BRAZIL-JINR FORUM
"Frontiers in Nuclear, Elementary Particle,
and Condensed Matter Physics"
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Accelerator complex of the Flerov Laboratory: present and future (Project DRIBs-III)

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Basic directions of researches at FLNR

1. Heavy and superheavy nuclei

- Synthesis and study of properties of superheavy elements
- Chemistry of new elements
- Fusion-fission and multi-nucleon transfer reactions
- Mass-spectrometry and nuclear spectroscopy of SH nuclei

2. Light exotic nuclei

- Properties and structure of light exotic nuclei
- Reactions with exotic nuclei

3. Radiation effects and physical bases of nanotechnology

4. Accelerator technology

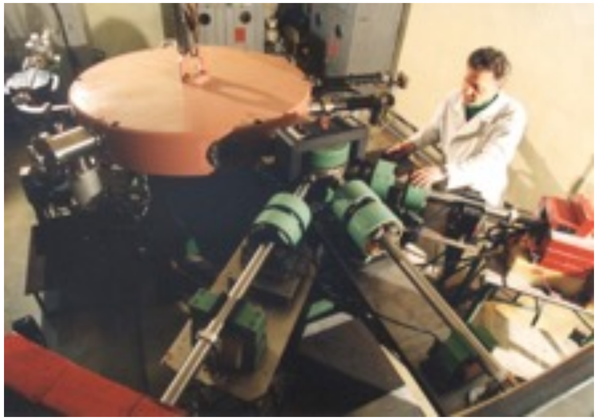
FLERQV LAB's ACCELERATORS
≈ 15,000 hours/year

U400M

U400

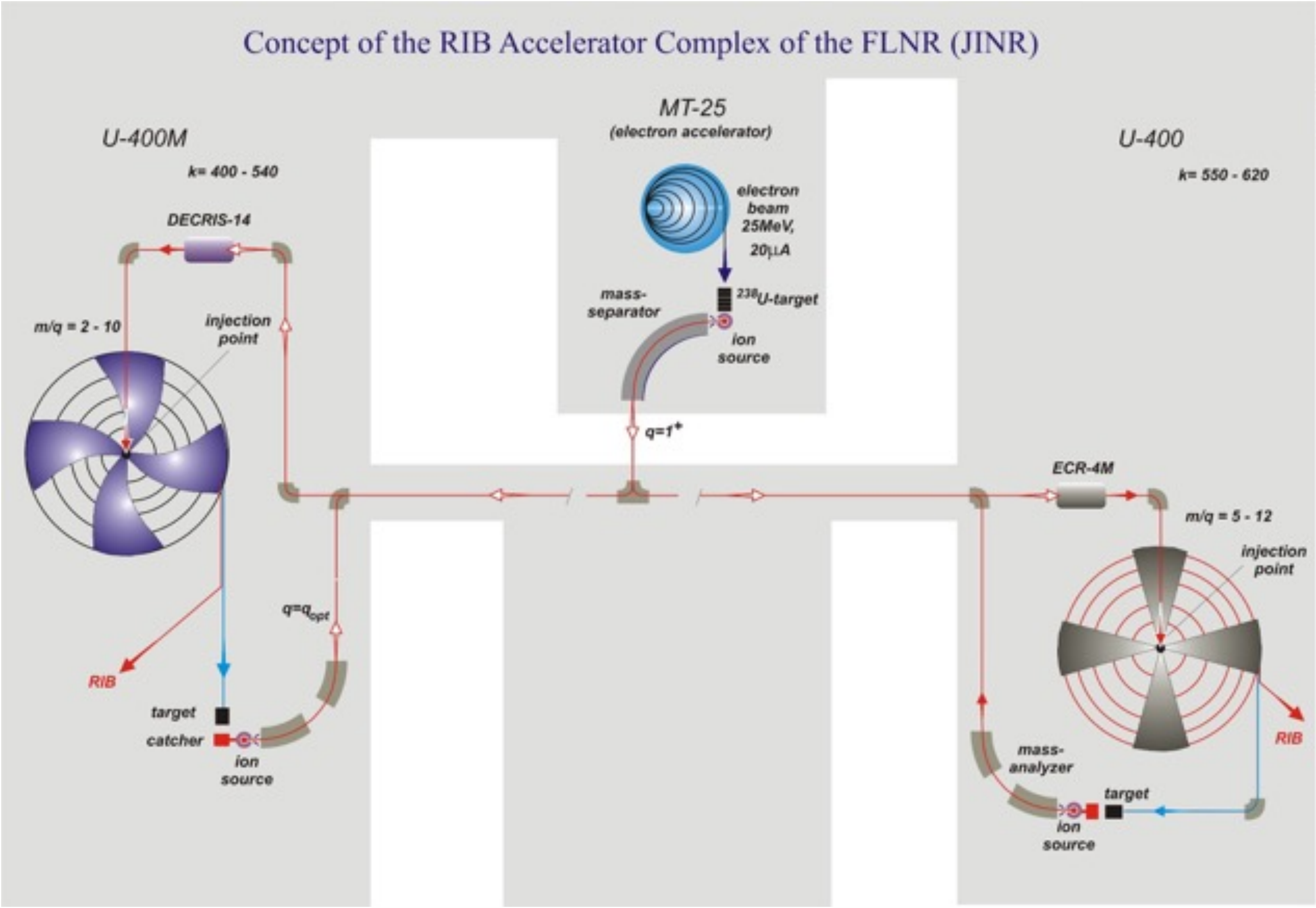
U200

IC-100

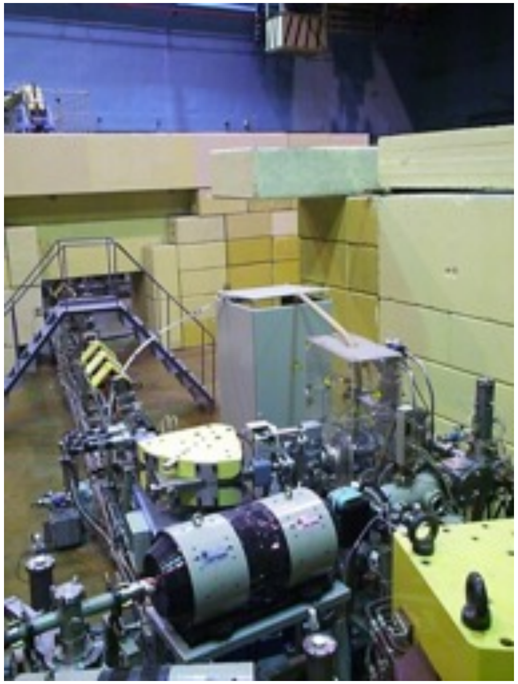


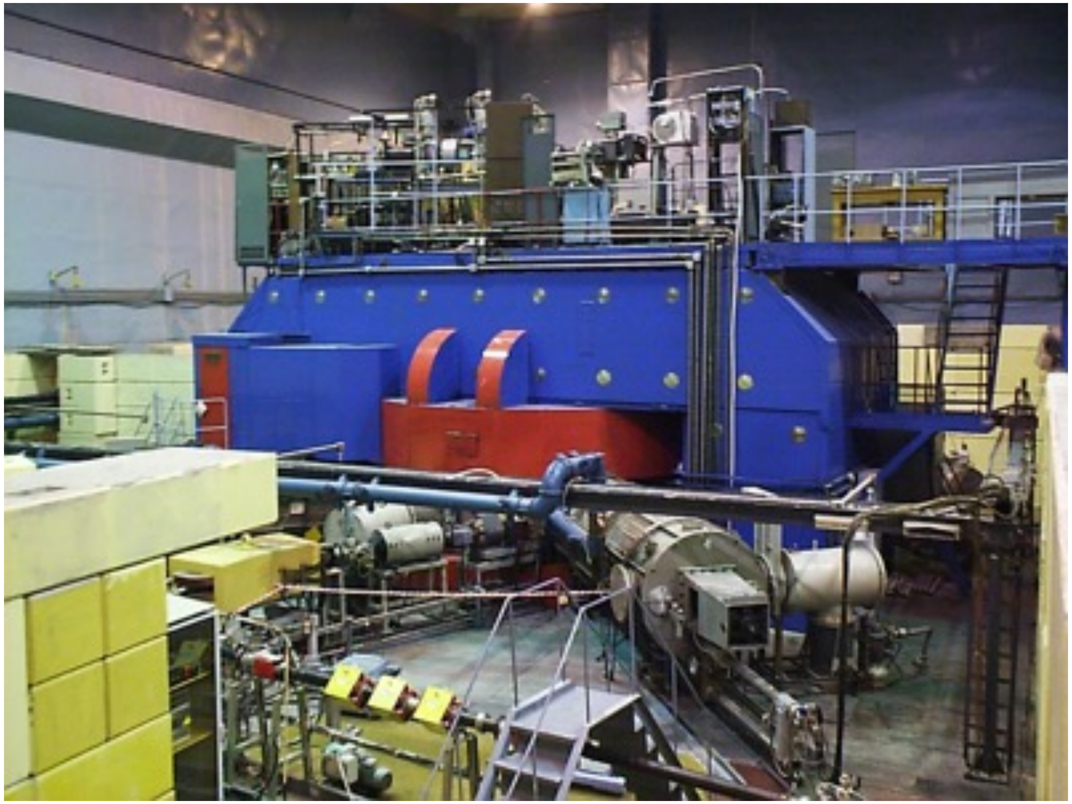
MT-25

Plan to upgrade the facilities of the Flerov Laboratory (DRIBs, 2002)



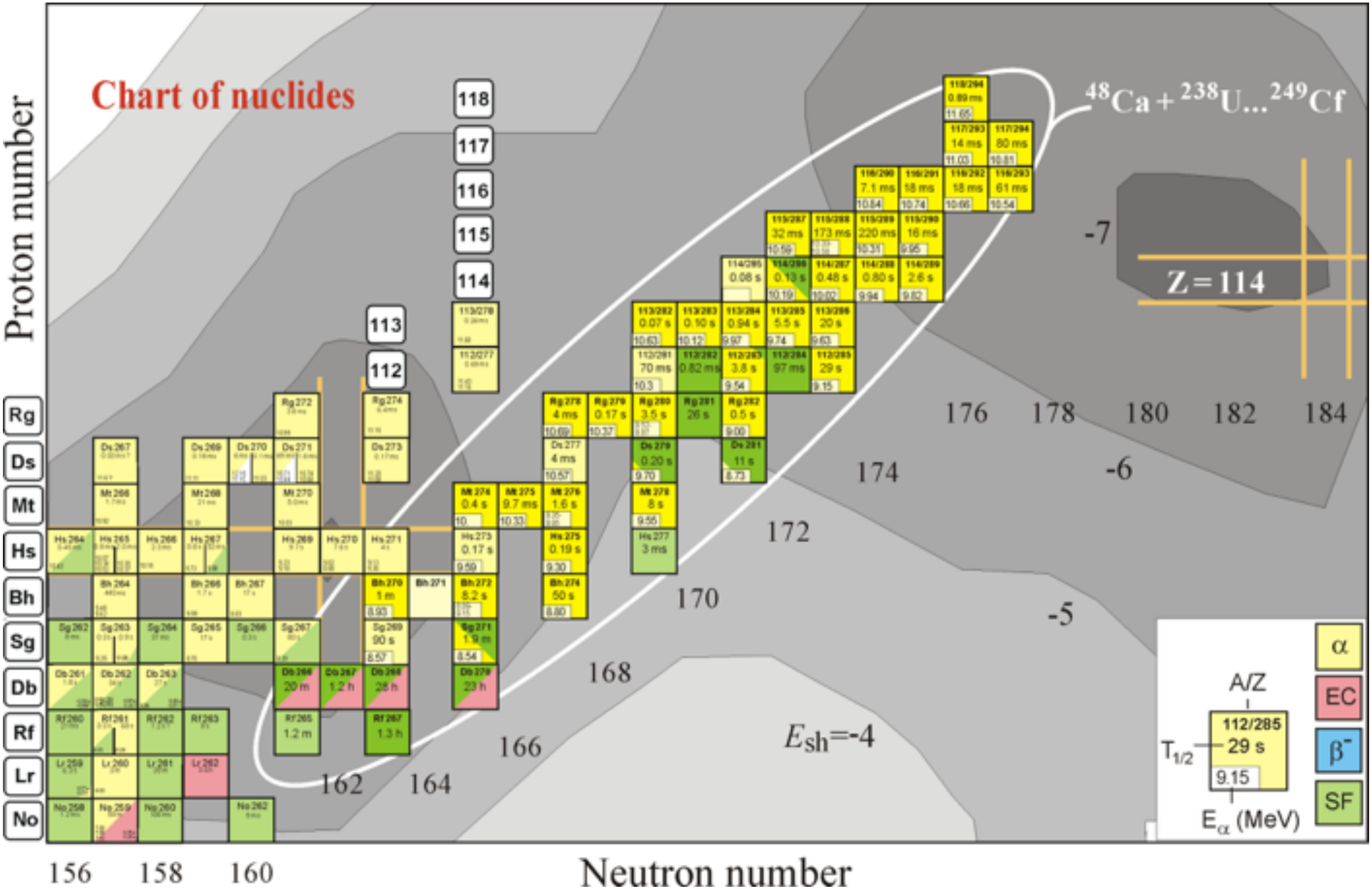
DRIBs – I
U400M – driver-accelerator
Production target
Beam transport line





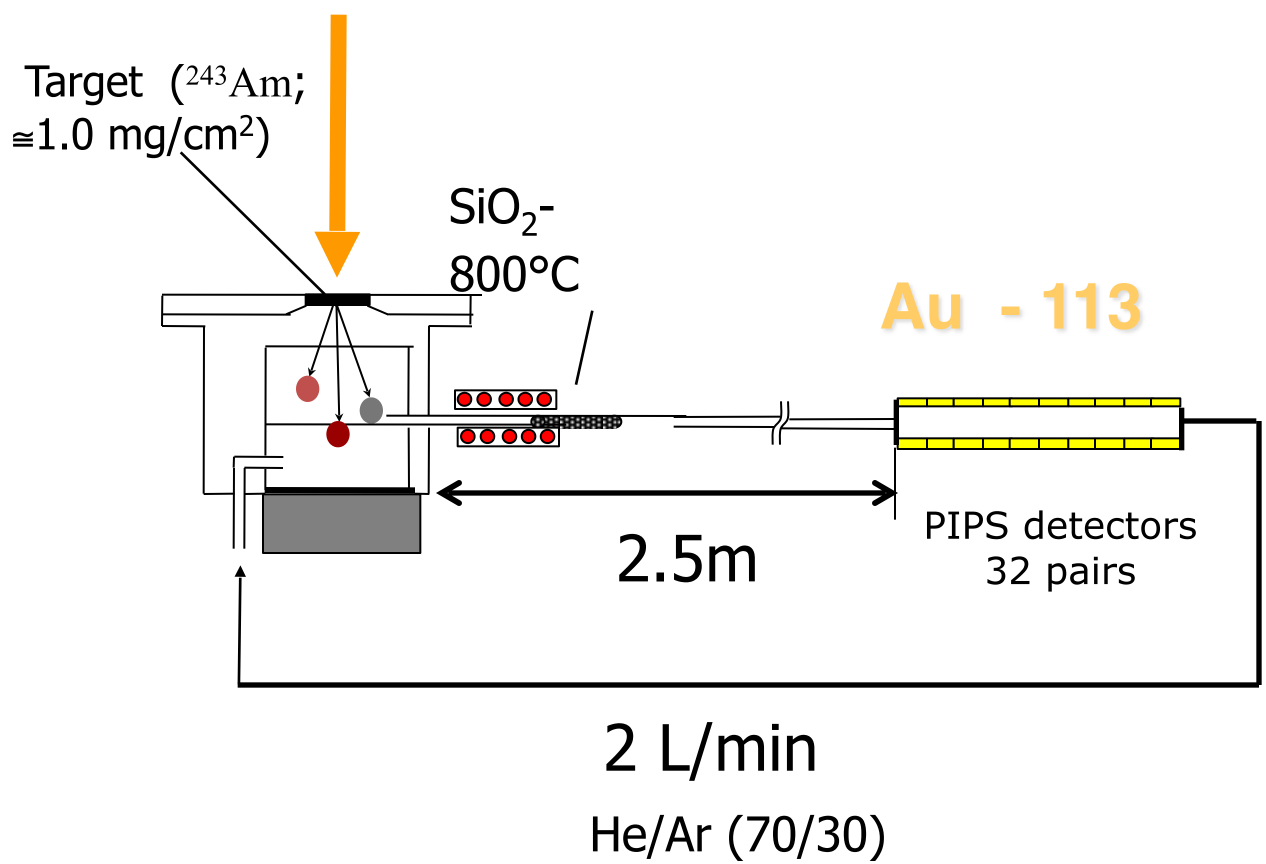
DRIBs – I
Transportation gallery
Beam injection
U400 – post accelerator

Chart of the Nuclides (decay modes)



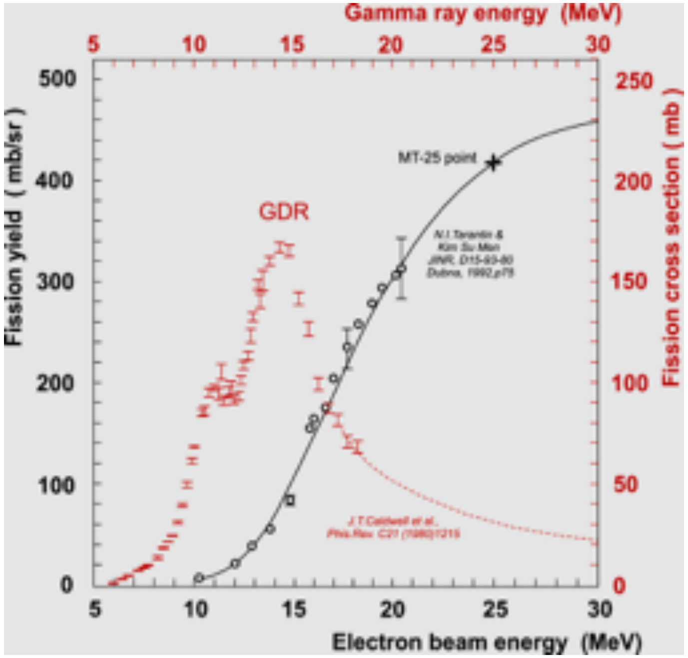
GAS PHASE CHEMISTRY WITH ELEMENT 113

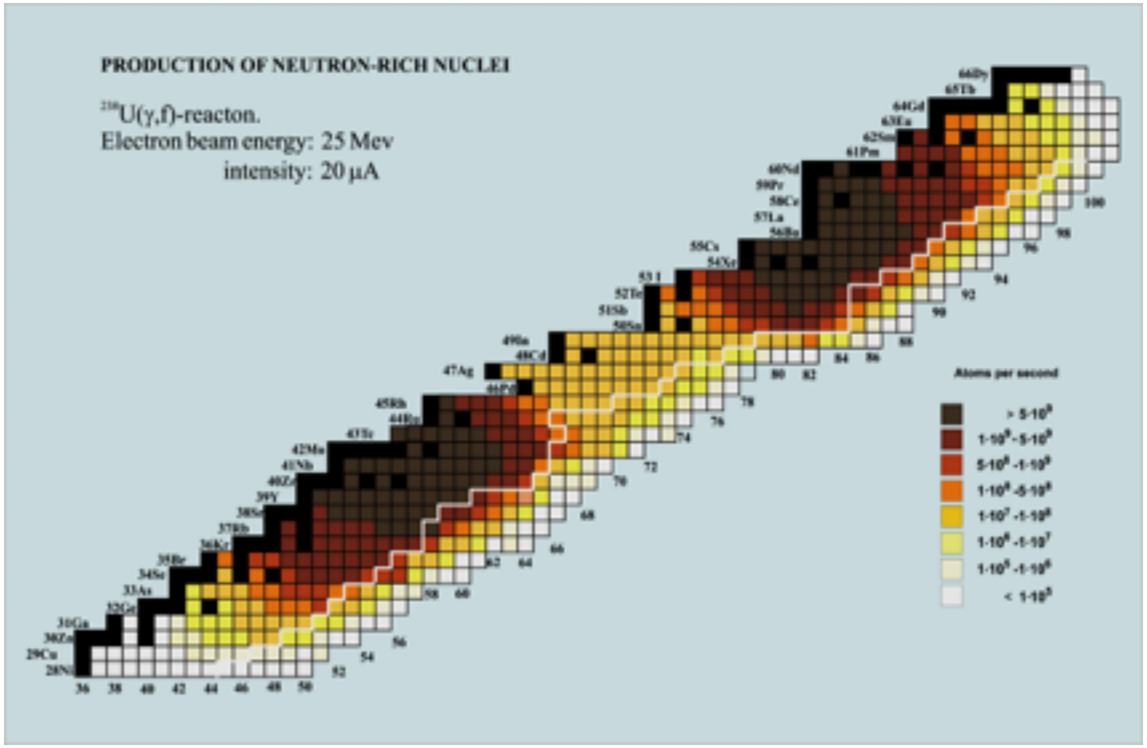
Whether the element 113 is a volatile metal?
Experiment is running. Preliminary results – it is volatile.



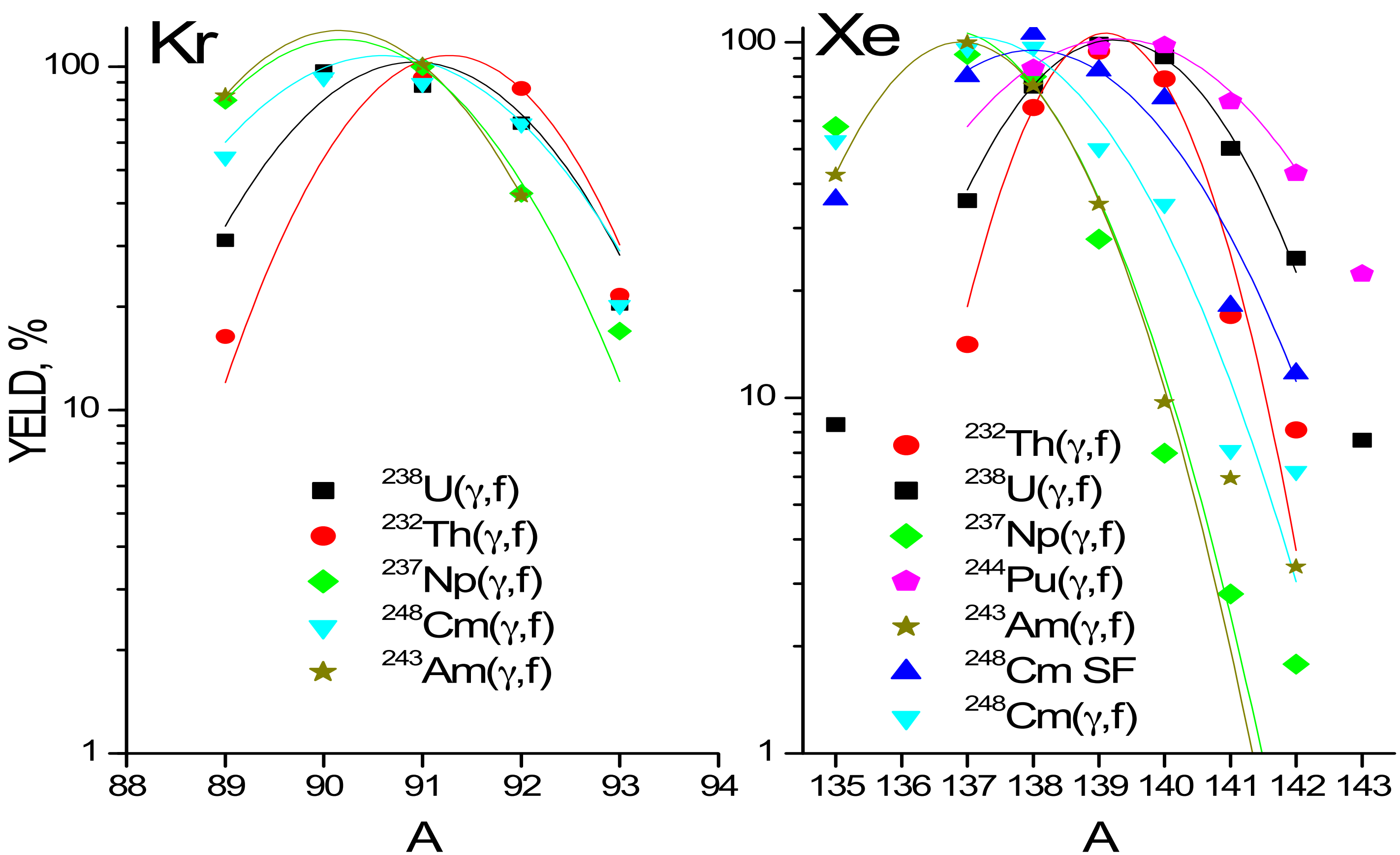
DRIBs-II

MICROTRON MT-25
Electron energy: 25 MeV
Beam intensity: 20 μA
γ-ray flux: 10^{14} s^{-1}
Target size: 30 × 15 mm^2 = 100g
Fission rate: 1.3×10^{11} s^{-1}



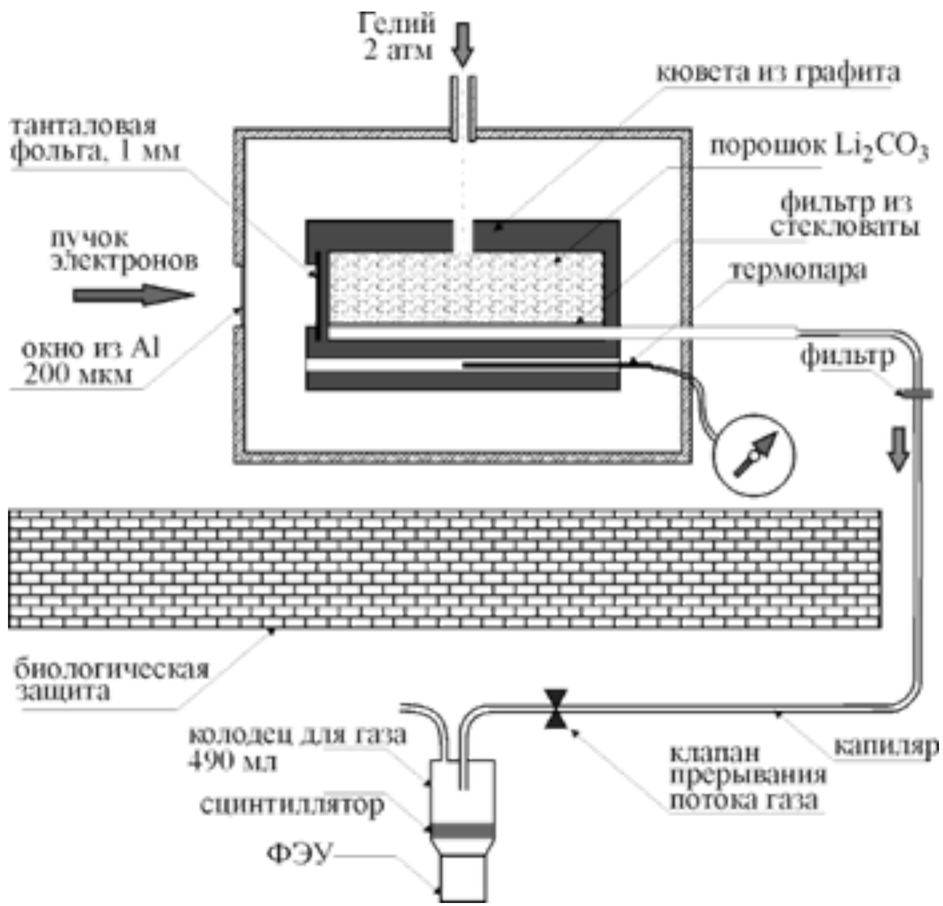


Yields of Kr and Xe isotopes in photofission of actinides at γ-energy of 25 MeV

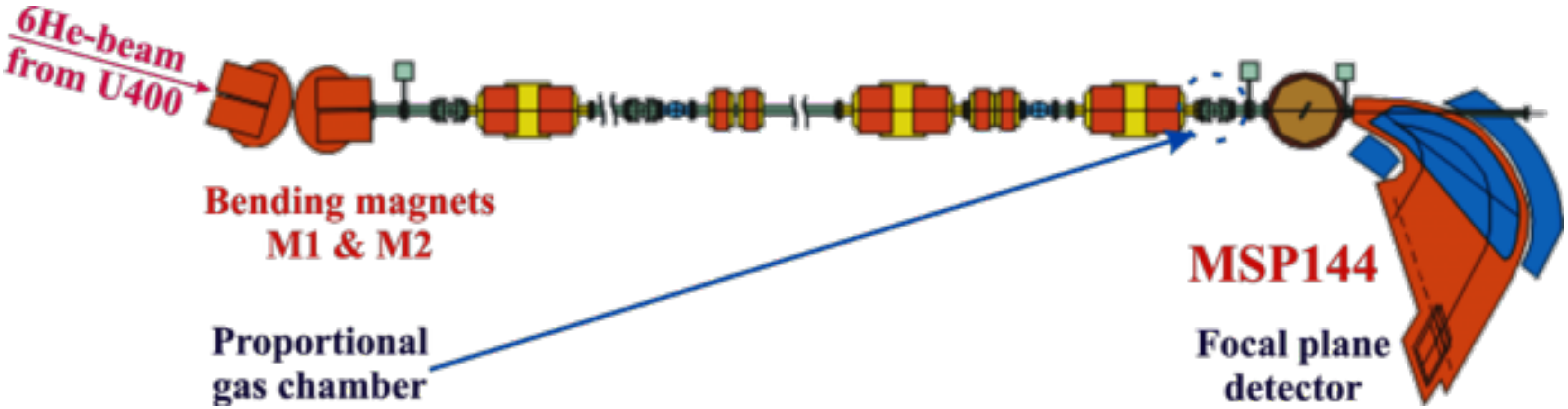


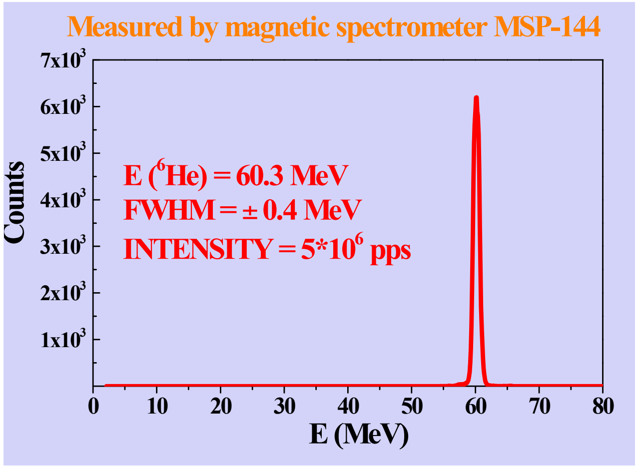
Due to hard radiation conditions the project was stopped (not cancelled!)

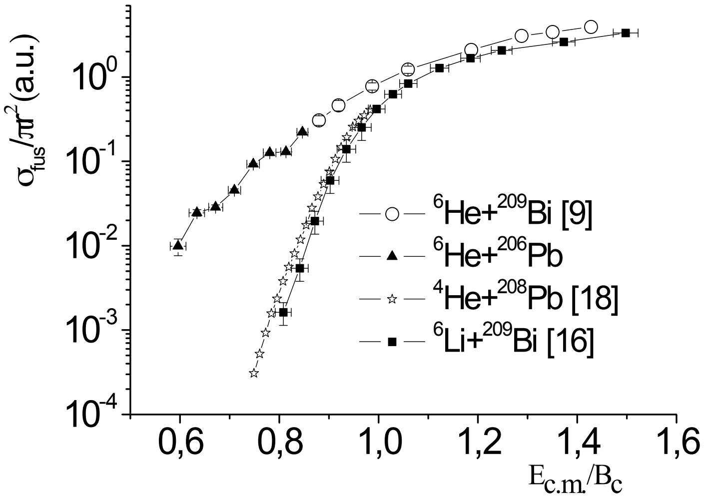
Setup for ^{6}He production study in ^{7}Li(γ,p)^{6}He reaction



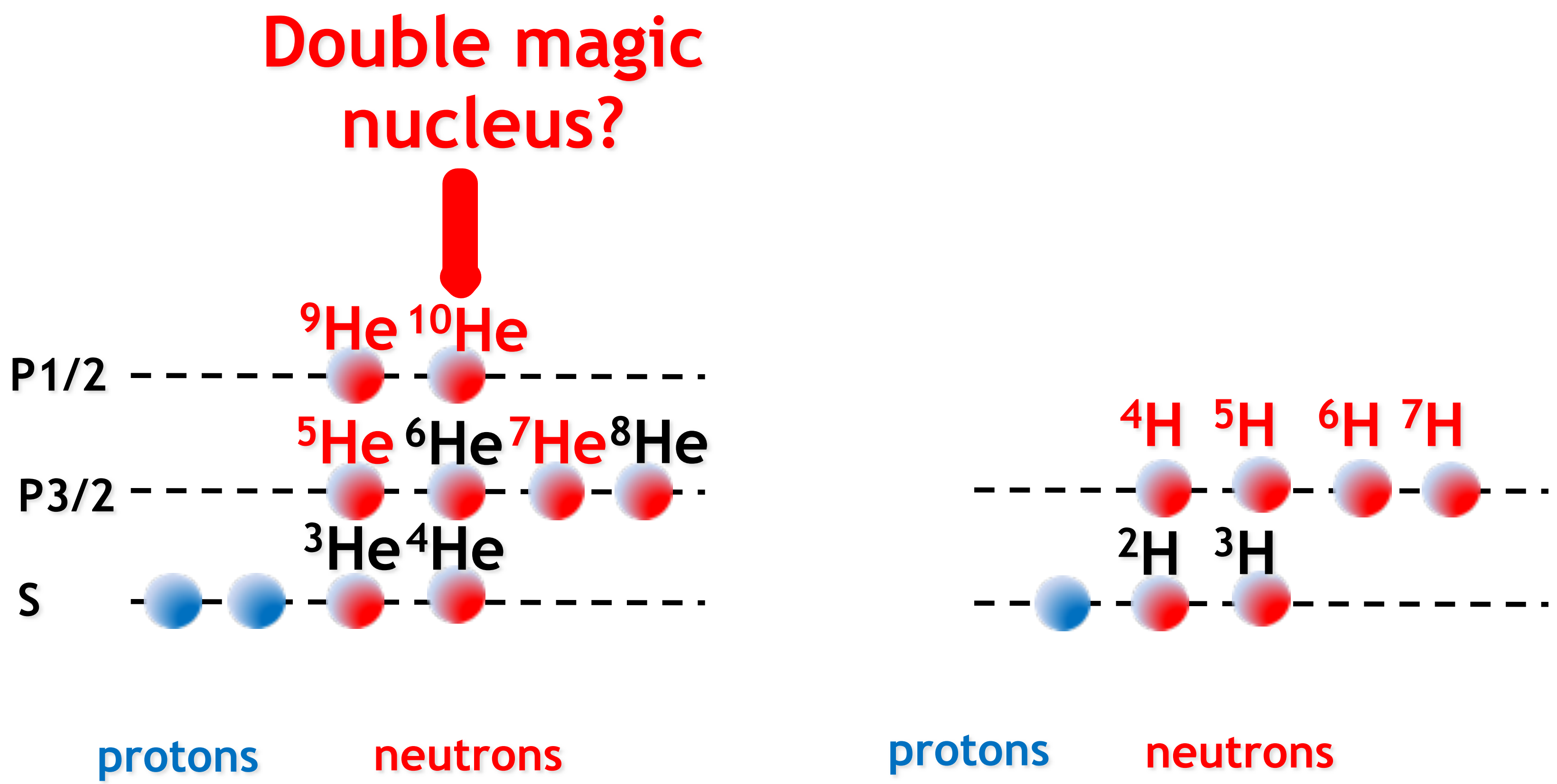
DRIBs-I: experiments with ^{6}He beam



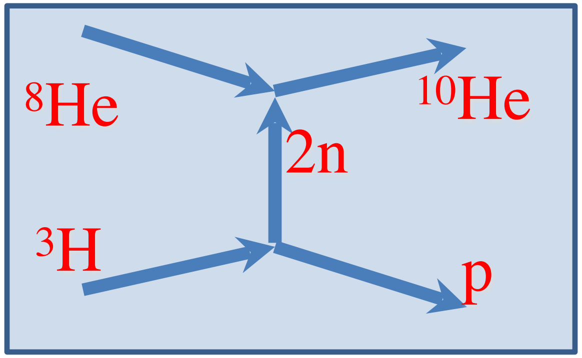


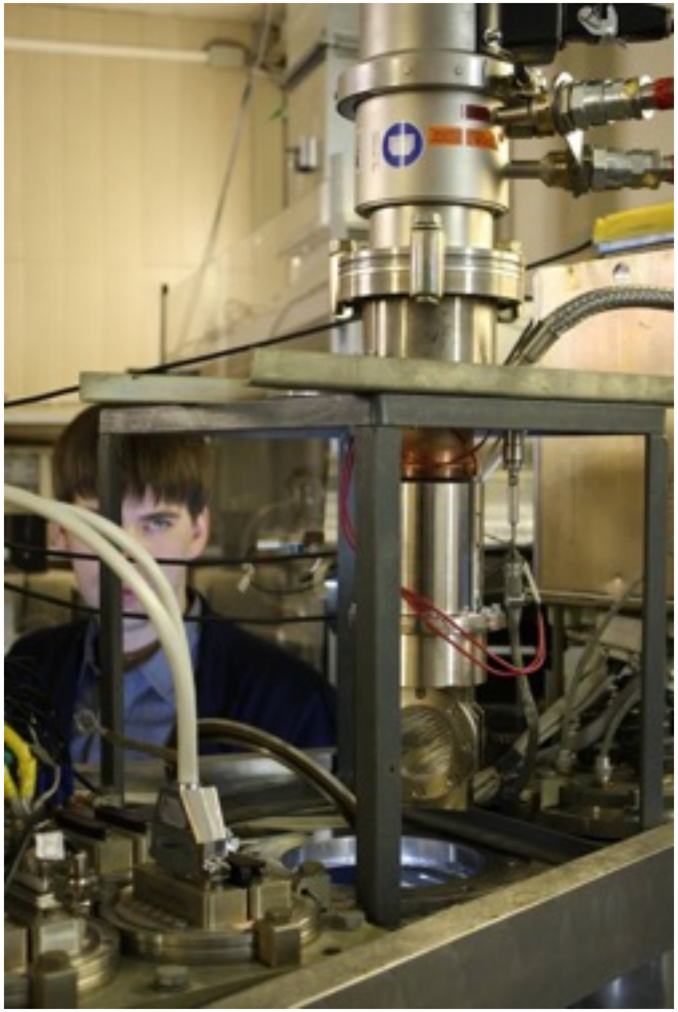


Light superheavies

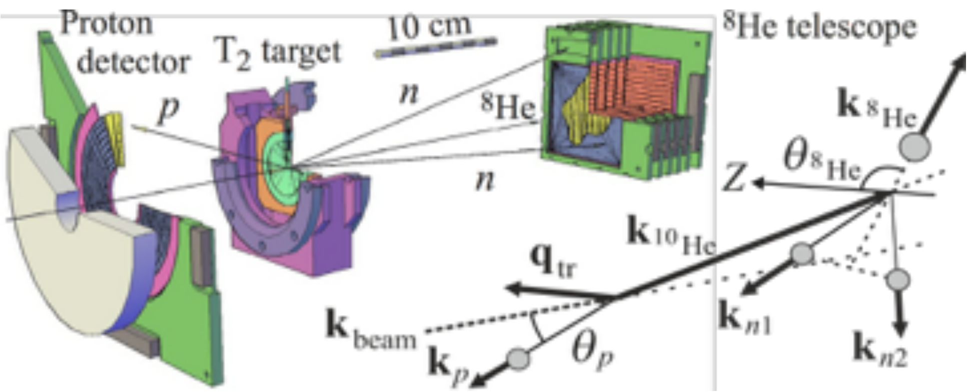


^{10}He: 2n-transfer



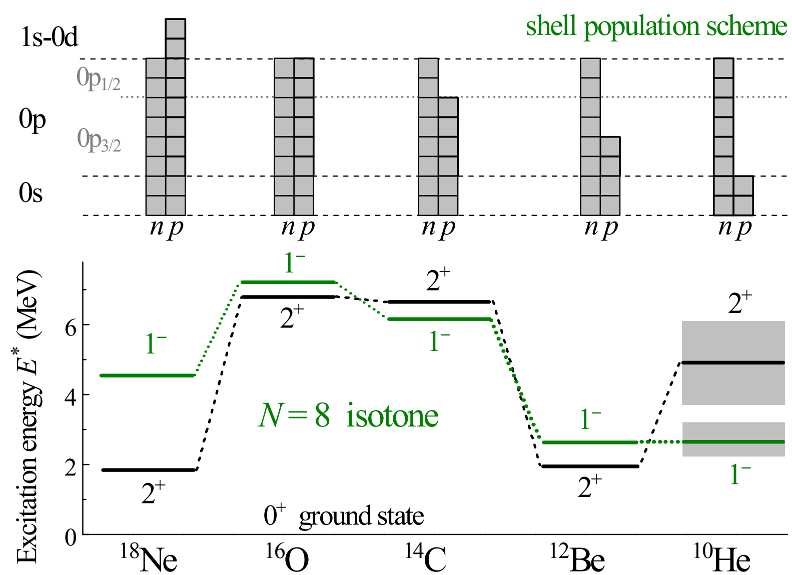


Breakdown of the N=8 shell in ^{10}He.



^{10}He was produced in the 2*n*-transfer reaction
with the use of the secondary ^{8}He beam and
cryogenic tritium target: ^{3}H(^{8}He,*p*)^{10}He.

Owing to specific angular and energy correlations of ^{10}He decay products for the first time the spin-parity assignment was made for the low-lying states of ^{10}He.
The experimental data were interpreted as a superposition of 0^+, 1^- and 2^+ states.
The established level sequence shows that ^{10}He is one more drip-line nucleus demonstrating the shell structure breakdown.

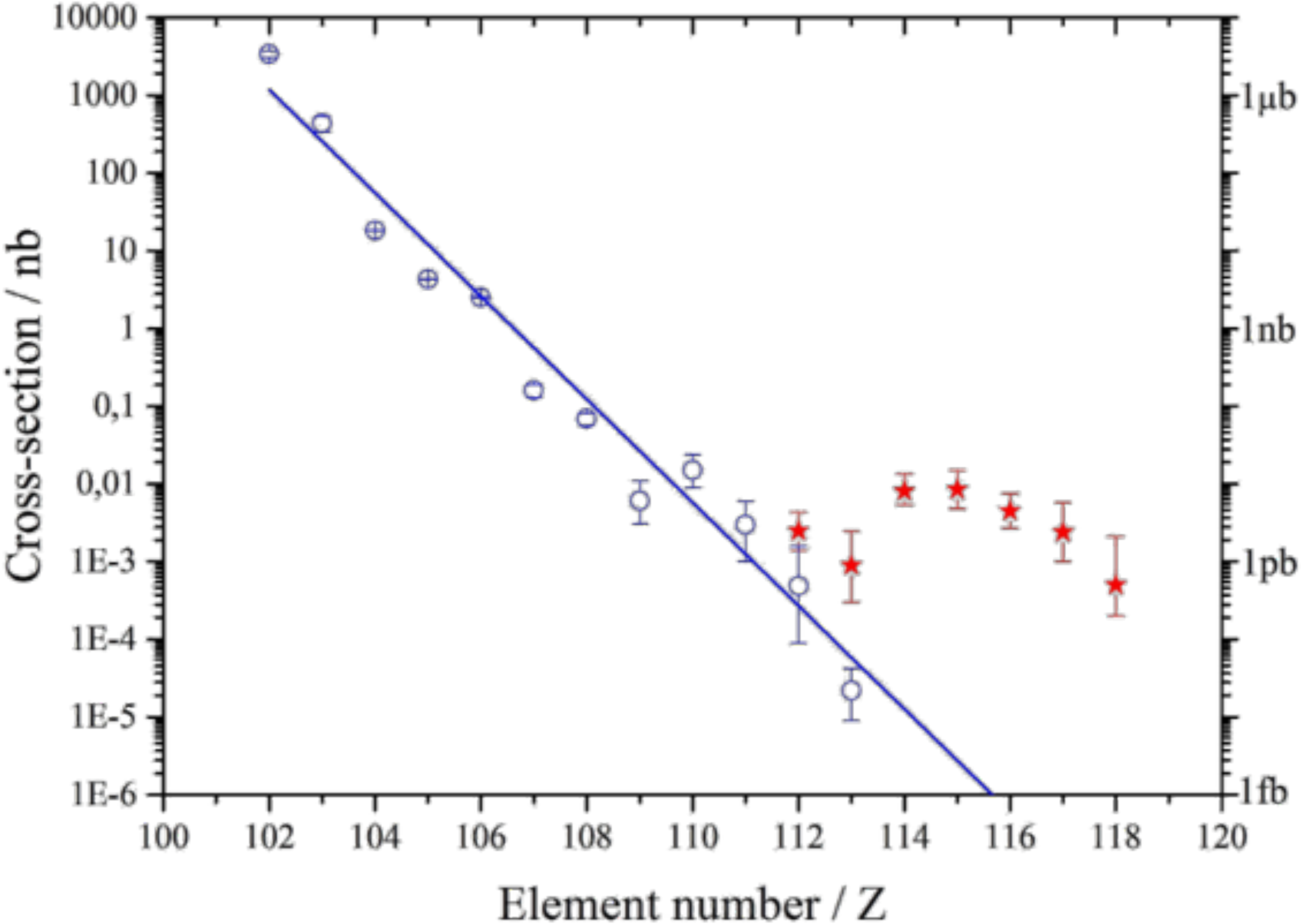


That we have learnt:

- SHE can be synthesized;
- Chemistry of SHE can be studied;
- We have only 12,000 hours beam time / year;
- We need new facilities;
- We have not enough experimental space;
- In the RIB-mode only one experiment can run;
- We can not accelerate ions heavier than Xe;
- Radiation safety requirements are strong;

Targets – radiation safety

Production cross-sections of heavy and super-heavy



100 / h

1 / week

1 / 20 y

What is beyond 118 element?

Heaviest target: $^{249}Cf \rightarrow Z_{max} = 118$

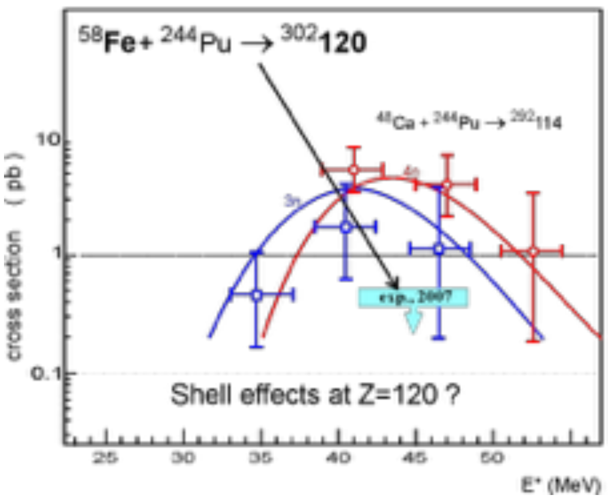
↓

- **Heavier projectiles (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni)**
- **Heavier targets (^{251}Cf, ^{254}Es -???);**
- **Symmetric reactions: $^{136}Xe+^{136}Xe$, $^{136}Xe+^{150}Nd$, $^{150}Nd+^{150}Nd$;**
- **Multi–Nucleon–Exchange - Reactions with RIB (??, or colliders – technique – (K4-K10)):**
- **Nucleon transfer reactions ($^{136}Xe+^{208}Pb$, $^{238}U+^{248}Cm$).**

Sufficient increasing of overall experiment efficiency is needed!

Alternative methods for synthesis of SHE

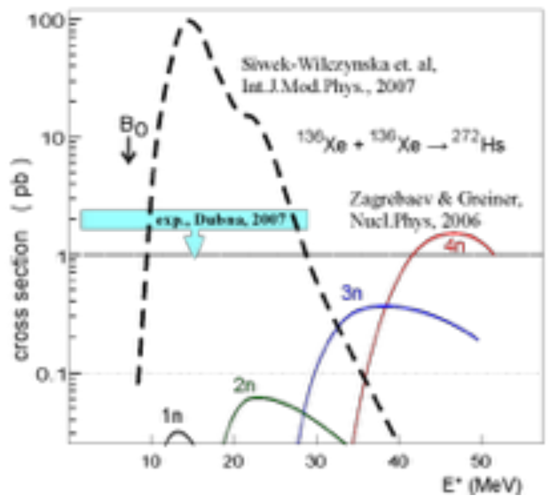
Heavier that ^{48}Ca projectiles



More intensive beam is needed

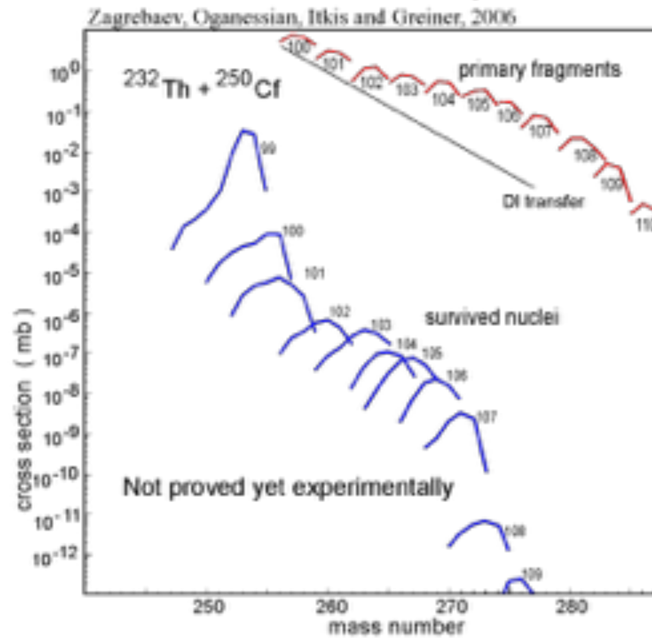
Fusion of accelerated fission fragments

$^{132}Sn + ^{176}Yb \rightarrow ^{308}120$



No chances for low-intensive beams of accelerated fission fragments like ^{132}Sn

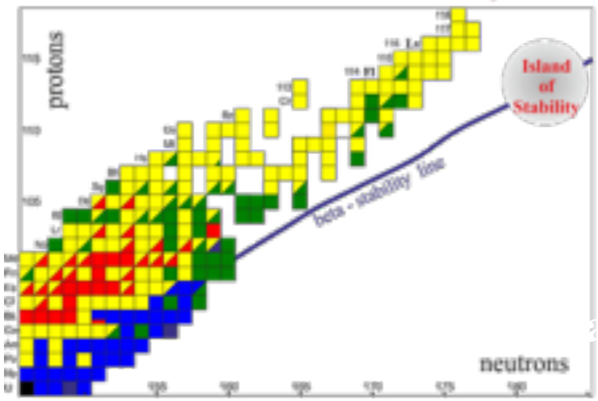
Multi-nucleon transfer in damped collisions



^{160}Gd + ^{186}W is a good testing reaction

In search of a new way to the Island of Stability

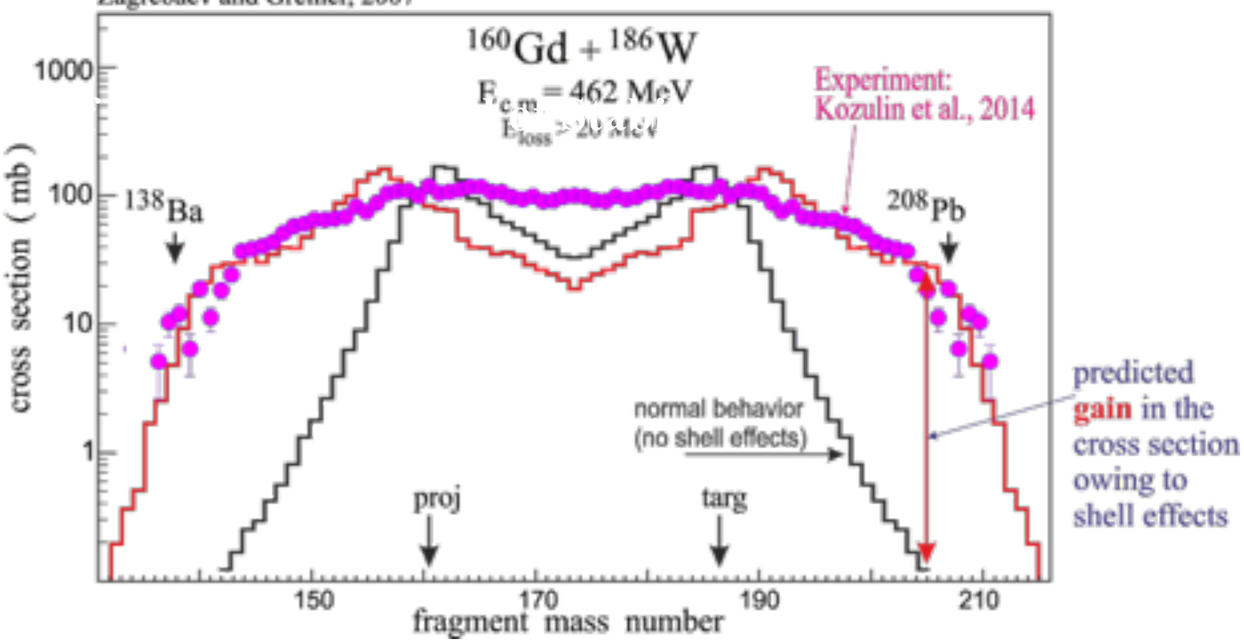
How to reach the Island of Stability ?



Production of neutron rich suuperheavy nuclei in transfer reactions

Test (surrogate) reaction (performed at Flerov Lab. in September of 2014) shows how much is the shell effects in multi-nucleon transfer reactions

Zagrebaev and Greiner, 2007



Super-heavy Element Factory @ FLNR
the goal: high production rate of SHE

- More beam time;
- More beam current;
- More transmission;
- Less background;
- More radiation safety.

Project DRIBs-III accepted for 2010 – 2016

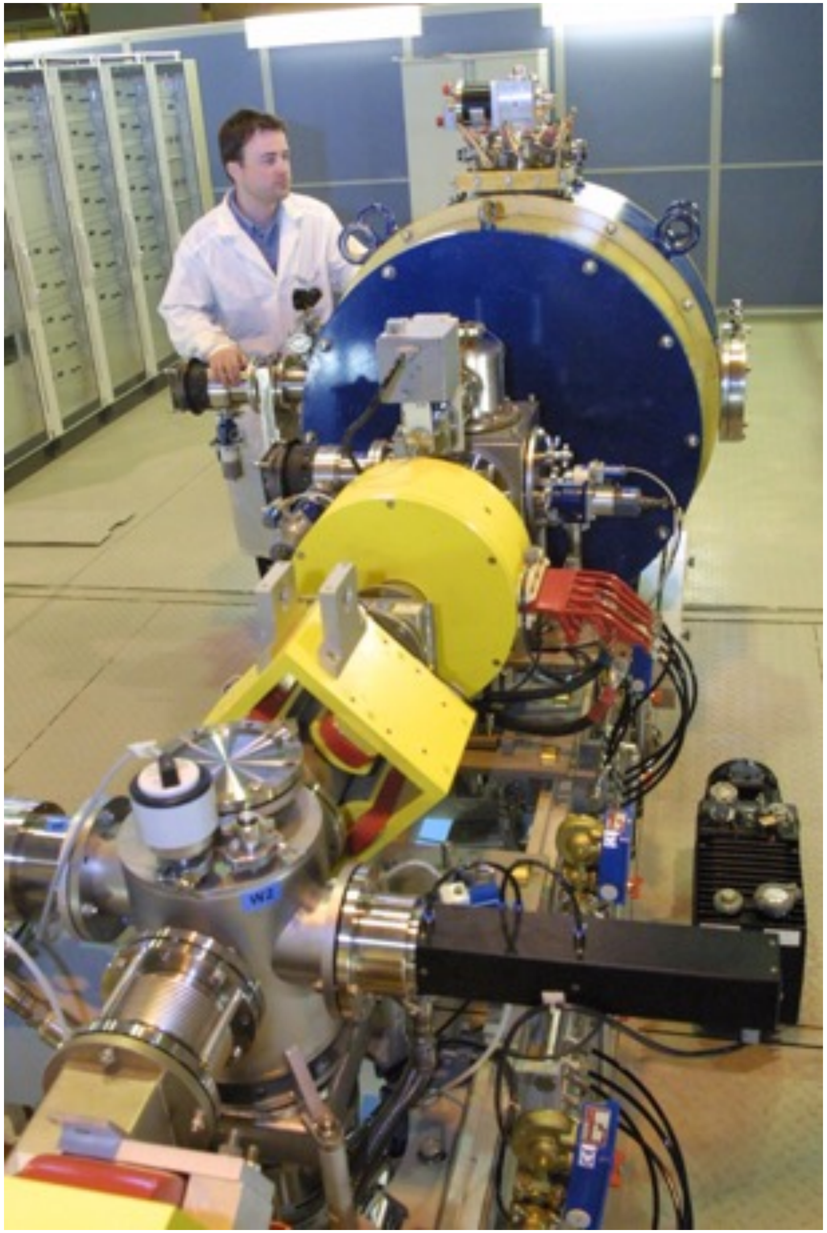
- ➢Creation of SHE factory based on the high-intensity universal DC280 cyclotron ($A \leq 238$, $E \leq 10$ MeV ·A , $I \leq 20$ pμA) in a new separate radiation safety class II experimental building.
- ➢Creation of new generation experimental set-ups.
- ➢Construction of a special building for physical groundwork of nanotechnology (1500 m^2), based on IC100 and U400M.

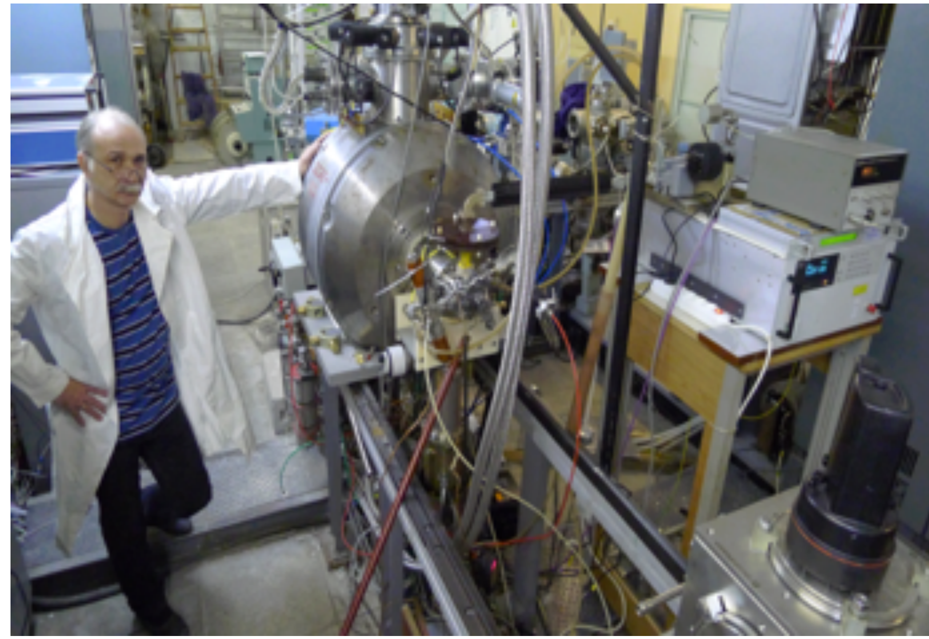
Further development proposed for 2017 – 2023

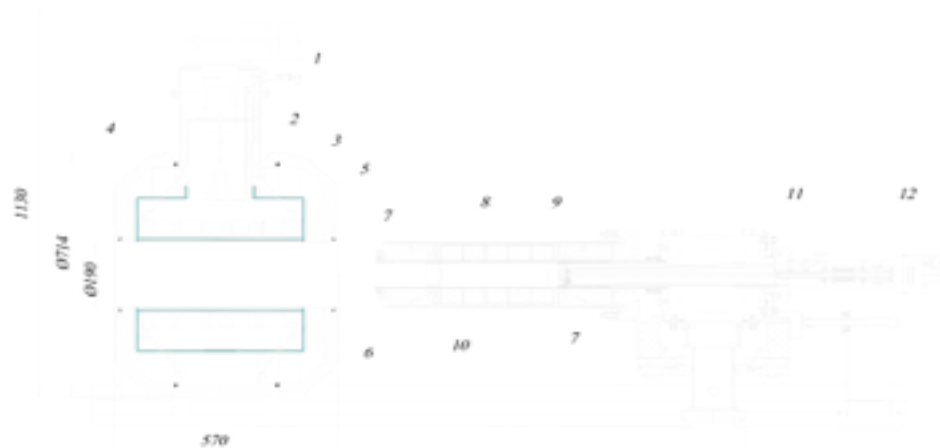
- ➢Completion of modernization of the cyclotron U400.
- ➢Total reconstruction of the U400 experimental hall, including 6 radiation safe experimental caves.
- ➢Completion of modernization of the cyclotron U400M.
- ➢Sharing of physical tasks between accelerators.
- ➢Reconstruction of the U200 cyclotron.

Basic facilities and SHE-factory

New 18 GHz Ion sources DECRIS-SC1, SC2



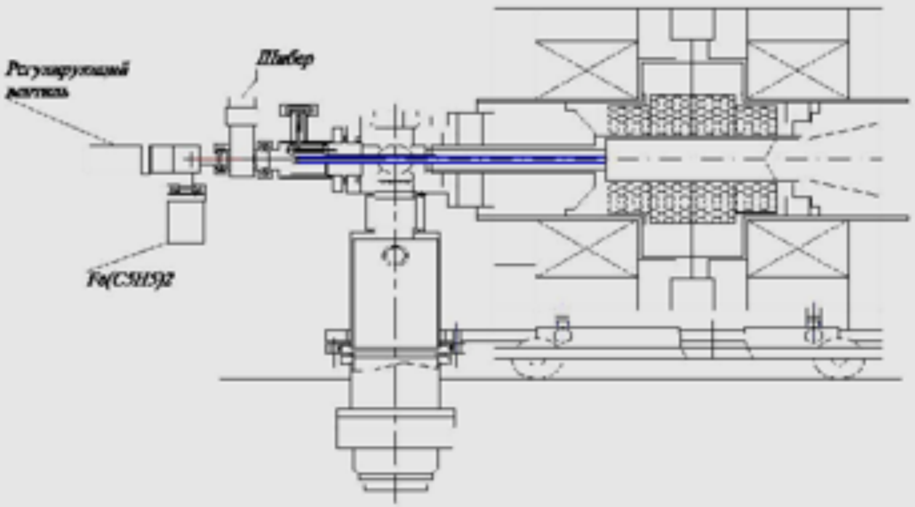


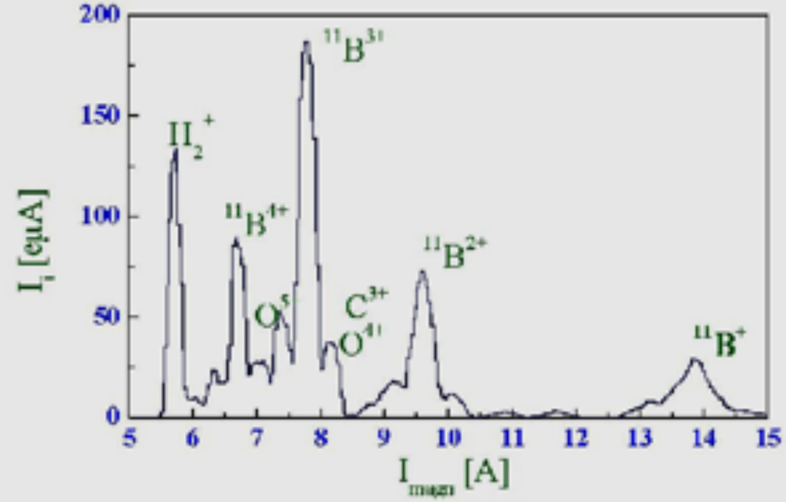


MIVOC-method (Metal Ions from VOlatile Compounds)

The vapour pressure of a compound should be about 10^{-3} torr

Evaporation of a compound and its diffusion into the source take place without dissociation.





The spectrum of boron ions

Working substance - $C_2B_{10}H_{12}$

Ti – $(CH_3)_5C_5$**Ti**$(CH_3)_3$

Fe – **Fe**$(C_5H_5)_2$; Ni – **Ni**$(C_5H_5)_2$

Cr – Cr$(CO)_6$; W – W$(CO)_6$

U-400 – $^{58}Fe^{7+}$ - 40÷50 μA

Material consumption ~ 3 mg/h

(~ 1.5 mg/h for ^{58}Fe)

DC280-cyclotron – stand-alone SHE-factory

DC280 (expected) E=4÷8 MeV/A		
Ion	Ion energy	Output intensity
^{7}Li	4	1×10^{14}
^{18}O	8	1×10^{14}
^{40}Ar	5	6×10^{13}
^{48}Ca	5	0,6-1,2×10
^{54}Cr	5	2×10^{13}
^{58}Fe	5	1×10^{13}
^{124}Sn	5	2×10^{12}
^{136}Xe	5	1×10^{14}
^{238}U	7	5×10^{10}

- ➢ **Synthesis and study of properties of superheavy elements.**
- ➢ **Search for new reactions for SHE-synthesis.**
- ➢ **Chemistry of new elements.**

The magnet of DC280

DC280

Main Parameters

Ion source	DECRIS-4 - 14 GHz DECRIS-SC3 - 18 GHz
Injecting beam potential	Up to 100 kV
A/Z range	4÷7
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.35 T
K factor	280
Gap between plugs	400 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV

DC280 Parameters and Goals

	DC280 Parameter	Goals
1.	High injecting beam energy (up to 100 kV)	Shift of space charge limits for factor 30
2.	High gap in the center	Space for long spiral inflector
3.	Low magnetic field	Large starting radius. High turns separation. Low deflector voltage
4.	High acceleration rate	High turns separation.
5.	Flat-top system	High capture. Single orbit extraction. Beam quality.

Experimental Hall of the SHE-Factory
radiation safety class-II

on-line: http://inflnr.jinr.ru/dc280.html

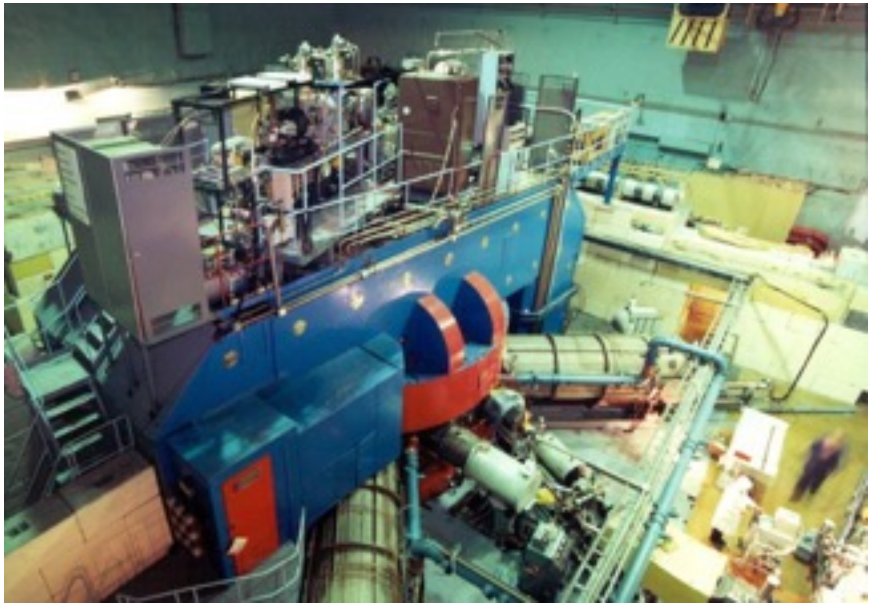
SHE Factory. Liquid radioactive waste tanks

U400R CYCLOTRON
stand-alone & post-accelerator

- Fusion-fission;
- Quasi-fission;
- Nuclear spectroscopy;
- New heavy isotopes;
- Multi nucleon transfer reactions;
- Sub-barrier fusion;
- Reactions with exotic nuclei
- Structure of light exotic nuclei.

U400R (expected)		
Ion	Ion energy [MeV/A]	Output intensity
^{6}He	2.8 ÷ 14	10^{8}
^{8}He	1.6 ÷ 8	10^{5}
^{7}Li	2-17	1×10^{14}
^{16}O	6,4 -27	1×10^{14}
^{40}Ar	1-5,1	6×10^{13}
^{48}Ca	1,6-11	1.5×10^{13}
^{50}Ti	4,1-21	6×10^{12}
^{58}Fe	1,2-7,5	6×10^{12}
^{84}Kr	0,8-3,5	2×10^{12}
^{132}Xe	0,8-3,5	3×10^{12}
^{238}U	1,5- 8	5×10^{11}

U400M CYCLOTRON
stand-alone & driving accelerator



- Properties and structure of light exotic nuclei;
- Astrophysics;
- Reactions with exotic nuclei;
- Light neutron-rich nuclei;
- Deep inelastic scattering;
- Producing of RIBs.

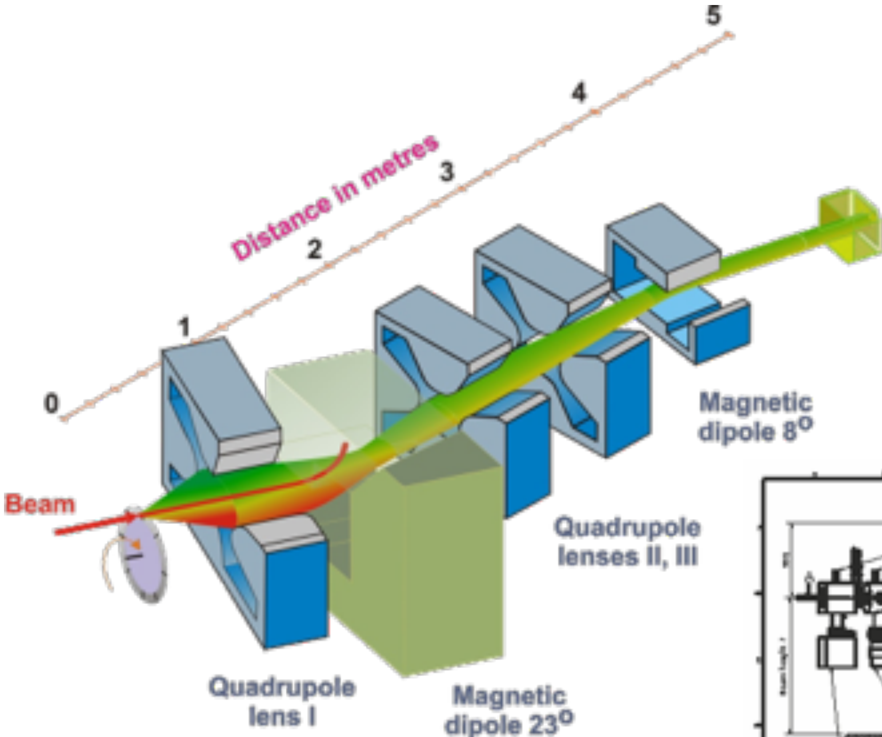
U400M E=30 ÷ 50 MeV/A E=4.5 ÷ 9 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	35	6×10^{13}
^{18}O	33	1×10^{13}
^{40}Ar	40	1×10^{12}
^{48}Ca	5	6×10^{12}
^{54}Cr	5	3×10^{12}
^{58}Fe	5	3×10^{12}
^{124}Sn	5	2×10^{11}
^{136}Xe	5	4×10^{11}
^{238}U	7	2×10^{10}

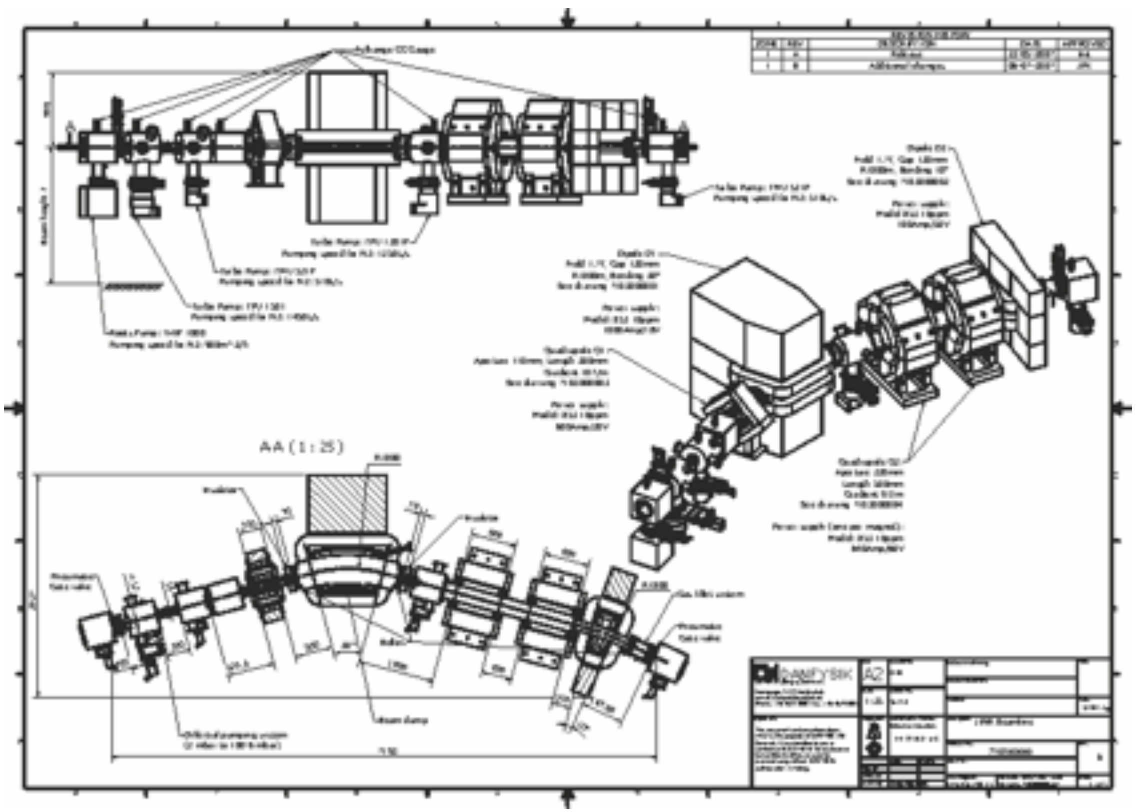
Instrumentation

New set-ups

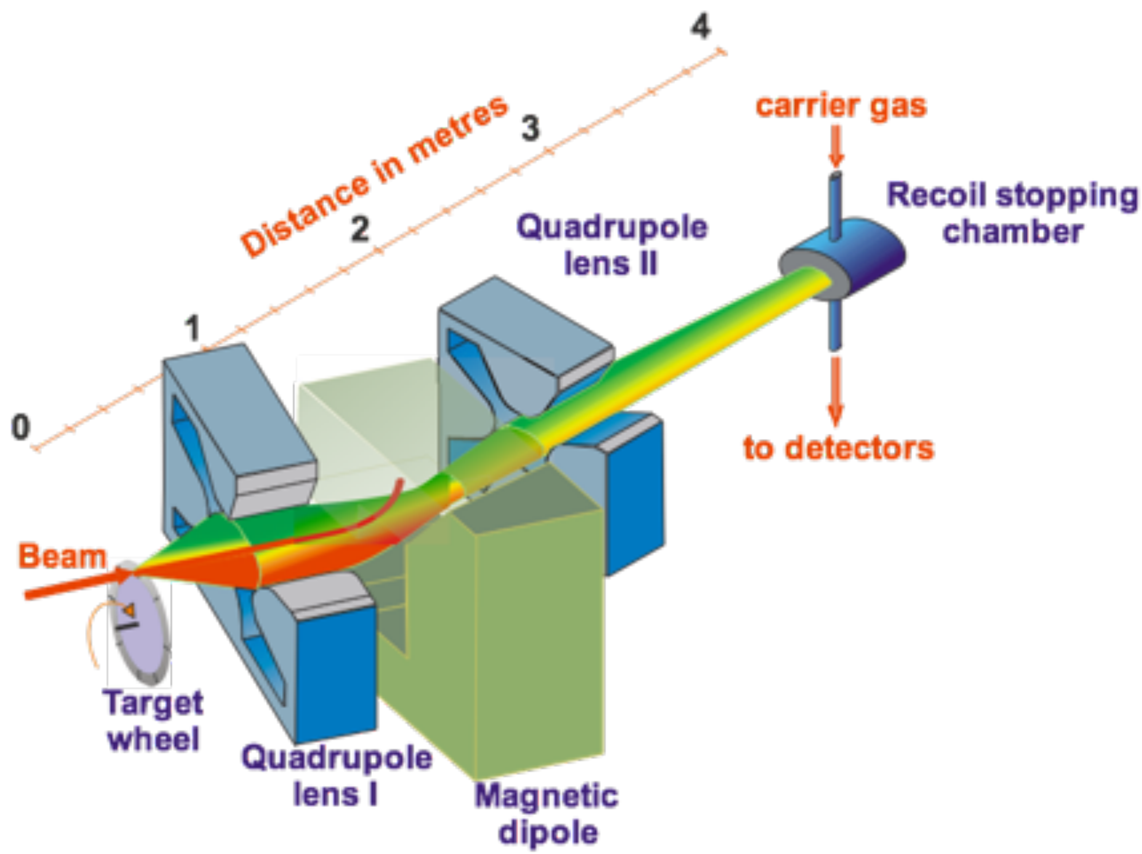
- New gas filled separators,
- New separators-spectrometers,
- Something for transfer reactions products,
- Preseparator,
- Gas catcher,
- Laser ionization,
- Fast radiochemical methods, …

New FLNR gas-filled “physical” separator





New FLNR gas-filled “chemical” separator



Velocity filter SHELS

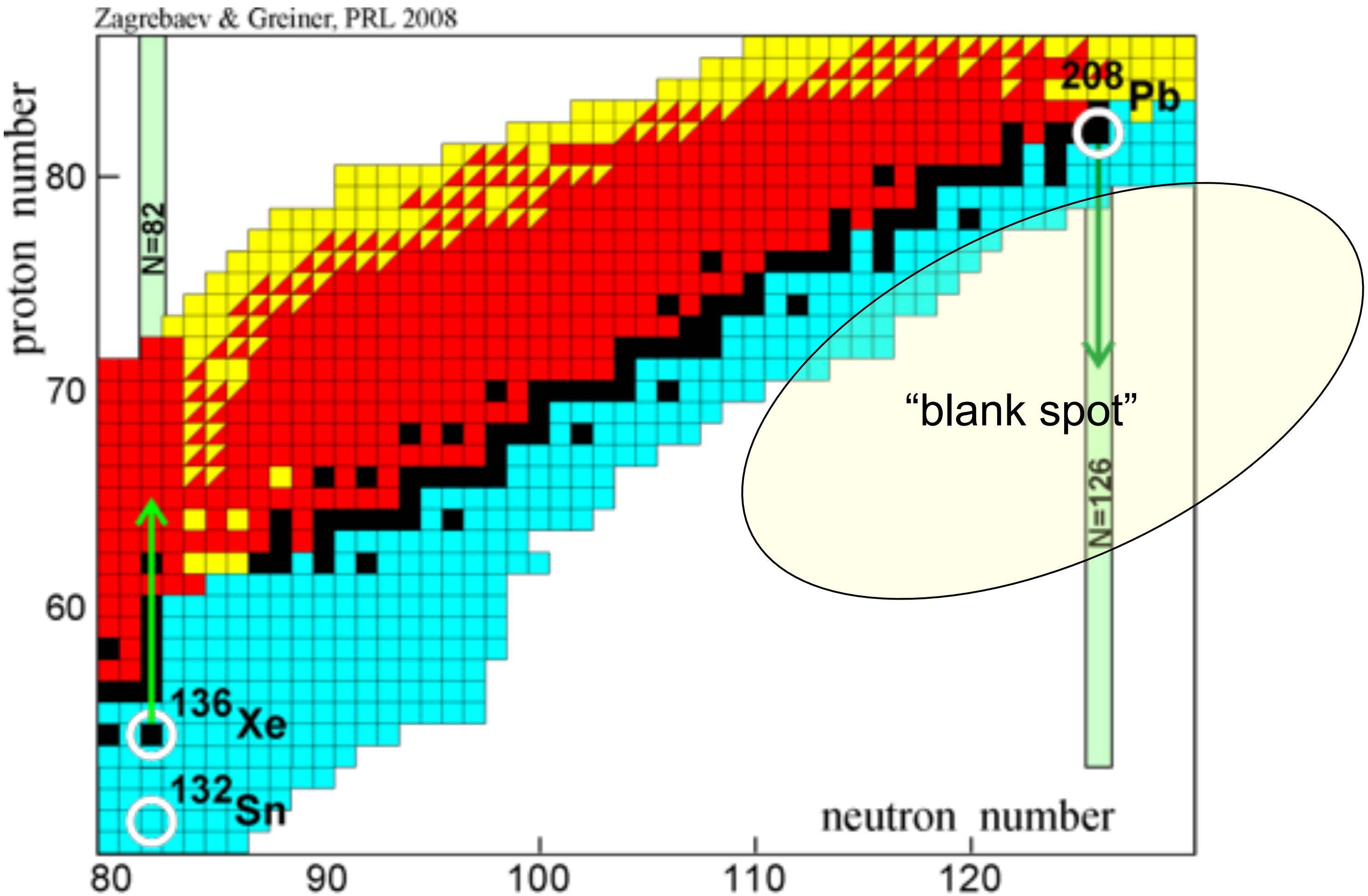
High transmission for asymmetric combinations (beams of ^{12}C, ^{14}N, ^{16}O, ^{22}Ne)
Availability for symmetric combinations ($^{136}Xe + ^{136}Xe \rightarrow ^{272}Hs^*$)

Mass-spectrometer MASHA

Fragment-separator ACCULINNA-2: assembling and testing.

January 2015

Production of new heavy nuclei in the region of N=126



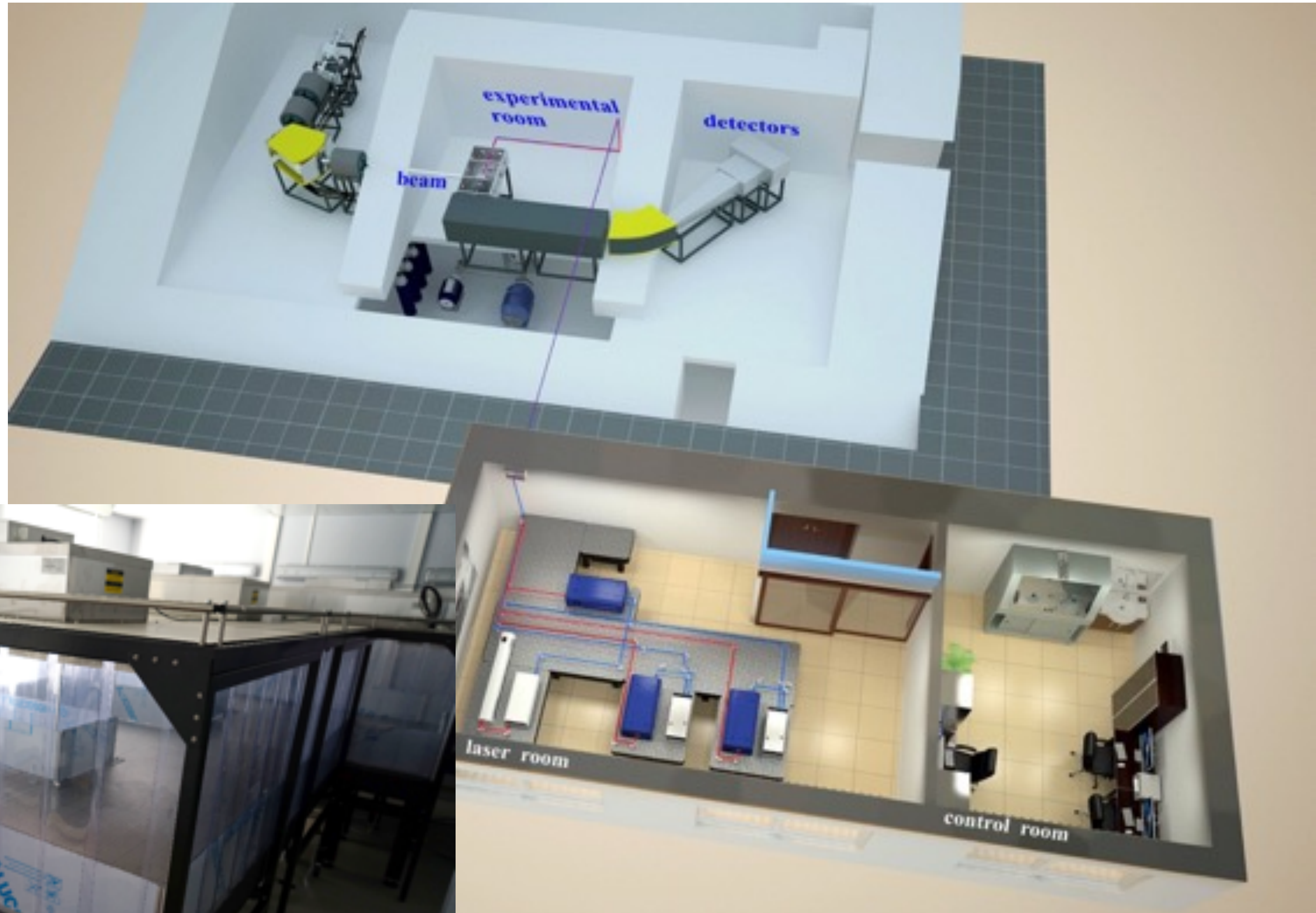
proton transfer along the neutron closed shells:

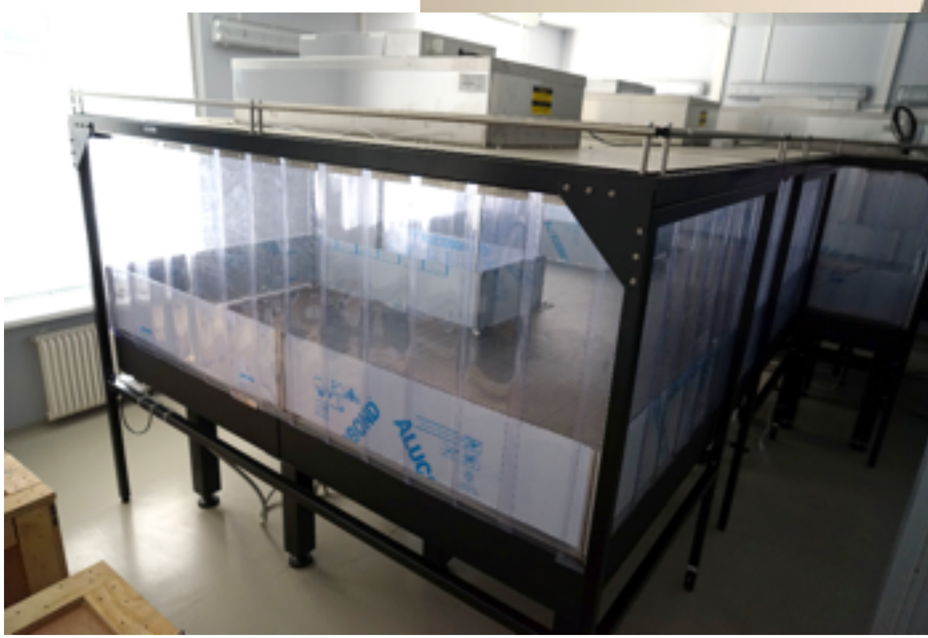
$^{136}Xe_{N=82} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=82} + {}^{208-\Delta Z}Y_{N=126} + Q \approx 0$

Reactions with $Q \approx 0$ are very favorable for proton transfer

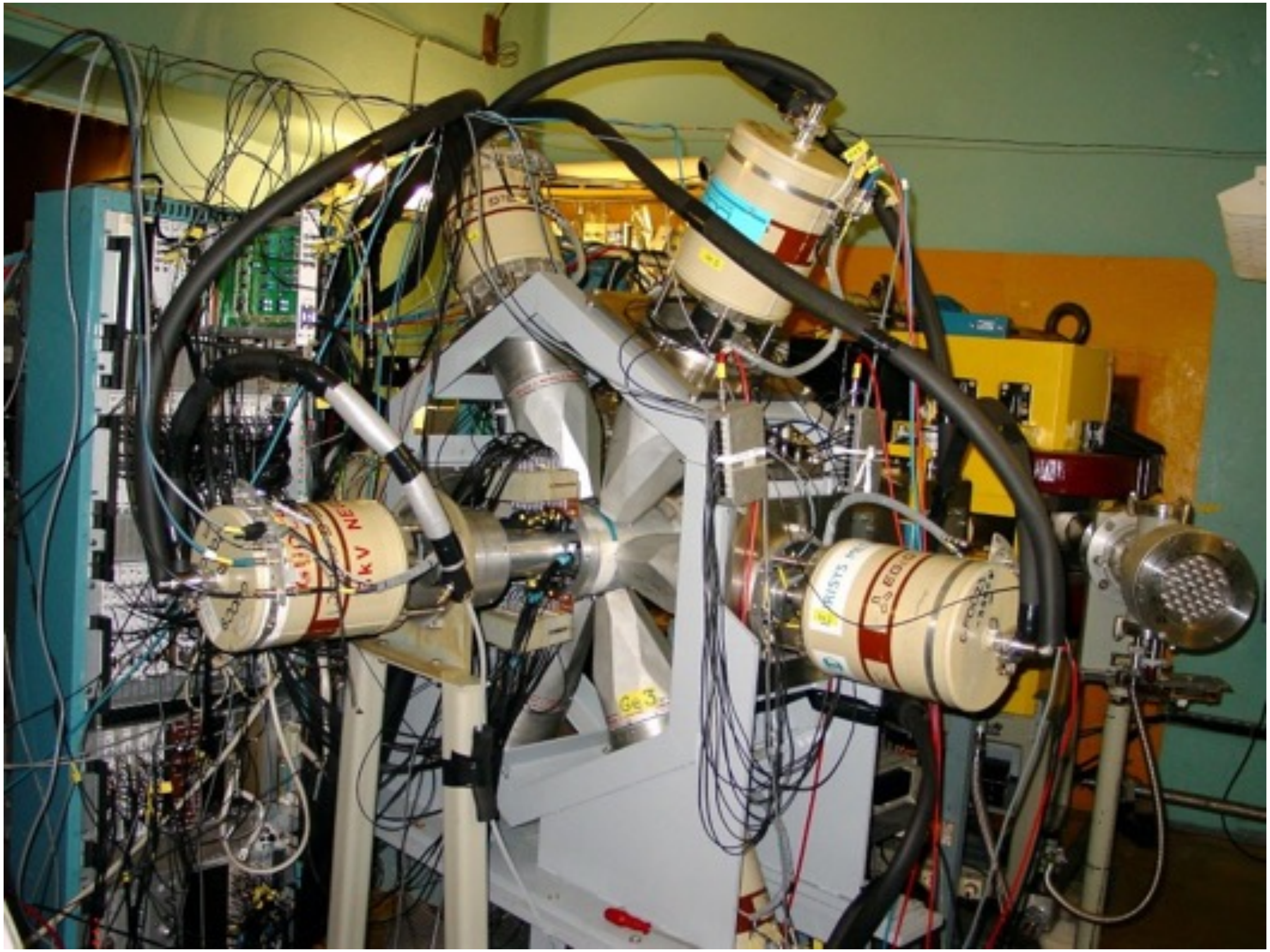
The use of ^{132}Sn is even better !

New setup for selective laser ionization (project GaLS)

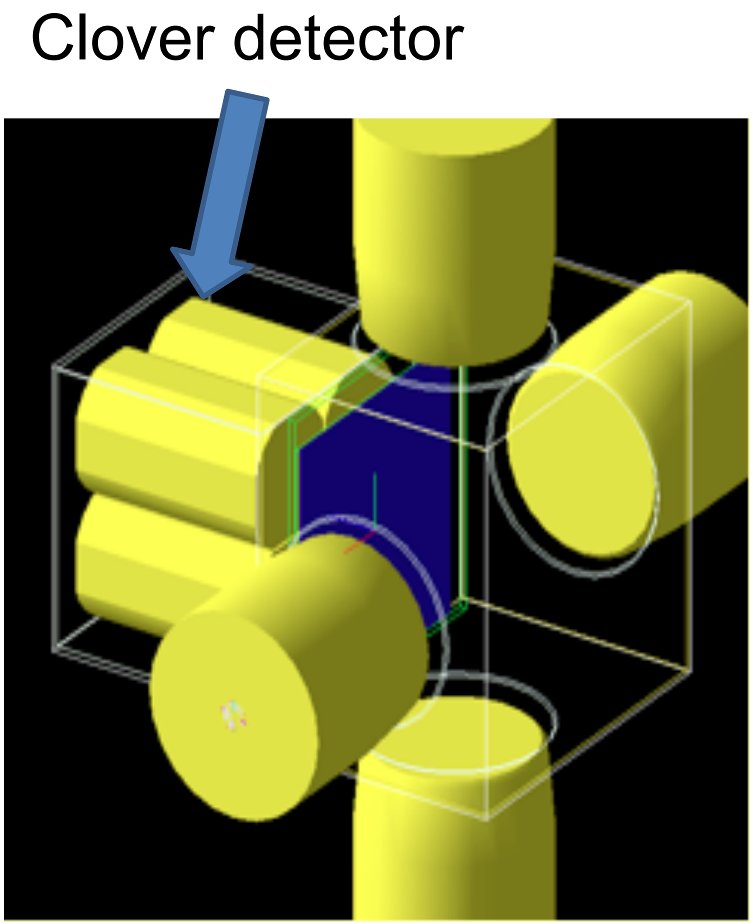


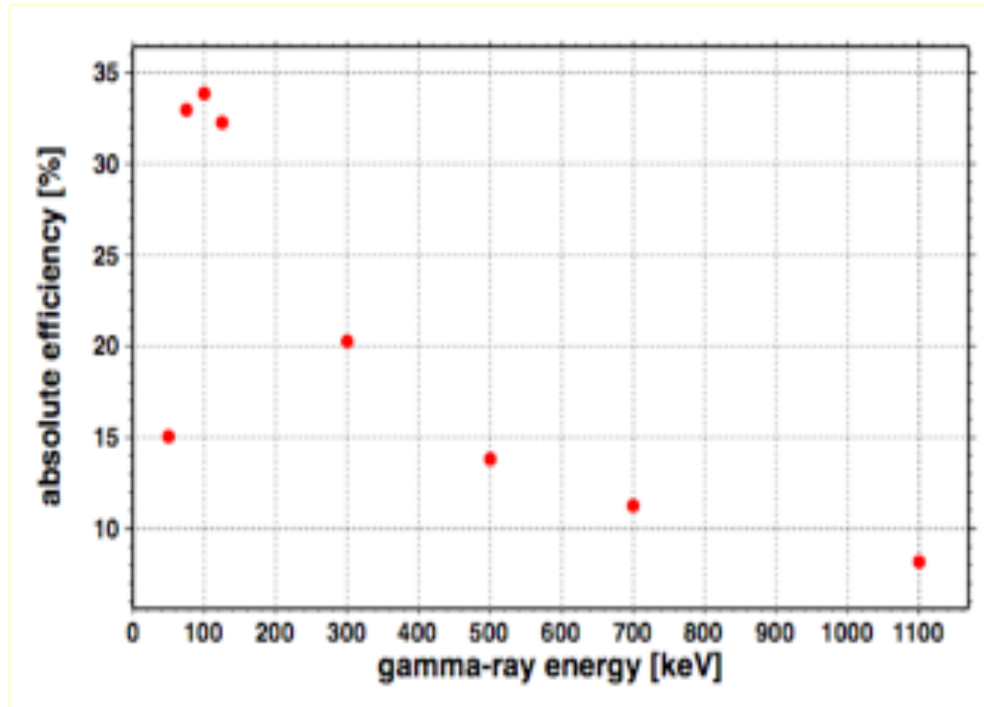


GABRIELA @ SHELS



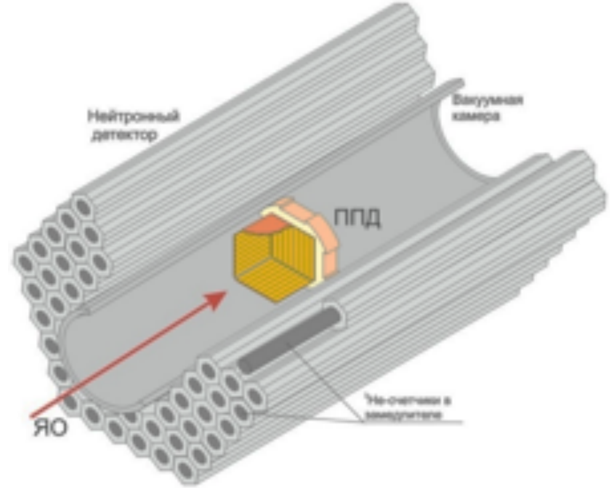
GABRIELA 2015: Gamma detection efficiency estimations for new detector set up



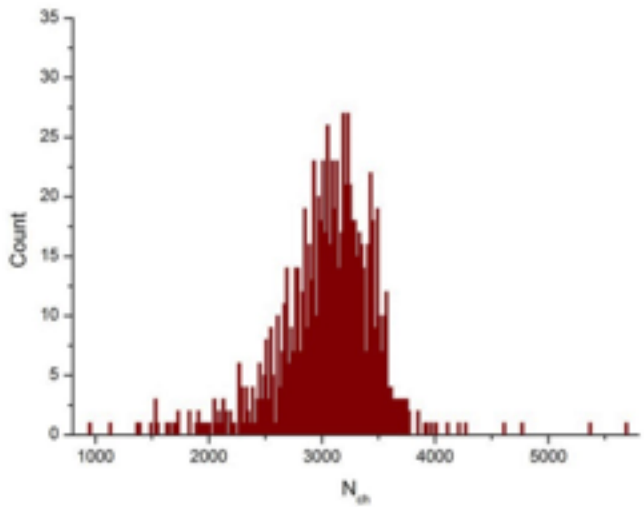


Preliminary GEANT4 detector arrangement including a Clover and 4 EUROGAM phase-I. These surround the 10x10 cm^2 implantation detector (in blue) and its PCB (green). Right : A first estimate of the achievable singles efficiency as a function of photon energy f or a distributed source.

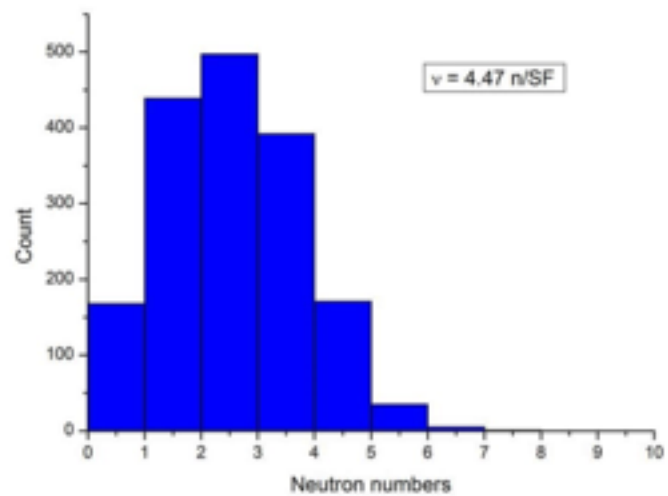
First research experiment with accelerated ^{50}Ti beam at FLNR U400 cyclotron.
^{50}Ti beam intensity – $3x10^{12}$ pps.
Modernized VASSILISSA separator and neutron detector at the focal plane.
$^{50}Ti + ^{208}Pb = 2n + ^{256}Rf$
more than 1500 events detected.



^{3}He neutron detector at the focal plane of separator



TKE spectra of ^{256}Rf s.f. fragments



For the first time: neutron multiplicity was measured for spontaneous fission of the ^{256}Rf isotope.

Other projects are under preparation

Innovation projects in the Nanotechnology Centre

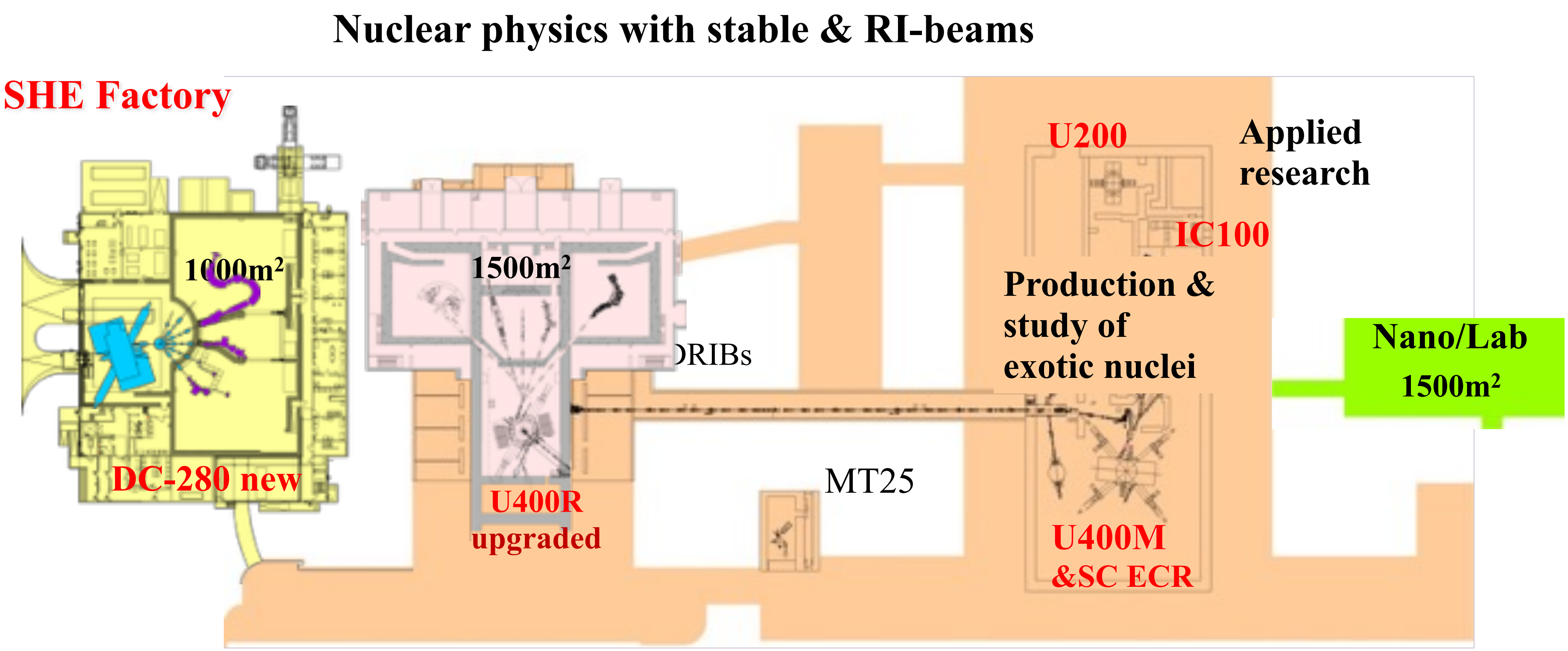
- A new roll-to roll etching facility for the development of new track-etch membranes

- Facilities for surface modification of nano-structured composite filmy materials

- A diversified electron microscopy laboratory for performing the studies of micro- and nano-structured materials produced using ion beam modification methods

- A diversified laboratory for the studies of ion-induced radiation effects in matter, including AFM, optical spectroscopy, IR Raman spectroscopy, luminescence, and others

Full-scale realization off the DRIBs-III




THANK YOU
FOR YOUR
ATTENTION !
Flerov Laboratory of Nuclear Reactions (JINR)