STATUS of DC280 CYCLOTRON PROJECT

Gulbekian G.G. and DC280 group

RUPAC 2014

FLNR's BASIC DIRECTIONS of RESEARCH according to the Seven-Year Plan 2010 - 2016

1. Heavy and superheavy nuclei:

- synthesis and study of properties of superheavy elements;
- chemistry of new elements;
- fusion-fission and multi-nucleon transfer reactions;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

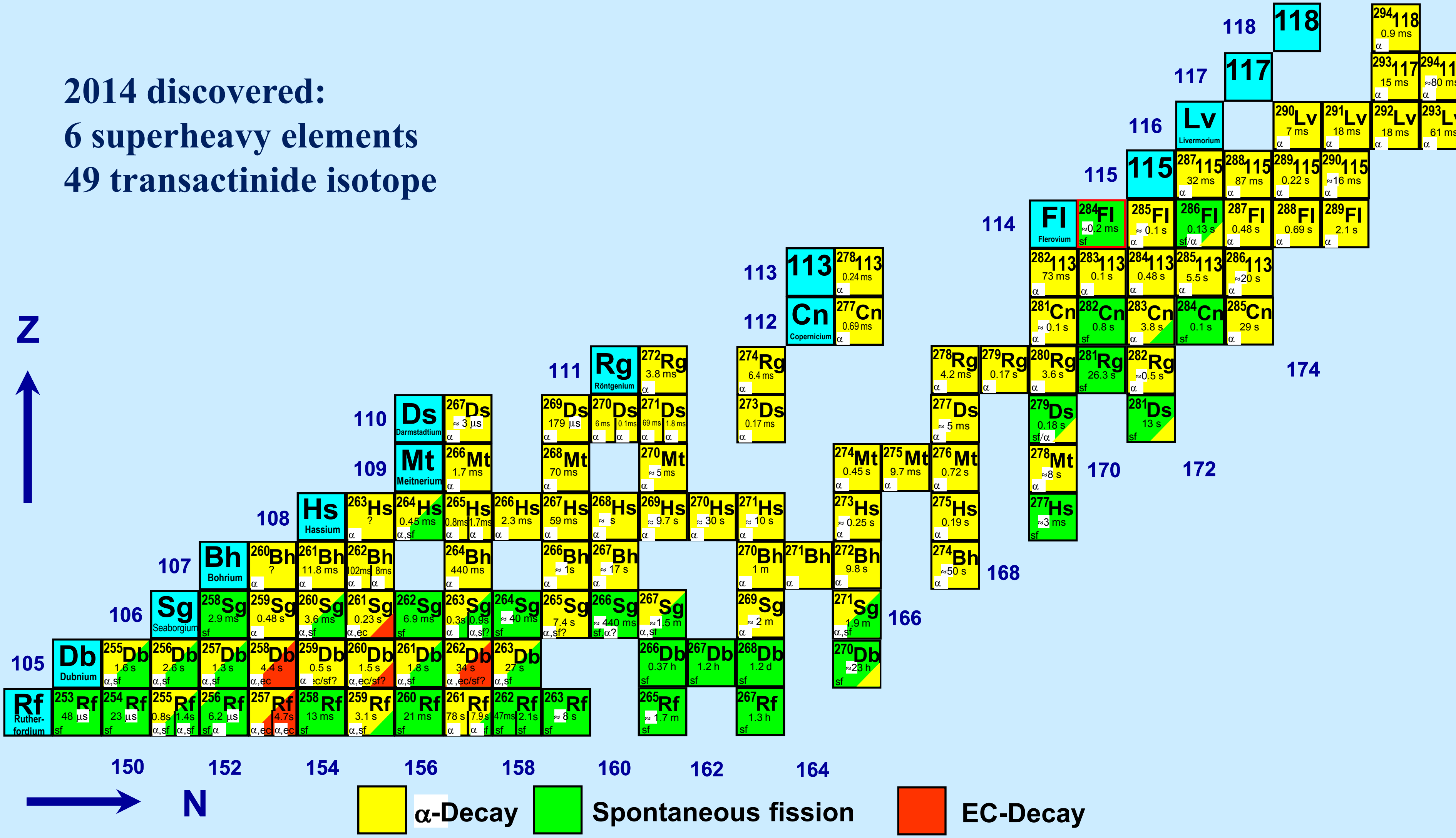
2. Light exotic nuclei:

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

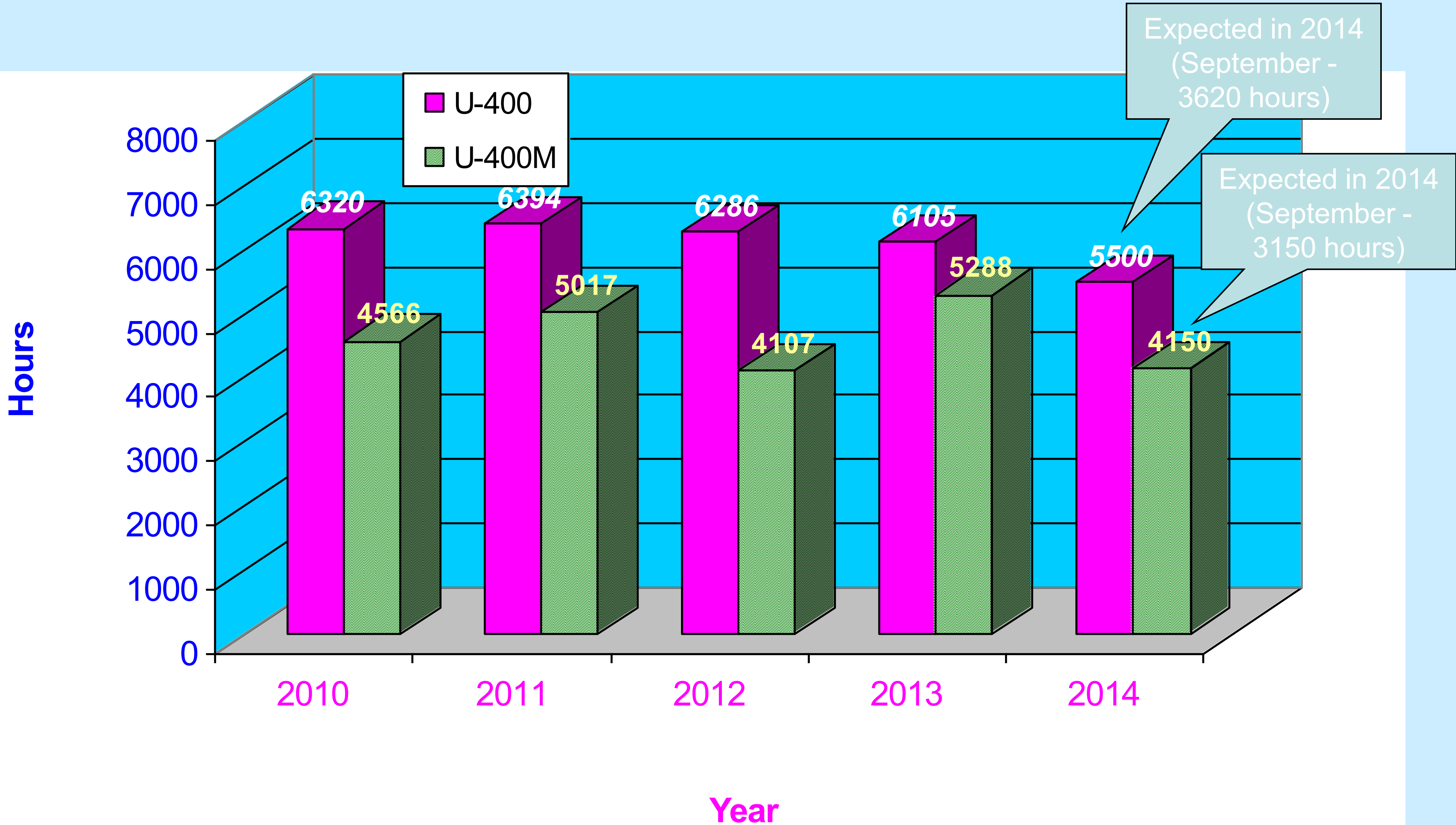
3. Radiation effects and physical groundwork of nanotechnology.

Superheavy Element Research

2014 discovered:
6 superheavy elements
49 transactinide isotope



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



Operation time of U-400 and U-400M accelerators in 2010-2014

NEW FLNR ACCELERATOR – CYCLOTRON DC280

In order to improve efficiency of the experiments for the next years it is necessary to obtain the accelerated ion beams with following parameters.

Energy	**4÷8 MeV/n**
Masses	**10÷238**
Intensity (up to A=50)	**>10 pμA**

Beam emittance less 30 π mm·mrad

Efficiency of beam transfer >50%

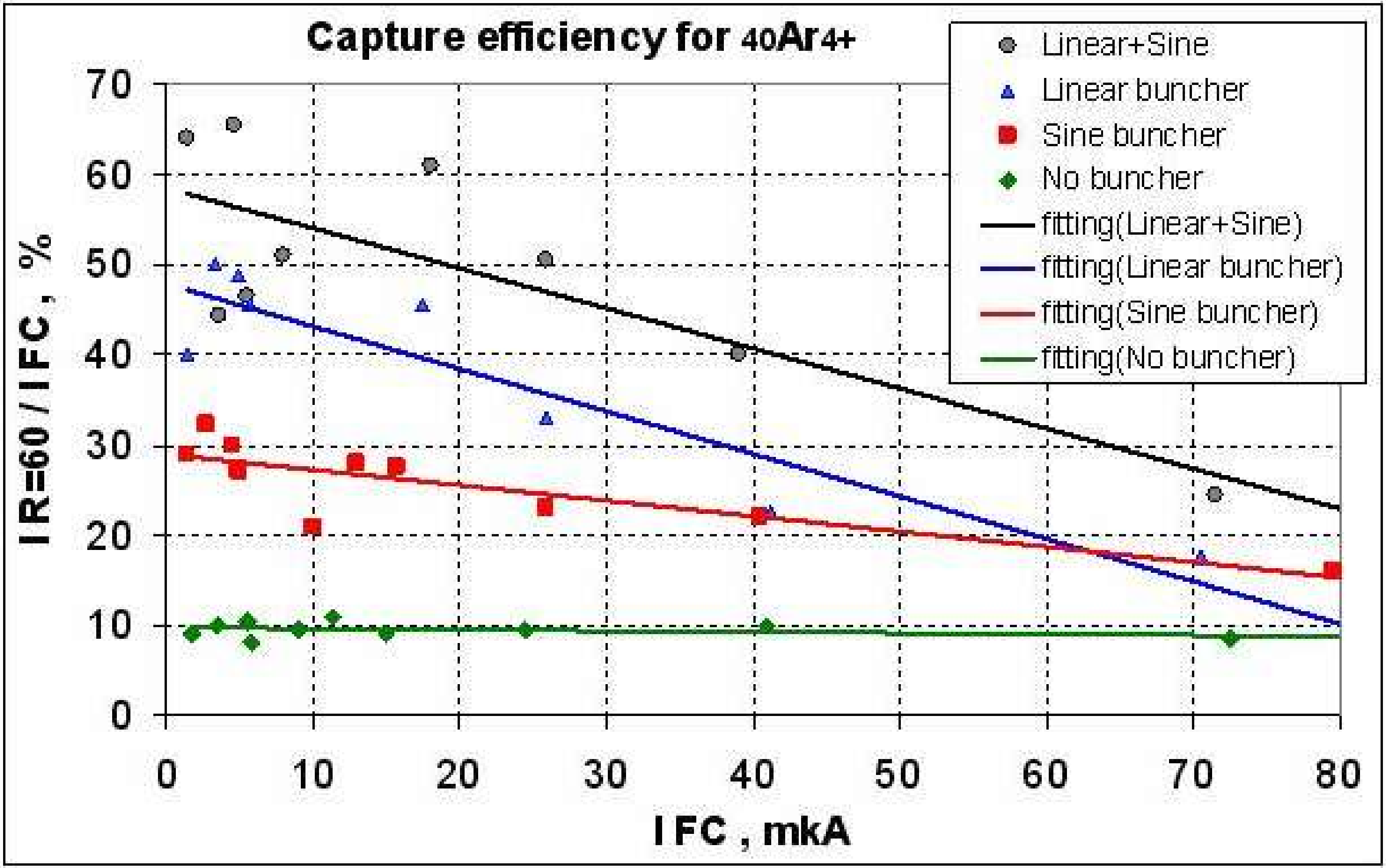
DC280-cyclotron – stand-alone SHE-factory

- Synthesis and study of properties of superheavy elements.
- Search for new reactions for SHE-synthesis.
- Chemistry of new elements.

DC280 (expected) E=4 8 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	4	1 10^{14}
^{18}O	8	1 10^{14}
^{40}Ar	5	6 10^{13}
^{48}Ca	5	0,6-1,2 10^{14}
^{54}Cr	5	2 10^{13}
^{58}Fe	5	1 10^{13}
^{124}Sn	5	2 10^{12}
^{136}Xe	5	1 10^{14}
^{238}U	7	5 10^{10}

DC280. Parameters and Goals

	DC280 Parameter	Goals
1.	High injecting beam energy (up to 100 kV)	Shift of space charge limits for factor 30
2.	High gap in the center	Space for long spiral inflector
3.	Low magnetic field	Large starting radius. High turns separation. Low deflector voltage
4.	High acceleration rate	High turns separation.
5.	Flat-top system	High capture. Single orbit extraction. Beam quality.

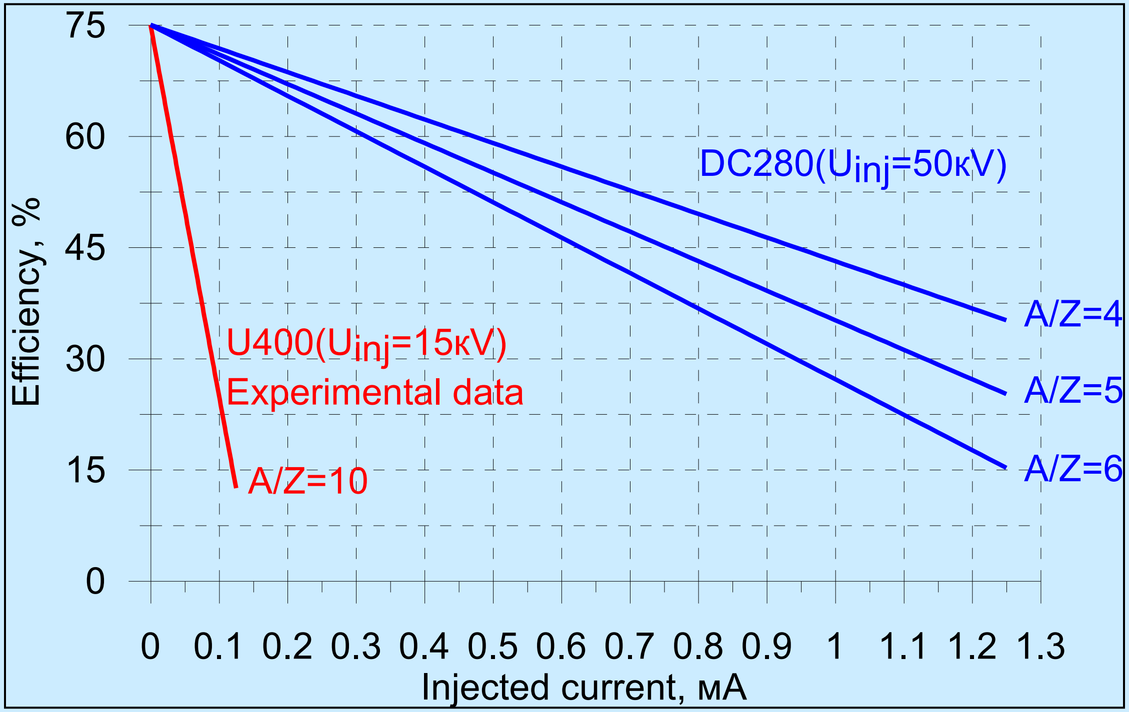


Иваненко И.А.

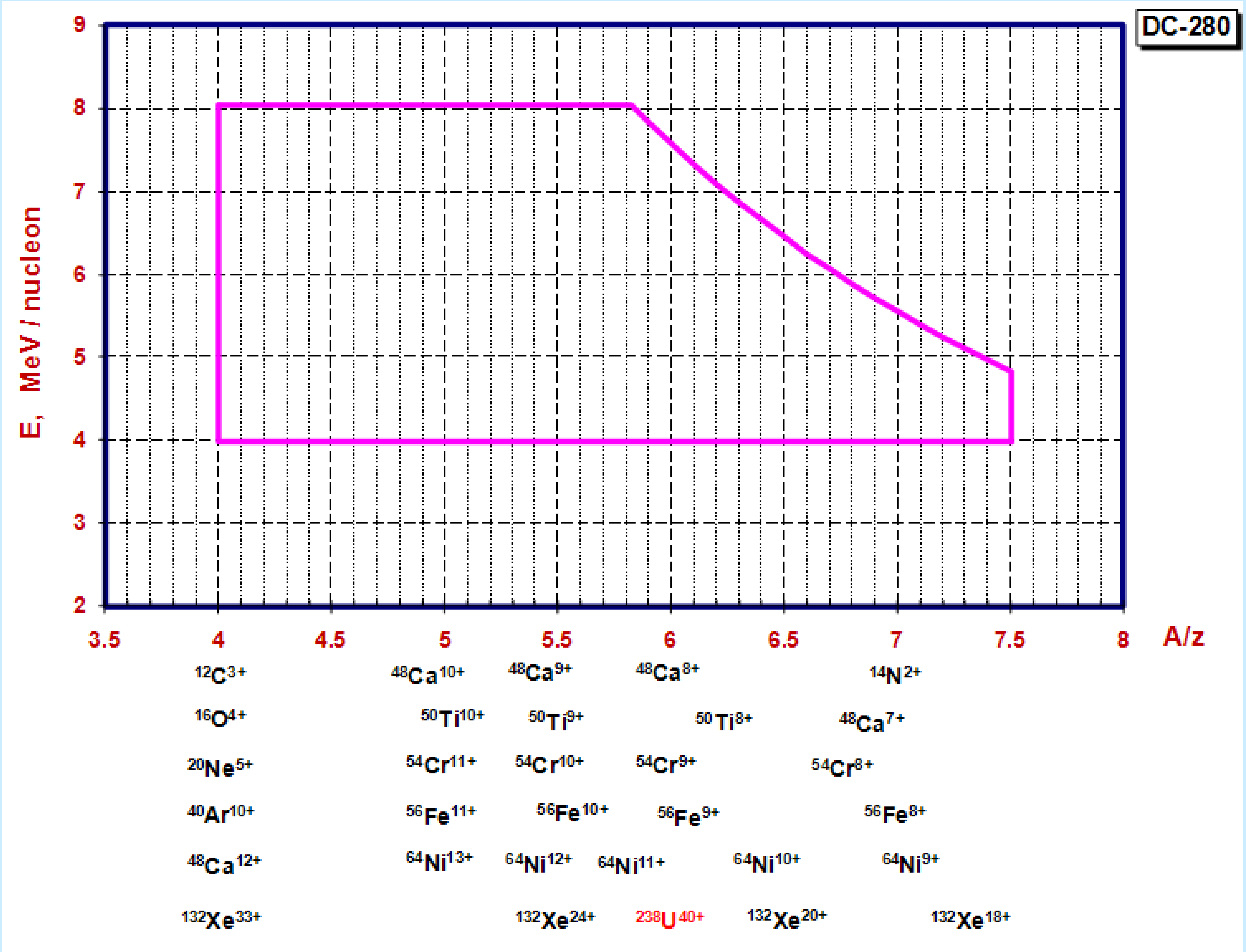
Калагин Н В

DC280

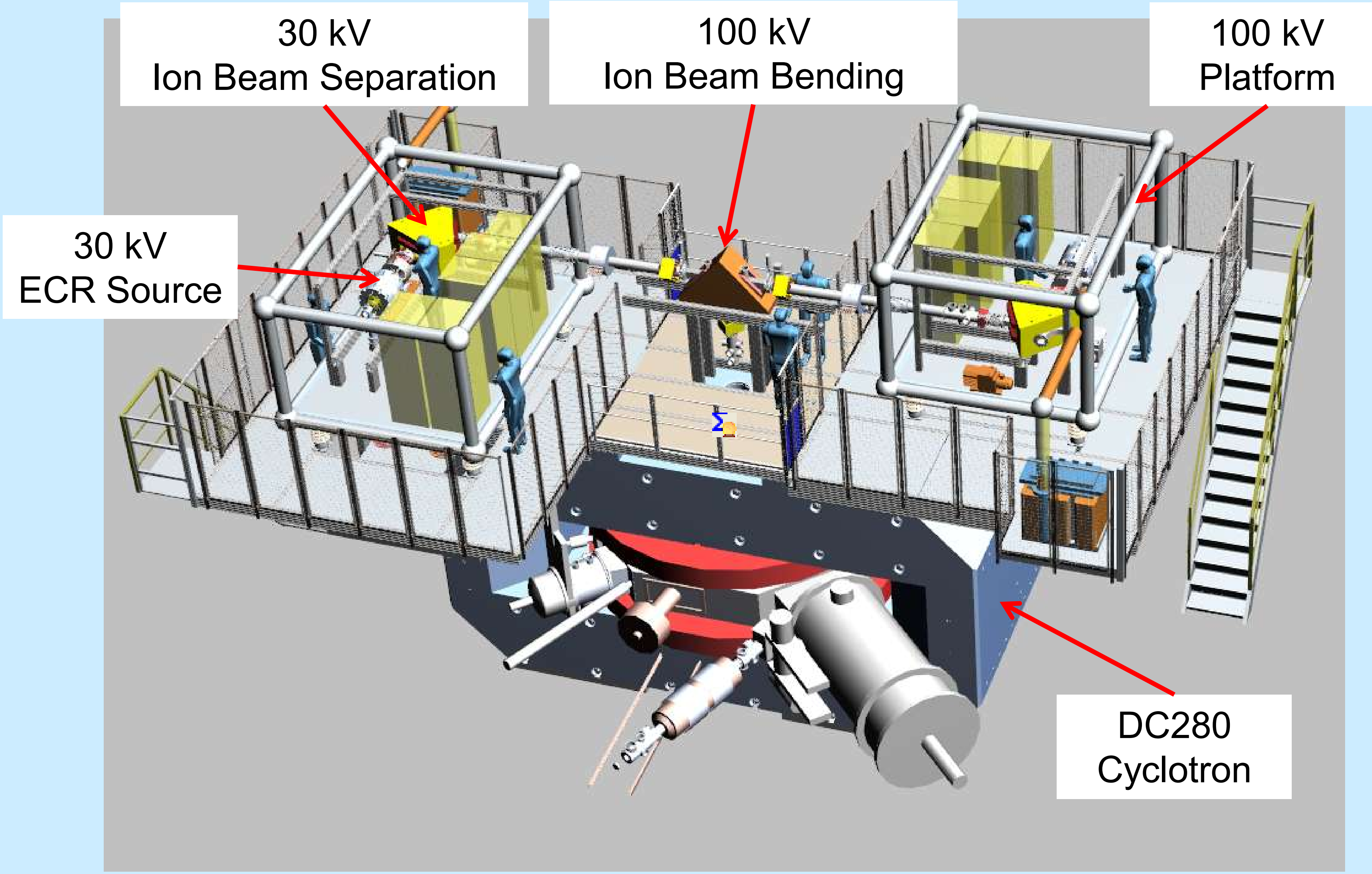
Overall (ion source ⟶ target) beam current transferring efficiency



Working Diagram of the DC280 Cyclotron



DC280 Cyclotron

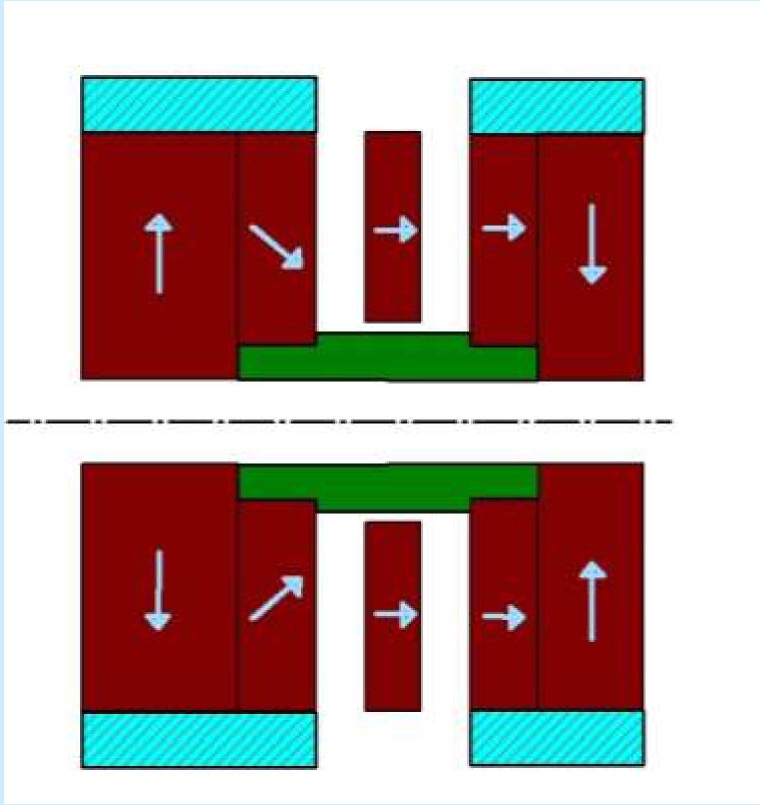


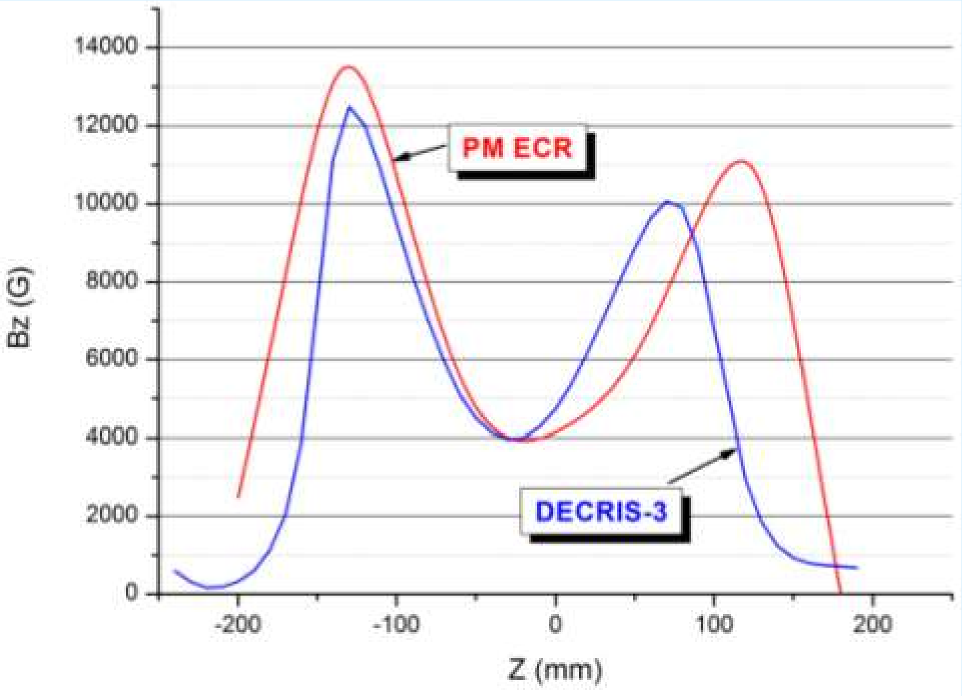
DC280

Main Parameters

Ion source	DECRIS-4 - 14 GHz DECRIS-SC3 - 18 GHz
Injecting beam potential	Up to 100 kV
A/Z range	4 7
Energy	4÷8 MeV/n
Magnetic field level	0.6 1.35 T
K factor	280
Gap between plugs	400 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV

PM ECR

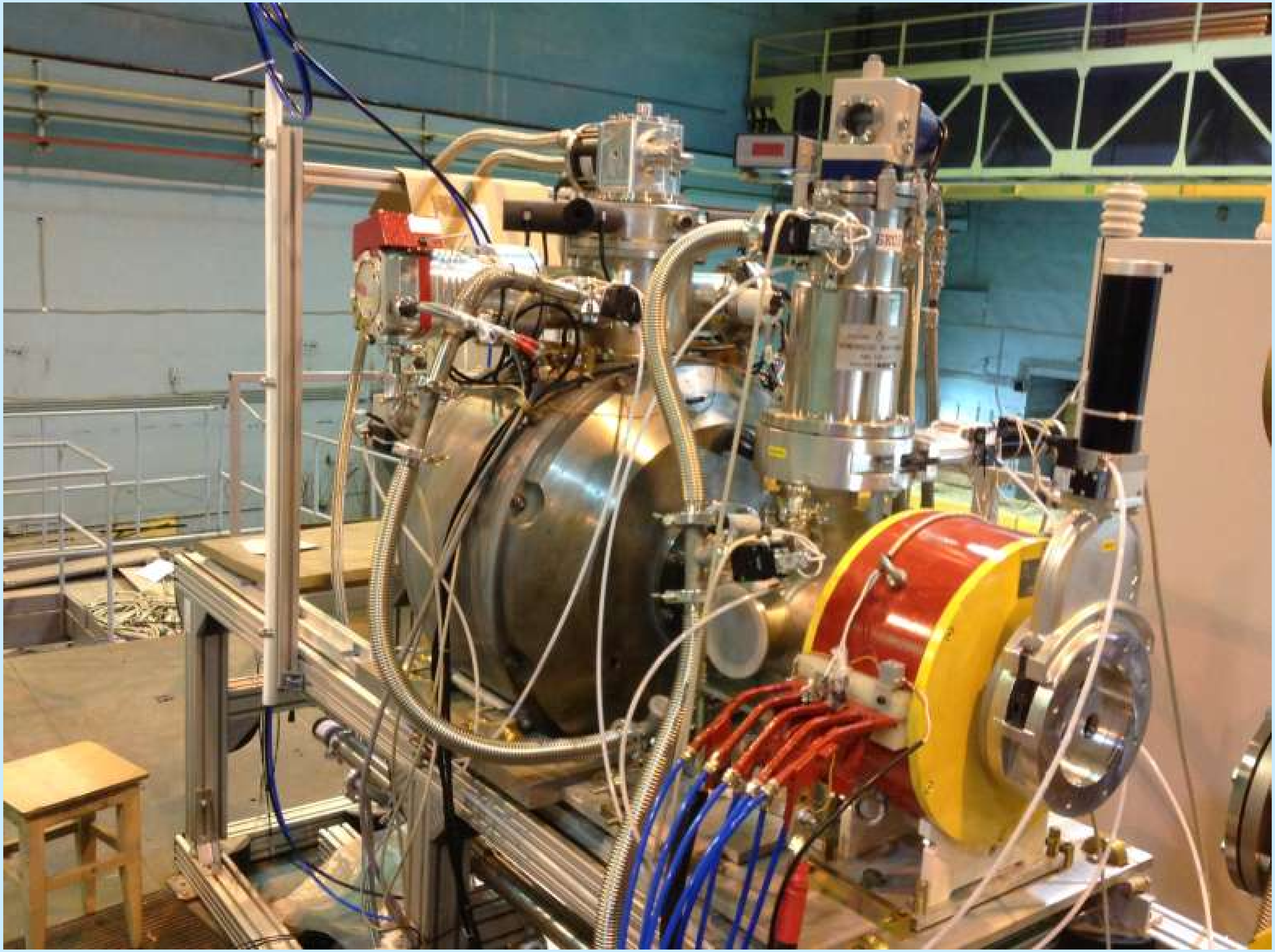




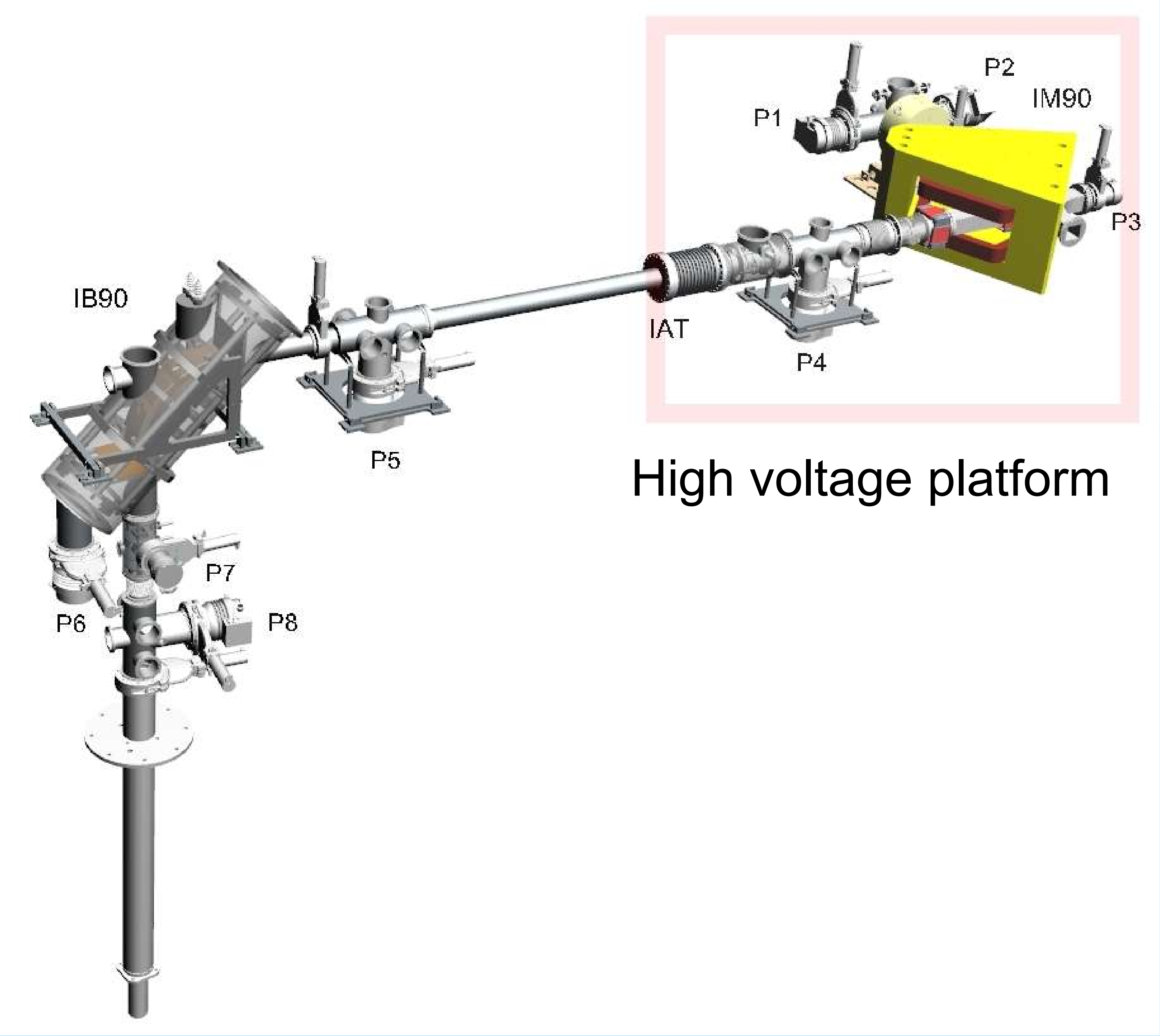
Вес (магниты): 650 + 30 кГ

	DECRIS-3	PM ECR
B_{inj}	12,5	13,5
B_{min}	3,95	3,93
B_{extr}	10,1	11,1
B_{rad}	9,5	11,0
$D_{pl.chamb}$	64	70
L_{mirr}	200	250

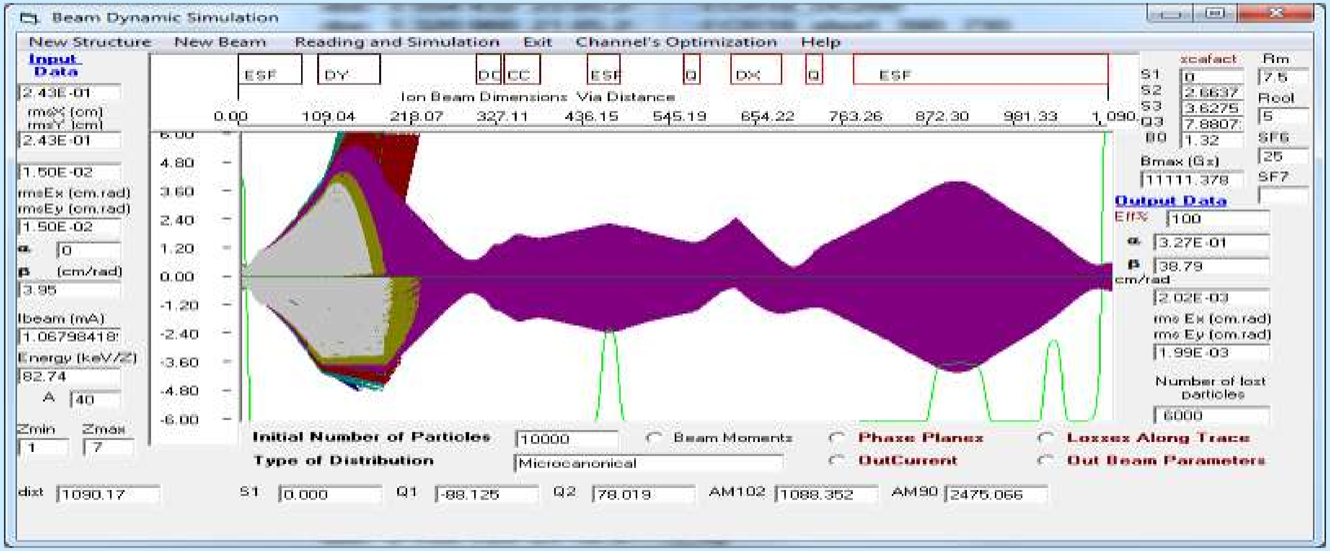
U400M ACCELERATOR COMPLEX
DECRIS-SC2 (18 GHz)



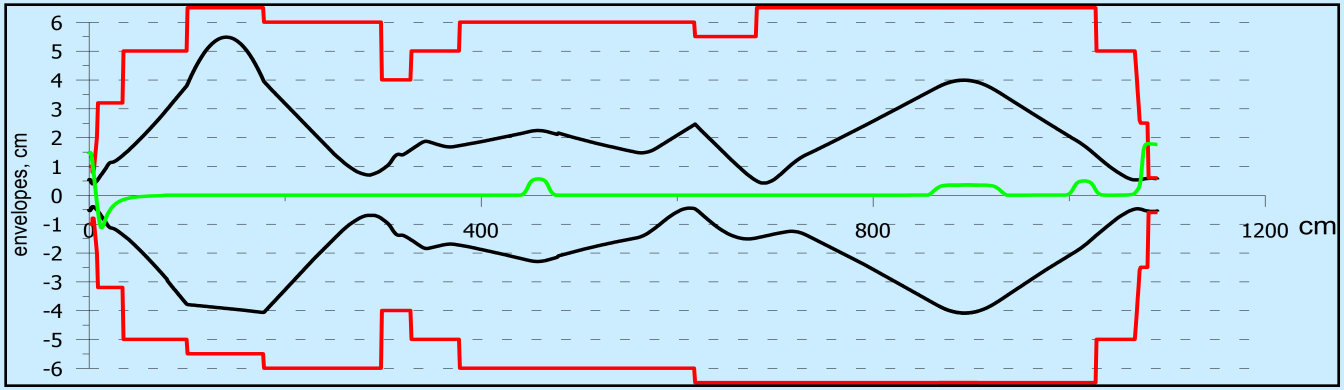
DC280. High voltage platform and axial injection system model



DC280 axial injection beam line

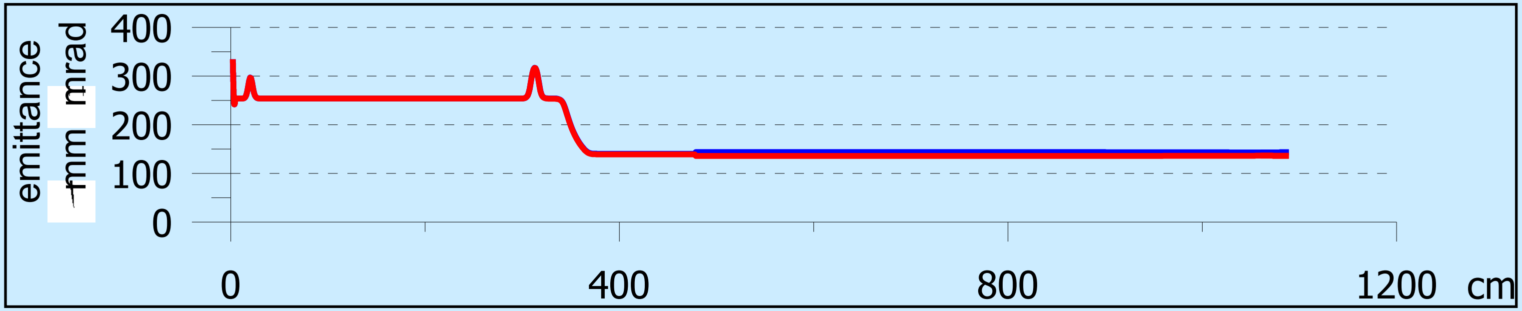


Particle trajectories

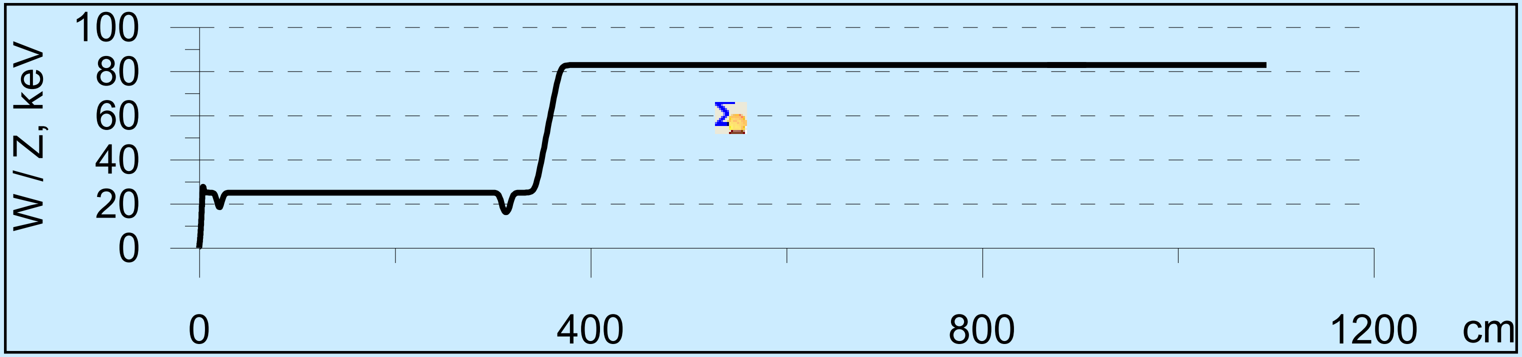


Horizontal (upper curve), vertical (lower curve) Ar^{7+} beam envelopes
Longitudinal magnetic field – green line, apertures – red line

DC280 axial injection beam line



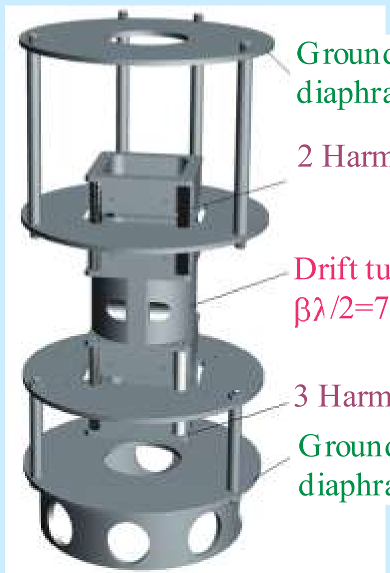
Ar^{7+} beam emittance (non-normalized)

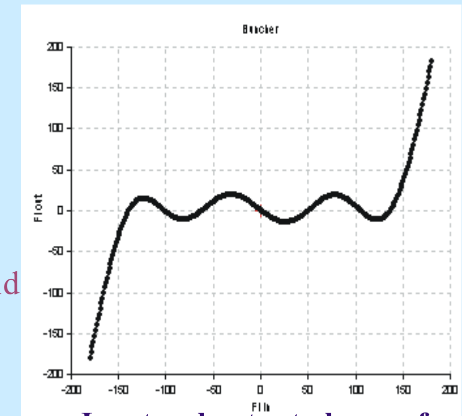


Ar^{7+} beam kinetic energy per unit charge

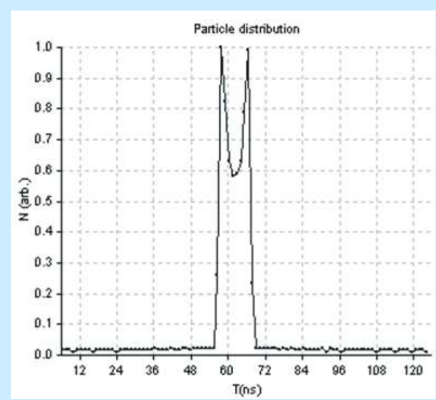
DC-280

POLYHARMONIC BUNCHER



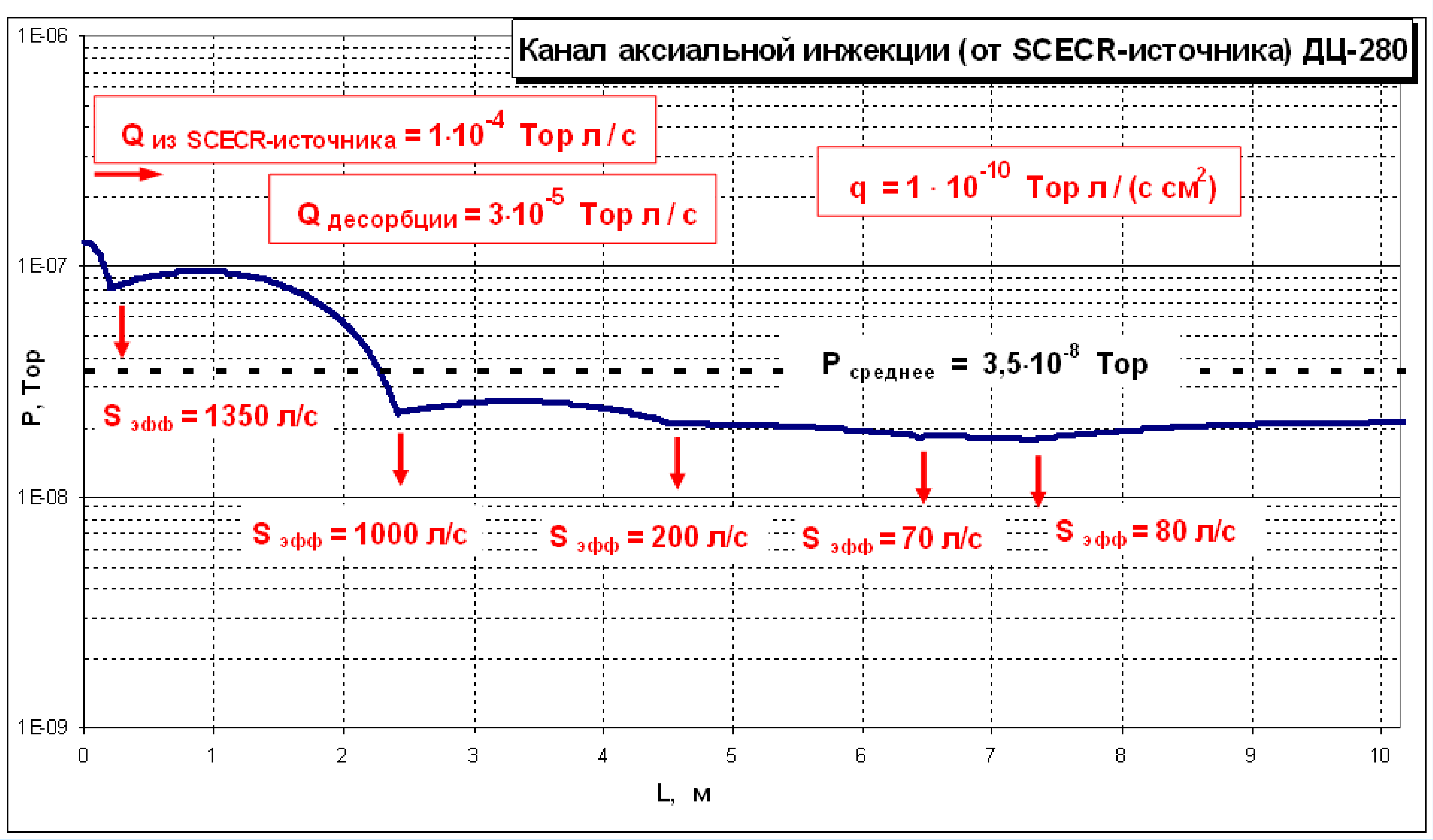


Input and output phases of ions at bunching



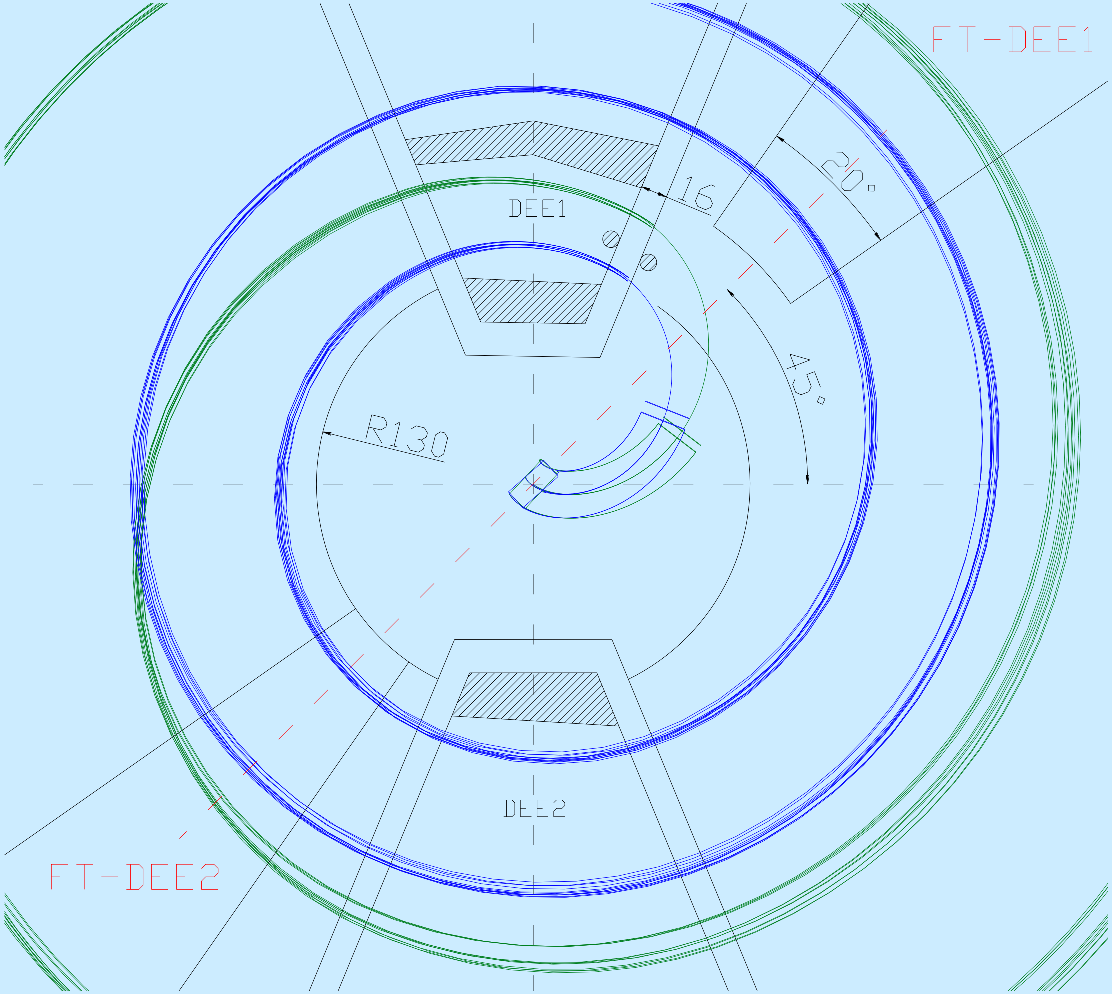
Particle distribution in the median plane of DC-280

Pressure distribution along axial injection beam line



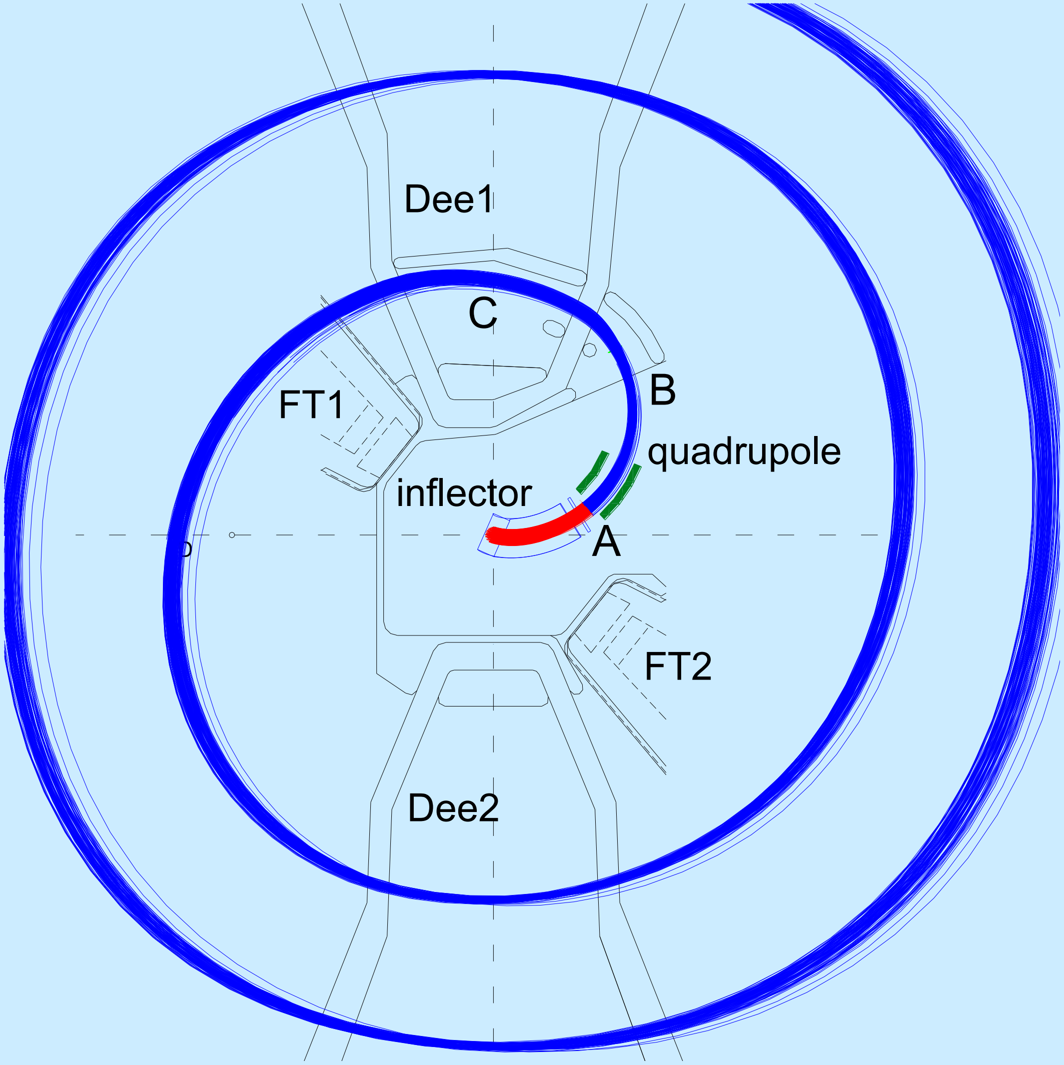
Тихомиров А.В.

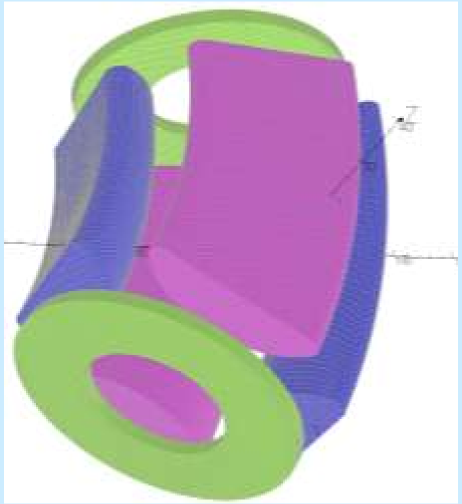
DC280 central region with Flat-Top system



The central region of DC280 cyclotron.
Positions of the main (Dee1 – Dee2) and independent «flat-top» (FT1 – FT2) RF systems.

Quadrupole lense at DC280 central region





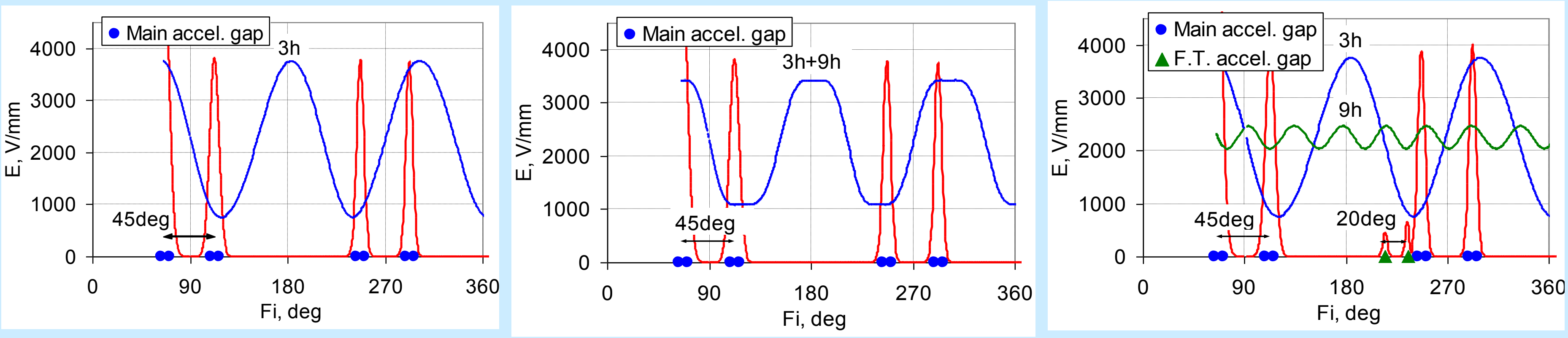
Quadrulole leanse:
+ Decrease aperture losses
+ Increase beam efficiency at first orbits
+ Permit to adjust the acceleration mode operatively

- Increase beam radial occilation
- Complicate central region construction

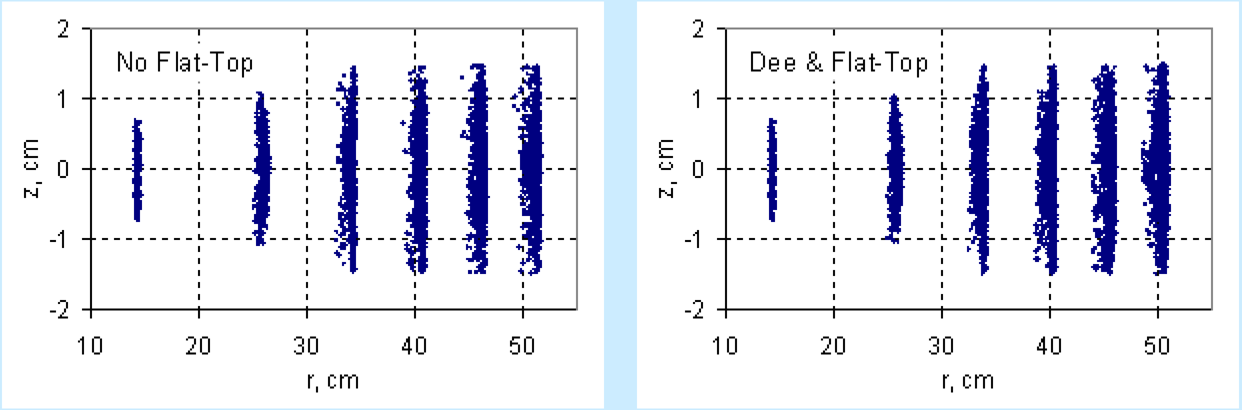
without «flat-top» system

combined main and «flat-top» systems

independent «flat-top» system

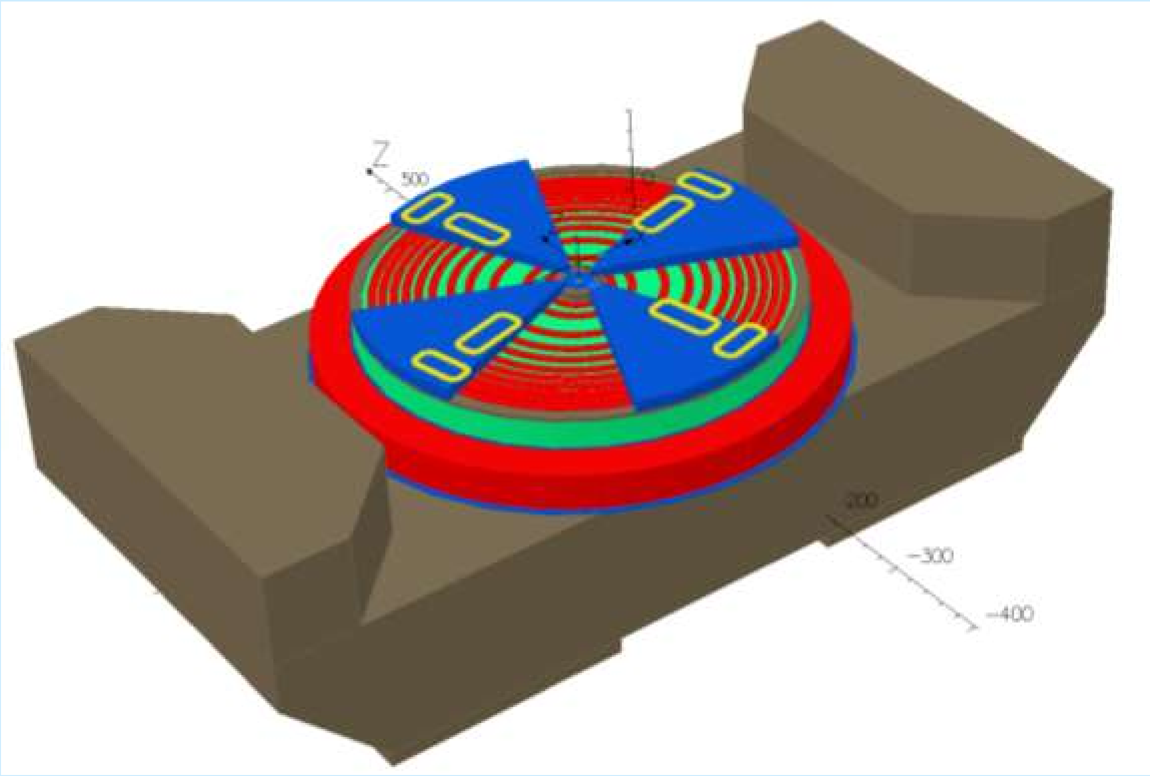


Acceleration voltage along the central ion trajectory at 1-t orbit and RF phases of main 3h and «flat-top» 9h dees voltage in the considered cases of «flat-top» system configuration

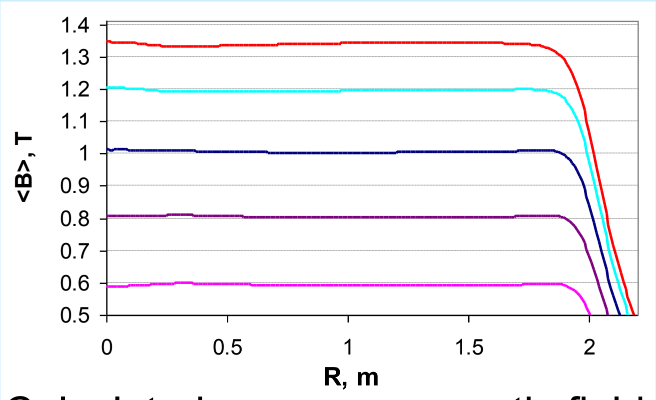


Beam transverse form for 5 initial orbits in the considered cases of «flat-top» system configuration

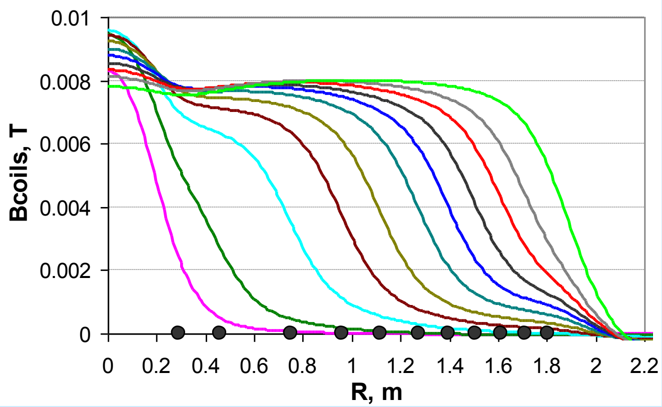
3D calculation of DC280 cyclotron magnetic field



Model of DC280 cyclotron magnet system



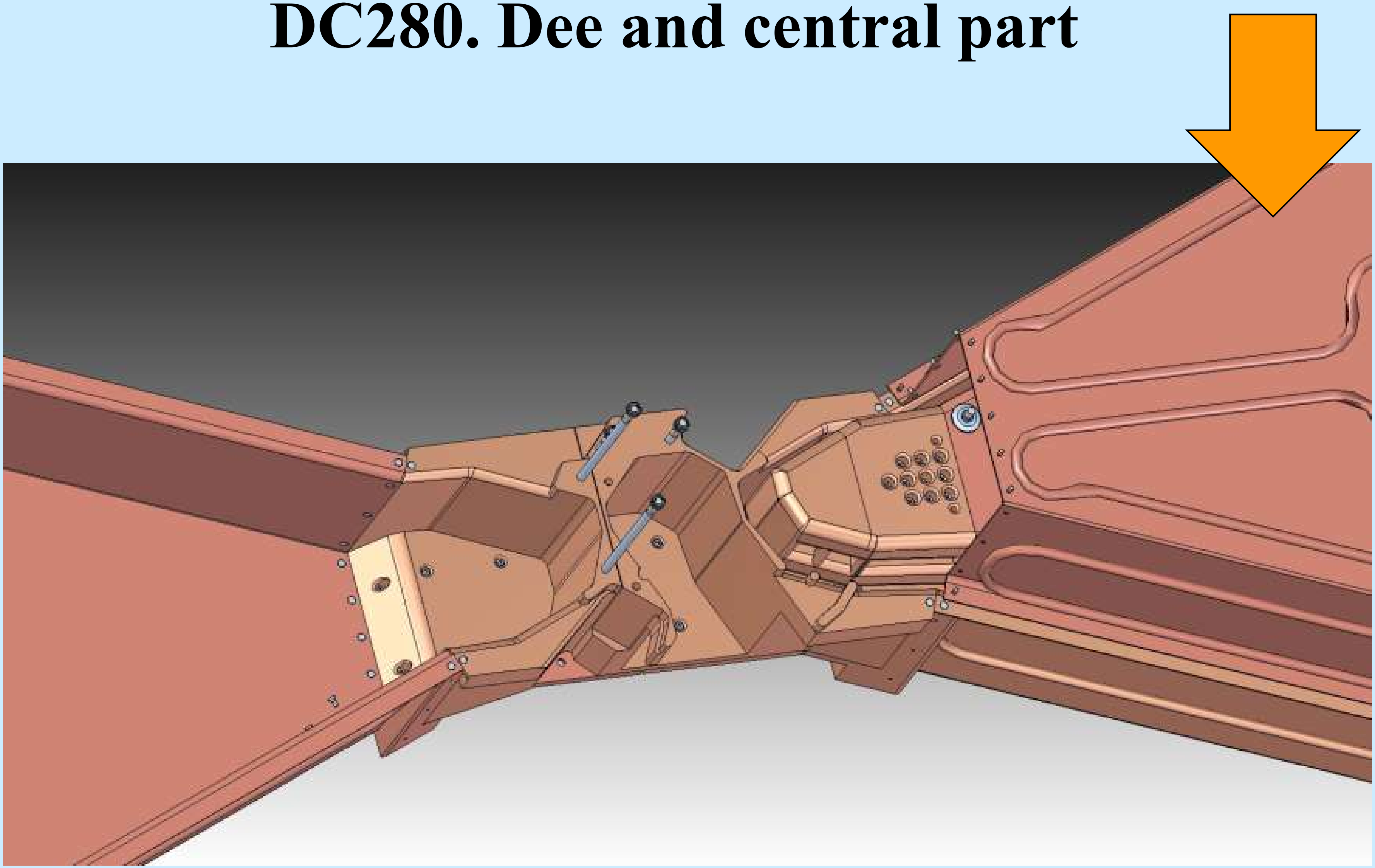
Calculated average magnetic fields



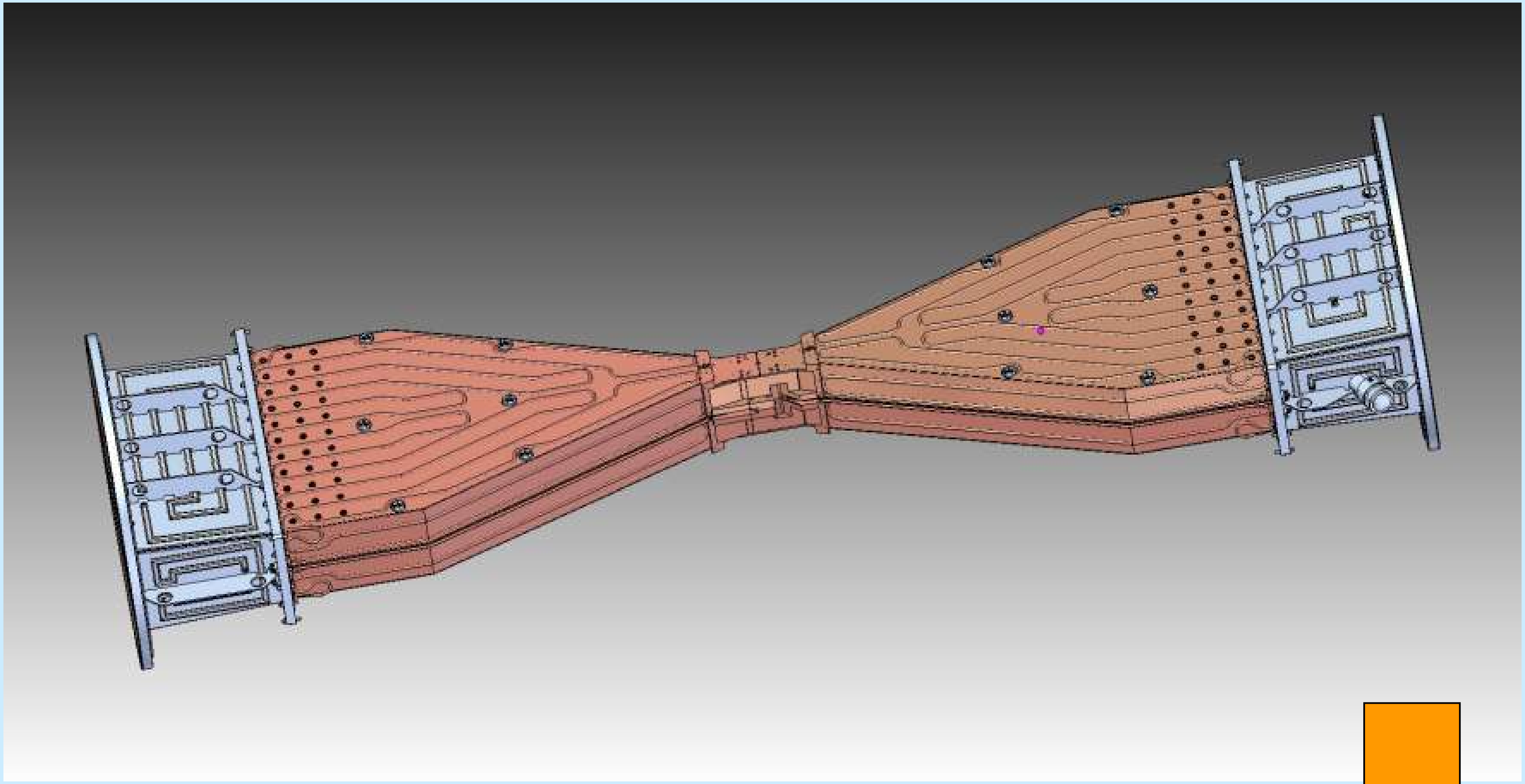
Contributions of the radial coils

The main magnet of DC280

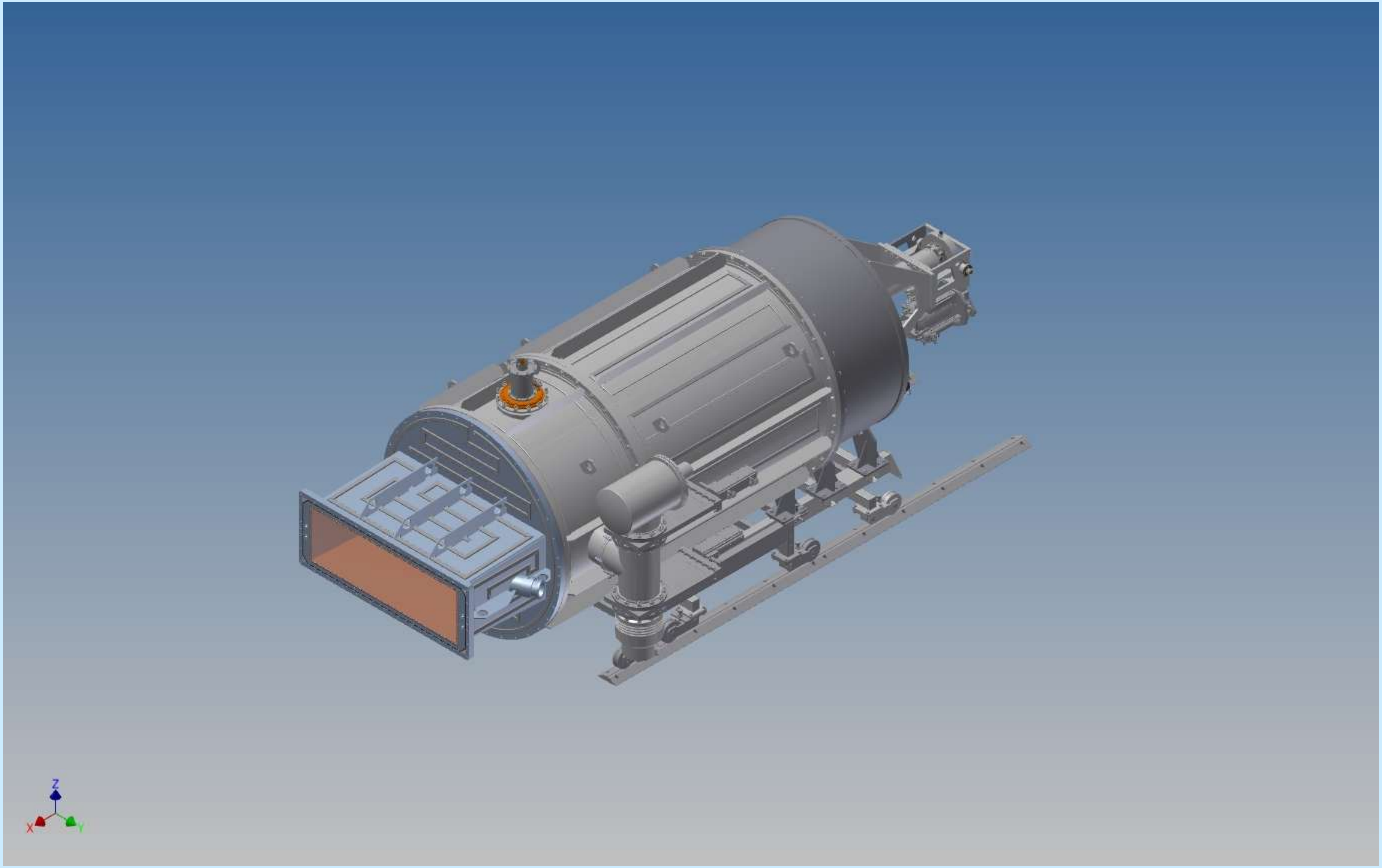
DC280. Dee and central part



DC280. Dees and ground plating



DC280. RF resonator

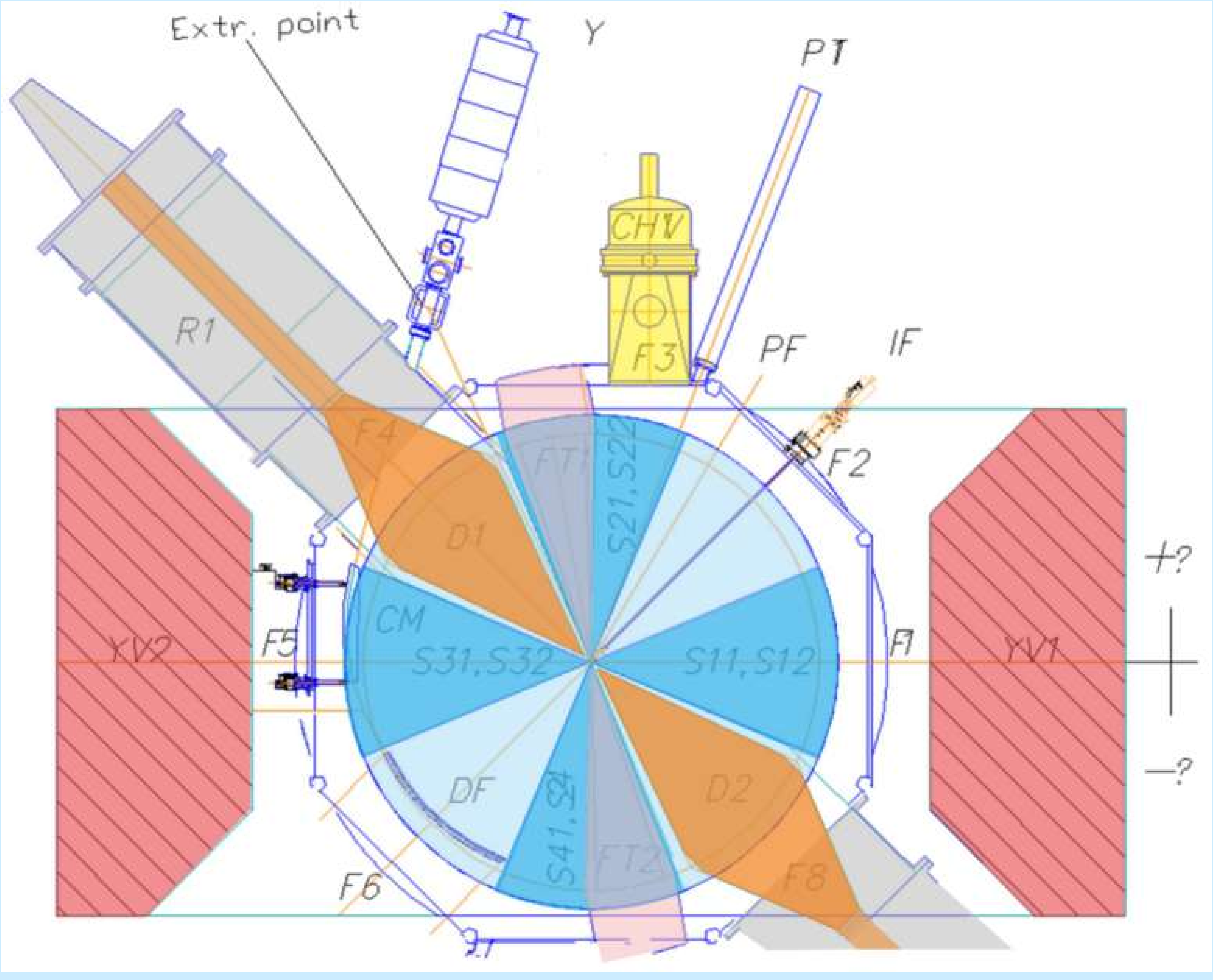


As an example - RF system

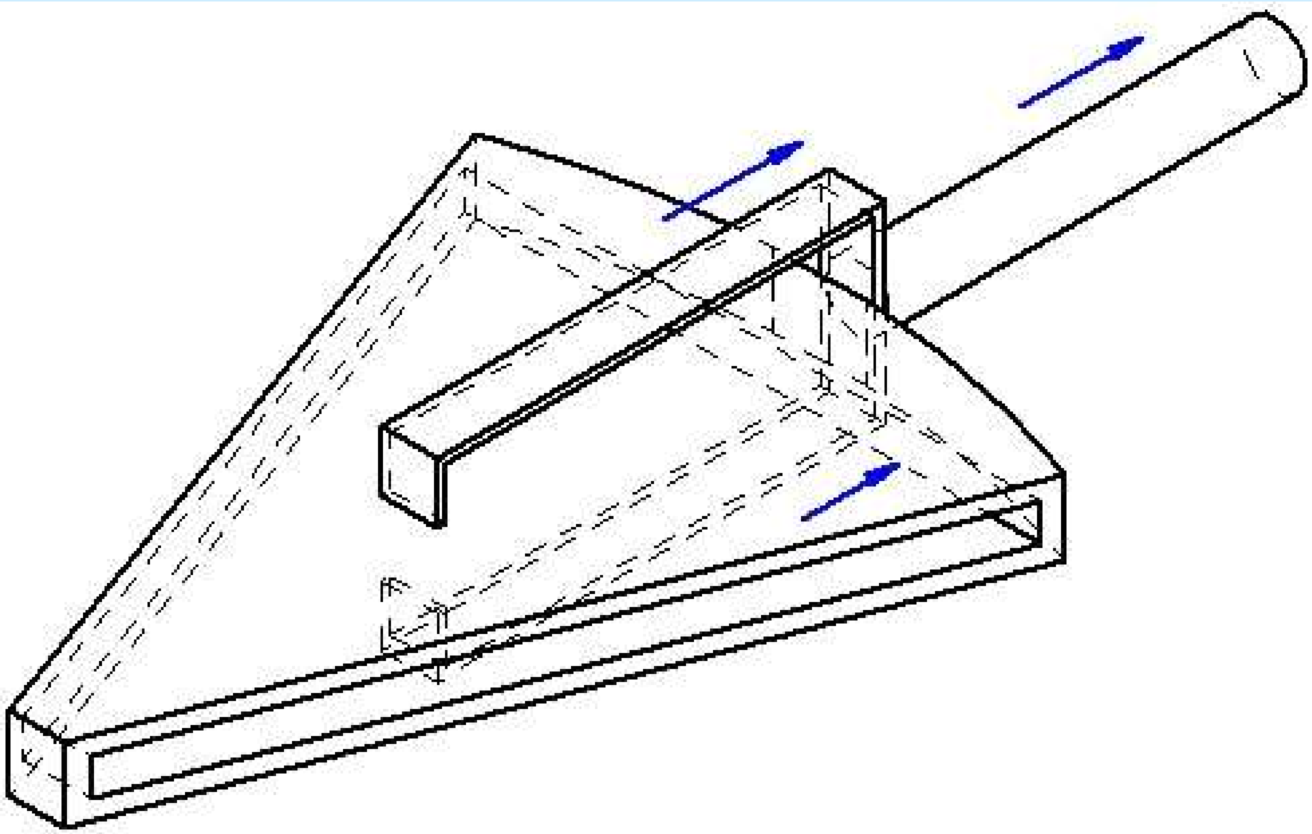
- Bimetallic resonators – copper plated stainless steel

- Copper balls used as contacts on shorting plate

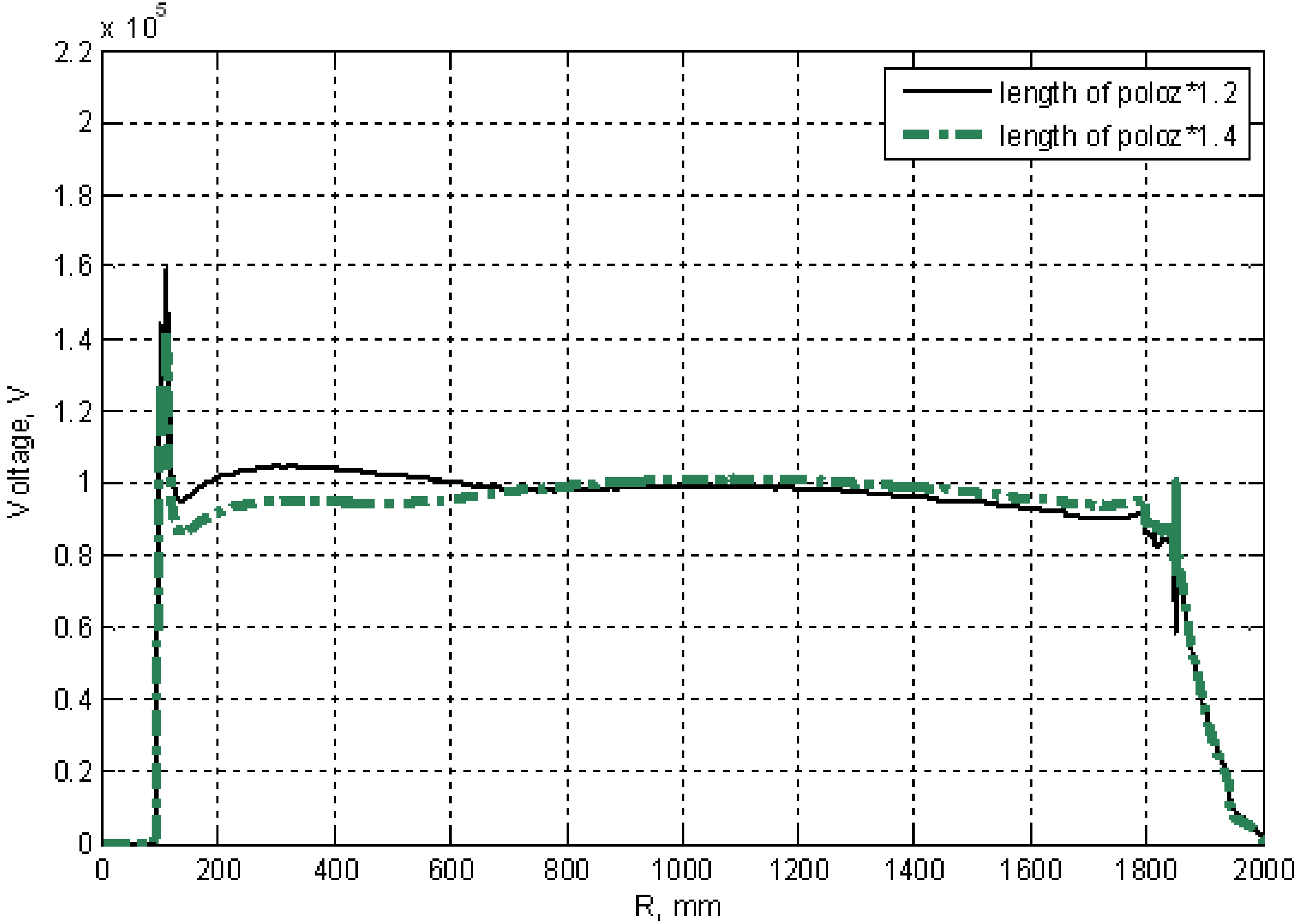
DC280 plan view and beam extraction structure



DC280.Structure of flat-top dee with resonator



Flat-Top dee voltage radial distribution



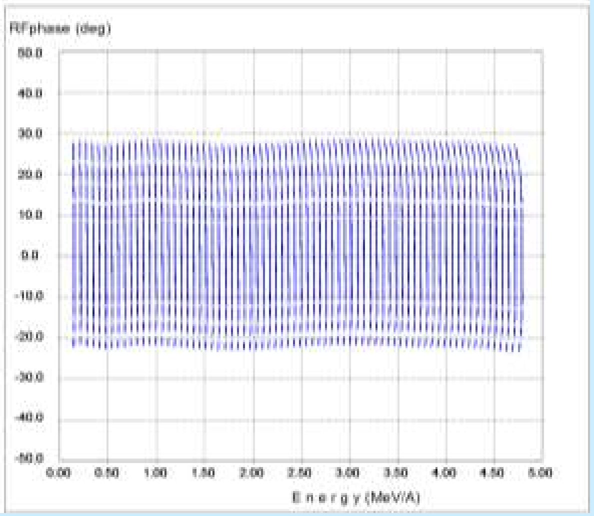
Зависимость напряжения от радиуса

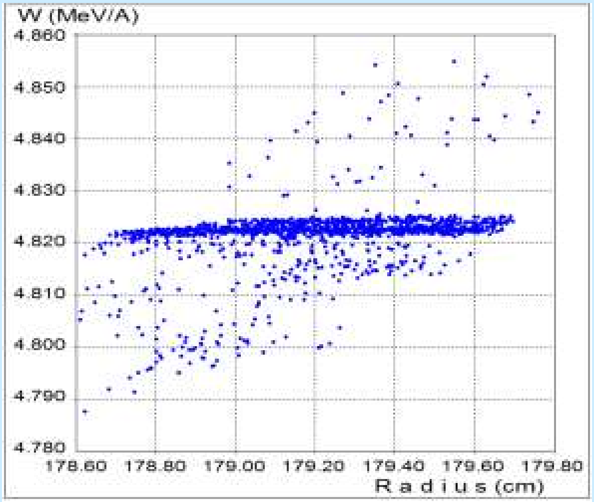
Карамышев О.В.

DC280 Flat Top system

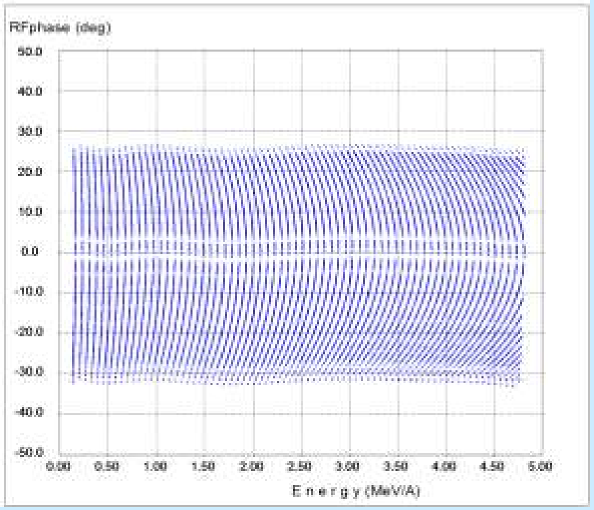
RF phase – energy position of ions along acceleration

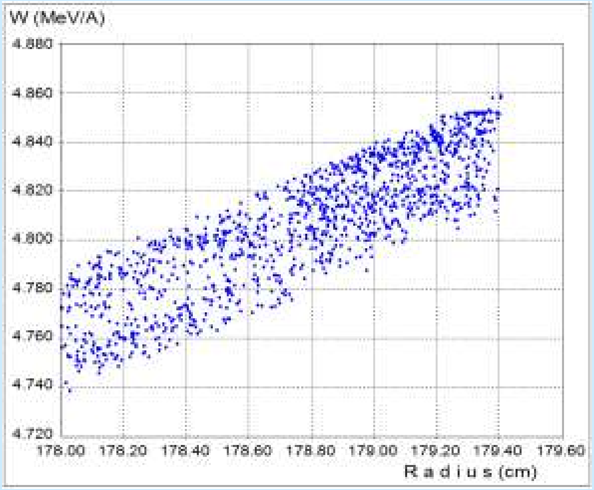
Radius – energy position of ions at the deflector entrance





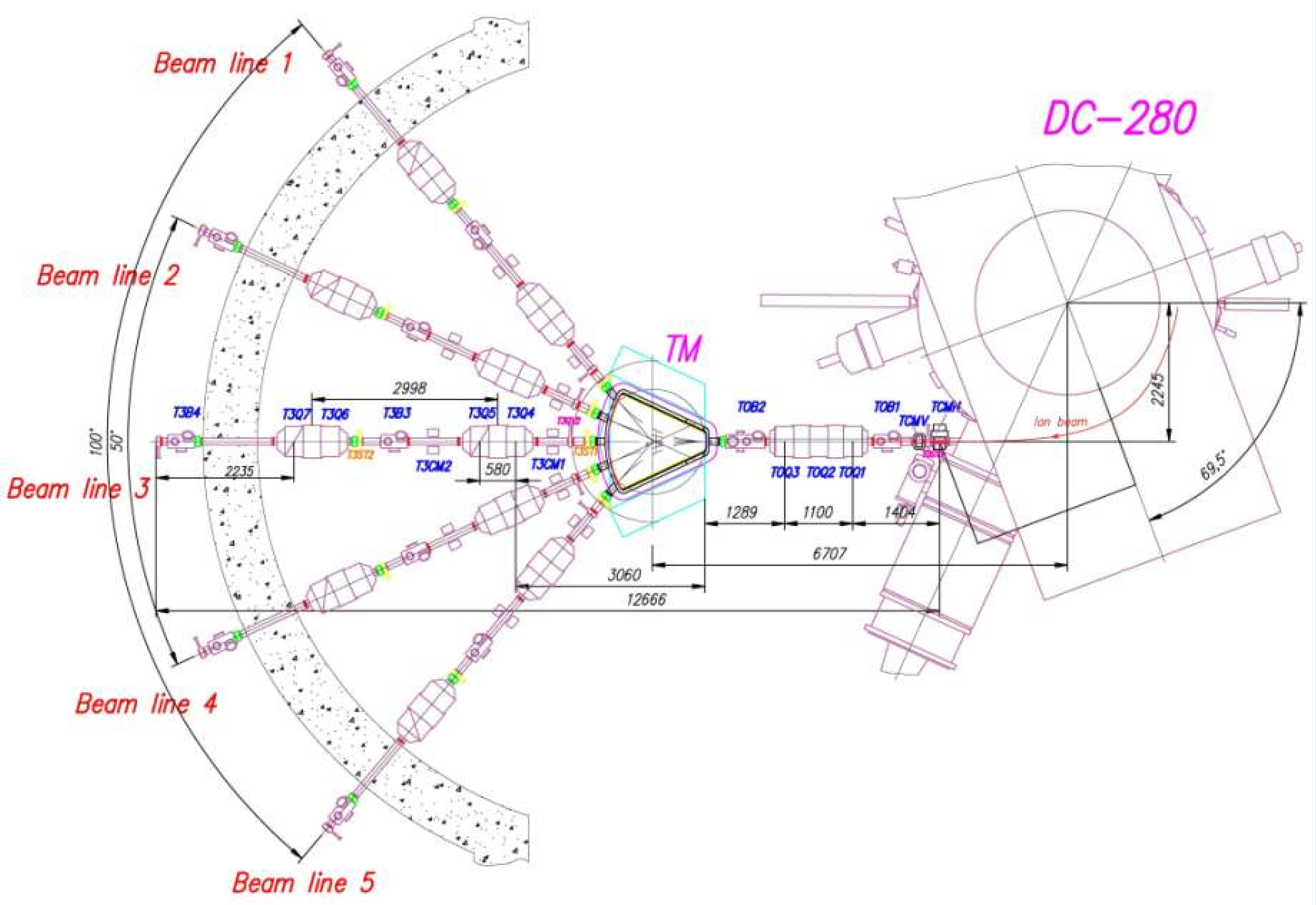
Flat-Top is turned on



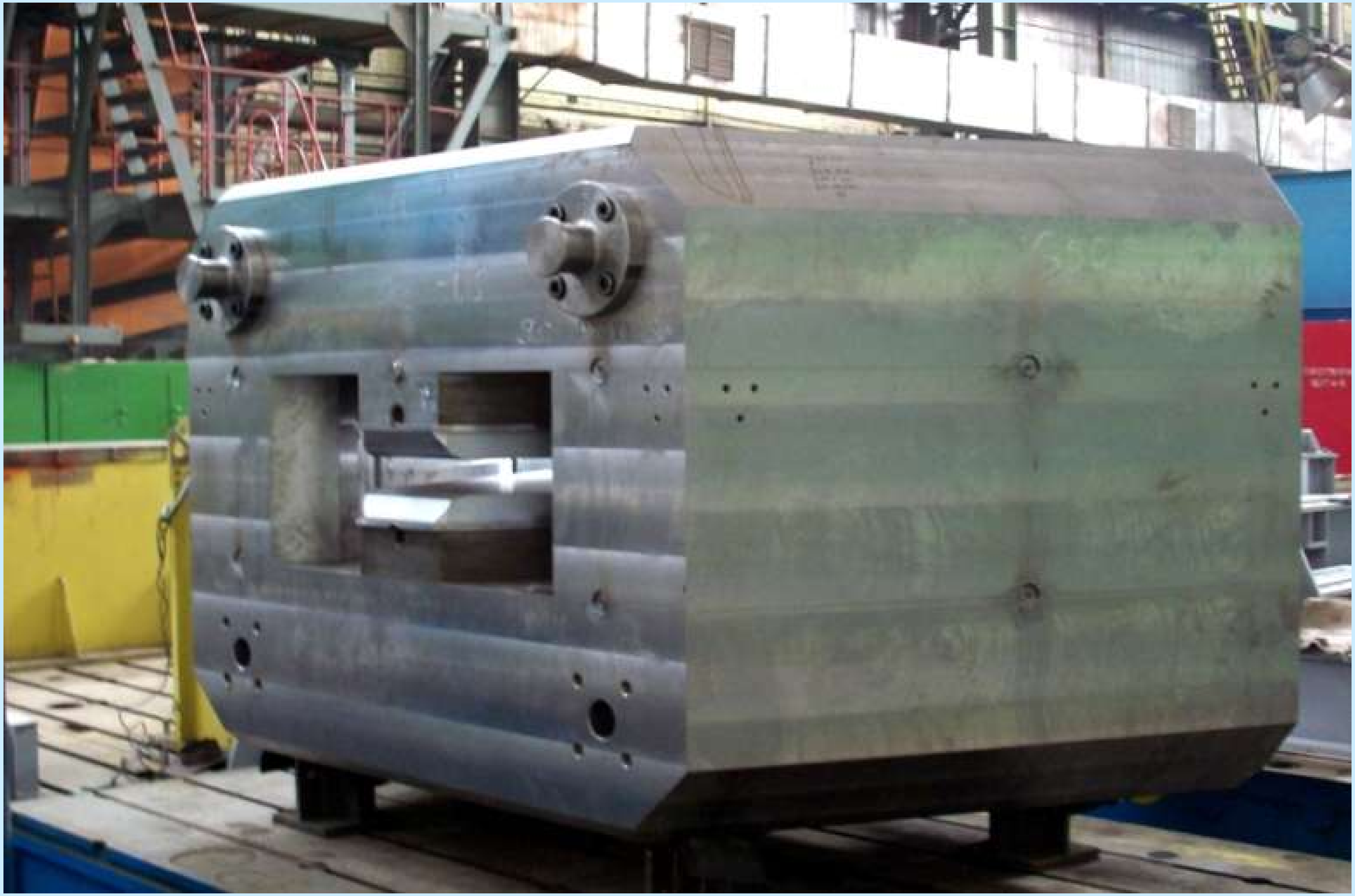


Flat-Top is turned off

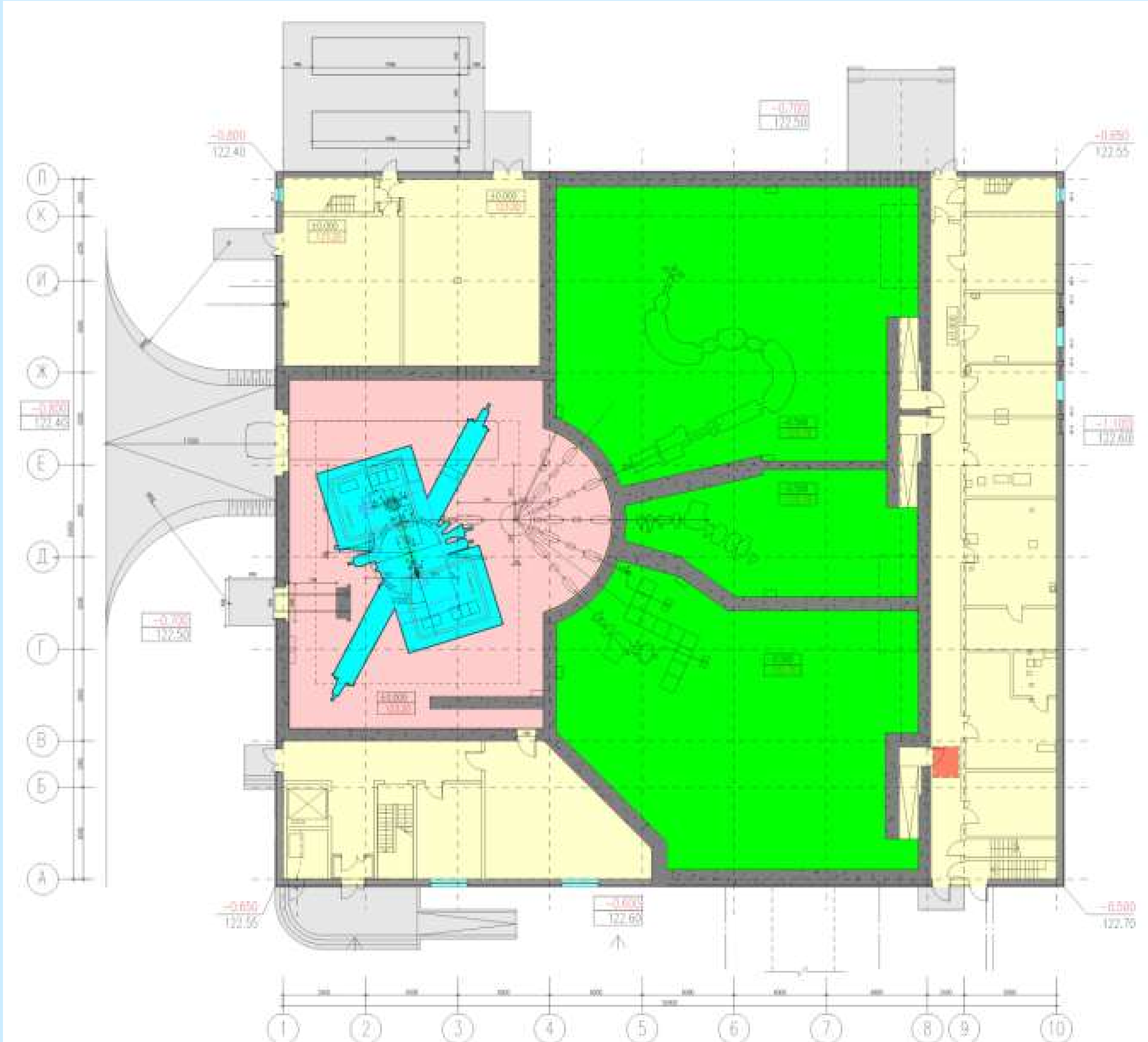
DC280. Plan view of the extracted beam lines



Switching magnet



New Experimental Building with DC280 accelerator complex

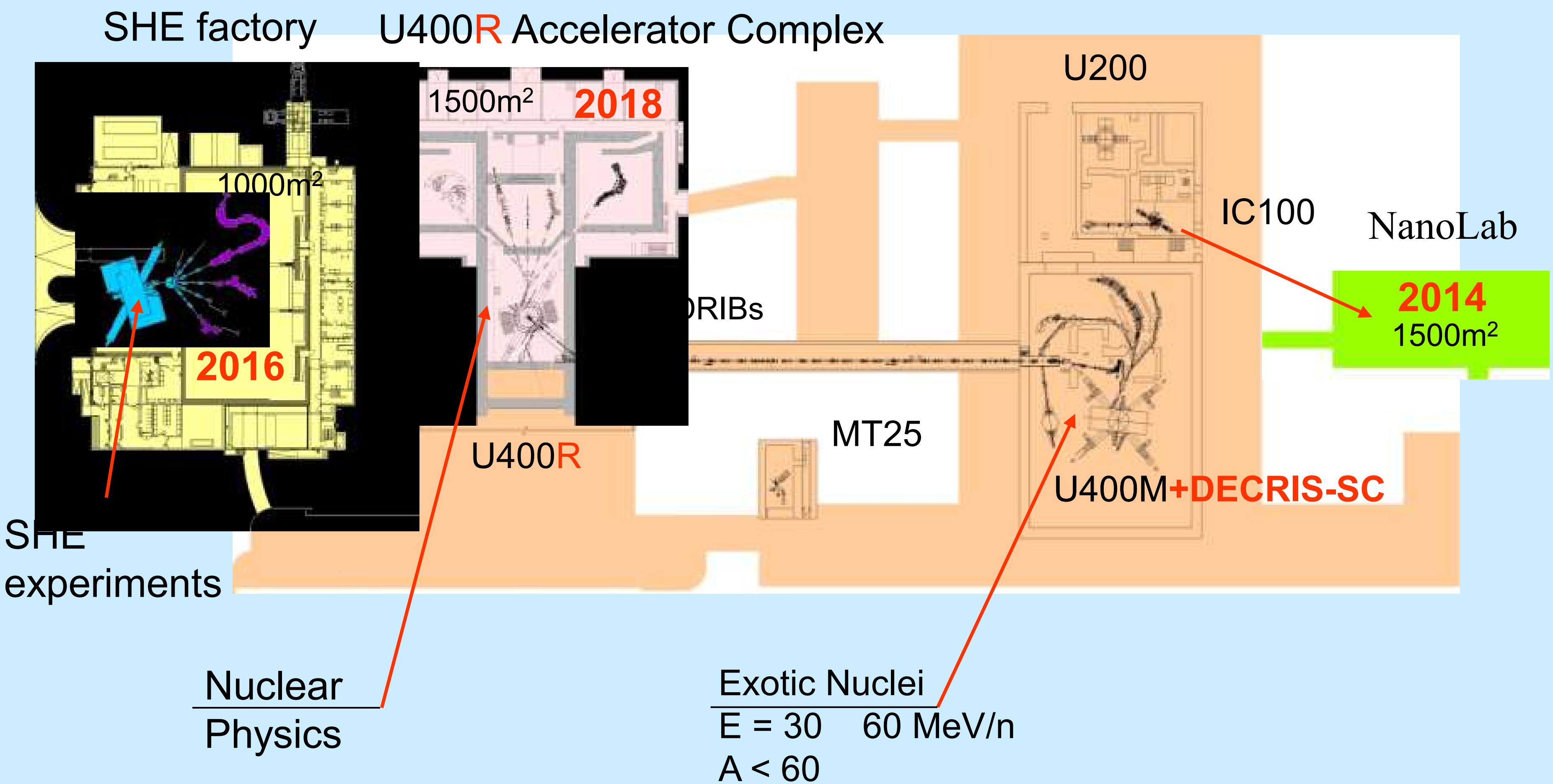


Гульбекян Г.Г., Костырев В.А., Башевой В.В.

Experimental Hall of the SHE-Factory 22.09.2014

on-line: http://inflnr.jinr.ru/dc280.html

FLNR – 2017(18)



SHE factory
U400R Accelerator Complex
1500m2
2018
1000m2
2016
SHE
experiments
)RIBs
U400R
U200
IC100
NanoLab
2014
1500m2
MT25
U400M+DECRIS-SC
Nuclear
Physics
Exotic Nuclei
E = 30 60 MeV/n
A < 60

SHE factory
DC280 equipment completion (k$).

№	Systems / years	2011	2012	2013	2014	2015	2016	Σ
1.	Main magnet DC-280	125	2 250	2 690	2 350	200		7 615
2.	Main coil			344	335	150	50	880
3.	Trim coils				115	130	70	298
4.	Cyclotron vacuum chamber			121	121	400	120	763
5.	Acceleration RF structure			202	521	350	70	1143
6.	R.F. power supplies			124	364	50	30	568
7.	Polyharmonic buncher		23	19		50	20	113
8.	Permanent magnet ECR ion source			184	83	200	60	527
9.	High voltage platform			99	53	550	90	793
10.	Beam transport channels		254	330	236	150	30	1001
11.	Two plane correction magnets			161				161

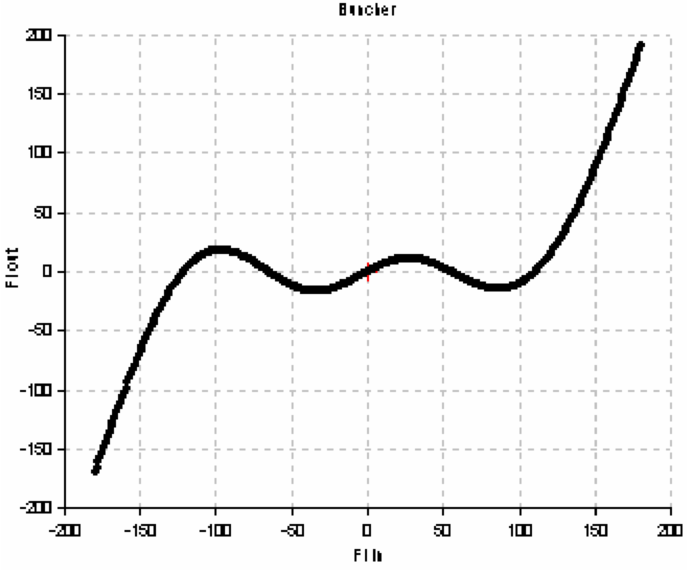
№	Systems / years	2011	2012	2013	2014	2015	2016	Σ
12.	Bending magnet with vacuum chamber			141	141	50		333
13.	Beam diagnostics			258	61	150	25	495
14.	Power supply transformers			249	228			478
15.	Power supplies of magnets			465	316	130		911
16.	Water cooling			365	342	150	20	878
17.	R.F. control system					550	50	600
18.	Simulation, drawing	30	15	17				64
19.	Dees, gound plates				96	190	32	319
20.	Beam injection system					450	20	470
21.	Vacuum system					850	60	910
22.	Control system					950	60	1010
23.	Transport					150		150
		← 14350 → 68 %				← 6700 → 32 %		∑∑ 21050

Thank you!

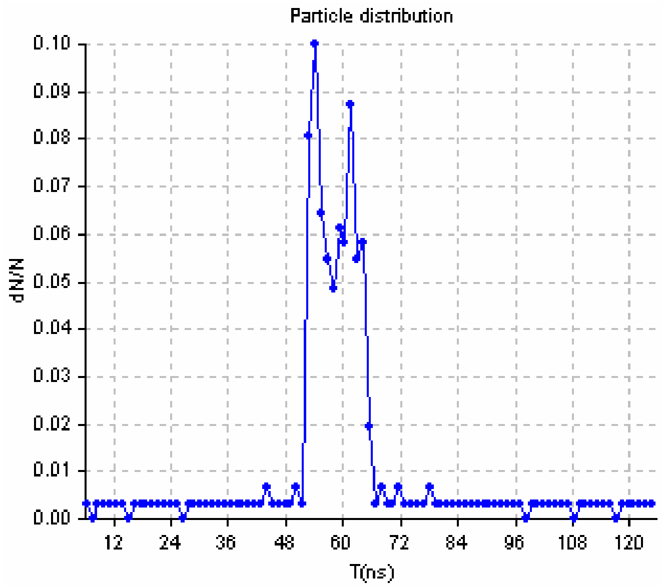
Super Heavy Element Factory

To enhance the efficiency of experiments for next few years it is necessary to obtain accelerated ion beams with the following parameters:

-
- Ion energy 4÷8 MeV/n
- Ion masses 10÷238
- Beam intensity (up to A=50) 10 pμA
- Beam emittance less 30 π mm×mrad
- Efficiency of beam transfer >50%



Входная и выходная фазы пучка для 2-х синусных банчеров

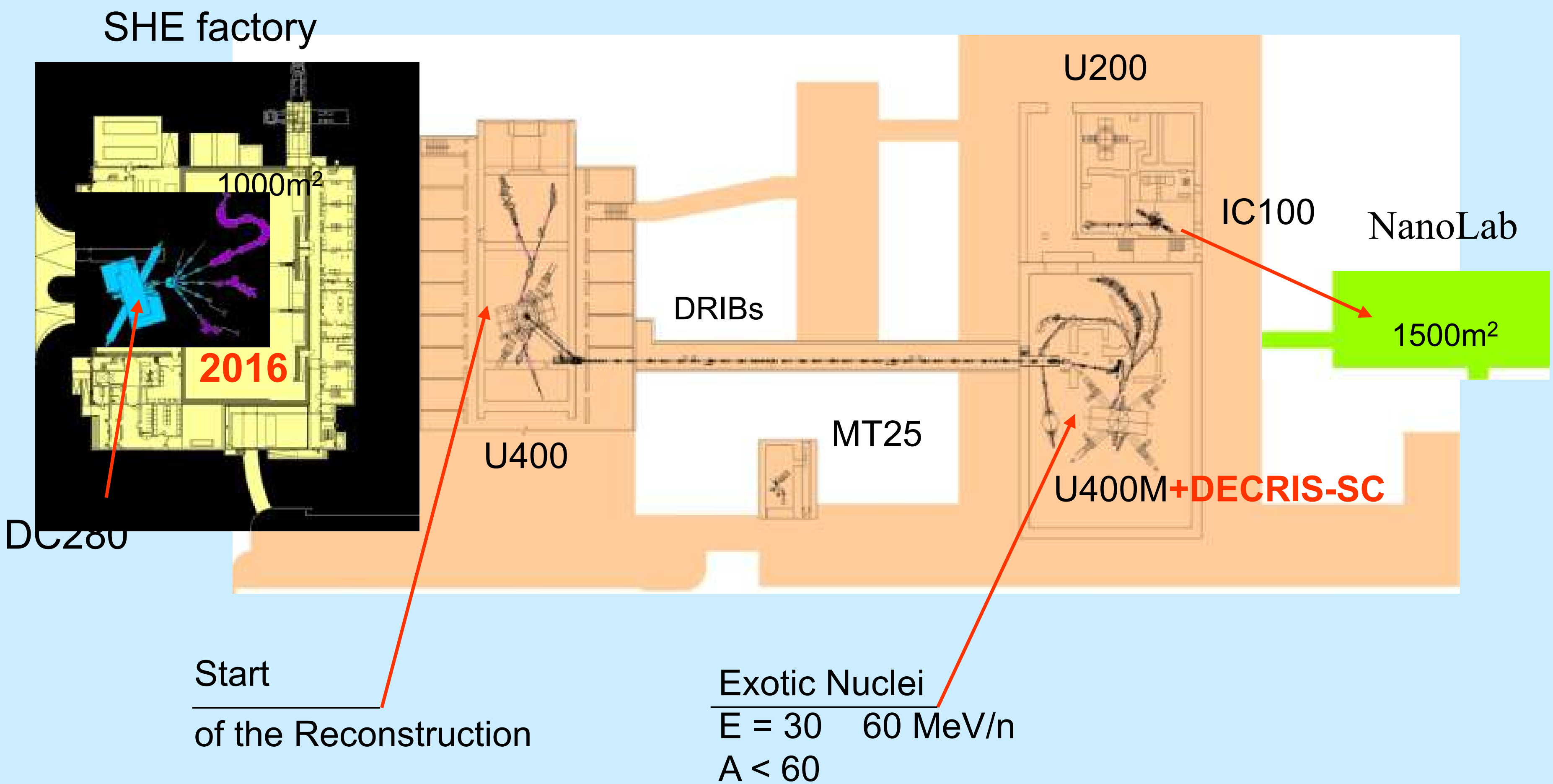


Временное распределение плотности частиц в медианной плоскости

Калагин И.В.

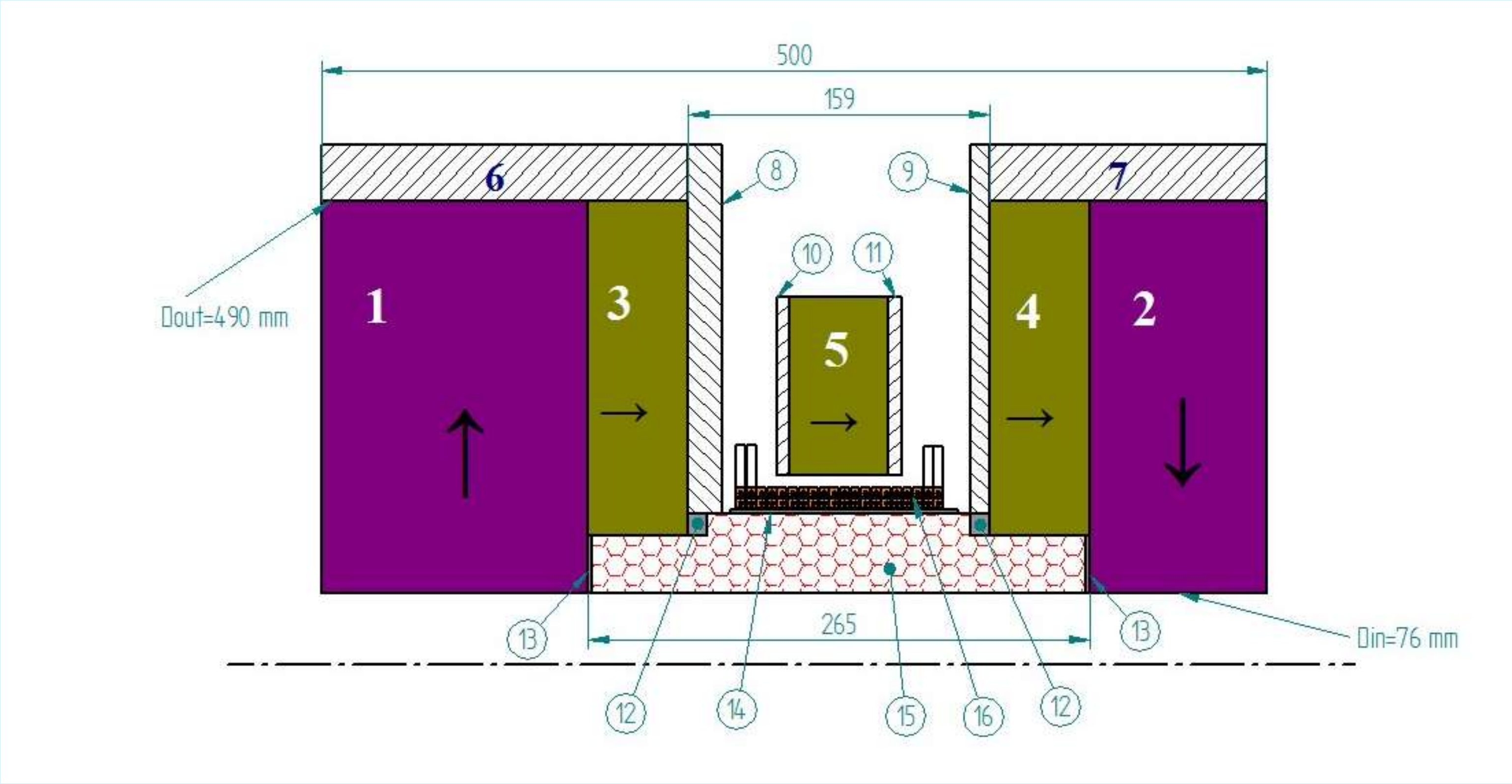
DC-280 Cyclotron

FLNR - 2015

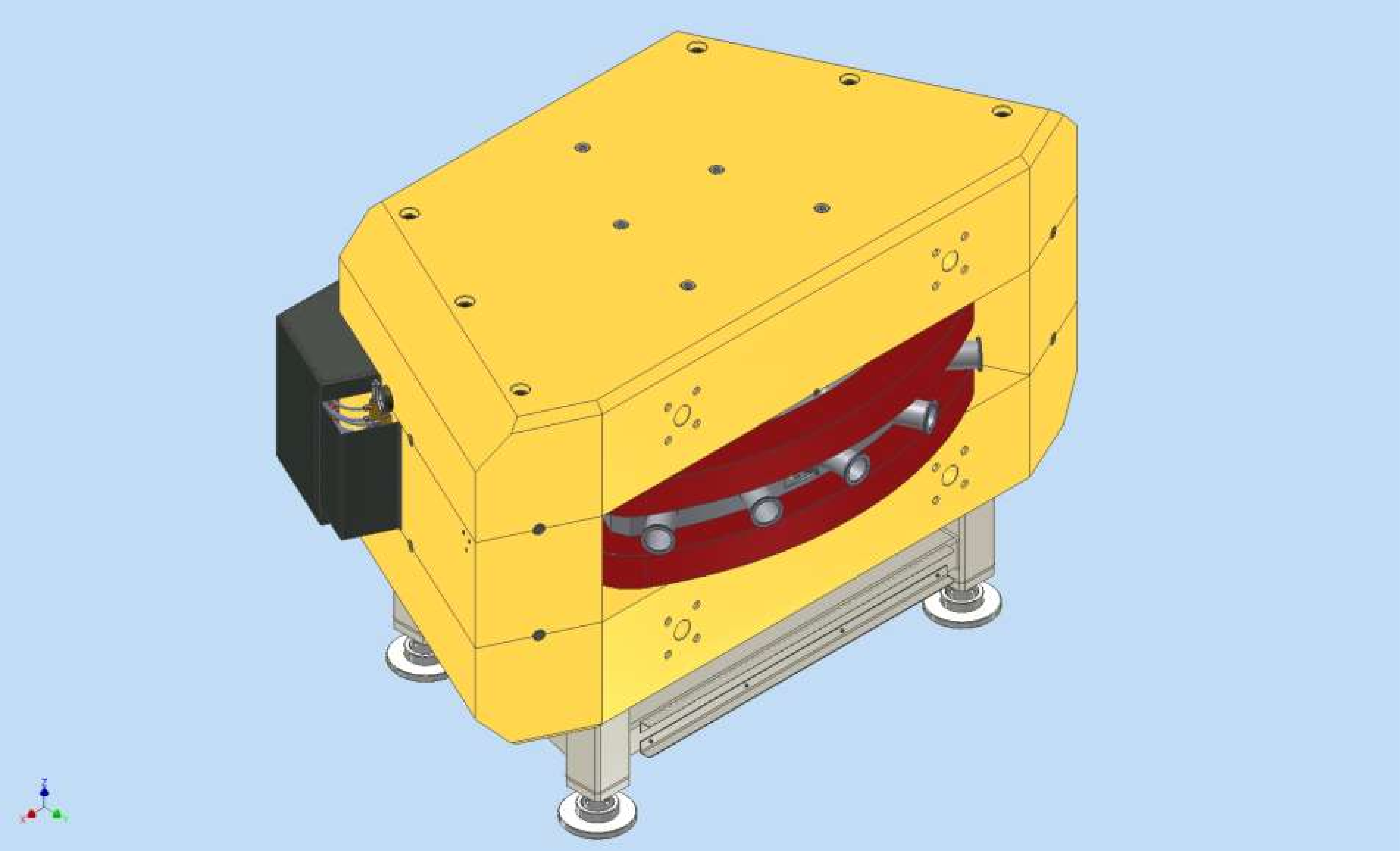


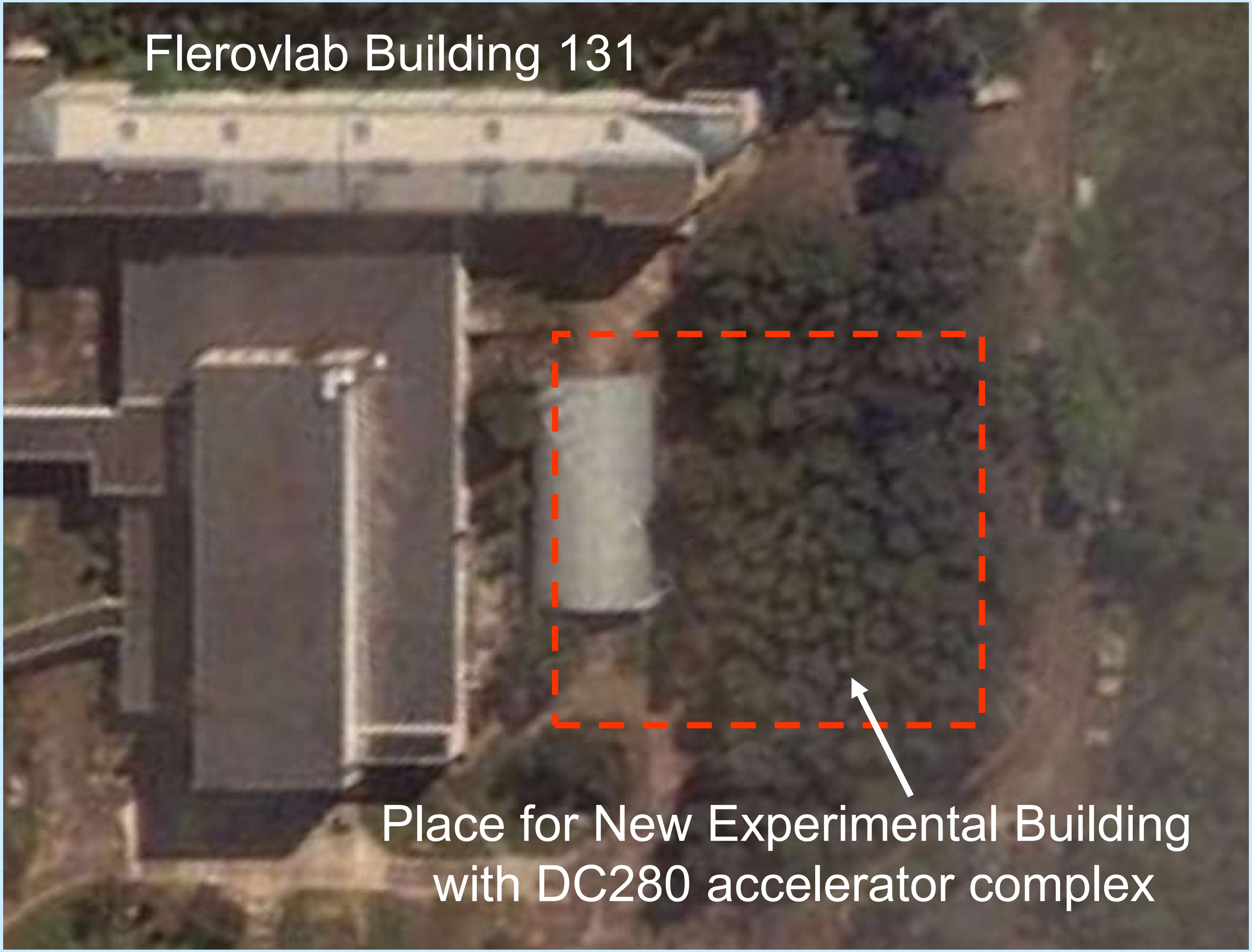
SHE factory
1000m²
2016
DC280
U400
DRIBs
MT25
U200
IC100
NanoLab
1500m²
U400M+DECRIS-SC
Start
of the Reconstruction
Exotic Nuclei
E = 30 60 MeV/n
A < 60

Magnetic structure of DECRIS-PM

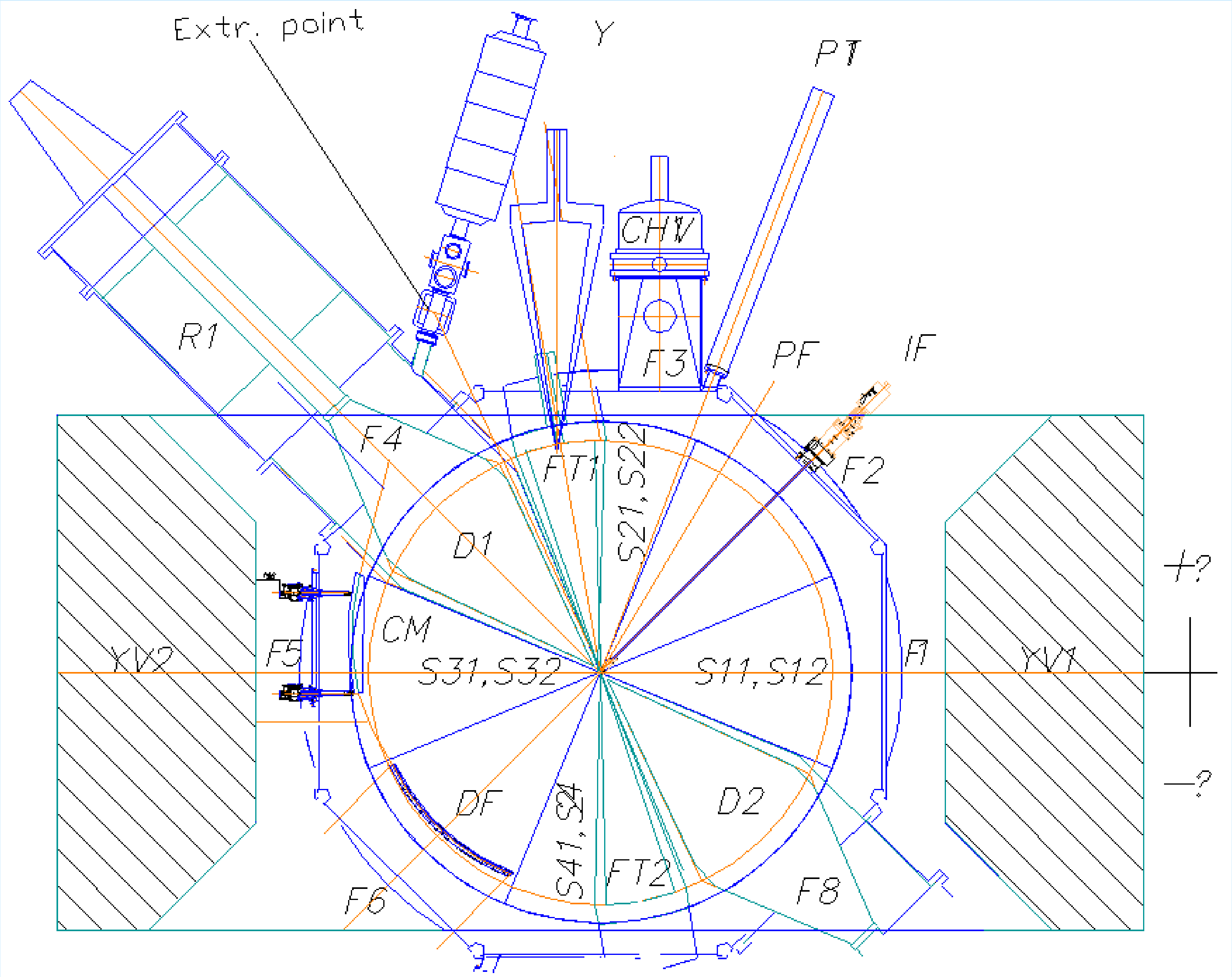


DC280. Swiching magnet TM 50




Flerovlab Building 131
Place for New Experimental Building
with DC280 accelerator complex

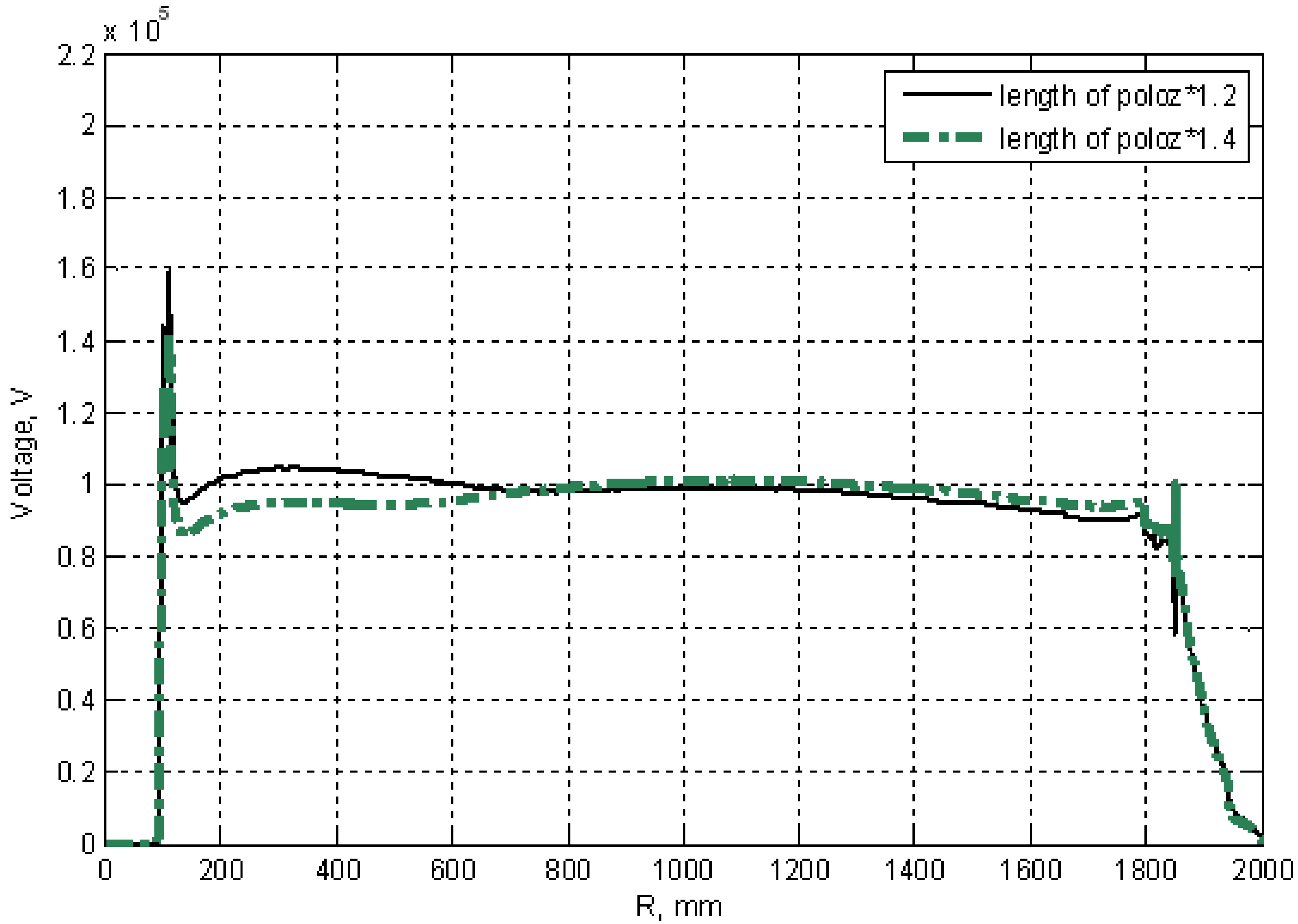
DC280 Plan Lay-out



SCHEDULE OF THE SHE FACTORY CREATION

	2011	2012	2013	2014	2015	2016
Experimental Building						
Cyclotron DC 280						
Main magnet yoke creation						
Equipment creation, completion.						
Assembling, testing						
First experiment						

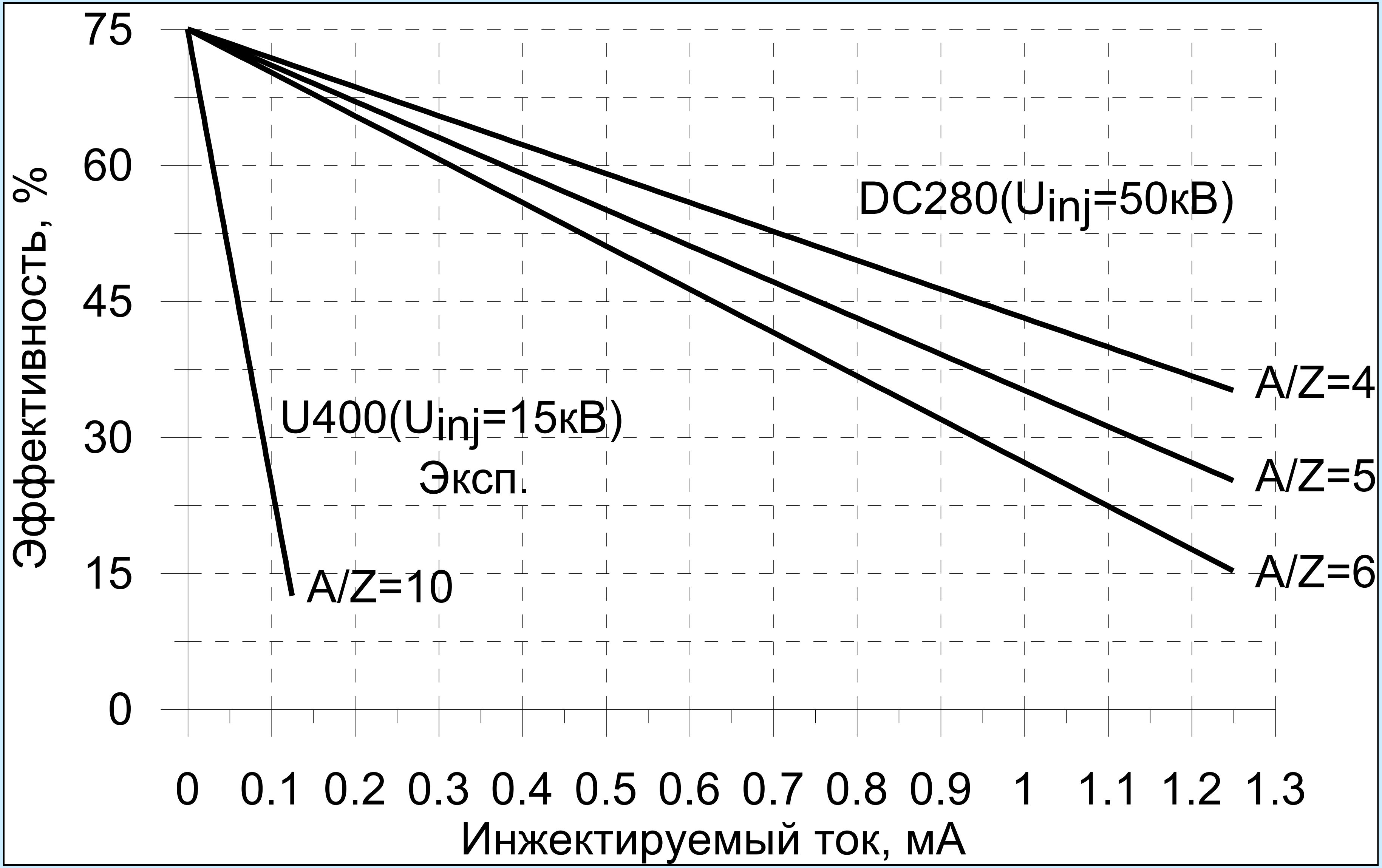
Flat-Top дуанты



Зависимость напряжения от радиуса

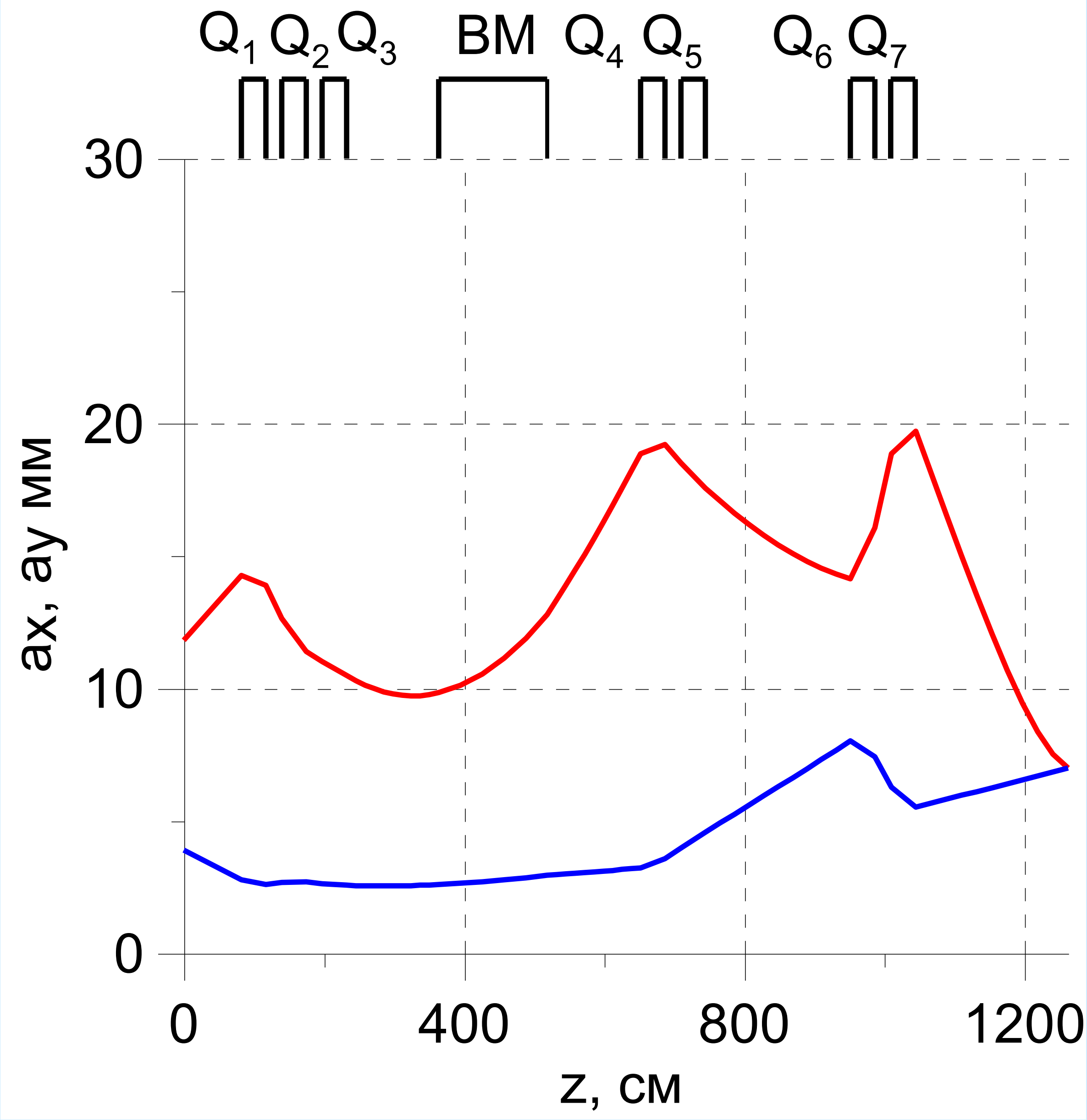
Карамышев О.В.

Эффективность ДЦ280



Казаринов Н.Ю.

Beam transport along channel №4



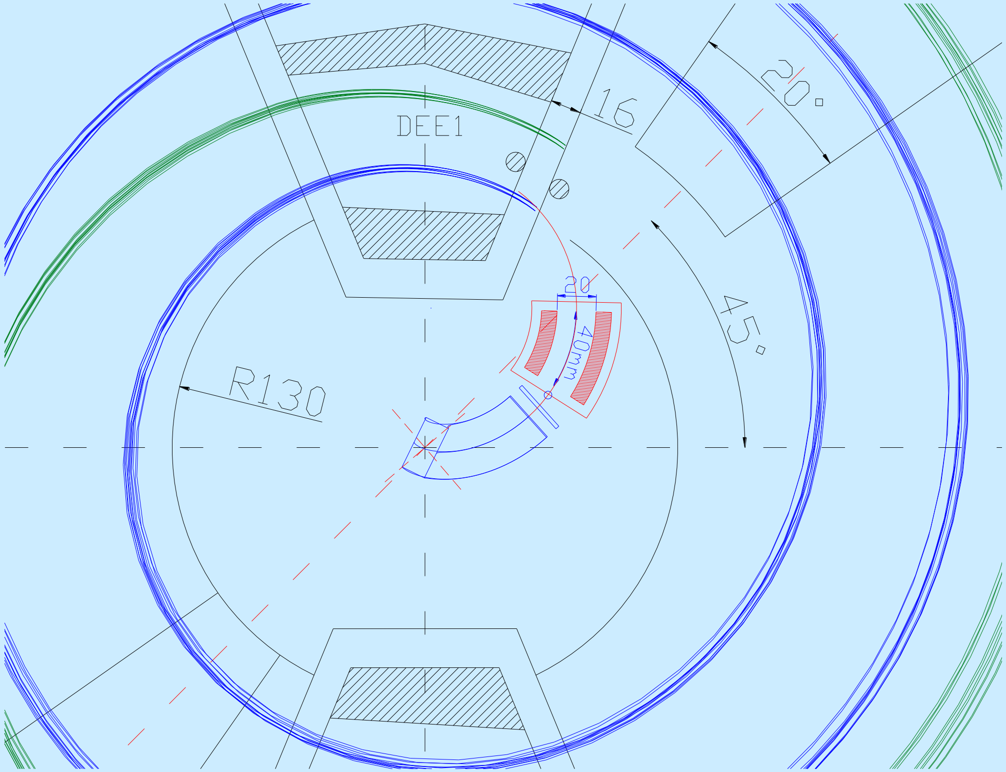
Казача В.И.

DC280

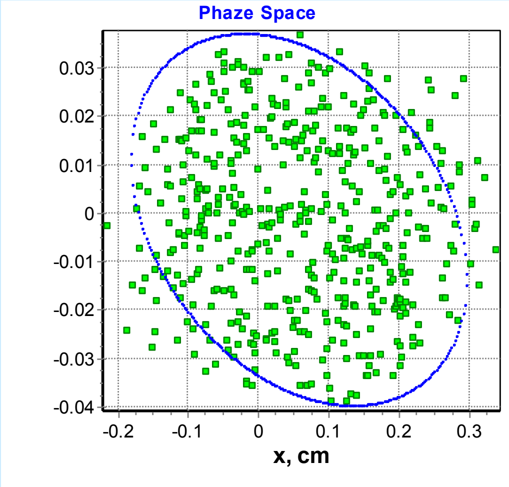
Main Parameters

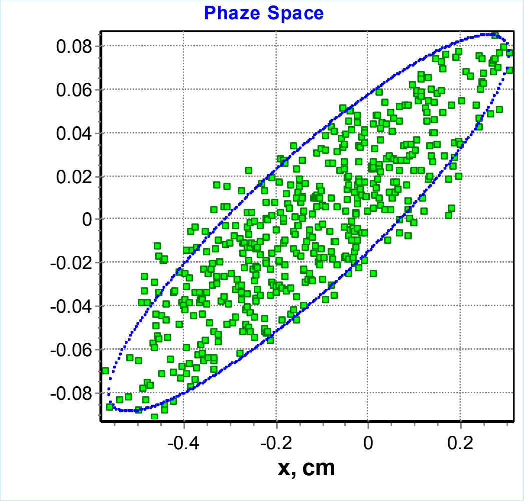
Ion source	DECRIS-4 - 14 GHz DECRIS-SC3 - 18 GHz
Injecting beam potential	Up to 100 kV
A/Z range	4 7
Energy	4÷8 MeV/n
Magnetic field level	0.6 1.35 T
K factor	280
Gap between plugs	400 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV

DC280 cyclotron central region



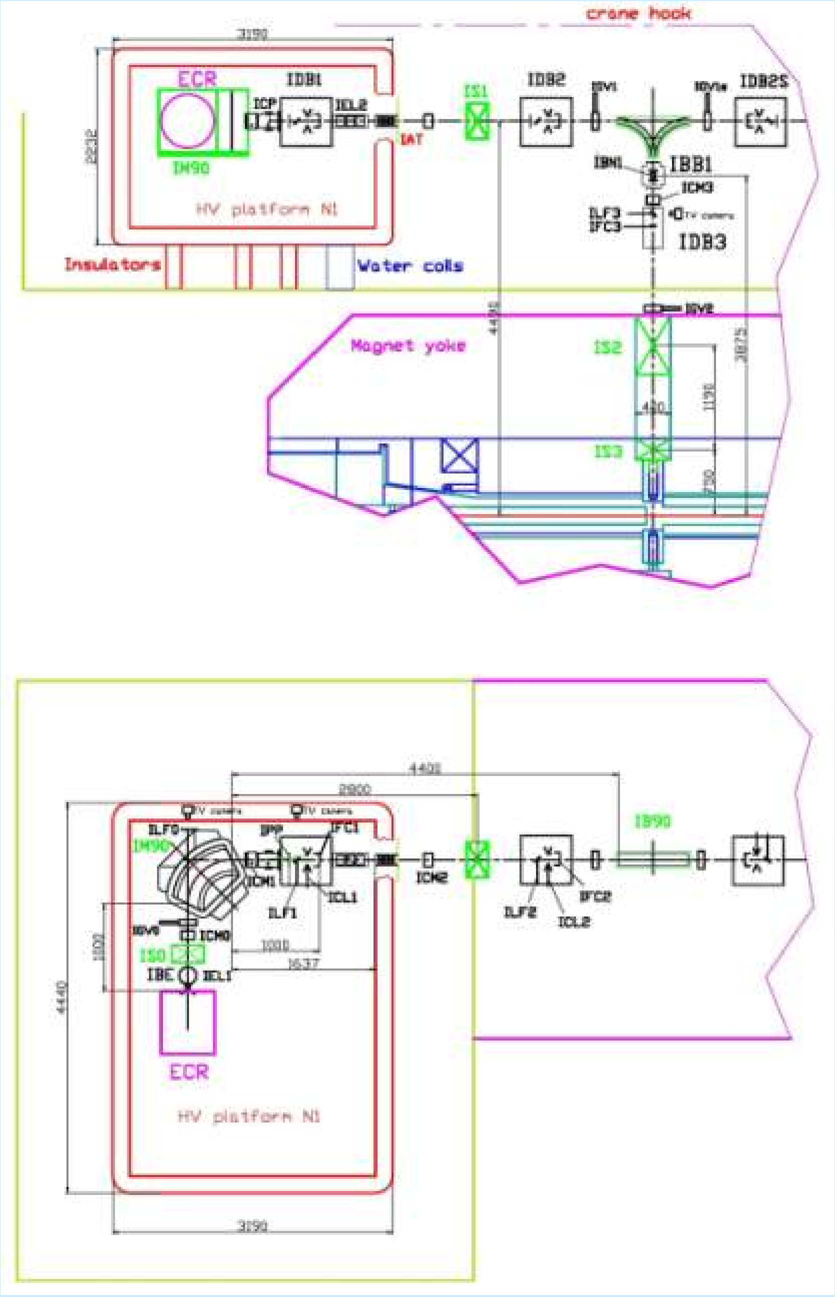
The view of DC280 cyclotron central region with inflector and quadrupole lens



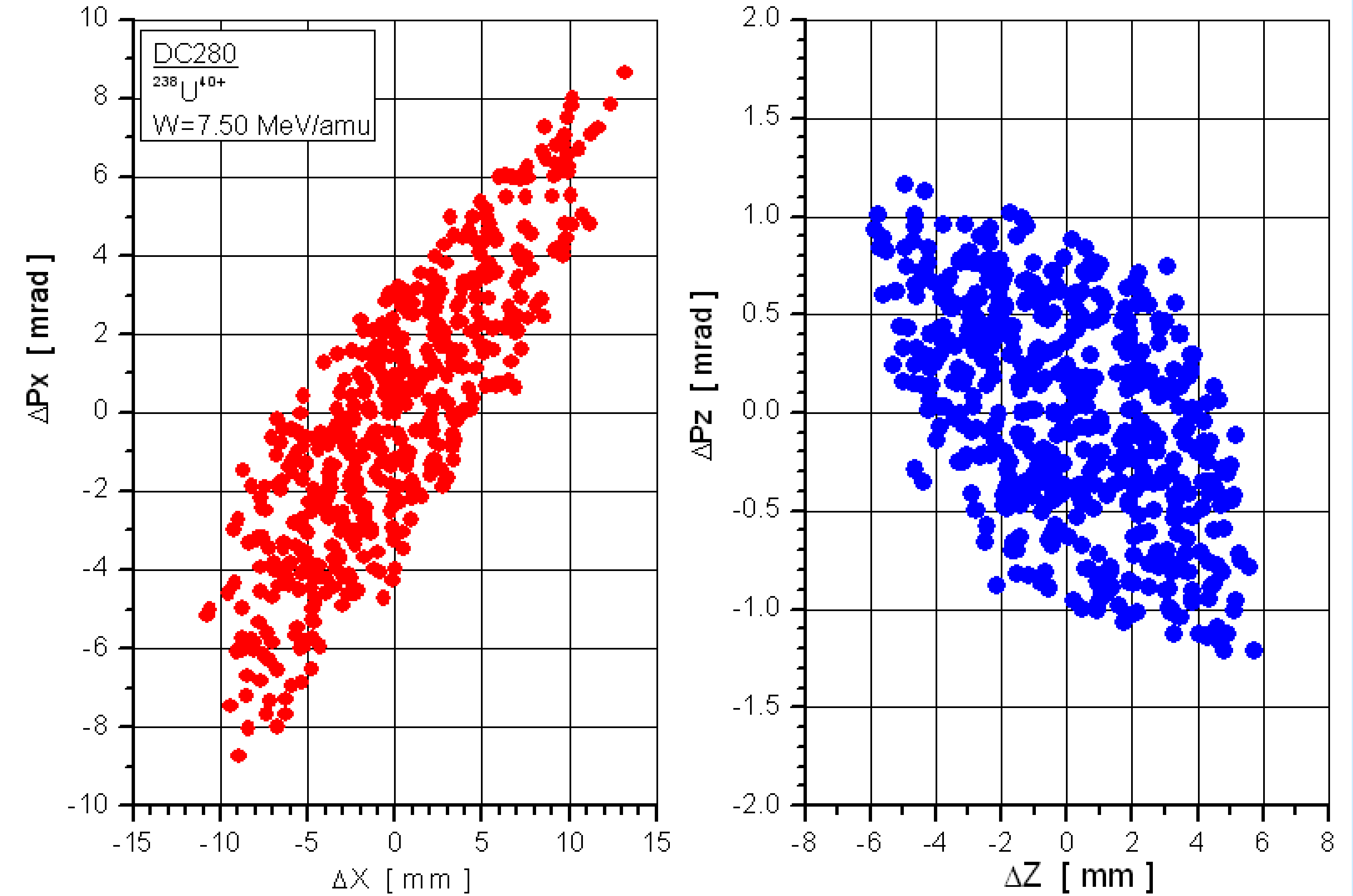


Radial and vertical emittances at the inflector exit

DC280. High voltage platform and axial injection system scheme



DC280. Emittances of the extracted beam



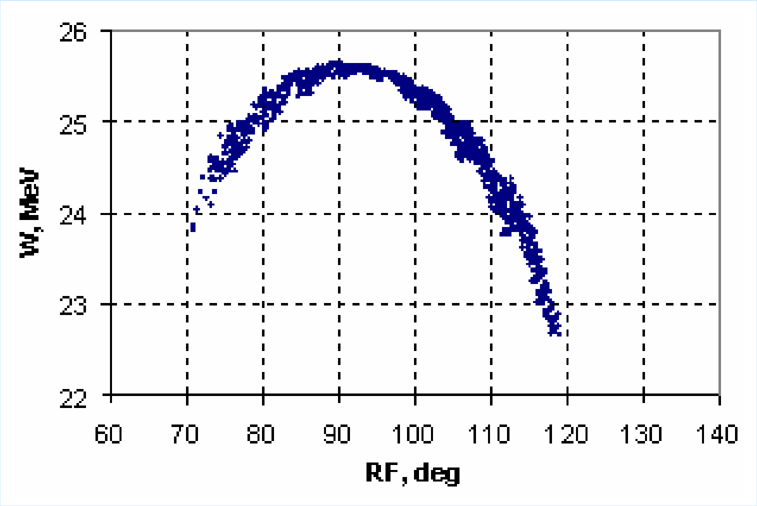
Эмиттансы пучка ионов $_{238}U^{40+}$ *с энергией 7.50 МэВ/н в конечной точке*

Борисов О.Н.

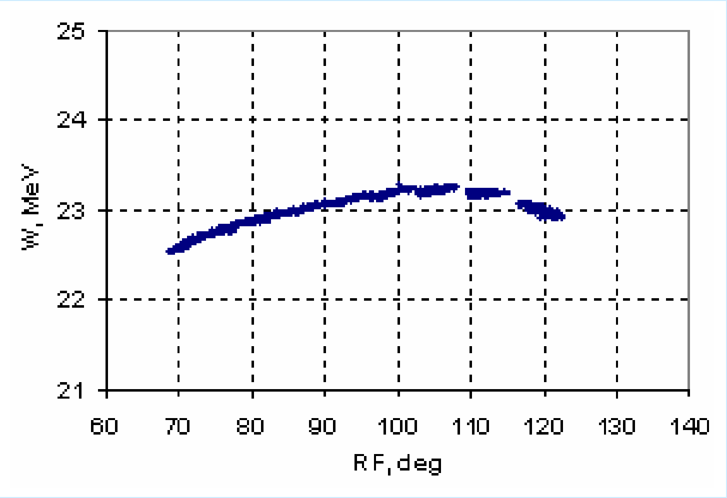
DC280. 90^{o} electrostatic axial injection bender model

POWER SUPPLIES OF MAGNETIC ELEMENTS

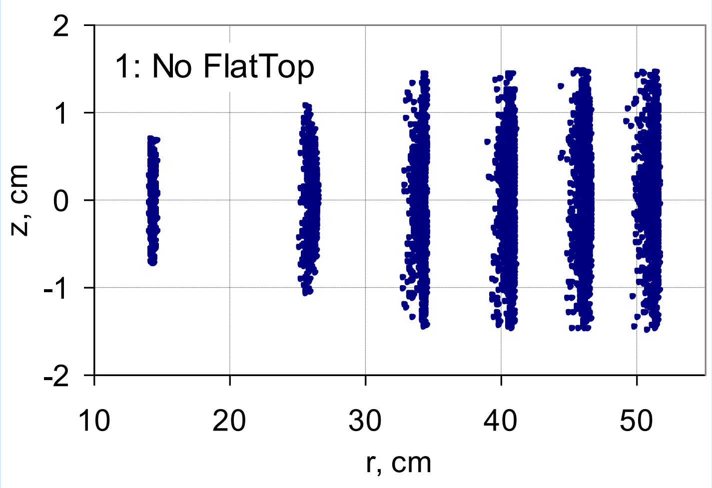
DC280 «FLAT-TOP» RF SYSTEM



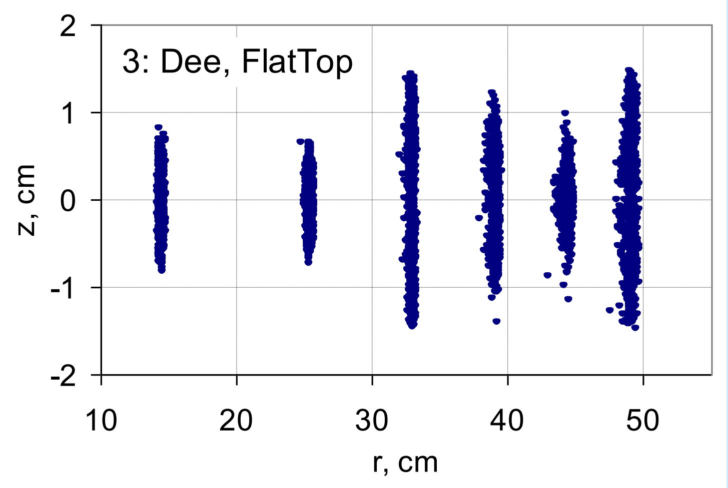
The beam energy spread at the 5-th orbit without «flat-top» RF system



The beam energy spread at the 5-th orbit with «flat-top» RF system

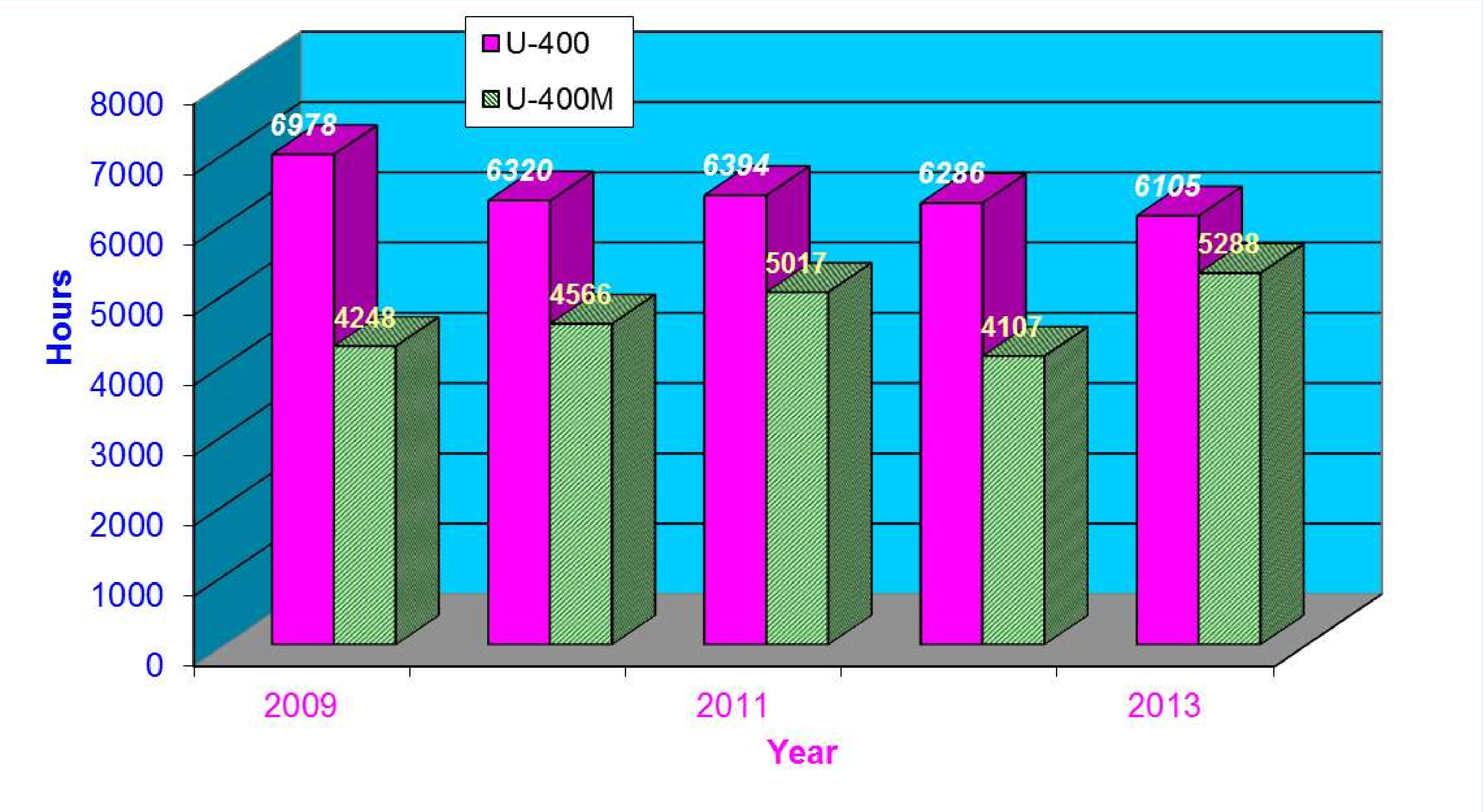


The beam transverse form for 5 initial orbits without «flat-top» system



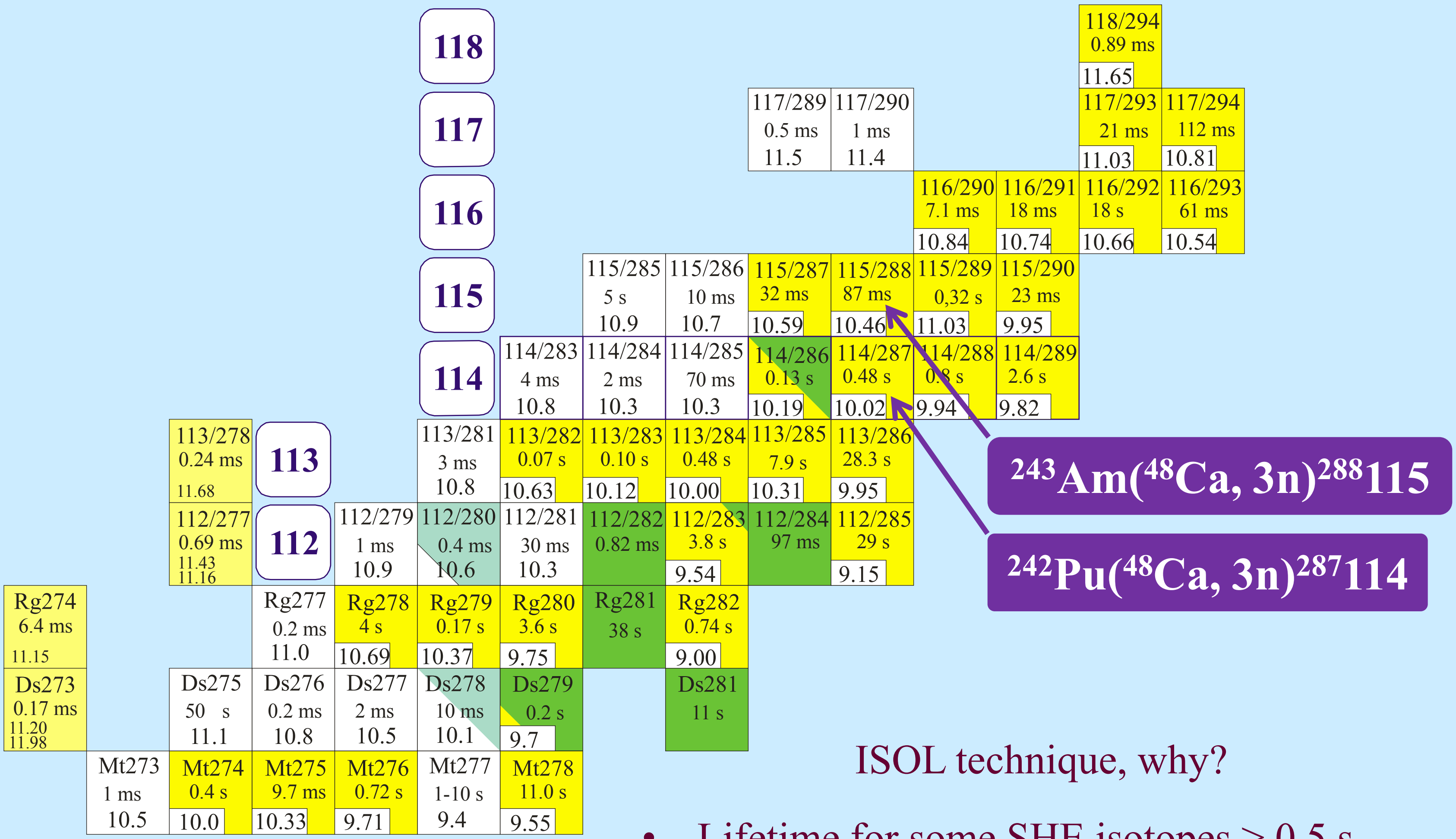
The beam transverse form for 5 initial orbits with «flat-top» system

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



Operation time of U-400 and U-400M accelerators in 2009-2013

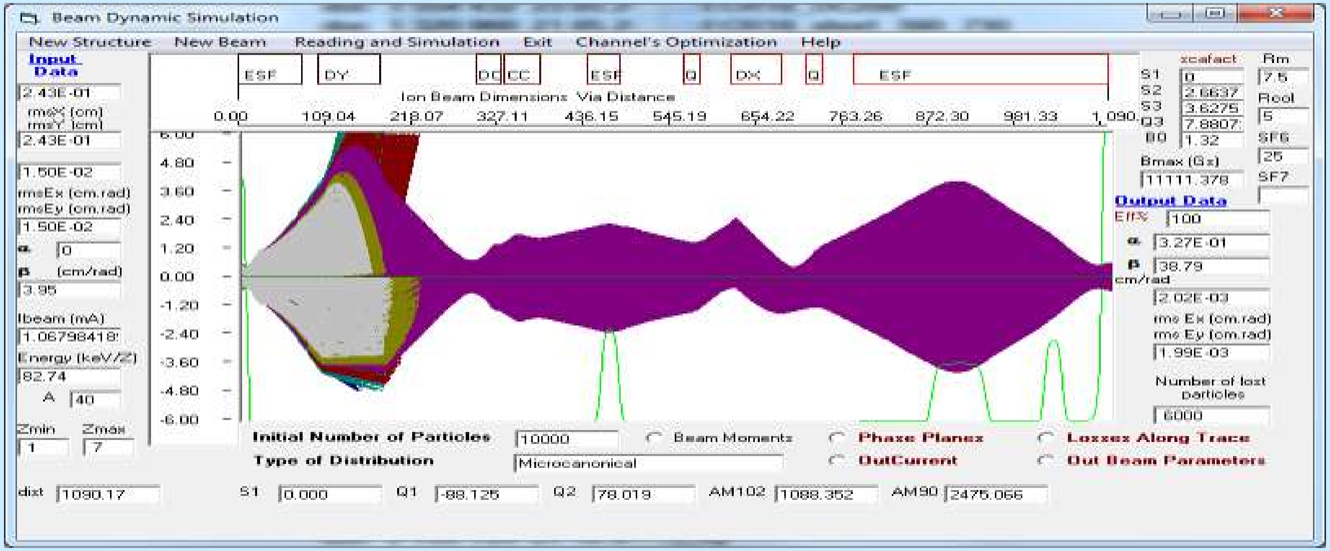
EXPERIMENTAL PROGRAM
for mass measurement of SHE



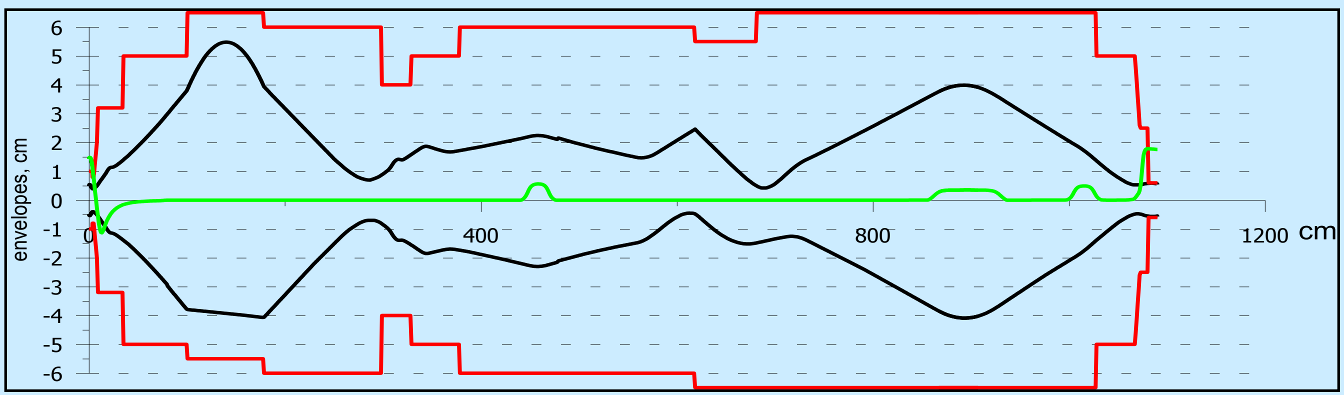
ISOL technique, why?

- Lifetime for some SHE isotopes > 0.5 s
- 112 and 114 elements have high volatility

DC280 axial injection beam line



Particle trajectories



Horizontal (upper curve), vertical (lower curve) Ar^{7+} beam envelopes
Longitudinal magnetic field – green line, apertures – red line

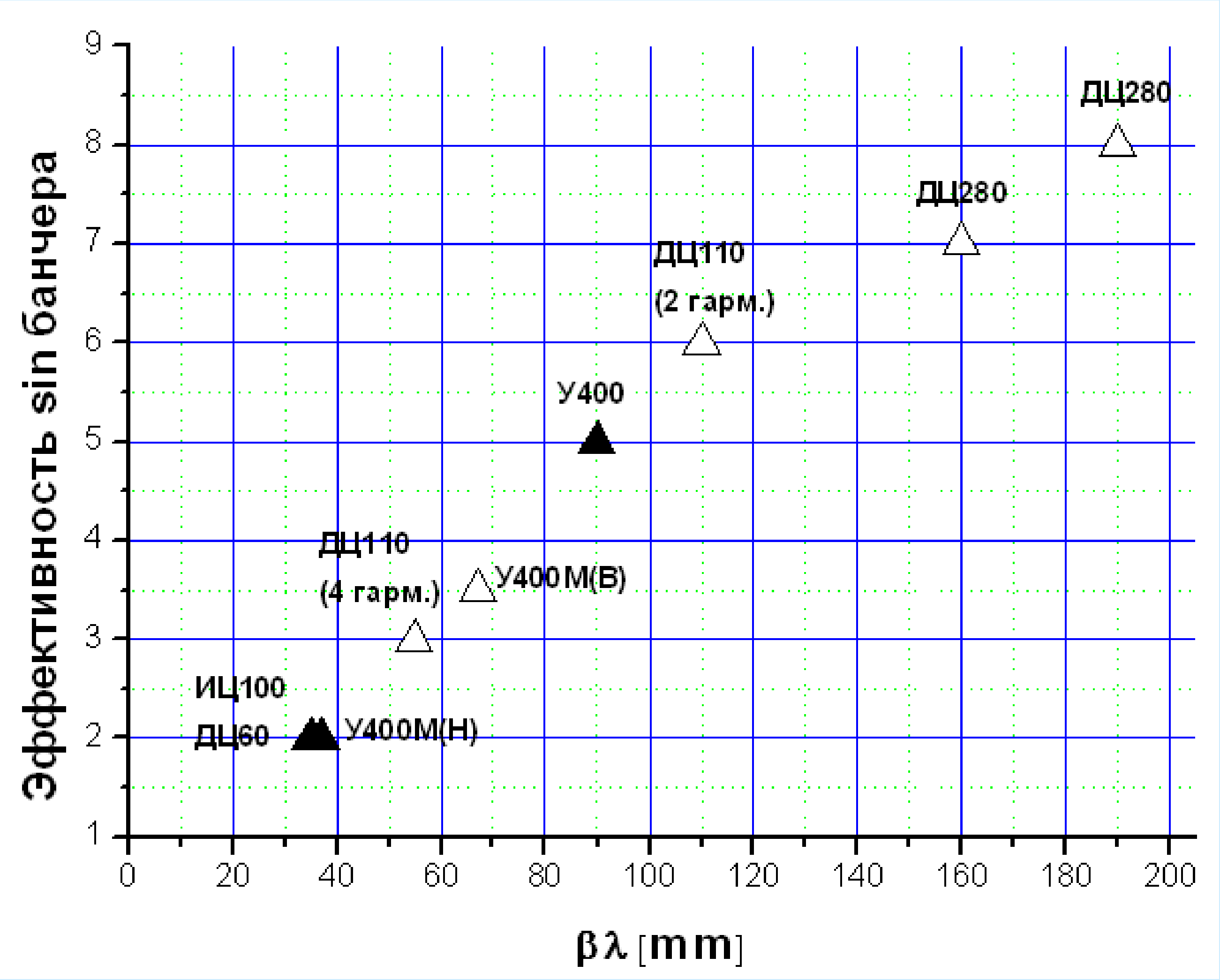
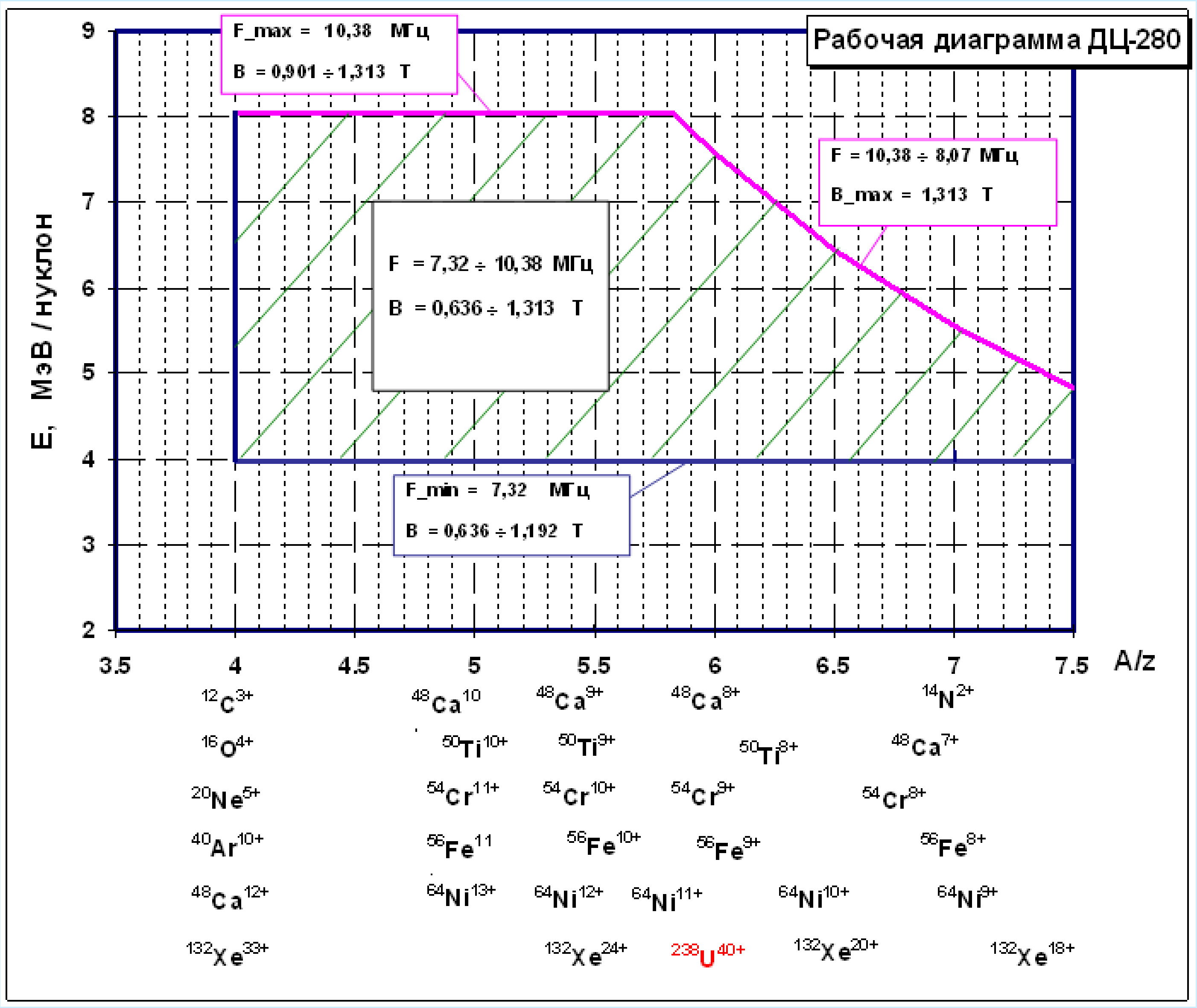


Рис.3. Предполагаемая зависимость эффективности синусного банчера от βλ инжектируемого пучка тяжелых ионов в циклотроны ЛЯР при оптимальном расположении банчера

▲ -экспериментальные данные

Δ- ожидаемые точки

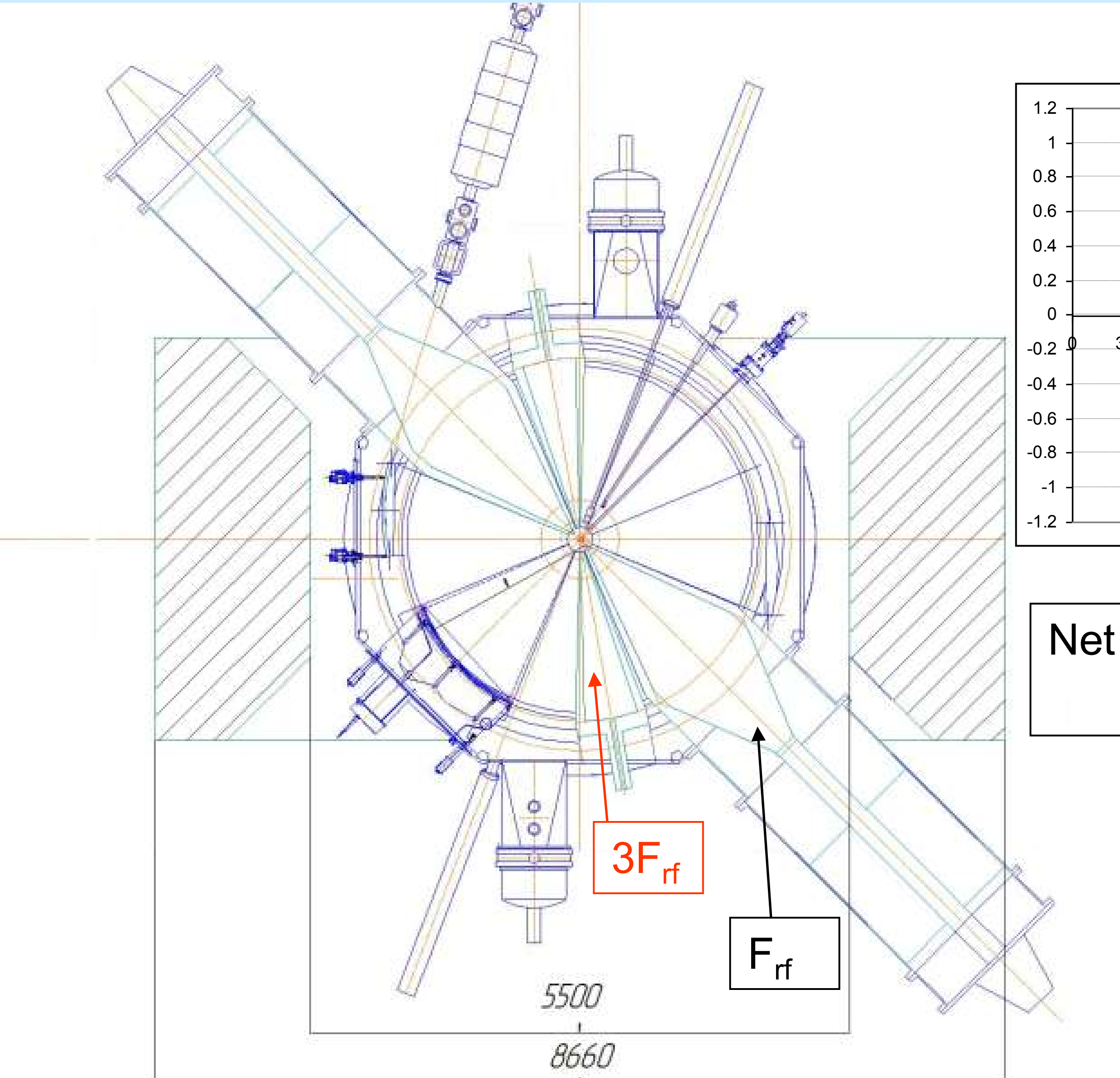
Гульбекян Г.Г.

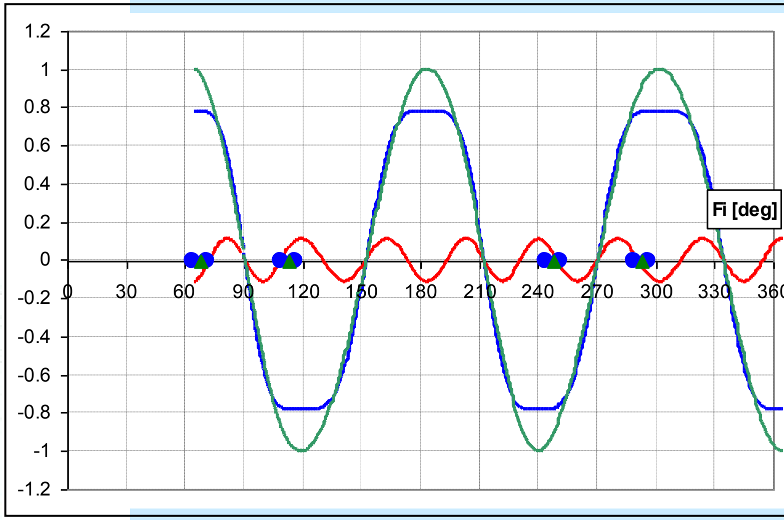


Рабочая диаграмма режимов ускорения ионов на циклотроне ДЦ-280
(на 3-й гармонике ВЧ)

Тихомиров А.В.

Flat-Top system





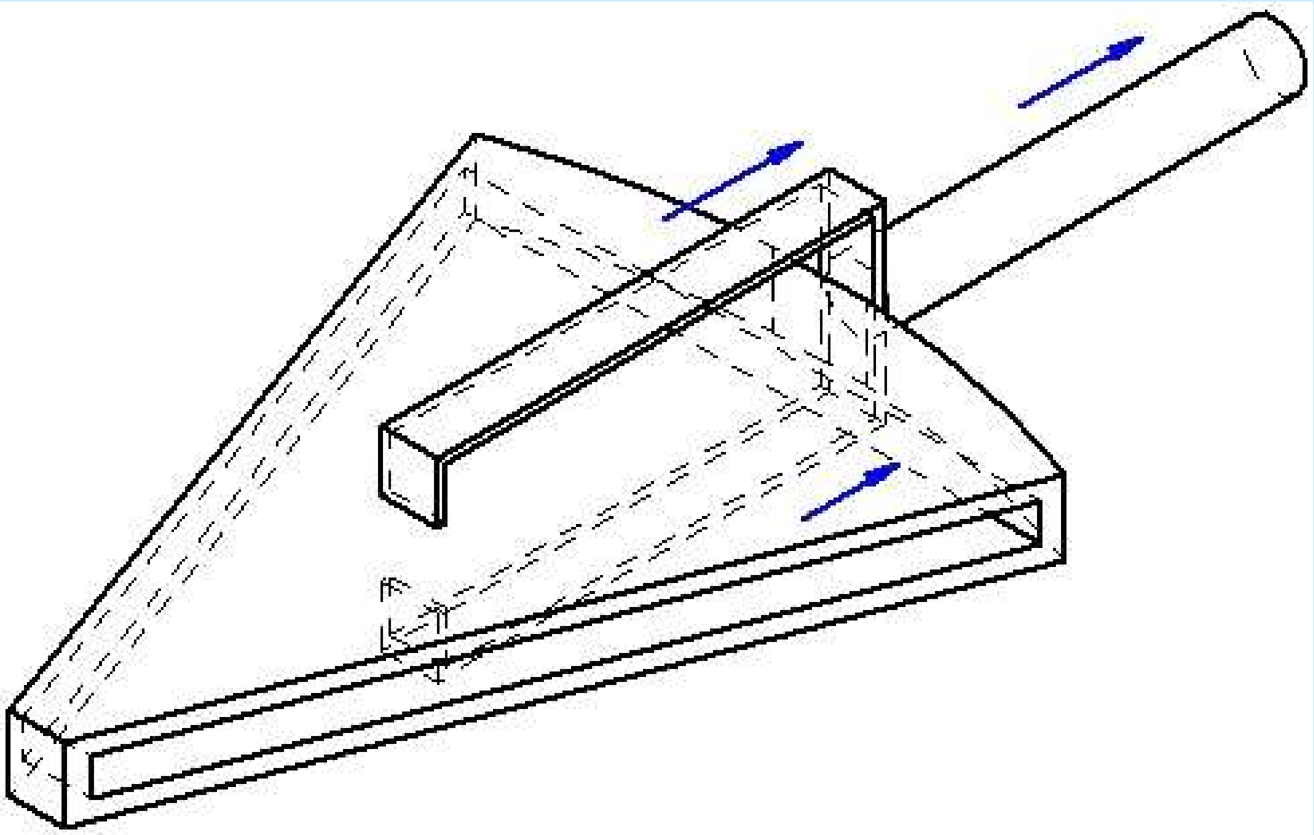
Net effect $A_1 Sin(\omega_{rf}\ t) + A_2 Sin(3\omega_{rf}\ t)$

$A_2 \approx 0.1 \cdot A_1$

Синтез структуры «Flat-Top» резонатора

Рис. 5

Эскиз финальной геометрии « Flat-Top» резонатора



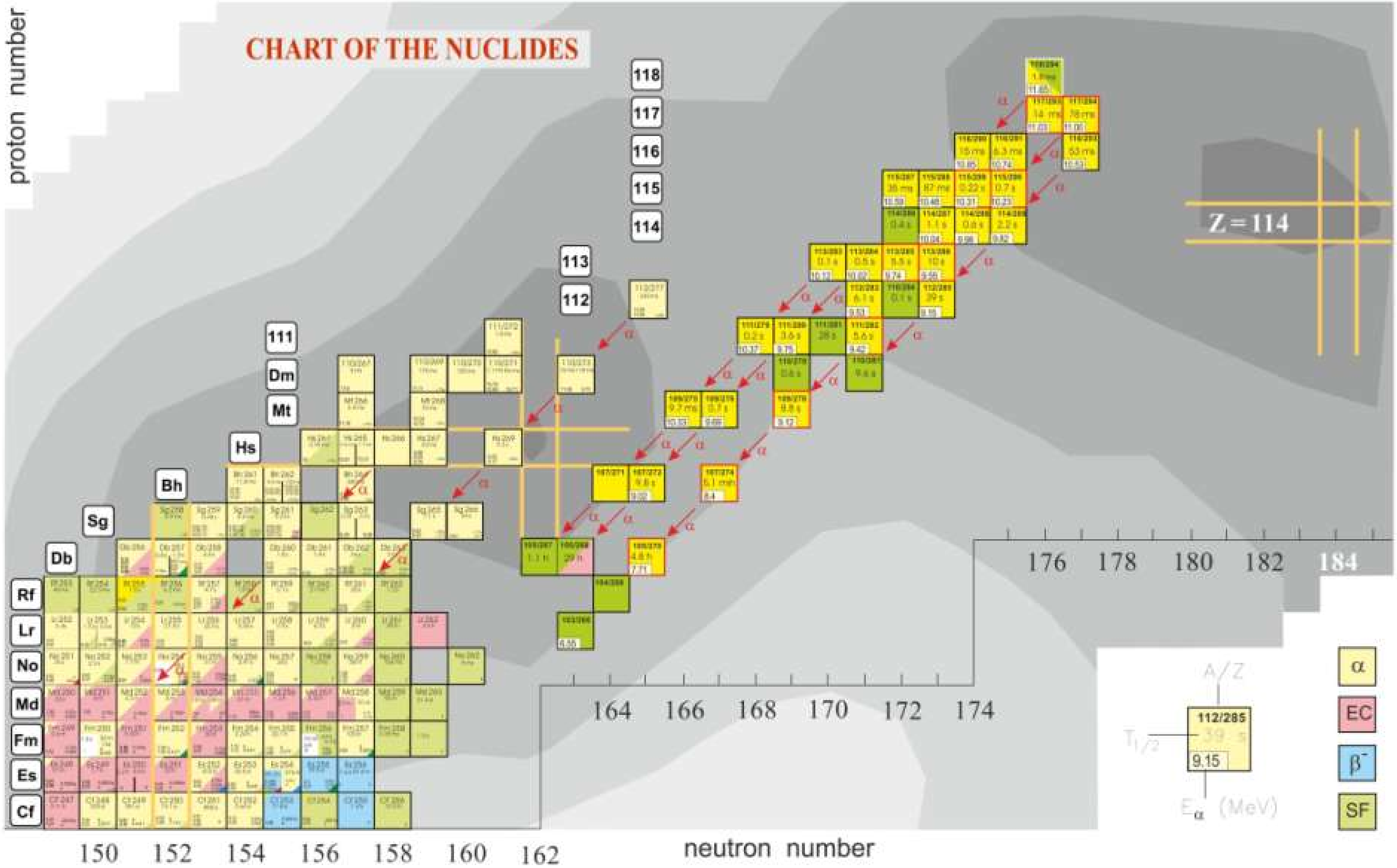
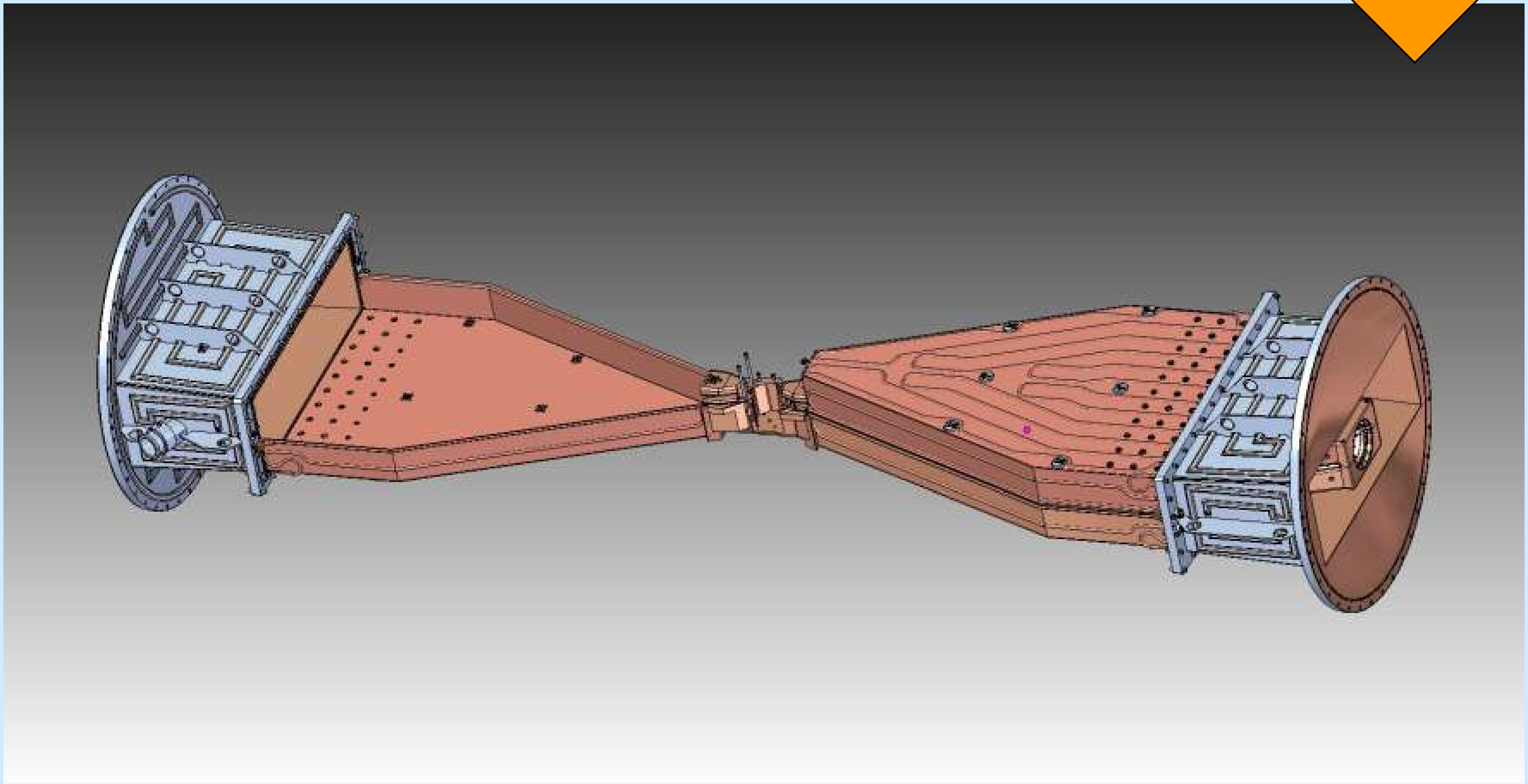


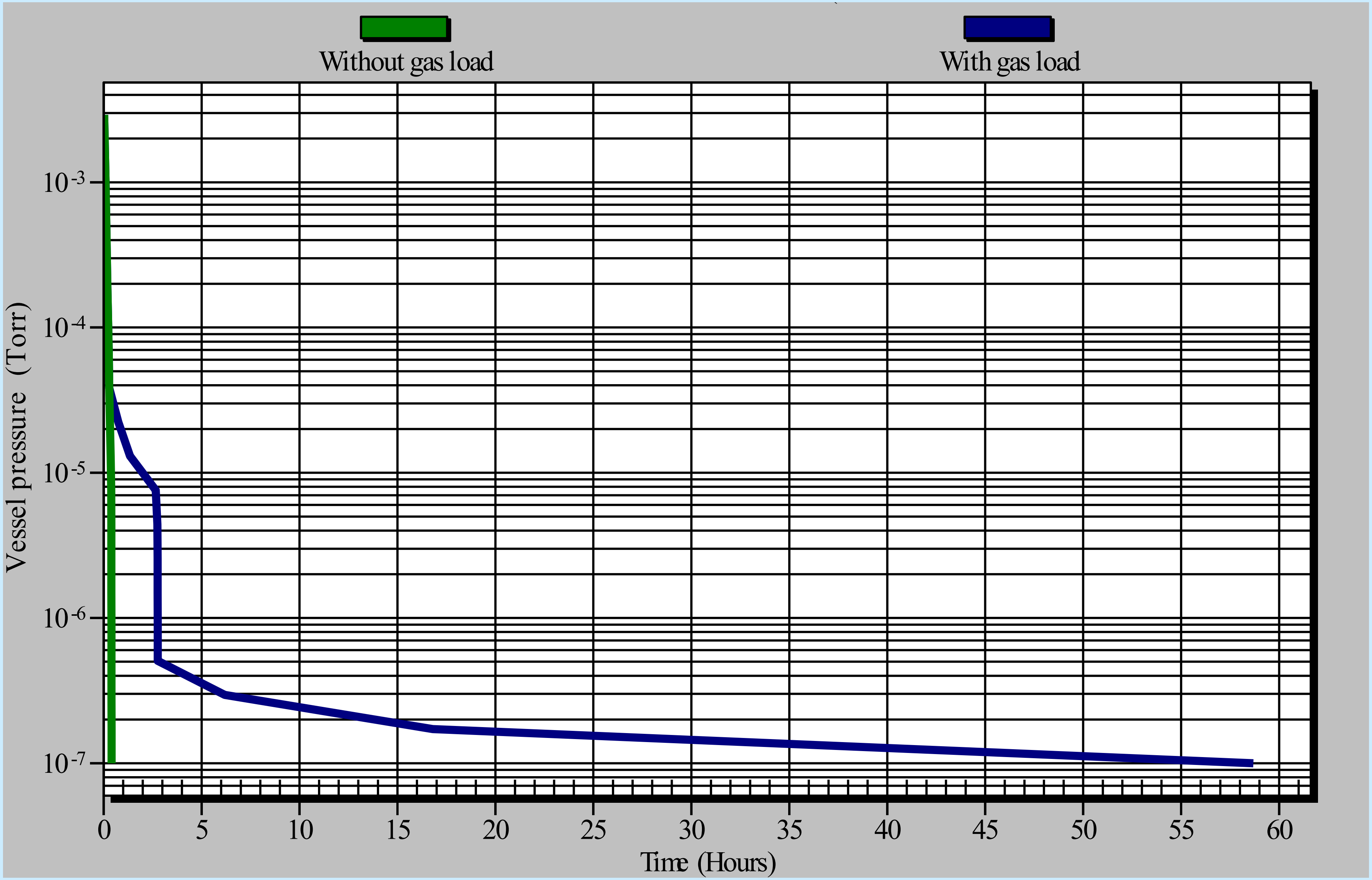
CHART OF THE NUCLIDES
proton number
neutron number
Z = 114
118
117
116
115
114
113
112
111
Dm
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
Md
Fm
Es
Cf
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
182
184
A/Z
112/285
$T_{1/2}$
9.15
E_{α} (MeV)
α
EC
β⁻
SF

DC280 . Intensity of some typical ion beams

20Ne	$1 \cdot 10^{14}$ pps
48Ca	$6 \cdot 10^{13}$ pps
50Ti	$3 \cdot 10^{13}$ pps
70Zn	$2{,}5 \cdot 10^{13}$ pps
86Kr	$3 \cdot 10^{13}$ pps
100Mo	$2 \cdot 10^{12}$ pps
124Sn	$2 \cdot 10^{12}$ pps
136Xe	$2 \cdot 10^{13}$ pps
208Pb	$1 \cdot 10^{12}$ pps
238U	$1 \cdot 10^{11}$ pps

Dee and ground plating

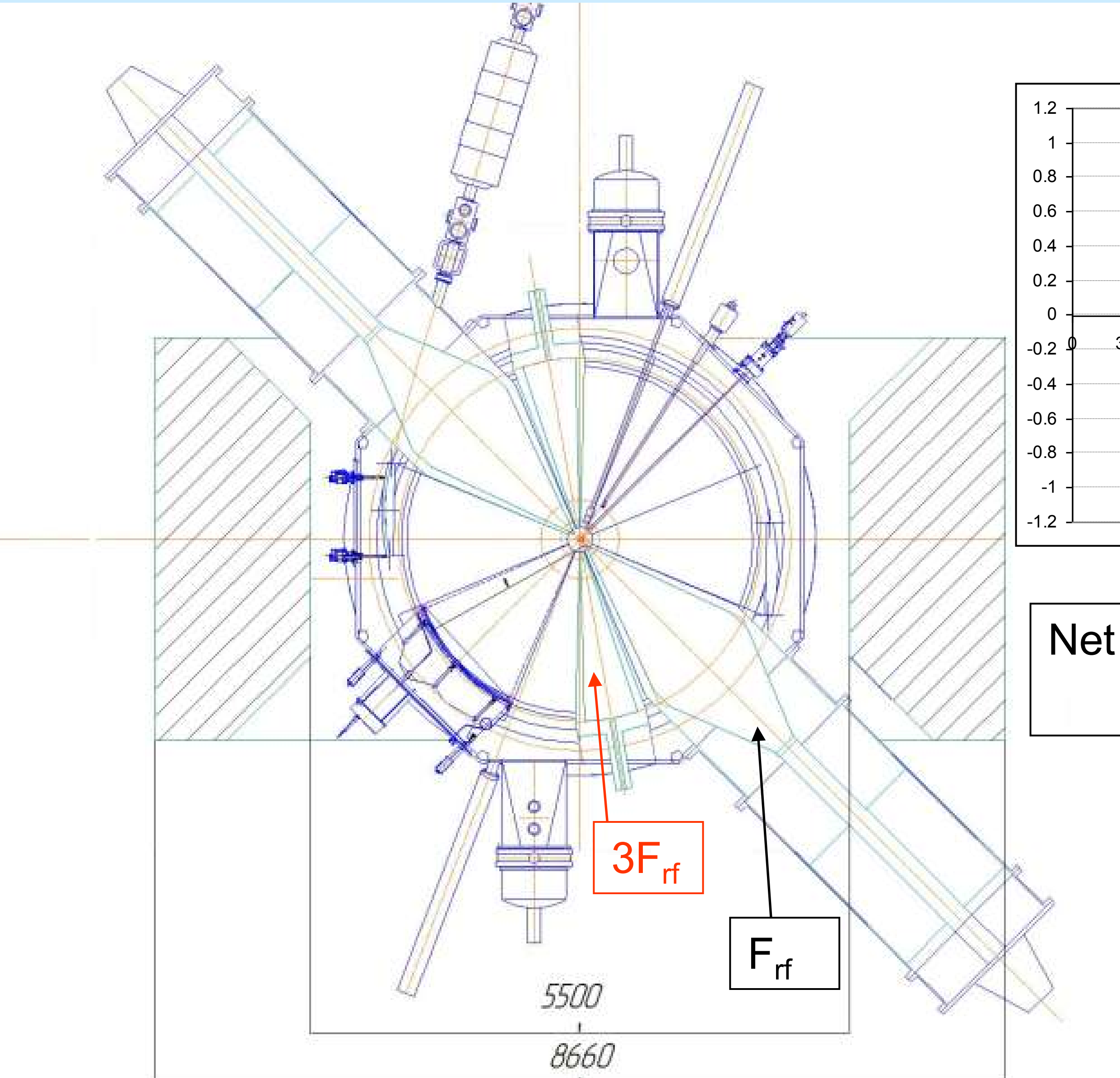


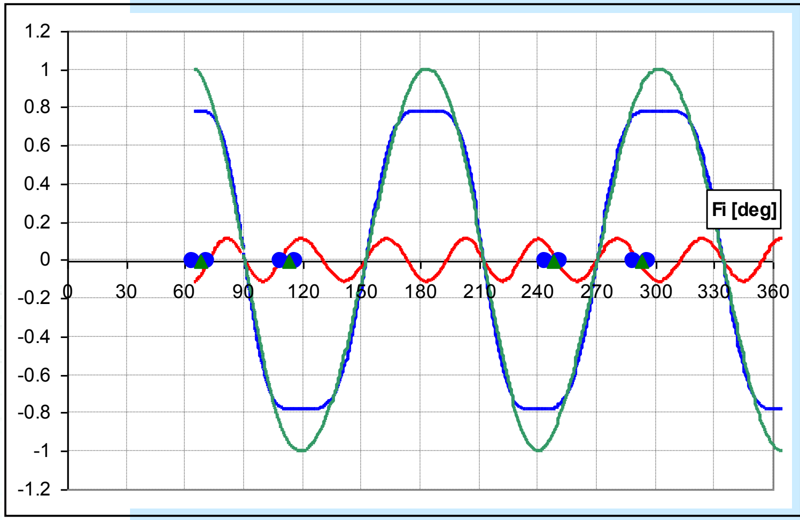


Without gas load
With gas load
Vessel pressure (Torr)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0 5 10 15 20 25 30 35 40 45 50 55 60
Time (Hours)

Хабаров М.В.

Flat-Top system

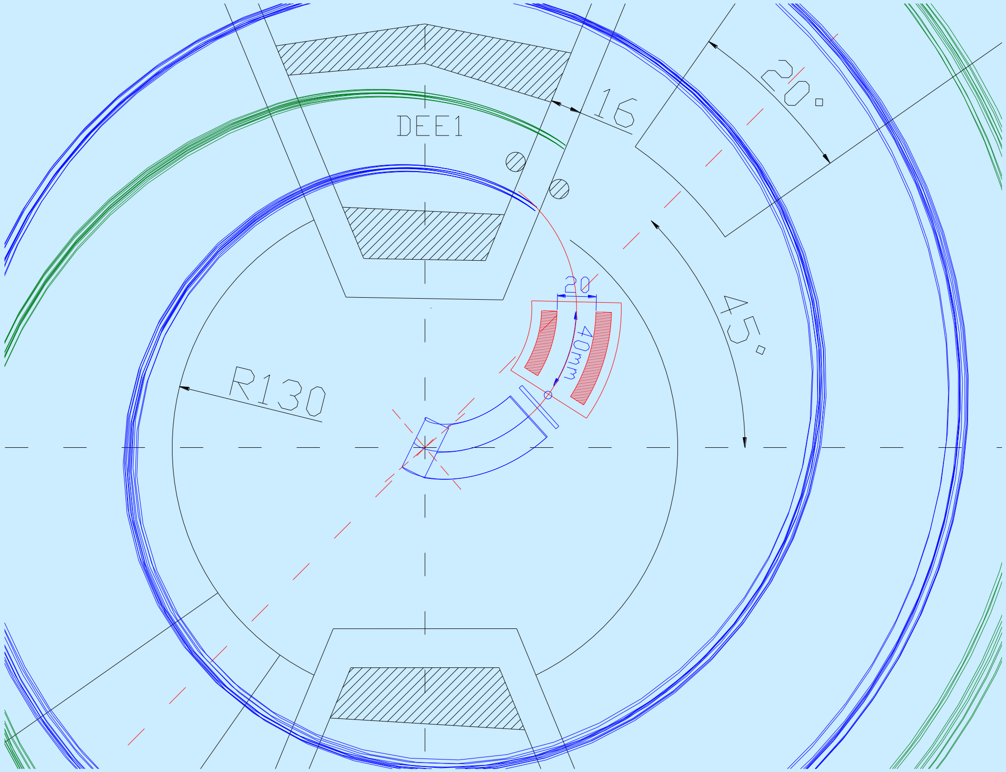




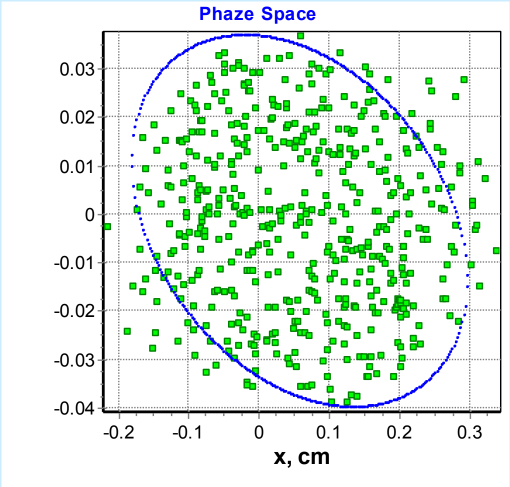
Net effect $A_1 Sin(\omega_{rf}\, t) + A_2 Sin(3\omega_{rf}\, t)$

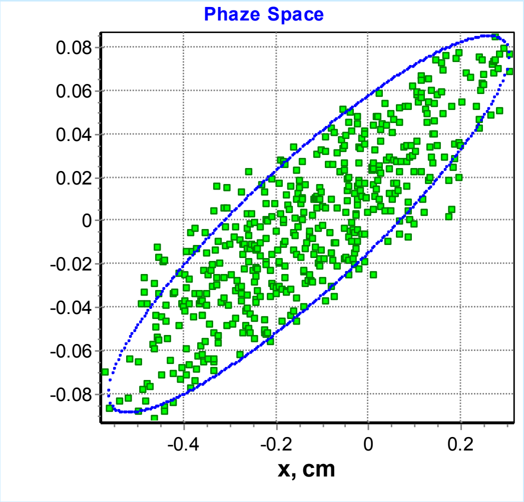
$A_2 \approx 0.1 \cdot A_1$

DC280 cyclotron central region



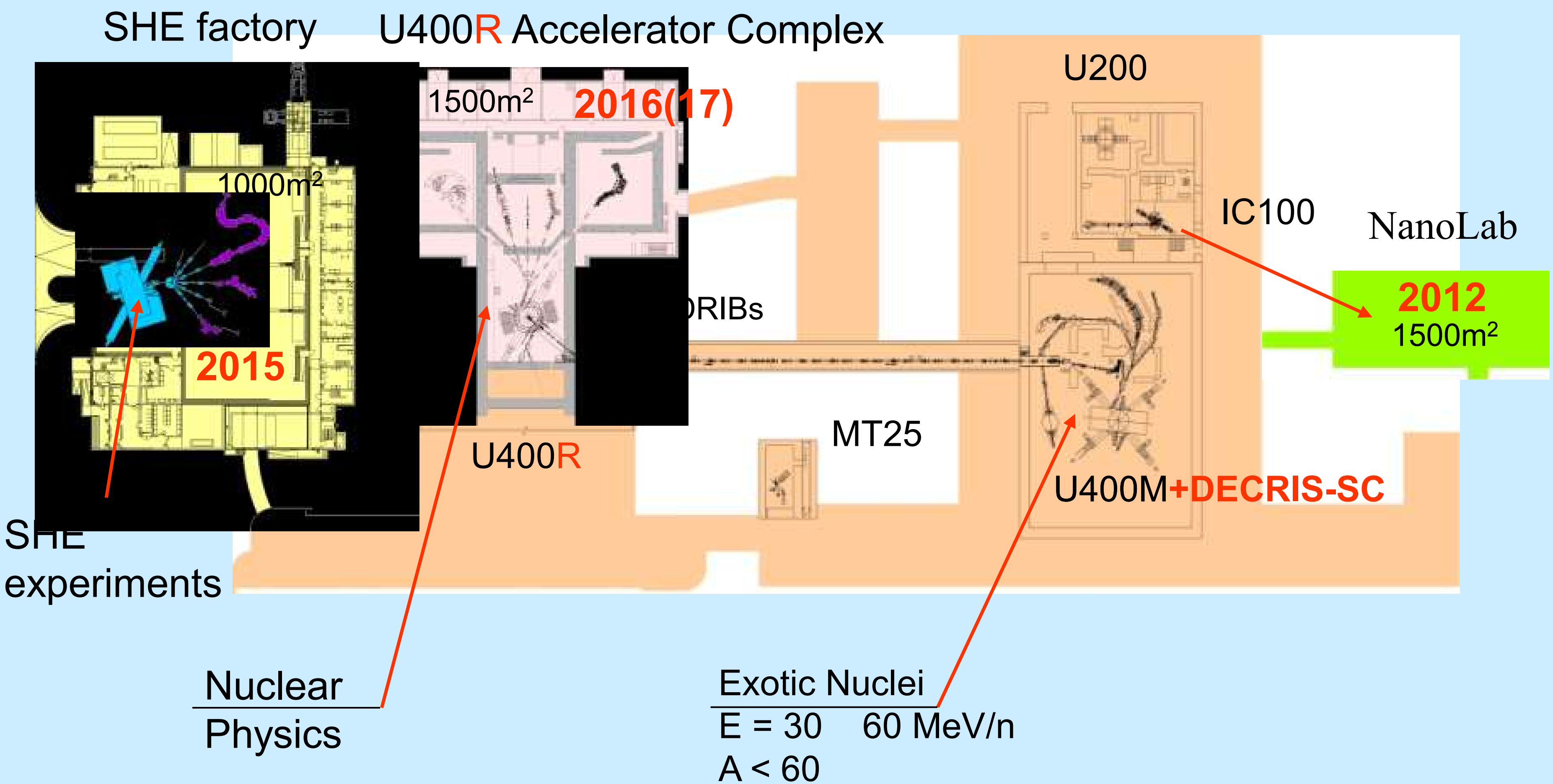
The view of DC280 cyclotron central region with inflector and quadrupole lens



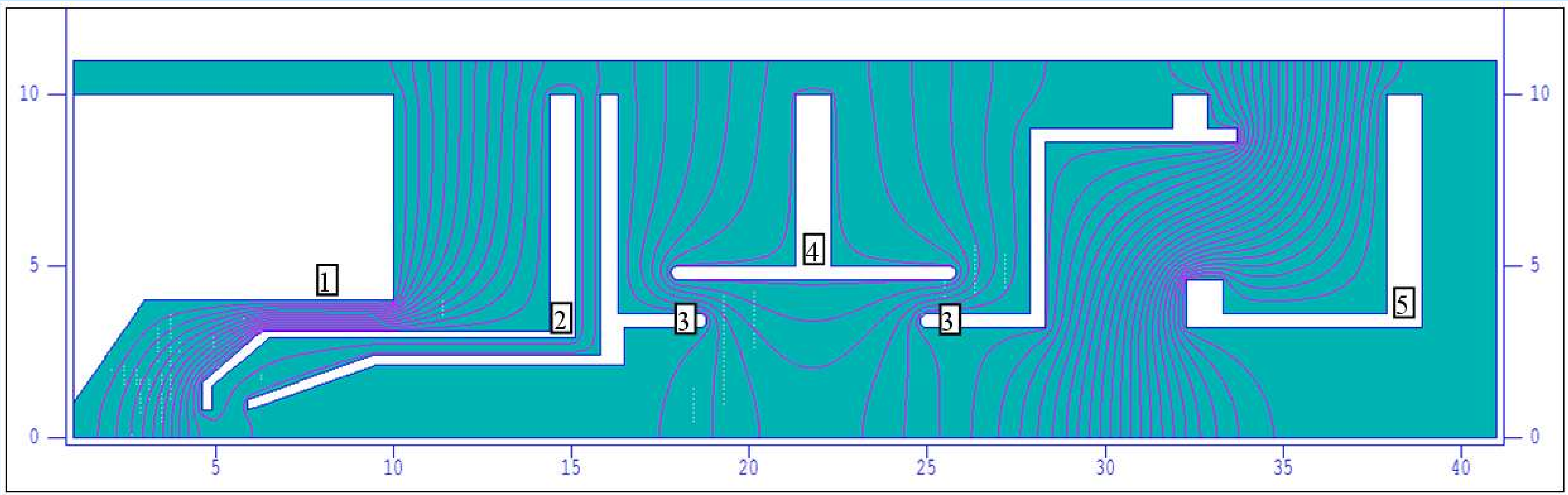


Radial and vertical emittances at the inflector exit

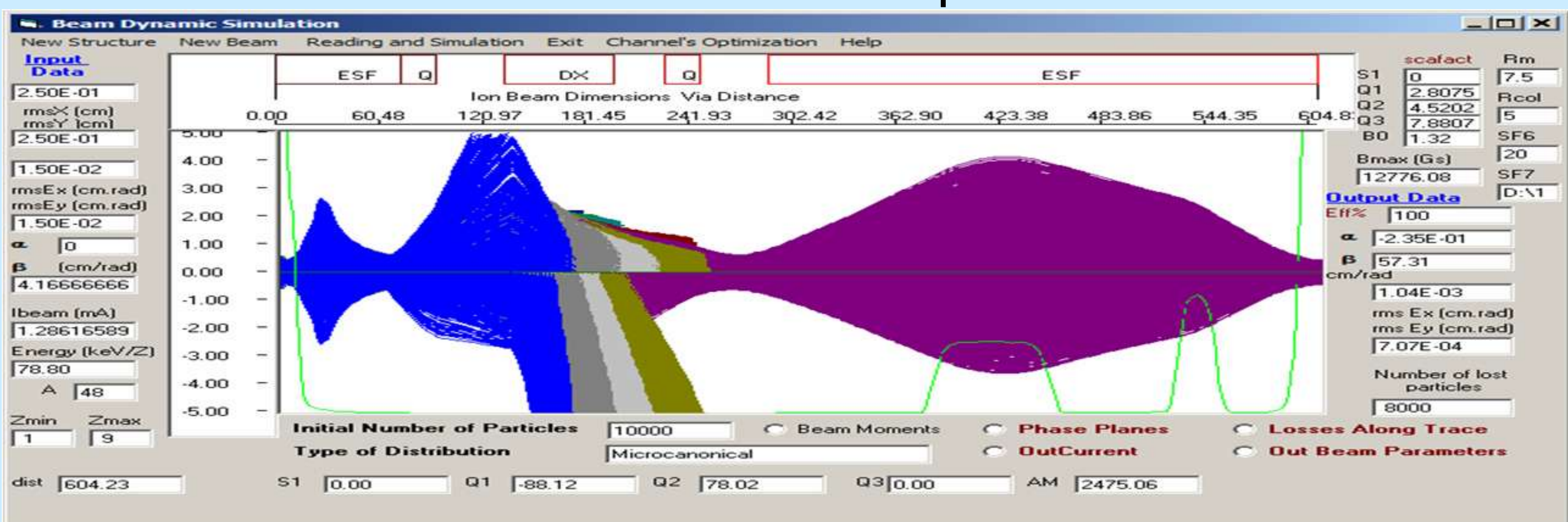
FLNR – 2016(17)


SHE factory
U400R Accelerator Complex
1500m²
2016(17)
1000m²
2015
U200
IC100
NanoLab
2012
1500m²
RIBs
MT25
U400R
U400M+DECRIS-SC
SHE
experiments
Nuclear
Physics
Exotic Nuclei
E = 30 60 MeV/n
A < 60

Model of ion beam extraction from ECR

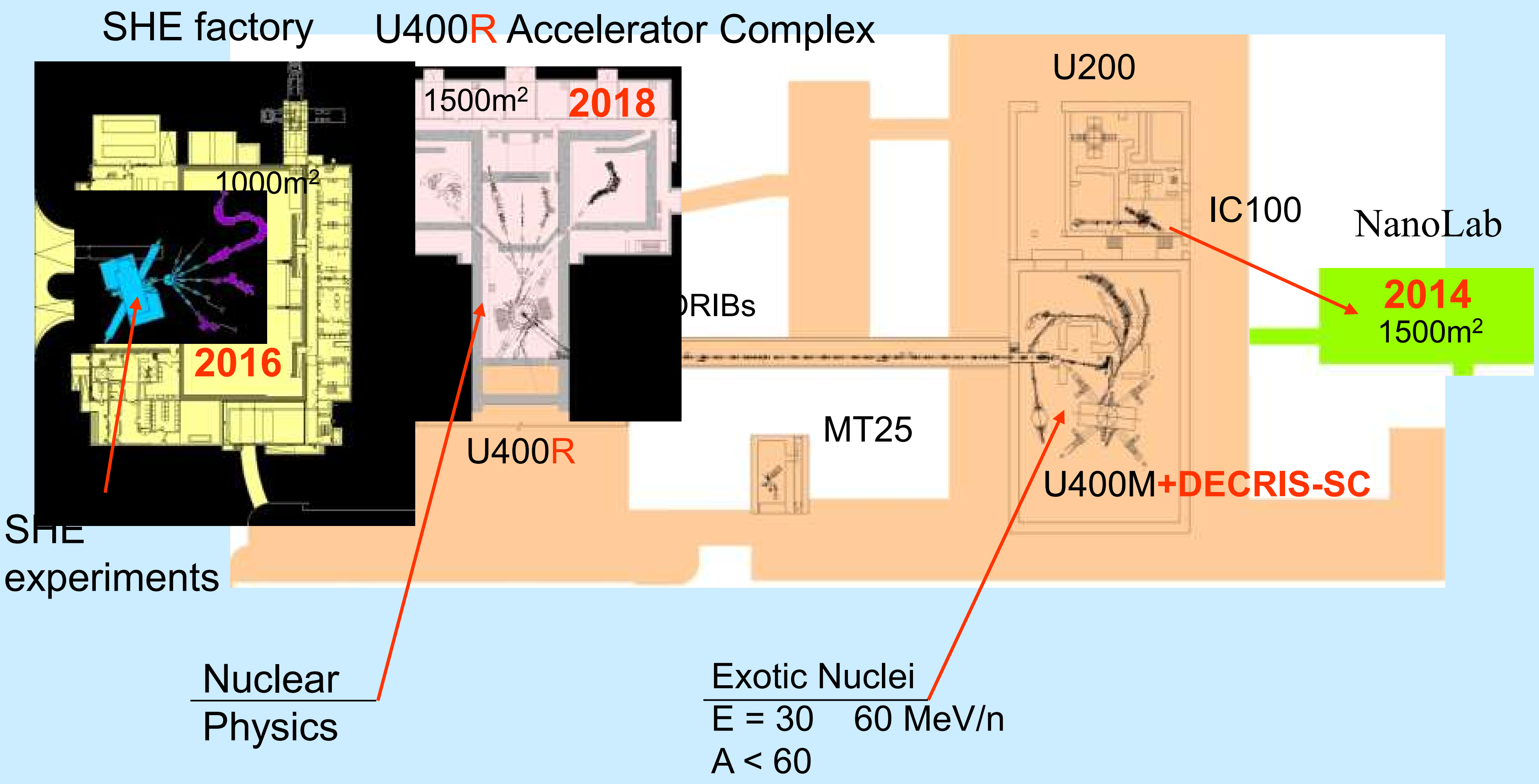


Beam envelopes



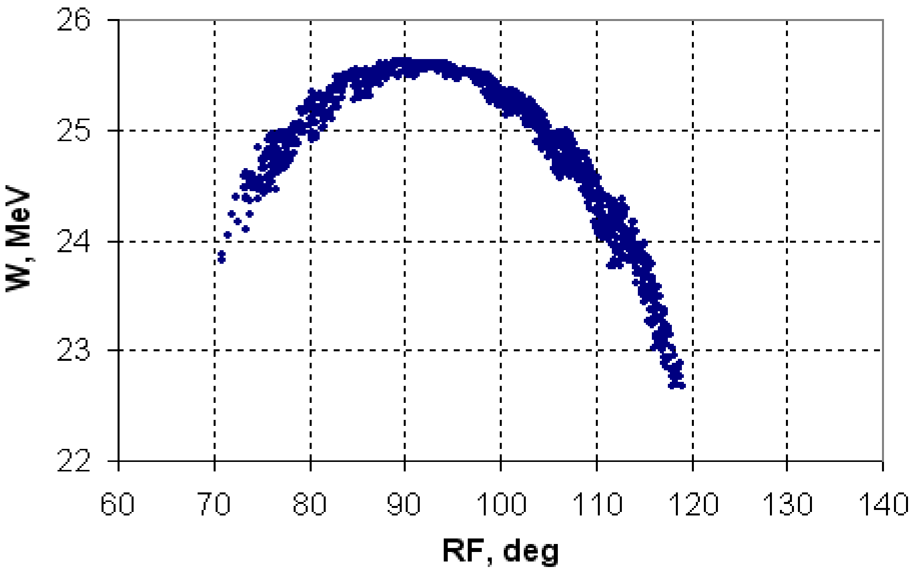
Казаринов Н.Ю.

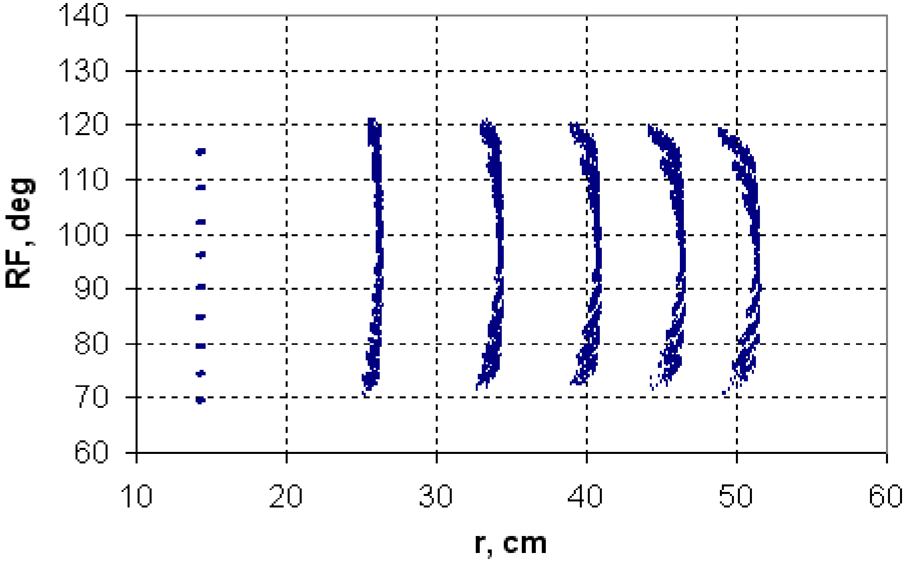
FLNR – 2017(18)



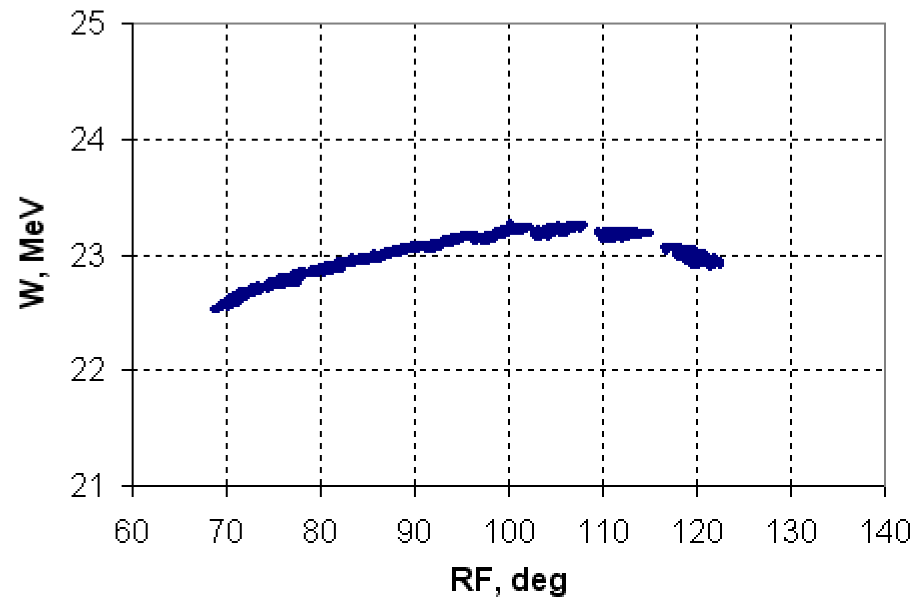
SHE factory
U400R Accelerator Complex
1500m²
2018
1000m²
2016
U200
IC100
NanoLab
2014
1500m²
RIBs
MT25
U400R
U400M+DECRIS-SC
SHE experiments
Nuclear Physics
Exotic Nuclei
E = 30 60 MeV/n
A < 60

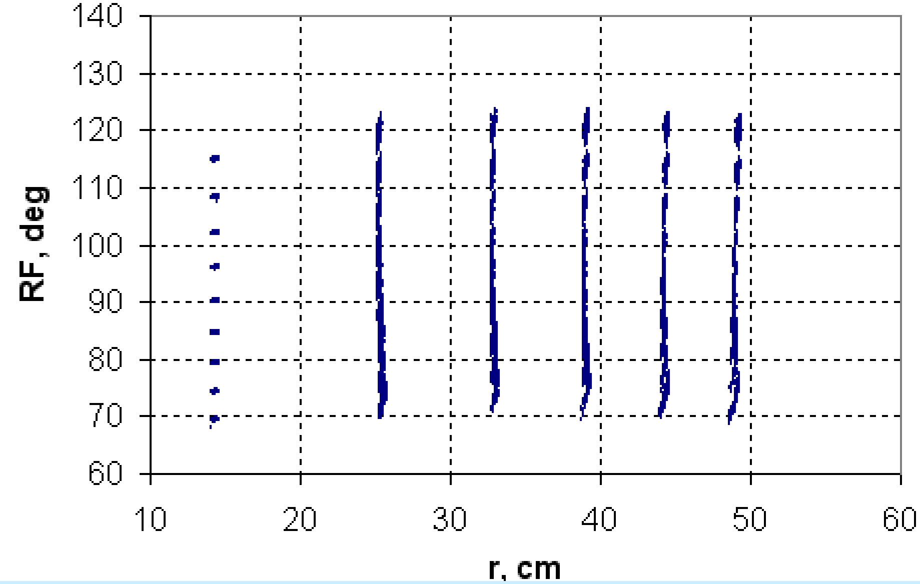
1. Ускорение без FlatTop





2. Ускорение с дополнительными Flat –Top дуантами, размещенными на 45º после основных дуантов

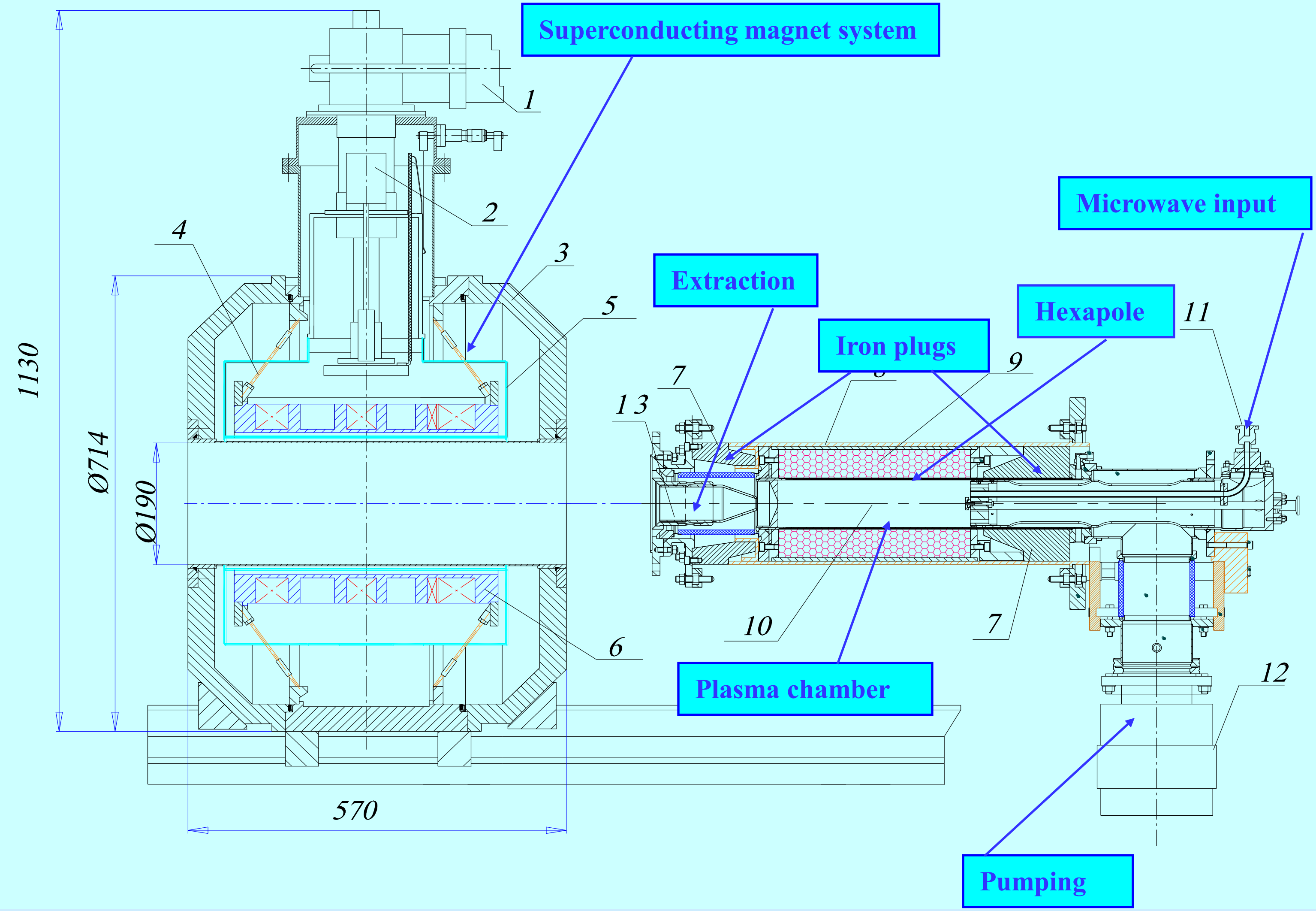




Иваненко И.А.

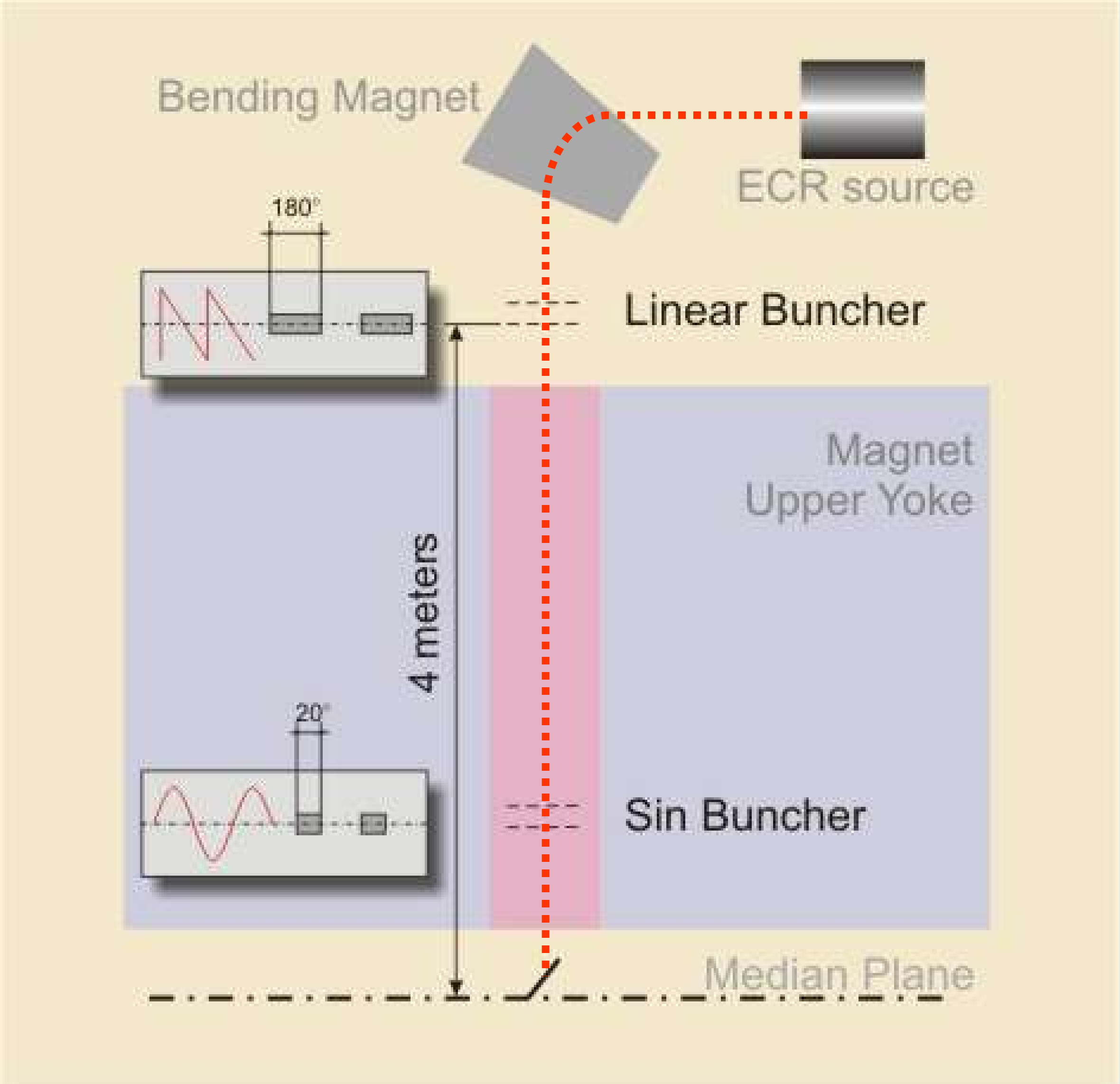
DECRIS-SC2

DECRIS-SC2 is the compact version of the “liquid He free” superconducting ion source. The axial magnetic field is created by superconducting coils and iron plugs. The radial magnetic field is formed by permanent magnet hexapole.



U400 Cyclotron

Buncher System

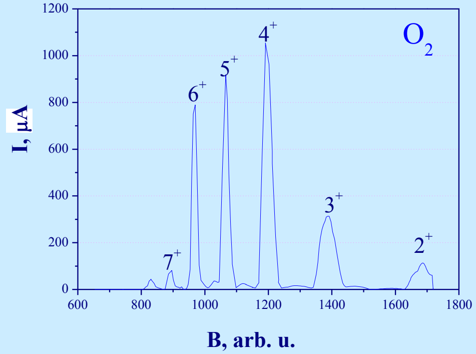


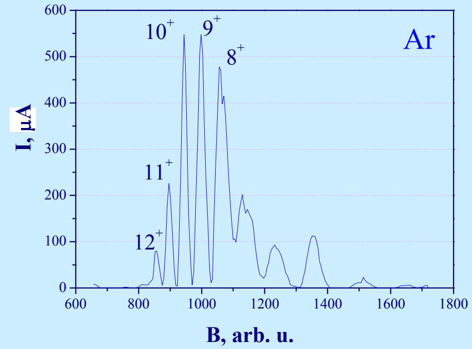
Efficiency of Buncher System (I_{inj} / I_{acc})

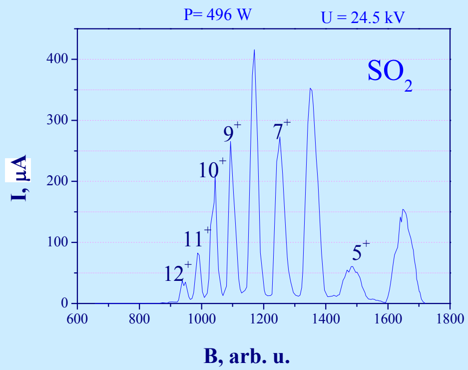
for 1 μA - 70%

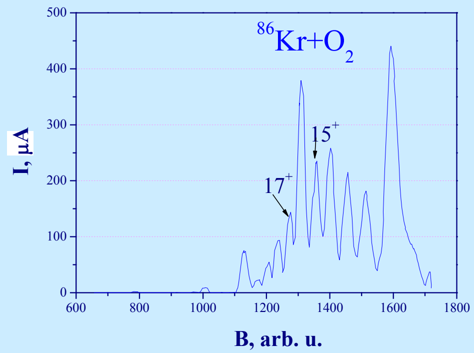
for 100 μA - 20%

DECRIS-SC2: results of the test





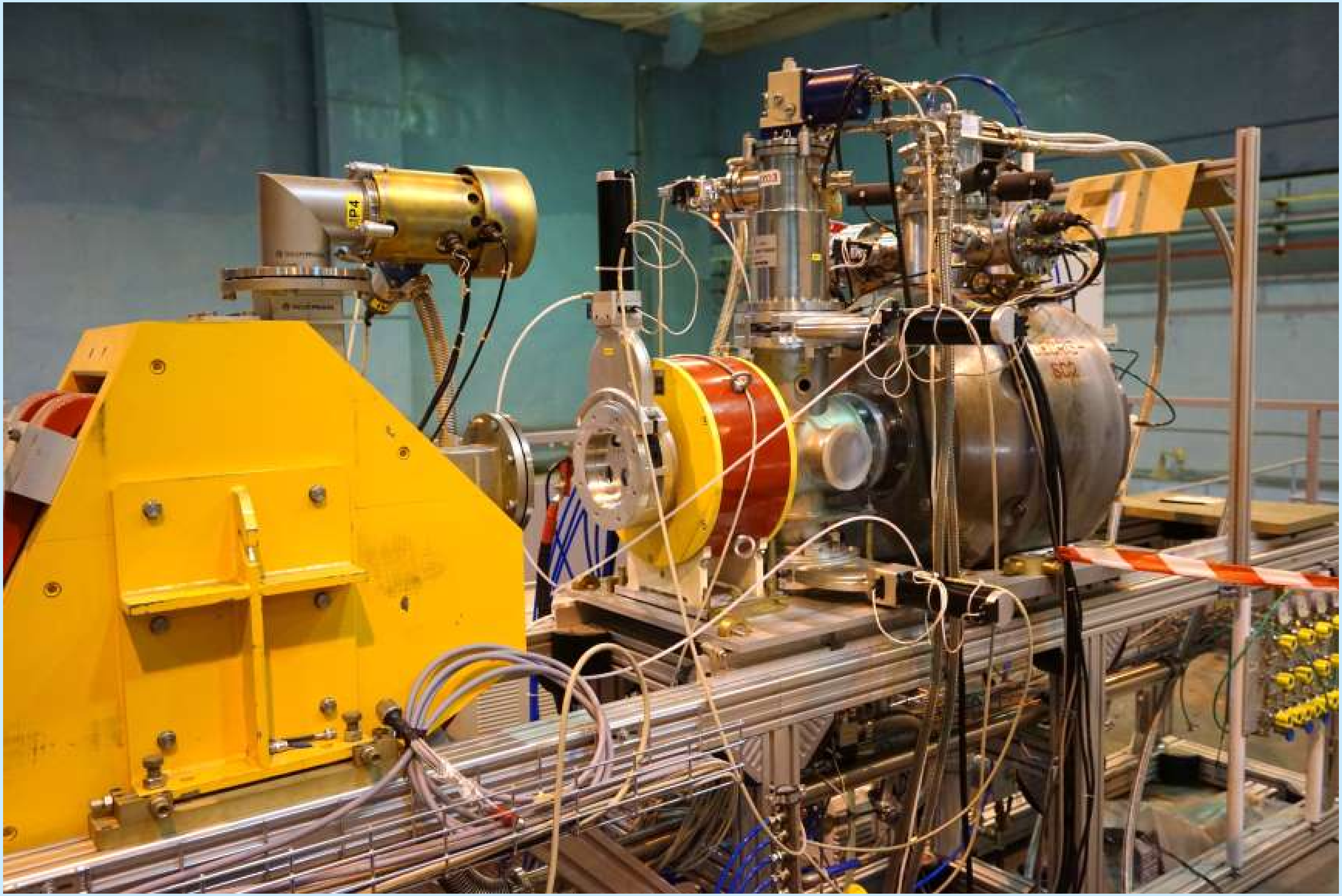




Ion	Current, (eµA)
O^{5+}	920
O^{6+}	820
S^{9+}	265
S^{11+}	90
Ar^{8+}	880
Ar^{9+}	680
Ar^{11+}	250
Ar^{12+}	120
Kr^{15+}	250
Kr^{17+}	150
Xe^{30+}	~ 1

Future plans: to test the source with 18 GHz frequency

Superconducting 18 GHz ion source DECRIS-SC2 at the U400M cyclotron



DC280 Cyclotron