54th ASRC International Workshop Sakura-2019 "*Nuclear Fission and Structure of Exotic Nuclei*"
Japan Atomic Energy Agency (JAEA), Tokai, Japan

I. Velocity filter SHELS:
performance, experimental results and plans
II. Status of the Factory of Superheavy Elements

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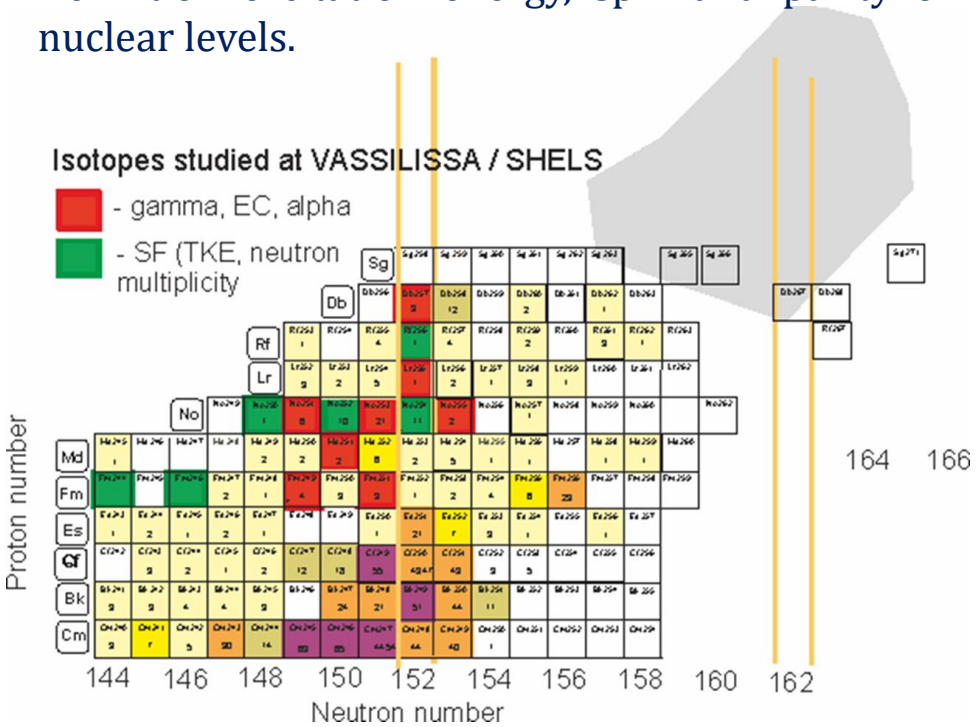
Velocity filter SHELS

- Determination of the partial half-lives of SF heavy nuclei
- Measure of TKE of fission fragments from the spontaneous fission of heavy short-lived isotopes.
- Measure of the average number and determining the multiplicity distribution of prompt neutrons.
- Study of the SF isomers.

GABRIELA

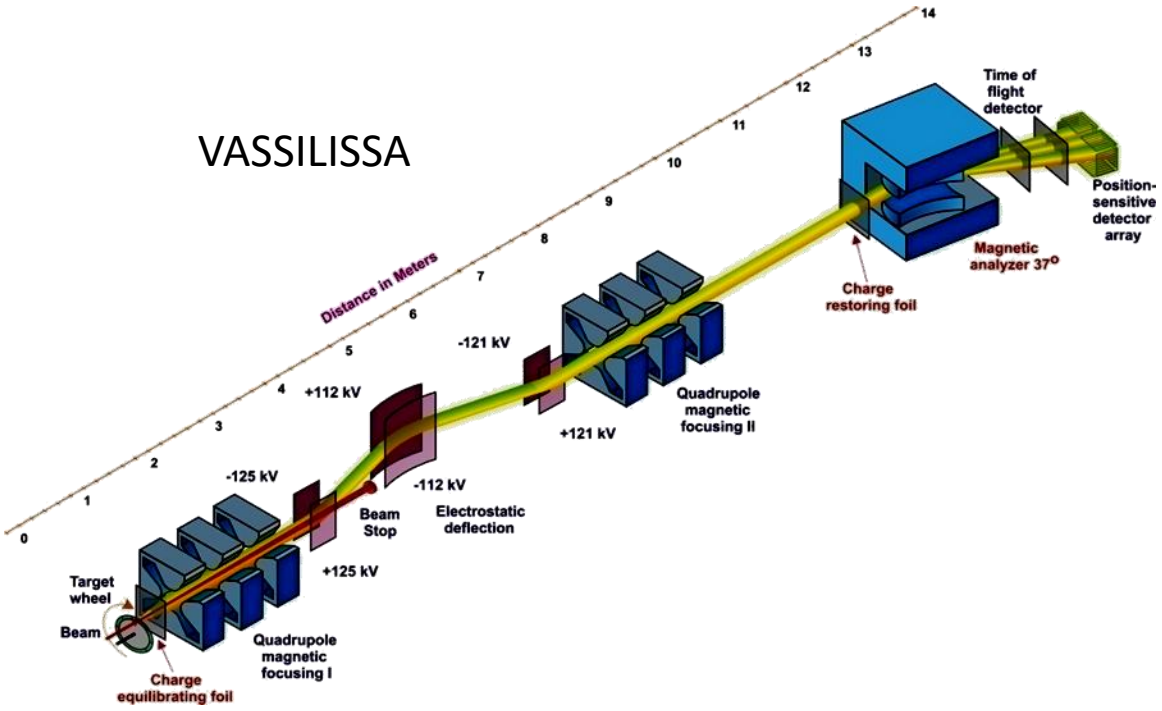
Gamma Alpha Beta Recoil Investigation with the Electromagnetic Analyser

- Study of the decay properties of heavy nuclei, isomeric and ground states, by α,β,γ-spectroscopy of mother (implanted) and daughter products of the evaporation residues.
- Study of the single particle level structure in Fm-Sg region, by moving away from the N=152 towards the N=162 shell.
- Definition excitation energy, spin and parity of nuclear levels.



Velocity filter SHELS

First stage – years 2010 - 2013



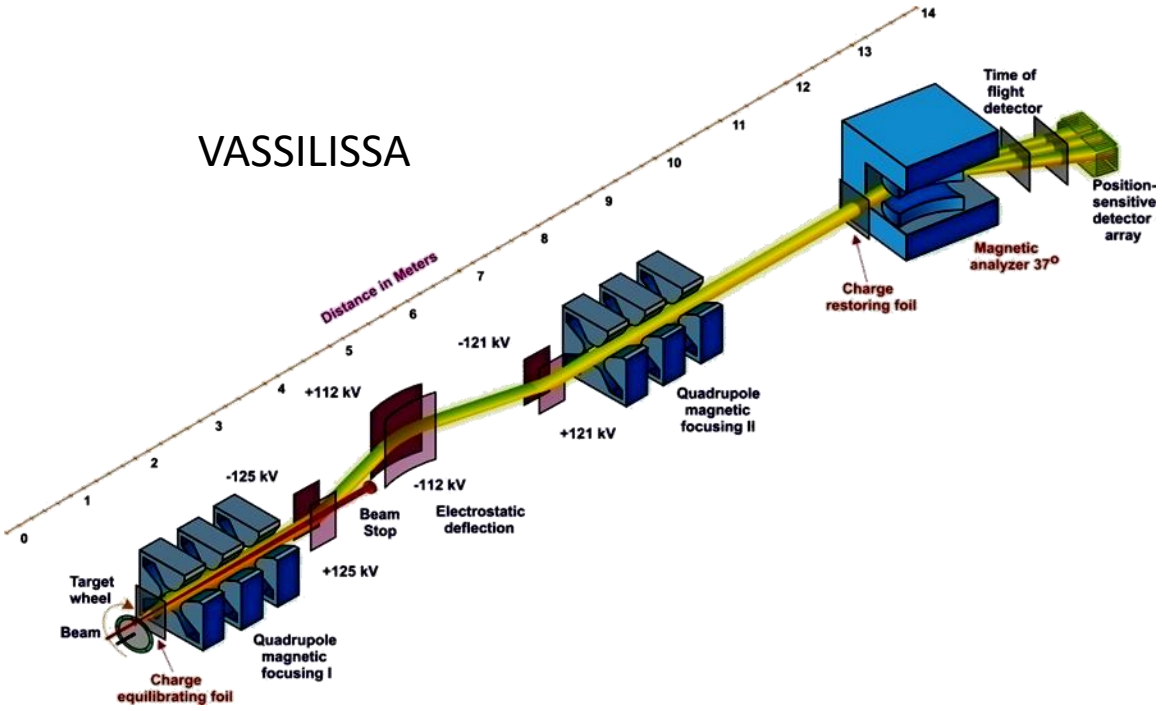
Velocity filter SHELS

First stage – years 2010 - 2013

New ion optical scheme

MQ-MQ-MQ-ES-MS-MS-ES-MQ-MQMQ-MS

Improvement of slow ERs transmission

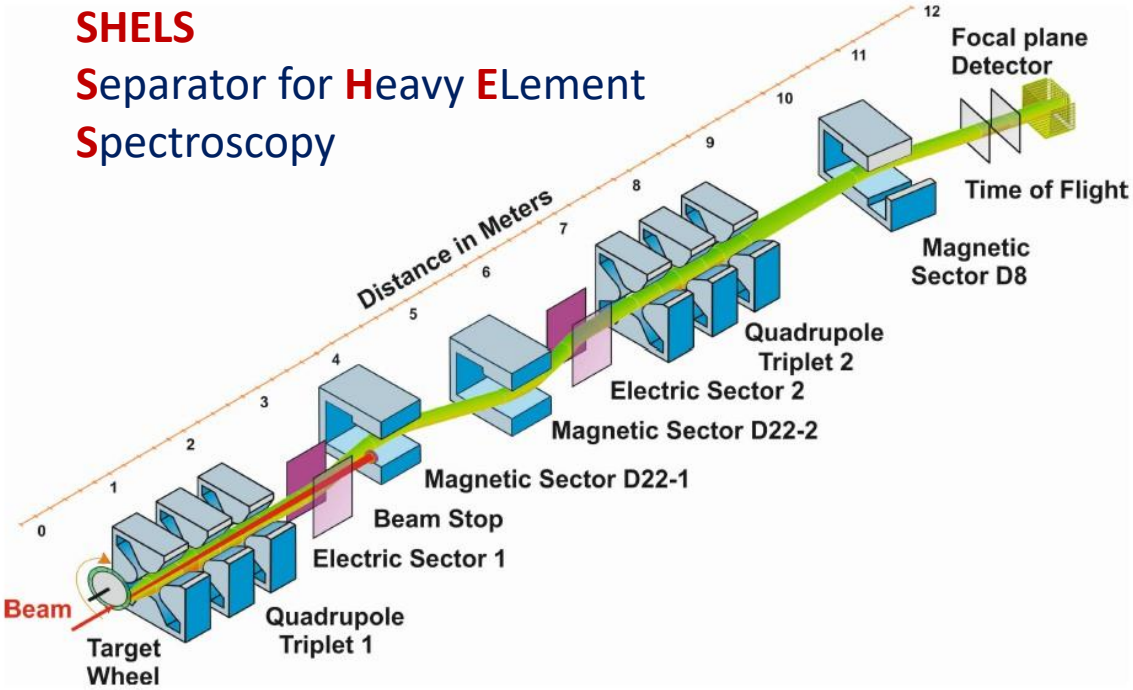


Velocity filter SHELS

First stage – years 2010 - 2013

New ion optical scheme
MQ-MQ-MQ-ES-MS-MS-ES-MQ-MQMQ-MS
Improvement of slow ERs transmission

SHELS
Separator for **H**eavy **E**Lement
Spectroscopy



Velocity filter SHELS

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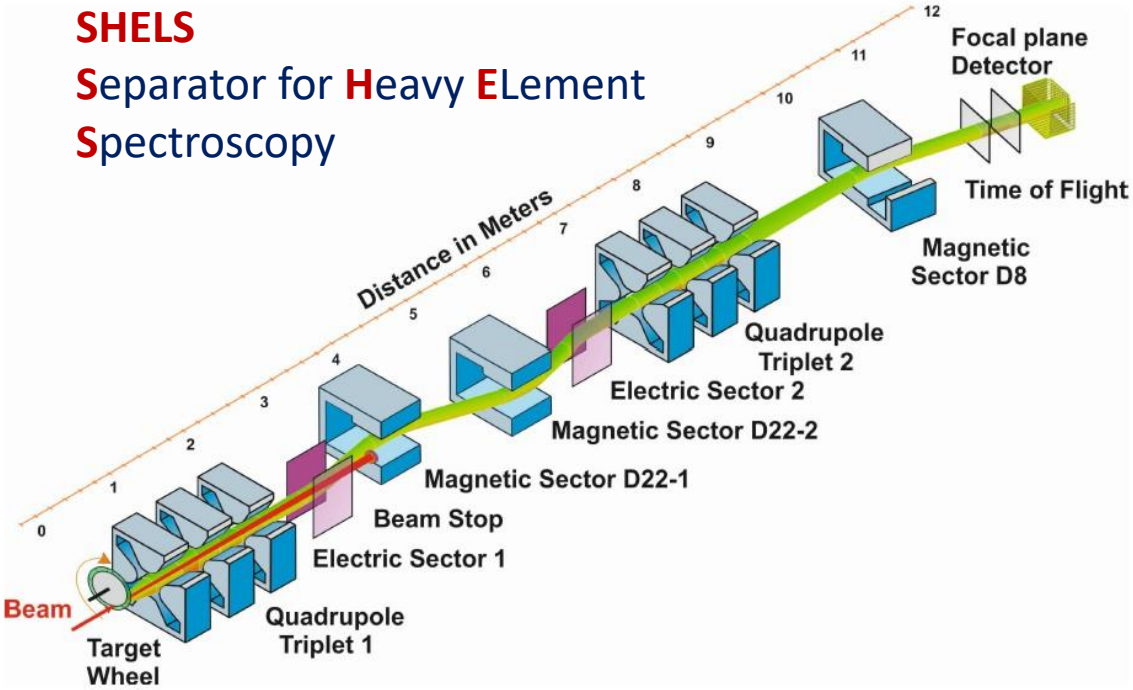


Table 3. Principal components of SHELS.

Quadrupole magnets	
Maximum field gradient	13 T/m
Effective length	38 cm
Aperture radius	10 cm
Electrostatic sectors	
Maximum field gradient	40 kV/cm
Effective length	65.7 cm
Distance between plates	10÷20 cm
Nominal deflection angle	8^o
Magnetic sectors D22-1,2	
Maximum field strength	0.8 T
Effective length	59.7 cm
Gap hight	13.5 cm
Nominal deflection angle	22^o
Magnetic sector D8	
Maximum field strength	0.2 T
Effective length	58.8 cm
Gap hight	14 cm
Nominal deflection angle	8^o

Velocity filter SHELS

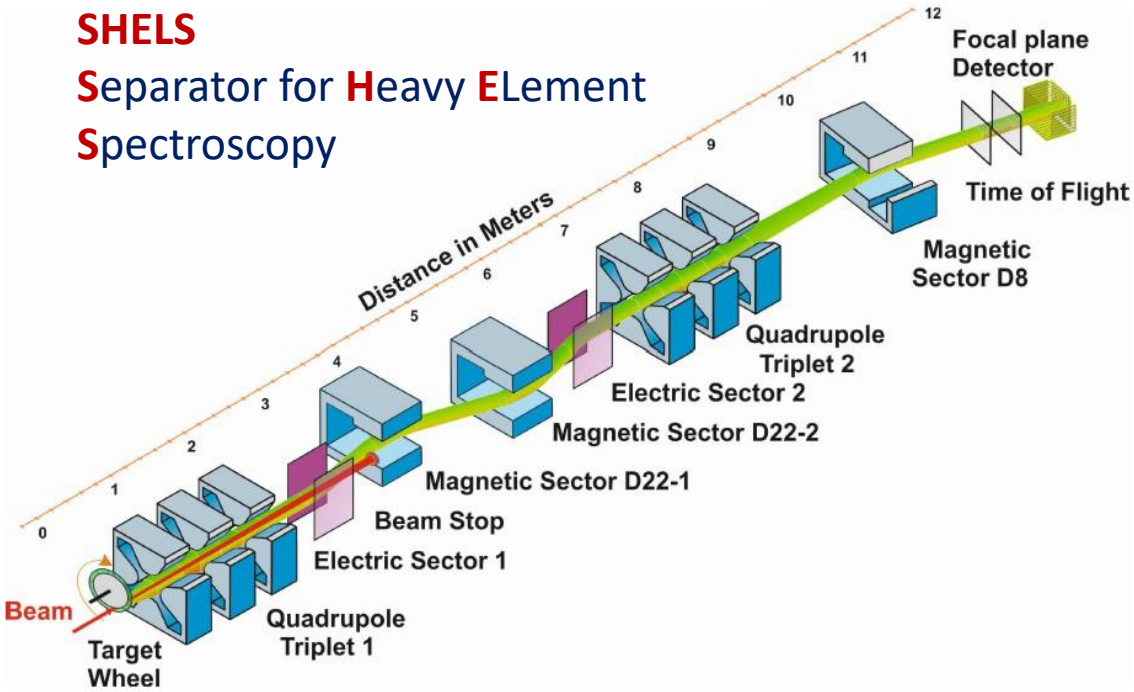
Tests 2013-2015

Table 5. Test reactions studied at the velocity separator SHELS.

Reaction	Beam energy (MeV)	Target thickness (mg/cm^2)	ERs transmission old	ERs transmission new	Ref.
^{22}Ne(^{238}U,4–5n)^{255,256}No	115	0.35 (U_3O_8)	0.01	–	
^{22}Ne(^{208}Pb,4n)^{226}U	117	0.36 (PbS)	0.02	–	
^{22}Ne(^{206}Pb,4n)^{224}U	117	0.23 (metal)	0.02	–	[11]
^{22}Ne(^{198}Pt,5-7n)$^{213-215}$Ra	115-125	0.30 (metal)	0.03	0.040±0.015	[12]
^{22}Ne(^{197}Au,4-6n)$^{213-215}$Ac	120	0.35 (metal)	0.03	0.065±0.030	[12]
^{40}Ar(^{208}Pb,2-3n)^{245,246}Fm	237	0.36 (PbS)	0.20	0.4	[13]
^{50}Ti(^{208}Pb,2n)^{256}Rf	237	0.36 (PbS)	0.20	0.3±0.1	[14]
^{50}Ti(^{164}Dy,3-5n)$^{209-211}$Ra	240	0.3 (Dy_2O_3)	0.3	0.4	[13, 15]

SHELS

Separator for **H**eavy **E**Lement **S**pectroscopy



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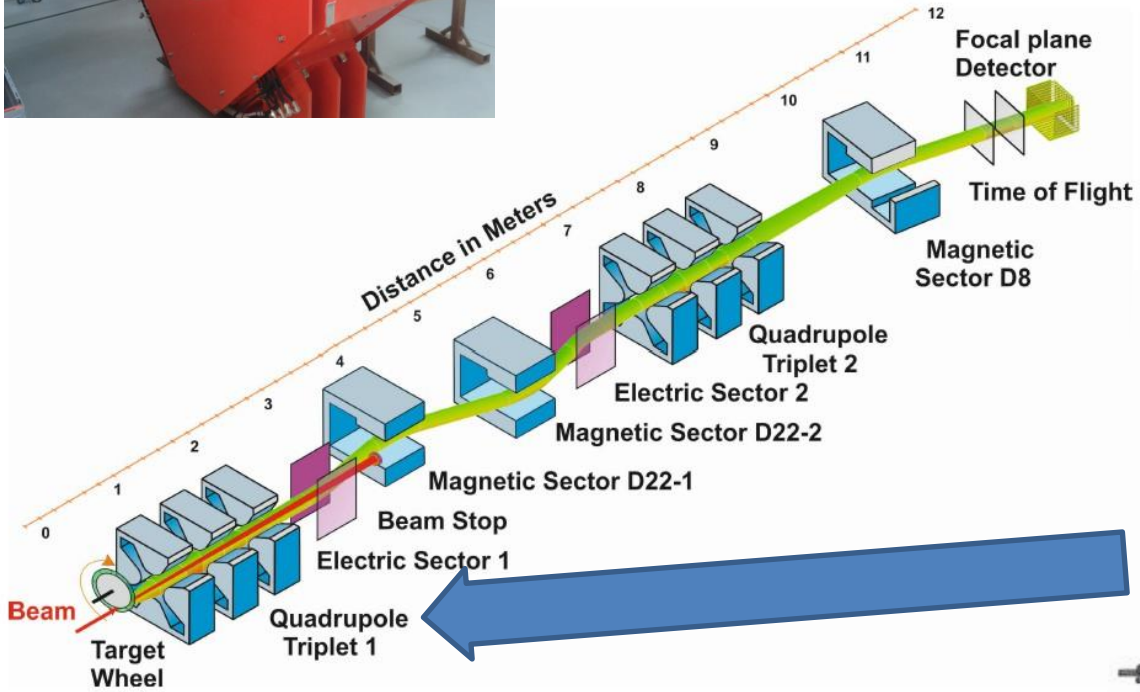
Velocity filter SHELS



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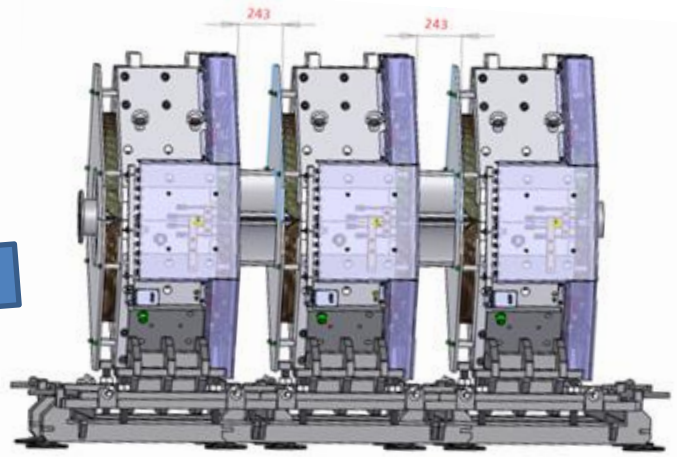
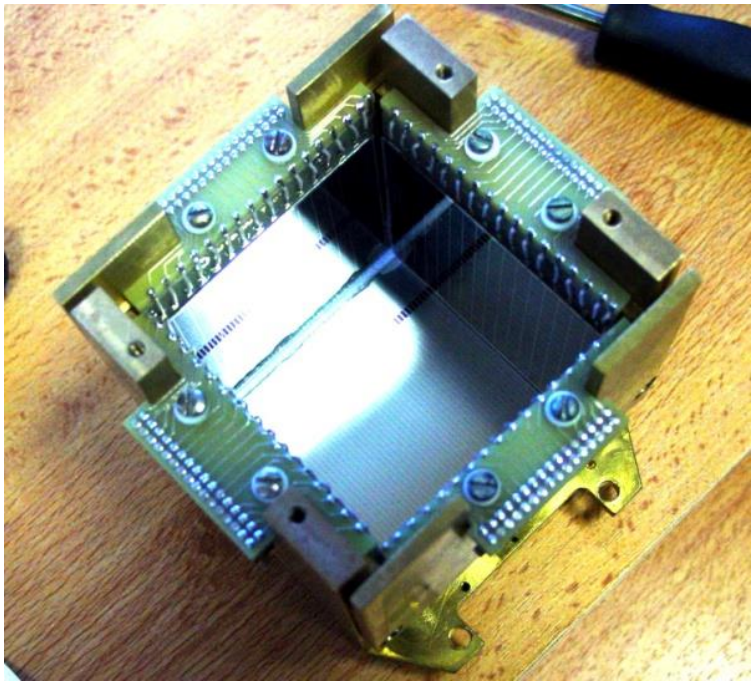


Velocity filter SHELS

Second stage – years 2014 - 2016

Improvement of GABRIELA detector array

New Si detectors : larger + more strips
⇒ 2 x ERs detection efficiency
⇒ higher CE detection efficiency



Focal plane DSSD

- 48x48 DSSSD
- the thickness is 300 μm
- the sensitive area is 58 mm^2
- the pos. resolution is 1 mm^2
- Energy resolution 12-15 keV

Side detectors

4x16-strip Si-plates
(no pos. sens.)

Detection efficiency:
For alpha-particles - **80 %**
For SF-fragments - **100 %**

Velocity filter SHELS

Second stage – years 2014 - 2016

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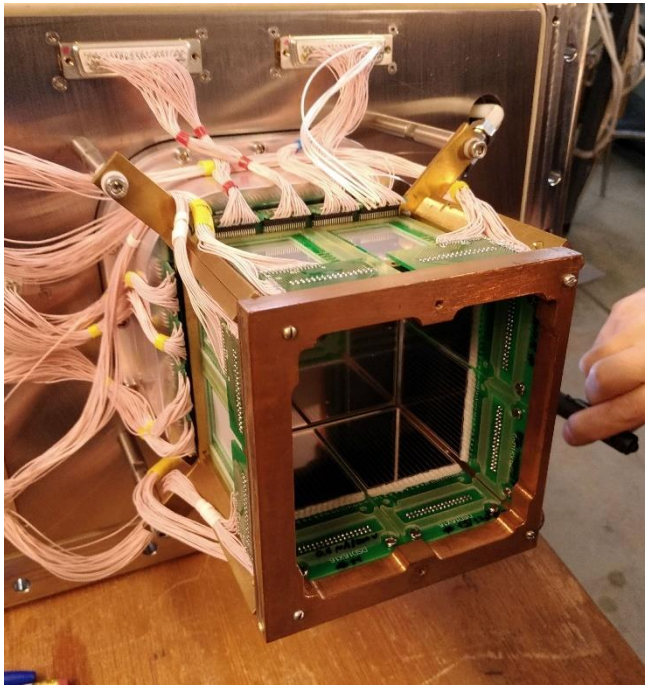


Focal plane DSSD

- 48x48 DSSSD ⇒ **128x128 DSSSD**
- the thickness is 300 μm ⇒ 500 μm
- the sensitive area is 58 mm^2 ⇒ 97.3 mm^2
- the pos. resolution is 1 mm^2 ⇒ 0.8 mm^2
- Energy resolution 12-15 keV

Side detectors

4x16-strip Si-plates (no pos. sens.) ⇒ 8x(16x32 DSSSD)
the thickness is 500 μm
the pos. resolution is 2 mm^2

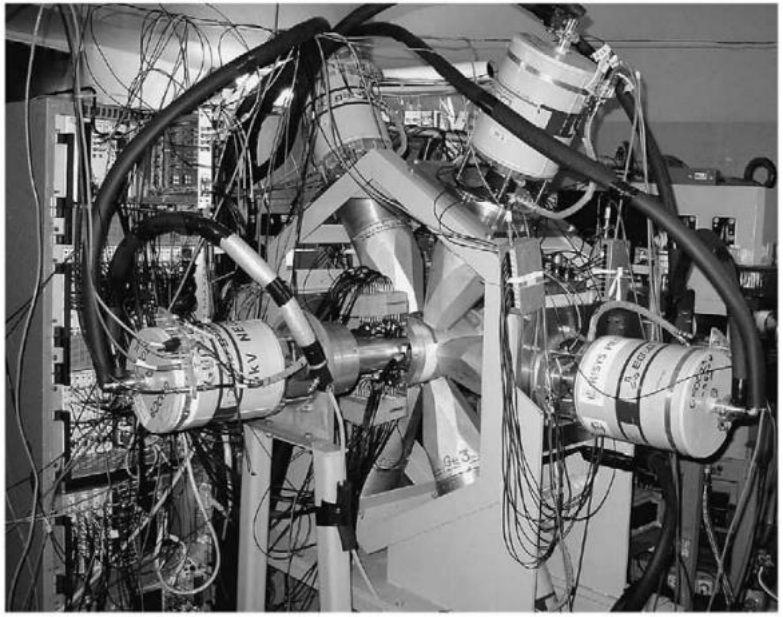
Detection efficiency:
For alpha-particles - **80 %**
For SF-fragments - **100 %**

focal plane area increased by 1.7!

Velocity filter SHELS

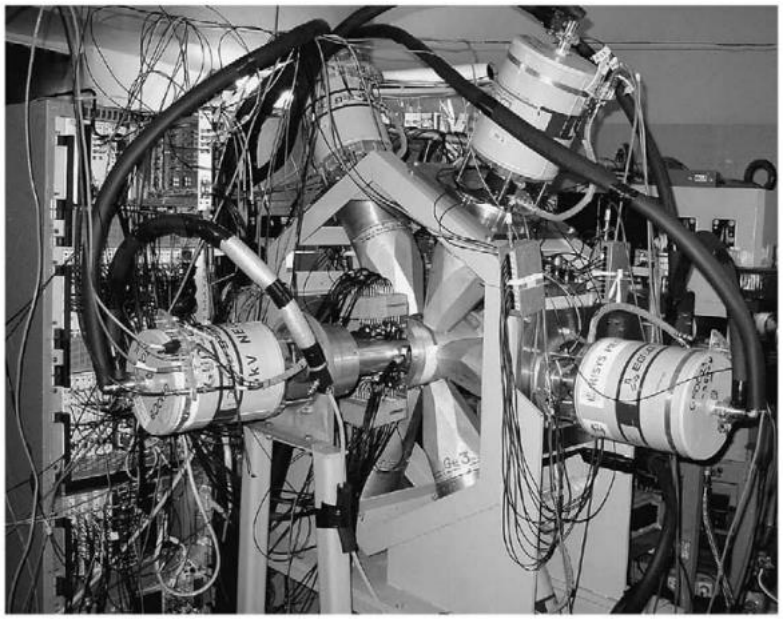
Second stage – years 2014 - 2016

Improvement of GABRIELA detector array



7 single crystal Ge-detectors
With BGO-shields

Velocity filter SHELS



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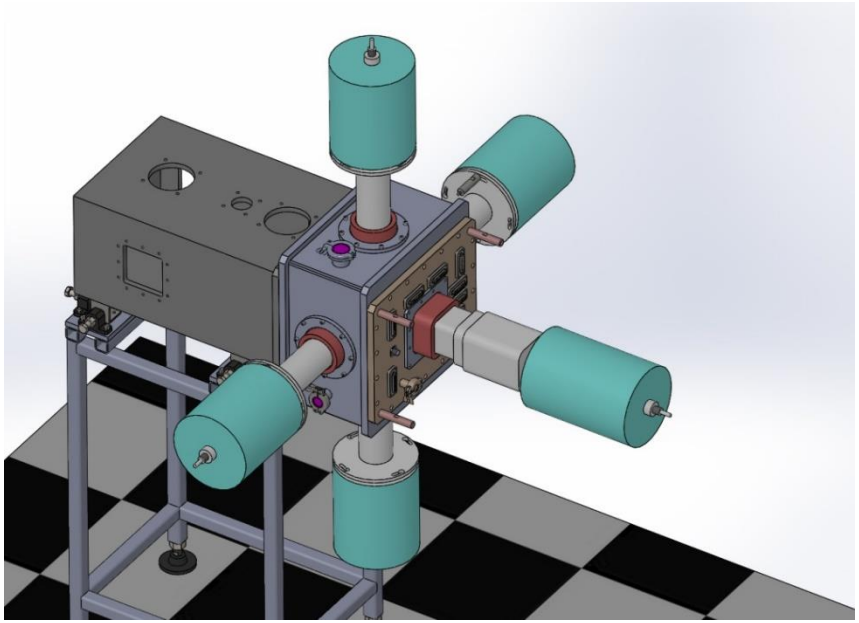
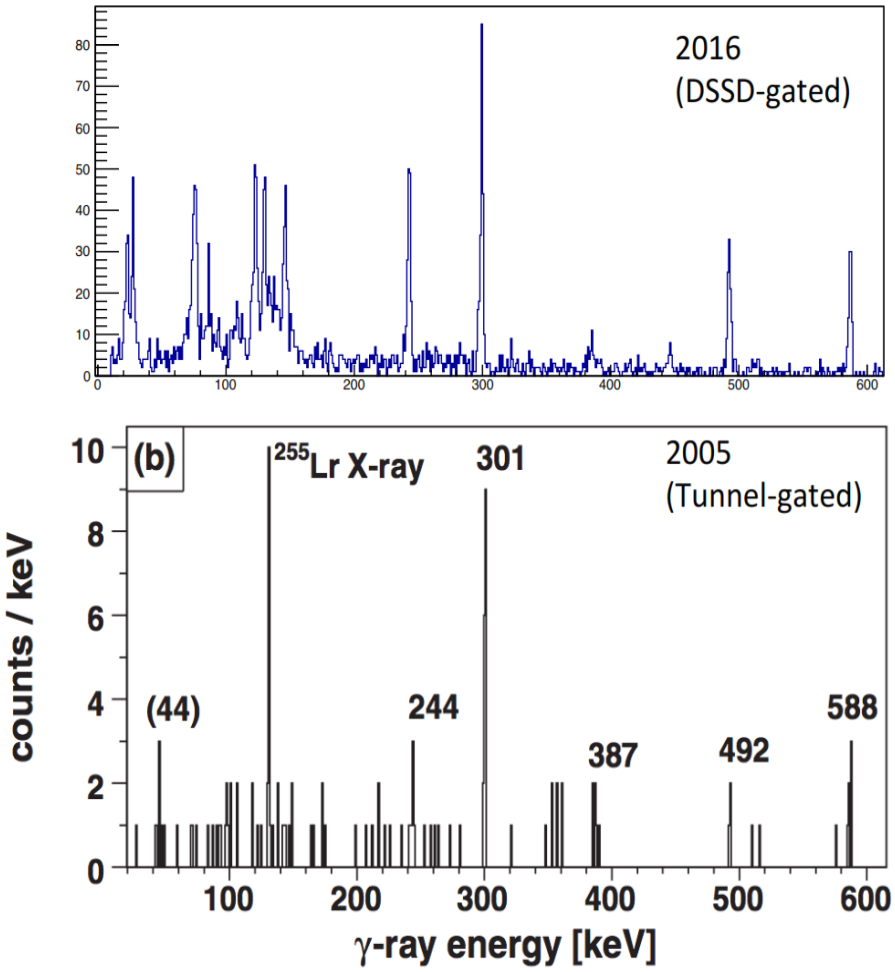


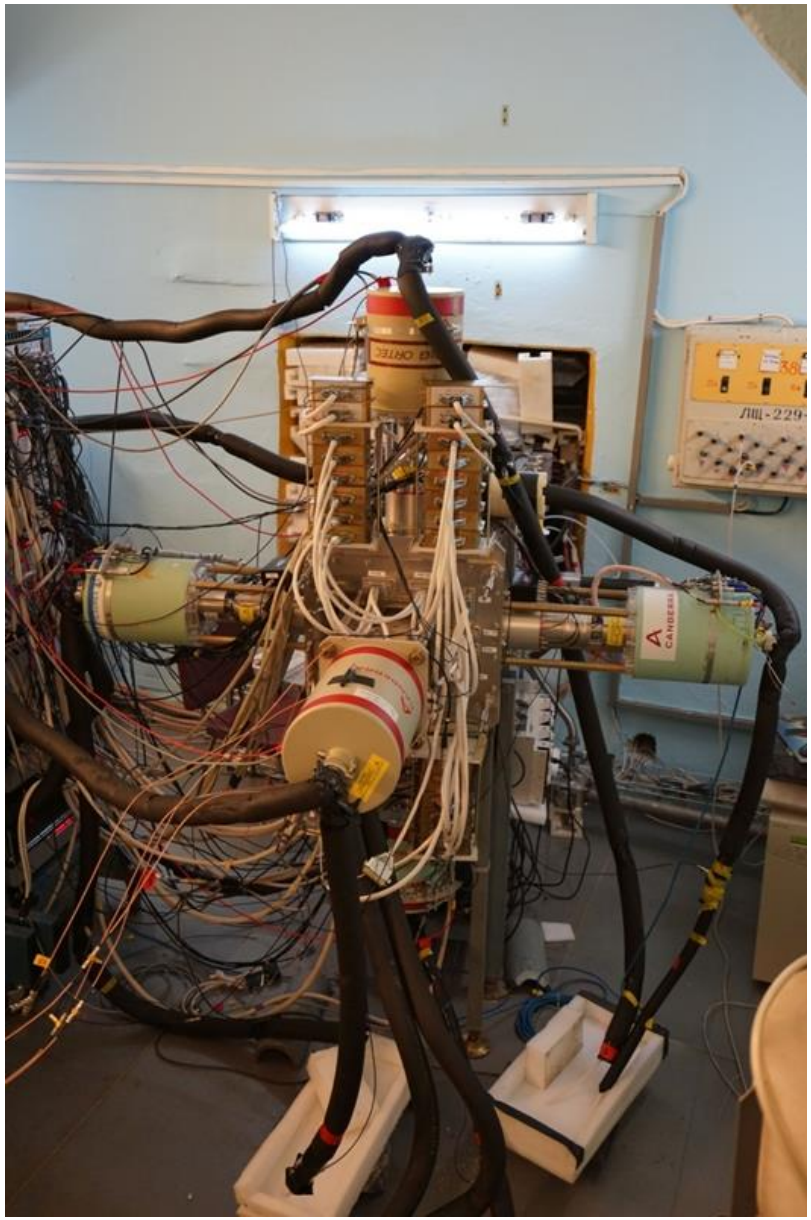
1 - 100x100 mm clover Ge-detector
4 - single crystal Ge-detectors
All with BGO-shield

Velocity filter SHELS

$^{48}Ca(^{209}Bi,2n)^{255}Lr$

Integral flux 1.4 x10^{18}



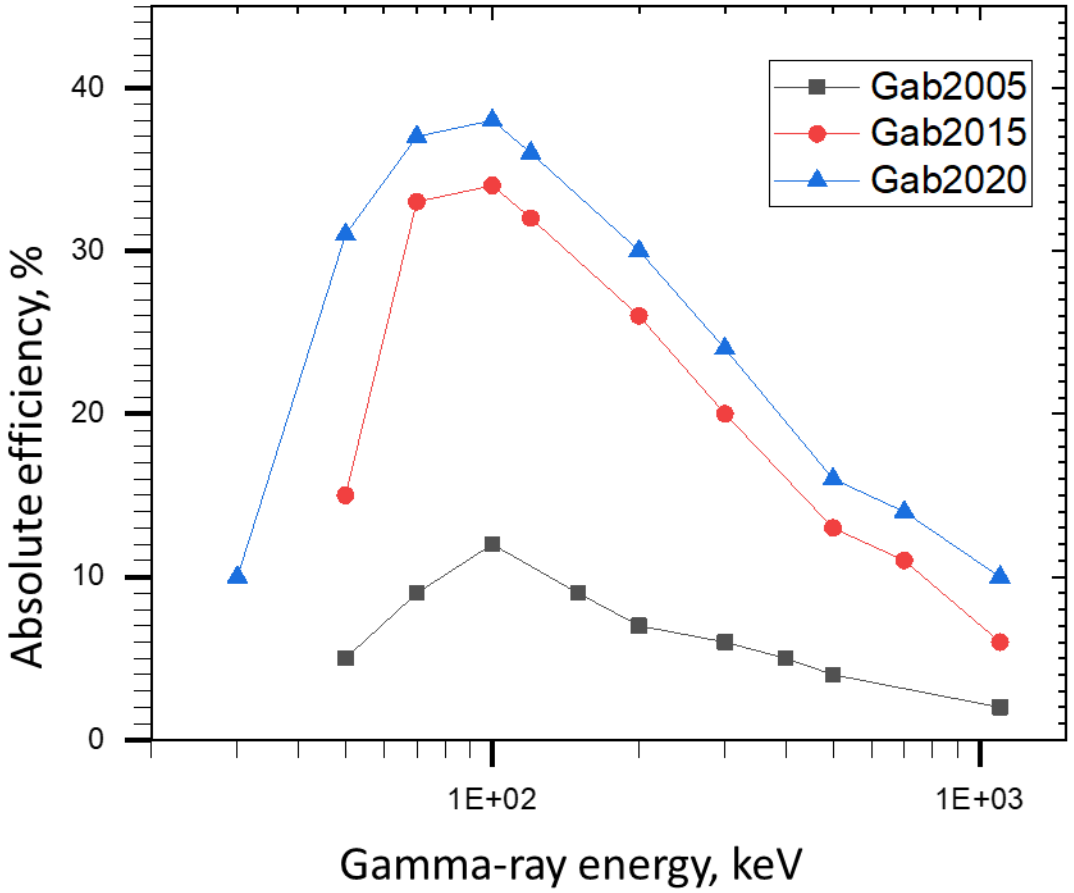


Velocity filter SHELS

Next stage – years 2019 - 2020

New Detection systems

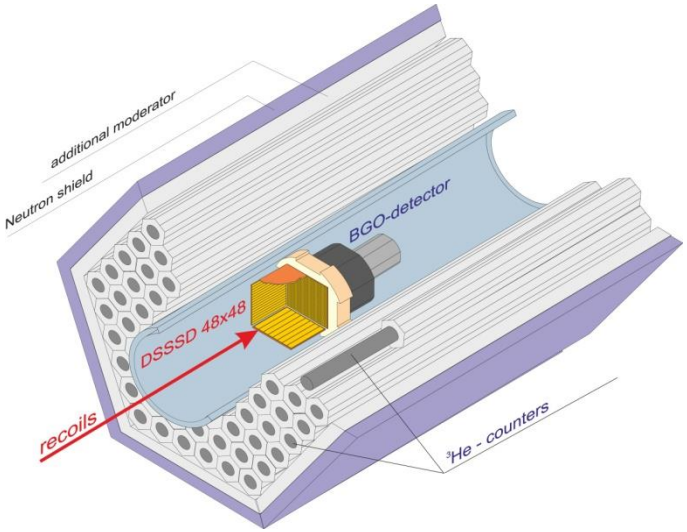
Further improvement of Ge detectors system (5 Clovers) => higher gamma detection efficiency

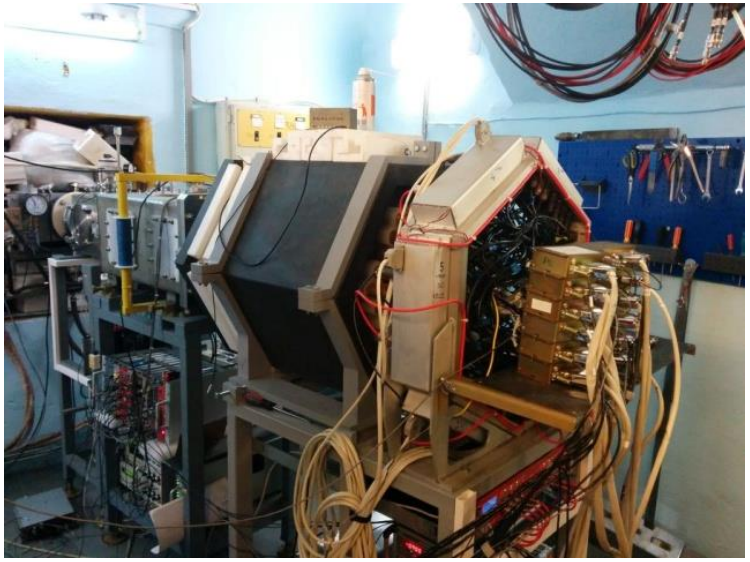


Velocity filter SHELS

Next stage – years 2019 - 2020

New Detection systems
Modernization of neutron detector





Neutron detector
54 ^{3}He-counters placed in moderator and surrounded by shield (polyethylene with boron)
Dimensions of counters: D=30mm, L=500mm
^{3}He pressure – 7 At

Efficiency for single neutrons: **45 %**
(^{248}Cm-source)

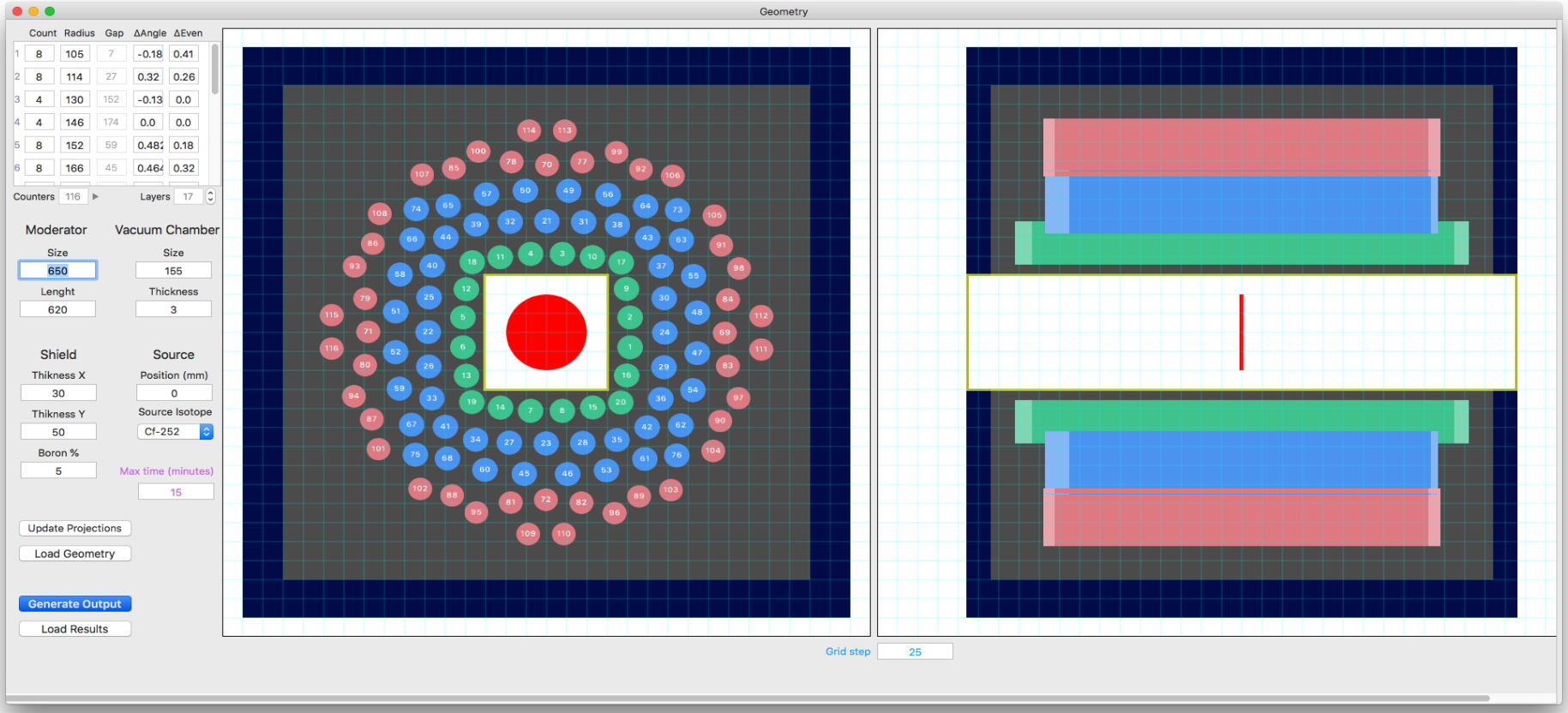
Velocity filter SHELS

Next stage – years 2019 - 2020

New Detection systems

Modernization of neutron detector

- ability to work in the SHE region (σ ≤ 1 nb)
- unification of silicon detectors and electronics with GABRIELA setup (large DSSSD and position sensitive side detectors)



Velocity filter SHELS

Next stage – years 2019 - 2020

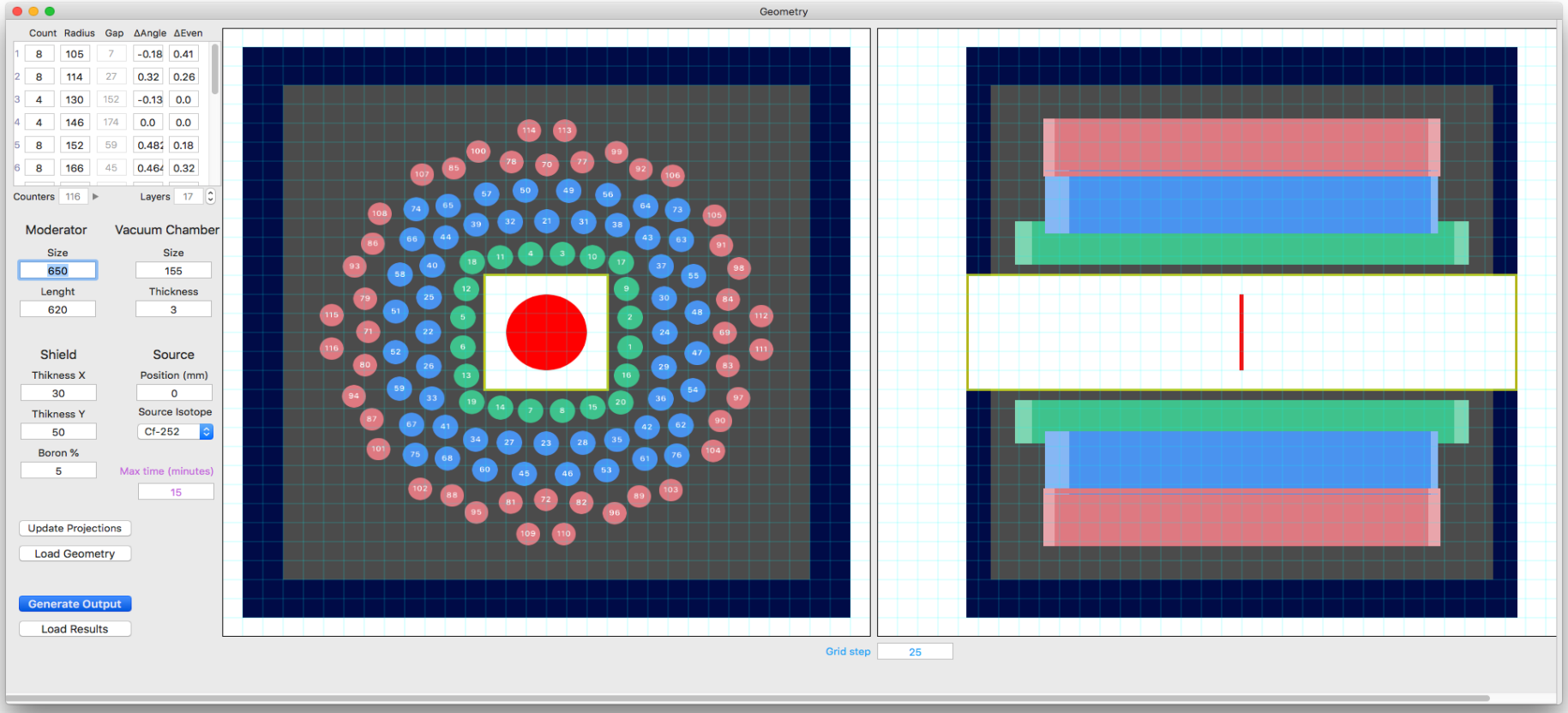
New Detection systems

Modernization of neutron detector

Counters count: **116 (4; 7 At ^{3}He)**

Efficiency: **57%** (MCNPX)

Average neutron lifetime: **24 μs** (MCNPX)



Velocity filter SHELS

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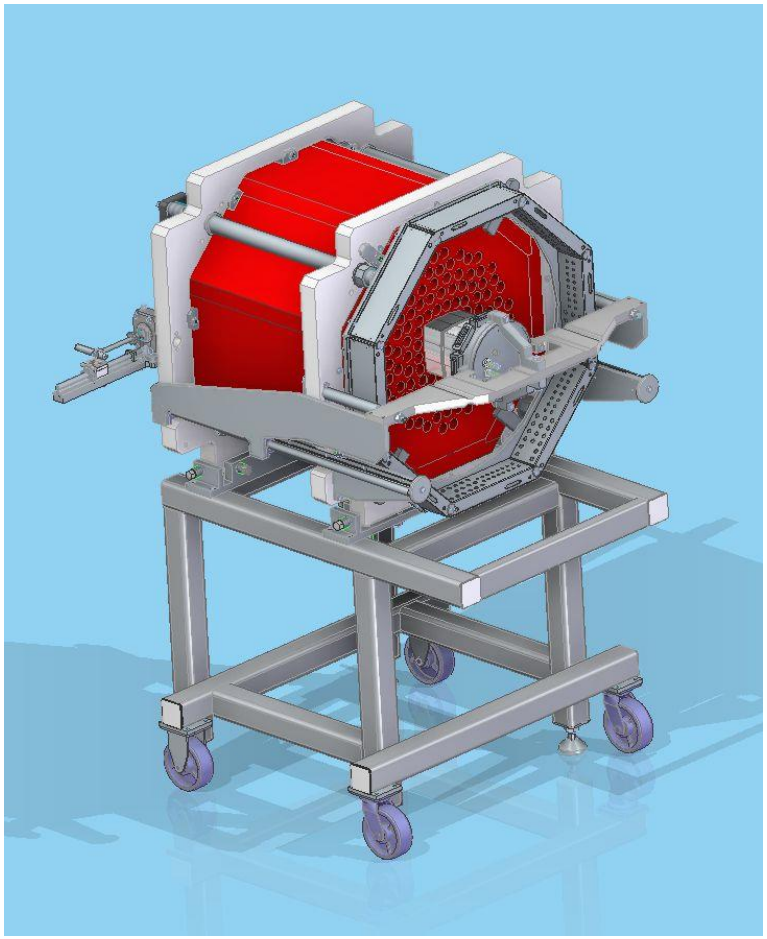
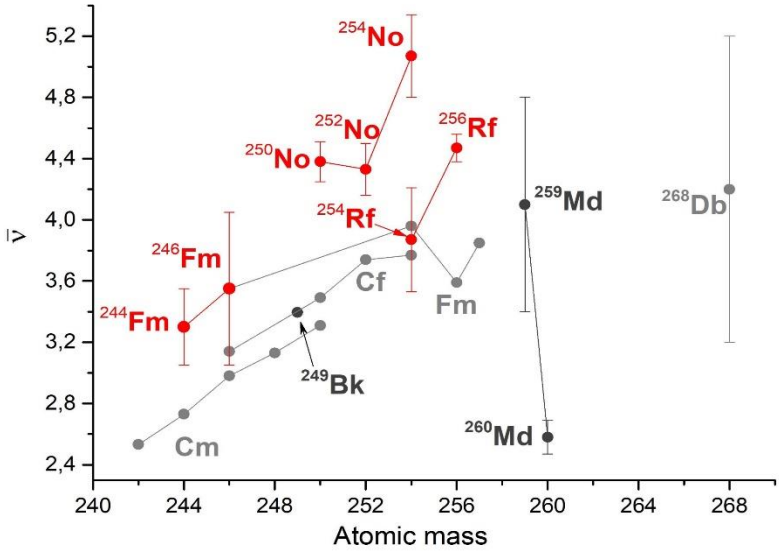


SHELS Results

Isotope	Calculated average number of neutrons,	Measured average number of neutrons,	Calculated average TKE (MeV)	Measured average TKE (MeV)
^{254}Rf*	4.7	**3.87±0.34**	209	-
^{256}Rf	4.6	4.47±0.09	208	-
^{250}No	4.3	4.38±0.13	202	192±2
^{250m}No	In progress	3.90±0.20	In progress	200±2 MeV
^{254}No*	In progress	5.07±0.27	In progress	184±2 MeV
^{252}No	4.1	4.33±0.17	201	198.7**
^{244}Fm	3.5	3.3±0.3	196	198±15
^{246}Fm	3.6	3.6±0.5	196	199±4

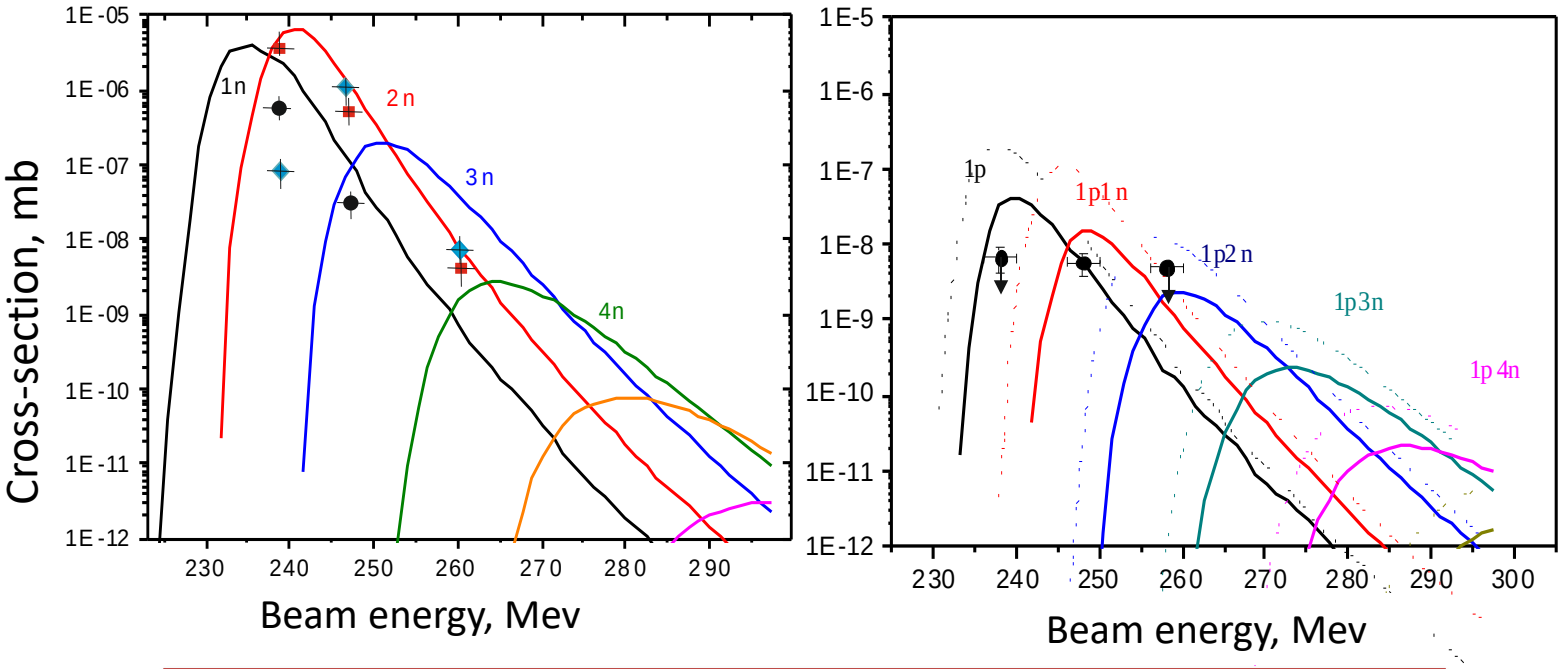


** - new data (SHELS separator)*
*** - values from literature*

In the present work we used an improved scission-point model (*see A.V. Andreev, Eur. Phys. J.* ***A 30****, (2006)*) which is powerful in description of various experimental data on binary and ternary fission of heavy nuclei: mass and charge distributions of fission fragments, their kinetic energies, prompt fission neutron multiplicities, etc.

SHELS Results

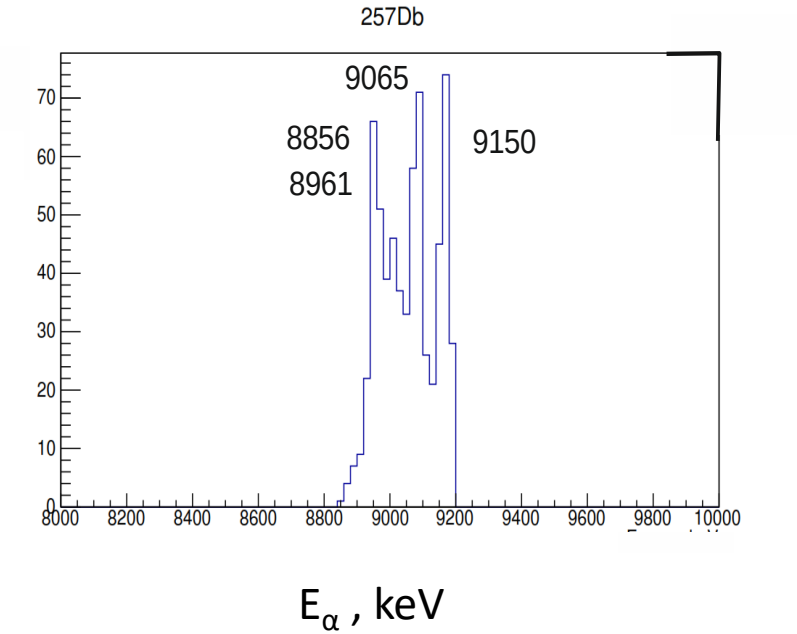
Cross-sections of xn and pxn channels were measured in experiment.

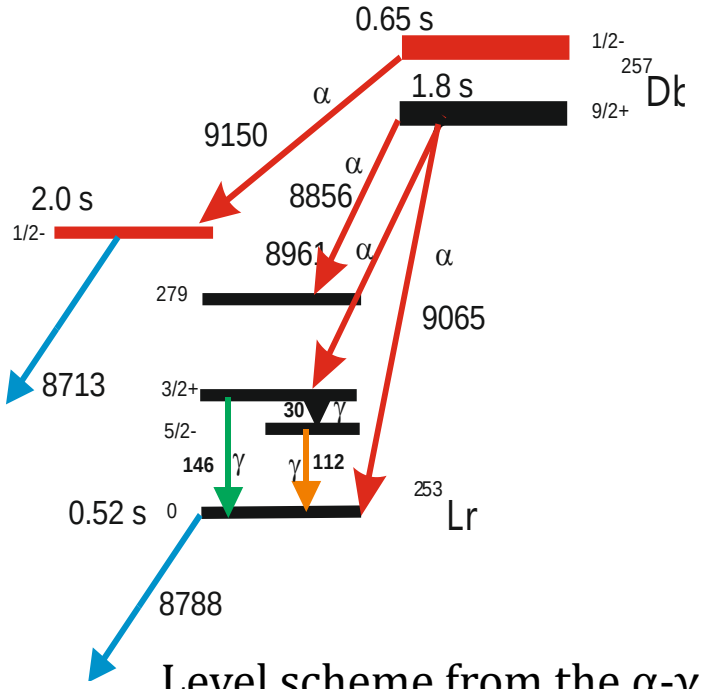


Energy beam in mid-target, MeV	Channels	Isotopes	Cross-section, pb
248	p0n	^{258}Rf	**5.7**
	2n	^{257}Db	600

SHELS Results

$$^{50}Ti + ^{209}Bi \rightarrow ^{257}Db + 2n$$





Level scheme from the α-γ correlations analysis.

SHELS Results

Preliminary experimental results: January 2019, GABRIELA setup

Reactions: $^{48}Ca + {}^{204,206,208}Pb = 2n + {}^{250,252,254}No$
SHELS separator transmission: **32%**
Beam: ^{48}Ca (18+), 0.4 pμA, $E_{1/2}$ = 225 MeV
Detectors: focal plane DSSSD-detector (128×128 strips), 4 side DSSSD-detectors (32×16 strips), 1 clover Ge-detector and 4 Ge-detectors (with BGO shields).
Registration: α, β, γ and fission fragments.

^{254}No

Target: 360μg/sm^2 PbS (99.57% of ^{208}Pb); **Beam dose:** 2.3E18 ^{48}Ca ions
Correlations: **600** Recoil – Fission Fragment (focal detector)
Measured: ff-TKE, **cross-section**, isomeric states, γ-multiplicity

^{252}No

Target: 400μg/sm^2 PbS (99.51% of ^{206}Pb)
Correlations: **15000** Recoil – Fission Fragment (focal detector)
Measured: ff-TKE (using for calibration), cross-section, γ-multiplicity

^{250}No

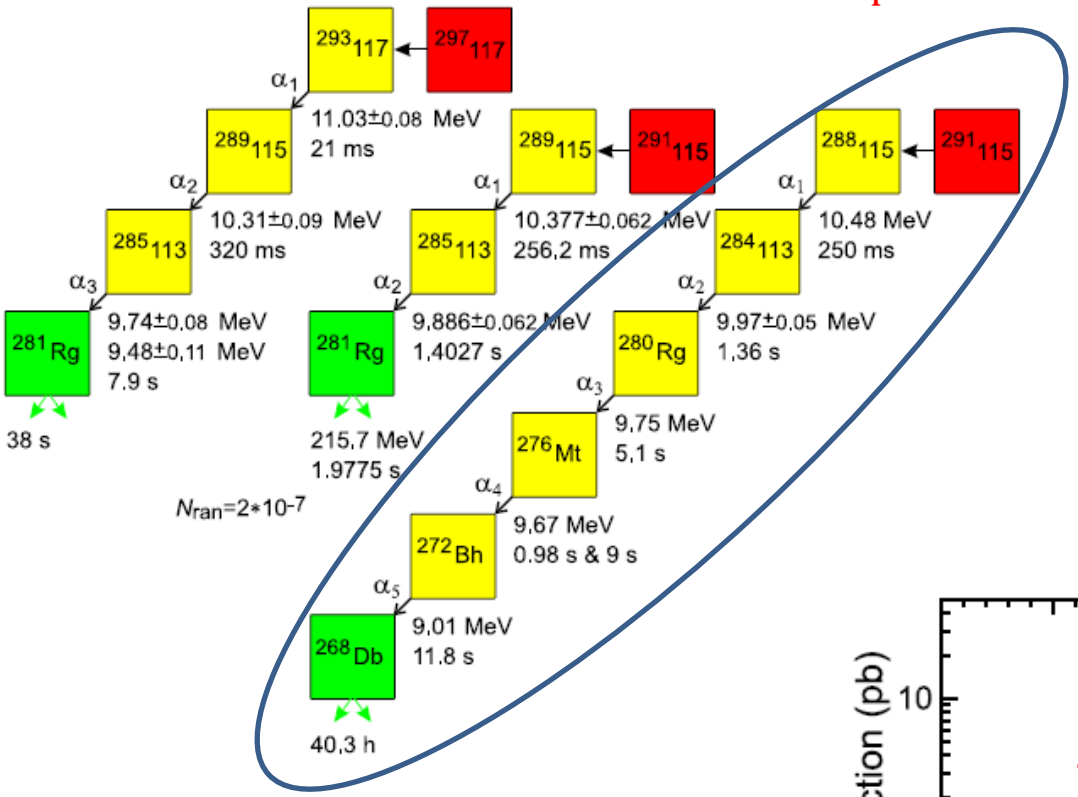
Target: 470μg/sm^2 PbS (99.94% of ^{204}Pb); **Beam dose:** 6E18 ^{48}Ca ions
Correlations: **19000** Recoil – Fission Fragment (focal detector, 0-500 μs), **no** Re – α correlations
Measured: ff-TKE, **b_{SF}**, cross-section (35 nb), **isomeric states**, γ-multiplicity

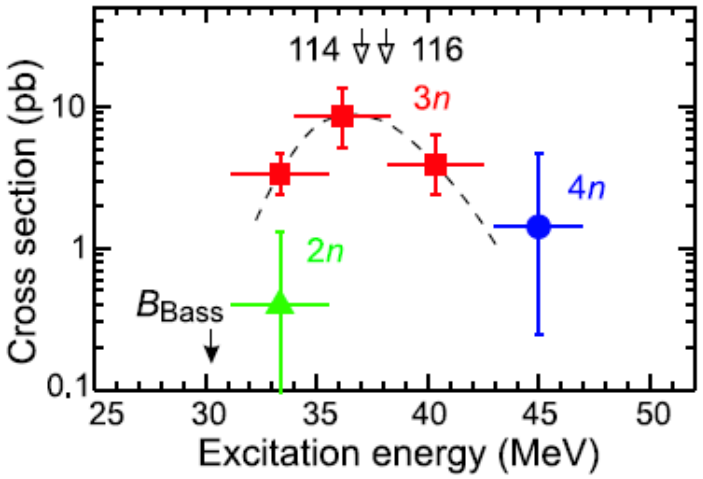
Plans for 2019-2020

Reactions	Goals
$^{238}U(^{22}Ne, xn)^{260-x}No$	Focal plane spectroscopy, xn-cross sections
$^{208}Pb(^{54}Cr, xn)\ ^{262-x}Sg$	SF with neutron detector
$^{208}Pb(^{48}Ca,2n)^{254}No$	Study of the decay modes, k-isomers.
$^{242}Pu(^{22}Ne,xn)^{264-x}Rf$	Study of the decay modes.

Future Plans

New insights into the $^{243}Am+^{48}Ca$ reaction products previously observed in the experiments on elements 113, 115 and 117

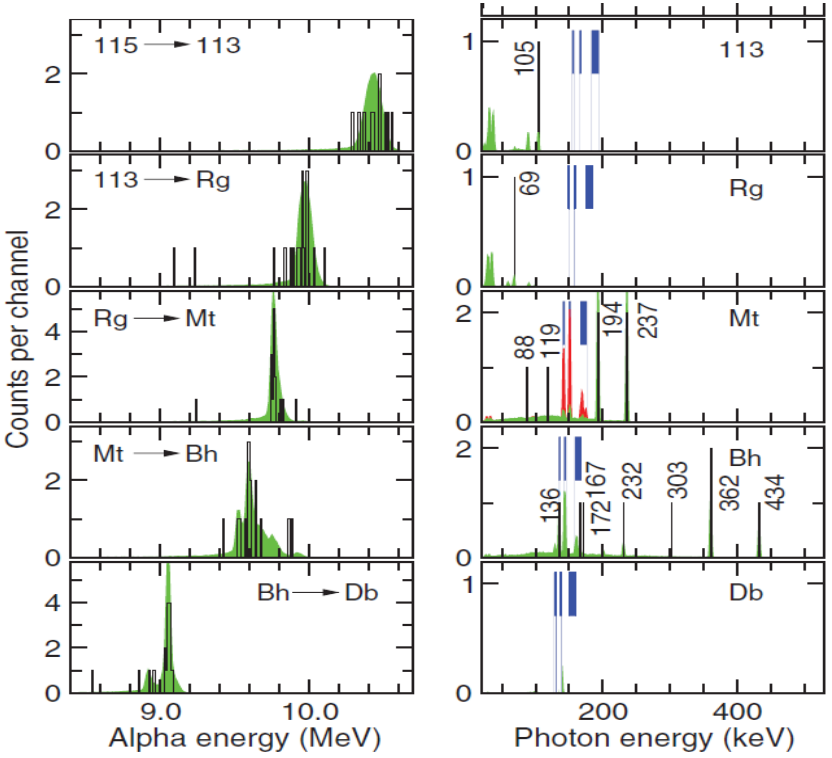




Future Plans

Existing experimental data:
DGFS: 2.5×10^{19} Beam energy 240 - 243 МэВ, 31 chains (no gamma)
TASCA + TASISpec: 6×10^{18} Beam energy 242 and 245 МэВ, 22 chains (16 gamma quanta)
Nuclear Instruments and Methods in Physics Research A 622 (2010) 164–170

Expectations (SHELS + GABRIELA)
Cross section ~ 8 pb
Target thickness ~ 10^{18} at/cm^2
Beam intensity ~ 5×10^{12} pps
If $\varepsilon_{transmission}$ ~ 40 %
1 event per day.
100 days (flux about 3×10^{19})
about 100 events → 75 gamma quanta



Yu. Ts. Oganessian et al.,Phys. Rev. C 87, 014302 (2013)
D. Rudolph et. al., PRL 111, 112502 (2013)

Future Plans

DC280 + GNSIII + GABRIELA
Cross section ~ 8 pb
Target thickness ~ 10^{18} at/cm^2
Beam intensity ~ 1.5x10^{13} pps
If $\varepsilon_{transmission}$ ~ 40 %
3 event per day.
100 days (flux about 10^{20})
about 300 events →
215 gamma quanta

Future Plans

DC280 + GNSIII + GABRIELA

Cross section ~ 8 pb

Target thickness ~ 10^{18} at/cm^2

Beam intensity ~ 1.5x10^{13} pps

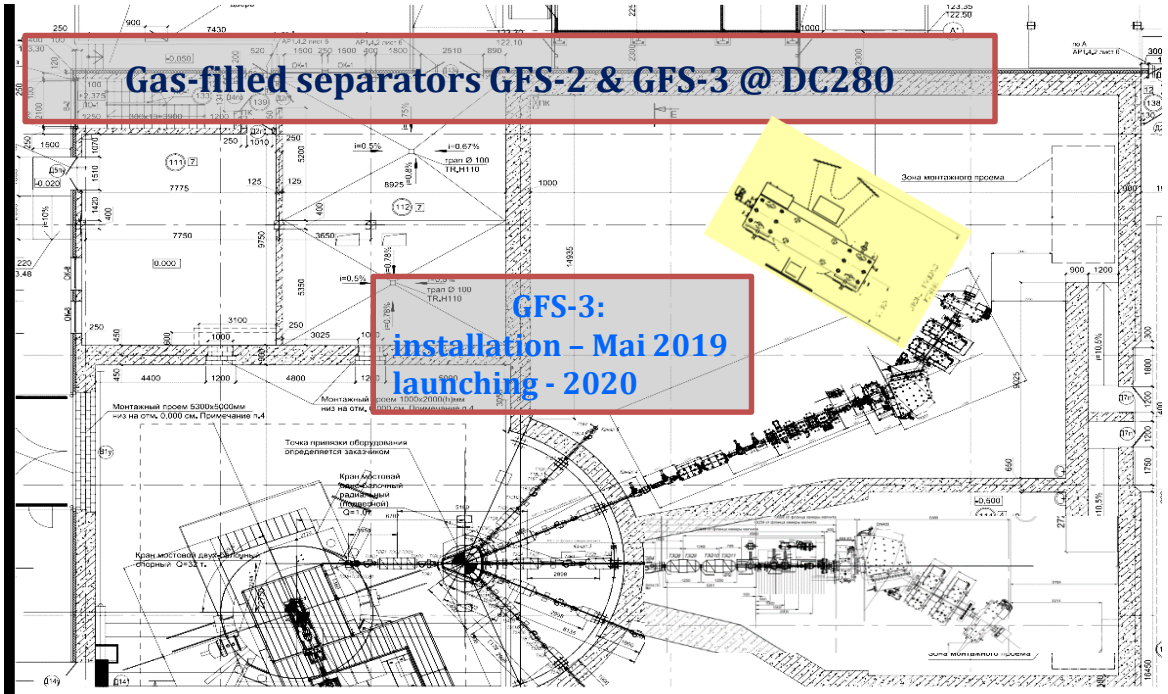
If $\varepsilon_{transmission}$ ~ 40 %

3 event per day.

100 days (flux about 10^{20})

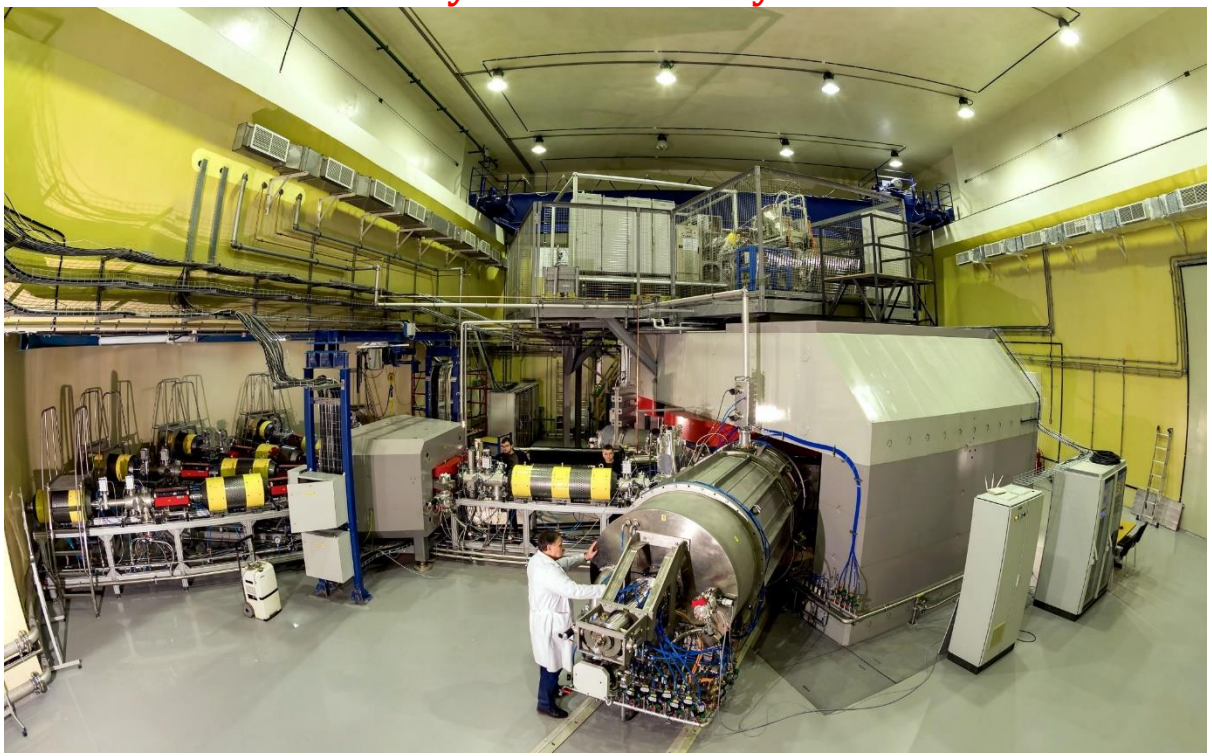
about 300 events →

215 gamma quanta



II. Status of the Factory of Superheavy Elements

Stand-alone SHE factory with DC-280 cyclotron



DC-280
Main Parameters

Ion sources	Permanent magnet ECR DECRIS-PM - 14 GHz
Injection energy	Up to 80 keV/Z
A/Z range	4÷7.5
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.3 T
K factor	280
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Deflector voltage	Up to 90 kV

II. Status of the Factory of Superheavy Elements

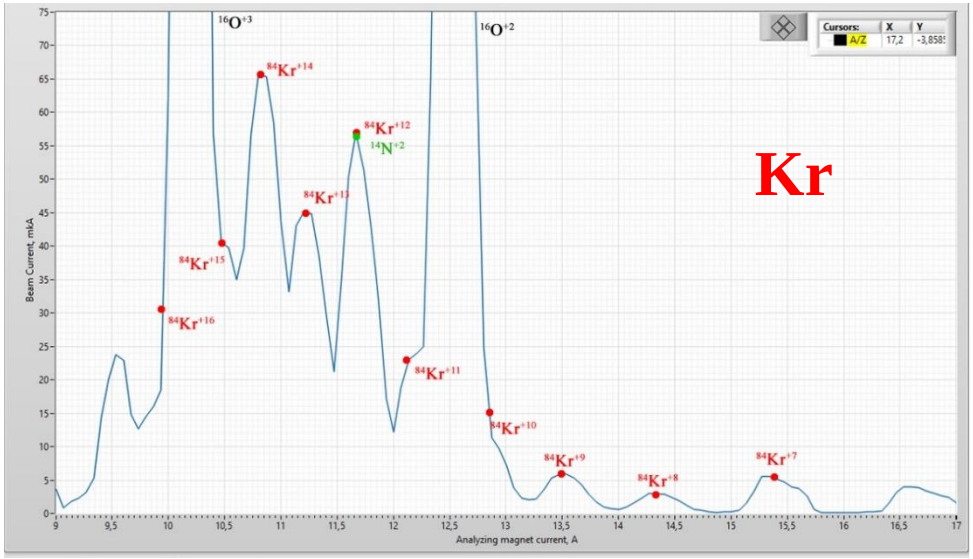
Tests of DECRIS-PM at the HV platform of DC-280

Ions for DC-280 tests

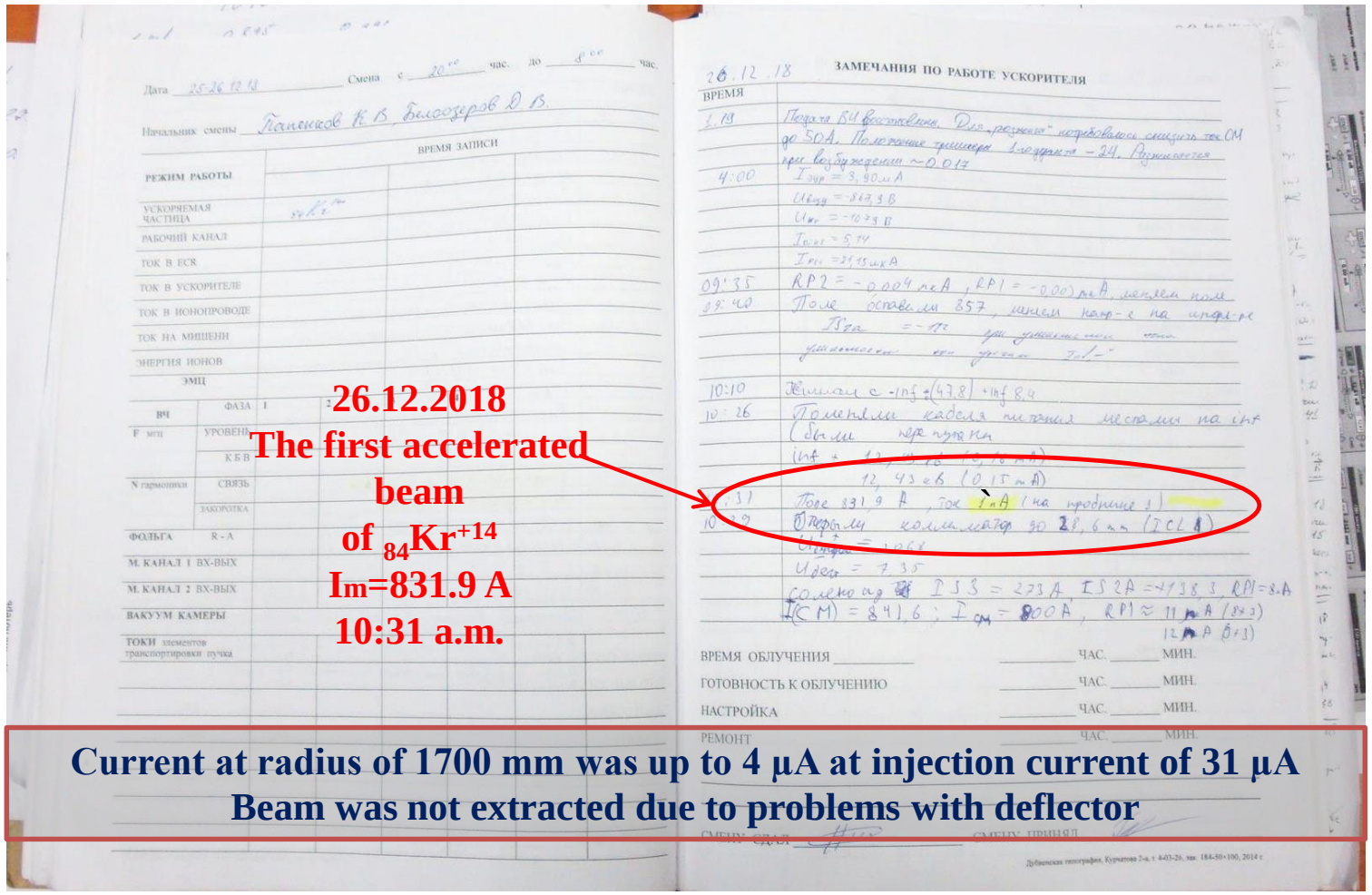
$_{40}Ar^{+7}$, A/Z=5.71
I max=190 μA

$_{40}Ar^{+8}$, A/Z=5
I max=290 μA

$_{84}Kr^{+14}$, A/Z=6
I max=65 μA

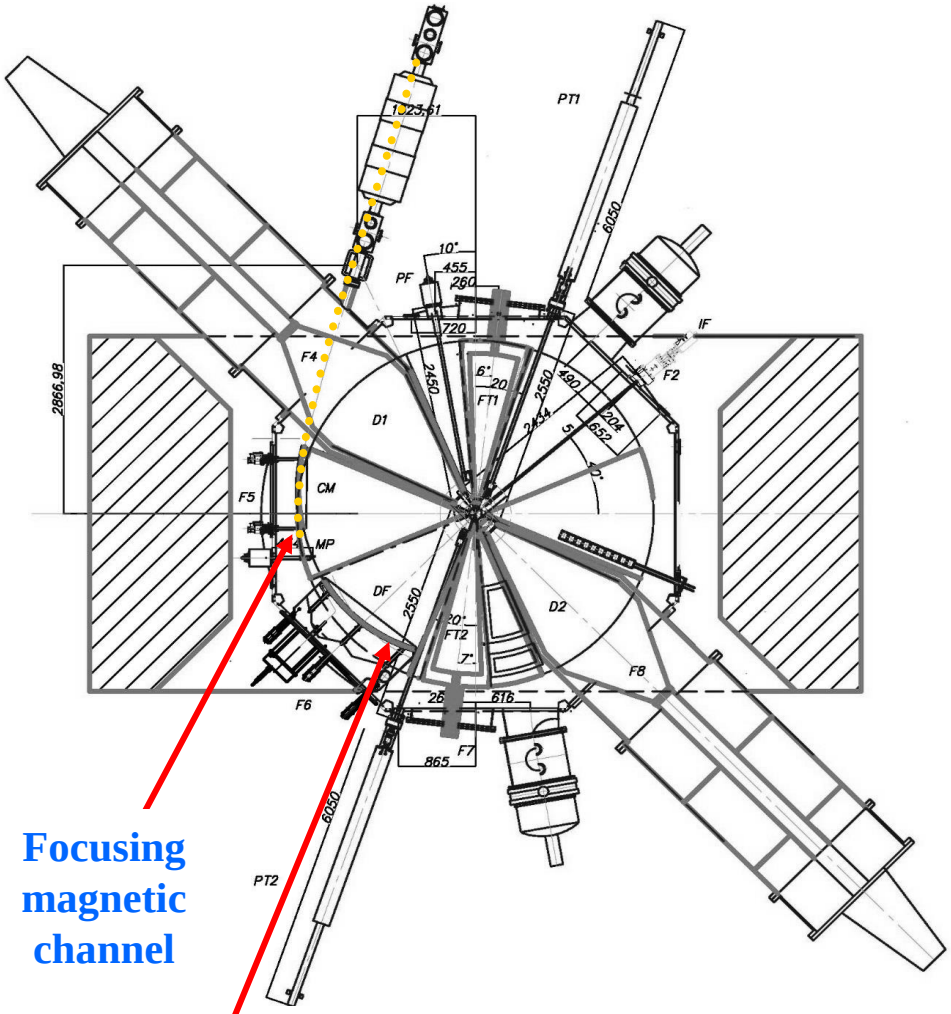


II. Status of the Factory of Superheavy Elements



Current at radius of 1700 mm was up to 4 μA at injection current of 31 μA
Beam was not extracted due to problems with deflector

Beam extraction system



Focusing magnetic channel

Electrostatic deflector

Extraction radius of
R_{ext}=1.79 m
U_d=75.55 kV

The first ion beam extracted from DC-280

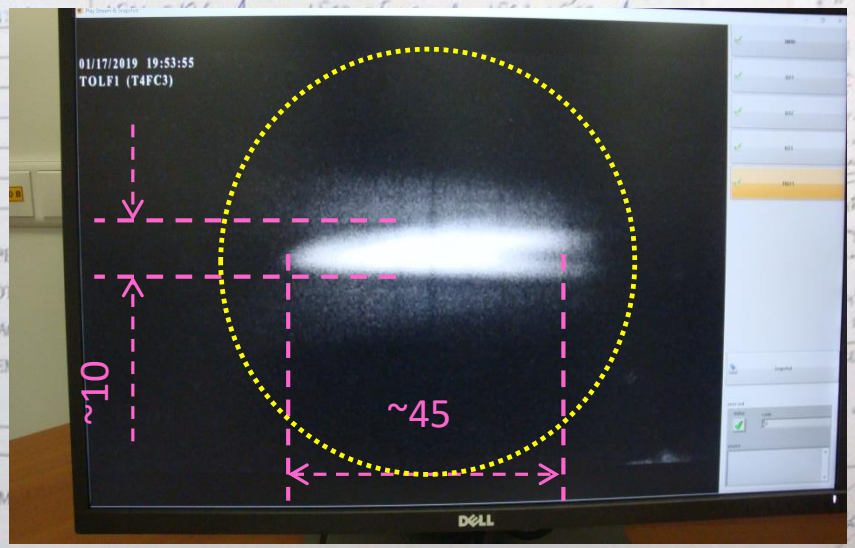
(without flat-top resonators)

17.01.2019

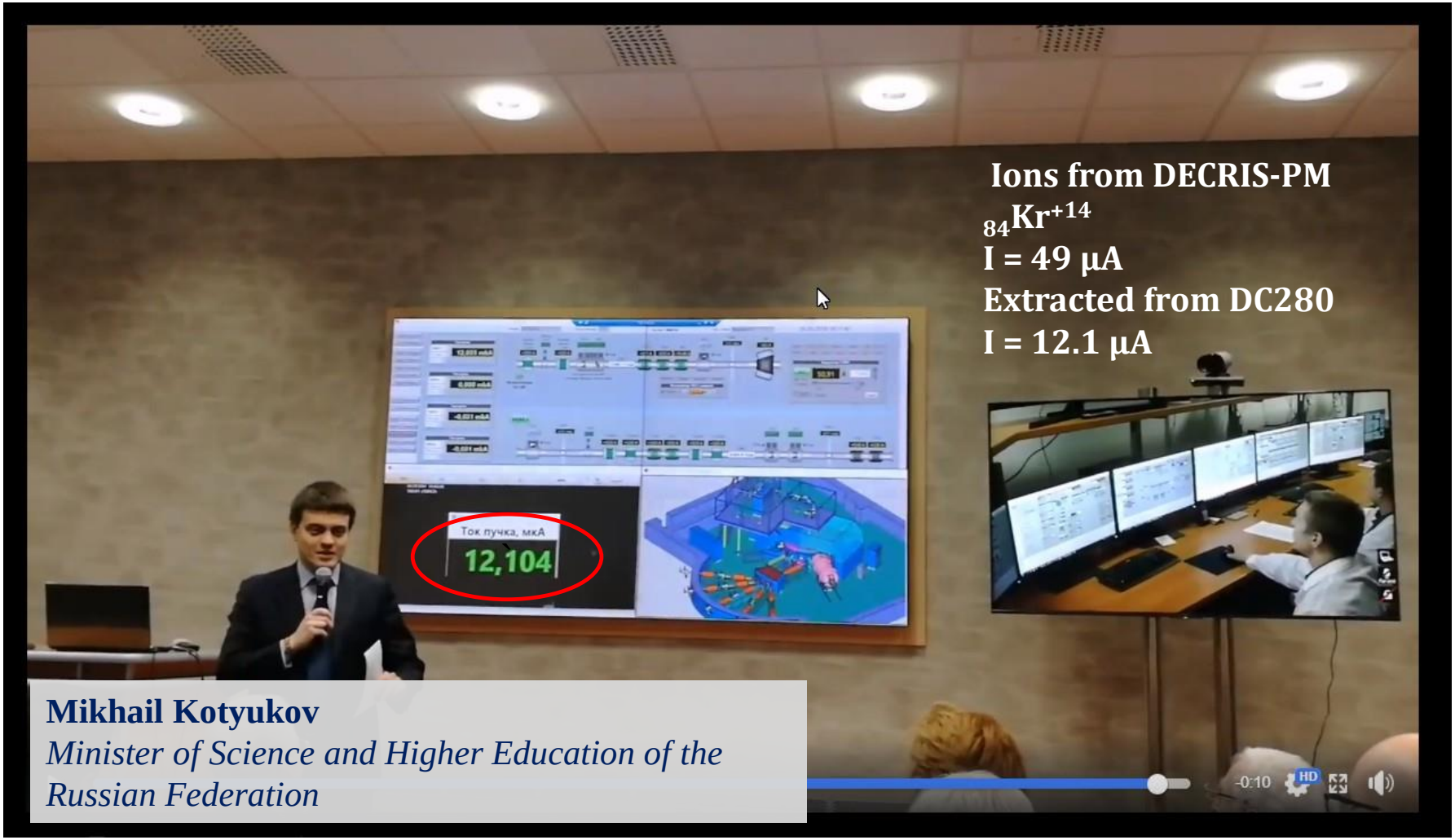
The first extracted beam

of $_{84}Kr^{+14}$ I_{RP1}=1nA

18:32



25.03.2019 The Factory of Superheavy Elements inauguration

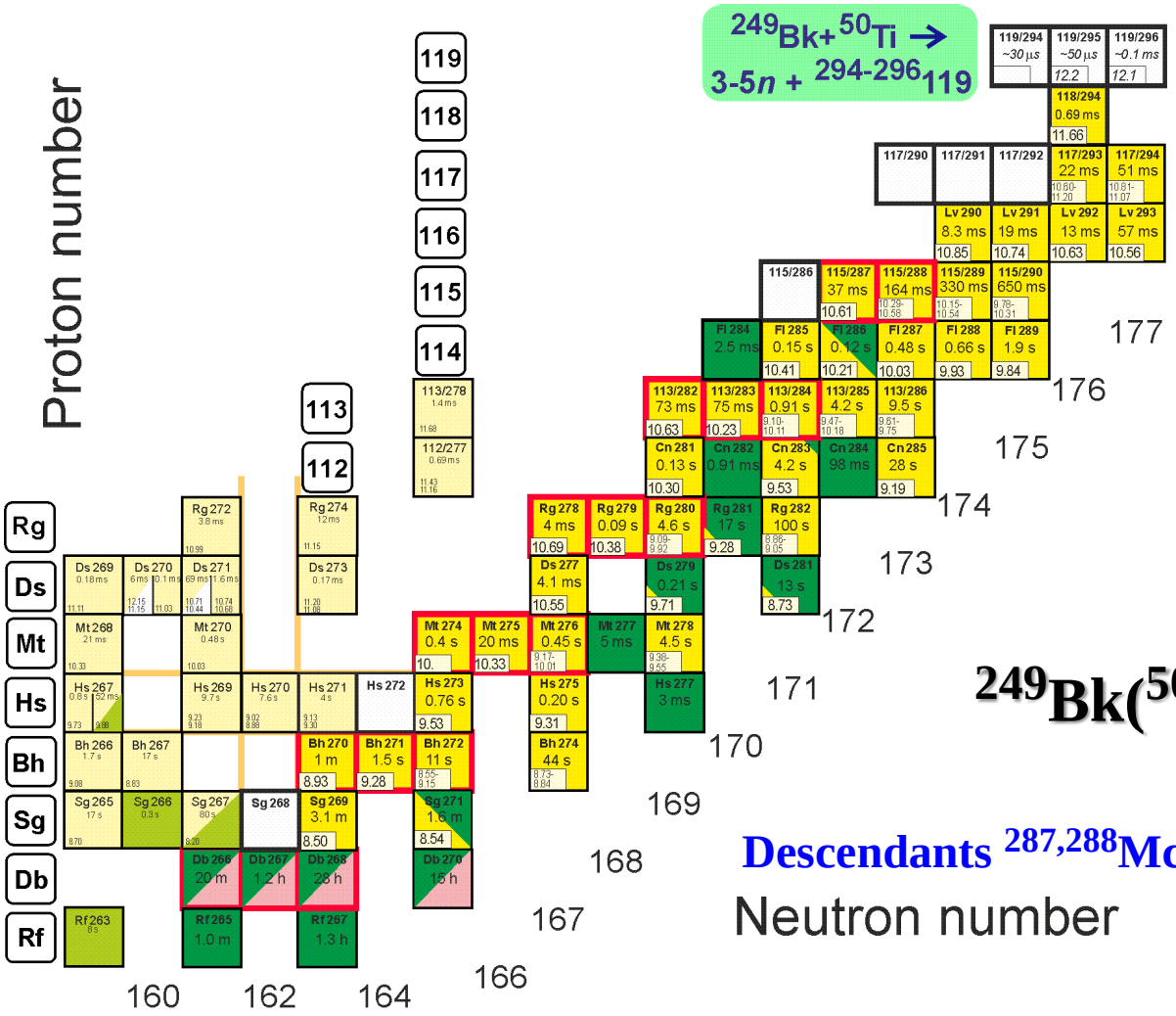


Immediate plans

- Carrying out radiation measurements with participation of FMBA representatives.
- Installation of flat-top resonators, installation of regular inflector, improving of vacuum conditions.
- Acceleration of $_{48}Ca^{+8,+9}$ $_{50}Ti^{+8,+9}$. Increasing of ion beam intensity, transportation of ion beams to the GFS-2.

First experiments at SHE Factory

Synthesis of new element 119



^{249}Bk(^{50}Ti,3-4*n*)^{295,296}119

Descendants ^{287,288}Mc, $^{282-294}$Nh… are known

σ=50 fb, h_t=0.3 mg/cm^2, ε_{coll}=0.6, I_{beam}=3 pμA $\rightarrow$ ≈1 event per month

SHE-Factory building, January 2019