“The First Commission Results of the High Voltage Magnetized Cooler for COSY"

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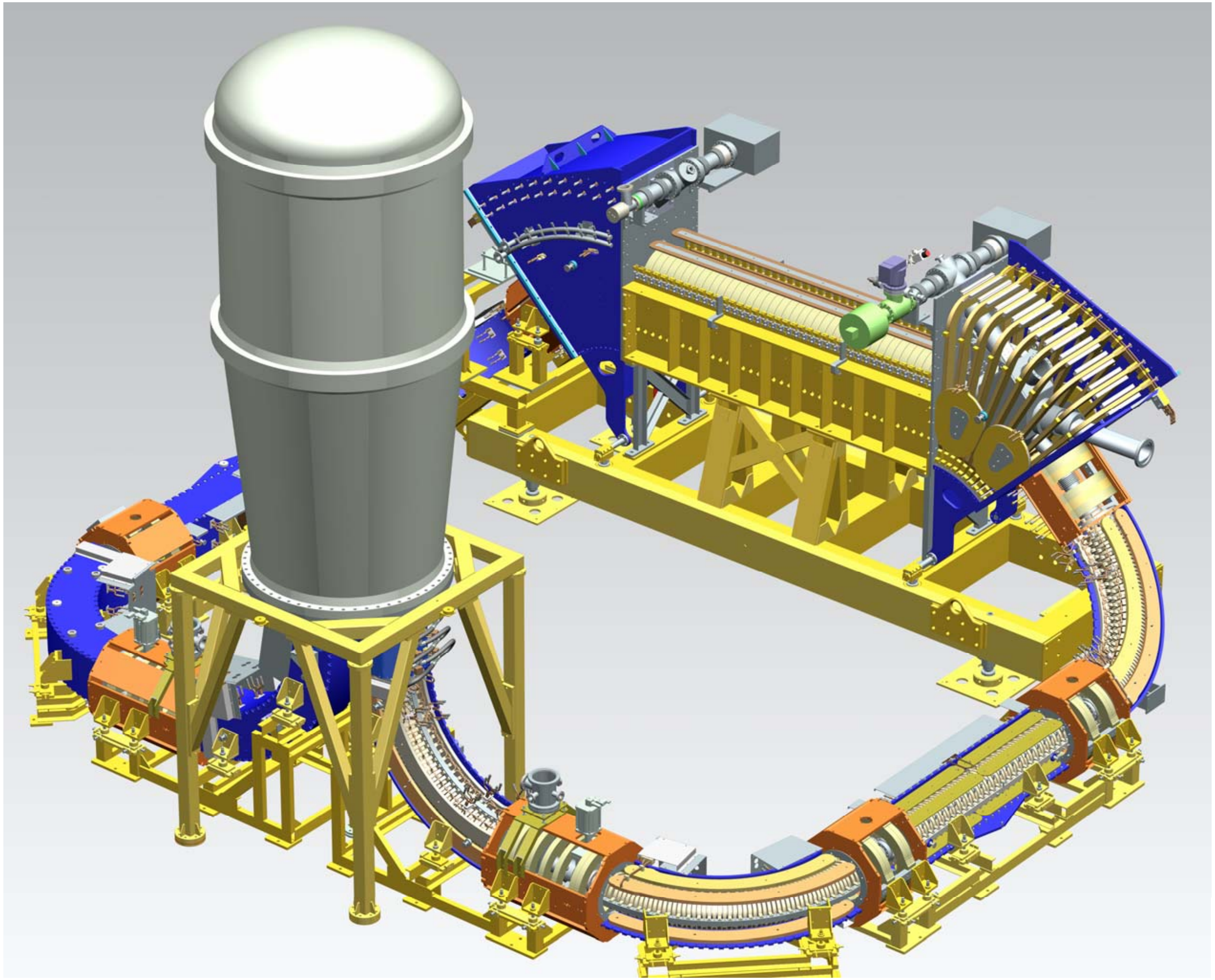
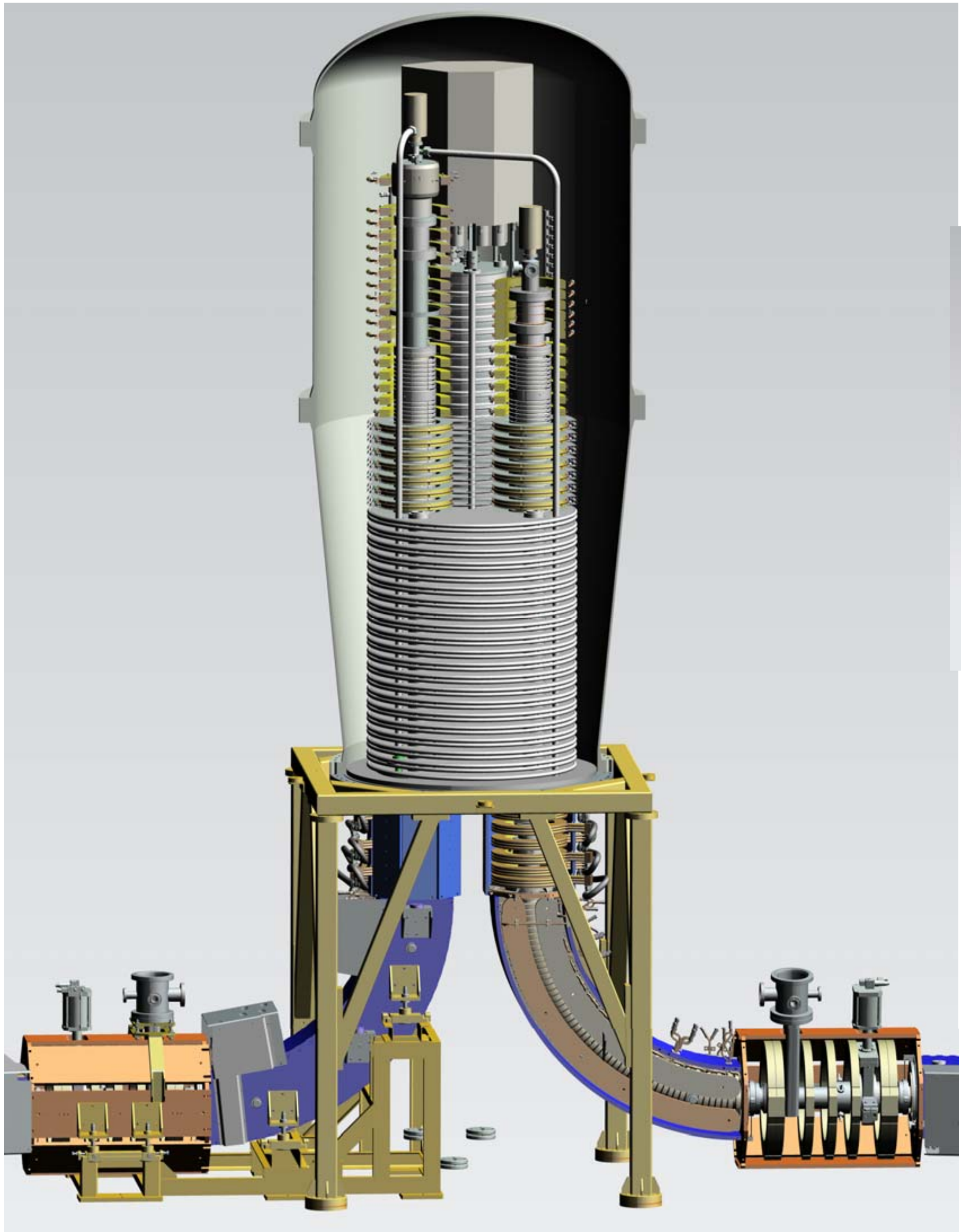
Contents

1. Description of COSY design;
2. Mapping of the magnetic fields of COSY cooler;
3. Compass measurement system;
4. Cascade Transformer for powering of high voltage sections;
5. Test-Bench: Gun and Collector;
   - Electron Gun with 4-sectors control electrode;
   - Electron Collector;
8. Summary

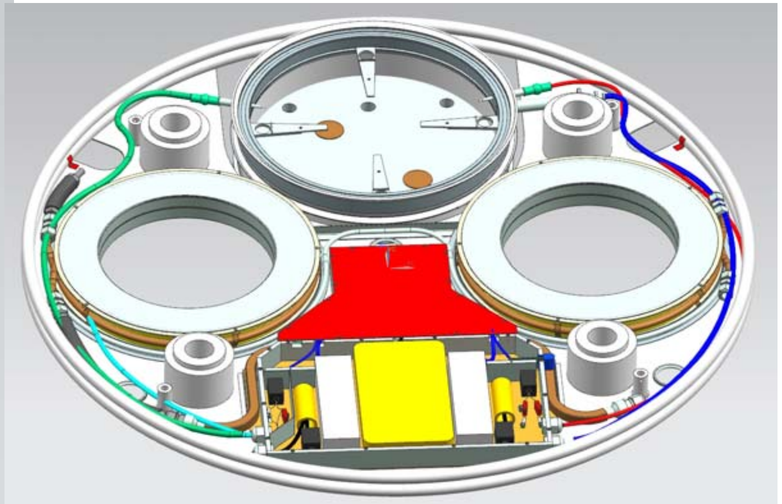
2 MeV Electron Cooler	Parameter
Energy Range	0.1 ... 2 MeV
Maximum Electron Current	3 A
Cathode Diameter	30 mm
Cooling section length	2.69 m
Toroid Radius	1.00 m
Magnetic field in the cooling section	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar
Available Overall Length	6.39 m

3D design of COSY Cooler





3D design of Accelerating Column



Each section contains;

- high-voltage power supply +/- 30 kV;

- power supply of the coils of the magnetic field (2.5 A, 500 G);

- section of the cascade transformer for powering of all electronic components;

33 high-voltage section

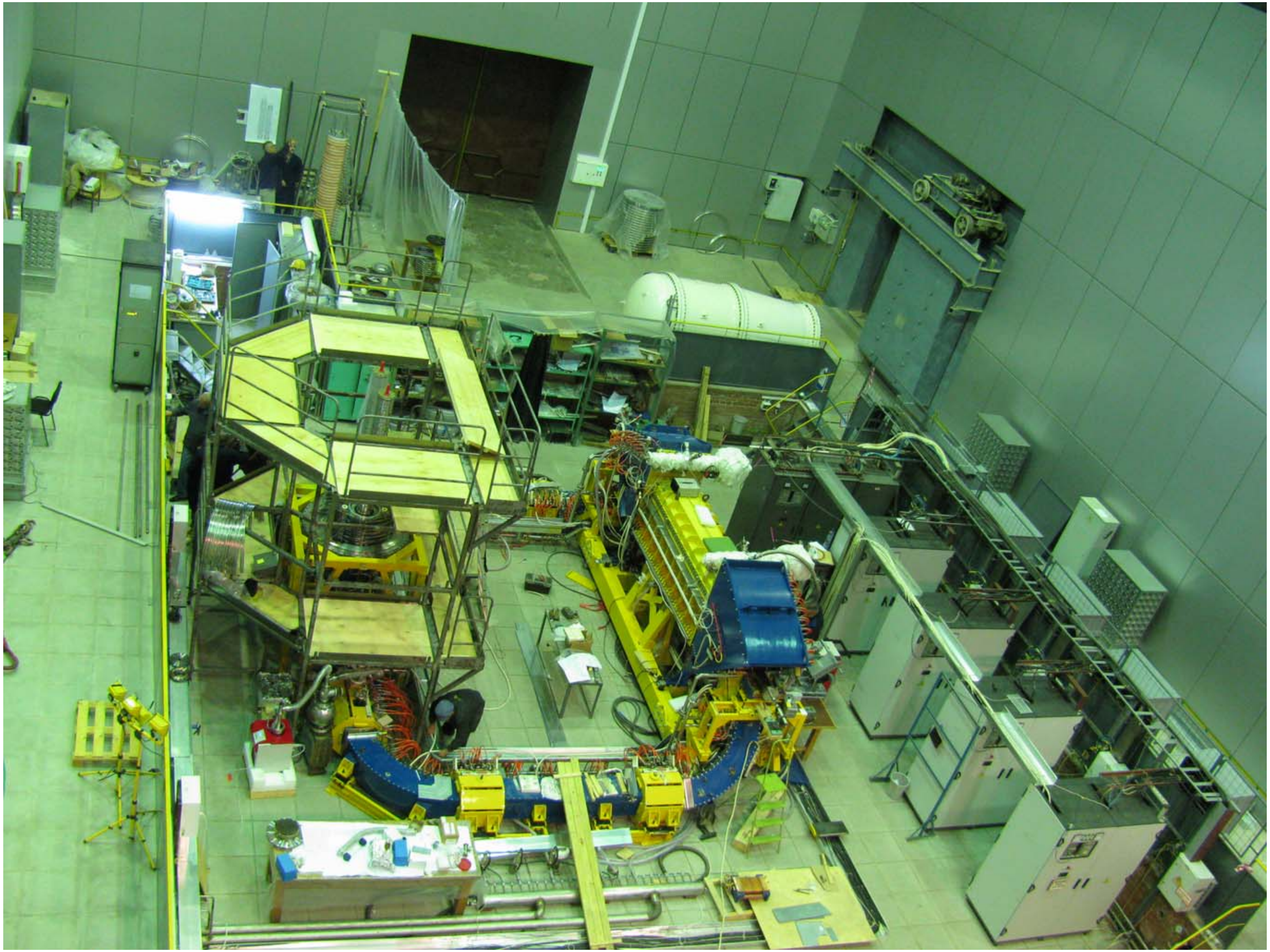


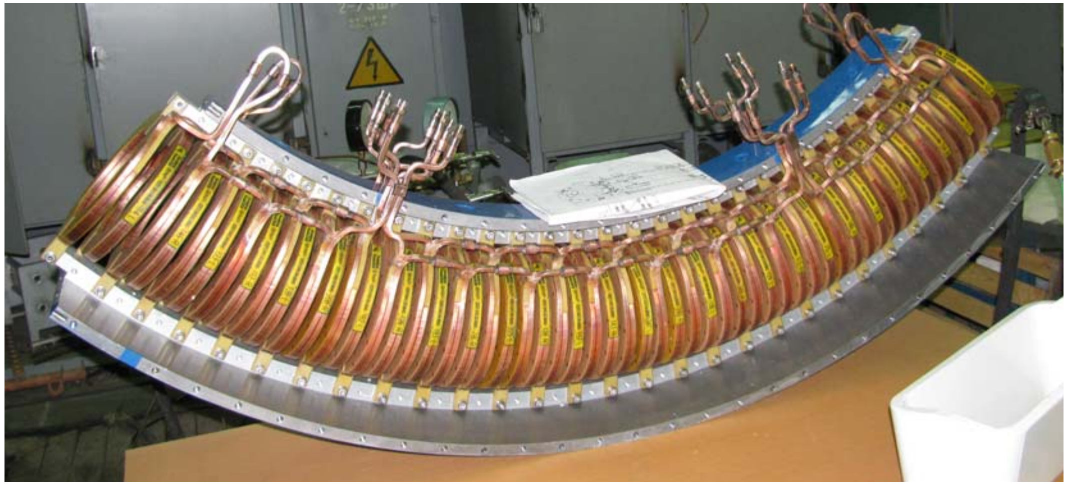
Photo of COSY Cooler during commissioning

Cooling section – standard BINP decision with pan-cake coils

Base Magnetic Elements

Magnetic System of transport channels of COSY cooler

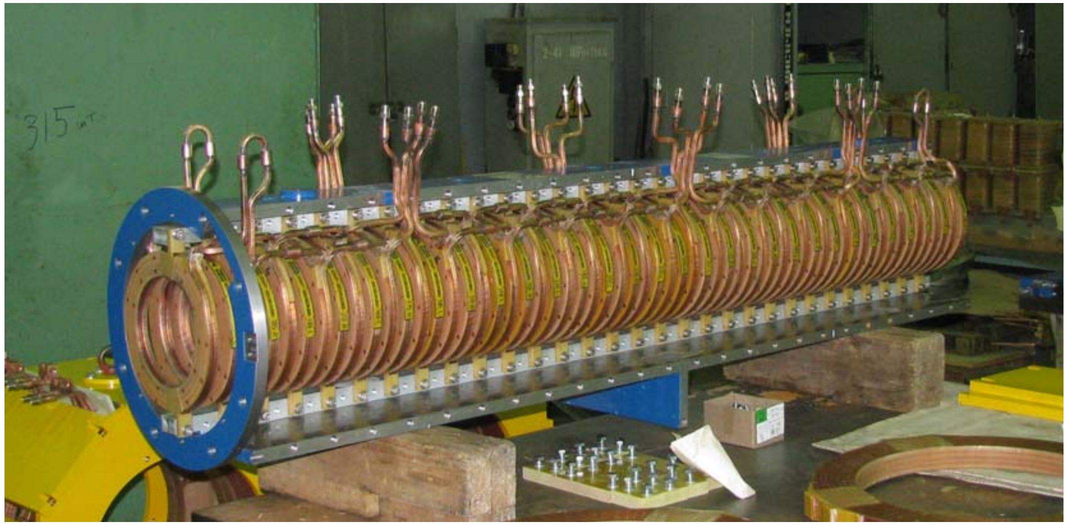
toroids 90 with bending field



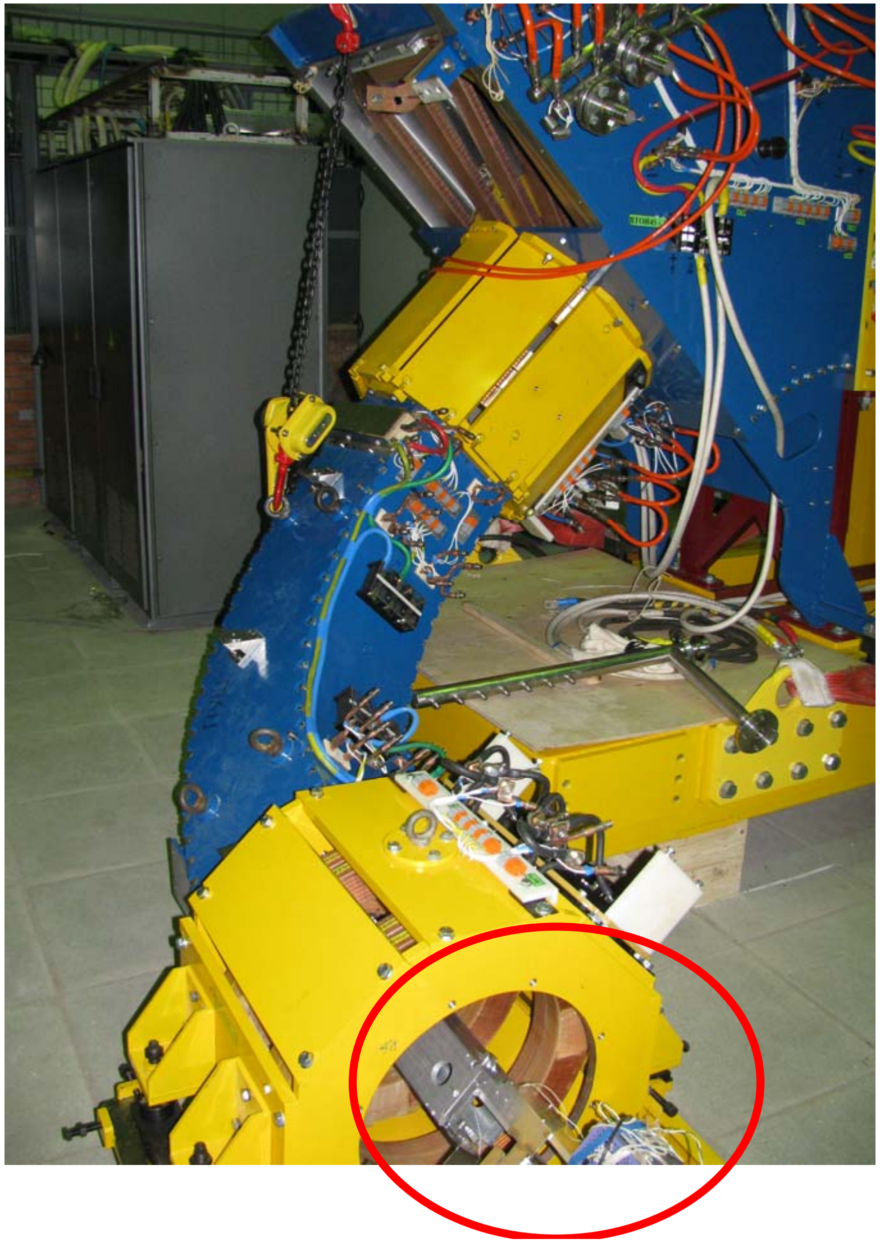
Base Magnetic Elements

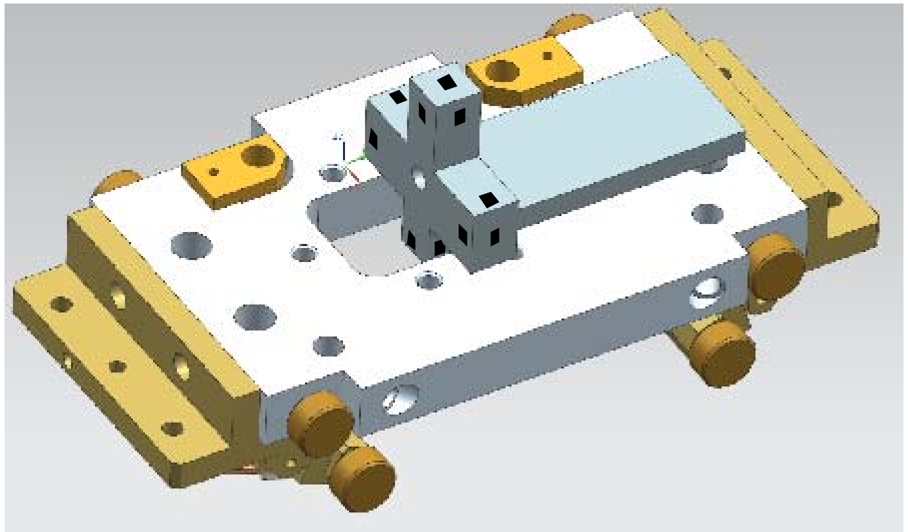
straight sections 0.5 m

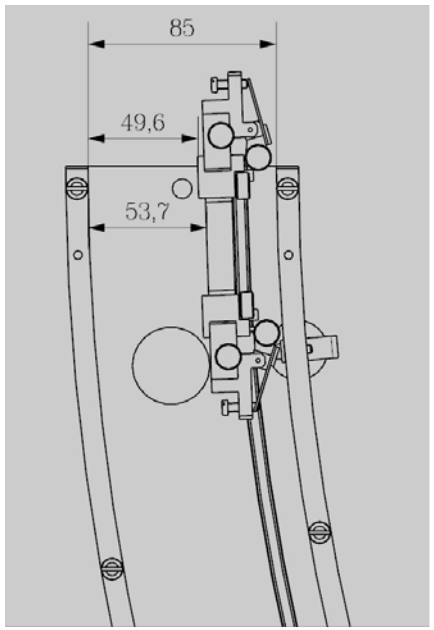
straight section 1.8 m



All Magnetic elements of transport channels was measured with Hall Probes System





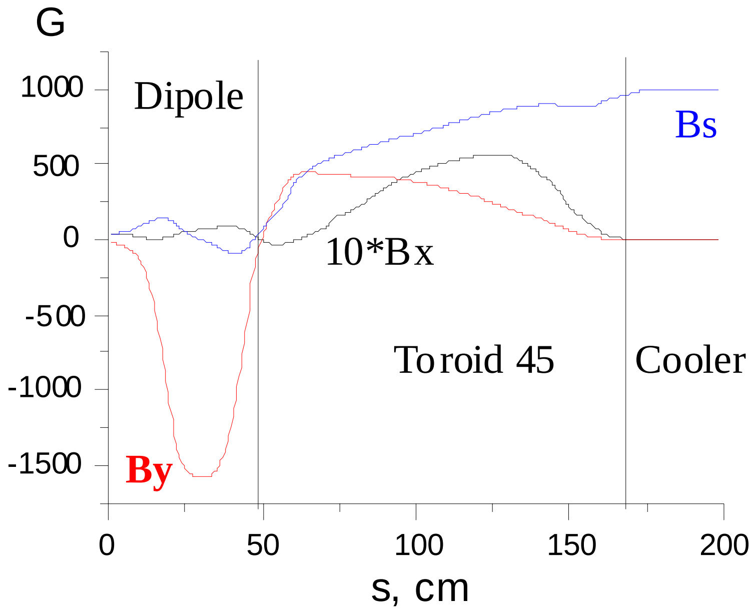


-Three component of the magnetic field in four points;

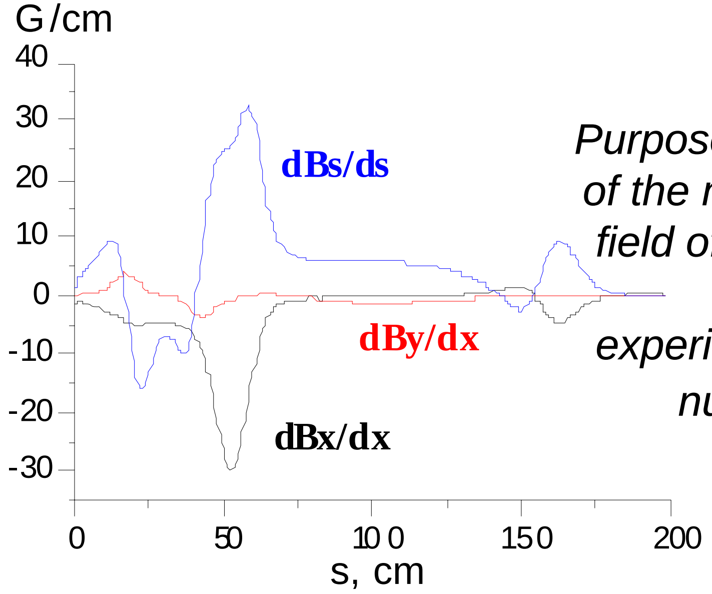
- Magnetic field and gradients of the magnetic fields was tested;

- Three or more elements connected together for magnetic measurements in order to accurate measure of one elements (edge effects);

Ion orbit

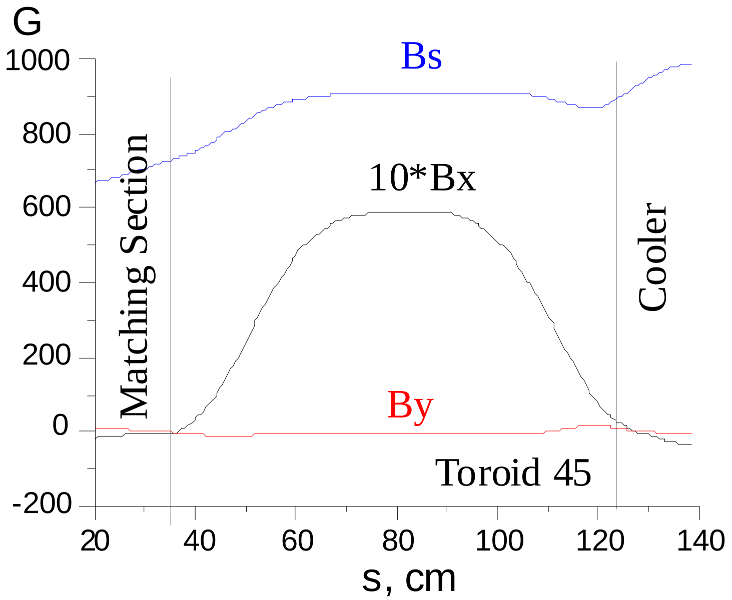


COOLER+TOR45+DIPOLE

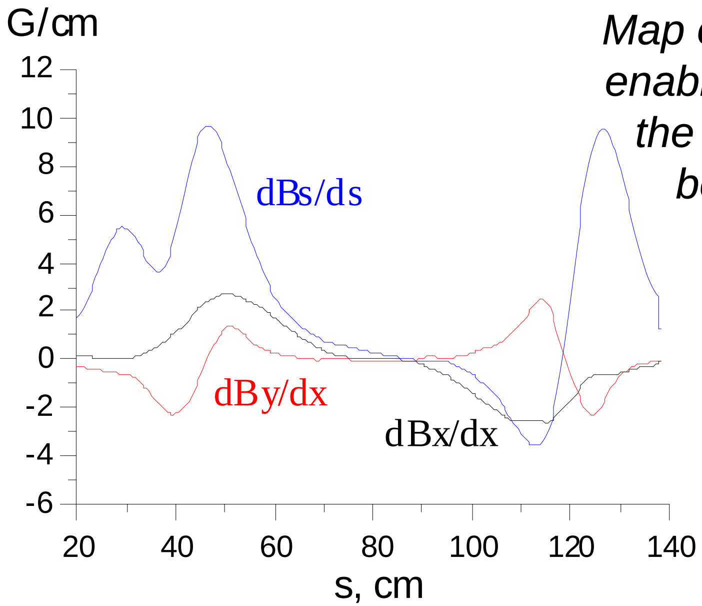


Purpose is the construction of the map of the magnetic field of all elements as the combination of the experimental data and the numerical calculation;

Electron orbit



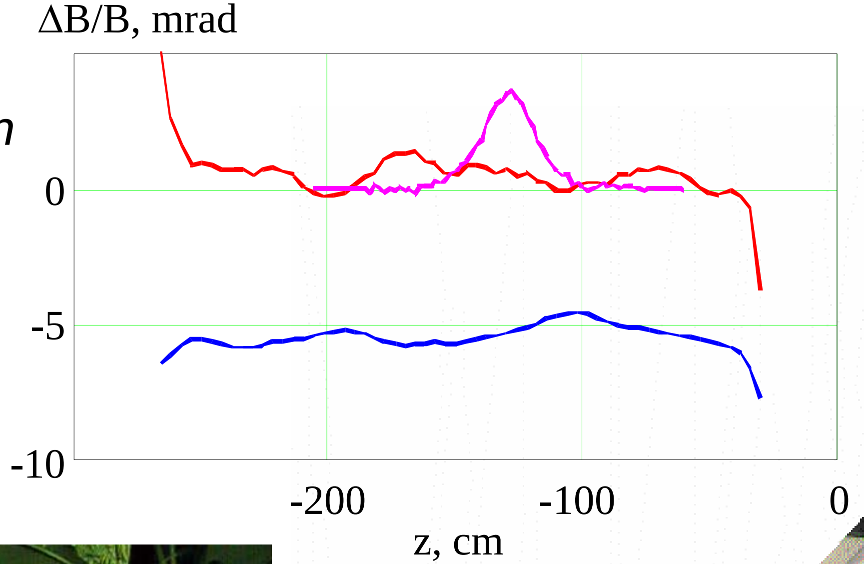
COOLER+TOR45+TORBND



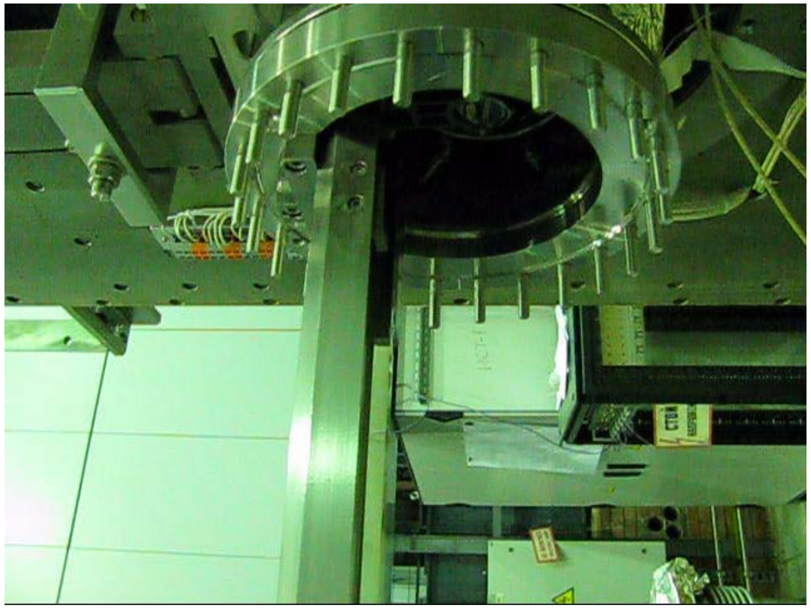
Map of the magnetic field enables the estimation of the optic of the electron beam along transport channel;

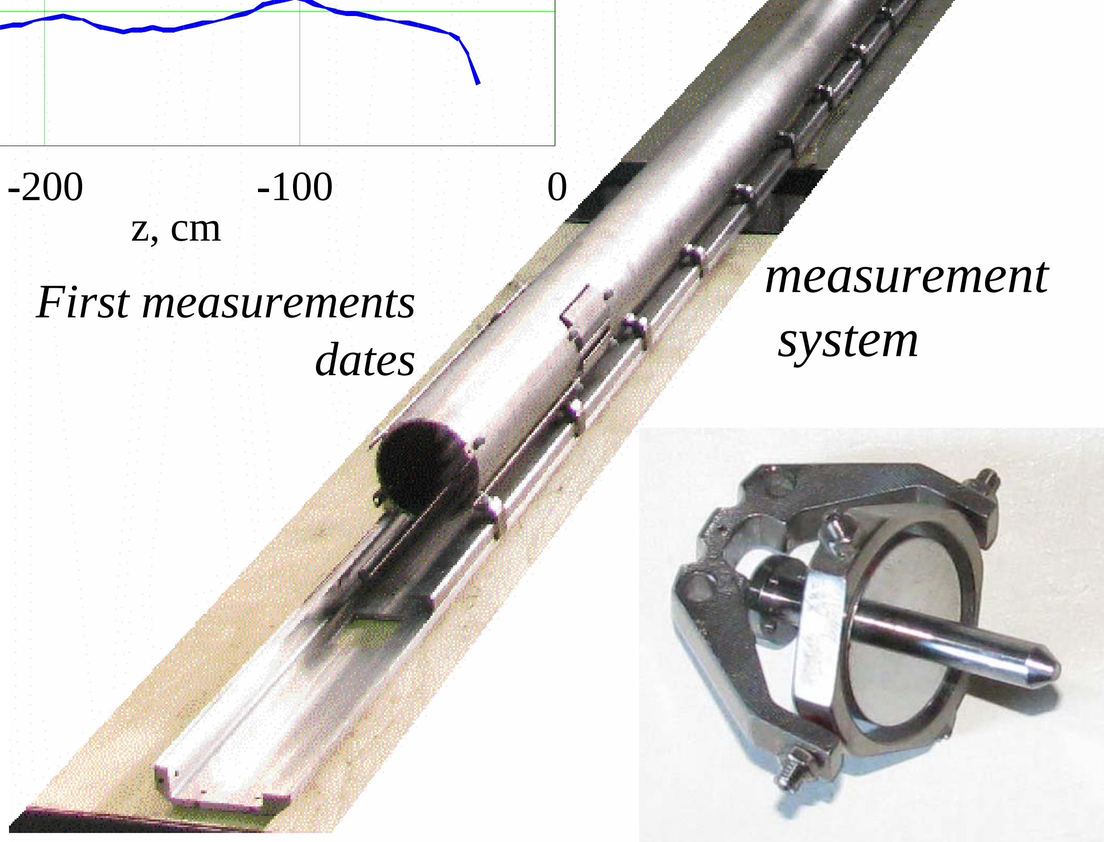
More Detail Information TUPS 08
“SYSTEM FOR MEASUREMENT OF MAGNETIC FIELD LINE STRAIGHTNESS IN SOLENOID OF ELECTRON COOLER FOR COSY”

According Parkhomchuk’s equation the cooling force strongly depends from the quality of the magnetic field in the cooling section



First measurements dates

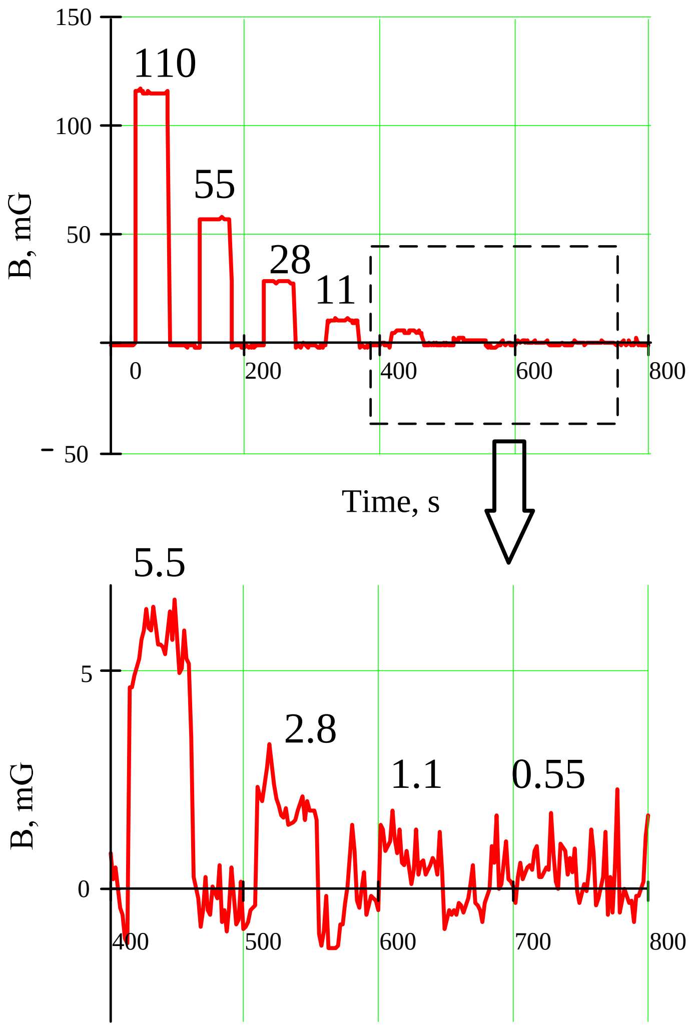




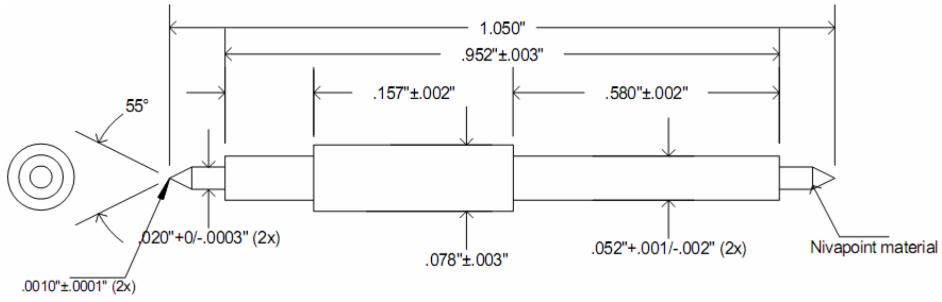
Guide rail of compass measurement system

Compass with gimbal suspension

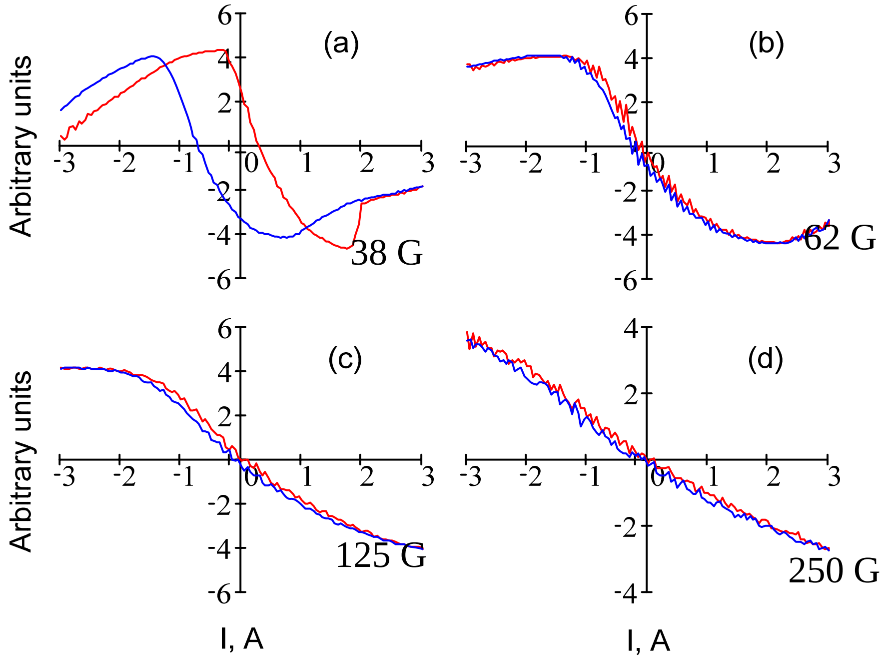
Sensitivity of the compass is about 10^{-6} in kG range of the magnetic field



Sensitivity of the compass to the transverse magnetic field (in mG).

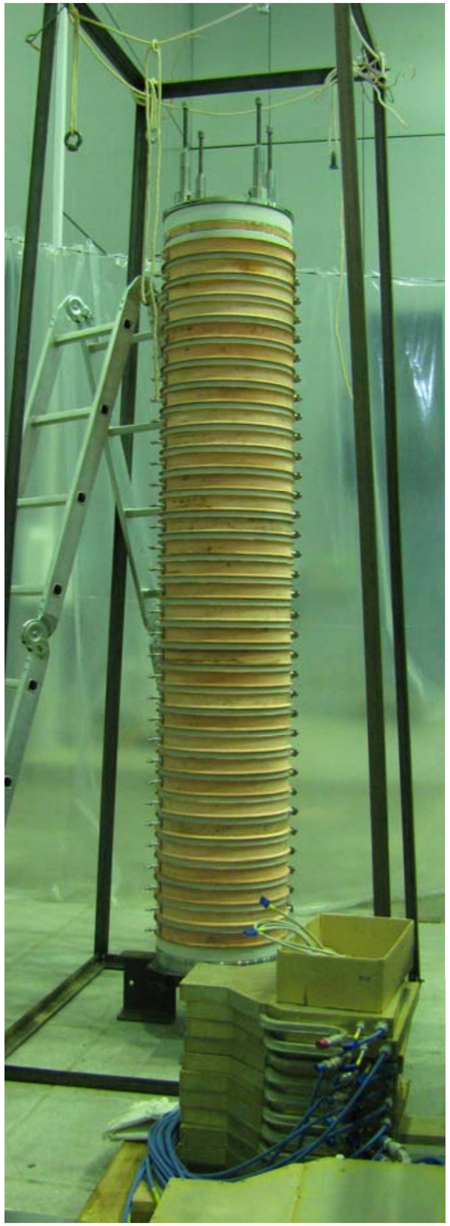


Interpolating the results for 2 kG we can get that uncertainty of angle related with friction in bearings is about $2 \cdot 10^{-7}$



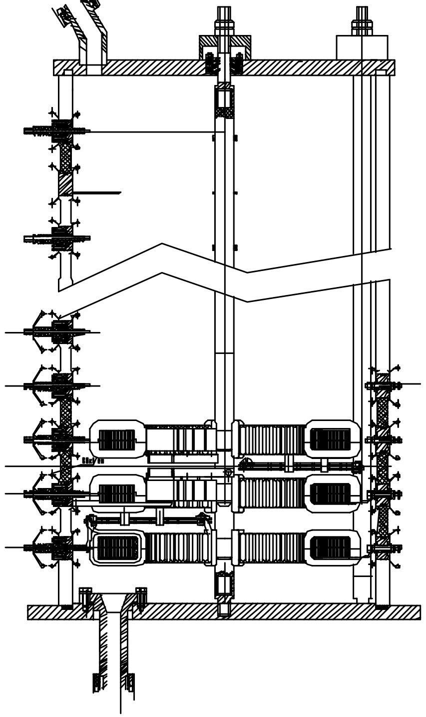
Hysteresis due to friction in the jewel bearing

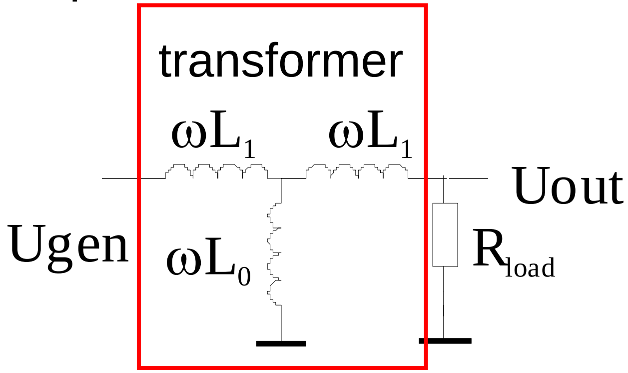
Power for Acceleration Column

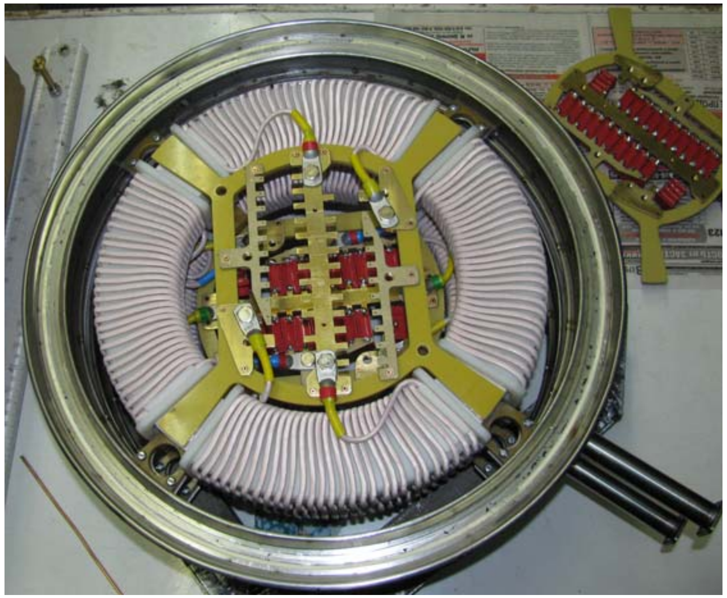


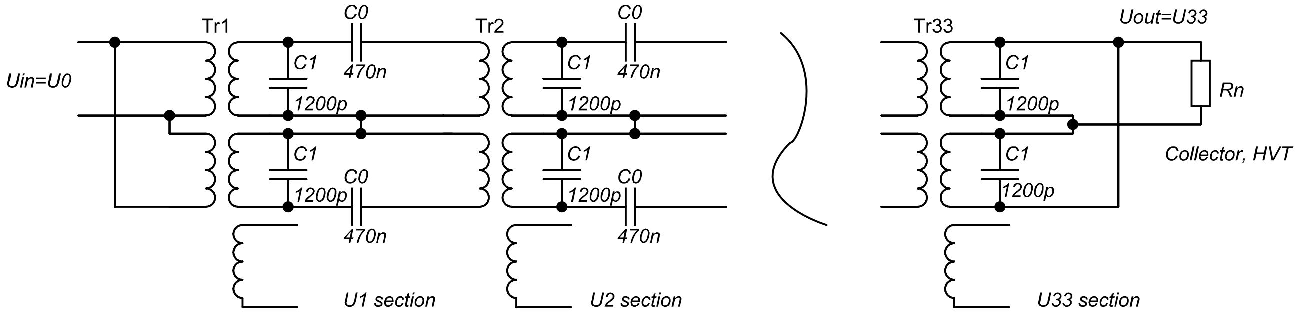
-*transformers connected to series;*
-*tube is alternation of the ceramic and metal rings (sections);*
- *tube is filled by oil;*
- *section has special spark-gaps;*

"Accelerating tube is composed with transformers"

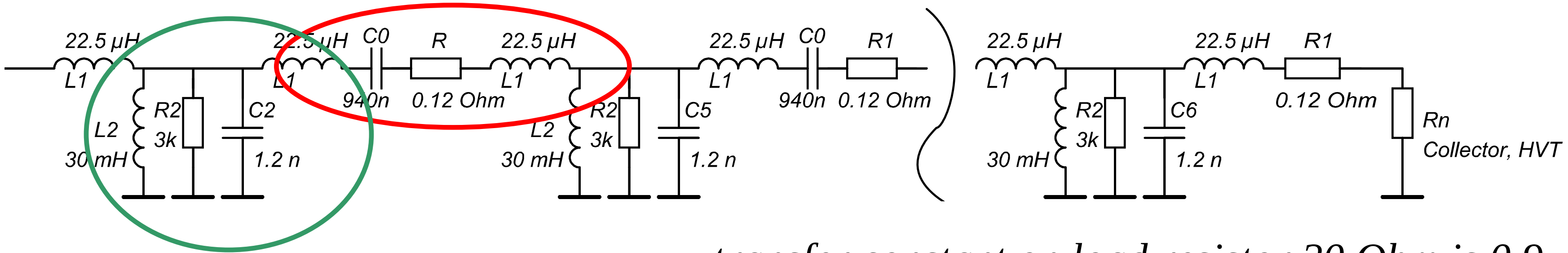






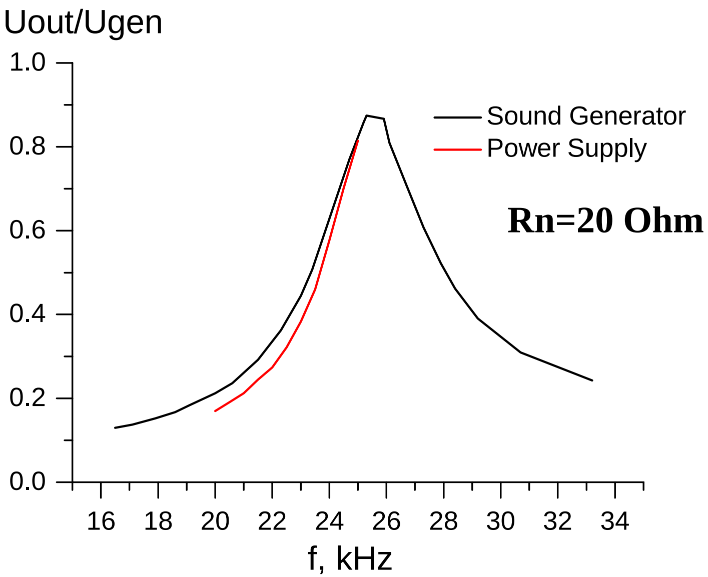


principle of operation of cascade transformer is combination of series and parallel resonances induced by the leakage inductance and compensative capacitances

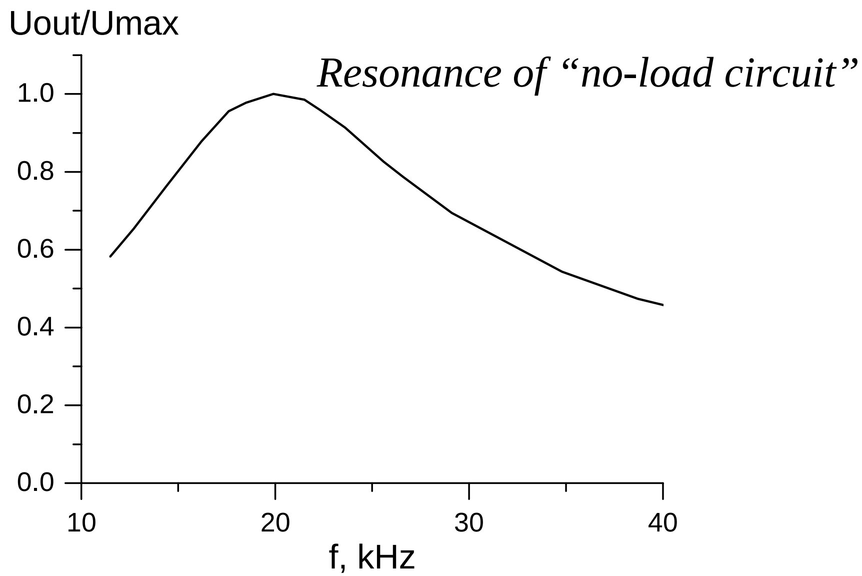


Resonance of "short circuit"

- transfer constant on load resistor 20 Ohm is 0.9, the r.m.s. voltage 700 V corresponds to 25 kW of power



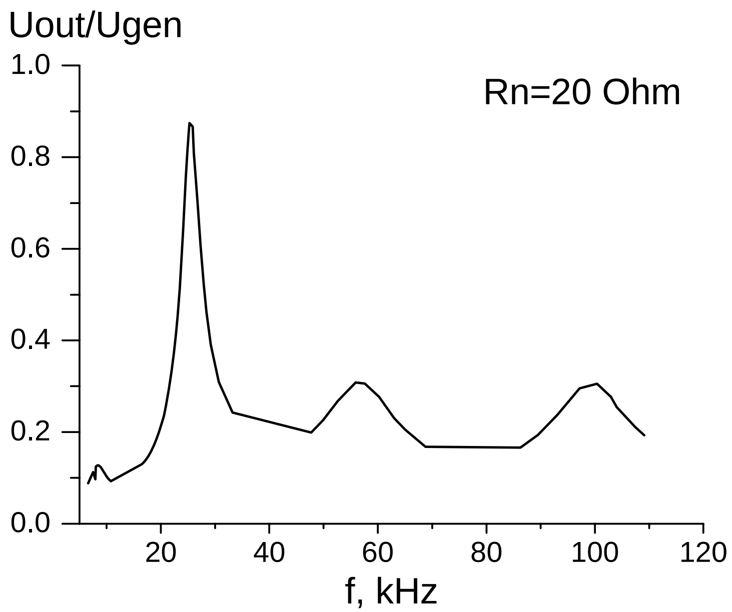
Series resonance curve



Parallel resonance curve

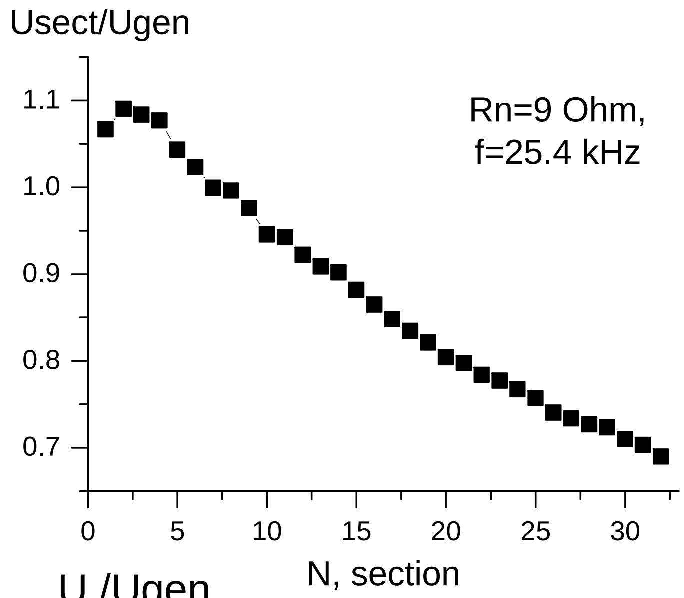
Decreasing of the voltage from section to section at load resistor 9 Ohm (54 kW at r.m.s. voltage 700 V)

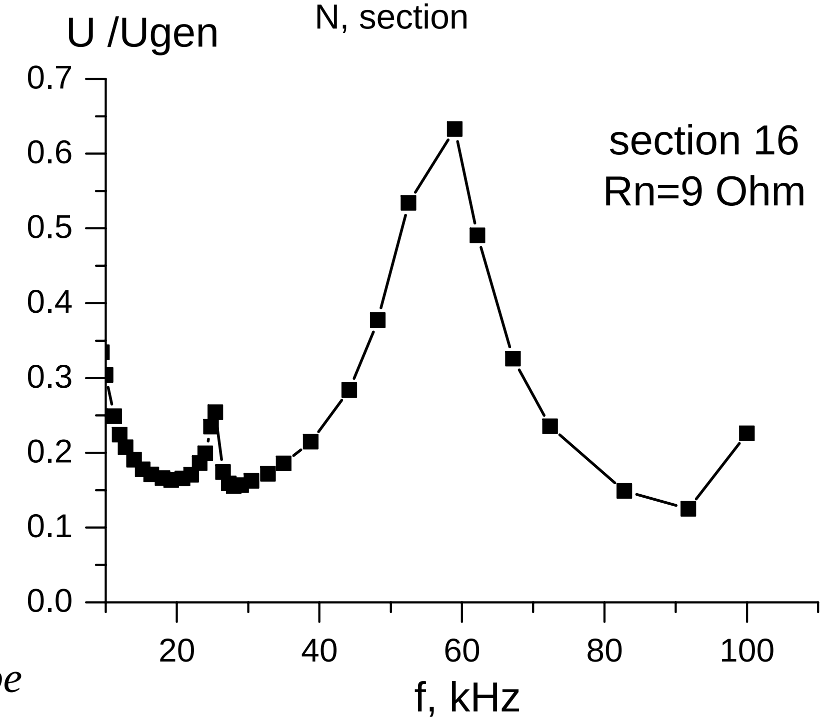
- *the voltage drop from maximum to minimum 1.6 times, but we needs only 40 kW of energy transfer;*
- *the variation of the supply voltage in 1.6 times isn’t problem for the modern electronics;*



Series resonance curve in wideband frequency range

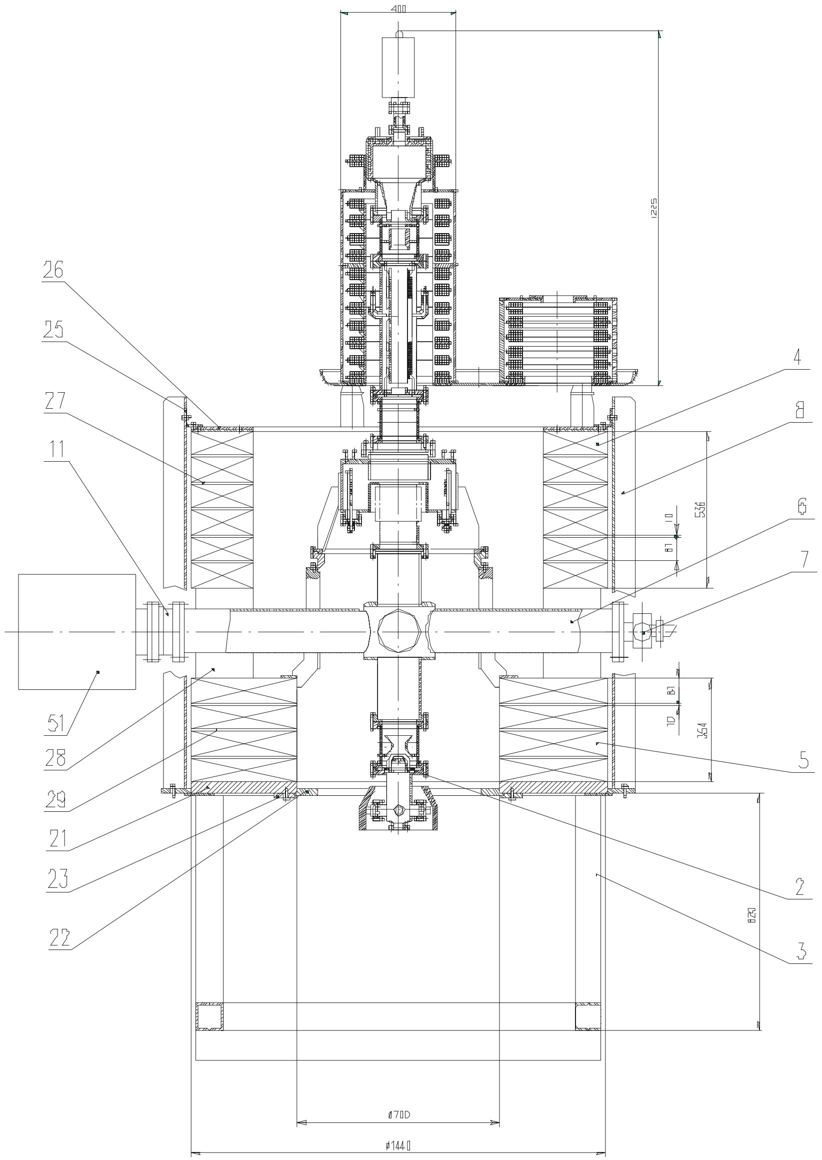
- *there are parasitic resonances at frequencies 60 and 100 kHz (about 3 and 5 harmonics of working frequency), may be problem with distortion of the voltage shape from the sinusoidal function*

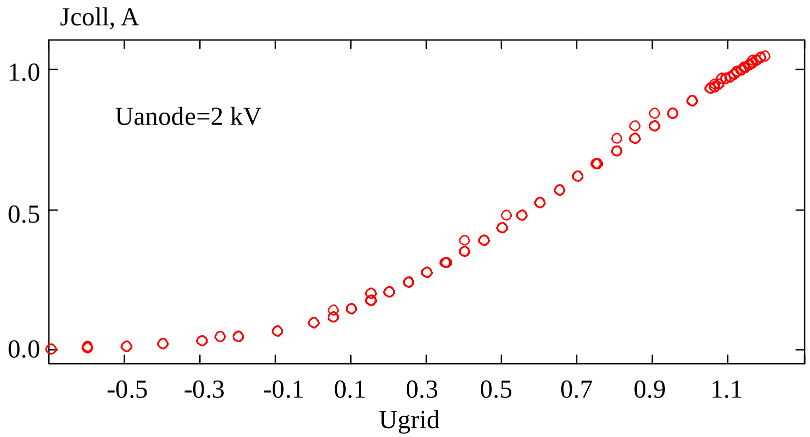




Series resonance curve in separate section

Test-Bench for the testing of High Voltage Terminal: gun, collector, electronics, one high-voltage section and model of cascade transformer





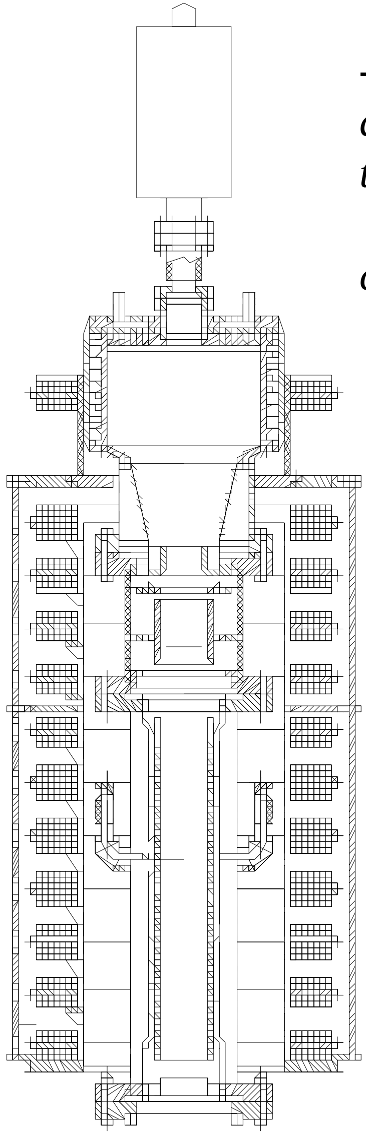
regime 1 A of electron current

High-voltage terminal electronics

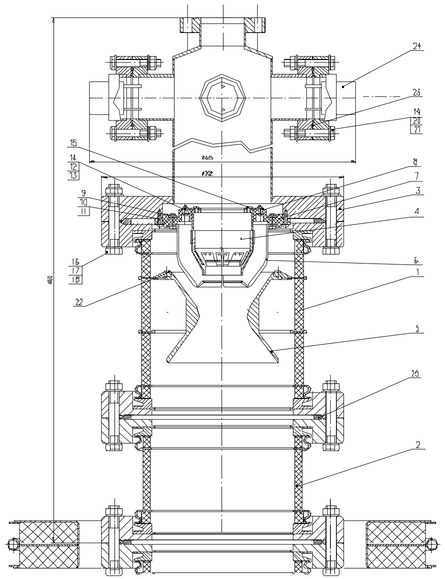
“The test bench for commissioning electron gun, collector and electronics component”

-Four sectors electron gun for diagnostics of the optics of the electron beam;

- Wien filter for improving collector efficiency;

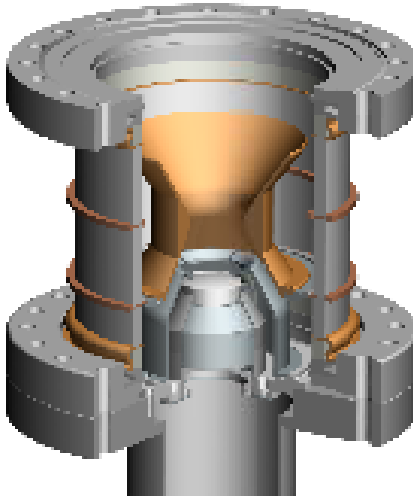


Collector



Gun

Diagnostics of the shape of the electron beam



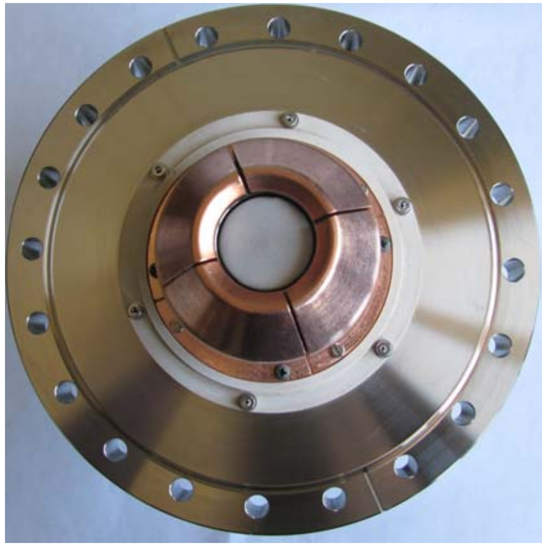
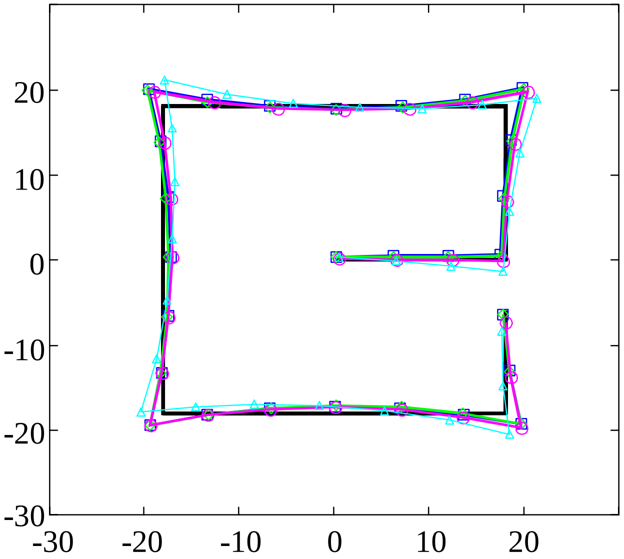


Photo Pick-Up System

4 sector electron gun

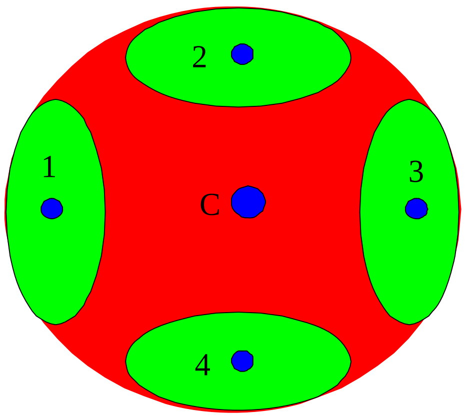
Pick-Up 2

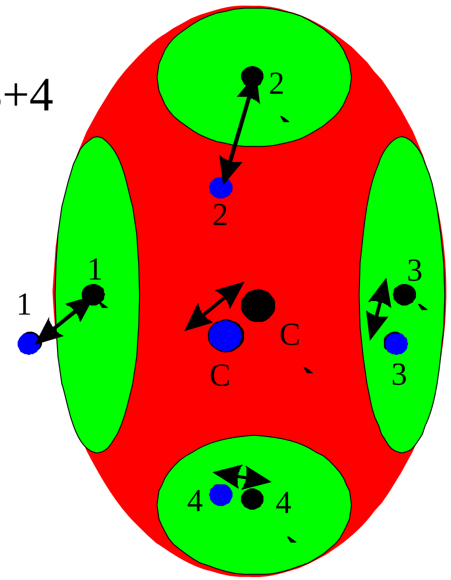


Pick-Up Calibration

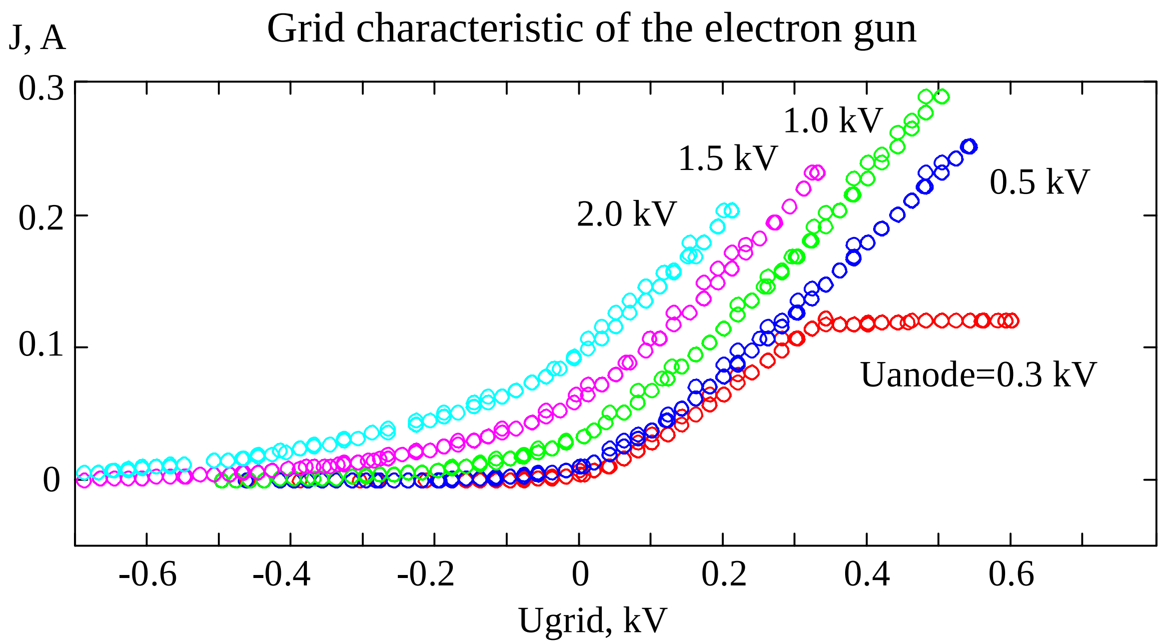
Pick-Up 1

Center=1+2+3+4

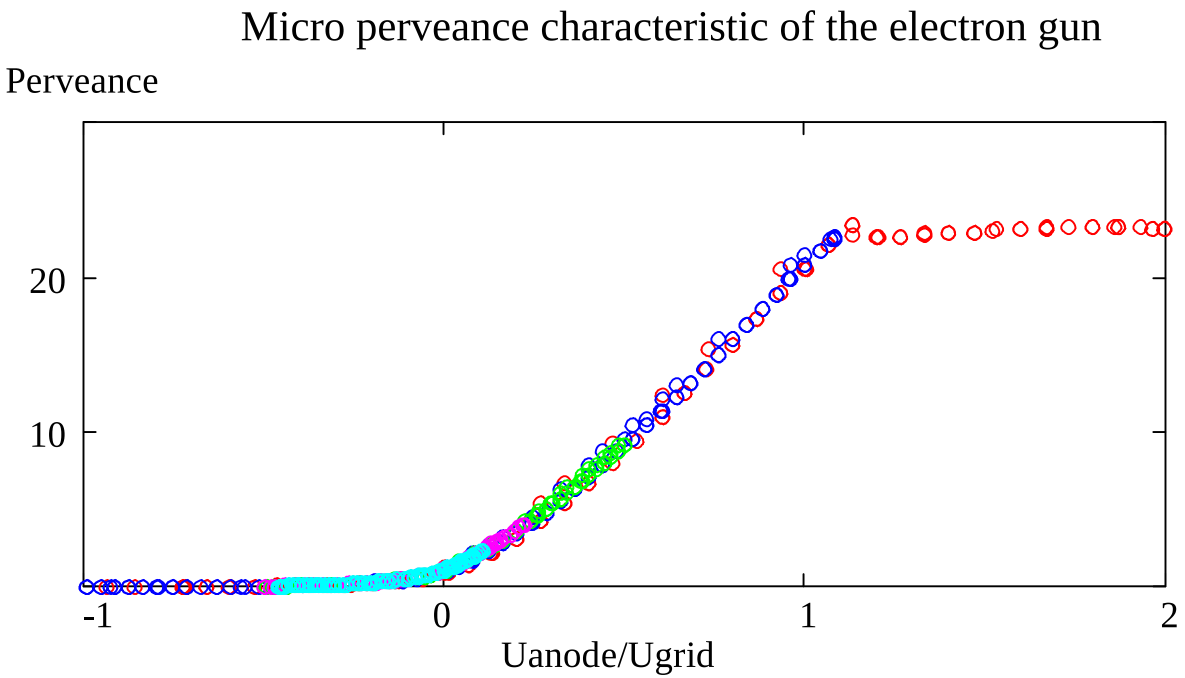




The combination of the constant and modulation voltage is applied to the electrodes

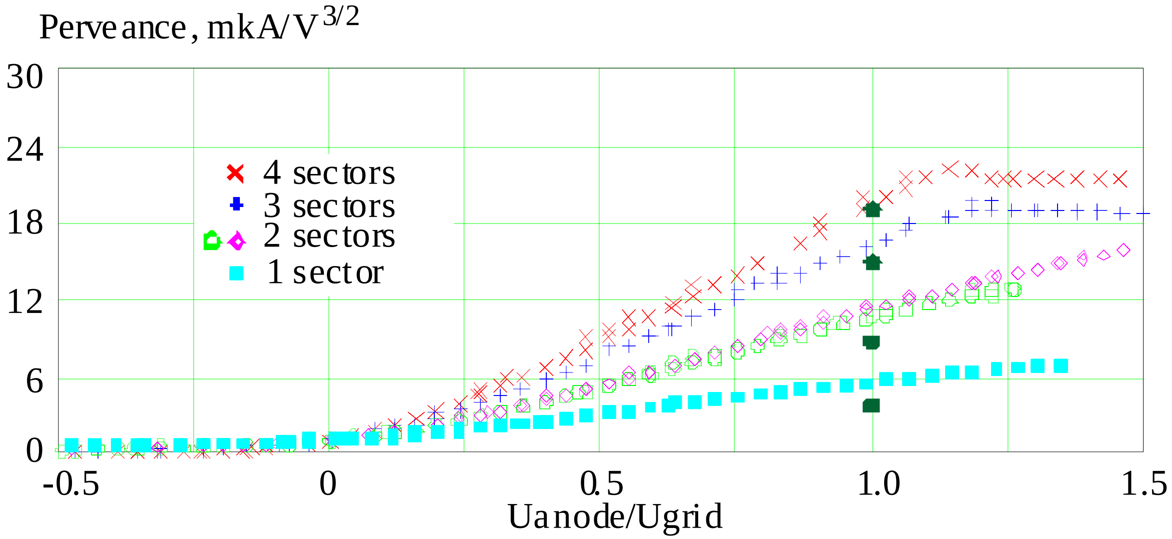


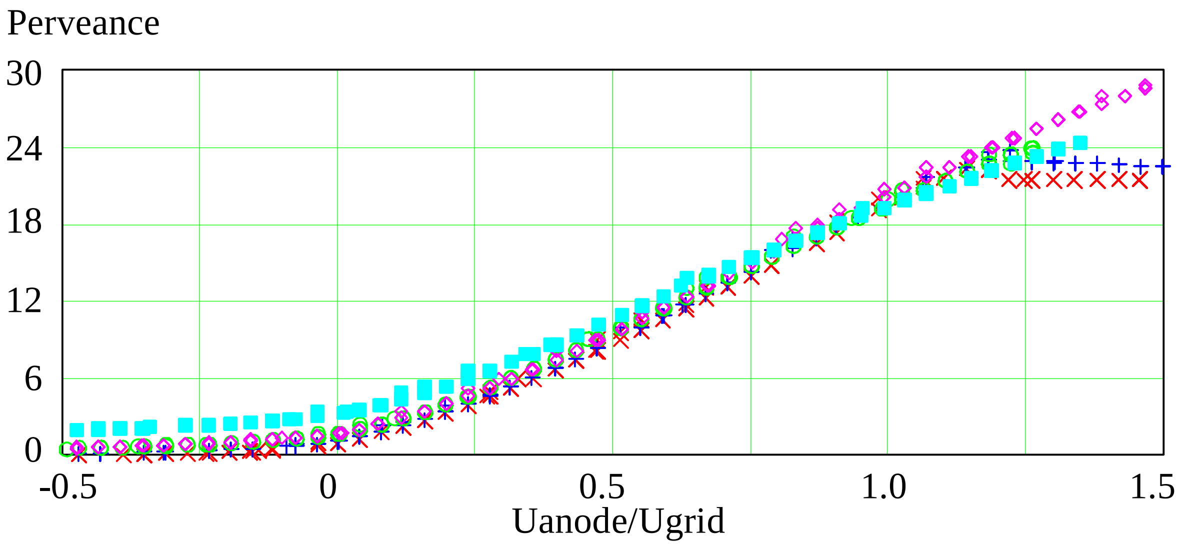
Standard regime of the electron gun: all sectors have an equal potential;



similarity principle:
all curves of the grid characteristics can be described by a single curve:

$$\frac{J[A]\cdot 10^{6}}{Uanode^{3/2}} = F\left(Ugrid/Uanode\right)$$

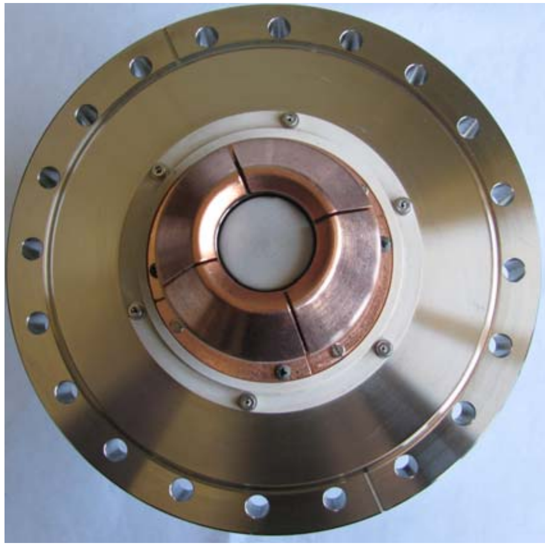




- regime for testing of section working;

- control voltage is applied to one, two, three or four sectors.

- sectors being in non-operation regime is connected with the ground of the high-voltage terminal (the relative applied voltage is zero)



All curves can be unified with coefficients

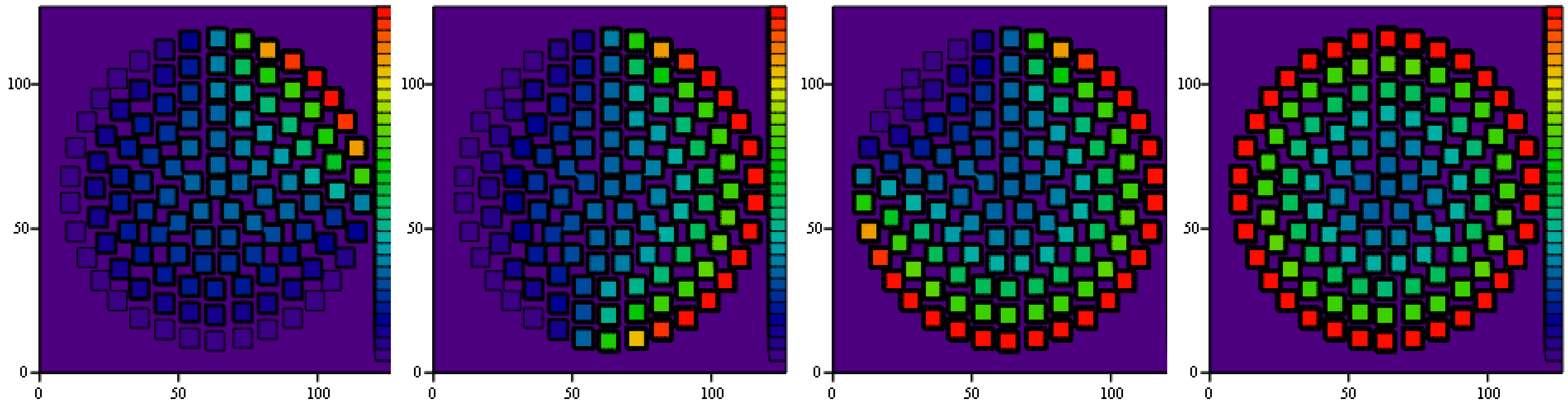
1 – 4 sectors in operation;

0.83 – 3 sectors;

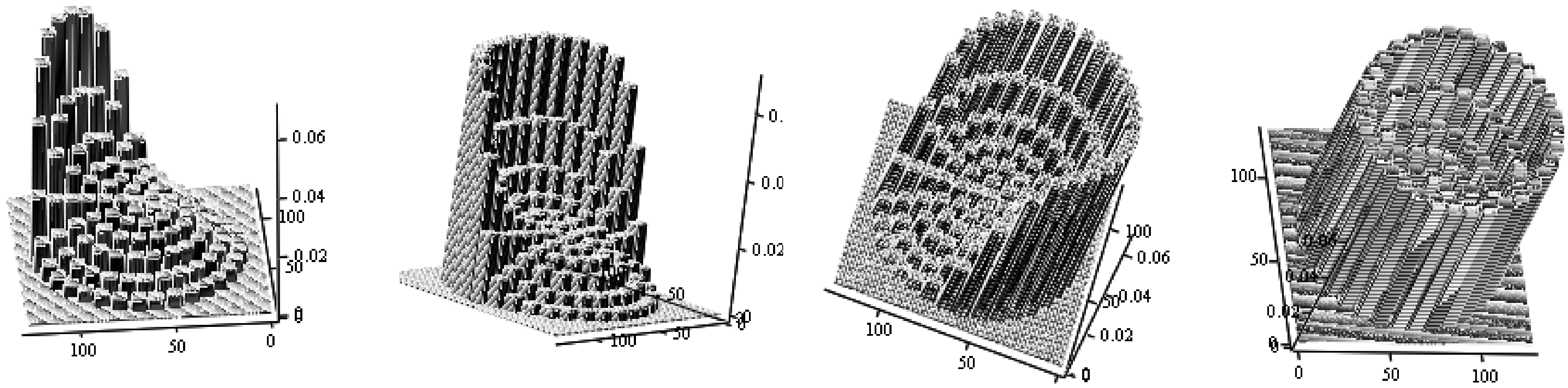
0.55 – 2 sectors;

0.29 – 1 sectors;

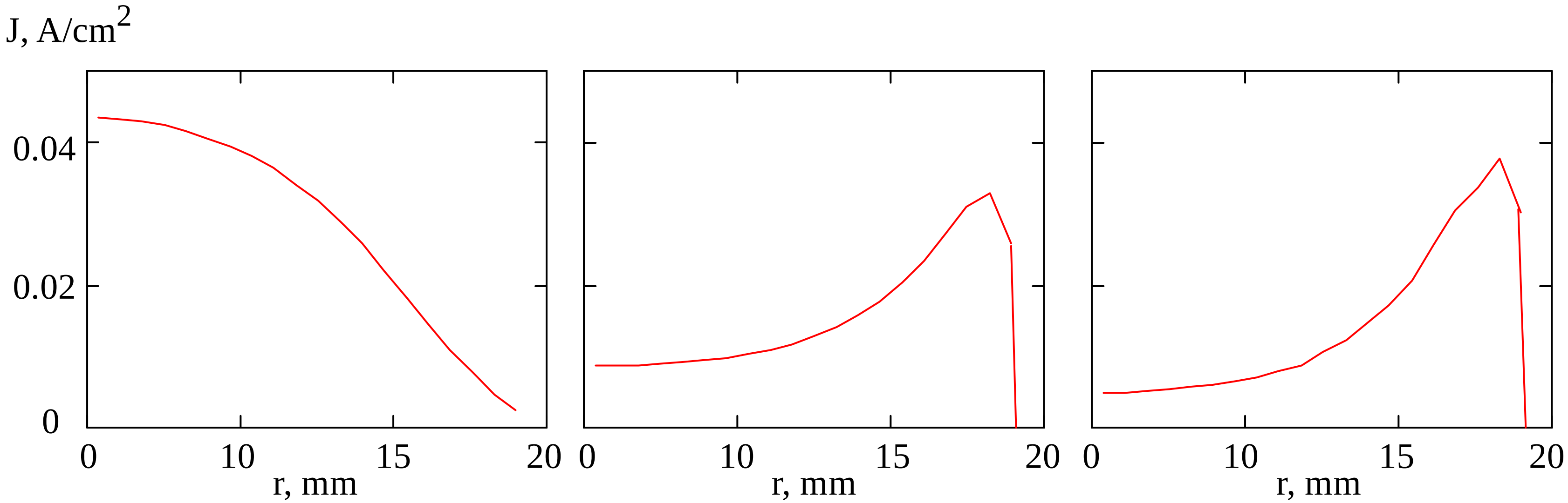
Distribution of the electron current at the turning on the different numbers of the sectors

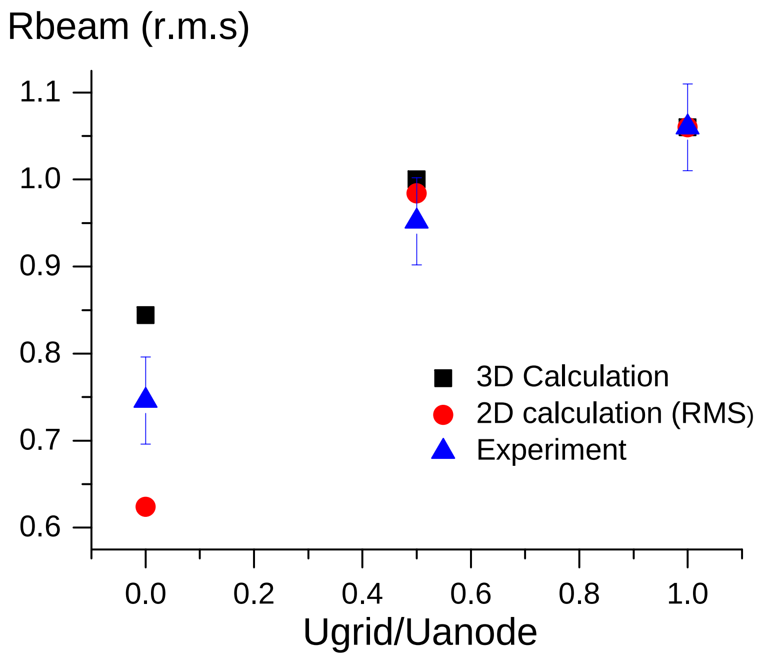


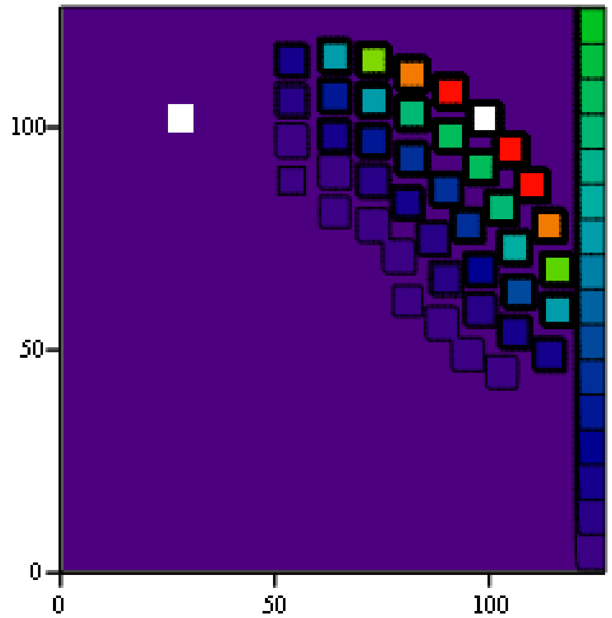
p p p p



Radial Profile of the Electron beam

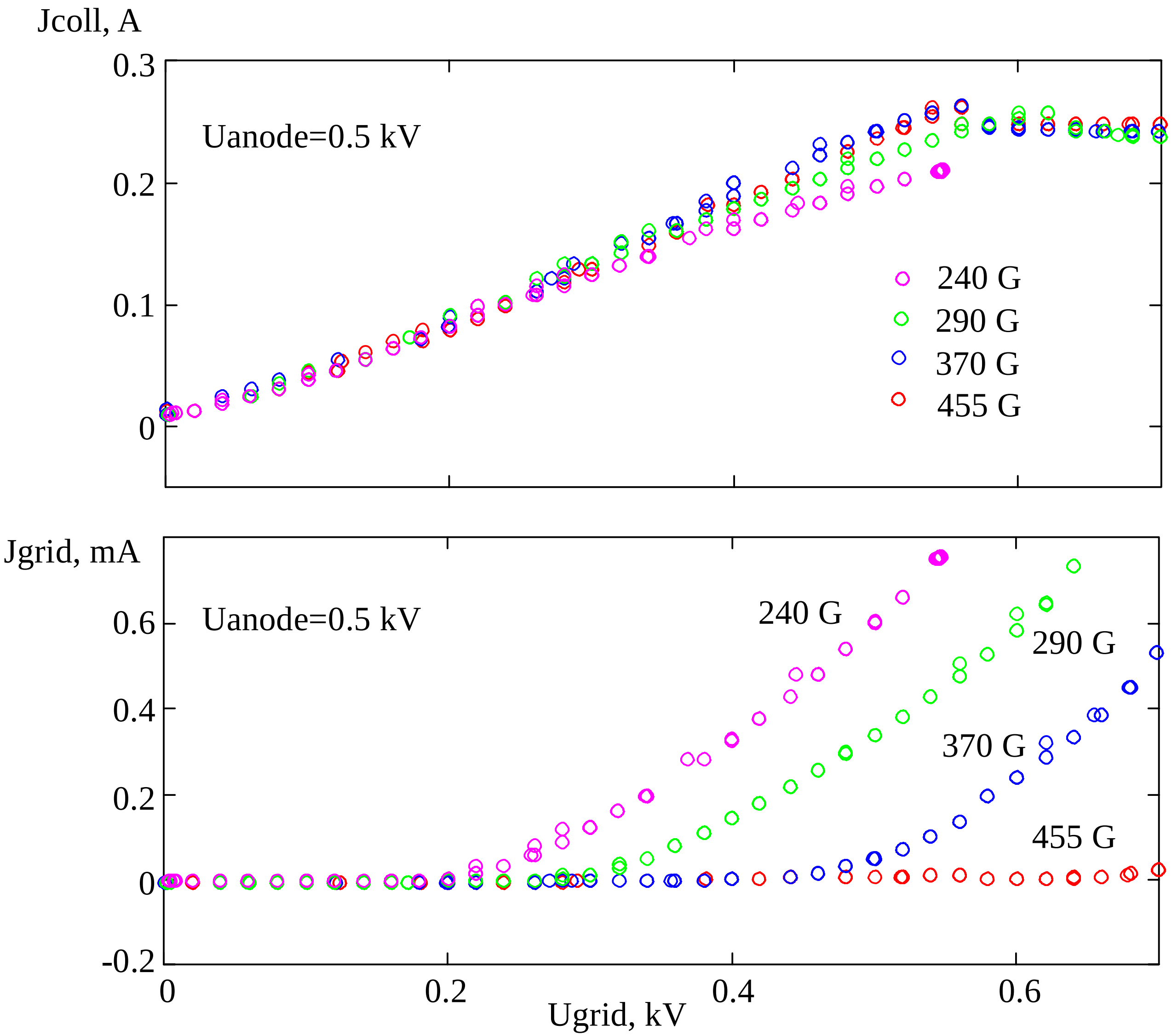






Comparison of the calculated and experimentally observed radius of the electron beam

Operation of the electron gun at the different magnetic fields



- perveance characteristics of the gun is modified at the magnetic field less than 370 G

- leakage current is growth significantly at the magnetic field less than 370 G

- essential leakage current to the anode isn't observed

Magnetic field in operation is 500-600 G

Wien Filter –
try to catch electrons that run away from collector

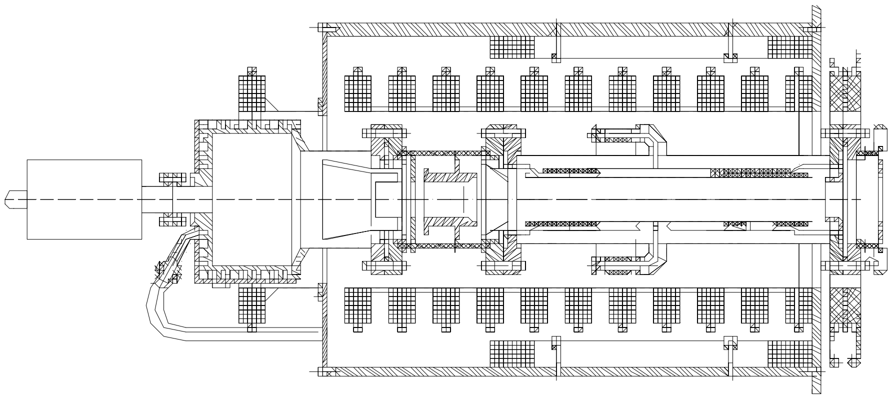
Area with crossed electrical and magnetic fields compensated each other

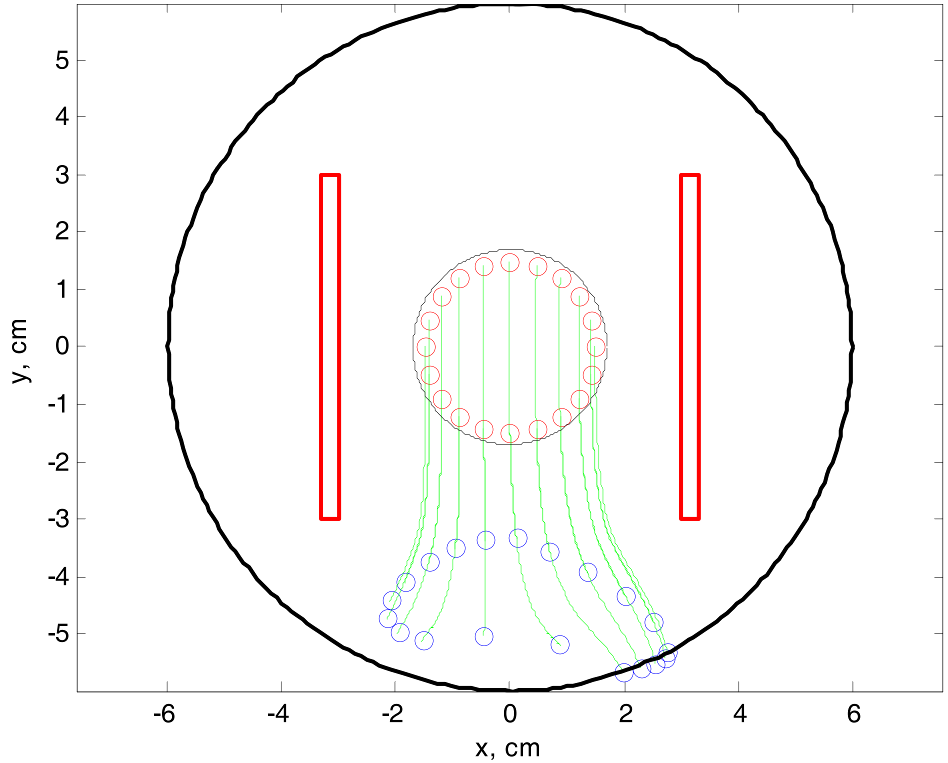
$$\vec{F}_{\perp} = e\vec{E} - \frac{e}{c}\left[\vec{v} \times \vec{B}\right] = 0$$

primary beam

$$\vec{F}_{\perp} = e\vec{E} + \frac{e}{c}\left[\vec{v} \times \vec{B}\right] \neq 0$$

secondary beam

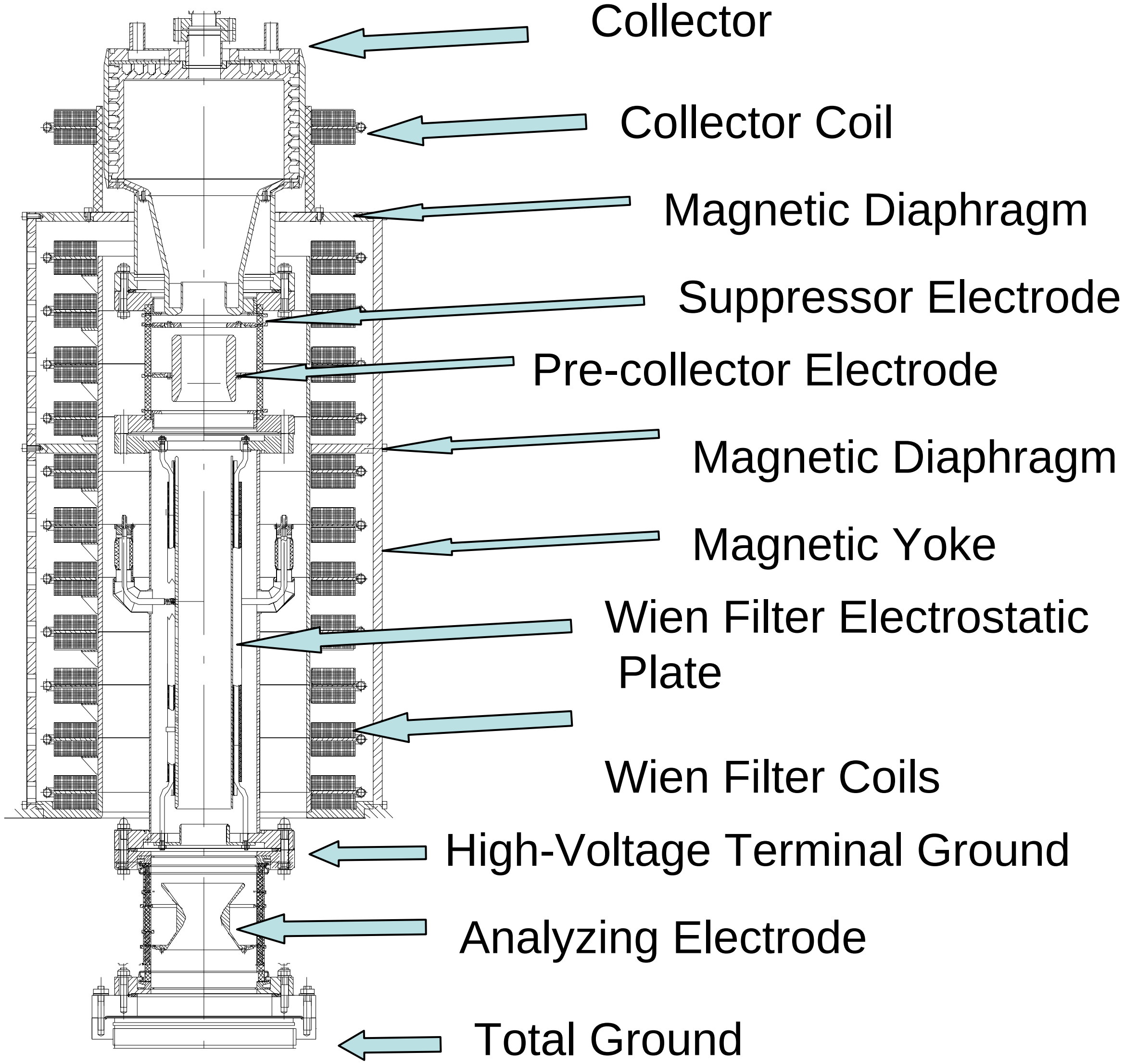




Motion of primary beam is red circle and motion of reflected beam is blue circle

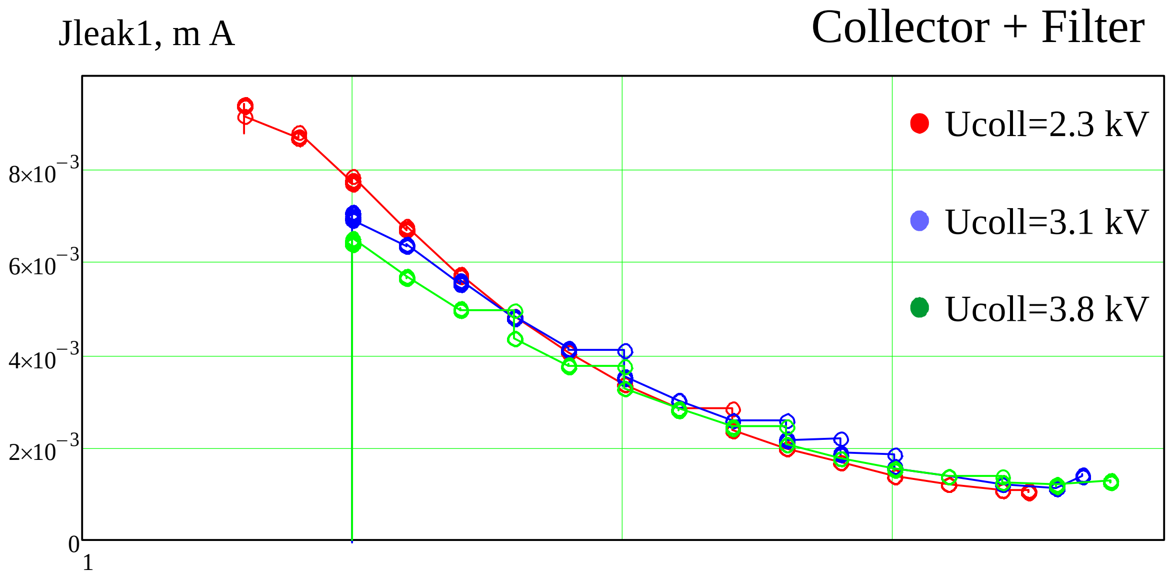
Aim is recuperation coefficient
10^{-5}-10^{-6}

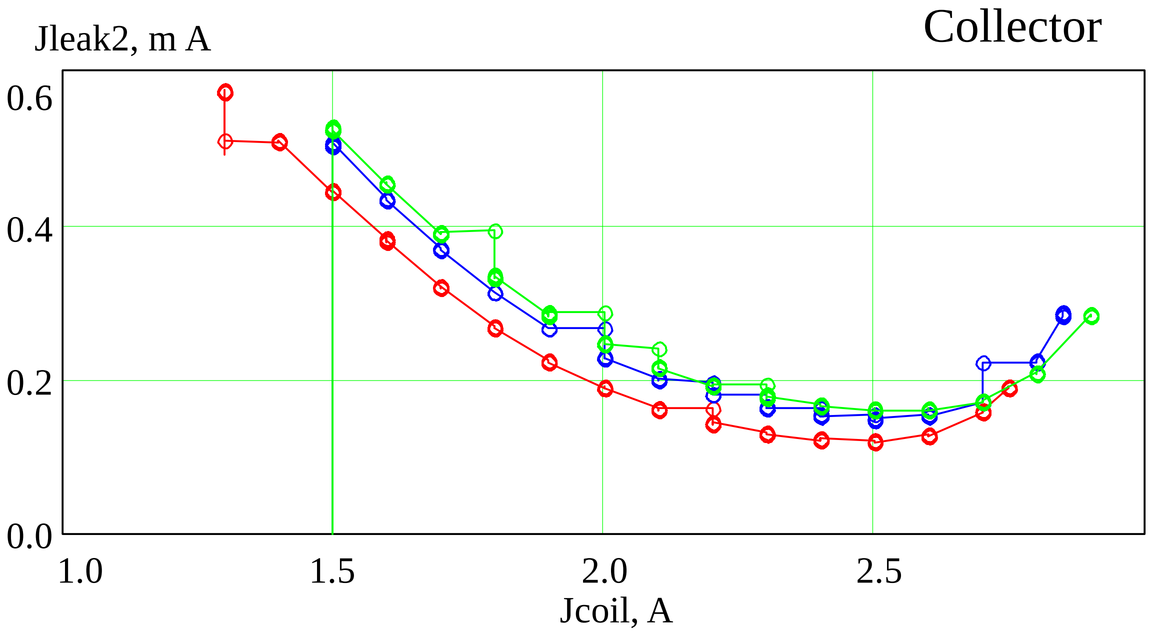
Main elements of the collector



The collector keeps the secondary electrons with help of the magnetic and electrostatic barriers. The magnetic barriers is formed by the collector coil connected in the opposite direction to the other coils of the collector. The electrostatic barrier is formed by combination voltage applied to collector, suppressor and pre-collector electrodes. The suppressor electrode is powered by the independent power supplies (+5 /– 3kV). The pre-collector electrode has the potential collector or one/half of the collector voltage.

Dependence of the leakage current from the current in the collector coil





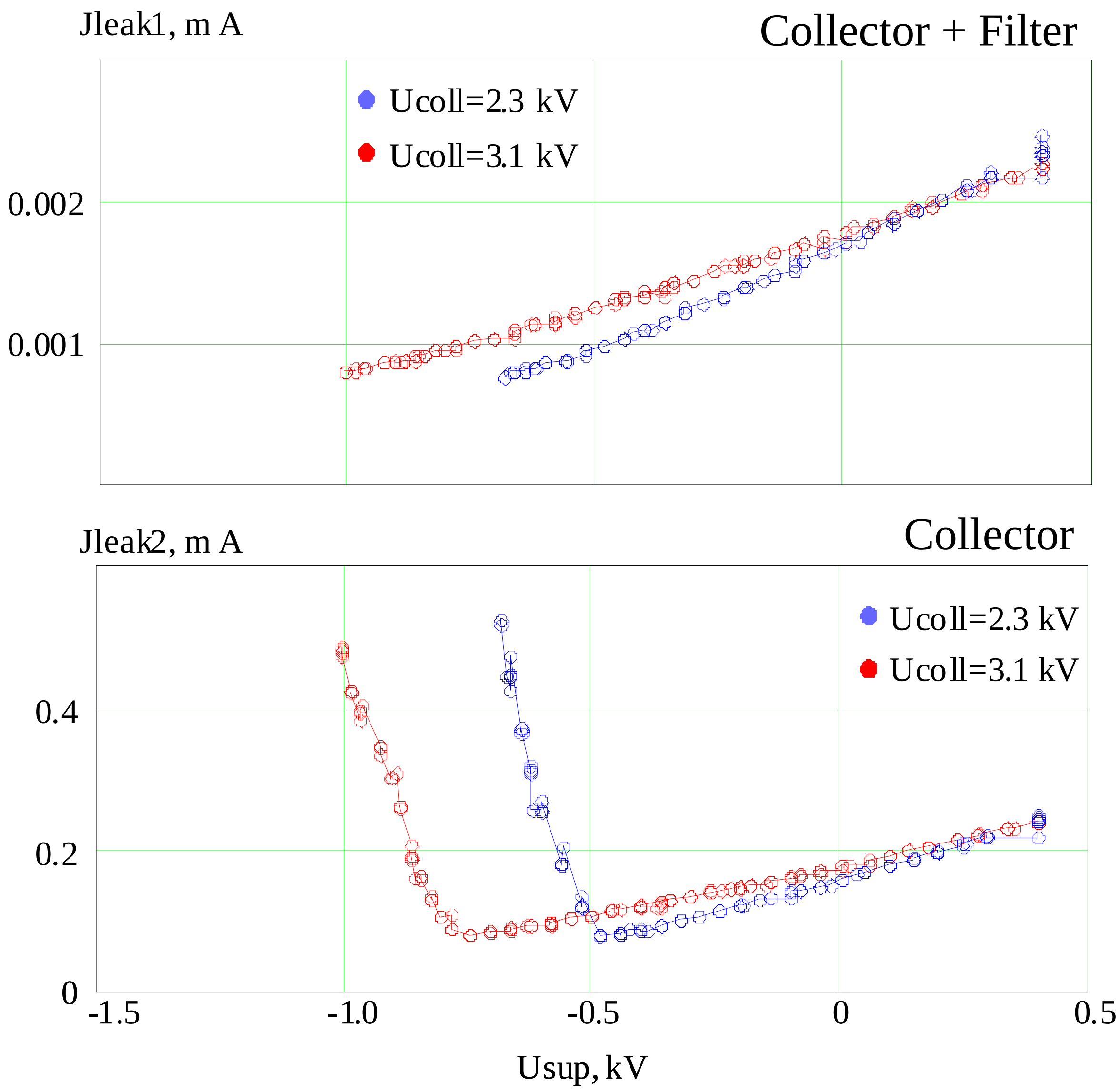
Jcoll = 220 mA,
Usup = -0.2 kV
Uan = 1.0 kV
Ugrid = 0.35 kV
Upre-coll=0.5*Ucoll

Recuperation Coefficient of System:
Collector + Wien Filter = $5*10^{-6}$

Optimization of the magnetic barrier of the collector

Recuperation Coefficient of Collector = $6*10^{-4}$

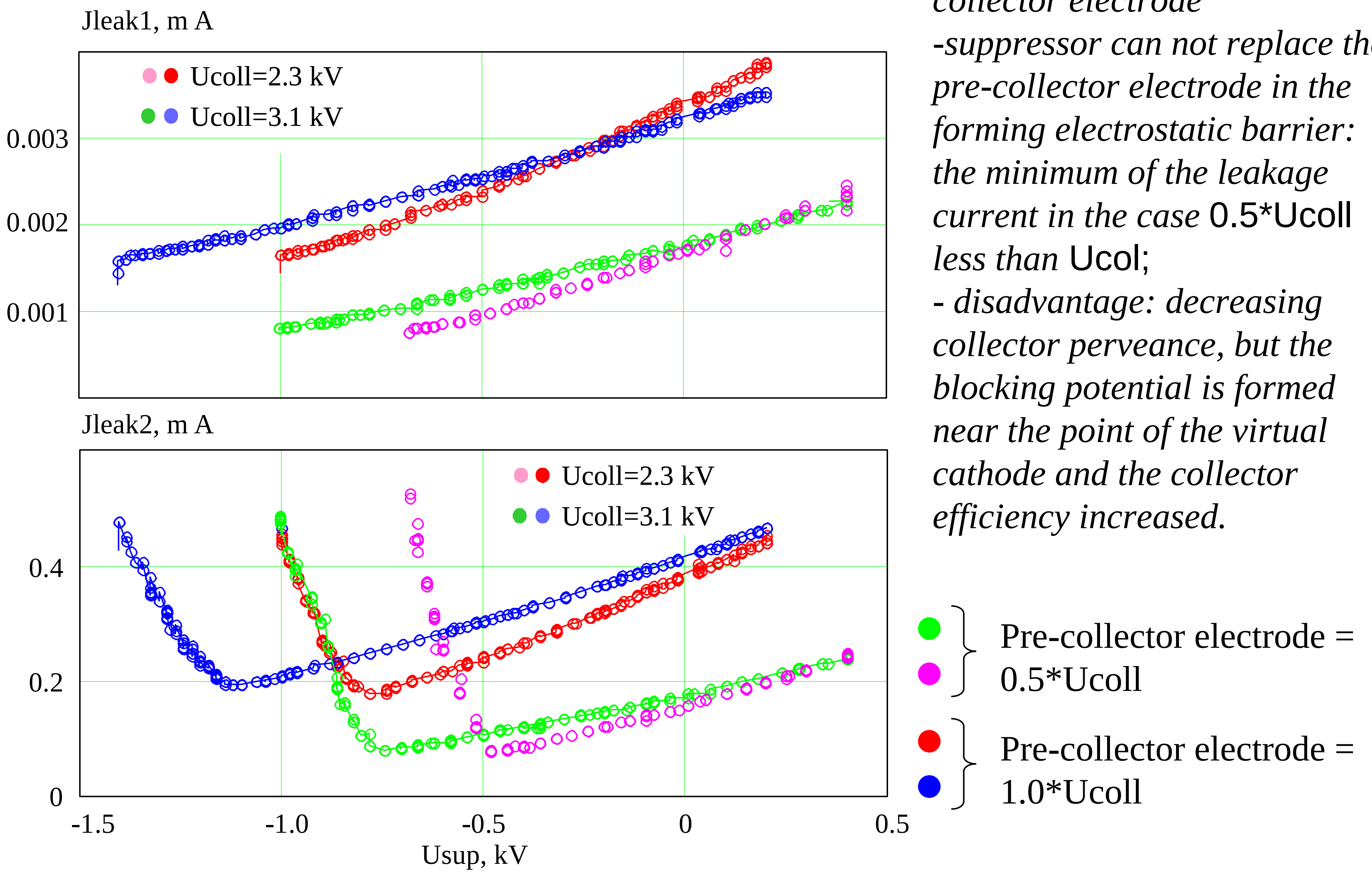
Dependence of the leakage current from the voltage applied to the suppressor



Optimization of the electrostatic barrier of the collector, Jcoll=220 mA

The lowest leakage current near the point of virtual cathode forming

Dependence of the leakage current from the voltage applied to the suppressor

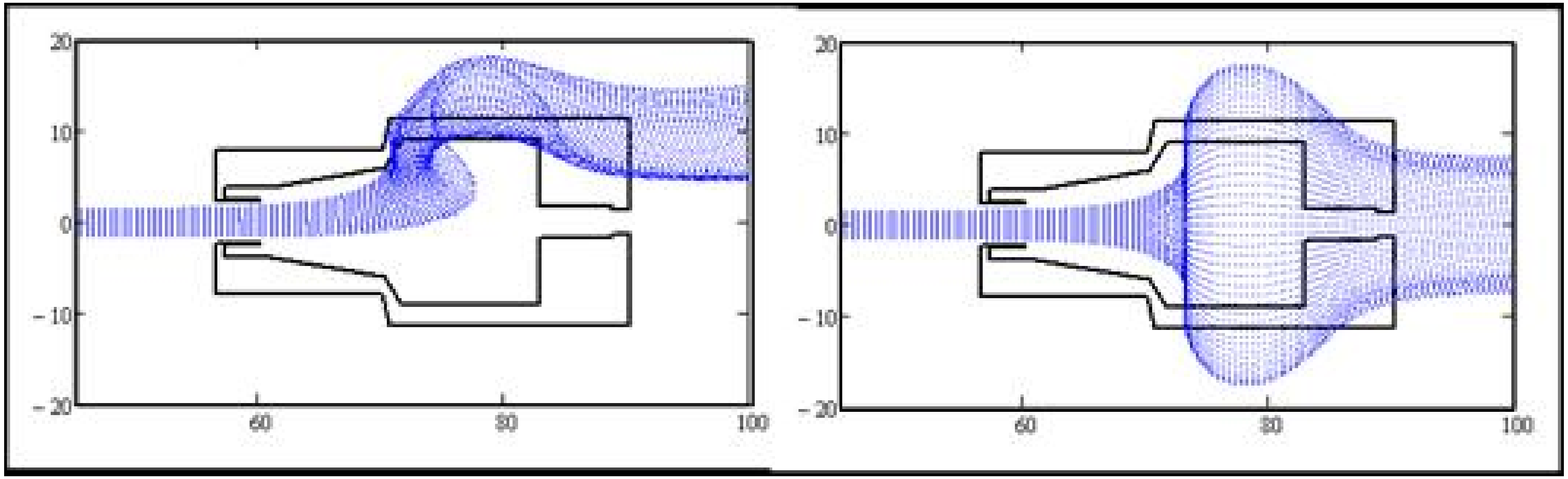


- influence of the additional electrostatic barrier with pre-collector electrode

-suppressor can not replace the pre-collector electrode in the forming electrostatic barrier: the minimum of the leakage current in the case 0.5*Ucoll *less than* Ucol;

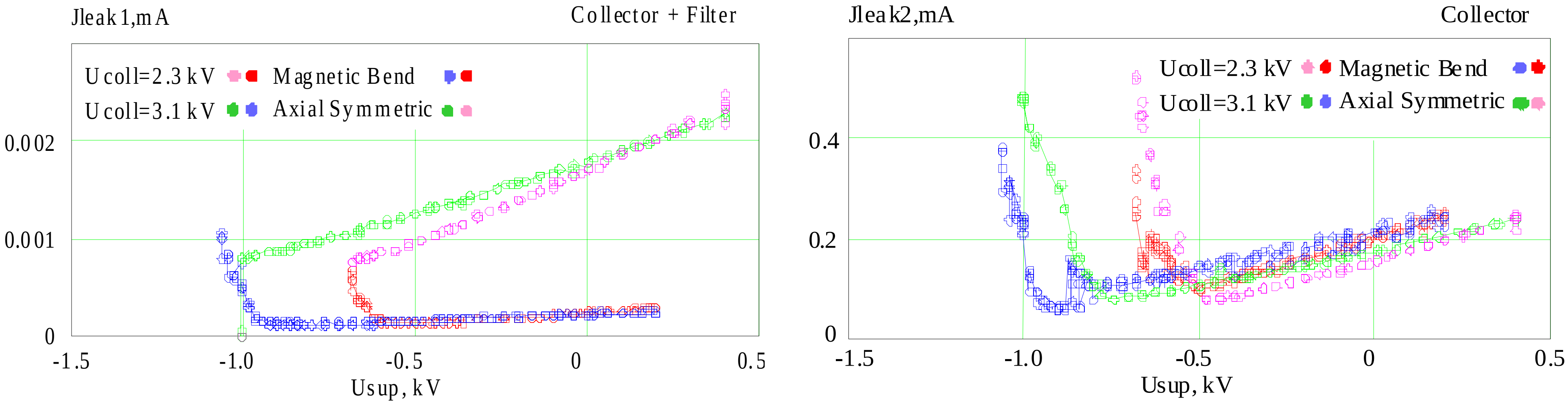
- disadvantage: decreasing collector perveance, but the blocking potential is formed near the point of the virtual cathode and the collector efficiency increased.

Collector with bending magnetic field



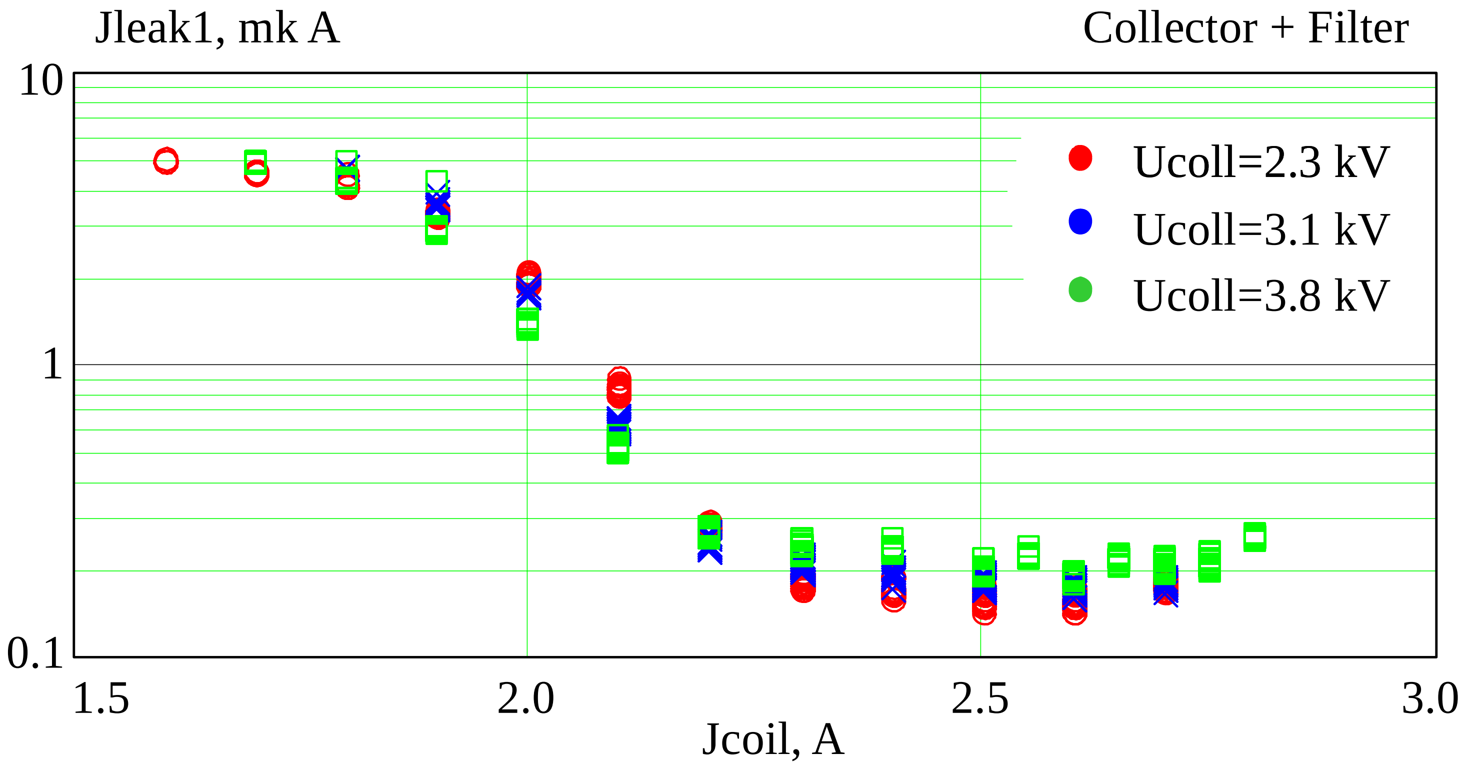
Distribution of the magnetic field in the collector configuration with bending field (left picture) and the collector configuration in the symmetrical case. The points are force lines of the magnetic field

Shemyakin. Electron beam collector with transverse magnetic field



Leakage currents in the symmetrical configuration of the collector and with bend component

Dependence of the leakage current from the magnetic field in the collector



Jcoll = 220 mA,
Usup = -0.2 kV
Uan = 1.0 kV
Ugrid = 0.35 kV
Upre-coll=0.5*Ucoll

The case of the collector with transverse magnetic field, the weak dependence from the collector voltage and the magnetic field in the collector in range 2.3 – 2.8 A

the efficiency of the system with the magnetic bend is better than 10^{-6}

Summary

The key problems of the electron cooler 2 MeV is experimentally verified in the different test-benches [1-4].
The strong surprises aren't observed and the elements of cooler are ready to continue assembly and commissioning.

[1] M. Bryzgunov, "Magnetic system of electron cooler for COSY", COOL'11, TUPS10, Alushta, Ukraine, September 2011, http://www.JACoW.org.
[2] M.I. Bryzgunov et al, "Electron collector for 2 MeV electron coller for COSY", COOL'11, TUPS07, Alushta, Ukraine, September 2011.
[3] M.I. Bryzgunov et al, "Electron gun with variable beam profile for COSY cooler", COOL'11, TUPS06, Alushta, Ukraine, September 2011.
[4] V.N. Bocharov et all, "System of Measurement of magnetic field line straightness in solenoid of electron cooler for COSY", COOL'11, TUPS08, Alushta, Ukraine, September 2011.