Budker INP proposals for HESR and COSY electron cooler system

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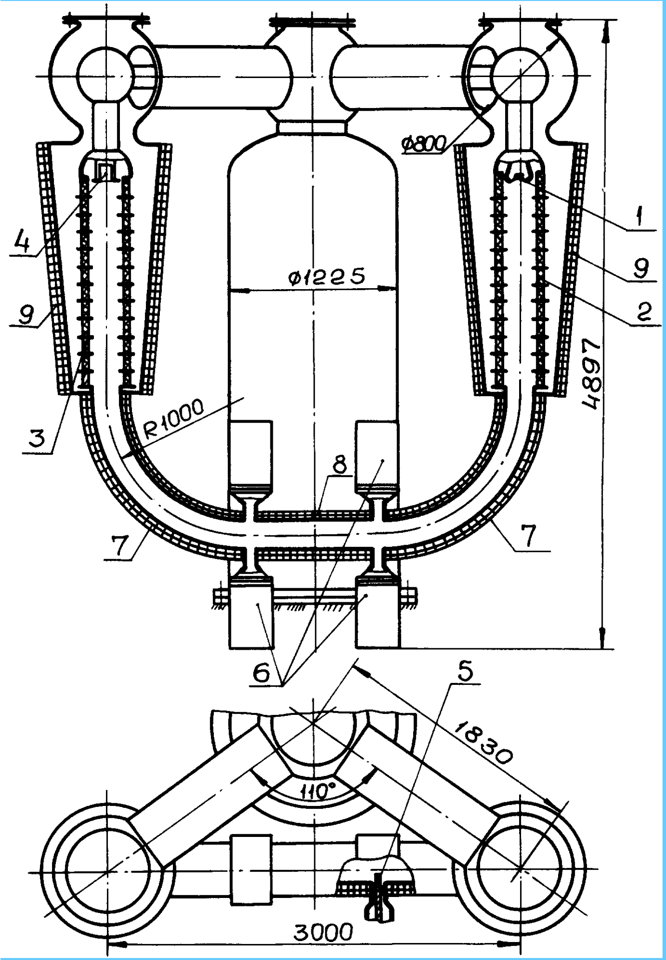
Selection of Parameters of the High Energy Storage Ring HESR

Injection (from SIS-100)	
Energy	0.8-14.5 GeV
Beam emittance (2σ-values at 3 GeV)	1 (h) / 1 (v) mm·mrad
Momentum spread (2σ-values at 3 GeV, bunched)	$\pm 1\times10^{-3}$
Parameters during experiments (values depend on beam intensity)	
Beam emittance (both planes)	0.001 – 0.1 mm·mrad
Momentum spread (coasting beam)	$\pm 2\times10^{-5} - \pm 2\times10^{-4}$
Max. luminosity	2×10^{32} cm^{-2} s^{-1}
Type of the internal target (hydrogen)	cluster jet or frozen pellets
Frozen pellets, Max. molecular thickness	1×10^{16} cm^{-2}
Max. molecular thickness	2.5×10^{15} cm^{-2}

High molecular thickness and low emittances and momentum spread of pbar beam demands high cooling rate

Electrostatic machine – classical scheme



Merits:

– a lot of experimental experience with a such scheme;

– small spread of the electron beam energy;

– high recuperation efficiency;

– continuous electron beam without any time structure;

–it enables to vary the electron energy in wide range;

Demerits:

-a large size;

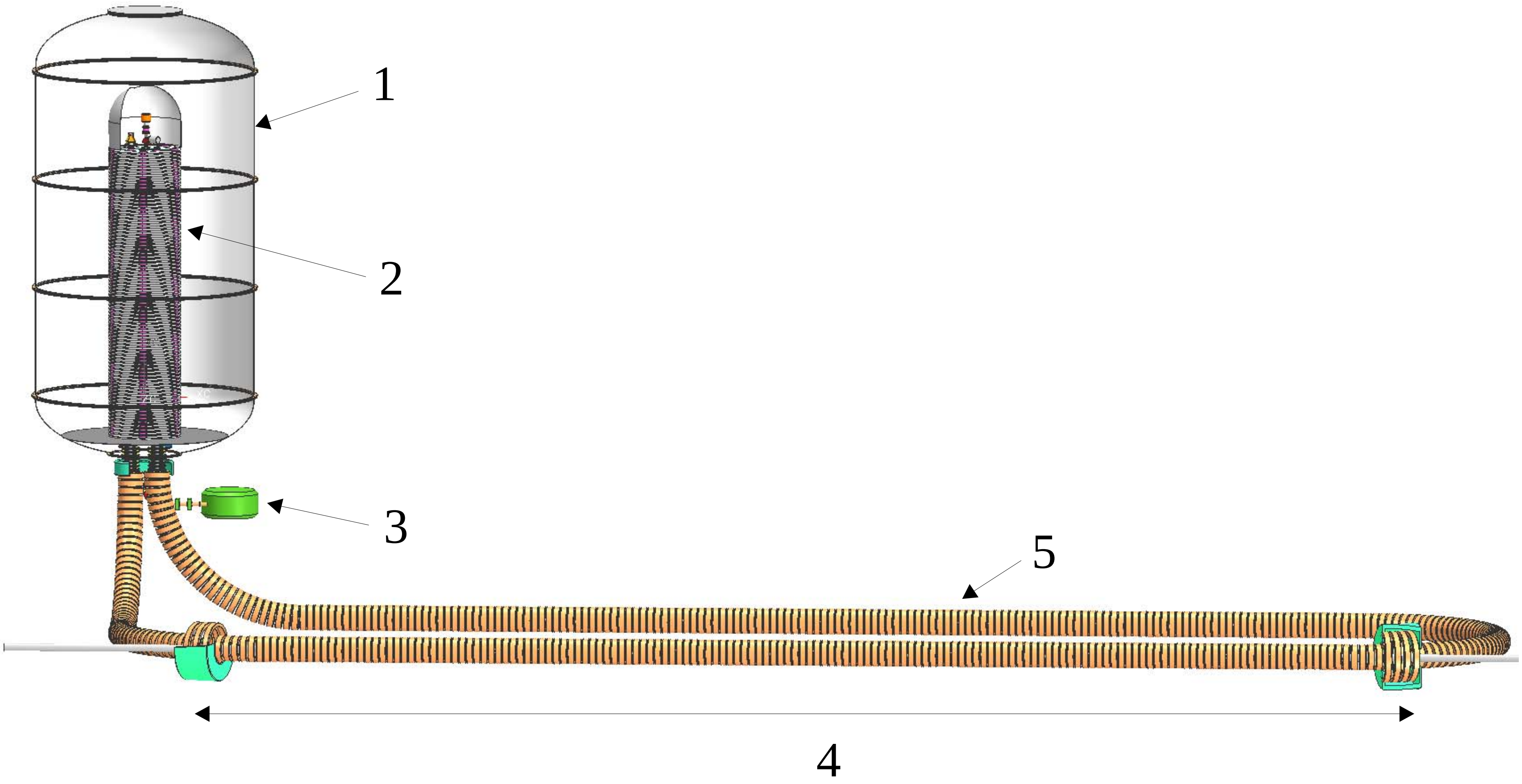
- restriction of the maximum electron energy

Technical solution of the BINP team is based on the standard low-energy design for the electron coolers.

- Acceleration tube located in the magnetic field with value about 500 G . Hardness of the optics is small sensitivity to the external impaction (effect of dust vaporation, secondary ion storage effect etc).
- Magnetic field in the cooling section (2 – 5 kG) is strong enough for guarantee magnetizing collision between the ions and electrons
- Longitudinal magnetic field in the kilogauss range is used for the transportation of the electron beam.

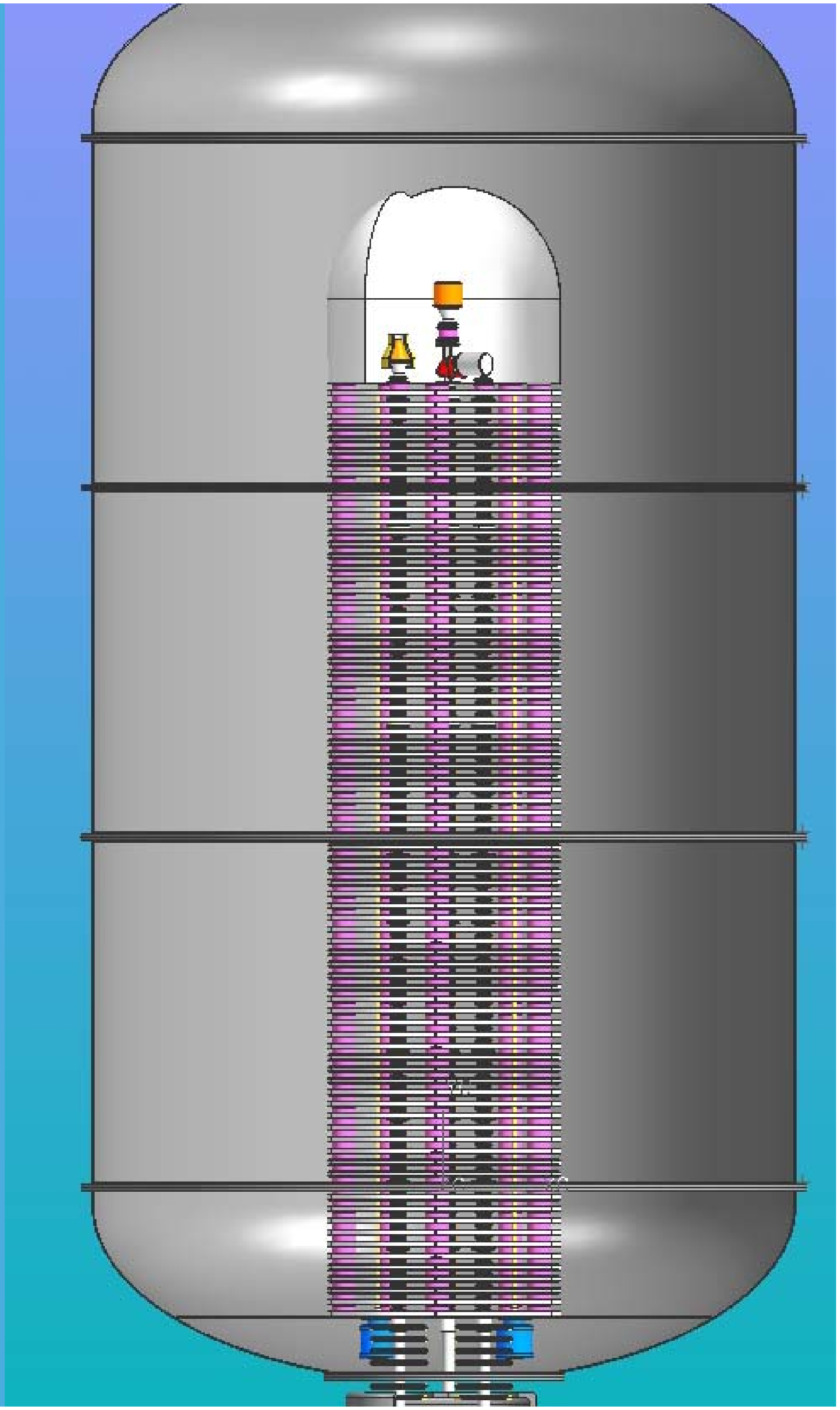
-Bending of the electron beam is realized with help of the electrostatic fields. In this case the high recuperation efficiency (10^{-6} or better) can be obtain.

Layout of the high voltage cooler for HESR (8 MeV)



1 – high voltage tank; 2 – electrostatic column; 3 – cyclotron for charging of the head of electrostatic column; 4 – cooling section; 5 – reversal track.

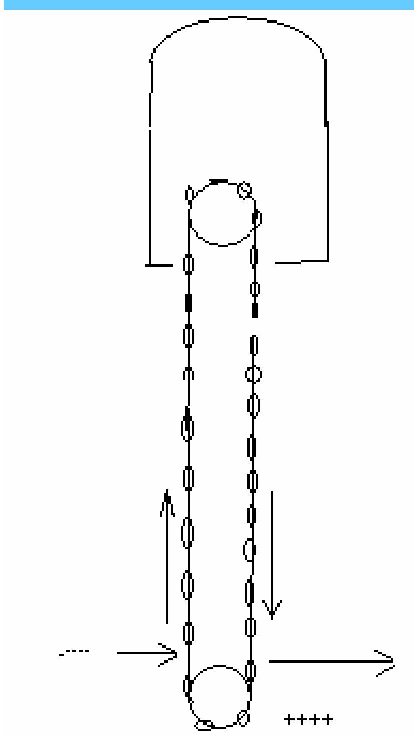
- length of electrostatic column 8 m (10 kV/cm)
- modular structure of the electrostatic column (80 sections)
- magnetic field in the acceleration tubes (500 G)
- power supply per section ~ 200 W
- magnetic field on the cathode 300 – 1000 G
- charging system is cyclotron at an energy 10 MeV H^- ions
- precise control of the high voltage is the energy analyze of the H^- ions generated in the column head

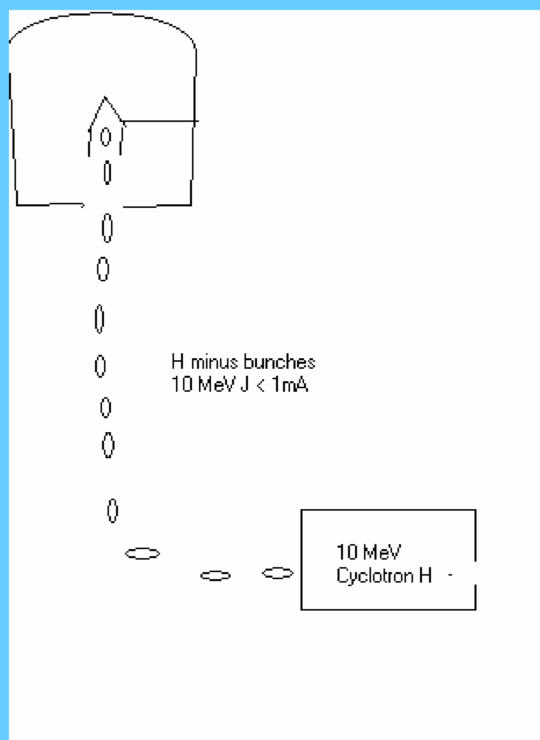


Merits of cyclotron charge system

- no mechanics
- safety at spark
- low ripple

	Pelletron	CYCLOTRON
Velocity of charge	10 m/s	4×10^{7} m/s
AC frequency charging	200 Hz	20 MHz
Charge (pellet/bunch)	500 nC	0.005 nC
Ripple for 100 mkA	800 V	0.008 V
C=100 pF $\Delta U/U$	10^{-4}	10^{-9}





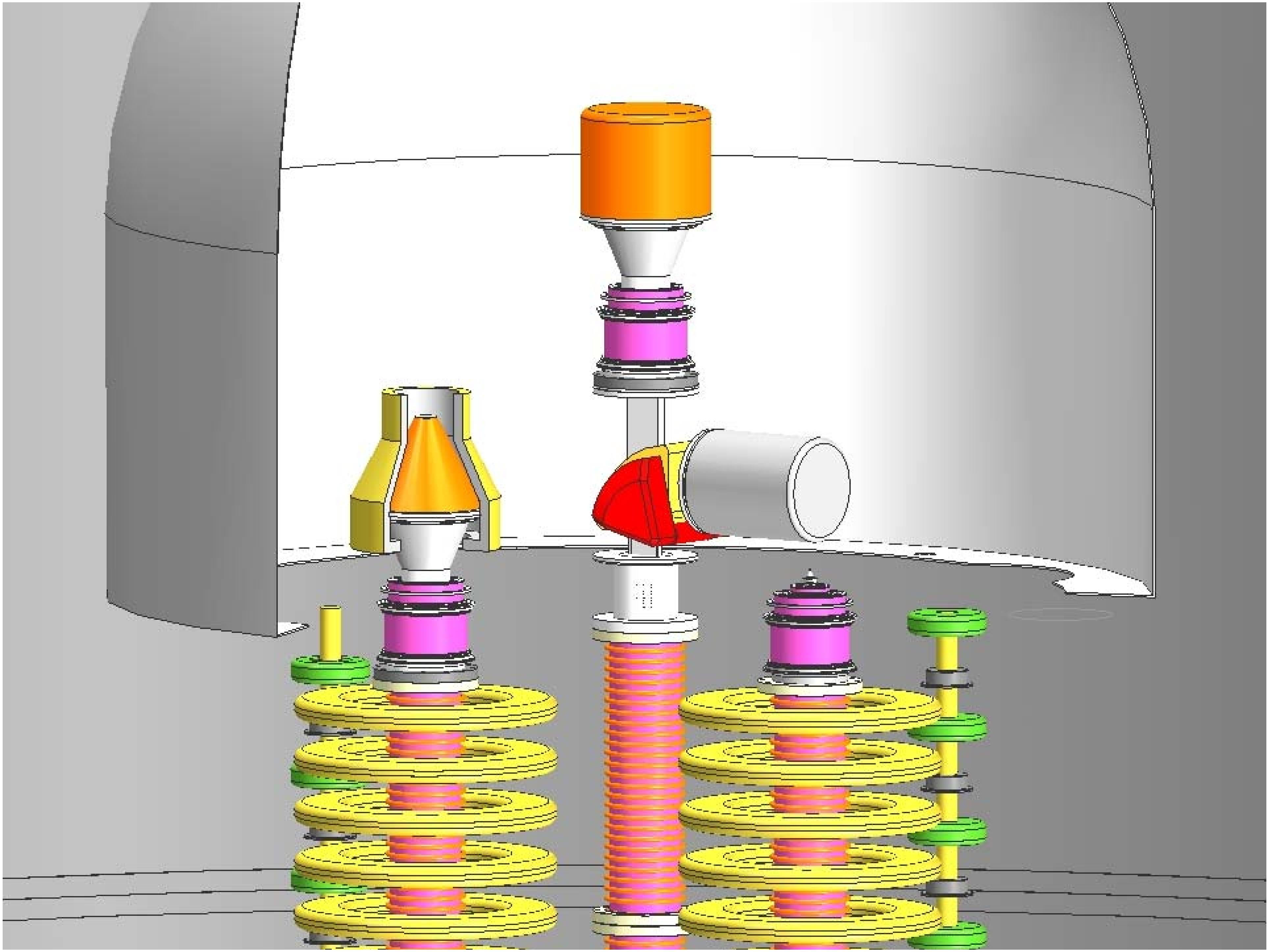
Variants

a) mechanical charging device like PELETRON or Van De Graff

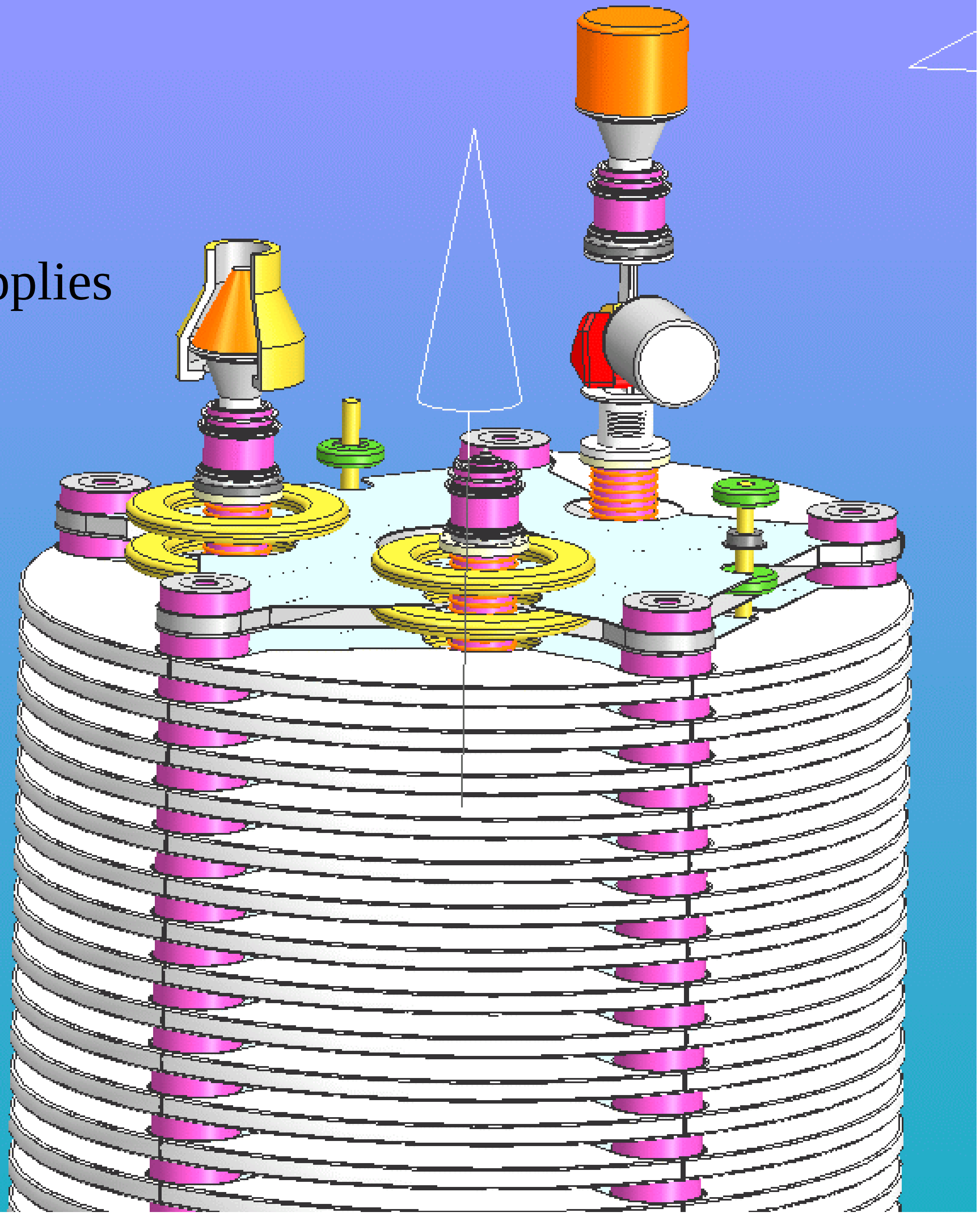
b) cyclotron at an energy 10 MeV H^{-} ions

c) electron linac

d) series of independent charging device in the each section

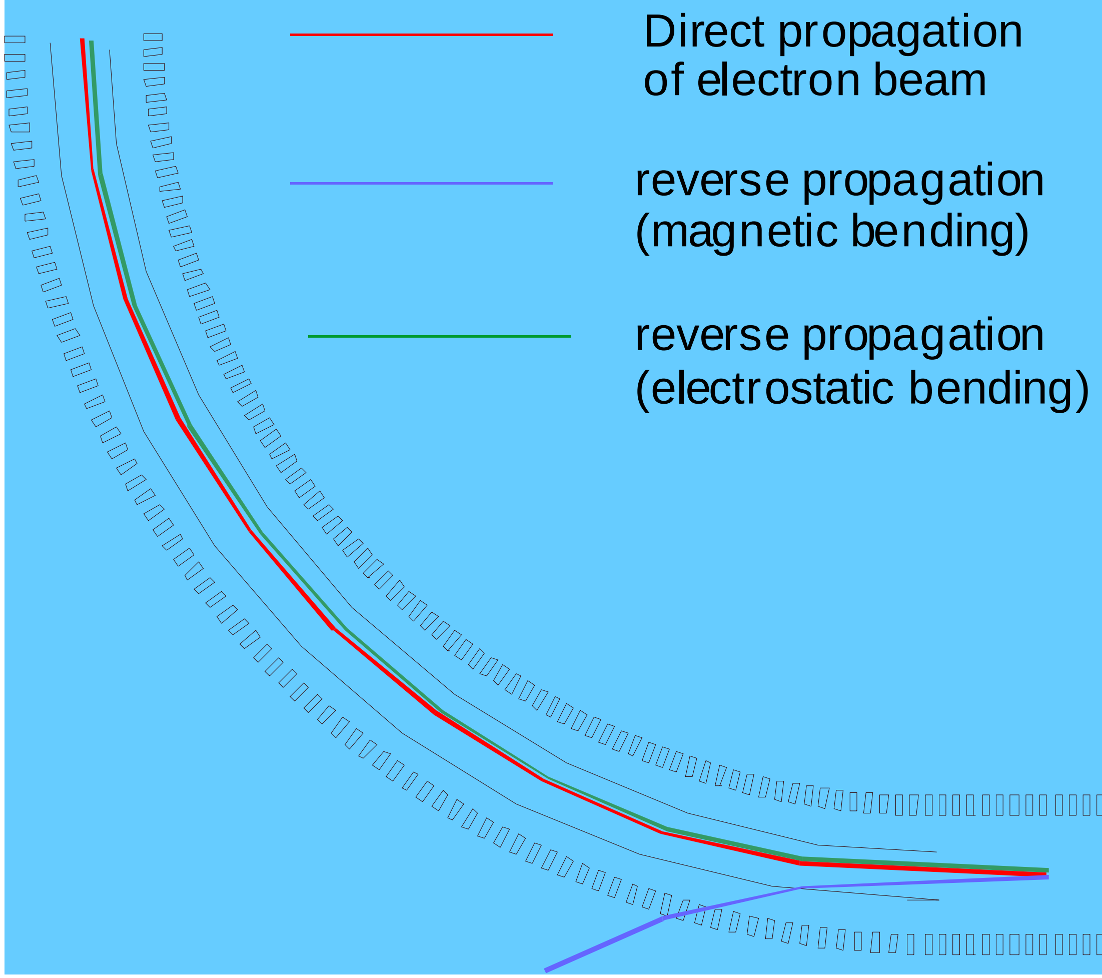


motor-generators,
auxiliary power supplies,
control electronics
two solenoids with power supplies



Toroid section

1 – reversibility of electron motion dynamic at electrostatic bending. The recuperation efficiency is about 10^{-6}. The low loss current improves the vacuum condition, the radiation condition and makes the easy design of the power supply system.

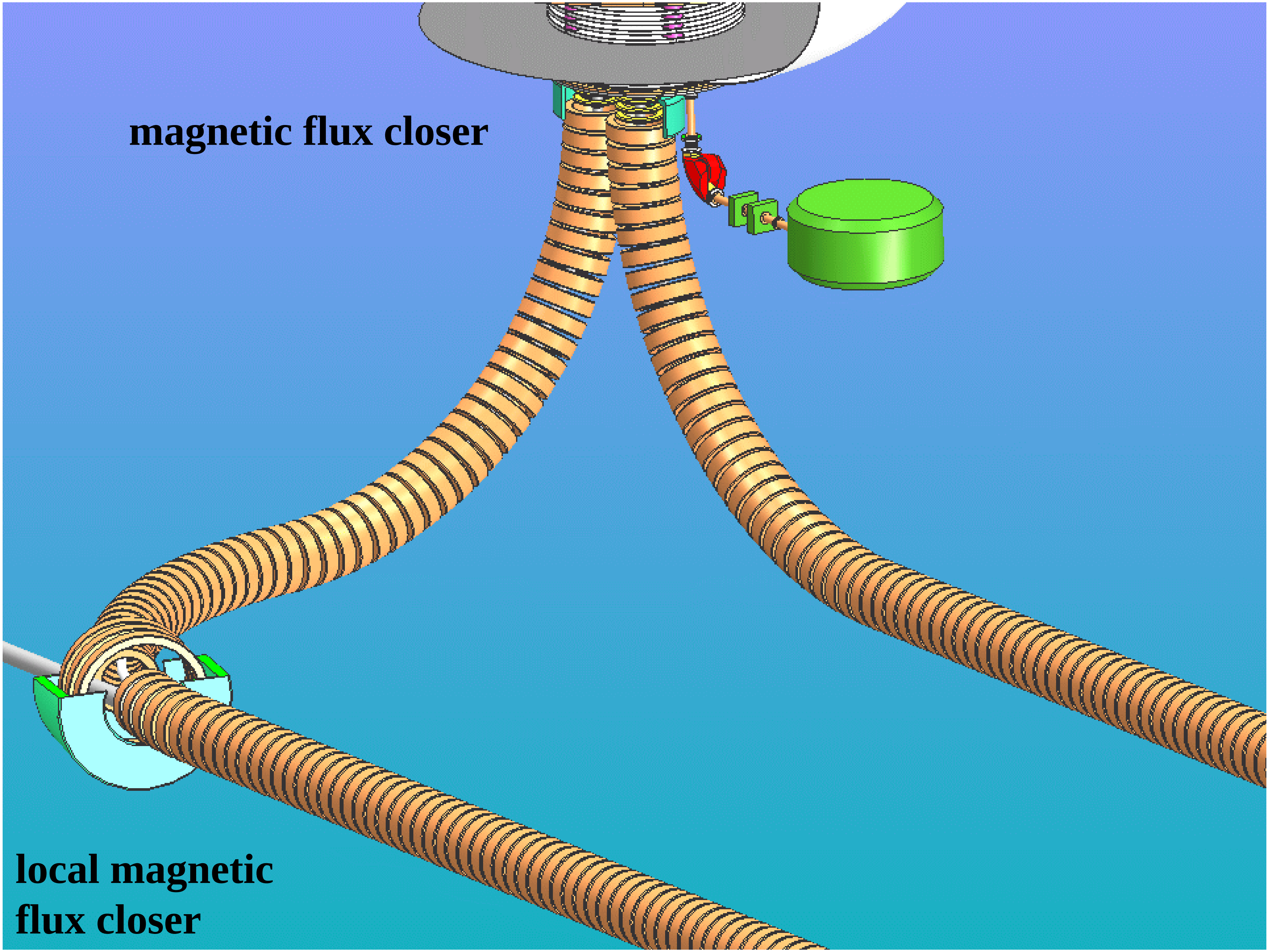


2 – bending radius is 4 m, the electrostatic field is 21 kV/cm;

3 – magnetic field in the toroid section is equal to the magnetic field in the cooling section;

a) small size of the electron beam in bending;

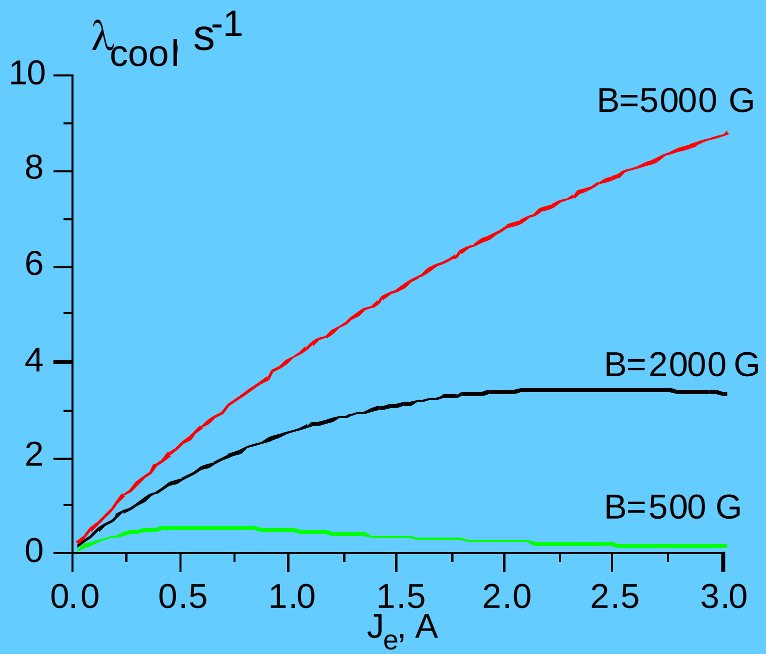
b) magnetic flux closing;

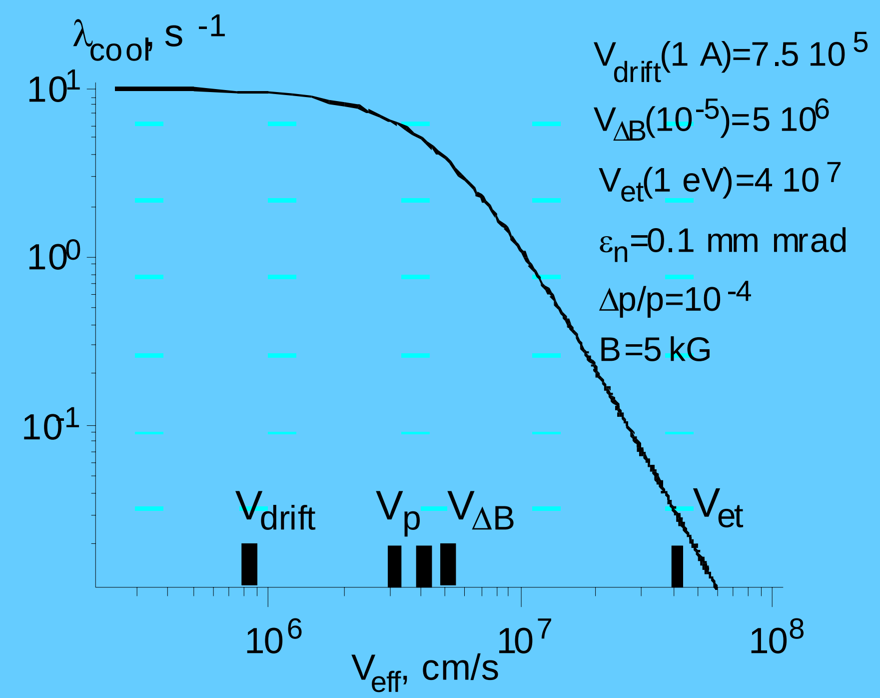

magnetic flux closer
local magnetic
flux closer

Cooling section

Key point is the value of the magnetic field

- **-- at magnetic field on the cathode and cooling section 300 G and 5 kG --- the density gain is 17**
- **-- magnetized cooling (the negligible role of the transverse electron velocity)**

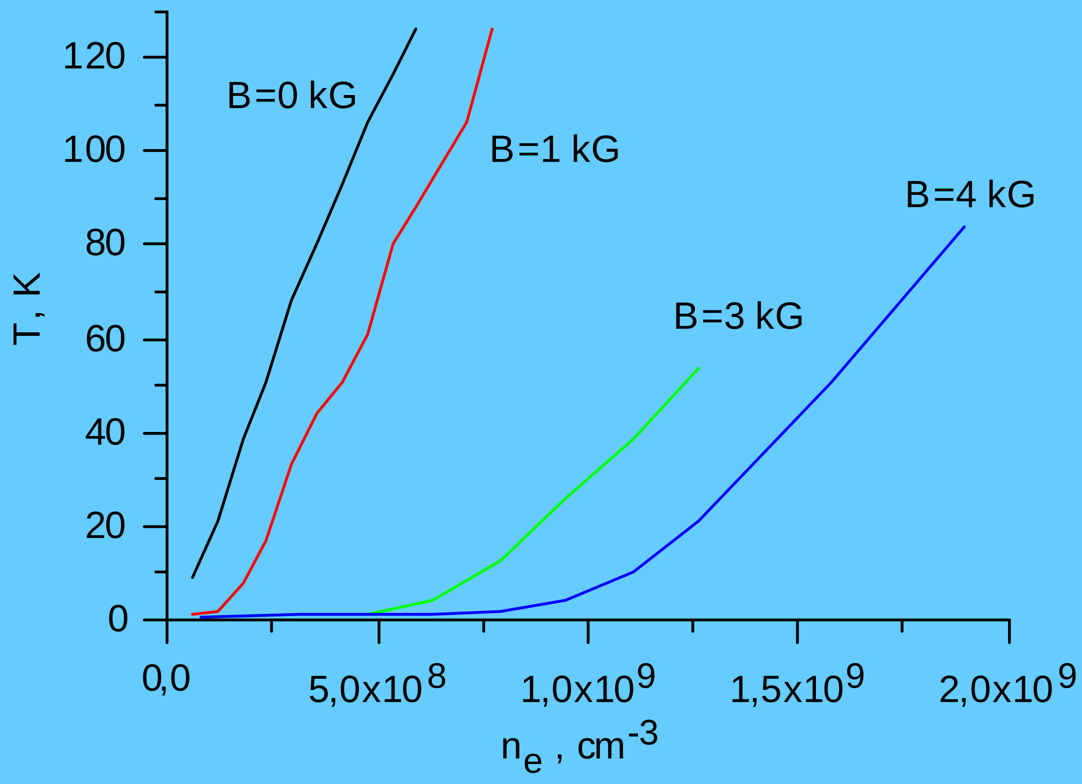




ε_n=0.1 mm·mrad, $\delta p/p=10^{-4}$, a_e=0.1 cm
$\Delta B/B=10^{-5}$, l_{cool}=30 m, E_e= 8 MeV

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

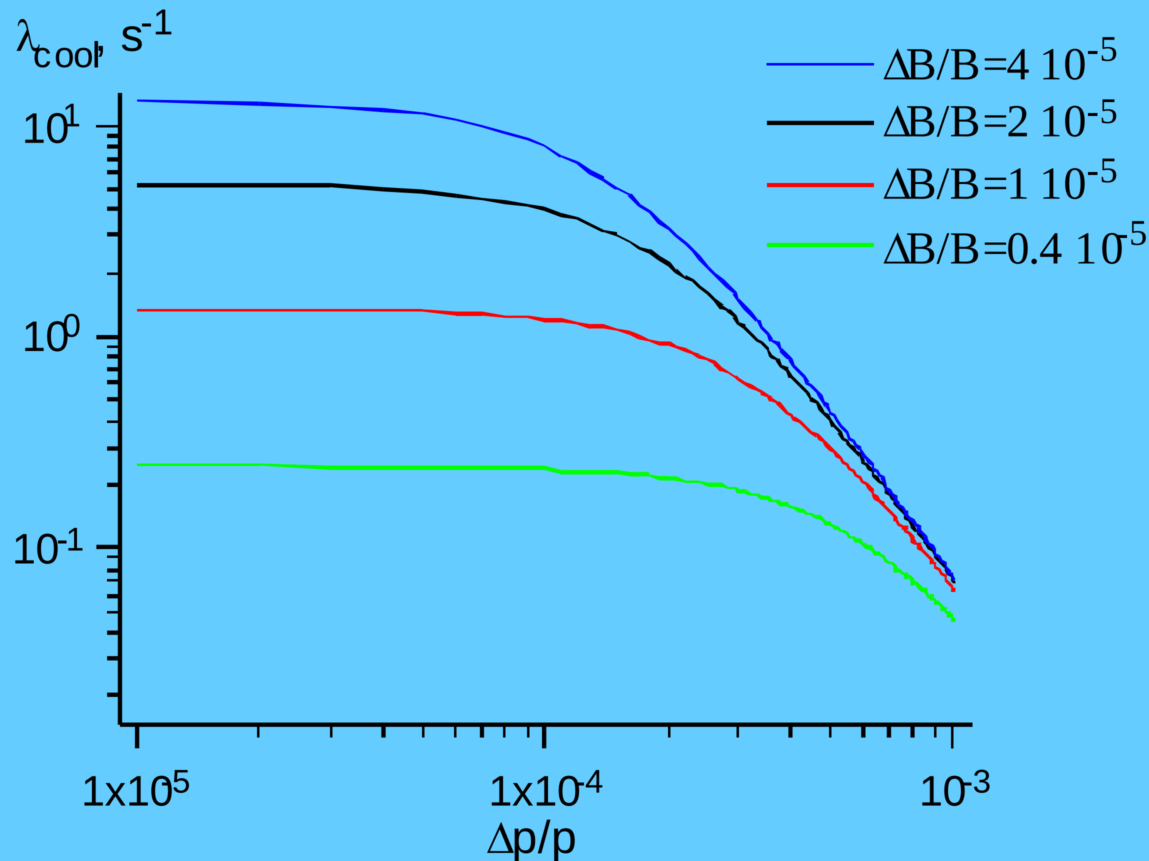
high cooling rate => high electron density => strong Tushek effect



Temperature of the electrons versus electron density and magnetic field.

Another harmful effect caused by IBS is the single Tushek effect. There exists a certain probability of an electron scattering at a large angle and of the velocity transfers from the transverse motion to the longitudinal one. If the electron gains a velocity exceeding δV it cannot be absorbed in the collector. After a certain period of time it will be lost.

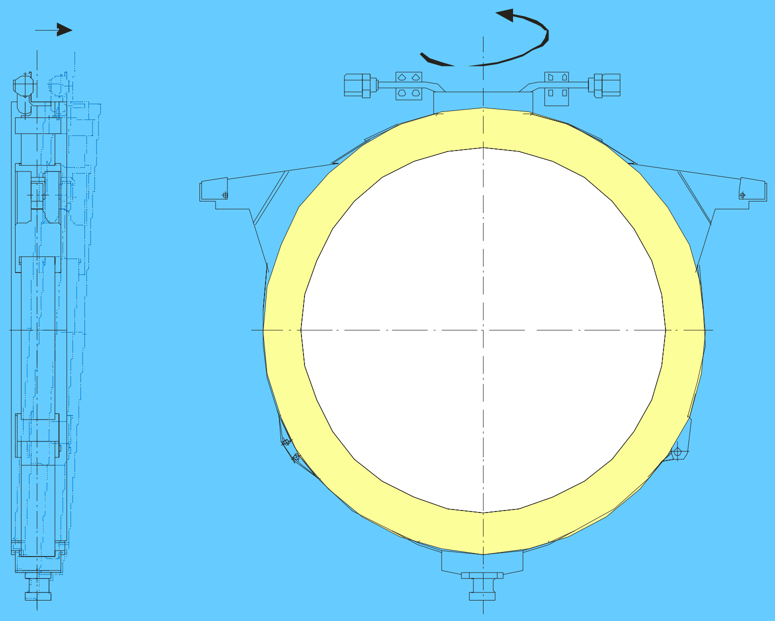
Non-parallelity of the magnetic field lines



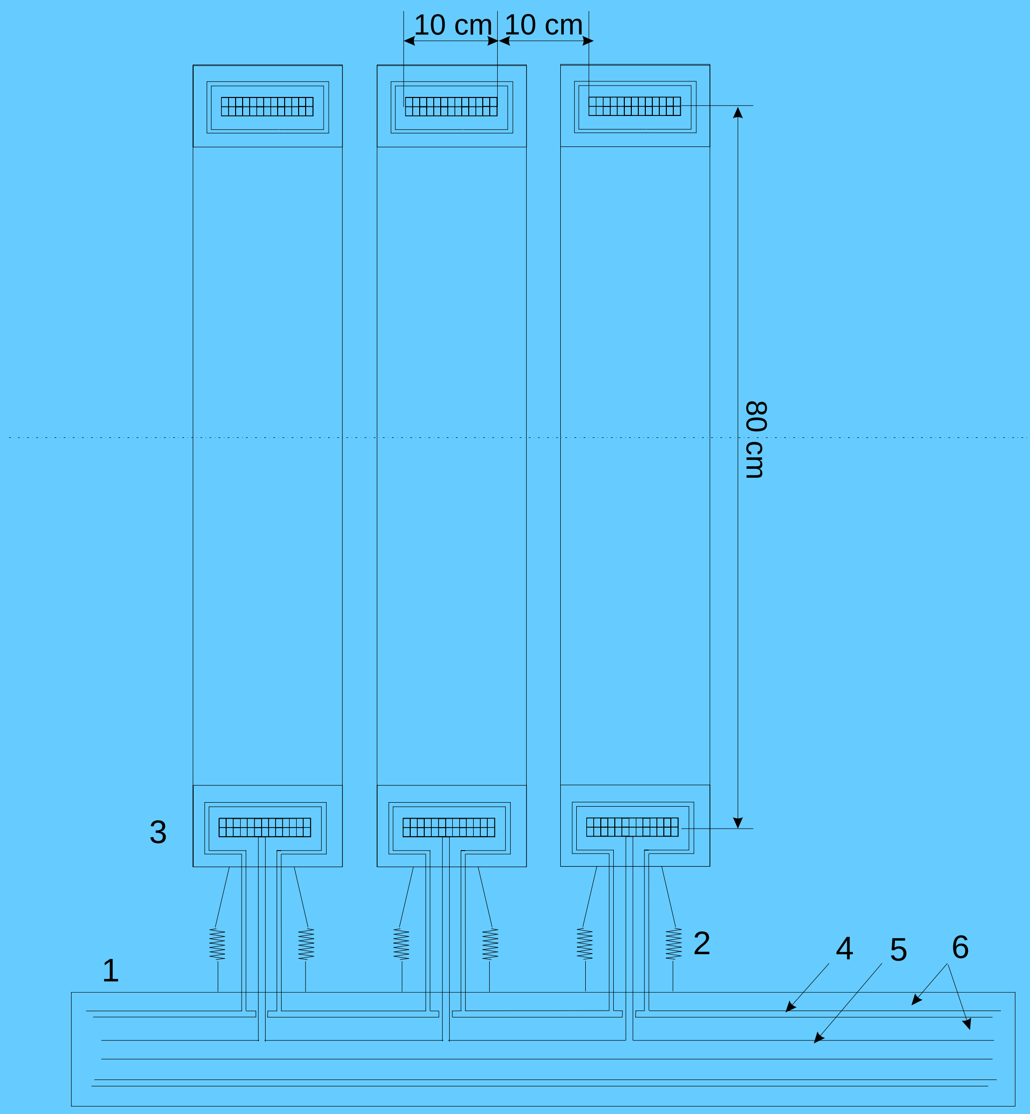
ε_n=0.1 mm·mrad,
a_e=0.1 cm
J_e=1 A
l_{cool}=30 m,
E_e= 8 MeV

Cooling rate versus the momentum spread for different values of angle spread between the magnetic field line and the device axis.

Cooling solenoid

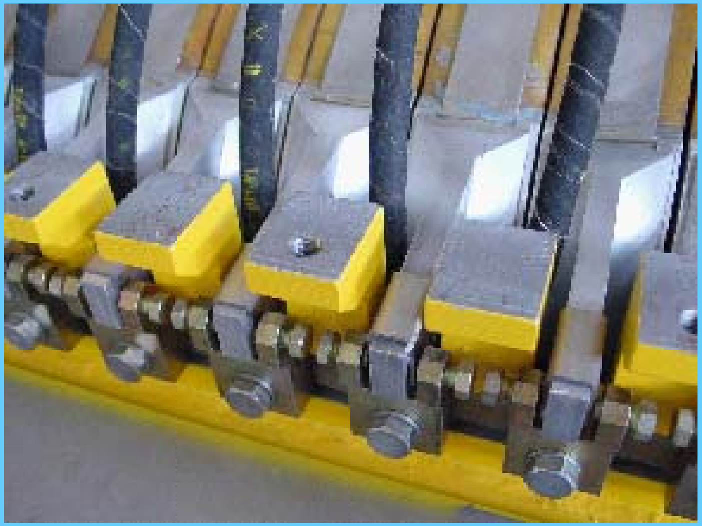


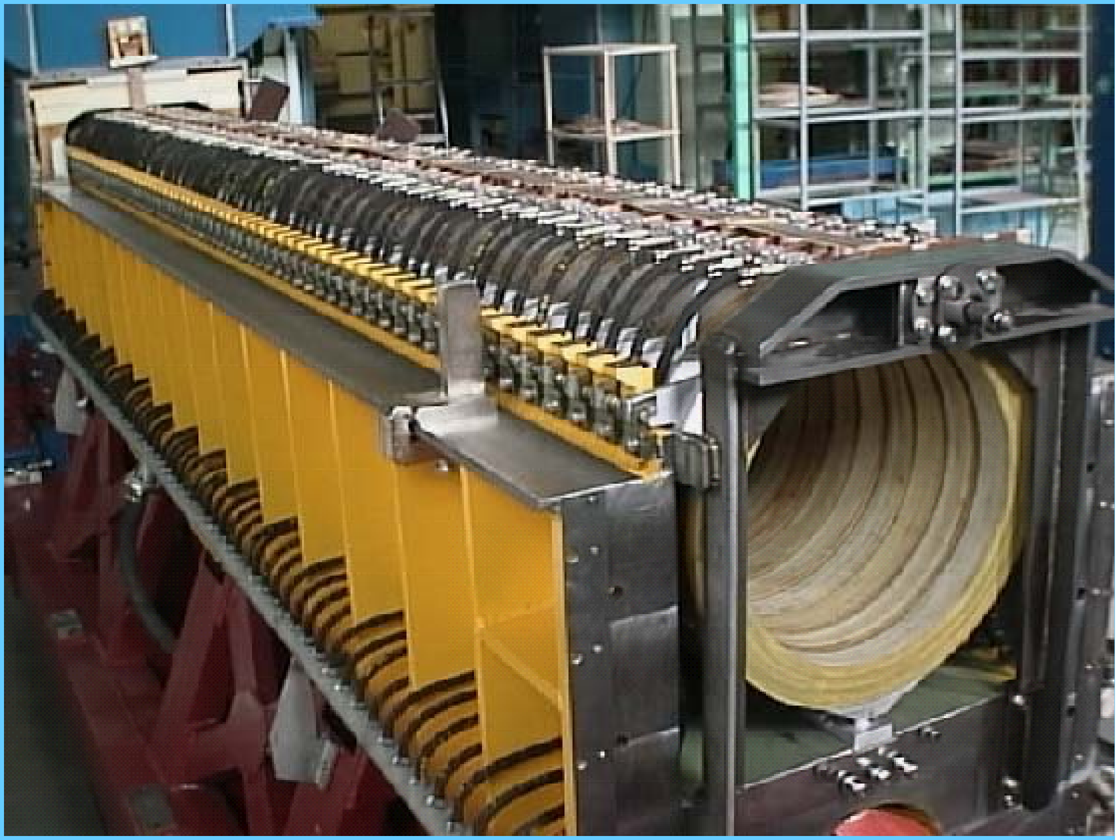
System for adjusting coils



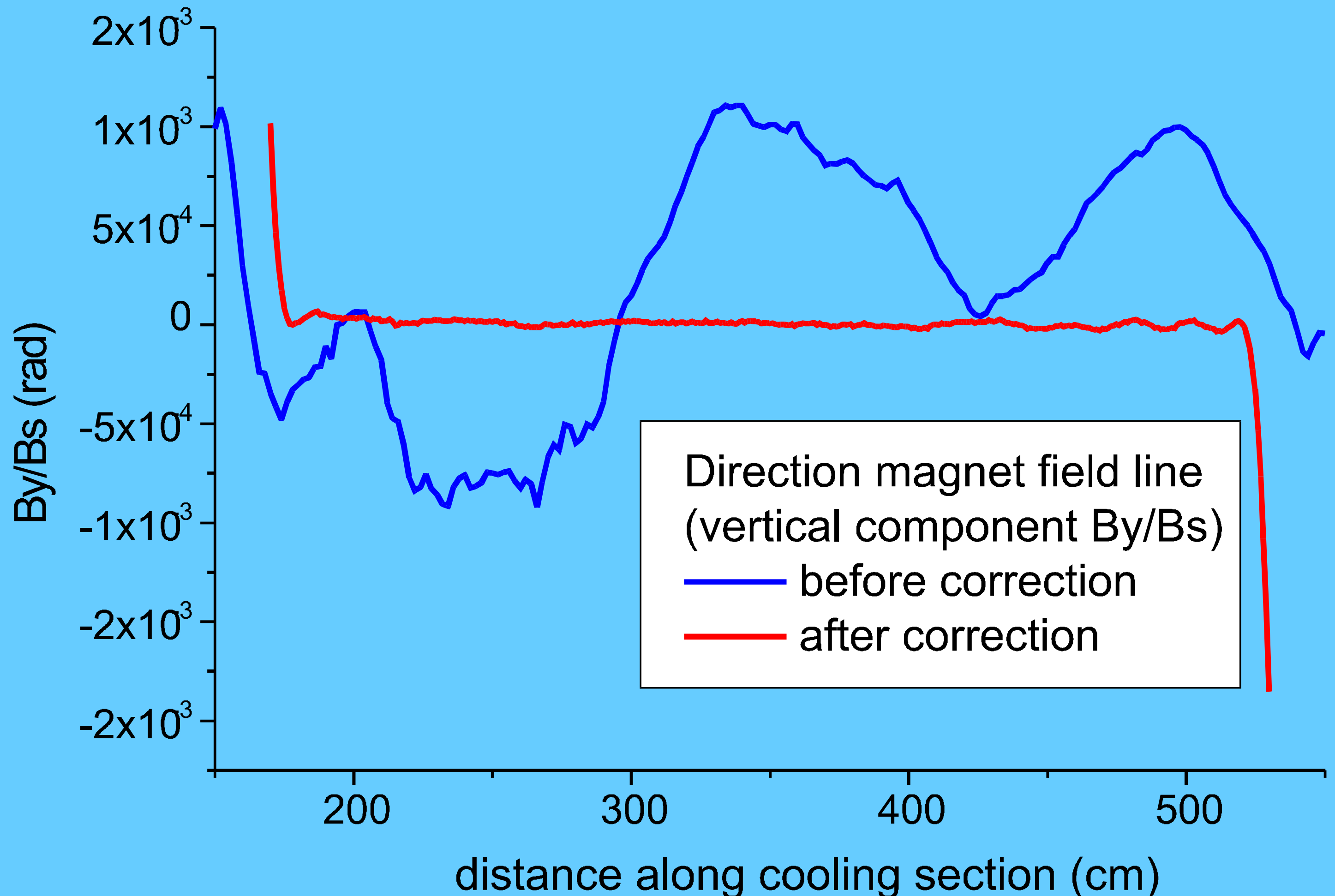
A sketch of the construction of the SC solenoid

Pan-cake solenoid in EC-300 cooler





Pan-cake correction system



A non-parallelity of the magnetic field lines of 8×10^{-6} over a length of 300 cm was obtained. Note, that the correction done by the incline of the separate coils is good for a fixed value of the magnetic field. Additional tuning may be needed after a variation of the magnetic field. This tuning is hard to be done "on-the- fly". Thus, a low-current correction coil system is desirable for additional correction of the magnetic field.

COSY 2 MeV cooler (prototype HESR cooler)

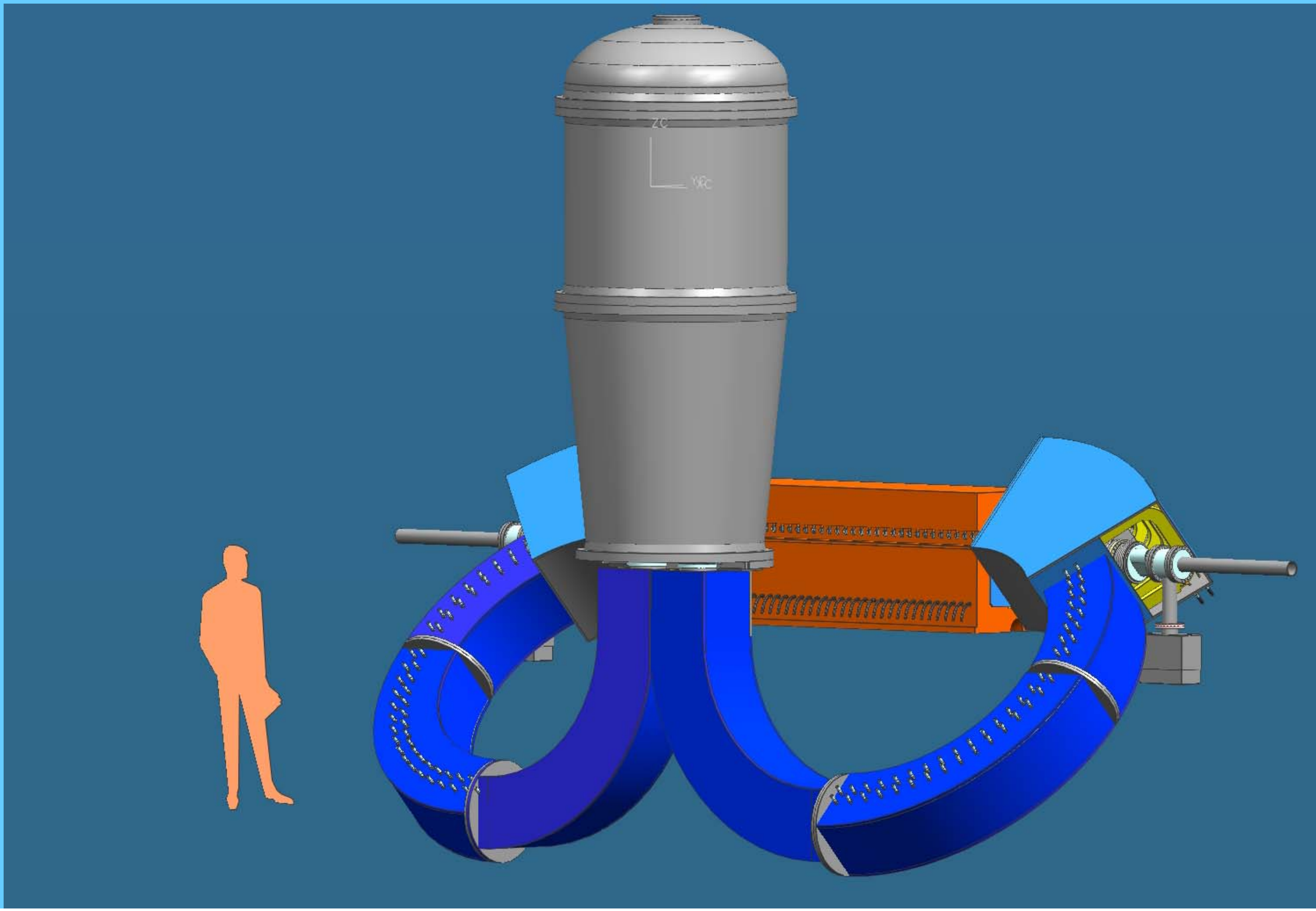
Table 1. Selection of Parameters of the COSY

Circumference of central orbit, *C*	184.0 m
Proton energy	1.0 – 2.7 GeV
Betatron function amplitudes in cooling section	13 - 15 m (h and v)
at target	2 - 3 m (h and v)
Number of stored protons	1×10^{10} to 1×10^{11}
Target thickness (H_2 jet or pellets)	1×10^{14} to 2×10^{16} atoms/cm ^{2}
Maximum luminosity	10^{32} cm^{-2} s^{-1}

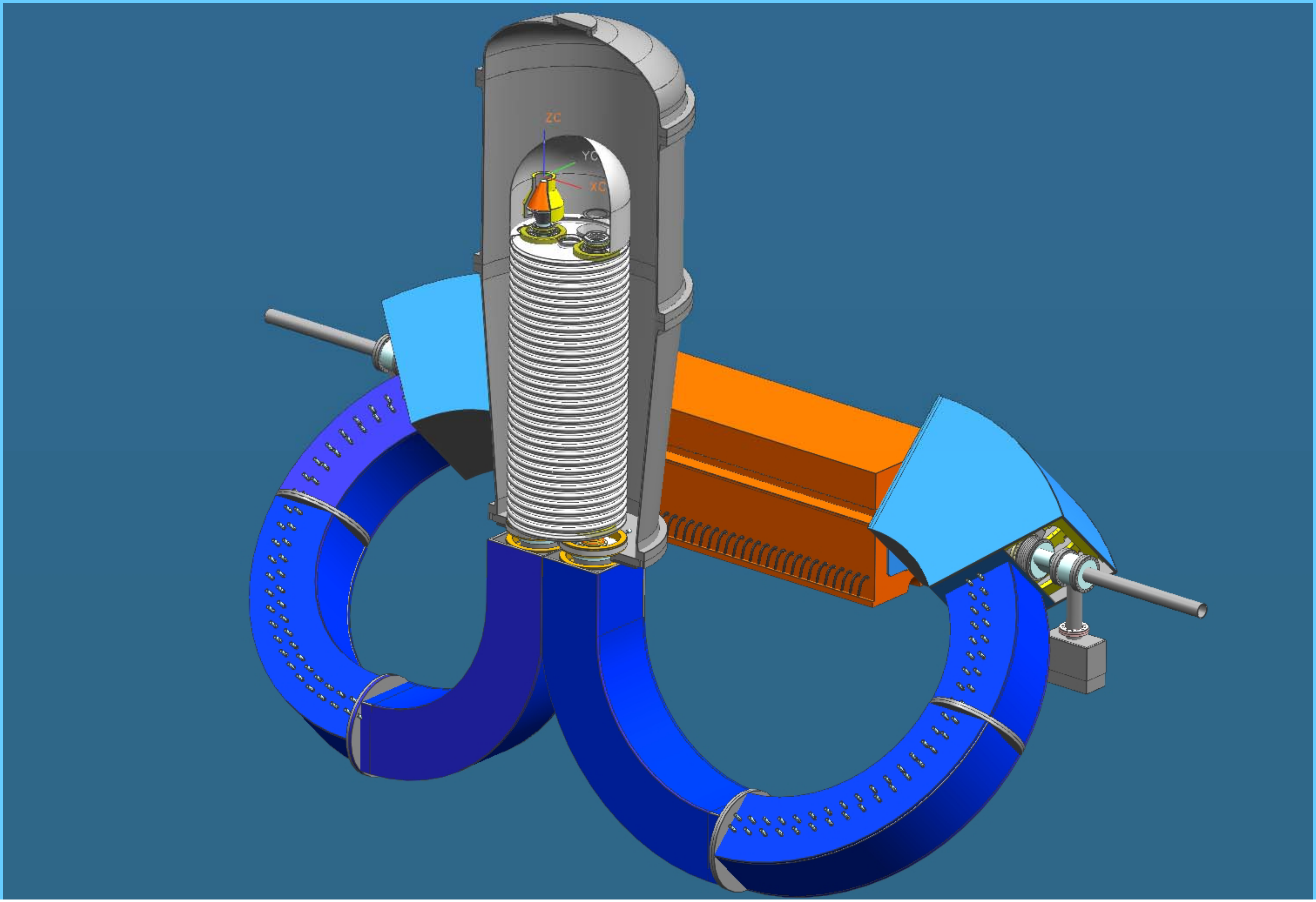
Table 2. Selection of Electron Cooler Parameters.

Energy	25 keV-2.0 MeV
Electron current	3 A
Radius of the electron beam	0.5 - 1.5 cm
Magnetic field, G	2000
Length of cooler section, cm	300

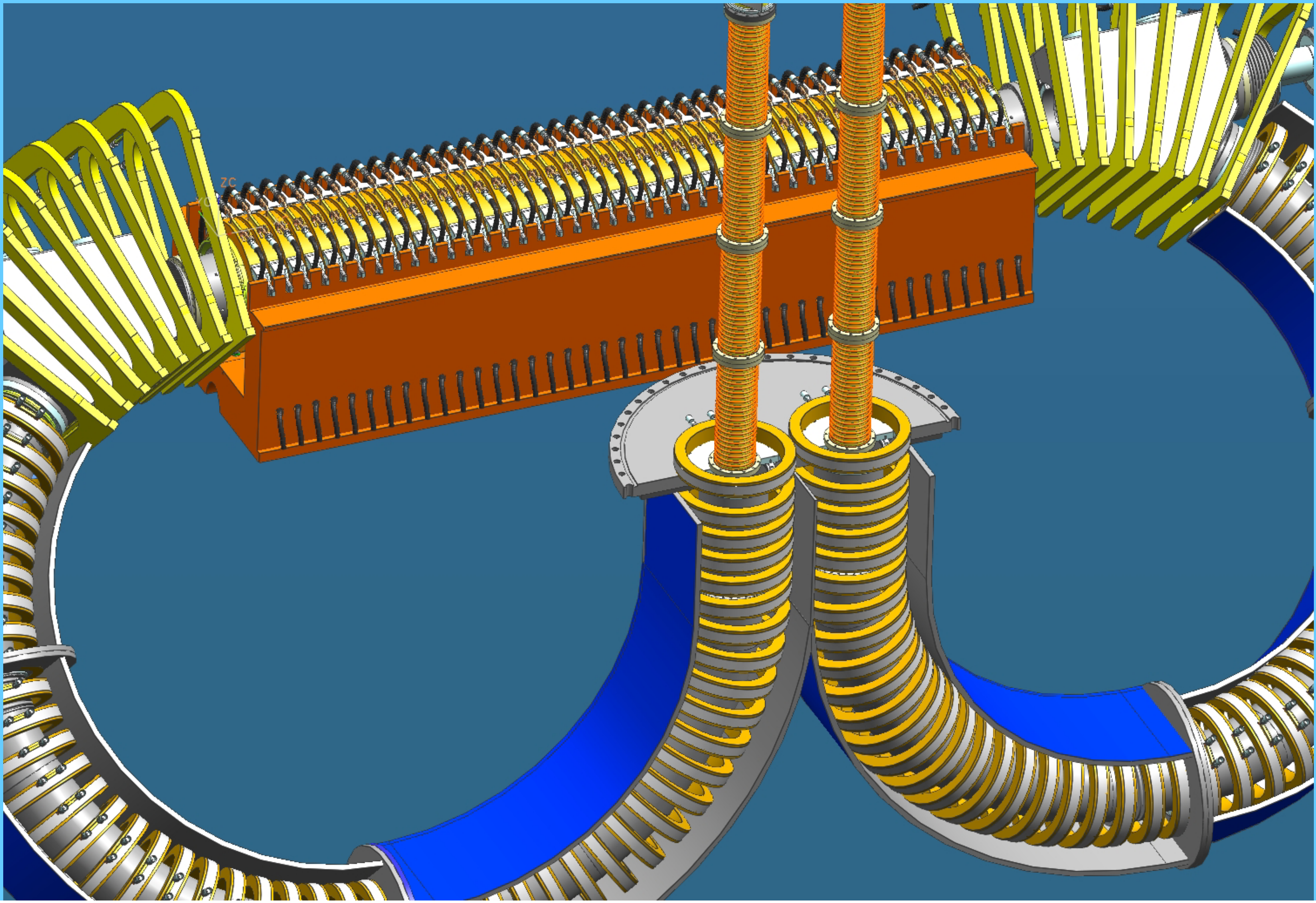
Layout of the high voltage cooler for COSY



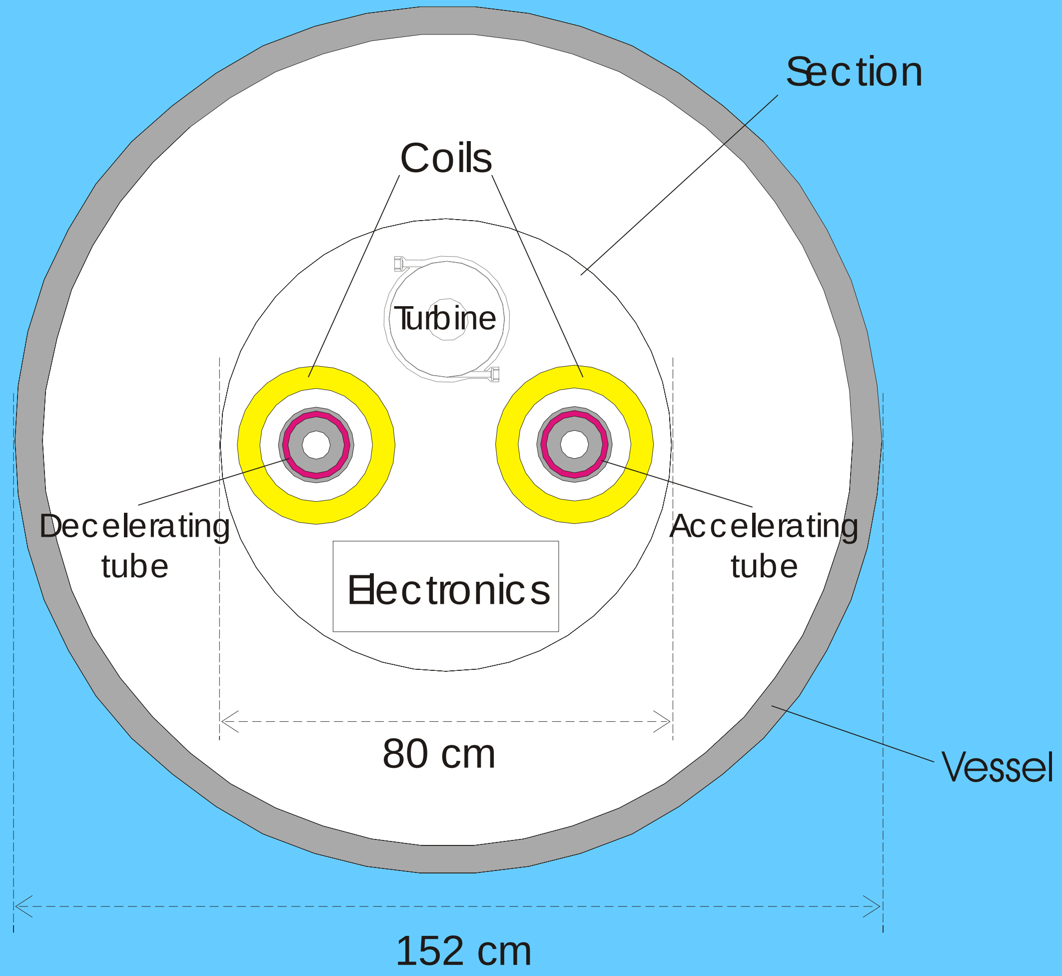
Modular structure of the accelerator (34 sections)



Magnetic systems of the cooler



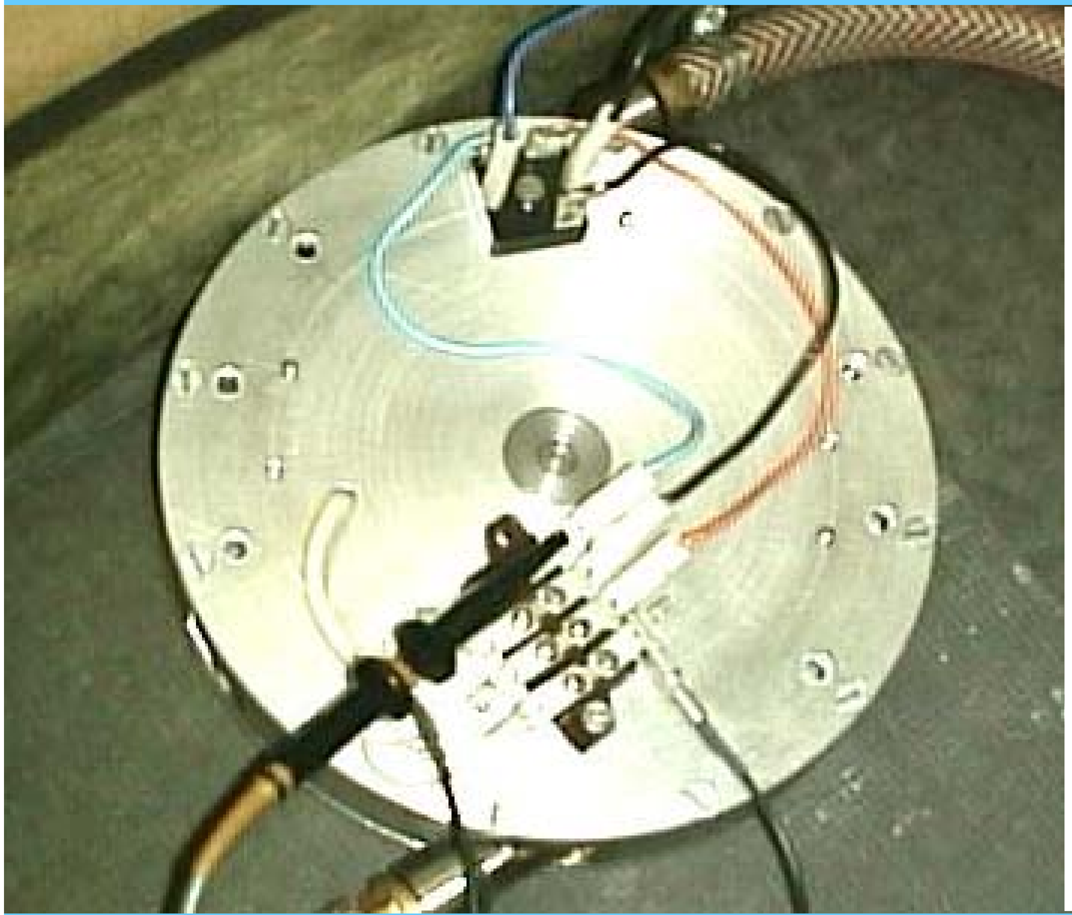
HV section of COSY cooler

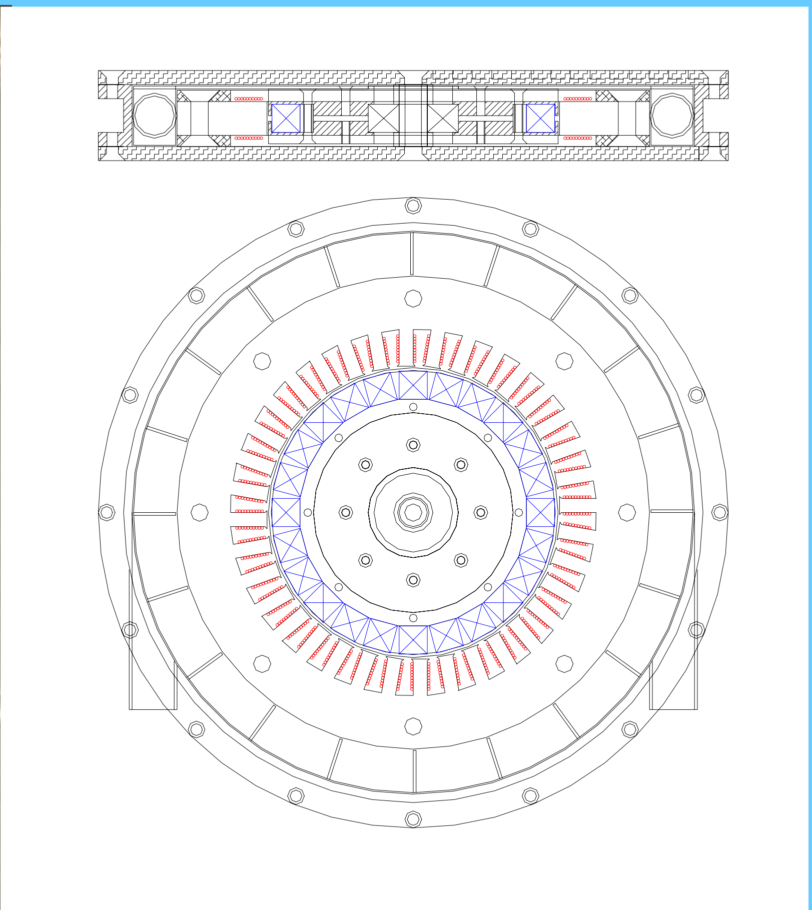


turbine power supply,
auxiliary power supplies, control electronics
two high voltage power units on 30 kV,
two solenoids with power supplies

Turbine Power Supply Net

-voltage frequency 2 kHz, voltage is up 150 V,
-prototype was tested in the power region 300 – 800 W.





CONCLUSION:

The magnetized cooling enables to obtain high cooling rate. The convenient technical decisions for the low energy coolers (up to 300 keV) can be extrapolated to the region of 2 MeV electron cooler (COSY project) or even of 8 MeV (HESR project). The projected based on the quality-checked solutions is reliable with phyics point of view. The technical problem related to this way looks solvable as it is shown in this report.

The HESR cooler project is a new step at cooling technique. COSY project may be a first step in the line of way.