CRyogenic IONizer with 6 T magnetic field (KRION-6T) - the prototype of the ion source for NICA/MPD

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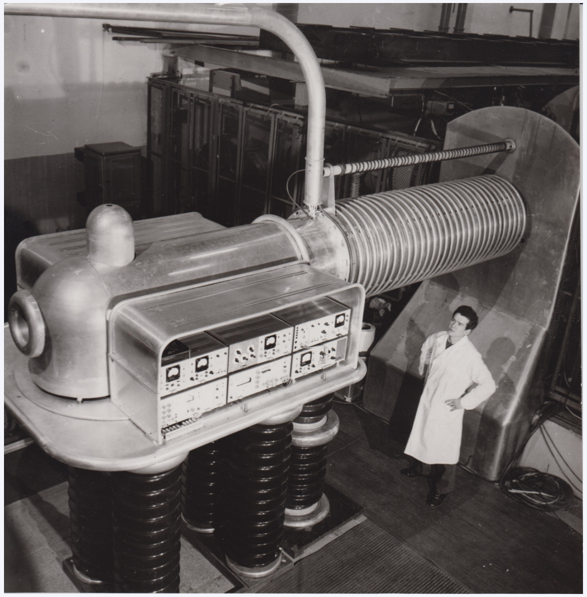
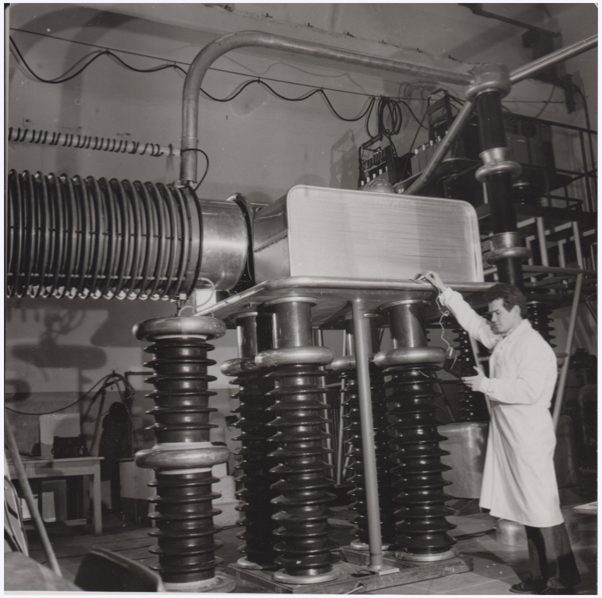
1. EBIS/ESIS timeline at JINR

1968	IEL1, IEL2	Au^{19+}	warm	0,4T	16 cm
1971	KRION1	C^{6+}, N^{6+}, O^{8+}, Ne^{10+}	SC	1,2T	1,2 m
1974	KRION2	Ar^{18+}, Kr^{36+}, Xe^{54+}	SC	2,2T	1,2 m
		…			
2014	KRION-6T	Au^{51+}, Tm^{50+}	SC	4,7T	1,2 m
soon	KRION-T	tubular design	SC	5T	1,2 m
soon	KRION-N1	special for NICA	SC	5T	1,2 m





2. Principle of EBIS/ESIS operation

1. Electron impact ionization

$X^{(n)+} + e \rightarrow X^{(n+1)+} + 2e$

$$P_{q \to q+1} = \sigma_{q \to q+1} (j\tau_i),$$

$P_{q \to q+1}$ - probability of the charge state gain

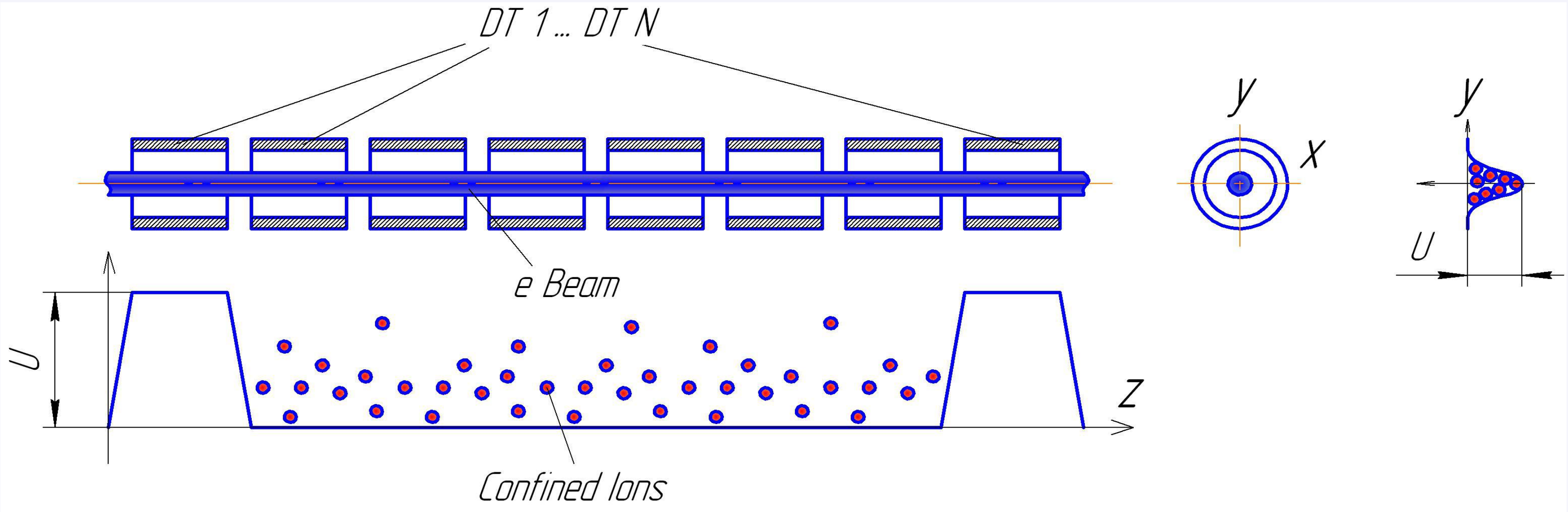
$\sigma_{q \to q+1}$ - effective cross section of ionization

$j\tau_i$ - ionization factor

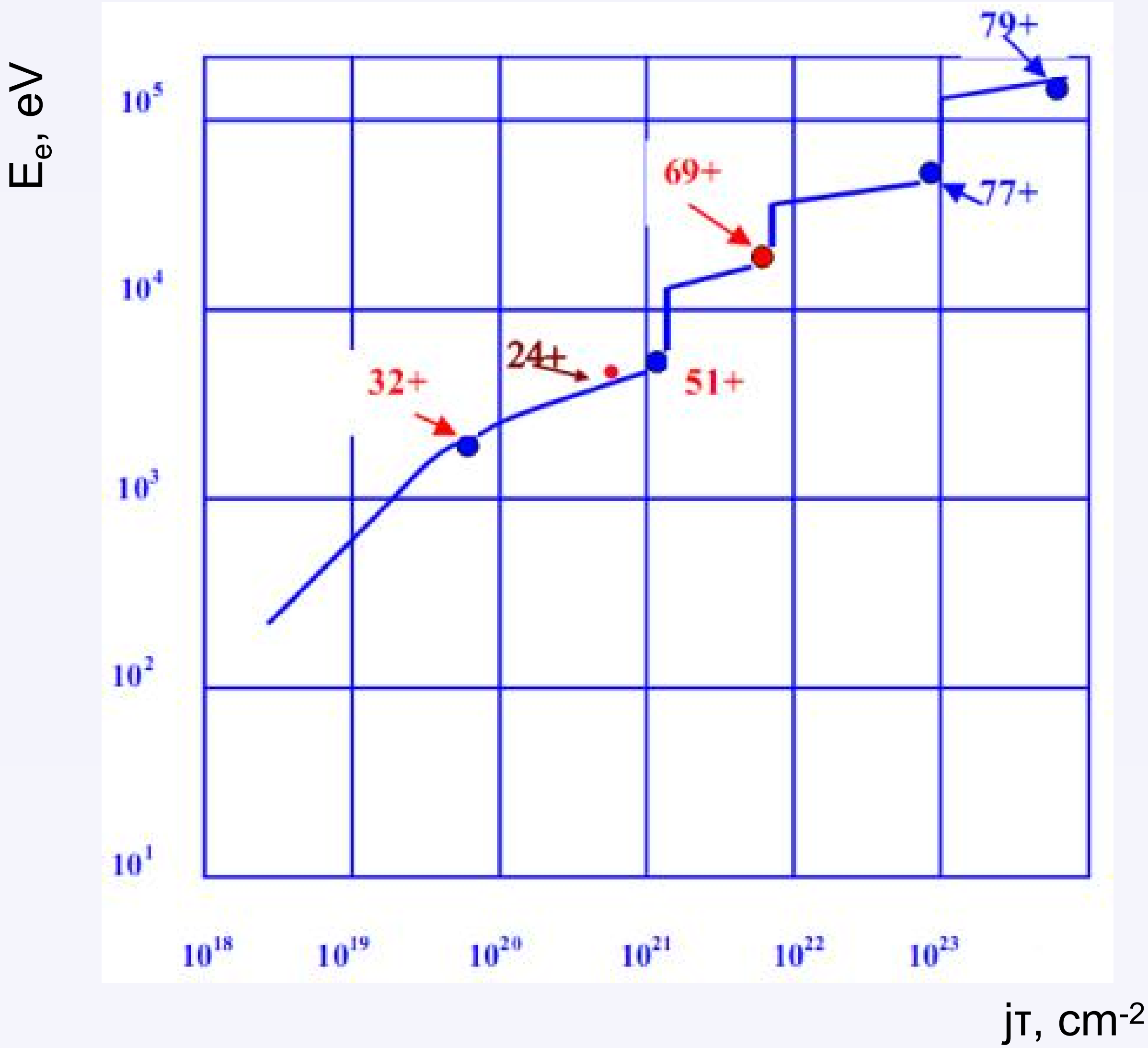
The ionization factor needed to obtain the ion of given charge state:

$$j\tau_i = \sum_{q=1}^{\bar{q}-1} \sigma^{-1}_{q \to q+1}$$

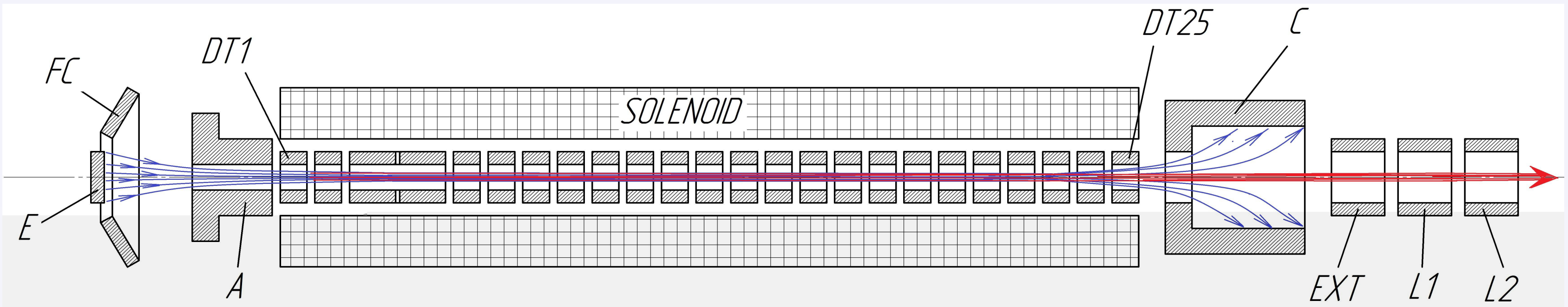
2. Confinement of the ions for step by step ionization (ion trap)



3. Characteristics of the electron beam required for ionization

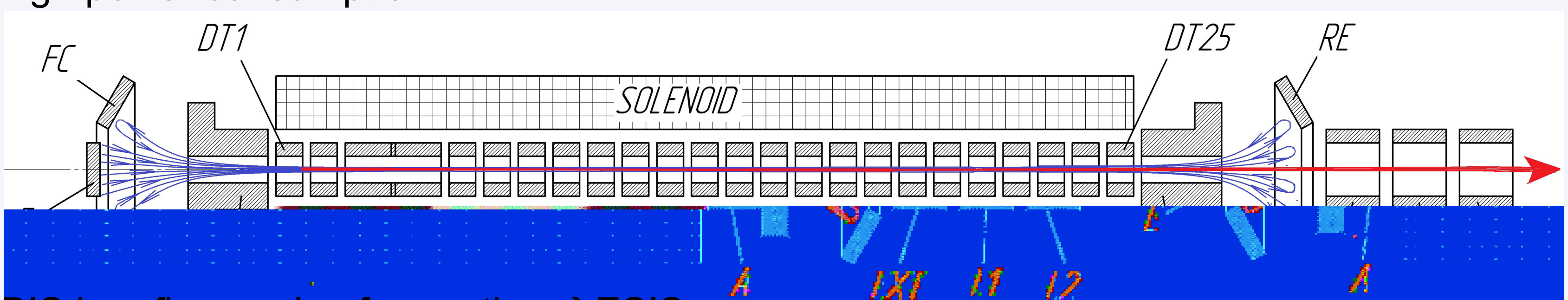


4. The difference between EBIS and ESIS



EBIS:

- one pass of each electron is used
- high e-beam current is needed to have high **j**
- electron collector should dissipate high power, water cooling is needed
- high power consumption

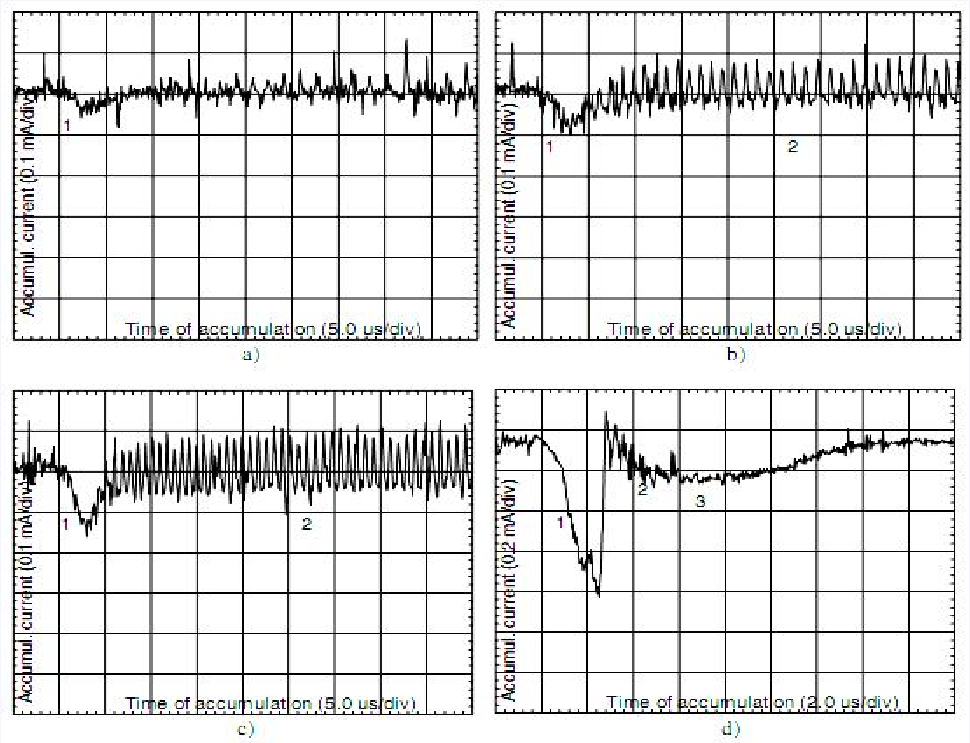


EBIS in reflex mode of operation →ESIS:

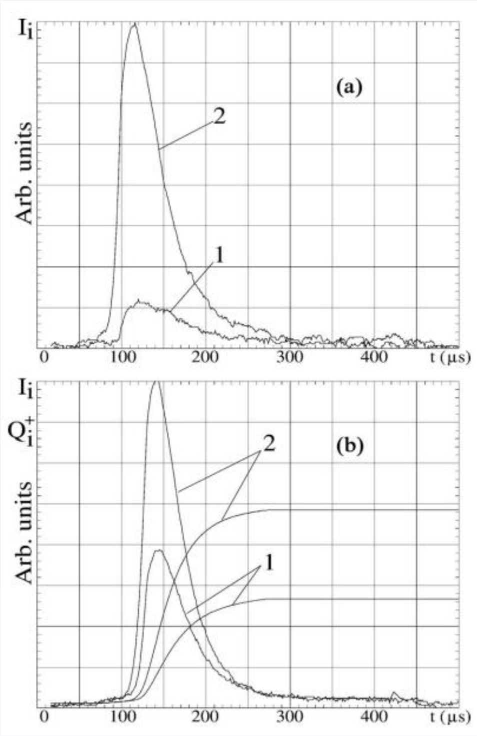
- 100~200 passes of each electron are used
- ~10 mA e-beam current is needed
- electron reflector instead of electron collector
- tiny heating, minimal power consumption, no special cooling

5. Electron string phenomenon

- reflex mode of operation doesn't suits well for efficient ionization because of instability
- under very specific conditions the stability can be achieved
- the stable mode of operation was called "electron string"
- transition to the electron string mode goes through strong instability and has 2 steps



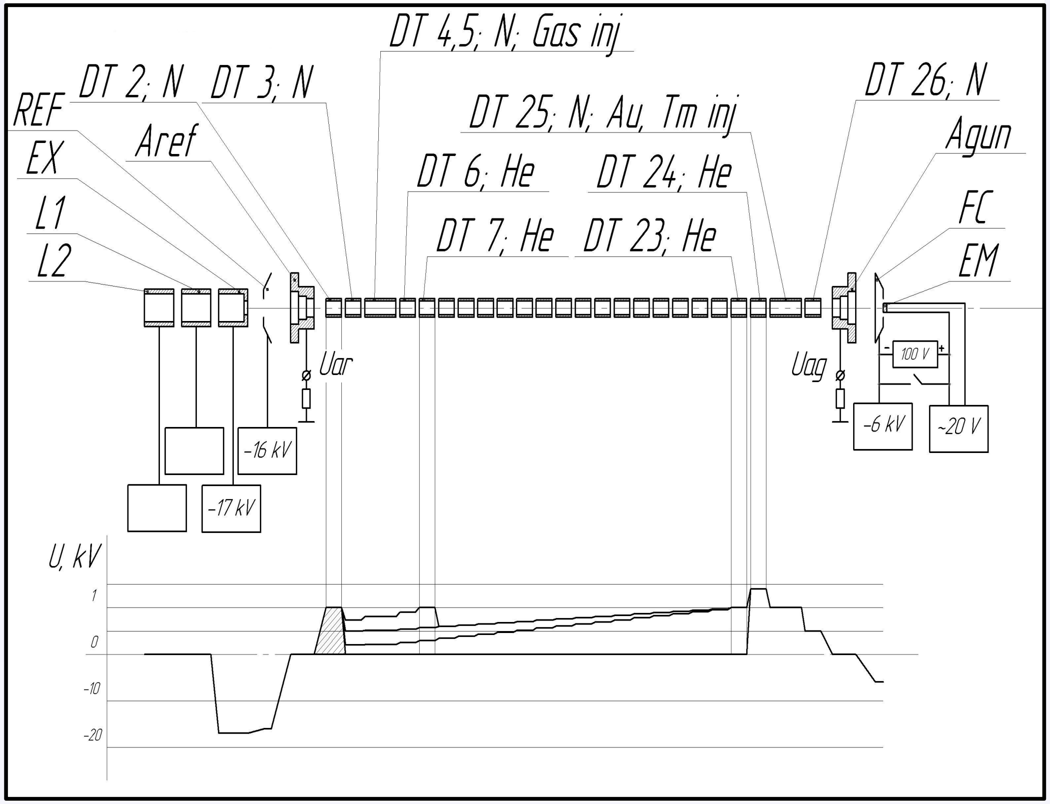
Electron charge accumulated at different
e-beam currents from the gun (5, 20, 50 and 300 uA)



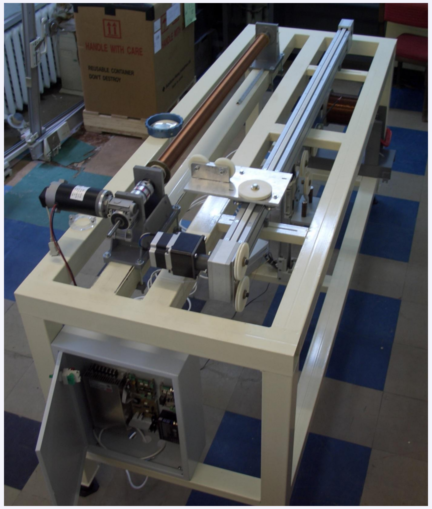
Effect of the electrong
string formation

6. Design of the KRION-6T

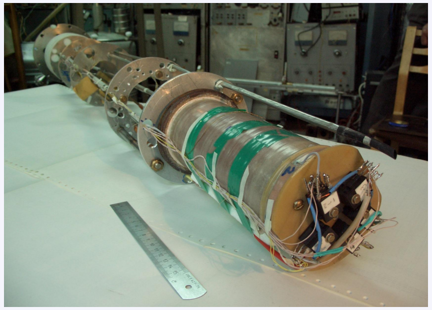
The design was based on the developments made first for the KRION-2



Electrode system of the KRION-6T



Solenoid winding machine



One of the short test solenoids

7. KRION-6T on the test bench

Specifications of KRION-6T

Length of the superconducting solenoid	1,2 m
Number of layers	24 layers
Induction	~10 H
Current in the solenoid	90 A (105 A planned)
Field on the axis in the middle (Bmax)	5,4 T (6T planned)
Length of the main ion trap	1 m
Maximum energy of the electrons	10 keV (11,5 keV with trap potential lift)
Emitter material	IrCe
Electron current from the gun	up to 30 mA
Capacity of the ion trap	up to 22 nC

8. Results achieved on the test bench

- the **jτ** ionization factor is the most important value giving information about the performance of the ESIS
- impossible to measure directly the electron string current, but possible to measure **effective jτ,** using the extracted ions spectrum.

Ion specious	Effective electron string current density **j**, A/cm^2
Kr^{15+}	665
Kr^{18+}	591
$Kr^{24,6+}$	847
$Xe^{23,2+}$	1090
$Xe^{24,9+}$	1579
$Xe^{25,4+}$	1587
$Tm^{40,8+}$	1092

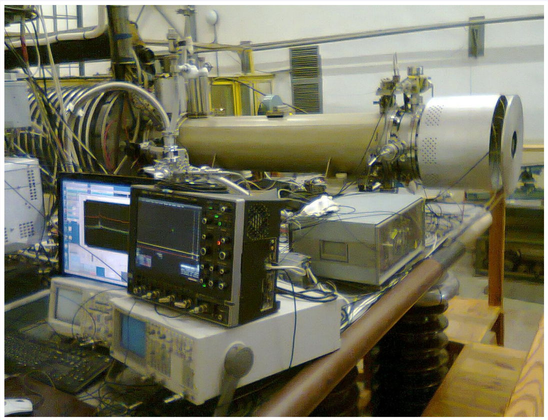
Examples of number of particles per pulse and times of ionization for different ions

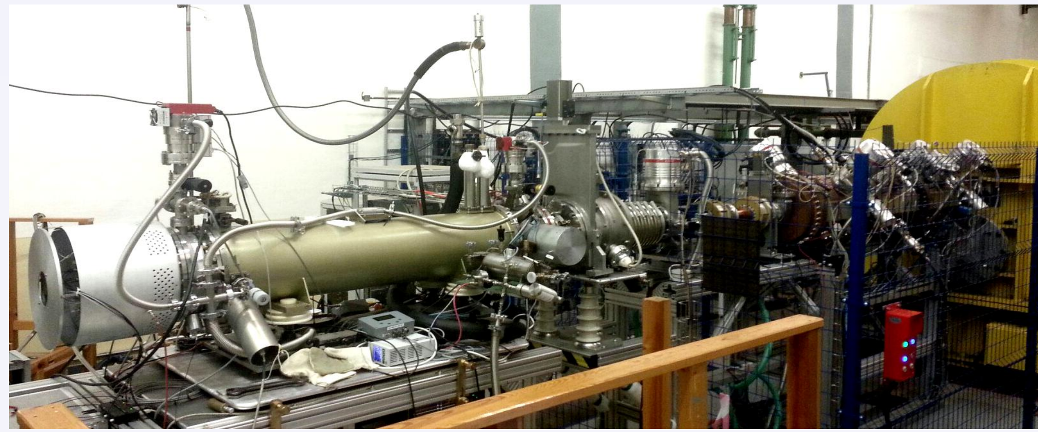
C^{4+}	$7x10^9$	-
Xe^{42+}	$5x10^9$	350 ms
Xe^{32+}	-	40 ms
Tm^{50+}	$3x10^7$	-
Au^{33+}	-	30 ms

The new KRION-6T ion source has much higher effective **j** (up to 1600 A/cm^2) in comparison with the KRION-2 which had only 200 A/cm^2. Another typical EBIS devices have only 100 - 300 A/cm^2.

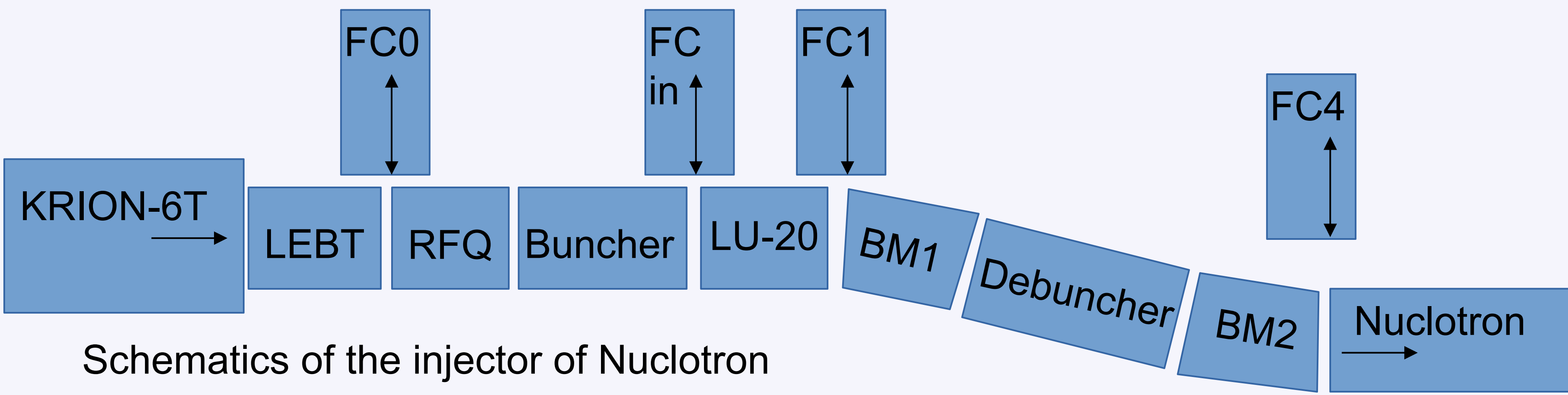
9. KRION-6T connected to the accelerator

- First time KRION-6T was in operation at Nuclotron at 50th run in May-June 2014
  The intensity of the Ar^{16+} beam was $3{,}9 \times 10^7$ ppp.





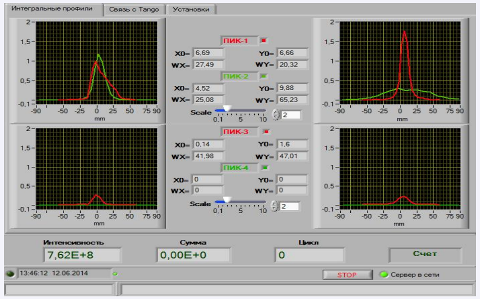
KRION-6T on the high voltage platform of the LU-20



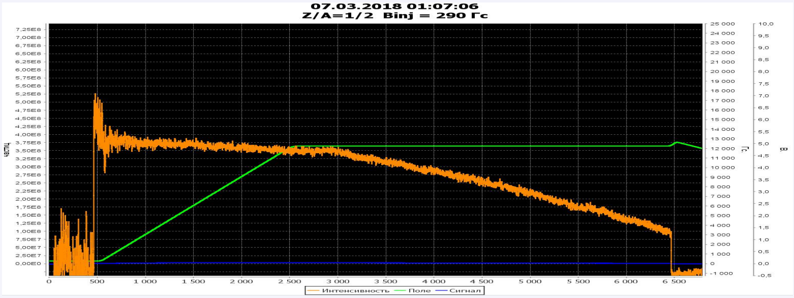
Schematics of the injector of Nuclotron

10. Technical results achieved on Nuclotron

C^{6+} 60 ms

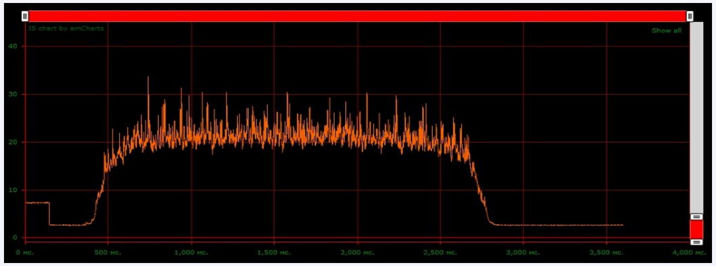


Profiles and extracted beam intensity 7,62x10^{8}

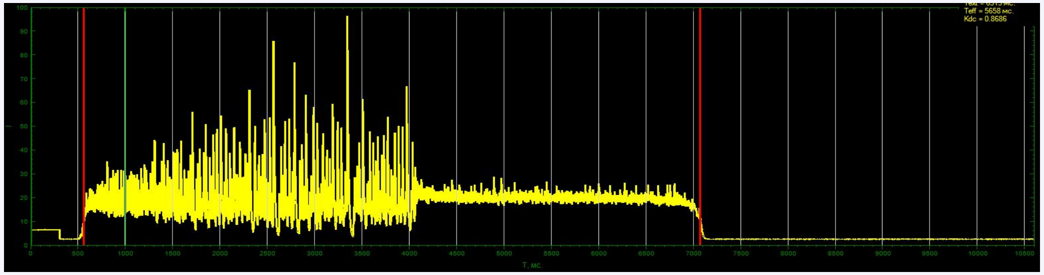


Intensity of the circulating beam 3,5x10^{8}

Ar^{16+} 2,35x10^{7}



$^{78}Kr^{26+}$ 75 ms 1x10^{7}



11. Physical results achieved with using of the beams from KRION-6T

Statictics of BM@N:

Beam of **Ar** with energie of **3,2** GeV/u:

Cu	$32{,}29\text{x}10^6$ events
Al	$35{,}88\text{x}10^6$ events
Sn	$30{,}75\text{x}10^6$ events
Pb	$14{,}28\text{x}10^6$ events
C	$12{,}12\text{x}10^6$ events

Beam of **Kr** with energie of **2,3** GeV/u:

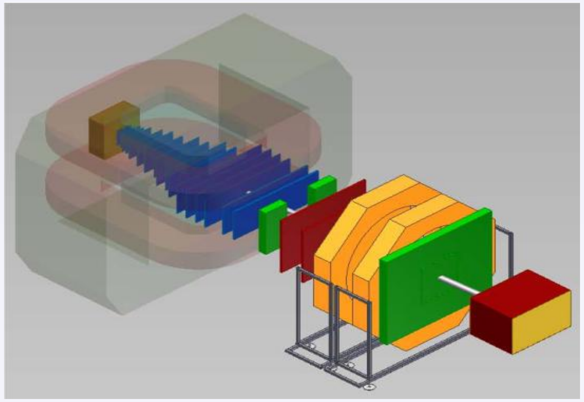
Cu	$1{,}28\text{x}10^6$ events
Al	$2{,}14\text{x}10^6$ events
Sn	$1{,}08\text{x}10^6$ events

Beam of **Kr** with energie of **3,2** GeV/u:

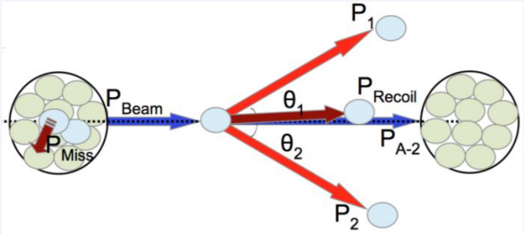
Cu	$14{,}43\text{x}10^6$ events
Al	$13{,}27\text{x}10^6$ events
Sn	$13{,}66\text{x}10^6$ events
Pb	$3{,}48\text{x}10^6$ events

Beam of **Kr** with energie of **2,94** GeV/u:

Cu	$2{,}37\ \text{x}10^6$ events



BM@N experiment



$$^{12}_{6}\mathrm{C} \to 2\mathrm{p} + {}^{10}_{5}\mathrm{B} + \mathrm{n}\ (\mathrm{np\ SRC})$$
$$^{12}_{6}\mathrm{C} \to 2\mathrm{p} + {}^{10}_{4}\mathrm{Be} + \mathrm{p}\ (\mathrm{pp\ SRC})$$

Process searched at SRC-BM@N experiment

Statistics of SRC-BM@N:

C beam with energy of **3,17** GeV/u:

H_2	$13{,}05\ \text{x}10^6$ events

Thank you for your attention