Budker Institute
of Nuclear Physics
Siberian Branch of the Russian Academy of Sciences

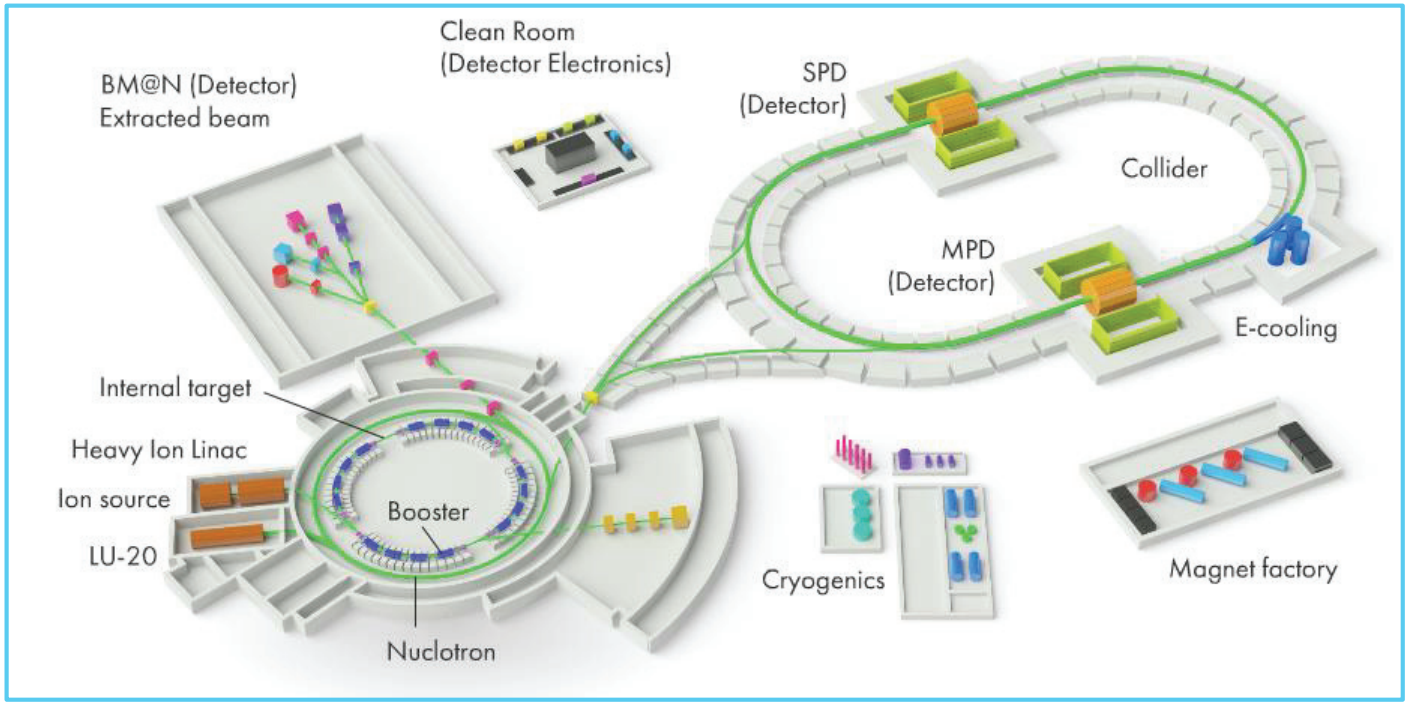
Status of the Electron Cooler for NICA Booster and Results of Its Commissioning

Bryzgunov Maxim + BINP and JINR

electron cooling teams

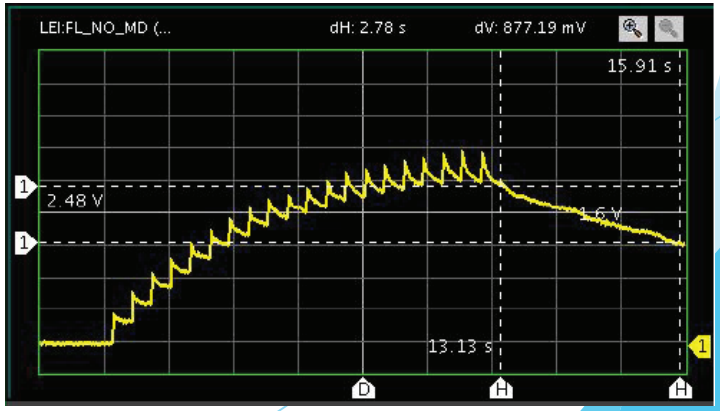
12th International Workshop COOL'19, September 23 - 27, Novosibirsk

Electron Cooler for NICA Booster



Goal of the cooler is work on injection energy for accumulation of ions, and cooling on intermediate energy before acceleration to extraction energy

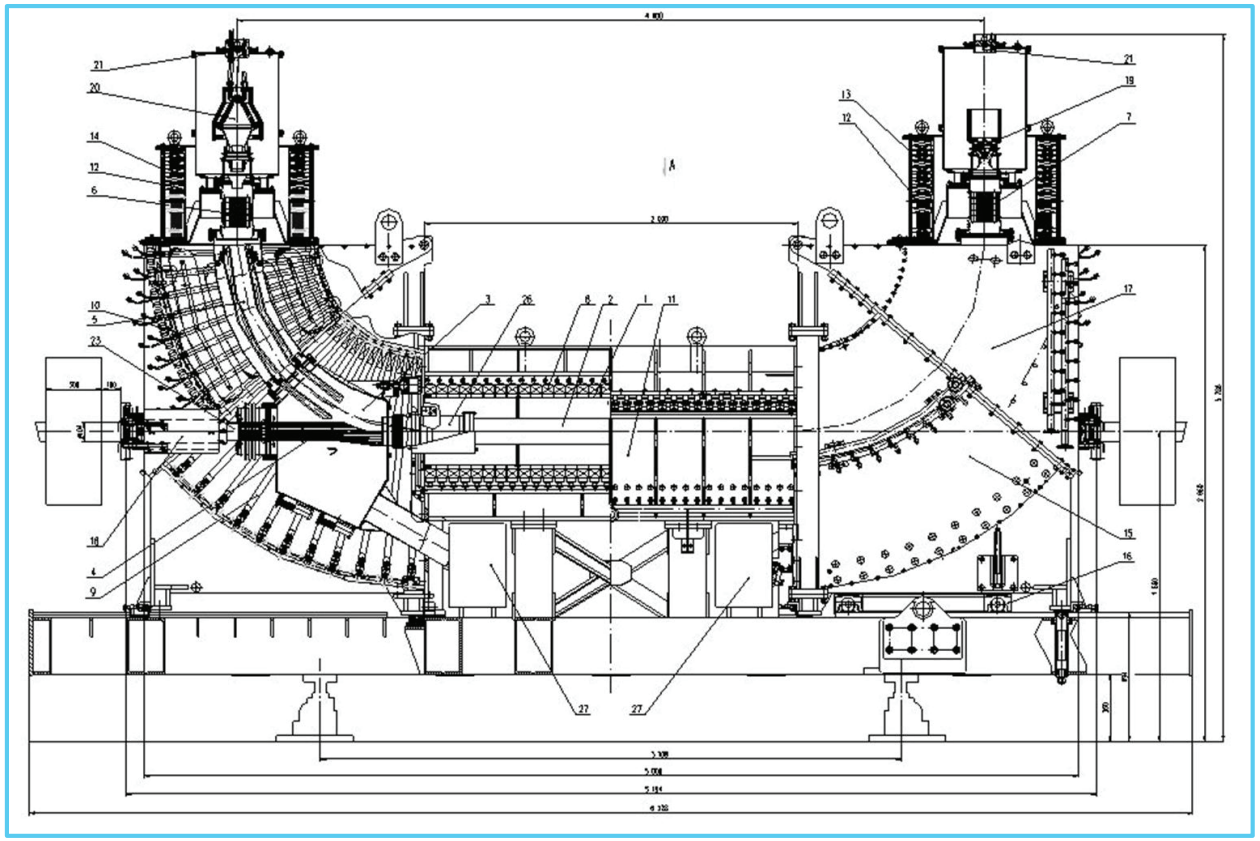
Accumulation of ions on LEIR



Main parameters of the system

Parameter	Value
Ion type	$^{197}Au^{31+}$
Electron energy, E	1.5÷60 keV
Electron beam current, I	0.2÷1.0 A
Energy stability, ΔE/E	$<10^{-5}$
Electron current stability, ΔI/I	$<10^{-4}$
Longitudinal magnetic field, B	0.1÷0.2 T
Electron current loses, I_{leak}/I	$<3\cdot10^{-5}$
Inhomogeneity of magnetic field, ΔB/B	$<3\cdot10^{-5}$
Transverse electron temperature, T	<0.3 eV
Vacuum pressure, P	$\approx10^{-11}$ mbar

Electron Cooler for NICA Booster

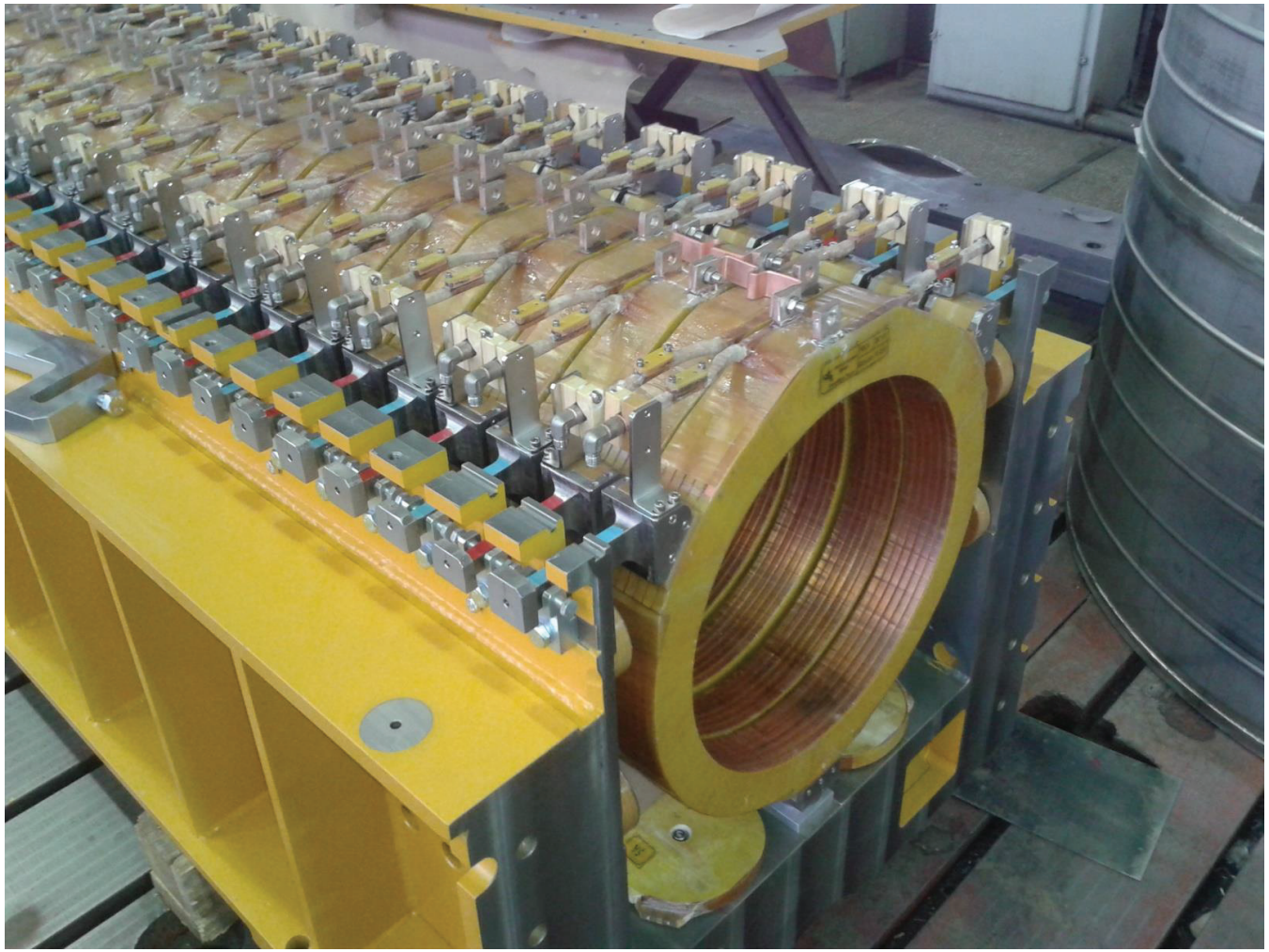


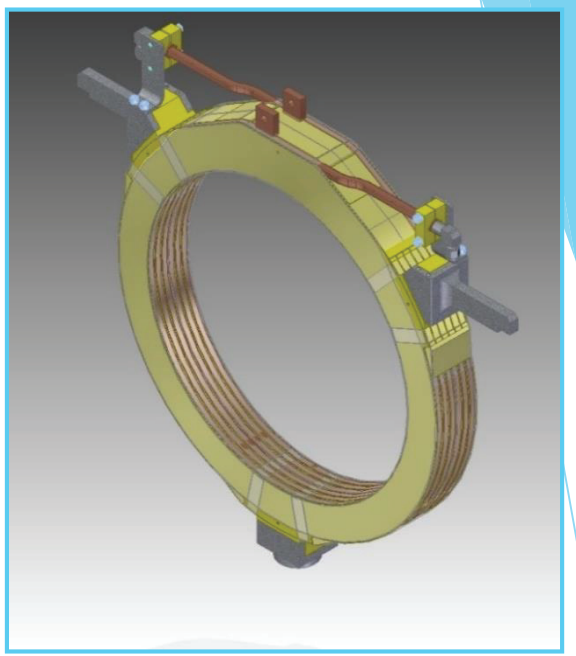
The cooler built with classical scheme.
On the way from gun to collector electrons move in longitudinal magnetic field.

December of 2016
Budker INP

Cooling section

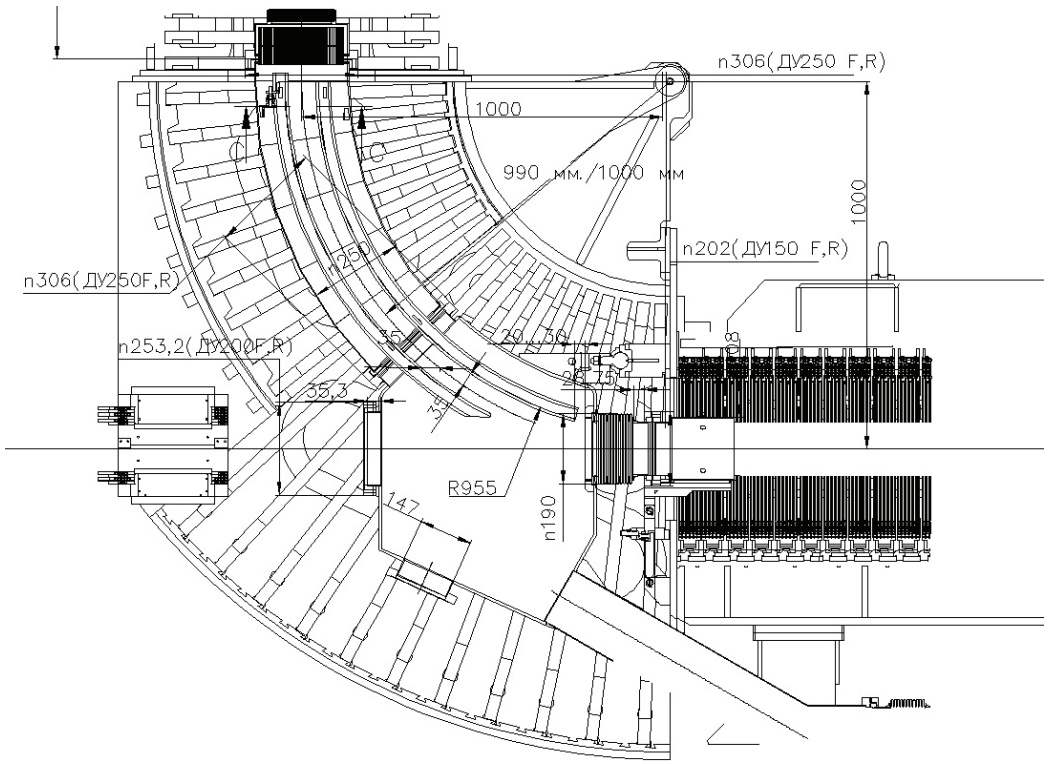
Homogeneity of magnetic field is very important for cooling force.





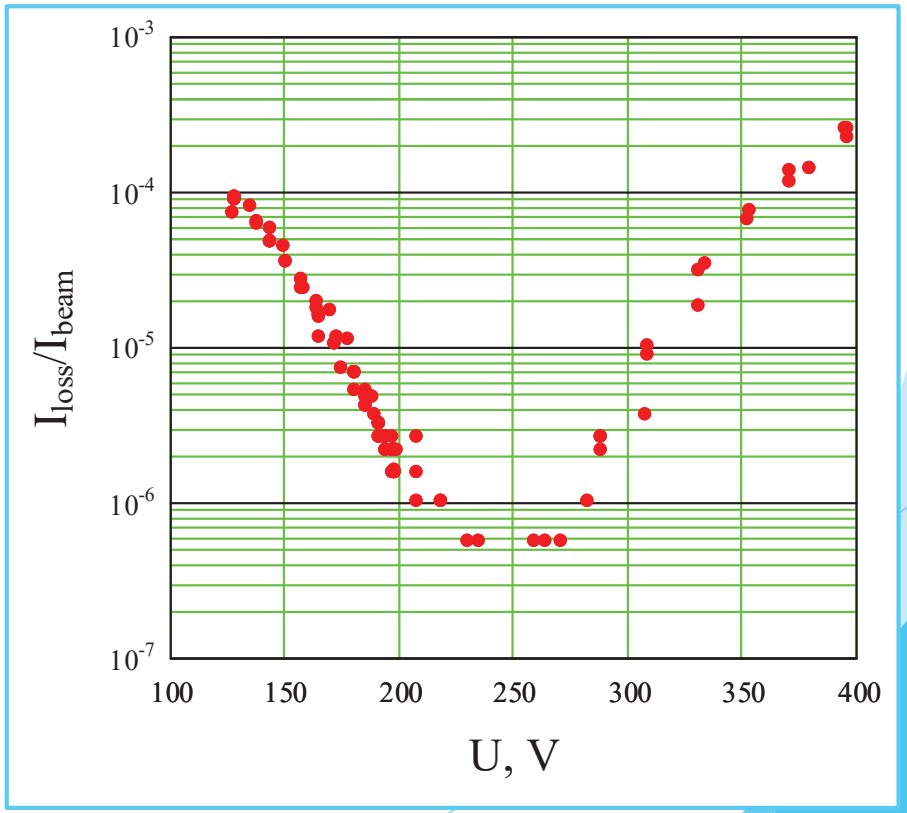
Solenoid consists of separate coils. Each coil can be rotated in two direction

Toroids



$$F = \frac{mV^2}{R} = eE + e\frac{[V \times B]}{c} = const$$

E=0 magnet bending B=pc/eR
B=0 electrostatic bending E=pV/eR

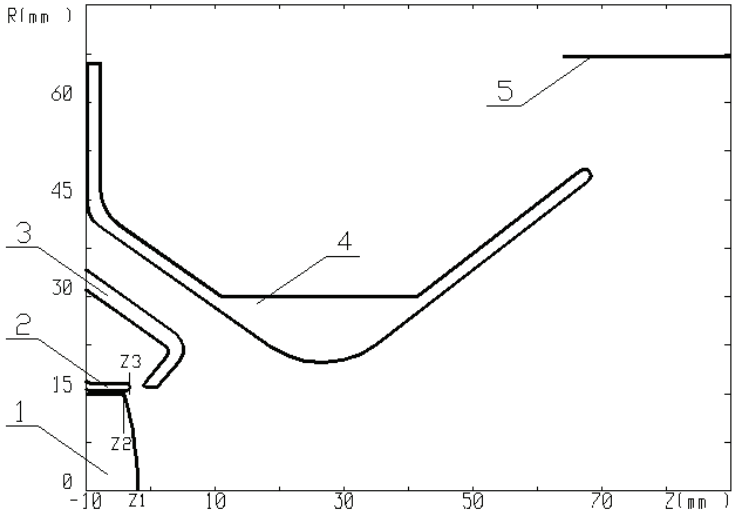


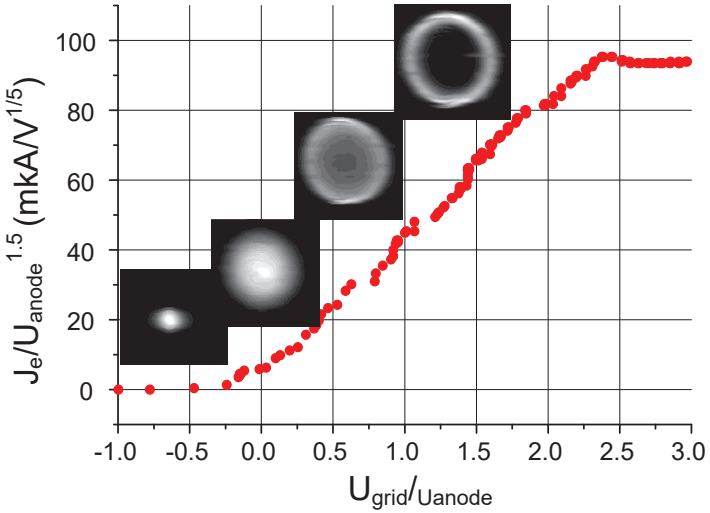
Electrostatic plates are used in toroid. Recuperation efficiency increases to

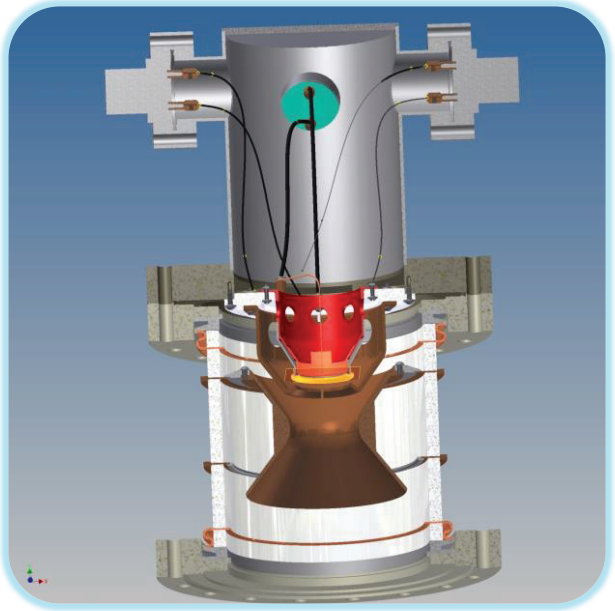
$$\frac{I_{leak}}{I} \approx 10^{-6}$$

Electron gun

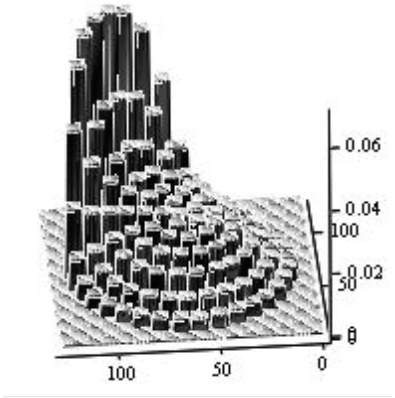
The gun is based on construction from HV COSY cooler.

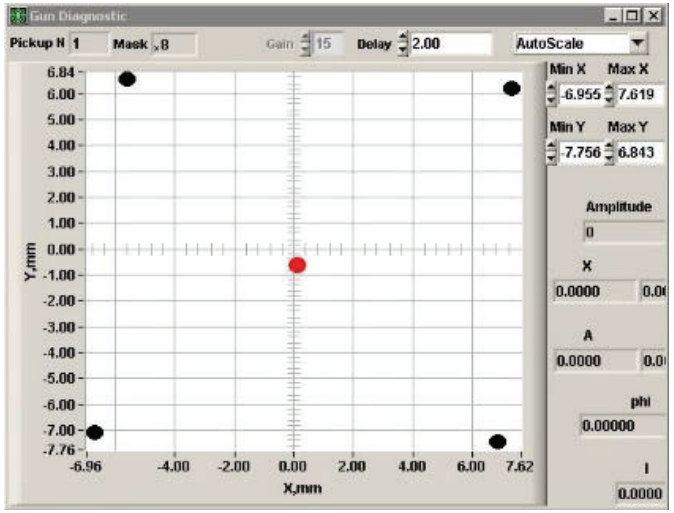






4-sector control electrode

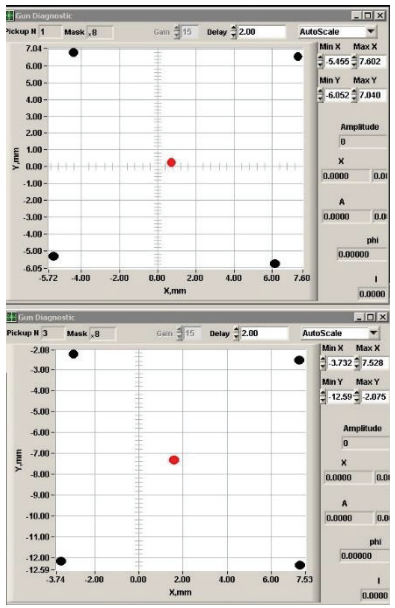




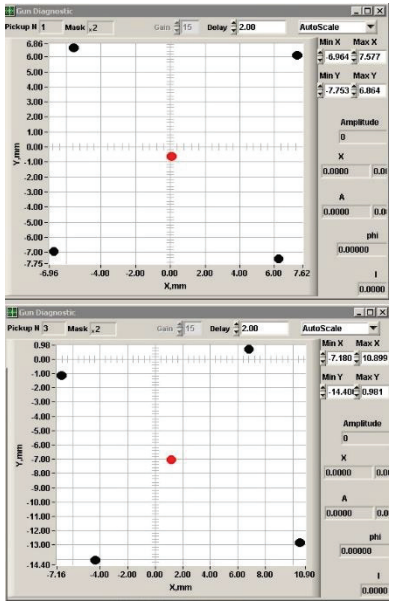
Voltage is applied to one sector

BPM 1

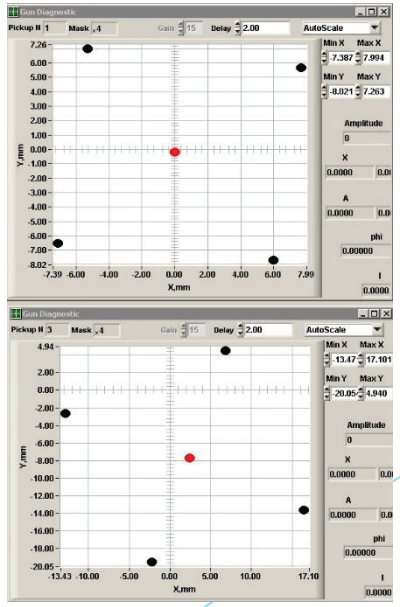
BPM 3



30 mA

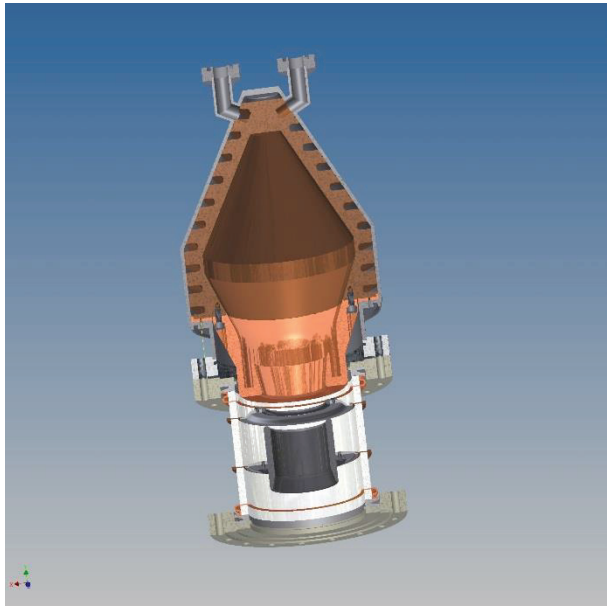


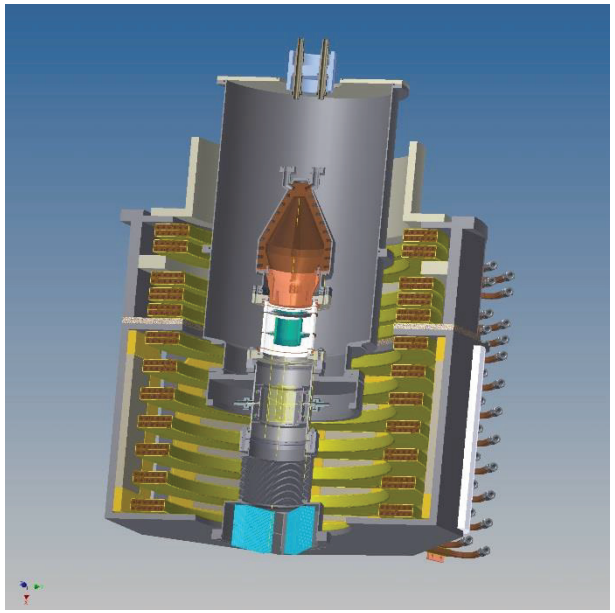
115 mA

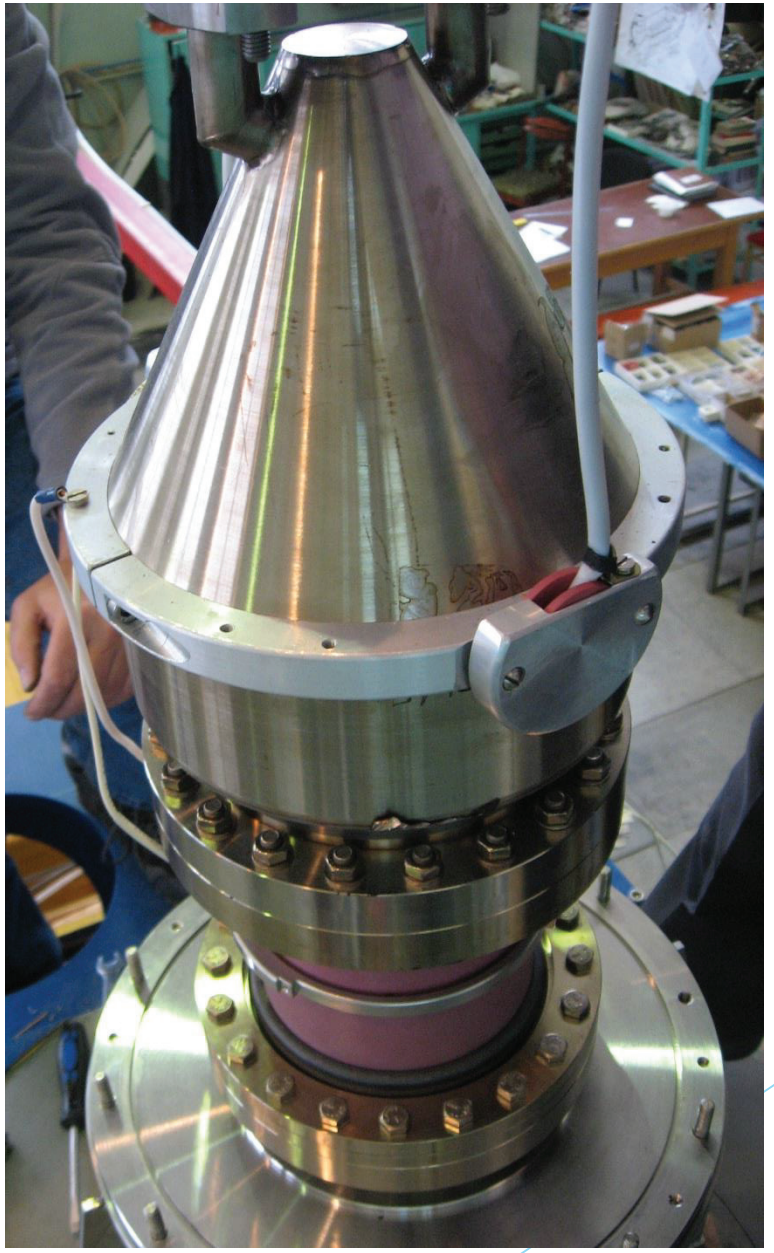


200 mA

Electron collector

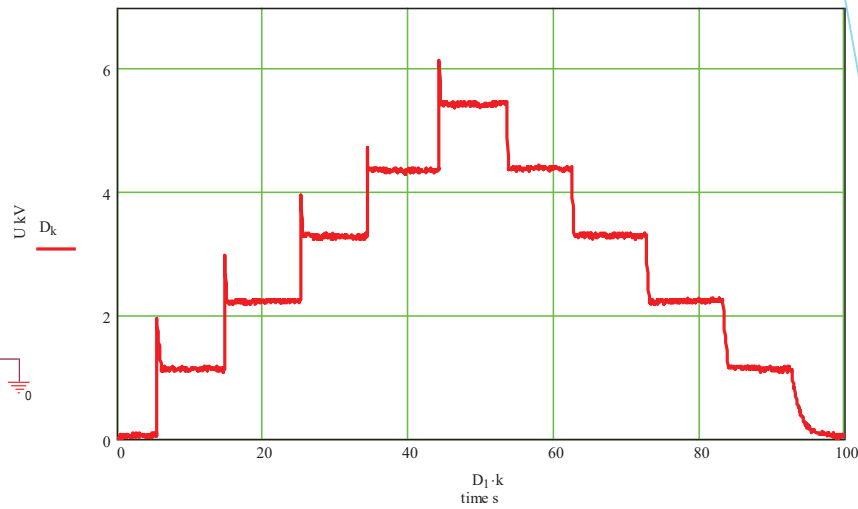


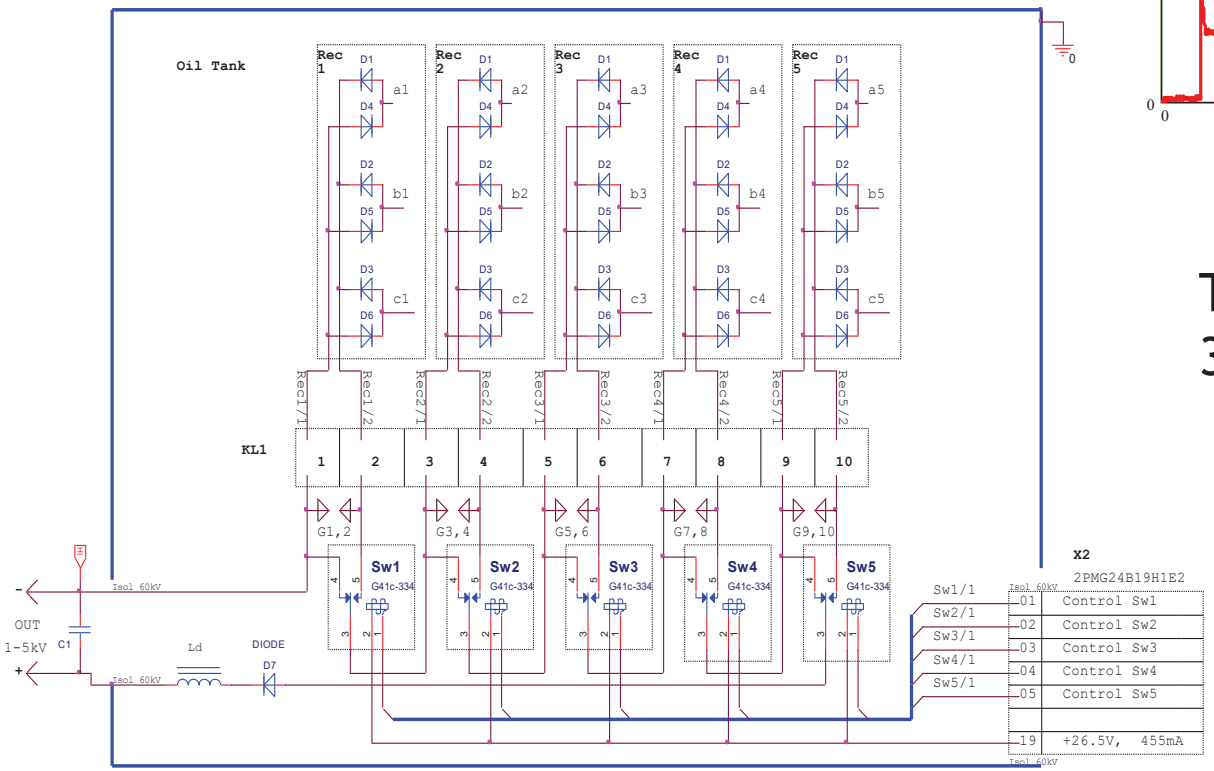




Collector power supply

The PS is based on isolation transformer. Each of 5 identical windings after rectifiers give 1 kV. Using HV relays we can get from 0 to 5 kV.

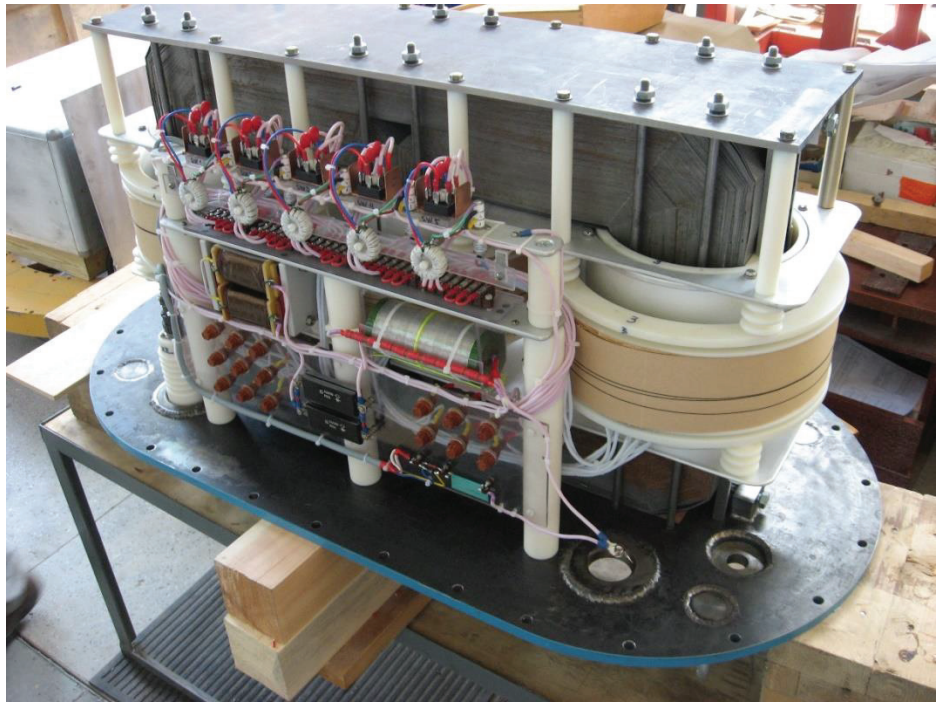


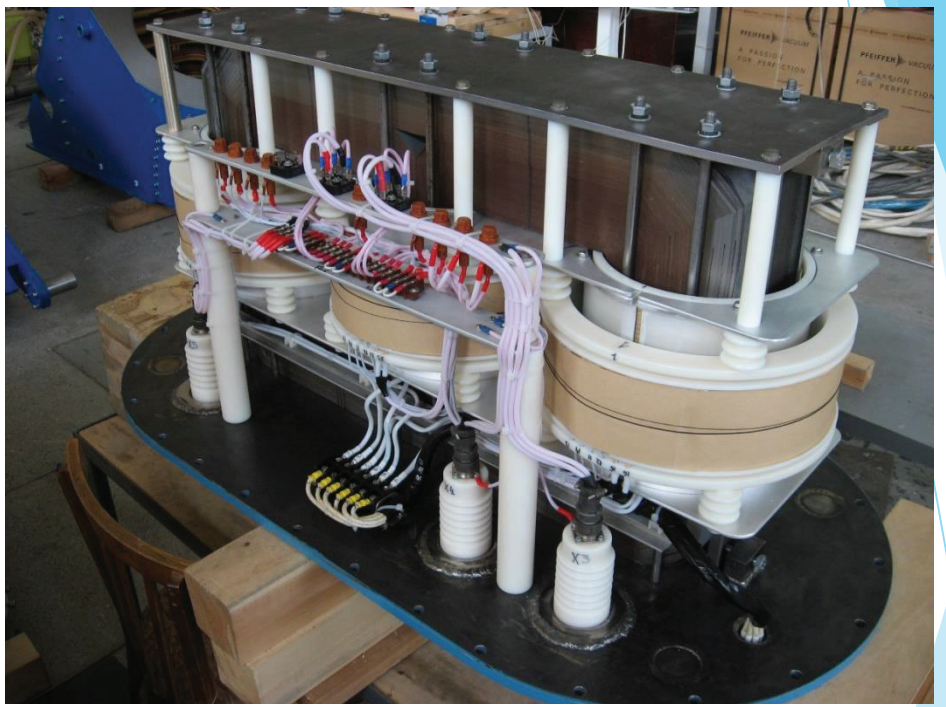


The PS gives up to 5 kV, 3 A (DC).

Collector power supply

The transformer is based on UNICORE core.





The transformer also contains winding to feed power supplies which control gun and collector.

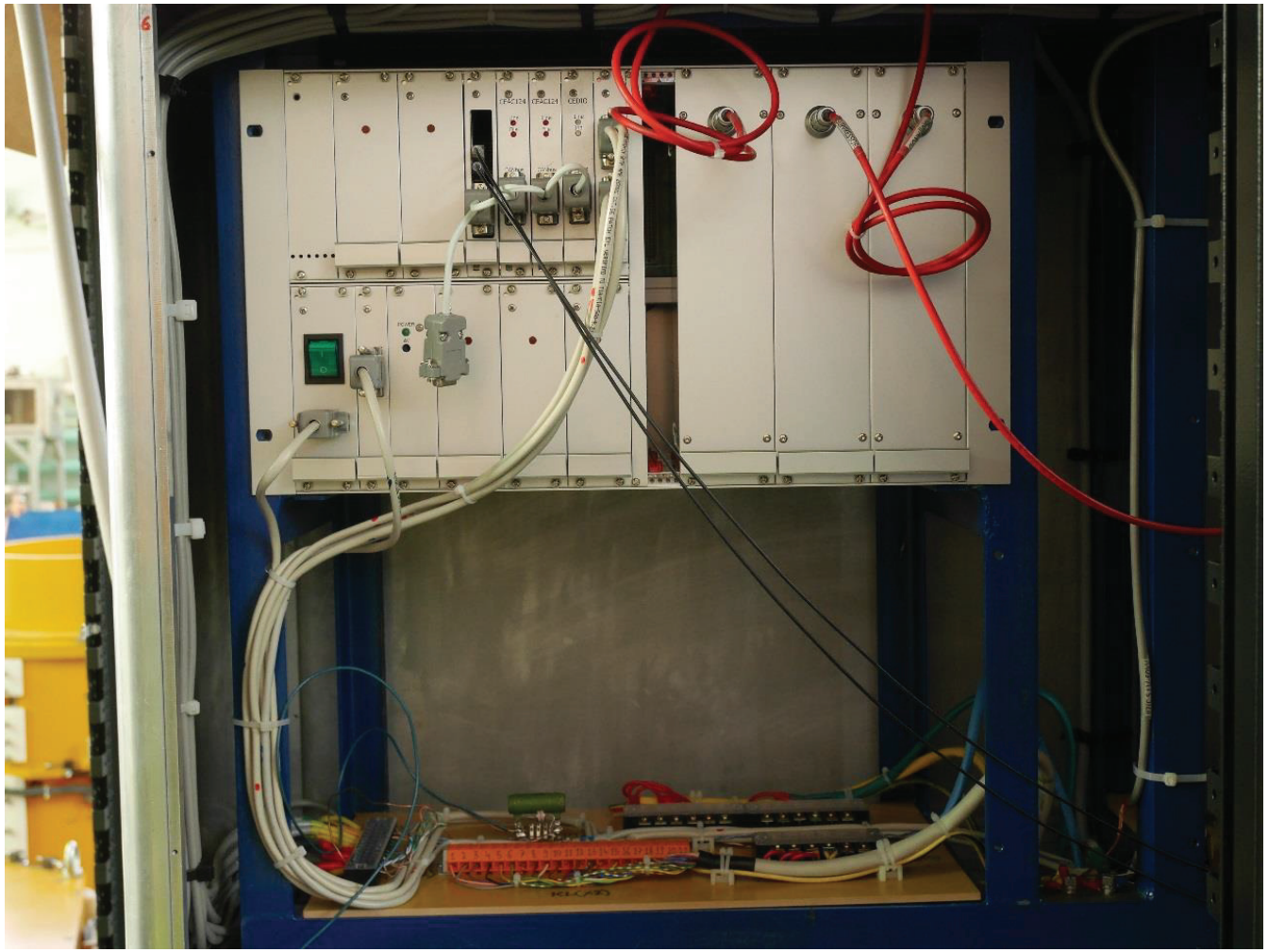
High voltage system

Transformer: 5 kV, 15 kW.
power supply: 60 kV 10 mA

High voltage system

60 kV power supply and oil cooling system

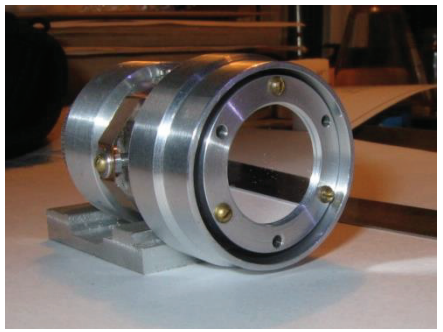
High voltage system

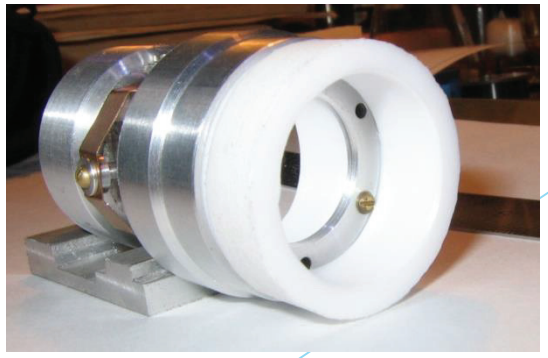


The crate contains power supplies for anode, grid, suppressor and filament.

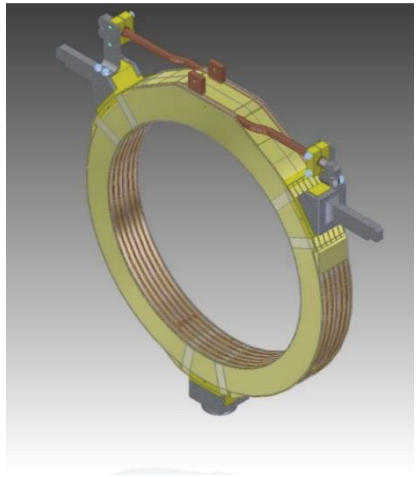
Compass like system for measuring of the transverse component of the magnetic field

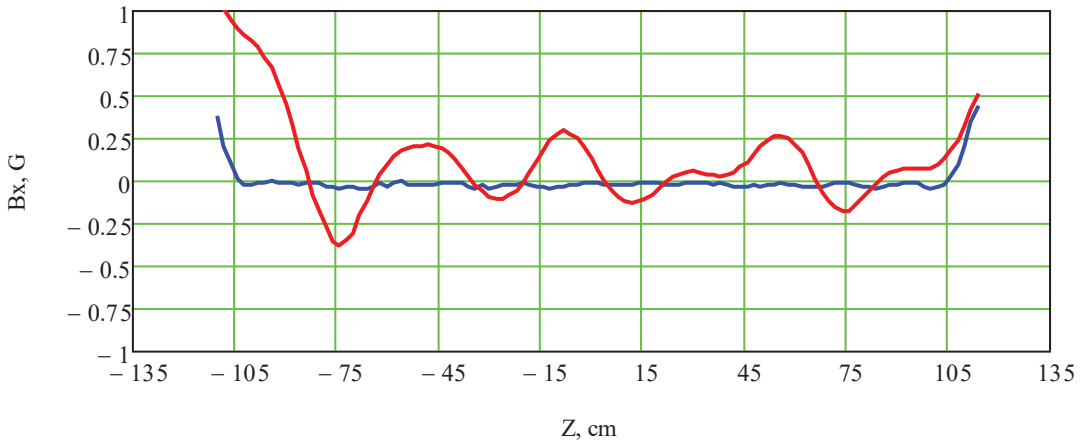
Diagram of the measuring device: *(1)* magnetic sensor, *(2)* conductors of the compensating circuits, *(3)* beam splitter, *(4)* photo-detector, *(*I-IV) photo-detector quadrants, and *(*X, Y) output current amplifiers.

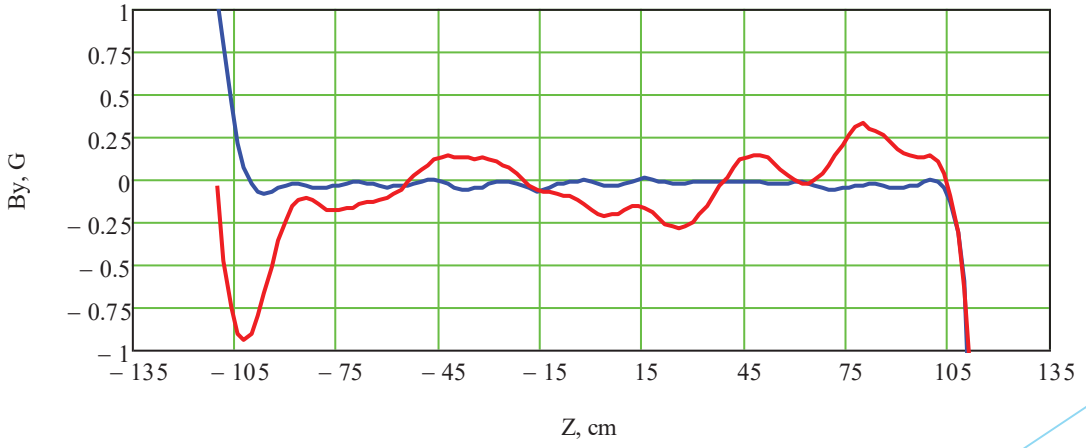




Correction of field line straightness



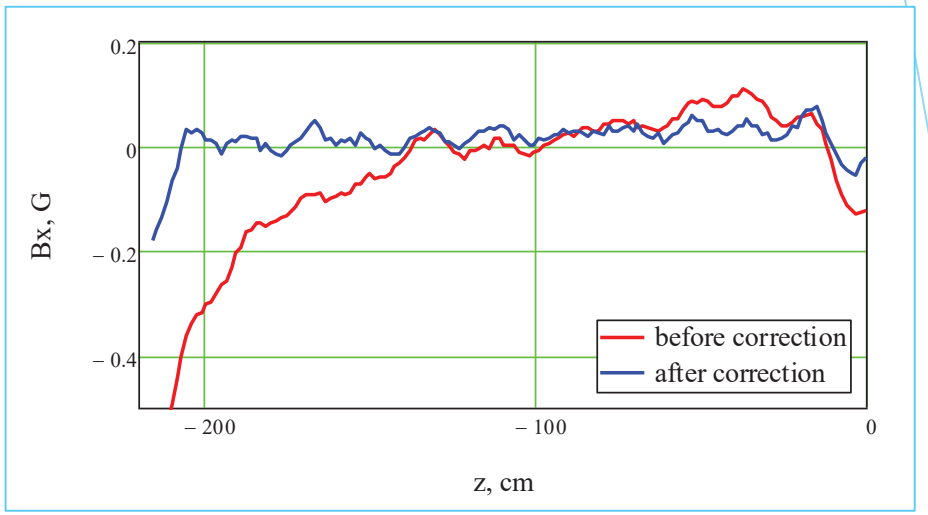


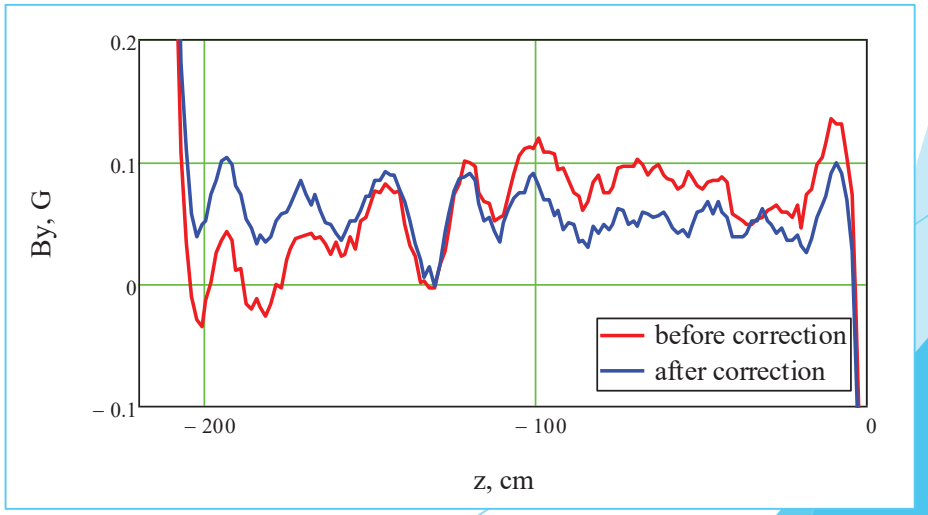


Inhomogeneity of longitudinal magnetic field in the cooling section $\Delta B/B \approx 10^{-5}$.

Correction of field line straightness in Dubna

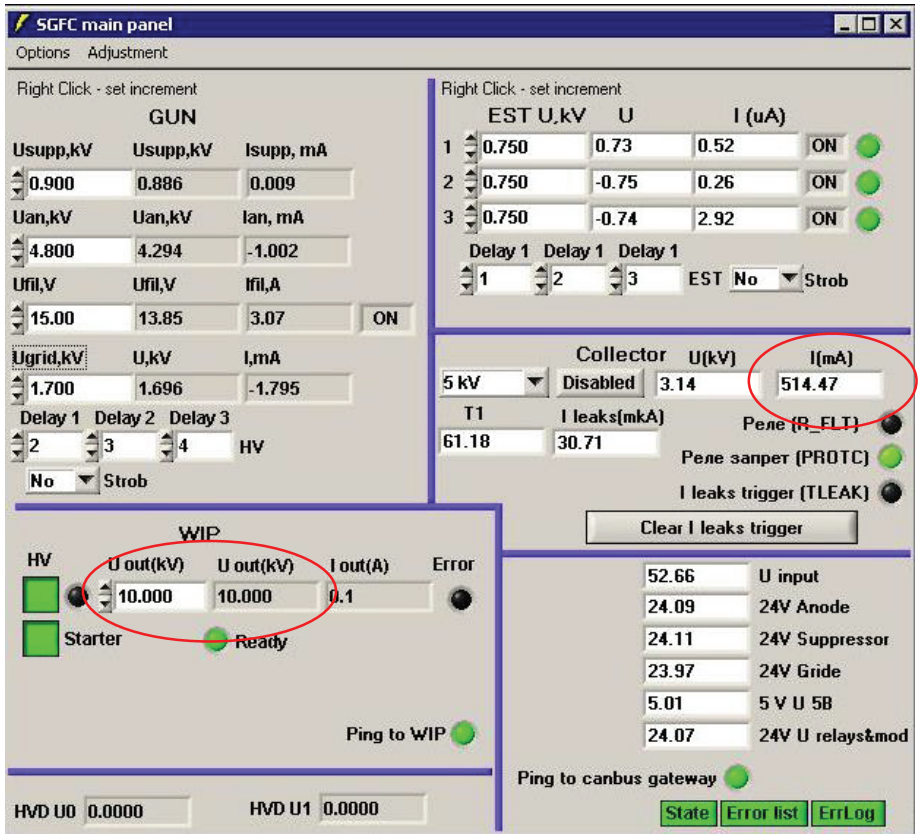
Transportation from BINP to JINR changes homogeneity not too much

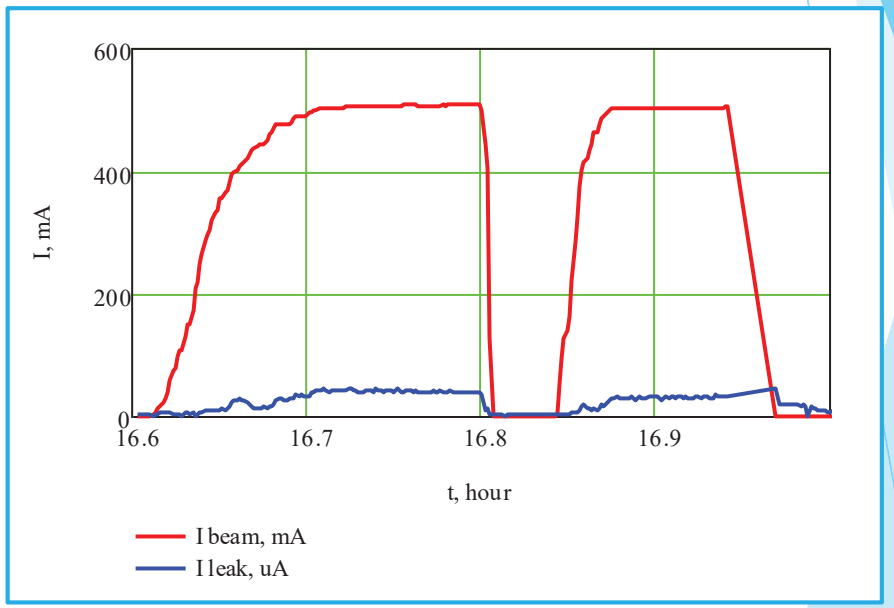




Beam tests in Dubna

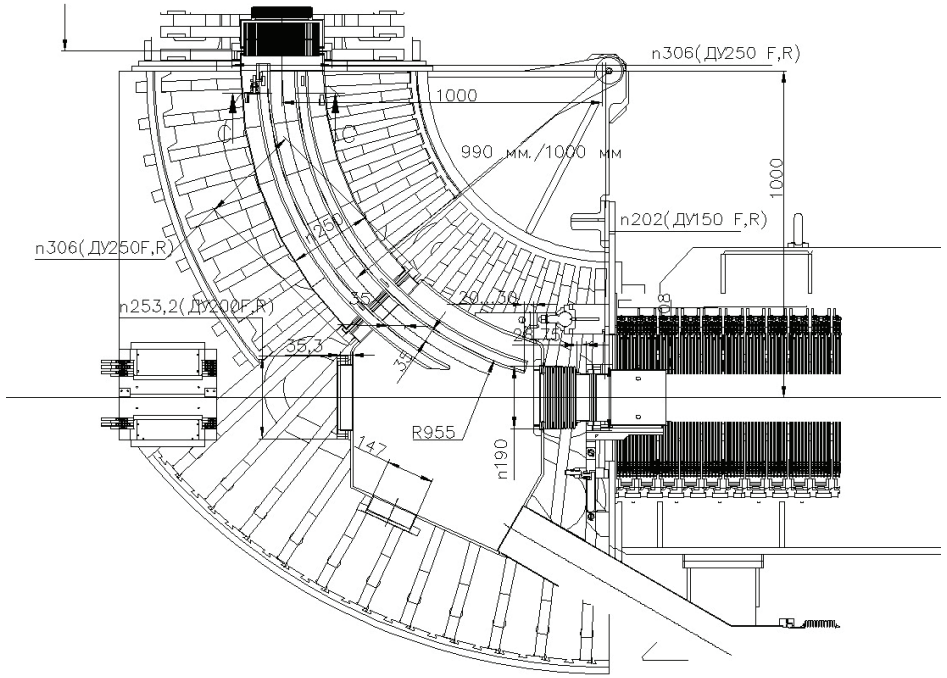
Up to 500 mA on different energies.

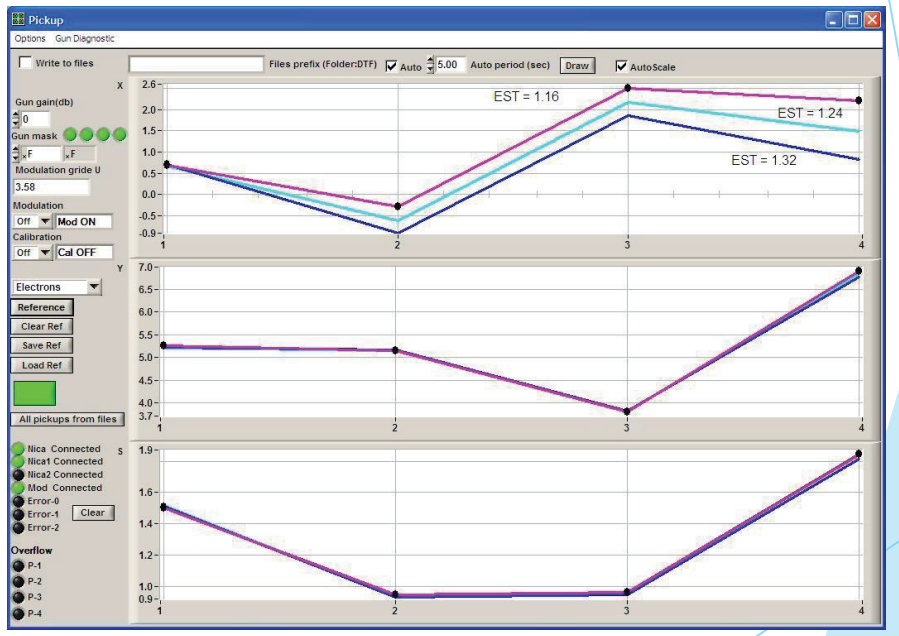




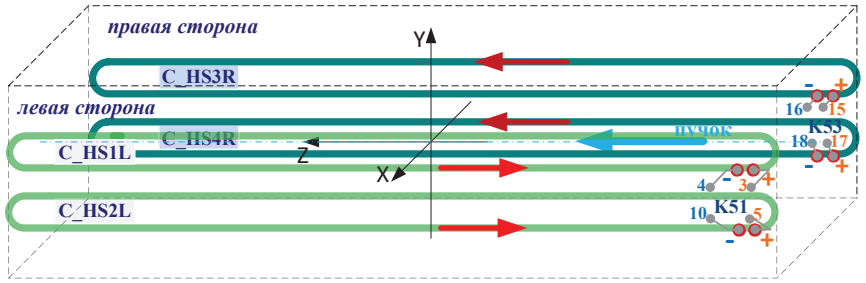
Beam position monitors

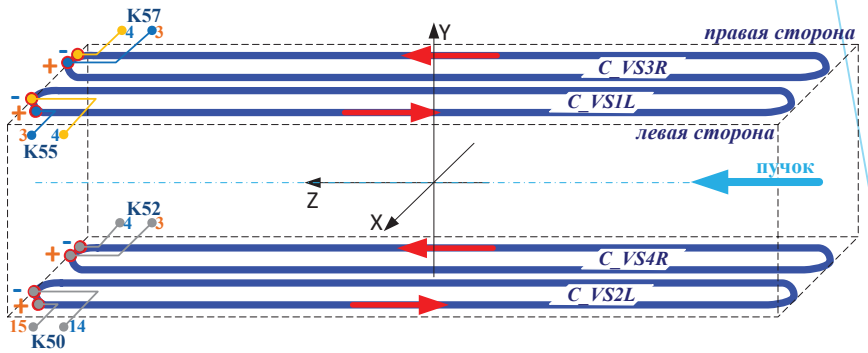
2 electrostatic bends shift beam in horizontal direction 2 times.

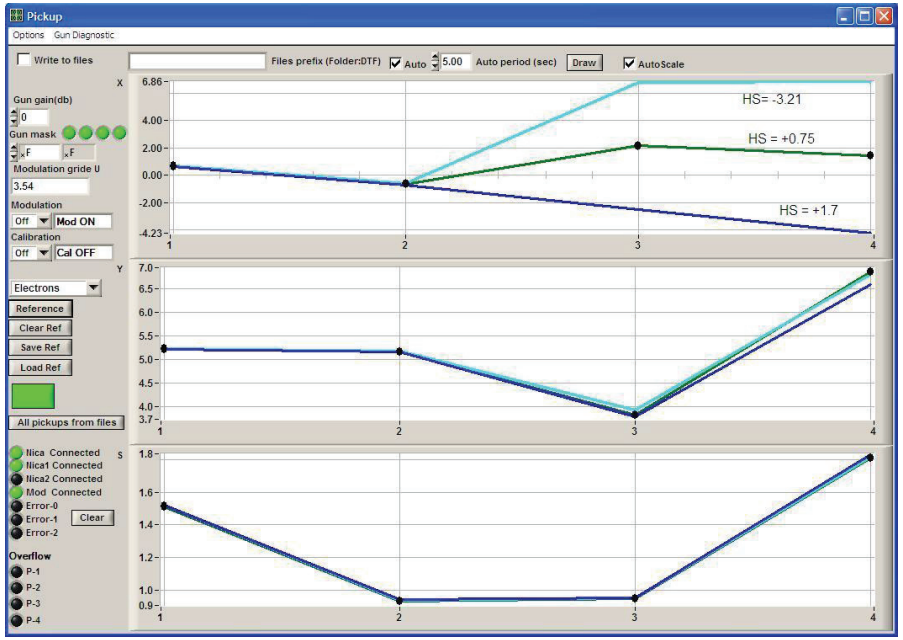


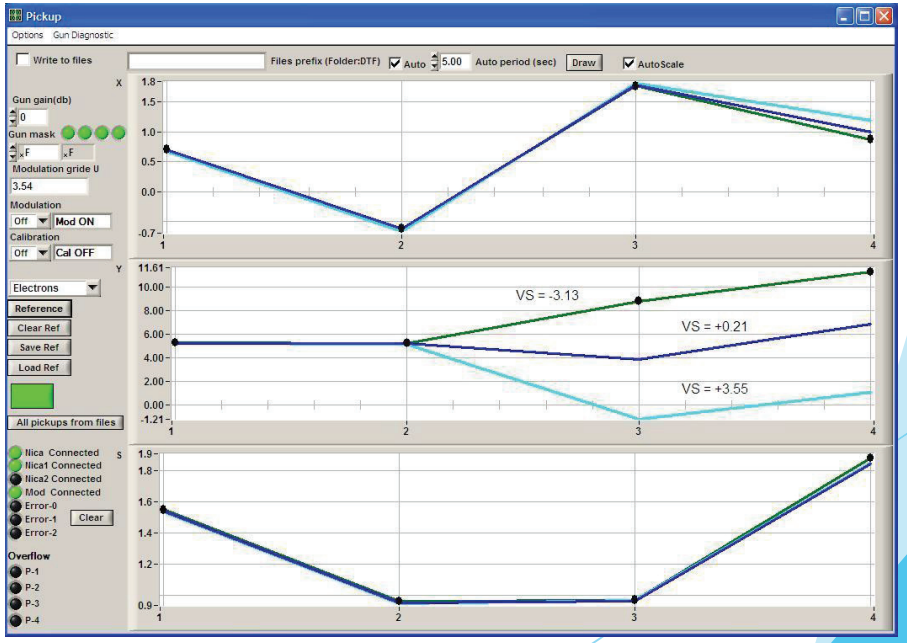


Magnetic correctors



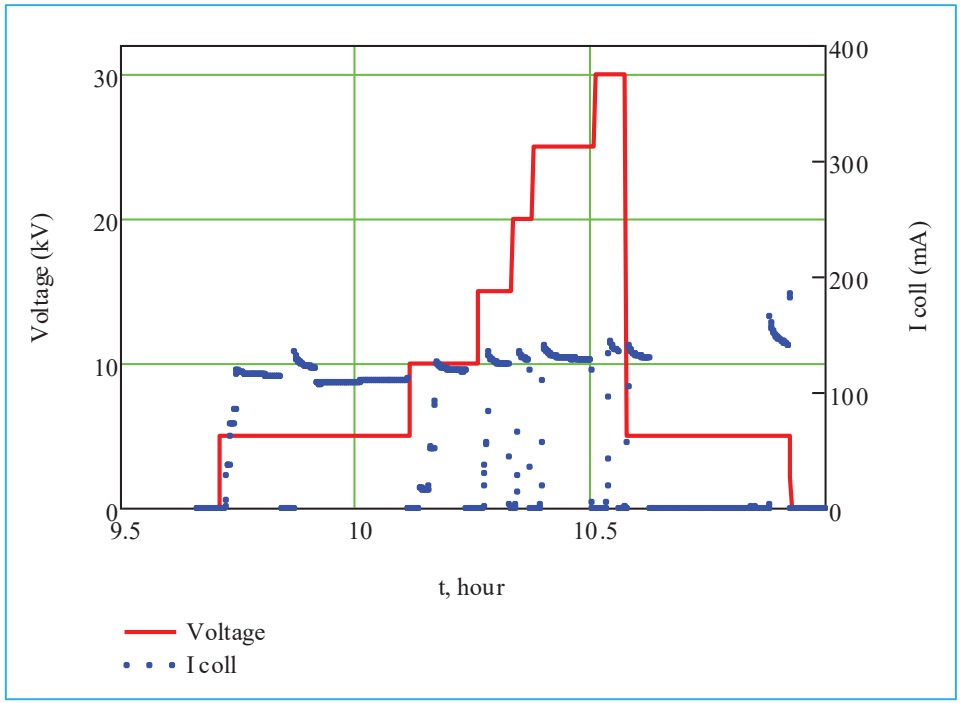


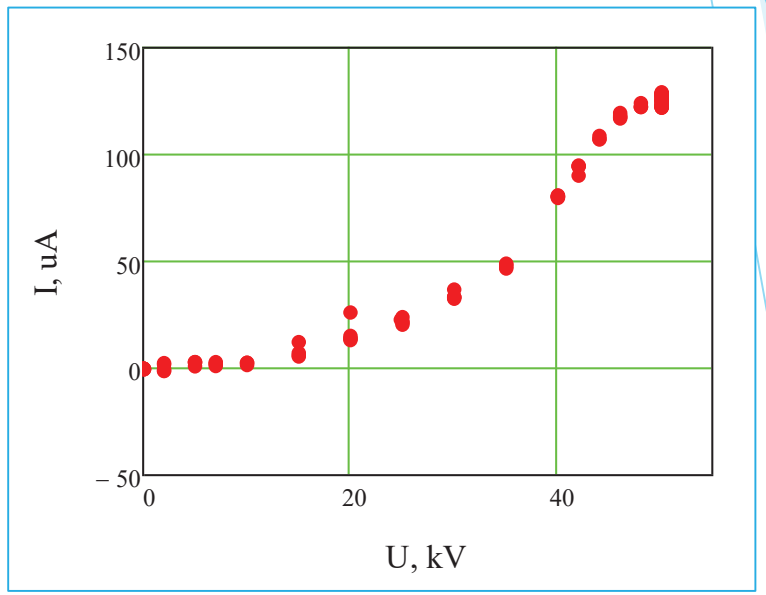


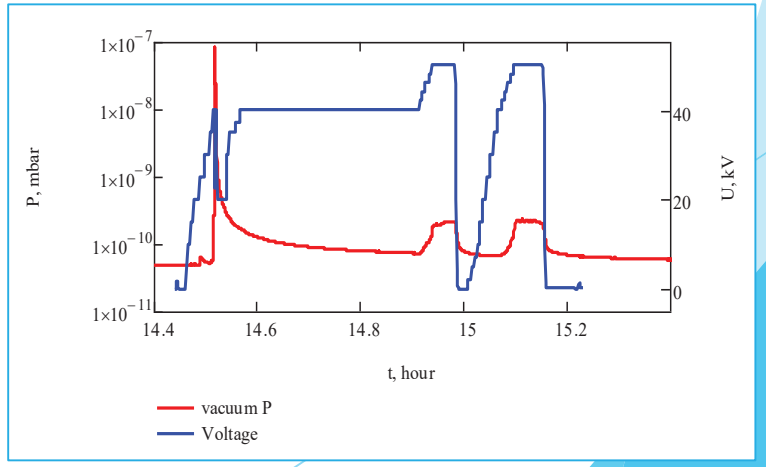


Work on different energies

For different energies only voltage on electrostatic plates was changed.





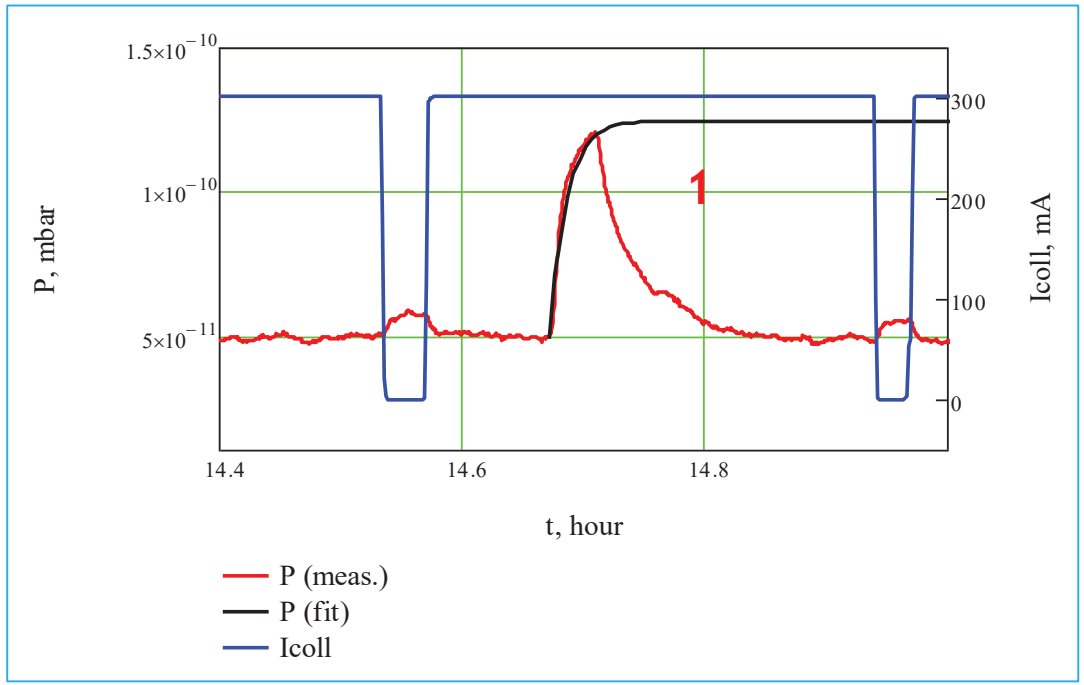


For every energy value current ≈130 mA was reached with appropriate leakage current.

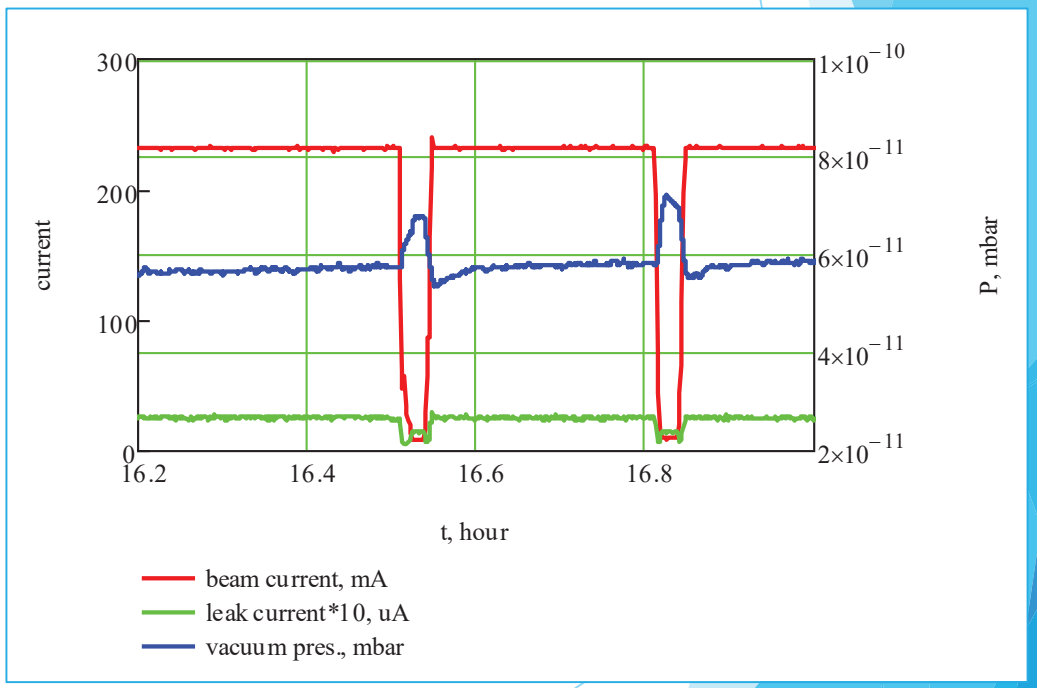
Influence of electron beam on vacuum

Vacuum conditions are important for ion beam lifetime. Electron beam improves vacuum in the cooler.

In BINP



In JINR



(1) - Turn off vacuum pump

Influence of electron beam on vacuum

$V_1 = \sigma L$ - 1 electron ionizes all molecules in volume V_1.

$\frac{dN}{dt} = \frac{I}{e}$ - Number of electrons in 1 second

$\frac{dV}{dt} = V_1 \frac{dN}{dt} = \frac{I\sigma L}{e}$ - Formula for estimation of pumping speed

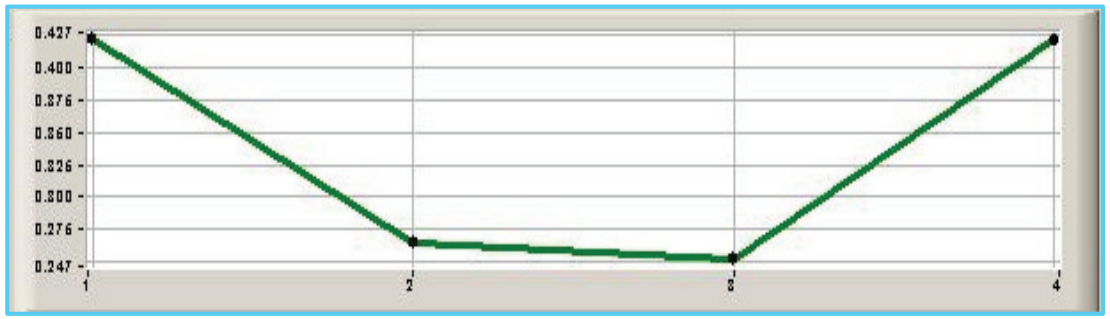
$\sigma \approx 6.5 \cdot 10^{-18}$ cm^2 (H_2)

L=6 m (trajectory length from gun to collector)

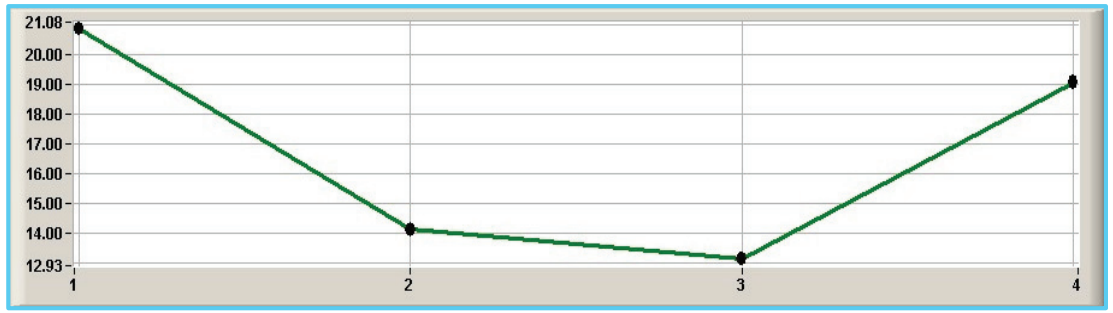
I=300 mA

$\frac{dV}{dt} \approx 7 \frac{l}{s}$

Sum signal on BPMs for different regimes

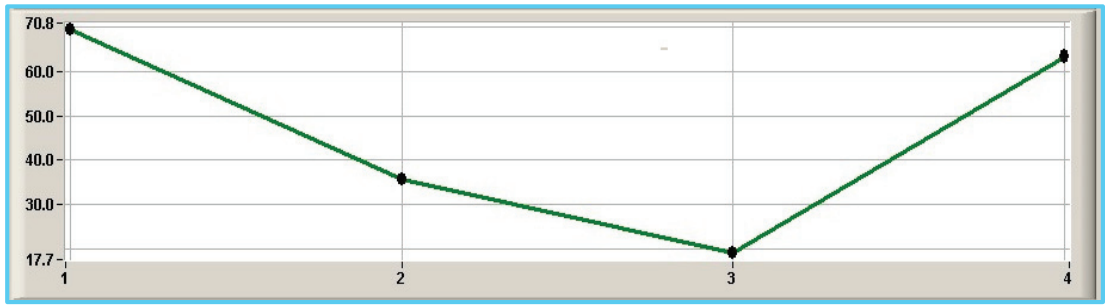


I=50mA, U=5kV



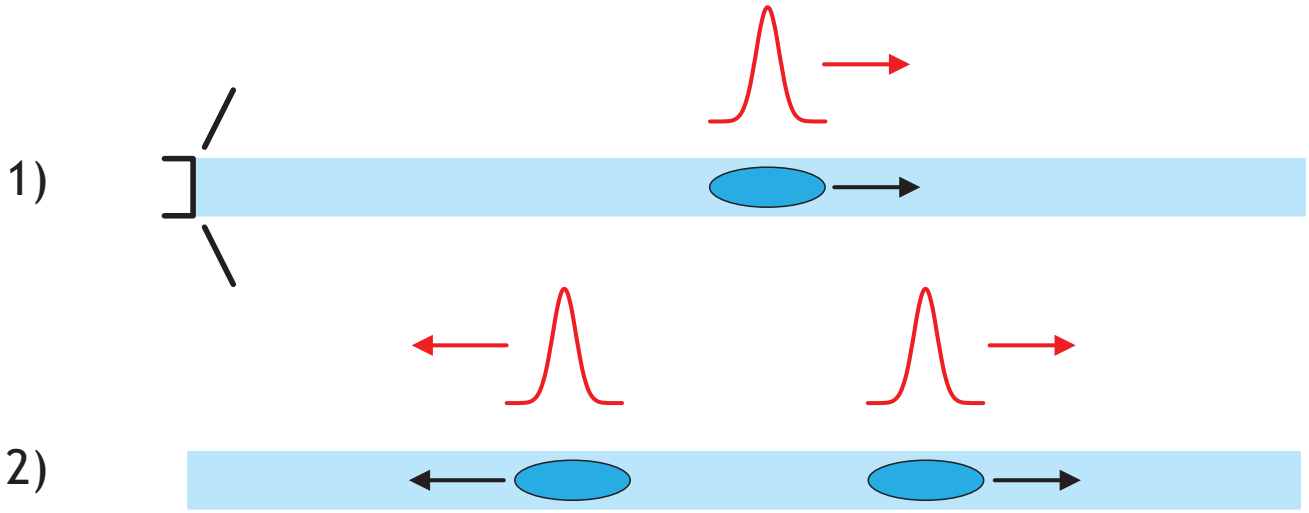
I=19mA, U=1.74kV

I=76 mA, U=1.74kV



I=200 мА, U=1.74kV

Plasma waves in electron beam



$$k_{\pm} = \frac{\omega}{V_0 \pm V_w} \qquad V_w = \omega_p a_b \qquad \omega_p = c\sqrt{2\pi r_e n_e \left(\ln\frac{b}{a} + \frac{1}{2}\right)}$$

a_b - beam radius

n_e - electron density

r_e - classical electron radius

Plasma waves in electron beam

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ELECTRON AND ION BEAMS, ACCELERATORS

Interaction between an Intense Proton Bunch and Electron Beam in a Tevatron

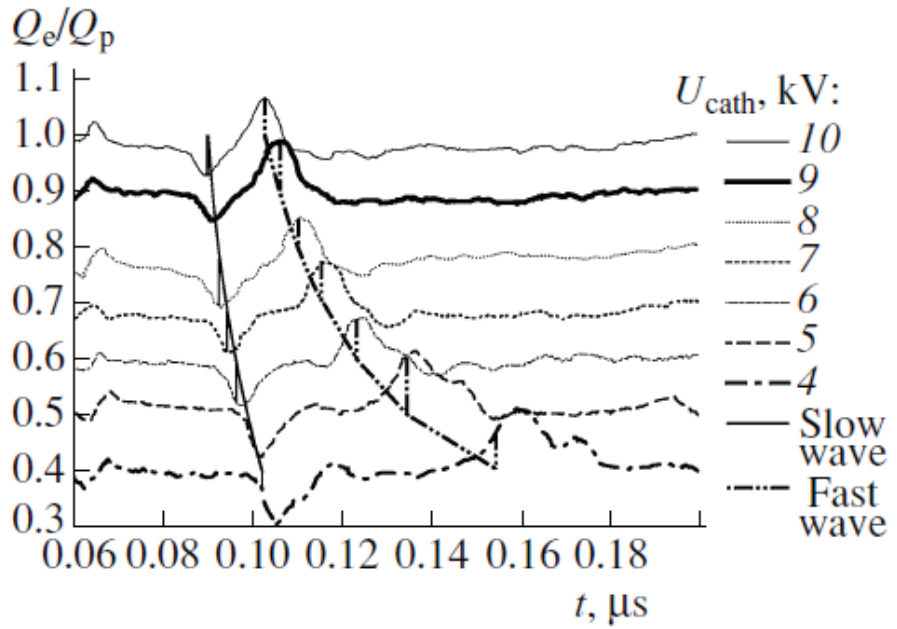
V. V. Parkhomchuk*, V. B. Reva*, and V. D. Shil'tsev**

** Budker Institute of Nuclear Physics, Siberian Division, Russian Academy of Sciences, pr. akademika Lavrent'eva 11, Novosibirsk, 630090 Russia*

e-mail: reva@inp.nsk.su

*** Fermi National Accelerator Laboratory, P.O.Box 500, Batavia, IL 60510-0500*

Received October 2, 2002



Waves in electron beam

COLD HEAVY ION BEAMS AT THE HEIDELBERG TSR+

M. Grieser, M. Blum, D. Habs, G. Huber*, M. Jung, E. Jaeschke, C.M. Kleffner, D. Krämer, W. Petrich, R. Repnow, S. Schröder*, M. Steck.
Max Planck-Institut für Kernphysik D-6900 Heidelberg, Germany
* University of Mainz

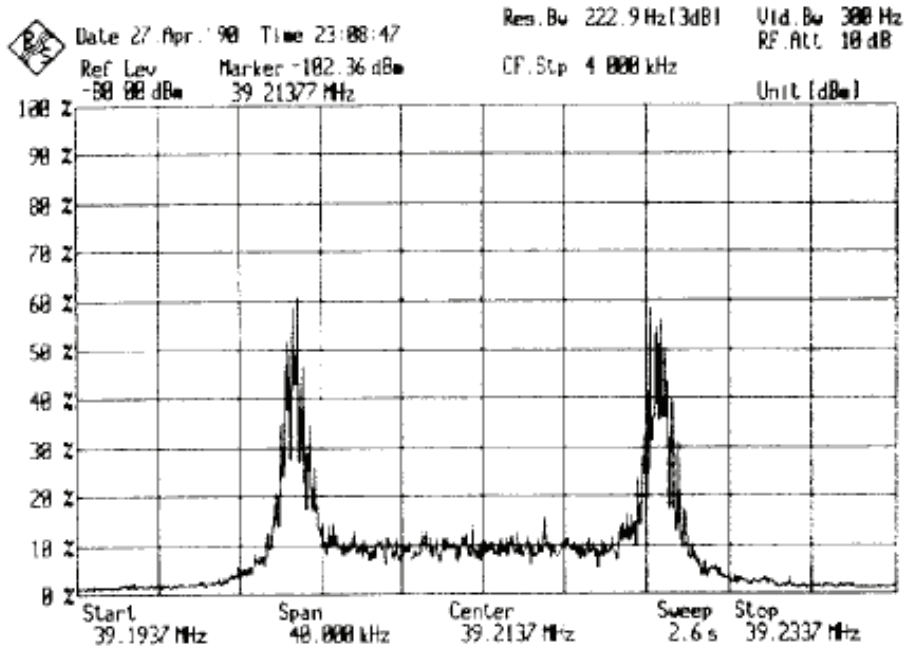
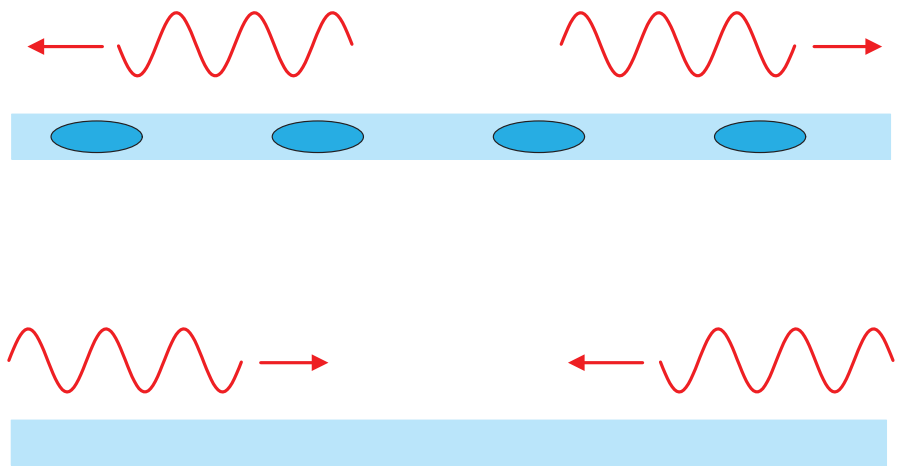


Fig.1: Schottky spectrum of $1 \cdot 10^9$ oxygen ions ($^{16}O^{8+}$ 98 MeV) stored with electron cooling

Waves in ion beam

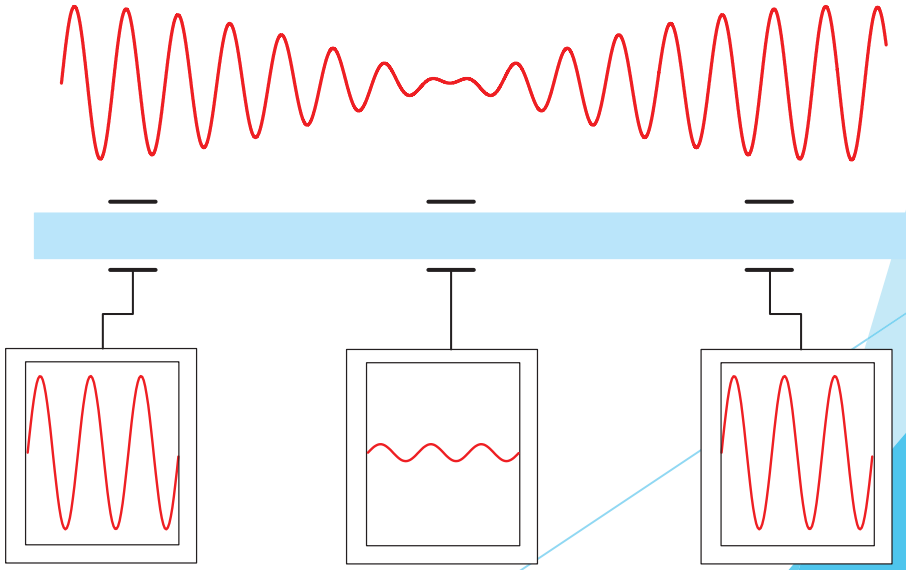
Plasma waves in electron beam

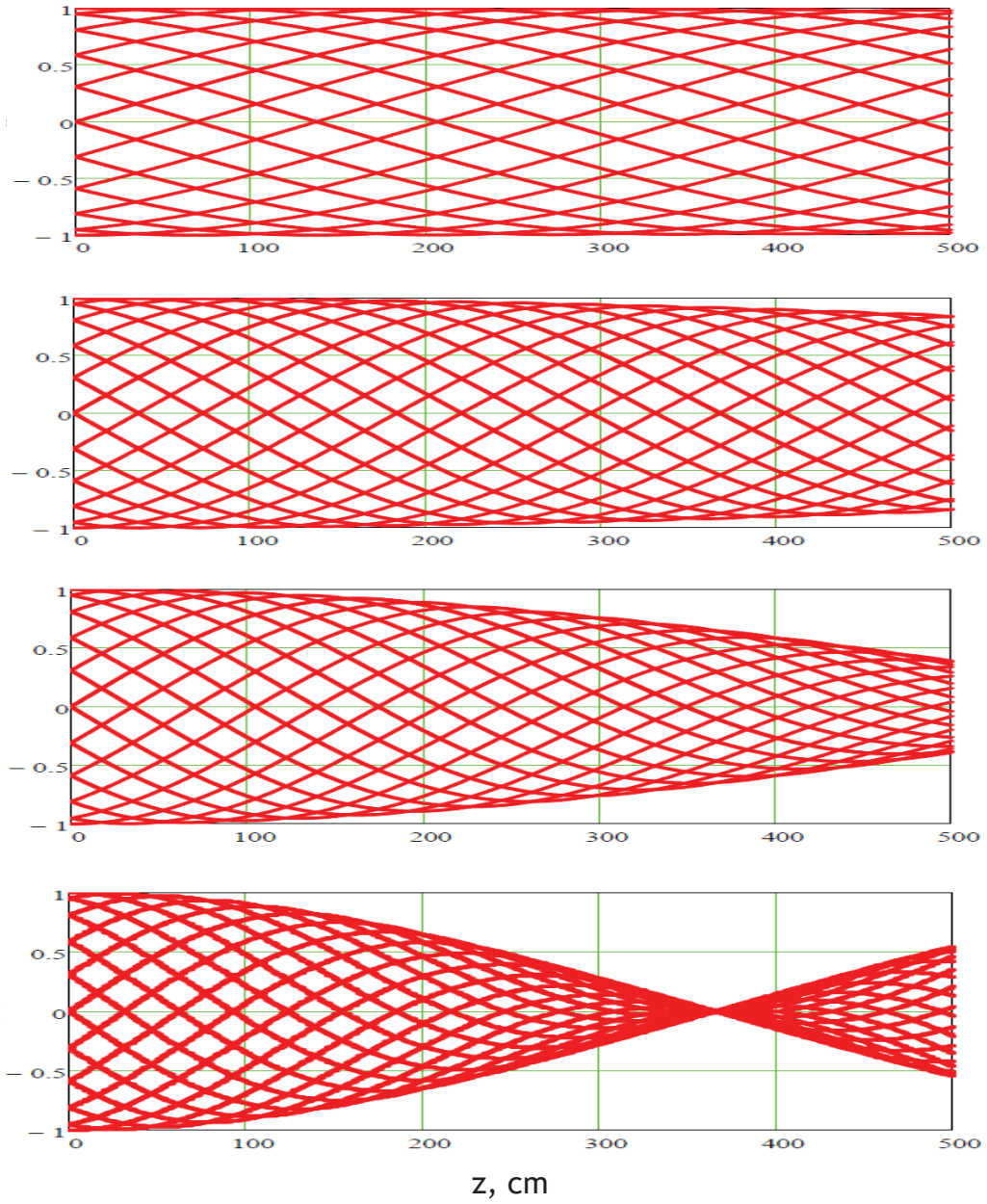


$$\delta n \propto \cos\left(\omega t + k_{+} z\right) + \cos\left(\omega t + k_{-} z\right) =$$

$$= 2\cos\left(\omega t + \frac{k_{+} + k_{-}}{2} z\right)\cos\left(\frac{k_{+} - k_{-}}{2} z\right)$$

Two traveling waves form standing wave. Depending on BPM position the signal change its amplitude.





I=50mA, U=5kV

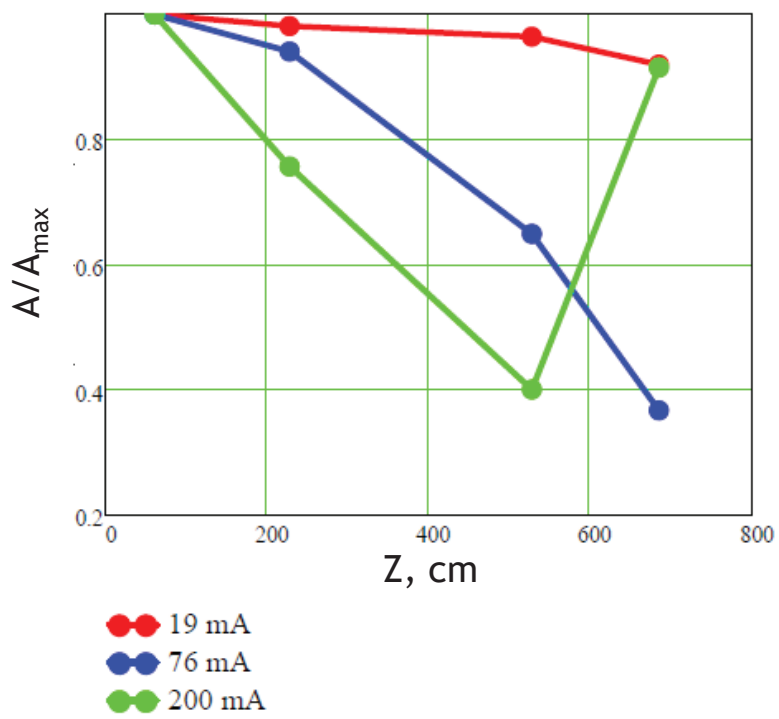
I=19mA, U=1.74kV

I=76 mA, U=1.74kV

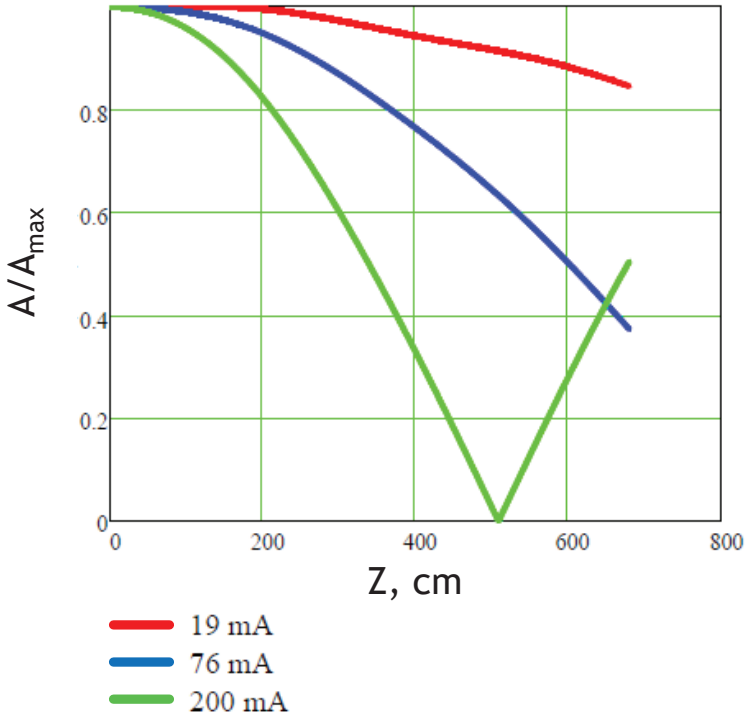
I=200 мА, U=1.74kV

Plasma waves in electron beam

Dependence of BPM sum signal on its position. U_{HV}=1.74 kV.



measurements



calculations

Thank you for your attention!