# Status of the 2.5 MeV electron cooling system for NICA collider

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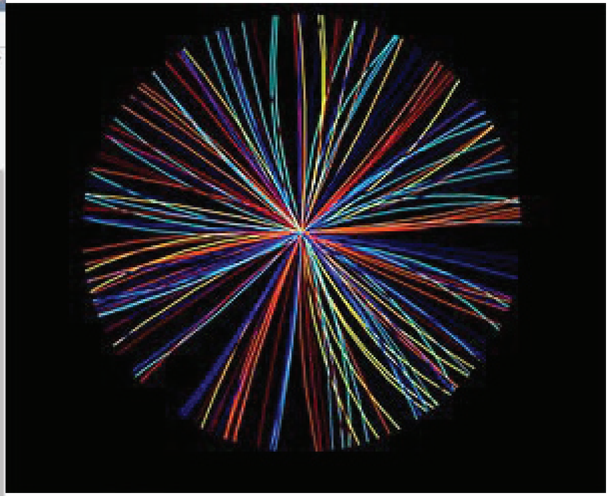
# Scientific problems

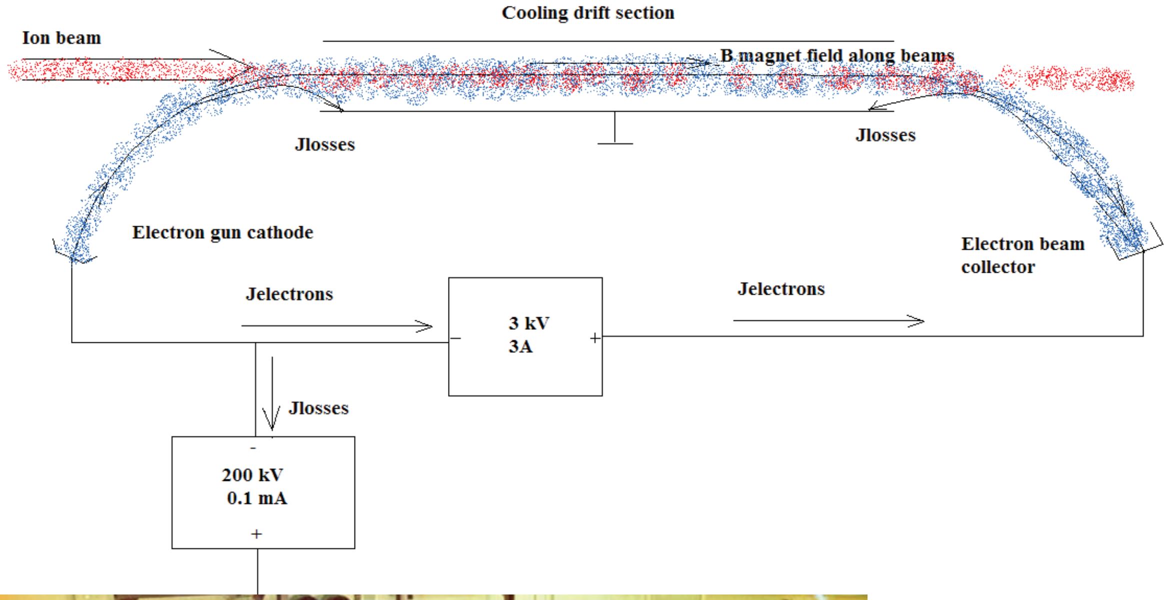
The most important fundamental problems in this area are:

- The nature and properties of strong interactions between elementary constituents of the Standard Model of particle physics – quarks and gluons
- The search for signs of the phase transition between hadronic matter and QGP; search for new phases of baryonic matter
- Study of basic properties of the strong interaction vacuum and QCD symmetries

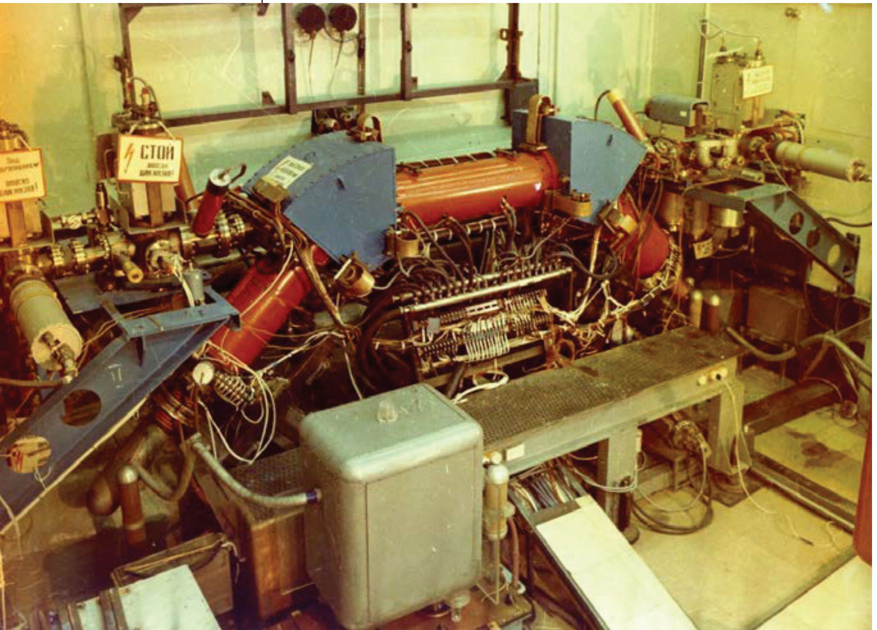
CERN physicists collider heavy ions to free quarks - recreating conditions that existed in the universe just after the Big Bang

# Electron cooling base on temperature exchange at gas of the hot ions beam and the cold electrons beam




Electron cooling was proposed 52 years ago G.I. Budker at 1966 in BINP. As it is generally known, the first estimation of the electron cooling was made with the plasma model of the temperature relaxation and the first experimental results confirmed this fact.

But after upgrading cooler experiments with cooling proton beam at BINP show that the longitudinal temperature (beam reference) very low. The theoretical and experiments show that longitudinal magnet field increase the cooling force at many order magnitude by the extremely low effective electrons temperature close to few degree of Kelvin.




## The first cooler in world on storage ring NAP-M orbit

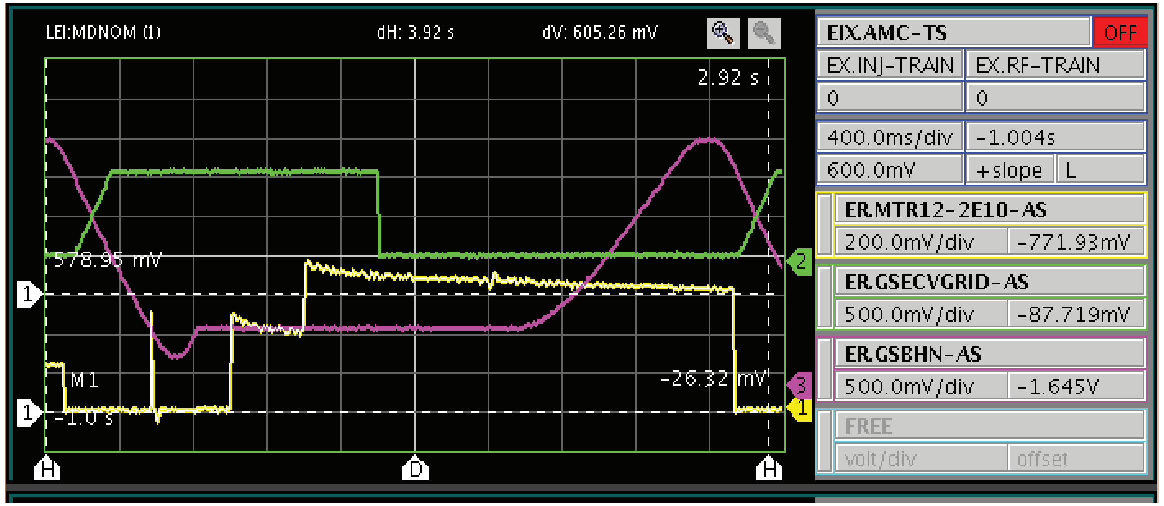
The ions beam $^{197}Ag^{31+}$ accelerate at Heavy Ion Linac to energy 6.2 MeV/n and then injected at the booster ring equipment the electron cooling system with voltage 3.3 kV. Task for cooler shrink the ion beam emittance and prepare the ion bunch parameters for acceleration and injection in NICA collider.

April 2017 delivery cooler from BINP to JINR
Moving by crane cooler at strait section booster at hall of JINR synhrophasatron.

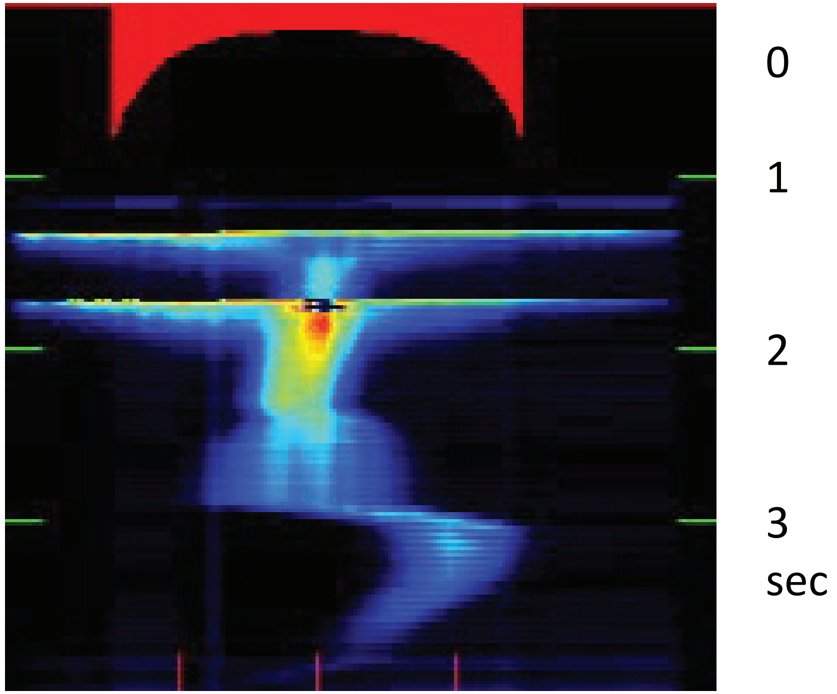
BINP will assembled at this year booster cooler and autumn cooler should be commissioning with electron beam.

The cooler at nominal position at straight section NICA booster (gap between dipole magnet of synhrophasatron)

The electron cooler at LEIR CERN (very similar to NICA booster cooler) used for two or three shoots accumulation by relatively low intensity Pb ion from Linac3. Results experiments of 2006 LEIR can used for illustration for future operation booster cooler.

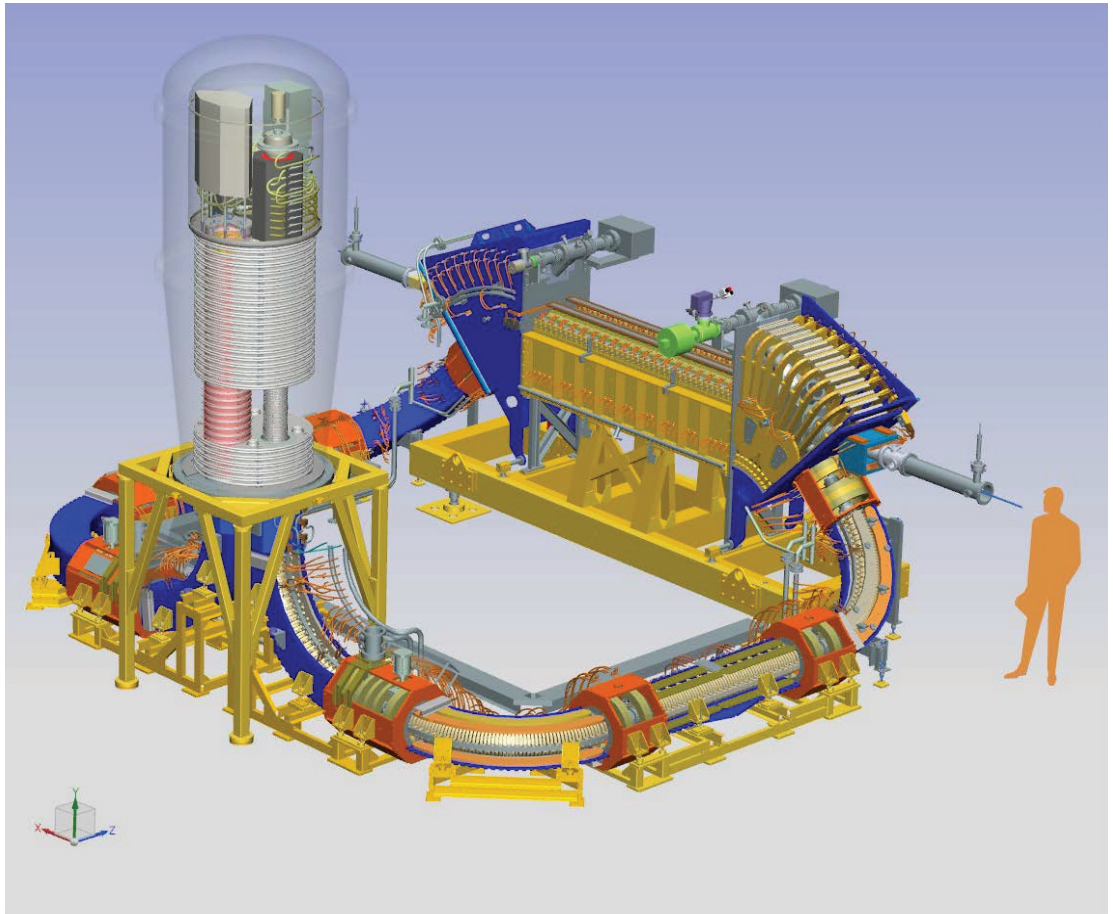


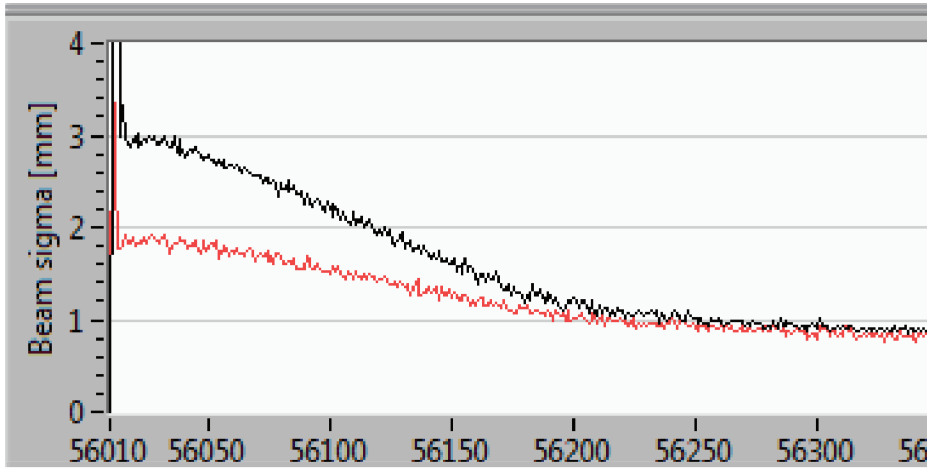

Cycle of running LEIR booster: 1-injection Pb ions current, 2-electron beam current in cooler, 3-magnet field at LEIR bend magnets.

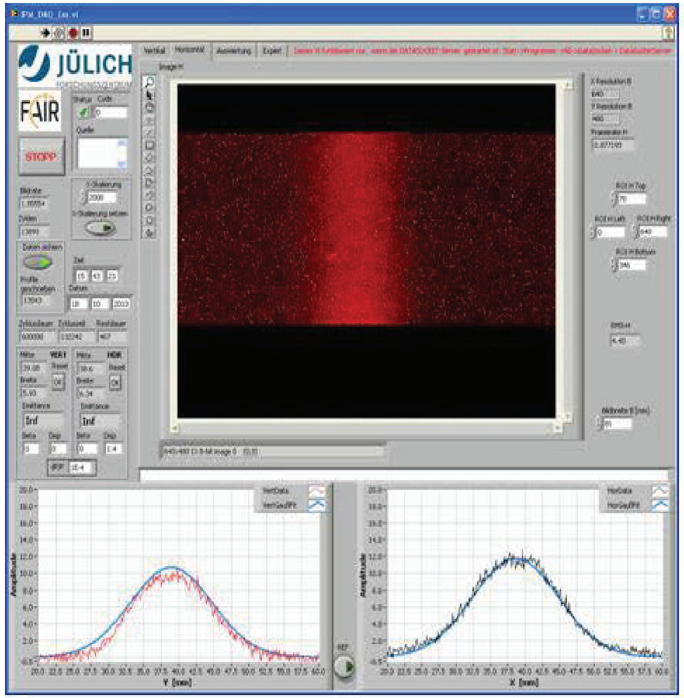



Demonstration of the profile ion beam at time of LEAR cycle. Just after injection diameter equal to 50 mm, after 0.2 s cooling diameter go to 1 mm, new injection and cooling to ion beam diameter 2 mm, then switch off electron beam (you can see as Intra Beam Scattering increased beam diameter) and then acceleration. Red color show profile of density electron beam for this experiments (with low density at center for suppressing recombination).

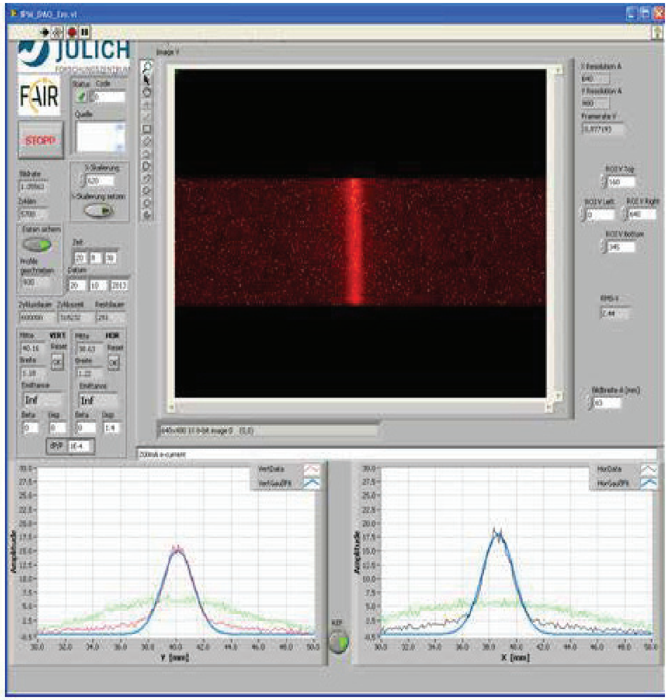
# First high voltage cooler produced at BINP was cooler for COSY that started operation at 2013



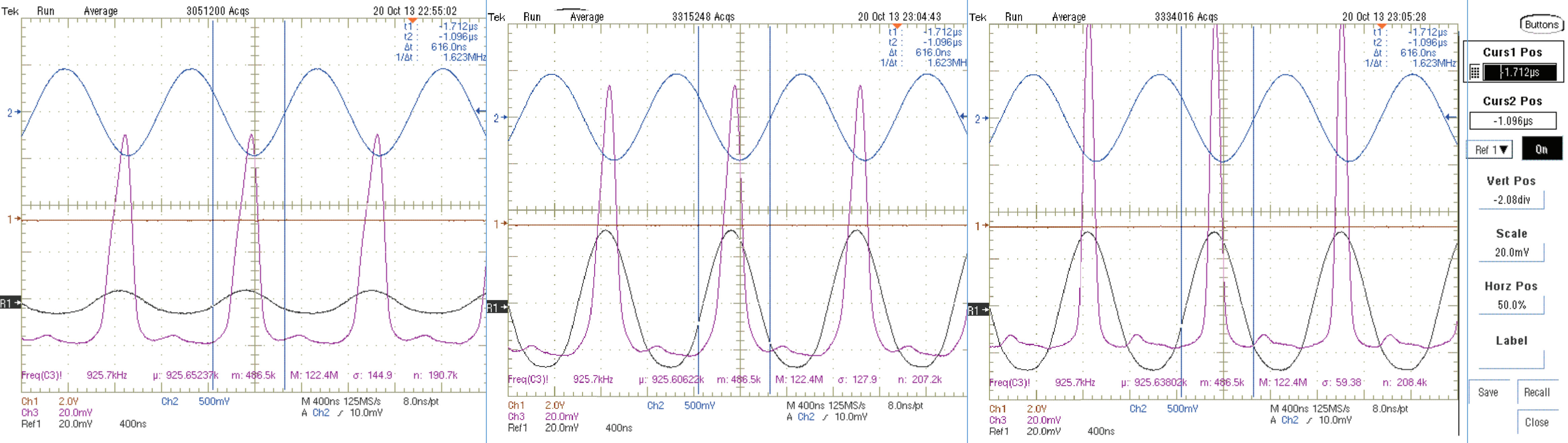



До охлаждения 200 МэВ протоны в COSY




После охлаждения




Ep=200 MeV, Je=50 mA

Ep=200 MeV, Je=100 mA

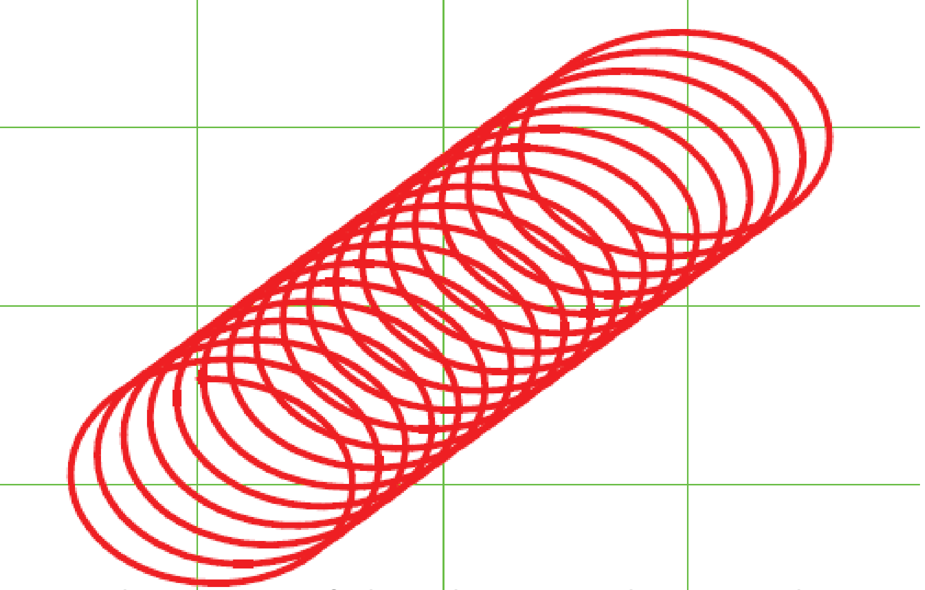
Ep=200 MeV, Je=200 mA

-------- RF voltage

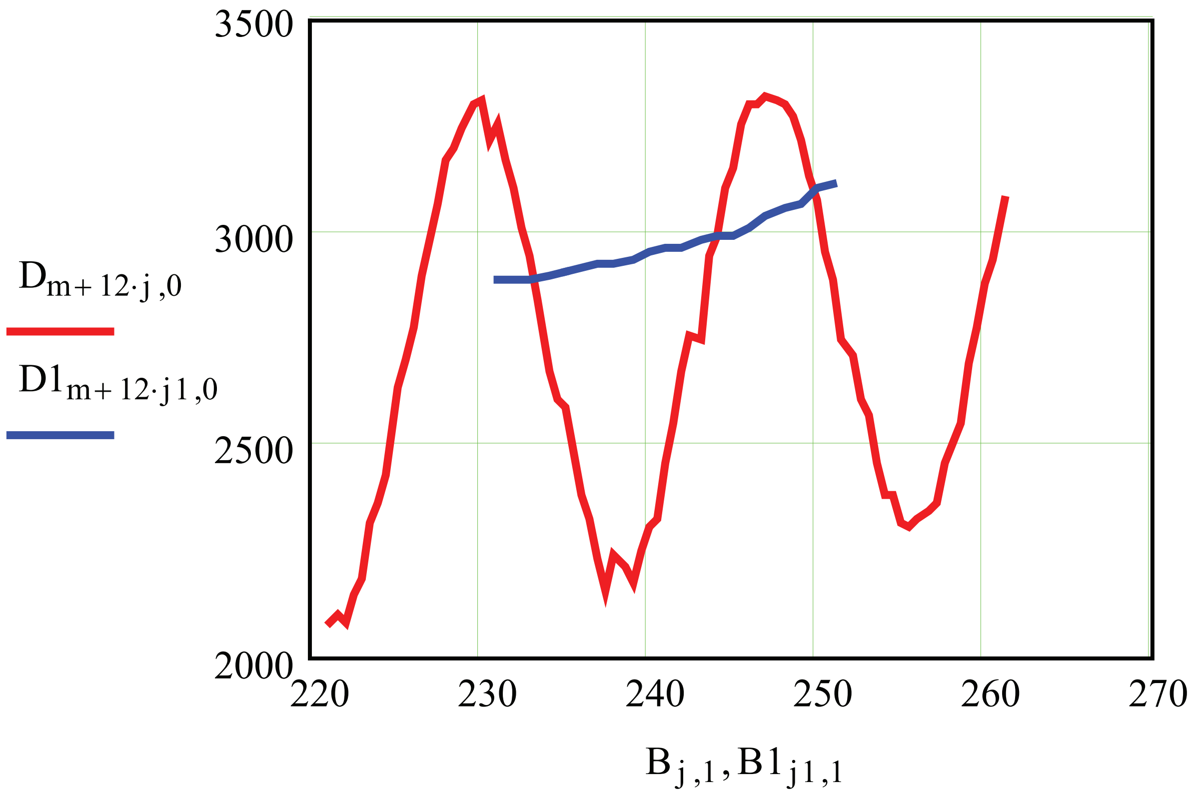
-------- Bunch profile (pick-up) after cooling

-------- Bunch profile just after acceleration

**Shrinking the ion bunch length by increasing the cooled electron current**

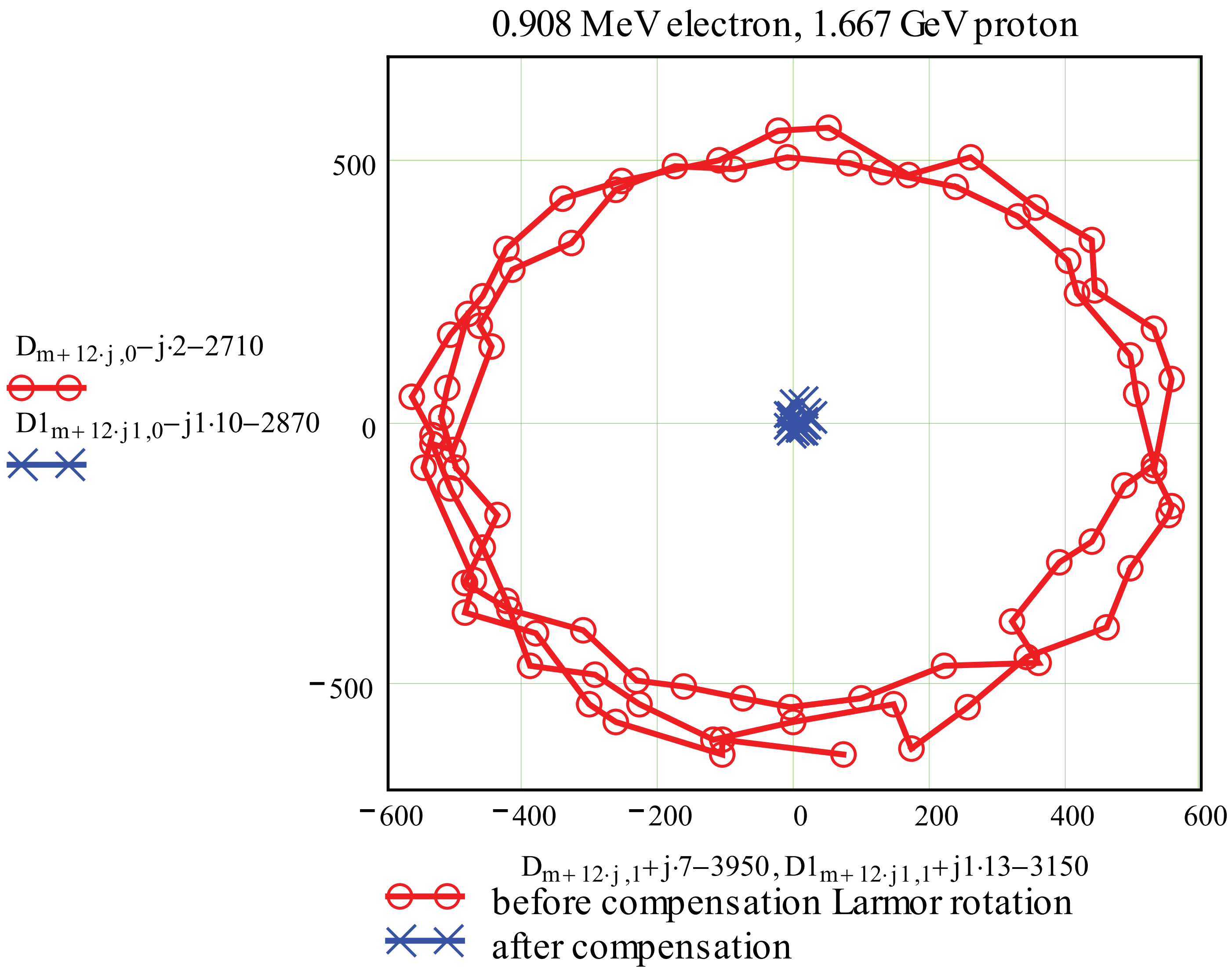


Spiral motion of the electron along cooling section




**Variation electron beam position (μm) at PM position monitor vs longitudinal magnet field (at unit current of solenoid J=220-260A, B≈1100-1145 Gauss) Before compensation Larmor radius was 0.5 mm after compensation less 10 μm. Transverse temperature for 0.5 mm 317 eV, 3*10^6 Kelvin degree**

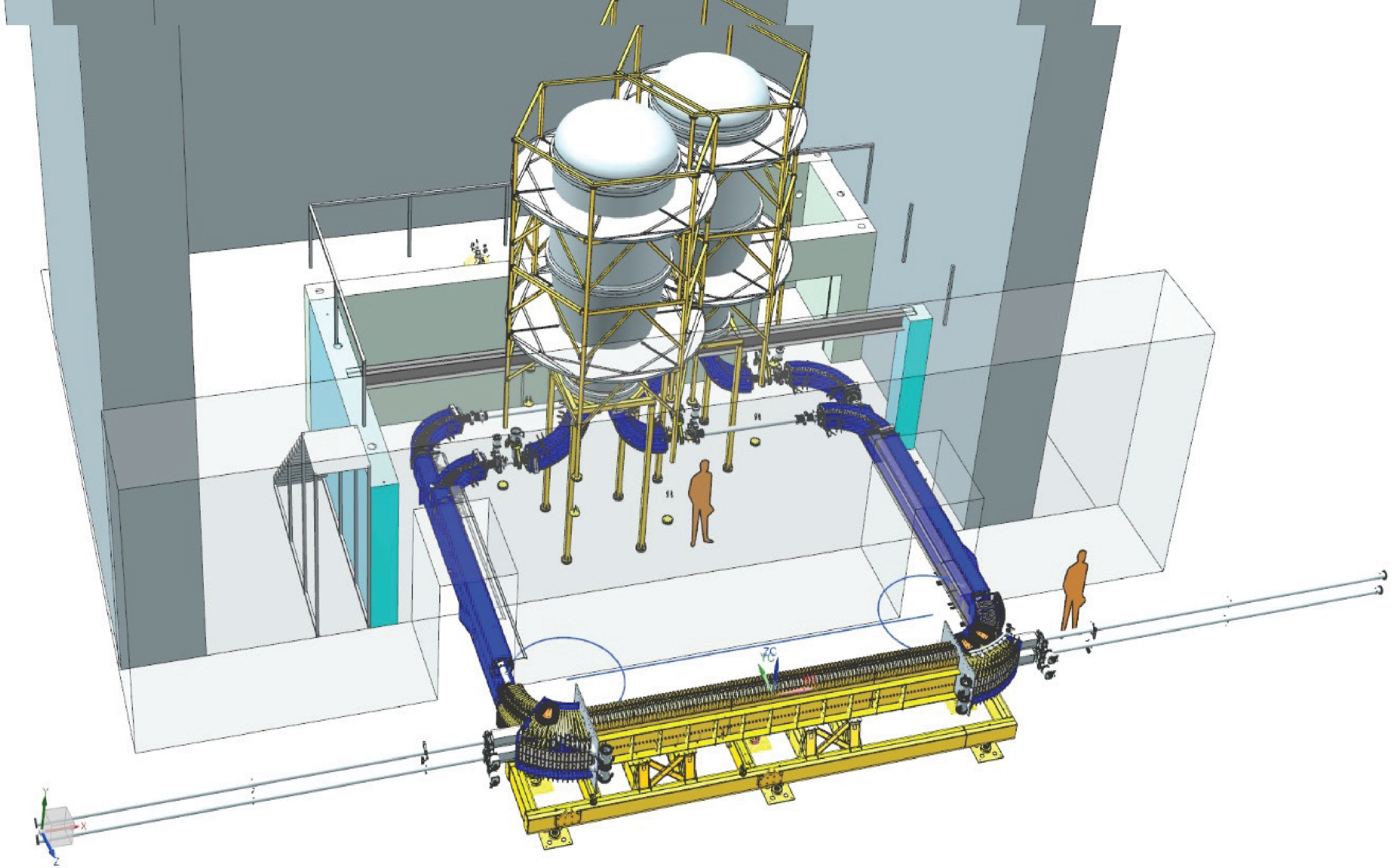
**Transverse temperature for 10 μm 0.13 eV, 1300 Kelvin degree**



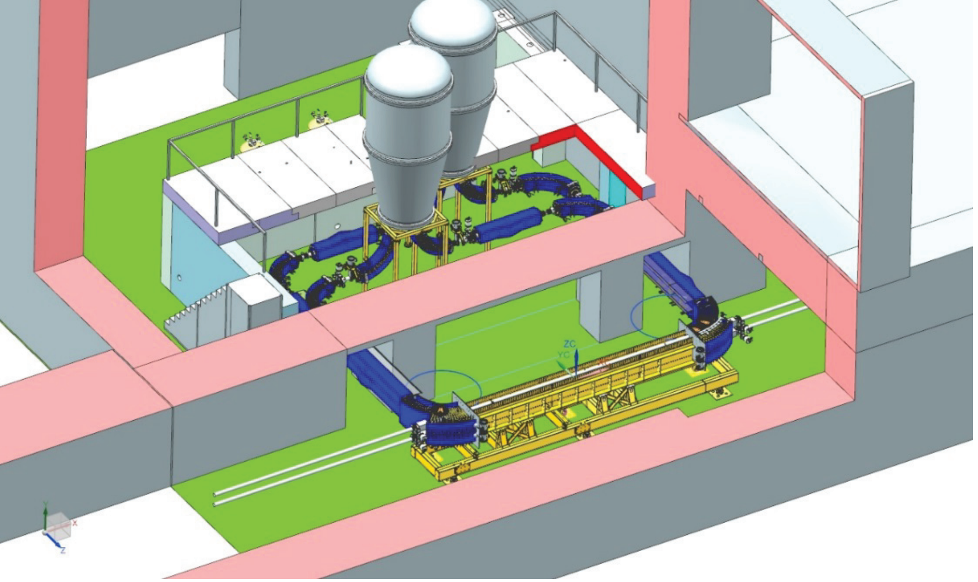

**For red line hot relectrons and no cooling**
**For blue cold electrons and good Cooling after compensations transverse motion electrons**

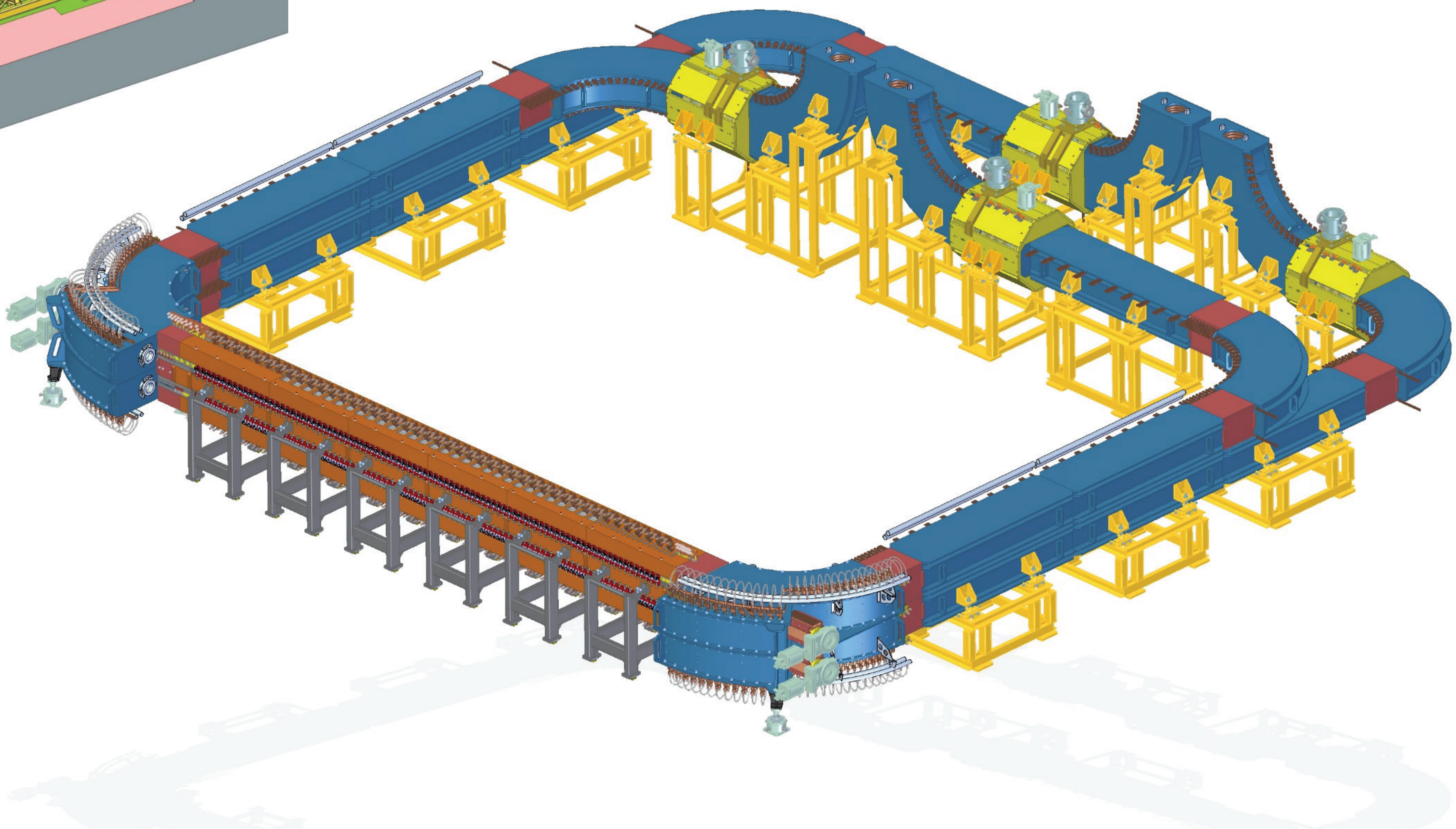
Measured motion of electron beam center by small changing magnet field. XY plane, units µm, red before correction, blue after correction.

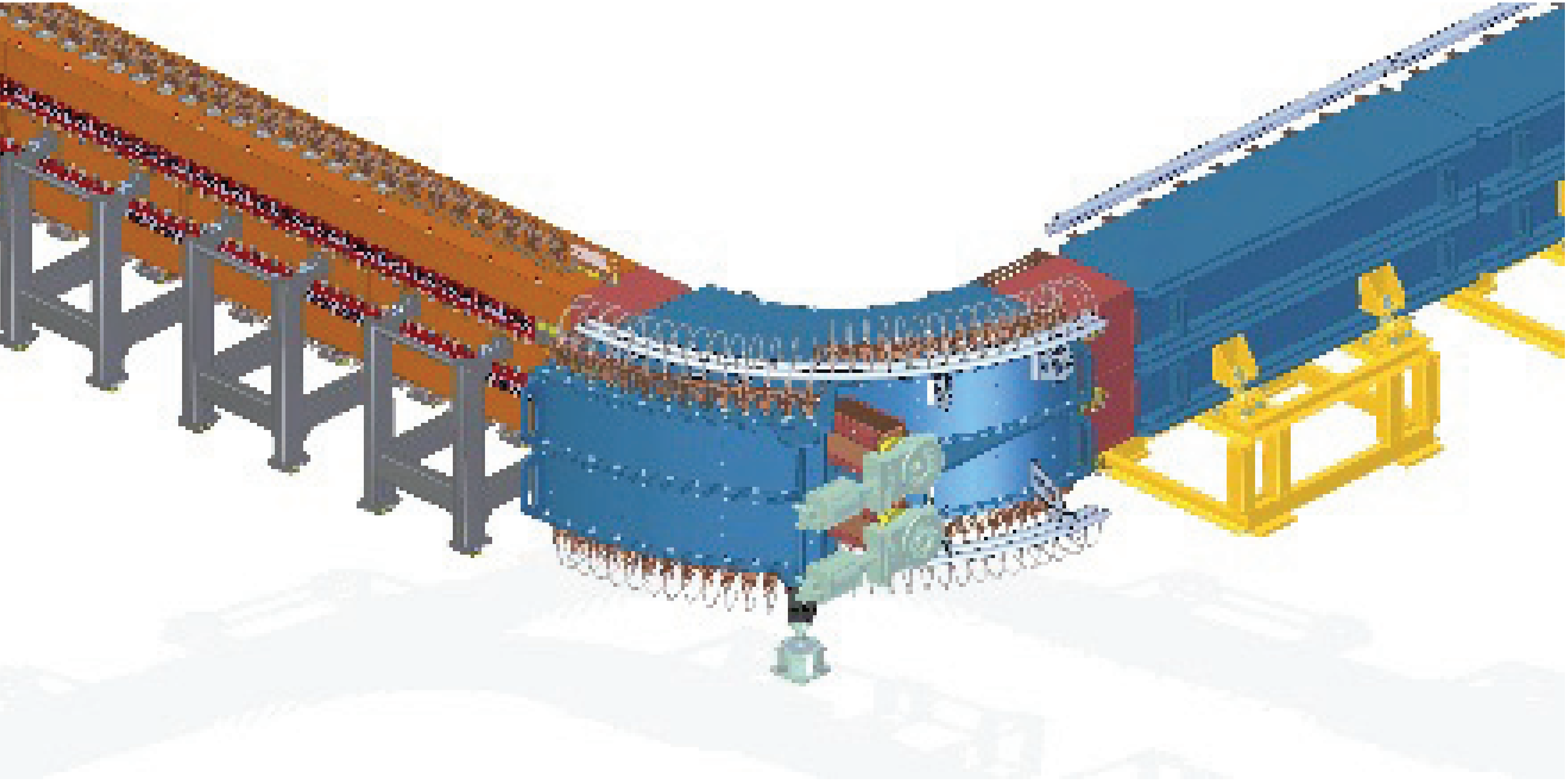
Production new NICA cooler started in 2016 with schedule to be ready for using at 2024
Figure show sketch of NICA cooler at special shielding hall with cooling straight section inside NICA tunnel

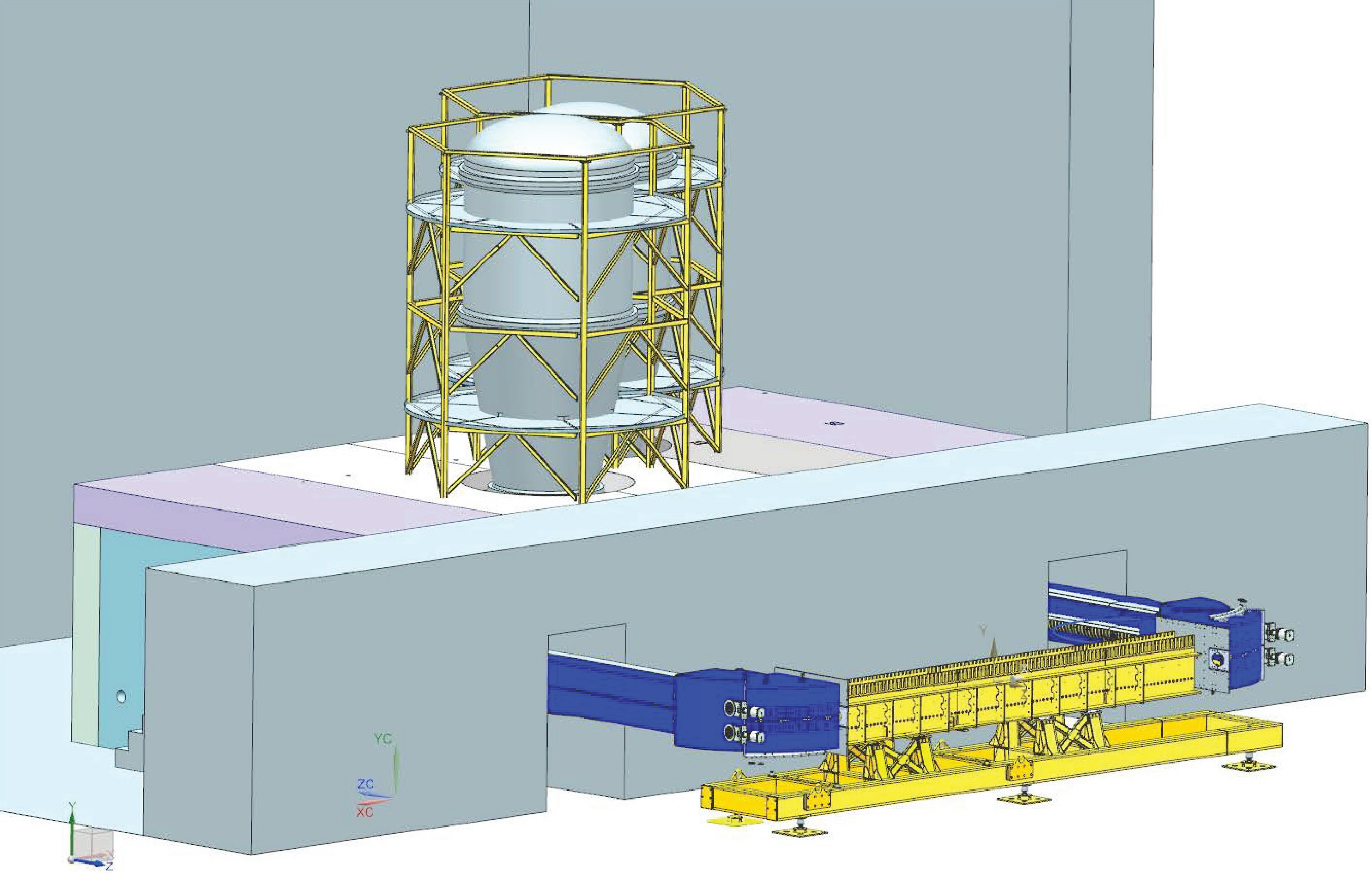


Electron beam at beam system have effective temperature can be control from few Kelvin to $10^4$ Kelvin. The beam of ion $^{197}Au^{79+}$ with energy 4.5 GeV/n and angel spread 3E-4 have temperature 3 GKelvin.
The electron cooling so hot ions very effective.



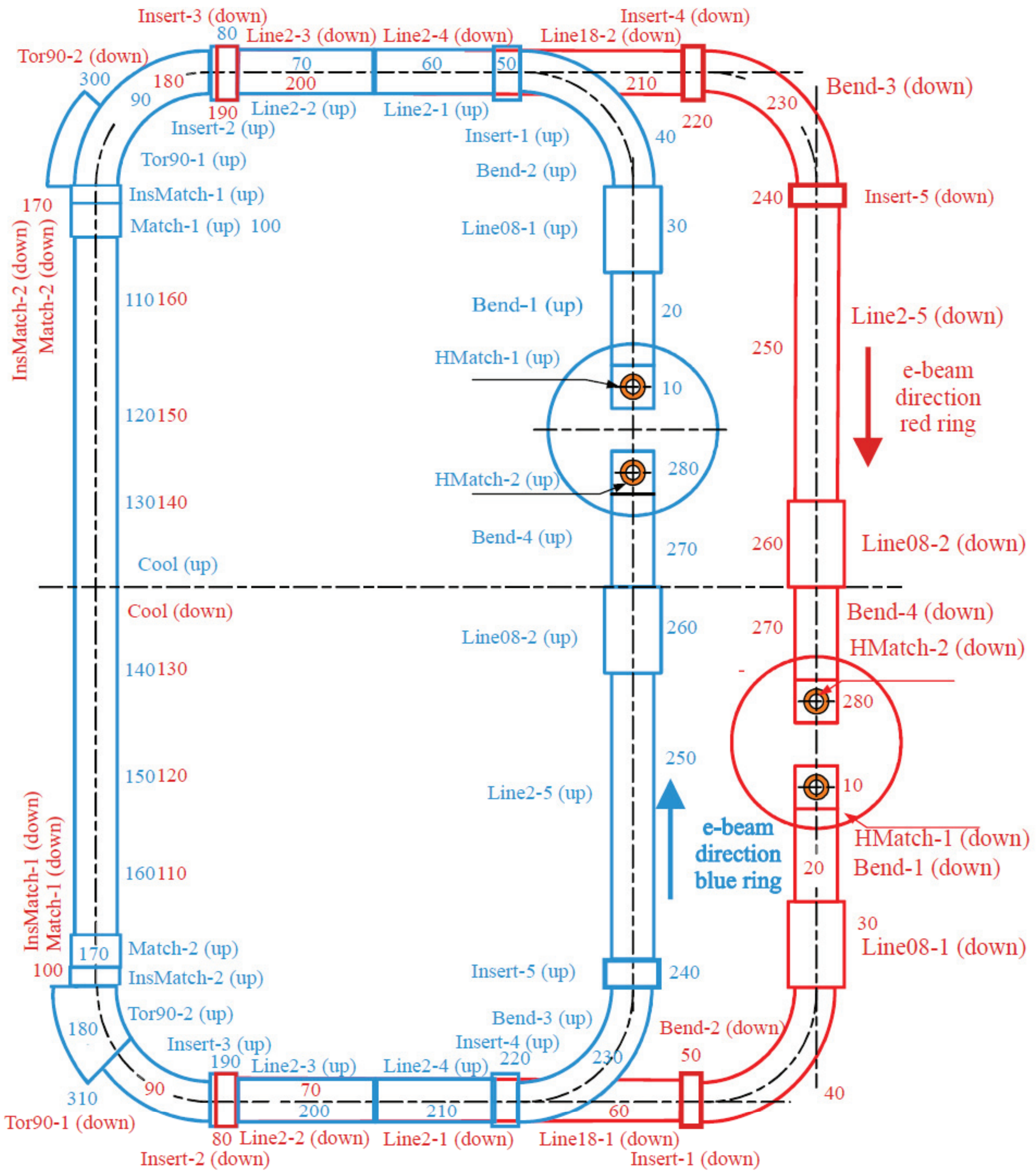




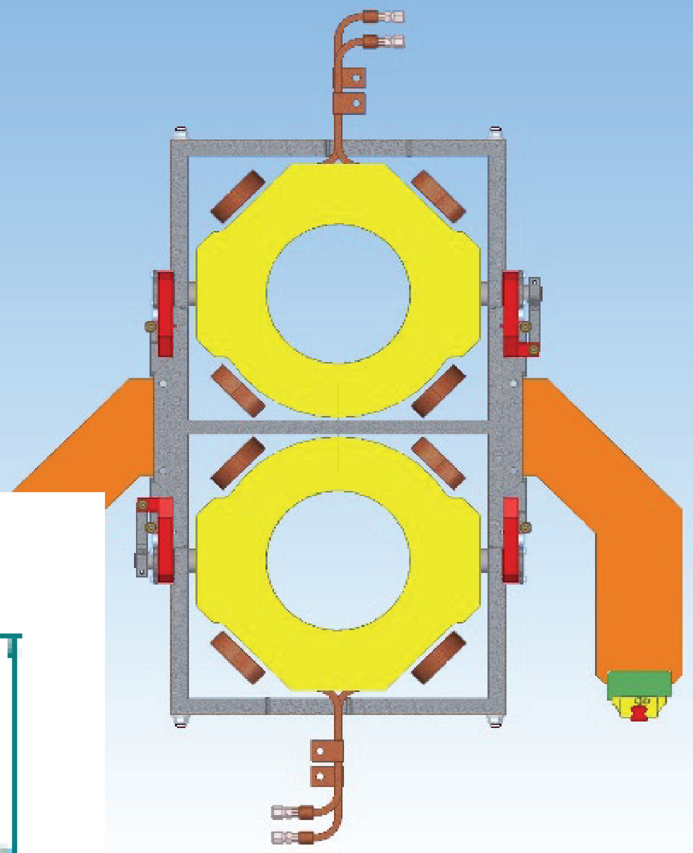

YC
ZC
XC
Y
Z

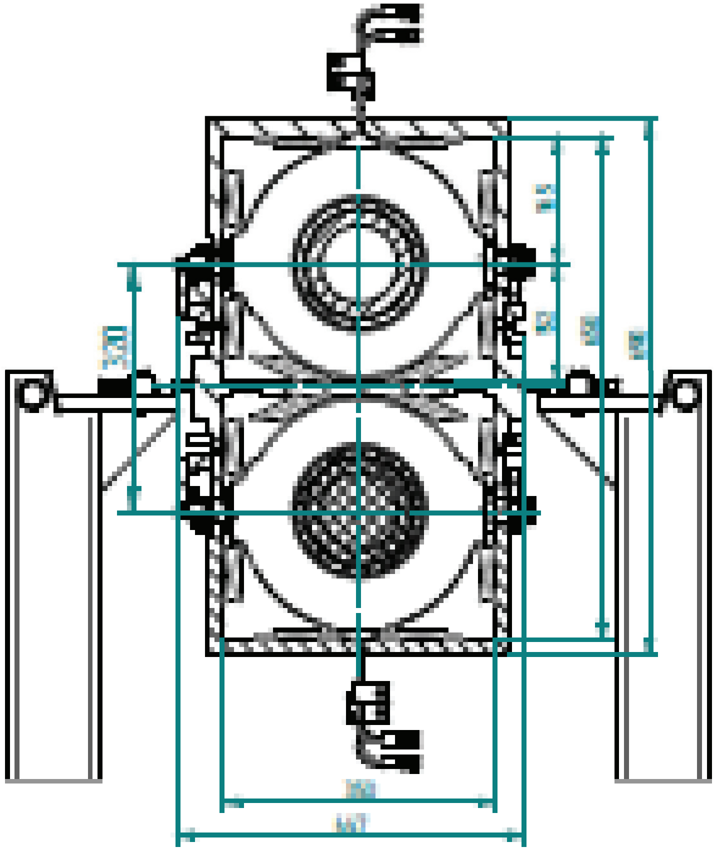
**Basic parameters cooler for NIKA**

| | |
|---|---|
| Electron beam energy | 0.2-2.5 MeV |
| Electron current | 0.1-1 A |
| Length of cooling section | 6.0 m |
| Vacuum | $10^{-11}$ mbar |
| Electric power for both cooler | 500 kWt |




The magnet elements along the electron beams orbits.

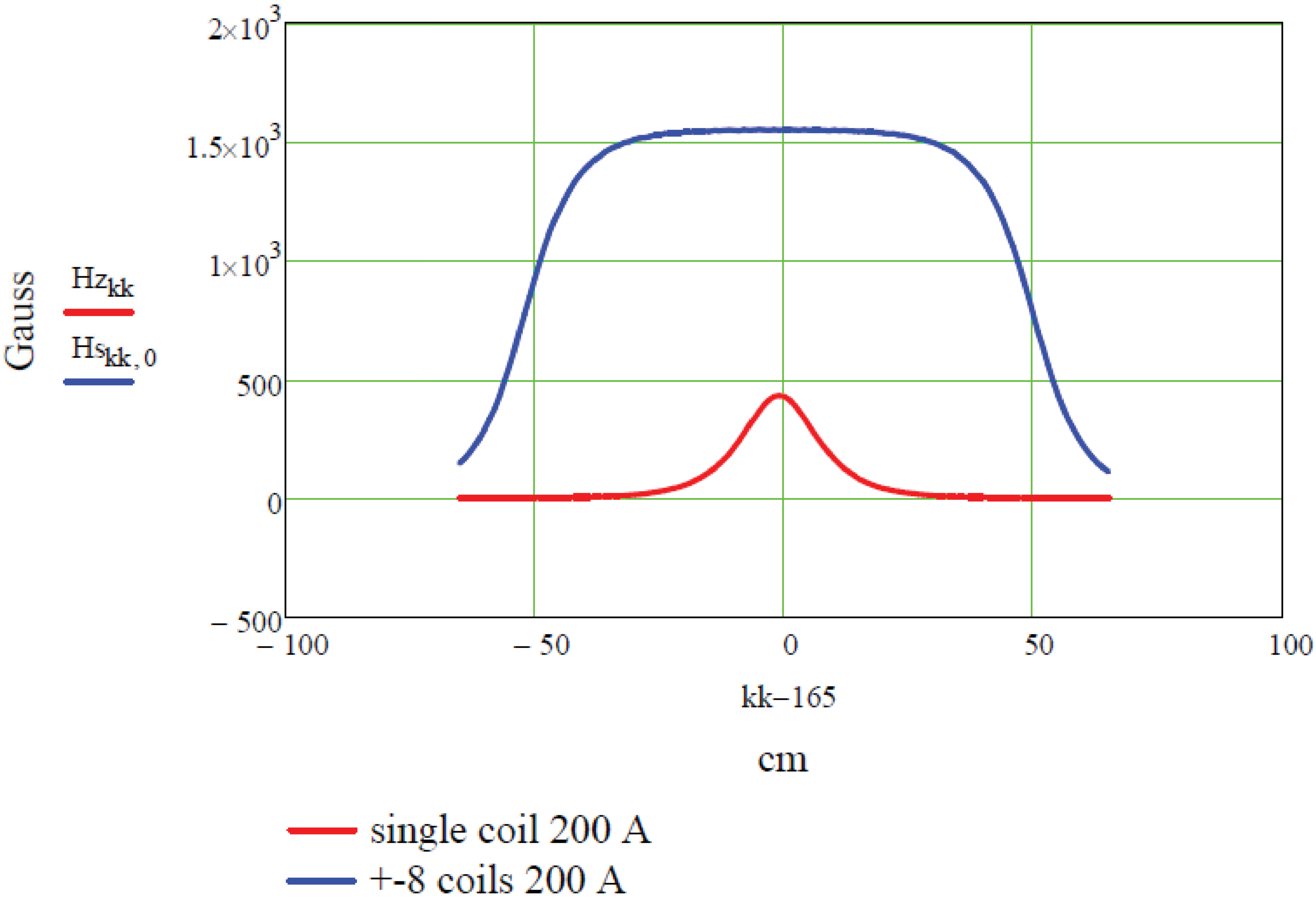




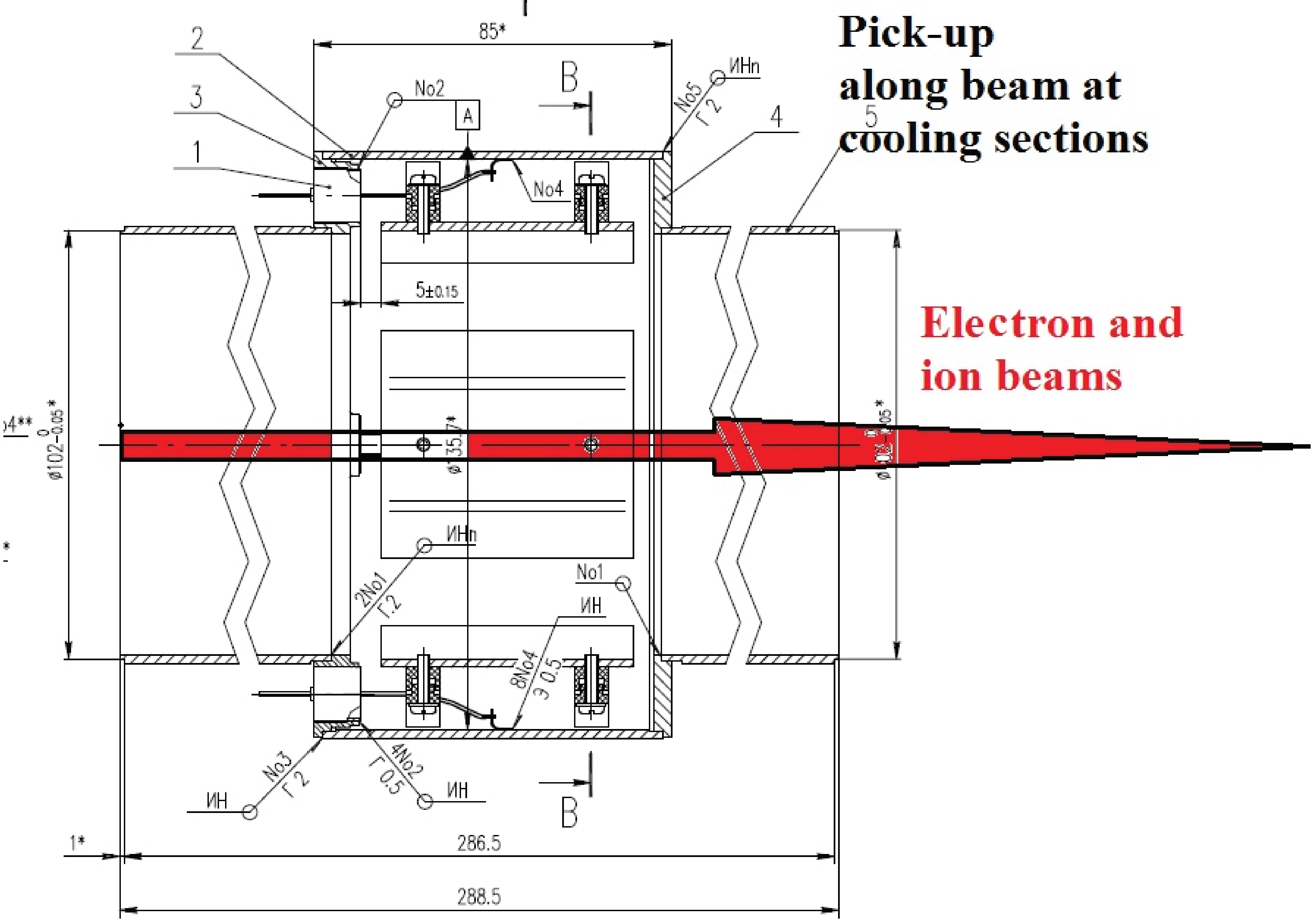
Cross section Two windows solenoids for both contra propagated electrons beams.

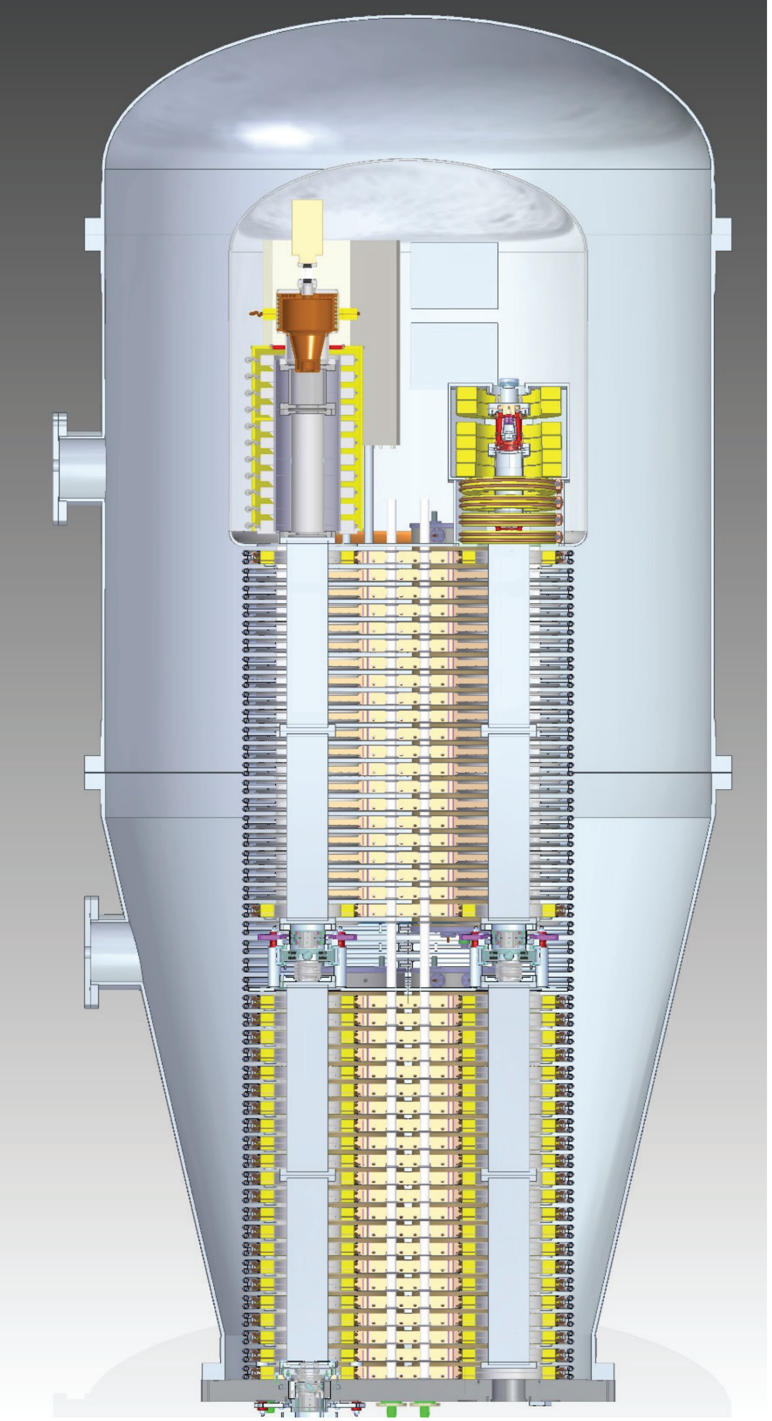
**Cooling section prototype at process of magnet fields measurement**

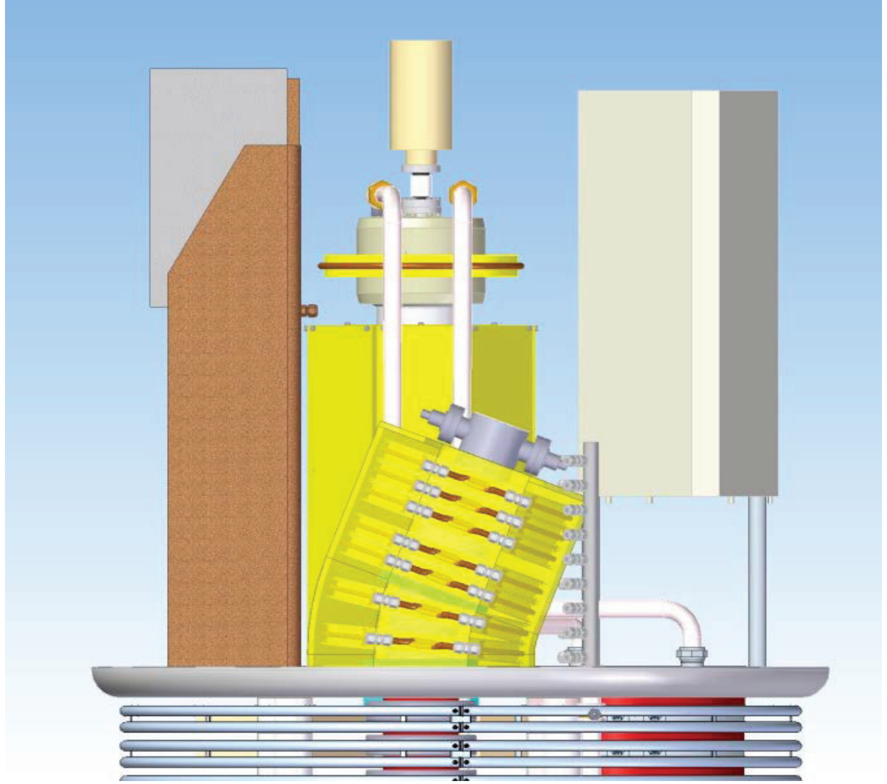
# Measuring magnetic field at prototype of cooling section 200A currents



# Pick-up along beam at cooling sections

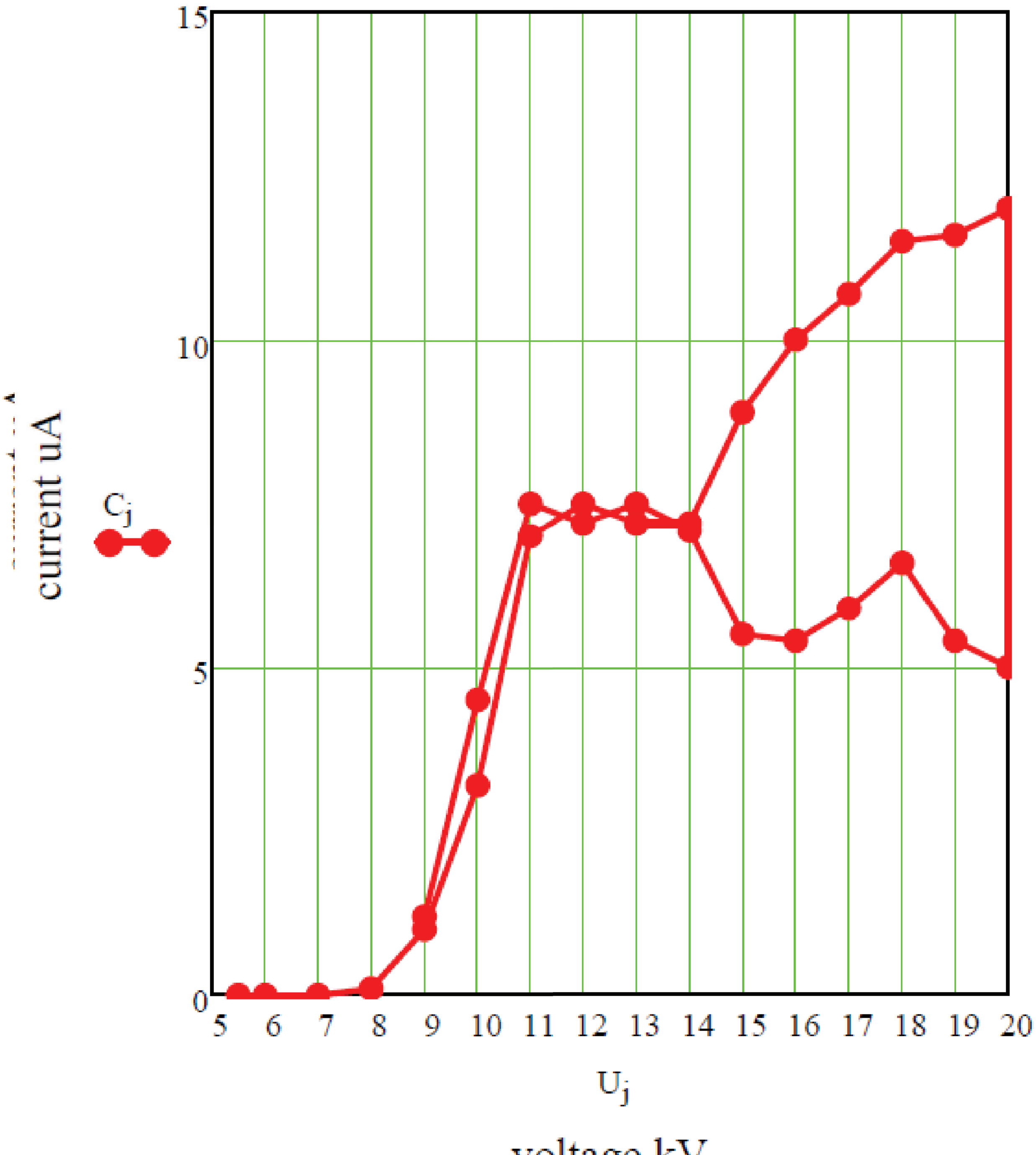






**The vessel for 2.5 MV electrostatic colon p<10bar SF6.**
**The electron gun and collector inside HV terminal**
**The electron gun with low energy bending for protection the cathode from secondary ion beam bombarding.**
**The collector equipped filter with crossing electrostatic and magnet fields for suppression reflected from collector electrons.**

**Bottom flange of high voltage vessel with 3 sections for testing sparking between sections**




**Sparking between sections at air.**

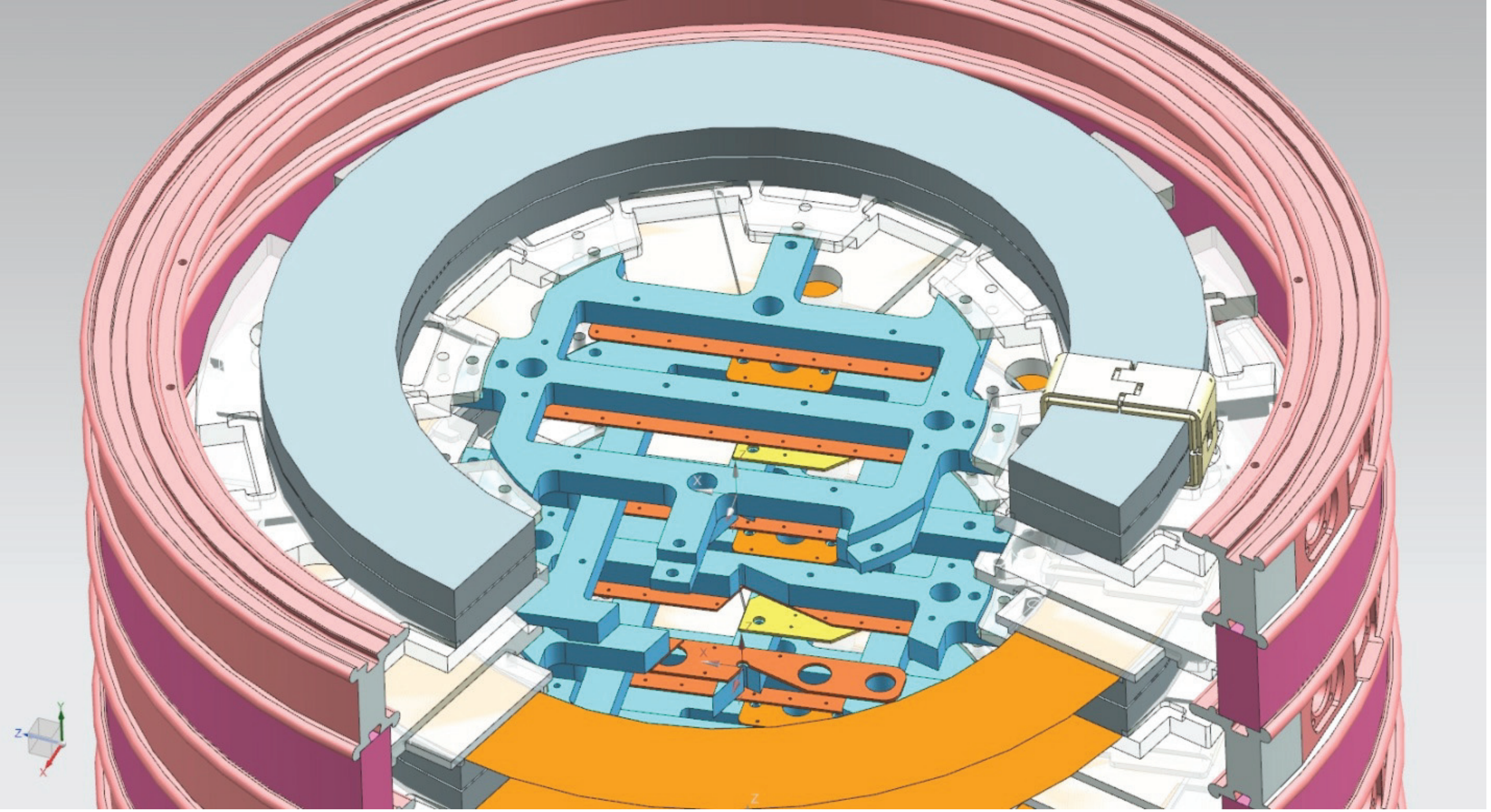
**First sparking 20 kV after few discharges corona current jumped from 13 uA to 5 uA by sparking** and **training.**

**10kV*2SF6*4bar=**

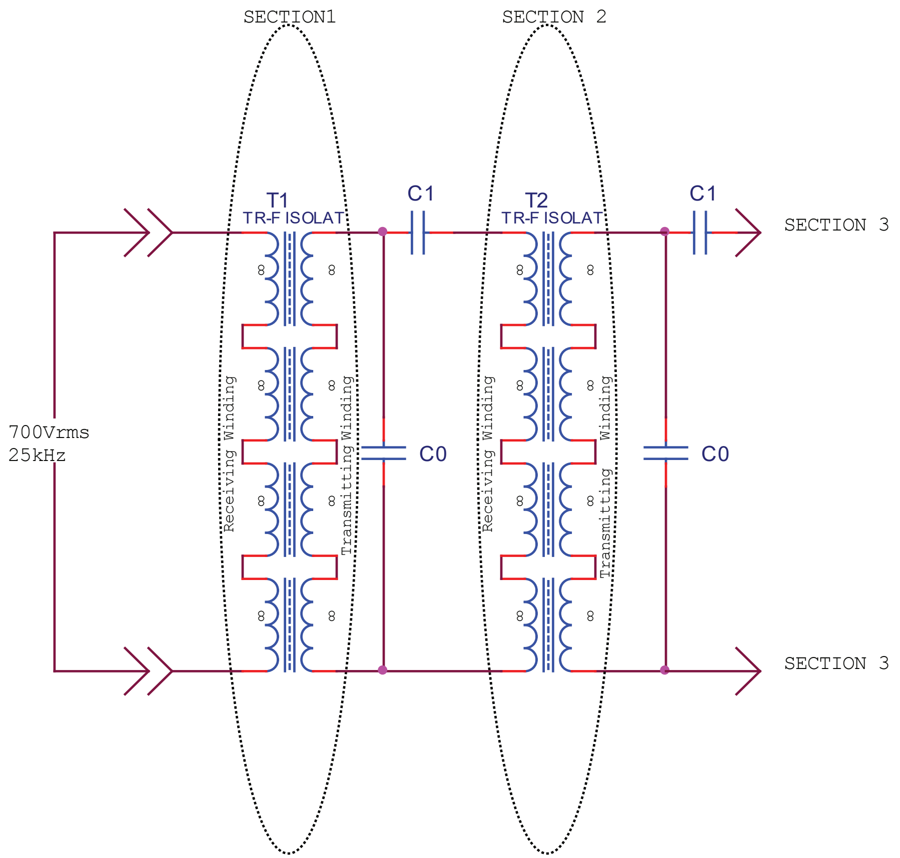
**For 40 sections limit 3.2 MV**

**With corona current less 5 uA**

The acceleration tube for NICA cooler under vacuum condition testing.

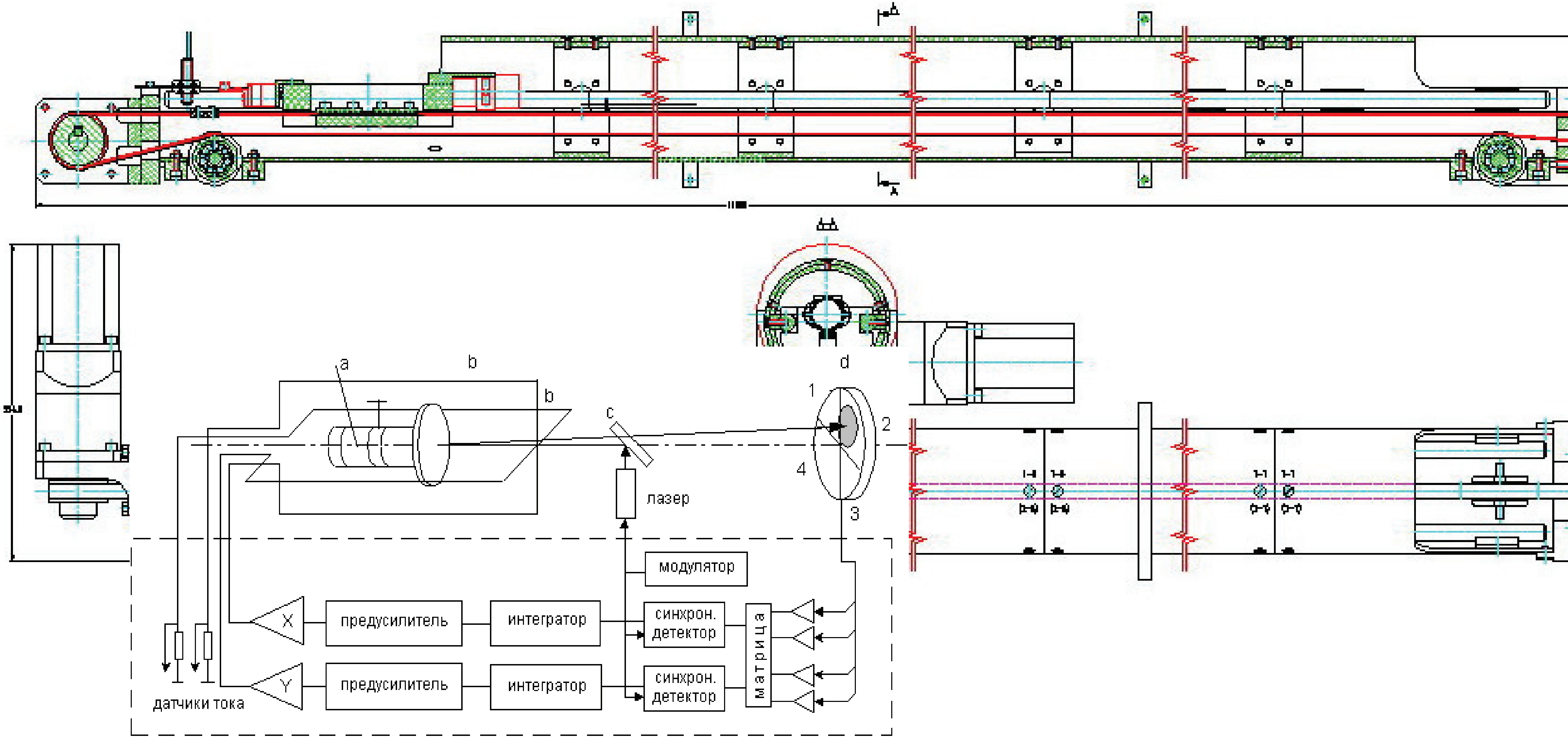


## Cascade transformer for powering Section along electrostatic column.



Testing cascade transformer for sending electric power along high voltage sections.

# Compass system for measuring straightness  the line of magnet field along cooling section 6m+2toroids(1m) Total length 11 m



The mirror compass for measuring of the straightness magnet field line at cooling section

$$\frac{d\varepsilon}{dt} = -\lambda(\varepsilon)\varepsilon + D$$

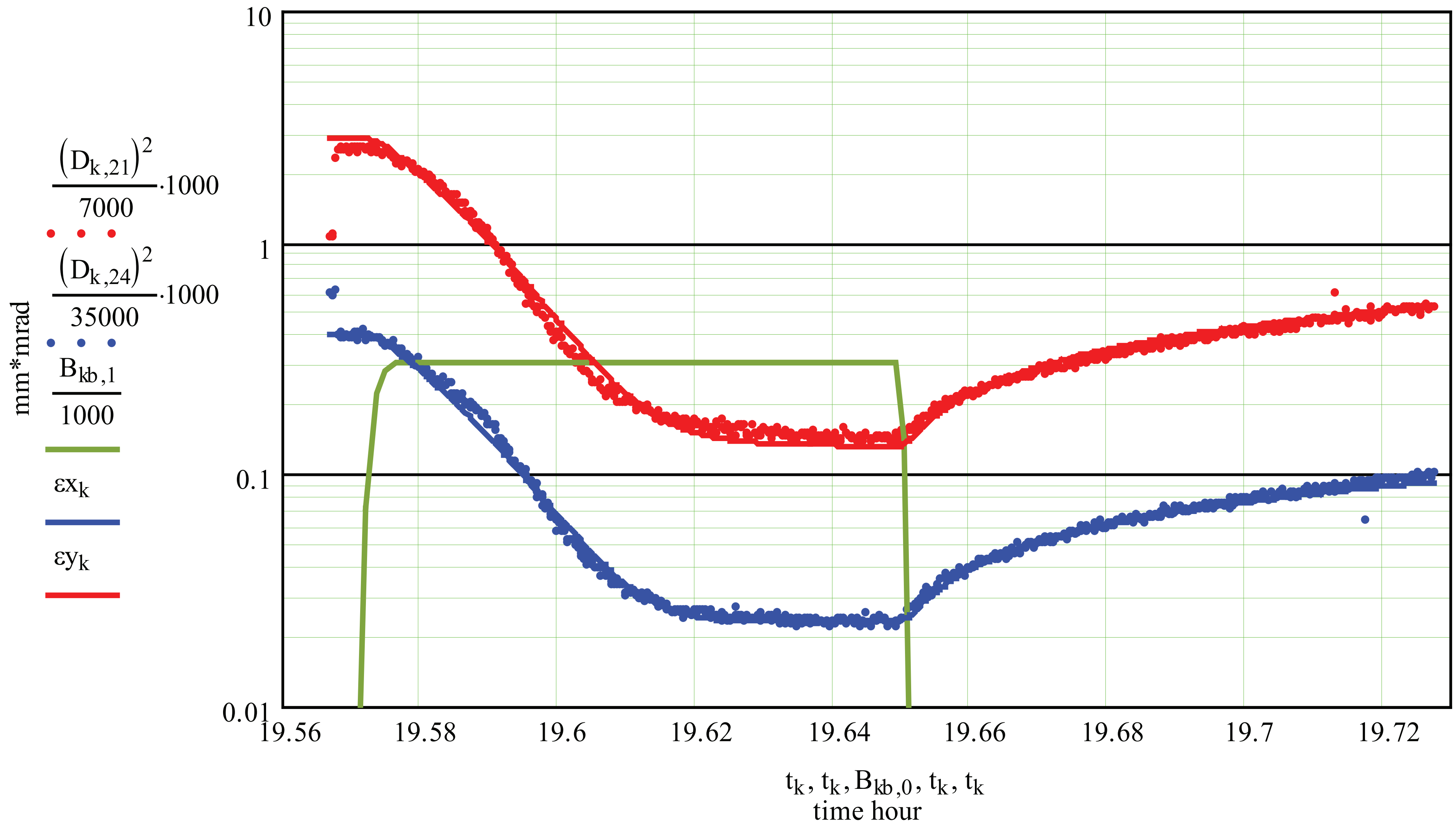
Equation for the ion beam emittance $\varepsilon$

$$\lambda(\varepsilon) = \frac{(\varepsilon_0)^{3/2}}{T_{cool}(\varepsilon_x + \varepsilon_y + \varepsilon_0)^{3/2}}$$

Cooling rate:
Tcool- cooling time small amplitude
$\epsilon_0$ efective emitanse,
cooling rate constant
for $\varepsilon \ll \varepsilon_0$

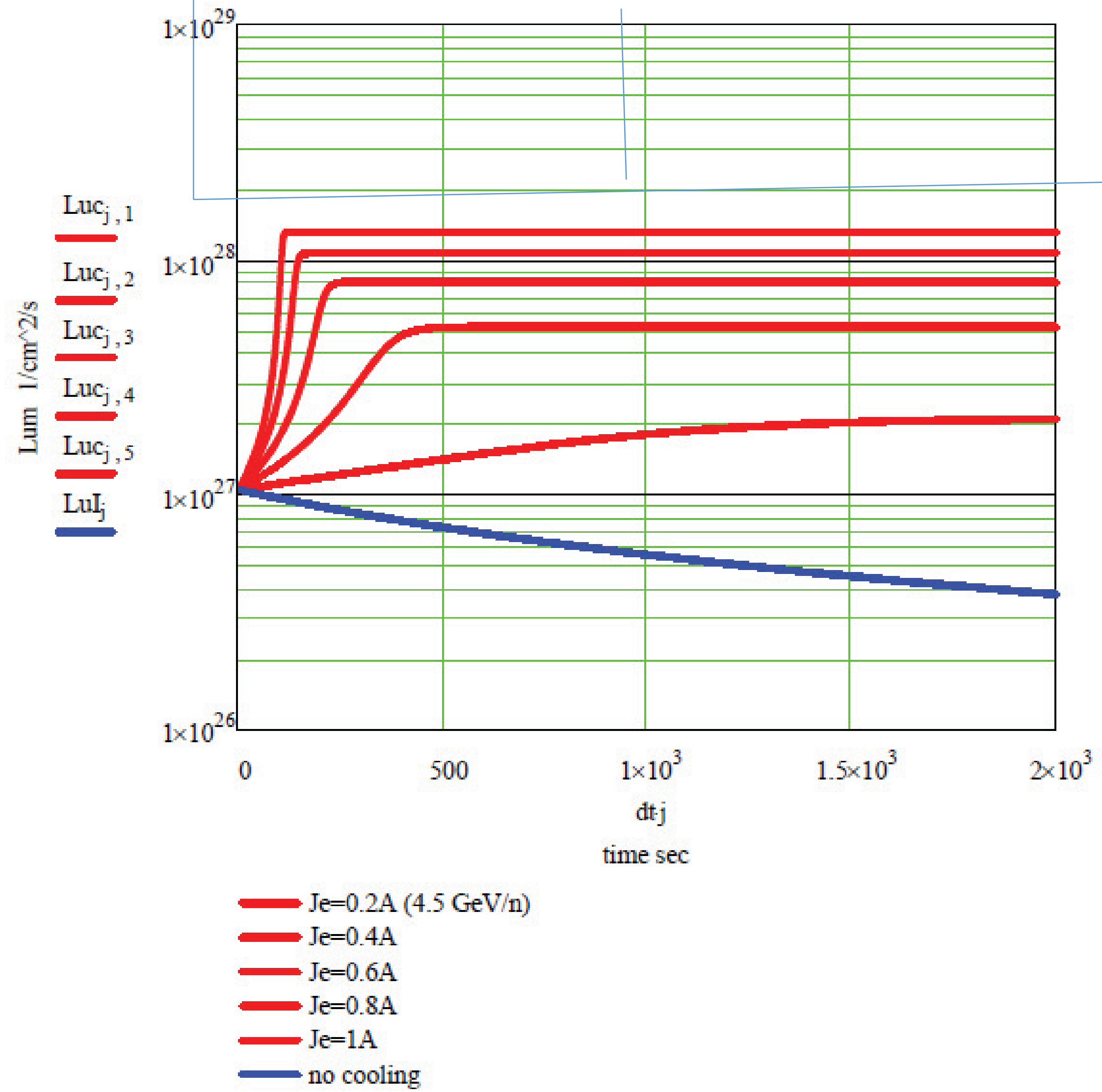
$$D_{xy} = \frac{IBS_{xy}}{\sqrt{\varepsilon_x \varepsilon_y}}$$

Heating: Intra beam scattering, beam-beam effect, scattering on residual gases and …….




**Measured at COSY and calculated ion beam emittance. After acceleration ion beam the electron current 0.3A switch on 300 seconds and after switch off easy see Intra Beam Scattering. Fitted line very closed to experimental points.**

$$\varepsilon cxt_{j+1,ke} := \varepsilon cxt_{j,ke} - \varepsilon cxt_{j,ke} \cdot \frac{dt}{\tau cool_3} \cdot \frac{ke}{5} \cdot \left(\frac{\varepsilon cxt_{0,ke}}{\varepsilon cxt_{j,ke}}\right)^{\frac{\cdot}{2}} + \frac{dt}{\tau IBS_3} \cdot \frac{(\varepsilon cxt_{0,ke})^2}{\varepsilon cxt_{j,ke}} \cdot \left(\frac{\frac{Ni \cdot ri}{4 \cdot \pi \cdot \varepsilon cxt_{j,ke} \cdot \gamma_3}}{0.01} + ( \ldots\right.$$




Simplest model electron cooling and IBS for NICA

Easy see more then 10 times increasing luminosity.

Thank you for attention!