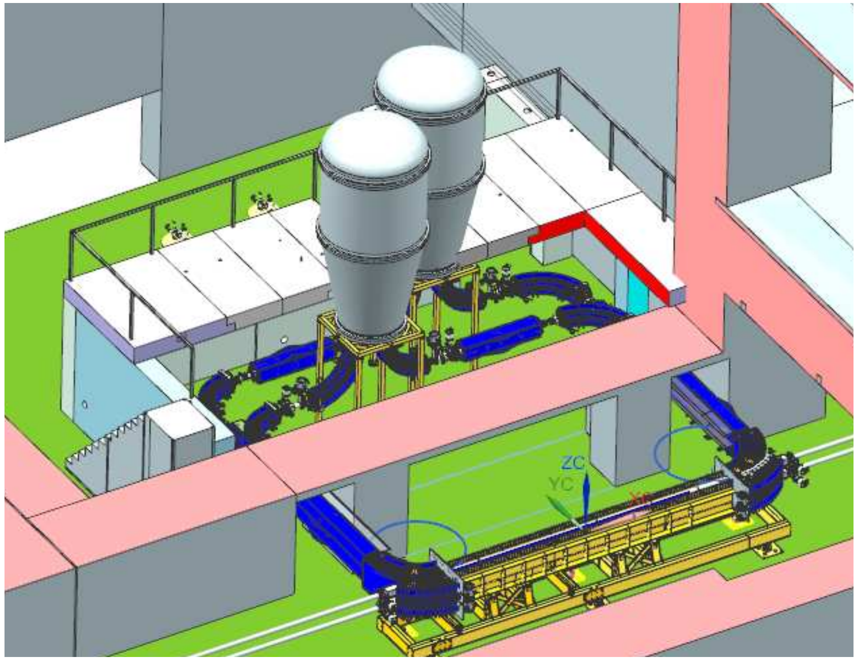
Electron cooling at the Collider

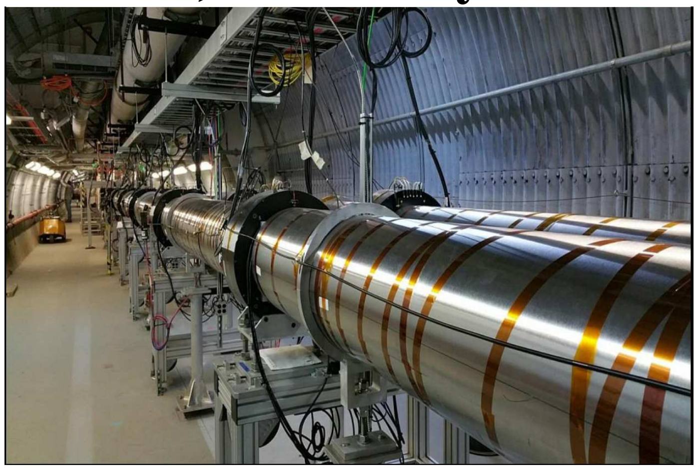
V.V. Parkhomchuk, V.B. Reva and BINP team

COSY, Germany



NICA, BINP&JINR, Russia

FERMILAB, USA



LERec, cooling section, BNL

online MAC
Dubna - Novosibirsk,
27-30 May, 2020

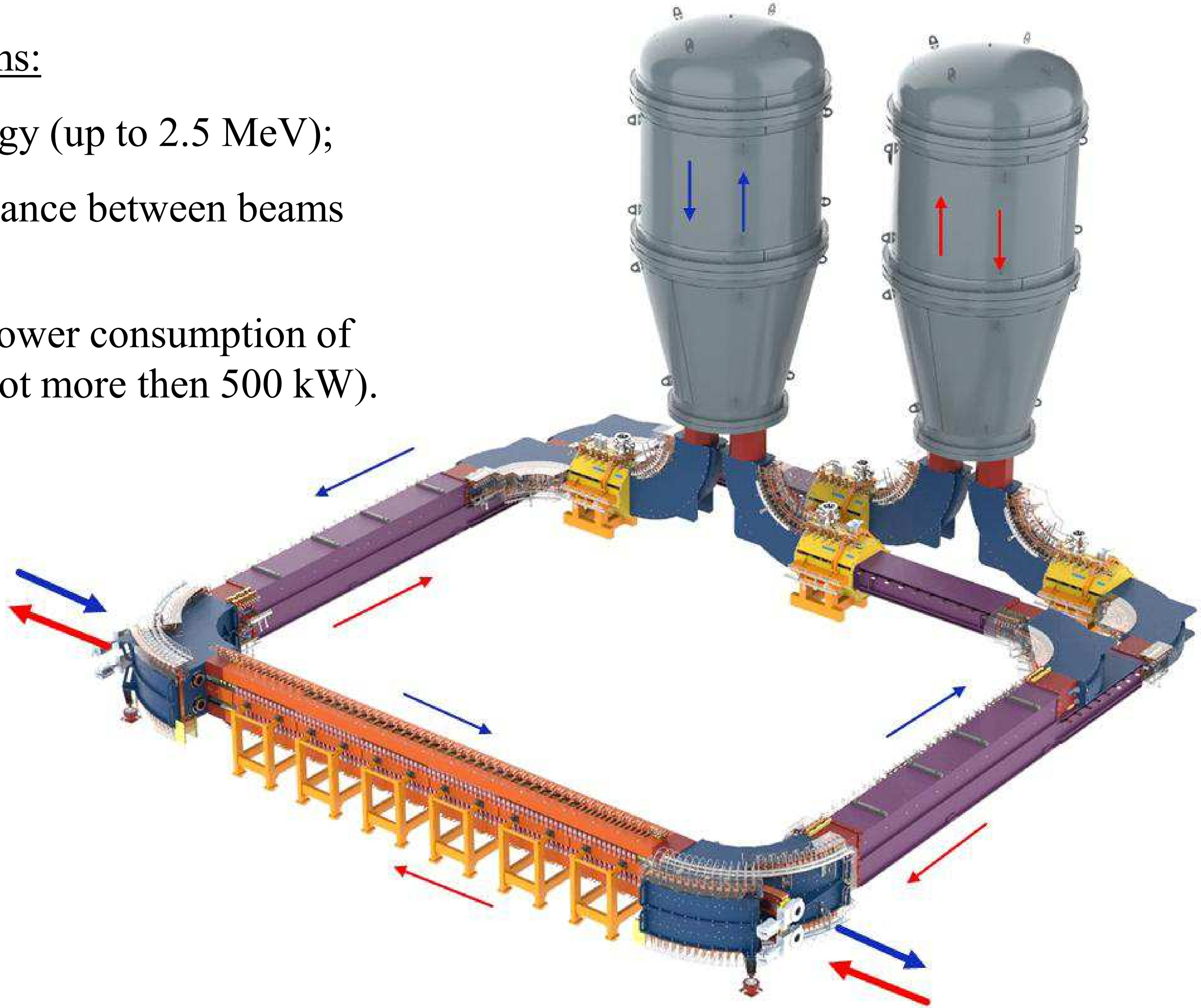
The new accelerator complex NICA is designed at the Joint Institute for Nuclear Research (JINR, Dubna, Russia) to do experiment with ion-ion and ion-proton collision in the range energy 1-4.5 GeV/u. The main regime of the complex operation is ion collision of heavy ion up to Au for study properties of dense baryonic matter at extreme values of temperature and density. The planned luminosity in these experiments is 10^{27} см$^{-2}\cdot$с$^{-1}$. This value can be obtained with help of very short bunches with small transverse size. This beam quality can be realized with electron and stochastic cooling at energy of the physics experiment.

The subject of the report the electron cooling for collider in the energy range between 0.2 and 2.5 MeV.

Cooler for the NICA collider

Main problems:

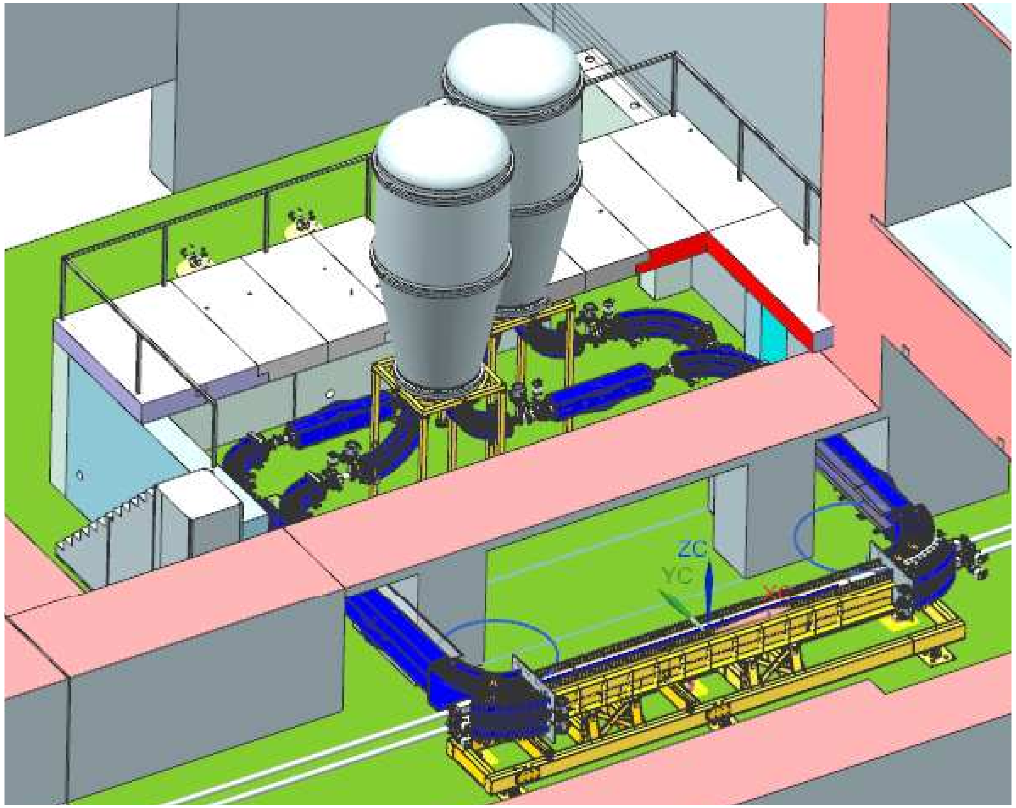
- High energy (up to 2.5 MeV);
- Small distance between beams (320 mm);
- Limited power consumption of the system (not more then 500 kW).

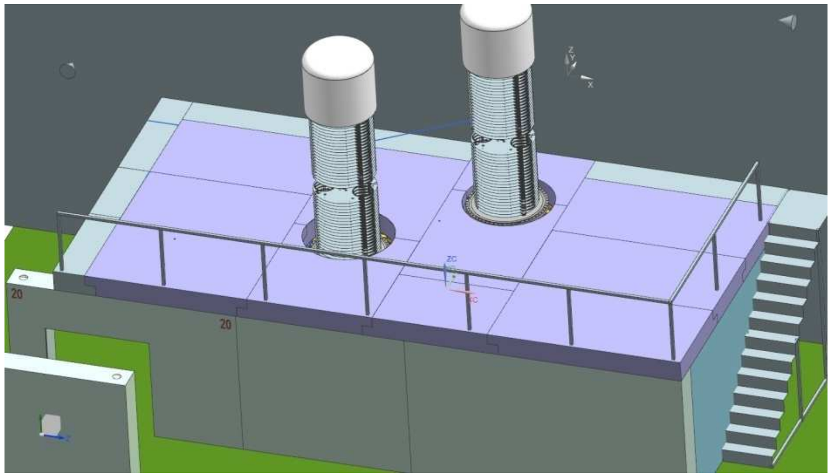


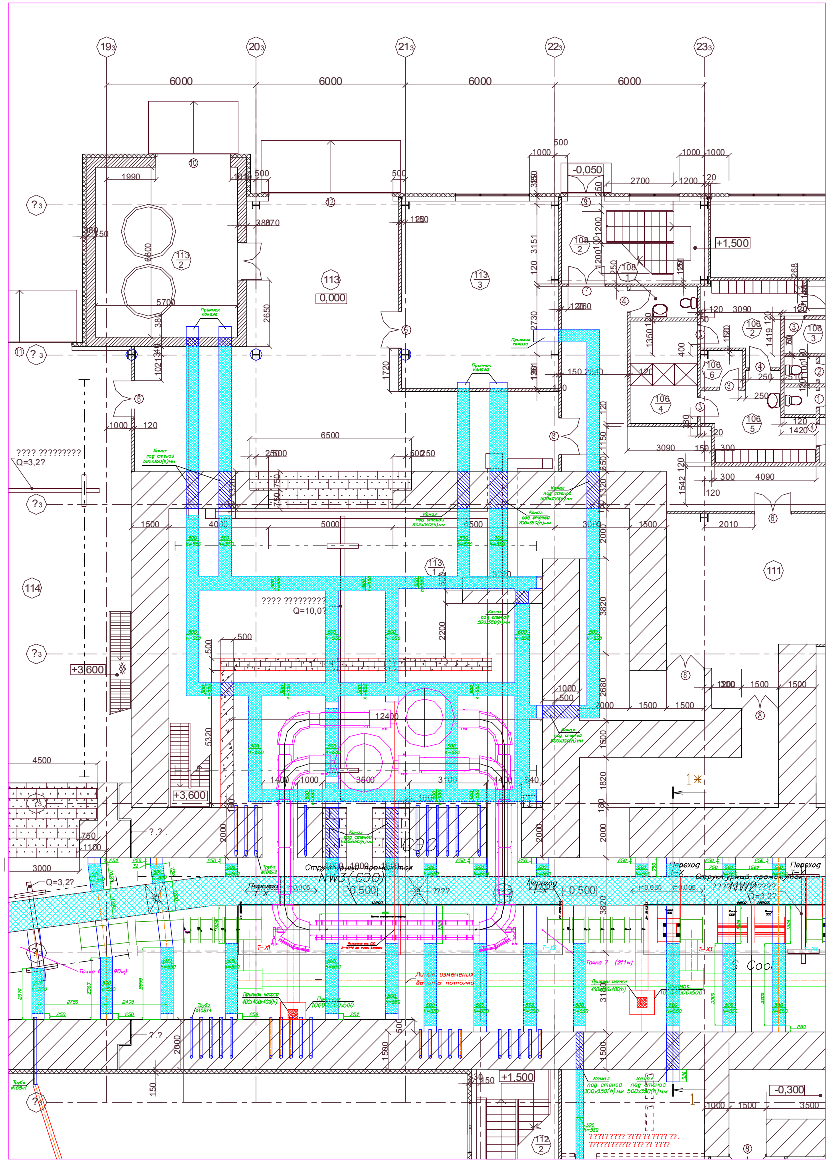
Main parameters of electron cooler for NICA collider

Parameter	Value
Energy range	0.2÷2.5 MeV
Number of the cooling section	2
Stability of energy ($\Delta U/U$)	$\leq 10^{-4}$
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	1340/1660 mm
Total power consumption	500-700 kW

2.5 MeV electron cooler – integration into NICA collider

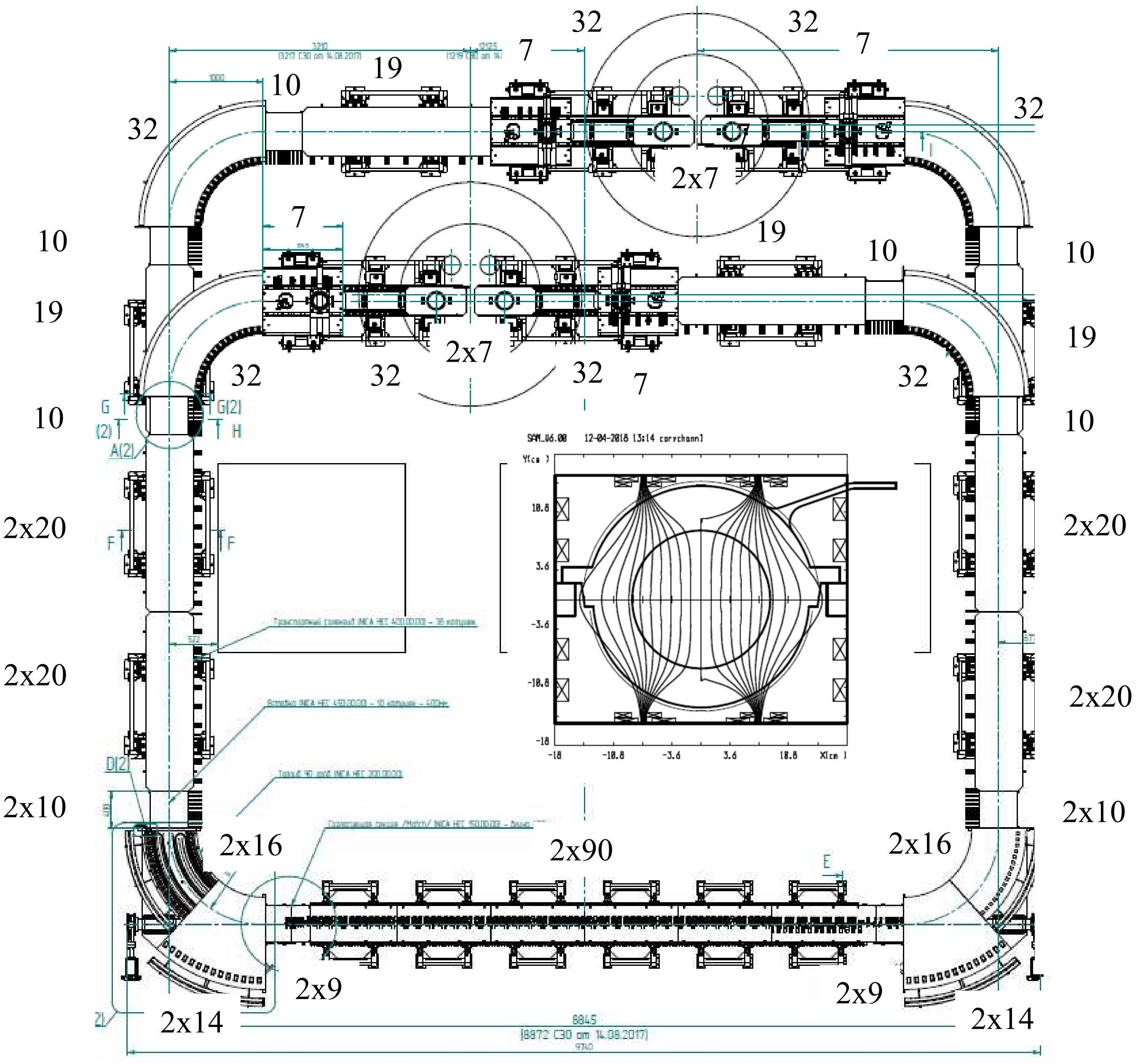






Low energy electron cooler is installed in Booster. The next step is high-voltage cooler for NICA collider

Magnetized motion requires the longitudinal field along whole trajectory



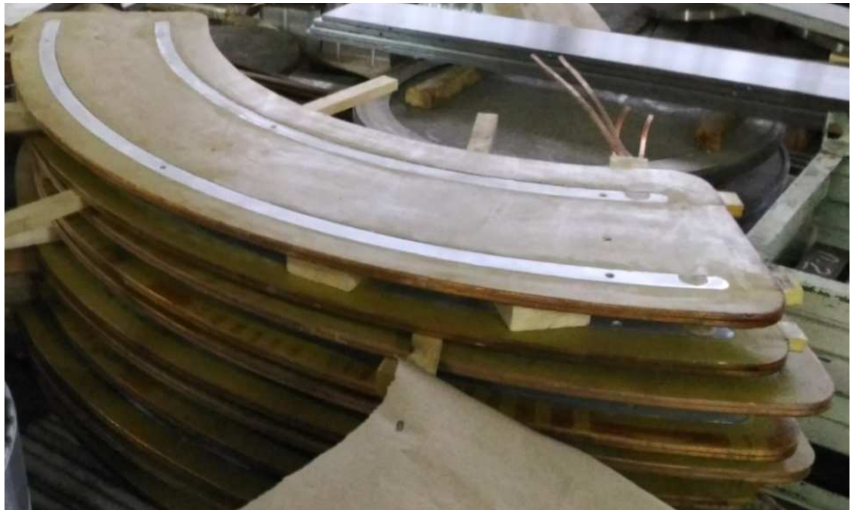
Longitudinal magnetic field

Cooling section –	180
Small toroids coils –	66
Large toroids coils –	60
Match sections –	48
Insert section –	110
Line transport section –	250
Bend section –	260
Line08 –	30
Hmatch section –	28
High Voltage Section –	90
HV Terminal –	23
Total	**1145**

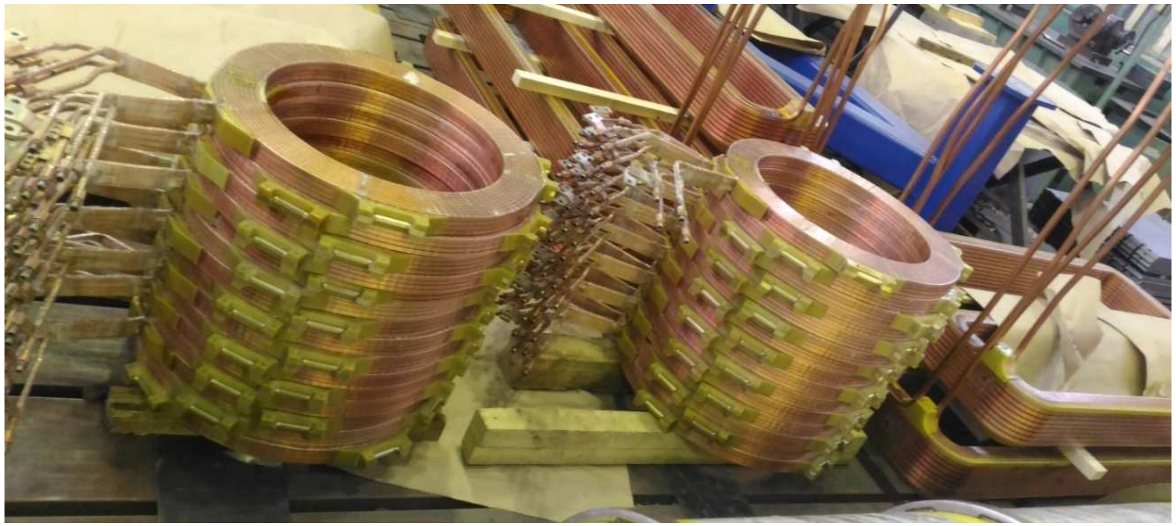
Type of coil types for longitudinal magnetic field is about 20

And plus many correctors coils of the vertical and horizontal magnetic fields

Process of coils production and testing



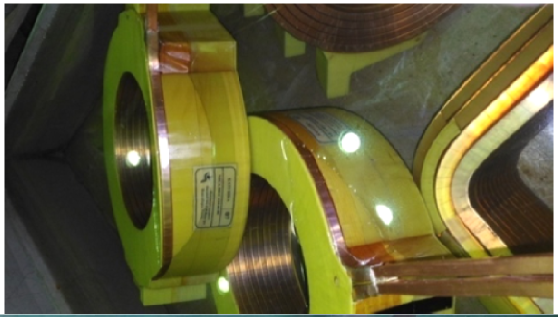
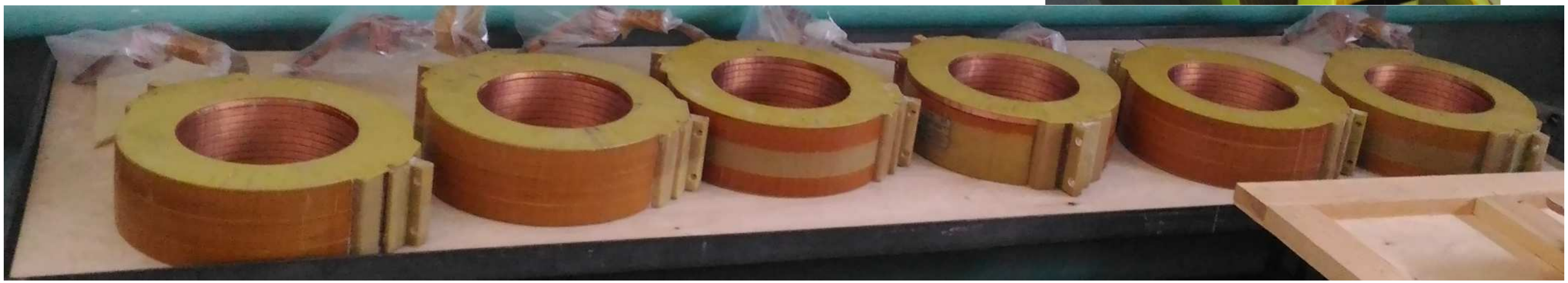
Process of coils production and testing



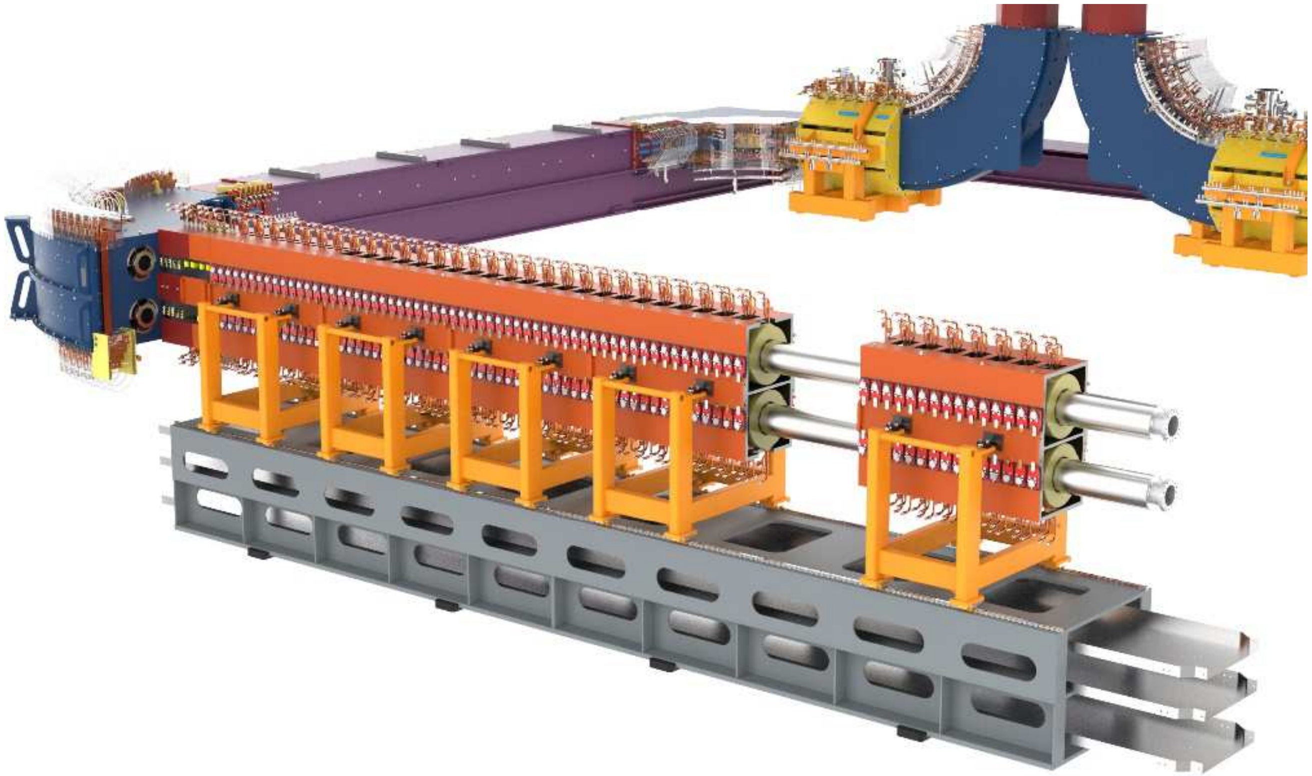
Process of elements production





Cooling section

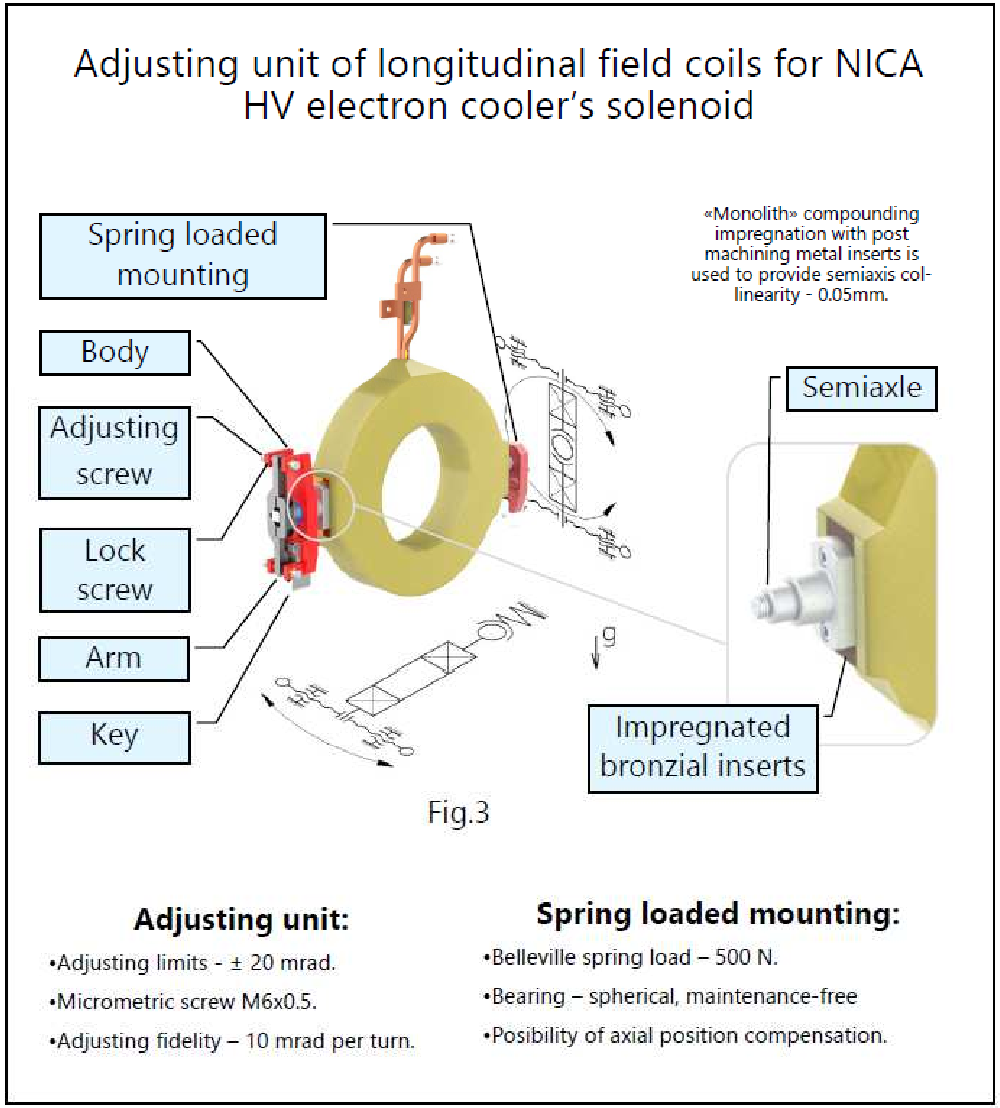


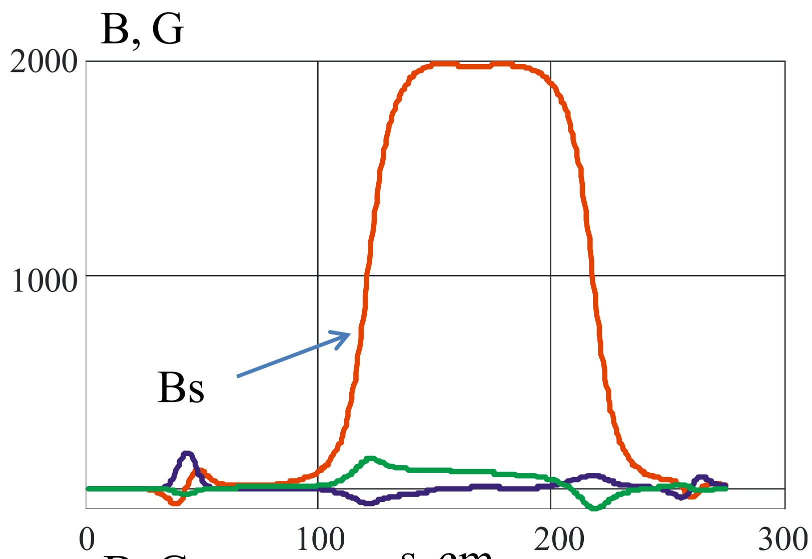
Section length 6 m. The section consists of 6 modules. Each module contains two solenoids with 15 coils of longitudinal field and dipole correctors.

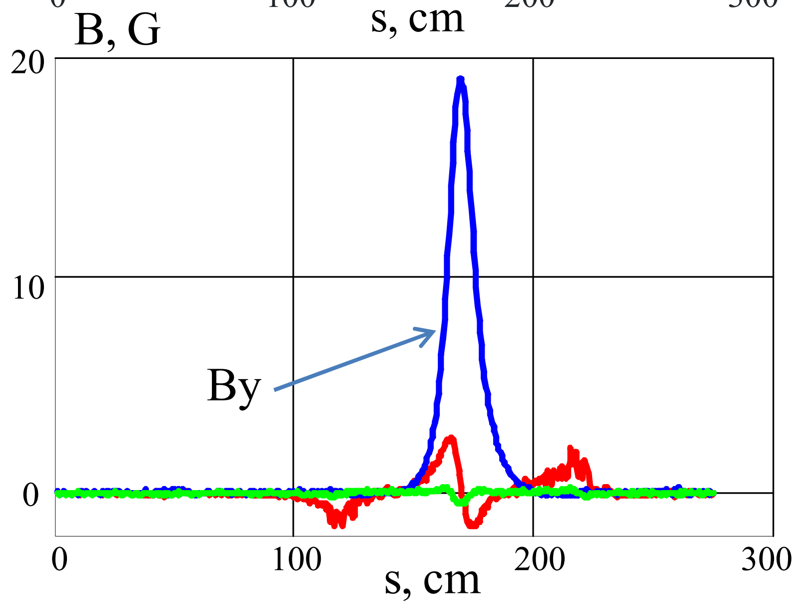
Results of magnet fields measurements with current 226 A. Transverse components is results of offset from axis Hall probe.

Transverse components possible to compensate with using incline coils as show figure:

Ecool -19, Novosibirsk, Russia

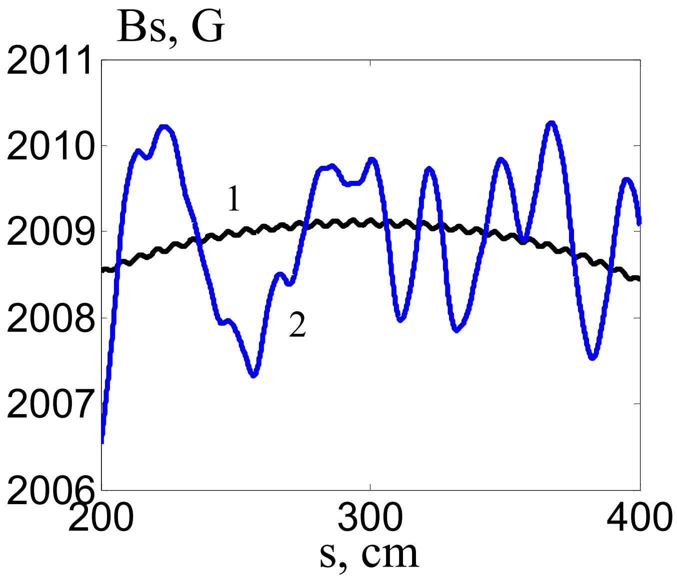


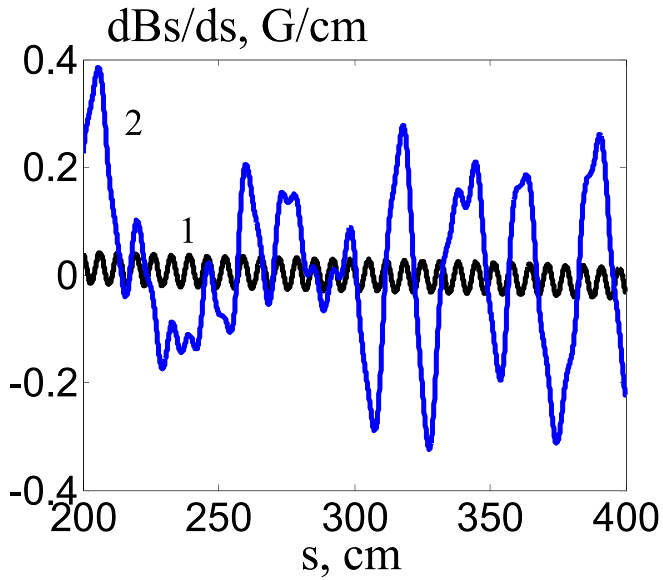




Error in longitudinal position

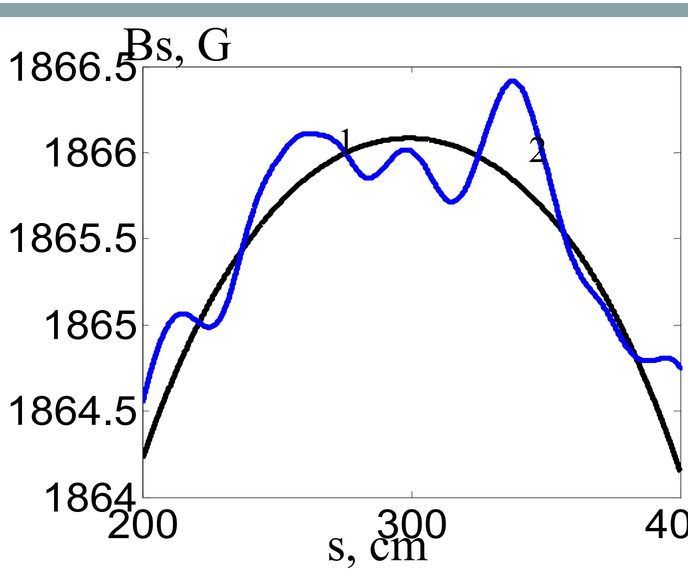
Small size of coils leads to pay attention to the longitudinal position of coils

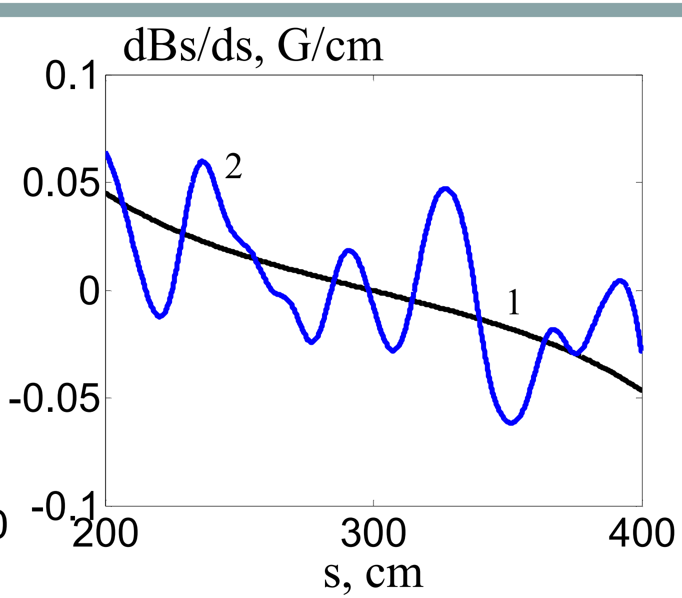




DUBNA HV cooler
A=11.55 cm
h=6 cm
hstep=6.6 cm

Field error for variant 2
in area r=±0.5 cm
θ_B(rms)=$2\cdot10^{-5}$





COSY
a=21.25 cm
h=6 cm
hstep=6.65 cm

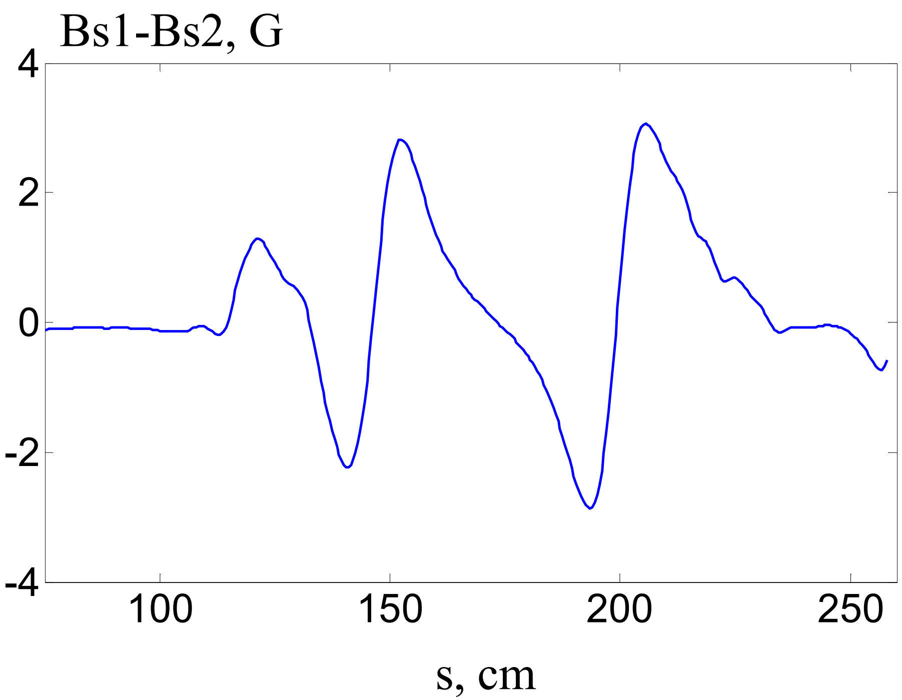
Field error for variant 2
in area r=±0.5 cm
θ_B(rms)=$0.5\cdot10^{-5}$

1 – ideal position of coils, 2 – random change position of coils with maximum values ±0.2 mm

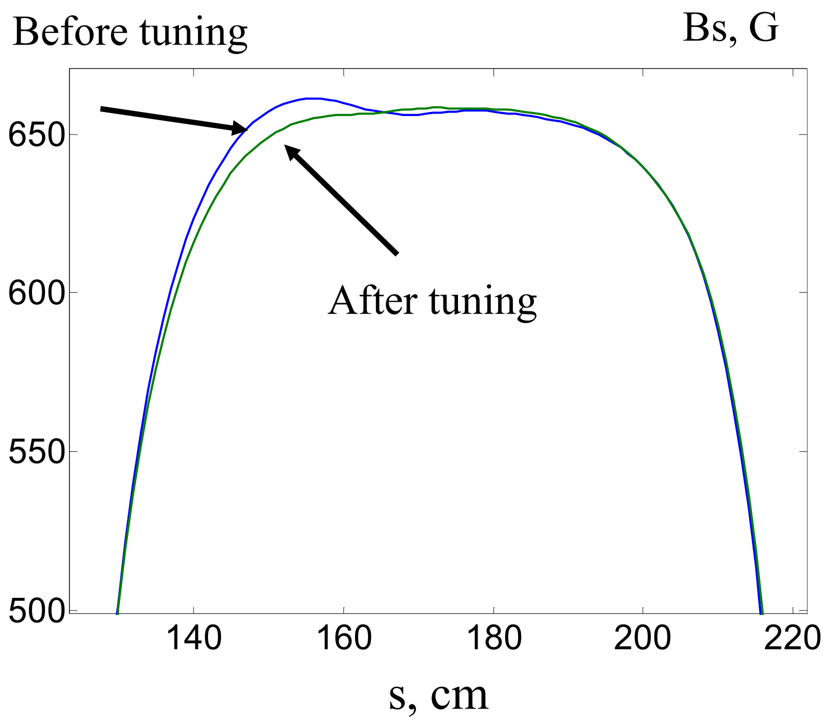
But the sensitivity of the Hall measurement system is enough for visualization error in the longitudinal position of coils.

It may be useful for obtaining large area with good field quality. The magnetic force line will be straight in the solenoid center with help of coils incline. But the variation of the value of longitudinal magnetic field leads to the transverse magnetic field on some distance from axis in paraxial approximation. So we should pay attention to longitudinal position of the coils.

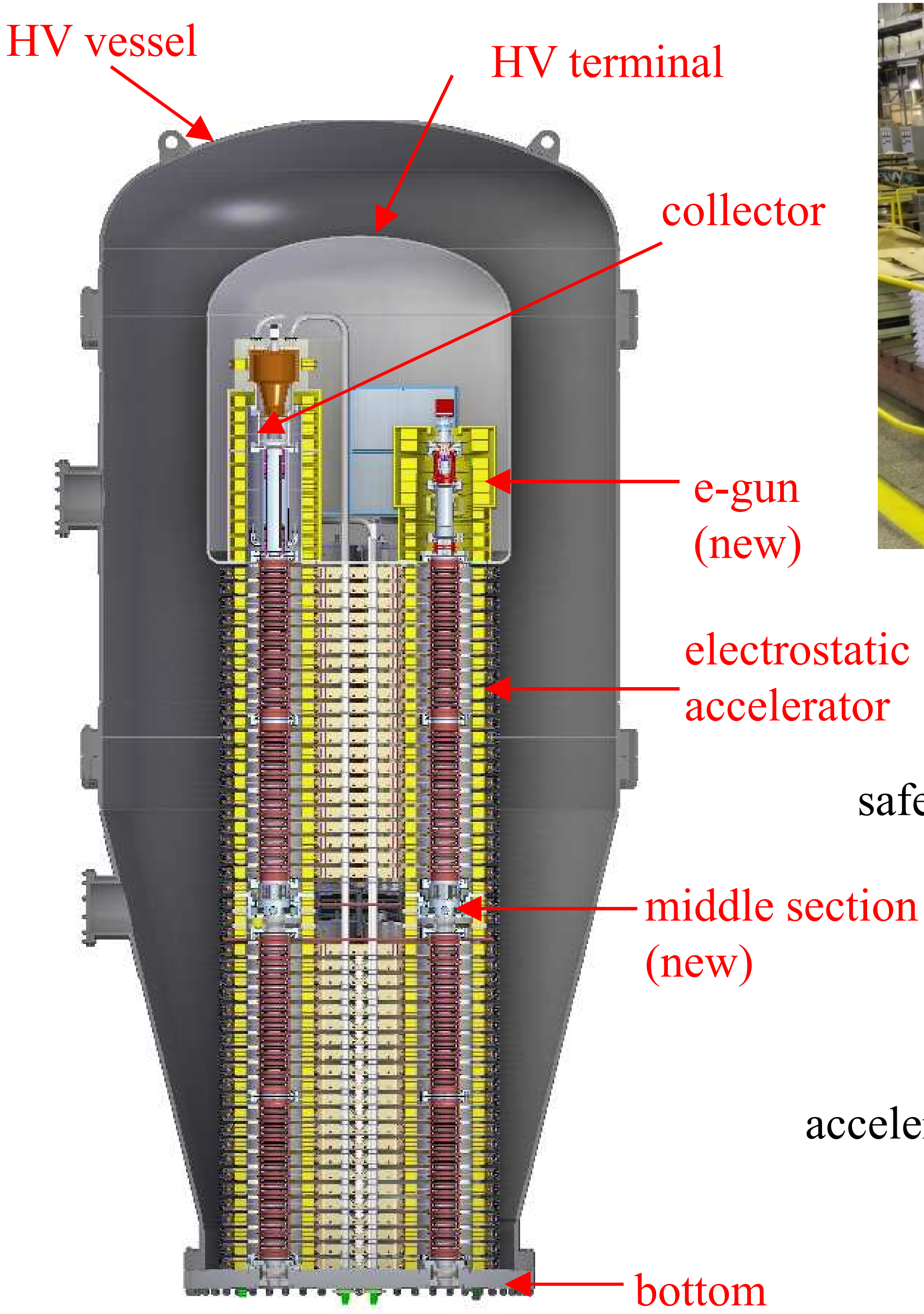
Response on longitudinal shift of two coil

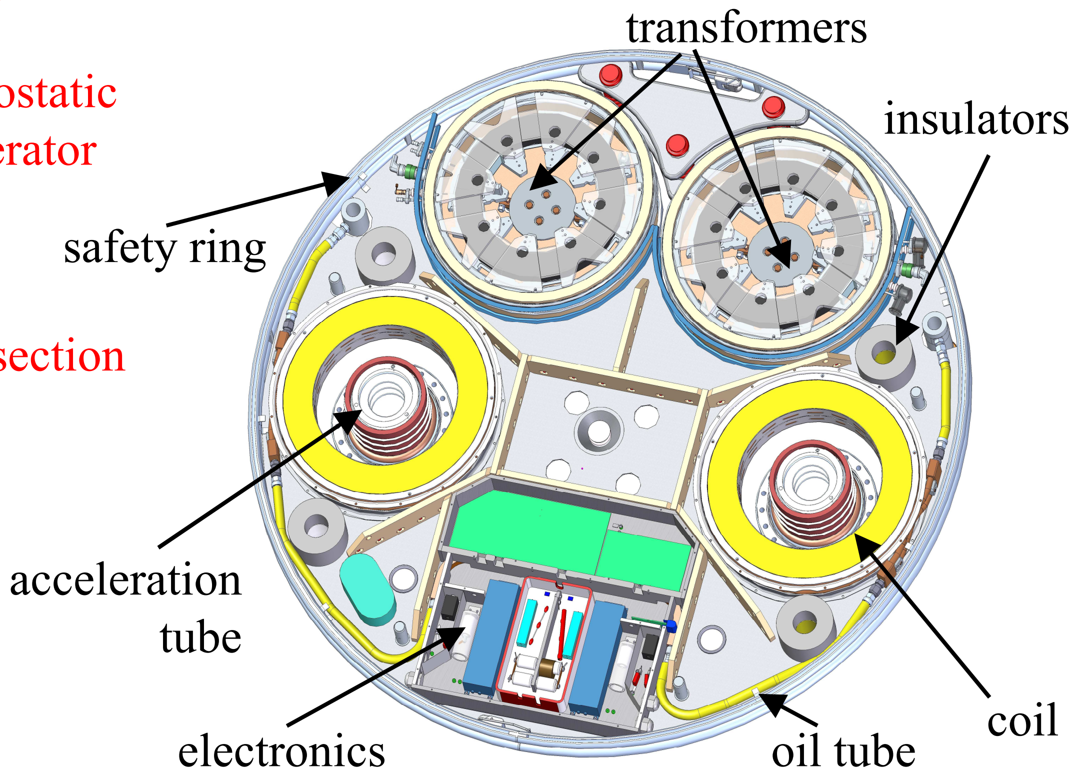


Shift of two coil 4 and 12 on distance 2 mm

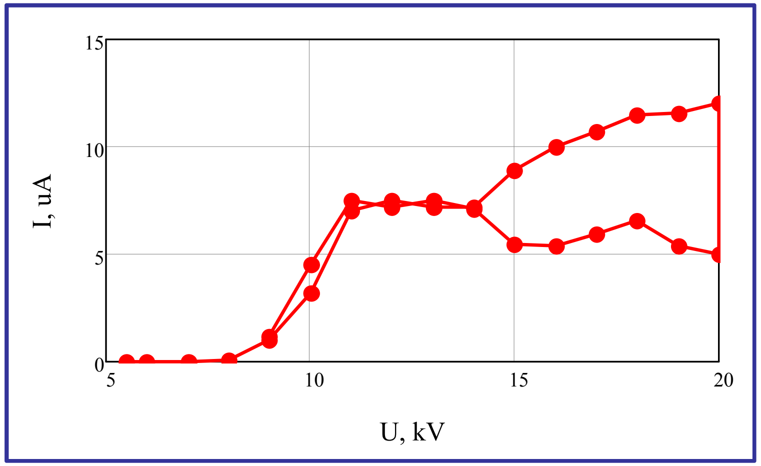


Electrostatic accelerator



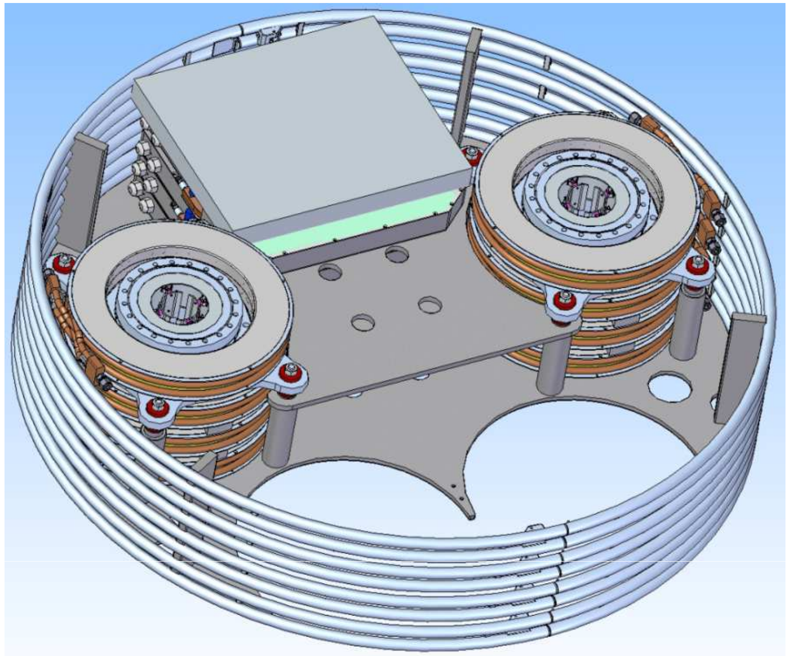


High voltage, high pressure vessel

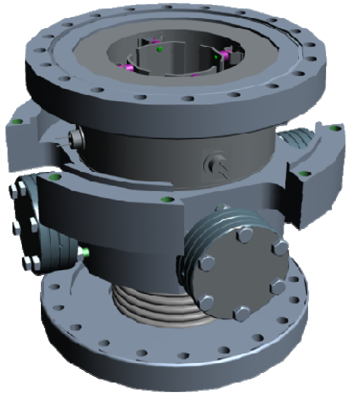


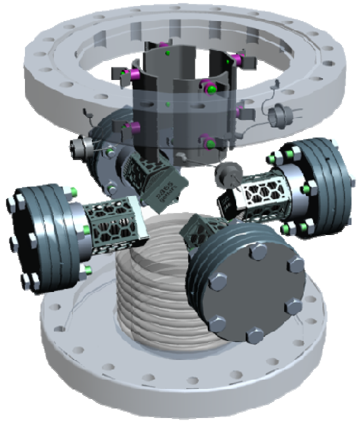
Results of high voltage tests in air. First discharge on 20 kV. After few discharges corona current decreased from 13 uA to 5 uA.

Middle section and high-voltage sections



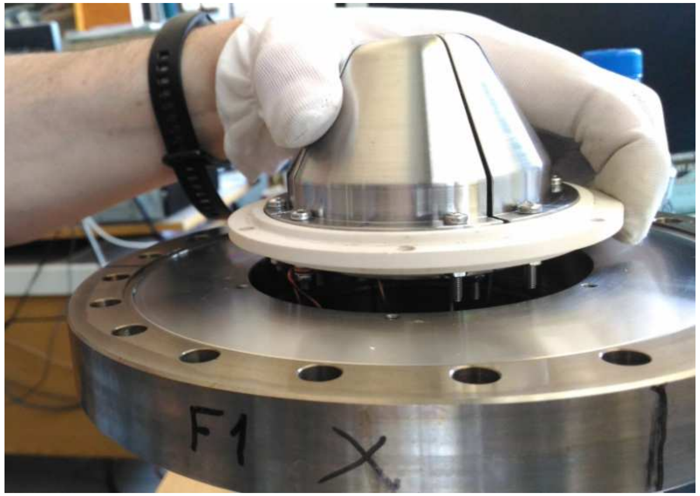
- mechanically divides HV column to 2 parts;
- doesn’t contain HV PS;
- contains 2 BPMs (1 for each tube) and vacuum pumps.

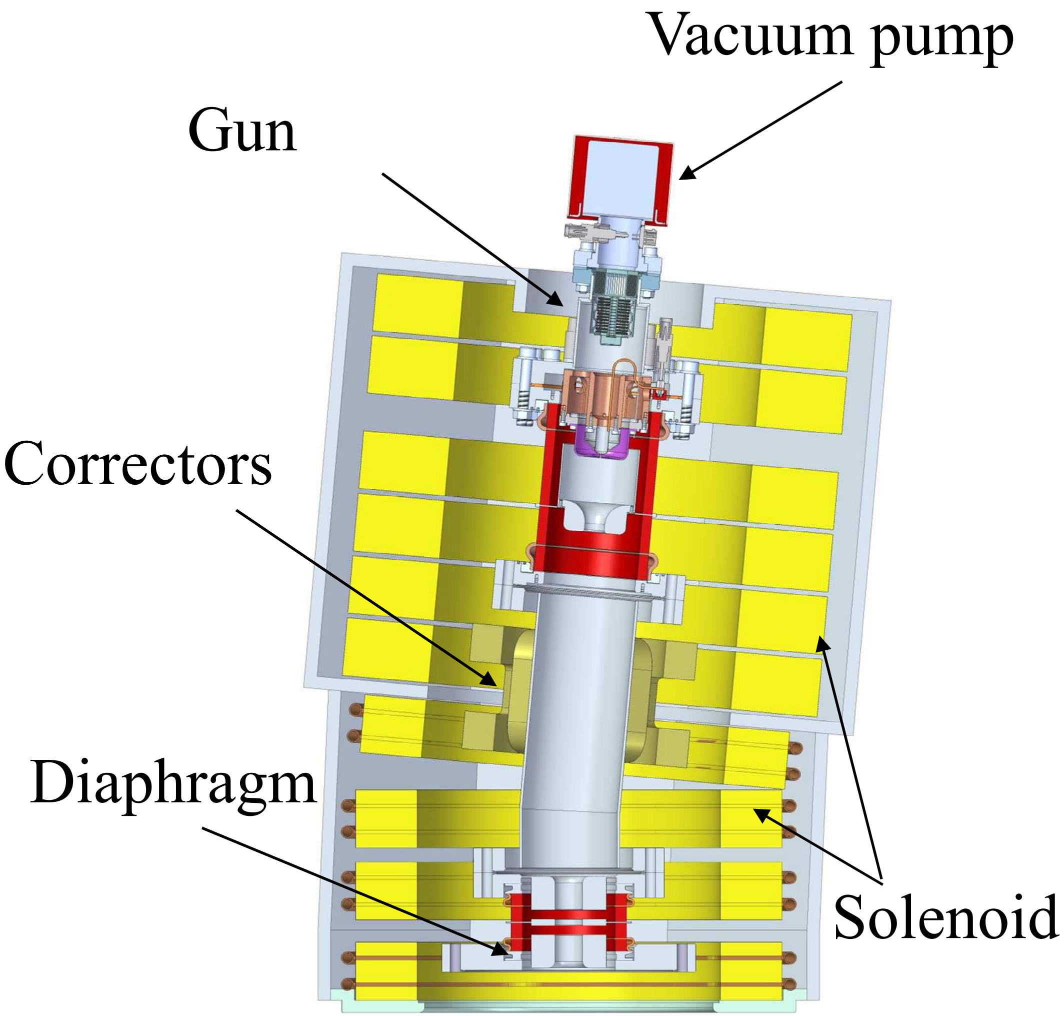




Electron gun

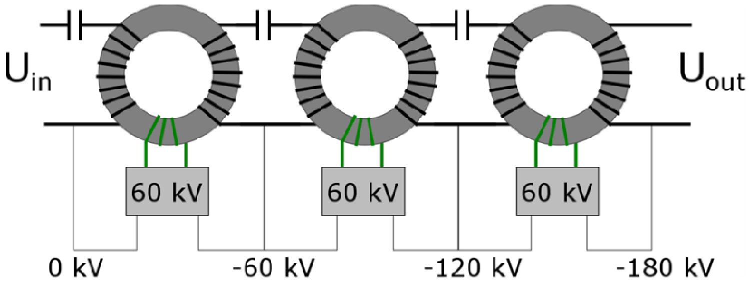
The bent solenoid shifts the gun from system axis and prevent the cathode of direct bombardment by secondary ions.





Cascade transformer and its elements

43 section for each e-cooler



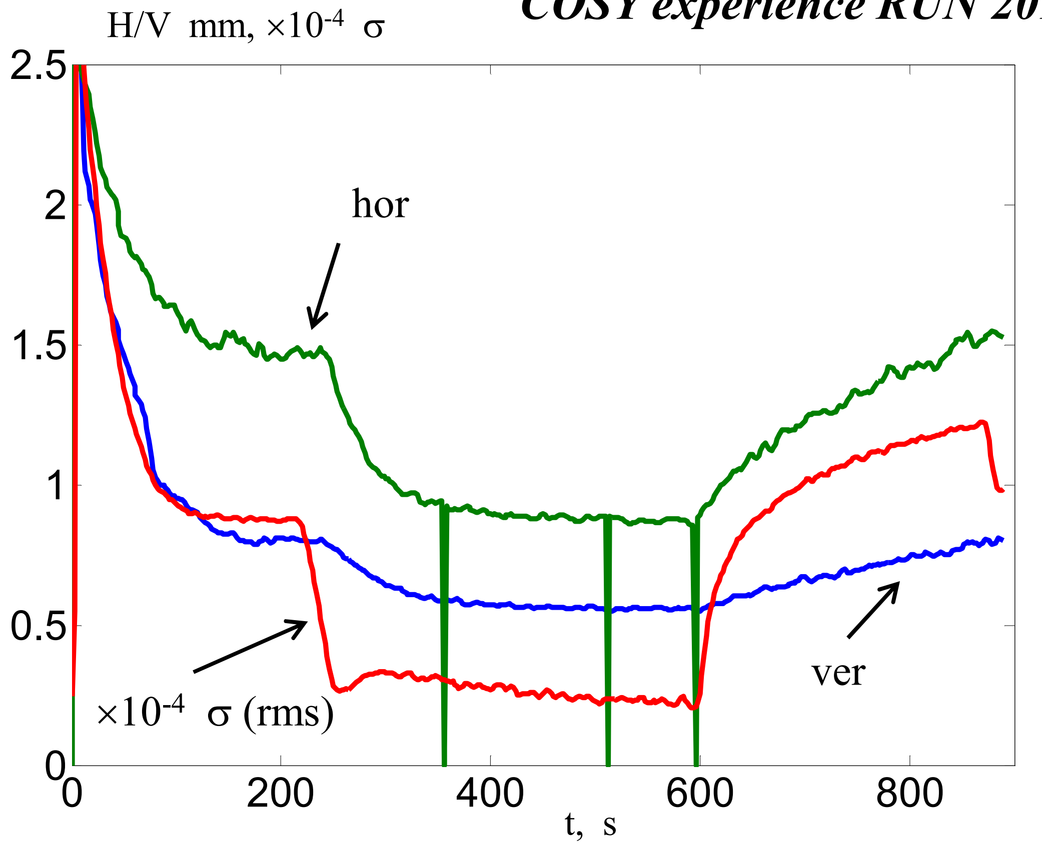
Power transfer

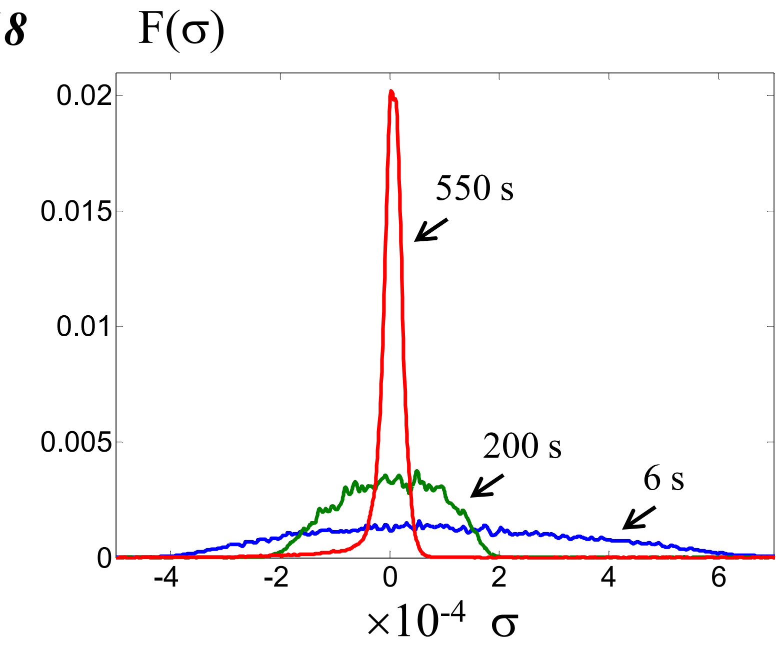
General readiness of all elements HV e-cooler may be estimated as 50 %

Stochastic and electron cooling
Je=600 mA, Ee=907.9 kV, Np=$3\cdot10^{8}$

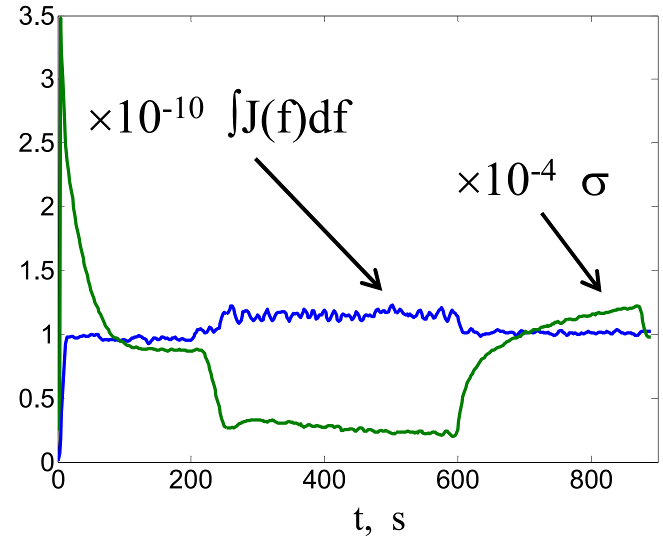
Now a little physics

COSY experience RUN 2018





The distribution function of longitudinal momentum spread in the different moment of time



000 –turn on longitudinal and transverse stochastic cooling,
200 – start electron cooling with current 600 mA, turn off longitudinal and transverse stochastic cooling
600 – turn off electron cooling

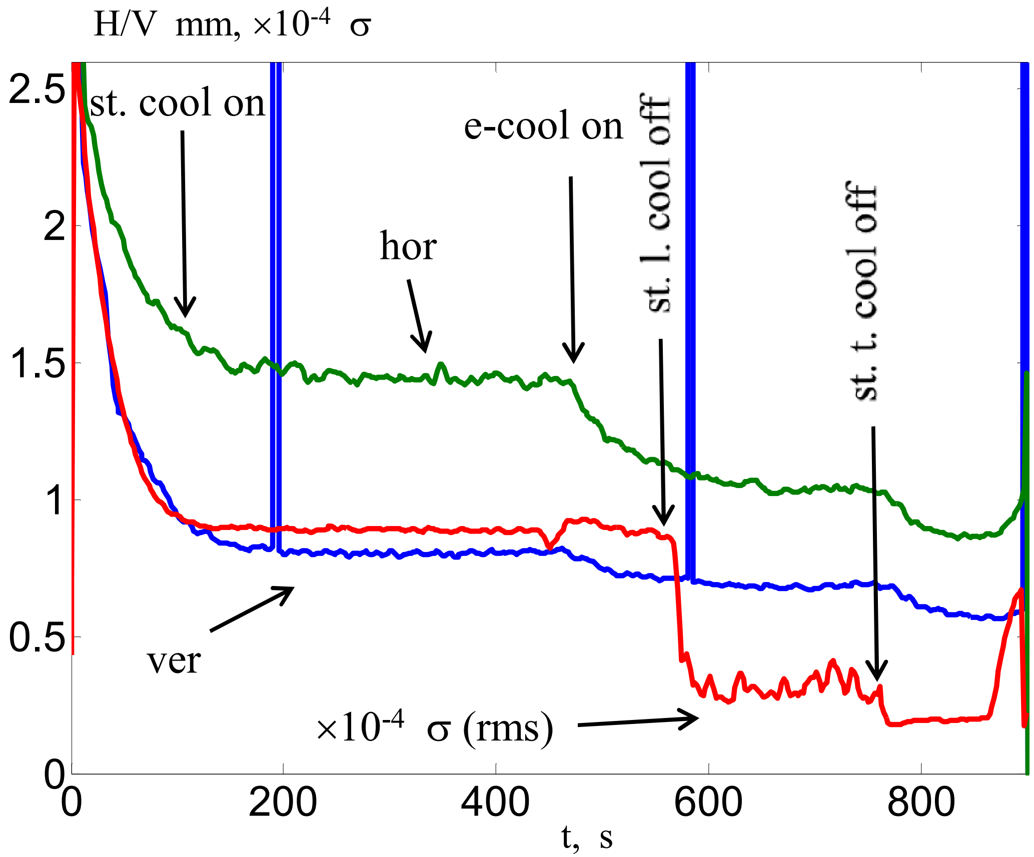
One can see that the proton beam can be fast cooled with electron beam after precooling with stochastic cooling

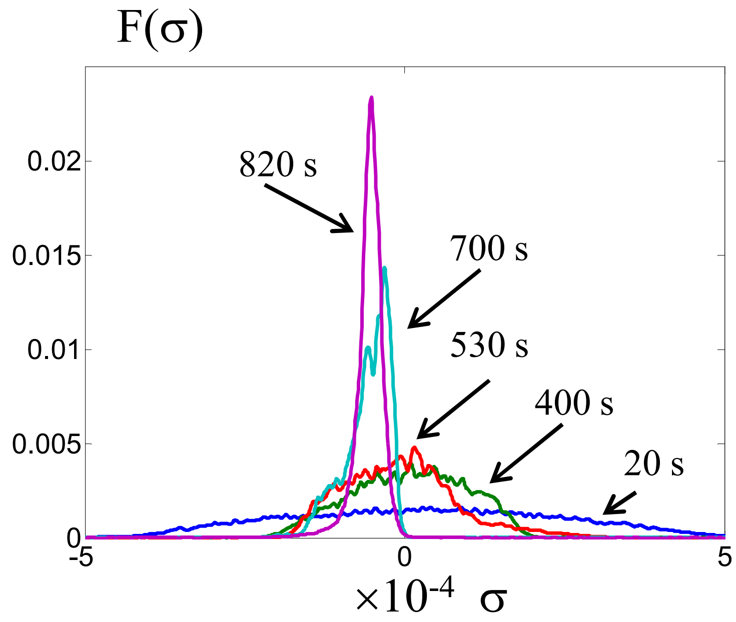
Now a little physics

COSY experience

Combine action of stochastic and electron cooling

Je=600 mA, Ee=907.9 kV, Ugr=0.83 kV, Uan= 3.27kV, Np=$3\cdot10^8$





The distribution function of longitudinal momentum spread in the different moment of time

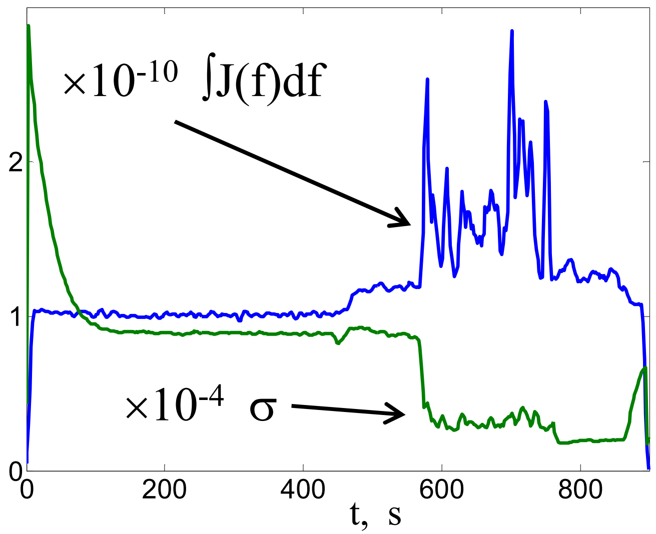
000 – turn on longitudinal and transverse stochastic cooling (ecool off),

450 – start electron cooling with current 600 mA,

570 – turn off longitudinal stochastic cooling (ecool on),

770 – turn off transverse stochastic cooling (ecool on),

$\int J(f)df$ – integral of intensity of spectrum power Schottky noise along whole frequency range. The ideal value is constant because it is proportional of number of chrage particle. At presence of collective instability this value can be increased.



The transverse stochastic cooling can shake the proton beam in the longitudinal direction. Fine adjust is necessary.

Low Energy RHIC Electron Cooling (LEReC) Report

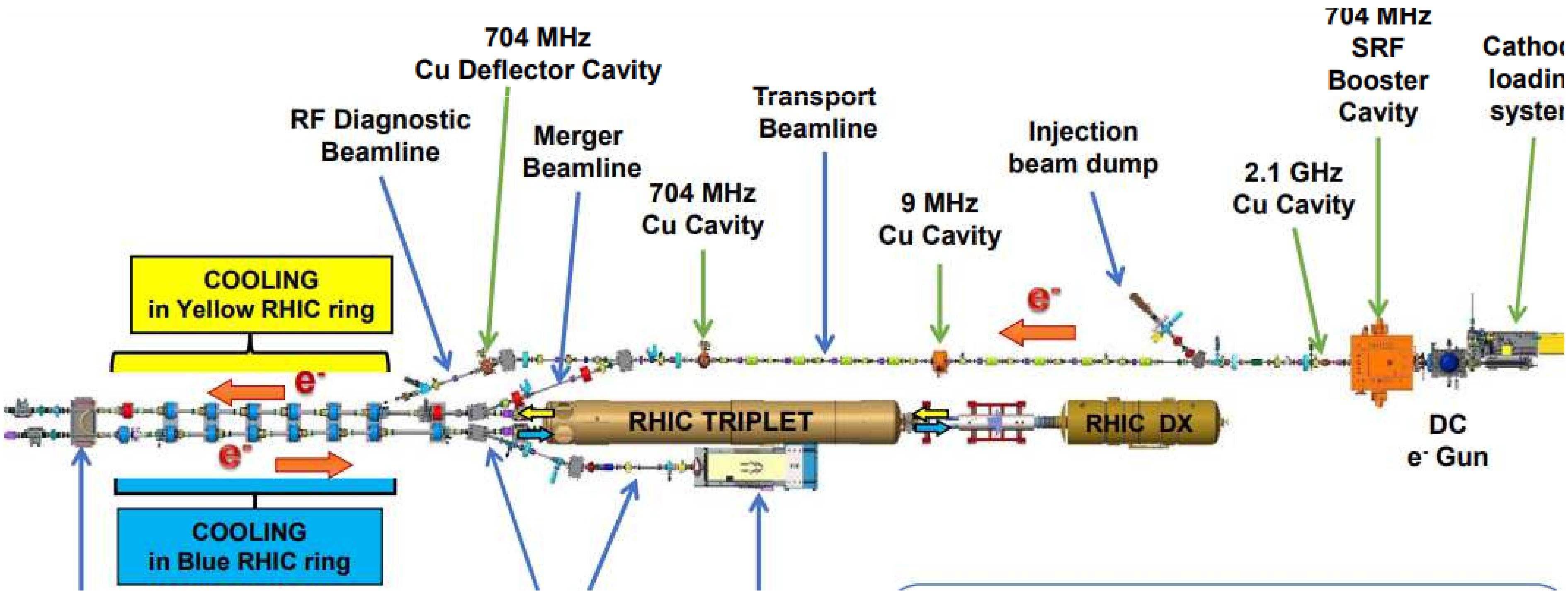
RHIC and AGS Users' Meeting
June 6, 2019

LEReC team

BROOKHAVEN NATIONAL LABORATORY

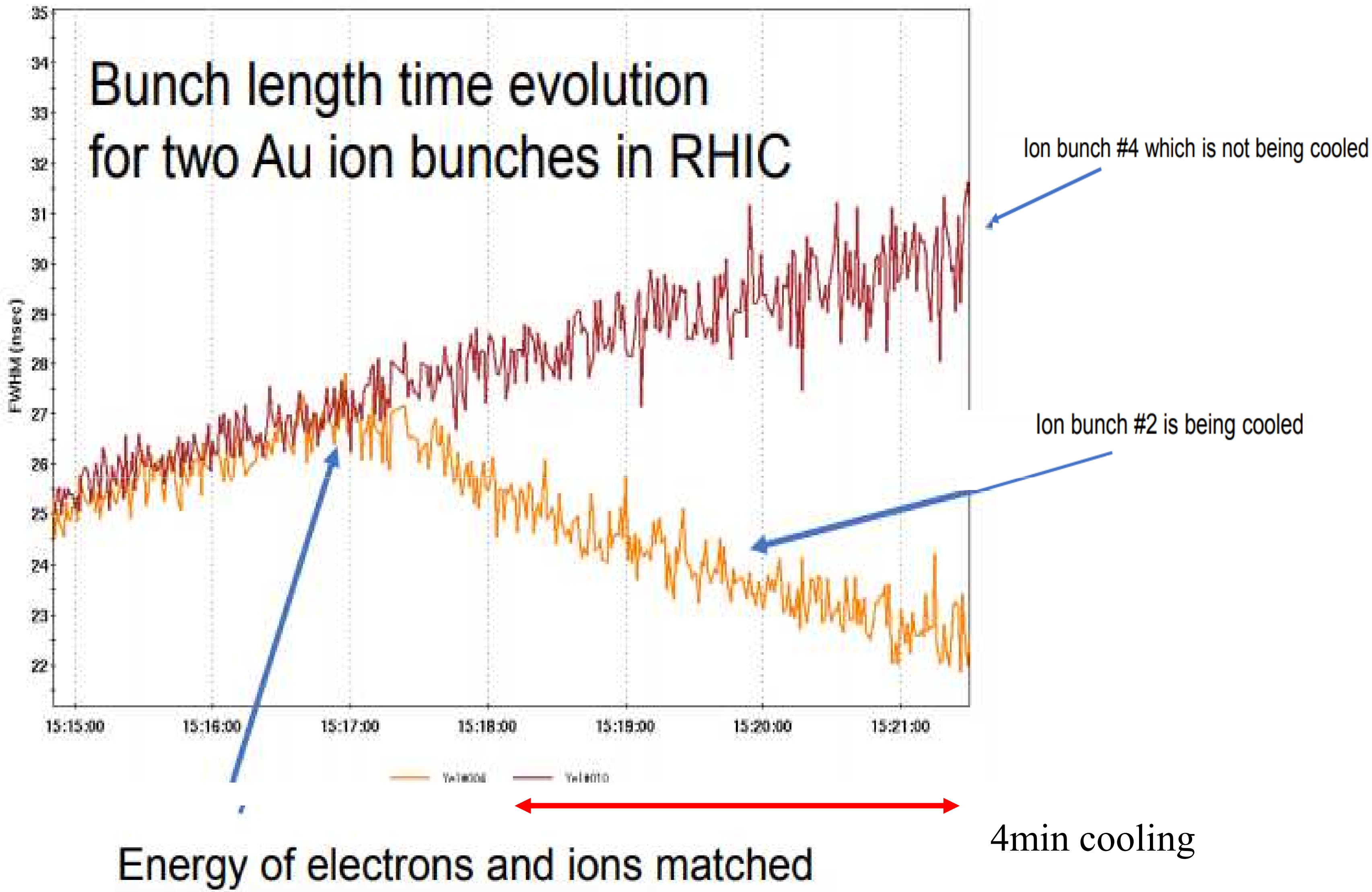
Kinetic energy, MeV	1.6*
Charge in macrobunch, nC	4
Average current, mA	36

Au beam energy 3 GeV/n



Electron cooling with RF technology

First demonstration of Au cooling in collider



COOL19 report:

Cooling commissioning results of first RF-based electron cooler LEReC,

Alexei V. Fedotov (BNL, Upton, Long Island, New York) (remote report)

Thank you for your attention

Now a little physics

COSY experience RUN 2018

Demonstration of pure electron cooling
Je=600 mA, Ee=907.9 kV, Np=$4.7\cdot10^{8}$