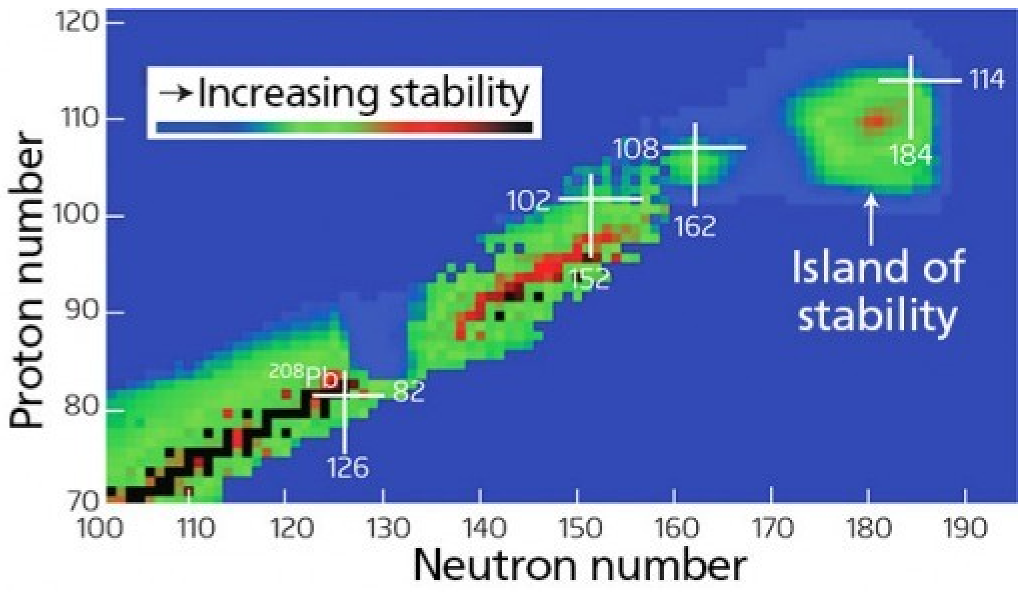
Test experiments at MASHA facility using reactions leading to Hg and Rn. The difference between the detectors. Advantages of using cryogenic gas stopping cell.

Forejtnik Jan   Minzina Luca-Ioan   Clisu Cristina
Skvara Jan   Ciobanu Andreea   Chiriacescu Lucia
L. Krupa   V. Vedeneev

Contents

Introduction

- **Nuclear stability** is a concept that helps to identify the stability of an isotope.
- The experiments were performed at the Flerov Laboratory of Nuclear Reactions, JINR where ions resulting from accelerated **Ca** ions bombarding targets of ^{238}**U,** ^{242,244}**Pu,** ^{242}**Am,** ^{245,248}**Cm** and ^{249}**Cf** were used for producion of the superheavy elements **(SHE)**.
- **MASHA** is the mass-spectrometer which can measure masses of the syntesized isotopes simultanousely with registration of their alpha-decay or spontaneous fission.



Motivation

- The fusion of new nuclides stimulated interest in finding methods of identifying super heavy elements
- To test the production methods of SHE, lighter elements with simillar chemical properties are used.
- Mercury is comparable with element 112-Copernicium and Radon is a radioactive noble gas.
- Hg and Rn isotopes were obtained in fusion-evaporation or multinucleon transfer reactions

$^{40}Ar + ^{148}Sm \rightarrow ^{188-x}Hg + xn$

$^{40}Ar + ^{166}Er \rightarrow ^{206-x}Rn + xn$

$^{48}Ca + ^{242}Pu \rightarrow ^{212,218,219}Rn$

Cyclotron

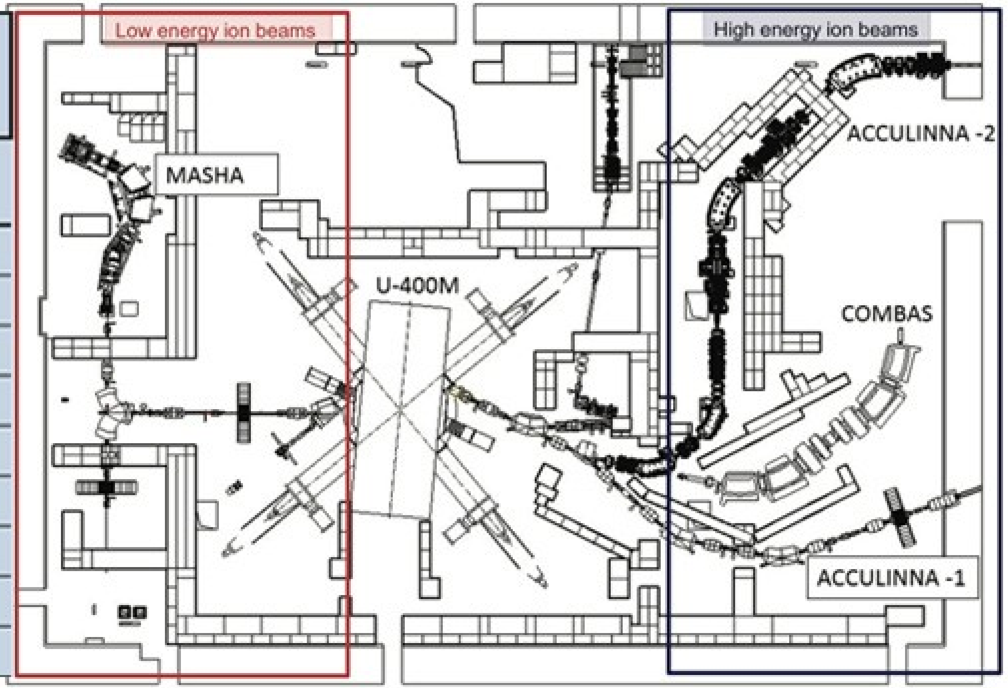
Characteristics:

-Pole diameter 4000 mm
-Finite radius of acceleration 175 mm
-Maximal avagare magnetic field in the center 19,5kGs

Main tasks:

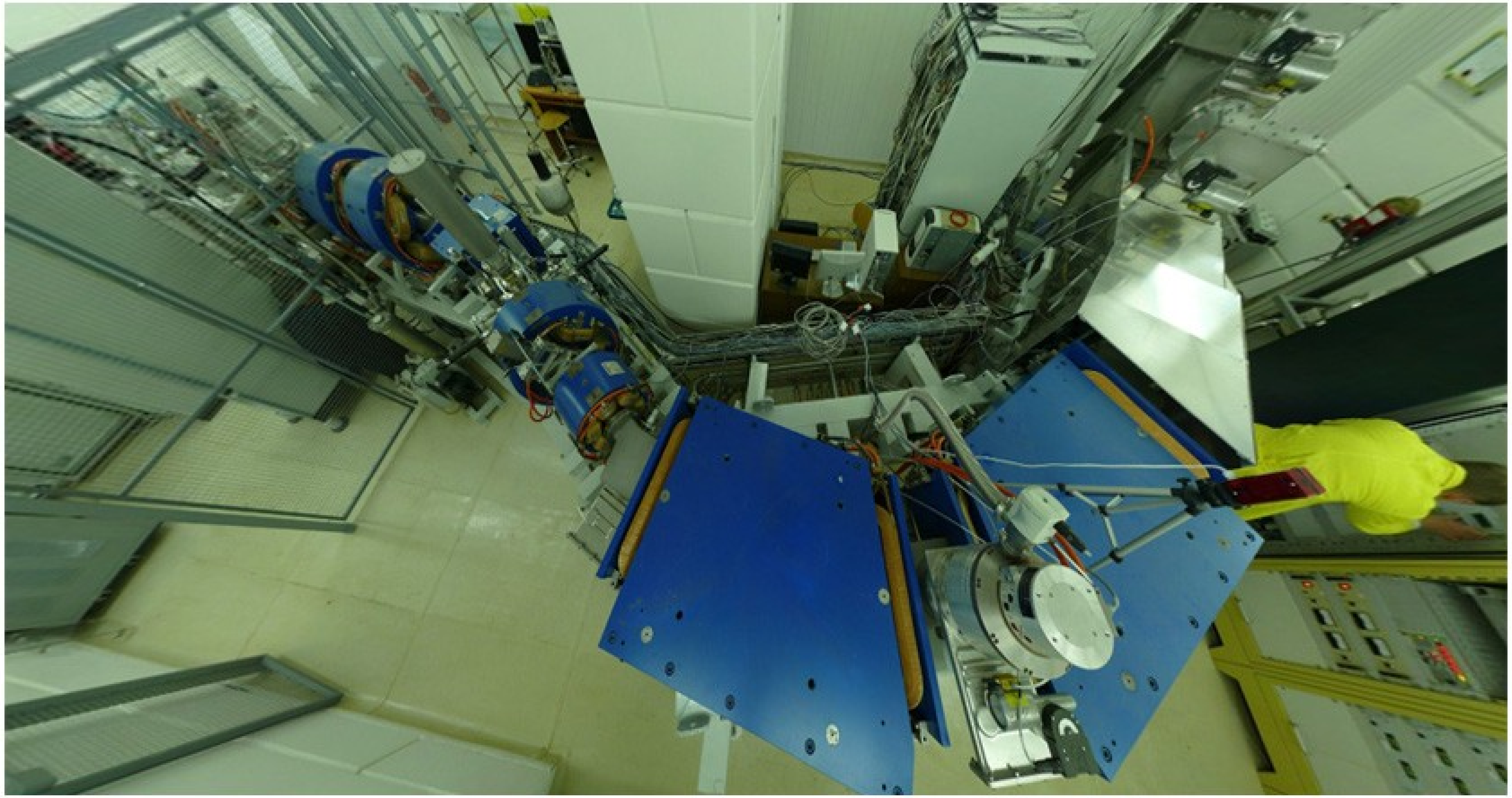
-Producing of RIBs.
-Reactions with exotic nuclei;
-Properties and structure of light exotic nuclei;

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}

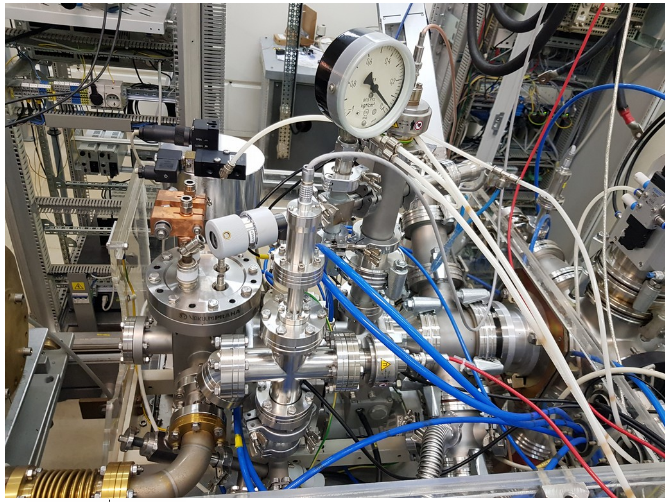


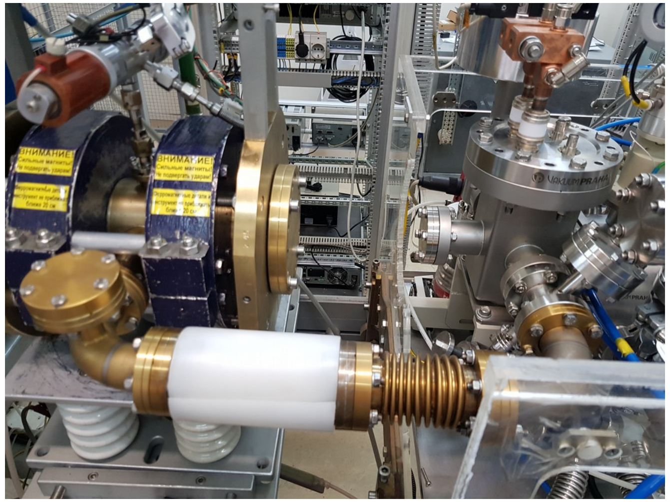
MASHA (Mass Analyzer of Super Heavy Atoms)

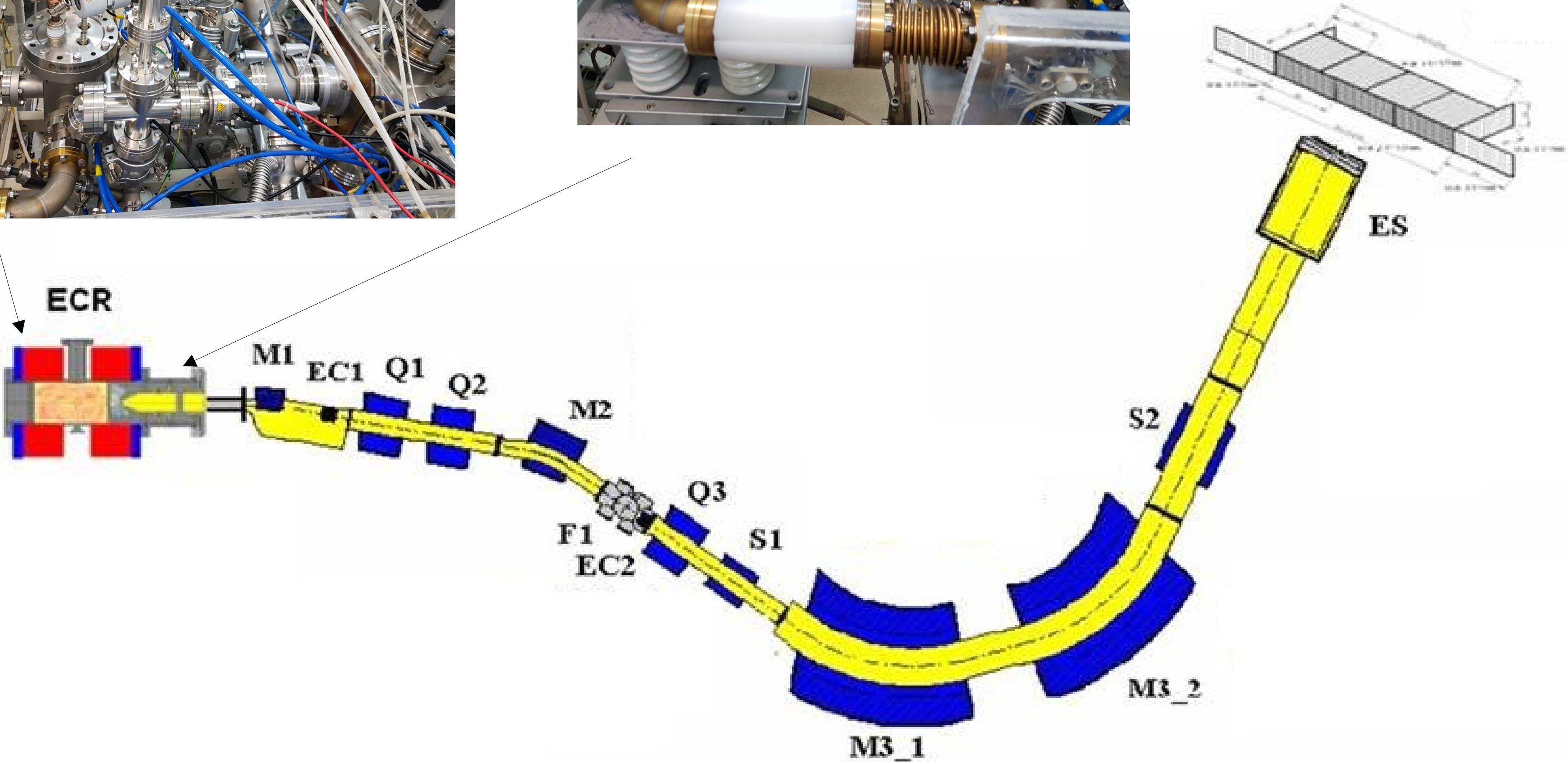
MASHA separator and analyzer is destined for separation and mass analysis of superheavy element ions with masses A=1-450, energy E=40 keV and charge state Q=+1. Separator mass resolution exceeds 1500. It's very important for superheavy elements separation and α-decay chain identification.



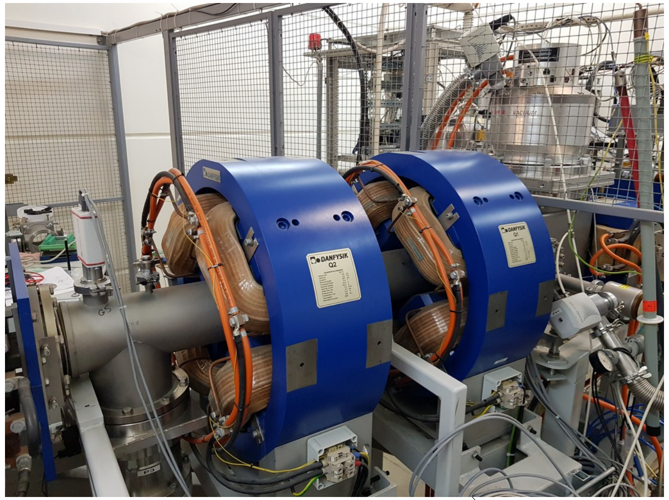
MASHA

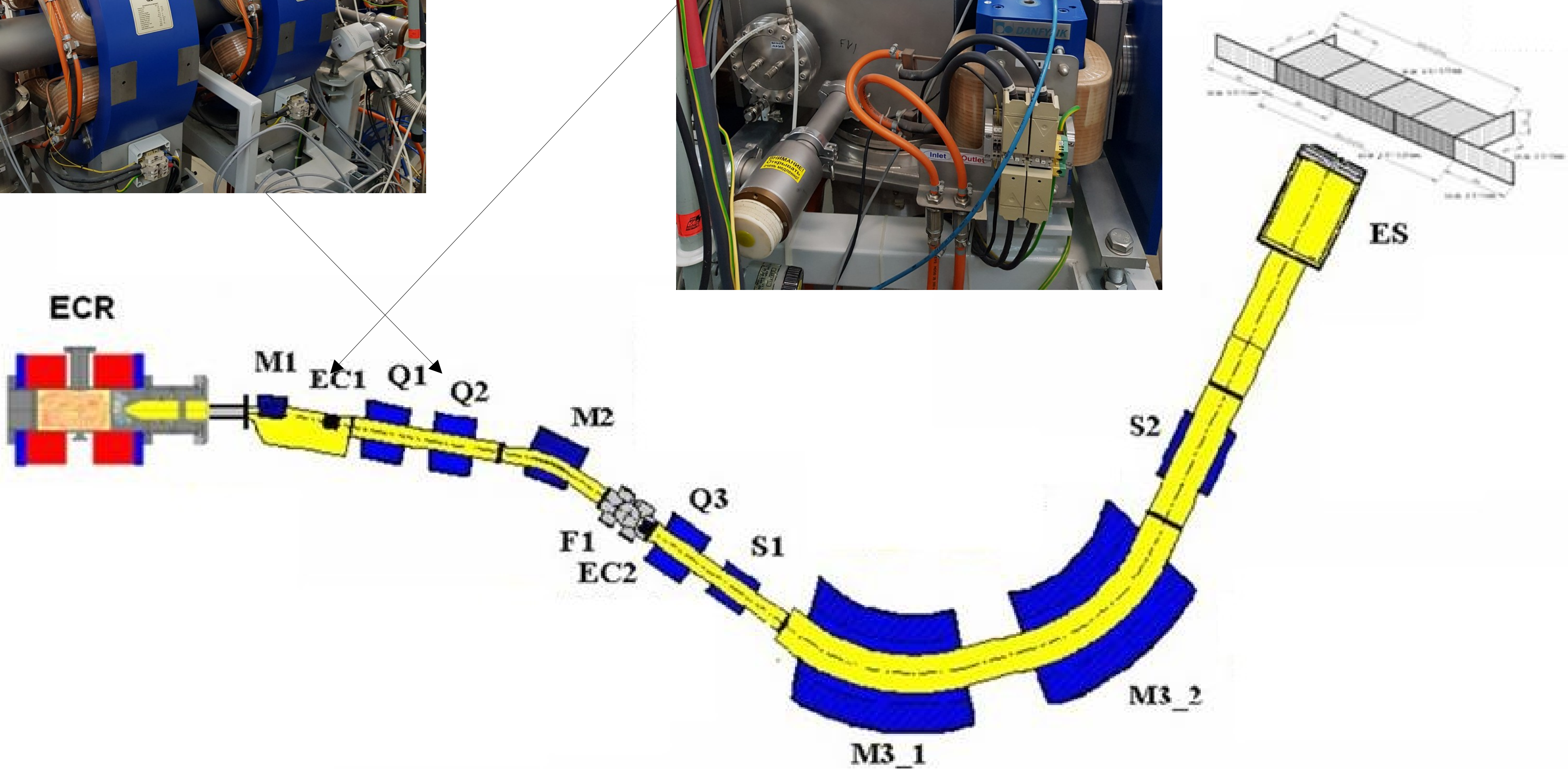




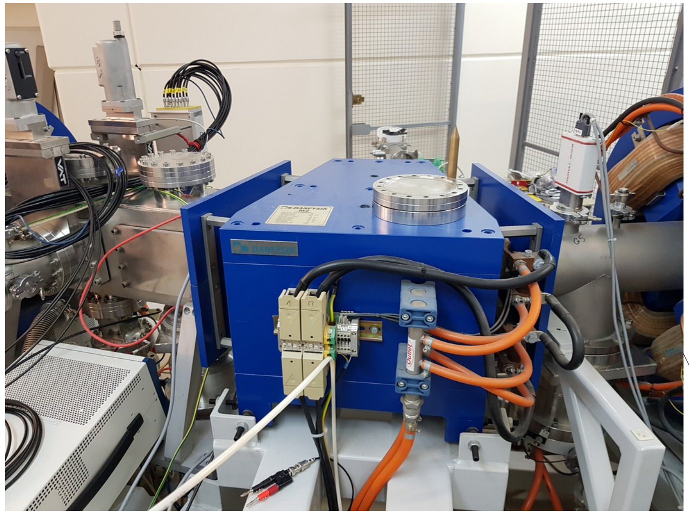


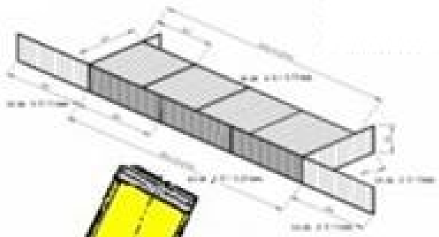
MASHA

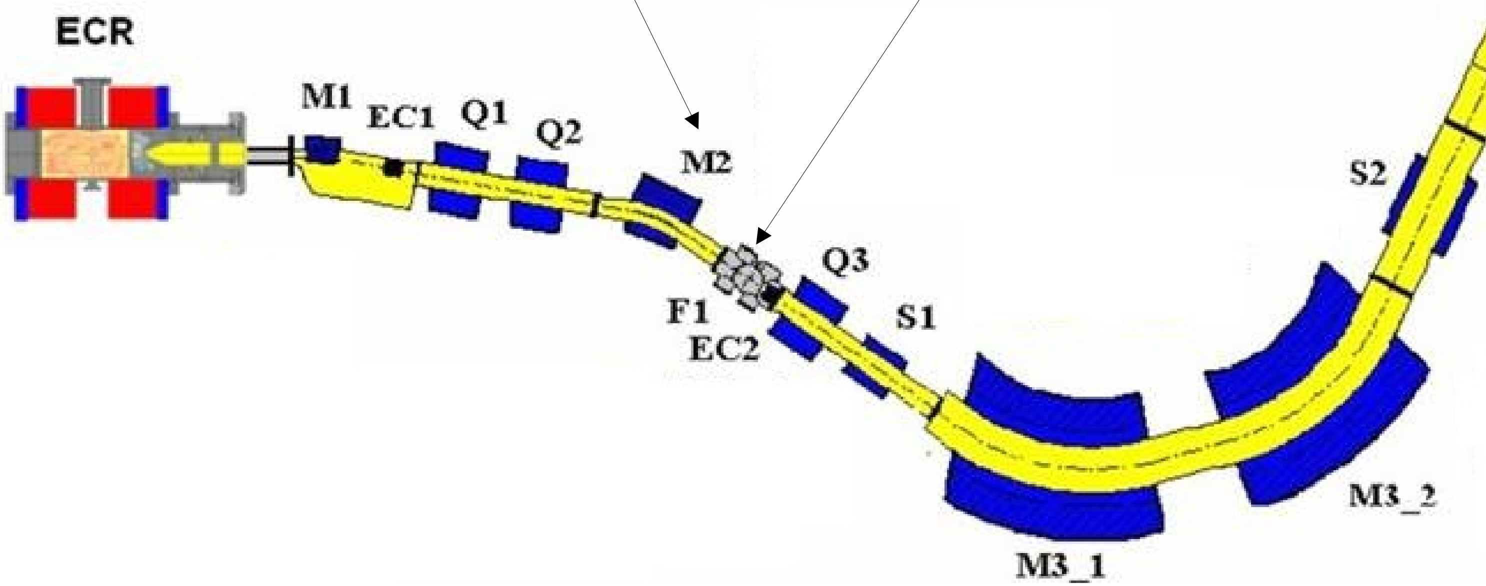




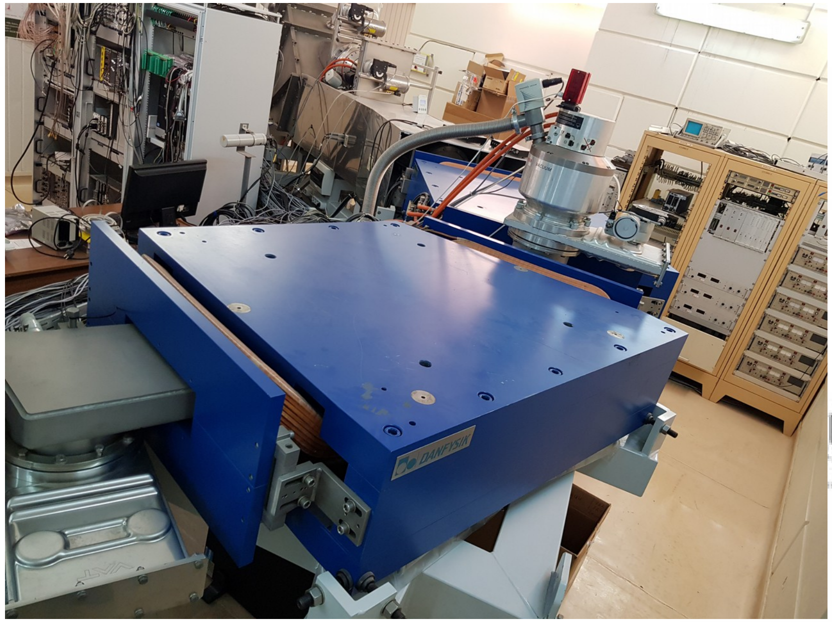
MASHA

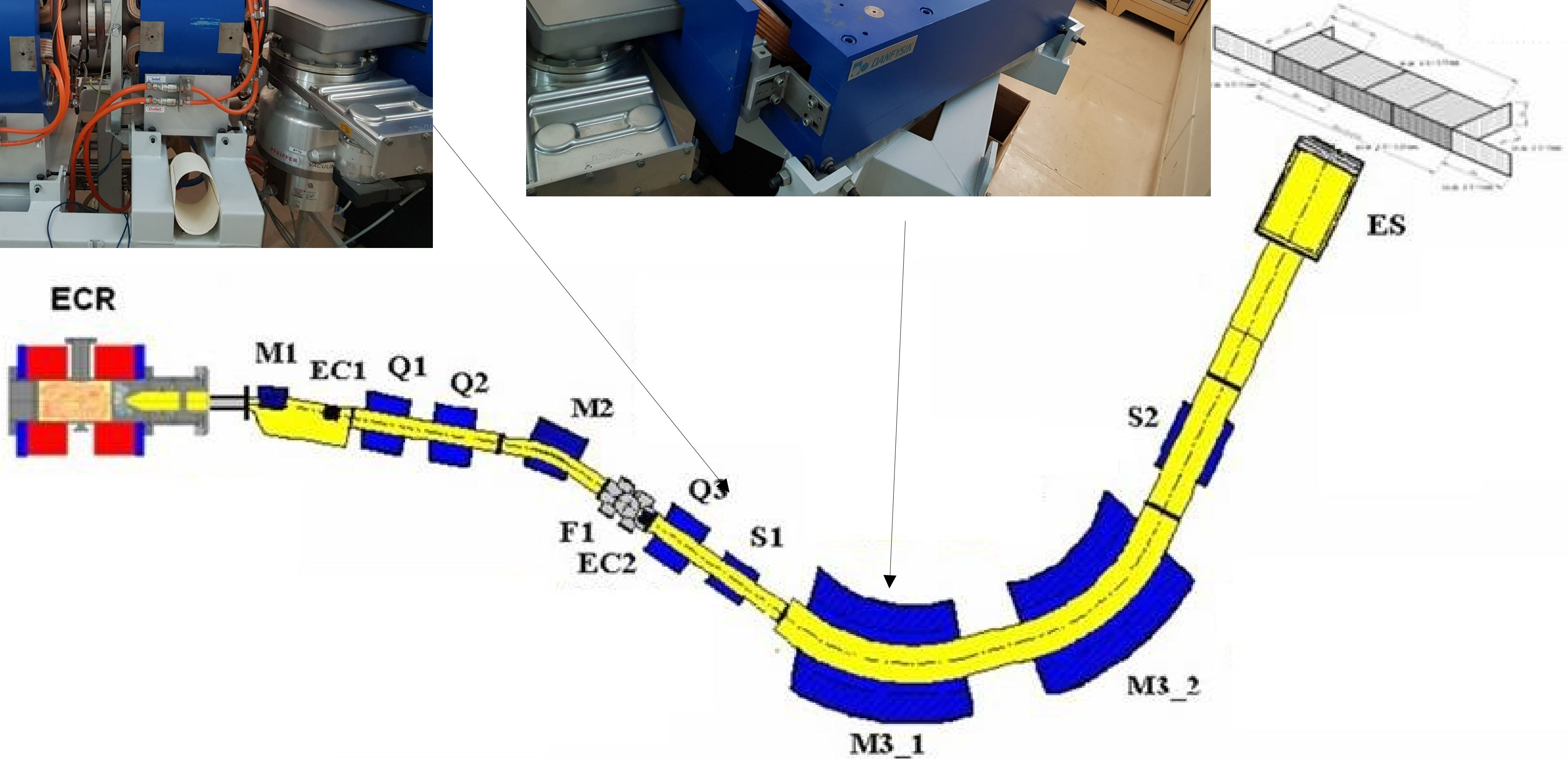




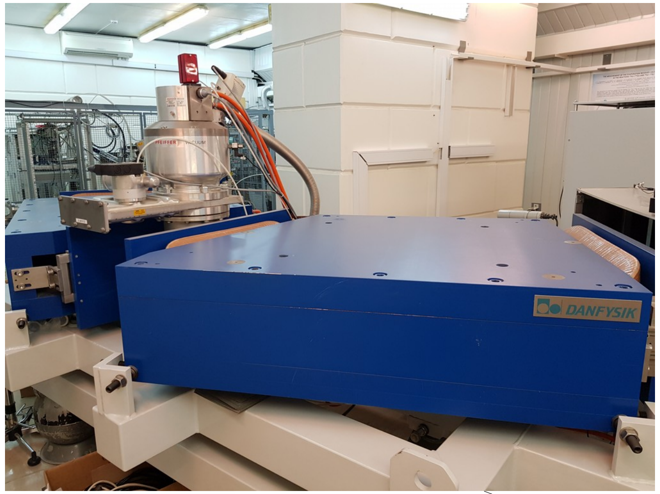


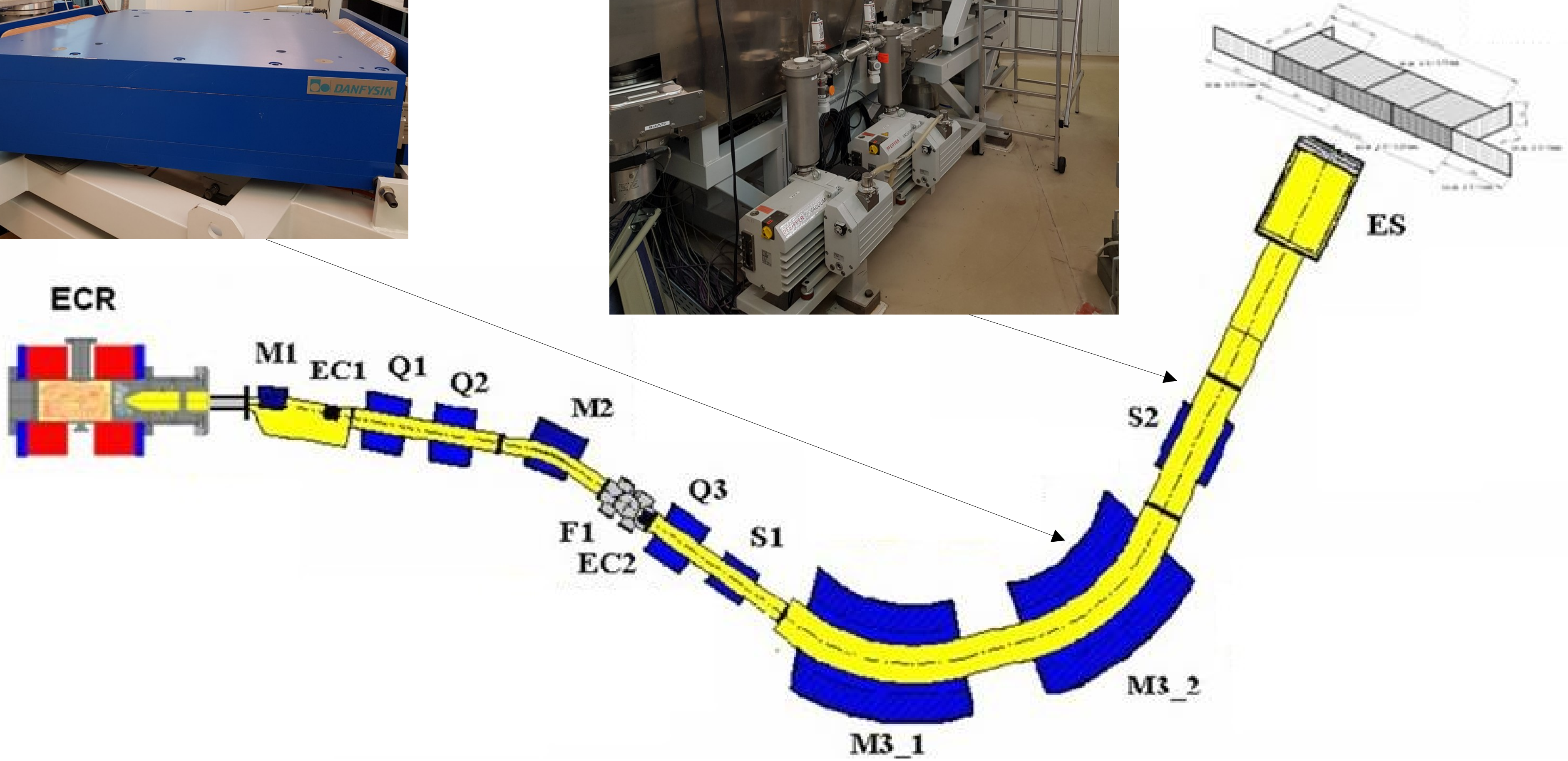
MASHA



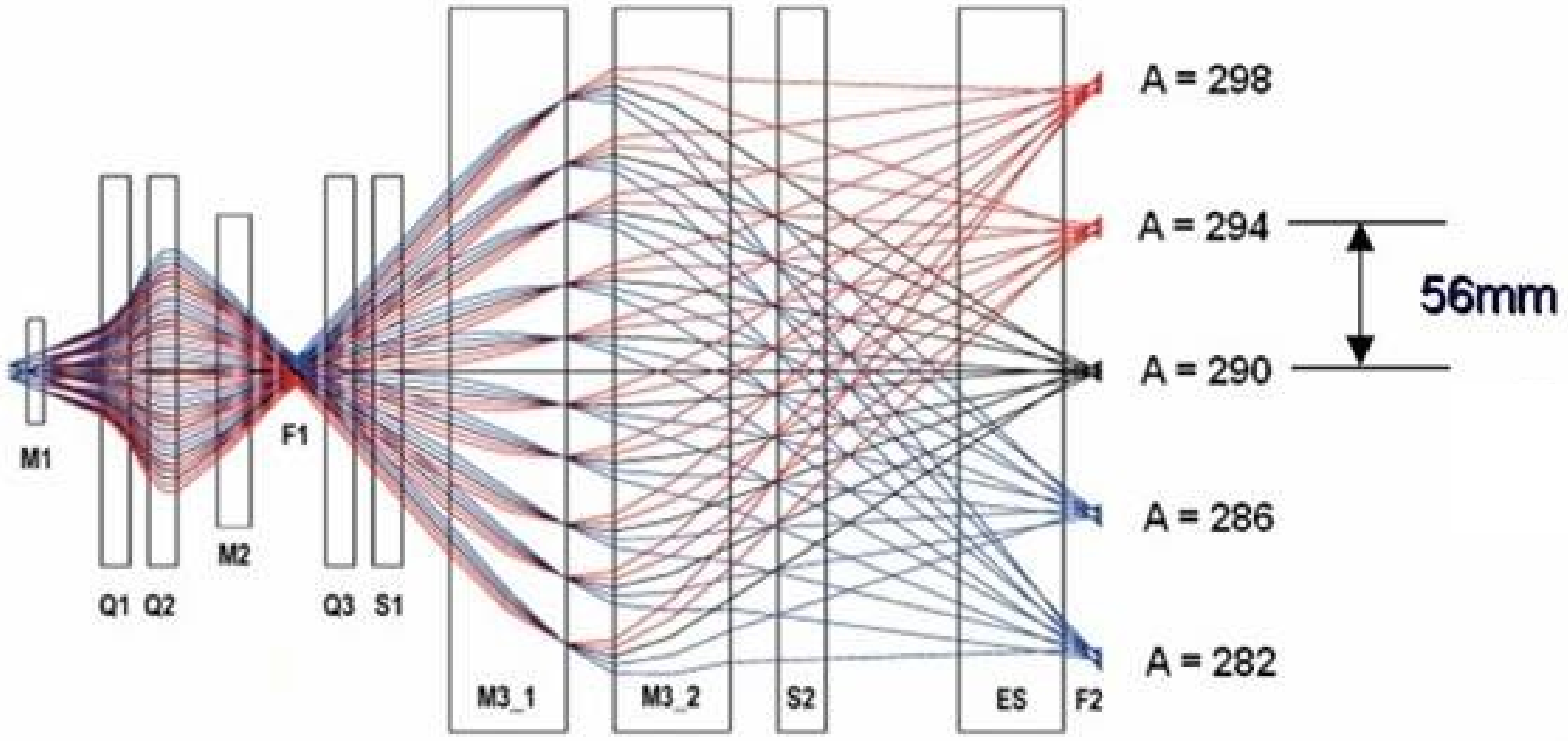


MASHA





MASHA



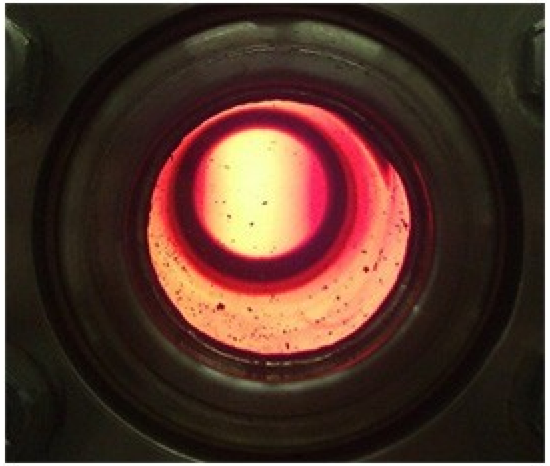
M1
Q1 Q2
M2
F1
Q3 S1
M3_1
M3_2
S2
ES
F2
A = 298
A = 294
A = 290
A = 286
A = 282
56mm

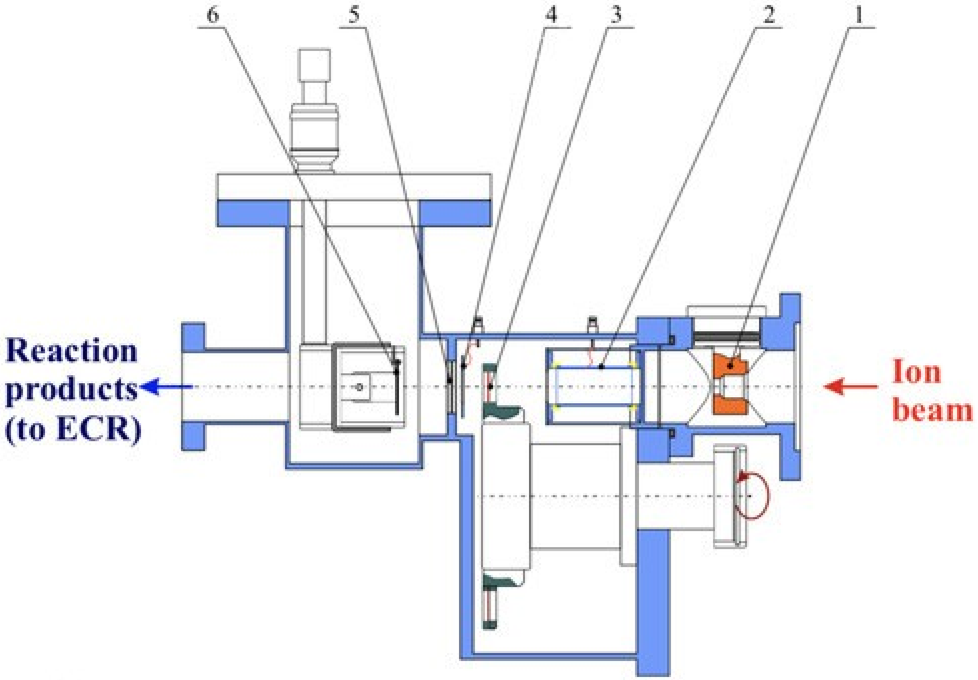
Target unit

Schematic overview of the target-hot catcher system.

1. diaphragm;
2. pick-up sensor;
3. target on the wheel;
4. electron emission beam monitor;
5. separating foil;
6. hot catcher.

The photo is of the rotating target cassette in assembly. 6 packs, 2 windows at 14 mm width each.The target is modular and it can fit different material types at the same time.



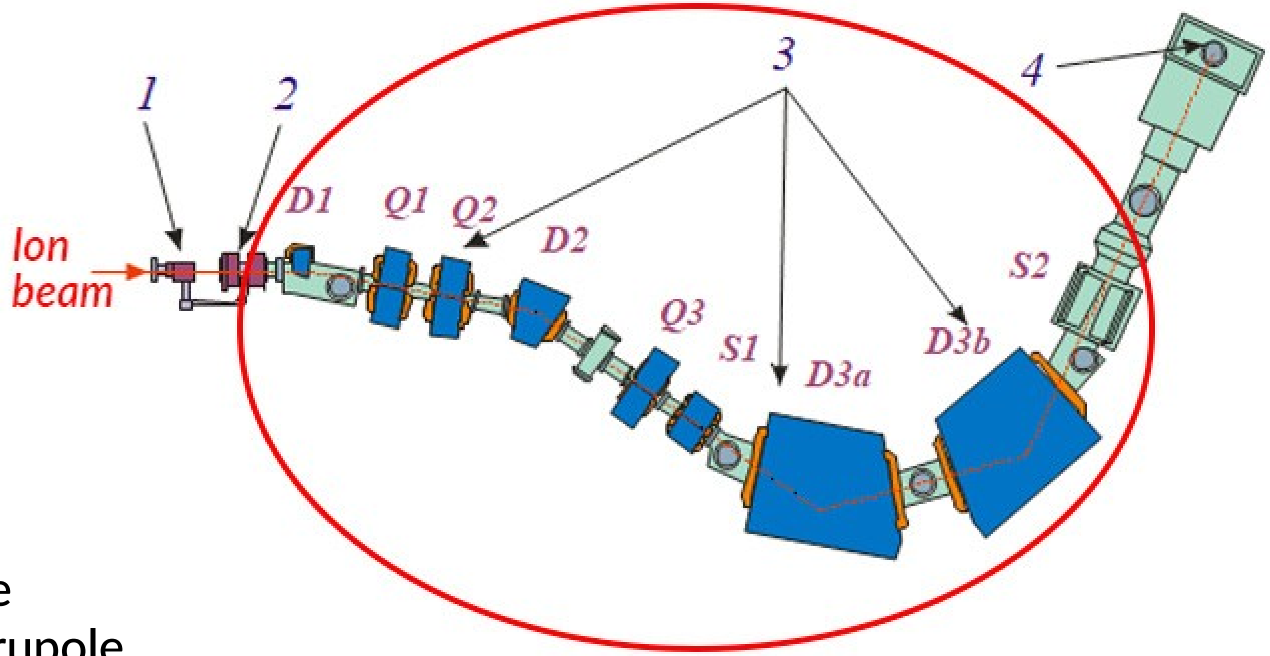


Mass Separator

General ion-optical parameters:
Range of energy variation, 15-40 keV
Mass acceptance, % +/-2.8
Angular acceptance, mrad +/-14
Diameter of the ion source exit hole, mm 5.0
Horizontal magnification at F1/F2 0.39/0.68
Mass dispersion at F1/F2, mm/% 1.5/39.0
Linear mass resolution at F1 75
Mass resolution at F2 1700

1 – Target block with hot catcher;
2 – Ion source;
3 – Mass separator;
4 – DAQ in the focal plane.

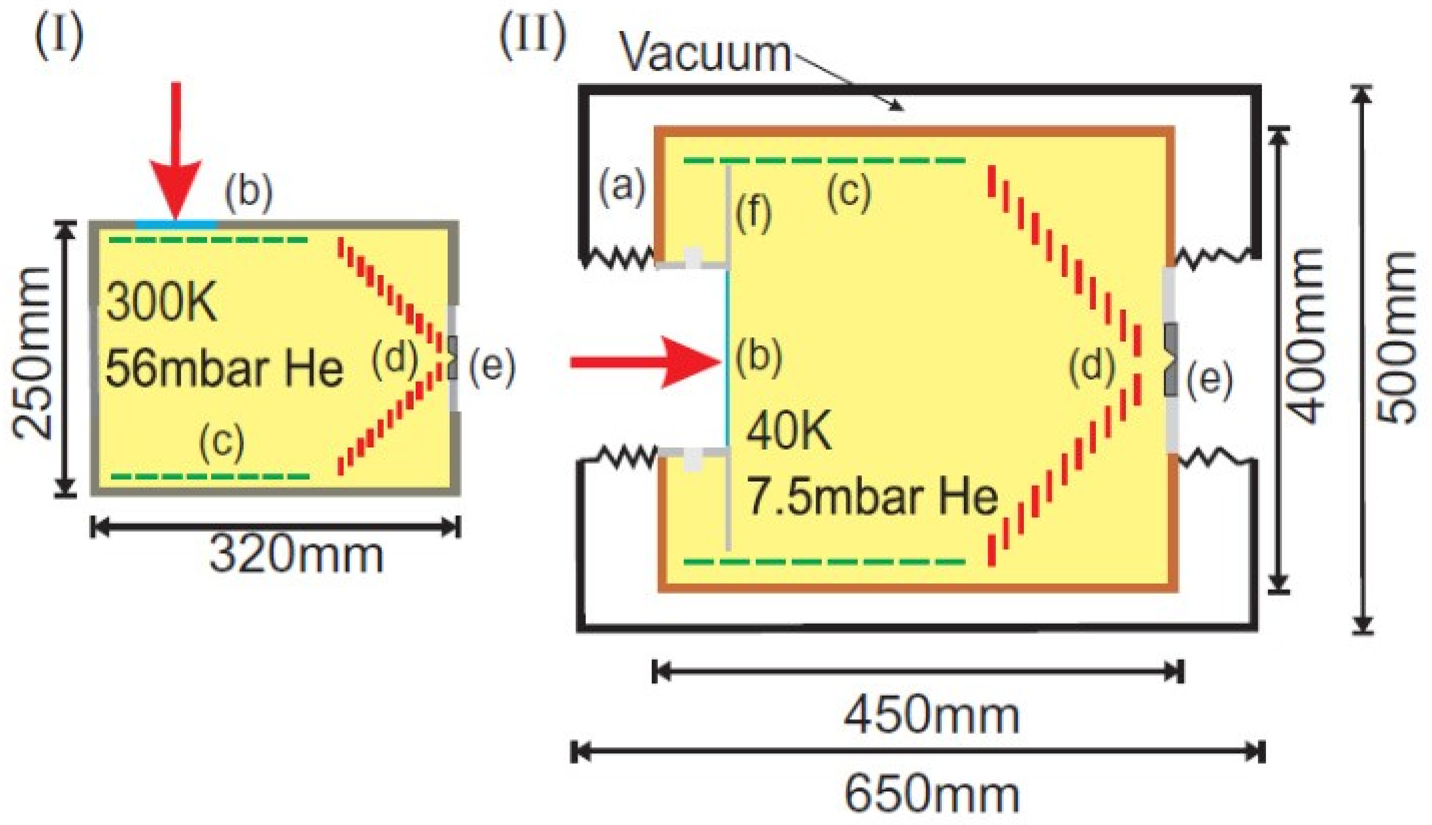
Notation:
D = dipole
Q = quadrupole
S = sextupole



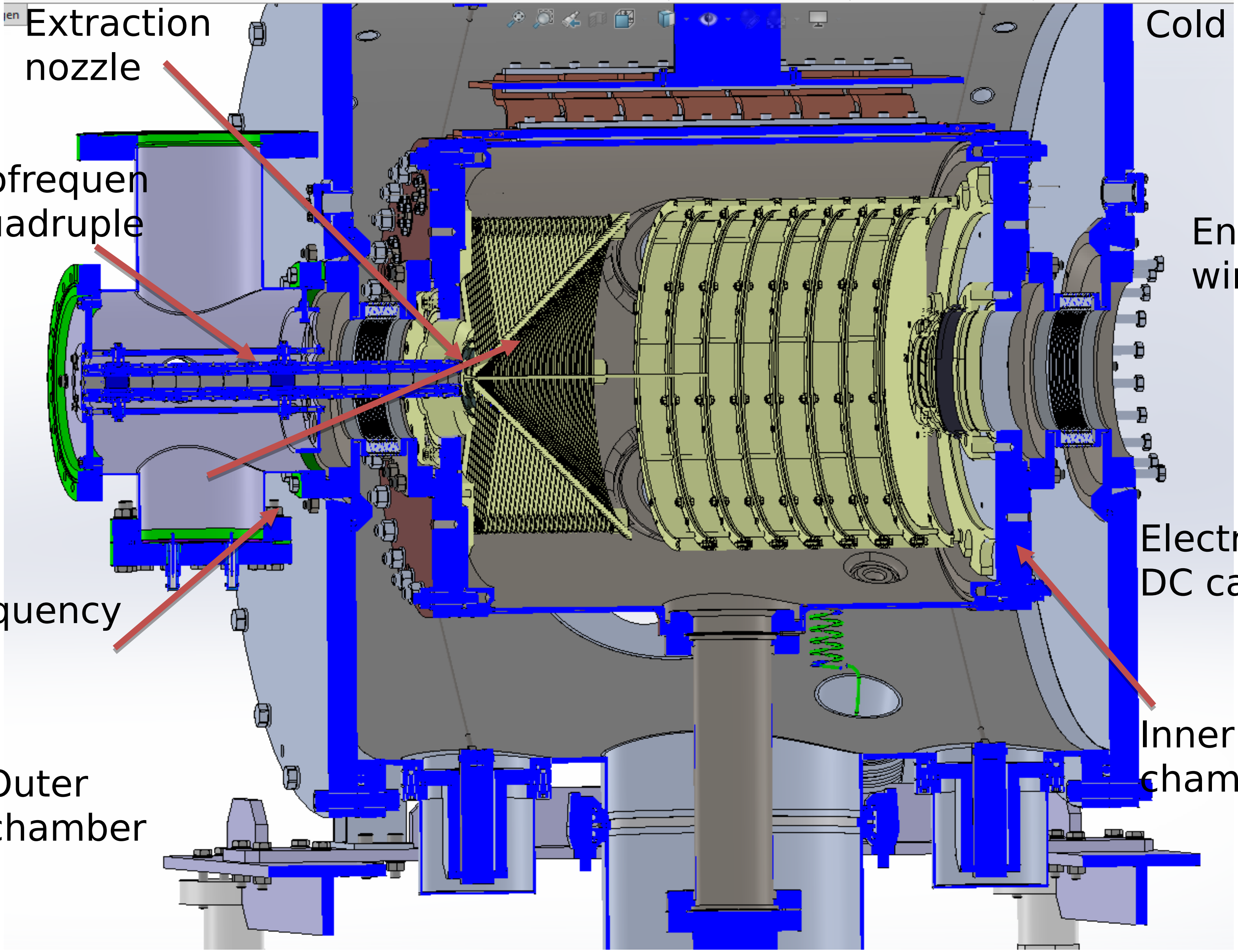
The differences in Gas Catcher generations

Schematic comparison between the first-generation gas stopping cell (I) and the cryogenic gas stopping cell (II). The difference of the gas stopping cells are:

-the outer chamber (a, CryoCell only)
-disc electrode (f, CryoCell only). -2nd generation is a cryogenic.

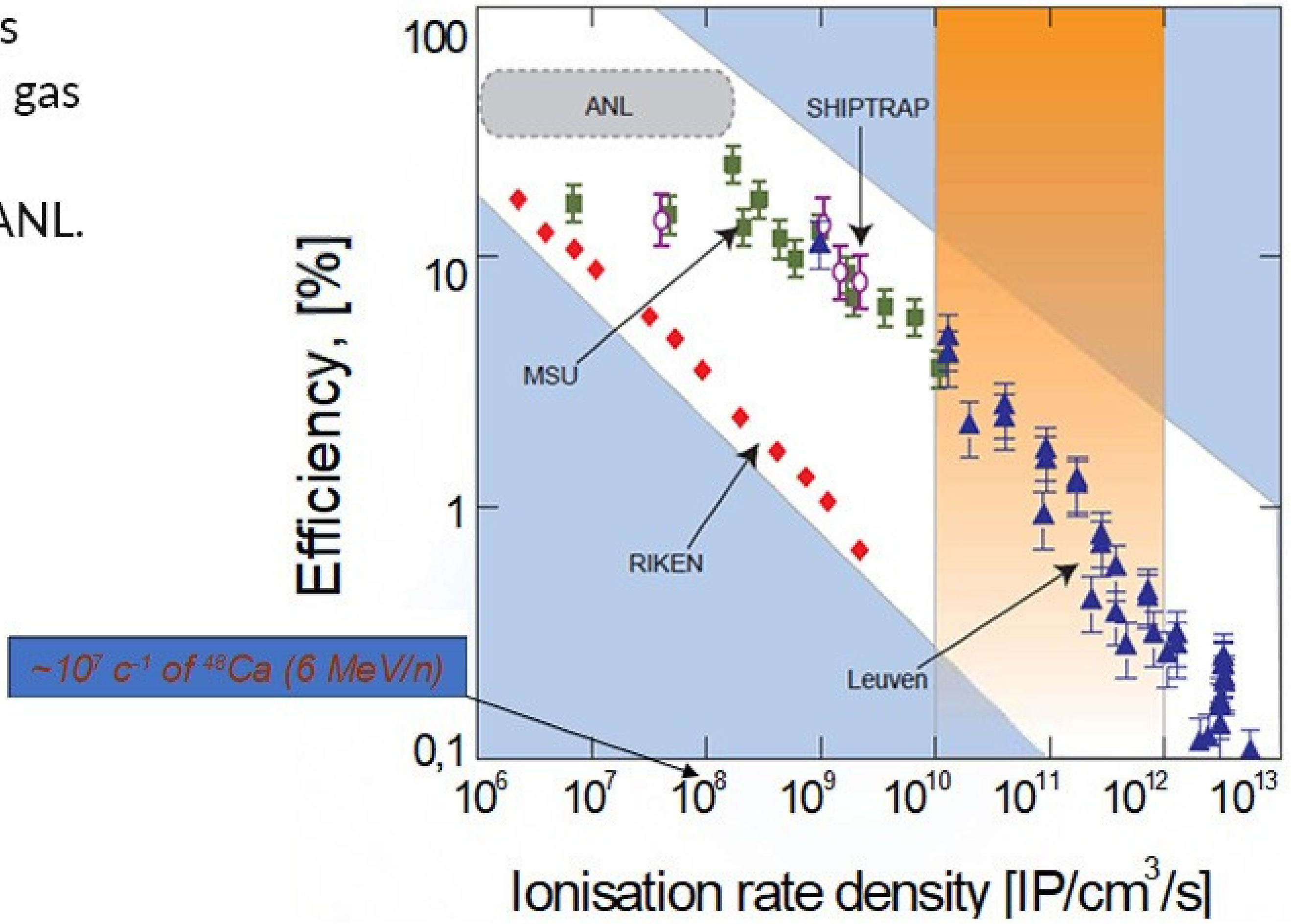


CryoCell- Cryogenic gas-filled ion stopper “Gas Catcher”



Extraction efficiency vs Ionisation rate density

Observation of extraction efficiencies as a function of the ionization rate in gas stopping systems at MSU, RIKEN, GSI/SHIPTRAP, LISOL/Leuven, and ANL.



Hot catcher vs Gas catcher

Main advantages of solid ISOL methodics:
-high intensity secondary beam (up to 108 pps);
-Small emittance and ΔE of the secondary beam;
-Ability to use in the multinucleon transfer reactions(the target material is dissolved inside graphite);
-Compact dimensions.

Disadvantages are:
-Extraction time is very long: 1.8 s;
-Small separation efficiency of ~ 7%;
-The selectivity of physical or chemical properties of a reaction products.

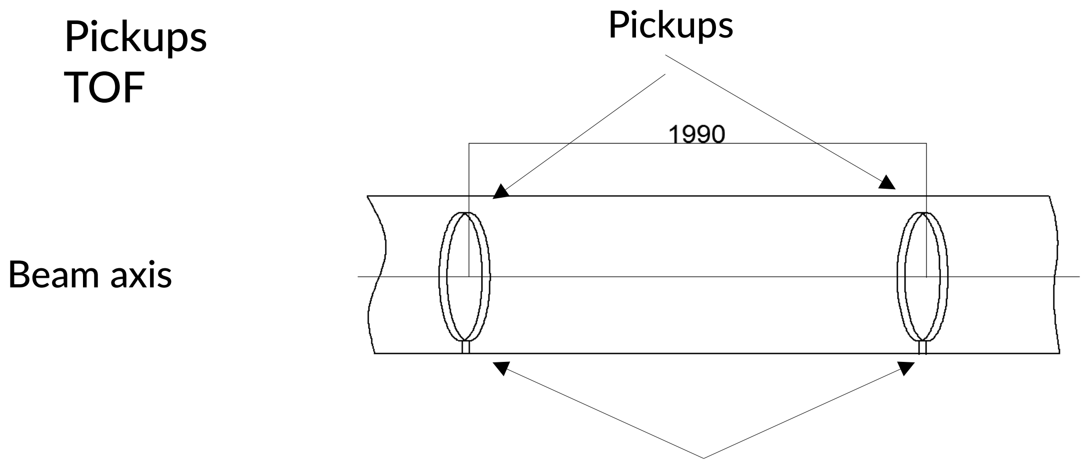
Main advantages of gas catcher:
-High separation efficiency;
-Very low separation time opens the huge variety of new short-living isotopes for the investigation;
-No need of additional ionization.
-Chemically inert environment, does not suffer from any physical isotopes properties.

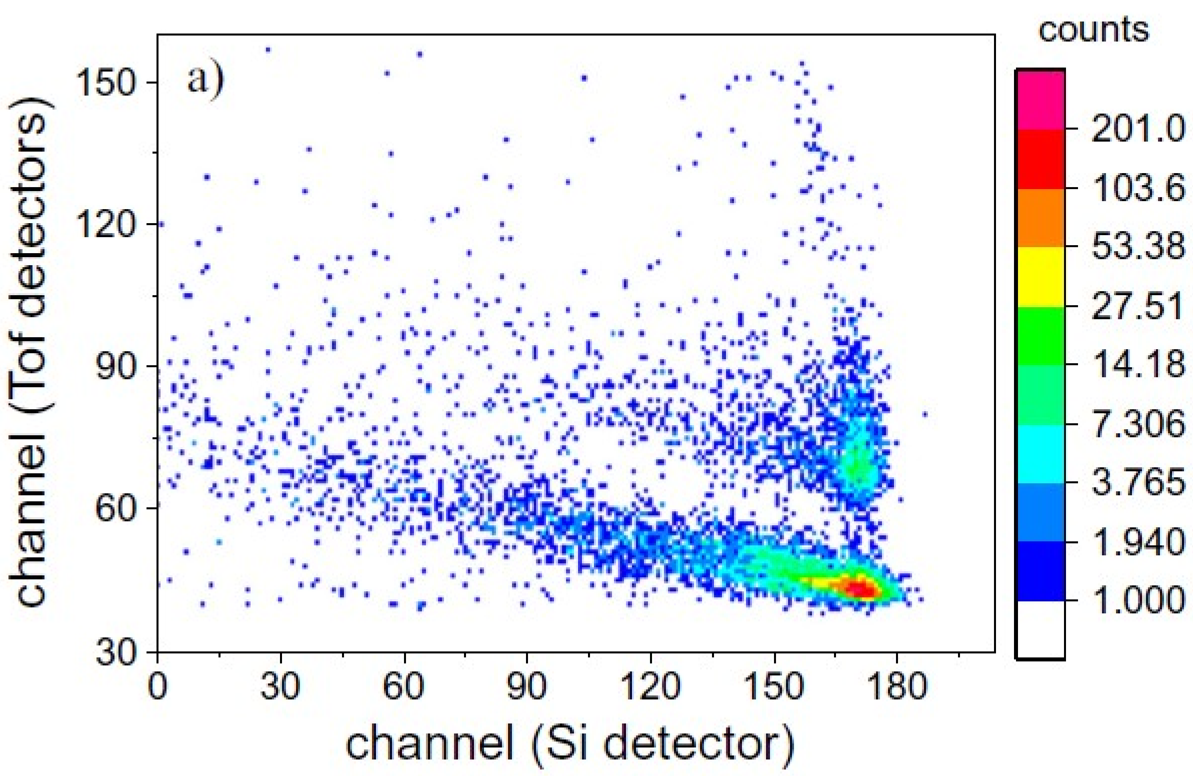
Disadvantages are:
-Strongly limited by ionization rate density.
-The extraction time is very sensitive to the buffer gas pressure, voltage gradient and geometry of Gas Cell.
-High demands of the vacuum technique and buffer gas purity (less than 10-9 mixture).

Detectors

- Energy measurement system
  - On-line - Pickups TOF
  - Off-line - MCP TOF, Pin-silicon

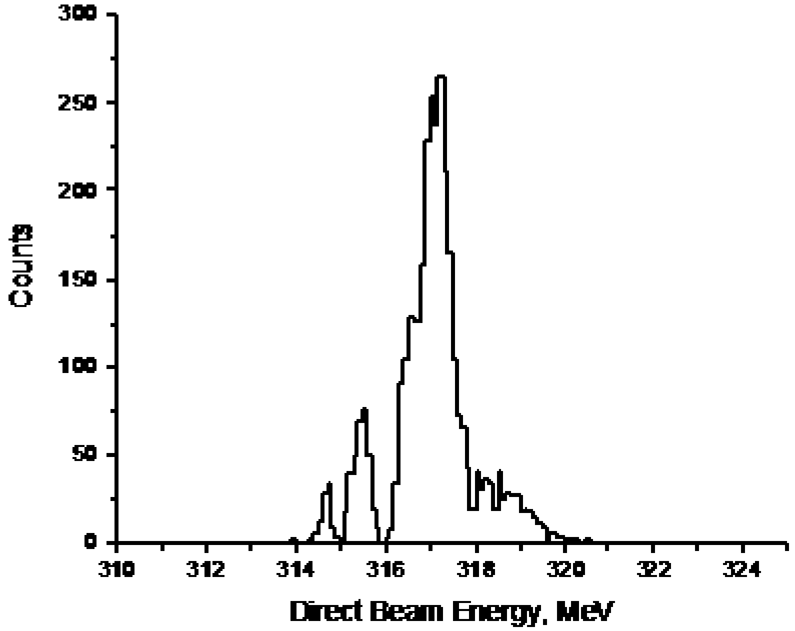
Pickups
TOF





Kinetic energy

Example of ^{48}Ca beam energy



- Current measurement system
    - Off-line - Faraday cups (interrupts the beam)
    - On-line - Emission monitor - measures emitted electrons from target during irradiation

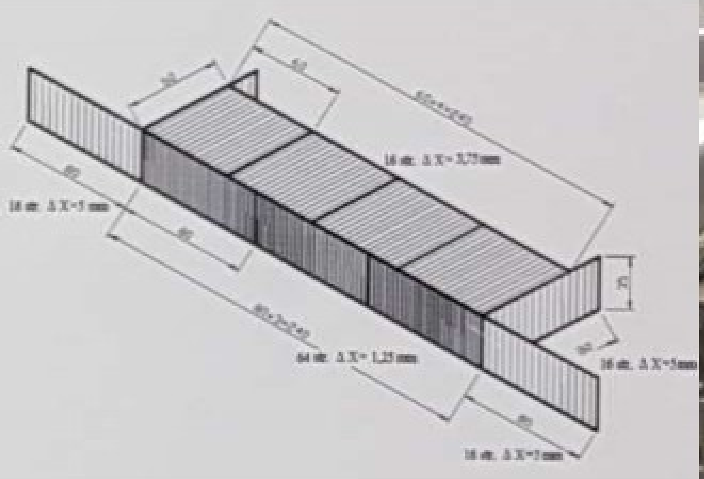
- Physical properties of superheavy elements measurement system (on-line)
    - Strip (position)
    - TIMEPIX

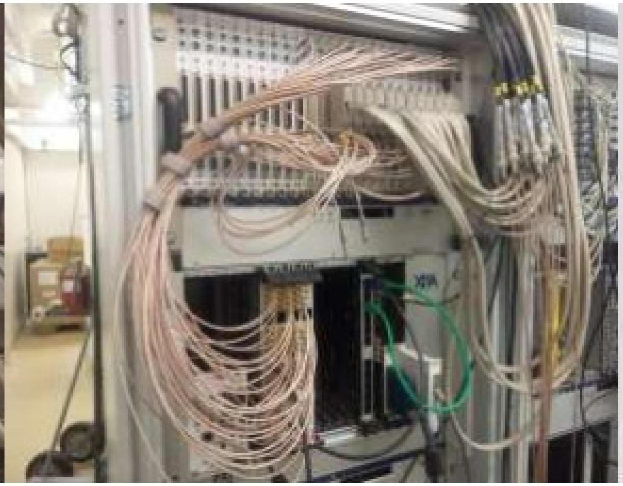
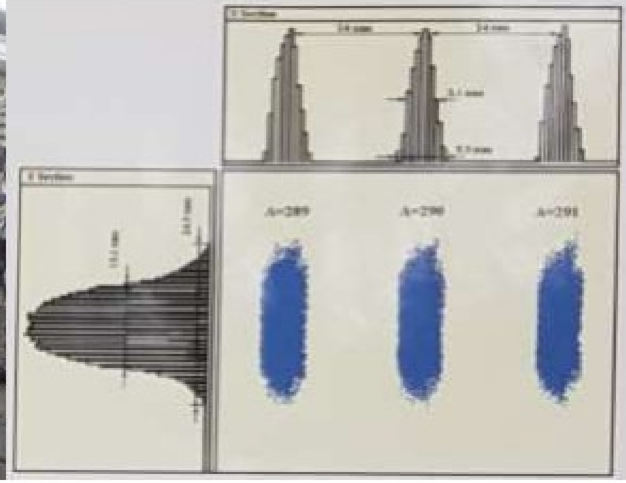
Strip and TIMEPIX

Strip

- Resolution 30 keV (α particles from ^{226}Ra source)

- DAQ (data acquisition)
    - silicon strip detector
    - 16-channel charge-sensitive preamplifiers
    - 8-channel driver amplifiers with built-in multiplexer (CAMAC system)
    - PC, graph



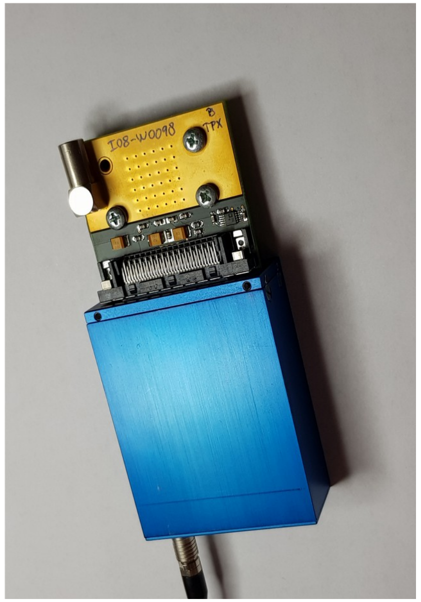
→ Signal processing

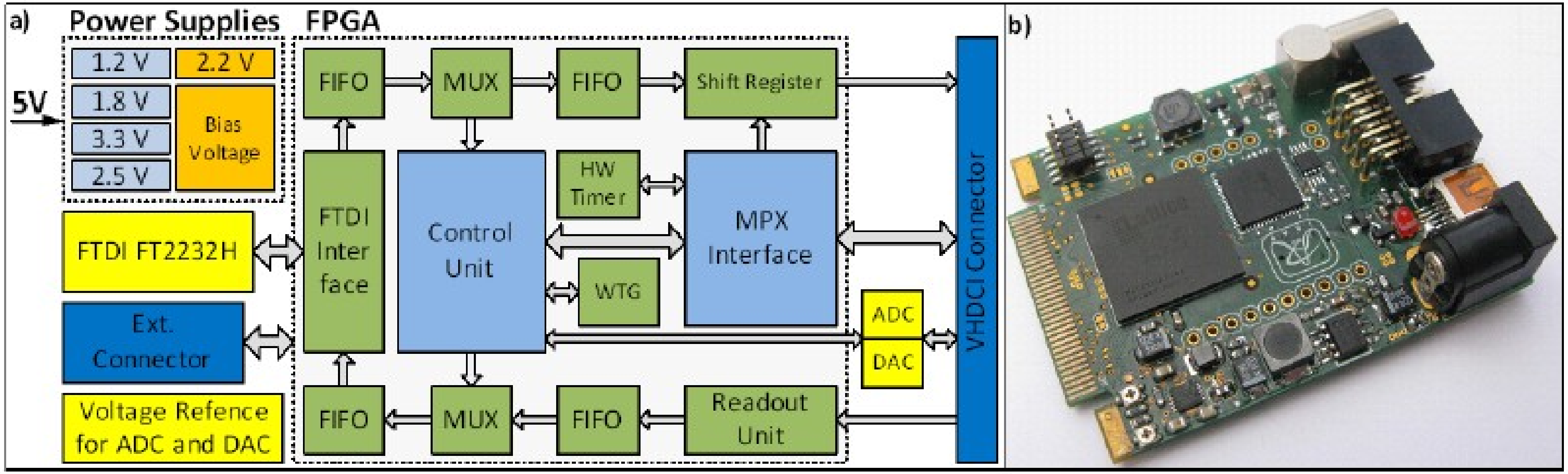
TIMEPIX

- Resolution 100 keV (α particles from ^{220}Rn source)
- Sensitive area 14*14 mm 256*256 pixels
- Silicon sensor 300 µm thickness
- Each pixel has preamplifier and digitizer
- Detect any type of radiation: α-, β-particles, fission fragments and electromagnetic radiation (γ- and X-rays)

FITPix

- successor of the USB 1.22 Interface
- developed in the IEAP CTU Prague
- FPGA integrated circuit





Comparison of Strip and TIMEPIX

Strip

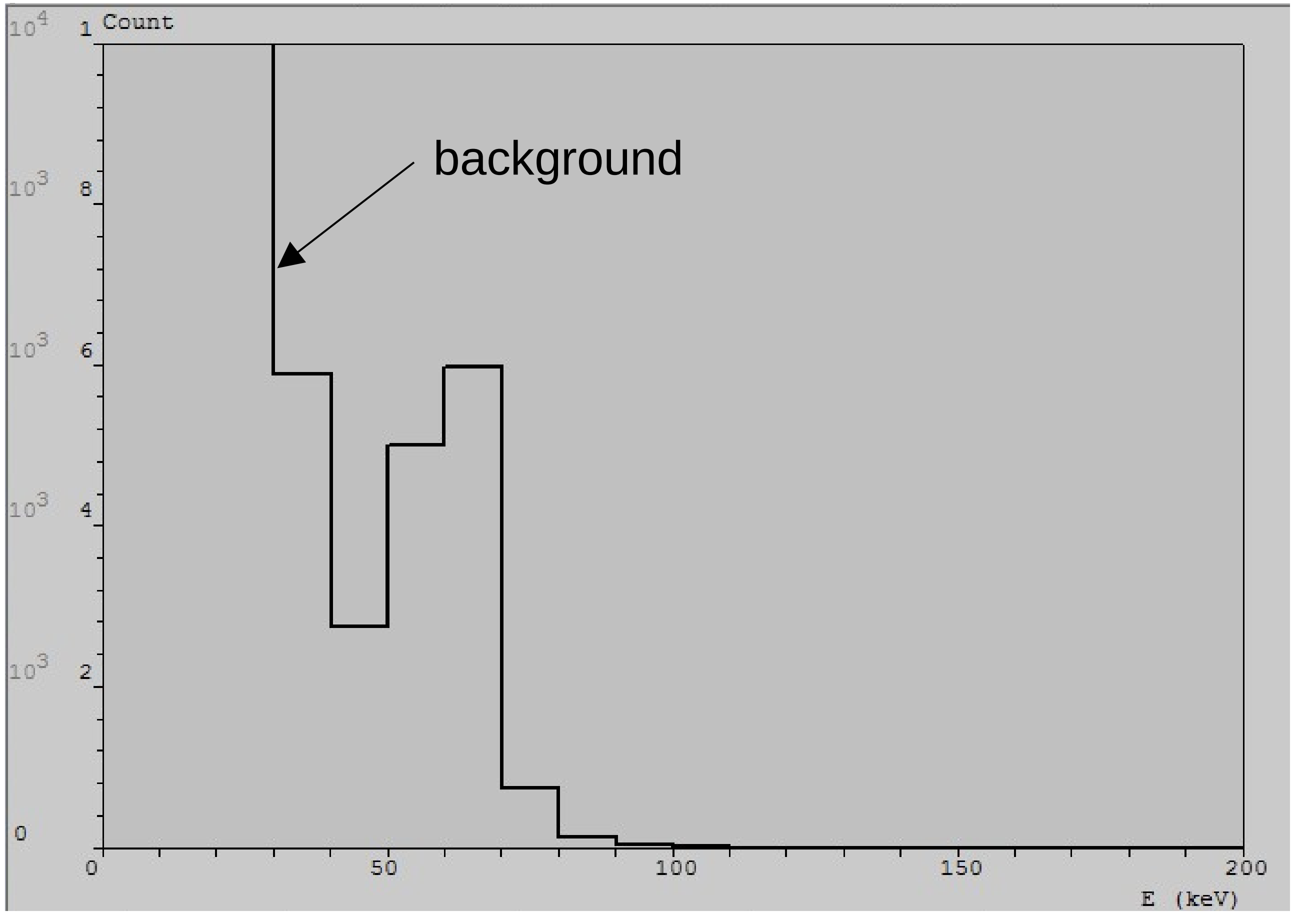
- α particles and fragments measurement
- high resolution
- not integrated electronic parts

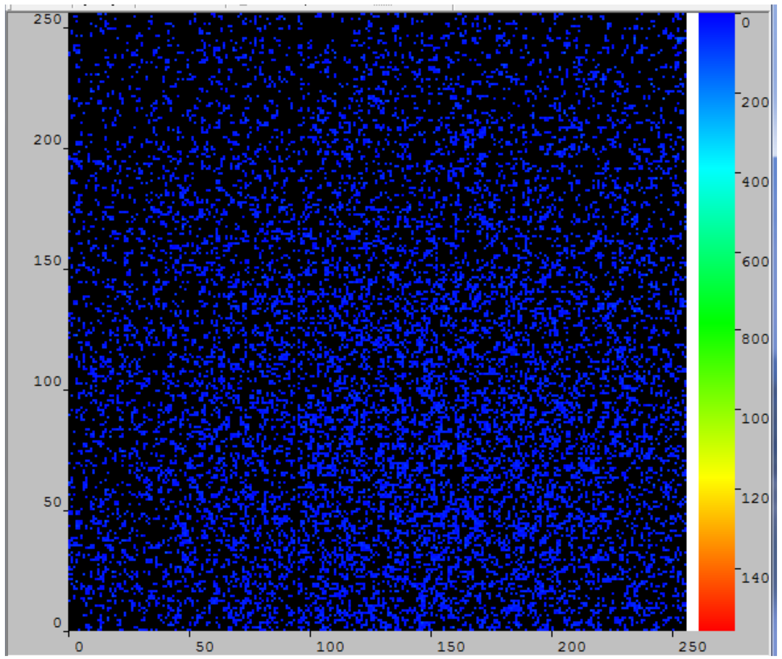
TIMEPIX

- detects any type of radiation and shape of particles
- smaller resolution
- integrated electronics

Calibration ^{241}Am

γ - low energy calibration



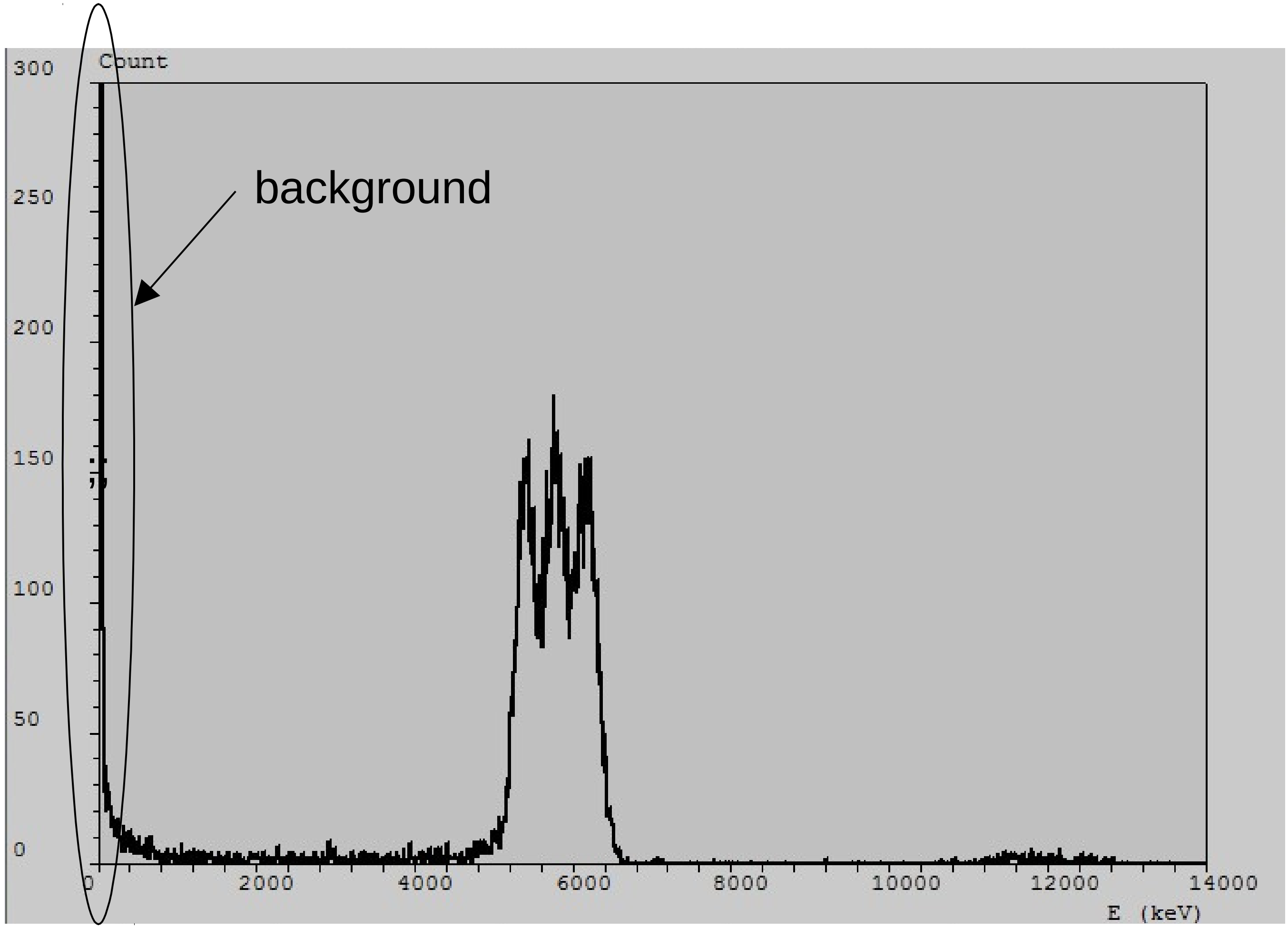


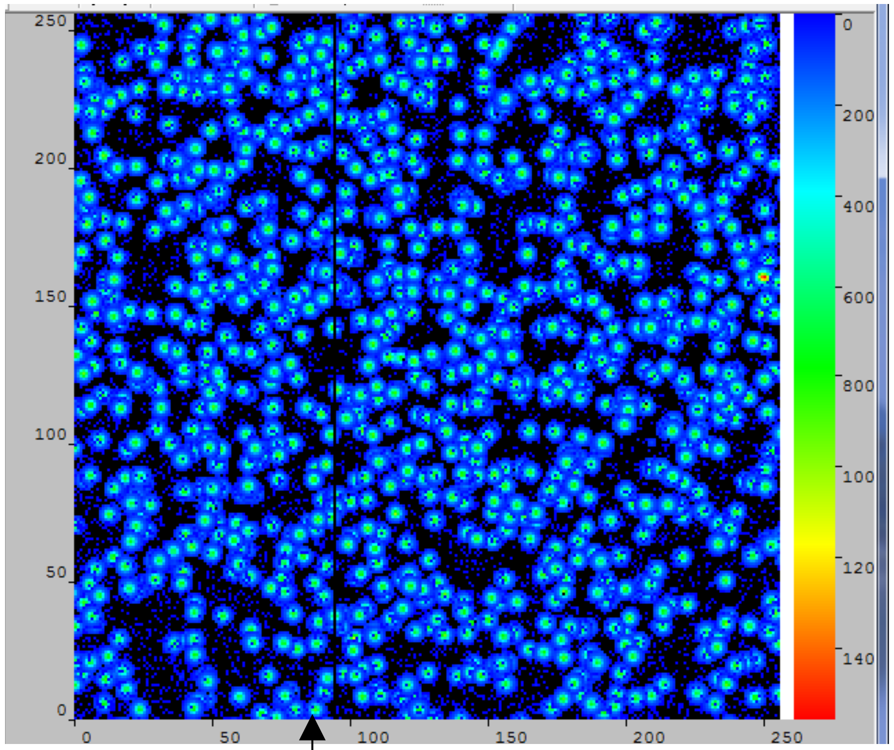
Image

Energy Distribution

Calibration ^{233}U, ^{238}Pu, ^{239}Pu

α - high energy calibration

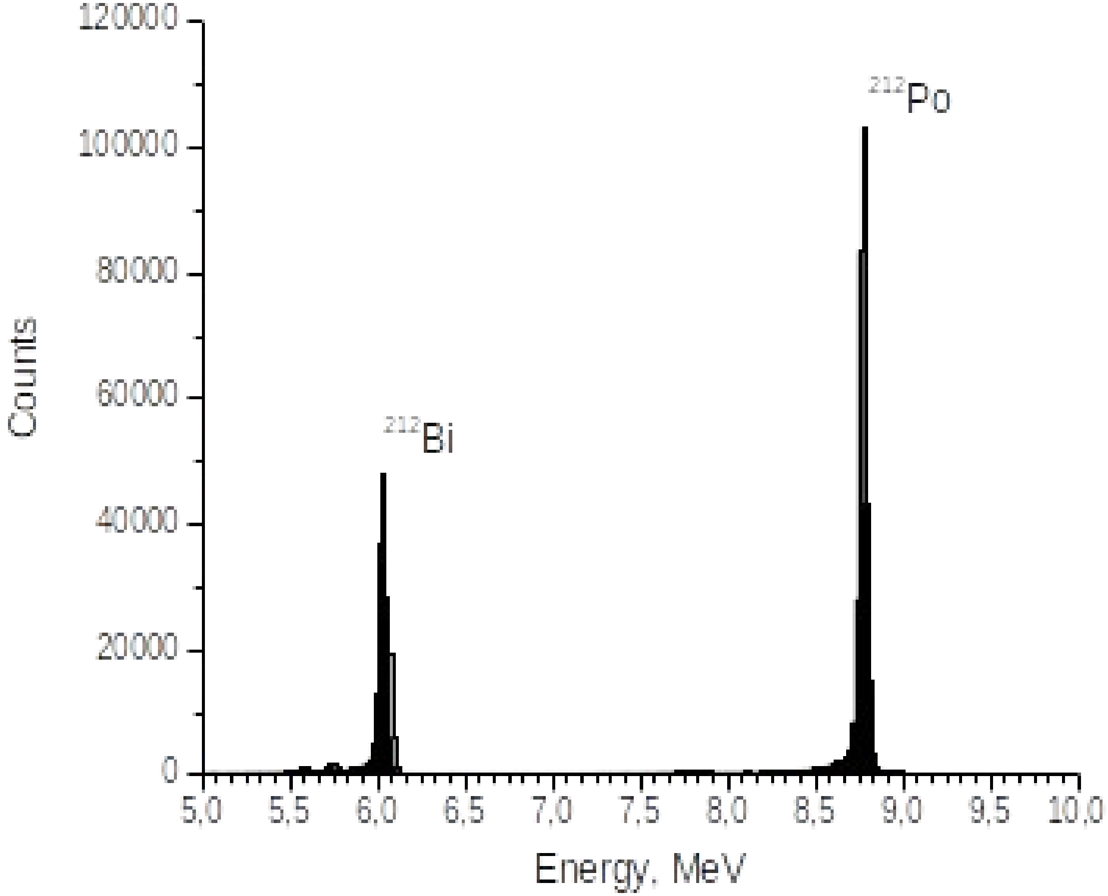


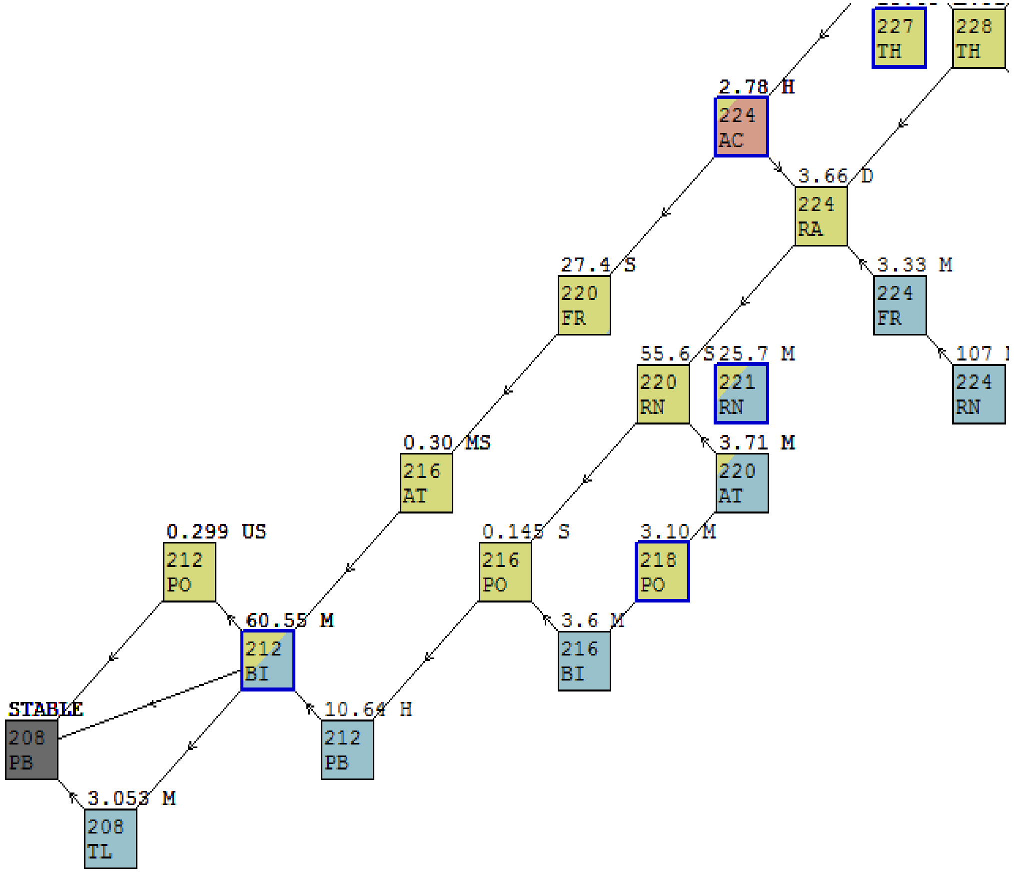


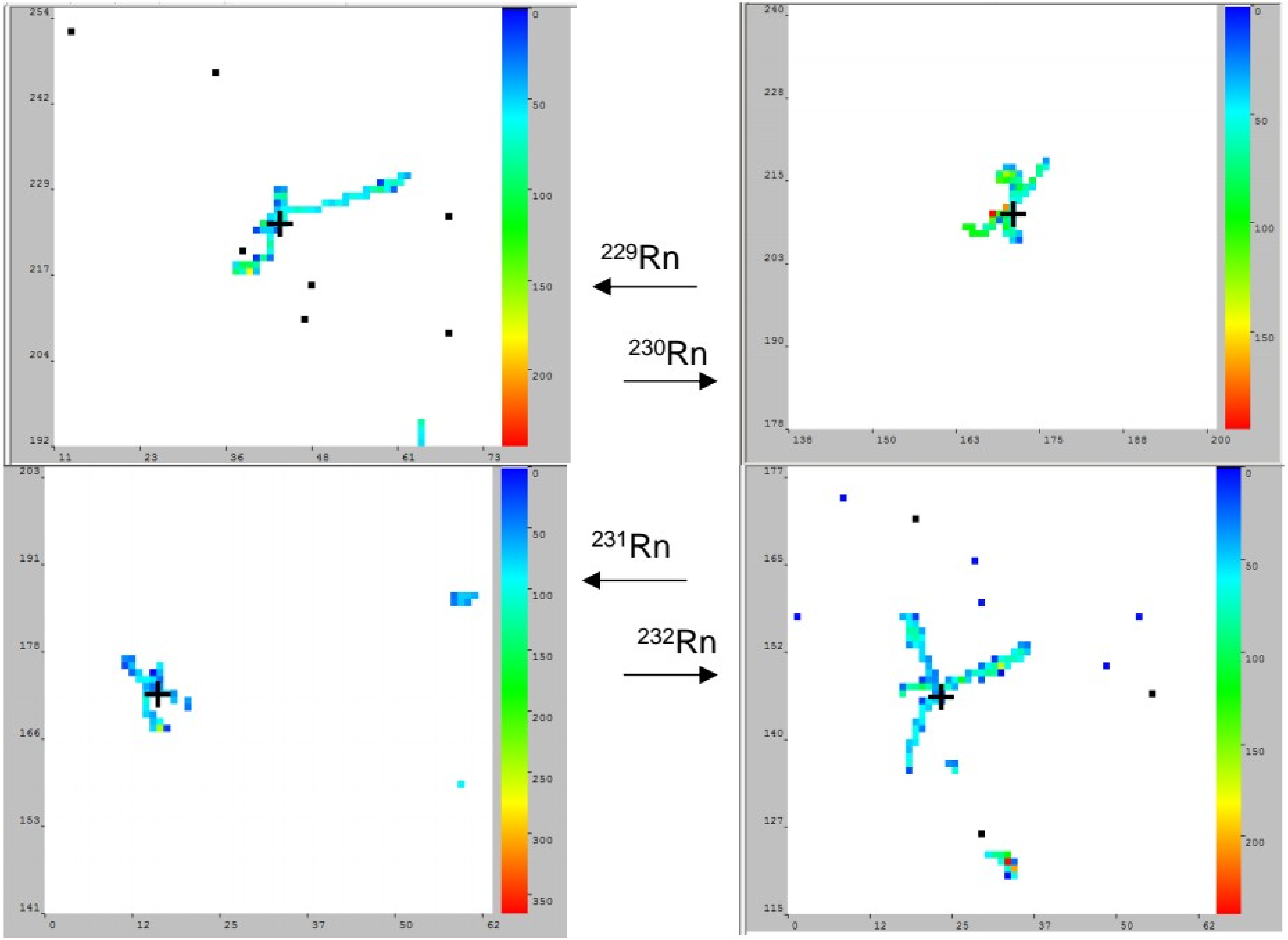
Image

Energy Distribution

Calibration with using ^{228}Th emanation

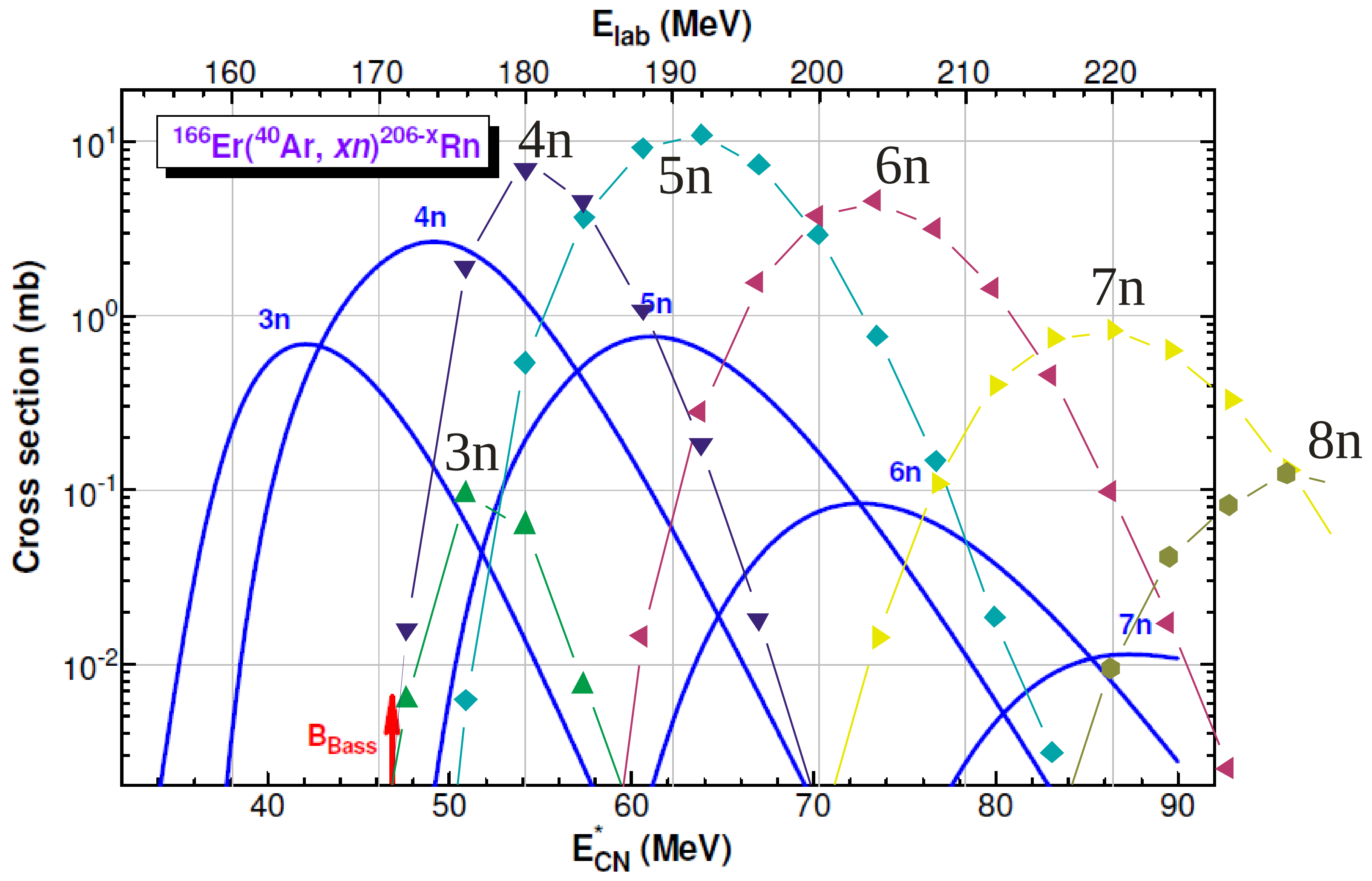


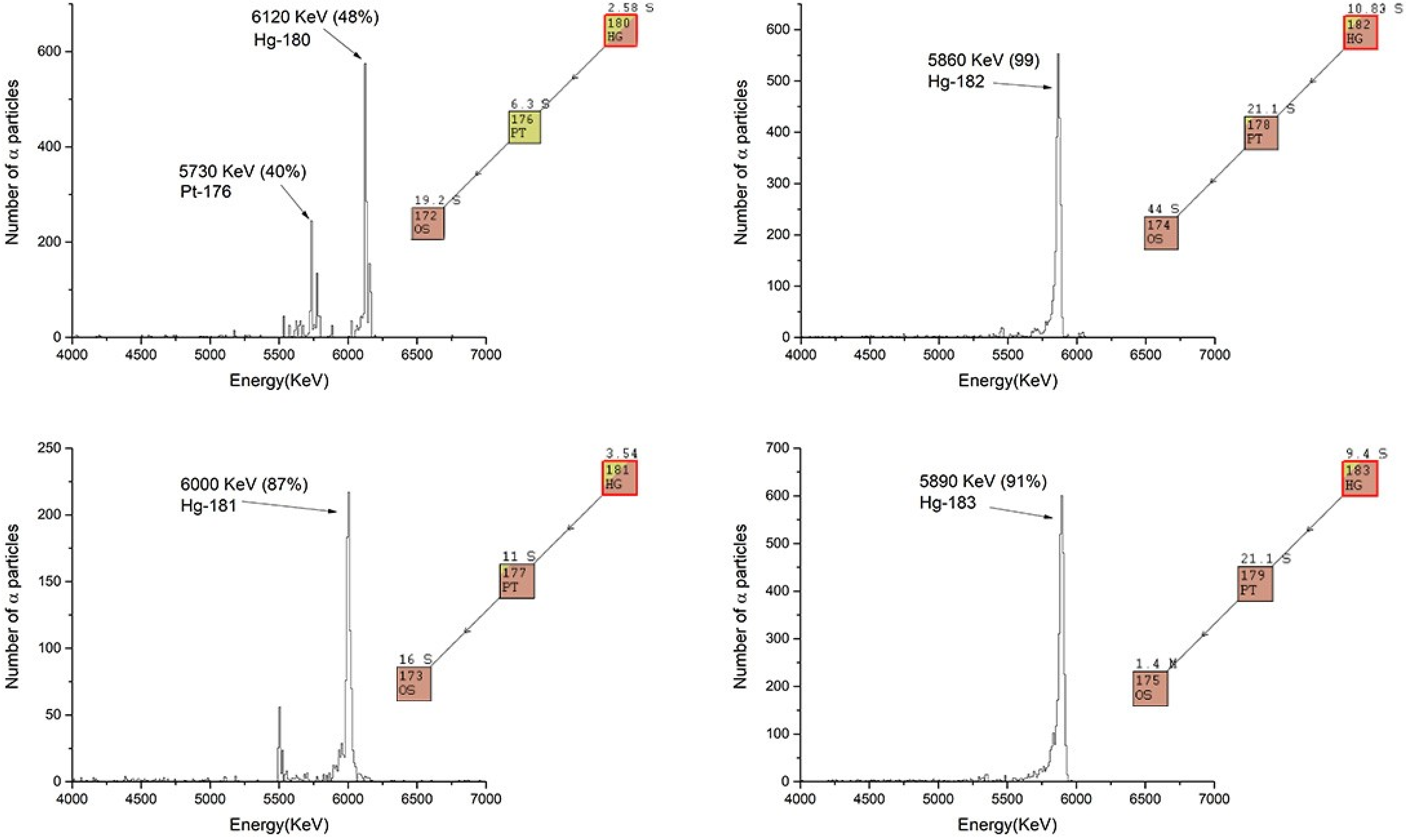




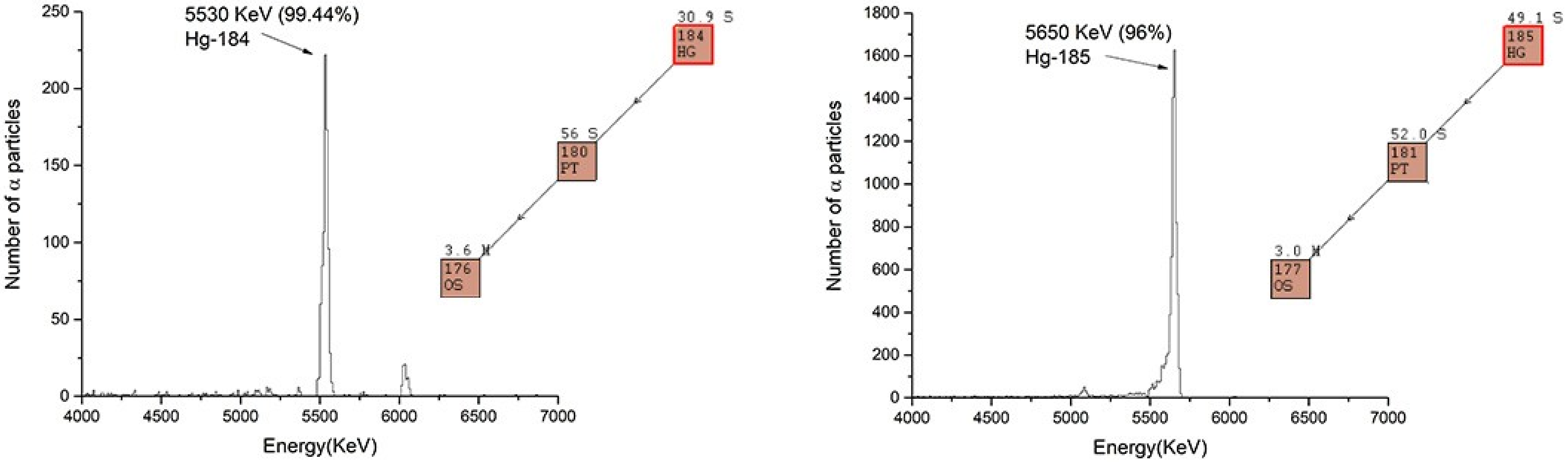
Rn → Fr → Ra → Ac → Th

Excitation functions of the fusion-evaporation reaction channels

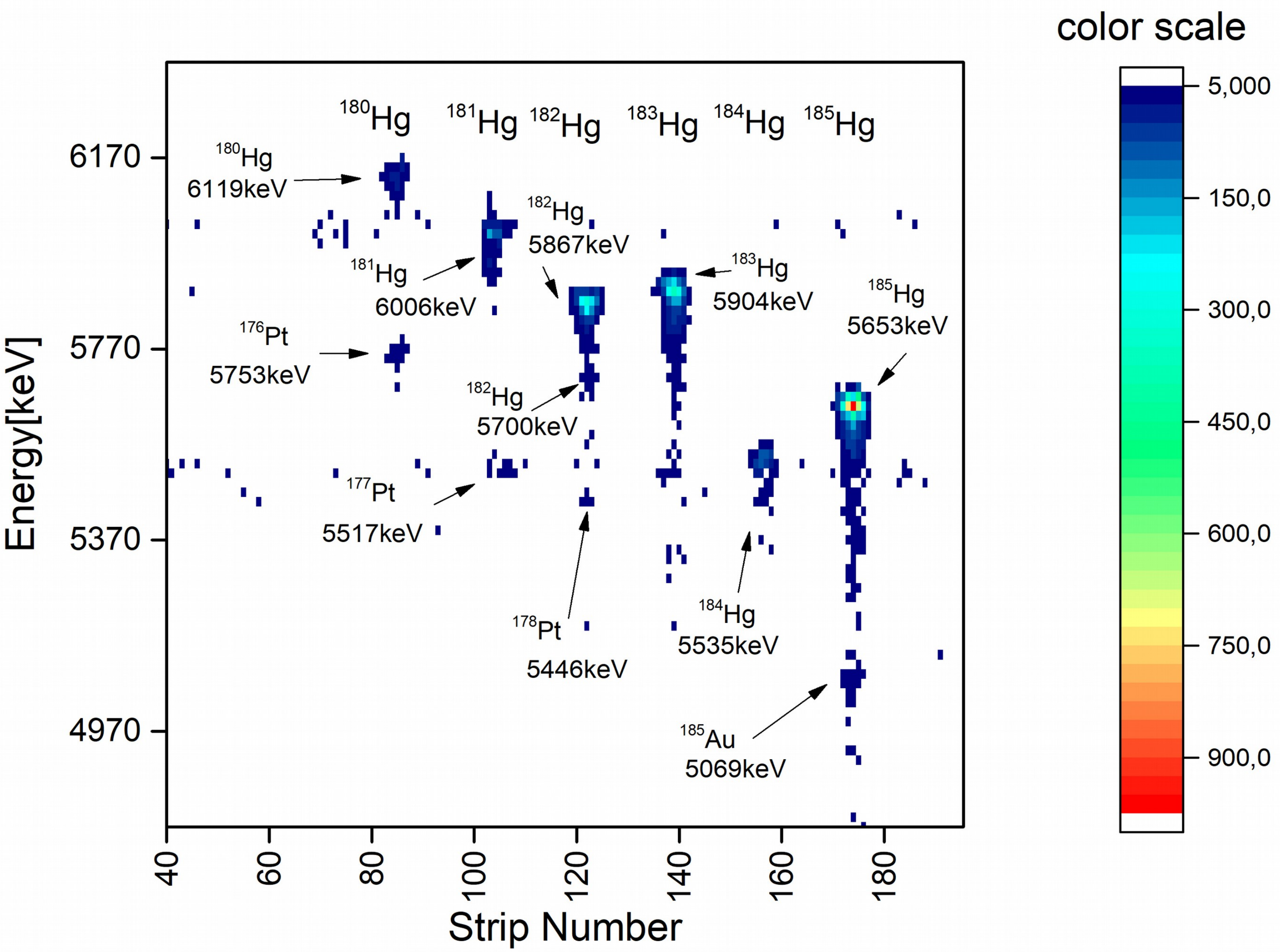


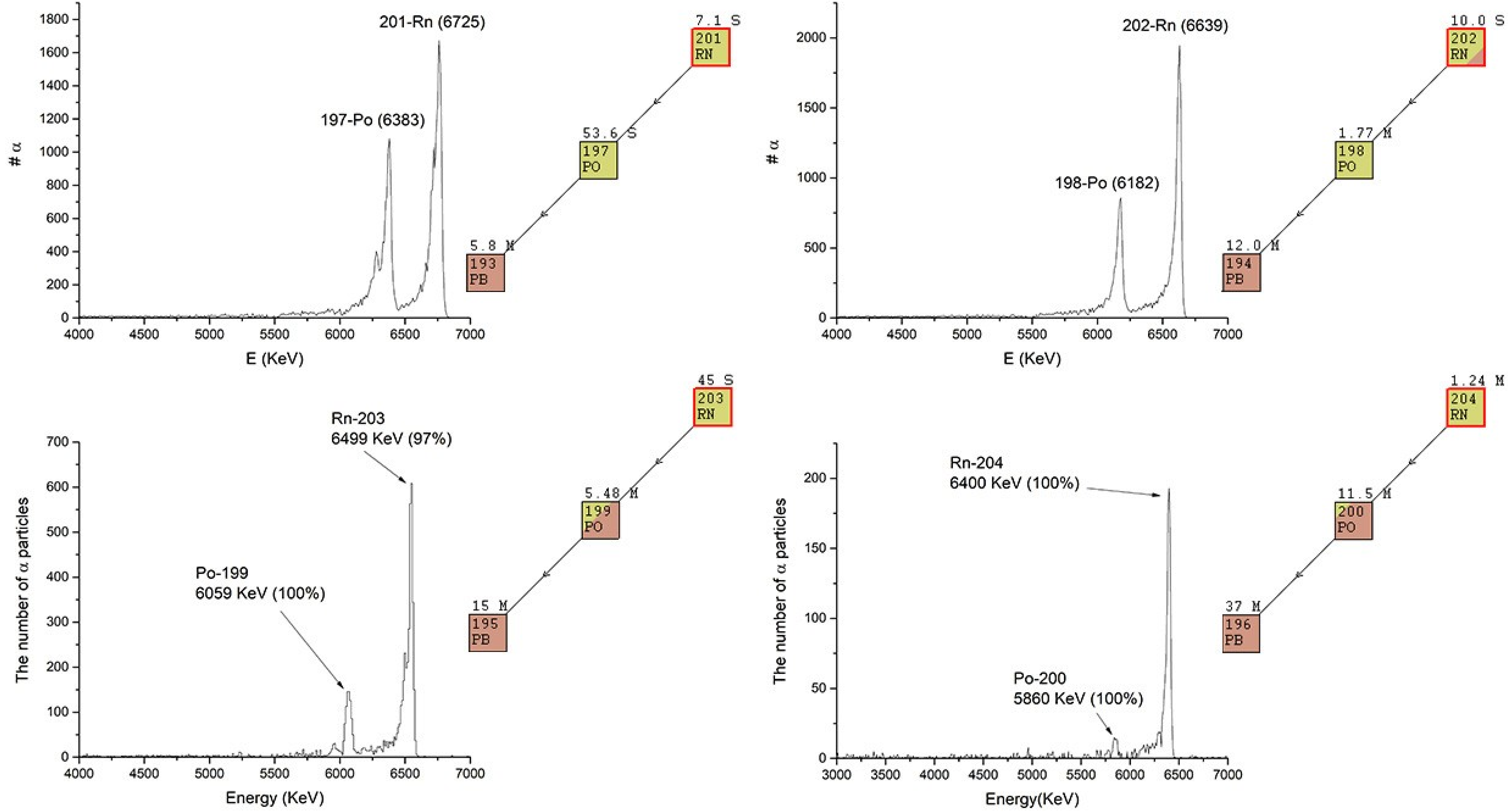


6120 KeV (48%)
Hg-180
5730 KeV (40%)
Pt-176
2.58 S
180 HG
6.3 S
176 PT
19.2 S
172 OS
Number of α particles
Energy(KeV)
5860 KeV (99)
Hg-182
10.83 S
182 HG
21.1 S
178 PT
44 S
174 OS
Number of α particles
Energy(KeV)
6000 KeV (87%)
Hg-181
3.54
181 HG
11 S
177 PT
16 S
173 OS
Number of α particles
Energy(KeV)
5890 KeV (91%)
Hg-183
9.4 S
183 HG
21.1 S
179 PT
175 OS
Number of α particles
Energy(KeV)

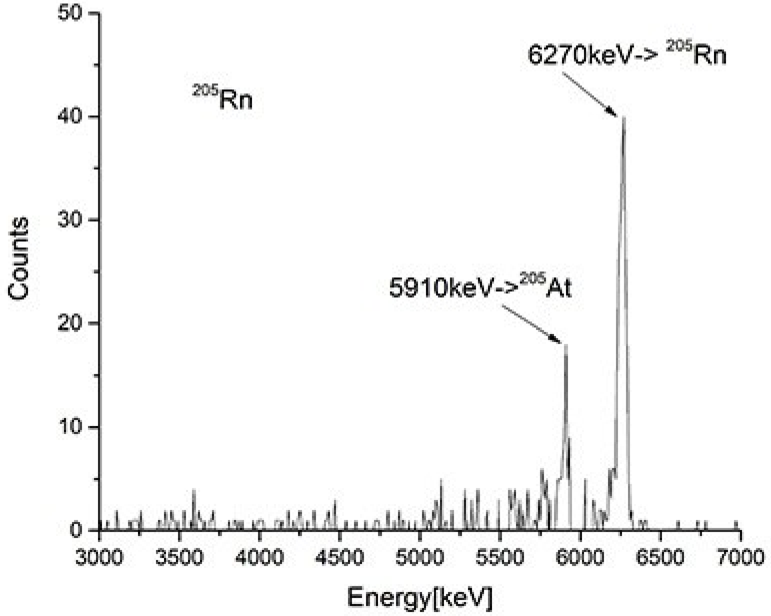


5530 KeV (99.44%)
Hg-184
30.9 S
184
HG
56 S
180
PT
3.6 M
176
OS
Number of α particles
Energy(KeV)
5650 KeV (96%)
Hg-185
49.1 S
185
HG
52.0 S
181
PT
3.0 M
177
OS
Number of α particles
Energy(KeV)

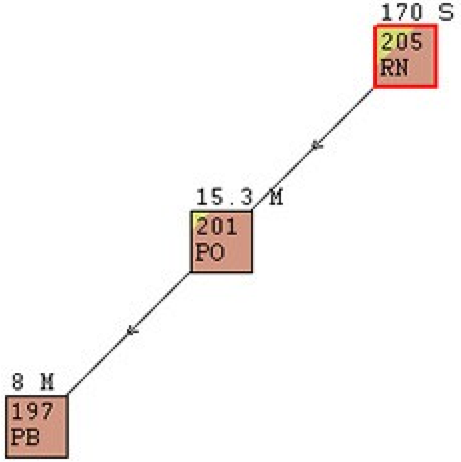

color scale
5,000
150,0
300,0
450,0
600,0
750,0
900,0
180Hg 181Hg 182Hg 183Hg 184Hg 185Hg
180Hg 6119keV
181Hg 6006keV
182Hg 5867keV
183Hg 5904keV
185Hg 5653keV
176Pt 5753keV
182Hg 5700keV
177Pt 5517keV
178Pt 5446keV
184Hg 5535keV
185Au 5069keV
6170
5770
5370
4970
Energy[keV]
40
60
80
100
120
140
160
180
Strip Number



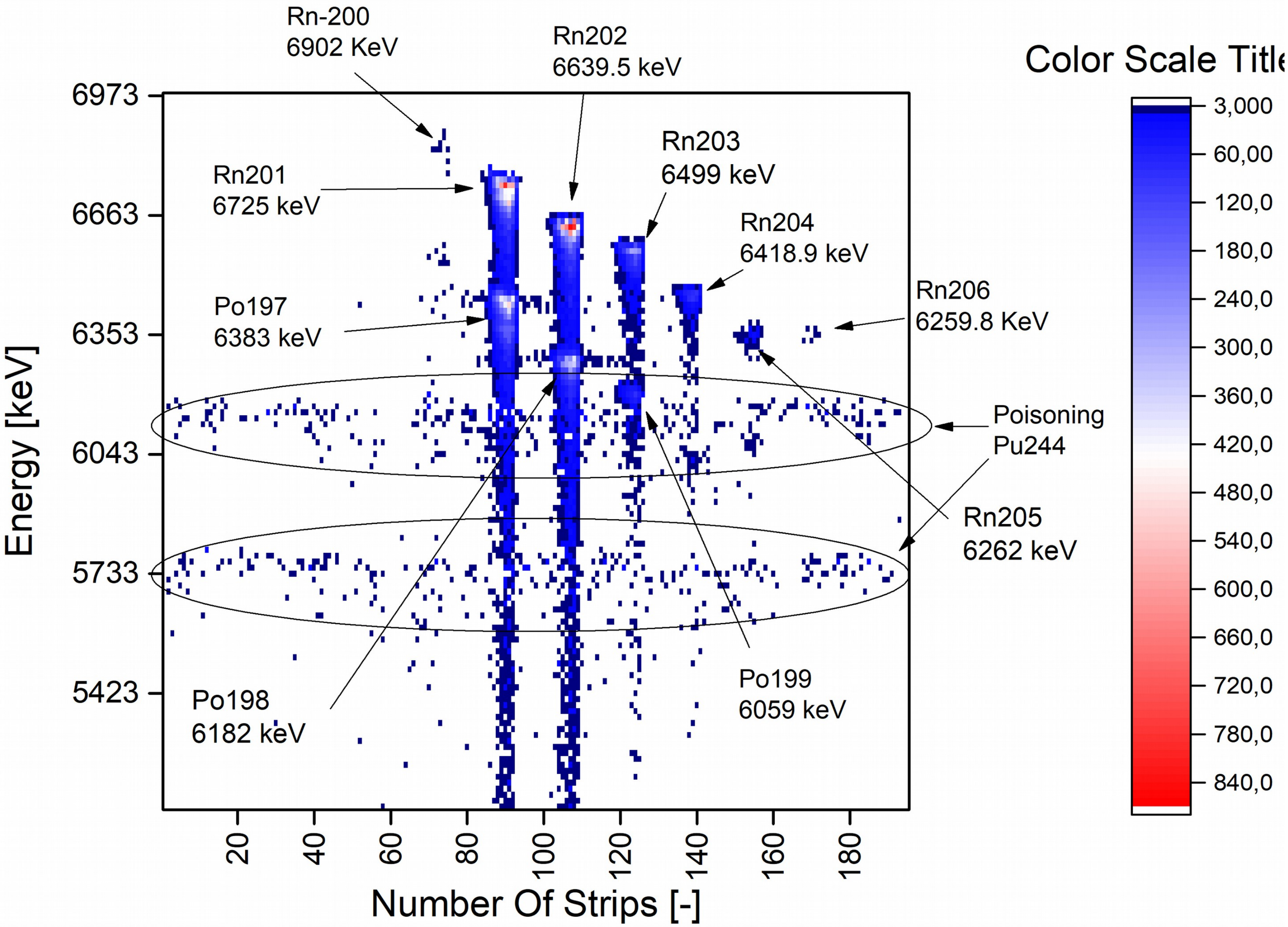
201-Rn (6725)
197-Po (6383)
α
E (KeV)
7.1 S
201
RN
53.6 S
197
PO
5.8 M
193
PB
202-Rn (6639)
198-Po (6182)
α
E (KeV)
10.0 S
202
RN
1.77 M
198
PO
12.0 M
194
PB
Rn-203
6499 KeV (97%)
Po-199
6059 KeV (100%)
The number of α particles
Energy (KeV)
45 S
203
RN
5.48 M
199
PO
15 M
195
PB
Rn-204
6400 KeV (100%)
Po-200
5860 KeV (100%)
The number of α particles
Energy(KeV)
1.24 M
204
RN
11.5 M
200
PO
37 M
196
PB



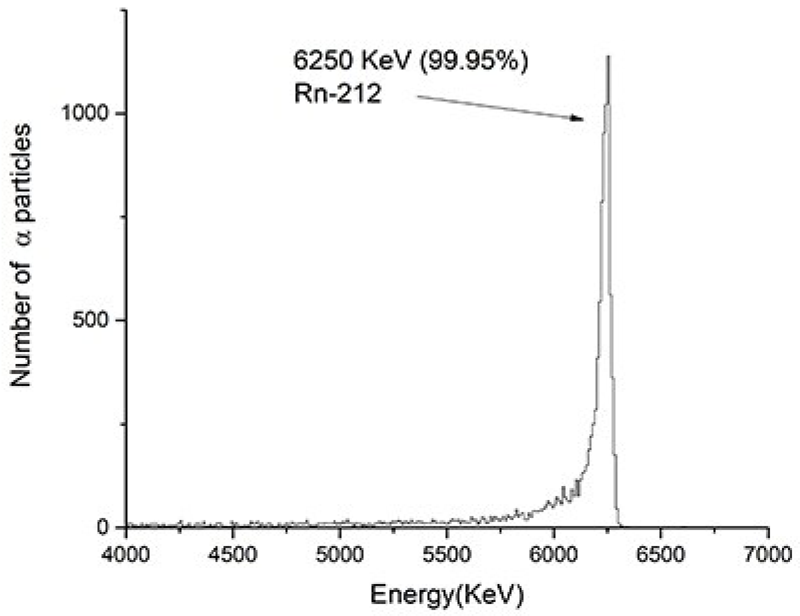
50
40
30
20
10
0
Counts
205Rn
6270keV-> 205Rn
5910keV->205At
3000
3500
4000
4500
5000
5500
6000
6500
7000
Energy[keV]

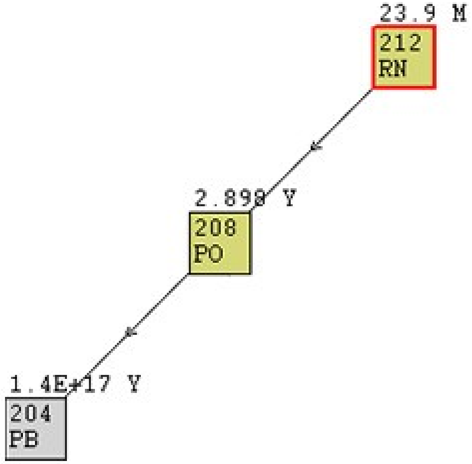


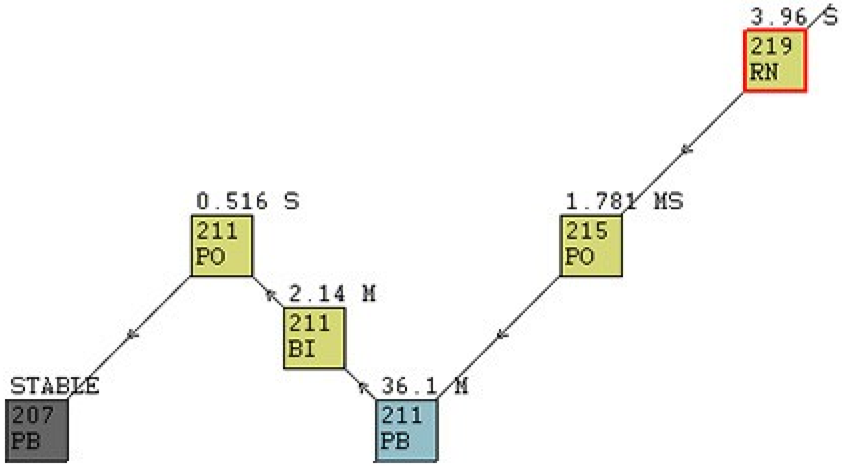
170 S
205
RN
15.3 M
201
PO
8 M
197
PB

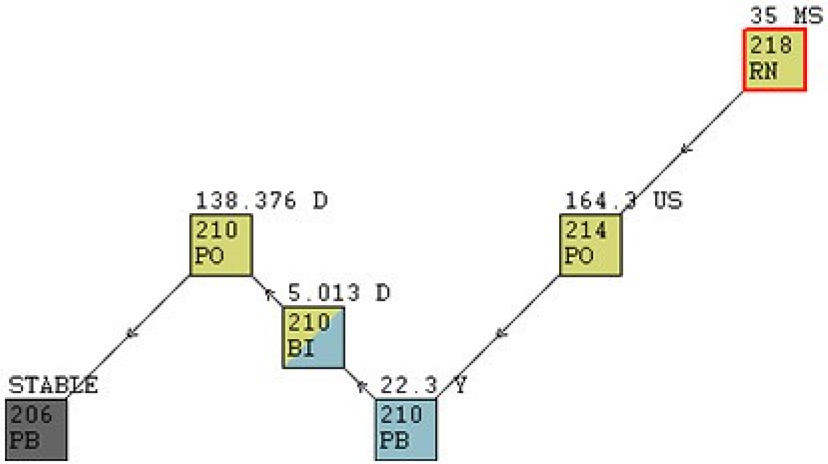


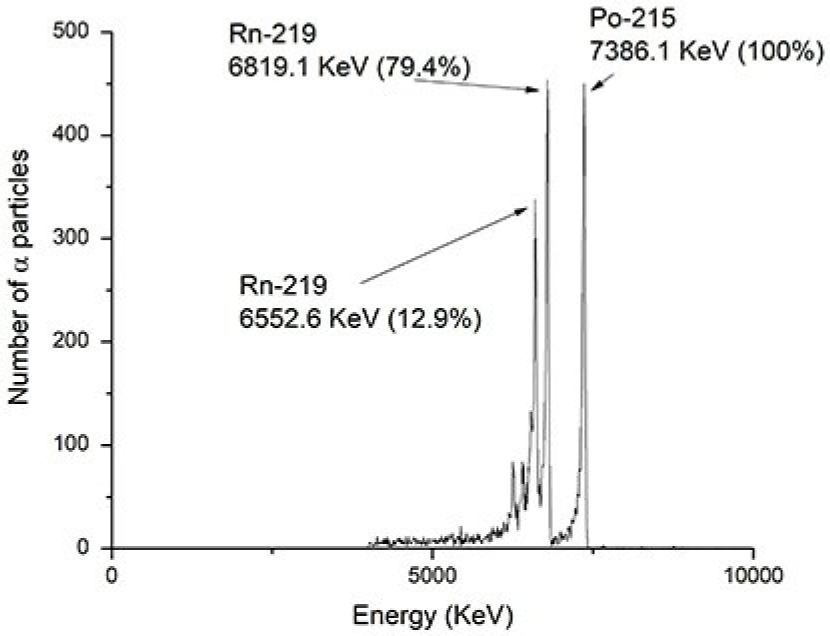
Rn-200
6902 KeV
Rn202
6639.5 keV
Color Scale Title
Rn203
6499 keV
Rn201
6725 keV
Rn204
6418.9 keV
Rn206
6259.8 KeV
Po197
6383 keV
Poisoning
Pu244
Rn205
6262 keV
Po199
6059 keV
Po198
6182 keV
6973
6663
6353
6043
5733
5423
Energy [keV]
20
40
60
80
100
120
140
160
180
Number Of Strips [-]
3,000
60,00
120,0
180,0
240,0
300,0
360,0
420,0
480,0
540,0
600,0
660,0
720,0
780,0
840,0

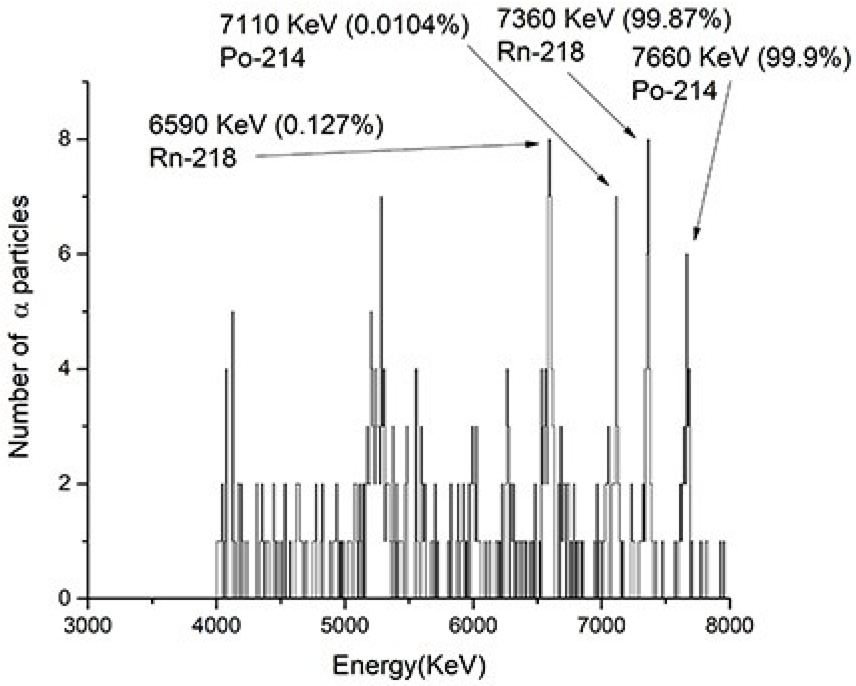

6250 KeV (99.95%)
Rn-212
Number of α particles
Energy(KeV)
0
500
1000
4000
4500
5000
5500
6000
6500
7000


23.9 M
212
RN
2.898 Y
208
PO
1.4E+17 Y
204
PB

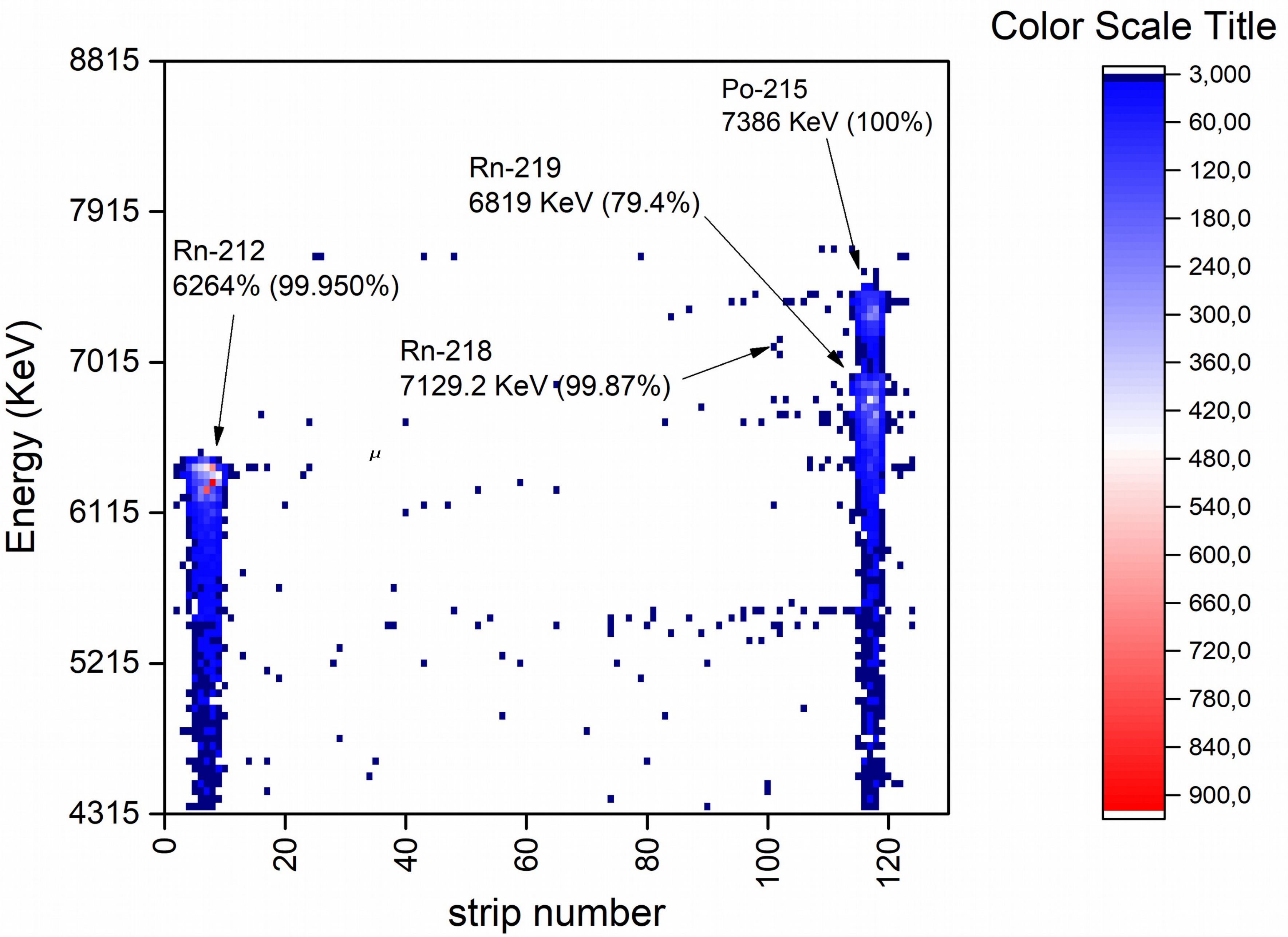

3.96 S
219 RN
1.781 MS
215 PO
0.516 S
211 PO
2.14 M
211 BI
36.1 M
211 PB
STABLE
207 PB


35 MS
218 RN
164.3 US
214 PO
138.376 D
210 PO
5.013 D
210 BI
22.3 Y
210 PB
STABLE
206 PB


Rn-219
6819.1 KeV (79.4%)
Po-215
7386.1 KeV (100%)
Rn-219
6552.6 KeV (12.9%)
Number of α particles
Energy (KeV)
0
100
200
300
400
500
0
5000
10000


7110 KeV (0.0104%)
Po-214
7360 KeV (99.87%)
Rn-218
7660 KeV (99.9%)
Po-214
6590 KeV (0.127%)
Rn-218
Number of α particles
Energy(KeV)
0
2
4
6
8
3000
4000
5000
6000
7000
8000

Isotopes	Halflife
^{212}Rn	23.9min
^{213}Rn	25ms
^{214}Rn	0.27μs
^{215}Rn	2.3μs
^{216}Rn	45μs
^{217}Rn	0.54ms
^{218}Rn	35ms
^{219}Rn	3.96s



Conclusion

- Study of Radioactive Nuclei produced in nuclear reactions at MASHA and its data acquisition
- Isotope identification using the alpha energy spectra
- Calibration of the energy axis of the Energy-Mass matrix using the energies of the alphas emitted by the produced isotopes
- Detection of superheavy elements and nuclei at the border of stability limits at MASHA is made by two types of detectors. Well type strip detector and TIMEPIX.
- Results interpretation

Thank you for your attention!