All-permanent magnet ECR Ion Source DECRIS-PM

A. Efremov, S. Bogomolov, V. Bekhterev, A. Bondarchenko,
A. Lebedev, V. Loginov, V. Mironov
JINR, Dubna, Moscow Region, Russia
N. Konev ITT-group, Moscow, Russia

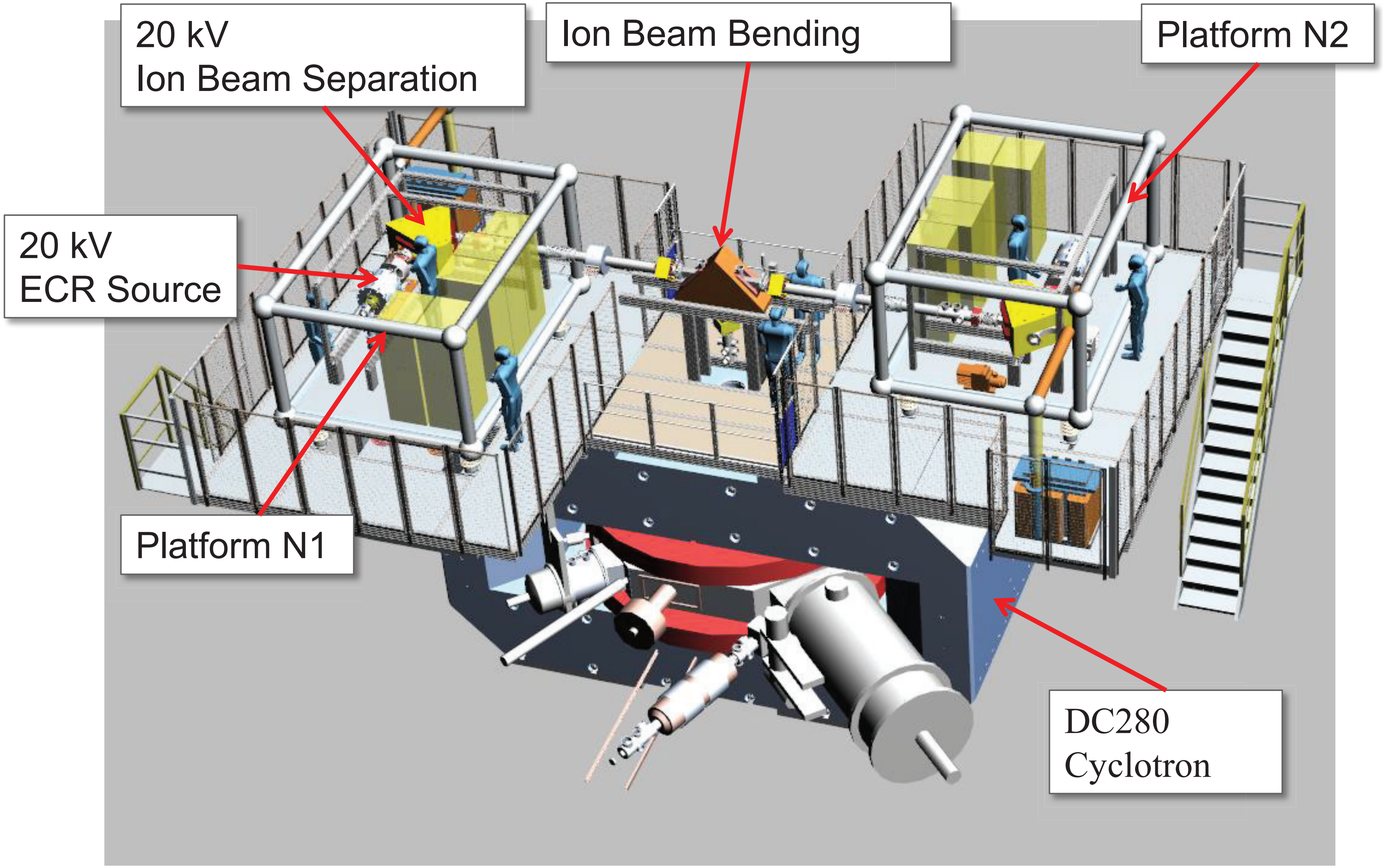
HIAT 2018, Lanzhou, China

OUTLINE

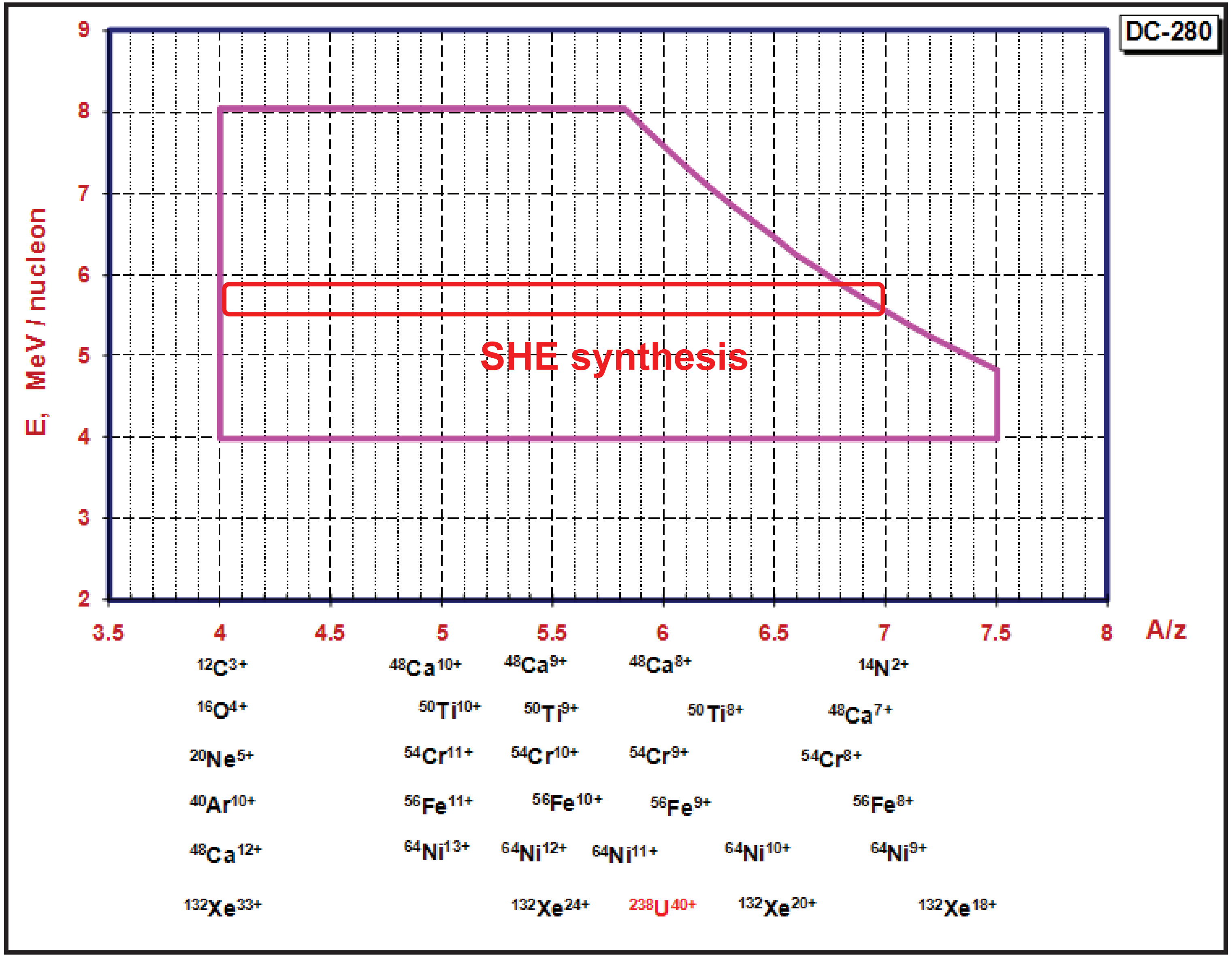
DECRIS PM: Dubna ECR Ion Source made of Permanent Magnets

- **Goals for DECRIS PM**
- **Magnetic Structure and unique features**
- **Commissioning results**
- **Summary and future plans**

DC-280 Cyclotron



Working diagram of the DC-280



Expected beam parameters of the DC-280

ION	Z	Beam Intensity from ECR		Efficiency of acceleration	Expected beam intensities of (4÷8) MeV/n ions on targets pps
		eμA	pps		
20Ne	3	150	3.10^{14}	50%	$1.5\cdot10^{14}$
40Ar	7	300	3.10^{14}	50%	$1.5\cdot10^{14}$
48Ca	7/9	160	$1.3.10^{14}$	50%	$6.2\cdot10^{13}$
^{50}Ti	8/9	80	$6.2.10^{13}$	50%	$3.1.10^{13}$
^{54}Cr	9	125	8.10^{13}	50%	4.10^{13}
58Fe	9/10	125	8.10^{13}	50%	$4\cdot10^{13}$
64Ni	10/11	125	8.10^{13}	50%	$4\cdot10^{13}$
70Zn	11/12	100	5.10^{13}	50%	$2,5.10^{13}$
136Xe	22/23	150	4.10^{13}	50%	$2\cdot10^{13}$

Basic requirements for the source design:

minimum energy consumption → **All-permanent magnet ion source**

high intensity of required ion beams → **“Full-size” ion source**

Ion source	Nanogan	SuperNanogan	LAPECR2
Frequency [GHz]	14.5	14.5	14.5
Plasma chamber [mm]	28	45	67
Ar^{8+} [eμA]	60	200 (300*)	460
Ar^{9+} [eμA]	20	90 (150*)	355
Weight of PM	90	220	~ 500

The goal was to reproduce parameters of CAPRICE-type RT ECR

Design parameters of DECRIS-PM	
Microwave frequency	**14.0 – 14.5 GHz**
$\mathbf{B_{inj}}$	$\geq$ 1.3 T
$\mathbf{B_{min}}$	0.4 T
$\mathbf{B_{extr}}$	1.0 ÷1.1 T
$\mathbf{B_{r}}$	1.05÷1.15 T
Plasma chamber ID	70 mm

All PM ECRIS advantages:

- low power consumption
- low pressure in the cooling water system
- simplified operation, etc.

All PM ECRIS drawbacks:

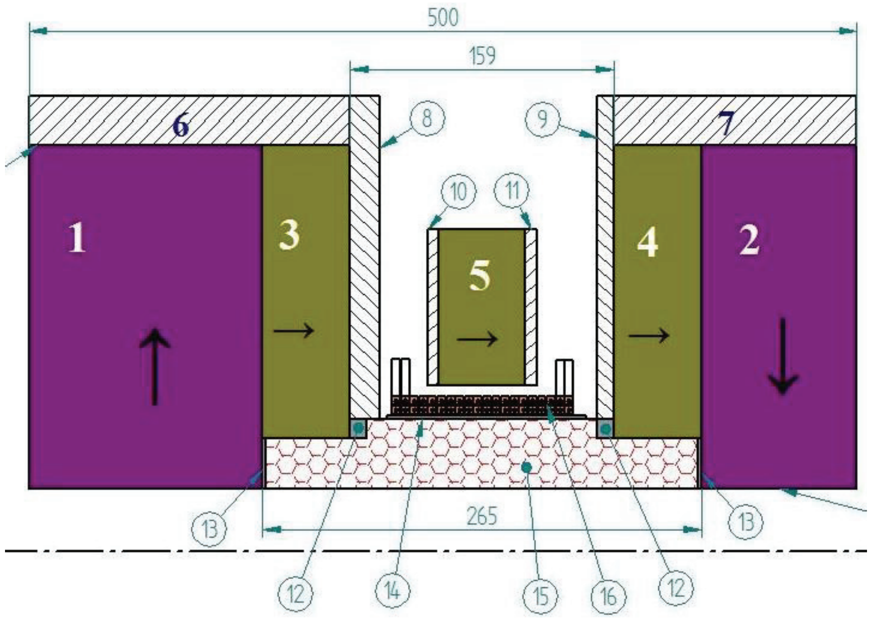
- ❑ the fixed distribution of the magnetic field → system should be strongly optimized for the desired operation mode

- ❑ strong forces between the individual parts of the system → the correction of the magnetic field after the assembly of the magnetic system is practically impossible without the degaussing of it

But:

the variation in properties of permanent magnets and the variation of easy axis direction for magnets with angular magnetization lead to a difference between the calculated and the actual distribution of the magnetic field.

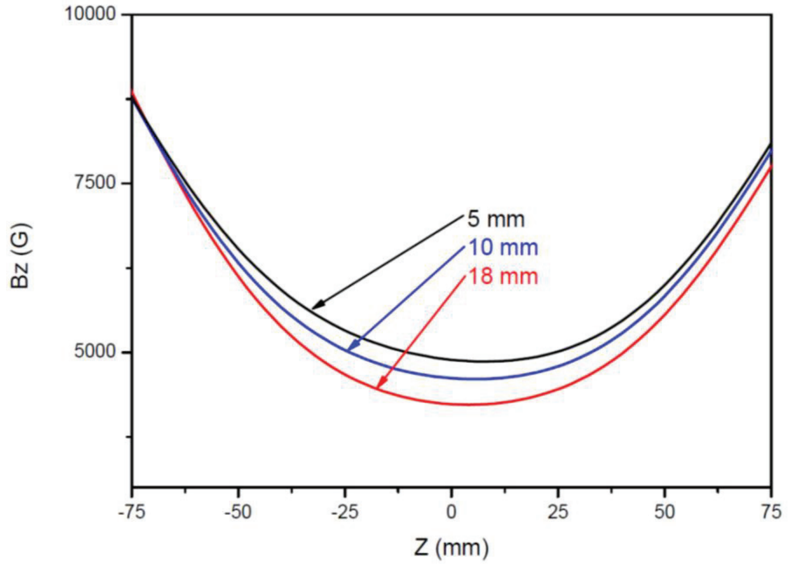
DECRIS-PM magnet system

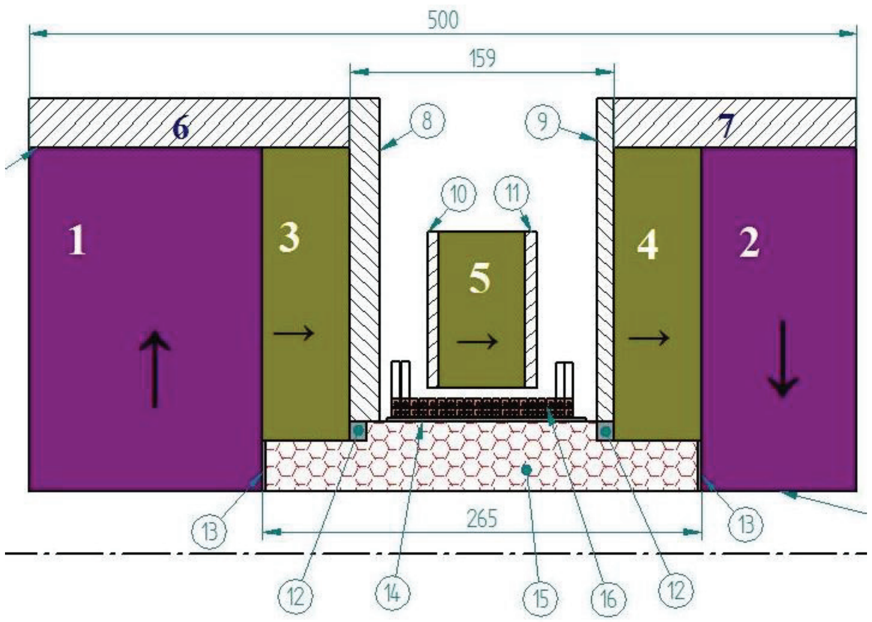


Magnetic structure of DERIS-PM.
1÷5 – PM rings; 6, 7 – soft iron rings;
8÷11 – soft iron plates,
12÷14 - auxiliary elements,
15 - hexapole, 16 – coil.

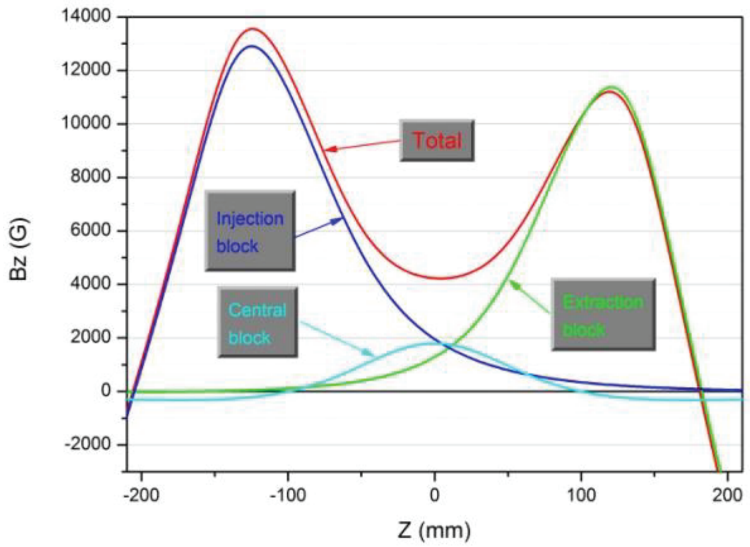
Some features:

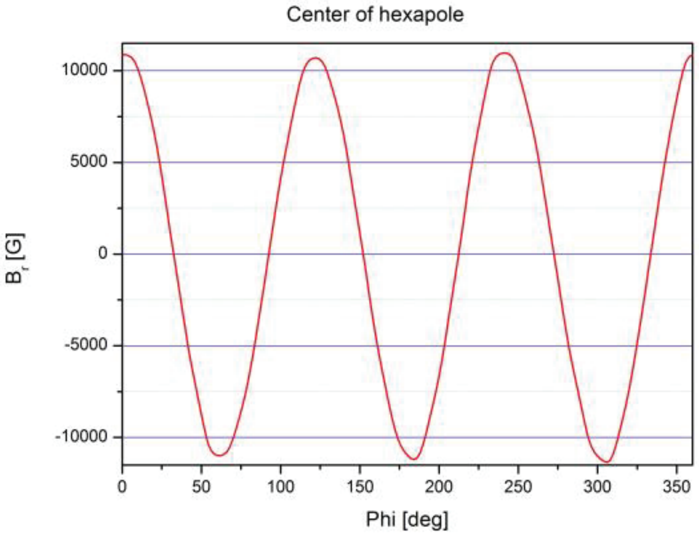
- Only magnets with radial and axial magnetization are used (there is no angular magnetization)
- Correction is possible due to changes in soft iron parts



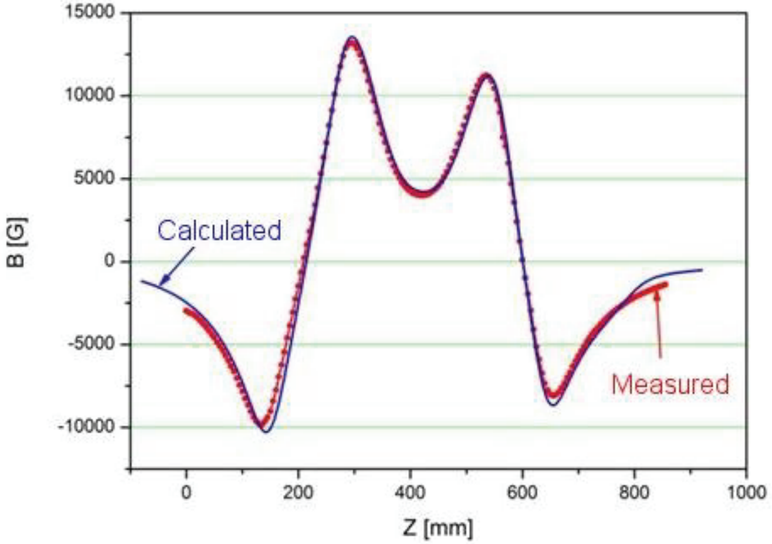


Axial magnetic field





Radial magnetic field



Coil effect

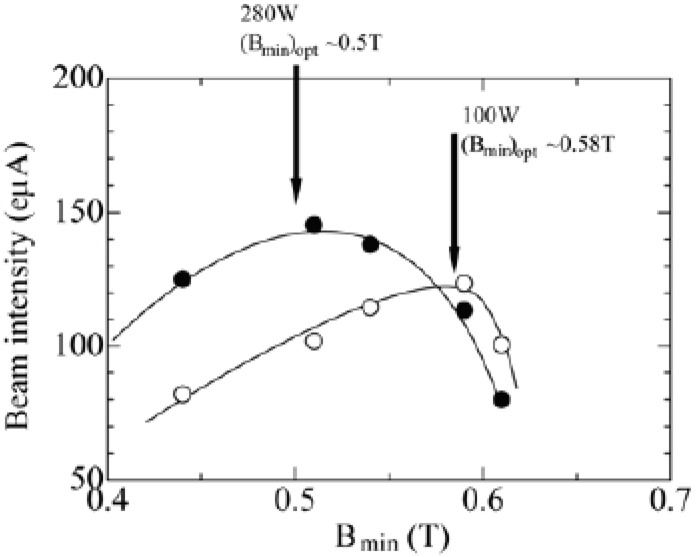


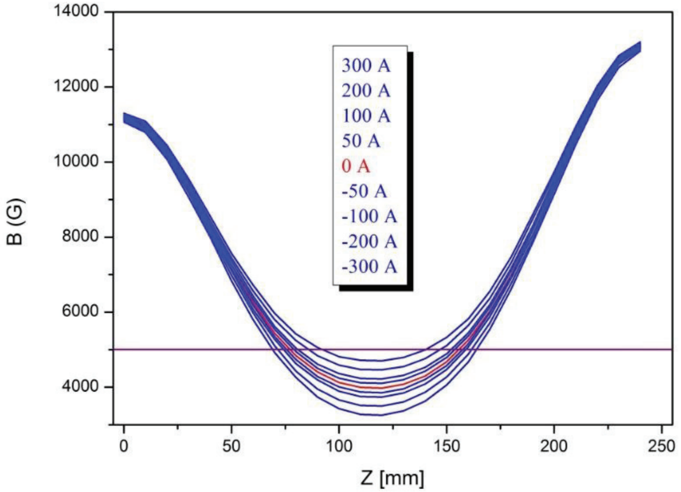
Fig.3 Beam intensity of Ar^{9+} as a function of B_{min} at the RF power of 100 and 280 W.

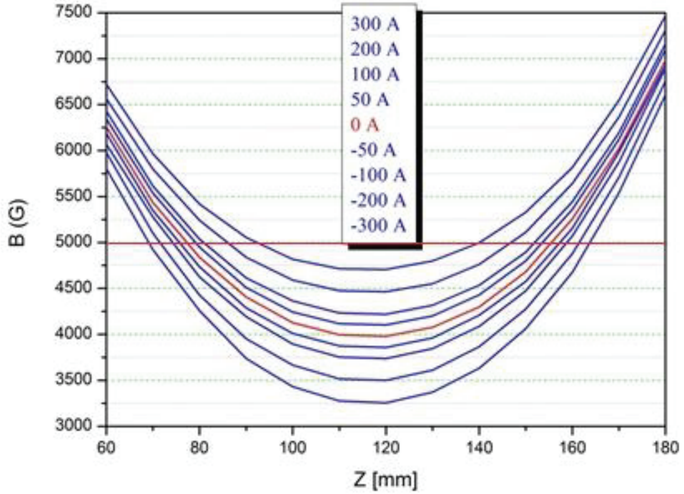
Coil parameters:

$I_{max} = 300$ A

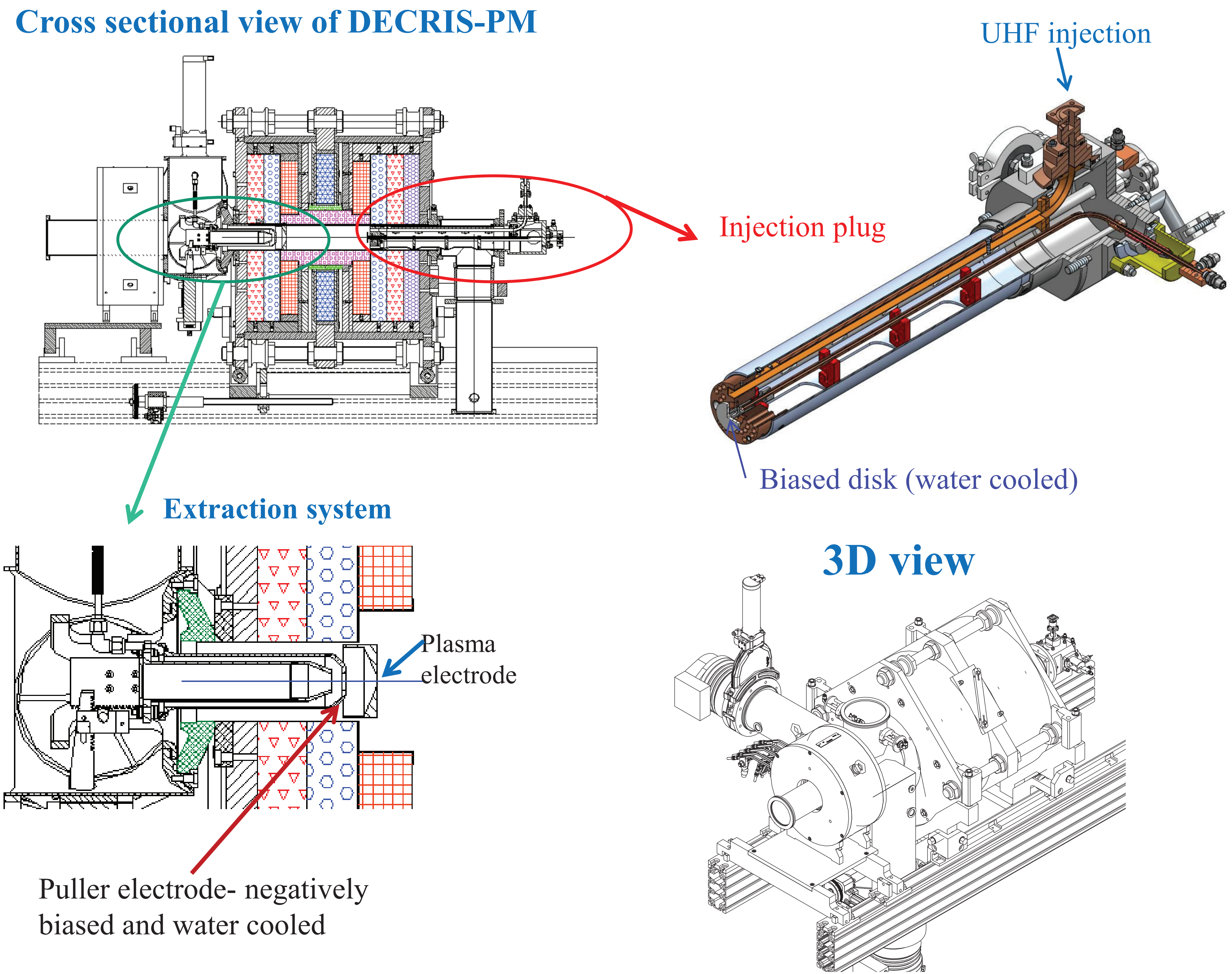
W < 1.6 kW

$\Delta P \leq 4$ bar

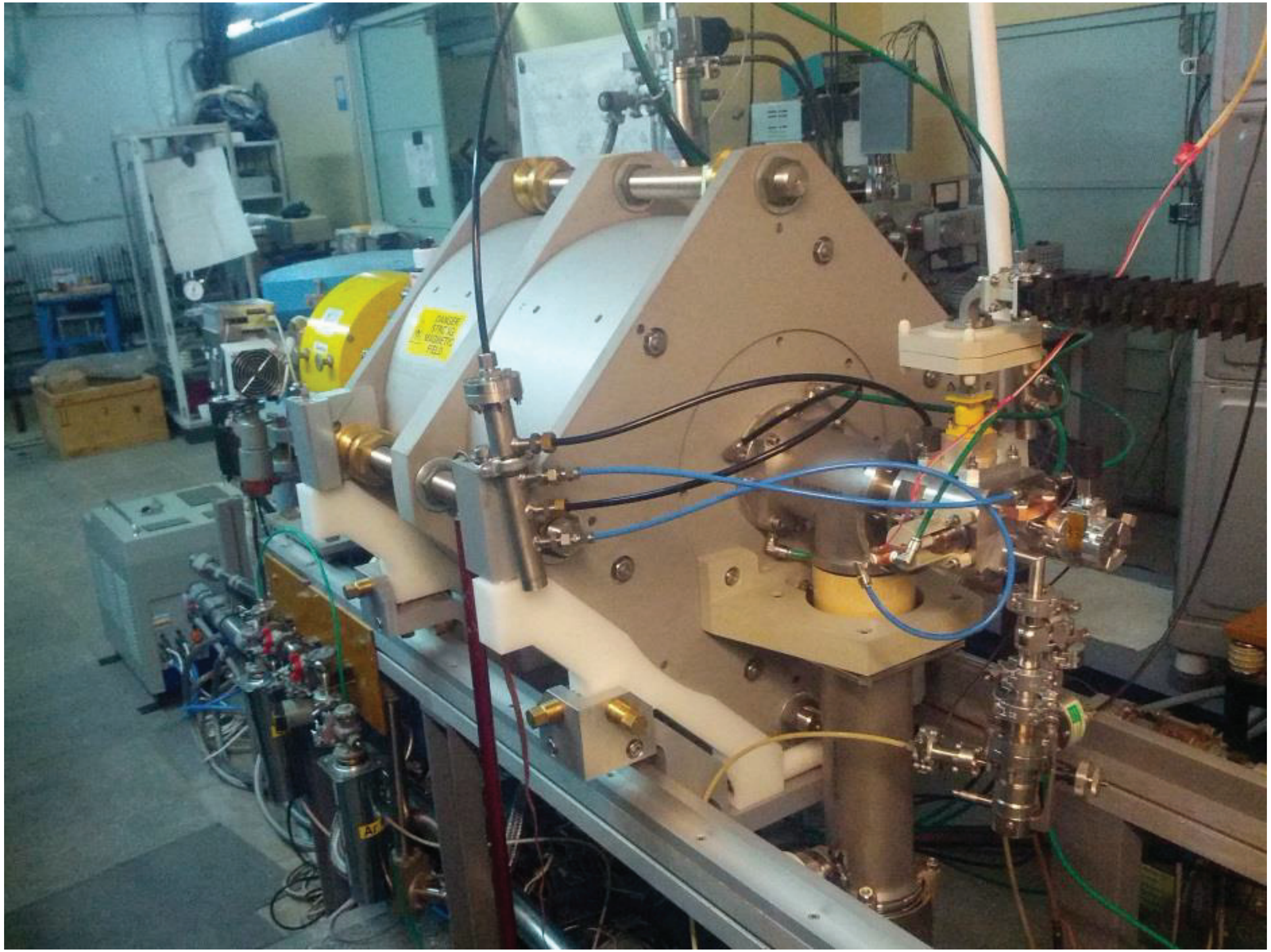




Adjustment of B_{min} ± 750 G

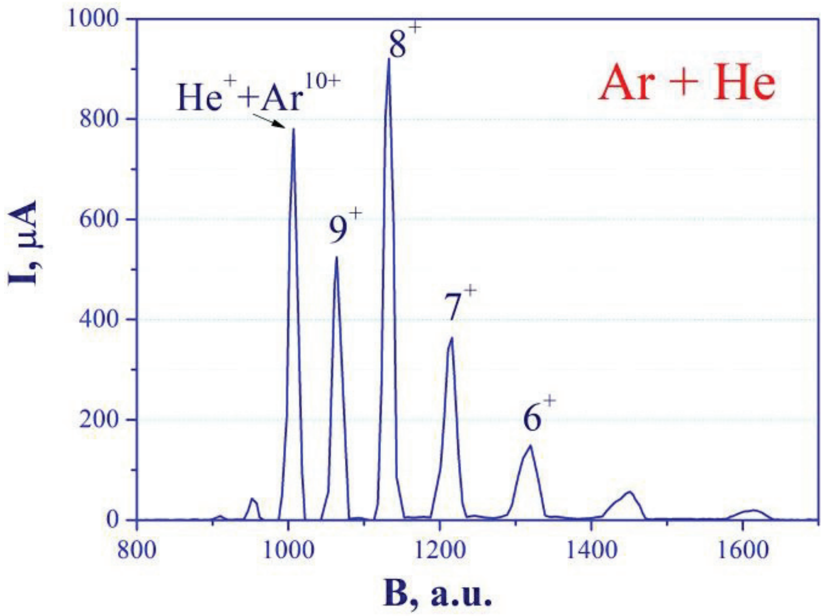

Cross sectional view of DECRIS-PM
UHF injection
Injection plug
Biased disk (water cooled)
Extraction system
3D view
Plasma electrode
Puller electrode- negatively biased and water cooled

DECRIS-PM at the test bench

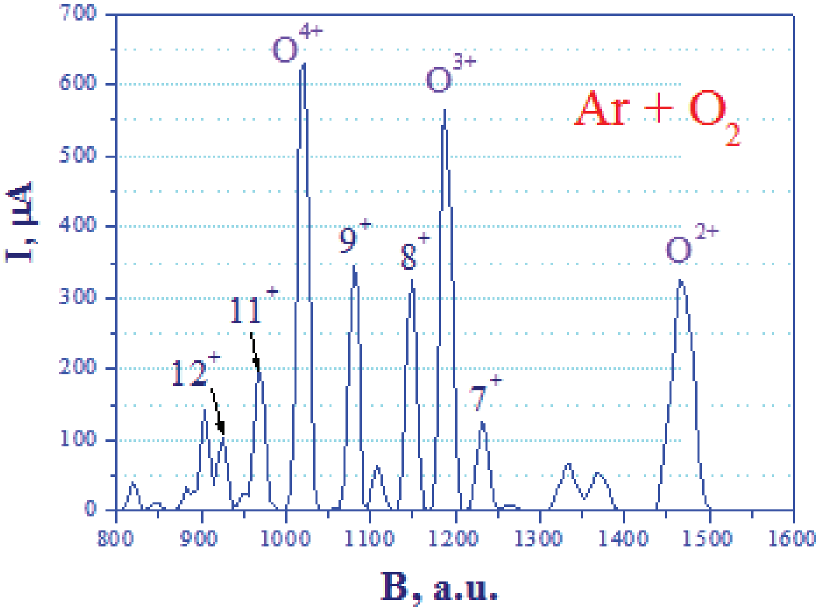


Ar charge state spectra

Ar^{8+} =926 μA

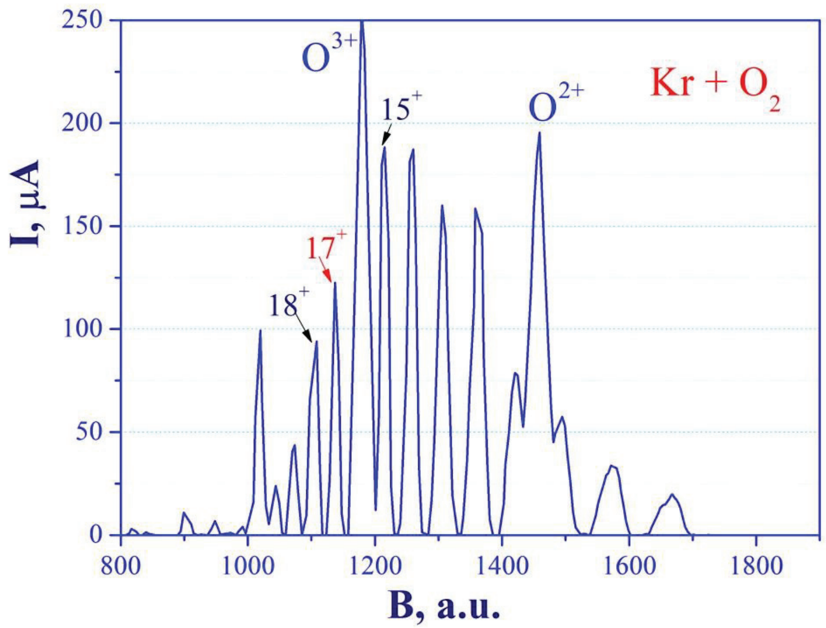


Ar^{11+} = 210 μA

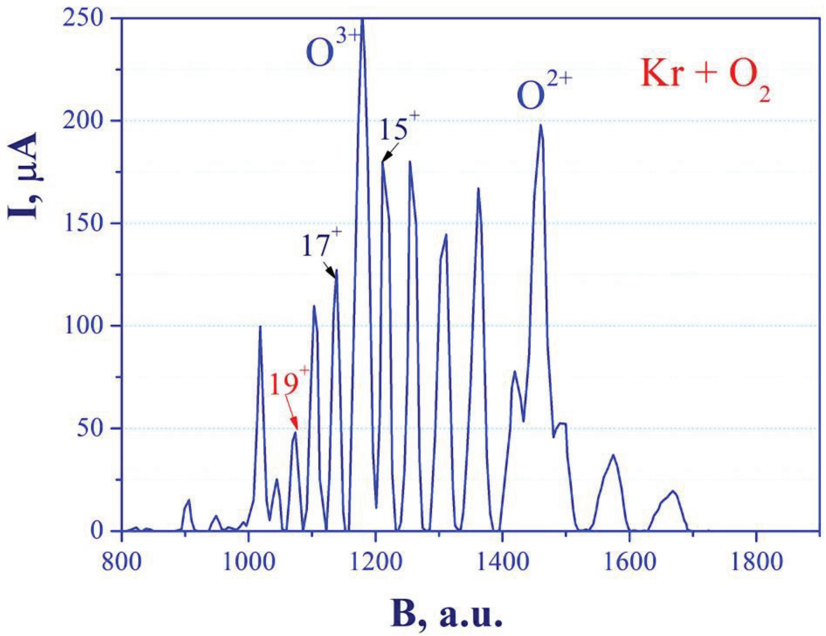


Kr charge state spectra

Kr^{17+} =125 μA

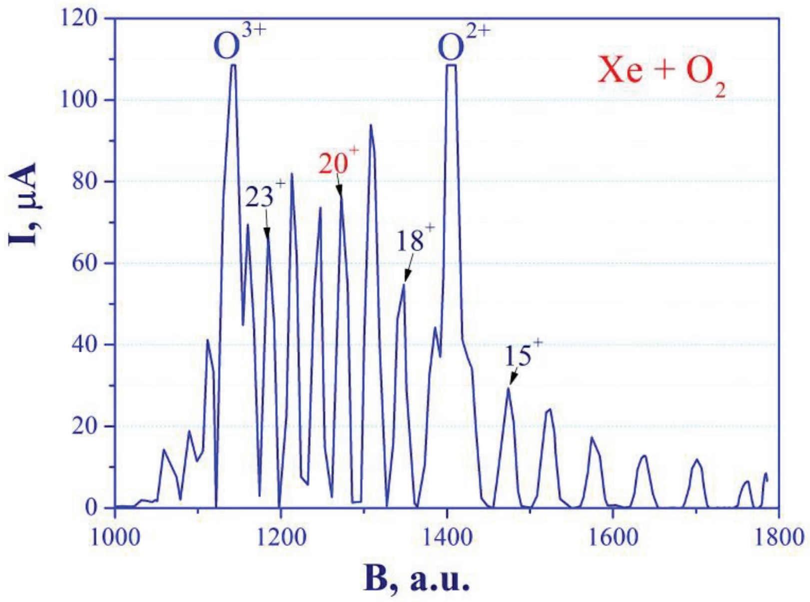


Kr^{19+} =50 μA

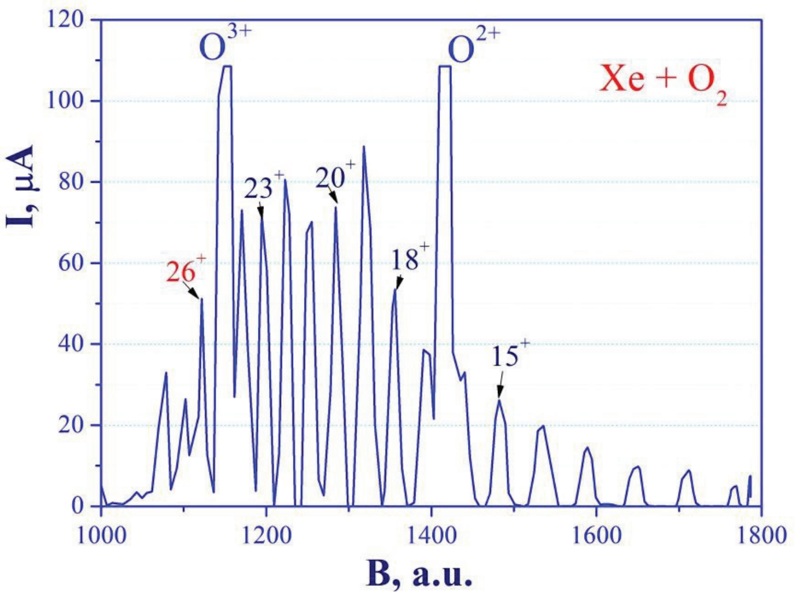


Xe charge state spectra

Xe^{20+}=77 μA



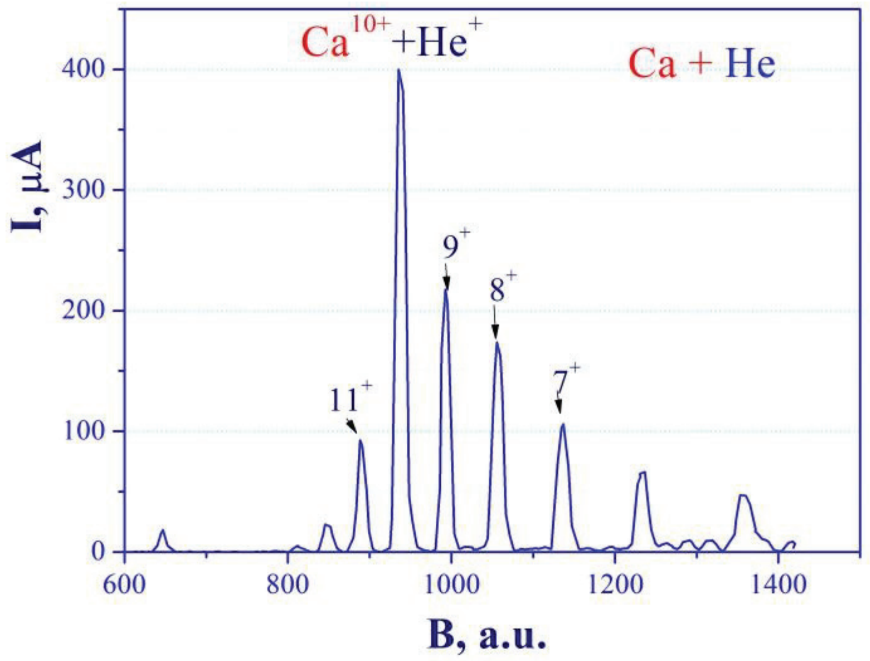
Xe^{26+} =50 μA



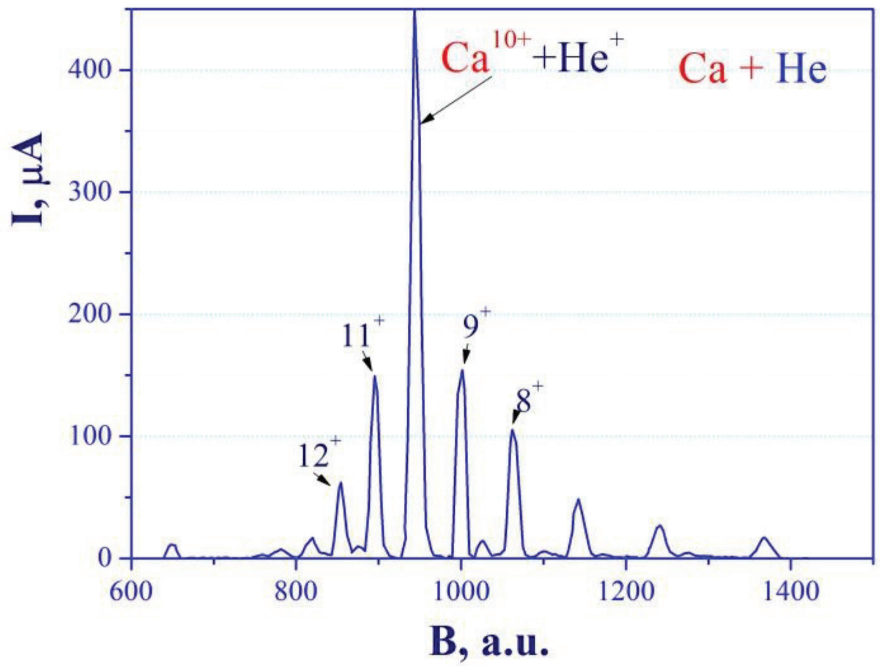
Ion	DECRIS-PM	LAPECR2	Supernanogan	DECRIS-3	ECR 4M
Ar^{8+}	920	460	300	720	600
Ar^{9+}	500	355	150		450
Ar^{11+}	210	166	35	156	200
Ar^{12+}	150	62	12	68	100
Xe^{20+}	75	85		84	
Xe^{26+}	50	40	7(Xe^{25+})	23	25(Xe^{25+})

Ca charge state spectra

Ca^{9+} =210 µA

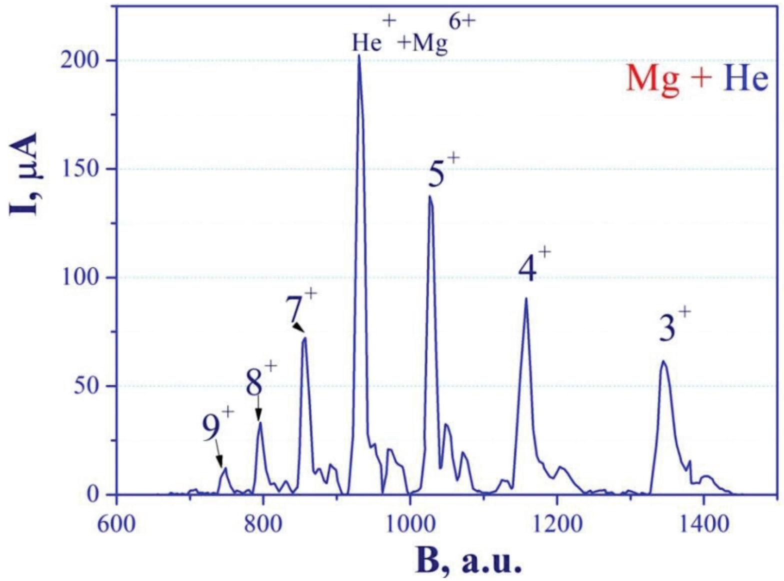


Ca^{11+} =150 µA

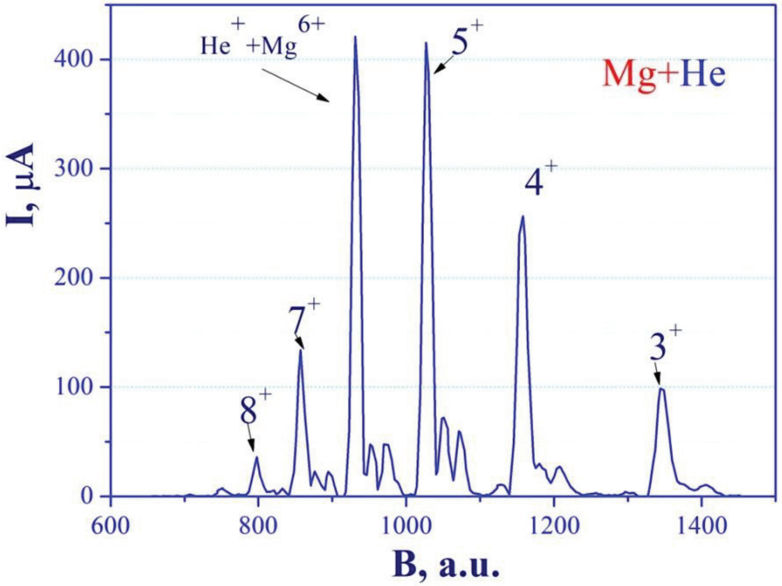


Mg, Fe and Ti charge state spectra

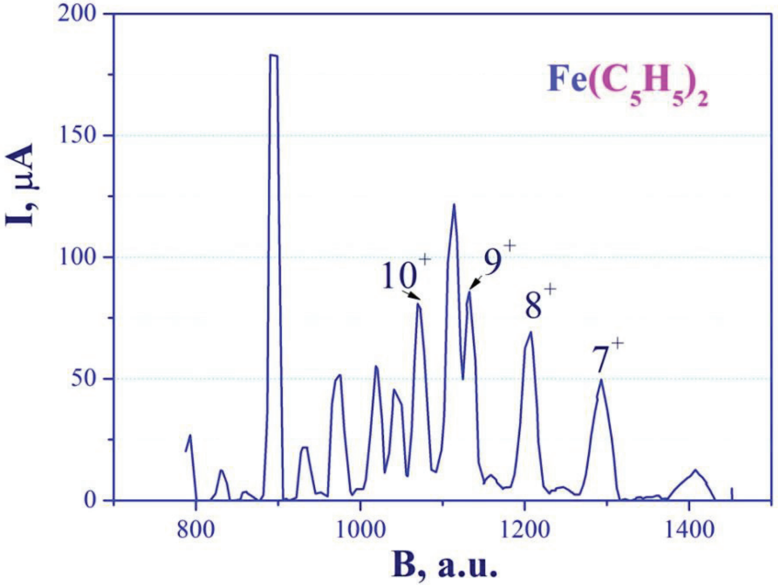
Mg^{9+} =15 μA



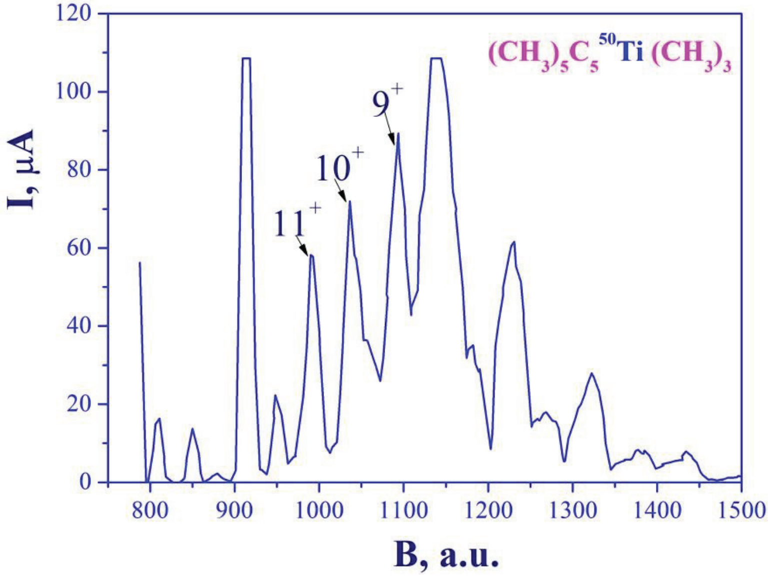
Mg^{5+} =400 μA



Fe^{10+} =80 μA

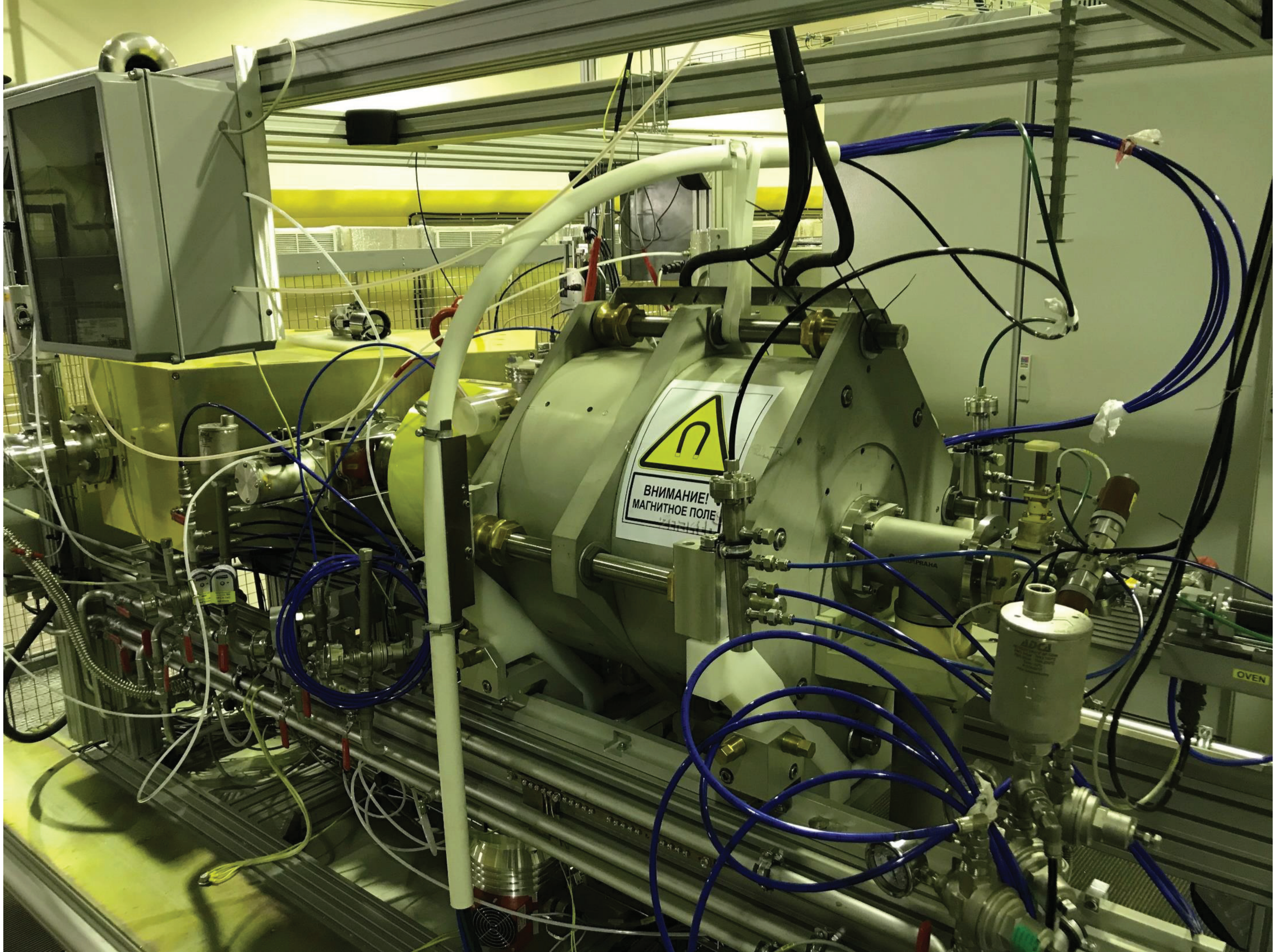


$^{50}Ti^{10+}$ =72 μA



DECRIS-PM: results of the test

Ion currents, eμA													
Q+	5+	7+	8+	9+	10+	11+	12+	15+	17+	19+	20+	23+	26+
Ar			926	500		210	154						
Kr							160	180	125	50			
Xe											77	70	50
^{24}Mg	450	140	40	15									
^{40}Ca		110	175	220		158	58						
^{50}Ti				90	72	60	23						
^{56}Fe			70	85	80	55							


ВНИМАНИЕ!
МАГНИТНОЕ ПОЛЕ
OVEN

Conclusion and future plans.

1. Some very promising results have been obtained from all-permanent magnet ECR ion source DECRIS-PM. The source can provide intense ion beams of gaseous and solid substances. During the tests the operation of the DECRIS-PM ion source was very stable and reproducible. The beam intensity produced by DECRIS-PM meets the requirements of DC-280 cyclotron (for elements from carbon to krypton).

2. We hope to improve the source performance at the high voltage platform due to the following:

- 3-electrode extraction system (single gap extraction at the test bench)
- Effect of the additional coil
- the larger gap between poles of the analyzing magnet (70 mm at the test bench; 110 mm at the HV platform)