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SHELS – Separator for Heavy ELement Spectroscopy

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BASIC DIRECTIONS of RESEARCH at FLNR JINR

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

Spectroscopy of Heavy Elements
Experimental Opportunities

Alpha spectroscopy - Q_α values and partial half lives, identification of new nuclides using α–α correlation method.

Spontaneous fission – TKE, FF mass distribution, prompt neutron multiplicity, partial half lives

Beta and gamma spectroscopy – E_γ, E_β (conversion electrons), isomeric states at mother and daughter nuclei

Correlation analysis – prompt and delayed α, β, γ correlations, assignment of isomeric states.

Spectroscopy of Heavy Elements
Experimental Requirements

High intensity heavy ion beams with good energy resolution 0.5 – 1.5 pμA – cyclotron Y400.

Appropriate experimental set ups – recoil kinematic separator VASILISSA

Sophisticated detector systems - GABRIELA, Neutron detector

At FLNR - Focal plane spectroscopy.

Presently Working Experimental Set Ups in the World

Dubna Gas Filled Separator (Russia)	★		Gas - filled
SHIP (Darmstadt, Germany)	★	✦	Vac. V filter
Berkeley Gas Filled Separator (USA)	★		Gas - filled
GARIS (Saitama, Japan)	★		Gas - filled
VASSILISSA (Dubna, Russia)	★	✦	Vac. E filter
LIZE3 (GANIL, France)	★	✦	Vac. V filter
RITU (JYFL, Finland)		✦	Gas - filled
FMA (Argonne, USA)		✦	Vac. RMS
JAERI-RMS (Tokai, Japan)	★		Vac. RMS
TASCA (Darmstadt, Germany)	★	✦	Gas - filled

★ Heavy element research ✦ Spectroscopy studies

VASSILISSA separator 1986 – 2011.

Experiments performed with the use of VASSILISSA separator were aimed to:

● collecting new data on the cross sections for the formation of evaporation residues (ERs) produced in the hot-fusion reactions during the compound-nucleus de-excitation with evaporation of a large number of neutrons (up to 14 neutrons);

● studying the survival probability of highly excited compound nuclei including highly fissile nuclei, i.e., those having a liquid-drop fission barrier close to zero;

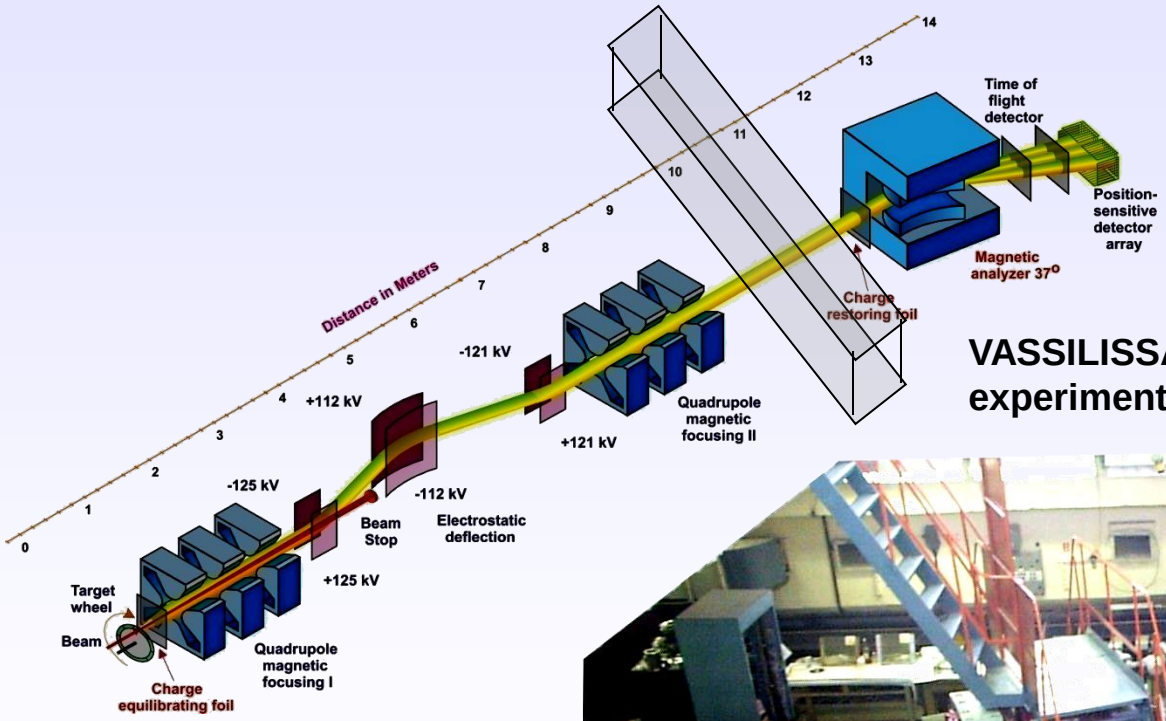
● studying the constraints on the fusion in the entrance channel for the complete-fusion reactions with massive nuclei;

● studying the nuclear-structure effect on the fusion and survival probabilities of the excited compound nucleus;

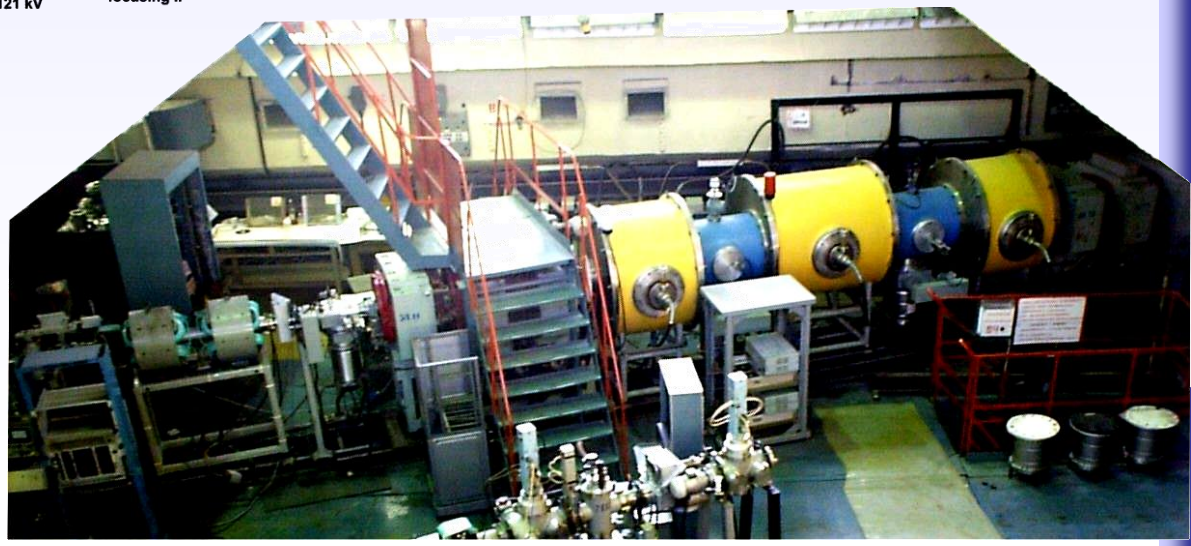
● studying the properties of the radioactive decay for newly synthesized isotopes with atomic numbers $Z \geq 92$ and investigating the structural features of heavy nuclei. 14 new isotopes from U to No were synthesized.

Experimental set-up

VASSILISSA + (α,γ,β)-detector array

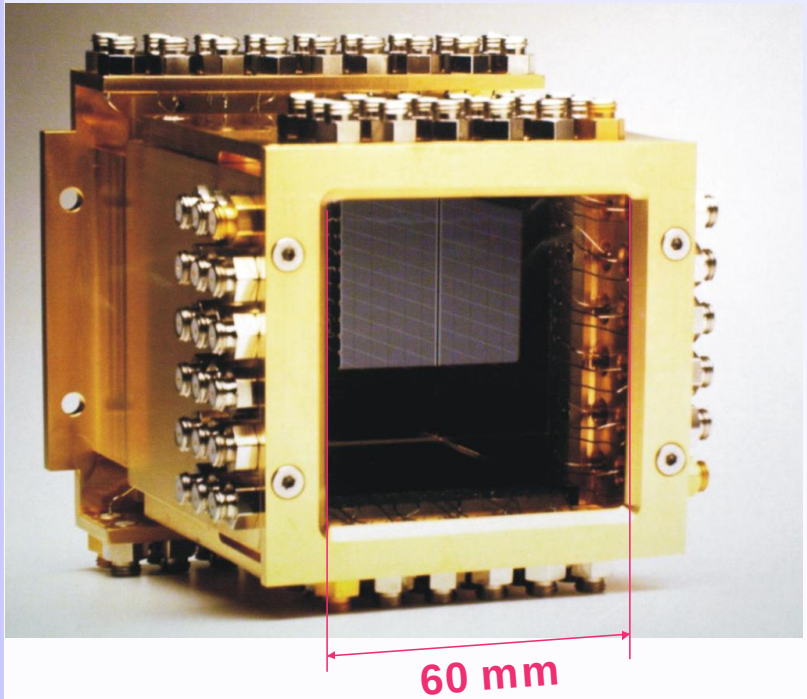


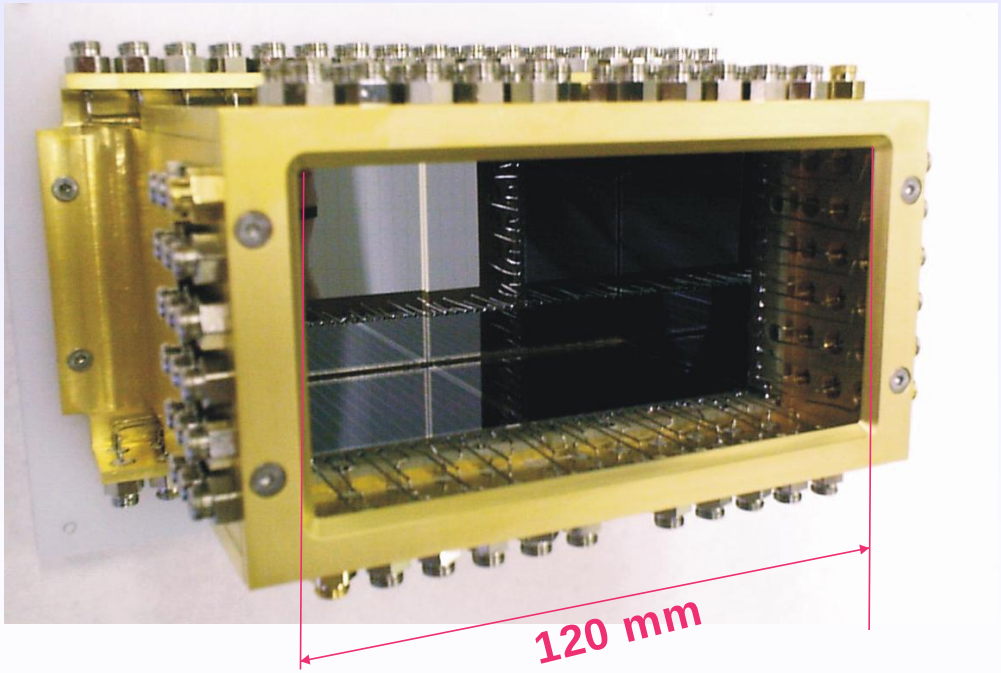
VASSILISSA set up at experimental hall of the U400 cyclotron



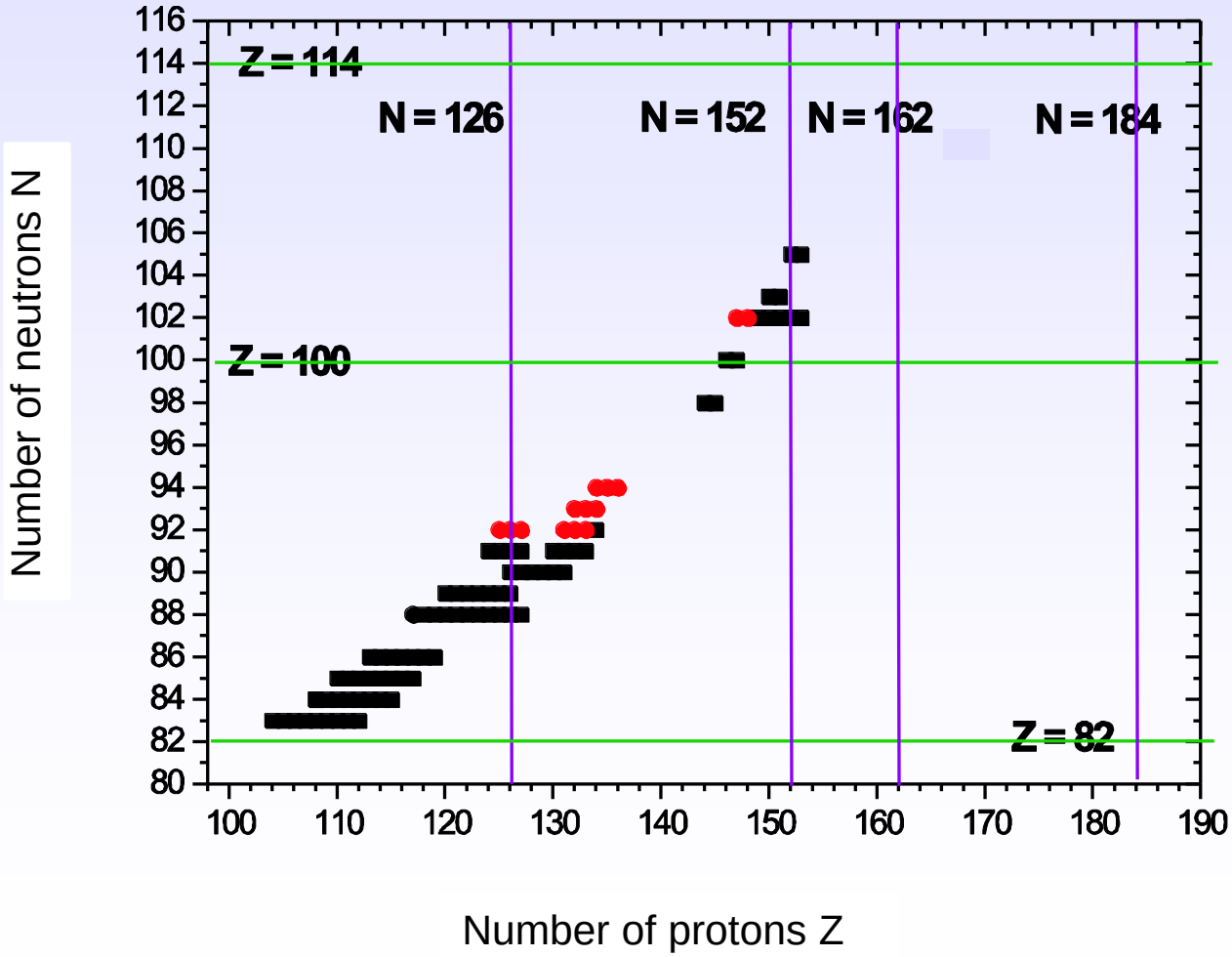
Focal plane detectors 1986 – 2004.

Registration of alpha particles and spontaneous fission fragments at the focal plane of separator.





VASSILISSA separator 1986 – 2004.



VASSILISSA separator - since 2004.

*GABRIELA (**G**amma **A**lpha **B**eta **R**ecoil **I**nvestigations with the **EL**ectromagnetic **A**nalyser)*

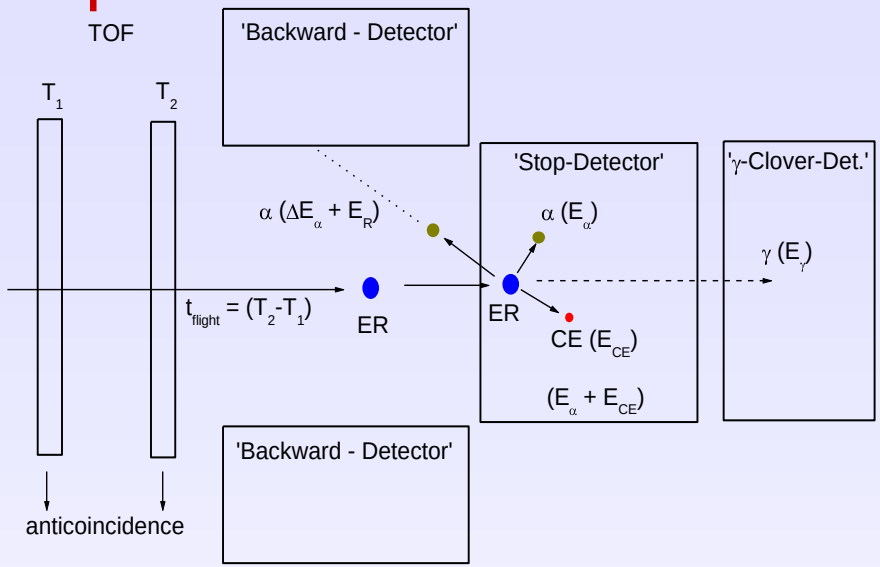
● The joint JINR – IN2P3 (France) project entitled “Study of nuclear structure and nuclear reaction mechanism of heavy and superheavy elements: Gamma and electron spectroscopy of very heavy nuclei with Z ≈ 104” started in year 2004.

● The scientific aims of the collaboration were approved by the Scientific Council of IN2P3 in December 2003 and by the Scientific Council of JINR in January 2004.

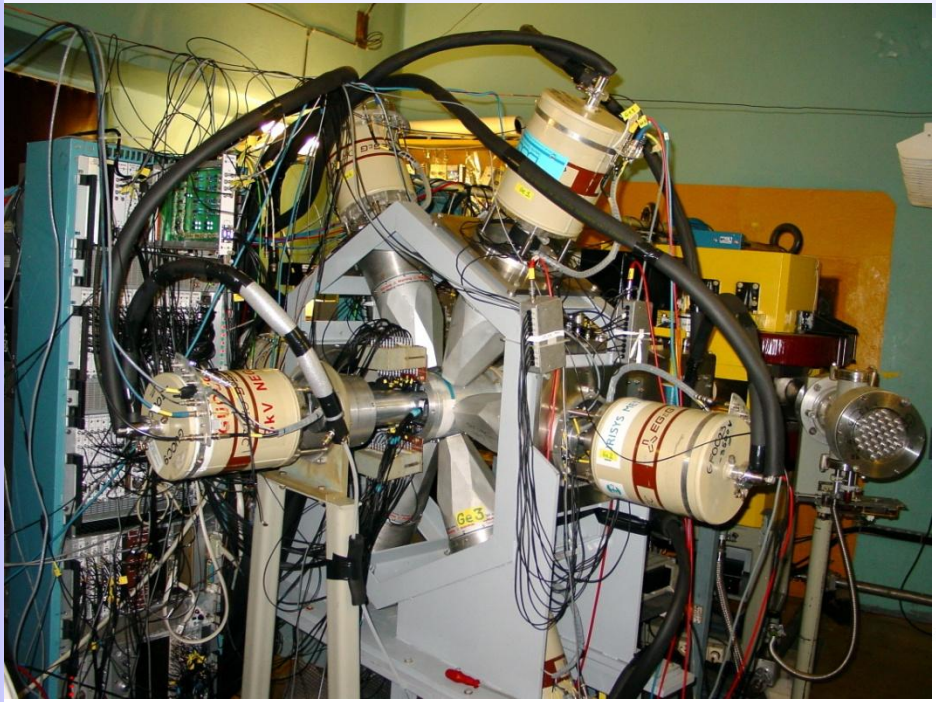
● The collaboration, which includes groups from CSNSM Orsay and IPHC Strasbourg for IN2P3 and for JINR, a group from the FLNR Laboratory, has led 5 experimental campaigns since 2004.

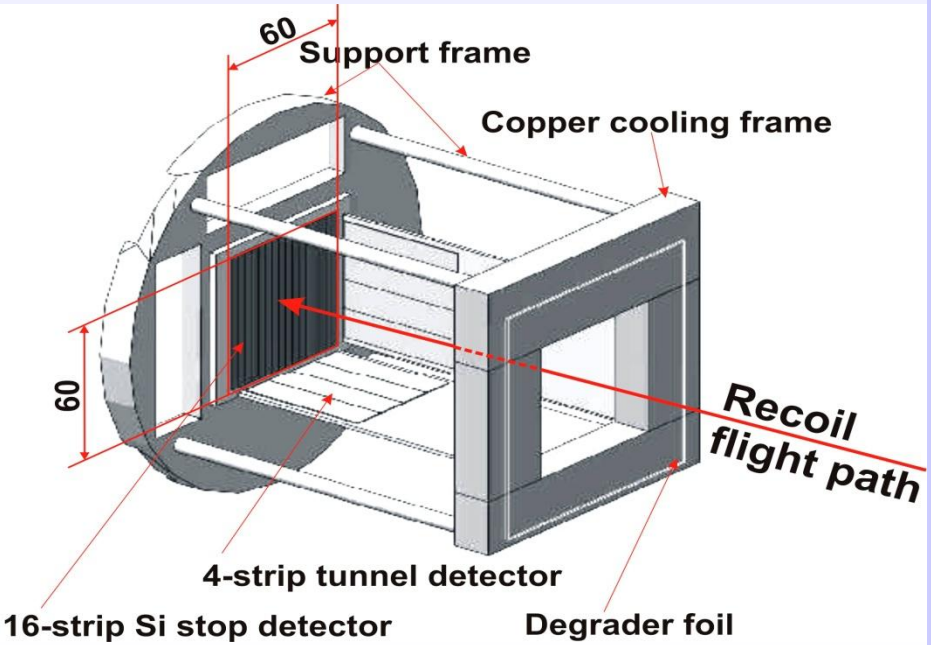
http://flerovlab.jinr.ru/flnr/vassilissa.html
http://www.csnsm.in2p3.fr/-GABRIELA-?lang=en

Experimental methods: Focal plane detector assembly



GABRIELA: Gamma Alpha Beta Recoil Investigation with the Electromagnetic Analyser





Decay (focal plane) studies

α-γ (CE) - decay measurements

→ **transitions gs(mother) → gs (daughter**) → Q-value

→ **transitions gs(mother) → excs (daughter**) followed by γ, CE

→ E^* excited levels

→ Multipolarity of transition(s) to gs or excs

→ spin and parity assignments

→ Q-value (if gs not or weakly populated)

(→ excs (daughter) might be isomeric)

→ **transitions isoms (mother) → isoms, excs, gs (daughter**)

→ E^* isomeric levels

→ spin and parity assignments (correlation between life-times and spin/parity differences)

ER-γ(CE) – decay measurements

→ **transitions isoms(mother) → excs, gs (mother**)

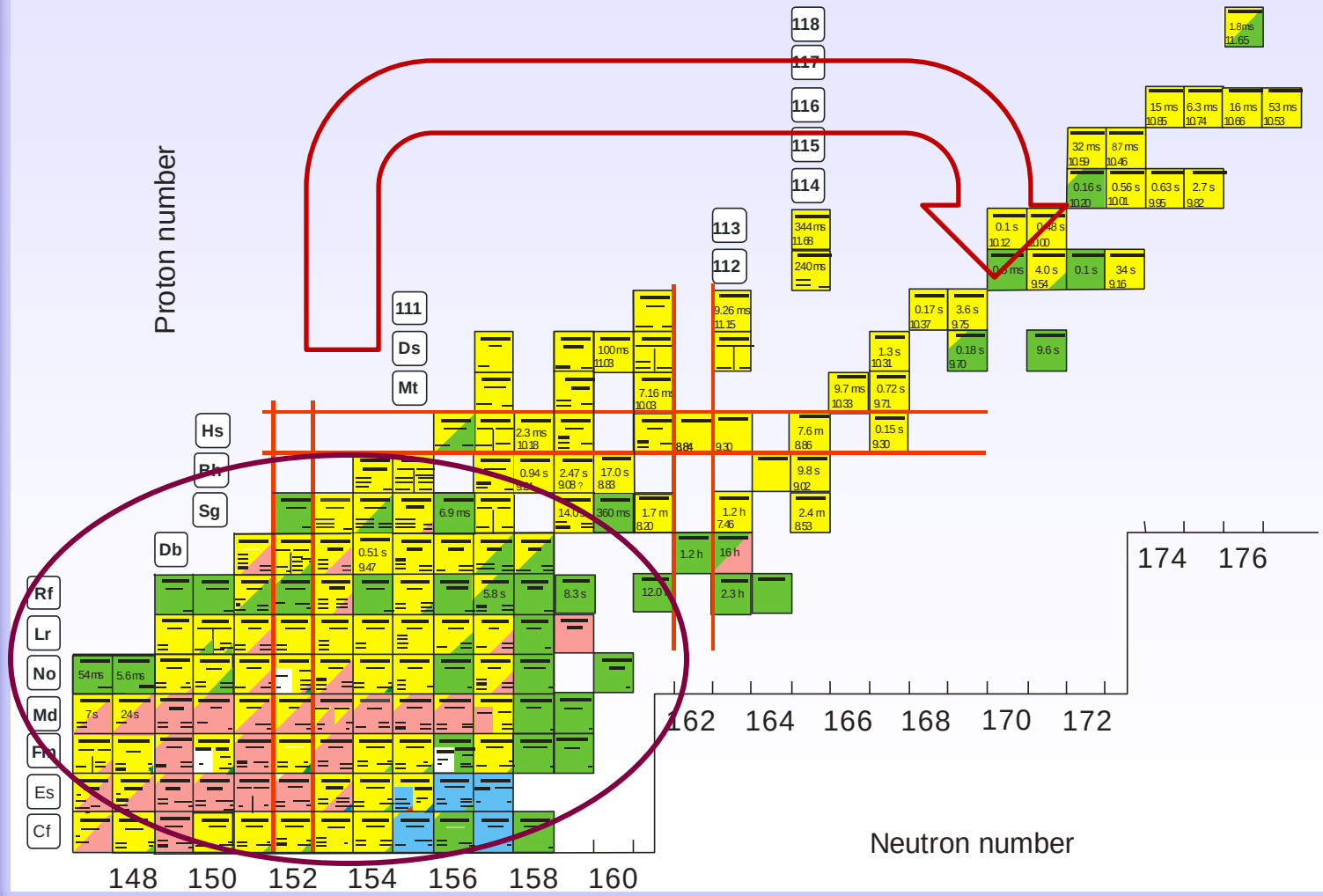
→ E^* isomeric levels

→ spin and parity assignments

Nuclear structure studies

Heaviest SHE - limited experimental data (E_α, $T_{1/2}$)
Deformed mid-shell nuclei: opportunity for detailed nuclear structure studies

Transfermium nuclei: Z > 100
Shell-stabilized nuclei
Large density of sp levels, strong Coulomb field
=> Heavy nuclei: demanding theoretical testing ground



Status of the GABRIELA campaigns

1. First full scale experiment: September 23d – October 25th 2004, 32 days

$^{48}Ca + ^{207,208}Pb \rightarrow ^{255,256}No^*$, $^{48}Ca + ^{209}Bi \rightarrow ^{257}Lr^*$

A. Lopez-Martens et al., Phys. Rev. C 74 (2006) 044303

2. October 3d – November 9th 2005, 36 days

$^{22}Ne + ^{238}U \rightarrow ^{260}No^*$, $^{22}Ne + ^{209}Bi \rightarrow ^{231}Np^*$,

$^{48}Ca + ^{208,210}Pb \rightarrow ^{256,258}No^*$, $^{48}Ca + ^{209}Bi \rightarrow ^{257}Lr^*$

K. Hauschild et al., Nucl. Instr. and Meth. A 560 (2006) 388-394.

A. Lopez-Martens et al., Eur. Phys. J. A 32, 245 - 250 (2007)

3. October 30th - December 4th 2006

$^{22}Ne + ^{238}U \rightarrow ^{260}No^*$, $^{40}Ar + ^{184}W \rightarrow ^{224}U^*$; $^{40}Ar + ^{181}Ta \rightarrow ^{221}Pa^*$

Popeko A.G. et. al., Phys. At. Nucl, 2006, vol. 69, 1183-1187

K. Hauschild et al., Phys. Rev. C 77, 047305 (2008).

4. February 1st – March 10th 2008:

$^{40}Ar + ^{182}W \rightarrow ^{218}U + 4n$; $^{40}Ar + ^{180}Hf \rightarrow ^{216}Th + 4n$; $^{22}Ne + ^{238}U \rightarrow ^{255}No + 5n$

K. Hauschild et al., Phys. Rev. C 78 (2008) 021302(R)

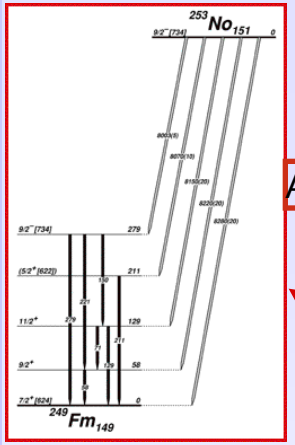
Yeremin A.V. et. al., NIM B 266 (2008) 4137-4142

5. February 9th – March 14th 2009:

$^{48}Ca + ^{207}Pb \rightarrow ^{255}No^*$, $^{40}Ca + ^{159}Tb \rightarrow ^{199}At^*$

$^{48}Ca + ^{181}Ta \rightarrow ^{224,225}Np^*$

Summary of results and on-going analysis



A. Lopez-Martens et al., PRC 74 (2006) 044303

K. Hauschild, Phys. Rev. C 78 (2008) 021302(R)

^{50}Ti + ^{208}Pb

^{22}Ne + ^{242} Pu

^{22}Ne + ^{238}U

K. Hauschild, in progress

				$_{104}$Rf				Rf253	Rf254	Rf255	Rf256	Rf257	Rf258	Rf259	Rf260
			$_{103}$Lr					Lr252	Lr253	Lr254	Lr255	Lr256	Lr257	Lr258	Lr259
		$_{102}$No					No250	No251	No252	No253	No254	No255	No256	No257	No258
	$_{101}$Md		Md245	Md246	Md247	Md248	Md249	Md250	Md251	Md252	Md253	Md254	Md255	Md256	Md257
$_{100}$Fm	Fm242	Fm243	Fm244	Fm245	Fm246	Fm247	Fm248	Fm249	Fm250	Fm251	Fm252	Fm253	Fm254	Fm255	Fm256

			$_{93}$Np						Np224	Np225	Np226	Np226	Np227	Np228	Np229
		$_{92}$U	U217	U218	U219	U220	U221	U222	U223	U224	U225	U226	U227	U228	U229
	$_{91}$Pa	Pa215	Pa216	Pa217	Pa218	Pa219	Pa220	Pa221	Pa222	Pa223	Pa224	Pa225	Pa226	Pa227	Pa228
$_{90}$Th	Th213	Th214	Th215	Th216	Th217	Th218	Th219	Th220	Th221	Th222	Th223	Th224	Th225	Th226	Th227

Published results

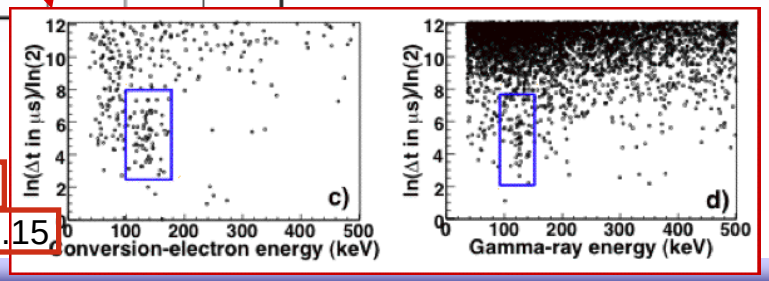
In progress

Future experiment

Failure from ^{210}Pb target

^{40}Ar + ^{182}W

^{40}Ar + ^{180}Hf



A. Lopez-Martens et al., EPJ A32 (2007) 245

A. Lopez-Martens et al., Nuclear Physics A.852 (2011) p.15

Summary of results and on-going analysis

Technique

K. Hauschild,et. al, "GABRIELA: A new detector array for γ-ray and conversion electron spectroscopy of transfermium elements." NIM A 560 (2006) 388

A. Yeremin, et. al., "Project of the experimental setup dedicated for gamma and electron spectroscopy of heavy nuclei at FLNR JINR.“ NIM B 266 (2008)4137

A. Isaev et. al., "Application of a Double Sided Stripped Si Detector in the Focal Plane of the VASSILISSA Separator.“ Instruments and Experimental Technique, v. 54 (2011) p. 37

Physics

^{249}Fm : A. Lopez-Martens et al., PRC 74 (2006) 044303
^{253}No : A. Lopez-Martens et al., EPJ A32 (2007) 245
^{255}Lr : K. Hauschild et al., PRC 78 (2008) 021302R
^{209}Ra : K. Hauschild et al., PRC 77 (2008) 047305
^{253}No : A. Lopez-Martens et al., Nuclear Physics A.852 (2011) p.15

More than 15 reports on International conferences

Analysis in progress

^{255}No $\rightarrow$ ^{251}Fm

^{217}Pa $\rightarrow$ ^{213}Ac

$^{213;214;217}$Th isomers

What can be (presently) achieved by decay studies ?

Advantages of Dubna => Acces to less neutron-deficient nuclei

$_{78}Pt, _{79}Au, _{80}Hg, _{81}Tl, _{82}Pb, _{83}Bi$ targets – « cold fusion »

$_{90}Th, _{92}U, _{94}Pu, _{95}Am, _{96}Cm$ targets – « hot fusion »

Present limits $\sigma \geq 3$ -5 nb for decay

$\sigma \geq 50$ - 100 nb for prompt

107			253 Bh	254 Bh	255 Bh	256 Bh	257 Bh	258 Bh	259 Bh	260 Bh	261 Bh	262 Bh	263 Bh	264 Bh	265 Bh	266 Bh	267 Bh	268 Bh
106			252 Sg	253 Sg	254 Sg	255 Sg	256 Sg	257 Sg	258 Sg	259 Sg	260 Sg	261 Sg	262 Sg	263 Sg	264 Sg	265 Sg	266 Sg	267 Sg
105			251 Db	252 Db	253 Db	254 Db	255 Db	256 Db	257 Db	258 Db	259 Db	260 Db	261 Db	262 Db	263 Db	264 Db	265 Db	266 Db
104			250 Rf	251 Rf	252 Rf	253 Rf	254 Rf	255 Rf	256 Rf	257 Rf	258 Rf	259 Rf	260 Rf	261 Rf	262 Rf	263 Rf	264 Rf	265 Rf
103			249 Lr	250 Lr	251 Lr	252 Lr	253 Lr	254 Lr	255 Lr	256 Lr	257 Lr	258 Lr	259 Lr	260 Lr	261 Lr	262 Lr	263 Lr	264 Lr
102			248 No	249 No	250 No	251 No	252 No	253 No	254 No	255 No	256 No	257 No	258 No	259 No	260 No	261 No	262 No	263 No
101	244 Md	245 Md	246 Md	247 Md	248 Md	249 Md	250 Md	251 Md	252 Md	253 Md	254 Md	255 Md	256 Md	257 Md	258 Md	259 Md	260 Md	261 Md
100	243 Fm	244 Fm	245 Fm	246 Fm	247 Fm	248 Fm	249 Fm	250 Fm	251 Fm	252 Fm	253 Fm	254 Fm	255 Fm	256 Fm	257 Fm	258 Fm	259 Fm	260 Fm
			146		148		150		152		154		156		158		160	

What can be (presently) achieved by decay studies ?

Production rates:

- $^{207}Pb(^{48}Ca,2n)^{253}No$, $\sigma \approx 1300$ nb, $I(^{48}Ca) \approx 0.5$ pμA N alpha's ~ 30 000 / day
- $^{208}Pb(^{48}Ca,2n)^{254}No$, $\sigma \approx 2000$ nb, $I(^{48}Ca) \approx 0.5$ pμA N alpha's ~ 40 000 / day
- $^{209}Bi(^{48}Ca,2n)^{255}Lr$, $\sigma \approx 300$ nb, $I(^{48}Ca) \approx 0.5$ pμA N alpha's ~ 6 000 / day
- $^{207}Pb(^{50}Ti,2n)^{255}Rf$: $\sigma \approx 10$ nb (50% sf), $I(^{50}Ti) \approx 0.4$pμA N alpha's ≈ 120 / day
- $^{209}Bi(^{40}Ar,2n)^{247}Md$: $\sigma \approx 2.5$ nb, $I(^{40}Ar) \approx 1$pμA N alpha's ≈ 120 / day

→ Collection of several (ten) thousands of decays within several days
→ Fine structure measurements possible, sufficient for detailed level schemes
→ Establishing global trends in nuclear structure (for some Nilsson levels)

→ Future possibilities: radioactive targets, light beams. Neutron rich isotopes of transfermium elements

→ $^{242}Pu(^{22}Ne,5n)^{259}Rf$: $\sigma \approx 3$ nb, $I(^{22}Ne) \approx 1.5$ pμA N alpha's ≈ 25 / day
If transmission is about 1.5 % (for VASSILISSA)

We need to increase transmission for slow ERs

Way to the asymmetric combinations

- Achievement: neutron rich isotopes, that could not be reached in more symmetric combinations.
- Disadvantage: very broad energy and angular distributions of recoils => low transmission of kinematic separators

Possible solutions

- Modernization of the kinematic separator, design for asymmetric combinations
- Increase of beam intensity (I_{Ne} ~ 2.5 pmA)

Improvements to experimental set up :

Improvement of slow ERs transmission

1) New ion optical scheme => 2 x efficiency
2) ToF : thinner windows => less straggling

Improvement of detector array

1) New Si detectors : larger + more strips => 2 x ERs detection efficiency, higher CE detection efficiency

2) Modified Ge detector => higher gamma detection efficiency

$T_x * \varepsilon_D \sim 3x$ ↑

Experimental tests :

1) VASSILISSAToF : 2 thin foils (20 μg each)

$^{22}Ne + ^{197}Au \longrightarrow ^{214}Ac + 5n$ ε = 2 %

2) VASSILISSA ToF : 1 thin foils

$^{22}Ne + ^{197}Au \longrightarrow ^{214}Ac + 5n$ ε = 5 %

1) VASSILISSA ToF : 1 thin foil

$^{22}Ne + ^{238}U \longrightarrow ^{255}No + 5n$ ε = 1.5 %

2) VASSILISSA ToF : without foils

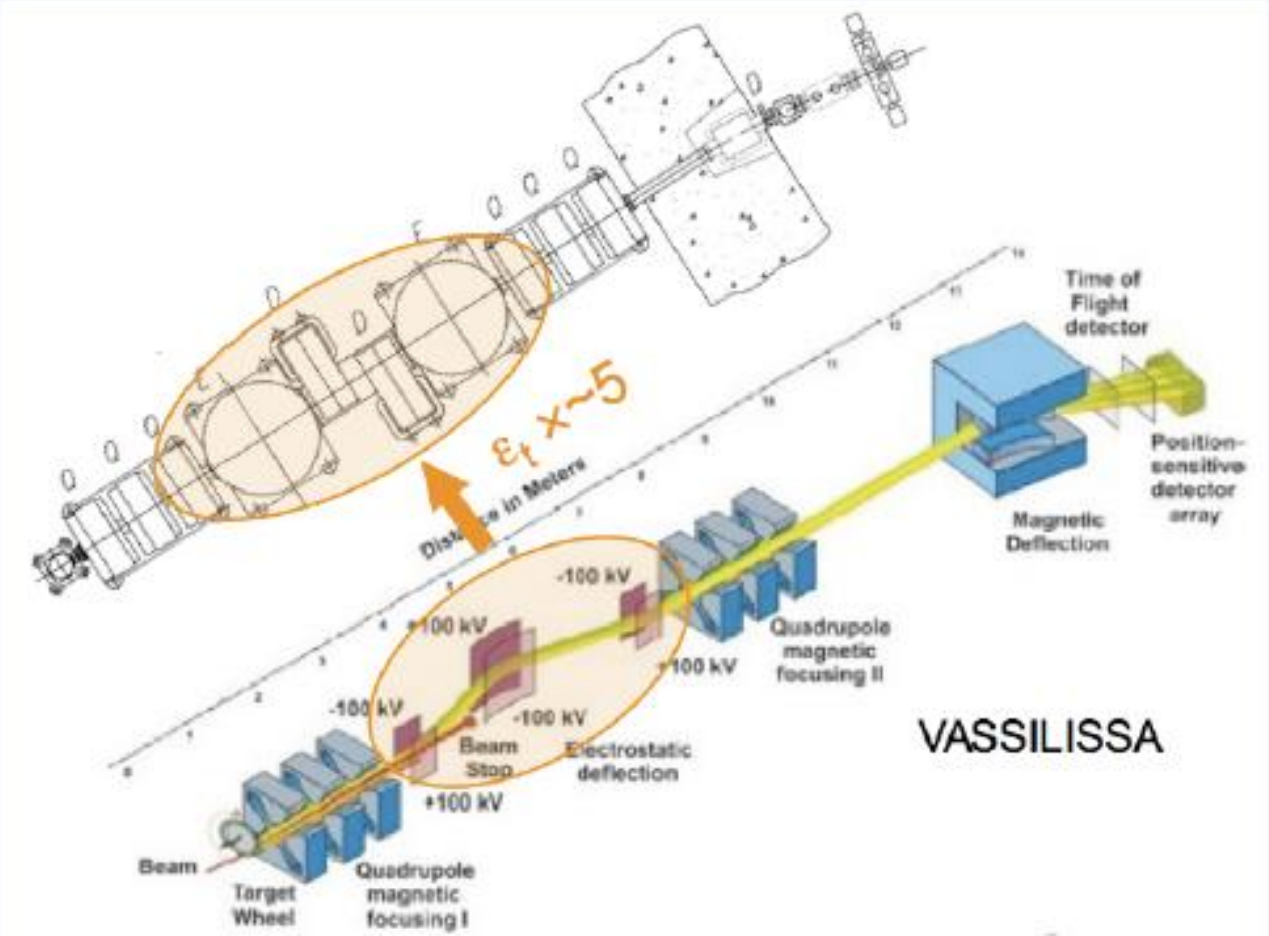
$^{22}Ne + ^{238}U \longrightarrow ^{255}No + 5n$ ε = 2 %

Using of metallic targets helps to improve transmission

1) SHIP: ToF : without foils

$^{22}Ne + ^{238}U \longrightarrow ^{255}No + 5n$ ε = 3 ± 1 %

- MOU between the IN2P3-JINR signed 2008
- Upgrade and modernisation of VASSILISSA
- French funding for large equipment via the ANR (National Research Agency)
- Funding also available from the FLNR/JINR



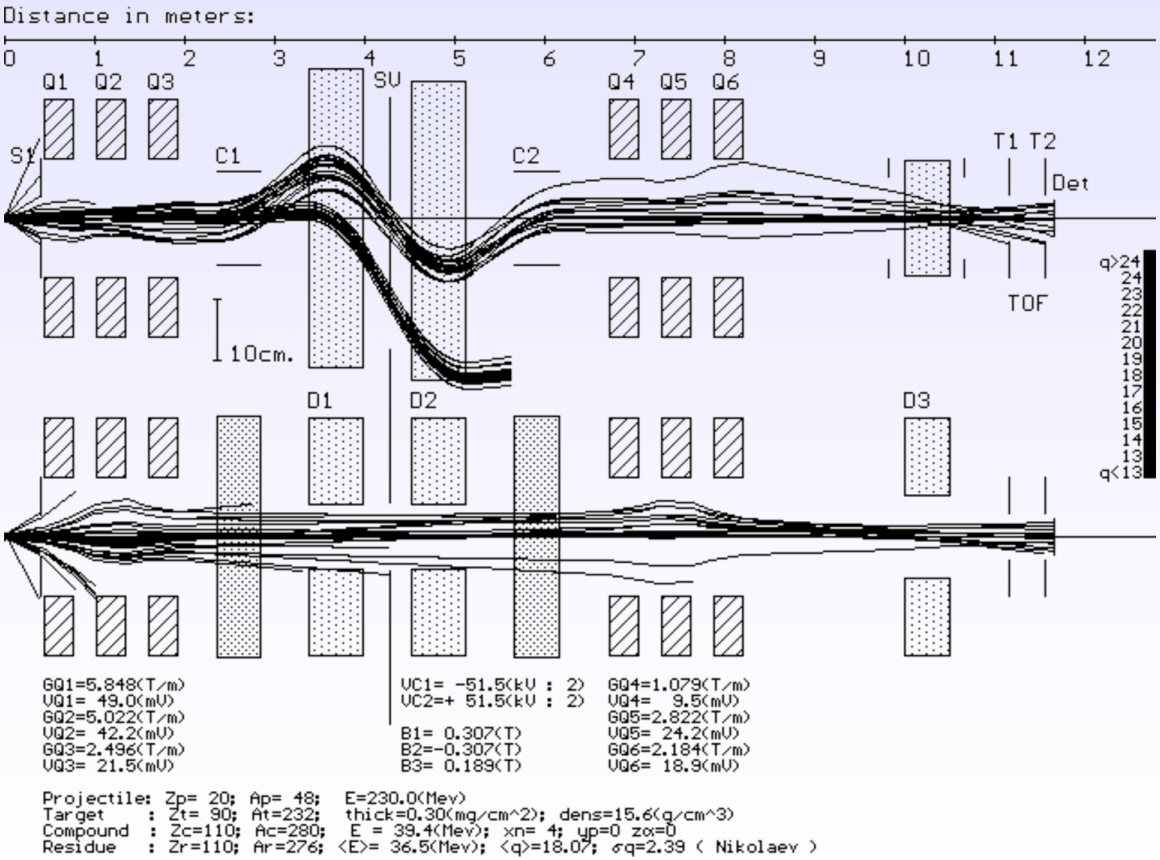
$^{22}Ne + ^{238}U \longrightarrow ^{260}No^*$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{22}Ne	112.4	0.76	0.76	0.76	3.14	11.7
^{260}No	9.5	0.74	1.82	2.45	**0.26**	**0.99**
^{238}U	34.8	0.72	1.89	2.01	0.53	1.93
^{4}He	58.5		1.1		5.3	
$^{1}H_2$	18.7			0.62	6.0	

$^{48}Ca + ^{244}Pu \longrightarrow ^{292}114^*$ (limit for VASSILISSA)

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{48}Ca	236	0.88	0.94	0.94	3.1	13.0
$^{292}114$	38.8	0.79	2.0	2.18	**0.51**	**2.0**
^{244}Pu	129.7	0.83	1.65	1.49	1.0	4.2
^{4}He	67		1.2		5.7	
$^{1}H_2$	18.8			0.62	6.02	

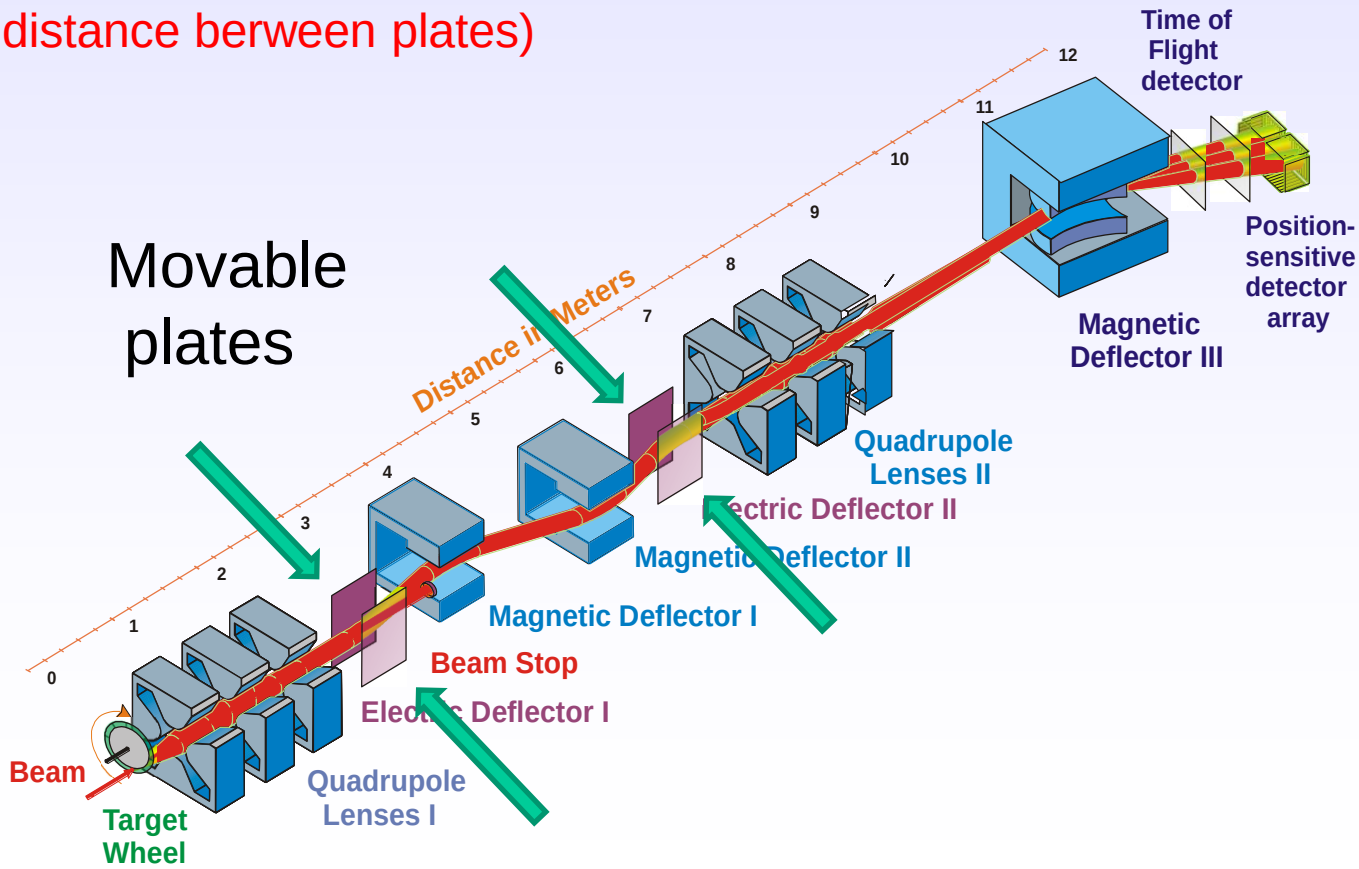
Simulation of ion trajectories



Velocity filter for asymmetric combinations (modernization of VASSILISSA)

High transmission for asymmetric combinations (beams of ^{12}C, $^{14,15}N$, $^{16,18}O$, $^{20,22}Ne$)
➔movable plates of electrostatic deflectors

Also availability for symmetric combinations ($^{136}Xe + ^{136}Xe \rightarrow ^{272}Hs^*$)
➔50 cm long plates, high electrostatic field strength
(decrease of the distance berween plates)



Calculated transmission efficiency for modernized separator.

Reaction	$E_{p1/2}$ MeV	Target thickness mg/cm^2	Transmission
$^{22}Ne(^{238}U,5n)^{255}No$	115	U_3O_8 – 0.2	0.09 (now – 2%)
$^{22}Ne(^{238}U,5n)^{255}No$	115	Met – 0.2	0.12
$^{22}Ne(^{197}Au,5n)^{214}Ac$	110	Met – 0.2	0.14
$^{40}Ar(^{181}Ta,4n)^{217}Pa$	182	Met – 0.3	0.28
$^{40}Ar(^{162}Dy,7n)^{195}Po$	198	DyO_2 – 0.3	0.28
$^{242}Pu(^{22}Ne,5n)^{259}Rf$	120	PuO_2 – 0.2	0.07
$^{48}Ca(^{208}Pb,2n)^{254}No$	216	Met – 0.4	0.42

Estimated counting rates

Reaction	Cross section	Transmission %	ERs counting rate per day
$^{242}Pu(^{22}Ne,5n)^{259}Rf$	3.0 nb	7	115
$^{244}Pu(^{22}Ne,5n)^{261}Rf$	5.0 nb	7	190
$^{248}Cm(^{18}O,5n)^{261}Rf$	13 nb	4	270
$^{243}Am(^{22}Ne,5n)^{260}Db$	2.0 nb	7	70
$^{243}Am(^{22}Ne,4n)^{261}Db$	1.5 nb	7	55
$^{248}Cm(^{22}Ne,5n)^{265}Sg$	0.3 nb	6	10
$^{208}Pb(^{54}Cr,1n)^{261}Sg$	0.5 nb	50	90

Planned set up parameters

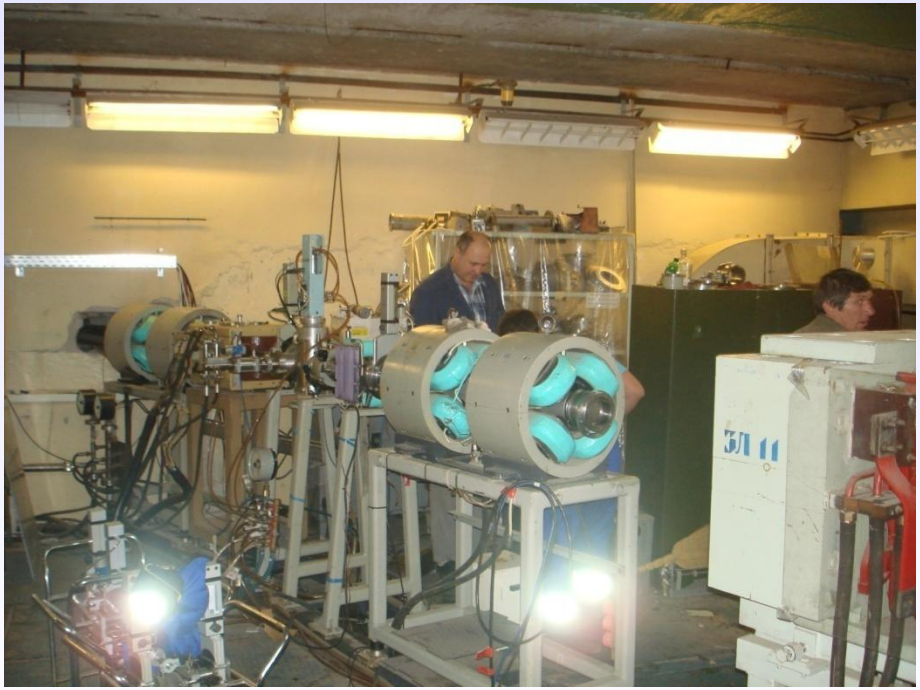
Maximum beam current on the target	10^{13} part/sec.
Target size	10 mm
Target thickness	100-500 μg/cm^2
Angular acceptance	± 4.0^o
Energy transmission range	±15%
Charge transmission range	±15%
Transmission efficiency for ER's	5 - 50%
Suppression factors for scattered beam	10^{10} – 10^{12}
Suppression factor for transfer products	10^3 - 10^4

Quadrupole lens	
Effective length of quadrupole lenses	37 cm
Quadrupole lens aperture	20 cm
Maximum field gradient in quadrupole lens	10 T/m

Electrostatic deflectors	
Effective length of electrostatic dipole (condenser)	65 cm
Distance between electrostatic plates	10 – 20 cm (variable)
Maximum electric rigidity	40 kV/cm
Deflection angle	8°

Dipole magnets	
Effective length of dipole magnet	68 cm
Dipole magnet aperture	15 cm
Maximum field of dipole magnet	1.4 T
Deflection angle	16°

Present status: Dismounting of VASSILISSA



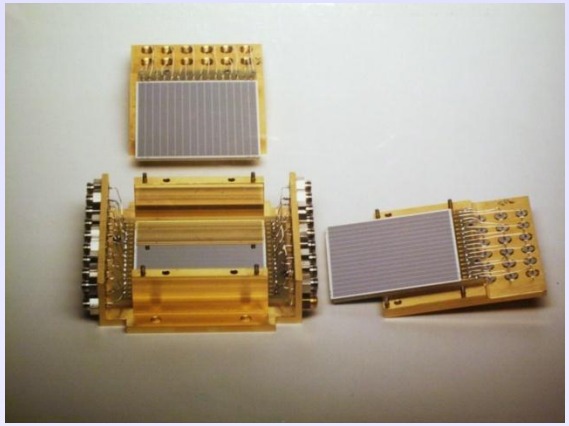
Present status: Dismounting of VASSILISSA

New power supplies for quadrupole lenses and dipole magnets.

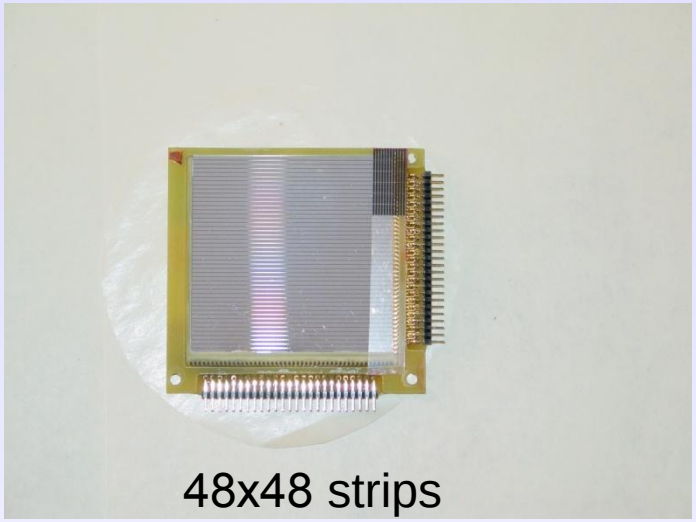
New high voltage power supplies for electrostatic deflectrors

New dipole magnets and HV vacuum tanks from St. Petersburg.

For asymmetric combinations – increase of the focal plane detector size



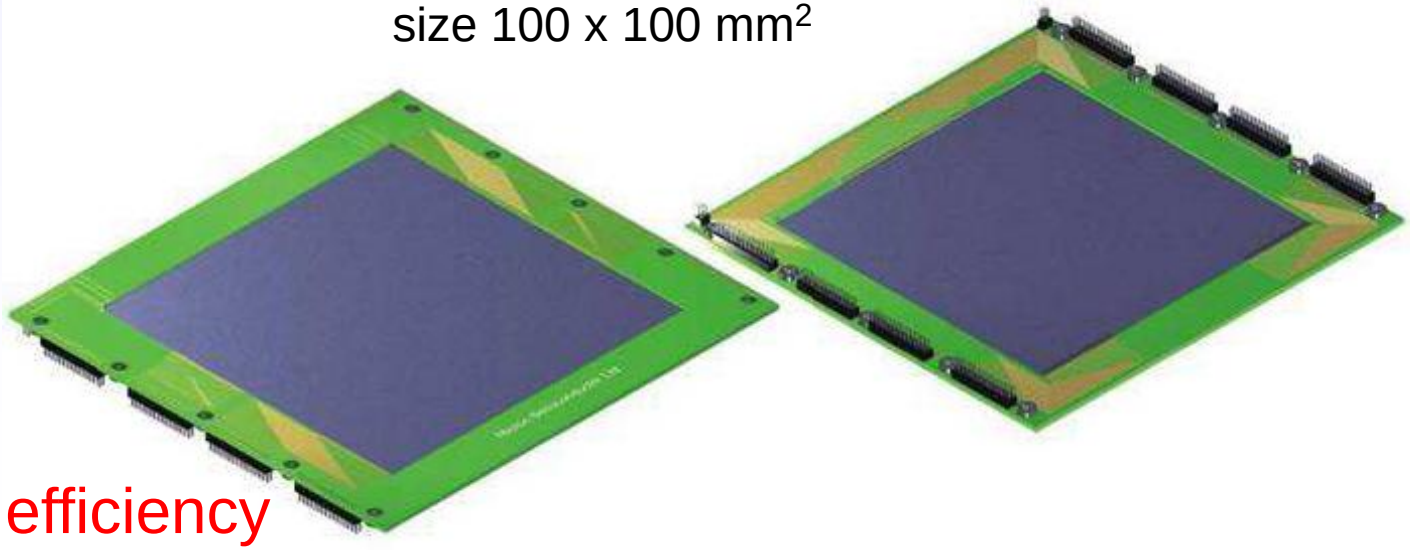
16 resistive strips
size 60 x 60 mm^2



48x48 strips

size 60 x 60 mm^2

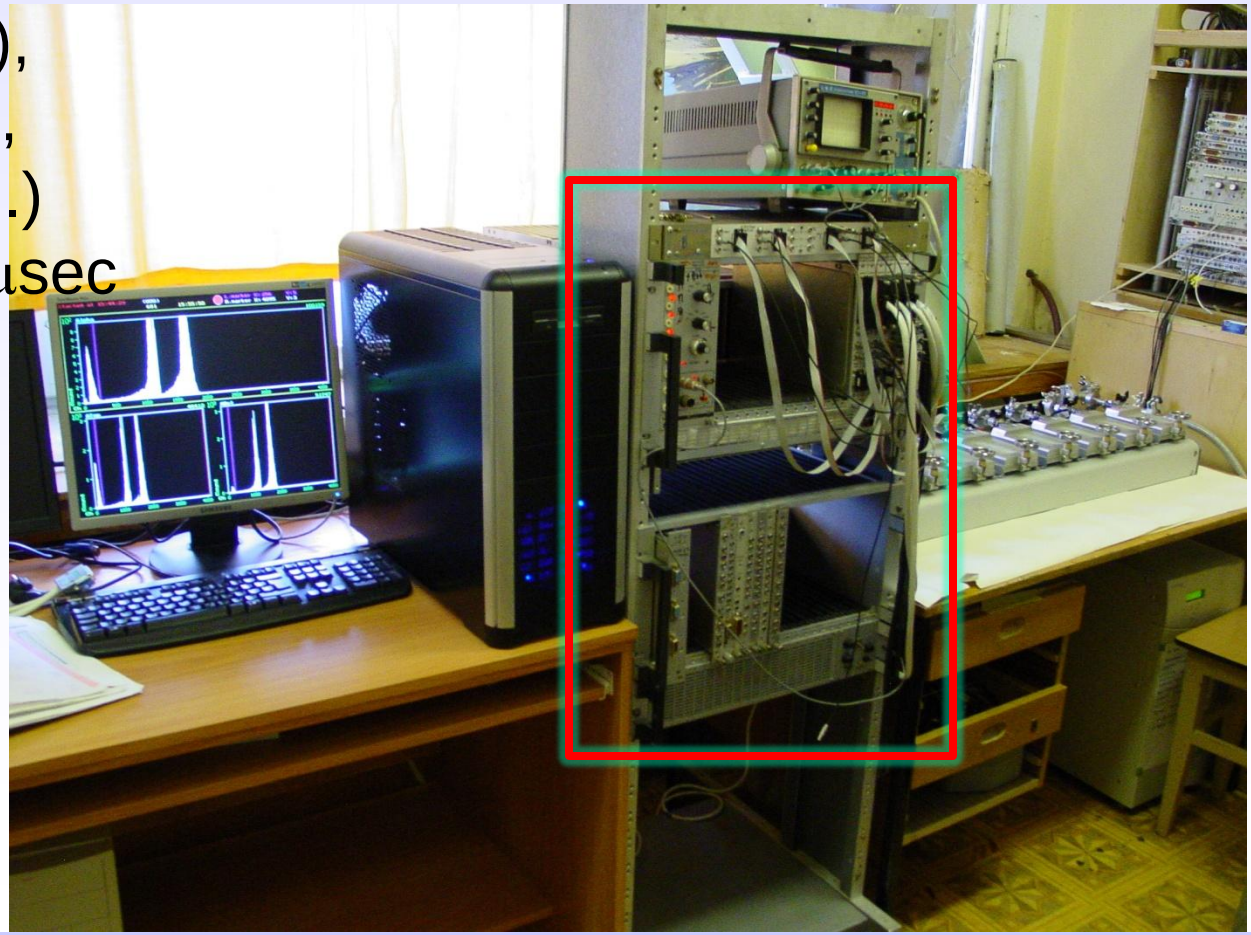
128x128 strips
size 100 x 100 mm^2



Factor of 2
in transmission efficiency

Development of the electronics

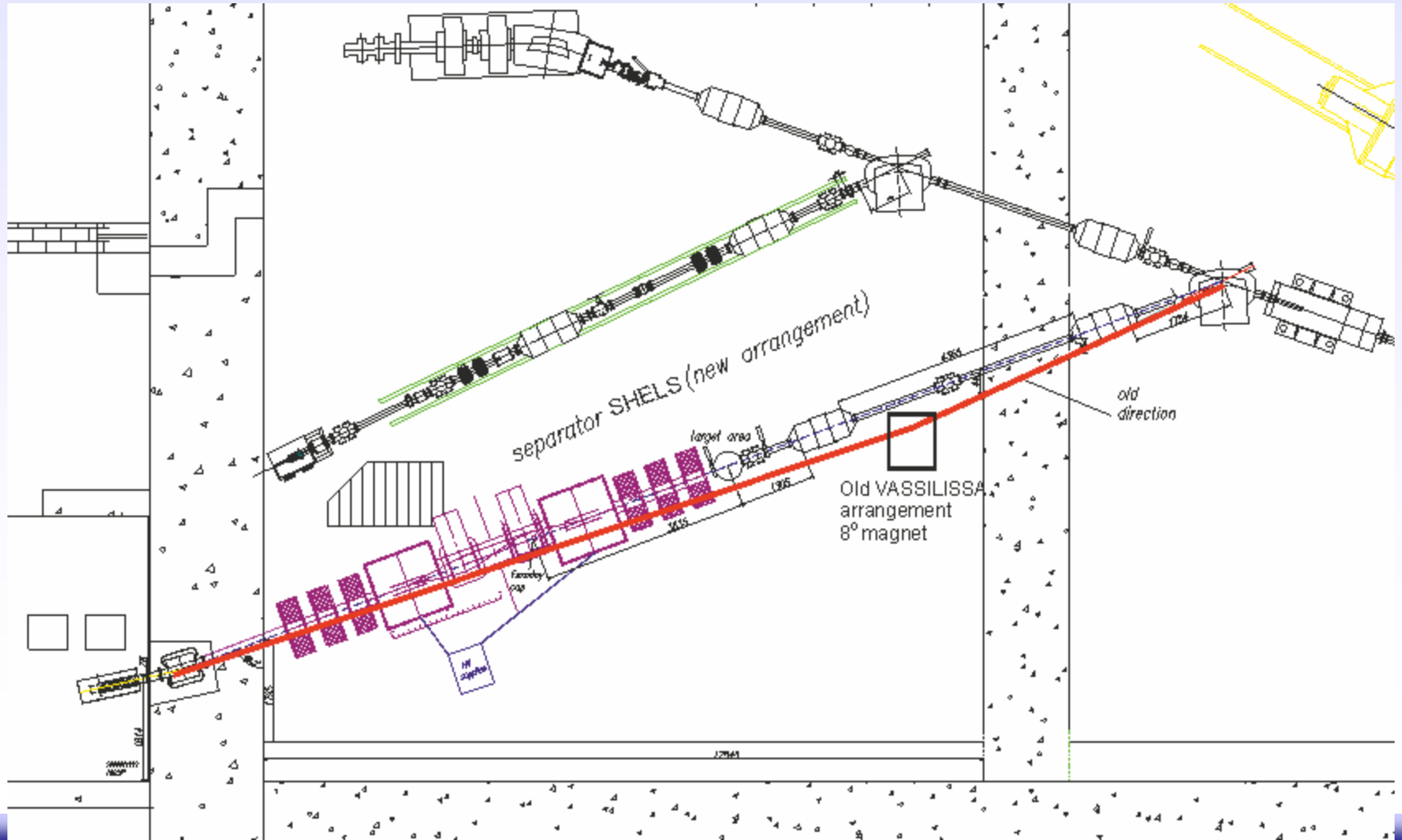
1 unit - 64 spectrometry channel system. 3 amplification chains
For **b** (energy range 0 – 2 MeV), α (energy range 0 – 20 MeV) and SF (energy range 0 – 200 MeV),
4 amplifiers with 16 channel built-in multiplexers
4 ADC β (8192 ch.),
4 ADC α (8192 ch.),
4 ADC SF (4096 ch.)
Conversion time 2 μsec



Realization period (execution plan)

- **1. Stage 1**: Month 1 – 3. Detailed ion optical calculations of the separator itself. Design of dipole magnets and vacuum tanks for electrostatic deflectors.
- **2. Stage 2:** Month 4 – 12. Manufacturing of the 2 dipole magnets, vacuum system of the separator, purchase of 3 turbo pumps, 1 fore pump and accessories, power supplies for dipole magnets.
  Required stage costs : 325 kEuros
- **3. Stage 3**: Month 7 – 18; Manufacturing of the 2 high voltage vacuum chambers, the electrostatic plates and the insulators, purchase of 2 high voltage power supplies.
  Required stage costs : 260 kEuros
- **4. Stage 4**; Month 10 – 21; purchase of the focal plane Silicon detectors (Canberra, Micron), the control system, spectroscopic electronics. Assembling, tests, mounting of the equipment.
  Required stage costs : 240 kEuros
- **5. Stage 5**; Month 19 - 24; Assembling of the separator, beam line and the beam diagnostics at the experimental hall of U400 cyclotron, tuning of the experimental set up, tets experiments.
  Required stage costs : 20 kEuros

Modernization of beam line



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$^{22}Ne + ^{238}U \longrightarrow ^{260}No^*$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{22}Ne	112.4	0.76	0.76	0.76	3.14	11.7
^{260}No	9.5	0.74	1.82	2.45	**0.26**	**0.99**
^{238}U	34.8	0.72	1.89	2.01	0.53	1.93
^{4}He	58.5		1.1		5.3	
$^{1}H_2$	18.7			0.62	6.0	

$^{48}Ca + ^{244}Pu \longrightarrow ^{292}114^*$ (limit for VASSILISSA)

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{48}Ca	236	0.88	0.94	0.94	3.1	13.0
$^{292}114$	38.8	0.79	2.0	2.18	**0.51**	**2.0**
^{244}Pu	129.7	0.83	1.65	1.49	1.0	4.2
^{4}He	67		1.2		5.7	
$^{1}H_2$	18.8			0.62	6.02	

Not available now without ER energy degrading

$^{86}Kr + ^{180}Hf \longrightarrow ^{266}Hs^*$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{86}Kr	400	0.96	1.12	1.12	3.0	14.3
^{266}Hs	130	0.82	1.60	1.50	**0.97**	**3.95**
^{180}Hf	350	0.92	1.23	0.92	1.94	8.96
^{4}He	68.0		1.2		5.7	
$^{1}H_2$	18.2			0.6	5.9	

$^{136}Xe + ^{136}Xe \longrightarrow ^{272}Hs^*$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{136}Xe	600	1.1	1.38	1.38	3.0	15.7
^{272}Hs	300	0.95	1.39	1.21	**1.46**	**6.85**
^{136}Xe	600	1.1	1.38	1.38	3.0	15.7
^{4}He	66.6		1.2		5.7	
$^{1}H_2$	17.4			0.6	6.0	