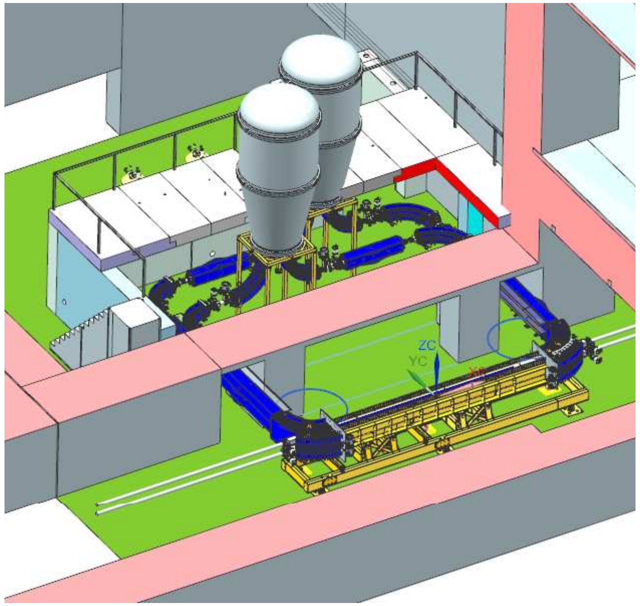
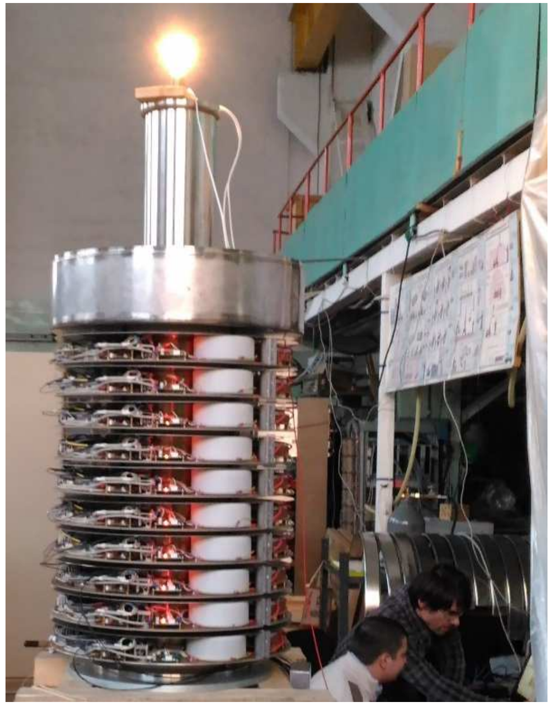
Электронное охлаждение

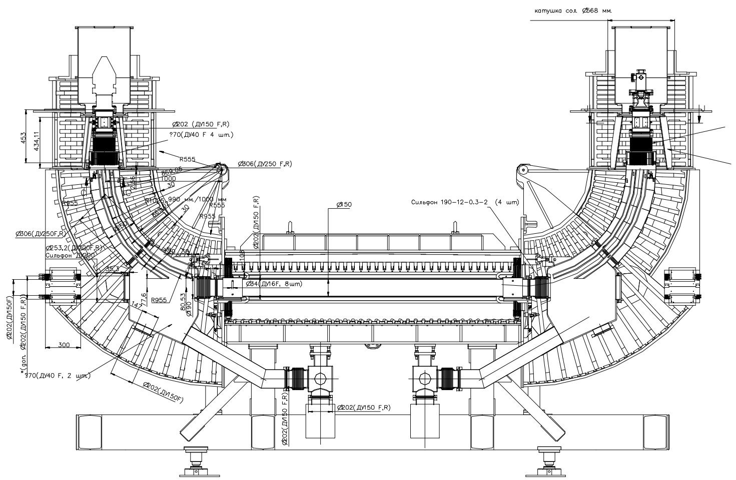
В.Б.Рева и команда ИЯФ СО РАН

Mainz, Germany





NICA, BINP & JINR, Russia

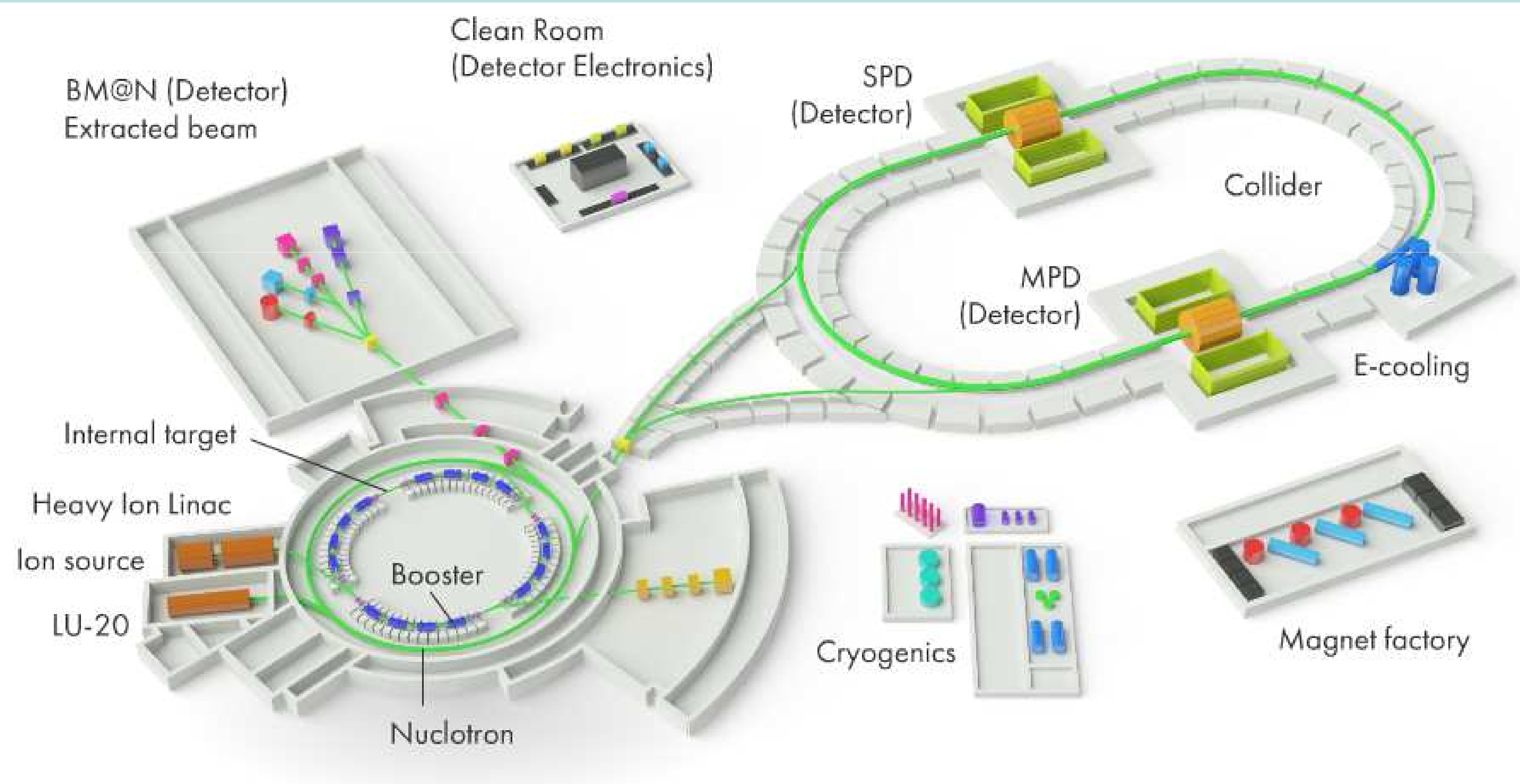


BINP & IMP

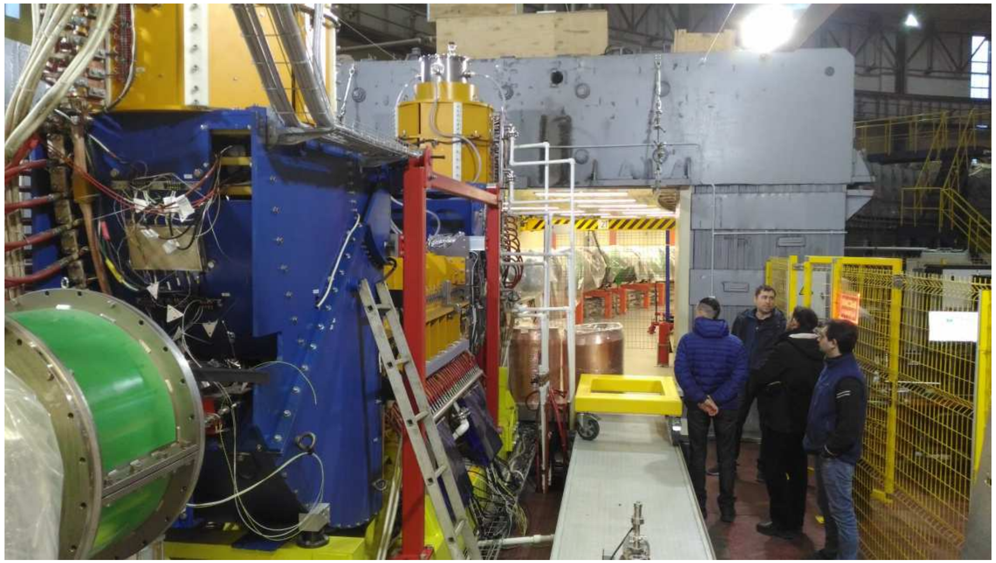
Научная сессия
ИЯФ СО РАН,
31 января, 2020

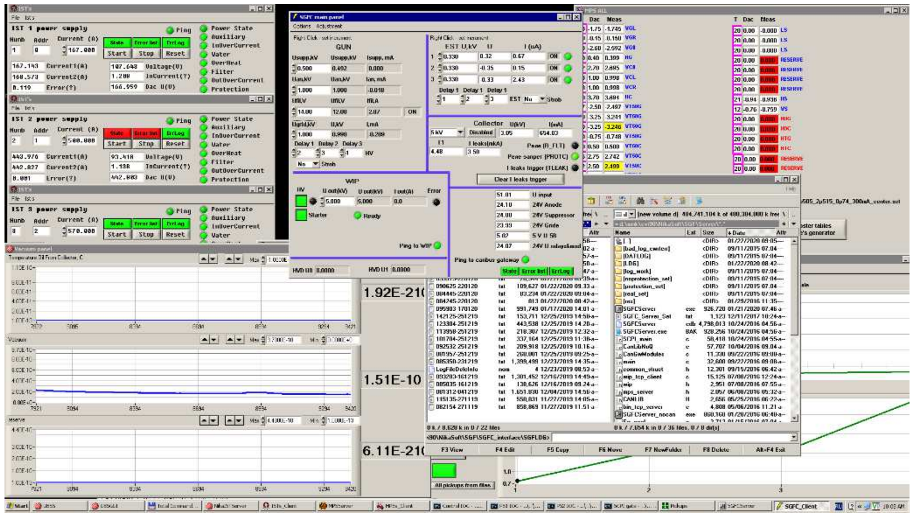
Проект НИКА

Для достижения проектной светимости комплекс НИКА оборудуется тремя системами охлаждения: две электронные (на низкую и высокую энергию) и одна стохастическая

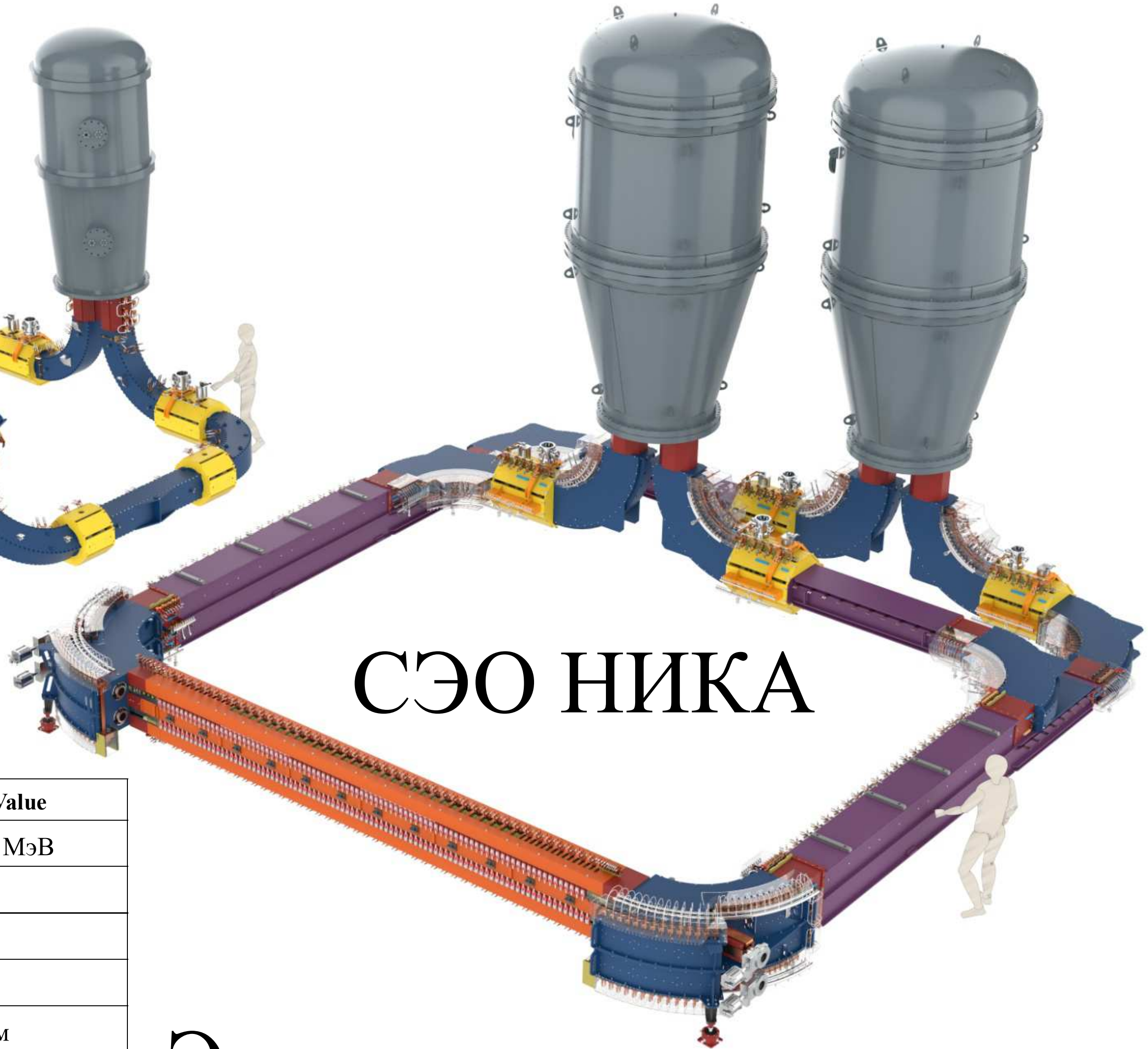


Электронное охлаждение на низкую энергию для бустера





Je=650 mA

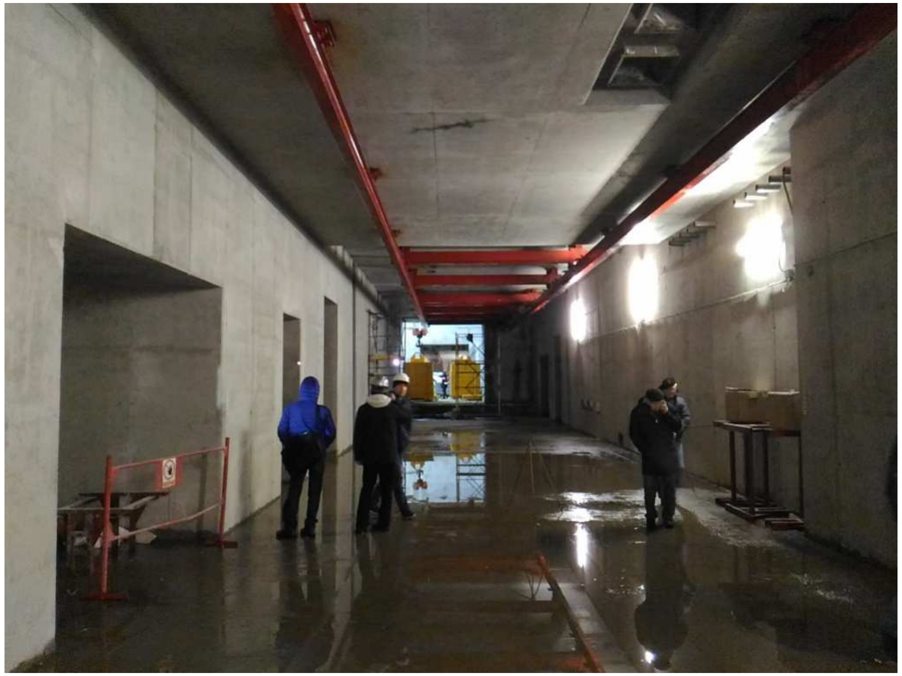


Parameter	Value
Область энергии	0.2÷2.5 МэВ
Число секций охлаждения	2
Стабильность энергии (ΔU/U)	$\leq 10^{-4}$
Электронный ток	до 1 А
Размер элект. пучка в секции охлаждения	5÷20 мм
Длина секции охлаждения	6 м
Радиус поворота транспортных каналов	1 м
Магнитное поле в секции охлаждения	0.5÷2 кГс
Вакуум в секции охлаждения	10^{-11} мбар
Высота пучков от пола	1340/1660 мм
Полная потребляемая мощность	500-700 кВт

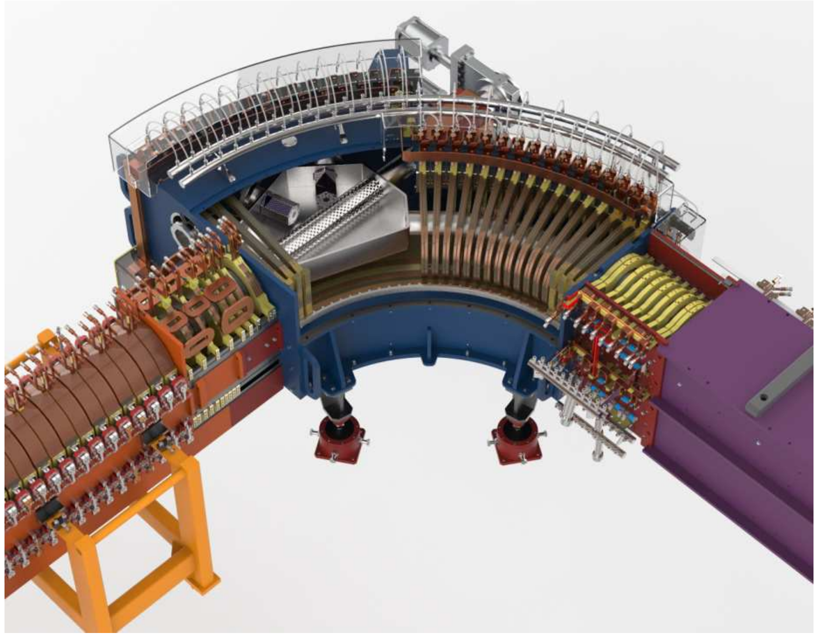
Электронное охлаждение на высокую энергию для коллайдера

http://nucloweb.jinr.ru/nucloserv/205corp.htm

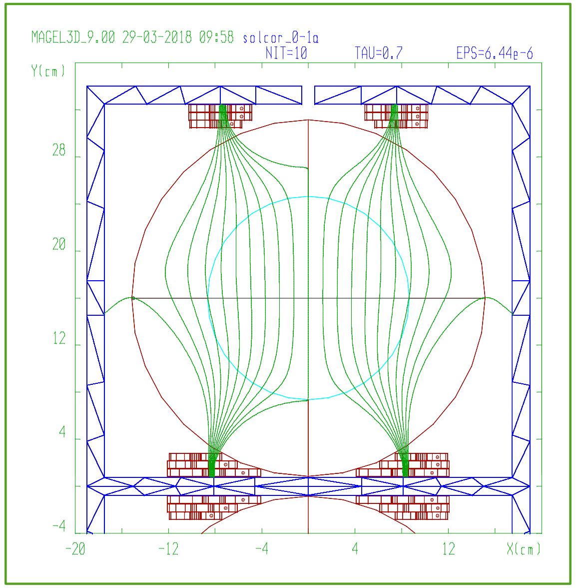
Помещение СЭО НИКА

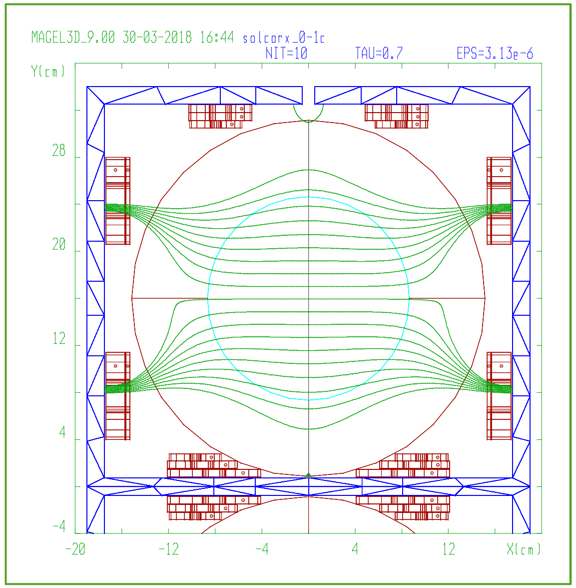


Магнитная структура СЭО НИКА



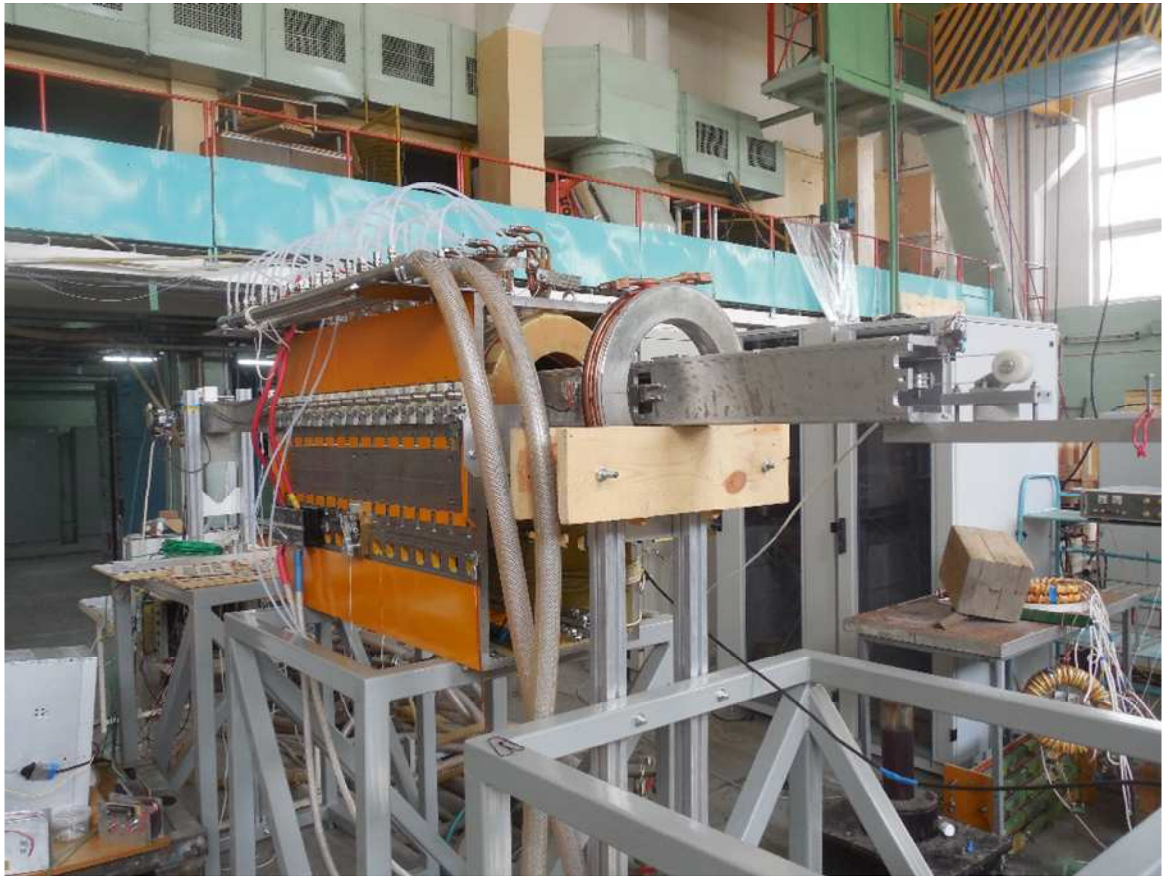
Тороид

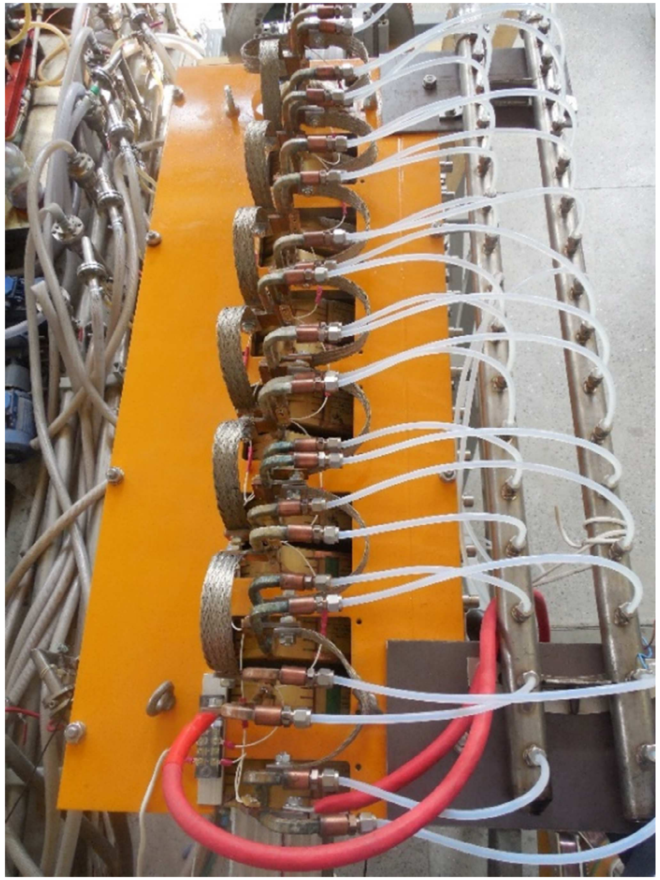




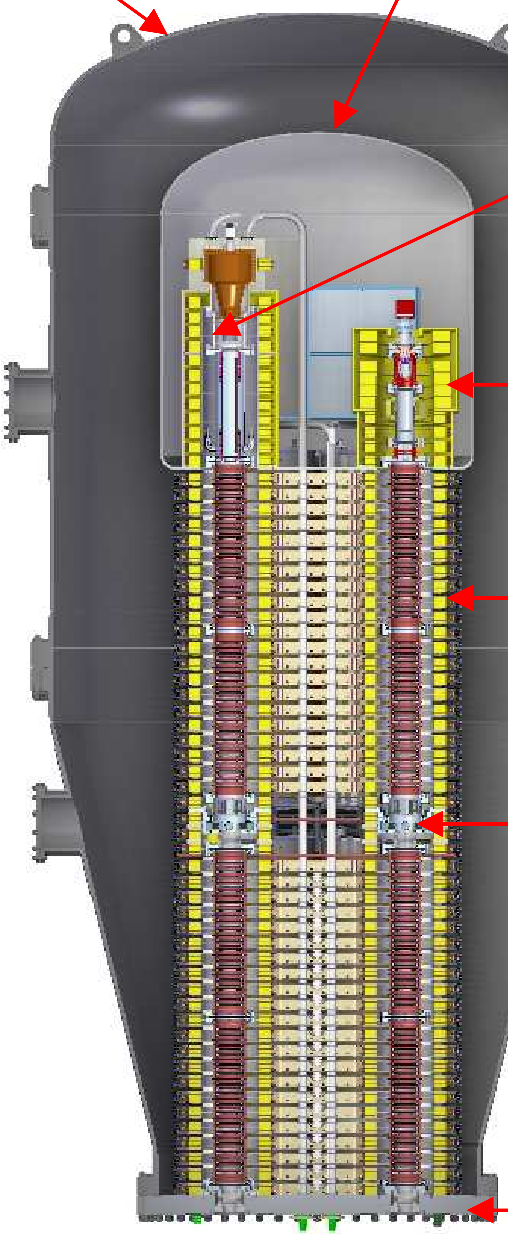
Секция охлаждения

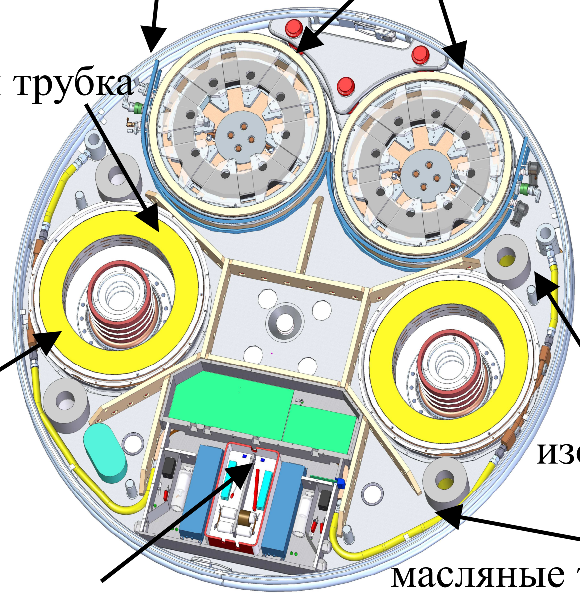
Прототип секции охлаждения



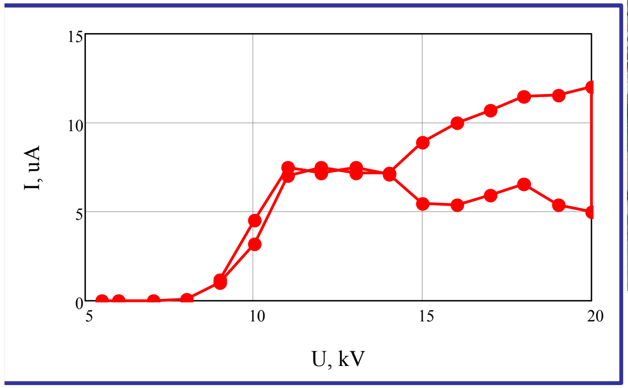


Электростатический ускоритель





Секции электростатического ускорителя в работе

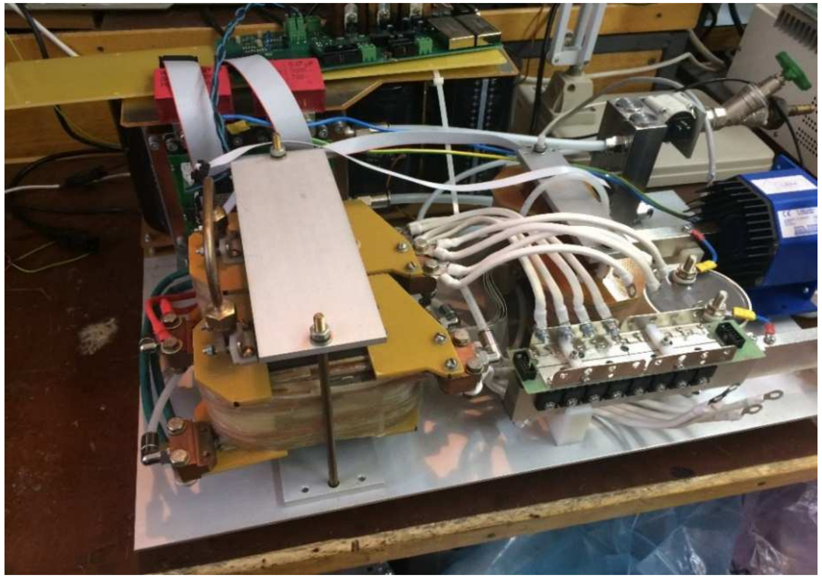


Катушки магнитных элементов






Производство источников питания



COOL'19

Number of Participants: 57

- 29 Foreign (Germany 11, China 9, United States 3, Switzerland 4, Japan 1, UK 1)
- 4 from Dubna
- 24 from Budker INP

Number of presentations:

- **28 oral talks (1 remote talk)**
- **19 posters**
- **Result of conference is published in https://www.jacow.org/**

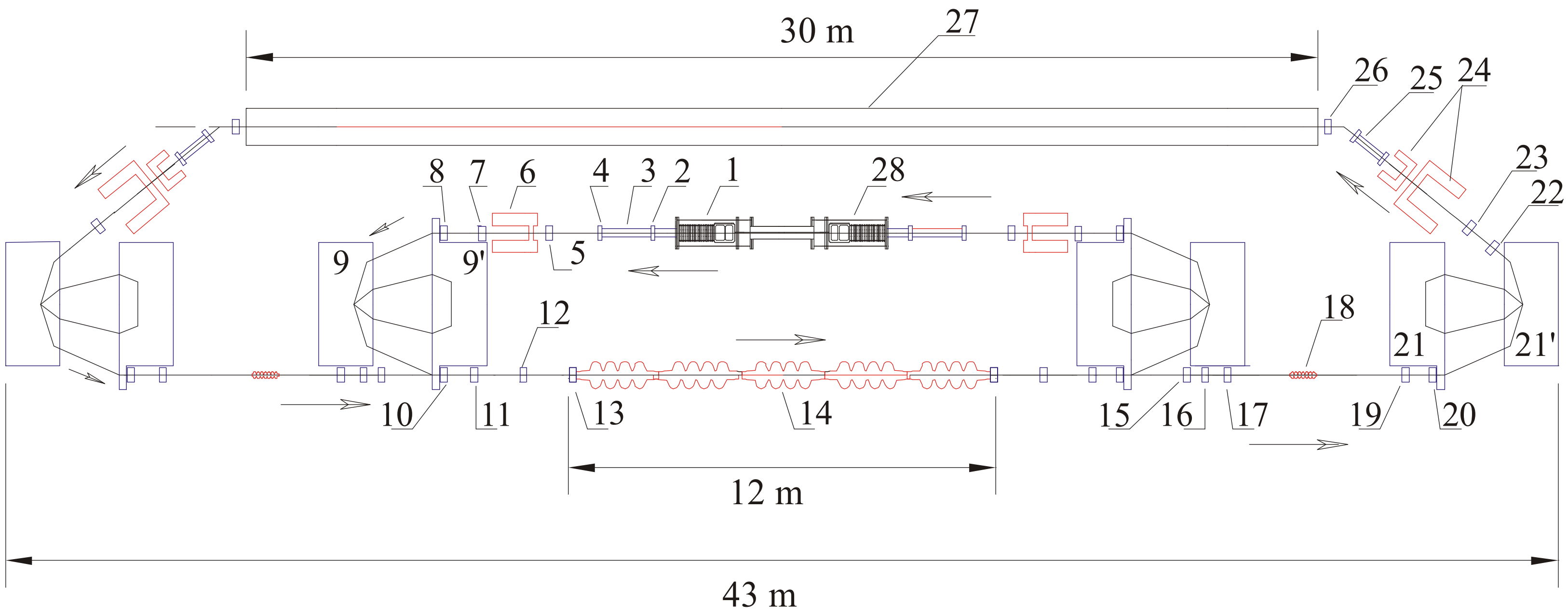
1. COSY EXPERIENCE OF ELECTRON COOLING V. B. Reva, M. I. Bryzgunov, V. V. Parkhomchuk, BINP, Novosibirsk, Russia A. Halama, V. Kamerdzhiev, P. Niedermayer FZJ, COSY, Jülich, Germany doi:10.18429/JACoW-COOL2019-MOX01
2. DESIGN OF A COMPACT ELECTRON GUN FOR THE HIGH-VOLTAGE ELECTRON COOLING SYSTEM OF THE NICA COLLIDER A. P. Denisov, M. I. Bryzgunov, A. V. Bubley, A. V. Ivanov, V. V. Parkhomchuk, A. A. Putmakov, V. B. Reva, Budker Institute of Nuclear Physics, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-MOA02
3. STATUS OF THE ELECTRON COOLER FOR NICA BOOSTER AND RESULTS OF ITS COMMISSIONING M.Bryzgunov, V.Parkhomchuk, V.Reva, A.Bubley, A.Denisov, V.Panasyuk, A.Goncharov, A.Putmakov, N.Kremnev, V.Polukhin, V.Chekavinskiy, I.Gusev, D.Senkov, G.Karpov, E.Bekhtenev, M.Kondaurov, A.Zharikov, Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia A.Kobets, I. Meshkov, S.Melnikov, O.Orlov, A. Sergeev, S.Semionov, A.A.Sidorin, A. Smirnov, Joint Institute for Nuclear Research, Dubna, Russia, doi:10.18429/JACoW-COOL2019-TUX01
4. 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. Shiyankov, Budker INP, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-THX01.
5. SIMULATION OF ELECTRON-OPTICAL SYSTEMS OF ELECTRON COOLERS A.V. Ivanov, M.I. Bryzgunov, V.M. Panasyuk, V.V. Parkhomchuk, V.B. Reva, The Budker Institute of Nuclear Physics, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-THB02
6. VACUUM SYSTEMS FOR THE COOLERS OF THE NICA PROJECT A. Bainazarova, M. Bryzgunov, A. Bubley * , N. Kremnev, V. Parkhomchuk, A.Putmakov, V. Reva, Budker INP SB RAS, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS03
7. THE HIGH VOLTAGE POWER SUPPLY SYSTEM FOR THE ELECTRON COOLER FOR CSRe D. N. Skorobogatov, M. I. Bryzgunov, M. Kondaurov, A. Putmakov, V. B. Reva, V. V. Repkov Budker Institute of Nuclear Physics of SB RAS, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS05
8. POWER SUPPLIES FOR CORRECTORS OF THE 2.5 ELECTRON COOLING SYSTEM FOR THE COLLIDER NICA O.V. Belikov, M.I. Bryzgunov, V.R Kozak, V.V. Parkhomchuk, V.B. Reva and D.S. Vinnik, BINP, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS10
9. THE CASCADE TRANSFORMER FOR THE HIGH-VOLTAGE ELECTRON COOLING SYSTEM FOR THE NICA COLLIDER A. P. Denisov, M. I. Bryzgunov, A. D. Goncharov, V. V. Parkhomchuk, V. B. Reva, D. N. Skorobogatov, Budker Institute of Nuclear Physics, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS13
10. THE MAGNETIC SYSTEM OF ELECTRON COOLERS OF COLLIDER NICA V. Panasyuk, M. Bryzgunov, A. Bubley, V. Parkhomchuk, V. Reva,V. Konstantinov, V. Korchagin, N. Kremnev, S. Pospolita, S. Ruvinskii, BINP SB RAS, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS15
11. ADJUSTING UNIT OF LONGITUDINAL FIELD COILS FOR NICA HV ELECTRON COOLER'S SOLENOID N.S.Kremnev1 , M.I. Bryzgunov, A.V. Bubley, V.V. Parkhomchuk1 , V.M. Panasyuk, V.B. Reva1 , A.A. Putmakov, S.V. Shiyankov, Budker Institute of Nuclear Physics of SB RAS, Novosibirsk, 630090 Russia 1 also at Novosibirsk State University, Novosibirsk, 630090, Russia, doi:10.18429/JACoW-COOL2019-TUPS21
12. RF ACCELERATOR FOR ELECTRON COOLING OF ULTRARELATIVISTIC HADRONS N. A. Vinokurov†1, V. V. Parkhomchuk1 , A. N. Skrinsky, Budker Institute of Nuclear Physics, Novosibirsk, Russia 1 also at Novosibirsk State University, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUY01
13.ELECTRON COOLING APPLICATION FOR HADRON THERAPY V. A. Vostrikov† , V. B. Reva, V. V. Parkhomchuk Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia and Novosibirsk State University, 630090 Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS14
14. RECENT DEVELOPMENTS AND EXPERIMENTAL RESULTS FROM ELECTRON COOLING OF A 2.4 GeV/c PROTON BEAM AT COSY P. Niedermayer∗, A. Halama, V. Kamerdzhiev, N. Shurkhno, R. Stassen, Institut für Kernphysik, Forschungszentrum Jülich, Germany V. Reva, Budker INP, Novosibirsk, Russia T. Katayama, Nihon University, Japan, doi:10.18429/JACoW-COOL2019-FRX01
15. BEAM POSITION MONITOR SYSTEM FOR HIGH VOLTAGE ELECTRON COOLER FOR NICA COLLIDER E.A. Bekhtenev1 , G.V. Karpov, V.B. Reva1 Budker Institute of Nuclear Physics, Novosibirsk, Russia 1 also at Novosibirsk State University, Novosibirsk, Russia, doi:10.18429/JACoW-COOL2019-TUPS08

RF ACCELERATOR FOR ELECTRON COOLING OF ULTRARELATIVISTIC HADRONS

V. V. Parkhomchuk, A. N. Skrinsky and N. A. Vinokurov

RHIC Project 2000

I. Ben-Zvi, L.A. Ahrens, M. Brennan, M. Harrison, J. Kewisch, W.W. MacKay, S. Peggs, T. Roser, T. Satogata, D. Trbojevic, V. Yakimenko, I.A. Koop, V.V. Parkhomchuk, V.B. Reva, Yu.M. Shatunov, A.N. Skrinsky. Electron Cooling for RHIC. Proceedings PAC 2001, Chicago, USA, June 18-22, p. 48-50.



Low Energy RHIC Electron Cooling (LEReC) Report

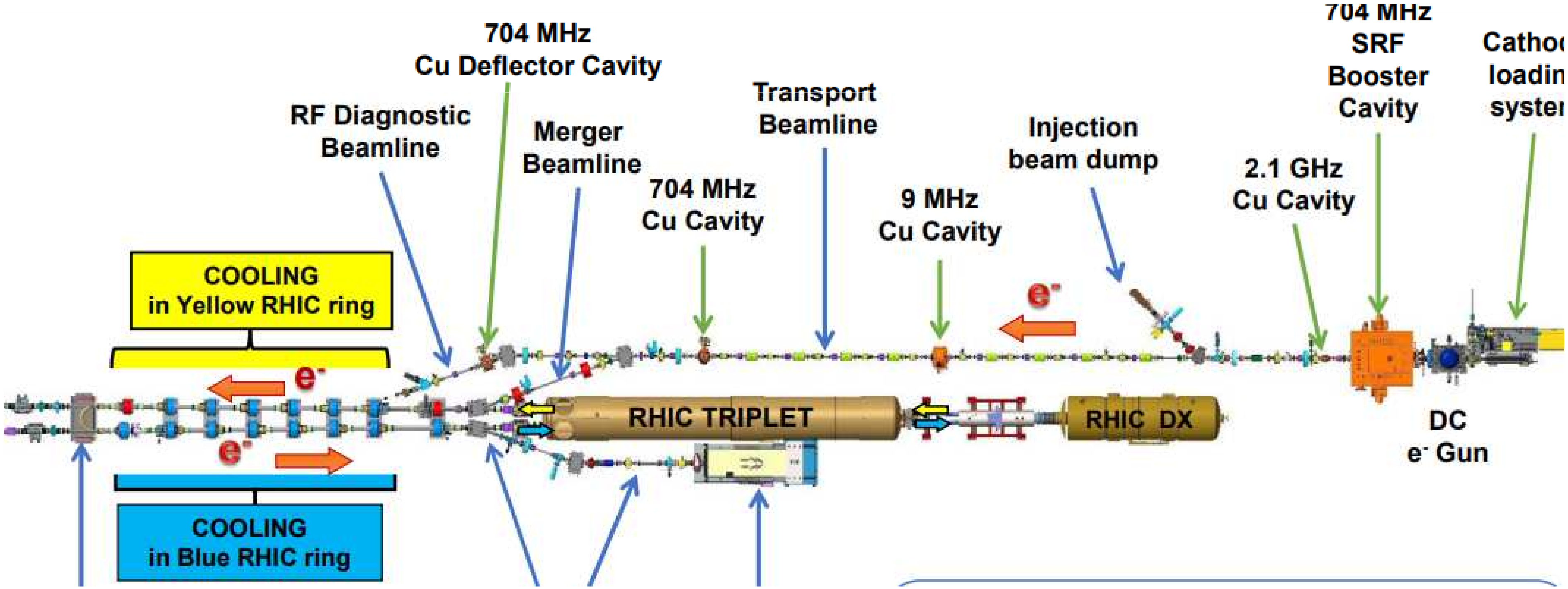
RHIC and AGS Users' Meeting
June 6, 2019

LEReC team

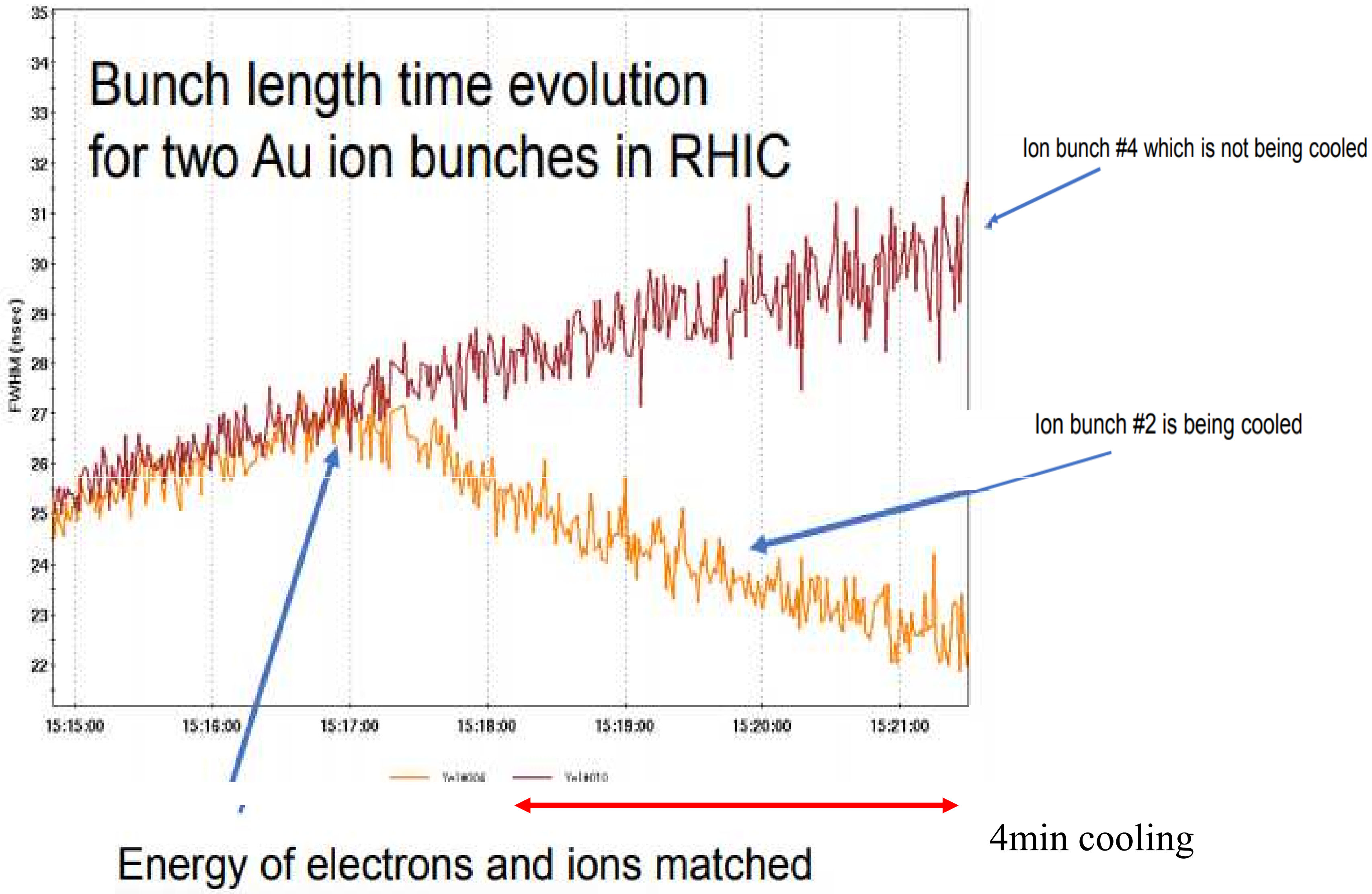
BROOKHAVEN NATIONAL LABORATORY

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

Au beam energy 3 GeV/n



Au – золото = большой заряд Zi = большая рекомбинация



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)

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

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

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Nuclear Instruments and Methods in Physics Research A 532 (2004) 427–432

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

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 velocity 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

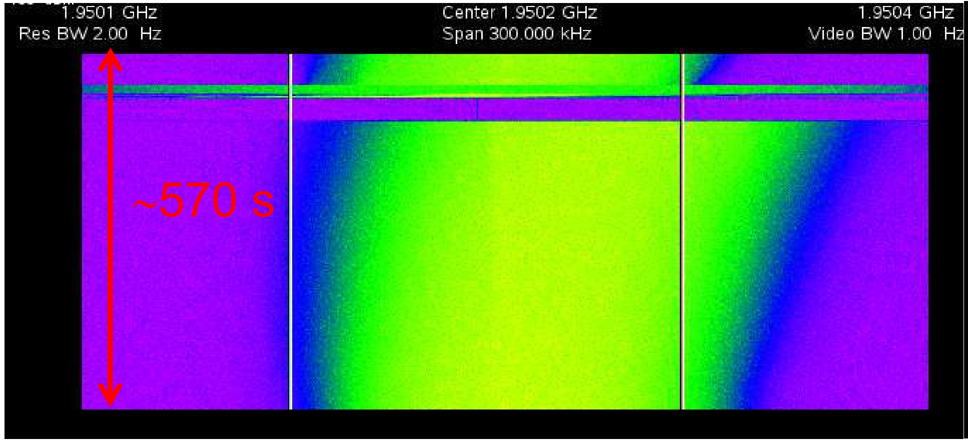
$trec := \frac{\gamma}{3.02\cdot 10^{-13}\cdot Zi^2\cdot ne\cdot\eta\cdot\sqrt{\frac{1}{Te}}\cdot\left[\ln\left(\frac{11.32\cdot Zi}{\sqrt{Te}}\right) + 0.14\cdot\left(\frac{Te}{Zi^2}\right)^{\frac{1}{3}}\right]}$ $trec = 1.073\times 10^{3}$ sec life time by recombination

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

Bs=0.2 T NICA

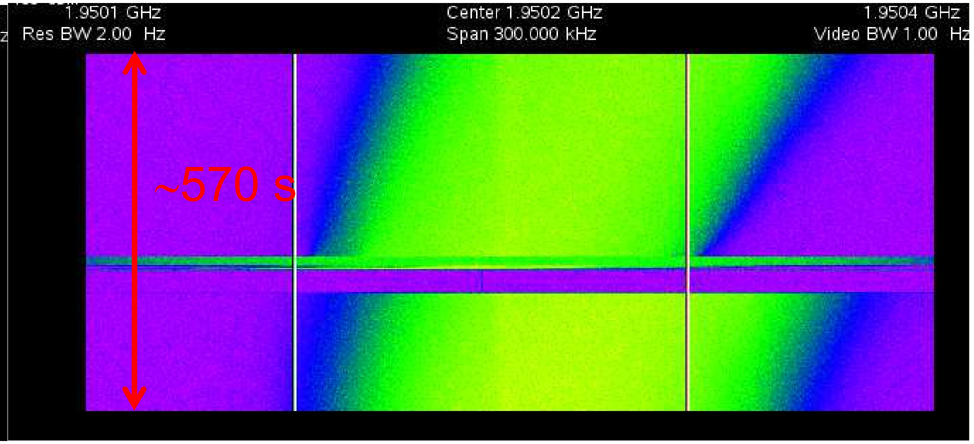
Milestones of the first cooling at new energy of the electron beam (1.25 MeV)

17:34



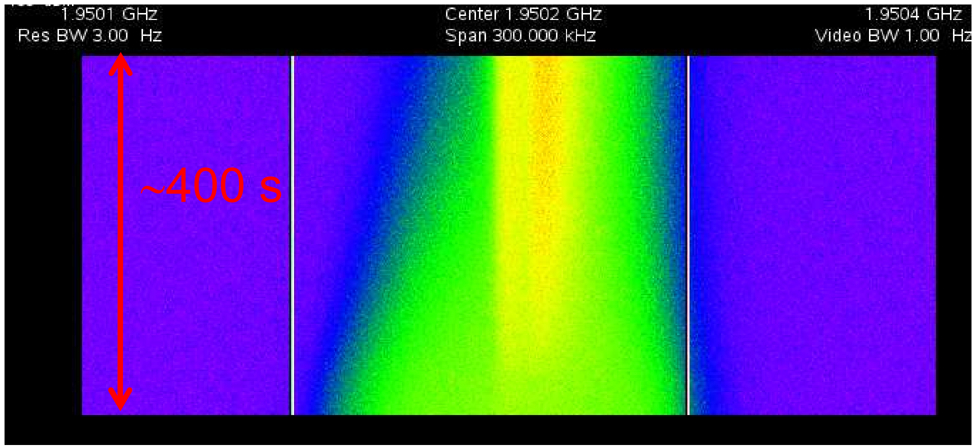
Weak shift to new energy Ee=1256 keV

17:38



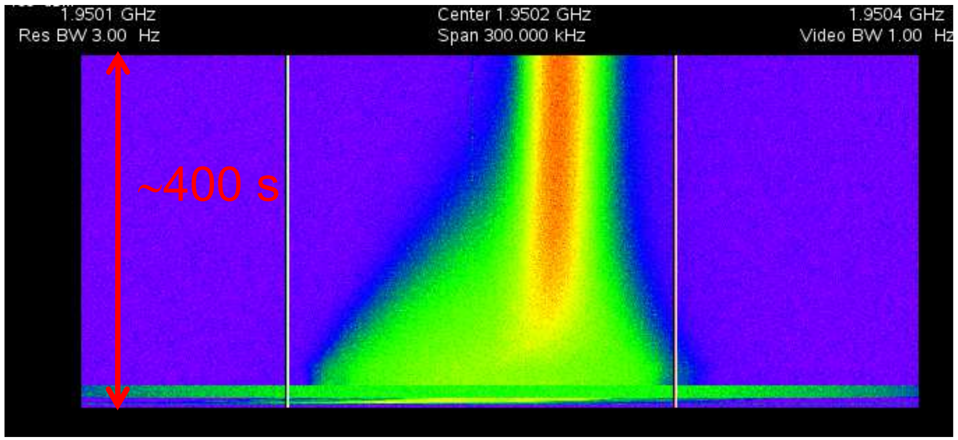
More strong shift to new energy Ee=1256.6 keV

18:47



First cooling at new energy Ee=1259.5 keV

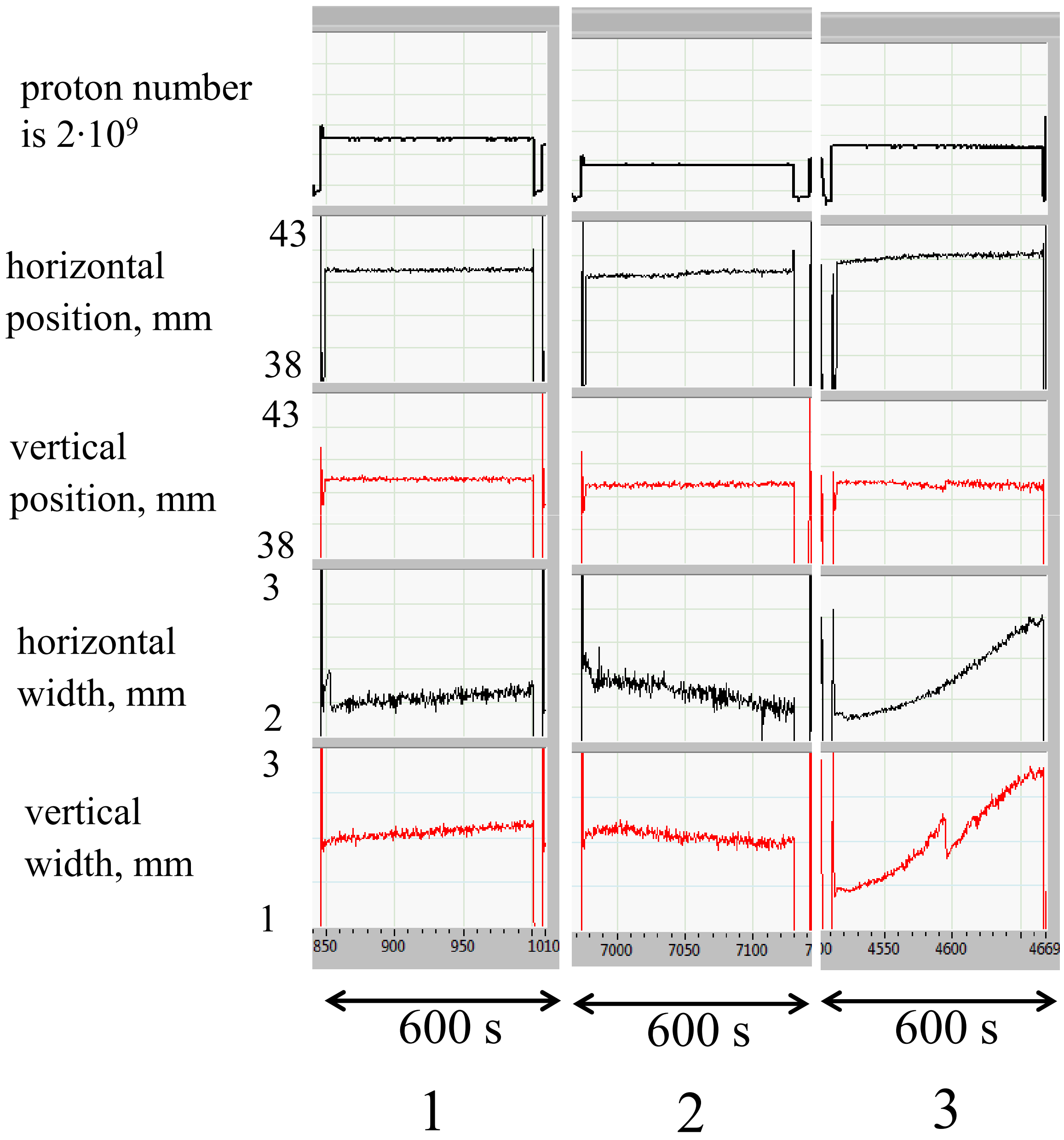
19:07



Good cooling at new energy Ee=1259.55 keV

After ~ 1.5 hours the longitudinal cooling process was obtained at new energy 1259.5 keV (after series experiments at 909 keV energy). The situation with transverse cooling isn’t such optimistic.

Transverse e-cooling at 1259 kV energy

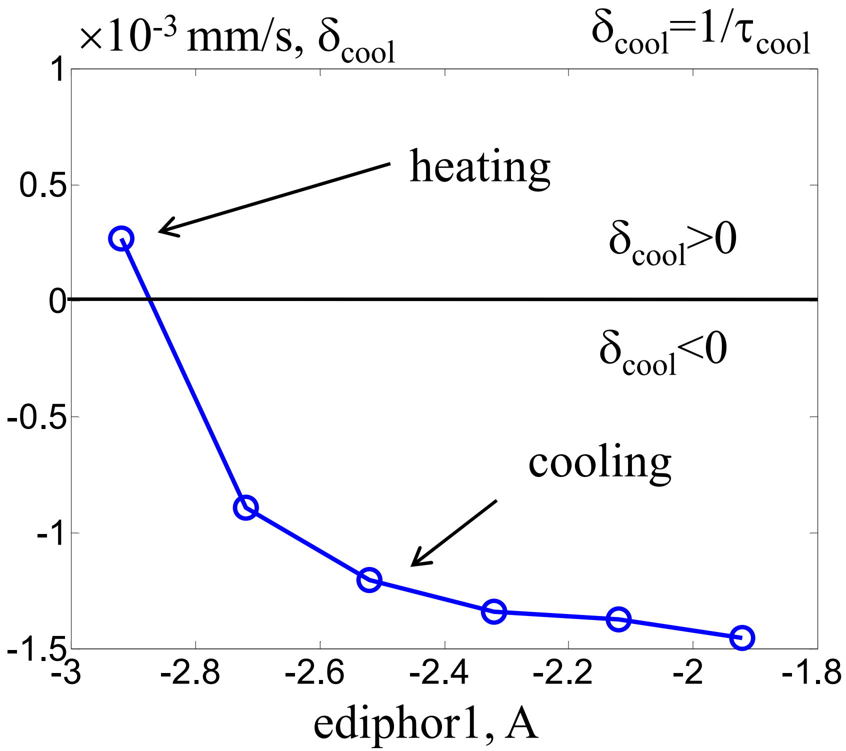


The transverse cooling process was observed after spending much time and efforts.

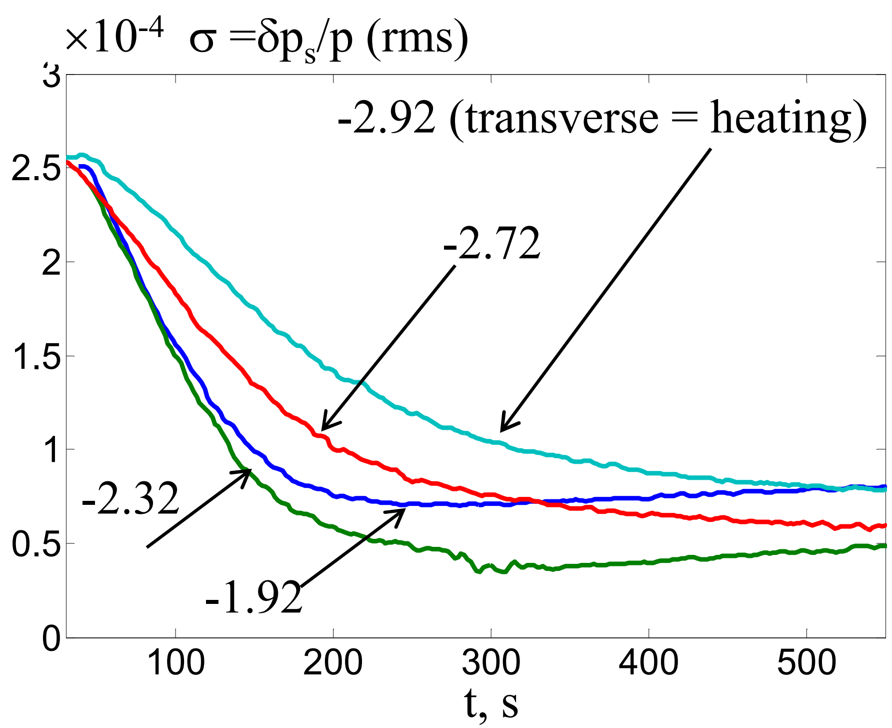
Maximum attention was given to looking for a working point of storage ring where the electron cooling had maximum effectiveness.

Changing transverse size during cooling experiments. Curve 1 is reference cycle without cooling , curve 2 is cooling at energy 1259 kV, curve 3 is growth of the transverse size at changing working point despite of electron cooling action. Tune was shift at $\Delta Qx/ \Delta Qy \approx 0.02/-0.01$ (estimation).

Another example of influence of Larmour oscillation to transverse cooling rate. It is possible to eliminate transverse cooling but the longitudinal decreases not so much



horizontal cooling decrement

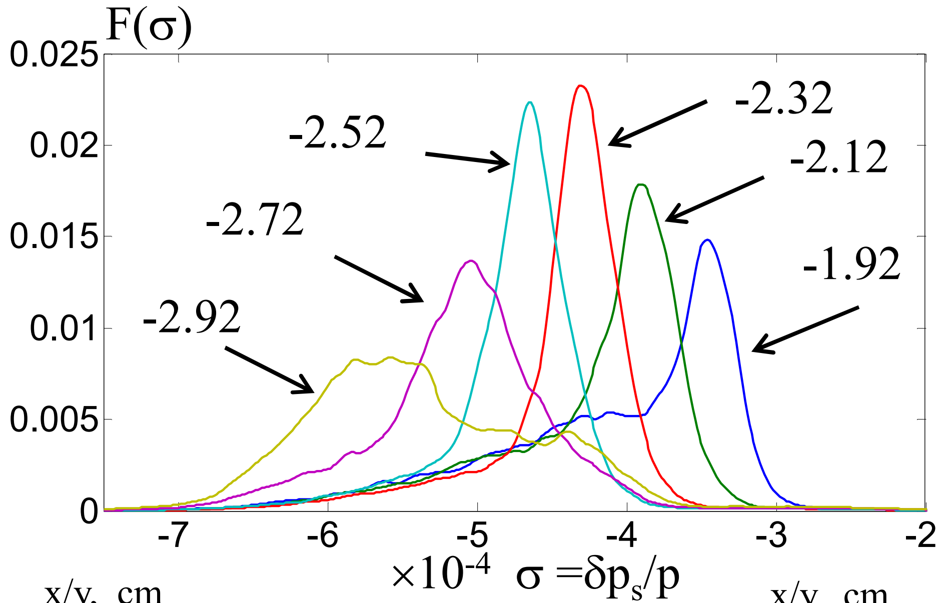


longitudinal momentum spread versus time for different value of current in electron dipole corrector ediphor1

Parameters of the experiments Ee=907.7 kV, Je=595 mA, Uan=3.27, Ugr=0.83 kV

If the Larmour rotation is strong enough it can kill the transverse cooling. The longitudinal cooling time is increased but it present.

It is interesting that the correlation between changing of the dipole corrector and equilibrium momentum of the proton beam. Figure shows the distribution function of the protons in time 500 s for the different value of ediphor1 corrector.



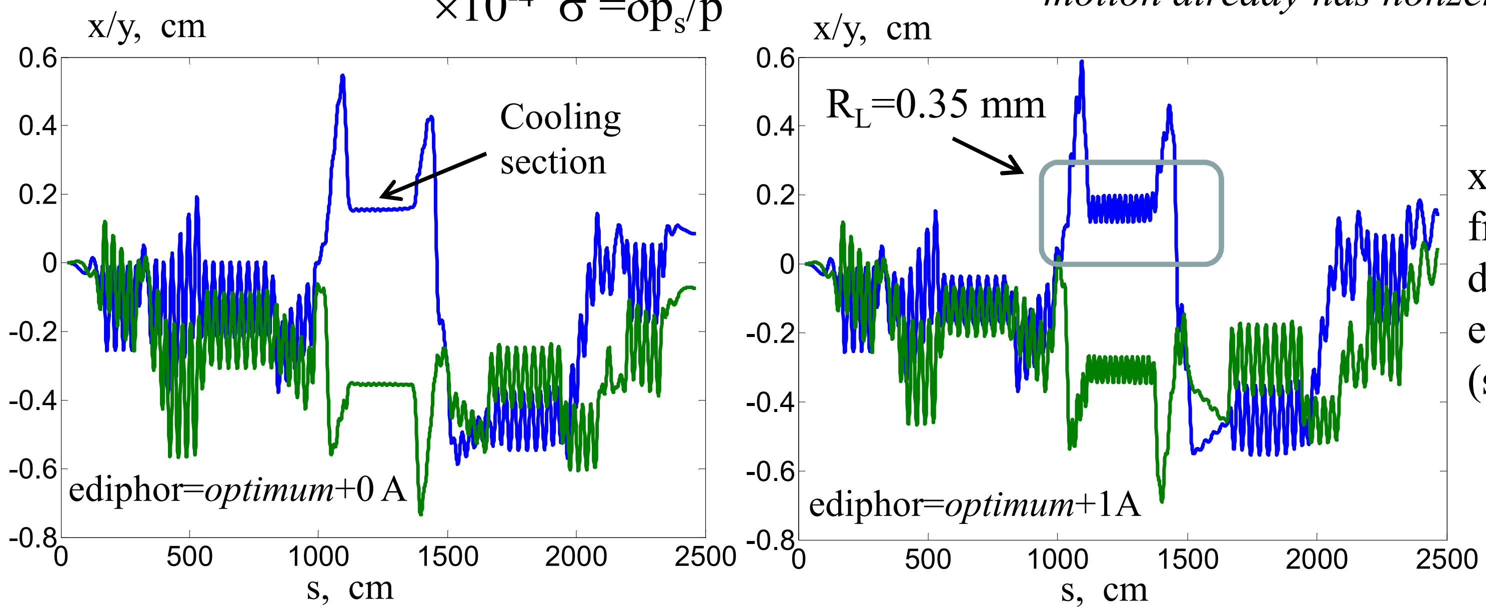
Increase the transverse momentum (Larmour oscillation) leads to <u>decrease the longitudinal momentum</u>

$$E_e = 909 \cdot 10^3\ keV \quad B_{cool} = 1380\,G \quad R_L = 0.35\,mm$$

$$\gamma = 1 + \frac{E_e}{mc^2} = 2.78 \qquad \rho = \frac{\gamma\beta m_e c^2}{eB_{cool}} = 3.2\ cm$$

$$\delta\sigma = \frac{\delta p_{II}}{p_0} = \frac{1}{2}\left(\frac{R_L}{\rho}\right)^2 = 6 \cdot 10^{-5} \qquad \frac{\delta p_{e\perp}}{p_0} = \frac{R_L}{\rho} = 0.011$$

The quality behavior is good. The quantitative difference can be explained that the transverse motion already has nonzero amplitude of Larmour oscillation.



x,y orbit of the electron from accelerating to decelerating tube along electron cooler (simulation)

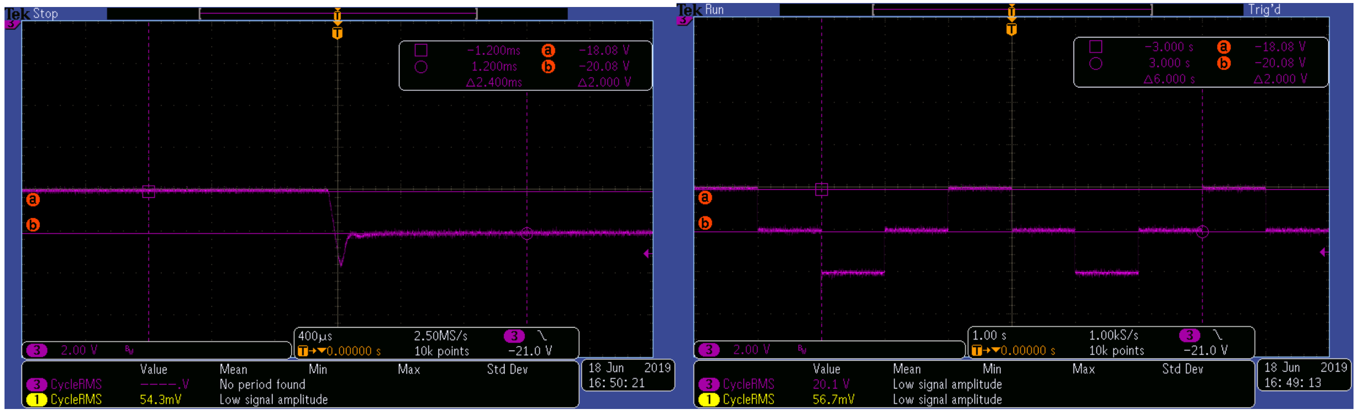
Demonstration of excitation of Larmour oscillation of electron induced by edip corrector.

Вперед к экспериментам по рекомбинации

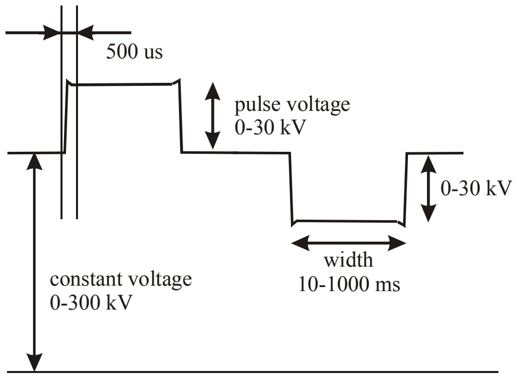
Previous high-voltage system before disassembling. Parts 1 – 6 were disassembled and assembled again. Collector is 1, high-voltage terminal is 2, collector PS is 3, gun is 4, high-voltage feeder is 5, high-voltage vessel is 6.

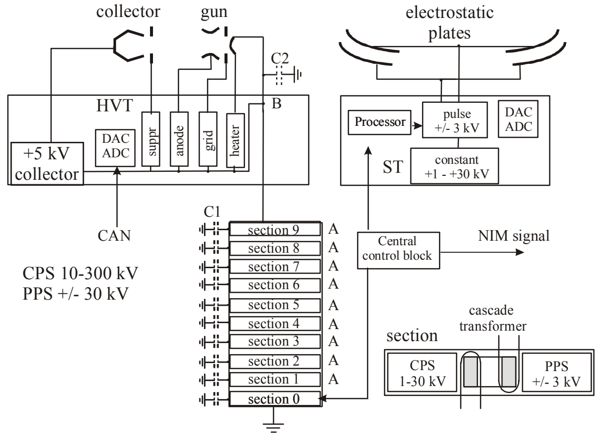
Test of the maximum detuning voltage on the air

Ланжоу 2019



Test of the maximum detuning voltage on the air. Maximum detuning voltage of main power supply on the air outside high-voltage vessel was obtained 20 kV (50 – +/- 20 kV). Electrostatic plates on the air was obtained 20 and 2 kV.





1.The maximum voltage of main power supply is 300 kV. The ripple of main power supply is less than 1×10^{-4} (p-p value).

2. The energy detuning system is worked on the CSRe high voltage platform.

3.The rise and fall time for each pulse should be less than 500 micro-seconds for maximum amplitude 30 kV (~15 μs/kV).

4. Pulse amplitude should be varied by program with step 1 V.

Both High-Voltage and Electrostatic Plates

Electron cooling with new system

Спасибо за внимание