Сверхтяжелые элементы на Фабрике СТЭ: первые достижения и перспективы

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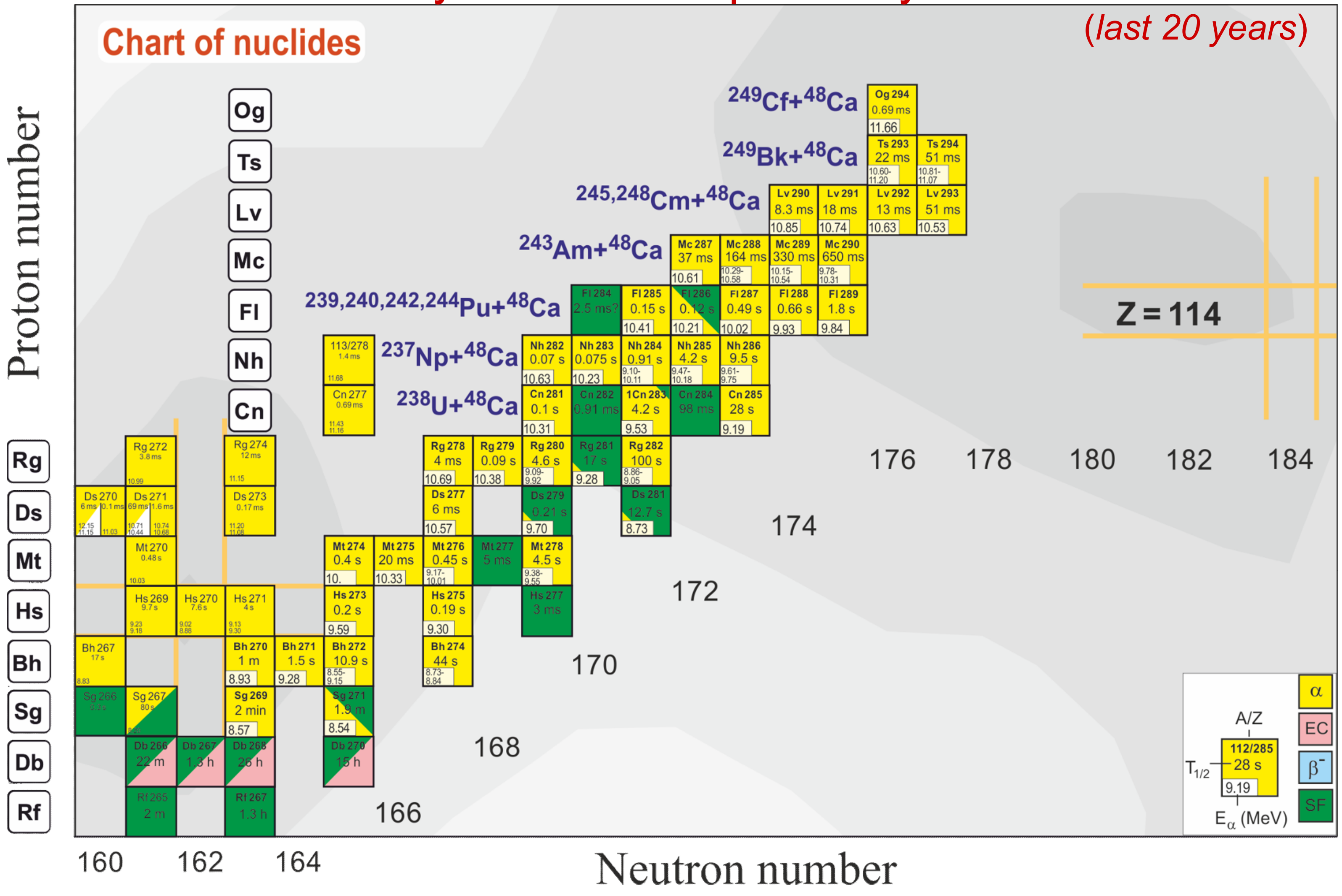
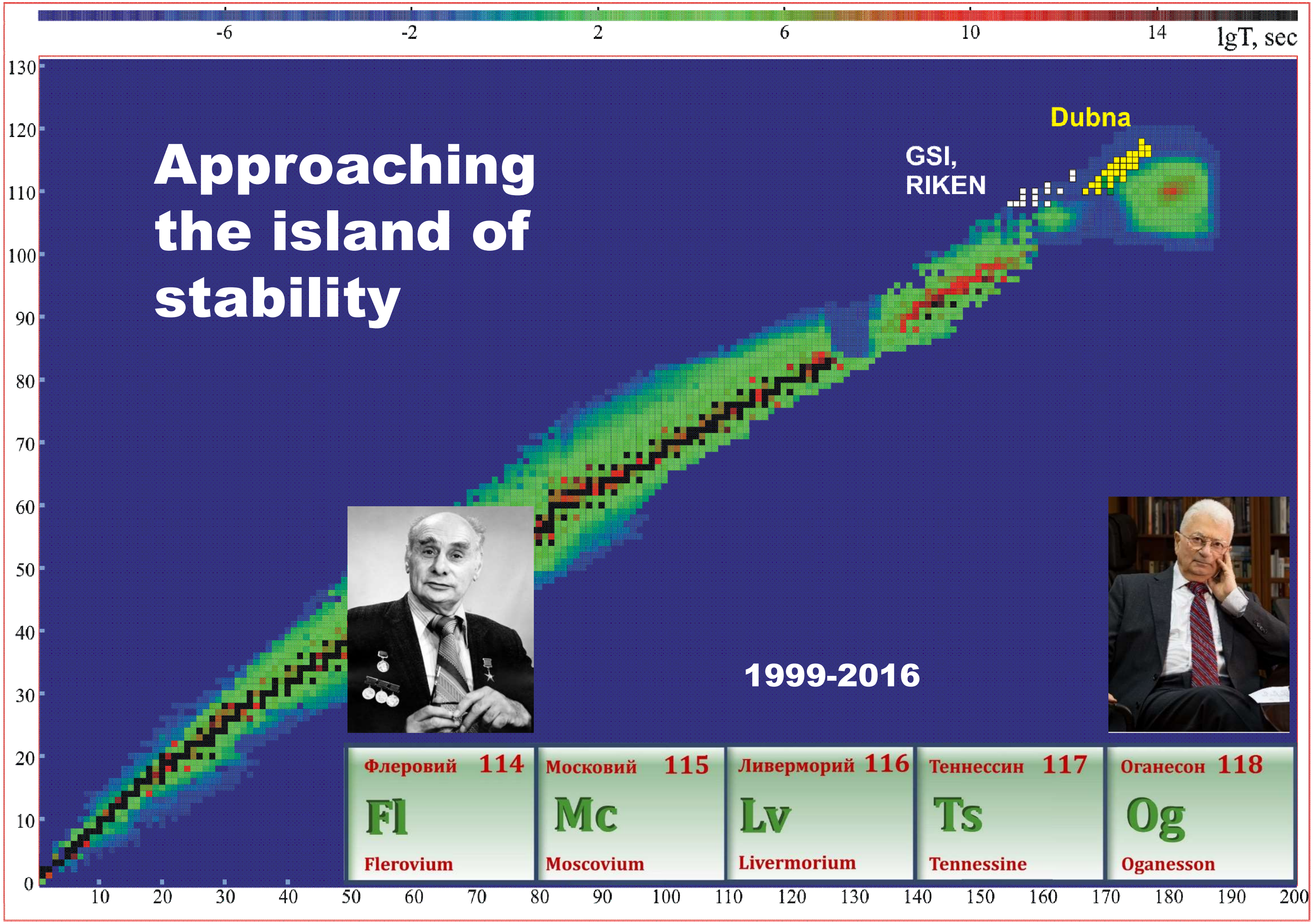
НИИЯФ МГУ, 2 марта 2023 г.

GREAT PROGRESS

in Synthesis of Superheavy Nuclei




Approaching the island of stability
Dubna
GSI, RIKEN
1999-2016
lgT, sec
-6
-2
2
6
10
14
Флеровий 114 Fl Flerovium
Московий 115 Mc Moscovium
Ливерморий 116 Lv Livermorium
Теннессин 117 Ts Tennessine
Оганесон 118 Og Oganesson

Periodic Table today (since November, 28, 2016)

JINR has priority for 10 of 18 elements discovered since 1956

Key: atomic number / Symbol / name / abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.0080 ±0.0002																	2 He helium 4.0026 ±0.0001
3 Li lithium 6.94 ±0.06	4 Be beryllium 9.0122 ±0.0001											5 B boron 10.81 ±0.02	6 C carbon 12.011 ±0.002	7 N nitrogen 14.007 ±0.001	8 O oxygen 15.999 ±0.001	9 F fluorine 18.998 ±0.001	10 Ne neon 20.180 ±0.001
11 Na sodium 22.990 ±0.001	12 Mg magnesium 24.305 ±0.002											13 Al aluminium 26.982 ±0.001	14 Si silicon 28.085 ±0.001	15 P phosphorus 30.974 ±0.001	16 S sulfur 32.06 ±0.02	17 Cl chlorine 35.45 ±0.01	18 Ar argon 39.95 ±0.16
19 K potassium 39.098 ±0.001	20 Ca calcium 40.078 ±0.004	21 Sc scandium 44.956 ±0.001	22 Ti titanium 47.867 ±0.001	23 V vanadium 50.942 ±0.001	24 Cr chromium 51.996 ±0.001	25 Mn manganese 54.938 ±0.001	26 Fe iron 55.845 ±0.002	27 Co cobalt 58.933 ±0.001	28 Ni nickel 58.693 ±0.001	29 Cu copper 63.546 ±0.003	30 Zn zinc 65.38 ±0.02	31 Ga gallium 69.723 ±0.001	32 Ge germanium 72.630 ±0.008	33 As arsenic 74.922 ±0.001	34 Se selenium 78.971 ±0.008	35 Br bromine 79.904 ±0.003	36 Kr krypton 83.798 ±0.002
37 Rb rubidium 85.468 ±0.001	38 Sr strontium 87.62 ±0.01	39 Y yttrium 88.906 ±0.001	40 Zr zirconium 91.224 ±0.002	41 Nb niobium 92.906 ±0.001	42 Mo molybdenum 95.95 ±0.01	43 Tc technetium [97]	44 Ru ruthenium 101.07 ±0.02	45 Rh rhodium 102.91 ±0.01	46 Pd palladium 106.42 ±0.01	47 Ag silver 107.87 ±0.01	48 Cd cadmium 112.41 ±0.01	49 In indium 114.82 ±0.01	50 Sn tin 118.71 ±0.01	51 Sb antimony 121.76 ±0.01	52 Te tellurium 127.60 ±0.03	53 I iodine 126.90 ±0.01	54 Xe xenon 131.29 ±0.01
55 Cs caesium 132.91 ±0.01	56 Ba barium 137.33 ±0.01	57-71 lanthanoids	72 Hf hafnium 178.49 ±0.01	73 Ta tantalum 180.95 ±0.01	74 W tungsten 183.84 ±0.01	75 Re rhenium 186.21 ±0.01	76 Os osmium 190.23 ±0.03	77 Ir iridium 192.22 ±0.01	78 Pt platinum 195.08 ±0.02	79 Au gold 196.97 ±0.01	80 Hg mercury 200.59 ±0.01	81 Tl thallium 204.38 ±0.01	82 Pb lead 207.2 ±1.1	83 Bi bismuth 208.98 ±0.01	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]
87 Fr francium [223]	88 Ra radium [226]	89-103 actinoids	104 Rf rutherfordium [267]	105 Db dubnium [268]	106 Sg seaborgium [269]	107 Bh bohrium [270]	108 Hs hassium [269]	109 Mt meitnerium [277]	110 Ds darmstadtium [281]	111 Rg roentgenium [282]	112 Cn copernicium [285]	113 Nh nihonium [286]	114 Fl flerovium [290]	115 Mc moscovium [290]	116 Lv livermorium [293]	117 Ts tennessine [294]	118 Og oganesson [294]

57 La lanthanum 138.91 ±0.01	58 Ce cerium 140.12 ±0.01	59 Pr praseodymium 140.91 ±0.01	60 Nd neodymium 144.24 ±0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ±0.02	63 Eu europium 151.96 ±0.01	64 Gd gadolinium 157.25 ±0.03	65 Tb terbium 158.93 ±0.01	66 Dy dysprosium 162.50 ±0.01	67 Ho holmium 164.93 ±0.01	68 Er erbium 167.26 ±0.01	69 Tm thulium 168.93 ±0.01	70 Yb ytterbium 173.05 ±0.02	71 Lu lutetium 174.97 ±0.01
89 Ac actinium [227]	90 Th thorium 232.04 ±0.01	91 Pa protactinium 231.04 ±0.01	92 U uranium 238.03 ±0.01	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]	103 Lr lawrencium [262]

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

DRIBS-III ACCELERATOR COMPLEX

FLEROV LABORATORY OF NUCLEAR REACTIONS

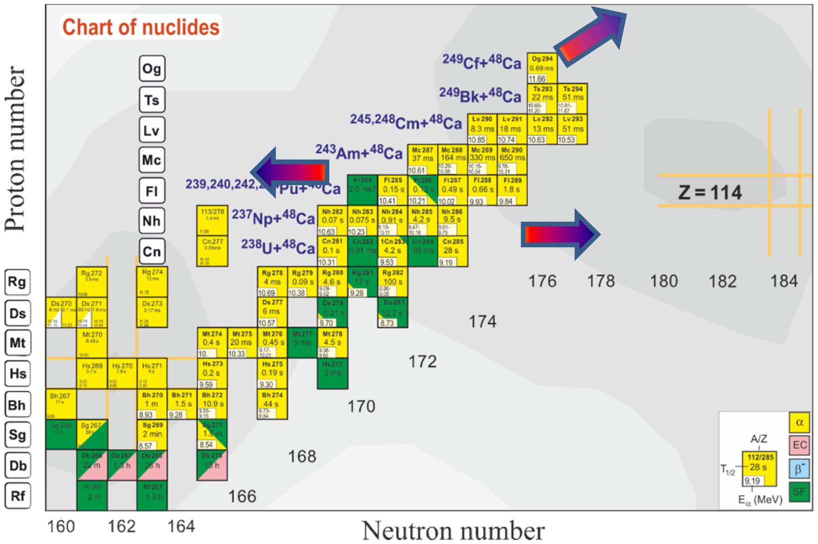
FLNR's basic directions of research:

- Heavy and superheavy nuclei
- Radioactive ion-beam research
- Radiation effects and physical groundwork of nanotechnology
- Accelerator technologies

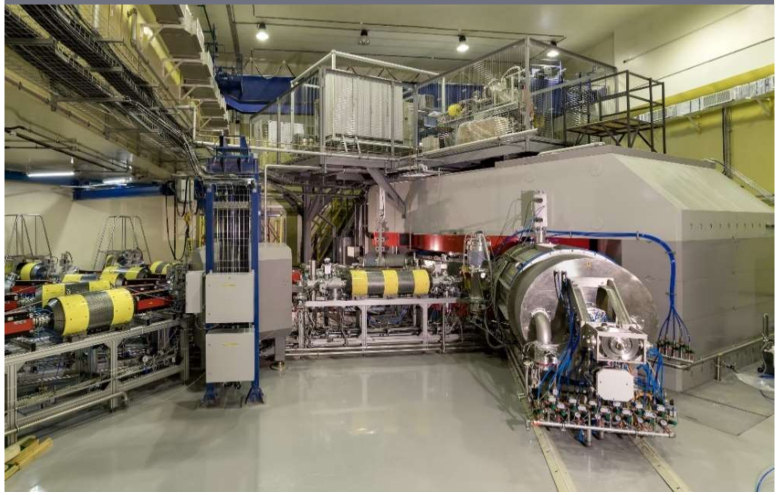
SHE research: Main tasks

Experiments at the extremely low (σ<100 fb) cross sections:
- Synthesis of new SHE with Z = 119 and 120 in reactions with ^{50}Ti, ^{54}Cr ...;
- Synthesis of new isotopes of SHE;
- Study of decay properties of SHE;
- Exploring limits the Island of Stability;
- Study of excitation functions.

Experiments requiring high statistics:
- Nuclear spectroscopy of SHE;
- Precise mass measurements;
- Study of chemical properties of SHE.



Beam of ^{48}Ca @ DC-280:
- *Intensity: up to $6 \cdot 10^{13}$ ions/s, 10 pμA*
- *Energy: 5 - 8 A·MeV*
- *Efficiency: ~50%*



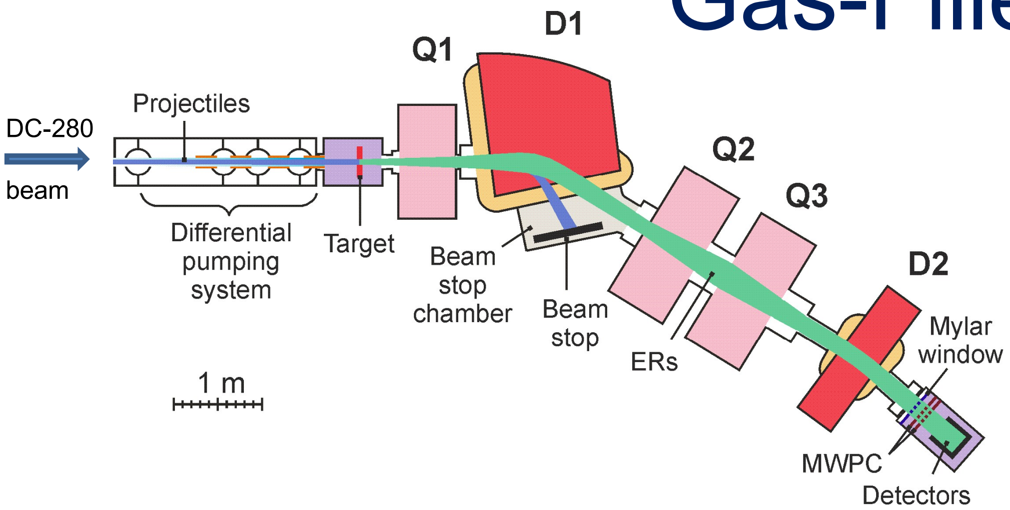
Cyclotron DC-280
Factory of superheavy elements

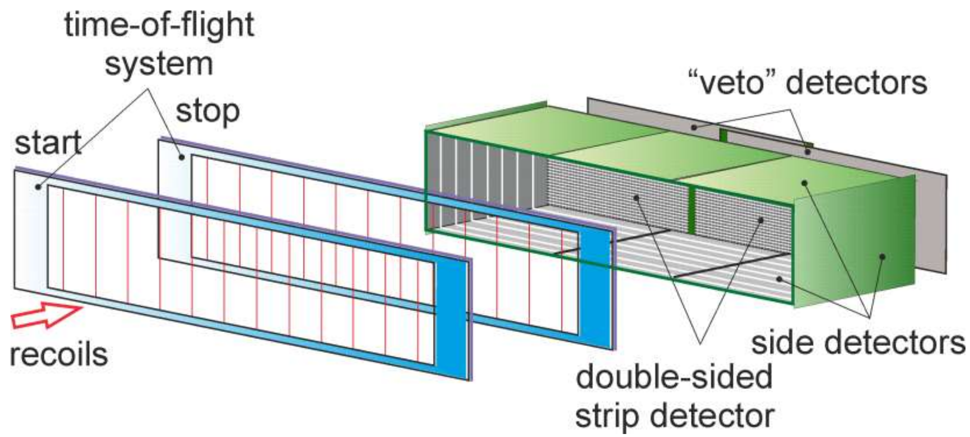
Beam of ^{48}Ca

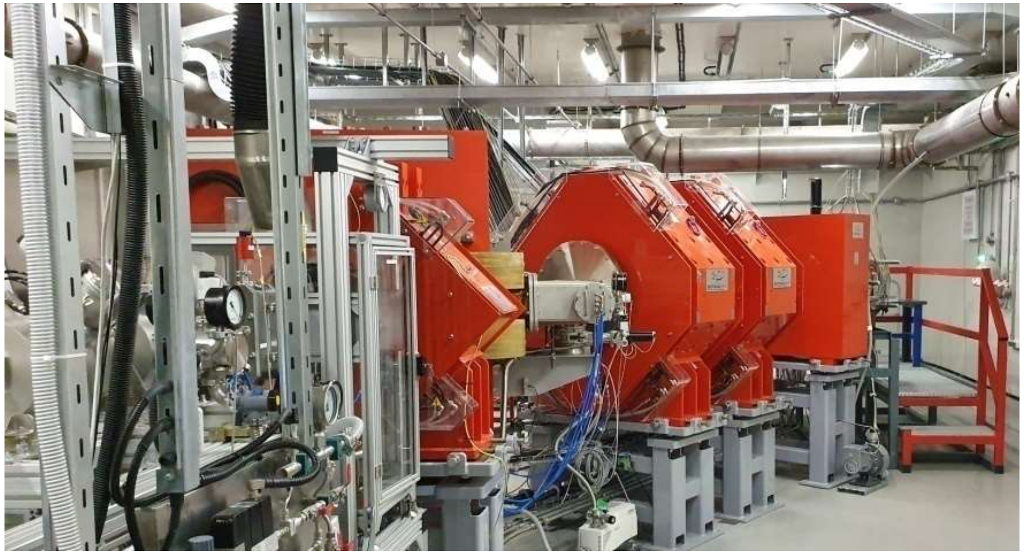
Achieved Intensity:
$4.3 \cdot 10^{13}$ ions/s

Efficiency:
~50%

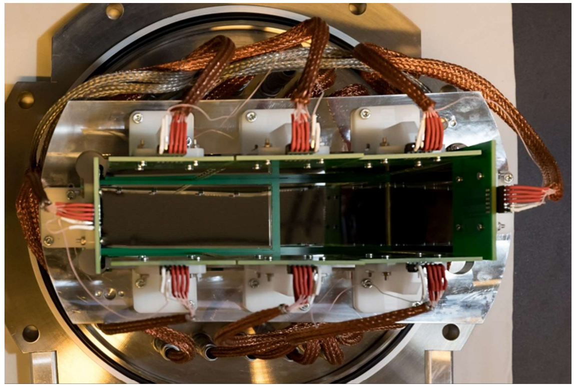
Gas-Filled Separator, **DGFRS-2**







^{242}Pu 24-cm target wheel
12 sectors



60×240 DSSD &
60×120 SSSD
Digital and analog electronics

$^{243}Am + ^{48}Ca \rightarrow ^{291}Mc^*$

~60 days

Nov.-Dec. 2020
Jan.-Feb. 2021
Jan.-Feb. 2022

Results of the first experiment ^{243}Am + ^{48}Ca

Technical tasks:

- Transmission
- Background
- Image size on detector
- Systematics of charge states
- Test of digital and analog data acquisition systems

Scientific tasks:

- Excitation function for *xn*-evaporation channels
- Decay properties
- Cross sections for the p*xn* channel
- EC branch for ^{288}Mc and ^{284}Nh

$I = 1.2\text{-}1.3$ pμA ~ $(7\text{-}8)\cdot 10^{12}$ ions/s

Transmission

- From ^{206}**Pb**(^{48}**Ca**,2n)^{252}**No** test reaction: 55±7%
- From ^{243}**Am**(^{48}**Ca**,2-3n)^{288,289}**Mc** reaction:

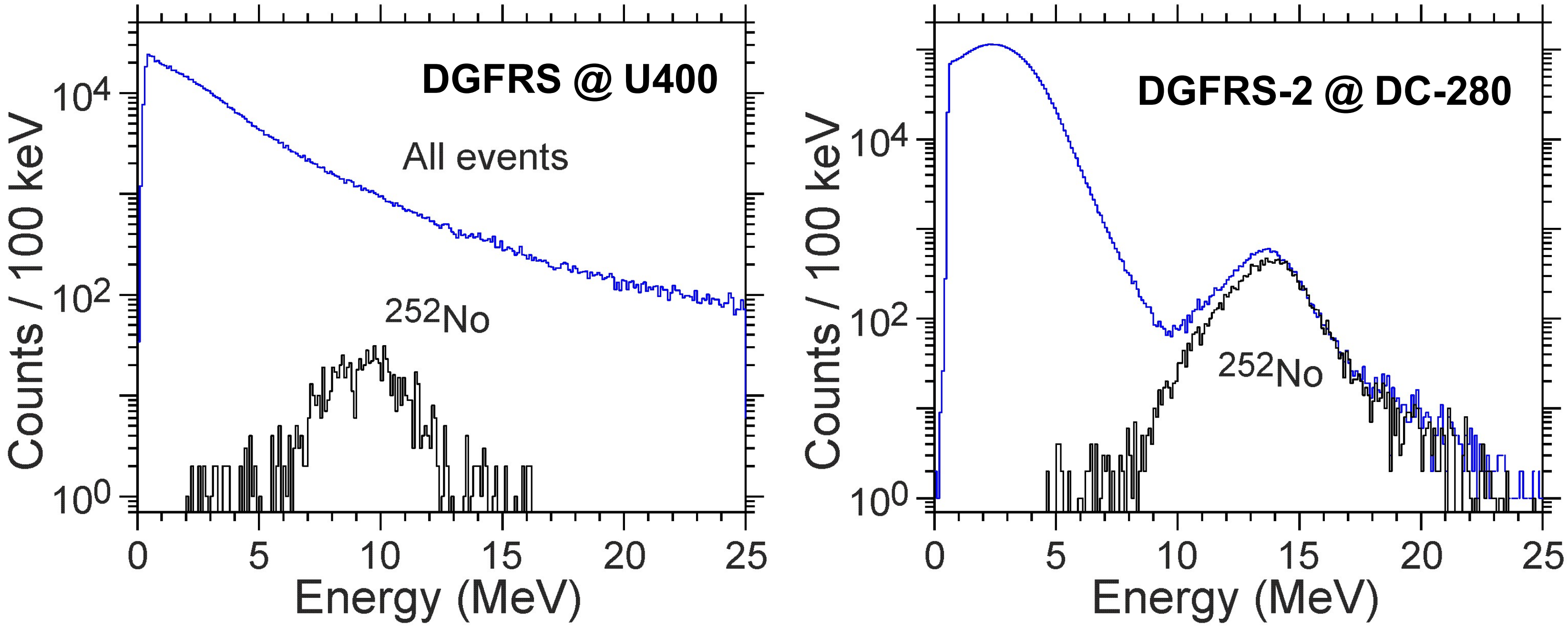
Comparison of results at the same ^{48}**Ca** energy

	DGFRS @ U400	DGFRS-2 @ DC-280
Target thickness, mg/cm^2	0.37	0.43
Beam dose, 10^{18}	3.3	3.4
No decay chains	^{288}Mc – 6 ^{289}Mc – 0	^{288}Mc – 13 ^{289}Mc – 2
Yield	1	1.8-2.1

Background conditions

$^{206}Pb + ^{48}Ca \rightarrow ^{252}No + 2n$ (Cross section 0.5 mb)

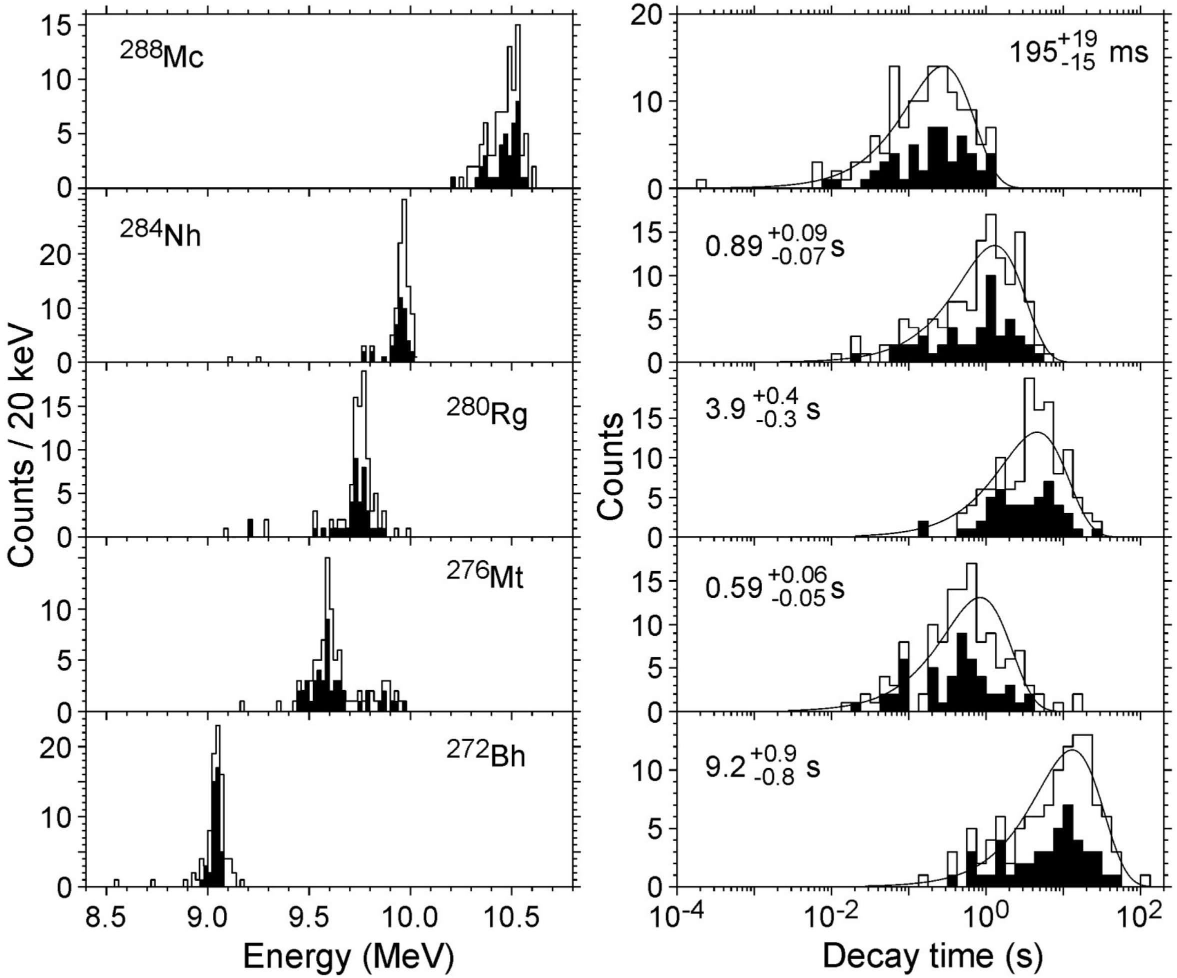
Background suppression is 200+ higher at the DGFRS-2 than at DGFRS



Energy spectra of all the particles registered by MWPC (top blue line) and of ^{252}No (bottom black line) nuclei produced in the $^{206}Pb(^{48}Ca,2n)$ reaction using separators DGFRS (a) and DGFRS-2 (b).

Results of the first experiment

^{288}Mc decay properties

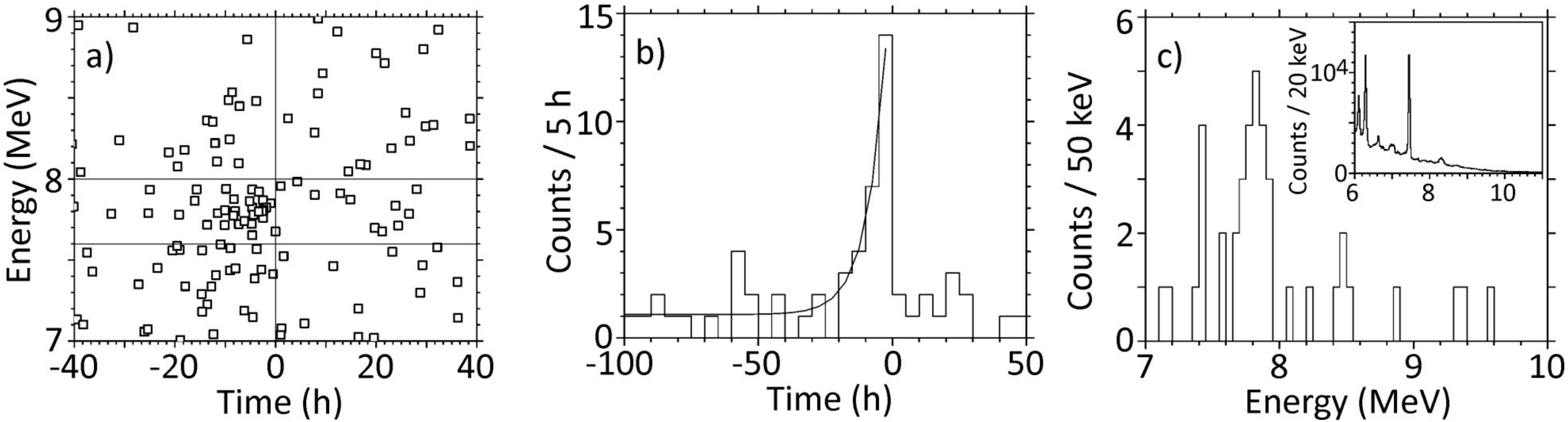


DGFRS, JINR
TASCA, GSI
BGS, LBNL

DGFRS-2, JINR

First observation of α–decay of ^{268}Db and new isotope ^{264}Lr

b_{α} (^{268}Db) = 55 ($^{+20}_{-15}$) % **$T_{1/2}$ (^{268}Db) = 16 ($^{+6}_{-4}$) h** **$T_{1/2}$ (^{264}Lr, SF) = 4.9 ($^{+2.1}_{-1.3}$) h**



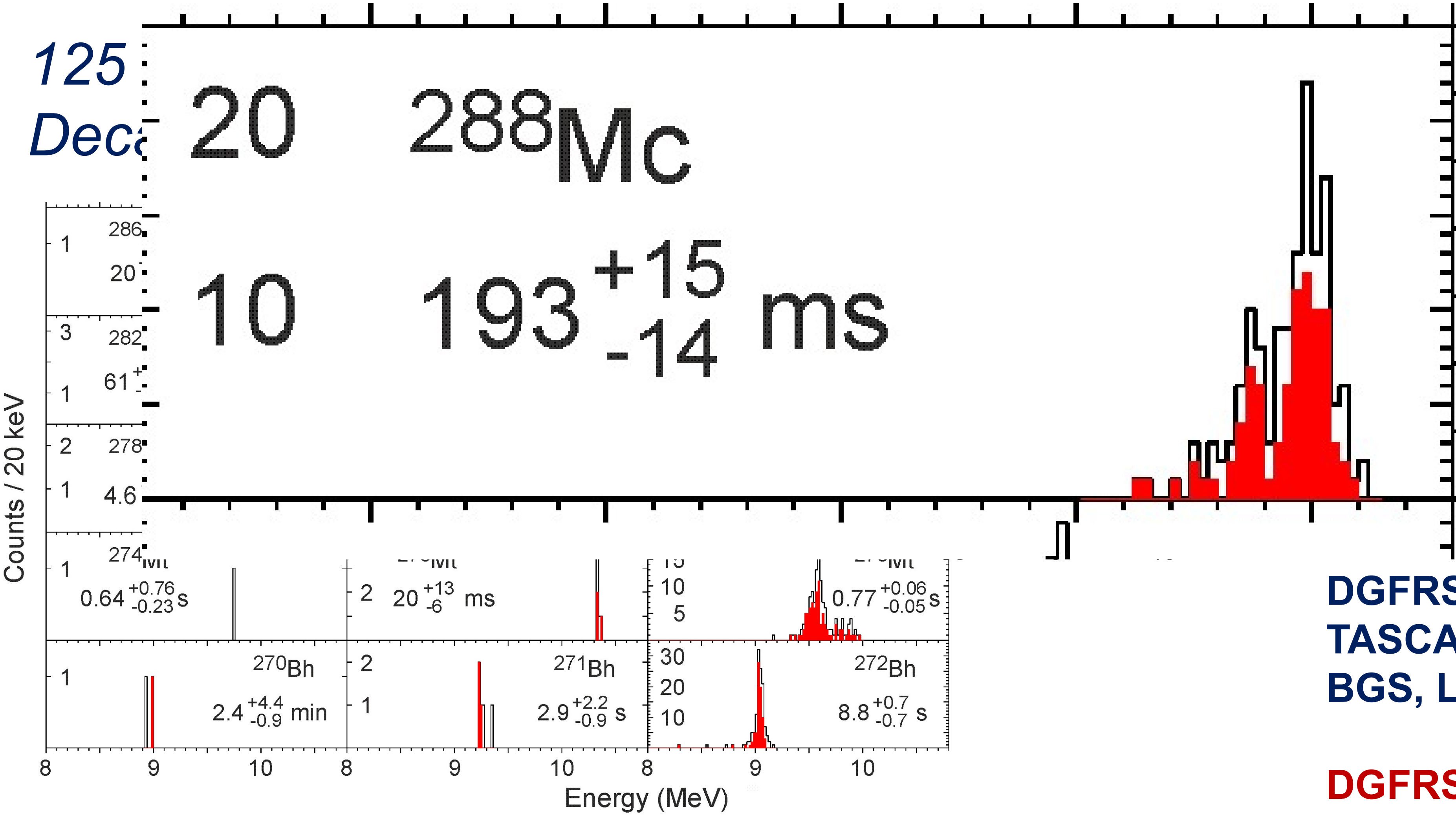
Эксперимент по исследованию характеристик распада ядер московия (Z=115), нарабатываемых на Фабрике сверхтяжелых элементов ОИЯИ

энергия (МэВ)	239.1	240.9	242.2	243.9	250.1	259.1	**Фабрика СТЭ**	*было до*
^{286}Mc (*5n*)	-	-	-	-	-	1	**1**	*0*
^{287}Mc (*4n*)	-	-	2	-	1	1	**4**	*3*
^{288}Mc (*3n*)	9	16	52	30	3	-	**110**	*31*
^{289}Mc (*2n*)	-	1	4	5	-	-	**10**	*18*

$^{243}Am(^{48}Ca,2\text{-}5n)^{286\text{-}289}Mc$ Reaction

125

Deca



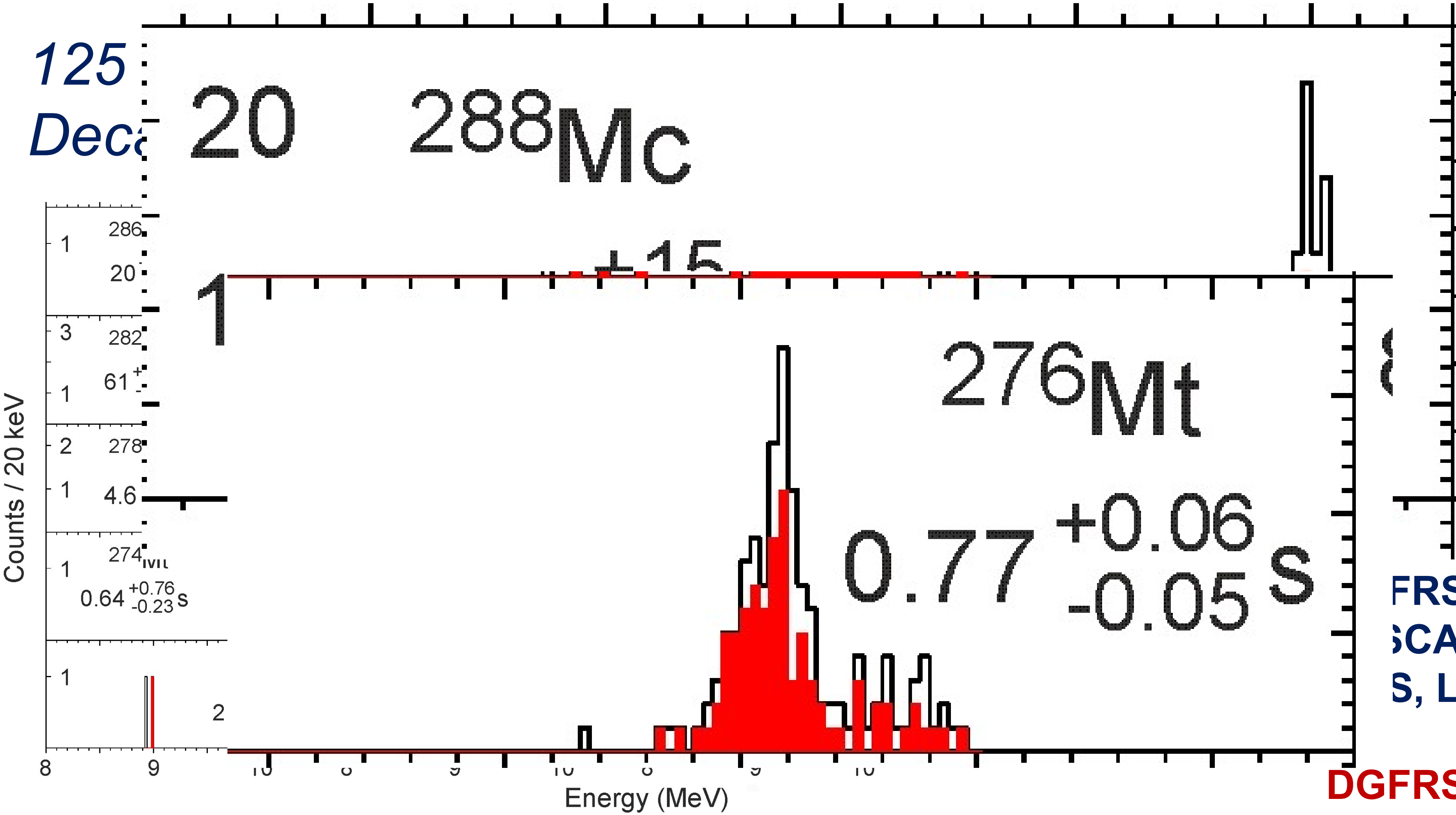
DGFRS, JINR
TASCA, GSI
BGS, LBNL

DGFRS-2, JINR

^{243}Am(^{48}Ca,2-5n)$^{286-289}$Mc Reaction

125

Deca



FRS, JINR

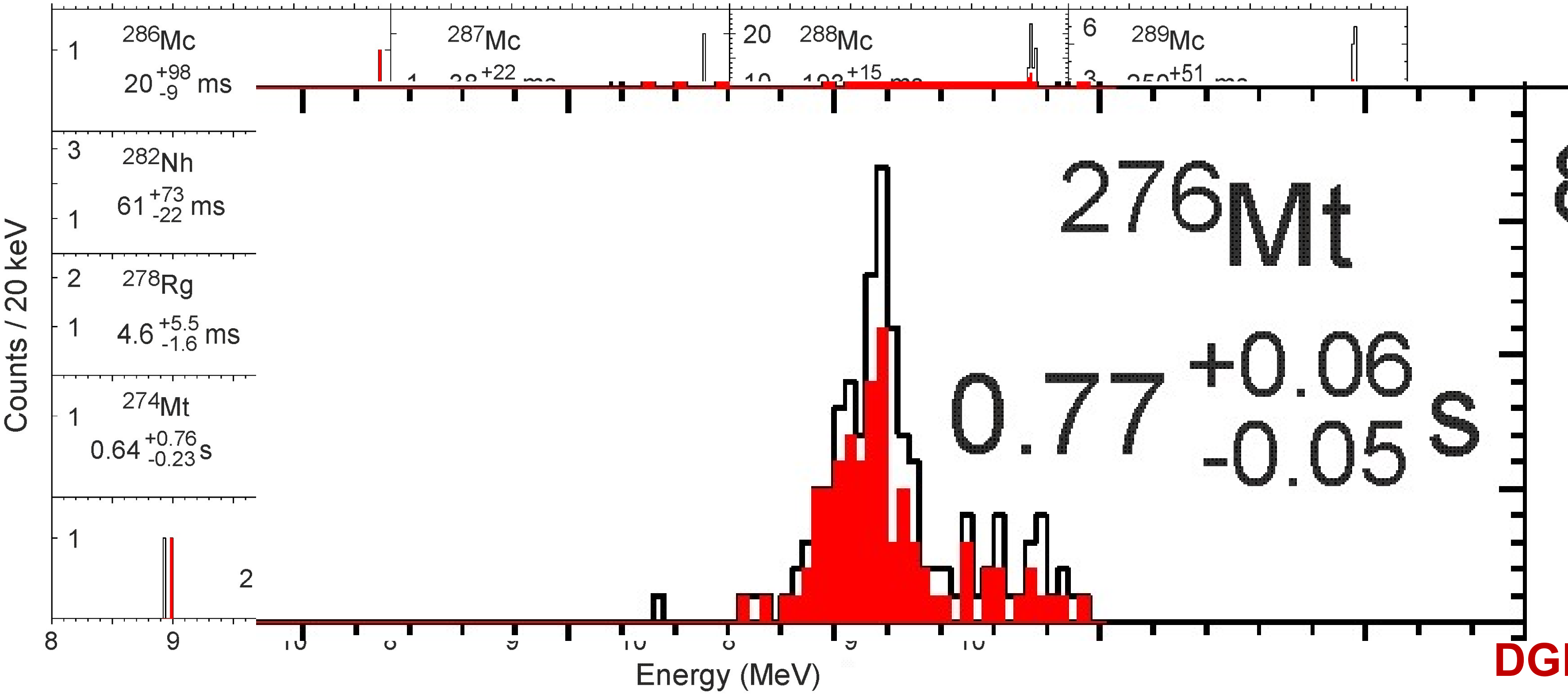
SCA, GSI

S, LBNL

DGFRS-2, JINR

$^{243}Am(^{48}Ca,2\text{-}5n)^{286\text{-}289}Mc$ Reaction

125 decay chains
Decay properties of 22 isotopes



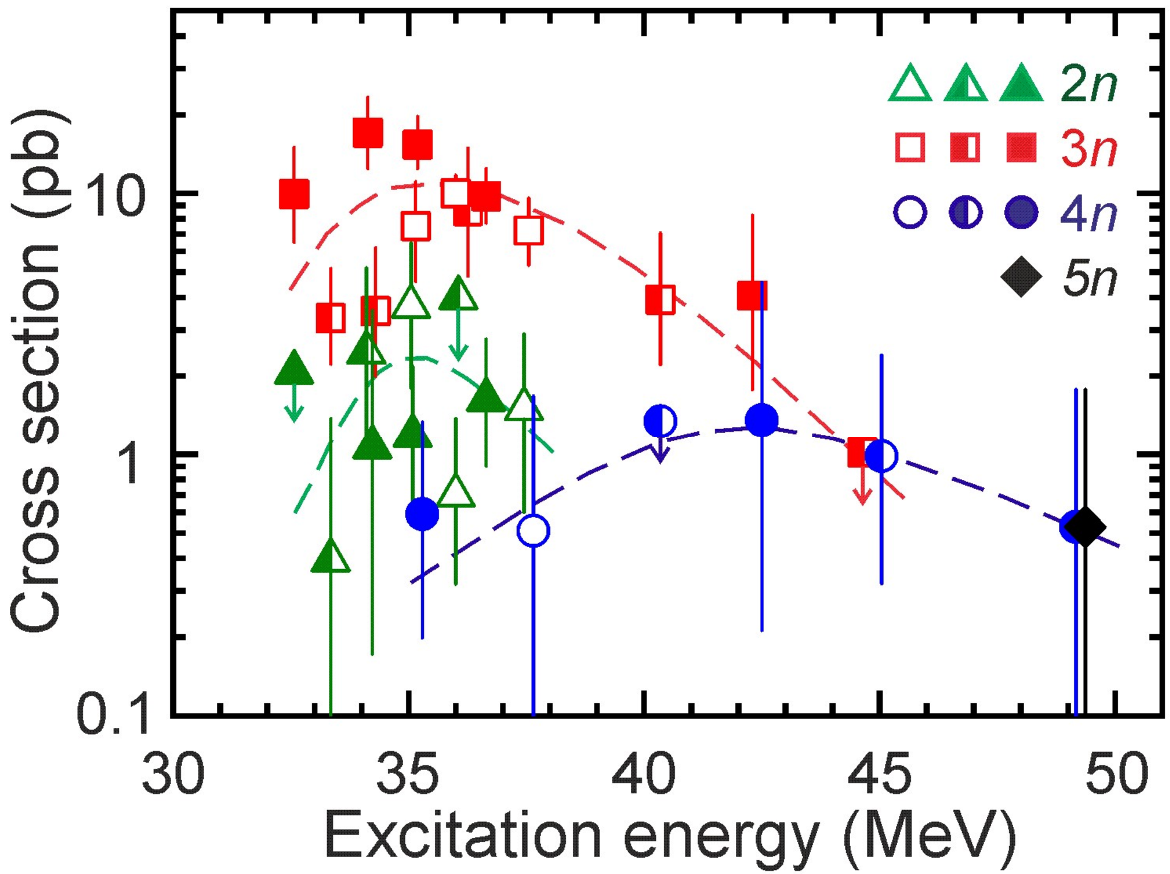
FRS, JINR
SCA, GSI
S, LBNL

DGFRS-2, JINR

Results of the first experiments

Excitation function

DGFRS (open),
TASCA (half open),
DGFRS-2 (filled)

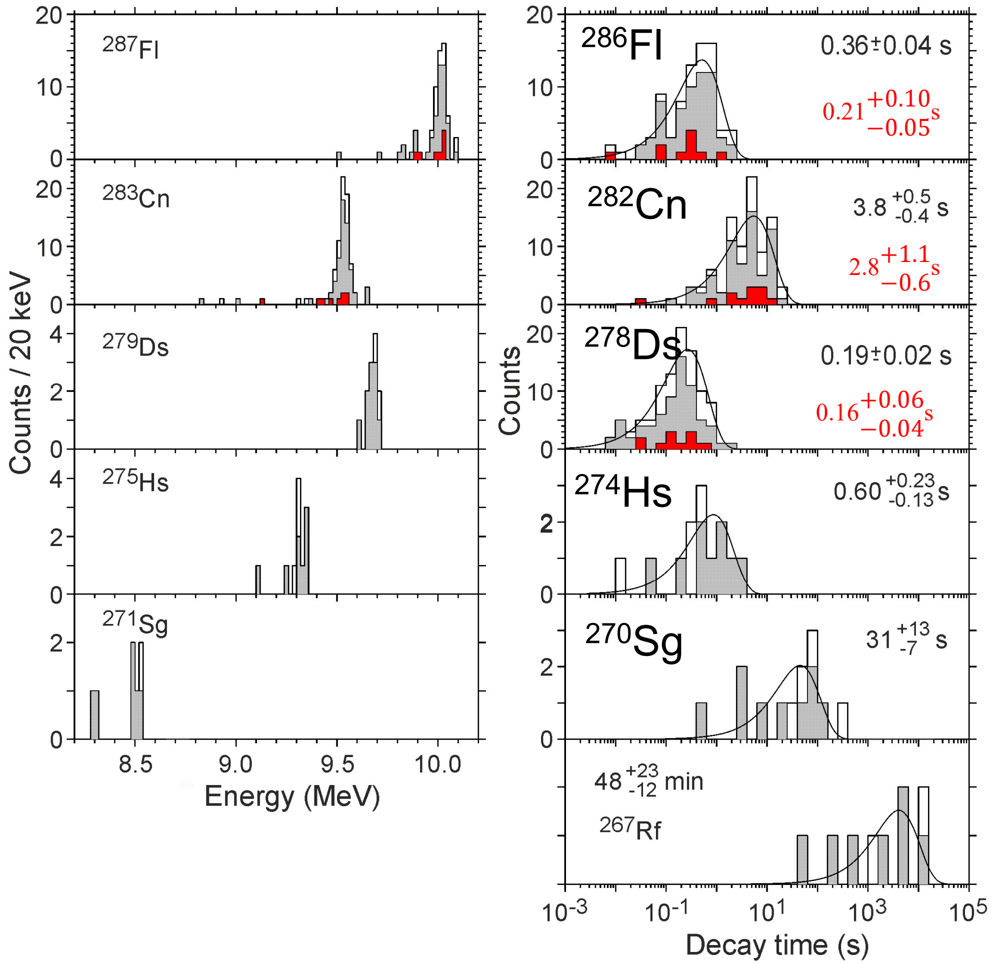


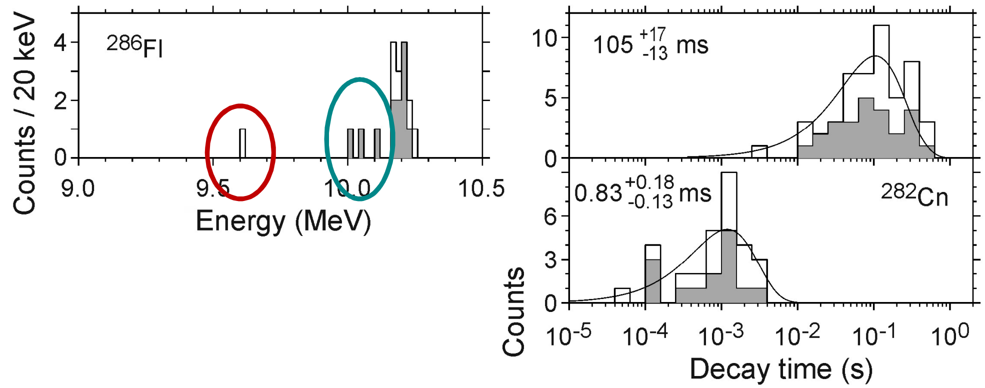
$$^{242}Pu + ^{48}Ca \rightarrow ^{290}Fl^{*}$$

Completed in June 2021

$^{242}Pu(^{48}Ca,3\text{-}4n)^{286,287}Fl$ and $^{238}U(^{48}Ca,3n)^{283}Cn$

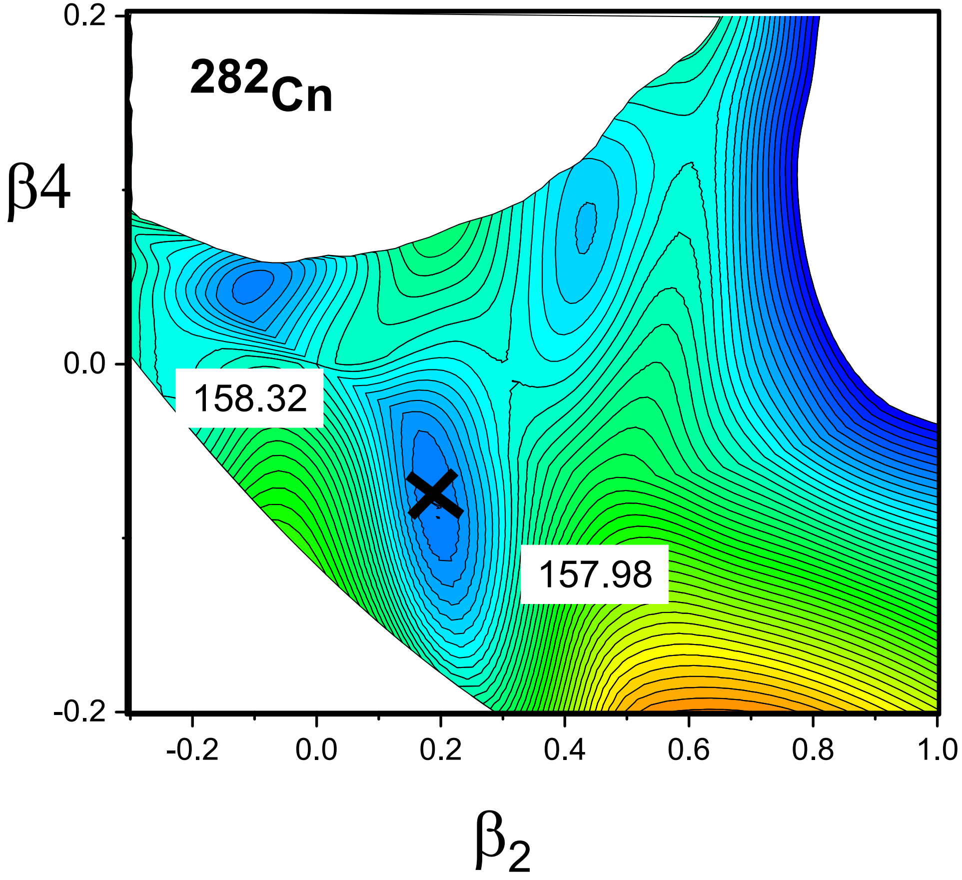
Decay properties of 8 isotopes





- ***^{287}Fl, ^{283}Cn, and ^{279}Ds**: decay through different states*
- ***^{286}Fl**: α–decay line 9.6 MeV for was not observed*
  A. Såmark-Roth et al., PRL (2021)
- ***^{286}Fl**: decay on 2$^+$ rotational state **^{282}Cn** or through isomeric states*

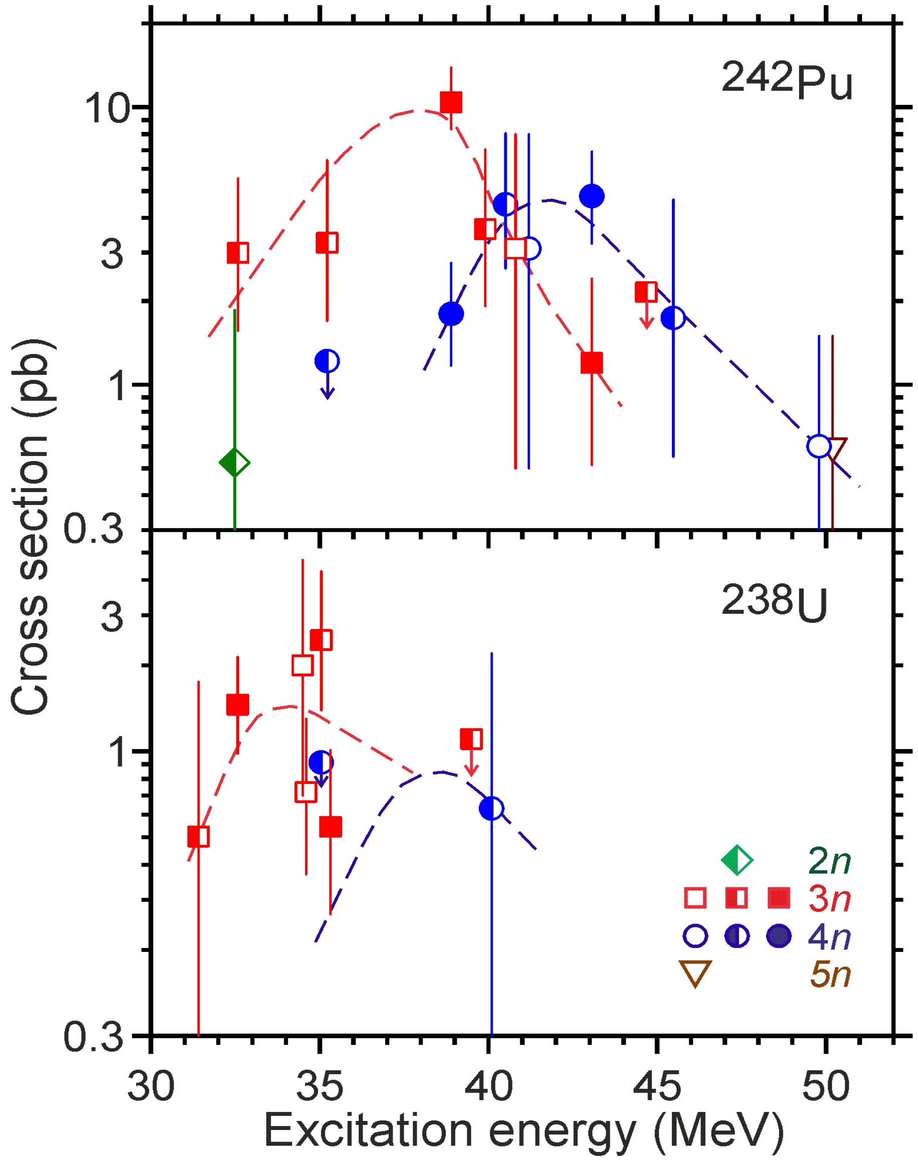
Presumable α-decay of ^{286}Fl on rotational 2^+-state of ^{282}Cn



"experiment":
E_{2+} = 100 - 200 keV
0^+: 82% and 2^+: 18%

deduced for 0^+: 82% and 2^+: 18%
β_2 = 0.13
E_{2+} = 101 keV

Nucleus	β_2	$E(2_1^+)$ (keV)
^{258}Fm	0.274	51
^{262}No	0.256	51
^{266}Rf	0.235	70
^{270}Sb	0.242	60
^{274}Hs	0.237	74
^{278}Ds	0.197	66
^{282}Cn	0.160	102
^{286}Fl	-0.154	144
^{290}Lv	0.078	431
^{294}Og	-0.105	242
^{298}120	-0.092	335



Excitation functions

$^{242}Pu(^{48}Ca,3\text{-}4n)^{286,287}Fl$

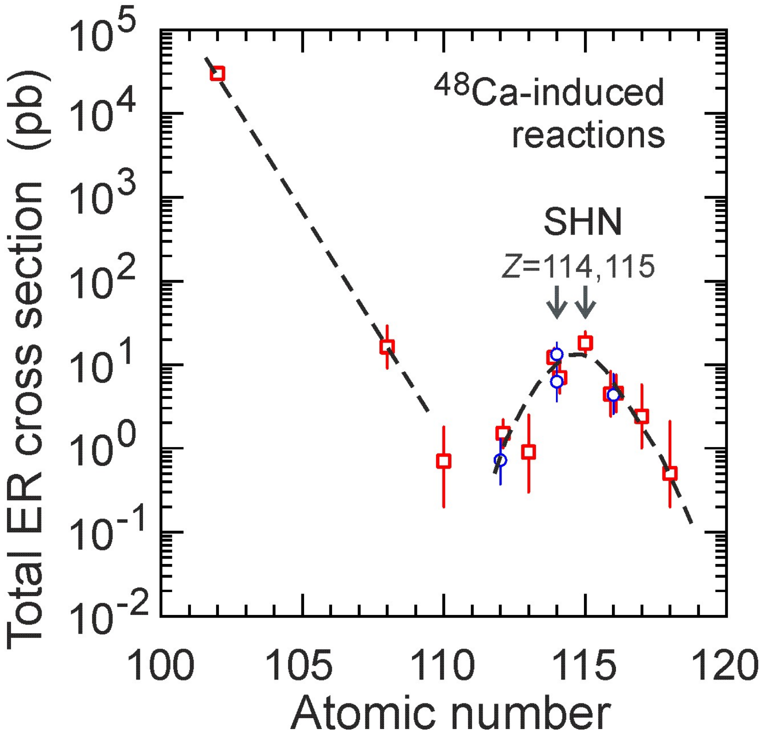
94 new events

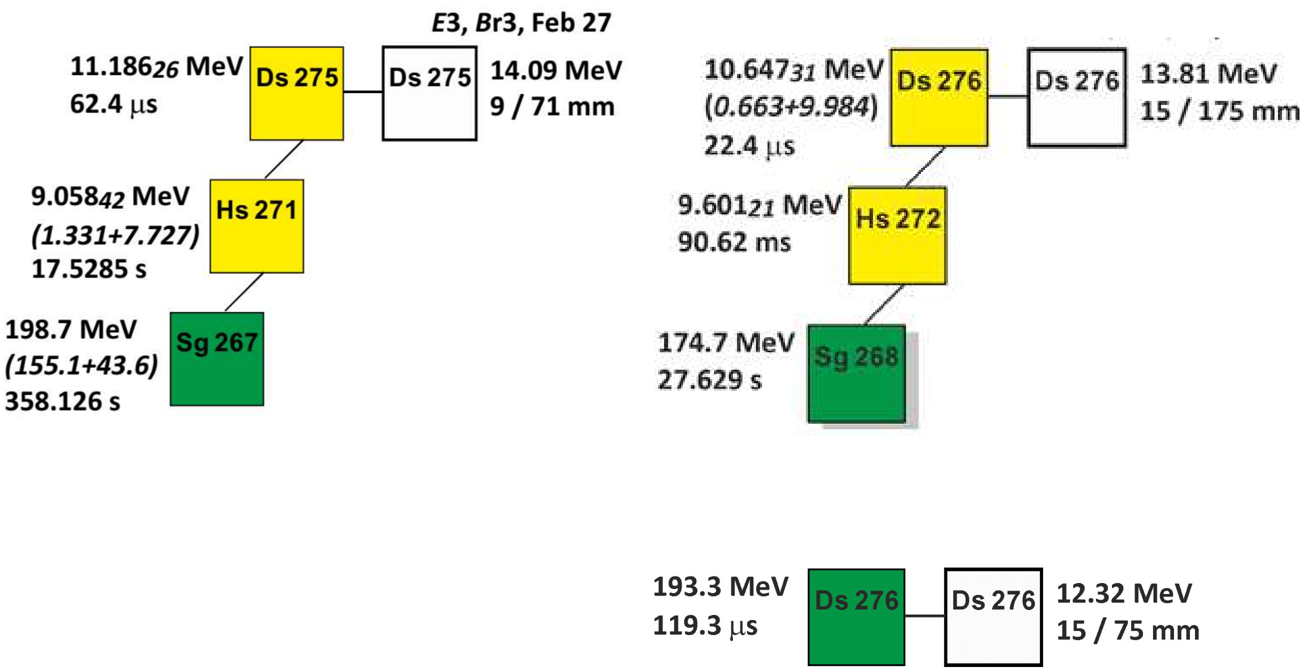
$^{238}U(^{48}Ca, 3n)^{283}Cn$

16 new decay chains

Towards element 120: the first experiment $^{48}Ca + ^{232}Th \rightarrow ^{280}Ds^*$

- Stability and production cross section is expected to have a minimum for the element 110. The fission barrier is predicted to be 3.3 MeV only.
- The same theory predicts 5.1 MeV barrier for the element 120.



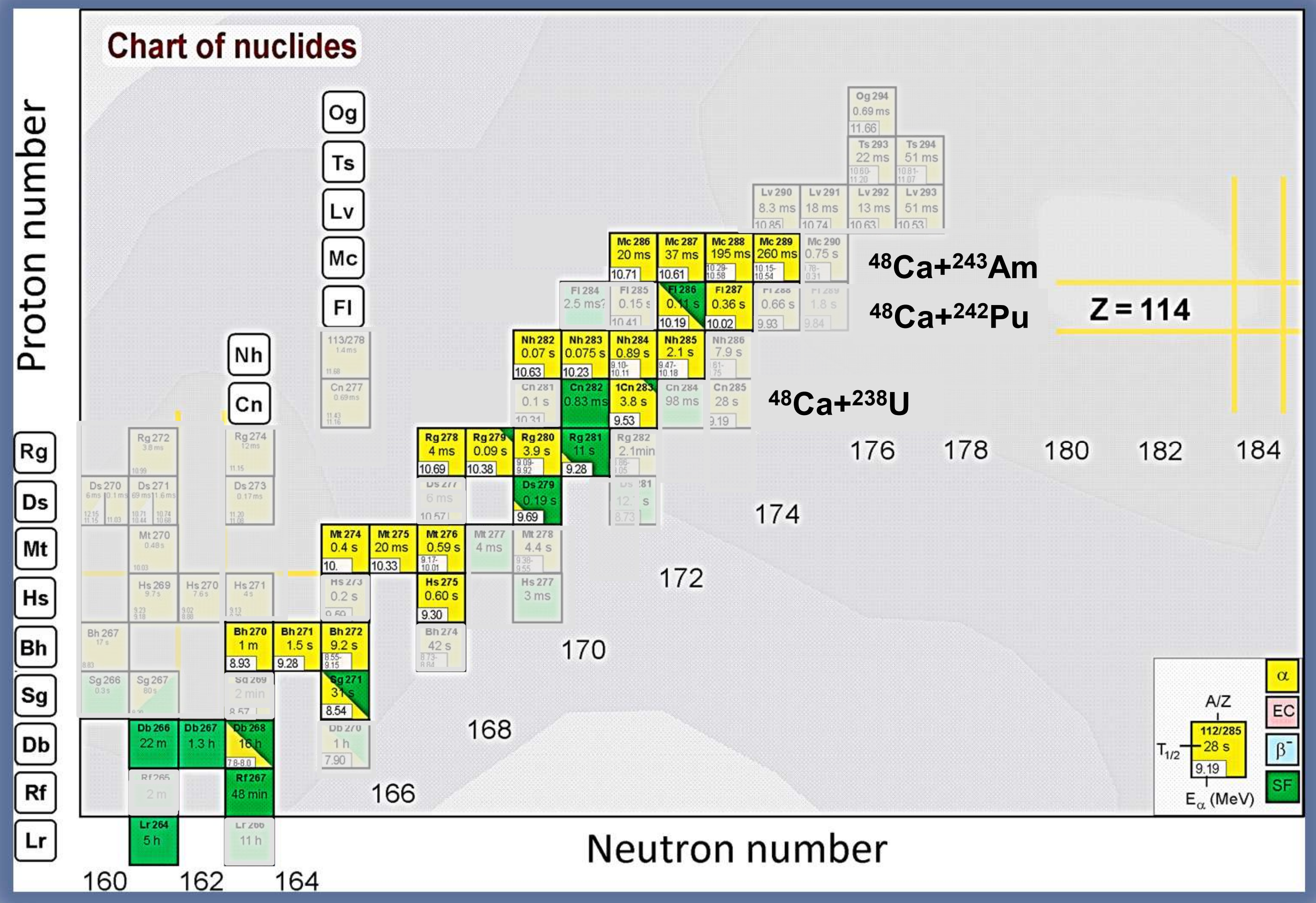


Summary of experiments @ Superheavy Element Factory in 2020-2023

Experiments:

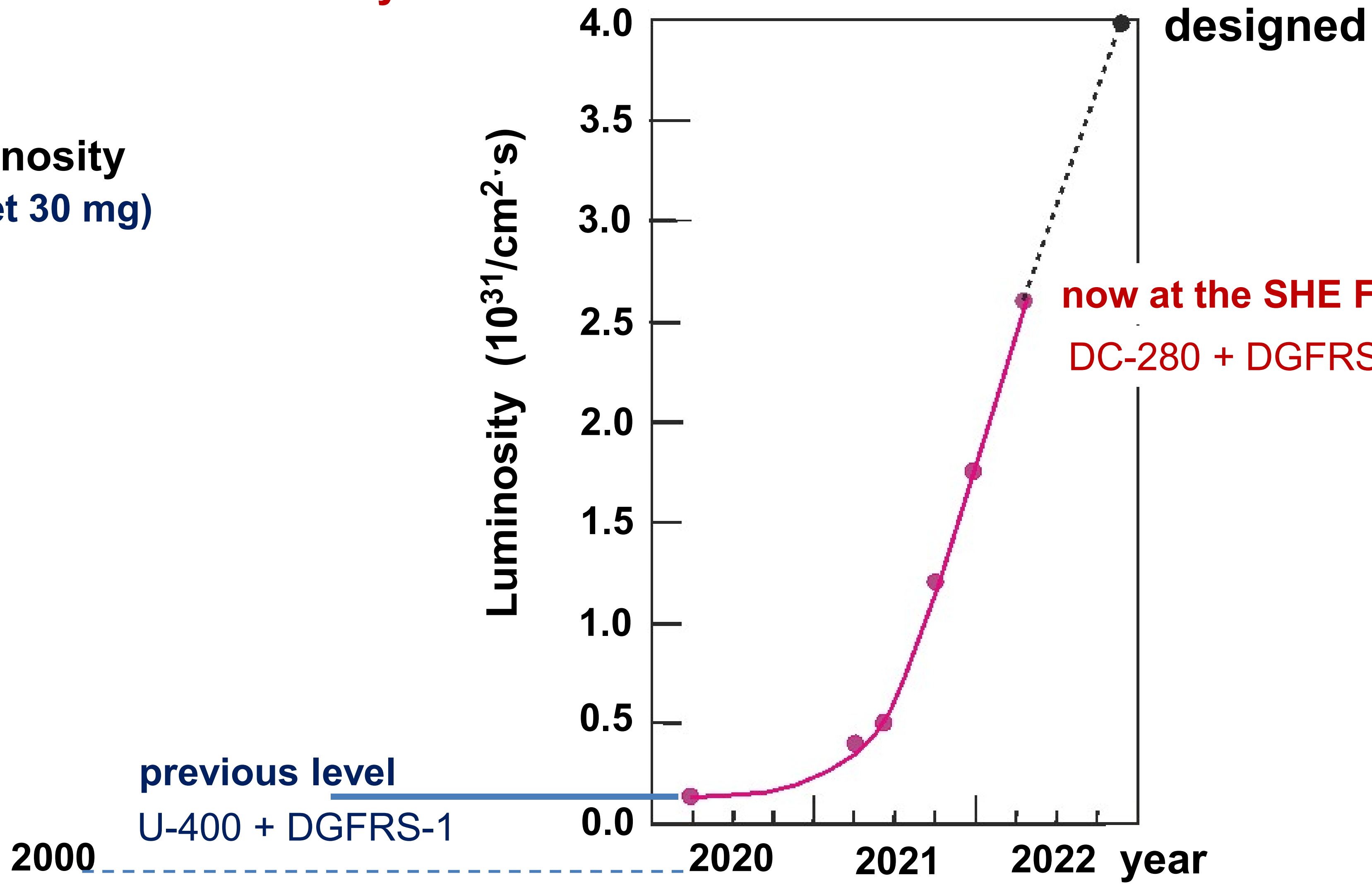
$^{243}Am + ^{48}Ca \rightarrow ^{291}Mc^*$
$^{242}Pu + ^{48}Ca \rightarrow ^{290}Fl^*$
$^{238}U + ^{48}Ca \rightarrow ^{286}Cn^*$
$^{232}Th + ^{48}Ca \rightarrow ^{280}Ds^*$

- 239 new events of synthesis of superheavy nuclides;
- Decay properties 36 isotopes;
- New isotopes: ^{286}Mc, ^{264}Lr, ^{275}Ds, ^{276}Ds, ^{272}Hs , ^{268}Sg , ^{267}Sg;
- New decay modes: ^{268}Db (alpha-decay), ^{279}Rg (spontaneous fission);
- Indication of the 1st excited state in ^{286}Fl;
- Test of target stability up to 6.5 pμA of ^{48}Ca;



Progress at SHE-Factory

Luminosity
(target 30 mg)



by Yu. Oganessian

SHE research program with existing separators @ SHE Factory

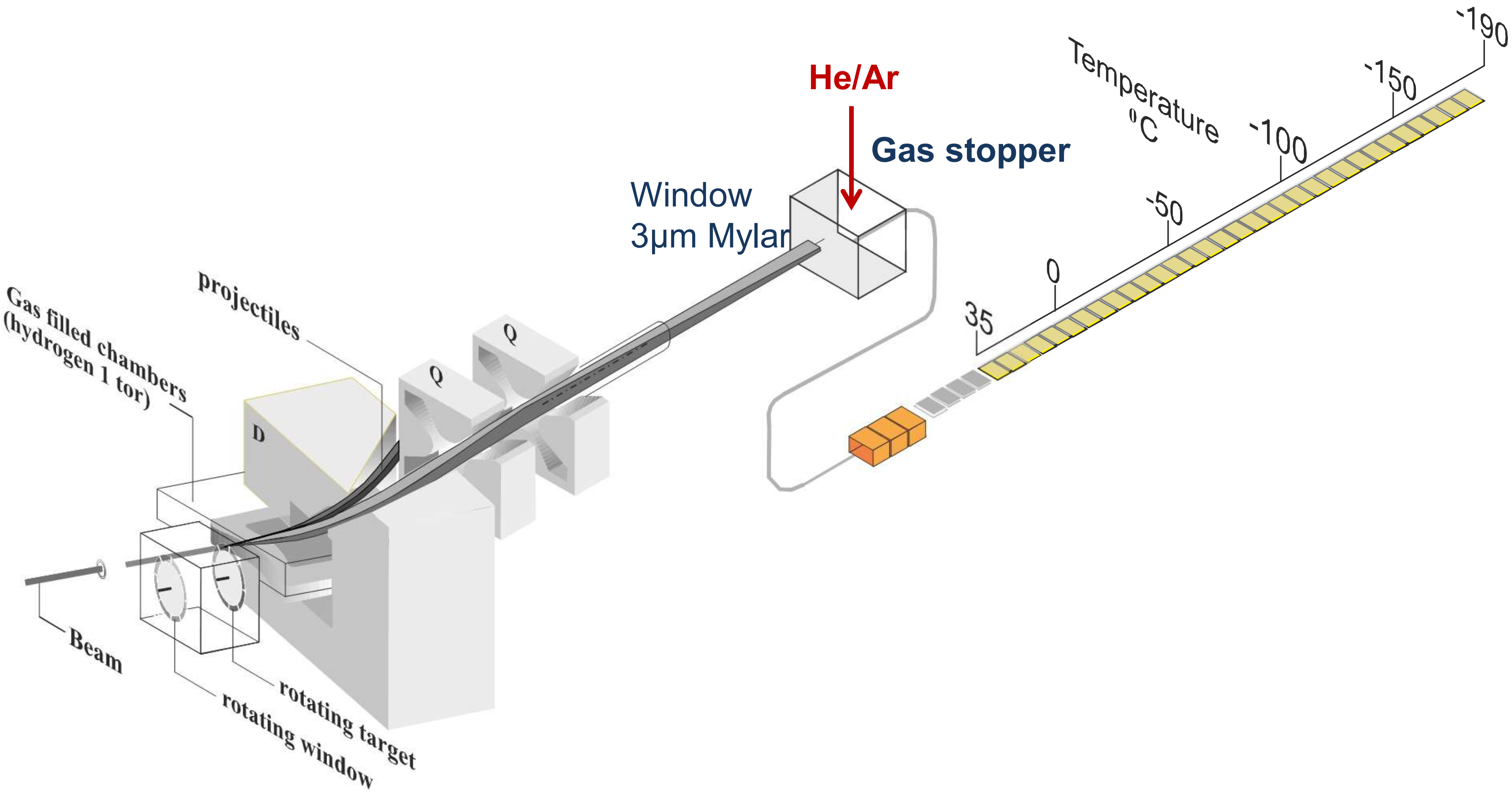
DGFRS-3:
launched in 2022

- Spectroscopy of SHE;
- Chemical studies for SH nuclei with half-lives **longer than 1 sec** (114 and lighter);
- Precise mass measurements (new developments are due);

DGFRS-2:
launched in 2020

- Synthesis of new SHE;
- Synthesis of new neutron-deficient isotopes of SHE: “shaping” of island of stability;
- Search for rear decay channels in ^{48}Ca-induced reactions (EC, pxn, 1-2n): towards island of stability;
- Decay modes, excitation functions, etc.

CHEMISTRY OF SHE



Недостатки: довольно большой объем “стоп” камеры.
Трансмиссия сепаратора ~ 35 %.

The relativistic effect and chemistry of SHE

In experiments (R. Eichler et al., 2007), the influence of the relativistic effect on the formation of the compound [CnAu] was studied in comparison with its light homologue [HgAu] at different temperatures.

The first experiments

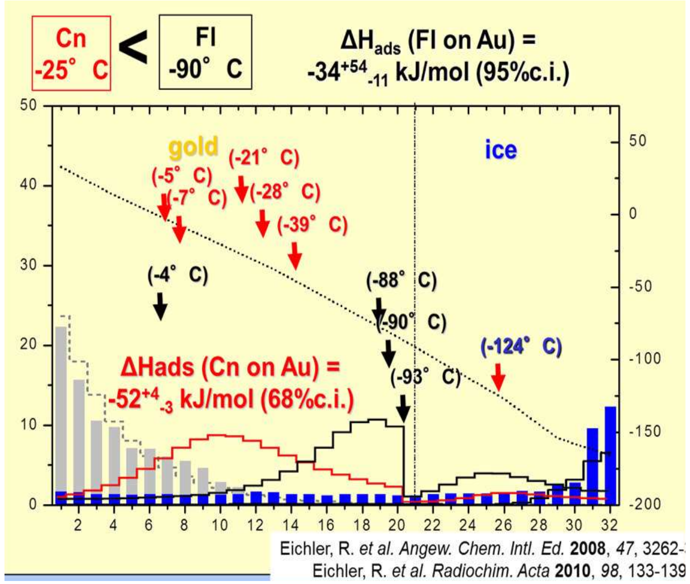
Z	Isotope	Half-life
112	^{283}Cn	3.6 s
113	^{284}Nh	0.9 s
114	^{287}Fl	0.5 s
115	^{288}Mc	0,16 s
116	^{293}Lv	57 ms
117	^{294}Ts	51 ms
118	^{294}Og	0.6 ms

The effect is expected to increase rapidly but not monotonically with increasing atomic number of SHE. In principle it may be observed today for all SHE from Z=112 to 118.

Radiochim. Acta **98**, 133–139 (2010) / **DOI** 10.1524/ract.2010.1705

Indication for a volatile element 114

By R. Eichler[1,2,*], N. V. Aksenov[3], Yu. V. Albin[3], A. V. Belozerov[3], G. A. Bozhikov[3], V. I. Chepigin[3], S. N. Dmitriev[3], R. Dressler[1], H. W. Gäggeler[1,2], V. A. Gorshkov[3], R. A. Henderson[4], A. M. Johnsen[4], J. M. Kenneally[4], V. Ya. Lebedev[3], O. N. Malyshev[3], K. J. Moody[4], Yu. Ts. Oganessian[3], O. V. Petrushkin[3], D. Piguet[1], A. G. Popeko[3], P. Rasmussen[1], A. Serov[1,2], D. A. Shaughnessy[4], S. V. Shishkin[3], A. V. Shutov[3], M. A. Stoyer[4], N. J. Stoyer[4], A. I. Svirikhin[3], E. E. Tereshatov[3], G. K. Vostokin[3], M. Wegrzecki[5], P. A. Wilk[4], D. Wittwer[2] and A. V. Yeremin[3]



- высокая летучесть и инертность в атомарном состоянии
- физисорбция на золоте
- благородный металл или газ

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TYPE Original Research
PUBLISHED 25 August 2022
DOI 10.3389/fchem.2022.976635

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On the adsorption and reactivity of element 114, flerovium

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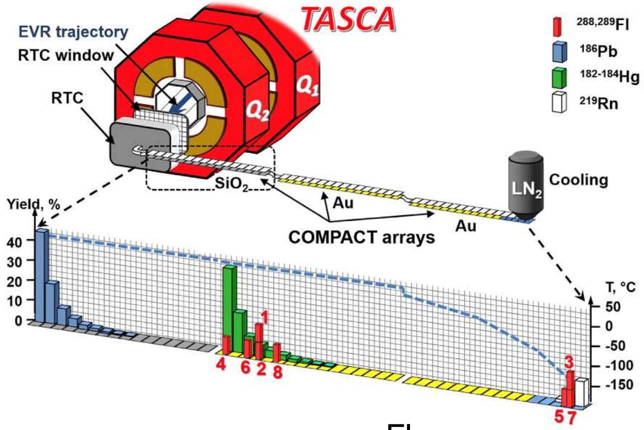
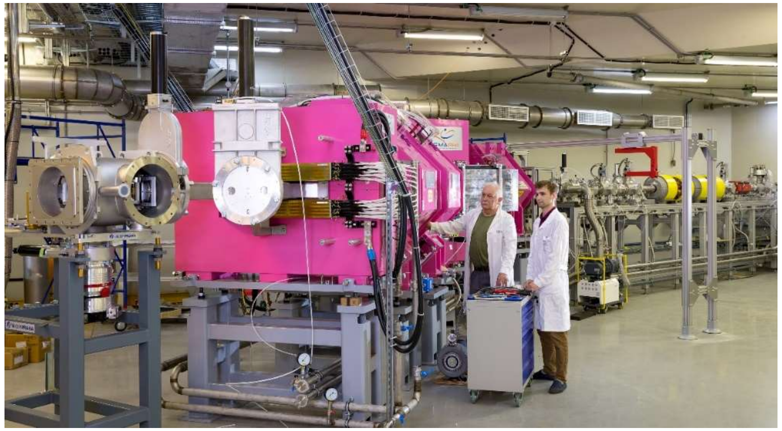
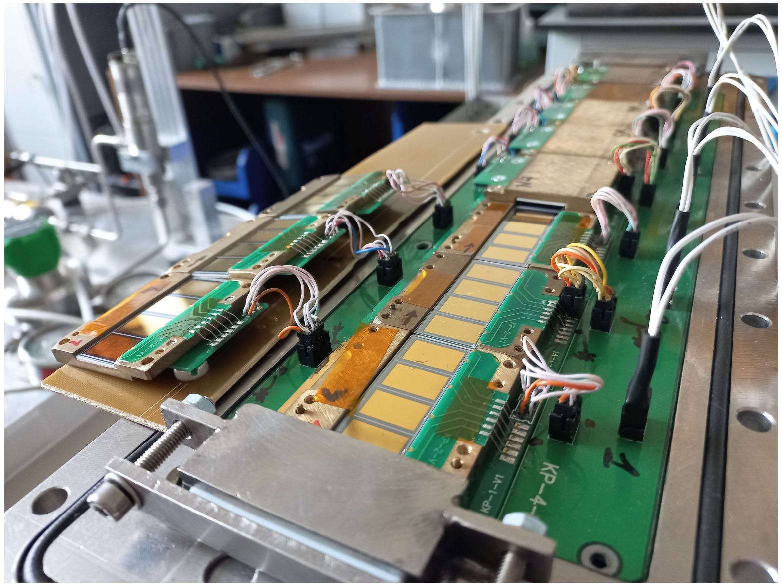


- высокая летучесть Fl
- хемосорбция на золоте
- металлические свойства
- две зоны осаждения Fl
- два сценария

Chemistry of elements Cn and Fl
GRAND (Gas-filled Recoil Analyzer and Nuclei Detector) DGFRS-3





Status:

- Detection setup was developed and installed at the GRAND separator.

- Test experiments were carried out with mercury and nobelium isotopes produced in fusion reactions. The purpose was testing and further setup optimization.

First run (Nov.-Dec. 2022) $^{48}Ca + ^{242}Pu$:

- 1 event of the element 112 was observed.
- 1 event of the element 114 was observed.

Second run of the chemical experiment is scheduled for the second half of 2023 following the improvement of the experimental setup.

Перспективы

Synthesis of new elements @ SHE Factory

$^{54}Cr + ^{248}Cm \rightarrow 3n + ^{299}120$

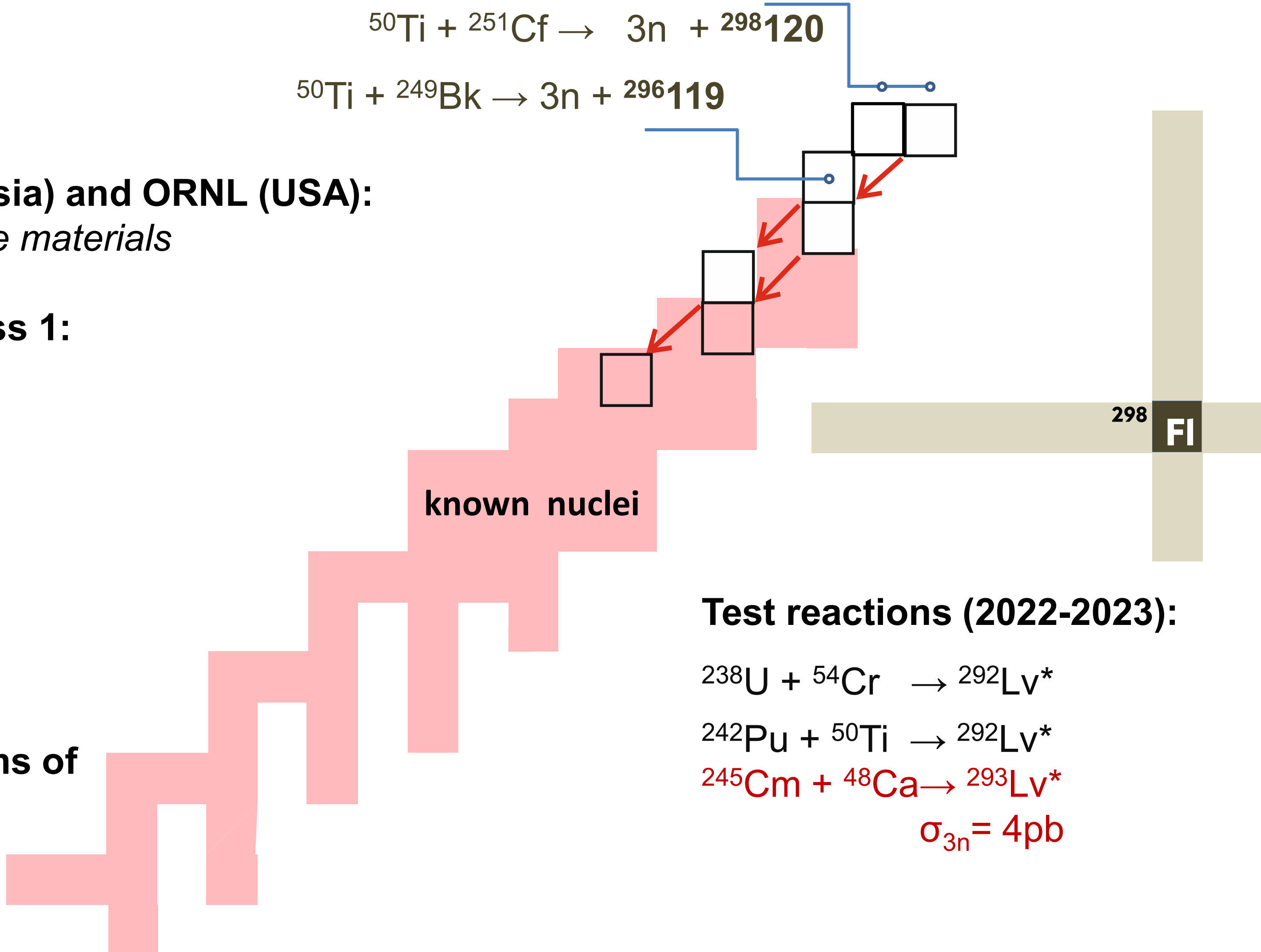
$^{50}Ti + ^{251}Cf \rightarrow 3n + ^{298}120$

$^{50}Ti + ^{249}Bk \rightarrow 3n + ^{296}119$

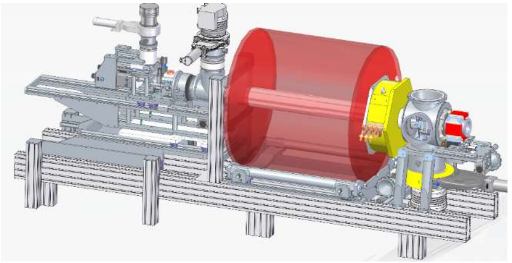
TARGETS

- **Cooperation with Rosatom (Russia) and ORNL (USA):**
  Isotopically enriched heavy actinide materials

- **Radiochemical laboratory of class 1:**
  Stability studies &
  Manufacturing and regeneration



BEAMS



- **Production of high-intensity beams of ^{50}Ti, ^{54}Cr and others**

- **New ECR-28 GHz (2024)**

Test reactions (2022-2023):

$^{238}U + ^{54}Cr \rightarrow ^{292}Lv^{*}$

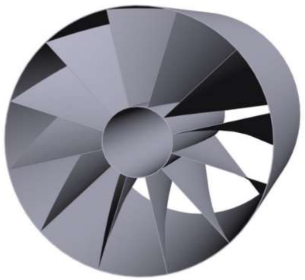
$^{242}Pu + ^{50}Ti \rightarrow ^{292}Lv^{*}$

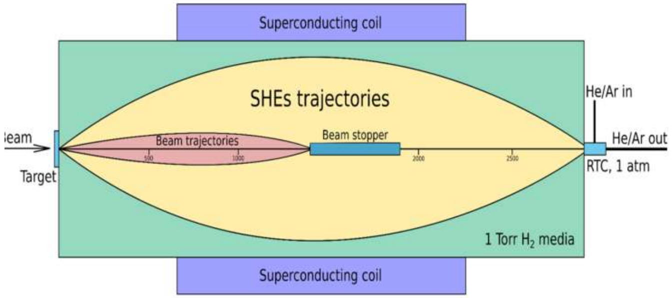
$^{245}Cm + ^{48}Ca \rightarrow ^{293}Lv^{*}$

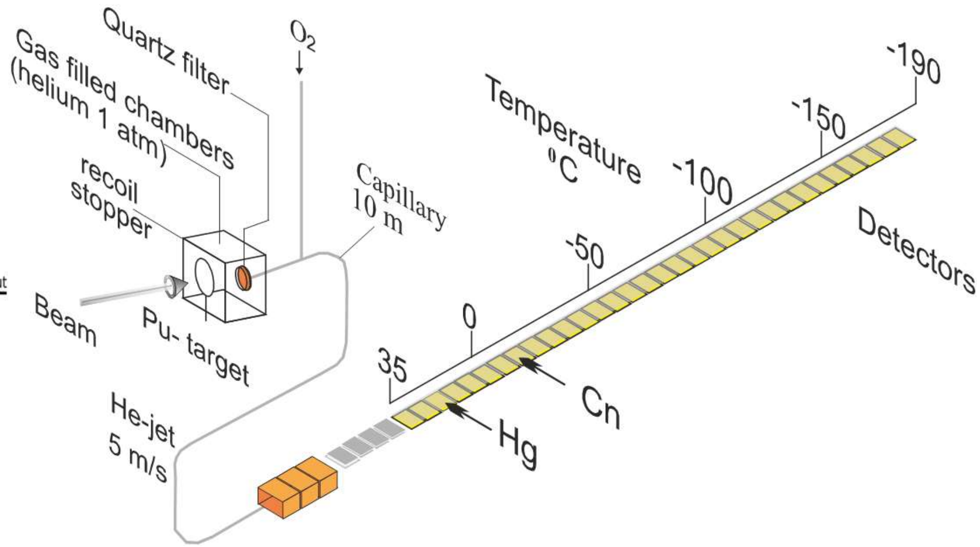
$\sigma_{3n} = 4pb$

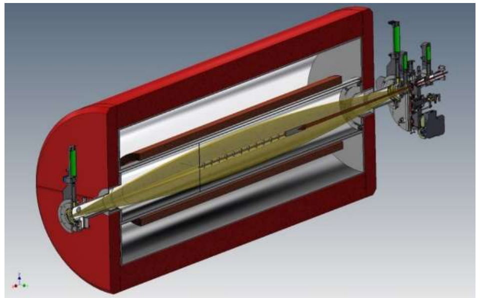
Future of SHE Chemistry

Fixed blades for beam suppression









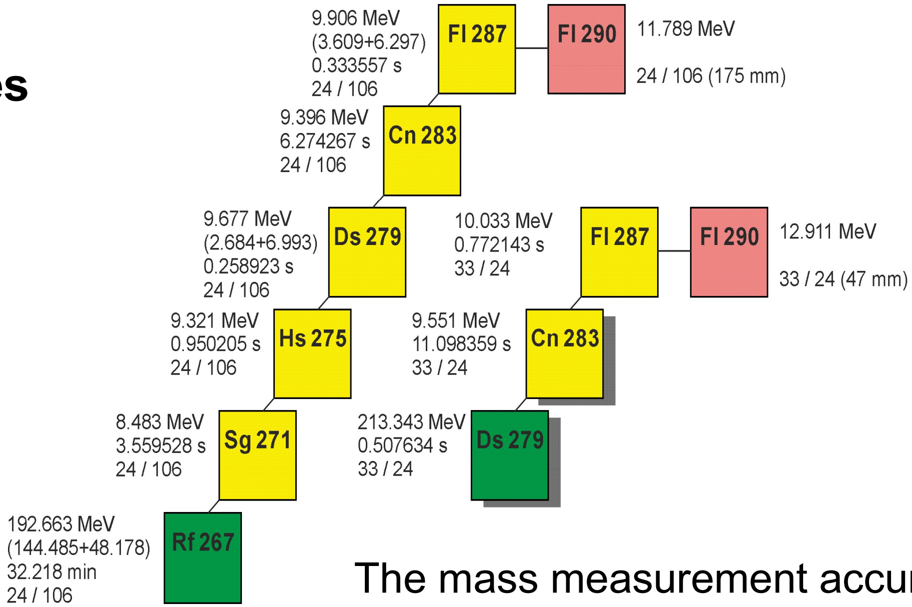
GASSOL – Solenoid-based separator (2025)

- *Stopping SH atoms in a small volume of 1-2 cm^3*
- *Chemistry of short-lived SHE $T_{1/2} \geq 30$ ms (up to element 117)*

Precise mass measurements of SH isotopes

Measuring masses of SH isotopes with accuracy 10^{-7} (30 кeV)

$T_{1/2} < 0.5$ s
Production rate ≤ 1 event/day
Background rate ≥ 1 event/s



Requirements for a facility:

- High rate of analysis;
- Low losses;
- High degree of purification;
- Accuracy 10^{-7} (30 кeV);
- Mass range 266 – 294.

The mass measurement accuracy depends on

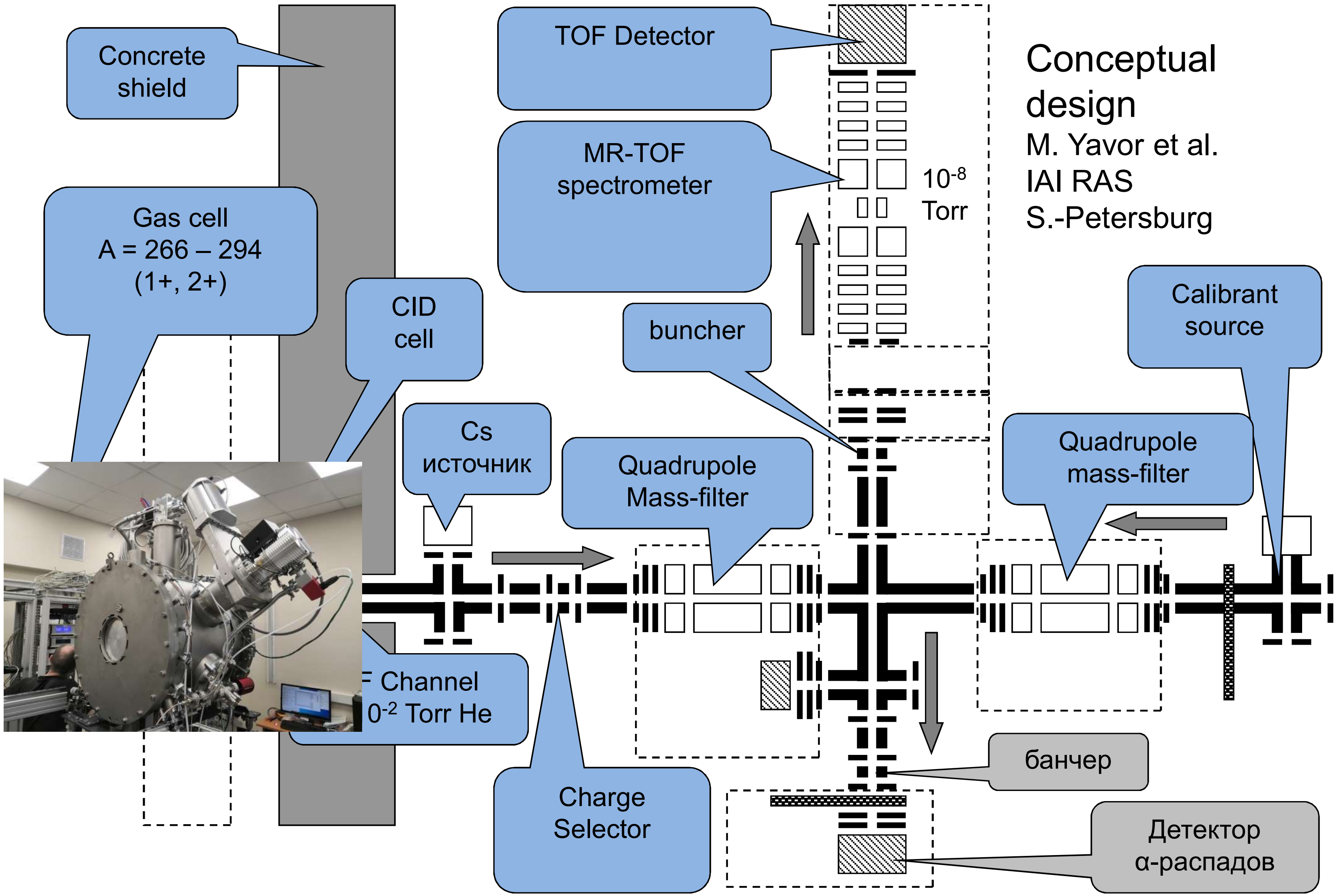
- Mass resolution R_m
- Statistics N

$$\frac{\delta m}{m} \approx \frac{1}{2R_m\sqrt{N}}$$

$\delta m/m = 10^{-7}$, N = 5 => R_m = 2 000 000

The only type of spectrometers gives an opportunity to reach Rm > 1 000 000 at the analysis time < 0.5 s: **MR-TOF Mass-Analyser**

Scheme of the MR-TOF spectrometer



Conceptual design
M. Yavor et al.
IAI RAS
S.-Petersburg

Spectroscopy of SH isotopes (SHE factory)

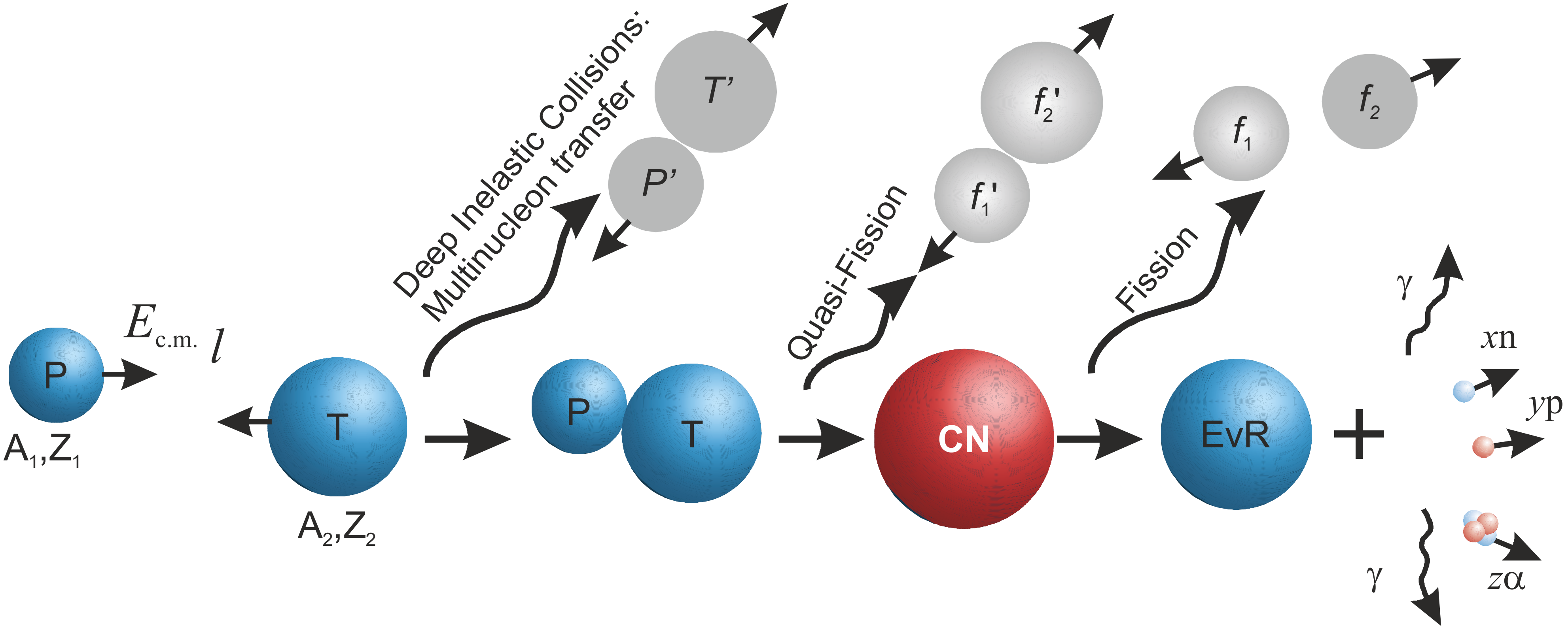
$^{48}Ca + ^{242}Pu \rightarrow ^{287}Fl + 3n$

$^{48}Ca + ^{243}Am \rightarrow ^{288}Mc + 3n$

Cross section ~ 10 pbarn;
Target thickness ~ 1.5×10^{18} at/cm^2;
Beam intensity of ^{48}Ca
~ 3.3×10^{13} pps (5 pμA);
$\varepsilon_{transmission}$ ~ 50 %;
12 events/day

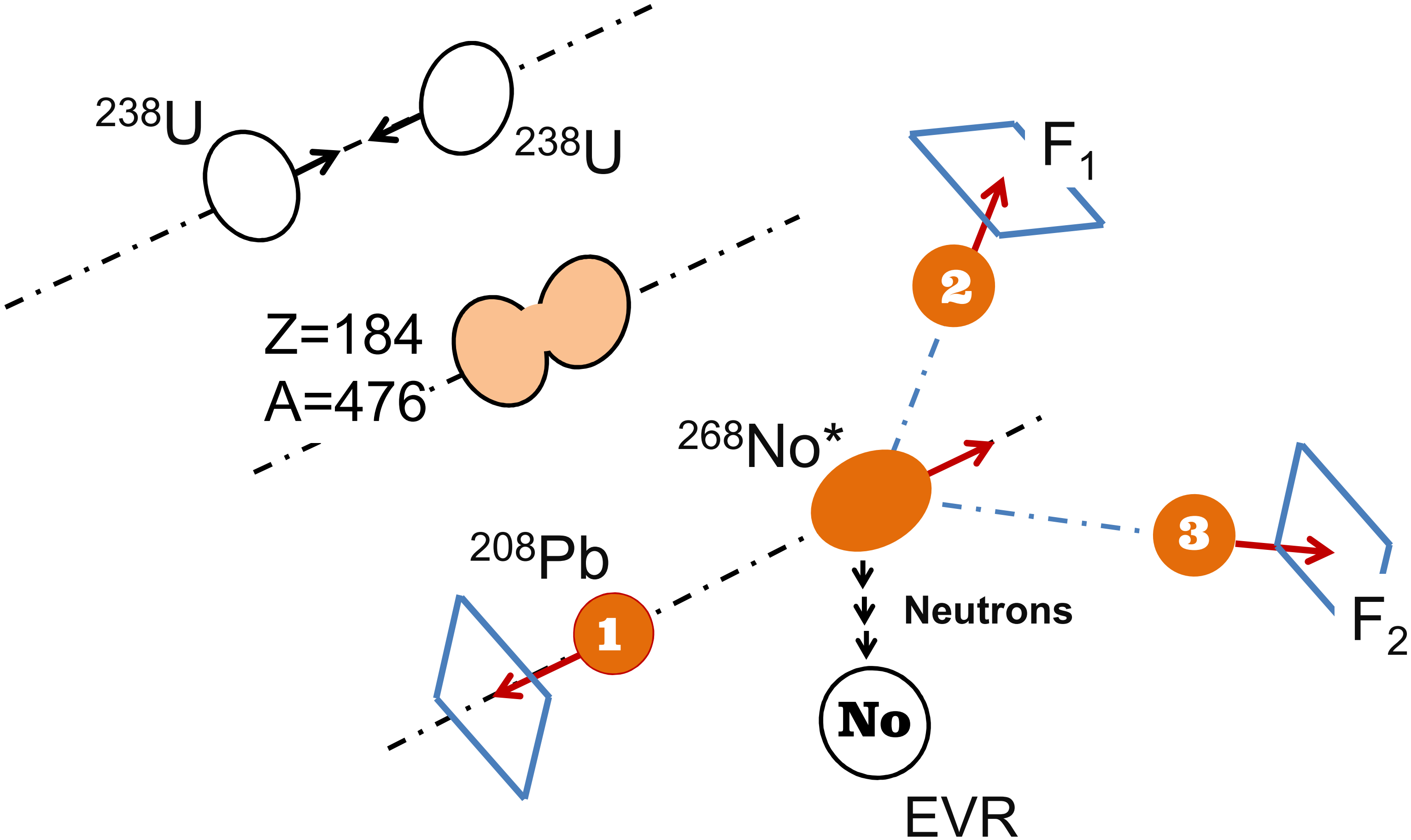
100 days – integral flux about 10^{20}, about 300 events

300 chains → 250 gamma quanta detected, acceptable statistics.
Important information about level structure, K-isomers.

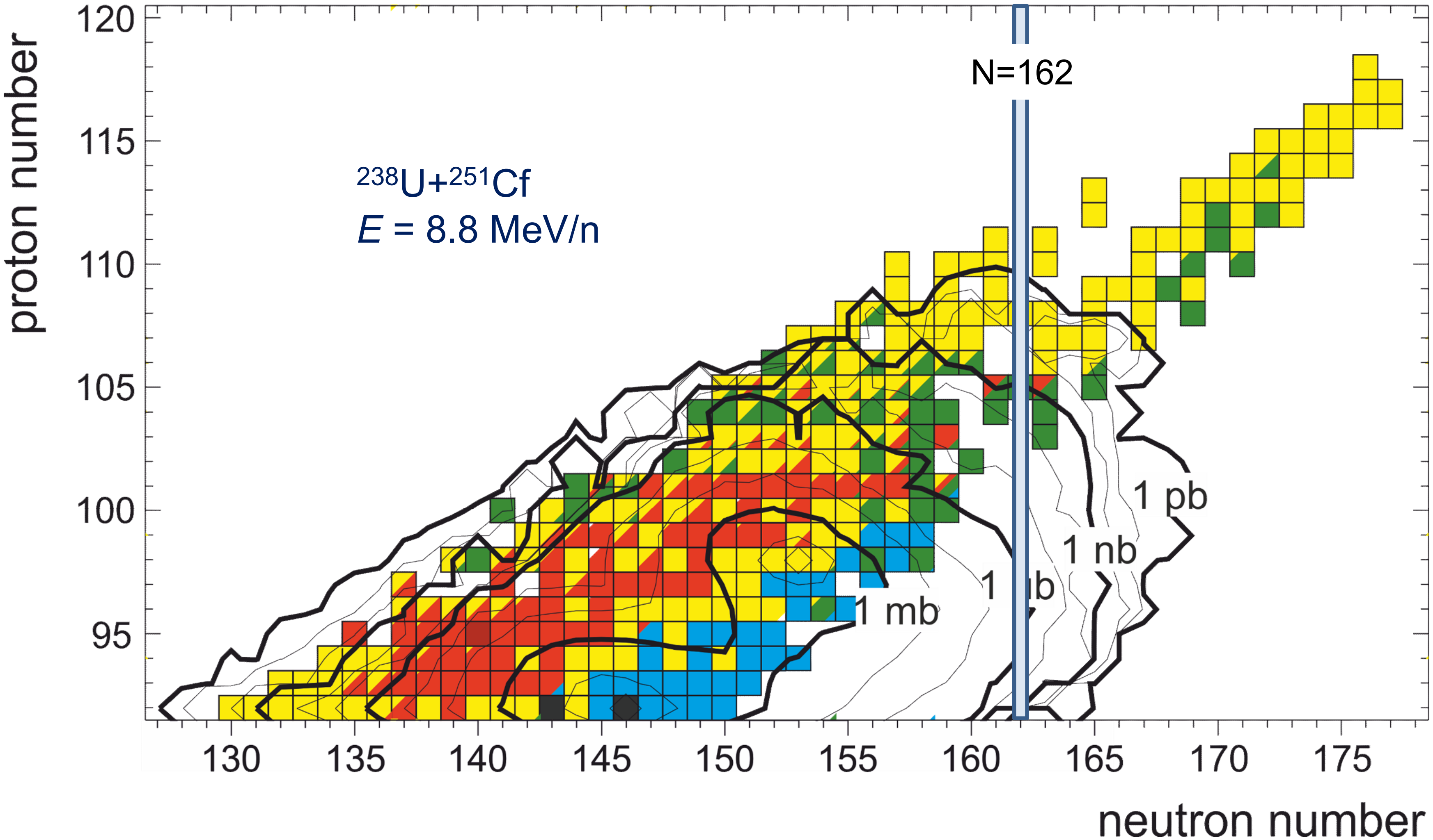


P
$E_{c.m.}$ l
A_1,Z_1
T
A_2,Z_2
Deep Inelastic Collisions:
Multinucleon transfer
T'
P'
P
T
Quasi-Fission
f_2'
f_1'
CN
Fission
f_1
f_2
EvR
+
γ
xn
yp
zα
γ

Studying the $^{238}U + ^{238}U$ reaction



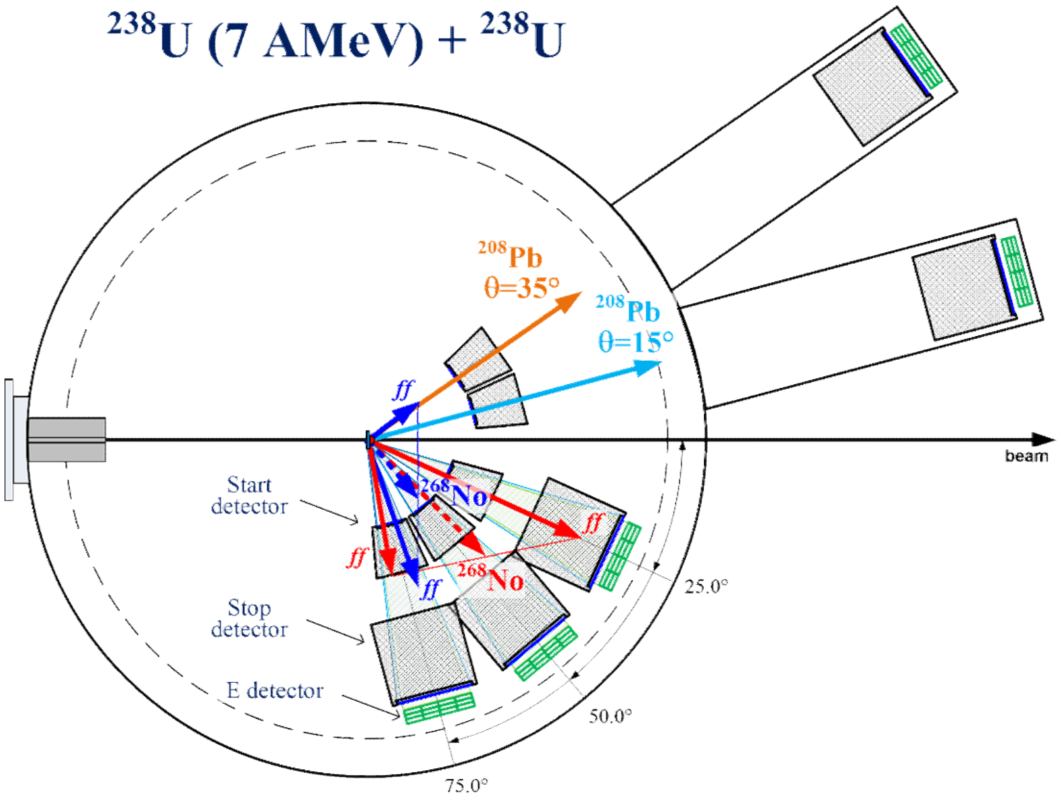
slide by Yu. Oganessian

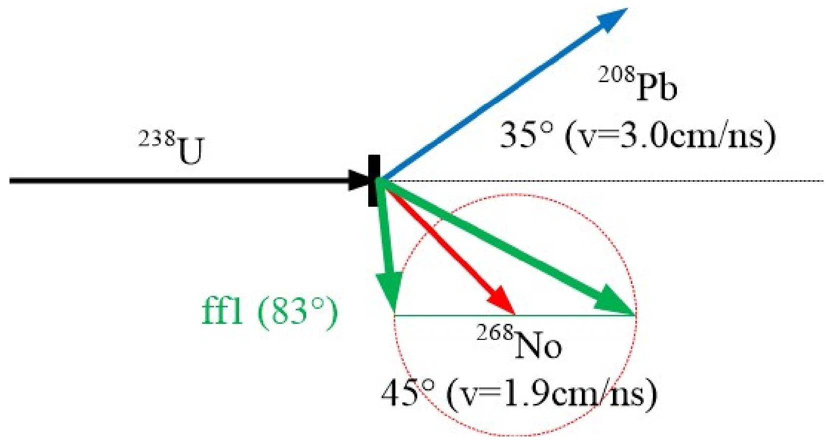


$^{238}U+^{251}Cf$
E = 8.8 MeV/n
N=162
1 mb
1 μb
1 nb
1 pb
proton number
neutron number
95
100
105
110
115
120
130
135
140
145
150
155
160
165
170
175

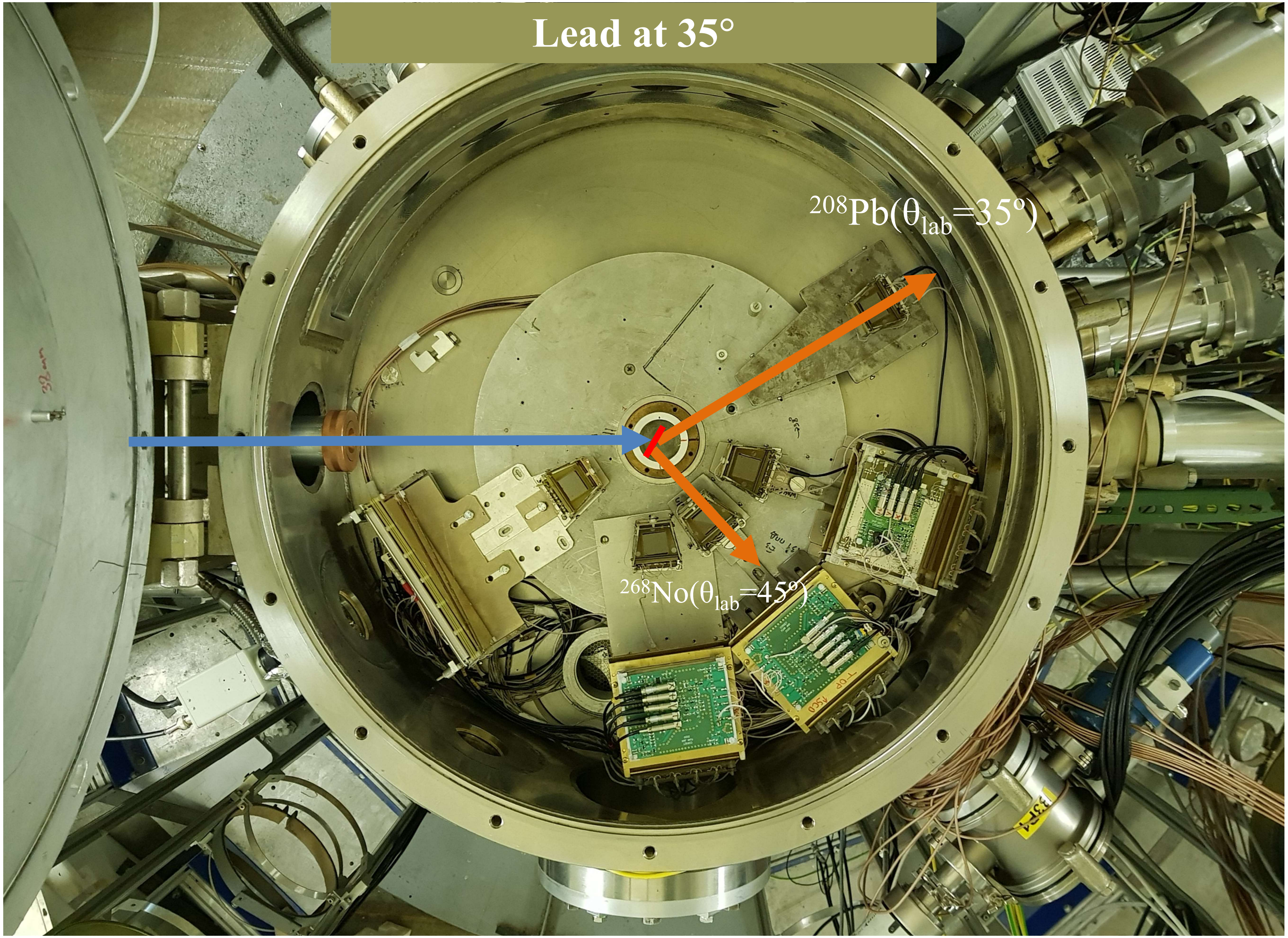
V.V. Saiko

Forthcoming experiment: ^{238}U + ^{238}U @ E_{lab} = 1666 MeV (7 MeV/n)

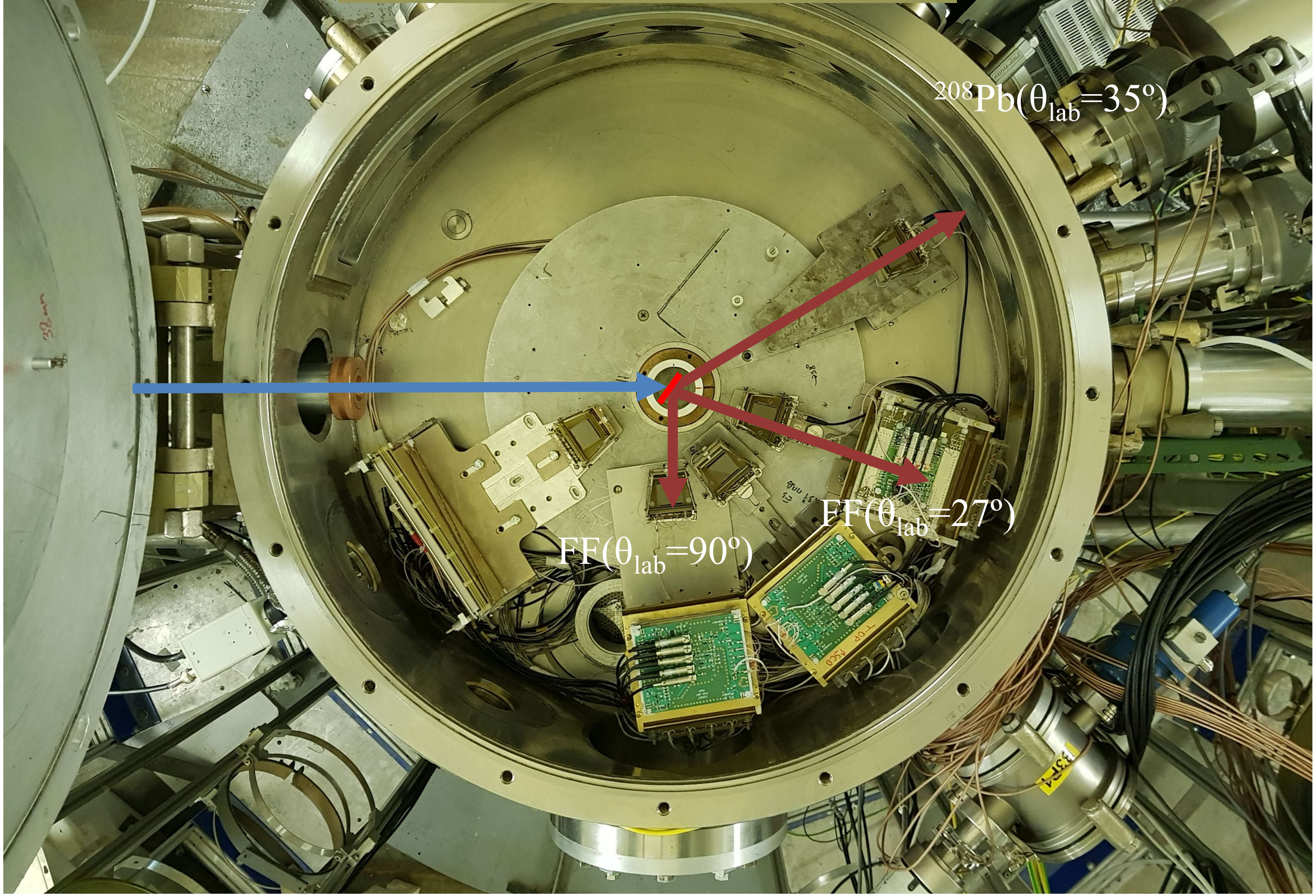




Lead at 35°



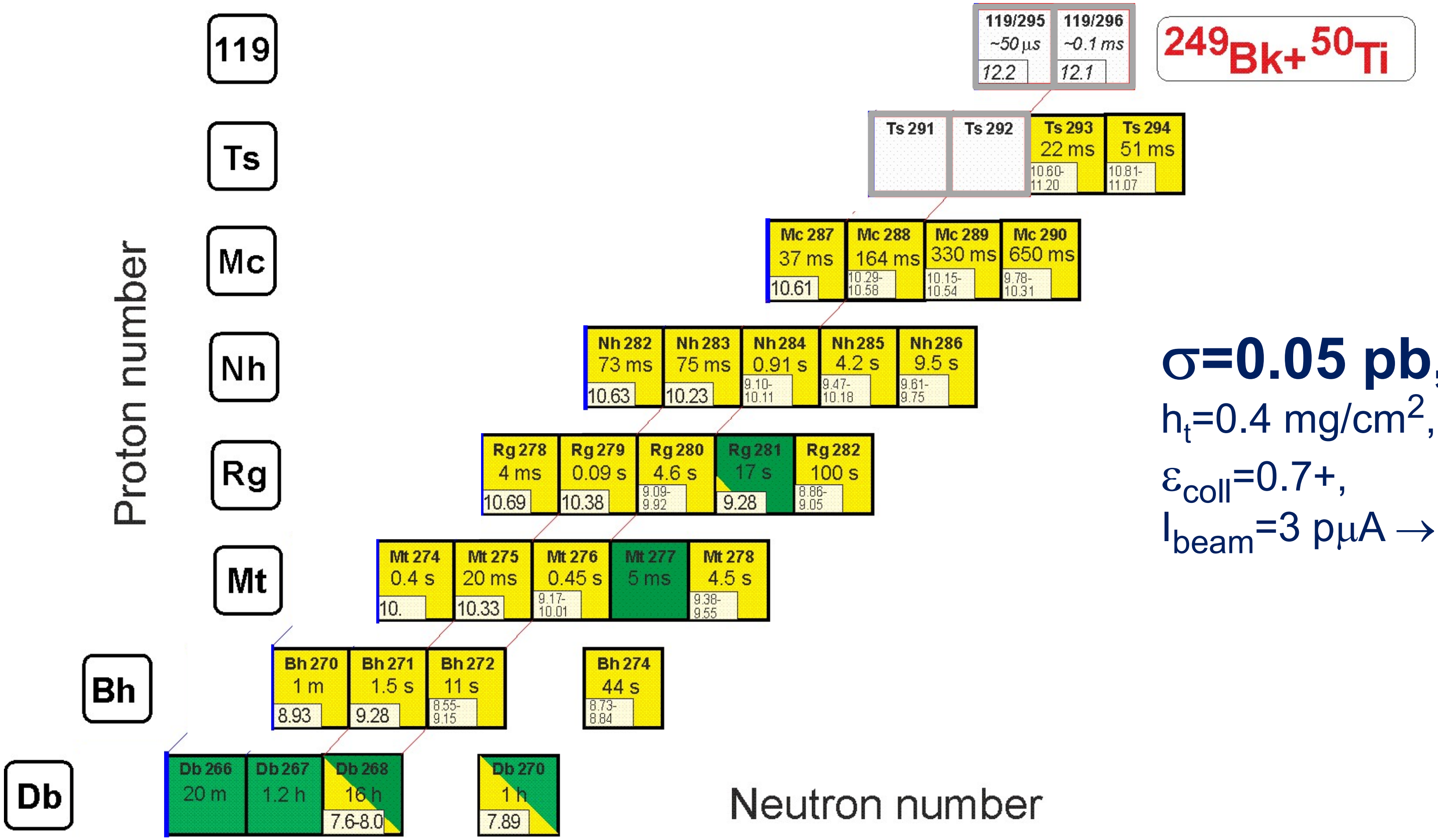
Lead at 35°



Thank you for your attention

Synthesis of new elements 119 and 120

Synthesis of element 119: $^{249}Bk+^{50}Ti$



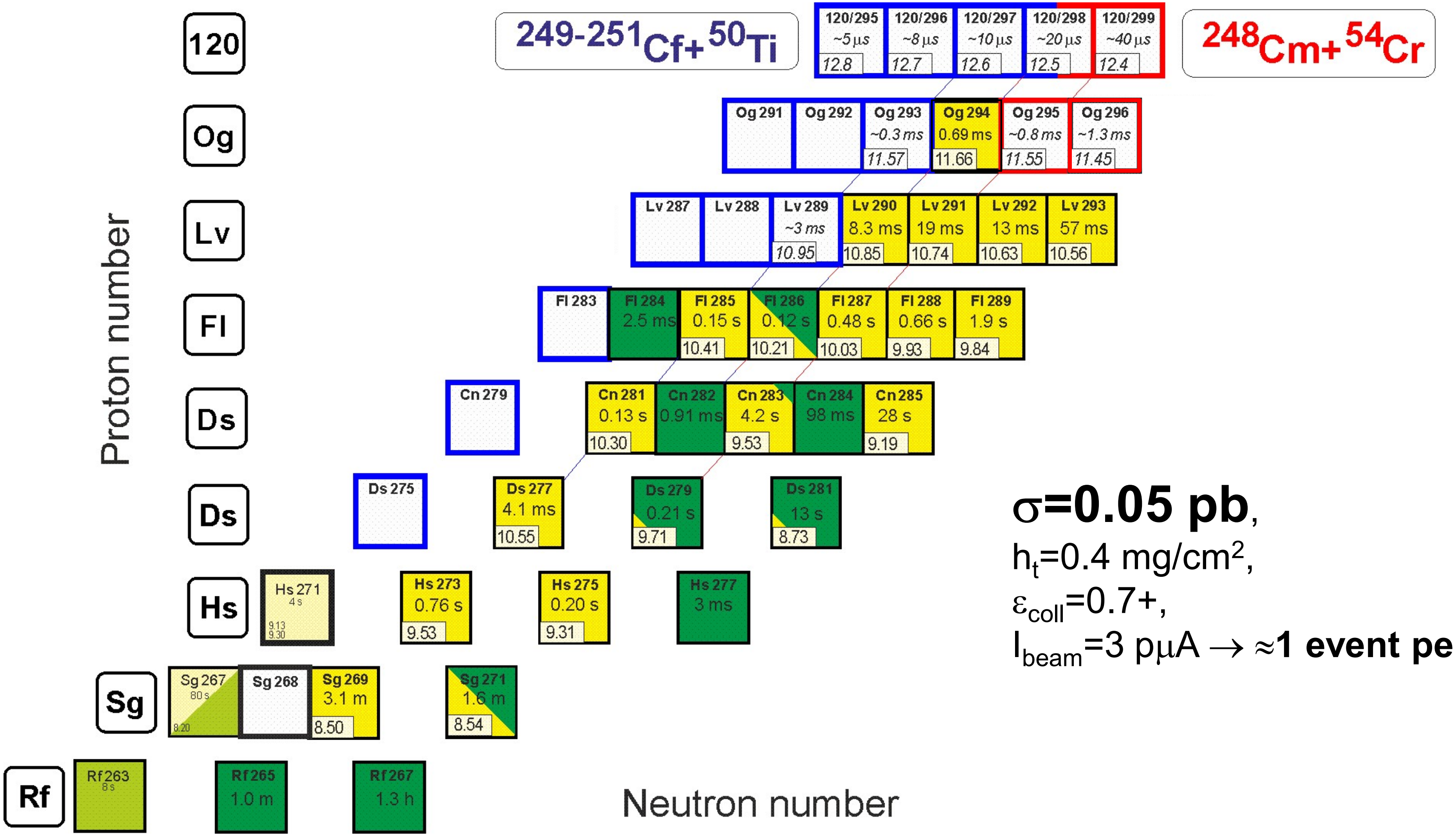
σ=0.05 pb,

h_t=0.4 mg/cm^2,

ε_{coll}=0.7+,

I_{beam}=3 pµA $\rightarrow$ **≈1 event per month**

Synthesis of element 120



σ=0.05 pb,

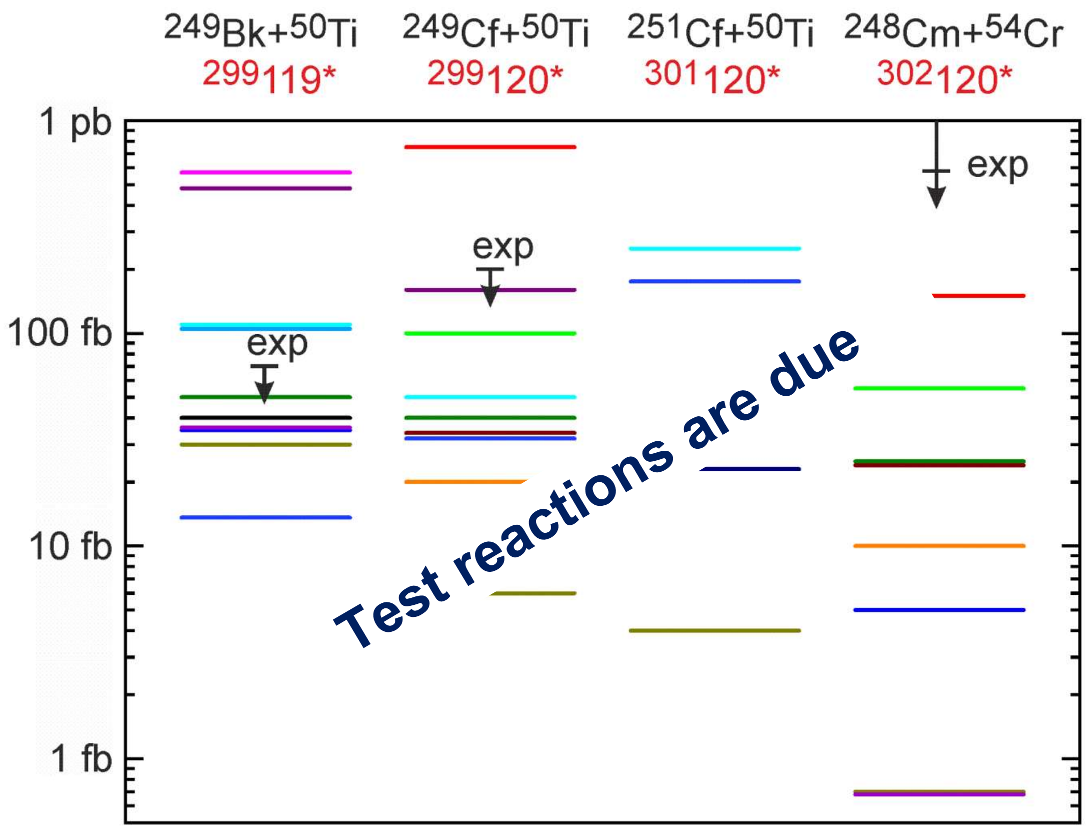
h_t=0.4 mg/cm^2,

ε_{coll}=0.7+,

I_{beam}=3 pµA → ≈**1 event per month**

Predicted cross sections for synthesis of elements 119 and 120

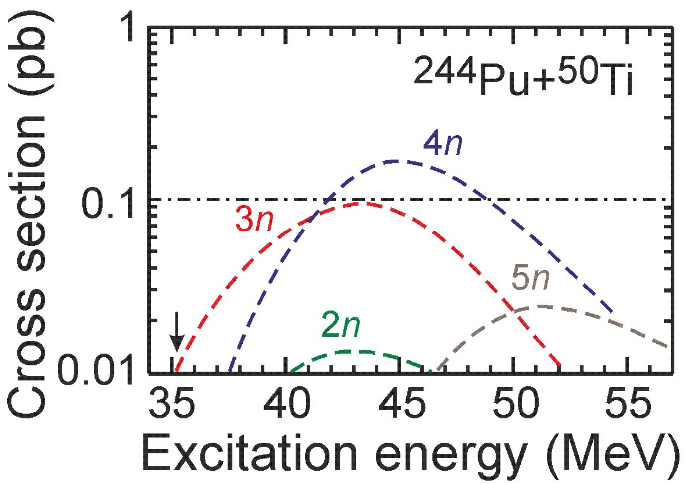
^{50}Ti + ^{249}Bk
^{50}Ti + $^{249\text{-}251}$Cf
^{54}Cr + ^{248}Cm



V.I. Zagrebaev *et al.*, Phys. Rev. C **78**, 034610 (2008)
K. Siwek-Wilczynska *et al.*, Int. J. Mod. Phys. E **19**, 500 (2010).
A.K. Nasirov *et al.*, Phys. Rev. C **84**, 044612 (2011).
Ning Wang *et al.*, Phys. Rev. C **84**, 061601 (2011).
Nan Wang *et al.*, Phys. Rev. C **84**, 061601 (2011).
Z.H. Liu *et al.*, Phys. Rev. C **84**, 031602(R) (2011).
K. Siwek-Wilczynska *et al.*, Phys. Rev. C **99**, 054603 (2019).
K.P. Santhosh *et al.*, Phys. Rev. C **96**, 034610 (2017).
K. Siwek-Wilczynska *et al.*, Phys. Rev. C **86**, 014611 (2012).
A.N. Kuzmina *et al.*, Phys. Rev. C **85**, 014319 (2012).
Jinjuan Zhang *et al.*, Nucl. Phys. A **909**, 36 (2013).
Z.H. Liu, J.D. Bao, Phys. Rev. C **87**, 034616 (2013).
V.I. Zagrebaev, W. Greiner, Nucl. Phys. A **944**, 257 (2015).
G. G. Adamian *et al.*, Phys. Part. Nucl. **47**, 387 (2016).
A. Ansari *et al.*, Int. J. Mod. Phys. E **26**, 1750050 (2017).

Preparation to synthesis of elements 119 and 120: $^{48}Ca \rightarrow {}^{50}Ti$

$^{244}Pu + {}^{50}Ti \rightarrow {}^{294}Lv^*$

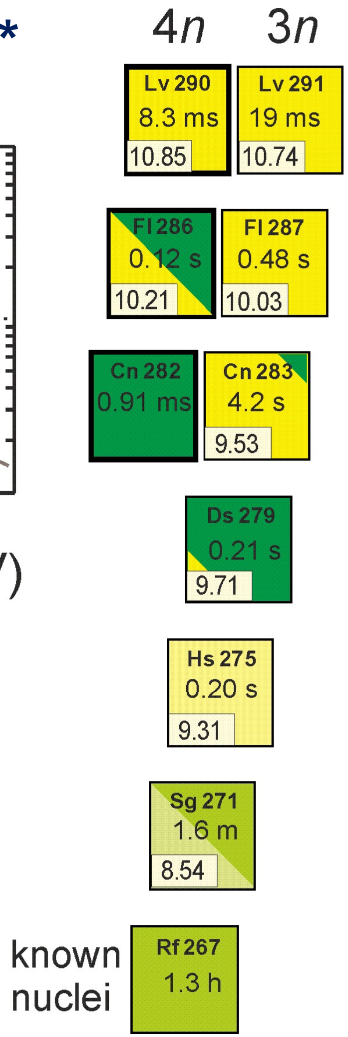


V. Zagrebaev and W. Greiner

0.2-0.3 pb

G. Adamian et al.

0.1 pb



$^{245}Cm + {}^{48}Ca \rightarrow {}^{293}Lv^*$ (~3 pb)

σ=0.2 pb,

h_t=0.3 mg/cm^2,

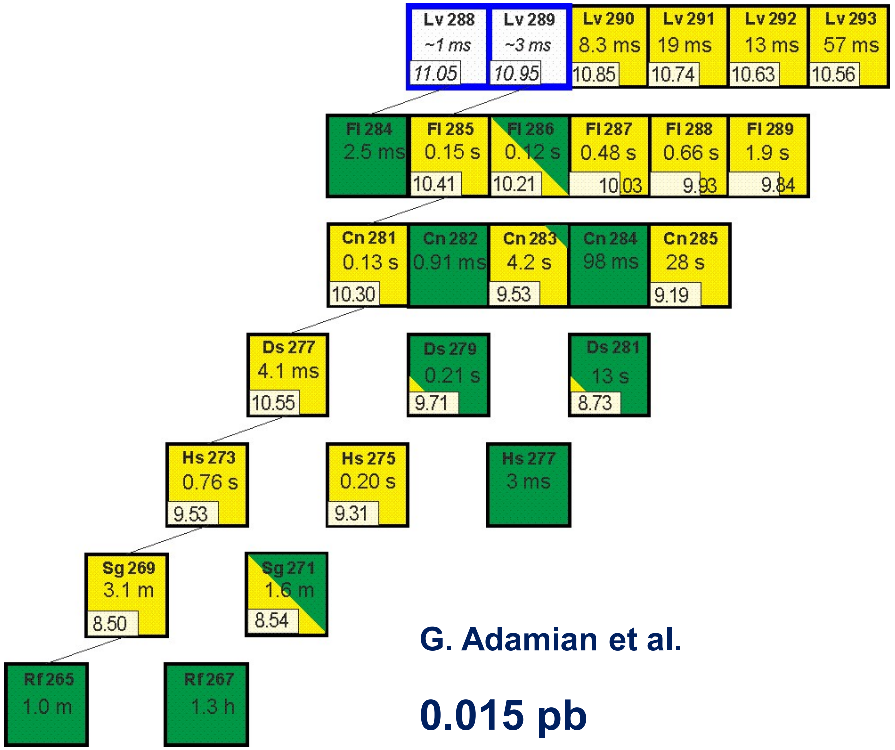
ε_{coll}=0.7+,

I_{beam}=1.5 pμA → ≈**3 events per 2 months**

Preparation to synthesis of elements 119 and 120: $^{48}Ca \to {}^{54}Cr$

$^{242}Pu + {}^{50}Ti \to {}^{292}Lv^*$

$^{238}U + {}^{54}Cr \to {}^{292}Lv^*$



G. Adamian et al.

0.015 pb

$^{245}Cm + {}^{48}Ca \to {}^{293}Lv^*$ (~3 pb)

σ=0.015 pb,

h_t=0.4 mg/cm^2,

ε_{coll}=0.7+,

I_{beam}=3 pμA → ≈**3 events per 9 months**