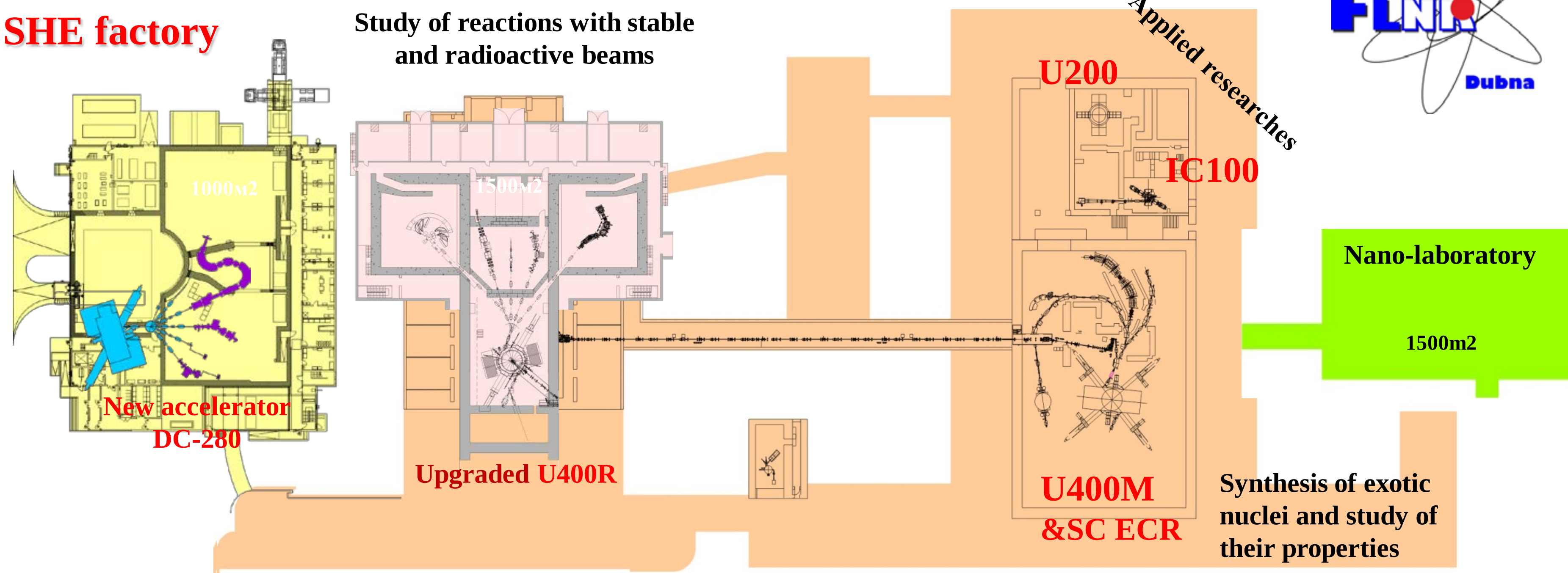
Novel instrumentation at JINR Dubna

Mikhail G. Itkis

COMEX-5, Cracow, 14-18 September 2015



FLNR's basic directions of research:

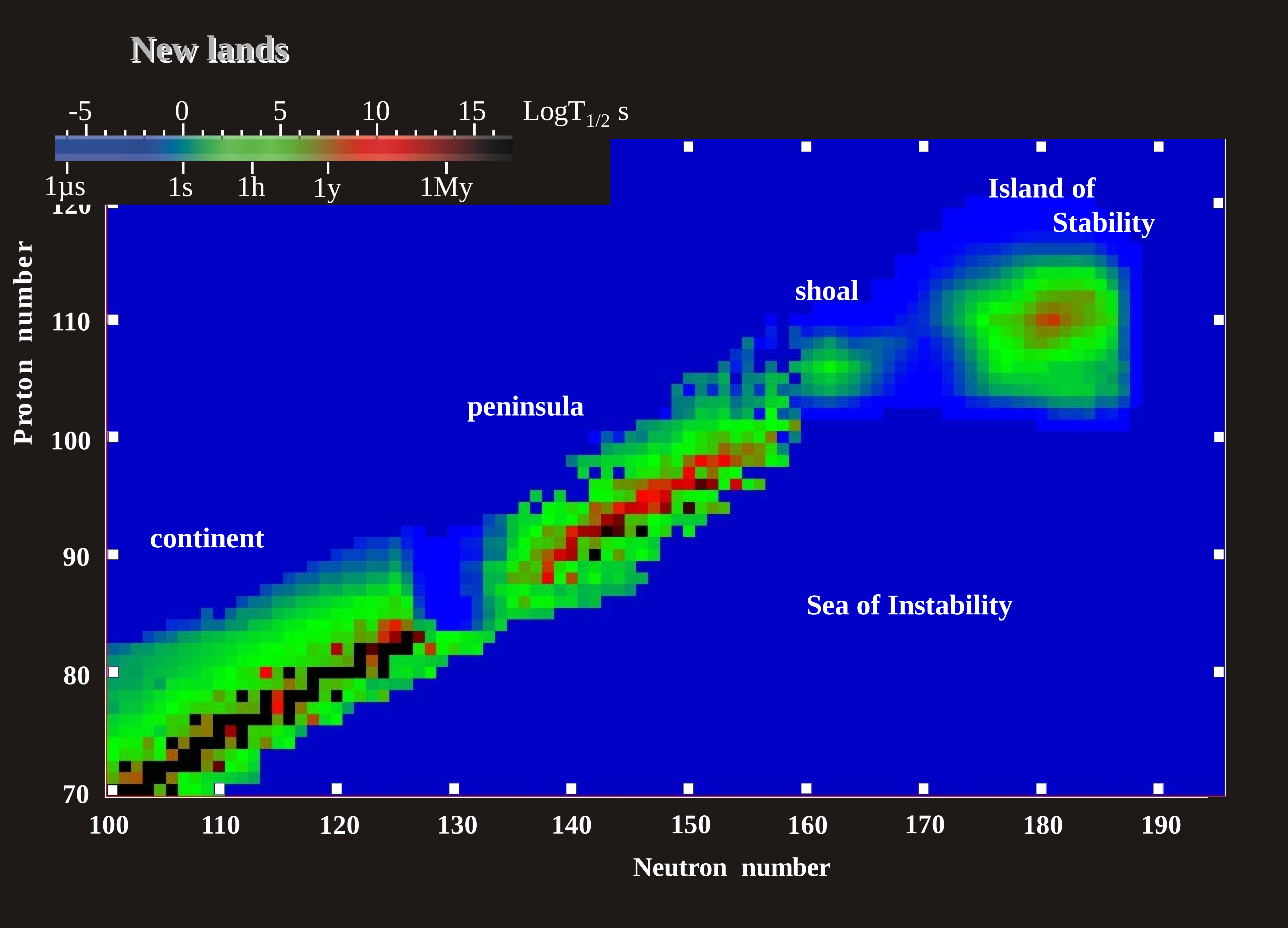
1. Heavy and superheavy nuclei:

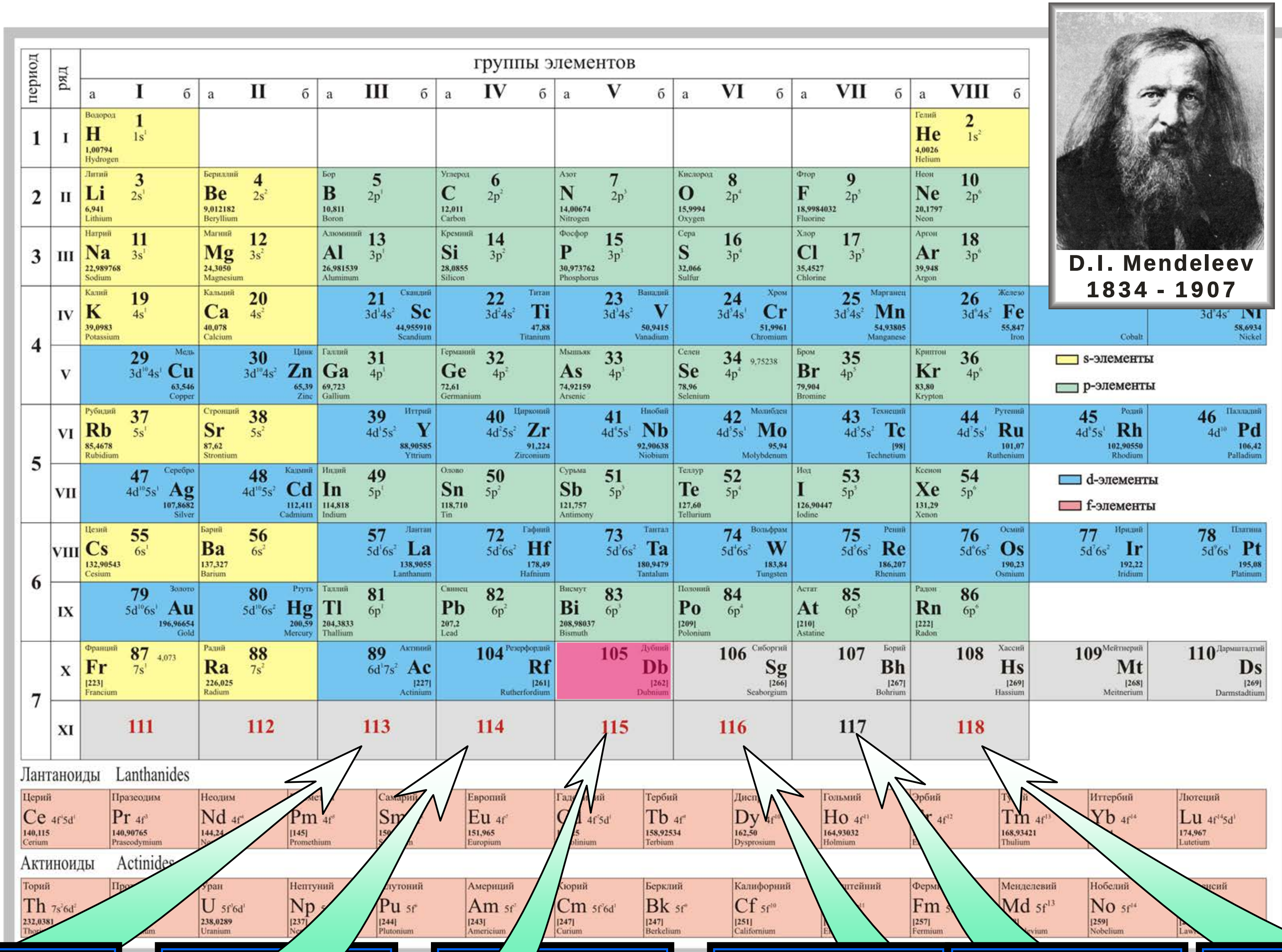
- synthesis and study of properties of superheavy elements;
- chemistry of new elements;
- fusion-fission and multi-nucleon transfer reactions;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

2. Light exotic nuclei:

- properties and structure of light exotic nuclei;
- reactions with exotic nuclei.

3. Radiation effects and physical groundwork of nanotechnology.


New lands
-5
0
5
10
15
LogT1/2 s
1μs
1s
1h
1y
1My
Island of
Stability
shoal
peninsula
continent
Sea of Instability
Proton number
120
110
100
90
80
70
100
110
120
130
140
150
160
170
180
190
Neutron number



113
Discovered at JINR in 2003

114
Discovered at JINR in 1999

115
Discovered at JINR in 2003

116
Discovered at JINR in 2000

117
Discovered at JINR in 2009

118
Discovered at JINR in 2001

Main tasks of the FLNR Seven-Year Plan for 2017–2023 (DRIBs-III Project)

Commissioning (~2017) and development of "SHE Factory" based on DC280 cyclotron:

- *smoothly variable energy;*
- *beam intensity up to 10 pμA for nuclei with $A \leq 100$;*
- *new modern and powerful setups*
- *infrastructure for accommodation of user setups;*

Reconstruction of the U-400 cyclotron (2018-2020):

- *new experimental hall*
- *accelerated ions from helium to uranium*
- *smoothly variable energy within a wide range 0.8–25 MeV·A*

Reconstruction of the U-400M cyclotron (2021-2022):

- *intensive beams of radioactive ions, advancing toward the boundaries of proton and neutron stability of nuclei;*
- *conduct of research on nuclear interactions with maximum proton and neutron excess, employing a new powerful ACCULINNA-II separator)*

Development of long-running experimental setups

SHE-factory: High-current cyclotron DC280

Main setups:

GFS (synthesis), GFS (chemistry), SHELS

Main tasks:

- *Synthesis of SHE.*
- *Properties and Spectroscopy of SHE;*
- *Chemistry of SHE;*
- *Searching for new reactions leading to SHE*

DC280 (expected) E=4÷8 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	4	1×10^{14}
^{18}O	8	1×10^{14}
^{40}Ar	5	6×10^{13}
^{48}Ca	5	$0,6\text{-}1,2\times10^{14}$
^{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}

DC280 cyclotron – production status

Main magnet

Vacuum chamber

Bending magnet

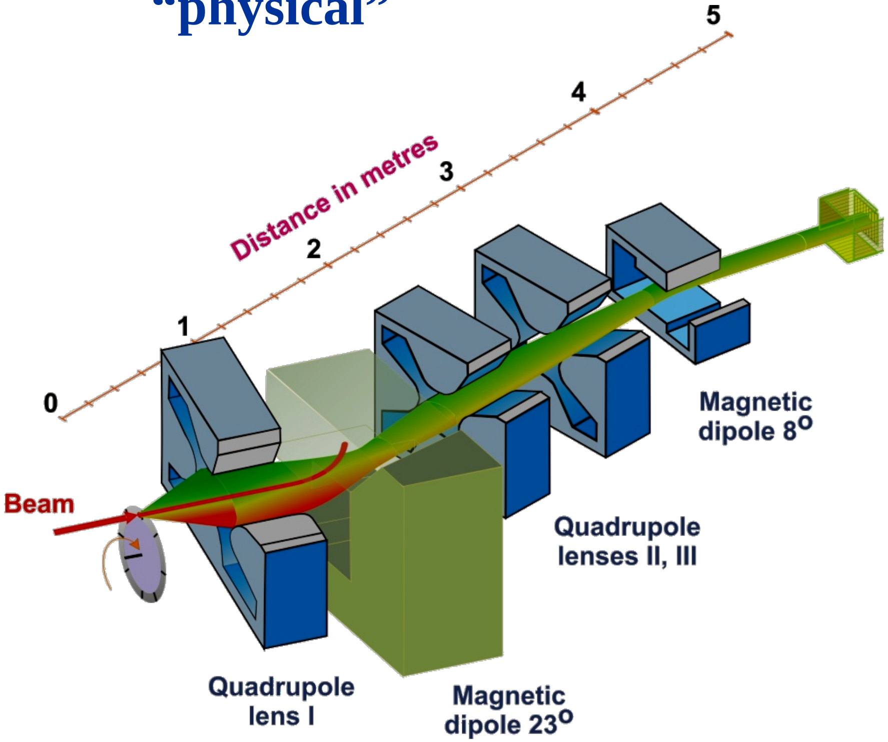
RF Amplifiers

Power supply

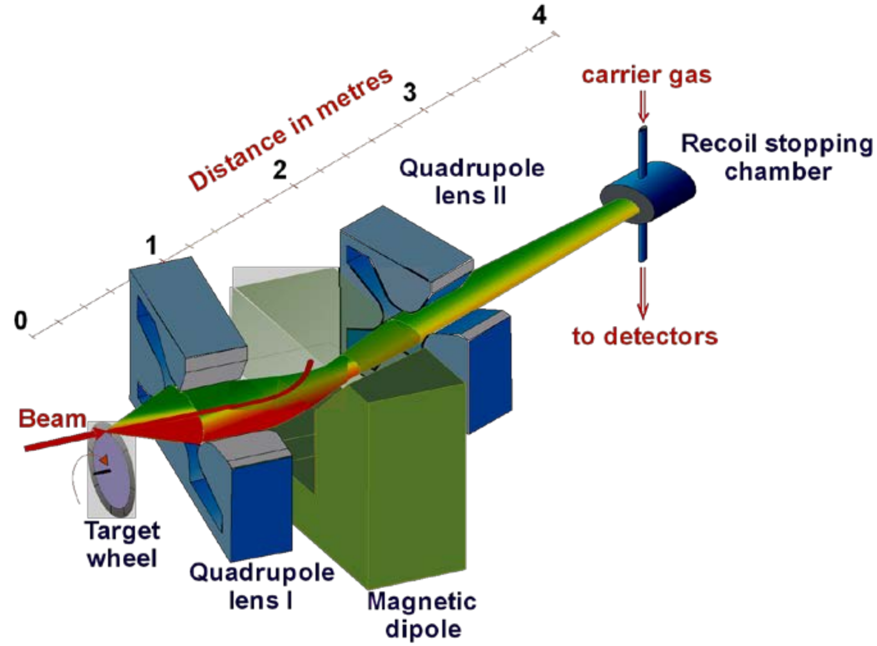
Water cooling system

New FLNR gas-filled separators

"physical"

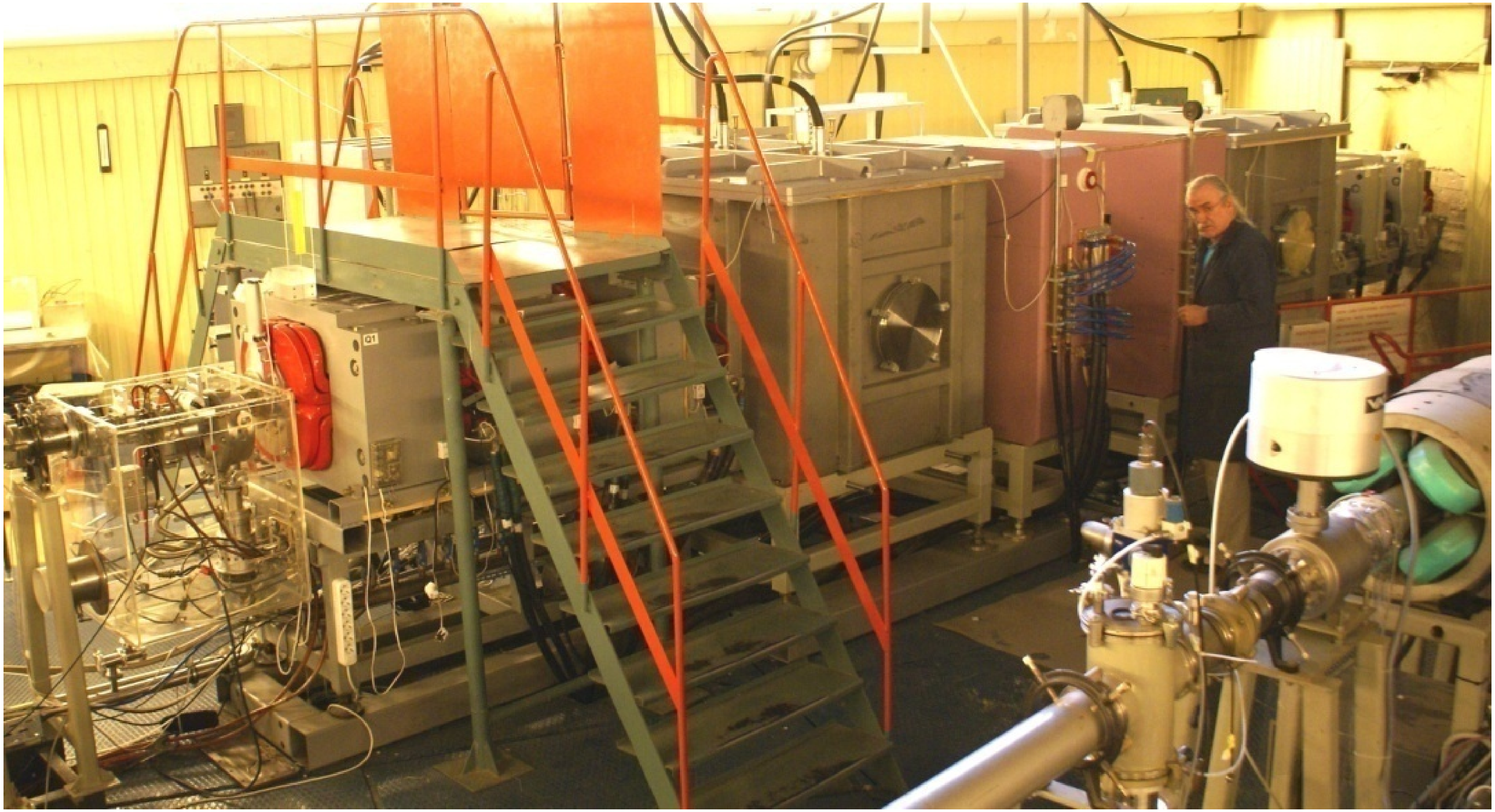


"chemical"



Reaction	Transmission
$^{244}Pu(^{48}Ca,3n)^{289}114$	60 %
$^{244}Pu(^{58}Fe,4n)^{298}120$	75 %

New experimental set up - velocity filter SHELS (Separator for Heavy ELement Spectroscopy)



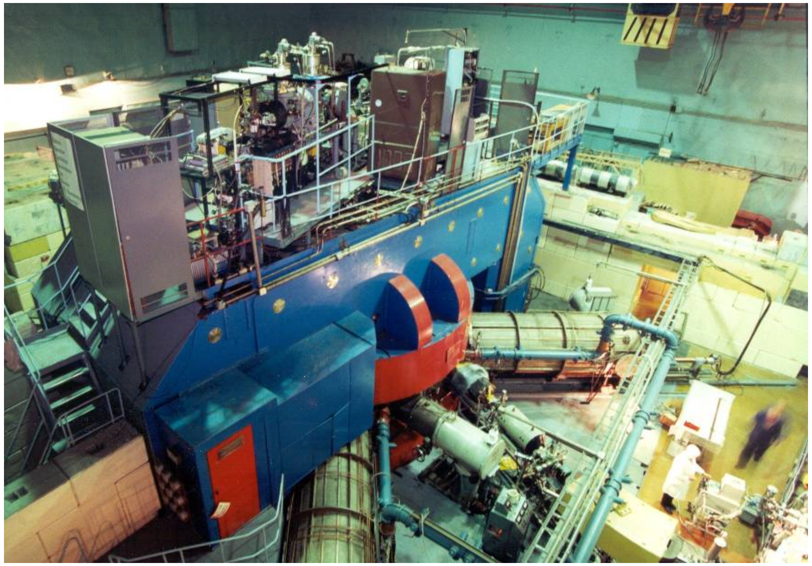
Mass-spectrometer MASHA

U400R CYCLOTRON
stand-alone & post-accelerator

U400R (*after modernization*)		
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}

Main tasks:
- *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*

U400M CYCLOTRON
stand-alone & driving accelerator



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}

Main setup:

Fragment separator ACCULINNA-2

Main tasks:

- *Producing of RIBs.*
- *Reactions with exotic nuclei;*
- *Properties and structure of light exotic nuclei;*

Fragment-separator ACCULINNA-2: assembling and testing.

ACCULINNA-2: Plans and prospects

2015/16: *commissioning test, 1st runs*

- Searching for 2*p* decay of the first excited state of ^{17}Ne in 1H(18Ne,d)17Ne reaction

- Study of 26S in the reaction 1H(28S,t)26S

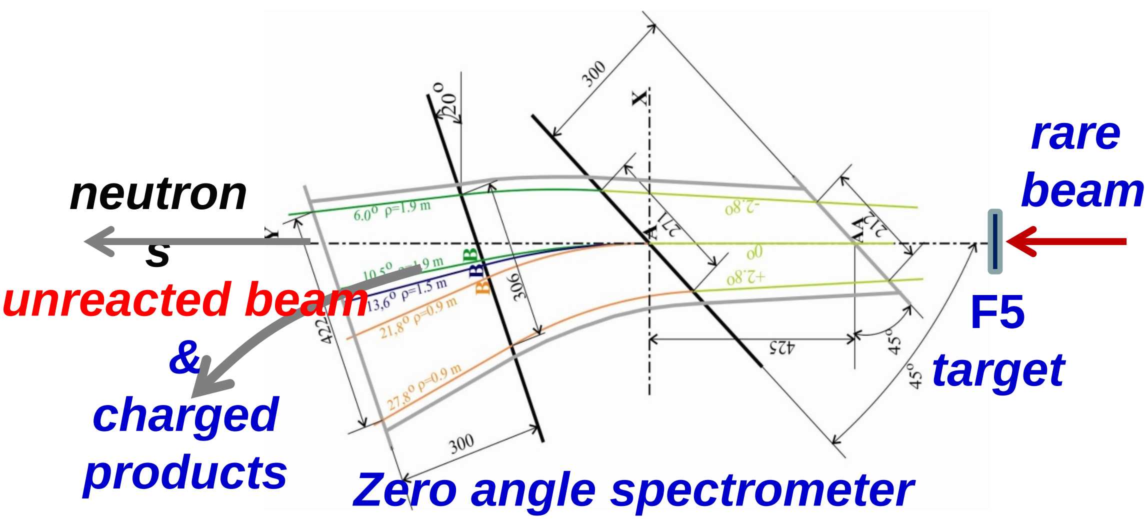
2016: *zero angle spectrometer at F5*

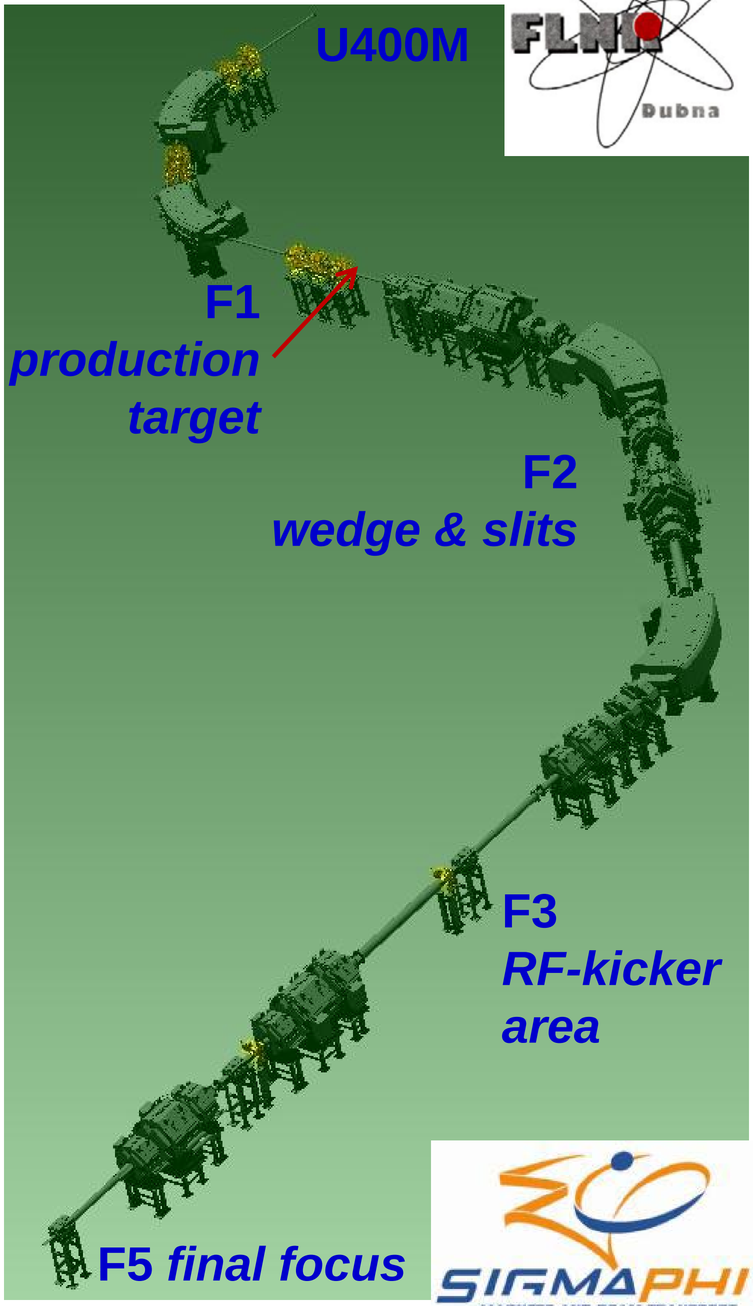
^{7}H - observation with the use of 11Li projectile

10Li - low energy states via 1H(11Li,d)10Li

2017: *cryogenic tritium target*

^{10}He, ^{11}Li, ^{16}Be – *E*, *Γ*, J^{π} for excitation states, search for new decay modes *n*, 2*n*, 4*n*





HIGH RESOLUTION MAGNETIC SPECTROMETER “MAVR” (double-arm)

Cooperation

FLNR (Dubna)

GANIL (Caen)

IPN (Orsay)

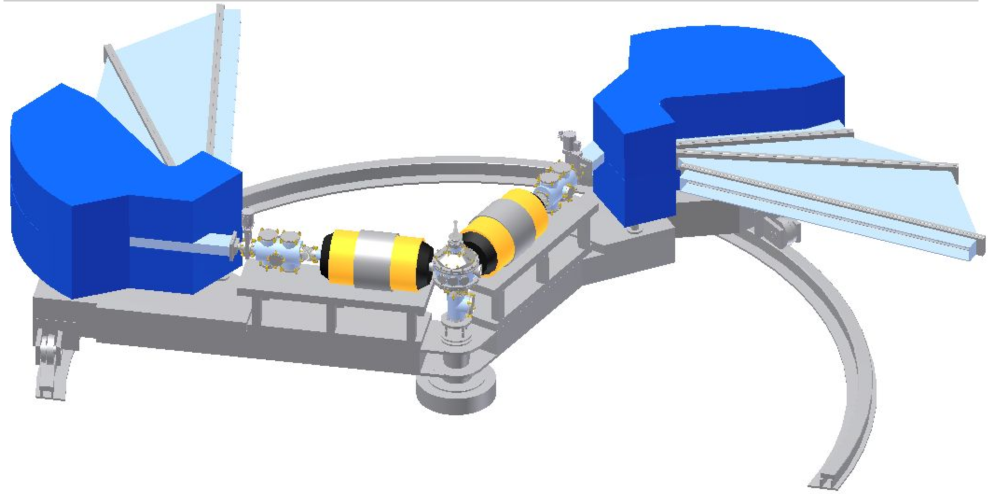
Cyclotron Laboratorie (Jyvaskyla)

NPI of ASCR, Czech Republic

YerPhI, Armenia

INRNE (Sofia)

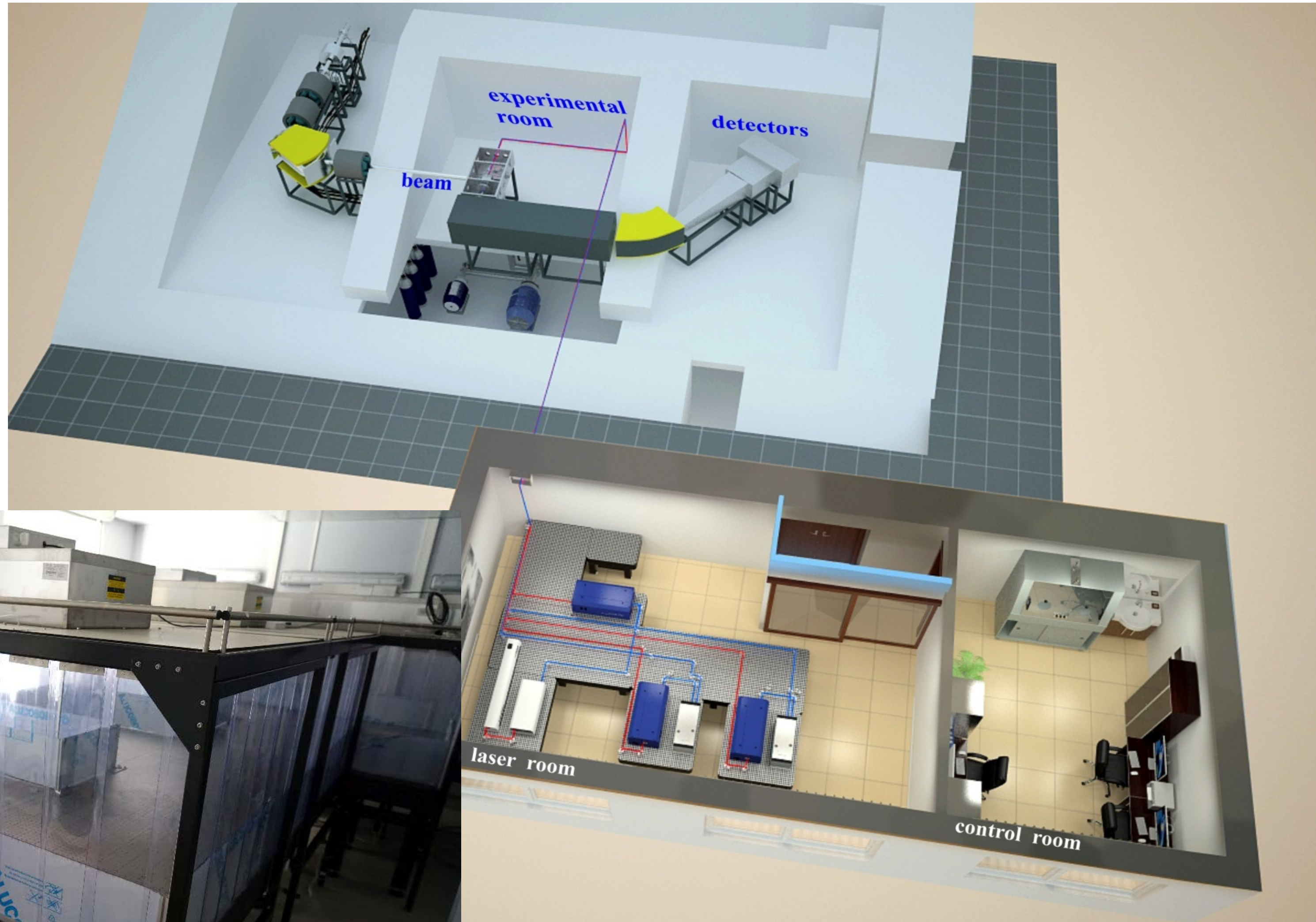
The MAVR double- arm magnetic spectrometer will be used both for primary and secondary beams for the accelerator facility U400 and U400R. It will be used for the energy measurement of the detected products as well as an energy beam monochromator.



The main aims of this project are:

1. High momentum resolution ($< 10^{-4}$) measuring of the mass, charge and energy distributions at the forward angles.
2. High energy resolution ($< 10^{-3}$) measuring of the nuclear reaction products induced by light exotic nuclei of the DRIBs-III – factory.

New setup for selective laser ionization (project GaLS)



New research instruments (the Nanotechnology Centre)

- Two scanning electron microscopes (Hitachi SU8020 and SU3400) with a number of options (microanalysis, catodoluminescence, etc)
- Specialized equipment for sample preparation for SEM
- Atomic force microscopy with various optical options
- X Ray photoelectron spectroscopy (K-Alpha instrument)
- Fourier-transform IR spectrophotometer
- UV-Vis spectrophotometers
- Specialized electronics for measurements on single nanopores: Axopatch 200B
- Capillary flow porometer and other equipment for membrane testing
- Versatile equipment for chemical lab, etc.

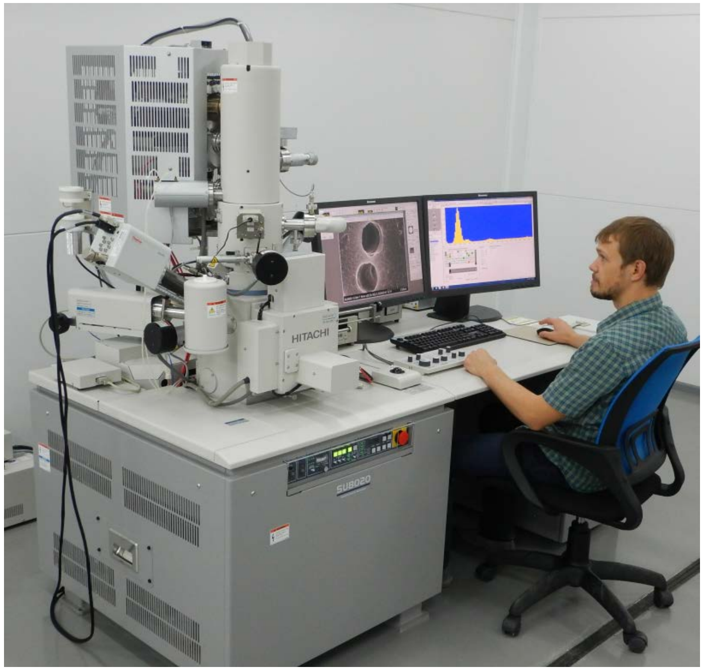
General view of the new laboratory building (Centre of Nanotechnology)

Centre of Nanotechnology, interior view

Hitachi SU8020 microscope

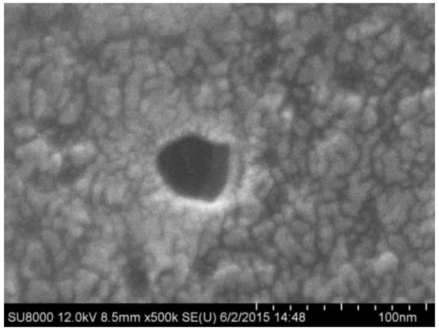
Unique possibilities to image the sample using low energy electron beam and low vacuum
Resolution 1.3 nm (U = 1 kV) and 1 nm (U = 15 kV)
Microanalysis: Energy-dispersive spectrometer, catodoluminescence spectrometer
Unique system of focused electron beam deceleration provides the resolution of 1.3 nm at the beam energy as low as 1 keV which makes it possible to image radiation-sensitive materials such as polymers on the nanometer scale

To be used for:
Observation and characterization of nano- and microporous materials, first of all membranes
Direct observation of radiation defects
Investigation of composite functional nano-structured materials

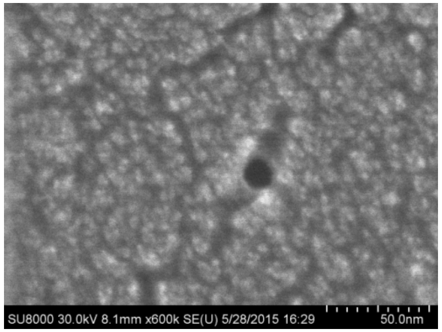


First images of PET nano-membranes at magnification **of 600 000x**

Pore diameter 30 nm



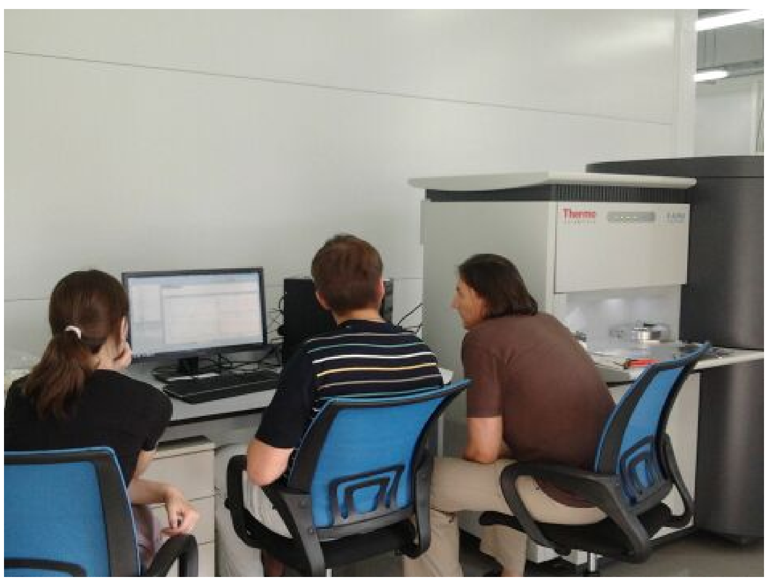
Pore diameter 12 nm



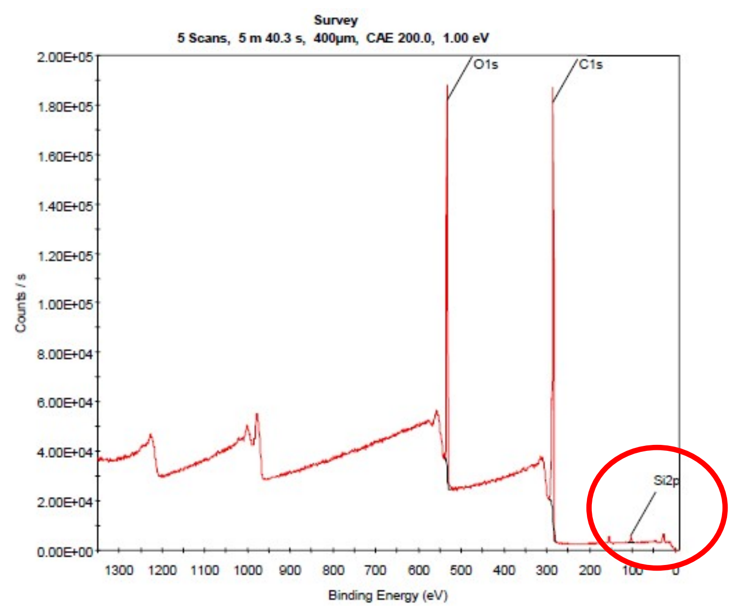
X ray Photoelectron Spectroscopy K-Alpha

High-resolution X ray photoelectron spectra of surface layers
Precise determination of chemical composition

To be used for:
Characterization of surfaces of versatile materials (polymers, crystals, metals, alloys, etc)
Development of modification methods of track membranes
Investigation and development of composite functional nano-structured materials
Investigation of processes of sorption/desorption, membrane fouling



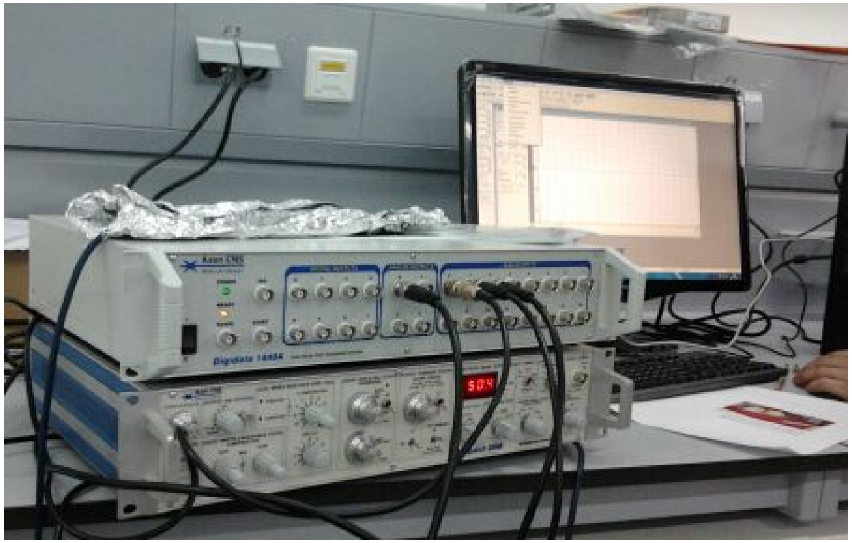
Silica impurities in surface layer of PET nanoporous membrane affecting its properties
(detected by X-ray photoelectron spectroscopy)



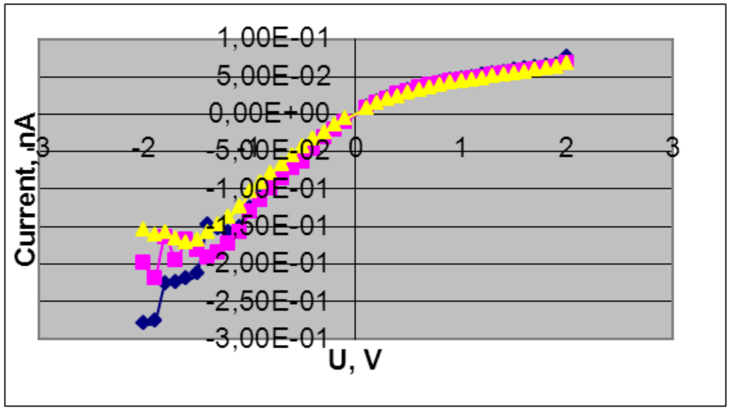
Patch-clamp amplifier Axopatch 200B

Originally developed for studying ion channels in living cells, this device provides unique possibilities in investigations of artificial nanopores in electrolyte solutions
Ion current measurements starting from ≤1 pA
Ultra-low noise

To be used for:
Investigation of properties of track-etched nanopores
Measurements on single nanopores, study of fine phenomena in nanocapillaries
Development of single-pore molecular sensor

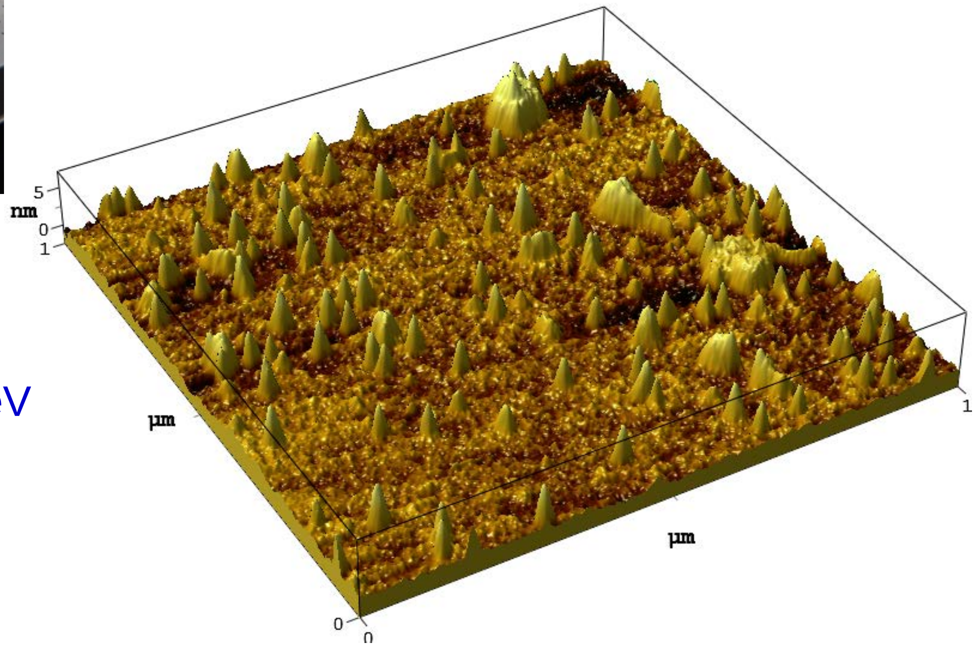


Example: observation of a “nano-precipitation” process in asymmetric nanopores



NTEGRA Spectra – Atomic force microscopy (AFM)/ Confocal Raman & Fluorescence

Set-up is used for:
- Studies of nanostructures induced by single ion impact on the surface of solids;
- Measurements of depth-resolved Raman and photoluminescence spectra for characterization of radiation defects and correlated mechanical stresses through the high energy heavy ion irradiated layers



3D AFM image of nanohillocks on the surface of $Y_3Al_5O_{12}$ produced by 1 GeV Bi ions (10^{10} cm^{-2})

NICA (Nuclotron based Ion Colider fAcility)
– the flagship project in HEP of Joint Institute for Nuclear Research (JINR)

Main targets of "NICA Complex":

- study of hot and dense baryonic matter
at the energy range of max baryonic density

- investigation of nucleon spin structure, polarization phenomena

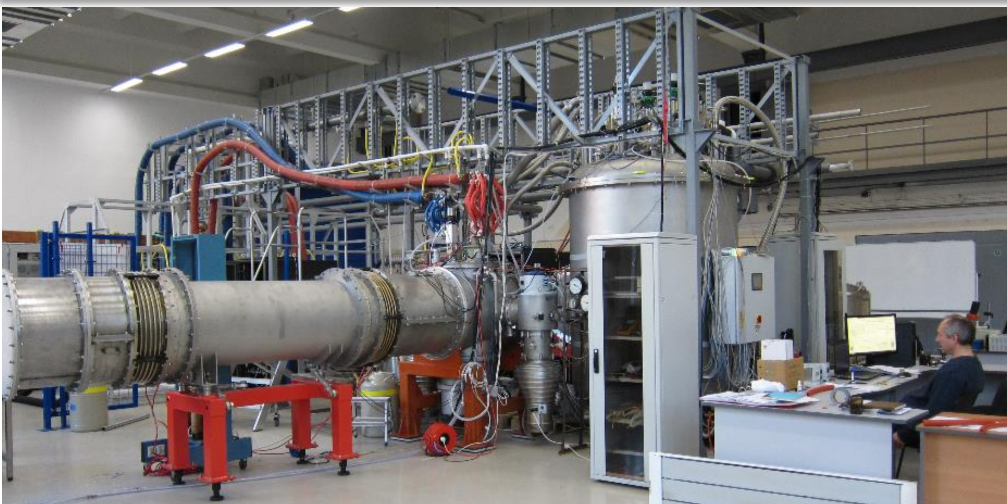
- development of accelerator facility for HEP @ JINR providing
intensive beams of relativistic ions from p to Au
polarized protons and deuterons

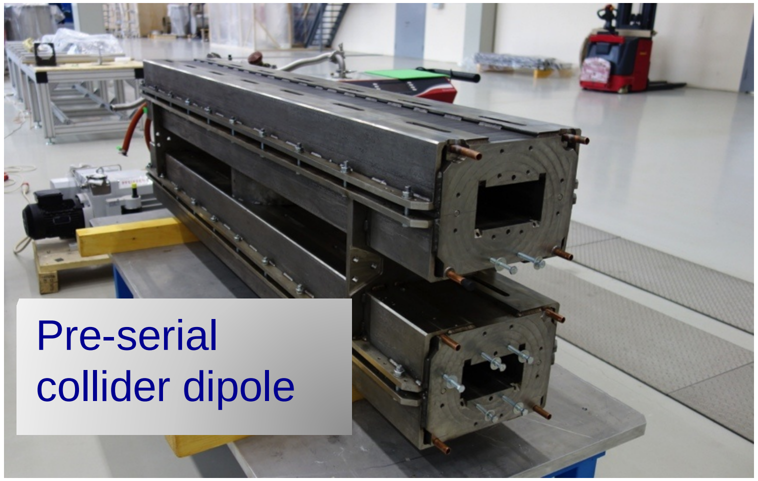
with max energy up to

$\sqrt{S_{NN}}$ *= 11 GeV (Au^{79+}) and =27 GeV (p)*

Test Facility for SC magnets of NICA and FAIR: excellent collaboration of JINR and Germany (BMBF). Start of operation – December'14. Serial assembly and cold tests (6 arms) – December 2015

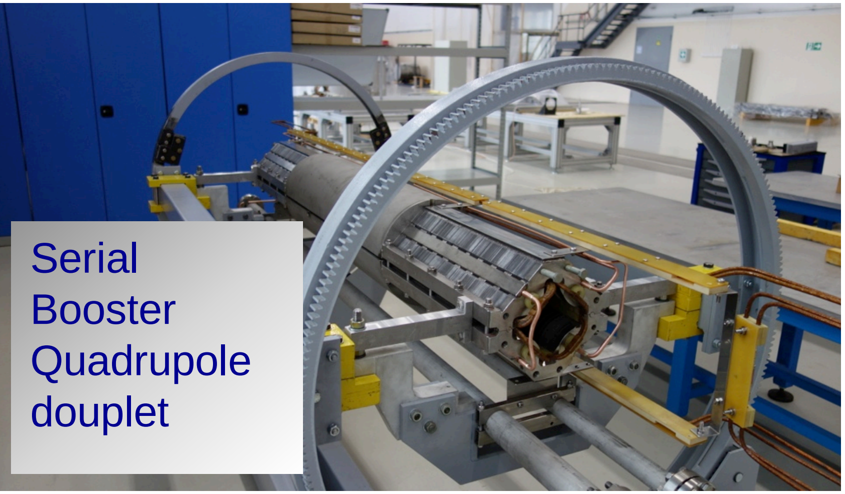
1st cold test of Booster dipole with magnetic measurements made in December'14
Cold test of serial quadrupole duplet – Feb-March 2015





Pre-serial collider dipole

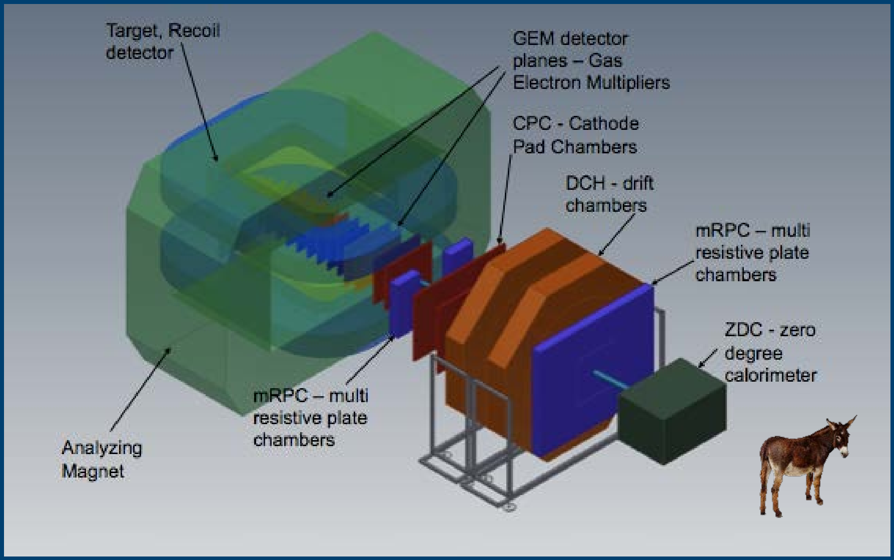
Serial production of Booster dipoles and quadrupoles started in Oct 2014



Serial Booster Quadrupole douplet

		2015				2016				2017				2018				
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
Booster																		
dipoles	40+3																	
quadrupoles	48+6																	
multipole correctors	40+4																	
Collider																		
dipoles	80+5																	
quadrupoles	86+5																	
multipole correctors																		
nonstructurals																		

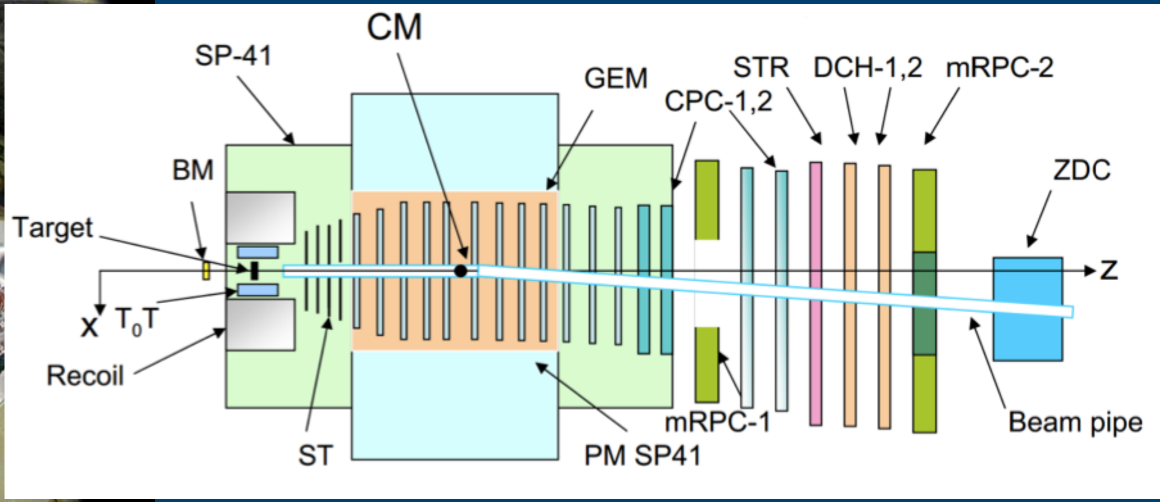
BM@N: *the 1st stage (2017)*



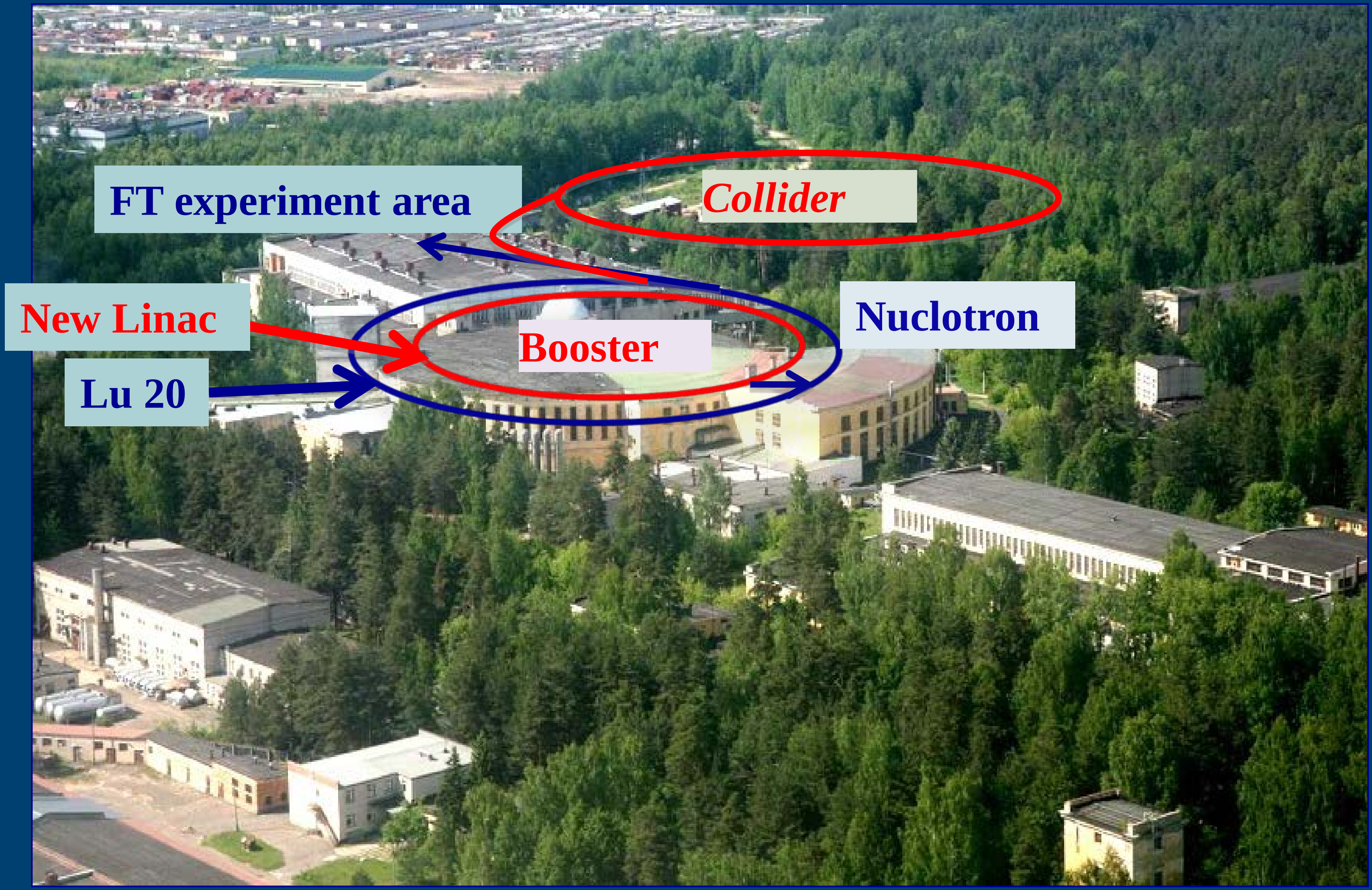
Collaboration of scientific centers:
IN, SINP MSU, IHEP + S-Ptr Univ. (RF);
GSI, Frankfurt U., Gissen U. (Germany):
+ CBM-MPD IT-Consortium,

Physics:
- ✓ *hyperon production*
- ✓ *hadron femtoscopy*
- ✓ *in-medium effects for strange & vector mesons*
- ✓ *electromagnetic probes (optional)*

BM@N *schematic view*

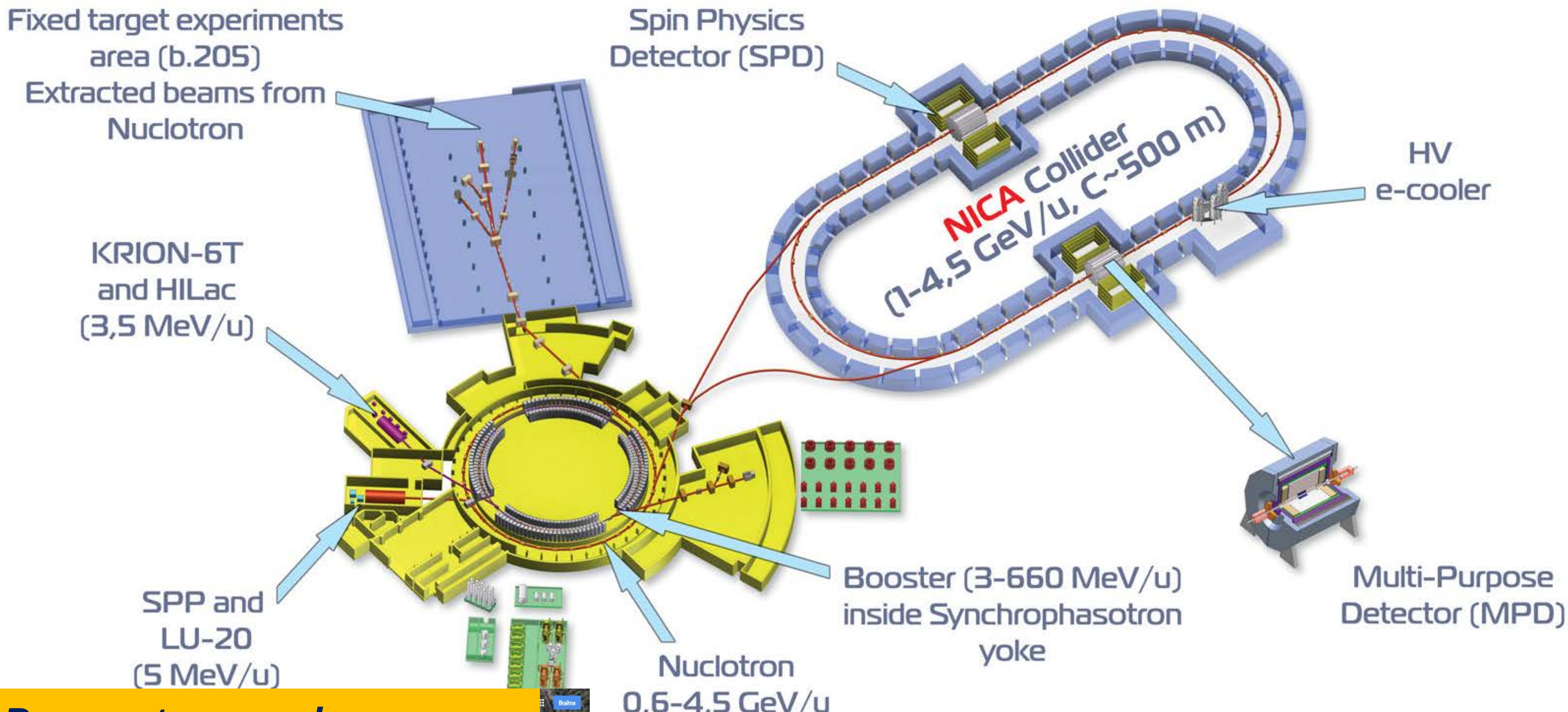


Area of Nuclotron-NICA Facility



Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)



Preparatory works are completed ~60 000 m²!

NICA parameters:

- Energy range: $\sqrt{s_{NN}}$ = 4-11 GeV
- Beams: from p to Au
- Luminosity: $L \sim 10^{27}$ (Au), 10^{32} (p)
- Detectors: MPD (ions), SPD (spin physics)

IBR-2: Pulsed reactor with fast neutrons

mean power ***2 MW***
pulse frequency ***5 Hz***
pulse width for fast neutrons ***200 μs***
thermal neutrons flux density on the moderator surface: ***10^{13}n/cm^2/s***
maximum in pulse: ***10^{16} n/cm^2/s***

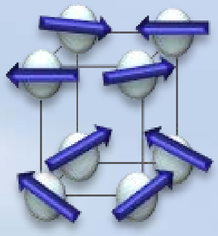
IBR-2 reactor is in operation for physical experiments

What do we need for its reliable and safe maintenance during the next 25 years?

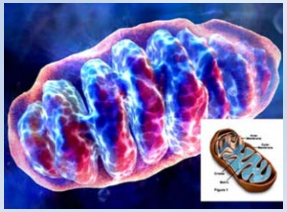
Main points:

- Radiation monitoring system
- Spare movable reflector
- Extension of service life of technological units
- Cryogenic moderators complex

What does the condensed matter studies with neutrons today and tomorrow mean?



- new materials created in extreme conditions
- micro amounts of samples

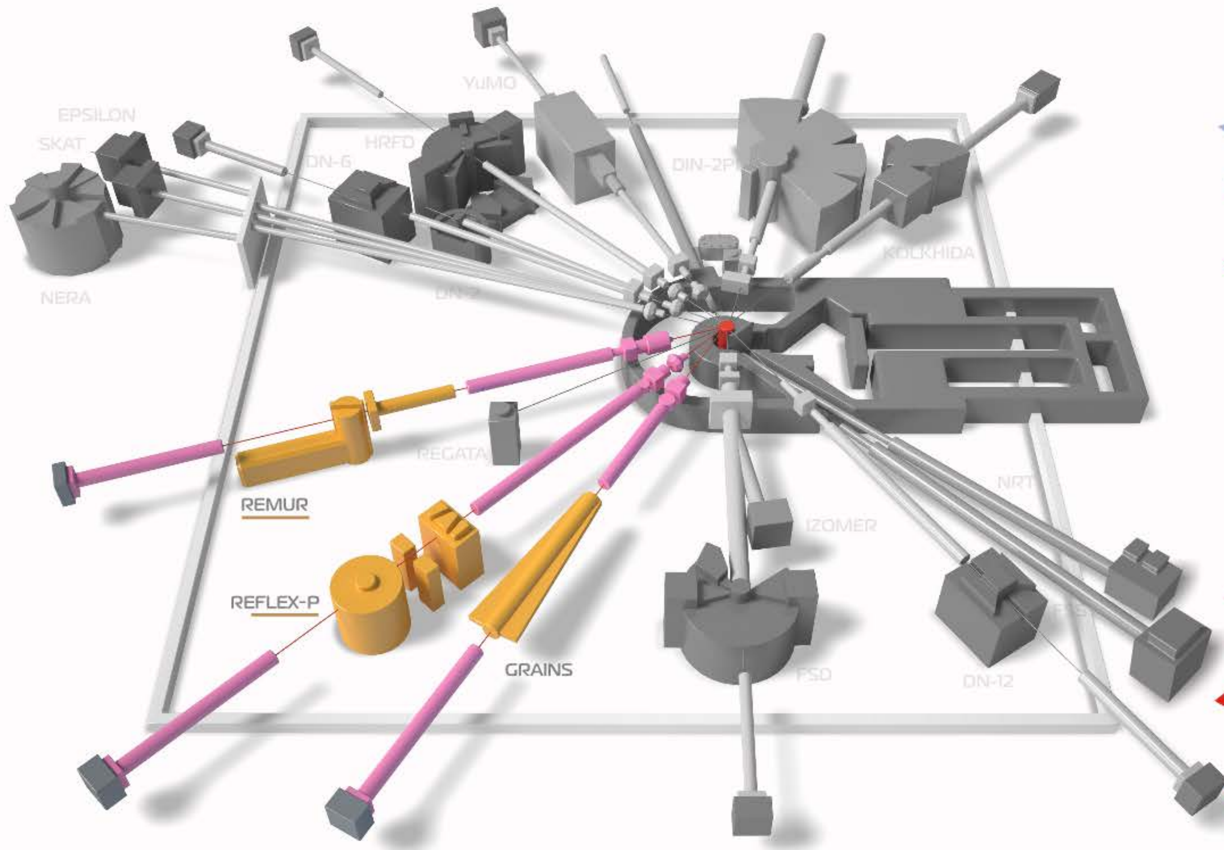


- more biological samples
- increased request for real-time studies

They all need cold neutrons!

Experimental facilities

MAIN MENU



Diffraction
DN-2, DN-12, DN-6, FSD, FSS, HRFD, SKAT, EPSILON

Small-angle scattering
YuMO

Reflectometry
GRAINS, REFLEX-P, REMUR

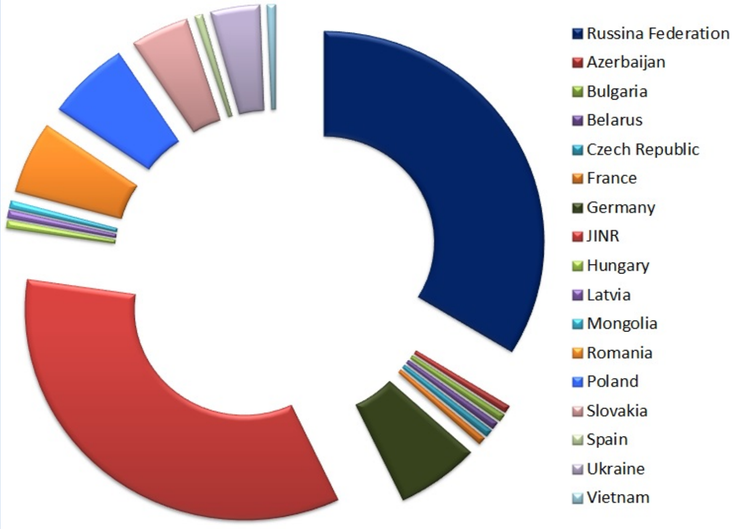
Inelastic scattering
DIN-2PI, NERA

Nuclear Physics
ISOMER, KOLHIDA

Neutron Activation Analysis
REGATA

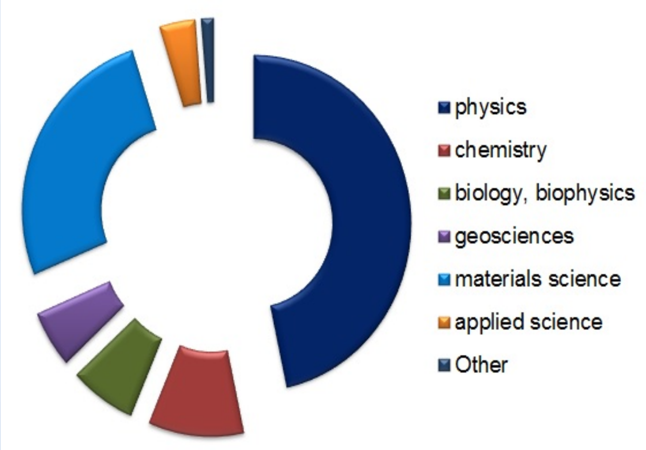
Neutron imaging
NRT

User policy at the IBR-2 (2014)

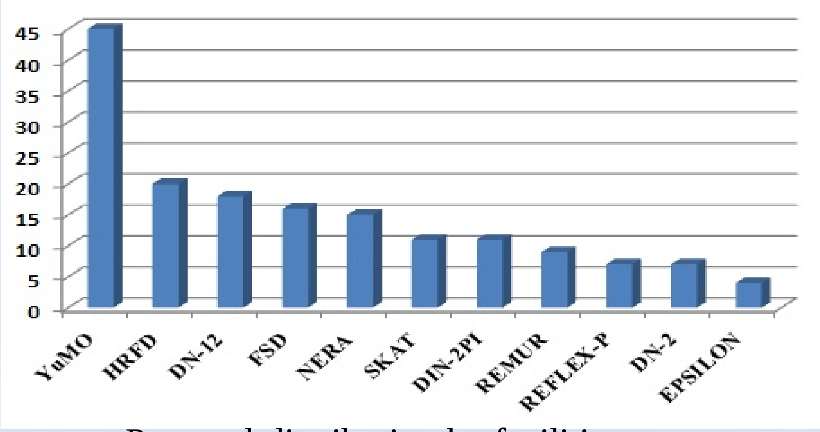


Proposal distribution by applicant’s affiliation

163 proposals were received in total
150 proposals accepted for realization



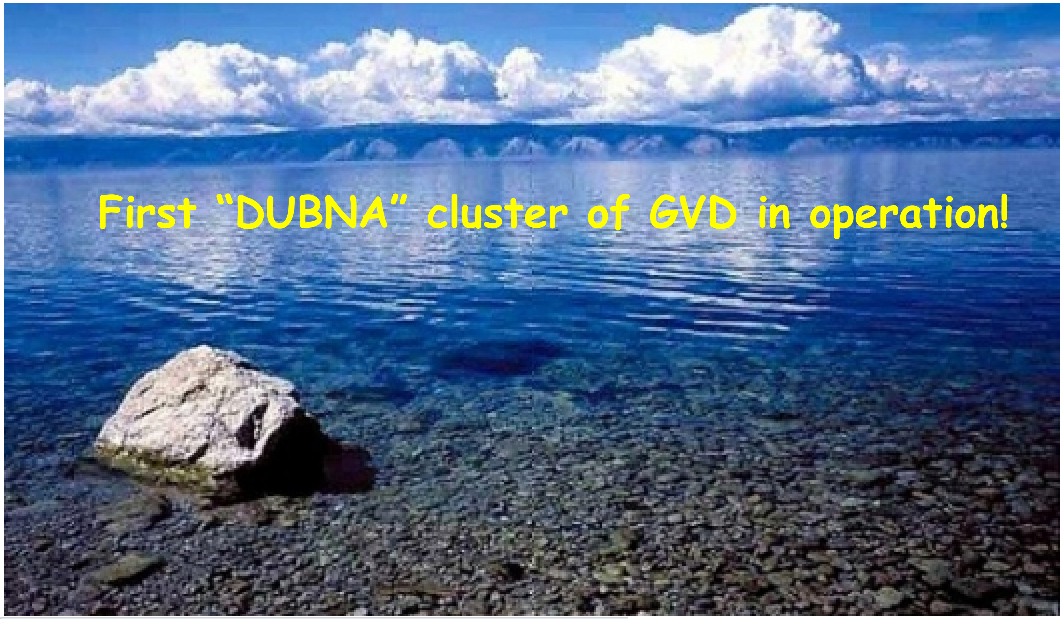
Proposal distribution by science

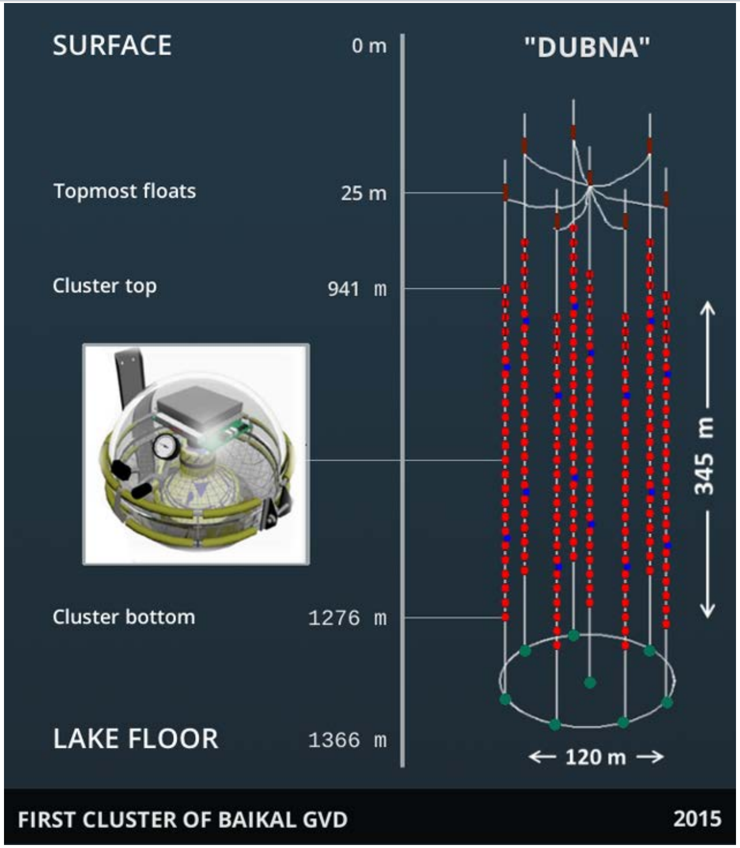


Proposal distribution by facilities

In 2014 the IBR-2 reactor operated for 2,492 hours for experiments.

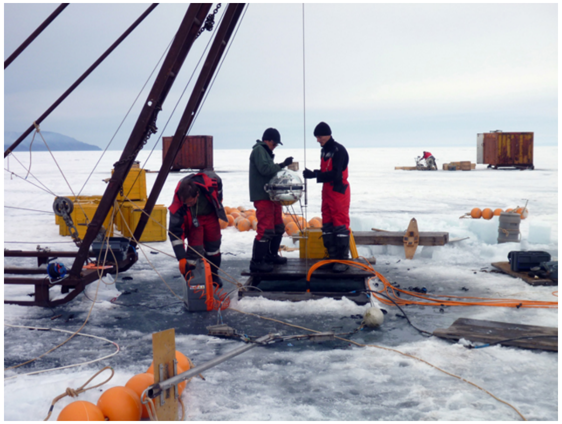
Baikal project: Gigaton Volume Detector (GVD)





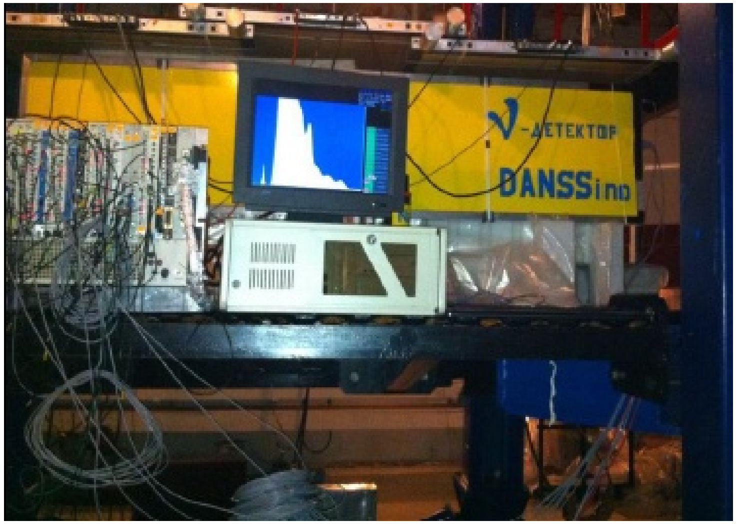
Central Physics Goals:

- Investigate Galactic and extragalactic neutrino "point sources" in energy range > 3 TeV
- Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
- Transient sources (GRB, …)
- Dark matter – indirect search
- Exotic particles – monopoles, Q-balls, nuclearites, …



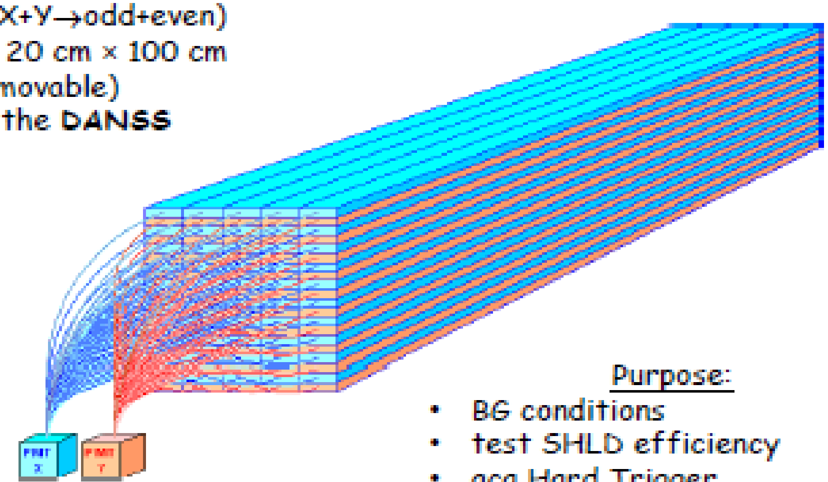
There is already a well working prototype:

DANSS = 25 DANSSino



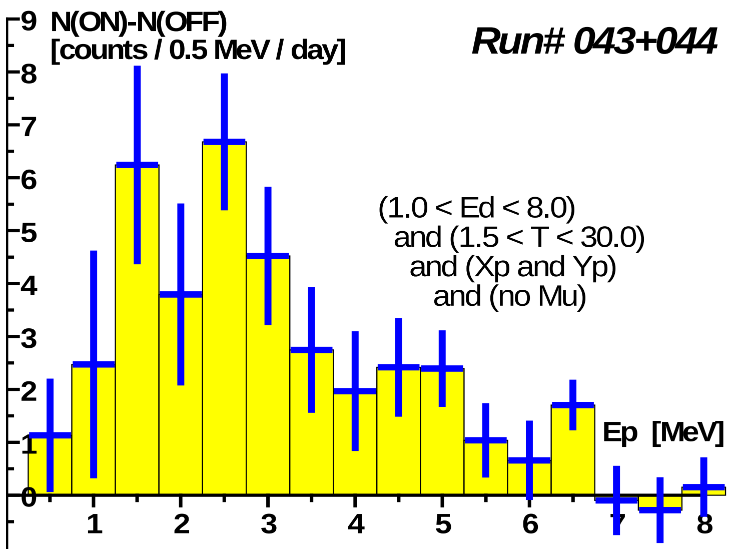
"DANSSino"

50+50=100 strips
2 PMT (X+Y→odd+even)
20 cm × 20 cm × 100 cm
40 kg (movable)
1/25 of the DANSS

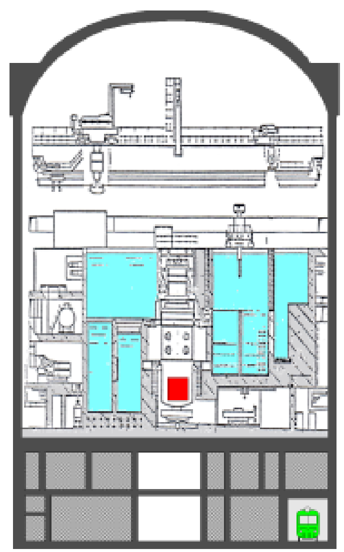


Purpose:

- BG conditions
- test SHLD efficiency
- acq Hard Trigger
- btw IBD count rate ~400/day



This is already measured reactor (anti)neutrino spectrum!



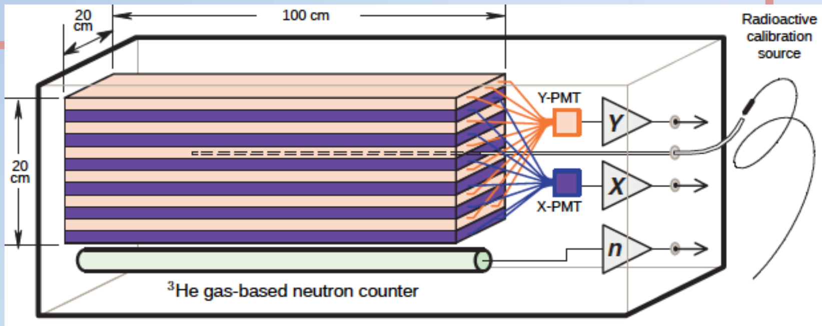
Conclusions :

- It works!!! ☺ *(even without flash ADCs and MPPC)*
- In spite of huge edge-effects, we see ν ☺
- 10 cm of (Pb+Cu) is enough to shield against γ
  The main (important) BG = fast *n* ☜
- Impossible to operate on-ground ☹
- ВВЭР-1000 shields well against cosmic *n* ☺
- μ-produced (secondary) fast neutrons = ☹
- Improve eff. of μ-veto (4π + "sandwich")
- Avoid heavy materials inside. *Change the shield composition (and mechanical construction?)*

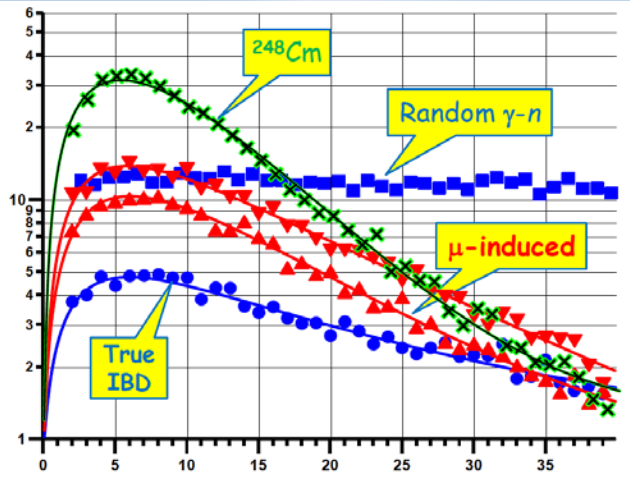
Neutrino physics

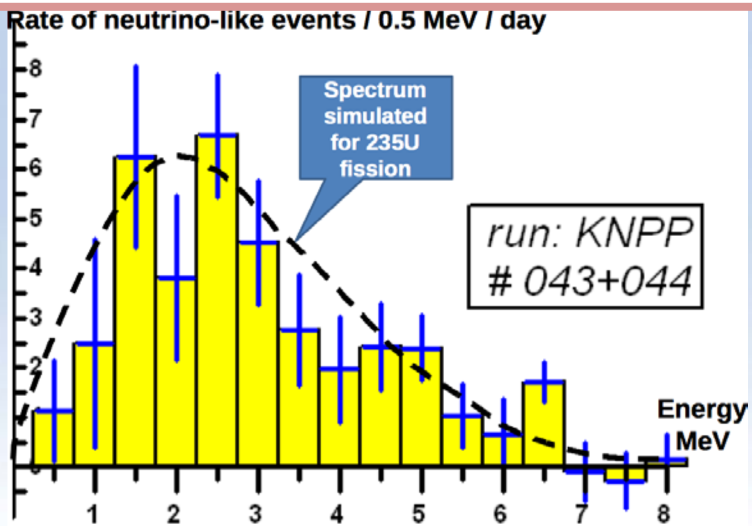
DANSS experiment at the Kalinin APS

To check the DANSS design, a pilot version
DANSSino (DANSS/25) was created !



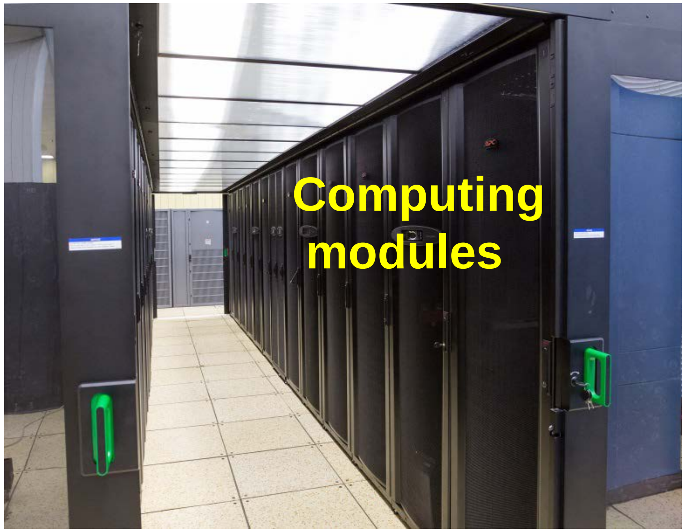
Measured reactor $\bar{\nu}$-spectrum!





JINR Multifunctional Centre for Data Storage, Processing and Analysis

- Grid-Infrastructure at Tier1 and Tier2 Levels
- General Purpose Computing Cluster
- Cloud Computing Infrastructure
- Heterogeneous Computing Cluster HybriLIT
- Education and Research Infrastructure for Distributed and Parallel Computing



In 2016 JINR will celebrate its 60th anniversary. You all are welcome to take part in this remarkable event !

Thank you and welcome to Dubna!