



# Статус Фабрики сверхтяжелых элементов

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ДЦ-280

# Ускорительный комплекс ЛЯР ОИЯИ



Radiochemical  
laboratory of class 1  
**(planned)**

DC-280  
SHE Factory

U-400R  
Nuclear reactions

U-400M  
RIBs research

Assembly  
workshop

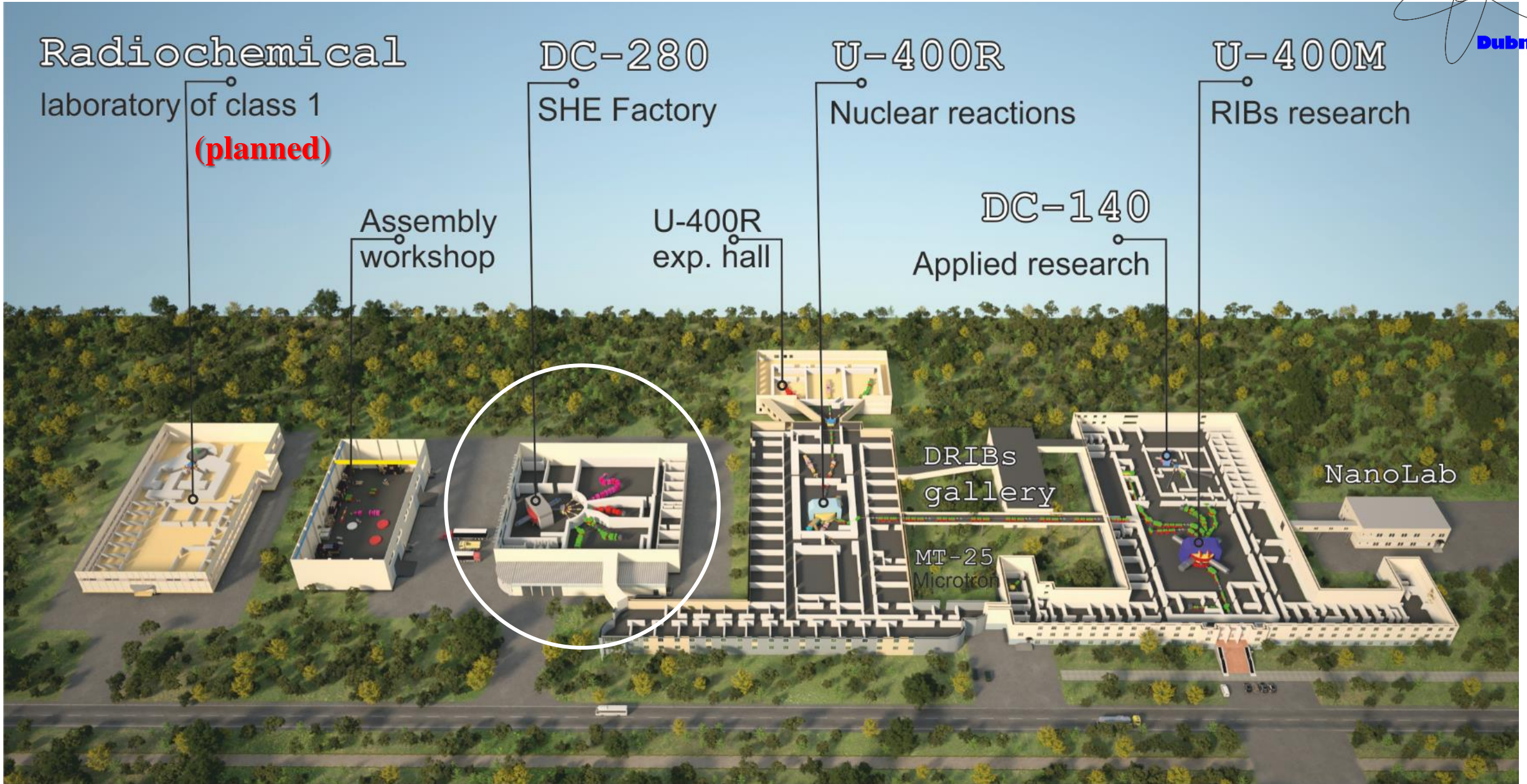
U-400R  
exp. hall

DC-140  
Applied research

DRIBs  
gallery

NanoLab

MT-25  
Microtron



# Периодическая таблица сегодня (с 28 ноября 2016 г.)

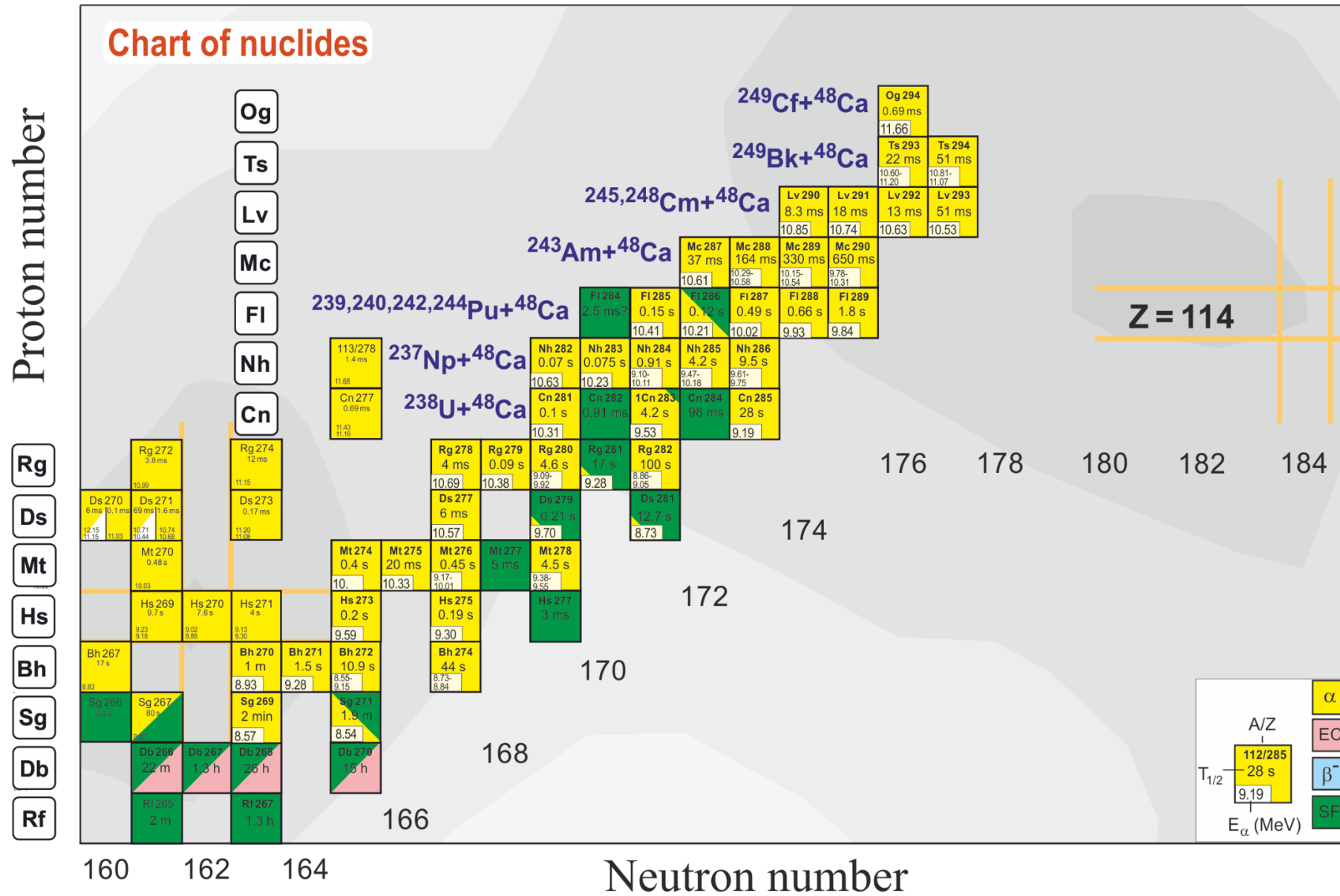
1 <b>H</b> hydrogen 1.0080 ±0.0002																	18 <b>He</b> helium 4.0026 ±0.0001
3 <b>Li</b> lithium 6.94 ±0.06	4 <b>Be</b> beryllium 9.0122 ±0.0001	Key: atomic number <b>Symbol</b> name abridged standard atomic weight										13 <b>B</b> boron 10.81 ±0.02	14 <b>C</b> carbon 12.011 ±0.002	15 <b>N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



INTERNATIONAL UNION OF  
PURE AND APPLIED CHEMISTRY

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

# Синтез сверхтяжелых ядер (1999-2019)



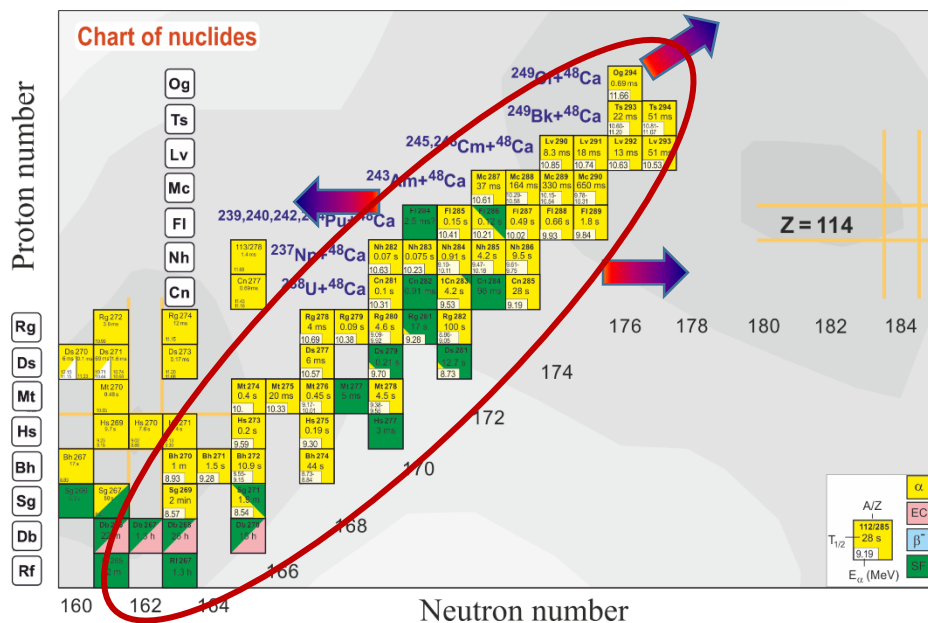
# Исследование СТЭ. Основные задачи:

Эксперименты при экстремально низких сечениях ( $\sigma < 100$  фб) :

- Синтез новых СТЭ  $Z = 119$  и  $120$  в реакциях с  $^{50}\text{Ti}$ ,  $^{54}\text{Cr}$  ...;
- Синтез новых изотопов СТЭ;
- Изучение свойств распада СТЭ;
- Исследование границ Острова стабильности;
- Измерение функций возбуждения.

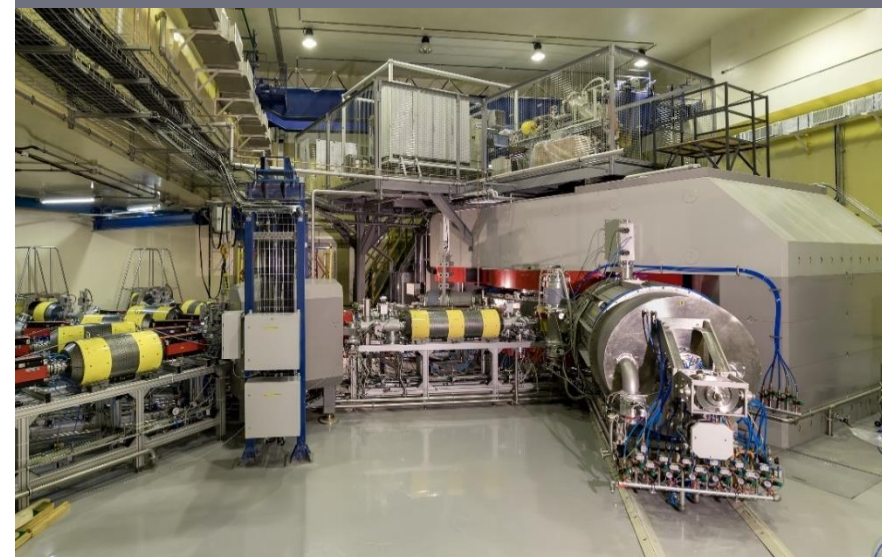
Эксперименты, требующие высокой статистики:

- Спектроскопия СТЭ;
- Измерение масс;
- Изучение химических свойств СТЭ.



Beam of  $^{48}\text{Ca}$  @ DC-280:

- Intensity:  $> 8 \mu\text{A}$
- Energy:  $5 - 8 \text{ A} \cdot \text{MeV}$
- Efficiency:  $\sim 50\%$

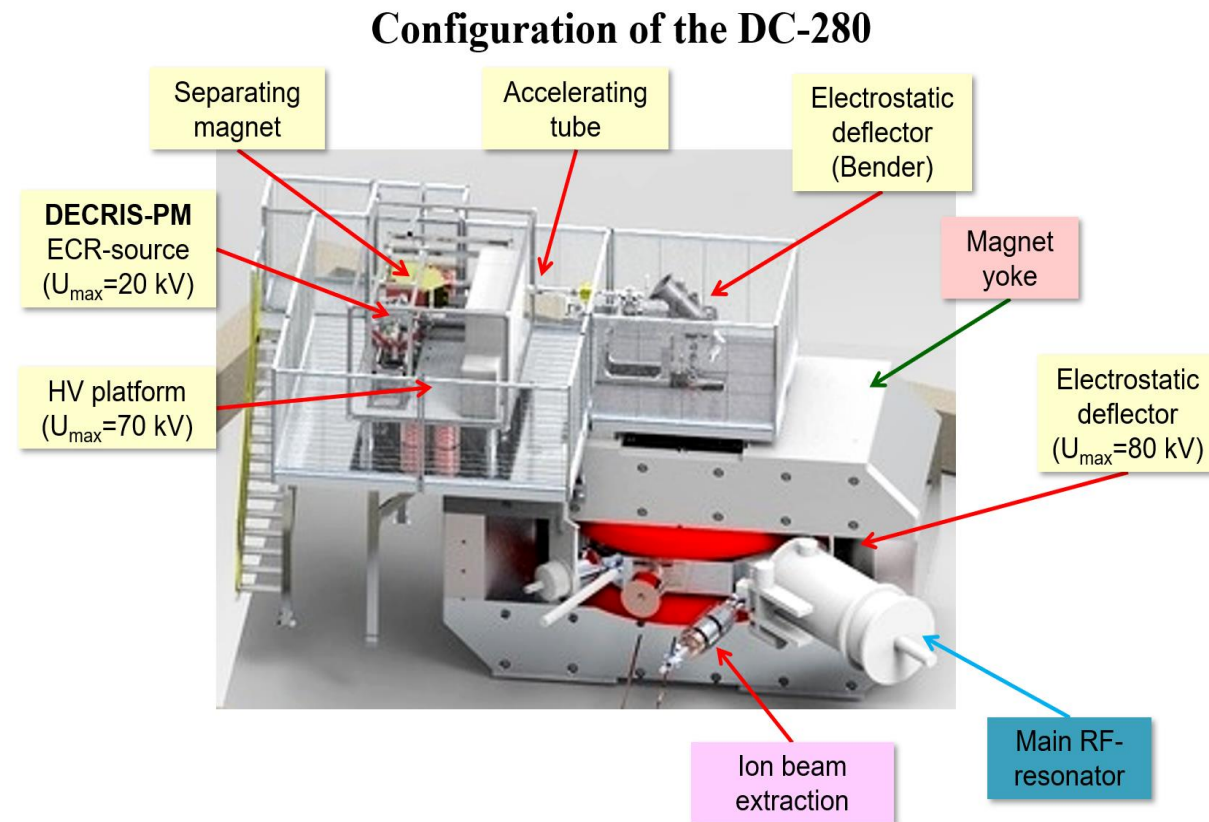


# Cyclotron DC-280

Year	Total work time	Ions
2018	First Beam	$^{84}\text{Kr}$
2019	3377	$^{12}\text{C}$ , $^{40}\text{Ar}$ , $^{48}\text{Ca}$ , $^{84}\text{Kr}$
2020	3705	$^{40}\text{Ar}$ , $^{48}\text{Ca}$ , $^{48}\text{Ti}$
2021	5357	$^{48}\text{Ca}$ , $^{48}\text{Ti}$ , $^{52}\text{Cr}$
2022	6037	$^{40}\text{Ar}$ , $^{48}\text{Ca}$ , $^{48}\text{Ti}$ , $^{52,54}\text{Cr}$
2023	6182	$^{26}\text{Mg}$ , $^{40}\text{Ar}$ , $^{48}\text{Ca}$ , $^{48}\text{Ti}$ , $^{52,54}\text{Cr}$ , $^{56}\text{Fe}$
2024	3993	$^{48}\text{Ca}$ , $^{40}\text{Ar}$ , $^{50}\text{Ti}$ , $^{54}\text{Cr}$
2025	3310	$^{48}\text{Ca}$ , $^{40}\text{Ar}$ , $^{50}\text{Ti}$

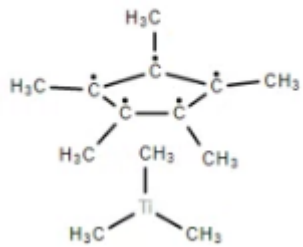
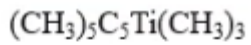
## Main parameters of the DC-280

parameters	design	realized
<b>Ion source</b>	<b>DECRIIS-PM - 14 GHz on the HV platform (<math>U_{\max}=60\text{kV}</math>)</b>	
<b>Injecting beam potential</b>	<b>Up to 80 keV/Z</b>	<b>38,04 – 72,89 keV/Z</b>
<b>A/Z</b>	4÷7.5	4,44 ( $^{40}\text{Ar}^{+7}$ ) – 6,86 ( $^{48}\text{Ca}^{+7}$ )
<b>Energy</b>	4÷8 MeV/n	4,01 – 7 MeV/n
<b>Ion (for DECRIIS-PM)</b>	<b>4-136</b>	<b>12 (<math>^{12}\text{C}^{+2}</math>) – 84 (<math>^{84}\text{Kr}^{+14}</math>)</b>
<b>Intensity (A~50)</b>	>10 $\mu\text{A}$	10,43 $\mu\text{A}$ ( $^{40}\text{Ar}^{+7}$ ), 8,4 $\mu\text{A}$ ( $^{48}\text{Ca}^{+10}$ )
<b>Magnetic field level</b>	<b>0.6÷1.3 T</b>	<b>0.8÷1.23 T</b>
<b>K factor</b>		<b>280</b>
<b>Dee voltage</b>	<b>2x130 kV</b>	<b>130 kV</b>
<b>Power of RF generator</b>		<b>2x30 kW</b>
<b>Flat-top dee voltage</b>	<b>2x13 kV</b>	<b>13 kV</b>
<b>Power of Flat-top generator</b>		<b>2x2 kW</b>
<b>Emittance</b>	<b>less than 30 <math>\pi</math> mm·mrad</b>	
<b>Accelerator effectivity</b>	>50%	51,9 % ( $^{48}\text{Ca}^{+10}$ 5 MeV/n 5 $\mu\text{A}$ )

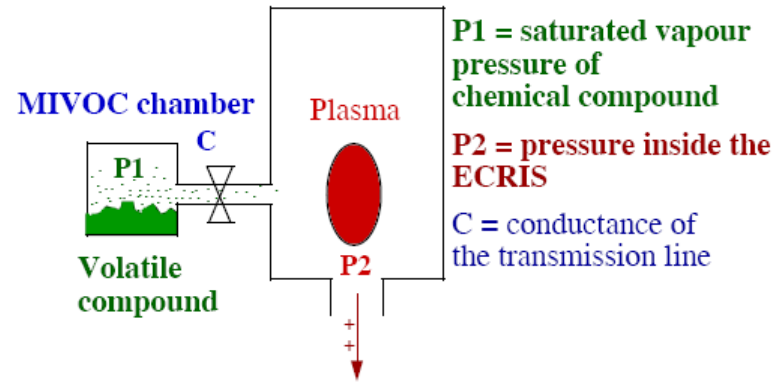


# Актуальные задачи

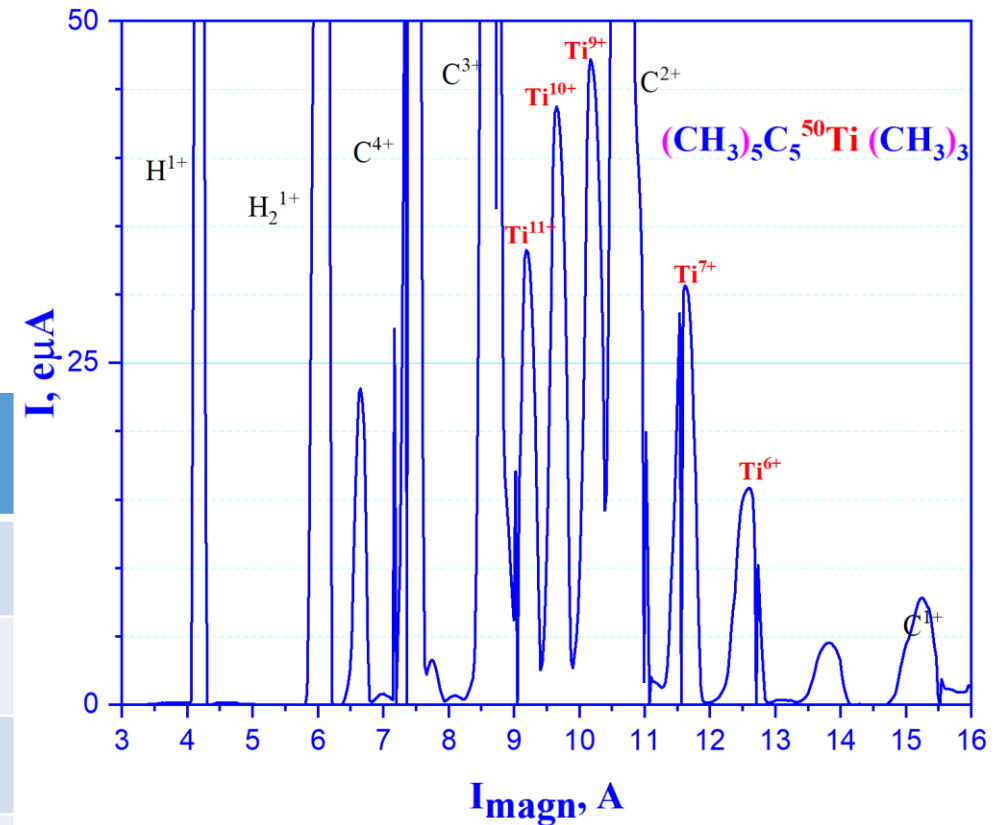
Получение ионов металлов: увеличение интенсивности Ti



## ECRIS



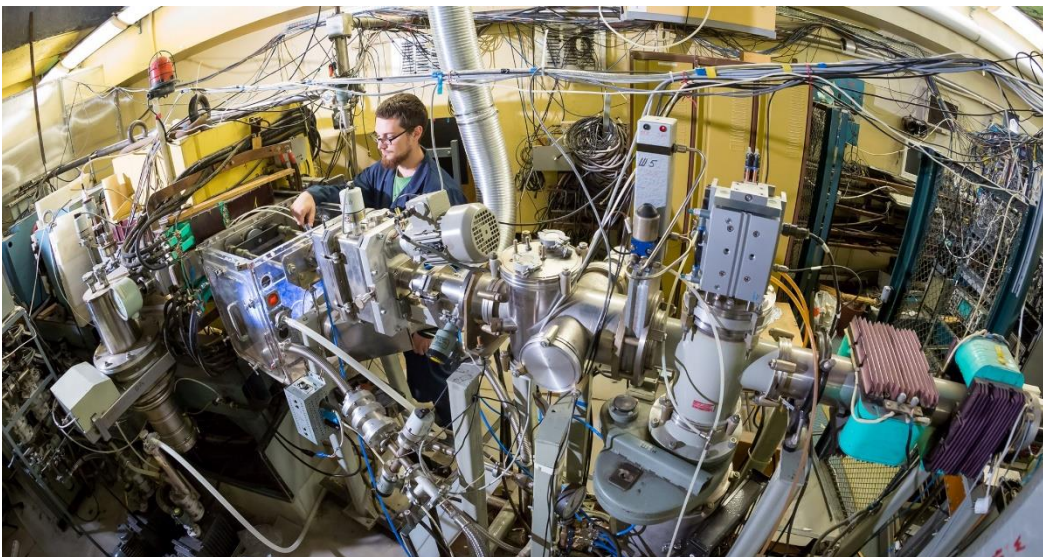
Compound	$(\text{CH}_3)_5\text{C}_5\text{Ti}(\text{CH}_3)_3$	$\text{C}_{10}\text{H}_{10}\text{Cr}$
<b>Properties</b>		
Molar mass, $\text{g}\cdot\text{mol}^{-1}$	228.3	182.2
Form	Yellow crystals	Dark red crystals
Density, $\text{g}/\text{cm}^3$	1.1	1.4
Vapor pressure, Torr	$10^{-2}$ (~0-15°C)	$\approx 0.35$ (~0-15°C)
Sensitivity	Light, air & moisture	Air & moisture



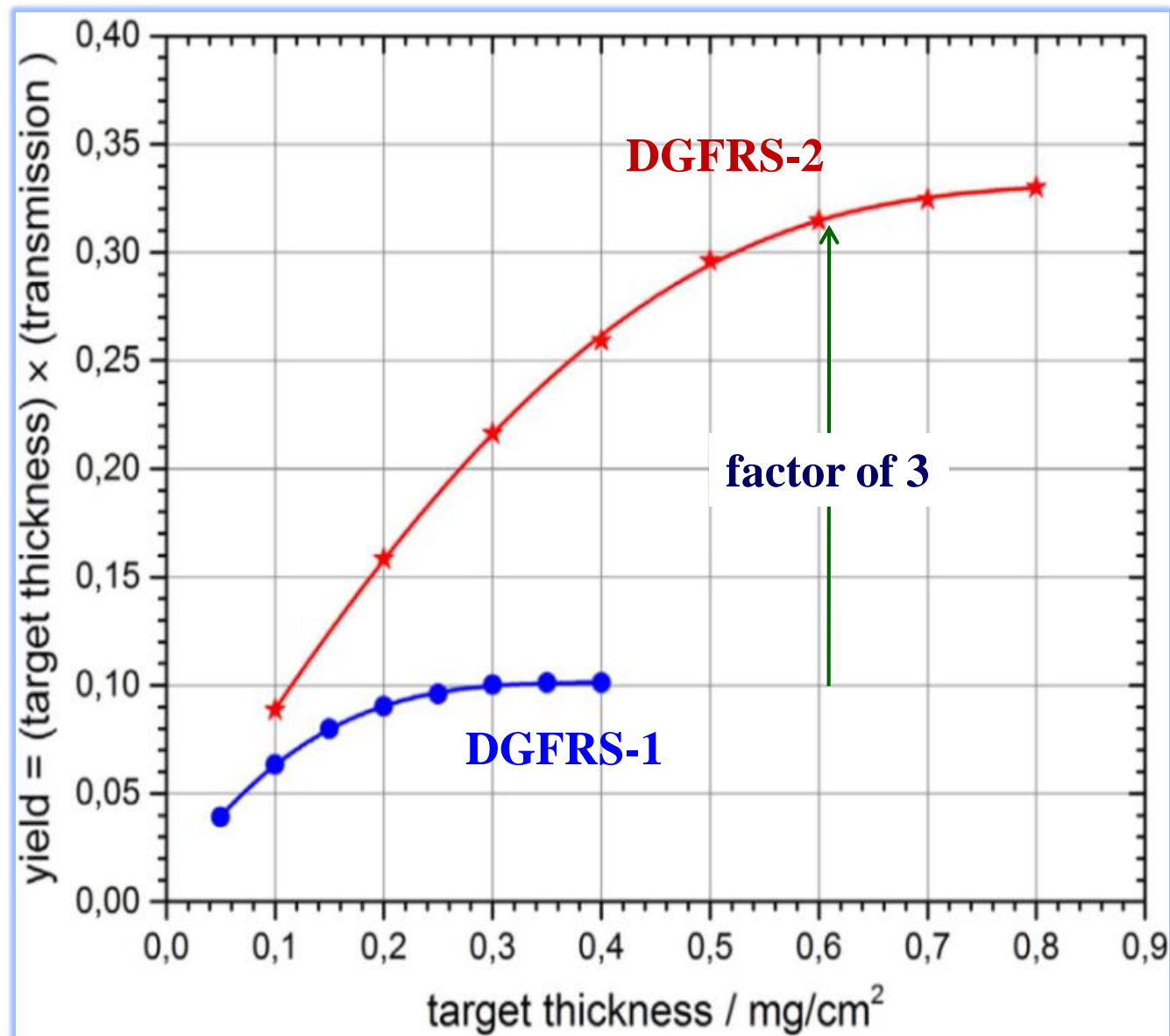
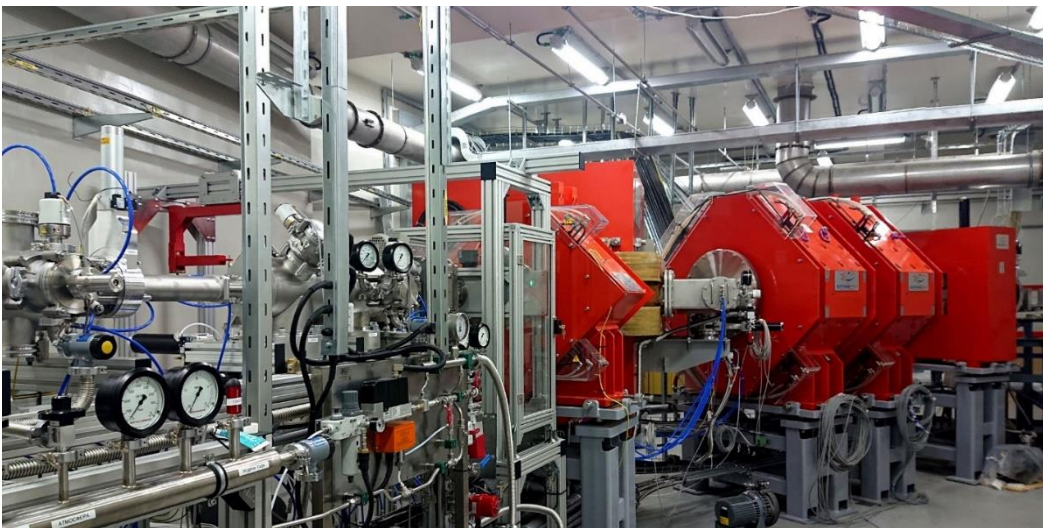
$^{50}\text{Ti}^{9+} \leq 2 \mu\text{A}$  на мишени

# Dubna Gas-Filled Recoil Separators

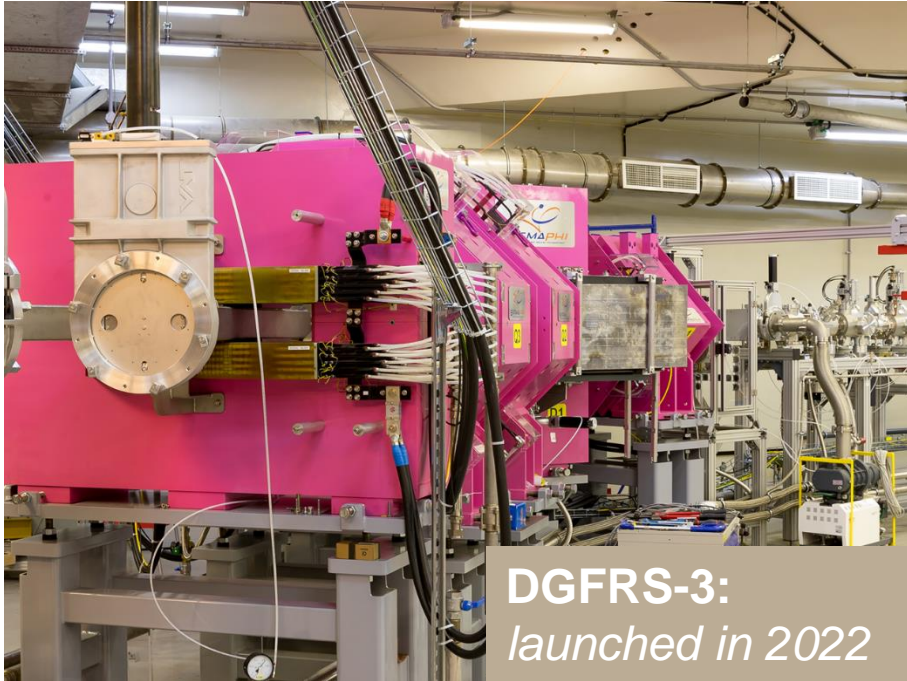
## DGFRS-1 @ U400



## DGFRS-2 @ DC280



# 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*

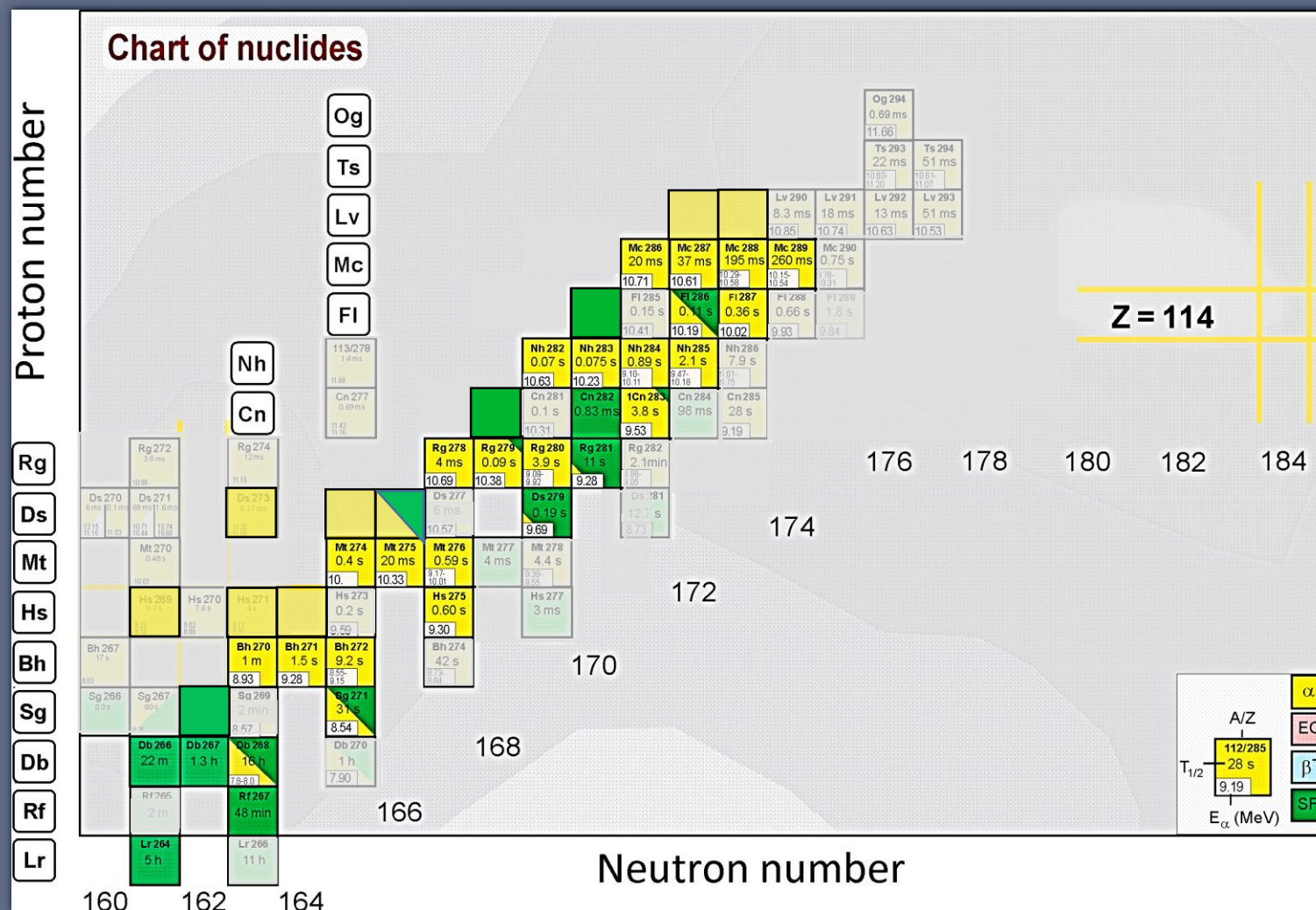
- Synthesis of new SHE;
- Synthesis of new neutron-deficient isotopes of SHE: “shaping” of island of stability;
- Search for rear decay channels in  $^{48}\text{Ca}$ -induced reactions (EC, pxn, 1-2n): towards island of stability;
- Decay modes, excitation functions, etc.

# Summary of experiments @ Superheavy Element Factory in 2020-2025

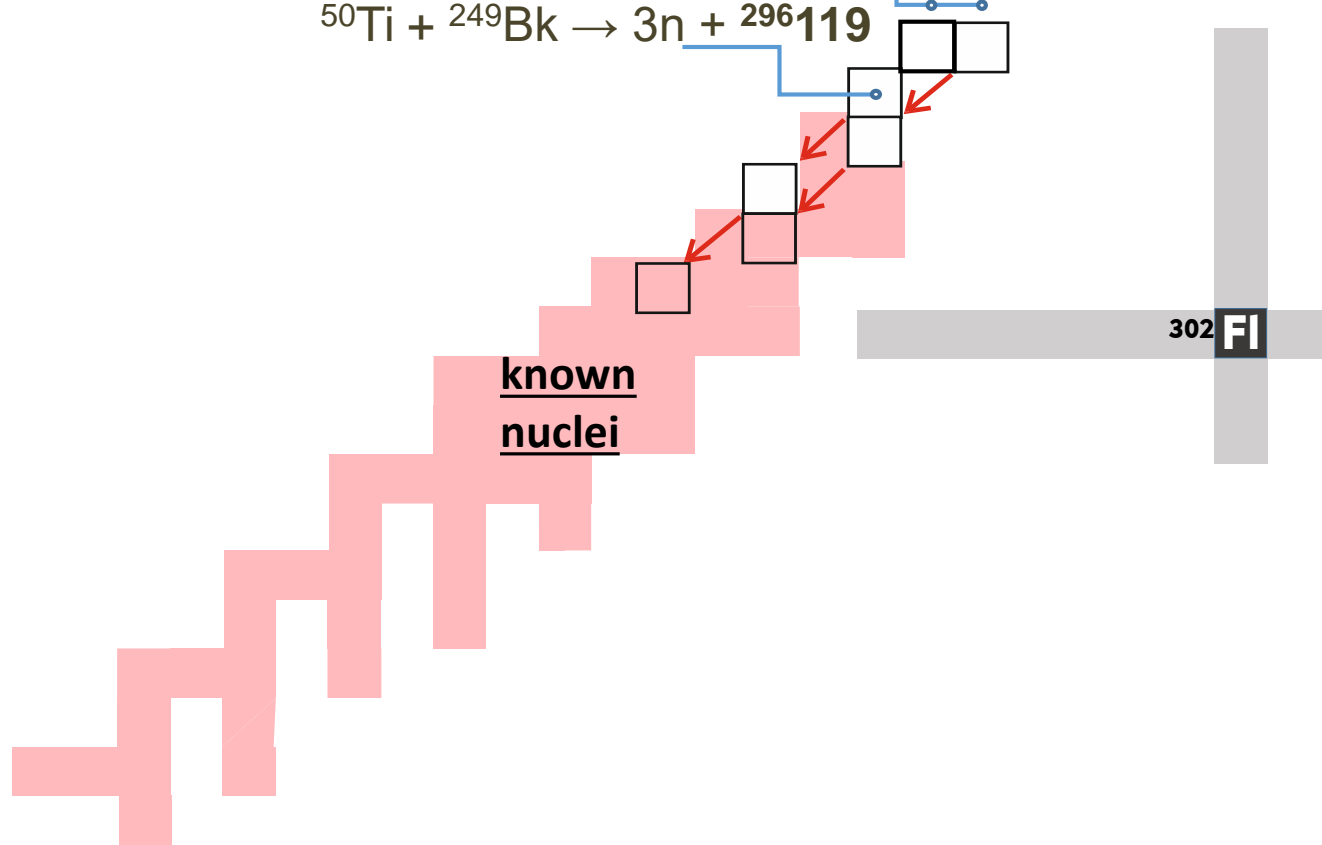
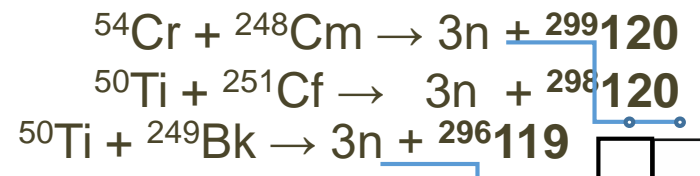
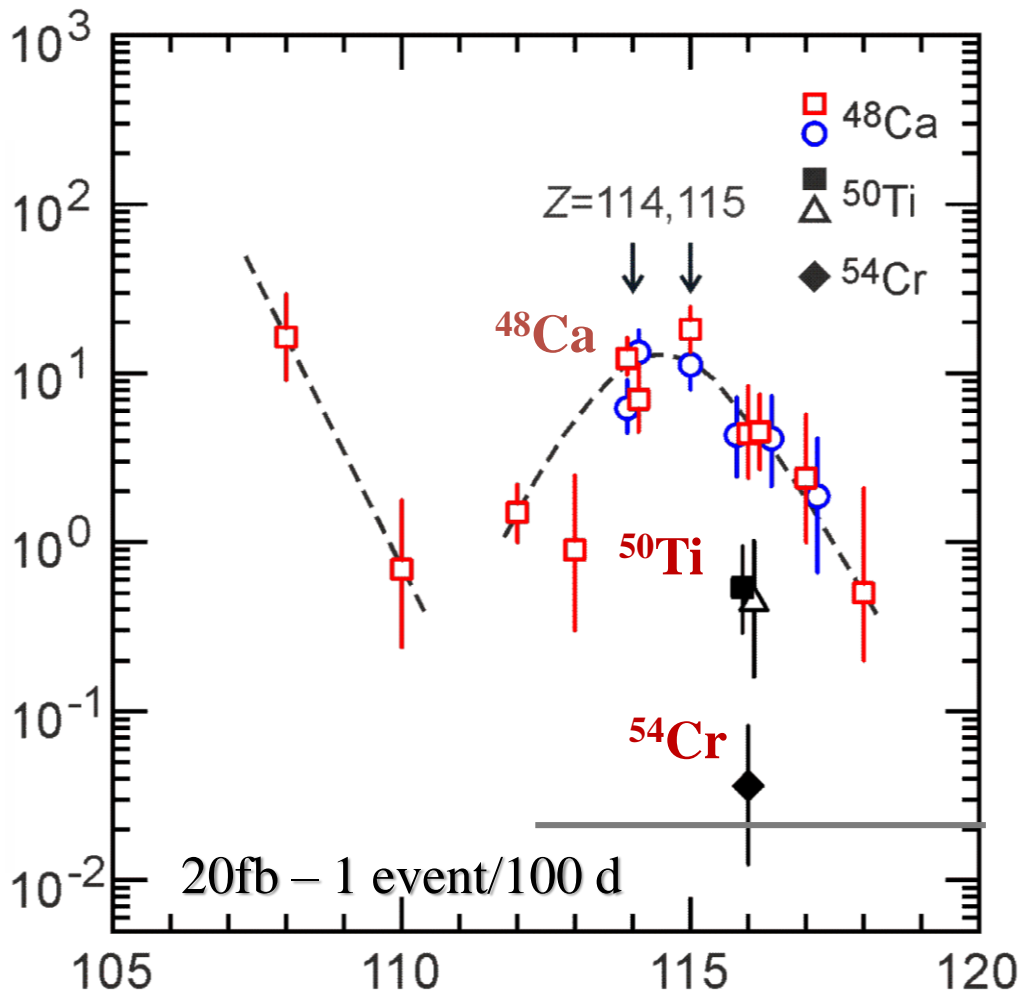
## Experiments:



- ~250 new events of synthesis of superheavy nuclides;
- Decay properties 45 isotopes;
- New isotopes:  $^{288,289}\text{Lv}$ ,  $^{286}\text{Mc}$ ,  $^{280}\text{Cn}$ ,  $^{275,276}\text{Ds}$ ,  $^{272}\text{Hs}$ ,  $^{268}\text{Sg}$ ,  $^{264}\text{Lr}$ ;
- New decay modes;
- Indication of the 1<sup>st</sup> excited state in  $^{282}\text{Cn}$ ;
- Test of target stability up to 6.5  $\mu\text{A}$  of  $^{48}\text{Ca}$ ;

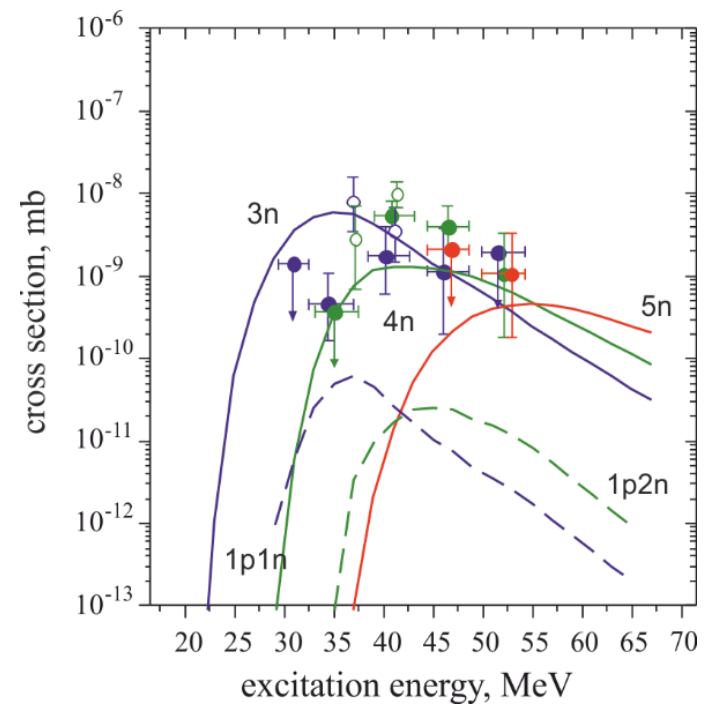
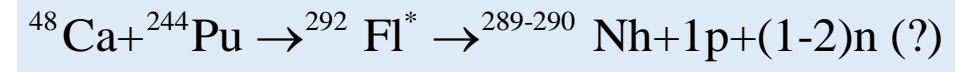
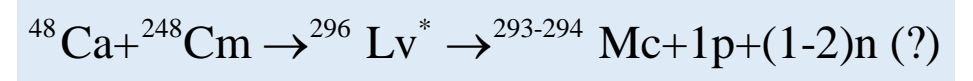
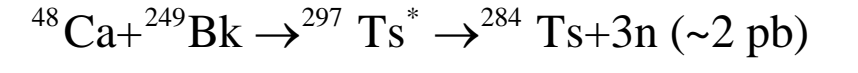
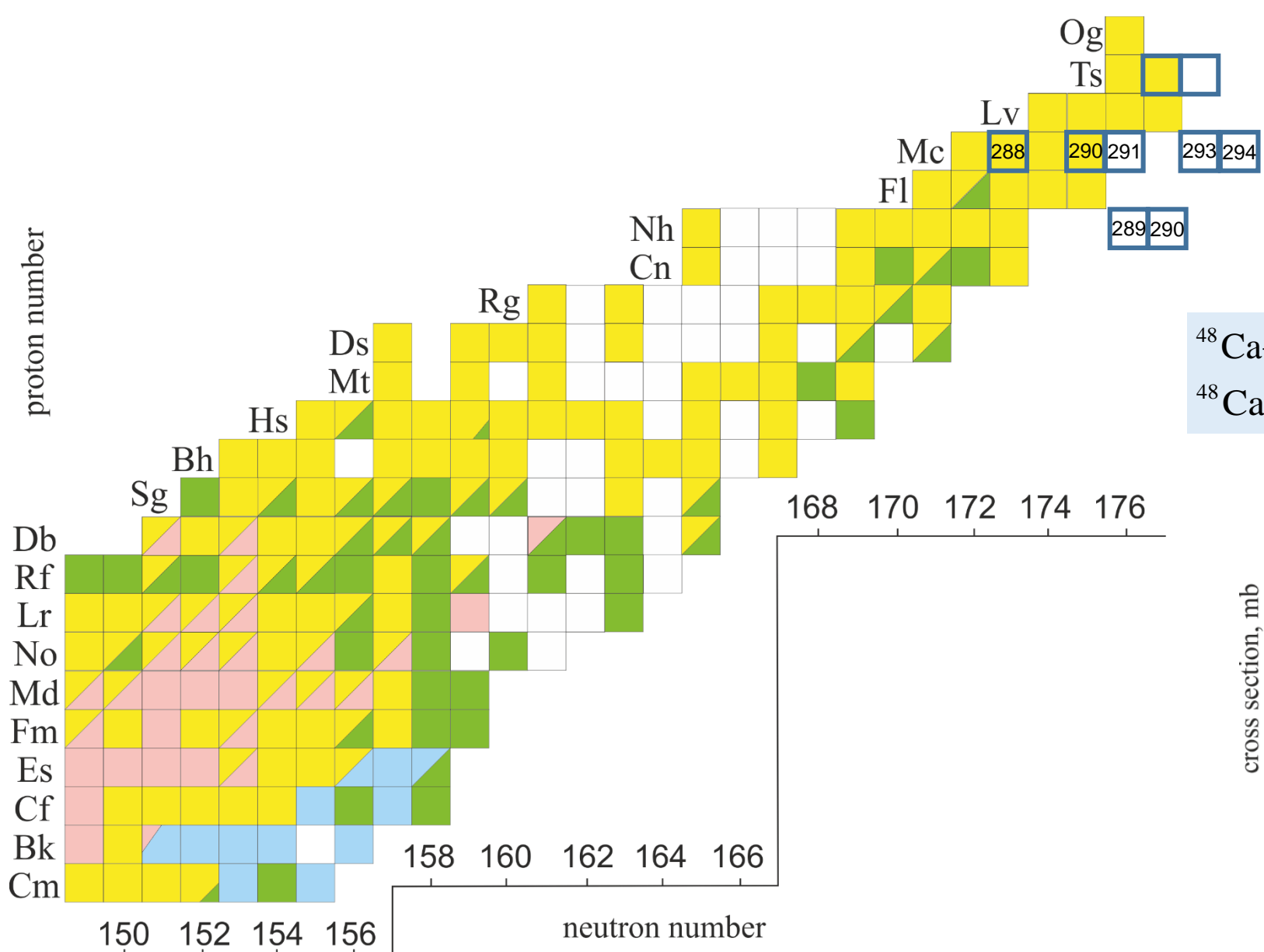


# Towards 119 and 120

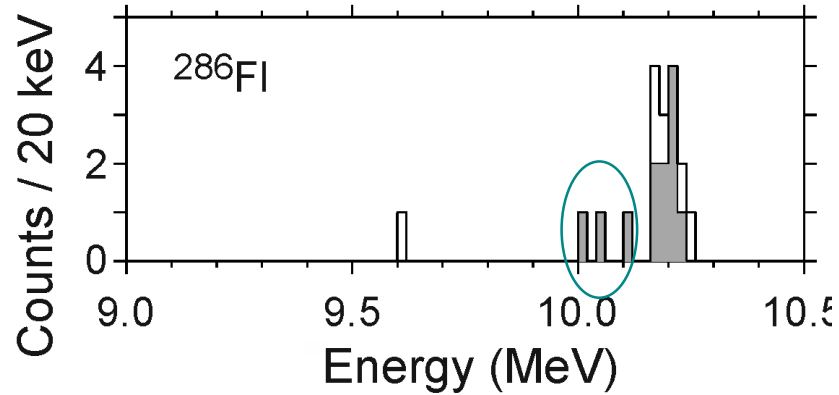


cross section decreases by ~10 times ( $^{50}\text{Ti}$ ) and ~150 times ( $^{54}\text{Cr}$ ) compared to the  $^{48}\text{Ca}$  case

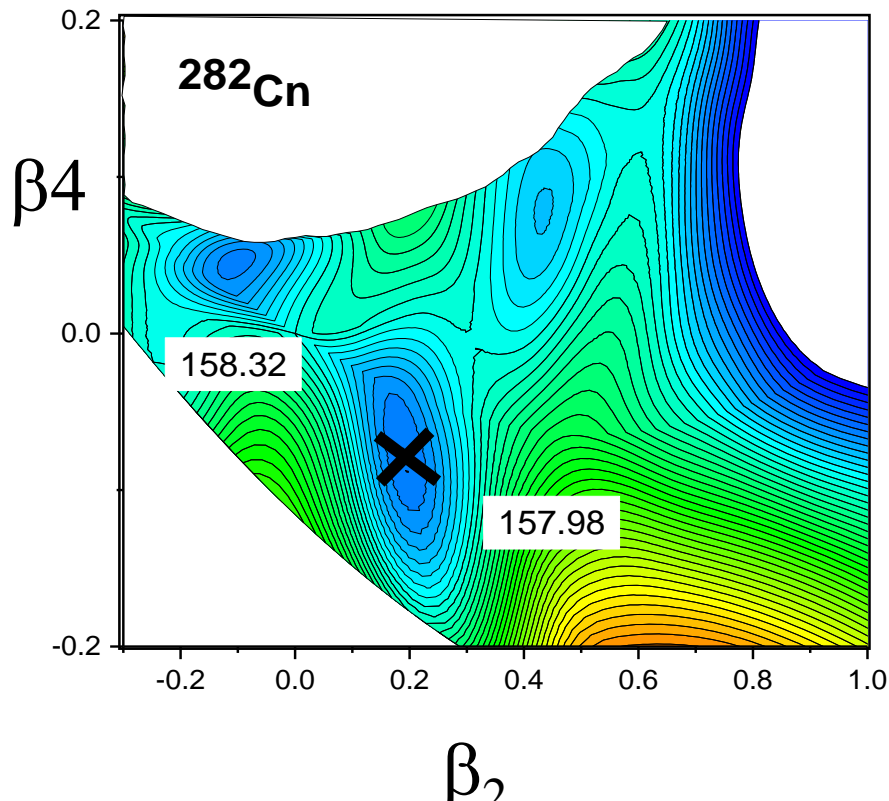
# Synthesis of SH nuclei in fusion reactions *pxn* evaporation channels



# Presumable $\alpha$ -decay of $^{286}\text{Fl}$ on rotational $2^+$ -state of $^{282}\text{Cn}$



- $^{286}\text{Fl}$ : decay on  $2^+$  rotational state of  $^{282}\text{Cn}$  or through isomeric states*



Nucleus	$\beta_2$	$E(2^+_1)$ (keV)
$^{258}\text{Fm}$	0.274	51
$^{262}\text{No}$	0.256	51
$^{266}\text{Rf}$	0.235	70
$^{270}\text{Sb}$	0.242	60
$^{274}\text{Hs}$	0.237	74
$^{278}\text{Ds}$	0.197	66
$^{282}\text{Cn}$	0.160	102
$^{286}\text{Fl}$	-0.154	144
$^{290}\text{Lv}$	0.078	431
$^{294}\text{Og}$	-0.105	242
$^{298}\text{120}$	-0.092	335

deduced for  $0^+$ : 82% and  $2^+$ : 18%

$$\beta_2 = 0.13$$

$$E_{2^+} = 101 \text{ keV}$$

“experiment”:

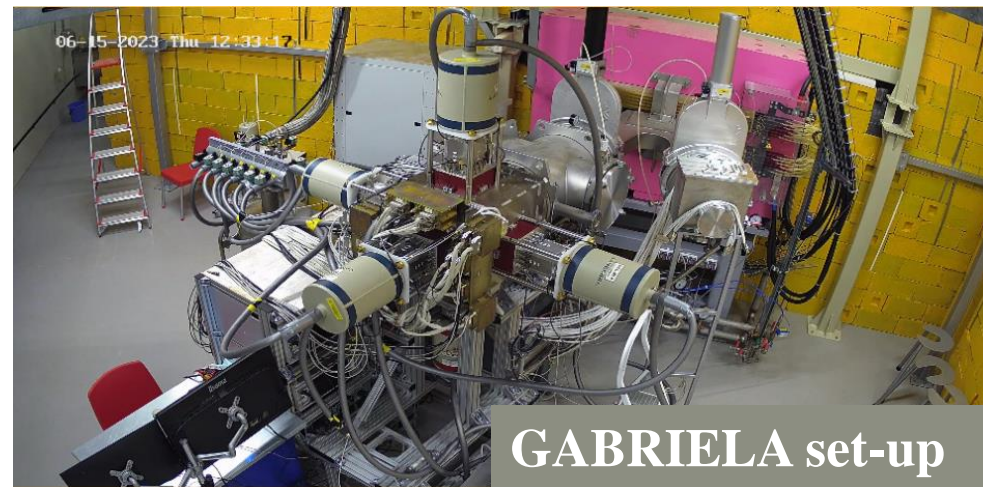
$$E_{2^+} = 100 - 200 \text{ keV}$$

$0^+$ : 82% and  $2^+$ : 18%

# Spectroscopy of SH isotopes @ SHE Factory

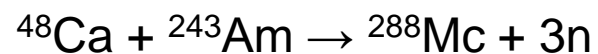
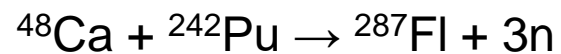


GRAND (DGFRS-3) separator



GABRIELA set-up

## planned experiments:



480 mm  
target unit

Cross section  $\sim 10$  pb;

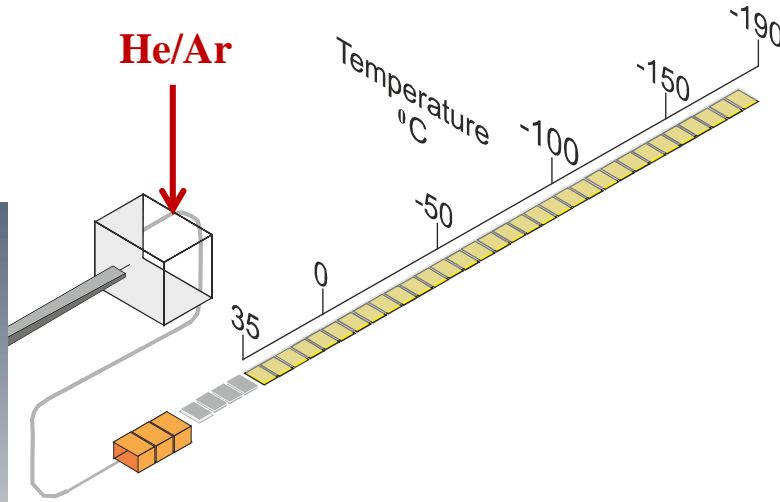
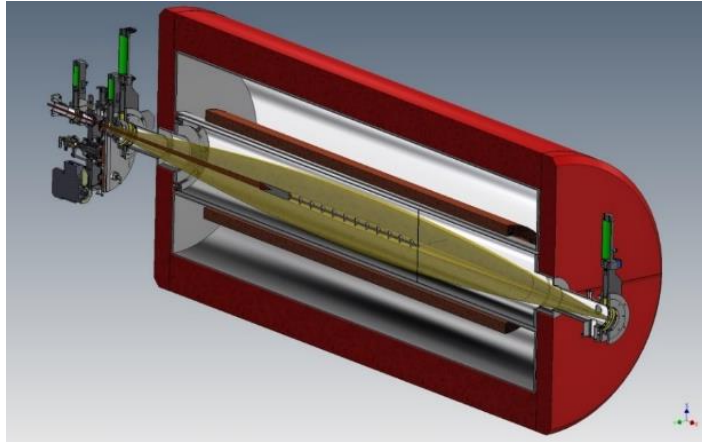
Target thickness  $\sim 1.5 \times 10^{18}$  at/cm<sup>2</sup>;

Beam intensity of <sup>48</sup>Ca  $\sim 3.3 \times 10^{13}$  pps (5 pμA);

$\epsilon_{\text{transmission}} \sim 50$  %;

100 days  $\rightarrow$  250 gamma quanta can be detected.

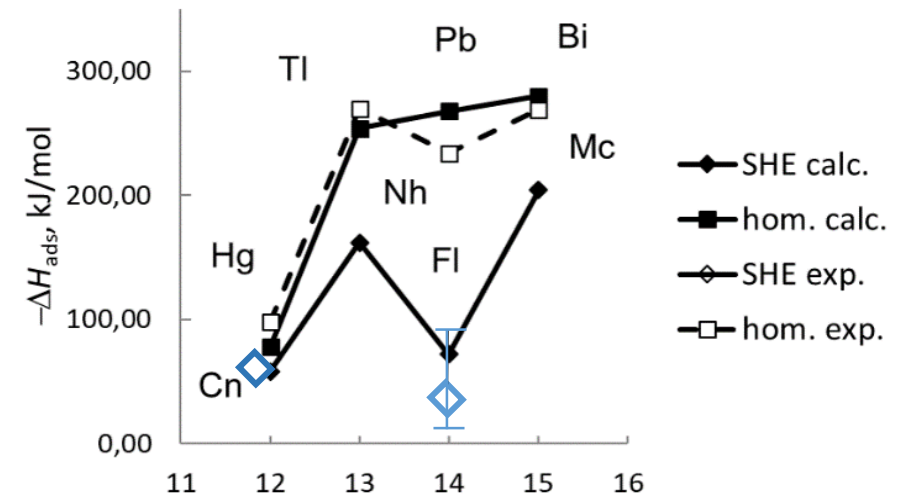
# CHEMISTRY OF SHE



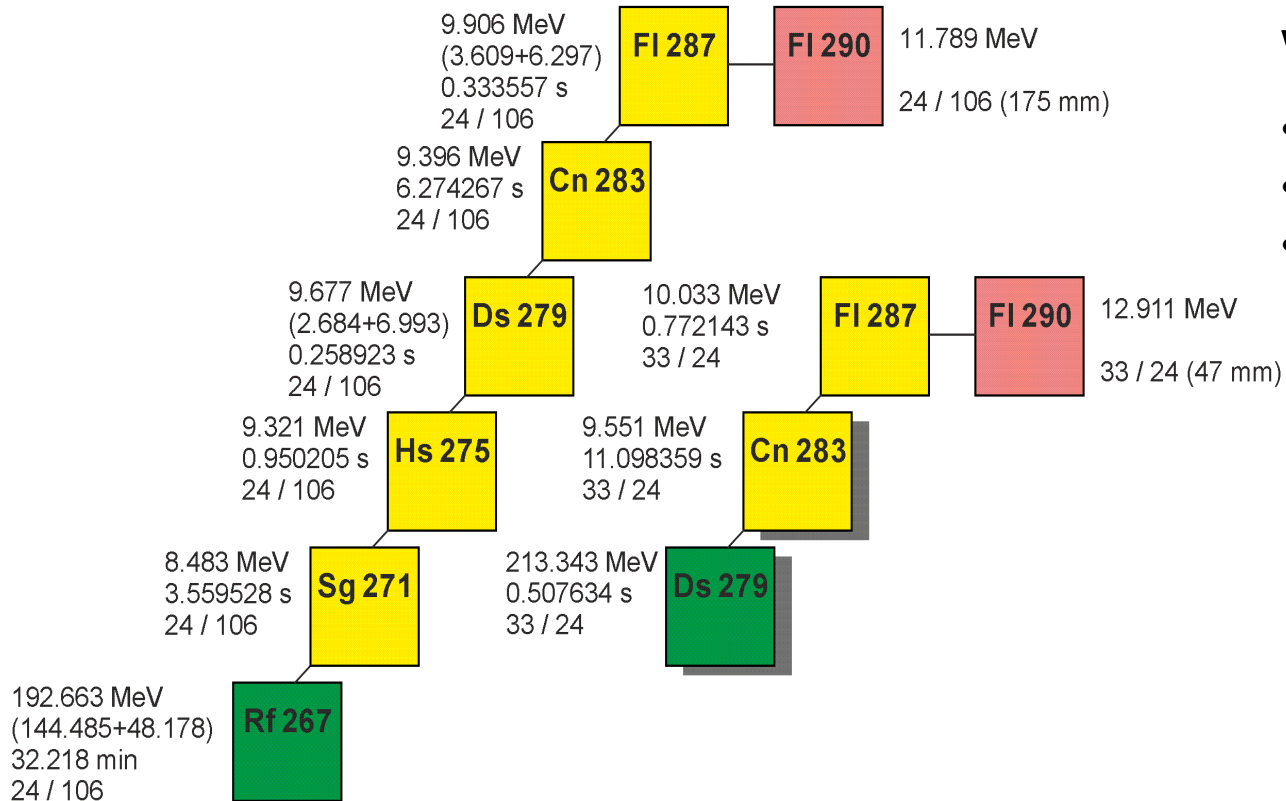
Z	Isotope	Half-life
112	$^{283}\text{Cn}$	3.6 s
113	$^{284}\text{Nh}$	0.9 s
114	$^{287}\text{Fl}$	0.3 s
115	$^{288}\text{Mc}$	0,16 s
116	$^{293}\text{Lv}$	57 ms
117	$^{294}\text{Ts}$	51 ms
118	$^{294}\text{Og}$	0.6 ms

## GASSOL – Solenoid-based separator

- Stopping SH atoms in a small volume of 1-2 cm<sup>3</sup>
- Chemistry of short-lived SHE  $T_{1/2} \geq 30$  ms (up to elements 116-117)

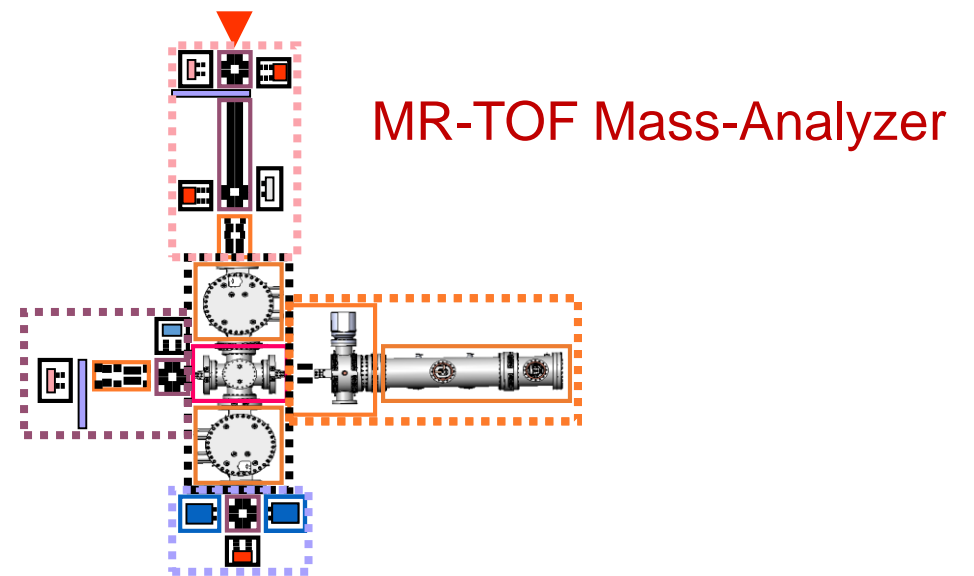


# Precise mass measurements of SH nuclei @ SHE Factory



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

- $T_{1/2} > 100$  ms
- Production rate  $\sim 1$  event/day
- Background rate  $\geq 1$  event/s



# Основные направления исследований на Фабрике СТЭ

- *Синтез новых сверхтяжелых элементов (119, 120)*
- *Синтез сверхтяжелых ядер и изучение свойств их распада*
- *Спектроскопия тяжелых и сверхтяжелых ядер*
- *Измерение масс сверхтяжелых ядер*
- *Изучение химических свойств СТЭ*

# Спасибо за внимание!

