The status of the electron cooling system for the NICA collider

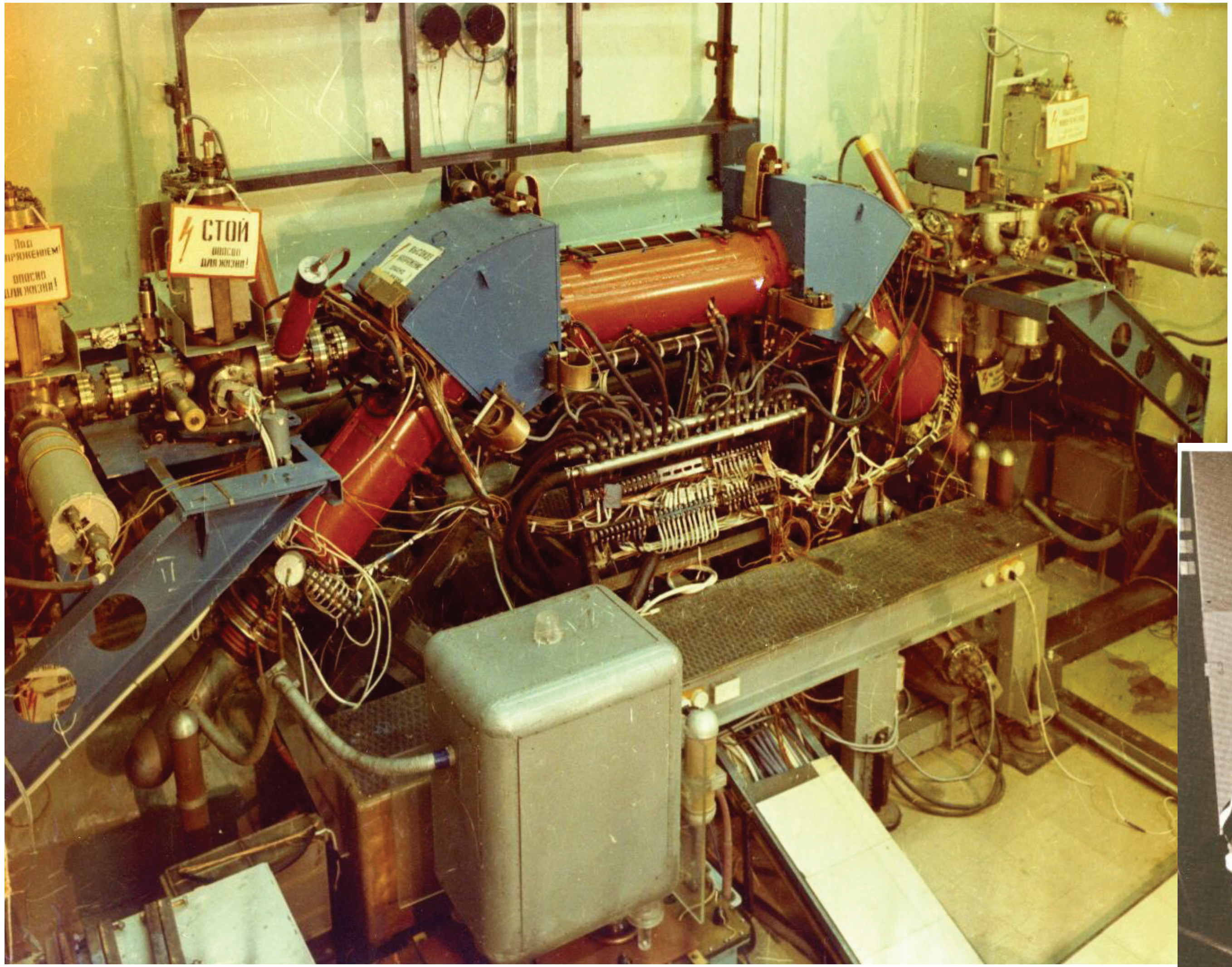
M.B. Bryzgunov, A.V. Bubley, A.D. Goncharov, A.P. Denisov, N.C. Kremnev, V.V. Parkhomchuk, V.M. Panasuk, A.A. Putmakov,

V.B. Reva, S.V. Shiynkov

COOL'19

New electron cooling system is designed to cool two heavy ion beams propagating in opposite directions at a distance about 30 cm from each other. Engineering solutions for its basic elements are presented. The measurements of the electron cooler magnetic system and the influence of the adjacent solenoids in the cooling section on the resulting magnetic field are described. The potential opportunities to improve parameters of the experiments with ion beams using the electron cooling system are discussed.

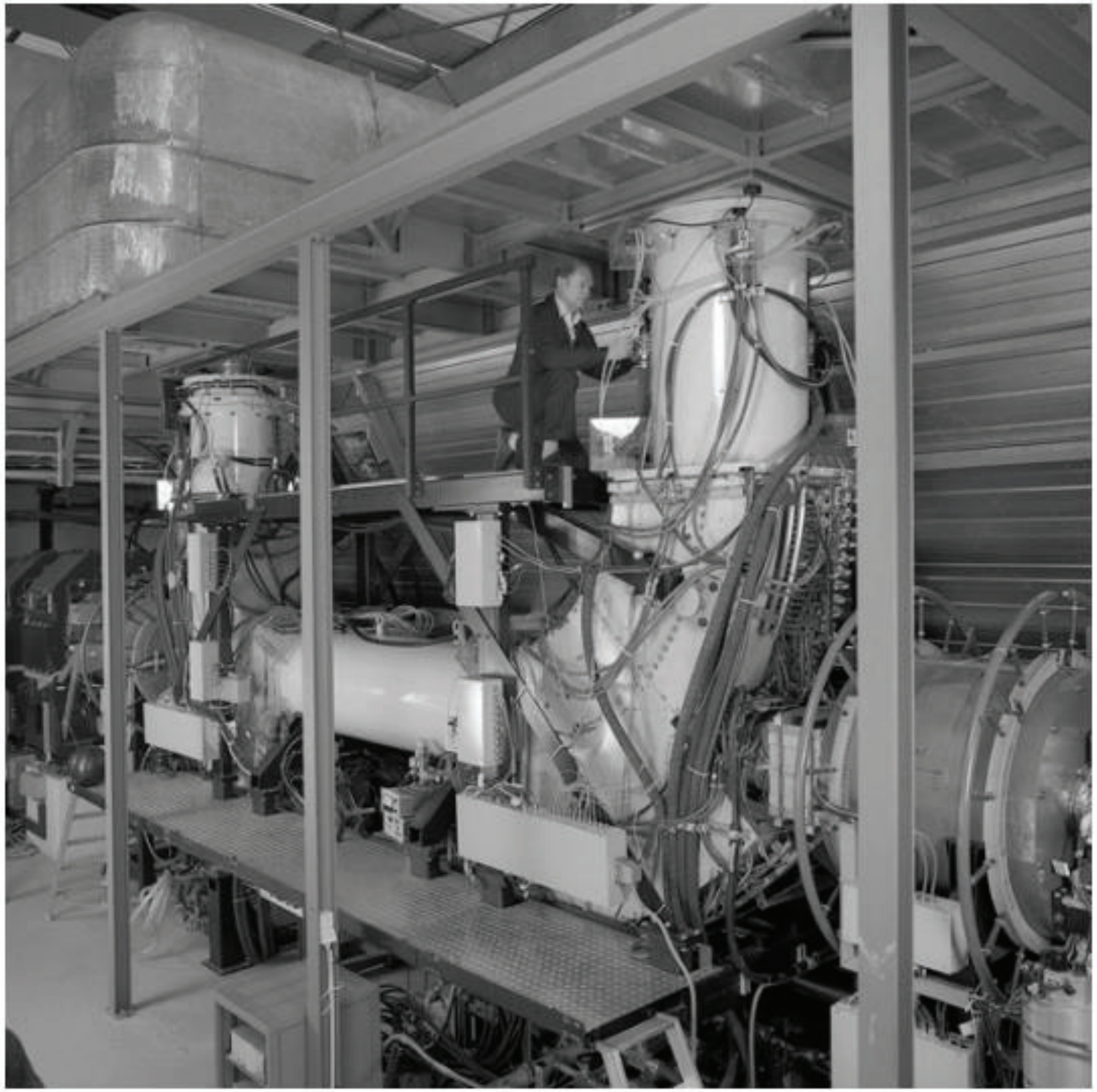
Figst coolers at storage ring NAP-M 1974 BINP



"First experiments with electron cooling", Proceeding of 4 All-Russian acceleration charge particle meeting, Moscow, 1974 v.2, p. 309

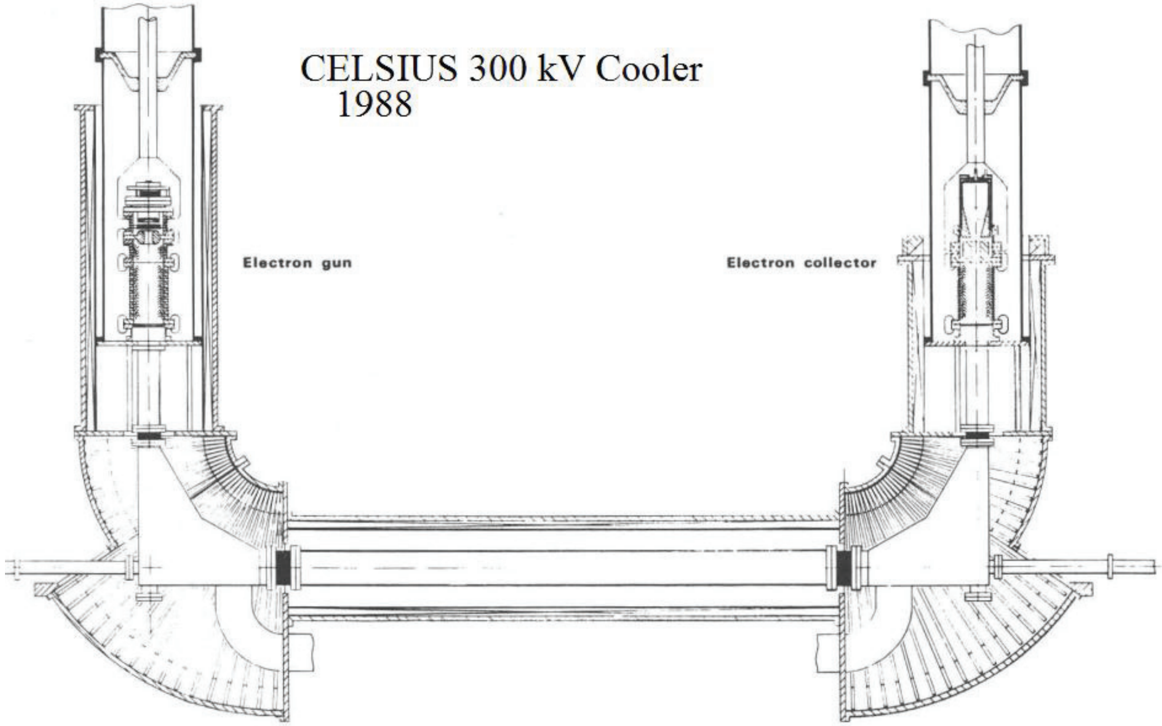
G. Budker, N. Dikanky, V. Kudelainen, I. Meshkov, V. Parkhomchuk, D. Pestrikov, A. Skrinsky, B. Sukhina

Medium Energy:
300 keV ESR/GSI



ESR, Darmstadt Germany, 1990

History high voltage coolers 200kV<V <1MV at figs



CSRe cooler (300kVC) China Lanzhou IMP 2002

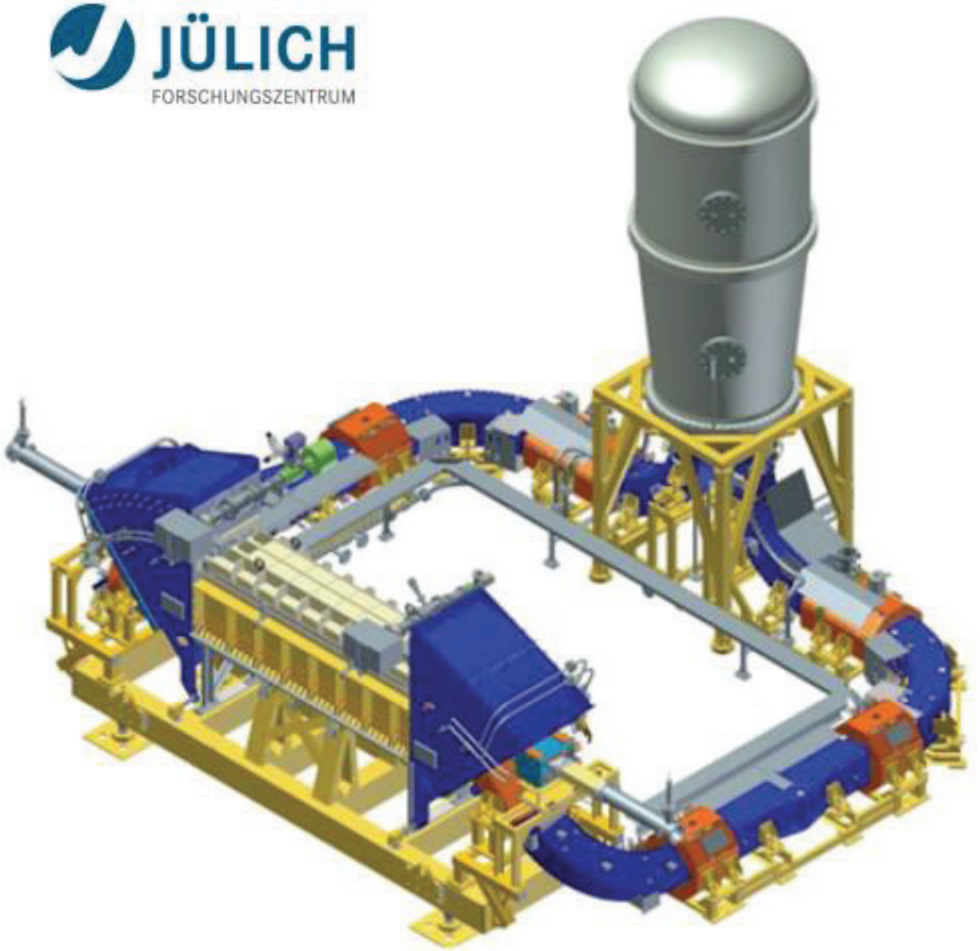
History high voltage coolers >1MV at figs

FNAL 4.3 MV TEVATRON cooler 2005

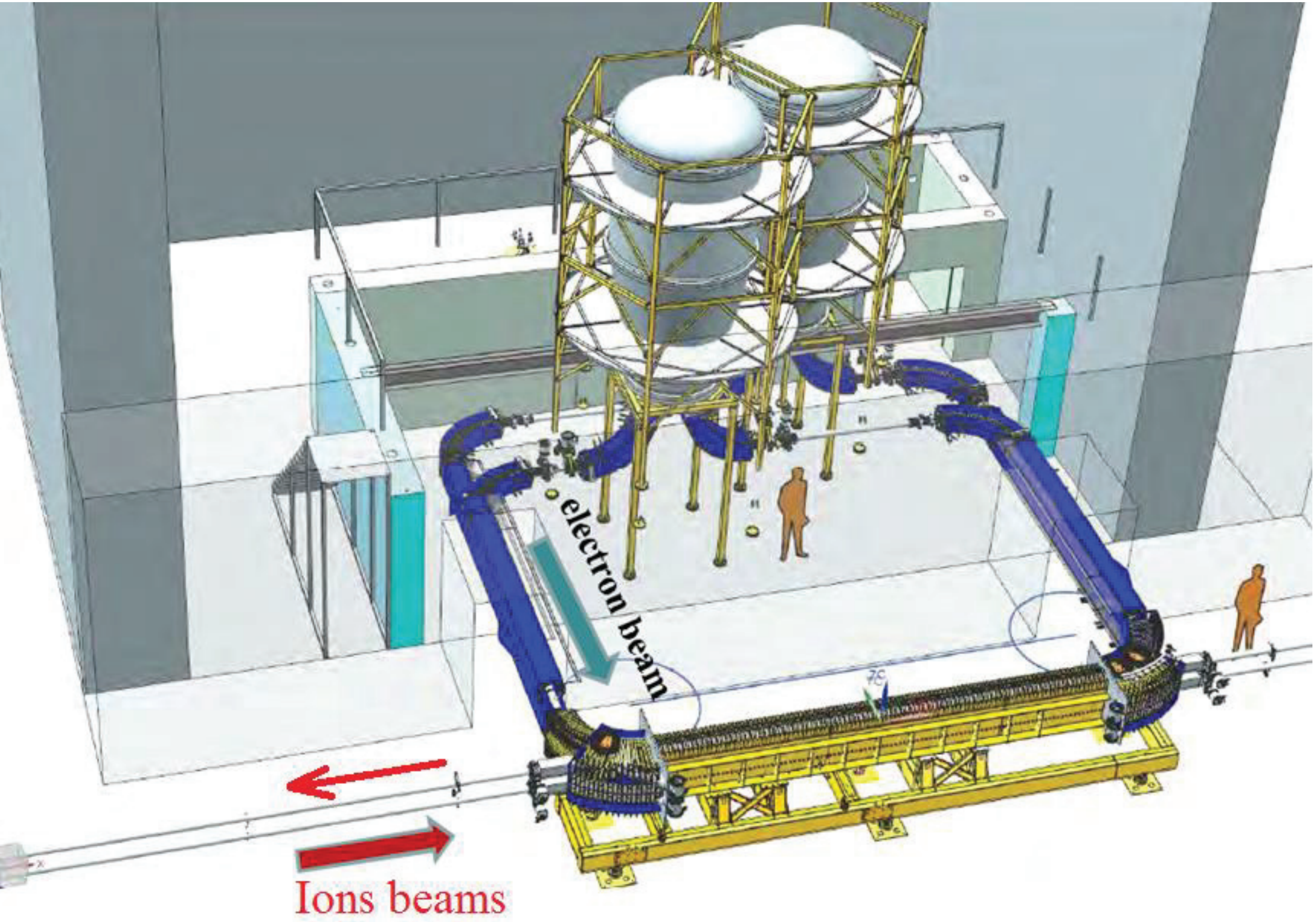
2 MeV electron cooler

COSY 2013

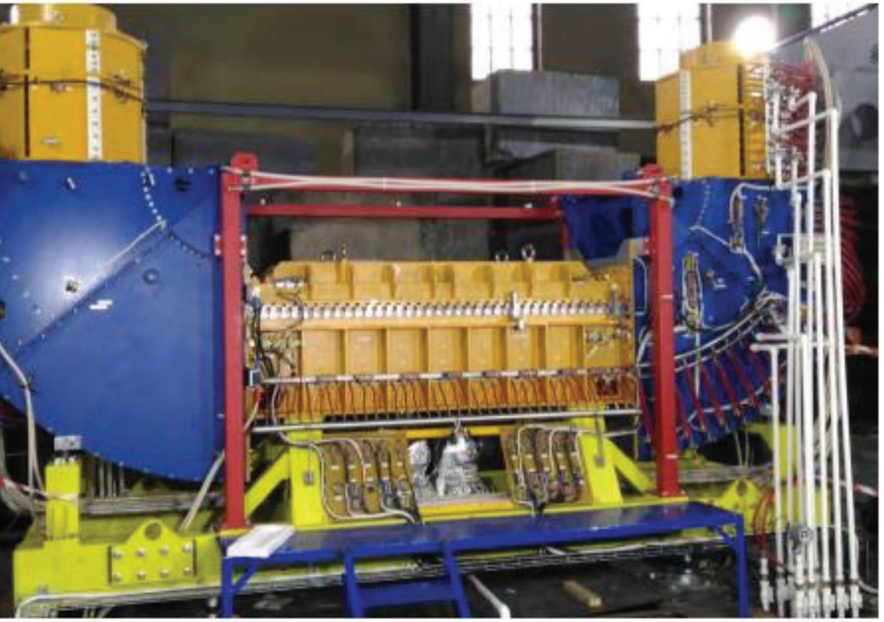
JÜLICH
FORSCHUNGSZENTRUM



3D design of NICA cooler 2.5 MV

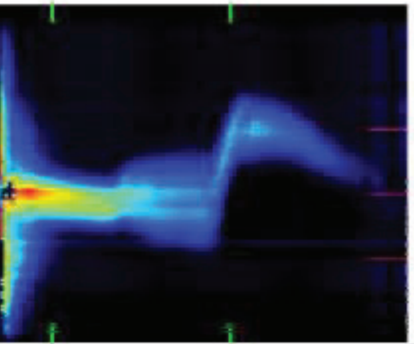


2.5 MV electron cooler for NIKA is development of ideas used in COSY cooler

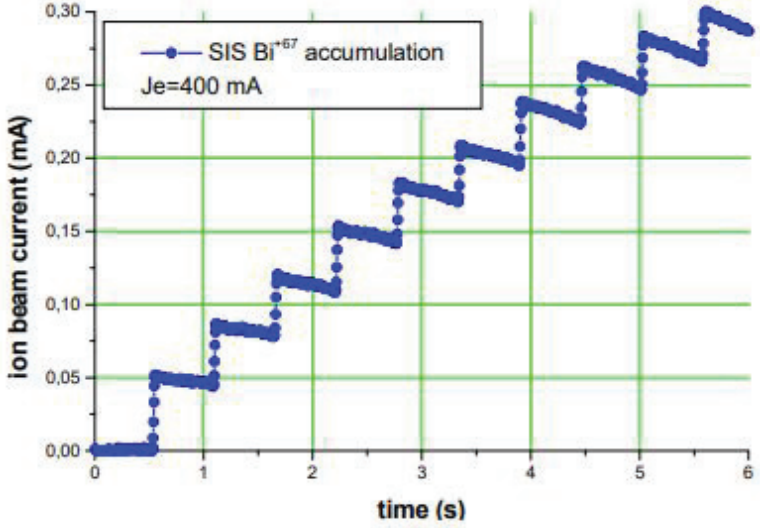


Assembling **NICA** Booster Cooler in JINR

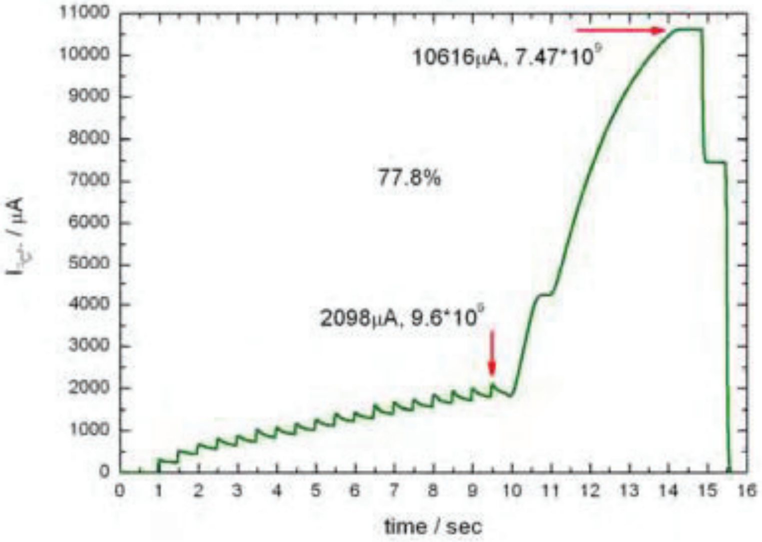
Vacuum level 10^{-11} is obtained



LEIR Lead ion cooling, accumulation, acceleration cooling time about 0.1 c



Accumulation Bi beam at **SIS-18**



Accumulation of carbon ion at energy 7 MeV/u in **CSRm**

Experience of the electron cooling of the high charge ions demonstrated shrinking beams at very small emittance. High magnet field at cooling section help to rich high cooling rate without losses on electron-ion recombination

Strong magnet field at cooler section nessesary for reduction recombination without reducing cooling rate

Table 1

Te eV	τcool sec	τrec sec	τrec/τcool
0.1	16	76	4.7
1	19	182	14
10	25	1000	42
100	35	4200	120
1000	55	17000	320

Bs=0.2 T

NICA

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Observation of a reduction of recombination between ions and electrons

P. Beller*, K. Beckert, B. Franzke, C. Kozhuharov, F. Nolden, M. Steck

Gesellschaft für Schwerionenforschung, Planckstraße 1, D-64291 Darmstadt, Germany

Available online 17 July 2004

$\eta := \frac{6}{580}$ $\gamma := \frac{4}{0.93} + 1$ $\beta := \sqrt{1 - \frac{1}{\gamma^2}}$ $Ai := 197$ $Zi := 79$

$q := 4.8 \cdot 10^{-10}$ charge CGS $c := 3 \cdot 10^{10}$ cm/c velosity light

$Bs := 2000$ Gauss longitudinal field at cooking section

$Te := 10$ eV Temperature Larmor rotation

$mc2 := 0.51 \cdot 10^{6}$ eV mass of electrons $re := 2.8 \cdot 10^{-13}$ cm electron radius

$\rho L := \sqrt{\frac{Te}{mc2}} \cdot \frac{q}{re \cdot Bs}$ $\rho L = 3.795 \times 10^{-3}$ cm Larmor radius

$\varepsilon x := 10^{-4}$ $\beta x := 1000$ cm*rad emitance ion beam; cm bettafuction in cooler

$\theta i := \sqrt{\frac{\varepsilon x}{\beta x}}$ $Vic := \theta i \cdot \beta \cdot \gamma$ $Vic \cdot c = 4.939 \times 10^{7}$ cm/s ion velosity

$ae := 0.3$ cm radius electron beams

$ne := \frac{1}{1.6 \cdot 10^{-19} \cdot \pi \cdot ae^2 \cdot \beta \cdot \gamma \cdot c}$ $ne = 1.415 \times 10^{8}$ 1/cm^3 density electron beam

$ri := \frac{re}{1836} \cdot \frac{Zi^2}{Ai}$ cm clasical radius ion

$\rho max := \theta i \cdot 600$ $\rho max = 0.19$ cm maximal impuct parameters

$\tau := \frac{\gamma \cdot Vic^3}{4 \cdot ne \cdot re \cdot ri \cdot \ln\left(\frac{\rho max + \rho L}{\rho L}\right) \cdot \eta \cdot c}$ $\tau = 25.309$ sec cooling time

$trec := \frac{\gamma}{3.02 \cdot 10^{-13} \cdot Zi^2 \cdot ne \cdot \eta \cdot \sqrt{\frac{1}{Te}} \cdot \left[\ln\left(\frac{11.32 \cdot Zi}{\sqrt{Te}}\right) + 0.14 \cdot \left(\frac{Te}{Zi^2}\right)^{\frac{1}{3}}\right]}$ $trec = 1.073 \times 10^{3}$ sec life time by recombination

$\frac{trec}{\tau} = 42.397$ Number of posible cyles of cooling

Low Energy RHIC Electron Cooling (LEReC) Report

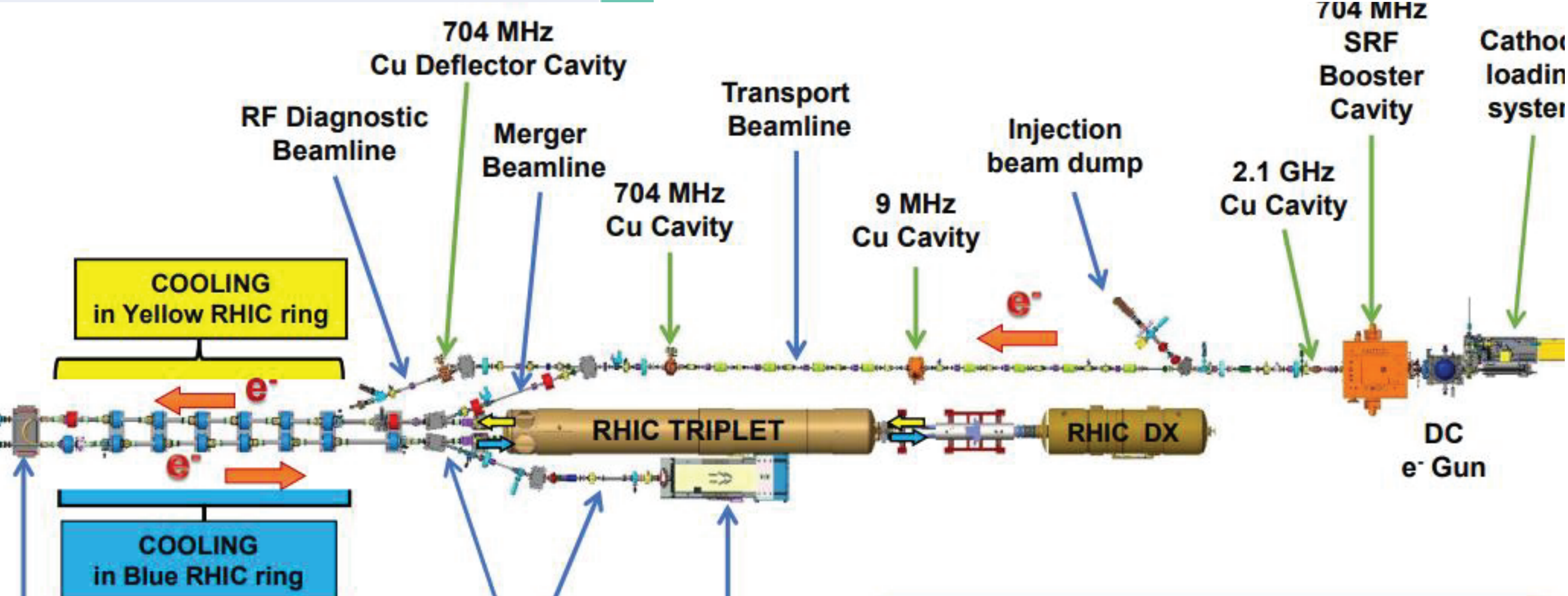
RHIC and AGS Users' Meeting
June 6, 2019

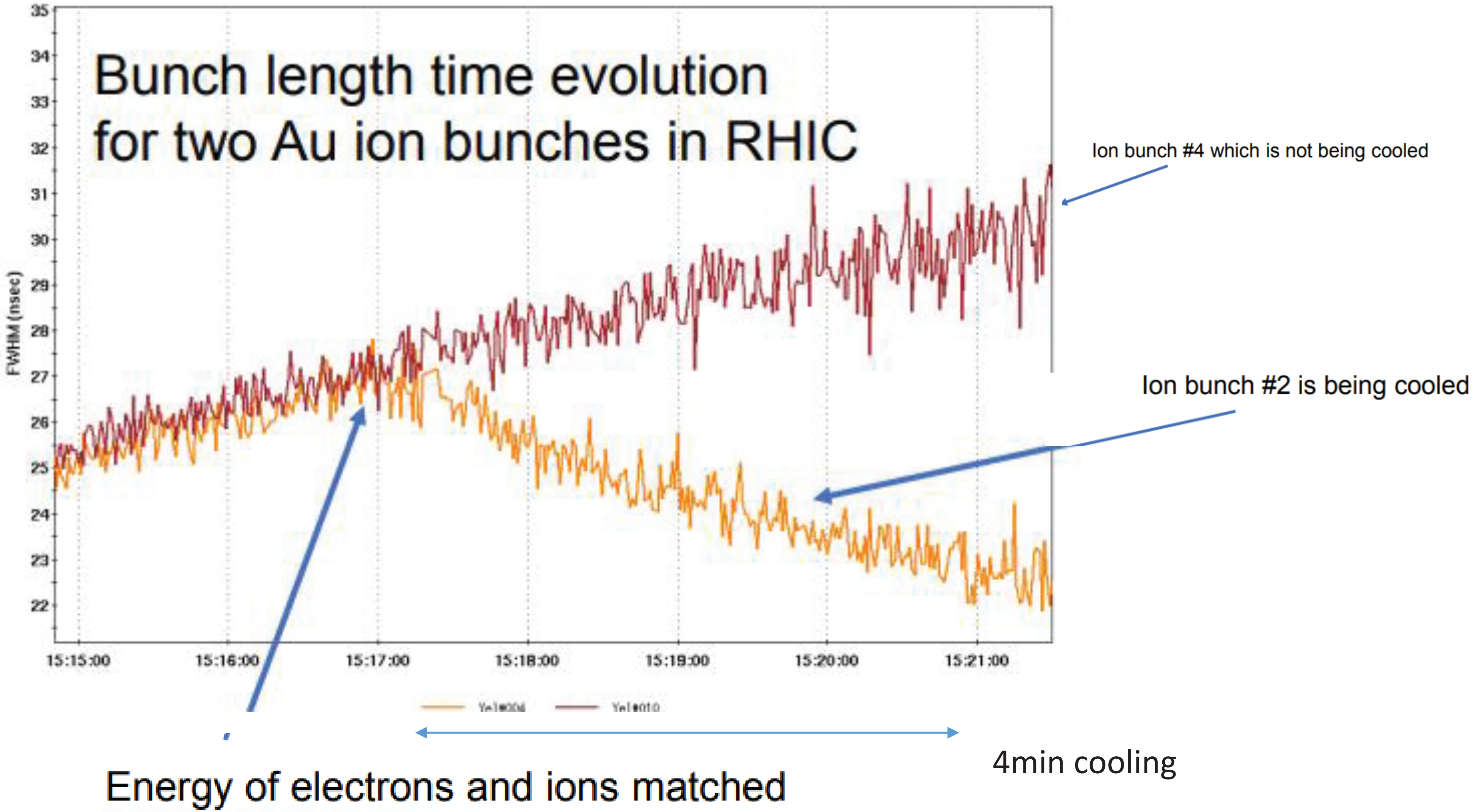
Dmitry Kayran
On behalf of LEReC team

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Kinetic energy, MeV	1.6*
Charge in macrobunch, nC	4
Average current, mA	36

Au beam energy 3 GeV/n



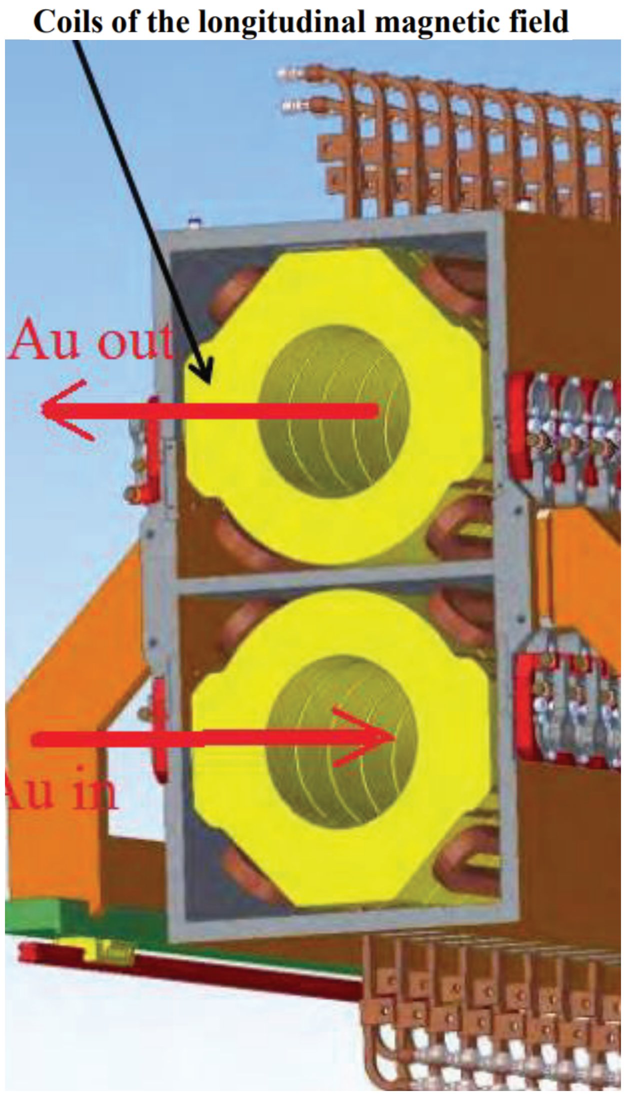


More information in COOL19 report:

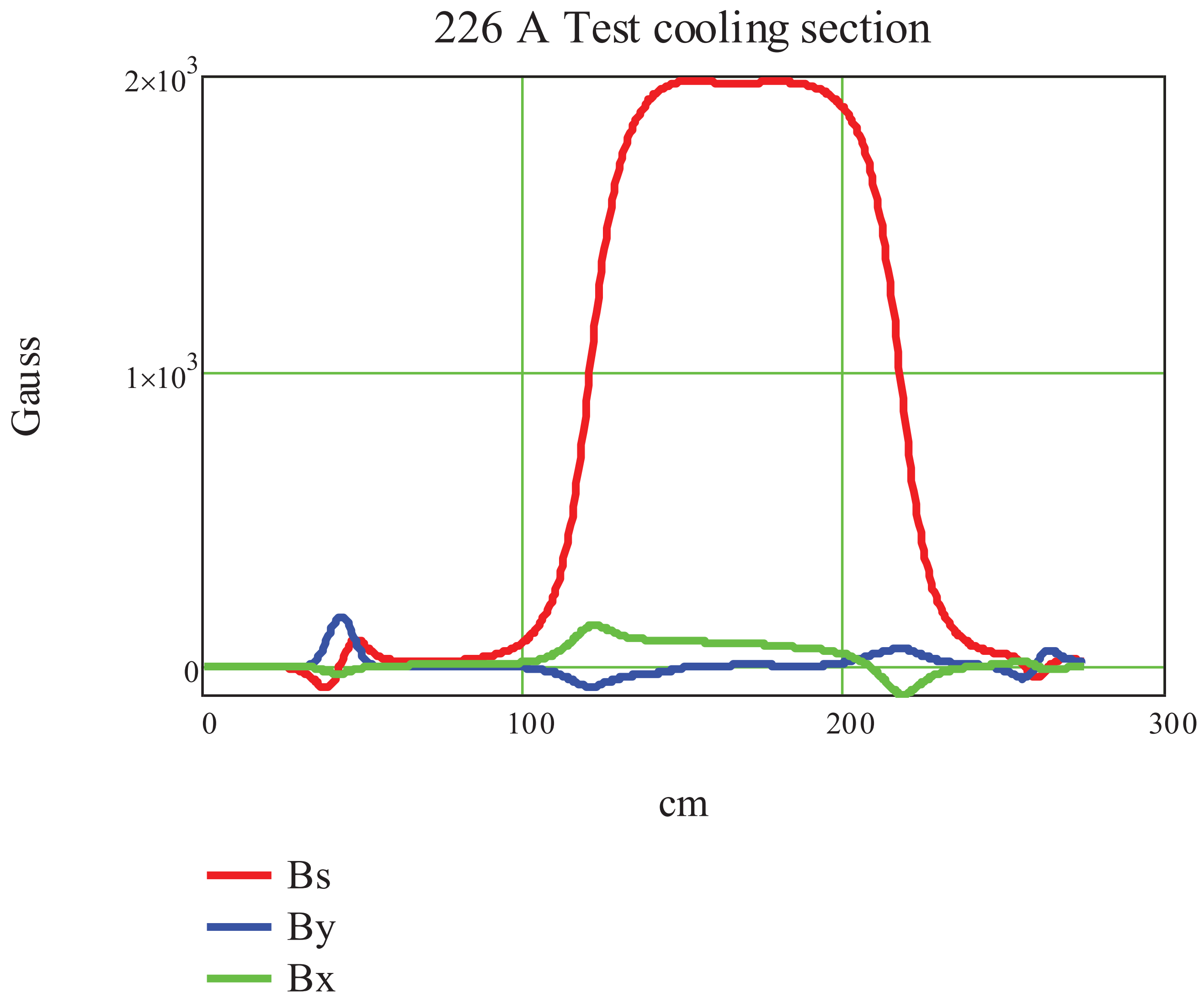
ID: 1521 Cooling commissioning results of first RF-based electron cooler LEReC, Alexei V. Fedotov (BNL, Upton, Long Island, New York) (remote report)

Main parameters cooler NICA

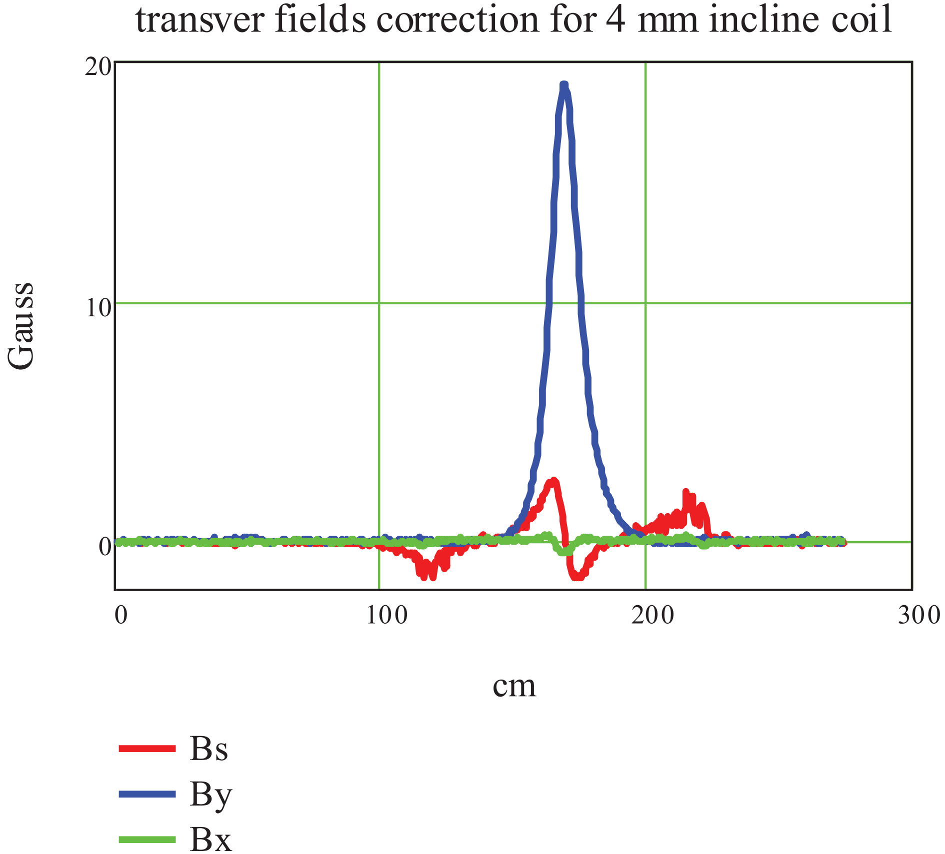
Parameter	Value
Energy range	0.2÷2.5 MeV
Number of the cooling section	2 for both beams
Stability of energy (ΔU/U)	$\leq 10^{-4}$
Electron current	0.1÷1 A
Diameter of electron beam in the cooling section	5÷20 mm
Length of cooling section	6 m
Bending radius in the transport channel	1 m
Magnetic field in the cooling section	0.5÷2 kG
Vacuum pressure in the cooling section	10^{-11} mbar
Height of the beam lines	1500/1820 mm
Total power consumption	500-700 kW

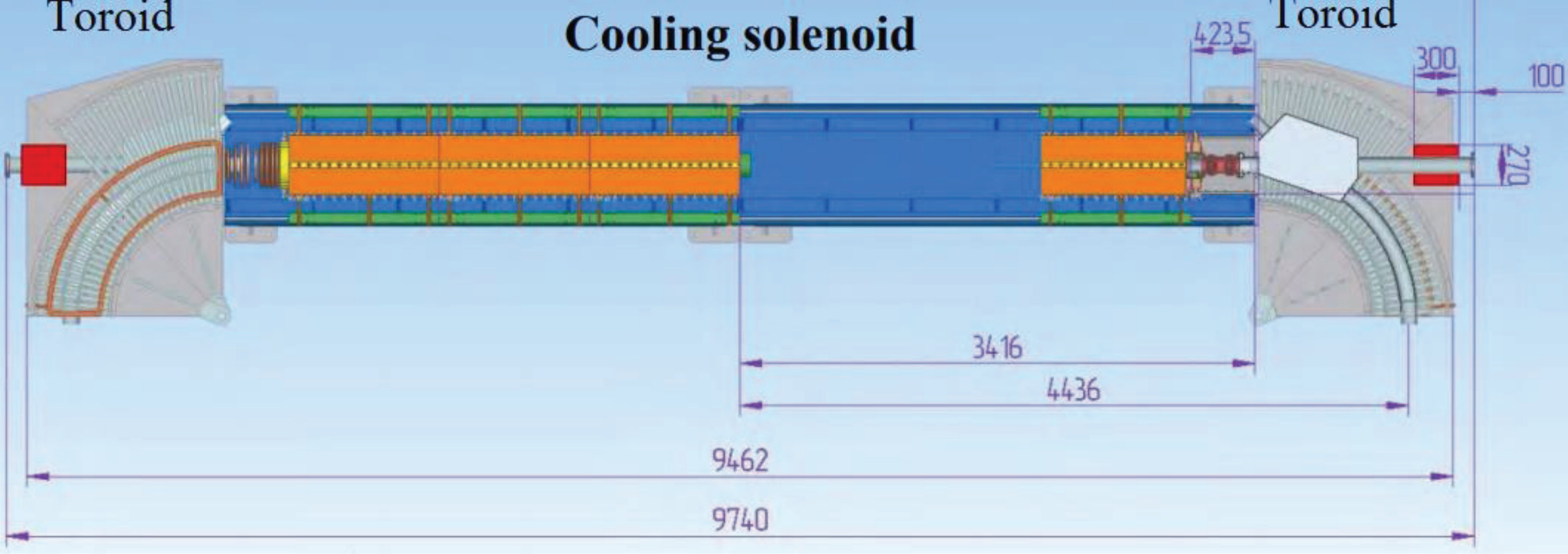


Prototype of cooling section at process of magnet fields measurement. Inside aluminum guide rail moved Hall probe with 3 D sensors of magnet field



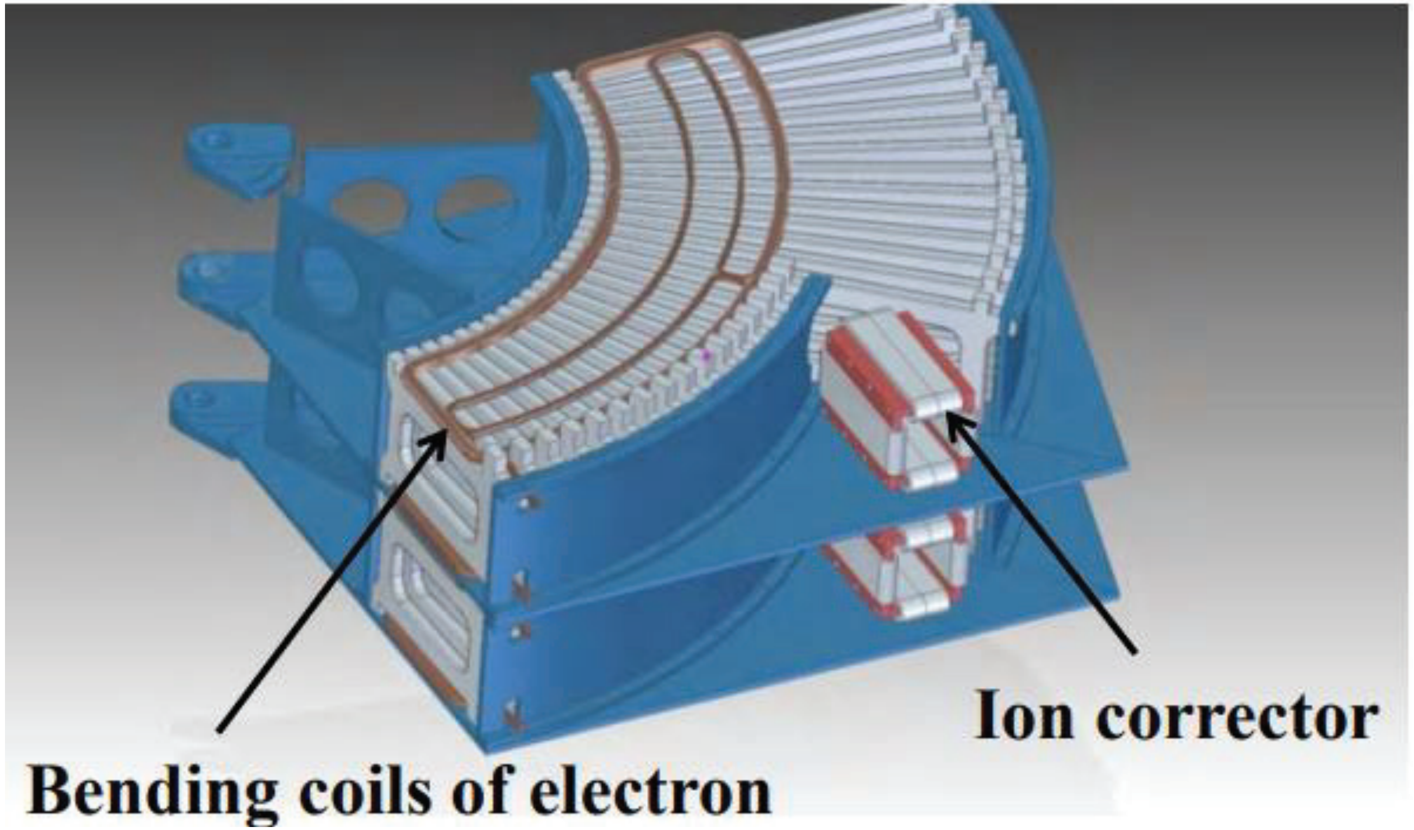
Prototype of 1m cooling results of magnet fields measurements
With current 226 A.
Transverse components is results of offset from axis Hall probe. Transverse components possible to compensate with using incline coils as show figure:



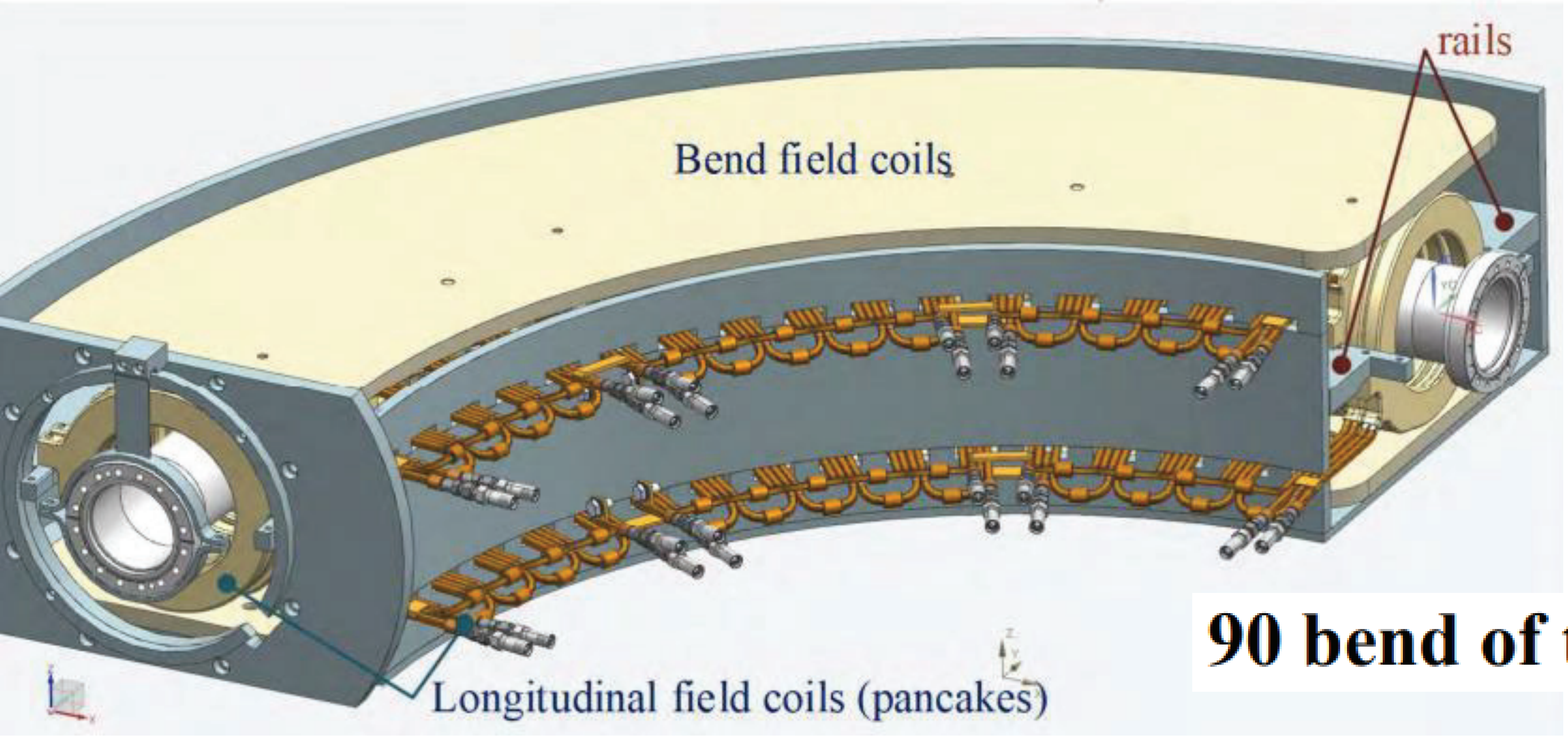


Design of cooling section NIKA cooler

Toroid section

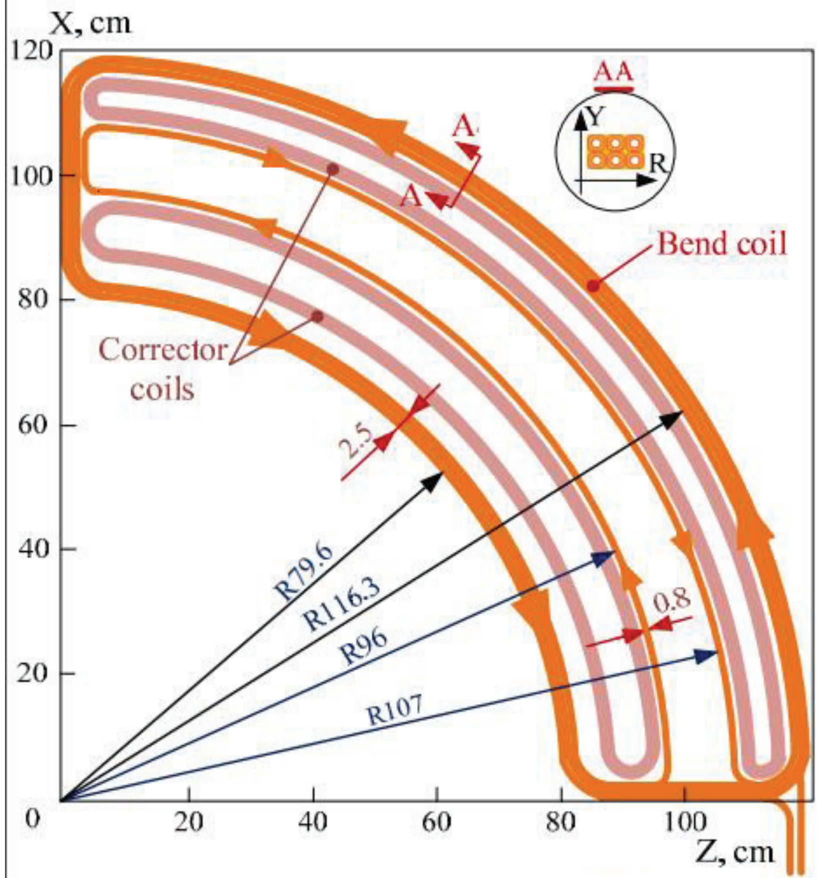


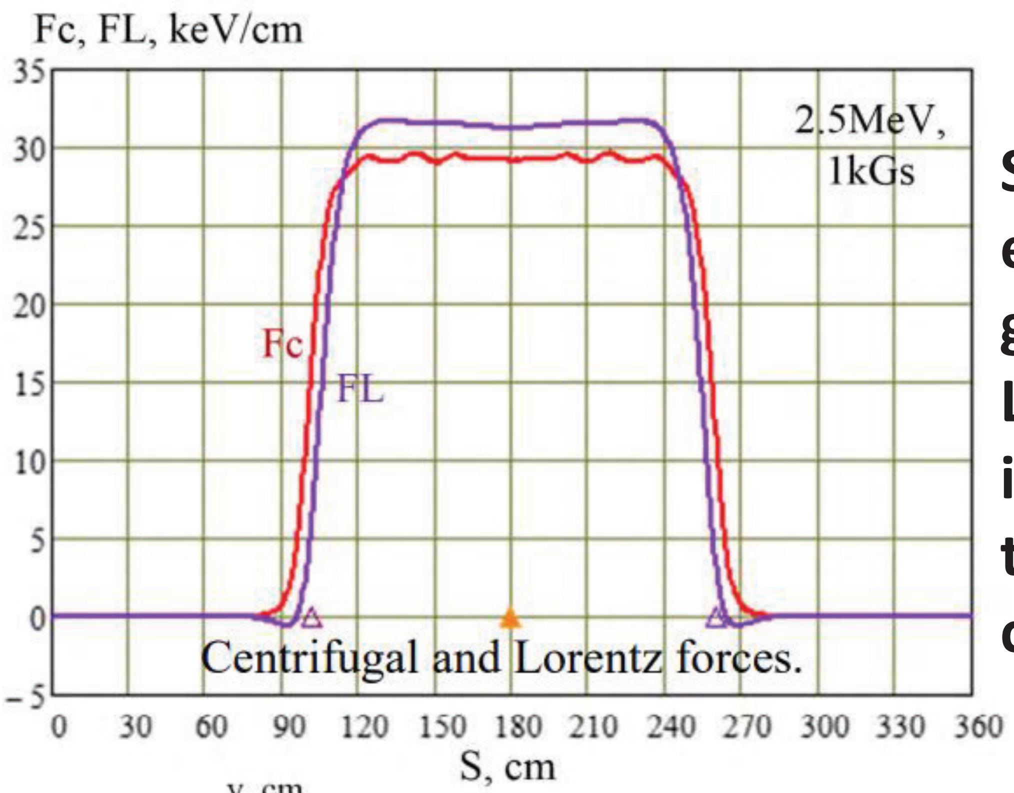
Toroid is the most complicated place where meet together two beam lines: electron and ion. Moreover the ion corrector should be located in this place. Also the it is place for vacuum pumps. The coils for bending field is placed on the toroid side. The power consumption is restricted so the coil should contains maximum value of copper. In addition to all problem two electron beam should be located with distance 32 cm.



90 bend of transport channel

Another problem place is the bending magnet of the transport channel. The problem is similar to toroid section. Two transport line is located together, there is lack of space. The power consumption is restricted and amount of copper should be maximum.

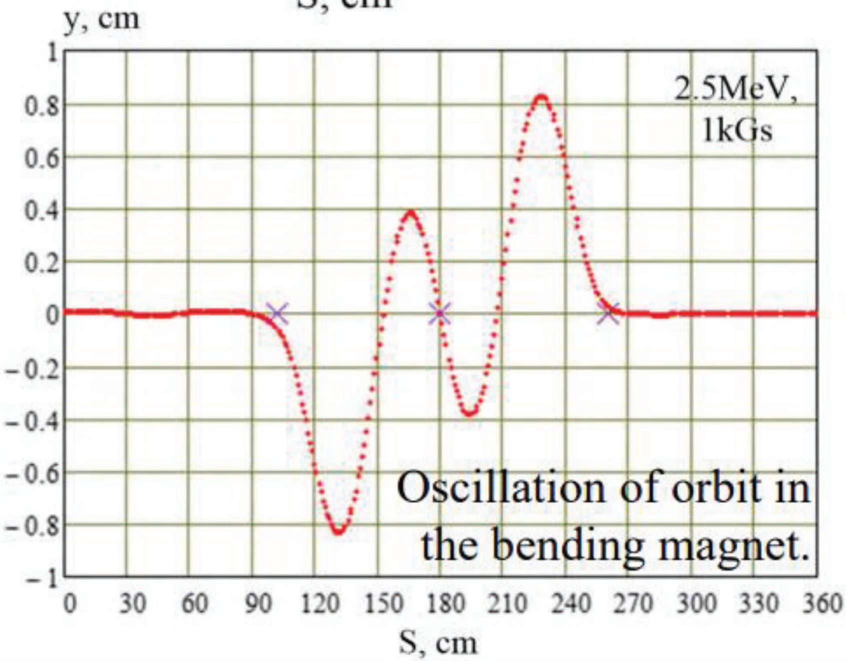




Centrifugal and Lorentz forces.

Small deviation of electrons orbit can generate fast Larmor osciallations in electron beam that will decrease cooling rate

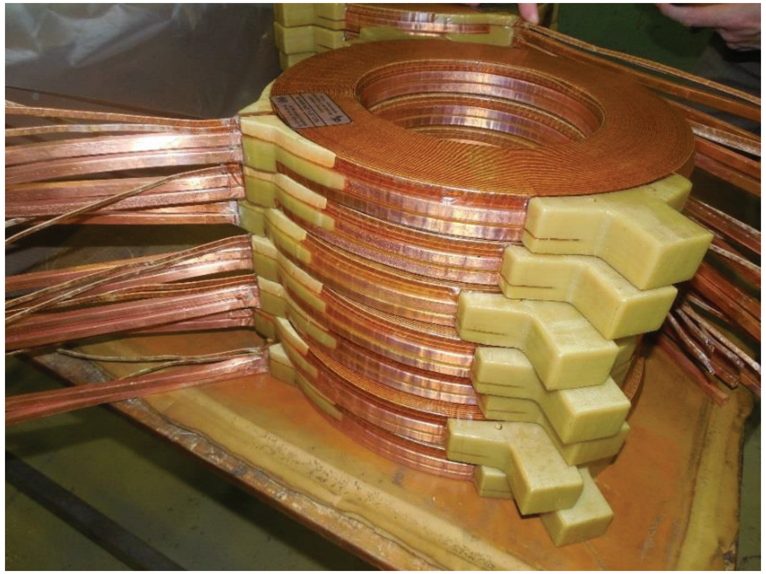
The curve of the bending field should be very close to the centrifugal force. In this case the oscillation of the transverse motion of electrons is minimal. Also field index n=0.5 is required in order to prevent changing transverse shape of the electron beam. The field index is produced with help of bend coils with special shape.

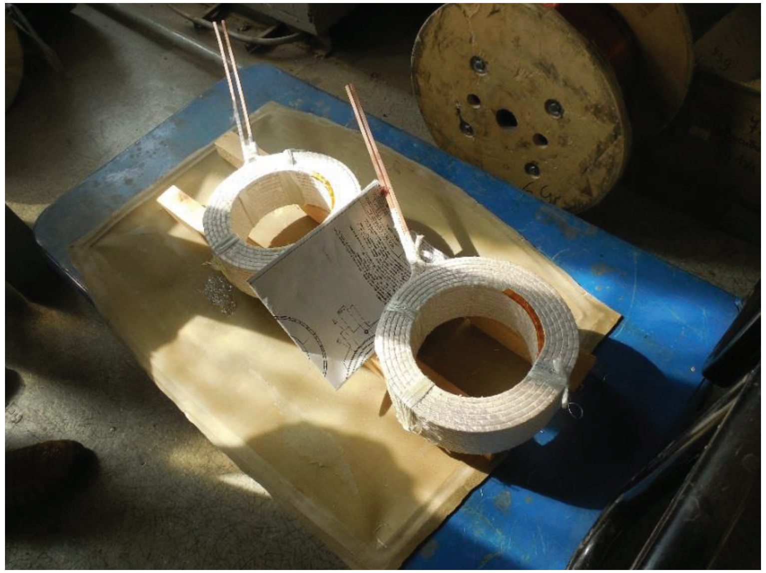


Oscillation of orbit in the bending magnet.

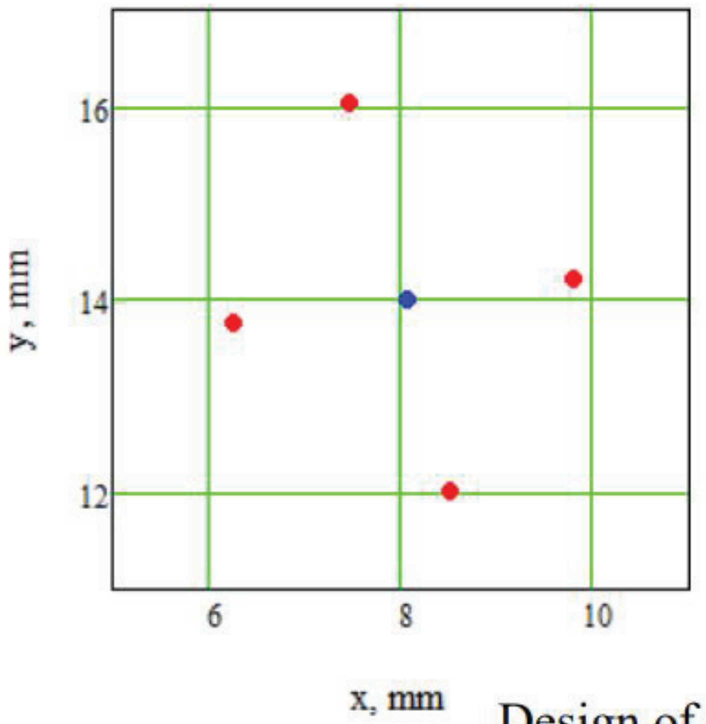
Production of magnetic elements

Production of magnetic elements

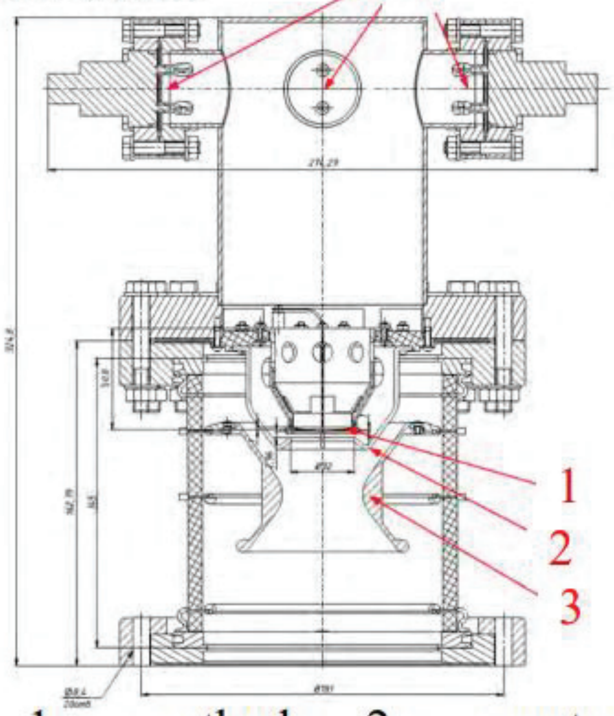




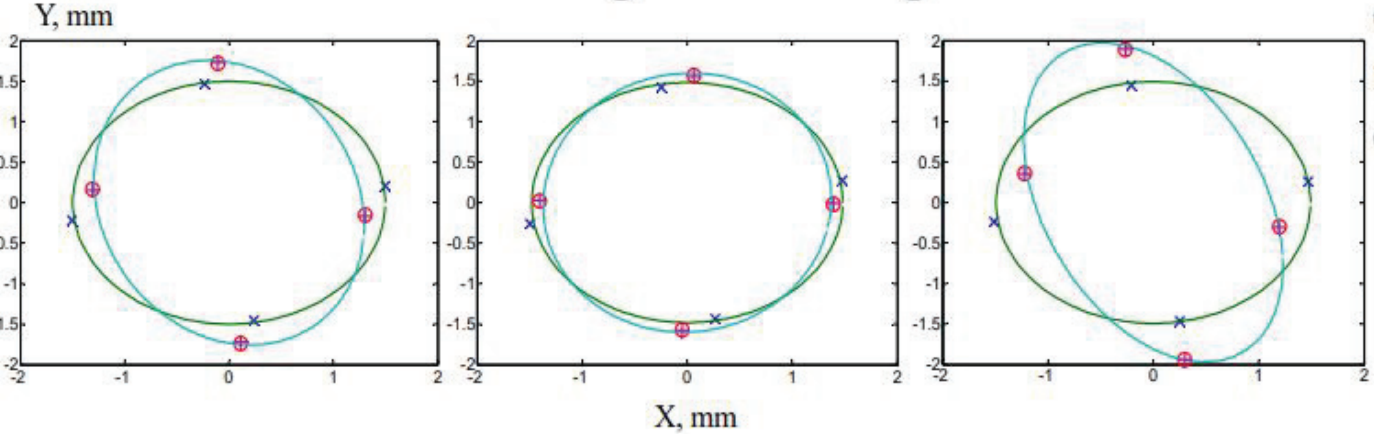
Diagnostics of the shape of the electron beam



Design of electron gun with 4 sector .



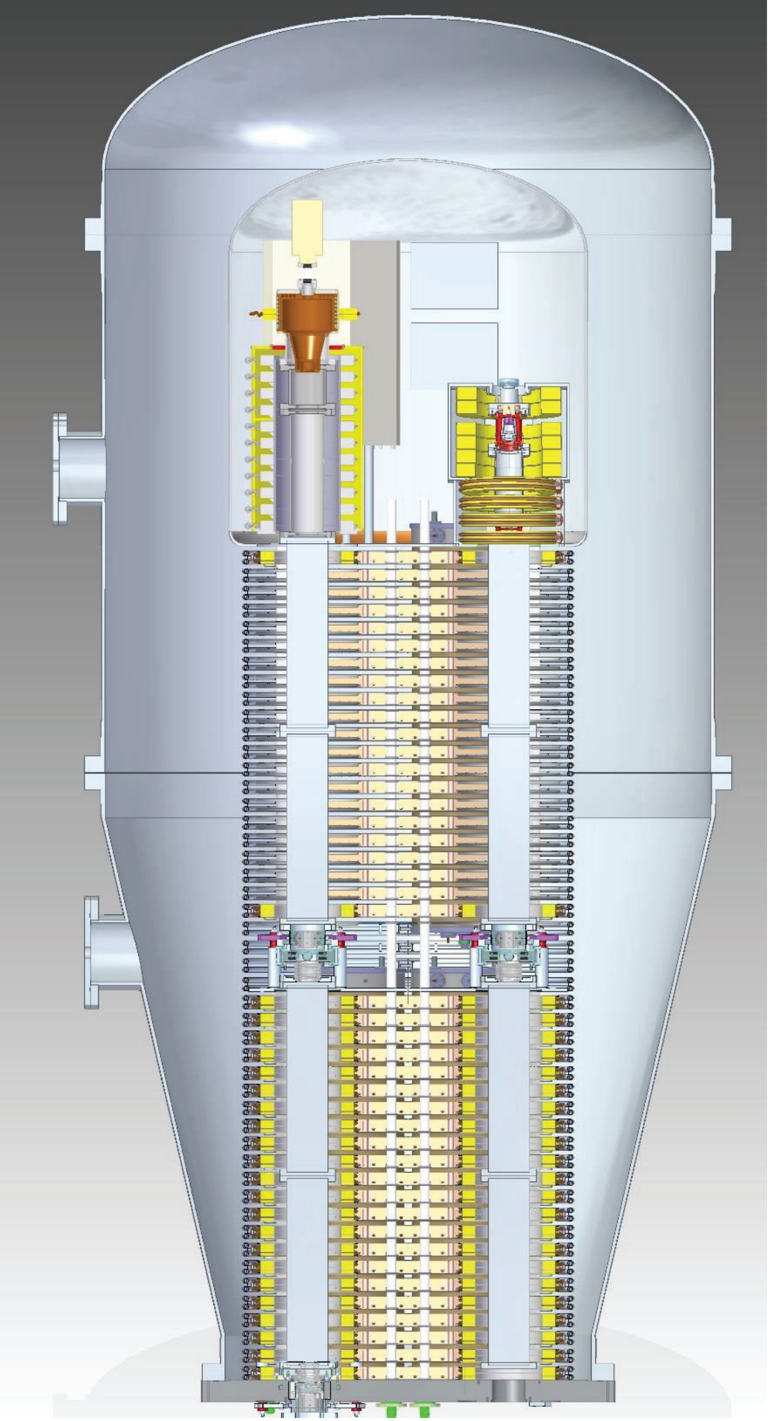
1 – cathode, 2 – control electrode, 3 anode, 4 – feedthrough for filament and control electrodes.

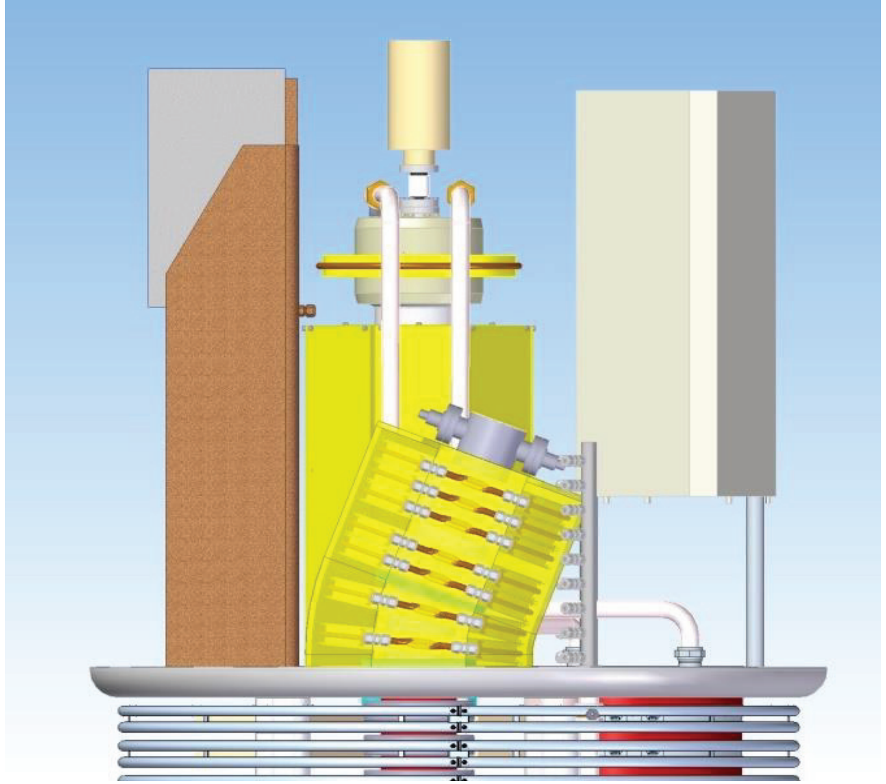


X is first BMP, O is last BPM.

Response of the beam shape induced by quadruple component of the bending magnet (n=0.5 and n≠0.5) . The experimental result from COSY cooler, energy Ee=910 keV.

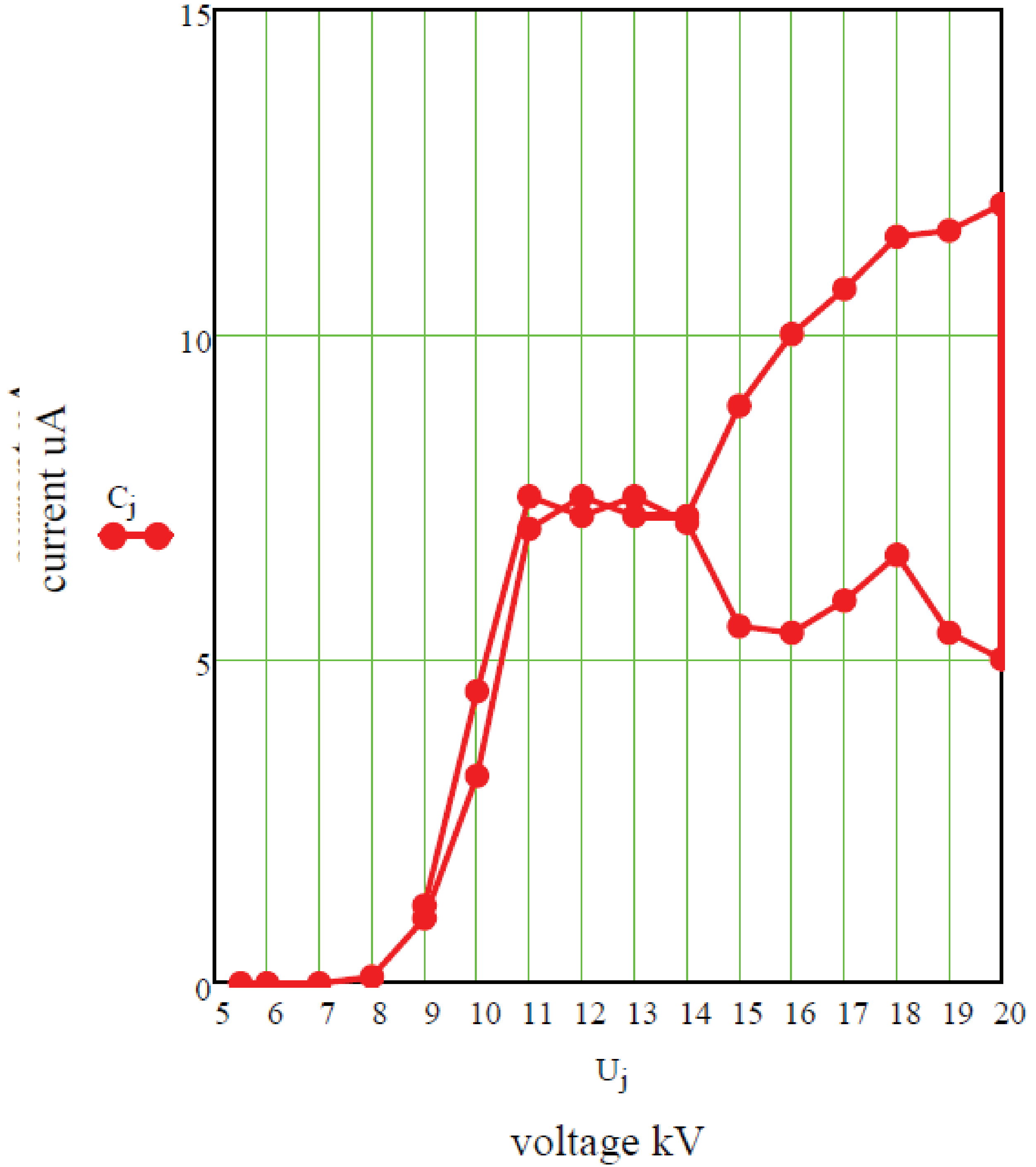
Design of the electron gun is the same as COSY cooler. Gun will modulated 5 beams at the transverse profile of electron beam. This will open possibility of detecte not only dipole shifting of beams but and quadrupole motion of elements of the electrons beam. With using this idea BPM became sensitive to space charge in electron beam. Easy detected the ions capture from the residual gas inside electron beam, beam size,…



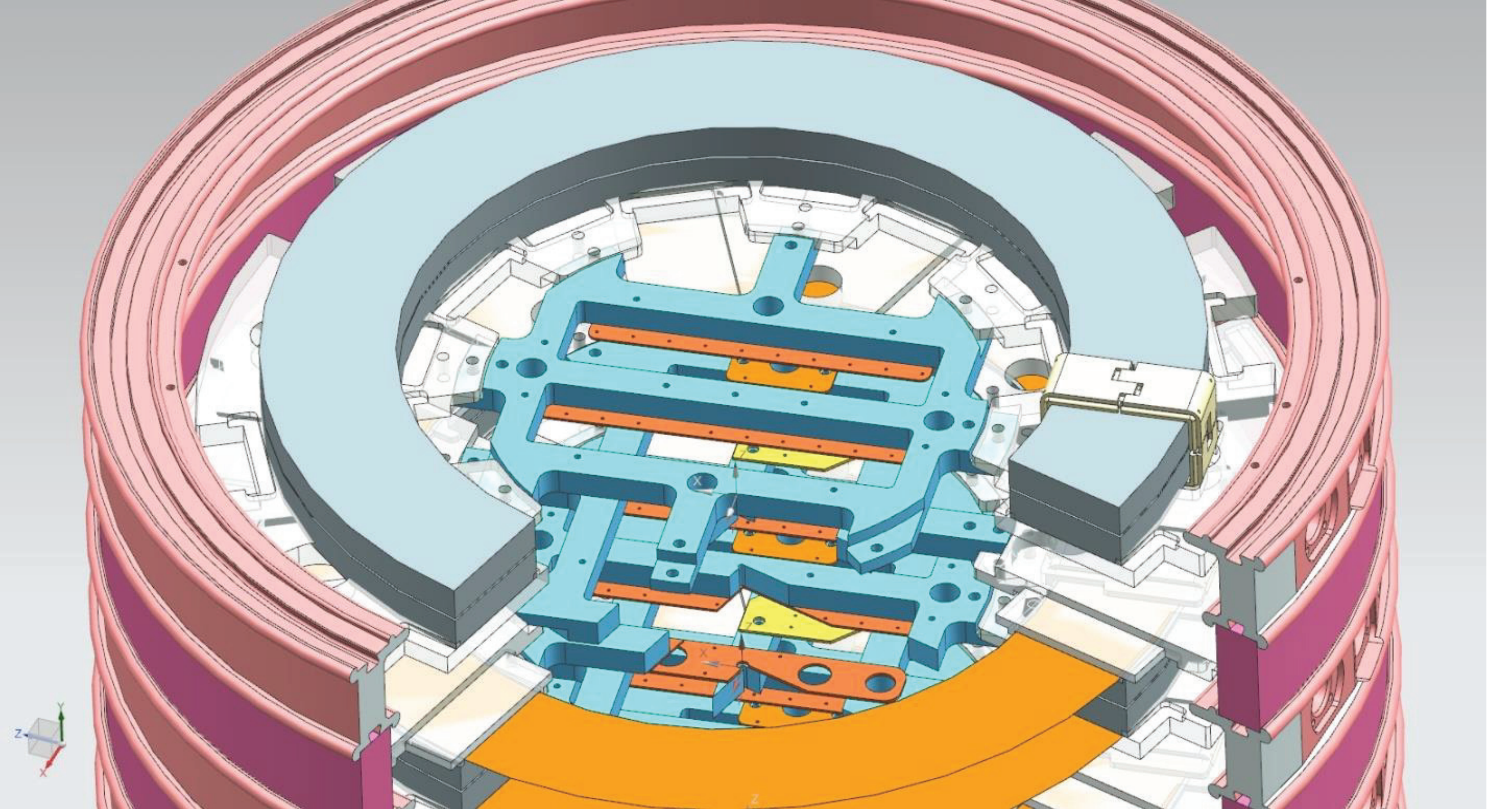


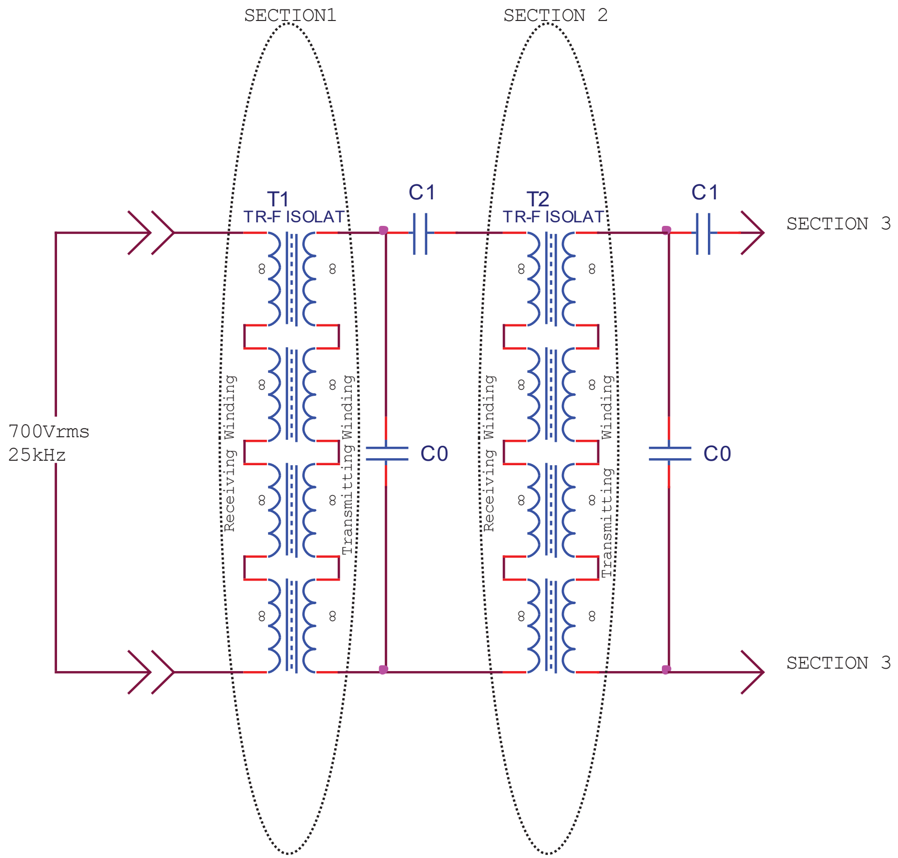
The vessel for 2.5 MV electrostatic colon p<10bar SF6.
The electron gun and collector inside HV terminal
The electron gun with low energy bending for protection the cathode from secondary ion beam bombarding.
The collector equipped filter with crossing electrostatic and magnet fields for suppression 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*40sect=
For 40 sections limit 3.2 MV
With corona current less 5 uA





Cascade transformer for powering
40 sections along electrostatic column.
COOL19:
ID: 1562 The Cascade Transformer for the High-Voltage Electron Cooling System for the NICA Collider, Andrey Petrovich Denisov (BINP SB RAS, Novosibirsk)

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

Rloss=1Ohm/section

U=1000V, J=70 A

W=35 kW

Wloss=250 W/section

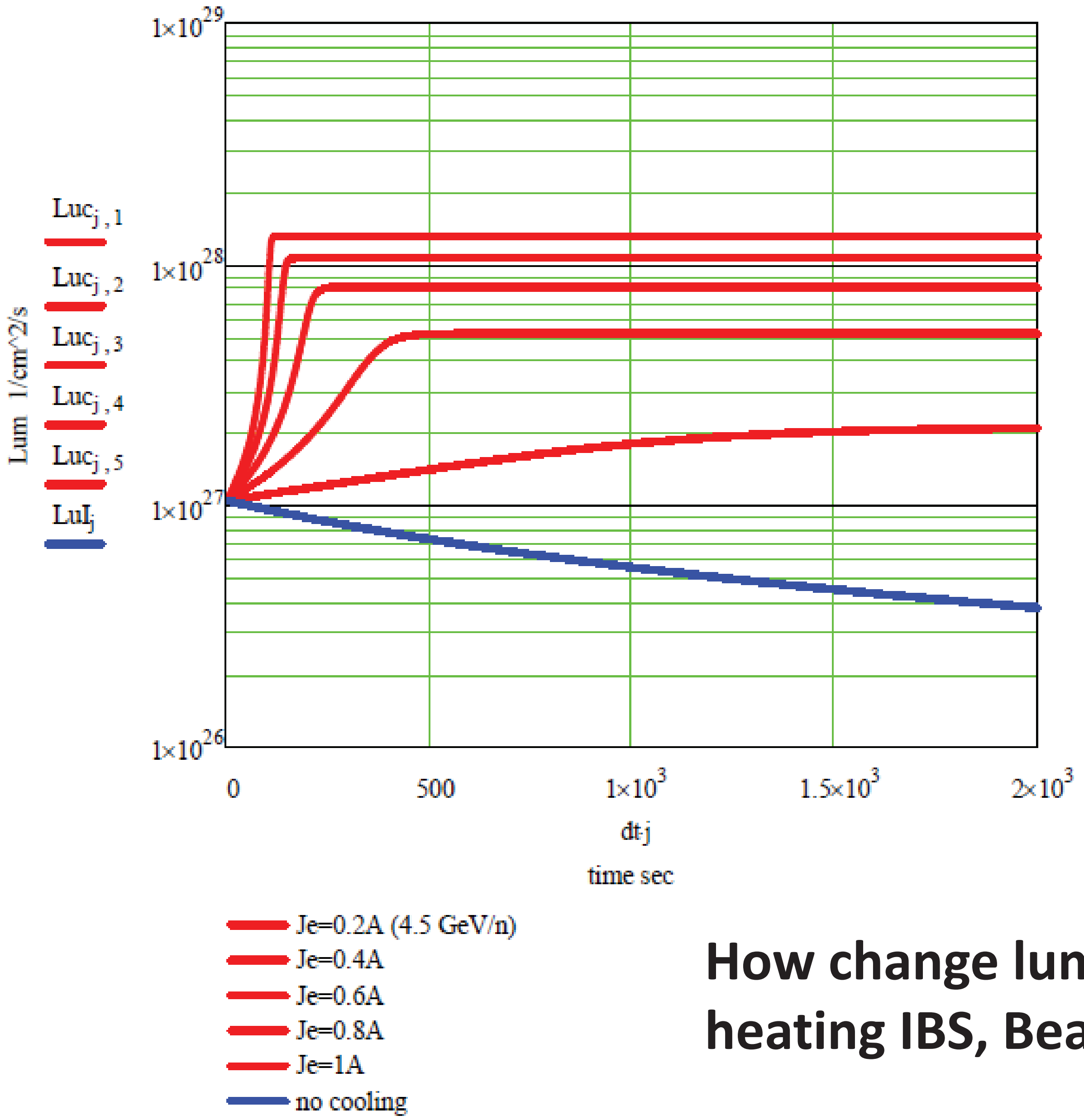
20 kHz

The acceleration tube for NICA cooler under vacuum condition testing.

COOL19, ID: 1581 Vacuum Systems for the Coolers of the NICA Project, Alexander Bubley (BINP SB RAS, Novosibirsk)

The vessels for high voltage colons ready for using

Conclusion



Simplest model electron cooling and IBS for NICA Easy see more then 10 times increasing luminosity. It depends of the initial number ions. For smaller number gain from initial luminosity will be large

How change luminosity NICA if cooling will compensated heating IBS, Beam-Beam effects. (For optimistic calculation)

NICA hall for detector

Hall for cooler 2.5 MV →
Vladimir Reva wait arriavel
2.5 MV cooler for commissioning
at 2020 year (if we're lucky).

Thank you for attention!