Tm)
Storage of
24 bunches by ~ 1x109 ions per ring
at 1 - 4.5 GeV/u,
electron and/or stochastic cooling

Booster (25 Tm)
1 multiturn injection,
storage of 2·(4-6)×109,
acceleration up to 100 MeV/u,
electron cooling, acceleration
up to 600 MeV/u

Stripping (80%) 197Au32+ => 197Au79+

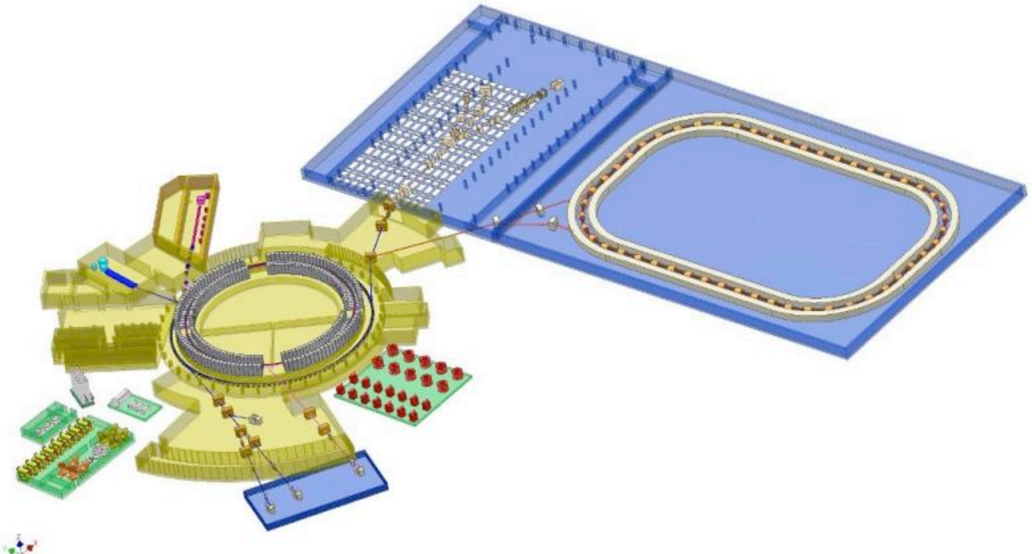


Nuclotron (45 Tm)
injection of one bunch
of 1.1×109 ions,
acceleration up to
1 - 4.5 GeV/u max.

Searching for nuclear matter at extreme states

NICA/MPD

***N**uclotron-based **I**on **C**ollider f**A**cility*

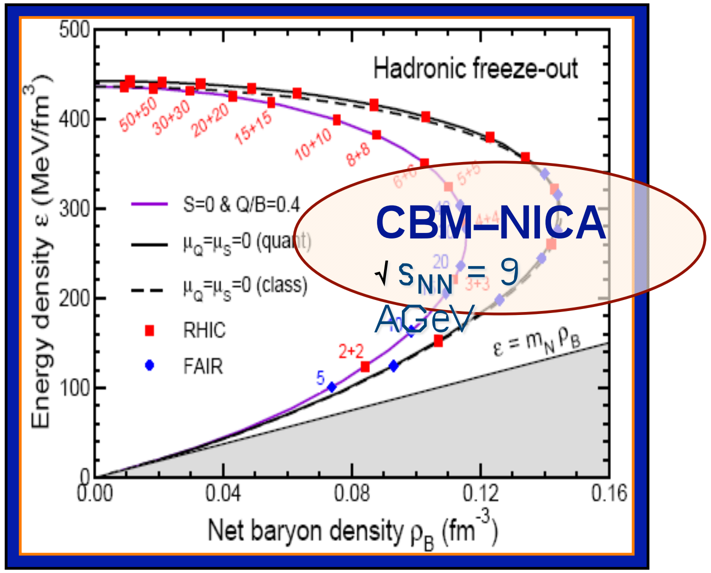


GSI: FAIR/CBM

E_{lab} < 60 GeV/n

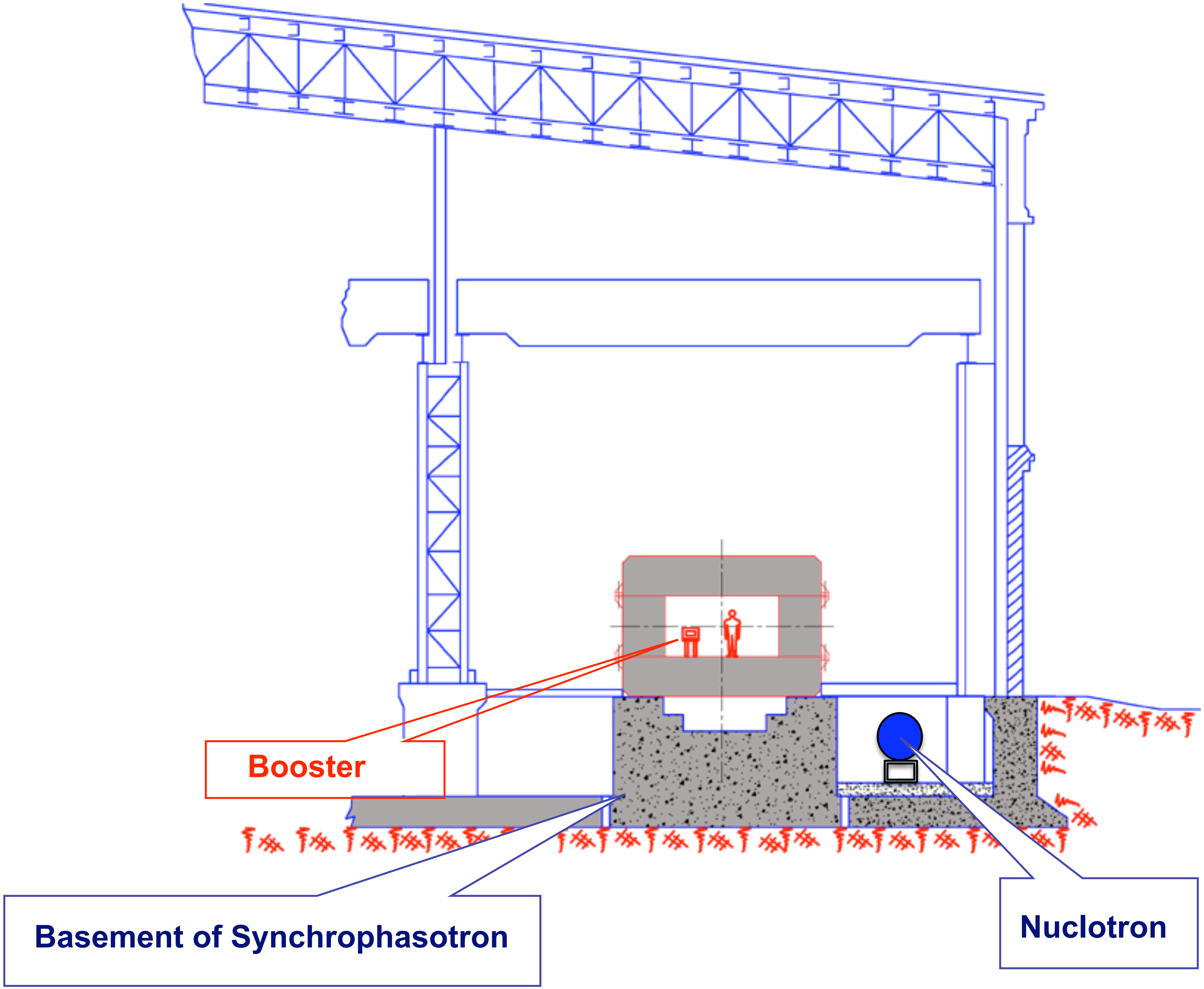
√sNN = 4 - 11 GeV/n

Average luminosity
10^{27}cm^{2}s^{-1} Au x Au



E_{lab} ~ 34 GeV/n

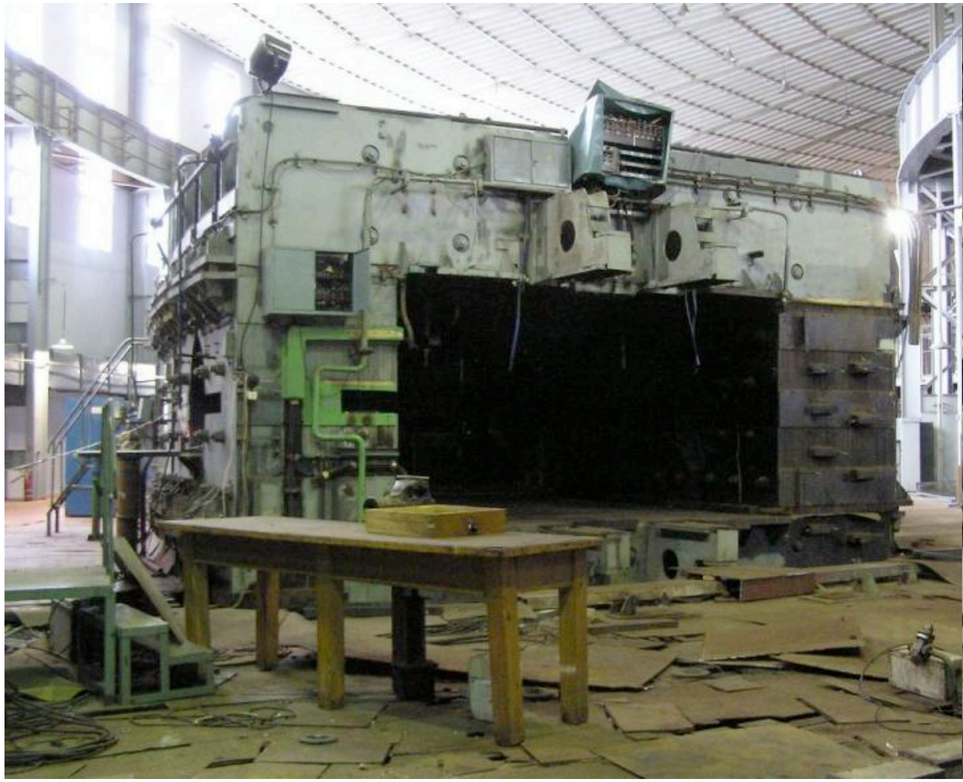
√ sNN = 8.5 GeV

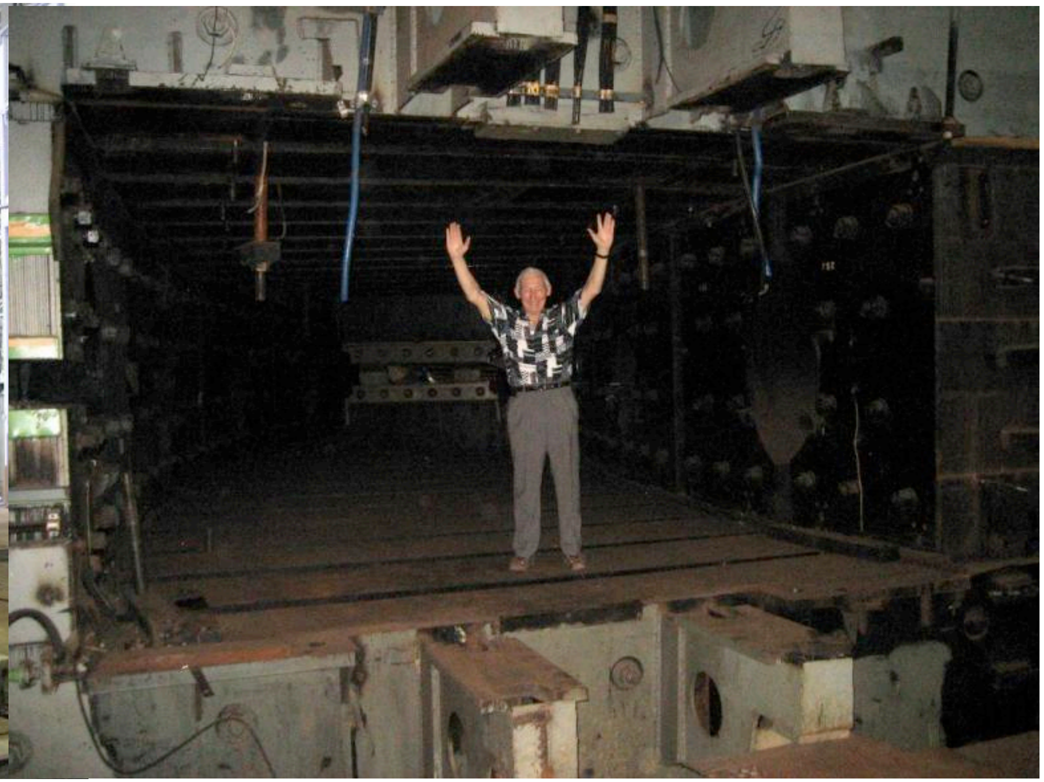

Booster
Basement of Synchrophasotron
Nuclotron

Booster

Synchrophasotron dismantling ⇒ in progress

Jan 2011: 90% are empty

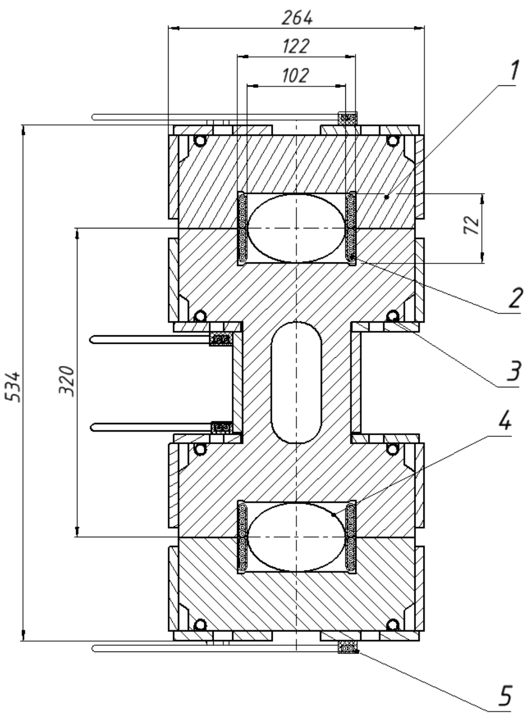




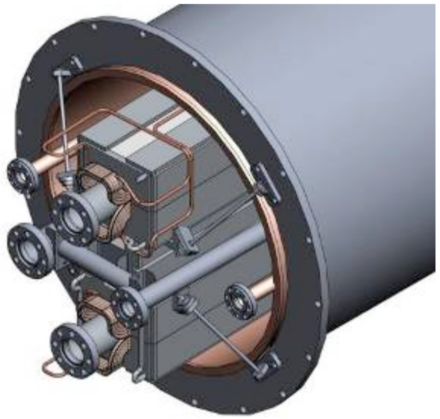
NICA

“Twin” magnets of NICA collider:
Max. field - 2T, super-ferric (Nuclotron-like), double aperture

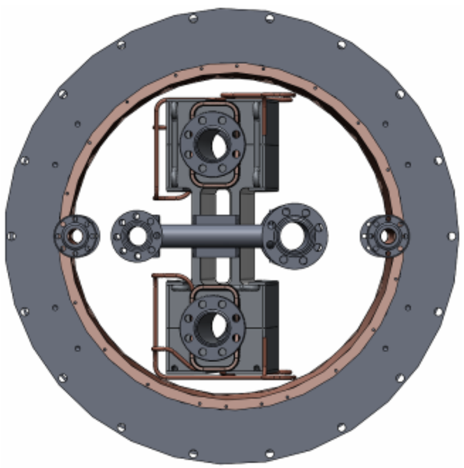
SC magnetic system: manufacturing of magnet prototypes

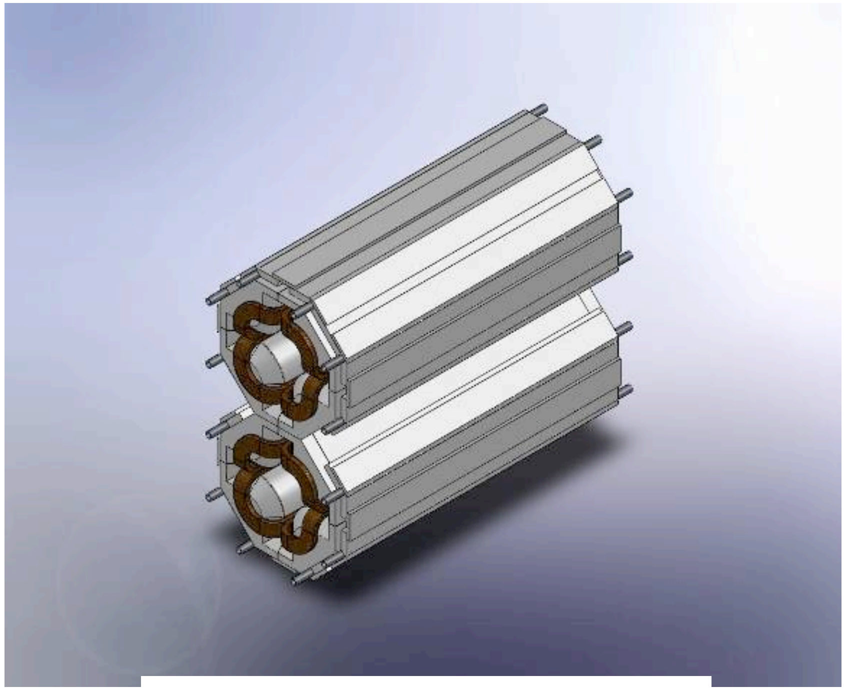


Dipole cross-section

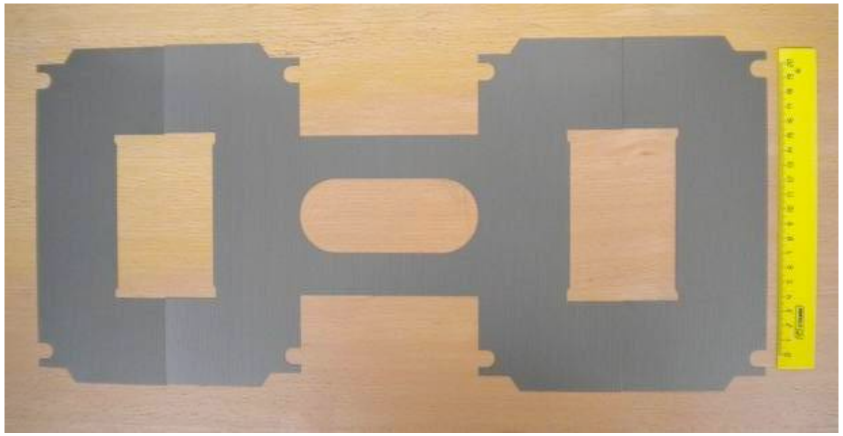


Dipole 3D view





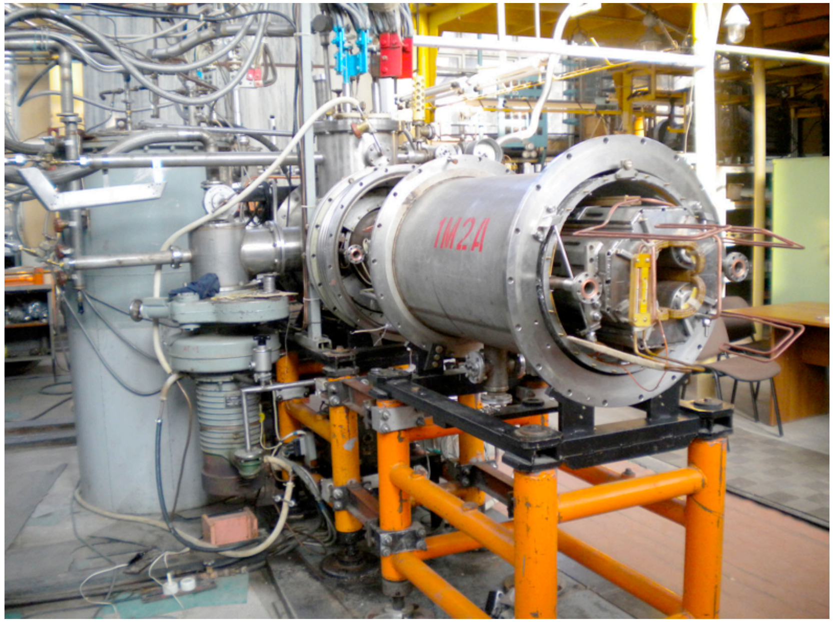
Quadrupole lense

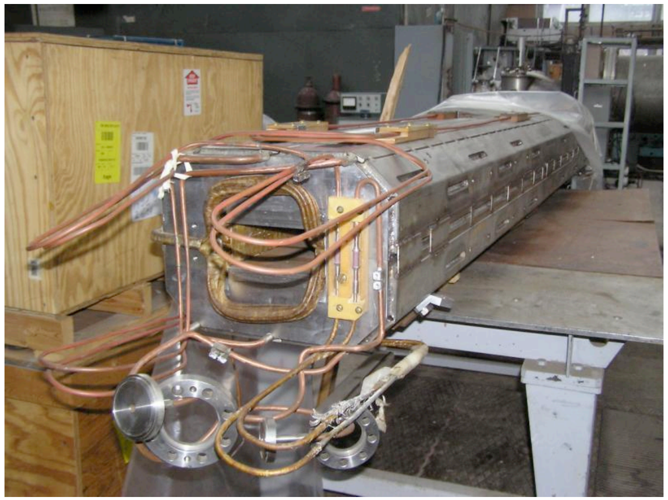


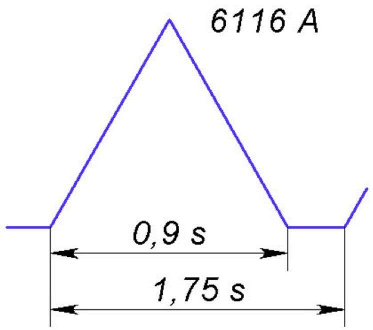
Collider dipole magnet is under assembly at JINR workshops

NICA

Prototypes of SIS-100 quadrupole and dipole.
We performed 5 tests during April-November 2010.







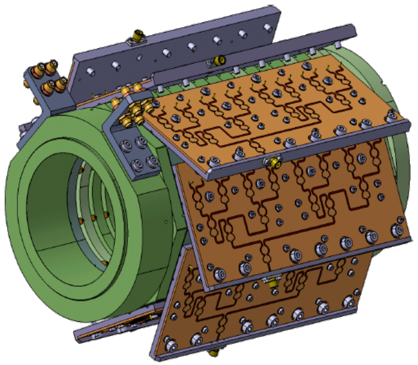
Test experiment on stochastic cooling at Nuclotron

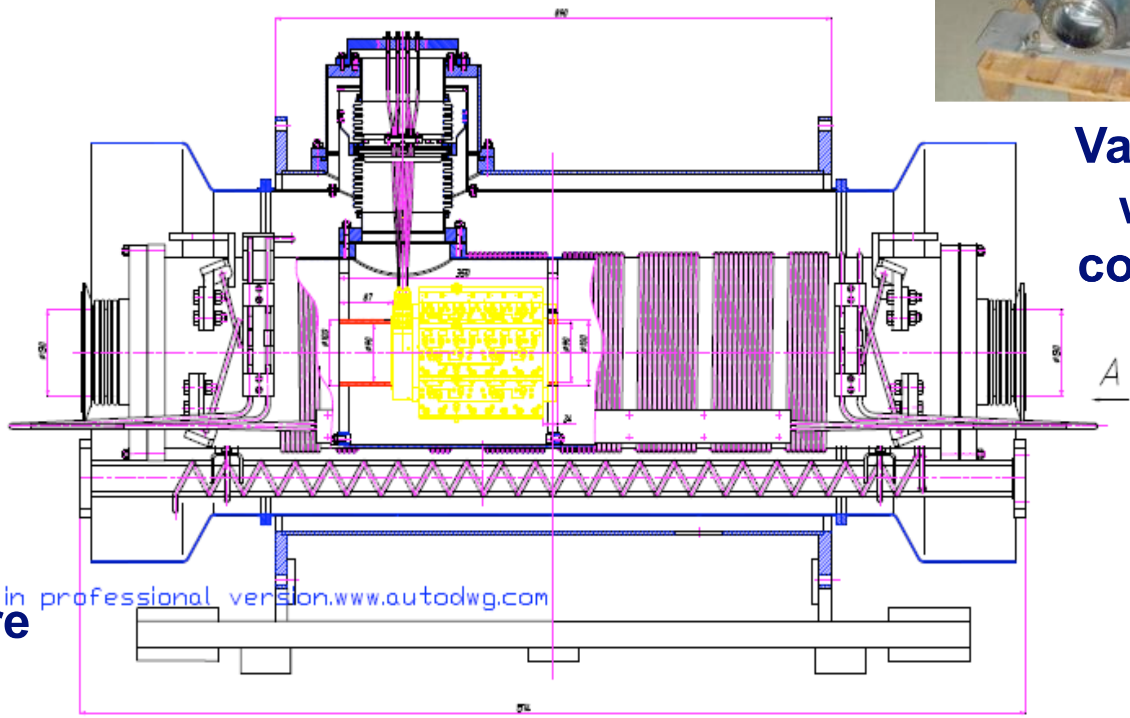
Collaboration JINR / FZ *Jülich*

Stochastic cooling system prototype at Nuclotron for HESR/NICA

2 ÷ 4 GHz, 100W

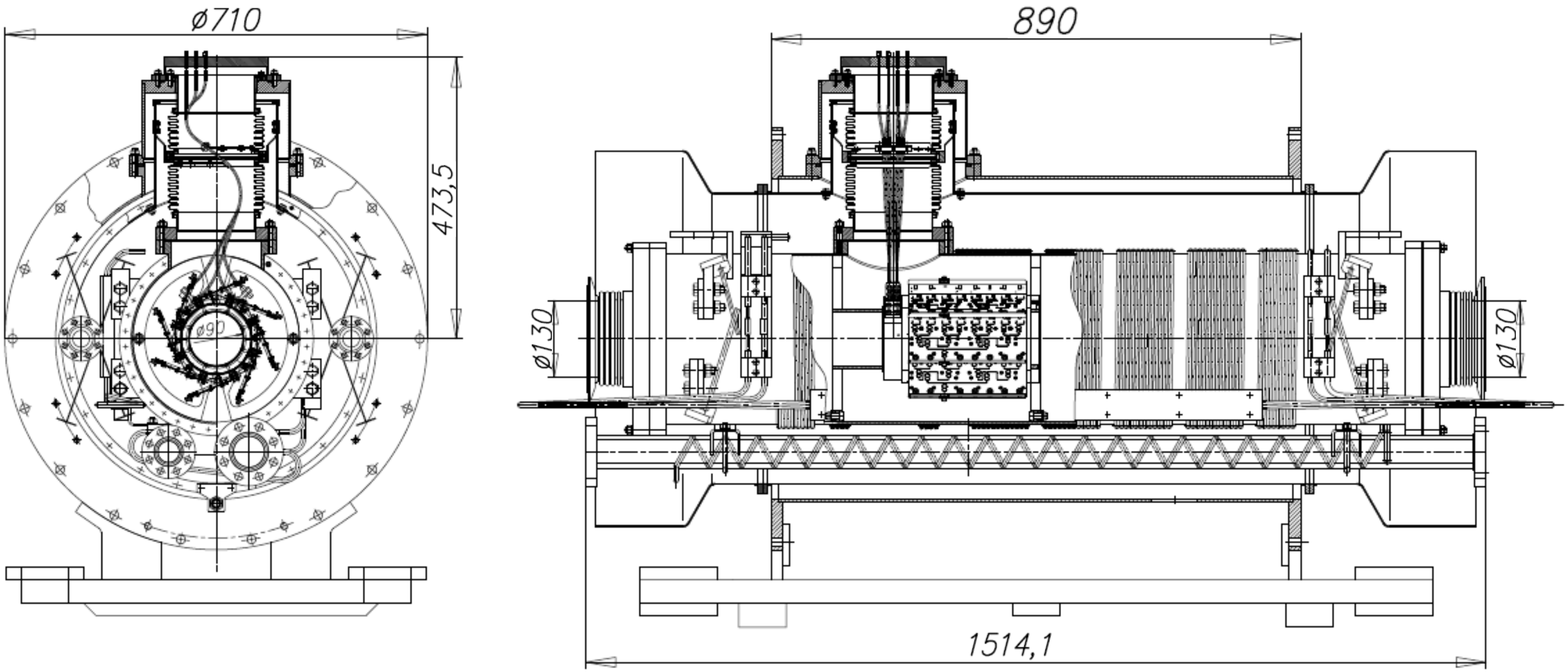
Vacuum tank with slot-coupler (FZJ)



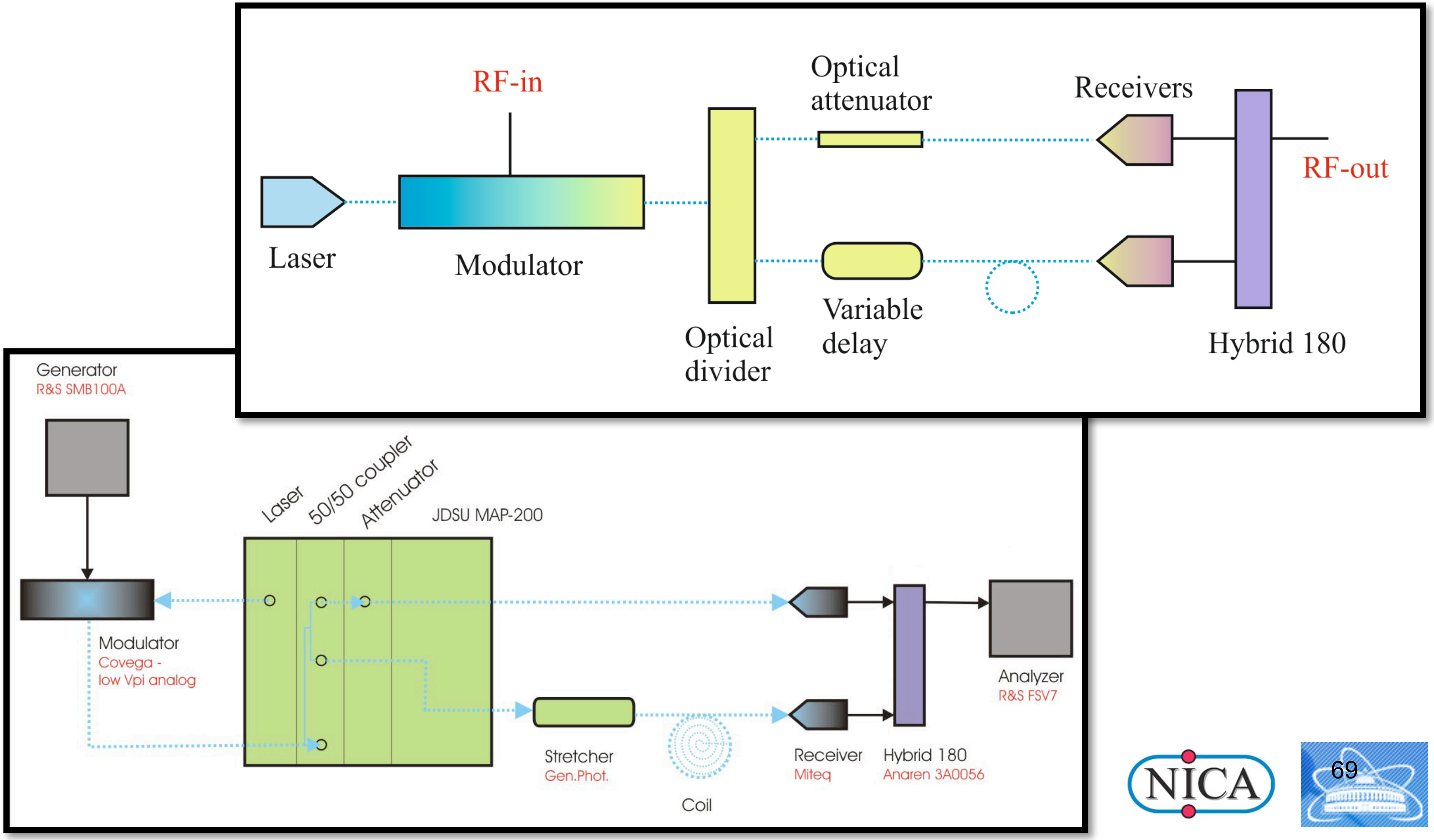


Slot-coupler structure (is made at FZJ now

Pick-up tank



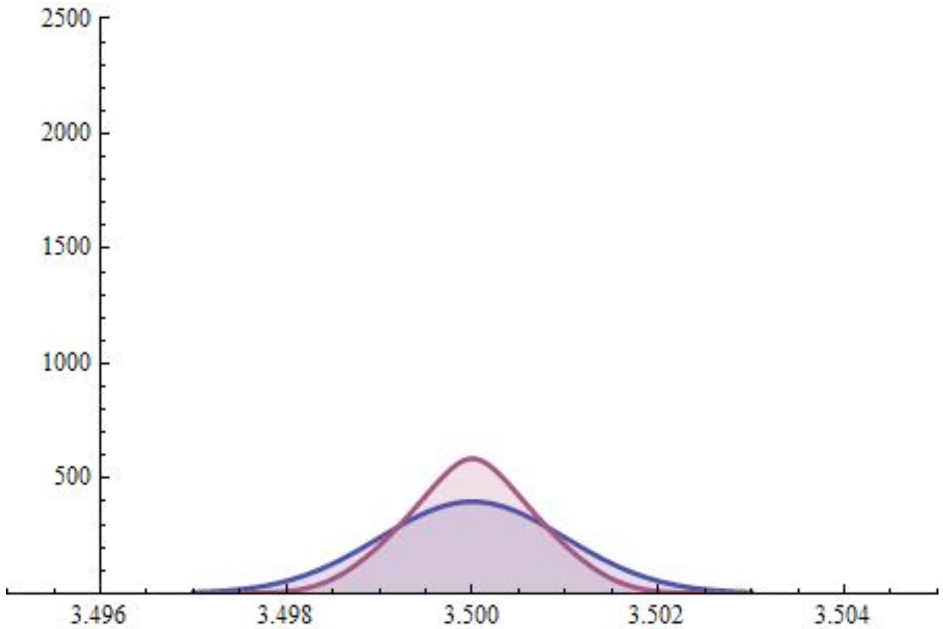
Optical notch filter

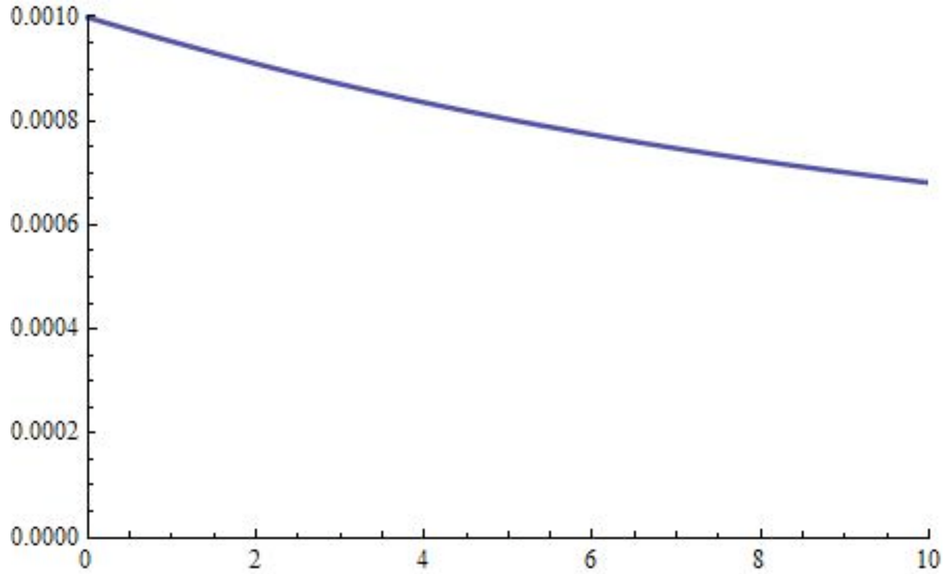


Simulations with protons

For protons power is around 35-40 W and gain is ~140 dB

Evolution of energy spectrum at time 0 and 10 sec. and rms value of dp/p as a function of time:

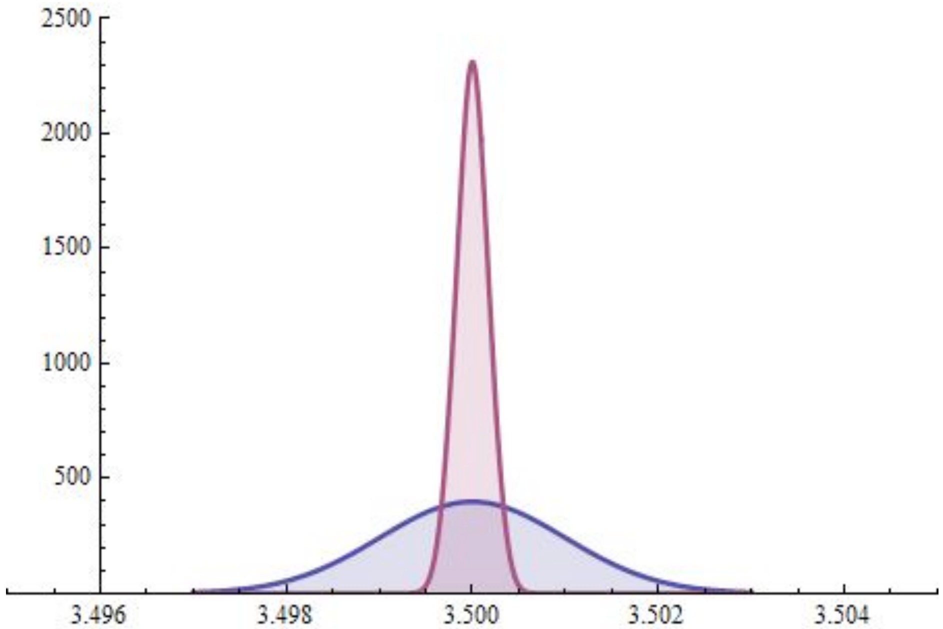


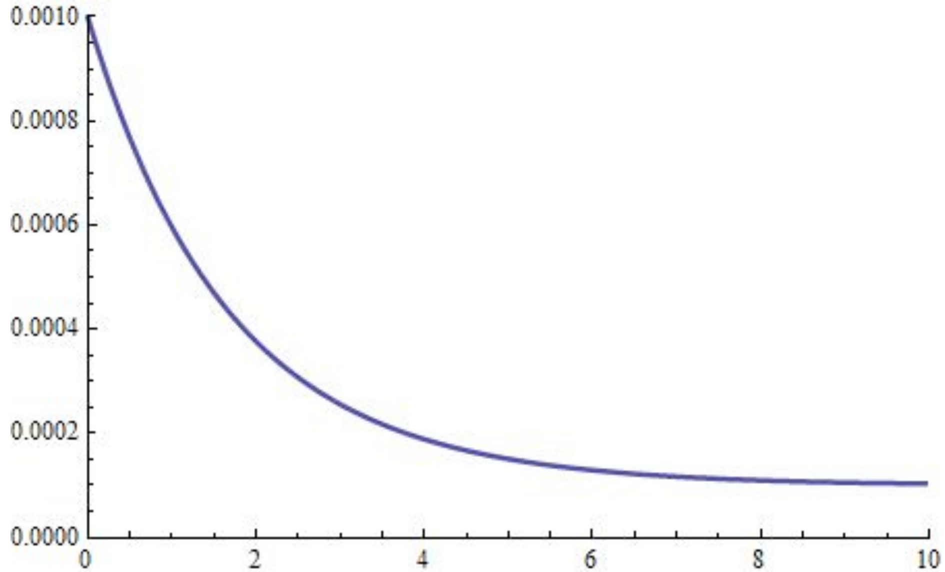


Simulations with carbon (C(+6))

For carbon ions power is around 35 W and gain 130 dB

Evolution of energy spectrum at time 0 and 10 sec. and rms value of dp/p as a function of time:





The NICA Collaboration

Budker INP

- ✓ Booster RF system
- ✓ Booster electron cooler
- ✓ Collider RF system
- ✓ Collider SC magnets (expertise)
- ✓ HV e-cooler for collider
- ✓ Electronics
- ✓ Injector linac (under discussion)

IHEP (Protvino): Injector Linac

FZ Jűlich (IKP): HV E-cooler & Stoch. cooling

Fermilab: HV E-cooler, Beam dynamics, Stoch. cooling

CERN: Beam dynamics, E-cooling, Acceler. technique

All-Russian Institute for Electrotechnique
HV Electron cooler

BNL (RHIC)
Electron & Stoch. Cooling

GSI/FAIR
ipoles for Booster/SIS-100
ipoles for Collider

ITEP: Beam dynamics in the collider

Corporation "Powder Metallurgy" (Minsk, Belorussia): Technology of TiN coating of vacuum chamber walls for reduction of secondary emission

Thank you for your attention