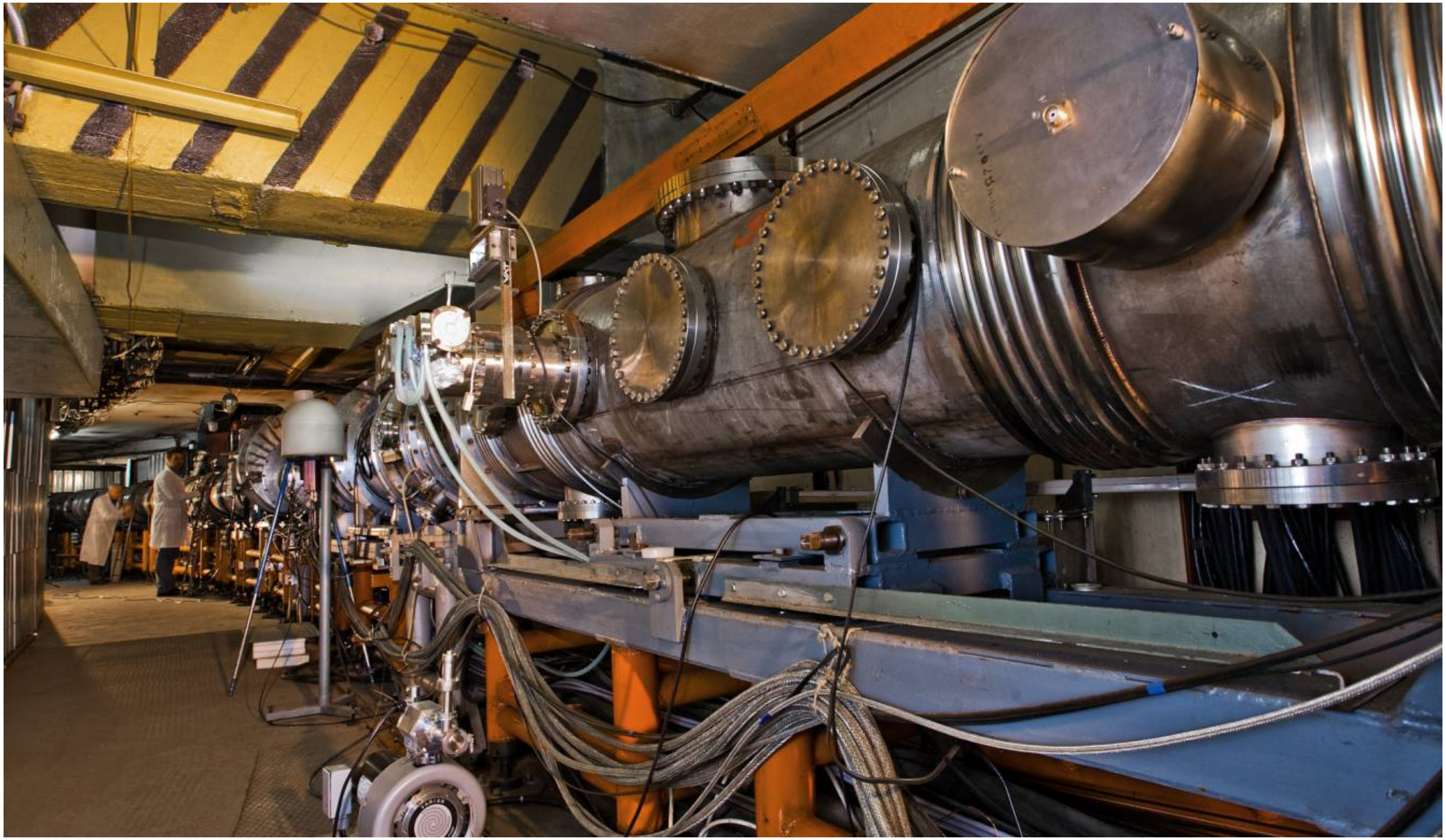
Status of the Nuclotron-M project

NICA Round Table V
Dubna, 28 August, 2010

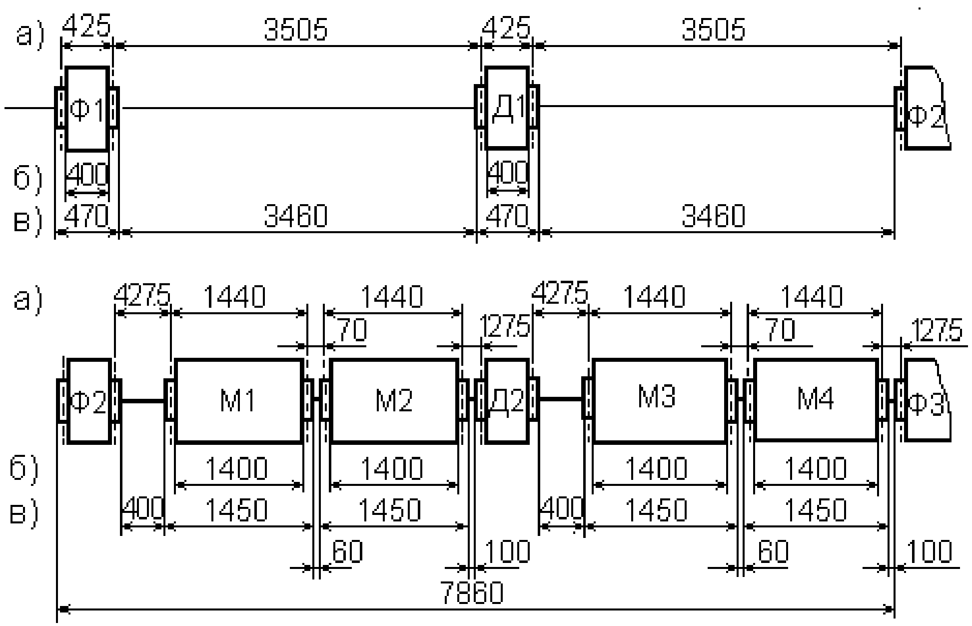
G. Trubnikov
for the project team

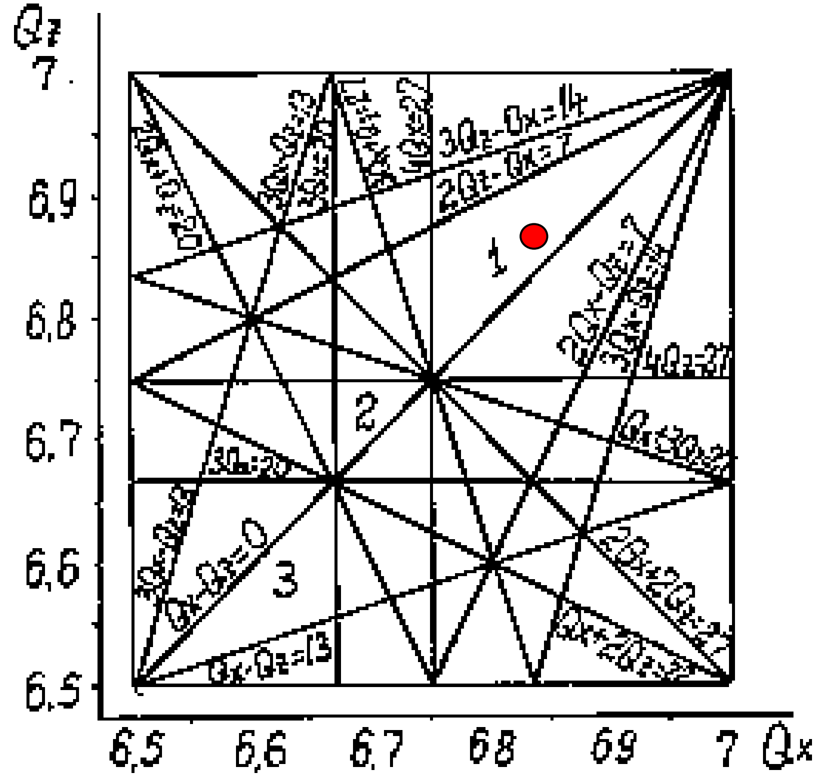
NICA: Nuclotron based Ion Collider fAcility



Nuclotron provides now performance of experiments on accelerated proton and ion beams (up to Fe^{24+}, A=56, *now Xe42+, A=124*) with energies up to 6 AGeV (Z/A = 1/2)

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.

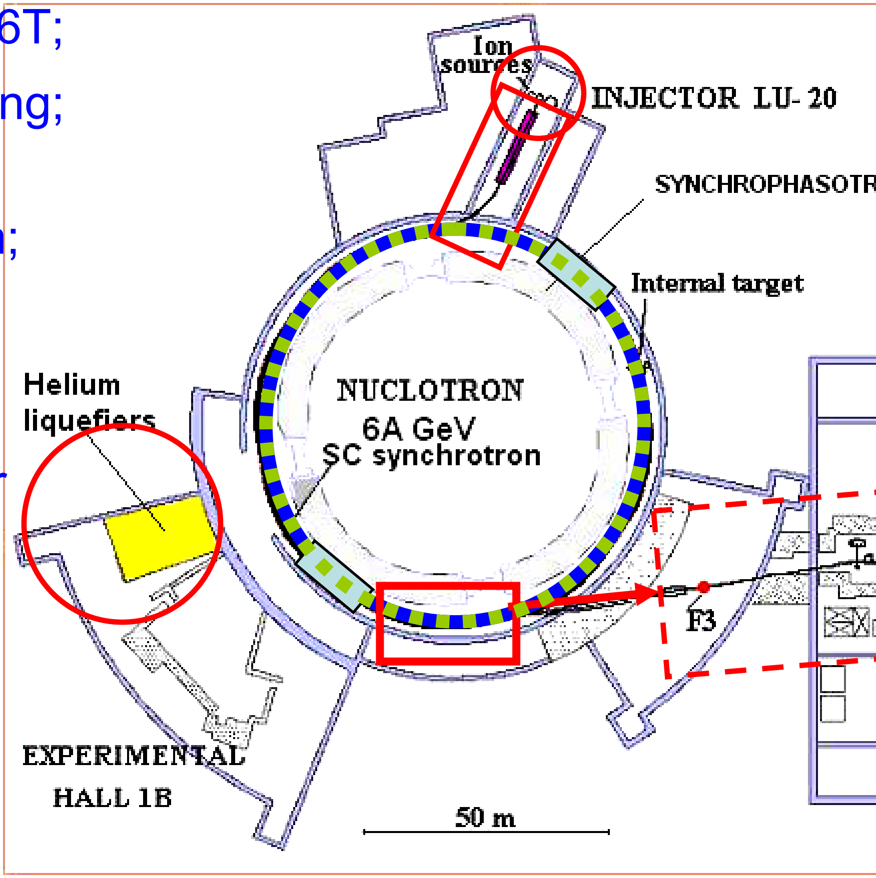




Chromaticity $\Delta Q_x/(\Delta p/p)$ and $\Delta Q_z/(\Delta p/p)$	~7.8 -10.0
Compaction factor	0,012
Corrected orbit amplitude	4 mm
Acceptance horiz/vert [pi mm mrad]	40 / 45
Emittance inj/acc [pi mm mrad]	30 / 1.7_x and 2.0_z
DP/P inj/max/accel	$\pm 10^{-3}$ / $4 \cdot 10^{-4}$ / $8 \cdot 10^{-3}$

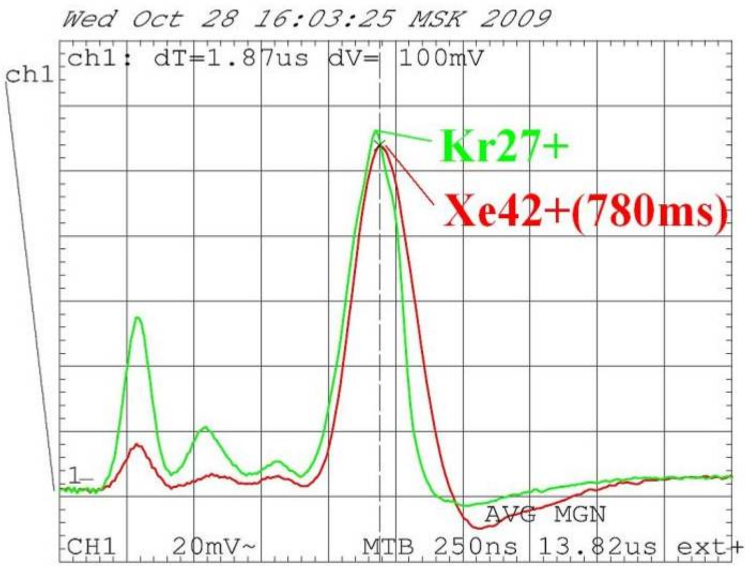
10 stages-subprojects of the Nuclotron-M project

- 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



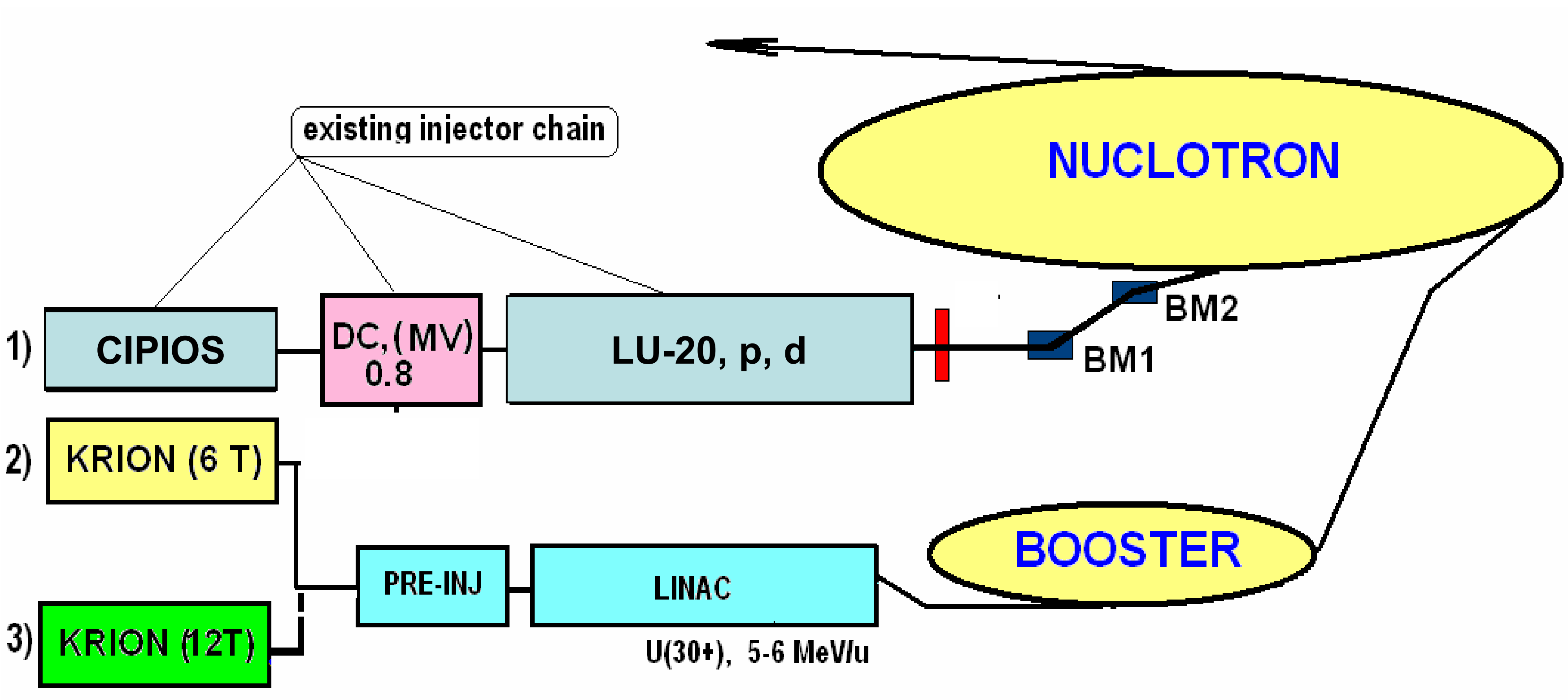
<u>Beam dynamics: minimization of the beam losses at all stages from injection to acceleration and to extraction of the beams (not more then 15-20%, we have about 50-80%).</u>

E.Donets and team.
Results of the runs at KRION in 2009

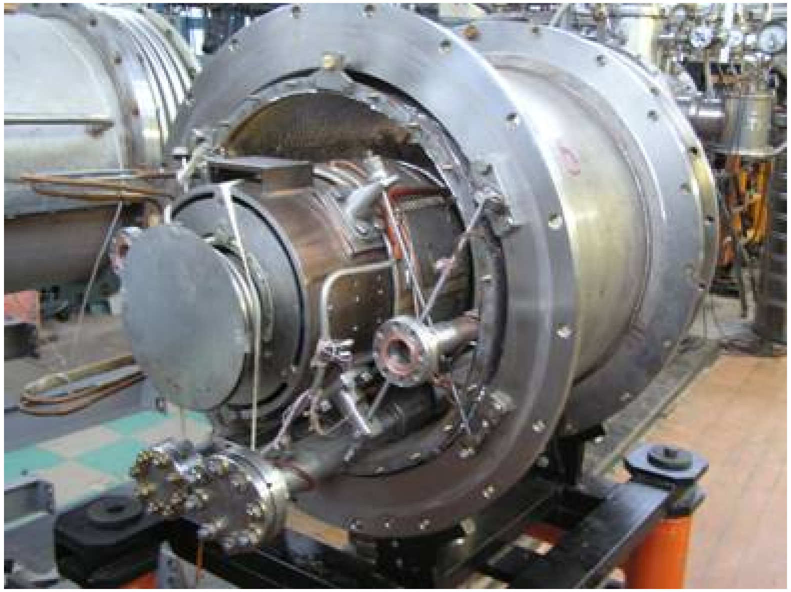


As LU-20 accepts ions with charge to mass ratio q/M>1/3 one should produce in ion source ^{124}Xe ion beams with the following charge states: ^{124}Xe41+, ^{124}Xe42+, ^{124}Xe43+, ^{124}Xe44+ This was done in October 2009 run with use of KRION-2T Electron String Ion Source. Highly charged Xe ion beams 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.

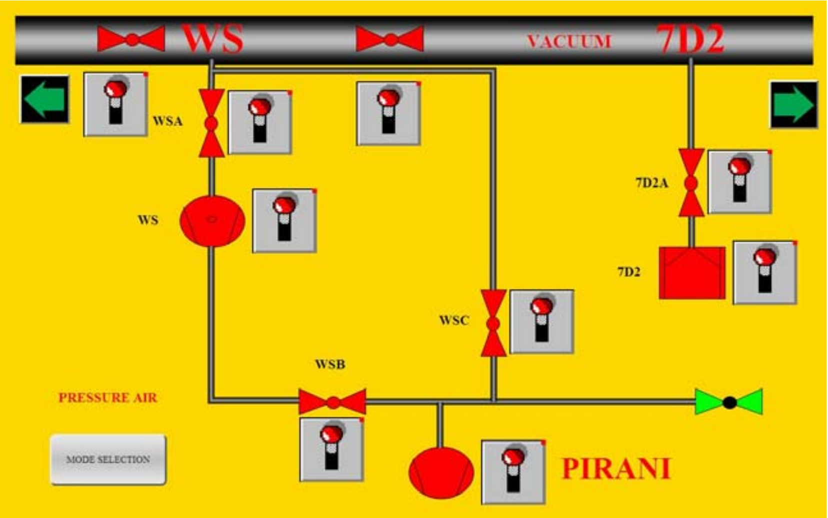
Conceptual scheme of the accelerator complex development



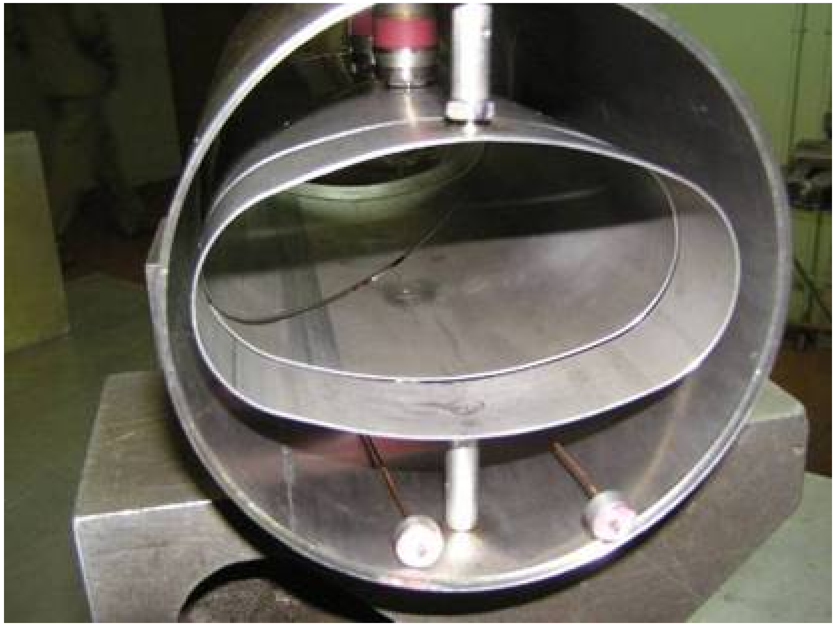
Experiments with polirized beams are planned at existing Linac LU-20, and accelerate ions at Nuclotron up to the max. energy.
Booster usage in such scheme is inexpedient because it has less periodicity.
Protons acceleration for p x U collisions is also with LU-20.



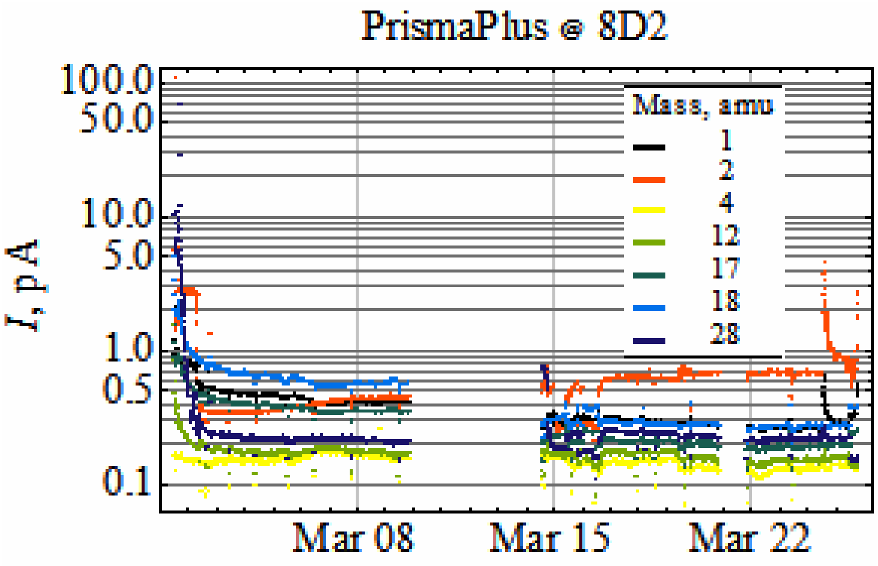
Assembled pick-up station



Touch-screen panel for vacuum system control



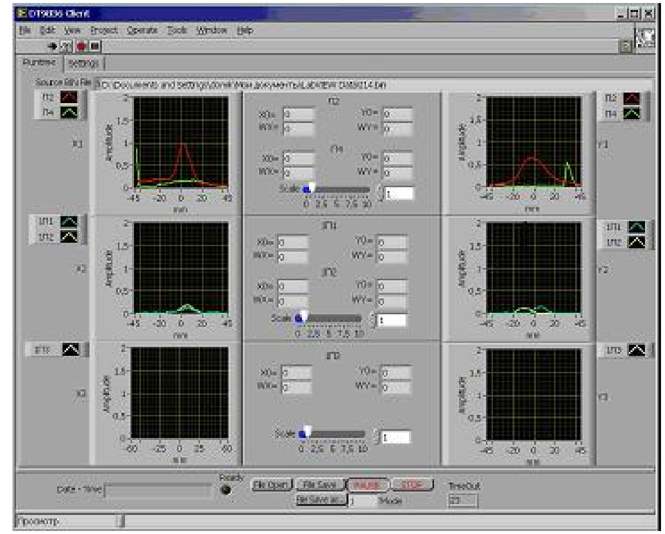
Assembled elliptical pick-up station



Monitoring of vacuum during run

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

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



Automatic system "INJECTION"

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

Since July'07 we performed 5 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 !):

ⓔ (Ⓐ=12, Z=4)

<u>ΠΣ (ℵ=124, Z=42)</u>

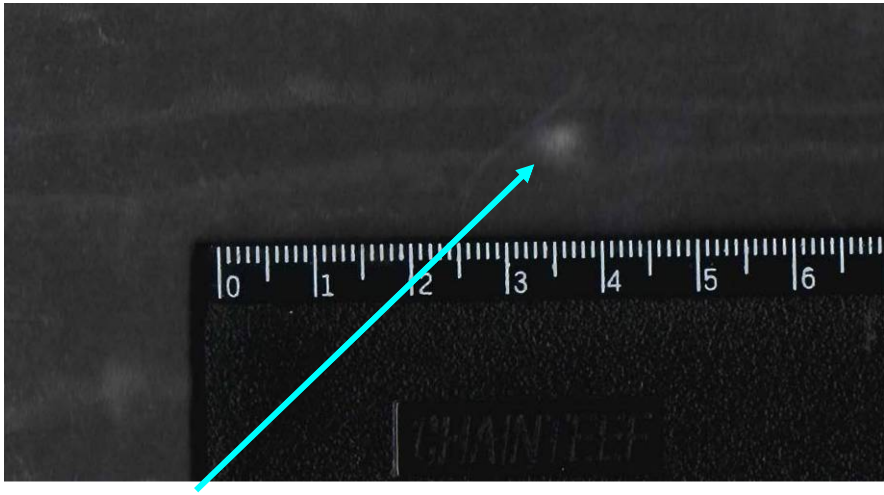
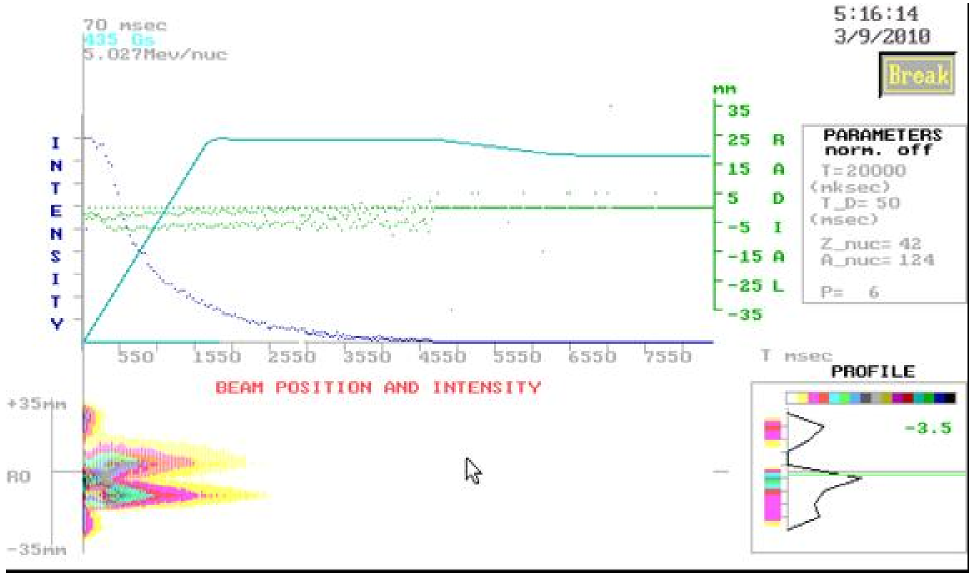
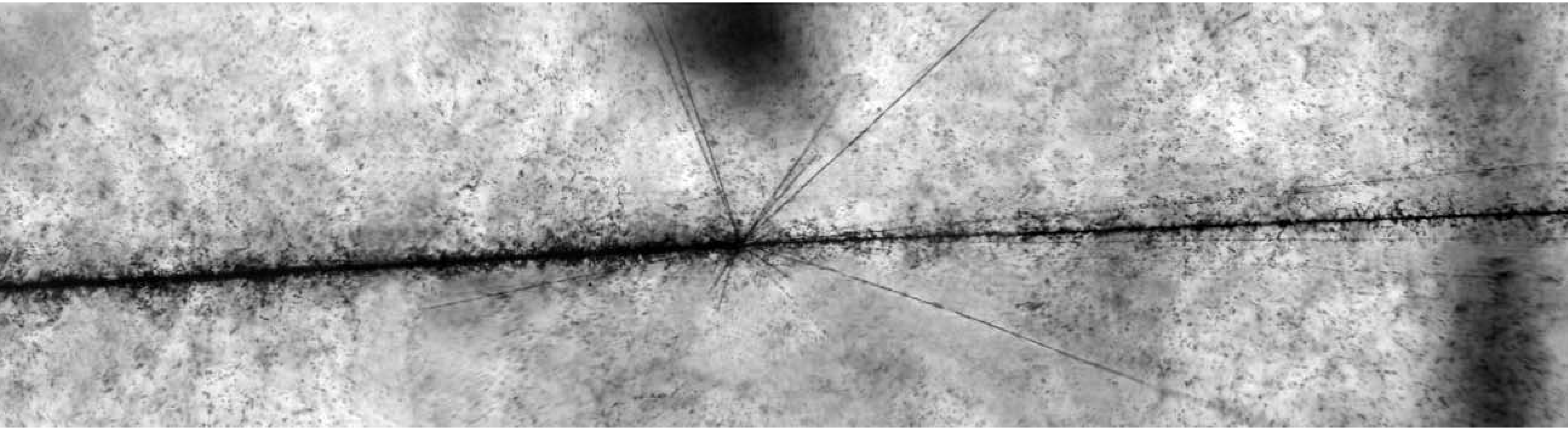


Image of the extracted Xe beam (⇖ = 0,6 GeV/) on photoplate

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



⌫⇙ beam (A=124, Z=42+) was accelerated up to <u>570 MeV/n & 1 GeV/n</u>, and succesfully extracted. Several shifts on the internal target experiments was succesfuly provided.

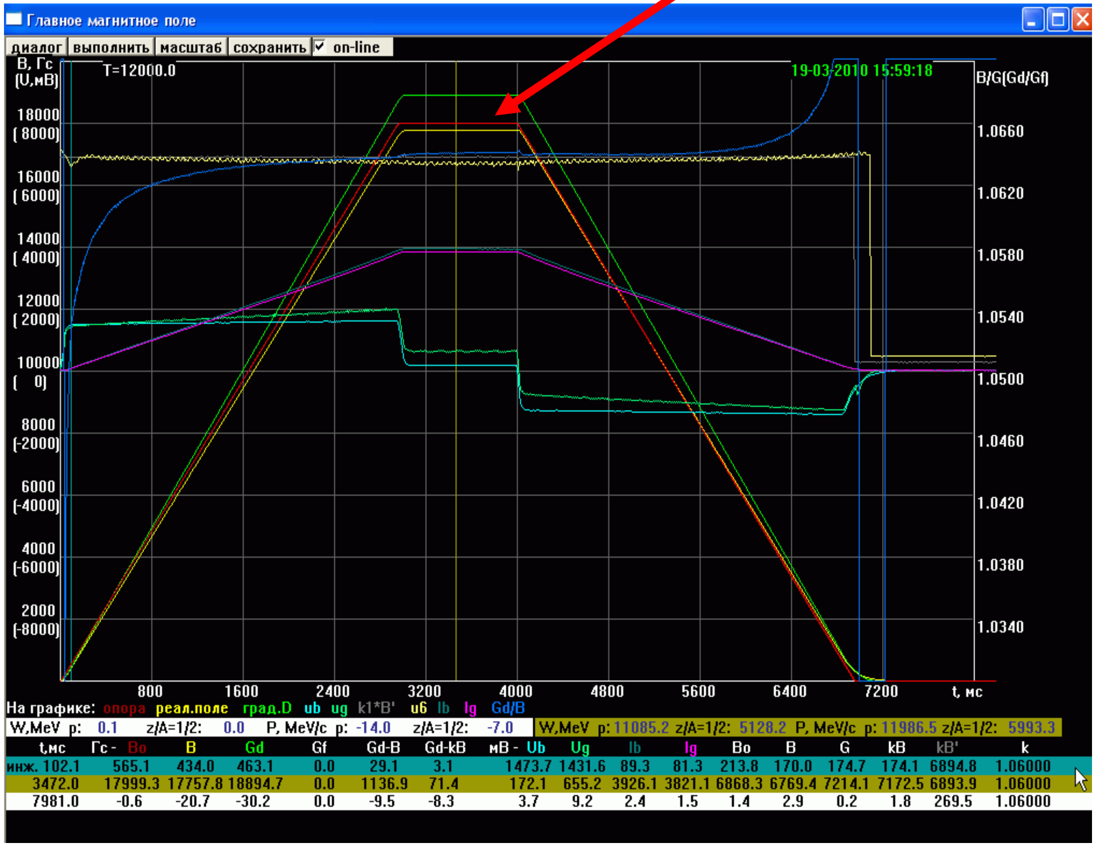


Xe (1 Gev/n) trace on photoemulsion
(experiment “Becquerel”)

Main magnetic field of the Nuclotron was increased up to **1.8 ®.**

In energy it corresponds to:
d (🕛=2, Z=1) - 5,2 GeV/n
⌫⇙ (A=124, Z=42) - 3.3 GeV/n
Au (A=197, Z=79) - 4.05 GeV/n

All systems of the accelerator showed stable and safe operation: quench detection, energy evacuation, etc.



During the run we tested new mode (4 days) of the cryogenics operation - partial warming-up of the ring from L-He (4K) up to L-Nitrogen (70K) without interruption of the operation of all other systems. After that ring was cooled down to 4K back during only 1 day. No additional helium or nitrogen losses. Such modes could be used for prolonged run operation (with short pauses up to 1 week).

Improvement of the power supplies, shielding and energy evacuation system of the magnets and lenses (V. Karpinsky)

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;***

Upgrade of the cryogenic supply system and cryogenics power increasing towards NICA (Prof. N. Agapov)

Additional screw compressor for helium (6000m^3/h) - from HELIIMASH (~1MEuro)

Succesfully commissioned and used during run #41 (step towards NICA)

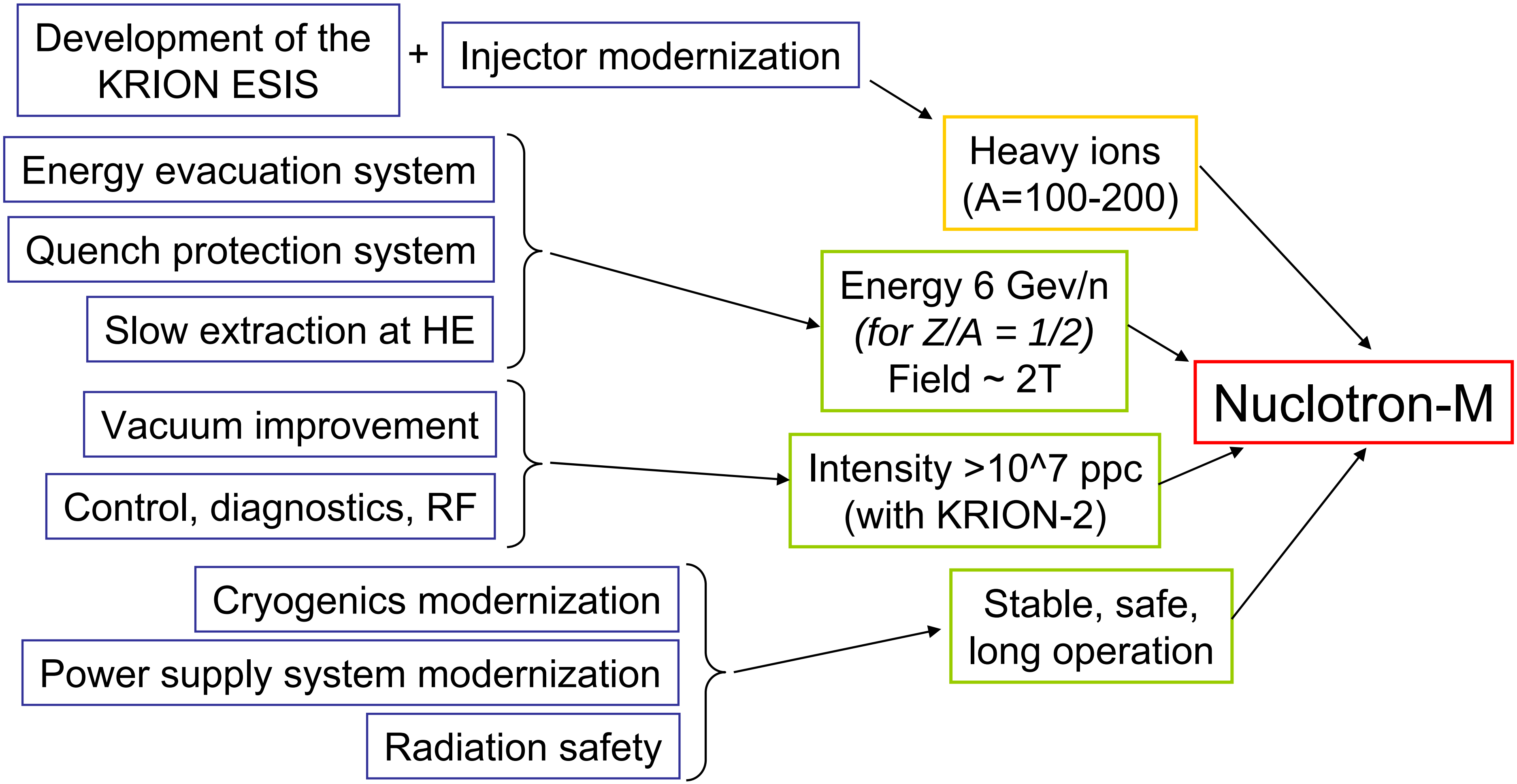
Resource saving:

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

During summer 2010 we plan to continue upgrade of the Plant and to 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.

Position	Required	Achiev. by 2007	Status by 08'2010	%
Ion source	$^{124}Xe^{44+}$ (2T)+new 6T	$^{56}Fe^{28+}$	$^{84}Kr^{28+}$ & $^{124}Xe^{42+}$	95
Linac	Vacuum+optimization New modulator and DT	No No	Ready Under manufacturing	90 30
RF system	Noise reduction Automatization Adiabatic capture Feedback with beam	1 no no No	1/15 partially yes No	95 70 80 30
Ring vacuum, Torr	5*10^-10	5*10^-7	2*10^-9	100
Field (energy)	2T (6 AGeV)	1T (2.2 AGeV)	1.4 (3.8 AGeV)	80
Intensity	10^11 (d), 10^8 (i)	2*10^10 (d)	$5*10^{10}$ (d), $5*10^{7}$ (Li)	70
Power supply	Serial connection of magnets, new EES, MF control	old (< 1Tesla) || connection 1 Gs prescision	Serial connection ESS - 90% ready 0.1 Gs	70 90 99
New quench protection system	200 sensors	200 old	New prototype tested 30 - for run	40
Slow extraction system (efficiency)	Extraction at 6 AGeV	Max energy 2.2 AGeV (95%)	Prototype for 6 AGeV ready (95%)	85
Control, diagnostics	Beam losses <10%	70-80% losses	30-40% losses	70
Cryogenics	Safety + stability	Worked-out	Ready	99
Run stability	6 months/year	3 runs x 1month	2 runs x 1month	80



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.)

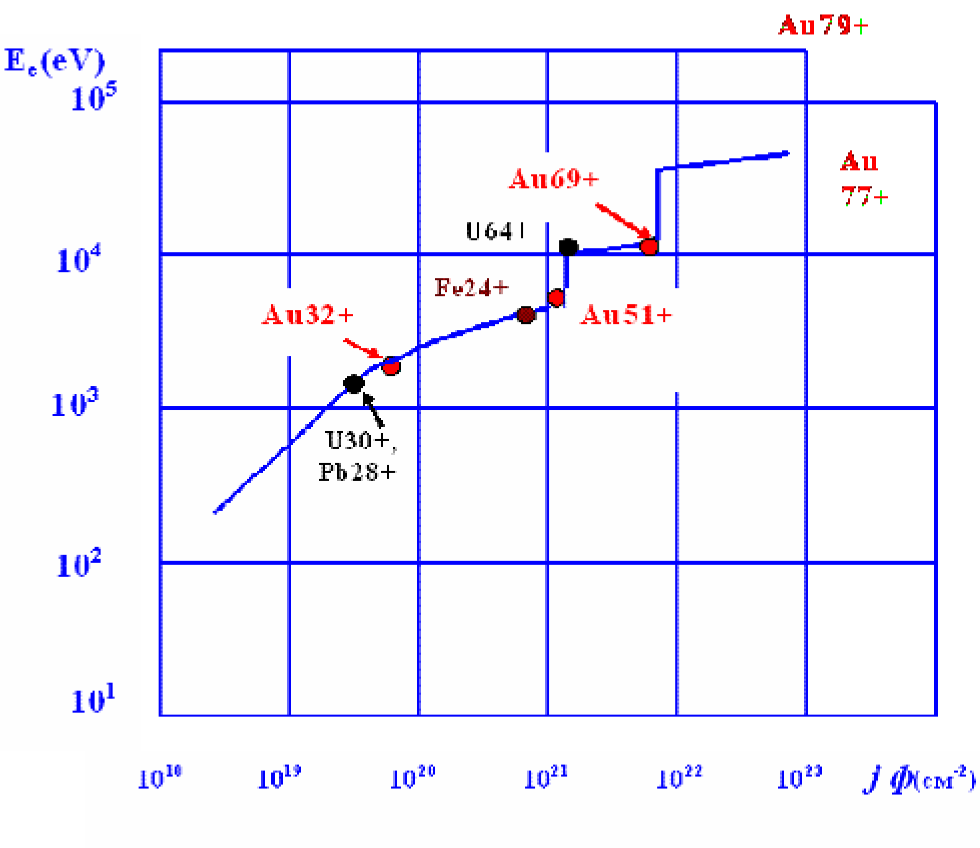
Run № 42: Nov-Dec 2010

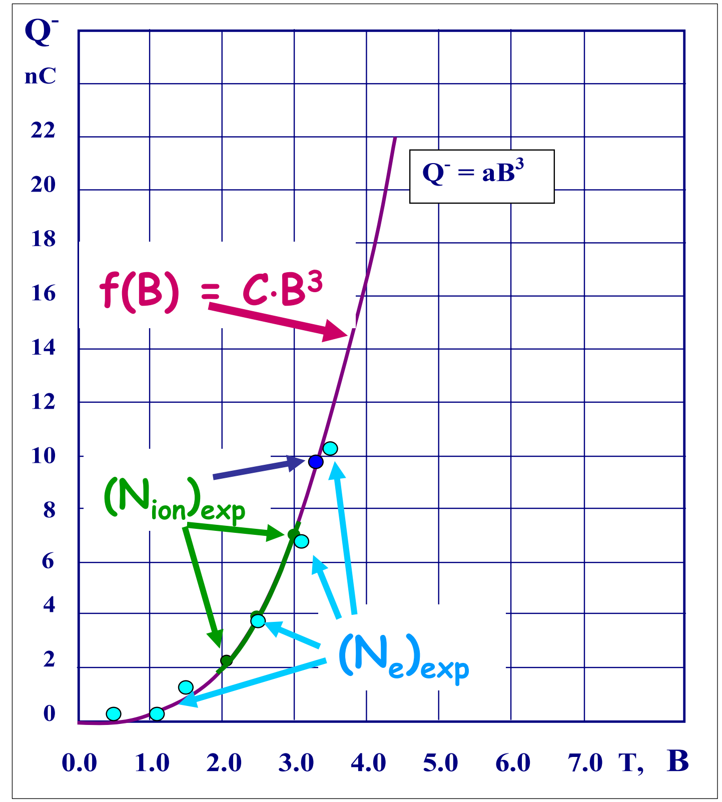
- 500-700 h

- Absolutely new power supply system of the accelerator, magnetic field – up to 1.9-1.95 T;

- Deutrons (probably(!) light ions);

- Fighting with beam losses – intensity increase (new pick-ups, new diagnostics, orbit correction)



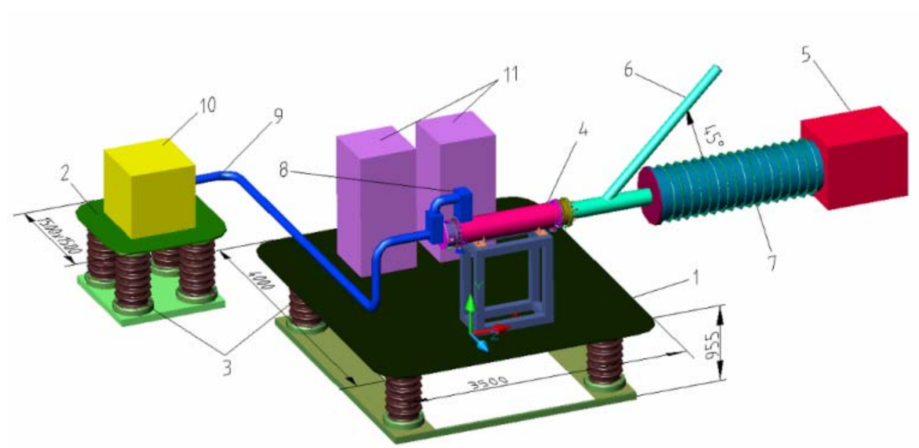


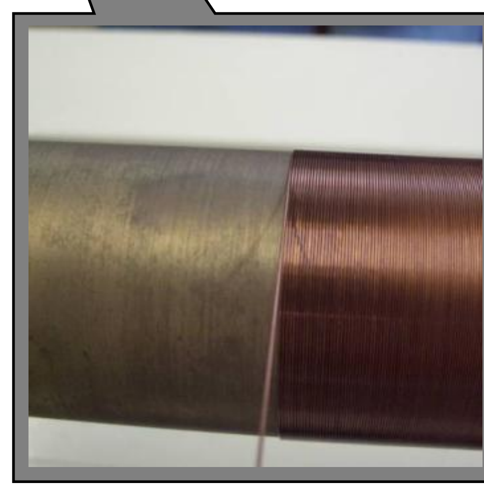
New ESIS "KRION-6T":
$B \leq 6.0$ T,
$E_e \leq 25$ keV

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)	$2 \cdot 10^9$	$5 \cdot 10^8$	$3 \cdot 10^8$
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.



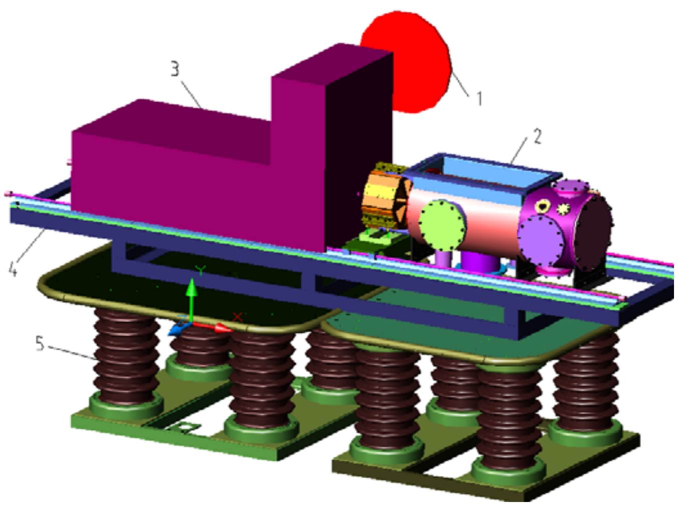


Development and creation of a high-intensity polarized deuteron source (V. Fimushkin)

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.**



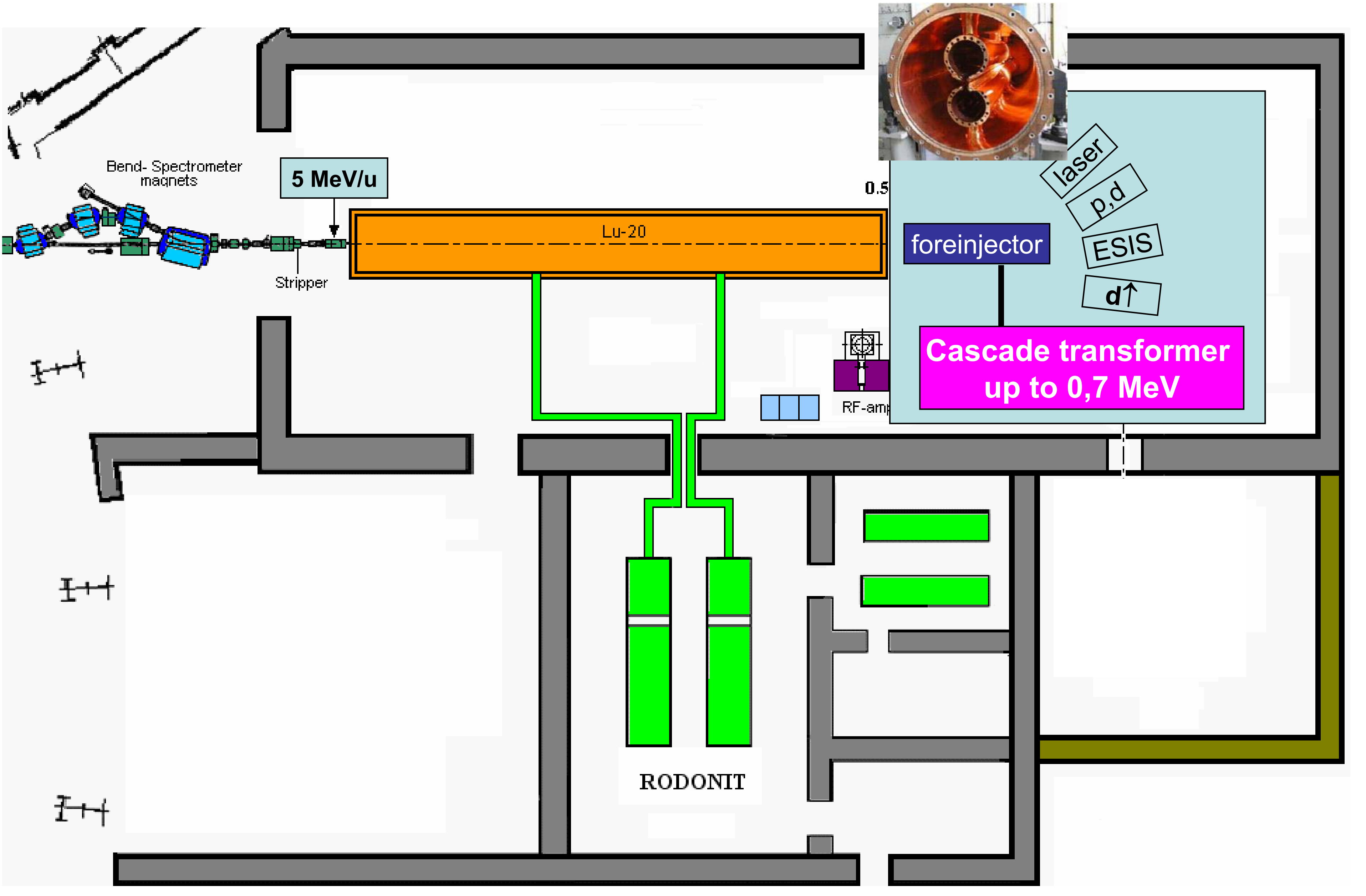
Вакуумная камера диссоциатора и постоянных шестиполюсных магнитов

Вакуумная камера масс-спектрометра

Течеискатель ТИ-14А

Турбомолекулярный насос V3-KT

Баллоны 5л для дейтерия и кислорода



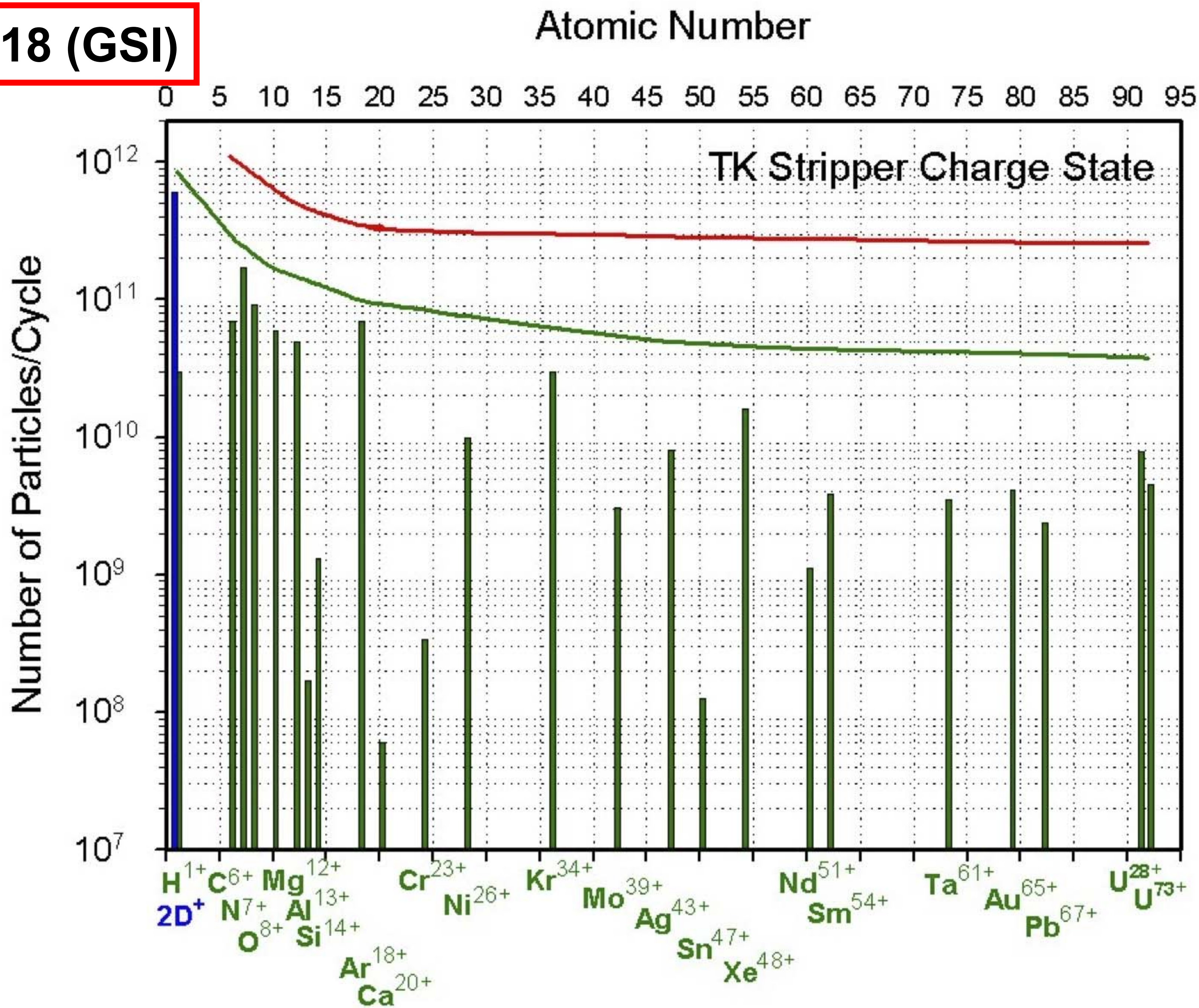
Bend- Spectrometer magnets
5 MeV/u
Lu-20
Stripper
0.5
laser
p,d
ESIS
d↑
foreinjector
Cascade transformer up to 0,7 MeV
RF-amp
RODONIT

Beam	Nuclotron beam intensity, particles per cycle				
	Current	*Ion source type*	*Nuclotron-M (2010)*	*Nuclotron-N (2012)*	*New ion source + booster (2013)*
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 (2013)*
p	4,5 GeV	$5 \cdot 10^{11}$	$8 \cdot 10^{10}$	$5 \cdot 10^{11}$	$5 \cdot 10^{12}$
d	2,2 GeV	$2 \cdot 10^{10}$	$8 \cdot 10^{10}$	$5 \cdot 10^{11}$	$5 \cdot 10^{12}$
^{4}He			$2 \cdot 10^{9}$	$3 \cdot 10^{10}$	$1 \cdot 10^{12}$
d↑			$2 \cdot 10^{8}$	$7 \cdot 10^{10}$ *(SPI)*	$7 \cdot 10^{10}$ *(SPI)*
$^{7}Li^{6+}$			$7 \cdot 10^{9}$	$3 \cdot 10^{10}$	$5 \cdot 10^{11}$
$^{12}C^{6+}$	300 MeV	$7 \cdot 10^{10}$	$6 \cdot 10^{9}$	$3 \cdot 10^{10}$	$3 \cdot 10^{11}$
$^{14}N^{7+}$	300 MeV	$1 \cdot 10^{11}$	$3 \cdot 10^{7}$	$3 \cdot 10^{8}$	$5 \cdot 10^{10}$
$^{24}Mg^{12+}$	300 MeV	$5 \cdot 10^{10}$	$7 \cdot 10^{8}$	$4 \cdot 10^{9}$	$5 \cdot 10^{10}$
$^{40}Ar^{18+}$	300 MeV	$6 \cdot 10^{10}$	$8 \cdot 10^{6}$	$2 \cdot 10^{9}$	$2 \cdot 10^{10}$
$^{56}Fe^{28+}$			$4 \cdot 10^{6}$	$2 \cdot 10^{9}$	$5 \cdot 10^{10}$
$^{58}Ni^{26+}$	300 MeV	$8 \cdot 10^{9}$			
$^{84}Kr^{34+}$	0,3 -1 GeV	$2 \cdot 10^{10}$	$2 \cdot 10^{5}$	$1 \cdot 10^{8}$	$1 \cdot 10^{9}$
$^{124}Xe^{48/42+}$	0,3 -1 GeV	$1 \cdot 10^{10}$	$1 \cdot 10^{5}$	$7 \cdot 10^{7}$	$1 \cdot 10^{9}$
$^{181}Ta^{61+}$	1 GeV	$2 \cdot 10^{9}$			
$^{197}Au^{65/79+}$		$3 \cdot 10^{9}$		$1 \cdot 10^{8}$	$1 \cdot 10^{9}$
$^{238}U^{28+}$	0,05-1 GeV	$5 \cdot 10^{9}$			

SIS18 (GSI)

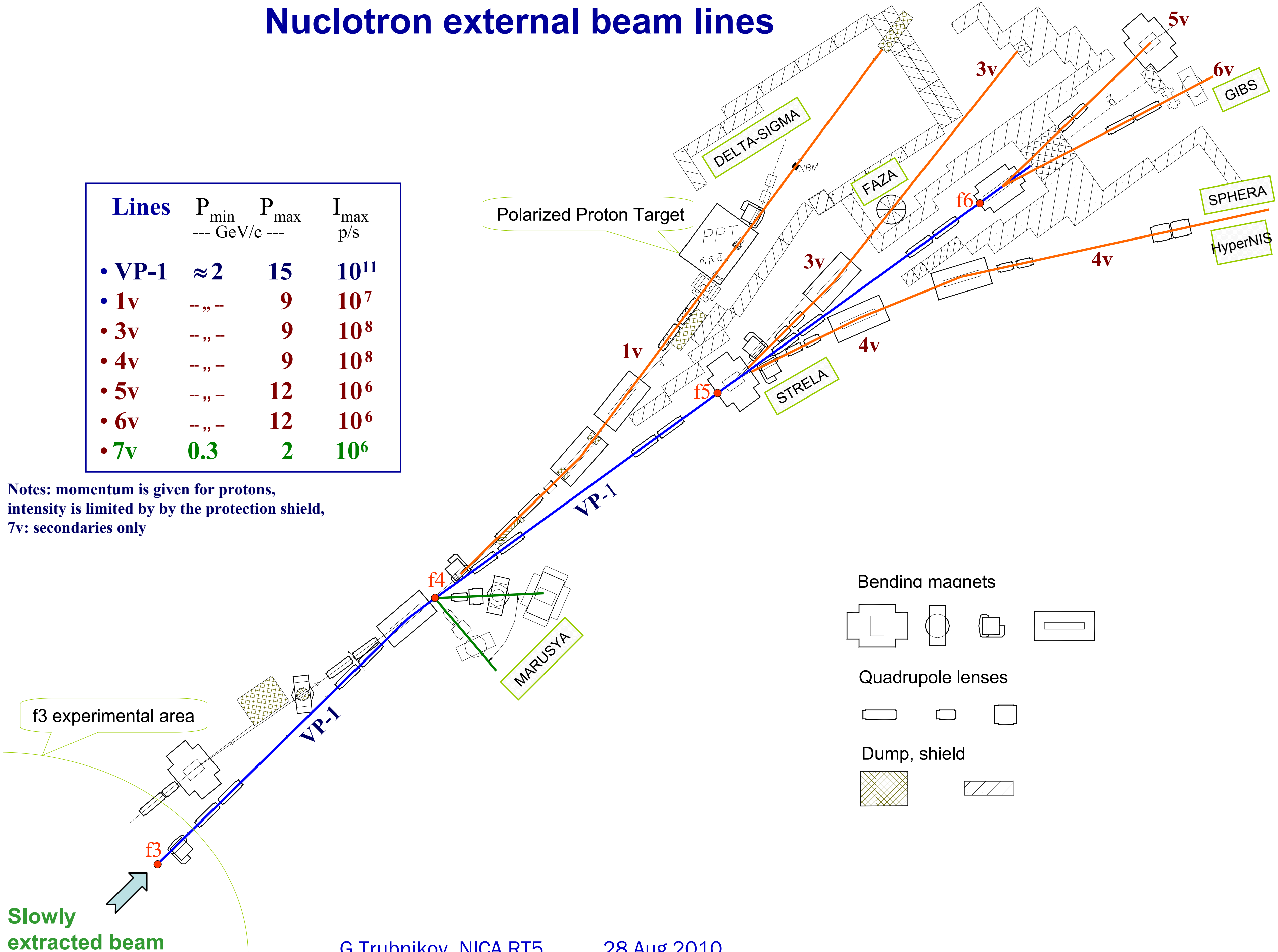


Atomic Number
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
TK Stripper Charge State
Number of Particles/Cycle
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
H^{1+}
$2D^{+}$
C^{6+}
N^{7+}
O^{8+}
Mg^{12+}
Al^{13+}
Si^{14+}
Ar^{18+}
Ca^{20+}
Cr^{23+}
Ni^{26+}
Kr^{34+}
Mo^{39+}
Ag^{43+}
Sn^{47+}
Xe^{48+}
Nd^{51+}
Sm^{54+}
Ta^{61+}
Au^{65+}
Pb^{67+}
U^{28+}
U^{73+}

Nuclotron external beam lines

Lines	P_{min}	P_{max}	I_{max}
	--- GeV/c ---		p/s
• VP-1	≈ 2	15	10^{11}
• 1v	-- „ --	9	10^{7}
• 3v	-- „ --	9	10^{8}
• 4v	-- „ --	9	10^{8}
• 5v	-- „ --	12	10^{6}
• 6v	-- „ --	12	10^{6}
• 7v	0.3	2	10^{6}

Notes: momentum is given for protons,
intensity is limited by by the protection shield,
7v: secondaries only



Nuclotron beam slow extraction.

Parameter	Design	Obtained
Energy range, GeV/amu	0.2 - 6.0	0.2 - 2.2
Duration, s up to	10	10
Extraction efficiency, %		
at 0.2 GeV/amu	90	95
at 2.2 GeV/amu	95	95
Extraction angles, mrad		
horizontal	5	5
vertical	96 ⌖ 6	96 ⌖ 1
Nominal ES voltage, kV	200	200
Exploitation ES voltage, kV	up to 200	up to 150
LM supply current, kA	up to 6.3	6.3
Repetition rate, Hz	1.0	1.0

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

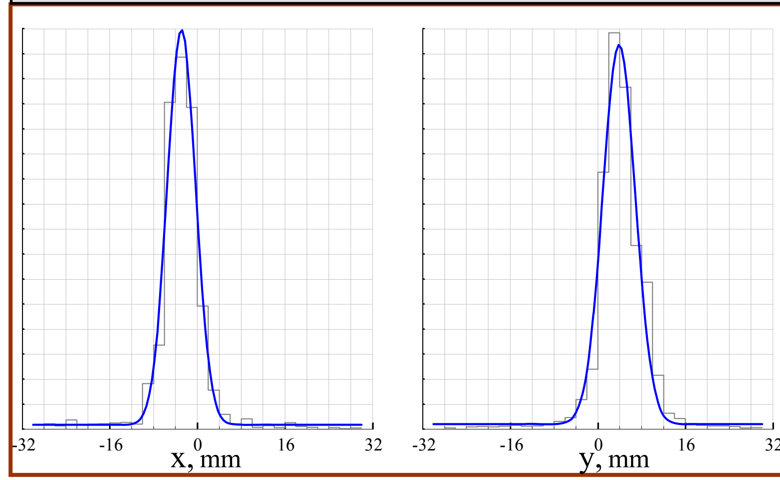
Prototype of new high voltage power supply for the electro-static septum was constructed and successfully tested up to **220 kV** (existing septum power supply allows up to 110 kV only – it corresponds to 2,3 GeV/n extracted beam).

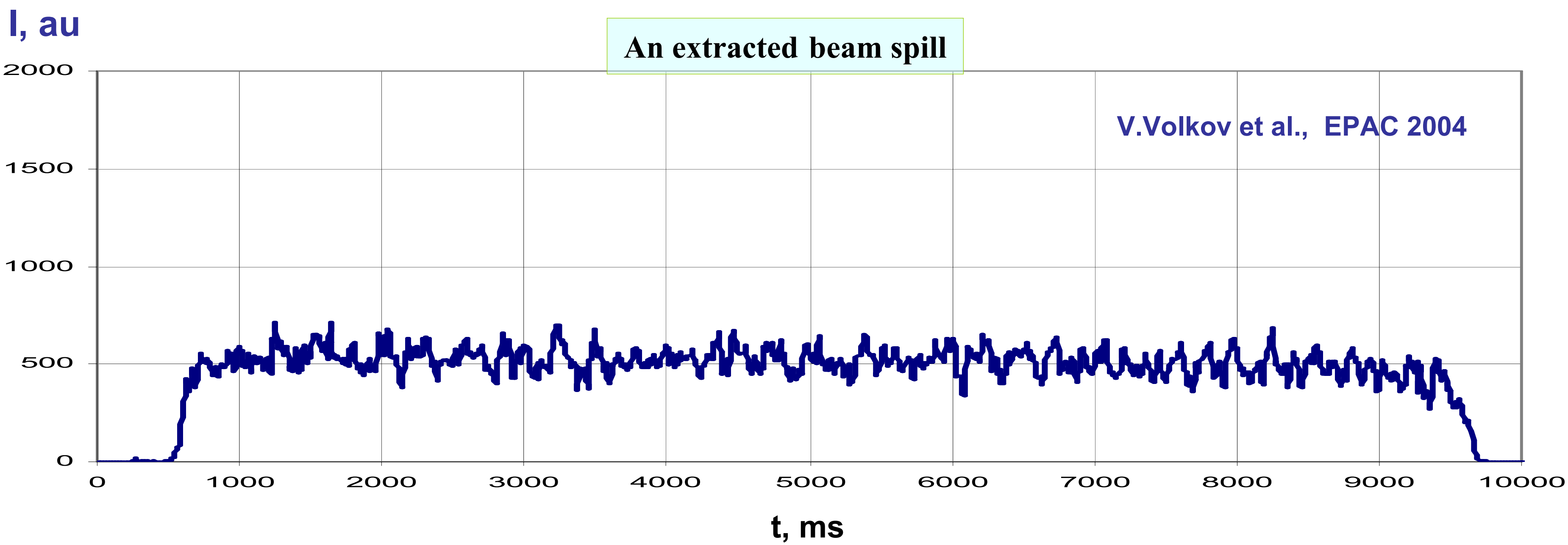
We plan to install it in the slow extraction sector in order to provide experiments on beam extraction at energy 4 GeV/n during next Nuclotron run - **done (tested at 150 kV).**

Nuclotron slow extraction

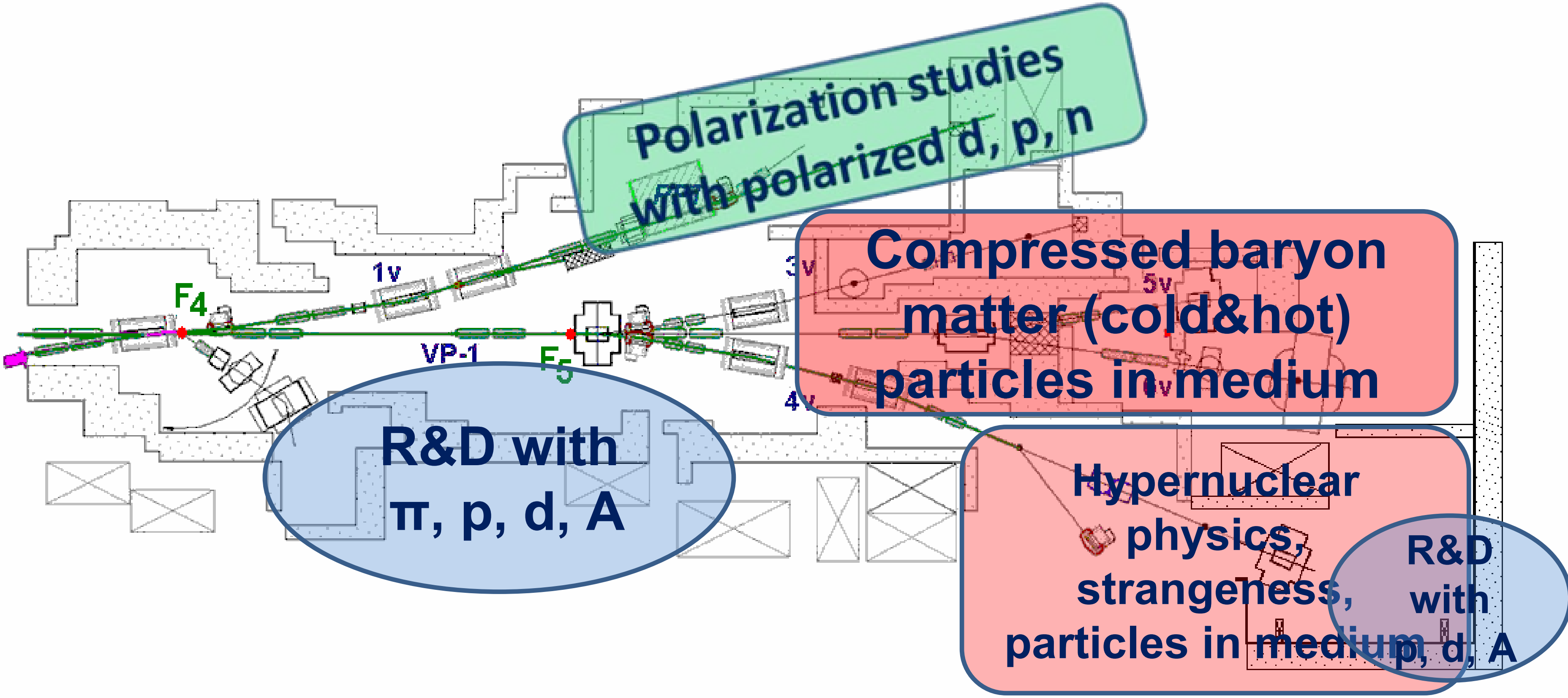
Parameter	@	Units	Value
Momentum range	Z/A = 1/2	Gev/c/amu	0.6 – 6.8
Momentum spread, σ		%	0.04 – 0.08
Extraction time		sec	10
Beam emittance	P_{max}	mm·mr	2π
Beam size in a waist, σ	P_{max}	mm	≤ 1
Extraction efficiency		%	> 90
Beams	p, d, d↑, α, ^{6,7}Li, ^{10,11}B, ^{12}C, ^{14}N, ^{24}Mg, ^{56}Fe		

Beam profiles at the F_5 focus.
Deuterons, p_{beam} = 4.3 GeV/c, σ_x = 2.6 mm, σ_y = 3.0 mm

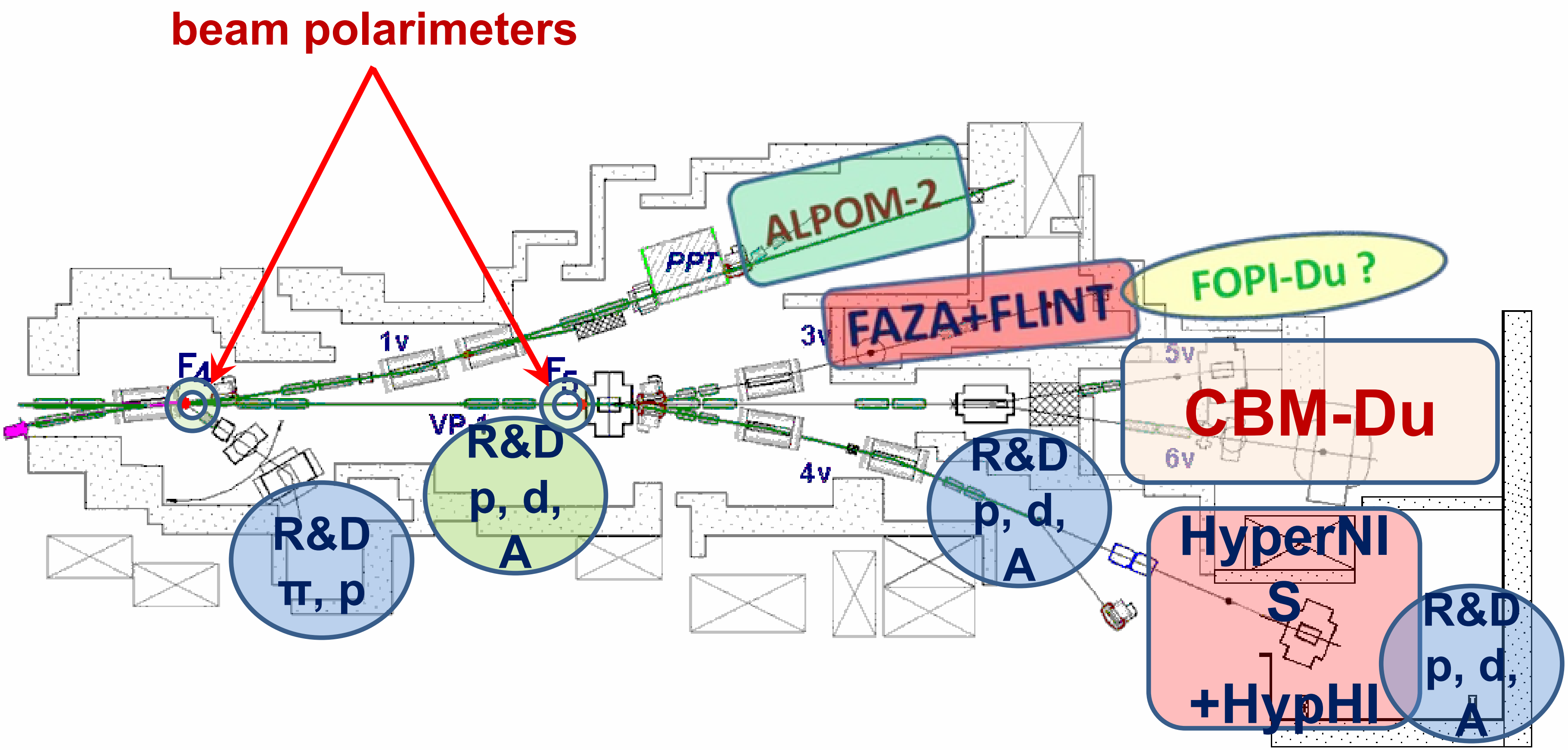




“Fixed target” experiments (2011-2015 - … years) at existing extracted beams



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



Summary

• The sufficient progress in Nuclotron upgrade is achieved;

• NICA project is going well and this is a main flagship and front activity of the LHEP/JINR;

• Nearest 1-2 years dedicated team will devote to modernization of fixed target experimental area and extraction beam channels (in parallel to NICA facility construction);

• Starting from 2011 LHEP is ready to offer extracted beams (p…Heavy Ions) for international collaborations. Beam intensity will be increasing from year to year up to frontier level at 2014;

• Beam users are very welcome to NICA ground to join with their installations for forming the international community on DBM physics.

Thank you for your attention.