The Electron String Ion Sources (ESIS) cathode node electronics development

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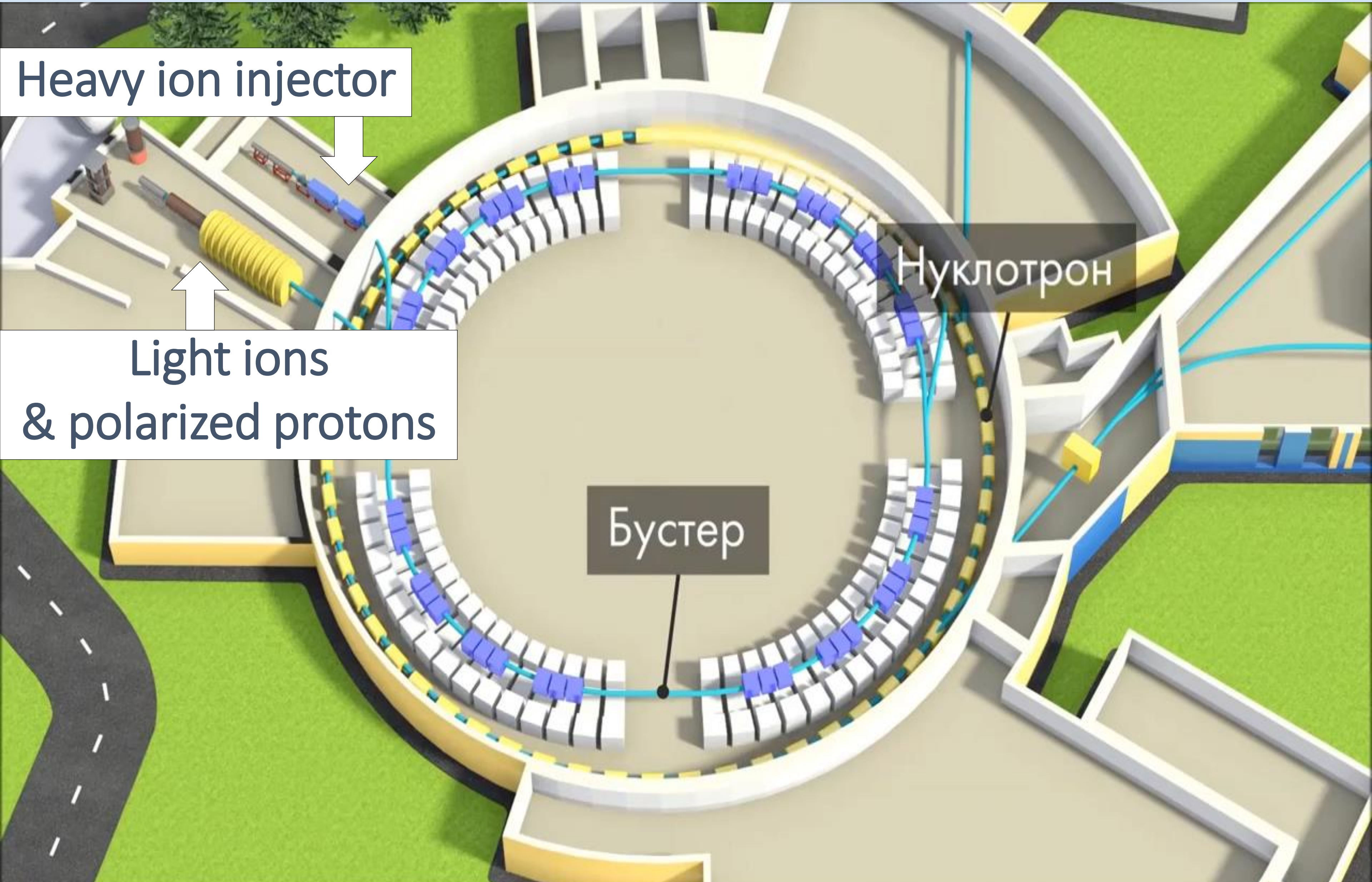
LHEP JINR senior engineer

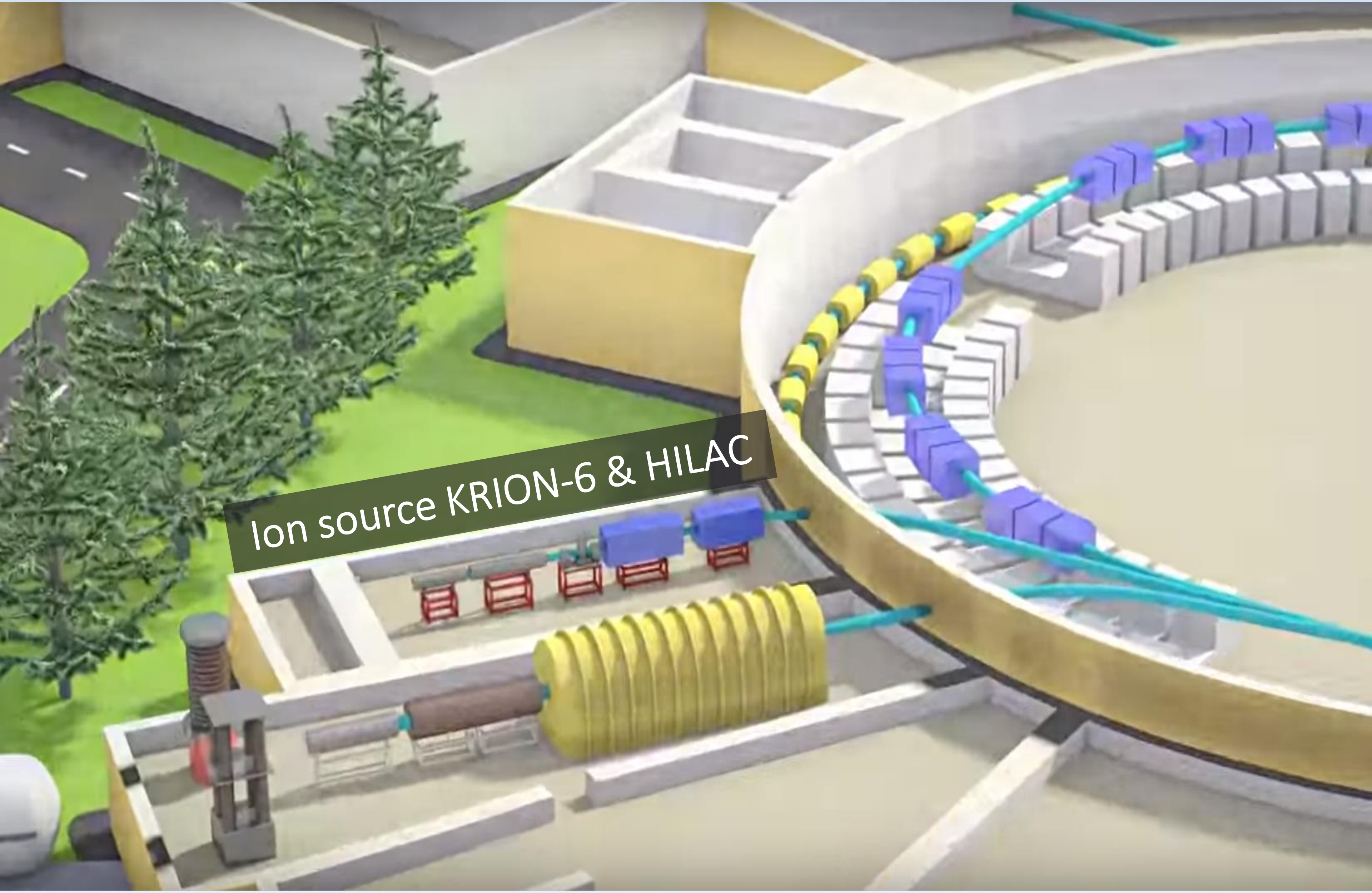
on behalf of the NICA acceleration division

Dubna, 24-28 October 2022

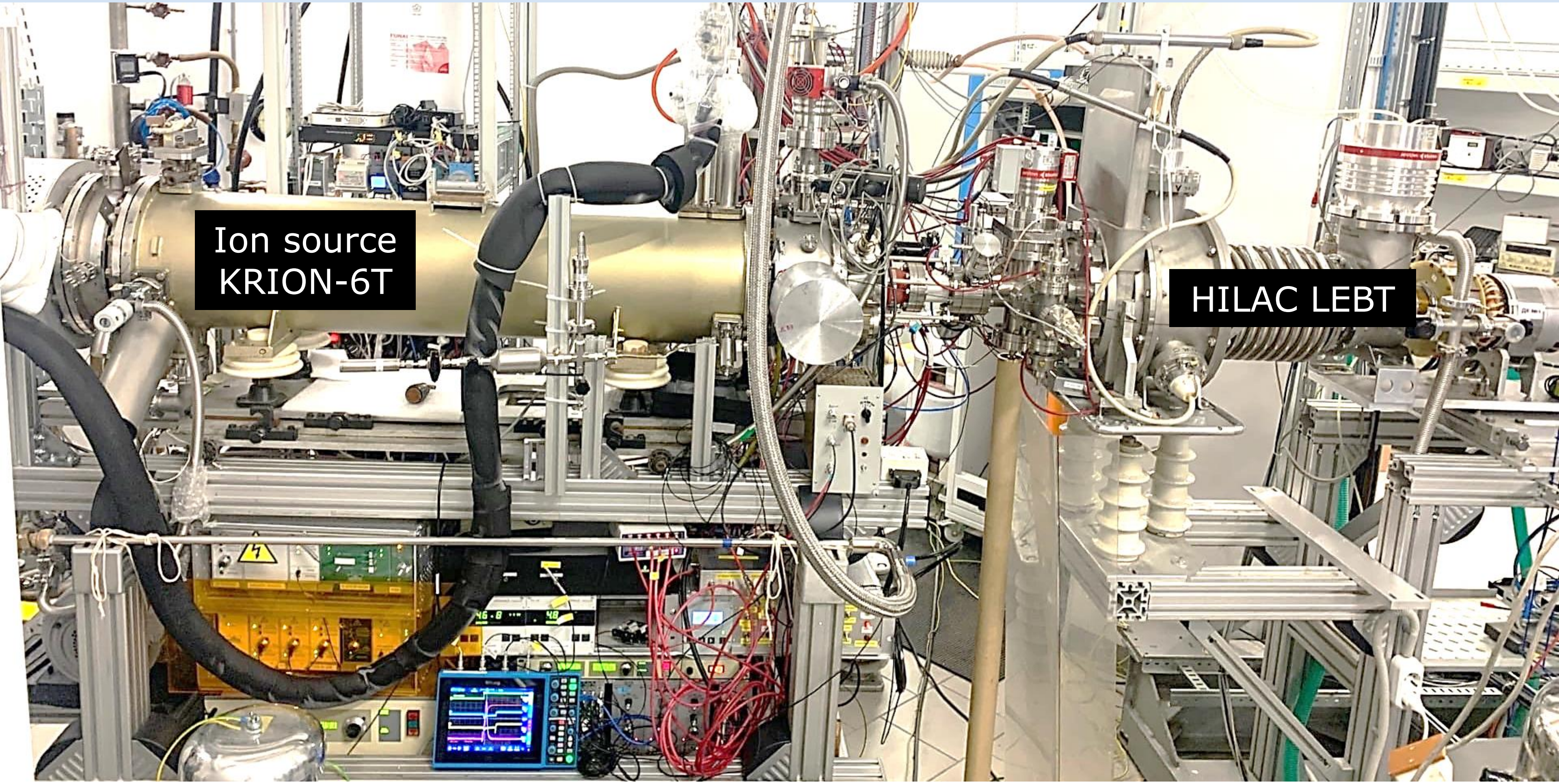
NICA injection complex



Heavy ion injection



Heavy ion source KRION 6T



Ions produced and injected: $^{78}Kr^{17+}$ $^{124}Xe^{41+}$ $^{40}Ar^{16+}$ $^{12}C^{6+}$ ...

- 5.4 T SC solenoid
- electron string
- highly charged ions
- pulsed ion source
- cryogenic
- unique technology

EBIS = Electron Beam Ion Source

History

•Invented by E.D. Donets at JINR,Dubna in 1968. Au^{19+} beam in 1969.

•1970-1985, in Dubna, cryogenic version of EBIS KRION-I,2, bare ions C, N, O, Ne, Ar, Kr, Xe. HCI physics begins.

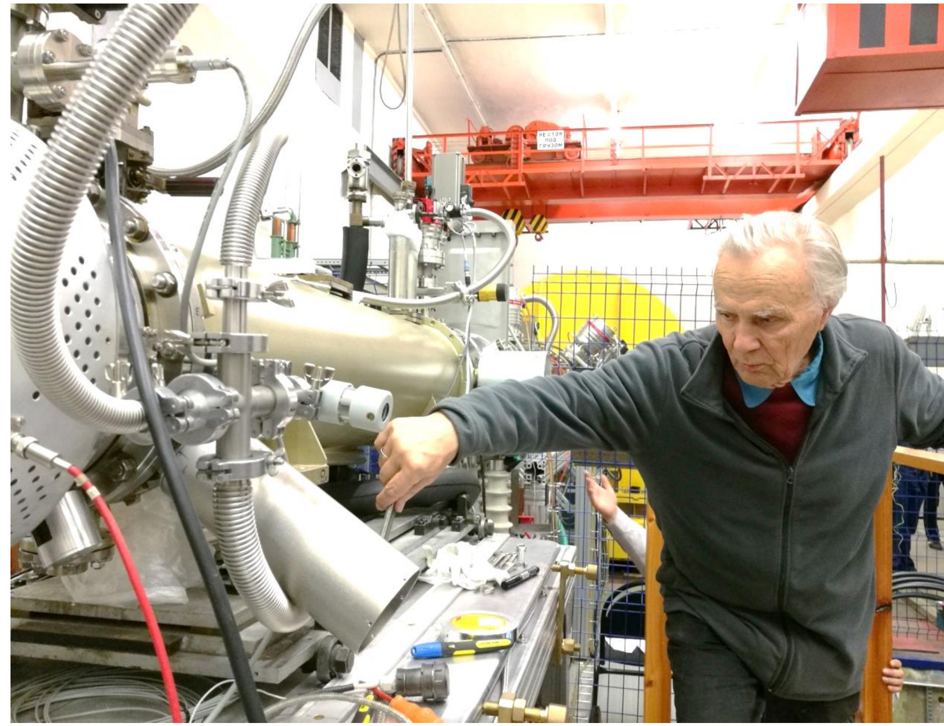
•1970-1985, Europe, US, Japan, a lot of EBIS (*EBIS time*), $\mathbf{U^{90+}}$ **!**

•1982, at Bekerley, EBIT, from EBIS, 1990s, SuperEBIT, U^{92+} !

•Since 1985, in accelerator fields, ECRIS time

•2001-2005, breakthrough of EBIS at JINR, new idea of ESIS, and high current EBIS at BNL.

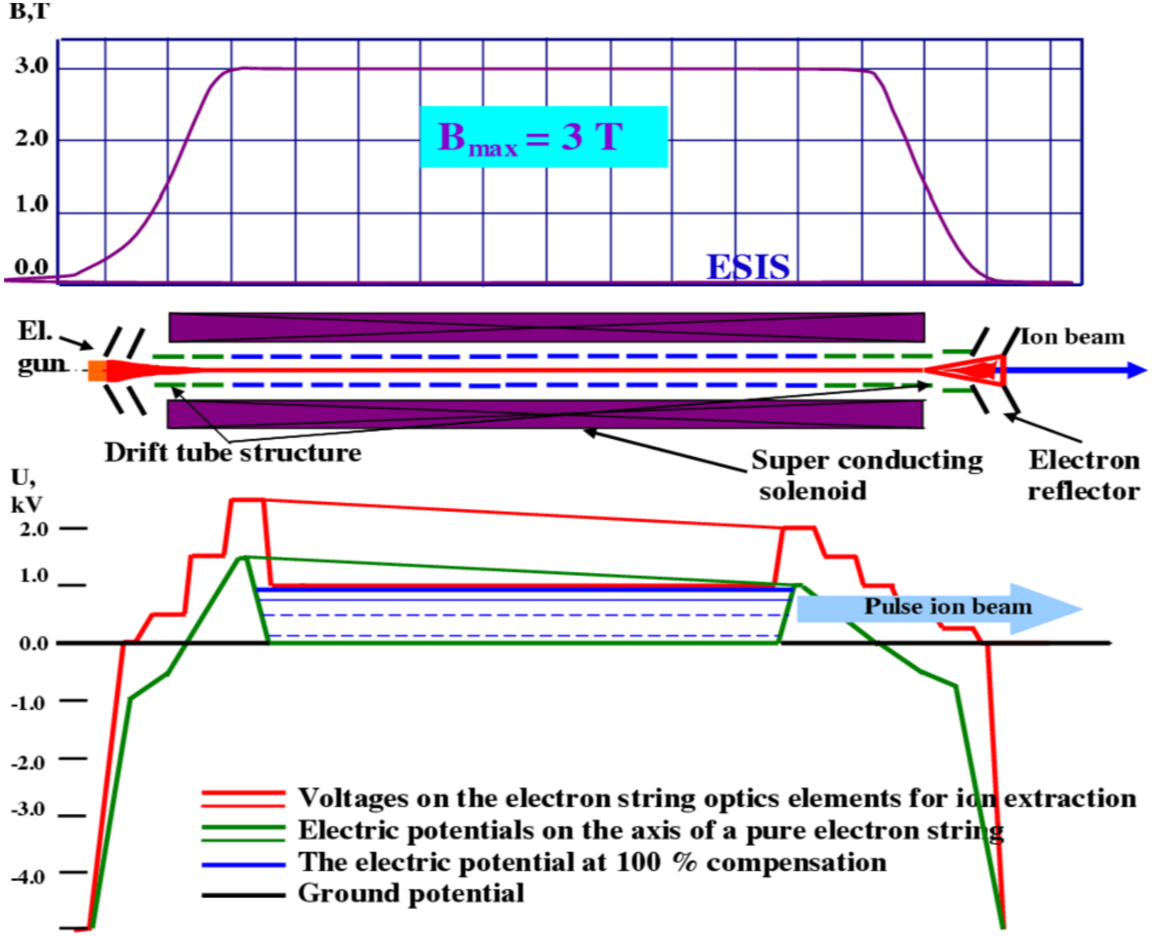
•In China, Shanghai EBIT



Prof. E.D. Donets near Krion-6T ESIS during Nuclotron run #55, JINR, Dubna, February 2018

• **ESIS Krion 6T and Krion N1 for NICA JINR**

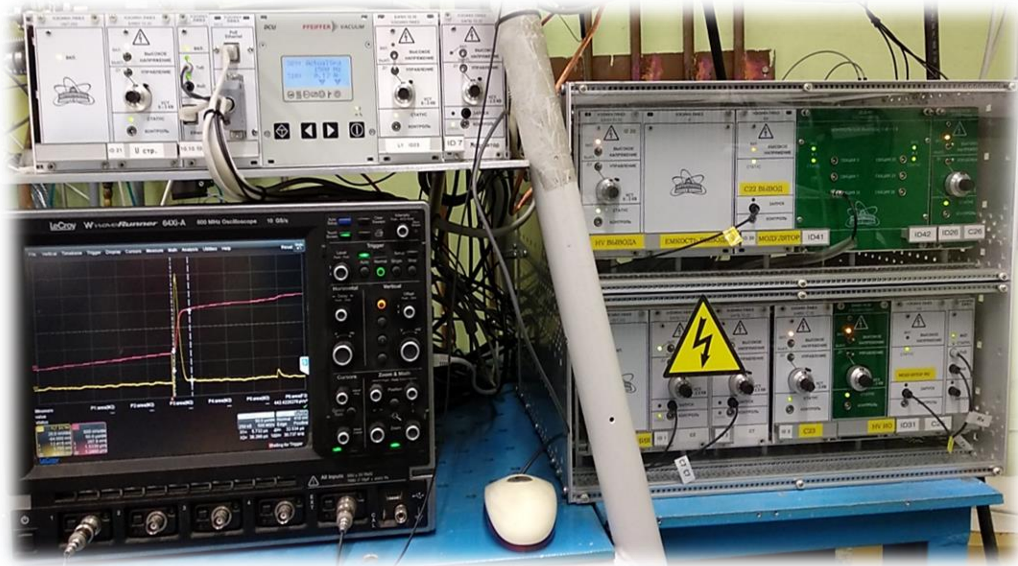
ESIS = EBIS in electron reflex mode of operation



ESIS KRION 6T electronics

Slow control

- vacuum
- ion optics supply
- HV electrodes
- electron gun supply
- synchronization
- thermometry



Ion motion control system

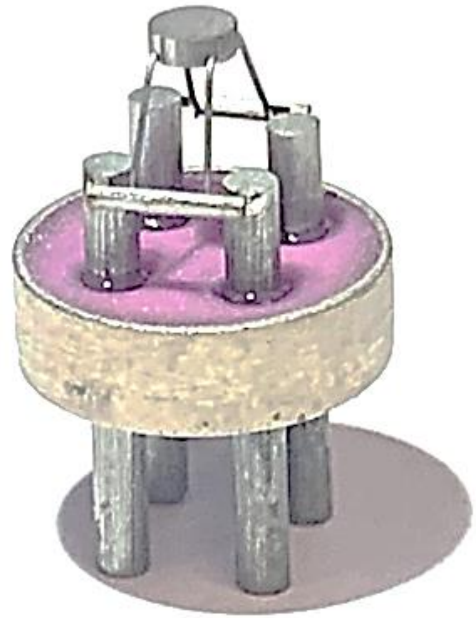
- DC barrier modules
- pulsed barriers modules
- extraction modules
- interface modules
- drift structure divider

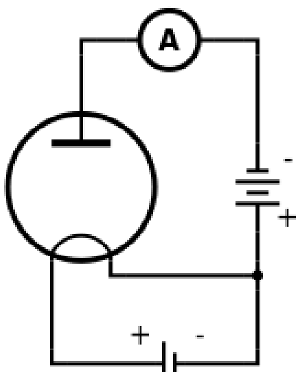
Beam diagnostics

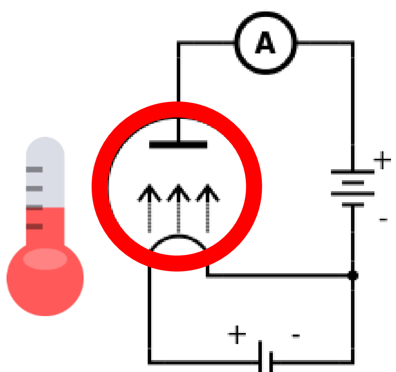
- beam profile monitor
- oscilloscopes
- ion collectors
- ToF system
- indused signals

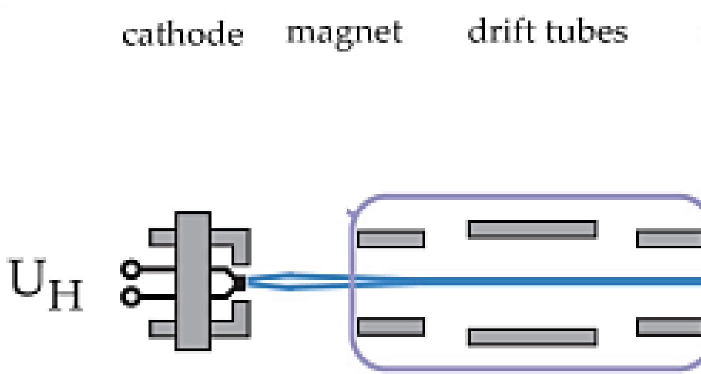
IrCe cathode

- material IrCe
- emission: thermionic
- small size 1.2 mm
- emission current 6 mA
- heating power AC 1.5V 10A

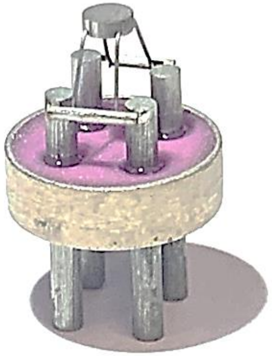




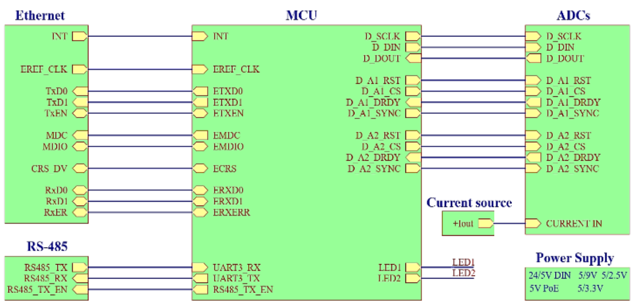


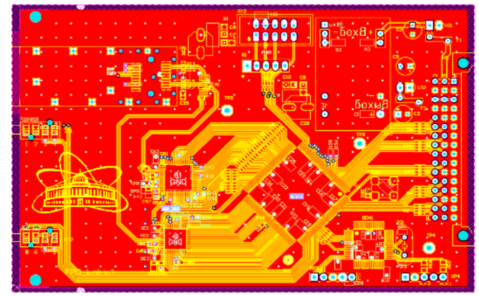


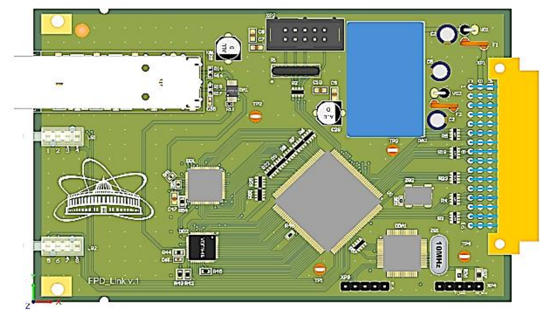
the design process

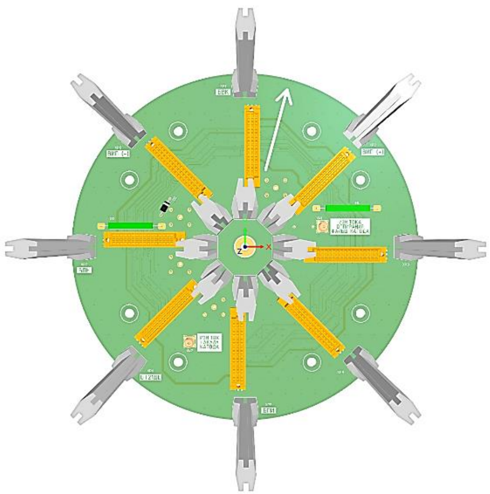


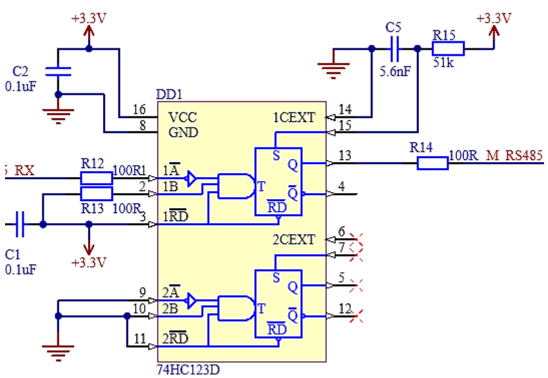
The design process



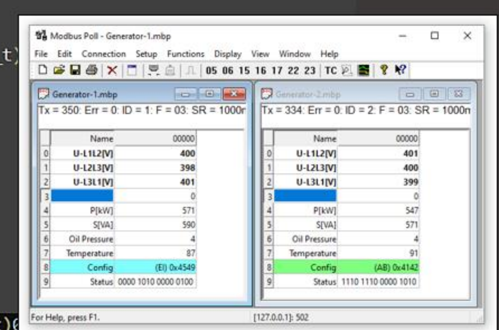




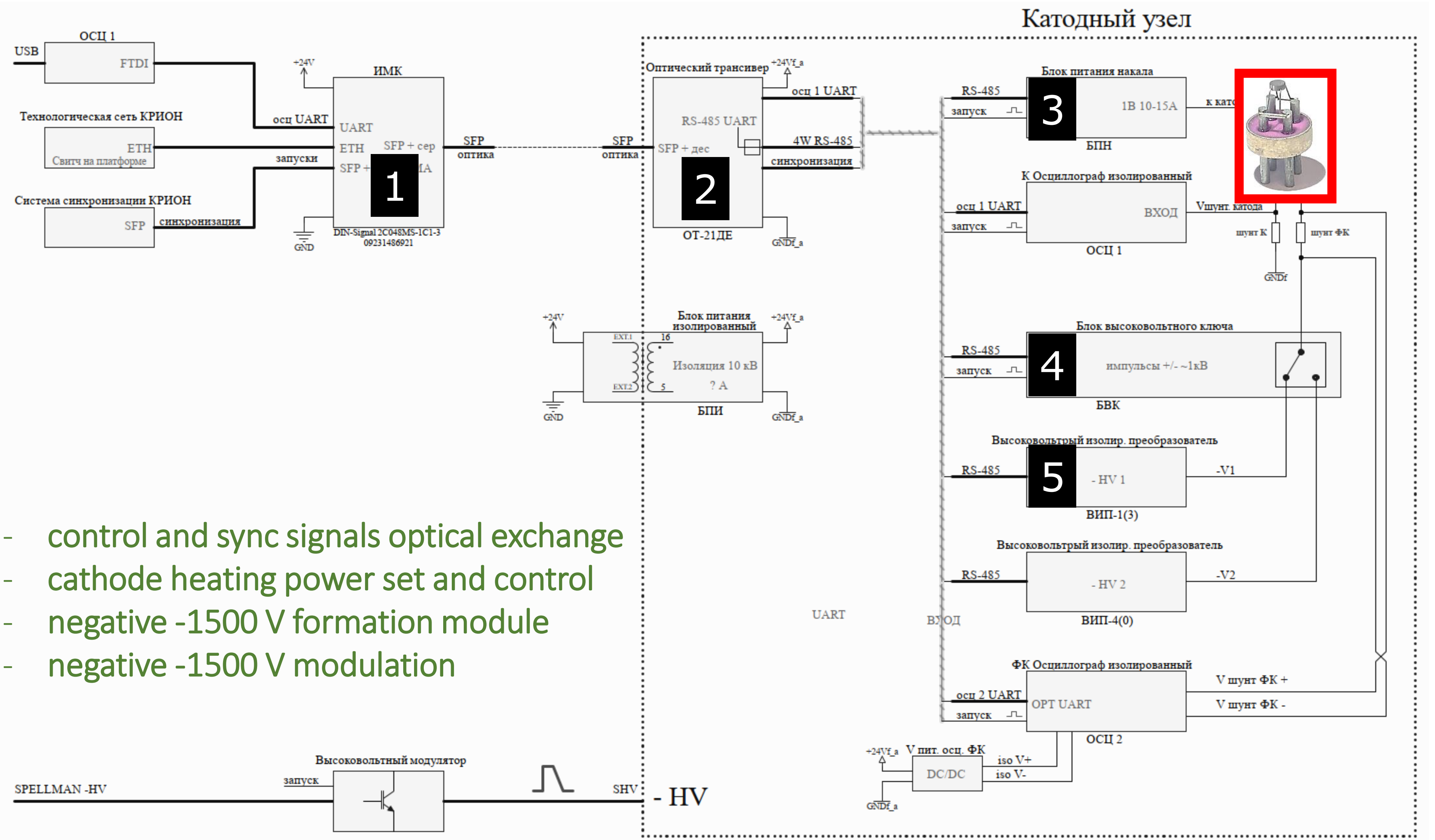





```
void task_KORAD(void *pvParameters)
{
    KORAD_params KORADp, KORADtemp;
    KORAD_state *src_state,src_stateTEMP;
    unsigned int V2set = 0, I2set = 0;
    unsigned int State2set = 0;

    while(1)
    {
        // set voltage level if queue not empty
        if(uxQueueMessagesWaiting(KORAD_SetV_q) > 0)
        {
            xQueueReceive(KORAD_SetV_q,(void*)&V2set, (TickType_t)0);
            KORAD_SetVoltage(V2set);
        }

        // set current value if queue not empty
        if(uxQueueMessagesWaiting(KORAD_SetI_q) > 0)
        {
            xQueueReceive(KORAD_SetI_q,(void*)&I2set, (TickType_t)0);
            KORAD_SetCurrent(I2set);
        }

        // set output state if queue not empty
        if(uxQueueMessagesWaiting(KORAD_SetState_q) > 0)
        {
            xQueueReceive(KORAD_SetState_q, &State2set, (TickType_t)
            KORAD_SetState(State2set);
        }

        // read measured V I, and V I sets
        KORADp.meas_v = KORAD_GetVoltage();
        KORADp.set_v  = KORAD_GetVSets();
        KORADp.meas_i = KORAD_GetCurrent();
        KORADp.set_i  = KORAD_GetISets();

        // clear prev measured data if queue is not empty
        if(uxQueueMessagesWaiting(KORAD_RdParams_q) > 0)
            xQueueReceive(KORAD_RdParams_q, &KORADtemp, (TickType_t)(
```

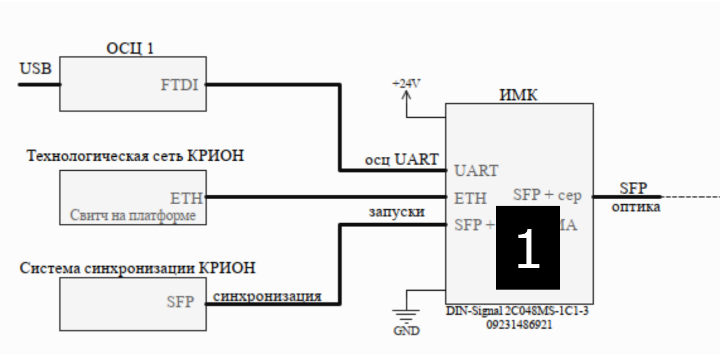


Cathode node schematic



- control and sync signals optical exchange
- cathode heating power set and control
- negative -1500 V formation module
- negative -1500 V modulation

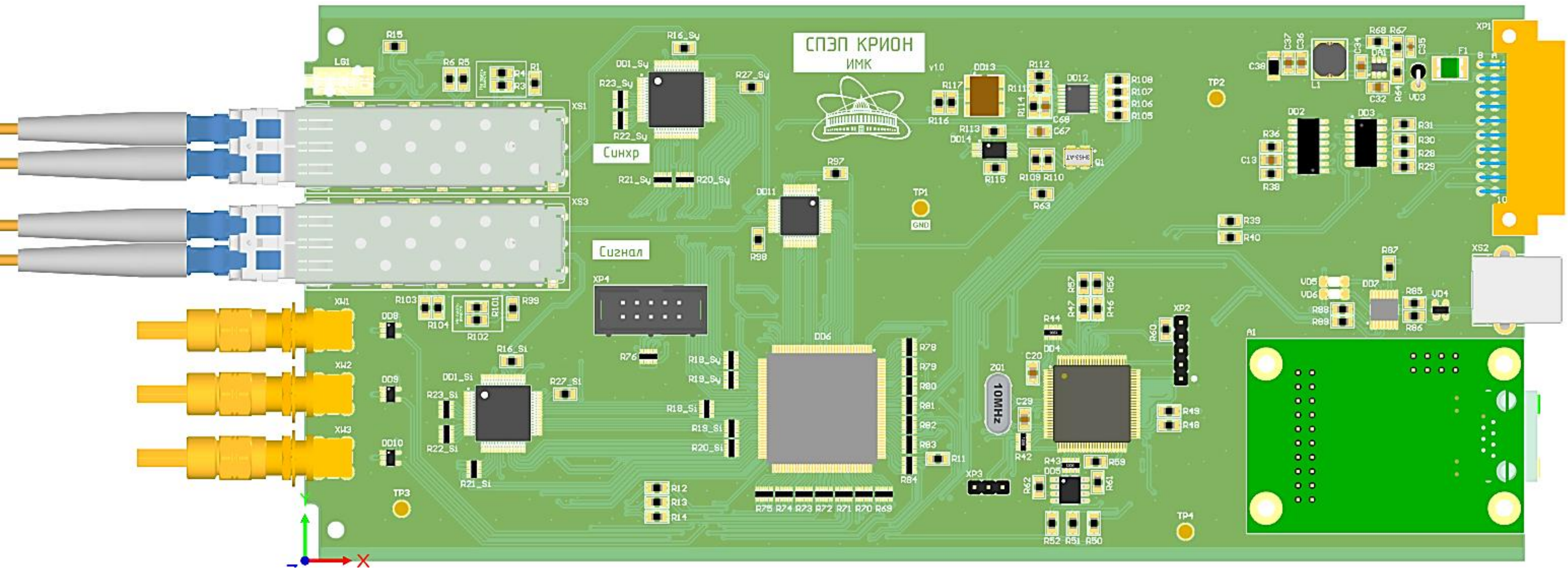
Cathode node => interface module



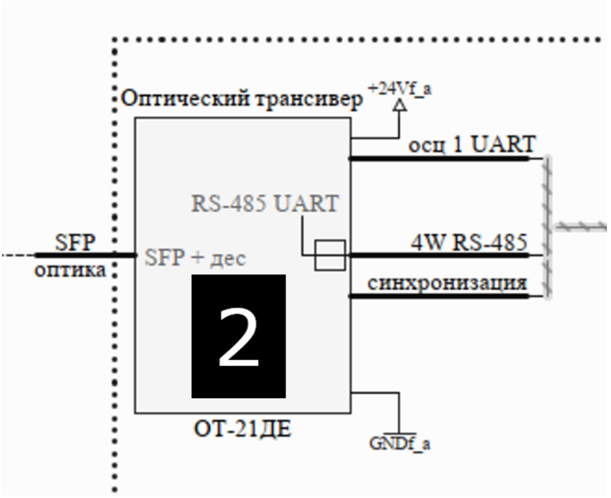
The main idea:

control and sync signals optical exchange

Interfaces: SFP, eth, RS-485, USB



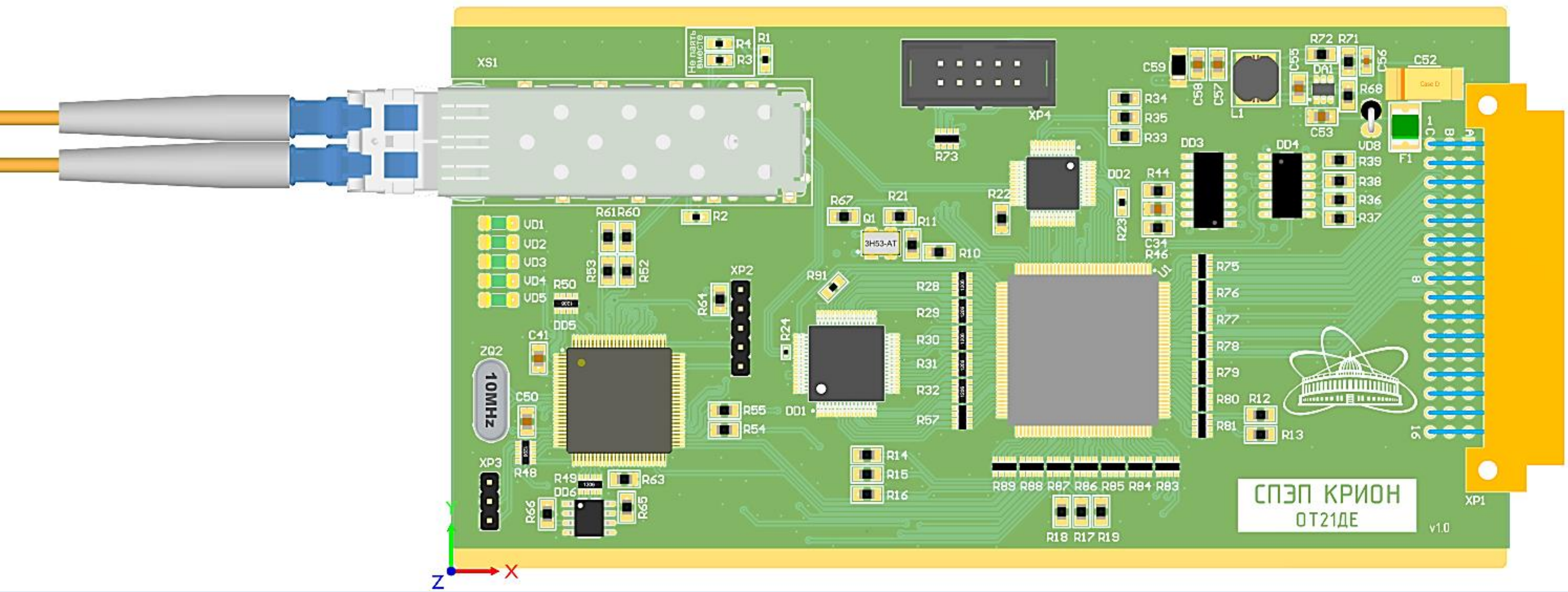
Cathode node => optical isolation module



The main idea:

control and sync signals optical exchange

Interfaces: SFP, RS-485

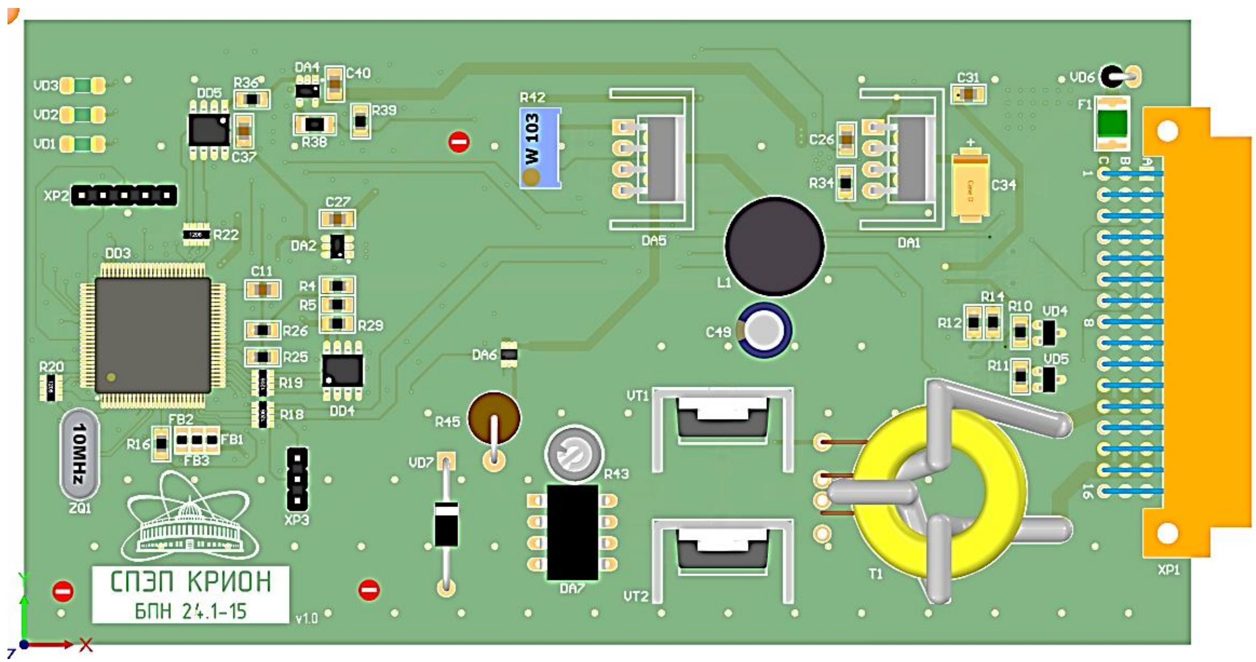


Cathode node => Heating module

The main idea:

cathode heating power set and control

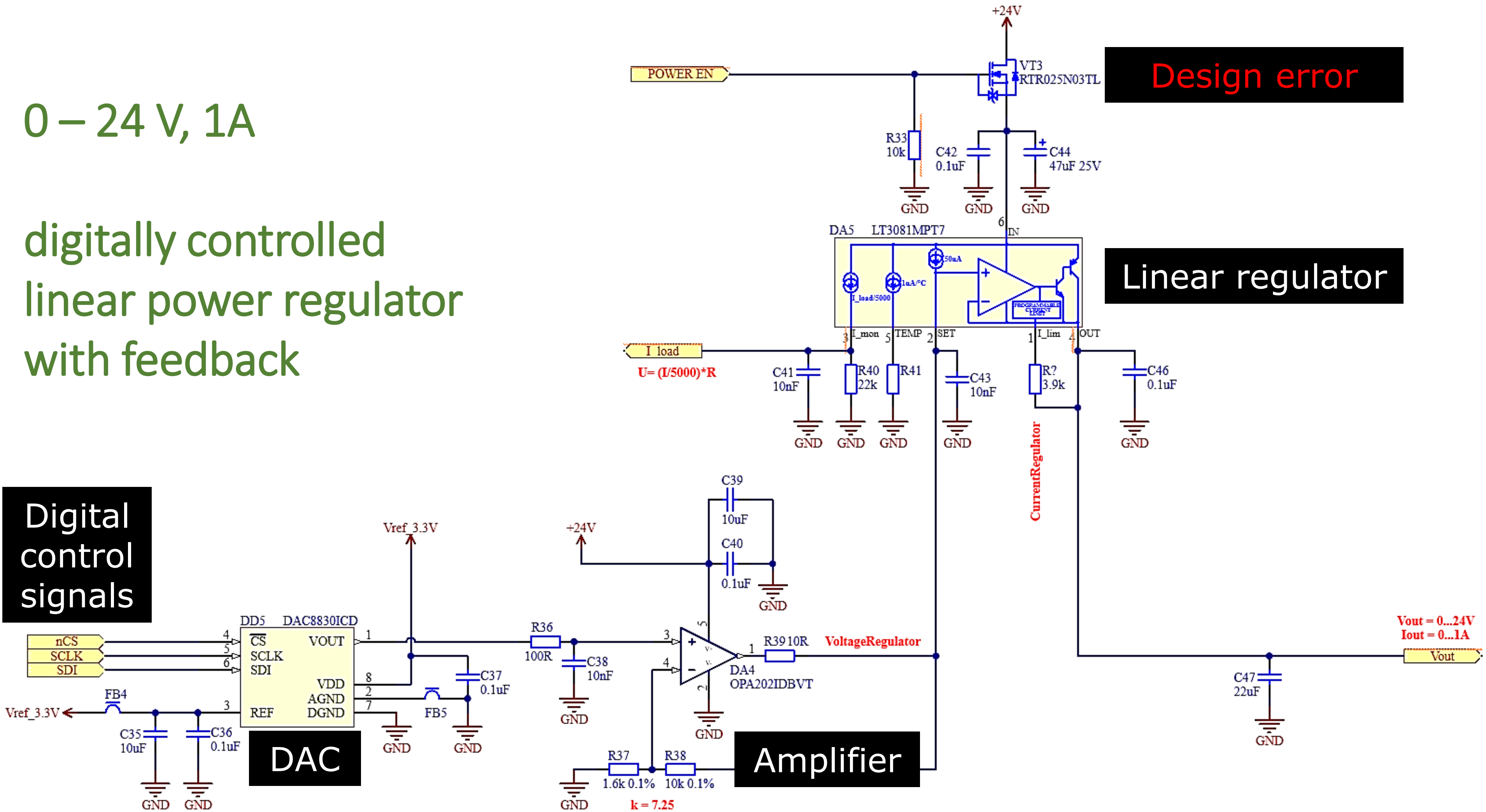
points: 10 kHz sine, 1.5 V, 10 A



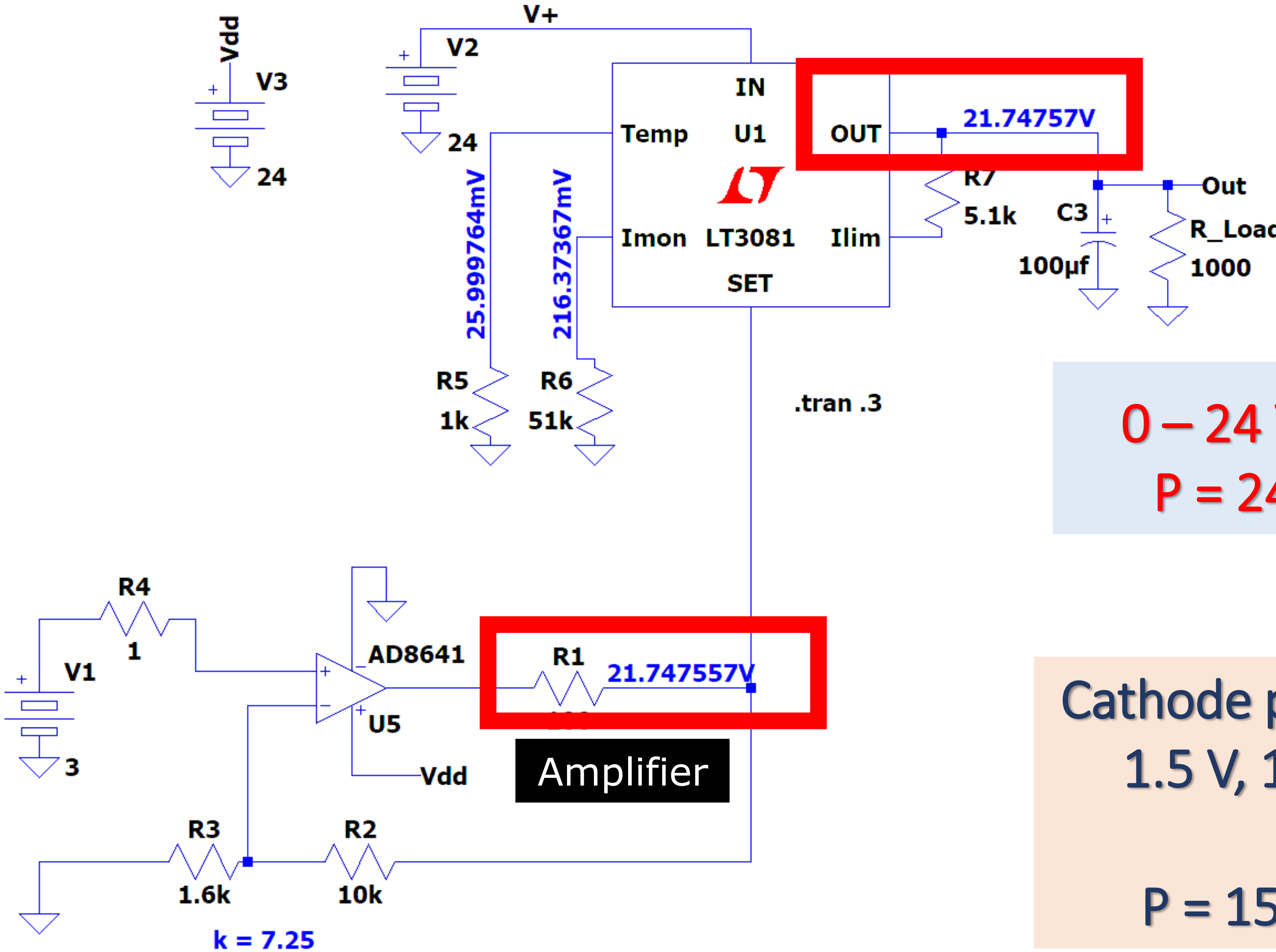
Cathode node => heating module schematic

0 – 24 V, 1A

digitally controlled
linear power regulator
with feedback



Tricky Linear regulator



Control voltage

0 – 3.3V
=
0 – 24V

0 – 24 V, 1A
P = 24 W

Cathode power:
1.5 V, 10 A

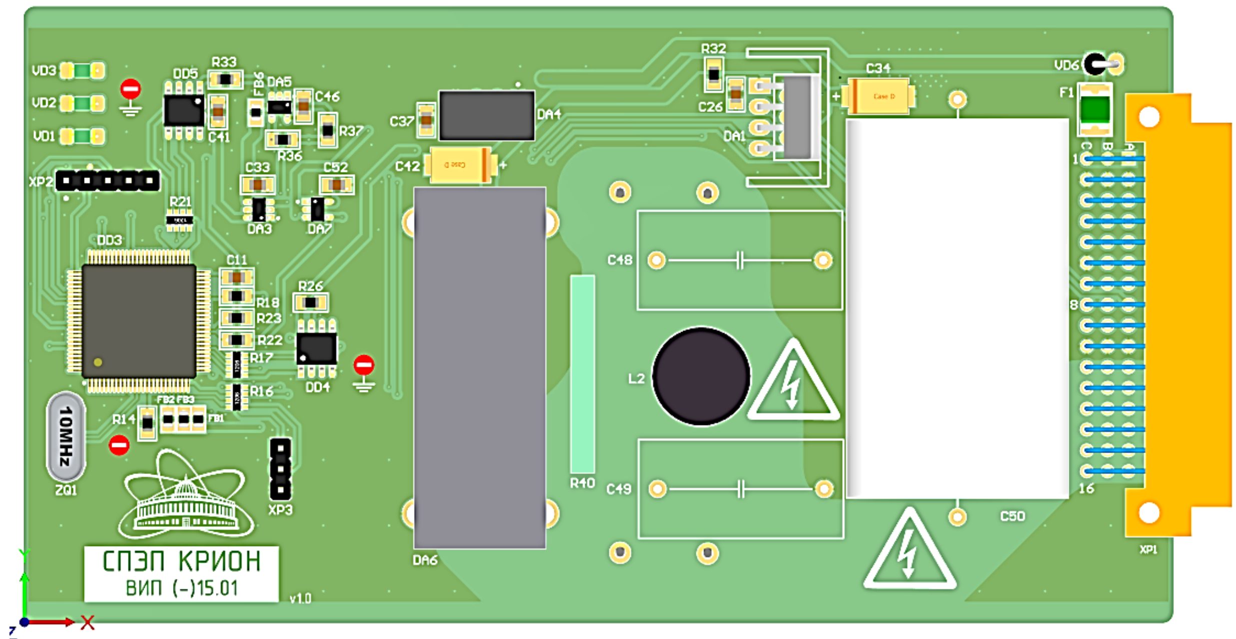
P = 15 W

Cathode node => DC HV module

The main idea:

Negative -1500 V formation module

Interfaces: RS-485, programmable

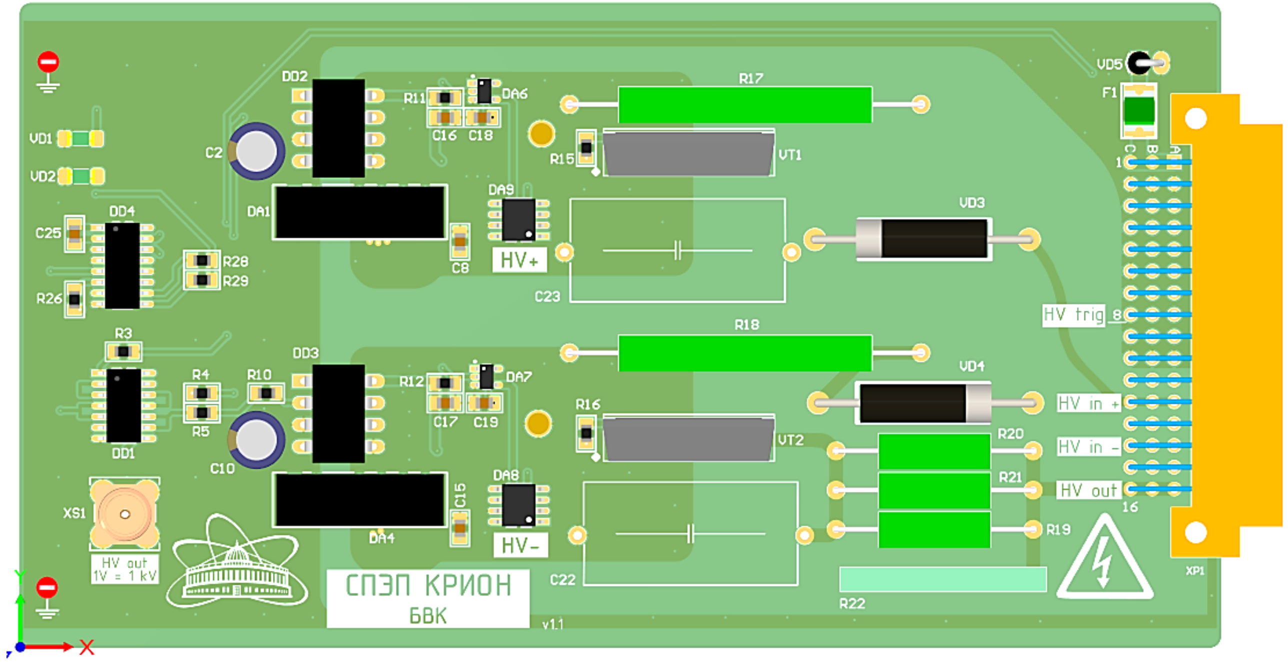


Cathode node => HV modulator

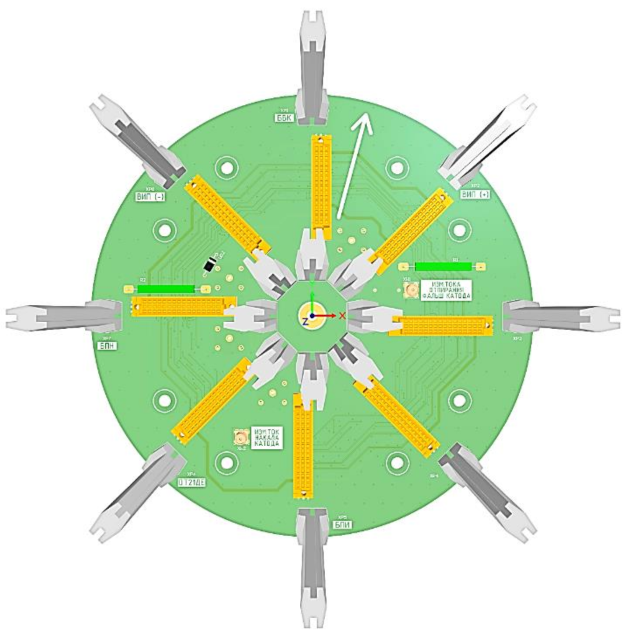
The main idea:

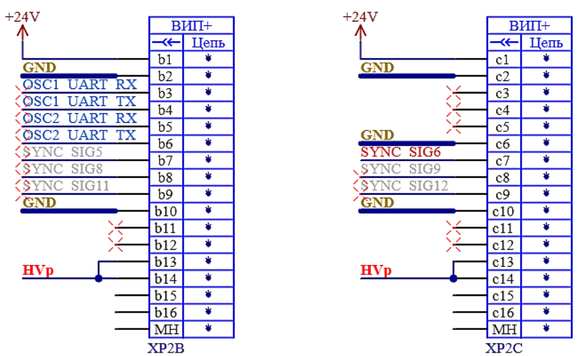
Negative -1500 V modulation module

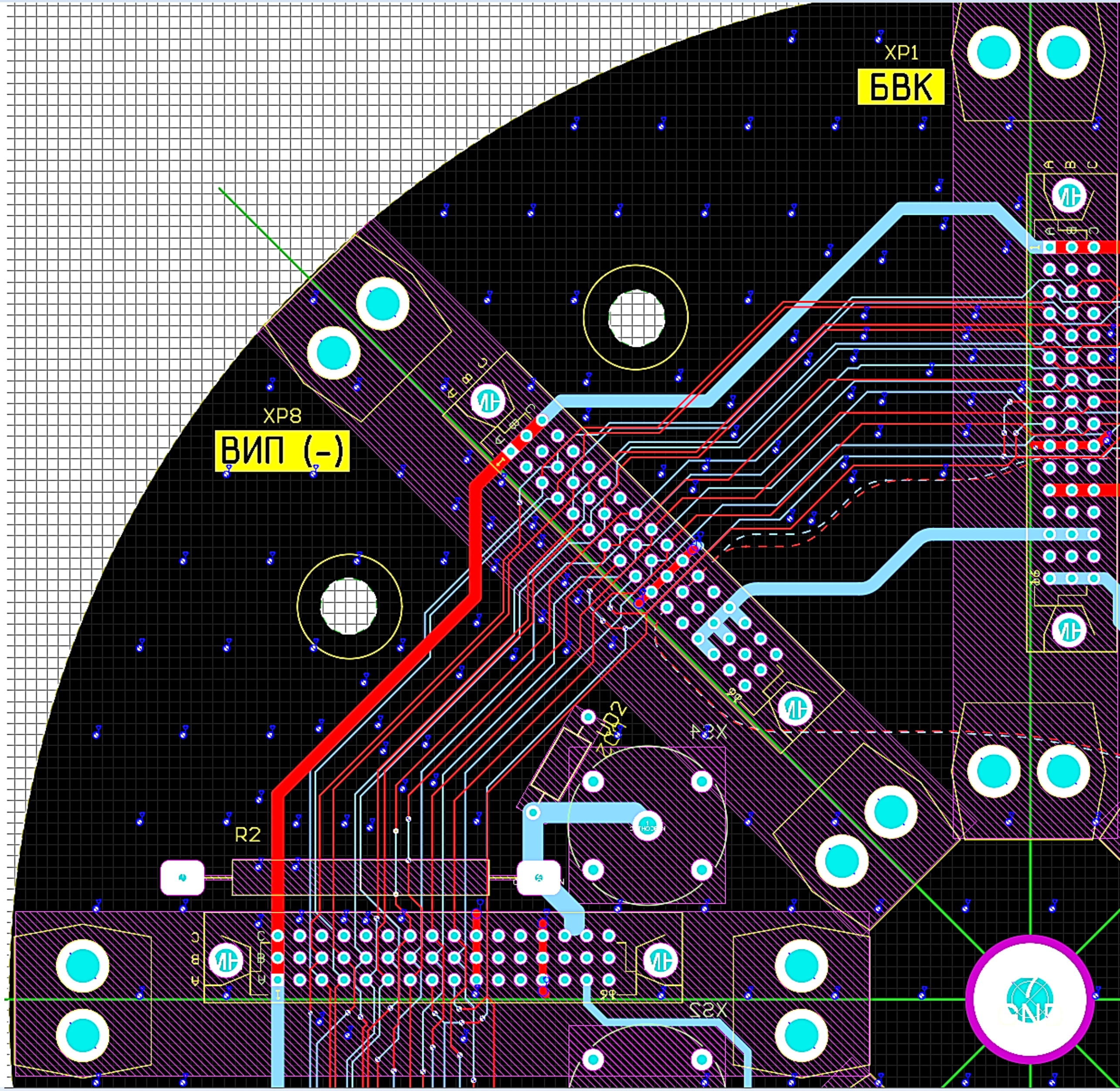
Interfaces: RS-485, pulsed, IGBT-sw



Cathode node => backbone board







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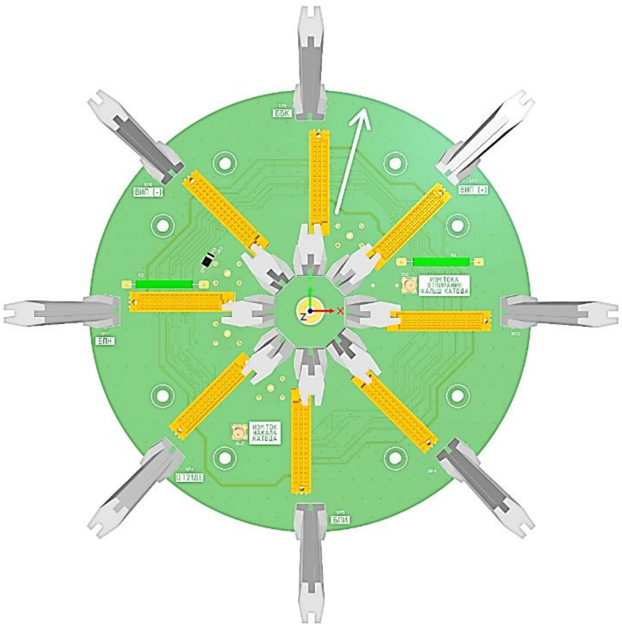
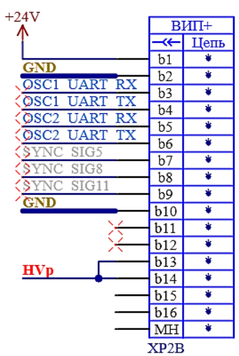
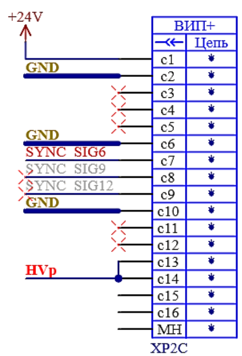
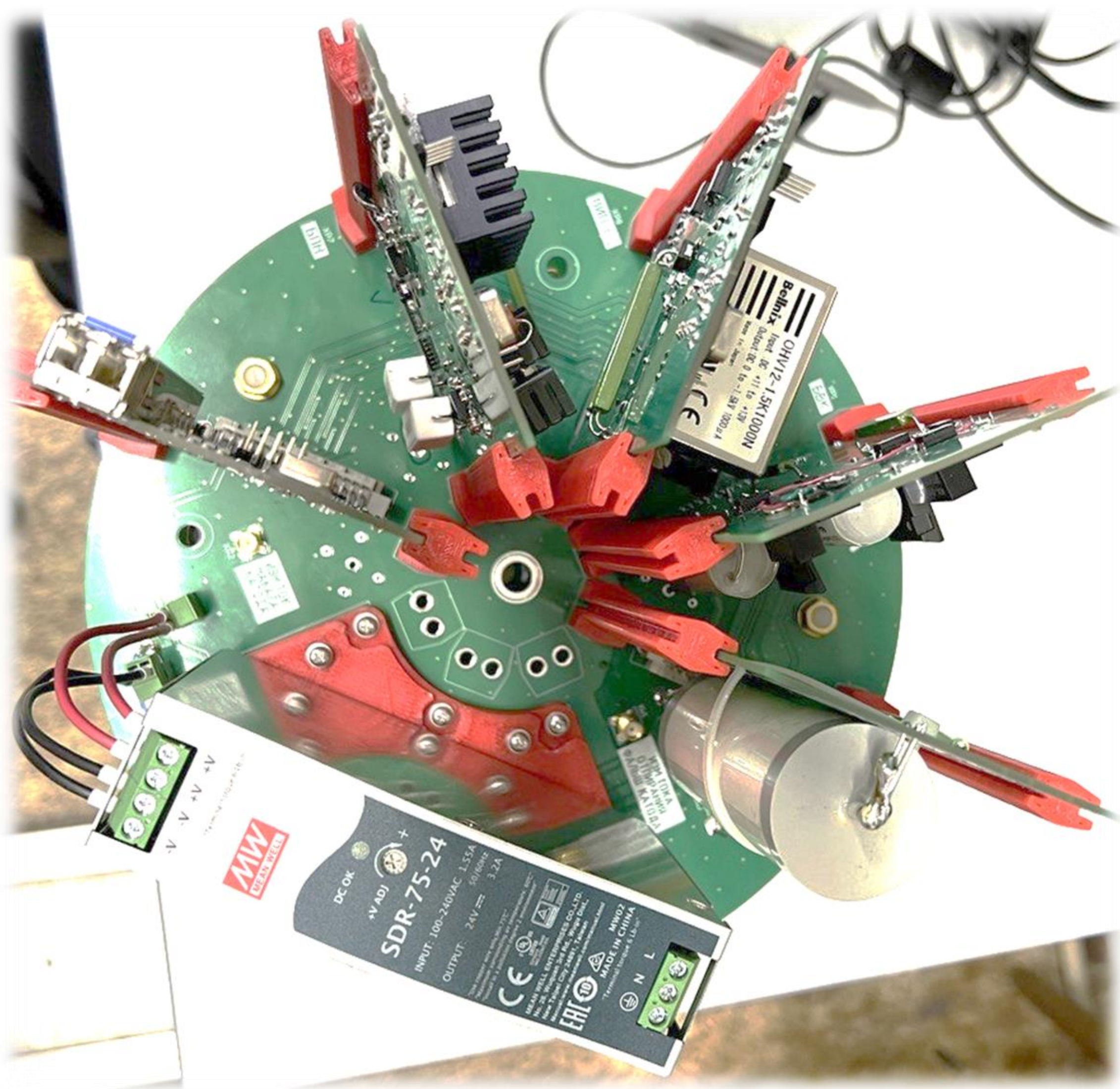


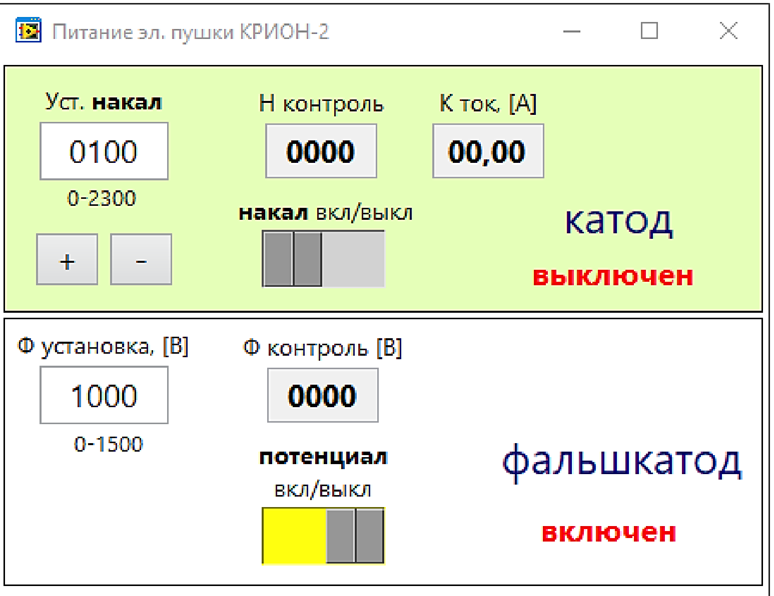


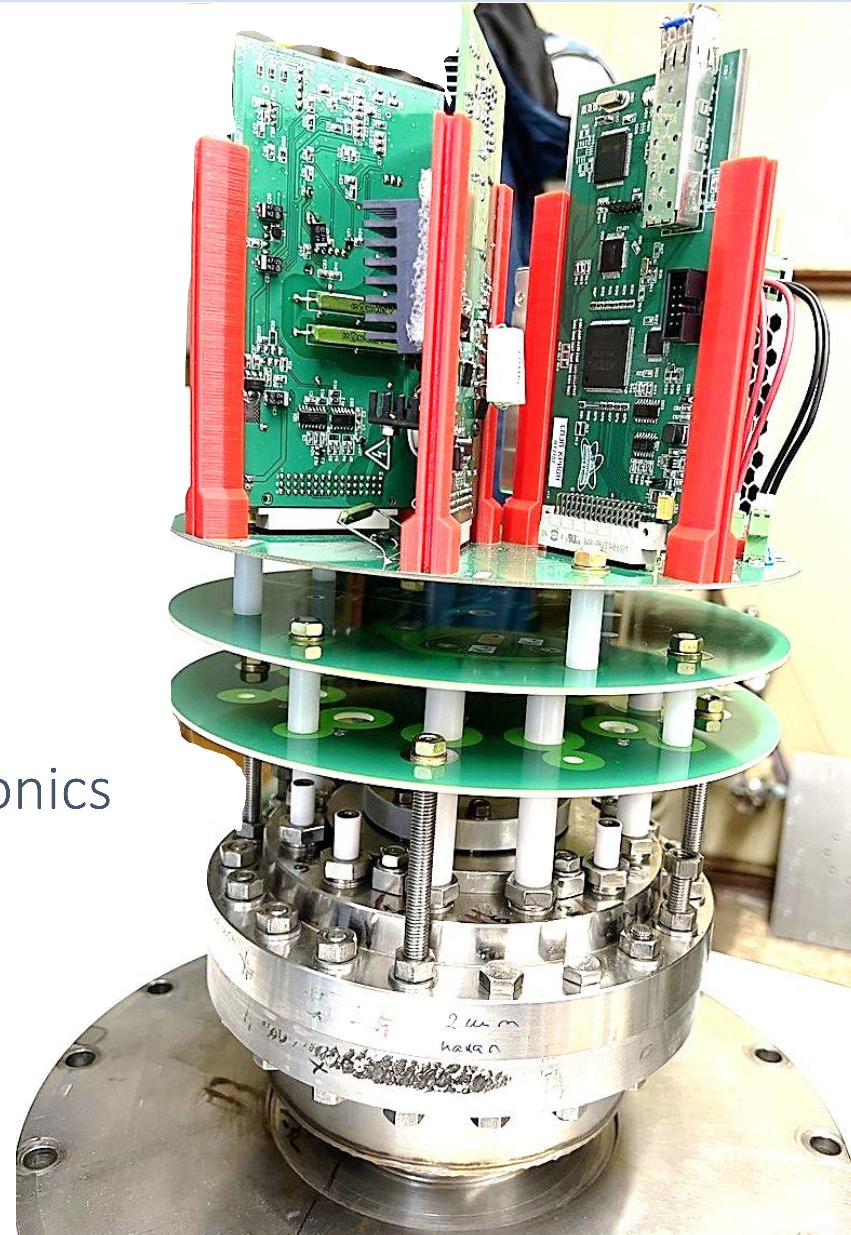




Summary

KRION-6T cathode node electronics





The NEW KRION-6T cathode node electronics was designed, produced and tested

At the moment is putting into operation

For technical details – please welcome!

We are ready for collaboration in any technical questions

email: **ponkin@jinr.ru**

Thank you!

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.