Brasil-JINR Forum
June 15, 2015, Dubna

Nuclear and Condensed Matter Physics at JINR

Mikhail Itkis

FLNR's BASIC DIRECTIONS of RESEARCH according to the Seven-Year Plan 2010 - 2016

1. Heavy and superheavy nuclei:

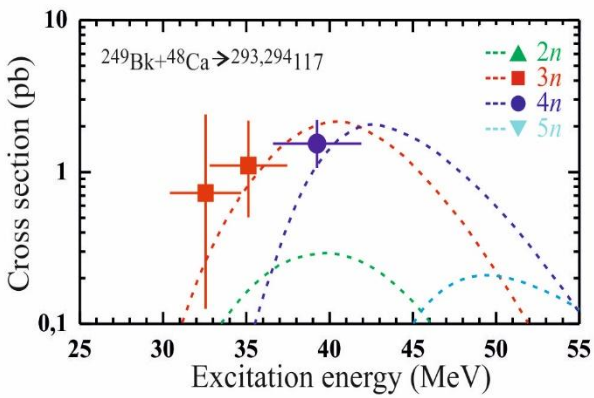
- synthesis and study of properties of superheavy elements;
- chemistry of new elements;
- fusion-fission and multi-nucleon transfer reactions;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

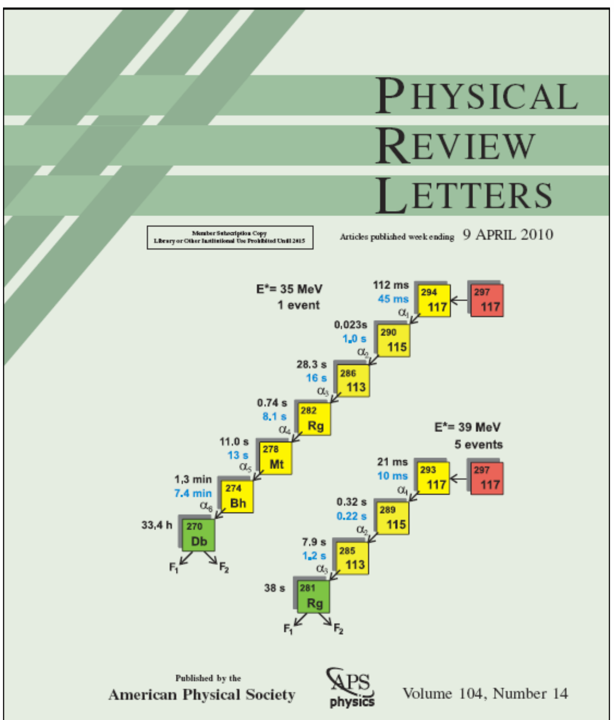
2. Light exotic nuclei:

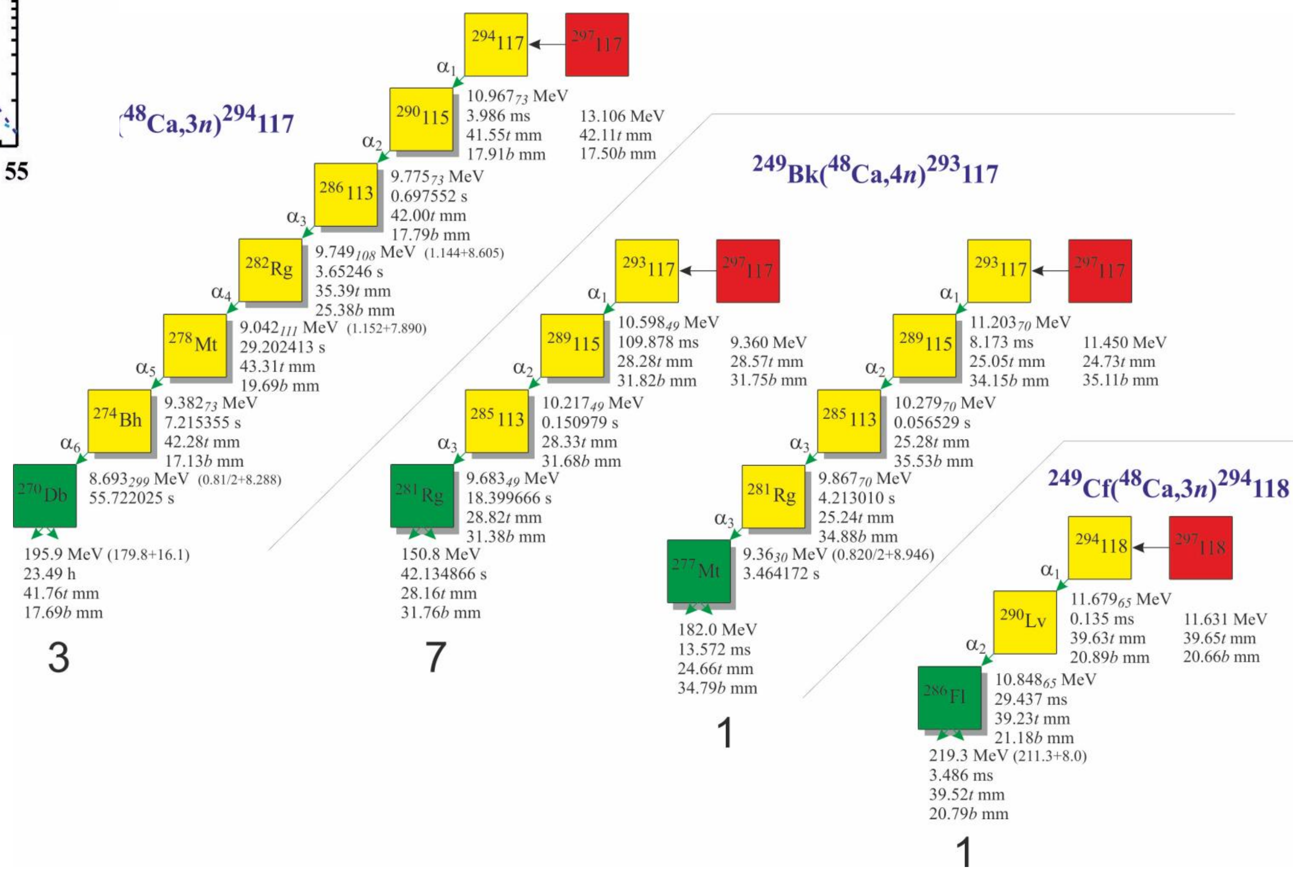
- properties and structure of light exotic nuclei;
- reactions with exotic nuclei.

3. Radiation effects and physical groundwork of nanotechnology.

Discovery of the 117th!







Phys. Rev. Lett 109, 2012

PRL 108, 022502 (2012) PHYSICAL REVIEW LETTERS week ending 13 JANUARY 2012

New Insights into the $^{243}Am + ^{48}Ca$ Reaction Products Previously Observed in the Experiments on Elements 113, 115, and 117

Yu. Ts. Oganessian,[1,*] F. Sh. Abdullin,[1] S. N. Dmitriev,[1] J. M. Gostic,[2] J. H. Hamilton,[3] R. A. Henderson,[2] M. G. Itkis,[1] K. J. Moody,[2] A. N. Polyakov,[1] A. V. Ramayya,[3] J. B. Roberto,[4] K. P. Rykaczewski,[4] R. N. Sagaidak,[1] D. A. Shaughnessy,[2] I. V. Shirokovsky,[1] M. A. Stoyer,[2] V. G. Subbotin,[1] A. M. Sukhov,[1] Yu. S. Tsyganov,[1] V. K. Utyonkov,[1] A. A. Voinov,[1] and G. K. Vostokin[1]

[1]*Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation*
[2]*Lawrence Livermore National Laboratory, Livermore, California 94551, USA*
[3]*Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, USA*
[4]*Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

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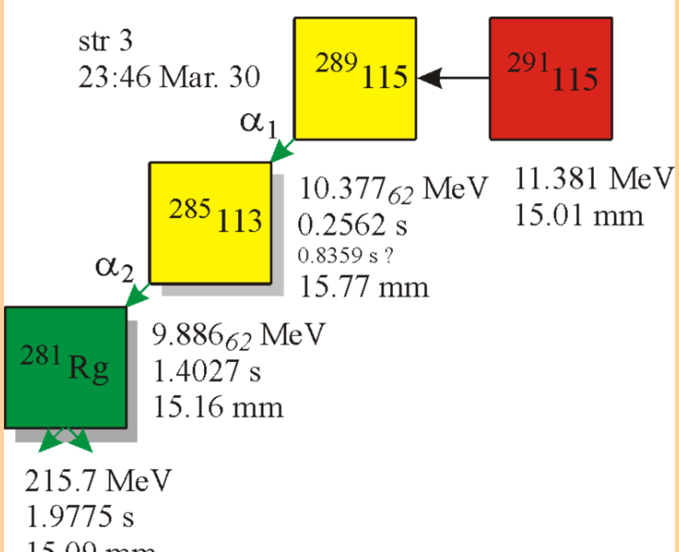
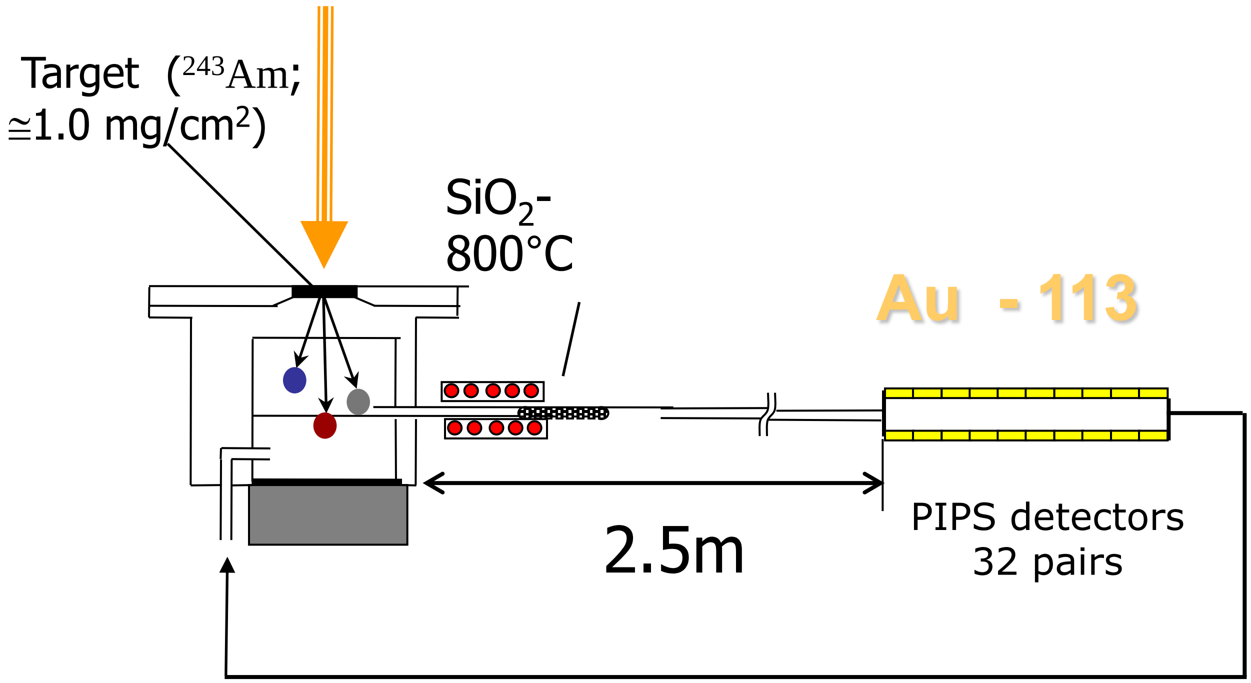
2*n* channel !



Observation of the 2n-evaporation channel opens up perspectives of chemical investigation of the element 113

GAS PHASE CHEMISTRY WITH ELEMENT 113

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



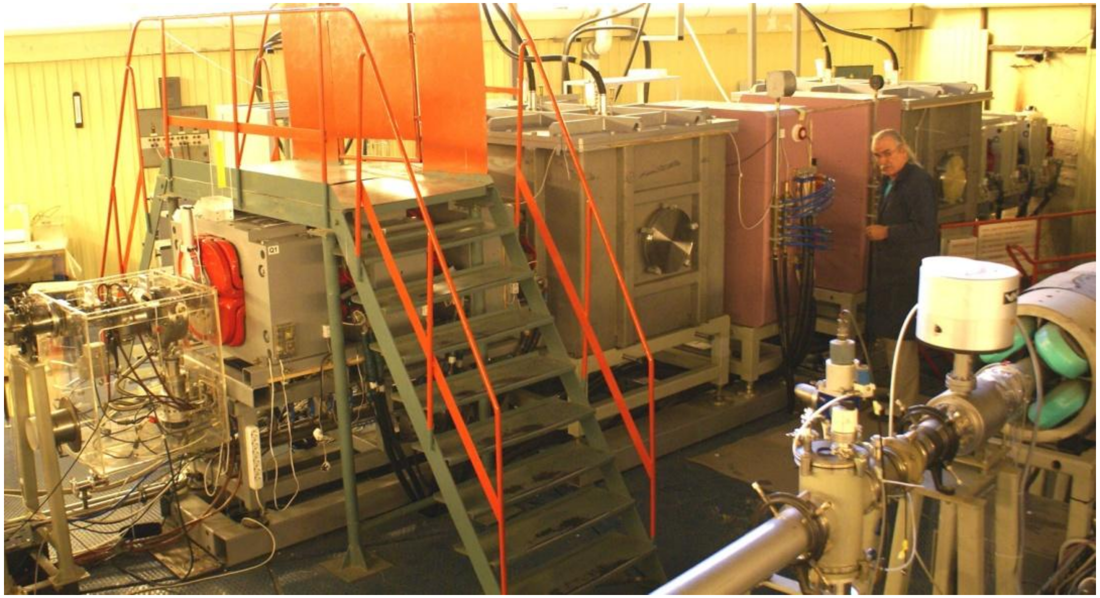
Data analysis running

Commissioning of the new experimental setup - velocity filter SHELS (Separator for Heavy ELement Spectroscopy)

June – Testing

$^{22}Ne(^{198}Pt,6n)^{214}Ra$

$^{22}Ne(^{197}Au,5n)^{214}Ac$

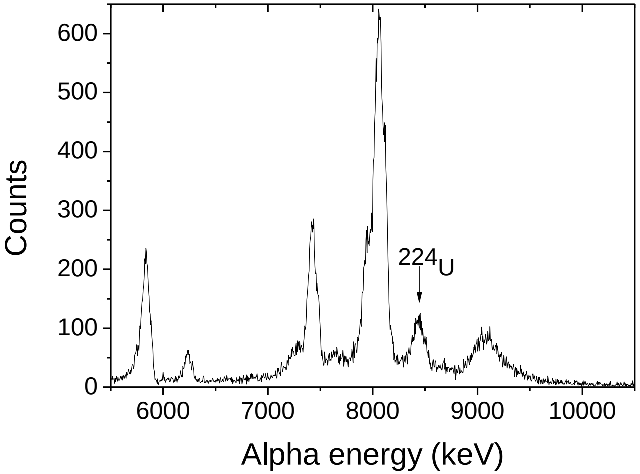


July - Spectroscopy:

$^{22}Ne(^{208}Pb,4n)^{226}U$

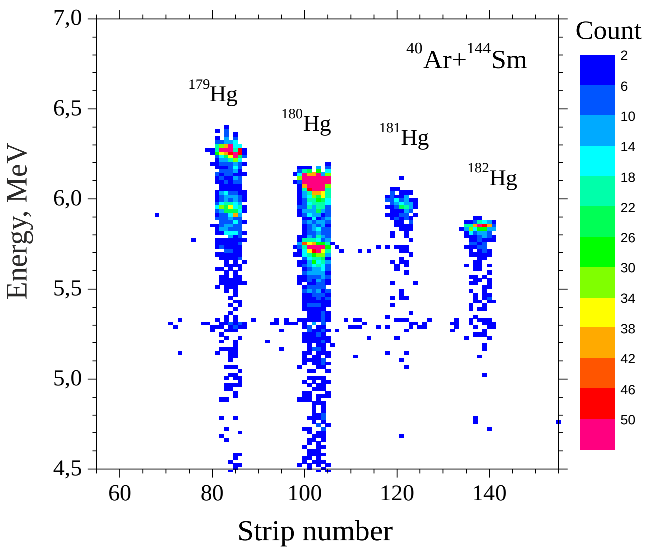
$^{22}Ne(^{206}Pb,4n)^{224}U$

$^{22}Ne(^{238}U,5n)^{255}No$



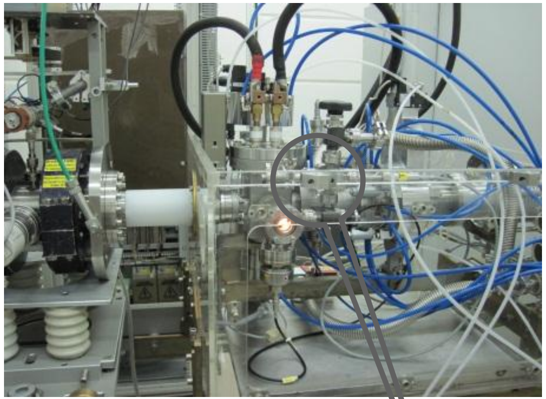
MAss-Separator of Heavy Atoms - “MASHA”

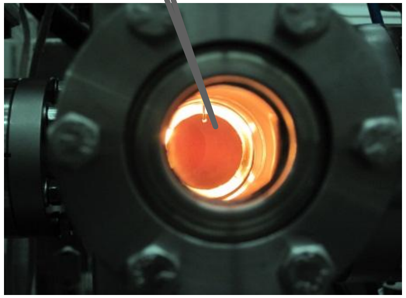
Mass-separator “MASHA” at the beam of U-400M



Detection of mercury isotopes at the focal plane

Hot catcher



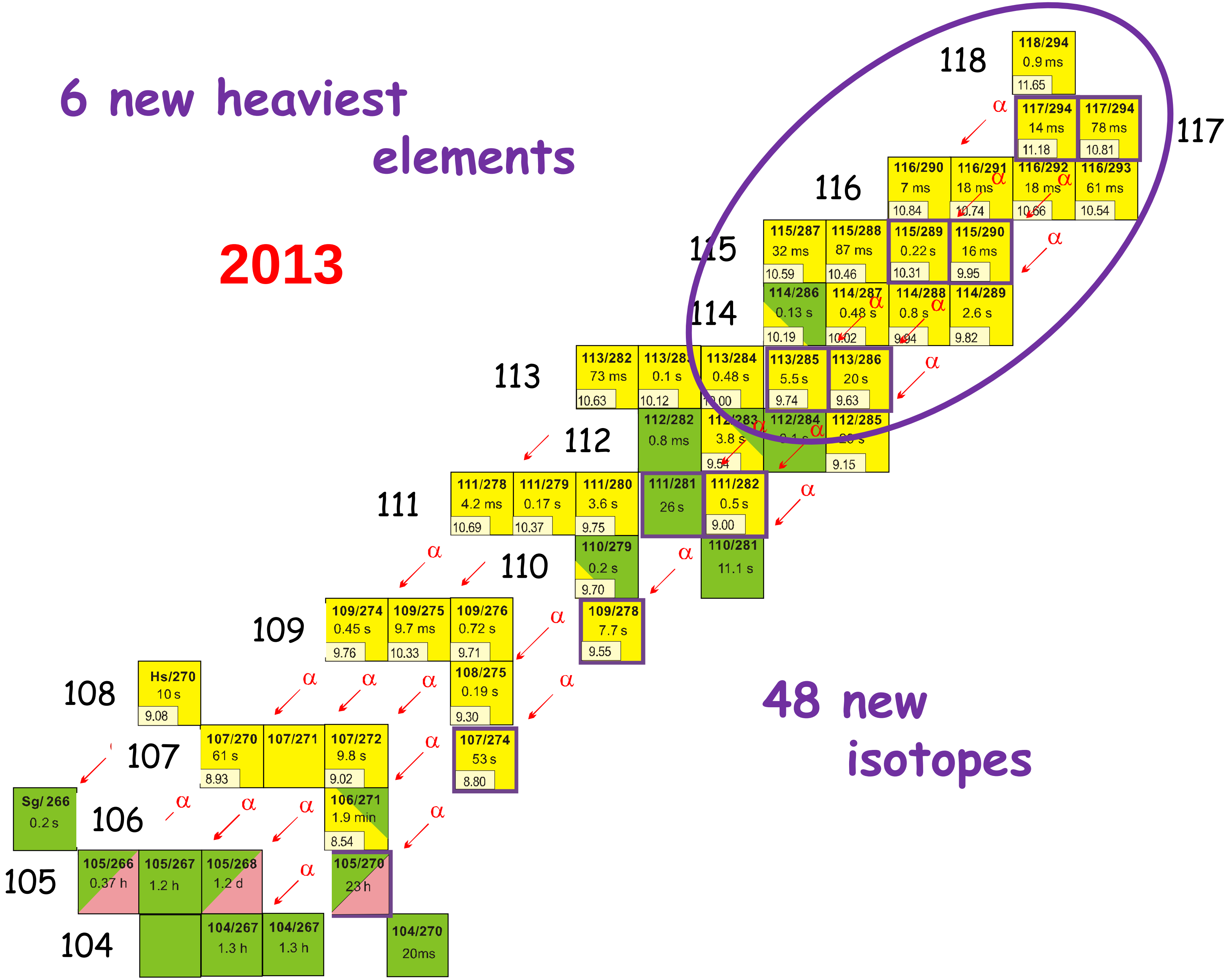


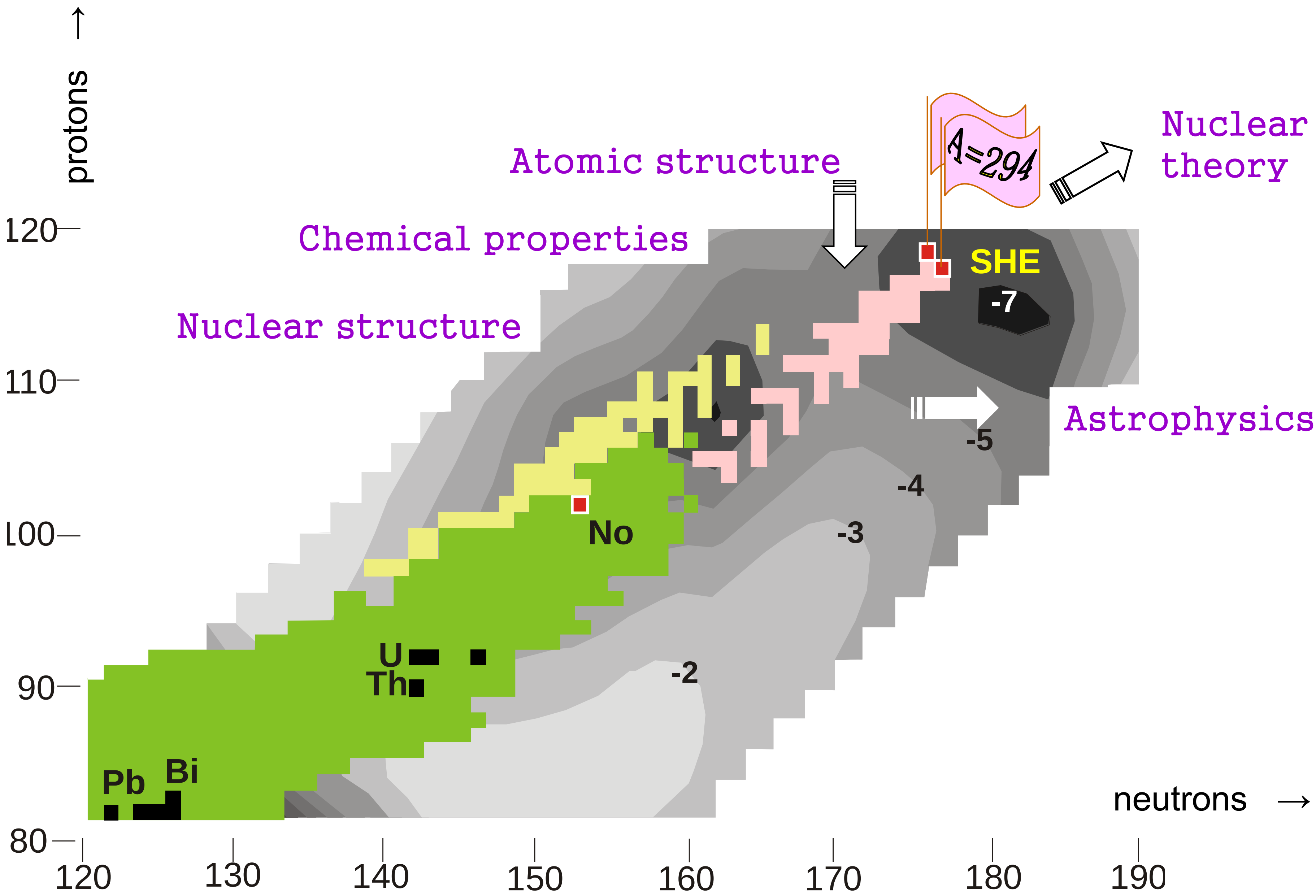
Mass measurement of ^{283}Cn in reaction $^{48}Ca+^{238}U$ started

6 new heaviest elements

2013

48 new isotopes





protons ↑
120
110
100
90
80
Chemical properties
Atomic structure
A=294
Nuclear theory
Nuclear structure
SHE
-7
Astrophysics
-5
-4
-3
-2
No
U
Th
Pb
Bi
neutrons →
120
130
140
150
160
170
180
190

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: $^{136}Xe+^{136}Xe$, $^{136}Xe+^{150}Nd$, $^{150}Nd+^{150}Nd$;**
- **Nucleon transfer reactions ($^{136}Xe+^{208}Pb$, $^{238}U+^{248}Cm$).**

Preparation to study $^{48}Ca + ^{251}Cf$ reaction (Spring 2014)

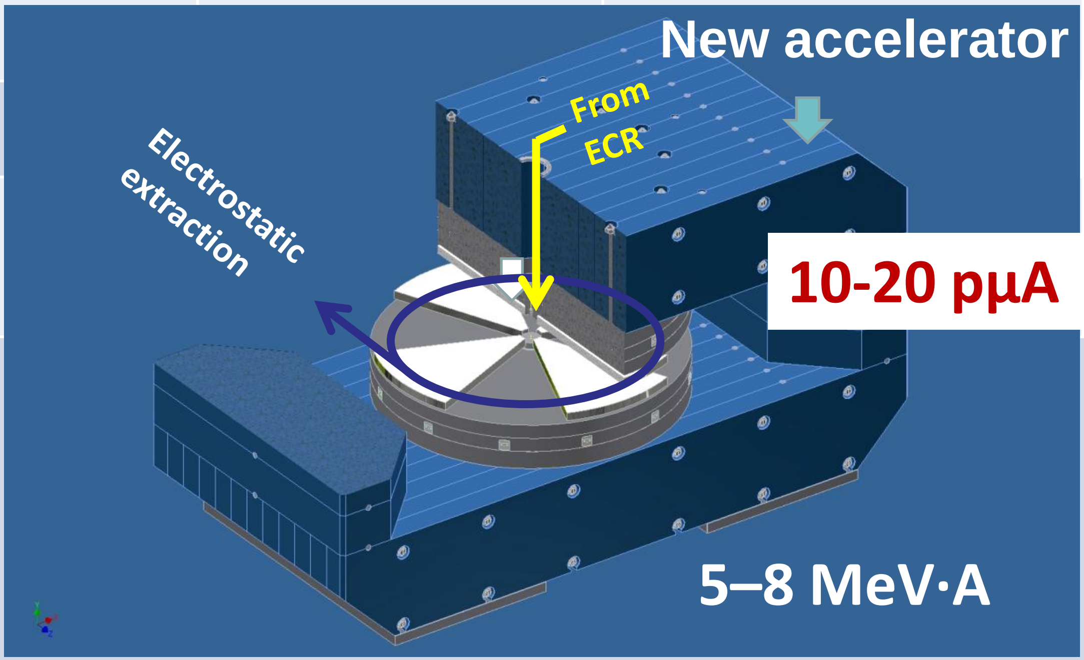
SHE-factory

Production

today: $4.5 \cdot 10^{19}$ **with factory: $1.3 \cdot 10^{21}$**

factor: 30

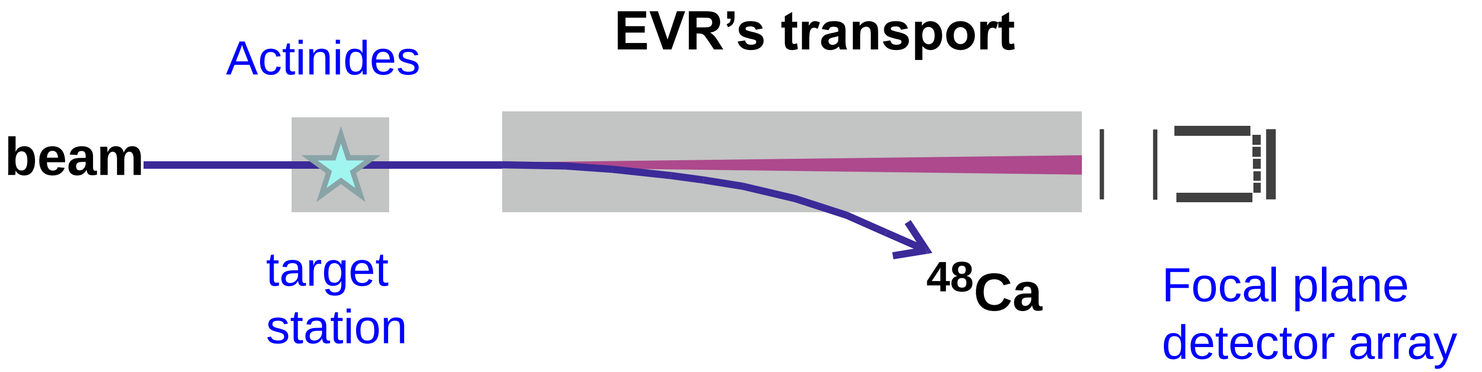
Increase a beam dose			
it requires to Increase:	**beam intensity**	and	**beam time**
			↓
			SHE-Factory
			↓
			~ 7000 h/year
			⇩



DC280 . Intensity of some typical ion beams

^{20}Ne	$1 \cdot 10^{14}$ pps
^{48}Ca	$\sim 10^{14}$ pps
^{50}Ti	$3 \cdot 10^{13}$ pps
^{70}Zn	$2{,}5 \cdot 10^{13}$ pps
^{86}Kr	$3 \cdot 10^{13}$ pps
^{100}Mo	$2 \cdot 10^{12}$ pps
^{124}Sn	$2 \cdot 10^{12}$ pps
^{136}Xe	$2 \cdot 10^{13}$ pps
^{208}Pb	$1 \cdot 10^{12}$ pps
^{238}U	$1 \cdot 10^{11}$ pps

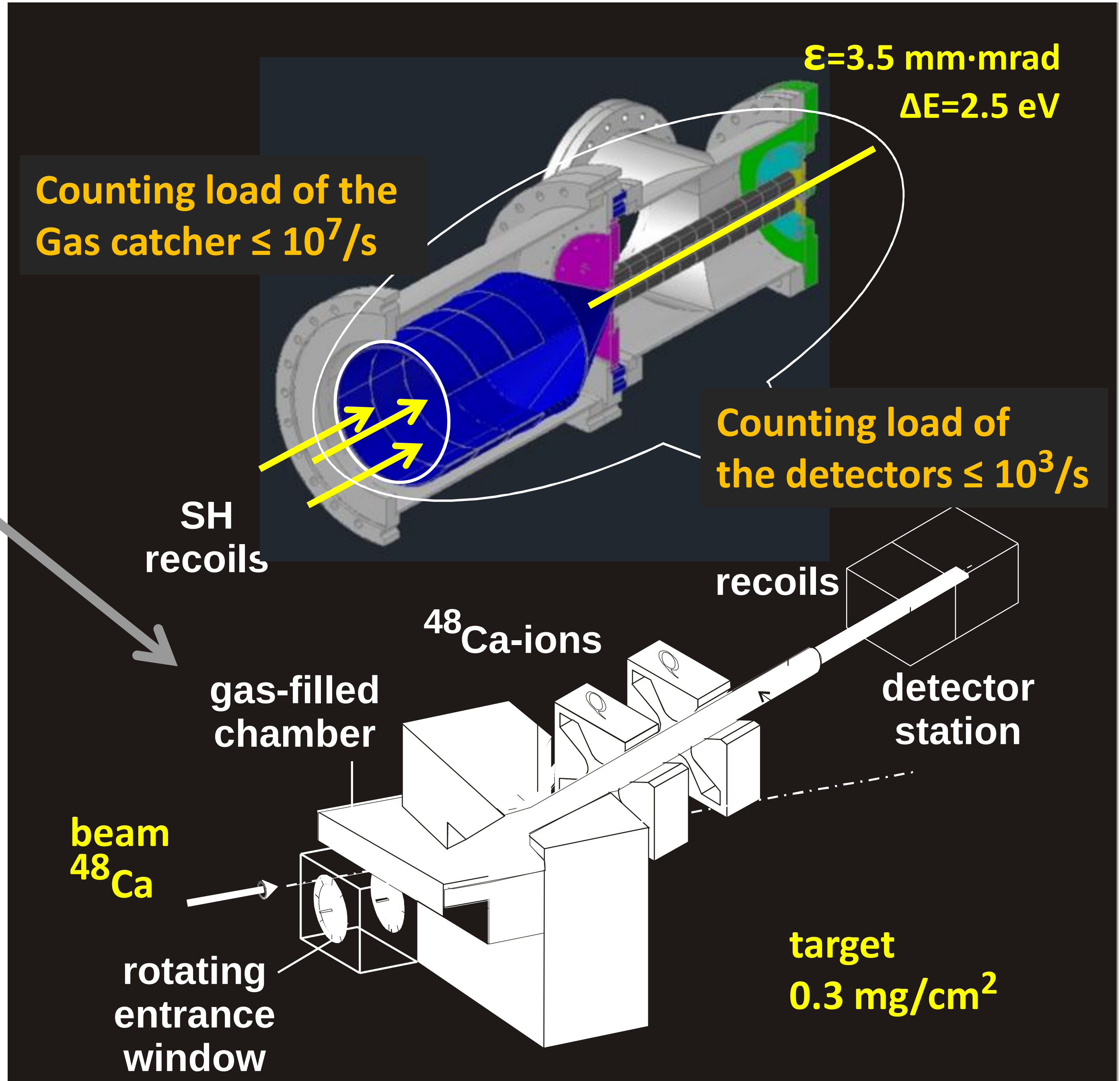
Scheme of the production and delivery SH-atoms at the detectors



NEW
SC GAS- FILLED
SEPARATOR

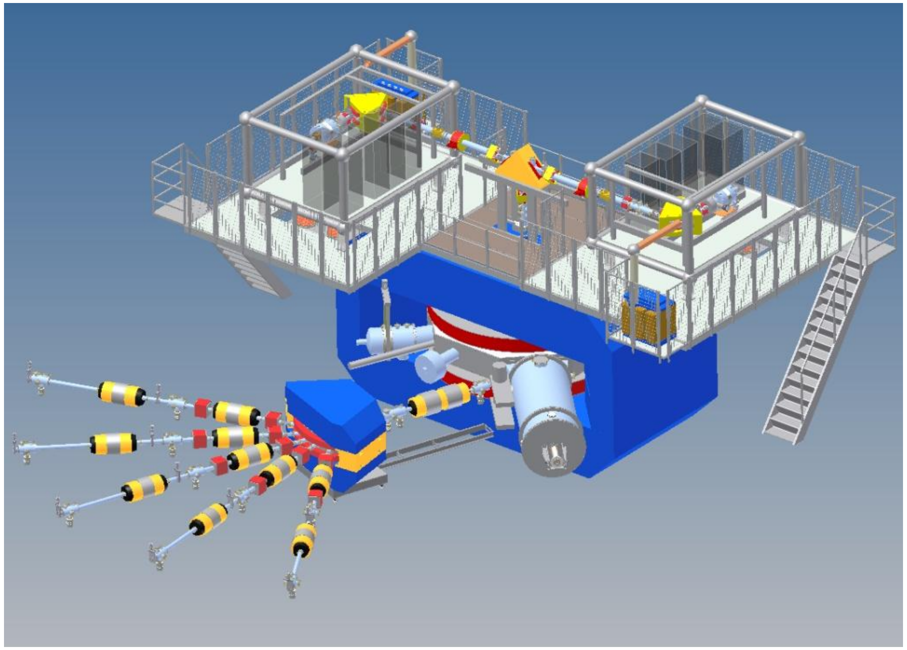
target
1.2 mg/cm^2

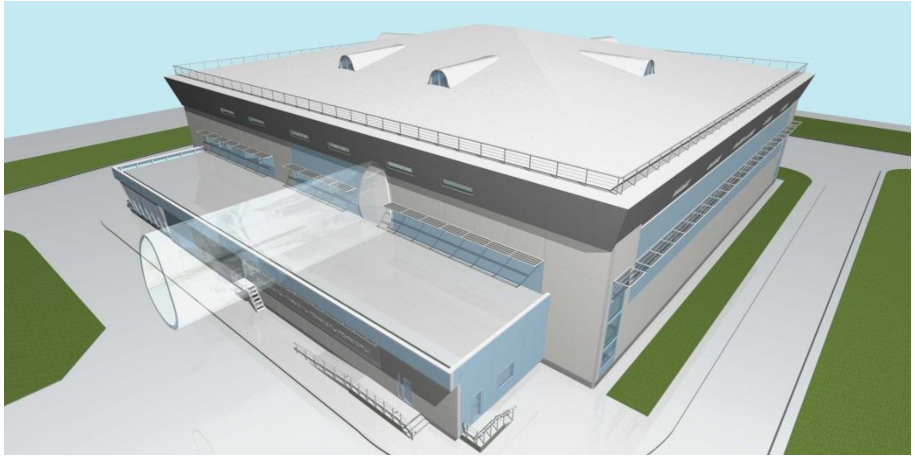
factor 4



Schedule of the SHE factory creation

	2011	2012	2013	2014	2015	2016
Experimental Building						
Cyclotron DC 280						
Main magnet yoke creation						
Equipment creation, completion.						
Assembling, testing						
First experiment						





DC280 cyclotron – production status

Main magnet

Vacuum chamber

Bending magnet

RF Amplifiers

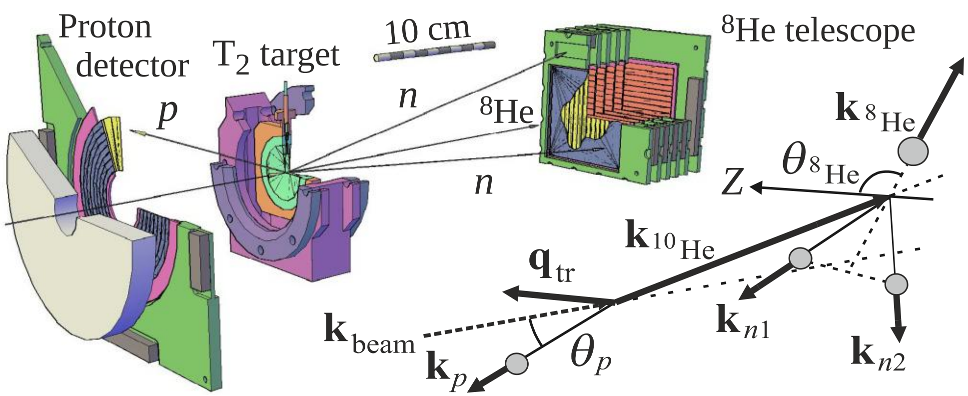
Power supply

Water cooling system

Studies of Exotic Nuclei in JINR

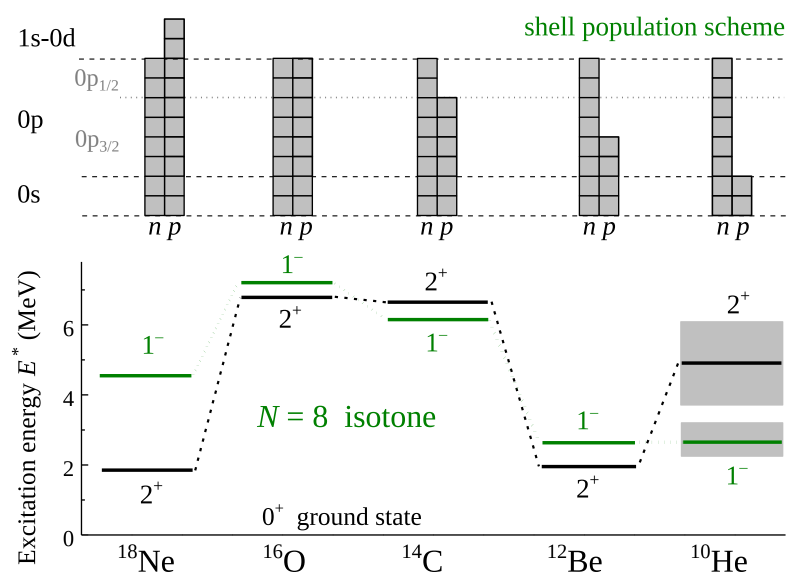
Breakdown of the N=8 shell in ^{10}He.

S.I. Sidorchuk. A.A. Bezbakh, V. Chudoba et al., PRL 108 (2012)



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

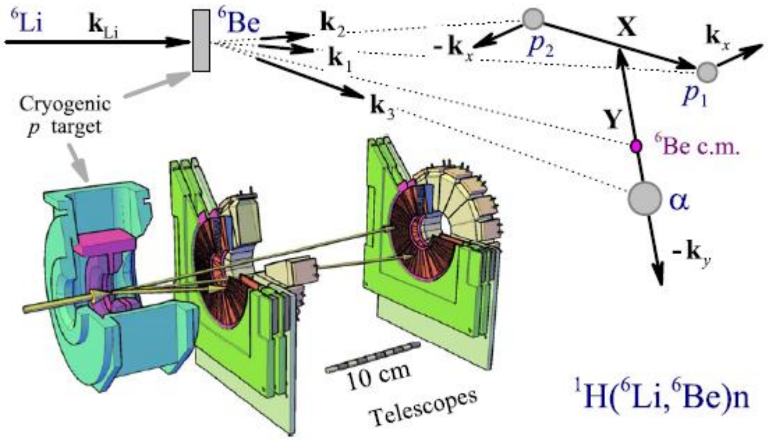
Owing to specific angular and energy correlations of ^{10}He decay products for the first time the **spin-parity assignment was made** for the low-lying states of ^{10}He.
The experimental data were interpreted as a superposition of 0^+, 1^- and 2^+ states.
The established level sequence shows that ^{10}He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



Studies of Exotic Nuclei in JINR

Isovector Soft Dipole Mode in ^{6}Be.

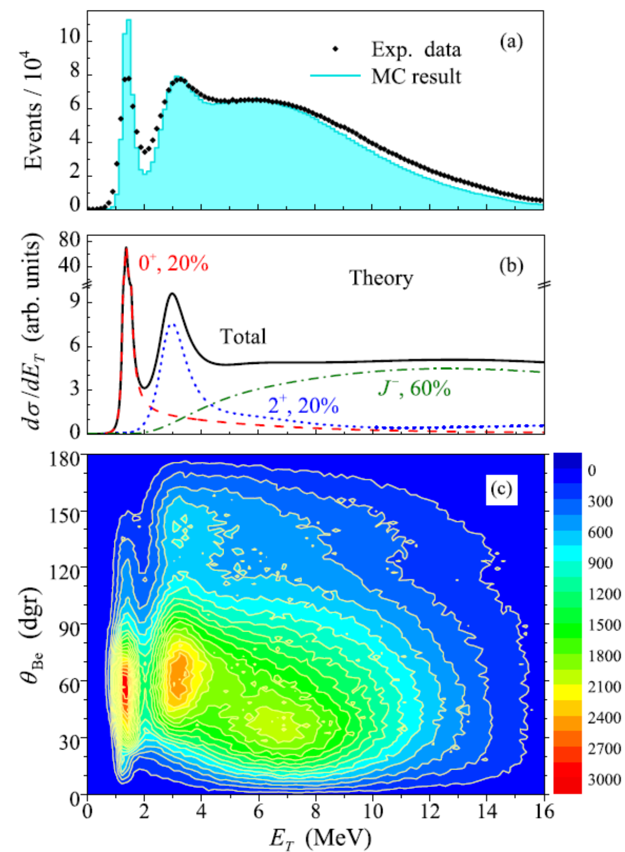
A.S. Fomichev. V. Chudoba, I.A. Egorova et al., PLB 708 (2012)



Spectrum of the unbound **^{6}Be** was produced in the **charge-exchange** reaction using the cryogenic hydrogen target: ^{1}H(^{6}Li, ^{6}Be)n.

The data obtained provide detailed correlation information about the well-known 0^{+} ground state and the 2^{+} state.

A broad structure extending from 4 to 16 MeV was observed. It contains negative parity states populated by the L=1 angular momentum transfer. This continuum structure can be interpreted as a novel phenomenon: **the isovector soft dipole mode** associated with the ^{6}Li ground state.



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

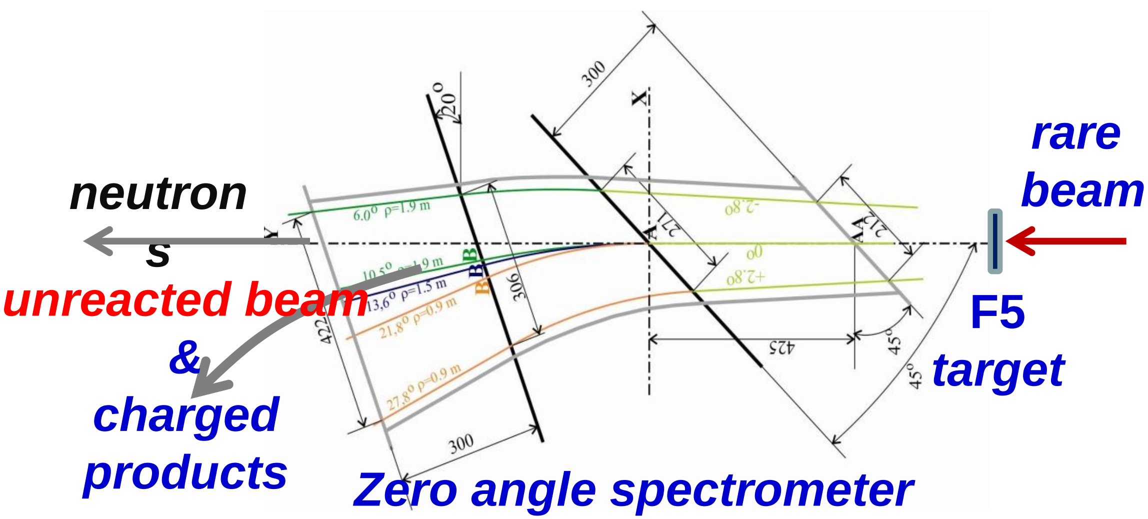
2016: *zero angle spectrometer at F5*

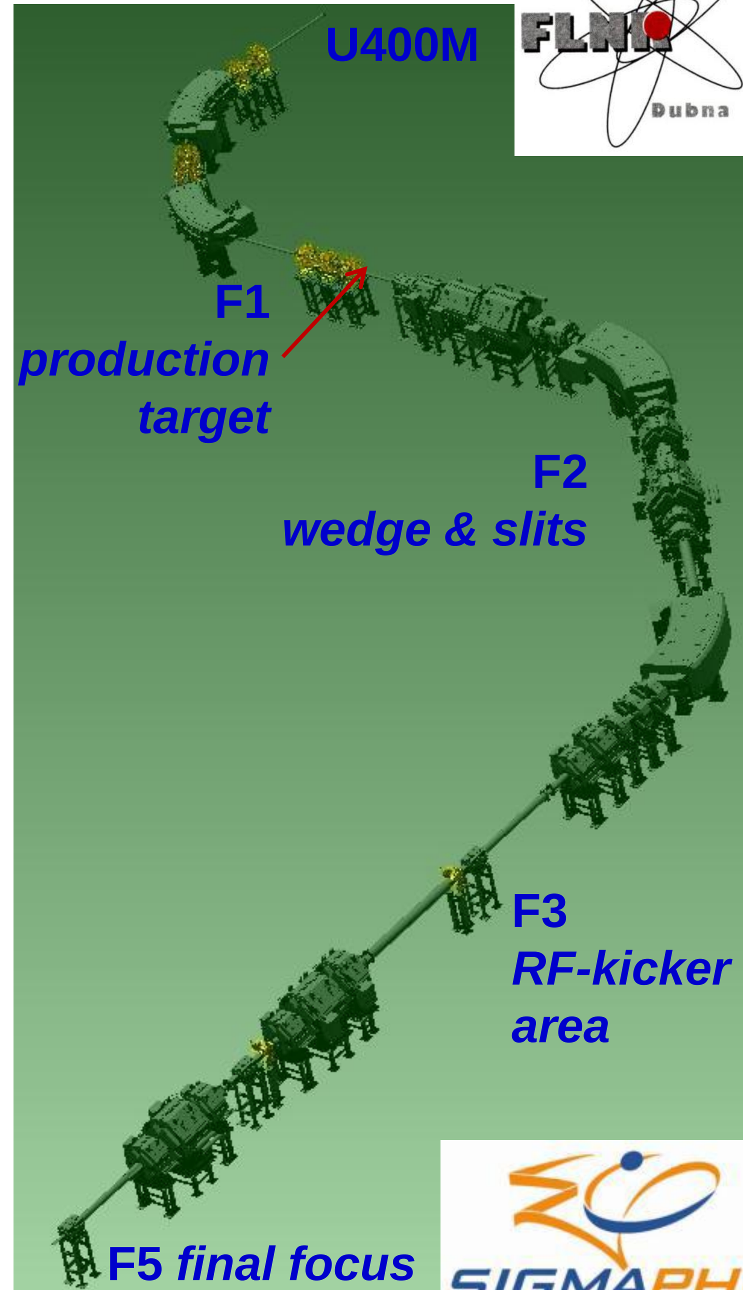
^{7}H - observation with the use of 11Li projectile

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

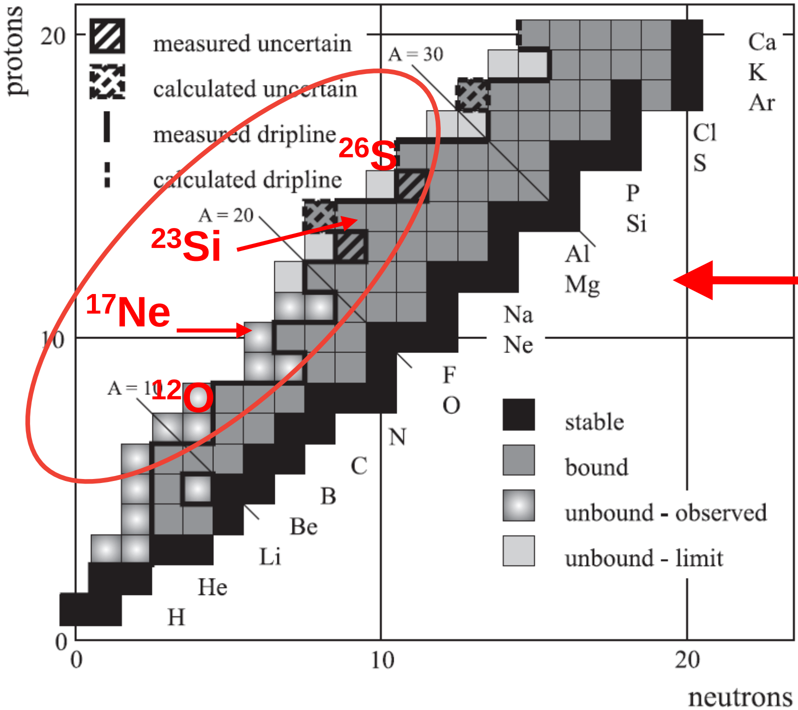
2017: *cryogenic tritium target*

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



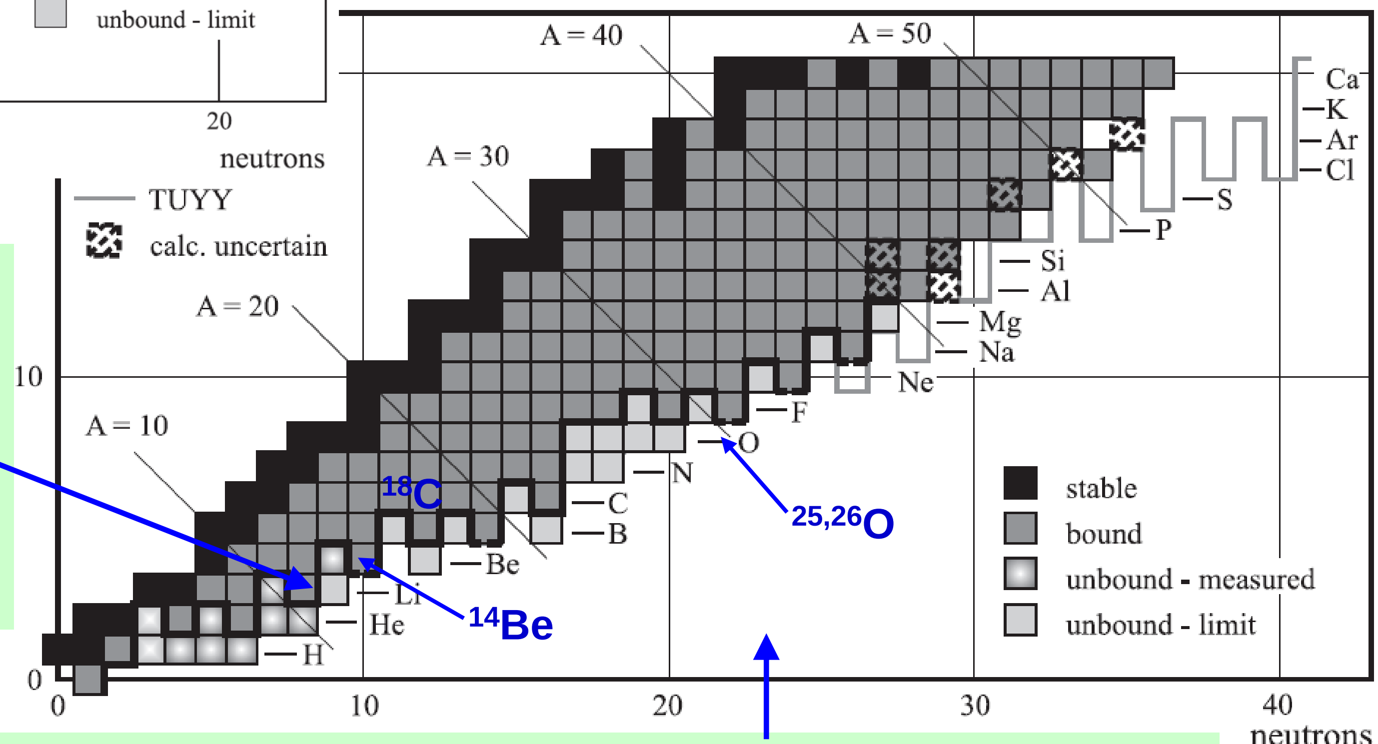


First day experiments



One, two and three **proton decays** of ^{12}O, ^{16,17}Ne, ^{26,27}S using the modern methods: decay in flight, OTPC, correlations in transfer reactions

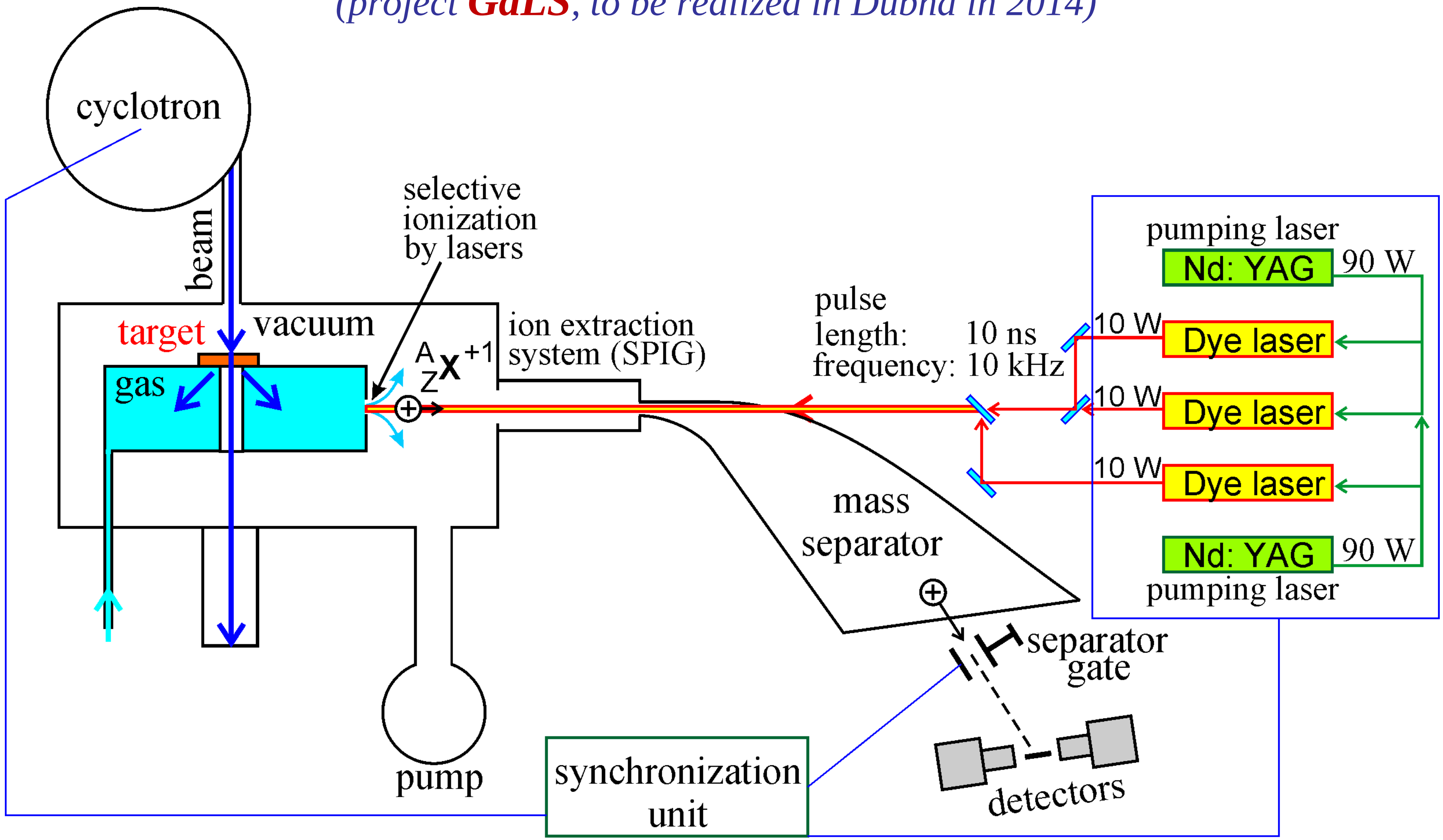
Reactions of complete and incomplete fusion near Coulomb barrier; fusion-fission, quasi-fission



Structure of **neutron rich nuclei:** ^{14,16}Be, ^{18,19}C, ^{25,26}O etc. with the use of cryogenic tritium target and ^{36}S & ^{48}Ca intensive primary beams

New setup for selective laser ionization of multi-nucleon transfer reaction products stopped in gas

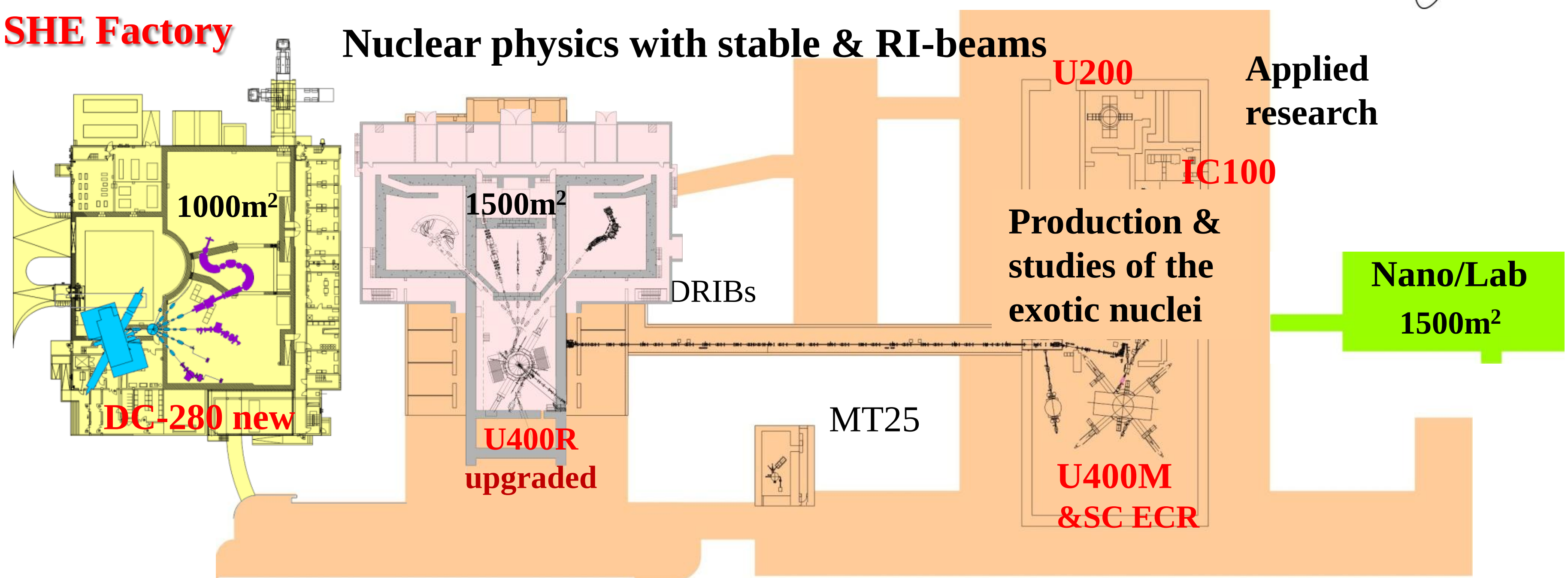
*(project **GaLS**, to be realized in Dubna in 2014)*



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

FLNR (JINR) – 2017



U400R - U400M
Accelerator Complex

Non-accelerator low-energy neutrino physics and dark matter search

In this field of research JINR participates in

1) neutrino-less double beta decay search within international projects NEMO (Mo, Se, etc), Super-NEMO (Se), GERDA (Ge-76), MAJORANA (Ge-76).
2) Neutrino magnetic moment study with GEMMA detector,
3) Sterile neutrinos, coherent scattering and direct measurements of antineutrino spectra from Kalinin Nuclear reactor with spectrometer DANSS.
4) As well as in search for forbidden muon-to-electron-and-gamma decay with MEG setup, study of astrophysical S-factors of dd and pd reactions at ultra low energy (LESI), etc.

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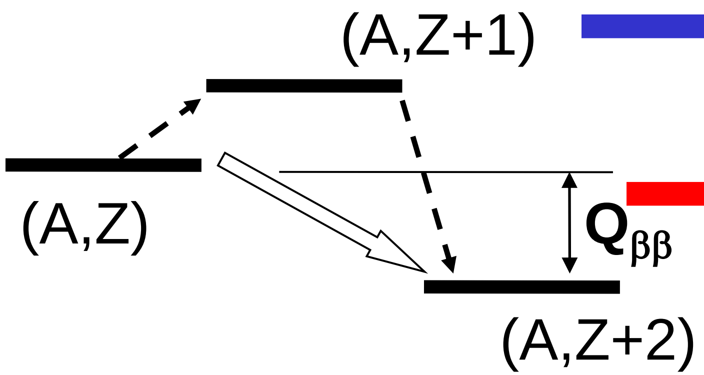
JINR takes place in direct Dark matter search experiment EDELWEISS, and plans to participate in international projects EURECA and Dark Side (within Borexino experiment)

Neutrino-less double beta nuclear decay is traditionally under study at DLNP



Double beta decay basic statements

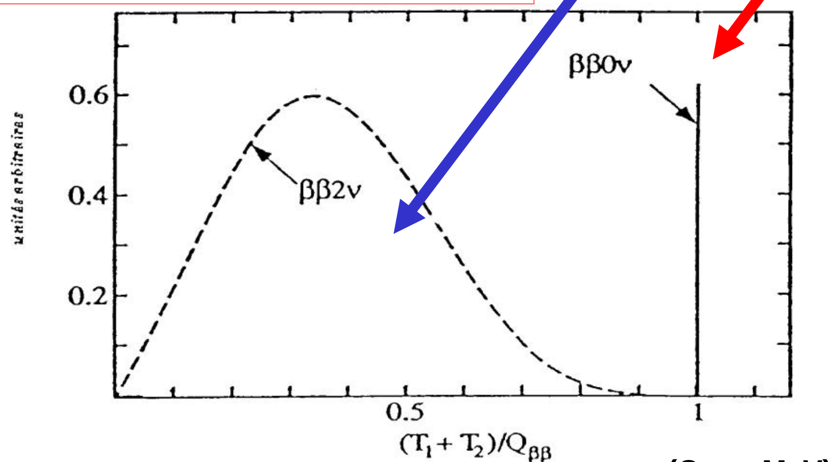
2νββ: allowed SM process $T_{1/2}$ ~ 10^{20}y

(A,Z)→(A,Z+2) + 2e⁻ + 2ν (2n → 2p + 2e⁻ + 2ν)

0νββ: beyond the SM $T_{1/2} \geq 10^{25}$y

(A,Z)→(A,Z+2) + 2e⁻ (2n → 2p + 2e⁻)

Neutrino nature – Dirac/Majorana
Neutrino absolute scale and hierarchy pattern



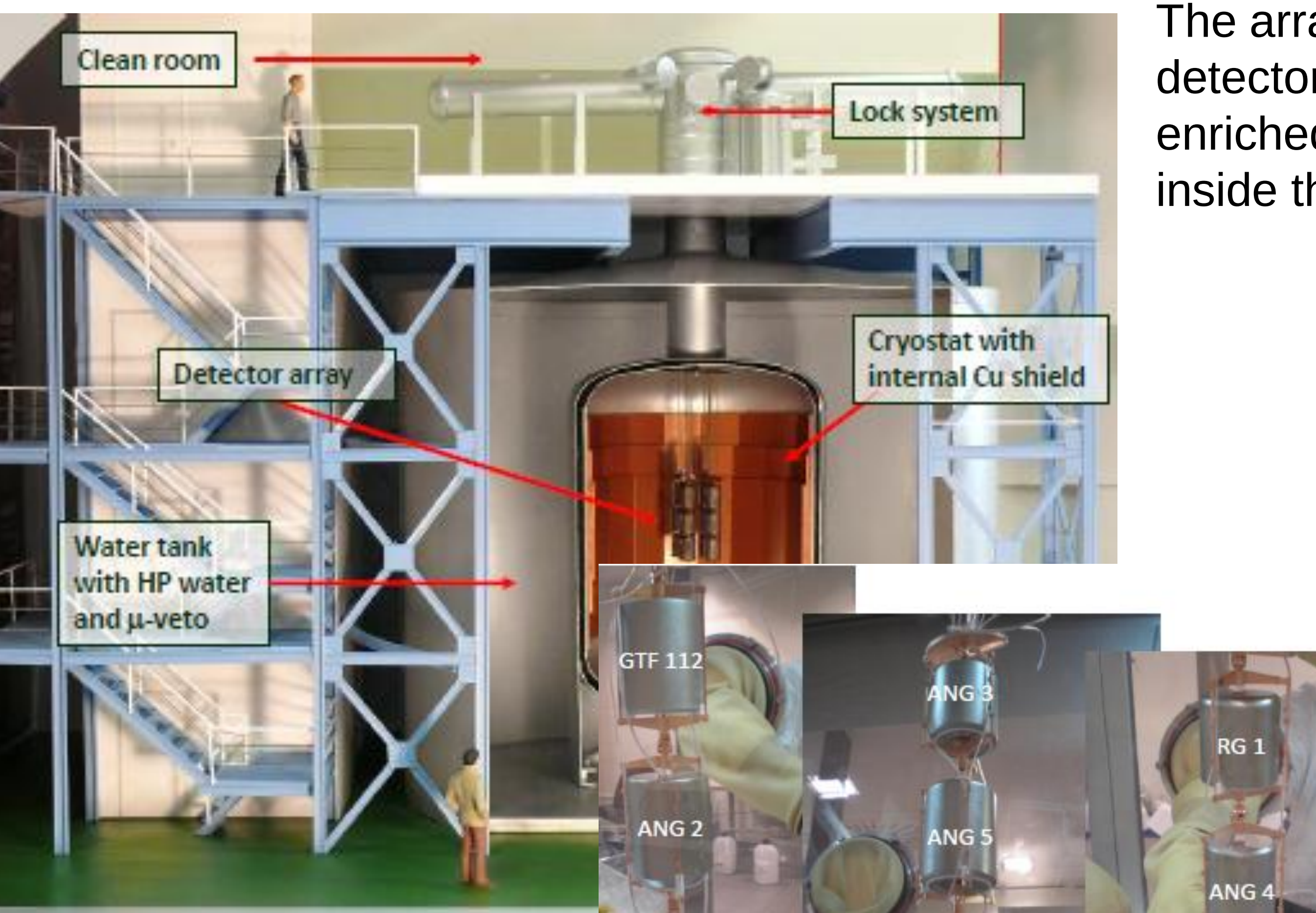
($Q_{\beta\beta}$ ~ MeV)

0νββ gives the evidence that the neutrino is a Majorana particle($\nu=\bar{\nu}$), and the 0νββ rates gives the effective Majorana mass, lepton number non-conservation and is therefore a direct probe for physics beyond the standard model

Precise measurements of 2v2β processes are important as they provide information on this irreducible background contribution (“tail” 2v2β) to 0v2β peak and leads to development of theoretical schemes for NME calculations for both 2v2β- and 0v2β-decays

JINR takes part in R&D of the semiconductor-based detecting systems for the GERDA and MAJORANA experiments with Ge

The GERDA experiment is looking for neutrino-less double beta decay of Ge-76 at Gran-Sasso deep underground.



The array of high purity Ge detectors (8 enriched and 1 non-enriched) is Installed inside the tank of LAr

GERDA time scale and next steps

Phase I: GERDA setup is working stable with 8 enriched detectors (17.66 kg (15.19 kg of ^{76}Ge)) since 1.11. 2011.

Background in ROI of 0νββ is 0.035 counts/(keV·kg·year), which is better than in predecessor experiments.

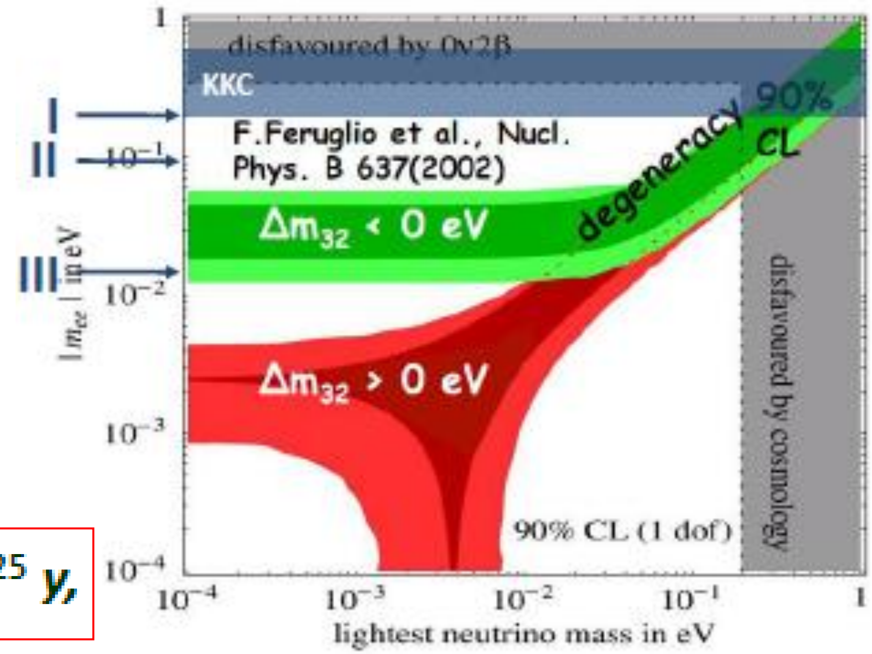
Two neutrino decay mode was measured and published.

The goal of Phase I –

Verification of the KK claim

-should be reached in 2013 year.

$T_{1/2} = 1.2\times10^{25}$ y,



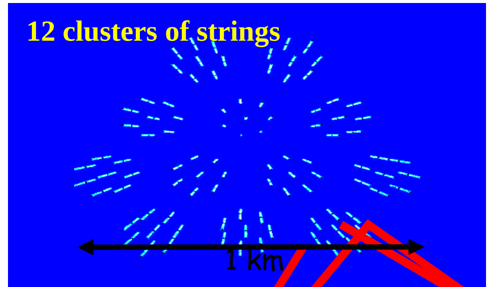
Future Phase II:

Will use very new detector geometry - BEGe.

The Phase II ^{76}Ge crystal pulling has started 17.11.2011 with 35.5 kg of ^{76}Ge. All new enriched BEGe detectors should be produced soon.

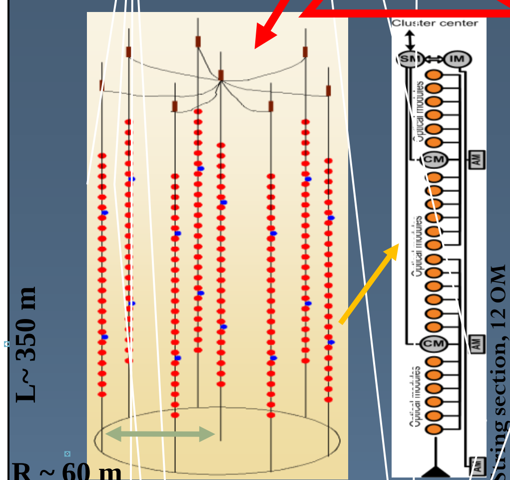
New detectors and LAr instrumentation planned to be implemented in GERDA within 2014-2016.

JINR takes part in the unique Baikal project. Its next step is a new Gigaton Volume Detector (GVD), which will be included into Global Neutrino Observatory (Northern Hemisphere)

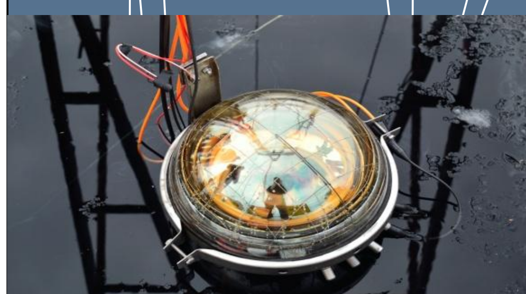


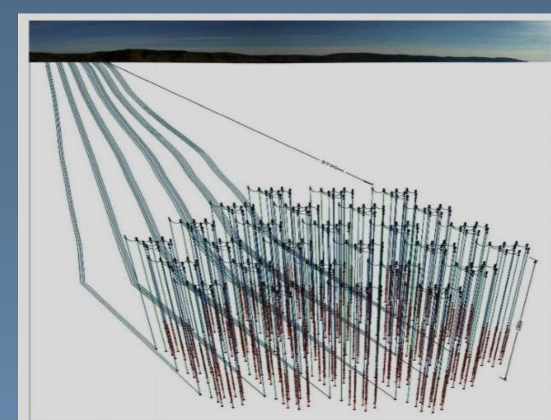
In 2014-2o15
the first
Full-Scale Cluster of
1 KM^3 will start.

Central GVD Physics Goals:
1) Investigate Galactic and extragalactic neutrino “point sources” in energy range > 3 TeV;
2) Diffuse neutrino flux energy spectrum, local and global anisotropy, flavor content.
3) Transient sources (GRB)
4) Dark matter indirect search
5) Exotic particles – monopoles, Q-balls, …



To be in time the Baikal-GVD should work hard. Financial support of 2M$ is very decisive (3 years).



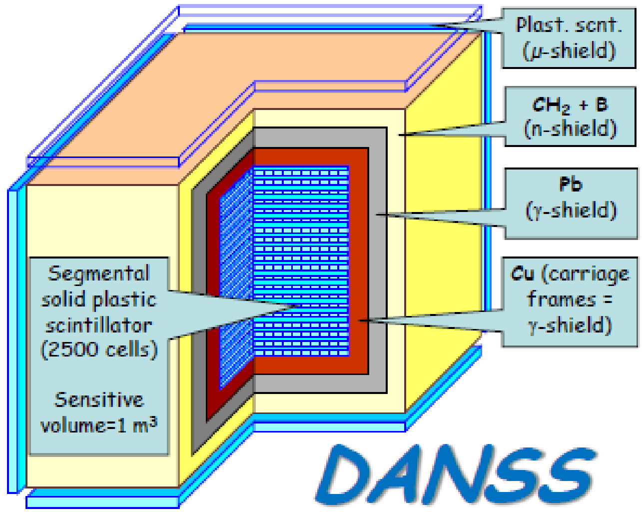


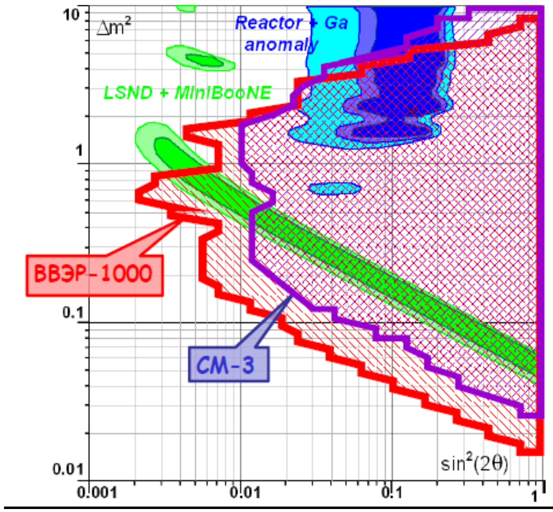
"**Neutrino interdisciplinary laboratory** at the Kalinin Nuclear Power Plant is *a unique opportunity that* ***will really allow Russia to be the world leader, both in fundamental research*** *on reactor antineutrinos* ***and in applied research for nuclear energy industry and safety of nuclear reactors"*** – *from decision of the RAS Scientific Council "Neutrino Physics and Neutrino Astrophysics" 26.06.2012*

Experiments GEMMA and DANSSino at the KNPP already work extremely well, Sterile neutrino and coherent scattering searches are very promising too – due to **UNIQUE FLUX** of **$5x10^{13}$** antineutrinos/s/cm^2 (at 10 m from the core).

1) JINR scientists are leaders in these projects.
2) With relevant financial support of 3$M very good scientific results are very visible in 3 years.

JINR has the DANSS - Detector of the reactor AntiNeutrinos based on Solid state plastic Scintillator





Goal of the project:

To build relatively small (1-2 m3) detector which
- would not contain any aggressive, cryogenic or other dangerous liquids in big amount
- could be installed close to the industrial power reactor (ВВЭР-1000)
- and detect about 104 neutrino/day with good S/B ratio.

Direct detection of the reactor antineutrino allows

Measure the actual reactor power (Nν)

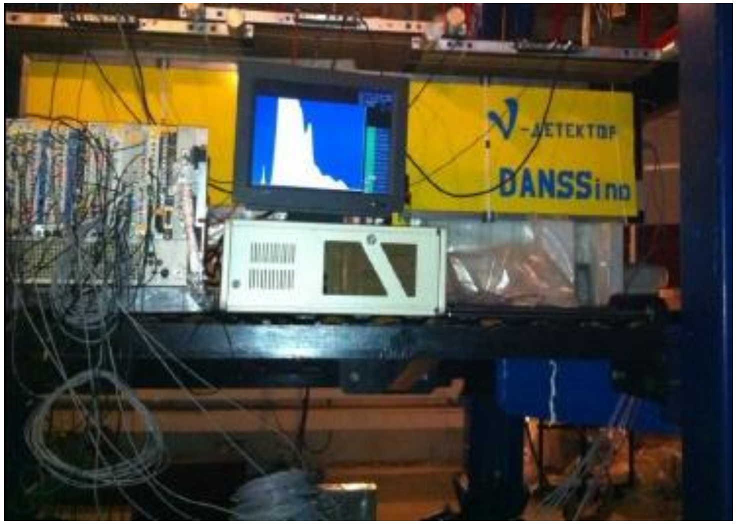
Deduce the actual fuel composition(Eν)

On-line reactor monitoring (tomography?) . Especially important in view of the future Non-proliferation (prevent unauthorized extraction of 239-Pu)

Weak (ν-e) cross-section (more precise)

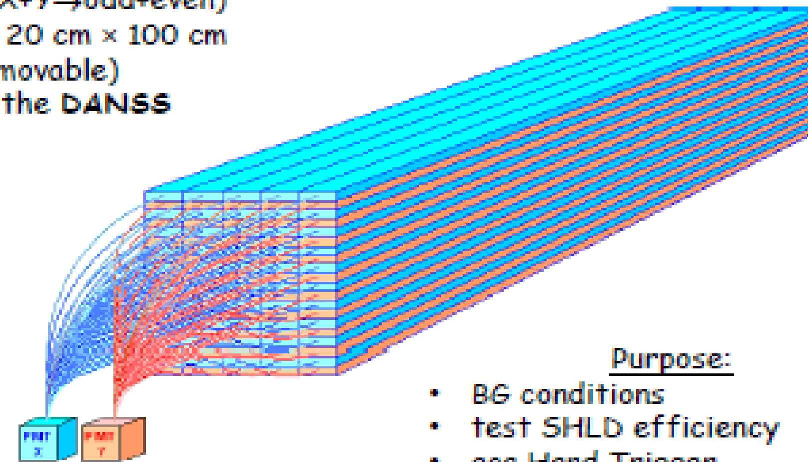
There is already a well working prototype:

DANSS = 25 DANSSino



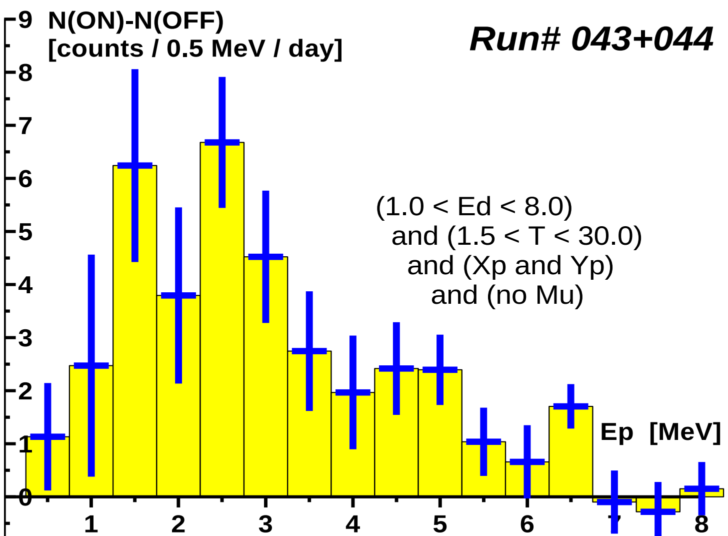
"DANSSino"

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

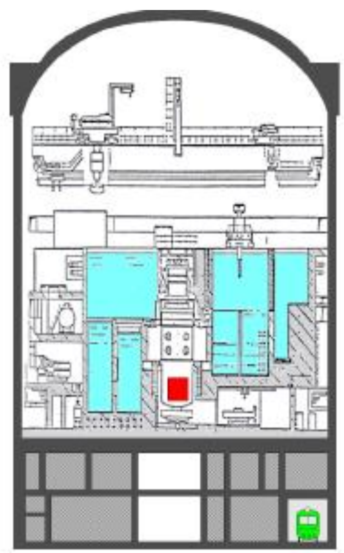


Purpose:

- 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?)*

IREN high-resolution pulsed neutron source

Year	2010	2011	2012	1st half of 2013
Time operation for experiment, hrs	807	618	1537	1045

Development of instrumentation at IREN facility

NEW!

Position-sensitive ionization chamber assembly

- It overcomes the limitation of the traditional method of prompt fission neutron (PFN) emission investigation

- It makes feasible the investigation of PFN emission process in resonance neutron induced fission

- The kinematics of PFN emission process can be investigated with any number of arbitrary allocated neutron detectors.

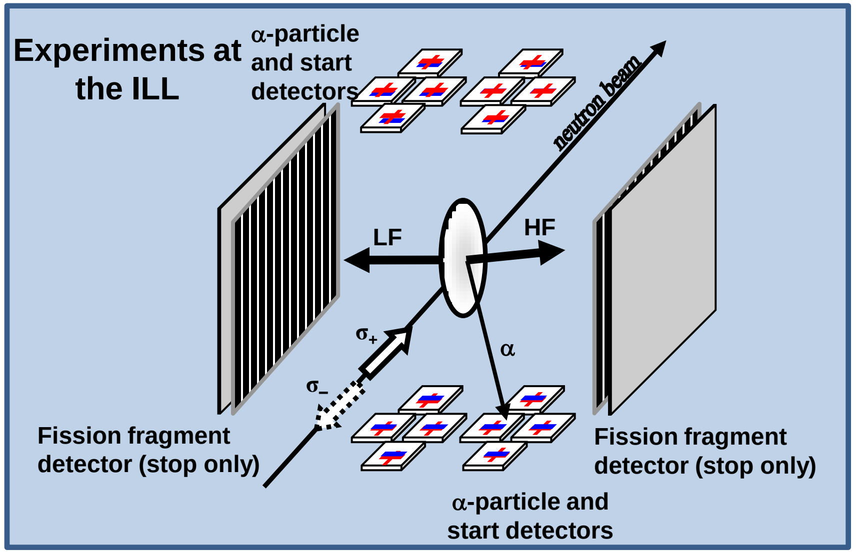
Measurements of T-odd effects in the polarized neutron induced fission

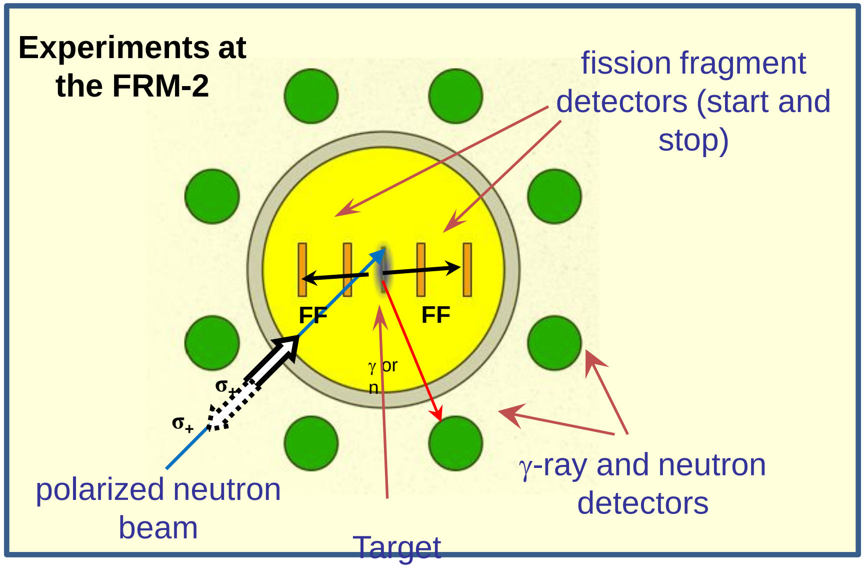
T-odd effects in fission:

TRI-effect: asymmetry of emission of a fission product (α-particle, γ-ray or neutron), which imitates the violation of **T**ime **R**eversal **I**nvariance.

- **ROT-effect:** angular anisotropy of a fission product, which appears due to the rotation of a polarized fissioning nucleus.

Experiments were performed at the ILL reactor in Grenoble and FRM-2 reactor in Munich within large international collaborations





ROT- and TRI-effects for the α-particle emission

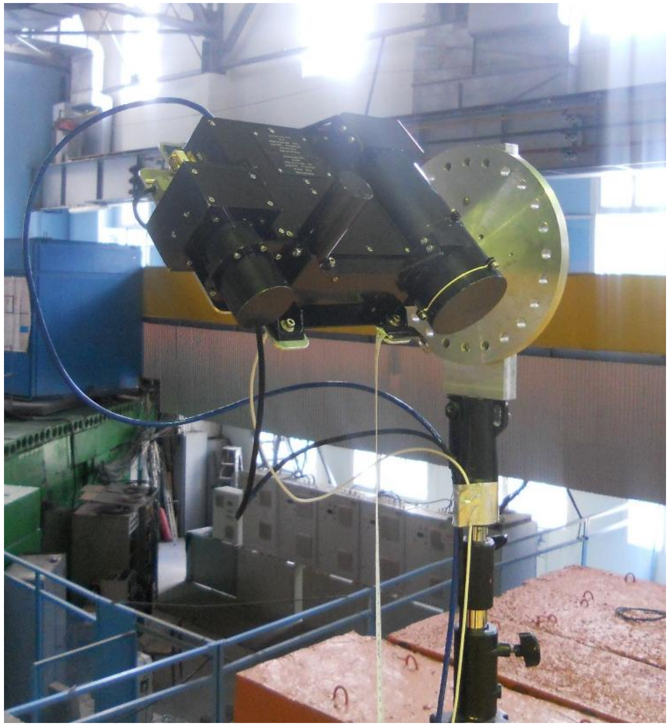
nuclei	spin	ROT (degree of rotation)	TRI (x 10^{-3})
^{233}U	2+, 3+	0.03(1)	-3.9(1)
^{235}U	3-, 4-	0.215(5)	1.7(2)
^{239}Pu	0^+, 1^+	0.020(3)	-0.23(9)

ROT-effect for the γ-ray and neutron emission

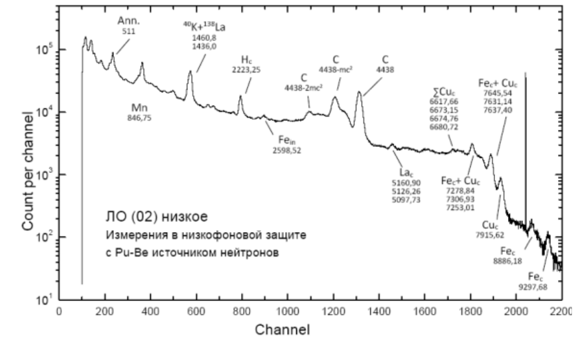
nuclei	Angle to the fission axis	γ-rays (x10^{-5})	Neutrons (x10^{-5})
^{233}U	22.5	+2.8±1.7	+4.8±1.6
^{235}U	22.5	-12.9±2.4	-21.2±2.5

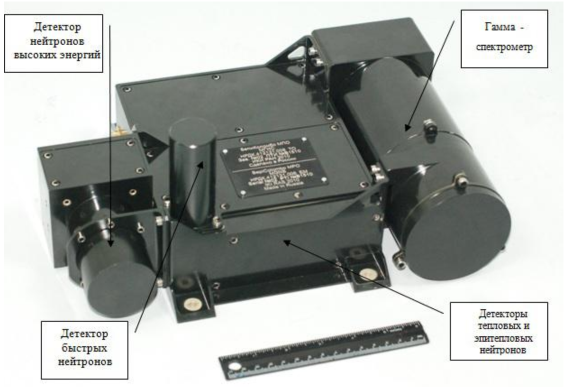
There are some plans for continuation of experiments at IBR-2

Mercurial Gamma Neutron Spectrometer Testing



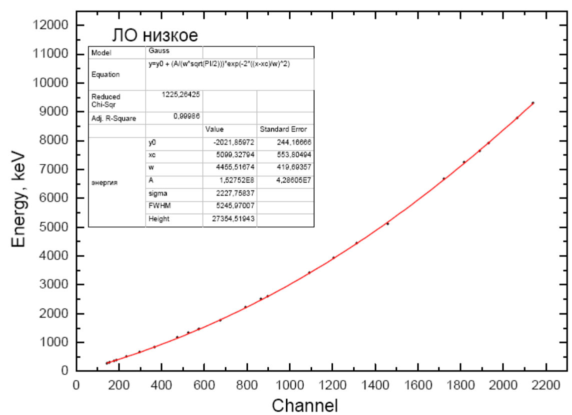
In July 2013 FLNP and LRB carried out calibrations of the Flight Unit 1 of the MGNS instrument





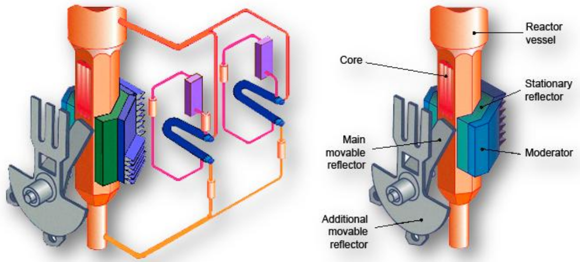
Mercurial Gamma-ray and Neutron Spectrometer (MGNS scientific instrument) is being developed to be placed onboard *BepiColombo* ESA interplanetary mission. MGNS project is multifunctional scientific instrument, comprising gamma-ray spectrometer and neutron detectors.

MGNS is aimed at measuring neutron fluxes in wide energy range (from thermal to 10 MeV) and gamma-ray with high energy resolution (approximately 3.5% at the energy of 662 keV) in the energy range from 300 keV to 10 MeV during interplanetary cruise and on the orbit around Mercury.



JINR's Large-Scale Basic Facilities

The IBR-2M pulsed reactor of periodic action is included in the 20-year European strategic programme of neutron scattering research.



Parameters

Fuel	PuO_2
Active core volume	22 dm^3
Cooling	liquid Na
Average power	2 MW
Pulsed power	1500 MW
Repetition rate	5 s^{-1}
Average flux	$8 \cdot 10^{12}$ $n/cm^2/s$
Pulsed flux	$5 \cdot 10^{15}$ $n/cm^2/s$
Pulse width (fast / therm.)	215 / 320 μs
Number of channels	14

Fundamental and applied research in condensed matter physics and related fields — biology, medicine, material sciences, geophysics, engineer diagnostics — aimed at probing the structure and properties of nanosystems, new materials, and biological objects, and at developing new electronic, bio- and information nanotechnologies.

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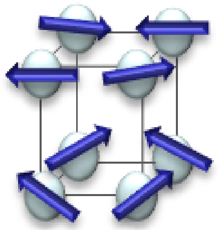
IBR-2 reactor is in operation
for physical experiments

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

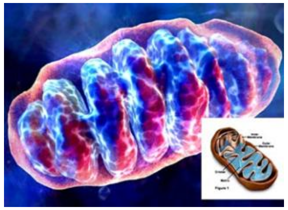
Main points:

- 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



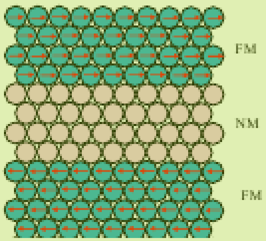
- micro amounts of samples
- more biological samples
- increased request for real-time studies

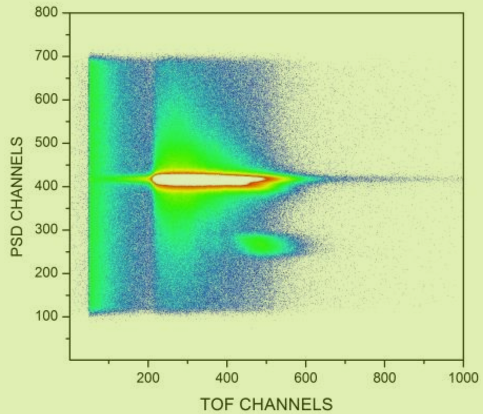
They all need cold neutrons!

Cold neutrons…

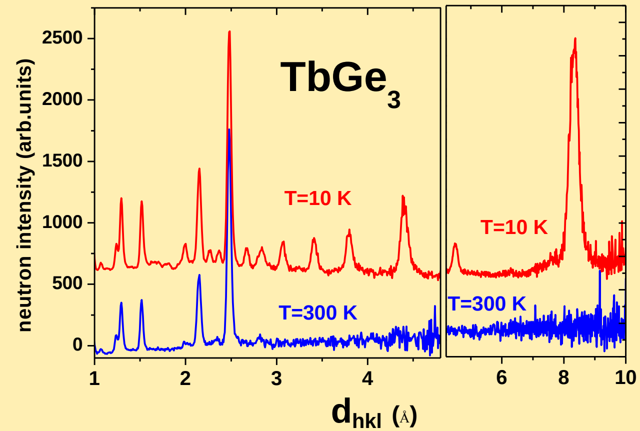
Why do we need cryogenic moderators at IBR-2 ?

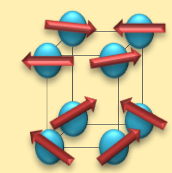
… are highly desirable for more precise characterization of magnetic structures !





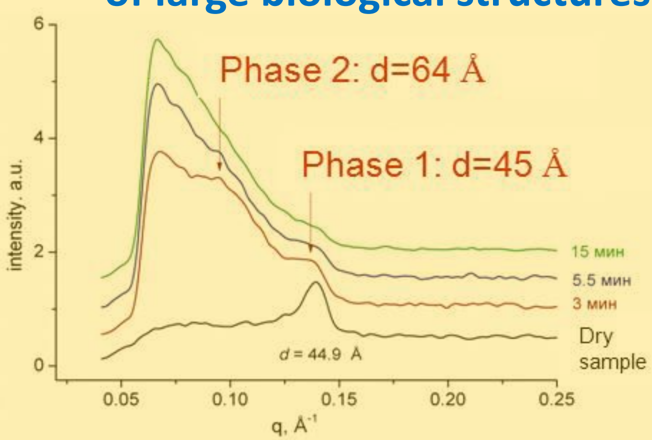
Nanoscale physical phenomena in layered magnetic heterostructures

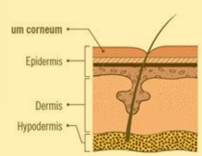




Crystal and magnetic structure parameters of novel materials

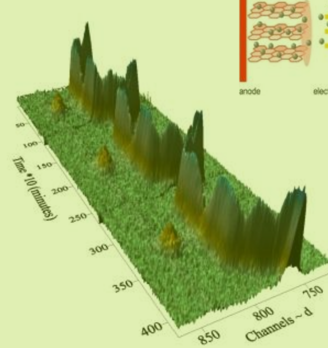
… are indispensable for studies of large biological structures !

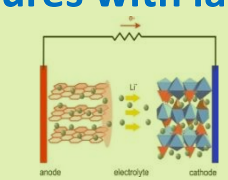


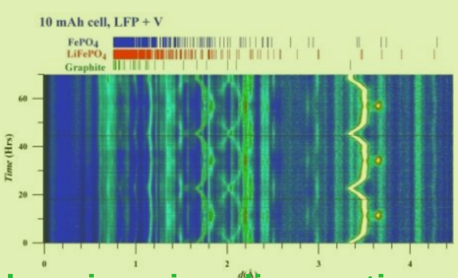


Structural organizations of biological objects

… are essential to study structures with large unit cells !

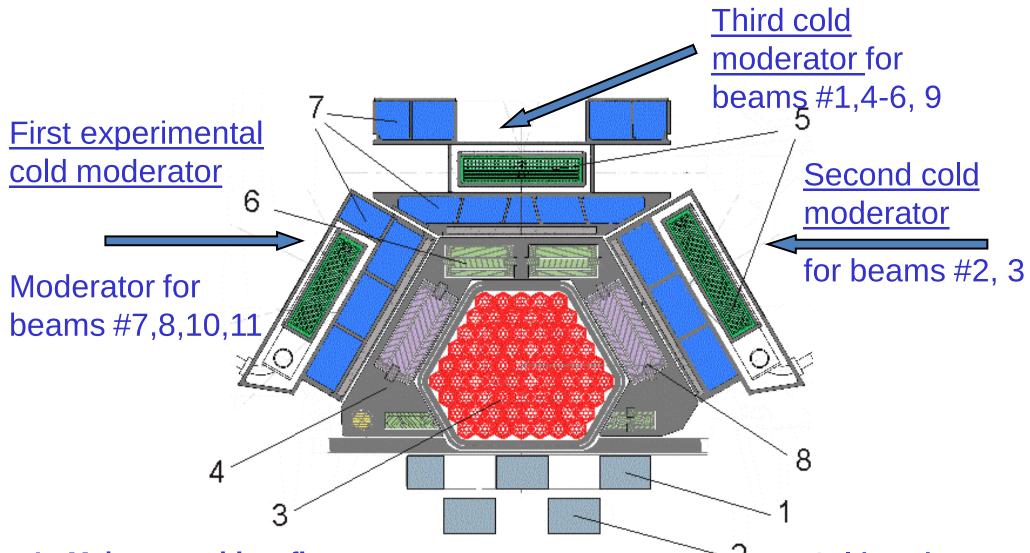




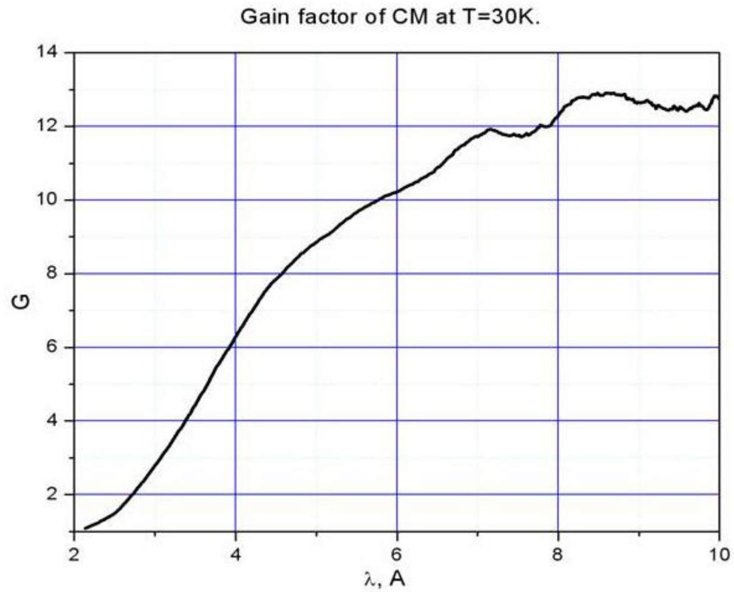


Real-time studies and engineering diagnostics

Cold neutron moderators of the IBR-2 reactor



1. Main moveable reflector
2. Auxiliary moveable reflector
3. Fuel assembly
4. Stationary reflector
5. Cold moderators
6. Emergency system
7. Water moderators
8. Control rods



- The first cold moderator is in operation!
- The cold neutron flux was increased up to the factor of 13 at the same reactor power.
- Three pelletized cold moderators should provide 12 spectrometers with cold neutrons practically at the same intensity as the most powerful nowadays pulsed neutron source SNS (Oak Ridge, USA).
- We know how it can be done!
- Let's embark on this challenging task!

JINR Multifunctional Centre for Data Storage, Processing and Analysis

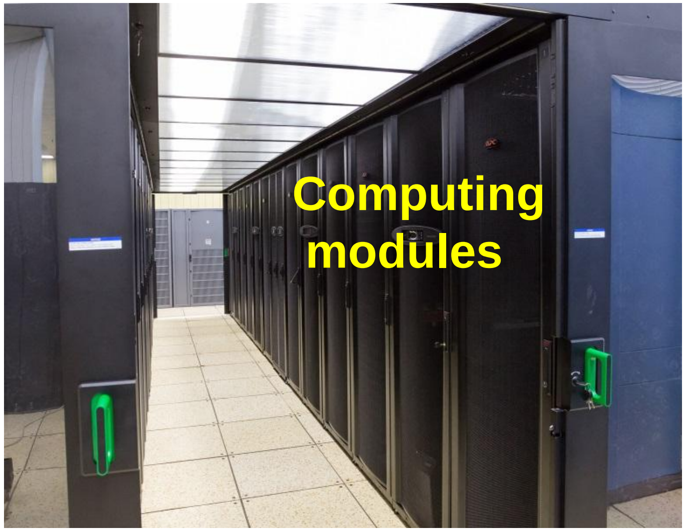
Grid-Infrastructure at Tier1 and Tier2 Levels

General Purpose Computing Cluster

Cloud Computing Infrastructure

Heterogeneous Computing Cluster HybriLIT

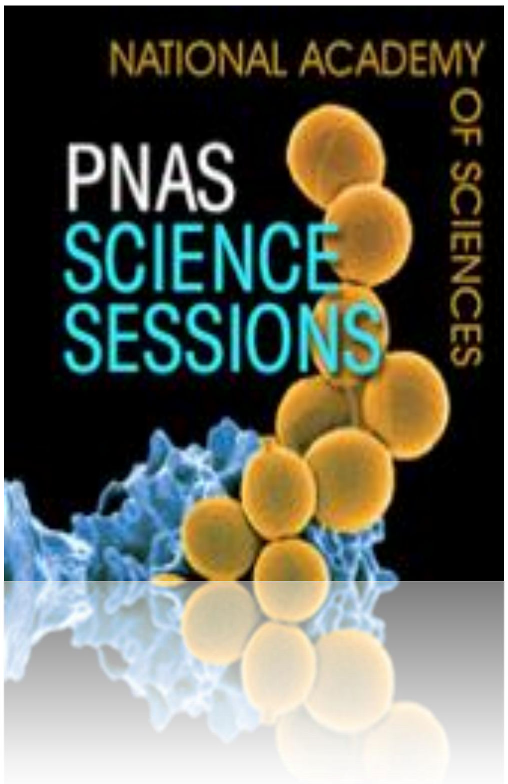
Education and Research Infrastructure for Distributed and Parallel Computing

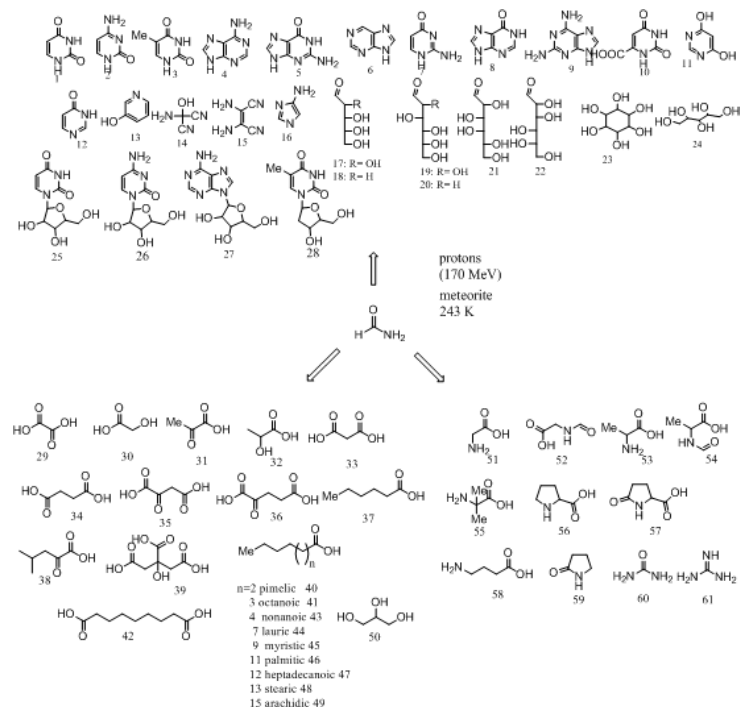


Astrobiology

Collaboration: University of Viterbo, Sapienza Università of Rome (Italy) and LRB (JINR)

Meteorite-catalyzed syntheses of nucleosides and of other prebiotic compounds from formamide under proton irradiation





JINR Educational Programs

At present **340** graduate students are taking part in various JINR educational programs. According to the law “On Education in RF” a new JINR **PhD program** has been started in 2015.

International Student Practice (ISP) and JINR Summer Student Program (SSP) in 2015

University Center is ready to run ISP in 2015 in three stages. Participation of students from 9 JINR MS is expected. The call for applications for SSP-2015 was launched on January 15.

JINR Outreach Activity in 2014-2015

Outreach programs for teachers and school students from JINR Member States at CERN and JINR have been continued in cooperation with the Centre of National Intellectual Reserve of Moscow State University.

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!