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Heavy Ion Cyclotrons of FLNR JINR

Status and Plans

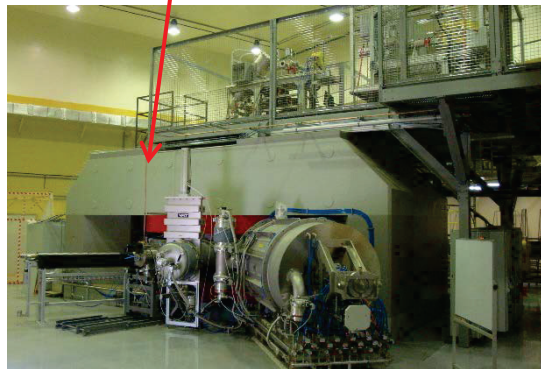
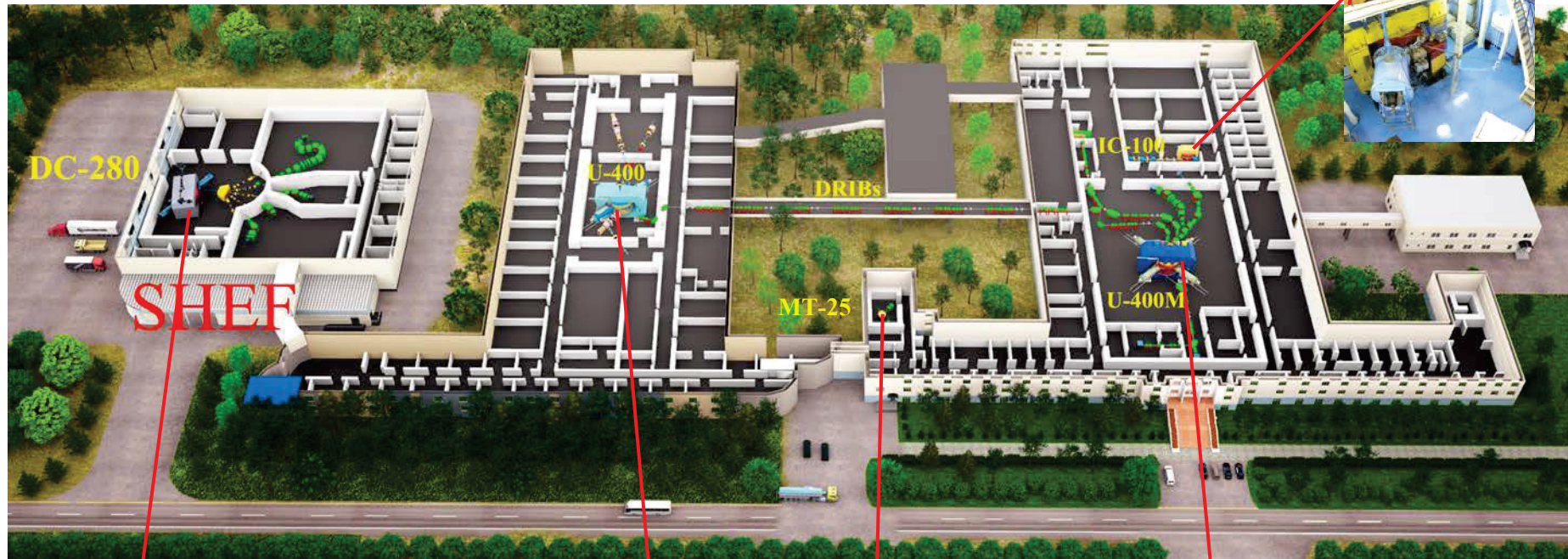
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Flerov Laboratory of Nuclear Reactions
Joint Institute for Nuclear Research

RUPAC-2018, Protvino

FLNR JINR Accelerator Complex

IC-100



DC-280



U-400



MT-25



U-400M

BASIC DIRECTIONS of RESEARCH at FLNR

U-400, U-400M & DC-280 cyclotrons (^{48}Ca , ^{50}Ti 5 ÷ 6 MeV/n)

- **synthesis and study of properties of super heavy elements;**
- **chemistry of new elements;**
- **fusion-fission reactions;**
- **nuclear- , mass- spectrometry of SH nuclei.**

U-400M cyclotron (ions 15 ÷ 60 MeV/n)

- **properties and structure of light exotic nuclei;**
- **reactions with exotic nuclei.**

IC-100 (C ÷ W 1.2 MeV/n), U-400 (Ar ÷ Bi 2.5 ÷ 3.5 MeV/n)

- **Radiation effects and physical groundwork of nanotechnology.**

U-400 & U-400M (O ÷ Bi 3 ÷ 5 MeV/n) and

U-400M (O ÷ Bi 15 ÷ 60 MeV/n)

- **SEE testing of electronic components**

Flerov Laboratory of Nuclear Reactions

**Total operation time of
U-400, U-400M, IC-100 and MT-25
accelerators**

2015

2016

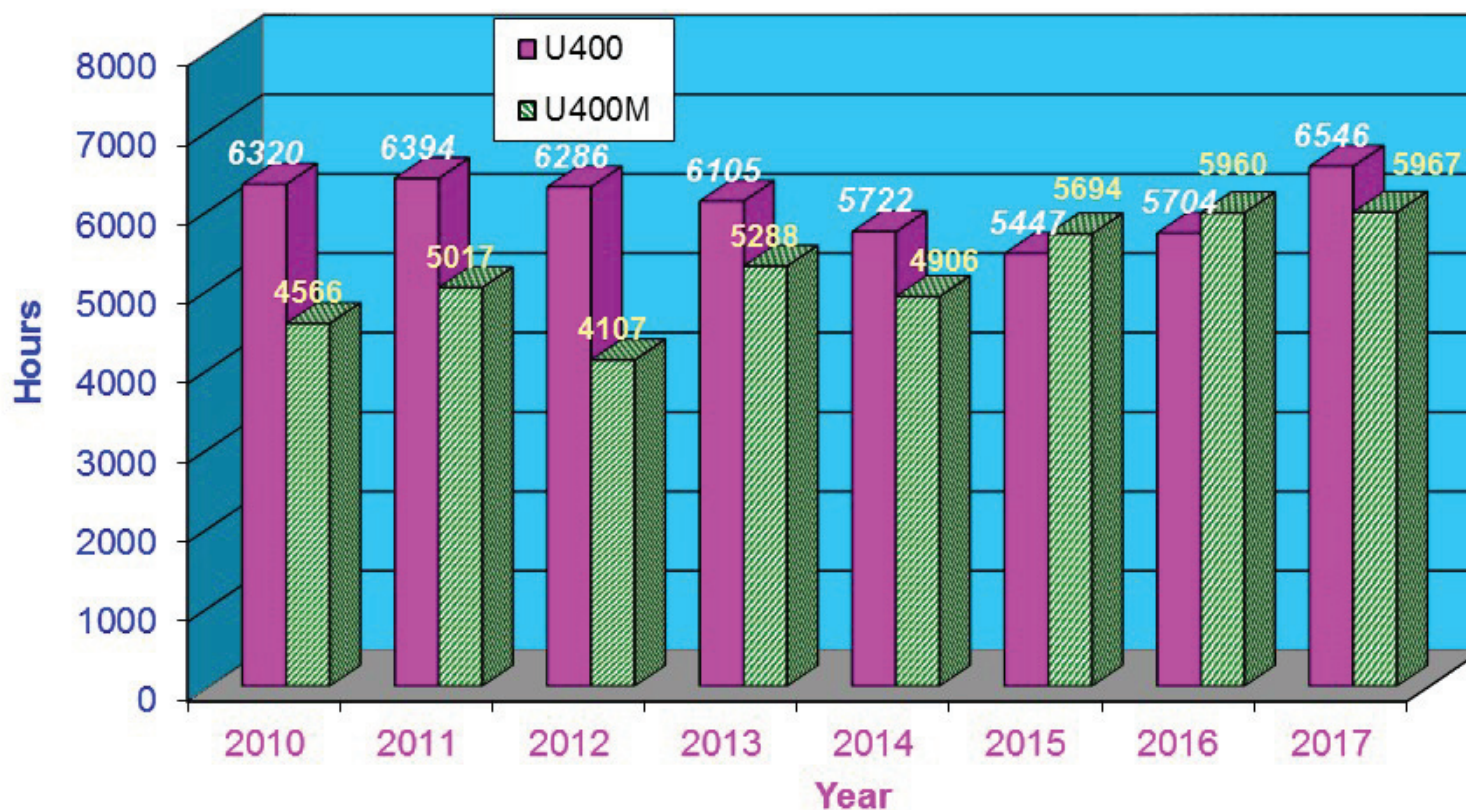
2017

14 034

15 724

16 657

OPERATION TIME OF U-400 AND U-400M ACCELERATORS



U400 CYCLOTRON (1978)

stand-alone & post-accelerator



Main tasks:

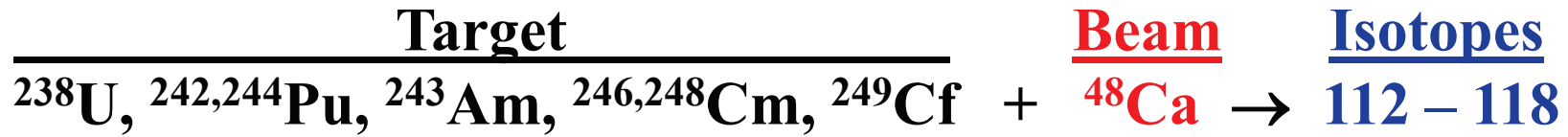
- New heavy isotopes
- Fusion-fission
- Nuclear spectroscopy
- SHE chemistry
- Multi nucleon transfer reactions;

Ion	Ion energy [MeV/A]	Output intensity
${}^6\text{He}^{1+}$	11	$3 \cdot 10^7$ pps
${}^{16}\text{O}^{2+}$	5.7; 7.9	5 pμA
${}^{18}\text{O}^{3+}$	7.8; 10.5; 15.8	4.4 pμA
${}^{40}\text{Ar}^{4+}$	3.8; 5.1 *	1.7 pμA
${}^{48}\text{Ca}^{5+}$	3.7; 5.3 *	1.2 pμA
${}^{48}\text{Ca}^{9+}$	8.9; 11; 17.7 *	1 pμA
${}^{50}\text{Ti}^{5+}$	3.6; 5.1 *	0.5 pμA
${}^{58}\text{Fe}^{6+}$	3.8; 5.4 *	0.7 pμA
${}^{84}\text{Kr}^{8+}$	3.1; 4.4 *	0.3 pμA
${}^{136}\text{Xe}^{14+}$	3.3; 4.6; 6.9 *	0.08 pμA
${}^{160}\text{Gd}^{19+}$	5.5	0.01 pμA
${}^{209}\text{Bi}^{19+}$	3.4	0.01 pμA

Experimental setups at U400 :

1. **GFRS** (Gas-Filled Recoil Separator), **channel N1**
2. **Chemical setup**, **channel N2**
3. **SHELS** (Separator for Heavy Element Spectroscopy), **channel N3**
4. **Corset** (Investigation of the fusion-fission reactions), **channel N6**
5. **SEE testing of electronic components**, **channel N8;**
6. **MAVR** (High-resolution magnetic analyser), **channel N9**
7. **Channel for applied research**, **channel N10**

DUBNA Gas Filled Recoil Separator

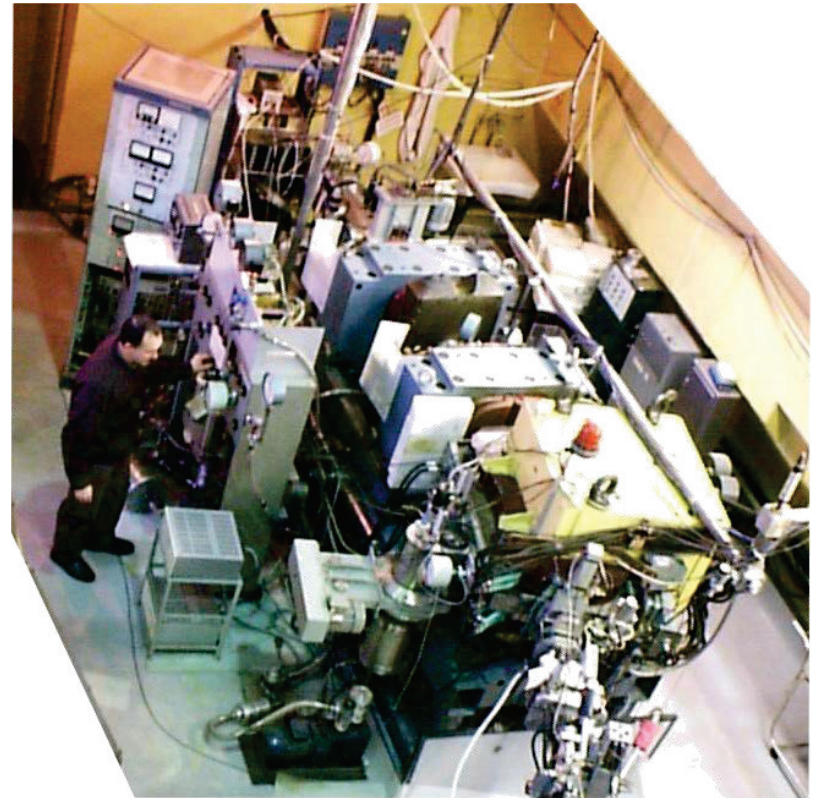
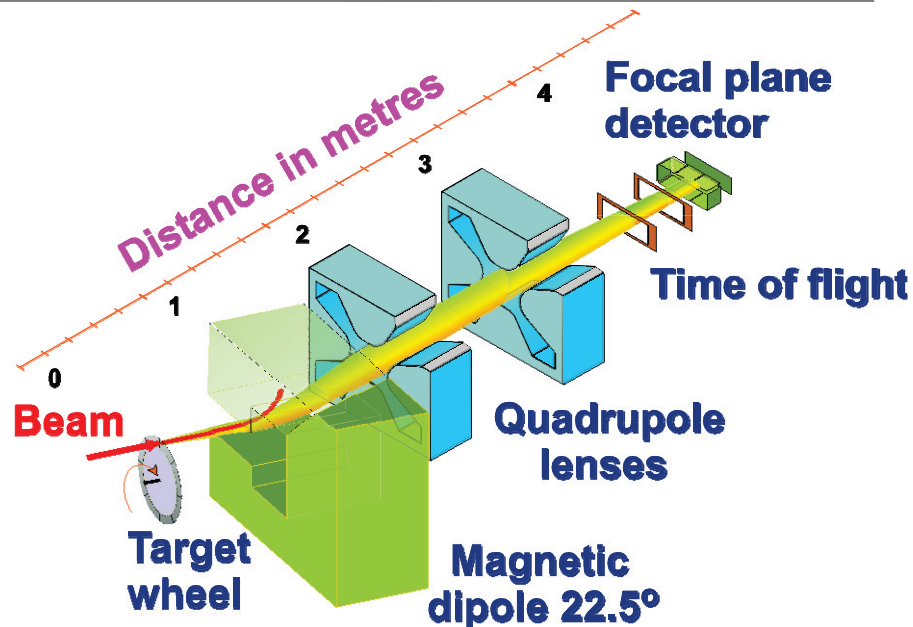


Ion beam energy: 5.00 – 5.75 MeV/A

Beam intensity: 6 - 8 · 10¹² pps

Consumption of ⁴⁸Ca = 0.5-0.7 mg/h

Beam time: 2000 – 4000 hours per year





ЛАБОРАТОРИЯ ЯДЕРНОЙ ФИЗИКИ

Периодическая таблица элементов Д.И. Менделеева D.I. Mendeleev's Periodic Table of Elements

1																		Периодическая таблица элементов																		18																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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Натрий 11 22.99 Sodium																		Магний 12 24.305 Magnesium																		Алюминий 13 26.982 Aluminum																		Кремний 14 28.085 Silicon																		Фосфор 15 30.974 Phosphorus																		Сера 16 32.06 Sulfur																		Хлор 17 35.45 Chlorine																		Аргон 18 39.948 Argon																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
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Рубидий 37 85.468 Rubidium																		Стронций 38 87.62 Strontium																		Иттрий 39 88.906 Yttrium																		Цирконий 40 91.224 Zirconium																		Нобий 41 92.906 Niobium																		Молибден 42 95.94 Mo																		Технеций 43 98 Ru																		Рутений 44 101.07 Rh																		Родий 45 106.3 Pd																		Серебро 46 107.86 Ag																		Кадмий 47 112.4 Cd																		Индий 48 114.8 In																		Олово 49 118.7 Sn																		Свинец 50 127.6 Pb																		Висмут 51 208.98 Bi																		Теллур 52 127.6 Te																		Йод 53 126.9 I																		Ксенон 54 131.29 Xe																																																																																																																																																																																																																																																																																																																																			
Цезий 55 132.91 Cesium																		Барий 56 137.33 Barium																		Лантан 57 138.91 Lanthanum																		Гафний 72 178.49 Hf																		Тантал 73 180.95 Ta																		Вольфрам 74 186.21 W																		Рений 75 186.21 Re																		Осмий 76 190.23 Os																		Иридий 77 192.22 Ir																		Платина 78 195.08 Pt																		Золото 79 196.97 Au																		Ртуть 80 200.59 Hg																		Таллий 81 204.38 Tl																		Свинец 82 207.2 Pb																		Висмут 83 208.98 Bi																		Полоний 84 209 Po																		Актиний 85 210 Ac																		Франций 87 223 Fr																		Радий 88 226 Ra																		Актиний 89 227 Ac																		Резерфордий 104 261 Rf																		Дубний 105 262 Db																		Сибгориум 106 266 Sg																		Бергмий 107 264 Bh																		Хассий 108 277 Hs																		Мейтнерий 109 278 Mt																		Дармштадтий 110 281 Ds																		Рентгений 111 282 Rg																		Коперниций 112 285 Cn																		Нихоний 113 286 Nh																		Флеровий 114 289 Fl																		Московий 115 290 Mc																		Ливерморий 116 293 Lv																		Теннессиум 117 294 Ts																		Оганесон 118 294 Og																	

Лантаноиды Lanthanoides

Первый 58 Ce 58.93 Cerium	Прозетимий 59 Pr 58.93 Praseodymium	Неодим 60 Nd 58.93 Neodymium	Прометий 61 Pm [145] Promethium	Самарий 62 Sm 58.93 Samarium	Европий 63 Eu 58.93 Europium	Гадолиний 64 Gd 58.93 Gadolinium	Тербий 65 Tb 58.93 Terbium	Диспрозий 66 Dy 58.93 Dysprosium	Гольмий 67 Ho 58.93 Holmium	Эрбий 68 Er 58.93 Erbium	Тулий 69 Tm 58.93 Thulium	Иттербий 70 Yb 58.93 Ytterbium	Лантан 71 La 58.93 Lanthanum
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Водород 1 H 1.00794 Hydrogen
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Актиноиды Actinoides

Торий 90 Th 232.04 Thorium	Протактиний 91 Pa 231.04 Protactinium	Уран 92 U 238.03 Uranium	Нептуний 93 Np 237 Neptunium	Плутоний 94 Pu 244 Plutonium	Америций 95 Am [243] Americium	Кюрий 96 Cm [247] Curium	Берклий 97 Bk [247] Berkelium	Калифорний 98 Cf [251] Californium	Эйнштейний 99 Es [252] Einsteinium	Фермий 100 Fm [257] Fermium	Мейтневий 101 Md [258] Mendelevium	Нобелий 102 No [259] Nobelium	Лавренсий 103 Lr [260] Lawrencium
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H - символ / symbol
1.00794 - атомная масса / atomic mass
1s² - электронная конфигурация / electron configuration
23.50664 - 1-я потенциал ионизации, эВ / 1st ionization potential, eV
0.899 - плотность, кг/м³ / density, kg/m³
-259.34 - температура плавления, °C / melting temperature, °C
-252.87 - температура кипения, °C / boiling temperature, °C

Axial injection system of U-400 Cyclotron

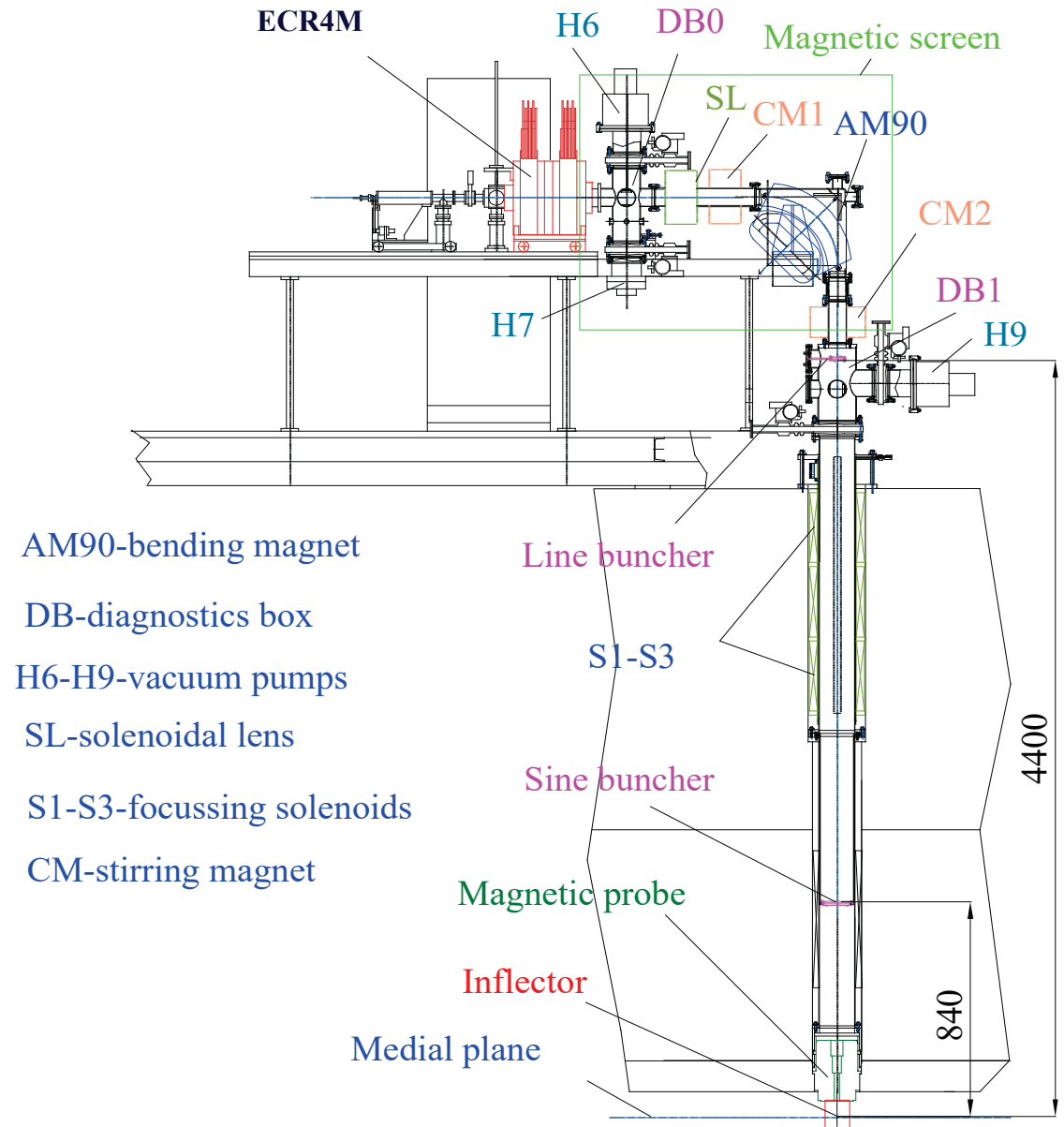
ECR4M ion source

made by GANIL 1995,
upgraded by FLNR 2013

$^{48}\text{Ca}^{5+}$ - 100 e μ A

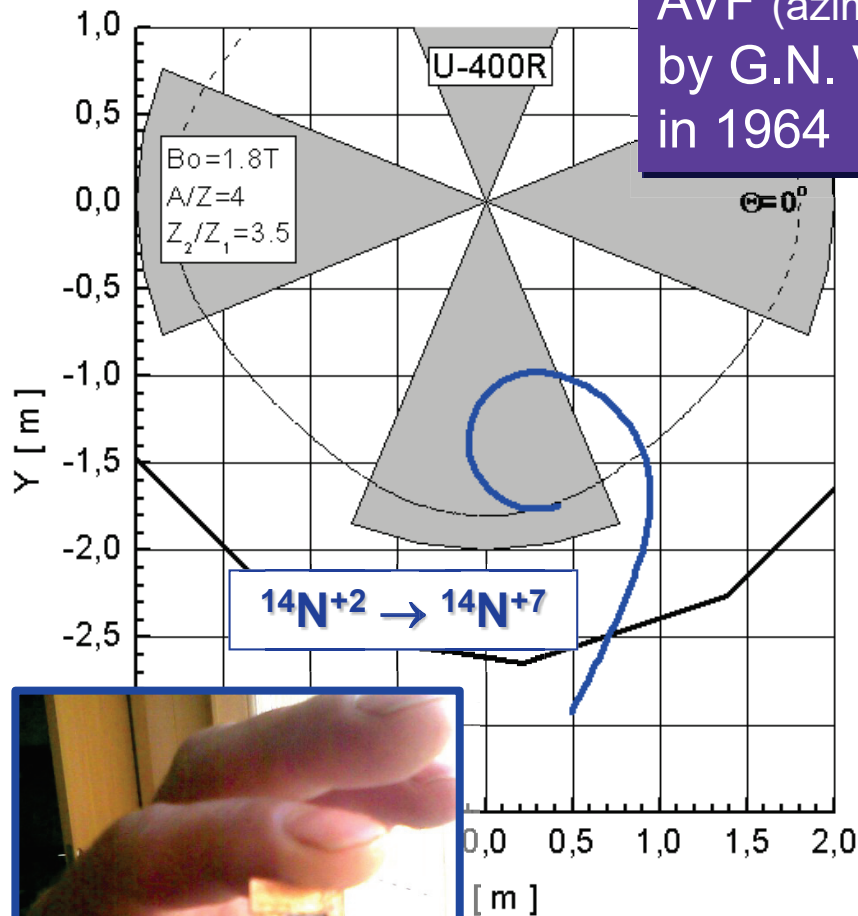
$^{132}\text{Xe}^{12+}$ - 50 e μ A

$^{209}\text{Bi}^{19+}$ - 20 e μ A

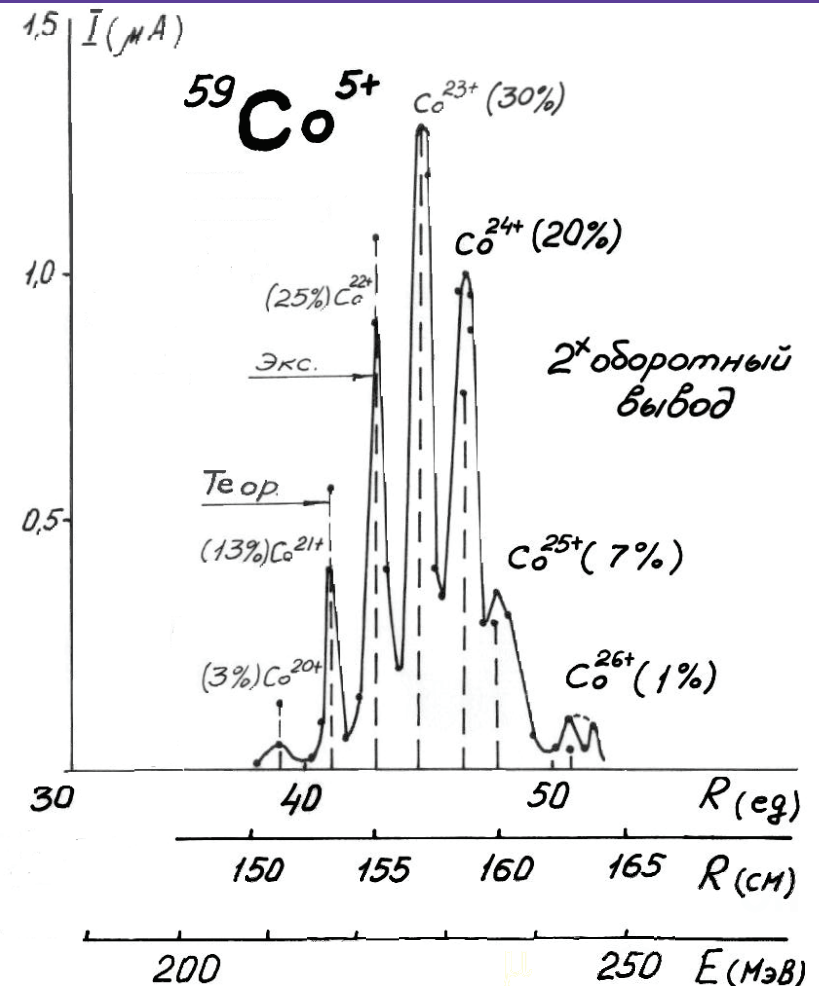


Heavy Ion Beam Extraction by Stripping Foil

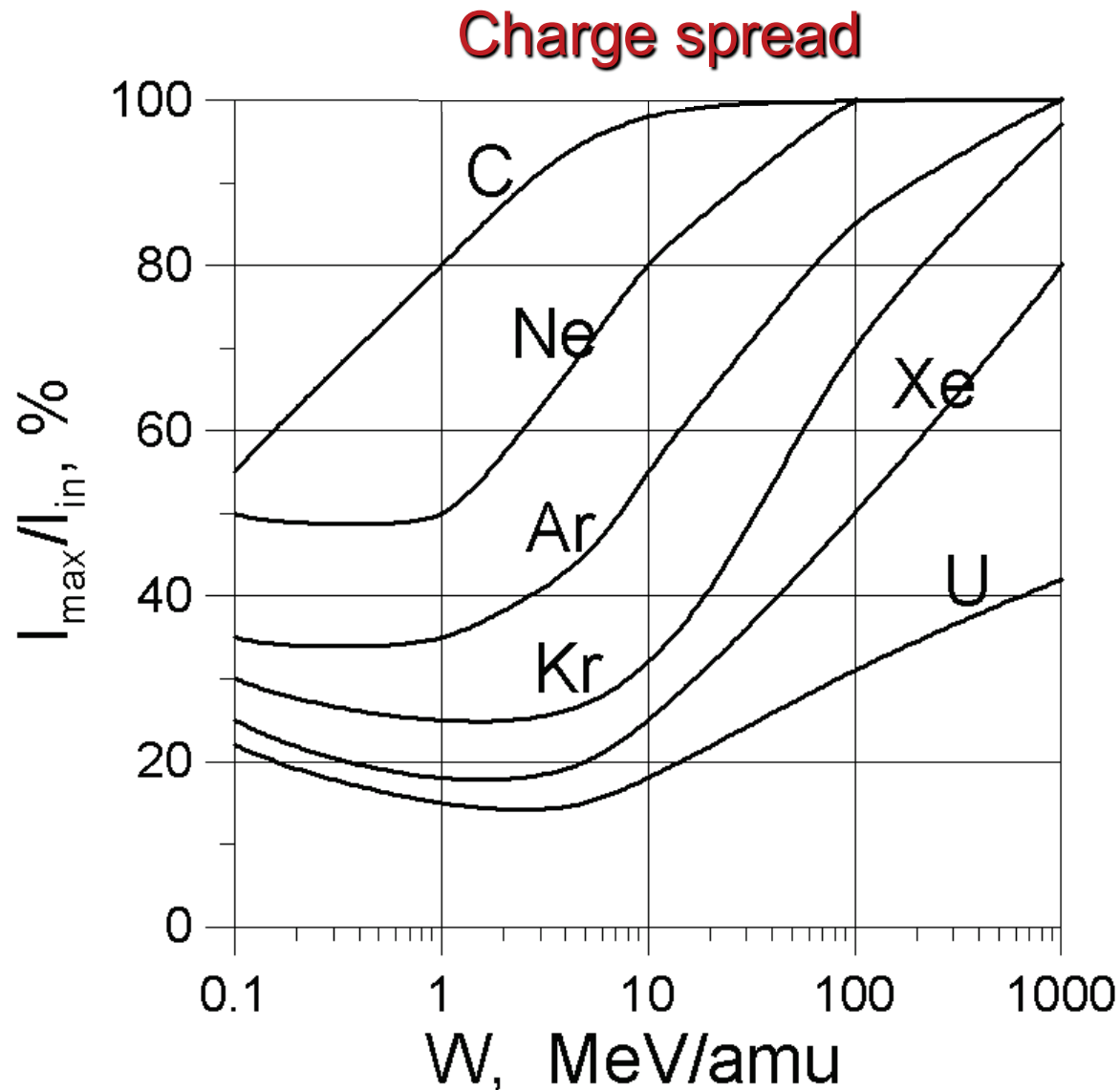
The method of heavy ion beam extraction from AVF (azimuthally-varying-field) cyclotrons suggested by G.N. Vialov, G.N. Flerov and Yu. Oganessian in 1964



Thickness of
stripping foils
 $20 \div 200 \mu g/cm^2$



Heavy Ion Beam Extraction by Stripping Foil



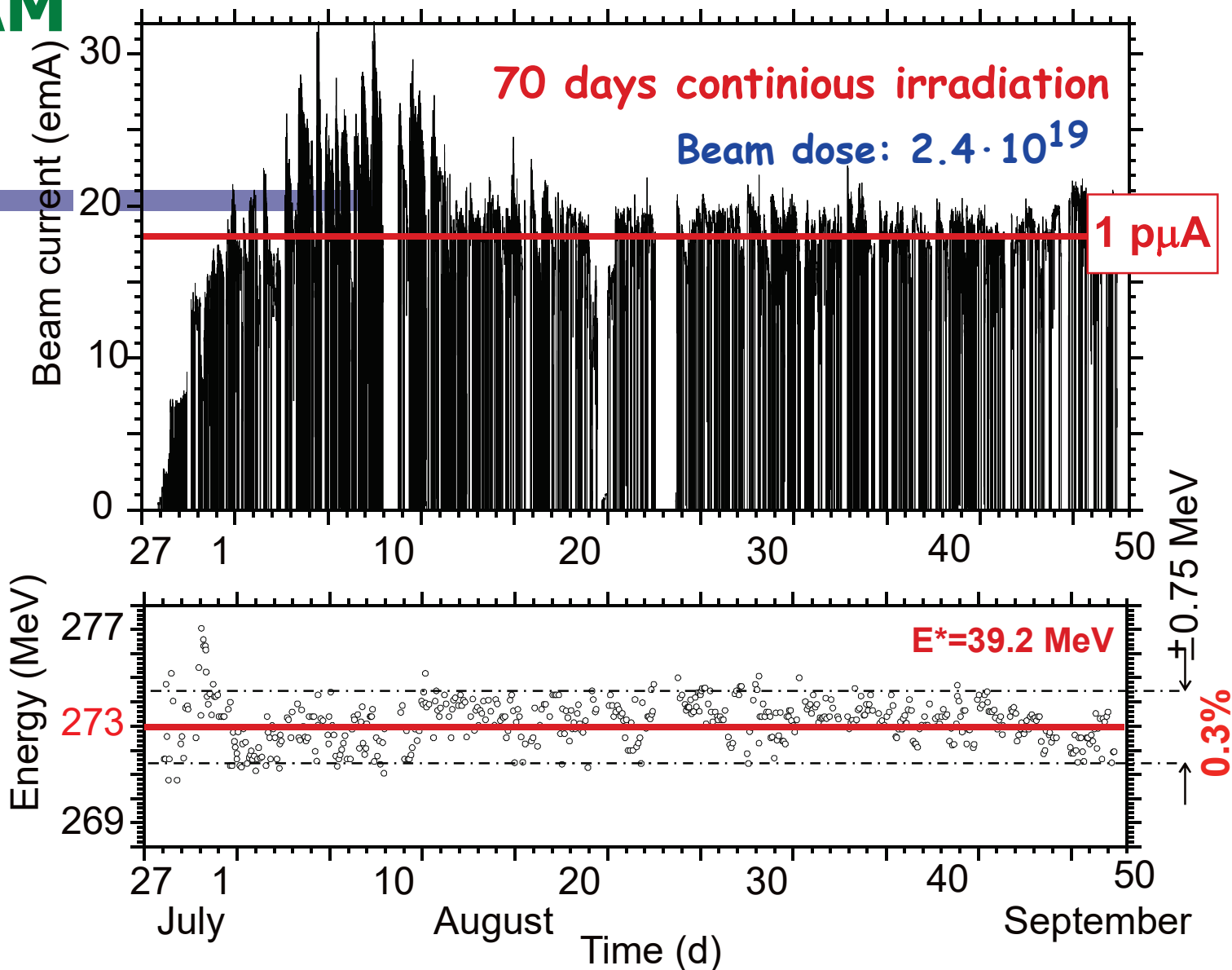
Dependence of the maximal efficiency of a single charge extraction by stripping on ion energy

Efficiency of transporting a $^{48}\text{Ca}^{5+}$ beam from the ECR source to a physical target

Measuring point	Beam intensity		Ion	Transmission factor				
ECR source, after separation	1·10 ¹⁴ pps	84 μAe	⁴⁸ Ca ⁵⁺	32%				8.5%
Cyclotron centre	3.5·10 ¹³ pps	27 μAe	⁴⁸ Ca ⁵⁺		81%			
Extraction radius	2.8·10 ¹³ pps	22 μAe	⁴⁸ Ca ⁵⁺			40%		
Extracted beam (by charge exchange)	9.7·10 ¹² pps	28 μAe	⁴⁸ Ca ¹⁸⁺				82%	
Target	8·10 ¹² pps	23 μAe	⁴⁸ Ca ¹⁸⁺					

- Ionization efficiency of ^{48}Ca (neutral) to $^{48}\text{Ca}^{5+}$ - about 10%
- Transformation of ^{48}Ca as working substance into the ^{48}Ca beam on target is about 1% in routine operation.

BEAM



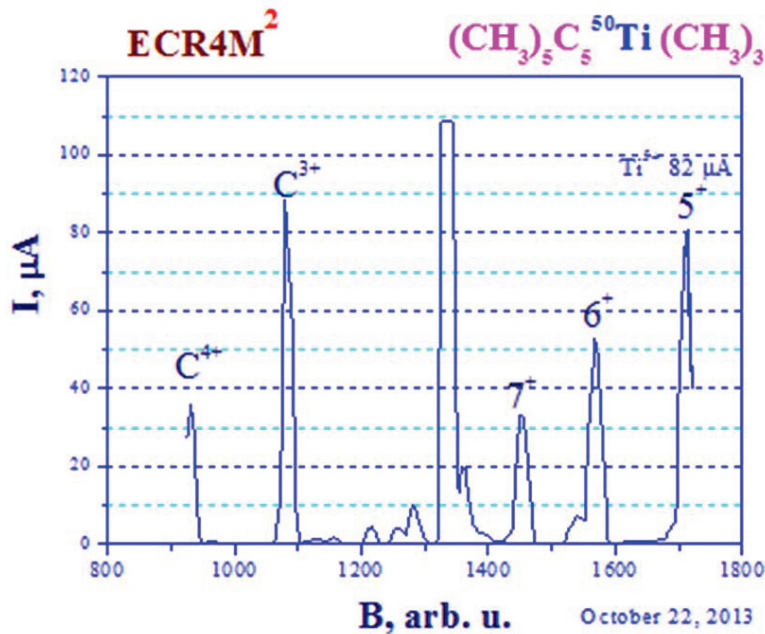
Development of ^{50}Ti beam using MIVOC method

(Collaboration between IPHC (Strasbourg, France) and FLNR JINR.)

Synthesis of compound (two steps)



where $\text{Cp}^* - (\text{CH}_3)_5\text{C}_5$



The spectrum of Ti ions, the source settings are optimized for $^{50}\text{Ti}^{5+}$ (82 mkA).

Acceleration at the U-400 cyclotron

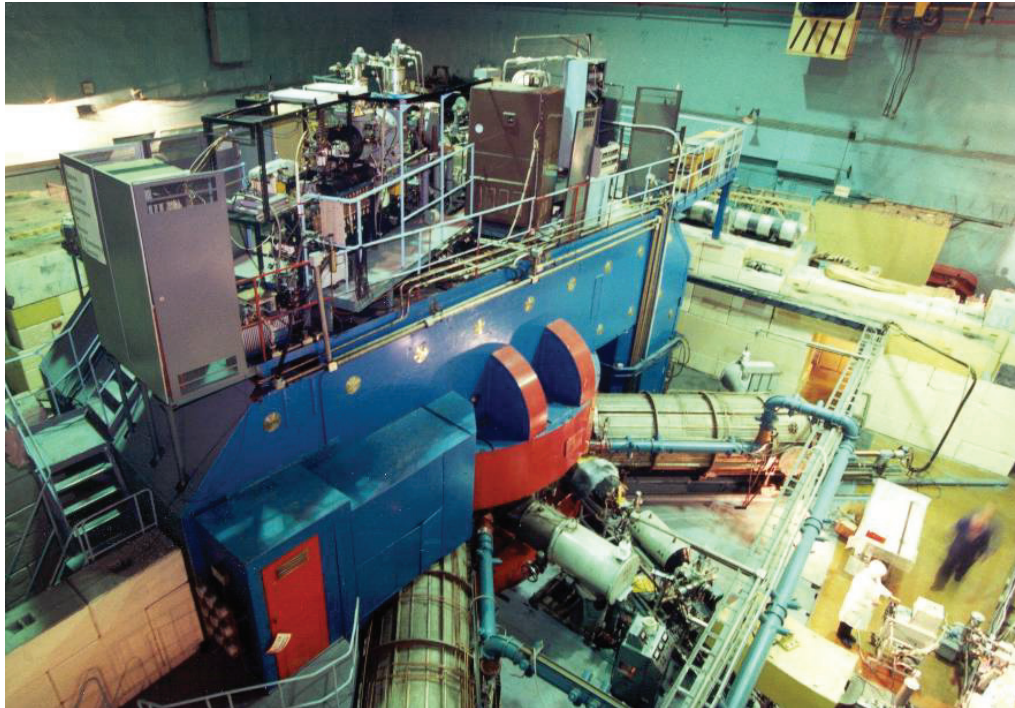
The intensity of the injected beam of $^{50}\text{Ti}^{5+} \geq 50 \text{ e}\mu\text{A}$

The intensity on the target $\sim 10 \text{ e}\mu\text{A}$ ($\sim 0.5 \text{ p}\mu\text{A}$)

The compound consumption rate of 2.4 mg/h (^{50}Ti consumption of 0.52 mg/h)

U400M CYCLOTRON (1991)

stand-alone & driving accelerator

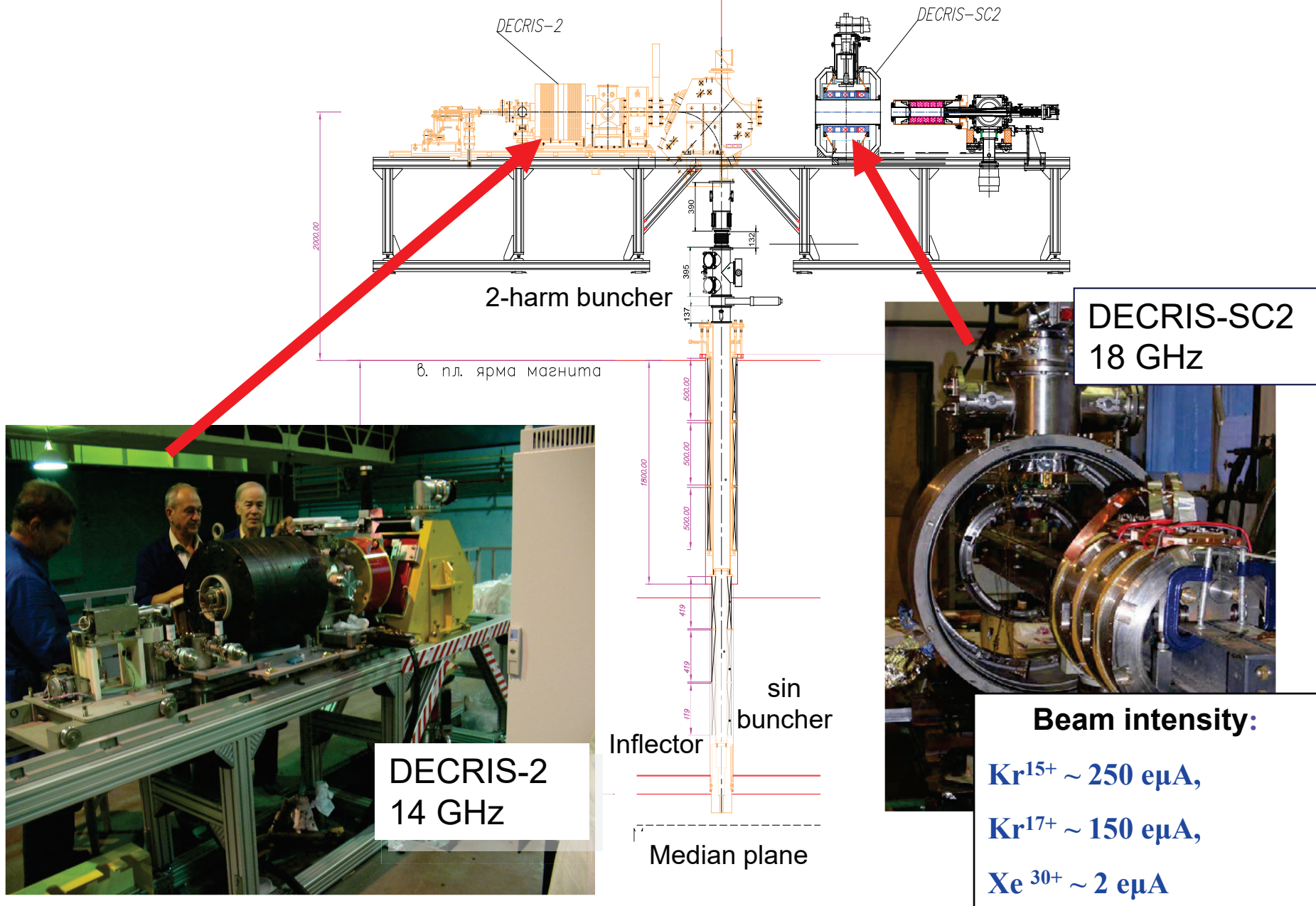


Main tasks:

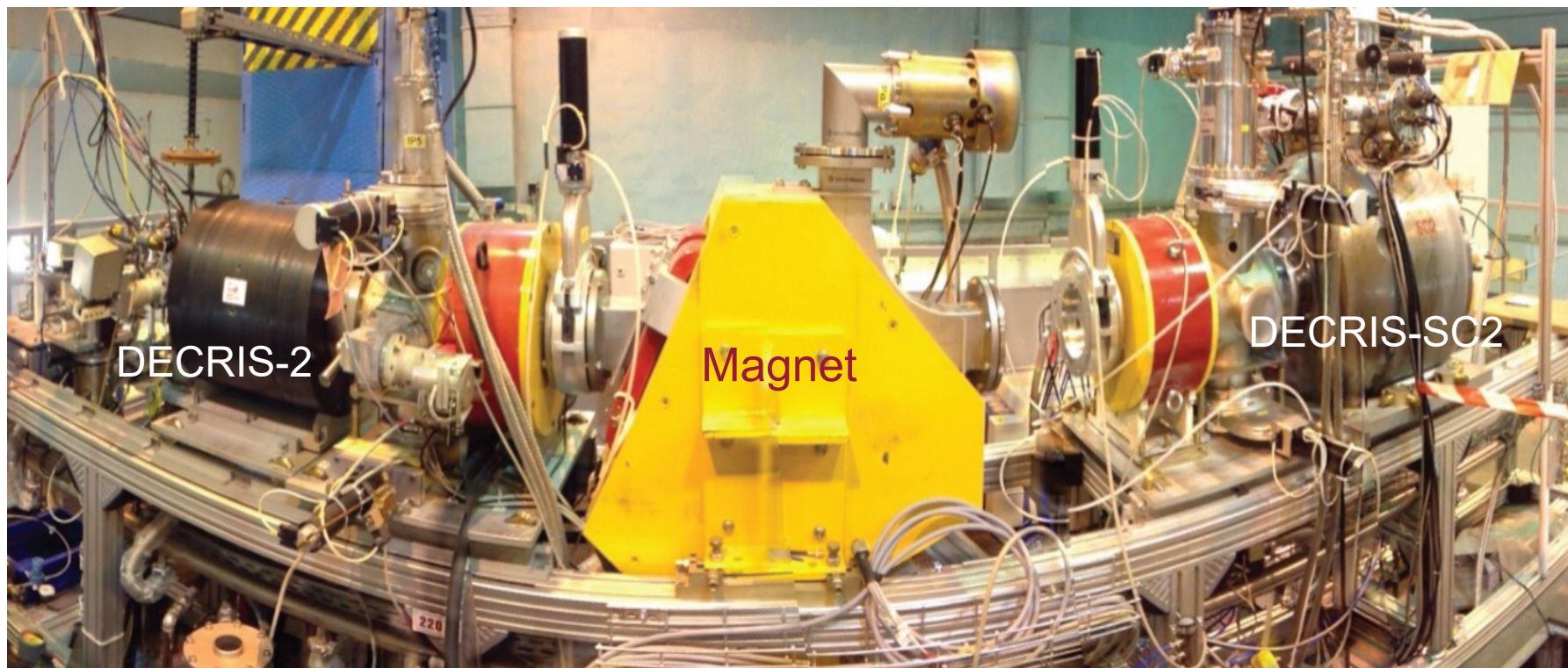
- *Producing of RIBs.*
- *Reactions with exotic nuclei;*
- *Properties and structure of light exotic nuclei.*

U400M E=15 ÷ 60 MeV/A E=4.5 ÷ 9 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity [pps]
${}^7\text{Li}$	35	6×10^{13}
${}^{18}\text{O}$	33	1×10^{13}
${}^{40}\text{Ar}$	40	1×10^{12}
${}^{48}\text{Ca}$	5	3×10^{12}
${}^{58}\text{Fe}$	5	1×10^{12}
${}^{124}\text{Sn}$	5	2×10^{11}
${}^{136}\text{Xe}$	5	4×10^{11}
${}^{132}\text{Xe}$	25	3×10^5
${}^{238}\text{Bi}$	5	3×10^8
${}^{238}\text{Bi}$	15	1×10^5

U-400M. Ion sources and axial injection system

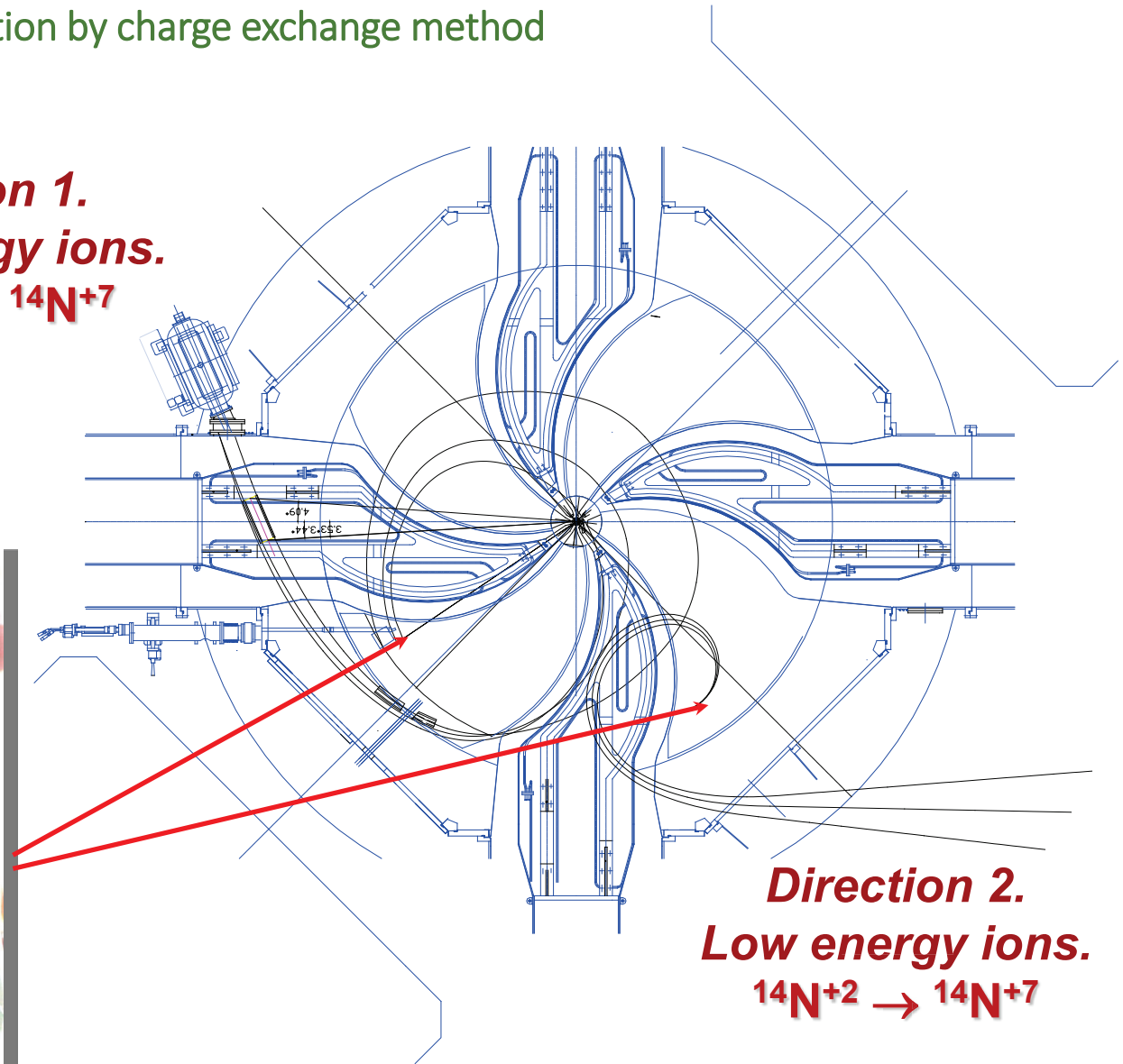


Ion sources of U-400M cyclotron DECRIS-2 (14 GHz) и DECRIS-SC2 (18 GHz)



U-400M. Ion beam extraction by charge exchange method

Direction 1.
High energy ions.
 $^{14}\text{N}^{+5} \rightarrow ^{14}\text{N}^{+7}$



Direction 2.
Low energy ions.
 $^{14}\text{N}^{+2} \rightarrow ^{14}\text{N}^{+7}$



Thickness of stripping foils
 $20 \div 200 \mu\text{g}/\text{cm}^2$

Experimental setups at U-400M

Low energy ion beams

MASHA

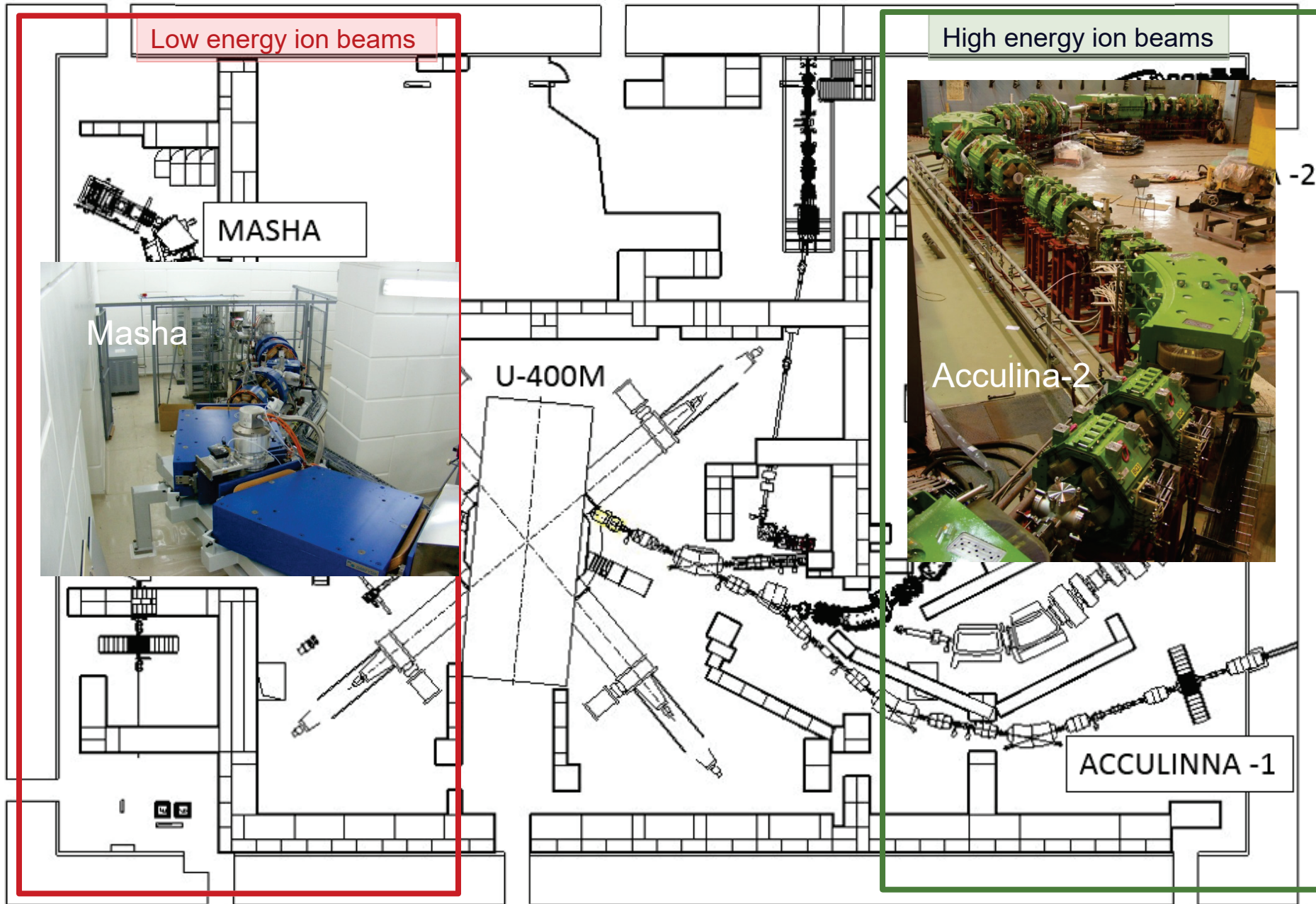
Masha

U-400M

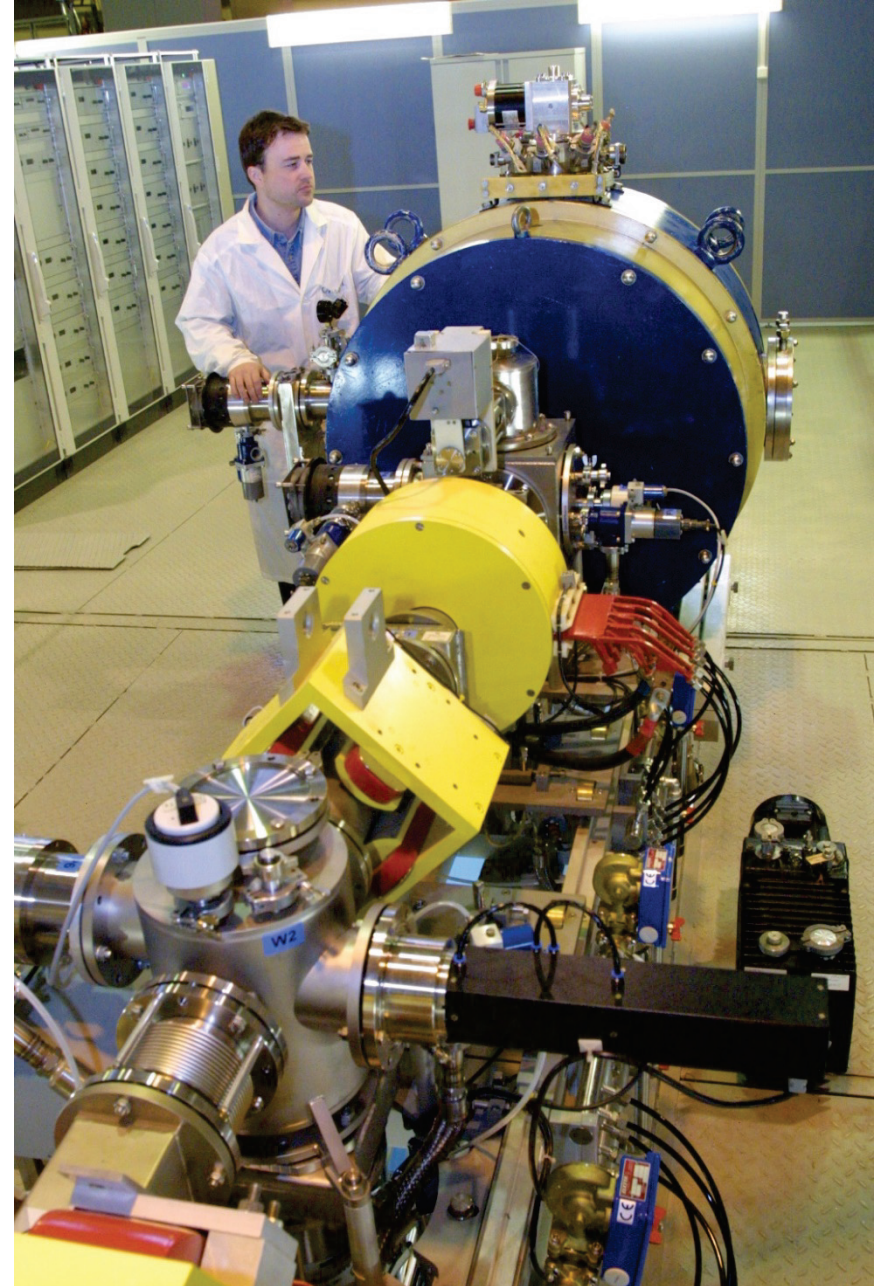
High energy ion beams

Acculina-2

ACCULINNA -1



IC-100 cyclotron after reconstruction (2001-2002)



Parameters of the IC-100 cyclotron

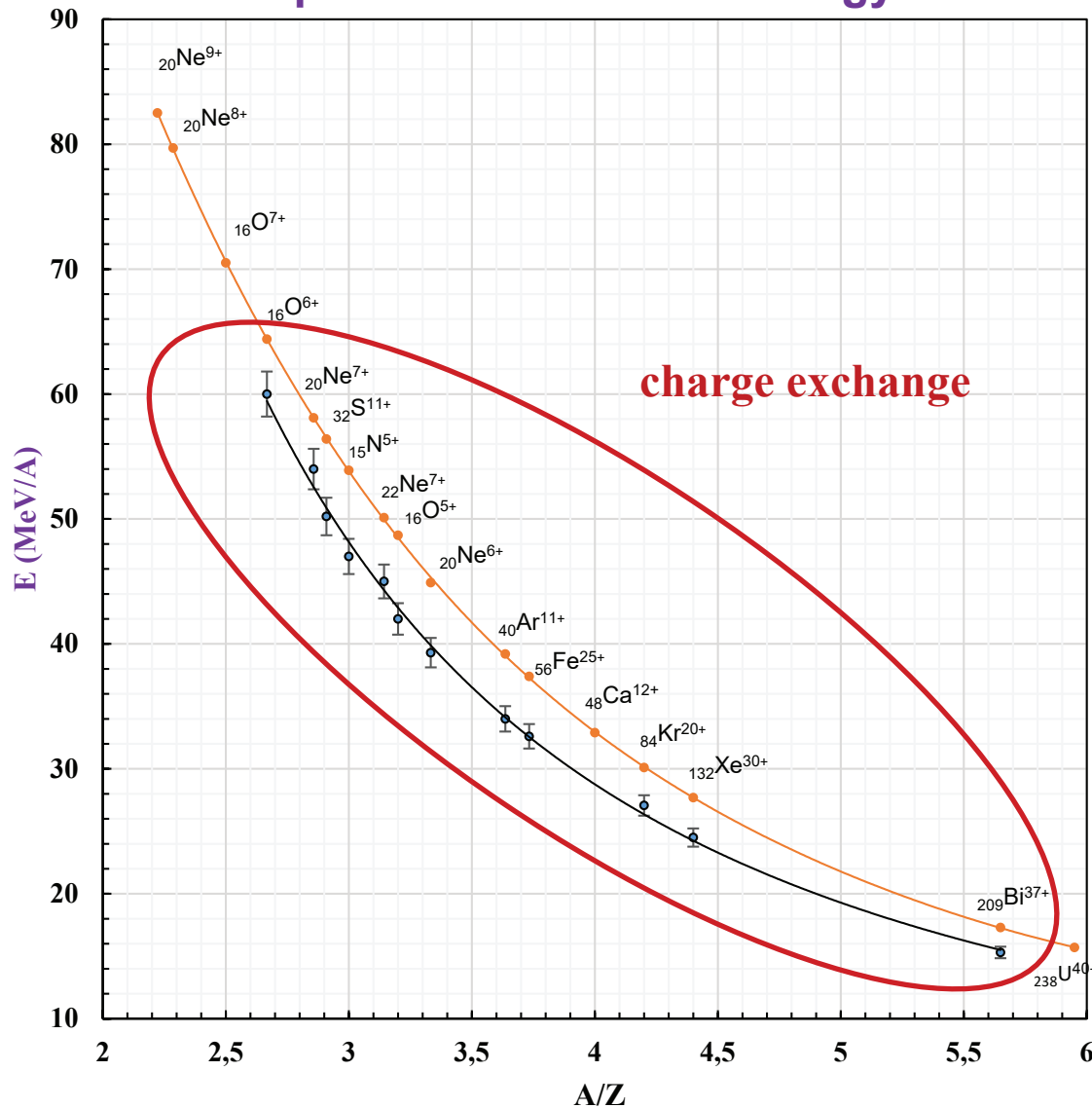
1	Ion source	DECRIS-SC
2	Accelerated ions	$^{22}\text{Ne}^{+4}$ $^{40}\text{Ar}^{+7}$ $^{56}\text{Fe}^{+10}$ $^{86}\text{Kr}^{+15}$ $^{127}\text{I}^{+22}$ $^{132}\text{Xe}^{+23}$ $^{132}\text{Xe}^{+24}$ $^{182}\text{W}^{+32}$ $^{184}\text{W}^{+31}$ $^{184}\text{W}^{+32}$
3	Mass-to-charge ratio of accelerated ions	$A/Z = 5.5 \div 5.95$
4	Ion energy	$0.9 \div 1.2 \text{ MeV/A}$
5	Diameter of the magnet pole	1 m
6	Average magnetic field	$1.78 \div 1.93 \text{ T}$
7	Frequency of the RF system	$19.8 \div 20.6 \text{ MHz}$
8	Injection energy	$14 \div 15 \text{ kV}$
9	Working vacuum in cyclotron	$5 \cdot 10^{-8} \text{ Torr}$
10	Voltage on the dees	$45 \div 55 \text{ kV}$
11	Intensity of the accelerated and extracted beam of $^{86}\text{Kr}^{15+}$	$1.4 \cdot 10^{12} \text{ pps}$ ($3.5 \mu\text{A}$)
12	Intensity of the accelerated and extracted beam of $^{132}\text{Xe}^{23+}$	$\sim 10^{12} \text{ pps}$ ($3.7 \mu\text{A}$)

The main tasks of the FLNR for 2018–2023 are:

1. **Commissioning of "SHE Factory" based on the DC-280** cyclotron (design parameters and energies of beams; attaining maximum beam intensity up to 10 pμA for nuclei with $A \sim 50$; development of infrastructure; first experiments); (2018-2019)
2. **Modernization of the U-400M** cyclotron (replacement of the main coils of the cyclotron magnet; correction of the first harmonic of magnetic field; replacement of vacuum pumping diffusion pumps to cryopumps; modernization of RF- resonators; modernization of RF control system- analog to digital LLRF; increasing intensities and energies of ion beams); (2019-2020)
3. **Reconstruction of the U-400** cyclotron (extension of the range of accelerated ions from helium to uranium with energies smoothly varying within a wide range 0.8–25 MeV·A; improve of the quality and intensity of stable and radioactive beams ($^{48}\text{Ca} - 2.5 \text{ p}\mu\text{A}$); decreasing the total cyclotron power consumption from 1 to 0.25 MW) and building of a new experimental hall ; (2020-2023)
4. **Development of long-running experimental set-ups.**

Modernization of the U400-M cyclotron

Prospects of increase in energy and intensity of extracted ions



Dependence of energy of extracted ions on A/Z

- Extraction by charge exchange (existing U-400M)
- Extraction by electrostatic deflector ($R_{\text{out}}=1.78$ m), after magnetic field correction

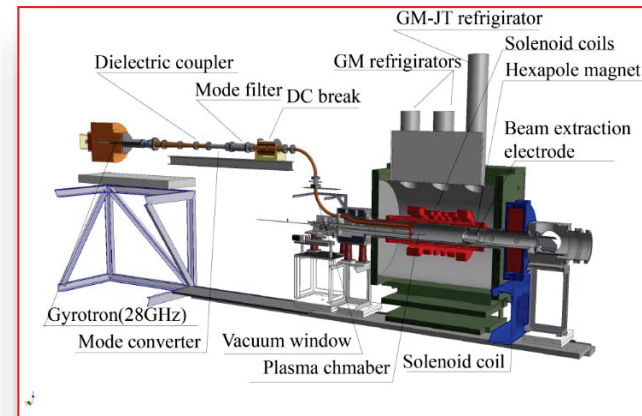
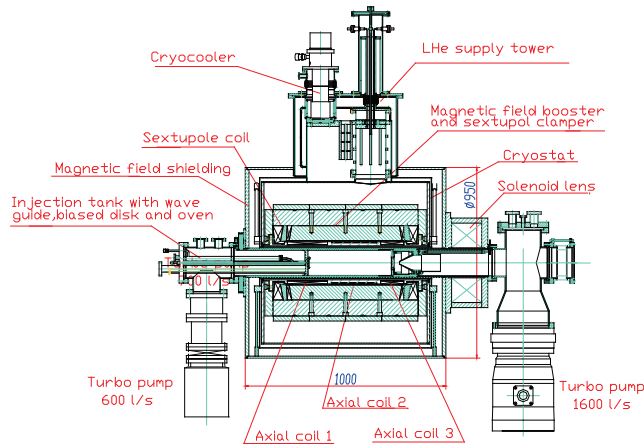
Ион	A/Z	Current from DECRI-2M DECRI-SC2 (18 GHz) μA	Estimation	
			Extracted current μA (10% of injected current)	Extracted current μA
$^{20}\text{Ne}^{9+}$	2.222	10	1	0.11
$^{16}\text{O}^{7+}$	2.2857	20	2	0.28
$^{20}\text{Ne}^{8+}$	2.5	70	7	0.875
$^{16}\text{O}^{6+}$	2.667	200	20	3.3
$^{20}\text{Ne}^{7+}$	2.857	100	10	1.43
$^{32}\text{S}^{11+}$	2.909	12	1.2	0.11
$^{40}\text{Ar}^{11+}$	3.636	65	6.5	0.59
$^{11}\text{B}^{3+}$	3.6667	180	18	6
$^{84}\text{Kr}^{20+}$	4.2	~ 10	1	0.05
$^{22}\text{Ne}^{5+}$	4.4	~ 200	20	4
$^{132}\text{Xe}^{30+}$	4.4	~ 1	0.1	0.003
$^{132}\text{Xe}^{24+}$	5.5	~ 50	5	0.21
$^{56}\text{Fe}^{10+}$	5.6	~ 40	4	0.4
$^{209}\text{Bi}^{37+}$	5.649	~ 4	0.4	0.011
$^{40}\text{Ar}^{7+}$	5.7143	~ 150	15	2.14
$^{132}\text{Xe}^{23+}$	5.7391	~ 50	5	0.22

Extraction by electrostatic deflector

Intensities of accelerated ions are determined by cyclotron transmission factor and ion source currents (I^q). As $I^q \propto \omega_{\text{ECR}}^2$ (1987 R. Geller) the new ECR ion source with $\omega_{\text{ECR}} = 24 \div 28$ GHz could be used for the U-400M.

28 GHZ ECR sources in the world:

SUSI – Michigan State University (MSU), USA; VENUS – Lawrence Berkeley National Laboratory (LBNL), USA; SC-ECRIS– RIKEN, Japan; SECRAL – Institute of Modern Physics (IMP), Lanzhou, China;



Ion	O ⁶⁺	O ⁷⁺	Ar ¹²⁺	Ar ¹⁶⁺ ₊	Ar ¹⁷⁺ ₊	Ca ¹²⁺	Ca ¹⁴⁺	Xe ³⁰⁺	Bi ³⁰⁺	Bi ⁴¹⁺	U ³⁶⁺	U ⁴⁰⁺
I, eμA	3000	1400	1400	350	50	670	270	320	710	100	150	20

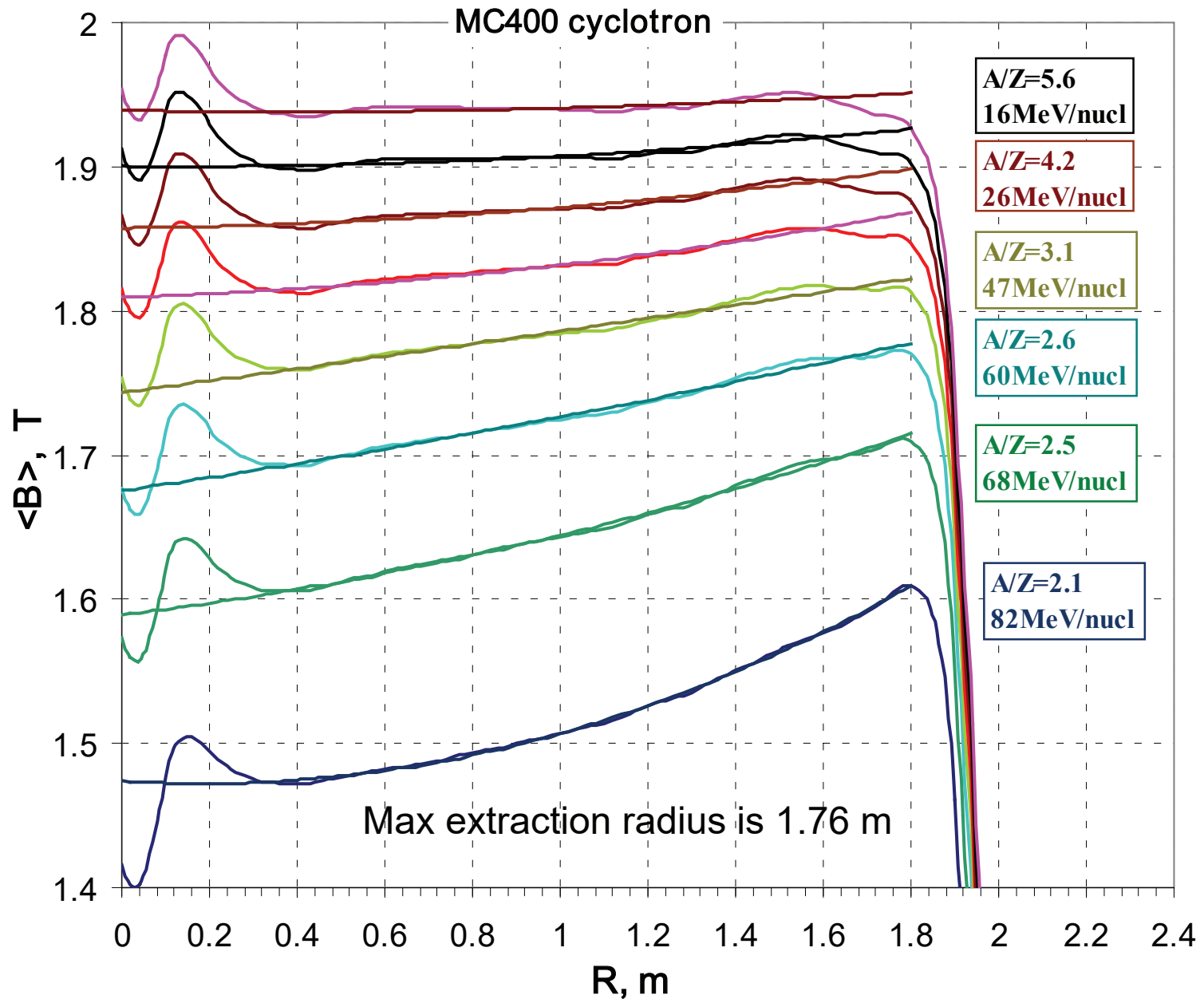
$P_{\text{UHF}} = 5 \div 10$ kW (28 GHz or 28 + 18 GHz)

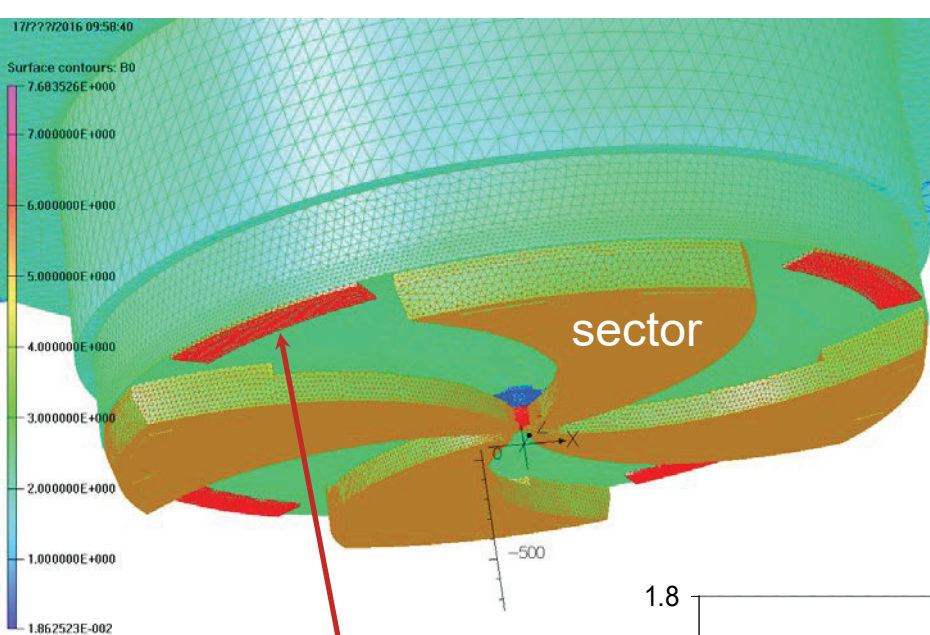
The 3rd generation ECRIS development demonstrates :

- Big technical challenge
- High cost (5-6 M\$)
- Very long time for R&D (10 years from R&D to High performance)
- Big risk (Could fail completely)
- But amazing performance and exciting results

L. T. Sun,
ECRIS2014,

Distribution of average magnetic field along the U-400M radius



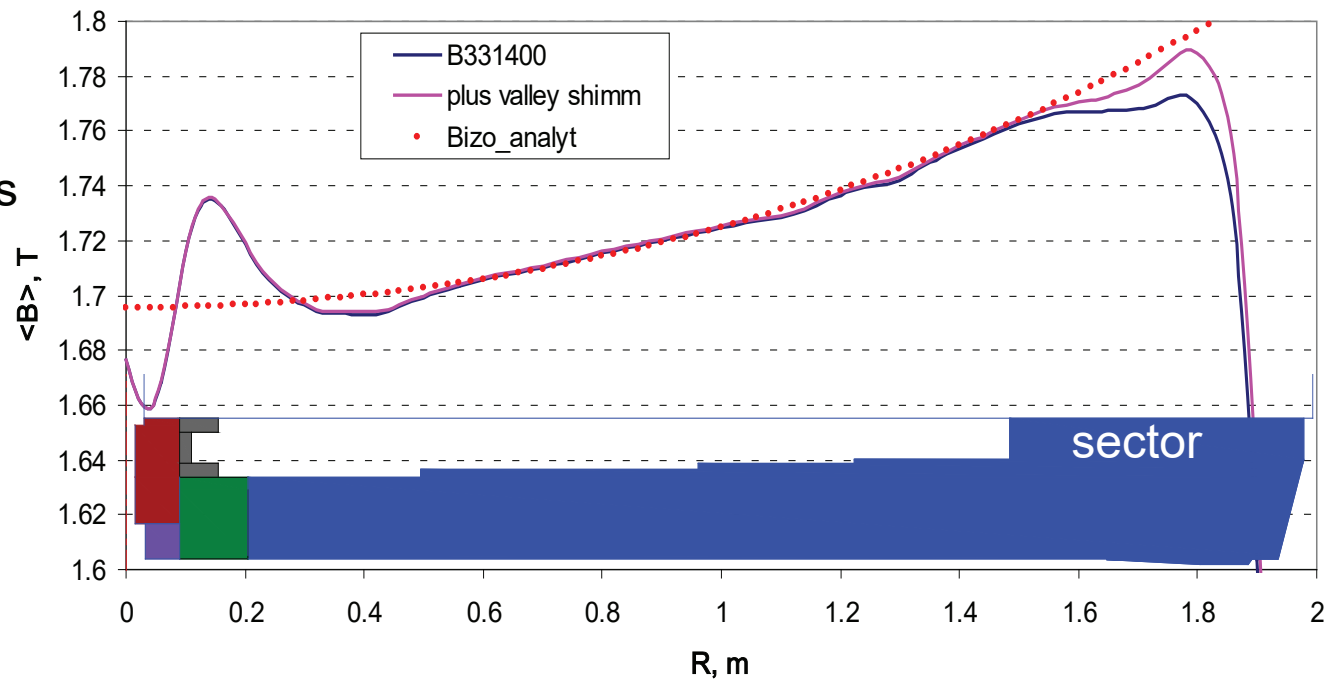


Additional valley shim

Tosca model with 4 shims
arranged in valley

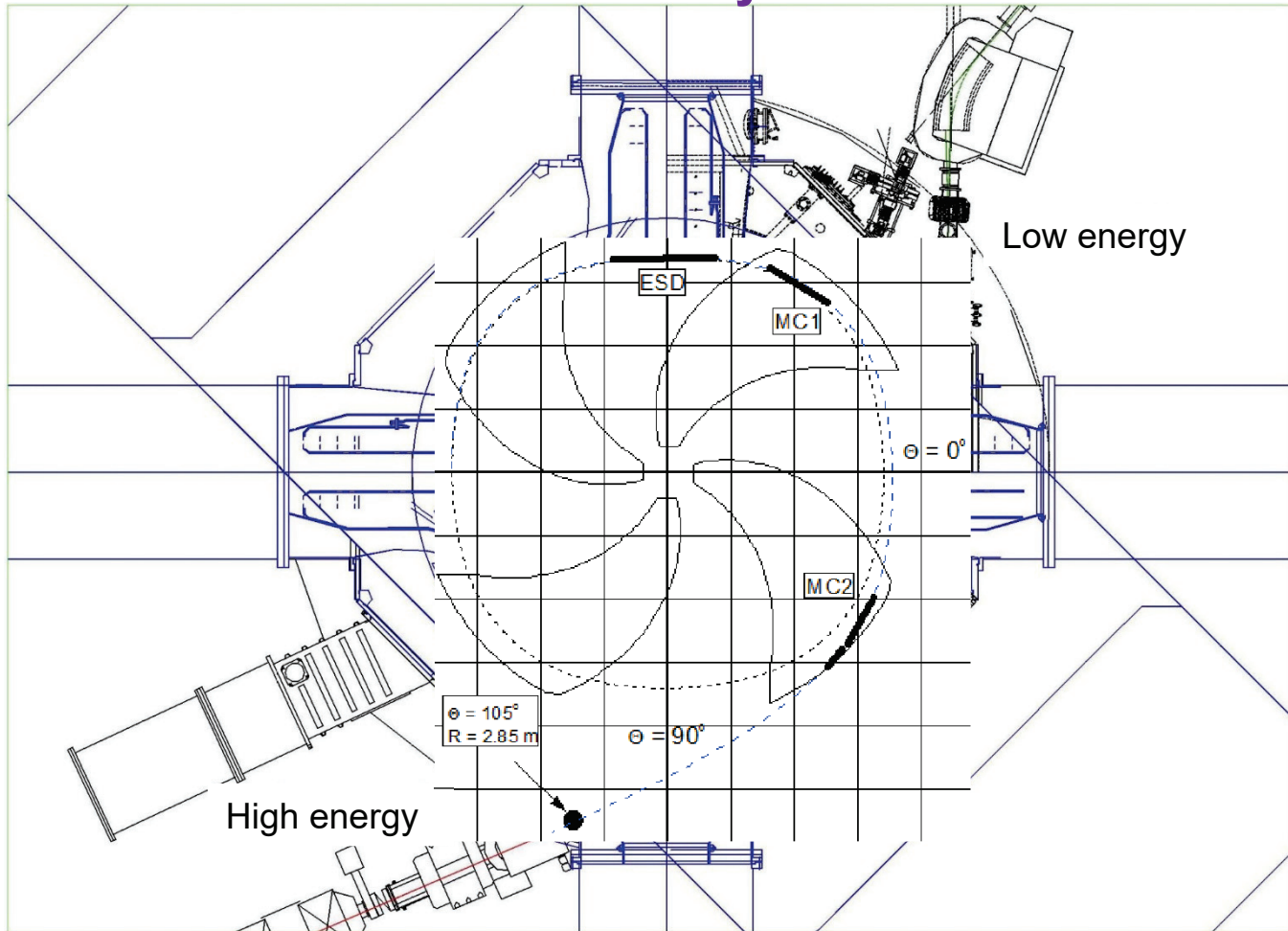
Cyclotron magnetic structure with additional shimming

Using valley shims for magnetic field
correction allows to increase the
average extraction radius on about 2 cm
(from 1.76 m to 1.78 m)



Estimation of valley shims influence at measured magnetic field (magenta).
Dots- isochronous field. Red line- resulting field after shimming.

Extraction system



Deflector parameters:

$L \approx 80 \text{ cm}$, aperture $\Delta X = 0.8 \text{ cm}$

$U_{\text{max}} = 59 \text{ kV}$ ($E = 74 \text{ kV/cm}$)

Modernization of the U-400 cyclotron (U-400R project)

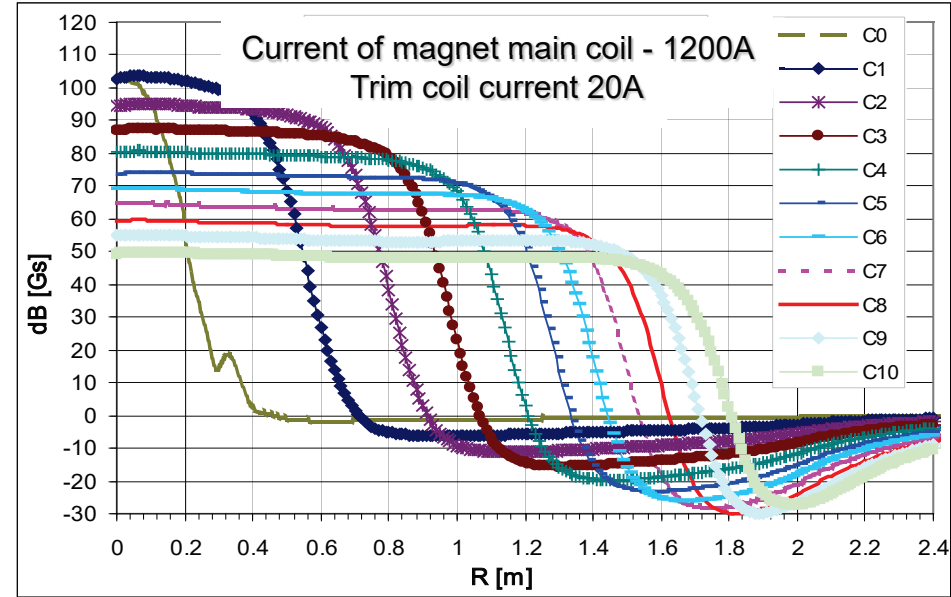
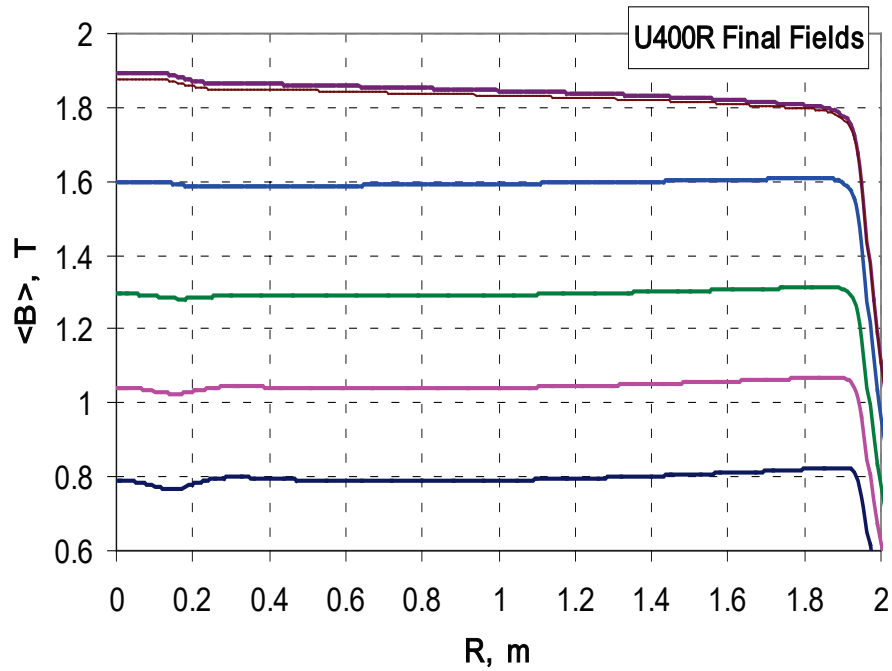
The project of the U-400 cyclotron modernization was developed.
The upgrade will be performed after the DC-280 cyclotron commission

MAIN PURPOSE

- Improvement of the quality and intensity of stable and radioactive beams (^{48}Ca – **2.5÷3 pμA**),
- Providing a smooth variation of ion energy in the range of **0.8 – 27 MeV/A**,
- Decrease the consumption of rare isotopes,
- Decrease the total cyclotron power consumption **from 1 to 0.25 MW**.

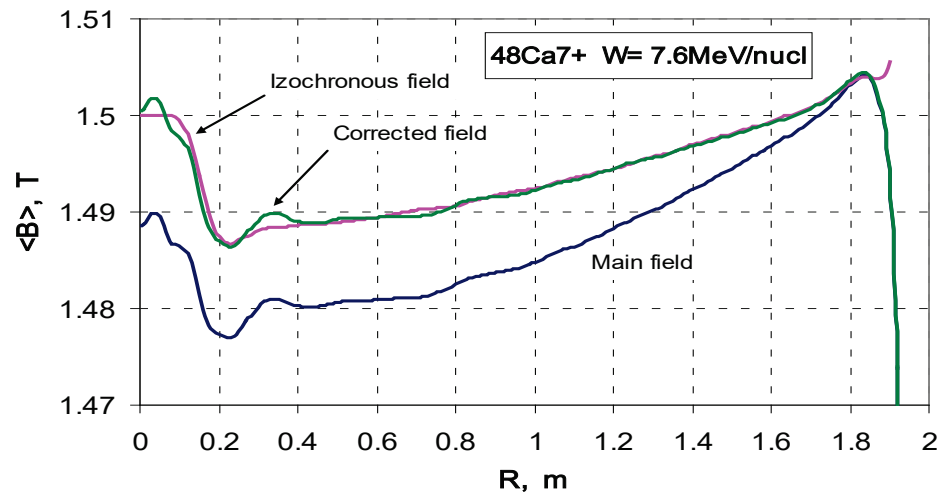
TABLE 1	U400	U400R
Parameters	Value/Name	
Electrical power of magnet power supply system	850 kW	200 kW
The magnetic field level in the magnet center	1.93÷2.1 T	0.8÷1.8 T
The hill angular width at the external radius	42°	43.7°
The hill gap at the external radius	42 mm	56 mm
The valley gap	300 mm	300 mm
The number of trim coils	8, radial 1, azimuthal	14, radial 4, azimuthal
The number of dees	2	2
The dee voltage (amplitude)	80 kV	80 kV
The A/Z range	5÷12	4÷12
The frequency range	5.42÷12.2 MHz	5.42÷12.2 MHz
Harmonic modes	2	2÷6
The ultimate extraction radius	1.72 m	1.8 m
K- factor	305÷625	100÷506
Vacuum level	(1÷5)·10 ⁻⁷ Torr	(1÷2)·10 ⁻⁷ Torr
Ion injection method	Axial with spiral inflector	Axial with spiral inflector
Ion extraction method	Stripping foil	Stripping foil Deflector
Number of directions for ion extraction	2	2

U400 → U400R



Radial Distribution of Average Magnetic Field without Trim Coil's Shimming

Radial Distribution of Magnetic Field of Trim Coils



Formation of Isochronous Magnetic Field

Parameters of U400 and U400R typical ions

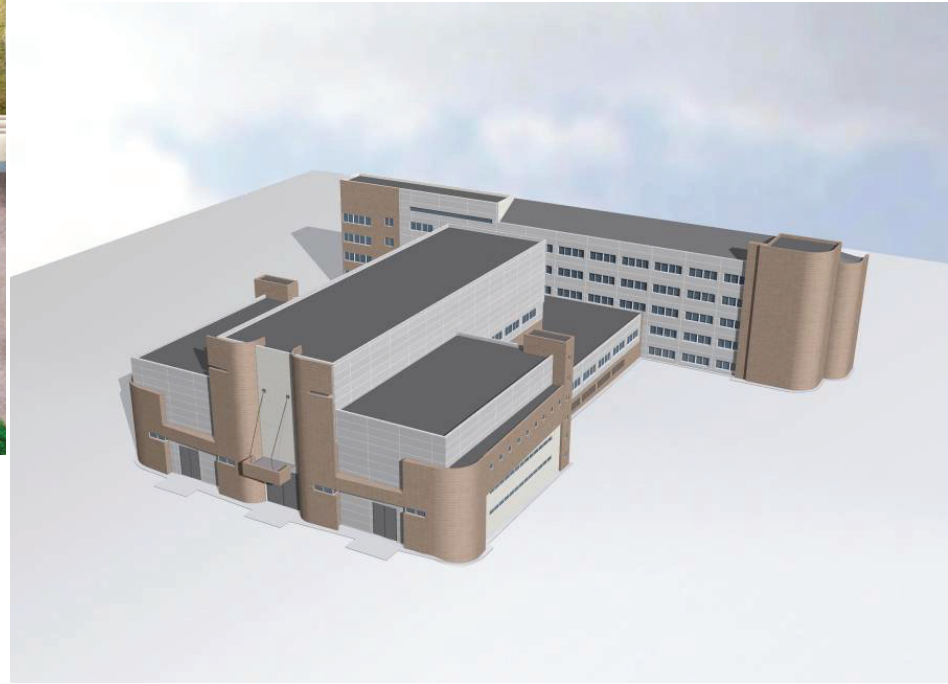
U400		
Ion	Ion energy [MeV/u]	Output intensity
$^4\text{He}^{1+}$	-	-
$^6\text{He}^{1+}$	11	$3 \cdot 10^7$ pps
$^8\text{He}^{1+}$	7.9	-
$^{16}\text{O}^{2+}$	5.7; 7.9	5 μA
$^{18}\text{O}^{3+}$	7.8; 10.5; 15.8	4.4 μA
$^{40}\text{Ar}^{4+}$	3.8; 5.1 *	1.7 μA
$^{48}\text{Ca}^{5+}$	3.7; 5.3 *	1.2 μA
$^{48}\text{Ca}^{9+}$	8.9; 11; 17.7 *	1 μA
$^{50}\text{Ti}^{5+}$	3.6; 5.1 *	0.4 μA
$^{58}\text{Fe}^{6+}$	3.8; 5.4 *	0.7 μA
$^{84}\text{Kr}^{8+}$	3.1; 4.4 *	0.3 μA
$^{136}\text{Xe}^{14+}$	3.3; 4.6; 6.9 *	0.08 μA

* Fixed ion energy of extracted beam

U400R (expected)		
Ion	Ion energy [MeV/u]	Output intensity
$^4\text{He}^{1+}$	$6.4 \div 27$	23 μA
$^6\text{He}^{1+}$	$2.8 \div 14.4$	10^8 pps
$^8\text{He}^{1+}$	$1.6 \div 8$	10^5 pps
$^{16}\text{O}^{2+}$	$1.6 \div 8$	19.5 μA
$^{16}\text{O}^{4+}$	$6.4 \div 27$	5.8 μA
$^{40}\text{Ar}^{4+}$	$1 \div 5.1$	4 μA
$^{48}\text{Ca}^{6+}$	$1.6 \div 8$	2.5 μA
$^{48}\text{Ca}^{7+}$	$2.1 \div 11$	2.1 μA
$^{50}\text{Ti}^{10+}$	$4.1 \div 21$	1 μA
$^{58}\text{Fe}^{7+}$	$1.2 \div 7.5$	1 μA
$^{84}\text{Kr}^{7+}$	$0.8 \div 3.5$	1.4 μA
$^{132}\text{Xe}^{11+}$	$0.8 \div 3.5$	0.9 μA

* Smooth variation ion energy of extracted beam

Reconstruction of the U-400 cyclotron experimental hall

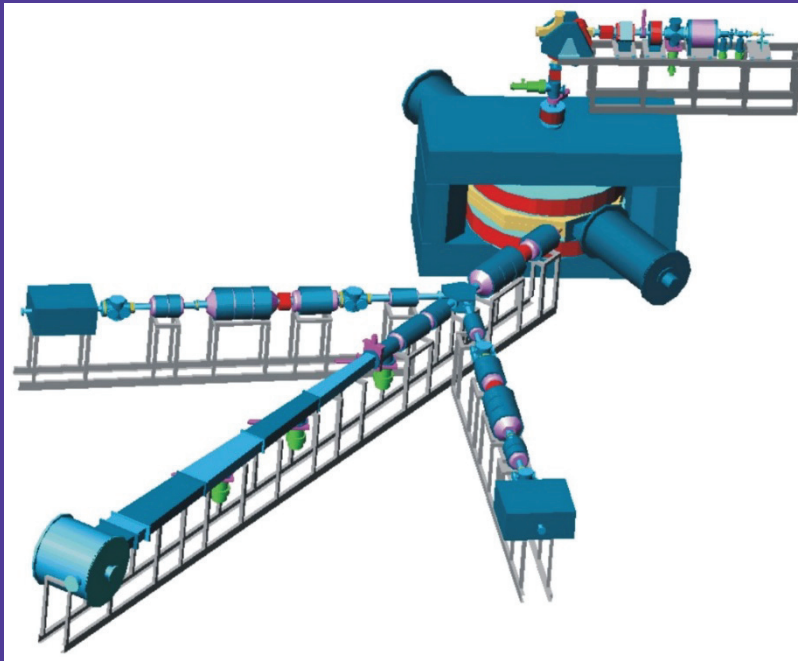


U-200 Cyclotron

In 1968 the U-200 was put into operation in the FLNR. In 2013 it was decommissioned, because of being outdated physically and technologically.

Parameters of U-200:

- Diameter of the magnet pole – 2 m
- Internal ion source of PIG type
- Accelerated ions – He – Ar
- The ion energy 3 -18 MeV/nucleon



The project of DC-130 cyclotron

The programme of applied research that is performed at the FLNR cyclotron IC-100, U-400, U-400M takes approximately 6000 hours of accelerator operation.

Main tasks for DC-130:

- research in the field of solid state physics,
- production of track membranes,
- See testing of electronic components,

Technical characteristics of DC-130:

- range of ions from O to Bi,
- external beam injection from ECR ion source,
- ion energies:

2 MeV/nucleon ($A/Z=7.818 - 8.25$)

4.5 MeV/nucleon ($A/Z=5.212 - 5.5$).

Physical installations:

- installation for scientific and applied research,
- facility for irradiation of polymer films,
- installation for testing of electronic components.

Factory of Super Heavy Elements (SHE)



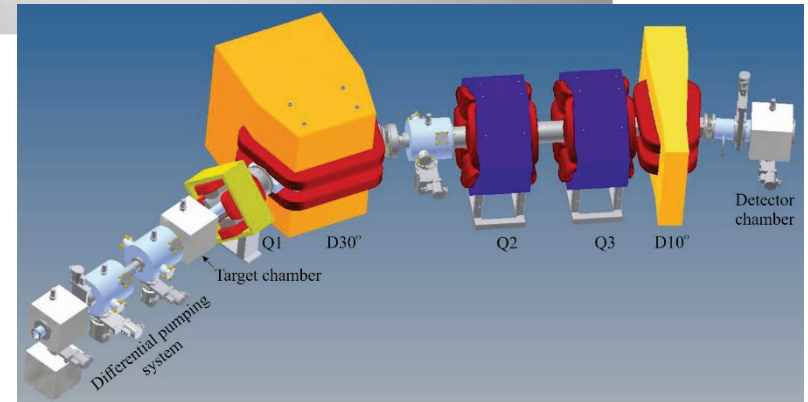
SHE Factory Building

High-current cyclotron DC-280



New facilities:

- New gas-filled separator
- Preseparator
- SHELS
- Etc.



Superheavy Elements (SHE) Factory – the Goals

- **Experiments at the extremely low ($\sigma < 100$ fb) cross sections:**
 - **Synthesis of new SHE in reactions with ^{50}Ti , ^{54}Cr ...;**
 - **Synthesis of new isotopes of SHE;**
 - **Study of decay properties of SHE;**

- **Experiments requiring high statistics:**
 - **Nuclear spectroscopy of SHE;**
 - **Study of chemical properties of SHE.**

DC-280 CYCLOTRON- THE NEW FLNR ACCELERATOR

To satisfy the **Goals**, the DC-280 has to provide the following parameters of ion beams:

Ion energies (smooth variation)	4÷8 MeV/n
Ion masses	10÷238
Intensities (A~50)	>10 pμA
Efficiency of beam transfer	>50%

Stand-alone SHE factory with DC-280 cyclotron



SHE factory building 2012



SHE factory building 2018



DC280 (expected)
E=4÷8 MeV/A

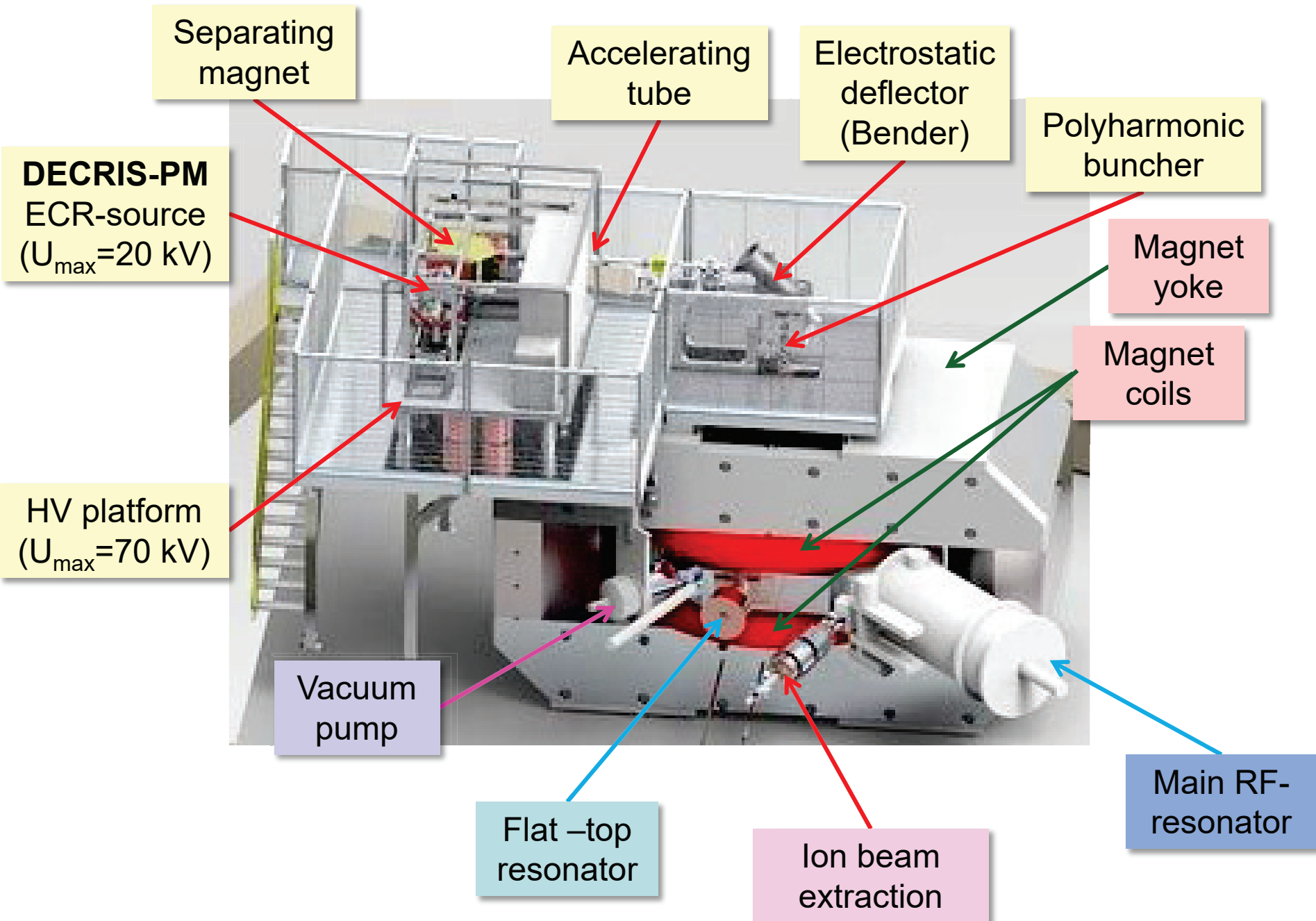
Ion	Ion energy [MeV/A]	Output intensity
${}^7\text{Li}$	4	1×10^{14}
${}^{18}\text{O}$	8	1×10^{14}
${}^{40}\text{Ar}$	5	6×10^{13}
${}^{48}\text{Ca}$	5	$6,2 \times 10^{13}$
${}^{54}\text{Cr}$	5	2×10^{13}
${}^{58}\text{Fe}$	5	1×10^{13}
${}^{124}\text{Sn}$	5	2×10^{12}
${}^{136}\text{Xe}$	5	1×10^{14}
${}^{238}\text{U}$	7	5×10^{10}

DC-280

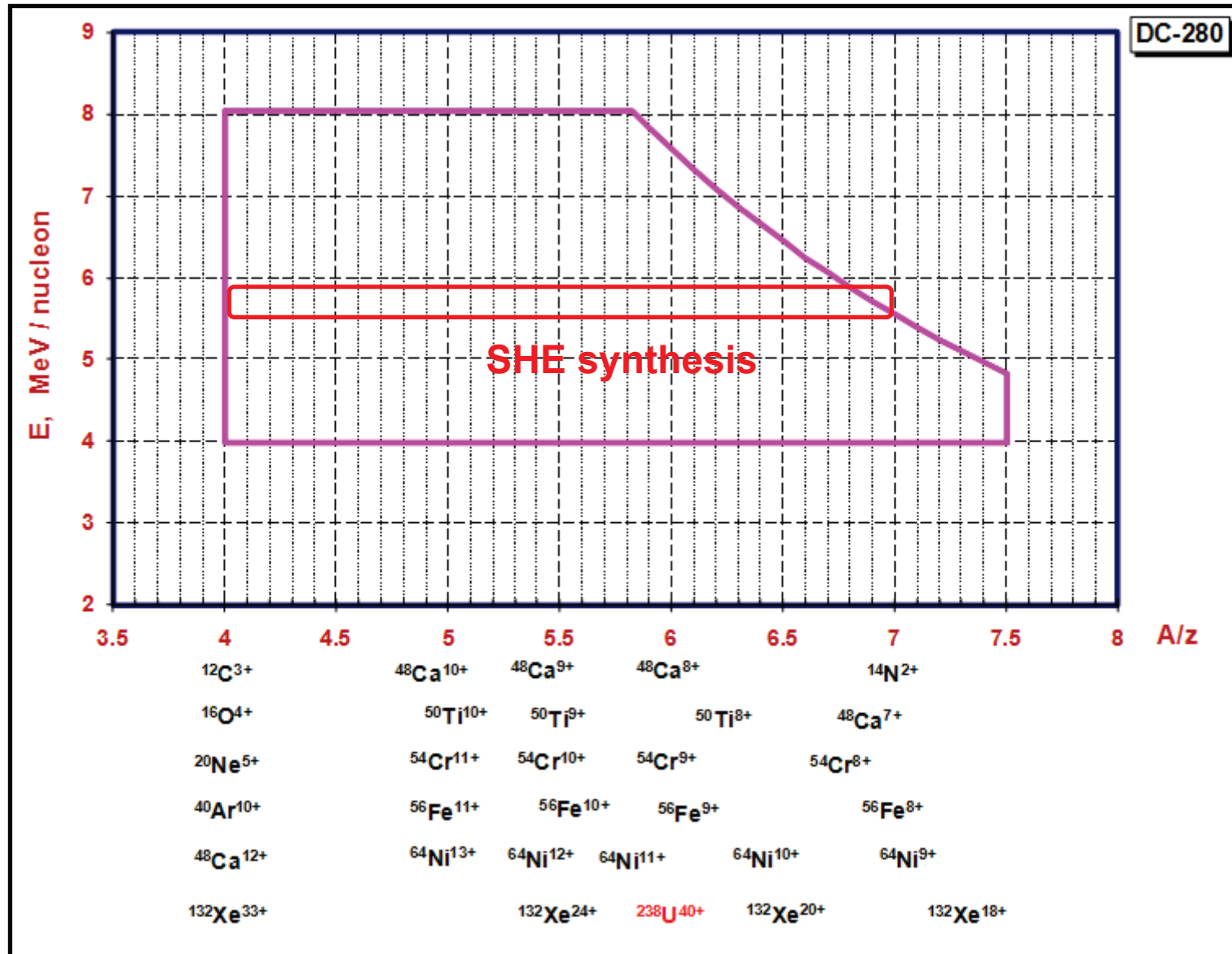
Main Parameters

Ion sources	DECRIS-PM - 14 GHz Superconducting ECR (developing stage)
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	90 kV

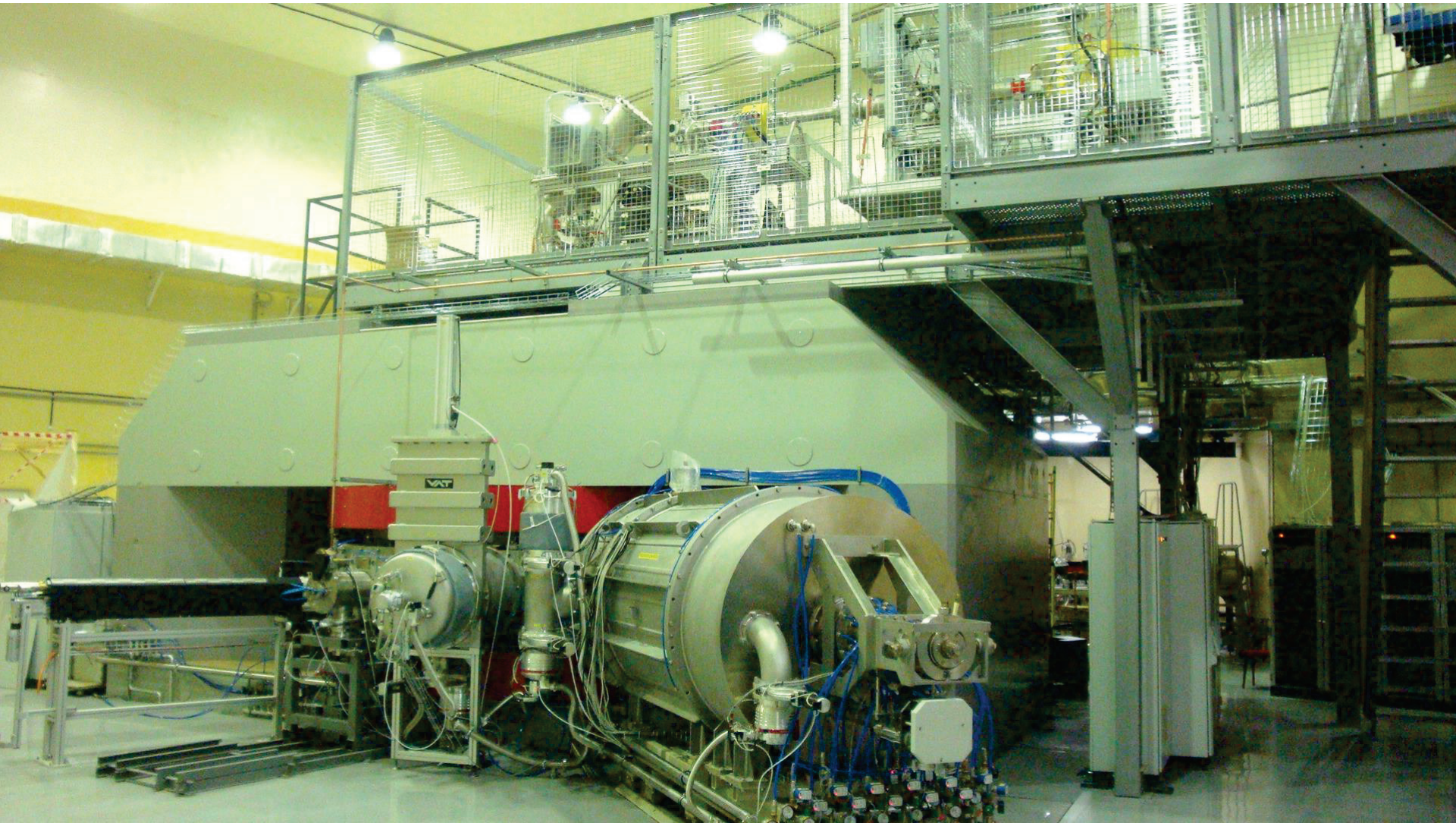
Configuration of the DC-280



Working diagram of the DC-280



DC-280 cyclotron



Main magnet was assembled in November 2016

Magnetic field measurements were carried out in June-September 2017

Cyclotron systems were assembled and now they are being tested

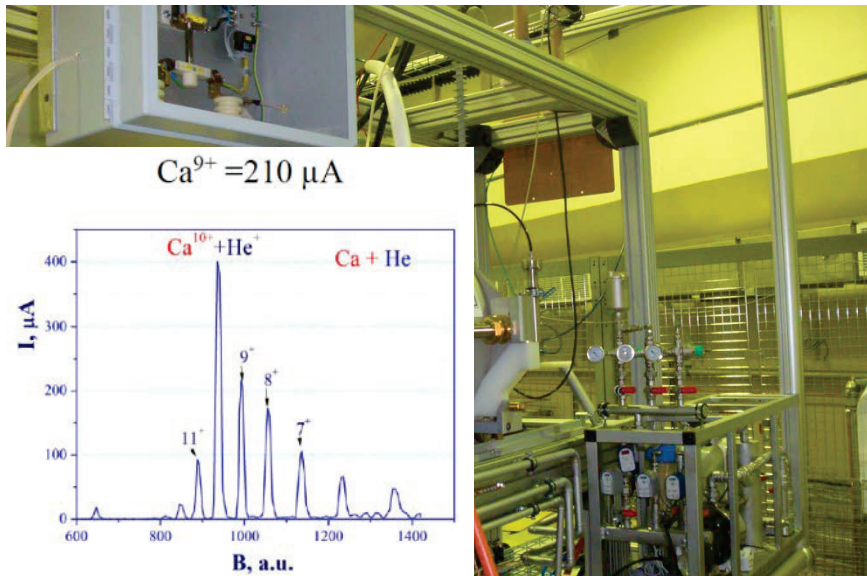
Beam injection system



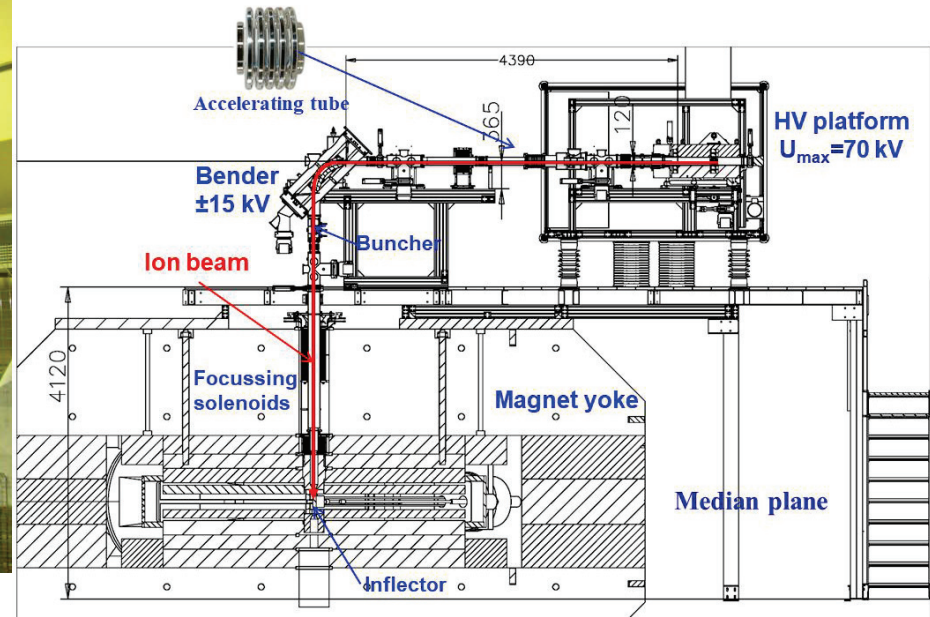
The HV platform



Area of the electrostatic deflector (Bender)



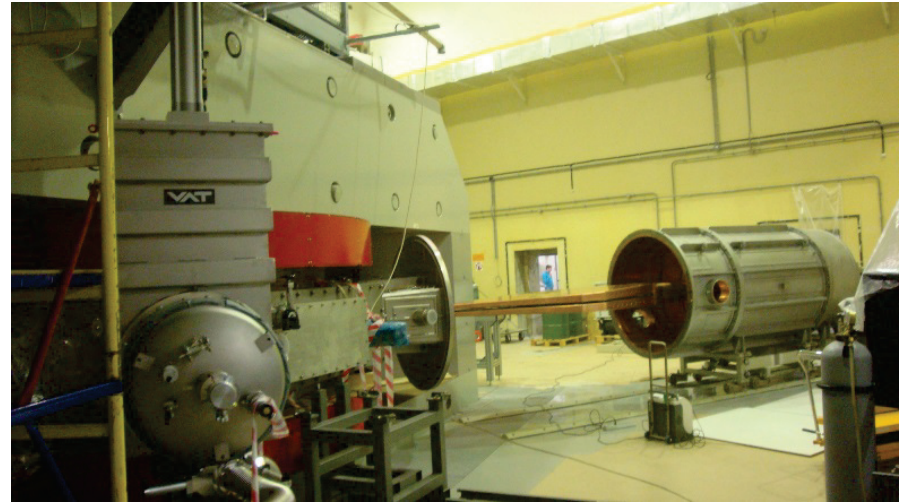
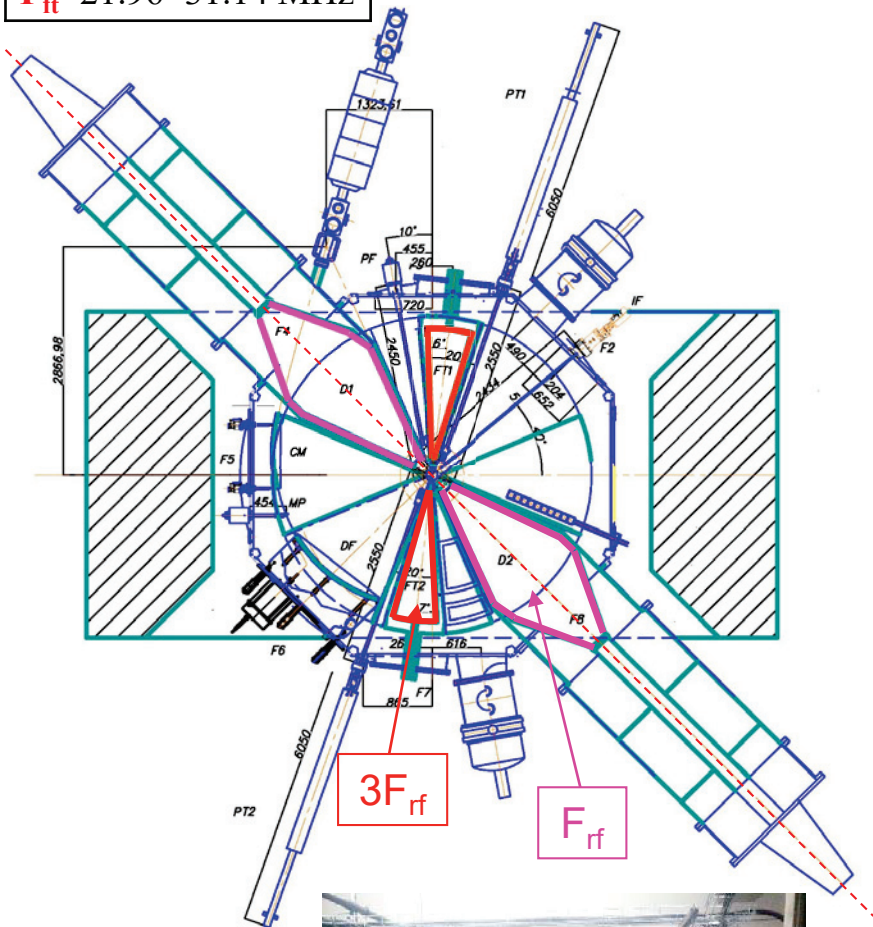
The DECRIS-PM ion source on the platform



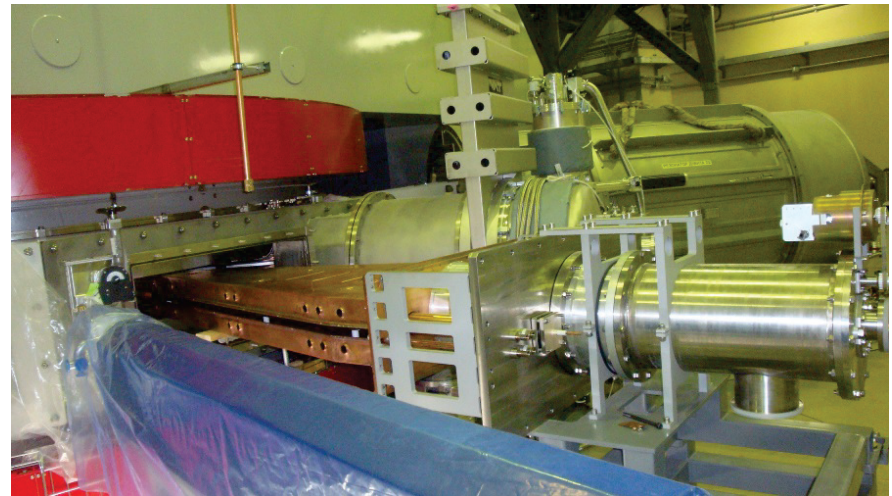
$$F_{rf} = 7.32 \div 10.38 \text{ MHz}$$

$$F_{ft} = 21.96 \div 31.14 \text{ MHz}$$

RF system



RF resonator with dee



Flat-top resonator

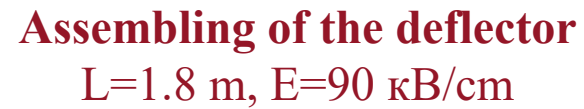
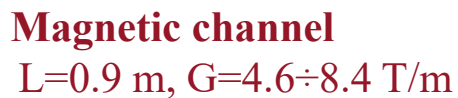
RF generators

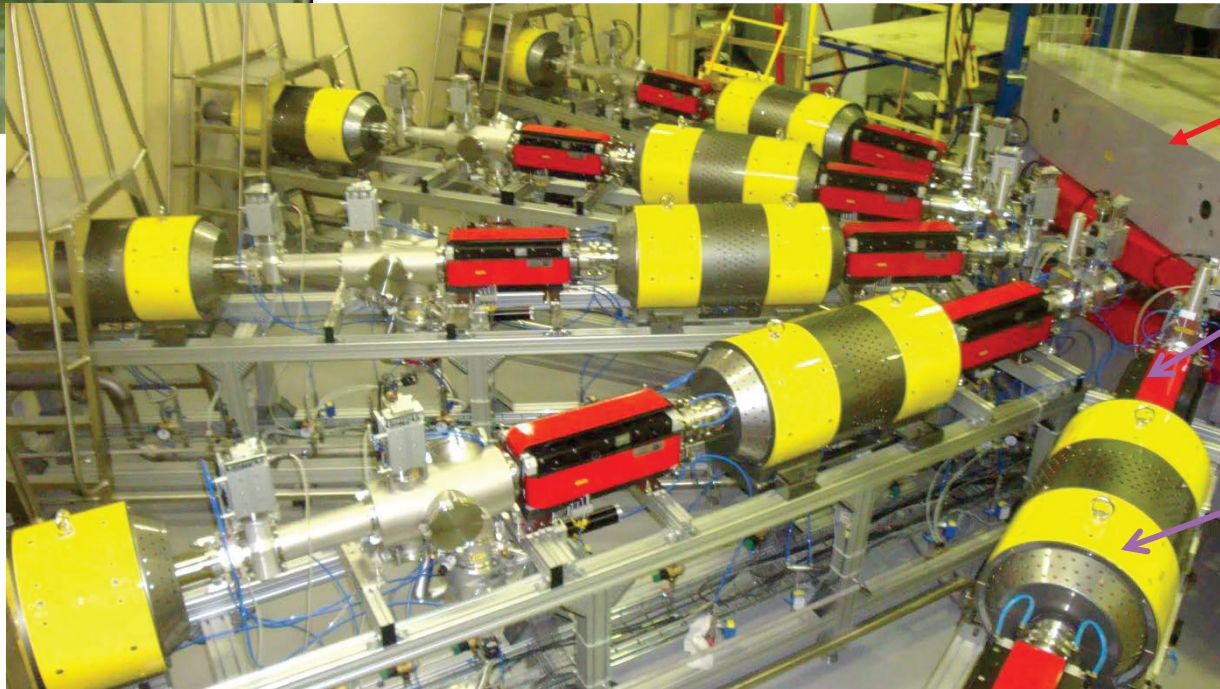
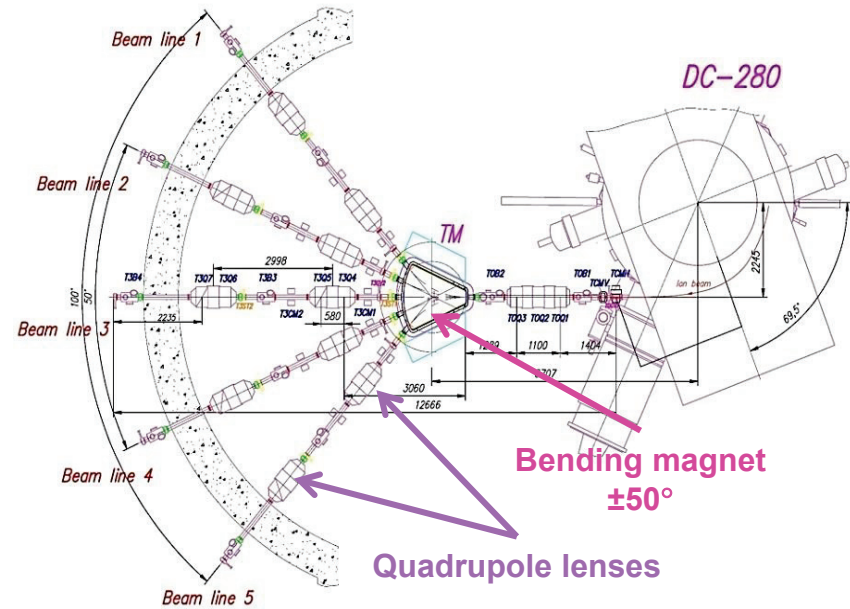


Extraction radius of
 $R_{\text{ext}}=1.79 \text{ m}$

The diagram illustrates the LHC interaction region, showing the focusing magnetic channel and the external radius $R_{\text{ext}} = 1.79 \text{ m}$. The diagram includes various components such as the F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23, F24, F25, F26, F27, F28, F29, F30, F31, F32, F33, F34, F35, F36, F37, F38, F39, F40, F41, F42, F43, F44, F45, F46, F47, F48, F49, F50, F51, F52, F53, F54, F55, F56, F57, F58, F59, F60, F61, F62, F63, F64, F65, F66, F67, F68, F69, F70, F71, F72, F73, F74, F75, F76, F77, F78, F79, F80, F81, F82, F83, F84, F85, F86, F87, F88, F89, F90, F91, F92, F93, F94, F95, F96, F97, F98, F99, F100, F101, F102, F103, F104, F105, F106, F107, F108, F109, F110, F111, F112, F113, F114, F115, F116, F117, F118, F119, F120, F121, F122, F123, F124, F125, F126, F127, F128, F129, F130, F131, F132, F133, F134, F135, F136, F137, F138, F139, F140, F141, F142, F143, F144, F145, F146, F147, F148, F149, F150, F151, F152, F153, F154, F155, F156, F157, F158, F159, F160, F161, F162, F163, F164, F165, F166, F167, F168, F169, F170, F171, F172, F173, F174, F175, F176, F177, F178, F179, F180, F181, F182, F183, F184, F185, F186, F187, F188, F189, F190, F191, F192, F193, F194, F195, F196, F197, F198, F199, F200, F201, F202, F203, F204, F205, F206, F207, F208, F209, F210, F211, F212, F213, F214, F215, F216, F217, F218, F219, F220, F221, F222, F223, F224, F225, F226, F227, F228, F229, F230, F231, F232, F233, F234, F235, F236, F237, F238, F239, F240, F241, F242, F243, F244, F245, F246, F247, F248, F249, F250, F251, F252, F253, F254, F255, F256, F257, F258, F259, F260, F261, F262, F263, F264, F265, F266, F267, F268, F269, F270, F271, F272, F273, F274, F275, F276, F277, F278, F279, F280, F281, F282, F283, F284, F285, F286, F287, F288, F289, F290, F291, F292, F293, F294, F295, F296, F297, F298, F299, F300, F301, F302, F303, F304, F305, F306, F307, F308, F309, F310, F311, F312, F313, F314, F315, F316, F317, F318, F319, F320, F321, F322, F323, F324, F325, F326, F327, F328, F329, F330, F331, F332, F333, F334, F335, F336, F337, F338, F339, F340, F341, F342, F343, F344, F345, F346, F347, F348, F349, F350, F351, F352, F353, F354, F355, F356, F357, F358, F359, F360, F361, F362, F363, F364, F365, F366, F367, F368, F369, F370, F371, F372, F373, F374, F375, F376, F377, F378, F379, F380, F381, F382, F383, F384, F385, F386, F387, F388, F389, F390, F391, F392, F393, F394, F395, F396, F397, F398, F399, F400, F401, F402, F403, F404, F405, F406, F407, F408, F409, F410, F411, F412, F413, F414, F415, F416, F417, F418, F419, F420, F421, F422, F423, F424, F425, F426, F427, F428, F429, F430, F431, F432, F433, F434, F435, F436, F437, F438, F439, F440, F441, F442, F443, F444, F445, F446, F447, F448, F449, F450, F451, F452, F453, F454, F455, F456, F457, F458, F459, F460, F461, F462, F463, F464, F465, F466, F467, F468, F469, F470, F471, F472, F473, F474, F475, F476, F477, F478, F479, F480, F481, F482, F483, F484, F485, F486, F487, F488, F489, F490, F491, F492, F493, F494, F495, F496, F497, F498, F499, F500, F501, F502, F503, F504, F505, F506, F507, F508, F509, F510, F511, F512, F513, F514, F515, F516, F517, F518, F519, F520, F521, F522, F523, F524, F525, F526, F527, F528, F529, F530, F531, F532, F533, F534, F535, F536, F537, F538, F539, F540, F541, F542, F543, F544, F545, F546, F547, F548, F549, F550, F551, F552, F553, F554, F555, F556, F557, F558, F559, F560, F561, F562, F563, F564, F565, F566, F567, F568, F569, F570, F571, F572, F573, F574, F575, F576, F577, F578, F579, F580, F581, F582, F583, F584, F585, F586, F587, F588, F589, F590, F591, F592, F593, F594, F595, F596, F597, F598, F599, F600, F601, F602, F603, F604, F605, F606, F607, F608, F609, F610, F611, F612, F613, F614, F615, F616, F617, F618, F619, F620, F621, F622, F623, F624, F625, F626, F627, F628, F629, F630, F631, F632, F633, F634, F635, F636, F637, F638, F639, F640, F641, F642, F643, F644, F645, F646, F647, F648, F649, F650, F651, F652, F653, F654, F655, F656, F657, F658, F659, F660, F661, F662, F663, F664, F665, F666, F667, F668, F669, F670, F671, F672, F673, F674, F675, F676, F677, F678, F679, F680, F681, F682, F683, F684, F685, F686, F687, F688, F689, F690, F691, F692, F693, F694, F695, F696, F697, F698, F699, F700, F701, F702, F703, F704, F705, F706, F707, F708, F709, F710, F711, F712, F713, F714, F715, F716, F717, F718, F719, F720, F721, F722, F723, F724, F725, F726, F727, F728, F729, F730, F731, F732, F733, F734, F735, F736, F737, F738, F739, F740, F741, F742, F743, F744, F745, F746, F747, F748, F749, F750, F751, F752, F753, F754, F755, F756, F757, F758, F759, F760, F761, F762, F763, F764, F765, F766, F767, F768, F769, F770, F771, F772, F773, F774, F775, F776, F777, F778, F779, F780, F781, F782, F783, F784, F785, F786, F787, F788, F789, F790, F791, F792, F793, F794, F795, F796, F797, F798, F799, F800, F801, F802, F803, F804, F805, F806, F807, F808, F809, F810, F811, F812, F813, F814, F815, F816, F817, F818, F819, F820, F821, F822, F823, F824, F825, F826, F

Electrostatic deflector





Quadrupole doublet

Control and power supply systems



Power supplies of cyclotron



Power supplies of injection

Water cooling system



DC-280 control room

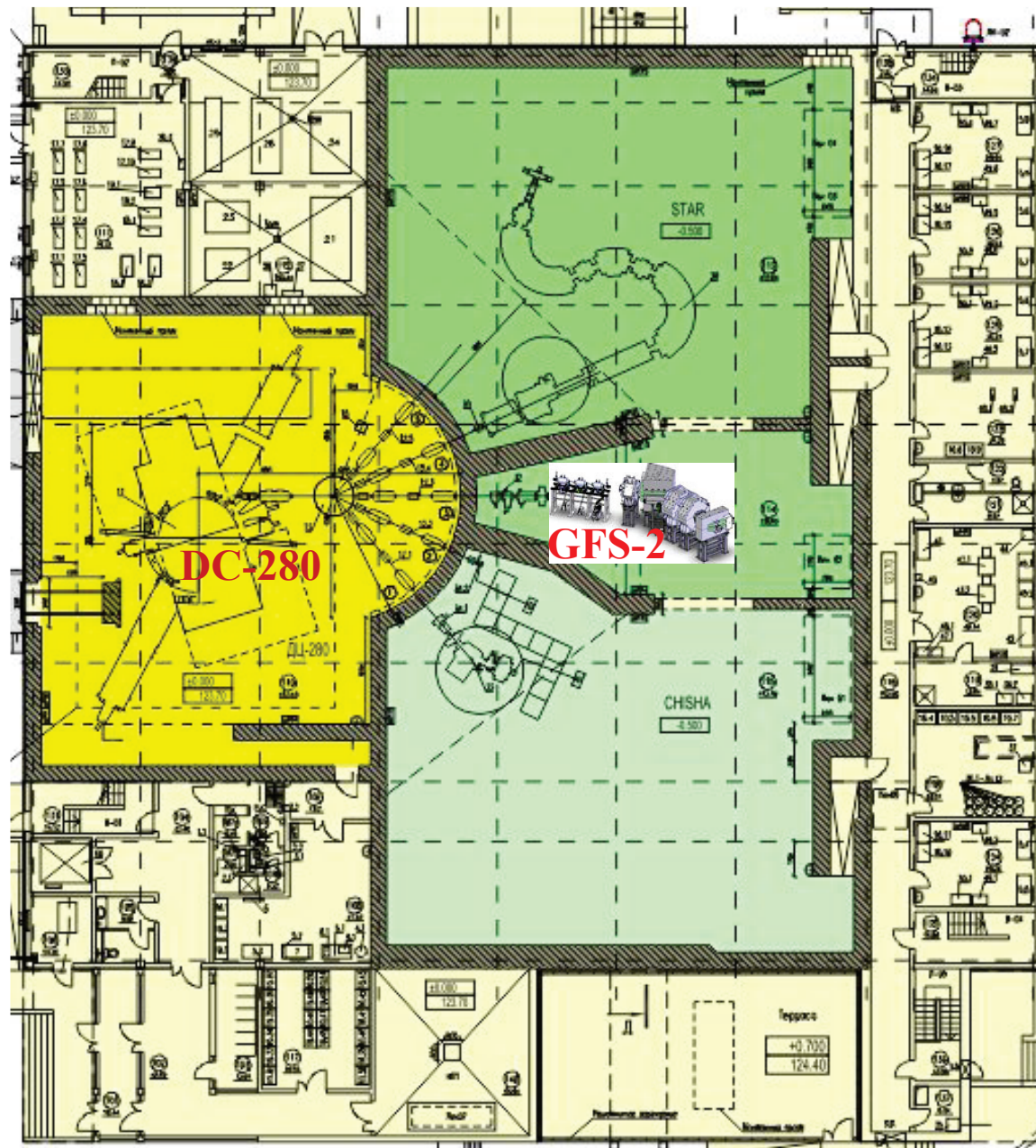


Launching and Tuning Works on the DC-280 systems without beam:
June – Oct. 2018

Obtaining licenses and permits : Nov. 2018

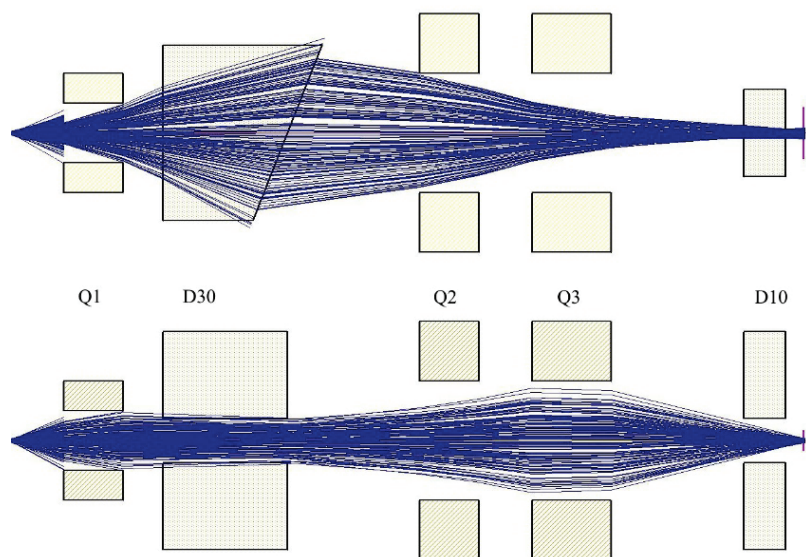
Commissioning: Nov. – Dec. 2018

Plan of the 1-st floor of the SHE Factory

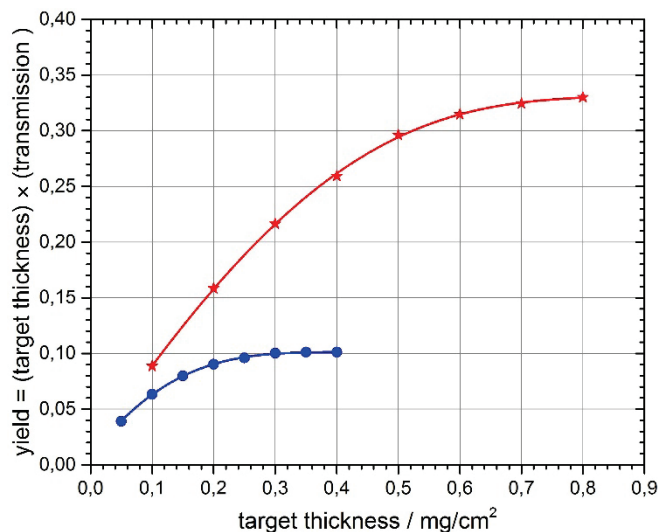
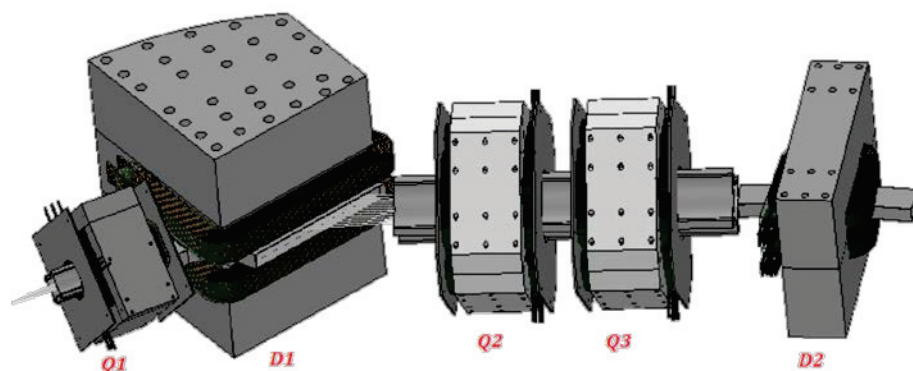


Experimental area ~1000 m² (3 halls)

New FLNR gas-filled separator (contracted)

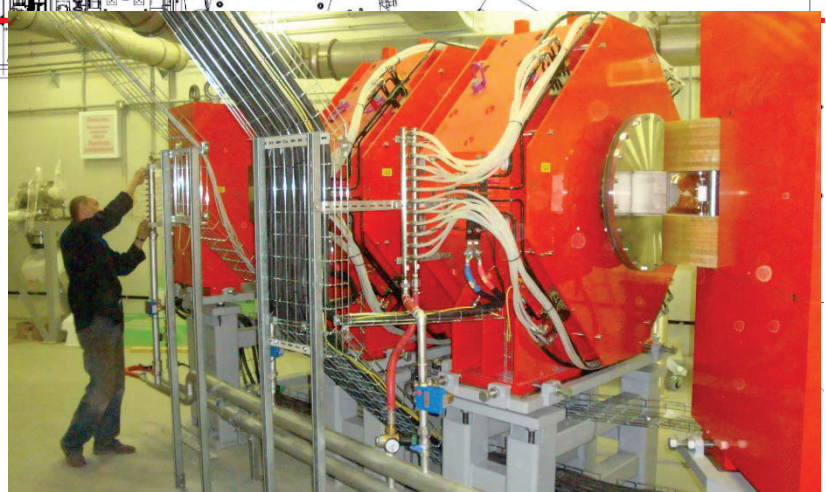
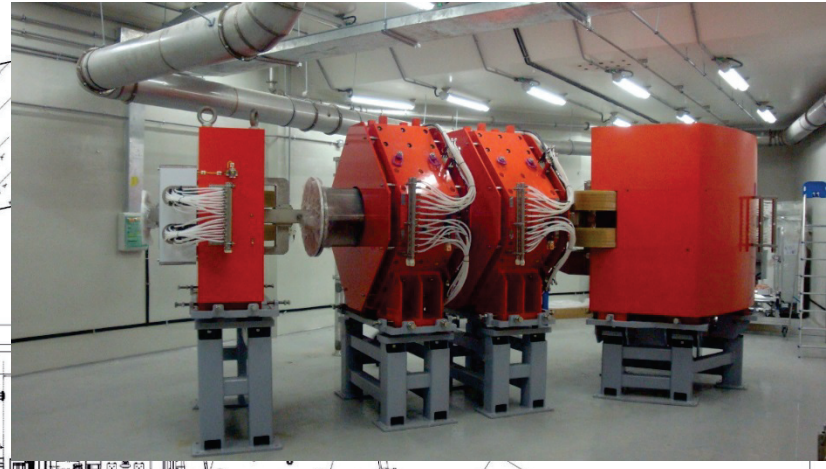


Technical Design
Report No 412923



Reaction	Transmission
$^{244}\text{Pu}(^{48}\text{Ca}, 3n)^{289}\text{114}$	60 %
$^{244}\text{Pu}(^{58}\text{Fe}, 4n)^{298}\text{120}$	75 %

Arrangement of GFS-2 at the beam line No3



Installation of magnets: **June 2018**

Commissioning: **Nov. – Dec. 2018**

Obtaining licenses and permits : **Nov. 2018**

Conclusion

- FLNR JINR Accelerator Complex is being developed
- Expected commissioning of the DC-280 together with the new GFS-2 separator: Nov.–Dec. 2018. First experiments at the SHE Factory: 2019
- We expect to have essential results of the Accelerator Complex modernization to 2023



**THANKS
FOR YOUR
ATTENTION !**

Flerov Laboratory of Nuclear Reactions , JINR