COMMISSIONING 2 MEV COOLER IN COSY AND NOVOSIBIRSK

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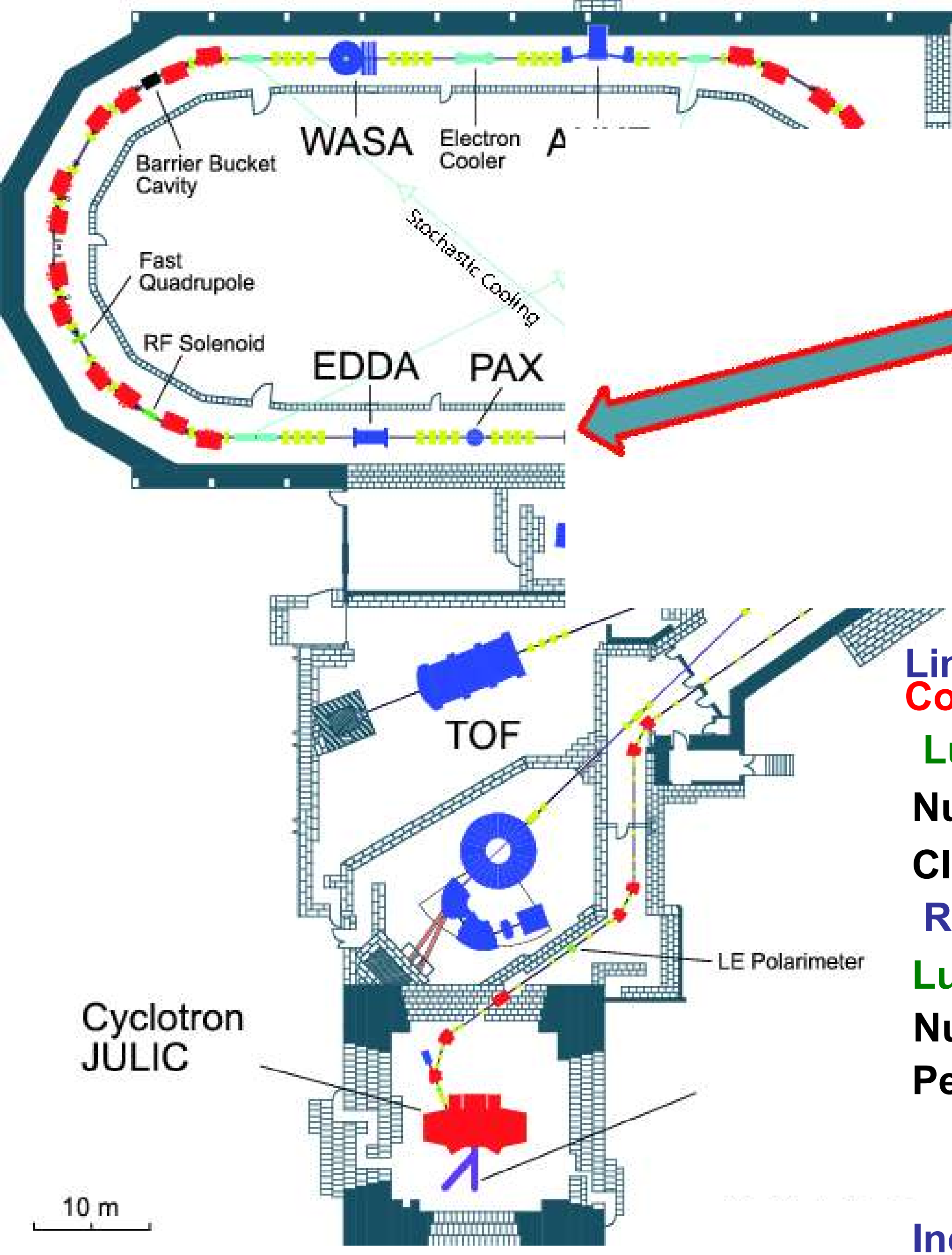
Vsevolod Kamerdzhiev, FZJ, Jülich, Juergen Dietrich, HIM, Mainz



P=183.6 m, E=2880 MeV

Limits of the COSY stochastic cooling system

Cooling time ~ number of particles / bandwidth

Luminosity	$\leq 10^{31}$ cm^{-2} s^{-1}
Number of particles	$6*10^{10}$
Cluster target thickness	10^{14} cm^{-2}

Requests for future COSY experiments

Luminosity	$\geq 10^{32}$ cm^{-2} s^{-1}
Number of particles	$6*10^{10}$
Pellet target thickness	10^{16} cm^{-2}

Possible solutions

Increase bandwidth of stochastic cooling

Electron cooling up to maximum momentum

Main feature of cooler COSY

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

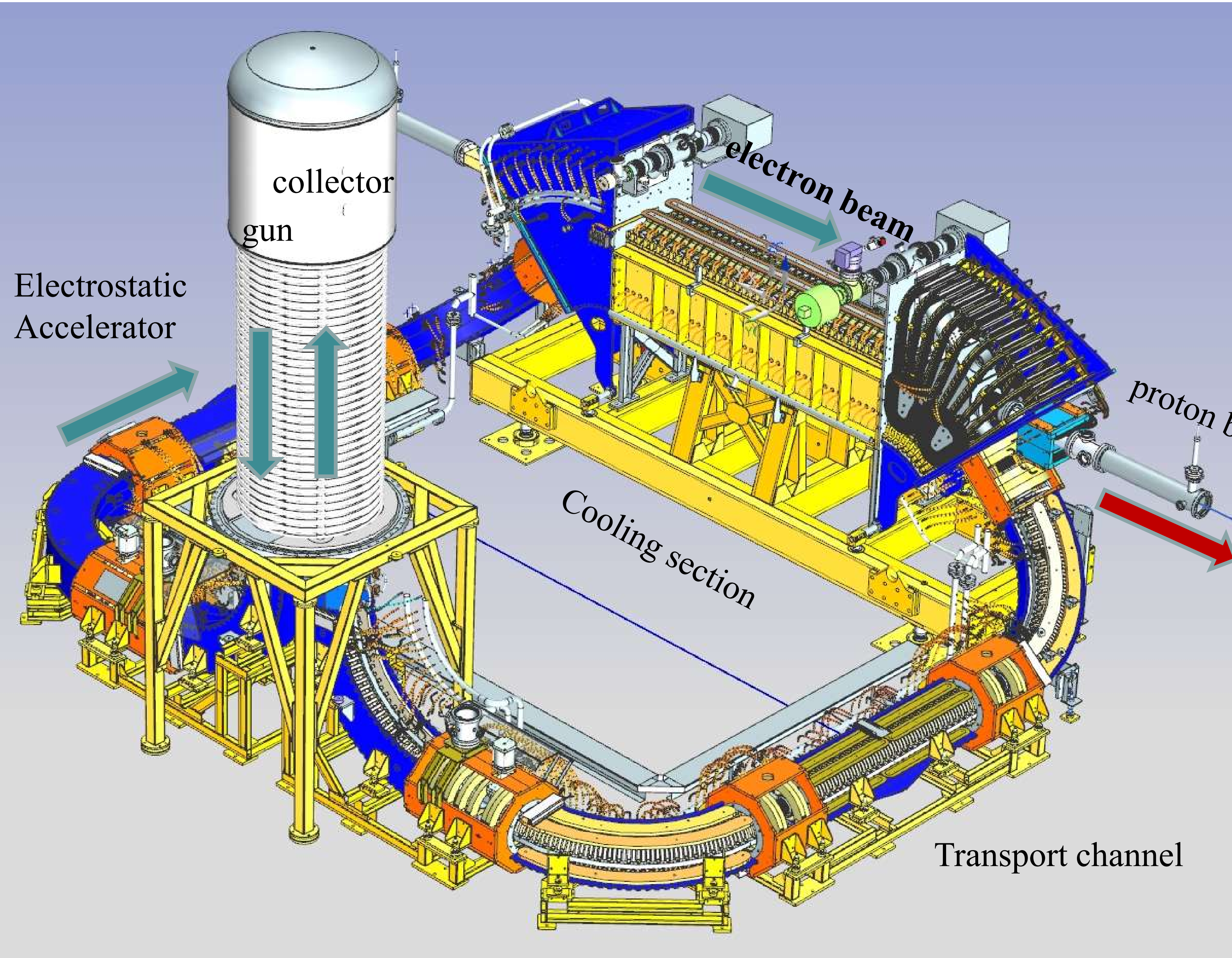
-in order to have small leakage current from the collector

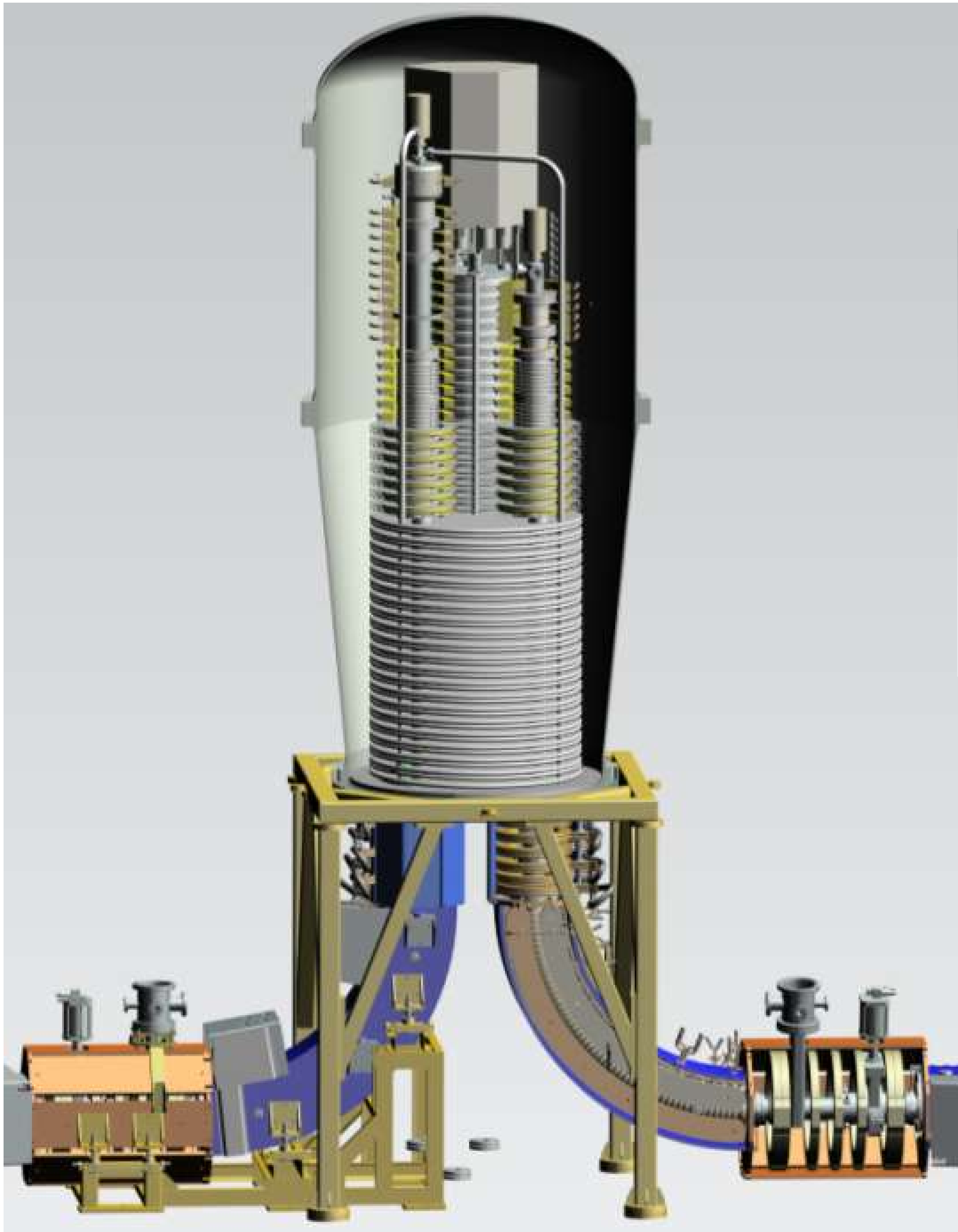
6. “Magnetized” electron motion

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

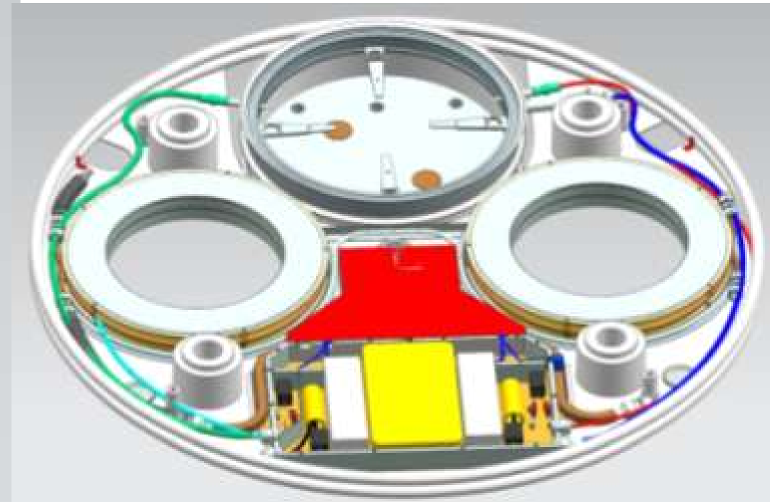
2 MeV Electron Cooler	Parameter
Energy Range	0.025 ... 2 MeV
Maximum Electron Current	1-3 A
Cathode Diameter	30 mm
Cooling section length	2.69 m
Toroid Radius	1.00 m
Magnetic field in the cooling section	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar
Available Overall Length	6.39 m

3D design of COSY Cooler





3D design of Accelerating Column



Each section contains;

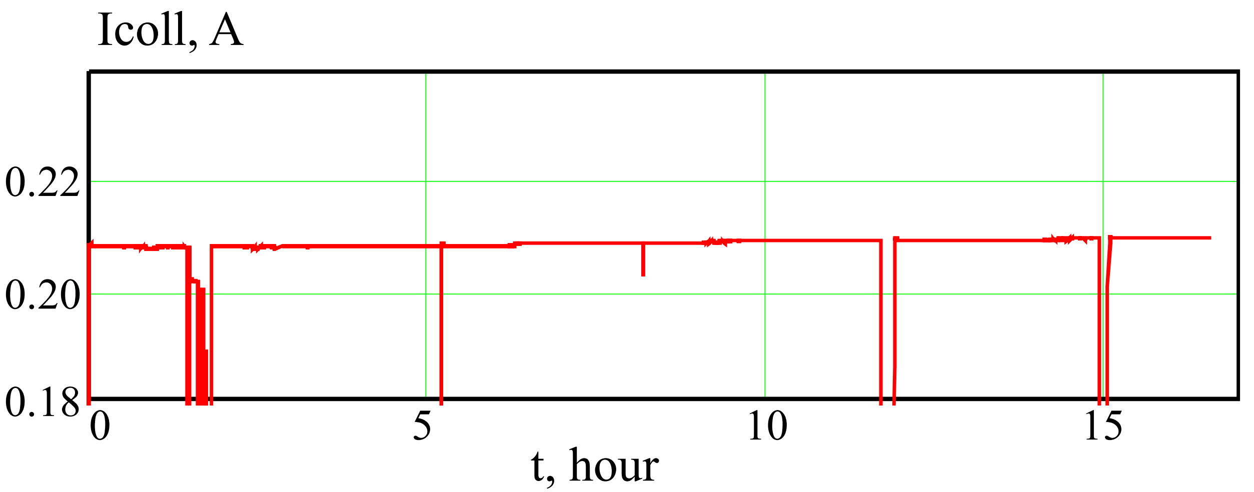
- high-voltage power supply +/- 30 kV;

- 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;

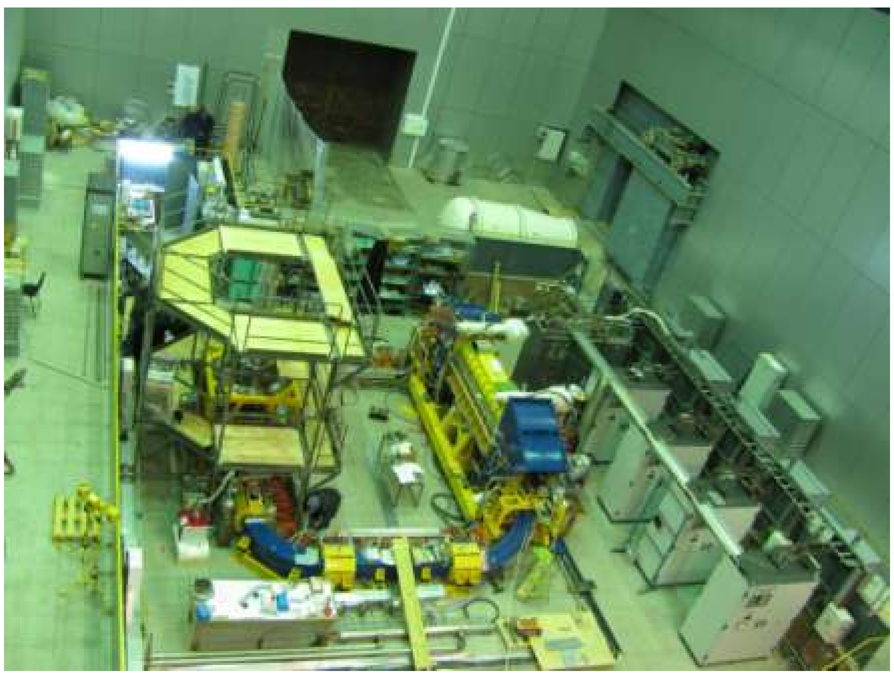
33 high-voltage section

Now in operation in COSY FZJ



Example of the long training regime in Novosibirsk. 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.

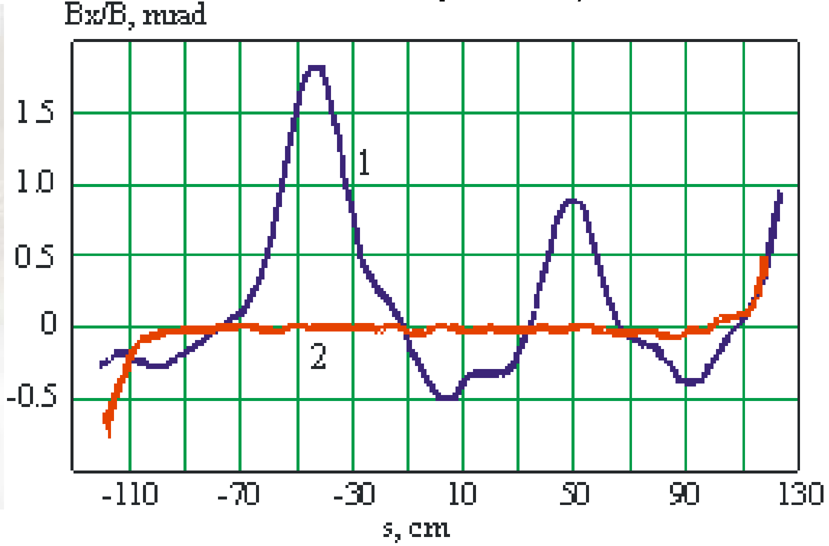
Novosibirsk



Germany

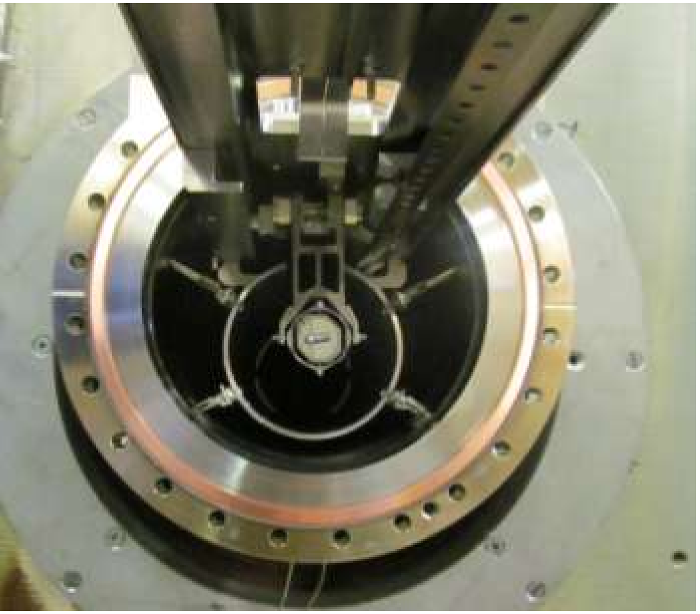
Possibility for on-line control of the quality of the magnetic field

Compass with gimbal suspension



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

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

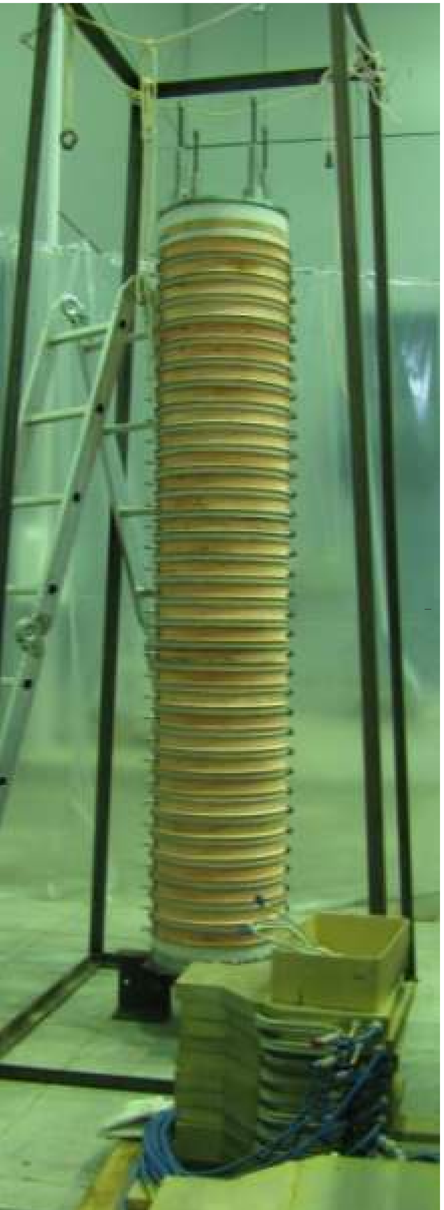


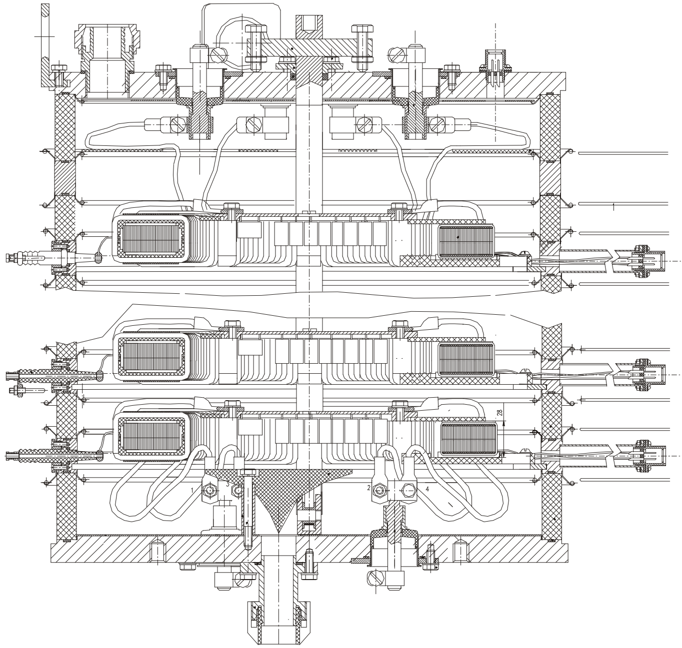
R.M.S. ripple of the magnetic force line was decreased from $6 \cdot 10^{-4}$ to $2 \cdot 10^{-5}$.

measurement system

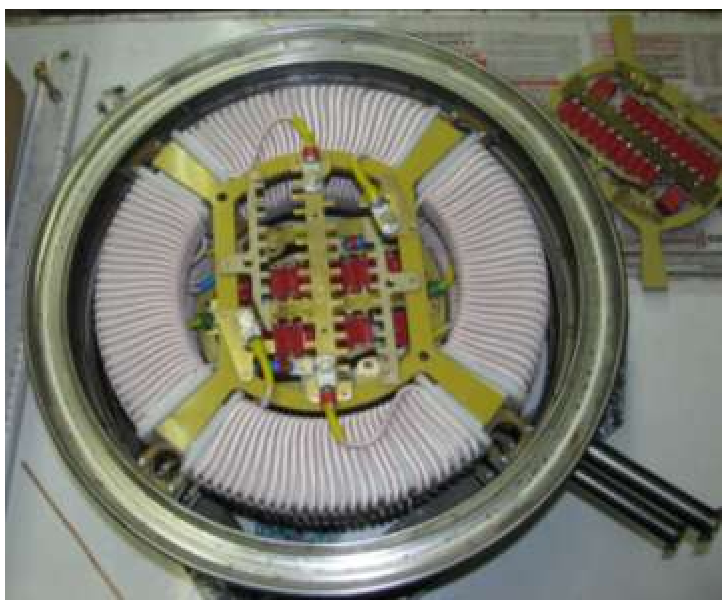
Cascade Transformer as Power Supply

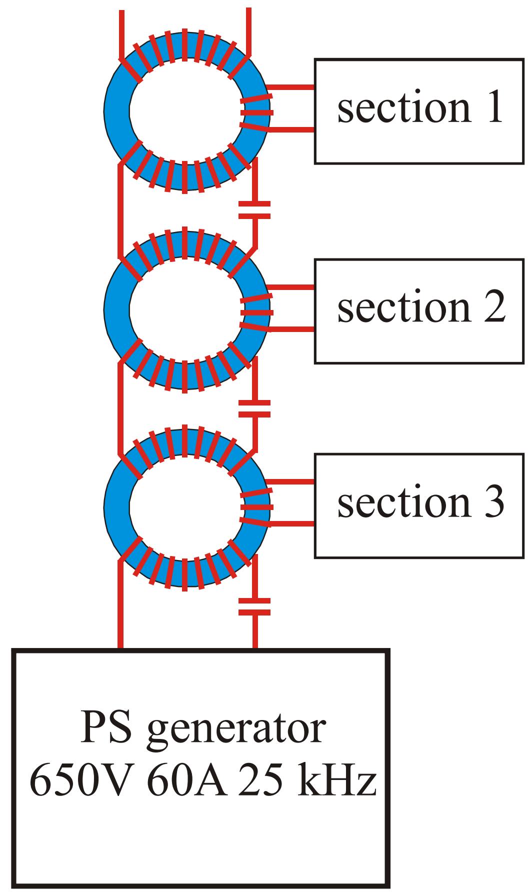
"Transformers section looks like accelerating tube"

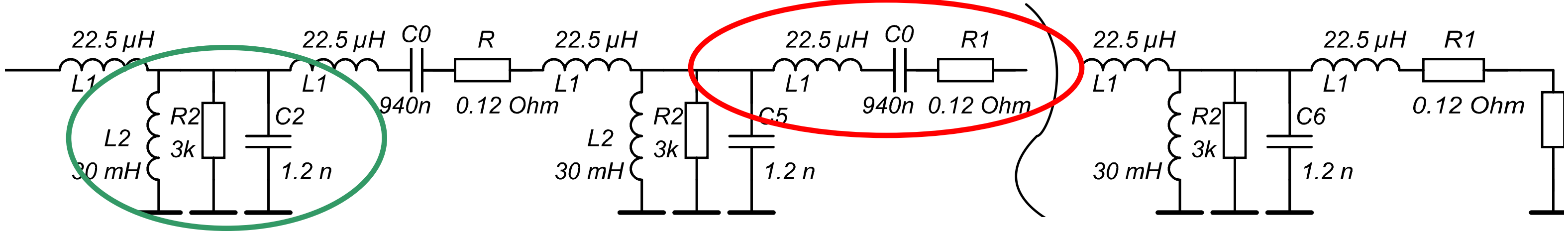




- *-transformers connected to series;*
- *-tube is alternation of the ceramic and metal rings (sections);*
- *- tube is filled by oil;*
- *- section has special spark-gaps;*

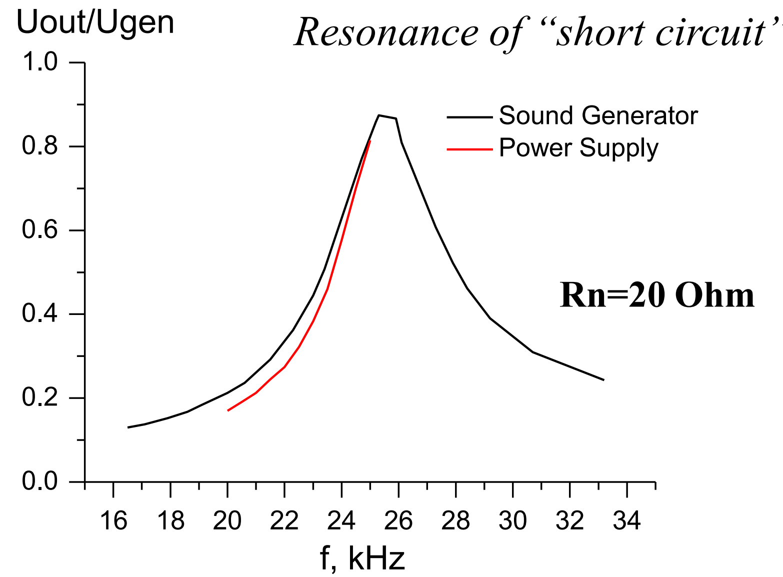






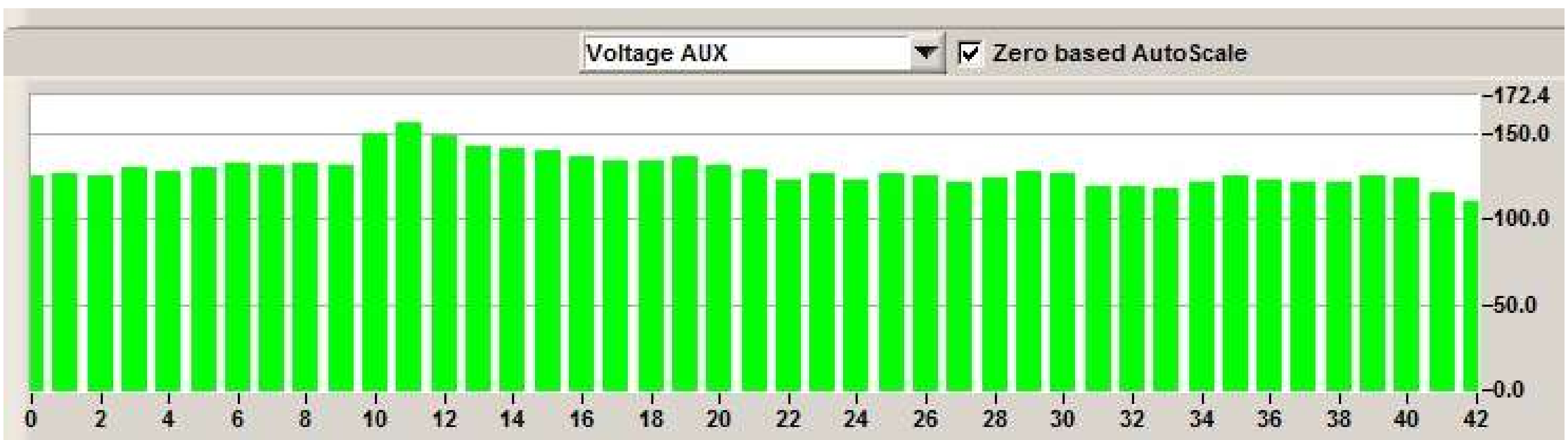
physics principle of operation of cascade transformer is combination of series and parallel resonances induced by the leakage inductance and compensative capacitances

- 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

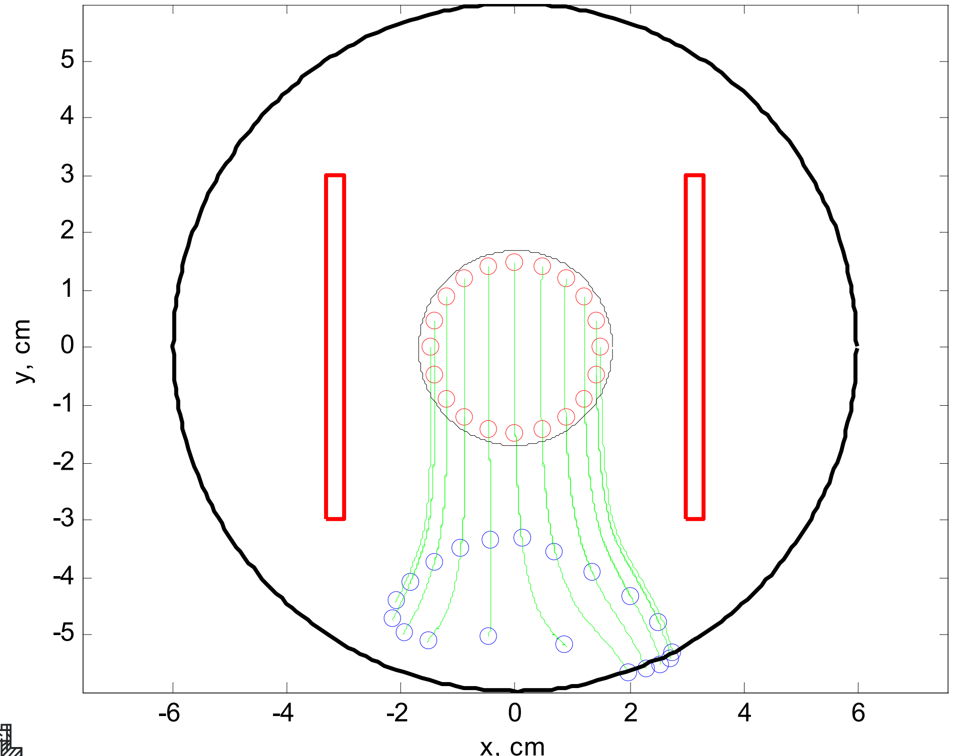
Area with crossed electrical and magnetic fields compensated each other

$$\vec{F}_{\perp} = \vec{\;} - {}_{c}\left[\vec{\;}\quad\right]$$

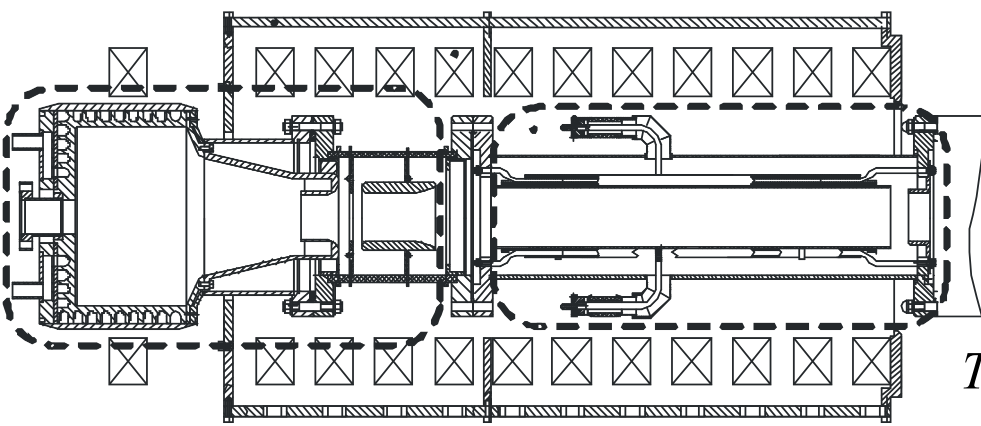
primary beam

$$\vec{F}_{\perp} = \vec{\;} + {}_{c}\left[\vec{\;}\quad\right]$$

secondary beam

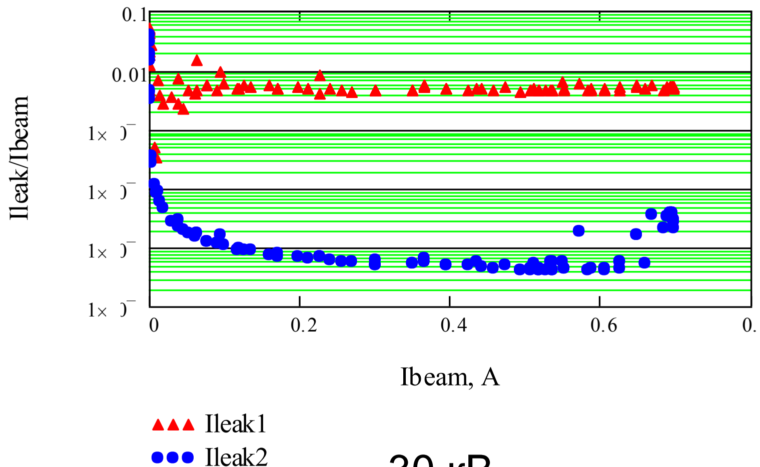


Motion of primary beam is red circle and motion of reflected beam is blue circle

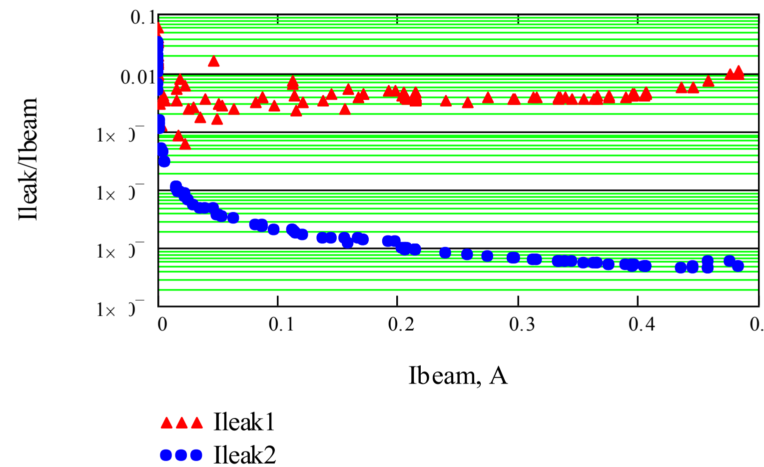


The experimental recuperation coefficient is 10^{-5} - 10^{-6}

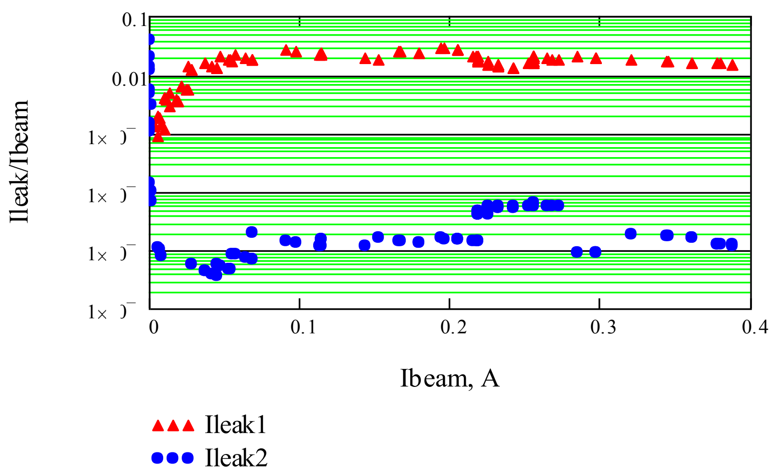
Исследование эффективности рекуперации при различных энергиях



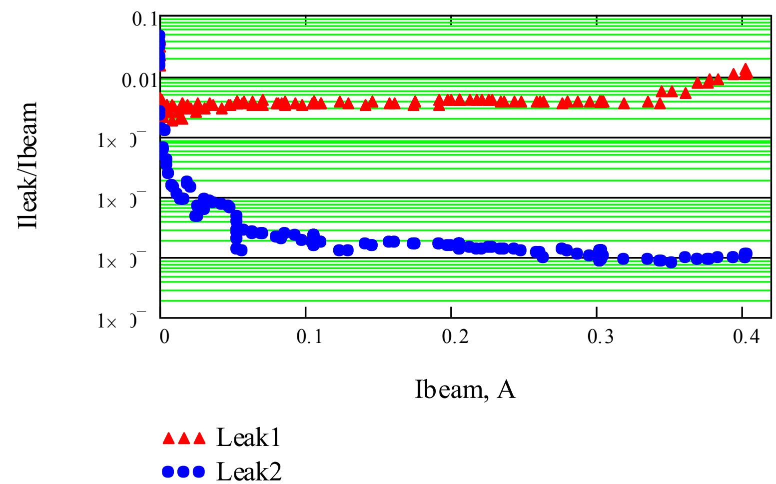
30 кВ



150 кВ

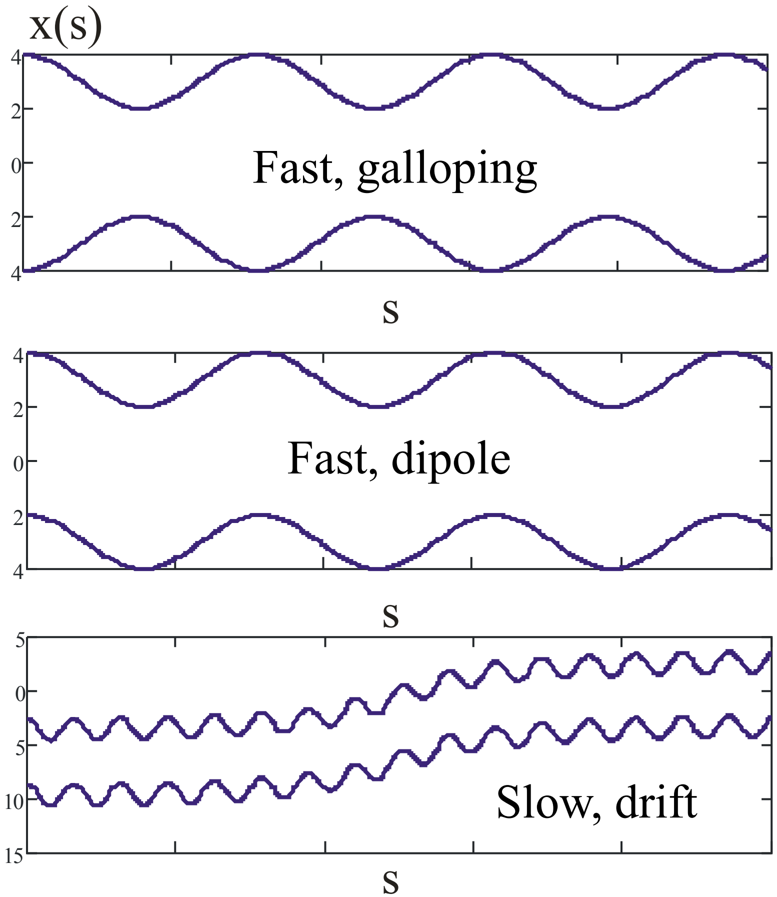


200 кВ

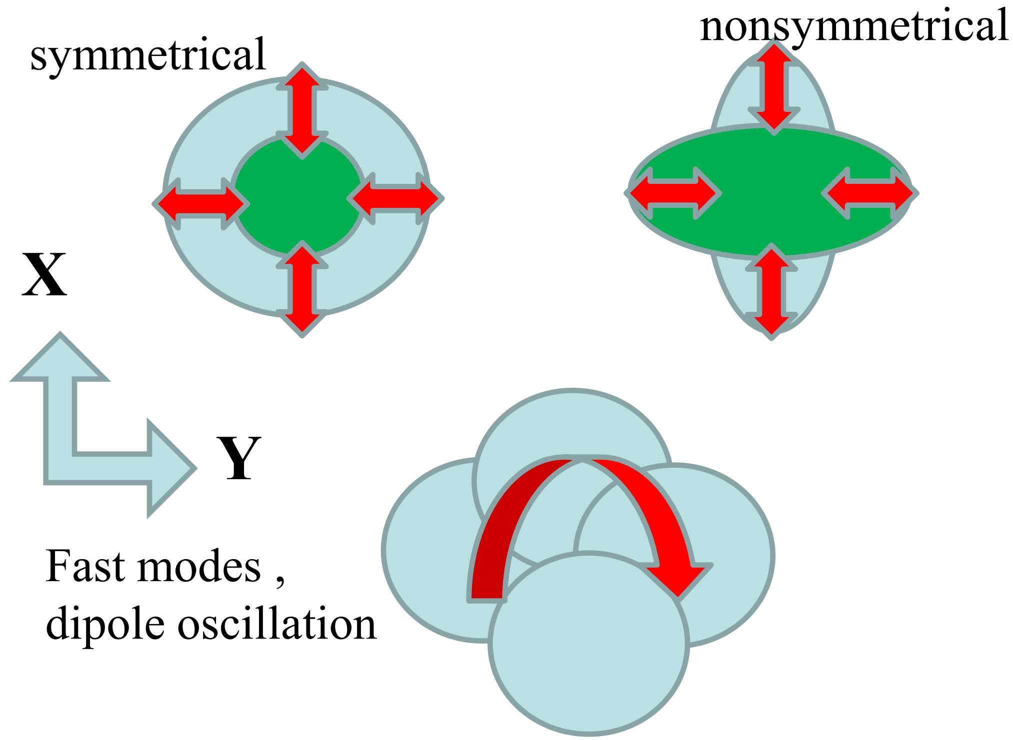


1 МВ

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

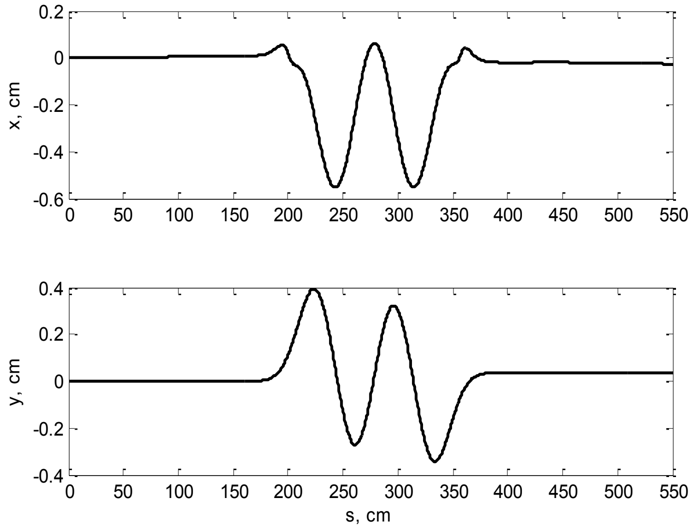


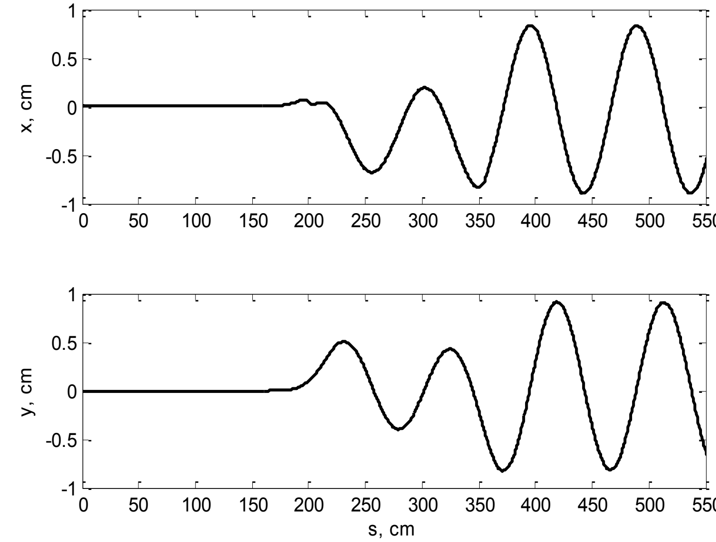
Modification of the beam shape and position

Transportation of the electron beam is also magnetized that has some features. The necessity to have the continuous magnetic field from gun to the collector is result of the operate range from 100 keV to 2 MeV.

Bends

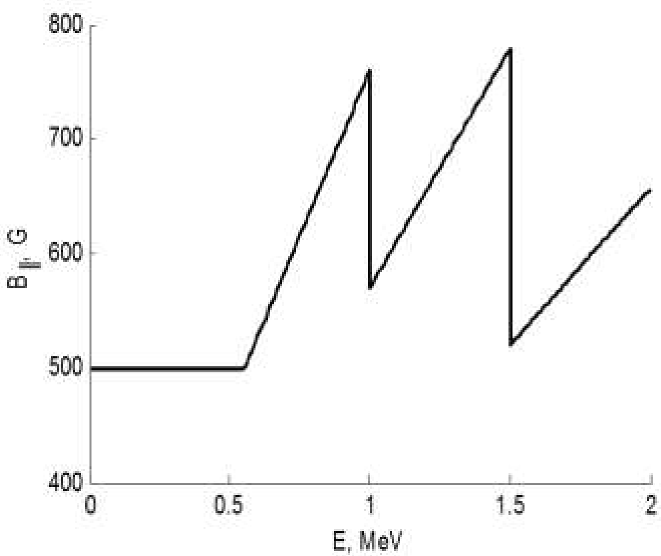
Trajectory of electron with energy 2 MeV in bend. Bend starts is s=200 cm, radius R=100 cm





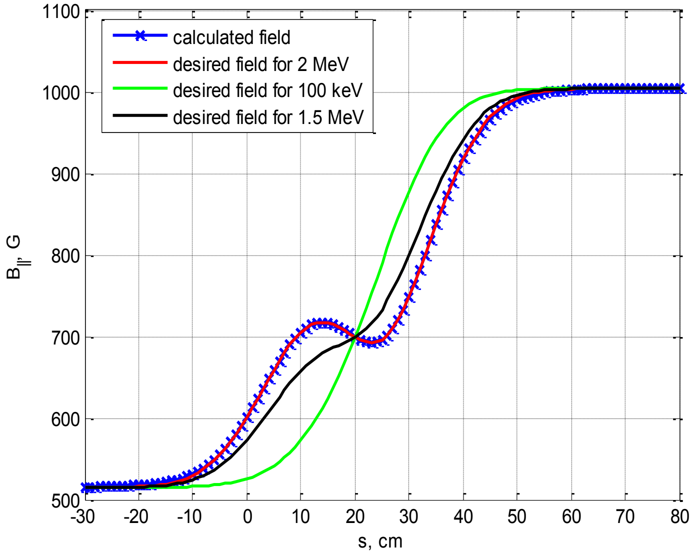
To decrease heating of the beam after transition through a bend, the length of the bend should be equal to integer number of Larmor length. In such a case kick on entry to bend in compensated by kick on leaving.

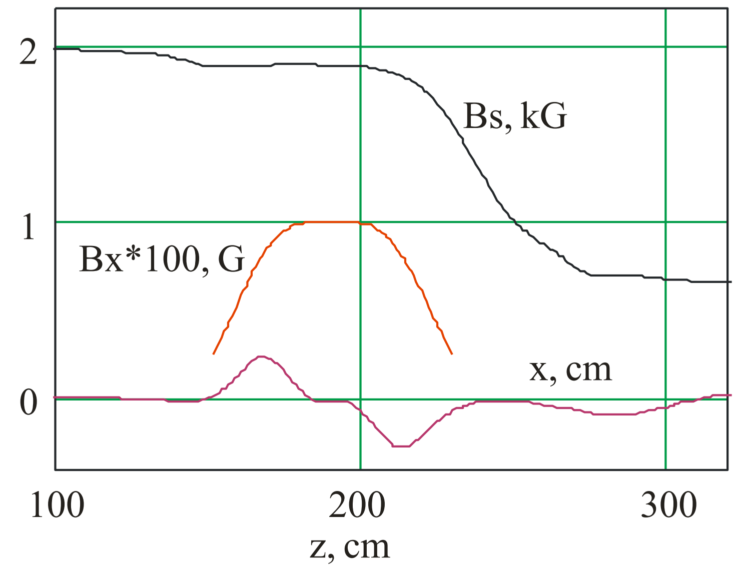
The worst situation, which one should avoid, occurs when length of bend is equal to n+1/2 of Larmor length. In such a case two kicks are added and resulting transverse velocity of electrons is very big from the point of view of cooling.

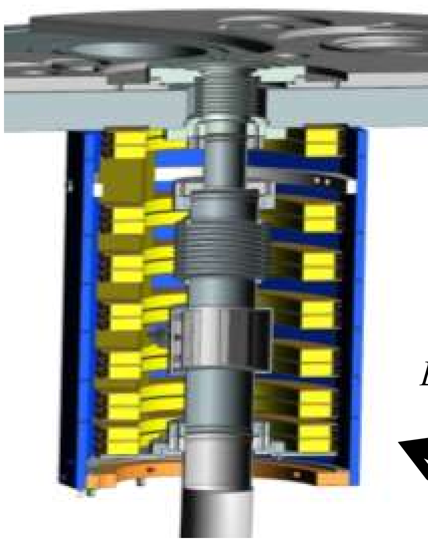


To adjust the optics for every energy is inconvenient. Another method was proposed for this system. The idea of the method is to change magnetic field in the cooler synchronously with beam energy. If magnetic sys was adjusted for 2 MeV electron beam then after the decreasing of energy for value U, we must decrease magnetic field (longitudinal and transverse) in α times where α is equal to ratio of momentums for 2 MeV and for U:

Matching section, non-adiabatic transition between the different value of the magnetic field

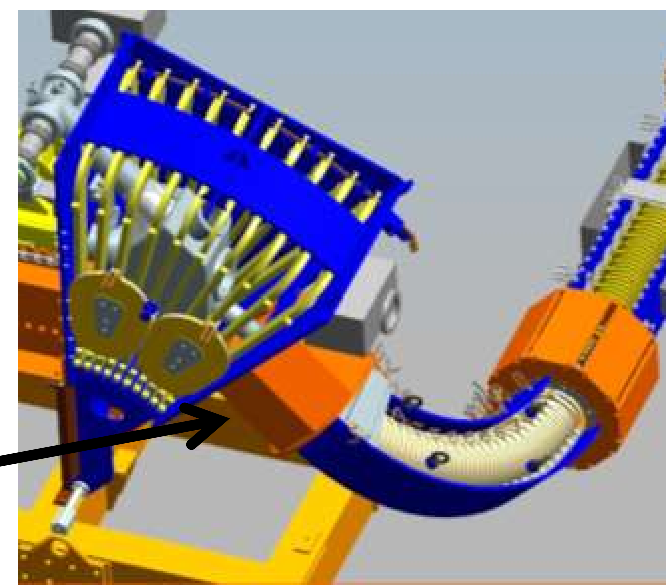






The special section with independent power supplies for forming proper profile the magnetic field

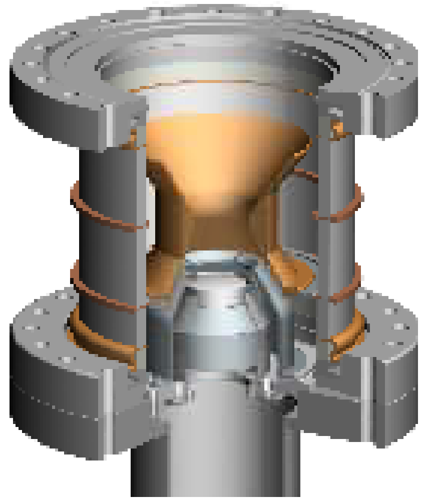
$$B(z) = \frac{\gamma\beta mc^2}{e} k_N(z) = \frac{2\gamma\beta mc^2}{e}\sqrt{\frac{1}{W^4} - \frac{W''}{W}}$$



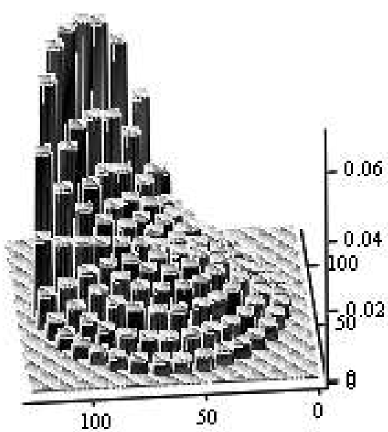
Two place for optic compensation

Diagnostics of the shape of the electron beam

Photo Pick-Up System

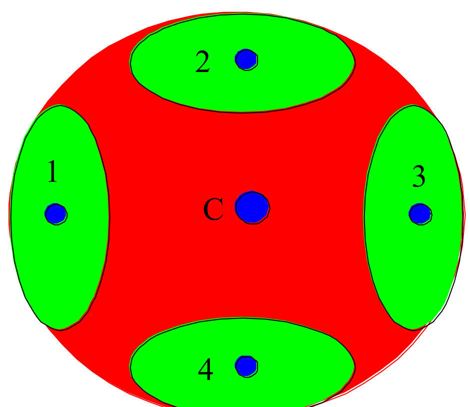


4 sector electron gun



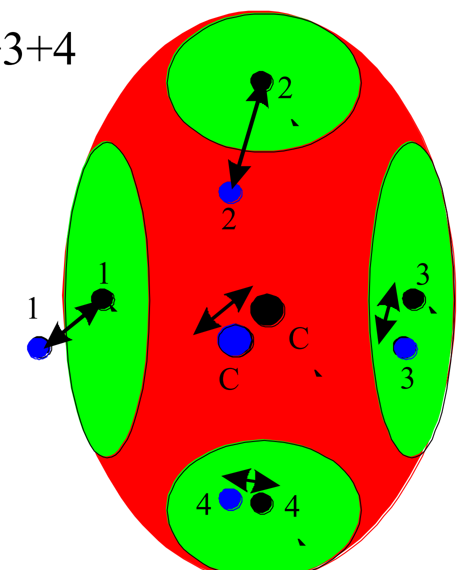
Voltage is applied to one sector

Pick-Up 1



Center=1+2+3+4

Pick-Up 2



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

Optic features of COSY cooler

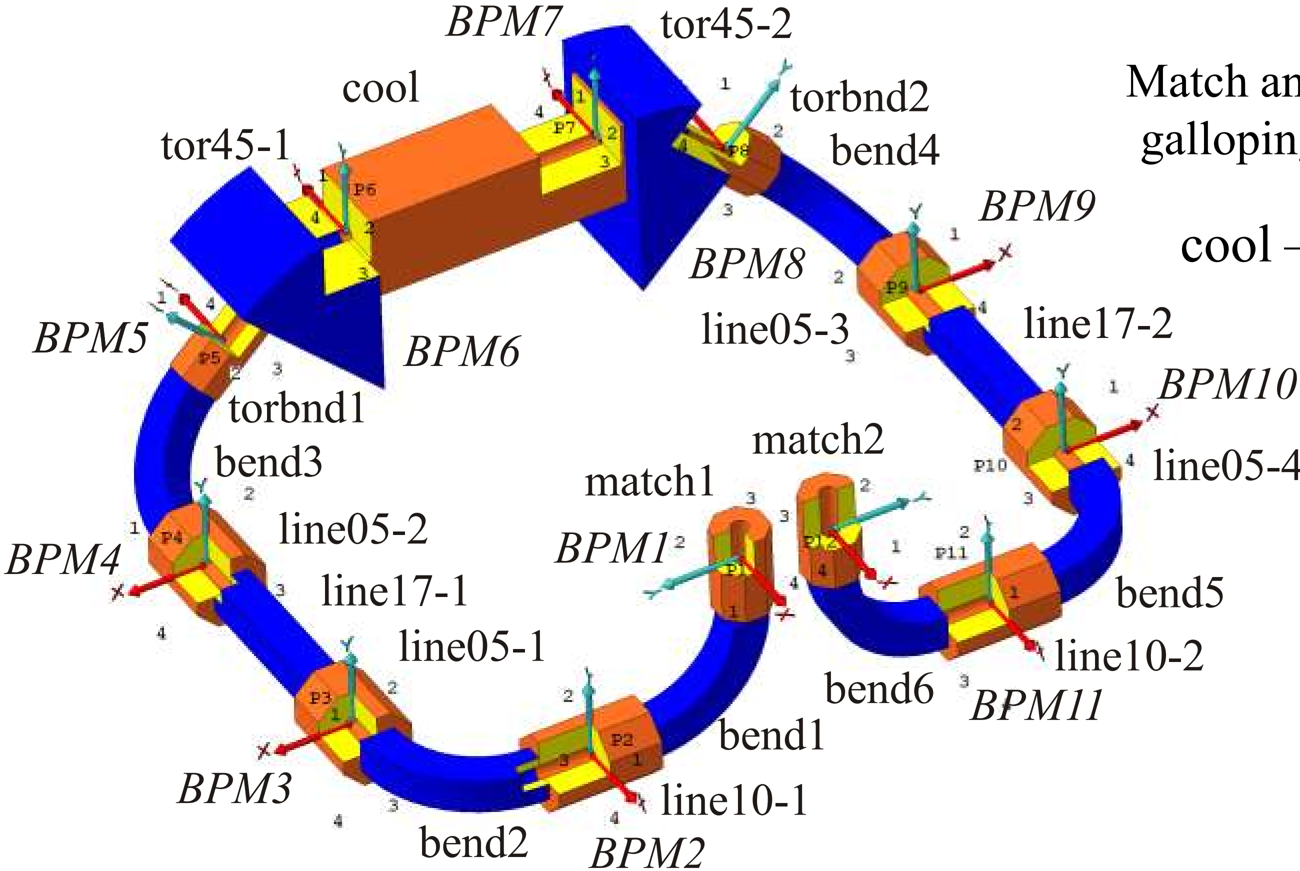
Lengthy coils in longitudinal direction the control the position of the center of Larmour rotation; Short coils control the amplitude of the Larmour oscillations

line17hor, line17ver, all bends– correctors of the beam shift

line10– correctors of the beam kick

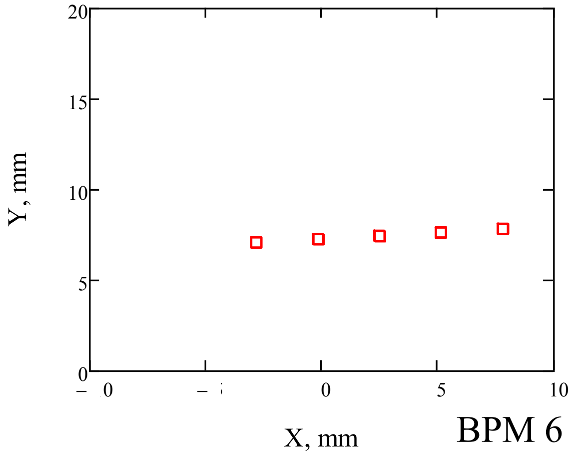
Match and torbnd– correctors of the galloping of beam shape correction

cool – convergence of ion and electron beams

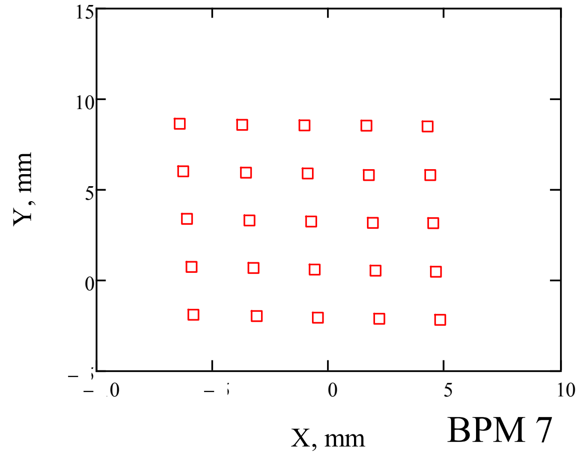


Location of BPMs and magnetic elements of COSY coolers

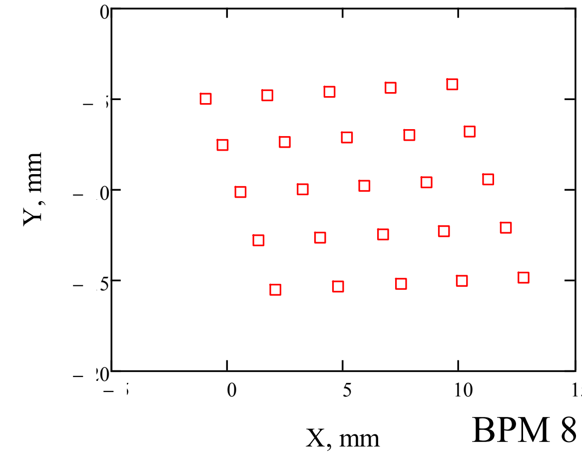
BPM 2



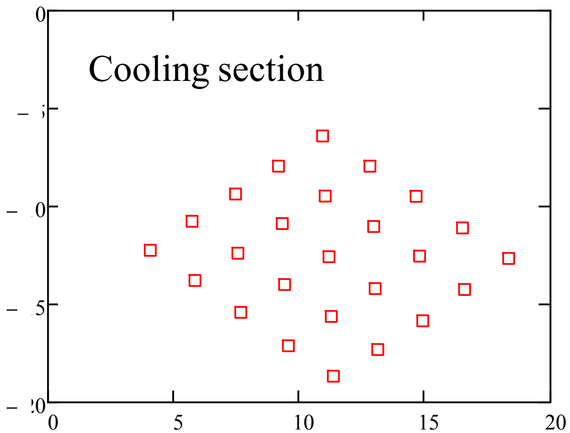
BPM 3



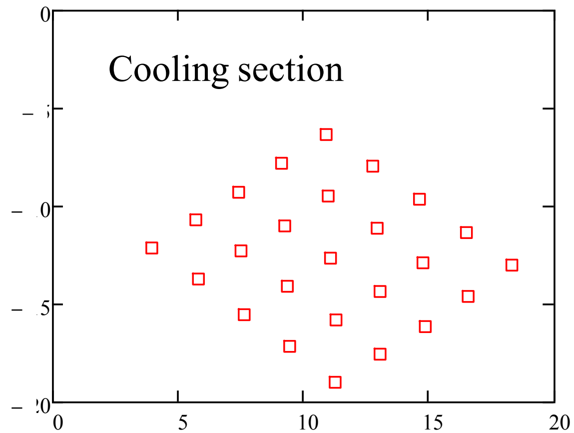
BPM 4



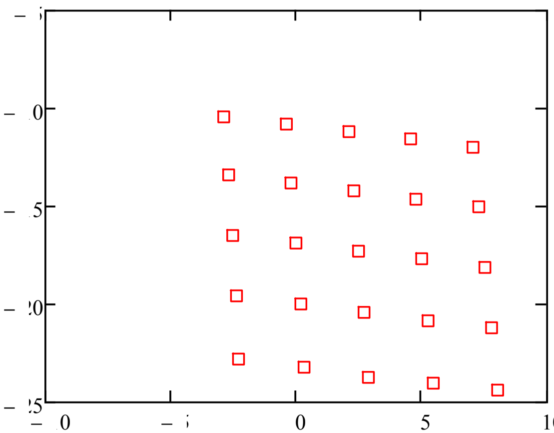
BPM 6



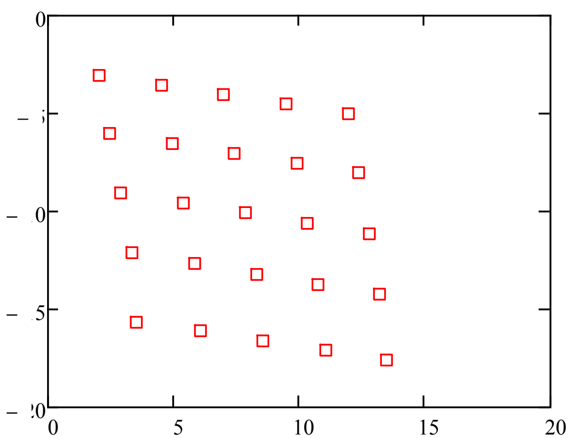
BPM 7



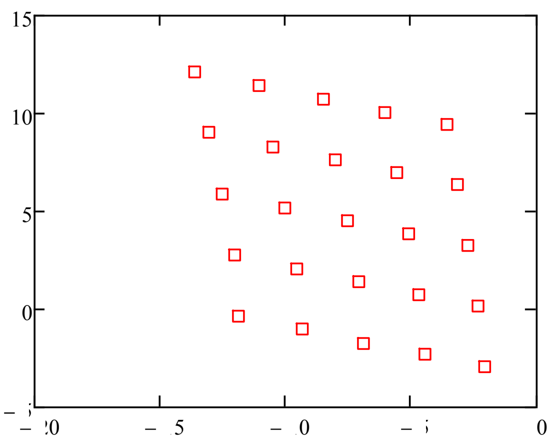
BPM 8



BPM 9



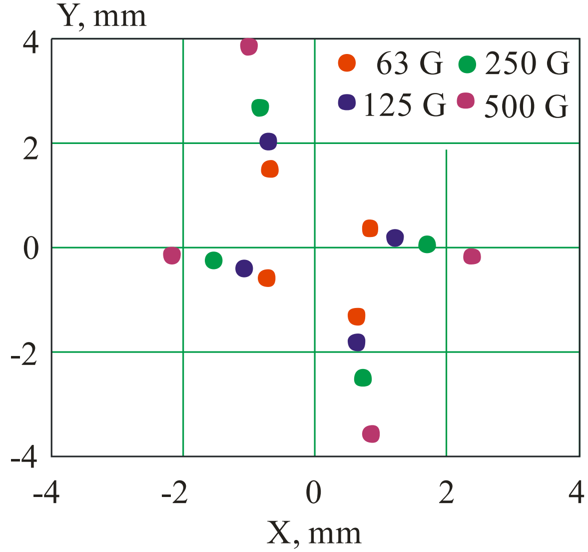
BPM 10



Demonstration of the BPM and correctors working. Scanning bend1 and bend2 magnets

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

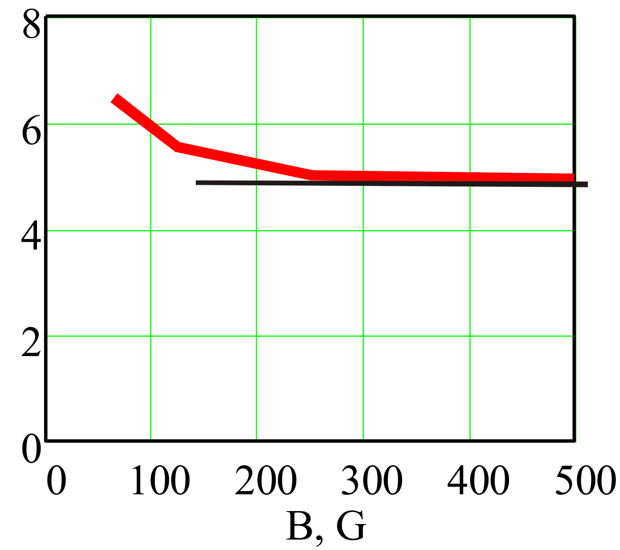
At small value of the magnetic field the size of the electron beam is determined not only by the magnetic field but the anode value also



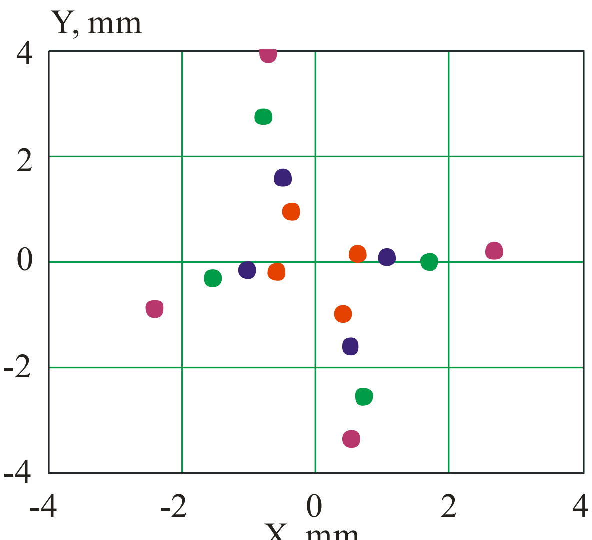
Conservation of the magnetic flux

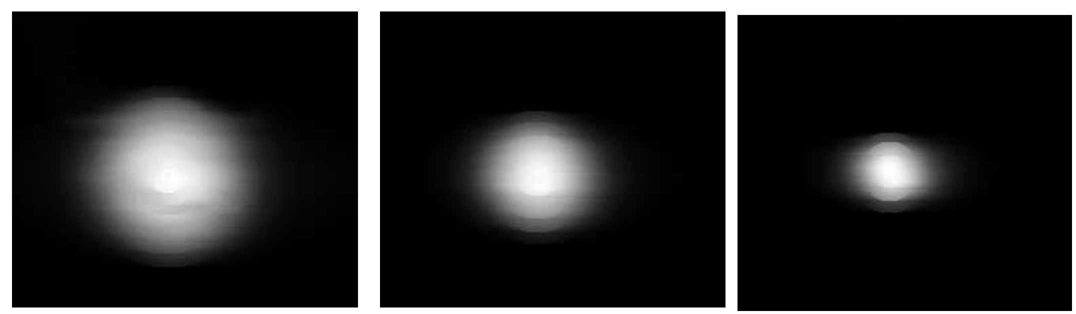
$$B_{gun} r_{gun}^2 =$$

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



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



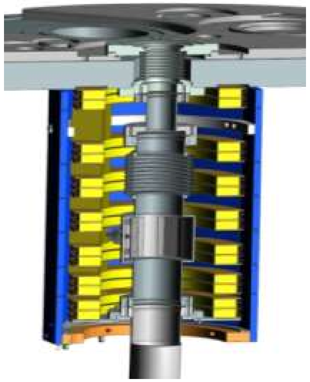


Ugr/Uan= –0.2/1.4 kV   -0.4/1.4 kV   –0.6/1.4 kV

Pictures was done with wire probe

Action of magnetic elements

Diagnostics of optic elements

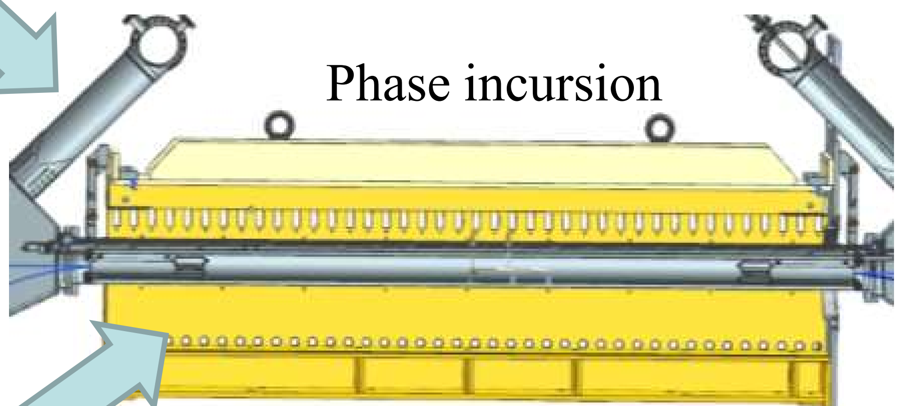


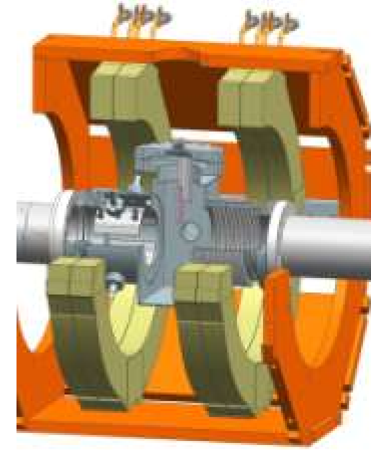
Registration Beam Motion

Line05, BPM

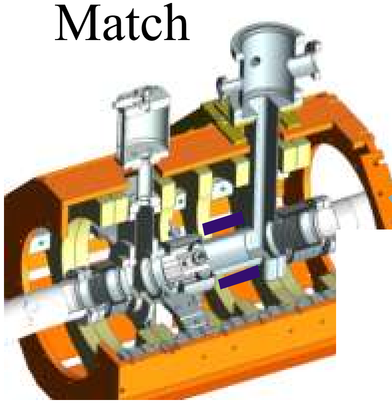
Cool

Phase incursion





Match



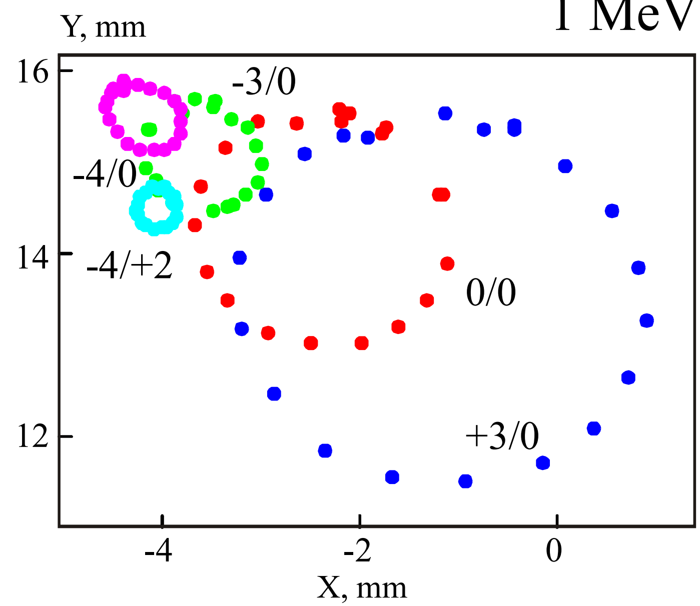
Short Electron Dipole Corrector

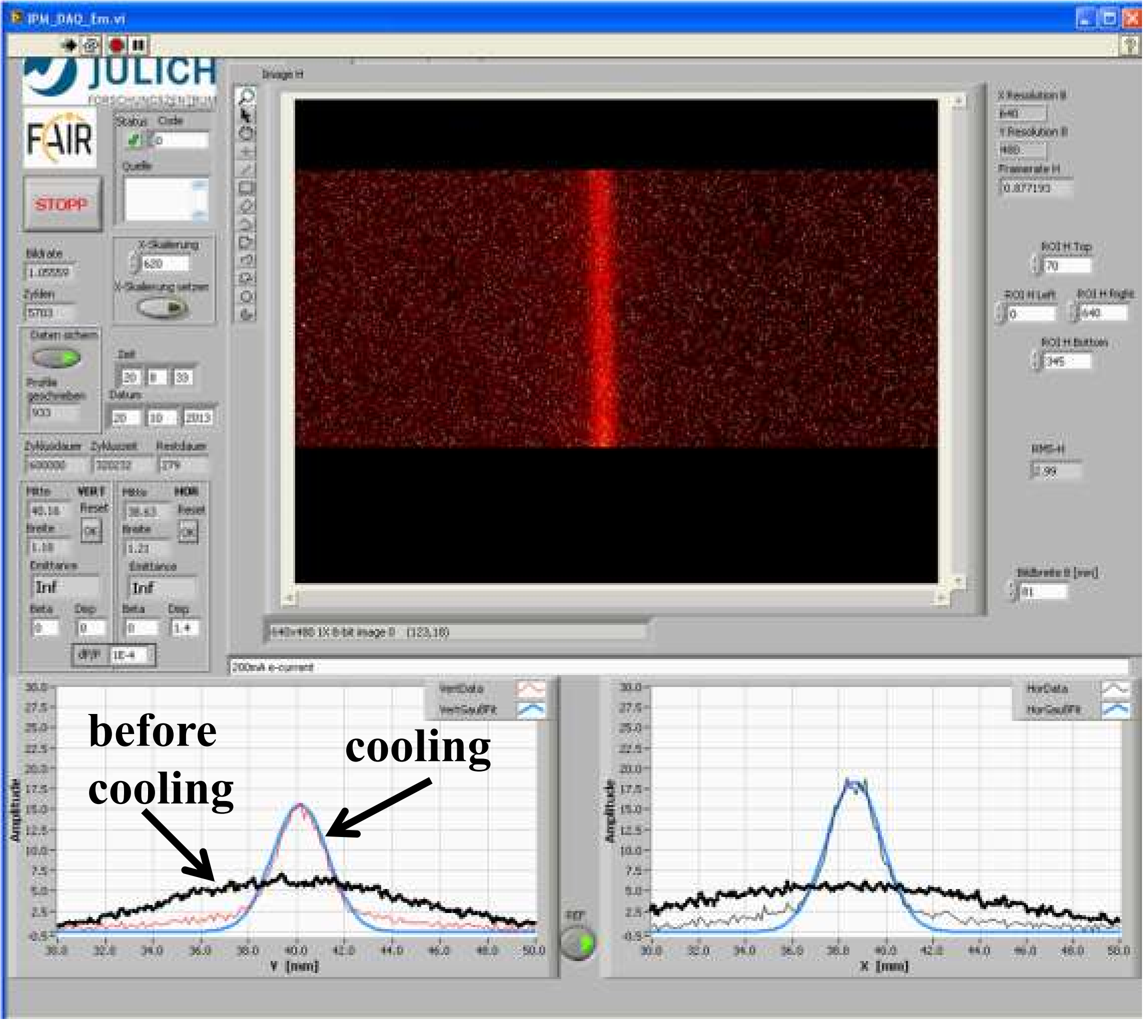
XXX, any element

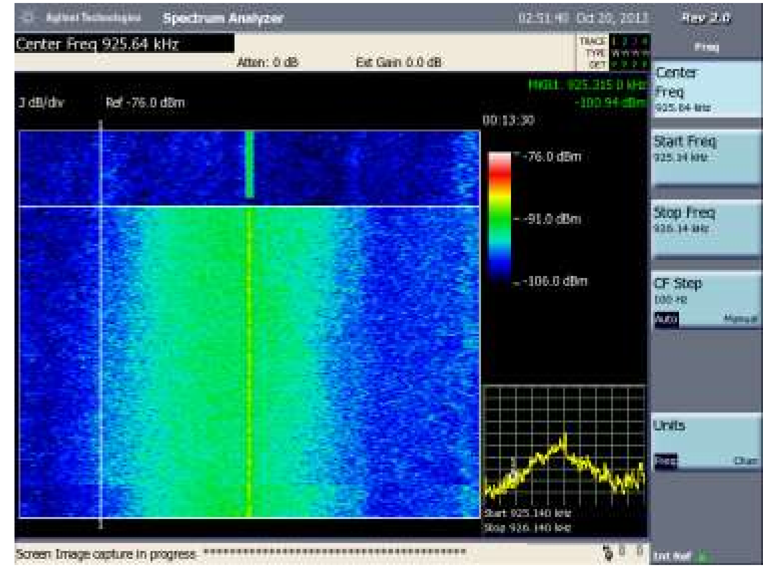
Effect of the short dipole corrector is combination of the shift of the center of electron beam with excitation of Larmour rotation

Compensation of Dipole Motion

1 MeV

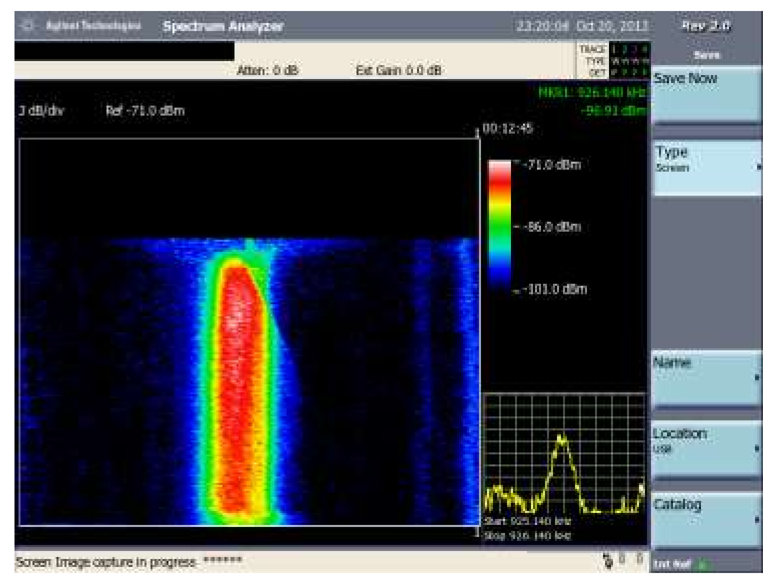






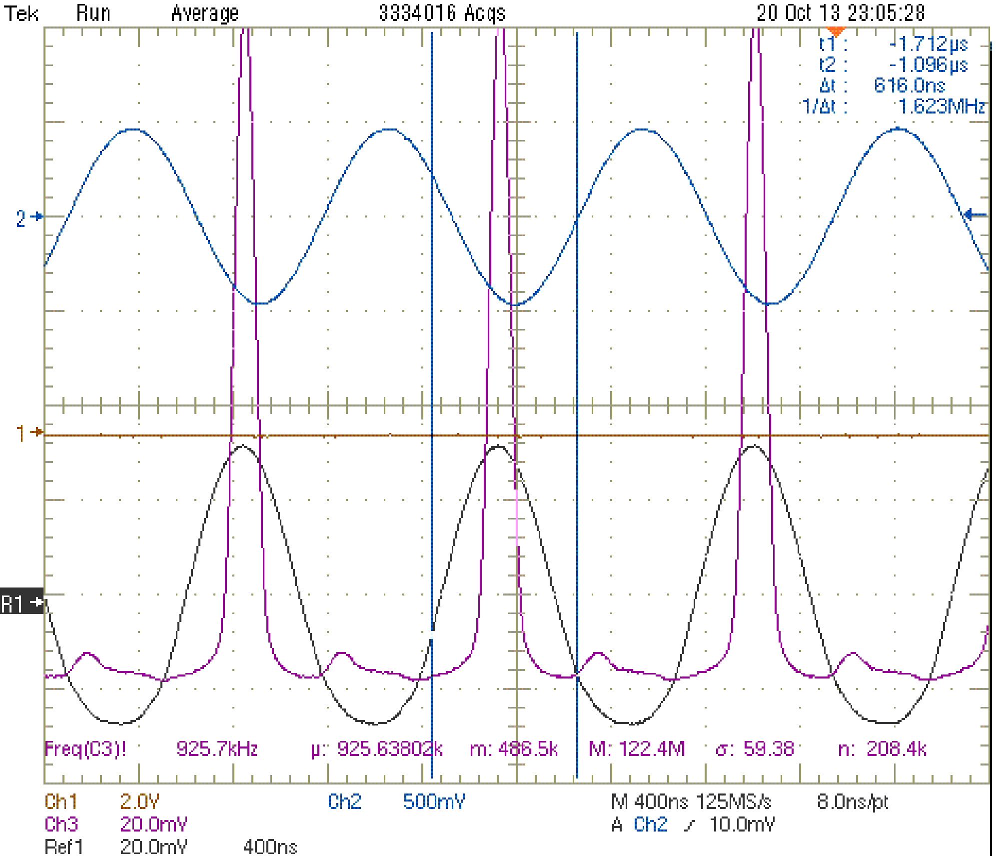
Before cooling

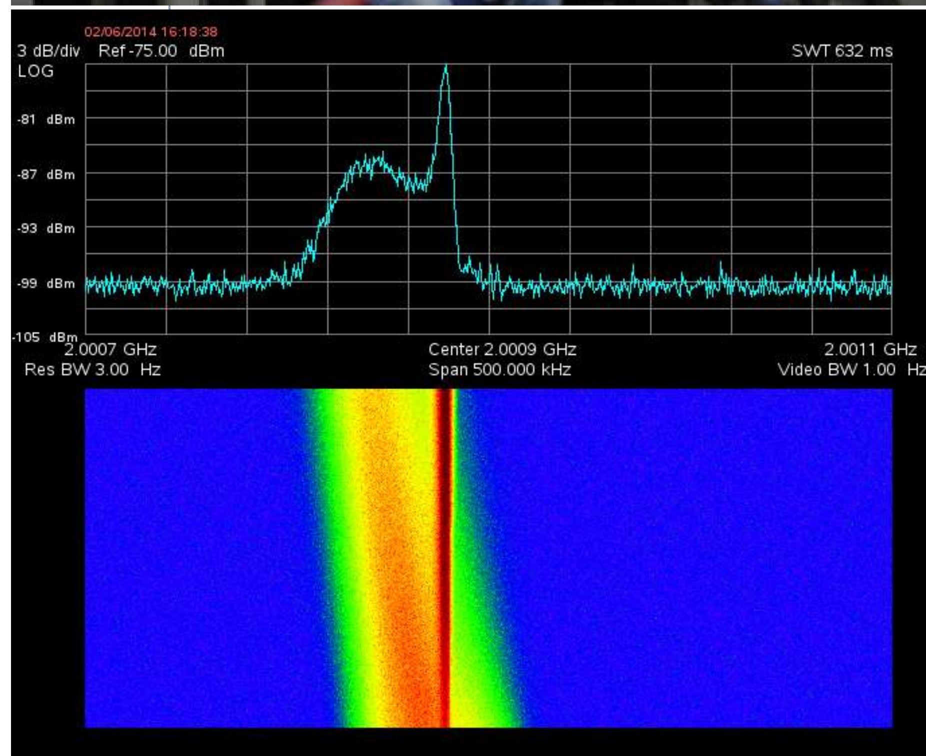
Transverse cooling at 109 kV



Longitudinal cooling at 109 kV

Cooling



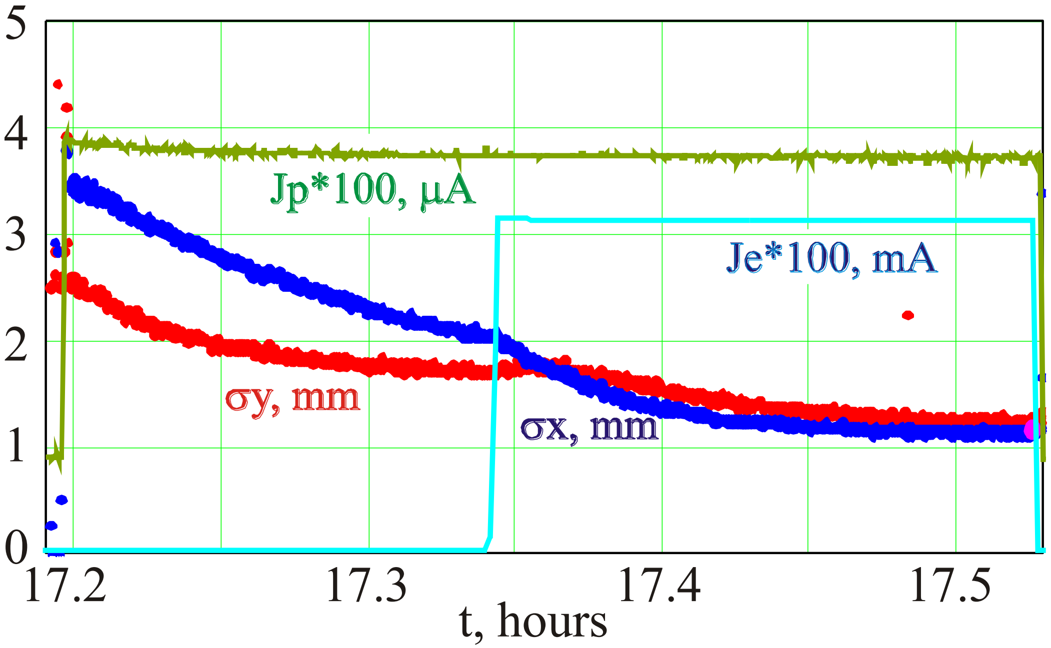


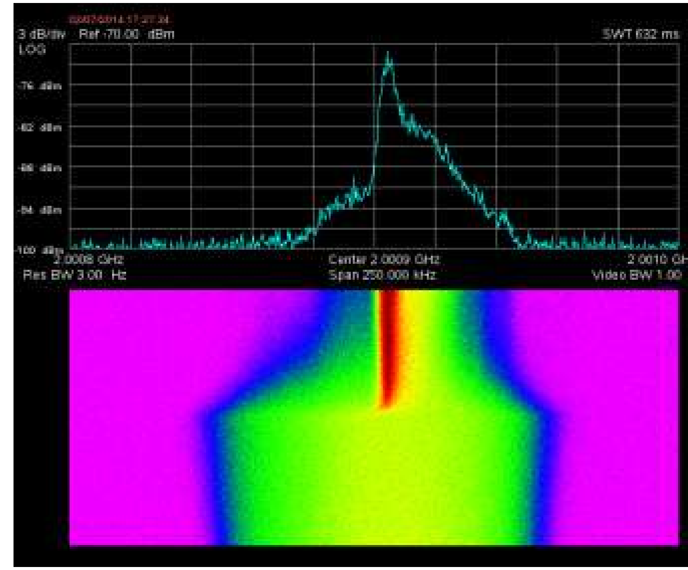
RF cooling with formation of very narrow ion beam

600 s

Cooling at 908 kV

Combine action of stochastic and electron cooling





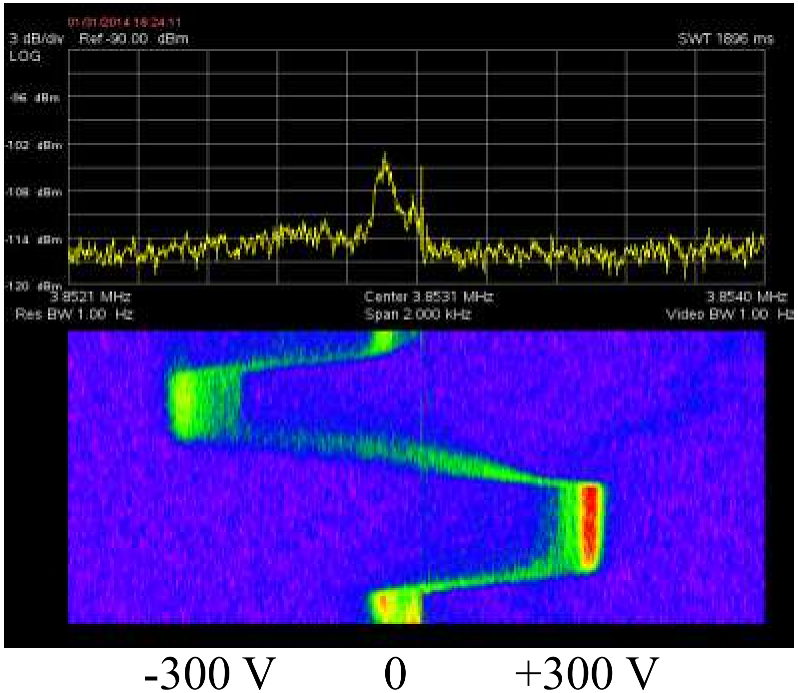
Only stochastic Stochastic+e-cooling

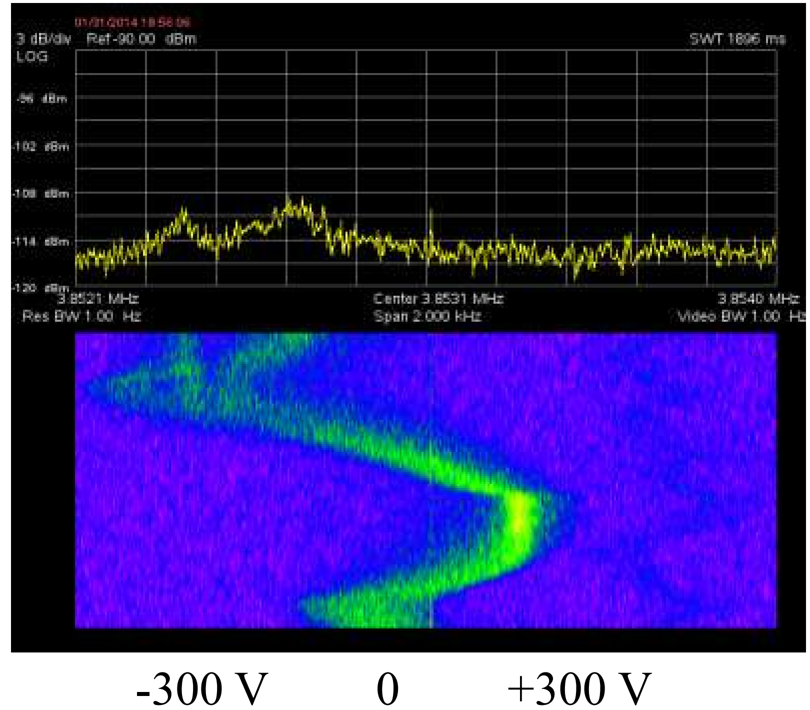
initial no longitudinal cool, after e-cooling

Electron energy	908 keV
Proton energy	1.66 Gev
Stochastic cooling	vertical and horizontal
E-cool time	120 s
Stochastic cooling time	400 s
Beta function x/y	4m/3m

Macroscopic Larmour rotation is essential

edip kick=+2/0 A





edip kick=+1/0 A

Electron energy 315.85 keV

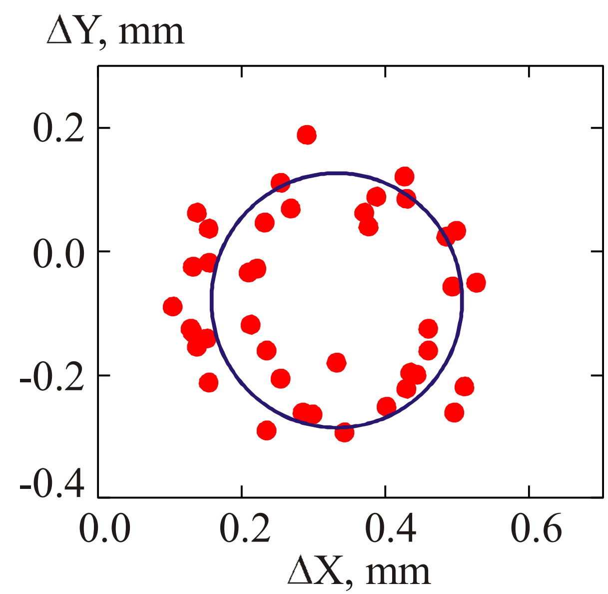
Jsol=225A=1275 G

cycle duration = 600 sec

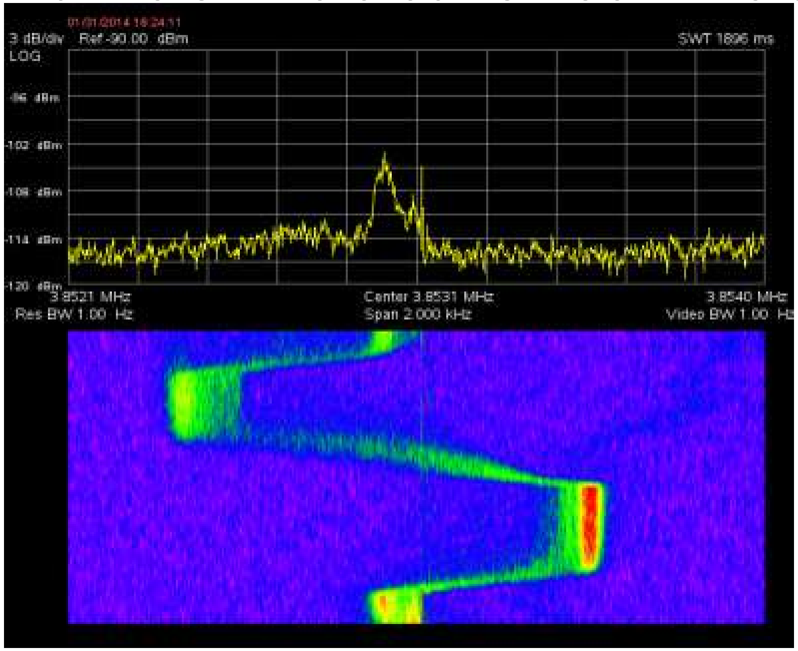
Je=0.26 mA

$$\lambda := \frac{\gamma \cdot \beta \cdot 0.511 \cdot 10^{6}}{B \cdot 300} \qquad \lambda = 1.697$$

$$\Delta := 0.02 \qquad \frac{\Delta}{\lambda} = 0.012$$

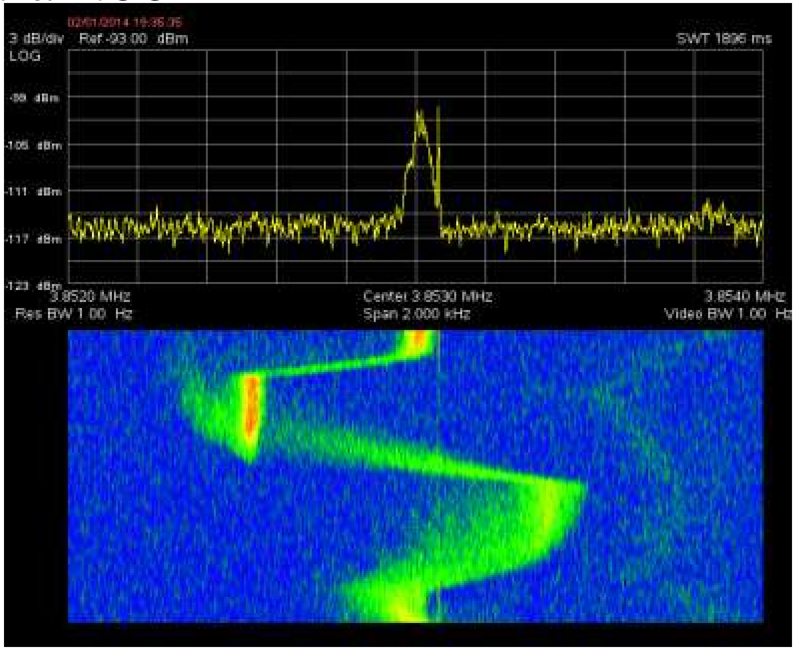


Incline of the electron beam is essential too



-300 V 0 +300 V

cool in=(4.9 1.6) out=(5.8 2.8) mm



-300 V 0 +300 V

cool in=(5.3 1.6) out=(5.4 2.8) mm

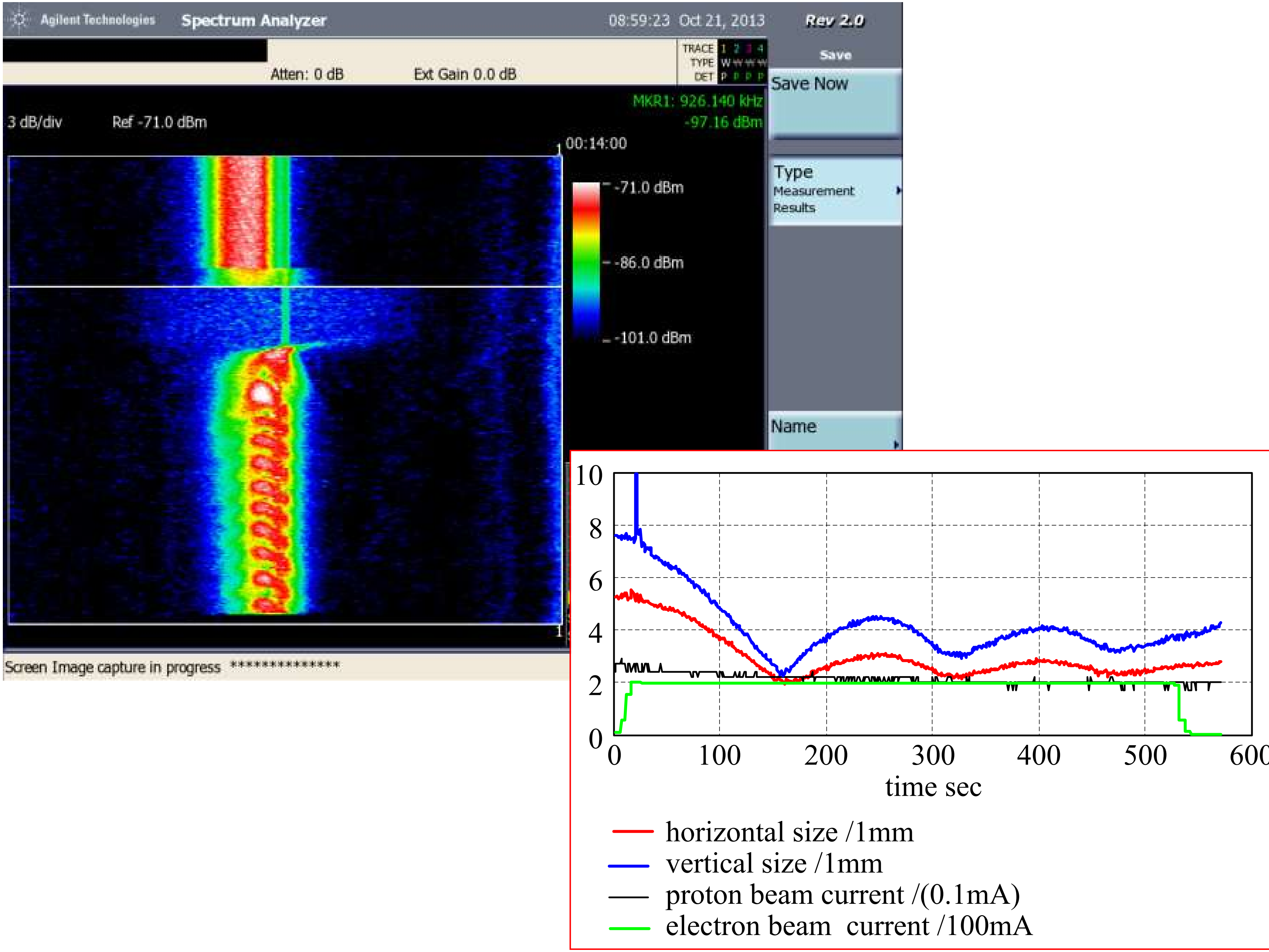
Electron energy 315.85 keV

Jsol=225A=1275 G

cycle duration = 600 sec

Je=0.3 mA

$$\frac{0.04}{125} = 3.2\times 10^{-4}$$



Agilent Technologies
Spectrum Analyzer
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DET P P P P
Save Now
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-97.16 dBm
3 dB/div
Ref -71.0 dBm
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-71.0 dBm
-86.0 dBm
-101.0 dBm
Type
Measurement
Results
Name
Screen Image capture in progress ***************
10
8
6
4
2
0
0
100
200
300
400
500
600
time sec
horizontal size /1mm
vertical size /1mm
proton beam current /(0.1mA)
electron beam current /100mA

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) are experimentally verified during commissioning in Novosibirsk and Juelich.
- The strong surprises aren't observed.
- The cooling experiments in COSY were started.
- The conception of magnetized cooling is useful until now

What is a next step of the cooling technique ?