# Commissioning COSY cooler with electron beam at Novosibirsk

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# Main feature of cooler COSY = contents of report

1. Classical design with longitudinal magnetic field;

*-very wide range of the operation, the preferable smallest energy is 25 keV, it is injection energy;*

2. Section-module principle of the design of the electrostatic accelerator ;

*-each section contains the high-voltage module and coils of the magnetic field;*

3. Possibility for on-line control of the quality of the magnetic field

*- in order to have high cooling rate;*

4. Cascade transformer for power supply of the magnetic coils;

*- smooth longitudinal magnetic field along accelerated tube demands power to many coils;*

5. Electron Collector with Wien Filter

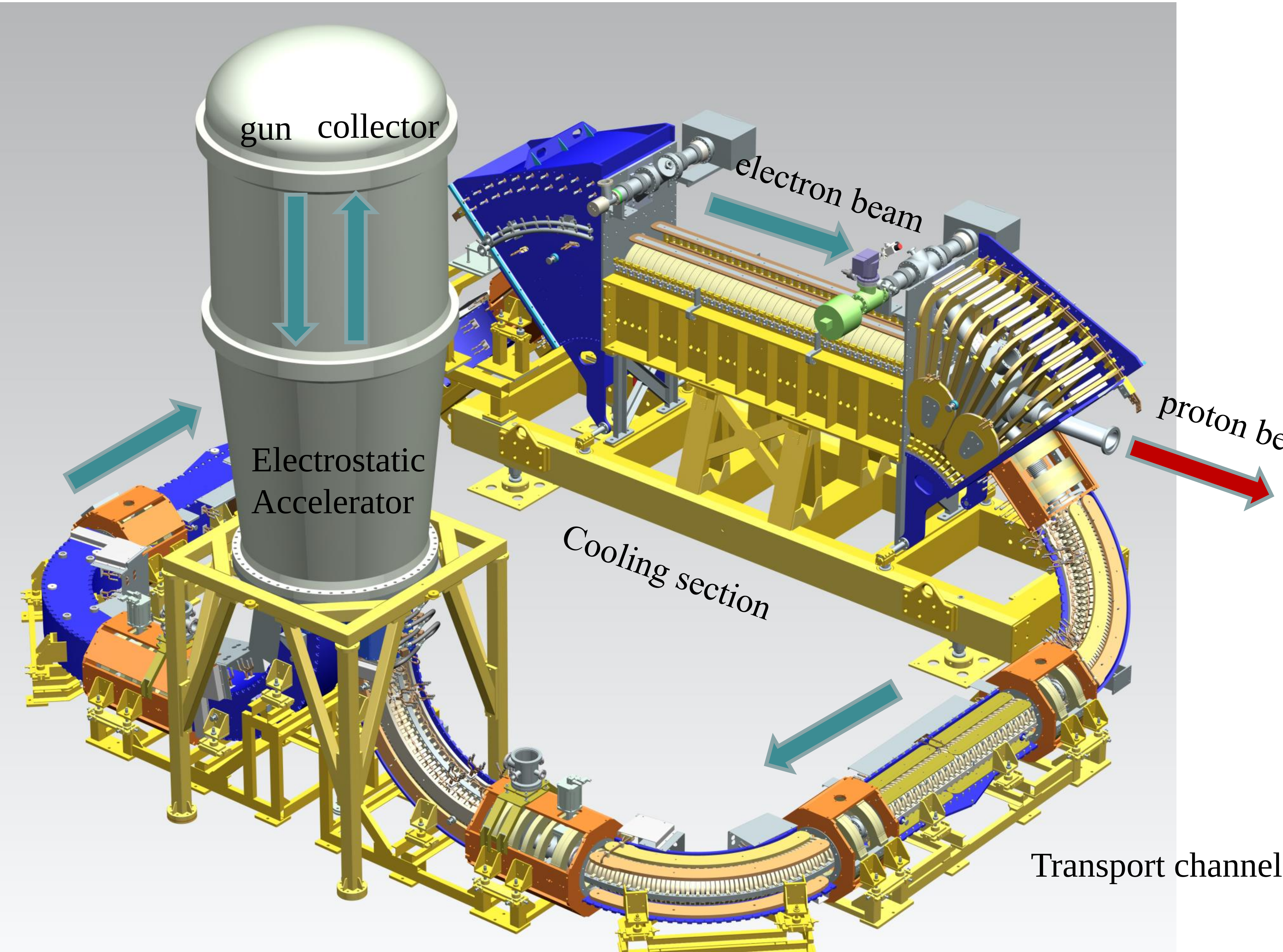
*-in order to have small leakage current from the collector*

6. "Magnetized" electron motion

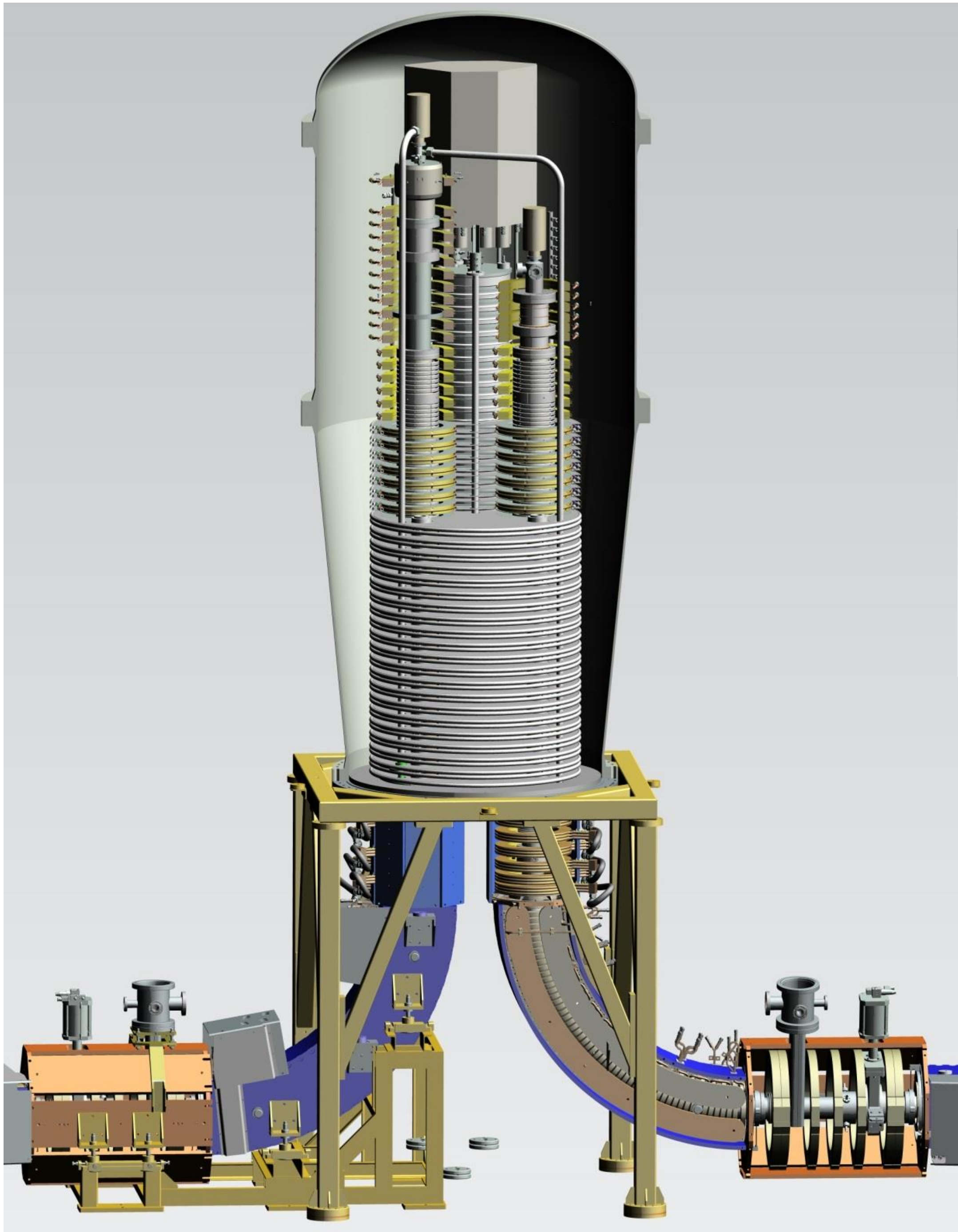
7. "4-sectors" electron gun for diagnostics of the electron beam motion

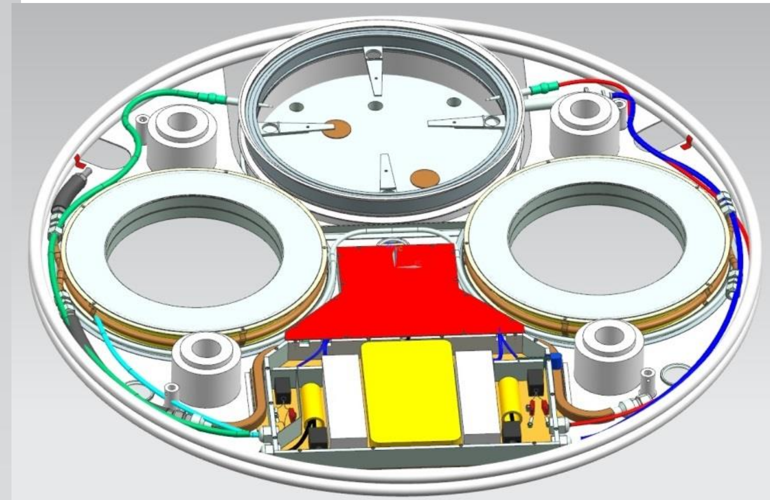
| 2 MeV Electron Cooler | Parameter |
|---|---|
| Energy Range | 0.025 ... 2 MeV |
| Maximum Electron Current | 1-3 A |
| Cathode Diameter | 30 mm |
| Cooling section length | 2.69 m |
| Toroid Radius | 1.00 m |
| Magnetic field in the cooling section | 0.5 ... 2 kG |
| Vacuum at Cooler | $10^{-9}$ ... $10^{-10}$ 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*

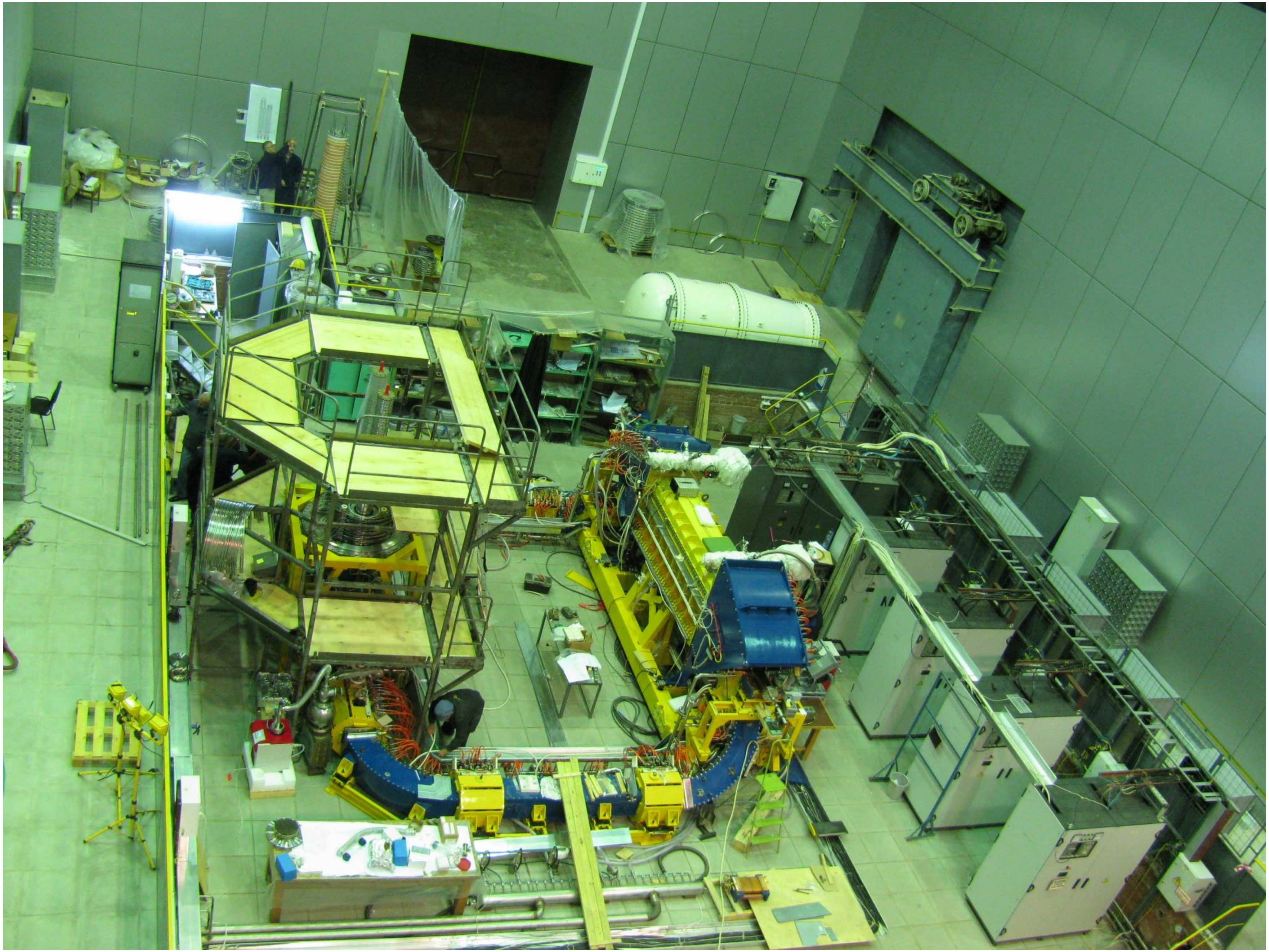


Photo of COSY Cooler during commissioning at Novosibirsk

Possibility for on-line control of the quality of the magnetic field.

*Decreasing of the distortion of the force line of the magnetic field increases the maximal value of the friction force. This effect is essential for small difference of  ion momentum from equilibrium value. So, this effect may is keyword parameter for the experiment with intrinsic target.*

$$\Delta\vec{p} = \vec{F}\cdot\tau = -\frac{4e^4 n_e \vec{V}\tau}{m_e(\sqrt{V^2+V_{eff}^2})^3}\ln\left(1+\frac{\rho_{max}}{\rho_L+\rho_{min}}\right)$$

$$V_{eff}^2 = V_{\Delta\Theta}^2 + V_{E\times B}^2 + V_e^2$$ *effective temperature*

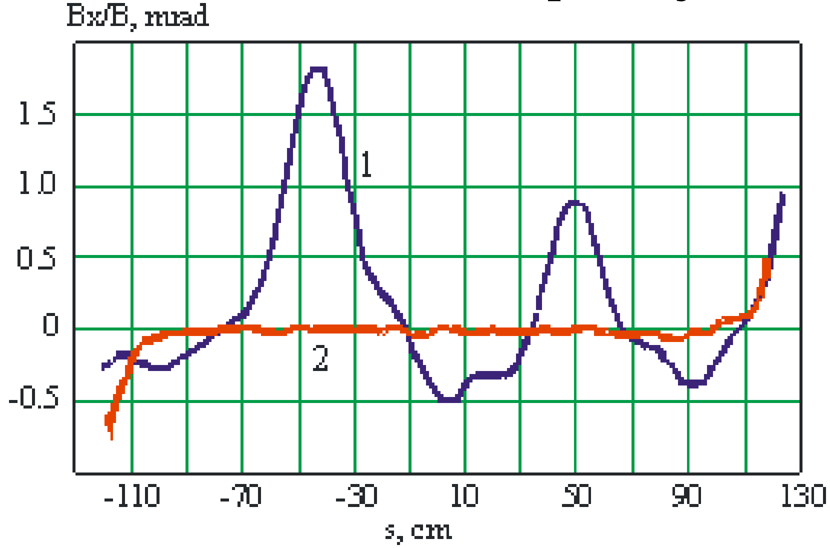
$$V_{\Delta\Theta} = \gamma\beta c\sqrt{\left\langle \triangle B^2\right\rangle}$$ $\left\langle \triangle B^2\right\rangle$ — *ripple of the magnetic field*

| $\gamma_E\beta_E/\gamma_{30}\beta_{30}$ | E, кэВ |
|---|---|
| 1.9 | 100 |
| 8.0 | 1000 |
| 13.8 | 2000 |

Cooling section – standard BINP decision with pan-cake coils

# Possibility for on-line control of the quality of the magnetic field

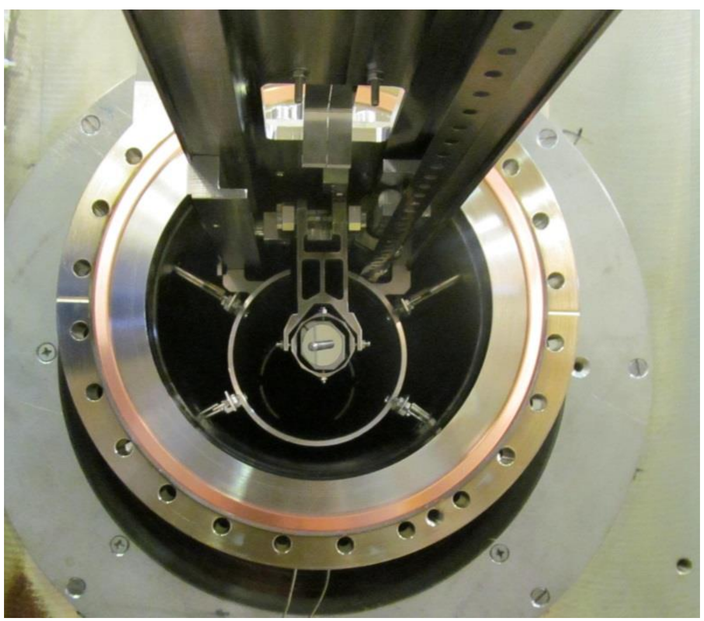
see more WEPPO12
***"Compass for Measuring the Magnetic Lines Straightness at the Cooling Section in Vacuum"***




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

*Horizontal magnetic field in the cooling solenoid initially (curve 1) and after few iteration of coil adjustment (curve 2).*

*measurement system*



*R.M.S. ripple of the magnetic force line was decreased from $6 \cdot 10^{-4}$ to $2 \cdot 10^{-5}$.*

*Compass with gimbal suspension*

# Cascade Transformer as Power Supply

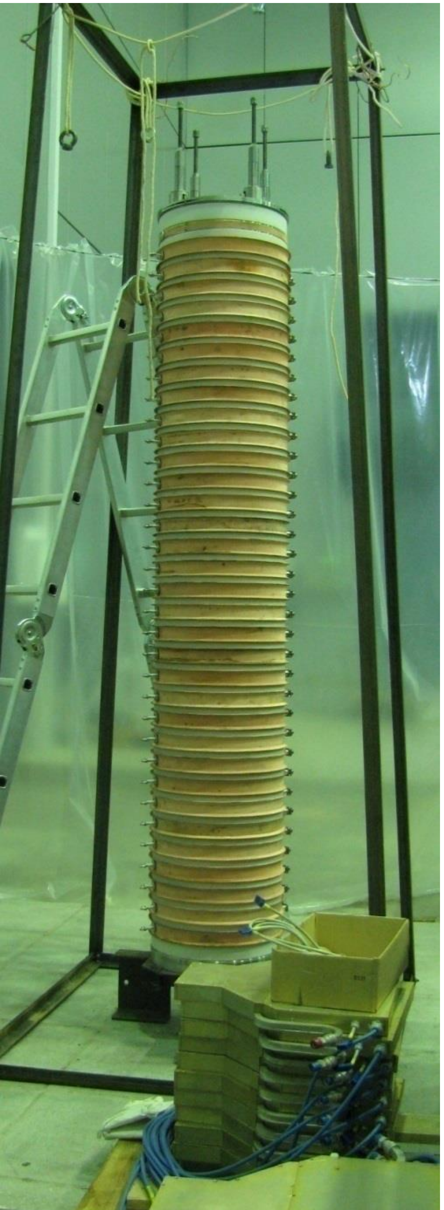
“Transformers section looks like accelerating tube”

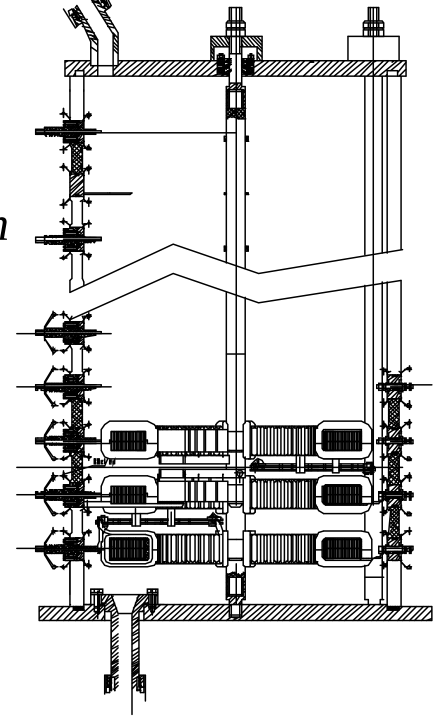
*-transformers connected to series;*

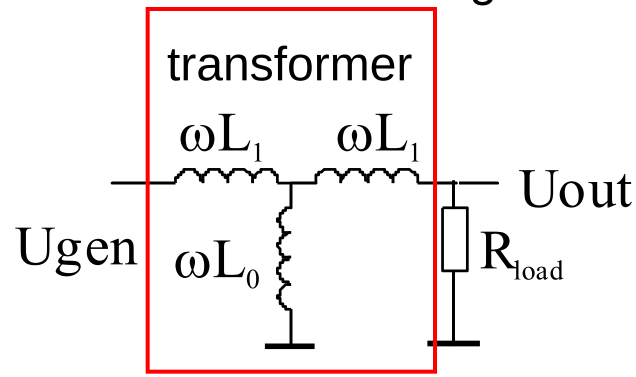
*-tube is alternation of the ceramic and metal rings (sections);*

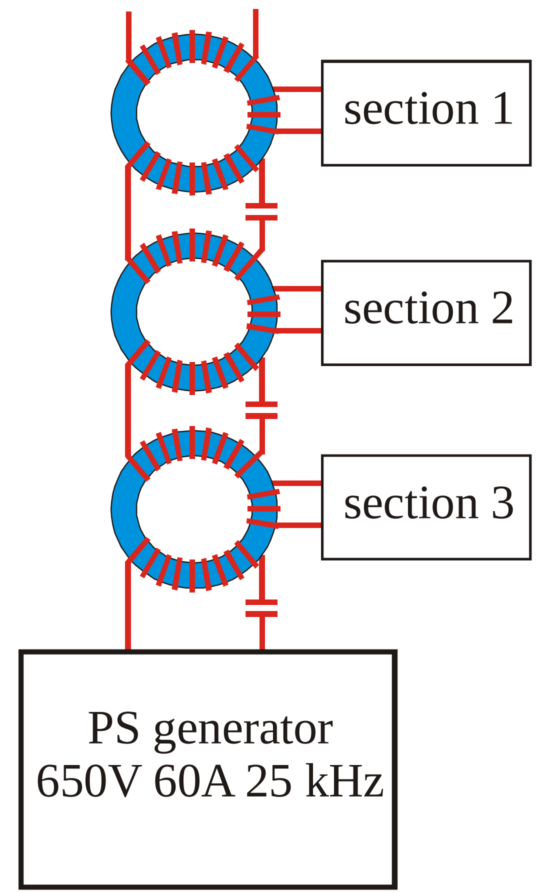
*- tube is filled by oil;*

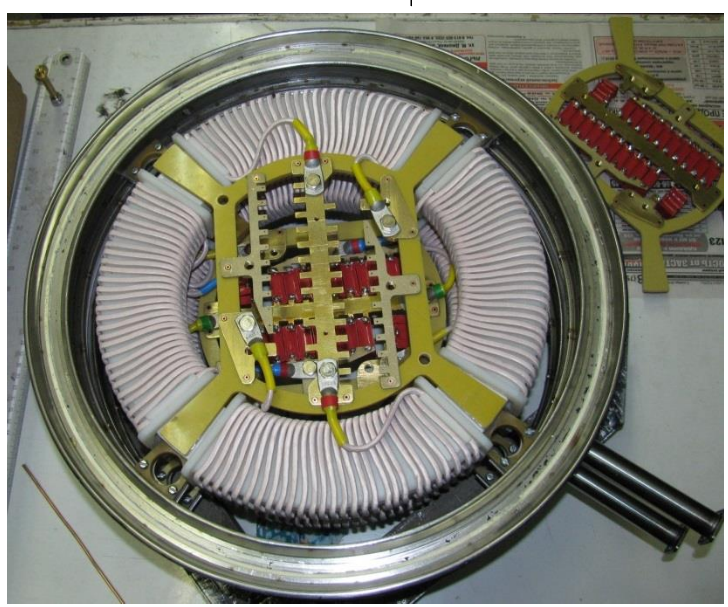
*- section has special spark-gaps;*

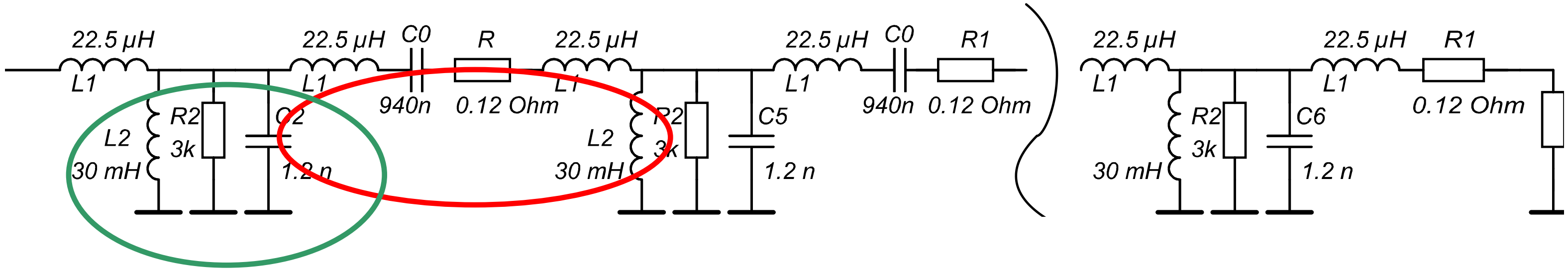






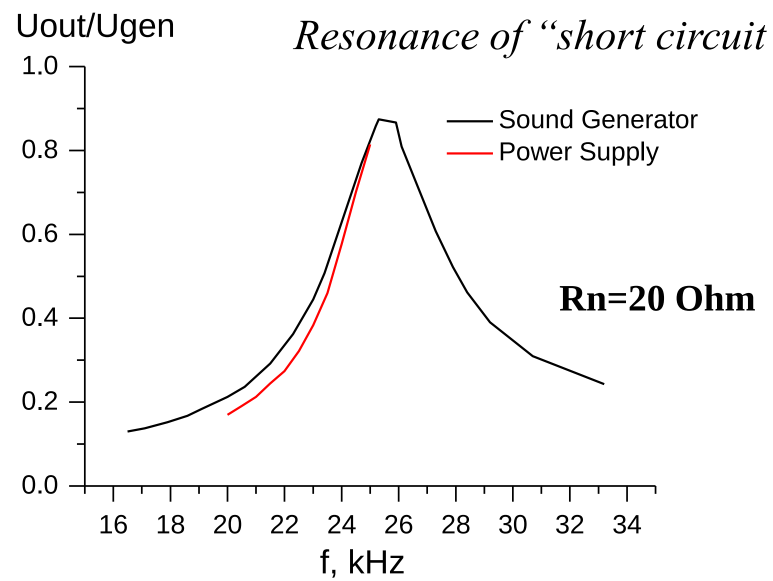





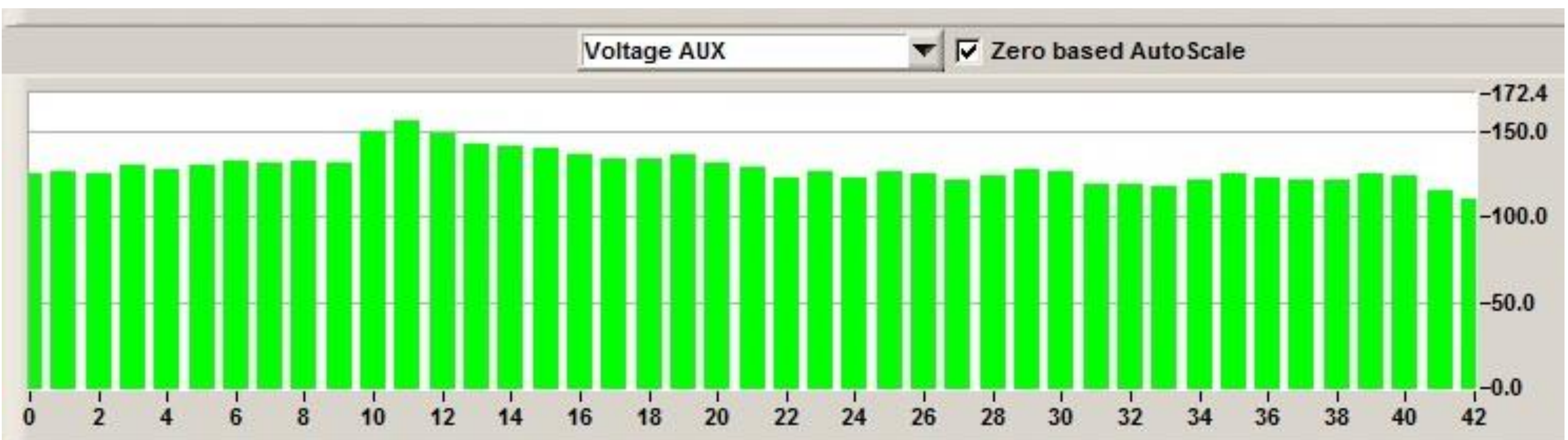

*physics principle of operation of cascade transformer is combination of series and parallel resonances induced by the leakage inductance and compensative capacitances*

*- 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

# Distribution Power Along Accelerated Column



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

see more WEPPO04

***"Collector for Electron Cooling Systems with Suppression of Reflected Electron Gun"***

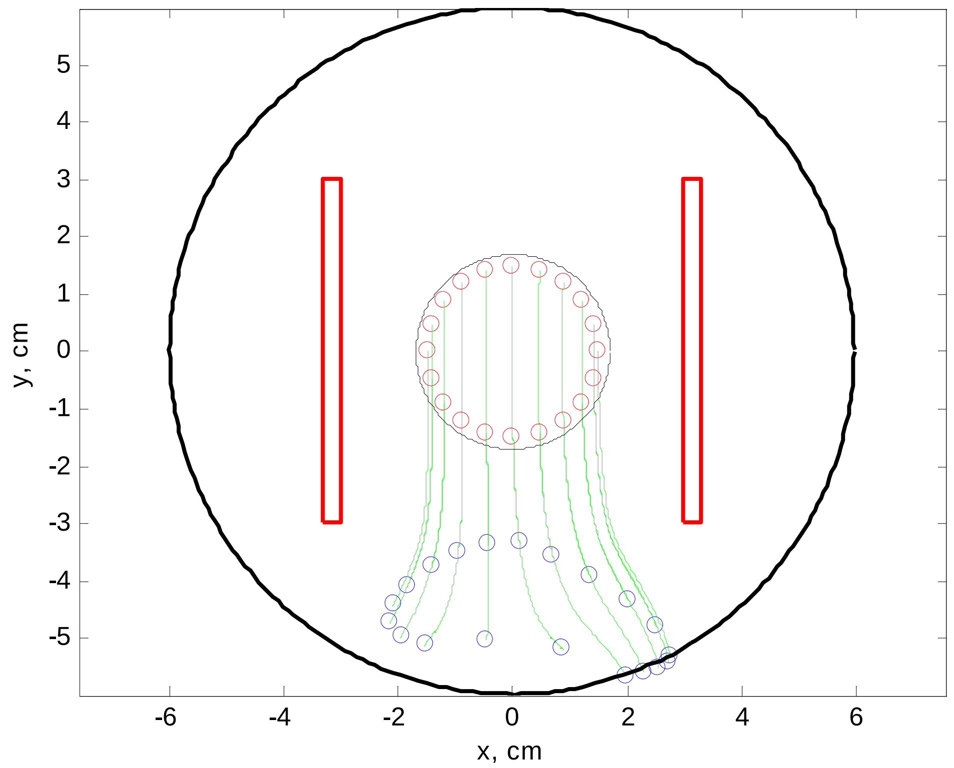
Area with crossed electrical and magnetic fields compensated each other

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

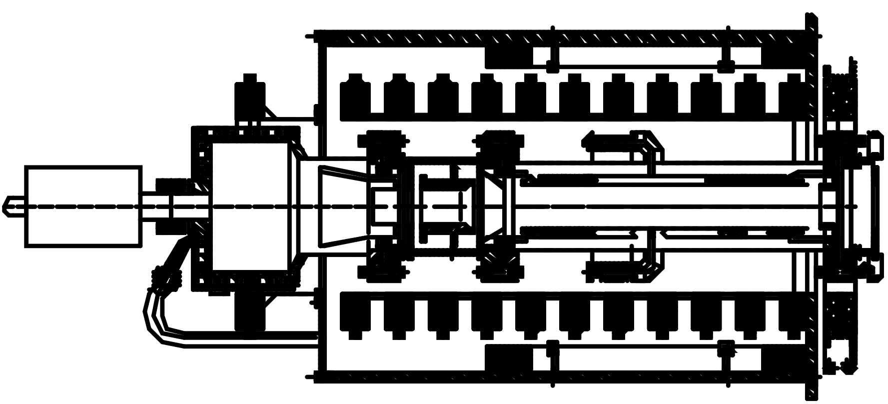
primary beam

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

secondary beam




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



*The experimental recuperation coefficient is* $10^{-5}$ - $10^{-6}$

# Operational aspects, section structure, accelerating column

Electrostatic accelerator

*High voltage terminal*

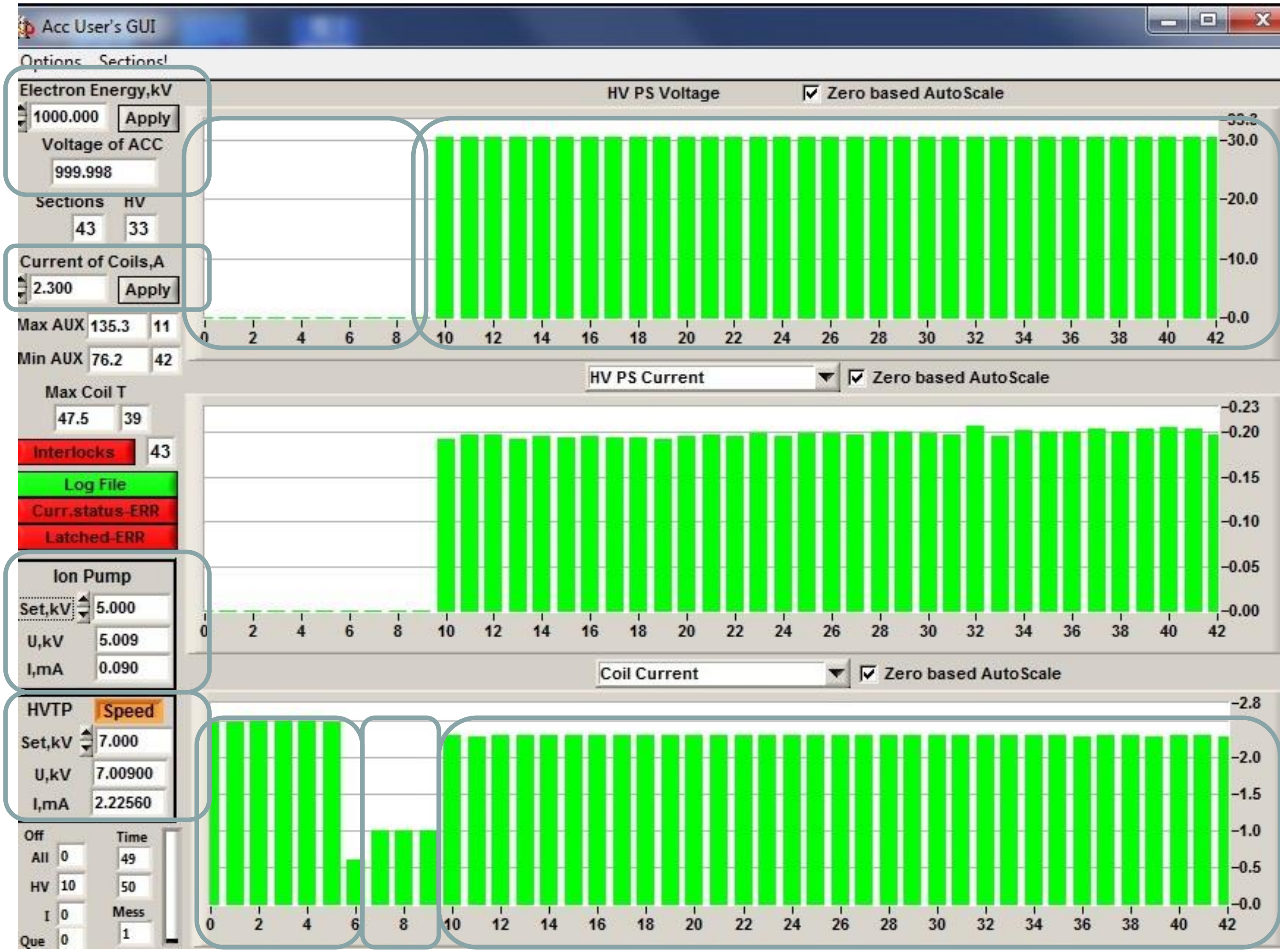
*Distribution of high voltage along accelerator column*

*Installed and measured energy is 1 MeV*

*Current in the coils of accelerator column*

*Ion pump in high-voltage terminal*

*Potential of the high-voltage terminal with reference to accelerator tube*

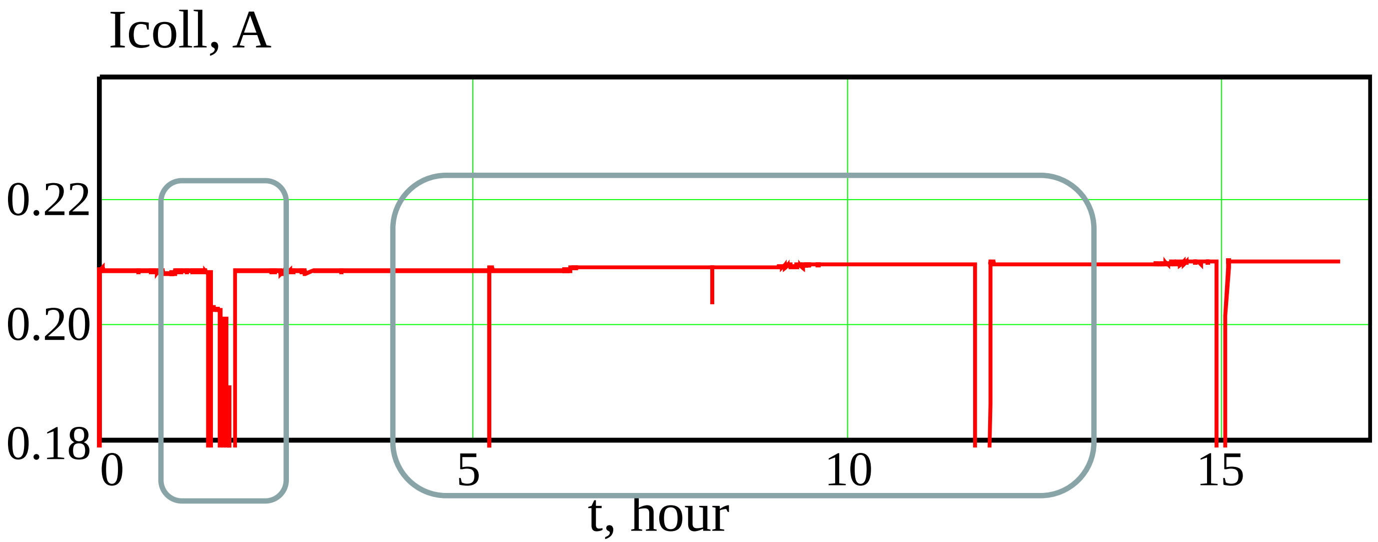


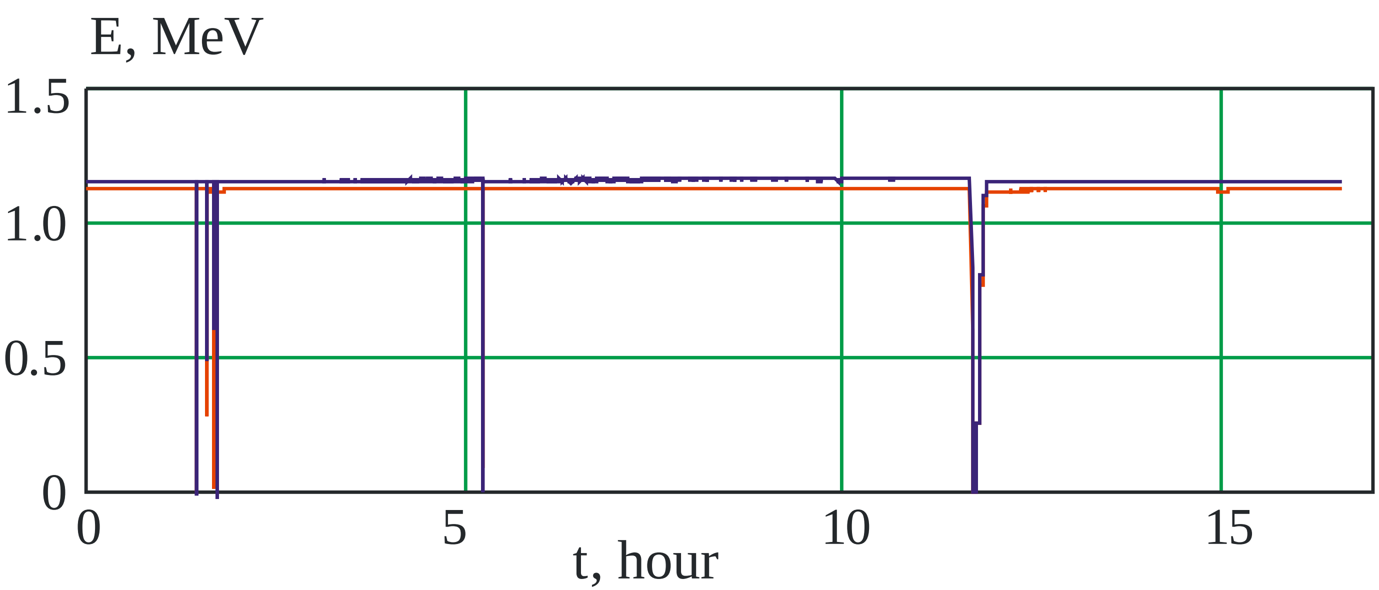

*Collector*

*Gun*

*Distribution of the magnetic field in the accelerator column*

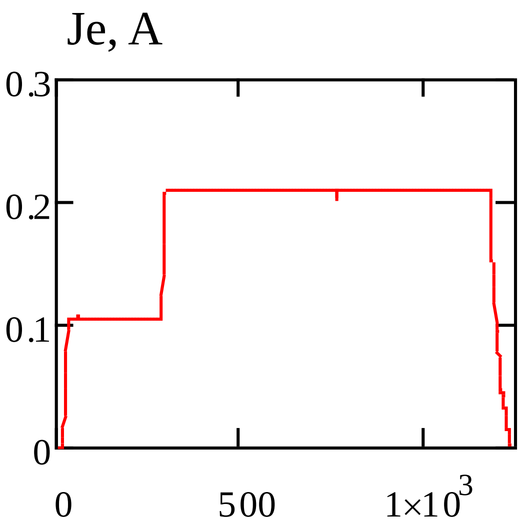
Operational aspects. Example of the long training regime, the electron current was about 200 mA. The electron energy was about 1 MeV. The total time of the training procedure is 6 day and night.

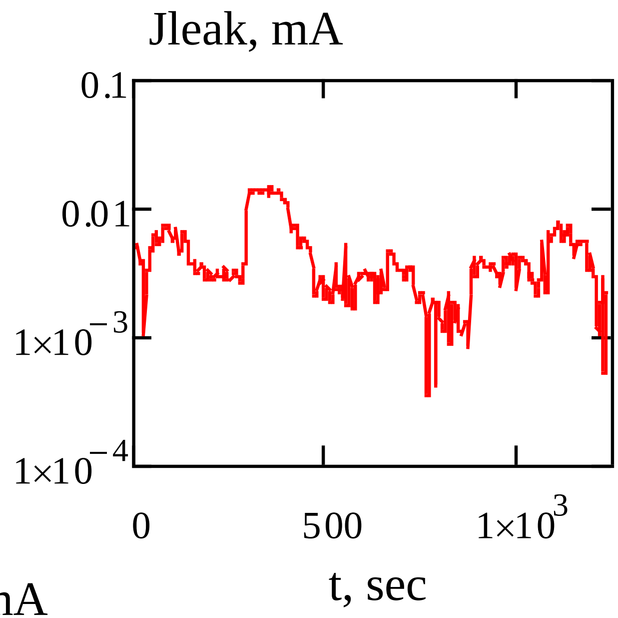


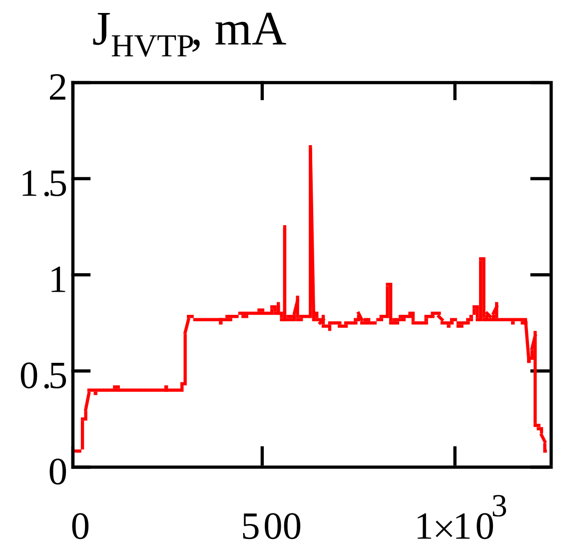



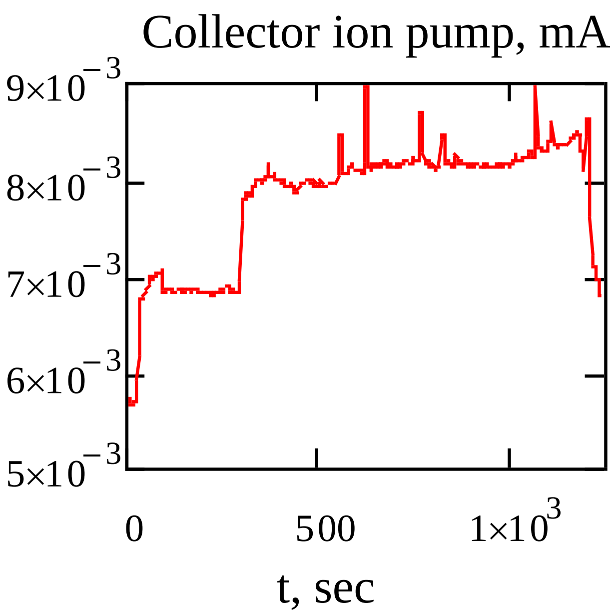

*Sometimes the recuperation breakdown occurs often and sometimes rarely. The nature of the breakdown is not made clear yet. It seems that this behavior can be improved by a training procedure. The possible reason of the breakdown are small dust particle, charge of the accelerator tube isolator …or ???*

# Operational aspects. Example of the short training regime, the electron current was about 200 mA. The electron energy 1 MeV

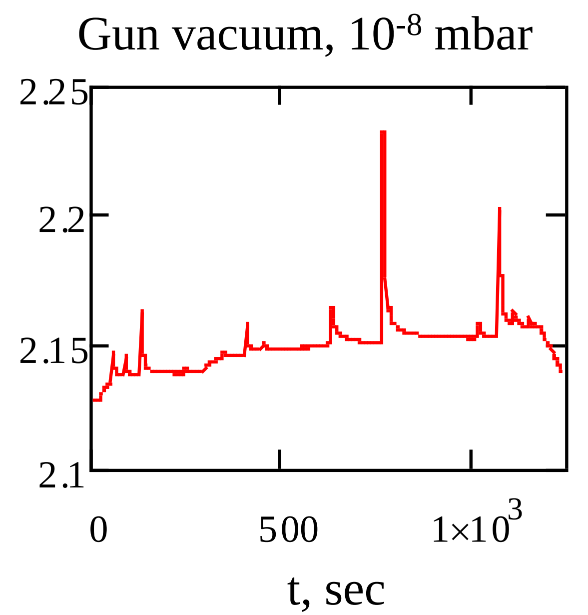


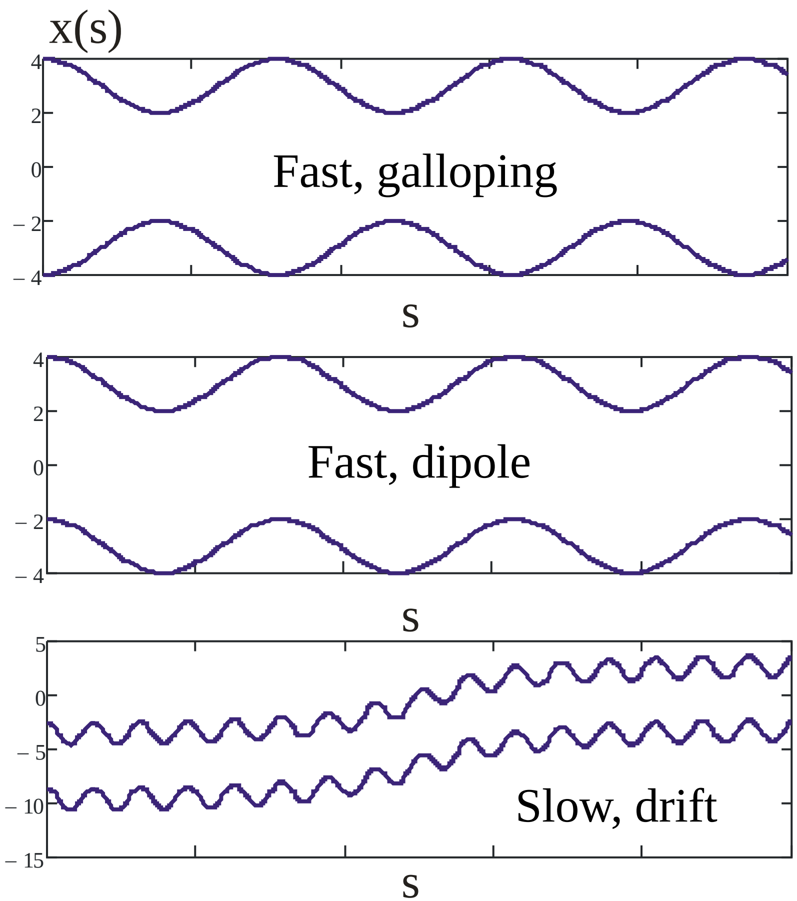




The regime with 200 mA current is stable enough. In time of the operation the vacuum fluctuation is observed. The typical vacuum value is a few $10^{-8}$ mbar in BINP. The evolution of the leakage current and peak of the HVTP current is observed also.

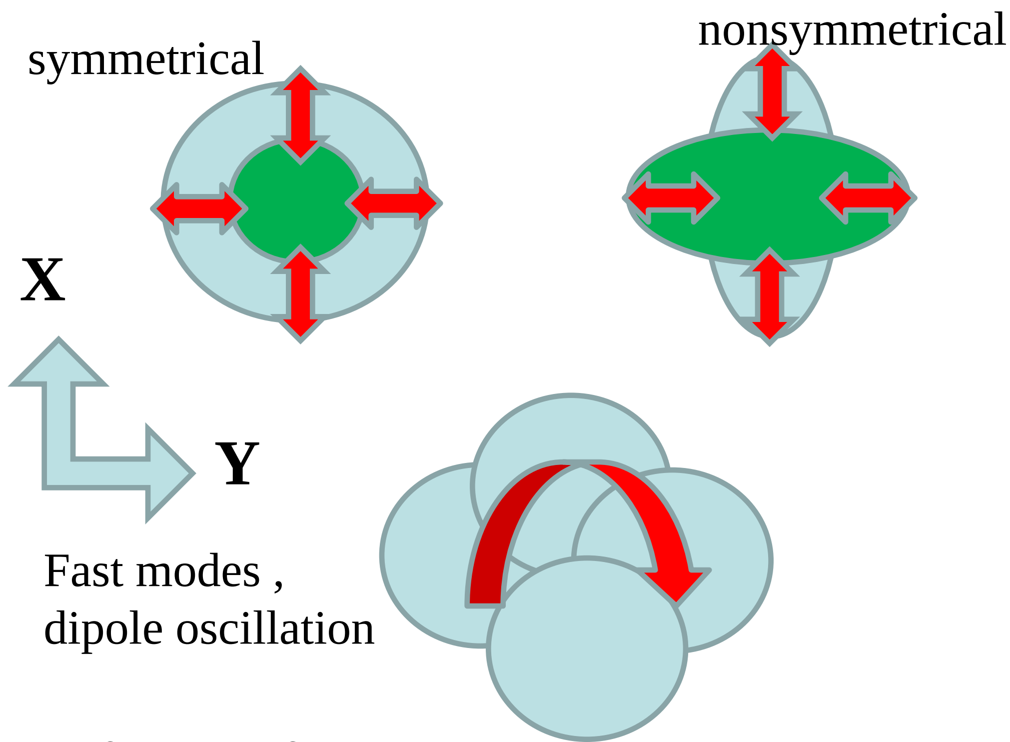


# “Magnetized” electron motion

The particle motion at a presence of a large magnetic field can be described as combination of the fast larmour oscillation and slow drift motion. In spite of the fact that, the adiabatic criteria isn’t satisfied the drift description of particle motion is correct. The reason is smallness of the transverse component of the magnetic field in comparison with the longitudinal component.

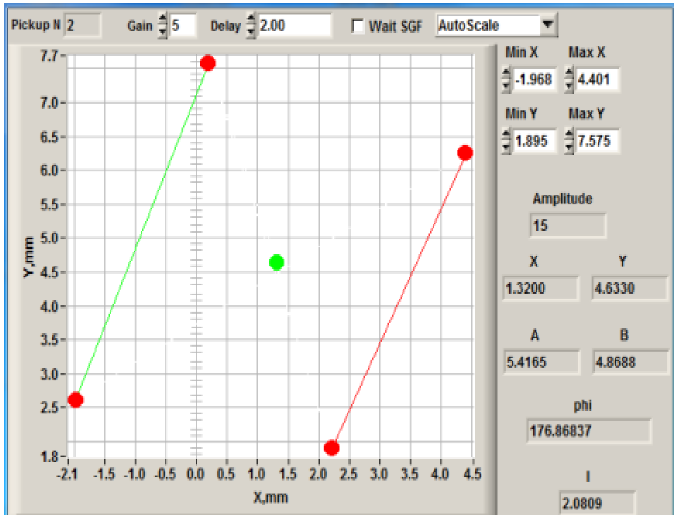



Fast modes, galloping of the shape of the electron beam




*Modification of the beam shape and position*

# Diagnostics of the shape of the electron beam



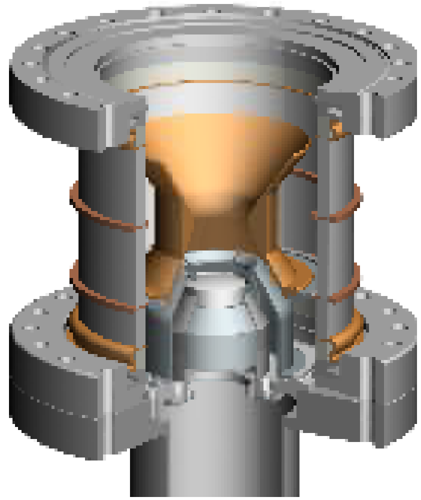
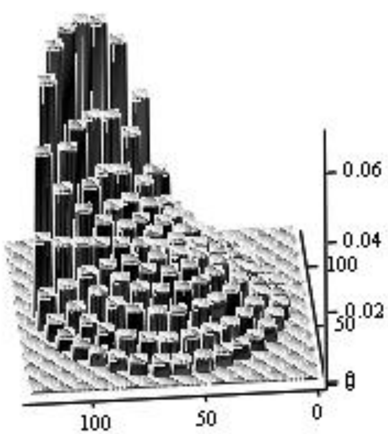
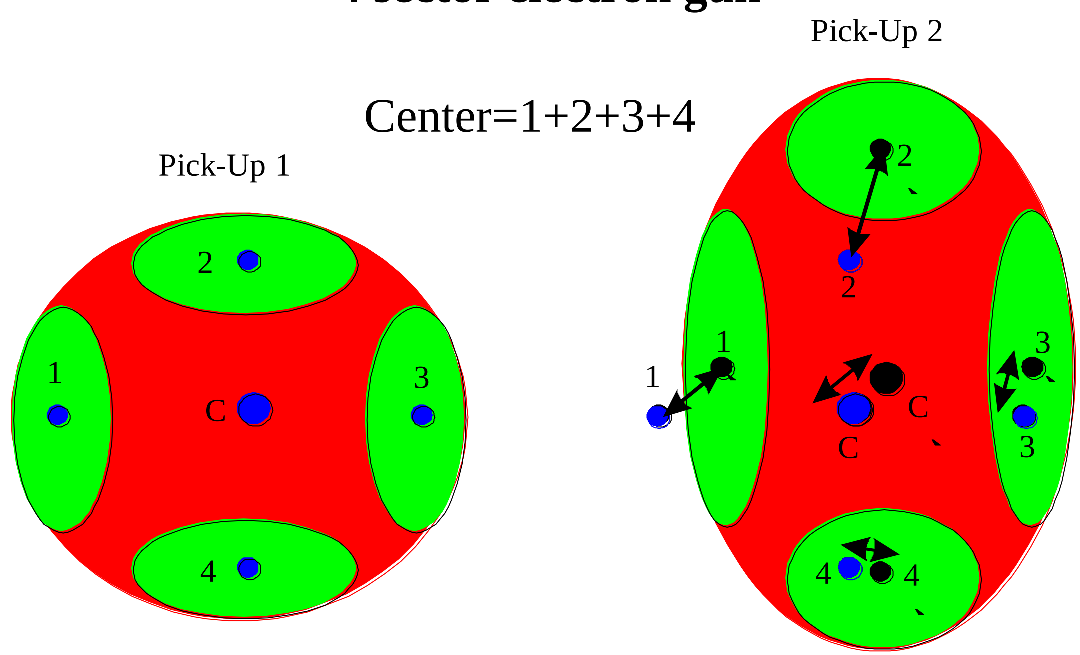



**Diagram Measurement System**

**4 sector electron gun**

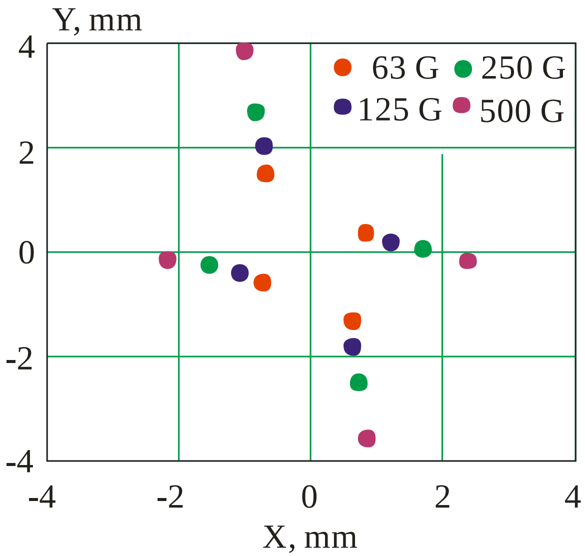



**Voltage is applied to one sector**

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

# The simple verification of the diagnostic tools at electron energy 30 keV

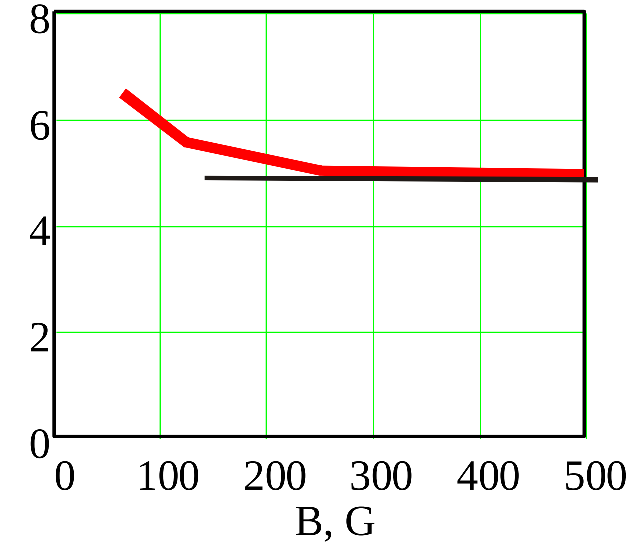



At small value of the magnetic field the size of the electron beam is determined not only by the magnetic field but the anode value also

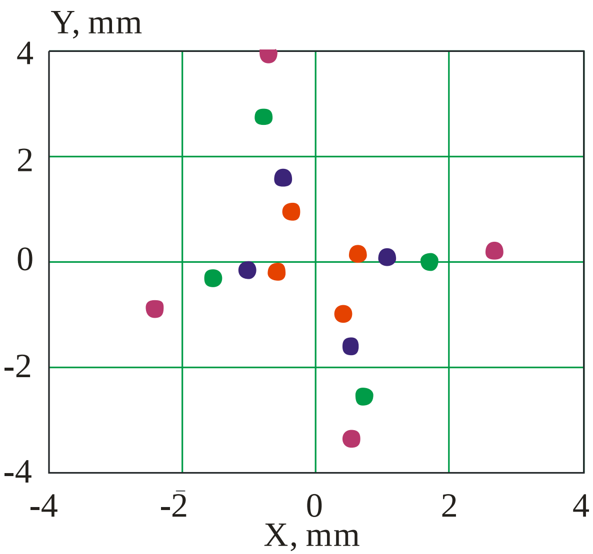
$$r_{BPM}^2 / B_{gun} = const$$

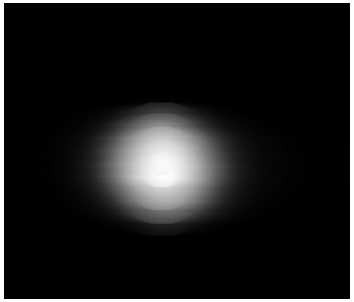
Conservation of the magnetic flux

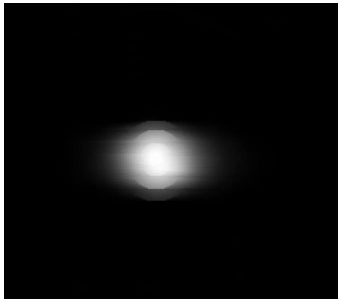
$$B_{gun} r_{gun}^2 = B_{BPM} r_{BPM}^2$$




Change shape of the electron beam by the potential of the control electrode





Ugr/Uan= –0.2/1.4 kV    -0.4/1.4 kV    –0.6/1.4 kV

Pictures was done with wire probe

# Optic features of COSY cooler

Long coils in longitudinal direction the control the position of the center of Larmour rotation; Short coils control the amplitude of the Larmour oscillations

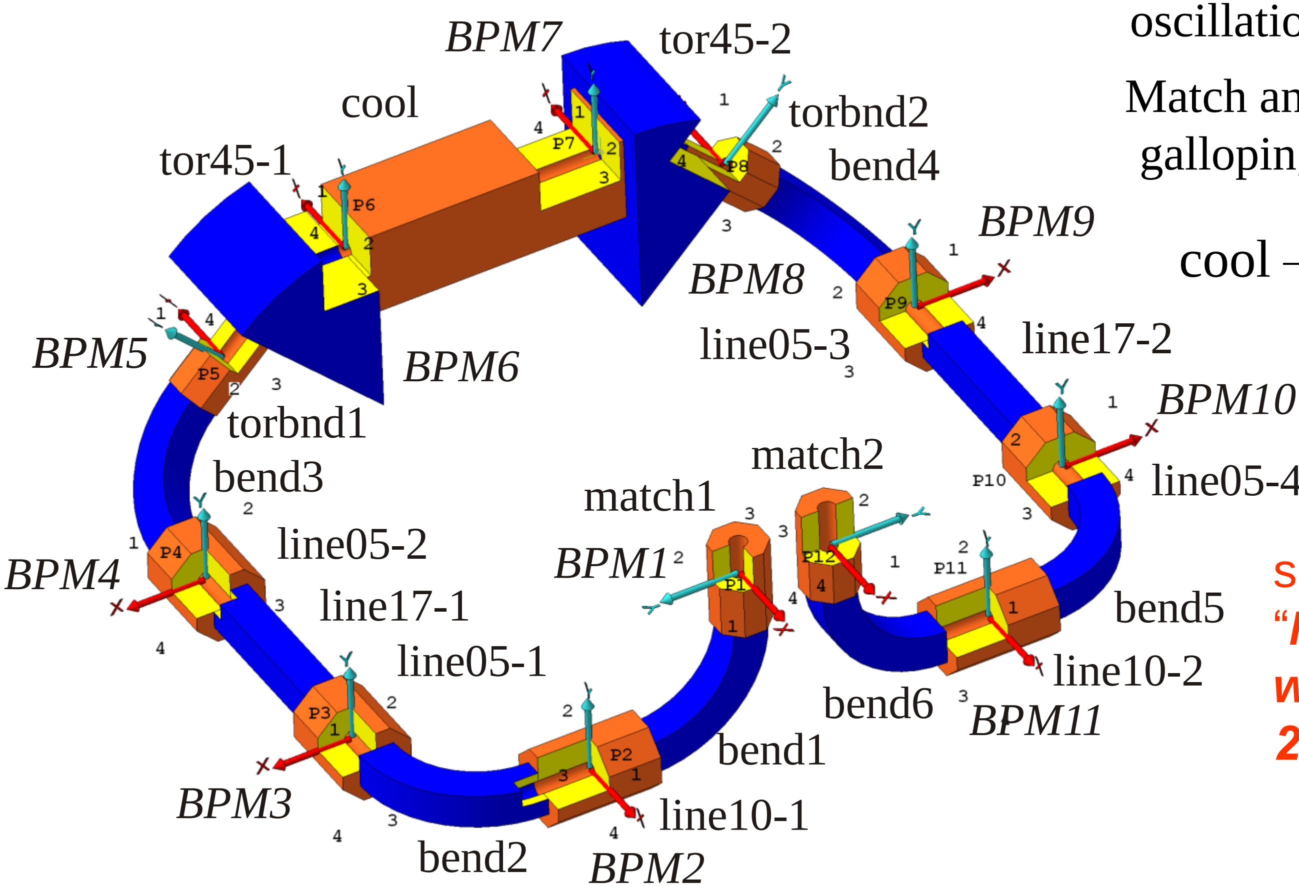
***Corrector groups***

line17hor, line17ver, all bends– change the electron beam position

line10– correctors of the larmour oscillation (beam kick)

Match and torbnd– correctors of the galloping of beam shape correction

cool – convergence of ion and electron beams

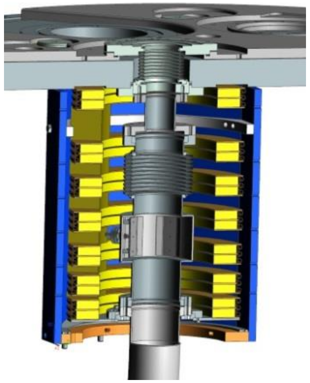



see more WEPPO07
***“Matching of magnetic field with energy of electrons in 2 Mev COSY Cooler”***

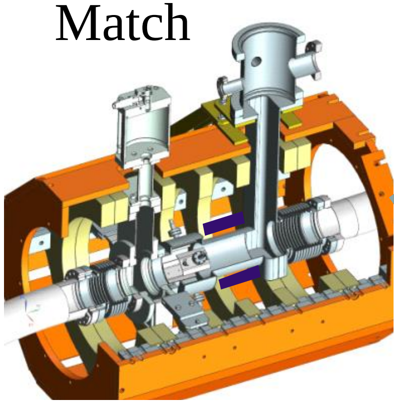
Location of BPMs and magnetic elements of COSY coolers

***Action of magnetic elements*** → ***Betatron phase incursion*** → ***BPM Registration***

# Diagnostics of optic elements



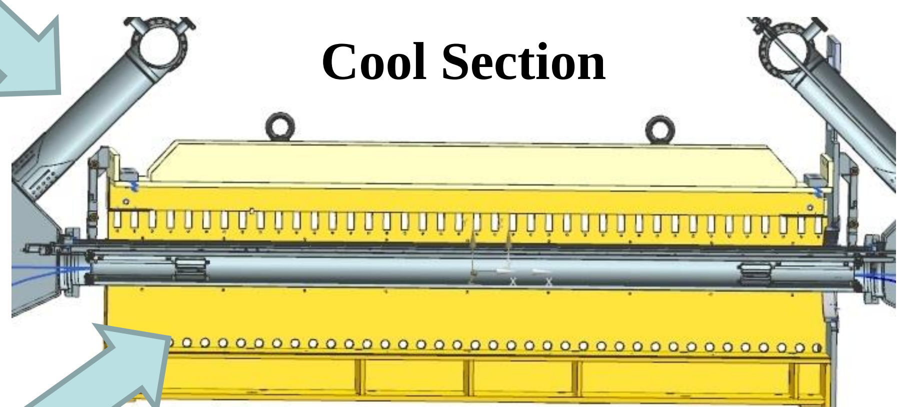
Match



Short Electron Dipole Corrector

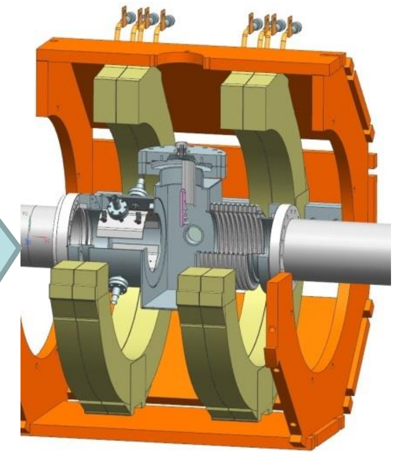
XXX, any element

**Cool Section**



e-beam

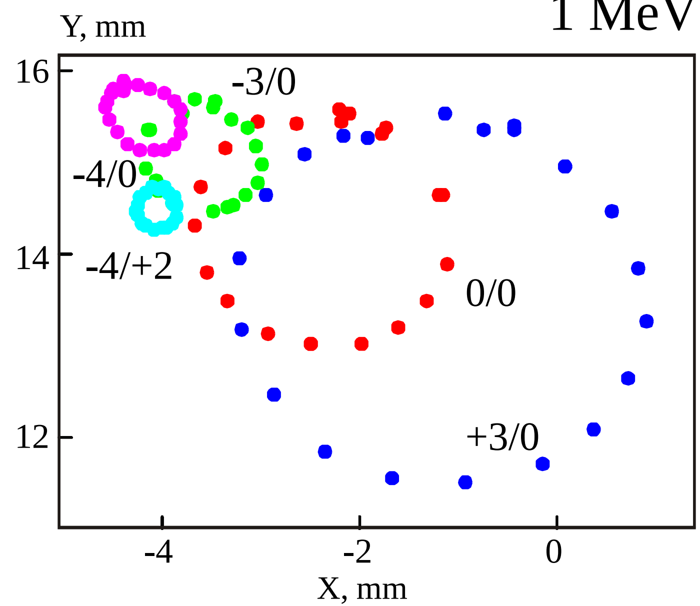
Line05, BPM



Effect of the short dipole corrector is combination of the shift of the center of electron beam with excitation of  Larmour rotation

Compensation of Dipole Motion

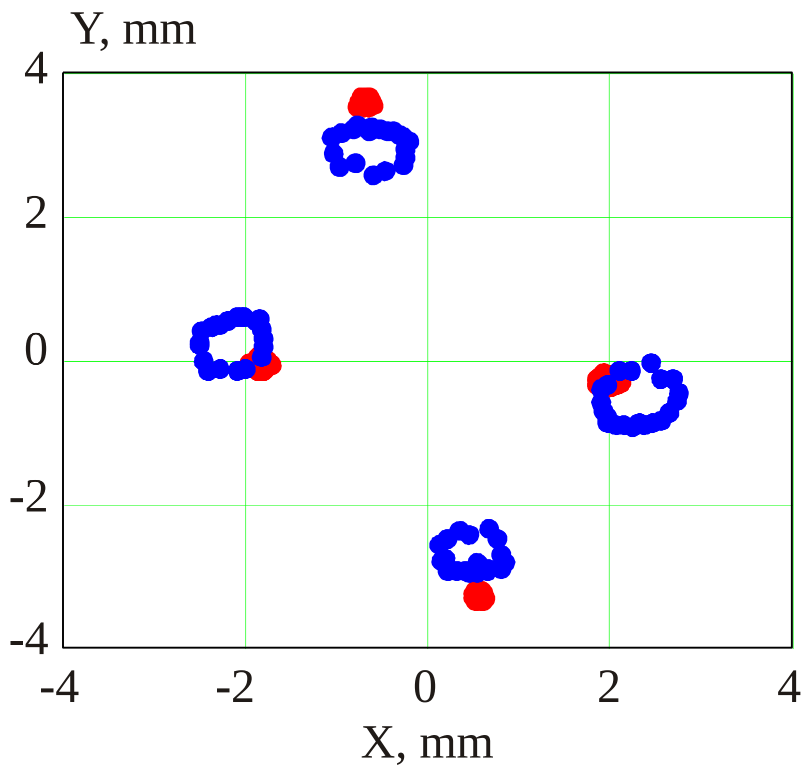
1 MeV



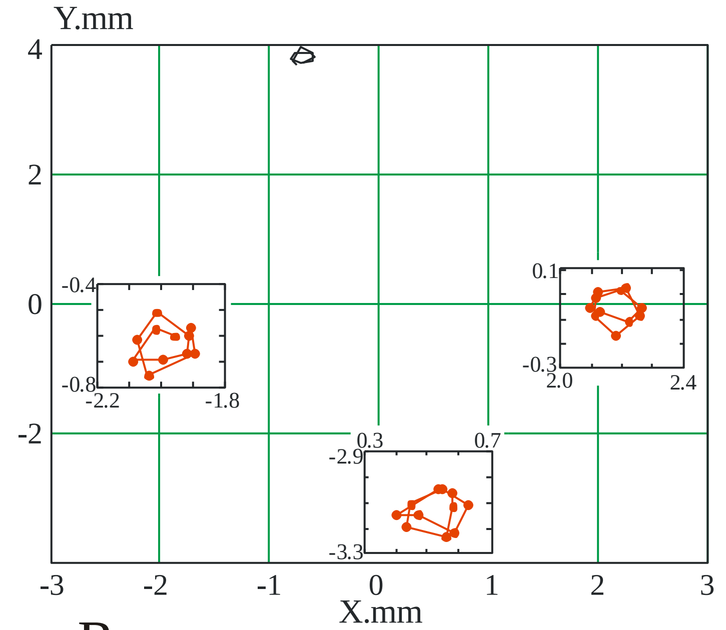
# Optic features of COSY cooler

***Oscillation of the beam shape (galloping)***

*Kick is produced by quadrupole corrector*

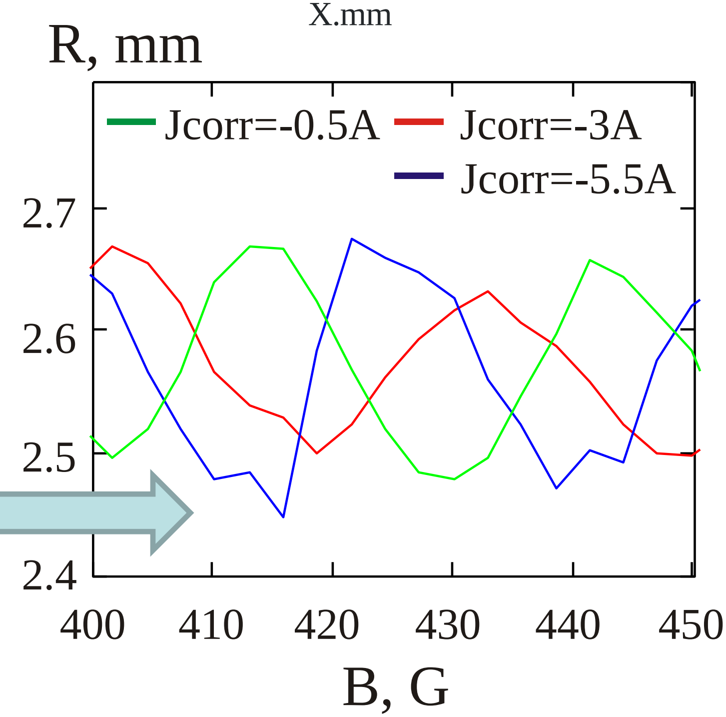



*Kick is produced by axial-symmetric corrector located in the matching section*




Electron energy E=150 keV

Fourier transform can strongly improve the sensitivity of the methods

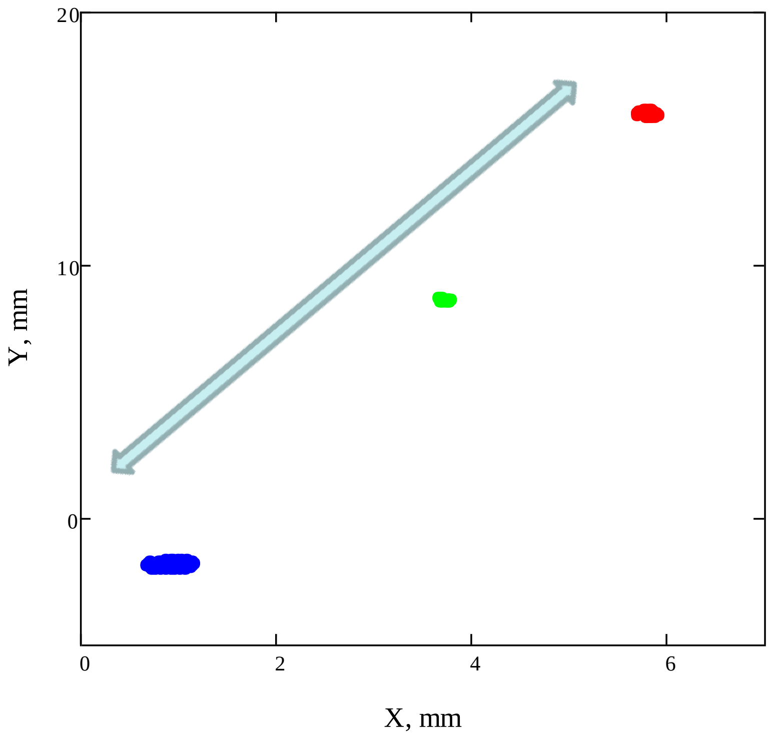


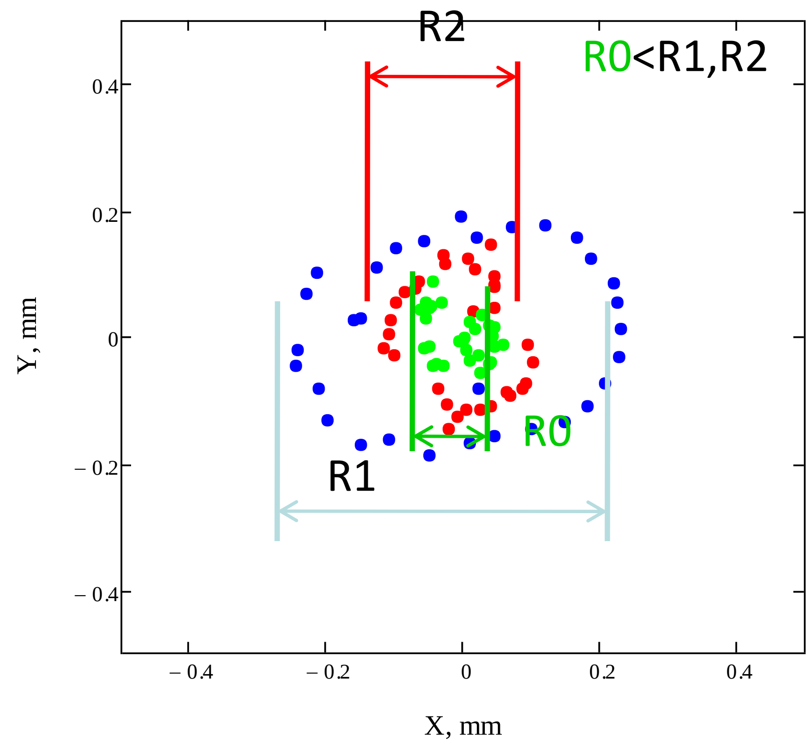
# Optic features of COSY cooler

Dispersion functions of the electron beam motion

First dispersion is the shift of the center of the electron beam

Second dispersion is the change radius of the larmour oscillation. The reason is the resonance or non-resonance between kicks of the electron at input and output of the bend magnets. This effect is observed at 150 keV energy yet.




The different values of the bending magnet fields; red curve is 14.2 G , blue curve is 15.5 G and green curve 14.7 G.

BPM=10, the curves is measured with scanning magnetic field in the cooling section

# Summary

- The key problems of the electron cooler 2 MeV (modular approach of the accelerator column, the cascade transformer, the compass base probe located in the vacuum chamber, the design of the electron gun with 4-sectors control electrode) is experimentally verified during commissioning in Novosibirsk.
-The strong longitudinal field is useful for the electron beam transportation
- The strong surprises aren’t observed and the cooler are ready to assembly and commissioning in COSY.

# Summary

Now we need to start operation in COSY

BINP → COSY